Terrestrial Observation and Prediction System: Development of a Biospheric Nowcast and Forecast Capability

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Collaborators:

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Ecological modeling workshop, Asilomar, CA
Turning Observations Into Knowledge Products

**Downlink Speed**

- **Petabytes $10^{15}$**
  - Multi-platform, multiparameter, high spatial and temporal resolution, remote & in-situ sensing

- **Terabytes $10^{12}$**
  - Calibration, Transformation to Characterized Geo-physical Parameters

- **Gigabytes $10^9$**
  - Interaction Between Modeling/Forecasting and Observation Systems

- **Megabytes $10^6$**
  - Interactive Dissemination and Predictions

**Advanced Sensors**

- [Image: Advanced Sensors]

**Data Processing & Analysis**

- [Image: Data Processing & Analysis]

**Information Synthesis**

- [Image: Information Synthesis]

**Access to Knowledge**

- [Image: Access to Knowledge]
GOAL

The project goal is to develop a data and modeling system that enables operational production of biospheric nowcasts and forecasts of ecosystem states and functions,

such that management strategies and options can be developed to prevent or reverse declining trends, reduce risks, and to protect important ecological resources and associated processes.
Objectives

• using internet as a backbone, develop a modeling framework for integrating satellite data, surface meteorology and ecosystem models,

• verify model results and perform hindcasts to produce historical normals for ecosystem states and functions,

• develop a near-realtime ecosystem analysis methodology for nowcasting ecosystem states and functions,

• explore opportunities of forecasting ecosystem behavior at various lead times.
Need for integration

- Integration of remote sensing, surface meteorology, and ecological models provides the best opportunity for comprehensive assessment of the state and activity of landscape processes.
- Disciplines are traditionally separate but can be highly complementary.
Terrestrial Observation and Prediction System

Key elements:
Monitoring
Modeling
Forecasting

Monitoring & Forecasting
Stream flow, soil moisture, phenology, fire risk, forest/range/crop production

Weather Networks
Temperature/rainfall/radiation/humidity/wind

Orbiting Satellites
Terra/Aqua/Landsat/Ikonos
Landcover/change, Leaf area index, surface temperature, snow cover and cloud cover

Ancillary Data
Topography, River networks, Soils

Ecosystem simulation models

Weather & Climate Forecasts
Large Data Flows: Extracting Knowledge from Petabytes of Data

NASA EOS Satellites

Observing Networks

Weather, soil moisture, streamflow etc.,

NASA EOS Satellites

Ancillary Data
Topography, River Networks, Soils, Biodiversity . . .

TOPS Architecture

Simulation Models
Biospheric models for ecological monitoring & forecasting

IMAGEbot Planner
Optimizes data processing plans and retrieves appropriate data for analyses

Causal Discovery
Autonomous analysis of data for discovery of novel causal models; integrated with TOPS for model validation

Knowledge: 100K to 10 MB
Nowcast / forecast maps, integrated datasets, images, and causal models

~3 TB/day

100 MB/day

.1 - 10 TB

.1 - 10 TB

250+ products, > 3.5 petabytes

Massive data sets, multiple products, heterogeneous data types.

Nowcast / forecast maps, integrated datasets, images, and causal models
Criteria for system evaluation:

Effort required to do

• new geographic area
• integrate a new sensor or a new data source
• integrate a new model
• adapt to a new domain
• allow measurement of improvements from new data sources or models.
Retrospective to real time gridding climate data

Data Retrieval

Unattended

Modular

Data Retrieval and Processing

Scheduler

SQL Database

Storage

Interpolation

Interpolation Logic

Prediction Control

Ancillary Inputs

Crossvalidation Statistics

Observations (X,Y,Z,R)

Prediction Points ([X,Y],[Z,R])

Interpolation Logic

Prediction (Rd)

Output Handling

Output

Tmax / Tmin
VPD, precipitation
Solar radiation
Daylength

Terra Launch on December 18, 1999
First Image: Feb. 24, 2000

Aqua Launch on May 4, 2002
First Image: June 24, 2002

Retrospective to real time
Operational remote sensing
<table>
<thead>
<tr>
<th>MOD01</th>
<th>Level-1A Radiance Counts</th>
<th>MOD23</th>
<th>Suspended-Solids Conc, Ocean Water</th>
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<tbody>
<tr>
<td>MOD02</td>
<td>Level-1B Calibrated Relocated Radiances</td>
<td>MOD24</td>
<td>Organic Matter Concentration</td>
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<tr>
<td></td>
<td>-also Level 1B “subsampled” 5kmX5km product</td>
<td>MOD25</td>
<td>Coccolith Concentration</td>
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<tr>
<td>MOD03</td>
<td>Relocation Data Set</td>
<td>MOD26</td>
<td>Sea Surface Temperature</td>
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<td>MOD04</td>
<td>Aerosol Product</td>
<td>MOD27</td>
<td>Sea Ice Cover</td>
</tr>
<tr>
<td>MOD05</td>
<td>Total Precipitable Water</td>
<td>MOD28</td>
<td>Sea Ice Cover</td>
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<tr>
<td>MOD06</td>
<td>Cloud Product</td>
<td>MOD29</td>
<td>Sea Ice Cover</td>
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<td>MOD07</td>
<td>Atmospheric profiles</td>
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<td>Monitoring Attributes Data Set</td>
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<td>Grided Atmospheric Product (Level-3)</td>
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<td>MOD09</td>
<td>Atmospherically-corrected Surface Reflectance</td>
<td>MOD32</td>
<td>Processing Framework &amp; Match-up Database</td>
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<td>Snow Cover</td>
<td>MOD33</td>
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<td>MOD11</td>
<td>Land Surface Temperature &amp; Emissivity</td>
<td>MOD34</td>
<td>Processing Framework &amp; Match-up Database</td>
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<tr>
<td>MOD12</td>
<td>Land Cover/Land Cover Change</td>
<td>MOD35</td>
<td>Cloud Mask</td>
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<td>MOD13</td>
<td>Vegetation Indices</td>
<td>MOD36</td>
<td>Total Absorption Coefficient</td>
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<td>MOD14</td>
<td>Thermal Anomalies, Fires &amp; Biomass Burning</td>
<td>MOD37</td>
<td>Ocean Aerosol Properties</td>
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<tr>
<td>MOD15</td>
<td>Leaf Area Index &amp; FPAR</td>
<td>MOD38</td>
<td>Ocean Aerosol Properties</td>
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<td>Surface Resistance &amp; Evapotranspiration</td>
<td>MOD39</td>
<td>Clear Water Epsilon</td>
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<td>MOD17</td>
<td>Vegetation Production, Net Primary Productivity</td>
<td>MOD40</td>
<td>Albedo 16-day L3</td>
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<td>MOD18</td>
<td>Normalized Water-leaving Radiance</td>
<td>MOD41</td>
<td>Albedo 16-day L3</td>
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<td>MOD19</td>
<td>Pigment Concentration</td>
<td>MOD42</td>
<td>Albedo 16-day L3</td>
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<td>MOD20</td>
<td>Chlorophyll Fluorescence</td>
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<td>Chlorophyll_a Pigment Concentration</td>
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<td>Vegetation Cover Conversion</td>
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<td>MOD22</td>
<td>Photosynthetically Active Radiation (PAR)</td>
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<td>Vegetation Cover Conversion</td>
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<td>MOD48</td>
<td>Vegetation Cover Conversion</td>
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</tbody>
</table>
Examples of operational MODIS products
Standard TOPS outputs

**MODIS PRODUCTS (8 days/Annual)**
1. LAI
2. FPAR
3. GPP/NPP*
4. LST-TERRA/AQUA
5. NDVI
6. EVI
7. LANDCOVER/Cont Fields*
8. ALBEDO
9. SNOW
10. FIRE

**METEOROLOGY (Daily)**
11. MAX TEMPERATURE
12. MIN TEMPERATURE
13. RAINFALL
14. SOLAR RADIATION
15. DEW POINT/VPD
16. DEGREE DAYS

**TOPS-NOWCASTS (daily)**
17. TOPS-SNOW
18. TOPS-SOIL MOISTURE
19. TOPS-ET
20. TOPS-OUTFLOW
21. TOPS-GPP/NPP
22. TOPS-PHENOLOGY
23. TOPS-VEG STRESS

**TOPS-ForeCASTS (5 days to 180 days)**
24. BGC-LAI/PHELNOLOGY
25. BGC-SOIL MOISTURE
26. BGC-OUTFLOW
27. BGC-ET
28. BGC-VEG STRESS
29. BGC-SNOW
30. BGC-GPP/NPP

**Applications:**

Earthwatch - NPP Anomalies
Mapping fire risk at continental scales
Water resources monitoring
Modeling in viticulture
  Irrigation requirements
  Climate-Wine
Net Primary Production

NPP is the balance between photosynthesis and respiration by plants

A substantial incentive to understand trends and variability in terrestrial Net Primary Production, because NPP:

- is the foundation of food, fiber and fuel for human consumption
- determines seasonal and interannual variations in atmospheric CO₂
- integrates climatic, ecological, geochemical and human influences on the biosphere
TOPS enables Biospheric Monitoring Near Realtime

Based on Running, S.W and R.R. Nemani et al., Bioscience, 2004
Summer 2003 European Heatwave

- Warmest summer in 500 years
- Large scale declines in plant growth
- High elevation Alps did better
- May have contributed to the record CO$_2$ increase in 2003 (2.54ppm)

Markus Reichstein, Carboeurope
Tropical regions dominate global carbon cycling

**CO₂ growth rate (ppm/y)**

- 2000 1.17
- 2001 1.56
- 2002 2.04
- 2003 2.54
<table>
<thead>
<tr>
<th>Year</th>
<th>NPP (Gt/y)</th>
<th>Trop. NPP (Gt/y)</th>
<th>CO2 growth rate (ppm/y)</th>
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<tbody>
<tr>
<td>2000</td>
<td>56.06</td>
<td>32.88</td>
<td>1.17</td>
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<tr>
<td>2001</td>
<td>57.74</td>
<td>33.21</td>
<td>1.56</td>
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<tr>
<td>2002</td>
<td>55.53</td>
<td>31.97</td>
<td>2.04</td>
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<tr>
<td>2003</td>
<td>54.80</td>
<td>31.25</td>
<td>2.54</td>
</tr>
</tbody>
</table>
ENSO as a possible mechanism for the enhanced behind CO$_2$ growth rates during 2002-2003

Global distribution of El Nino impacts on NPP based on data from 1982 to 1999

2002-2003 a mild El Nino

Hirofumi et al., JGR-atm, december, 2004
Milesi et al., Glob. Pl. Change, 2005

China! Increased fire activity!
The Growing Season Monitoring System

based on

First Tier
- RAWS
- CPC

Second Tier
- NCDC

SOGS

GSI Phenology Model

Image Generator

MODIS NDVI And RG / DA product Retrieval

Point Retrieval Interface
Train the algorithms on all the non-arson fires during 2000-2002

Methods include:
- Support Vector Machines
- Artificial Neural Networks
- Logistic Regression

Data-driven models
TOPS data in mapping wildland fire risk
Predicting fire risk

7-Day Fire Forecast Map for 3/24/2003

7-Day Fire Forecast Map for 6/23/2003

Brian Bonnlander/Clark Glymour/Votava, IHMC/ARC
Hydrologic modeling with TOPS

MODIS

MODEL

Snow Season Length (days)

0 100 200 300

Itchii/ARC/SJSU
Snow Cover Area : Interannual Variability

![Graph showing snow cover area over time](image)
TOPS - California

Direct Broadcast
TERRA/AQUA/MODIS

GOES based Insolation at 2km

Seasonal forecasts from Scripps

Models include:
BGC, RHESSys, CASA, VSIM

Partners include:
Napa vintners, California Health,
Dept. of Water Resources,
CIMMIS,
Maintaining optimal water stress for better vintages

TOPS Irrigation Scheduling

LAI from NDVI Imagery

Limited Farm-scale Soils Data

Crop Params from Variety

Met Data from CIMIS

Forecast from NWS

Inputs → Modeling → Outputs

VSIM Model

Inputs

Climate: ETo, Ppt, T
LAI: NDVI
Soils: Geophys. Data

Vine ET
ETv = ETo * kv

Vine Water Stress = f(Soil Moisture)

Soil Moisture = Precip + Irrig – ET - Runoff

Cover Crop ET
ETc = ETo * kc

Runoff = SM - SWHC

Data → Water

Irrigation Forecasts
Crop Monitoring

1999
Red & Blue Treatments
$R^2 = 0.85$

(Stem Water Potential Measurements courtesy of Thibaut Scholasch, RMV)
Modeled water stress as a predictor of vintage

1997 moderate water stress, best vintage

Cumulative Water Stress, Veraison to Harvest, 1997-2002
Enhancing National Weather Service Forecasts

Temperature (F) and Wind for Wed Jul 21 2004 2PM PDT
NWS San Francisco Bay Area/Monterey, CA
Experimental graphic created 07/19/2004 11:08PM PDT

Sky Condition (%) for Wed Jul 21 2004 8AM PDT
NWS San Francisco Bay Area/Monterey, CA
Experimental graphic created 07/19/2004 11:08PM PDT
Irrigation Forecast for week of July 19-26, 2004

Tokalon Vineyard, Oakville, CA

CIMIS Measured Weather Data through July 18, 2004

NWS Forecast Weather Data July 19-26, 2004

0 30
Forecast Irrigation (mm)
interannual climate-wine quality

Co-variation of SST and $T_{ave}$

SST: $0.72^\circ C/47yr$, $p = 0.0030$

$T_{ave}$: $1.14^\circ C/47yr$, $p < 0.001$

Shift in Pacific climate

Nemani et al., 2001 Climate Research
changing appellations!!

Average climatic conditions 1980 - 1997

Climatic changes from 1950 - 1993
Unprecedented data volumes and sources need a comprehensive framework

*retaining and maintaining data sources is important*

Working with large data sets requires robust automation

*we can learn a lot from the tech industry*

Potential for mimicking the weather service with ecological nowcasts and forecasts of various lead times

*weaknesses include rule-based methods, past as indicator of future*

Characterizing and communicating the uncertainty in ecological forecasts remains a challenge

*non-linear responses, new thresholds, sequence of events complicate uncertainty estimation*

more information at: http://ecocast.arc.nasa.gov
What is Ecocasting?
Ecological forecasting (or ‘ecocasting’) is the prediction of ecosystem parameters. NASA Ames is developing advanced computing technologies for converting massive streams of satellite remote sensing data into ecocasts that are easy to read and use.

NASA Ames, UWF IHMC, CMU, CSUMB, UMT, UW, and Fetch Technologies are collaborating to develop a distributed computing architecture for the production of ecocasts from satellite remote sensing data and other ancillary data sources.

Applications of the Ecocast technology include fire forecasting, crop quality forecasting, snowpack and flood monitoring, and identification of anomalies in the carbon cycle and other biospheric processes.

News
Daily updates of biospheric parameters are now available. See below for a selection of available parameters. Or download data and images here.

Nowcasts & Forecasts
- Meteorology
- Hydrology
- Carbon Cycle