Hydrology Virtual Mission

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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
Synthetic Experiments

- Identical twin experiment
- Model used to generate true fields (water surface elevation, discharge etc)
- Observations generated from true fields through an instrument simulator
- Artificial errors introduced to the model to generate “first guess” estimate
- Synthetic observations assimilated into the model to correct for the errors
Experimental Design

Baseline Meteorological Data → Hydrologic Model

Baseline Boundary and Lateral Inflows

Baseline Water Depth and Discharge

JPL WatER Simulator

updated Water Depth and Discharge

"Observed" WSL

Kalman Filter

Perturbed Meteorological Data

Perturbed Boundary and Lateral Inflows

Perturbed Water Depth and Discharge
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

- Ohio River basin
- Small upstream reach (~ 50 km) near Martin's Ferry, OH
- Drainage area of ~ 60,000 km²
Model Implementation

- VIC simulated streamflow provides boundary and lateral inflow to LISFLOOD
- Precipitation corrupted with log-normally distributed, spatially correlated errors
- Perturbed inflows used for open-loop and filter simulations
- Spatially uniform Manning's coefficient
- 1 April – 23 June 1995
- 270 m spatial resolution
- 20 s time step
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)
Assimilation Results - WSL

- Spatial snapshots of WSL and WSL difference from the Truth 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 from Apr 1 to Jun 27](image)
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

![Discharge (m$^3$/s) vs. Time (Apr 1 to Jun 15)](chart.png)
Sensitivity to Observation Error

- Nominal experiment observation error $N(0, 5\text{cm})$
- 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) $N(0, 25\text{cm})$

- Filter 5 cm: 76.3 m$^3$/s
- Filter 0 cm: 82.1 m$^3$/s
- Filter 25 cm: 98.7 m$^3$/s
Summary

- Preliminary feasibility test shows successful estimation of discharge and water surface elevations by assimilating WatER satellite observations
- 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, hydrologic model errors, and more topographically complex basins are needed
- Assumption that “truth” and filter models (both hydrologic and hydrodynamic) are identical needs to be investigated
Next steps...

- Parallelized hydrodynamics model (OSU Cluster)
- Extended study domains
  - Ohio River
  - Other global regions (e.g. Amazon River)
- Additional evaluation of different observation spatial resolution and overpass frequency
- More realistic errors (e.g. Manning's coefficient, channel geometry)
- Simultaneous state/parameter estimation
- Boundary inflow error model
Questions?
Performance statistics