Intersection of SAR imagery with medium resolution DEM for the estimation of regional water storage changes

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Background

Previous study (GRACE data analysis) in the Amazon basin: huge change of water storage within the continental hydrology between two extreme events in 2009. April (“flood of the century” [State of the Climate]) and November (drought).

- How are such mass variations and related effects reflected in other contemporary observation systems (satellite altimetry, SAR/optical remote sensing, gauges,...)

- Potential and spatial/temporal consistency of observed changes of water mass and water surface extent caused by extreme weather situations

- Can these techniques be used to infer alternative estimates for mass variations that could be compared with GRACE?
Total water storage change from GRACE

- Analysis of 97 monthly GRACE solutions (August 2002 and March 2011)
- GFZ RL04 (degree/order =70), reduced by mean field over the entire period
- Treatment of mission-specific errors in the Level-2 data ("stripes" due to satellite orbit characteristics and high-frequent aliasing of to non-modeled mass variations):
  - Reduction of correlated errors by a least squares polynomial filer
  - Filtering of noisy short wavelength components using an isotopic Gaussian filter with a half-width of 300km.
Total water storage change from GRACE
Total water storage change from GRACE

Change between the absolute maximum and the absolute minimum of the curve within only half a year
2009 extreme conditions in GRACE

April 2009 anomaly
2009 extreme conditions in GRACE

Nov. 2009 anomaly
2009 extreme conditions in GRACE

- Dec. 2008 – Apr. 2009: heavy rainfall, 100% above normal in the north (Rio Negro) and the northeast
- Flood 2009: highest ever registered water levels of Rio Negro and Amazon
- Above average (2-3°C) temperatures from June 2009 in the North-East
- ENSO-related below average precipitation in the last three months of 2009
Observations of water levels

Water level at Obidos

Water level at Manacapuru

in-situ gauge stations (water level)
altimetry observations (ENVISAT)
Observations of water surface extent

- Phased Array type L-band Synthetic Aperture Radar (PALSAR) onboard ALOS
- L-band is especially useful in areas covered by vegetation
- ScanSAR wide beam mode (100 m spatial resolution)
- Swath width ~300 km
Observations of water surface extent

- Flooded open water areas appear as dark areas
- Flooded areas with vegetation appear as bright areas (double bounce)
Observations of water surface extent

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- Flooded areas with vegetation appear as bright areas (double bounce)
Observations of water surface extent

April 2009

Total area of each image:
~ 12 Mio Pixel
~ 100,000 km²

Rough estimation of flooded area:
Application of a simple threshold for dark and bright pixels based on image histogram.

[Meyer, 2004; Hedman, 2010]
Observations of water surface extent

April 2009

Black: areas under water

[Meyer, 2004; Hedman, 2010]
Observations of water surface extent

- ALOS PALSAR images are a useful source of information for the detection of areas covered by water.
- Periods of flood and drought are clearly distinguishable.

April 2009: Area covered by water: larger by about 12% in April

November 2009
Towards the assessment of water volume changes

Estimation of water mass variations in the regime of surface water between extreme situations from volume changes:

- Geometrical intersection of surface water mask with a DEM
- Data from gauges and altimetry as vertical constraints

ACE-2 DEM:
- Combination of SRTM data with satellite altimetry
- Horizontal resolution ~ 90 m
**Step 1: Generation of the water mask**

Generate water mask, reduce speckle, extract the largest connected component, intersect the boundary with DEM using transformation polynomials.

[Hedman, 2012]
Step 2: Computation of water heights along the river boundary

Derive the heights along the boundary, process for error reduction.

- Extract constant segments
- Errors in heights are caused by displacements of the river boundary w.r.t. the DEM
- Remove very short segments and then interpolate in gaps
- Interpolate heights in gaps
Water height differences (April – November 2009)
Resume & Outlook

- Extreme events (e.g. floods, droughts) are clearly identifiable in the analysed data sets from GRACE, satellite altimetry, SAR and in-situ gauges.

- Next step: Volume computation
  → How do volume changes compare with GRACE mass variations?

- Problems and challenges:
  - coarse horizontal resolution of SAR scenes and DEM (~90 m)
    → large uncertainty of computed volume
  - no bathymetry information available
  - small flooded areas are even more difficult to intersect
  - incorporation of information on water stages: altimetry, gauges
  - comparability of GRACE and geometrical approach

- Multi-sensor data combinations are an important step towards the separation of integral geodetic signals.
END
Total water storage change from GRACE

GRACE accuracy: 1-2 cm EWH (~ 60-120 km³)

DDK1 / DDK3: Results from two versions of non-isotropically smoothed GFZ RL04 solutions [Kusche et al., 2007]. DDK1 smoothes over larger areas than DDK3.
Total water storage change from GRACE

- Dec. 2008 – Apr. 2009: heavy rainfall, 100% above normal in the north (Rio Negro) and the northeast
- Flood 2009: highest ever registered water levels of Rio Negro and Amazon
- Severe damage and impact on humans and wildlife
- Above average (2-3°C) temperatures from June 2009 in the North-East
- ENSO-related below average precipitation in the last three months of 2009
- Worst drought since 40 years
- Record low water levels
- Worst drought since 40 years
- Record low water levels
Observations of water surface extent

- Phased Array type L-band Synthetic Aperture Radar (PALSAR) onboard ALOS
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Approach

SAR image data (high and low water levels)

Extract water mask from SAR data

Extract the largest connected component as the primary water body

Intersect water boundaries with DEM and extract boundary heights

DEM

Altimetry data

Estimation of water mass variations

Interpolate water heights