Advances in the Remote Sensing of Terrestrial Vegetation and the Development of a Predictive Science of the Biosphere

Paul R. Moorcroft
The Greening of Global Climate Models

SiB Terrestrial Biosphere model (Sellers 1986)
The Greening of Global Climate Models

SiB2 Terrestrial Biosphere model (Sellers 1996)
The 1st generation of terrestrial biosphere models captured biophysical biosphere-atmosphere feedbacks

CLIMATE & CO₂

VEGETATION PHYSIOLOGY AND BIOPHYSICS
minutes to hours

VEGETATION PHENOLOGY
days to weeks

SOIL HYDROLOGY
minutes to hours
Satellite-Derived Predictions of Terrestrial Carbon, and Water Fluxes and its impact on Atmospheric CO2 Concentrations

(Sellers et al. 1997)

Fig. 4. Global fields used in or generated by a third-generation LSP. (A) Global field of FPAR calculated from AVHRR SVI data (Eq. 9). (B) Canopy transpiration and (C) canopy net photosynthetic productivity (NPP, in grams of carbon per square meter) calculated by a third-generation LSP from within an AGCM, using the FPAR field shown in (A) (8436). (D) Annual mean CO2 concentration in the planetary boundary layer (55).
Mission to Planet Earth (MTPE)

MTPE Website (1997): “NASA's Mission to Planet Earth (MTPE) is dedicated to understanding the total Earth system and the effects of natural and human-induced changes on the global environment.”

Earth Observing System (EOS) (Feb. 2015)
Moderate Resolution Imaging Spectrometer (MODIS)

Aboard: Terra (EOS AM-1, launched December 1999), & Aqua (EOS PM-1, launched May 2002)

MODIS-derived Estimates of Leaf Area Index (LAI)

- MODIS-derived estimates of surface albedo
The 1st generation of terrestrial biosphere models captured biophysical feedback processes. DGVMs incorporate the effects of long-term ecosystem change and thus incorporate both biophysical and biogeochemical feedback mechanisms.
- because of feedbacks onto the atmosphere, the response of the terrestrial biosphere to changes in climate is one of the largest sources of uncertainty for the amount of climate change that will occur over the coming century.
2nd Generation Dynamic Global Vegetation Models (DGVMs)

DGVMs incorporate the effects of long-term ecosystem change and thus incorporate both biophysical and biogeochemical feedback mechanisms.

**CLIMATE & CO₂**

**VEGETATION DYNAMICS**
(Changes in composition & structure)
years to many decades

**SOIL BIOGEOCHEMISTRY**
years to many decades

**VEGETATION PHENOLOGY**
days to weeks

**SOIL HYDROLOGY**
minutes to hours

**VEGETATION AND**
minutes

DGVMs incorporate the effects of long-term ecosystem change and thus incorporate both biophysical and biogeochemical feedback mechanisms.
What role can NASA’s Earth Observing System (EOS) play in constraining dynamic global vegetation model predictions for the fate of the terrestrial biosphere over the coming century?
DGVMs incorporate the effects of long-term ecosystem change and thus incorporate both biophysical and biogeochemical feedback mechanisms.
Using Remote Sensing Measurements to Estimate Ecosystem Composition, Structure, and Function

- AVIRIS Spectrometer
- Lidar Waveform
- spectral ratios
- Canopy Gap Profile
- Leaf Area Index Profile
- CANOPY COMPOSITION
- CANOPY STRUCTURE
- ED2 Terrestrial Biosphere Model
- Meteorological Forcing

(Antonarakis et al. 2014)

Spectral mixture analysis
Leaf traits and Canopy Allometry
Ecosystem Carbon Fluxes
Estimated Sub-Grid Scale Ecosystem Composition, Structure, and Carbon Fluxes at Harvard Forest LTER site

(Antonarakis et al. 2014)
Results: Composition and Structure at 3 Harvard Forest Flux-tower sites

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<tr>
<th>REMOTE SENSING-BASED</th>
<th>GROUND-BASED</th>
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(Antonarakis et al.)

*Plant Functional Types*
- Early Conifers
- Late Conifers
- Early hardwoods
- Mid hardwoods
- Late hardwoods
Seasonal Patterns of Carbon Fluxes (2003-2009)

EMS  LPH  HEM

(Antonarakis et al.)
Yearly Carbon Fluxes (2003-2009)

G = ground-inventory initialized  RS = remote sensing initialized  PV = potential vegetation

(Antonarakis et al.)
DGVMs incorporate the effects of long-term ecosystem change and thus incorporate both biophysical and biogeochemical feedback mechanisms.
MODIS Derived Estimates of Burned Area Obtained from the Global Fire Emissions Database, Version 3 (GFEDv3.1)

Giglio et al. 2010
Landsat TM-derived estimates of disturbance frequency
DGVMs incorporate the effects of long-term ecosystem change and thus incorporate both biophysical and biogeochemical feedback mechanisms.
AIRMOSS EV
Walnut Gulch, AZ Subsurface Retrievals
L2/3-RZSM From Radar data 9/20/2012

Surface soil moisture

soil moisture @ -10 cm

soil moisture @ -30 cm

soil moisture @ -75 cm

The Global Ecosystem Dynamics Investigation (GEDI)

Lidar-Based Vegetation structure sampling mission

PI: R Dubayah (UMD/GSFC)

Water stress is quantified by the Evaporative Stress Index, which relies on evapotranspiration measurements.

Evapotranspiration!

Stomata close to conserve water!

Evaporative Stress Index

Water Stress Threatens Ecosystem Productivity

Water Stress Drives Plant Behavior

Aug 2012

High Water Stress

Low Water Stress

Evapotranspiration!

Stomata close to conserve water!

6 AM 12 PM 6 PM

Thermally-based measurements of Plant Water Stress

PI: Simon Hook (JPL)
Remote Sensing Measurements of Ecosystem Structure

Above-Ground Biomass estimation from TanDEM-X (X-band InSAR) at Tapajos National Forest Brazil

InSAR Coherence from TanDEM-X over a 47km x 18km box of the Tapajos National Forest. The center of the image is at 3.0114°S and 54.9900°W. The white dots indicate the locations of the 30 sites. Coherence scale is indicated, along with true north. The spacecraft trajectory points downward, parallel to the long side of the box.

Treuhaft et al. (2014)
Orbiting Carbon Observatory (OCO-2)
Laser-guided Spectroscopy
Asner, Martin et al. Carnegie Airborne Observatory

High functional diversity  Low functional diversity
HyspIRI Preparatory Airborne Science Mission

Estimates of ecosystem composition obtained from imaging spectrometry (Bogan et al. unpublished)

Remote Sensing Measurements of Ecosystem Composition
Conclusions

- The current and planned NASA Earth Observation System (EOS) has a high potential to constrain Dynamic Global Vegetation Model (DGVM) predictions for the fate of the terrestrial biosphere over the coming century.

From the MTPE Website (1997): “MTPE addresses the fundamental question: How can we utilize the knowledge of the Sun, Earth, and other planetary bodies to develop predictive environmental, climatic, natural disaster, and natural resource models to help ensure sustainable development and improve the quality of life on Earth?”
Acknowledgements

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**References:**

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