Observing Earth’s water cycle from space

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A satellite system comprising active and passive microwave remote sensors enables synchronous accurate acquisition of key elements in the Earth’s water cycle.

The global water cycle is the continuous transformation and movement of water on, above, and below the surface of the Earth through the phases of liquid, solid (ice and snow), and gas (vapor). It is the most active and important of the planet’s cycles, defining Earth’s mass, energy transportation, and transitions, and is influenced by factors such as global climate and human activity. To measure the effects of these transformations, scientists examine spatial distribution and temporal variations in images of cycle processes. However, such studies are currently limited by shortfalls in knowledge and observational capabilities. Existing systems offer satellite monitoring of the cycle, but the images they produce would benefit from improved temporal resolution, for example.

Here, we present an integrated satellite-based observation system for the key elements and corresponding processes of the global water cycle. Our approach enhances observing and retrieval capabilities, to improve Earth science and global change studies. The proposed system, the Water Cycle Observation Mission (WCOM; see Figure 1), monitors soil moisture, ocean salinity, snow water equivalent, soil freeze-thaw processes, atmospheric water vapor, and precipitation. Moreover, its optimized payload configuration and design enable the mission to provide observations of all the environmental parameters—dominant and auxiliary—required for accurate retrieval of water cycle information. We can use the resulting datasets to refine the long-term satellite observations made during recent decades, and to monitor changes in hydrological elements.

The WCOM satellite contains a combination of active and passive microwave remote sensors with wide frequency coverage, and hosts three main payloads (see Table 1). The first is an L-S-C-band tri-frequency fully polarized interferometric synthetic aperture microwave radiometer (FPIR), comprising a 9×6m mesh reflector and a 1D thinned array as the feed. These components enable spatial resolution ranging from 15 to 50km for soil moisture and ocean salinity. The second WCOM payload is a polarized microwave radiometric imager (PMI) covering bands in the range 6.8–150GHz, with a 1.8m-diameter reflector antenna for conical scanning (most of the frequency channels are capable of full polarization). The unit is designed to gather information on atmospheric properties and surface temperatures. The third payload is a X-Ku band dual-frequency polarized SCATterometer (DFPSCAT) with 2–5km resolution and a 1000km swath for mapping of snow

Figure 1. An artist’s impression of the Water Cycle Observation Mission (WCOM) satellite for observing the Earth’s water cycle.

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Table 1. Performance characteristics of the WCOM system payloads. FPIR: Fully polarized interferometric synthetic aperture microwave radiometer. PMI: Polarized microwave radiometric imager. DFPSCAT: Dual-frequency polarized SCATterometer.

<table>
<thead>
<tr>
<th></th>
<th>FPIR</th>
<th>PMI</th>
<th>DFPSCAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequencies</td>
<td>L, S, C, 6.8, 10.65, 18.7, 23.8, 37, 89, 150GHz</td>
<td>6.8, 10.65, 18.7, 23.8, 37, 89, 150GHz</td>
<td>X, Ku</td>
</tr>
<tr>
<td>Mean spatial resolution (km)</td>
<td>15~50</td>
<td>4~50</td>
<td>&gt;1000</td>
</tr>
<tr>
<td>Swath width (km)</td>
<td>&gt;1000</td>
<td>1000</td>
<td>&gt;1000</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.1~0.2K</td>
<td>0.3~0.5K</td>
<td>0.5dB</td>
</tr>
<tr>
<td>Polarization mode</td>
<td>Full-pol</td>
<td>Full-pol for selected frequencies</td>
<td>Full-pol</td>
</tr>
<tr>
<td>Detection elements</td>
<td>Soil moisture, ocean</td>
<td>Land/sea surface temperature, water vapor, precipitation</td>
<td>Snow water equivalent, soil freeze-thaw</td>
</tr>
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</table>

water equivalent and freeze-thaw processes. Our system would achieve fine resolution by linear frequency modulation pulse compression along the elevation direction, and by unfocused synthetic aperture processing (a technique where the Doppler effect is exploited to synthesize a longer aperture to achieve an improved resolution), as well as super-resolution reconstruction by oversampling in the direction of the azimuth. We plan to fly the satellite system with a 6:00 am/pm sun-synchronous polar orbit at a height of 600km, to make the surface resolution and satellite power feasible.

Our design uses a wide multi-frequency range of 1.4~150GHz that, when applied with the active and passive remote observations, provides highly sensitive microwave information of the target elements and the environmental variables needed for retrieval algorithms. For soil moisture retrieval, the combination of L and S bands provides an efficient way to account for the attenuation of soil emissions by vegetation cover.\(^1\) Alternating between these bands, we could avoid radio frequency interference, which can lead to loss of data coverage and underestimation of soil moisture. The K\(_\alpha\) band observation from the PMI provides simultaneous physical temperature information,\(^2,3\) offering an advantage over other contemporary satellite missions, such as the SMOS\(^2\) and SMAP\(^3\) of the European Space Agency (ESA). The high-resolution active microwave observation of DFPSCAT can be used for downscaling models of soil moisture (deriving smaller-scale features for localized studies) with benefits for agricultural and hydrometeorology applications. The PMI-K\(_\alpha\) band observation helps indicate the temperature change (freeze-thaw) in soils,\(^4\) and the L band provides useful information about soil water phase transition during freeze-thaw processes. Combined with the passive information, DFPSCAT’s observations would enable mapping of the soil freeze-thaw state using a time-series algorithm. For snow-water equivalent, the X-K\(_u\) band observations are sensitive to snow volume scattering.\(^5\) The system’s configuration is similar to that of the ESA’s CoReH2O Mission,\(^6\) but with a wider swath of >1000km, to significantly improve the temporal resolution. Furthermore, the PMI and FPIR observations can provide information for snow temperature profiles and about the underlying soils. The FPIR-L band observation is highly sensitive to changes in ocean surface salinity. DFPSCAT and PMI observations offer information on ocean surface roughness, temperature, and precipitation, which are critical for accurate retrieval of salinity data. The system can identify water vapor and precipitation and differentiate between snow and rain, although its temporal resolution in this area is currently limited.

In summary, WCOM is China’s first satellite mission to combine active and passive microwave measurements on the key water cycle elements of land, sea, and atmosphere. Exploiting multi-frequency active and passive microwave sensors, we can develop high-performance retrieval algorithms based on the multi-source data gathered.

The system is currently in early development, and our future work focuses on its implementation, scheduled for 2016–2020.

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References


