Land Hydrology:
The contribution of satellite radar altimetry to science investigations and operational programs

Continental 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.
Causes of spatio-temporal change of the continental water cycle

- Climate variability (natural and anthropogenic)

- Direct human effects:
  - groundwater mining
  - irrigation
  - dam building
  - urbanization
  - deforestation
  - change in land use
Water Balance Equation (river basin scale)

Water mass balance: \[ \frac{dW}{dt} = P - E - R \]

- \( W \): Land water mass (surface and underground waters; snowpack)
- \( P \): Precipitation
- \( E \): Evapotranspiration
- \( R \): Runoff
Applications

- Weather forecast
- Climate modelling
- Water resources management
- Natural Hazards:
  - floods, droughts
- Agriculture (irrigation)
- Hydro-electric energy production
- Fluvial navigation
- Land use and management
- Carbon cycle
- Sediment transport
- Sea level change
- Etc.
River level and discharge knowledge also needed for various applications (water resource management, irrigation, flood/drought prediction, etc.)
Water level and discharge

Global Runoff Data Center

All 7,222 GRDC river discharge gauging stations (monthly data including data derived from daily data), 264,743 station years (Status: 24 March 2005)
Time distribution of in situ gauges
Indus River

Indus river TP131: lon = 68.13, lat = 27.08

Niger River

Niger river TP237: lon = 359.26, lat = 11.63
Comparison of altimetry and in situ water levels

PARAGUAY

AMAZON

DANUB

CONGO
Nile River floods in Sudan leaving 200,000 homeless

KHARTOUM, Sudan (AP) - Floods and heavy rains have destroyed 119,000 houses and left more than 200,000 people homeless in nine Sudanese states, the government said.

The government’s Humanitarian Aid Commission said 65 schools and 60 health institutions have also been destroyed and vast tracts of farmland have been inundated.

The government has mobilized troops to fight the worst flooding along the Nile River in a half century and is considering evacuating thousands of people in districts near Khartoum.

The worst hit regions in Sudan, Africa’s largest country, are the Shamal and el-Nil states north of Khartoum.

On Tuti Island, located in the Blue Nile, a few hundred yards from where the river meets the White Nile, more than 10,000 inhabitants have been battling the surging river for three days. A 2.5-mile-long wall of sandbags has been erected to save thousands of homes.

Sudan has flooding problems in September, when the rivers peak and seasonal rains begin.

Meanwhile, air drops and feeding centers operated by international agencies hoping to alleviate a famine in southern Sudan are relieving some suffering, but people are still dying at an alarming rate, the United Nations.

Birkett, Murtugudde and Allan
Mercier, Cazenave and Maheu
Tropical disease and water levels (Amazonia)
Seasonal flood monitoring in the Mekong Basin

ERS/ENVISAT altimetry + SPOT/VGT imagery

Frappart et al., 2006
Monitoring of the 2004 flood event along Diamentina River (Australia) using MODIS images and Topex altimetry

Sequence of flood on Diamentina river in 2004 From Modis data

Black: water, Red: Aquatic Vegetation, Orange: Vegetation, White: dry land

Topex / Poseidon on Goyder Lagoon, Diamantina River

 Courtesy J.F. Crétaux
Potential GRACE Based Prediction of Lake Chad Water Levels

Due to an arid climate, Lake Chad and its tributaries are the primary source of water for residents of that region. These people alternate between fishing and farming, depending on river flows in a given year.

By observing variations in water stored in the uplands which drain to Lake Chad, GRACE satellite observations may soon enable forecasts of these river flows.

Figure 1. The catchment of the Chari/Logone river system (top), which drains into Lake Chad, in the Sahel region of central Africa (left). The basin uplands are shown in greens to blues to violet, with increasing elevation.

Figure 2. Annual cycles of terrestrial water storage anomalies in the uplands of the Chari and Logone River basins (from GRACE satellite observations) and Lake Chad elevation anomalies (from TOPEX/Poseidon satellite altimetry).

Matt Rodell, NASA/GSFC
Altimetric Levels from CropExplorer/Birkett
Surface water volume change from multi-satellite techniques: Combining surface water extent and altimetry-derived water height

Rio Negro basin
Altimeter track (T/P)
Altimeter station
In situ gauge station

floodplains/inundation using multi-satellite technique

water level time series Topex/ Envisat

water level variation maps

Papa et al., 2006, 2008 GRL, 2007, JGR
Prigent et al., 2007 JGR; Frappart et al., JGR, 2008

Computation of surface water volume variations
Surface water volume change from multi-satellite techniques: Combining surface water extent and altimetry-derived water height

GRACE: groundwater + surface water + SM

Multi-sat + alimeter: surface water volume

Decomposition of the GRACE signal to extract soil moisture + ground water

More opportunities with SMOS, SMAP

Longer time series thanks to Jason2

Surface water volume change from multi-sat/alti is ~ 38% of Grace total storage

GRACE Total

Surface volume change

SM+GW
Rating curve: Observed discharge versus Topex water level

Discharge (m³/s)

In situ
Topex

Zakharova et al., 2005
Surface Water Dynamics and Discharge Determination along the Amazon River

(Example by Chin, Jasinski, Birkett, Bjerklie)

Amazon River: surface water slope from the Topex NRA

River slope from altimetry + Manning’s equation = discharge

Qs1: Variable slope from depth from Oltman, 1968

Qs2: Depth/slope relation with range of slope values taken from Birkett, 2002.

Qs3: Constant slope 1.5cm/km from Birkett, 2002

Qs4: Depth/discharge rating from Oltman, 1968
Near Real Time Monitoring of Reservoirs and Lakes: Crop Irrigation and Water Resources

http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir

(Birkett, Beckley, Doorn, and Reynolds)
Rivers and Lakes ESA Data Base (P. Berry, UK) mainly ERS1/2 and ENVISAT

http://earth.esa.int/riverandlake

Lake Edouard (Africa)

Also: near real time water levels from ENVISAT in some regions
HYDROWEB data base:
Altimetric water level + total water volume
In major river basins from GRACE

Not yet NRT products

100 lakes,
50 reservoirs,
250 sites on rivers,
several sites on wetlands,
30 largest river basins

LEGOS
JF Cretaux/MC Gennero

www.legos.obs-mip.fr/en/soa/hydrologie/hydroweb/
Data Source:
Historical water level gauge data from Jinja, Uganda (near Lake Victoria’s outlet).
Satellite radar altimeter data from USDA/NASA/UMD at:
http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/

Historical Water Level Elevations for Lake Victoria

Owens Falls Dam was commissioned in 1954 at Jinja Uganda, Lake Victoria’s only outlet.

Lake level begins to rapidly drop in 2001, after the Owens Falls Dam Extension is inaugurated.

Lake Victoria’s water level on October 21, 2006 is approximately 10.41 meters, the lowest water level since 1923.

U.S. Department of Agricultural (USDA)
Foreign Agricultural Service (FAS)
Impact Analysis Division (IAD)
International Production Assessment (IPA)

Courtesy of C. Birkett
Middle East and Turkey: Warmer Than Normal and Plenty of Moisture

Shown are relative lake height variations for Lake Beyşehir in Turkey, Lake Buhayrat in Central Iraq and Lake Urmia in northwest Iran. A period of drought occurred from 1999 to 2001. Rainfall in Turkey, northern Iraq and adjacent regions increased in both 2002 and 2003 and has gradually recharged reservoirs.

Problems....
Amazon Basin

Nadir-viewing radar altimetry coverage
Topex/Jason (red) and ERS/Envisat (black)

• in situ gauges in situ
Radar waveforms on rivers

Example 3: Danub (track 033)

70 km

Courtesy of F. Mercier
Retracking efforts

- P. Berry (expert system)
- CLS (use of ENVISAT trackers; application to Topex)
- New methods:
  - Wavelets (F. Frappart)
  - Enjolras/Rogriguez method
Retracking of Jason-1 waveforms using Ice2

Amazon: Negro, Trace 241

Retracking Ice2

Courtesy of F. Mercier
V. Enjolras/E. Rodriguez waveform fitting method

(use of the whole set of waveforms at satellite-river intersection)

• Simulation of radar waveforms on rivers using SRTM DEM, water/non water mask based on Landsat/MODIS images, CIA world data bank for river location, radar characteristics (system point target response, altimeter antenna pattern, instrument thermal noise...) and target parameters (water height)

• Simulated waveforms are generated for a large range of parameters values (water height, radar cross section)

• A least-squares adjustment is performed to extract the best fitting parameters

• Applications to Meuse (Europe) and Lena (Siberia) rivers
New retracking method developed by V. Enjolras & E. Rodriguez

Meuse River

Range gate

Actual Topex waveforms

Range gate

Simulated waveforms

Courtesy of V. Enjolras
wet tropospheric correction on land
Topex/Poseidon MGDRs

TMR

ECMWF model

Courtesy of F. Mercier
Lake Mead
2119_002_0370_2_02_0001 (10 Apr 2007, 23:01:27)

ID Saturated Waveforms

L3H GLA01,05,06
Elevtn (top), illuminated area (below)
Preliminary validation of GLAS elevation: comparison to gauge data for Lake Mead.

Note: GLAS data and gauge data should be converted into the same reference frame of Geoid. Gauge data is from Bureau of Reclamation (http://lakemead.water-data.com/).
Why 2-D (wide-swath) altimetry is required

- Profiling altimeters miss too many rivers and lakes whereas imaging methods sample all of the world’s water bodies.

- Profiling altimeters
  - 10-day repeat: i.e. Topex/Jason, misses ~45% of rivers and 80% of lakes
  - 35-day repeat: i.e., ERS/ENVISAT, misses ~20% of rivers and ~55% of lakes

- Swaths from an interferometric radar altimeter
  - 10-day repeat: misses ~7% of the rivers and lakes
  - 16-day repeat: samples all (misses only ~1% of rivers and lakes)

Courtesy of D. Alsdorf/ E. Rodriguez
The Solution

KaRIN: Ka-band Radar Interferometer.
SRTM, WSOA heritage. Maps of h globally and ~weekly.

Courtesy of E. Rodriguez (JPL)