Estimating Hydrological Connectivity in Coastal Wetlands Using UAVSAR and Numerical Modeling

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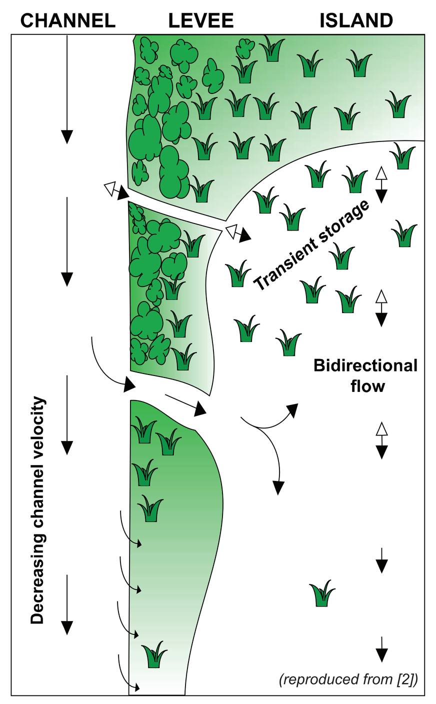
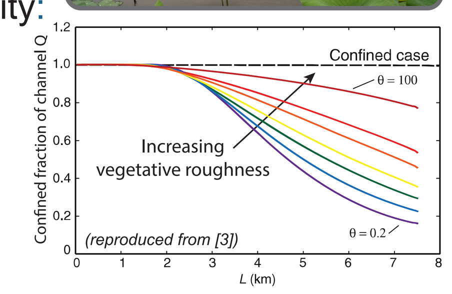
(1) Hydrological Connectivity in Coastal Deltas



Hydrological connectivity (in this context) means the physical exchange of water and water-mediated substances between different components of the landscape (channels and wetlands)[1].



In the Wax Lake Delta, channel-island connectivity:

- Is significant (28% - 59% of total flow[2,3,4,5])
- Controls hydraulics of entire delta system[3,5]
- Affects locations of aggradation and erosion[5]
- Can affect biotic nutrient processing[3,5,6]
- May play a role in ecological succession[5]
- Facilitates cross-delta information transfer[7]

However, it is difficult to measure, and has traditionally required detailed field work or computationally limited computer modeling.

Can we use UAVSAR to measure connectivity rapidly over large spatial scales?

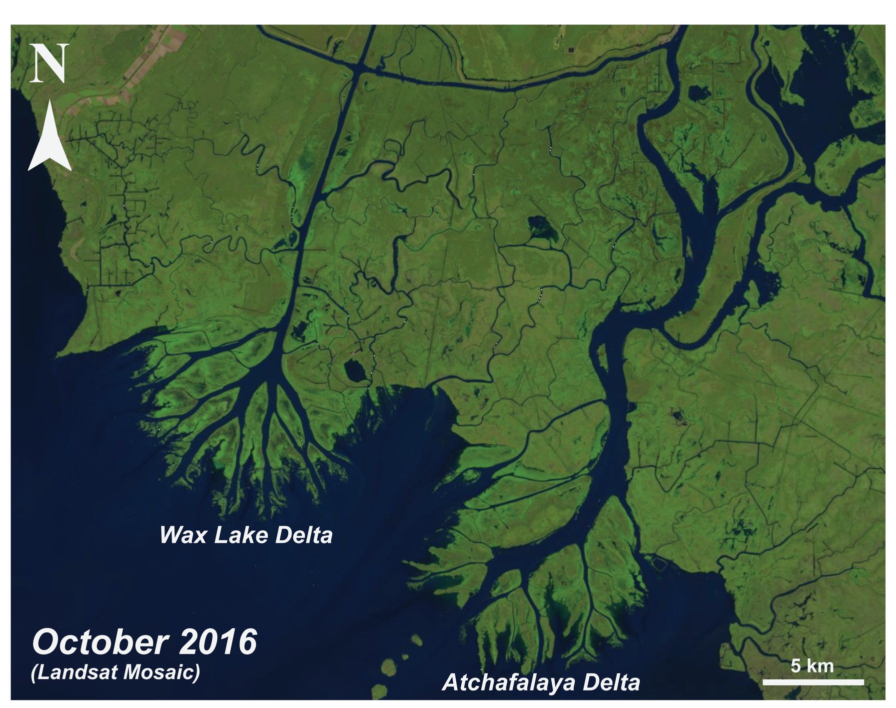
(2) Remote Sensing with Synthetic Aperture Radar (SAR)

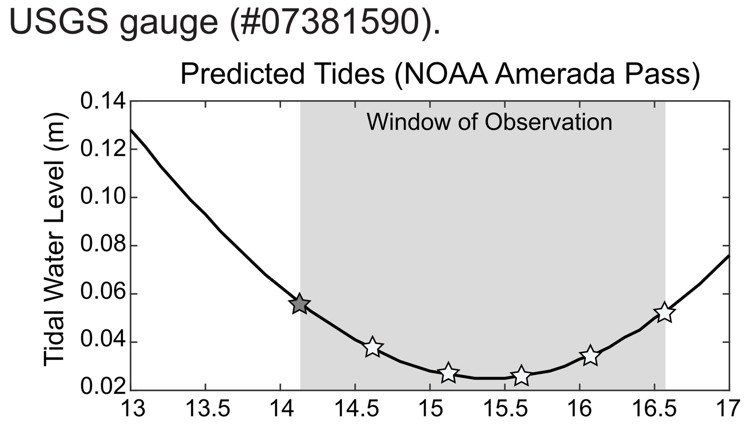
The NASA airborne Uninhabited Aerial Vehicle SAR (UAVSAR) is an L-band (1.2575-GHz) SAR polarimetric instrument with an 80-MHz bandwidth[8,9]. Used in repeat-pass interferometric mode, the backscatter signals can be used to infer water level changes between repeated flights[10]. The SAR images have a swath of ~22 km and a spatial resolution of ~7 m, and can be collected over several hours[8,9].

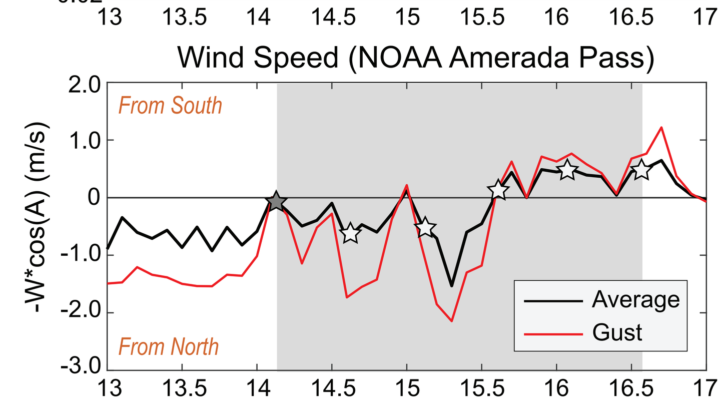
(3) Which Environmental Forcings Control Water Levels?

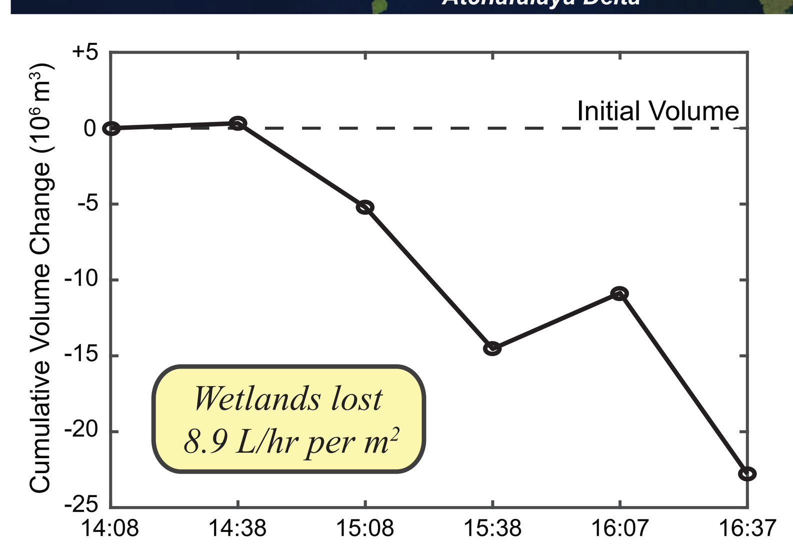
On October 16th, 2016, UAVSAR was used to monitor water level change in the Wax Lake and Atchafalaya Deltas over a course of 2 h 29 min. Six flights (one every half-hour) ran from 14:08 - 16:37 UTC, yielding five interferometric maps of water level change.

Tide and wind information obtained from NOAA Amerada Pass tide gauge (#8764227). Average discharge was 1620 m^3/s, as measured at the Calumet USGS gauge (#07381590).









Over span of observation, non-channelized wetlands lost a total of over 22.8 megatons of water!

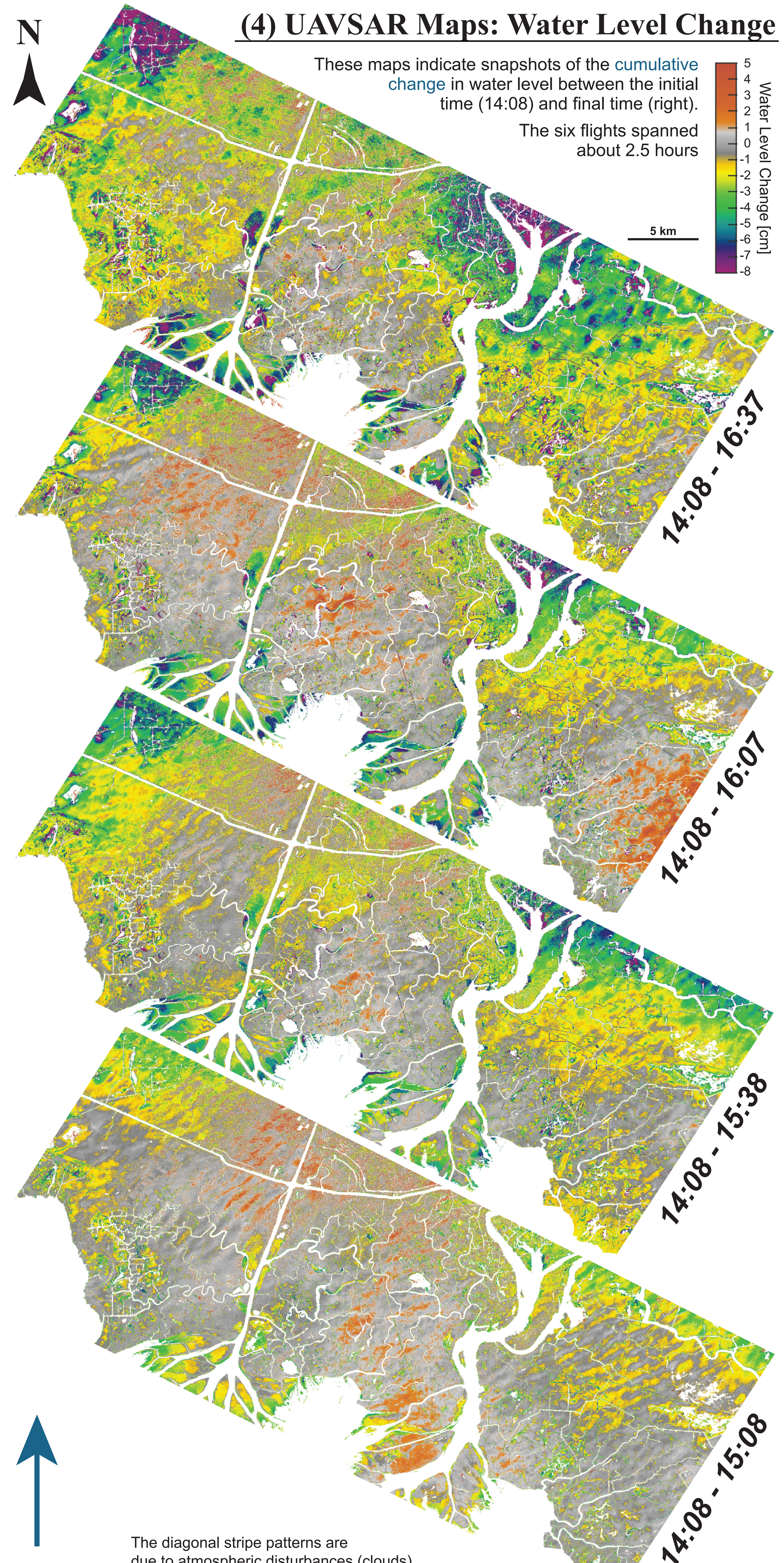
Connectivity is not isolated to the deltas, similar magnitude of losses observed upstream.

To understand causes and implications of this data, we developed a hydrodynamic model to explore influence of tides, wind, and vegetation on water levels. We focus the modeling analysis on the Wax Lake Delta, which has been the focus of many studies(e.g. 2-7,9).

(4) UAVSAR Maps: Water Level Change

These maps indicate snapshots of the cumulative change in water level between the initial time (14:08) and final time (right).

The six flights spanned about 2.5 hours



The diagonal stripe patterns are due to atmospheric disturbances (clouds).
Tides only seen falling within window.

(5) Hydrodynamic Modeling with ANUGA

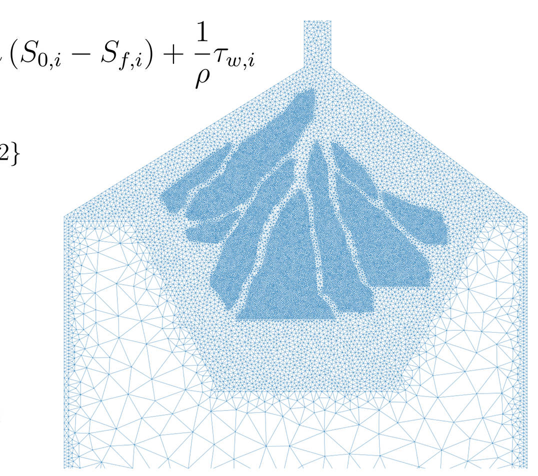
Model built using the modeling software ANUGA[11], which is a flexible, fast, open source (Python) model which solves the 2D shallow water equations given as:

$$\frac{\partial u_i h}{\partial t} + \frac{\partial u_i u_j h}{\partial x_j} + \frac{g}{2}\frac{\partial h^2}{\partial x_i} = gh\left(S_{0,i} - S_{f,i}\right) + \frac{1}{\rho}\tau_{w,i}$$

$$\frac{\partial h}{\partial t} + \frac{\partial u_j h}{\partial x_j} = 0 \qquad i,j = \{1,2\}$$

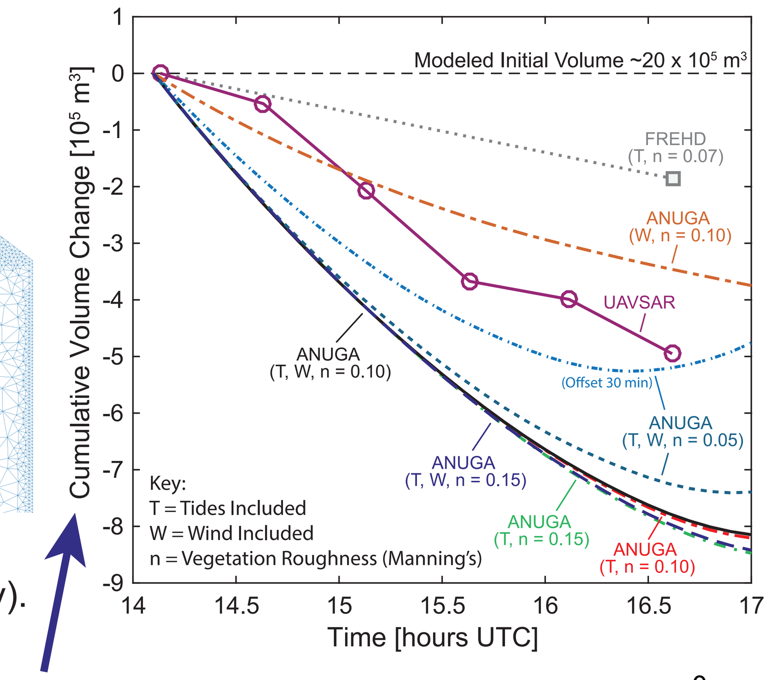
$$S_{f,i} = \frac{u_i n^2 \sqrt{u_1^2 + u_2^2}}{h^{4/3}}$$

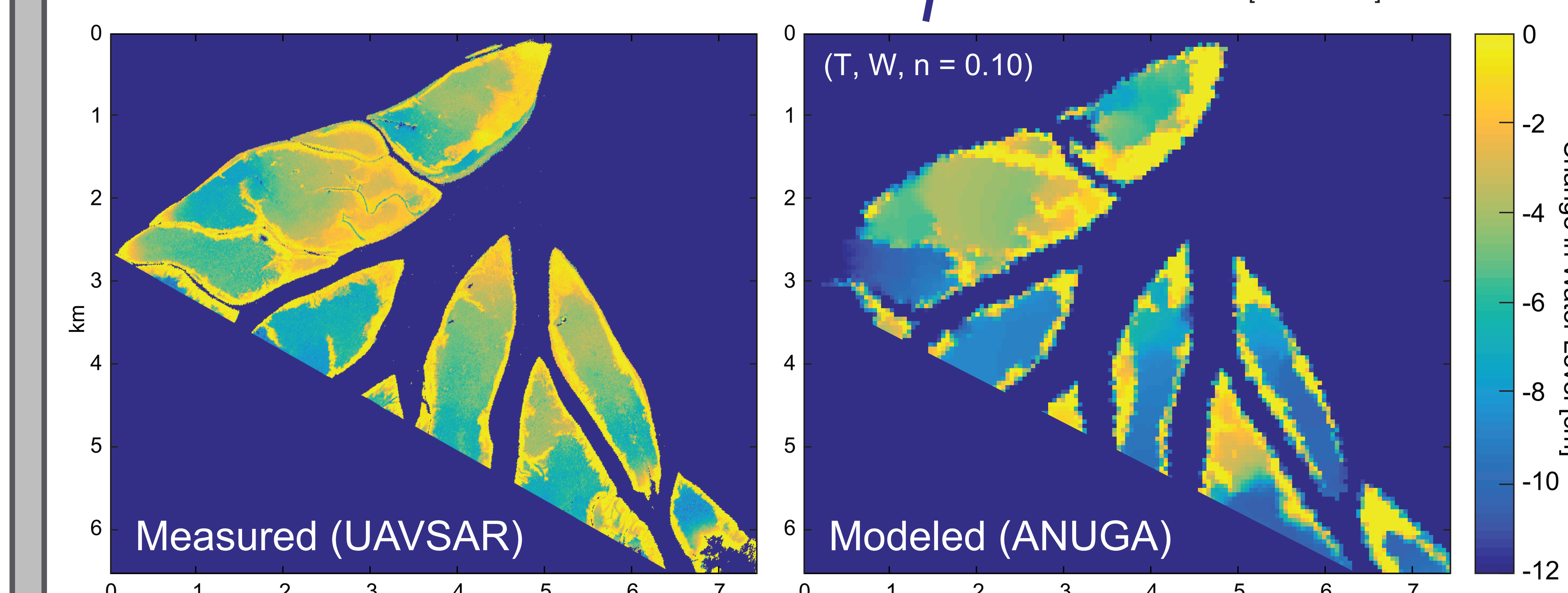
$$\frac{1}{\rho}\tau_{w,i} = \frac{\rho_a}{\rho} C_D u_{w,i}\sqrt{u_{w,1}^2 + u_{w,2}^2}$$



DEM of Wax Lake Delta used for bathymetry[12].

Mesh resolution varies by region for efficiency; highest resolution (~2500m^2) in islands, lowest (1x10^7 m^2 in bay).





(6) Spatial Statistics: Variogram and Entrogram

To quantify connectivity scales in non-channelized wetlands, variogram and entrogram methods were used to measure scale of spatial correlation in the final interferogram (14:08 - 16:37; Top).

The variogram[13] quantifies the mean correlation between two points (x_1,y_1) and (x_2,y_2) separated by a distance h:

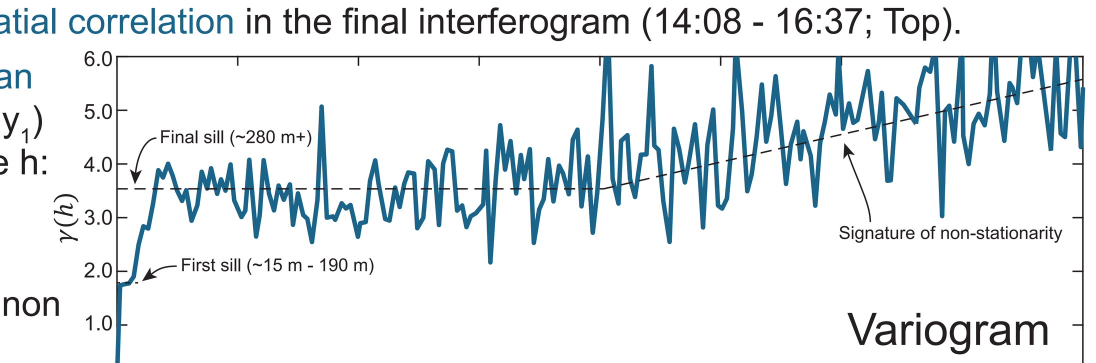
$$\gamma(h) = \frac{1}{2}E\left[\left(z(x_1,y_1) - z(x_2,y_2)\right)^2\right]$$

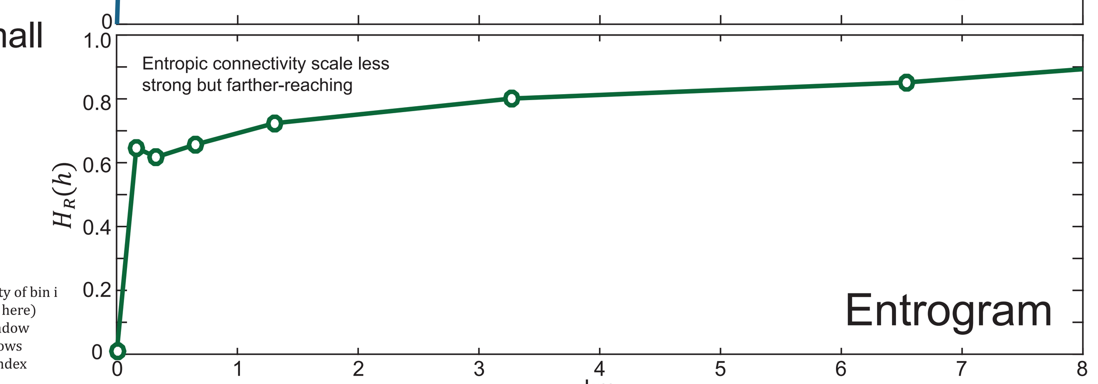
The entrogram[14] is based on Shannon entropy, and compares the mean local entropy (measured over a small window of length h) to the global entropy of the field. High values correspond to greater uncertainty.

$$H_{R,k}(h) = \frac{-\sum_{i=1}^{N} p_{L,i}(h)\ln\left(p_{L,i}(h)\right)}{-\sum_{i=1}^{N} p_{G,i}\ln\left(p_{G,i}\right)}$$

$$H_R(h) = \frac{1}{n_s(h)}\sum_{k=1}^{n_s} H_{R,k}(h)$$

p = marginal probability of bin i
i = index of bin (3 bins here)
k = index of "local" window
n_s = number of k windows
H_R = relative entropy index





(7) Conclusions and Future Work

While this analysis is ongoing, preliminary conclusions include:

(1) Hydrological connectivity is not limited to the downstream areas of the delta. The upstream wetlands also see substantial water exchange with channels over short time scales.

(2) Understanding the signature of tides, wind, and vegetation in the UAVSAR data requires better knowledge of the influence of these processes on coastal systems (which can be aided by SAR).

(3) UAVSAR can become a powerful tool for monitoring coastal systems, but supplemental information on the physical dynamics of the system are essential for intepreting the remotely-sensed data.

Future plans include improving (and expanding) the hydrodynamic model, comparing these results with those of other models, investigating the influence of more complex vegetation distributions, and computing additional spatial information-theory statistics.

Acknowledgements

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