The Water And Terrestrial Elevation Recovery Hydrosphere Mapper (WATER-HM) mission: the need for a dedicated surface water mission

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OUTLINE

1. The global water cycle
2. Results from profiling altimeters
3. Challenges and the scientific questions
4. The WATER HM mission
Global Water Cycle

Water exchange between reservoirs:
- Water mass exchanged
- Time scales of exchange
- Reservoirs capacities
- Rate of water renewal inside reservoirs

Processes involved
- Energy transfer between land surface and atmosphere
- Lower atmosphere dynamics
- Gravity effects
- Biological processes
- etc.
Water Balance Equation
(river basin scale)

Water mass balance: \( \frac{dW}{dt} = P - E - R \)

- **W**: Land water mass (soil, underground reservoirs and snowpack)
- **P**: Precipitation
- **E**: Evapotranspiration
- **R**: Runoff
Water cycle from space: missions

Precipitation: TRMM (USA/Japon, 1997), GPM (USA/Japon; 201?)

Soil moisture: SMOS (ESA, 2008), HYDROS (201?; USA)

Evaporation: none

Land water storage: GRACE (in orbit)

Surface waters: Satellite altimetry, active and passive microwaves

Snow: active and passive microwaves (CORE-H2O), GRACE
Mekong Basin: Comparison between altimeter-derived water level and in situ data

From Frappart F. et al., Water volume change in the lower Mekong basin from satellite altimetry and imagery data, Geophy. J. Int., 167, 570-584, 2006
Mekong Basin: (July to December 2003)

Seasonal spatio-temporal change of water volume (by combining altimetry and imagery from SPOT/Vegetation)

Water storage change in the MEKONG Basin from GRACE and from combined altimetry and optical imagery

Rating curve: (Observed discharge versus T/P water level)

« La Grande Rivière » basin, N-E Canada: Prediction and Optimisation for hydro-electric production

http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/
• Our knowledge of the spatial and temporal distribution of surface waters is poor
  – Unconfined hydraulics of wetlands
  – Lakes and reservoirs are globally distributed but not measured
  – Under-developed economic and political infrastructures

• Hydrologic Science and Applications Issues:
  – Need to constrain water and energy cycle models with surface water discharge and storage changes, globally & consistently
  – Improve understanding of flow hydraulics, especially for flood hazards
  – Trans-boundary water flows are poorly known but critical for water resource management
... from international water programs

World Water Assessment Programme
Water for People

Potential Conflict to Co-operation Potential
Water for Peace

Real people Real catchments Real answers

From international water programs...
Hydrology Science Questions

What is the spatial and temporal variability in the world's terrestrial surface water storage and how can we estimate (and predict) these variations more accurately?

How much water is stored on a floodplain and subsequently exchanged with its main channel?

What are the policy implications that freely available water storage data would have for water management?

How much carbon is potentially released from inundated areas?

Can health issues related to waterborne diseases be predicted through better mappings?
WATER Measurement Goals

- **Hydraulics Required**: \( h, \frac{dh}{dx}, \frac{dh}{dt} \)
- **Spatial Sampling**: Images with pixels of \(~100\ m\)
  - Need between track sampling, not just conventional altimeter profiles.
  - Image pixel sizes should be small enough to measure \(~100\ m\) wide channels.
  - Height accuracy needs to be capable of deriving slope from lowland rivers.
  - Geographic coverage to 75 degrees North.
- **Temporal Sampling**: Repeats \(~\text{weekly}\)
  - Need to capture the majority of discharge from any basin.
    - Amazon floodwave is regular and lasts almost a year.
    - Arctic floods occur during annual spring melt and last for less than a month.
Only method capable of producing *images* of high resolution water surface *elevation* measurements  
- can provide $h$, $dh/dx$, and $dh/dt$

Strong Heritage: Is technology evolution, not revolution  
- Radar altimetry has already been successfully used in space on a number of missions  
  (Topex/POSEIDON, ERS1/2, ENVISAT, JASON,..)  
- SRTM was a radar interferometer  
- Extensive JPL technology investment in WSOA

*Courtesy E. Rodriguez, JPL*
TABLE ES.2. Launch, orbit, and instrument specifications for the recommended NASA missions. Shade colors denote mission cost categories as estimated by the NRC ESAS committee. Pink, green, and blue shadings represent large ($600 million to $900 million), medium ($300 million to $600 million), and small (<$300 million) missions, respectively. Missions are listed in order of ascending cost within each launch timeframe. Detailed descriptions of the missions are given in Part II, and Part III provides the foundation for selection.

<table>
<thead>
<tr>
<th>Decadal Survey</th>
<th>Mission Description</th>
<th>Orbit</th>
<th>Instruments</th>
<th>Rough Cost Estimate</th>
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<tr>
<td><strong>Timeframe 2010 – 2013, Missions listed by cost</strong></td>
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<tr>
<td>CLARREO (NASA portion)</td>
<td>Solar radiation: spectrally resolved forcing and response of the climate system</td>
<td>LEO, Precessing</td>
<td>Absolute, spectrally-resolved interferometer</td>
<td>$200 M</td>
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<tr>
<td>SMAP</td>
<td>Soil moisture and freeze/thaw for weather and water cycle processes</td>
<td>LEO, SSO</td>
<td>L-band radar, L-band radiometer</td>
<td>$300 M</td>
</tr>
<tr>
<td>ICESat-II</td>
<td>Ice sheet height changes for climate change diagnosis</td>
<td>LEO, Non-SSO</td>
<td>Laser altimeter</td>
<td>$300 M</td>
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<tr>
<td>DESDynl</td>
<td>Surface and ice sheet deformation for understanding natural hazards and climate, vegetation structure for ecosystem health</td>
<td>LEO, SSO</td>
<td>L-band InSAR, Laser altimeter</td>
<td>$700 M</td>
</tr>
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<td><strong>Timeframe: 2013 – 2016, Missions listed by cost</strong></td>
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<tr>
<td>HyspIRI</td>
<td>Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health</td>
<td>LEO, SSO</td>
<td>Hyperspectral spectrometer</td>
<td>$300 M</td>
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<tr>
<td>ASCENDS</td>
<td>Day/night, all-latitude, all-season CO₂ column integrals for climate evaluations</td>
<td>LEO, SSO</td>
<td>Multifrequency laser</td>
<td>$400 M</td>
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<td><strong>SWOT</strong></td>
<td>Ocean, lake, and river water levels for ocean and inland water dynamics</td>
<td>LEO, SSO</td>
<td>Ka-band wide swath radar, C-band radar</td>
<td>$450 M</td>
</tr>
<tr>
<td>GEO-CAPE</td>
<td>Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions</td>
<td>GEO</td>
<td>High-spatial resolution hyperspectral imagers</td>
<td>$550 M</td>
</tr>
<tr>
<td>ACE</td>
<td>Aerosol and cloud profiles for climate and water cycle, ocean color for open ocean biogeochemistry</td>
<td>LEO, SSO</td>
<td>Backscatter lidar, Multispectral polarimeter, Doppler radars</td>
<td>$800 M</td>
</tr>
<tr>
<td><strong>Timeframe: 2016 -2020, Missions listed by cost</strong></td>
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<td></td>
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</tr>
<tr>
<td>LIST</td>
<td>Land surface topography for landslide hazards and water runoff</td>
<td>LEO, SSO</td>
<td>Laser altimeter</td>
<td>$300 M</td>
</tr>
<tr>
<td>PATH</td>
<td>High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*</td>
<td>GEO</td>
<td>MW array spectrometer</td>
<td>$450 M</td>
</tr>
<tr>
<td>GRACE-Ⅱ</td>
<td>High temporal resolution gravity fields for tracking large-scale water movement</td>
<td>LEO, SSO</td>
<td>Microwave or laser ranging system</td>
<td>$450 M</td>
</tr>
<tr>
<td>SCLP</td>
<td>Snow accumulation for fresh water availability</td>
<td>LEO, SSO</td>
<td>Ku and X-band radars, K and Ka-band radiometers</td>
<td>$500 M</td>
</tr>
<tr>
<td>GACM</td>
<td>Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction</td>
<td>LEO, SSO</td>
<td>UV spectrometer, IR spectrometer, Microwave limb sounder</td>
<td>$600 M</td>
</tr>
<tr>
<td>3D-Winds (Depco)</td>
<td>Tropospheric winds for weather forecasting and pollution transport</td>
<td>LEO, SSO</td>
<td>Doppler lidar</td>
<td>$650 M</td>
</tr>
</tbody>
</table>

*Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high accuracy SST measurement.

- 100+ submitted mission ideas
  - SWOT is WATER HM
- 115 people involved
  - committee members and referees
- 17 missions selected
  - 14 are exclusively NASA
- 3 "NASA only" are in the launch timeline ahead of WATER HM
  - The 3 have been previously proposed in full

In a sense, WATER HM is top 5!

www.nap.edu/catalog/11820.html
Surface Water and Ocean Topography (SWOT)

Launch: 2013-2016
Mission Size: Medium

- Lake, wetland, and reservoir storage
- Ocean eddies and currents
- River discharge estimates
- Sea level measurements extended into coastal zones

- Flood forecasts
- Marine forecasts
- Inundation and malaria zone identification and forecasts
- Prediction of changes in sea level
From the standpoint of global water issues, what would be the impact of the proposed WATER mission?

- Freely available data on water storage for water bodies larger than ~1 km
- Capability to produce river discharge estimates for many rivers with width > ~50-100 m
- Understanding how reservoirs are operated (presently there is no coherent data base for reservoir storage)
- Major implications for the ability to predict floods and droughts globally
- Major implications for water resources and human health (2 billion incidences of water borne diseases per year globally!)
Conclusions

• **Scientific Objectives:** WATER will measure terrestrial surface water storage changes and discharge, which are critical for understanding the land surface water balance.

• **Measurements Required:** WATER will provide repeated (at time intervals of ~3 to ~16 days, depending on location) measurements of spatial fields of water surface elevations \( h \) for wetlands, rivers, lakes, and reservoirs. Each successive \( h \) measurement will allow computation of both spatial variations (water surface slope, \( \partial h / \partial x \)) and temporal changes in elevation \( \partial h / \partial t \), hence allowing computation of both storage changes, and hydraulic gradients which are a primary determinant of river discharge.

• **Technology Description:** WATER is an interferometric altimeter which has a rich heritage based on (1) the many highly successful ocean observing radar altimeters, (2) the Shuttle Radar Topography Mission (SRTM), and (3) the development effort of the Wide Swath Ocean Altimeter (WSOA). It is a near-nadir viewing, 120 km wide swath based instrument that will use two Ka-band synthetic aperture radar (SAR) antennae at opposite ends of a 10 m boom to measure the highly reflective water surface. Interferometric SAR processing of the returned pulses yields a 5m azimuth and 10m to 70m range resolution, with elevation accuracy of \( \pm 50 \) cm. Polynomial based averaging increases the height accuracy to about \( \pm 3 \) cm. The repeat cycle will be 16 days thus yielding a global \( h \) map every 8 days. Estimated cost, including launch vehicle, bus, interferometer, downlinking, and ground segments is about 300ME.
WATER-HM: Water And Terrestrial Elevation Recovery Hydrosphere Mapper satellite mission

Thank You for your Attention

www.legos.obs-mip.fr/recherches/missions/water
www.geology.ohio-state.edu/water