Assimilating terrestrial remote sensing data into carbon models: Some issues

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Development of Carbon Cycle Data assimilation system

Georeferenced emissions inventories

Atmospheric measurements

Remote sensing of Atmospheric CO2

Optimized Fluxes

Optimized model parameters

Data assimilation link

Climate and weather fields

Ocean time series

Biogeochemical pCO2

Surface observation pCO2 nutrients

Water column inventories

Ocean remote sensing

Ocean colour
Altimetry
Winds
SST
SSS

Ocean carbon model

Coastal studies

Terrestrial carbon model

Rivers

Lateral fluxes

Remote sensing of Vegetation properties

Growth Cycle
Fires
Biomass
Radiation
Land cover/use

Eddy-covariance flux towers

Biomass soil carbon inventories

Ecological studies

Ciais et al. 2003 IGOS-P Integrated Global Carbon Observing Strategy
Remote Sensing Technologies

- Multispectral
- Hyperspectral
- RADAR / SAR
- Thermal
- Atmospheric LIDAR
- Surface LIDAR
- Passive Microwave
- RADAR Altimetry
- Limb Sounding
- Microwave Ranging
- Irradiance/Photometry
- Scatterometry
Terrestrial remote sensing products for C studies

- Land cover & land use
- Leaf area index (LAI) & FPAR
- Vegetation indices (e.g., NDVI) & phenology
- Incident PAR
- Canopy height
- Foliage nitrogen
- Forest age class
- Biomass
- Fires, disturbances
MODIS Anisotropy and Albedo

White sky albedo April 2004

C. Schaaf, Boston University
MODIS Terra 8-day FPAR (185-192.2000)

Collection 5

Collection 4

R. Myneni, Boston University
Leaf type

% broadleaf

% needleleaf

Leaf longevity

% deciduous

% evergreen

MODIS product, John Townshend at University of Maryland
Production Efficiency Principles:

\[ GPP = \varepsilon_g \cdot f\text{PAR} \cdot \text{PAR} \]

\[ NPP = \varepsilon_n \cdot f\text{PAR} \cdot \text{PAR} \]

Grid cell level regression of net primary production (NPP) (kg C yr\(^{-1}\) m\(^{-2}\)) against absorbed photosynthetically active radiation (APAR) (GJ yr\(^{-1}\) m\(^{-2}\))

Cramer, et al., 1995, Net primary productivity model inter-comparison activity, IGBP/GAIM report series 5
Incident direct & diffuse PAR from MODIS

• The increasing availability of spatial data and the growing interest in quantifying terrestrial carbon flux have driven rapid progress in the integration of modeling and remote sensing.

• Most studies use remote sensing data to drive models.

• Few studies integrate terrestrial remote sensing and carbon models through data assimilation at the regional scales.
Many C studies have used remote sensing products as inputs.

Radiometric information
(reflectance/radiance or Vegetation indices)

Model state variable
(e.g., LAI)

Inversion model
(physical model or empirical relationship)

estimated LAI profile

Carbon process model
Few studies are assimilating terrestrial remotely sensed products into carbon models spatially.
Two data assimilation schemes

Remote sensing data → Estimation Algorithms → LAI → Carbon Model

- Adjust model parameters
- Minimization

method (A)

Observation operator: Radiative transfer models → Carbon model → Time

Remote sensing data → Minimization → Adjust model parameters

method (B)
Surface energy balance estimation

- The objective is to assimilate land surface temperature (LST) from remote sensing to a land surface model to estimate latent heat and sensible heat.
Coupled model

- Canopy radiative transfer model: Kuusk Markov reflectance model
- Leaf optical model: PROSPECT
- DSSAT crop growth model produces LAI, leaf nutrition -> leaf chlorophyll -> leaf optics

Fig. 3. (a) A sample time series of MODIS EVI data and the estimated phenological transition dates for a corn pixel in Indiana, 2000. (b) The LAI products.
Fig. 4. Comparison of the simulated corn yield and USDA NASS yield data for selected counties (43) in Indiana, 2000. (a) S1 (LAI); (b) S2 (EVI); (c) S3 (NDVI); (d) S4 (EVI+LAI); (e) S5 (NDVI+LAI).
Data Issues

- Since the number of unknowns $\gg$ number of observations, remote sensing inversion is always an ill-posed problem.
- Although extensive validation efforts have been made, product uncertainties have not well characterized.
- It is difficult to define the error matrix in the cost function.

Validation of MODIS leaf area index (LAI) collection-4 product
Data Issues

Remotely sensed products are not continuous in space and time due to cloud contamination and other factors.

Data Issues

- Multiple satellite sensors are producing the same product with variable accuracies, spatial and temporal characteristics
- The instrument teams continuously update the versions of their products
- It makes the user difficult to select

Fig. 2, Mean and variance of 2003 LAI of four cover types from MODIS (collection 4), VGT (Version 3.1) and MISR (Version 3) products over North America. Note that the MISR LAI product is systematically higher.
Fraction of the absorbed PAR by the green vegetation (FPAR) products

<table>
<thead>
<tr>
<th>Product</th>
<th>Spatial resolution (km)</th>
<th>Temporal resolution (day)</th>
<th>Time coverage</th>
<th>Reference</th>
</tr>
</thead>
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<tr>
<td>MOD15</td>
<td>1</td>
<td>8</td>
<td>2000-</td>
<td>Knyazikhin et al., 1999</td>
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<td>2000-</td>
<td>Knyazikhin et al., 1998</td>
</tr>
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<td>1997-2003</td>
<td>Bacour et al., 2006</td>
</tr>
<tr>
<td>MERIS</td>
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<td>daily</td>
<td>2002-</td>
<td>Gobron et al., 1999</td>
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<tr>
<td>SeaWiFS</td>
<td>1.5</td>
<td>1/10/30</td>
<td>1997-2004</td>
<td>Gobron et al., 2006c</td>
</tr>
</tbody>
</table>
Other data issues

• Data products may not have the consistent spatial and temporal resolutions, upscaling and downscaling often cause problems;

• The generated remotely sensed products may not be consistent with what the model defines
  – Remotely sensed skin temperature is an average measure of the mixed pixel, while many models define leaf/soil sunlit/shadow temperatures
  – Some models calculate NDVI above the canopy, but many remotely sensed NDVI products are calculated from the top of the atmosphere

• The volume and format (e.g., HDF, map projections) of the products may be very challenging to many users
Final remarks

• NDVI is not everything, and remote sensing can produce much more than just NDVI
• Interactions between remote sensing scientists and carbon modelers are critical
• Joint activities to bridge the disciplines, for example, joint workshops, training classes, joint textbooks, joint research projects…
Thank you!