Hydrologic-hydrodynamic modelling and perspectives of SWOT data applications in the Amazon

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Topics

- Hydrological hydrodynamic modelling of the Amazon
  - the model
  - input variables
  - relevant features
  - current state
  - results (hydrographs, flooded area)
  - restrictions
- Perspective use of SWOT data
  - How SWOT data will possibly improve the modelling
  - What changes are needed to take advantage of SWOT data
  - Virtual mission tests conducted by Rodrigo Paiva and Jhan
The model
HYDROLOGICAL MODEL OBJECTIVE

- Development of a hydrological model for the whole Amazon river basin
- Now: preliminary results
- Future: real time hydrological forecasting system.
HYDROLOGICAL MODEL

MGB - IPH (Collischonn, 2001; Paiva, 2009)
“Modelo de Grandes Bacias” = Large basins hydrological model

- Physically-based / conceptual model
- Daily time step
- Distributed

Catchment discretized
~ 6,900 catchments
MGB-IPH HYDROLOGICAL MODEL

• Hydrological Response Units approach for Water Balance
• Linear reservoirs for in-catchment propagation
• Muskingum-Cunge or Hydrodynamic river routing
Flow routing modelling

Muskingum Cunge at large slope rivers
Hydrodynamic Model at low slope rivers
Hydrodynamic Model

- Hydrodynamic 1D model IPH-IV (Tucci, 1978; Tucci, 2005)
  - Full Saint Venant equations solved with finite difference method
  - Improved Skyline algorithm for river network solution
  - matrix solution method further improved by Rodrigo Paiva

Model discretization:
- Catchments
- River reaches
- River cross sections
- Floodplain units
Hydrodynamic Model

- Flood inundation model:
  - floodplains act only as storage areas
  - which means $v = 0$
  - horizontal water level across cross section
  - river – floodplain lateral exchange:

  \[
  t \frac{\partial}{\partial z} \left( z \frac{\partial}{\partial x} \right) = 0
  \]

- Model discretization:
  - Catchments
  - River reaches
  - Floodplain units

\[
 b \quad b + L
\]
DEM and GIS based algorithms for HD parameter estimation

Geomorphologic equations:

\[ B = a \cdot A_d^b \]

\[ H = a' \cdot A_d^{b'} \]

DEM corrections (vegetation, water):

Water level _versus_ flooded area curve for each floodplain unit

Corrected DEM
DATA

Precipitation and Meteorological Data

- Remote sensed estimates from Tropical Rainfall Measurement Mission
  - Daily rainfall data from TRMM 3B42 algorithm
  - Spatial resolution of \(0.25^\circ \times 0.25^\circ\)

- Climatic Research Unit (CRU) data for meteorological variables for Penman-Monteith evapotranspiration model (air temperature, pressure, solar radiation, air moisture and wind speed)

Digital Elevation Model

- HydroSHEDS - Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales (500 m resolution)

Soil Type and Soil Use Data

- A Vegetation map of South America (1 km resolution) from Eva et al. (2002)

- Soil maps:
  - SRIC (World Soil Information) / SOTERLAC (Soil and Terrain database for Latin America and Caribbean) (1:5.000.000)
  - Exploratory Soil Map from RADAMBRASIL (1:1.000.000)
MODEL CALIBRATION

- 172 stream gauges
- Manual calibration and MOCOM-UA optimization (Yapo et al., 1998)
Discharge results – Purus River

- Acre River at Rio Branco city
  - Rapid floods
  - Good model performance

- Lower Purus
  - Delay and attenuation
  - Good model performance
Discharge results – Ucayali River (Peru)

- **Ucayali river (Pucallpa)**
  - Delay and attenuation OK
  - Underestimation due to rainfall data

- **Ucayali river (Requena)**
  - Delay and attenuation OK
Discharge results – Solimões River

- **Solimões river at Peru**
  - **Tamshiyaco**
    - Delay and attenuation OK
    - Volume error ~ -12%

- **Lower Solimões / Manacapuru**
  - Delay and attenuation OK
  - Volume error ~ -11%
Discharge results – Madeira River

- **Mamoré river at Guajará-Mirim**
  - Brazil/ Bolivia border
  - Good model performance

- **Madeira river**
  - Good model performance
Discharge results – Tapajós River

- **Juruena river**
  - Excellent model performance
  - High base flow

- **Tapajós river**
  - Excellent model performance
Discharge results – Amazon River

- **Amazon at Óbidos**
  - Delay and attenuation OK
  - Volume error ~ -5%
  - Excellent model performance
Water level results – Solimões River

Solimões at S.P. Olivença
- Peru/Brazil border
- Phase OK
- Amplitude OK
- Good model performance

Solimões river
- Phase OK
- Amplitude OK
- Good model performance
Water level results – Madeira River

- Madeira river at Porto Velho
  - Phase OK
  - Amplitude OK
  - Good model performance

△ Lower Madeira
  - Amplitude and phase ±
Floodplain inundation - method

**INPUT**

- TRMM rainfall
- CRU data

**OUTPUT**

- MGB-IPH model

Discharge

Water level

Floodplain inundation map
Floodplain inundation - method

Flood inundation model

- **Water depth:**

Water level from 1 D model

![DEM](image1.png)

![2 D flood inundation results](image2.png)

Floodplain units

![Floodplain units](image3.png)
Floodplain inundation - results

Central Amazon – Minimum water depth from the 2001/2002 year
Floodplain inundation - results

Central Amazon – Maximum water depth from the 2001/2002 year
Previously flood inundation model validation

Validation in Solimões river basin (Paiva, 2009)

Simulated water depth
High water
may/jun 1996

Model Validation with remote sensing estimates from HESS et al (2003) using JERS-1 data
Perspectives of the use of SWOT data

• From the work of Rodrigo Paiva and Jhan Carlo Espinoza, using virtual Swot data
SWOT virtual measurements are obtained by using an instrument measurement model coupled to simulated water surface elevations from the hydrodynamic model MGB-IPH.

Orbit SWOT (22-day) + Water surface elevation (MGB-IPH) + Error (instrument noise)
Virtual SWOT data 2002-2005 in Solimões River basin

Considering SWOT at 01 January 2004

Region where Water level results would be available
Water level and flood extent estimation

SWOT data

Mean water level and total flooded area

Overlay of SWOT band and floodplain units

Time series

Water level

Flooded area

\( z \)

\( A(t) \)

\( t \)
Water level: 4 years
Flooded area: 4 years (2002 – 2005)
Discharge estimation algorithm

-Input data:
  - SWOT data
  - Flow direction raster from DEM
  - Drainage raster
    - MGB-IPH data base
      - Cross sections XY
      - width B
      - Manning n,
      - bed level $z_0$
Discharge estimation algorithm

For each cross section and time interval:

1) “Walk” downstream and upstream pixel per pixel
   1.1) Compute distance $\Delta x$ and total distance $x = x + \Delta x$
   1.2) Get SWOT water level $z(x)$

2) Calculate water slope $S_{swot} = -a$:

3) Compute discharge using Manning equation:

$$Q = \frac{1}{n} B(z(0) - z_0)^{0.667} S_{swot}^{0.5}$$
Estimation of discharge: 2004-2005

Large river

small river

*SWOT

MGB-IPH
Error < 10% in 60% of model sections

For sections with discharge > 2000 m$^3$/s. Error is 5% in average

\[ Err_i = \frac{\sum_{t=1}^{t=n} \sqrt{(Q_{SWOT(i)} - Q_{MGB(i)})^2}}{N_i} \]
Spatial distribution of the Errors

Error < 5% in the main rivers
2005 Drought at Manacapuru Station as seen by SWOT VM

- **Observed Discharge**
- **MGB-IPH Discharge**
- **SWOT estimates**

2005 drought
Expected benefits from SWOT

SWOT data assimilation within the model for real time forecasts

SWOT data to estimate indirectly depth and width of rivers

SWOT data to estimate inundated areas

Merging SWOT and hydrological model to obtain a “current state” scenario