Earth Science Enterprise

Satellite Remote Sensing of Water Resources:

Applications for Predicting and Monitoring Diseases

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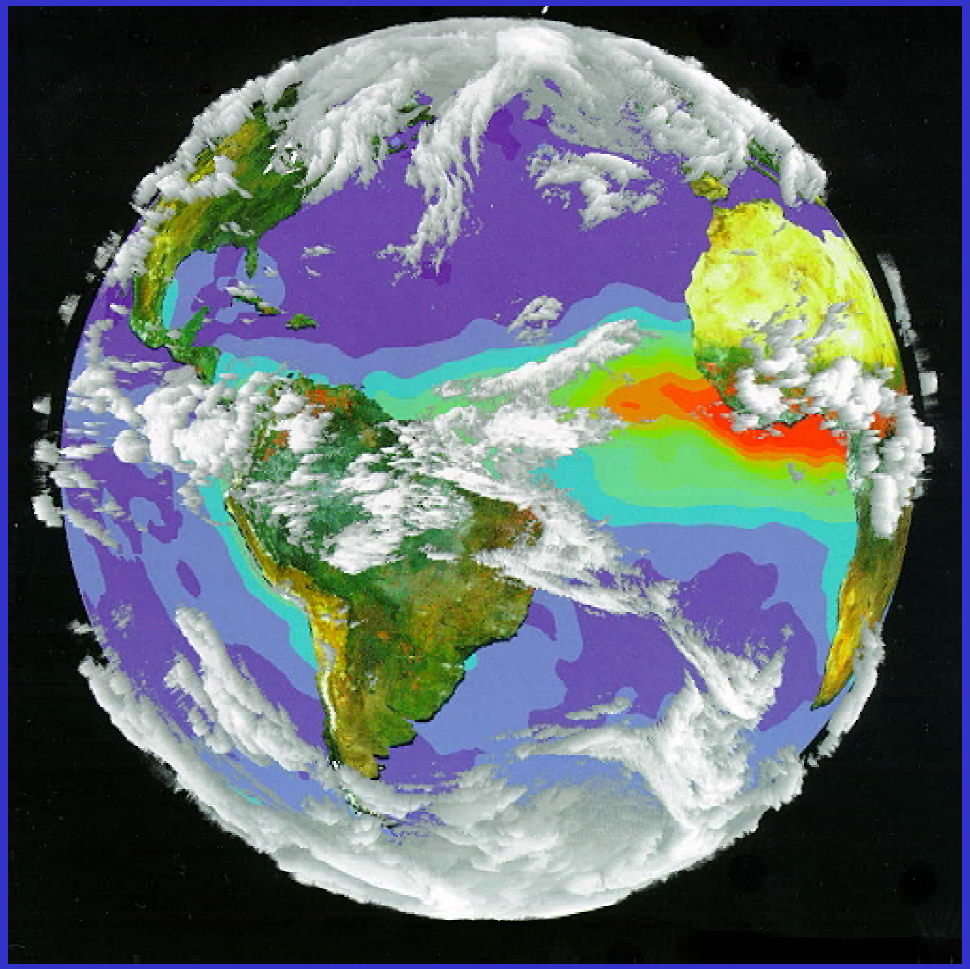
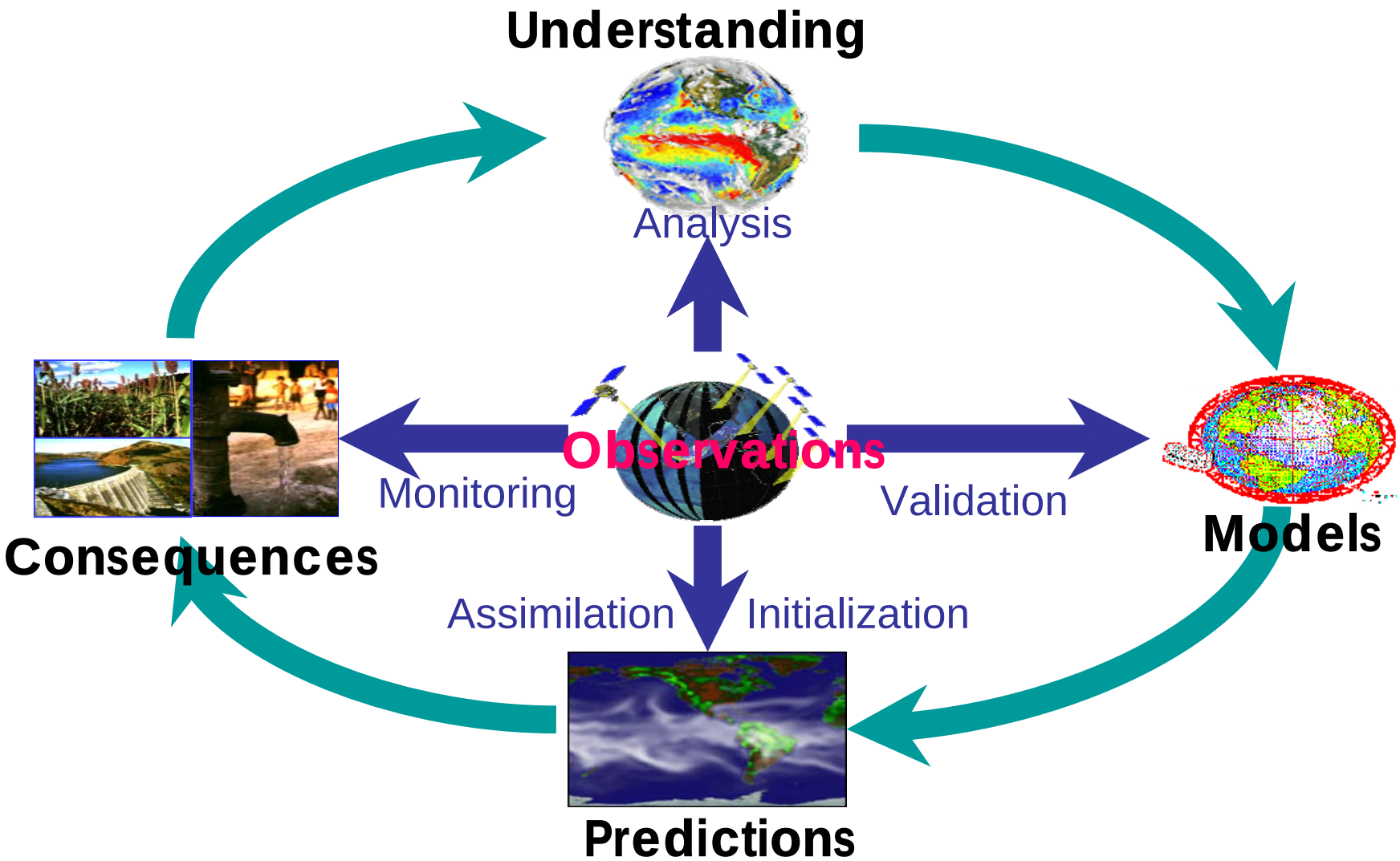


NASA Earth Science Remote Sensing and Modeling Information

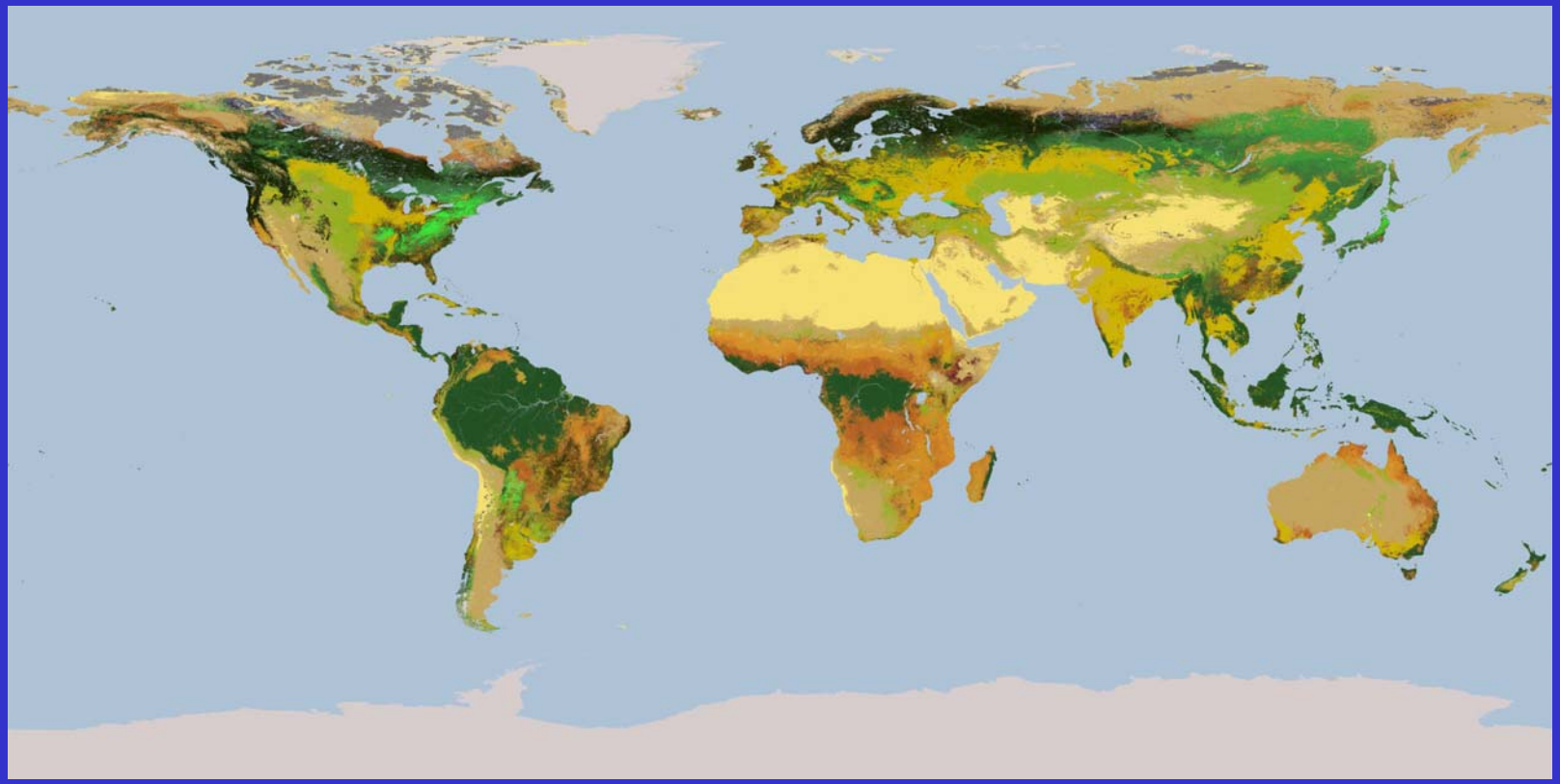


NASA is *the U.S. space agency* and should exploit its unique capabilities for space-based observations to promote scientific understanding

Earth Science Enterprise

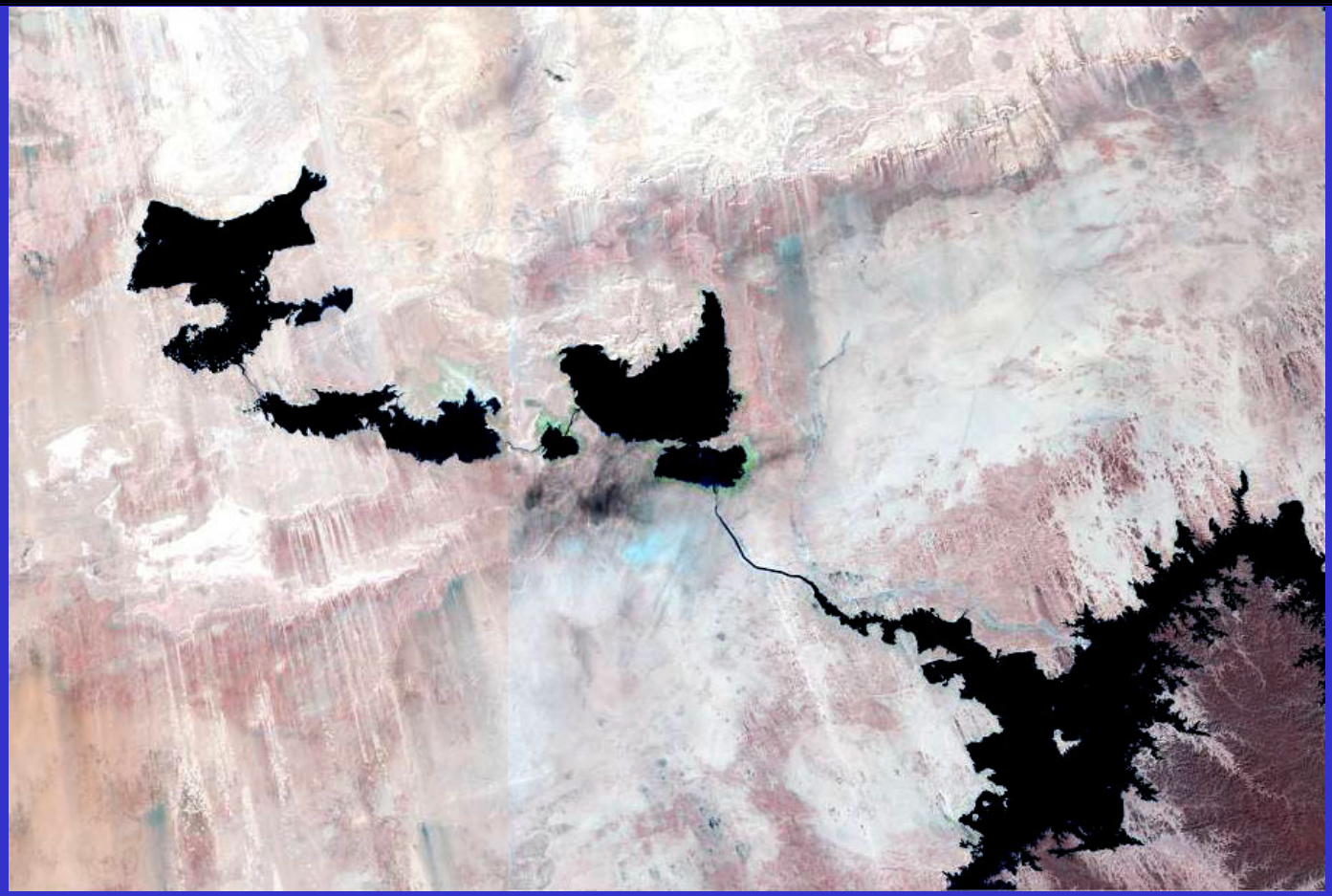
- Satellite Remote Sensing of Water Resources
  - Direct Measurements of Hydrologic Variables
    - Snow cover
    - Vegetation cover
    - Lakes, water bodies
  - Indirect or Model Produced Hydrologic Variables
    - Air and soil temperature
    - Specific humidity
    - Precipitation
    - Soil moisture
    - Stream flow

MODIS Land Cover Classification



- 0 Water
- 1 Evergreen Needleleaf Forest
- 2 Evergreen Broadleaf Forest
- 3 Deciduous Needleleaf Forest
- 4 Deciduous Broadleaf Forest
- 5 Mixed Forests
- 6 Closed Shrublands
- 7 Open Shrublands
- 8 Woody Savannas
- 9 Savannas
- 10 Grasslands
- 11 Permanent Wetlands
- 12 Croplands
- 13 Urban and Built-Up
- 14 Cropland/Natural Veg. Mosaic
- 15 Snow and Ice
- 16 Barren or Sparsely Vegetated
- 17 Unclassified

LANDSAT TM - NEW WATER BODIES



West of Lake Nasser, Southern Egypt, August 23 and November 4, 2000. Over the past two years, four lakes have been created from Nasser's excess water, bringing new lakes to this part of the Sahara for the first time in 6000 years.

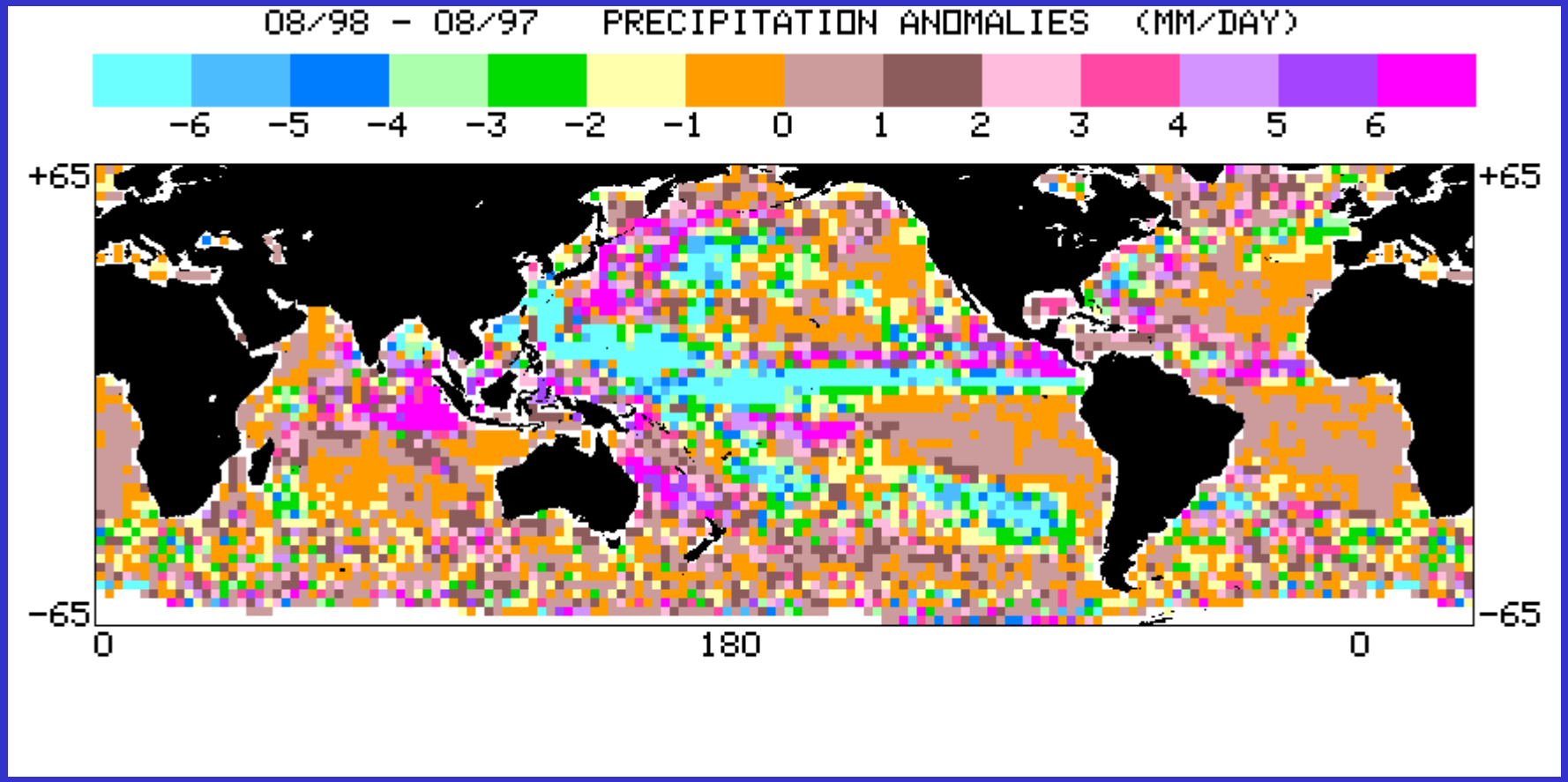
Predicting and Monitoring Diseases

Disease vectors are sensitive to climate which is generally expressed as:

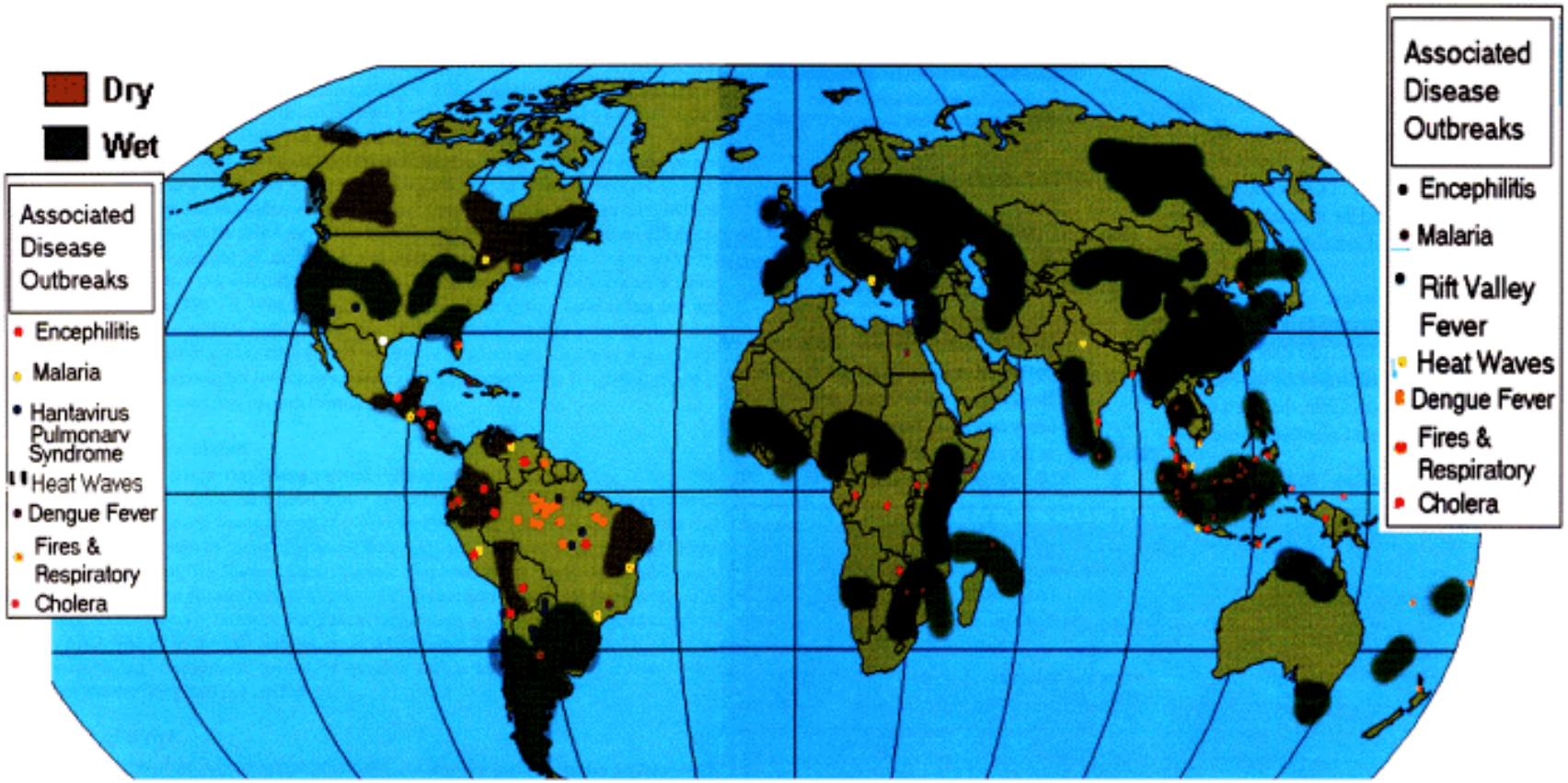
- Temperature
- Humidity or saturation deficit
- Rainfall
- Water table/soil moisture
- Standing water

These data are not generally available at spatial and temporal scales needed for prediction.

Precipitation Difference Associated with El Nino – 97/98



Global Precipitation Anomalies and Associated Disease Outbreaks



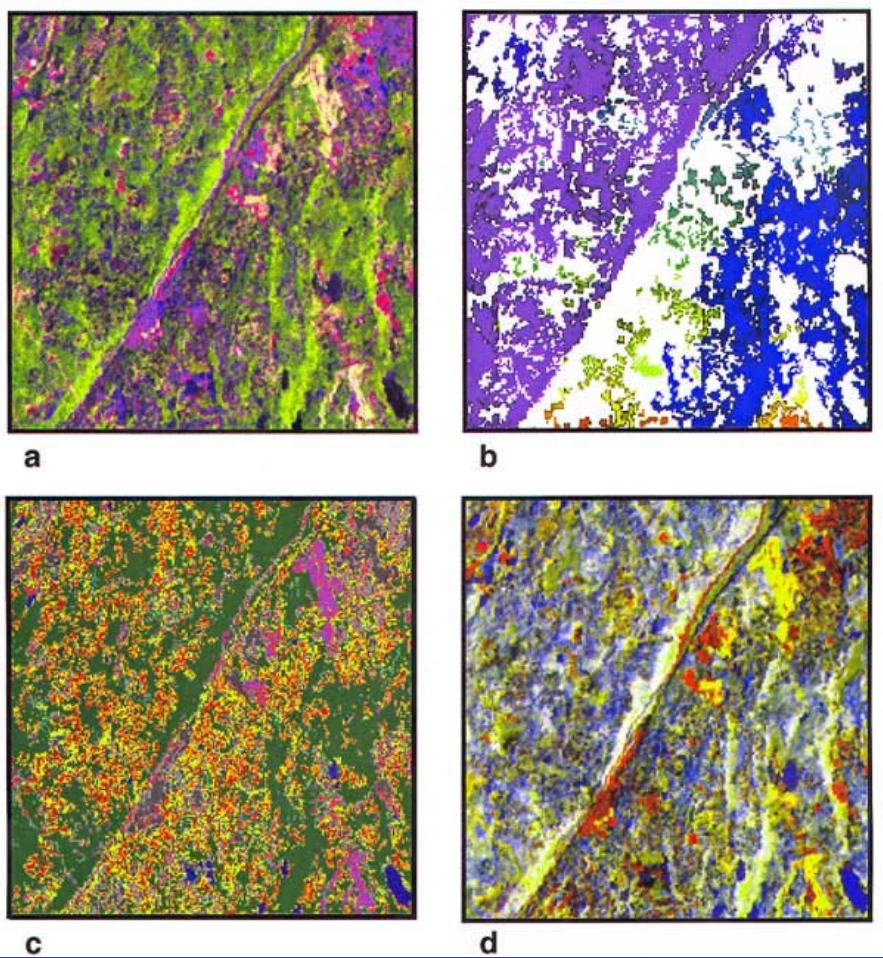
June 1997-May 1998

Satellite Remote Sensing for Monitoring, Surveillance or Risk Mapping of Vector-borne Diseases

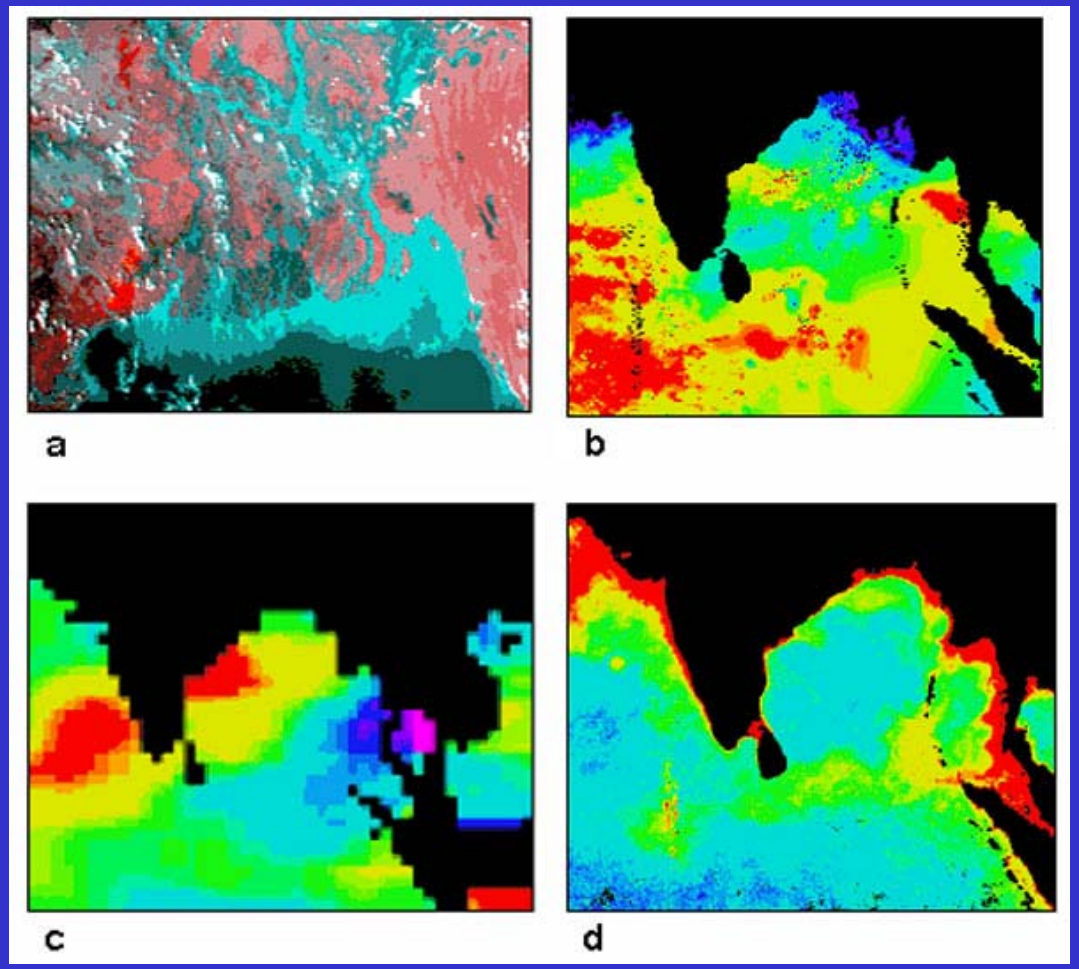
Cannot measure directly, use surrogates

- Vegetation cover
- Landscape structure
- Water bodies

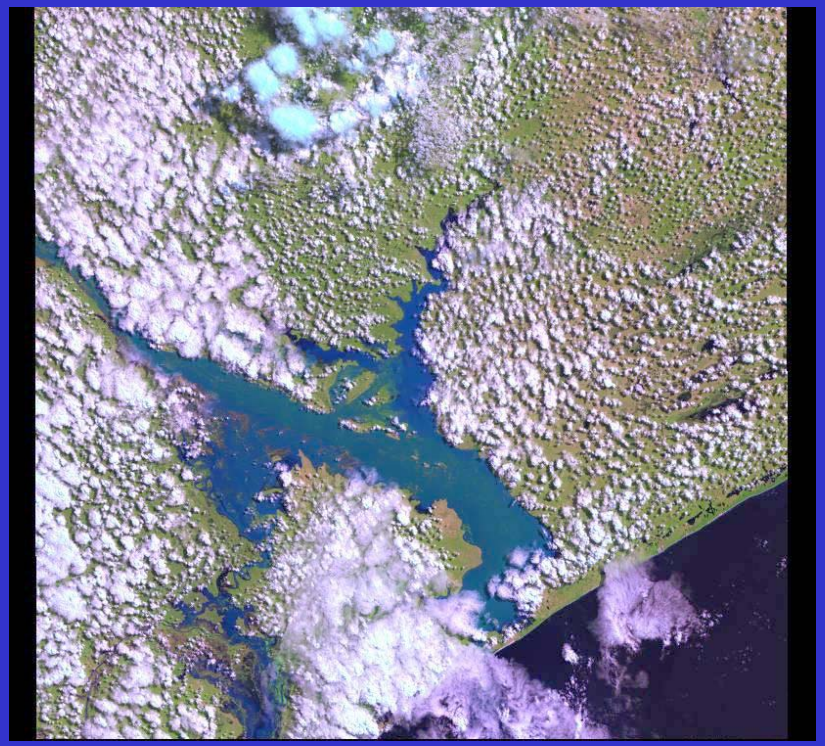
Landsat imagery processed to identify potential locations for Lyme disease from ticks in the Northeastern US



Bay of Bengal illustrating sediment plumes, sea surface temperature and plankton blooms, all of which are related to *cholera*



LANDSAT TM IMAGES SHOWING FLOODING

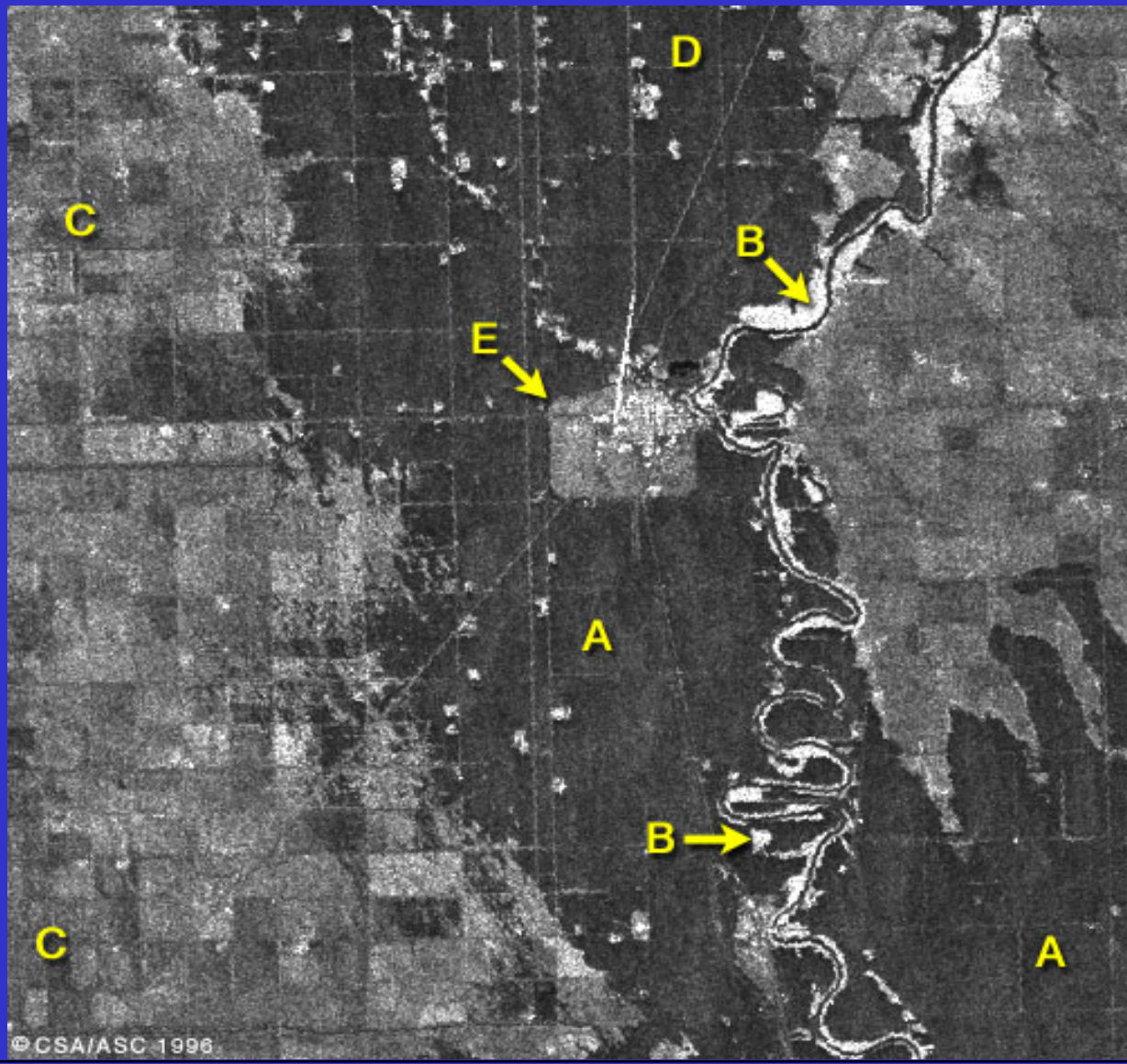


Mozambique coastline, August 22, 1999. Water level prior to flooding. Mozambique coastline, March 1, 2000. Severe flooding caused by heavy rains during late January and early February.

RADARSAT of Red River Flood, 9 May 1996

Active Radar (27m) from Canada (CCRS). Penetrates clouds.

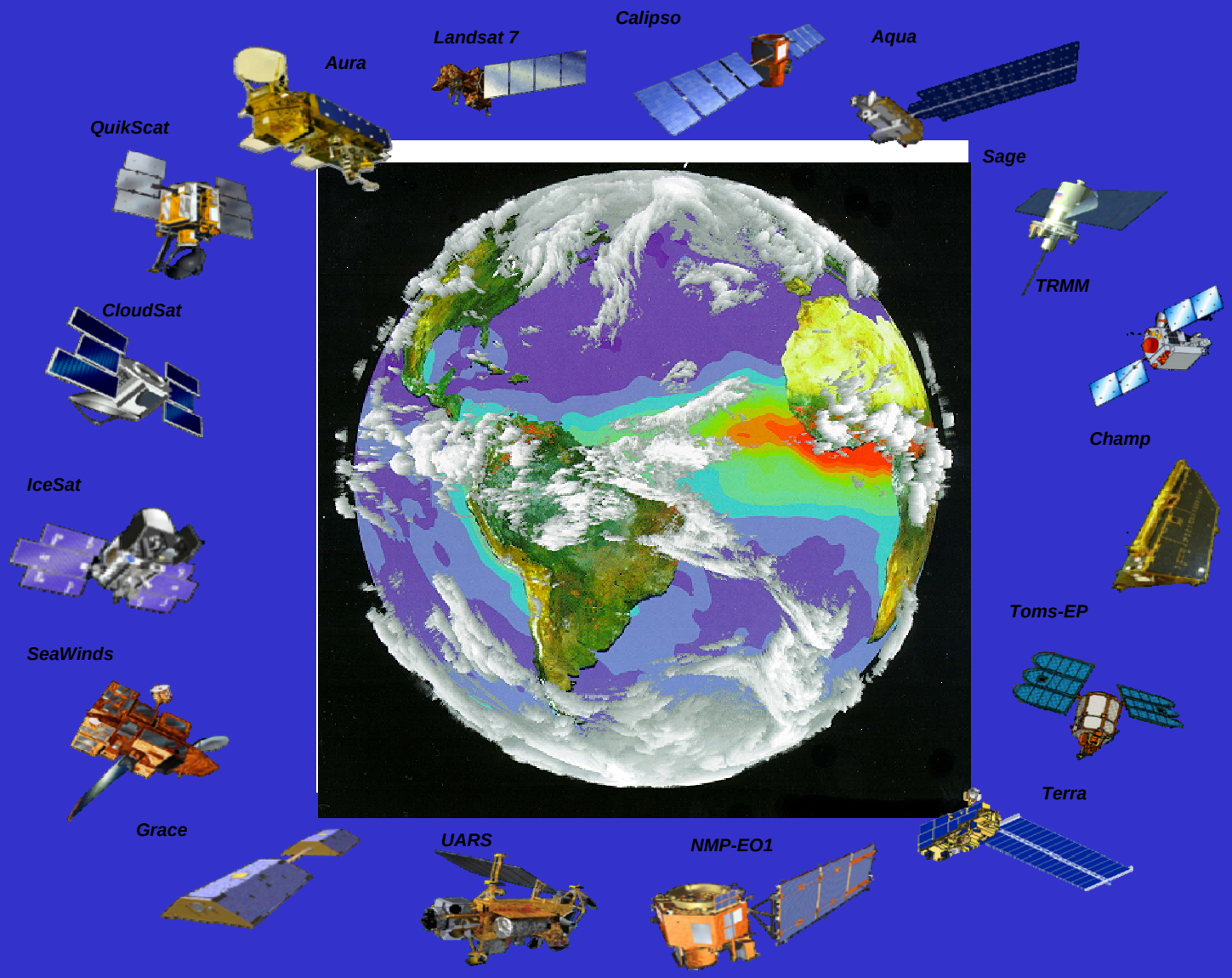
A – Standing Water
B – Standing water under trees (corner reflector)
C – Morris City, protected by levees (not flooded)



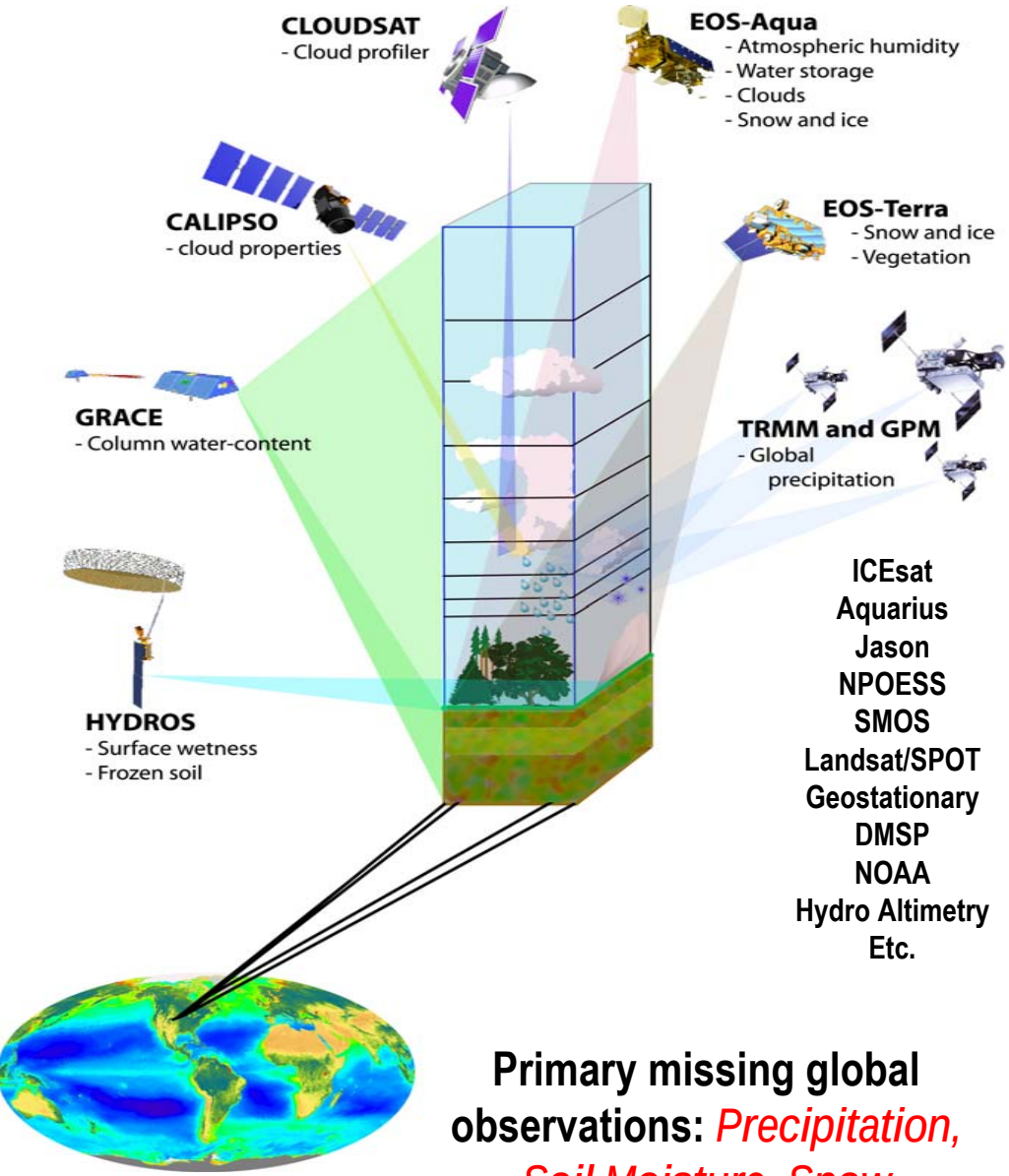
Predicting and Monitoring Diseases

- Satellite data has been effective in monitoring and predicting diseases, particularly in areas with little or no weather and climate data.
- Future applications should be even more effective because:
  - New and better satellite sensors
  - Four dimensional data assimilations

Newer and Better Satellites Providing Global Measurements



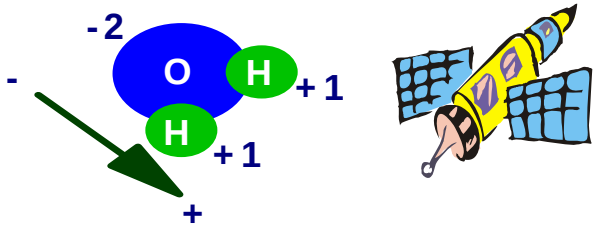
Global Water-Cycle: Observation Strategy



Primary missing global observations: *Precipitation, Soil Moisture, Snow*

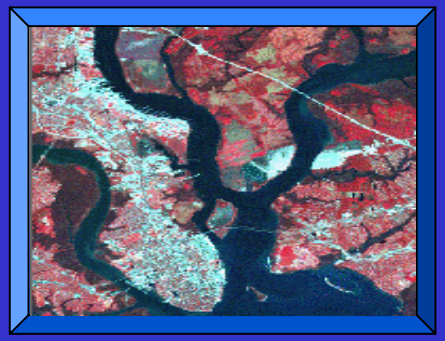
Future: *Water Cycle Mission*

Observation of water molecules through the atmosphere and land surface using an *active/passive hyperspectral* microwave instrument.

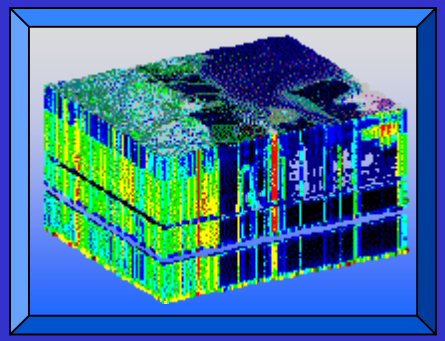


Quantity	Spatial Resolution	Temporal Resolution	Frequency
Groundwater	50 km	2 weeks	100 MHz?
Soil Moisture	10 km	3 days	1.4 GHz
Salinity	50 km	2 weeks	1.4 GH
Freeze/thaw	1 km	1 day	1.2 GHz
Rain	5 km	3 hour	10-90 GHz
Falling Snow	5 km	3 hour	150 GHz
Snow	1-5 km	1 day	10-90 GHz
TPW	10 km		
	(sea)	3 hour	6-37 GHz
	(land)	3 hour	183 GHz
Temperature	10 km		
	(sea)	3 hour	6-37 GHz
	(land)	3 hour	6-37 GHz
ET (4DDA)	5 km	3 hour	1.4-90 GHz

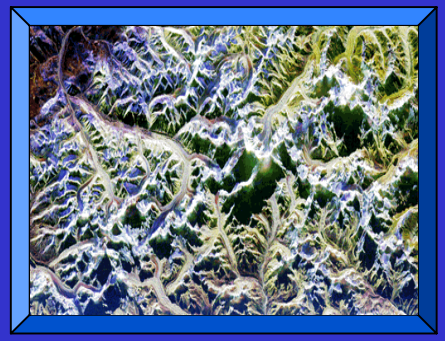
Using Remote Sensing Technologies



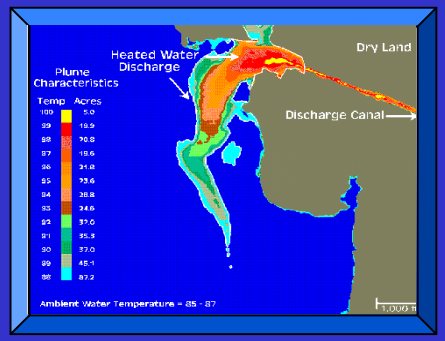
Multispectral



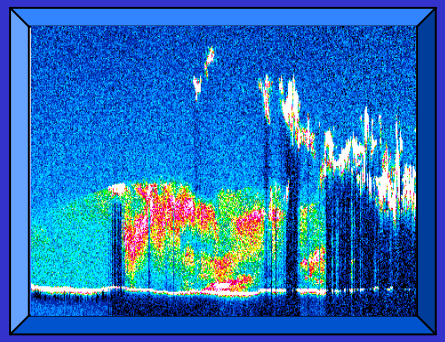
Hyperspectral



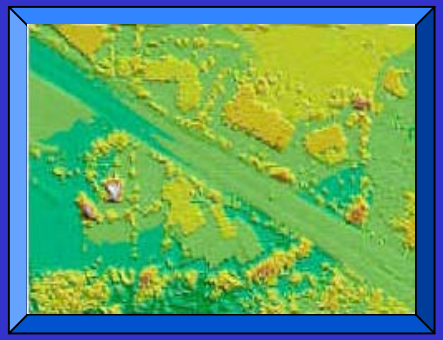
RADAR / SAR



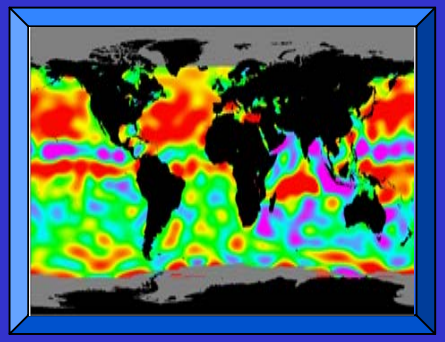
Thermal



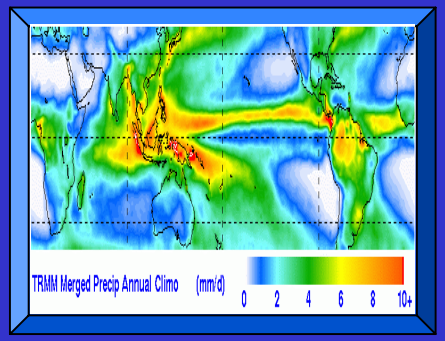
Atmospheric LIDAR



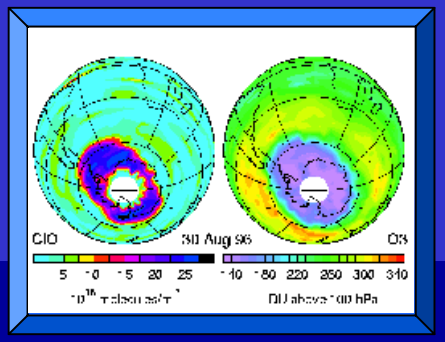
Surface LIDAR



RADAR Altimetry

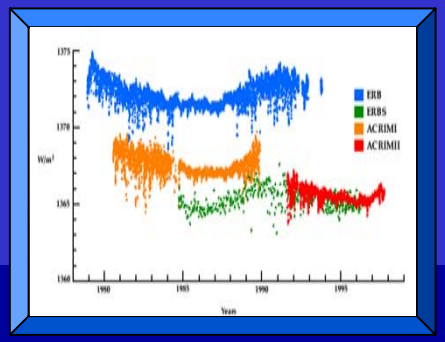


Passive Microwave

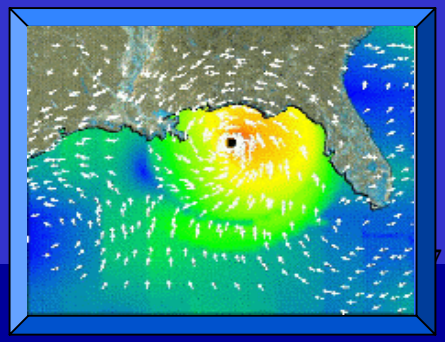


Limb Sounding

Microwave Ranging



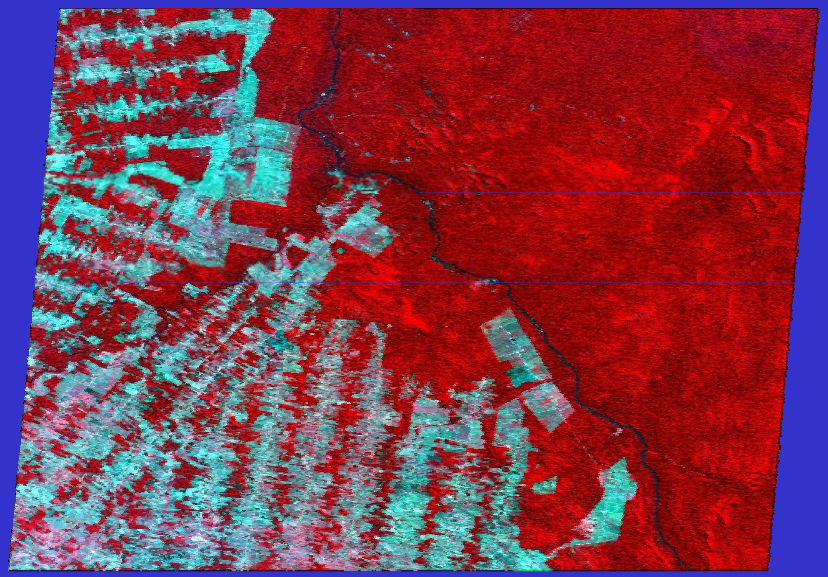
Irradiance/Photometry

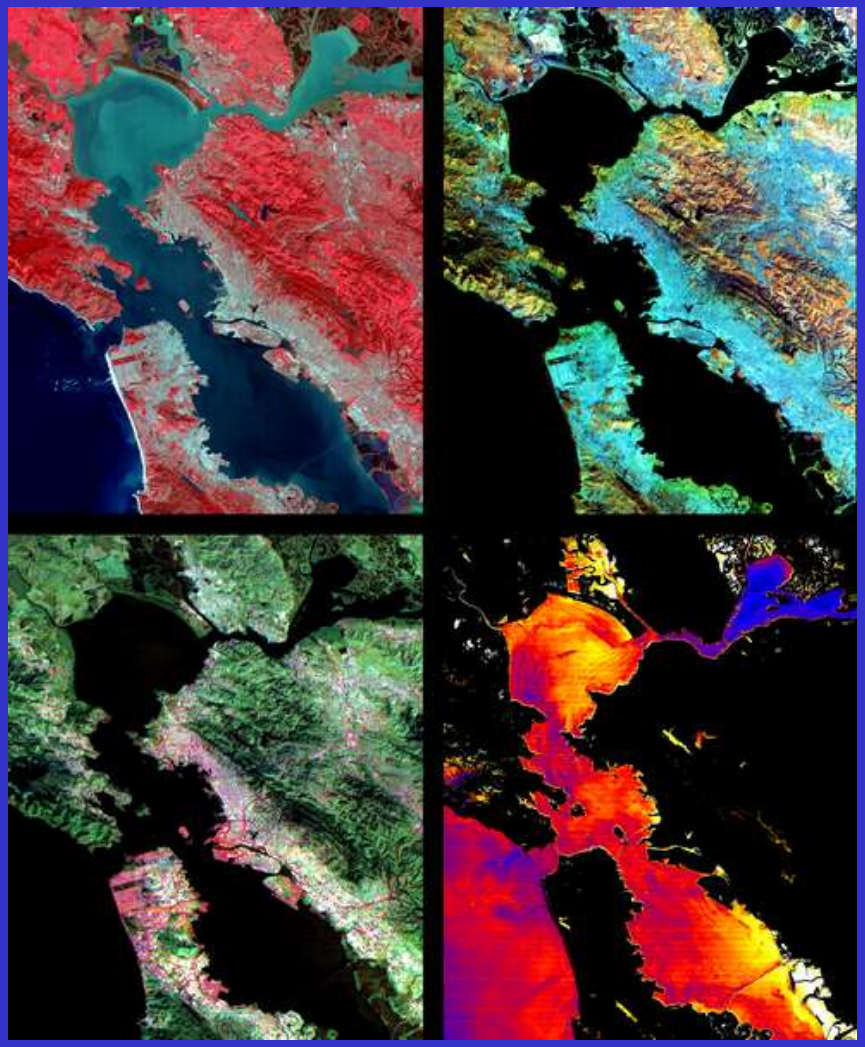


Scatterometry

ASTER Measurements

- Spectral reflectances of the Earth's surface at 15-30 m
- Surface temperature and emissivities at 90 m
- Digital elevation maps from stereo images
- Surface composition and vegetation maps (deforestation)





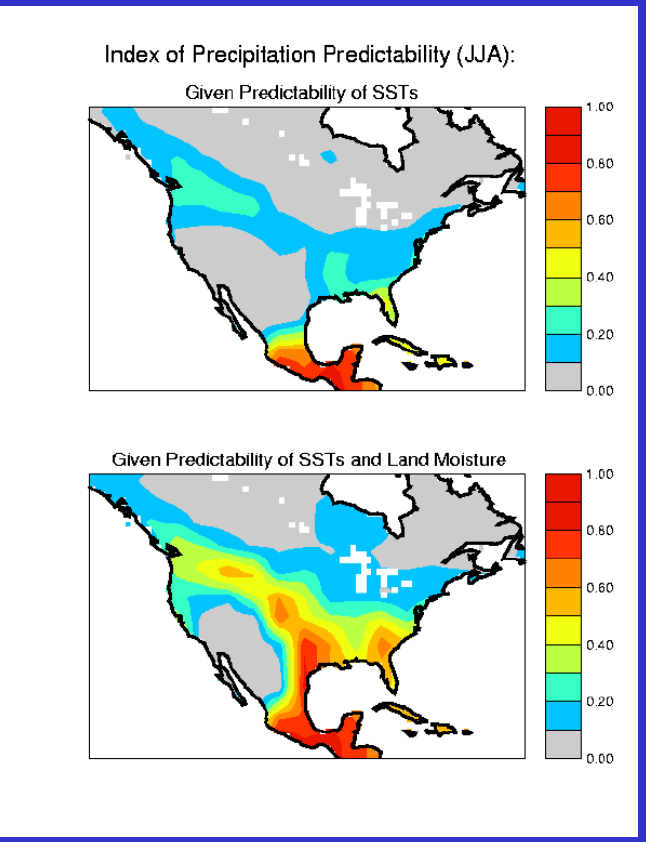
NASA Earth System Science Pathfinder

HYDROS provides the first global view of the Earth's changing soil moisture and surface freeze/thaw conditions, enabling new scientific studies of global change and and atmospheric predictability, and making new hydrologic applications possible

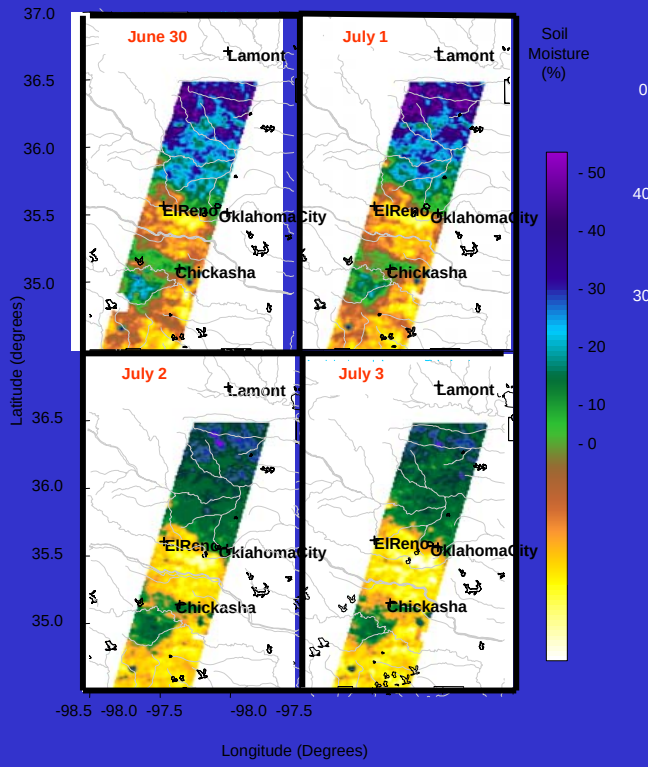
HYDROS

HYDROS Soil Moisture Mission

Understand the impact of soil moisture and on flood/drought prediction, weather forecasting, and agriculture.



Global soil moisture observation using microwave observations

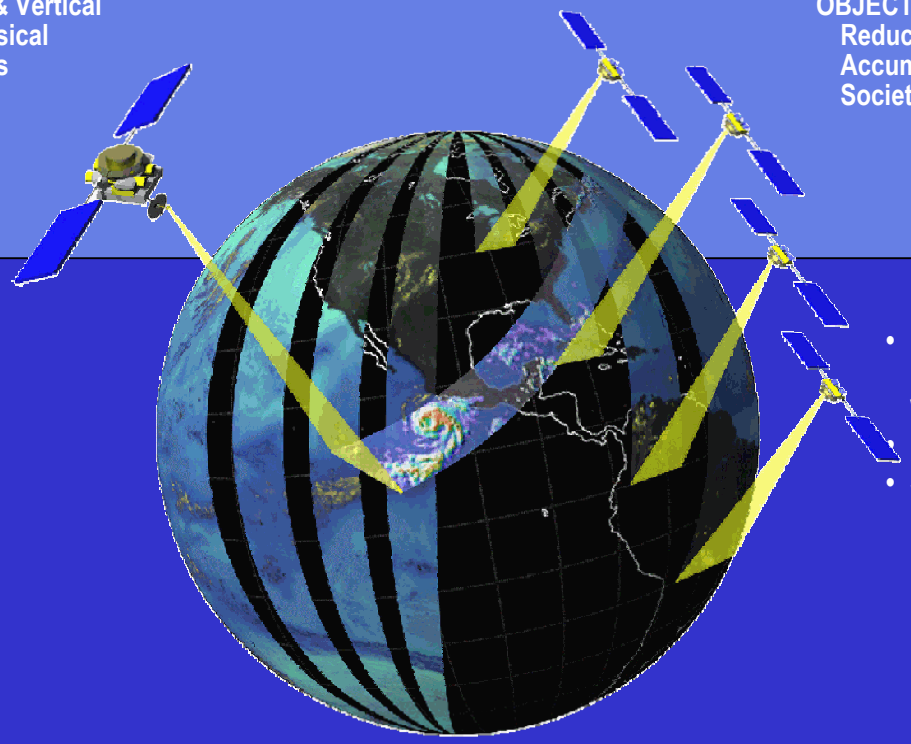


Global Precipitation Mission

Reference Concept

OBJECTIVE: Understand Horizontal & Vertical Structure of Rainfall & Its Microphysical Nature. Train & Calibrate Algorithms Constellation Radiometers.

OBJECTIVE: Provide Sufficient Sampling to Reduce Uncertainty in Short-term Rainfall Accumulations. Extend Scientific and Societal Applications.



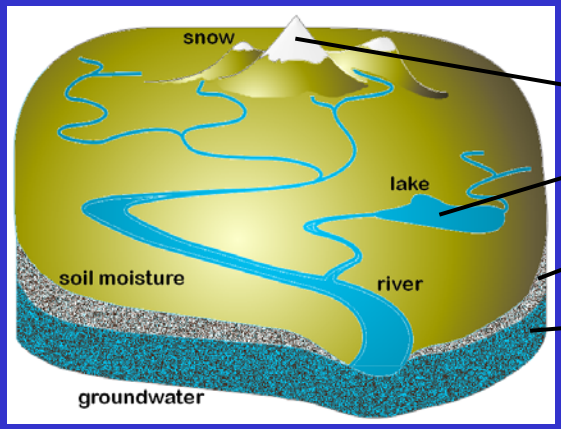
- TRMM-Like S/C, NASA
- H2A Launch, NASDA
- Non-Sun Synchronous Orbit
  ~ 70° Inclination
  ~450 km Altitude
- Dual Frequency Radar, NASDA
  Ku & Ka Bands
  ~ 4 km Horizontal Resolution
  ~250 m Vertical Resolution
- Multifrequency Radiometer, NASA
  10.7, 19, 22, 37, 85 GHz V&H Pol

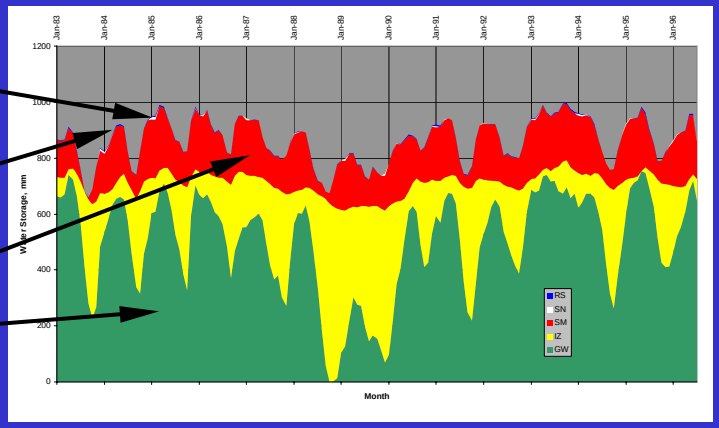
- Dedicated Small or Pre-existing Experimental & Operational Satellites with PMW Radiometers
- Revisit Time: 3-Hour goal
- Sun-Synchronous Polar Orbits
  ~600 km Altitude

- Selected & Globally Distributed Ground- Based Supersites (polarimetric radar, radiometer, raingages, & disdrometers) & Dense Regional Raingage Networks

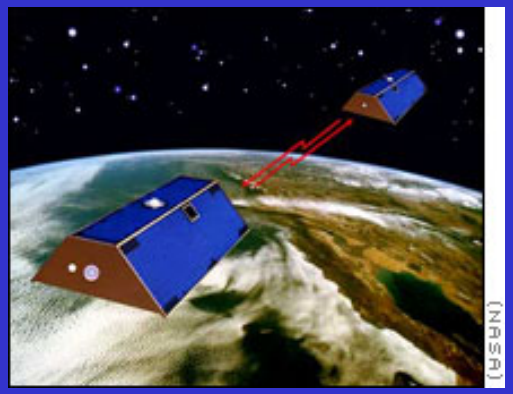
- Produces Global Precipitation Data Product Streams Defined by GPM Partners

Remote Sensing of Terrestrial Water Storage Using



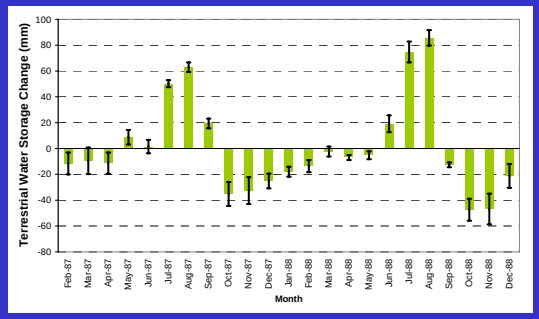


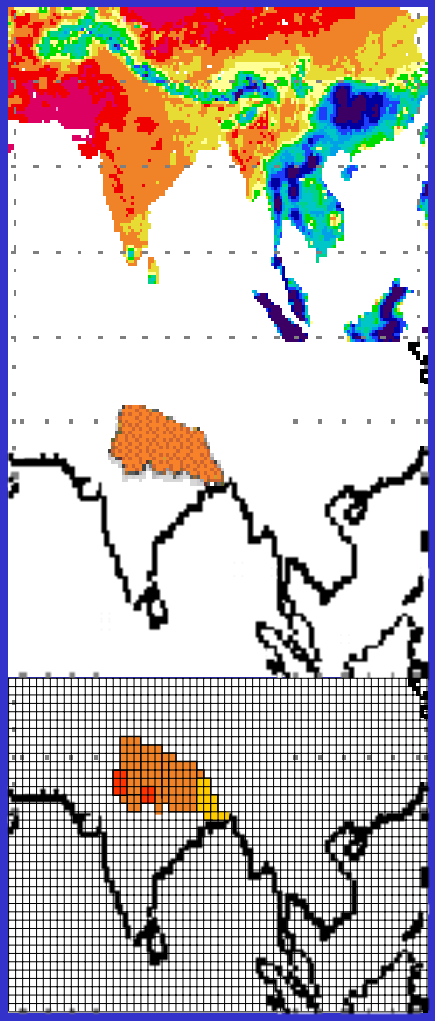
Above left: **Terrestrial water storage components**
***Above right*: Time series from Illinois** *(Rodell & Famiglietti, 2001)*



Above: **The Gravity Recovery and Climate Experiment (GRACE) satellites**

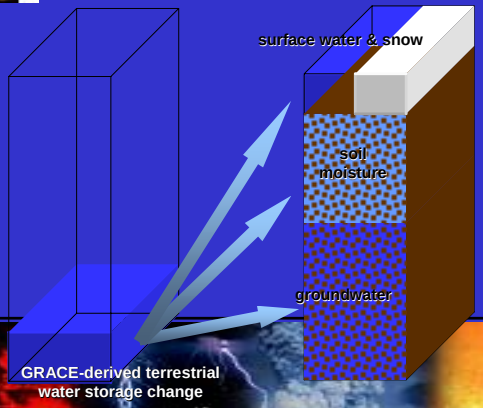
Right: **Predicted accuracy of GRACE-derived monthly changes in terrestrial water storage, Ganges River basin**





Right, top to bottom: **(simulated) TWS changes, SE Asia; GRACE product, Ganges; Model assimilation product**

Right: **Vertical and Temporal Disaggregation of GRACE products**



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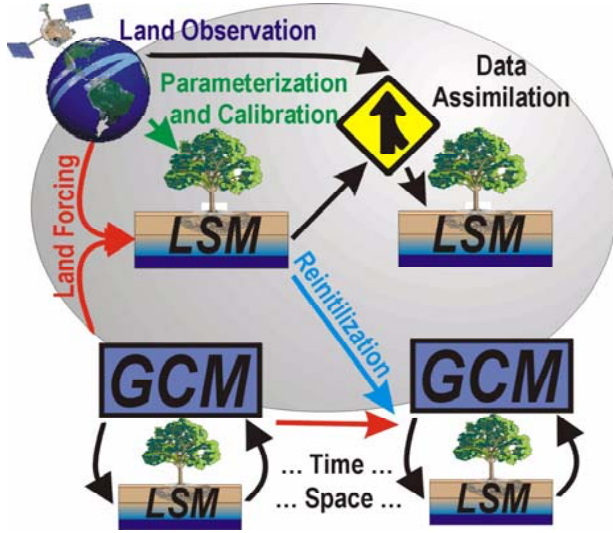
Rodell et al. 2002

Four Dimensionl Data Assimilation

- Data assimilation techniques allow us to use a variety of data (satellite, point, aircraft, weather station, etc.), along with equations and models to develop a complete description of all of the land surface water resources variables.

Land Data Assimilation Systems: Motivation



Quantification and prediction of hydrologic variability

- Critical for initialization and improvement of weather/climate forecasts
- Critical for applications such as floods, agriculture, military operations, etc.

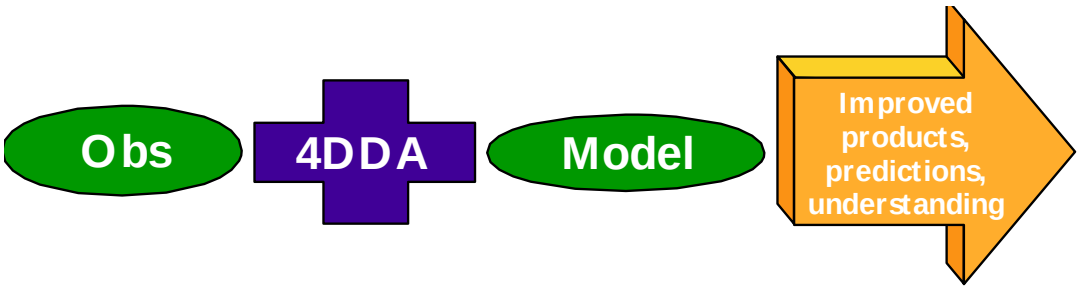
Maturing of hydrologic observation and prediction tools:

- Observation: Forcing, storages(states), fluxes, and parameters.
- Simulation: Land process models (Hydrology, Biogeochemistry, etc.).
- Assimilation: Short-term state constraints.

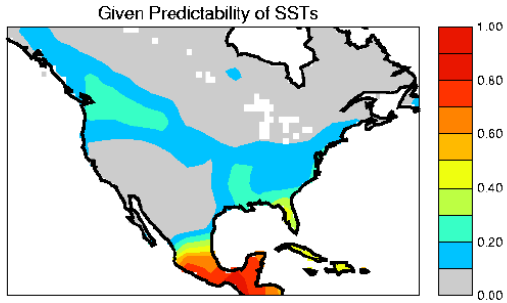
"LDAS" concept:

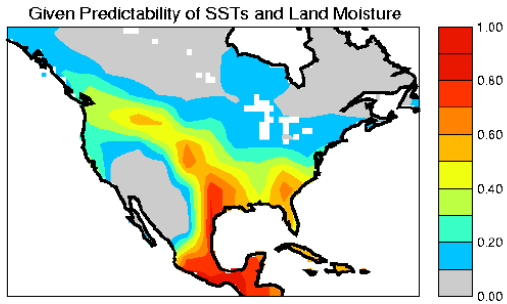
Bring state-of-the-art tools together to *operationally* obtain high quality land surface conditions and fluxes.

- Optimal integration of land surface observations and predictions.
- Continuous in time&space; multiple scales; retrospective, realtime, forecast



Index of Precipitation Predictability (JJA):

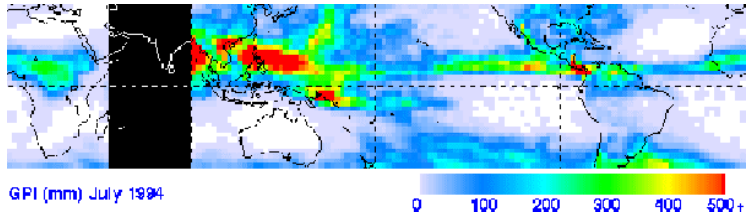




Background: Land Surface Observations

Precipitation: *Remote-Sensing:* SSM/I, TRMM, AMSR, GOES, AVHRR

In-Situ: Surface Gages and Doppler Radar

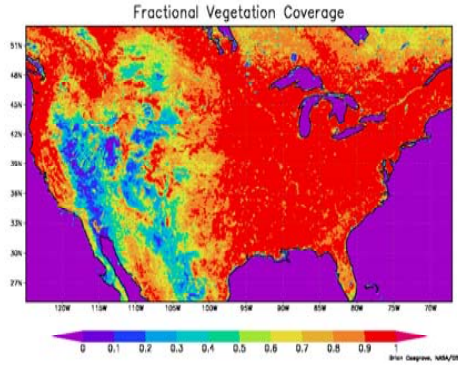


Radiation: *Remote-Sensing:* MODIS, GOES, AVHRR

In-Situ: DOE-ARM, Mesonets, USDA-ARS

Surface Temperature: *Remote-Sensing:* AVHRR, MODIS, SSM/I, GOES

In-Situ: DOE-ARM, Mesonets, NWS-ASOS, USDA-ARS

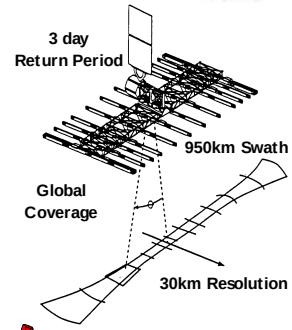


Soil Moisture: *Remote-Sensing:* TRMM, SSM/I, AMSR, **HYDROS**, ESTAR, NOHRSC, SMOS

In-Situ: DOE-ARM, Mesonets, Global Soil Moisture Data Bank, USDA-ARS

Groundwater: *Remote-Sensing:* GRACE

In-Situ: Well Observations

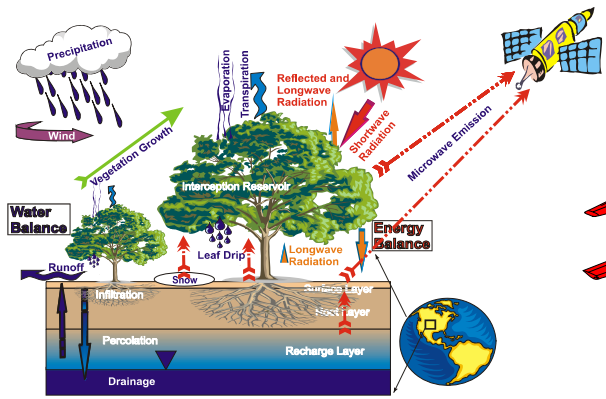


Snow Cover, Depth & Water: *Remote-Sensing:* AVHRR, MODIS, SSM/I, AMSR, GOES, NWCC, NOHRSC

In-Situ: SNOTEL

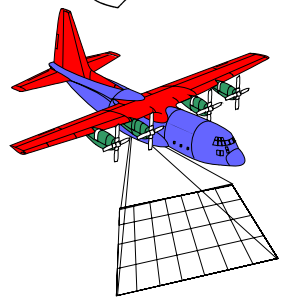
Streamflow: *Remote-Sensing:* Laser/Radar Altimiter

In-Situ: Real-Time USGS, USDA-ARS



Vegetation: *Remote-Sensing:* AVHRR, TM, VCL, MODIS, GOES

In-Situ: Field Experiments



Others: Soils, Latent & Sensible heat fluxes, etc.

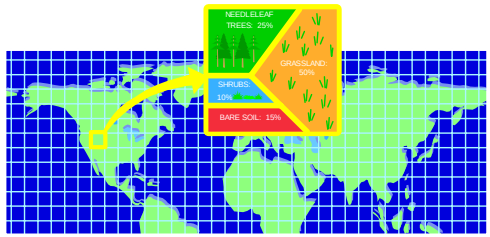
Background: Land Surface Modeling

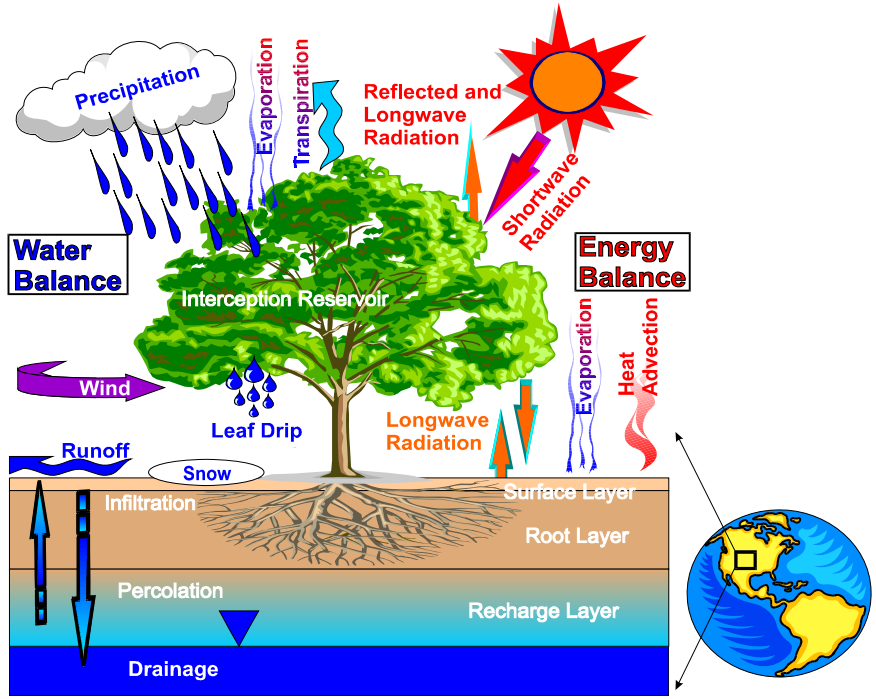
Land Surface Prediction: Accurate land model prediction is essential to enable data assimilation methods to propagate or extend scarce observations in time and space. Based on *water and energy balance*.

Input - Output = Storage Change

P + Gin –(Q + ET + Gout) = ΔS

Rn - G = Le + H





Mosaic (Koster, 1996):

- Based on simple SiB physics.
- Subgrid scale "mosaic"

CLM (Community Land Model, ~2001):

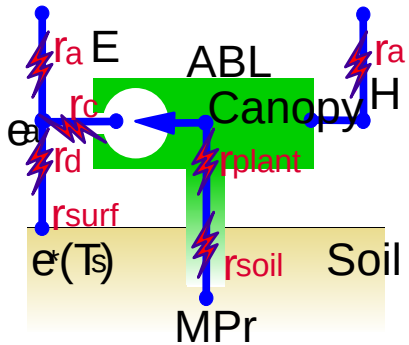
- Community developed "open-source" model.
- 10 soil layers, 5 layer snow scheme.

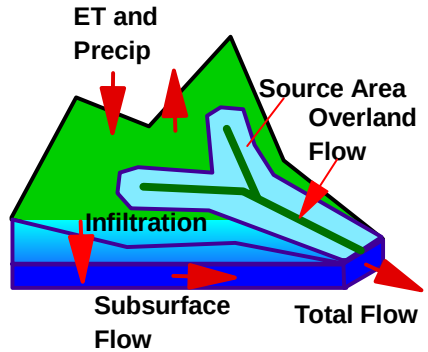
Catchment Model (Koster et al., 2000):

- Models in catchment space rather than on grids.
- Uses Topmodel concepts to model groundwater

NOAA-NCEP-NOAH Model (NCEP, ~2001):

- Operational Land Surface model.



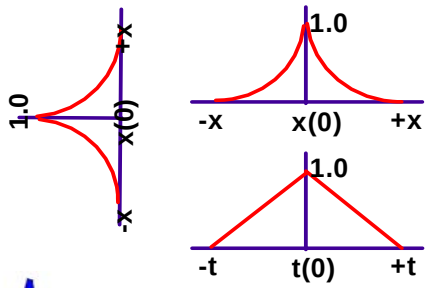


Also: vic, bucket, SiB, etc.

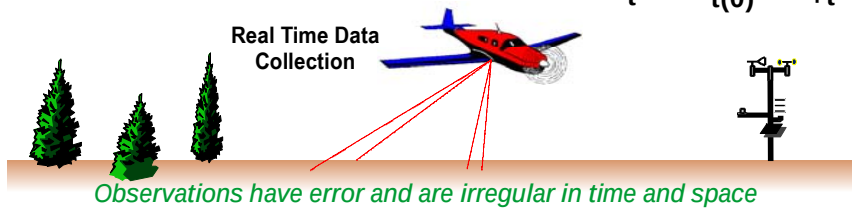
Background: Data Assimilation

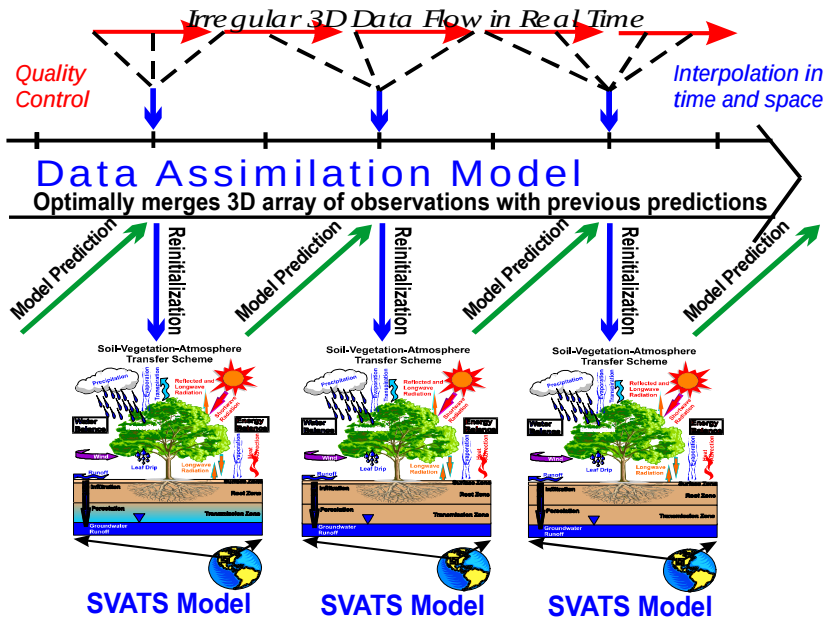
Data Assimilation Methods: Numerical tools to combine disparate information.

$$A = B + \sum_{k=1}^{K} W_{ik}[O_k - B_k]$$



1. **Direct Insertion, Updating, or Dynamic Initialization:**
2. **Newtonian Nudging:**
3. **Optimal or Statistical Interpolation:**
4. **Kalman Filtering: EKF & EnKF**
5. **Variational Approaches - Adjoint:**



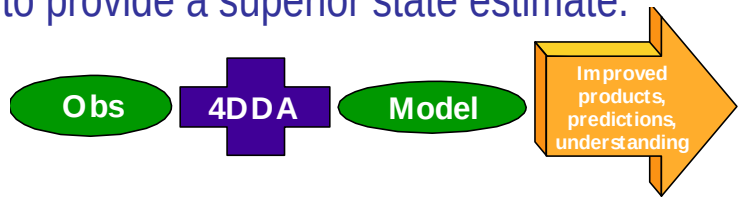


GOAL: Understand algorithm differences to use the most appropriate method for the problem to be addressed

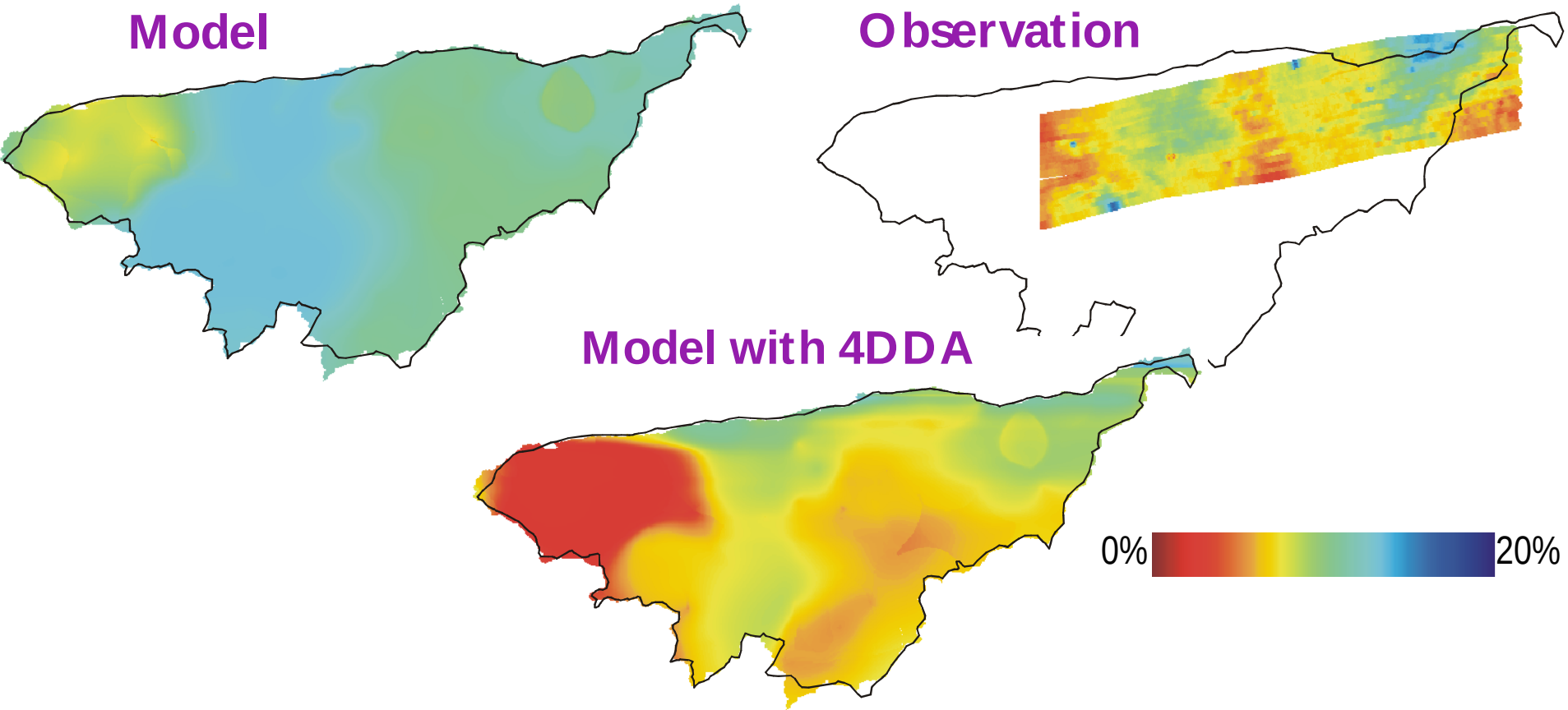
Land *Data Assimilation*

Data Assimilation merges observations & model predictions to provide a superior state estimate.

$$\partial x / \partial t = dynamics + physics + \Delta x$$

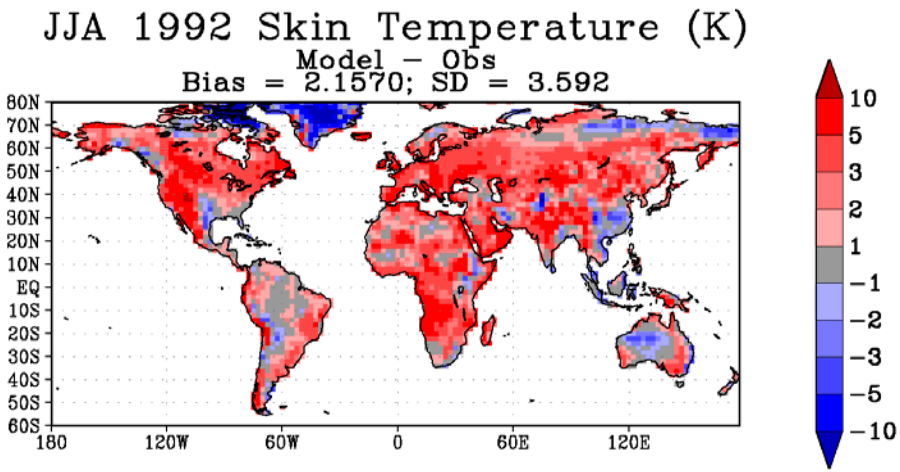


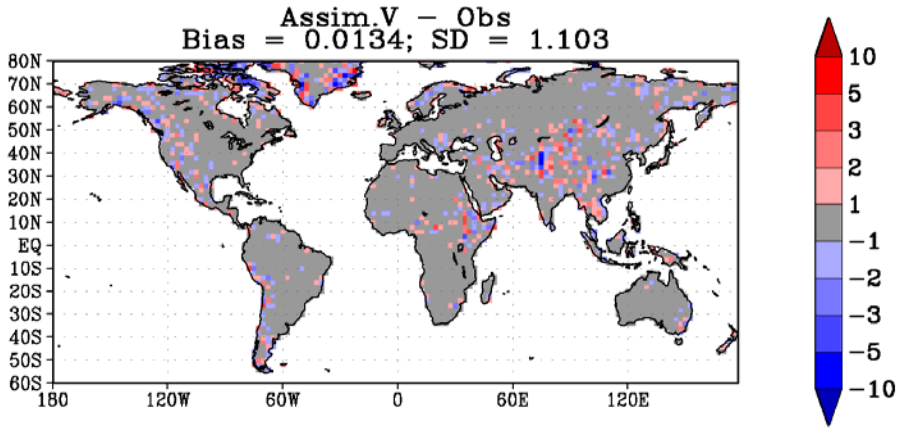
Remotely-sensed hydrologic **state** or storage observations (**temperature, snow, soil moisture**) are integrated into a hydrologic model to improve prediction, produce research-quality data sets, and to enhance understanding of complex hydrologic phenomenon.

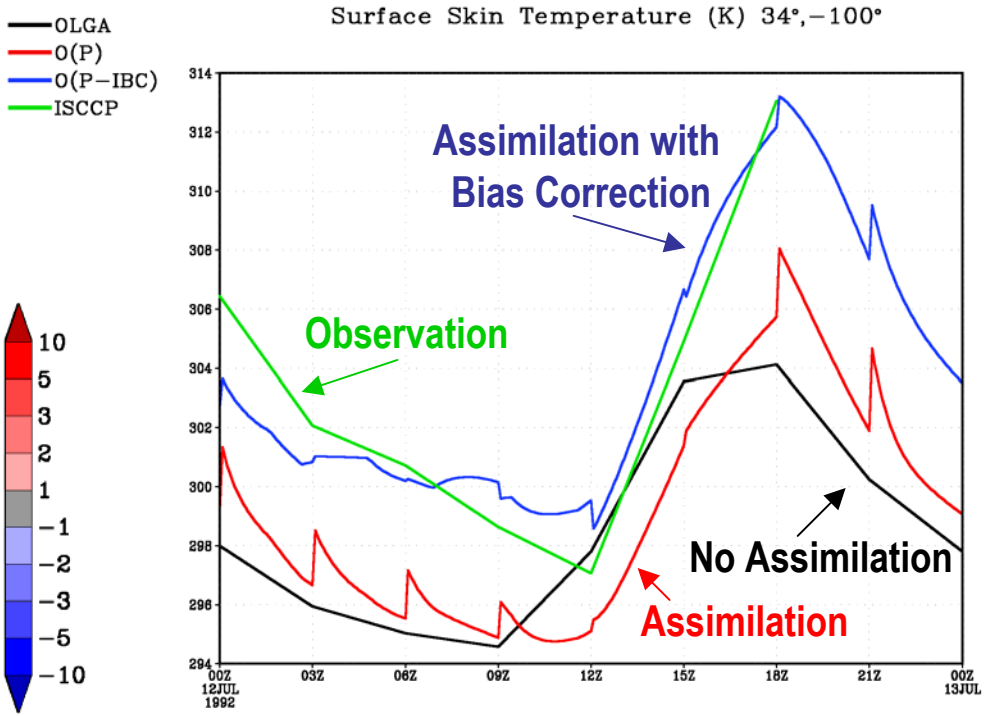


Surface skin temperature data assimilation

DAO-PSAS **Assimilation** of **ISCCP (IR based) Surface Skin Temperature** into a global 2 degree uncoupled land model.

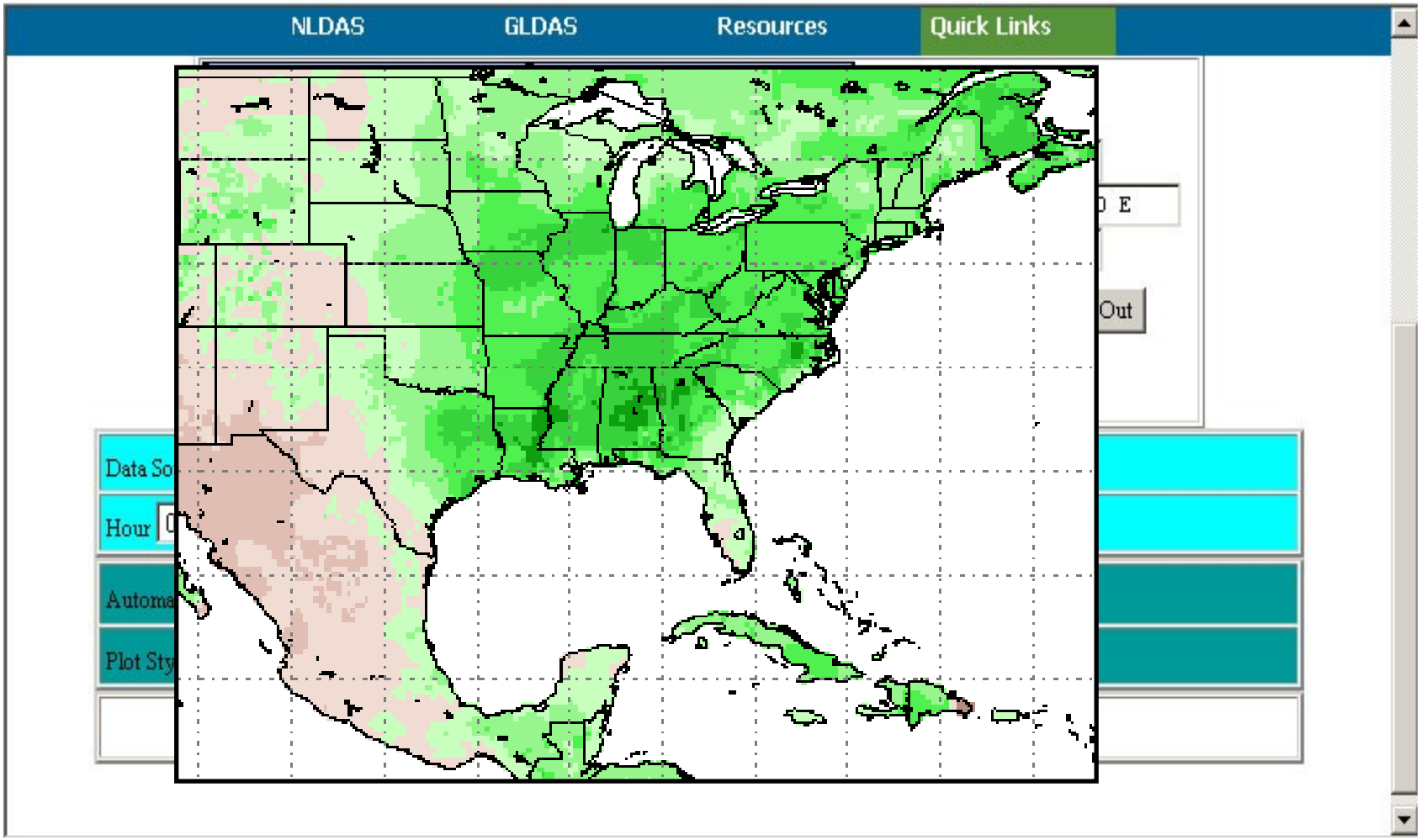






Surface temperature has **very little memory** or inertia, so without a continuous correction, it tends drift toward the control case very quickly.

Land Data Assimilation System – Interactive Link



“http:ldas.gsfc.nasa.gov”

Land Information System: *A high-performance extension of GLDAS*

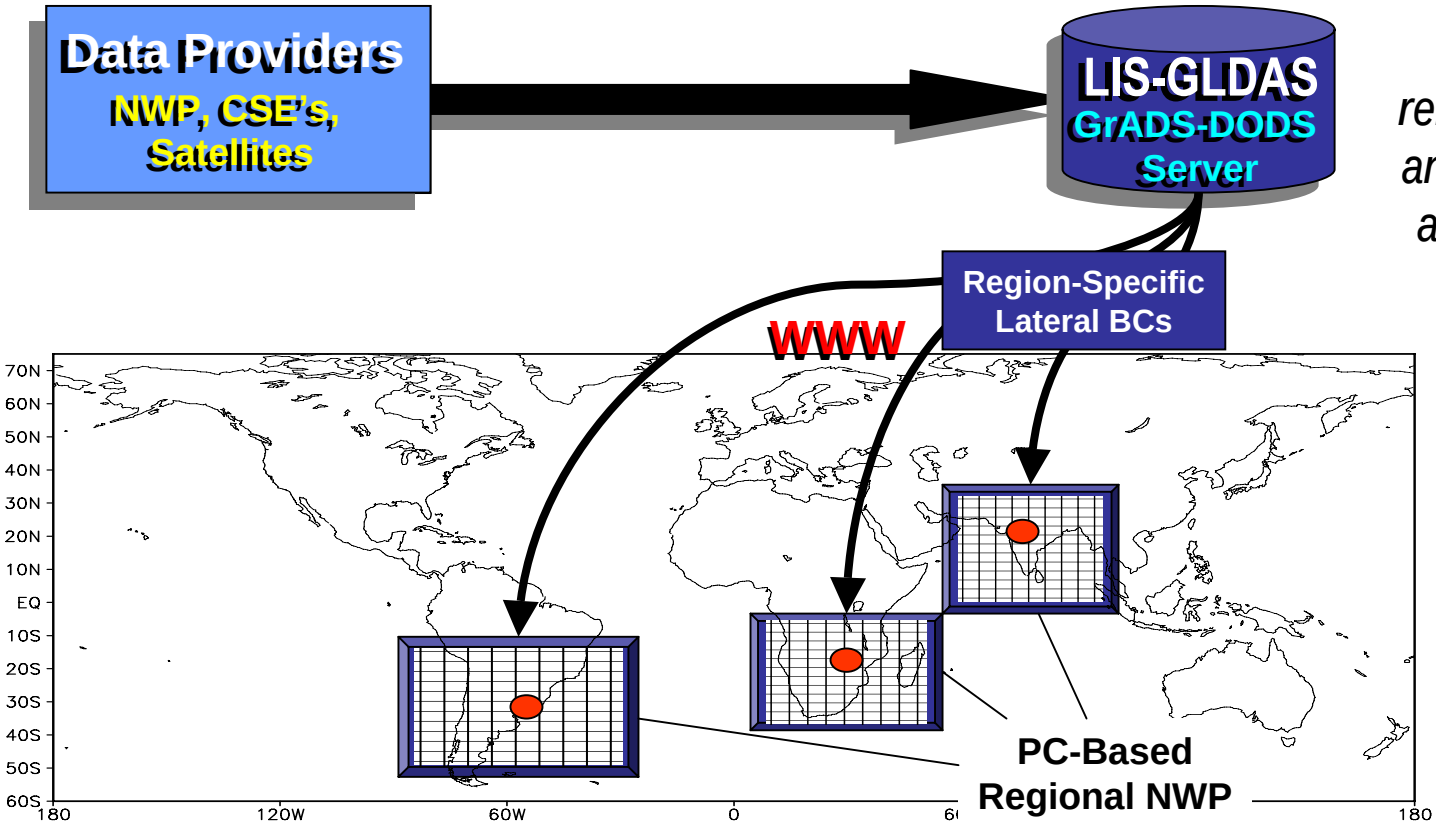
LIS components:

(1) A high-resolution (1km) Global Land Data Assimilation System running several land surface models, land surface data assimilation, and integrated database operations.

(2) A web-based user interface for data mining, modeling, and visualization.

(3) A portable platform-independent, web-database system.

(4) Explicit integration to the Earth System Modeling Framework (ESMF).



Data can be remotely accessed and analyzed from a GUI, web page, or model code

One km resolution land surface data assimilation possible with LIS will approach aerial photographs

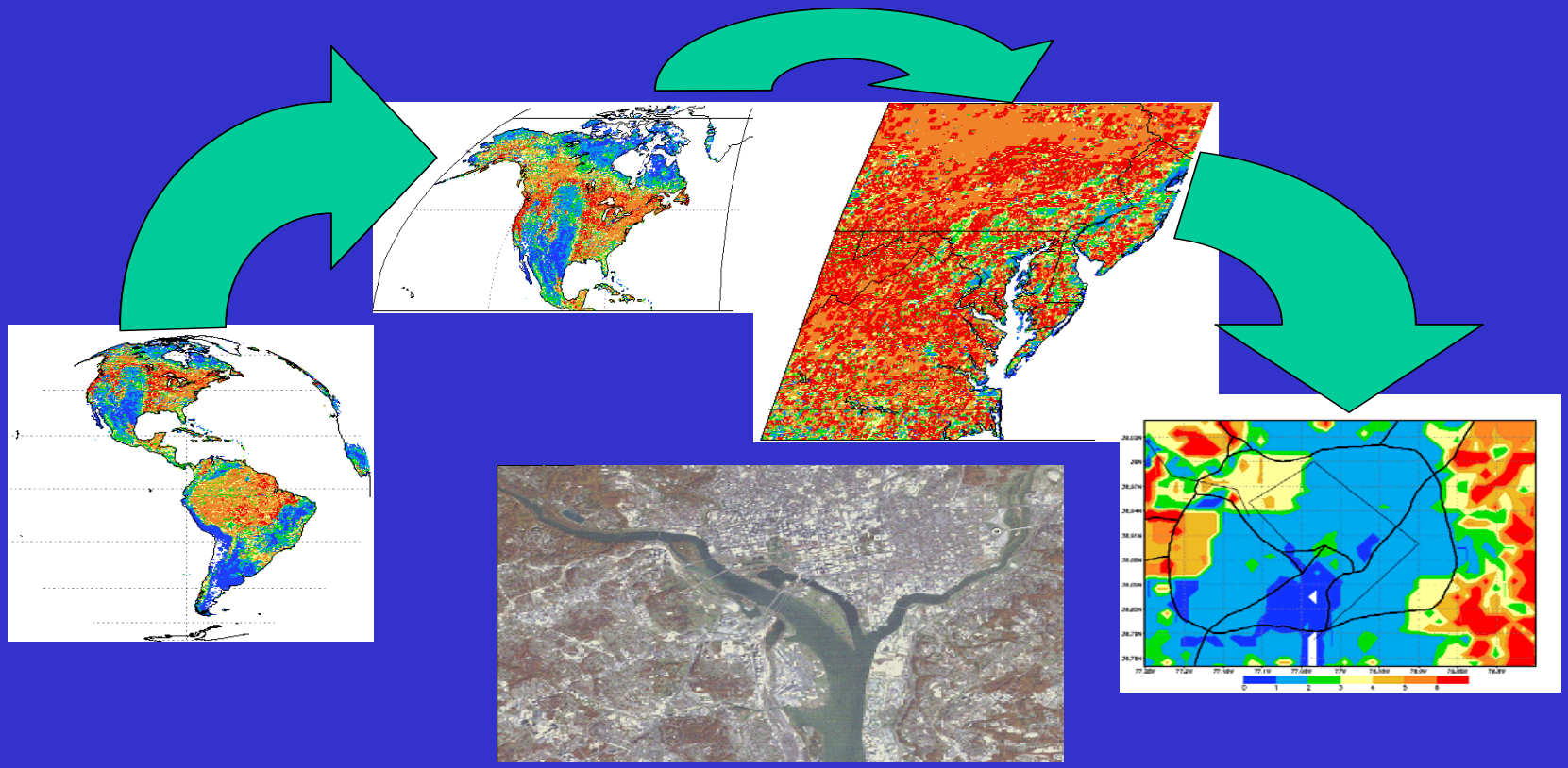


Figure 12. **The 1-km resolution land surface data assimilation possible with LIS will approach that of an aerial photo.**

LIS Results for Houston Area

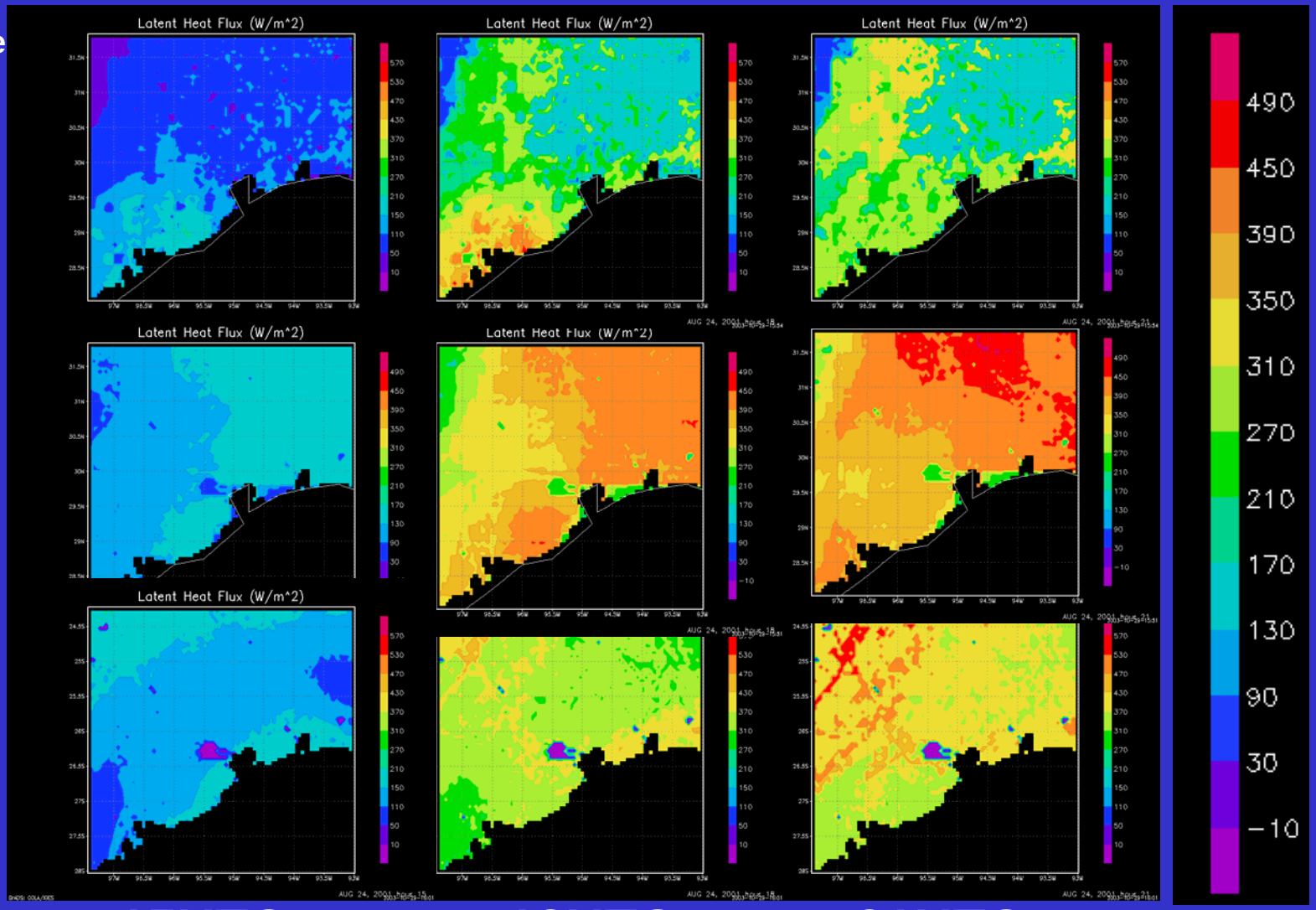
Latent Heat (Evapotranspiration) {Output suite of water and land products}

Land Surface Models

CLM

Noah

VIC



15UTC **18UTC** **21UTC**

Predicting and Monitoring Diseases: Summary

- Satellite Remote Sensing Data Have been successfully used for monitoring and predicting diseases, but limited to surrogate status for inferring weather and climate.
- New satellites will have improved spatial resolution and capabilities for measuring more weather and climate variables.
- 4D data assimilation can provide land surface water resources variables at scales approaching one km.

Predicting and Monitoring Diseases: Summary

- Improvements in Satellite Remote Sensing Data should dramatically improve our capabilities for monitoring and predicting diseases.
  - More specific spatial detail
  - More frequent observations
  - Estimate all of the important weather and climate variables that affect disease outbreaks