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.)
- 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
- High river discharge results in large vertical salinity differences up to 15 g kg^{-1} at boundaries
- Normalize salinity structure using total exchange flow

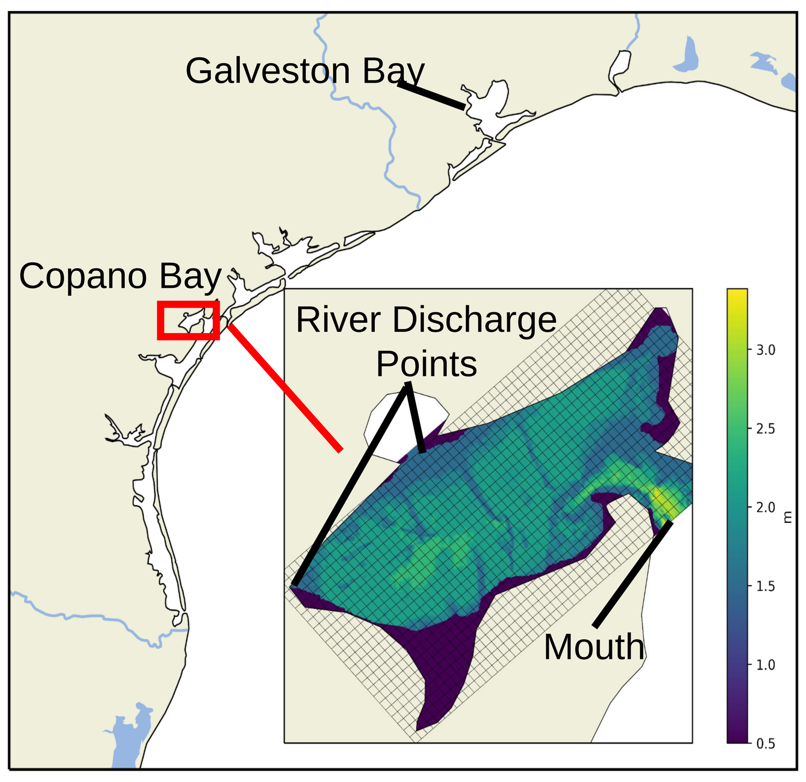
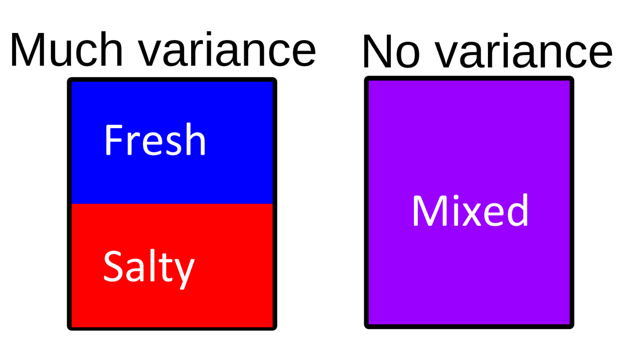


Figure 1: Study site location along the Gulf Coast with model grid and bathymetry

II. Salinity Variance

$$s'^2 = \left(s - \frac{1}{V}\int_V s\,dV\right)^2$$



- Used as a metric for salinity structure
- Copano East has twice the salinity variance as Copano West

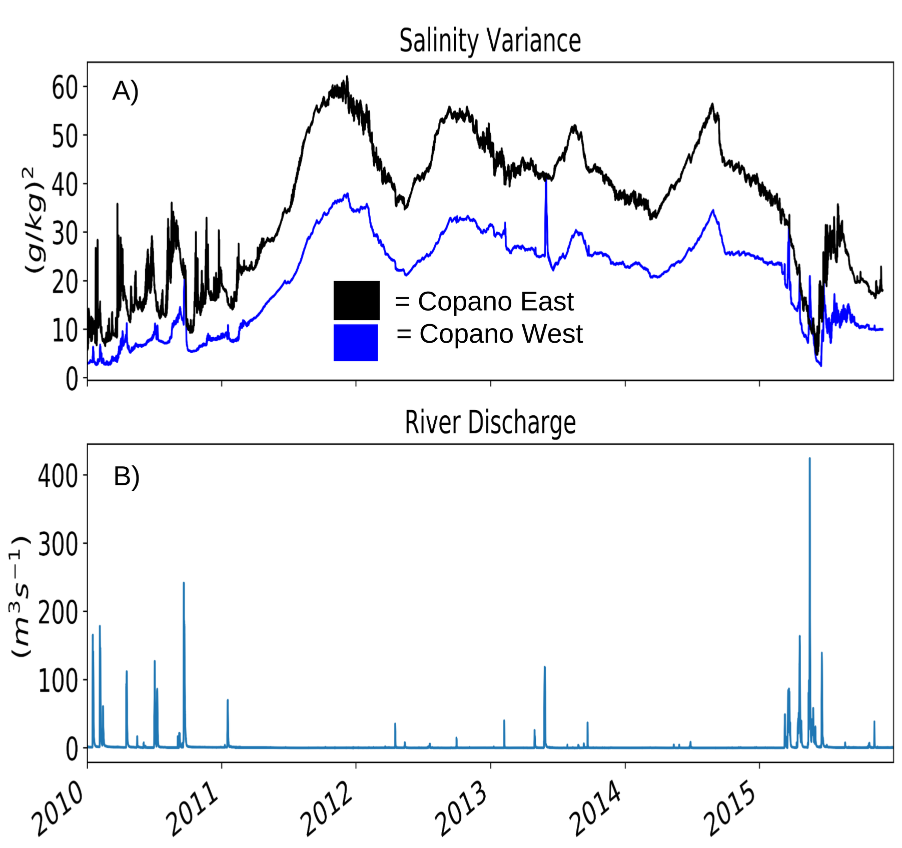


Figure 2: Time series of A) Salinity variance, B) River discharge. The black and blue lines represent Copano East and West, respectively. Variance climbs during low river discharge due to development of large lateral salinity differences.

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

- TEF describes the interaction of saltier, ocean water with less salty, estuary water
- Determine salt flux across an isohaline
- Used to normalize the salinity structure and compare to other estuaries

$$V\frac{d\bar{s}}{dt} + \frac{1}{V}\int_V s\,dV * \left(\frac{dV}{dt}\right) = Q_{in}S_{in} + Q_{out}S_{out}$$

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

- The changes in salinity and volume are balanced out by salt flux at the mouth and the river discharge

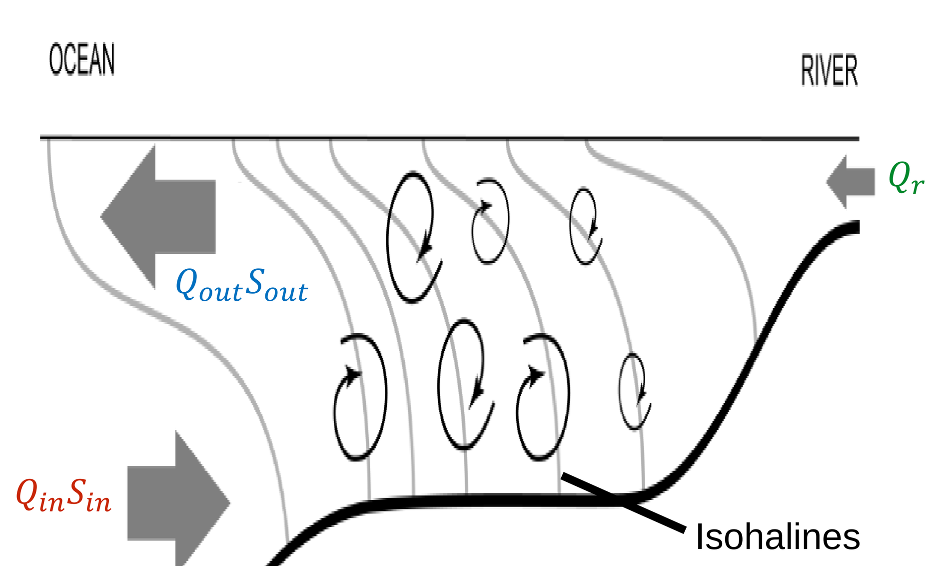


Figure 3: Along-channel cross section of an idealized partially-mixed estuary. $Q_{in}S_{in}$ and $Q_{out}S_{out}$ represent the salt flux at the mouth, and Q_r is the river discharge. Salinity with higher variance enters the estuary at rate Q_{in} and Q_r . Mixing inherently destroys salinity variance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

IV. Normalized Salinity and Stratification

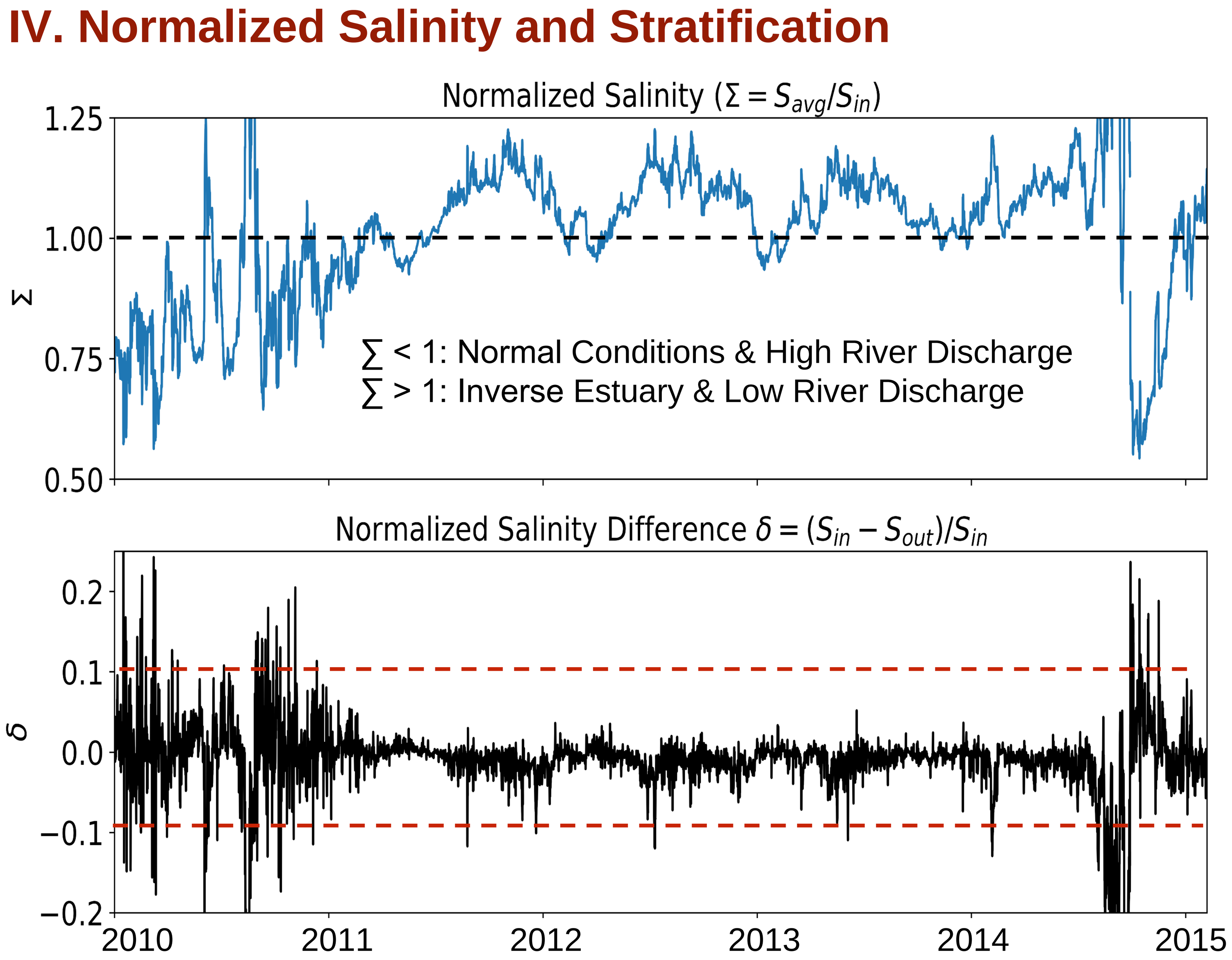


Figure 4: Time series of A) Normalized salinity and B) Normalized stratification. Both quantities were determined using the results from the Total Exchange Flow

V. Comparison to Other Estuaries

- High river discharge corresponds to large dot size
- Red line is the solution of Rayson et al. 2017 for Galveston Bay

$$\delta = (1 - \Sigma)^2$$

- Values inside the box are close to literature for unsteady estuaries
- Not even close to Galveston Bay!
- This pattern is a combination of model error, and a lack of forcing that happens within the estuary

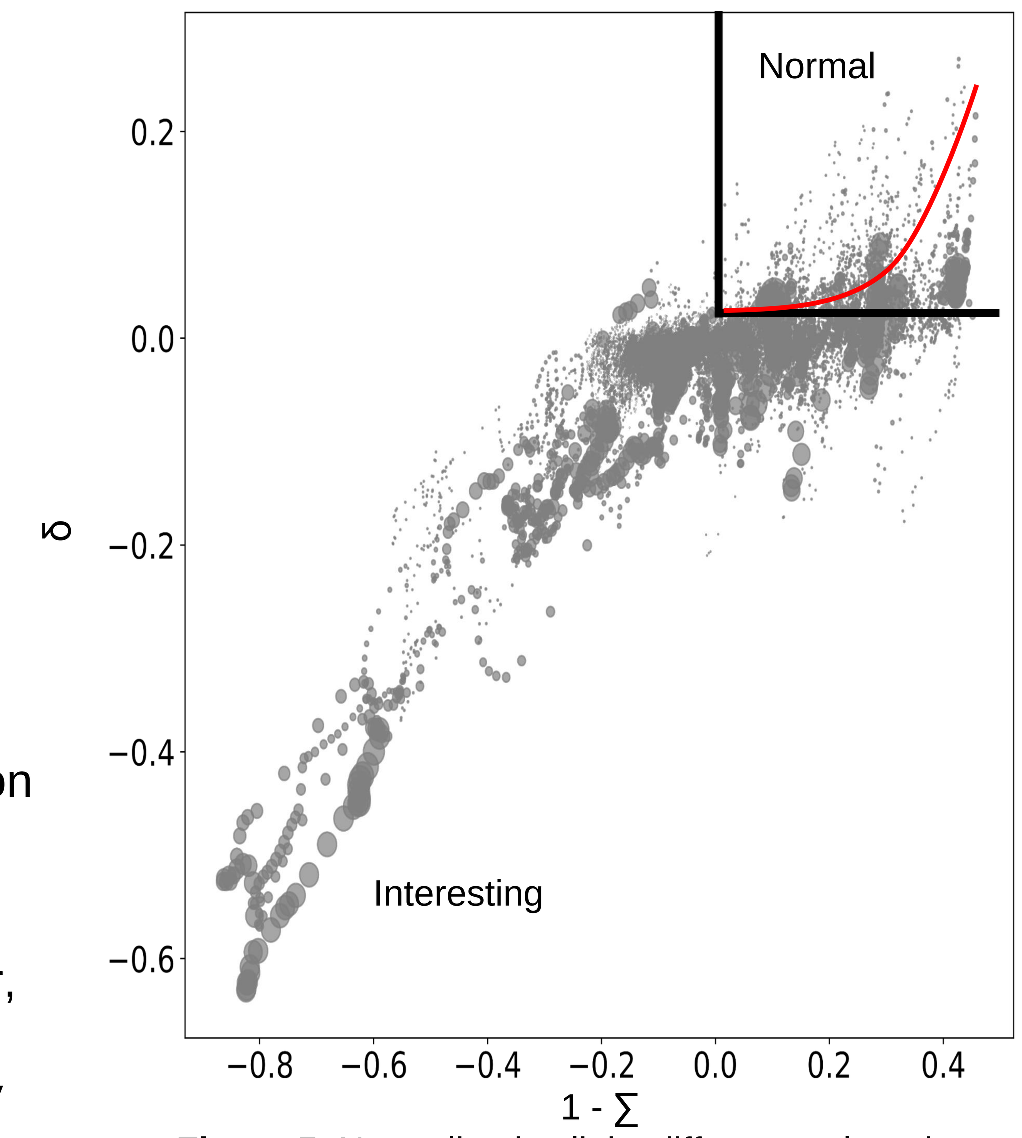


Figure 5: Normalized salinity difference plotted against the longitudinal salinity gradient

VI. Time Scales in Copano Bay

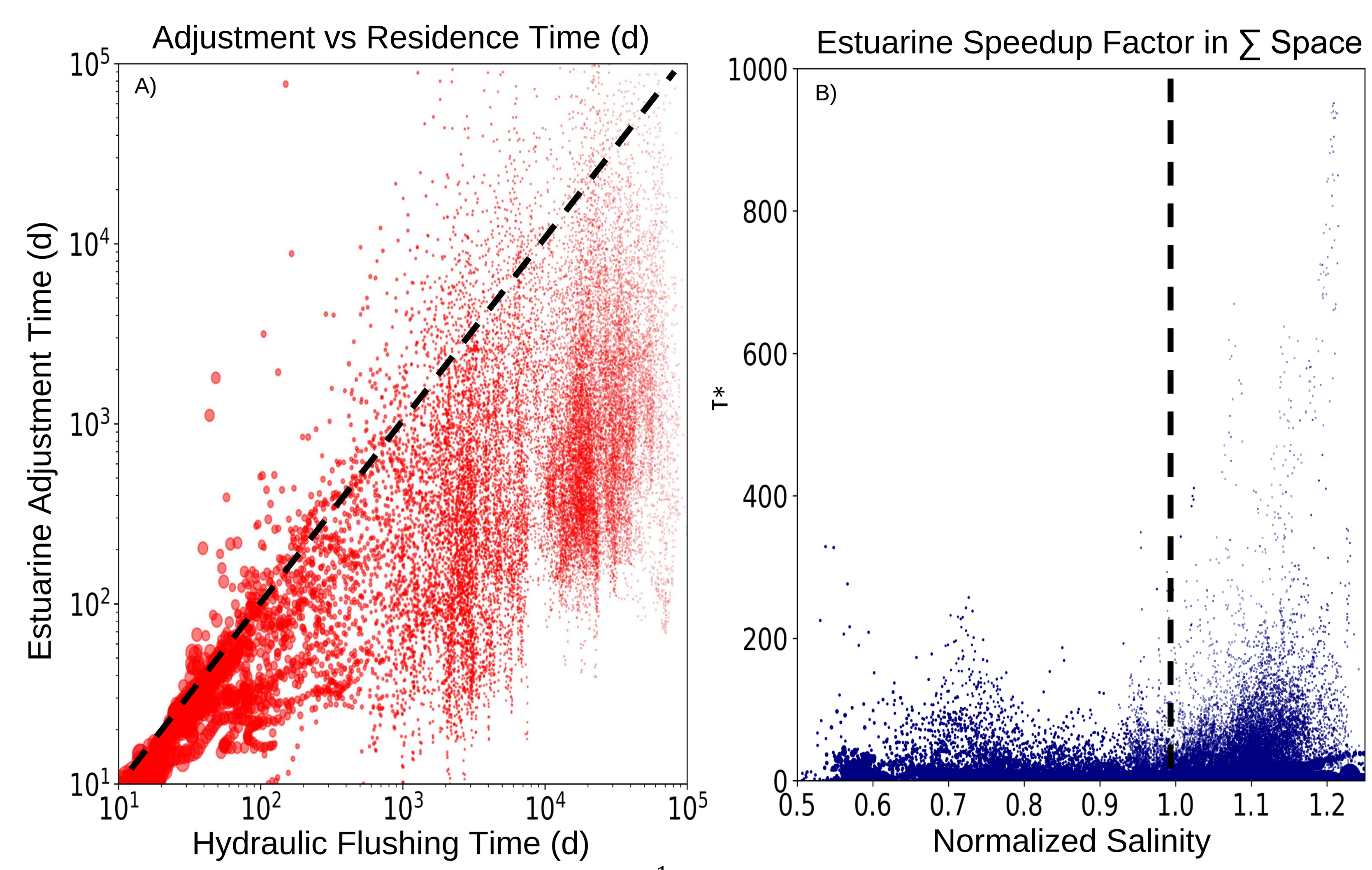


Figure 6: A) Adjustment time $\tau_{adj} = \sum \frac{d\Sigma}{dt}^{-1}$ vs hydraulic flushing time $\tau_h = V/Q_R$. Dashed line indicates where $\tau_{adj} = \tau_h$ B) Estuarine speedup factor $\tau_* = \tau_h / \tau_{adj}$ in normalized salinity space. Dashed line indicates inverse estuary condition.

VII. Discussion: Model Error

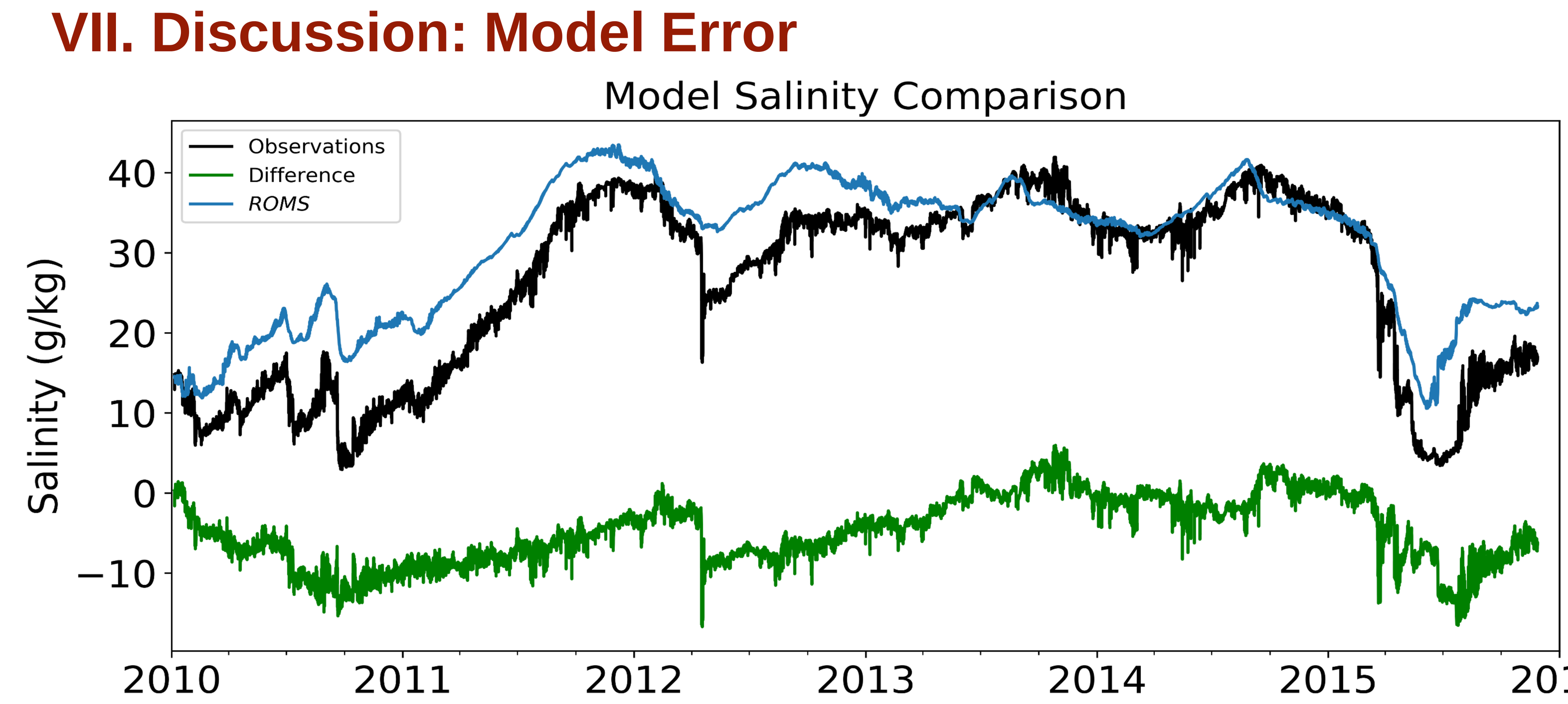


Figure 7: Comparison of modeled salinity vs moored salinity data and the difference between the two. Moored salinity data was obtained by averaging Copano East and Copano West data stations.

- Overestimation of salinity contributes to patterns displayed in Figure 4, but to an unknown extent
- Calculation of the unsteadiness parameter confirms that Copano Bay behaves as an unsteady estuary
- What are the possible causes for the behavior seen in Copano Bay?

VIII. Conclusions

- High river discharge and the exchange flow are the primary forcing mechanisms in Copano Bay
- Normalized salinity patterns depart from the literature of other broad, shallow, unsteady estuaries
- Long adjustment time scales indicate that Copano Bay is highly unsteady

IX. Acknowledgements

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