Regional Training Workshop
"Advances in Remote Sensing Application in Water Resources Management"

Flood and Drought Monitoring and Prediction by Satellite-based Microwave Remote Sensing

Toshio Koike
Director, International Centre for Water Hazard and Risk Management (ICHARM)
Council Member, Science Council of Japan (SCJ), Cabinet Office of Japan
Professor Emeritus, the University of Tokyo
Chair, River Council of Japan
Definition of Remote Sensing

Remote Sensing is a technology for identifying a target and estimating its physical, chemical and biological conditions without touching by using its inherent characteristics of emission, reflection, absorption and transmission of electromagnetic wave and its radiation transfer.
Electromagnetic Waves | Wavelength | generated by
--- | --- | ---
γ-RAY | 0.1 nm | atomic nucleus interaction
X-RAY | 0.1 - 10 nm | core electron ionization
UV | 10 nm - 0.4 μm | hull electron ionization
VISILE | 0.4 - 0.7 μm | hull electron excitation
INFRARED | NEAR | 0.7 - 1.3 μm
SHORT WAVE | 1.3 - 3 μm | thermal vibration of molecule
MEDIUM | 3 - 8 μm | and lattice of the substance
THERMAL | 8 - 14 μm |  
FAR | 14 μm - 1 mm |  
MICROWAVE | 1mm - 1m | rotation/reversal mode
WATER  Microwave Remote Sensing

Unique Roles in the Earth Environment

- Large Specific Heat of Liquid Water: 
  ➔ *Ocean as a heat transporter*
- Large Heat Exchange through Liquid – Gas Phase Transition ➔ *Water vapor as a heat transporter*
- Solid ICE Crystal Lattice: 
  ➔ *Ice floats in water & bine drives the great ocean conveyor belt.*
Microwave Remote Sensing of Land Hydrology

- Soil Moisture
- Vegetation/Snow
- Active & Passive Microwave Sensors
- Precipitation
- Surface Emissivity & Temp.

Satellites:
- GCOM-W1
- GPM-Core
- ALOS-2
Satellite Precipitation Sensors

Visible/Infrared Radiometer

Radar

Microwave Radiometer

Rain Gauge

On site calibration

3-D Observation Narrow Swath

Radiation from the rain field

Homogeneous Small Radiation

Surface radiation attenuated by precipitation field

Heterogeneous Large Radiation
Land Surface Monitoring by SAR

SAR measures an intensity of microwaves reflected from the earth’s surface.

The intensity is called “backscattering coefficient"
\[ \sigma^0 = f(M_v, S_d, C_l, S_v, D) \]

Soil moisture:
\( M_v \): Volume fraction of soil moisture (vol.)

Surface roughness:
\( S_d \): Standard deviation of surface height (cm)
\( C_l \): Surface correlation length (cm)

Soil parameter:
\( S_v \): Volume fraction of soil grains (vol.)
\( D \): Mean diameter of soil grains (cm)
Nigeria Flood in September 2018

Nigeria declares 'national disaster' after severe floods kill 100

By Damilola Odutuwa and Bukola Adebayo, for CNN

Updated 1029 GMT (1829 HKT) September 18, 2018

A man gestures next to his flooded house following heavy rain near the Nigerian town of Lokoja, in Kogi State, on September 14, 2018.

Residents steer a dugout canoe past flooded houses in Lokoja capital of Kogi State on September 14.


Identify inundation area on Sep-22, 2018

**MODIS (optical)**

- Easily identification & high frequency
- but covered with cloud

**Sentinel1 (SAR)**

- All weather & high spatial resolution
- but low frequency

Source of back image: "NASA Worldview"
Niger River Flood Area Map

1) Sep-04, 2018
2) Sep-16, 2018
3) Sep-22, 2018
4) Sep-28, 2018
5) Oct-10, 2018
6) Oct-22, 2018
7) Nov-03, 2018
8) Nov-15, 2018

Source of back image: "NASA Worldview"
Physical Measurement Approach

The Radiative Transfer Equation

\[ T_b = T_{bs} e^{-\tau_c} e^{-\tau_r} + \left( 1 - \omega_c \right) \left( 1 - e^{-\tau_c} \right) T_c e^{-\tau_r} + \sum \left( 1 - \omega_i \right) \left( 1 - e^{-\tau_i} \right) T_i \]

- surface radiation
- vegetation emission
- rainfall emission

Precip. layer
Vegetation layer
Snow layer
Surface
Location of AWS and ASSH in AMSR experimental fields of the study area
(UB: Ulaanbaatar, CY: Choir, MG: Mandalgobi, SA: Study area)
Temporal Variation of Spatially Averaged Validation

![Graph showing temporal variation of spatially averaged validation with data points for estimated and observed MV, precipitation, and soil moisture at 5 cm depth. Annotations include data missing due to Aqua Maneuver.]
Seasonal Variation of the Soil Moisture in the Tibetan Plateu
Microwave Remote Sensing of Land Hydrology

Soil Moisture

- Land Surface Scheme
  - GCOM-W1

Vegetation/Snow

- Vegetation/Snow Model
  - ALOS-2

Active & Passive Microwave Sensors

Precipitation

Cloud Physics Model

Surface Emissivity & Temp.
Coupled Atmosphere-Land Data Assimilation System (CALDAS)

The grant which financed this Pilot for Agriculture Drought Monitoring and Prediction in Brazil was received under the Japan-Bank Program for Main-streaming DRM in Developing Countries which is financed by the Government of Japan.

**Background:**

**Scientific Contribution**

Dynamic Vegetation Model

- Sawada & Koike, JGR (2014)

**Data Assimilation**

Coupled AMSR-E AMSR2 Electronic-Magnetic Wave

Carbon-LAI conversion model, Leaf Biomass, Root Biomass, Carbon pool Update Model

Impervious Boundary, Aquifer Model, Net Primary Production (NPP), Carbon Allocation Model, Stress-induced loss, turnover.
Natural climate variability

Precipitation deficiency, high temperature etc...

Soil water deficiency

Reduced stream flow, inflow to reservoirs, Groundwater deficiency

Plant water stress, reduced biomass and yield

Economic, Social, and Environmental impacts

→ Relationship between ecological and hydrological processes is important for analyzing drought process.
Hydrometeorology-Agriculture Droughts Prediction System

DIAS Archives

Hydromet Data
- NASA GLDAS
- JMA Reanalysis
- NCDC Global Met

Satellite
- AMSR2
- MODIS

Seasonal Forecast
- GFDL
- APCC

Global CLVDAS Outputs
- Optimized LDAS Parameters
- Optimized RTM Parameters
- LDAS Reanalysis Statistics

Real Time Data Management System

Satellite-based Land Data Assimilation (CLVDAS)

Water-Energy Budget Hydrological Model (WEB-DHM)

River Discharge
- Soil Moisture
- Ground Water
- Dam Storage
- Crop Production
Drought analysis

Wheat production

2007 Morocco Drought

LAI anomaly from CLVDAS

from Sawada & Ikoma
Hydrometeorology-Agriculture Droughts Prediction System

**DIAS Archives**

**Hydromet Data**
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**Satellite**
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**Global CLVDAS Outputs**
- Optimized LDAS Parameters
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**Real Time Data Management System**

**Satellite-based Land Data Assimilation (CLVDAS)**

**Water-Energy Budget Hydrological Model (WEB-DHM)**

**River Discharge**
- Soil Moisture
- Ground Water
- Dam Storage
- Crop Production

**Prediction Accuracy Evaluation**

**Bias Correction Weighting**

**Prediction**
- Ensemble Rainfall Prediction
- Rainfall Pattern 1
- Rainfall Pattern 2
- Rainfall Pattern n

** Ensemble Drought Prediction**
- River Discharge
- Soil Moisture, Ground Water
- Dam Storage
- Crop Production
Agricultural Drought Monitoring-Prediction

Aqua AMSR-E

North Africa

Drought Early Warning System based on Satellite Land Data Assimilation
From 20070101 to 20070331 = 90 days, 30frames

<table>
<thead>
<tr>
<th>200701</th>
<th>200801</th>
<th>200802</th>
<th>200803</th>
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</thead>
<tbody>
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</table>

Reanalysis LAI anomaly 20070101

Forecast LAI anomaly ave 20070101 from 200701

[Maps and graphs showing LAI anomaly for different regions of North Africa]
Background: Long-term Serious Droughts

Rainfall Anomaly

Number of Dry Days

Vegetation Water Supply Index (VWSI) Anomaly

Marengo et al., 2017
<table>
<thead>
<tr>
<th>#</th>
<th>Deliverable</th>
<th>Expected Date</th>
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<tbody>
<tr>
<td>0</td>
<td>On signing of the Contract and commencement of the Services</td>
<td>On or around May 31, 2018</td>
</tr>
<tr>
<td></td>
<td><strong>Component 1: Northeast Agriculture Drought Overview</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Action Plan for Components 1 and 2</td>
<td>On or around June 18, 2018</td>
</tr>
<tr>
<td>2</td>
<td>First Face to Face exchange in Fortaleza, Brazil</td>
<td>Week of 18-22 June, 2018</td>
</tr>
<tr>
<td>3</td>
<td>Agricultural drought monitoring: system parameter confirmation</td>
<td>On or around August 31, 2018</td>
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<tr>
<td>4</td>
<td>Agricultural drought monitoring and seasonal prediction system for the Northeast of Brazil</td>
<td>On or around December 31, 2018</td>
</tr>
<tr>
<td></td>
<td><strong>Component 2: Agricultural Drought Monitoring and Forecasting Pilot for the Ceará State</strong></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Second Face to Face exchange, training activities in Tokyo, Japan</td>
<td>October (4 weeks), 2018</td>
</tr>
<tr>
<td>6</td>
<td>Pilot agriculture-drought monitoring and prediction system for the Ceará State</td>
<td>On or around March 31, 2019</td>
</tr>
<tr>
<td></td>
<td><strong>Component 3: Assess the pilot’s results and establish a strategy to scale up the system</strong></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Action Plan to scale up the system in other States of Brazil and in LAC (roadmap and guidelines) and Final Report</td>
<td>On or around April 30, 2019</td>
</tr>
<tr>
<td>8</td>
<td>Third Face to Face exchange to present preliminary results of Components 1 and 2 and discuss scaling up strategy</td>
<td>On or around March 31, 2019</td>
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</table>
Drought Early Warning System at Brazil based on Satellite Land Data Assimilation

<table>
<thead>
<tr>
<th>Year</th>
<th>LAI (m2/m2)</th>
<th>Evapotranspiration (J/m2)</th>
<th>Vegetation water stress factor (–)</th>
<th>Land surface soil moisture content (m3/m3)</th>
<th>Root-zone soil moisture content (m3/m3)</th>
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</thead>
<tbody>
<tr>
<td>2013</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
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<td>2017</td>
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<td><img src="image25.png" alt="Image" /></td>
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<td>2018</td>
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<td><img src="image29.png" alt="Image" /></td>
<td><img src="image30.png" alt="Image" /></td>
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<tr>
<td>2019</td>
<td><img src="image31.png" alt="Image" /></td>
<td><img src="image32.png" alt="Image" /></td>
<td><img src="image33.png" alt="Image" /></td>
<td><img src="image34.png" alt="Image" /></td>
<td><img src="image35.png" alt="Image" /></td>
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</tbody>
</table>

LAI Monitoring at Ceará (Average)

<table>
<thead>
<tr>
<th>Year</th>
<th>Monitoring 2013-2019.12</th>
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</thead>
<tbody>
<tr>
<td>2013</td>
<td><img src="image36.png" alt="Image" /></td>
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<tr>
<td>2014</td>
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<td><img src="image38.png" alt="Image" /></td>
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<tr>
<td>2016</td>
<td><img src="image39.png" alt="Image" /></td>
</tr>
<tr>
<td>2017</td>
<td><img src="image40.png" alt="Image" /></td>
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<tr>
<td>2018</td>
<td><img src="image41.png" alt="Image" /></td>
</tr>
<tr>
<td>2019</td>
<td><img src="image42.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Mejerda River

It is virtually certain that drought will become more severe.

Annual Average Rainfall

<table>
<thead>
<tr>
<th></th>
<th>1986-2000</th>
<th>2051-2065</th>
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<tbody>
<tr>
<td>KALAAT ESSENAM</td>
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<td>AIN BEYA OUED</td>
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Groundwater Level Variations (satellite-observed)

Groundwater Level Variations (ground-observed)

Bir Lakhdar
Souk Sebt 2
Inter-comparison

GW storage anomaly (cm)

GW (LDAS-WEBDHM)
GW (TWS – SM)

Future GW Variations

GW storage anomaly (cm)

-1.3mm/year

2003 2004 2005 2006 2007 2008
2011 2021 2031 2041 2051 2061 2071 2081 2091
Microwave Remote Sensing of Land Hydrology

Soil Moisture

Vegetation/Snow

Land Surface Scheme

Active & Passive Microwave Sensors

Precipitation

Cloud Physics Model

Surface Emissivity & Temp.

Vegetation / Snow Model

GCOM-W1

GPM-Core

ALOS-2
Preliminary outputs
Gautemala

Lake Atescata
CLVDAS LAI and major products
3.3. Application: Horn of Africa drought

We cannot have the access to many ground observations to develop the drought prediction system.
Leaf Area Index timeseries

Blue: Prediction
Green: Horn of Africa drought (reanalysis)

Predictions: starting from 1 Oct 2010

Predictions: starting from 1 Jan 2011

Predictions: starting from 1 Mar 2011

[Sawada and Koike, JGR-A, submitted]
The grant which financed this Pilot for Agriculture Drought Monitoring and Prediction in Brazil was received under the Japan-Bank Program for Main-streaming DRM in Developing Countries which is financed by the Government of Japan.

**DIAS**

- **Monitoring**
- **Prediction**

**AMSR2**
- Satellite microwave brightness temperature

**Bias Corrected Rainfall & Hydro-met Forcing**

**Previous Year Hydro-met Forcing with Modified Rainfall by Seasonal Prediction**

- Dec.1
- Dec.15
- Jan.1
- Jan.15
- Feb.1
- Feb.15
- Mar.1
- Mar.15

**GLDAS 2.1**
- Meteorological forcing

**GFDLCM2p5**
- Seasonal prediction precipitation

The University of Tokyo
The grant which financed this Pilot for Agriculture Drought Monitoring and Prediction in Brazil was received under the Japan-Bank Program for Main-streaming DRM in Developing Countries which is financed by the Government of Japan.
Application to estimate required irrigation water volume without the irrigated water volume and its supply timing

Precipitation + Irrigation water

Input

DIAS drought system

Output

Irrigation water volume and its supply timing

Irrigated area

LAI deviation

Crop yield under irrigation condition

Effectiveness of irrigation

Crop yield under rain-fed condition

Precipitation

Irrigated area, water volume and its supply timing: Input

Output

Precipitation

Irrigated area, water volume and its supply timing: Input

Output

Precipitation

Input
Estimation of the required irrigation water volume:

We assumed the averaged crop yield in the period between 2003 and 2017 as the target crop yield of each farmer. The required irrigation water volume was estimated by comparing the target crop yield and the relationship between assumed irrigation water and estimated crop yield. In consequence, our simulations clearly show consistent decreases in required irrigation water volume as the drought condition improved gradually in 2015 and 2016 after a severe drought in 2014.