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Pronounced impact of salinity on rapidly intensifying tropical cyclones

24th PIRATA/TAV Meeting

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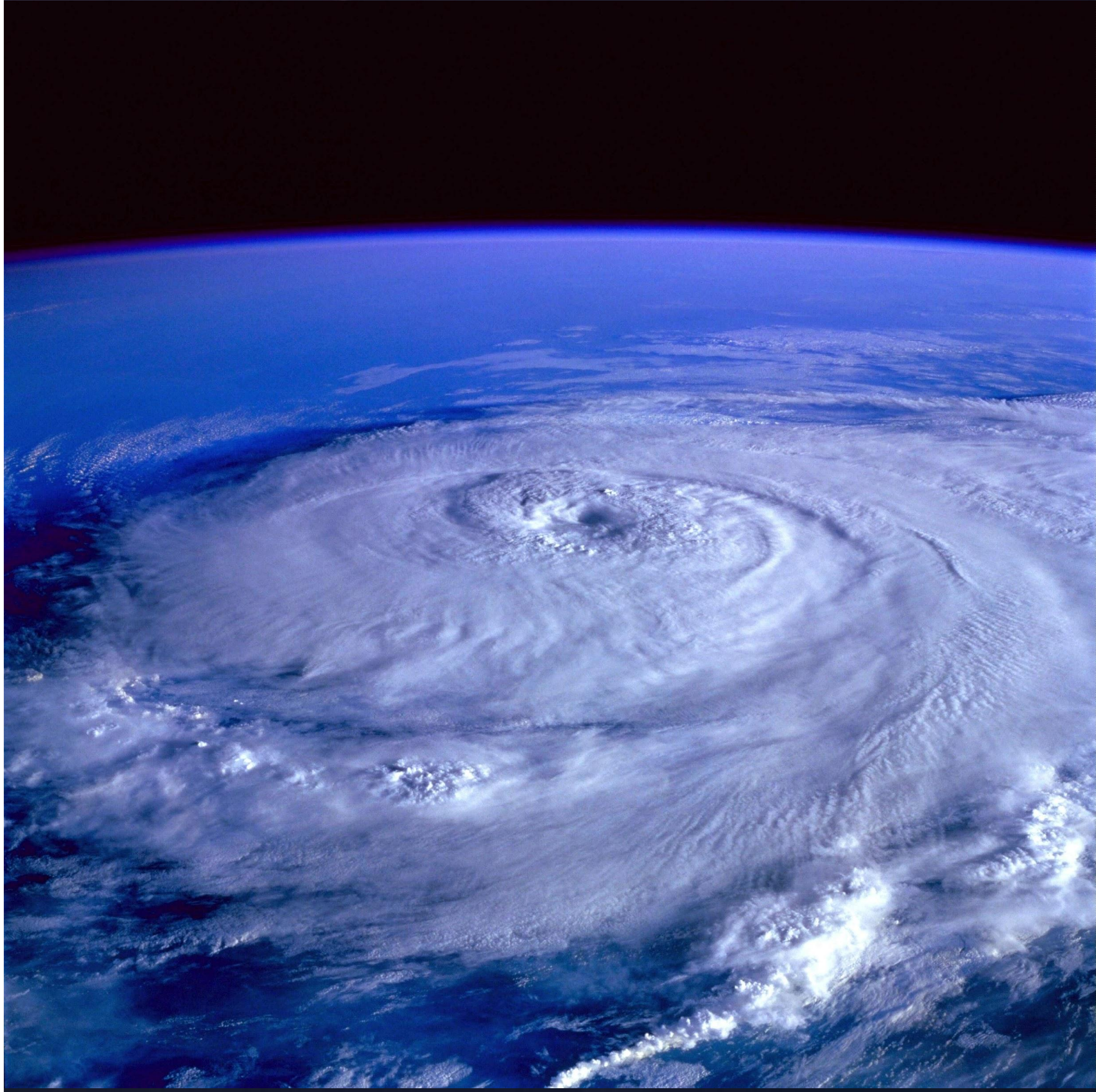
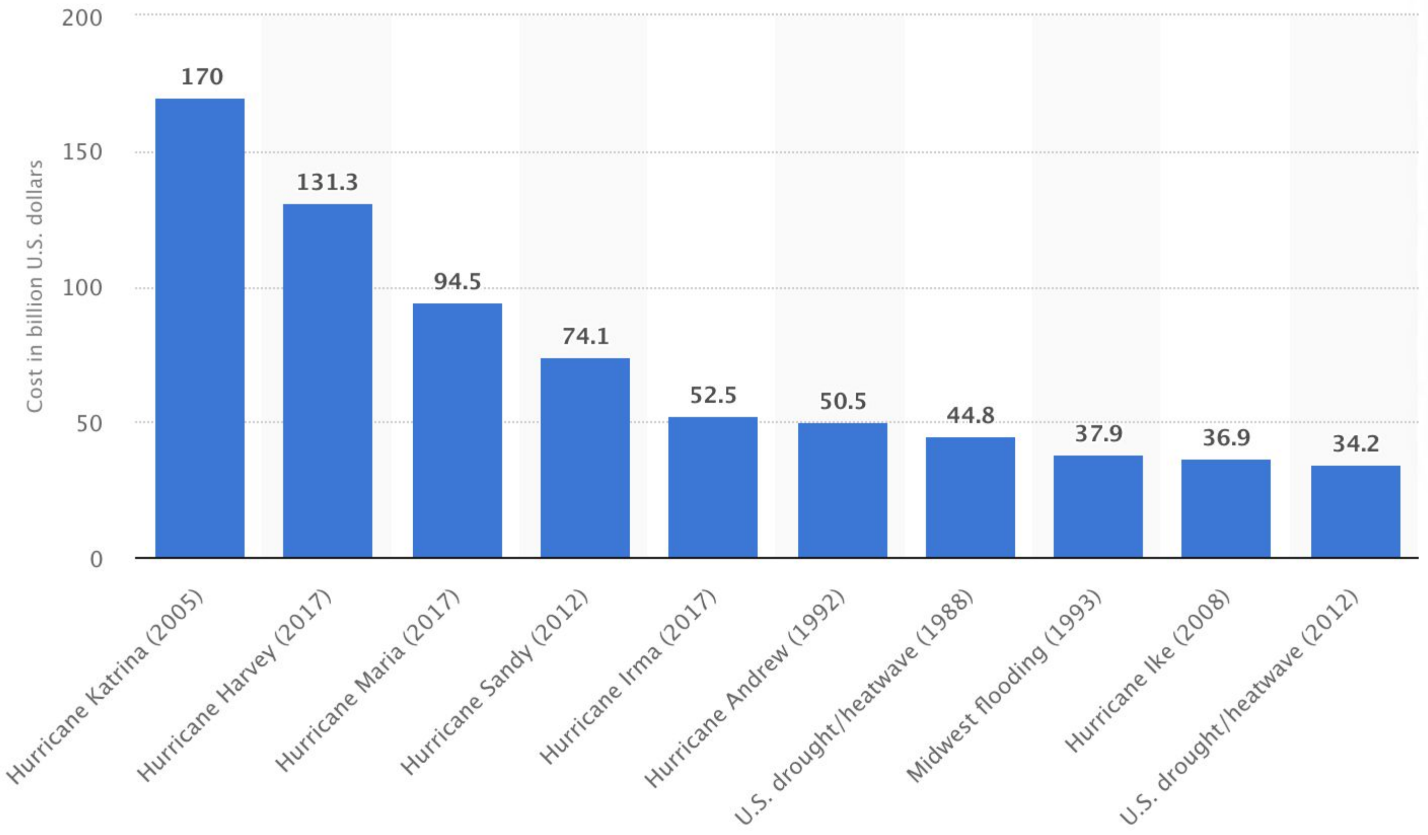


The problem of Rapid Intensification

- To date, they are the deadliest (Galveston Hurricane – 1900) and costliest (Hurricane Katrina – 2005) natural disasters in US history.
- Track forecasts have improved over time, intensity forecast improvements have been modest.
- The problem is particularly severe in the case of Rapid Intensification (RI)

Costliest natural disasters in the US



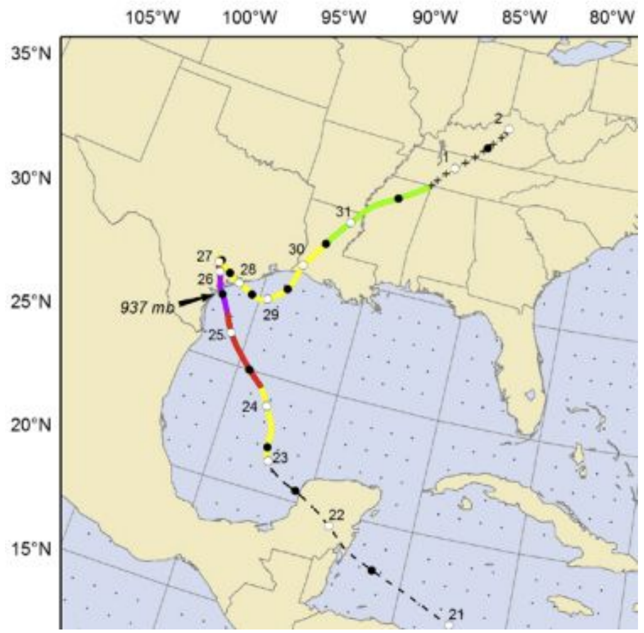
Source: statista

Top 5, 7 in top 10 are hurricanes

Definition and significance of RI

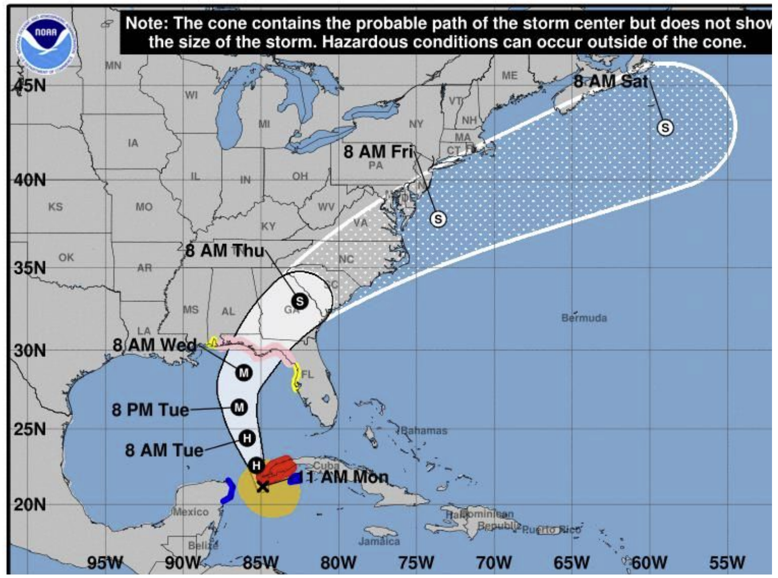
- Maximum sustained surface wind **increase of 30 kt over a 24-hr period (Kaplan and DeMaria, 2003)**.
- 95th percentile of over-water 24-hr intensity changes.
- Probability of RI:

- 31% of all TCs
- 60% of hurricanes
- 83% of major hurricanes
- **100%** of cat. 4-5 hurricanes



Source: NHC

Hurricane Harvey (2017)



Source: NHC

Hurricane Michael (2018)

SHIPS-RII (Kaplan et al. 2015), an important tool for RI prediction

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Ocean

- Maximum potential intensity minus maximum surface wind speed
- Ocean heat content
- Intensity change during previous 12 hours
- 850-200 hPa vertical wind shear
- 200 hPa divergence
- Spatial pattern of convection (based on satellite IR imagery)
- Total precipitable water (from satellite)
- Inner-core dry air predictor
- Std. dev. of cloud-top brightness temperature (from satellite)

Atmosphere

No salinity-based predictor !

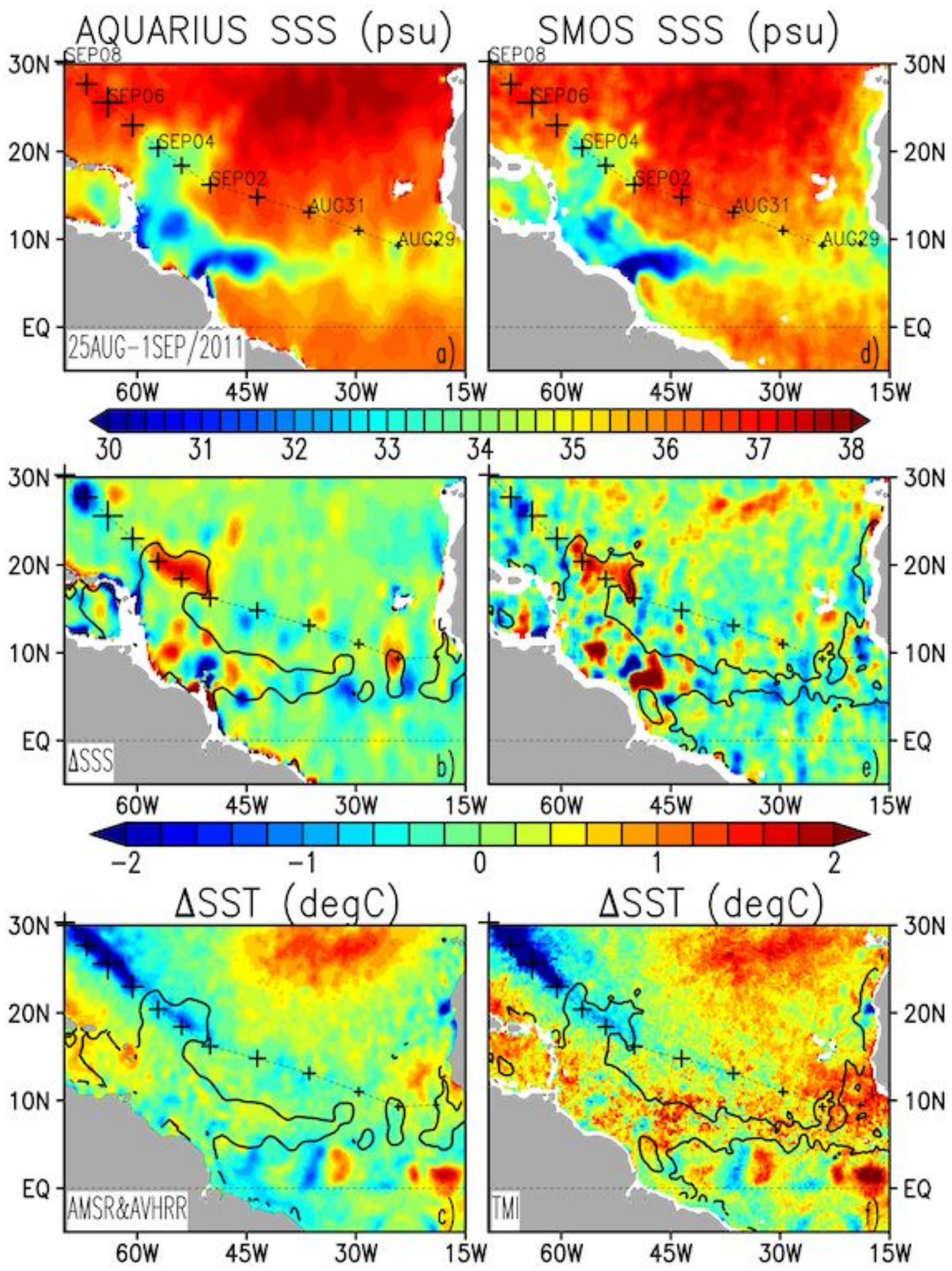
The role of salinity in RI

- But previous work suggests that salinity could significantly affect TC intensity (Balaguru et al., 2012, 2016; Grodsky et al., 2012; Reul et al., 2014).

- **Does salinity play a role in RI?**

- **Can the use of salinity improve RI prediction?**

Over Amazon-Orinoco plume: **Large increase in SSS, small decrease in SST**

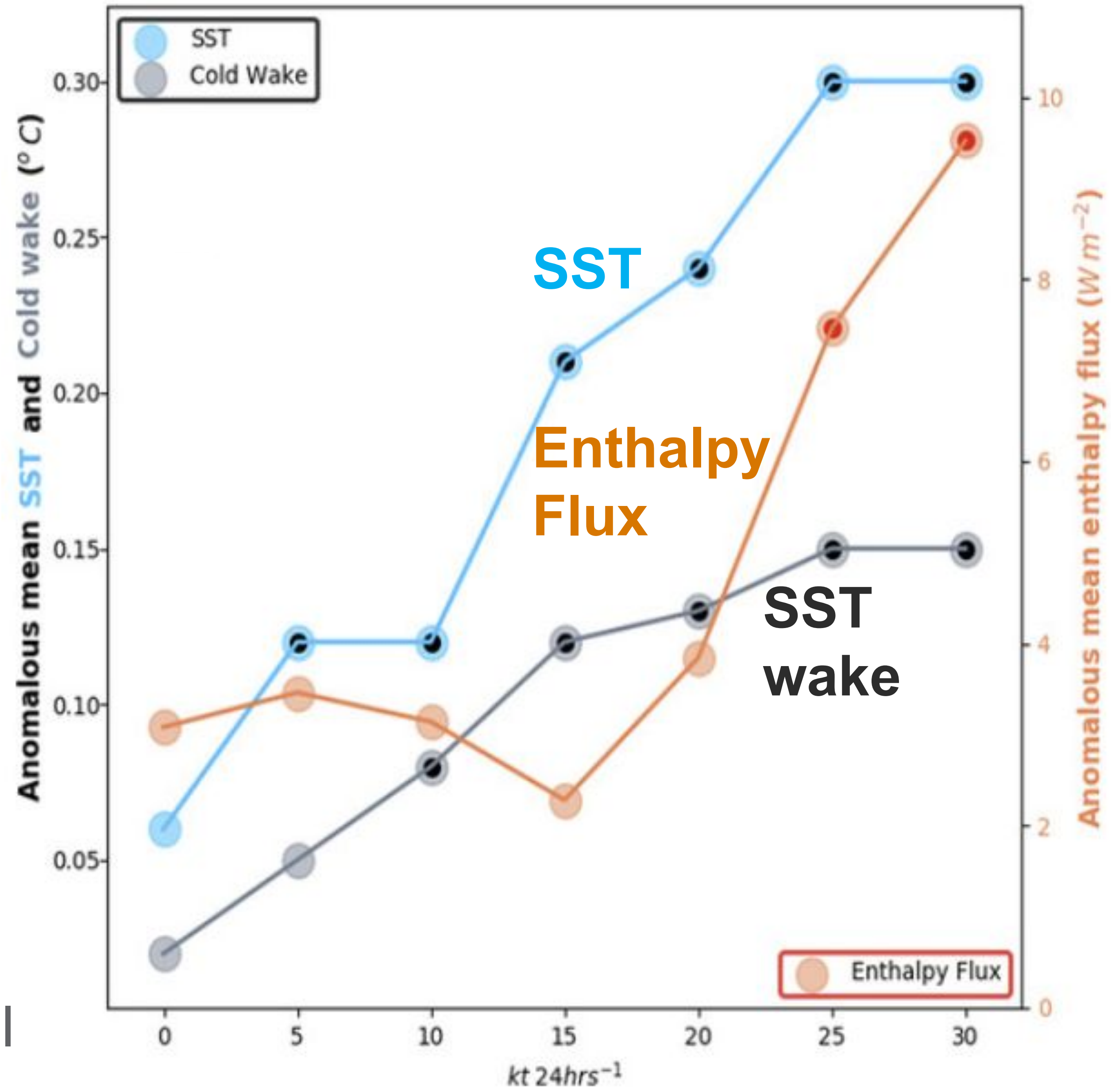


Source: Grodsky et al., 2012

Dependence of TC intensification on ocean stratification

Microwave SST, OAFlux enthalpy flux

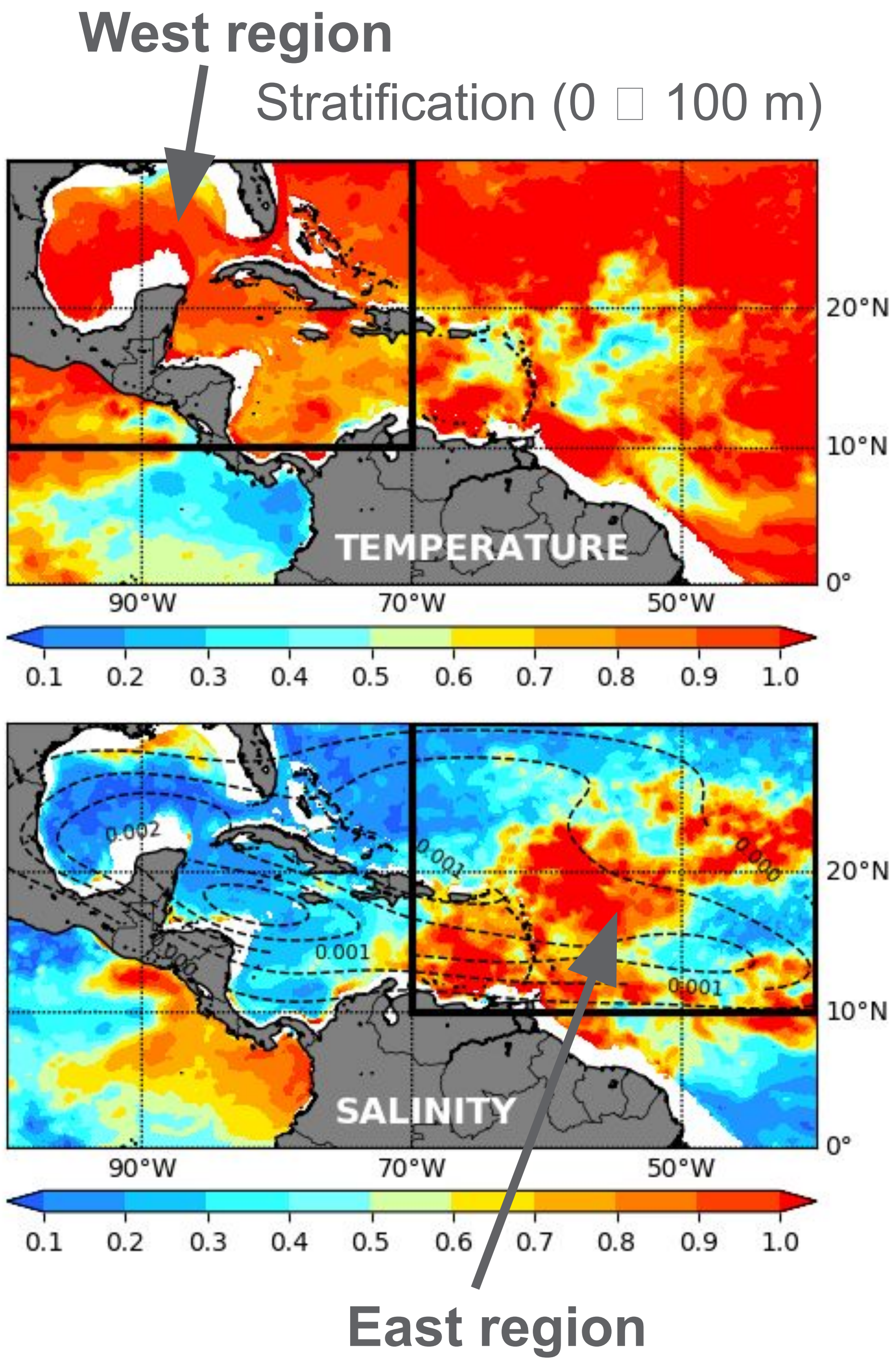
- SST is nearly always important.
- Interestingly, cold wake magnitude decreases with intensification rate.
- Enthalpy flux not important for weaker intensification, significant for RI. Highlights the crucial role of ocean stratification for RI.



Anomalous mean: Mean value for certain subset of conditions (e.g., RI) minus the mean value for all conditions (e.g., all intensification rates).

Relative significance of temperature and salinity

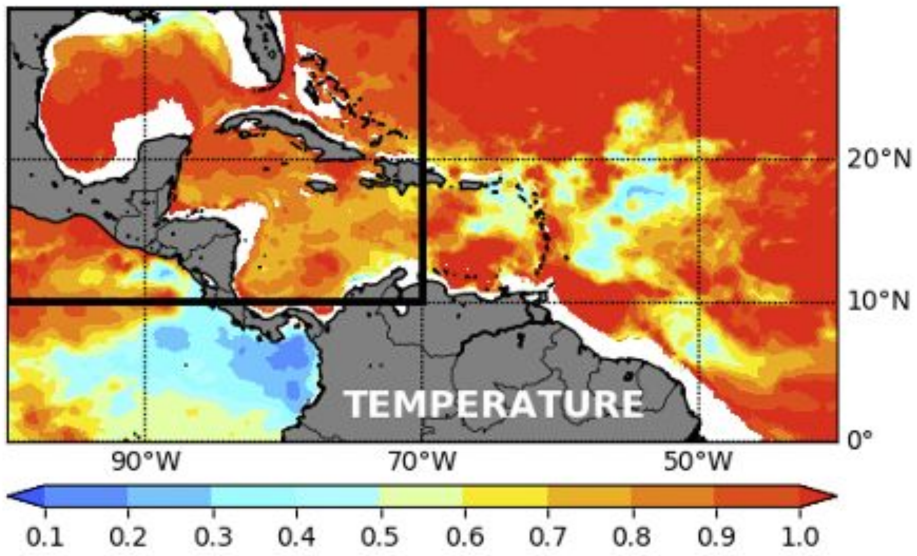
- **Temperature contribution**: Regression coeff. between $(T_z - \langle T_z \rangle)/std(T_z)$ and $(rho_z - \langle rho_z \rangle)/std(rho_z)$
- **Salinity contribution**



- Daily HYCOM data, 2004-2015

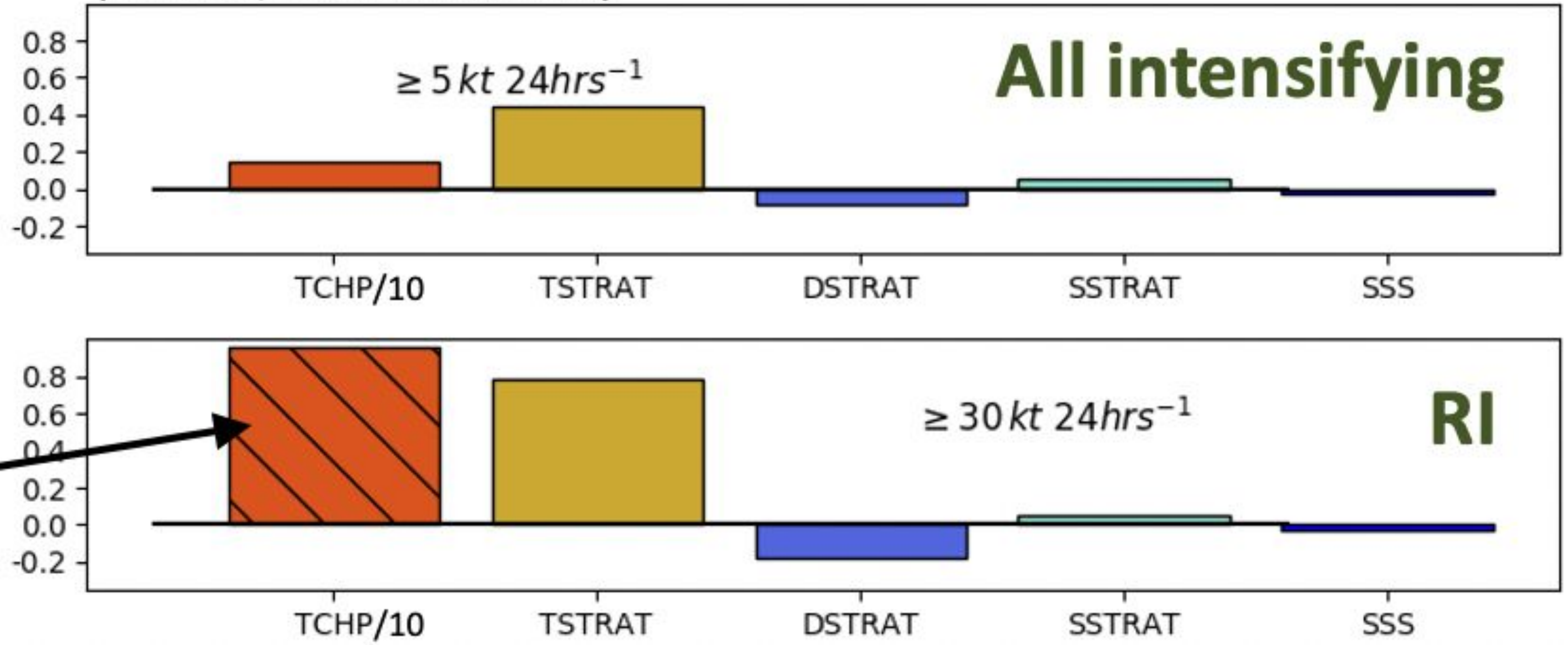
Western region

- **Ocean temp. important for RI**, salinity is not



Warm upper-ocean features such as the Loop Current and associated eddies promote RI.

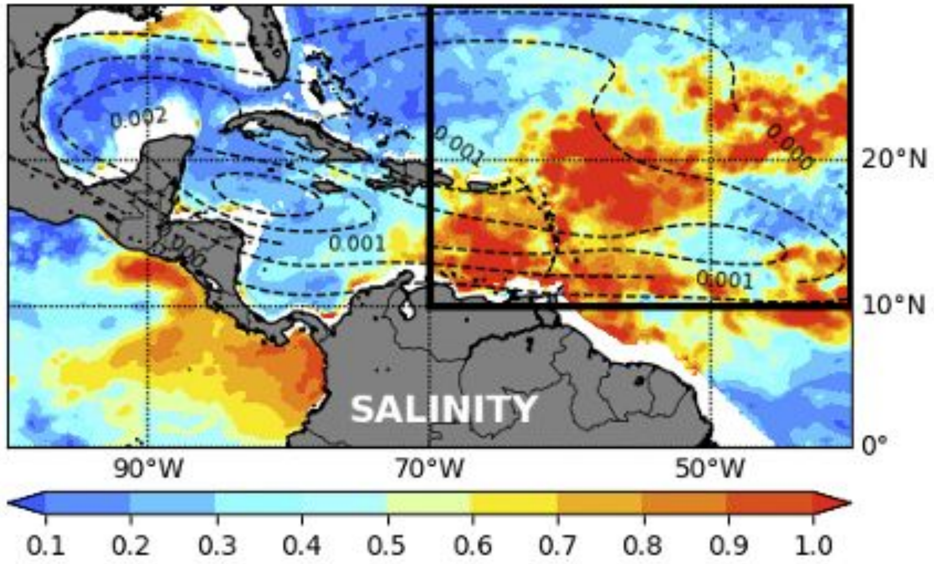
Anomalous means
(HURDAT, HYCOM: 2004-15)



Significant at 95%

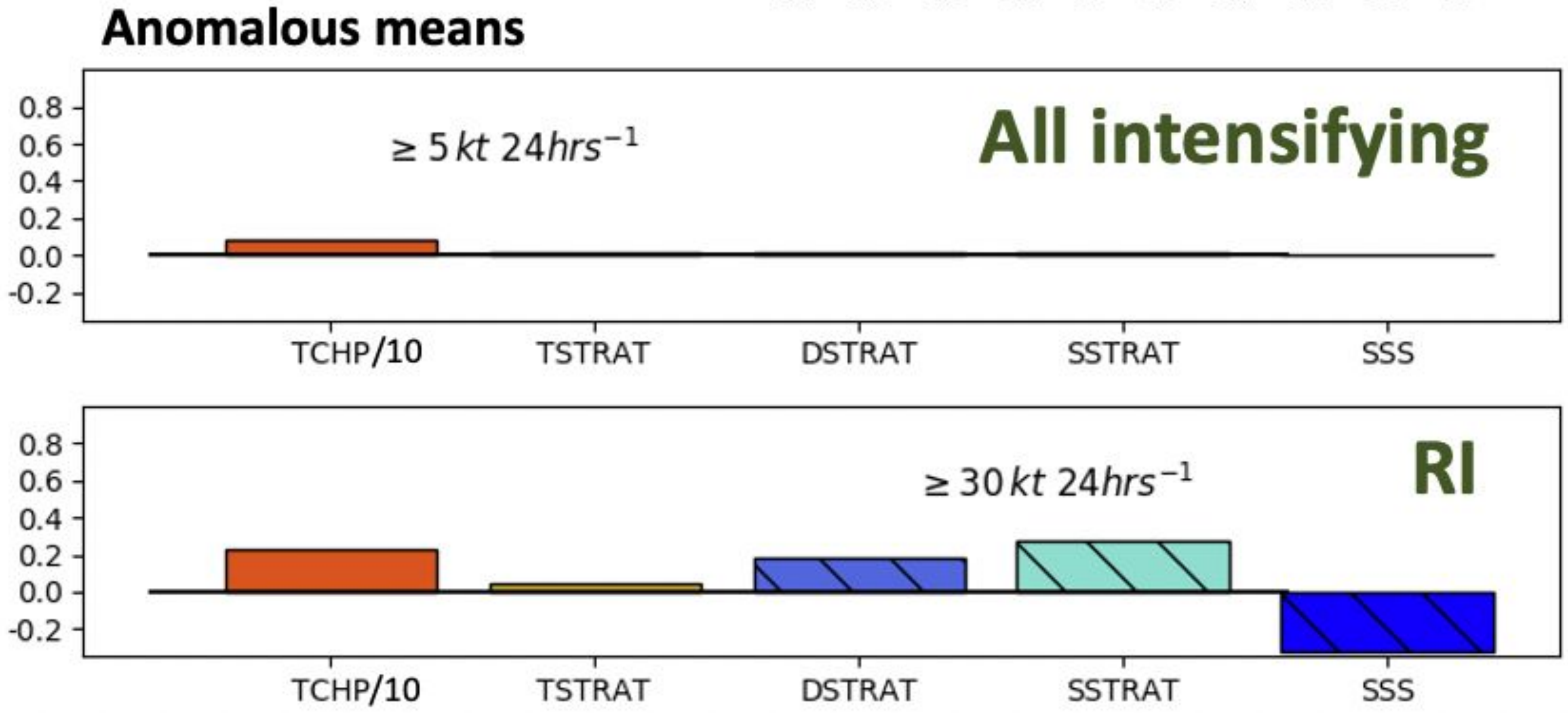
Eastern region

- **Ocean salinity important for RI**, temp. is not



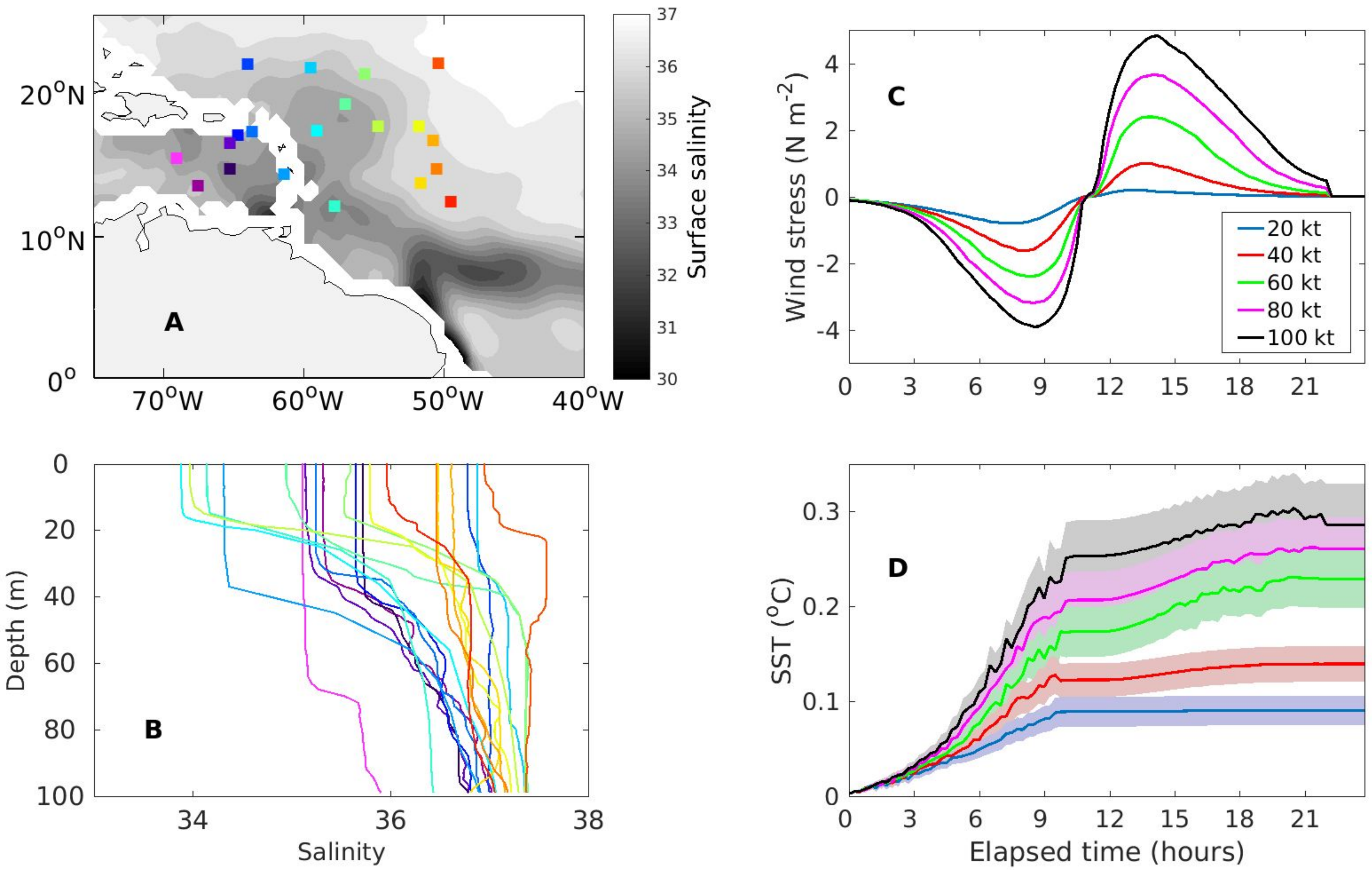
Salinity stratification, enhanced by the Amazon-Orinoco River system, favors RI.

Similar results are obtained using SODA3, an eddy-permitting ocean reanalysis.



Numerical experiments with the 1D PWP model

- Model was initialized with varying initial conditions in the eastern region with profiles from Argo.
- Model forced with idealized TC winds representing different rates of intensification.
- Simulations were performed with and without salinity.
- Results consistent with observational analysis.



Using salinity for RI prediction

- To test the value of salinity for RI prediction, we employed Logistic regression or Binary Classification.
- Model was trained with predictors from SHIPS-RII on training data (55-65% of the data set) and predictions made on test data.
- Salinity was added as an additional predictor to see its effect on model performance.
- Results indicate that the use of salinity may improve RI prediction in the eastern region.

	POD	FAR	AUROC	BS
SHIPS-RII	0.35	0.89	0.58	0.19
SHIPS-RII + SSS (HYCOM)	**0.44**	**0.85**	**0.62**	0.18
SHIPS-RII	0.53	0.77	0.70	0.18
SHIPS-RII + SSS (SMOS)	**0.58**	**0.74**	0.71	**0.17**

POD: Probability of Detection

FAR: False Alarm Ratio

AUROC: Area Under the Receiver Operating Characteristic

BS: Brier Score

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Summary and conclusions

- In the western Atlantic and eastern Caribbean, **SSS is significantly lower and salinity stratification significantly higher for TCs that undergo RI** compared to those that do not.

- We think there are two main reasons for this:
  - **Enthalpy flux (energy transfer to the storm) is more sensitive to SST as TC intensity increases**, so TC-induced SST cooling can be important.
  - **Intensifying TCs cause more vigorous mixing** so that subsurface ocean conditions have a bigger impact on TC-induced SST cooling.

- **Inclusion of SSS in SHIPS-RII may improve prediction of RI** events in the Atlantic (Preliminary tests with SHIPS-RII show encouraging results).

New Orleans after Katrina, 2005

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Thanks!

Balaguru, K., Foltz, G. R., Leung, L. R., Kaplan, J., Xu, W., Reul, N., & Chapron, B. (2020). Pronounced Impact of Salinity on Rapidly Intensifying Tropical Cyclones, *Bulletin of the American Meteorological Society*, *101*(9), E1497-E1511.