Final Workshop Report

The global water cycle describes the circulation of water as a vital and dynamic substance in its liquid, solid, and vapor phases as it moves through the atmosphere, oceans and land. Life in its many forms exists because of water, and modern civilization depends on learning how to live within the constraints imposed by the availability of water. The scientific challenge posed by the need to observe the global water cycle is to integrate in situ and space-borne observations to quantify the key water-cycle state variables and fluxes. The vision to address that challenge is a series of Earth observation missions that will measure the states, stocks, flows, and residence times of water on regional to global scales followed by a series of coordinated missions that will address the processes, on a global scale, that underlie variability and changes in water in all its three phases. The accompanying societal challenge is to foster the improved use of water data and information as a basis for enlightened management of water resources, to protect life and property from effects of extremes in the water cycle. A major change in thinking about water science that goes beyond its physics to include its role in ecosystems and society is also required. Better water-cycle observations, especially on the continental and global scales, will be essential. Water-cycle predictions need to be readily available globally to reduce loss of life and property caused by water-related natural hazards. There are important gaps in knowledge of where water is stored, where it is going, and how fast it moves.

Global measurements from space open a vision for the advancement of water science. This vision includes advances in understanding, data, and information that will improve the ability to manage water and to provide the water-related infrastructure that is needed to provide for human needs and to protect and enhance the natural environment and associated biological systems. The 2007 Decadal Survey identified 17 missions (3 water), and envisioned a future where surface, subsurface, and atmospheric water will be tracked continuously over the entire globe and at resolutions useful for timely inclusion into models for prediction and decision support related to use of water for agriculture, human health, energy generation, and hazard mitigation. So the question is, what will we do in the next decade (~2020-2030)? This motivated the workshop “Water Cycle Missions for the Next Decade” to identify the vision for the next decade of water cycle satellite observations, and to develop a roadmap and action plan for developing the foundation for these missions.

On April 29-30, 2013 CREW Services LLC (CREW) facilitated the workshop “Water Cycle Missions for the Next Decade” at the Baltimore-Washington International (BWI) Embassy Suites Hotel. This workshop was done in close collaboration with the NASA Energy and Water cycle Study (NEWS) PI meeting conducted on the subsequent two days at the nearby Goddard Space Flight Center. The overall goal of the workshop was to gather wisdom and determine how to prepare for the next generation of water cycle missions in support of the second Earth Science Decadal Survey. The workshop gathered over 100 water cycle scientists (130 registered) from around the world to brainstorm future water cycle missions ideas, and to develop preliminary concepts.

Building on the first Earth Science Decadal Survey, NASA’s Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space, and the 2012 Chapman Conference on Remote Sensing of the Terrestrial Water Cycle, the objective of this workshop is to gather wisdom and determine how to prepare for the next generation of water cycle missions in support of the second Earth Science Decadal Survey. Following a short plenary, conference participants discussed the intersection between science questions,
technology readiness and satellite design optimization in a series of breakout group discussions designed to form the seeds of a set of water cycle mission formulation groups. The primary outcome of the workshop was to formulate next-generation water cycle mission working groups and white papers, designed to identify capacity gaps and inform NASA.

The primary workshop goals and outcomes were as follows:
Identify key water cycle science questions and application needs.
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- Provided basic information regarding existing, proven and emerging technology available for next-generation water cycle missions;
- Identified science and user needs for next-generation water cycle satellite missions, and the required development of science and applications needed to use this technology;
- Provided an opportunity for applications and users of water cycle satellite systems to identify potential applications; and
- Developed roadmaps and working groups for fostering the next-generation water cycle satellite mission science, technology and applications.

The outcome of this workshop was to identify the vision for the next decade of water cycle satellite observations, and to develop a roadmap and action plan for developing the foundation for these missions. Our hope is that this outcome will result in optimized community investments and better functionality of these future missions, and will help to foster broader range of scientists and professionals engaged in water cycle observation planning and development around the country, and the world. Attendees developed 1-page “Future Water Cycle Mission Concept Papers” for presentation and discussion during the breakout sessions, and were the focus of the workshop survey. These papers briefly outlined the mission (1) concept, (2) measurement technique, (3) application benefits, and (4) multi-process integration. Development, discussion, and revision of these 1-pagers were the focus of the breakouts and of the workshop.

CREW facilitated this workshop by:
1) Finalize workshop objectives, vision, goals and format with organizing committee
2) Advertise and announce workshop broadly to the community.
3) Develop a workshop website (http://www.crew-services.com/decadal).
4) Managed workshop budget and track expenses.
5) Managed registration and logistics services.
6) Secured invited speakers and breakout facilitators.
7) Provided travel for a limited number of key participants.
8) Develop pre-workshop information package for participants to review.
9) Develop a workshop information package and nameplate available at registration.
10) Rent workshop venue, including space, equipment, furniture, and coffee breaks.
11) Providing audio-visual support during the meeting, including dial-in access and remote presenters
12) Take notes and collect breakout summaries, to be distributed to the workshop participants, and made available on-line.
13) Develop and implement workshop survey.
14) Develop this workshop final report and made available on-line
Background:

Global Water Cycle:

The global water cycle describes the circulation of water as vital and dynamic substance in its liquid, solid, and vapor phases as it moves through the atmosphere, oceans and land. Life in its many forms exists because of water, and modern civilization depends on learning how to live within the constraints imposed by the availability of water.

Water controls the growth of plants through water availability related to soil moisture and through radiation reaching the land surface - controlled largely by clouds - that is available for photosynthesis. Evaporation and transpiration from plants act to transfer not only water vapor but also energy from the surface to the atmosphere, enabling a feedback that has important implications for precipitation over global land areas. The carbon, water, and energy cycles are strongly interdependent - latent heat flux is essentially proportional to evaporation, and photosynthesis is closely related to transpiration. Snow cover, glaciers, and sea ice affect climate through feedback between reflected solar energy and temperature. The melting of ice sheets is a major contributor to sea-level rise, and mid- and low-latitude glaciers, although much smaller in comparison with polar ice storage, are important contributors to water supply in some parts of the globe.

There are important gaps in knowledge of where water is stored, where it is going, and how fast it is moving. Global measurements from space open a vision for the advancement of water science. This vision includes advances in understanding, data, and information that will improve the ability to manage water and to provide the water-related infrastructure that is needed to provide for human needs and to protect and enhance the natural environment and associated biological systems.

The scientific challenge posed by the need to observe the global water cycle is to integrate in situ and space-borne observations to quantify the key water-cycle state variables and fluxes. The vision to address that challenge is a series of Earth observation missions that will measure the states, stocks, flows, and residence times of water on regional to global scales followed by a series of coordinated missions that will address the processes, on a global scale, that underlie variability and changes in water in all its three phases.

The accompanying societal challenge is to foster the improved use of water data and information as a basis for enlightened management of water resources, to protect life and property from effects of extremes in the water cycle. A major change in thinking about water science that goes beyond its physics to include its role in ecosystems and society is also required. Better water-cycle observations, especially on the continental and global scales, will be essential. Water-cycle predictions need to be readily available globally to reduce loss of life and property caused by water-related natural hazards. (summarized from the 2007 Decadal Survey)

Decadal Survey:

NASA relies on the science community to identify and prioritize leading-edge scientific questions and the observations required to answer them. One principal means by which NASA's Science Mission Directorate engages the science community in this task is through the National Research Council (NRC). The NRC conducts studies that provide a science community consensus on key questions posed by NASA and other U.S. Government agencies. The broadest of these studies in NASA's areas of research are decadal surveys. As the name implies, NASA and its partners ask the NRC once each decade to look out ten or more years into the future and prioritize research areas, observations, and notional missions to make those observations.

The NRC completed its first decadal survey for Earth science, Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (NRC, 2007) in January 2007 at the request of NASA, NOAA, and USGS. At the highest level, the report recommends that: “The U.S. government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth-observing systems and restore its leadership in Earth science and applications.” Detailed recommendations in the decadal survey are provided in three categories:

- Setting the Foundation: Observations in the Current Decade
- New Observations for the Next Decade
- Turning Satellite Observations into Knowledge and Information

For the next decade, the decadal survey identified 17 new space missions, presented in three time-phased blocks as the result of a "prioritization methodology designed to achieve a robust, integrated program" and the "missions listed...form a minimal, yet robust, observational component of an Earth information system that is capable of addressing a broad range of societal needs."

The 2007 NRC panel envisioned a future in which surface, subsurface, and atmospheric water will be tracked continuously in time and space over the entire globe and at resolutions useful for timely inclusion into models for prediction and decision support related to use of water for agriculture, human health, energy generation, and hazard mitigation. Space-based observations and supporting infrastructure can help to make that vision a reality for the next generation. Such predictions will have enormous social and economic value for the management of water, food security, energy production, navigation, and a range of other water uses.

In late 2010, NASA requested that the NRC create an ad hoc committee to review the alignment of NASA’s Earth Science Division’s program with previous NRC advice, primarily the decadal survey’s 2007 final report. The 2005 interim report of the Earth science and applications from space decadal survey discussed the importance of the U.S. civilian Earth observing system of environmental satellites and warned, “Today, this system of environmental satellites is at risk of collapse.” It went on to list a number of canceled, descoped, or delayed Earth observation missions. The 2007 decadal survey report warned in its preface that at the time of the report’s release, this foundation was continuing to deteriorate because of descopes in the NPOESS and GOES-R programs and possible delay of the flagship Global Precipitation Measurement (GPM) mission. In the time since the 2007 report’s release, the anticipated program has eroded further due to significant budget shortfalls, the loss of two missions due to launch vehicle failures, changes in direction from the executive branch and Congress, and cost overruns on predecadal survey missions still in development.

Yet NASA has continued to make substantial technical progress on the missions that were already in development at the time of the survey’s release, including the successful launches of the Ocean Surface Topography mission in 2008 and Aquarius and the NPOESS Preparatory Project (NPP) in 2011. NASA has also effectively implemented decadal survey recommendations related to its new Earth Venture line of solicitations, the suborbital program, and the applied sciences program. Still, there is room for improvement. Improved coordination across missions and between disciplines is key to weathering this near-perfect storm of a decline in resources, increase in demands, and loss of heritage assets. Using realistic budget projections, the Earth science community cannot afford an all-encompassing program to enhance every aspect of Earth system science, nor can it afford collapse of the mission queue to save just a handful of missions. To this end, the committee reiterated the 2007 survey’s call for a balanced set of good Earth science missions rather than just a few missions that strive for perfection in limited disciplines.

Workshop Overview

Building on the first Earth Science Decadal Survey, NASA’s Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space, and the 2012 Chapman Conference on Remote Sensing of the Terrestrial Water Cycle, the objective of this workshop was to gather wisdom and determine how to prepare for the next generation of water cycle missions in support of the second Earth Science Decadal Survey.

The workshop started with a short plenary that briefly provided the historical context, reviews lessons learned from the post-2002 Easton workshop, the first Decadal Survey, results and gap analysis from a water cycle observations synthesis project, and presents an overview of relevant technology advancements and readiness.
Following the plenary, we discussed the intersection between science questions, technology readiness and satellite design optimization in a series of breakout group discussions designed to form the seeds of a set of water cycle mission formulation groups. The workshop formulated next-generation water cycle mission working groups and white papers, designed to identify capacity gaps and inform future NASA solicitations (e.g. ESTO, NEWS, THP, etc.?).

As the workshop will covered the breadth of the water cycle, an in-depth pre-meeting information packet was provided prior to the workshop for participants to learn the “basics” of near-term planned missions and activities (e.g. GPM, SMAP, Earth Ventures).

This workshop was originally suggested at a NASA Energy and Water cycle Study Investigators workshop in 2010. Since then the need for this workshop was been highlighted by significant gaps in the water cycle observational capabilities identified by the NEWS team. Therefore, in 2012 a steering committee for this workshop was formed, consisting of:

- Christa Peters-Lidard, NASA/GSFC, USA, Christa.Peters@nasa.gov
- Paul Houser, CREW and George Mason University, USA, prhouser@gmail.com
- David Toll, NASA/GSFC, USA, David.L.Toll@nasa.gov
- Bob Schiffer, USRA, USA, rschiffer@usra.edu
- Debbie Belvedere, MSU, USA, drbelvedere@gmail.com

The workshop steering committee has met many times to develop and plan the workshop. These planning meetings, and subsequent actions by the planning committee, identified the format, scope, agenda, and invitation list of the workshop.

Workshop Goals and Outcomes

The objectives of this workshop were to:
- Identify key water cycle science questions and application needs.
- Provide basic information regarding existing, proven and emerging technology available for next-generation water cycle missions;
- Identify science and user needs for next-generation water cycle satellite missions, and the required development of science and applications needed to use this technology;
- Provide an opportunity for applications and users of water cycle satellite systems to identify potential applications; and
- Provide a roadmap and working groups for developing the next-generation water cycle satellite mission science, technology and applications.

The intended outcome of this workshop was to identify the vision for the next decade of water cycle satellite observations, and to develop a roadmap and action plan for developing the foundation for these missions. Achieving this outcome will result in optimized community investments and better functionality these future missions, and will help to foster broader range of scientists and professionals engaged in water cycle observation planning and development around the country, and the world.

The workshop is directly relevance and in direct support of the NASA Earth Science Water and Energy Cycle Focus area, including its NEWS, Precipitation Sciences, and Land Surface Hydrology programs. It also helps to support and plan for the goals forwarded by the NRC Panel on Water Resources and the Global Hydrologic Cycle.

The workshop agenda is provided below, identifying the topics that were covered during the workshop, and the speakers that participated in the workshop. In addition, a widely distributed request for participation...
was distributed, and breakout facilitators were identified. Interagency participation, as well as broad participation from the technology, science, and application fields was actively pursued.

**Workshop Logistics**

The workshop was held at the Embassy Suites at the Baltimore-Washington International (BWI) Airport on April 29-30, 2013. The BWI venue provides easy access to the many governmental, academic and industrial participants that are interested in the workshop topics. The agenda for the workshop was developed by the planning committee, which is shown below. The workshop was open to the public with no registration fee; it is estimated that 100 participants attended the workshop in person, and many more attended virtually through multiple telecoms for various breakout sessions.

**Mission Concepts**

The primary products produced by the workshop were 1-Page Mission Concepts. These 1-page "Future Water Cycle Mission Concept Paper" briefly outlined the mission (1) concept,(2) measurement technique, (3) application benefits, and (4) multi-process integration. 11 mission concepts were developed as shown below. These mission concepts are attached in the subsequent appendix pages.

**Survey Results**

A survey was developed by the advisory committee and distributed at the end of the workshop to gather ideas and impressions of the developed mission concepts (attached). 30 people returned the surveys, with 27 ranking the missions they prefer on a scale of 1 to 3. A value of 3 was given to their top choice, and 1 to their third choice. The points for each concept were summed and are shown below in red. Some surveys responded with only check marks on their top 3 mission concepts, where a value of 2 was given to each.

- **Subsurface temperature sensing satellite (STEMSS)**, Kenneth Jezek and Joel Johnson (2)
- **The aerosol, clouds, ecosystem (ACE) decadal survey mission**, Jay Mace (13)
- **Precipitation and cloud processes mission concept v2**, Gail Skofronick-Jackson (47)
- **L-band microwave remote sensing and W-train concept**, Dara Entekhabi, Simon Yueh, Eni Njoku (17)
- **Short time scale processes GNSS-R Mission**, Chris Ruf (9)
- **Water cycle mission**, Paul Houser (43)
- **Next generation surface energy balance**, Rachel Pinker (8)
- **Visible, short-wave and thermal sensing at the field scale**, Ayse Kilic (7)
- **Space snail**, John David (0)
- **Moderate spatial resolution infrared sounder**, Thomas Pagano (4)
- **Global geostationary drought monitoring constellation**, Will Pozzi (5)

The survey results clearly show that the Precipitation and Cloud Processes Mission Concept, and the Water Cycle Mission Concept were the most highly rated by the participants. The W-Train and ACE concepts also receive considerable attention. It should be noted that there was a lot of interest in the W-Train concept for demonstrating some of the integrated water cycle observation concepts with currently planned missions such as GPM, Aquarius, and SMAP. It should also be noted that a number of the survey participants suggested that extensive OSSE studies be conducted to help narrow candidate mission concepts. Survey participants also emphasized the importance of measurement long-term measurement continuity and change detection (reflected by the favorability of a follow-on precipitation mission), low latency, adequate repeat time, user-need focused observations, and measurements that help to close global and regional water balance. Finally, a number of survey responses emphasized the need to better measure and constrain evaporation, snow, and deep soil moisture.
APPENDICIES:

Workshop Agenda (as provided to participants)

Thank you for participating for this important workshop to help define the next generation of water cycle satellite missions. The workshop is sold out, and we are expecting a very engaging discussion. However, we still need your help to make this workshop as successful as possible:

1. 1-Page Mission Concepts: Please consider developing a 1-page “Future Water Cycle Mission Concept Paper” for presentation and discussion during the breakout sessions, and will be the focus of the workshop survey. These papers should briefly outline the mission (1) concept, (2) measurement technique, (3) application benefits, and (4) multi-process integration. Please send these papers to prhouser@gmail.com before the workshop so they can be posted, shared, and discussed. 1-pagers may also be developed during the breakout sessions.

2. Breakout contributions: Please take a look at the updated agenda, and contact the breakout leads if you want to give a special presentation. We are looking for each breakout session to have several overview presentations or mission concepts presented to help start the discussion.

3. Background reading material: We have posted some very relevant background materials on the workshop website for your preparation. Believe it or not, we are not first group to think about this topic, so we can save a lot of time by standing on their shoulders. Please also send me anything you think is missing from this material.

4. Remote access: The workshop will be accessible via telecom (see agenda), so please redistribute this information to any colleagues who want to participate remotely. Note that all times are in Eastern Daylight Time (GMT-4hrs), and all recordings and presentations will be posted on the workshop website.

Day 1 (April 29, 2013)

08:30 Background and Overview

08:30 Workshop Objectives and Charge: P. Houser (JFK (805)399-1200, Code:658496)

09:00 Water Cycle Science Questions and NASA Missions: J. Entin (JFK (805)399-1200, Code:658496)

09:30 Lessons Learned from 2007 Decadal Survey: C. Clayson (JFK (805)399-1200, Code:658496)

10:00 Coffee Break

10:30 Breakout A: Current and Future Water Cycle Mission Evolution – How will we observe these critical water cycle variables in the next decade?

- Group A5 (LAX 2 (559)726-1300, Code: 163934): Surface Vegetation/Surface Moisture
  Fluxes: Kustas, Anderson

12:00 Lunch (on your own)

13:00 ESTO Water-Cycle Ready Technology: M. Seablom (JFK (805)399-1200, Code:658496)

13:30 Breakout B: Measurement Techniques – will we use different wavelengths/techniques to observe the water cycle in the next decade, including cost considerations? Are we looking for a few well instrumented platforms or many less well instrumented?
- Group B3 (Heathrow 2 (559)726-1300, Code: 835143): Lidar: C. Ferreira
- Group B4 (LAX 1 (559)726-1300, Code: 155998): Vis/IR/Thermal: K. Hsu
- Group B5 (LAX 2 (559)726-1300, Code: 163934): Gravimetry: M. Rodell

15:00 Coffee Break

15:30 Plenary (JFK (805)399-1200, Code:658496): Breakout A & B Summary and Discussion

17:00 Adjourn

19:00 Special Screening of “Last Call at the Oasis”, with snacks and discussion (JFK)

Day 2 (April 30, 2013)

09:00 GEWEX and the need for new water-cycle observations: K. Trenberth (JFK (805)399-1200, Code:658496)

09:30 Water Resources Applications: K. Mohr (JFK (805)399-1200, Code:658496)

10:00 Breakout C: Applications – How will we provide actionable water resource management remote sensing in the next decade?
- Group C1 (JFK (805)399-1200, Code:658496): Drought: W. Pozzi
- Group C2 (Heathrow 1 (559)726-1300, Code: 557280): Flood: B. Cosgrove, D. Kirschbaum
- Group C3 (Heathrow 2 (559)726-1300, Code: 835143): Water Availability: J. Bolton
- Group C4 (LAX 1 (559)726-1300, Code: 155998): Climate Extremes: S. Nigam
- Group C5 (LAX 2 (559)726-1300, Code: 163934): Weather & Forecasting: M. Ek

12:00 Lunch (on your own)

13:00 Water Cycle Synthesis: What we know and don’t know: M. Rodell

13:30 Breakout D: Multi-process Synthesis – How will we observe integrated water cycle processes in the next decade? What are the top mission concepts?
- Group D1 (JFK (805)399-1200, Code:658496): C. Peters-Lidard
- Group D2 (Heathrow 1 (559)726-1300, Code: 557280): R. Schiffer
- Group D3 (Heathrow 2 (559)726-1300, Code: 835143): P. Houser
- Group D4 (LAX 1 (559)726-1300, Code: 155998): K. Mohr
- Group D5 (LAX 2 (559)726-1300, Code: 163934): D. Toll

15:00 Coffee Break

15:30 Plenary (JFK (805)399-1200, Code:658496): Breakout C & D Summary and Discussion

16:30 Survey (JFK (805)399-1200, Code:658496)
- What would you need to pick the top mission concepts?
- How would you reduce the concepts to 3-5?
- Would you be interested in leading or participating in a water cycle mission white paper and/or working group? If so, which one?
17:00 Workshop Summary & Actions (JFK (805)399-1200, Code:658496)

- Future Mission Options and priorities
- Instrumentation/Measurement Challenges
- Technology Challenges and Options
- Workshop Consensus Recommendations

17:30 Adjourn

Background Reading Materials

The following information was provided to the workshop participants as background material prior to the workshop:

2007 DECADAL SURVEY

2012 MIDTERM ASSESSMENT

2012 CHAPMAN CONFERENCE
AGU Chapman Conference on Remote Sensing of the Terrestrial Water Cycle, 2012 REPORT

2013 NATIONAL STRATEGY
National Strategy for Civil Earth Observations, National Science and Technology Council, 2013

2010 MULTI-MISSION STRATEGY
IGWCO THEME
Integrated Global Water Cycle Observations (IGWCO) Theme, Overview Report

GEOSS WATER STRATEGY REPORT

GEWEX SCIENCE QUESTIONS
GEWEX “Global Energy and Water Exchanges” Project Science Questions

POST-2002 EARTH OBSERVING MISSIONS
The Aerosol, Clouds, Ecosystem (ACE) Decadal Survey Mission
Jay Mace, jay.mace@utah.edu

ACE is a tier 2 Decadal Survey mission focusing on clouds and aerosols as well as ocean ecosystems. The primary objective of the clouds component of this mission is to advance our ability to observe and predict changes to the Earth’s hydrological cycle and energy balance in response to climate forcings, especially those changes associated with the effects of aerosol on clouds and precipitation. The critical information required to understand these influences and predict their effects on our changing climate revolves around more advanced information on the microphysics of clouds, precipitation and aerosol.

ACE will build upon the experience gained from the current generation of Earth observing satellites and will extend-in-time many key measurements from these systems. In particular, the ACE measurement concept embraces measurement synergy as the only viable path to meeting the process level science requirements of the next decade. This means that the ACE suite of instruments is being designed to meet the level 1 science requirements through retrieval algorithms that take input from multiple active and passive instruments.

The core instruments for ACE will include a dual frequency Doppler cloud/precipitation radar that has the capability to scan, a high spectral resolution lidar, and a multi angle wide-swath polarimeter. These instruments when considered as a single observing system can sense the fundamental microphysical processes that converts vapor into precipitation via cloud processes modulated by aerosol. The measurements provided by these sensors will enable determination of many cloud, aerosol properties and processes that are out of reach of current satellites or can be determined only poorly (with large uncertainties). Examples of these properties include vertical distributions of cloud and precipitation water content and particle size, as well as aerosol number concentration and single scattering albedo. Accurate determination of microphysical properties such as these is critical to furthering our understanding cloud-aerosol interactions that drive much of the uncertainty in our understanding of climate change.

We envision that ACE will continue and extend the measurement heritage that began with the A-Train and that will continue through Earthcare. In particular, ACE will continue the detailed vertical profiling of cloud properties into a second decade and will allow for the documentation of changes in certain key characteristics of the hydrological cycle over this extended period of time thus enabling the examination of such change to dominant modes of variability that occur on annual to decadal time scales.
Mission Concept

Global Geostationary Drought Monitoring Constellation

Application Benefits—Drought at Continental and Global Scale

Many regions of the world have surface-based observation networks that are below the minimum World Meteorological Organization recommended station density. In addition, Global Precipitation Climatology Centre precipitation is coarse-scale (one degree) and at monthly time scales which does not provide the high temporal resolution required to provide mission critical information for famine relief (drought-produced famine). Many stations do not report in a timely fashion. Given the limitations and uncertainty on precipitation measurements, alternate space-based technologies on global drought monitoring are being explored.

Global Configuration

A thermal-band, global geostationary satellite configuration is proposed that would provide coverage continuous in time but at lower spatial resolution. Such a configuration can be assembled out of existing geostationary satellite coverage of JAXA, ESA, and NOAA satellites. Atmosphere Land Exchange inverse (ALEXI) methodology would prepare Evaporative Stress Index maps globally to provide drought briefing inputs to compare with Standardized Precipitation Index (SPI).

Upgrading the Existing Proposed Configuration

Launch of ESA Global Monitoring for Environment and Security (GMES) Sentinel series and HyspIRI.

This project would be carried out concurrently with a global radiative fluxes project, including cloud quantification and improvement of cloud profiling upon the longwave budget.
Future Water Cycle Mission Concept – Visible, Short-Wave and Thermal Sensing at the Field Scale

Ayse Kilic, Univ. Nebraska-Lincoln, April 2013

The mission concept. A long-term, continuously operating, multi-satellite system having moderate resolution at the scales of human activities: approx. 30 m, should be a fundamental support component of the United States Earth Observation and Water Cycle programs. The mission should be a continuation of the long-standing Landsat program which:

a. has a continuous archive of imagery dating from 1972 for short-wave and from 1982 for thermal data
b. provides a time machine for viewing visible near infrared (VNIR), shortwave infrared (SWIR) and thermal infrared (TIR) over the entire Globe for monitoring change in vegetation and water resources, including evapotranspiration (ET).
c. has pixel resolution of 30 m for shortwave data and 60-120 m for coincident thermal data, which is ideal for monitoring land use change and water consumption of human-related features - agricultural fields, riparian systems, forest clearings, vegetation disease outbreaks, disasters.
d. fits a critical niche between the high resolution commercial satellites (IKONOS, QuickBird, GeoEye-1) that have very low revisit time (temporal constraints) and the 'daily' low-resolution satellites like MODIS, VIIRS and AVHRR, which cannot resolve most human-related land features (spatial constraints).

Measurement technique. The system should contain all current features of the Landsat system (VNIR, SWIR, Thermal) for sustaining long-term data continuity. The pixel resolution should be approximately 10 to 30 m and the revisit time should be 4 days (possible with four systems each having a 16 day return time (160 km swath) or with two systems each having an 8 day return time (320 km swath)) to mitigate impacts of clouds. Multiple operating satellites should be in orbit at all times for system risk mitigation. The view angle should be less than about 15 degrees to assure high data-accuracy and fidelity.

Application benefits. The continuity of a Landsat-like system sustains long-term data continuity, is essential for producing ET coverage at the field scale for water resources management and for monitoring land use change and water consumption of human-related features -- agricultural fields, riparian systems, forest clearings, vegetative disease outbreaks and natural disasters. The high-frequency (4-day revisit) coverage supports monitoring the dynamic evolution of vegetation and water consumption and is advocated by the Western States Water Council. Data availability at no cost to the public fosters substantial growth in usage, technology and economy. A Landsat-like system directly supports American water resources management and needs.

Multi-process integration. Coincident collection of VNIR, SWIR and TIR at 30 m resolution and 4-day revisit time supports all water-cycle processes at the important spatial definition of human activities.
L-band Microwave Remote Sensing and W-Train Concept

Dara Entekhabi, Simon Yueh, Eni Njoku

L-Band Microwave Remote Sensing:
- Applicable Measurements: Soil moisture, ocean salinity, ocean vector winds for severe storm freeze-thaw, and sea ice
- Science and Applications, such as:
  - E-P balance
  - Weather predictions
  - Drought/Flood predictions/monitoring
  - Crop yield
  - Ocean circulation

Next Generation Capabilities for L-band Remote Sensing:
- Polariometric Active/Passive
- 1.2 to 1.4 GHz
- 10 km resolution for passive; 10s m for active
- Swath width > 1000 km
- Low Earth Orbit

Synergism with other microwave and optical sensors:
- Microwave sensors for snow water equivalent to provide of the soil state below the snowpack
- Microwave radiometers for precipitation over land to provide land surface emissivity
- In combination with Lidar, higher microwave frequencies and Vis/IR/fluorescence to infer vegetation canopy structure, water status and photosynthetic activity
- Altimetry for surface water level in lakes and inland water bodies, flow in rivers, and the thickness, extent and physical attributes of land glaciers
- Hyperspectral Vis/IR measurements for the composition of open ocean and coastal waters (phytoplankton composition and concentrations, salinity, turbidity)

W-Train Concept

04/2013 Future Water Cycle Mission Workshop
Radiative Fluxes: 1-page Mission Concept - R.T. Pinker

1. Concept

Radiative fluxes, shortwave (SW \downarrow), longwave (LW \downarrow) and spectral are important components of the energy budget over land and oceans and they also control the Primary Productivity, namely, the carbon budget. Progress has been made on deriving both SW\downarrow and LW\downarrow components from satellite observations at climate model resolutions. Several available methodologies have demonstrated skill over land; lower accuracies exist over oceans and at high latitudes. Less work was done at higher spatial resolutions as required for hydrological modeling at basin scales or for assessing snow-melt, snow-albedo feedbacks over complex terrain such as Polar Regions or glacier melting.

2. Measurement

Not all available satellite observations have been fully utilized for estimating radiative fluxes mainly due to trade-offs between spatial and temporal resolutions and spectral resolutions. While MODIS has a large number of spectral channels, the temporal resolution is limited. Since future geostationary satellites will have improved spectral resolutions (e.g., GOES-R, METEOSAT 3rd generation, Japanese HMAWARII), there is a need to prepare for the utilization of such observations. Information from the A-Train satellite configuration not fully utilized for improving estimates of radiative fluxes.

3. Application benefits

Some specific examples:

a) Global climate model simulations show loss of snow-pack, sensitive areas losing as much as 70%. Factors that affect the rate of snow melt: SW and LW radiation, surface albedo, snow emissivity, snow surface temperature, sensible and latent heat fluxes, ground heat flux, and energy transferred from deposited snow or rain. Net radiation makes up about 80% of the energy balance. The greatest potential sources of error in simulating snowmelt rates and timing are inaccurate solar and longwave radiation.

b) As stated in the Arctic Climate Impacts Assessment (ACIA) Report: “over the past 50 years, it is probable that Arctic amplification of greenhouse warming has occurred”. This amplification can be partly explained by the feedback associated with the high albedo of polar snow and ice. Satellite observations revealed large seasonal change in the Arctic sea ice extent; in 2007 the annual minimum was 37% lower than the 1979–2006 average. Factors believed to play a role in the seasonal Arctic sea ice anomaly include: changes in the thickness of sea ice, the ice-albedo feedback, Arctic Ocean heat transport, atmospheric heat transport SW\downarrow and LW\downarrow radiation.

c) Improvement in surface radiative fluxes over oceans from MODIS have been demonstrated. As yet, MODIS not fully utilized for such applications.

4. Multi-process applications

Radiative fluxes are needed in all aspects of hydrological modeling.
1) Mission Concept: Moderate Spatial Resolution Infrared Sounder
   a. One component of a mission that would measure the water cycle
   b. **Infrared Sounding** of Boundary Layer Water Vapor and Water Vapor Profile with high accuracy for Climate, Weather and Applications at higher vertical and horizontal resolution than current sounders
   c. Temperature and Water Vapor measurements are among the several measurement identified by the NASA NRC Decadal Survey for Earth Science that “are providing critical information now which need to be sustained into the next decade”

2) Measurement Technique
   a. Moderate spatial resolution (1km) hyperspectral infrared (HSIR) sounder with global daily coverage
   b. Modest instrument, (5 cm aperture) would be less than $100M, 75 kg, 100W.
   c. Recommended Other Instruments: Vis/NIR Imager (1km), Microwave Sounder (10-20 km)

3) Application Benefits
   a. **Climate**:
      i. Improve sounding over land, especially in the boundary layer because small scale variability in surface emissivity and topography are better characterized. ([Sounding Workshop, 2010](#))
      ii. Improved land and ocean surface skin temperature, spectral emissivities, surface leaving radiance fluxes and cloud radiative properties. ([Sounding Workshop, 2010](#))
      iii. Improved characterization of subgrid-scale variability of temperature and water vapor for better understanding and prediction of the physics and dynamics of the atmospheric hydrologic cycle across a variety of scales ([Kahn, 2009](#))
   b. **Weather**:
      i. NOAA currently running an OSSE to determine the impact of higher spatial and temporal resolution IR sounder data on hurricane prediction
      ii. Higher spatial resolution water vapor needed for assimilation into next gen of NWP models
   c. Applications of moderate spatial resolution sounding
      i. Drought Conditions
      ii. Fire Conditions
      iii. Mosquito Habitat
      iv. Agriculture: Temperature Extremes, Heat Wave, Frost
      v. Air Quality: Temperature inversions
      vi. Disasters: How are extreme events likely to change with changing atmospheric temperature, humidity, aerosol content, and wind patterns? ([Disasters Panel on National Strategy for Civil Earth Observations](#))

4) Multi-process integration
   a. Water Vapor is a primary transport mechanism in the water cycle
   b. Enables process studies for surface-atmosphere exchange and moist thermodynamics relating to cloud properties.
   c. Complementary to SMAP and GPM, HySpIRI, CLARREO
   d. Provides atmospheric correction for most surface measurements.

5) Submitted by Tom Pagano, AIRS Project (NASA/JPL)
Bandwidth Limited

- Datasets are too large to move around easily or quickly. This brings about interesting situations where unconventional data transfer is more reliable and faster.
- Wi-Fly - pigeon-empowered wireless protocol
- SMTP - snail mobile transfer protocol
- “Never underestimate the bandwidth of a semi-truck full of DVD’s”

- Could a robotic service mission transfer large amounts of low-value data, and make it worth keeping long term?
Water Cycle Missions for the Next Decade Workshop
29-30 April 2013
Linthicum, MD

Future Water Cycle Mission Concept Paper

Short Time Scale Processes GNSS-R Mission

The NASA Cyclone Global Navigation Satellite System (CYGNSS) mission (launch 2016) will demonstrate two significant new capabilities in Earth remote sensing from space: the ability to make well calibrated forward scattering measurements of the Earth surface, to meet the needs of the scientific community; and the ability of a constellation of small satellites in low Earth orbit to resolve short time scale processes on a global scale. The CYGNSS low inclination orbit is optimized for very frequent sampling in the tropics to support its primary science objective—the study of tropical cyclone inner core processes. The extension of its mission architecture to a polar orbit is straightforward and would result in hourly sampling times in the mid-latitudes and cryosphere.

The GNSS-R measurement technique relies on quasi-specular forward scattering of signals of opportunity generated by GPS, Galileo, and other constellations of geo-navigation satellites. The science payload is a GPS receiver, modified to measure the scattered signal near the specular point on the Earth surface. It is a simple, low power, light weight sensor that can operate on small, low cost satellite platforms. This is what makes a large satellite constellation affordable and possible. The response of the forward scattered signal to surface geophysical conditions has some of the properties of a conventional backscatter radar (i.e. scatterometer) and some of the properties of a passive microwave radiometer. Its operation at the L-Band geo-navigation frequencies also makes it relatively insensitive to atmospheric conditions such as clouds and precipitation. For the CYGNSS mission, the primary retrieved geophysical parameter is ocean surface wind speed. L-Band forward scattering has also been shown to be sensitive to subsurface soil moisture (similar to the SMOS, Aquarius and SMAP radiometers and radars that operate at nearby frequencies). Its sensitivity to ice type, ice thickness and freeboard height (when operating in an altimeter mode) has also been demonstrated. The uncertainty and precision of individual measurements using the GNSS-R technique can be comparable to that of conventional active/passive sensors, but reduced quality performance enhances its low size, power and cost features, thus enabling a larger number of spacecraft in the constellation, which improves the temporal sampling properties. As a result, use of the GNSS-R approach is especially suitable for scientific problems where the ability to continuously sample short (hourly) time scale processes on a global scale is critical.

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Subsurface Temperature Sensing Satellite (STemSS)

Kenneth Jezek and Joel Johnson

The Ohio State University

Concept: Spaceborne and airborne remote sensing instruments characterize most of the important variables necessary to understand current ice sheet behavior and to predict future changes in ice sheet volume. At present, internal ice sheet temperature is absent from the parameters list, yet temperature is a primary factor in determining the ease at which ice deforms internally and also the rate at which the ice flows across the base. We outline a multi-frequency radiometry concept that, for the first time, enables this critical temperature-measurement remotely.

Measurement Technique: We envision using ultra high frequency (UHF) radio emission to probe the subsurface physical temperature of the polar ice sheets. Thus far, we have completed several modeling studies which suggest that relative changes in average ice sheet internal temperature can be gleaned from single frequency emission data (Jezek and others, 2012). We also showed that brightness temperature anomalies observed in ESA’s 1.4 GHz Soil Moisture and Ocean Salinity (SMOS) satellite (SMOS) data over subglacial Lake Vostok Antarctica are correlated with the lake location. We attribute the correlation to subglacial emission that is extinguished at the lake-surface ice-bottom interface. Although we have yet to complete our full analysis, we suspect that additional information about the details of ice sheet temperature with depth can be determined using multi-frequency data. Our conjecture is based on the frequency dependence of UHF emission once the infra-red dispersion of ice is included in our models.

Based on our models and our work with SMOS we think there is value in developing a multi-frequency radiometer operating from P- to S- band. The system would rely on increased radiometric accuracy (better than 0.25° K) and wide swath (500 km). Similar to SMAP, our concept also includes an L-band, low-resolution, synthetic aperture radar. The SAR is used primarily to support the radiometric observations by measuring relative changes in near surface scattering.

Application benefits: Numerous applications in cryospheric science are possible; our research to date has focused on ice sheet applications. We anticipate there could be additional research applications for permafrost, boreal forests, soil moisture, and seasonal snow cover.

Multi-Process Integration: Temperature information leading to improved prediction of ice-sheet dynamics would contribute greatly to an improved cryospheric monitoring network. Polar change is one of the key Earth Science issues in the coming decade.

Future Mission Concept: Water Cycle Mission
Paul R. Houser, April 2013

Background: In its 2007 report "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond", the National Research Council recognized that the current paradigm is for satellite missions that focus on single primary measurements designed to address a primary science question, and endorses an alternative paradigm that attempts to address measurements of the in a more coordinated fashion—for example, by focusing on a broader set of issues and attempting to realize synergies associated with multiple, coordinated observations. One such paradigm endorsed by the 2007 NRC “decadal survey” report is the coordinated measurement of global water-cycle variables.

The components of the water cycle need to be measured simultaneously in order to allow the estimation of fluxes between the components of the climatic system. For example, precipitation and evapotranspiration over land and ocean surfaces require that the state of the system at the surface and in the atmosphere be monitored simultaneously. Therefore, a central challenge of a future earth system observation strategy is to progress from single-variable water-cycle instruments to multivariable integrated instruments, probably in electromagnetic-band families. Experience has shown that the microwave range is ideally suited for sensing the state and abundance of water because of water’s dielectric properties. Integrated observations require the simultaneous retrieval of related water cycle variables. Technically this requires a satellite platform with sensors for multiple microwave frequencies, combining passive and active sensors, and perhaps lidar.

Mission Concept: At its ultimate realization, the Water Cycle Mission concept would expand on the multi-frequency capabilities of AMSR, SMAP, and GPM by providing hyper-frequency active and passive microwave observations from a single platform or antenna extending from 1.200GHz. A reasonable target resolution would be 1km for the longest wavelengths, and variable temporal resolutions depending on the variable’s rate of change. The challenge of providing simultaneous space and time observations across this large bandwidth could be facilitated by a selectively sampling, or downscaling observations from a large patch-based antenna. Alternatively, the range of observations could be obtained from a constellation of coordinated platforms such as the “A-Train”.

The radiation measured by satellite instruments combines information from different atmospheric constituents and conditions, as well as earth surface influences. Disentangling the various effects in order to quantify a given variable can be very challenging, and has been the main topic of remote sensing research. Traditionally, methodologies have been developed to use a single wavelength to derive a single earth system parameter. However, simultaneous observations of the desired state in different wavelength ranges could help separate the different contributions in order to obtain better estimates of a given parameter, and could be fully exploited to obtain simultaneous estimates of many earth system parameters. Therefore, this mission would require the development of advanced multi-variate retrieval methods that can exploit the totality of the spectral information. Simultaneous multichannel retrievals of multiple water and energy variables in a vertical ocean/land-atmosphere column will (a) allow improved-accuracy retrievals that are not possible with isolated measurements, (b) allow for water balance concepts to be employed to help guide and improve retrievals, and (c) produce synergies that will substantially enhance understanding of the water and energy cycle as a system.

Benefits: Simultaneous multichannel active and passive microwave retrieval would allow improved-accuracies that are not possible with isolated measurements. Furthermore, the simultaneous monitoring of several of the land, atmospheric, oceanic and cryospheric states brings synergies that will substantially enhance understanding of the global water and energy cycle as a system. The multichannel approach also affords advantages to some constituent retrievals—for instance, simultaneous retrieval of vegetation biomass would improve soil-moisture retrieval by avoiding the need for auxiliary vegetation information.

The proposed water cycle mission will observe the water cycle as a connected system, allowing water conservation principles to be used to help constrain and improve the geophysical retrievals. This will result in greater precision and understanding of water cycle processes than can be obtained by single-variable missions. Ultimately, this improved understanding will translate into better predictions for use in critical water cycle applications that are being continuously challenged by climate, environmental, and population changes.
Global Precipitation and Cloud Processes Measurement Mission Concept

**Background:** There is an inherent synergy and common interest linking precipitation to clouds for joint mission goals and requirements, including the mapping of precipitation and related cloud processes across the globe. The overarching goal of a Global Precipitation and Cloud Processes Measurement Mission is to bring the capabilities of Global Precipitation Measurement (GPM) mission and proposed capabilities of the Aerosols, Clouds, Ecosystems (ACE) mission together to advance our understanding of the precipitation forming processes across the globe and provide a detailed mapping of global precipitation. The GPM and ACE mission communities, in coordination with JAXA and the support of NASA HQ, Goddard and JPL, are working to develop a mission concept for next-generation spaceborne precipitation and cloud measurements in preparation for the upcoming decadal survey. These activities will be pursued under a broader science theme with strong science drivers to support multiple scientific and application communities. This new mission builds upon the success of TRMM, CloudSat and GPM.

**Measurement Techniques:** The proposed Precipitation and Clouds mission will build upon enhanced radar capabilities (to gain better physical insights) together with complementary passive sensors (for spatial coverage). Initial sensor concepts include:
- A baseline radar system would comprise a triple-frequency system centered upon scanning Ku, Ka and W-band (13, 35 and 94 GHz) radars, with Doppler capability at all frequencies. To retrieve light, shallow precipitation the radar system would need a high-sensitivity, fine range resolution capability.
- For extended spatial coverage, a multi-channel, wide frequency range microwave radiometer will provide information from surface characteristics to thin cirrus clouds.
- A multi-channel visible/infrared radiometer would provide additional complementary information on atmospheric and cloud-top properties.

**Application Benefits:** This mission will provide a “physics processes observatory” to serve as a calibration reference and transfer standard for inter-satellite calibration of sensors capable of mapping cloud and precipitation information globally with finer temporal scales. The transfer standard will greatly enhance the value of individual missions. We also are already planning on addressing at least these science themes: (1) physical insights into precipitation and cloud mechanisms in a changing climate, (2) the linkages between clouds and precipitation, (3) identifying and quantifying falling snow and light rain.

**Multi-Process Integration:** While there is a high occurrence of clouds across the globe, only a small fraction of clouds actually precipitate; although we know in principle what makes clouds precipitate, the mechanisms that regulate the initiation of precipitation from clouds, thereby governing the cloud-precipitation efficiency remain less clear. In addition, high latitude regions are undergoing tremendous change due to global warming, with significant alterations in the surface water and energy fluxes. This data is of great importance to global hydrology and energy cycles and atmospheric dynamics.

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