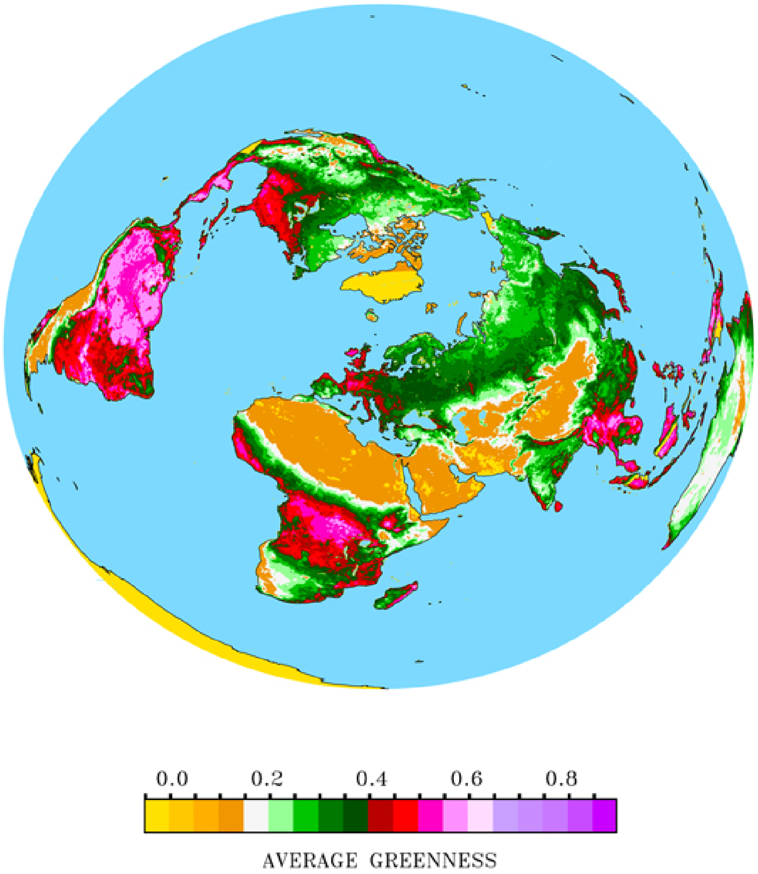
# Ecological Forecasting
## by integrating satellite and climate data with ecosystem models




**Ramakrishna Nemani**

**Ames Research Center**
**Moffett Field, CA**

Material presented here are personal opinions only, not of NASA

**China Ecological Forum, May 17, 2006**

# Outline

Van Gogh (1853-1890)
The Garden of Saint Paul's Hospital (1889)
Vincent van Gogh Foundation

- Ecological forecasting
- Why we need it?
- Types of ecological forecasts
- Need for a common framework for producing EF
  - the Terrestrial Observation and Prediction System
- Ecological nowcasts and forecasts
  - Global net primary production monitoring
    - historical analysis of global NPP
    - realtime mapping of NPP anomalies
    - tropical NPP
  - Ecological forecasts for premium wine industry
    - -seasonal/interannual
    - -decadal/century

Needs for accelerating ecological forecasting
- -unresolved issues

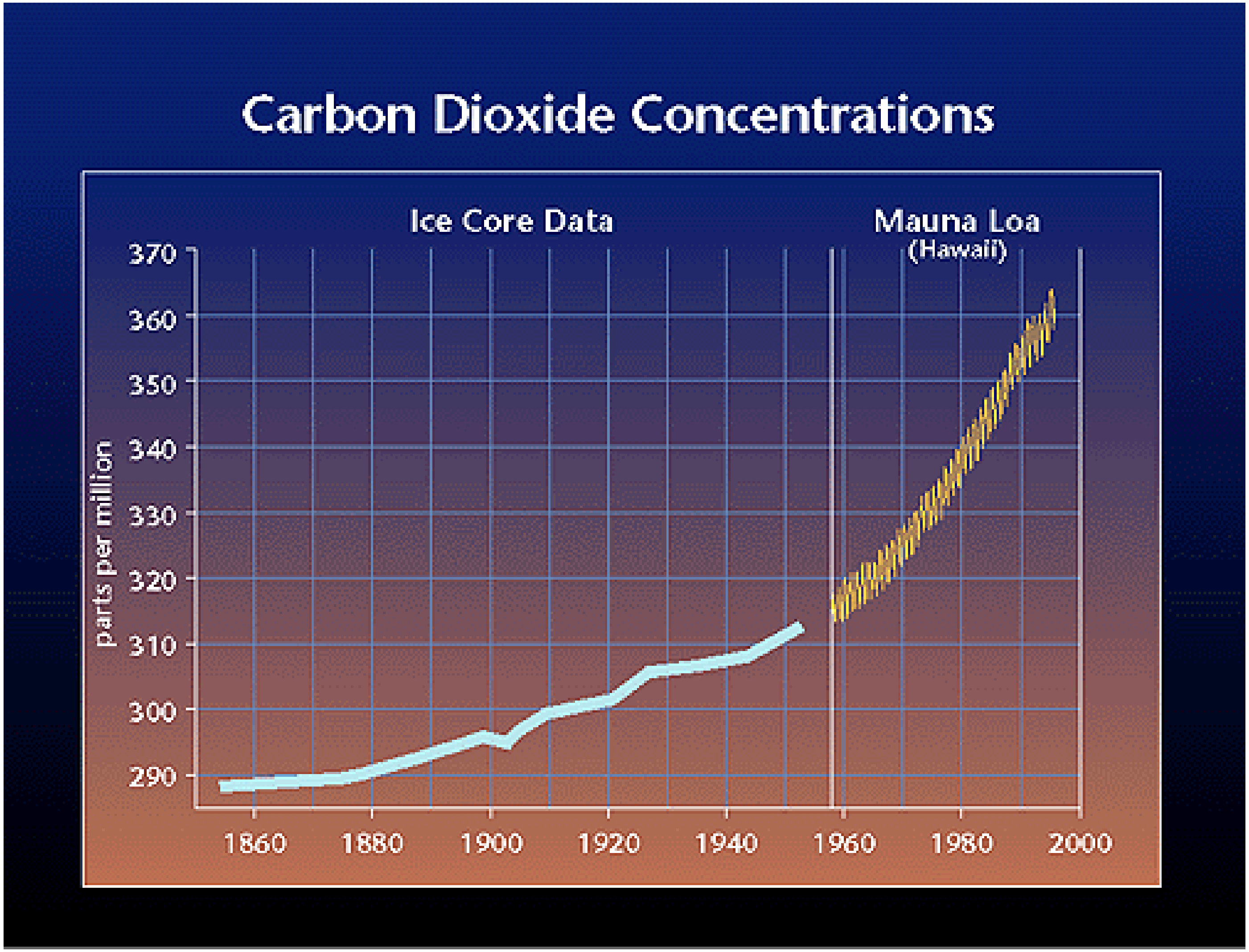
Summary

# What is Ecological Forecasting?

- Ecological Forecasting (EF) predicts the effects of changes in the physical, chemical, and biological environments on ecosystem state and activity.
- Forecasting differs from prediction in that “a forecast is the best estimate from a particular method, model, or individual given a set of specific assumptions.  The public and decision makers understand that a forecast may or may not turn out to be true.”
- Ecological forecasts need to be associated with estimates of uncertainty or “error bars” so that decision makers using them have information as to the likelihood of a given forecast.

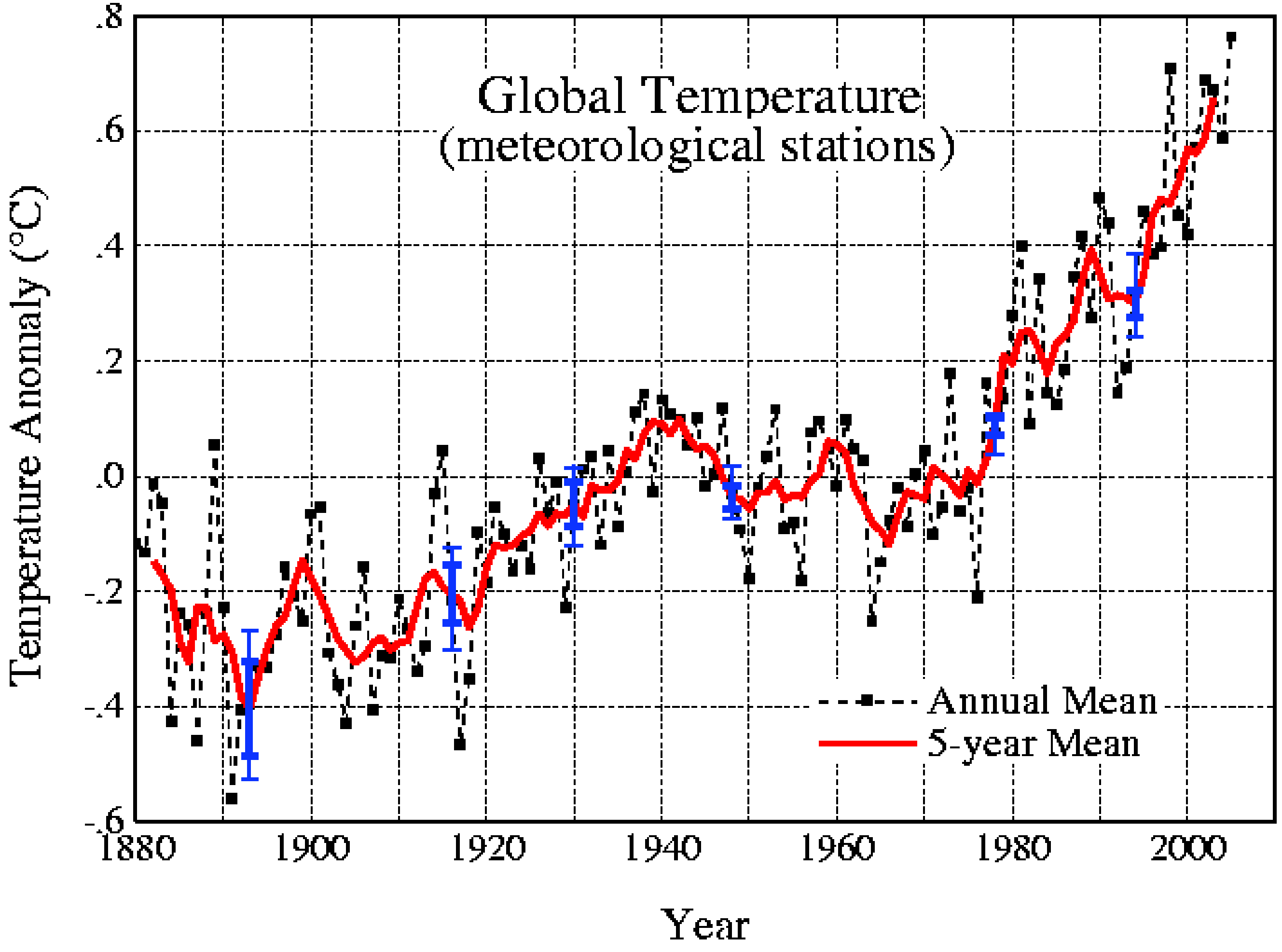
Clark et al., Science 293: 657–660

# Changing atmospheric composition



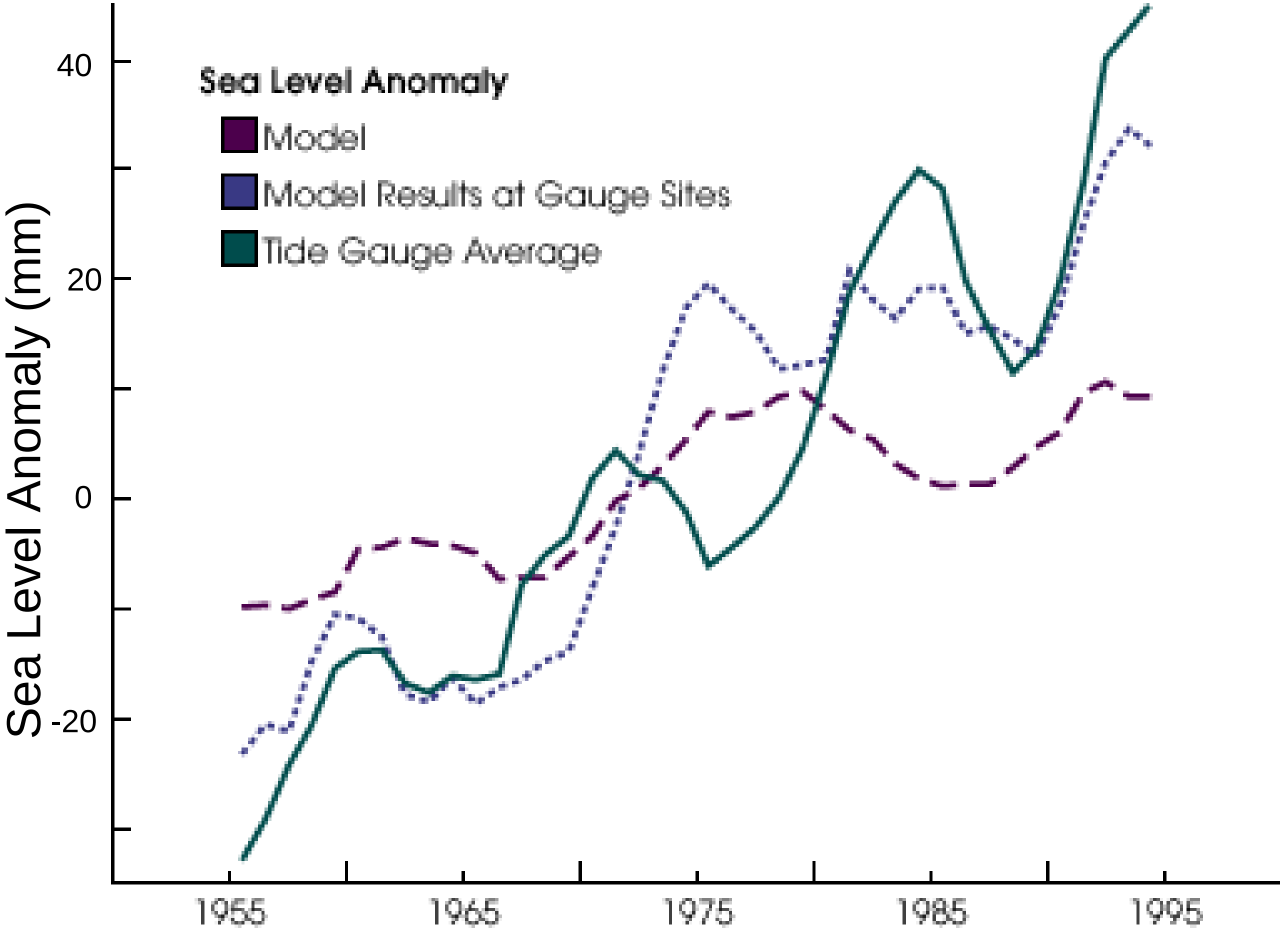

Why we need ecological forecasting?

# Changing surface temperatures




Why we need ecological forecasting?

# Changing Sea Levels




Why we need ecological forecasting?

Cabanes, C. et. al.,, *Science,* 294, pp. 840-842, 2001)

# Why are Ecological Forecasts important?

- Ecological forecasts offer decision makers estimates of ecological vulnerabilities and potential outcomes given specific natural events, and/or management or policy options.

- Ecological forecasting is critical in understanding potential changes in ecological services, before they happen (early warning), and are critical in developing strategies to off-set or avoid catastrophic losses of services

- Goal is to develop management strategies and options to prevent or reverse declining trends, reduce risks, and to protect important ecological resources and associated processes

# Types of Ecological Forecasts

- Vulnerability assessments based on current conditions … likelihood of change
- Short-term forecasts/vulnerability assessments (days/months)
- Longer-term forecasts/vulnerability assessments (years)

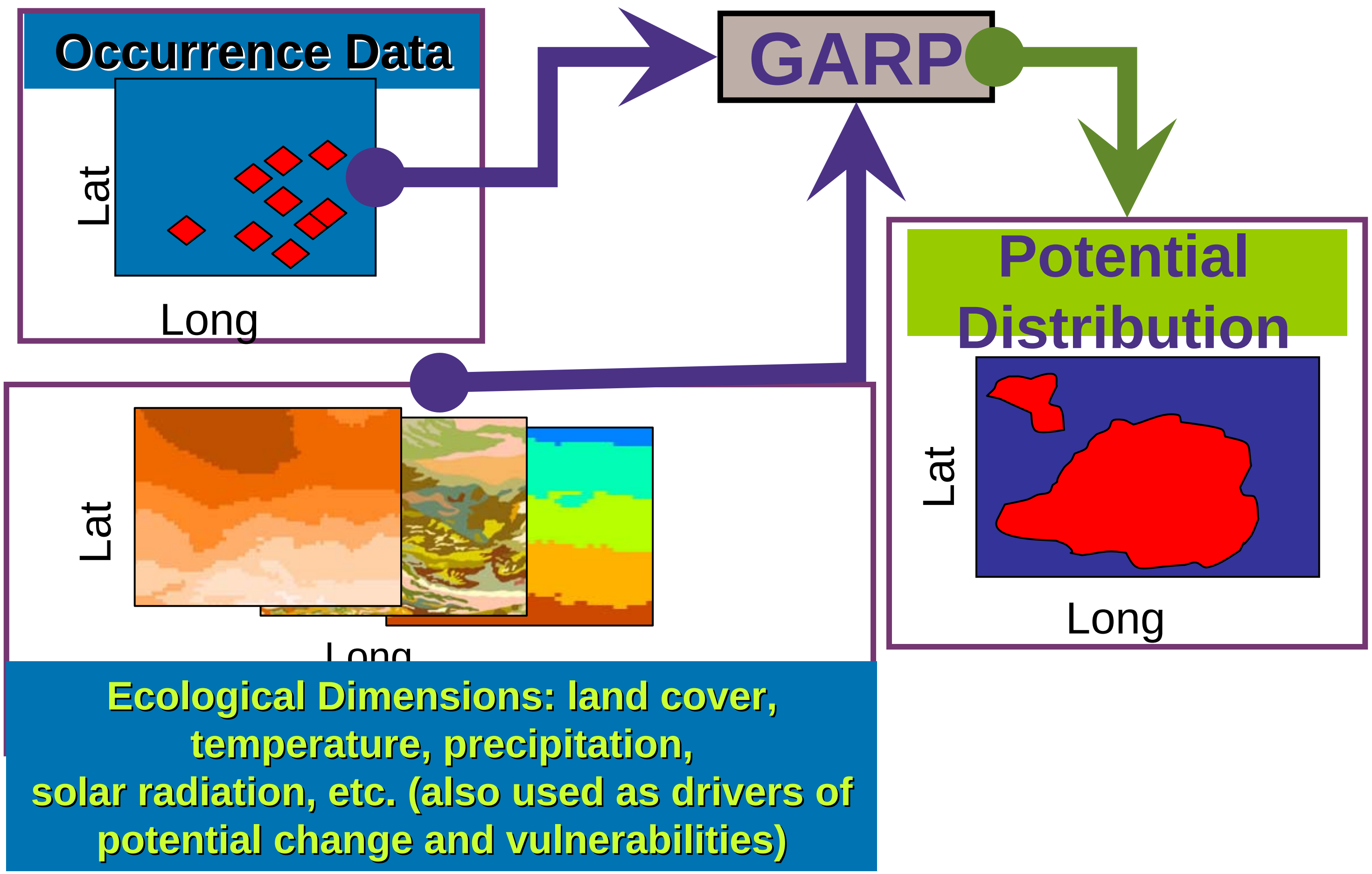
# Examples of Vulnerability Assessments and Forecasts Based on Current Conditions

- Space for Time

- Some Use of Historical Patterns

- Site and Spatially Continuous Data

## *Genetic Algorithm for Rule-set Prediction*
## *… Invasive Species e.g.*



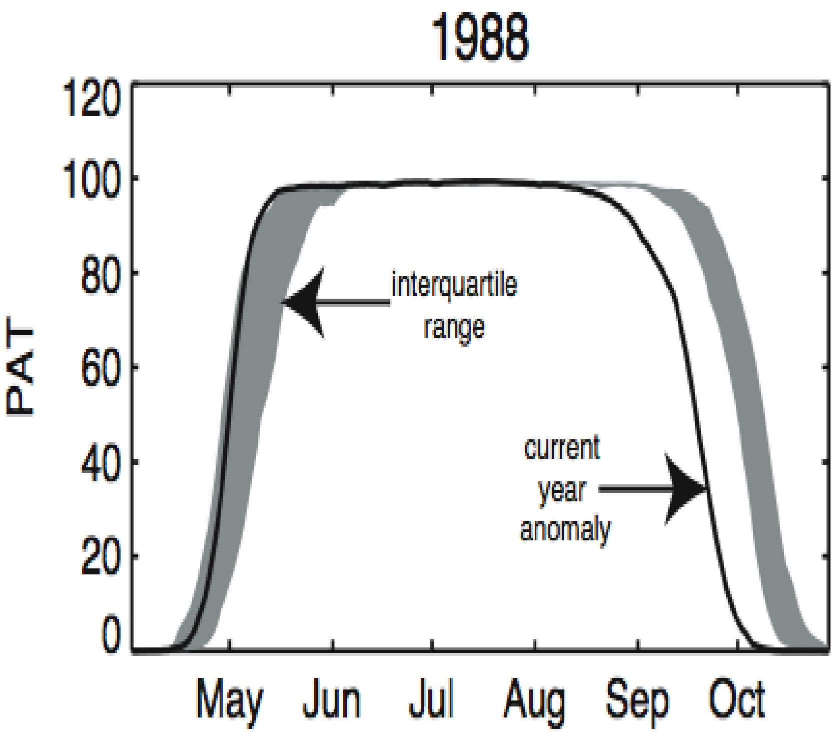

Stockwell, D.R.B. and I.R. Noble 1991, *and Computers in Simulation.* **32**:249-254.

# Examples of Shorter-term Forecasts

- **Real- or near-real time data (site or remotely sensed)**
- **Base biophysical conditions that don’t change (biophysical characterizations/sensitivity)**
- **Models relate conditions/species occurrences to important drivers that change (e.g., air temperature)**
- **Web-based**

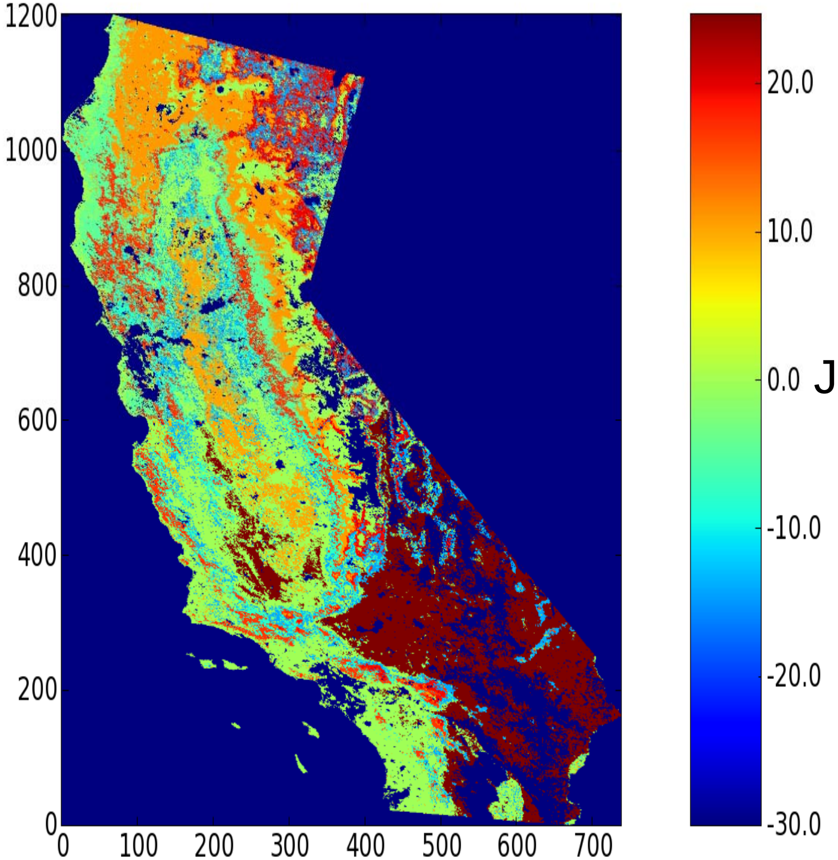
# Phenology

Changes in vegetation growth patterns, strongly influence by weather/climate




Satellite-derived seasonal profile

Predicted date of Leaf-On

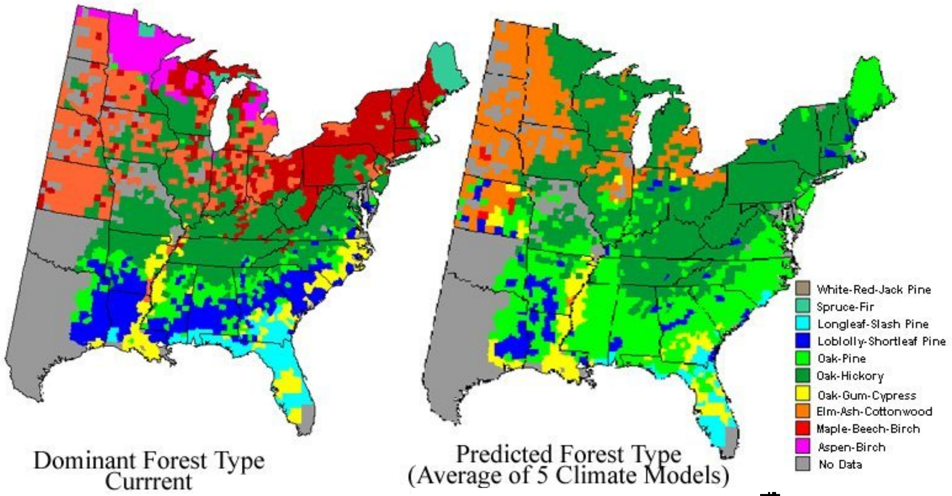


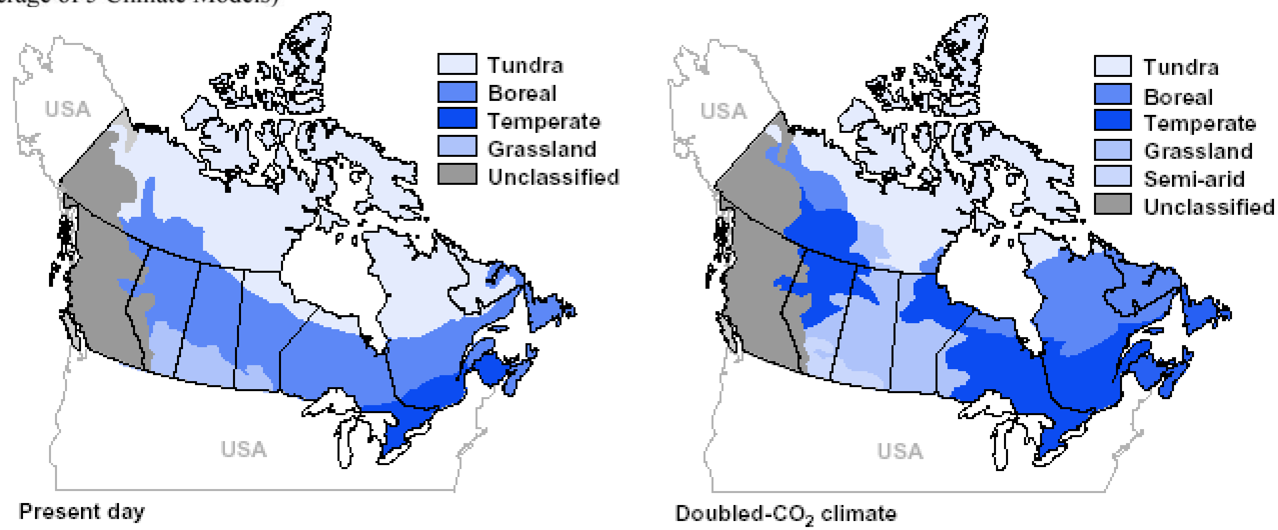

Customers include farmers, ranchers, health professionals

# Longer-term Forecasts and Vulnerability Assessments

- **Scenario-based**
  - **Stakeholders**
  - **Models of change in important biophysical conditions and drivers (economic, population growth, transportation networks)**
- **Base biophysical relationships that don’t change (biophysical characterizations/sensitivities)**
- **Models relate conditions/species occurrences to important drivers that change**
- **Goal is to develop decision tools and web-based applications**

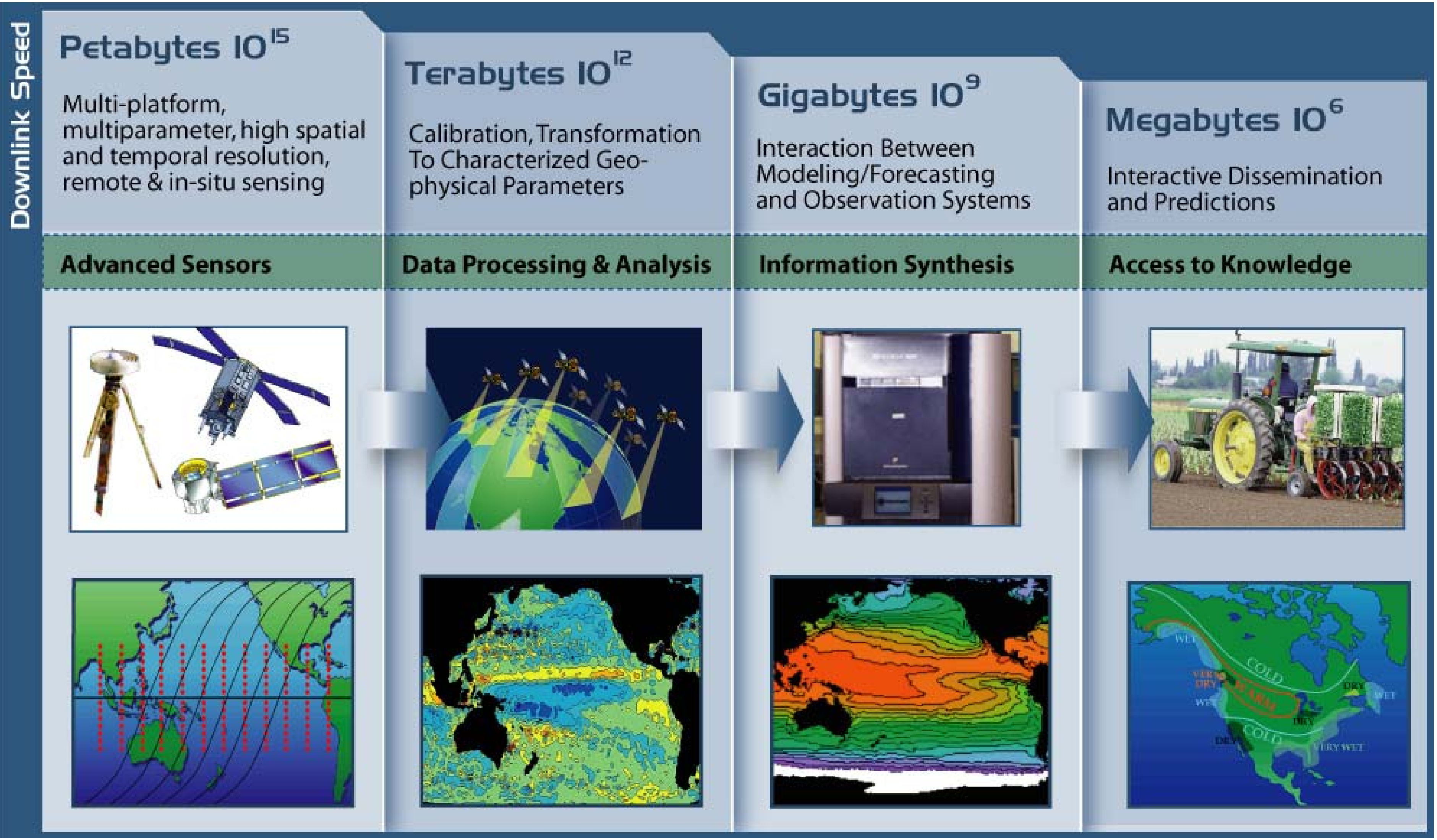
# Projected changes in vegetation distribution



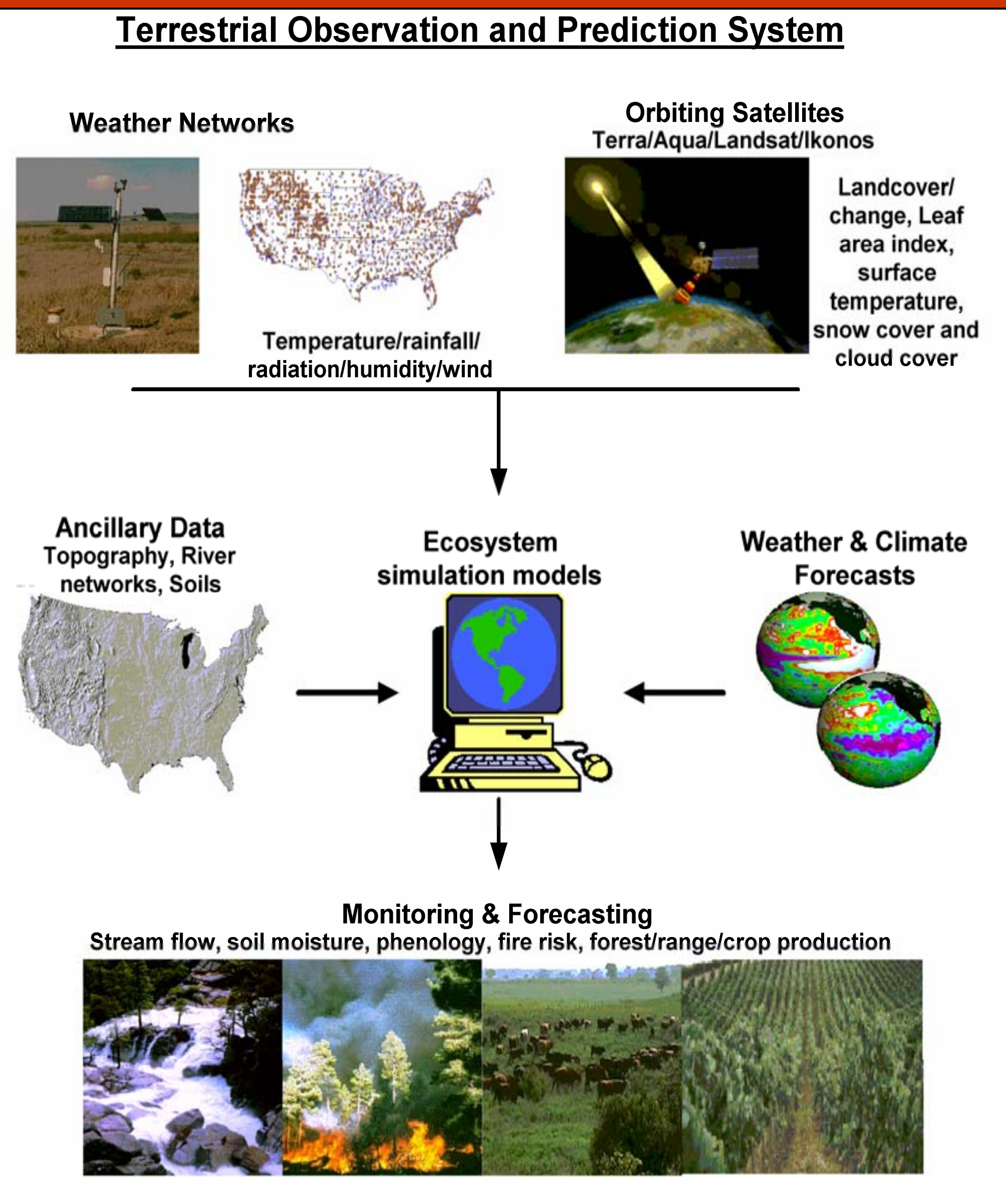




SOURCE: Rizzo 1990.

# From data to knowledge/decisions



# Need for a common modeling framework




**Monitoring**

**Modeling**

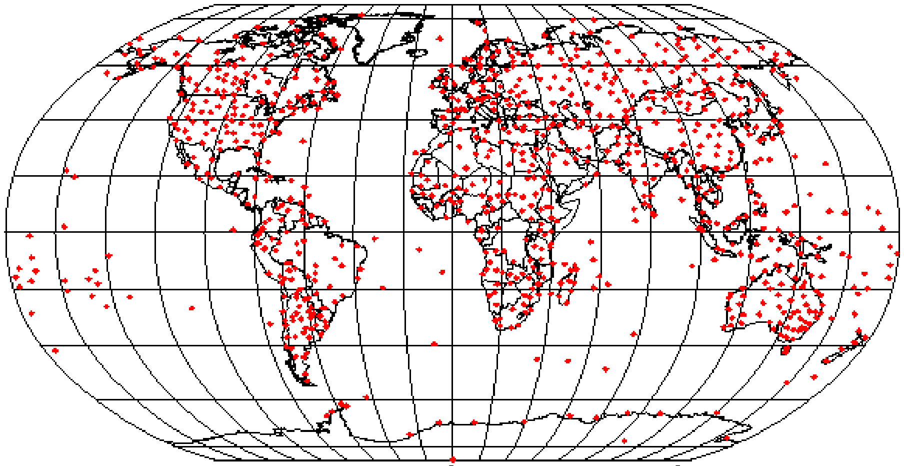
**Forecasting**

**Multiple scales**

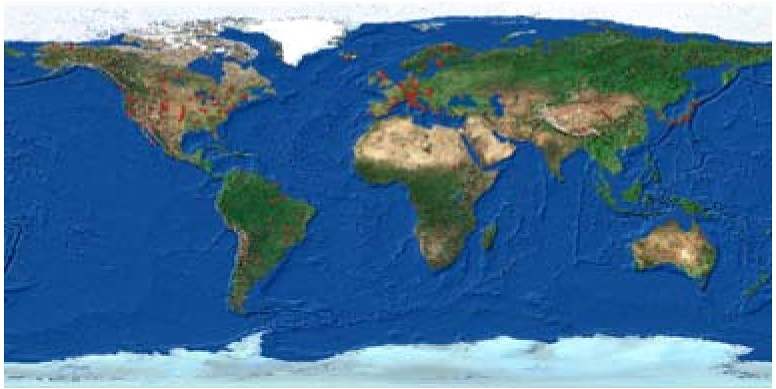
Nemani et al., 2003, EOM

White & Nemani, 2004, CJRS

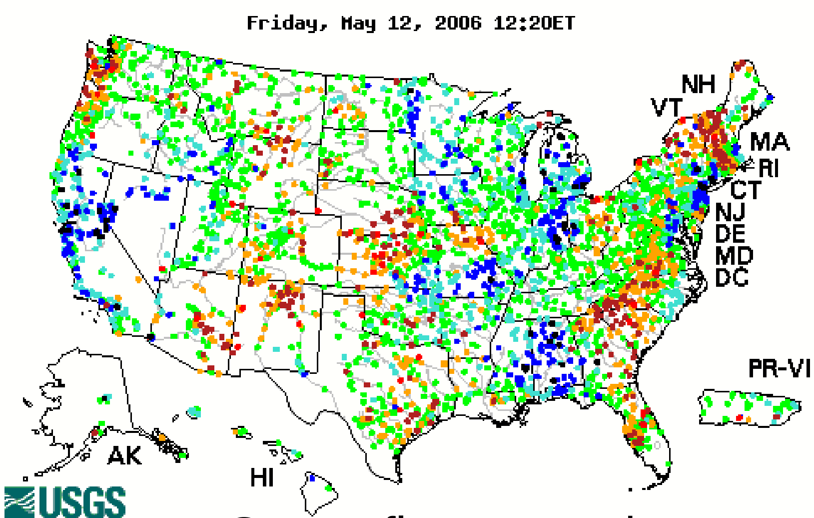
# Access to a variety of observing networks



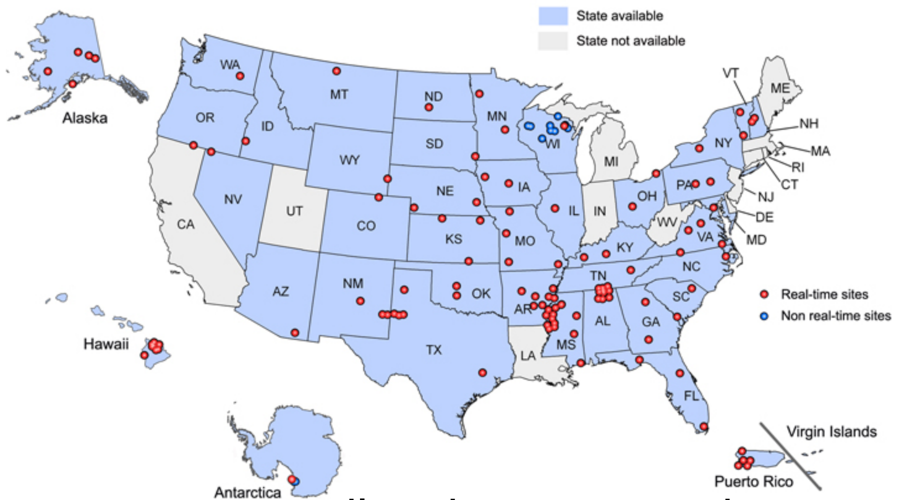
Weather network



Fluxnet

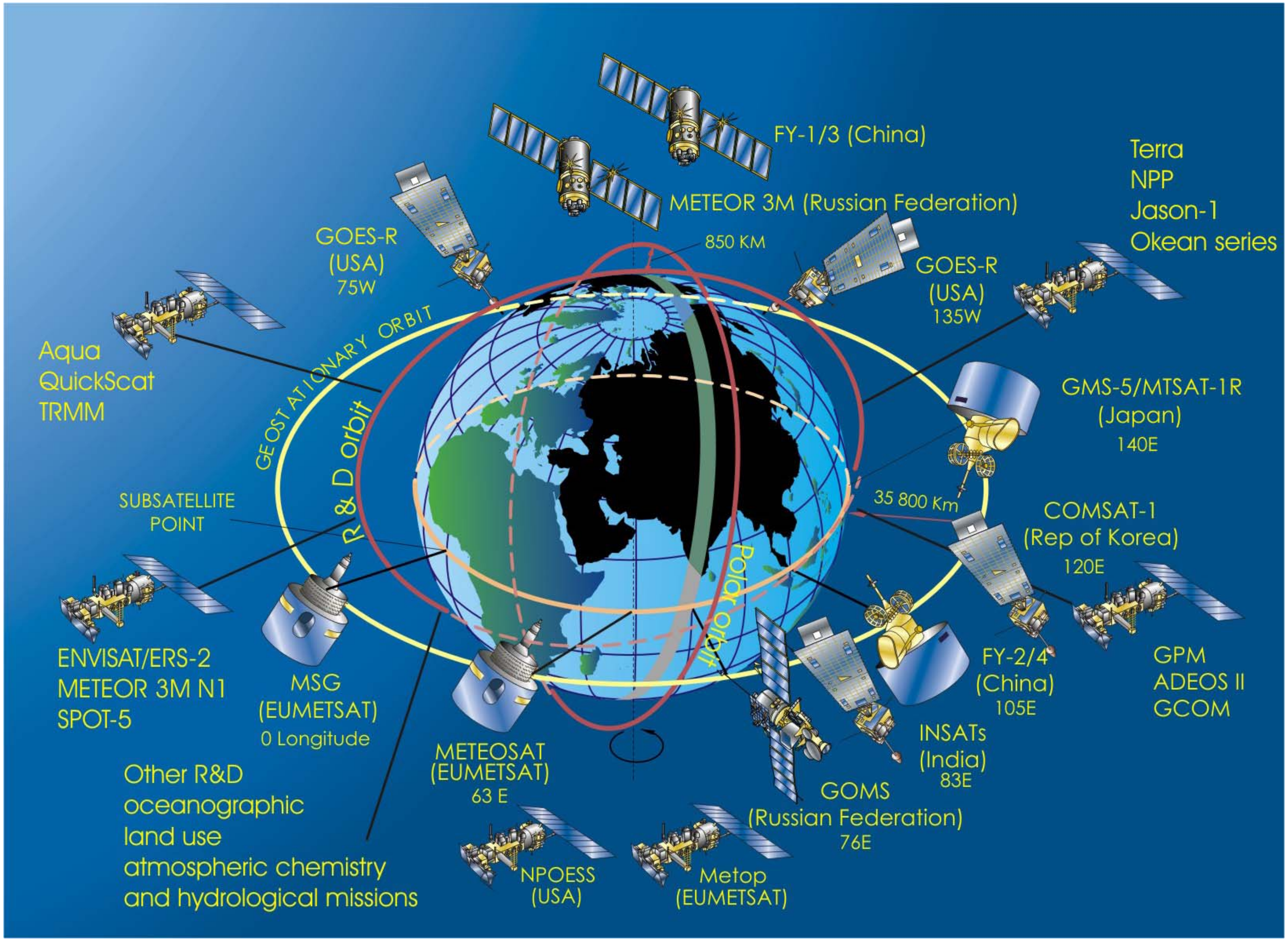



Streamflow network



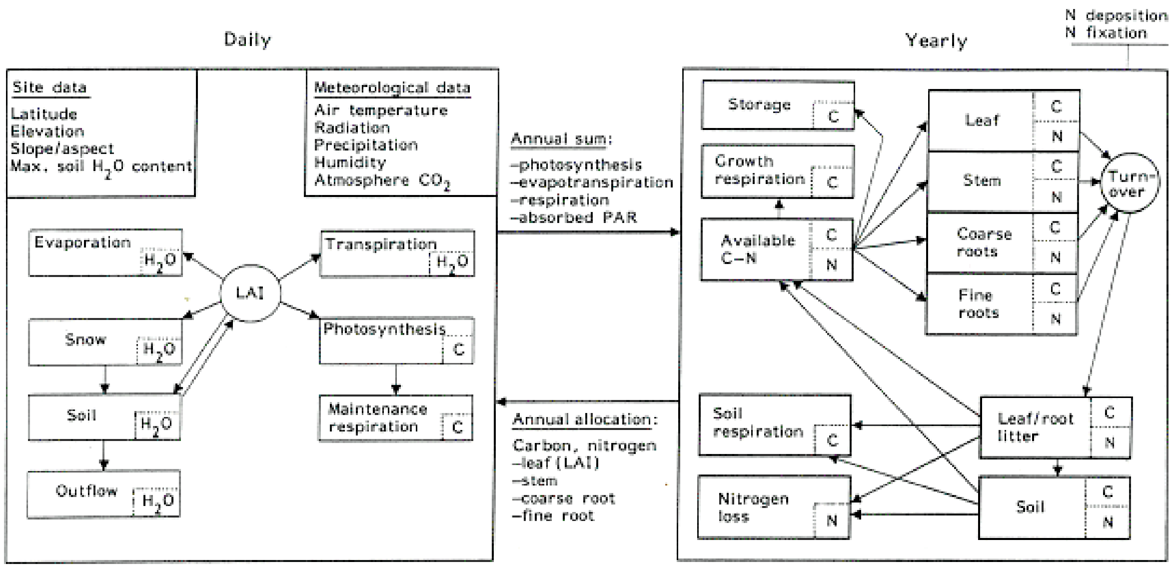

Soil moisture network

# Access to a variety of remote sensing platforms




**Integration across Platforms, Sensors, Products, DAACs *..Non-trivial***

# Ability to integrate a variety of models

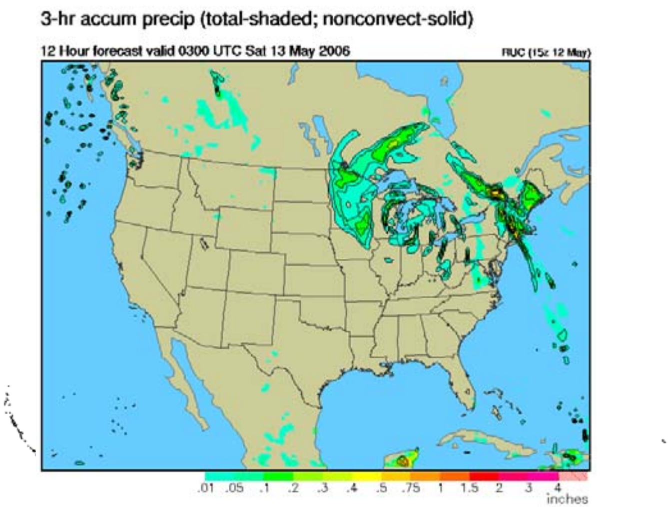



Biogeochemical Cycling
Crop growth/yield
Pest/Disease
Global carbon cycle

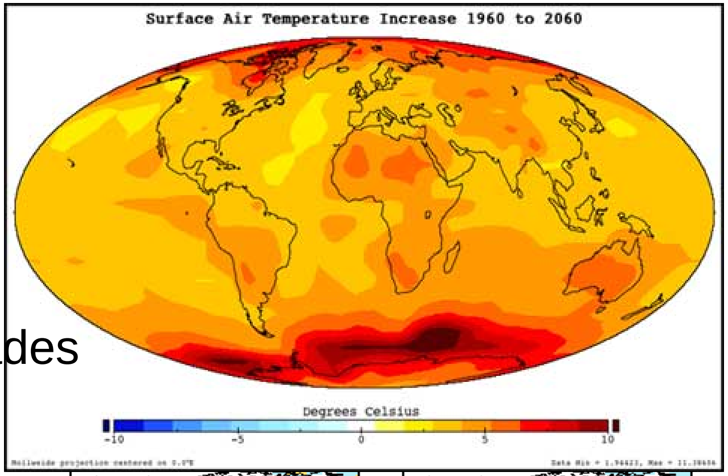
Prognostic/diagnostic models

# Ability to work across different time and space scales

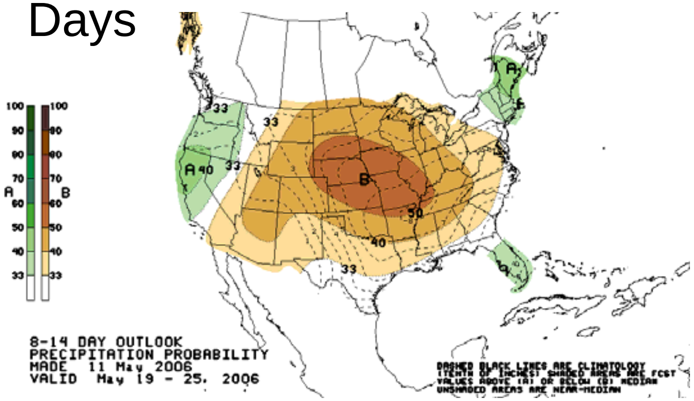
Hours



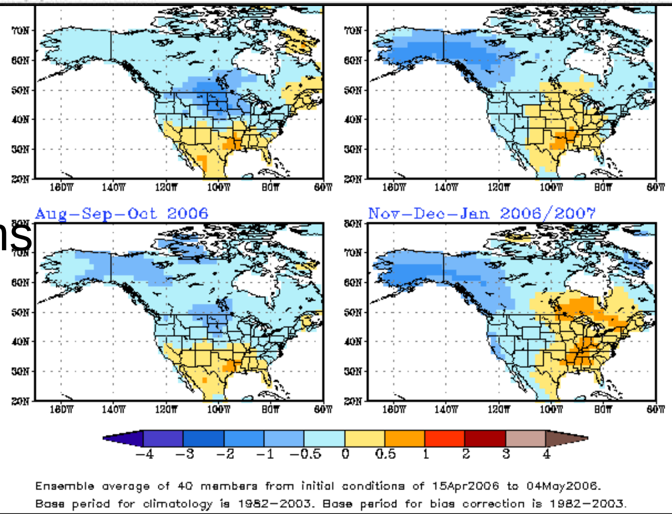

Years/Decades




Days

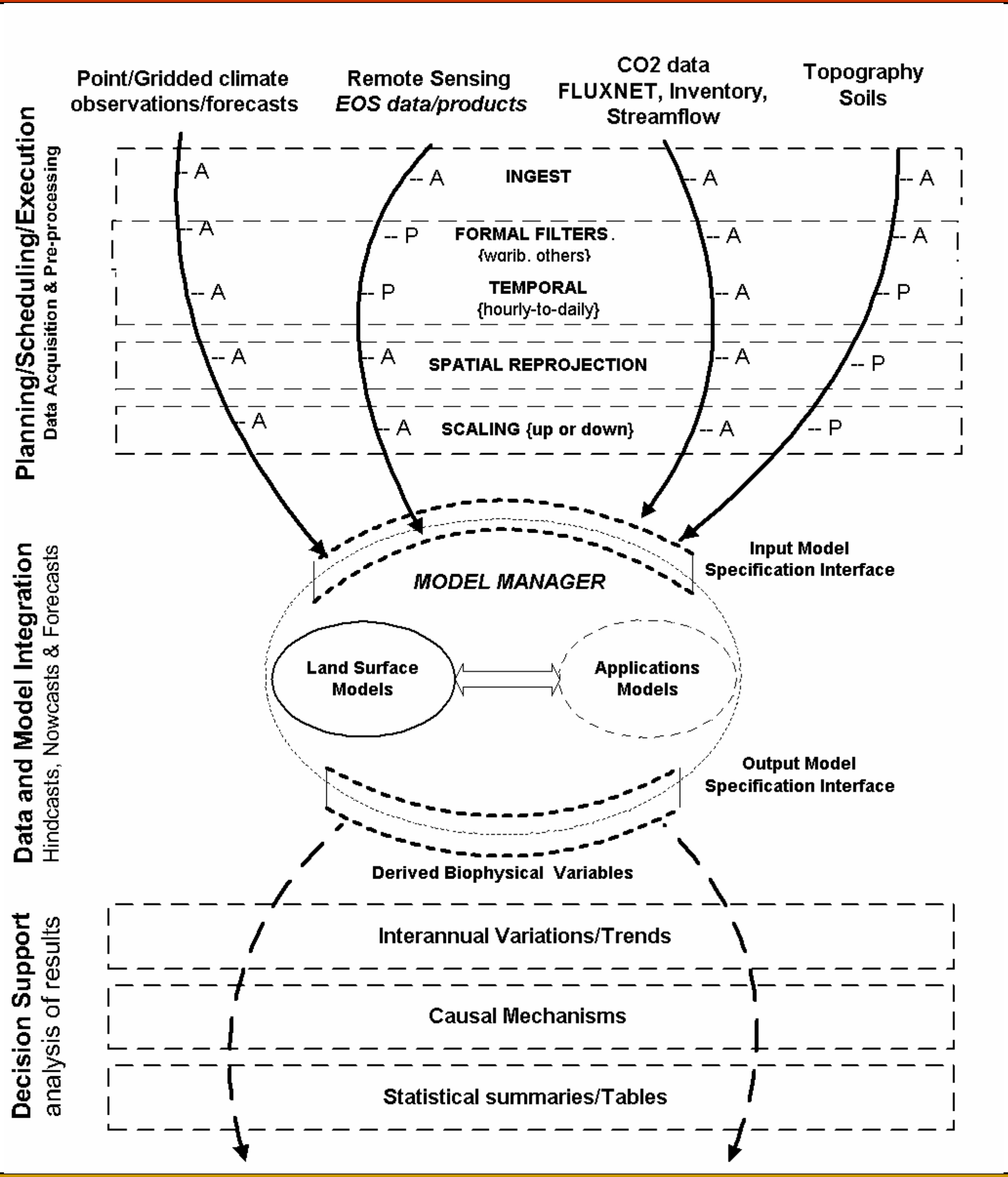



Weeks/Months



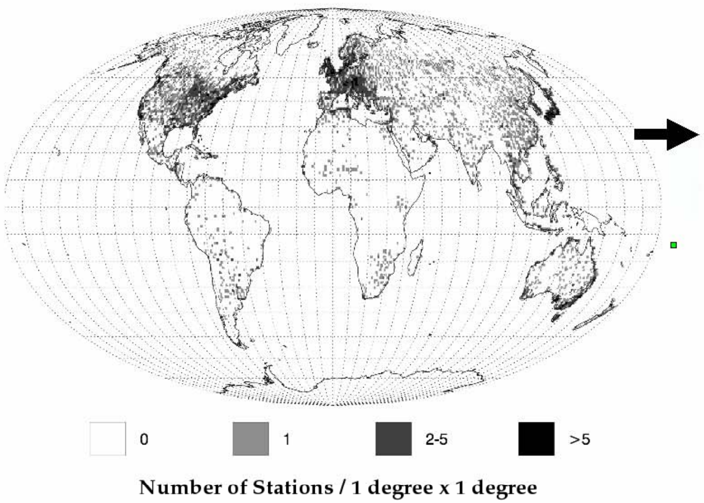

Weather/Climate Forecasts at various lead times

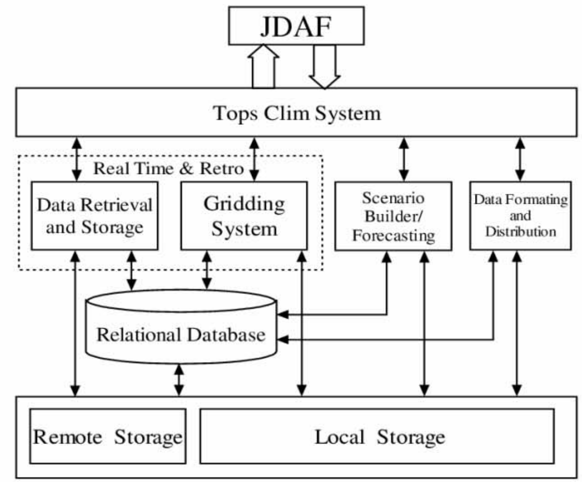
# TOPS Data & Modeling Software System Architecture

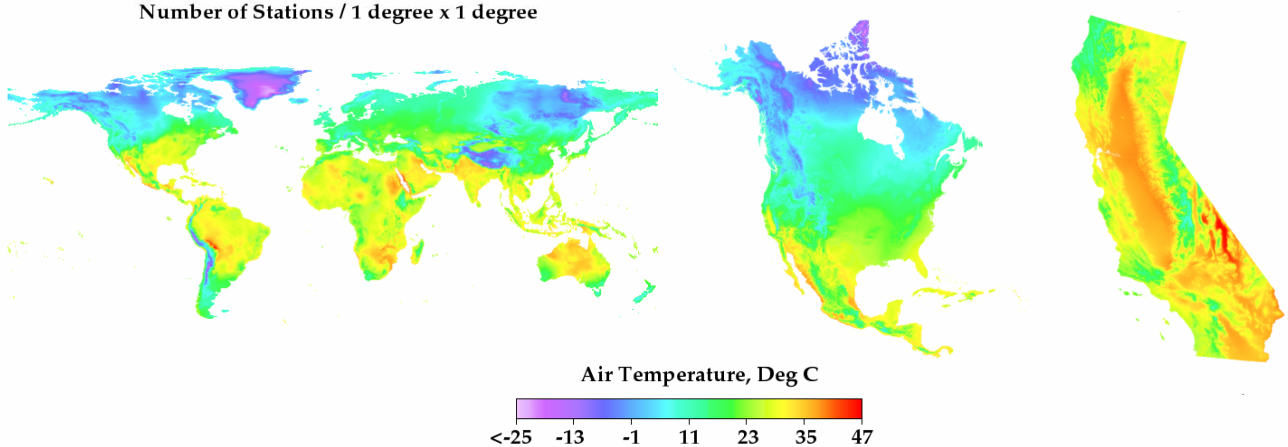



Java based, re-useable code

# Gridding weather data



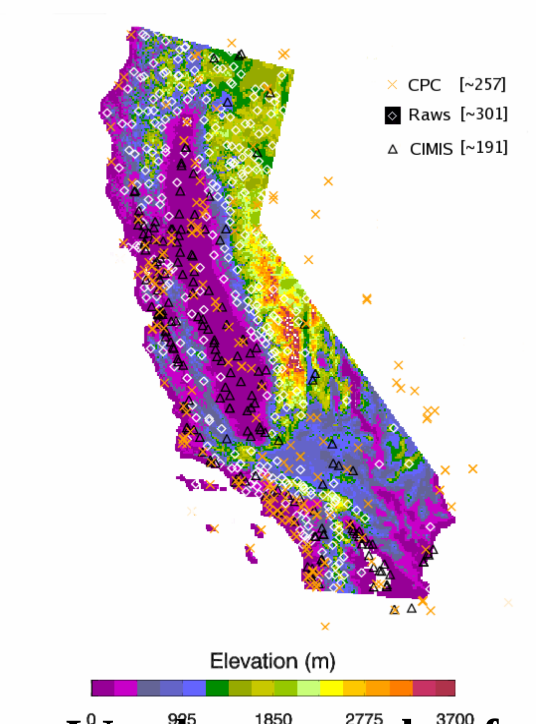



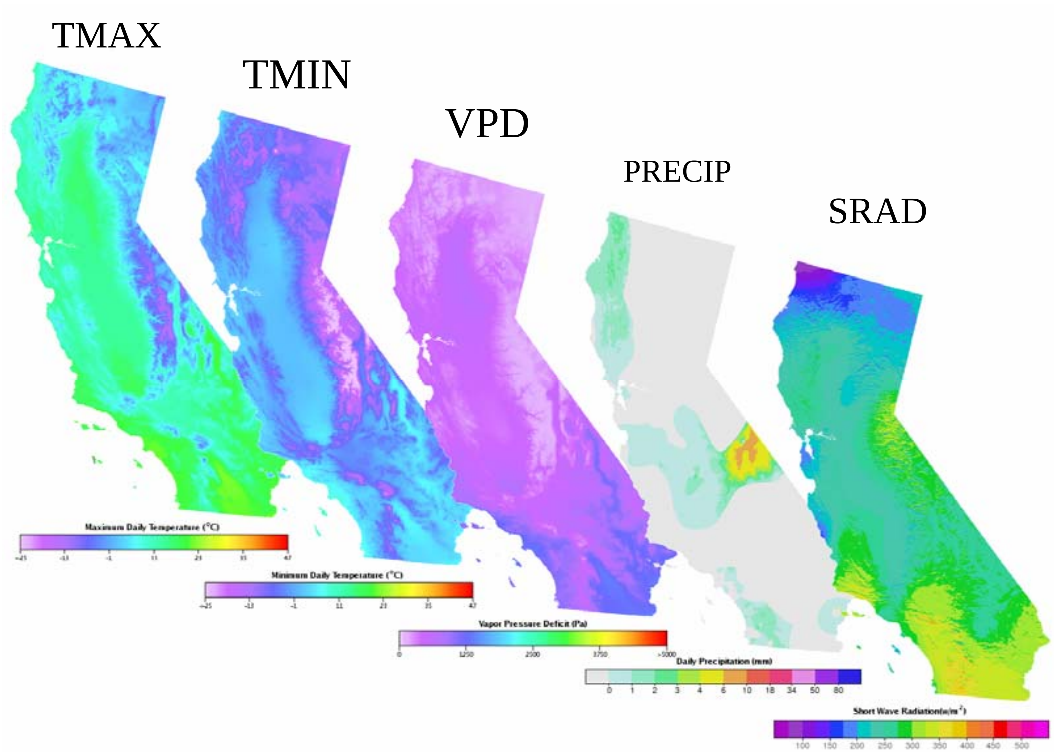




pre-requisite for spatial modeling

# Gridded Weather Surfaces for California

## using nearly 700 weather stations daily



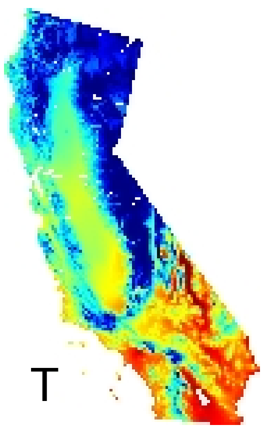

**Weather networks often operated by different govt. agencies and/or private industry. Rarely integrated because they are intended for different audiences. We specialize in bringing them together to provide spatially continuous data.**

maps come with cross-validation statistics

# California : Ecological Daily Nowcast at 1km

## [Feb/01/2006]

**Climate + Satellite**



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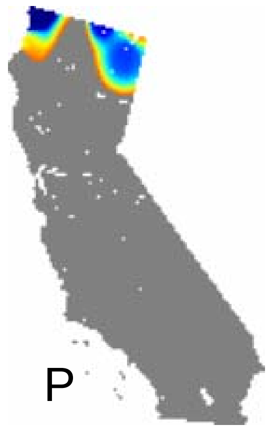

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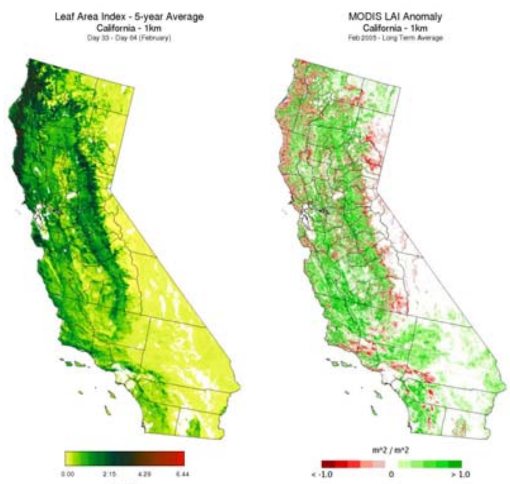
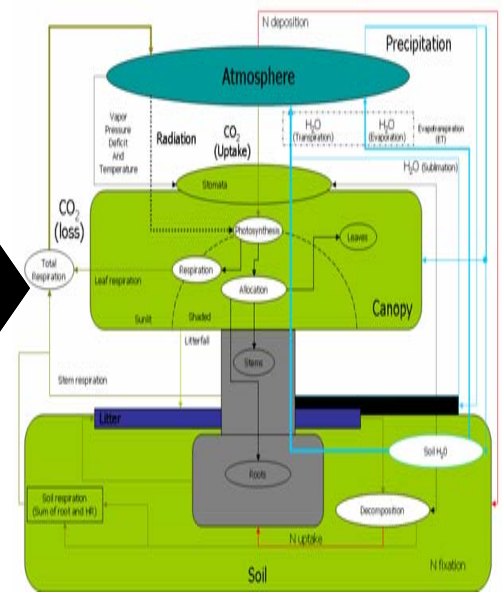
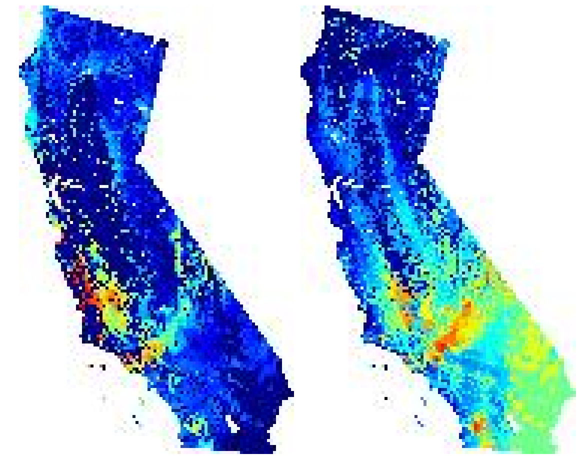



**Biome-BGC**

**Simulation models**

**Carbon and water cycles**



GPP ET

0 2.5 5

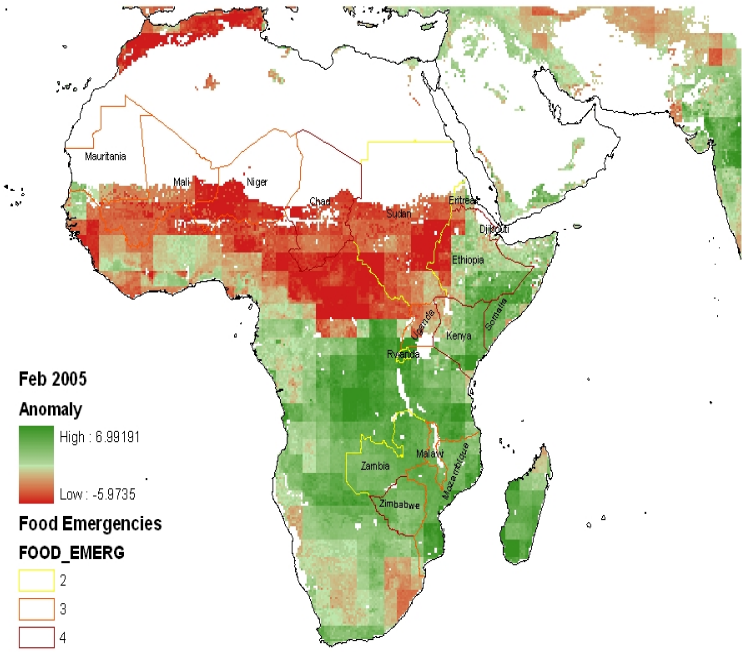
GPP (gC/m2/d)

ET (mm/d)

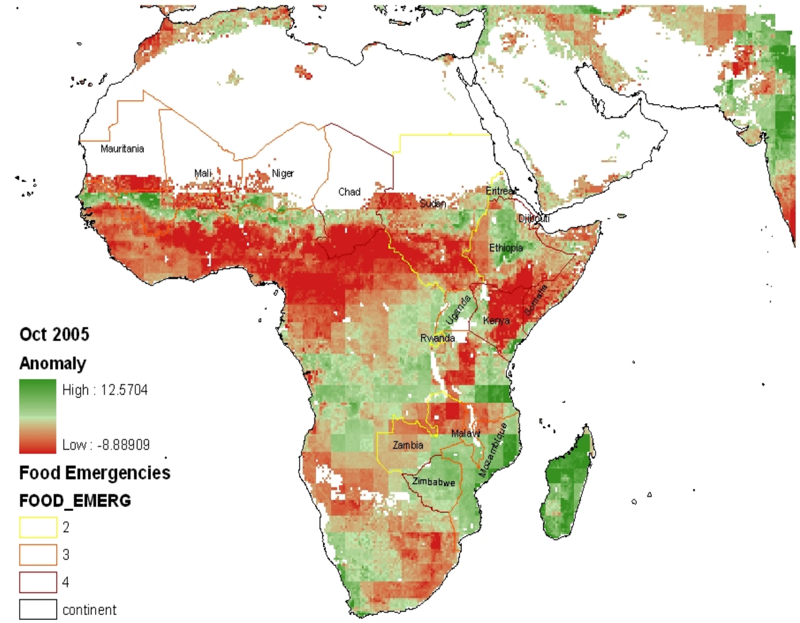
Outputs include plant growth, irrigation demand, streamflow

# Global Nowcasts of Net Primary Production monitoring food security

Global NPP Anomalies and Food Security
February 2005




Global NPP Anomalies and Food Security
October 2005




In collaboration with UNEP

# What is NPP?

## NPP is the balance between photosynthesis and respiration by plants

image credit: fao

**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 $CO_2$**

**- integrates climatic, ecological, geochemical and human influences on the biosphere**

# How do we estimate NPP from satellites?

**Step 1**:
convert absorbed radiation to optimal gross production

**Step 2**:
downgrade by climate limiting factors to obtain gpp

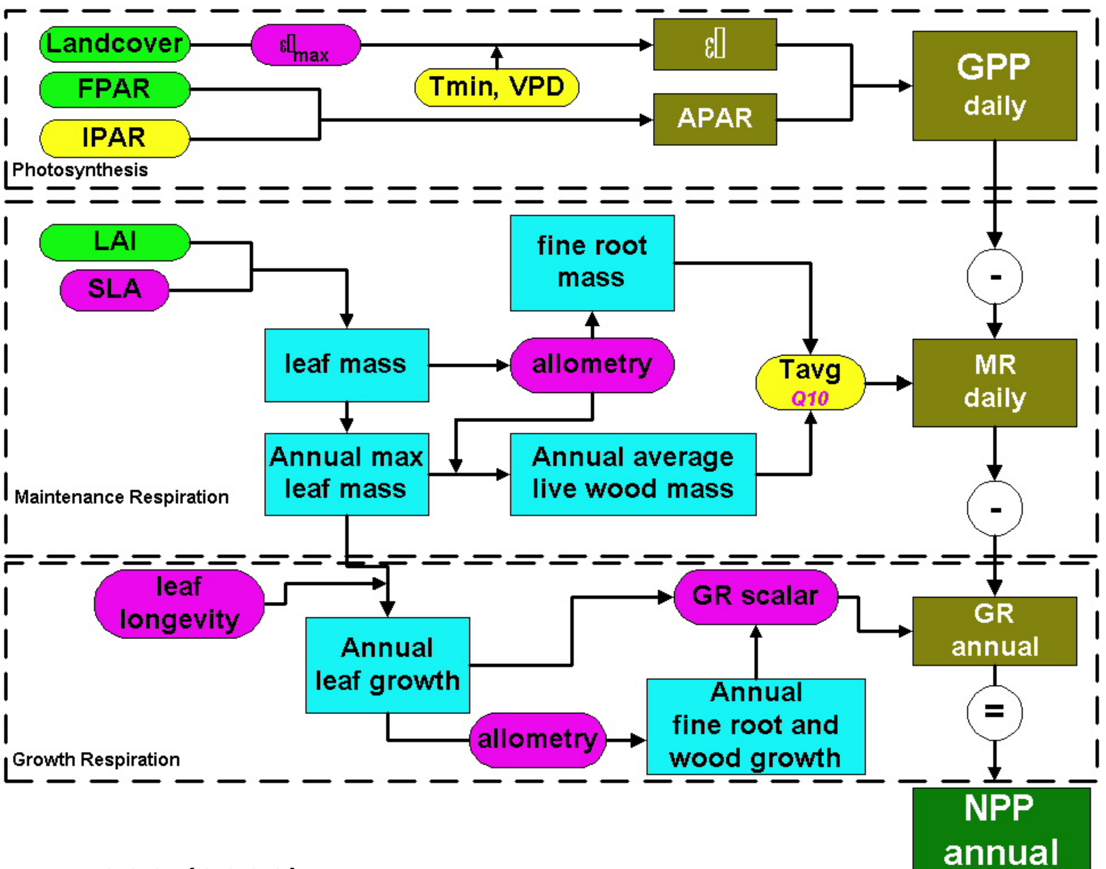
**Step 3**:
subtract respiration to obtain npp

## Components of the NPP algorithm

**satellite-derived vegetation properties**: Land cover, Leaf Area Index (LAI) and fraction of absorbed photosynthetically active radiation (FPAR)

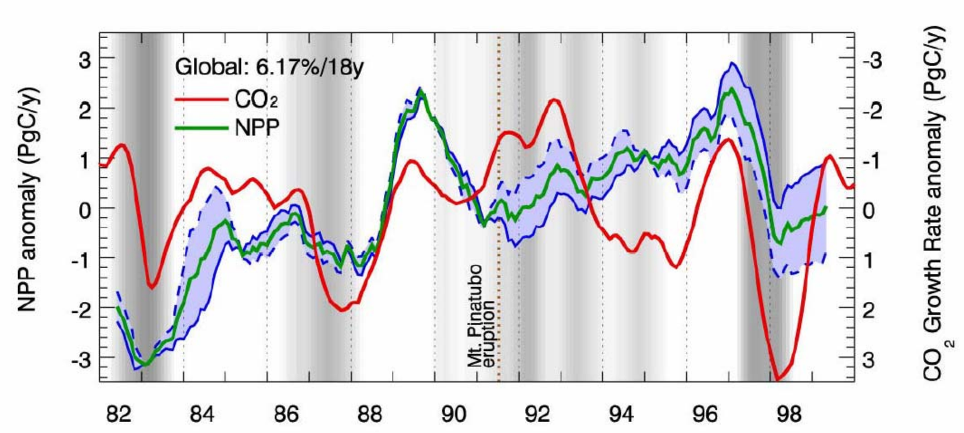
**daily climate data**: incident radiation (IPAR), minimum and average air temperatures and humidity

**efficiencies**: a biome specific parameterization to convert absorbed PAR to NPP

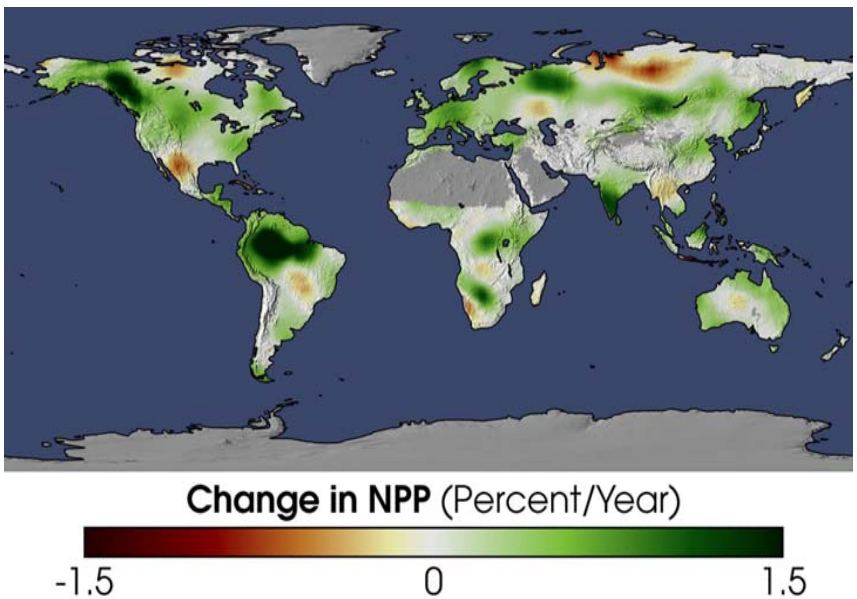



Nemani et al., Science, 300 (2003)

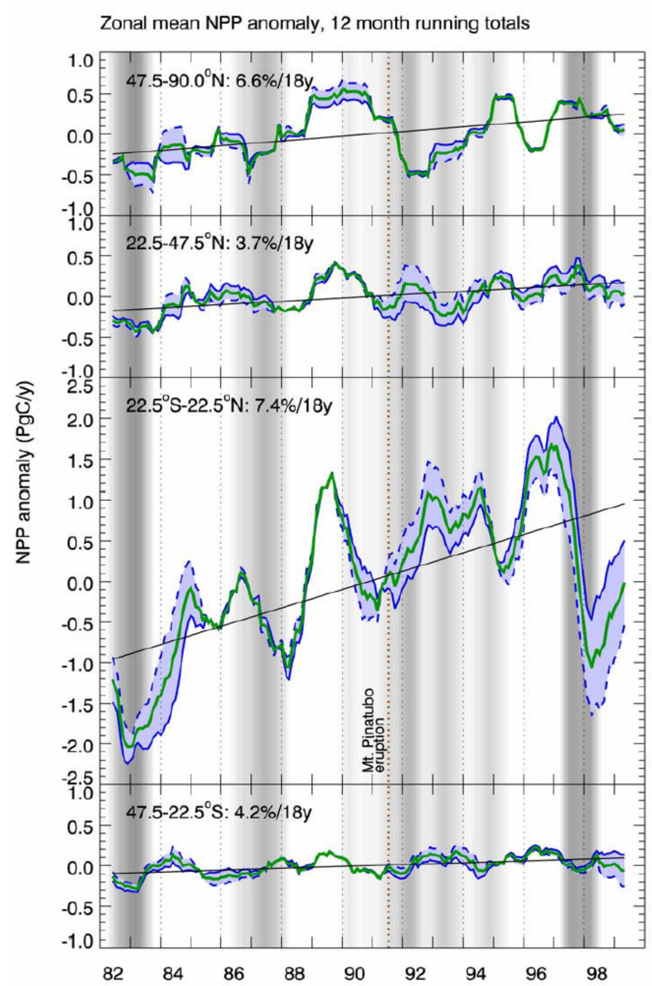
# Greening of the Biosphere between 1982 and 1999




A 6% increase in NPP



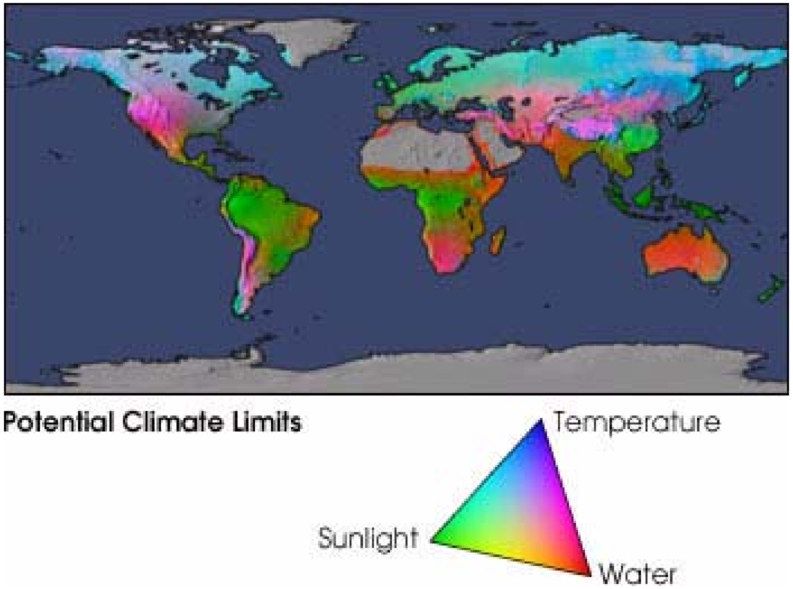

Large increases over Amazon

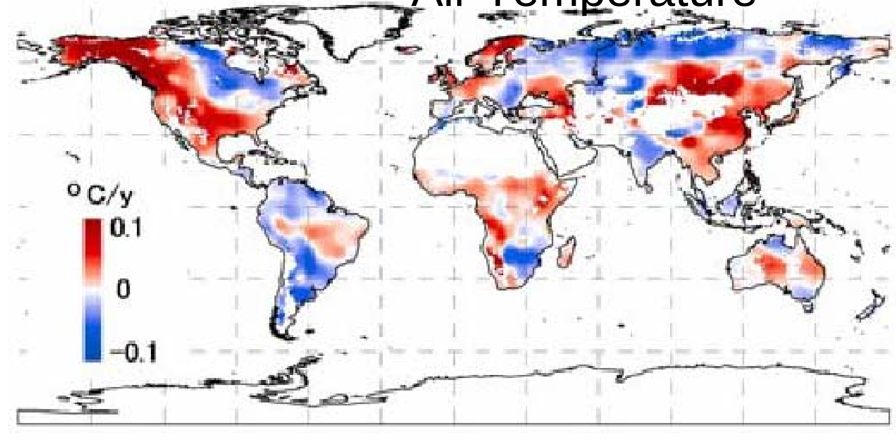



**Divergent climate impacts on NPP**

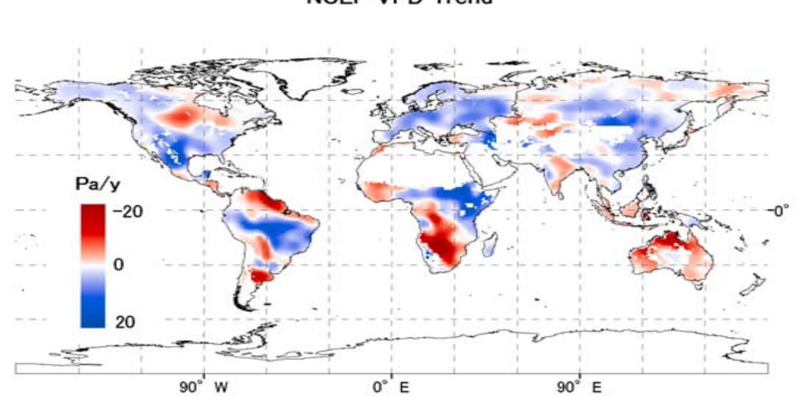
Nemani et al., Science, 300 (2003)    Historical trends & Variability using 1982-1999 AVHRR data

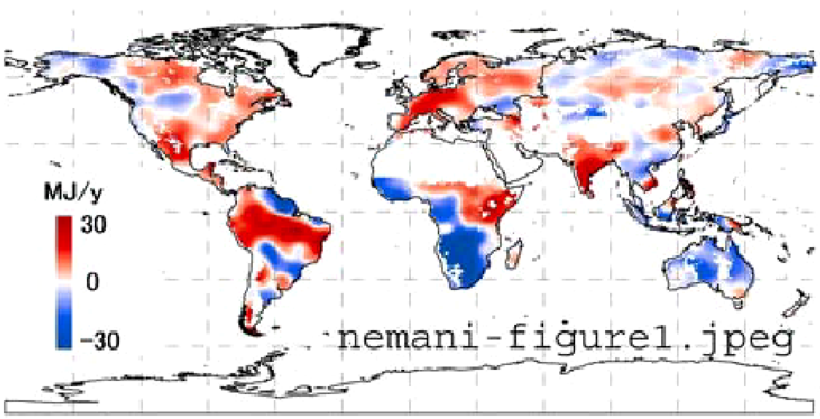
# Changes in climate between 1982-1999 played a big role




Water



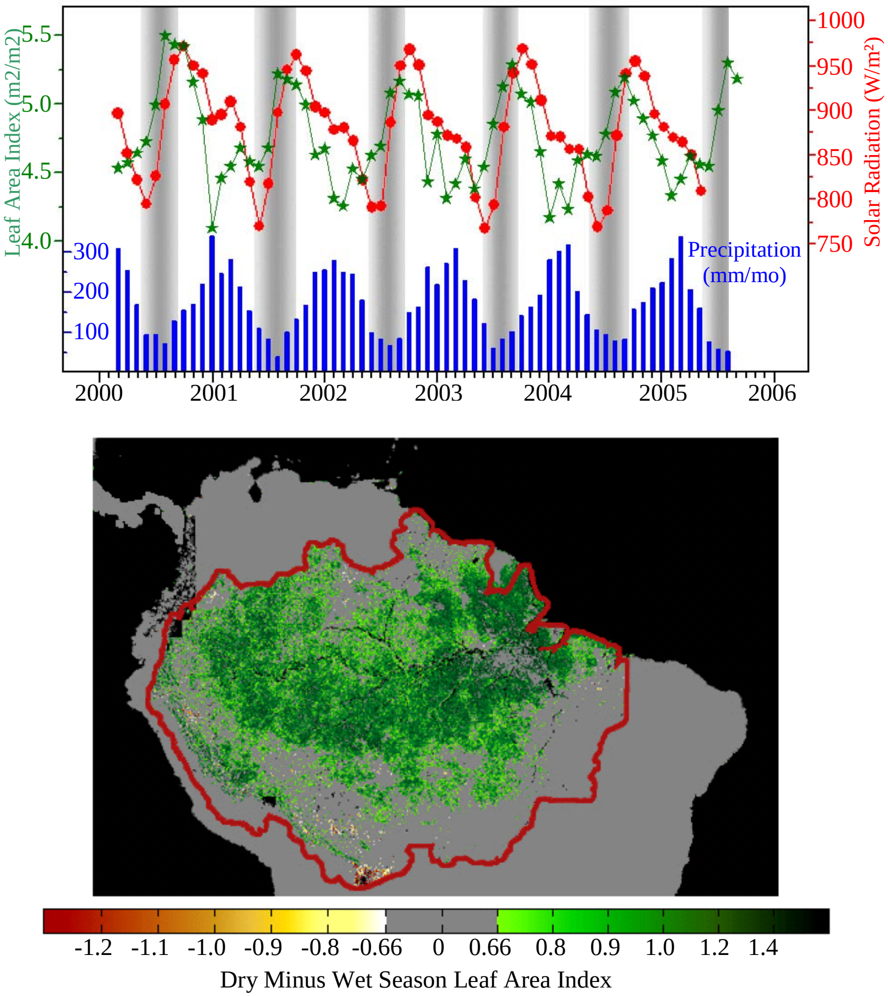

Sunlight

**The observed climatic changes have been mostly in the direction of reducing climatic constraints to plant growth. Therefore, it seems likely that vegetation responded to such changes positively.**

**Nemani et al., Science 300 (2003)**

But changes in land use could be equally large

# Amazon rainforests green up in the sunny dry season

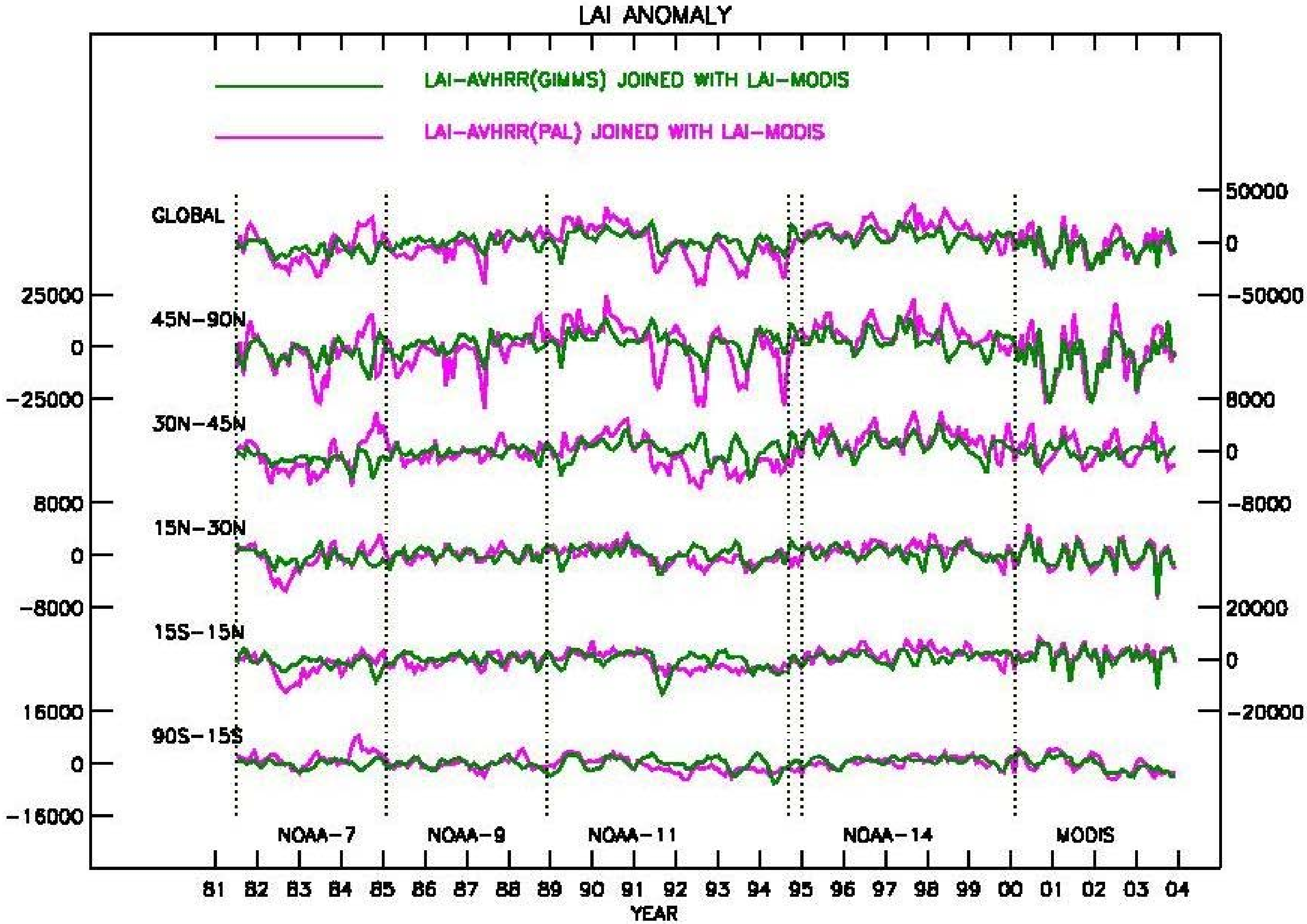



Huete et al., GRL 2006; Myneni et al.,

MODIS unveils hitherto unknown phenomenon

# Sensor transition: AVHRR to MODIS

**AVHRR (1981-2000), MODIS (2000 onwards)**

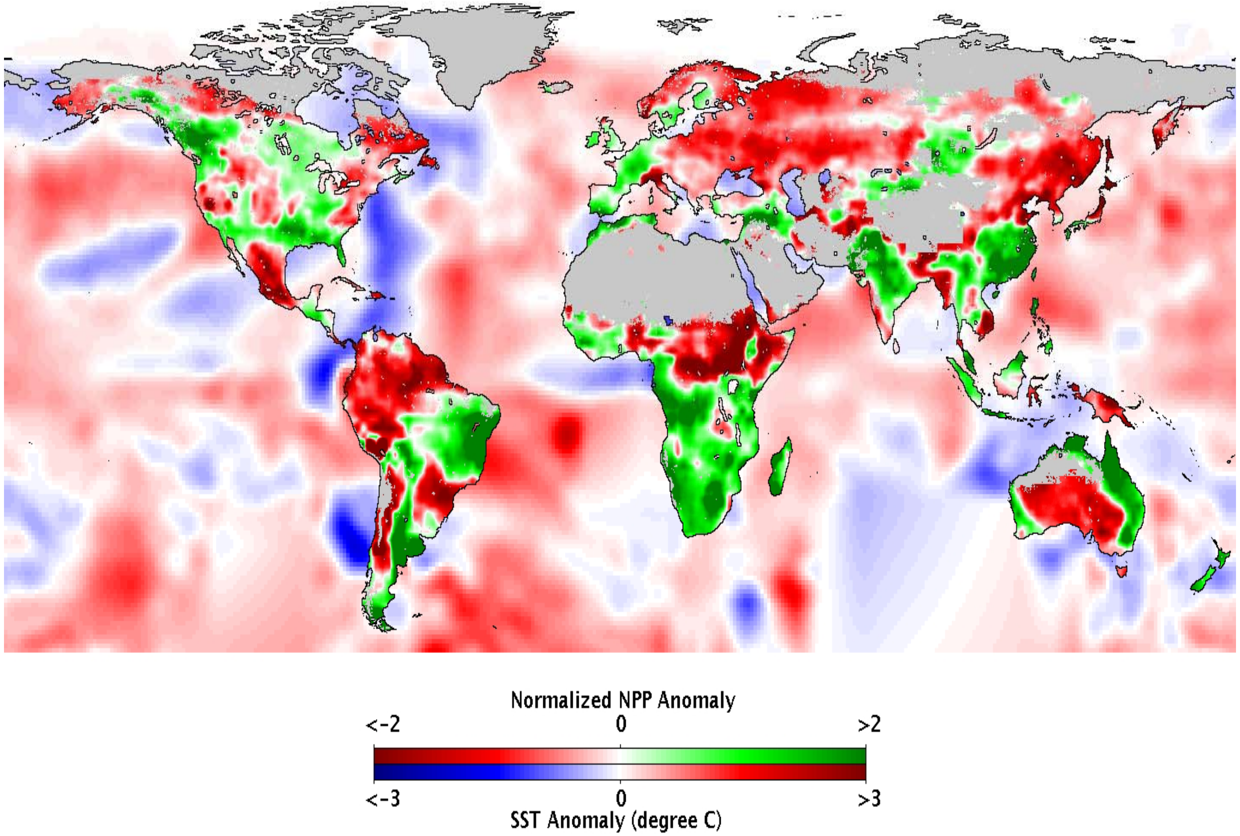



Collaboration with Ranga Myneni/Boston University

# Near realtime monitoring of global NPP anomalies

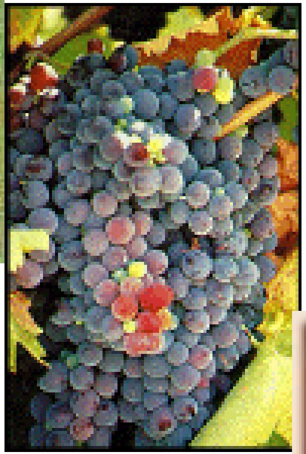
## Mapping changes in global net primary production

**near real-time depiction of the droughts in the Amazon and Horn of Africa, May 2005**




Running et al., 2004, Bioscience, 54:547-560

# Ecological Forecasting with economic implications



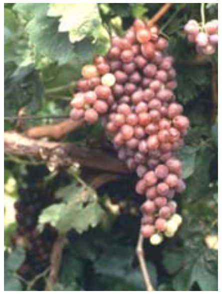
**Annually worth $30 Billion**
**Intense capital investment**
**$50-70K per acre to acquire land**
**Produces nearly 80% of U.S premium wine**
**Highly sensitive to weather events**

In collaboration with Mondavi Wineries

# Grapevine Growth Stages and Climate Influences

Dormancy through Bud Break: Effective Chilling Units (+) (bud hardiness, disease vectors), Hard Freezes (-), and Rainfall (+)

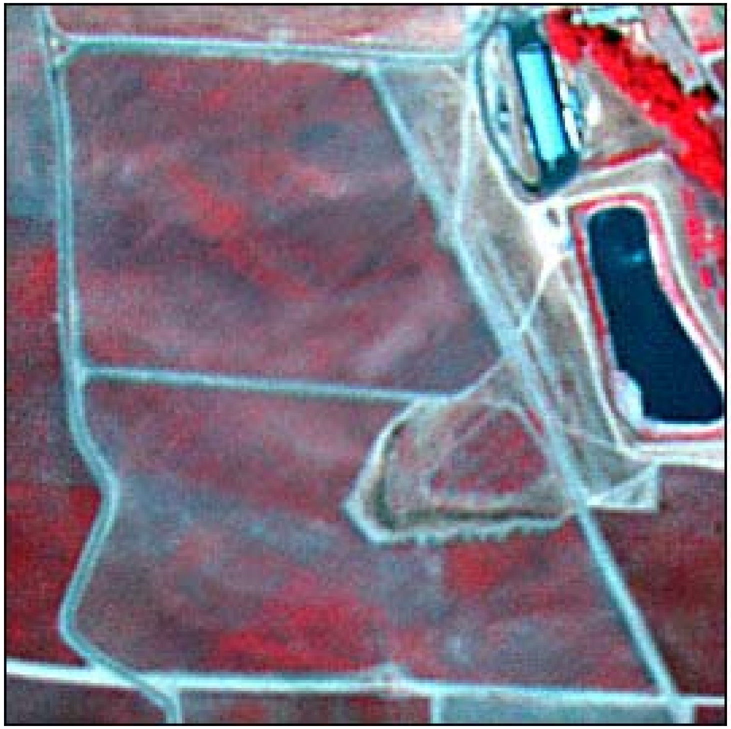
Floraison: Insolation (+), Frosts (-), and Storminess (-)



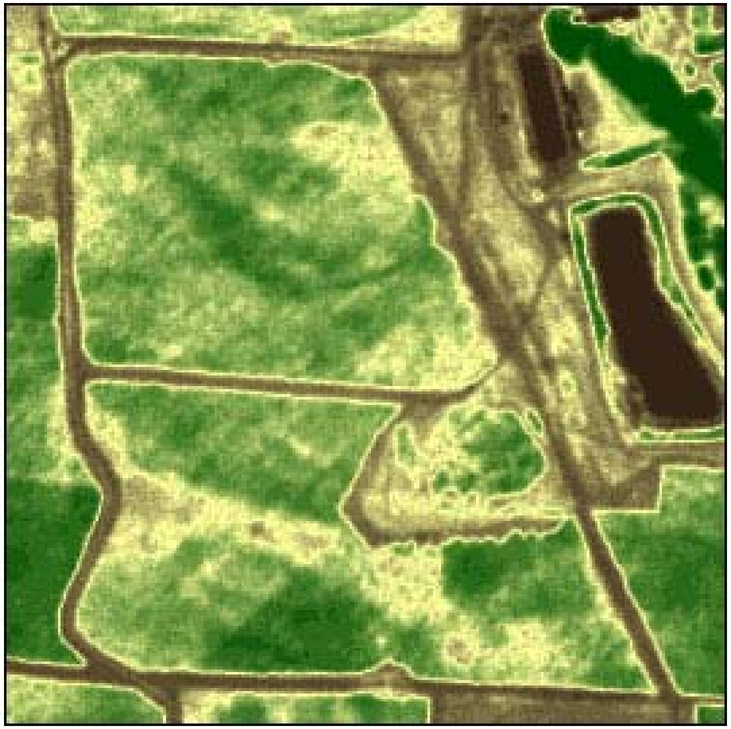
Veraison: Insolation (+), Heat Accumulation (+), and Low Temperature Variability (+)

Harvest: Insolation (+), Heat Accumulation (+), Low Temperature Variability (+), and Rainfall (-)

# Satellite data help in vineyard management
# Eye in the sky knows a lot more



Multispectral data from IKONOS



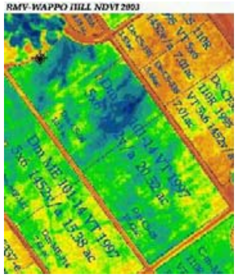
Map of leaf area index

Seasonal

Large spatial variability within a block results in poor wine quality

# TOPS Irrigation Scheduling

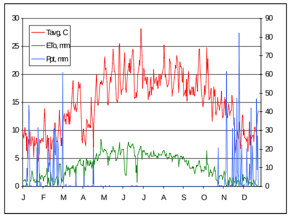
**LAI from NDVI Imagery**



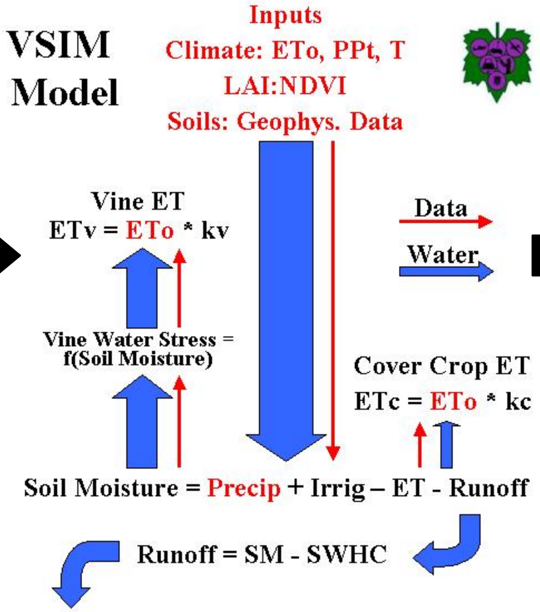

**Limited Farm-scale Soils Data**

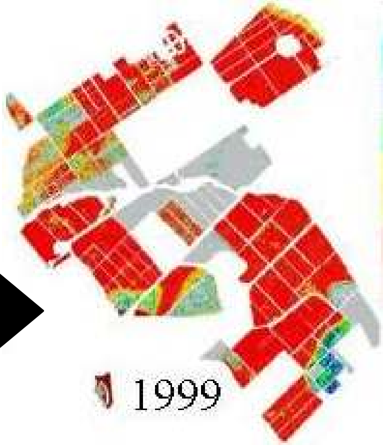
**Crop Params from Variety**

**Met Data from CIMIS**




**Forecast from NWS**




**Irrigation Forecasts**
**Crop Monitoring**

Inputs → Modeling → Outputs

# Irrigation Forecast for week of July 19-26, 2005

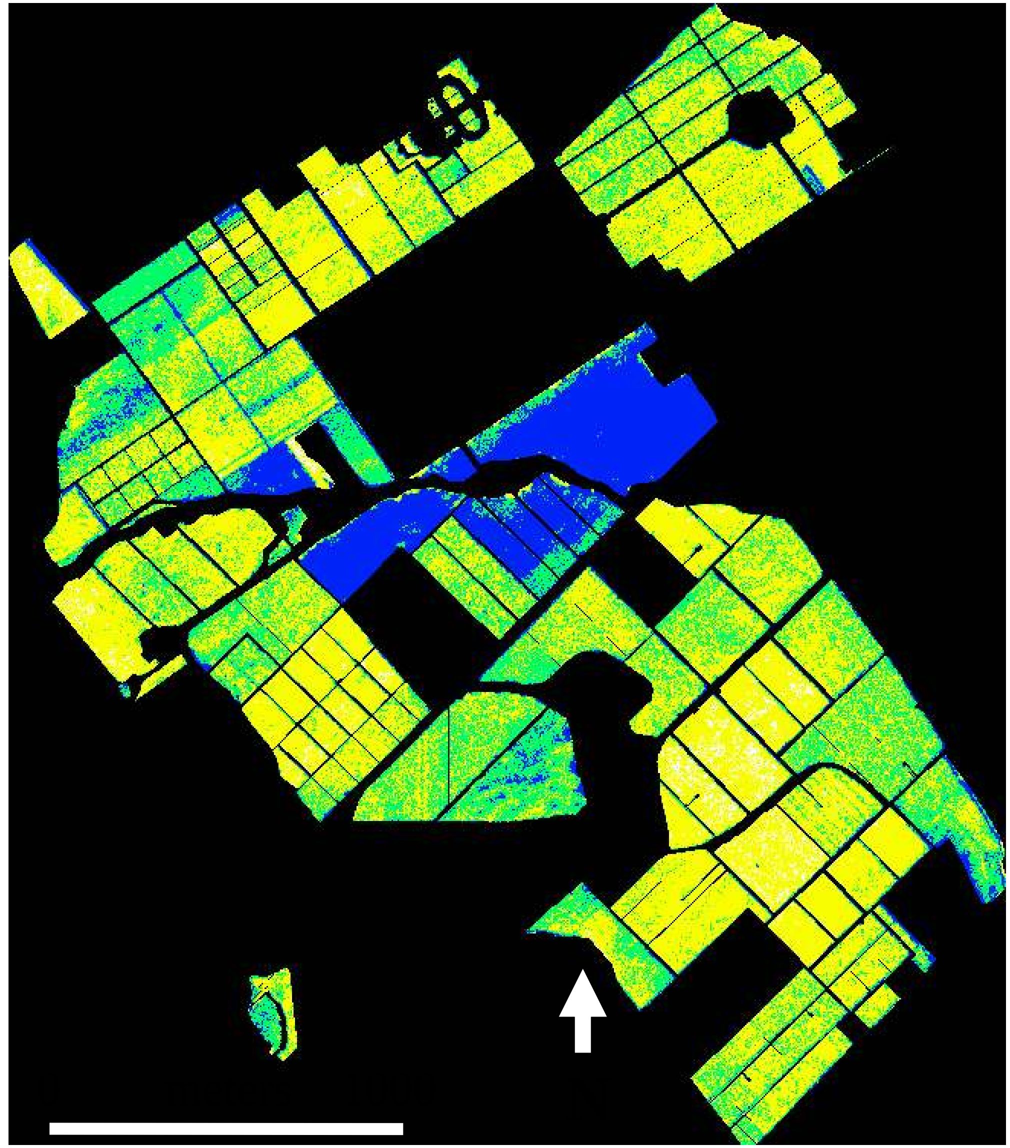
## Tokalon Vineyard, Oakville, CA

CIMIS Measured Weather Data through July 18, 2005

NWS Forecast Weather Data July 19-26, 2005

0 30

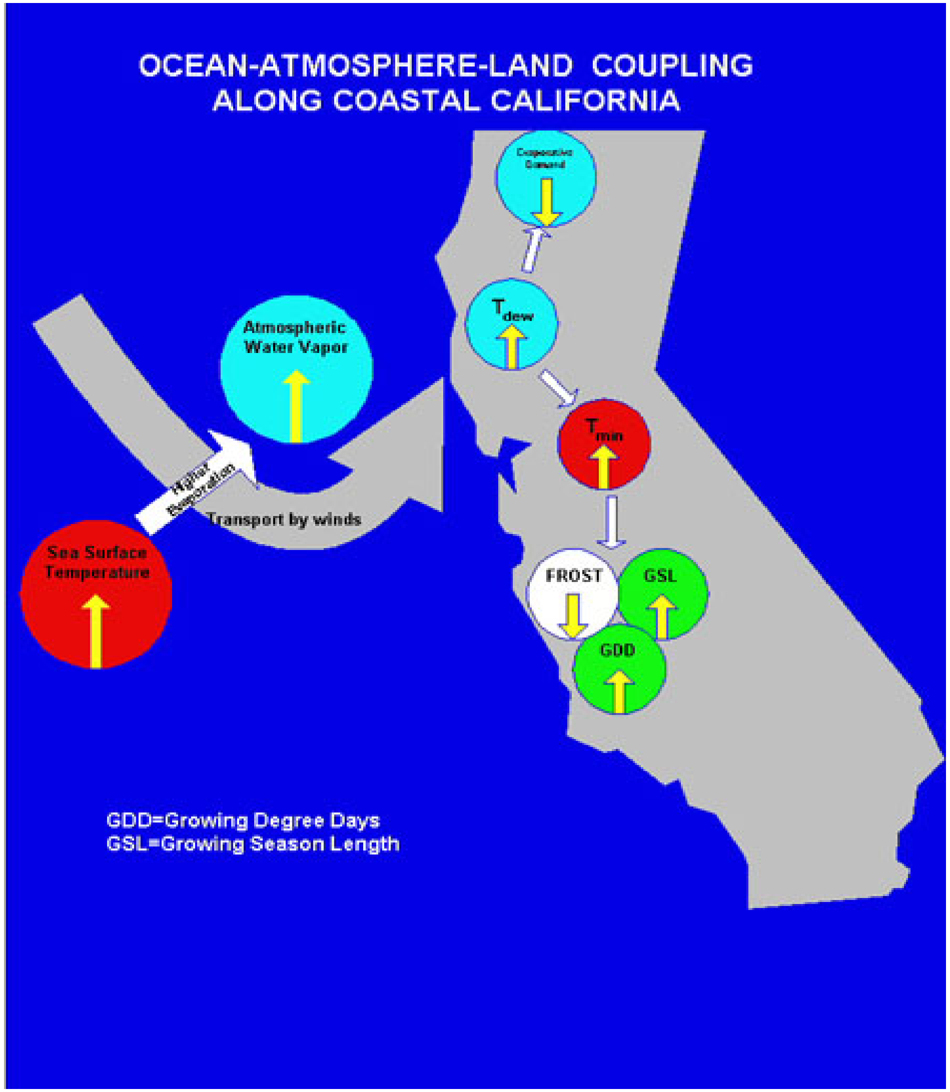
Forecast Irrigation (mm)



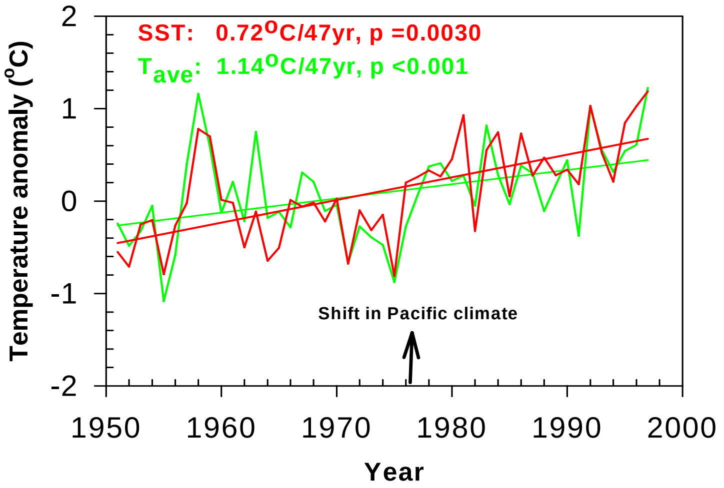


Fully automated web delivery to growers

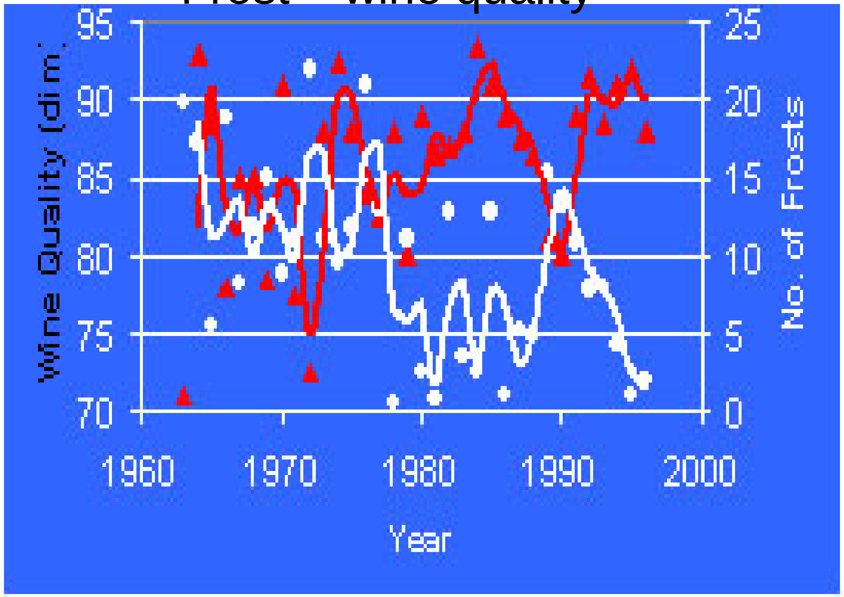
# Strong maritime influence creates ideal wine producing climate




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



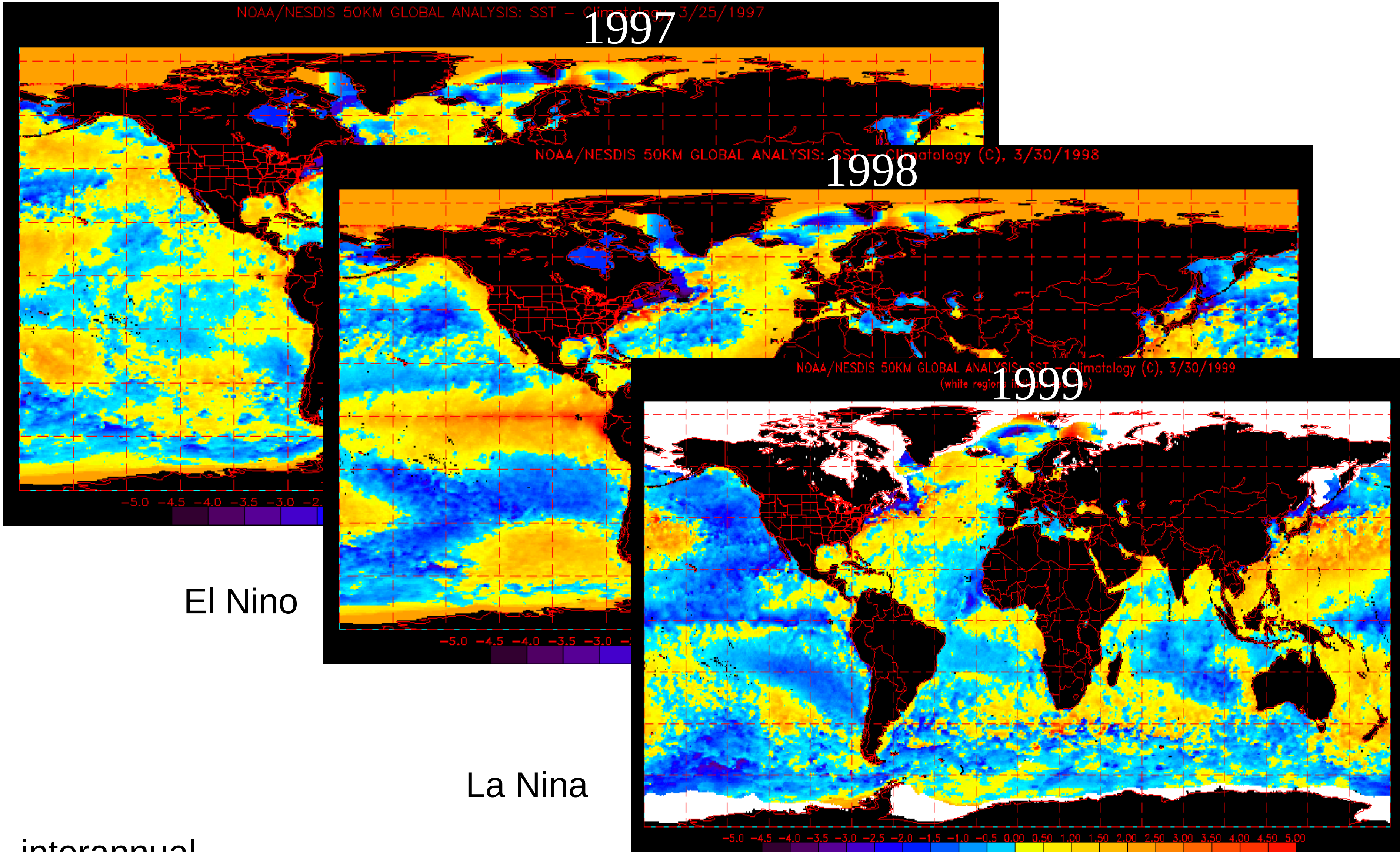

Frost – wine quality




interannual

Nemani et al., 2001 Climate Research, 19: 25-34

# Interannual changes in SST from Satellites



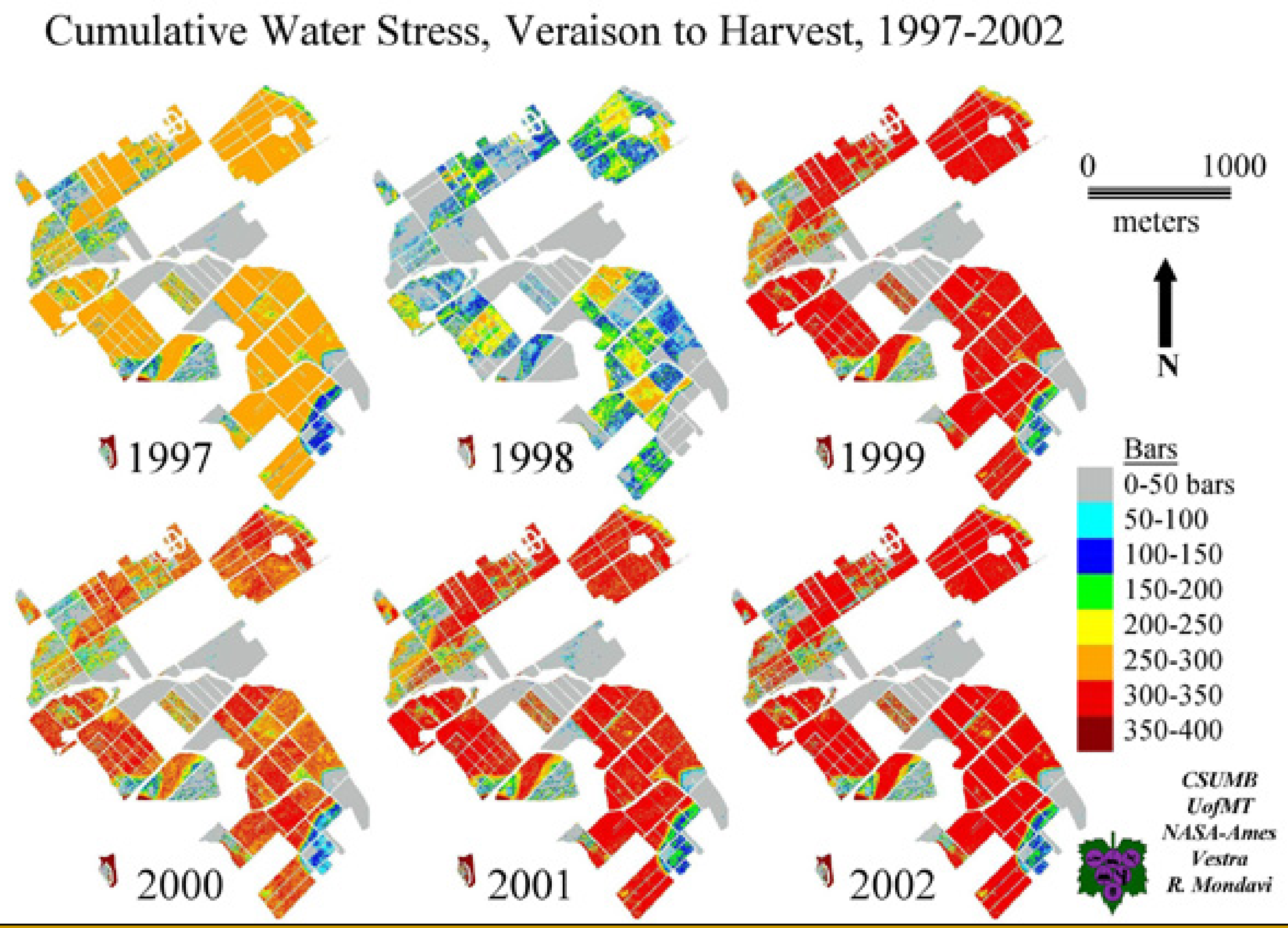

El Nino

La Nina

interannual

# Modeled water stress as a predictor of vintage

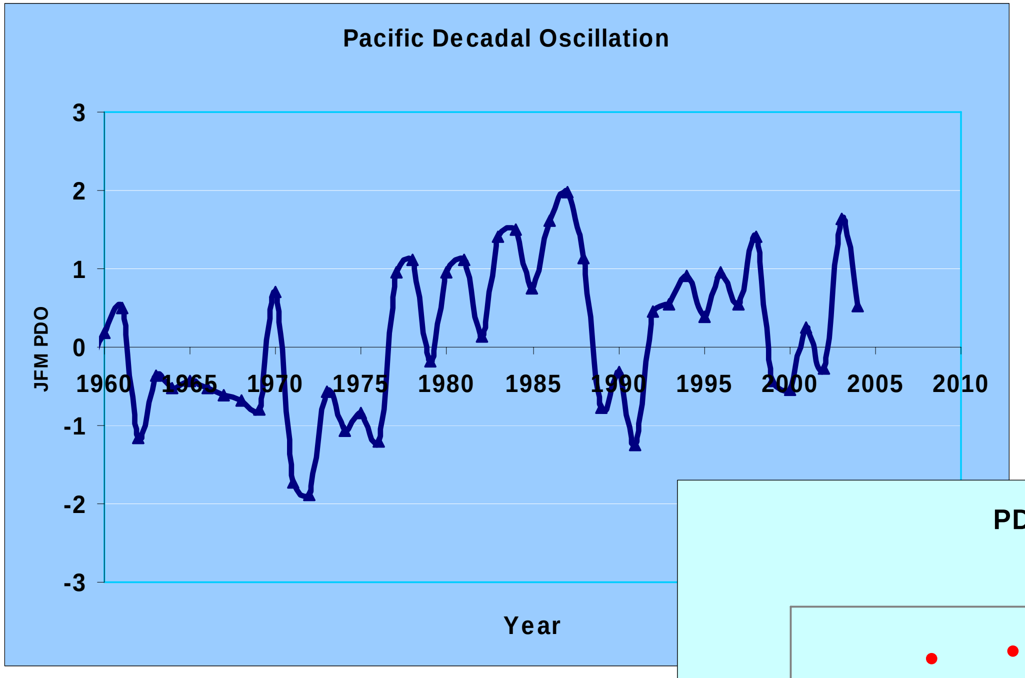
## 1997 moderate water stress, best vintage

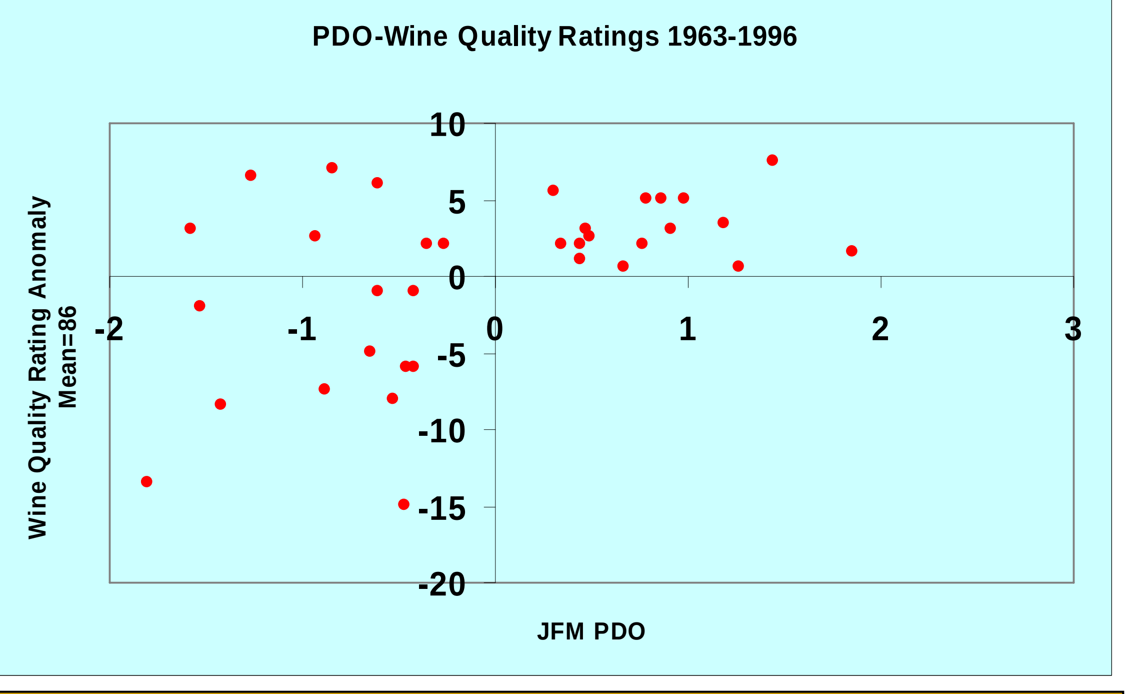



interannual

1998 is warm and wet, 1999 cool, dry

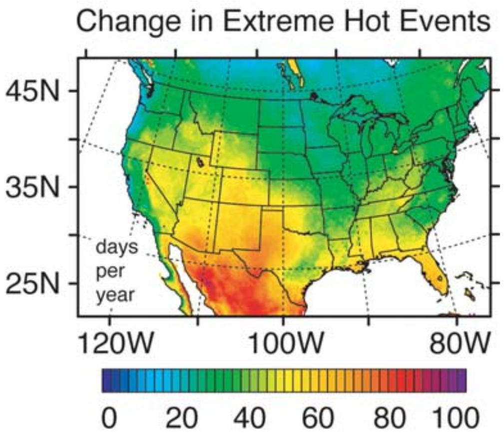
# Predictability on the decadal scales

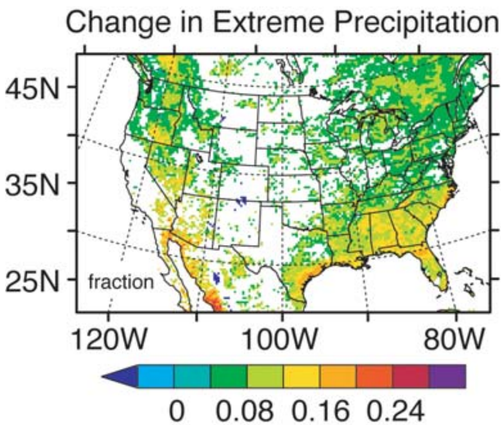



decadal

# Long-term viability of premium wine industry: *seriously in doubt*

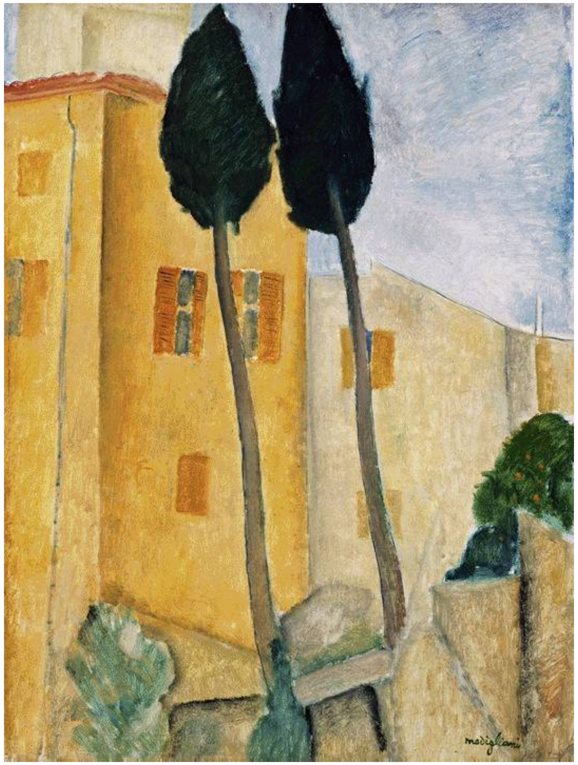



- Extremes in temperatures are difficult to protect against
- Hot Events are particularly difficult
- Currently, Napa valley averages about 3-4 days with temperatures above 95F
- Projected number of days with extreme temperatures is over 20
- Projections do not include additional rainfall, creating extremely difficult water management issues

Diffenbaugh et al., PNAS, 102: 15774-15778

# What do we need to accelerate ecological forecasting?



Amedeo Modigliani (1884-1920)
Cypress Trees (1919)
Barnes Foundation

- **Retaining and upgrading remote sensing platforms that measure land-surface, freshwater, and ocean conditions**
- **Improved biophysical data (extent and scale)**
- **Improved models/linkages among models**
- **Improved in-situ monitors of biogeochemical characteristics and processes (NEON)**
- **Improved compatibility among data (e.g., near-real time data input into models and integration with other biophysical data)**
- **Comprehensive framework and data management (IWGEO/GEOSS)**
- **Improved delivery systems to decision makers (organizations and individuals) … web-based tools/the Weather Channel**

# Further Research is required to address:

Gustav Klimt (1862-1918): Der Park (1910)
New York, Sammlung The Museum of Modern Art

- Many forecasting programs rely on rule-based models developed from space-for-time studies, need more data
- Assumption that past events reflect what will happen in the future, what about
  - Sequence and frequency of events/drivers/stressors
  - Changes in scaling functions
- Non-linearity of responses and new thresholds

# Summary

Willem de Kooning (1904-1997)
A Tree in Naples (1960)
Museum of Modern Art

**potential for mimicking the weather services with ecological forecasts of various lead times.**

**characterizing and communicating the uncertainty in ecological forecasts remains a challenge.**

**producing the forecasts may be the easy part, convincing the users may take years and careful communication.**

**more information at: http://ecocast.arc.nasa.gov**

**the end**