# Satellite Remote Sensing Missions for Monitoring Water, Carbon, and Global Climate Change

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In recent years, the subjects of water, carbon, and global climate change have attracted worldwide attention by scientists and the media. Climate change, whether associated with human- induced or natural variations, has and will continue to be important to policy makers and the public. It is clear from reports such as that by the Intergovernmental Panel on Climate Change (IPCC) [1] that Earth observations play a critical role in providing information for assessment and modeling. Improving these observations, better quality and new variables, is a goal of most national and intergovernmental space agencies. Major initiatives are under way that will result in benefits to a broad range of our global society.

This Special Issue covers recent and future Earth observing satellites including the purpose of each mission, technology of the measurements, modeling of the physics and data, image and signal processing.

In the United States, a decadal study [2] was recently completed by the Committee on Earth Science and Applications of the US National Research Council. The committee called for a commitment from the U.S. administration to Earth observations to secure benefits for mankind. The report gives both direction and a large boost to U.S. satellite programs as it recommended NOAA to restore key observational capabilities of satellite missions and also that NASA and NOAA launch 17 new satellite missions in the next 10 years. The study also adds an additional focus to these missions: societal benefits.

Other countries have also been expanding their Earth observation programs with numerous advanced concept satellite missions. Of particular relevance to this issue are articles describing the Earth observing programs of the European Space Agency (ESA), the Japanese Aerospace Exploration Agency (JAXA), the China National Space Administration (CNSA), the Canadian Space Agency (CSA), and the National Space Program Office (NSPO) of Taiwan.

The ESA has a long history of Earth observation from space that began with meteorological missions and has included a series of increasingly sophisticated radars that have provided valuable data about climate and the changing environment. The ESA's current and future Earth observing is under its Living Planet Programme and includes the Earth Explorer, meteorological, and Sentinel missions.

JAXA has supported a wide range of satellite-based instruments and platforms that have and will provide global Earth observations for water, carbon, and climate. Of particular note for the future is the commitment to the Global Change Observation Mission (GCOM) that will launch a series of two types of satellites (water

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and climate) to provide consistent and continuous observations of key variables over a 15-year period.

In addition to the United States, ESA, and JAXA programs, there are strong satellite-based Earth observing programs in Canada, China, Argentina, Taiwan, and Brazil.

In this Special Issue some of the most significant recent and future Earth observing satellites planned to monitor water, carbon and global climate change are described. Each paper will attempt to describe the purpose of the scientific mission, the technology of the measurements, the modeling of the physics, and the data, image, and signal processing.

Four of the papers describe aspects of missions that are highly complementary (SMOS, Aquarius, and SMAP). The Soil Moisture Ocean Salinity (SMOS) mission is presented in two papers by Font *et al.* and Kerr *et al.* These papers each address one of the two science goals; soil moisture (Kerr *et al.*) and sea surface salinity (Font *et al.*). SMOS was developed under the European Space Agency Living Planet Program. It was successfully launched in November 2009. The importance of SMOS to Earth science and remote sensing is tremendous. It is the first satellite mission designed specifically for the science objectives of soil moisture and ocean salinity, the first satellite L-band radiometer, and the first Earth science radiometer to incorporate a two-dimensional synthetic aperture antenna. The antenna design was critical to overcoming the spatial resolution problems encountered when using low frequencies.

Aquarius is described in the paper by LeVine *et al.* It was initiated under the NASA Earth Science System Pathfinder program in cooperation with the Argentine Space Agency and has a planned launch date in late 2010. Aquarius will also study ocean salinity but will enhance the passive-only approach of SMOS with a combined passive-active push-broom type L-band system. The high sensitivity radiometer and the radar measurements are expected to increase the quality of retrievals.

The Soil Moisture Active Passive (SMAP) mission is expected to be the first satellite resulting from the NASA decadal survey. As described in Entekhabi *et al.*, SMAP will provide high spatial resolution soil moisture and freeze-thaw observations using a large aperture antenna and enhanced data processing achieved by combining the radiometer retrievals with the very high resolution radar data. SMAP will build from the radiometer-only approach of SMOS and the coarser resolution passive-active Aquarius satellite. The enhanced resolution of SMAP will allow its use in a broader range of science and applications. The SMAP mission will also incorporate higher level products that integrate the observations with models to provide water and carbon cycle information. Launch is expected in 2014.

JAXA is making a major commitment to monitoring climate with its GCOM satellite series. GCOM will involve two polar-orbiting satellite series, spread over three generations to achieve long-term and consistent data records. The two satellite series are the GCOM-W (Water) and GCOM-C (Climate). The first-generation satellite, GCOM-W1, will carry the AMSR2 instrument, which is a multifrequency, total-power microwave radiometer system with dual polarization channels for all frequency bands. The frequency bands include 6.925, 7.3, 10.65, 18.7, 23.8, 36.5, and 89.0 GHz. The GCOM-C1 will carry the SGLI instrument, which is a versatile, general-purpose optical and infrared radiometer system from near ultraviolet to infrared. The paper by Imaoka *et al.* describes the GCOM objectives, observing instruments, products, and the sciences and applications to monitoring of the carbon, water, and climate change.

Abdalati *et al.* point out that satellite observations have made significant contributions to our awareness of the remarkable changes in the Earth's polar ice cover that have occurred in the last decade. NASA's Ice, Cloud and land Elevation Satellite-2 (ICESat-2) will provide continuing and improved observations of polar ice. ICEsat-2 is a follow-on of ICESat and is also a NASA decadal survey mission planned for 2015. It will provide precision laser measurements of surface elevation. ICESat-2 will measure the temporal and spatial character of ice sheet elevation change to enable assessment of ice sheet mass balance and examination of the underlying mechanisms that control it.

Understanding the dynamics of water storage in seasonal snowpacks is critical to the effective management of water resources globally. There are two related space-borne missions for the measurements of global snow water equivalent (SWE) under development. The ESA Cold Regions Hydrology High Resolution Observatory (CoReH2O) mission addresses the observation of physical properties and temporal dynamics of the elements of the cryosphere including seasonal snow cover. The sensor is a dual frequency, X- and Ku-band (9.6 and 17.2 GHz), dual-polarized (VV and VH) SAR. The NASA Snow and Cold Land process (SCLP) Satellite Mission has similar objective with the CoReH2O. It was recommended by the Decadal Study to be a tier-3 mission. The proposed SCLP is a three-year mission that will provide high-resolution snow water equivalent (SWE) observations using active microwave remote sensing (SAR) at Ku-band and X-band. In January 2009 CoReH2O was selected by ESA for detailed feasibility studies. In the paper by Rott *et al.*, the authors describe the scientific drivers and technical approach of CoReH2O satellite mission.

The dynamics and the amount of water stored in lakes, streams, reservoirs, and wetlands globally are poorly known. For sea surface heights, the current generation of nadir pointing altimeters limits resolution of ocean surface topography to spatial scales exceeding about 100 km. Thus, the surface water hydrology and physical oceanography communities are in need of measurements of water elevations along rivers, lakes, streams, and wetlands and over the ocean surface using swath altimetry. The Surface Water and Ocean Topography (SWOT) mission will make such measurements. In the paper by Durand *et al.*, the authors present the hydrology and oceanography science questions and requirements that the mission will address and describe the Ka-band radar interferometer that is the core technology for SWOT.

One of the major satellite success stories in recent years has been the Advanced Land Observing Satellite (ALOS) launched in 2006 by JAXA. As described by Shimada *et al.*, ALOS consists of several environmental remote sensing systems. These include high-resolution optical (visible and near infrared push-broom) and active microwave sensors (L-band synthetic aperture radar). ALOS has four mission objectives: cartography, regional observations, disaster observations, and resource exploration. Through its three sensors, acquisition strategy, and communication infrastructure, the ALOS mission is aimed to contribute to monitoring water, carbon, and global climate change. Shimada *et al.* present several excellent examples of the contributions ALOS has made. The success of the mission has resulted in a plan for a follow-on mission.

RADARSAT-2 is the second in a series of Canadian space-borne synthetic aperture radar (SAR) satellites and was launched in 2007. The RADARSAT-2 sensor is an advanced single-sensor polarimetric C-band SAR (5.405 GHz). It acquires data in three polarization configurations: single, dual, and quad polarization. In the paper by Moon *et al.*, several applications of the various modes of SAR data to coastal zone problems are described, including coastal surface wind, waterline mapping and polarimetric SAR data inversion for topographic and geological parameters of tidal flats. Estimation of wind speeds and directions in coastal areas are empirically formulated and are further improved with the available fully polarimetric data from RADARSAT-2.

The German Aerospace Center (DLR) has put particular emphasis on the development of space SAR technology for high-resolution radar images. Radar interferometry is the coherent combination of complex SAR images. Most interferometric applications, however, have been based on a repeat-pass orbit scenario. In their paper, Krieger *et al.* describe single-pass interferometric SAR missions employing two or more satellites in a closed formation. The paper further describes the designs of the twin satellite missions, TanDEM-X and Tandem-L. These missions can enable the determination of global 3-D forest structure, large-scale measurements of millimeter-scale displacements due to tectonic shifts, and glacier movements.

Two Chinese Earth observation satellites series are described by Jin *et al.* These are the meterological Feng-Yun (FY, wind-cloud series) and the oceanic Hang-Yang (HY ocean series). The first FY was launched in 1988. The most recent is the FY3, which was launched with a microwave temperature sounder, microwave humidity sounder, and a microwave radiometer imager. Development of the HY series was initiated in 1997. The first oceanic satellite HY-1 was launched in 2002 and focused on ocean color. HY-2 will have four microwave sensors, including a Ku-band scatterometer, double altimeter, and two radiometers; it will be launched in 2010. HY-3 with high-resolution polarimetric SAR will be launched in 2013.

The Precipitation and All-weather Temperature and Humidity (PATH) mission is another of the NASA decadal survey missions. As described by Lambrigtsen *et al.*, PATH will focus on the hydrologic cycle in the atmosphere and address applications that range from weather forecasting to climate research. The primary instrument will be a microwave sounder that measures upwelling thermal radiation. This instrument will utilize synthetic aperture radiometry to achieve required spatial resolution. The new aspect of the mission is that it will make these measurements from a geostationary orbit, which will for the first time provide a time-continuous view of atmospheric temperature and all three phases of water under nearly all weather conditions.

The paper by Chen *et al.* describes the FORMOSAT II, the first earth observation satellite mission launched by Taiwan. The FORMOSAT II has the capability of daily revisits and the data have been very useful when used in conjunction with existing high spatial resolution imaging satellites such as SPOT-5, IKONOS, QuickBird, etc. This daily revisit capability is especially valuable in supporting emergency responses to disasters. The paper further shows several examples of recent disasters including the May 2008 earthquake of Richter magnitude 8.0 that occurred in Sichuan, China.

In addition to the missions described in this set of papers, there are other exciting and innovative satellites under development. The next decade of advances and observations will certainly bring societal benefits.

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