River levels from multi-mission satellite altimetry, a statistical approach

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DTU Space
National Space Institute

RIDESAT

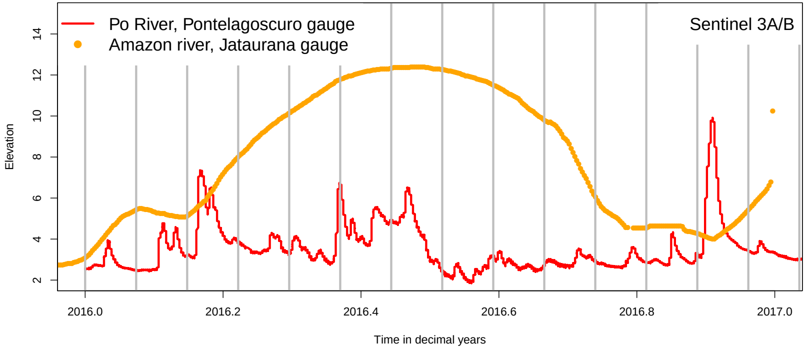
RIDESAT: **RI**ver flow monitoring and **D**ischarge **E**stimation by integrating multiple **SAT**ellite data

A collaboration between:

- Estimate river discharge from the use of multiple sensors; **Altimetry**, thermal, and optical (NIR bands)

Background and motivation

- **Goal**: To estimate the river levels as accurate and detailed as possible
- **Limit**: Single altimetry missions have limitations in temporal and spatial coverage



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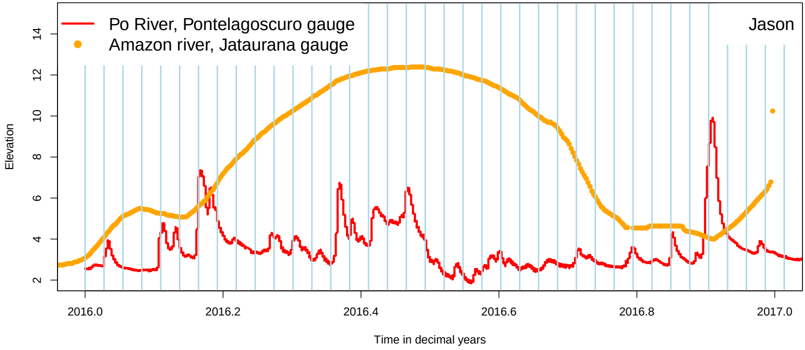
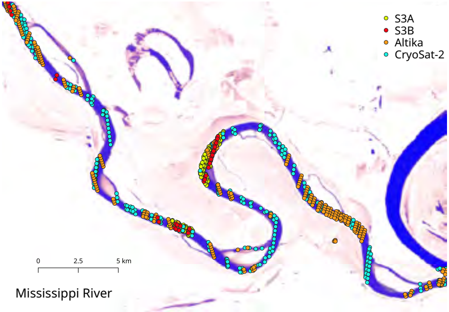


Background and motivation

- **Goal**: To estimate the river level as accurate and detailed as possible
- **Challenge**: Topography and erroneous observations makes this challenging

Google earth



Global surface water, occurrence mask

River model, state-space model

River model observation part

$$H_i = \eta_{t_i}\alpha(x_i) + \tau(x_i) + \beta(sat_i) + \epsilon_i$$

- **Amplitude**: $\alpha(x_i)$ is a cubic spline that describes the amplitude term assumed to be positive
- **Topography** :$\tau(x_i)$ is a cubic spline that describes the topography term assumed to be increasing as a function of distance.
- **Bias**: $\beta(sat_i)$ is a bias term depending on the satellite
- **Error term**: ϵ_i follows a normal distribution $\epsilon_i \sim \mathcal{N}(0, \sigma_\epsilon^2)$

River model process part (AR1)

$$\eta_{t_i} = \rho\eta_{t_{i-1}} + \xi_i, \quad -1 < \rho < 1, \quad \xi_i \sim \mathcal{N}(0, \sigma_\xi^2)$$

Implementation

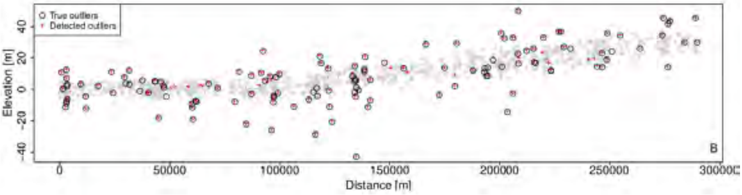
The model is implemented using the 'R' package TMB (Template Model Builder)

Ensuring robustness

- Letting the error term ϵ_i follow a mixtures between a normal and a Cauchy distribution makes the solution more robust
- **Problem**: convergence problems (encounter ridge problem) :-(
- **Solution**: Apply weights iterative, convergence :-), and fast :-)

Weights:

- Compare predicted and observed river levels
- Down weight upper $p100$ percentile, where p is a small number below 0.1
- Estimate new river levels, ... repeat

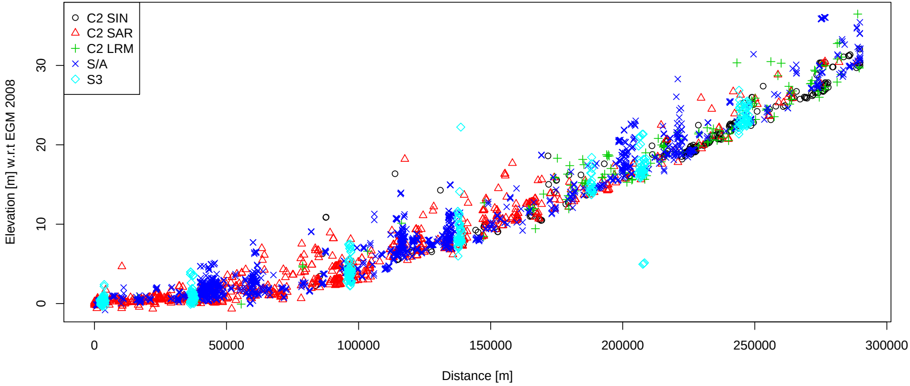


Model input and data preparation

We apply water levels from CryoSat-2, Altika, and Sentinel-3A/B

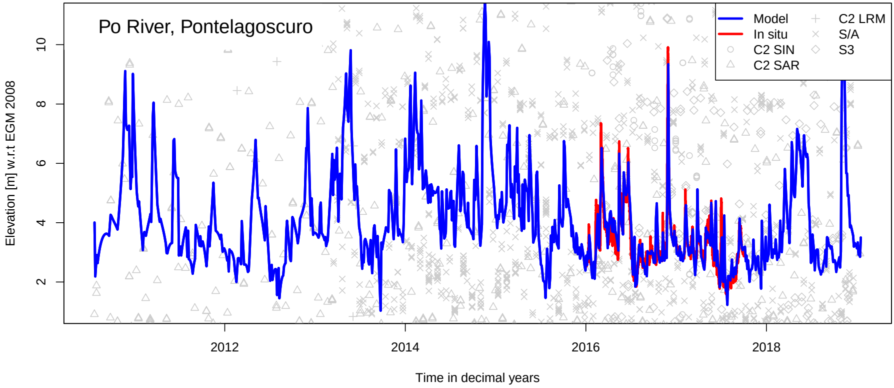
- Use a mask to extract observation over the river
- Water level positions are projected to the center line of the river
- Model input
    - Choose number of time steps for the joint solution N_t
    - Choose number of knots in the spline functions x_{knot}
    - The size of N_t and x_{knot} depends on the data
- The model allows evaluation of the water level at any given distance along the considered stretch of the river
- On the following results plot the water level is evaluated at the position of the in-situ station

Examples, Po river



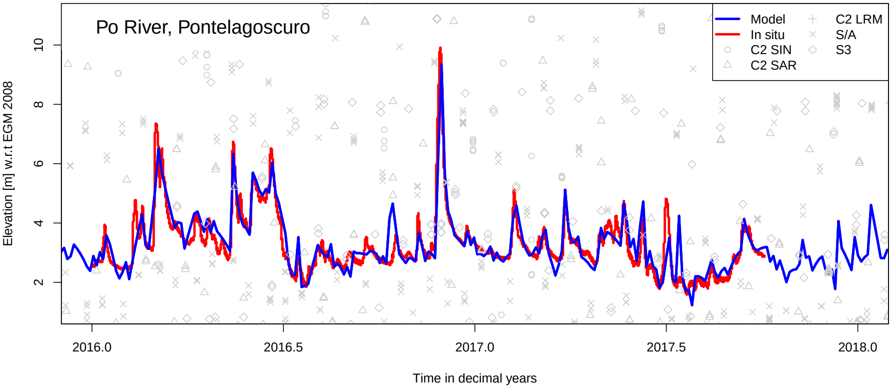
- Consider a river segment of 300 km
- The temporal resolution of the data is 3 days (mean)
- East-West orientation, Optimal for satellite altimetry

Examples, Po river Pontelagoscuro gauge



- $N_t = 1000$ equivalent to 3 days $, x_{knot} = 7$

Examples, Po river Pontelagoscuro gauge



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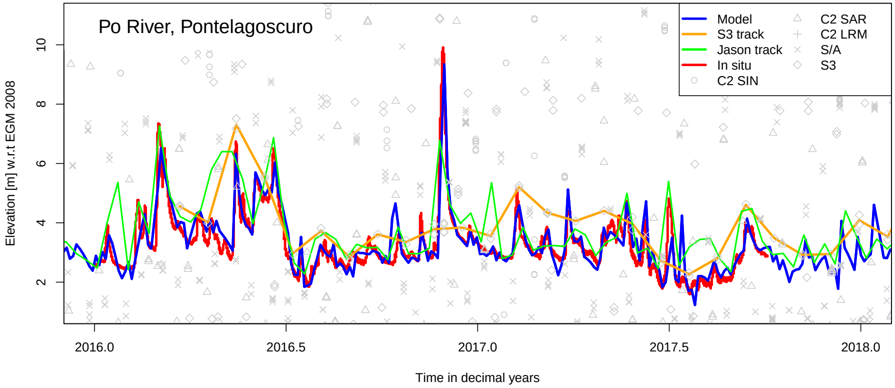
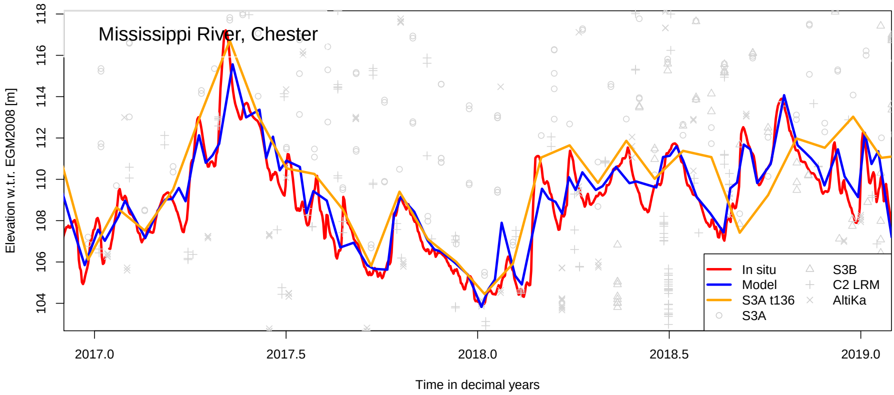


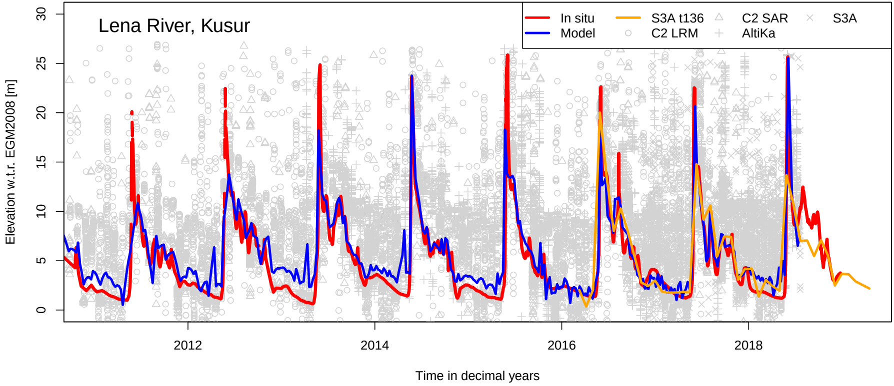
- Combined solution have added detail compared to the single missions
- Jason time series downloaded from DAHITI `https://dahiti.dgfi.tum.de/en/` (adjusted in elevation to fit the gauge!)

Examples, Mississippi river Chester gauge



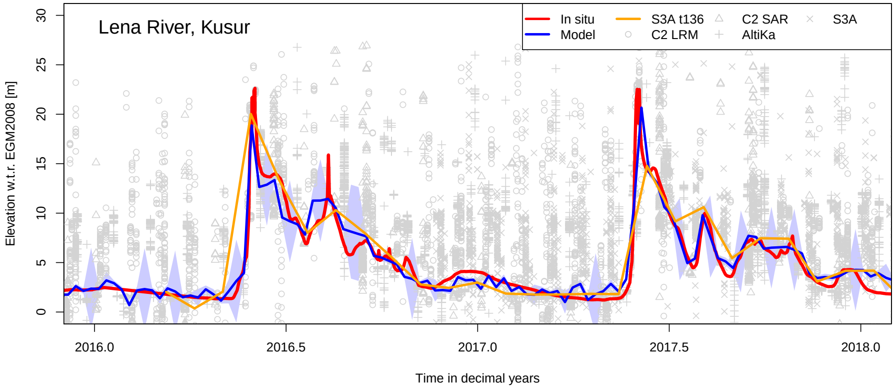
- consider a segment of 300 m
- The temporal resolution of the data is 9 days (mean)
- River orientation North-South -> less data

Examples, Lena river kusur gauge



- consider a segment of 300 m
- The temporal resolution of the data is 4 days (mean)
- Improved fit as more missions are added

Examples, Lena river kusur gauge



Summary

- **Combining several mission** in an integrated solutions **can add more detail** to the river level time series for smaller rivers
- The approach makes it **possible** to use missions with **drifting orbits** when deriving **time series**
- The method **adds flexibility** in the sense that the river level time series can be constructed at any location along the considered segment
- **Important** to have missions in both **repeat** and **drifting orbit**
- **Future work:** Integrate other missions; ICESat-2, Jason-2/3,...

Thank you for your attention :-)