A Water Cycle Observation Mission (WCOM)

Jiancheng Shi

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Sanya, China
Introduction of WCOM

• 2013, WCOM was selected as one of 8 candidate science driving missions to be launched before 2020; It is only one that for EO in China.

• 2014-2015: Phase-A to study key technologies;

• In Feb., 2015, 3 from 8 candidate missions were selected as the key support missions with full funding for 2014-2015. WCOM is one of them;

• WCOM has passed PDR and CDR. Now, it is under the engineering phase;

• Launch date around 2020.
Water Cycle & Climate Change

Water Cycle /Climate Linkage

• One of the Earth system’s major cycles
• The Clausius–Clapeyron equation governs the water-holding capacity of the atmosphere that increases by about 7% per degree Celsius.

Expectations: drizzles, storms, ET, speed of water cycle, therefore, hydrological extreme events

Application Linkage
Basic requirements for monitoring and prediction of water resource, flood, drought, agricultures …..

Key Science Questions
What are the spatial-temporal distribution characteristics of water cycle components and processes? Are the changing speeding up?

Clausius-Clapeyron_Equation

Water in the climate system functions on all time scales (from hours to centuries)
## Available Sensors for Water Cycle

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Frequency (GHz)</th>
<th>vapor</th>
<th>Preci.</th>
<th>Temp.</th>
<th>Soil Moisture</th>
<th>Freeze Thaw</th>
<th>SWE</th>
<th>Sea Salinity</th>
<th>Sea Surface Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multiple Frequency Sensor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMSR–E</td>
<td>6.925;10.65;18.7;23.8;36.5;89</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>GCOM/AMSR2</td>
<td>6.9;7.3;10.65;18.7;23.8;36.5;89</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>FY–3/MWRI</td>
<td>10.65;18.7;23.8;36.5;89</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SMMR</td>
<td>6.6;10.7;18;21;37</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SSM/I</td>
<td>19.35;22.235;37.0;85.5</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>TRMM/TMI</td>
<td>10.65;19.35;21.3;37;85.5</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>WindSat</td>
<td>6.8;10.7;18.7;23.8;37</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSMIS</td>
<td>19.35;22.235;37;50–60;91.655;150;183.31</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

| **Single Frequency Sensor** |                                      |       |        |       |               |             |     |              |                  |
| ASCAT                    | 5.255                                 |       |        |       |               |             |     |              | ✓                |
| ERS                      | 5.3                                   |       |        |       |               |             |     |              | ✓                |
| QuikSCAT                 | 13.4                                  |       |        |       |               |             |     |              | ✓                |
| Aquarius                 | 1.413                                 |       |        |       |               |             |     | ✓            |                  |
| SMOS                     | 1.41                                  |       |        |       |               | ✓           |     | ✓            |                  |
| SMAP                     | 1.26; 1.41                            | ✓     | ✓      | ✓     |               |             | ✓   | ✓            |                  |
Problems in SWE inversion

- Passive microwave (~25km):
  - SMMR
  - SSM/I
  - AMSR-E
  - AMSR2
  - FY-3

\[ SD(\text{SWE}) = a + b \cdot \left( T_{Bp} (18) - T_{Bp} (37) \right) \]

1. Semi-empirical algorithm:
   Regional differences, inconsistent accuracy globally

2. Vertical inhomogeneous (layered snow), changes in snow characteristics

3. Atmospheres

4. Insufficient spatial resolution, horizontally in homogenous of snow (mixed pixel)

**Need:** Spatial observation capacity
# Problems of Current Techniques

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Disadvantages in Observations</th>
<th>Disadvantages in Inversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Moisture</td>
<td>Weak penetration for high freq.; lack of temperature for low freq.; RFI</td>
<td>Lack of valid inversion technique on vegetation and surface roughness</td>
</tr>
<tr>
<td>SWE</td>
<td>Low spatial resolution of passive microwave</td>
<td>More considerations needed for snow process and atmosphere conditions</td>
</tr>
<tr>
<td>FT</td>
<td>Low spatial resolution for passive microwave</td>
<td>Limited validity for using fixed Threshold values</td>
</tr>
<tr>
<td>Sea Salinity</td>
<td>Lack of temperature and atmosphere observations</td>
<td>Lack of surface roughness correction</td>
</tr>
<tr>
<td>Sea Evaporation</td>
<td>Lack of simultaneous observations on both sea surface and atmosphere</td>
<td>Uncertainties in the inversion of related parameters</td>
</tr>
<tr>
<td>Precip.</td>
<td>Cloud 3D properties</td>
<td>Need to Discern rain and snow</td>
</tr>
</tbody>
</table>

1、**Single-Frequency:** Lack of synergistic observations on the other affecting factors

2、**Multi-Frequency:** Lack of optimal frequency on the surface water cycle components

3、**Both:** Lack of systematical observations on the characteristics the water cycle
Payloads and Configurations

- **1. IMI, Full Polarized Interferometric Radiometer:** Soil Moisture and Sea Salinity
- **2. DPS, Dual Frequency Polarized Scatterometer:** SWE and FT
- **3. PMI, Polarimetric Microwave Imager, 6.8～89GHz:** Temperature, rain, water vapor, atmosphere correction, and bridge to historical data

<table>
<thead>
<tr>
<th>Payloads</th>
<th>IMI</th>
<th>PMI</th>
<th>DPS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency (GHz)</strong></td>
<td>L, S, C (1.4, 2.4, 6.8)</td>
<td>C~W (7.2, 10.65, 18.7, 23.8, 37, 89)</td>
<td>X, Ku (9.6, 14/17)</td>
</tr>
<tr>
<td><strong>Spatial Resolution (km)</strong></td>
<td>L: 50, S: 30, C: 15</td>
<td>4~50 (frequencies)</td>
<td>2~5 (processed)</td>
</tr>
<tr>
<td><strong>Swath Width (km)</strong></td>
<td>&gt;1000</td>
<td>&gt;1000</td>
<td>&gt;1000</td>
</tr>
<tr>
<td><strong>Polarization</strong></td>
<td>Full-Pol</td>
<td>Full-Pol</td>
<td>Full-Pol</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>0.1~0.2K</td>
<td>0.3~0.5K</td>
<td>0.5dB</td>
</tr>
<tr>
<td><strong>Temporal Resolution (Day)</strong></td>
<td>2~3</td>
<td>2~3</td>
<td>2~3</td>
</tr>
</tbody>
</table>
Instrument Concept: 1D Microwave Interferometric Radiometer with parabolic cylinder reflector antenna

- Use parabolic cylinder reflector and interferometric technology to achieve High spatial resolution
- Patch feeds and shared reflector to achieve the multi-frequency ability
- Dual-size feeds to enhance the system sensitivity performance

<table>
<thead>
<tr>
<th>System</th>
<th>1D Interferometry + parabolic cylinder reflector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>L: 1.4<del>1.427GHz, S: 2.64</del>2.70GHz, C: 6.6~6.9GHz</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>L-band: 0.1K; S-band: 0.4K; C-band: 0.4K</td>
</tr>
<tr>
<td>Polarization</td>
<td>Full pol (H,V,Q,R)</td>
</tr>
<tr>
<td>Antenna</td>
<td>Reflector: 6.0m×6.0m (after deployment)</td>
</tr>
<tr>
<td>Feed array</td>
<td>4m×0.5m</td>
</tr>
<tr>
<td>FOV</td>
<td>&gt;1000km</td>
</tr>
<tr>
<td>Incidence</td>
<td>30~55°</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>L-band: 50km, S-band: 30km, C-band: 15km</td>
</tr>
<tr>
<td>Revisit</td>
<td>2-3 days</td>
</tr>
<tr>
<td>Weight</td>
<td>250kg</td>
</tr>
<tr>
<td>Data rate</td>
<td>&lt; 1Mbps</td>
</tr>
</tbody>
</table>

Simulated footprints on the ground
Advantages in soil moisture retrieval

- **IMI**
  1) Combination of L- and S-band can solve the polarization effects in vegetation correction.
  2) The probability of RFI occurrence at the same area and frequency is very small. RFI can be avoided by switching L- and S-band.

- **DPS**
  Vegetation information of high resolution

**PMI**: Surface effective temperature

**Various vegetation types**

**PALS**
SMEX02 experiment area

**RFI influence**
FPIR-L&S
Atmosphere
PMI
**Vegetation correction**
FPIR-L&S
Surface effective temperature
PMI-Ka

**DPS**
Vegetation information of high resolution

**PALS**
SMEX02 experiment area

**PALS**
SMEX02 experiment area

**Various vegetation types**

**Only L-band**
RMSE=0.047

**L+S-band**
RMSE=0.035
Soil moisture Products

A) Passive microwave (IMI)

L/S/C-bands: 50/30/15 km

Experiment with Airborne data:
Downscale the L-band Tb (4km) at a scale of 800m using higher resolution Tb of S-band, and its validation with original L-band data

Passive: Sensitive to soil moisture but low resolution
Active: High resolution but sensitive to vegetation and roughness

B) Active/passive microwave (IMI/PMI+DPS)

\[ T_{BP} = A + C \frac{\sigma_{v}^{p}}{\sigma_{h}} + \left( B + D \frac{\sigma_{v}^{p}}{\sigma_{h}} \right) \sigma_{pp} \]

Active /passive combination of C and X band:

Products: Soil moisture estimates at a scale of both 15km and 5km over nominal areas and 30km over forests.
Advantages of WCOM Payloads Design

<table>
<thead>
<tr>
<th></th>
<th>IMI</th>
<th>PMI</th>
<th>DPS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soil Moisture</strong></td>
<td>1 More sensitive to land surface</td>
<td>1 Sensitive to temperature</td>
<td>1 Surface Roughness and vegetation</td>
</tr>
<tr>
<td></td>
<td>2 Minimizing vegetation effects</td>
<td>2 Observing large-scale surface roughness</td>
<td>2 high resolution soil moisture</td>
</tr>
<tr>
<td></td>
<td>3 Mitigating RFI</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sea Salinity</strong></td>
<td>1 More sensitive to sea surface</td>
<td>1 effective correction on atmosphere</td>
<td>High resolution Wind Vector</td>
</tr>
<tr>
<td></td>
<td>2 Faraday rotation correction</td>
<td>2 sensitive to sea temperature</td>
<td></td>
</tr>
<tr>
<td><strong>Sea Evaporation</strong></td>
<td>Corrections on sea surface roughness</td>
<td>Sensitive to temperature</td>
<td>High resolution Wind Vector</td>
</tr>
<tr>
<td><strong>FT</strong></td>
<td>Obtaining Soil Surface Parameters</td>
<td>Sensitive to temperature changes</td>
<td>1 Time series techniques for FT detection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 Downscaling techniques for FT inversion</td>
</tr>
<tr>
<td><strong>SWE</strong></td>
<td>Obtaining Soil Surface Parameters</td>
<td>Obtaining SWE by scattering effects</td>
<td>1 Estimating SWE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 Mitigating Mixed pixel effects</td>
</tr>
<tr>
<td><strong>Vapor and Precip.</strong></td>
<td>Helping determine land surface emissivity</td>
<td>1) obtaining Water Vapor</td>
<td>High resolution observations on precip.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2) Precip. Rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3) Discerning Rain and snow</td>
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</tr>
</tbody>
</table>

The Payloads Design: 1）Optimal channels for inversion，2）Effective corrections on affecting factors，3）Simultaneous observations
Objectives of WCOM

• Overall scientific objectives of WCOM
  
  • To significantly improve the accuracy and synchronization of measurements for spatial and temporal distribution of global water cycle key elements and system

  • To refine the long-term satellite observations over past decades, and to provide a new opportunity to improve water cycle related model.
2014-2016 Objectives

Science part

1）Further evaluation of science objectives; further optimization of payloads, to achieve higher precision water cycle parameters observation than any existing satellites;

2）Based on the simultaneously multi-sensor observation, to achieve joint key water cycle parameters and environmental parameters retrieval, and the preliminary algorithm validation;

3）The study of the method to calibration of historical observations of other satellites based on WCOM observations; Water cycle models parameter optimization;

Technology part

1）Design and evaluation of payloads: FPIR, PMI and DFPSCAT

2）To make breakthroughs in key technologies in payloads, and the experimental validation of the key technologies ;

3）WCOM satellite platform design and evaluation based on the requirement of payloads and their observation; Design and evaluation of interface between satellite system and other systems
Scientific Application System

1) Subsystem of Joint Retrieval and Validation
   - Retrieved high accuracy scientific products of major water cycle components

2) Subsystem for historical data reprocessing
   - Long-term remote sensing data products of water cycle components

3) Subsystem for Modeling and Data Assimilation of Water Cycle
   - Parameter optimization and refinement of hydrological models

Scientific objective 1:
- Spatial and Temporal Patterns and Trends of the Water Cycle
- Spatial or temporal distributions of current water cycle system
- Spatial or temporal variations of water cycle in a long-term period

Scientific objective 2:
- Responses of Water Cycle to Global Change and Its Feedback
- Historical observations
- L4 data
- L2/L3 data
- L1 data

Responses of Water Cycle to Global Change and Its Feedback

Spatial and Temporal Patterns and Trends of the Water Cycle

Scientific objective 1:
Design and test the prototype algorithms for snow water equivalent, soil moisture, soil freeze/thaw, ocean salinity, atmosphere water vapor and precipitation.
SWE retrieval and Validation

SWE inversion algorithm for DPS scatterometer is developed based on Bicontinuous+VRT model.

Three-year time series measurements at dual-polarization X and Ku bands in Finland Nosrex campaign.
WCOM data simulator

Dynamic forcing data module

WCOM payloads configuration

1. FPIR/PMI Brightness temperature
2. DFPSCAT Backscatter coefficient

Initial WCOM data

Final WCOM data

Satellite orbit, Sensor gain function, footprints and resampling

Calibration with current satellites (SMOS/SMAP, AMSR2, etc)

2) Evaluate instrument error on science requirements

3) Parameter optimization of hydrologic model

1) Retrieval algorithm development and validation
Establishments of Historical Data

Improving the algorithms using the accurate WCOM measurements

Form long time series measurements to analyze the change characteristics

**Establishments of Historical Data**

**TMI/TRMM** 1998–GPM

**SSM/I(R): 1978 – Now**

**ERS + ASCAT 1991—Now**

Combined Passive/Active

**WindSat**

**AMSR-E**

**ASCAT** on **METOP Series**

**ERS** + **ASCAT** 1991—Now

**Combined Passive/Active**

**Establishments of Historical Data**

**TMI/TRMM** 1998–GPM

**SSM/I(R): 1978 – Now**

**ERS + ASCAT 1991—Now**

Combined Passive/Active
Test from SMOS-AMSR-E

- **input:** SMOS soil moisture and AMSR-E observations;
- **output:** simulated SMOS soil moisture with AMSR-E.
1、Parameter optimization using single-element observation

<table>
<thead>
<tr>
<th>Case</th>
<th>Changes in model performances</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil temperature</td>
</tr>
<tr>
<td>soil temperature observation</td>
<td>21.99%</td>
</tr>
<tr>
<td>Soil moisture observation</td>
<td>-0.46%</td>
</tr>
</tbody>
</table>

Test experiments by CoLM demonstrate that: the model error will transfer to another state variables when only one state is optimized by using single-element observation.

2、Parameter optimization using multi-element observation

- **Parameter Selection**: Select the most sensitive and controlling parameters
- **Building Surrogate Models**: Building statistical models to surrogate the physical models
- **Multi-Object Optimization**

Simultaneous multi-parameters optimization provide a much better chance for the model improvement.
Form a global water cycle consolidation
Water Cycle Observation Mission (WCOM) Summary

Systematic and Simultaneous Observations For Water Cycle

Accurate Inversion of Water Cycle Parameters based on Synergistic Observations

- Soil Moisture
- Freeze/Thaw
- SWE
- Ocean Salinity
- Precipitation
- Ocean Evaporation

Key Science Questions:
1) Improving on understanding of spatial/temporal distribution characteristics of water cycle key parameters and related physical processes?
2) Response and feedback of water cycle to global changes?

Science and measurements current drawbacks

New Payloads Designs

Demand and feasibility analysis for the sensors

1) Accurate key components measurement;
2) Improve historical measurements and to Improving the related models