Satellite Remote Sensing of Water Resources:
Applications for Predicting and Monitoring Diseases

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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
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.
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

08/98 - 08/97 PRECIPITATION ANOMALIES (MM/DAY)
Global Precipitation Anomalies and Associated Disease Outbreaks

June 1997-May 1998
Earth Science Enterprise

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*.
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

- Aura
- Terra
- NMP-EO1
- Aqua
- Calipso
- Sage
- TRMM
- Champ
- Toms-EP
- Terra
- Landsat 7
- QuickScat
- CloudSat
- IceSat
- SeaWinds
- Grace
- UARS
- NMP-EO1
- Sage
**Global Water-Cycle: Observation Strategy**

- **Quantity**
- **Spatial Resolution**
- **Temporal Resolution**
- **Frequency**

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

**Future: Water Cycle Mission**

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

**Primary missing global observations:** Precipitation, Soil Moisture, Snow
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)
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 atmospheric predictability, and making new hydrologic applications possible.
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


- 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 GRACE

Above left: Terrestrial water storage components

Above right: Time series from Illinois (Rodell & Famiglietti, 2001)

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

Above right: Vertical and Temporal Disaggregation of GRACE products

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

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Rodell et al. 2002
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
**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 Altimeter  
**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*.

\[
\text{Input - Output} = \text{Storage Change} \\
P + \text{Gin} - (Q + \text{ET} + \text{Gout}) = \Delta S \\
\text{Rn} - G = \text{Le} + H
\]

**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.

\[ A \otimes B \otimes W_{ik}[O_k \otimes B_k] \]

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

\[ \frac{\Delta x}{\Delta t} = \text{dynamics} + \text{physics} + \Delta x \]

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.

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.
• 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