# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF PARTNERS</td>
<td>3</td>
</tr>
<tr>
<td>CONFERENCE COMMITTEES</td>
<td>4</td>
</tr>
<tr>
<td>LETTERS</td>
<td>5</td>
</tr>
<tr>
<td>PROGRAM AT A GLANCE</td>
<td>7</td>
</tr>
<tr>
<td>PARTNER MATERIALS</td>
<td>8</td>
</tr>
<tr>
<td>MULTITEMP 2013 PUBLICATION OPPORTUNITIES</td>
<td>10</td>
</tr>
<tr>
<td>TECHNICAL PROGRAM</td>
<td>13</td>
</tr>
<tr>
<td>PROGRAM ABSTRACTS</td>
<td>28</td>
</tr>
<tr>
<td>INDEX OF AUTHORS</td>
<td>193</td>
</tr>
</tbody>
</table>
THANK YOU TO OUR PARTNERS

Canadian Remote Sensing Society

IEEE Geoscience and Remote Sensing Society

The University of Calgary, Faculty of Arts

TECTERRA Inc.

ISIS Geomatics Inc.

University of Lethbridge NSERC CREATE AMETHYST Program

The Banff Centre
CONFERENCE COMMITTEES

General Conference Chair
Mryka Hall-Beyer, Univ. of Calgary, Canada

Technical Program Chair
Greg McDermid, Univ. of Calgary, Canada

Local Organizing Committee
Derek Peddle, Univ. of Lethbridge, Canada
Joe Piwowar, Univ. of Regina, Canada
Guillermo Castilla, Univ. of Calgary, Canada
Julia Linke, Univ. of Toronto, Canada
Jennifer Hird, Univ. of Calgary, Canada
John Yackel, Univ. of Calgary, Canada

Permanent Steering Committee
Lorenzo Bruzzone, Univ. of Trento, Italy
Pol Coppin, Katholieke Univ. Leuven, Belgium
Ross S. Lunetta, U.S. Env. Protection Agency
Roger King, Mississippi State Univ., USA

Science Committee
Greg McDermid, Univ. of Calgary, Canada
Mryka Hall-Beyer, Univ. of Calgary, Canada
Derek Peddle, Univ. of Lethbridge, Canada
Joe Piwowar, Univ. of Regina, Canada
Guillermo Castilla, Univ. of Calgary, Canada
Julia Linke, Univ. of Toronto, Canada
Paul Treitz, Queens Univ., Canada
Pol Coppin, Univ. of Leuven, Belgium
Stephen Howell, Environment Canada
Stuart Phinn, Univ. of Queensland, Australia
Xulin Guo, Univ. of Saskatchewan, Canada
Anne Smith, Agriculture and Agri-Foods Canada
Richard Fernandes, Canada C. for Remote Sensing
Gustavo Camps-Valls, Univ. de València, Spain
Nicholas Younan, Mississippi State Univ., USA
Niko Verhoest, Ghent Univ., Belgium
Peijun Du, Nanjing Univ., China
Urs Wegmuller, Gamma Remote Sensing, Switzerland
Quazi Hassan, Univ. of Calgary, Canada
Ron Hall, Canadian Forest Service
Luis Carvalho, Federal Univ. of Lavras, Brazil
Geoffrey Hay, Univ. of Calgary, Canada
Karl Staenz, Univ. of Lethbridge, Canada
Darren Pouliot, Canada Centre for Remote Sensing
Brian Brisco, Canada Centre for Remote Sensing
Chris Hopkinson, University of Lethbridge, Canada
Jordi Inglada, Cen. D'Estudes Spatiales de la Biosphere, France
Allan Nielsen, Technical Univ. of Denmark
Yifang Ban, KTH Royal Institute of Technology, Sweden
Ross Lunetta, United States Env. Protection Agency
Peng Gong, Berkeley, USA
Dear Delegates,

A very warm welcome to all Multi-Temp 2013 panelists, authors, researchers and guests! This is the seventh in the Multi-Temp Workshop series. The 12 years since the first workshop in Trento, Italy, have seen remarkable advances in the technical ability of researchers and policy makers to make use of multi-temporal remote sensing information. It has also seen the beginning of an explosion of high-quality datasets that can be used to extract ever more information from Earth observation. This conference will share information and ideas on the latest opportunities to use long-established data. It will also allow us to think about how to apply the concepts of time series to new kinds of just-in-time customized data; for example acquisitions from UAVs. Radar data are beginning to figure prominently in the multi-temporal field. The Landsat keynote and panel will bring us all up to date on this vital ingredient in long-term multi-temporal analysis.

Novel applications are just as important as the data. Multi-Temp 2013 has dedicated sessions for urban, forestry and agricultural areas, among others.

The local organizing committee is very excited to welcome you all to Canada – and Banff Alberta in particular. Working out the requirements for responsible environmental stewardship over these vast territories requires imagery at many scales, and requires that it be well integrated with the monitoring sciences. We have devoted one panel to what we are learning collectively here in Alberta: this can open a dialog with other areas that have the same challenges and commitment to solving them. Within Alberta, there are few finer meeting places than the Banff Centre, which is a post-secondary institution with expertise in supporting and developing leadership and the arts.

Scientific communication is developing as fast as imaging science. Our international panel of Editors-in-Chief brings together a large concentration of expertise to discuss trends and to help us all be effective high-quality communicators.

Thank you to all the members of the International Steering Committee who are shepherds of all the past and future Multi-Tems. Thanks to our main supporters, the IEEE GRSS and the Canadian Remote Sensing Society: without them this conference would not have happened. Thanks also to members of the Scientific Committee, who have selected excellent presentations and posters for MultiTemp 2013. We thank all of our supporters and partners, whose logos, links and information you will find throughout the conference materials. Finally of course a huge thank you to our volunteers!

Have a wonderful Multi-Temp!

Mryka Hall-Beyer
MultiTemp 2013 General Conference Chair
University of Calgary, Canada
Dear MultiTemp 2013 Delegates:

On behalf of the Executive of the Canadian Remote Sensing Society / Société canadienne de télédiffusion (CRSS-SCT), it is my pleasure to welcome you to Canada and Banff for the 7th International Multi-Temp Remote Sensing Conference. The CRSS Executive is pleased to collaborate with the Multi-Temp 2013 Organizing Committees and provide financial and personnel support, and also to be partnering with the IEEE Geoscience and Remote Sensing Society (GRSS) as technical co-sponsors. MultiTemp has a strong IEEE GRSS heritage from its very beginning in 2001, and we are honoured to be working with GRSS for this year's MultiTemp event. We are also grateful for the partnership with The University of Calgary and the Banff Centre as our hosts, and to the other event partners listed in the Program, and of course, our team of volunteers! Most of all, we thank you – the delegates and authors, panelists and keynotes – for your expertise and contributions that are the backbone of this event.

Under the leadership of General Conference Chair Dr. Myra Hall-Beyer and Technical Program Chair Dr. Greg McDermid, the MultiTemp 2013 Organizing and Scientific Committees have worked very hard to create an innovative program with top-rate international science. I wish to thank all on these Committees, which include several members from our CRSS Executive, as well as our colleagues from the IEEE GRSS and the Permanent Steering Committee for together carrying forward the valuable traditions from previous Multi-Temp events for which we are grateful.

Our CRSS partnership with IEEE GRSS for MultiTemp 2013 is set in the context of the CRSS-IEEE GRSS Memorandum of Understanding (MOU) that promotes various collaborations that we enjoy between our Societies. Next year, CRSS will again be partnering with IEEE GRSS as we host IGARSS-2014 in Québec City 13-18 July 2014. This is the largest remote sensing conference in the world and it will be held in conjunction with the 35th Canadian Symposium on Remote Sensing / 35e Symposium canadien de télédiffusion. In the meantime, after MultiTemp we invite you to join the remote sensing community this summer at IGARSS 2013 in Melbourne Australia (21-26 July 2013) and also at our 34th Canadian Symposium on Remote Sensing / 34e Symposium canadien de télédiffusion in Victoria BC (27-29 August 2013).

The use of multi-temporal remote sensing imagery and data sets for monitoring our planet is vital to the proper care of the environment, management of resources, and for many purposes involving the Earth's land, oceans, and atmosphere. As you gather together in Banff, I encourage each of you to consider taking some time either before or after the conference to appreciate the beauty and splendour of the Canadian Rocky Mountains and this UNESCO World Heritage Site – as a time to reflect and renew ourselves together.

We are excited that this is the first time this conference is being held in Canada. I wish you the very best at MultiTemp 2013 - enjoy the science, enjoy the socials, and enjoy the setting!

Yours sincerely,

Monique Bernier

President, Canadian Remote Sensing Society / Société canadienne de télédiffusion
# MultiTemp 2013: Our Dynamic Environment – Program at a Glance

## Mon. June 24
- **Registration (Galleria)**

## Tues. June 25
- **07:30**
  - Registration (Galleria)
- **08:30-08:40**
  - Welcome and Opening Remarks (KC103/105)
  - Dr. Mryka Hall-Beyer, Conference Chair
- **08:40-10:40**
  - Panel I (KC 103/105)
  - International Editors-in-Chief Forum
- **10:40 – 11:10**
  - Break and Poster Session P1 (KC 101)
- **11:10 – 12:50**
  - Oral Session T2a (KC 201)
  - Agriculture and Grasslands I
  - Oral Session T2a (KC 103/105)
  - Forestry
  - Oral Session W2a (KC 103/105)
  - Change Detection
  - Oral Session W2b (KC 201)
  - Water and Hydrology
- **12:50-13:50**
  - Lunch (Vistas Dining Room, Sally Borden Building)
- **13:50-15:30**
  - Oral Session T3a (KC 103/105)
  - Phenology and Vegetation Dynamics
  - Oral Session T3b (KC 201)
  - SAR-Microwave
- **15:30-16:00**
  - Break and Poster Session P1 (KC 101)

## Wed. June 26
- **07:30**
  - Registration (Galleria)
- **08:20-10:00**
  - Plenary Session W1 (KC 103/105)
  - Cross-Sectional Topics in Multi-Temporal Analysis I
- **10:00-10:30**
  - Break and Poster Session P2 (KC 101)
- **10:30-12:10**
  - Oral Session T2a (KC 103/105)
  - Agriculture and Grasslands II
  - Oral Session W3a (KC 103/105)
  - Environmental Monitoring
  - Oral Session W3b (KC 201)
  - Urban
- **12:10-13:20**
  - Lunch (Vistas Dining Room, Sally Borden Building)
- **13:20-15:00**
  - Oral Session T3a (KC 103/105)
  - Phenology and Vegetation Dynamics
  - Oral Session T3b (KC 201)
  - SAR-Microwave
- **15:00-15:30**
  - Break and Poster Session P2 (KC 101)

## Thurs. June 27
- **07:30**
  - Registration (Galleria)
- **08:10-9:50**
  - Plenary Session R1 (KC 103/105)
  - Cross-Sectional Topics in Multi-Temporal Analysis II
- **9:50-10:20**
  - Break and Poster Session P3 (KC 101)
- **10:20-12:00**
  - Oral Session R2a (KC 103/105)
  - Agriculture and Grasslands II
  - Oral Session R2b (KC 201)
  - Innovative Applications I
- **12:00-13:00**
  - Lunch (Vistas Dining Room, Sally Borden Building)
- **13:00-14:40**
  - Oral Session R3a (KC 201)
  - Calibration and Data Processing
  - Oral Session R3b (KC 103/105)
  - Innovative Applications II
- **14:40-15:10**
  - Break and Poster Session P3 (KC 101)

## Fri. June 28
- **07:30**
  - Registration (Galleria)
- **16:00-17:00**
  - Keynote Address (KC 103/105)
  - Dr. Curtis Woodcock
  - Boston University
  - Landsat 8: The Landsat Data Continuity Mission (LDCM)
- **17:10**
  - Farewell Social and Awards (Galleria)

## MultiTemp 2013 Signature Excursion: Columbia Icefield
Investing in innovation

TECTERRA provides funding for the development and commercialization of Canadian geomatics technology solutions for integrated resource management and other geospatial applications.

- Low-risk investments
- No IP or equity taken
- Fast turn-around on all programs

Calls for Proposals are now open!

Contact us today!

TECTERRA
www.tecterra.com
ISIS geomatics

UAV Geospatial Imagery, Aerial Mapping, and Aerial Photography Provider

www.isisgeo.com
1-855-ISIS-GEO
MultiTemp 2013 Publication Opportunities

We are pleased to offer Multi-Temp 2013 delegates several publication options:


   Papers – both poster and oral – must have been presented at MultiTemp 2013 to be eligible for the MultiTemp 2013 Proceedings Volume. Proceedings papers are unrefereed but must follow the provided format and be 4 pages maximum. Proceedings papers are not mandatory, but are strongly encouraged with the goal to have a complete record of the science presented at MultiTemp 2013. The Proceedings will be published later in 2013 via IEEE XPlore, which provides extensive international exposure.

2. Special Issues of Refereed Journals:

   • These Special Issues are open to any scientist, although we expect strong interest from Multi-Temp 2013 authors.
   • Authors are strictly not permitted to submit the same or similar manuscript to J-STARS and CJRS, and it must not have been published or currently submitted to any other journal or publication.
   • Authors of shorter papers submitted to the Multi-Temp 2013 Proceedings are welcome to submit longer, full-length versions of their paper to one of the Special Issues, provided their Proceedings paper and their Special Issue submission are sufficiently different – for example, the Proceedings Paper could be a summary, but the full paper submitted for peer-review would have additional results, discussion, scope, and breadth.
   • The policies, guidelines, regulations and submission protocols of the Special Issue journal that you submit to must be followed. These are described further below.
   • Both Special Issues are planned for publication in 2014.

1. MultiTemp 2013 Proceedings

   Submission deadline July 30, 2013

   Proceedings Editor Dr. Greg McDermid, University of Calgary, Canada

   The official electronic proceedings of MultiTemp 2013 will be published in IEEE Xplore. Submission of a proceedings paper (4-page maximum, IEEE format) is not mandatory, but strongly recommended, for all papers presented.

   Proceedings Paper Format
   Papers must be formatted according to the template contained in this Microsoft Word document: MultiTemp2013ProceedingsTemplate.doc, available on the MultiTemp web site.
File Format and Size
Papers must be submitted as an Adobe Portable Document Format (PDF) file. It should not exceed 5 MB (megabytes) in size (before any compression)

Electronic Paper Submission
The IEEE Xplore portal for submitting conference proceedings papers will be opened in July, closer to the deadline. All MultiTemp 2013 authors will be notified when this is available, at which time further submission instructions will be provided.

2. Call for Papers – Special Issues of:

IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (J-STARS)

and

Canadian Journal of Remote Sensing (CJRS)

TOPIC: "Analysis of MultiTemporal Remote Sensing Data"

In the last decade, advances in sensors, techniques and applications have elevated multitemporal imagery to be one of the most important uses of remote sensing. These two Special Issues invite a diversity of papers on this theme, and will be of interest to authors at Multi-Temp 2013 as well as any scientist working in this field. Papers are invited from, though not limited to, topics relating to sensors, techniques and applications of multi-temporal imagery.

Journal-Specific Information:

J-STARS Special Issue on the Analysis of MultiTemporal Remote Sensing Data

Submission deadline 30 September 2013

Guest Editors
Dr. Joseph Piwowar, University of Regina, Canada
Dr. Yifang Ban, Royal Institute of Technology (KTH), Sweden
Dr. Greg McDermid, University of Calgary, Canada
Dr. Lorenzo Bruzzone, University of Trento, Italy

J-STARS is a journal of the IEEE and Geoscience and Remote Sensing Society (GRSS). All submissions will be peer reviewed according to the IEEE GRSS guidelines. Manuscripts are to be submitted online at http://mc.manuscriptcentral.com/jstars using the Manuscript Central interface. Prospective authors should consult this site for guidelines and information on paper submission. Please select « Special Issue: Analysis of Multitemporal Remotely Sensed Data » as the manuscript type. Information about the Journal can be found at http://www.grss-ieee.org/Publications/JSTARS/. Normal page charges, peer-review, and editorial procedures will apply.
CJRS Special Issue on the Analysis of MultiTemporal Remote Sensing Data

Submission deadline 30 September 2013

Guest Editors: Dr. Greg McDermid, University of Calgary, Canada
Dr. Joseph Piwowar, University of Regina, Canada
Dr. Nicholas Coops, University of British Columbia, Canada

The Canadian Journal of Remote Sensing (CJRS) is the official journal of the Canadian Remote Sensing Society. MultiTemp authors are invited to submit full-length versions of their manuscripts to CJRS for possible publication. To submit a paper, log in to the journal submission portal at http://mc.manuscriptcentral.com/cjrs-jct and follow the instructions. Indicate in your cover letter that the paper is to be considered as part of the MultiTemp Special Issue. Normal page charges, peer-review, and editorial process will apply.

Authors are strictly not permitted to submit the same or similar manuscript to J-STARS and CJRS, and it must not have been published or currently submitted to any other journal or publication.
**TECHNICAL PROGRAM**

**Tuesday, June 25, 2013**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30-08:40</td>
<td>Welcome (KC103/105)</td>
</tr>
<tr>
<td>08:40-10:40</td>
<td>Panel I: International Journal Editors-in-Chief Forum (KC103/105)</td>
</tr>
</tbody>
</table>

Organizer and Moderator: Derek Peddle (Lethbridge, Alberta, Canada)

- Marvin Bauer - Minnesota USA: EiC - *Remote Sensing of Environment*
- Russ Congalton - New Hampshire USA: EiC - Photogrammetric Engineering & Remote Sensing
- Nicholas Coops - Vancouver Canada: EiC - *Canadian Journal of Remote Sensing*
- Bill Emery - Colorado USA: IEEE GRSS Vice-President, Founding EiC - *IEEE Geoscience and Remote Sensing Letters*
- Derek Lichti - Calgary Canada: EiC - ISPRS Journal of Photogrammetry and Remote Sensing

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:40-15:20</td>
<td>P1: Poster Session I (KC 101)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Authors / Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alexander Marx, Birgit Kleinschmit and Katrin Möller</td>
<td>Mapping insect defoliation and change intensities using RapidEye data in pure Scots pine stands infested by the nun-moth (Lymantria monacha)</td>
</tr>
<tr>
<td>Valeria Osvaldo, Florence Lafon, Suzanne Brais and Ahmed Laamrani</td>
<td>The use of Landsat time series imagery for characterizing and monitoring young plantations over a boreal forest region in northwestern Quebec, Canada</td>
</tr>
<tr>
<td>Allan A. Nielsen, Knut Conradsen, Henning Skriver and Morton J. Canty</td>
<td>Change detection in dual polarization and fully polarimetric, single- and multi-frequency SAR data and the complex Wishart distribution</td>
</tr>
<tr>
<td>Benjamin Deschamps and Michael D. Henschel</td>
<td>Multi-sensor/multi-beam InSAR ground deformation monitoring of water-flood oil fields</td>
</tr>
<tr>
<td>Fekir Mohamed, Hocine Faiza, Haddoud Affifa, Belhadj-Aissa Aichouche and Belhadj-Aissa Mostepha</td>
<td>Efficient selection of temporally coherent targets in the series of interferometric SAR pair images</td>
</tr>
<tr>
<td>Authors</td>
<td>Title</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Johnson Chan, Torsten Geldsetzer, Nidhi Bishnoi, Jagvijay Gill and John Yackel</td>
<td>Estimating snow thickness distributions on first-year sea ice with enhanced resolution ASCAT microwave satellite data</td>
</tr>
<tr>
<td>Sebastian Aleksandrowicz, Anna Wawrzaszek, Michał Krupiński and Wojciech Drzewiecki</td>
<td>Application of multifractal spectrum to change detection analysis of satellite images</td>
</tr>
<tr>
<td>Jagvijay Pratap Singh Gill, Torsten Geldsetzer, John Yackel and Nidhi Bishnoi</td>
<td>Assimilation of multi-temporal remote sensing-based evapotranspiration into SWAP model for agriculture monitoring</td>
</tr>
<tr>
<td>Daniela Faur, Daniela Espinoza Molina, Inge Gavat and Mihai Datcu</td>
<td>Multi temporal analysis of floods and tsunami effects: annotation and quantitative analysis</td>
</tr>
<tr>
<td>Teodosio Lacava, Emanuele Ciancia, Irina Coviello, Mariapia Faruolo, Francesco Marchese, Giuseppe Mazzeo, Nicola Pergola and Valerio Tramutoli</td>
<td>A multi-year analysis of AMSR-E radio frequency interference in C-, X- and Ku-bands</td>
</tr>
<tr>
<td>Jon Pasher and Jason Duffe</td>
<td>Multi-temporal Radarsat-2 data for semi-automated mapping of high and low waterlines in Canada’s north</td>
</tr>
<tr>
<td>Jennifer D. Watts, John S. Kimball, Lucas A. Jones, Ronny Schroeder and Kyle C. McDonald</td>
<td>Detecting recent changes in surface water inundation across Arctic-Boreal permafrost zones using satellite microwave remote sensing</td>
</tr>
<tr>
<td>Sergey Samsonov, Don White and Michael Craymer</td>
<td>Time series of ground deformation for the Aquistore CO2 Storage Site located in SE Saskatchewan, Canada and computed from five beams of Radarsat-2 data combined using MSBAS methodology</td>
</tr>
<tr>
<td>Zhen Li and Panpan Tang</td>
<td>The Monitoring Surface Deformation of Permafrost in the Qinghai-Tibet Plateau with Time-Series DInSAR</td>
</tr>
<tr>
<td>Jagvijay Pratap Singh Gill, Torsten Geldsetzer, John Yackel and Nidhi Bishnoi</td>
<td>Signature analysis and modeling of multi-temporal multi-frequency polarimetric microwave backscatter from snow covered first-year sea ice</td>
</tr>
</tbody>
</table>
**11:10-12:50 Oral Session T2a: Agriculture and Grasslands I (KC 201) – Session Chair: Greg McDermid**

<table>
<thead>
<tr>
<th>Brent Smith and Greg McDermid</th>
<th>Examination of fire-related plant succession within the dry mixedgrass subregion of Alberta using MODIS and Landsat imagery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menaka Chellasamy, Rafal Tomasz Zielinski and Mogens Humlekrog Greve</td>
<td>A multi-evidence approach for crop discrimination using multi-temporal WorldView-2 imagery</td>
</tr>
<tr>
<td>Carolien Tote, Mouhamadou Bamba Diop, El Hadji Mamadou Ngom, Antoine Royer and Else Swinnen</td>
<td>Improved early warning analysis for crop monitoring in Senegal</td>
</tr>
<tr>
<td>Mutlu Ozdogan</td>
<td>Crop Type Classification by Simultaneous Use of Satellite Images of Different Resolutions</td>
</tr>
</tbody>
</table>

**11:10-12:50 Oral Session T2b: Forestry (KC103/105) – Session Chair: Andrew Hudak**

| Evan Brooks, Randolph Wynne, Valerie Thomas and John Coulston | A Recovery Trajectory Method for Reducing Post-Stratification Variation in Forest Productivity Estimation |
| Todd Schroeder, Gretchen Moisen, Karen Schleeweis, Chris Toney, Warren Cohen and Sam Goward | Developing a Modeling and Rule-based Framework for Mapping Cause of Disturbance in US Forests: Results and Insights from the North American Forest Dynamics (NAFD) Project |
| Oumer S. Ahmed, Steven E. Franklin, Michael A. Wulder and Joanne C. White | Characterizing forest structure using time series Landsat imagery, airborne LiDAR, and machine learning algorithms |
| Ben Devries, Arun Kumar Pratihast, Jan Verbesselt, Lammert Kooistra, Sytze de Bruinand Martin Herold | Near Real-Time Tropical Deforestation Detection Using Dense Landsat Time Series and Local Expert Monitoring Data |
| Andrew Hudak, Benjamin Bright and Robert Kennedy | Predicting bark beetle-induced tree mortality from multitemporal Landsat using LandTrendr |
# 13:50-15:30 Oral Session T3a: Phenology and Vegetation Dynamics (KC103/105) – Session Chair: Yuhong He

<table>
<thead>
<tr>
<th>Speaker(s)</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alexandre Verger, Frederic Baret and Marie Weiss</td>
<td>GEOV2/VGT: continuous, consistent and near real time estimation of global land surface biophysical variables from VEGETATION-P data</td>
</tr>
<tr>
<td>Eli Melaas, Mark Friedl and Zhe Zhu</td>
<td>Detecting Interannual Variation in Deciduous Broadleaf Forests Phenology Using Landsat TM/ETM+ Data</td>
</tr>
<tr>
<td>Yuhong He</td>
<td>Temporal dynamics of vegetation cover in response to precipitation: a comparison over three plant functional groups in a protected semi-arid grassland</td>
</tr>
<tr>
<td>Alexandre Verger, Frederic Baret, Marie Weiss, Iolanda Filella and Josep Peñuelas</td>
<td>Global response of land surface phenology to climate variability</td>
</tr>
<tr>
<td>Pieter Hawinkel, Else Swinnen and Jos Van Orshoven</td>
<td>Assessing vegetation response to climate variability at different time scales</td>
</tr>
</tbody>
</table>

# 13:50-15:30 Oral Session T3b: SAR-Microwave (KC 201) – Session Chair: Yifang Ban

<table>
<thead>
<tr>
<th>Speaker(s)</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shiyong Cui and Mihai Datcu</td>
<td>Cascade Active Learning for Evolution Pattern Extraction from SAR Image Time Series</td>
</tr>
<tr>
<td>Sergey Samsonov and Nicolas D'Oreye</td>
<td>Multidimensional Small Baseline Subset (MSBAS) methodology for spatio-temporal analysis of ground deformation</td>
</tr>
<tr>
<td>Fanny Ponton, Renaud Fallourd, Andrea Walpersdorf, Emmanuel Trouvé, Michel Gay, Flavien Vernier, Jean-Marie Nicolas and Jean-Louis Mugnier</td>
<td>Observation of the Argentière glacier flow variability from 2009 to 2011 by TerraSAR-X and GPS displacement measurements</td>
</tr>
<tr>
<td>Ken Whitehead and Brian Moorman</td>
<td>An integrated system for monitoring patterns of mass change and flow dynamics of a small arctic glacier</td>
</tr>
<tr>
<td>Yifang Ban and Hongtao Hu</td>
<td>Multitemporal RADARSAT-1/-2 SAR for Change Detection in Urban Areas</td>
</tr>
</tbody>
</table>
16:00-17:00  **Keynote Address (KC103/105)**

Dr. Curtis Woodcock  
**Landsat 8: The Landsat Data Continuity Mission (LDCM)**

Boston University
### Wednesday, June 26, 2013

#### 08:20-10:00  
**Plenary Session W1: Cross-Sectional Topics in MultiTemporal Analysis I (KC103/105) – Session Chair: Ron Hall**

<table>
<thead>
<tr>
<th>Presenter(s)</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matthew Jones, John Kimball and Lucas Jones</td>
<td>Satellite Microwave Time Series Detection of Boreal Forest Recovery from Wildfires in Alaska and Canada</td>
</tr>
<tr>
<td>Zhe Zhu and Curtis E. Woodcock</td>
<td>Continuous Change Detection and Classification of Land Cover Using All Available Landsat Data</td>
</tr>
<tr>
<td>Ron Hall, Robert Skakun, Sylvia Thomas and Michelle Filiatrault</td>
<td>Monitoring Forest Change Caused by Insect Defoliation and Drought: What have we learned, What are the Challenges?</td>
</tr>
<tr>
<td>Carina Kübert, Christopher Conrad, Doris Klein and Stefan Dech</td>
<td>Land Surface Phenology from MODIS data in Germany: How does the Remote Sensing based Start of Season reflect inter-annual climate variability?</td>
</tr>
<tr>
<td>Ning Qiao and Xulin Guo</td>
<td>Variation in Distribution and Size Structure of Prairie Pothole Lakes</td>
</tr>
</tbody>
</table>

#### 10:00-15:30  
**P2: Poster Session II (KC 101)**

<table>
<thead>
<tr>
<th>Presenter(s)</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiago S. F. Silva, Maycira P. F. Costa, Evlyn M. L. M. Novo and John M. Melack</td>
<td>A multisensor, multitemporal approach for monitoring herbaceous vegetation growth in the Amazon floodplain.</td>
</tr>
<tr>
<td>Pekka Hurskainen</td>
<td>Agricultural intensification and fragmentation of natural vegetation in the Southern slopes and lowlands of Mt Kilimanjaro, Tanzania</td>
</tr>
<tr>
<td>Arun Govind and Scott Bell</td>
<td>Vegetation mapping in the northern mixed prairie using spectral unmixing approaches</td>
</tr>
<tr>
<td>Kenneth J. Grogan, Dirk Pflughmacher, Rasmus Fensholt and Patrick Hostert</td>
<td>Using MODIS Time-Series for Detecting Multi-Scale Processes of Forest Disturbance in the Challenging Environment of Southeast Asia</td>
</tr>
<tr>
<td>Alisdair Cunningham, Richard Lucas and Pete Bunting</td>
<td>Application of multi-resolution remotely sensed imagery for the monitoring of land cover / habitat change in Wales, U.K.</td>
</tr>
<tr>
<td>Marion Stellmes, Achim Röder,</td>
<td>Using multi-sensor high temporal resolution imagery</td>
</tr>
<tr>
<td>Authors</td>
<td>Title</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Thomas Udelhoven and Joachim Hill</td>
<td>to map land use transformations in Spain under changing socio-economic boundary conditions</td>
</tr>
<tr>
<td>Sandra Dalton</td>
<td>Albertan Sage Grouse: What went wrong?</td>
</tr>
<tr>
<td>Marion Stellmes, Achim Röder and Joachim Hill</td>
<td>A multi-component characterization of the active Okavango Catchment and Delta based on diverse MODIS products</td>
</tr>
<tr>
<td>Jeffrey Cardille and Paul Del Giorgio</td>
<td>Continual refinement of lake carbon estimates using historical, current, and future field and satellite data</td>
</tr>
<tr>
<td>Els De Roeck, Frieke Van Coillie, Robert De Wulf, Hantson Wouter, Els Ducheyne and Guy Hendrickx</td>
<td>Object-based change detection: case study on small water bodies</td>
</tr>
<tr>
<td>Erik Zillmann and Horst Weichelt</td>
<td>Grassland identification using multi-temporal RapidEye image series</td>
</tr>
<tr>
<td>Carolien Tote, Vincent Imala, Charles Situma, David Remotti, Qinghan Dong and Else Swinnen</td>
<td>Fusion of high resolution and multi-temporal remote sensing data for crop mapping in Kenya</td>
</tr>
<tr>
<td>Dennis Chao, Todd Shipman, Ying Zhang and Bret Guindon</td>
<td>Comparative Analysis of SPOT5 Multispectral and Panchromatic Imaginary for Anthropogenic Change Detection and Feature Extraction</td>
</tr>
<tr>
<td>Derek Peddle, Joseph Piwowar and David Sauchyn</td>
<td>Temporal Mixture Analysis of a 21-Year Satellite Image Sequence for Assessing Environmental Variability in Western North America</td>
</tr>
<tr>
<td>Jagvijay Pratap Singh Gill, John Yackel, Torsten Geldsetzer and Nidhi Bishnoi</td>
<td>Near real time landcover information extraction using local maximum fitting and neural network</td>
</tr>
<tr>
<td>Weixin Xu, Daqing Yang, Xulin Guo, Ruixiang Xiao and Jianshe Xiao</td>
<td>Snow Cover Variation of Geladandong Glacier in Hinterland of Qinghai-Tibet Plateau from 2001 to 2012</td>
</tr>
<tr>
<td>Xiaolei Yu, Xuling Guo and Tengfei Cui</td>
<td>Potential for using GIMMS and MODIS NDVI date set for investigating deciduous broadleaf forest carbon sink over continental U.S.</td>
</tr>
<tr>
<td>Eduardo Maeda</td>
<td>Assessing altitudinal dependency of temperature trends in Mount Kilimanjaro using multi-temporal satellite data</td>
</tr>
<tr>
<td>Sinhoi Goo, Seongsam Kim and Youngjin Park</td>
<td>Snow Cover Mapping for Response in Heavy Snow Events with Multi-temporal MODIS Imagery</td>
</tr>
</tbody>
</table>
### Oral Session W2a: Change Detection (KC103/105) – Session Chair: Robert Fraser

<table>
<thead>
<tr>
<th>10:30-12:10</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lionel Gueguen and Fabio Pacifici</td>
<td>The Local Mutual Information Invariance: Application to Change Detection Between Multispectral Images</td>
</tr>
<tr>
<td>Robert Fraser, Ian Olthof, Alice Deschamps, Marilee Pregitzer, Steve Kokelj, Trevor Lantz, Steve Wolfe, Alex Brooker, Denis Lacelle and Steve Schwarz</td>
<td>Documenting Land Cover and Vegetation Productivity Changes in the Northwest Territories using the Landsat Satellite Archive</td>
</tr>
<tr>
<td>Boulerbah Chabira, Takieddine Skanderi, Mohamed Fekir and Aichouche Belhadj Aissa</td>
<td>Unsupervised Change Detection of Multitemporal Multichannel SAR Images based on Stationary Wavelet Transform</td>
</tr>
<tr>
<td>Greg McDermid</td>
<td>Multi-Temporal Change Analysis: How Relative Change Should be Measured</td>
</tr>
<tr>
<td>Steven Vanonckelen, Stefaan Lhermitte and Anton Van Rompaey</td>
<td>Do combined atmospheric and topographic correction methods improve land cover change classification in mountain areas?</td>
</tr>
</tbody>
</table>

### Oral Session W2b: Water and Hydrology (KC 201) – Session Chair: L. Monika Moskal

<table>
<thead>
<tr>
<th>10:30-12:10</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Linda Moser and Stefan Voigt</td>
<td>Multi-scale and multi-temporal wetland monitoring in sub-Saharan West-Africa using time series of medium and high resolution optical satellite data</td>
</tr>
<tr>
<td>Yuanzhi Zhang, Chuqun Chen and Zhaojun Huang</td>
<td>Chlorophyll-a estimation in the Pearl River estuary, China</td>
</tr>
<tr>
<td>Meghan Halabisky and L. Monika Moskal</td>
<td>Time Series Analysis of Wetland Dynamics through Spectral Mixture Analysis of Landsat Satellite Imagery</td>
</tr>
<tr>
<td>Daniel Gann, Jennifer Richards and Himadri Biswas</td>
<td>Evaluating accuracy improvements in wetland vegetation classification at two scales using bi-seasonal remotely sensed data</td>
</tr>
<tr>
<td>Andy Dean, Olivier Tsui, Agus Salim, Martin Davies, Yves Crevier, Martin Hebert, Heather Kieth and Wade Gibbons</td>
<td>Remote monitoring of regional water quantity and water quality in the Athabasca oil sands region – lessons learned and future opportunities</td>
</tr>
</tbody>
</table>
### Oral Session W3a: Environmental Monitoring (KC103/105) – Session Chair: Rasim Latifovic

<table>
<thead>
<tr>
<th>13:20-15:00</th>
<th><strong>Oral Session W3a: Environmental Monitoring (KC103/105) – Session Chair: Rasim Latifovic</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>He Yin, Dirk Pflugmacher, Zhengguo Li and Patrick Hostert</td>
<td>Assessing land degradation in Inner Mongolia using MODIS time series</td>
<td></td>
</tr>
<tr>
<td>Baudouin Desclee, Frederic Achard and Philippe Mayaux</td>
<td>Monitoring forest degradation with SPOT imagery: First Assessment in the Congo Basin</td>
<td></td>
</tr>
<tr>
<td>Darren Pouliot and Rasim Latifovic</td>
<td>Accuracy Assessment of Annual Land Cover Time Series Based on Change Updating</td>
<td></td>
</tr>
<tr>
<td>Dirk Pflugmacher, Kenneth J. Grogan, Robert E. Kennedy, Sithong Thongmanivong, and Patrick Hostert</td>
<td>Using annual Landsat time series for detecting deforestation and forest degradation in mosaic landscapes of Southeast Asia</td>
<td></td>
</tr>
<tr>
<td>Ryan Frazier, Nicholas Coops and Mike Wulder</td>
<td>Recovery Focused Temporal Trajectories and Recovery Rates of Northern Boreal Forests</td>
<td></td>
</tr>
</tbody>
</table>
Organizer and Moderator: **Greg McDermid** (Calgary, Alberta, Canada)

**Kirk Andries**: Executive Director, Alberta Biodiversity Monitoring Institute. Edmonton, Alberta, Canada.

**Paola de Rose**: Director Earth Observation and GeoSolutions Division, Canada Centre for Remote Sensing, Ottawa, Canada.

**Shane Patterson**: Science and Technology Specialist, Alberta Environment and Resource Development. Edmonton, Alberta, Canada.

**Jennifer Grant**, Oil Sands Program Director, Pembina Institute. Calgary, Alberta, Canada.
### Thursday, June 27, 2013

#### 08:10-9:50  
**Plenary Session R1: Cross-Sectional Topics in MultiTemporal Analysis II (KC103/105) – Session Chair: Brian Brisco**

<table>
<thead>
<tr>
<th>Speaker(s)</th>
<th>Presentation Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Stow, Lloyd Coulter, Christopher Lippitt, Richard McCreight and Yu-Hsin Tsai</td>
<td>Implementations of a Repeat Station Imaging Approach for Precise Image Registration and Detailed Change Detection at Varying Temporal Resolutions and Durations</td>
</tr>
<tr>
<td>Brian Brisco and Marco van der Kooij</td>
<td>Exploiting Multi-temporal SAR for Monitoring Applications</td>
</tr>
<tr>
<td>Chris Hopkinson, Laura Chasmer, Natascha Kljun, Eva van Gorsel, McCaughey Harry, Alan Barr, Andy Black and Heather Keith</td>
<td>Monitoring tree growth and harvest related changes in forest biomass and carbon using lidar</td>
</tr>
<tr>
<td>Inacio Bueno, Jennifer Hird, Guillermo Castilla and Greg McDermid</td>
<td>Applying a new decadal change product in the monitoring of urban expansion around Calgary, Alberta</td>
</tr>
<tr>
<td>Carlo Marin, Francesca Bovolo and Lorenzo Bruzzone</td>
<td>An approach to the detection of changed buildings in multitemporal very high resolution SAR image</td>
</tr>
</tbody>
</table>

#### 9:50-15:10  
**P3: Poster Session III (KC 101)**

<table>
<thead>
<tr>
<th>Speaker(s)</th>
<th>Presentation Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xulin Guo and Xiaohui Yang</td>
<td>Remote Sensing of Vegetation Productivity in Northern Ecosystems</td>
</tr>
<tr>
<td>Laura Chasmer, Kayla Giroux, Chris Hopkinson, Richard Petrone, Natascha Kljun and Kevin Devito</td>
<td>Incorporating porometry measurements, multi-temporal airborne LiDAR, and high resolution WorldView2 data to better understand competition and growth within a heterogeneous forest regeneration stand</td>
</tr>
<tr>
<td>Thuan Chu and Xulin Guo</td>
<td>Logistic Regression Modeling for Reconstructing Long Time Series of Burned Areas</td>
</tr>
<tr>
<td>Ehsan Chowdhury and Quazi Hassan</td>
<td>Can remote sensing be effective for forecasting forest fire danger conditions?</td>
</tr>
<tr>
<td>Carolien Tote, Francisco Tauacale, Domingos Patricio and Else Swinnen</td>
<td>Remotely sensed time series for monitoring the effects of the Limpopo River flooding on agriculture in Mozambique</td>
</tr>
</tbody>
</table>
Ajira Tiangtrong, Pasu Kongapai and Somrudee Jitprapai

Land Cover Change from Tsunami and Recovery Monitoring in Ban Nam Khem, Phang Nga Province, Thailand Using IKONOS Imagery

Pasu Kongapai, Ajira Tiangtrong, Somrudee Jitprapai and Penjai Sompongchaiyakul

Coastal vegetation change using Muti-temporal remotely sensed data at Ban Nam Khem, Southern, Thailand, by Tsunami 2004

Seongsam Kim, Sinhoi Goo and Youngjin Park

Data Integration of Multi-temporal disaster imagery for Timely Natural Disaster monitoring

Carly Mertes, Annemarie Schneider, Damien Sulla-Menashe, Bin Tan and Andy Tatem

Monitoring urban expansion using a multitemporal data fusion approach: First results for South and East Asia

Richard Fernandes and Fuqun Zhou

Characterizing snowpack properties through particle filter assimilation of AVHRR data into a global snow depth analysis

Jennifer Hird, Inacio Bueno, Riley Iwamoto, Guillermo Castilla and Greg McDermid

A new MODIS product for visualizing multi-temporal regional change on a decadal scale

Youngwook Kim, John Kimball and Kamel Didan

Satellite detection of changing frozen seasons and associated impacts on northern hemisphere vegetation growth

Joanna Adamczyk and Dirk Tiede

Multitemporal structural variability analysis of vegetation patterns in the Sierra Nevada Mountains (Spain): an object-based framework to integrate archived remote sensing images of different sensors

Loïc Dutrieux, Jan Verbesselt, Lammert Kooistra and Martin Herold

Combining medium and high resolution data in a multiscale approach to detect breaks in satellite image time series

Hantson Wouter, Els De Roeck, Els Ducheyne and Guy Hendrickx

Multi-temporal UAV Image Processing for Habitat Modeling

Tengfei Cui, Xulin Guo and Xiaolei Yu

A Comparison of the climate-impacted variation in phenological metrics of the grassland ecoregions in northern Tibet and southern Saskatchewan from 1982 to
<table>
<thead>
<tr>
<th>Name(s)</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toshihiro Sakamoto, Anatoly Gitelson and Timothy Arkebauer</td>
<td>Spatio-temporal analysis using MODIS time-series data for early prediction of US corn yield</td>
</tr>
<tr>
<td>Sarah Asam, Luca Pasolli, Claudia Notarnicola and Doris Klein</td>
<td>Comparison of Leaf Area Indices for Alpine grasslands based on multi-scale satellite data time series and radiation transfer modeling</td>
</tr>
<tr>
<td>Erik Zillmann, Enrique Montero Herrero, Thomas Esch, Manfred Keil, Joeri van Wolvelaer and Horst Weichelt</td>
<td>Mapping of grassland using seasonal statistics derived from multi-temporal satellite images</td>
</tr>
<tr>
<td>Josh Gray, Mark Friedl and Steve Frolking</td>
<td>Large scale maps of cropping intensity from MODIS</td>
</tr>
<tr>
<td>Will McInnes, Brent Smith and Greg McDermid</td>
<td>Separating herbaceous land cover in three prairie natural subregions with multi-temporal MODIS imagery</td>
</tr>
<tr>
<td>Dandan Xu, Xulin Guo, Zhaoxin Li, Xiaohui Xiao and Han Yin</td>
<td>Measuring the dead component of mixed grassland with remote sensing</td>
</tr>
<tr>
<td>Julia Linke, Greg J. McDermaid, Marie-Josee Fortin and Gordon B. Stenhouse</td>
<td>Multi-annual landscape monitoring using the disturbance-inventory framework and its application to grizzly bears in west-central Alberta</td>
</tr>
<tr>
<td>Richard Fernandes and Nadia Rochdi</td>
<td>An approach for physically consistent multi-scale LAI retrieval from Sentinel-3 OLCI and Sentinel-2 MSI</td>
</tr>
<tr>
<td>Daniel Kristof and Robert Pataki</td>
<td>Pushing MODIS to the edge: high-resolution applications of moderate-resolution data</td>
</tr>
<tr>
<td>David Colville, Sarah Marie McDonald, Christina Plumridge and Suzanne Monette</td>
<td>Assessing impacts of coastal landscape change on Piping Plover habitat in New Brunswick, Canada using multitemporal LiDAR and aerial photography</td>
</tr>
<tr>
<td>Francesca Bovolo and Lorenzo Bruzzone</td>
<td>A tool for image time series representation</td>
</tr>
</tbody>
</table>
### 13:00-14:40

**Oral Session R3a: Calibration and Data Processing (KC 201) – Session Chair: Rene Colditz**

<table>
<thead>
<tr>
<th>Presenter(s)</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>John Schott, Michael Gartley, Aaron Gerace and Scott Brown</td>
<td>The potential for using synthetic image simulation tools to study multi-temporal phenomenology and support multi-temporal algorithm development.</td>
</tr>
<tr>
<td>Jordi Muñoz-Mari, Luis Gómez-Chova, Julia Amorós, Emma Izquierdo and Gustavo Camps-Valls</td>
<td>Multiset Kernel CCA for Multitemporal Image Classification</td>
</tr>
<tr>
<td>Else Swinnen, Bart Deronde and Roel Van Hoolst</td>
<td>Monitoring data consistency between SPOT-VEGETATION to Proba-V</td>
</tr>
<tr>
<td>Julia Amorós Lopez, Emma Izquierdo Verdiugier, Luis Gómez-Chova, Jordi Munoz and Gustavo Camps-Valls</td>
<td>A Kernel Regression Approach to Cloud and Shadow Detection in Multitemporal Images</td>
</tr>
<tr>
<td>Rene Colditz</td>
<td>The impact of the day of observation of image composites on adequate time series generation</td>
</tr>
</tbody>
</table>

### 13:00-14:40

**Oral Session R3b: Innovative Applications II (KC103/105) – Session Chair: Scott Nowicki**

<table>
<thead>
<tr>
<th>Presenter(s)</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rasim Latifovic and Darren Pouliot</td>
<td>Cumulative Impact Assessment: Monitoring land surface condition at regional scale using satellite remote sensing</td>
</tr>
<tr>
<td>Scott Nowicki</td>
<td>Thermophysical Analysis of the Southwestern US from Multi-Year MODIS Land Surface Temperature</td>
</tr>
<tr>
<td>Antoine Masse, Danielle Ducrot and Philippe Marthon</td>
<td>Supervised classification on large area with temporal/spectral statistical database of radiometric values, sentinel-2 preparation program</td>
</tr>
<tr>
<td>Gary Borstad, Leslie Brown, Richard Thomson, James Irvine and Scott Akenhead</td>
<td>Using satellite imagery to explore linkages between the growth and survival of Pacific sockeye salmon and variability in their marine and terrestrial environments</td>
</tr>
<tr>
<td>Francesco Marchese, Teodosio Lacava, Nicola Pergola, Emilio Miraglia, Katsumi Hattori and Valerio Tramutoli</td>
<td>Thermal monitoring of Japanese volcanoes by using a multitemporal method (RSTVOLC) of satellite data analysis</td>
</tr>
</tbody>
</table>
Organizer and Moderator: **Warren Cohen** (Corvallis, Oregon, USA)

**Curtis Woodcock**, Boston University, Massachusetts, USA.

**David Roy**, South Dakota State University, USA.

**Joanne White**, Canadian Forest Service, British Columbia, Canada.

**Richard Allen**, University of Idaho, USA

**Todd Schroeder**, U.S. Department of Agriculture Forest Service, Utah, USA.
Multitemporal structural variability analysis of vegetation patterns in the Sierra Nevada Mountains (Spain): an object-based framework to integrate archived remote sensing images of different sensors

Joanna Adamczyk¹, Dirk Tiede²
¹ Warsaw University of Life Sciences - SGGW, Faculty of Forestry
² University of Salzburg, Department of Geoinformatics - Z_GIS

The process to elaborate solutions for fulfilling the monitoring requirements for the Natura 2000 network (Habitats Directive (92/43/EEC) and the Birds Directive (79/409/EEC)) is currently ongoing. There is also a need for supplementing short time series of EO data collected in the framework of European initiatives with archived remote sensing data containing information on the Earth environment from the past decades. The object-based image analysis approach (GEOBIA) shows a great potential in elaboration of methods addressing such data integration challenges.

The aim of our work was to develop transferable rule-sets, which integrate expert knowledge to provide information layers on changes in the vegetation pattern of the Sierra Nevada Mountains (Spain). The area is one of the pilot sites for establishing a multiscale monitoring service, pre-operationally developed within the EU FP7 Project MS.Monina (Multi-scale Service for Monitoring NATURA 2000 Habitats of European Community Interest). During the last 30 years some processes are hypothesized to occur in vegetation pattern of this area: altitudinal shift of the oak (Quercus Pyrenaica) forests - habitat loss in low altitudes and colonization in high elevation, colonization of abandoned mountain crops and pastures, changes in area occupied by pine (Pinus Silvestris) plantations. The occurrence of forest fires and impact from the skiing area are also observed.

We investigated the feasibility of obtaining and comparing structural indices from the multitemporal data. Our data set consists of series of Spot 1, 2 and 5 images from the years 1990 (10 m, BW), 1998 (10 m, C), 2005-2011 (2.5-5 m resolution BW, C). The current spatial structure of the vegetation cover was identified on a WorldView-2 image from 2011 (Pan 0.5 m, MS 2m). The topography-dependent characteristics are assessed based on a Digital Elevation Model (10m), which has been additionally integrated into the analysis.

The discussion is focussing on the strengths and limitations of the developed method with regard to the robustness of the obtained information across different sensors.
Characterizing forest structure using time series Landsat imagery, airborne LiDAR, and machine learning algorithms

Oumer S. Ahmed a, Steven E. Franklin a, Michael A. Wulder b, Joanne C. White b

a Geomatics, Remote Sensing and Land Resources Laboratory, Department of Geography, Trent University

b Canadian Forest Service (Pacific Forestry Centre), Natural Resources Canada

Canopy cover and height are important forest variables that provide information relating to forest structure, volume, and standing biomass, thereby informing on carbon stocks. Many forest management activities, including the development of forest inventories, require spatially detailed information on forest structure. The relationship between single-date Landsat imagery and forest structure weakens under certain canopy conditions since the structure and composition of a forest stand at any point in time is linked to the stand’s disturbance history. One option for enhancing our capacity to characterize forest structure with Landsat data is to include information on historic forest disturbance trends, which can inform on forest succession and growth characteristics. In this study we present an approach for modeling spatially exhaustive estimates of forest canopy cover and height using spectral indices derived from a 32-year (1972–2004) time series of Landsat imagery in a coastal temperate forest on Vancouver Island, British Columbia, Canada. Forest attributes generated from a sample of LiDAR data provide the terminal forest structural conditions circa 2004 for model calibration and validation. We applied a trajectory-based approach to Landsat time series analysis, which provided information regarding the intensity and year of disturbance. This disturbance information was used to differentiate disturbed and undisturbed strata within the study area. Canopy cover and height were then modelled separately for each stratum using multiple regression and machine learning algorithms and the results were compared. This study demonstrates the value of using the full depth of the Landsat archive to improve and extend estimates of forest canopy cover and height over large areas using machine learning algorithms and strata defined by disturbance history information.
Application of multifractal spectrum to change detection analysis of satellite images

Sebastian Aleksandrowicz¹, Anna Wawrzaszek¹, Michał Krupiński¹, and Wojciech Drzewiecki²

¹ Space Research Centre of the Polish Academy of Sciences
² AGH University of Science and Technology

Multifractal image analysis base on a statement that image can be treated as a multifractal which is a nontrivial combination of a number of fractals. Hence, multifractal decomposition, as the generalization of the fractal geometry can be considered as a convenient mathematical tool for description, modelling, processing and analysis of different complex shapes and signals. In our work we use multifractal formalism for analysis of inhomogeneous measures and structures presented on satellite images. In particular, we consider one of the multifractal functions: singularity spectrum (f(α)) in the context of land cover change detection. The singularity spectrum, as a function of the singularity strength α, allows detailed local and global characterisation of images. Exponent α describes the local irregularity, while values of f(α) are a global distribution of the irregularity in the whole scene. Moreover, by using f(α) we can consider the strongest and the weakest singularities existing on considered image.

In this study we determine singularity spectra f(α) and parameters related with them for the pair of very high spatial resolution IKONOS images in order to detect land cover changes. As the full IKONOS scene is too big for such analysis and it will contain lot of changes caused by sensor viewing angle difference, various illumination conditions etc., we decided to split it into a number of tiles and analyse them separately. Comparison of singularity measures computed for all tiles of both images allows for evaluation whether change in land cover happened. Results of our analysis show that the singularity spectrum can effectively reflect the non-uniform property of the image. Moreover, changes of the shape of singularity spectrum inform about changes in land cover on pair of images acquired in two points in time. On the basis of our study, we can conclude that multifractal formalism can be considered as a promising and useful tool for the change detection analysis that has not been widely tested so far.
A Kernel Regression Approach to Cloud and Shadow Detection in Multitemporal Images

Image Processing Laboratory (IPL) Universitat de València Spain

1 Motivation and Introduction

In the upcoming years, there will be a growing interest in exploiting multitemporal data from the next constellation of Earth Observation satellites. The recent launch of the new Landsat 8 spacecraft and the Sentinels mission will provide global and systematic coverage with high spatial resolution and high revisit time. In this scenario, and for a proper exploitation of the temporal domain, a first critical step is the detection and elimination of clouds and shadows, as they introduce artifacts in the time series and represent a common error source for further multitemporal analysis. Several approaches for cloud screening have been developed over the last decades, which are usually designed on a single-image basis and are mainly based on combination of rules and thresholds over a set of spectral filters or indices. This is for example the case of the Automated Cloud Cover Assessment (ACCA) system [1] and the recently proposed Fmask (Function of mask) [2] for the cloud detection in Landsat images. However, the availability of image time series with higher revisit time allows to consider the cloud screening problem as an anomaly detection problem in the multitemporal domain. Certain spectral features are mainly due to clouds and shadows.

2 Cloud Screening of Image Time Series

We cast the problem of cloud screening in multitemporal images as a multitemporal anomaly detection problem. The field of change detection is vast and many approaches are available in the literature [3]. Change detection boils down to identify the abnormality buried in the background, and a particularly interesting approach is the so-called chronochrome method [4]. The chronochrome essentially assumes that the background is stationary in wide sense (in our case the time series follows smooth variations) and hence the anomalies (e.g. clouds) will deviate from the predicted values. Chronochrome relies on applying a regularized regression method that approximates the underlying system that generated the data: while originally a linear least squares fit was proposed [4], nonlinear regression has been shown to provide some advantages related to deal with the (somewhat strong) assumption of non-Gaussian noise and linearities [5]. After the estimation is done, one simply look into the residuals: the anomalies are simply identified as those features whose associated residuals stand out most.

In this paper, we propose a cloud screening and a cloud shadow detection method for image time series based on linear and nonlinear regression analysis. The intuition behind this approach is simple: the predicted values will be presumably similar to the previous images for a given land cover, and only when an abrupt change occurs, the predicted and actual values from the acquired image will be different. Despite these abrupt changes usually comes from clouds and shadows, we also need to consider that other sudden changes may occur, such as fires, floods, harvesting, etc. For these reasons, a set of features based on the clouds and shadows physical properties should be taken into account in order to develop the regression method. Furthermore, the regression applied to the temporal
signature of the different land covers could provide useful information to fill the gaps in the cloud-masked regions.

Under the light of the previous premises, we need several ingredients for the multitemporal algorithm: a set of rich and discriminative features for cloud screening, and a (possibly nonlinear) regression algorithm that can efficiently approximate eventually complicated time series dynamics, which in turn can estimate several variables simultaneously. Linear and nonlinear regression methods are explored in this paper to estimate (interpolate) the expected image value of a set of image features at a certain instant in the time series. In particular, we focus on the regularized least squares linear and kernel regression methods [6, 7]. Both approaches allow multi-output regression in a natural way (so several features of interest can be estimated at each time instant) and intuitive parameters that control the regularization (smoothness and nonlinearity) are adjusted.

3 Experiments and Results

Experiments presented in the paper are carried out using a Landsat time series acquired over Albacete (Spain) in 2009. The set of the most relevant features for cloud detection used in this paper is selected by analyzing their physical properties and attending to previous cloud screening approaches for Landsat images [1, 2]. Figure 1 shows an example of a subset of the Landsat time series. The images acquired in a temporal window at the instants T1 to T3 are used to predict the image at T4 using as inputs the spectral bands and the extracted features. Figure 2 shows the magnitude of the RMSE between the predicted and the acquired Landsat image, and the sign indicates whether there is an increase or a decrease in the spectrum intensity, which is relevant to distinguish clouds from their shadows. Figure 2(a) and (b) show the residuals from the linear and non-linear regression methods, respectively. Some observations can be raised: (1) the use of the most relevant

![Figure 1: RGB composition of four selected images from the Landsat time series acquired in Albacete, Spain (2009).](image-url)
features for cloud detection allows to distinguish the clouds and shadows from other land-cover changes in the surface; and (2) the nonlinear regression method based on kernels provides an improved rejection of the non-relevant changes over its linear counterpart. Finally, a simple unsupervised classification of the residual norm image (norm of the difference between the observed and predicted features) using $k$-means clustering ($k = 3$ for clouds, shadows and background) provides an accurate cloud-shadow mask in Fig. 2(c). Quantitative results and a benchmarking of the detection performance against other methods will be also given at the time of the conference.

References


This work is supported by the projects UN-INV-PRECOMP12-80539, FP7-SPACE-2012-313117 and TIN2012-38102-C03-01
Comparison of Leaf Area Indices for Alpine upland grasslands based on multi-scale satellite data time series and radiation transfer modeling

Sarah Asam¹, Luca Passoli², Claudia Notarnicola², Doris Klein³
¹ University of Würzburg, Department of Remote Sensing
² EURAC Research, Institute for Applied Remote Sensing
³ German Aerospace Center (DLR), German Remote Sensing Data Center (DFD)

Remote sensing time series can be used to monitor biophysical variables such as the Leaf Area Index (LAI), which is a key parameter of vegetation structure and particularly important for modeling energy and matter fluxes in the biosphere. Medium resolution satellite systems are well suited for this aim thanks to their high temporal acquisition frequency. However, the scientific community is moving towards exploiting new generation high resolution sensors, such as RapidEye, in view of the upcoming Landsat 8 and Sentinel 2 satellites. These systems offer new opportunities for the monitoring of ecosystems, especially when dealing with challenging environments such as the Alpine region with its small-scale land use pattern and highly dynamic grasslands.

Recently, an algorithm based on an inverted radiation transfer model (RTM) has been applied to MODIS imagery to derive regionally adapted LAI estimates over Alpine grasslands with improved performance with respect to standard LAI products (see Pasolli et al. 2011). In our study, this approach is applied to MODIS as well as to high resolution RapidEye images acquired over the TERENO-prealpine site in the Bavarian alpine upland. On one hand, this work aims at understanding the challenges and effectiveness of the inverse RTM when applied to high resolution data. On the other hand, the possibility to compare LAI estimates derived from different sensors in the complex Alpine environment offers the opportunity to investigate the role of spatial resolution on the retrieval process.

On the high spatial resolution scale, four RapidEye scenes from May 9, May 25, July 16, and September 6, 2011 are available. The data have five bands in the visible, red edge and near infrared domain and a spatial resolution of 6.5 m. The preprocessing consisted of geometric correction, orthorectification, topographic and atmospheric correction (DLR 2013). Grassland masks were derived based on a land cover classification. All results are validated with in situ LAI measurements, which have been collected during the four corresponding weeks of the RapidEye data acquisitions at 14 – 33 locations using a LICOR LAI-2000 PCA and corrected using destructive LAI samplings from the same sites and dates. The LAI in situ values per plot cover a data range from 1.5 to 7.4 with a mean of 3.6.

In a RTM, the transmittance and reflectance of light within a canopy are simulated. The model is characterized in a first step by its leaf and canopy variables. For the RapidEye scale, the PROSAIL model (see Jacquemoud et al. 2009) is parameterized based on values collected in the field and on literature values. After calculating the reflectances of multiple canopy realizations,
the model is inverted, i.e. the parameter set (including LAI) which produced the most similar reflectances is selected for each pixel of the remote sensing data. For the inversion, look up tables and a cost function based on the normalized RMSE are applied. Additionally to the RapidEye bands, two vegetation indices are used as input data to the inverted RTM. The MODIS LAI time series was derived according to the algorithm described in Pasolli et al. (2011) using the 250 m MODIS Terra reflectance in the PROSAIL model inversion.

The four resulting high resolution LAI maps overestimate the in situ LAI data with a medium accuracy (in terms of RMSE) ranging from 0.86 - 0.97 for the individual time steps, with higher the accuracies in the middle and end of the season. However, the spatially variable patterns of growth stages of the individual meadows within the scenes are clearly captured. With regard to its effectiveness, the method is computationally very extensive.

The 8-day MODIS LAI time series reflects the temporal pattern of green-up, senescence, and mowing events satisfactorily. Considering the resolution of the sensor and the heterogeneity of the area, this algorithm achieved good results in comparison with the in situ LAI data (RMSEs ranging from 0.83 – 1.68). However, the MODIS LAI also tends to overestimate the in situ LAI and does not fully catch the variability of all field measurement plots. Thus, while the RapidEye LAI aims at characterizing the spatial pattern of grasslands, the MODIS LAI is better suited to monitor detailed temporal patterns such as sudden LAI reduction caused by mowing due to its higher temporal resolution. This time series information could be used for the fitting of RapidEye time series interpolation in future work.

To analyze systematically the role of the data spatial resolution on the LAI retrieval accuracy, synthetic datasets with intermediate resolutions (19.5 m, 45.5 m, and 97.5 m) were created from the RapidEye scenes by pixel aggregation. The simulated reflectances were then used as input data for the PROSAIL model inversion for each time step. The resulting LAI maps show RMSEs of 0.87 – 0.99 (19.5 m resolution), 0.93 - 1.11 (45.5 m), and 0.98 – 1.12 (97.5 m). With regard to the persistence of spatial patterns, the 19.5 m resolution map provides a sufficient level of detail for the specific landscape. Although small fields are no longer recognizable on the 45.5 m scale, the range of LAI values is still captured, i.e. the distinction of different growth stages is still possible for the larger meadows. The 97.5 m data show only few similar patterns compared to the original data, as do the MODIS LAI data. Based on those results, a scaling effect with regard to the recognition of spatial patterns can be observed for the synthetic 45.5 m and less resolution data, constituting the suitability of future LDCM and Sentinel 2 data for the accurate LAI mapping in Alpine environments.

Multitemporal RADARSAT-1/-2 SAR for change detection in urban areas

Yifang Ban¹ and Hongtao Hu¹
¹ KTH Royal Institute of Technology

Multitemporal SAR images have been increasingly used in change detection studies due to SAR’s independence of atmospheric and solar illumination conditions and the availability of spaceborne SAR images with medium or high resolutions. However, SAR images suffer from the presence of speckle which makes analysis and processing of such imagery a difficult task. In this research, an effective non-local means (NLM) filtering algorithm that combines local structures with a global averaging scheme will be investigated in the context of change detection using multitemporal SAR images. Then change detections will be performed using supervised and unsupervised methods. For supervised change detection, Support Vector Machines (SVM) was used to classify the change images into three classes, positive change, negative change and no change. For unsupervised change detection, it involves the thresholding of the difference image that was generated by ratioing of the two SAR image. Image thresholding becomes very difficult, however, when the difference image exhibits a strongly unimodal histogram. In this paper, we present an automatic and effective approach to the thresholding of the difference image whose histogram may be bimodal or unimodal. A bimodality test is performed to determine whether the histogram of the difference image is bimodal. If it is bimodal, the generalized Kittler and Illingworth thresholding algorithm is used to find the optimal threshold value. If it is unimodal, a window selection process is carried out to select windows which are a balanced mixture of unchanged and changed classes. The selected windows are combined to generate a new bimodal histogram. The optimal threshold value obtained from the new histogram by the generalized Kittler and Illingworth thresholding algorithm is then used to separate unchanged and changed classes in the difference image.

The study area is located in the northwest part of the Greater Toronto Area where rapid urban expansion occurred. RADARSAT-1 fine-beam C-HH SAR image acquired in summer, 2002 and RADARSAT-2 fine-beam C-HH SAR image in summer, 2008 were selected for this experiment. Preliminary results show that the proposed approaches are effective for urban change detection using multitemporal RADARSAT-1/-2 SAR images.
Using satellite imagery to explore linkages between the growth and survival of Pacific sockeye salmon and variability in their marine and terrestrial environments

G. A. Borstad¹, L. N. Brown¹, S. A. Akenhead¹, R. E. Thomson³ and J. R. Irvine⁴
¹ASL Environmental Sciences Inc., Victoria, British Columbia (*corresponding author)
²Ladysmith Institute, Ladysmith, British Columbia
³Fisheries and Oceans Canada, Sidney, British Columbia
⁴Fisheries and Oceans Canada, Nanaimo, British Columbia

The numbers of Pacific sockeye salmon (*Oncorhyncus nerka*) returning to spawn in the Fraser River in British Columbia have varied drastically during the last decades. There is a pressing need to better understand the factors controlling variation, so that this economically and culturally important fish can be protected and the fishery properly managed. Fraser sockeye have a complicated life cycle, moving downstream from freshwater lakes and rivers, through the Strait of Georgia and into the Northeast Pacific Ocean, and eventually back to freshwater to spawn and die. In the freshwater phase, factors such as water quality, nutrients, plankton production, and flow rates are known to affect salmon productivity. Many of these factors have been linked to vegetation phenology in the watershed. In the marine phase, several studies have shown that food availability shortly after the fish enter the ocean is critical to survival.

Again, these factors have been related to the vegetation phenology, in particular the timing of the spring plankton bloom.

Sockeye are wide-ranging, much of their very large habitat is impractical to sample and in situ data are sparse. Satellite imagery is the only source of consistent and synoptic information available at the relevant temporal and spatial resolutions, and we have now accumulated continuous time series of 30 years or longer for some variables. In this paper we show how we were able to exploit these long satellite time series to test hypotheses about the relationships between variations in Fraser sockeye abundance and variations in their terrestrial and marine habitats. Our discussion is limited to Fraser sockeye from Chilko Lake, located in the BC central coastal mountains, because this stock has the longest and most complete time series for freshwater and marine survivals. We used satellite-derived Normalized Difference Vegetation Index (NDVI) as an index of terrestrial vegetation phenology and cover for the entire province of British Columbia, from 1984 to 2007 with 1 km and 10 day resolution. In the marine environment, we assembled SeaWiFS and MODIS data to examine time-series of phytoplankton chlorophyll in the coastal areas of the North East Pacific from 1997 to 2010 with 9 km and 8 day resolution. We extracted spatially-averaged time series for several regions of interest (watersheds and coastal zones) and from these we calculated secondary indicators such as means, trends, monthly and annual anomalies, and the timing of seasonal events. Correlations were then calculated between these indices and time series for salmon growth and survival provided by Fisheries and Oceans Canada, taking care to avoid relationships driven by outliers. The most robust relationships
were then mapped on a pixel-by-pixel basis across wide areas to look for spatial patterns that might hold explanatory power.

Of course, even strong correlations are only clues to causation, possibly from unobserved drivers behind both of the correlated variables. Statistical issues, including non-normal distributions, autocorrelation, and observation error in both fish and satellite data preclude relying on the statistical significance of these correlations. With these caveats, comparison of the satellite-derived metrics to salmon survival calculated separately for marine and freshwater phases of their life do suggest that watershed and regional changes captured by the satellite time-series are related to the production of sockeye salmon from Chilko Lake.

Our hypotheses were that marine and freshwater survival could be related to geographically identifiable stressors such as a widespread infestation mountain pine beetle and other changes to terrestrial physiognomy (NDVI greenness) in the Chilko Lake watershed and the surrounding Fraser Basin. We were able to reject the null hypothesis in both cases. We found that freshwater survival was positively correlated (n=20, p < 0.05) with changes in NDVI during their freshwater brood year, but only in localized areas – in some but not all valleys at the south end of the lake, in the burns from large forest fires within the watershed that drain into the habitat of this salmon stock. We can now focus more effort on understanding the history of those areas. Marine survival was negatively related (n=20, p < 0.05) to summer NDVI in most of the forested area of the Chilko watershed, and across broad areas of the forested area the southern part of British Columbia, but not in northern part. We interpreted this result as a large-scale climate affect that acts on both terrestrial and oceanic plants. To add to our caveats, the increase in NDVI across most of the province and the decline in the sockeye survival are both long-term trends, and further work to examine these correlations after removing shared autocorrelation is planned.

During a six week period centered on May 6, smolts (8 cm juveniles) of Chilko Lake sockeye move down the Fraser River, then north through the Strait of Georgia and into Queen Charlotte Sound, and by September they have entered Northeast Pacific Ocean. Following our success in linking changes in terrestrial vegetation to salmon survival, we hypothesized that the marine survival of Chilko sockeye was related to phytoplankton chlorophyll in the coastal zone just before the juvenile sockeye pass through that zone (there is a lag between the spring bloom of phytoplankton and the bloom of zooplankton that sockeye can eat). We found significant positive correlations between sockeye marine survival and April chlorophyll concentrations, and these were confined to the central coast of British Columbia, and were able to reject the null hypothesis (n=20, p<0.05). The strong correlation we observed is consistent with other recent studies. The most important part of our result is that we have constrained the relationship between phytoplankton and chlorophyll to a specific time in a specific area. Going ahead, we will focus our attention on the timing, production, and species composition of the phytoplankton and zooplankton in this window of space and time.

As a final caveat, we view this work as the early exploration of the scientific benefits from this new ability to observe our planet. Our results and our explanations for these correlations are not yet definitive, but we are certainly past the speculation stage. Of course, by showing...
fisheries biologists a view of the world that they have never seen before, we are generating more questions than answers, but it is clear that this approach will be interesting to a wide variety natural resource managers and scientists.
Exploiting Multi-temporal SAR for Monitoring Applications

Brian Brisco\textsuperscript{1} and Marco van der Kooij\textsuperscript{2}
\textsuperscript{1}Canada Centre for Remote Sensing
\textsuperscript{2}MDA

Numerous SAR systems are now operational such as RADARSAT-2, TerraSAR-X, and COSMOS as well as the upcoming ALOS-2, Sentinel, and RADARSAT Constellation Mission (RCM) which has resulted in a regular supply of data due to the all weather, day/night capabilities for the data collection. Consequently, multi-temporal SAR data stacks over many regions of the world are becoming available on a routine basis which is particularly attractive for SAR applications for two reasons. First, because single channel SAR data sets are quite noisy averaging temporal data stacks can significantly reduce the noise while maintaining the effective resolution. Secondly, due to the timely data acquisition capability the data stream can match the target calendar in terms of observation timing and frequency. This paper discusses the image processing approach and advantages to using time-series SAR data stacks for a wide range of monitoring applications including forest condition and harvesting, land cover mapping and updates, wetland hydrology, flood mapping, landslide monitoring, and terrain stability for permafrost monitoring and subsidence due to mining or groundwater extraction. The techniques are generally simple to use and can be applied to a wide range of other types of applications now that SAR image stacks are becoming routinely available. Research needs for the future development of SAR image stacks for monitoring applications will also be presented.
A Recovery trajectory method for reducing post-stratification variation in forest productivity estimation

Evan Brooks¹, Randolph Wynne¹, Valerie Thomas¹, and John Coulston²

¹Virginia Polytechnic Institute
²USGS Forest Service

Descriptive forest parameters, such as forest growth, have significant variability at regional scales. The reduction of variability in the estimation of forest parameters using ancillary satellite data, such as Landsat or MODIS, is an established practice. By stratifying pre-existing Forest Inventory and Analysis (FIA) sites along target variables, one may make more precise estimates of those variables than if one had taken a simple random sample (SRS), measurable as an increased relative efficiency (RE). Various methods are employed to obtain estimates of proportion of forest in areas of study as well as estimates of forest volumes and biomass. These estimates are largely based on ancillary data tailored to the variables in question, such as forest-nonforest classifications. When reducing the post-stratification variability in estimates for forest productivity variables such as forest growth, it is thus logical to use a productivity-related stratum map. At the stand level, time series of Landsat images are ideally suited for producing such a map. While other Landsat-based techniques such as the Vegetation Change Tracker (VCT) have been employed to this purpose by indicating the time of forest disturbance, they have generally shown only slightly improved RE’s over taking a SRS. In this study, we generate a stratum map based on the trajectory of forest recovery, as measured in the Normalized Difference Vegetation Index (NDVI) derived from Landsat TM data from 1984 through 2011, after a disturbance over a period of six years. These trajectories are classified according to a hierarchical clustering algorithm from a training sample, resulting in classes that resemble site index curves. The resulting stratum map is then used to improve the relative efficiencies for forest productivity variable estimation in an Alabama, USA study area. This technique of using forest recovery strata has promising implications in the area of monitoring and modeling forest productivity.
Applying a new decadal change product in the monitoring of urban expansion around Calgary, Alberta

Inacio Bueno¹, Jennifer Hird², Guillermo Castilla², Greg McDermid²
¹ Department of Forest Sciences, University of Lavras, Brazil
² Department of Geography, University of Calgary

The mapping of urban development is an important component in urban monitoring, which itself is of great importance from both urban and environmental perspectives alike. Remote sensing and GIS are increasingly popular tools for these types of analyses. However, in most cases, these studies are limited to small, local areas because they frequently rely on high resolution imagery that provides high levels of spatial detail. These data sets are often costly and do not generally provide a short return period, which limits the frequency with which repeating imagery is available. Moderate resolution data sets, on the other hand, often capture images across the globe on a daily or near-daily basis. In this study we asked: can urban sprawl be reasonably detected using a moderate resolution satellite data set, by taking advantage of the higher temporal resolution it offers? To answer this question, we employed a new MODIS NDVI-based decadal change image to detect urban sprawl in and around the city of Calgary, Alberta, between 2001 and 2011. The NDVI reflects vegetation greenness, and would thus also reflect changes to vegetated surfaces as is seen in the conversion of rural landscapes into urban. The advantages of the MODIS NDVI data include i) its provision as radiometrically- and geometrically corrected, freely-available, NDVI data, ii) its ability to offer regional coverage due to its moderate spatial resolution, rendering our methods more widely applicable, and most importantly, iii) its one- to two-day return period, which offers a very high temporal resolution.

To general our new decadal change product, we first generated a MODIS NDVI time series comprising 121 images covering late spring (May) to early fall (October) for each year from 2001 to 2011. This time series was reduced to 11 images through the calculation of the per-pixel second-highest value of NDVI (shNDVI) for each year, which reduced the effects of spurious spikes observed in the 16-day NDVI time series. A multi-temporal analysis was performed on this new time series using ENVI/IDL image analysis software, in which for each pixel we derived: i) the maximum inter-annual difference in shNDVI between consecutive years for the observed period, ii) the minimum shNDVI observed between consecutive years for the observed period, and iii) the slope of a linear regression applied to the 11-year shNDVI series. A false-colour composite of these three resulting layers, placed in the red, green, and blue bands, respectively, highlighted areas of urban development in our study area, providing a stunning visualization of decadal urban expansion. With a simple decision tree classifier, we were able to successfully extract areas of urban development from in and around the city of Calgary, distinguishing them from the ever-changing spectral signatures of surrounding agricultural crops and pastures. The resulting classification was better able to distinguish urban development from other spectral changes occurring on the landscape than a two-date change detection. An accuracy assessment of change (in the form of urban development) versus no change was conducted using ground truth derived from multi-date, high-resolution orthophotos. We obtained an overall classification accuracy of 95.2% with our method, versus 93.7% with a bi-temporal approach. Producer’s and user’s accuracies were also higher with the
multi-temporal approach (i.e., 66.4% and 66.9%, respectively, versus 60.3% and 56.1%). Errors of omission were found in new urban areas containing relatively low percentages of impervious surfaces (i.e., containing large parks, big lawns, and other green spaces), which reduced the detection of urban development in these areas. Errors of commission were often located close to infrastructure development or over ephemeral water bodies. Nevertheless, our results proved not only that a multi-temporal approach to urban sprawl detection was more effective than a bi-temporal approach, but also that it is possible to detect urban expansion using MODIS NDVI time series following a simple and effective methodology that makes the mapping of such areas feasible on a regional scale.
Continual refinement of lake carbon estimates using historical, current, and future field and satellite data

Jeffrey Cardille\textsuperscript{1} and Paul Del Giorgio\textsuperscript{2}
\textsuperscript{1} McGill University
\textsuperscript{2} Université du Québec à Montréal (UQÀM)

As increasing attention is paid to the storage and flux of carbon in and around boreal lakes, strategies to make and refine credible region-wide estimates of stocks and fluxes will be increasingly important. Given that there are hundreds of thousands of lakes in the world’s lake-rich regions, concerted field campaigns can reach only a minuscule fraction of the lakes. Although remote sensing would appear to be of obvious potential, limnologists interested in satellite detection of lake color have been limited by many factors, primarily (1) the low spectral and radiometric resolution of earlier Landsat imagery; (2) the limited coverage of the experimental ALI sensor; and (3) the high cost of alternative imagery.

The launch of Landsat 8 promises a revolution in estimating carbon content in the world’s small lakes. Yet as Landsat 8 become operational, the prospect of sampling and validating for hundreds of thousands of boreal lakes is nearly impossible using the standard approach of carefully timing lake sampling with satellite overpass. We have recently shown that multi-temporal imagery from the similar ALI sensor can be used for a high-quality estimation of colored dissolved organic matter (CDOM), an important lake property. For that relation we used a legacy field data set collected at irregular times over more than a decade, which greatly expanded the amount of field observation available for building the model. In this setting with multi-temporal field data matched with multi-temporal image data, the challenge of updating estimates will be increasingly important as Landsat 8 produces a stream of images of varying utility. Meanwhile, field data in newly sampled lakes may be plausibly used for a variety of purposes: for fits with imagery that is near in time, as validation of an existing estimate, or to refine fits from old imagery.

In this presentation, our objective is to present a first look of the fit of this legacy field data set with Landsat 8 data from early summer 2013. Whether or not Landsat 8 will have produced cloud-free data over our boreal lakes by the time of the conference, we will describe our expected protocol for treating and refining an ongoing series of imagery-driven estimates. The workflow is intended to automatically incorporate new evidence to continually sharpen the estimates of lake carbon content across a vast area. The prospect of long-term observation of lake properties is arriving, and it promises a clearer picture of one of the world’s great storehouses of carbon.
Unsupervised change detection of multitemporal multichannel SAR images based on stationary wavelet transform

Boulerbah Chabira\textsuperscript{1}, Takieddine Skanderi\textsuperscript{1}, Mohamed Fekir\textsuperscript{1}, Aichouche Belhadj-Aissa\textsuperscript{1}

\textsuperscript{1}USTHB, Algeria

Synthetic aperture radars (SARs) have demonstrated their high efficiency in environment monitoring and disaster management, due to the short revisit time provided by them, their ability to operate in day and/or night and their independence of weather conditions. One of their applications that receives a lot of attention in the last few years is the change detection of the observed earth surface by exploiting the multitemporal multichannel (multipolarization and/or multifrequency) SAR images. The change and non-change areas can be discriminated better when analyzing multitemporal multichannel SAR images due to the fact that they provide complementary and additional information. In this context, we propose an unsupervised process for the change detection of multitemporal multichannel SAR images that does not require any speckle filtering. This process is based on: i) generating a multiresolution set of each single-channel log ratio image using stationary wavelet transform (SWT); ii) applying the T-point algorithm for all the images of the multiresolution sets; iii) fusing all the channels using linear discriminant analysis (LDA) for each scale; and iv) fusing the obtained images to generate the change map. The first step aims at identifying a set of reliable scales for each pixel of each single-channel. These reliable scales represent a trade-off between speckle reduction and geometrical detail preservation and they are identified using multiscale local coefficient of variation. For the second step, the T-point algorithm has been chosen because it has shown its robustness when dealing with multiresolution transformations. The obtained thresholded images are used in the third step and a set of multiresolution change maps are derived. In the final step, the fusion is conducted through the use of an optimum reliable scale selected from the channel that best discriminates between the change and non-change classes. The final change map is then generated. The proposed process was experimentally validated using semisimulated and real dual polarimetric images acquired by RADARSAT-2 satellite. Tests have been conducted using two-look HH and HV dual polarimetric semisimulated datasets consisting of 455x540 pixels. Results show that, out of 4365 simulated change pixels, a detection accuracy of 92.70\%, a false-alarm rate of 0.333\% and an overall error rate of 0.462\% are obtained. For the HH and HV dual polarimetric real datasets, the assessment is performed visually and good change detection is obtained.
Estimating snow thickness distributions on first-year sea ice with enhanced resolution ASCAT microwave satellite data

Johnson Chan¹, Torsten Geldsetzer¹, Nidhi Bishnoi¹, Jagvijay Gill¹ and John Yackel¹
¹ Department of Geography, University of Calgary

Time series of active microwave backscatter (ASCAT data) are used to investigate geophysical changes to the snow thickness distribution over first-year sea ice near Cornwallis Island in the Canadian Arctic. Multiple sites with varying snow thicknesses are monitored. The period from May 1 to June 30, 2012 encompasses the transition from late-winter dry snow to spring melt ponds. In-situ field observations, local meteorological data, snow-melt modelling, aerial surveys, and RADARSAT-2 SAR imagery provide supporting evidence. We show that melt-onset is readily identified, and that shallower snow areas reach the melt pond stage earlier; thus providing a method for estimating pre-melt snow thickness distributions, based on enhanced resolution microwave imagery.
Comparative Analysis of SPOT5 Multispectral and Panchromatic Imaginary for Anthropogenic Change Detection and Feature Extraction

Dennis Chao¹, Todd Shipman¹, Ying Zhang², Bret Guindon²
¹ Alberta Geological Survey
² Canada Centre for Remote Sensing

Petroleum exploration and extraction are an important industry to the economy of Alberta. Since 1990s, most of these activities have been concentrated in the Athabasca Oil Sands play, where resources are extracted via open pit mining and in-situ steam injections (Steam Assist Gravity Drainage and Cyclic Steam Stimulation). Natural and agricultural lands are converted into mining facilities with permanent and temporary road networks, well pals, tailing ponds and other structures. Monitoring their growth over time is essential to the sustainable management of Alberta energy resources and the environment. The Alberta Geological Survey (AGS), with collaboration of the Canada Centre for Remote Sensing (CCRS) and contracted BlackBridge Geomatics, created this project to explore the capability of change detection to identify anthropogenic disturbance over time. Study sites are chosen due to their continuing expansion in the past years and therefore good candidates to exhibit change. Two sites are selected to study: in-situ operations at Christina Lake covering 586km² and an open pit mine at Kearl Lake covering 276km², 110km south east and 63km north of City of Fort McMurray respectively.

Through this project, we evaluated the performance and advantages of scale and spectral analysis to identify change through remote sensing. To accomplish this, we acquired SPOT5 10m multispectral, RapidEye 6.5m multispectral and 2.5m panchromatic image data captured between 2007 and 2011 for both sites.

Supervised automated feature extraction, used to identify the timing of anthropogenic activity, can be effective in mapping change with great frequency. To evaluate the accuracy of this automated process, five panchromatic images of Kearl Lake and 12 images of Christina Lake captured between summer or fall of 2007 and 2011 are used for the analysis. A multiscale feature extraction approach – large, small, linear objects and water body, is employed to address and compensate the variation in acquisition dates (different sun elevations and gains) and different landscape between study areas. Detection of large objects such as building compounds, DN values of each image are first converted to top of atmosphere reflectance to normalize solar position and irradiance; gradient magnitude is used to detect amplitude edges where there is sudden a change of gray-level; and candidate objects are selected based on multiple image morphology calculations. When detecting small objects such as well pad boundaries and clear cut areas, contract enhancements are applied to images and a customized well pad extraction program is modified to identify other man-made structures. Linear objects are highlighted using contrasted-limited adaptive histogram equalization and median filter; and delineated with Standard Hough Transform. Water bodies are identified using the valley point in the histogram of image pixel intensities. Objects from each image are extracted and converted into polygon shapefile. Accuracy of this automated approach is validated by comparing polygon shapefile with polygons digitized by technologists through photo
There are a multitude of sensor options available to remote sensing community; however we were investigating the most cost effective imagery that meets the requirements for regulatory delivery. SPOT5 multispectral 10m was compared to SPOT5 panchromatic 2.5 m to evaluate its application on anthropogenic feature extraction potential. Five multispectral images from 2007 to 2011 for Kearn Lake and 3 images from 2006, 2008 and 2011 for Christina Lake are used. A hybrid object- and pixel-based processing approach was developed for the change detection analysis. The change magnitude calculation is performed between spectrally enhanced images to highlight anthropogenic disturbances. It is based on the concept of change vector analysis methodology to calculate differences in the spectral space before and after the change and to determine the optimal threshold. Anthropogenic changes between years are extracted and combined to create polygon shapefile. The extracted results are compared with Worldview 2 imagery and other ancillary data for accuracy and validation.

After comparing results from both sensors, we conclude that panchromatic data has exceeded our initial expectation by out-performing the multispectral images. It is largely due to its higher image resolution for detecting smaller footprints such as well pads more accurately than multispectral data. Image acquisition dates play a critical role as gain and sun elevation can affect the accuracy on detecting and comparing footprints. Neither approach can successfully detect linear features such as road networks. It indicates that there is a need to undertake an evaluation of the utility of other high and very high resolution sensor data imagery available currently and in near future for characterizing infrastructure components of processing facilities including fine linear features.
Incorporating porometry measurements, multi-temporal airborne LiDAR, and high resolution WorldView2 data to better understand competition and growth within a heterogeneous forest regeneration stand

Laura Chasmer¹, Kayla Giroux², Chris Hopkinson³, Richard Petrone¹, Natascha Kliune⁴ and Kevin DeVito⁵

¹ Wilfrid Laurier University ² AECOM ³ University of Lethbridge ⁴ Swansea University ⁵ University of Alberta

The composition, distribution, and structure of regenerating forest species likely influence site net carbon and water balances, especially where vegetation canopy structure affects the penetration of light through canopies. The ability to quantify the influence of vegetation structure and species type on energy and mass exchanges within these stands is an important challenge to land surface models.

To address this problem, this study quantifies links between stomatal conductance (gc) and vegetation growth over three years in two regenerating aspen stands located within the Western Boreal Plain, Alberta Canada. Integration of porometry measurements, site energy balance and eddy covariance, and multi-temporal, spectral and 3D remote sensing data enable assessment of meteorological, topographic and structural influences on gc and vegetation growth. The results of this study indicate that significant differences in gc are found within shade tolerant species by the second year of regeneration due to optimised competition for light and localised feedbacks. A semi-variogram analysis of vegetation structure over the three-year period indicates that sites become structurally less diverse with age, and this occurs within the first three years of growth. Differences in gc and growth between species groupings can be observed within the Soil Adjusted Vegetation Index (SAVI) obtained using very high resolution WorldView2 data. This provides some justification for resampling of lower resolution remote sensing data used to characterise heterogeneous ecosystems within land surface models.
A Multi-evidence approach for crop discrimination using multi-temporal WORLDVIEW-2 imagery

Menaka Chellasamy\textsuperscript{1}, Rafar Tomasz Zielinski\textsuperscript{1} and Mogens Humlekrøg Greve\textsuperscript{1}

\textsuperscript{1} Department of Agroecology, Aarhus University

Multi-temporal satellite images providing crop details at different growing season have been an important source to reduce the misclassification that occurs during single date image based crop classification. But it is also necessary to consider the more useful temporal information that aids high discrimination ability. Spectral Reflectance (SR) and Vegetation indices (VI) at different growing season are often used for crop classification however temporal texture information has not been widely investigated. Thus a new pixel based multi-temporal image classification that incorporates seasonal texture information to discriminate crops is proposed. The study pursue two goals namely i) increasing crop classification accuracy by using Gabor Textures (GT) in addition to SR and VI derived from multi-temporal data and ii) optimal pooling of the outputs from multiple classifiers each trained with separate input dataset that outperforms winner-takes-all classification approach. Stacking approach is traditionally used in the multi-temporal image classification but the data set contribution to classification is often being affected by data having poor discrimination ability. Hence there is a need for an approach to use the available data sets effectively to improve classification accuracy. The proposed approach considers the contribution of each data set for classifying a pixel based on training individual Neural Network (NN) classifier with multi-temporal SR, GT, and VI dataset separately and pooling their outputs using Endorsement Theory (ET). Each NN classifier trained on different input dataset produce prediction probability as an evidence for a pixel against each crop class. An integration rule based on ET is applied to these multiple evidence and the most probable class of a pixel is identified. Multi-Layer Perceptron (MLP) neural network with backpropagation learning algorithm is used for training the classifiers in this study. WorldView-2 (WV2) multi-spectral data of 8 bands and spatial resolution of 2m captured on spring and summer season of 2011 are used to discriminate the crops in Vennebjerg area of Denmark. WV2 data of spring and summer are stacked together and three different input dataset are derived from them such as SR of each band, GT derived for each spectral band and ten different VI of both season. Evaluation of the classification accuracy is carried out based on confusion matrix with an investigation of contribution of evidence from SR, GT and VI and their combination to overall accuracy. The proposed integrative approach is compared with the traditional approach of classifying multi-temporal images with different input dataset stacked altogether (winner-takes-all approach). Also single-date image based classification is done using spring and summer WV2 imagery and the results are compared with that of classification using multi-temporal information. Classification results show that addition of Gabor Textures information which is invariant to change in illumination, rotation, scale and translation between seasonal images increases the crop classification accuracy. GT has the ability to discriminate different crops having similar spectral value due to its high spatial localizing characteristics. The technique of integrating information using ET is found to be effective when comparing to conventional stacking approach for crop discrimination while using different multi temporal data sets.
Change detection after earthquake from multi-resolution remotely sensed images with a multi-temporal geostatistical measure

Dongmei Chen\textsuperscript{1}, Shanshan Li\textsuperscript{2}, Qunjun Jiao\textsuperscript{2}, Bing Zhang\textsuperscript{2}
\textsuperscript{1} Queen’s University, Canada
\textsuperscript{2} Center for Earth Observation and Digital Earth, Chinese Academy of Sciences

Quick change detection is essential to estimate the loss and help relief planning after an earthquake. Multi-temporal remotely sensed data are commonly used in this type of change detection. However, due to the urgency of this kind of change detection and reasons such as weather conditions and image availability, it is often necessary to conduct change detection right after an earthquake from images acquired from different satellite sensors with different spectral and spatial resolutions. However, many traditional spectral value-based change detection methods do not work well for multi-temporal images from different sensors. In this paper, we present a novel multitemporal pattern measure into multitemporal change detection and apply it into change detection before and after the 2008 Wenchuai Earthquake in China. The performance of the proposed multitemporal pattern measure was evaluated and compared with conventional change detection methods using both multi-temporal TM and Aster images. The results demonstrate that the proposed multi-temporal measure performs better than traditional methods in detecting structure changes caused by the earthquake.
Can remote sensing be effective for forecasting forest fire danger conditions?

Ehsan Chowdhury and Quazi Hassan

1 Department of Geomatics Engineering, University of Calgary

Forest fire is a natural phenomenon in many ecosystems of the world that burns approximately 350 million hectares of forested land annually. It has both beneficial and harmful effects on the ecosystem; and impacts us in many ways, profoundly influence the environment, social and economic activities. One of the most important components of integrated forest fire management is the forecasting of fire danger conditions (i.e., probability of fire occurrence). In general, fire danger conditions are dynamic in both spatial and temporal dimension. Here, our aim is to review two issues, such as (i) the current operational forest fire forecasting systems and their limitations; and (ii) remote sensing-based fire danger systems and its operational implications. Among the operational systems, the most prominent ones are the Canadian Forest Fire Danger Rating System (implemented in Canada, European Union, New Zealand, and Argentina), US National Fire Danger Rating System, Australian McArthur Forest Fire Danger Index, and Russian Nesterov Index. These systems use the point-based measurements of meteorological variables (e.g., temperature, precipitation, relative humidity, wind speed, etc.) to produce surface map for the variable of interest using spatial interpolation techniques prior to forecasting danger conditions at landscape scale. However, these interpolation techniques (i.e., spline, kriging, inverse distance weight, etc.) usually generate different outcomes even using the same input dataset. The uncertainty associated with these interpolation techniques can be reduced substantially by incorporating more point-based measurements of meteorological variables, which ought to be expensive and difficult to acquire over remote areas. In order to address this, remote sensing-based methods may be useful due to their ability to view large geographic extent in a timely fashion. During the last several decades, significant amount of efforts have been given to develop fire danger conditions. For example: (i) normalized difference vegetation index (NDVI) and surface temperature (TS) images were used to calculate the codes of the Canadian Forest Fire Weather Index System; (ii) normalized difference moisture index, topographic variables (that includes slope, elevation, and aspect), proximity from road and settlements were used to develop a fire risk index; and (iii) vegetation relative greenness using NDVI or visible atmospheric resistant index or normalized difference water index to compute fire potential index. Most of these developments cannot be adopted for forecasting as they focus on determining the danger during the period of image acquisition (i.e., during or after the fire occurrences). However, a limited number of studies have been conducted to forecast fire danger conditions, which can be adaptable. Among them: (i) a combination of NDVI and difference between TS and air temperature were used to derive the water deficit index for evaluating the forest fire danger; (ii) TS condition prior to fire event was assessed and an increase of TS were led to high fire risk due to water stress of vegetation; and (iii) integration of TS, normalized multiband drought index and temperature vegetation wetness index were used for forecasting fire danger conditions. Thus, it would be worthwhile to determine the areas for further improvements in the context of making them operational.
Logistic regression modeling for reconstructing long time series of burned areas

Thuan Chu\textsuperscript{1} and Xulin Guo\textsuperscript{1}
\textsuperscript{1} University of Saskatchewan

Among the multivariate techniques used to predict a binary dependent variable from a set of explanatory variables, logistic regression models are valuable tools in survival analysis in which the dependent response variable is dichotomous and is assigned as 0 or 1. The overall purpose of this paper is to assess the influence of several spectral bands and indices on the performance of logistic regression and spatially explicit models for mapping long time series burned areas. The development of a suitable logistic regression model for burned area mapping was based on a group of spectral bands, spectral bands and indices, and spectral indices derived from MODIS data (MOD09A1 product) as explanatory variables. The estimated accuracy of the results and other statistical indications denote that logistic regression modeling with MODIS data can be used successfully for burned area mapping. The spectral bands and indices based model proved to be the most suitable, while spectral indices based model performed worst. The inclusion of interaction terms between independent variables did not improve the discrimination of burned and unburned areas compared with without the consideration of interactions. The suitable predictors were used to create burned maps for each year in the period from 2000 to 2012 in northern Mongolia. The results suggest that logistic regression models are valuable tools not only for burned area mapping but also for the identification and management of fire risk.
The Impact of the day of observation of image composites on adequate time series generation

Rene Colditz

1 National Commission for the Knowledge and Use of Biodiversity (CONABIO), Mexico

Many time series analysis techniques such as harmonic analysis require equidistant observations of a time series. In addition, ecological studies monitoring the phenological state of the vegetation (start, end, middle of the growing season) rely on highly accurate time series. Many remote sensing products useful for time series analysis and seasonal monitoring studies are offered in form of composites, because the view to the ground is often obscured by clouds or haze or the sensor may have failures such as missing lines. A composite combines a number of observations of a defined period and either selects the best value or computes a new value such as the mean. For vegetation indices (VI) common compositing rules use the maximum value or combine this rule with a selection of observations that are close to nadir; both are based on the assumption that VIs with high values were less likely obscured by atmospheric constituents or sensor issues. That, however, results in observations sampled at varying time intervals and rules out a large number of time series analysis techniques. If the day of observation is not known or not used in time series generation, it is common to define the starting day as the day of observation. One the one hand this assumption, from a practical point-of-view, overcomes the issue concerning potential time series analysis techniques but temporally shifts the series to earlier days. The issue may be mitigated by assuming the middle of the compositing period as the day of observation. However, it would be certainly preferable to use the actual day of observation and estimate from that time series any other day to sample a new time series at any desired interval.

This study investigates the impact of either using the day of observation to generate a time series or to assume the starting or middle day of the compositing period. For this study daily MODIS surface reflectance (reference set) and 16-day MODIS VI composites of 500m spatial resolution were employed. A 1000x500km region in central Mexico served as study site. Several statistical measures were used for time series analysis, including temporal cross-correlation, the root mean square error, and harmonic analysis. A temporal shift of approximately seven days with a high variability is introduced when using the starting day of the compositing period. The middle day mitigates the mean error close to zero but results in a high variation in error. Only time series that take into account the day of observation and estimate from that samples at equidistant intervals can be used for correct estimation of temporal characteristics and are also reliable for time series analysis techniques from a theoretical point-of-view. The latter will be exemplarily demonstrated for phenological states such as the start and end of the growing season.
Assessing impacts of coastal landscape change on Piping Plover habitat in New Brunswick, Canada using multitemporal LiDAR and aerial photography

David Colville and Sarah Marie McDonald

The Piping Plover (Charadrius melodus) has been listed as a Canadian endangered species by the Committee On the Status of Endangered Wildlife In Canada (COSEWIC) since 1985. Habitat destruction is one of the known contributing factors impacting their decline. While major coastal storms and associated storm surges can significantly alter a coastal beach and create new Piping Plover habitat, they can also destroy existing habitat. In defense of shoreline properties, people strive to create barriers (or coastal hardening features) which have a tendency to limit the generation of new habitat. Thus existing Piping Plover habitat can be negatively impacted by storms and new habitat creation can be restricted by anthropogenic action.

On December 21, 2010 coastal New Brunswick experienced a significant storm with a record high storm surge. Fortunately this lengthy coastline had been surveyed using LiDAR and aerial photography in 2009. The Canadian Wildlife Service (CWS) was interested in assessing the impact of the 2010 storm on Piping Plover habitat and thus worked with the Applied Geomatics Research Group (AGRG) to conduct another LiDAR and aerial photography survey of the coastline in 2011. These two datasets were then used to assess the coastal changes that occurred in the two year period.

The multitemporal datasets were used to rate the risk of susceptibility on Piping Plover habitat based on mapping four factors: landscape development; coastal hardening features; coastline change detection; flooding potential. The LiDAR datasets were processed into 1m resolution Digital Elevation Models (DEMs) and used to process the aerial photography into orthoimagery. These processed layers were then used to map the four factors and calculate relative risks of susceptibility; increased presence of each factor resulted in a higher risk. A susceptibility weighting scheme was then applied to each factor; landscape development and coastal hardening features both received a higher weight than coastline change and flooding potential given that they represent relatively permanent features and thus greater impedance to habitat adaptation and relocation.

A final ranking scheme was then applied to classify coastal areas into low, medium, or high levels of susceptibility for 13 study area beaches. Four beaches were ranked as low, five were medium, and the remaining five were high. Based on these results, decisions as to which areas are of greatest concern and which would benefit the most from conservation efforts can more easily be made. Those ranked as medium were felt to be most worthy of immediate attention given that they shared high rates of change and moderate amounts of development, hardening features, and flooding results. This indicates that they are good candidates for conservation effort in that there is still time to have a positive impact on their development. The use of the high-resolution datasets did pose data quantity and quality challenges for this study.
Nevertheless, the multitemporal LiDAR and aerial photography proved to be invaluable datasets for this application.
Content extraction of long-term satellite image time series: Spatiotemporal analysis of Bucharest metropolitan area

Teodor Costachioiu\textsuperscript{1}, Corina Vaduva\textsuperscript{1}, Vasile Lazarescu\textsuperscript{1} and Mihai Datcu\textsuperscript{2}

\textsuperscript{1} University Politehnica of Bucharest
\textsuperscript{2} DLR

Current earth observation data repositories enable us to extract observations of the same geographical area over the course of time and to create satellite image time series (SITS). Such SITS are data sets of high complexity, embedding spatial, spectral and temporal information. The rich content of SITS has generated a great interest in the recent years, many SITS analysis methods being developed. Many of these methods are focused towards improving the precision of land use/land cover detection by exploiting the inherent redundancy of SITS data. Some other methods focus on the evolution of a specific land use/land cover type. Often these methods are applied on SITS that span over a short period of time, typical one or several years.

In this paper we focus on a different use scenario of SITS analysis by extracting classes of dynamic evolutions from long-term satellite image time series. As such we create a SITS of over 100 Landsat datasets, spanning from 1984 to 2011, covering the metropolitan area of Bucharest, Romania – perhaps the longest SITS ever being used. The analysis of this SITS aims to evaluate the spatio-temporal evolutions, focusing on finding classes of temporal dynamics of the main land use/land cover classes of the studied area, such as urban areas, agricultural land, forestry and water bodies, identifying interesting evolutions in the studied area. Furthermore, the extracted dynamic classes are used to establish relationships with known ancillary data such as CORINE Land Cover vector data sets or statistical datasets for demographics of the studied area.
Cascade active learning for evolution pattern extraction from SAR image time series

Shiyong Cui\textsuperscript{1} and Mihai Datcu\textsuperscript{1}
\textsuperscript{1} DLR

Presented by Corina Vaduva on behalf of Mihai Datcu

In this paper, a cascade active learning approach relying on a coarse-to-fine strategy for evolution pattern indexing is developed, which allows fast indexing and hidden spatial and temporal pattern discovery in multi-temporal SAR images. In this approach, a hierarchical multi-level image representation is adopted and each level is associated with a specific patch size. SVM active learning is applied at each level to obtain reliable samples and reduce the manual effort in labeling the images. When moving to a new level, all the negative patches are neglected and the learning at the new level focuses only on the positive patches. In this way, the computation burden in annotating large data set could be remarkably reduced while keeping the accuracy. Through temporal pattern retrieval, the cascade active learning has been compared with a baseline SVM active learning operating only at the last level in terms of both accuracy and time complexity. We have demonstrated that cascade active learning can not only achieve better accuracy but also reduce remarkably the computation time.
A Comparison of the climate-impacted variation in phenological metrics of the grassland ecoregions in northern Tibet and southern Saskatchewan from 1982 to 2006

Tengfei Cui¹, Xulin Guo¹ and Xiaolei Yu¹
¹ University of Saskatchewan

Grasslands in Tibetan plateau and Canadian prairie represent climate sensitive ecosystems in high elevation and high altitude regions. Comparing the responses of the two ecosystems to climate variation will help understand the interaction of atmosphere and vegetation and prepare for better management strategies for adaptation. Normalized Difference Vegetation Index (NDVI), derived from Advanced Very High Resolution Radiometer (AVHRR) from 1982 to 2006 facilitating the long-time phenology monitoring over large-scale region were acquired for this study. Specifically, groups of scientific objectives are expected to be achieved using certain approaches: 1) multi-temporal maps of phenological metrics from 1982 to 2006 for each grassland ecoregion and sub-ecoregion will be produced with the methods of HANTS-FFT and Midpointpixel; 2) multi-temporal maps of temperature and precipitation from 1982 to 2006, with a relatively high spatial resolution, for each grassland ecoregion and sub-ecoregion will be produced, based on the ground measured climatic data interpolated with Inverse Distance Weighted Averaging (IDWA) algorithm; 3) the approximate annual variation trend of temperature, precipitation, and phenological metrics for each grassland ecoregion and sub-ecoregion will be revealed; and 4) the limiting climatic factor for each phenological metric of each grassland ecoregion and sub-ecoregion will be determined through correlation analyses. Preliminary results indicate that remotely sensed data are sufficient to investigate the ecosystem phenology.
Application of multi-resolution remotely sensed imagery for the monitoring of land cover / habitat change in Wales, U.K.

Alisdair Cunningham¹, Richard Lucas¹ and Pete Bunting¹
¹ Aberystwyth University

The provision of remotely sensed imagery of the Earth’s surface has provided a significant resource for the characterisation and monitoring of temporal vegetation characteristics, and many methods of utilising this resource have been developed globally. Analysis of optical multi-temporal analysis of time-series data can however, be impeded by changing atmospheric conditions and cloud cover, as is the case in Wales (U.K.), which can also cause gaps within the time-series. This research has developed a method for detecting changes in vegetation cover and condition for study sites in Wales, for the period of 2000-2012. The study integrated high-temporal, low spatial-resolution data from the Moderate Resolution Imaging Spectroradiometer (MODIS) with higher spatial-resolution sensors, including Landsat Thematic Mapper (TM) / Enhanced Thematic Mapper (ETM+) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) to allow comparison of the low temporal resolution high resolution data to be normalised for seasonality. Absolute correction of the moderate resolution imagery is implemented using radiative transfer code 6S and meteorological information, in order to achieve comparable surface reflectance measurements. Variations from the normal observed behaviour of MODIS vegetation indices time-series data are explored spatially, and characterized through the classification of the Landsat and ASTER imagery, giving indications of the potential temporal and conditional changes in vegetated land cover; vital information required for the monitoring of key protected habitats.

Results indicate that both abrupt conversions (e.g. woodland-clearing or urban development) and gradual changes (e.g. decreasing productivity as a result of various stresses, both natural and artificial) are identifiable over annual time-steps throughout the series, as illustrated in Figure 1 and Figure 2. Additionally, any change pixels identified in the MODIS data are spatially targeted using the higher spatial resolution imagery to provide change objects, and therefore, ancillary thematic information, including broad vegetation class, from-to information and extent.
Albertan Sage Grouse: What went wrong?

Sandra Dalton and Greg McDermid
University of Calgary

100 years ago, Sage Grouse roamed the great wild sagebrush prairies and deserts of North America. They were reportedly seen from as north as Calgary, Alberta, down to New Mexico. Now, they sit in a perilous position: Over half of their native range has been developed and changed from sagebrush, and what was once a large expanse is now cut up into smaller discontinuous units (Schroeder et al., 2004).

In Alberta especially have the Sage Grouse lost their native home. Rather than half of their habitat gone, it is more than nine tenths that have disappeared (Aldridge et al., 2008). In the 1960's Alberta Fish and Wildlife began to track the number of displaying males in the spring mating season. Where once groups of many hundreds congregated, today are dozens. Sage grouse are all but extirpated in the province. A translocation effort is underway to supplement the population, aimed to help it back from the brink (ESRD, 2012).

The goal of this analysis was to quantify the extent that proximal human development has influenced sage grouse populations in SE Alberta since 1970. Presented with historical proxy population counts and current development, historic human development data was required. To gain access to that information historical airphotos were acquired for the years 1970, 1982, 1992, and 2001. Each set was geo-referenced and mosaicked to guide digitizing development in each year. Once development of roads and farms were digitized, the total length of roads and area of farms was summed within 0.4, 3.2, and 6.4 km of known Sage Grouse mating locations (leks) for each year. Drilling incidents were also counted within those distances, organized through time by spud date.

The summary fields were tested statistically in a panel Poisson regression. Results indicate that instead of any one specific development, each development type has a mild negative impact on sage grouse population counts. The results also indicate that a 0.4km radius around a lek does not gather enough information for analysis.

References:
ALDRIDGE, C. L., NIELSEN, S. E., BEYER, H. L., BOYCE, M. S., CONNELLY, J. W., KNICK, S. T. & SCHROEDER, M. A.

ENVIRONMENT and SUSTAINABLE RESOURCE DEVELOPMENT (ESRD), Alberta Government. 2012.
Alberta Wildlife Animal Care Committee Class Protocol #010, Wildlife Research Licences and Collection Permits.

SCHROEDER, M. A., ALDRIDGE, C. L., APA, A. D., BOHNE, J. R., BRAUN, C. E., BUNNELL, S. D., CONNELLY, J. W.,
DEIBERT, P. A., GARDNER, S. C., HILLIARD, M. A., KOBRIGER, G. D., MCADAM, S. M., MCCARTHY, C. W., MCCARTHY,
106, 363-376.
Object-based change detection: case study on small water bodies

Els De Roeck1, Frieke Van Coillie1, Robert De Wulf1, Hantson Wouter2, Els Decheyne2, Guy Hendrickx2

1 Laboratory of Forest Management and Spatial Information Techniques - University Ghent
2 Avia-GIS

Knowledge of experienced mappers is very valuable for change detection in natural landscapes. Hence, object-based image analysis (OBIA) provides an ideal platform for the translation of this knowledge into a computer-understandable language by means of algorithms and rule sets. For this purpose segmentation, classification and change analysis are consecutively performed. The multi-resolution segmentation algorithm creates contiguous regions in input space. The resulting objects are homogeneous in terms of the phenomenon under investigation. Objects are not only characterized by their spectral signature, but also their shape, size, texture and context (relation to neighbouring objects). These features are extremely relevant for classification or change detection purposes.

In this presentation object-based change detection (OBCD) techniques, their restrictions and opportunities are discussed and compared with pixel-based approaches. We develop OBCD techniques within a case study on small water bodies (project SATHELI; www.satheli.be). These ecosystems and their transition zones are the main habitat of the freshwater snail vector that transmits the liver fluke disease. Infection of cattle with liver fluke causes major economic losses, but can be prevented by appropriate farm management. Mapping small water bodies and their dynamics is thus essential for the development of infection risk maps. These maps can in turn be translated into farm management advice.

Seasonal WorldView-2 satellite imagery (spatial resolution of 0.5m for the PAN band, 2m for the 8 multispectral channels) is acquired over two regions in Flanders, Belgium. Four images, one for each season, are integrated and compared using multiscale OBCD. As different kinds of small water bodies are present (ponds, channels, inundated grassland,…), different change types are detected. Within one year, open water can change to aquatic vegetation and dry out later on, while dry grassland can inundate completely. Since these ecosystems are complex, contain transition zones and are temporally as well as spatially highly dynamic, it is crucial to translate expert knowledge into OBIA rule sets in order to accurately study their dynamics in terms of size, shape and typology. The results are discussed in view of their value as input data for the creation of liver fluke infection risk maps.
Remote monitoring of regional water quantity and water quality in the Athabasca oil sands region – lessons learned and future opportunities

Andy Dean\textsuperscript{1}, Olivie Tsui\textsuperscript{1}, Agus Salim\textsuperscript{1}, Martin Davies\textsuperscript{1}, Yver Crevier\textsuperscript{2}, Martin Hébert\textsuperscript{2}, Heather Keith\textsuperscript{1} and Wade Gibbons\textsuperscript{1}
\textsuperscript{1} Hatfield consultants
\textsuperscript{2} Canadian Space Agency

Water resources management is a particular field of interest with regard to satellite remote sensing. Regular, repeated observations of large areas of the Earth’s surface can complement and extend water resources data acquired through in situ observations, and contribute to hydrological model development and validation.

The quality and quantity of the water in the Athabasca River and throughout the oil sands region has been a key concern due to the disturbance of catchments that result from large scale mining operations and in situ operations. Oil-sands mining and in situ operations also withdraw water from the Athabasca River for use in oil-sands processing and site utilities. Industrial water withdrawals from the Athabasca River could impact aquatic ecosystems, including the connectivity of river channels to allow fish access to spawning grounds in late winter. In addition to physical disturbance, a range of contaminants produced by industrial activities could end up in lakes and rivers in the region.

Hydrology, water quality, and aquatic biota monitoring has been conducted in the Athabasca oil sands by the Regional Aquatics Monitoring Program (RAMP) since 1997. Monitoring in the oil sands area is undergoing significant change following a recent federal and provincial review of existing programs and institutional arrangements. A review of the remote sensing contribution to RAMP is timely, as well as a review of potential future areas where remote sensing can contribute to water quantity and quality management in the oil sands region.

RAMP has completed an annual assessment of the hydrologic conditions and impacts for each watershed in the Athabasca oil sands area since 2005. Land cover and use change is mapped using SPOT-5 multi-spectral satellite imagery in conjunction with data provided by companies. Water withdrawal and discharge data are collected from RAMP industry members and incorporated into a hydrologic water balance model. Watersheds that do not contain active oil sands projects are identified and also monitored to provide baseline data. The water balance model identifies the influence of oils sands projects on the overall hydrograph for a particular year. RAMP watershed monitoring and modelling provides valuable experience in operational application of remote sensing in the oil sands region. Image processing methods were designed to be simple and repeatable. More recently, new approaches have been successfully developed, including multi-temporal image segmentation and the development of classification ‘rulesets’ that incorporate spatial and spectral parameters.

A review of additional areas where satellite remote sensing could support water resources monitoring in the oil sands has been conducted as part of the Canadian Space Agency’s water monitoring initiatives. The review identified several areas where remote sensing could meet...
water resources information requirements, where information is currently lacking or partially available through other methods. The most promising areas for future development include radar and optical sensors: surface water extent and water level monitoring; wetland classification and monitoring; snow extent and snow water equivalent modelling; channel morphology and connectivity in the Peace Athabasca Delta; and river ice classification and fish habitat model development. The requirements, challenges, and potential solutions for each area are summarized. Importantly, remote sensing professionals should not focus on providing standalone or separate information products. The greatest potential for increased and sustainable application of remote sensing is as a contributing data source in integrated monitoring and modelling. Ongoing engagement with researchers and agencies involved in water monitoring is required, to ensure that the capabilities of space technologies are understood and can become part of the integrated solutions.
Multi-sensor/multi-beam InSAR ground deformation monitoring of water-flood oil fields

Benjamin Deschamps\textsuperscript{1}, Michael D. Henschel\textsuperscript{1}
\textsuperscript{1} MDA Geospatial Services Inc.

InSAR is a well-developed and calibrated technique for precisely measuring ground heave and subsidence in a wide range of environments. It is especially suited for the monitoring of oil fields (steam-assisted gravity drainage, cyclical steam, water-flood, etc.) experiencing rapid deformation linked to oil extraction activities. In recent years, a number of commercial sensors with different orbit parameters, beam modes, frequencies, etc. have been available, and this number continues to increase. Integrating information from various sensors and beam modes can increase the temporal frequency and reliability of deformation measurements in an operational monitoring context.

We will present the results of multiyear monitoring and modeling of ground deformation over a water-flood oil field. Deformation measurements were obtained from long time-series of repeat-pass interferometric acquisitions from multiple satellite SAR sensors in multiple beam modes. The independent measurements from each beam mode were integrated into a unified cross-stack inversion, to obtain cumulative deformation measurements at a very fine temporal resolution (as fine as a few days). The precision of estimates is improved versus single-stack interferometry due to the increased temporal overlap in interferometric pairs, and because acquisitions can be made from opposite (ascending/descending) or complimentary geometries concurrently. The method also allows for a robust integration of deformation profiles from multiple sensors when there is little temporal overlap, and alleviates the impact of temporal gaps in the acquisitions.

The spatial and temporal deformation time-series were modeled using a point-source linear deformation model. The model results will be verified with results over an operational oil field using multiple observations and error statistics.
Monitoring forest degradation with SPOT imagery: First assessment in the Congo Basin

Beaudoin Desclee¹, Frederic Achard¹ and Philippe Mayaux¹

¹ EC- Joint Research Centre

Forest degradation is one key process to be considered for the UNFCCC REDD+ mechanism (Reduction of emissions from Deforestation and forest Degradation). Operational methods are needed to monitor forest degradation in tropical countries as one main component of future REDD+ MRV systems (Monitoring, Reporting and Verification). Such systems require efficient tools for providing accurate and updated information on forest cover changes. Whereas existing operational forest cover monitoring tools focus mainly on the assessment of deforestation, new tools are required for detecting and measuring forest degradation, namely assessing areas within forest land where forest carbon stocks have decreased during a short time period (yearly to 5 years). Monitoring forest cover degradation or forest regrowth in tropical countries requires fine resolution imagery from Earth Observation satellites and consequently more sophisticated image analysis techniques.

The European Commission’s (EC) Joint Research Center has developed methods to generate continental forest maps (Mayaux et al, 2004), to identify areas of sudden forest change and to provide estimates of forest cover change at pan-tropical to regional levels for the current and previous decades (Achard et al, 2002, Mayaux et al, 2013). Such estimates of deforestation in tropics were produced from medium resolution satellite images (Desclée et al, 2013).

Recently, a large dataset of SPOT-4 and -5 HRV images (about 650 images) acquired around year 2010 has been made available over the Congo Basin for REDD+ projects. This recent dataset gives the opportunity to assess finer scale imagery (10 m to 20 m resolution) for the detection of degradation processes. Our study aims at evaluating SPOT imagery for assessing forest cover degradation and at developing tools which can contribute to a regional monitoring system. An automated and multi-sensor processing approach is needed. It needs also to be flexible to incorporate other possible fine resolution optical sensors such as imagery from Sentinel-2 satellites.

A new processing chain is designed for the assessment of forest cover degradation from SPOT imagery. The approach is implemented on SPOT image extracts at each half-degree of geographical confluence points over the Congo Basin. The image analysis includes several steps: co-registration, cloud masking, calibration, forest masking and change detection. These steps are designed in order to be as automated as possible. The resulting maps include a degraded forest class. The study provides a first assessment of forest degradation over the Congo Basin based on a large sample of fine resolution images.

This new automatic processing chain can be applied over larger areas. It is expected to adapt the chain to the specifications of Sentinel-2 sensors (with finer spatial resolution and more spectral bands) to use Sentinel-2 imagery in the assessment of forest degradation in next years.
Near real-time tropical deforestation detection using dense Landsat time series and local expert monitoring data

Ben Devries¹, Arun Kumar Pratihast¹, Jan Verbesselt¹, Lammert Kooistra¹, Sytze de Bruin¹ and Martin Herold¹

¹ Laboratory of Geo-Information Science and Remote Sensing, Wageningen University

Introduction
With deforestation in the tropics accounting for nearly 20% of global carbon emissions [1], tropical forests are known to play a key role in the mitigation against global climate change. For this reason, efforts as the Reduction of Emissions from Deforestation and Degradation in developing countries (REDD) require the establishment of robust forest monitoring systems, for which remote sensing data are an important component. As remote sensing data such as imagery from the Landsat satellite missions become increasingly available to the public, methods are needed to utilize these data to their maximum potential. These methods should also integrate existing local monitoring efforts to ensure accuracy of the results and sustainability of the system.

In this paper, we present an integrated near real-time forest disturbance monitoring system which utilizes temporally dense Landsat time series in combination with a continuous local expert based system in an afromontane tropical forest ecosystem in south-western Ethiopia. Landsat time series is analyzed using the Break detection For Additive Season and Trend (Bfast) Monitor method, a statistical method which detects time series breakpoints in near real-time [2]. In situ local expert data is in turn facilitated by the use of mobile devices programmed to be able to classify land use changes. The objective of the study was to assess the capability of Bfast Monitor integrated with continuous in situ forest data to detect deforestation and forest degradation in near real-time. To this end, field observations related to recent disturbances are used to determine whether statistical breakpoints relate to actual recent forest disturbance events.

Methods
The integrated near real-time forest monitoring system described in this study is based on two key data streams. First, time series data from the Landsat 5 TM and Landsat 7 ETM+ sensors were preprocessed to correct for atmospheric and terrain effects using the LEDAPS preprocessing environment [3] and to mask cloud and cloud shadow pixels using the FMASK algorithm [4]. Preprocessed time series data were analyzed using the pixel-based Bfast Monitor algorithm, which detects breaks in time series by decomposing a defined stable historical time series into linear, harmonic and noise components and testing whether observed data during a defined monitoring period deviates from this stable historical time series [2].

Second, local expert based disturbance data related to deforestation and forest degradation was collected by local experts or forest communities using mobile devices [5]. These data included several parameters of the change event, including location, type, timing, scale and drivers of the reported change. The local expert data was facilitated by the design of interactive
forms on a mobile device which allow the user to classify Land Use, Land Cover and Land Cover Change based on a decision-tree based design. Near real-time disturbance data received from local experts was used to validate the change results obtained from the Bfast Monitor analysis. Bfast Monitor change polygons were stratified with the aid of ancillary data based on the types and intensity of changes, and random polygons were sampled in each stratum for verification of the detected change.

Results and Discussion
Bfast Monitor was found to be capable of detecting deforestation events and to a lesser extent, forest degradation. The timing of deforestation is a key output of the Bfast Monitor method, where the breakpoint date is derived from the acquisition date of the scene in which the breakpoint occurs. In areas where the time series are sufficiently dense, deforestation timing was generally fairly accurate when aggregated by year of change. Bfast Monitor was found to be sensitive to areas of low data availability, including persistently cloudy areas and areas near scene edges which are heavily affected by striping arising from Landsat 7 scan line corrector (SLC) associated gaps. In general, lack of data to sufficiently model the stable history period resulted in high commission errors, which could be eliminated to a certain extent by introducing a change magnitude threshold.

In addition to providing a continuous data stream against which the Bfast Monitor time series analysis could be validated, integration of local expert data with the Bfast Monitor analysis was found to reveal the dynamics of land use change in the study area. Given the dominance of small-holder agriculture as a driver of deforestation in Southwestern Ethiopia, deforestation was found to occur in small incremental changes rather than large discrete clearances. These small changes were usually preceded by heavy degradation of edge forest, which in many cases could also be observed using the Bfast Monitor method.

The integration of local drivers assessment into the in situ monitoring methods was shown to explain the patterns of deforestation and degradation observed by both the Bfast Monitor and the local expert based methods. Local expert data also revealed that major drivers of deforestation are smallholder agriculture, which is largely tied to degradation by fuel wood extraction and smallholder coffee cultivation.

The results in this study demonstrate the potential benefit of integrating dense remote sensing time series using such methods as Bfast Monitor with a continuous in situ data stream. Such deforestation monitoring systems will play an important role in developing countries that are currently establishing monitoring systems for REDD. With the recent launch of the Landsat Data Continuity Mission (LDCM) [6] and the anticipated launch of the ESA Sentinel-2 mission [7], the methods described in this study will play an even more important role in ongoing forest monitoring efforts.

References


Combining medium and high resolution data in a multi-scale approach to detect breaks in satellite image time series

Loïc Dutrieux\textsuperscript{1}, Jan Verbesselt\textsuperscript{1}, Lammert Kooistra\textsuperscript{1}, Benjamin Devries\textsuperscript{1} and Martin Herold\textsuperscript{1}

\textsuperscript{1}GRS Laboratory, Wageningen

Monitoring of forest dynamics has gained in importance in recent years as change in forest cover is likely to affect aspects of the biosphere such as carbon cycle and biodiversity. Remote sensing time series are very well suited to monitor land dynamics such as deforestation thanks to their systematic and consistent acquisition of data and their archives dating back to the 80's. However, there is usually a challenge that consists in extracting the right information from a natural temporal signal that may contain temporal trends, seasonality, and noise. The recently developed BFAST (Breaks For Additive Season and Trend) method has been shown successful in detecting breaks from times series of vegetation indices regionally and globally. The principle behind the BFAST algorithm is that it decomposes a time series signal in trend, seasonal and residual components and allows for the detection of abnormal behaviors, called breaks or anomalies. BFAST has been used for moderate spatial resolution data that deliver dense and regular time series, but the method would gain from being applied to higher resolution data as land monitoring requirements tend to move toward higher levels of details.

Although BFAST is directly applicable on high resolution data, ongoing investigations using Landsat time series show that fitting a seasonal trend model on these data can be sub-optimal, depending on the temporal density of observations and on the quality of pre-processing applied. As a consequence, while both Landsat and MODIS types of data can be used separately in the break detection process, both have limitations for forest monitoring applications. For medium resolution data like MODIS, the pixel size tends to be larger than the focal scale of most deforestation processes, while the revisit frequency of Landsat data does not allow a good modeling of vegetation seasonal behaviors. Although, the potential of a combined sensor approach has been suggested in earlier studies in order to deal with such space-time trade-offs, this has not been adopted for the BFAST approach yet. The present study proposes, based on the existing BFAST method, to combine Landsat and MODIS for change detection. Such method benefits from the advantages of both sensors, namely the high spatial resolution of Landsat and the high temporal resolution of MODIS. Given that vegetation trends and phenology are mostly regional parameters, the seasonal-trend model required by the BFAST algorithm for defining a stable history period can be fitted using MODIS data. Later, the actual break detection is done at 30m resolution by comparing more recent observations derived from Landsat to the seasonal trend model derived at MODIS scale. The above described method is applied and tested over a tropical dry forest area located in lowland Bolivia.
Multi temporal analysis of floods and tsunami effects: annotation and quantitative analysis

Daniela Faur¹, Daniela Espinoza Molina², Inge Gavat¹ and Mihai Datcu²
¹ University Politehnica of Bucharest
² German Aerospace Center

This paper addresses the problem of multi temporal analysis of available TerraSAR-X data of Sendai region in order to assess flood extent and damages caused by Tohuku-oki tsunami. Over the last decade the use of Earth Observation satellites to support disaster and emergency relief has considerably grown. The 11 March 2011 earthquake northern Japan and the tsunami that followed left thousands persons dead or missing. The destructive tsunami, originated by the earthquake hit the coastline several minutes after the earthquake causing huge causalities, damages and the crisis at the Fukushima Daiichi nuclear plant. Particularly on March 12 the Japan region Sendai was partially clouded so that only the use of microwave data SAR data, able to penetrate clouds, allows a detailed and complete evaluation of the region.

Therefore, to evaluate the effects of tsunami, the analysis of remotely sensed imagery is based on a TerraSAR-X post seismic satellite time series of 3-month duration covering the area around Sendai in ascending and descending orbits in stripmap mode and on a few TerraSAR-X scenes acquired before the earthquake, between 2008 and 2011. DLR (German Aerospace Center) and Astrium GEO Information Services provided data for research purposes.

The proposed scenario considers knowledge discovery from pre and post disaster EO images by mapping the extracted data features into semantic classes and symbolic representations like “urban areas”, “agriculture”, “mountains”, “bridges”, “aquaculture”, “high voltage pylons”, “flooded areas”, etc. In order to fully exploit high-resolution satellite images a method based on patches is proposed to extract relevant contextual information. Consequently each TerraSAR-X image is divided into non-overlapping tiles, obtaining thus sub images over which are applied feature (texture and spectral) extraction algorithms. The local features of each patch act as a compact content descriptor, such that each patch is semantically labeled to describe the main information revealed.

Further, considering the available descriptors, the next step is to cluster the data in order to find similar semantic classes. The SVM classifier implements the concept of query by example using image content. The result includes well-recognized patches sharing the same semantic label.

Following the processing chain described above it is possible to determine tsunami effects on several levels: assessment of transportation infrastructure post disaster, possible power outages due to the damaged high voltage pylons, flooded urban regions, evaluate agricultural fields, damaged crops and estimate loses, etc. The results include well-defined semantic
classes, derived through semiautomatic methods thus developing an effective approach of multitemporal analysis.
Efficient selection of temporally coherent targets in the series of interferometric SAR pair images

M. Fekir, F. Hocine, A. Haddoud, M. Belhadj-Aissa and A. Belhadj-Aissa
Laboratory of Image Processing and Radiation (LTIR), Faculty of Electronics and Computer Science (FEI).
Algiers, Algéria

Selecting targets having a very low temporal variation in backscattering coefficient is an important step in the process of differential interferometry for detecting and monitoring surface deformation. This step is performed to select pixels that have stable backscattering for a long time period, i.e. they are not affected by the decorrelation constraints mainly due to the backscatterer instability due to vegetation or other processes like temporal change of the surface, large orbital distances between the two acquisitions and the delay introduced by the atmospheric layer. There are several algorithms for the selection of stable targets and are classified into two main approaches, the first is based on the amplitude processing of image series and the second is based on the analysis of interferometric coherence images. However, both approaches have their own defects. The first approach considers the threshold amplitude dispersion, which is the ratio between the amplitude standard deviation and its mean. To ensure the accuracy of the selection results, this approach requires a dataset of SAR images greater than 30 images. The second approach is based on coherence maps calculated from the average of a neighborhood window and it depends strongly on the baselines. In this paper, we propose a robust selection of stable targets for small dataset SAR images based on the minimization of the spatial decorrelation by constructing subsets of pair images with small baselines, where each subset is formed with respect to a master image. We then generate coherence maps on which we analyze both temporal coherence and distribution. Indeed, for each coherence map in a subset, a percentage of the best coherent targets are selected from the histogram and additional statistical analysis which includes the temporal evolution and both global and partial distributions of coherence. This allows us to have a threshold on which a first selection in each subset is accomplished, then a final selection is done on all available data. All coherent targets selected in a form of a sparse grid represent the pixels that the process of differential interferometry is based on, firstly subtract the contribution of the atmospheric layer and then estimate the ground movements and the topographic errors. A first experiment is conducted using ERS SAR data acquired on Houdh Berkaoui region in the south of Algeria. Indeed, this region is characterized by crater and surface deformation appeared after operations of oil wells.
An Approach for physically consistent multi-scale LAI retrieval from Sentinel-3 OLCI and Sentinel-2 MSI

Richard Fernandes\textsuperscript{1} and Nadia Rochdi\textsuperscript{2}
\textsuperscript{1} Canada Centre for Remote Sensing
\textsuperscript{2} University of Lethbridge

Leaf area index is a fundamental land surface parameter used both in models and as an indicator of vegetation patterns over space and time. Optical sensors such as Landsat Thematic Mapper and ETM+, SPOT HR and the upcoming Sentinel-2 MSI have demonstrated capacity (<20\% uncertainty) for LAI retrieval over homogenous targets under cloud free conditions. However, seasonal LAI monitoring requires LAI estimates at monthly to weekly intervals. Coarse resolution sensors (e.g MODIS, MERIS, Sentinel-3 OLCI) can provide this revisit but suffer from increased uncertainties due to mixed pixels. A theoretical basis is developed and tested for fusing data from the upcoming Sentinel-3 OLCI and Sentinel-2 MSI imagers in a physically consistent manner to update medium resolution (20m) LAI estimates on a frequent (<1 month) interval. The basis relies on the use of canopy recollision probability theory to provide a scaling rule between both imagers. This rule is then applied to update fine resolution LAI estimates by constraining the fine scale area average recollision probability with coarse resolution estimates. Verification is performed using MERIS (for OLCI) and CASI (for MSI) imagery acquired during 2008 over a mixed land use site. Results suggest that the multi-scale inversion improves significantly over a MERIS only estimate. Requirements for implementing this approach with the planned OLCI and MSI data streams are discussed.
Characterizing snowpack properties through particle filter assimilation of AVHRR data into a global snow depth analysis

Richard Fernandes¹ and Fuqun Zhou¹
¹ Canada Centre for Remote Sensing

Snowpack information such as snow cover fraction (f), snow water equivalent (SWE) and depth (d) are critical for a range of applications related to climate, weather, transport, water resources and habitat. In-situ datasets are available but are spare and costly. Satellite snow products from optical sensors are limited to cloud free periods while microwave sensors have insufficient resolution for many applications. We present here an approach for assimilating AVHRR satellite imagery within an off-line version of the Canadian Meteorological Service global snow depth analysis to resolve snowpack information on a continuous daily basis at 1km resolution. The methodology, based on a particle filter, allows for consistent estimates of f, SWE and d in addition to uncertainty intervals that reflect availability of cloud free data and the nature of snowpack dynamics over time.

The system is applied to produce Canada wide snow cover datasets extending back to 1998. Assessment of the system for mapping snow cover is performed through intercomparison with in-situ and satellite based (Landsat and MODIS) clear sky products over Canada. Issues related to mismatch in spatial scale and gridding of input climate data forcings and snow depth estimates are discussed. A prototype regional application of the system focusing on ingesting local snow depth measurements is also presented.
Documenting land cover and vegetation productivity changes in the northwest territories using the Landsat satellite archive

Robert Fraser¹, Ian Olthof², Alice Deschamps¹, Marilee Pregitzer¹, Steve Kokolj², Trevor Lantz³, Steve Wolfe⁴, Alex Brooker⁵, Denis Lacelle⁵ and Steve Schwartz⁶

¹Canada Centre for Remote Sensing  ²Northwest Territories Geoscience Office  ³University of Victoria  
⁴Geological Survey of Canada  ⁵University of Ottawa  ⁶NWT Centre for Geomatics

The 40-year continuity of the Landsat series of satellites provides a powerful means of detecting land cover changes occurring over the earth’s surface during this time. Several million images from the 30 m resolution TM and ETM+ sensors, including those collected by Canada’s Prince Albert Satellite Station, are now freely available from the US Geological Survey’s National Satellite Land Remote Sensing Data Archive. We are investigating the potential to use this archive as a cost-effective means for detecting land cover and productivity changes in subarctic environments covering a large area of Canada’s Northwest Territories (NWT). Landsat images with < 50% cloud cover during peak growing season were collected for the period 1984-2012 over 24 overlapping Landsat Worldwide Reference System frames. These 260 images cover 300,000 km², or 25% of NWT’s land area, and include two study regions spanning the forest-tundra transition zone. Each Landsat image was masked for cloud and shadow, and converted to top-of-atmosphere reflectance and Tasseled Cap and NDVI spectral indices. Each pixel’s unique time series of clear-sky index values was then analyzed using robust linear regression to characterize the magnitude and statistical significance of long-term spectral changes. The high frequency of observations is well-suited to detect changes in northern environments where large inter-annual variation in vegetation and hydrologic conditions may occur.

The processed imagery provided an average of 16 clear Landsat observations for each pixel during the 28-year analysis period. Compositing of the Tasseled Cap brightness, greenness, and wetness trends (slopes) as enhanced RGB images created a highly effective means of interpreting the physical characteristics of surface changes. Many of the change features identified this way could be corroborated using a range of reference data: time series of air photos, recent oblique photos from aircraft, high resolution satellite imagery, databases of forest fire and thaw slump disturbances, and circa 1950’s lake perimeters from a topographic database. A wide variety of natural and anthropogenic changes could be identified using the trend composites, including widespread forest fires, previously unmapped tundra burns, eroding coastlines and lake shorelines, draining of shallow lakes, forest succession following old (pre-1965) disturbances, seismic line disturbance, thaw slumps, municipal and road developments, and the footprint of recent and regenerating mining operations. The Landsat spectral trends are being classified into categorical change products representing the above change classes using decision trees and ancillary GIS data.

We also observed a strong Landsat NDVI greening trend over 6,000 km² (62% of the tundra land area) within the Tuktoyaktuk Coastal Plain Ecoregion. A rapid increase in greening began in
1992, corresponding to a series of years with mild winters and warmer than average July temperatures. NDVI trends were summarized by 30 m resolution land cover types and terrain attributes, including landscape position and a topographic wetness index. Many areas of dense shrub cover above treeline, especially those resulting from fire regeneration, demonstrated a saturating NDVI trajectory. This highlights the need to apply other vegetation indices (e.g. infrared simple ratio and Tasseled Cap brightness) to detect further increases in biomass. The long-term greening trend will be validated by recapturing a series of 1:2,000 scale colour-infrared air photos acquired over the Tuktoyaktuk Peninsula in 1980. The rapid, post-1992 greening will be investigated using growth ring chronologies from willow and alder stems collected from the region.

Geospatial products resulting from this work will be made available through the NWT Spatial Data Warehouse and are being targeted to decision makers as part of the NWT Cumulative Impacts Monitoring Program (CIMP) and Natural Resources Canada's project on Transportation Risk and Climate Sensitivity (TRACS).
Recovery focused temporal trajectories and recovery rates of northern boreal forests

Ryan Frazier\textsuperscript{1}, Nicholas Coops\textsuperscript{1} and Mike Wulder\textsuperscript{2}

\textsuperscript{1} University of British Columbia \, \textsuperscript{2}Canadian forest Service

Canada supports a large forested area, of which only a portion of this land is actively managed. Much is known about the condition and state of the more southern managed forests, however in the less-managed boreal areas, limited information exists describing species, age class distribution, and disturbance regimes. As a consequence, monitoring these forests over long time periods using satellite observations provides an increasingly reliable and cost effective option to obtain many of these critically needed forest descriptors.

While largely absent of anthropogenic disturbance, large areas of the less managed boreal forests are impacted annually by wildfire. We propose to focus on recovery of treed vegetation to better understand these unmanaged areas after disturbance, regardless of agent. In our boreal forest study area located on the border of British Columbia and southeastern Yukon we acquired a dense time-series of Landsat imagery spanning the Thematic Mapper and Enhanced Thematic Mapper Plus eras. Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) atmospheric correction is applied to a single image to which all other images are relatively normalized. A single image date is used to spatially segment pixels into homogenous groups and multiple image dates within one year are composited into a single image representing one year. Temporal segmentation was applied to the yearly composited stack and various metrics describing the temporal trajectory of a pixel are extracted, and also summarized by the previously made spectrally homogenous polygons.

Focusing on the recovery segments of the temporal trajectory and how they have changed through the time series, we are able to demonstrate that rates of recovery are dynamic and have changed over the 30 year time period. Within this forested environment we also found Tasseled Cap Wetness recovery rates increased in polygons that were younger rather older. A breakpoint of 19 years was determined through an analysis of slopes of linear trend lines fit to each yearly grouping. For example, younger recovering polygons had higher rates of recovery than older recovering polygons.
Evaluating accuracy improvements in wetland vegetation classification at two scales using bi-seasonal remotely sensed data

Daniel Gann¹, Jennifer Richards¹ and Hamadri Biswas¹
¹ Florida International University

Detection of plant communities in wetlands using a single remotely sensed data set is often confounded by frequently changing water levels, movement of floating vegetation and the formation of benthic and floating periphyton (algal) mats, as well as the phenological cycles of the species present. The use of remotely sensed images acquired at different seasons of the yearly water cycle can exploit these confounding factors and convert them to an advantage in the classification process. We evaluated the gain in accuracy using combined wet and dry season images versus single wet or single dry season images. In addition we were interested in the performance of two classification algorithms applied at two different spatial scales. We used wet and dry season images of Digital Globe’s WorldView 2 (WV2) sensor with a spatial resolution of 2m; for the same time frames we used two Landsat Thematic Mapper (TM) datasets with a spatial resolution of 30m. In addition to seasonal differences we included a local texture variable (variance for a 3x3 kernel) for the WV2 data sets. We tested the performance of two recursive partitioning algorithms: single tree vs. multiple tree or random forest approaches classifying wetland communities at the community and the structure level. The adequacy of each data set to map wetland plant communities with the single dry or wet and the combined bi-seasonal set was evaluated based on model-based cross-validated accuracy estimates. The analysis was performed in two distinct wetland types of the Florida Everglades: a ridge, slough, tree island (RS) patterned landscape located in Water Conservation Area (WCA) 3A; and a mosaic of shrub, sawgrass and short graminoid wet prairie (WP) located in the southern part of WCA 3B and the northeastern edge of Everglades National Park.

For both scales and for RS and WP landscape types, the model-based accuracy assessment indicated that the random forest classifier performed better than the single tree procedure, increasing accuracy an average of 2.4% and ranging from 1.3% for structural classes in the RS landscape up to 4.1% for community class level classification in the WP landscape. Including texture for the WV2 imagery increased the accuracy on average by 5% at the community class level and by 2.5% at the structural class level. Considering only the random forest classifier applied at the community class level for the WV2 data, the wet season datasets outperformed the dry season by an accuracy increase of 14% (dry = 73.1%; wet = 86.7%) in the RS landscape and 6% in WP (dry = 74.1%; wet = 79.6%). Combining the wet and dry season datasets increased the accuracy by an additional 4% (90.9% accuracy) and 6% (85.8% accuracy) for the RS and WP landscapes, respectively. For the TM data, accuracy was 11% higher for the wet season data in RS (dry = 79.5%; wet = 90.1%) for a combined season total of 93.1% accuracy. For the WP landscape the dry versus wet relationship was reversed; accuracy was 11% higher for the dry season only data (dry = 90.2%; wet = 78.8%) with a combined season total of 94%.

Community classes that benefitted most from the bi-seasonal WV2 classification approach in
the RS landscape were the tall graminoids (*Cladium jamaicense* and *Typha ssp.*) that were on average 10% and 5.5% less likely to be misclassified as the shrub *Salix caroliniana* or broadleaf classes (*Peltandra virginica*, *Blechnum serrulatum*, and mixes of *Sagittaria lancifolia*, *Pontederia cordata*, and *Crinum americanum*), respectively. Slough classes (*Nymphaea odorata*, periphyton and open water) were on average 4.1% and 2.6% less likely to be committed to the broadleaf and tall graminoid classes, respectively. In the WP landscape shrubs were misclassified by 6.3% less as trees and by 5.4% less as broadleaf classes, while broadleaf classes were committed by 5.4% less to the shrub class. Tall graminoids were less confused with broadleaf classes by 6.2% and with the short graminoid classes (*Eleocharis ssp.*, *Rhynchospora ssp.*, and *Panicum ssp.*) by 5.1%. 
Assimilation of multi-temporal remote sensing-based evapotranspiration into SWAP model for agriculture monitoring

Jagvijay P.S. Gill, Torsten Geldsetzer, John J. Yackel and Nidhi Bishnoi
Department of Geography, University of Calgary

In the past few decades, field-to-regional-scale, physical agro-hydrological models have provided a robust mechanism not only to investigate the cause-effect relationship between the interrelated variables, but also for forecasting. This has enabled efficient management of agricultural practices such as irrigation scheduling, water budgeting, crop growth monitoring and yield estimation. However the results from these models rely heavily on input parameters, which are in most cases difficult to acquire using field surveys. Remote sensing on the other hand can provide a variety of information over large spatial and temporal scales. This information can be combined with physical models using data assimilation techniques to derive model input parameters.

In the current study, we demonstrate an assimilation technique used to combine multi-temporal remotely-sensed evapotranspiration (ET) data derived from Moderate Resolution Imaging Spectro-radiometer (MODIS) with results from a physical one-dimensional SWAP (Soil-Water-Atmosphere-Plant) model. ET was calculated from MODIS using the Surface Energy Balance Algorithm for Land (SEBAL). A robust search and optimization technique called Genetic Algorithm (GA) was integrated with SWAP to achieve the best estimate of the system. The derived input parameters were finally used in SWAP to simulate. SWAP-GA simulations were extended to model for three scenarios: a) water budgeting; b) crop growth monitoring and c) crop yield estimation.

Our results show that SWAP-GA estimated parameters fairly accurately. A close match between the simulated and remotely sensed ET observations was found. Yield was found to be within the minimum-maximum range for the region. Actual yield values were not available for comparison.
Near real time landcover information extraction using local maximum fitting and neural network

Jagvijay P.S. Gill, John J. Yackel, Torsten Geldsetzer and Nidhi Bishnoi
Department of Geography, University of Calgary

Information about land-use-landcover type, especially agricultural crops is important for economic planning and policy making. Estimating this at large spatial (regional to national) and high temporal scales (weekly) is laborious and economically unviable using conventional surveying techniques. Further complexity is added due to the seasonal, spatial and behavioral shift in cropping practices. Remote sensing in this respect has proved to be an indispensable tool. Supervised classification of satellite images is one classical way of discriminating landcover types. This approach, however, is rather weak when considering the temporal element.

In this study, we test a promising alternative, where time-series Normalized Difference Vegetation Indices (NDVI) from different landcover types are used to build an annual signal database, which is further utilized for landcover discrimination using an Artificial Neural Network Image Classifier (ANNIC). A previously-trained ANNIC using signal database obtained through backward propagation is capable of differentiating between 8-day composite NDVI patterns acquired from Moderate Resolution Imaging Spectro-radiometer (MODIS) at spatial resolution of 250 meters. Signal contamination due to clouds, systematic, or acquisition errors in time series NDVI are removed using a Local Maximum Fitting (LMF) algorithm. LMF simulates the fluctuations in signals by fitting a limited number of harmonic curves. The number of harmonic curves in the LMF is selected using the Akaike Information Criterion.

Our results demonstrate a successful near-real-time application of initially trained ANNIC for landcover classification. However a large amount of ground truth information is required for initial training.
Signature analysis and modeling of multi-temporal, multi-frequency polarimetric microwave backscatter from snow covered first-year sea ice

Jagvijay P.S. Gill, Torsten Geldsetzer, John J. Yackel and Nidhi Bishnoi
Department of Geography, University of Calgary

The importance of snow cover on Arctic sea ice has been recognized at different levels. At micro level, the absorption properties of snow for Photosynthetic Active Radiation (PAR) determines the life cycle of epontic algal communities. At local to regional level, snow cover controls the life cycle of Arctic seals and polar bears. At global level, snow cover dominates the energy balance of the Ocean-Sea ice-Atmosphere (OSA) system, making it one of the most important variables in the climate change scenario.

The magnitude of these snow cover effects is a factor its thickness. Estimation of snow thickness on sea ice has been a challenge to date. Microwave remote sensing through its sensitivity to thermal variations in snow cover over diurnal to seasonal scales exhibits a promising approach towards estimation of snow thickness.

In the current study, multi-frequency polarimetric microwave signatures of thick and thin snow covers, co-incident to in-situ measured snow properties are analyzed at diurnal and seasonal scales. The multi-temporal polarimetric microwave signatures are derived from field based C, X and Ku-band scatterometers deployed on first-year sea ice. The interaction of the multi-frequency microwaves with snow cover properties of variable thicknesses are modeled and explained. The dependence of polarimetric signatures on incidence angle is also evaluated. We show the differences in microwave signatures between C, X and Ku-band for thick and thin snow covers and their covariance with respect to snow properties over daily and seasonal scale. The data utilized in the study was collected from 10-25 May, 2012 in Resolute Bay over smooth first-year sea ice.
Snow cover mapping for response in heavy snow events with multi-temporal MODIS imagery

Sinhoi Goo\(^1\), Seongsam Kim\(^1\) and Youngjin Park\(^1\)

\(^1\) National Disaster Management Institute, Republic of Korea

The number of great catastrophes and damages are increasing in the last sixty years. Climate change is leading to a rise in extreme weather events and its effect on natural catastrophe losses will increase. This study is conducted with an aim to facilitate the process of selecting effective disaster prevention measures by performing scientific analyses of disaster affected areas caused by heavy snow. The mapping methodologies for the regions with heavy snow and related products are developed by analyzing and applying the suitable mapping algorithm using Moderate Resolution Imaging Spectroradiometer (MODIS). Furthermore, the study presents a module that can materialize the developed mapping algorithm and product a snow-covered map automatically, which will help establish the basis of analysis for a proactive response in the cases of disasters caused by heavy snow. A heavy snow analysis module with the MODIS imagery, is developed by utilizing ENVI and IDL. It includes the functions of data pre-processing, Normalized Difference Snow Index (NDSI) mapping, and Fractional Snow Cover (FSC) mapping; and is also able to calculate snow-covered areas from snow cover mapping products and retrieve and visualize meteorological data from Korea Meteorological Administration.
Vegetation mapping in the northern mixed prairie using spectral unmixing approaches

Arun Govind\textsuperscript{1} and Scott Bell\textsuperscript{1}

\textsuperscript{1} University of Saskatchewan

Efficient landscape-level vegetation mapping in semi-arid regions with sparse vegetative cover and high surface heterogeneity (spatial and spectral) poses challenges of ‘mixed pixels’ and non-linear mixing when traditional whole pixel-based image classification approaches are used on medium-resolution imagery. Spectral unmixing methods such as the multiple endmember spectral mixture analysis (MESMA) have been suggested to overcome these limitations to a certain extent and also for estimating sub-pixel fractions of ground cover.

MESMA was used in this study to unmix three multispectral satellite images: SPOT-5, SPOT-4 and Landsat-5 with 2-em and 3-em models created using combinations of 97 optimal field- and image-endmembers (em) representing green vegetation (GV), non-photosynthetic vegetation (NPV) and soil, identified for the West Block of Grasslands National Park of Canada.

Results showed MESMA to be more effective than the simple SMA and to produce superior vegetation mapping compared to the whole pixel-based or object-oriented classifiers. MESMA was successful in capturing the spatial heterogeneity of vegetation and incorporating the spectral variability of the GV, NPV and soil surface materials within the study area. Optimal endmembers used in MESMA successfully mapped the dominant vegetation types and estimated sub-pixel fractions of GV, NPV and soil for the entire study area. Accuracy assessment using field-collected ground cover estimates and leaf area index (LAI) showed image classification accuracies >65%. Spectral unmixing efficiency was found to be highly dependent on the identification of optimum type and number of region-specific endmembers. Comparison of spectral unmixing results for the three imagery suggested spectral resolution to be important over spatial resolution. 3-em models were found to be better suited than the 2-em models for modeling vegetation types in the study area, however the availability of only multispectral imagery limited the full unmixing capability. The number of successful 2-em unmixing models for SPOT-5, SPOT-4 and Landsat-5 were 69, 76 and 70, respectively. The number of 2-em models required to model 99.9% of SPOT-5, SPOT-4 and Landsat-5 were 42, 58 and 45. The number of 3-em models required to model 99.9% of SPOT-5, SPOT-4 and Landsat-5 were 189, 458 and 221, respectively. The methodology presented can be used to a greater degree of success when hyperspectral imagery becomes available for the northern mixed prairie. Map products derived from spectral unmixing may be used for habitat- and fire-modeling, effective Park management, monitoring and management of invasive plant species.
Detecting spatio-temporal changes to the northern mixed prairie vegetation using multiple endmember spectral mixture analysis

Arun Govind¹ and Scott Bell¹
¹ University of Saskatchewan

Spatio-temporal change-detection in terrestrial ecosystems has become readily possible with open access to historical Landsat imagery, thereby permitting researchers to utilize archived imagery for a variety of studies on ecosystem monitoring and environmental change. This study used a 25-year period time-series Landsat-5 TM imagery at ~5-year intervals (1984-2011) to identify the spatio-temporal changes to the northern mixed prairie vegetation. Multiple endmember spectral mixture analysis (MESMA) and NDVI time-series analyses were performed on the historical imagery. A comprehensive region-specific endmember spectral library comprising of 1150 reference endmember spectra of green vegetation, non-photosynthetic vegetation and soils were collected through intensive field sampling at 41 sites in the West Block of the Grasslands National Park of Canada (GNPC). 97 optimal endmembers were identified and used to create 2-endmember models for image unmixing to map the dominant vegetation types and estimate sub-pixel fractions of surface or land cover in each historical image. Spatio-temporal change detection was performed by image-differencing each consecutive 2-em fraction or NDVI image pair in the historical time-series. Image unmixing and change detection analysis revealed that MESMA can be used as a standard tool for spatio-temporal change detection of the northern mixed prairie vegetation. MESMA was effective in mapping the dominant vegetation types and produced comparable results when used with the time-series TM imagery. Climatic variables of temperature and precipitation were found to affect the number of successful image unmixing models, with lesser number of models for years of climatic extremes. The number of successful 2-em models for 1984, 1999, 2005 and 2011 images were 49, 83, 64 and 84, respectively, and the corresponding mean NDVI values were 0.25, 0.43, 0.36 and 0.52, respectively. Results further indicate that the spatial distribution and variability of vegetation has increased in the study area. Change detection revealed the effectiveness of the biodiversity conservation or management practices since GNPC’s establishment and indicating that its conservation strategies were effective in controlling or minimizing disturbances in the Park region and increasing the overall cover of native vegetation. The methodology presented can be continued to be used to monitor spatio-temporal changes in the northern mixed prairie, and may be tested in other areas to gain valuable insight into their ecosystem dynamics.
Using MODIS time-series for detecting multi-scale processes of forest disturbance in the challenging environment of Southeast Asia

Kenneth J. Grogan\textsuperscript{1}, Dirk Pflugmacher\textsuperscript{2}, Rasmus Fensholt\textsuperscript{1} and Patrick Hostert\textsuperscript{2}  
\textsuperscript{1} University of Copenhagen \textsuperscript{2} Humboldt University Berlin

Southeast Asia continues to experience high rates of forest disturbance due to a diverse variety of underlying processes operating at similarly diverse spatial scales. Using remote sensing to monitor these disturbances over time provides a crucial component of understanding regional change patterns and dynamics. The MODIS Vegetation Index (VI) time series have largely been underused for change detection in the Southeast Asia, primarily due to the challenges presented by persistent cloud cover, dry season aerosol contamination, and pronounced phenological variation, resulting in a highly noisy dataset. Currently available processing and signal analysis techniques may, however, be able to overcome these obstacles. This paper examines the utility of MODIS VI time series (MOD/MYD13Q1) for the detection of abrupt change in a number selected study sites throughout the region. The study sites were chosen to represent different phenological conditions (evergreen & deciduous forest) and encompass varying patterns of disturbance found throughout the region, ranging from large scale processes (e.g. commercial plantations) to more discreetly scaled processes (e.g. smallholder agriculture). MODIS Terra and Aqua datasets were first combined to increase the probability of clear observations. The influence of artifacts in the time series was reduced by using MODIS supplied quality ratings and an additional quality screening step. The time series is smoothed and interpolated in TIMESAT using a weighted Savitski-Golay filter, and Breaks For Additive Season and Trend (BFAST) is utilized for the detection of breakpoints from 2000 to 2012. The accuracy of the approach is assessed using a reference dataset derived from Landsat time series and image chips. Samples of change and no-change pixels in both evergreen and deciduous forest are chosen using a stratified random sample design. Change pixels are ranked by percent disturbance within each 250m MODIS pixel and used to assess accuracy and disturbance scale dependencies. Combining Terra and Aqua datasets and including the extra quality screening step improved the stability of the signal. The detectability of different disturbances processes is presented with consideration given to spatial scale and phenological influence.
The Local Mutual Information Invariance: Application to change detection between multispectral images

Leone Gueguen\textsuperscript{1} and Fabio Pacifici\textsuperscript{1}
\textsuperscript{1} DigitalGlobe Inc.

This paper proposes an experimental analysis of the Local Mutual Information (LMI) invariance in the context of unsupervised change detection between multi-spectral images. The conversion from Digital Numbers to Surface Reflectance does not affect theoretically the LMI based change map under the assumption of homogeneous atmospheric conditions. Experiments are conducted with QuickBird bi-temporal images to assess the robustness of the LMI to conversion to Surface Reflectance. Results show that the probability estimation, upon which the LMI depends on, is critical for maintaining invariant LMI based change detection values.
Remote sensing of vegetation productivity in northern ecosystems

Xulin Guo\textsuperscript{1} and Xiaohui Yang\textsuperscript{1}
\textsuperscript{1} University of Saskatchewan

With the establishment of a set of NDVI norms (park level, ecodistrict and ecoregion) for Canada’s northern parks based on 23 years (1985-2007) of Advanced Very High Resolution Radiometer (AVHRR) baseline data, it is possible for park managers and some agencies to determine the current vegetation status in these parks by comparing the current NDVI values against the corresponding NDVI norms. We collected and compiled the satellite image data from AVHRR for the past three years (2008-2010). In conjunction with previous collected AVHRR data, the project monitors how vegetation changes in Canada northern parks over the past five years (2006-2010) by addressing the following questions: 1) how great is the departure from “norms” is the current ecosystem? 2) Is the departure above or below normal range, and by how much, where? 3) How does vegetation change in these parks in the long term?
Time series analysis of wetland dynamics through spectral mixture analysis of Landsat satellite imagery

Meghan Halabisky¹ and L. Monika Moskal¹
¹ School of Forest and Environmental Sciences, University of Washington

Wetlands are dynamic systems that have complex hydrological regimes, which are not well understood as it is time consuming and expensive to monitor landscape level wetland dynamics using current field methods. The consequences of this data limitation have prevented assessment of regional trends over time, including shifts in the relative coverage of different wetland types and changes in wetland function critical to understanding the full picture of wetland dynamics beyond “no net loss”. These consequences are now becoming increasingly severe, particularly in semi-arid and arid regions, since it is unknown how climate changes will alter the hydrological dynamics of wetlands and small ponds. This research addresses this need by combining field data and aerial imagery with multitemporal Landsat imagery to map and capture wetland dynamics at a finer scale than previously attained, which can be used both to study historical changes in wetland function and composition and to forecast future changes.

To understand wetland dynamics at both intra- and inter-annual scales we used over 200 dates of Landsat satellite imagery to reconstruct the hydrograph of each wetland within our study area in the Columbia Plateau ecoregion for 30 years (1981 – 2011). First, we used object-based image analysis (OBIA) to delineate wetlands using 2006 and 2011 aerial photography. Next, we used mixture tuned matched filtering (MTMF), a spectral mixture analysis method that requires only one target endmember, to detect percent water for each pixel within each Landsat scene. Finally, we used the delineated wetland polygons derived from the OBIA method to extract the associated MTMF pixel values to determine the percent inundation of each wetland for each date of imagery. Results are being validated by manually delineating the water surface area for 50 wetlands using two dates of high resolution aerial imagery and comparing it to the results from the corresponding dates of satellite imagery. Future validation will rely on data collected from field sensors currently monitoring water level changes in 30 wetlands. Given the extreme shortage of data on wetland dynamics, this research provides a critical historical dataset to support retrospective analyses of wetland change, and to calibrate and test climate-hydrologic models.
Insect defoliation and drought-induced dieback of forests are important natural disturbance agents on Canada’s forests that are anticipated to increase under projections of climate change (Volney and Fleming 2000; Dale et al. 2001; Allen et al. 2010). There are limitations with mapping precision and areal coverage from provincial and territorial aerial and field surveys that are the primary methods for assessing insect disturbances, and there is no current operational program for monitoring and mapping drought damage on forests (Hodge and Westfall 2009). The result is limited understanding of the spatial and temporal characteristics of insect outbreaks (Hicke et al. 2012) and drought damage resulting in forest dieback (Michaelian et al. 2011). The social license associated with the economic competitiveness of the forest sector and questions about ecological sustainability creates a need for monitoring forest change to quantify and track the status and health of Canada’s forests.

The broad spatial extent of forests in Canada and the need to monitor forest change caused by natural disturbances creates an ideal opportunity for implementing remote sensing based approaches. For insect defoliation alone, numerous multi-temporal remote sensing approaches have been undertaken, but reported to varying degrees of success (Hall et al. 2006). The lessons learned suggest tracking pixel change alone is insufficient, and acquisition of cloud-free satellite imagery during peak infestation is not guaranteed. The translation of pixel change to forest change is also necessary if information relevant to sustainable forest management is to be achieved. This is particularly true given change can be seen as categorical (class) or in a continuum, and thus recognizing how to describe change is important to establishing a link between the change event and the causal agent (Coppin et al. 2004).

The objective of this presentation is to describe the advances and challenges associated with the use of remote sensing to characterize change that results from a range of forest damage relating to insect defoliation and drought. Several questions will be posed to structure the presentation:

1. What is the manifestation of damage from defoliation and drought?
2. Mapping damage from aerial surveys and remote sensing: are they the same?
3. Tracking the change: How is defoliation and drought spatially distributed? How is it changing from year to year? Can remote sensing detect real change?
4. How do you validate multi-temporal remote sensing-detected change due to defoliation and drought?
5. What are the components of a national, operational monitoring system?

Question 1 addresses the challenges of monitoring defoliation from different insect species that include understanding their manifestation of damage, recognizing the influence of stand
composition on defoliator damage, and capturing their activity across a geographic distribution that could cover much of Canada. Drought damage on forest vegetation is more challenging than foliage loss caused by defoliation due to the dynamic process of mortality to the tree crown and branches. Understanding question 1 is therefore a fundamental element of a successful remote sensing application.

Question 2 recognizes that aerial surveys undertaken annually have been used to train remote sensing detection of insect damage, but with limited success. A difficult challenge has been to relate aerial estimates of defoliation severity to remotely sensed data when the ratings are based on broad categories of light, moderate, and severe damage (Hall et al 2006). This difficulty arises from defining a remote sensing spectral basis to broad class limits of defoliation severity. Based on the concept of relative change between pre- and post-disturbance, the presentation highlights research results of models developed between field-based percent defoliation and changes in remote sensing spectral response, and contrasts damage assessment between aerial surveys and remote sensing.

Question 3 will highlight case studies of methods and results for mapping of aspen defoliation, spruce budworm defoliation and aspen dieback caused by drought. To ensure defoliation can be mapped consistently from remotely sensed images, image pre-processing entailing geometric, radiometric, and topographic corrections, along with normalization of images between pre- and post-defoliation image dates is considered essential. These procedures support use of an image severity model for a geographic area that can be subsequently applied to another location.

Question 4 raises one of the most problematic issues in remote sensing of forest change relative to validation and accuracy assessment. Knowledge of the true magnitude of forest change is seldom available but there are ways of presenting evidence from alternative data sources that can be used as a source of validation. The concept of relative change is a method by which trends in damage assessment can be compared between aerial survey and a remote sensing time series.

Question 5 addresses the challenges of operational monitoring by introducing the components of a proposed system that combines information from remote sensing and aerial surveys, the National Defoliation and dieback Area Composite (NDAC).

In summary, a number of challenges exist across the spectrum of forest pest, host, and remote sensing perspectives. Research has addressed several of these challenges to varying degrees, but many remain. The presentation is organized to identify these challenges, highlight research advances, and present a framework for a national monitoring system contingent upon integrating aerial survey and remote sensing data products as a potential approach for annual detection and monitoring of insect defoliation and drought damage resulting in forest dieback.

Literature Cited


Assessing vegetation response to climate variability at different time scales

Pieter Hawinkel\textsuperscript{1,2}, Else Swinnen\textsuperscript{2} and Jos Van Orshoven\textsuperscript{1}
\textsuperscript{1}KU Leuven \textsuperscript{2}VITO

To evaluate human impacts on forests and other carbon-storing ecosystems, temporal patterns of vegetation cover status must be explained in terms of their causal factors. More specifically, the impacts of climate variability on vegetation dynamics must be identified, quantified, and separated from the impacts of human disturbances such as land use changes. A generic approach is to combine remote sensing-derived information about the vegetation cover status with meteorological data for a corresponding period and study area. To date, the most common approach consists of correlation analyses between time series of Normalized Difference Vegetation Index (NDVI) and precipitation depths. Various authors have examined the strength and the lag of the correlation between monthly, seasonal or annual vegetation indices on the one hand, and rainfall depths on the other hand. Thereafter, the findings were spatially related to various environmental conditions, such as soil and vegetation types. We propose a number of methodological improvements related to the choice of variables, and the handling of periodic fluctuations at different time scales.

Previous studies have utilized standardized NDVI anomalies and anomalies of precipitation accumulated over variable time spans. However, we found that off-site and lag effects are better accounted for by using anomalies of soil moisture content as an indicator of climate variability. Since the soil pore space can be regarded as a buffering reservoir for precipitation, we observed a more instantaneous and site specific correlation of soil moisture content with vegetation growth over a study area spanning East and Central Africa. Furthermore, the fraction of absorbed photosynthetically active radiation (fAPAR) is, as opposed to NDVI, a biophysical variable and is considered here to replace NDVI for further temporal analysis. Moreover, it is derived from multispectral satellite imagery, and its sensor-independent characteristics allow the compilation of a 30-year long time series.

The methodology to quantify the response of vegetation to variable climate conditions must be capable of detecting the time scales at which fluctuations occur. Time series of soil moisture content and vegetation indices display a clear annual periodicity, arising from the annual cycles of precipitation and the growing seasons of dominant vegetation types. As the objective is to understand climatic forcing beyond this seasonal response, all possible time scales must be accounted for in the analysis of the temporal signals of the explanatory variables. After the detection of trends in the time domain, spectral analysis of the temporal signals may reveal significant underlying periodic components, other than the annual cycle. As it is expected that the studied phenomena show changing behavior over time, the applied spectral decomposition methods must allow for flexibility in the basic periodic function. Therefore, time adaptive expansions of regular harmonic analysis are considered, and applied on univariate time series. Ultimately, bivariate analysis on a meteorological variable and a vegetation index will indicate which climatic fluctuations affect vegetation growth most.
Empirical Mode Decomposition (EMD) was tested for its performance in extracting the original components from simulated time series with varying mixtures of seasonal, long periodic, trend, step and noise components. The first results indicate the ability of EMD to reconstruct the short and long periodic components, as well as the residual trend. However, detection of abrupt changes still requires a preceding analysis step. Moreover, increasing levels of random noise introduce distortions that propagate throughout all detected periodic components, prompting a priori noise reduction.

The preliminary results for real time series will also be presented for the case of fAPAR (derived from NOAA-AVHRR and SPOT-VEGETATION imagery) and GLDAS soil moisture content, over East and Central Africa for a period of over 30 years (1981 to present) at a 10 km spatial resolution.
Temporal dynamics of vegetation cover in response to precipitation: a comparison over three plant functional groups in a protected semi-arid grassland

Yuhong He
University of Toronto Mississauga

The principal drivers that effectively determine the vitality of semi-arid grassland ecosystems are the amount and timing of precipitation. In contrast to well-established relationships between precipitation and some vegetation biophysical properties such as vegetation productivity and biomass, the effect of precipitation on percent vegetation cover in semi-arid grasslands are poorly understood. Consequently, this study used field data, high spatial resolution SPOT satellite images, and low spatial but high temporal resolution AVRHH images to (1) analyze temporal variations in maximum percent vegetation cover in a protected grassland over three plant functional groups from 1988 to 2007, and (2) investigate the performance of three commonly used drought indices (accumulated precipitation – P; climate moisture index - CMI; and the modified Palmer drought severity index - MPDSI) in estimating percent vegetation cover. The results revealed fairly strong links between percent vegetation cover and precipitation in three plant functional groups over the 20 years. The selected indices were able to explain a relatively high variation in percent vegetation cover in the upland plant group (R² = 0.41 for P, 0.45 for CMI, and 0.53 for MPDSI), low variation in the shrub group (R² = 0.25 for P, 0.28 for CMI, and 0.32 for MPDSI), and lower variation in the valley plant group (R² = 0.09 for P, 0.14 for CMI, and 0.21 for MPDI). In comparison with accumulated precipitation, the CMI and MPDSI which considered water availability, was able to explain a much higher variation in percent vegetation cover over the three functional plant groups.
A new MODIS product for visualizing multi-temporal regional change on a decadal scale

Jennifer Hird\(^1\), Inacio Bueno\(^2\), Riley Iwamoto\(^1\), Guillermo Castilla\(^1\) and Greg McDermid\(^1\)

\(^1\) Department of Geography, University of Calgary
\(^2\) Department of Forest Sciences, Federal University of Lavras, Brazil

We present a simple method for visualizing non-seasonal, inter-annual vegetation change over an entire decade in a single synthetic colour image. In this ‘decadal’ image, areas where the amount of vegetation has drastically changed between two consecutive years, whether through reduction or increase, are highlighted. We demonstrate our method for the period 2001-2011 over the province of Alberta, Canada. First, a time series of MODIS NDVI 16-day composite images from May through October for each year (11 observations per year) of our decadal time period was compiled into a single data set. From this, the second-highest NDVI (shNDVI) was extracted for each year, creating an 11-band data set in which each band represented per-pixel shNDVI for each year, and for which the effects of spurious spikes in the 16-day NDVI time series were minimized. We derive three new bands from this time series: 1) the maximum absolute difference (MAD) in shNDVI between consecutive years within the observed period, ii) the mean shNDVI for those years following the year when the MAD occurred, and iii) the slope of a linear regression applied to the 11-year shNDVI time series. These three bands are combined into a false-colour composite image, with each raster being placed in the red, green, and blue channels, respectively. This combination creates a striking synthetic colour image where:

- Areas that were converted from mostly vegetated to mostly non-vegetated, such as new urban developments are highlighted in bright red across the province
- Areas where vegetation was completely removed in one year of the eleven covered by the observation period, but gradually recovers in subsequent years, such as forestry clearcuts or wildfires, appear in light to dark orange
- Areas where vegetation slowly increases in density or biomass, such as those recovering from a pre-2001 disturbance (e.g., wildfire), appear in light blue
- Newly-irrigated agricultural fields appearing within the observed period appear in pinkish-white

We interpreted portions of the image for which we had aerial photography for various years of that decade and confirmed the overall the semantic consistency of the different colours. We suggest these decadal images could become an easily-interpretable standard product providing an effective, spatio-temporally informative depiction of landscape structure and change at regional or continental scales.
Monitoring tree growth and harvest related changes in forest biomass and carbon using lidar

Chris Hopkinson¹, Laura Chasmer², Natascha Kljun³, Eva van Gorsel⁴, Harry McLaughney⁵, Alan Barr⁶, Andy Black⁷ and Heather Keith⁸

¹ University of Lethbridge  ² Wilfrid Laurier University  ³ University of Swansea  ⁴ CSIRO  
⁵ Queen’s University, Canada  ⁶ Environment Canada  ⁷ University of British Columbia  ⁸ Australian National University

Multi-temporal airborne lidar and field plot data are used to model changes in biomass carbon storage through time at jack pine (6 years) and eucalyptus (10 years) forest stands in Canada and Australia, respectively. The Canadian jack pine sites represent a chronosequence of varying stand maturity, while the Australian eucalyptus site illustrates biomass changes resulting from different harvesting practices through time. Through the integration of eddy covariance tower flux footprint weighting procedures, the Lidar change detection results are compared with continuous estimates of CO2 flux to place the static remote sensing observations into an ecosystem - atmosphere flux context. Combined, these carbon monitoring techniques yield improved partitioning of forest carbon storages and pathways through time.
Recent bark beetle outbreaks in western North America have been widespread and severe. To provide perspective on the scale of the problem, effects on ecosystem carbon dynamics related to insect mortality may outweigh the effects of increasingly widespread and severe wildland fires. Forest managers need accurate information on beetle-induced tree mortality to make better decisions on how best to remediate beetle-killed forests and restore healthy ecosystem services. We mapped beetle-induced tree mortality using outputs from the LandTrendr analysis tool applied to Landsat image time series (1984-2010) at study areas in Oregon, Alaska, Idaho, Colorado, and Arizona. LandTrendr outputs indicating the timing, magnitude, and duration of disturbance events were generated consistently in all study areas considered and were used as inputs to empirical models predicting tree mortality as measured and summarized at forest inventory field plots geolocated within each study area. Predictive modeling was performed using the Random Forest machine-learning algorithm. Preliminary results from Arizona show that independent Random Forest models predicting four response variables: Dead Basal Area (BA), Live BA, Total BA, and Percent Dead BA, from LandTrendr outputs, explained only slightly less variance (10-56%) than these same response variables predicted from LiDAR data-derived canopy structure metrics (17-74%). At MultiTemp 2013, we will present predictive modeling results from across the different study areas, and evaluate the ability to apply LandTrendr and generalize outputs across different forest types with different beetle and host species. Our results will help forest scientists and managers to better map, manage, and monitor beetle-infested coniferous forests.
Agricultural intensification and fragmentation of natural vegetation in the Southern slopes and lowlands of Mt. Kilimanjaro, Tanzania

Pekka Hurskainen
University of Helsinki

Kilimanjaro, situated in Northeastern Tanzania, is considered the highest free-standing mountain in the world and highest peak in Africa (5895 m). Being a dormant volcano, deep and fertile volcanic soils have been formed especially in the southern, western and northern sides of the mountain. Precipitation in Kilimanjaro is in general higher than in other East African mountains. Exposure to the dominant wind from the Indian Ocean leads to higher annual precipitation (1900 mm to 2700 mm depending on elevation) on the southern slopes than on the other slopes. This has made Kilimanjaro region attractive for agricultural production especially in the Southern slopes, foothills and adjacent plains.

Exceptionally good agricultural productivity in Kilimanjaro region has attracted settlers already for the last 2000 years. During the last 100 years, population has multiplied 10 times and currently stands at well over one million inhabitants. Population densities vary from 500 to 1000 people/km².

Land cover in Kilimanjaro is heavily modified by humans. Savanna woodlands and grasslands surrounding the mountain base between 700 and 1000 m a.s.l., especially on the southern side, have been converted into rain fed or irrigated agricultural use. This dry and hot savanna zone changes into cooler and wetter submontane zone between 1000 and 1800 m a.s.l. In the submontane zone, most of the natural forest has been converted into a complex small-holder multicropping agroforestry system (Chagga home gardens) where food crops (maize) and cash crops (coffee) are shaded by banana trees and a scattered upper tree layer. The submontane belt is followed by four distinct forest zones, including a community forest buffer zone, forest reserve and finally the Kilimanjaro Natural Park.

In spite of the very high population densities and intensive agriculture in the Chagga home gardens, land has been used in a relatively sustainable way in regard to the high biodiversity and ecosystem service values in the submontane zone. Although the sizes of agricultural properties are small, the use of limited land has been maximized. The home garden zone has evolved over several centuries and its expansion has already stabilized, simply because it has no area to grow up- or downhill. Therefore, most of the agricultural intensification has been taken place in the lowlands, where potential for agricultural productivity is however much lower due to higher temperatures, generally poorer soils, erratic rainfall and dependency on irrigation.

Most of the research on land use / land cover (LU/LC) changes in Kilimanjaro so far have been concentrating on the impacts it has on the forest ecosystems, biodiversity, livelihoods, regional
climate and glacier retreat, for example. The lowlands in particular have received less attention, although the biggest pressure for new land to be converted into agricultural use is there. In many areas in the lowlands, soils cannot sustain yearly cropping, and shifting cultivating has to be practiced instead. Furthermore, severe droughts in the recent years have revealed the risks of over-exploiting the water resources of Kilimanjaro. Water is not only used for irrigation of food and cash crops, but also to feed the Nyumba ya Mungu reservoir and hydroelectric power station inside the Kilimanjaro catchment further south. Loss of natural vegetation, especially forest cover, has also reduced the availability of groundwater and surface water. Loss and fragmentation of natural vegetation in the region thus accelerates the need for agricultural expansion and intensification.

The general objective of this study is to analyse the general trends in LU/LC change during the last four decades in southern Kilimanjaro. Data used in the study include multi-temporal satellite imagery using different sensors (Landsat MSS/TM/ETM, SPOT 1-5, and Formosat-2). Each image is classified separately using multi-scale image segmentation and object-oriented classification using the LCCS nomenclature. Classifications are compared using post-classification change detection.

The ability to quantify landscape structure is prerequisite to the study of landscape function and change. The hypothesis of agricultural intensification and natural vegetation fragmentation in Kilimanjaro is scrutinized by analysing and quantifying the LU/LC changes with different landscape metrics. Landscape metrics from each time series are calculated and compared. The suitability of these metrics to explain agricultural intensification and natural vegetation fragmentation in different analysis scales will be analysed. Landscape metrics have the potential to quantify and categorize complex landscape into identifiable patterns and they might also reveal ecosystem properties that are not directly observable.

Preliminary results show that anthropogenic land use change in the lowlands has led to increased fragmentation of natural vegetation. For example, the few remaining natural groundwater forest patches in the lowlands have been encroached for agriculture and degraded by overgrazing, logging and burning. Agricultural intensification is clearly visible in the savanna woodlands and grasslands, which are burnt and cleared for rain-fed crops (mostly maize). Wetlands have been drained into irrigated agriculture use, mostly rice and sugarcane. In fact, current precipitation rates in the lowlands would not allow such intensification of agriculture — crop production is heavily dependent on irrigation and groundwater yield coming from natural springs originating from Mt Kilimanjaro.

At landscape level, fragmentation of natural vegetation has dire consequences on ecosystem services and ecological processes. Possible effects include, among others, loss of biodiversity, changes in species composition, loss of habitats, decreased connectivity between habitats, edge effects and changes in microclimate. Loss of wetlands means crucial ecosystem services, like water regulation, recharging and purification, are threatened. These, in turn, have an effect on
agricultural productivity and food security through increased soil erosion, less habitats for pollinators, reduced shade, reduced groundwater levels and changing microclimate.
Satellite microwave time series detection of boreal forest recovery from wildfires in Alaska and Canada

Matthew Jones¹, John Kimball¹ and Lucas Jones¹
¹ University of Montana

The rate of vegetation recovery from boreal wildfire influences terrestrial carbon cycle processes and climate feedbacks by affecting the surface energy budget and land-atmosphere carbon exchange. Rapid post-fire vegetation canopy recovery within 5 to 10 years has been reported from satellite optical-infrared forest recovery assessments using normalized difference vegetation index (NDVI) and CO2 eddy covariance techniques. These techniques however are not directly sensitive to changes in vegetation biomass. Alternatively, the vegetation optical depth (VOD) parameter from satellite passive microwave remote sensing can detect changes in canopy biomass structure and may provide a useful metric of post-fire vegetation response. We analyzed a multi-year (2003-2010) satellite VOD record from the NASA AMSR-E (Advanced Microwave Scanning Radiometer for EOS) sensor to estimate forest recovery trajectories for 14 large boreal fires from 2004 in Alaska and Canada. The VOD record confirmed generally rapid post-fire recovery (3 to 5 years) for 5 of the burned areas, while lagging NDVI recovery by approximately two years. The relative VOD lag was attributed to greater microwave sensitivity to woody and foliar biomass regeneration which is expected to show a slower response than canopy greenness recovery. The duration of VOD recovery to pre-burn conditions was also directly proportional (p<0.05) to satellite (MODIS) estimated tree cover loss used as an independent metric of fire severity. Our results indicate the VOD parameter enables more comprehensive assessments of boreal forest recovery and that vegetation recovery from boreal fire disturbance is generally slower than reported from previous assessments.
Data integration of multi-temporal disaster imagery for timely natural disaster monitoring

Seongsam Kim¹, Sinhoi Goo¹ and Youngjin Park¹
¹ National Disaster Management Institute, republic of Korea

Recent natural disasters have occurred in a different and unexpected aspect unlike the past. Both the intensity of hazard and the damage size of disaster are more increasing than over the last decades. These situations of recent disasters require a strategic approach with the multi-sensors data integration to respond the natural disaster effectively.

The purpose of this study is to suggest a data integration approach from different type of sensors and evaluate the applicability for timely natural disaster monitoring. The data fusion methodologies are based on photogrammetric process: georeferencing, image registration using remote multi-sensors such as the satellite imagery, aerial photos from UAVs and Aircraft, and aerial and terrestrial LiDAR point clouds in damaged areas. Damage assessment was implemented by change detection using pre- and post-disaster imagery. Disaster information produced from multi-temporal data are expected to apply for disaster management activities such as more accurate damage analysis and rapid disaster mapping.
Satellite detection of changing frozen seasons and associated impacts on northern hemisphere vegetation growth

Youngwook Kim\textsuperscript{1}, John Kimball\textsuperscript{1} and Kamel Didan\textsuperscript{2}
\textsuperscript{1} University of Montana \textsuperscript{2} University of Arizona

The annual frozen season length strongly influences vegetation dormancy and productivity at higher latitudes and upper elevations where frozen temperatures are a major constraint to vegetation growing seasons. The landscape freeze-thaw (FT) signal from satellite microwave remote sensing is closely linked to frozen temperature constraints to surface water mobility, vegetation phenology, productivity and land-atmosphere trace gas exchange. We developed a consistent global record of daily landscape FT dynamics at moderate (~25-km) spatial resolution using a temporal change classification of overlapping 37GHz frequency brightness temperatures (Tb) from AM and PM overpass retrievals of the Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave Imager (SSM/I) satellite sensor records. A temporally consistent and continuous long-term (from 1979) FT record was created that distinguishes daily frozen, non-frozen and transitional (AM frozen and PM non-frozen) conditions. The FT results show mean annual spatial classification accuracies of 91 (+/-8.6) and 84 (+/-9.3) percent for PM and AM overpass retrievals relative to global weather station observations. The FT record is used to quantify variability and regional trends in Northern Hemisphere frozen seasons and transitional frost days. The significance of these changes for vegetation productivity is evaluated over regional climate zones and ecoregions using satellite (MODIS, AVHRR) based NDVI summer growth anomalies.

The FT metrics show a significant mean regional trend toward shorter (-2.4 days per decade; p<0.001) frozen seasons over the 30+ year record, driven largely by earlier spring thawing (-2.1 days per decade; p<0.001). The FT record also shows an increasing (2.0 days per decade; p<0.001) number of transitional frost days coinciding with reduced vegetation productivity in some areas. A declining frozen season with continued warming is predominantly enhancing vegetation growth in cold temperature constrained regions, while these effects are reversed or reduced in more water constrained areas. The lengthening transitional frost period is a consequence of regional warming and may be offsetting potential productivity and carbon gains from earlier/longer non-frozen season trends.
Coastal vegetation change using multi-temporal remotely sensed data at Ban Nam Khem, Southern, Thailand, by Tsunami 2004

Pasu Kongapai\textsuperscript{1}, Ajira Tiangtrong\textsuperscript{2}, Somrudee Jitprapai\textsuperscript{1} and Penjai Sompongchayakul\textsuperscript{1}

\textsuperscript{1} Marine Science Department, Faculty of Science, Chulalongkorn University, Thailand
\textsuperscript{2} Southeast Asia START Regional Center, Chulalongkorn University, Thailand

The massive Indian Ocean tsunami on 26 December 2004 brings significant loss to coastal ecosystems even economic, social and environmental change. One of the affected areas is Ban Nam Khem located in Phang Nga Province, the South, Thailand, where is a fishery community areas effected huge loss on coastal areas. After Tsunami impact the community realized in role of coastal vegetation in mitigation. The restoration of coastal forests both mangrove and beach forest has initiated by the community. The aims of this study were estimated by using change detection supervised classification approach based on pre-tsunami imagery (13 January 2003) and post-tsunami imagery (26 January 2005) and post-tsunami imagery for change detection. Monitoring of coastal vegetation along the coast was analyzed by using imagery on 20 February 2008. The coastal vegetation areas were carried out by using Remote sensing techniques with High-resolution satellite imagery (IKONOS) and geographic information systems (GIS). The results showed the thematic layers classified various land cover types: 1) vegetation 2) barren land 3) urban and 4) water, demonstrated the vegetation areas classified in 2003, 2005 and 2008 were 121.36 ha, 12.14 ha and 9.02 ha respectively. The vegetation cover areas decreased during 2003 to 2005 by 71.06 %. But after tsunami the vegetation cover in 2008 intensified 156.83 % from 2005. It could be concluded that increasing vegetation could be change by rehabilitation of coastal forest.

In present study, the generated coastal vegetation detection map for understanding in changing vegetation thus identified in forest type especially in beach forest and plants diversity. It further study will illustrate how to plant and manage vegetation.
Pushing MODIS to the edge: high-resolution applications of moderate-resolution data

Daniel Kristof¹ and Robert Pataki¹
¹ FÖMI - Institute of Geodesy, Cartography and Remote Sensing, Hungary

The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments mounted on NASA’s Terra and Aqua satellites have been providing continuous observations on 36 spectral bands between 0.405 and 14.385 micrometers, with three spatial resolutions: 250m, 500m and 1km nominal pixel sizes at nadir every one to two days. MODIS data are made available free of charge to the scientific community. A whole suite of derived products is produced in a systematic manner and can be used for research purposes. A time-series of more than a dozen years of observations and data products is available in the MODIS archives, making it a data source of inestimable value. Therefore, MODIS data have been extensively used among different disciplines.

However, these data have some intrinsic characteristics that make their processing a delicate issue. In our previous works, we have developed and tested a novel preprocessing (or reprocessing) method, based on an alternative representation of MODIS data. By using MODIS swath products and geolocation datasets instead of gridded MODIS data, all necessary information is available to determine the accurate ground location, dimensions and orientation of each MODIS sample (“pixel” in the raster representation). Here, each observation sample is stored as a polygon covering its calculated actual observation footprint, along with the corresponding radiometric values. It was shown that the above-mentioned method can correctly handle the e.g. the off-nadir increase of observation dimensions and the resulting overlap of the scan lines. Geometric representation of daily MODIS reflectance data at its original resolution was thus enhanced to enable pixel- or subpixel-level studies such as spectral unmixing or pixel-level change detection, without performing filtering, spatial or temporal aggregation.

The current work focuses on practical applications based on reprocessed MODIS daily reflectance data yielded by the above-mentioned method. Two application areas are investigated.

First, MODIS reflectance data were used for the radiometric rectification of high-resolution (HR) satellite images. This is especially useful when quantitative change analysis has to be carried out on the time-series of HR images. After reprocessing, MODIS daily reflectance data taken at (or very close to) the acquisition date of each HR image was used as radiometric reference to calculate a one-step linear transformation from digital counts to reflectance values. Each HR image was then converted to “MODIS-based” reflectance. Invariant features, previously identified on the HR images, were then used to assess the quality of radiometric calibration among the images of the time series. The results are encouraging, showing that this method can be efficiently used for the simple radiometric rectification of HR images taken in the lifespan of the MODIS archive.
Second, we investigated on the adequacy of reprocessed MODIS reflectance data for the monitoring and detection of abrupt changes on agricultural parcels. The primary aim is to determine the date of interventions, such as the harvesting of crops or the mowing of grass, at the parcel level. We used parcel polygons of a crop map based on high-resolution imagery, and calculated parcel-level red and NIR reflectance values as area-weighted average after intersecting the parcels with the overlapping MODIS polygons for each MODIS observation date. Our results show that although the processing in polygon format is more computationally intensive, it can offer a much “cleaner” time series and thus increased detection accuracy of temporal phenomena at the parcel level compared to the original gridded MODIS products – and this, without the need of filtering or temporal/spatial aggregation.

**Land surface phenology from MODIS data in Germany: How does the remote sensing based start of season reflect inter-annual climate variability?**

Carina Kübert¹, Christofer Conrad¹, Doris Klein² and Stefan Dech¹

¹ Department of Remote Sensing, Institute of Geography and Geology, Julius-Maximilians-University Würzburg
² German Remote Sensing Data Center, German Aerospace Center (DLR)

In the light of climate change, the derivation of phenological metrics by the means of remote sensing experiences an increasing relevance for numerous interdisciplinary research questions. Usually time series of remotely sensed parameters such as NDVI are used to describe the seasonality of vegetation canopy. In particular, phenological points in time, such as Start of Season (SOS), End of Season and Length of Season (referred to as Land Surface Phenology (LSP)) are derived and their changes are analyzed in order to detect climatic changes.

This study aims at the derivation and analysis of land cover specific changes of SOS over 12 years and their relation to ground based phenological observations using 16day MODIS NDVI time series for Germany covering the time period between 2001 and 2012. Focus was set on the generation of time series and deriving SOS. As a first step, MOD13Q1 product was downloaded for the tiles h18v03 and h18v04. The files were mosaicked, subsetted, reprojected and converted to GeoTiff using NASA’s MODIS Reprojection Tool. Gap filling and smoothing of time series was done in TIMESAT using the Savitzky-Golay filter with a moving window of 5 time steps as a first straightforward approach. SOS was derived as the date when the local NDVI reaches 40% of amplitude.

As land cover data set, two CORINE Land Cover (CLC) products were converted to the same spatial resolution as the 250m MODIS pixels: The latest available CLC classification of 2006 was used to assign land cover information, and the CORINE change file from 2000 to 2006 gives information about stable classes within CLC. Seventeen vegetation classes such as “Non-irrigated arable land”, “Broad-leaved forest”, “Natural grasslands” and “Moors and heathland” were chosen for analyzing temporal and spatial variability of SOS. All pixels that do not belong
to a vegetation class in CORINE land cover classification of 2006 or those that changed in land cover from 2000 to 2006 were not considered.

By computing and analyzing the descriptive statistics of SOS values, the phenological development of each CLC class was characterized. As a second step, the mean Start of Season over the twelve years was computed and considered as a predictor for mean phenological development. By comparing each single year to this data set, the yearly deviation caused by varying climate conditions was quantified. German Weather Service phenological data was selected for validation. This data is freely available and contains the dates of 167 phenological phases belonging to all meteorological seasons of different plants and crops for more than 2000 stations in Germany.

The results show reasonable dates for lowlands, basins and escarpments. The CLC class “Broad-leaved forest” with a mean SOS at Julian day 97 and a standard deviation of 11.7 days in 2012 can be distinguished from “Pastures” with an earlier onset of greenness at day 84 and a standard deviation of 20.8 days. This result coincides with phenological dates observed on the ground: Grasslands stay green in winter and are distributed mainly in the German lowlands, so they show an earlier onset of greenness. The higher standard deviation can be explained by the fact that they can be found in different climatic zones whereas broad-leaved forests are limited by their climatic envelope to the more elevated mountain regions.

The mean Start of Season shows good accordance with spatial patterns of topography, that can be seen as indicator for mean temperature development. The temporal deviation of the single-year SOS from the mean value indicated the rate of plant development for the year under consideration compared to an average year. In 2012 for instance, a mild and rainy January was followed by a dry and very cold February. This affects the SOS for all elevated regions in Germany. In comparison to a “normal” year, only maritime regions have an earlier onset of greenness.

Single years, especially 2002 and the period from 2009 to 2011, contain a numerosness of values that must be considered as too early or too late for a phenological onset of greenness. The mathematical deviation must be regarded as correct, but the fitted time series do not capture the real NDVI development in a satisfying manner. One reason is changing snow cover conditions in winter and early spring as missing values accumulate in the alpine foothills of Southern Germany and average mountains that lead to earlier SOS dates. SOS is detected later during the year, if the time series of a pixel shows only small amplitude. For these regions an advanced approach for generating the time series is concluded as an option for improvement: Time Series Generator (TiSeG) tool will be used to interpolate time series using I) the quality information delivered with the MOD13Q1 product to account for quality assessment regarding snow and cloud cover for time series construction and furthermore II) the day of acquisition that was selected for the NDVI value within MODIS maximum value compositing algorithm. It is expected, that this method avoids illegitimate early or late SOS values that result from lower quality data.
A Multi-year analysis of AMSR-E radio frequency interference in C, X- and Ku-bands

Teodosio Lacava¹, Emanuele Ciancia², Irina Coviello¹, Mariapia Faruolo¹, Francesco Marchese¹, Gieseppe Mazzeo¹, Nicola Pergola¹ and Valeria Tramutoli²

¹IMAA-CNR ²University of Basilicata

Radio Frequency Interference (RFI) in passive microwave radiometer data is a sensitive topic which, in the last years, has increasingly affected scientific products as well as the overall performance of a few specific satellite missions with a consequent economical impact. In detail, RFI is often caused by man-made emission sources such as telecommunication transmissions, civilian and military radars, high-bandwidth point-to-point terrestrial wireless communication links and wireless routers which transmit signals in a protected band. Also unwanted high emissions of active service stations operating at bands adjacent to the protected ones may produce RFI.

The Advanced Microwave Scanning Radiometer (AMSR-E) on Earth Observing System (EOS) Aqua is a clear demonstration of the high impact that RFI might have for a satellite mission and, in particular, for the retrieval of geophysical parameters. AMSR-E is a twelve-channel, six-frequency system, which measured for about nine years, from June 2002 to October 2011, brightness temperatures (BT), polarized horizontally and vertically, at 6.9 GHz (C-band), 10.7 GHz (X-band), 18.7 GHz (Ku-band), 23.8 GHz (K-band), 36.5 GHz (Ka-band) and 89.0 GHz (W-band). Soon after its launch, occurred on May 2002, RFI was discovered contaminating mainly its C- and X-bands and, with less relevance, Ku-band. For this reason, often C-band data have not used anymore or carefully used and X-band (less RFI affected) based soil moisture (one of the parameters planned to be measured by AMSR-E) retrieval algorithms have been preferred to the original C-band ones. As a consequence, the sensitivity of such measurements decreased, because of the lower penetrating capability of the X-band wavelengths than C-band, as well as for their greater noisiness, due to their high sensitivity to the presence of vegetation and/or precipitation in the sensor field of view.

RFI impact also on more recent missions has been further confirmed by data acquired at protected L-band (1.40-1.427 GHz) by MIRAS (Microwave Imaging Radiometer with Aperture Synthesis) aboard ESA/SMOS (European Space Agency/Soil Moisture and Ocean Salinity) mission: notwithstanding the efforts that ESA has produced during last three years in contrasting illegal emissions in L-band, no retrieval of soil moisture was possible for the whole month of October 2012 because of the high level of RFI contaminating SMOS ascending orbits over Western Europe. Thus, if for future missions RFI detection and mitigation strategies are required to ensure that radiometer measurements will not be degraded by extreme RFI, for past data developing new suitable and reliable data post processing strategies to reduce the impact of RFI is fundamental. In addition, the precise localization of RFI sources as well as their temporal variability may contribute to better understand and contrast the origin of the phenomenon.
Recently, the multi-temporal Robust Satellite Techniques (RST) approach, a general methodology for multi-temporal satellite data analysis, has been implemented on AMSR-E data in order to identify areas systematically affected by different levels of RFI in C-band. Nine years of AMSR-E data have been investigated to this aim, in particular exploiting the difference between the measurements acquired in the same polarization at two different consecutive bands (i.e. C- and X-band), which were recognized to be sensitive to RFI presence in C-band. Achieved results have shown that RST, taking into account the historic variability, at pixel level, of the studied signal, can help in identifying high level RFI affected areas as well as in providing a first indication about areas where weak RFI signals, but still significant, may be present.

In this work, considering that any concurrent presence of RFI both in C- and in X-band, may have reduced the sensitivity of the previously obtained results, further investigations have been made: in particular the whole data set (June 2002 - October 2011) of AMSR-E C-, X- and Ku-band data, has been analyzed, trying to better identify RFI sources at global level (on land) at these specific wavelengths, looking at single channel behavior without considering any kind of signals combination. In detail, according to RST prescriptions, for each land pixel the monthly mean and the standard deviation of the brightness temperature measured at C- (BT06.9), X-(BT10.7) and Ku-band (BT18.7) have been computed for all the 12 calendar months of the year. The applied procedure can be summarized as follows: (i) as a first step, all the required AMSR-E data acquired for every calendar month have been collected together (i.e. for the first month: January 2003, January 2004,...January 2011, for the second: February 2003, February 2004,...February 2011; and so on...), stratifying them on the basis of their orbit type (i.e. ascending or descending) and polarization (i.e. horizontal or vertical); (ii) then, for each of these 48 data-sets (i.e. 2 polarizations+2orbit types for each calendar month), temporal mean and standard deviation of the above mentioned signals (i.e. BT06.9, BT10.7 and BT18.7, respectively) have been computed. For each channel more than 3200 AMSR-E data have been processed to this scope.

Such “reference fields” have been used in this study to try to achieve a wide and clear view of RFI over land on a global scale. Areas where the analyzed signal showed high variability and/or persistent high values, both in intensity and time, should be in fact related to the presence of RFI. We expect, in fact, that anthropogenic noise, as RFI, appears stable in space and time domain, whereas natural (e.g. geophysical and/or meteorological) processes are likely to occur with peculiar seasonality and/or periodicity. In detail, such an analysis will help us in assessing global RFI contamination in each of the considered band (for each polarization and each orbit), overcoming the main limit of the previous work. The single based channel analysis should in fact provide a reference map, at global level, of the RFI sources in C-, X- and Ku-bands, useful for a their preliminary discrimination exploiting the RFI specific behavior in each band. Besides, thanks to the used long-term data series, such a study will also give us the opportunity of identifying RFI inter-annual variations both at global and regional scale. A clear identification of multi-band RFI sources and of their time-persistence, as well as of their first occurrence, could
be a first step in limiting signal transmission in protected band, and can obviously help in understanding signal transmission degradation in those unprotected.
Cumulative Impact Assessment: Monitoring land surface condition at regional scale using satellite remote sensing

Rasim Latifovic\textsuperscript{1} and Darren Pouliot\textsuperscript{1}

\textsuperscript{1} Canadian centre for Remote Sensing (Natural Resources Canada)

An integral part of environmental protection is the systematic monitoring of landscape dynamics. Landscape pattern at any given time is the stage at which dynamic processes have occurred. In order to improve our understanding of complex interactions between the biosphere and atmosphere and to make reliable predictions, quantitative landscape studies that consider time, or temporal changes are required. The difficulties in addressing the effects of mining development on landscape dynamics are accentuated by the fact that vegetative cover responds similarly to different stressors. Stress has many causes and collateral effects such as insects and disease that further damage plants that are otherwise weakened. Sorting out causes and effects is a challenging task and is critical for assessing and mitigating the impact mining might have on the surrounding environment.

A successful monitoring approach for evaluating surface processes and their dynamics at the regional scale requires observations with frequent temporal coverage over a long period of time in order to differentiate natural changes from those associated with human activities. However, long-term field observations in remote areas that have recently become suitable for mining development are typically not available. Systematic long-term measurements of vegetation properties in such remote areas usually cannot be economically justified prior to mining development. In most cases, remote sensing is the only alternative to field collected observations when an historical record is needed for studying long-term vegetation cycles. Long Term Satellite Data Records (LTSDR) are an essential component for any EO based land surface monitoring framework required to address regional scale reporting needs. The systematic implementation of such a framework offers a long-term capacity to generate, archive and access to satellite data and thematic products that support a broad range of research objectives. This talk will describe ongoing work and provide an outline of the framework and available long term satellite data record generated by Canadian Center for Remote Sensing appropriate for investigating cumulative impact at regional scale. Detailed information on data processing techniques used in generating these data, analysis of data quality and limitations will be discussed. Different information extraction techniques and examples that employ long-term satellite data records with 250m and 30m spatial resolution over Athabasca Oil Sands Region will be illustrated.
The Monitoring of surface deformation of permafrost in the Qinghai-Tibet Plateau with time-series DInSAR

Zhen Li and Panpan Tang

1 Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences

Permafrost covers approximately 53 percents of the Qinghai-Tibet Plateau, which is famous as the highest altiplano in the world. With the global warming and increased frequency of the human activities, the active layer become thinning at the permafrost area in the plateau, and serious surface deformation has been occurring in some region which is mainly due to the freezing-thawing circle and permafrost degradation. The deformation monitoring has an important significance for science research and engineering constructions. In this paper, we present the results of investigating long-term surface deformation of the permafrost in large areas with time-series differential SAR interferometry technique, which is more convenient and low cost, although GPS technique and leveling have been widely used to monitor the local deformation.

The study site is selected in Beiluhe(34°51.26′N, 92°56.35′) permafrost region of the Qinghai-Tibet Plateau, and the railway and road go through this region. Total 45 scenes ENVISAT-ASAR C-band images, acquired from April 2003 to July 2010 with descending orbits, were used in this study.

Two different algorithms are compared and used in this paper. The first one is referred to as Small Baseline Subset(SBAS), which utilizes interferograms with small space and time baselines, and allows us to generate mean deformation velocity maps and time series displacement. The other method is distributed scatterer (DS) InSAR technique. It is a new developed method mainly in order to solve the problem that in the suburbs permanent scatterers (PS) are very scarce. To reduce the speckle noise, a multi-look operation is applied. Medium scale information with a ground resolution of 40×40m (corresponding to 2×10 looks in range and azimuth respectively ) has been exploited. The minimum cost flow optimization technique is applied to unwrap the differential interferograms, and SVD (singular value decomposition) approach is used to estimate the time-series deformations from the unwrapped interferograms. For the second method, the process includes three steps. First Anderson-Darling (AD) Test is used to identify the homogeneous areas, then optimal phase is estimated by the method of maximum likelihood, Last, the same SVD approach is used to estimate the time-series deformations. At same time, several corner reflectors were built in 2007, the change values of corner reflectors from GPS and leveling measurement are used to evaluate the quality of the SBAS and DS InSAR products.

The deformation maps indicate a general subsidence in the study site, the average rate is about -5mm/a. In some place, the subsidence rates may be up to several centimeters per year, such as along the road, the reason is that human activities accelerate the thawing of permafrost. While the Qinghai-Tibet Railway and its embankment present a high stability and little
subsidence has been monitored, the uplift phenomenon is also visible in the time-series displacements. The seasonal deformation has occurred and makes the surface greatly uncorrelated and rugged, mainly caused by cycle of freezing and thawing, especially in the place near the river and road.

The results acquired with different ways agree well with each other, it showed that SBAS and DS InSAR technique can be used to monitor the surface deformation of the permafrost. The DS InSAR method is better than the SBAS, because it could exploit full resolution information relative to the low resolution of SBAS approach, and the number of DS is much more than PS, so the useful information could cover more areas. So, it is more suitable to the Qinghai-Tibet Plateau, where the surface is covered with exposed soil, grassland, moss and lakes, which are all good distributed scatterers exhibiting the same statistic characteristics in large areas and low coherence in time dimension.
Multi-annual landscape monitoring using the disturbance-inventory framework and its application to grizzly bears in west-central Alberta

Julia Linke\(^1\), Greg McDermid\(^2\), Marie-Josée Fortin\(^1\) and Gordon B. Stenhouse\(^3\)
\(^1\) University of Toronto \(^2\) University of Calgary \(^3\) Foothills Research Institute Grizzly Bear Research Program

The grizzly bear (\textit{Ursus arctos}) population of Alberta, Canada is threatened by human-induced disturbances that degrade and disrupt their habitat and increase the risk of human-caused mortality. However, the details surrounding the impact of cumulative human effects are neither yet fully understood, nor have the disturbances been monitored consistently over space and time. Monitoring of large areas is typically conducted via multi-temporal land-cover maps derived from remote-sensing imagery, but automated and efficient change-analysis procedures that are reliable enough for operational applications are still under development. This paper (1) highlights the conceptual foundations of our disturbance-inventory framework to reliable multi-temporal mapping, designed to address this need, (2) summarizes its application to western-central Alberta using a series of annual Landsat Thematic Mapper images between 1998 and 2004, and 3) presents relationships between multi-annual disturbance patterns and grizzly bears.

The 8800 sq km application area has been undergoing rapid development from timber harvest, petroleum extraction, and coal-mining and is host to a sub-population of about 42 grizzly bears. We used relative-abundance information from a grizzly bear DNA census conducted in 2004 alongside the generated disturbance-inventory database documenting changes in land cover and human footprint over the preceding six years to gain insight into the relative importance of disturbance and landscape processes on the spatial distribution of individuals in this population.

Using multi-temporal indicators for disturbance and landscape processes alone, we were able to explain about 57\% of the overall variation in relative grizzly bear abundance. Areas with lower disturbance exposure (mean distance to new annual disturbances), higher availability of regenerating forest, and lower disturbance context (neighborhood disturbance gradient) were associated with higher relative bear abundance. Areas located further away from an adjacent protected area (Jasper National Park) exhibited a higher probability of absences, accounting indirectly for the cumulative effects of human disturbance and the history of human-caused mortality.
Assessing altitudinal dependency of temperature trends in Mount Kilimanjaro using multi-temporal satellite data

Eduardo Maeda
University of Helsinki

In the backdrop of increasing evidences of human induced global warming, the effects of climate change on high altitude regions remain poorly understood. In general, current global circulation models (GCMs) indicate that warming trends are likely to be stronger at higher altitudes, reaching maximum values at altitudes corresponding to a pressure of 200–400 hPa. Although a number of recent studies confirm an altitudinal dependency of temperature trends, GCM simulations are often contradicted by independent observational data. Therefore, further studies are essential for confronting model simulations with in situ measurements, leading to a better understanding of the physical processes driving changes in atmospheric temperatures.

This study aims to apply multi-temporal satellite measured LST to evaluate the altitudinal dependency of temperature trends in Mount Kilimanjaro, Tanzania. Kilimanjaro is considered the highest free-standing mountain in the world and it is a symbol of the African continent. During the past years, widespread reports have warned about potential deglaciation associated with rising temperature trends. Nevertheless, few scientific evidences are currently available for linking glaciers loss with human induced climate change. In this study, monthly time-series of land surface temperature (LST) is used to evaluate temperature trends over Kilimanjaro. Particularly, long-term LST datasets, from 2001 to 2011, at monthly time scale, were obtained from the MODIS sensor. The product used was the MOD11A2, which offers daytime and nighttime LST data stored on a 1-km Sinusoidal grid as the average values of clear-sky LSTs during an 8-day period. Monthly means were calculated as an average of the 8-day LST composites inside the month. For each 8-day composite image, only pixels with at least four days of clear-sky were considered. Namely, pixels with five or more days of cloud cover, within the 8 days period, were discarded. Potential trends in LST change within the time-series were assessed using simple linear regression method and parametric t-test. Two levels of significance were considered: 0.05 and 0.1. In order to evaluate the altitudinal dependence of the trends, the LST dataset were divided into multiple elevation ranges. Preliminary results, obtained at altitude ranges of 1500-2000 m, 2000-3000 m and above 4000 m, show no evidence of altitudinal dependence of temperature trends. In fact, at both significance levels, no significant positive trends were found at daytime LST measurements. At nighttime, although significant trends were found during June, July and August, the magnitude of the trends are not necessarily correlated with altitude.
Thermal Monitoring of Japanese Volcanoes by Using a Multitemporal Method (RSTVOLC) of Satellite Data Analysis

Francesco Marchese¹, Teodosio Lacava¹, Nicola Pergola¹, Emilio Miraglia², Katsumi Hattori³, Valeria Tramutoli²
¹ CNR-IMAA  ² School of Engineering - University of Basilicata ³ Graduate School of Science, Chiba University, Japan

The RSTVOLC algorithm is an optimized configuration of the Robust Satellite Technique (RST) multitemporal approach for volcanological applications, developed for improving identification and monitoring of volcanic hot spots from space. This algorithm was first tested on Mt. Etna area, analyzing a long time series of Advanced Very High Resolution Radiometer (AVHRR) infrared records, showing a high confidence level in detecting thermal anomalies also of lower intensity, and highlighting a good potential for a possible usage in operational contexts. For a further assessment of these performances, RSTVOLC was then implemented and tested on Moderate Resolution Imaging Spectroradiometer (MODIS) infrared records and compared to MODVOLC, a largely accepted two-channel automated algorithm for near real time monitoring of active volcanoes at a global scale. This comparison has shown that RSTVOLC is capable of guaranteeing similar performances of MODVOLC in terms of reliability, together with an increased sensitivity to subtle hot spots, which may sometimes announce impending eruptions. Such a potential, was further assessed in a recent work, where RSTVOLC was specifically used to infer information about possible thermal precursory signals of Mt. Asama (Honshu, Japan) September 2004 eruption. This eruptive event is particularly interesting because it was preceded by different signs of unrest, including a thermal activity observed on the ground since mid-July 2004 and independently detected by satellite starting from the second half of August 2004. The RSTVOLC implementation on MODIS data has confirmed the occurrence of a phase of thermal unrest at Mt. Asama before 1 September eruption, well detailing its temporal features in better agreement with field observations. In addition, the performed analysis revealed signs of thermal unrest also for the following minor eruption, occurred on 14 September 2004. These outcomes were compatible with the different mechanisms of magma uplift speculated by in previous independent studies on the basis of field observations. Moreover, starting from detected hot spots, the intensity of thermal emissions was also quantified, giving information about the radiated energy during both pre-eruptive and co-eruptive thermal phases of volcano.

In this work, the occurrence of thermal precursory signals of Mt. Asama September eruptions is further investigated by using AVHRR records provided by the Chiba University of Japan, comparing achieved results with the previous satellite observations. In addition, potential of RSTVOLC in monitoring Japanese volcanoes by using Multi-Functional Transport Satellite (MTSAT) data is for the first time assessed here, performing a retrospective analysis of the recent Shinmoedake eruptions of 26-27 January 2011, when some strong sub-Plinian explosions occurred at volcano emitting significant amount of ash in the atmosphere causing air traffic disruption.
Outcomes of this work show that, although in a less continuous and evident way than MODIS observations, signs of thermal unrest preceding Mt. Asama September 2004 eruptions were potentially recognizable by satellite also analyzing infrared AVHRR records. The study of Shinmoedake eruption shows instead that RSTVOLC may be implemented with success also on data provided by geostationary satellites, for timely detecting hot spots before to characterize thermal volcanic activity from a quantitative point of view. These results confirm the great potential offered by the proposed algorithm to be used in the framework of an operational warning process, exploiting high temporal resolution satellites data for promptly recognizing anomalous changes in thermal activity indicating incoming eruptive events.
An Approach to the detection of changed buildings in multitemporal very high resolution SAR images

Carlo Marin, Francesca Bovolo and Lorenzo Bruzzone
Department of Information Engineering and Computer Science, University of Trento

This abstract presents a novel approach to change detection (CD) in very high resolution (VHR) SAR images aimed at detecting changes affecting building in urban areas (e.g., for damage assessment after natural disasters or for urban growth monitoring). Despite the strong interest on this topic from both the scientific and user communities, only few papers have been presented in the literature that address the problem of CD in man-made infrastructures in VHR SAR images [1-3]. In order to overcome the limitations of the state-of-the-art methods, which rely on the division of the scene in blocks [2] and grids [3], in this paper we propose a novel approach to building change detection in VHR SAR that works at level of each single building. The proposed approach takes explicitly advantage from the exploitation of the expected backscattering proprieties of buildings to detect changes associated to both new and fully destroyed buildings.

It is known from the literature that buildings in VHR SAR images can be modeled with specific primitives [1]. Simplifying, it is possible to state that the footprints of isolated buildings in a VHR SAR image are given by a specific pattern: a bright area (due to layover and double bounce effects) followed by a dark area (due to the shadow effect). These features may have different thickness, shape and internal intensity of backscattering depending on the considered building structure and size. The pattern associated to a building is oriented according to the viewing geometry of the SAR sensor: bright areas are closer to the sensor than the dark ones. Therefore, if we consider the case in which a new building fully appears between two acquisitions, we expect that a structured pattern made up of two regions having increase and decrease in the backscattering values will arise in near-to-far-range direction. This pattern will be distributed so that the surface of the dark area due to shadow cast by the new building is larger (or at least equal) to the surface of the bright area due to new structural components of the building (i.e., walls and roof). Vive-versa, a complementary behavior appears if a building fully disappears between the two acquisitions.

According to this observation, we propose an approach based on three steps: i) selection of the proper scale of representation for buildings; ii) detection of changed buildings by the analysis of all backscattering changes; and ii) discrimination between new and destroyed buildings among all changed buildings. The proposed approach exploits a multilevel representation of the multitemporal information. This is derived according to a multiscale decomposition of the log-ratio image obtained by the pixel-by-pixel comparison of the two images to be analyzed [3]. Images in the multilevel set exhibit different trade-offs between details preservation and homogeneity. Hence by knowing the expected building size, it is
possible to identify one (or more) optimum resolution level(s) to be used to seek for changes associated to buildings. Once the optimum resolution level has been selected, a map $M^\text{opt}$ highlighting only the areas of increase and decrease in the backscattering values is computed according to a thresholding procedure. The second step of the proposed approach aims at detecting all the areas of change in $M^\text{opt}$ that are comparable, in terms of extension, with the expected size of buildings. This is achieved counting the changed pixels in $M^\text{opt}$ inside a moving window with size $W_x \times W_y$ set according to the typical size of buildings in the considered scene. In this way it is possible to derive the candidate areas of change $CB_h$, $(h=1,...,H)$, which represent the candidate building radar footprint areas with size comparable or larger than the average building dimension. The third step of the changed building detection aims at associating the proper class of change (i.e., new or fully destroyed building) to each candidate $CB_h$, $(h=1,...,H)$. The classification is achieved testing 3 hypotheses. If one of the hypotheses is not satisfied, the candidate is rejected (i.e., changes that are comparable to the size of a building, but that do not present the typical pattern of new/destroyed buildings). The first test is devoted to identify the presence of both increase/decrease backscattering areas inside candidate regions. The pair increase/decrease is needed to identify a building (new or destroyed). The second test is devoted to reject the candidates that show a ratio between the surface of increase and the surface of decrease that is not included in a given range expected for a building. The third test is devoted to eliminate the candidates that present a pattern increase/decrease that do not respect the viewing geometry of SAR sensors. For those areas that satisfy the three aforementioned tests, the minimum estimated oriented bounding box is computed and shown in the final change-detection map. The discrimination between new and destroyed buildings is finally obtained considering the order of the pair increase/decrease of backscattering inside each building candidate with respect to the range direction. For space constraints the analytical description of the proposed method will be reported in the full paper.

Experimental results were carried out on a data set made up of two COSMO-SkyMed spotlight (1m×1m resolution, with 0.5m×0.5m pixel spacing, X-band) images acquired over the city of L'Aquila, Italy before and after the earthquake that hit the region in 2009. The log-ratio image $XLR$ was computed from the two calibrated and co-registered CSK© images. From $XLR$ a set with five resolution levels was computed according [4]. In the considered scene, it is expected that the minimum size of a building is 20×10 m².

Therefore the level $N=3$, which gives a resolution of approximately 8×8 m², and a window size of $W_x=35$ were selected. The proposed method extracted 13 changed areas $CB=\{CB_1,...,CB_{13}\}$. Each area has been analyzed in order to detect the fully destroyed buildings and derive the final change detection map. Since no ground truth was available for the investigated scene we validated the proposed approach considering the multitemporal aerial images available in Bing map© and the multitemporal satellite images in Google Earth©.
This analysis confirmed that all the identified destroyed buildings completely collapsed because of the earthquake and no new buildings were built up. At the same time the result presents a low rate of false alarms. Further results will be documented in the full paper.

REFERENCES


Mapping insect defoliation and change intensities using RapidEye data in pure Scots pine stands infested by the nun-moth (*Lymantria monacha*)

Alexander Marx¹, Birgit Kleinschmit², Katrin Möller³

¹ RapidEye AG  ² Technical University Berlin  ³ State Forest Competence Center, Germany

Defoliator infestations in pure pine plantations are a frequent and recognized problem in German Scots pine plantations. Existing damage mapping procedures are exclusively achieved by terrestrial sampling and surveys. Usually, foresters drive on the forest roads through the compartments and look for defoliation symptoms in the canopy on the stand edges. If a symptomatic site is identified, the forester walks into the attack area and estimates the defoliation status according to 3 generalized defoliation classes:

- light till moderate defoliation (corresponding with >20-50% defoliation),
- severe defoliation (corresponding with >50-90% defoliation),
- total defoliation (corresponding with >90% defoliation).

Too often, defoliator “nests” deeply inside the compartments are completely missed out, and prevailing defoliation classes are wrongly estimated. Delineating the true extent of an infestation area is almost impossible by terrestrial methods. As a result, control measures such as pesticide application in the following year cannot be precisely planned.

To overcome the described problem, an operational remote sensing-based method using RapidEye data has been developed. It was the objective to come up with maps which do not require ground samples (with one exception) for their production and which help guide the foresters to the potential infestation sites. The outcome was a mapping product bundle composed of 4 thematic layers. This product bundle consists in particular of:

Layer 1: Relative Canopy Vitality
Layer 2: Defoliation Classes
Layer 3: Relative Canopy Vitality Change (between two years)
Layer 4: Change Polygons

The product bundle was demonstrated to, evaluated and accepted by the state forest authorities as a valid data collection and decision support tool to be integrated in the existing state forest protection monitoring process.

The basic research and analysis supporting the method is subject of this study.

The study investigates the relationship between defoliation in pure pine stands infested by the nun-moth and spectral bands of the RapidEye sensor including the derivative products NDVI and NDRE. Furthermore, it demonstrates how the most suitable variable is exploited in order to retrieve the above described thematic layers.
The ground reference data required for analysis of the spectral variables was collected by an experienced specialist from the state forest service centre together with the foresters. The potentially infested sites were easily located using Layer 1 “Relative Canopy Vitality” of the product bundle. Sampling occurred irregularly on transects through the principal areas of infestation. Sample points were selected according to a visible, relatively homogeneous defoliation status in a radius of 5-8 meters. For each sample plot, the centre coordinates were recorded using a Magellan Mobile Mapper equipped with ESRI ArcPad8 software. Defoliation was visually estimated in 10%-classes and the average defoliation value recorded for each sample plot. The objective of our sampling strategy was to cover the entire range of occurring defoliation classes. A total of 95 GPS measured sample plots met this objective. The ground samples were then correlated with the spectral variables.

The investigation suggested that a linear relationship exists between all normalized spectral variables and defoliation. The strongest linear relationship ($R^2=0.74$) was observed in the NDRE (Normalized Difference Red Edge Index, $\frac{(NIR-\text{RedEdge})}{(NIR+\text{RedEdge})}$). The other variables showed the following determination coefficients: blue: 0.29, green: 0.55, RedEdge: 0.06, NIR: 0.27, NDVI: $R^2=0.56$. From these results it was concluded that the NDRE is the variable most suitable for mapping defoliation symptoms visible in the pine forest canopy.

All Layers of the product bundle were derived from the NDRE. Layer 1 “Relative Canopy Vitality” is a thematic raster calculated using a pine forest mask derived from a supervised decision tree-based classification relying on Ross Quinlans C5 machine learning algorithm. The NDRE is classified into 15 equally scaled classes applied within the empirically determined minimum (0.2) and maximum (0.7) values. Extreme values outside these boundaries are allocated to class 1 (lowest vitality) and 15 (highest vitality), respectively. The thematic raster obtains a particular intuitively interpretable color scheme allowing for the easy identification of disturbed areas and the visual recognition of varying disturbance (defoliation) intensities.

Layer 2 “Defoliation Classes” is the only Layer which needs ground samples in the first year for the identification of the suitable NDRE thresholds. If the same site is monitored in the second year, no ground reference data is necessary, as long as the images are taken in the same TOI, atmospherically corrected and normalized. Remaining radiometric differences between the years are reduced by radiometric image-to-image calibration using the IR-MAD algorithm (M.J. Canty and A. Nielsen 2008). Only a few samples may optionally be collected for verification and fine tuning of the thresholds. In our test case we used an iterative approach to identify most favorable threshold setting for the distinction of the defoliation classes. It was analyzed, which threshold setting would yield the highest accuracies when compared to our ground sample data. The following accuracies were achieved:

- light till moderate defoliation: producer’s: 100%, user’s: 68%, kappa:0.59
- severe defoliation: producer’s: 57%, user’s: 92%, kappa:0.87
- total defoliation: producer’s: 88%, user’s: 67%, kappa:0.60.

The overall accuracy amounted to 80% with an overall kappa of 0.73.
Layer 3 “Relative Canopy Vitality Change” is a simple difference Layer between the NDRE Layers of 2 dates (T1 and T2). The difference layer is classified into 20 5% difference classes. Only negative changes are considered. A standardized color scheme is assigned to this layer. Layer 4 “Change Polygons” is extracted from Layer 3 at a threshold of >=40% change. It serves the cartographic simplification of particularly strongly affected sites.

Layer 1 was produced for the years 2009, 2010, 2011, and 2012. This thematic time series clearly displays the change dynamics of the observed infested test area.
Supervised classification on large area with temporal/spectral statistical database of radiometric values, sentinel-2 preparation program

Antoine Masse\textsuperscript{1}, Danielle Ducrot\textsuperscript{1} and Philippe Marthon\textsuperscript{2}
\textsuperscript{1}Cesbio \textsuperscript{2}IRIT

As acquisition technology progresses, remote sensing data contains an ever increasing amount of information. Future projects in remote sensing like Sentinel will give a high temporal repeatability of acquisition and will cover large geographical area.

Sentinel-2 is a European project satellite from ESA. The satellite will carry an optical payload with visible, near infrared and shortwave infrared sensors comprising 13 spectral bands: 4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m spatial resolution (the latter is dedicated to atmospheric corrections and cloud screening), with a swath width of 290 km. Sentinel-2 combines a large swath, frequent revisit (5 days), and systematic acquisition of all land surfaces at high-spatial resolution and with a large number of spectral bands, all of which makes a unique mission to serve GMES.

For land cover mapping of large area, ground truth acquisition is not time and human possible. So, a methodology is developed to interpolated statistical information from available dataset of dates to dataset to classify. Then, a classification is performed with this spectral/temporal interpolated database. This methodology is thanked for automation of land cover mapping of large dataset of data.

Firstly, spectral and temporal signature is computed by interpolation on the missing dates. Two statistical objects are estimated on dates to classify: mean and covariance. The covariance interpolation needs more dates of sampling to be significant. Approach based on kriging method [Nielsen, 2005] is applied to for interpolation.

Secondly, a parametric classification based on maximum likelihood with Markovian probabilistic weighting of spatial context (Iterated Conditional Mode) is performed. Lastly, application of Selection-Classification-Fusion process [Masse et al, 2011] will be discussed and adjusted to this new methodology. This process will be able to select dataset of dates, samples and classifier to optimize the final quality of classification image.

Applications of this methodology are proceed on sensors similar to Sentinel-2 [Inglada, 2010]. We present tests performed on Spot 2/4/5, Formosat-2, and Landsat images. These tests have the advantage to give a wide range of resolution [Wemmert et al, 2009] and data type [Forestier et al, 2009], they allow validation of the statistical interpolation and the classification quality.
For Formosat-2 application, a database of radiometric statistics is computed on year 2006 to 2009 (84 images and 20 ground truth samples) and interpolated on available dates of year 2010. Ground truth samples of year 2010 are acquired to validate the interpolation and classification processes. Interpolation root mean square error is about 15, which is pretty good for an interpolation with multiple year data. Producer accuracies of classification performed with ground truth (GT) and classification performed with interpolated statistics (Interp) are closer. For example among the 28 thematic classes and respectively for GT and Interp classifications producer accuracy, woods class is 96.52% and 81.98%, wheat class is 65.5% and 85.47%, sunflower class is 74.15% and 77.52%. Results are closer and in some case better.

Tests on Landsat 5/7 images for large area land cover mapping and Spot 2/4/5 for long temporal series of images will be also presented.
Multi-temporal change analysis: How relative change should be measured

Greg McDermid
Department of Geography, University of Calgary

As our capacity to perform multi-temporal analysis is bolstered by the ever-expanding satellite-image archive, the importance of the metrics we use to characterize ground features takes is enhanced. In this paper, I reveal a series of issues related to the manner in which we measure changes on the ground and in common multi-temporal remote-sensing algorithms; highlighting how subtle mis-matches in ground- and remote-sensing-based metrics can impact the quality of our results.

Relative changes in geographic phenomena, such as those typically measured as percentages of difference on a ratio scale (e.g. percent mortality; percent increase) or ordered transformations on an ordinal scale (e.g. low/medium/high), are not well-captured by absolute indicators of change, and require the use of relative indices for optimal performance. However, most of the common measurements of relative change, including percentages and proportions, are asymmetric and non-additive: factors that can complicate the characterization and communication of relative dynamics. The natural-log change of two values, ln(x/y) is the only symmetric, additive, and normed indicator of relative change, but it has yet to be adopted widely in multi-temporal remote-sensing analysis. Through a theoretical discussion, I show how variables measured on a ratio scale are best summarized by natural-logarithmic changes in percent, and how these indicators could be successfully adopted in multi-temporal change-analysis procedures if a linear relationship can be established between dynamic ground-phenomena-of-interest and corresponding spectral indices. In testing these concepts, I used two variations of the enhanced wetness difference index (EWDI), one called the normalized enhanced wetness difference index (NEWDI), and another called the log-enhanced wetness difference index (LEWDI), to classify four categories of relative forest disturbance in a model environment, using the 5-scale canopy reflectance model. LEWDI (90% overall accuracy; kappa=0.79) outperformed EWDI (59% overall accuracy; kappa=0.25) and an alternative relative index called the percent enhanced wetness difference index (PEWDI: 83% overall accuracy; kappa=0.76), demonstrating the value of this new approach to remote sensing change analysis. These concepts are applied to a practical example analyzing the frequency of stand-replacing disturbances in west-central Alberta, Canada using the MODIS archive.
Separating herbaceous land cover in three prairie natural subregions with multi-temporal MODIS imagery

Will McInnes¹, Brent Smith¹ and Greg McDermid¹
¹ F3GISci, Department of Geography, University of Calgary

Separating native grasses from tame pastures is important for assessing biodiversity, mapping species habitat, and informing rangeland management. Native grasslands (primarily naturally occurring species) and tame pastures (primarily exotic grasses planted for hay, pasture, or seed) are spectrally similar and difficult to differentiate with traditional remote sensing techniques. However, seasonal vegetation profiles derived from multi-temporal remote-sensing data sets have the potential to differentiate spectrally similar grassland types. In this study, we use the seasonal profile of normalized difference vegetation index (NDVI) from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument to examine the separability of the two grassland types. Native grasses and tame pastures were found to have different rates of green-up that allow separation of the two classes with a linear discriminant function. Temporally smoothed 16-day composite 250m resolution NDVI values were used as independent variables in the discriminant function. Our initial study, in formerly-cultivated areas of Canadian Forces Base Suffield, showed a significant kappa improvement for the multi-temporal classification when compared to a traditional single-date method, and to an air-photo interpreted grassland vegetation inventory. The focus of this study, experiments in other natural subregions of Alberta, produced mixed results. An analysis of the 20 most homogeneous pixels in the dry mixedgrass natural subregion showed 100% classification accuracy. Larger sample sets in the dry mixedgrass (n=63), northern fescue (n=68), and central parkland subregions (n=25) highlighted the limits of the moderate spatial resolution associated with current high temporal resolution remote sensing, however. We found the multi-temporal method to produce overall accuracies of 81% in the dry mixedgrass subregion, 66% in the northern fescue subregion, and 76% in the central parkland. While we did obtain a significant kappa improvement when using the multi-temporal method over a single-date approach for two of the natural subregions, there was no improvement when compared to a human footprint map created through air-photo interpretation and remote sensing. Temporal trajectory indices were also tested, and were not found to significantly improve any of the classifications. This study showed that the multi-temporal method that was effective in homogeneous grassland had greater difficulty separating native and non-native grasses in heterogeneous agricultural areas. Future increases in the spatial resolution of high temporal remote sensing platforms could increase the effectiveness of this method; however, at this time it is worth exploring fusion with higher spatial resolution sensors.
Detecting interannual variation in deciduous broadleaf forests phenology using Landsat TM/ETM+ data

Eli Melaas\textsuperscript{1}, Mark Friedl\textsuperscript{1} and Zhe Zhu\textsuperscript{1}
\textsuperscript{1}Boston University

Observations of vegetation phenology provide valuable information regarding ecosystem responses to climate variability and change. Phenology is also a first-order control on terrestrial carbon and energy budgets, and remotely sensed observations of phenology are often used to parameterize seasonal vegetation dynamics in ecosystem models. Current land surface phenology products are only available at moderate spatial resolution and possess considerable uncertainty. Higher resolution products that resolve finer spatial detail are therefore needed. A need also exists for data sets and methods that link ground-based observations of phenology to moderate resolution land surface phenology products. Data from the Landsat TM and ETM+ sensors have the potential to meet these needs, but have been largely unexplored by the phenology research community. In this paper we present a method for characterizing both long-term average and interannual dynamics in the phenology of temperate deciduous broadleaf forests using multi-decadal time series of Landsat TM/ETM+ images. Results show that spring and autumn phenological transition dates estimated from Landsat data agree closely with in-situ measurements of phenology collected at the Harvard Forest in central Massachusetts (R-square = 0.80), and that Landsat-derived estimates for the start and end of the growing season in Southern New England varied by as much as 4 weeks over the 30-year record of Landsat images. Application of this method over larger scales has the potential to provide valuable information related to landscape-scale patterns and long term dynamics in phenology, and for bridging the gap between in-situ phenological measurements collected at local scales and land surface phenology metrics derived from moderate spatial resolution of instruments such as MODIS and AVHRR.
Monitoring urban expansion using a multitemporal data fusion approach: First results for South and East Asia

Carly Mertes¹, Annemarie Schneider¹, Damien Sulla-Menashe², Bin Tan³ and Andy Tatem⁴
¹ Center for Sustainability and the Global Environment and the Department of Geography, University of Wisconsin-Madison
² Geography Department, Boston University
³ NASA Goddard Space Flight Center
⁴ Emerging Pathogens Institute, University of Florida-Gainsville

The objective of this work is to present results from our recent efforts to monitor urbanization at regional to continental scales. The heterogeneous nature of cities and their surroundings makes classification with single source satellite imagery difficult given the trade-offs inherent to remote sensing data: very high resolution data is needed to accurately map urban features, yet large-area mapping makes use of VHR data impractical.

This research builds on our past work using Moderate Resolution Imaging Spectroradiometer (MODIS) data at 500 m spatial resolution to map global urban extent. The goal of the new research is to expand the original approach to map changes in urban areas globally for the period 2000-2010. To this end, the new change maps are produced by fusing datasets derived from multitemporal MODIS 500 m multispectral data (visible, near-infrared wavelengths) with multispectral MODIS 250 m enhanced vegetation index (EVI) data.

The overall approach to monitor change is based on the premise that any conversion of land to urban uses is unidirectional and absolute; any urban expansion 2000-2010 will appear as urban land in 2010. This assumption allows us to work ‘backwards’: once a final map of circa 2010 urban areas is created (step 1), we determine which areas within this 2010 extent were not urbanized in 2000 (step 2).

The heart of the methodology is the development of the data fusion approach for step 1, mapping circa 2010 urban extent. The fusion technique employed here combines information from the two MODIS datasets using Bayes’ Rule in a post-processing step to produce a final map of 2010 urban extent.

First, multiple years of smoothed, gap-filled MODIS 250 m EVI data for the growing season are combined within a logistic regression model to produce a probability surface for urban land. We theorize that maximum greenness (EVI) over the growing season differs significantly between urban areas and their surroundings. In tropical and temperate regions, EVI is higher in vegetated areas outside the city, while in arid/semi-arid regions, EVI is higher within the city due to tree/grass cover planted alongside roads and buildings. In either scenario, we assume that while not sufficient to separate urban and nonurban classes absolutely, vegetation content is an informative measure of the likelihood of observing an urban area. To predict whether a pixel is urban or nonurban, we estimate a logit function using a sample of urban and nonurban
sites collected on a per-region basis using very high resolution Google Earth imagery. The model is then applied to the corresponding maximum EVI data to produce an a priori urban probability surface.

Second, multispectral MODIS 500 m data and a global set of training exemplars are used as input to a supervised classification algorithm to compute conditional probabilities for both urban and non-urban classes. Using a decision tree classifier (C4.5) as the base algorithm, boosting is used to generate an ensemble of ten trees that allow estimation of the conditional probabilities that a given pixel belongs to each class. In the final step, we use Bayes’ Rule to compute the posterior probability of observing urban land cover at each pixel by combining the probabilities given by both datasets individually. The final pixel label is then assigned by thresholding the \textit{a posteriori} probabilities.

To map change within the circa 2010 urban extent (step 2), ten years of maximum EVI data (2001-2010) are used with a set of stable urban and urban change exemplars as input to the boosted decision tree classifier. This approach relies on the observed relationship between maximum EVI and urban areas described above: any conversion from a nonurban land cover into an urban land cover is detectable through changes in vegetation content. The premise of this method is similar to that of EVI trajectory analysis, but the use of supervised classification avoids the challenges associated with the large amount of missing data in South and East Asia.

Preliminary results show that significant improvements in map accuracy are achieved by fusing two sources of multitemporal data during post-processing. The technique was successful in addressing the unique challenges of mapping urban land cover over large geographic extents. The method has worked particularly well given the predominance of cloud cover and the local scale heterogeneity within and across cities in the Asian region. The framework presented here will ultimately be applied to global land areas to produce a consistent map of urban expansion for the 2000-2010 period.
Multi-scale and multi-temporal wetland monitoring in sub-Saharan West Africa using time series of medium and high resolution optical satellite data

Linda Moser and Stefan Voigt
German Aerospace Center (DLR)

Surface water is a critical resource in the Sahel region. The Sahel has been found to be extremely vulnerable to climate change and variability, and has suffered severe droughts in the mid-1970s, mid-1980s and the last ten years, among them in 2012. Farmers, pastoralists and villagers strongly depend on the availability of water in wetlands, particularly during and towards the end of the dry season. A case study carried out in Burkina Faso where more then 2000 small dams have been built, shows the strong human influence on water management driven by land use change, agricultural intensification and urban growth. Three different wetlands in the study area are part of the Ramsar List of Wetlands of International Importance.

Wetland detection and monitoring is commonly applied using satellite imagery and is of particular interest in areas where ground sampling and data are not very dense, or larger time periods or regions need to be covered. However, there are still many uncertainties and challenges due to the spatio-temporal dynamics of wetlands in semi-arid areas. Strong seasonal variations account for limitations when using spatially high resolution (HR) imagery, and small extension of significant wetlands cause limitations for spatially medium resolution (MR) imagery. Since spatial and temporal monitoring requirements cannot easily be satisfied using solely one sensor or method, in this work a multi-temporal and multi-scale approach is investigated. The three parameters: wetland type, surface water area, and flooding regime are monitored by image to image change detection of HR images in combination with MR time series analysis. In a further step it is examined how wetland changes are related to the occurrence of droughts. Time series imagery used in this study origin from MODIS (250m, since 2000) and the recently developed BioPar Surface Water Body product (1km, since 1998) based on SPOT VEGETATION. On the high resolution scale, two Landsat time series, one acquired at the end of the rainy season (Oct/Nov, where wetlands reach their maximum water level) and one at the end of the dry season (Mar/Apr), are used. For both MODIS and Landsat, spectral bands in the range of red and NIR serve to identify wetlands and build indices where NIR is employed as a proxy for flooding/standing water and the Normalized Differenced Vegetation Index (NDVI) as a proxy for dry season vegetation. Long-term seasonal variability is computed by automatic derivation of surface water using a dynamic NIR threshold on MODIS time series supported by topographic information from the SRTM digital elevation model (DEM); the BioPar Surface Water product serves for validation. Anomalies of surface water coverage are determined using time series of computed water layers (8-day and monthly means) based on MODIS, and Landsat images covering wet and dry seasons from several years. These bi-seasonal Landsat data are also used for wetland type classification based on approaches building dynamic classes in ongoing wetland and land cover mapping projects (GlobWetland-II, Landcover CCI), focusing on distinction between natural and artificial wetlands. The final classification is a combined result of the Landsat analysis and the derived flooding regime (number of inundated months) from MODIS. Preliminary results show an increase of artificial
wetlands, differences in flooding regime between northern and southern Sahel and also that wetland parameters would be suitable to monitor water stress. As a result of this, the study can show how spatio-temporal wetland dynamics can be captured using multi-scale remote sensing imagery and thus can provide a better understanding of the relationship between available water in wetlands, drought occurrence and agricultural development as critical elements of livelihoods in semi-arid areas.
Multiset Kernel CCA for Multitemporal Image Classification

Jordi Muñoz-Marfí, Luis Gómez-Chova, Julia Amorós, Emma Izquierdo, Gustavo Camps-Valls
Image Processing Laboratory (IPL) – Universitat de València, Spain. http://isp.uv.es, jordi.munoz@uv.es
This work is supported by the projects UN.INV.PRECOMP12-80639, FP7.SPACE-2012-313117 and TIN2012-38102-C03-01

1 Motivation and introduction

In this work, in order to deal with nonlinearities present in multitemporal analysis, we propose to use kernel Canonical Correlation Analysis (KCCA) [1,2] to exploit the wealth of temporal image information and to handle nonlinear relations in a natural way via kernels. To achieve this goal, we use the generalization of KCCA for several datasets, Multiset Kernel CCA (MKCCA) [3], which allows us to analyze more than two datasets simultaneously. The nonlinearly obtained features with MKCCA can be directly used in linear classification. We illustrate the use of MKCCA for land-use classification in a multitemporal setting. The proposed MKCCA method updates the projection transformation to the feature space as new images are acquired.

2 MKCCA: Multiset Kernel Canonical Correlation Analysis

Multivariate analysis methods look for projections optimizing a particular objective. For example, classical Principal Component Analysis (PCA) maximizes the covariance between input features, whereas CCA maximizes the correlation between projected input and output data [4], and reduces to solving the problem:

\[
\begin{pmatrix}
0 & C_{xy} \\
C_{yx} & 0
\end{pmatrix}
\begin{pmatrix}
u \\
v
\end{pmatrix}
= \lambda
\begin{pmatrix}
C_x & 0 \\
0 & C_y
\end{pmatrix}
\begin{pmatrix}
u \\
v
\end{pmatrix}
\]

Unfortunately, CCA can just perform linear transformations of the data. The framework of kernel MVA (kMVA) algorithms is aimed at extracting nonlinear projections while actually working with linear algebra. Let us first consider a function \( \phi : \mathbb{R}^d \rightarrow \mathcal{F} \) that maps input data into a Hilbert feature space \( \mathcal{F} \). The new mapped data set is defined as \( \Phi = [\phi(x_1), \ldots, \phi(x_l)]^T \), and the features extracted from the input data will now be given by \( \Phi' = \Phi U \), where matrix \( U \) is of size \( \dim(\mathcal{F}) \times l \). Now one relies on the availability of a kernel matrix \( K_x = \Phi \Phi^T \) of dimensions \( l \times l \), and on the Representer's Theorem [5], which states that the projection vectors can be written as a linear combination of the training samples, i.e., \( U = \Phi^T A \), matrix \( A = [a_1, \ldots, a_n] \) which yields:

\[
\begin{pmatrix}
0 & K_xY \\
YK_x & 0
\end{pmatrix}
\begin{pmatrix}
\alpha \\
\nu
\end{pmatrix}
= \lambda
\begin{pmatrix}
K_xK_x + \kappa I & 0 \\
0 & C_y + \kappa I
\end{pmatrix}
\begin{pmatrix}
\alpha \\
\nu
\end{pmatrix}
\]

(2)

Where \( \kappa I \) is a regularization term needed to obtain a meaningful estimation of canonical correlations in RKHS [3]. It should be noted that the output data could also be mapped to some feature space \( \mathcal{H} \), as it was considered for KCCA in [2] for a multi-view learning case. Here, we consider that the actual labels in \( Y \) (the land-use map across all time instants) can help to extract a set of features representing well the original target data.

Multiset CCA was presented for multitemporal remote sensing data [6]. In this paper, we propose a Multiset KCCA, so the image data at different time instants, \( x_t, t = 1, \ldots, n \), and the training labels \( Y \) enter the formulation. The proposed MKCCA reduces to solving:

\[
\begin{pmatrix}
0 & \ldots & K_{x2}K_{x3} & \ldots & K_{x1}K_{x2} & K_{x1}Y \\
\vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\
K_{x2}K_{x3} & \ldots & 0 & \ldots & K_{x2}K_{x3} & K_{x2}Y \\
\vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\
YK_{x3} & \ldots & \ldots & \ldots & 0 & K_{x2}K_{x3} + \kappa I \\
\vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\
YK_{x1} & \ldots & \ldots & \ldots & 0 & 0
\end{pmatrix}
\begin{pmatrix}
\alpha_1 \\
\alpha_2 \\
\alpha_3 \\
\alpha_n \\
\nu
\end{pmatrix}
= \lambda
\begin{pmatrix}
K_{x2}K_{x3} + \kappa I & \ldots & 0 \\
\vdots & \ddots & \vdots \\
0 & \ldots & K_{x2}K_{x3} + \kappa I \\
0 & \ldots & 0
\end{pmatrix}
\begin{pmatrix}
\alpha_1 \\
\alpha_2 \\
\alpha_3 \\
\alpha_n \\
\nu
\end{pmatrix}
\]

(3)

For multitemporal remote sensing image classification, MKCCA can be used to find a feature space where several datasets are correlated between them and the desired labels.

3 Experiment and results

For the experiments we used the fifth version of Dutch land-use database, LGN5, and MERIS Full Resolution L1b images conforming a time series covering the The Netherlands between February and December 2003. We focus on a image area of 400x400 pixels size and used a total of 7 images. Clouds were masked using the method in [7] on all the images. The ground truth contains 9 classes covering most of the observed area and it remains the same across all time instants (static land-use map for 2003). Figure 1 shows RGB compositions and the considered land-use map.
We compare standard classifiers that use the information available at a given instant, and a dynamic MKCCA approach that exploits the information of the current and previous images. For the monontemporal approach, we use canonical linear discriminant analysis (LDA) and SVM with RBF Gaussian kernel. For the multitemporal approach, for each time instant \( t_i \), we include in the MKCCA the image at \( t_i \) plus the two previous images that better correlate with the available labels. Finally, we train a LDA over the projections obtained with MKCCA. We refer to this multitemporal procedure as MKCCA+LDA.

Figure 2 shows the results obtained using 10 labeled samples per class. The results obtained by the standard classifiers, nonlinear SVM and LDA, show very different accuracies depending on the time instant considered, being the most favorable the image acquired in \( t_2 \), April 2003. The results also show the efficiency of the proposed MKCCA+LDA method. As new incoming images are used, the results improve and more accurate classifications are obtained. It is also worth noting that the accuracy slightly degrades for images at \( t_6 \) and \( t_7 \), which are the most difficult ones to classify, but the proposed method shows its robustness exploiting the correlations with other images.

![Figure 2: Results for the classification of 9 classes for nonlinear SVM, LDA, and the proposed MKCCA+LDA, for 10 labeled samples per class.](image)

**References**


Change detection in dual polarization and fully polarimetric, single- and multi-frequency SAR data and the complex Wishart distribution

Allan A. Nielsen¹, Knut Conradsen¹, Henning Skriver¹ and Morton J. Canty²
¹ Technical University of Denmark  ² Research Center Juelich, Germany

With the advent of several spaceborne dual polarization and (fully) polarimetric synthetic aperture radar (SAR) instruments (the Japanese ALOS, the Canadian Radarsat-2, the German TerraSAR-X, the Italian COSMO-SkyMed, and the future European (ESA) Sentinel-1 to be launched in 2013) this type of data are no longer reserved for a select few with access to airborne instruments but are becoming widely available.

When the covariance matrix formulation is used for multi-look SAR data, the complex Wishart distribution is useful. Based on this distribution a test statistic for equality of two complex variance-covariance matrices and an associated asymptotic probability of obtaining a smaller value of the test statistic are given in [1]. For single frequency, dual polarization data the covariance matrix is 2 by 2, for fully polarimetric data it is 3 by 3. For fully polarimetric combined C- and L-band covariance data, for example, in principle we get a 6 by 6 covariance matrix. The C- and L-band responses are, however, uncorrelated because of the difference in radar frequency, and hence difference in backscatter and backscatter mechanisms from the natural objects in the image. Therefore, the 6 by 6 covariance matrix will be a block diagonal matrix (with two 3 by 3 blocks). In this case the 6 by 6 covariance matrix does not follow a complex Wishart distribution. However, we can still use results from [1] to perform the change detection.

To illustrate the technique C- and L-band SAR images from the Danish airborne EMISAR acquired on 20 May and 15 July 1998 and covering agricultural fields and wooded areas near Foulum, Denmark, are used in single and dual frequency, bi-temporal change detection with dual polarization and polarimetric data.

As an example of a change detection result Figures 1 and 2 show RGB images of C- and L-band data from the two time points, and a representation of the test statistic in the case of dual frequency, fully polarimetric data with the associated probability measure. The very dark/black no-change regions in Figure 2 are mostly forested areas and the bright/white change regions are fields with various crops at different phenological stages at the two data acquisition time points.
Unlike most other change detection methods for polarimetric SAR data, the proposed method uses the polarimetric information in a unified way. Future work will include the extension of the test statistic for comparison of several (more than two) matrices which can be applied for change detection in truly multi-temporal polarimetric SAR data.
Software in Matlab, ENVI/IDL and Python to perform this type of analysis will be made available from the authors’ homepages.

References
Thermophysical Analysis of the Southwestern US from Multi-Year MODIS Land Surface Temperature

Scott Nowicki
University of Nevada Las Vegas

The spatial variation of arid land surface materials provides insight into a number of important mapping and modeling efforts, including habitat, surface-atmospheric feedback, sediment mobility, and global climate modeling. The degree to which bare soil and geologic surfaces vary in their contribution to the overall energy flux is not well understood, although they can be characterized using thermal infrared (TIR) remote sensing datasets. Surface characteristics such as mechanical composition (grain size, rock abundance), degree of soil induration (soil crusts), and soil moisture each produces different diurnal and seasonal temperature curves. These characteristics are difficult to map over large areas, given the small scale field observations that are required. Thermal mapping (thermal inertia) has the ability to map these features over a wide spatial and temporal range. In order to distinguish these surface material properties, the naturally-occurring diurnal, seasonal and weather-related surface temperature variations must be accounted for. The two primary research objectives of this project are to: (1) quantify the physical variation of widespread unvegetated surfaces in the western United States as a function of the naturally-occurring diurnal and seasonal thermal response, and (2) establish the limits of climate, season, precipitation, and vegetation cover under which the thermophysical observations can be utilized for surface-type mapping. NASA’s Moderate Resolution Imaging Spectroradiometers (MODIS) on-board the Terra and Aqua satellites have generated over a decade of global daily thermal observations, which are ideally suited for observing and differentiating the surface’s physical, climatic, and weather-related temperature variations. Five years (2005-2009) worth of daytime and nighttime 1-km TIR observations have been compiled to develop a long-term multi-temporal dataset used to map the areal extent of surface thermophysical units, identify anomalous surfaces and weather events, and establish time windows for using other remote sensing datasets with higher spatial resolution and lower temporal resolution (eg. ASTER with a 16-day repeat). Higher-resolution ASTER scenes have been used to map morphologic units in the Mojave desert for habitat modeling, but the perspective is limited with only one set of diurnal observations. MODIS scenes taken at multiple dates can be used to distinguish subtle differences in sub-pixel material mixtures, seasonal soil moisture changes, and physical changes that are occurring to the surface due to human disturbance. Our results suggest that the thermophysical differences between morpho-climatic surfaces may be more significant than existing climates models suggest for homogeneous bare soil. The region investigated in this research is based upon the footprint of the US southwesternmost MODIS data scene, which covers portions of CA, NV, NM, AZ, UT and Mexico. This encompasses the entirety of the Mojave desert, much of the Sonoran and Great Basin, and includes a number of the metropolitan areas of the West. The study region was selected because it contains a diverse set of ecosystems, is readily accessible for field work, and is being affected by anthropogenic processes, from climate change to urbanization. Most importantly, it is dominated by arid landscapes that are unobscured by clouds during most of the year, producing an ideal remote sensing dataset to characterize geologic landscapes.
Use of Landsat time series imagery for characterizing and monitoring young plantations over a boreal forest region in northwestern Québec, Canada

Valeria Osvaldo¹, Florence Lafon², Suzanne Brais¹ and Ahmed Laamran¹
¹ Institut de recherche sur les forêts (IRF), Université du Québec en Abitibi-Témiscamingue
² Université du Québec en Abitibi-Témiscamingue

Harvested areas in northwestern of Quebec are mostly planted with coniferous trees (typically black spruce and/or jack pine), but after 10-15 years they are often invaded by deciduous species which can reduce the growth of the coniferous trees. Information on multi-temporal land cover change is key requirement to assist forest monitoring and management of young forest plantations. Multi-temporal remote sensing seems to be more economical for the collection of such information rather than doing exhaustive ground based monitoring. The objective of this study was to investigate the potential contribution of a time series of Landsat imagery to characterize and monitor young forest plantations over an area (31 500 ha) of boreal forest. For this purpose, winter and summer Landsat imagery were acquired for three time periods (2000-2005-2010). Landsat images were radiometrically normalized and three metrics were derived to detect the rate of change and its directionality. The main inputs for the identification of changes in the area were derived from the Tasseled Cap Transformation components, greenness and brightness. Time series of the Normalized Difference Vegetation Index (NDVI) was another metric that provided important information on the state of spatiotemporal change over the study area. Our results showed that Landsat winter images successfully discriminated between planted coniferous and invasive deciduous species. The total area of coniferous forest visible from satellite imagery has increased by 34%, from 4736 ha to 7130 ha during a period of 10 years. The initial distribution of coniferous-dominated has changed and is in a constant state of change. The amount of total plantation modified per period decreased from 4736 ha in 2000 to 3177 ha in 2005. Overall, after 20 years the oldest plantation (1980-1985) showed a lower proportion of coniferous trees (7%) compared to 34% for the youngest plantations (1991-1995). In all cases mixed stands dominated the planted area with more than 53% after 20 years. Finally, matrix correlation highlighted interactions between type of planting, initial cover (coniferous and mixed) and plantation age have a great influence in the results. The probability of change from a cover type to another after 20 years is greater for deciduous (68%), followed by coniferous and mixed stands with 52% and 30% respectively. These results are useful for improving the identification of plantations that will require thinning as well as for predicting of expected forest-dominated landscape.
Crop type classification by simultaneous use of satellite images of different resolutions

Mutlu Ozdogan
University of Wisconsin Madison

Accurate and timely identification crop types has significant economic, agricultural, policy, and environmental applications. Existing remote sensing methods to identify crop types over large areas rely on remotely sensed images of high temporal frequency in order to utilize phenological changes in crop reflectance characteristics. However, image sets with high temporal frequency generally have relatively low spatial resolution. This tradeoff makes it difficult to classify remotely sensed images in fragmented landscapes where field sizes are small. This research seeks to develop a new method for combining high spatial resolution data with data of low spatial resolution but high time frequency in order to achieve a superior classification of crop types. We have built a rigorous mathematical framework to describe precisely the problem that requires solution, and we propose a principled solution to solve it. This solution is then implemented and tested on both synthetic and real datasets as a proof of concept. We show that by merging data with different spatial and temporal resolutions, an improvement in accuracy up to 20 percent can be achieved even if very few high spatial resolution images are available for a scene. This boost in accuracy is roughly equivalent to including an additional high resolution image to the temporal stack during the classification process. This significant boost in accuracy can help researchers create superior crop type classification maps, thereby creating the opportunity to make more informed decisions.
Multi-temporal Radarsat-2 data for semi-automated mapping of high and low waterlines in Canada’s north

Jon Pasher and Jason Duffe
Environment Canada

The intertidal zone represents the area that is above water at low tide and under water at high tide. The temporal changes associated with intertidal zones provides different types of habitats and therefore generally hosts a high level of species diversity. Depending on offshore and onshore topography along with local tide levels, the intertidal zone can vary greatly in width within a small geographic area. The Canadian Space Agency’s Arctic Coastal Initiative ("MORSE") focuses on information needs of Arctic coastal ecosystems that can be satisfied by Earth Observation (EO) data from satellites. Within this initiative, we investigated the use of multi-temporal RADARSAT-2 data for delineating and extracting northern coastlines in order to improve on, or in some cases create, maps for intertidal zones. Radar provides ideal data for this type of work with its ability to image large areas, even through cloud-cover and darkness, which hampers the collection of optical data, especially in Canada’s north. Generally speaking the separation of land and water using radar data is relatively easy, however saturated beaches, ocean waves, and potential signal penetration through shallow water, can cause confusion in the segmentation of the land-water interface. In a pilot project, Fine Beam RADARSAT-2 data was acquired over the west coast of King William Island. The scenes that showed the highest and lowest tide levels were selected, and through a semi-automated process involving, lines representing the shoreline at each of the time periods were extracted. The extracted data was compared to high resolution optical data as well as to manually interpreted shorelines. Preliminary results were quite promising; with further work ongoing to evaluate the results using ground data as well as test the methods under different coastal conditions to allow widespread mapping.
Spectral Mixture Analysis of a 21-Year satellite image sequence for assessing environmental variability in western North America

Derek Peddle\textsuperscript{1}, Joseph Piwowar\textsuperscript{2}, and David Sauchyn\textsuperscript{2}
\textsuperscript{1} University of Lethbridge \textsuperscript{2} University of Regina

Temporal Mixture Analysis (TMA) of satellite image sequences provides a useful time-series analysis framework for assessing vegetation dynamics and responses to land cover change, disturbance, and climatic variation. TMA was applied to a 21-year annual sequence of NOAA AVHRR 8-km NDVI data for a study region that encompassed considerable surface and climatic variability from deserts bordering southern Oregon-Nevada-California USA, to the boreal-taiga transition zone in northeastern Manitoba Canada near the Arctic Ocean. Results were assessed using precipitation anomaly data from the Global Historical Climatology Network (GHCN) and the Palmer Drought Severity Index (PDSI). Moderate relationships were found between temporal endmembers and climate data, particularly PDSI ($r=0.72$; $r^2=0.53$), attributed to that index incorporating temperature and soils in addition to precipitation. Vegetation responses were identified in TMA fraction map products and their temporal response patterns related to vegetation type, location, and stress regime (e.g. C3 vs. C4 grasses). Forests were differentiated by varied climatic response, elevation and/or latitude, with temporal patterns of drought response identified for eastern vs. western prairies. Isolated areas of differing response in ecologically sensitive zones were also revealed, as well as multi-year time-lagged vegetation dynamics. TMA can capture more complex vegetation-climate interactions with explicit time series references (yearly endmember data) compared with traditional change detection methods that identify major landcover state change vectors only. TMA can also be suitable for other time scales (e.g. centuries, decades, seasonal or diurnal cycles) and thus warrants attention for improved time series analyses and as input to climate and other time-sensitive predictive models.
Using annual Landsat time series for detecting deforestation and forest degradation in mosaic landscapes of Southeast Asia

Dirk Pflugmacher¹, Kenneth Grogan² and Patrick Hostert¹
¹ Humboldt University Berlin  ² University of Copenhagen

In mainland Southeast Asia, much of the forest is found in complex mosaic landscapes dominated by forest succession of different ages and composition, a result of the shifting cultivation practices of the indigenous people. Quantifying extent and quality of these forests is important for a variety of ecological and socio-economic reasons, but mapping with remote sensing has been challenging as these landscapes are characterized by high temporal dynamics and fine spatial patterns. The challenge is exacerbated by the persistence of cloud cover and atmospheric aerosols in tropical regions. Recently, there has been a promising development towards methods that can utilize uneven and (compared to hyper-temporal sensors) relatively sparse time series of high-resolution multi-spectral imagery from Landsat to detect forest vegetation changes. The complexity of these algorithms ranges from simple threshold models to more complex functional or segmentation based time series models. In this study, we tested and compared several of these time series approaches to map extent and timing of vegetation changes associated with shifting cultivation practices using Landsat time series. As study area we selected a Landsat scene in Northern Laos. The dominant land cover and land-use ranged from intense agriculture, short rotation (< 2 years), medium (3-10), and long rotation (>10 years) fallows to protected primary and secondary natural forest. We constructed a time series using all orthorectified Landsat images with less than 80% cloud cover available from the USGS archive between 1985 and 2012 (148 images). Then, we performed atmospheric correction using the Landsat Ecosystem Disturbance Adaptive Processing Systems, and cloud and cloud-shadow masking using the automated Fmask algorithm. The resulting time series were then spectrally enhanced by using the tasselled cap (TC) transformation and the normalized burn ratio (NBR), and temporally aggregated to annual time steps using different functions such as median and maximum value compositing and compositing based on acquisition day of year. We validated our results using a combination of recent high resolution RapidEye imagery and visual interpretation of Landsat image chips.
Observation of the Argentière Glacier flow variability from 2009 to 2011 by TerraSAR-X and GPS displacement measurements

Fanny Ponton¹, Renaud Fallourd², Andrea Walpersdorf¹, Emmanuel Trouvé², Michel Gay³, Flavien Vernier², Jean-Marie Nicolas⁴ and Jean-Luis Mugnier¹

¹ ISTerre, CNRS, Université Joseph Fourier
² 2- LISTIC, Polytech Annecy-Chambéry, Université de Savoie
³ GIPSA-lab, INPG, Université Joseph Fourier, CNRS
⁴ LTCI, Télécom ParisTech, CNRS

In this paper, 3 years of surface velocity measurements obtained by spaceborne SAR observations are presented over the Argentière Glacier in the Mont-Blanc massif, France. This temperate glacier is instrumented by corner reflectors and a network of 4 GPS stations used as ground truth. 34 couples of descending and ascending high resolution TerraSAR-X acquisitions covering the study region are used to derive displacement fields at 11-day intervals in spring and summer 2009 and summer 2011. The 2D velocity fields are derived by offset power tracking using the processing chain developed in the EFIDIR-tools during the ANR EFIDIR project (http://www.efidir.fr). The combination of ascending and descending couples acquired over a same period allows occasionally 3D velocity fields to be inverted. These displacement results are compared with in-situ GPS measurements. In the upper part of the glacier, the lack of texture prevents the offset power tracking method to provide reliable results. Only the continuous GPS measurement of the upper station (2770m) is available with the 13.2 cm/day flow rate. In the lower part of the glacier, the textured area due to rocks accumulation and crevasses makes SAR correlation measurement successful. In these areas which are the most changing in time and space, SAR data provide the same order of magnitude of velocity than the GPS station set up at the altitude of 2441m with an average of 17.7 cm/day. The variation of the displacement velocity across the glacier can be observed thanks to the SAR data. The temporal fluctuations are observed by both GPS and SAR data and can be related to the global acceleration of the glacier during the summer season and to meteorological variables such as strong precipitations.
Accuracy assessment of annual land cover time series based on change updating

Darren Pouliot and Rasim Latifovic
NRCan\Canada Centre for Remote Sensing

Detailed information on the spatial and temporal distribution of land cover is required to evaluate the effects of land cover change on environmental processes. The development of temporally consistent land cover time series from satellite-based earth observation has proven difficult due to variability in sensor observations. This leads to spurious land cover differences between maps when standard supervised classification approaches are applied for land cover time series generation. To reduce this effect a common solution has been to first detect change and update a base map for only these change areas. As long as the change commission error is low this approach will ensure high consistency between maps in the time series. Here we describe the implementation and accuracy assessment of a change based updating approach used to develop a (2000-2010) annual land cover time series over Canada from MODIS 250 spatial resolution data. The method incorporates both abrupt and gradual changes in an effort to capture a range of change types. To predict the new land cover label, an evidential reasoning approach was used to combine spectral, spatial, and temporal sources of evidence.

Assessing the accuracy of land cover time series is challenging because multiple maps need to be assessed for both land cover classification and change detection accuracies. Regarding a change based updating approach, for a time series where only a small percent change occurs, accuracy is close to that of the original base map. Over longer periods where significant change has accumulated the accuracy becomes more dependent on the change and update labelling accuracy. Thus, accuracy for a change based approach can be seen as a function of the base map, change detection, and update accuracies. A specific formulization is developed to summarize these components. Results show that the time series accuracy was in a large degree predetermined by the base map accuracy because there was only a small amount of change (~5%) over the period and the base map and update accuracies were similar. As the time series is extended and more change accumulates results suggest a slight decrease due to the accumulation of omission error assuming that change and update accuracies are temporally invariant. Increasing the update accuracy by a few percent, within the precision of the accuracy estimates, would result in more accurate time series.
Variation in distribution and size structure of prairie pothole lakes

Ning Qiao and Xulin Guo
University of Saskatchewan

The Prairie Pothole Region of North America is characterized by numerous small ponds, lakes and wetlands and it is changing dramatically in the last century. Pothole wetlands serve biological, ecological and hydrological functions in terms of providing habitat for countless species, supplying primary productivity, and transforming nutrients for maintaining stream water quality. However, pothole wetlands have been substantially altered since human settlement and over half of the wetlands have been estimated lost due to human disturbance and climate change in the last 50 years. In addition, the power law relationship is reflected by the properties of many natural and human systems. Some studies have demonstrated that the frequencies of lakes of different sizes follow a power law. This study examines the historical spatial distribution and size structure change of prairie pothole lakes on Canadian prairie. The focus is on the lakes and wetlands of Smith Creek Watershed in southeast of Saskatchewan, Canada between 1958 and 2008. First, the lake area maps of 1958, 1988, 1998 and 2008 were extracted from historical aerial photos, Landsat TM, and SPOT image. Then, the variation of spatial distribution was estimated from different aspects including total basin area, total wet area and sub basin analysis. Subsequently, the power law relationship between the frequencies of lakes of different sizes in the years under consideration was calculated and compared to assess power law in a period of 50 years. Preliminary results of this study have shown that wetlands and basin area significantly decreased in the recent last 50 years and a systematic variation in sizes for lakes and wet areas was also observed. Moreover, the areas for smaller lakes were more affected than the areas for larger lakes. A relatively constant slope is expected to be shown in the power laws from 1958 to 2008. This research will illustrate prairie wetlands loss in the recent past half century through mapping and testing the power law relationship between frequencies and lake sizes over time. It will also provide information for future change prediction and management.
Comparison of eight radiometric normalization techniques for mosaicing h-res airborne multi-temporal TIR flight-lines of a complex urban scene

Mir Mustafiz Rahman, Geoffrey Hay, Bharani Hemachandran and Isabelle Couloigner
Foothills Facility For Remote Sensing and GIScience, University of Calgary

High-spatial resolution (H-res) thermal infrared (TIR) airborne cameras, such as the new TABI-1800 (Thermal Airborne Broadband Imager), provide unique temperature information for surficial heat loss mapping, heat island analysis, and land cover classifications. For mapping large urban areas at a high spatial resolution (i.e., sub-meter), airborne TIR imagery needs to be acquired in a number of flight-lines and each of these (20-30%) overlapping scenes need to be mosaiced together. However, due to time/micro-climatic differences during data acquisition, radiometric variations occur within and between each flight line. Consequently, the same objects (observed within the scene overlap) tend to have different temperature characteristics. If these changes are not normalized, they result in reduced visual and radiometric agreement between flight-lines composing the final mosaic product; which in-turn increases the challenge of automated feature detection. To mitigate the between flight-line effects, Relative Radiometric Normalization (RRN) methods can be applied to produce a ‘seamless’ large area mosaic. However, which method is best suited to mosaic H-res TIR urban imagery?

In this presentation, we describe results from applying eight relative radiometric normalization methods on two (of 43) adjacent flight-lines of TABI-1800 data (each 35km x 1.8km, at 50cm spatial resolution and 5/100 °C thermal resolution). Data were acquired in May 2012 over the South West quadrant of The City of Calgary, Alberta, Canada (between 23:00 – 4:00 hrs). The first six methods exist within the literature, while the last two are newly proposed. These include: (i) Histogram Matching, (ii) Contrast Matching, (iii) Linear Regression based on Pseudo Invariant Features (PIF), (iv) Theil-Sen Regression based on PIF, (v) Linear Regression based on No-Change Stratified Random Samples (NCSRS), (vi) Theil-Sen Regression based on NCSRS, (vii) Polynomial Regression based on NCSRS and (viii) Polynomial Regression based on PIFs. Based on visual comparison and total scene RMSE, results show that Histogram matching generates strong visual results. This method is also conceptually simple, easy to execute and is computationally the fastest method tested. However, the newly developed NCSRS polynomial regression produces the strongest results; though it is more computationally expensive. Optimization methods are currently being investigated to mitigate this effect. When NCSRS based polynomial regression is applied to generate a H-res multi-temporal TIR mosaic of the entire City of Calgary [a large (600GB+ and 43 flight line) complex urban scene (i.e., 875km2) at 50cm spatial resolution], the significant visual improvement in radiometric agreement between flight lines results in a ‘seamless’ image product that provides enhanced data for TIR-based energy models, roof-top delineation and hot-spot detection.
We aimed to develop a method for the early prediction of corn yield in US. The method was based on a corn-yield estimation model using the time-series MODIS data. The new method was developed to avoid relying on the release of precise land-use map (Crop Data Layer) by the USDA/NASS. The new method incorporates the shape-model fitting procedure to detect the phenological stages of corn (VE: emergence, R1: silking stage). It can generate a corn distribution map by using limited-term (near real-time) MODIS data at a sensor resolution scale of 250 m/pixel. In combination with the map, the final grain yield of corn was forecasted at a county or state scale by MODIS WDRVI observed on 7 days before the silking stage. We calibrated and validated the new method by using the MODIS/Terra and Aqua data obtained over the past decade. In addition, we also evaluated the practical applicability of the new
A novel, Multidimensional Small Baseline Subset (MSBAS), methodology is presented for integration of multiple InSAR data sets for computation of two or three dimensional time series of deformation. The approach allows combination of all possible air-borne and space-borne SAR data acquired with different acquisition parameters, temporal and spatial sampling and resolution, wave-band and polarization. The proposed method has four main advantages: (i) it achieves combined temporal coverage over an extended period of time when data from many different sensors with different temporal coverages are available; (ii) temporal resolution of produced time series increases since it includes the combined sampling from all data sets, which helps to observe signal in more details and also to improve the quality of post-processing (i.e. filtering); (iii) two or three components of ground deformation vector are computed, which helps in interpretation of observed ground deformation and further modeling and inversion; (iv) various sources of noise (i.e. tropospheric, ionospheric, topographic, orbital, thermal, etc.) are averaged out during the processing improving a signal-to-noise ratio. For demonstration purposes we apply MSBAS methodology for mapping natural ground deformation in Virunga Volcanic Province in Congo (Samsonov and d’Oreye, GJI 2012), Mt Kilauea (Hawaii, USA), Campi Flegrei-Vesuvius (Italy) and Greater Vancouver (Canada) and anthropogenic ground deformation caused by mining along the French-German border (Samsonov et al., IJAEOG 2013) and ground water extraction in Southern Saskatchewan, Canada (Samsonov et al, CJRS 2013) and Bologna (Italy) regions. The procedure for running the freely available MSBAS software code is discussed in details.
Time series of ground deformation for the Aquistore CO2 Storage Site located in SE Saskatchewan, Canada and computed from five beams of Radarsat-2 data combined using MSBAS methodology.

Sergey Samsonov\textsuperscript{1}, Don White\textsuperscript{2} and Michael Craymer\textsuperscript{3}

\textsuperscript{1} Canada Centre for Remote Sensing, NRCAN
\textsuperscript{2} Geological Survey of Canada, NRCAN
\textsuperscript{3} Geodetic Survey Division, NRCAN

This work was completed under the framework of the Aquistore CO2 storage project with objectives to design, adapt, and test non-seismic monitoring methods that have not been systematically utilized to date for monitoring CO2 storage, and to integrate the data from these various monitoring tools to obtain quantitative estimates of the change in subsurface fluid distributions, pressure changes and associated surface deformation. Since spring of 2012 Radarsat-2 data from five beams (ascending and descending Spotlight, UltraFine Wide and Fine Quad) was regularly (with the individual frequency of 24 days) collected and used for calculation of ground deformation time series over the Aquistore CO2 storage site located in SE Saskatchewan. In the fall of 2012 a few coupled trihedral corner reflectors and continuous GPS receivers were installed near the injection well for high precision deformation monitoring and cross validation. The initial InSAR analysis based on data acquired in the second half of 2012 revealed slow ground deformation not related to CO2 reinjection but caused by various natural and anthropogenic processes – snow melting, surface moisture variation, ground and surface water level changes and post-mining activities. In this work we provide updated results based on over one hundred RADARSAT-2 images acquired during last twelve months. We perform seasonal noise level analysis and impact of snow coverage on the time series precision. Multidimensional time series of ground deformation are produced using MSBAS technique (Samsonov and d’Oreye, 2012). The necessity and benefits of corner reflectors for monitoring of ground deformation during winter months is analysed and precision of ground- and corner reflector-based measurements is compared.
Monitoring land cover change in urban and peri-urban areas using Landsat dense time stacks and a data mining approach

Annemarie Schneider and Carly Mertes
University of Wisconsin-Madison

Given the pace and scale of urban expansion in many parts of the globe, urban environments are playing an increasingly important role in daily quality-of-life issues, ecological processes, climate, material flows, and land transformations. During the last two decades, we have made important strides toward developing remote sensing methods that allow for the accurate characterization of land cover change (Rogan et al., 2004), including urban expansion. Mapping urban areas remains a complex challenge, however, because of the many combinations of materials present and the variations in size/shape of urban features that can lead to different ‘mixtures’ within pixels. Particularly troublesome is the fact that newly developed urban areas typically appear identical to fallow farmland at any given time, since both exhibit high reflectance in the visible-infrared wavelengths. These issues are further compounded in developing countries such as China and India, since new development is often small, patchy in nature, and located in peri-urban areas up to 100 km from the urban core.

To deal with the high temporal and spatial variability as well as complex, multi-signature classes within settlements, this work presents a new approach that exploits multi-seasonal information in dense time stacks of Landsat imagery using a multi-date composite change detection technique. The central premise of the approach is that lands within/near urban areas have distinct temporal trajectories both before and after change occurs, and that these lead to characteristic temporal signatures in several spectral regions. The method relies on a supervised classification that exploits training data of stable/changed areas interpreted from Google Earth images and on-site visits, and a 'brute force' approach of providing all available Landsat data as input, including scenes with data gaps due to the Scan Line Corrector (SLC) problem. Because of the complexity and size of the datasets for a given study area (~35-50 Landsat scenes), three supervised classification algorithms were tested: a traditional maximum likelihood classifier, and two machine learning algorithms, boosted decision trees, and support vector machines. The methods were tested for their ability to isolate and correctly classify urban expansion for five time periods (1988-1995, 1996-2000, 2001-2003, 2004-2006, 2007-2009). To prevent the methodology from being applicable in only one study area, the algorithms were tested on three cities with different city sizes, diverse ecosystem characteristics, as well as differential rates/patterns of urban development. Both the decision trees and support vector machines outperformed the maximum likelihood classifier (overall accuracy of 90-93 percent, compared to 65 percent), but the decision trees were superior at handling missing data. Adding transformed features such as annual band metrics to the Landsat data stack increased accuracy 1-4 percent, while experiments with a reduced number of features (designed to mimic noisy or missing data) led to a drop in accuracy of 1-9 percent. The methodology also proved particularly effective for monitoring peri-urbanization outside the urban core, capturing >98 percent of village settlements. Following testing, the dense time stacks approach was applied to twelve study areas to improve understanding of the rates and
patterns of land cover change in rapidly developing urban regions in China for the post-reform period 1988-2010, including small town and village development. Map accuracies averaged 88-94 percent across the twelve case study cities.
The potential for using synthetic image simulation tools to study multi-temporal phenomenology and support multi-temporal algorithm development.

John Schott, Michael Gartley, Aaron Gerace and Scott Brown
Rochester Institute of Technology

In studying images over time to detect changes (e.g. ground vehicle motion), monitor processes (e.g. over a season for crop yield) or to track long term land cover trends (e.g. forest impact and recovery from insect stress or harvesting) there are three very different potential sources of confusion. The first is caused by real changes in the scene that are not of interest. This temporal clutter may be people or cars moving, snow accumulation, or even trees blowing in the wind when we are interested in tracking the motion of trucks. The second source of confusion is apparent changes in the scene caused by real changes in the illumination, viewing or atmospheric conditions (both aerosol loadings and clouds in the surround). The third source is apparent change due to differences in sensors (e.g. sensor gain or bias change within a sensor or spectral response differences between sensors). Whether it is the resolved movement of shadows or the un-resolved lengthening of shadows these temporal clutter effects complicates change detection, tracking and process monitoring algorithms. Many multi-date algorithms use curve fitting to filter out clutter due to these unaccounted variations, as well as, to compensate for sparse temporal data.

Simulation and modeling of the impact of temporal clutter on imagery can be useful in trying to develop algorithms to reduce clutter (e.g. correct atmospheric effects) and/or to mitigate or understand the impact of clutter. This can be particularly important when trying to understand the impact of temporal clutter on sparsely sampled data (e.g. Landsat). The wide range and complexity of phenomena that induce temporal clutter in imagery represent a serious challenge to image simulation and modeling tools. These tools have advanced significantly in the last two decades with dramatic advances in simulation of spatial and spectral phenomenology and the resultant spatial-spectral target to background clutter.

In this paper we attempt to address some of the current capabilities and limitations of synthetic image generation models for supporting temporal image phenomenology and algorithm development studies. The Digital Imaging and Remote Sensing Image Generation (DIRSIG) model is used to illustrate how some sources of signal and motion induced clutter can be simulated in high spatial resolution imagery. This includes motion by non target objects (people, blowing trees, cars) and apparent motion (shadows, parallax). The relative impacts of these clutter sources as a function of spatial and temporal sampling is also demonstrated. In many ways, the more difficult phenomena to model include the impact of coupled illumination, atmospheric and sensor effects on long time series studies of phenological processes. Some of these phenomena are very well modeled with existing tools [e.g sensor relative spectral response (RSR) and view angle effects], other can be modeled but may have significant scene construction and run time issues [e.g. volumetric scattering from complex
canopies as a function of varying sunlight to skylight (i.e. direct to diffuse illumination ratios)] and finally, some need better parameterized models to drive simulation of the imaged observables (e.g. validated models of canopy senescence). Modeled time series showing how variations in illumination, observation, atmospheric and sensor parameters can impact images and image derived parameters will be demonstrated. In addition, limitation of current tools and parameters that are either not yet modeled or which are poorly modeled will be addressed (e.g. clouds in surround).
Currently in its third phase, the NASA/NACP funded North American Forest Dynamics (NAFD) project has launched nationwide processing of historic Landsat data to provide a comprehensive annual, wall-to-wall map of US forest disturbance over the last 30+ years. Because understanding the cause of disturbance is important to quantifying carbon dynamics, work is underway to attribute causal agents to these nationwide change maps. Developing empirical models to predict the diverse causal agents found across the US involves many decisions. Alternative response designs (such as varying size, shape, quantity and level of detail in training data) are being evaluated in terms of their costs and benefits for national mapping applications. Many classes of predictor variables (such as spectral trajectories, textural metrics, extant geospatial disturbance libraries, and bioclimatic information) are being tested to assess their potential contribution to classification models. Flexible modeling techniques such as Random Forests are powerful predictive tools, but must be coupled with simple rule-based models reflecting expert knowledge. Additionally decisions about appropriate modeling sub-populations must be made in light of available training data, diversity of ecological zones, and computational efficiency. Here, we present results from our initial exploratory work involving analyses conducted in 10 pilot scenes representing diverse causal agents, forest types, and forest prevalence levels found across the country. In this presentation we will discuss the construction and importance of various predictor variables as well as examine how model prediction accuracy varies as a function of geographic location and forest type. Lastly, we will discuss how these new nationwide maps will enable improved quantification and analysis of the rates and types of disturbance impacting US forests over the last two decades.
Exploration of the characteristics of urban surface temperature (LST) in the city of Saskatoon (SK, Canada) using multi-temporal Landsat and MODIS imagery

Li Shen ¹, ² and Xulin Guo ¹

¹ Department of Geography and Planning, University of Saskatchewan
² Sustainable Cities International Vancouver

Since over 50% world population reside in cities, large-scale urbanization has been posing a serious threat to urban environmental sustainability as well as socioeconomic development. In particular, increasing impervious surface and decreasing green space has become a great contributor to the rising urban heat island (UHI) phenomenon. As one of the most rapid growing prairie city in Canada, Saskatoon (SK) was determined as our study area. Eleven Landsat TM and ETM+ images from 1991 to 2011 were selected to derive land surface temperature (LST) for the City of Saskatoon. A linear regression model was established for satellite-retrieved LST and historical recorded air temperature based on eighteen points provide by Saskatoon weather station. Results show that 91.1% of air temperature variation in Saskatoon can be explained by LST at a significant level of 0.05. In addition, a significant negative relationship between LST and Normalized Difference Vegetation Index (NDVI) exist in summer Saskatoon (June to July) with the $R^2 0.68$ ($P<0.05$), but not significantly in fall due to the dramatic change of green vegetation. NDVI can also significantly account for 64.8% of the air temperature change in summer Saskatoon but not in fall. Furthermore, the spatial analysis of LST and NDVI has also been investigated based on ten points randomly selected from each image of Saskatoon for both summer and fall. A significant negative correlation can be shown between LST and NDVI for all of the 6 images obtained in fall. However, such correlation cannot be found in all of the 5 images acquired in fall. We also investigated the capability of multi-temporal Daily MODIS LST product (1000 m) in estimating air temperature for Saskatoon from 1991 to 2011. However, results show no significant correlation due to limitation of coarse spatial resolution of MODIS LST imagery in urban study. However, Monthly MODIS LST products have better estimation of historical monthly averaged air temperature in June, July, and August for Saskatoon. This further demonstrated that Monthly MODIS LST products have great potential in demonstrating air temperature trend in Saskatoon from June to August.
A Multisensor, multitemporal approach for monitoring herbaceous vegetation growth in the Amazon floodplain

Thiago Silva¹, Maycira Costa², Evlyn Novo¹ and John Melack³
¹ Instituto Nacional de Pesquisas Espaciais – INPE, Brazil
² University of Victoria
³ University of California Santa Barbara

The Amazon River floodplain is one of the largest natural wetlands in the world, and an important source of atmospheric CO2 and CH4. Aquatic herbaceous vegetation (macrophytes) have been shown to contribute significantly to floodplain net primary productivity (NPP), supporting some of the highest methane emission rates in the region. The combination of fast growth rates, ability to grow under both flooded and dry conditions, and capacity to colonize newly exposed substrata make herbaceous vegetation the most variable element in the Amazon floodplain NPP budget, and therefore the most susceptible to environmental changes. Remote sensing is often used for studying vegetation processes at landscape scales, but high spatial and temporal variability combined with near constant cloud cover challenge the application of traditional remote sensing methods for studying herbaceous vegetation dynamics in the Amazon floodplain. Synthetic aperture radar (SAR) systems circumvent some of these limitations by providing regular acquisitions of information on vegetation structure and flooding status, but target delineation and separability on single scene SAR data is a difficult task, and the use of multitemporal information can significantly improve the results. The combination of optical and SAR data can also enhance classification results, exploiting the synergy between information recorded at different regions of the electromagnetic spectrum. The MODIS optical sensor offers near twice-daily acquisitions at the expense of spatial resolution, minimizing the cloud cover problem and still providing valuable information about land cover and vegetation processes for large areas such as the Amazonian environments. Therefore, the present study combines Radarsat-1 and MODIS images, using a hierarchical, object-based classification method, to monitor the spatial and temporal changes in the extent of herbaceous vegetation cover in the Amazon floodplain. Two large floodplain units in the Lower Amazon were studied: Curuai (2º08’S, 55º35’W) and Monte Alegre (2º16’S, 54º15’W), within the state of Pará, Brazil. Both regions are characterized by large shallow lakes (3-6 m depth), where shrubland and herbaceous vegetation dominate over forest cover. Herbaceous communities are mostly composed by C3 and C4 rooted grasses, with the occasional occurrence of free-floating species assemblages, and most species have both terrestrial and aquatic life phases. Radarsat-1 (C-band SAR) images were acquired at ST2 mode, with an incidence angle of 24.1º - 30.9º and a pixel spacing of 12.5m, in HH polarization, from Dec/2003 to Oct/2005 period. MODIS daily surface reflectance products (MOD09 GQ), at 250m spatial resolution, were acquired for the two closest cloud free dates of each Radarsat-1 acquisition. The Shuttle Radar Topography Mission (SRTM) V. 4.1 digital elevation model was also used during image classification. The object-based image analysis (OBIA) hierarchical algorithm was developed using eCognition 8.0. It uses the temporal SAR information to discriminate the classes of Permanent Open Water (OW), Floodplain (FP) and Upland (UL) at Level 1, and then further subdivide the FP class into Woody Vegetation (WV) and Possible Macrophytes (PM) at Level 2,
the latter corresponding to areas were herbaceous cover is likely to be observed at least once throughout the year. At Level 3, optical and SAR information were combined to discriminate actual herbaceous cover (Macrophytes vs. Not Macrophytes) at each date, constrained by the delineation of the PM class, where objects previously delineated using SAR imagery were labelled according to MODIS spectral response at the examined date. The class hierarchy assumes that woody vegetation, upland and permanent open water classes cannot transition into herbaceous vegetation, and thus L3 only identifies the relative proportion of vegetated versus non-vegetated cover (open water or bare soil) within the PM parent class. Gamma-filtered images of mean and standard deviation of annual backscattering and the lowest water level image were used as inputs for segmentation, to ensure optimal object delineation at the highest available resolution. At each classification level, simple threshold rules were first applied to classify easily separable objects, followed by a supervised nearest neighbor (n-n) algorithm. A total of 33 object features were used as inputs for the classification, including average seasonal backscattering, maximum seasonal backscattering, average and standard deviation of backscattering at each date, and user-defined seasonal backscattering indices. Classification results were assessed using standard accuracy metrics, using a set of ~350 validation points distributed randomly over each study area. Each validation point was classified based on visual interpretation of Landsat imagery, high-resolution imagery provided by GoogleEarth™, and the researcher’s knowledge of the region. The resulting maps had overall accuracies ranging from 80% to 90% for Level 1 and 2 classifications, and from 60% to 70% for Level 3 classifications, with kappa values ranging between 0.7 and 0.9 for Levels 1 and 2 and between 0.5 and 0.6 for Level 3. All study sites had noticeable variations in the extent of herbaceous cover throughout the hydrological year, with maximum areas up to four times larger than minimum areas. Herbaceous spatio-temporal dynamics for the 2003-2004 and 2004-2005 hydrological cycles revealed distinct expansion patterns for each of the studied landscapes, but similar effects were observed for both sites as a result of extremely low water levels observed in the 2004-2005 cycle. The proposed classification method was able to capture the spatial pattern of macrophyte growth and development in the studied area, and the multitemporal information was essential for both separating vegetation cover types and assessing monthly variation in herbaceous cover extent. The use of object-oriented analysis and hierarchical classification methods allowed the partitioning of scene variability among multiple steps, facilitating the classification process. The inclusion of MODIS images at Level 3 was necessary for the separation of bare soil and herbaceous areas during low water stages. Given the coarse resolution, spatial resolution and cartographic accuracy were limited, but produced useful results in terms of areal estimation. We expect that current and forthcoming polarimetric SAR sensors operating at multiple frequencies could offset the need for optical imagery, therefore improving accuracy. The present method has also been successfully adapted for other applications, including flood monitoring and species mapping using SAR polarimetric information.
Examination of fire-related plant succession within the dry mixedgrass subregion of Alberta using MODIS and Landsat imagery

Brent Smith and Greg McDermid
Department of Geography, University of Calgary

Fire is an important landscape disturbance process historically present across the northern Great Plains. However, fire regimes have been altered, as a result of human settlement. While fire effects have been studied in the tall grass prairie and mesic northern mixed prairie, they are less well understood in northern dry mixed prairie. Fire has been recommended as a management tool, in order to restore disturbance processes and to promote biodiversity. However, historical fire regime information is limited, and management must therefore be guided by experimental research. Previous research in northern dry mixed prairie suggests that repeated fire, particularly in the spring, results in succession where warm season grass species (using the C4 photosynthetic pathway) gradually replace dominant cool season C3 species. To test this hypothesis at a landscape scale, we first employed a logistic regression-based multi-temporal Plant Functional Type (PFT) classification using temporally-smoothed MODIS NDVI 250 m 16 day composites (pseudo R2: .598, AIC: 379, overall accuracy: .74, weighted kappa: .53) representing 3 ecosystem states from the year 2009 (C3 dominant, C3/C4 co-dominant, C4 dominant), and compared them against archival Landsat data, where we digitized 36 years of fire history (1972 to 2007) at Canadian Forces Base Suffield, Alberta. Probit regression models were run to test whether statistically significant relationships existed between the proportion of each ecosystem state within the study area, and the total number of fires. Results show that succession processes were different between ecological units, with statistically significant models for C3 and C4 dominant pixels on Loamy range sites (P < .001), where C4 dominant pixels completely replaced C3 dominant pixels after 14 fires in 36 years. In contrast, only C3 dominant pixels yielded a statistically significant relationship with fire (P < .001) on Blowouts range sites, where the proportion of C3 dominant pixels decreased but the proportion of C4 dominant pixels did not change after 9 fires in 36 years. For Sands range sites, C3 pixels did not yield a statistically significant relationship, but C4 pixels were completely removed after 14 fires in 36 years. Analysis of recovery shows that after Loamy pixels experienced 3 fires in 18 years followed by 18 years of rest, less than 70 % of pixels were comprised of C3 dominant communities, suggesting that re-establishment of climax species takes decades. Finally, the MODIS monthly 500 m burned area product (MCD45) was used to determine the seasonal timings of fire between 2001 and 2009. Fires were shown to occur during the entire growing season with a peak in late summer, when C3 species are typically dormant. We therefore suggest that with respect to long-term plant community changes in the northern dry mixed prairie, the primary driver for fire-related succession from C3 to C4 species appears to by via the alteration of structure (by reducing litter which conserves scarce moisture), rather than fire timing.
A Multi-component characterization of the active Okavango Catchment and Delta based on diverse MODIS products

Marion Stellmes, Achim Röder and Joachim Hill
University of Trier, Faculty of Geography/Geosciences, Environmental Remote Sensing and Geoinformatics

The Okavango River is one of the large lifelines of Southern Africa. It has its source in the rainy highlands of Angola, forms part of the northeastern border of Namibia and terminates in the Okavango Delta, the world’s largest inland delta and the largest freshwater swamp south of the equator. Accelerating climate change, population growth, and anthropogenic over-utilization of natural resources turn the Okavango Basin with its variety of savannah woodlands and wetland ecosystems into a global hotspot of biodiversity loss and potential land use conflicts.

One major component for optimizing land-use management is the assessment of resources, particularly their spatial distribution, variability and long-term behavior.

To contribute to this aim at a trans-regional scale a multi-component product was developed employing time series of satellite images with high temporal resolution, in this study data provided by the MODIS system. Phenology indicators derived from a MODIS vegetation index product were analyzed to characterize major land use systems and functional vegetation types and by employing trend analysis to identify areas where changes have occurred. Furthermore, an unbiased assessments of ecosystem productivity realized by linking MODIS-derived vegetation indices, serving as a proxy of net primary productivity, and long-term climate data (spatially interpolated fields of rainfall and temperature). Even though the aforementioned analyses are the major descriptors further components have to be considered for a comprehensive picture of the study area. One important factor is the fire regime, its spatial pattern and frequency, which are provided by the MODIS fire product. Furthermore, the highly variable water availability strongly affects the flooding area and therefore play an important role for ecosystems along the river and in the Delta region. For this purpose, MODIS vegetation index data as well as reflectance data were utilized to derive a temporally explicit series indicating flooded areas.

The integration of these products will help to better understand ecological dynamics in the whole Okavango system and to supports the development of sustainable land use management strategies.
Using multi-sensor high temporal resolution imagery to map land use transformations in Spain under changing socio-economic boundary conditions

Marion Stellmes, Achim Röder, Thomas Udelhoven and Joachim Hill
University of Trier, Faculty of Geography/Geosciences, Environmental Remote Sensing and Geoinformatics

The present study aimed at setting up a framework to identify major land cover changes and their driving forces for the mainland of Spain, and therewith assess areas with increasing or decreasing human influence on land cover. Further approaches were included in the framework to distinguish between areas where vegetation cover and its development is mainly caused by human actions or where external factors, such as climatic fluctuations and or disturbances (e.g. wildfires, drought years) might be dominating.

Spain has undergone extensive political, economic and social developments within the 20th century, in particular after it joined the European Union in 1986 and benefitted from various European subsidy instruments, like for instance the Common Agricultural Policy (CAP), the European Regional Development Fund, the European Social Fund and the Cohesion Fund. This change in socio-economic conditions characterized by the implementation of directing policy instruments like subsidies have caused major land use transformations.

In 2005, the new Common Agricultural Policy (CAP) reform was coming into force. The reform decoupled subsidies from particular crops and acknowledged consideration of environmental issues (“cross-compliance”). This and other policies and directives like for instance the EU Rural Development Policy, EU Water Frame Directive or the National Water Plan of Spain altered the socio-economic framework and consequently, led to shifts in the dominating land use transformation processes.

Based on NOAA AVHRR time series (1989-2004) with a geometric resolution of 1 x 1 km2 and MODIS time series (2004 – 2012) with a geometric resolution of 250 x 250 m2 the two different earth observation data archives were analysed comparative to reveal major land transformations that have taken place within the above outlined periods. For both archives phenological parameters were derived on a yearly basis and subsequently, a combined time series analysis was conducted to identify the dominant land change processes.

The analysis was extended by including land use information (CORINE land cover) and statistical data on the demographic development that served as a proxy for socio-economic changes. Moreover, climate data were included by employing distributed lag-models to reveal areas where observed land cover changes are mainly driven by climatic inter-annual variability.
Implementations of a repeat station imaging approach for precise image registration and detailed change detection at varying temporal resolutions and durations

Douglas Stow¹, Lloyd Coulter¹, Christopher Lippitt², Richard McCreight and Yu-Hsin Tsai
¹ San Diego State University
² University of New Mexico

The success and reliability of multitemporal analyses of remotely sensed imagery for the purpose of detecting, identifying and quantifying changes in land surface objects and phenomena can be highly dependent on the accuracy of image registration. Achieving accurate spatial co-registration between high spatial resolution multitemporal image sets using automated procedures is not trivial, particularly for time sensitive applications. However, we have developed and repeatedly demonstrated an approach for collecting and spatially co-registering multitemporal airborne imagery with high precision (Coulter et al. 2003; Stow et al. 2003; Coulter and Stow 2005; Coulter and Stow 2008; Coulter et al. 2012d). The approach referred to as repeat-station imaging (RSI) (formerly called frame center matching) is based upon matching imaging stations in terms of horizontal position and altitude between multitemporal image acquisitions, with the aid of GPS-based aircraft navigation and camera triggering systems. When image frames are captured from exactly the same imaging station in the sky between multitemporal acquisitions, there is little to no parallax between time sequential images and they exhibit similar terrain and building related geometric distortions. Further, the relative spatial position of features within the images is consistent between image frames. Since three-dimensional relief displacement is virtually identical, only platform attitude (unless a gyro-stabilized mount is utilized) and sensor-related distortions are present between images. However, sensor distortions can be removed using camera calibration information and systematic differences in sensor attitude between station matched images may be corrected using simple warping functions such as 2nd-order polynomial warping.

The objective of this presentation is to share research results pertaining to three distinctly different implementations of RSI for land surface change detection. All three examples pertain to high spatial resolution airborne imagery captured with digital frame cameras. In each case, the platform was a piloted light sport aircraft and the sensor was a 21 megapixel digital color camera.

The first example involves bi-temporal change detection approaches for detecting damage to critical infrastructure (e.g., bridges, hospitals and power plants) following a major earthquake. Post-event imagery was captured at the same imaging stations as pre-event imagery, co-registered and semi-automated change detection routines were applied to identify land surface anomalies associated with pseudo-infrastructure damage. In this case, we simulated an event by displacing objects (e.g. boxes and tarps) and creating artificial cracks. Results for simulated damage features show that features as small as 0.3 m² are detected with few false positives associated with misregistration or shadow differences.

A hyper-temporal example in the context of wide-areas surveillance for law enforcement or
search & rescue will also be presented. Repetitive RSI with 8 cm spatial resolution imagery was conducted approximately every four minutes over a 55 minute period for each of three remote rural sites. People and vehicles were moved within the scenes between imaging passes. Following image registration, the trend of the time history of image brightness for each pixel was characterized and then brightness anomalies were detected over extensive areas as departures from the trends, effectively minimizing variations due to illumination changes and vegetation shadow movements. All moving targets were identified with a false alarm rate under 5%.

A fine-temporal resolution RSI example will be presented, also in the context of law enforcement and search & rescue. Very high spatial resolution (10 cm) images were captured over public spaces (e.g., shopping centers and schools) in rapid succession. Sequential image pairs were co-registered with simple polynomial warping functions. Image differencing and low-pass convolution filtering was applied, the latter to remove false alarms associated with parallax of features having vertical relief (e.g., buildings and light poles). Thresholding of image brightness differences yielded anomalies associated with moving objects. Moving automobiles and pedestrians were readily detected. Rates of movement were estimated from the displacement differences between sequential image pairs.
Monitoring data consistency between SPOT-VEGETATION and Proba-V

Else Swinnen, Bart Deronde and Roel Van Hoolst
VITO, Belgium

The sensor onboard the Proba-V satellite was specifically designed to ensure the continuity of the SPOT-VEGETATION mission. This was done not only at the level of the spectral characteristics of the sensor, but also in the choice of the pre-processing algorithms. Nevertheless this pursuit of continuity, distinct differences remain between the sensors. These will inevitably affect the consistency between the data sets of the successive sensors, e.g. the orbital overpass time is not controlled. Evidently, this will impact many applications dealing with time series analysis based on SPOT-VEGETATION data (e.g. the MARS programme of the EC). The overall aim of this study is to serve the user community of the SPOT-VEGETATION programme with relevant information on how to assimilate the Proba-V data into their specific application and/or research.

This study presents the set up of the evaluation scheme to assess the continuity of the data between SPOT-VEGETATION and Proba-V. Global, 10-daily composites of the 4 reflectances (Blue, Red, NIR and SWIR) and the NDVI are used in the assessment. Ultimately, the analysis will be applied on the overlapping time series of SPOT-VEGETATION and Proba-V data (where relevant), but also on the time series of these two sensors compared to METOP-AVHRR, and the comparison to high resolution data. In this presentation we focus on the comparison between SPOT-VEGETATION and METOP-AVHRR.

It is envisaged to perform the evaluation into different levels. The first level concerns correlation analysis, where the similarity of different data sets can be evaluated using different metrics (coefficient of determination, agreement coefficient, geometric mean regression, histogram comparison, etc.). A high similarity at this level is crucial, but not sufficient to conclude data consistency if the sensitivity to certain events (e.g. drought, land cover change) is different. Therefore, the second level focuses on the evaluation of the anomalies, i.e. the time series from which the seasonality is removed. Here, the sensitivity to seasonal changes will be assessed. Last, the interannual evolution of the SPOT-VEGETATION time series will be compared with the future Proba-V dataset. Data from the METOP-AVHRR sensor will have a central role in this, but other sensors will be evaluated as well.
Land cover change from tsunami and recovery monitoring in Ban Nam Khem, Phang Nga Province, Thailand using IKONOS imagery

Ajira Tiangtrong\textsuperscript{1}, Pasu Kongapai\textsuperscript{2} and Somrudee Jitprapai\textsuperscript{2}

\textsuperscript{1} Southeast Asia START Regional Center, Chulalongkorn University
\textsuperscript{2} Marine Science Department, Faculty of Science, Chulalongkorn University

The impact of tsunami disaster on 26 December 2004 devastated the coastal areas along southern Thailand including Ban Nam Khem in Phang Nga province. High-spatial resolution IKONOS satellites images can be observed and detected major changes to land cover caused by tsunami. Land cover was classified by using before (13 January 2003) and after (26 January 2005) event imagery. Recovery of tsunami-affected areas was estimated by using imagery on 20 February 2008. A supervised classification approach was interpreted time-series IKONOS images. A classification scheme was developed with five land cover classes; vegetation, barren land, urban, water bodies, aquaculture. The results showed that vegetation was greatest areas and peaked at 2,417 ha in year 2003. In contrast, aquaculture was fewest areas and approximated at 27 ha between 2003 and 2005. Accuracy assessment using 219 pixels that were randomly distribution was necessary evaluated for change analysis. The overall accuracy was found as 93.15 \%, 80.82 \% and 84.93 \% and the overall Kappa statistics was found as 0.86, 0.68 and 0.69 for year 2003, 2005, and 2008 respectively. A post-classification change detection approach was analyzed. This study found that the increased areas of approximately 76.83 \%, 42.58 \% and 6.63 \% for water bodies, barren land and urban respectively but the lost areas as 17.99\% and 2.31 \% for vegetation and aquaculture from 2003 to 2005. However, monitoring during 2005 to 2008 indicated that the increased areas of approximately 122.16 \% and 9.35 \% for aquaculture and vegetation whereas the lost areas as 36.57 \%, 17.79 \% and 11.62 \% for barren land, water bodies and urban respectively. The results of this study can be used to identify areas for conservation, restoration and rehabilitation from natural disasters.
Agriculture is a key economic sector in Africa with more than 60% of its population depending upon it. FAO estimates that nearly 265 Million people are currently under nourished in Sub-Saharan Africa, representing more than 25% of its total population. Good management of agricultural resources, in order to ensure stable food supply, is imperative to the livelihoods of millions of people and is key for development, but requires good information to base decisions on. Remote sensing can contribute significantly to these information needs and for this reason more and more institutes and agencies integrate this technology into their daily work. The main focus of the FP7-AGRICAB project, is to link European and African research capacity in the use of remote sensing for agriculture and forestry management. The project is based upon interconnected research activities in several use case countries. In Senegal, rainfall is concentrated between June and September but shows a spatial and temporal variability that results in local or general dry spells that may affect crops and rangeland production. A large part of the Senegalese population lives in rural areas, and thus depends on early identification and localization of drought affected areas. This study focuses on new methodologies for the integration of time series of low spatial-high temporal resolution SPOT-Vegetation derived vegetation indicators in the near-real time (early warning) monitoring of crop status over Senegal, including spatio-temporal cluster analysis, start of season anomalies detection and yield forecasting. The introduction of new time series analysis software called SPIRITS [1] is facilitating the operational tasks of the ‘Centre the Suivi Ecologique’, with focus on time efficiency, reliability and quality of the output early warning products. SPIRITS includes functions to automate the data processing chain in an operational framework. The aim is to improve the regularly published crop monitoring bulletins and to provide more comprehensive and timely information to the end-users and policy makers.

Fusion of high resolution and multi-temporal remote sensing data for crop mapping in Kenya

Carolien Tote\textsuperscript{1}, Vincent Imala\textsuperscript{2}, Charles Situma\textsuperscript{2}, David Remotti\textsuperscript{3}, Qinghan Dong\textsuperscript{1} and Else Swinnen\textsuperscript{1}

\textsuperscript{1} Flemish Institute for Technological Research
\textsuperscript{2} Department of Resource Surveys and Remote Sensing, Kenya
\textsuperscript{3} Consorzio ITA, Italy

About 75\% of Kenya\textquotesingle s population depends on agriculture for food and income. However, only about one-quarter of the total land area of Kenya is viable for crop production, including the highlands, coastal plains and the lake region. Good management of agricultural resources, particularly food crops, is imperative to the sustainability of the livelihoods of millions of people and is key for development, but requires good information to base decisions on. The main focus of the FP7-AGRICAB and FP7-E-AGRI projects, is to link European and African research capacity in the use of remote sensing technologies for agriculture management. This case study focuses on the use of remote sensing technology for crop mapping in the Western Region of Kenya. During the 2013 long rains crop season, one high resolution SPOT-5 and three Deimos-1 acquisitions (between April-July/2013) are planned. Moreover, an extensive field survey is planned in April/2013 in order to generate crop area statistics and ground truth data for image interpretation. The very high and multi-temporal high resolution satellite data will be fused with hyper-temporal MODIS composite products, in order to generate crop masks in the study area.
Remotely sensed time series for monitoring the effects of the Limpopo River flooding on agriculture in Mozambique

Carolien Tote¹, Frincisco Tauacale², Domingo Patricio³ and Else Swinnen¹
¹ Flemish Institute for Technological Research
² Universidade Eduardo Mondlane
³ Instituto Nacional de Meteorologia, Mozambique

The main focus of the FP7-AGRICAB project is to link European and African research capacity in the use of remote sensing for agriculture and forestry management. The project is based upon interconnected research activities in several use case countries. The southern part of Mozambique is characterized by a semi-arid climate and is vulnerable to extreme events such as droughts, tropical cyclones and floods. Both recent trends in observations and long term modeling outcomes suggest that climate change is affecting the characteristics of tropical cyclones in the south-western Indian Ocean, with a likely increase both in frequency and intensity of cyclones. The Limpopo river basin, one of the largest river basins in southern Africa, was the worst affected basin in the 2000 flood following heavy rains and four tropical cyclones hitting the coast in a short time span. Also this year, in January 2013, torrential rains (reaching two thirds of mean yearly rainfall) have pushed the Limpopo River over its banks in Gaza province, inundating agricultural land. In this study, time series of near-real time rainfall estimates derived from Meteosat Second Generation and vegetation indicators derived from SPOT-Vegetation, MetOp-AVHRR and MODIS are analyzed using a new time series analysis tool called SPIRITS [1]. The objective is to monitor the effects of the Limpopo River flooding on agricultural production, by analyzing cumulative estimated rainfall, vegetation index anomalies and phenological parameters. The extent and duration of the current floods are compared to the 2000 event, and the recovery of vegetation and crops after the flooding is monitored. SPIRITS includes functions to automate the data processing chain in an operational framework. The aim is to provide a basis for early warning and qualitative crop monitoring using remote sensing at the partner institutes in Mozambique. The methodology, as tested on the Limpopo River, can then also be applied on other vulnerable areas, such as the Pungoe and Buzi river basins.

Do combined atmospheric and topographic correction methods improve land cover change classification in mountain areas?

Steven Vanonckelen, Stef Lhermitte and Anton Van Rompaey

1Division of Geography, Katholieke Universiteit Leuven
2Royal Netherlands Meteorological Institute

Assessing the rate and spatial pattern of land cover change is challenging given the ruggedness and inaccessibility of mountain areas. Mapping of vegetation in mountain areas based on remote sensing is hampered by atmospheric distortions and differential illumination effects due to topography. During the past 10 years, several atmospheric and topographic corrections (AC and TC) have been evaluated individually. In literature, though, only a limited number of AC and TC combinations has been tested and described so far. At present, a systematic comparison of the performance of different combined corrections on classification accuracy is lacking. Therefore, three atmospheric and five topographic corrections are applied in all possible combinations on two Landsat acquisitions (2009 and 2010) in the Romanian Carpathian Mountains. The overall research question of this paper is to evaluate the impact of 15 combined AC and TC corrections on the accuracy of land cover classification. The highest accuracy (average kappa value of 0.93) was achieved after combination of an atmospheric correction based on transmittance functions and a pixel-based Minnaert topographic correction. Currently, further research is performed on the application of all combined corrections to a large temporal and spatial data set. Therefore, a temporal series of Landsat images covering six time steps between 1985 and 2012 is being analyzed in the entire Romanian Carpathian Mountains. The results will be finished in the following months.

Study area and methodology

A mountain study area of 915 km² in the Romanian Carpathian mountains was selected. The Landsat-5 TM images were captured on July 24, 2009 and August 12, 2010. The digital elevation model used is the STRM from NASA. Ground control points were gathered through field visits and the analysis of high-resolution satellite imagery (WorldView-2). The supervised maximum likelihood classifier was used and the six land cover classes were: broadleaved forest, bare soil, coniferous forest, grassland, mixed forest and water surface. The classification procedure was based on a 10-fold cross validation where the image was repeatedly trained with two-thirds of the reference points and validation with the remaining one-third.

Calibrated radiance values \((L_{S,\lambda})\) were corrected for atmospheric path radiance \((L_{P})\). The atmospheric correction was performed by means of 3 different AC methods (including no AC) as described in Table 1. The AC methods were selected with an increasing modeling complexity: i) no AC, ii) Dark Object Subtraction (DOS) and iii) correction based on transmittance functions (TF). Next, the target radiance \((L_{T,\lambda})\) was converted to at-surface reflectance \((\rho_{T,\lambda})\). In a final step, the normalized reflectance of a horizontal surface \((\rho_{H,\lambda})\) was calculated using the five topographic corrections described in Table 1.
The five selected TC methods were: no TC, band ratioing, cosine correction, pixel-based Minnaert correction (PBM) and pixel-based C-correction (PBC).

The performance of land cover classification maps was examined based on three statistical analyses:

1. Which AC and TC combinations result in the best overall classification accuracy? Overall classification accuracy of land cover maps is examined. Thereby, two validation datasets are used: a set containing all validation pixels and a so called difference subset. This subset includes the validation pixels that are classified differently between the classification of one of the combined corrections and the classification of the un-preprocessed image.

2. How big is the impact of AC and TC combinations on land cover class accuracies? Delta-kappa values between the un-preprocessed and preprocessed images are calculated for each land cover type. Positive delta-kappa values indicate a more accurate classification after combined correction.

3. In which specific illumination conditions are overall classification accuracies increasing most after combined correction? Therefore, overall classification accuracy is evaluated for three illumination conditions separately. The validation set is divided in three illumination zones
based on the illumination parameter \( \cos \beta \): low \([\cos \beta \leq 0.65]\), moderate \([0.65 < \cos \beta < 0.85]\), and high illumination \([\cos \beta \geq 0.85]\).

Results and discussion

In this section, the results of the 2009 image are presented. The results of the 2010 image are not included in this short abstract. These results clarify the impact of the AC corrections under different atmospheric conditions (2009 vs. 2010 acquisition). Figure 1 presents the 2009 classification accuracy of the un-preprocessed and the different preprocessed classifications using both validation sets. The overall accuracies for the full set are generally high, ranging between 92.2% (no AC and no TC) and 94.8% (TF combined with PBM). The classification accuracy of the un-preprocessed image in the difference area (49.1%) is much lower than the overall classification accuracy (92.2%). All combined corrections result in significantly higher classification accuracies. The highest accuracies in the difference area are achieved after combinations of a TF and PBC correction (83.1%) or a TF and PBM correction (81.4%).

A visual analysis of composites without preprocessing (Fig. 2a) shows differences in illumination on opposite slopes. Combination of TF and cosine correction (Fig. 2b) causes an overcorrection in the visible bands. Combination of TF and PBC correction (Fig. 2c) reduces the differential illumination effects. The results of class accuracies show positive delta- kappa values for coniferous and mixed forest which implies that for these land cover categories most of the combined corrections improve the classification accuracy. The combination of a TF with a PBM correction produces the best results: an increase in kappa values of about 0.16 for both the CF and MX forest types.
The classification accuracy is also evaluated within the difference area for three illumination conditions separately. In the low illumination zone, the accuracy of the un-preprocessed image is low (48.6%). After preprocessing, the accuracy is improving, especially for the combination of TF with PBC or PBM. For those two combinations, accuracy is almost doubling (from 48.6% to 79.6% and 80.2%, respectively). The same trends are visible in the moderate and high illumination zone. Here, accuracies are improving, although the increases are smaller than in the low illumination zone. In the moderate zone, the largest improvement in accuracy is an increase from 56.1% to 84.6% (TF with PBC). Overall, the accuracy is the highest in the high illumination zone for the combination of TF with PBM (89.0%). In the bi-temporal study, results indicate that the influence of the topographic component on classification accuracy is higher than the atmospheric component.

Further research that is currently going on focuses on the application of the combined corrections to other study sites and to temporal series. Therefore, a temporal series of Landsat images covering six time steps between 1985 and 2012 is being analyzed in the entire Romanian Carpathian Mountains. The impact of several factors (demography, social system, land tenure and forest protection) on forest conservation is also investigated and outcome of the study provides new insights for forest mapping and environmental research in mountain areas.
Global response of land surface phenology to climate variability

Aleixandre Verger\textsuperscript{1}, Frédéric Baret\textsuperscript{2}, Marie Weiss\textsuperscript{2}, Iolande Filella\textsuperscript{1} and Josep Peñuelas\textsuperscript{1}
\textsuperscript{1} EMMAH -UMR1114- INRA / CREAF-CEAB-CSIC-UAB Global Ecology Unit
\textsuperscript{2} EMMAH -UMR1114- INRA France

Phenology is a critical component in understanding ecosystem response to climate variability. Long term data records from global mapping satellite platforms are valuable tools for monitoring vegetation responses to climate change at the global scale. Phenology satellite products and trend detection from satellite time series are expected to contribute to improve our understanding of climate forcing on vegetation dynamics. The capacity of monitoring ecosystem responses to global climate change was evaluated in this study from the 32-year time series of global Leaf Area Index (LAI) which have been recently produced within the geoland2 project. The long term GEOV1 LAI products were derived from NOAA/AVHRR (1981 to 2000) and SPOT/VGT (1999 to the present) with specific emphasis on consistency and continuity. Since mid-November, GEOV1 LAI products are freely available to the scientific community at geoland2 portal (www.geoland2.eu/core-mapping-services/biopar.html). These products are distributed at a decadal time step for the period 1981-2000 and 2000-2012 at 0.05° and 1/112°, respectively. The use of GEOV1 data covering a long time period and providing information at dense time steps are expected to increase the reliability of trend detection.

In this study, GEOV1 LAI time series aggregated at 0.5° spatial resolution are used. The CACAO (Consistent Adjustment of the Climatology to Actual Observations) method (Verger et al, 2013) was applied to characterize seasonal anomalies as well as identify trends. For a given pixel, CACAO computes, for each season, the time shift and the amplitude difference between the current temporal profile and the climatology computed over the 32 years. These CACAO parameters allow quantifying shifts in the timing of seasonal phenology and inter-annual variations in magnitude as compared to the average climatology. Interannual variations in the timing of the Start of Season and End of Season, Season Length and LAI level in the peak of the growing season are analyzed. Trend analysis with robust statistical test of significance is conducted. Climate variables (precipitation, temperature, radiation) are then used to interpret the anomaly patterns detected in vegetation response.
GEOV2/VGT: Continuous, consistent and near real time estimation of global land surface biophysical variables from VEGETATION-P data

Aleixandre Verger¹, Frédéric Baret² and Marie Weiss²
¹ EMMAH -UMR1114- INRA / CREAF-CEAB-CSIC-UAB Global Ecology Unit
² EMMAH -UMR1114- INRA France

Near real time estimation of global biophysical variables from moderate spatial resolution satellite sensors are of high interest in a range of application areas including numerical weather forecasting or monitoring of rapid land surface changes (e.g. droughts, hurricanes, forest fires, floods) to support of policies on environment and water management, agriculture and food security. A part from the near real time delivery of data requirement, consistent and long time series of global land surface variables are essential variables for discerning trends, detecting anomalies, analyzing inter-annual variability and identifying high risk areas. This contribution describes the GEOV2 algorithm for continuous, consistent and near real time estimation of Leaf Area Index (LAI), fraction of absorbed photosynthetic active radiation (FAPAR) and vegetation cover fraction (FCOVER) from daily VGT-P satellite data. It consists of a series of procedures including (1) neural networks for providing instantaneous estimates from VGT-P reflectances, (2) a multi-step filtering approach to eliminate contaminated data mainly affected by atmospheric effects and snow cover, and (3) temporal techniques for ensuring consistency and continuity as well as short term projection of the product dynamics. Decadal GEOV2/VGT products will be freely available at geoland2 portal (www.geoland2.eu/core-mapping-services/biopar.html) for the period 1999-present at 1/112° spatial resolution over the Globe. First validation results show that GEOV2/VGT products significantly improve GEOV1/VGT (Baret et al., 2013) products’ limitations (mainly observed at high latitudes and Equatorial areas) in terms of consistency and continuity (less than 1% of missing data as compared to the 20% of gaps in GEOV1 over the BELMANIP2 sites from 1999 to 2010). GEOV2/VGT products are based on the same principles used for the generation of GEOV1/AVHRR (1981-2000) products from AVHRR data (Verger et al., 2013). Combination of GEOV1/AVHRR and GEOV2/VGT are expected to provide continuous and consistent long time series of global LAI, FAPAR and FCOVER variables for the last three decades.
Detecting recent changes in surface water inundation across Arctic-Boreal permafrost zones using satellite microwave remote sensing

Jennifer D. Watts¹, John S. Kimball¹, Lucas A. Jones¹, Ronny Schroeder² and Kyle C. McDonald²

¹ Flathead Lake Biological Station; NTSG, The University of Montana
² Earth and Atmospheric Sciences, City College, New York and Jet Propulsion Laboratory, California Institute of Technology

Surface water inundation strongly influences land-atmosphere water, energy and carbon (CO2, CH4) exchange in high latitude systems. We examine recent (2003-2010) surface water inundation patterns across the Arctic-Boreal region (≥ 50ºN) and within major permafrost zones using satellite passive microwave remote sensing retrievals of fractional open water extent (Fw) derived from Advanced Microwave Scanning Radiometer for EOS (AMSR-E) 18.7 and 23.8 GHz brightness temperatures. The daily Fw retrievals are sensitive to sub-grid scale (~25-km resolution) open water inundation area and are insensitive to solar illumination and signal attenuation from clouds, smoke, and other atmosphere effects that often constrain optical remote sensing. A forward model error sensitivity analysis indicates that total Fw retrieval uncertainty is within ±4.1% (RMSE), and AMSR-E Fw compares favorably (0.71 < R² < 0.84) with alternative static open water maps derived from finer scale (30-m to 250-m resolution) Landsat, MODIS and SRTM radar-based products. The Fw retrievals also show dynamic seasonal and annual variability in surface inundation that corresponds well with regional wet/dry cycles inferred from discharge records for the Yukon, Mackenzie, Ob, Yenisei, and Lena river basins. A regional change analysis shows no significant trend in Arctic-Boreal wide Fw, and instead reveals contrasting inundation changes within permafrost zones. Widespread Fw wetting is observed within continuous (92% of grid cells with significant trend show wetting; p < 0.1) and discontinuous (82%) permafrost, while the sporadic/isolated permafrost zone shows regional Fw drying. These results are consistent with previous studies showing evidence of changes in regional surface hydrology influenced by permafrost degradation under recent climate warming, and may also be linked to shifts in regional precipitation patterns and evapotranspiration. Changes in Arctic surface inundation observed in the AMSR-E Fw record compliment finer-scale regional monitoring efforts, and documented variability in surface inundation extent may help constrain high latitude lake and wetland CO2, CH4 emission estimates.

This work was supported under the Jet Propulsion Laboratory, California Institute of Technology under contract to the National Aeronautics and Space Administration, NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs) programs.
An Integrated system for monitoring patterns of mass change and flow dynamics of a small arctic glacier

Ken Whitehead and Brian Moorman
University of Calgary department of Geography

In comparison to other glaciated areas around the world, the glaciers and small icecaps of the Canadian Arctic Archipelago are known to have lost disproportionate amounts of ice in recent years (Oerlemans et al. 2005; Gardner et al. 2011). While much of this loss may be attributed to a series of warmer than average summers which have occurred over the last few years, there is an urgent need to understand many of the underlying processes and feedbacks driving this change. In order to provide estimates of ice loss and to quantify changes to system dynamics there is a requirement for data, both from remote-sensing satellites and from direct field measurements. Data from all sources needs to be timely and to be frequently updated in order to provide a framework within which measurements may be analysed and trends identified.

An integrated data-collection strategy was used to provide a combination of remotely-sensed and in-situ data over a period of several years for Fountain Glacier on Bylot Island, which is located at latitude 72° 58’ N, longitude 78° 25’ W. Fountain Glacier is a small polythermal glacier, which is approximately 16 km long and 1.2 km wide. In recent years, a number of studies have suggested that this glacier has been losing mass rapidly (e.g. Wainstein et al. 2008; Wainstein 2011), and this is confirmed by the current study, which shows current annual melt rates to be two to three times greater than that which occurred between 1958 and 1982.

The study consisted of three main components. Historical and contemporary aerial photography was used to establish recent and long-term patterns of change. Historical photography was available from 1958, and 1982. Contemporary aerial photography of the terminus region was acquired during an overflight using an Unmanned Aerial Vehicle (UAV) in the summer of 2010, and by a helicopter survey the following summer. Comparison of Digital Elevation Models (DEMs) produced from each set of photos allowed long-term and recent changes in marginal extents and ice thickness to be quantified.

Radar Imagery from ERS-1, TerraSAR-X, and RADARSAT-2 was also used to provide information on dynamic processes. By using a combination of radar images from different platforms and with different imaging geometries, it was possible to establish the full 3D motion field of the glacier using SAR interferometry. By assuming that there was no significant change in down-glacier speed over the winter period, it was then possible to extract the vertical component of surface motion at different points in time. Feature tracking of TerraSAR-X and SPOT images was used to confirm estimates of down-glacier speed derived from SAR interferometry.

The third component of the study used ground-based time-lapse photography. A time series of
photos was analysed and daily photogrammetric measurements were made of the position of targets located on the surface of the glacier. From these measurements it was possible to create a series of temporal profiles showing detailed changes in the glacier surface elevation over a three year period. Photogrammetric measurements were also used to measure the down-glacier motion over the same time period. All photogrammetric measurements were compared against GPS measurements of the targets made during field visits each summer.

Putting together the measurements derived from each of the three components allowed a comprehensive picture to be built up of the changes occurring to Fountain Glacier in terms of mass loss and marginal retreat. The use of SAR interferometry allowed the full 3D motion field of the glacier to be measured, while the use of SPOT feature tracking made it possible to estimate the differences between summer and winter flow rates. The measurements made from the time-lapse photography added the temporal component, making it possible to view seasonal melt patterns and seasonal flow patterns in great detail. By providing such detailed information on glacier conditions over time it becomes possible to provide a realistic assessment of the overall health of the glacier and predict likely future changes.

References:
Multi-temporal UAV image processing for habitat modeling

Hantson Wouter¹, Els De Roeck², Els Ducheyne¹ and Guy Hendrickx¹
¹ AviaGIS ² UGhent

Recently, Unmanned Aerial Vehicles (UAVs) became available for high resolution remote sensing. The advantages are unparalleled, very high temporal and spatial resolutions, flexible deployment, relatively simple operation and they have the potential for very rapid data acquisition and processing. We used a multi-copter (FALCON 8 by Ascending Technologies) as opposed to a fixed wing model because it is able to hover and hence to hop within its action radius from one landscape element to another, allowing us to focus on the relevant parts (SWBs) of the landscape. The payload of 500g allows using a high quality consumer camera (Sony NEX5) for image acquisition.

Monthly imagery, with at least 50% overlap, was obtained from the SWBs in the four farms and processed using direct geo-referencing, the process of registering an image frame to a map coordinate system through direct measurement of the image exterior orientation parameters by a GPS. APERO was used for automatic tie point extraction, initial solution computation and bundle adjustment. MicMac continues with the orientations and calibrations processes by Apero to create depth maps, 3D point clouds, and ortho imagery. APERO and MicMac are powerful open source tools developed by MATIS laboratory (Universit. Paris-Est, IGN, Laboratoire MATIS).

Using direct geo-referencing, we obtained an accuracy of 0.6 - 3m compared to ground control points (GCPs) measured with differential GPS. The obtained accuracy is not accurate enough for change detection or time-series analysis.

For this reason we used first direct geo-referencing followed by a co-registration based on automated generated (SIFT) and filtered Ground Control Points (GCPs).

A detailed workflow and accuracy assessment will be presented on the poster.
Liver fluke epizootic outbreaks in livestock may cause spontaneous mortality and production losses. The liver fluke parasite (*Fasciola hepatica*) is transmitted by an intermediary snail-host, mainly *Galba truncatula* in Europe. These species proliferate in Small Water Bodies (SWBs) such as ponds, ditches, trenches and their transition zones. The abundance of these vectors shows seasonal peaks and is strongly influenced by SWB dynamics. Current modelling tools for the spatial distribution of disease vectors are limited to area-wide distribution models or static landscape models. SATHELI focuses on the development of earth-observation based tools to detect these SWBs and their dynamics. This will allow spatio-temporal forecasting of areas under potential liver fluke threat. Recently, Unmanned Aerial Vehicles (UAVs) became available for high resolution remote sensing. The advantages are an increased very high temporal and spatial resolution, flexible deployment, relatively simple operation and the potential for very rapid data acquisition and processing. Within SATHELI, a multi-copter (FALCON 8 by Ascending Technologies) was selected as opposed to a fixed wing model because it is able to hover and hence hop from one landscape element to another, which allows focusing on the SWBs within the landscape. Monthly imagery, with at least 50% overlap, was obtained for all the SWBs in four selected farms and stitched and processed using direct geo-referencing. Using direct geo-referencing, we obtained an accuracy of 0.6 - 3m compared to ground control points (GCPs) measured with a differential GPS. As this accuracy does not allow detection nor time-series analysis a co-registration procedure based on automatically generated and filtered GCPs was added to the processing workflow. In order to detect the SWBs a segmentation and classification algorithm will be used to create an object-based characterization of SWBs. This algorithm will be applied to classify the series of monthly co-registered UAV images enabling to study the dynamic behavior of the SWBs. The obtained SWBs behavior will be used to define the status of surface water objects: water, mixture, or humid area, and over time permanent wet objects will be distinguished from temporally wet objects to produce a probability map of snail occurrence for the study sites. In a final step, the UAV imagery will be co-registered with the satellite imagery obtained from World View II. After co-registration the UAV time series will be compared with the time-series from the WV-II satellite.
Snow cover variation of Geladandong Glacier in the hinterland of Qinghai-Tibet Plateau from 2001 to 2012

Weixin Xu, Ruixiang Xiao, Jianshe Xiao, Juan Zhang and Wenjiang Su
Meteorology Institute of Qinghai Province, China

The Geladandong Glacier, located in the hinterland of the Qinghai-Tibet Plateau (QTP), China, is a region of headwater both for of the Yangtze and the Mekong Rivers - two largest rivers in East Asian. Over the past four decades, a significant warming (0.373°C/10a) has occurred over the QTP, which has caused a remarkable decrease in the glacier area. In this study, daily snow cover extent, including total area and the area for three sub-glacier-zones were derived from the MODIS data (500m resolution) during the hottest season (1st Jul to 31st Aug) from 2001 to 2012 and using a discriminated model in basic of Normalized Difference Snow Index (NDSI). The minimum snow cover extent and its date in each year, which may be generally considered as the glacier ice area and the time of climatic snowline in this year respectively, were determined to form a time serial from 2001 to 2012. Analyses of these data show that the total snow cover area has significantly decreased at rate of -5.0km²/a, or corresponding to 5.3% area lost since 2001. We also found that smaller glacier have greater changes than the bigger glaciers. However, the variation pace of glacier area among the three sub-glaciers with different location, area, and orientations are much more similar after 2008 although they were distinctly different before. The relationship between the glaciers areas and local air temperature and precipitation also been analyzed as well.
Assessing land degradation in Inner Mongolia using MODIS time series

He Yin¹, Dirk Pflugmacher¹, Zhengguo Li² and Patrick Hostert¹
¹ Geography Department, Humboldt-Universität zu Berlin
² Institute of Agriculture Resource and Regional Planning, Chinese Academy of Agricultural Sciences

Debates are ongoing over the effectiveness of China’s re-vegetation programs in arid, semi-arid and sub-humid environments. Large-scale afforestation efforts are criticized due to potential negative impacts on soils and vegetation cover in drylands (Cao et al. 2010). However, it has also been argued that afforestation projects contributed to environmental improvements in drylands and socioeconomic effects are mostly positive nationwide (Liu et al. 2008; Yang et al. 2010).

The objective of this study was to monitor land cover dynamics across broad scales under China’s current ecological restoration programs. We focus on mapping land cover conversions and modifications using MODIS time series. We selected Inner Mongolia as our study region because it is one of the most severely degraded regions in China and a global hot-spot of land degradation (Sneath 1998). We employed MODIS-Terra Vegetation Index (VI) products (MOD13Q1, Collection 5) from 2000 to 2011 for land cover classification and trend analysis. We used annual spectral statistics, a collection of ground references from Google Earth and a Random Forest classifier to produce annual land cover maps differentiating forests, cropland, grassland, water and non-vegetated area. The validation was performed on both the respective land cover maps and the post-classification change map based on Google Earth and Landsat imagery. To monitor more subtle land cover modifications, such as double cropping due to irrigation, linear trend in MODIS NDVI and Tropical Rainfall Measuring Mission (TRMM) -based precipitation time series were calculated, respectively.

We found that: i) Forest cover overall increased in mountainous areas, while forests in the Greater Khingan Mountains at the same time exhibited higher disturbance rates due to fire and logging in remote regions ii) cropland expansion in previous grasslands and agricultural intensification is ongoing; iii) Lakes were shrinking severely despite no significant changes in precipitation occurred. Our results suggest that afforestation and forest protection policies that were implemented in the past decade play a positive role for forest regrowth and recovery in general. However, illegal cropland expansion and unsustainable agricultural management may negatively affect water resources and increase the risk of ongoing or in some regions increased land degradation. Overall, time series analysis based on remote sensing data allowed a consistent characterization of land cover dynamics over large areas, which is crucial in gaining a better understanding of environmental changes in light of new information.
Potential for using GIMMS and MODIS NDVI date set for investigating deciduous broadleaf forest carbon sink over continental U.S.

Xiaolei Yu, Xulin Guo and Tengfei Cui
University of Saskatchewan

Several remote sensing based normalized difference vegetation index (NDVI) data sets have been established to monitor and analyze the global vegetation changing condition, and proved to be decent approach. Quantificational estimation for the land surface ecosystems’ carbon sink is of scientific importance and also relevant to climate-policy making, as the carbon cycling between the terrestrial biosphere and the atmosphere plays an important role in earth system dynamic modeling. In this paper, we use the sequence of 15-day composite Advanced Very High Resolution Radiometer (AVHRR)-derived NDVI data from the Global Inventory Modeling and Mapping Studies (GIMMS) and the 16-day composite Moderate Resolution Imaging Spectroradiometer (MODIS)-derived NDVI data from the Land Processes Distributed Active Archive Center (LP DAAC), along with carbon flux from Ameriflux to study the potential of using time series NDVI date set for investigating deciduous broadleaf forest carbon sink over continental U.S., as the deciduous broadleaf forest is largely affecting the global climate change. The objectives of this paper are to: 1) investigate whether the NDVI series can represent the carbon sink for different deciduous broadleaf forest sites and how much it can explain the carbon sink, and 2) compare the explanatory powers for multi-sensor NDVI data set. To fulfill these objectives, we will subset the NDVI time series for both GIMMS and MODIS data set, corresponding with the flux sites measurements’ period. After the noise remove and reconstruction for the NDVI time series, the relationship between them and carbon sink will be analysis along with the general weather data. Result will help us using the NDVI data sets to evaluate the carbon sink for deciduous broadleaf forest at a large scale and for a long time period.
Chlorophyll-a estimation in the Pearl River estuary, China

Yuanzhi Zhang\textsuperscript{1}, Chuqun Chen\textsuperscript{2} and Zhaojun Huang\textsuperscript{1}
\textsuperscript{1} The Chinese University of Hong Kong
\textsuperscript{2} Chinese Academy of Sciences

This study is to estimate chlorophyll-a (chl-a) concentration in the Pearl River estuary in China. We first examined the performance of algorithms for the estimation of the chl-a concentration in the turbid waters, the maximum band ratio (MBR) and near-infrared–red (NIR–red) models using our local datasets. The objective of this study is specifically focused on (a) comparing the ability of the models to estimate chl-a in the low concentrations at range 1–12 mg m\textsuperscript{-3}, which is typical for coastal and estuarine waters, and (b) assessing the potential of the Moderate Resolution Imaging Spectrometer (MODIS) and Medium Resolution Imaging Spectrometer (MERIS) to estimate chl-a concentrations.

We collected the reflectance spectra and water samples in the Pearl River estuary in 2008-2010 with chl-a ranging from 0.83 to 11.8 mg m\textsuperscript{-3} and total suspended matter from 9.9 to 21.5 g m\textsuperscript{-3}. It is found that there is a close relationship between chl-a concentration and total suspended matter concentration with the determining coefficient (R\textsuperscript{2}) above 0.89. The MBR calculated in the spectral bands of MODIS proved to be a good proxy for chl-a concentration (R\textsuperscript{2} > 0.90). On the other hand, both the NIR–red three-band model (at around 665, 700, and 730 nm) and the NIR–red two-band model (at around 665 and 700 nm) explained more than 90 \% of the chl-a variation. The results show that it is able to estimate chl-a concentrations with a root mean square error below 1 mg m\textsuperscript{-3}. The two- and three-band NIR–red models with MERIS spectral bands accounted for 90 \% of the chl-a variation. The findings also show that the potential use of MODIS and MERIS images could be used to estimate chl-a concentrations in the Pearl River estuary.
Continuous change detection and classification of land cover using all available Landsat data

Zhe Zhu and Curtis Woodcock
Boston University

In a new algorithm for Continuous Change Detection and Classification (CCDC) of land cover using all available Landsat data is developed. This algorithm is capable of detecting many kinds of land cover change continuously as new images are collected and providing land cover maps for any given time. To better identify land cover change, a two-step cloud, cloud shadow, and snow masking algorithm is used for eliminating “noisy” observations. Next, a time series model that has components of seasonality, trend, and break estimates the surface reflectance and brightness temperature. The time series model is updated dynamically with the newly acquired observations. Due to the large difference in spectral response for various kinds of land cover change, the CCDC algorithm uses a data-driven threshold derived from all seven Landsat bands. When the difference between observed and predicted exceeds the thresholds three consecutive times, a pixel is identified as land surface change. Land cover classification is done after change detection. Coefficients from the time series models and the Root Mean Square Error (RMSE) from model estimating are used as classification inputs for the Random Forest Classifier (RFC). We applied the CCDC algorithm for one Landsat scene at Worldwide Reference System (WRS) Path 12 and Row 31. All available (a total of 519) Landsat images acquired between 1982 and 2011 were used. The accuracy assessment shows that CCDC results were accurate for detecting land surface change, with producer’s accuracy of 97.72% and user’s accuracies of 85.60% in the spatial domain and temporal accuracy of 79.91%. Most of the temporal errors (65.12%) are within a month of the first date when a change is observable. At the same time, the 16-categories land cover classification map from the CCDC algorithm also showed high accuracy with an overall accuracy of 90.20%. Recently, we are testing the CCDC algorithm by using more sophisticated time series model that have components capturing the bimodal and trimodal annual difference, applying a more advanced regression method called Lasso (least absolute shrinkage and selection operator), improving the thresholding method by calculating RMSE using a nearest-neighbor method that making threshold varies temporally, and reducing the number of regression times to make it more efficient. The preliminary results show the recent improvements are significant both in change detection and classification.
Mapping of grassland using seasonal statistics derived from multi-temporal satellite images

Erik Zillmann\textsuperscript{1} and Enrique Montero Herrero\textsuperscript{2}
\textsuperscript{1} RapidEye AG  \textsuperscript{2} INDRA, Spain

In the framework of Global Monitoring of Environment and Security (GMES) land monitoring services a multi-temporal classification approach used for pan-European grassland discrimination is being carried out. Since the canopy density, chlorophyll status and ground cover of grasslands is highly dynamic throughout the growing season, no unique spectral signature for grassland exists. Therefore, it is necessary to use time series to characterize the phenological dynamics of grasslands throughout the year to be able to discriminate among them and cropland. To this end, a methodology based on a multi-temporal analysis of multi-scale image series of three different multi-spectral sensors was developed for land-cover classification. Image data of the satellite systems IRS-P6 / ResourceSat and RapidEye was used. The objective of this paper is to present the results on one of our study areas.

TOA calibrated reflectance images of 2012 were used to achieve consistency throughout the entire time series and to retrieve a set of biophysical parameters characterizing the spatio-temporal behavior of vegetation cover and growth status. In order to fully utilize the information of the multi-temporal data set, various statistical features of each biophysical parameter were calculated and used as the main basis for subsequent classification.

A supervised object-based image classification using different object features was adopted to classify grasslands. The main advantage of the object–based approach is to provide efficient handling and analysis of multi-scale data (i.e. 60 m AWiFS and 20 m LISS III / RapidEye). The Classification and Regression Tree (CART) classifier C5 was used to analyze the data and assign the terrain classes. The CART approach is well suited for non-normally distributed data, as it happens when each land-cover class is represented by more than one point cluster in the spectral feature space. In addition, the CART approach allows the ingestion of a large number of input features. C5’s boosting algorithm reviews the results multiple times to iteratively refine the resulting decision tree and generates confidence intervals for each classified object.

The results presented in this paper correspond to the entire Hungary, which is characterized by large areas of finely fragmented agricultural landscapes. The accuracy of the grassland classification (vs. non-grassland areas) was assessed by using approximately 340 sample points derived from a ground-based European field survey program (LUCAS) and a selection of points from the CORINE landcover data (2006). The multi-temporal grassland classification of Hungary reached an overall accuracy of 92.2 \%. 
Grassland identification using multi-temporal RapidEye image series

Erik Zillmann and Horst Weichelt
Rapideye AG

The RapidEye satellite constellation represents a unique potential of multi-temporal acquisition of high resolution image data, therefore, offering completely new ways of detailed multi-temporal analysis. The full utilization of this information for land-cover classification is yet to be brought forward and new approaches need to be developed or existing methods adapted.

The incorporation of multi-temporal data into image classification can help to overcome the problem of discriminating land cover classes that have similar spectral signatures but different phenological dynamics, such as the case of cropland and grassland. A semi-automatic land-cover classification approach with emphasis on grassland based on a multi-temporal analysis of RapidEye image series was developed. The objective of this paper is to present the results of grassland identification in our study area in Brandenburg / Germany.

TOA calibrated reflectance images of 2011 were used to achieve consistency throughout the entire time series and to retrieve a set of biophysical parameters characterizing the spatio-temporal behavior of vegetation cover and growth status. In order to fully utilize the information of the multi-temporal data set, various statistical features of each biophysical parameter were calculated and used as the main basis for subsequent classification. A supervised object-based image classification using different object features was adopted to classify grasslands. A Classification and Regression Tree (CART) classifier was used to analyze the data and assign the terrain classes. The CART approach is well suited for non-normally distributed data, as it happens when each land-cover class is represented by more than one cluster in the spectral feature space.

The results presented in this paper correspond to an area of 2500 km² in the State of Brandenburg, Germany. The landscape is mainly characterized by a mixture of forest and grassland. The accuracy of the grassland classification was assessed by using the administrative field block cadaster (MIL Brandenburg, Feb.2012). The grassland classification of the test area reached an overall accuracy of about 90%.
AN APPROACH TO THE DETECTION OF CHANGED BUILDINGS IN MULTITEMPORAL VERY HIGH RESOLUTION SAR IMAGES

Carlo Marin, Francesca Bovolo, Lorenzo Bruzzone
Department of Information Engineering and Computer Science, University of Trento
Via Sommarive, 5 I-38123, Povo, Trento, Italy, Fax: +39-0461-282093,
e-mail: lorenzo.bruzzone@ing.unitn.it

This abstract presents a novel approach to change detection (CD) in very high resolution (VHR) SAR images aimed at detecting changes affecting building in urban areas (e.g., for damage assessment after natural disasters or for urban growth monitoring). Despite the strong interest on this topic from both the scientific and user communities, only few papers have been presented in the literature that address the problem of CD in man-made infrastructures in VHR SAR images [1-3]. In order to overcome the limitations of the state-of-the-art methods, which rely on the division of the scene in blocks [2] and grids [3], in this paper we propose a novel approach to building change detection in VHR SAR that works at level of each single building. The proposed approach takes explicitly advantage from the exploitation of the expected backscattering proprieties of buildings to detect changes associated to both new and fully destroyed buildings.

It is known from the literature that buildings in VHR SAR images can be modeled with specific primitives [1]. Simplifying, it is possible to state that the footprints of isolated buildings in a VHR SAR image are given by a specific pattern: a bright area (due to layover and double bounce effects) followed by a dark area (due to the shadow effect). These features may have different thickness, shape and internal intensity of backscattering depending on the considered building structure and size. The pattern associated to a building is oriented according to the viewing geometry of the SAR sensor: bright areas are closer to the sensor than the dark ones. Therefore, if we consider the case in which a new building fully appears between two acquisitions, we expect that a structured pattern made up of two regions having increase and decrease in the backscattering values will arise in near-to-far-range direction. This pattern will be distributed so that the surface of the dark area due to shadow cast by the new building is larger (or at least equal) to the surface of the bright area due to new structural components of the building (i.e., walls and roof). Vive-versa, a complementary behavior appears if a building fully disappears between the two acquisitions.

According to this observation, we propose an approach based on three steps: i) selection of the proper scale of representation for buildings; ii) detection of changed buildings by the analysis of all backscattering changes; and ii) discrimination between new and destroyed buildings among all changed buildings. The proposed approach exploits a multilevel representation of the multitemporal information. This is derived according to a multiscale decomposition of the log-ratio image obtained by the pixel-by-pixel comparison of the two images to be analyzed [3]. Images in the multilevel set exhibit different trade-offs between details preservation and homogeneity. Hence by knowing the expected building size, it is possible to identify one (or more) optimum resolution level(s) to be used to seek for changes associated to buildings. Once the optimum resolution level has been selected, a map Mopt highlighting only the areas of...
increase and decrease in the backscattering values is computed according to a thresholding procedure. The second step of the proposed approach aims at detecting all the areas of change in Mopt that are comparable, in terms of extent, with the expected size of buildings. This is achieved counting the changed pixels in Mopt inside a moving window with size Wx and Wy set according to the typical size of buildings in the considered scene. In this way it is possible to derive the candidate areas of change CBh, (h=1,...,H), which represent the candidate building radar footprint areas with size comparable or larger than the average building dimension. The third step of the changed building detection aims at associating the proper class of change (i.e., new or fully destroyed building) to each candidate CBh, (h=1,...,H). The classification is achieved testing 3 hypotheses. If one of the hypotheses is not satisfied, the candidate is rejected (i.e., changes that are comparable to the size of a building, but that do not present the typical pattern of new/destroyed buildings). The first test is devoted to identify the presence of both increase/decrease backscattering areas inside candidate regions. The pair increase/decrease is needed to identify a building (new or destroyed). The second test is devoted to reject the candidates that show a ratio between the surface of increase and the surface of decrease that is not included in a given range expected for a building. The third test is devoted to eliminate the candidates that present a pattern increase/decrease that do not respect the viewing geometry of SAR sensors. For those areas that satisfy the three aforementioned tests, the minimum estimated oriented bounding box is computed and shown in the final change-detection map. The discrimination between new and destroyed buildings is finally obtained considering the order of the pair increase/decrease of backscattering inside each building candidate with respect to the range direction. For space constraints the analytical description of the proposed method will be reported in the full paper.

Experimental results were carried out on a data set made up of two COSMO-SkyMed spotlight (1m×1m resolution, with 0.5m×0.5m pixel spacing, X-band) images acquired over the city of L’Aquila, Italy before and after the earthquake that hit the region in 2009. The log-ratio image XLR was computed from the two calibrated and co-registered CSK© images. From XLR a set with five resolution levels was computed according [4]. In the considered scene, it is expected that the minimum size of a building is 20×10 m2. Therefore the level N=3, which gives a resolution of approximately 8×8 m2, and a window size of Wx=Wy=35 were selected. The proposed method extracted 13 changed areas CB={CB1,...,CB13}. Each area has been analyzed in order to detect the fully destroyed buildings and derive the final change detection map. Since no ground truth was available for the investigated scene we validated the proposed approach considering the multitemporal aerial images available in Bing map© and the multitemporal satellite images in Google Earth©. This analysis confirmed that all the identified destroyed buildings completely collapsed because of the earthquake and no new buildings were built up. At the same time the result presents a low rate of false alarms. Further results will be documented in the full paper.

REFERENCES


INDEX OF AUTHORS

A
Achard, 68
Adamczyk, 28
Ahmed, 29
Akenhead, 39
Aleksandrowicz, 30
Amorós-López, 31
Arkebauer, 151
Asam, 35

B
Ban, 38
Baret, 176, 177
Barr, 100
Belhadj-Aissa, A., 47, 75
Belhadj-Aissa, M., 75
Bell, 87, 88
Bishnoi, 48, 83, 84, 85
Biswas, 81
Black, 100
Borstad, 39
Bovolo, 122, 190
Brais, 142
Bright, 101
Brisco, 42
Brooker, 78
Brooks, 43
Brown, L. N., 39
Brown, S., 156
Bruzzone, 122, 190
Bueno, 44, 99
Bunting, 62

C
Camps-Valls, 31
Canty, 139
Cardille, 46
Castilla, 44, 99
Chabira, 47
Chan, 48
Chao, 49
Charlier, 182
Chasmer, 51, 100
Chellasamy, 52
Chen, Chuqun, 186
Chen, Dongmei, 53
Chowdhury, 54
Chu, 55
Ciancia, 112
Cohen, 158
Colditz, 56

D
D’Oreye, 152
Dalton, 63
Datcu, 59, 60, 73
Davies, 65
de Bruin, 69
De Roeck, 64, 181, 182
De Wulf, 64, 182
Dean, 65
Dech, 110
Decheyne, 64
Del Giorgio, 46
Deschamps, 67, 78
Desclée, 68
DeVito, 51
Devries, 69, 72
Didan, 107
Dip, 169
Dong, 170
Drzewiecki, 30
Ducheyne, 181, 182
Ducrot, 128
Duffe, 144
Dutrieux, 72

E
Espinoza Molina, 73

F
Fallourd, 147
Faruolo, 112
Faur, 73
Fekir, 47, 75
Fensholt, 89
Fernandes, 76, 77
Filella, 176
Filiatrault, 93
Fortin, 118
Franklin, 29
Fraser, 78
Friedl, 132

G
Gómez-Chova, 31
Gann, 81
Gartley, 156
Gavat, 73
Gay, 147
Geldsetze, 84
Geldsetzer, 48, 83, 85
Gerace, 156
Gibbons, 65
Gill, 48, 83, 84, 85
Giroux, 51
Gitelson, 151
Goo, 86, 106
Govind, 87, 88
Goward, 158
Greve, 52
Grogan, 89, 146
Gueguen, 90
Guindon, 49
Guo, 55, 61, 91, 149, 159, 185

H
Haddoud, 75
Halabisky, 92
Hall, 93
Hassan, 54
Hattori, 120
Hawinkel, 96
Hay, 150
He, 98
Hébert, 65
Hemachandran, 150
Hendrickx, 64, 181, 182
Henschel, 67
Herold, 69, 72
Hill, 163, 164
Hird, 44, 99
Hocine, 75
Hopkinson, 51
Hostert, 89, 146, 184
Hu, 38
Huang, 186
Hudak, 101
Hurskainen, 102
<table>
<thead>
<tr>
<th>Name</th>
<th>Page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vaduva</td>
<td>59, 60</td>
</tr>
<tr>
<td>Van Coillie</td>
<td>64, 182</td>
</tr>
<tr>
<td>van der Kooij</td>
<td>42</td>
</tr>
<tr>
<td>van Gorsel</td>
<td>100</td>
</tr>
<tr>
<td>Van Hoolst</td>
<td>167</td>
</tr>
<tr>
<td>Van Orshoven</td>
<td>96</td>
</tr>
<tr>
<td>Van Rompaey</td>
<td>172</td>
</tr>
<tr>
<td>Vanonckelen</td>
<td>172</td>
</tr>
<tr>
<td>Verbesselt</td>
<td>69, 72</td>
</tr>
<tr>
<td>Vercruysse</td>
<td>182</td>
</tr>
<tr>
<td>Verger</td>
<td>176, 177</td>
</tr>
<tr>
<td>Vernier</td>
<td>147</td>
</tr>
<tr>
<td>Voigt</td>
<td>135</td>
</tr>
<tr>
<td>Walpersdorf</td>
<td>147</td>
</tr>
<tr>
<td>Watts</td>
<td>178</td>
</tr>
<tr>
<td>Wawrzaszek</td>
<td>30</td>
</tr>
<tr>
<td>Weichelt</td>
<td>189</td>
</tr>
<tr>
<td>Weiss</td>
<td>176, 177</td>
</tr>
<tr>
<td>White</td>
<td>29, 153</td>
</tr>
<tr>
<td>Whitehead</td>
<td>179</td>
</tr>
<tr>
<td>Wolfe</td>
<td>78</td>
</tr>
<tr>
<td>Woodcock</td>
<td>187</td>
</tr>
<tr>
<td>Wouter</td>
<td>64, 181, 182</td>
</tr>
<tr>
<td>Wulder</td>
<td>29</td>
</tr>
<tr>
<td>Wynne</td>
<td>43</td>
</tr>
<tr>
<td>Xiao, Jianshe</td>
<td>183</td>
</tr>
<tr>
<td>Xiao, Ruixiang</td>
<td>183</td>
</tr>
<tr>
<td>Yackel</td>
<td>48, 83, 84, 85</td>
</tr>
<tr>
<td>Yang</td>
<td>91</td>
</tr>
<tr>
<td>Yin</td>
<td>184</td>
</tr>
<tr>
<td>Yu</td>
<td>61, 185</td>
</tr>
<tr>
<td>Zhang, Bing</td>
<td>53</td>
</tr>
<tr>
<td>Zhang, Juan</td>
<td>183</td>
</tr>
<tr>
<td>Zhang, Ying</td>
<td>49</td>
</tr>
<tr>
<td>Zhang, Yuanzhi</td>
<td>186</td>
</tr>
<tr>
<td>Zhou</td>
<td>77</td>
</tr>
<tr>
<td>Zhu</td>
<td>132, 187</td>
</tr>
<tr>
<td>Zielinski</td>
<td>52</td>
</tr>
<tr>
<td>Zillmann</td>
<td>188, 189</td>
</tr>
<tr>
<td>Xu</td>
<td>183</td>
</tr>
<tr>
<td>Zhang, Ying, Yuanzhi</td>
<td>186</td>
</tr>
<tr>
<td>Zhou</td>
<td>77</td>
</tr>
<tr>
<td>Zhu</td>
<td>132, 187</td>
</tr>
<tr>
<td>Zielinski</td>
<td>52</td>
</tr>
<tr>
<td>Zillmann</td>
<td>188, 189</td>
</tr>
</tbody>
</table>