An Overview of Ecological Modeling and Machine Learning Research Within the U.S. National Aeronautics and Space Administration

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Earth Science http://is.arc.nasa.gov

Purpose of Presentation

- Describe the goals, organization and significance of the research and technology development within NASA and provide examples of how NASA achieves these goals via programs.

Outline

- Background
  - Earth Science
    - Why NASA
    - Past work 80-present
    - Earth Observing System (EOS)
  - Machine Learning
    - Intelligent Systems
  - Population models – Watson
  - Coupled models – Vadium
  - Ecoforecasting
  - Science paper

Machine Learning

- *Machine Learning is the study of computer algorithms that improve automatically through experience.*
  - Machine Learning, Tom Mitchell, McGraw Hill, 1997.

- *Machine Learning is … research on computational approaches to learning.*
  - Machine Learning, Kluwer

- Learning Problems: Classification, regression, recognition, and prediction; Problem solving and planning; Reasoning and inference; Data mining; Web mining; Scientific discovery; Information retrieval; Natural language processing; Design and diagnosis; Vision and speech perception; Robotics and control; Combinatorial optimization; Game playing; Industrial, financial, and scientific applications of all kinds.

- Learning Methods: Supervised and unsupervised learning methods (including learning decision and regression trees, rules, connectionist networks, probabilistic networks and other statistical models, inductive logic programming, case-based methods, ensemble methods, clustering, etc.); Reinforcement learning; Evolution-based methods; Explanation-based learning; Analogical learning methods; Automated knowledge acquisition; Learning from instruction; Visualization of patterns in data; Learning in integrated architectures; Multistrategy learning; Multi-agent learning.

Environmental & Ecology

- Environmental: Relating to or being concerned with the ecological impact of altering the environment
- Ecology: The science of the relationships between organisms and their environments
- Environment The totality of circumstances surrounding an organism or group of organisms, especially:
  - The combination of external physical conditions that affect and influence the growth, development, and survival of organisms: “We shall never understand the natural environment until we see it as a living organism” (Paul Brooks).
  - The complex of social and cultural conditions affecting the nature of an individual or community.

– Dictionary.com

US funding of Earth Science

- Who pays for federal Earth science research and applications in the United States?

  Definition: Any of the sciences that deal with the Earth or its parts.

  - NSF - National Science Foundation
  - **DOE** - Department of Energy (CO_2)
  - **EPA**- Environmental Protection Agency
  - **Dept of Commerce** / NOAA - National Oceanic and Atmospheric Administration
  - **Dept Agriculture** / USFS - US Forest Service
  - **Dept of Interior** / NPS National Park Service; BLM - Bureau Land Management / USGS - US Geologic Survey
  - NASA - National Aeronautic and Space Administration
    - NASA Funds Earth science because of NASA's unique vantage point from space. NASA develops technology to make measurements (observations) and build predictive models of the Earth system.

  - No single agency is assigned the lead role for research and monitoring of climate or global environmental change.

Why NASA

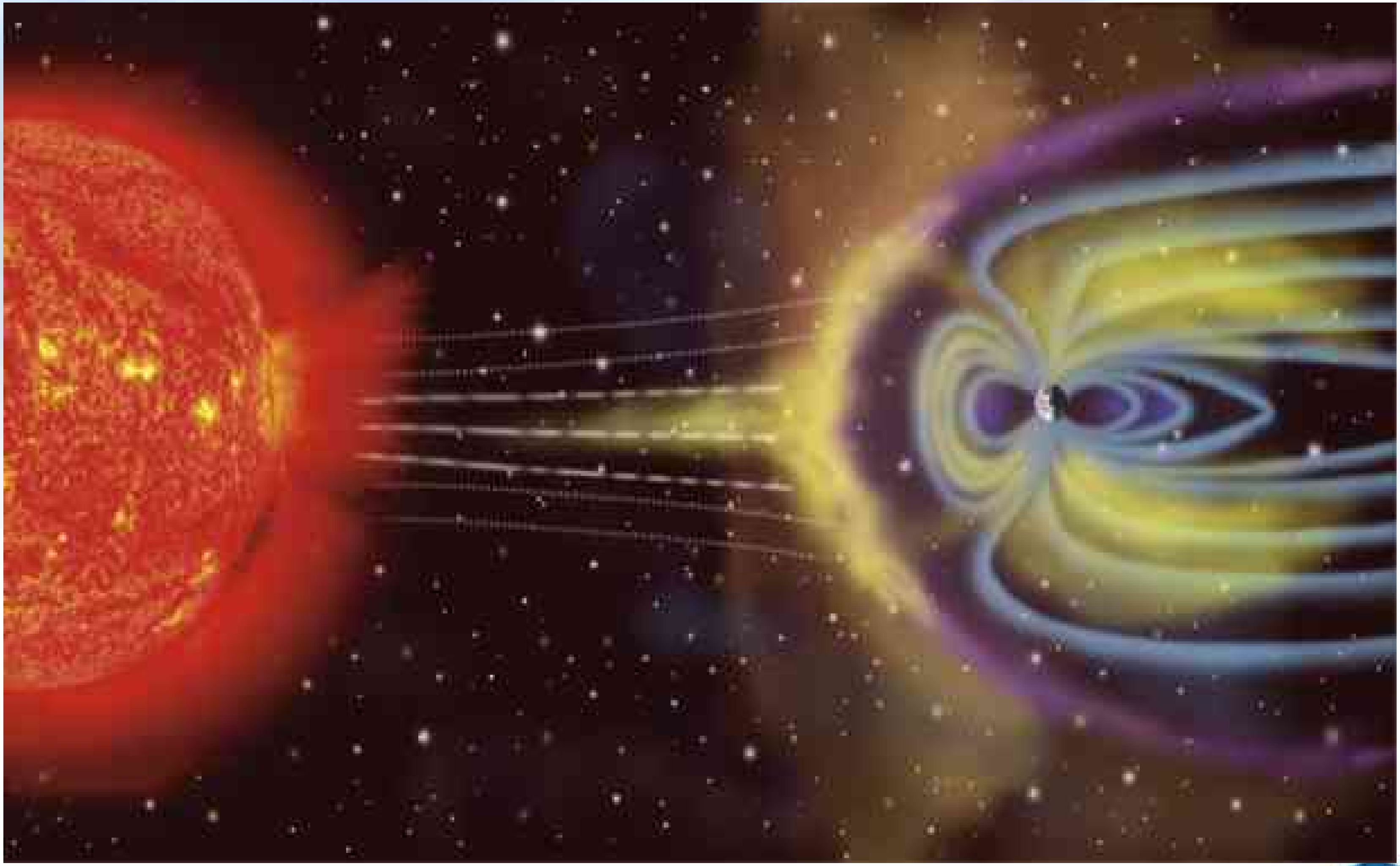
– **The NASA Vision**
To improve life here,
To extend life to there,
To find life beyond
...as only NASA can.

– **NASA Mission Statement:**
To understand and protect our home planet
To explore the universe, and search for life
To inspire the next generation of explorers, as only NASA can.

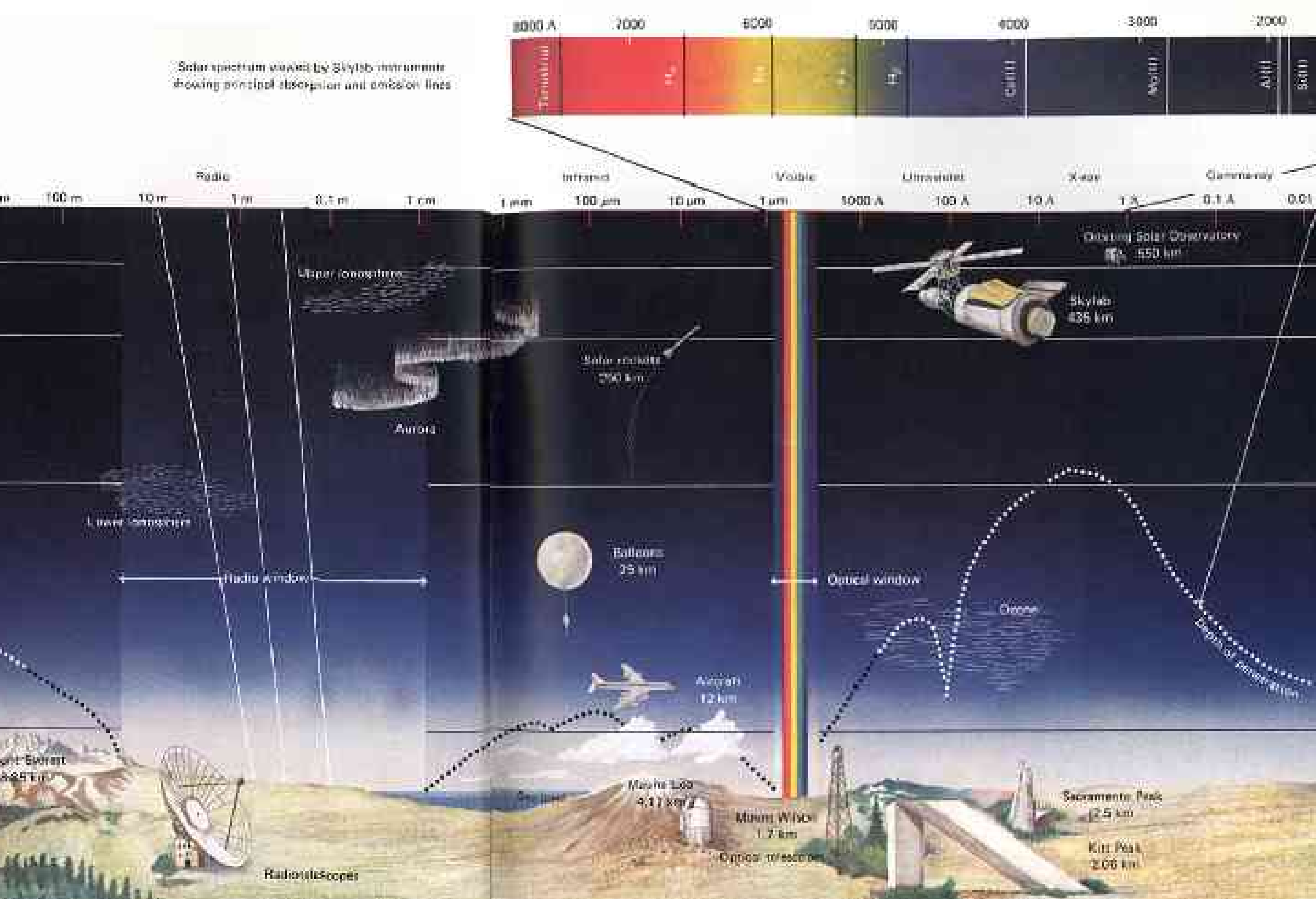
– **1958 NASA Mission Statement**
To advance and communicate scientific knowledge and understanding of the Earth, the solar system, and the universe and use the environment of space for research. To explore, use, and enable the development of space for human enterprise. To research, develop, verify, and transfer advanced aeronautics, space, and related technologies.

Relationship Between Local, Regional, Global and…

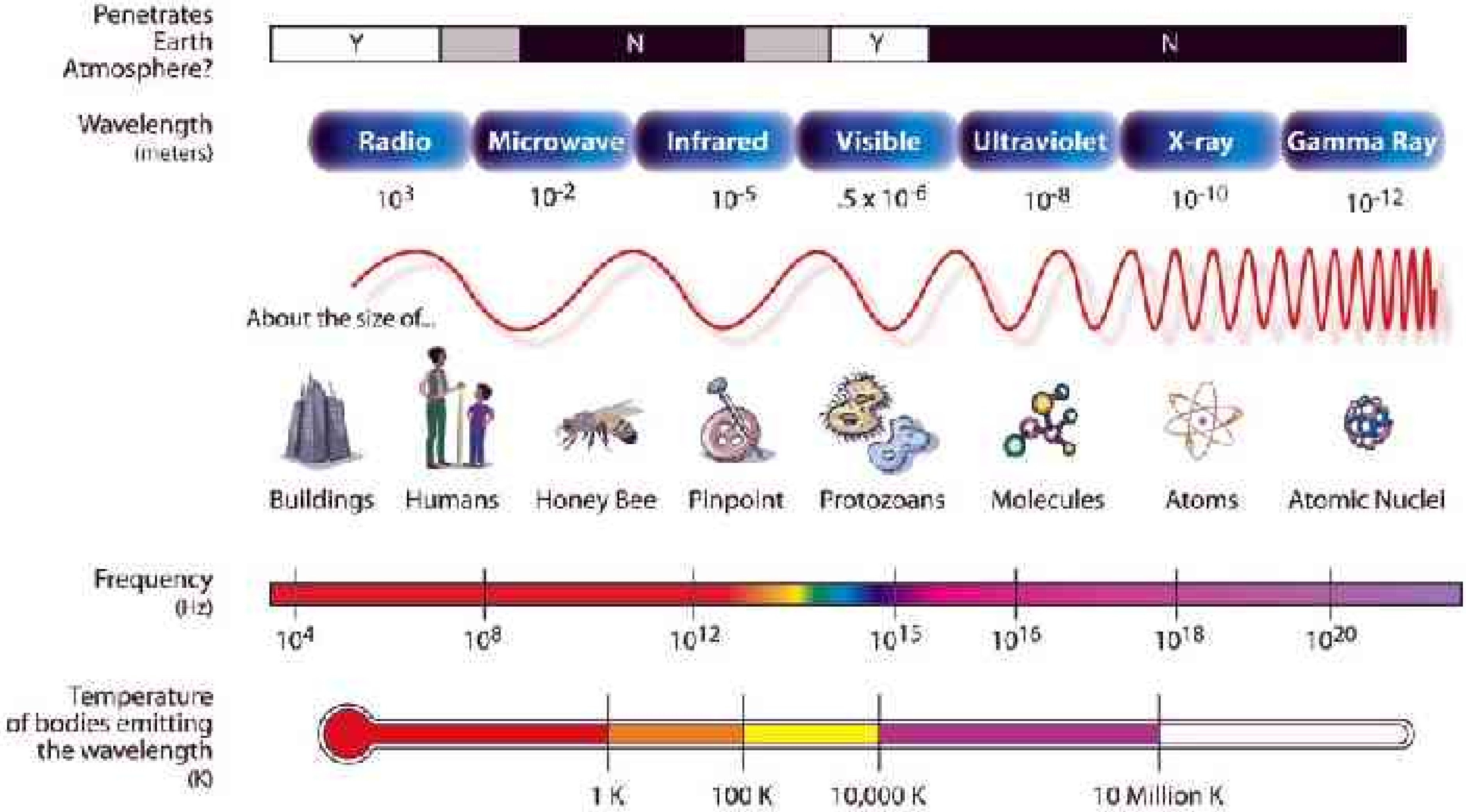
…Extraterrestrial: Living with a Star



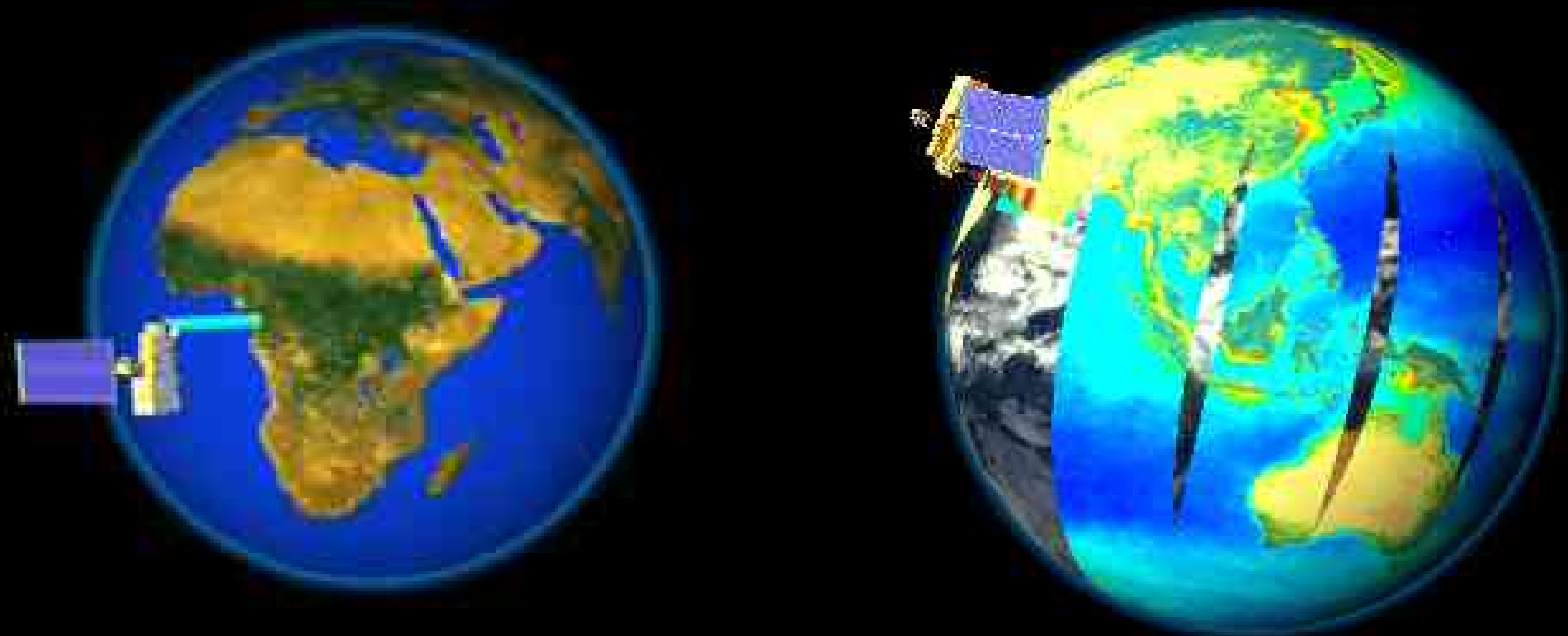
Extraterrestrial Electromagnetic Energy that Reaches the Earth



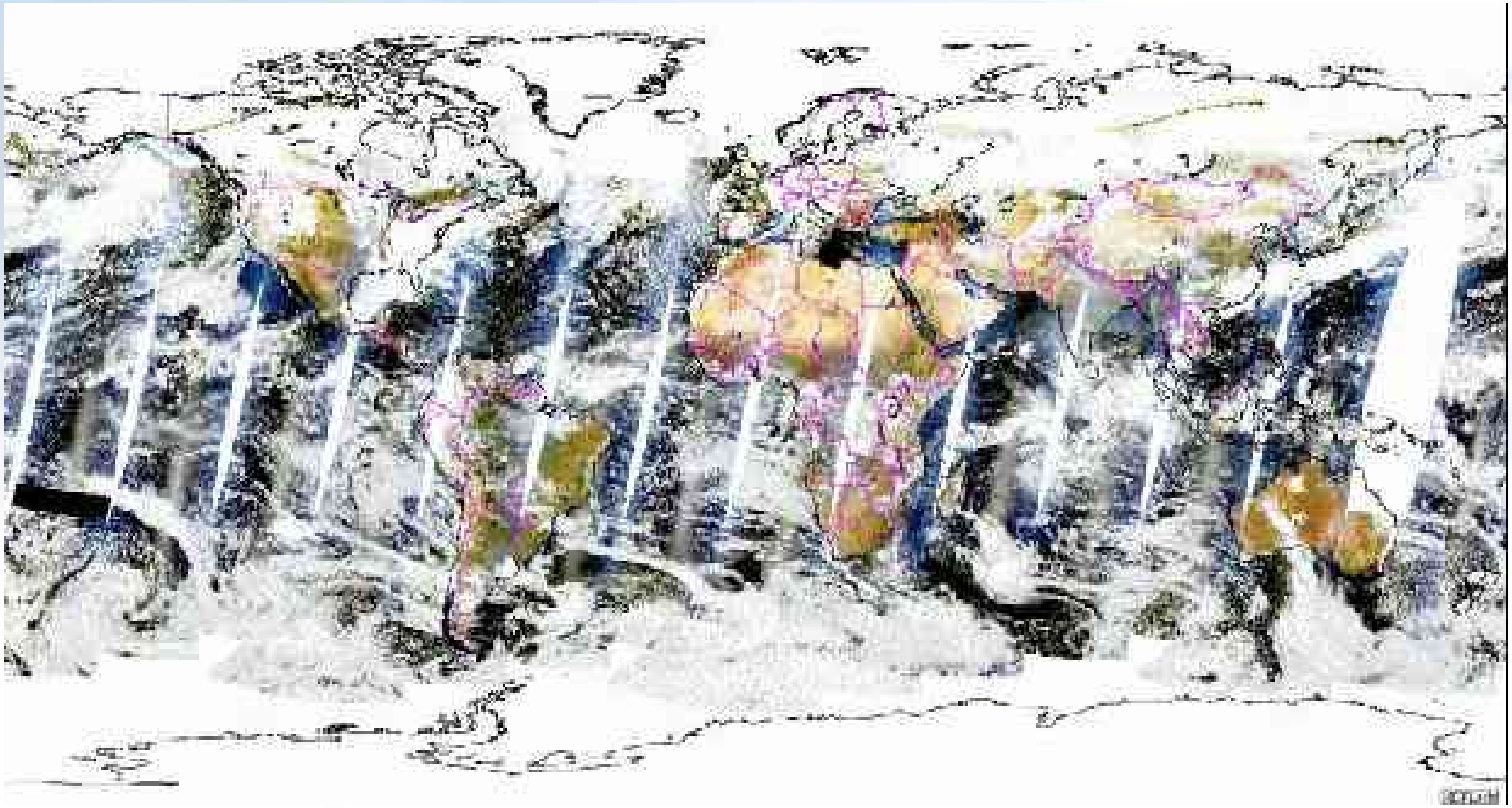
THE ELECTROMAGNETIC SPECTRUM



TERRA & AQUA Platforms; MODIS Sensor Scanning the Earth

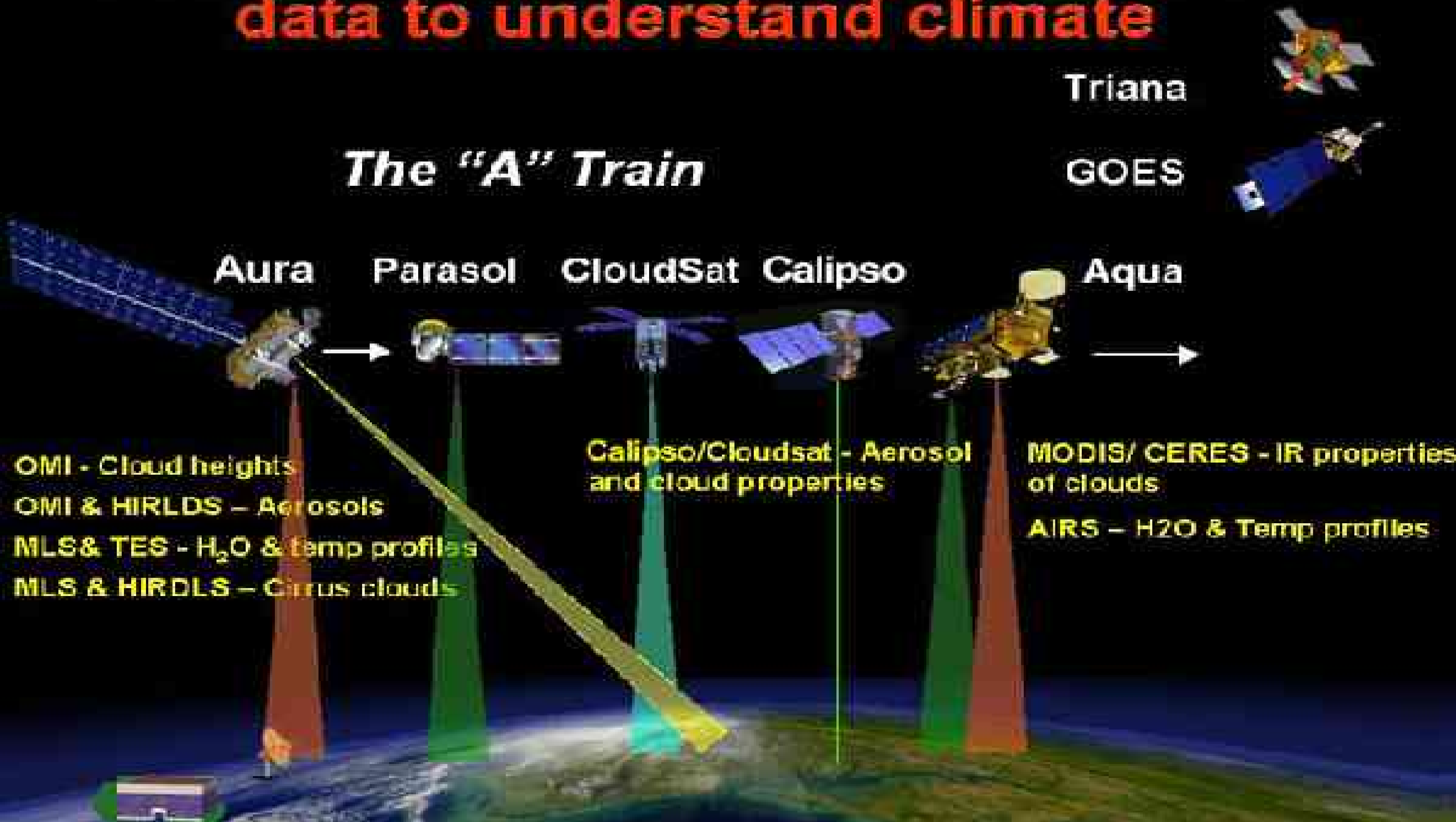


MODIS on TERRA Platform; November 16th 2002

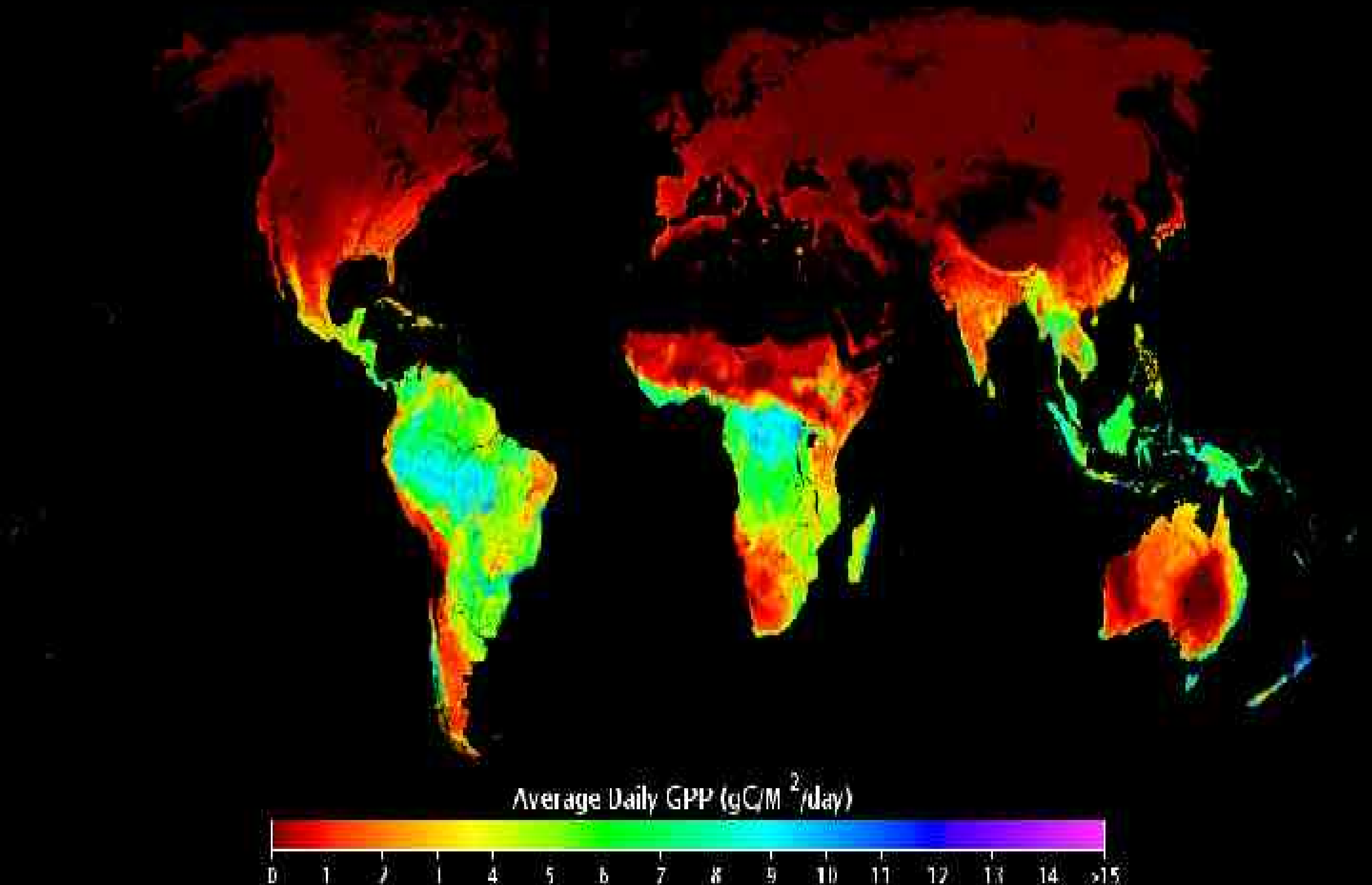


MODIS True-Color Composite
Composite Period: June-September 2001
1 kilometer resolution

Formation flying will provide better data to understand climate



MOD17A2 v105 (Enhanced GPP) over the Globe, December 27 - December 31, 2003



Example of NASA Data Product, Gross Primary Production 27-31, 12, 2003

24 EOS Measurements

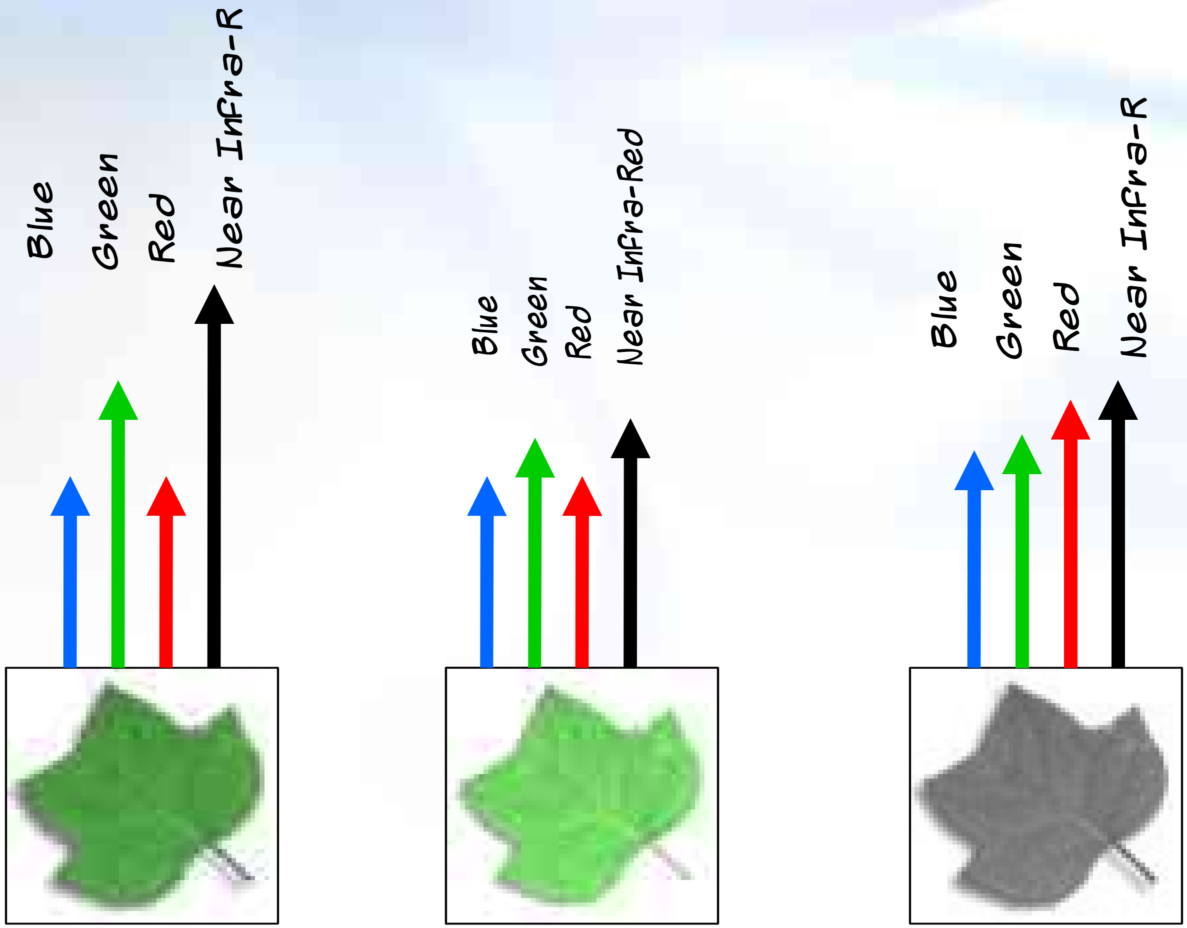
ATMOSPHERE	**Cloud Properties** ***(amount, optical properties, height)***	**MODIS, GLAS, AMSR-E, *MISR, AIRS, ASTER*,** SAGE III
	Radiative Energy Fluxes ***(top of atmosphere, surface)***	**CERES, ACRIM III, MODIS, AMSR-E, *GLAS, MISR, AIRS*,** ASTER, SAGE III
	Precipitation	**AMSR-E**
	Tropospheric Chemistry ***(ozone, precursor gases)***	**TES, MOPITT,** SAGE III, MLS, HIRDLS, LIS
	Stratospheric Chemistry ***(ozone, ClO, BrO, OH, trace gases)***	**MLS, HIRDLS, SAGE III, OMI, *TES***
	Aerosol Properties ***(stratospheric, tropospheric)***	**SAGE III, *HIRDLS*** **MODIS, MISR, *OMI*, GLAS**
	Atmospheric Temperature	**AIRS/AMSU-A, MLS, *HIRDLS*,** TES, MODIS
	Atmospheric Humidity	**AIRS/AMSU-A/HSB, *MLS, SAGE III, HIRDLS*,** Poseidon 2/JMR/DORIS, MODIS, TES
	Lightning ***(events, area, flash structure)***	**LIS**
SOLAR RADIATION	**Total Solar Irradiance**	**ACRIM III, TIM**
	Solar Spectral Irradiance	**SIM, SOLSTICE**

24 EOS Measurements

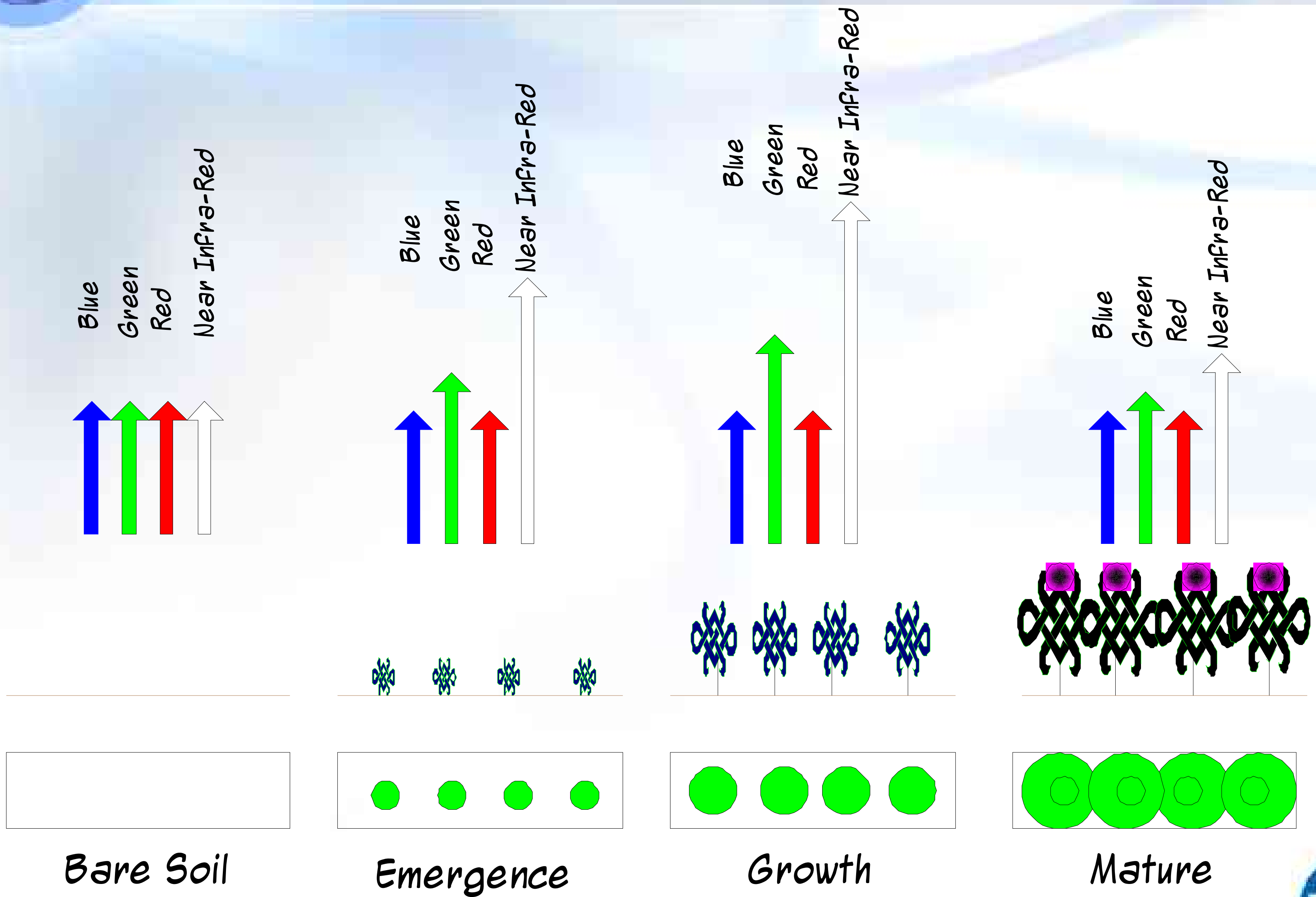
LAND	**Land Cover & Land Use Change**	**ETM+, MODIS, *ASTER, MISR***
	Vegetation Dynamics	**MODIS, MISR, ETM+, *ASTER***
	Surface Temperature	**ASTER, MODIS, *AIRS*, *AMSR-E***, ETM+
	Fire Occurrence ***(extent, thermal anomalies)***	**MODIS, ASTER, *ETM+***
	Volcanic Effects ***(frequency of occurrence, thermal anomalies, impact)***	**MODIS, ASTER, ETM+, *MISR***
	Surface Wetness	**AMSR-E**
OCEAN	**Surface Temperature**	**MODIS, AIRS, *AMSR-E***
	Phytoplankton & Dissolved Organic Matter	**MODIS**
	Surface Wind Fields	**SeaWinds, *AMSR-E***, Poseidon 2/JMR/DORIS
	Ocean Surface Topography ***(height, waves, sea level)***	**Poseidon 2/JMR/DORIS**

24 EOS Measurements

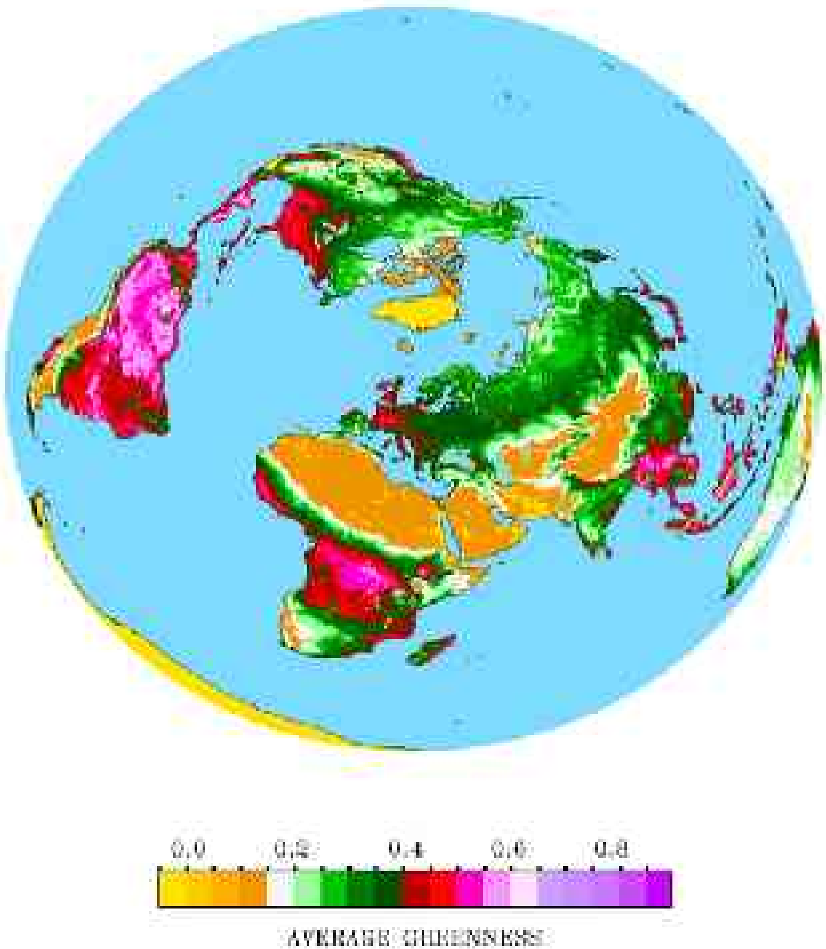
CRYOSPHERE	**Land Ice** *(ice sheet topography, ice sheet volume change, glacier change)*		GLAS, ASTER, ETM+
	Sea Ice *(extent, concentration, motion, temperature)*		**AMSR-E**, ***Poseidon 2/JMR/DORIS,*** MODIS, ETM+, ASTER
	Snow Cover *(extent, water equivalent)*		**MODIS, AMSR-E,** ***ASTER, ETM+***



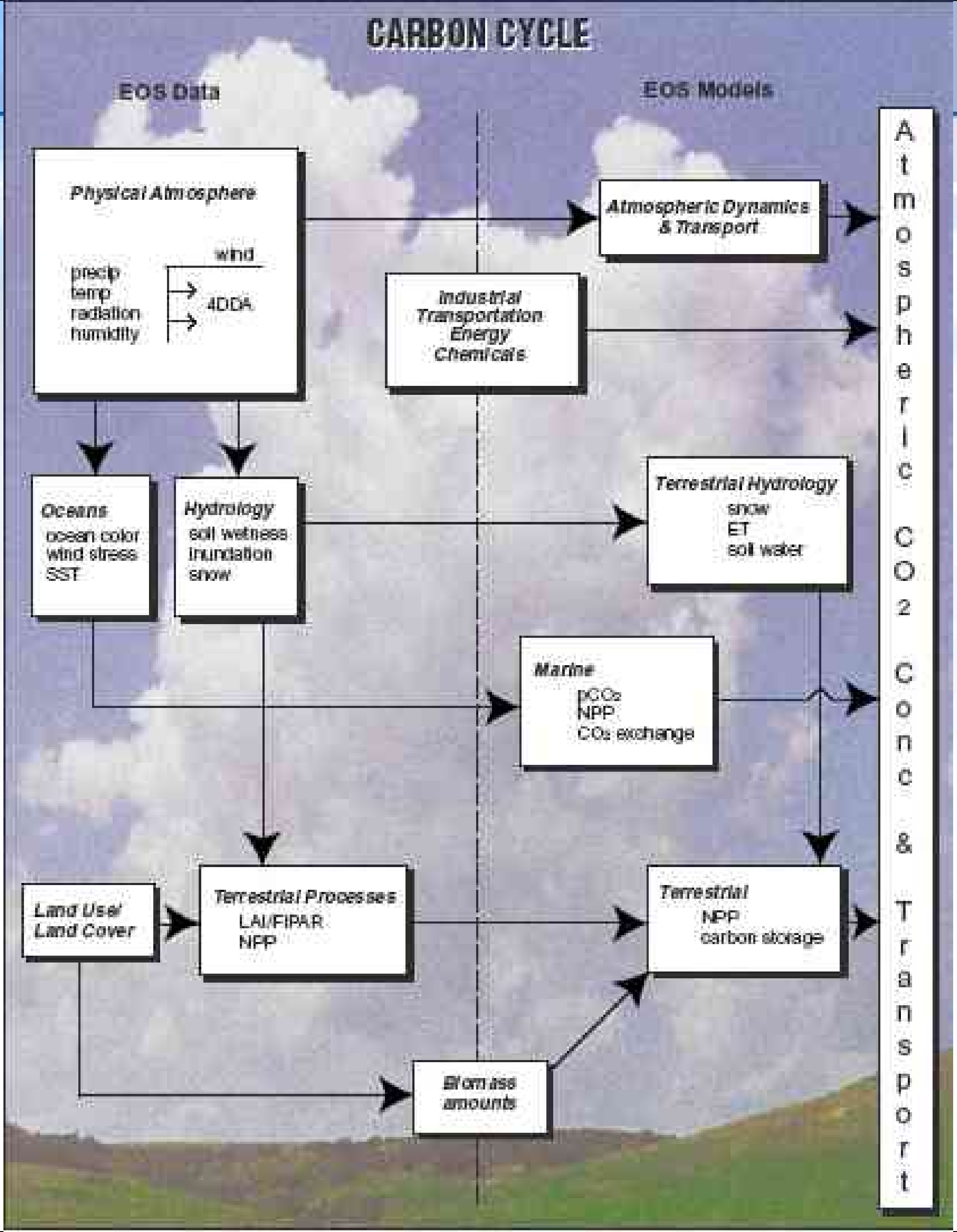
Healthy leaf Sick leaf Dead leaf

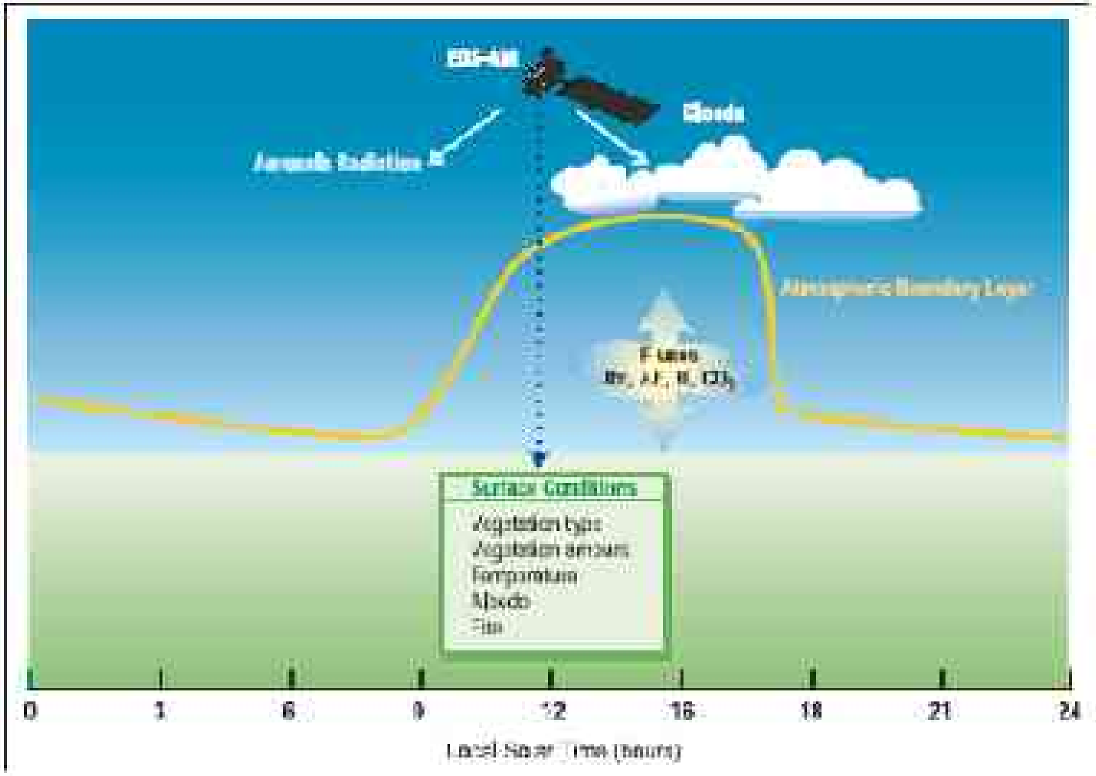

Blue
Green
Red
Near Infra-Red
Blue
Green
Red
Near Infra-Red
Blue
Green
Red
Near Infra-Red
Blue
Green
Red
Near Infra-Red
Bare Soil
Emergence
Growth
Mature

A Satellite Based Vegetation Index (NDVI) (1981 to present)

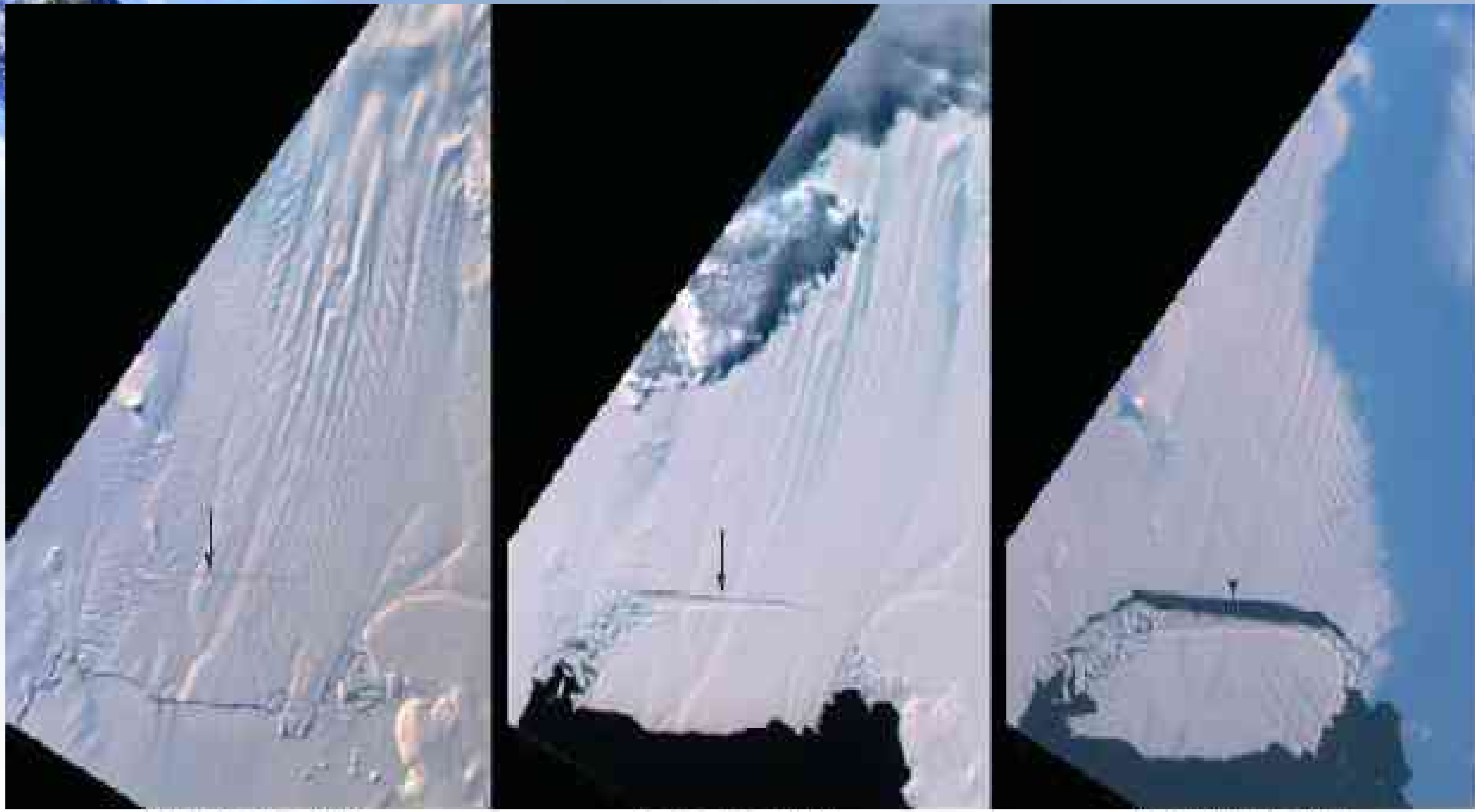


Rene Magritte (1989-1967)
The Beautiful Season


CARBON CYCLE
EOS Data
EOS Models
Physical Atmosphere
wind
precip
temp
radiation
humidity
4DDA
Atmospheric Dynamics & Transport
Industrial
Transportation
Energy
Chemicals
Oceans
ocean color
wind stress
SST
Hydrology
soil wetness
inundation
snow
Terrestrial Hydrology
snow
ET
soil water
Marine
pCO2
NPP
CO2 exchange
Land Use/ Land Cover
Terrestrial Processes
LAI/FIPAR
NPP
Terrestrial
NPP
carbon storage
Biomass amounts
Atmospheric CO2 Conc & Transport



AM-1 Platform diagram showing types of measurements made from the EOS AM-1 satellite platform that will contribute to parameterization and testing of land-surface models. Note that the morning equatorial overpass will improve measurements of surface conditions by avoiding interference from afternoon convective clouds.



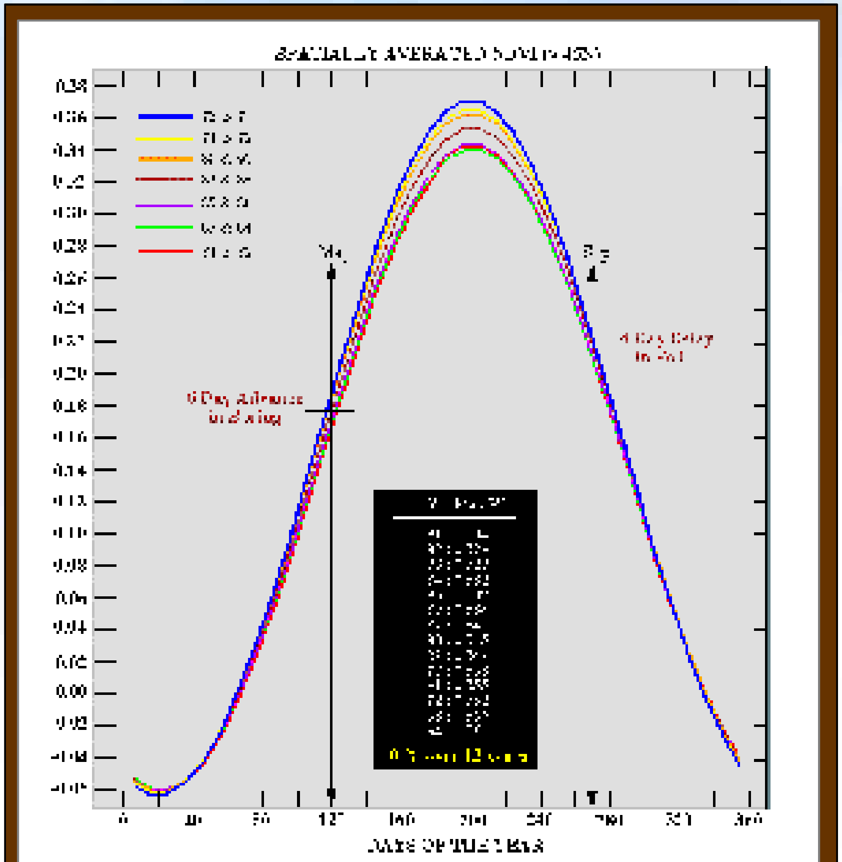
September 16, 2000 | November 4, 2001 | November 12, 2001

Land Cover Land Use Change & Ecology

- **Land Cover Land Use Change**
  http://www.usgcrp.gov/usgcrp/ProgramElements/land.htm
  - What tools or methods are needed to better characterize historic and current land-use and land-cover attributes and dynamics?
  - What are the primary drivers of land-use and land-cover change?
  - What will land-use and land-cover patterns and characteristics be 5 to 50 years into the future?
  - How do climate variability and change affect land use and land cover, and what are the potential feedbacks of changes in land use and land cover to climate?
  - What are the environmental, social, economic, and human health consequences of current and potential land-use and land-cover change over the next 5 to 50 years?

- **Ecology**
  http://www.usgcrp.gov/usgcrp/ProgramElements/bio.htm
  - What are the most important feedbacks between ecological systems and global change (especially climate), and what are their quantitative relationships?
  - What are the potential consequences of global change for ecological systems?
  - What are the options for sustaining and improving ecological systems and related goods and services, given projected global changes?

Satellite Observed: Longer growing season trend in the north (1980s)



From Myneni et al. (Nature, 386:698-701, 1997)

Analyses of two independent data sets for the period 1981 to 1994 suggest that -

- Vegetation greenness averaged over the peak boreal growing season months of July and august increased by 10%

- The timing of spring green-up advanced by about 6 days

- The satellite data are concordant with an increase in the ampli-

tude of the seasonal cycle of atmospheric CO_2 exceeding 20% since the early 1970s, and an advance in the timing of the draw-down of CO_2 in spring and early summer of up to 7 days

(Keeling et al., Nature, 382:146-149, 1996)

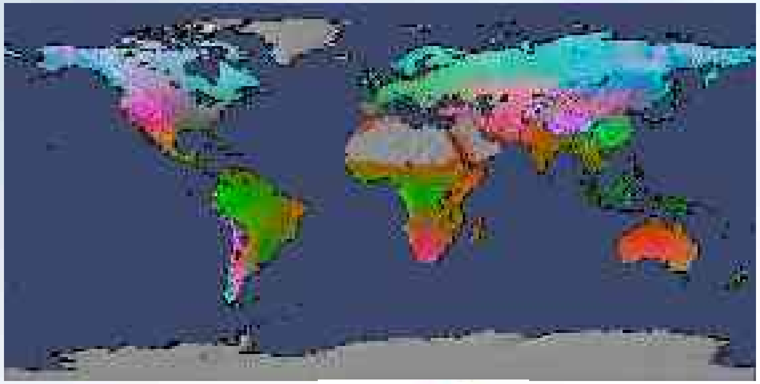
Greenness during the boreal forest growing season months of May to September increased by about 10%, the timing of spring green-up advanced by about 6 days

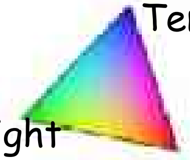
- greening in the north/the northern latitude greening trend during the 1980s & 1990s

Limiting Factors

Plant growth is assumed to be principally limited by sub-optimal climatic conditions such as low temperatures, inadequate rainfall and cloudiness (Churkina and Running, 1998). Using 1960-1990 average climate data (Leemans and Cramer, 1991) to develop scaling factors between 0 and 1 that indicate the reduction in growth potential. (0 is low and 1 high)

Potential Climate Limits for Plant Growth





Dominant Controls

water availability 40%

temperature 33%

solar radiation 27%

total vegetated area 117 M km2

- **black (no limits) and white (all at maximum limit)**
- **primary colors represent respective maximum limits**
- **cyan (temperate and radiation) represents cold winters and cloudy summers over eurasia**
- **magenta (water and temperature) represents cold winters and dry summers over western north america**
- **yellow (water and radiation) represents wet-cloudy and dry-hot periods induced by rainfall seasonality in the tropics**
- **these limits vary by season (e.g., high latitude regions are limited by temperature in the winter and by either water or radiation in the summer)**

- the greening earth and increasing terrestrial npp

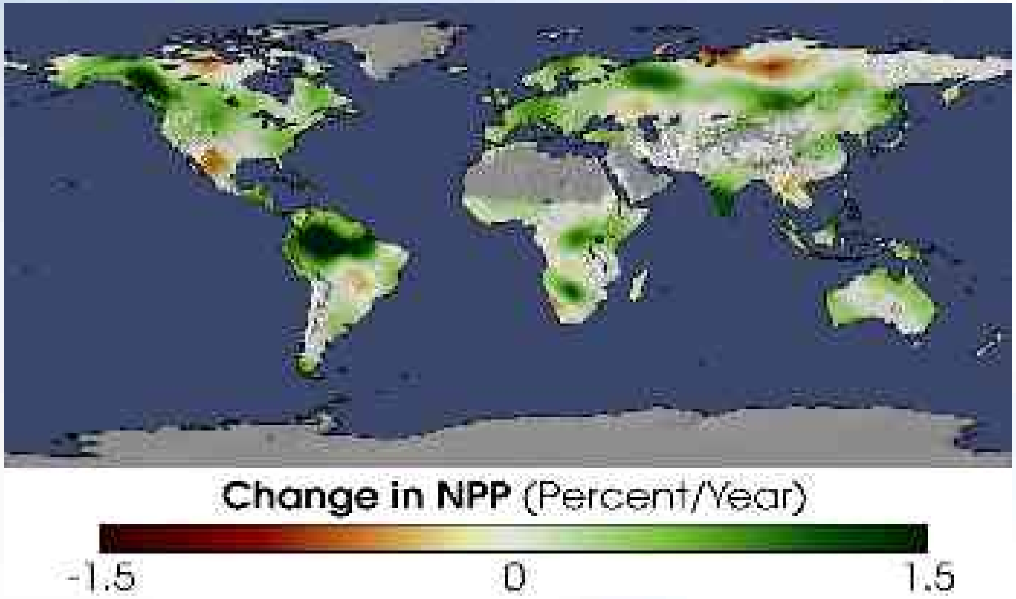
NPP: Net Primary (Plant) Production

The NPP Algorithm

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



Average of interannual trends (1982-99) in growing season NPP estimated with GIMMS and PAL (v3) FPAR

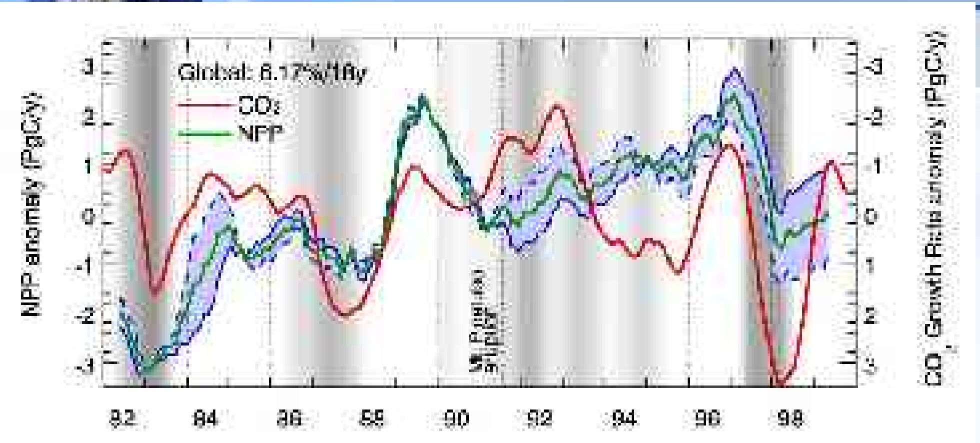
In water and radiation limited regions NPP showed the highest increase (6.5%) followed by those in temperature and radiation (5.7%), and temperature and water (5.4%) limited regions.

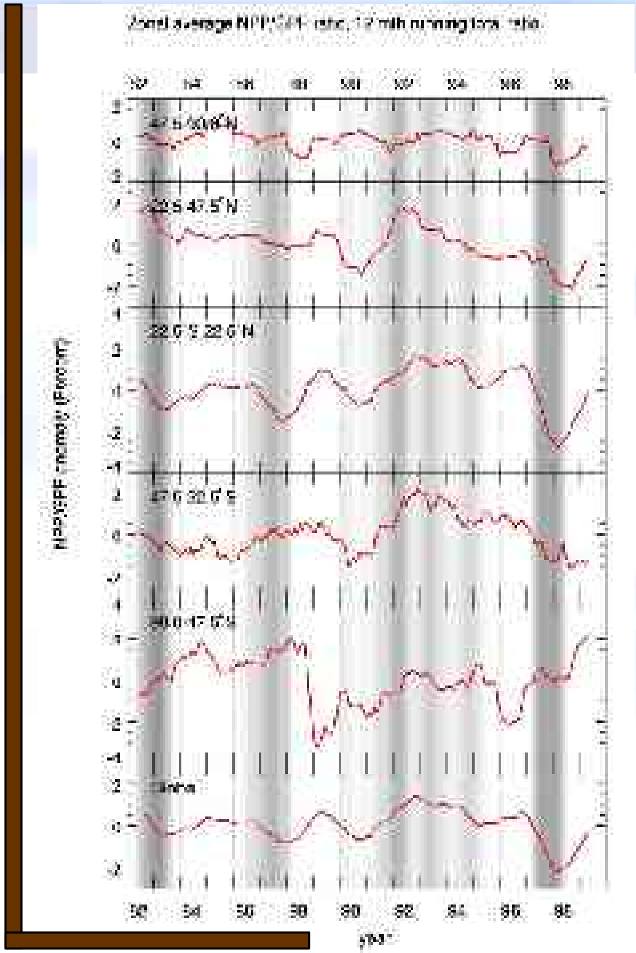
Globally all biomes, except open-shrubs, showed an increasing NPP trend from 1982 to 1999 with the largest increase in evergreen broadleaf forests.

Trends in NPP are positive over 55% of the global vegetated area and are statistically more significant than the declining trends observed over 19% of the vegetated area.

- the greening earth and increasing terrestrial npp

climate, NPP and atmospheric CO_2 growth rate





A moderately increasing trend (6% or 3.42 PgC/18yr, $p<0.001$) in global NPP was observed between 1982 and 1999, suggesting that the terrestrial biosphere may have been actively sequestering carbon in biomass.

Interannual variations in global NPP are correlated with global atmospheric CO_2 growth rates ($r = 0.70$, $p<0.001$).

NPP declined during all three El Niño events.

High CO_2 growth rates during El Niño years correspond to declines in global NPP.

Analyses of variation in the plant photosynthesis-respiration balance, expressed as NPP/GPP ratio (right panel), showed observed declines in NPP during El Niño years to be dominated by increases in respiration due to warmer temperatures.

Although the atmospheric CO_2 growth rate depends on the net air-sea and land-atmosphere exchanges, these Results highlight the preeminent role of plant growth in global carbon cycle.

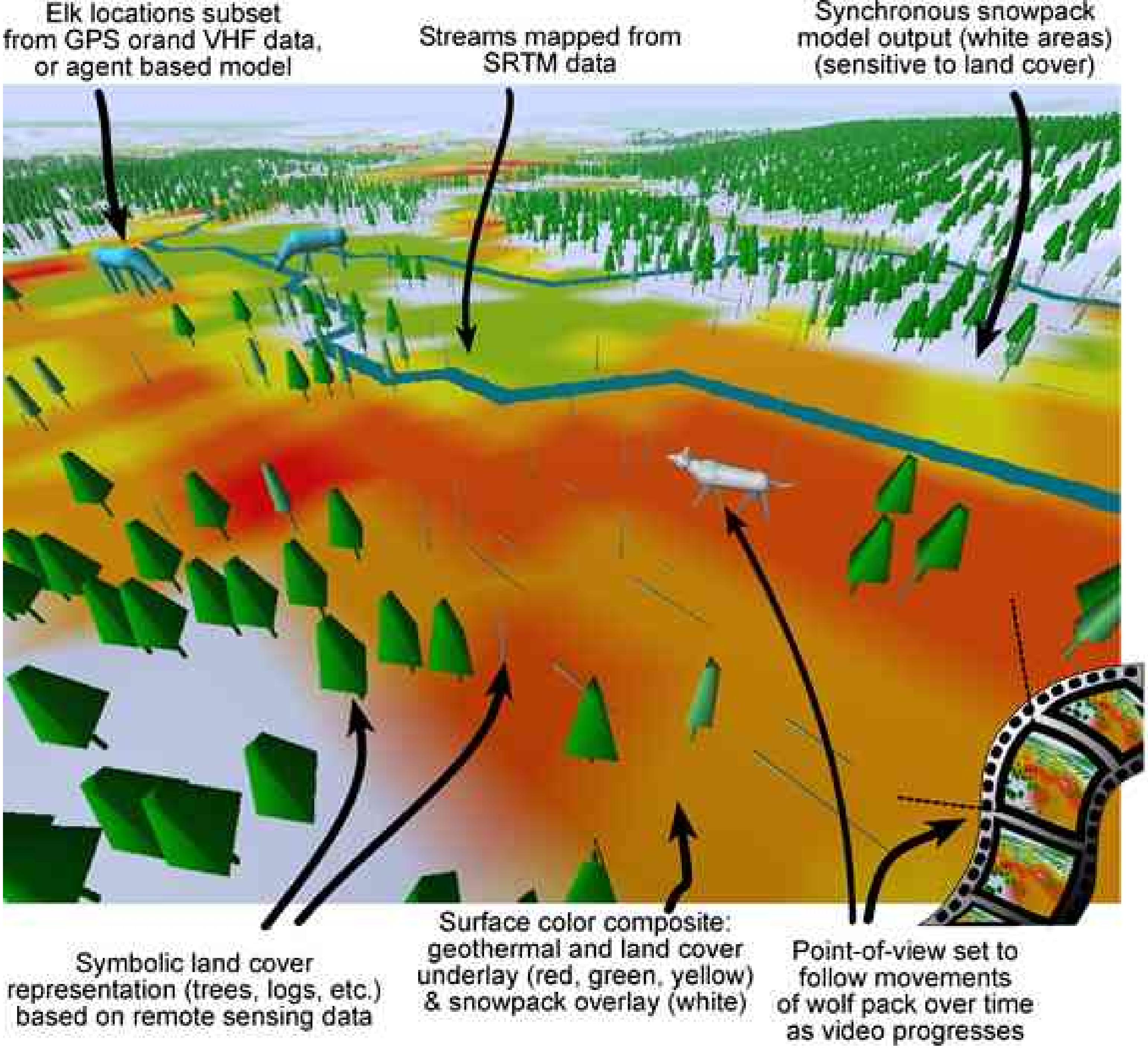
- the greening earth and increasing terrestrial npp

Technology to-date

- Examples assume reliable facts and outcomes are made within a multi-month to year time frame. Current systems exchange human labor in place of machine automation.
- Large teams of scientists working for years building customized but brittle systems – EOS science teams have ~10 year time frame to develop maps and maps are of recent past.
- Combining diverse data types, sources with computer models for forecasting is very difficult so it isn't done often and is done at "high cost".
- Social-economic needs can require faster timeframes for data utilization e.g. Hurricane landfall. (Evacuation costs $1,000,000 per mile)
- How do we fully utilize and exploit these data?

Intelligent Systems

- Designed to be cross cutting – service basic computer science needs of the agency.
- Theory and experimentation


Elk locations subset
from GPS orand VHF data,
or agent based model
Streams mapped from
SRTM data
Synchronous snowpack
model output (white areas)
(sensitive to land cover)
Symbolic land cover
representation (trees, logs, etc.)
based on remote sensing data
Surface color composite:
geothermal and land cover
underlay (red, green, yellow)
& snowpack overlay (white)
Point-of-view set to
follow movements
of wolf pack over time
as video progresses