Spectrodirectional Remote Sensing
From Pixels to Processes

Michael Schaepman
History of Spectroscopy

Sir Isaac Newton (1642-1727)  
Joseph von Fraunhofer (1787-1826)  
Gustav Robert Kirchhoff (1824-1887)  
Robert Wilhelm Bunsen (1811-1899)  
Sir William Huggins (1824-1910)  
NASA MODIS on TERRA 1999

- Spectral dispersion
- Continuous spectrum, interrupted by dark lines
- Explanation of Fraunhofer lines
- Absorption in gas
- Composition of astronomical objects
- First imaging spectrometer in space

Source: Newton, I.: Opticks: or, a Treatise of the Reflexions, Refractions, Inflexions, and Colours of Light, Book I, Plate IV, Part I, Fig. 18, Sam Smith and Benj. Walford, St. Paul's Church-yard, 1704 – Burndy Library
History of Directionality

Leonardo Da Vinci (1452-1519)

Pierre de Fermat 1658

John W. Strutt (Third Baron Rayleigh) 1871

Cox and Munk 1954

Fred Nicodemus 1965

ESA ATSR-1 on ERS-1, 1991

Experimental methods

Geometric optics

‘Rayleigh’ scattering

Hot spot

BRDF

First directional satellite in space

Sources:

Nicodemus, F.: Geometrical Considerations and Nomenclature for Reflectance, NBS Monograph 160, 52 pp., 1977
# History of Spectrodirectional Remote Sensing

<table>
<thead>
<tr>
<th>Year</th>
<th>Platform</th>
<th>Bands</th>
<th>View Angles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1958</td>
<td>V.V. Kolcov</td>
<td>4</td>
<td>2</td>
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<tr>
<td>1991</td>
<td>ESA ATSR-1 on ERS-1</td>
<td>4</td>
<td>2</td>
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<tr>
<td>1996</td>
<td>CNES POLDER on ADEOS</td>
<td>9</td>
<td>var.</td>
</tr>
<tr>
<td>1999</td>
<td>NASA MISR on Terra</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>2001</td>
<td>ESA CHRIS on PROBA</td>
<td>62</td>
<td>5</td>
</tr>
<tr>
<td>2002/03</td>
<td>Gabriela Schaepman-Strub</td>
<td>4 spectral bands</td>
<td>2 view angles</td>
</tr>
</tbody>
</table>


NASA MISR Website, 2004
Quantitative Evolution of Spectrodirectional Research

Source: Internet - Altavista / Google keyword search per year; Citation Database – ISI Web of Science / Scopus search per year

Exclusive keyword match: hyperspectral, BRDF, directional, imaging spectroscopy, imaging spectrometry, spectrodirectional
The Art of Imaging Spectroscopy

Source:
Sol LeWitt, Cubes in Color on Color, 2003, B. Krakow Gallery, USA
Schaepman, M. Lecture notes in imaging spectroscopy, Univ. Zurich, 2002
The Art of Directional Remote Sensing

Source:
Paul Klee, Ueberschach (1937), Kunsthaus Zurich
Beisl, U. (2001), Correction of Bidirectional Effects in Imaging Spectrometer Data, RSL, Univ. Zurich, p. 188
The Art of Spectrodirectional Modelling

Source:
Johannes Itten, Offenbarung (1967), Container Corp., New York
Spectrodirectional Remote Sensing is defined as the simultaneous acquisition of:

- Spatially *coregistered images*,
- In many, *spectrally contiguous bands*,
- At *various observation angles*,
- In an internationally recognized *system of units*

from a remotely operated platform (aircraft, satellite).

Source: NASA MISR; ESA SPECTRA, 2004
Research Agenda: Spectrodirectional Remote Sensing

- Research
- Products / Applications
- Observations by Data Acquisition Systems
- Technology
Research Agenda: Research

- Research
  - Focus on carbon cycle and ecosystems
- Products / Applications
- Observations by Data Acquisition Systems
- Technology
Research – Carbon: Model Divergence

Research – Global Net Carbon Balance

Bars indicate a decade each
Uncertainties are in black

Remote Sensing is particularly good suited to:

- Map spatially distributed phenomena at various scales
  - Ecosystems – Habitats – Plant Functional Groups/Types – Species
  - Continuous fields, such as biophysical and biochemical variables
- Map temporal phenomena
  - Successional stages
- Map spatio-temporally coupled processes
  - Phenology
- Record disturbance
  - Human (land use change), fire, volcanoes

But Remote Sensors must approximate:

- NPP = aNPP (aboveground Net Primary Productivity)
Research – Major Controls on NPP

Abbreviations:
NPP: Net Primary Productivity (Carbon fixed during photosynthesis minus respiration due to plant growth and maintenance)
SOM: Soil organic matter
PAR: Photosynthetically active radiation
Plant Adjustments: Refers to changes in both physiology and biomass allocation
Temperature and moisture not shown, due to impact on almost all parameters

Spectrodirectional Measurements at Pixel Level

Source:
Spectral Field/Laboratory Measurements

Source:
HyEco'04 campaign, Wageningen and Millingerwaard, NL, 2004
CGI course 'Integration of GIS and Remote Sensing', 2004
MERCI programme, Bily Kriz, CZ, 2004
Biochemicals Present in Vegetation Spectra

Source: Schaeppman, M., Koetz, B., Schaeppman-Strub, G., Itten K., Spectrodirectional Remote Sensing for the Improved Estimation of Biophysical and -Chemical Variables: Two Case Studies, JAG, accepted, 2004
Biochemical Compounds of Interest in Vegetation

Decay of a *Ficus benjamina* L. Leaf

Each time step is 10 mins., total duration 8 hrs
Measurement is reflectance plus reflected transmittance

Source:
Decay of *Ficus benjamina* L. in 10 minutes steps over 8 hrs, unpublished
Maximal Spectral Resolution

Source:
Directional Field/Laboratory Measurements

View Angle Dependence of Reflectance Products

MISR Green Spectral Band at 558 nm

Bordeaux – Forest/Croplands
Railroad Valley – Open Shrubland/Grassland

Source:
Research Agenda: Products / Applications

- Research
- Products / Applications
  - Parameters (Variables)
  - Products
  - Processes
- Observations by Data Acquisition Systems
- Technology
## Vegetation Variables (Parameters) of Interest

- **Vegetation spatial distribution and phenology**
  - Fractional vegetation cover (fCover)
  - Leaf Area Index (LAI)
  - Fraction living / dead biomass
  - Canopy structure
  - Vegetation height

- **Vegetation interaction with radiation**
  - Albedo
  - Fraction of Absorbed Photosynthetically Active Radiation (fAPAR)

- **Foliage chemistry and water status**
  - Leaf chlorophyll
  - Leaf water content
  - Leaf dry matter
  - Leaf nitrogen / foliage nitrogen

- **Vegetation energy balance**
  - Foliage temperature (related to stomatal evaporation rate)
  - Soil temperature (related to water stress)
Directionality and Impact on Product Quality

GRVI (non corrected) → BRDF Correction (Class specific Ambrals fit) → Green/Red Vegetation Index Difference → GRVI (corrected)

Source:
Vegetation Variables (Barrax Examples)

Land biosphere models – Processes to be mapped

- Carbon engine
  - $f(CO_2,\ light,\ water\ availability,\ temperature,\ nutrients)$
- Carbon allocation
  - $f(geometry,\ physiology,\ plant\ functional\ type,\ species)$
- “Remineralisation”
  - $f(plant\ functional\ type,\ physiology,\ microbiology,\ molecular\ structure\ (e.g.\ lignin\ vs.\ waxes\ or\ cellulose))$
- Hydrology
  - root depths
- Population dynamics
  - Succession
    - $f(stand\ height,\ stand\ age,\ physiology)$
  - Disturbance
    - $f(climate,\ humans)$

Source: Gloor, M., pers. comm., 2004
Land biosphere models – Processes Supported

- Carbon engine
  - $f(\text{CO}_2, \text{light}, \text{water availability}, \text{temperature}, \text{nutrients})$

- Carbon allocation
  - $f(\text{geometry}, \text{physiology}, \text{plant functional type}, \text{species})$

- “Remineralisation”
  - $f(\text{plant functional type}, \text{physiology}, \text{microbiology}, \text{molecular structure})$
  - (e.g. lignin vs. waxes or cellulose)

- Hydrology
  - root depths

- Population dynamics
  - Succession
    - $f(\text{stand height}, \text{stand age}, \text{physiology})$
  - Disturbance
    - $f(\text{climate}, \text{humans})$
Research Agenda: Observations

- Research
- Products / Applications
- Observations by Data Acquisition Systems
- Technology
Observations by Data Acquisition Systems

- Four categories of sensors
  - Exploratory missions
    - ESA: SPECTRA (1) and APEX (1/2); NASA: ESSP and AVIRIS
  - Technology demonstrators / operational precursor missions
    - ESA: CHRIS/PROBA (2) and APEX (1/2); NASA: Hyperion/EO-1
  - Systematic measurement missions
    - ESA: MERIS/ENVISAT (3); NASA: MODIS/TERRA and on AQUA
  - Operational missions
    - ESA: MSG-1 (4); NASA: NOAA AVHRR

Source:
http://www.esa.int
http://www.apex-esa.org
Research Agenda: Technology

- Research
- Products / Applications
- Observations by Data Acquisition Systems
- Technology
Technology

Integration of GIS and Remote Sensing

- Integrated systems solutions
  - Scalable approaches
  - Integration of multiple data sources
  - Collaborative environments
  - Intelligent distributed systems
  - Quantitative methods
Technology

- Focus on technology shall aim at cost reduction and increase of detectability by smart sensor development

- SensorWeb specifying interoperability interfaces and metadata encodings that enable real time integration of heterogeneous sensor webs into the information infrastructure

Source: http://www.opengeospatial.org
Achievements

- Spectrodirectional Remote Sensing enables biophysical and biochemical variables of the Earth’s surface to be mapped with unprecedented accuracy.

- The particular success is based on improved data quality and wider availability of consistent observations to the user community.

- Significant advances have been made in the quantitative understanding of the interaction of light with matter.
Future

New emerging applications in spectrodirectional remote sensing will focus on

- Transitional zones (Ecotones)
  - Ecosystem, communities, or habitat boundaries (e.g., Tundra – Boreal forest, Forest – heathland, etc.)
- Managed ecosystems
  - Precision appliance
- Unmanaged ecosystems
  - Succession, plant functional types, invasive species
Challenges

- Potential mismatch of spatio-temporal scales of field, airborne and spaceborne measurements, and model requirements
- Spatio-temporal discontinuities in measurements may result in variable data and product quality
- Disturbance processes difficult to capture, due to limited mission duration times and missing backward compatibility
- Convergence to Earth System Sciences
Solution – A Multidisciplinary Curriculum

Soil Science Centre
Erosion and Soil and Water Conservation
Laboratory of Soil Science and Geology
ISRRC – World Soil Information

Centre for Ecosystem Studies
Resource Ecology
Nature Conservation and Plant Ecology
Forest Ecology and Forest Management

Centre for Water and Climate
Soil Physics, Agrohydrology and Groundwater Management
Hydrology and Quantitative Water Management

Centre for Ecosystem Studies
Resource Ecology
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Soil Physics, Agrohydrology and Groundwater Management
Hydrology and Quantitative Water Management

Centre for Water and Climate
Meteorology and Air Quality

Centre for Geo-Information

Centre for Ecosystem Studies
Resource Ecology
Nature Conservation and Plant Ecology
Forest Ecology and Forest Management

Centre for Water and Climate
Soil Physics, Agrohydrology and Groundwater Management
Hydrology and Quantitative Water Management

Centre for Water and Climate
Meteorology and Air Quality

… and certainly our institutional counterparts
Alterra
Plant Research International etc.

WAGENINGEN UNIVERSITY
WAGENINGEN UR
300 years later ...

- Spectral Dispersion of Light
  - Newton 1704
  - APEX 2004
Thank you for your attention!