The role of technology in global water problems: The proposed Water Elevation Recovery mission

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A thumbnail sketch of global water issues

- Approximately 25,000 people die each year due to floods
- Drought losses globally have exceeded $300B over the last decade
- More than 1.2 billion have inadequate drinking water (poor quality, insufficient quantity)
- Twice that many (2.5 billion) lack adequate sanitation facilities.
- Approximately 10% of the annual discharge of the world’s rivers is used consumptively, and several major continental rivers (e.g., Colorado, Nile, Yellow) are dry for at least part of the year
- The quality of many of the world’s rivers has been seriously degraded by a combination of pollution, land cover change, dams, and other factors
- Many, if not most, of these problems are not amenable to technological solutions – but some are
- One such example is the acquisition of data about river discharge, and the storage of water in reservoirs, lakes, and wetlands
Why do we care about streamflow?

• Rivers are the earth’s arteries
• Rivers are a primary source of water for human consumption, food production, transportation, and many other uses
• Riparian corridors (including wetlands) are extraordinarily productive and diverse biologically
• Much of the world’s population lives in flood plains
• Rivers also pose major hazards to human life and well being (due to both floods and droughts)
How is streamflow measured?
Summary of river discharge data archived by the Global Runoff Data Center for the world’s major rivers
The problem of globally declining hydrologic observations

• “Many of the countries whose hydrological networks are in the worst condition are those with the most pressing water needs. A 1991 United Nations survey showed "serious shortcomings" in sub-Saharan Africa. "Many stations are still there on paper … but in reality they don't exist." Maintenance (and hence data quality) are also major concerns. Zimbabwe has two vehicles for maintaining hydrological stations throughout the entire country, and Zambia just has one. [Stokstad, E., *Science*, 285, 1199, 1999]

• “Operational river discharge monitoring is also declining in both North America and Eurasia. This problem is especially severe in the Far East of Siberia where 73% of river gauges were closed between 1986 and 1999, respectively. These reductions will greatly affect our ability to study variations in and alterations to the pan-Arctic hydrological cycle.” [Shiklomanov et al., *EOS*, 83, 13-16, 2002]
Some problems with stream gauges (and the need for a spatial view)
An alternative to in situ stream gauges (and lake and reservoir level recorders): Radar Altimetry

Limitation: Altimeters currently in space (e.g., Topex-Poseidon, Jason) are configured for oceanographic applications, and lack the spatial resolution needed for inland water applications

Case study – Ganges – Brahmaputra River flood forecasting

<table>
<thead>
<tr>
<th>River</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ganges</td>
<td>1,087,300</td>
</tr>
<tr>
<td>Brahmaputra</td>
<td>552,000</td>
</tr>
<tr>
<td>Meghna</td>
<td>82,000</td>
</tr>
</tbody>
</table>

Source: Jorgensen and Host-Madsen, 1997
Brahmaputra River 25-day lead forecasts using experimental ECMWF long-lead precipitation forecasts

Visual courtesy Tony Hollingsworth, ECMWF
• Question: why not just use discharge at upstream gauges in India?
• Answer: Because India won’t release the data (at least in anything close to real-time)
Global observation of water stored in wetlands and lakes also requires a satellite perspective

- Wetlands are distributed globally, ~4% of Earth’s land surface, but many locations known to be much larger than thought in this view (e.g., Amazon, Arctic).

- Mean interannual storage variability for 5 lakes in Africa is ~200 mm; averaged over all of Africa is 5 mm, about 1/10th the equivalent value for soil moisture. What is the summed effect of all smaller water bodies? \( \Delta S \) is not negligible and likely at least half that of soil moisture.

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Surface Water Interferometric Altimeter Concept (WatER – Water Elevation Recovery Mission)

- Ka-band SAR interferometric system with 2 swaths, 50 km each
- WSOA and SRTM heritage
- Produces heights and co-registered all-weather imagery
- 200 MHz bandwidth (0.75 cm range resolution)
- Use near-nadir returns for SAR altimeter/angle of arrival mode (e.g. Cryosat SIRAL mode) to fill swath
- No data compression onboard: data downlinked to NOAA Ka-band ground stations

These surface water elevation measurements are entirely new, especially on a global basis, and thus represent an incredible step forward in hydrology.

Courtesy of Ernesto Rodriguez, NASA JPL
Coverage Study Results

Coverage from a pulse limited altimeter severely under samples rivers and especially lakes

- 16-day repeat (i.e., Terra) coverage misses ~30% of rivers and ~70% of lakes in the data bases (CIA-2; UNH; UH)

- If one restricts the study to the largest rivers and lakes, coverage is much better, but still misses some major rivers and lakes
  - 16-day repeat coverage misses 14 rivers and 9 lakes in the top 150 as ranked by discharge and area, respectively
  - The rivers which are covered can have only a few visits per cycle, leading to problems with slope calculations

- 120 km swath instrument misses very few lakes or rivers
  - ~1% for 16-day repeat and ~7% for 10-day repeat

- A detailed analysis of the science impact of these results is being developed through a “Virtual Mission” being conducted jointly by Ohio State University, the University of Washington, Jet Propulsion Laboratory, University of Bristol (UK), and University of California, Irvine

Courtesy E. Rodriguez, JPL
Some characteristics of the proposed mission relevant to hydrologic prediction

- Duration ~3 years (but most successful missions last longer)
- Nominal 2 x 10 m pixel size provides ~ 1 m vertical resolution – but data are spatially uncorrelated, hence over 5 km of river 100 m wide, error in mean is ~ 10 cm (sufficient to resolve slope o(10^{-4})
- Hence swath (vs track as in current altimeters) is key aspect of the instrument
- Overpass – 3-10 days, would cover all major land areas of globe
- Discharge estimation would be via data assimilation (combination of hydraulic modeling with satellite observations
- Over dry land, instrument provides SRTM-like topographic estimates, hence channel characteristics (for the portion that is seasonally dry) are “painted out” over multiple overpasses
Assessing the impact -- Hydrologic simulation framework

Ohio River basin as represented by the Variable Infiltration Capacity model
Hydraulic simulation framework – Ohio River case study

Water depth and extent on Jan. 21, 1995. (High flows).

Water depth and extent on April 4, 1995. (Low flows).

Water depth (m)
- 0
- 0 - 6
- 6 - 12
- 12 - 25
- 25 - 41
- 41 - 61

Elevation (m)
- 0
- 150
- 320
- 623

from LISFLOOD-FP
dynamic simulation
from SRTM 1 a-s data set
Data assimilation framework for producing river discharge estimates globally

Hydrologic Model (VIC) → Simulated Stream flow → Hydraulics Model (LISFLOOD-FP) → Simulated Surface Water Extent and Elevation → NASA/JPL Instrument Simulator

Simulated Interferometric Altimeter Swaths

Spatial and Temporal Resolution Tradeoffs

Back Calculation of Discharge

Data Assimilation
The Need for Global, Satellite-based Observations of Terrestrial Surface Waters

Floods, water is a basic requirement for terrestrial life, yet knowledge of its occurrence and magnitude is not well known. Floods are a major source of water in river basins, and their occurrence can be predicted with confidence. The performance of climate models with respect to land surface hydrology also cannot be evaluated without consistent and accurate measurements of soil moisture and runoff. To monitor the occurrence and magnitude of floods, a network of flood-gauging stations is required. However, the gauging networks used for the flood measurements are often incomplete and data are particularly sparse outside of the populated regions (2). Furthermore, the estimates of the amount of surface water leaving a drainage basin, which is the runoff that enters the river channels, are often not accurate. The challenge is to develop an empirical relation between the level and streamflow of the river discharge using an empirical relation.

“The ability to measure, monitor, and forecast the U.S. and global supplies of fresh water is another high-priority concern. Agencies, through the NSTC (National Science and Technology Council), should develop a coordinated, multi-year plan to improve research to understand the processes that control water availability and quality, and to collect and make available the data needed to ensure an adequate water supply for the Nation's future.”
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
• Major implications for the ability to predict floods and droughts globally
• Elimination of “competitive advantage” of upstream countries in trans-boundary rivers
• Implications for global markets (especially food)
Current status

- European Space Agency will issue its Explorer AO (for “small” satellite missions) 3/15/05
- CNES (French Space Agency) has identified surface water as its highest priority
- In the U.S., JPL is the technology lead (and has committed internal resources to proposal development)
- NASA is currently in disarray due to uncertainty about Mars-Moon exploration (and the future of earth science at NASA); ESSP (Earth System Science Pathfinder) call has been indefinitely delayed