Thermohaline response of the upper ocean to tropical cyclones.
Observations and modelling

This presentation participates in OSPP

EGU

Outstanding Student & PhD candidate Presentation contest

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Introduction

Importance of the upper ocean response study:

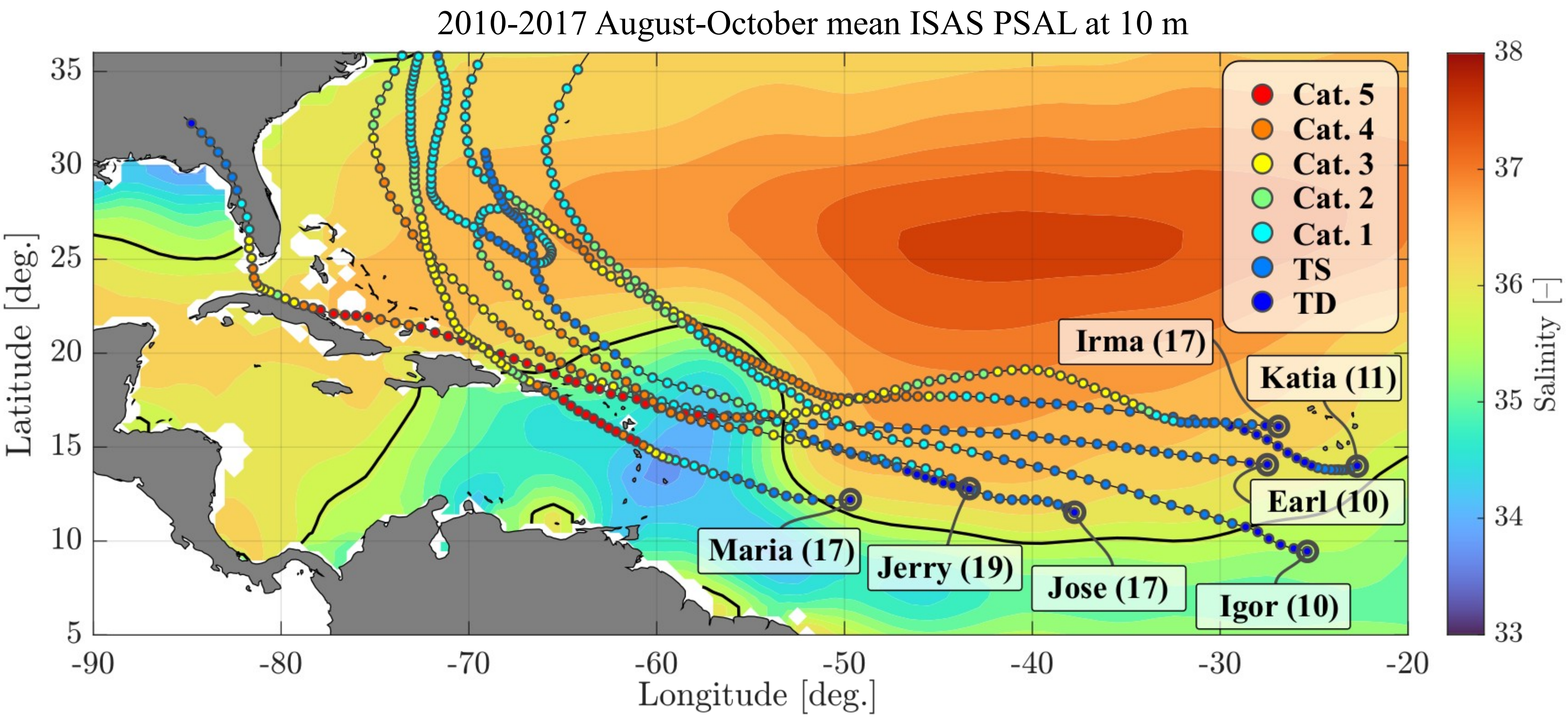
- Negative feedback mechanism between sea surface cooling and TC intensity [back to Emmanuel, 1999].
- Interpretation of observed anomalies is still an issue

Simplified models are necessary for practical applications.
- modelling at low computational cost (memory, time).
- easily interpretable.
- favour better understanding of the processes in play (self-similarity exploration)

Aim:
Revisit and simulate well documented cases of thermal, haline responses of the ocean to various hurricanes with a simplified model of the upper ocean response.

Investigation area – Amazon-Orinoco river plume [Grodsky et al, 2011, Balaguru et al, 2012, Reul et al, 2014, Androulidakis et al, 2016, Balaguru et al, 2020]

Hurricanes over Amazon-Orinoco River Plume

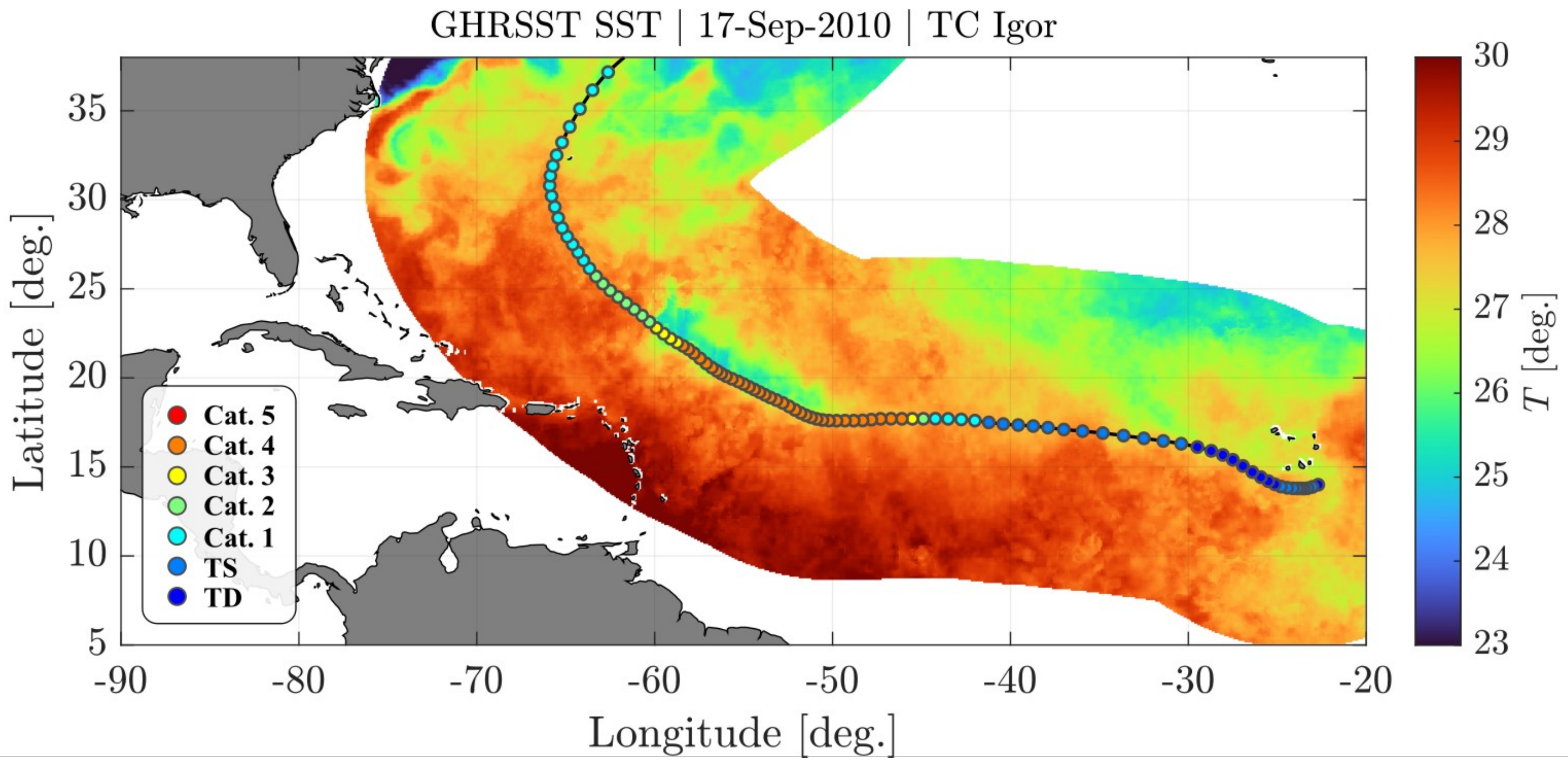


Data

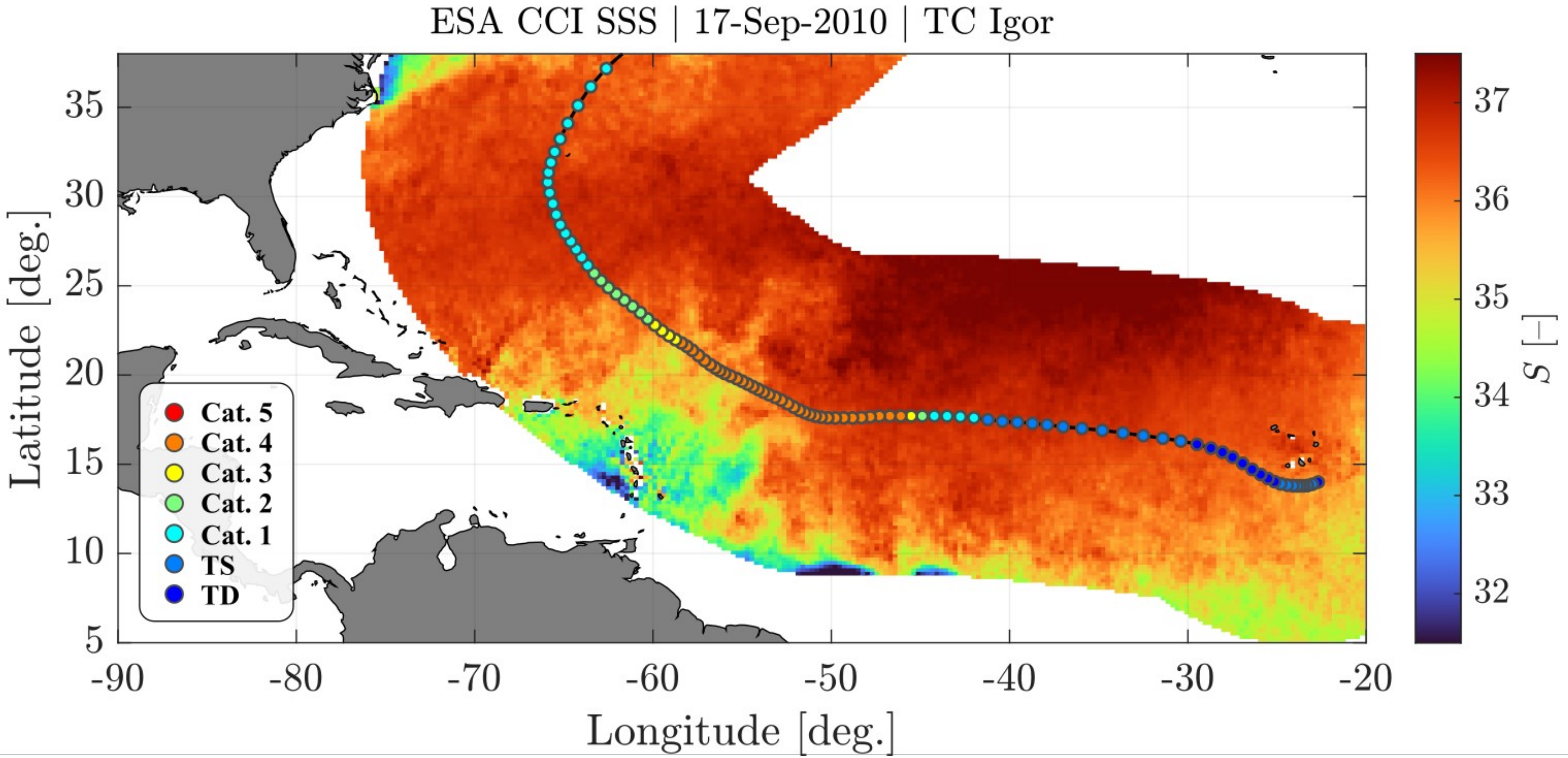
Dataset	Resolution	
IBTrACKS – TC parameters	dt = 1 hour	
GHRSST – sea surface temperature (SST)	dt = 1 hour	dx,dy = 0.09^0
ESA CCI SSS – sea surface salinity (SSS)	dt = 1 day	dx,dy = 25 km
ISAS20 – temperature and salinity vertical profiles	dt = 1 month	dx,dy = 0.5^0, dz: 187 z-levels from 1 to 5500 m
TRMM – rain rate	dt = 3 hour	dx,dy = 0.25^0
ERA5 – evaporation rate	dt = 3 hour	dx,dy = 0.25^0

Data overview:
Igor (2010) case

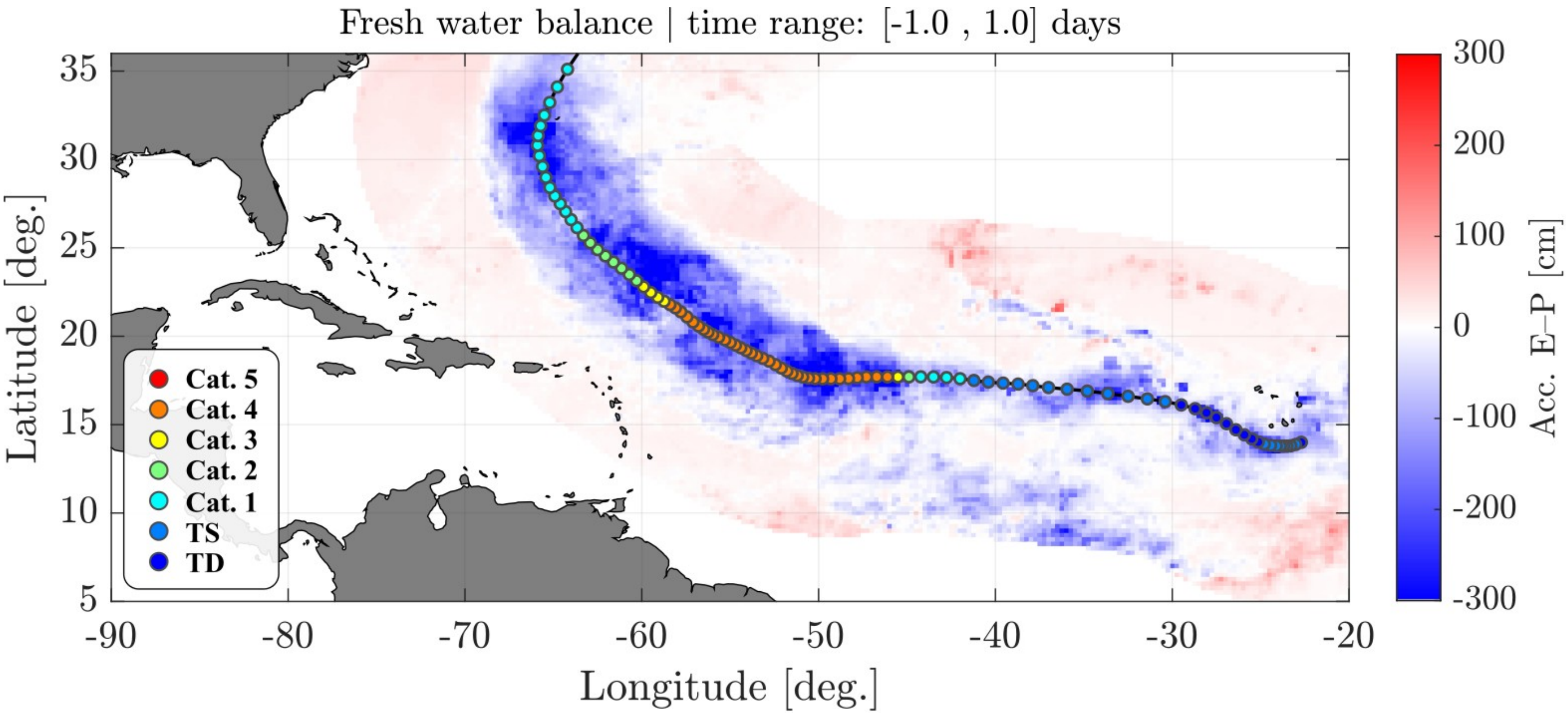
Data overview



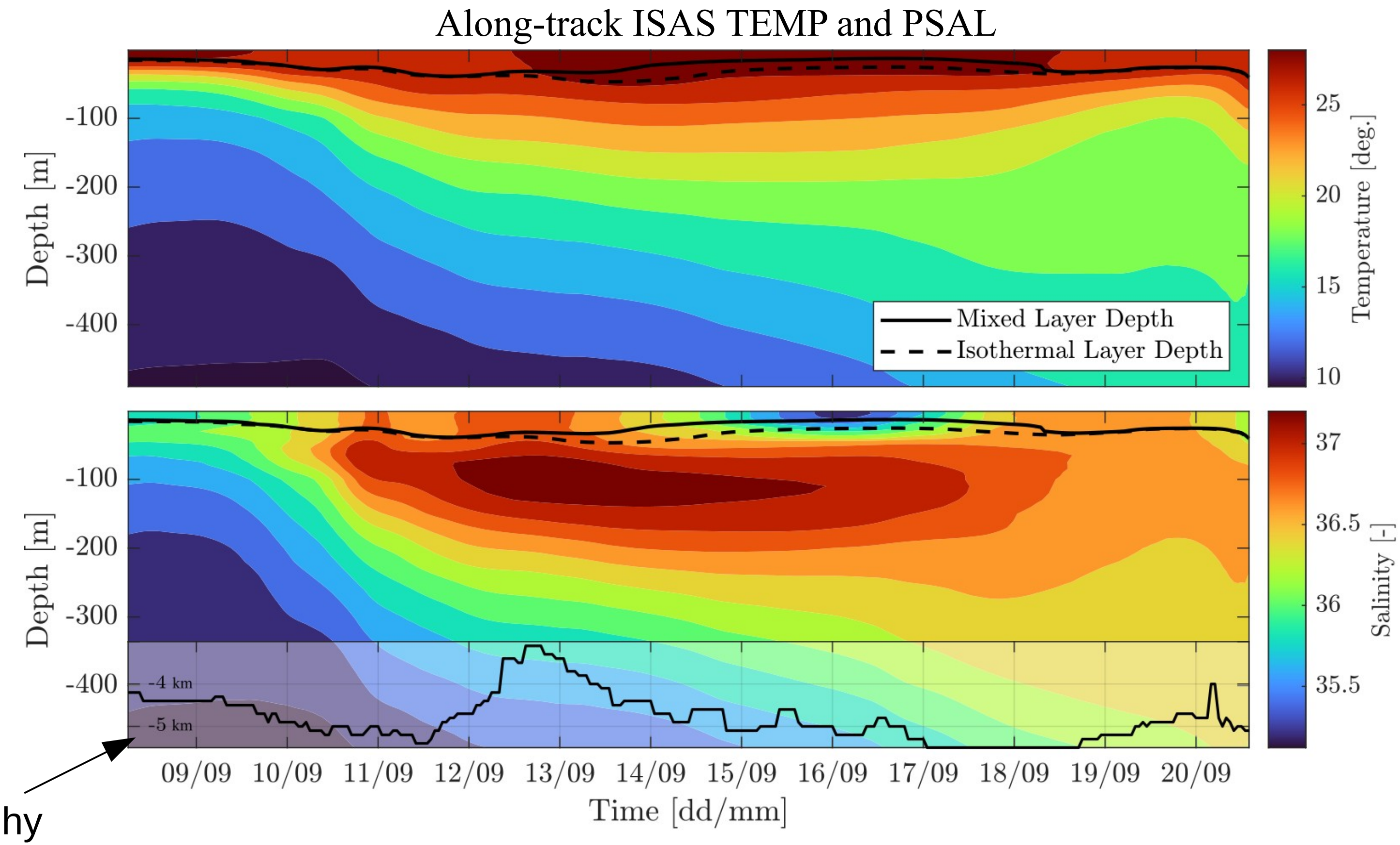
Data overview



Data overview

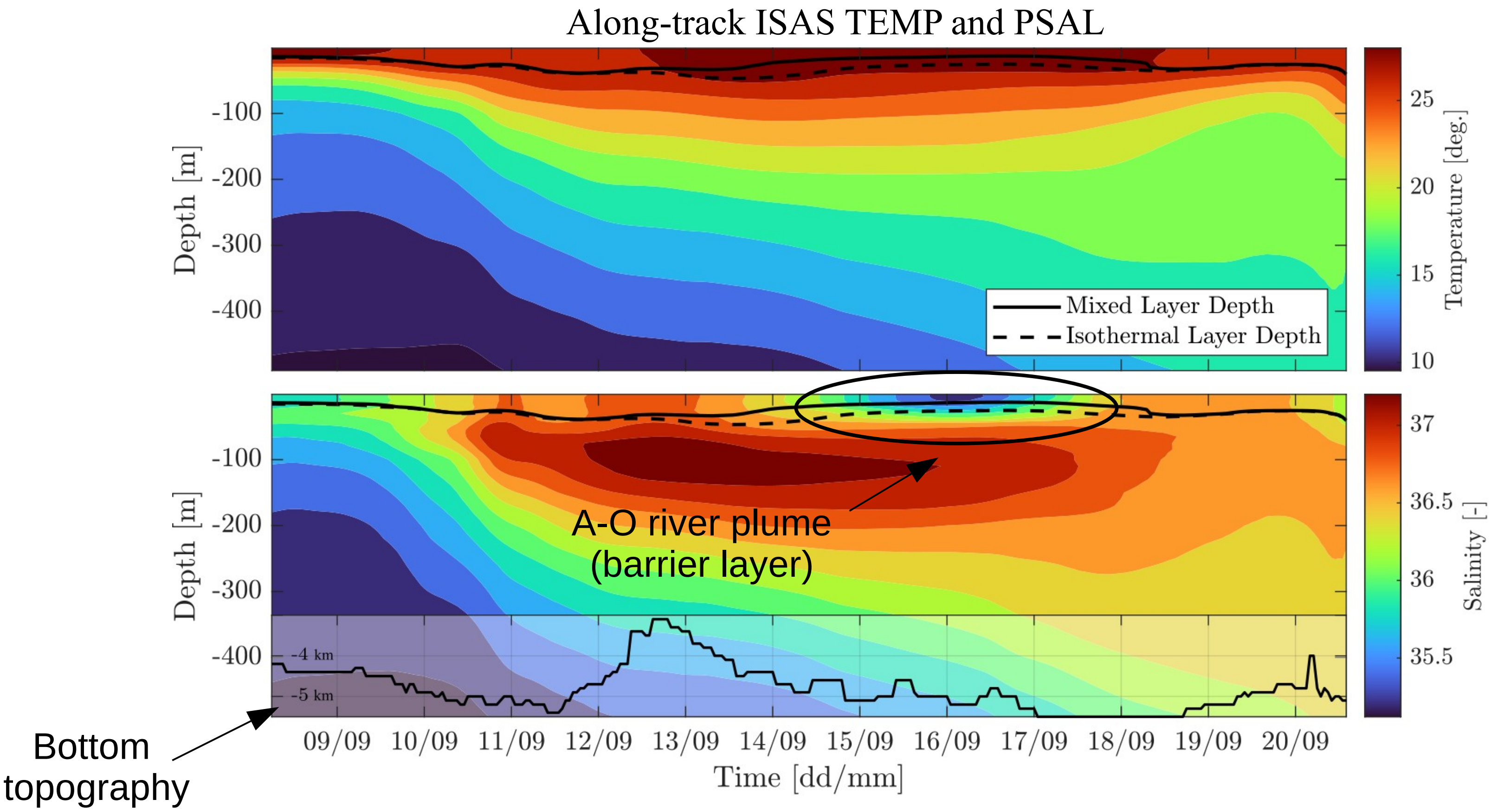


Data overview



Bottom topography

Data overview

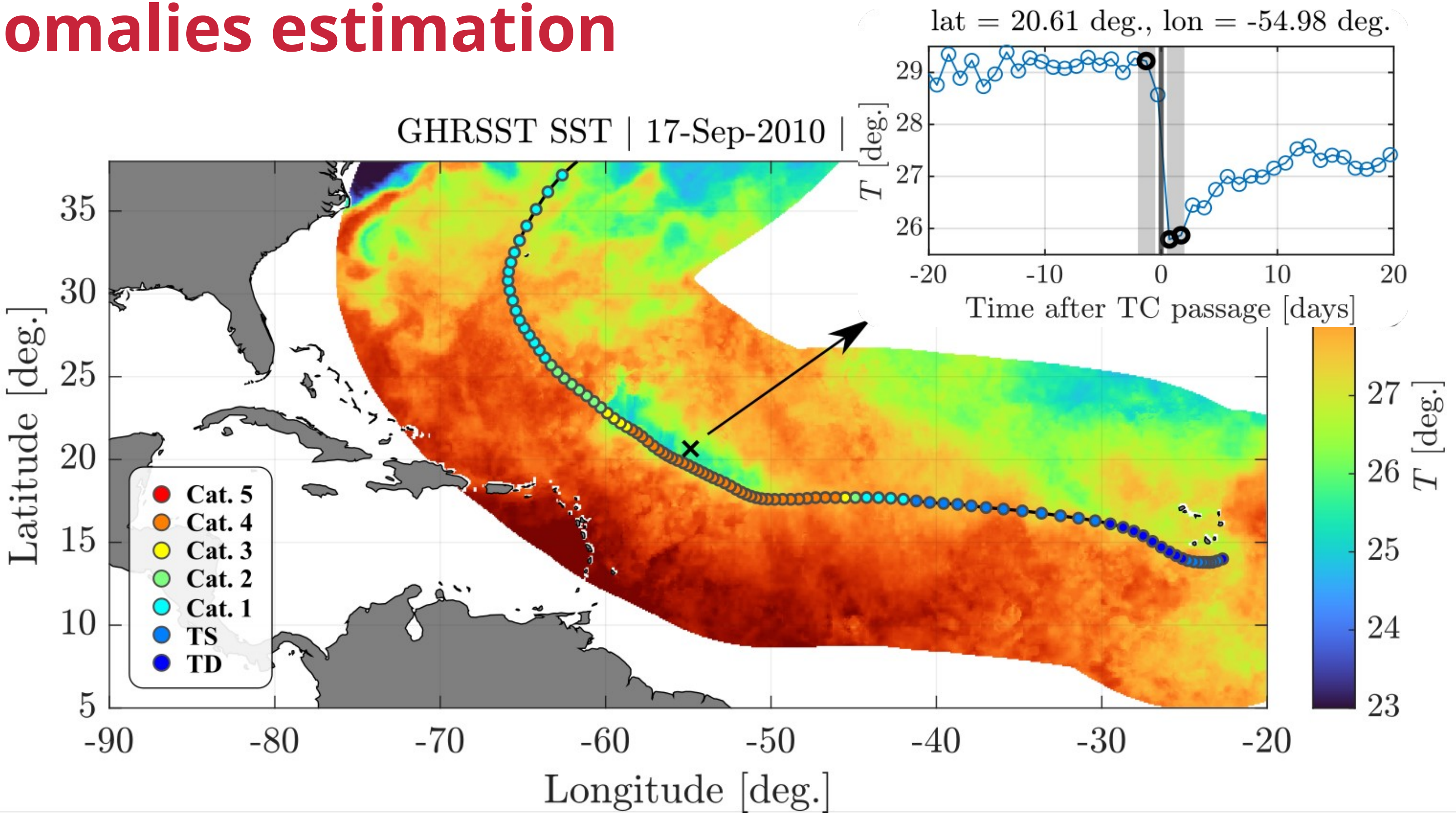


Anomalies estimation

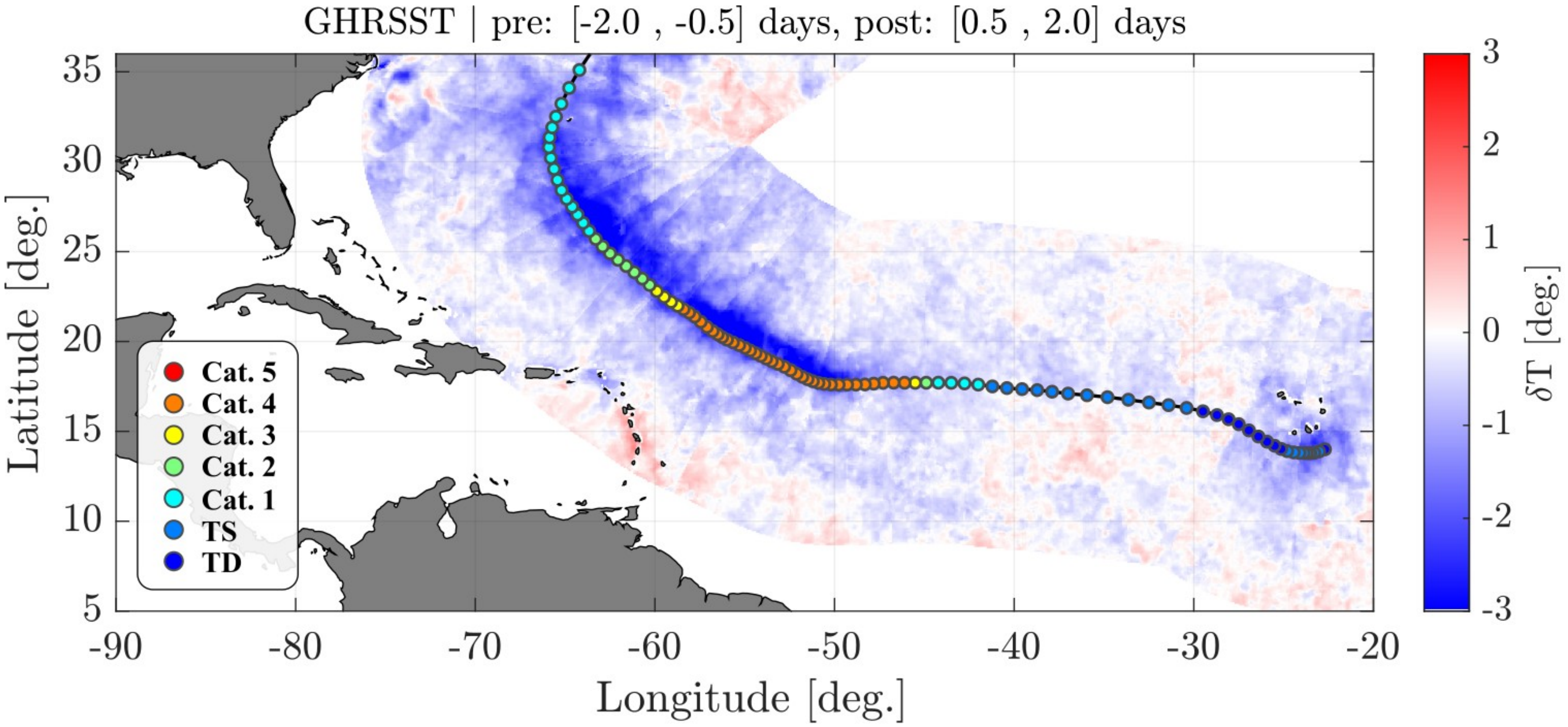
SST and SSS anomalies estimation similar to
Lloyd and Vecchi, (2011), Reul et. al (2021)

Time ranges:
SST – pre-storm [-2, 0.5] days, post-storm [0.5, 2] days
SSS – pre-storm [-10, -3] days, post-storm [0, 5] days

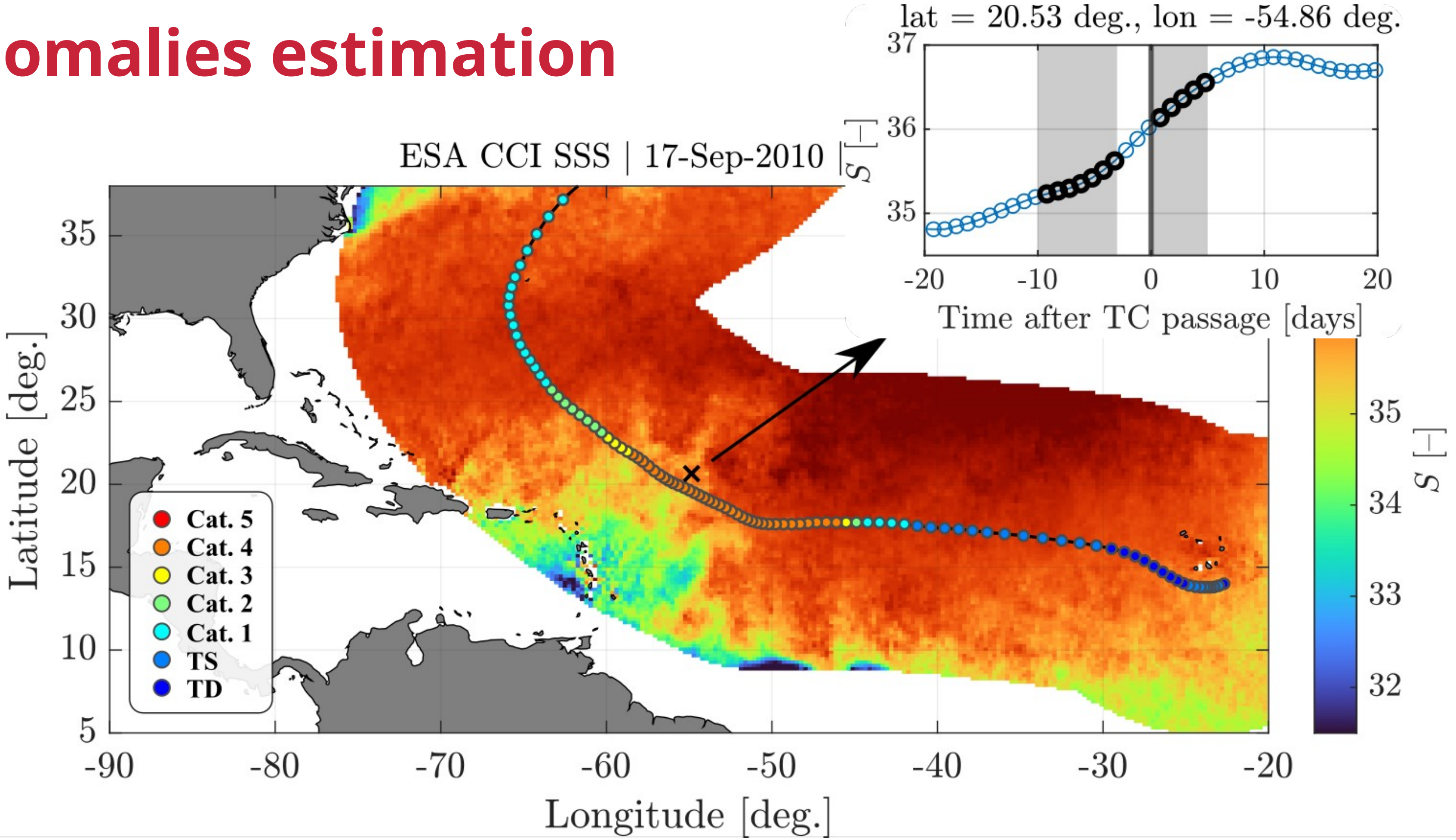
Anomalies estimation



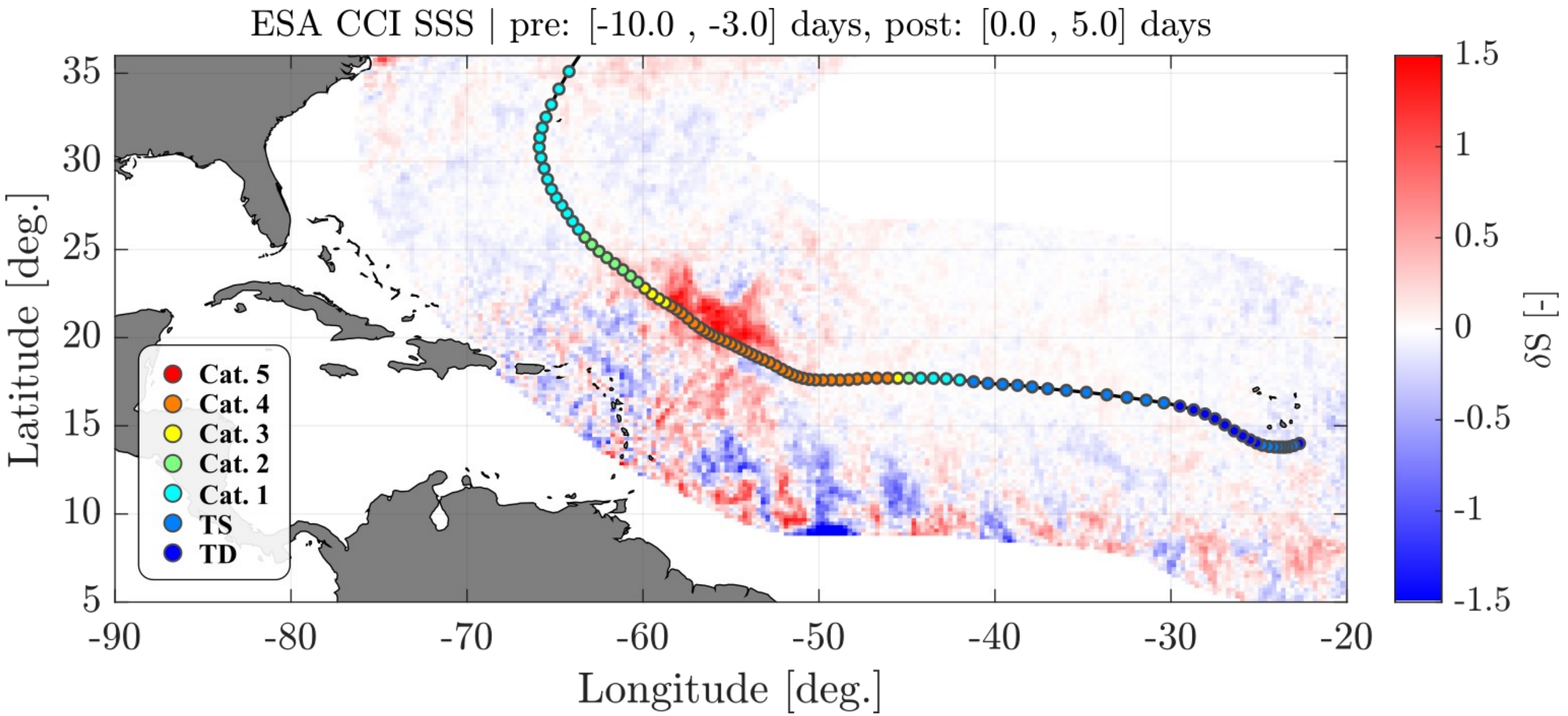
Anomalies estimation



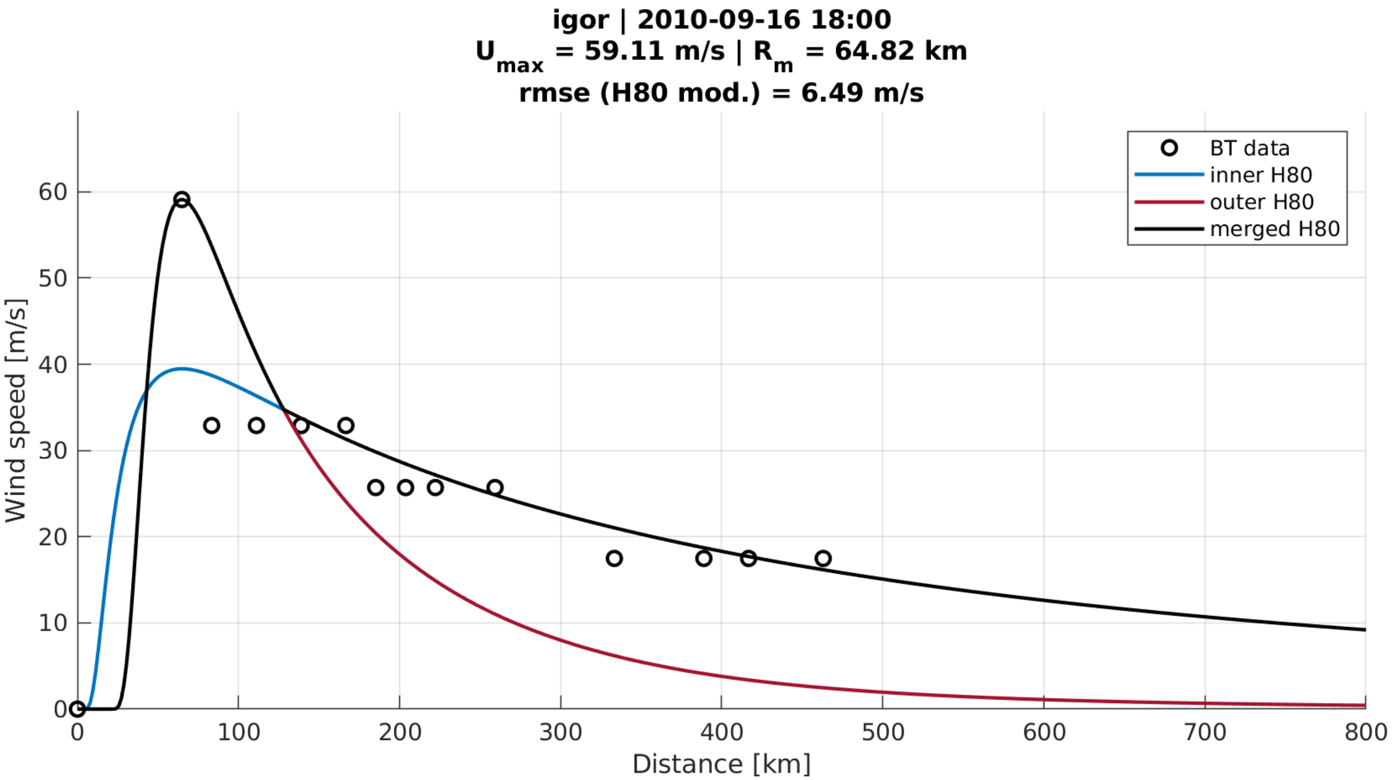
Anomalies estimation



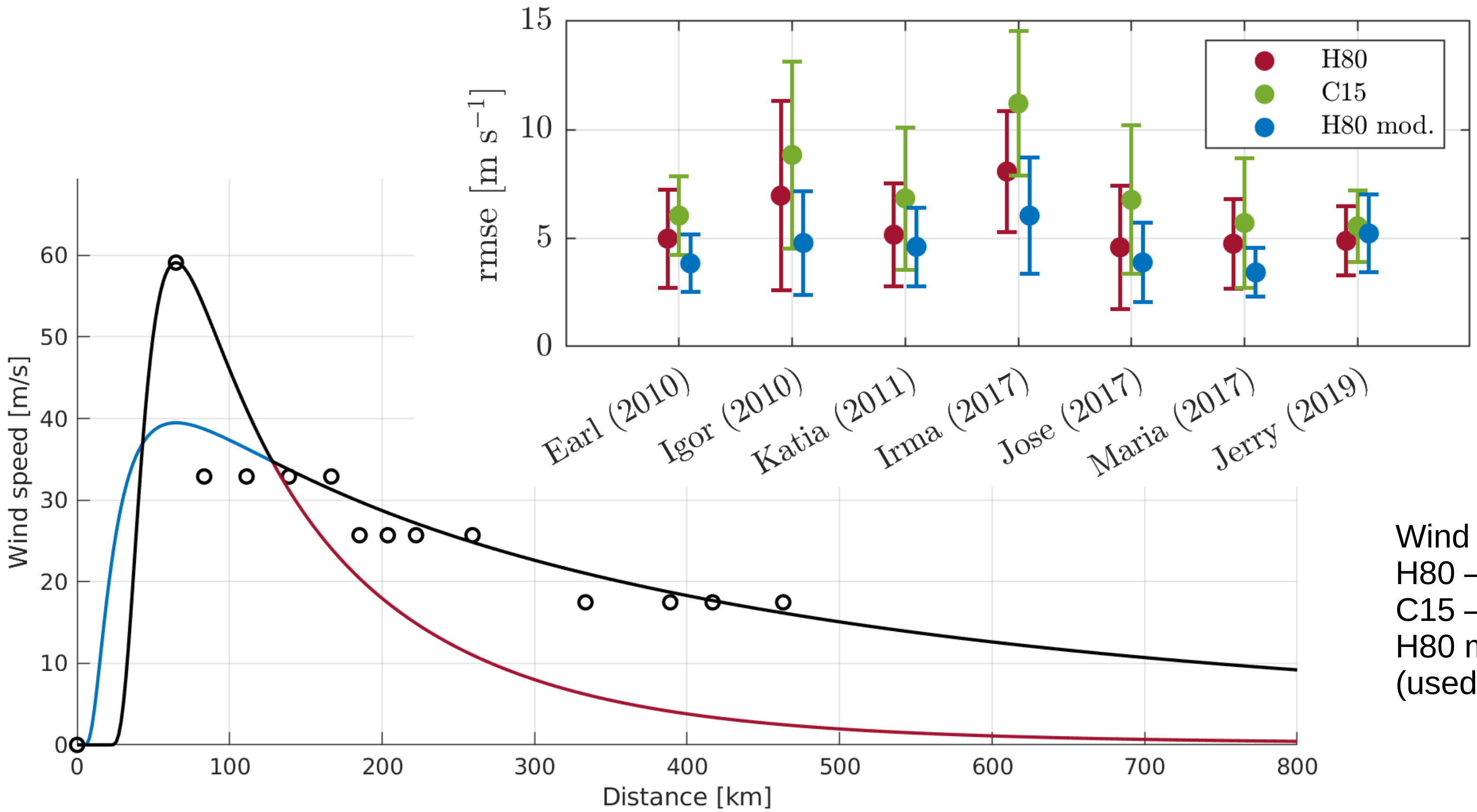
Anomalies estimation



Wind speed profile



Wind speed profile



Wind speed profiles:
H80 – Holland (1980)
C15 – Chavas et al. (2015)
H80 mod. - modified H80
(used in this study)

Upper ocean response model

Kudryavtsev et al. (2019):

A Simplified Model for the Baroclinic and Barotropic Ocean Response to Moving Tropical Cyclones: 2. Model and Simulations

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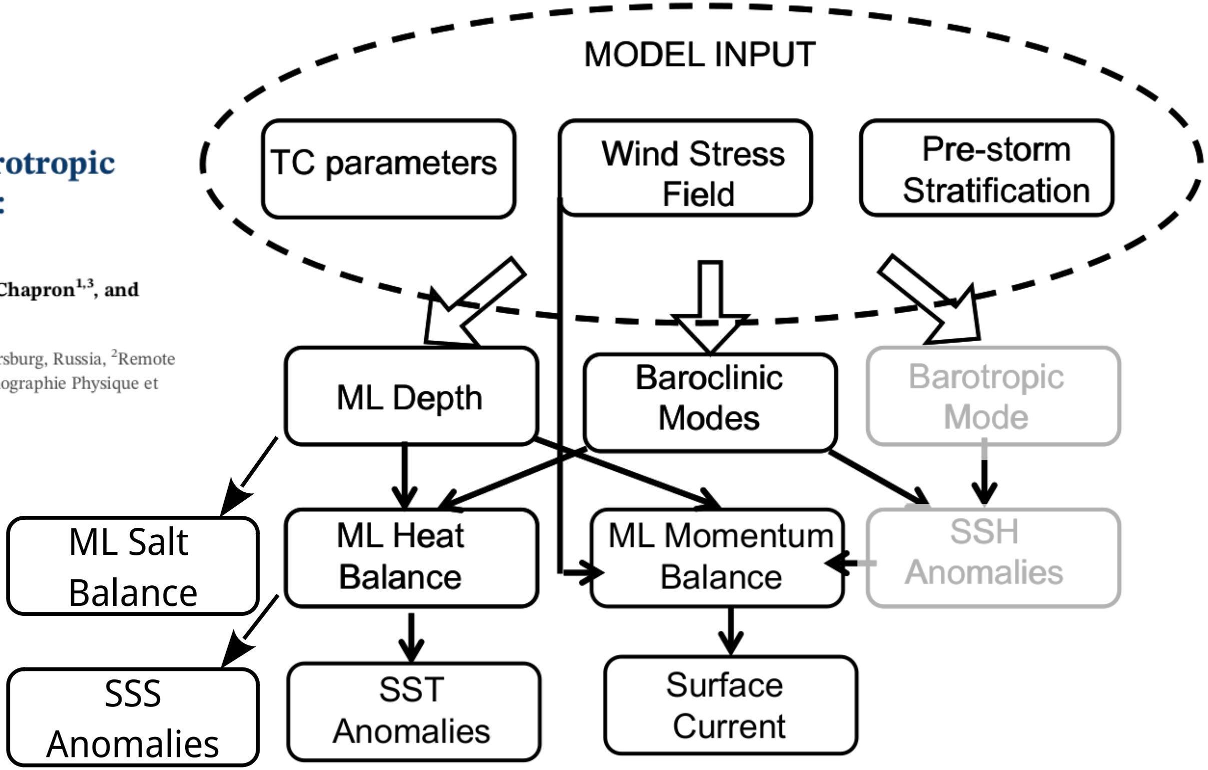


Upper ocean response model

Mixed layer depth equation following Zilitinkevich and Esau (2005).

$$c_h M^2 = h^2 \left[(Mf)^2 + \left(\frac{h^2 N_{eff}^2}{2} \right)^2 \right]^{1/2}$$

where c_h = 0.63, f – Coriolis parameter, M – wind driven mass flux from ML-averaged momentum balance equation

$$M(x_1, x_2) = f^{-1} \int_{x_1^0}^{x_1} \tau^s (x_1, x_2) \exp\left[-ik_0 \left(x_1 - x_1'\right)\right] \mathrm{d}\left(k_0 x_1'\right)$$

and weighted buoyancy frequency estimated from known pre-storm stratification

$$N_{eff}^2 = \frac{2}{h^2} \int_{-h}^{0} z N^2 dz$$

Upper ocean response model

SST and SSS anomalies from heat and salt balance equations

$$h\frac{\partial T_m}{\partial t} = -\Delta T w_e$$

$$h\frac{\partial S_m}{\partial t} = -\Delta S w_e + (E-P)S_m$$

$$\frac{\partial}{\partial t} = V\frac{\partial}{\partial x}$$ (*V* – TC translation speed)

$$\frac{\partial T_m}{\partial x} = -w_e\frac{1}{2V}\bar{\Gamma}_T$$

$$\frac{\partial S_m}{\partial x} - \frac{1}{Vh}(E-P)S_m = -w_e\frac{1}{2V}\bar{\Gamma}_S$$

w_e – entrainment velocity

$$w_e = \frac{\partial h}{\partial t} + w_{-h}$$

w_{-h} – baroclinic velocity at the base of ML

Temperature and salinity gradients are found from pres-torm stratification

$$\bar{\Gamma}_S = \frac{2}{h^2}\int_{-h}^{0} z\frac{\partial S}{\partial z}dz \qquad \bar{\Gamma}_T = \frac{2}{h^2}\int_{-h}^{0} z\frac{\partial T}{\partial z}dz$$

E, *P* – evaporation and pricipitation rates

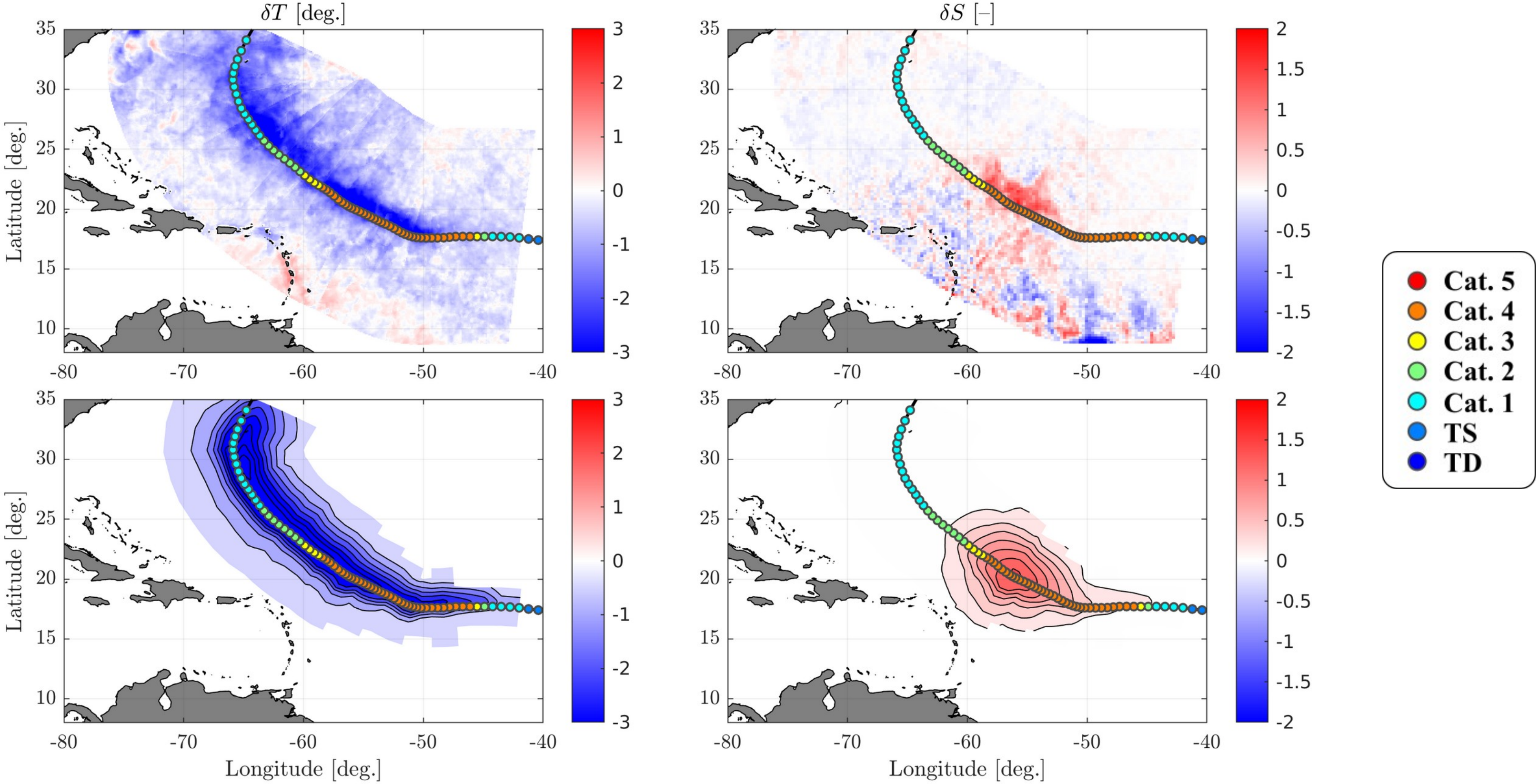
Modelling:
Igor (2010) – A-O plume case

Results

Georeferenced view

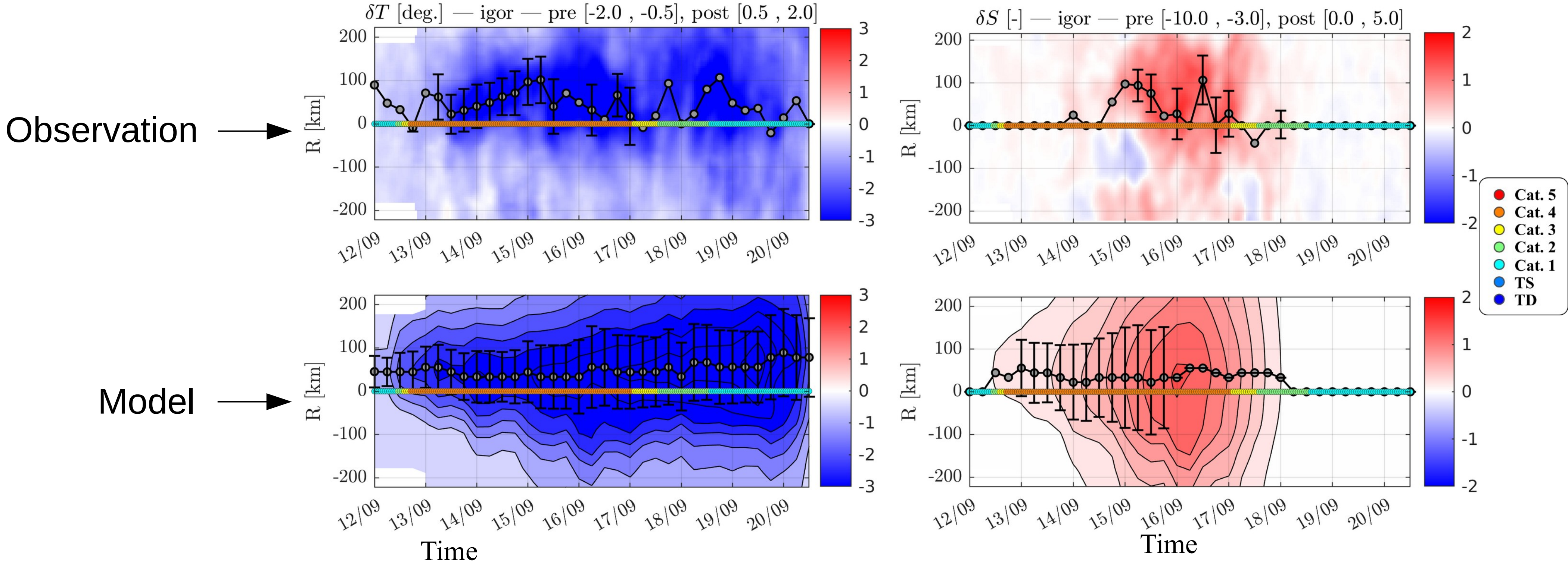
Observation →

Model →

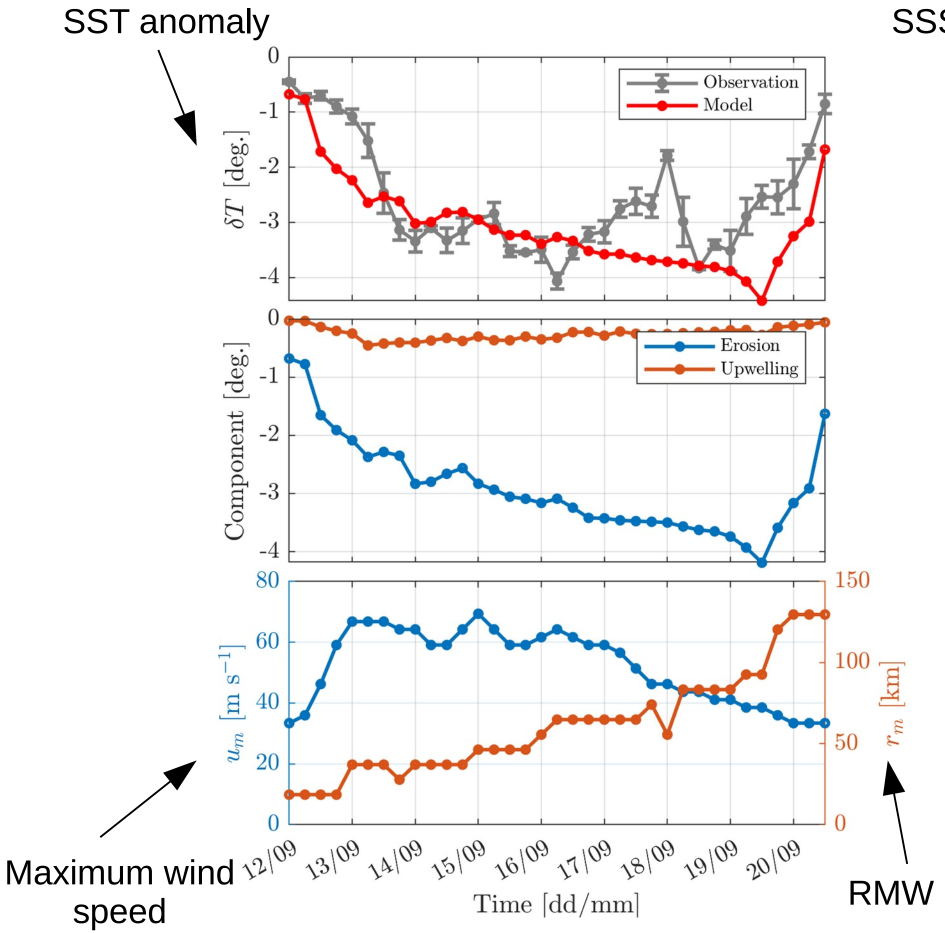


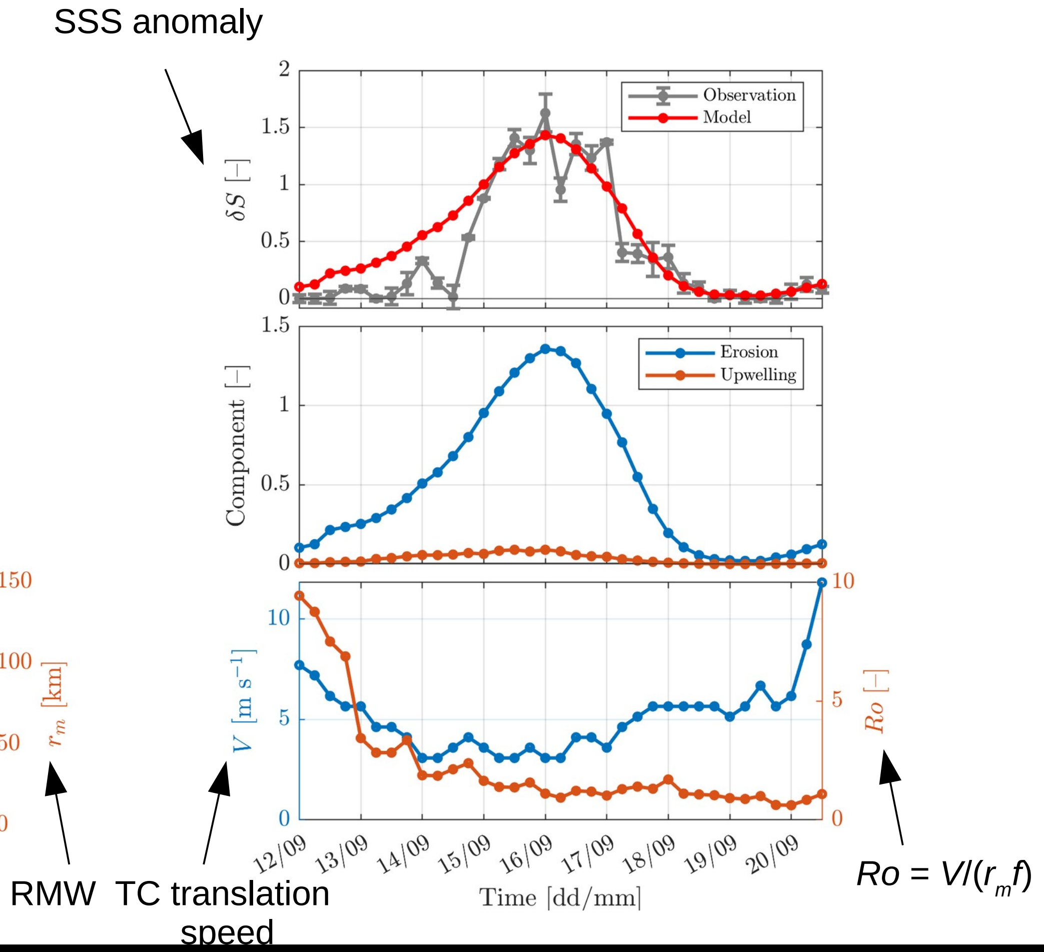
Results

Series of anomaly transections perpedicular to TC's track:
Cross-track distance–time view

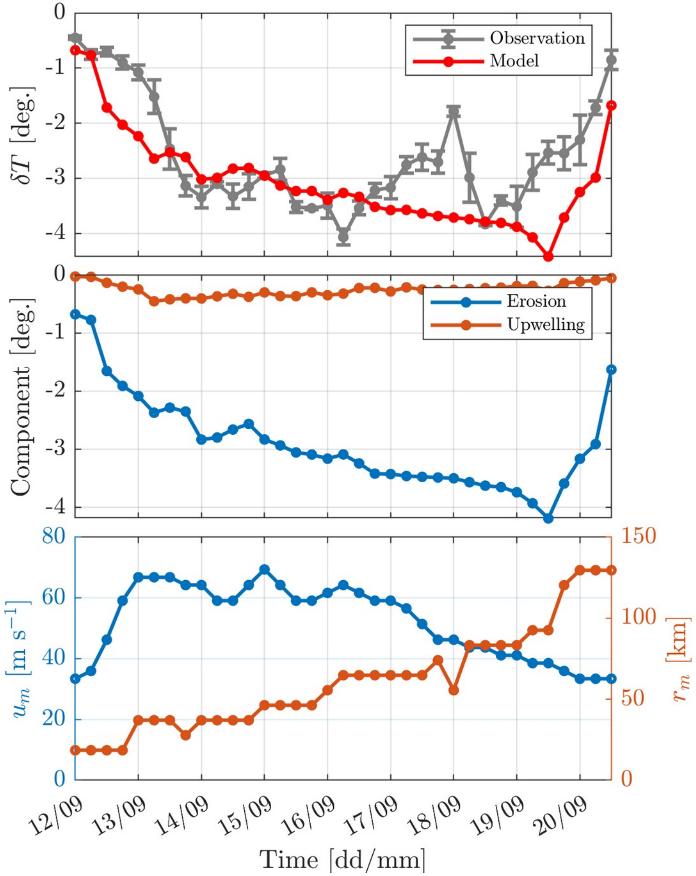


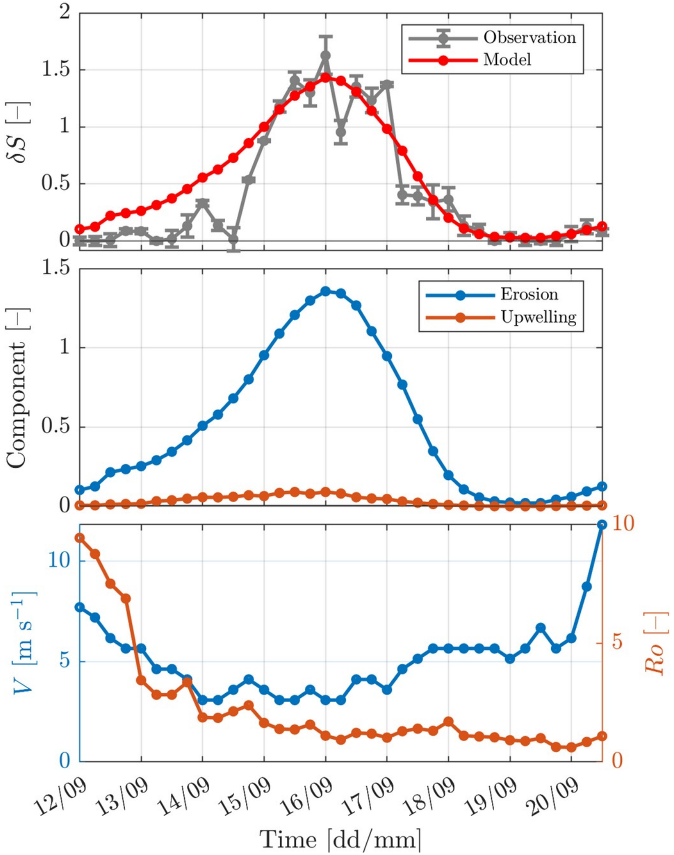
Results


SST anomaly
Observation
Model
δT [deg.]
Erosion
Upwelling
Component [deg.]
u_m [m s^{-1}]
r_m [km]
Time [dd/mm]
Maximum wind speed
RMW

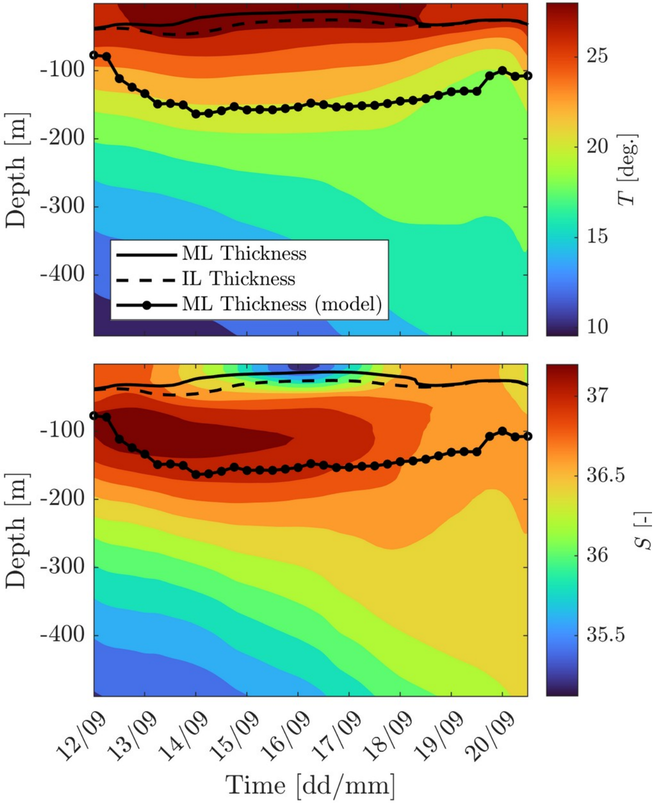

SSS anomaly
Observation
Model
δS [–]
Erosion
Upwelling
Component [–]
V [m s^{-1}]
Ro [–]
Time [dd/mm]
TC translation speed
$Ro = V/(r_m f)$

Results

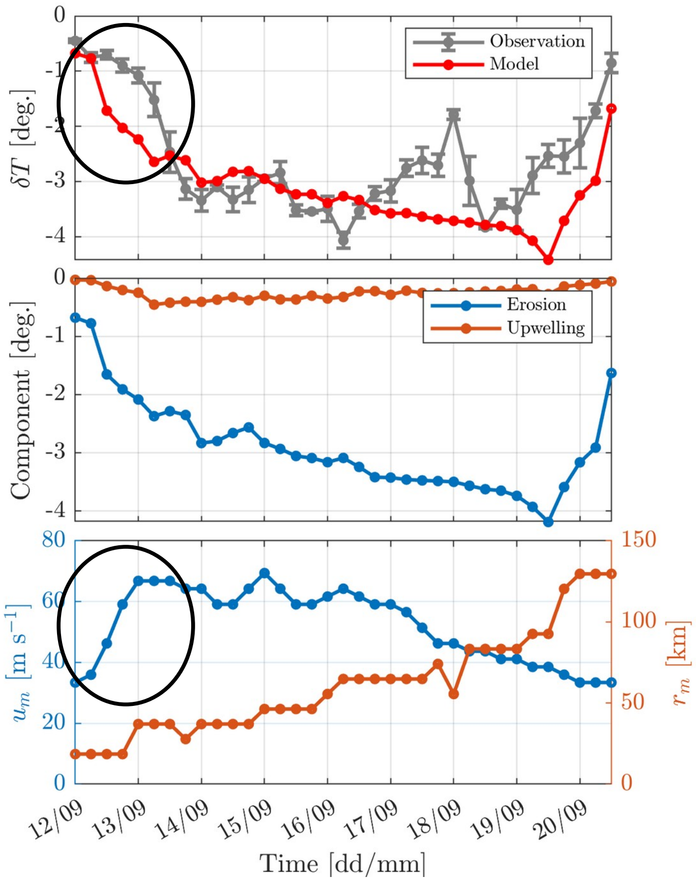


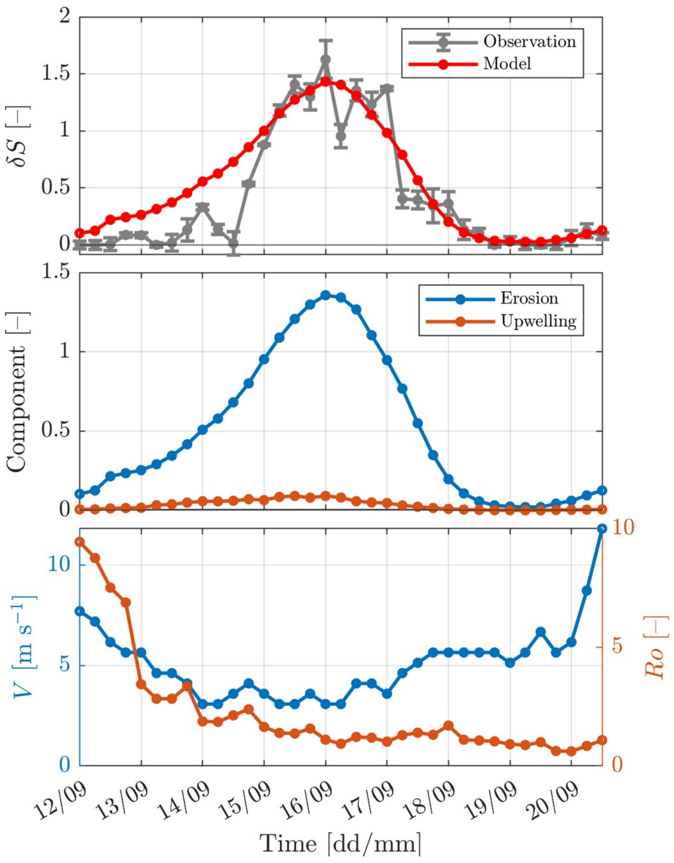


Along-track ISAS TEMP and PSAL



Results





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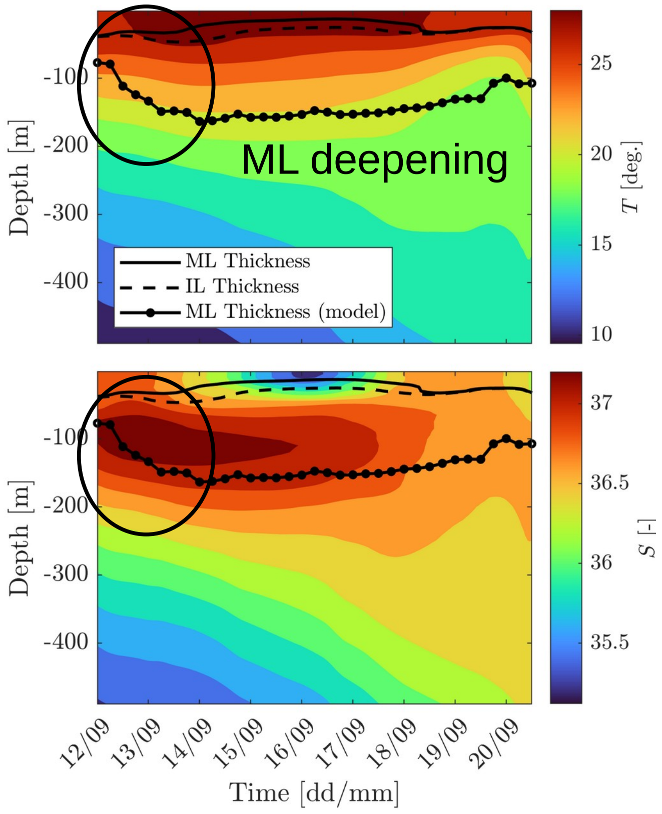
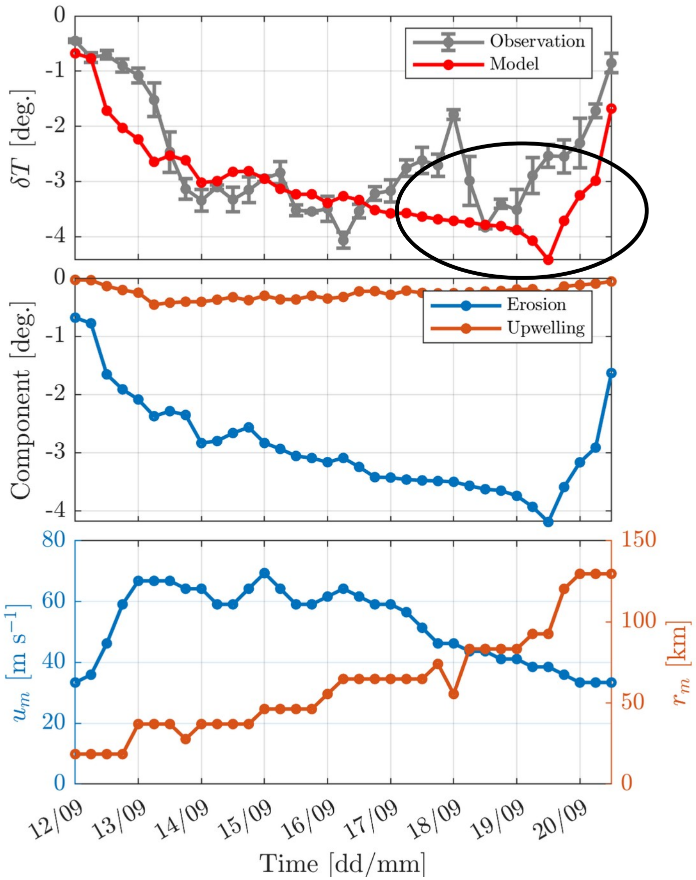
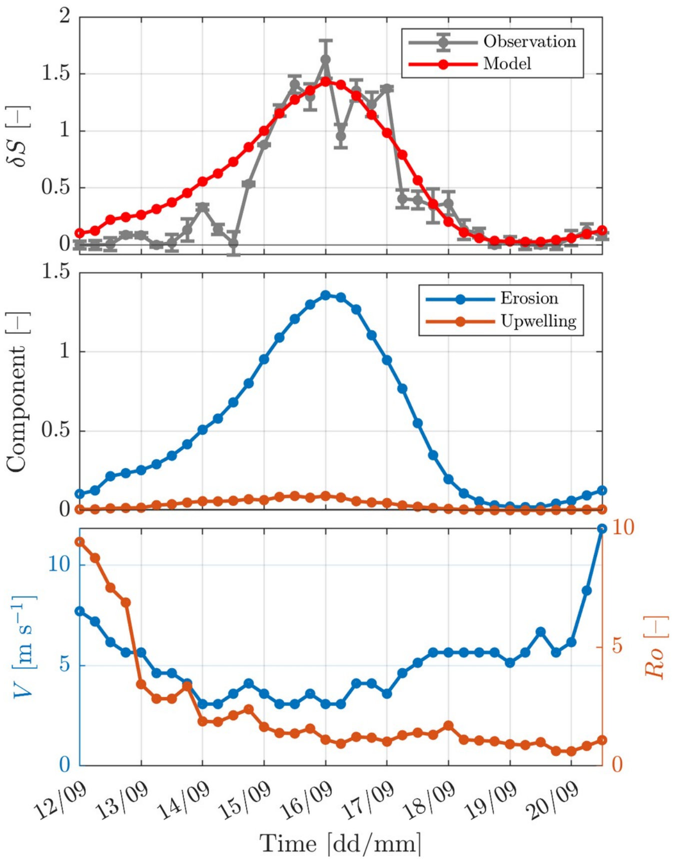
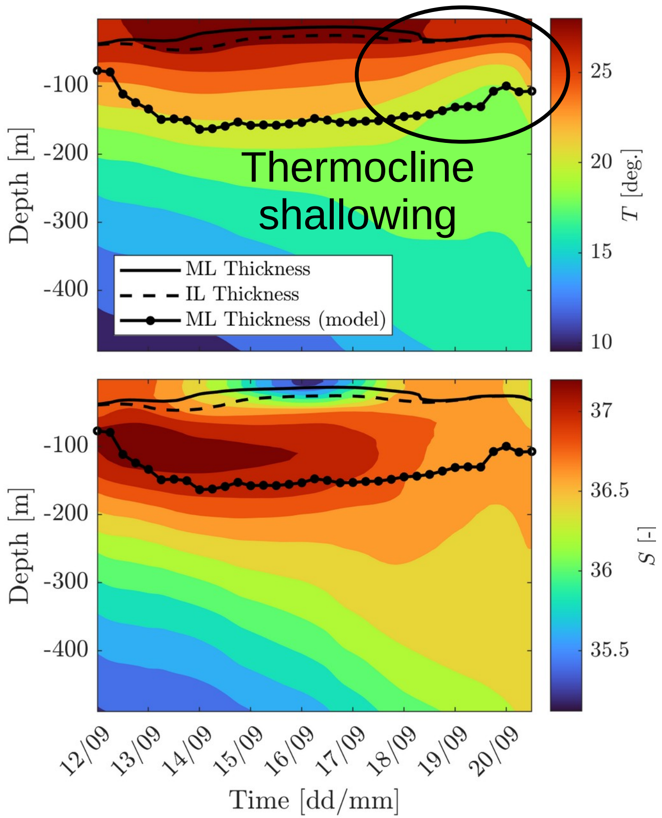


Results

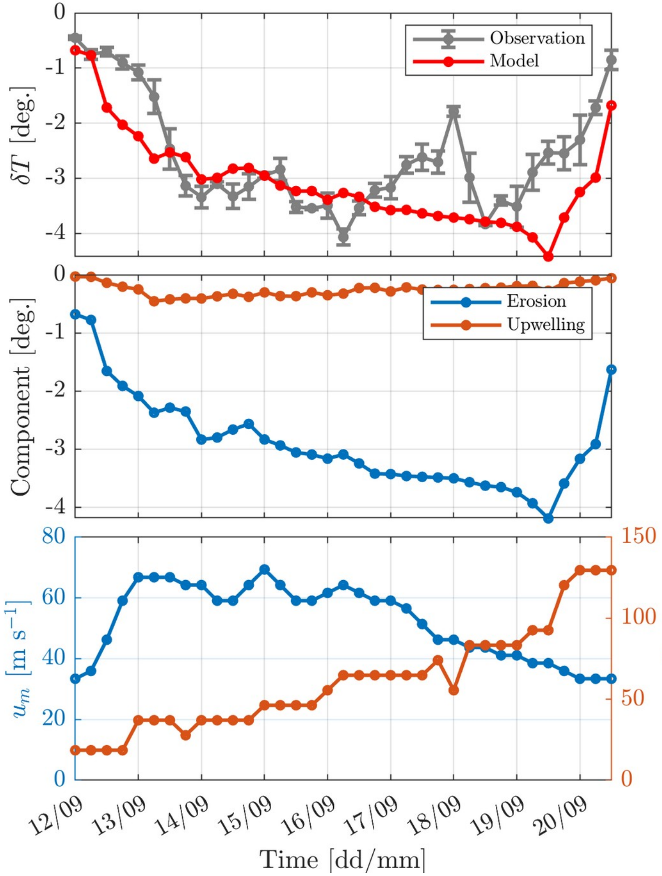


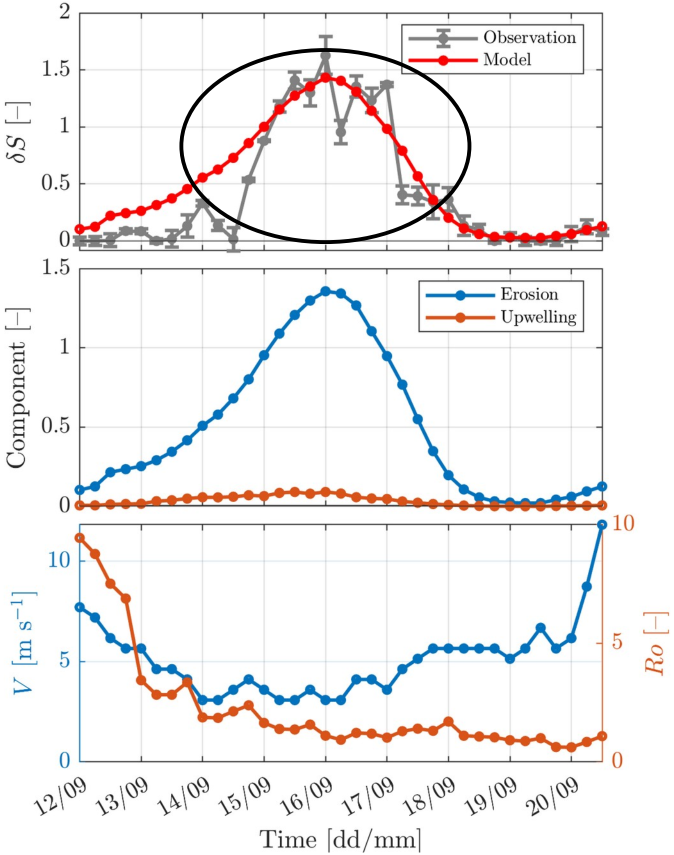


Along-track ISAS TEMP and PSAL

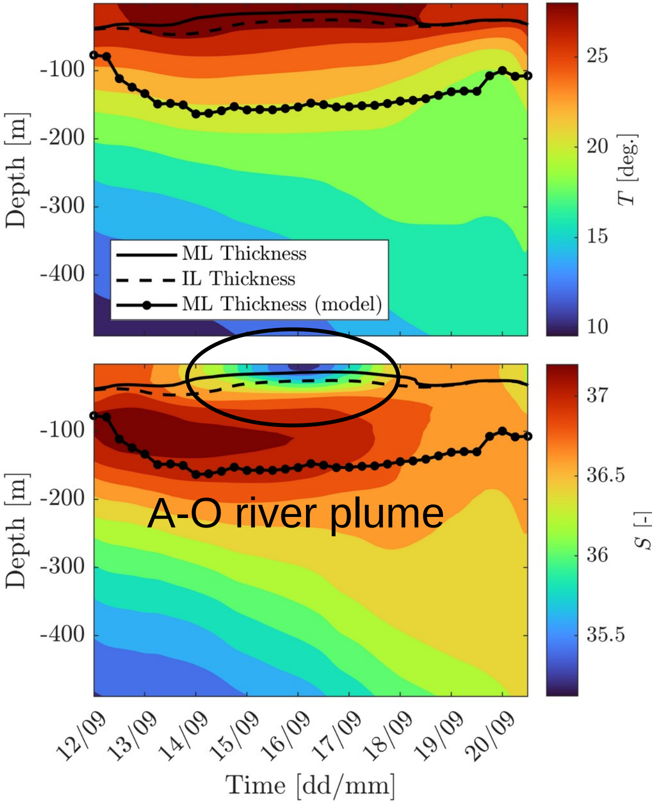


Results



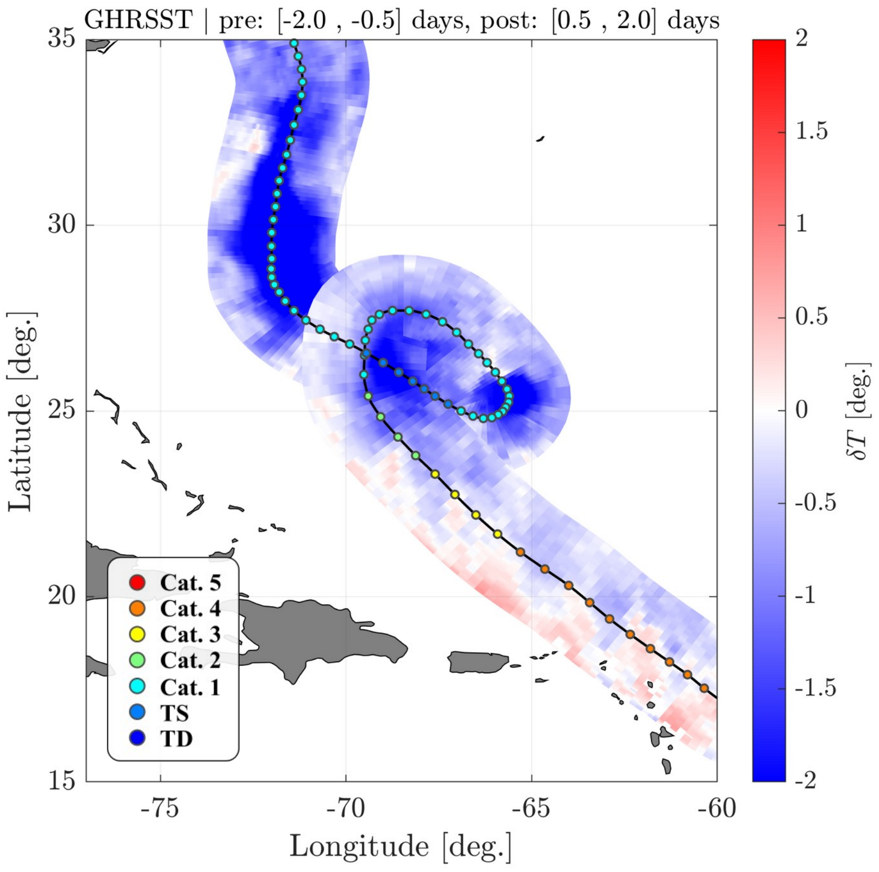


Along-track ISAS TEMP and PSAL

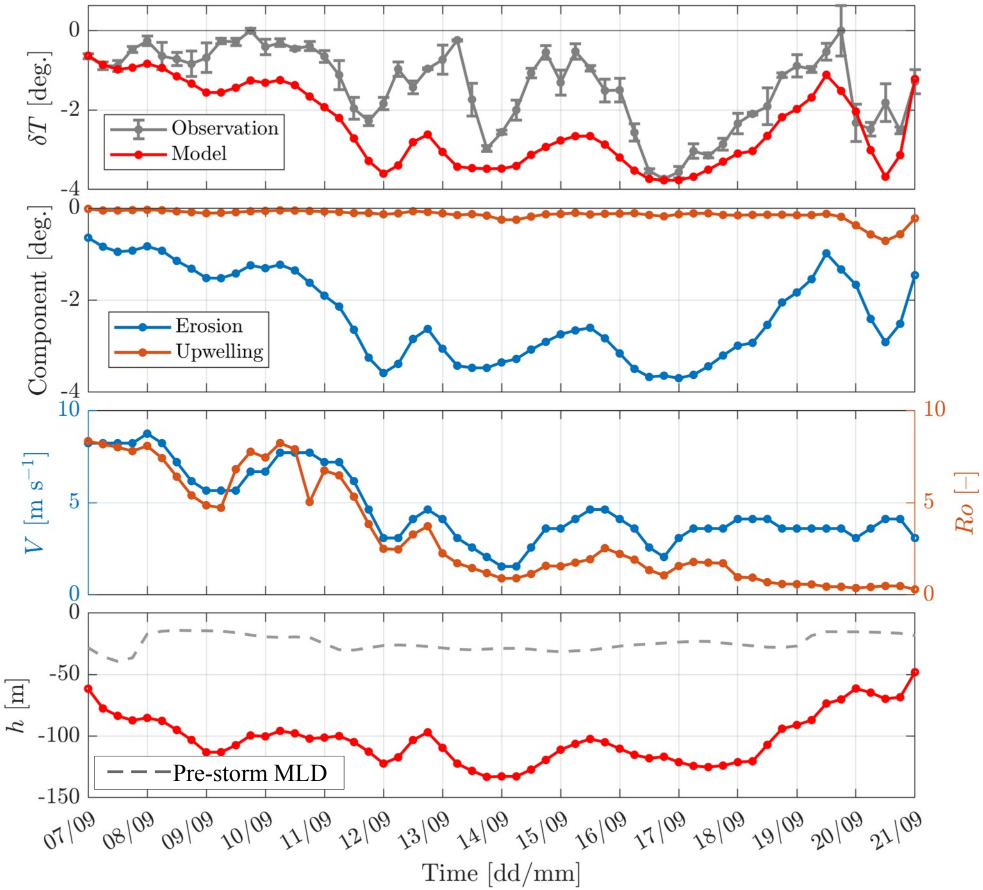


Modelling:
Jose (2017) – TC deceleration case

Results

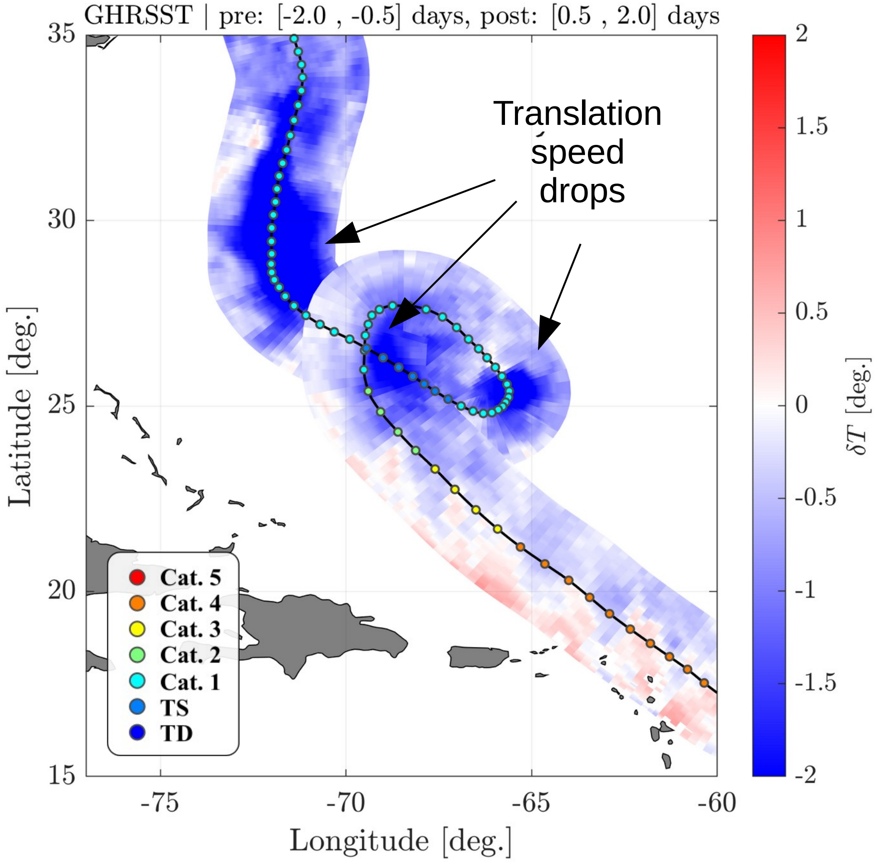


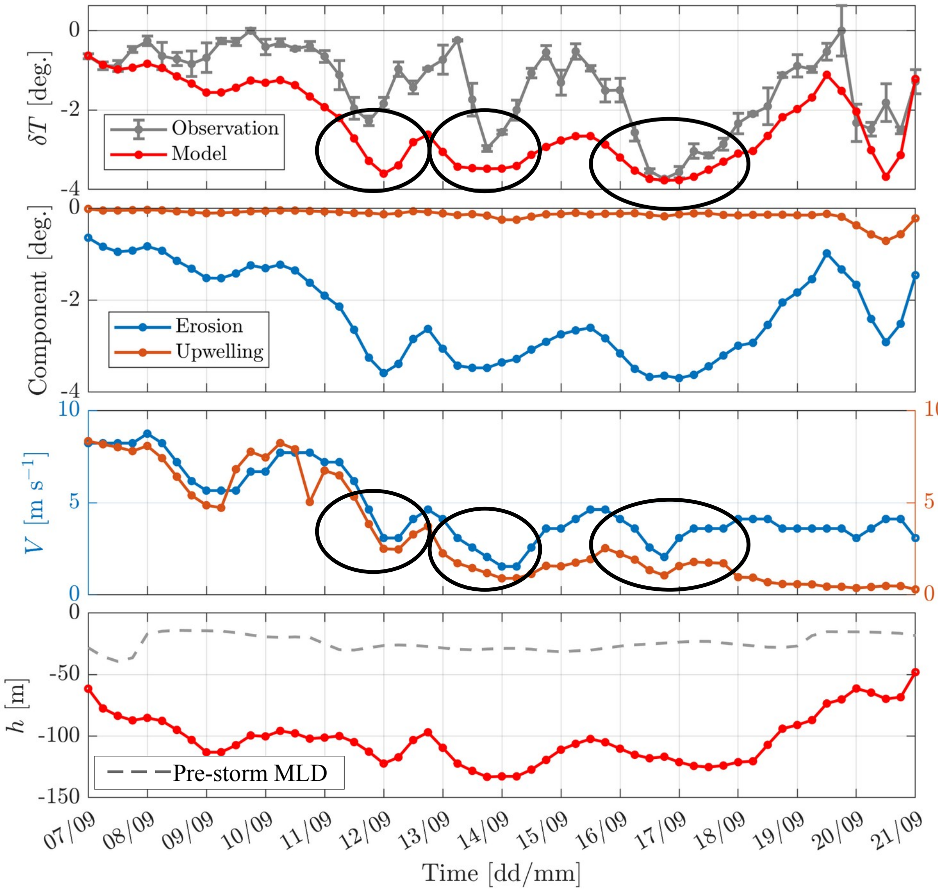
GHRSST | pre: [-2.0 , -0.5] days, post: [0.5 , 2.0] days
Latitude [deg.]
Longitude [deg.]
δT [deg.]
Cat. 5
Cat. 4
Cat. 3
Cat. 2
Cat. 1
TS
TD



δT [deg.]
Observation
Model
Component [deg.]
Erosion
Upwelling
V [m s−1]
Ro [−]
h [m]
Pre-storm MLD
Time [dd/mm]

Results


GHRSST | pre: [-2.0 , -0.5] days, post: [0.5 , 2.0] days
Translation speed drops
Latitude [deg.]
Longitude [deg.]
δT [deg.]
Cat. 5
Cat. 4
Cat. 3
Cat. 2
Cat. 1
TS
TD


δT [deg.]
Observation
Model
Component [deg.]
Erosion
Upwelling
V [m s−1]
Ro [−]
h [m]
Pre-storm MLD
Time [dd/mm]

Modelling:
All chosen TCs over A-O plume

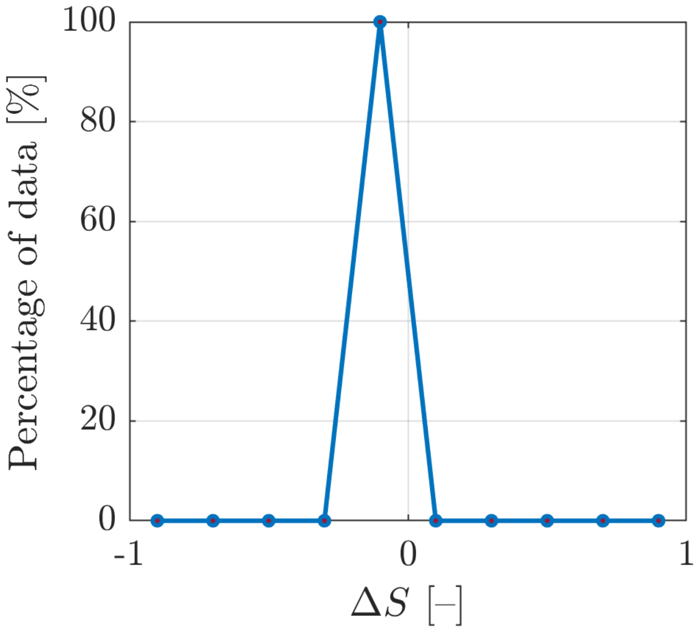
Results

Precipitation effect:

$$\frac{\partial S_m}{\partial x} - \frac{1}{Vh}(E - P)S_m = -w_e \frac{1}{2V}\bar{\Gamma}_S$$

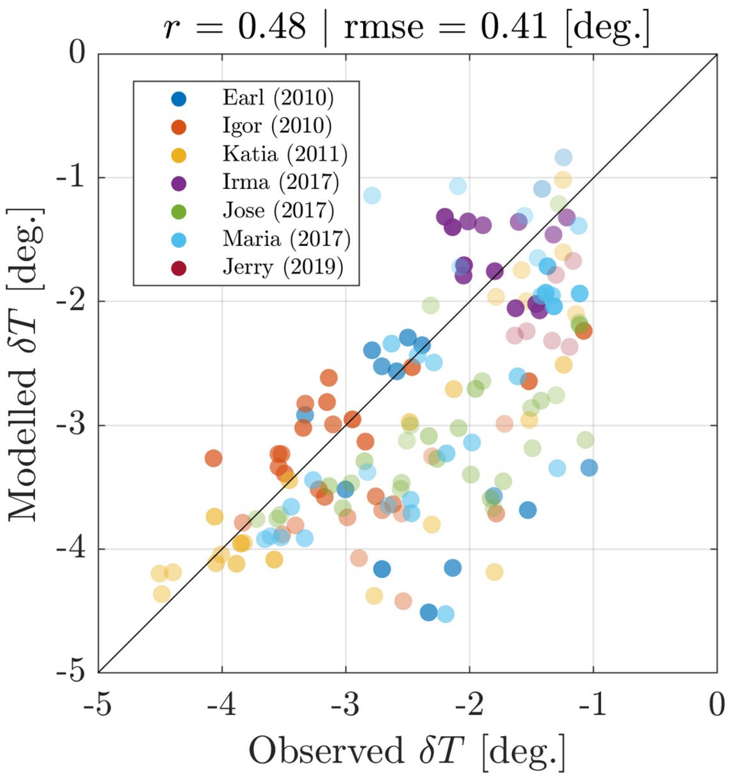
assumption *E*<<*P*

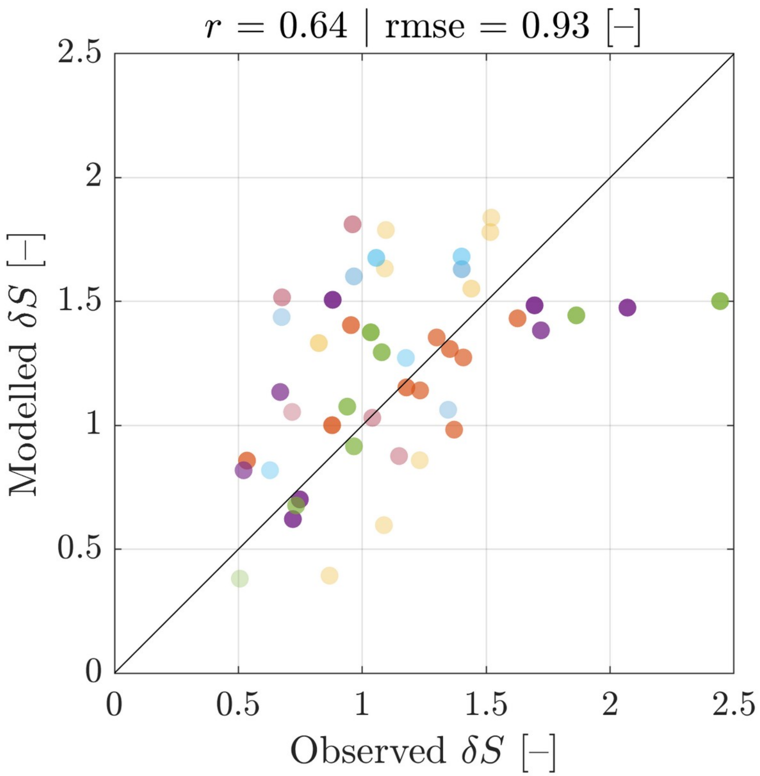
Weak influence of precipitation
[Steffen and Bourassa, 2020,
Jacob and Koblinsky, 2007,
Balaguru et. al, 2022]



ΔS = with *P* – without *P*
(*P* – precipitation rate)

Results





Transparency = best-track maximum wind speed:
from 10 m/s (transparent) to 85 m/s (opaque)

Results

Self-similarity check

SST and SSS anomalies

$$\delta T = \bar{\Gamma}_T h/2$$

$$\delta S = \bar{\Gamma}_S h/2$$

MLD scaling

$$h = u_*/\sqrt{f N_{eff}}\phi^{1/2}(Ro^{-1})$$

where u_* – friction velocity in water and
ϕ – nondimensional function of $Ro = V/(r_m f)$ such that

$$\phi(Ro^{-1}) \to Ro^{-1} \text{ at } Ro \to 1$$

$$\phi(Ro^{-1}) \to 1 \text{ at } Ro \ll 1$$

Self-similar solutions:

$$\tilde{\delta T} = \delta T/T_* \propto \phi^{1/2}(Ro^{-1})$$

$$\tilde{\delta S} = \delta S/S_* \propto \phi^{1/2}(Ro^{-1})$$

$$T_* = 2 \times 10^{-3} u_m/\sqrt{f N_{eff}}\bar{\Gamma}_T$$

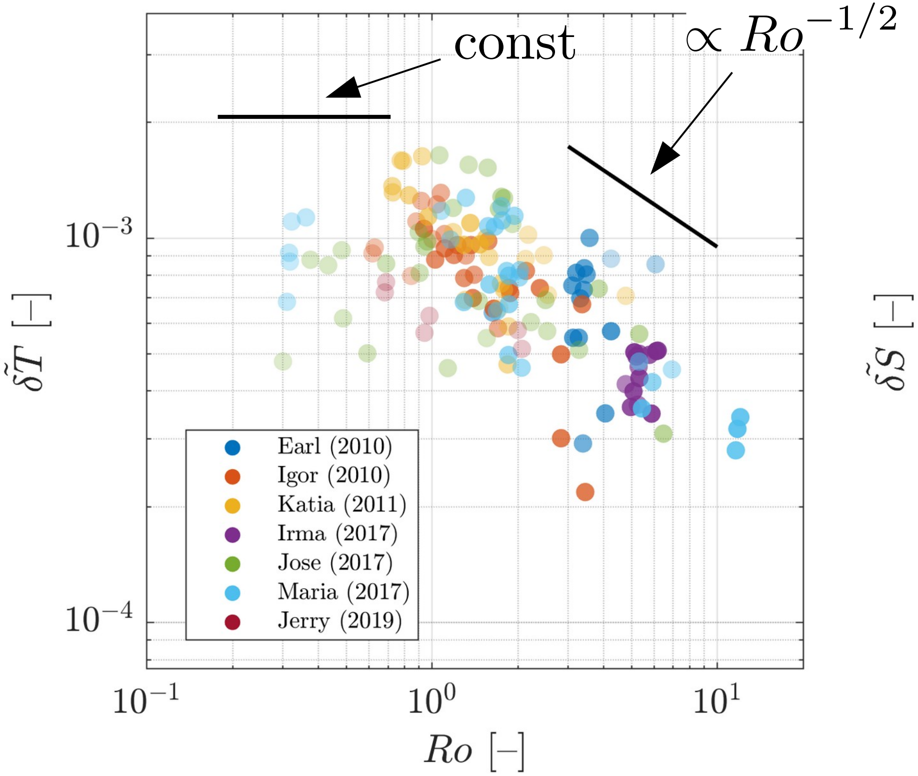
$$S_* = 2 \times 10^{-3} u_m/\sqrt{f N_{eff}}\bar{\Gamma}_S$$

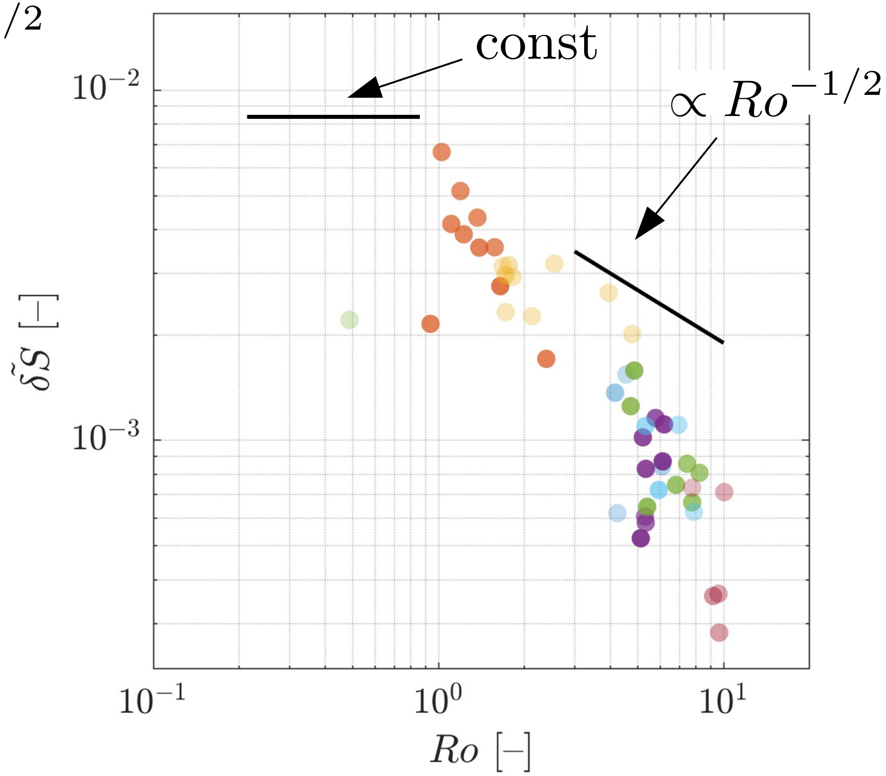
where u_m – maximum wind speed,
f – Coriolis parameter and

$$N_{eff}^2 = \frac{2}{h^2}\int_{-h}^{0} z N^2 dz$$

$$\bar{\Gamma}_S = \frac{2}{h^2}\int_{-h}^{0} z\frac{\partial S}{\partial z}dz \qquad \bar{\Gamma}_T = \frac{2}{h^2}\int_{-h}^{0} z\frac{\partial T}{\partial z}dz$$

Results





Transparency = best-track maximum wind speed:
from 10 m/s (transparent) to 85 m/s (opaque)

Conclusion

Main points:

- Thermal and haline responses to 7 major hurricanes passing over Amazon-Orinoco river plume were analyzed within a single simplified framework.
- Observations and model calculations confirm that the magnitude of SST and SSS anomalies is governed by magnitude of subsurface T and S gradients and TC translation speed.
- Influence of precipitation on SSS anomalies is rather weak for intense TCs.
- Obtained self-similar solutions give a possibility to predict SST and SSS anomalies based on TC's parameters and pres-storm stratification.

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Thank you for your attention!

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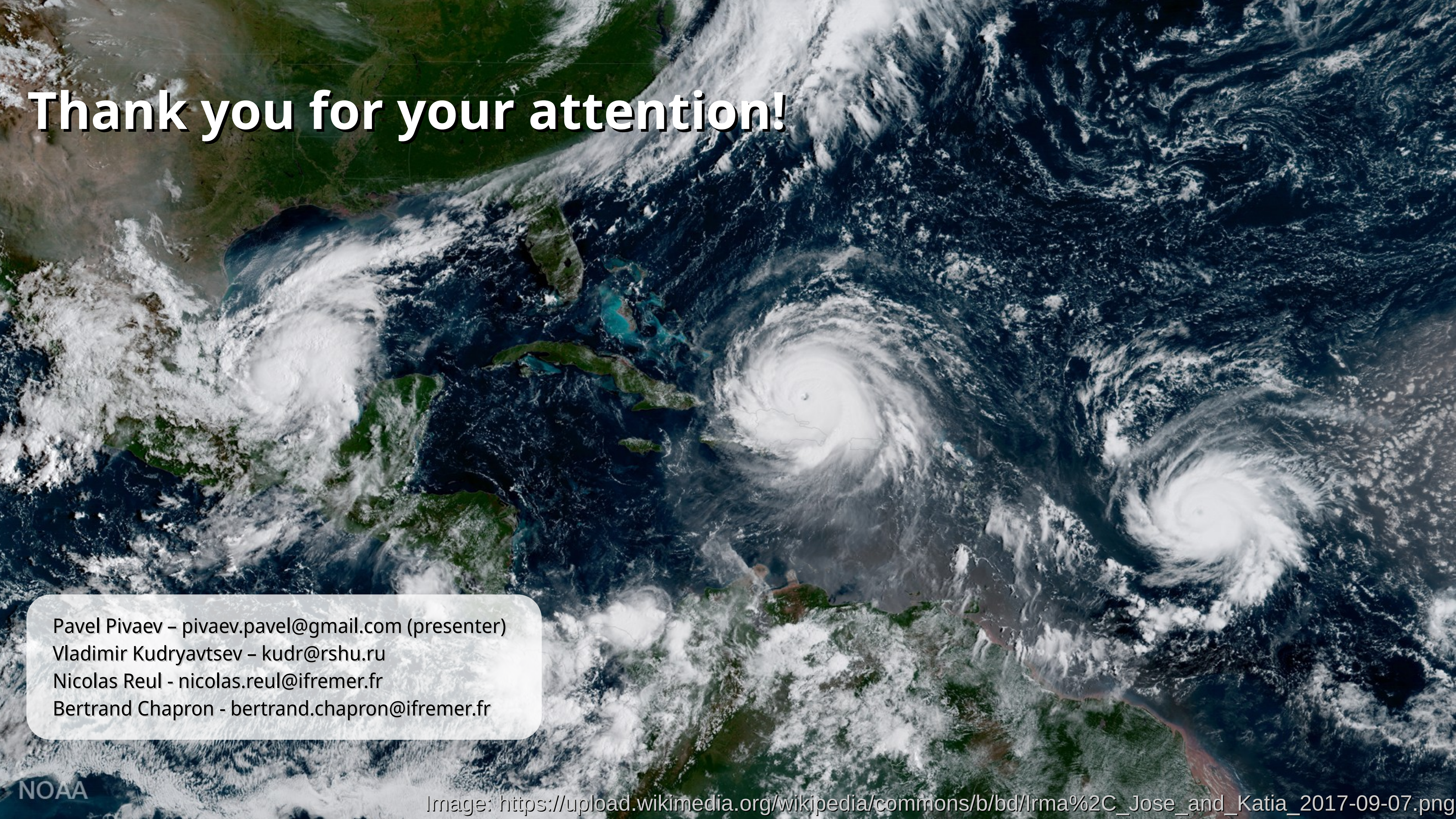

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