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

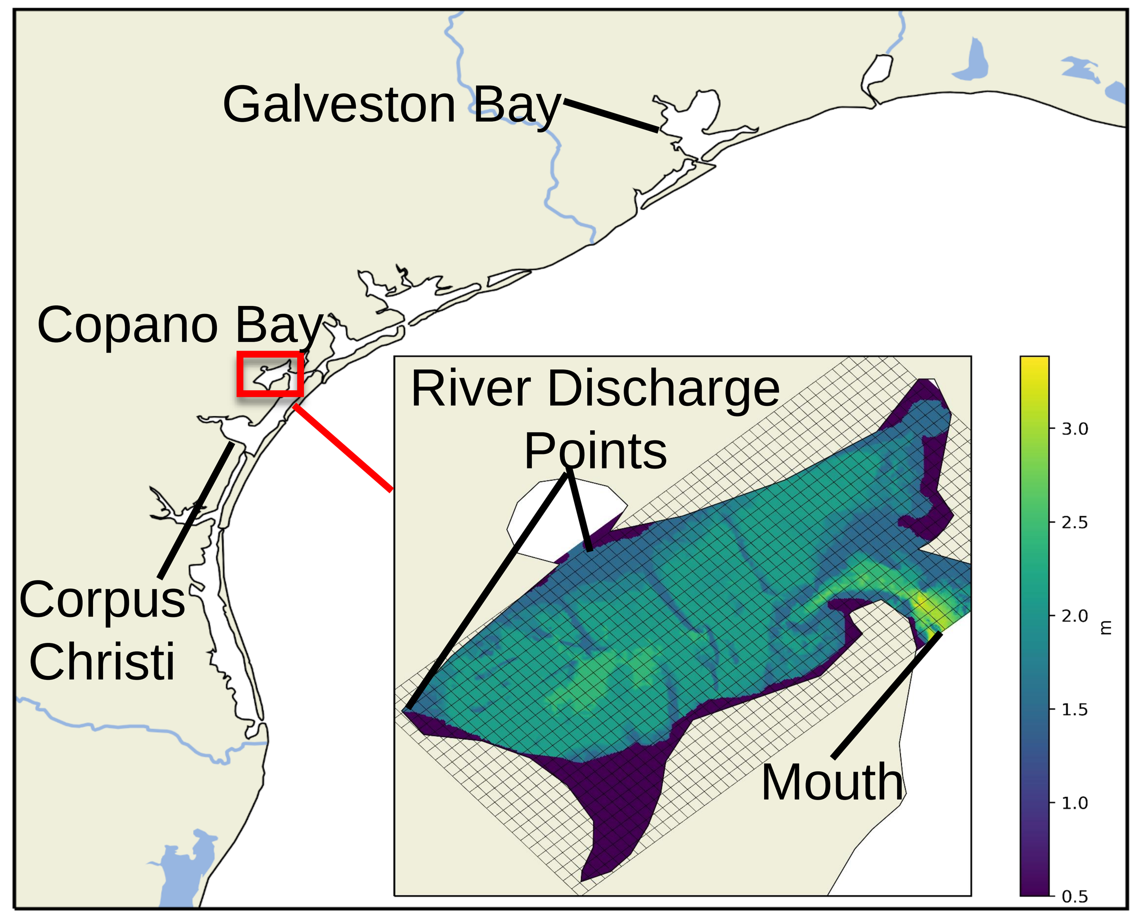

Figure 1: Study site location along the Gulf Coast with model grid and bathymetry

II. Salinity Variance

- 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 gradual increase in variance

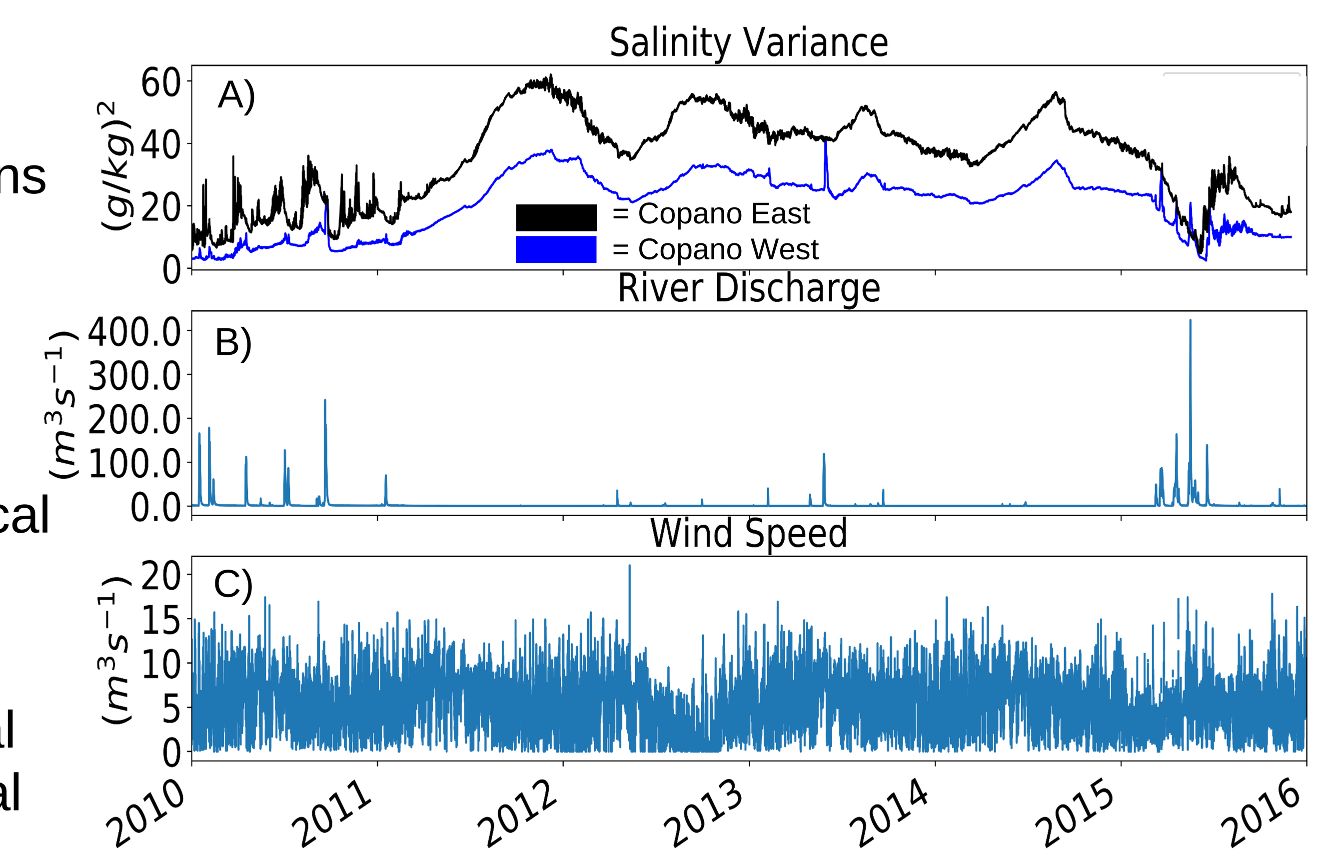

Figure 2: Time series of A) Salinity variance, B) River discharge, and C) Wind speed. The black and blue lines represent Copano East and West, respectively. R^2 values for salinity variance, river discharge, and wind were 0.05 and 0.001, respectively.

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

- TEF describes the interaction of saltier, ocean water with less salty, estuary water
- Expressed via 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

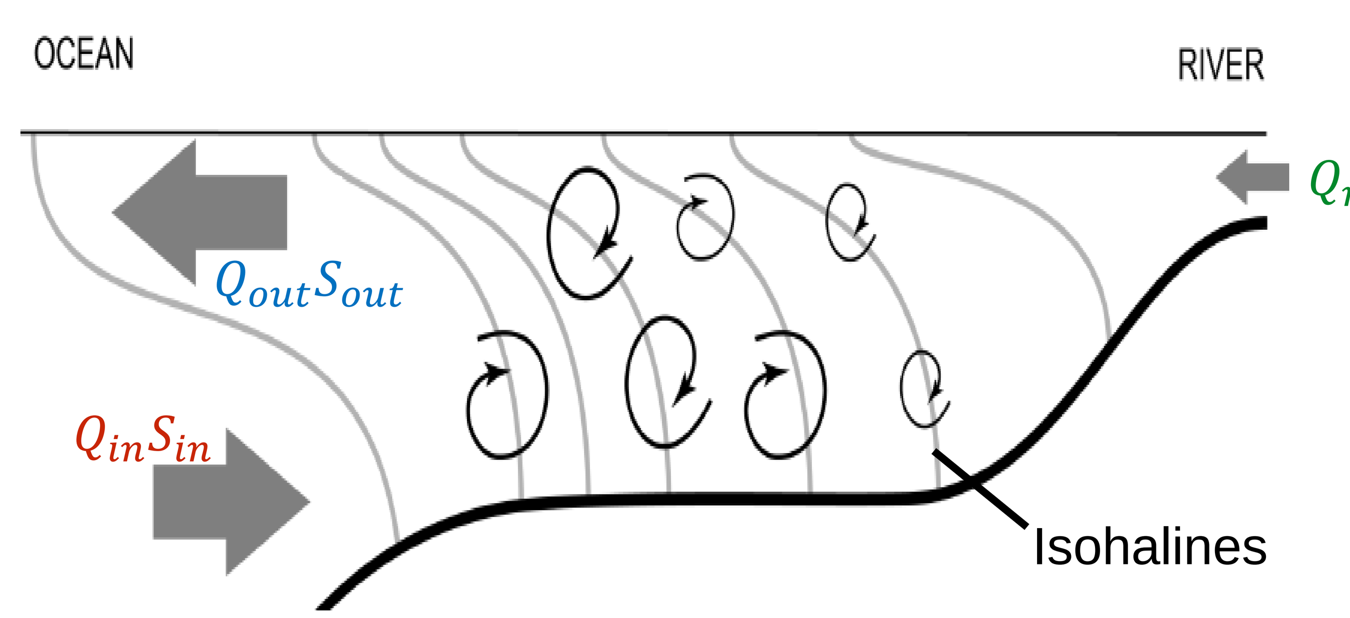

Figure 3: Along-channel cross section of an idealized partially-mixed estuary. $Q_{in}S_{in}$ and $Q_{out}S_{out}$ represent the salt flux at the mouth, and Q_r is the river discharge. Salinity with higher variance enters the estuary at rate Q_{in} and Q_r. Mixing inherently destroys salinity variance.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

IV. Normalized Salinity Structure

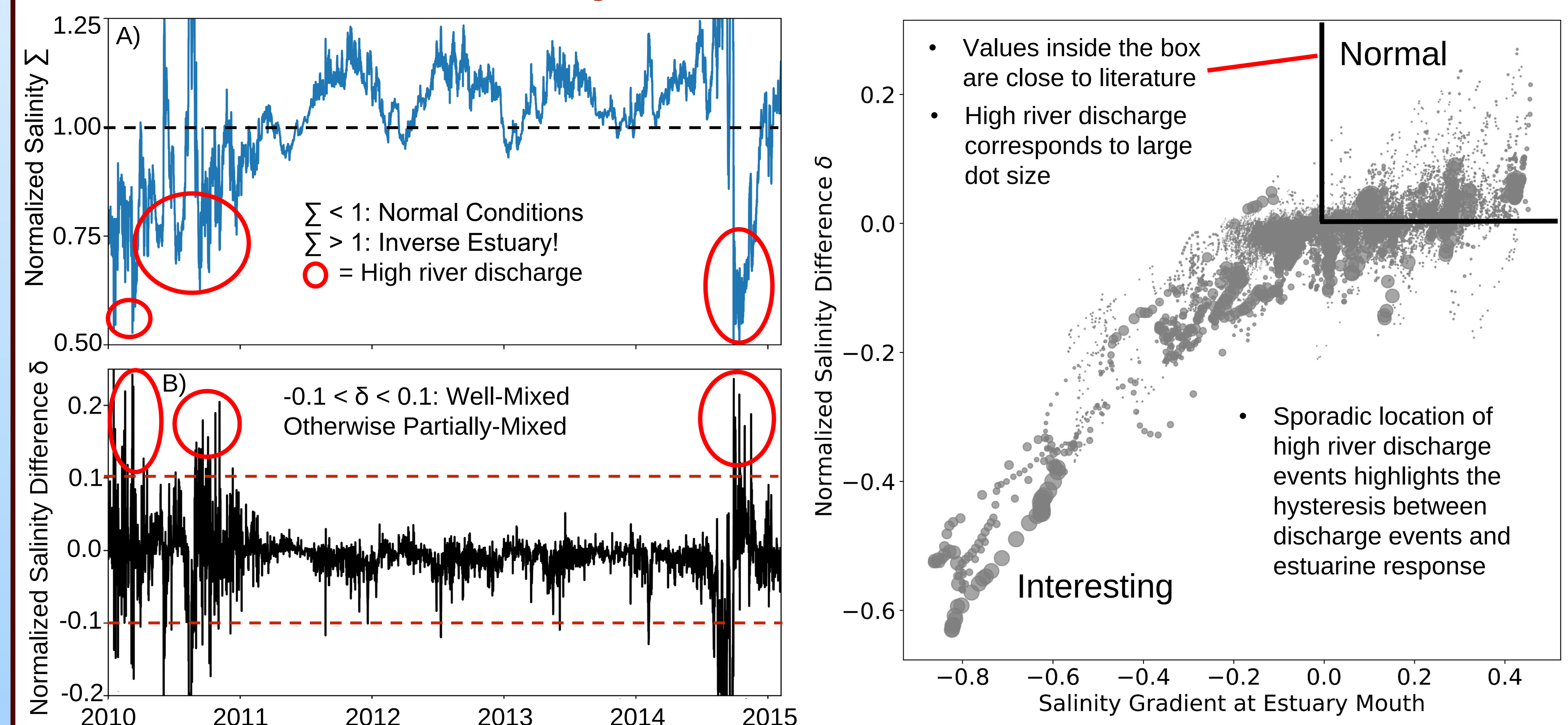

Figure 4: A) Time series of normalized Salinity $\sum = \bar{s}/s_{in}$ and B) normalized salinity difference $\delta = (s_{in} - s_{out}) / s_{in}$. C) δ vs salinity gradient at the mouth $1 - \sum$. Note that time series length is shortened because of filtering applied through the TEF technique .

V. Time Scales in Copano Bay

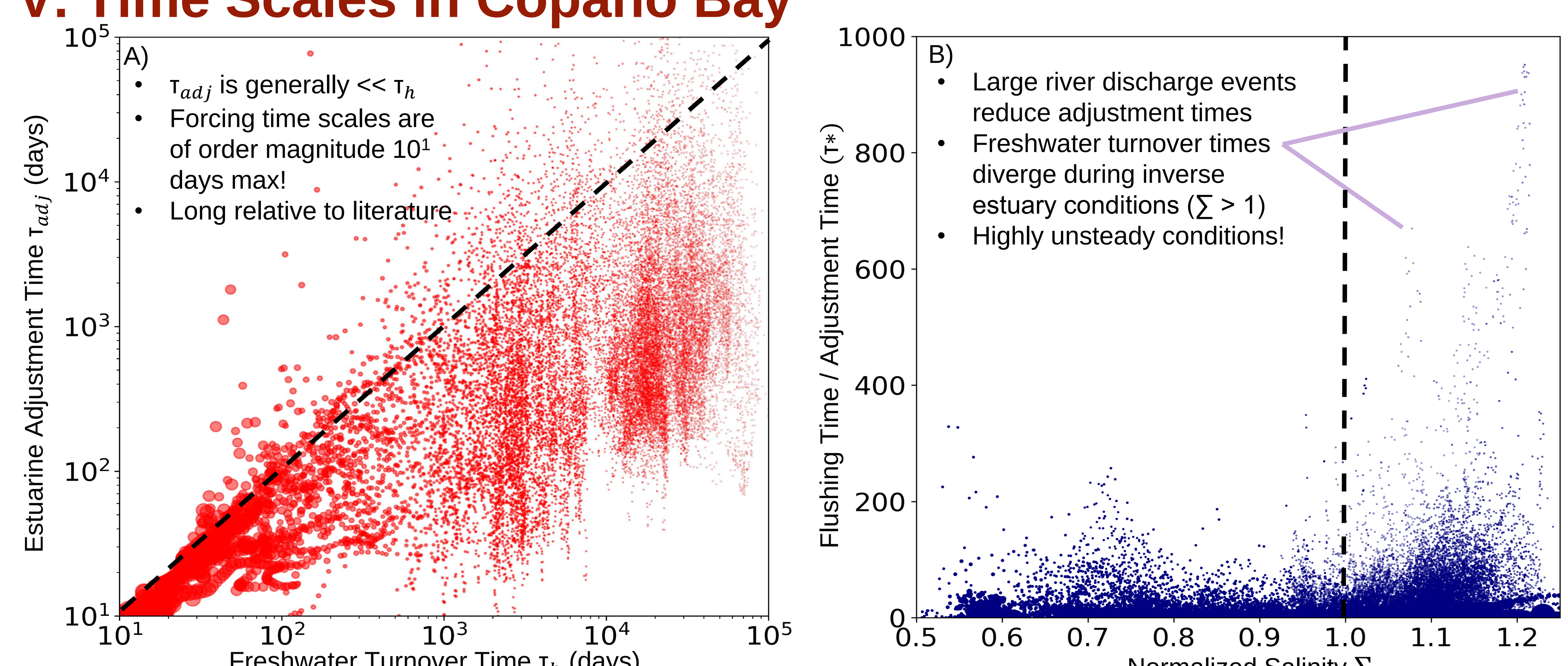

Figure 5: A) Adjustment time $\tau_{adj} = \sum \frac{d\Sigma}{dt}^{-1}$ vs hydraulic flushing time $\tau_h = V/Q_R$. Dashed line indicates where $\tau_{adj} = \tau_h$ B) Estuarine speedup factor $\tau_* = \tau_h / \tau_{adj}$ in normalized salinity space. Dashed line indicates inverse estuary condition

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, departing from values shown in the literature
- Copano Bay is partially-mixed following high river discharge events and well mixed otherwise
- Long adjustment time scales indicate that Copano Bay is highly unsteady