Using Salinity Variance and Total Exchange Flow to Analyze Salinity Structure in an Unsteady Estuary

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I. Background and Motivation

- Understanding salinity structure is important for estuarine management (population dynamics, material transport, etc.)
- Improve the accuracy of salinity prediction in Regional Ocean Modeling System (ROMS)
- ROMS was used to hindcast six years of salinity structure in Copano Bay: A shallow, unsteady estuary
- Quantitatively examine the relationship between salinity structure, river discharge, and exchange flow
- Salinity concentrations range from 5 g kg^{-1} to 40 g kg^{-1} from 2010 to 2016

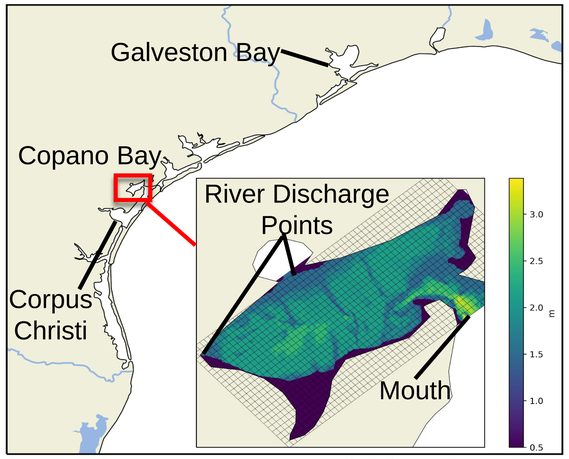

Figure 1: Study site location along the Gulf Coast with model grid and bathymetry

II. Salinity Variance

- Used as a metric for salinity structure
- Tell us spatiotemporal stratification patterns

$$s'^2 = (s - \bar{s})^2$$

- Copano East has twice the salinity variance as Copano West
- High river discharge results in large vertical salinity differences up to 15 g kg^{-1} at boundaries
- Low river discharge results in large lateral salinity differences, explaining the increased variance during the time period

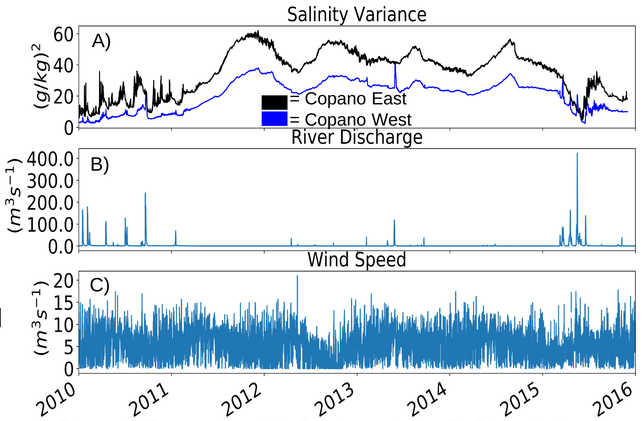

Figure 2: Time series of A) Salinity variance, B) River discharge, and C) wind speed. The black and blue lines represent Copano East and West, respectively. R^2 values for salinity variance, river discharge, and wind were 0.05 and 0.001, respectively.

III. Total Exchange Flow (TEF) and the Salt Balance

- TEF describes the interaction of saltier, ocean water with less salty estuary water
- Expressed in terms of the unsteady Knudsen Relations and volume conservation

$$V\frac{d\bar{s}}{dt} + \bar{s}\left(\frac{dV}{dt}\right) = Q_{in}S_{in} + Q_{out}S_{out}$$

$$\frac{dV}{dt} = Q_{in} + Q_{out} + Q_r$$

- Used to normalize salinity structure and determine unsteadiness

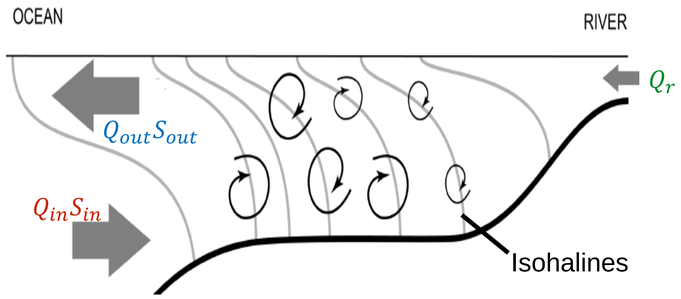

Figure 3: Along-channel cross section of an idealized partially-mixed estuary. $Q_{in}S_{in}$ and $Q_{out}S_{out}$ represent the salt flux at the mouth, and Q_r is the river discharge. Salinity with higher variance enters the estuary at rate Q_{in} and Q_r . Mixing inherently destroys salinity variance. (Macready et al. 2018)

IV. Normalized Salinity Structure

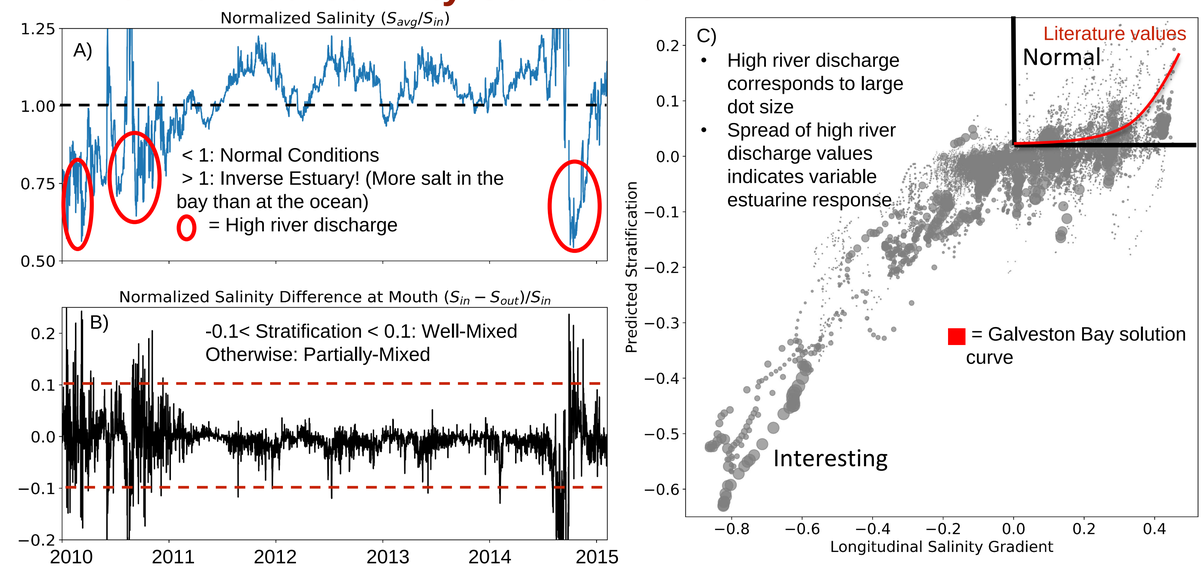

Figure 4: A) Time series of normalized Salinity s_{avg}/s_{in} and B) normalized salinity difference (s_{in} - s_{out}) / s_{in} . C) Comparison of predicted stratification in Copano Bay & Galveston Bay in normalized salinity space

V. Time Scales in Copano Bay

- Estuarine unsteadiness is determined by how long it takes for the system to respond to a small change in forcing
- Normalized salinity response in Copano Bay is >> freshwater response time, opposite of the literature
- Copano Bay likely has the longest adjustment time and Lagrangian residence time in the Gulf of Mexico
- Only 4 other documented estuaries in the world behave like this!

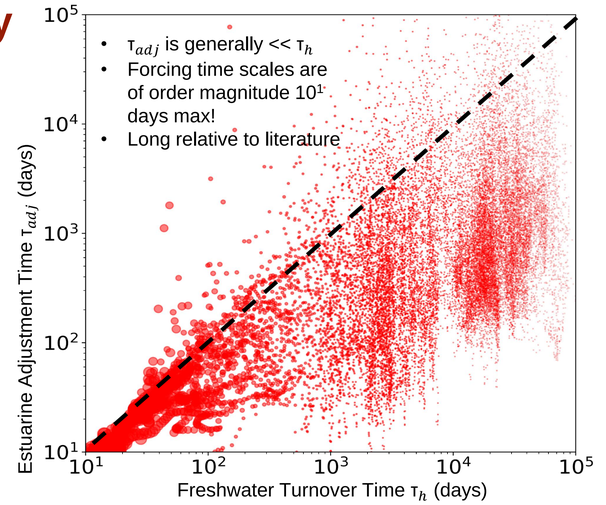

Figure 5: A) Adjustment time τ_{adj} = Normalized salinity * 1/ rate of change of normalized salinity vs hydraulic flushing time $\tau_h = V/Q_R$. Dashed line indicates where $\tau_{adj} = \tau_h$

VI. Conclusions

- High river discharge and the exchange flow are the primary forcing mechanisms in Copano Bay
- Salinity structure inverts during low river discharge periods for several years
- Copano Bay is partially-mixed during high river discharge events and well mixed otherwise
- Long adjustment time scales indicate that Copano Bay is likely the most unsteady estuary in the Gulf of Mexico with the longest Lagrangian residence time