Integrating remote sensing with ecosystem modeling at multiple scales

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Driving ecosystem models with satellite data, concept for NASA Global Habitability, 1983

Figure 2. Organizational diagram of a proposed model of net primary production for a coniferous forest. All driving variables are derived from satellite data. Potential linkages to a global carbon model are shown by dashed lines (Running, 1984).
NDVI Related to Photosynthesis

- Running and Nemani 1988
Original FOREST-BGC flow diagram, emphasizing dual time steps, critical role of LAI, C-H2O-N interactions, and remote sensing applications, 1988

Figure 1.2. Compartment flow diagram for the FOREST-BGC ecosystem simulation model. This diagram illustrates the state variables of carbon, water, and nitrogen, the critical mass flow linkages, the combined daily and annual time resolution, and the daily meteorological data required for executing the model. The major variables and underlying principles associated with the model were developed specifically for application at multiple time and space scales, and for compatibility with remote-sensed definition of key ecosystem properties.
First spatial ecosystem model driven by remote sensing

GEOSS
(Global Earth Observation System of Systems)

Earth System Models
- Oceans
- Cryosphere
- Land
- Atmosphere
- Solid Earth
- Biosphere

Prediction and Analysis
High Performance Computing; Communication Visualization

Decision Support
- Assessment
- Decision Support Systems

Policy Decisions
Management Decisions

Ongoing feedback to optimize value, reduce gaps, and account for human activity

Earth Observation Systems
- In Situ
- Airborne
- Space-based

Other Data Sources
Socio-economic data

Assimilation

Standards & Interoperability Observations

9 Societal Benefit Areas
Health  Energy  Climate  Water  Weather  Ecosystems  Agriculture

Disasters

Biodiversity
Terrestrial Carbon Monitor

SATTELITE DATA

LANDCOVER

GROWING SEASON

PRIMARY PRODUCTION

GROUND DATA

FLUXNET CONFIGURATION

Harvard Forest

CO₂ Flux Density (gC m⁻² d⁻¹)
DYNAMIC GLOBAL LAND TRANSITIONS

LANDUSE
[Human control]

LANDCOVER
[Biophysically controlled]

Human Systems
- Institutions
- Culture
- Technology
- Population
- Economic

HUMAN DECISION MAKING
political/economic choices

Ecological Systems
- Biogeochemistry
- Genetic bank
- Water
- Air

Economic Problems
- poverty
- unequal wealth
- war
- globalization

Ecological Problems
- pollution
- diseases
- food/fibre/fuel shortages
- overcrowding

Ecosystem goods & services
- clean air/water
- waste recycling
- food/fibre/fuel
- recreation
GLOBAL Generalized Disturbance Index

\[ DI_{LST/EVI} = \frac{LST_{\text{max}}}{LST_{\text{mean max}}} \times \frac{EVI_{\text{max}}}{EVI_{\text{mean max}}} \]

Mildrexler et al. 2006
MOD12Q2: Global Vegetation Phenology

From Mark Friedl, Boston Univ.

First global products for vegetation phenology based on MODIS EVI data released for 2001-2004
- Identifies key transition dates in growing season
Map (a) of the statistical correspondence ($r^2$) between growing season 8-day composite MODIS LAI (MOD15A2) and SeaWinds Ku band backscatter for January 2000 through August 2002 for North America. Statistical correspondence is lower where LAI seasonal variability is small (e.g., evergreen forests) and where biomass is low (arid and semiarid shrublands). The combined information from MODIS and SeaWinds may provide an improved measure of vegetation phenology that is less constrained by atmospheric aerosol contamination (e.g., clouds, smoke) and solar illumination effects.

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GEOSS Standards & Interoperability Management

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GEOSS
Potential climate limits to plant growth derived from long-term monthly statistics of minimum temperature, cloud cover and rainfall.

Water = 40%, Temperature = 33%, Radiation = 27%

Nemani et al., Science June 6th 2003
Global Effective Growing Season Length

Legend
Effective Growing Season Length (days)
- High: 363.859436
- Low: 0.000000

Jolly, Nemani, Running. Global Change Biology 2005
Seasonal Growing Season Constraints

Russia, Boreal

Africa, Savannah

Jolly, Nemani, Running. Global Change Biology 2005
Architecture of Global/Regional Flux Networks

Global Network

Regional Networks

AmeriFlux
EUROFLUX
MedeFlu
JapanNet
OzNet

Tower Sites

Data Users

Under development

Non-network Sites

Data Users

Networks:
- AmeriFlux
- EUROFLUX
- MedeFlu
- JapanNet
- OzNet

Maps show distribution of network sites globally.
GPP = Light X Conversion Efficiency

GPP = f (PAR) x $\varepsilon$

Biome Properties Look-Up Table ($\varepsilon_{\text{max}}$)

GPP

fPAR, PAR

Temperature

VPD
FLUX TOWER BASED VALIDATION FOR MODIS GPP/NPP

SPACE

EOS - APAR + Global Climate
Satellite GPP/NPP

Global Climate Validation

EOS algorithm validation
Flux Scaling

SVAT Simplification
Validation

BGC Model + Tower Climate
Modeled GPP, NPP, NEE, ET

SVAT Simplification
Validation

BGC Model Validation

TOWER CLIMATE

Flux tower + Tower Climate
Measured NEE, ET
Derived GPP, NPP

TOWER CLIMATE

APAR logic validation

TIME
MODIS GPP Validation with Fluxnet

Tundra, Barrow, Alaska

Evergreen Needleleaf Forest, Niwot Ridge, CO

Chaparral, Sky Oaks, CA

Mixed Forest, Park Falls, WI

GPP (gC m$^{-2}$ d$^{-1}$)

Julian Day

GPP (gC m$^{-2}$ d$^{-1}$)

Julian Day

GPP (gC m$^{-2}$ d$^{-1}$)

Julian Day

GPP (gC m$^{-2}$ d$^{-1}$)

Julian Day

MODIS

Tower

MODIS w/Tower Met
Erosion and organic matter transport

Carbon-containing pollutant transport: 10s-1000s of km

Downslope flows and subsequent venting of CO$_2$

Wildfire source

Footprint

Upwind Profiles

Wind

Downwind Profiles

Aquatic NEE

Floating chamber

Soil Chamber

CH$_4$

VOC

CO

Biogenic source

Missoula: Urban source

Wind

VOC

CO

CO$_2$

Wildfire source
Uncertainties from Algorithm and BPLUT

- Assume ratio of NPP:GPP = 0.47 across all biomes (Waring et al., 1998)

- Large algorithm uncertainty is in estimating respiration coefficients
Grassland, Vaira Ranch, CA, 2001

MODIS GPP = 1134.86 gC m\(^{-2}\)  
Tower GPP = 776.37 gC m\(^{-2}\)  
Biome-BGC GPP = 614.64 gC m\(^{-2}\)

GPP (gC m\(^{-2}\) d\(^{-1}\))

MODIS
Tower
Biome-BGC

Julian Day
Seasonal Light Use Efficiency

![Graph showing seasonal light use efficiency with two lines representing M-ENF and M-EBF.](image)

**X-axis:** Month

**Y-axis:** RUEmax [gC/MJ APAR]

**Legend:**
- M-ENF
- M-EBF
Dynamic recalibration of satellite GPP algorithm with flux tower data

\[ \text{GPP} = f(\text{PAR}) \times \varepsilon_{\text{max}} \]

recompute monthly
$LUE_{\text{max}}$ estimates by PFT versus $LUE_{\text{max}}$ in BPLUT
Sensor webs

A sensor web is a coherent set of distributed “nodes”, interconnected by a communications fabric, that collectively behave as a single, dynamically adaptive, observing system.
GEOSS - Integrated Biospheric Monitoring concept for Global GPP

GPP = \( f \text{(PAR)} \times E_{\text{max}} \)

recompute monthly
NEWSFOCUS

Budget, technical, and administrative problems continue to plague a fleet of U.S. polar satellites being built for the military, weather forecasters, and climate researchers.

Stormy Skies for Polar Satellite Program

With more uses than a Swiss Army knife, the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) was supposed to be the world's most sophisticated series of weather satellites. But somewhere in its 12-year history, the multibillion-dollar NPOESS has also become one of the country's most troubled technology projects. Next week, the Pentagon will issue binding plans on how to fix the project now behind schedule and massively over budget. The expected overhaul could shape for decades how well U.S. forces prepare for battle, civilian authorities anticipate killer storms, and scientists understand Earth's ever-changing climate.

Since the 1960s, the U.S. Department of Defense and the National Oceanic and Atmospheric Administration (NOAA) have used separate north-south orbiting satellite systems to provide daily global weather coverage and crucial midday forecast data. In 1994, President Bill Clinton proposed to merge those systems into a $8.5 billion program that is set to cost an estimated $1.8 billion over its lifetime. The system would pack 14 sensors—half of them new—onto three 7-meter-long craft, each equipped with a quantum leap over decades-old NOAA and Pentagon polar systems. “We have made major strides to converge military and civilian weather requirements,” Air Force Maj. Gen. Robert Dickman told Congress in 1995.

But now, more than a decade later, technical problems on one of the sensors have rippled through the program and pushed estimated cost overruns into the billions of dollars. As currently configured, the system is as much as 3 years behind schedule and carries, by the Pentagon's latest estimate, a lifetime price tag of $14 billion (see graph). The overrun triggered an automatic top-to-bottom review, which the Secretary of Defense is set to present to lawmakers next week.

The delay could leave U.S. forces without the best data on sandstorms or ocean currents, military planners wary, and to mention a possible weakening of civilian weather coverage if there are problems with a NOAA satellite scheduled to be launched in 2007. What the Government Accountability Office (GAO) calls “a program in crisis” is really the “mellowness of America,” according to Representative Bart Gordon (D-TN), ranking Democrat on the House Science Committee, who wants NOAA Administrator Conrad Lautenbacher to resign for ignoring what Gordon says were clear warning signs about NPOESS. “This is a program that is being debated by a thread,” says one congressional aide who follows the project.

NPOESSing a challenge

Polar satellites are wonderfully useful because their 106-minute orbits provide coverage of nearly every point on Earth. But their attractiveness didn’t forge an automatic alliance between defense and research bureaucrats operating in two different cultures. “NOAA looked at the Air Force and said, ‘Huh, geosynchronous junk,’ ” and the Air Force looked at NOAA and said, “Fish-killing tree huggers,” said former program manager John Cunningham at a 2003 briefing on the project.

Their needs were different as well. The Pentagon wanted sensors with high resolution and speedy delivery of the data, whereas NOAA sought instruments with a multitude of spectral bands for weather research. NASA agreed to join in, canceling planned follow-ons for environmental missions while selling environmental and climate sensors to the NPOESS fleet after its scientists lusted after the chance to use systems whose sequential platforms will stay aloft for 20 years rather than the usual 5-year windows.

“I thought [NPOESS] was the right thing to do, and in some ways, the only way to do it,” says biogeochemical modeler Bernard Moore of the University of New Hampshire, Durham, who has long advised the government on behalf of the climate community.

The initial cooperation went “surprisingly well,” says the Navy’s Robert Winsor, then head of NOAA’s satellite program. The package would include everything from an ozone detector to a device for aerosol studies (see graphic, p. 1297). The microwave imager would provide more channels for detailed moisture profiles than existing instruments. And the Visible/Infrared Imager Radiometer...
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