Prospects for river discharge and depth estimation through assimilation of swath–altimetry into a raster–based hydraulics model

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Motivation

• Swath altimetry provides measurements of water surface elevation, but not discharge (key flux in surface water balance)
• Satellite dataset, spatially and temporally discontinuous
• Data assimilation offers the potential to merge information from swath altimetry measurements over medium to large rivers with discharge predictions from river hydrodynamics models
• Key questions include role of satellite overpass frequency and model uncertainties: synthetic experiment ideal to address these
Experimental Design

Baseline Meteorological Data \rightarrow Hydrologic Model \rightarrow Perturbed Meteorological Data

Baseline Boundary and Lateral Inflows \rightarrow Hydrodynamics Model \rightarrow Perturbed Boundary and Lateral Inflows

Baseline Water Depth and Discharge

JPL WatER Simulator

“Observed” Water Depth and Discharge

Updated Water Depth and Discharge

Kalman Filter

WSL
Hydrologic & Hydrodynamics Models

- Variable Infiltration Capacity (VIC) hydrologic model to provide the boundary and lateral inflows
- Has been applied successfully in numerous river basins

- LISFLOOD-FP, a raster-based inundation model
- Based on a 1-D kinematic wave equation representation of channel flow, and 2-D flood spreading model for floodplain flow

- Over-bank flow calculated from Manning’s equation
- No exchange of momentum between channel and floodplain
Data Assimilation Methodology

- Ensemble Kalman Filter (EnKF)
- Widely used in hydrology
- Square root low-rank implementation
- Avoids measurement perturbations
Study Area and Implementation

- Ohio River basin
- Small (~ 50 km) upstream reach
- 270 m spatial resolution and 20 s time step
- Spatially uniform Manning’s coefficient

- Nominal VIC simulation provides input to LISFLOOD for “truth” simulation
- Perturbing precipitation with VIC provides input to LISFLOOD for open-loop and filter simulations
- Precipitation only source of error for this feasibility test
WatER Observation Simulations

- NASA JPL Instrument Simulator
- Provides “virtual” observations of WSL from LISFLOOD simulations
- 50 m spatial resolution
- ~8 day overpass frequency

- Spatially uncorrelated errors
- Normally distributed with (0,20 cm)

Goteti et al. (to be submitted)
Assimilation Results - WSL

- Spatial snapshots of WSL for the different simulations (28 April 1995, 06:00)
- Satellite coverage limited by the orbits used in the simulator
Effects of Boundary & Lateral Inflow Errors

- Upstream boundary inflow dominates simulated discharge
- Persistence of WSL and discharge update not adequate
- Correction of upstream boundary inflow errors necessary
- Simple AR(1) error model with upstream discharge as an exogenous variable

![Graph showing Channel Discharge RMSE (m³/s) from April 1 to June 27]
Assimilation Results - Channel Discharge

- Discharge along the channel on 13 April 1995, for the different simulations

- Discharge time series at the channel downstream edge
• Spatially averaged RMSE of channel discharge
• Open-loop RMSE = 161.5 m$^3$/s (23.2%)
• Filter RMSE = 76.3 m$^3$/s (10.0%)
Sensitivity to Satellite Overpass Frequency

- Additional experiments with 16- and 32-day assimilation frequencies
- Downstream channel discharge time series
Sensitivity to Observation Error

- Nominal experiment observation error N(0,5cm)
- Contrary to a synthetic experiment, true observation errors might not be known exactly
- Sensitivity of results to different assumed observation errors: (1) perfect observations and (2) N(0,25cm)

- Filter 5 cm: 76.3 m³/s
- Filter 0 cm: 82.1 m³/s
- Filter 25 cm: 98.7 m³/s
Conclusions

• Preliminary feasibility test shows successful estimation of discharge by assimilating satellite water surface elevations

• Nominal 8 day overpass frequency gives best results; effect of updating largely lost by ~ 16 days

• Results are exploratory and cannot be assumed to be general -- additional experiments with more realistic hydrodynamic model errors (Manning’s coefficient, channel width etc), hydrologic model errors, and more topographically complex basins (e.g. Amazon River) are needed.

• Assumption that “truth” and filter models (both hydrologic and hydrodynamic) are identical needs to be investigated
Questions?