Global monitoring of Terrestrial ecosystem: challenges and opportunities

Jadunandan Dash

Geography and Environment, University of Southampton, UK

J.Dash@soton.ac.uk
Geography and Environment@soton

- Global Environmental Change and Earth Observation one of the five research group

- Five Academic staffs +1 (advertised) work with Geodata institute, Three research staffs, Seventeen graduate students

- Key research areas ‘development and application of models and algorithms for retrieving information from earth observation data from airborne and satellite platforms, field instrumentation and surveys’
With Contribution from ....

C. Jeganathan, P. Atkinson, B. Ogutu, E.J. Milton,

W. Frampton and F. Vuolo (UoS)

A. Harris (University of Manchester)

T. Lankaster and S. Hubbard (Infoterra Ltd.)

P. Curran (City University)
What is terrestrial Ecosystem?

- Atmosphere
- Biosphere
- Pedosphere
- Lithosphere
- Hydrophere
- Gas exchange
- Evaporation
- Nutrient Exchange
- Leaching
- Sedimentation
- Weathering
- Precipitation
- Runoff
Why study terrestrial Ecosystem?

Terrestrial ecosystems occupy 144,150,000 km$^2$, or 28.2%, of Earth's surface.

On the land the major exchange of carbon with the atmosphere results from photosynthesis and respiration

- To understand regional to global scale environmental phenomena

http://www.esd.ornl.gov/iab/iab2-2.htm
What Remote Sensing offer?

- Inter- and intra-annual global vegetation monitoring on a periodic basis
- Global biogeochemical, climate and hydrological modelling
- Net primary production and carbon balance
- Anthropogenic and climate change detection
- Agricultural activities (plant stress, harvest yields, precision agriculture)

What we could measure?

1. Amount
2. Structure
3. Pigment content (chlorophyll etc.)
What Remote Sensing offer?

- We use individual/multiple bands, but more frequently Vegetation indices.

- Most probably NDVI (Normalised Difference Vegetation Index) is the widely used VI.

- Key sensors for global studies:
  - AVHRR -> longest NDVI time series (issues with Data quality)
  - SPOT VEGITATION-> From 1998, 1km Spatial resolution
  - MODIS-> From 2000, 250m Spatial resolution, NDVI, EVI

Most of the information are on Structure and amount and not on chlorophyll content.
A step change!

- MEdition Resolution Imaging Spectrometer (MERIS) launched 2002 onboard ESA’s ENVISAT

- 15 programmable bands in region of 390-1040nm
- 1150km swath on ground
- 300m, 1.2 km spatial resolution

Position of MERIS standard band setting on a vegetation reflectance spectrum
A chlorophyll Index: Opportunity I

Aim

- Easy to calculate from MERIS data
- Sensitive to wide range of chlorophyll
MERIS MTCI: Opportunity I

- MTCI makes use of the high spectral resolution of the Medium Resolution Imaging Spectrometer to track the position of the Red Edge (Dash and Curran, 2004).

\[
MTCI = \frac{R_{\text{Band 10}} - R_{\text{Band 9}}}{R_{\text{Band 9}} - R_{\text{Band 8}}}
\]

- The magnitude of the MTCI is positively related to the total chlorophyll content.

- This, in turn, is a function of chlorophyll concentration and leaf area index which reflect plant growth and biomass.
MTCI: ESA L2 Product

November-2003

Observed Issues and Recommendations

New L2 products

- Need for defining new L2 land products by fully exploiting the capabilities of the MERIS instrument not available from other sensors.
  - **ESA response:**
    - for the land community at present we have MGV1, NDVI, rectified reflectances at 665 and 865nm, DDV AOT, surface pressure.
    - new **MERIS Terrestrial Chlorophyll Index (MTCI)** will be provided in the L2 product replacing the NDVI.
    - algorithms for experimental MERIS products, i.e. LAI, fraction cover, chlorophyll content, surface reflectance under development; shall be made available in source code under the BEAM software.

- Need for defining new atmospheric L2 products:
  - Aerosol path radiance at 665 nm
  - Particular Matter: PM 10
  - Aktinic fluxes
NRT data distribution

UK-MM-PAF hpg02
Level 3 workstation

UK-MM-PAF Level 3
Internet server

Envisat Rolling Archives

Web connection

DDS receiver

FTP connection

NEODC Web site

EOLI Web client

User’s Web browser
MERIS Terrestrial Chlorophyll Index (MTCI)

Global MTCI in 2003
A chlorophyll Index: Challenge I

• **Calibration**
  The relationship between DN measured at the sensor and the actual geophysical value of the object viewed. Calibration can be absolute or relative.

• **Vicarious calibration**
  Calibration achieved using a method that is independent of that used to establish the primary calibration.

• **Validation**
  The process of assessing, by independent means, the uncertainties of the data products derived from the system outputs (NASA, 2003)
Validation of MTCI: Challenge I

6 Field validation campaigns

- Dorchester, UK (crop) (MERIS, Field)
- New Forest, UK (forest) (MERIS, CASI, Field)
- Campania region, Italy (tree/crops) (MERIS, Rapid Eye, Field)
- Barrax, Spain (Crops) (MERIS, ATM/CHRIS, Field)
- Sicily, Italy (tree/crops) (MERIS, Eagle/Hawk, Field)
- Harwood Forest, UK (Coniferous forest) (MERIS, Eagle/Hawk, Field)
# The process of Validation

**Field data and processing**

<table>
<thead>
<tr>
<th>Issue</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequate sampling scheme</td>
<td></td>
</tr>
<tr>
<td>Crop specific equations</td>
<td></td>
</tr>
<tr>
<td>Relative to absolute Leaf chl</td>
<td></td>
</tr>
</tbody>
</table>

**Issues**

- Leaf Area Index (LAI-2000)
- Relative leaf chl (SPAD)
- Canopy chl content (LAI * Leaf chl)

**VHR multispectral data**

<table>
<thead>
<tr>
<th>Issue</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric correction (GCPs)</td>
<td></td>
</tr>
<tr>
<td>Atmospheric correction (ATCOR)</td>
<td></td>
</tr>
<tr>
<td>Estimation of canopy parameters (model inversion)</td>
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</tbody>
</table>

**Issues**

- Adequate ancillary data for ATM correction
- Model inversion parameterization

**Canopy chl content (LAI * Leaf Chl)**

<table>
<thead>
<tr>
<th>Scale</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESU: 20 x 20 m</td>
<td></td>
</tr>
<tr>
<td>Pixel size 20 x 20 m</td>
<td></td>
</tr>
</tbody>
</table>

**Validation of VHR canopy chlorophyll maps**

**Aggregation of VHR chlorophyll maps**

**Medium and Coarse chlorophyll maps**

<table>
<thead>
<tr>
<th>Scale</th>
<th>Description</th>
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<tbody>
<tr>
<td>ESU: 300 x 300 m</td>
<td></td>
</tr>
<tr>
<td>Pixel size 300 x 300 m</td>
<td></td>
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<tr>
<td>MERIS</td>
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</tbody>
</table>

**Direct calibration and validation procedure at medium resolution**

**If adequate field size**

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<thead>
<tr>
<th>Scale</th>
<th>Description</th>
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<tbody>
<tr>
<td>ESU: 300 x 300 m</td>
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</table>
The process of Validation-1

January 2007

MElis chlorophyll data proves positive

30 January 2007

Scientists have, for the first time, devised and tested a method for correlating spaceborne data derived from Envisat’s MERIS instrument on the amount of chlorophyll present in terrestial vegetation with actual chlorophyll measured in field experiments. Positive correlations further confirm that MERIS is providing an accurate picture of the health our planet.
The process of Validation-2

Campania region, Italy (2009)

RapidEye data, August 2009
The process of Validation

Variability

<table>
<thead>
<tr>
<th>Peach tree</th>
<th>Actinidia</th>
<th>Poplar (biomass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>Artichoke</td>
<td>Poplar</td>
</tr>
</tbody>
</table>

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The process of Validation-2

Aggregation based on MTCI values

\[ y = 0.57x - 0.82 \]
\[ R^2 = 0.92 \]
The process of Validation-2

Aggregation at gridcell level

The process of Validation-2

Aggregation at gridcell level
Applications

Space-time RS data
Phenology from Space: Opportunity II

Leaf Cycle

Chlorophyll  Carotenoids/Xanthophylls  Anthocyanins

Credit: dmlawnca.re.com
Methodology

STEP-1  Data cleaning and flagging

STEP-2  Data smoothing

STEP-3  Temporal base information extraction

STEP-4  Phenological variable extraction
Methodology

MTCI data
(8 day composite)

Dropout Corrected
MTCI data

check & correct noise

Apply Fourier
(inverse with n harmonics)

Fourier Smoothed
MTCI data

Extract base information

1st Derivative

Annual Minimum
(value & week)

Annual Maximum
(value & week)

Peaks
(value & week)

Iteratively search valley points

Is it a local fluctuations?

Yes

No

Phenology Extraction

Dash et al., (2010), RSE, 114, 1388–1402
Results - India

First Growing season
Results - India

Second Growing season
Long term phenology change using GIMMS NDVI data
Climate Impact on Phenology

Initial annual cycle

Altered annual cycle

early spring

delayed fall

January

Jun-Jul-Aug

Mar-Apr-May

Sep-Oct-Nov

December
Mean OG variation (above 45N)

\[ y = -0.1306x + 119.54 \]

\[ R^2 = 0.2049 \]
Mean ES variation (above 45N)

\[ y = 0.1734x + 286.35 \]

\[ R^2 = 0.1928 \]
Onset of Greenness (OG)

End of Senescence (ES)

Degree of Change in OG & ES
Phenology from Space: Challenge II

Inconsistency in Definition

What is start of season?

**Aim:**
- Independent of the study site and phenological pattern
- Can detect multiple annual cycles
- Cycles which spread across calendar years
Phenology from Space: Challenge II
Validation

Ground based
Citizen science, voluntary based, point-to-pixel problem

Satellite based (!)
High spatial resolution data, scaling up, Data availability

Camera based
High spatial (mostly horizontal) and hyper temporal resolution, effect of understorey, dominate foreground
Within the newly created working group structure of the LPV subgroup, a Phenology focus area was initiated in 2010, led by Jeff Morisette of the UGSG Fort Collins Science Center and Jadu Dash of the University of Southampton.

**Phenology Focus Area Objectives**

The newly formed Phenology Focus Group is currently in the process of developing a plan on how to effectively use ground- to airborne-level phenological measurements to validate satellite-based phenology products. This plan will involve an internationally-coordinated remote sensing phenology validation and inter-comparison activity that was initiated at the LPV workshop held following the recent Phenology 2010 Conference at Trinity College in Dublin, Ireland.

**The Challenges**

- Vegetation phenology involves an examination of both a physical signal as well a temporal component
- In situ phenology networks are often making observations that are not directly comparable to the aggregate vegetation response observed via satellite
- Developing a protocol to link ground phenological observations to satellite measurements

**Possible Solutions**

- Ground phenological observations (in situ phenological networks, such as Nature's Calendar and the USA National Phenology Network)
- PAR@METER network (F. Baret)
- Phenological Eyes Network (S. Nagai)
- USA Phenocam Network (A. Richardson)
Ecosystem productivity: Opportunity-III

Ideally, the output of these model’s should match-up to ground data from validation sites.
Ecosystem productivity: Challenge-III

- One of the possible sources of uncertainties in the PEM models may be due to misrepresentation of FAPAR (an important input into the models)

- Current FAPAR products represent the whole canopy FAPAR

- Canopy composed of photosynthetic and non-photosynthetic components
Canopy chlorophyll content is a very direct expression of the photosynthetic apparatus of a plant community and may be strongly related to productivity and net photosynthesis (Medina and Leith, 1964)

The potential of the MERIS Terrestrial Chlorophyll Index for carbon flux Estimation (Harris and Dash, 2010)

Remote estimation of gross primary production in maize and support for a new paradigm based on total crop chlorophyll content (Peng et al, 2011)
Ecosystem Productivity

Temporal variation

[Graphs showing temporal variation of GDP, MTCl, GPP, and EVI for Willow Creek and Bondville]
Ecosystem Productivity

- **Deciduous Sites**
  - Willow Creek
  - Harvard Forest
  - Lost Creek
  - Bartlett
  - Missouri Ozark

- **Cropland Sites**
  - Bondville
  - Mead Rainfed
  - Mead Rotation

The graphs show the relationship between GPP (g cm⁻² day⁻¹) and MTCI, EVI, and MODIS GPP for different sites.
Conclusions

- MERIS MTCI is only product available operationally to estimate canopy chlorophyll content globally.
- More than 8 years of global data now available.
- MTCI has a strong phonological signal and links well with data from Flux tower and has potential for estimation of global GPP.
- Can be used as a complementary to other biophysical products for global scale application.

Thank you