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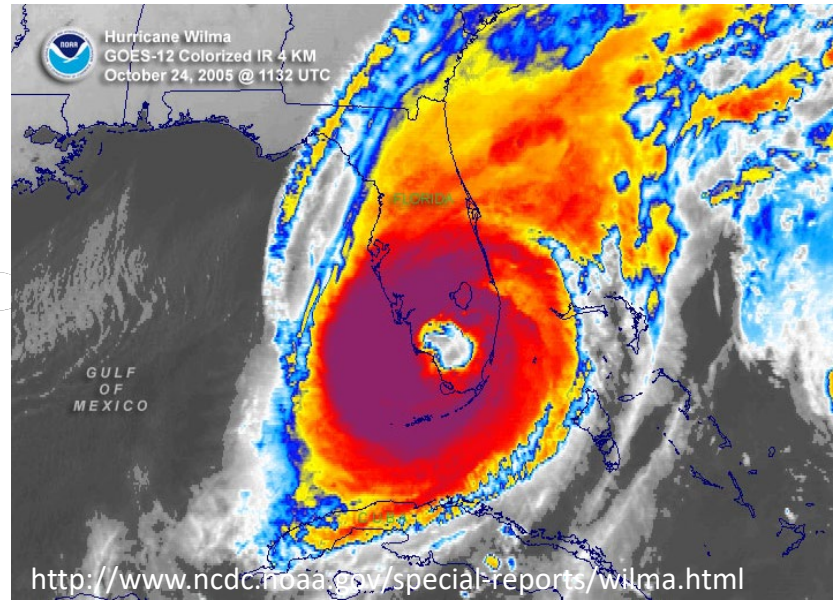


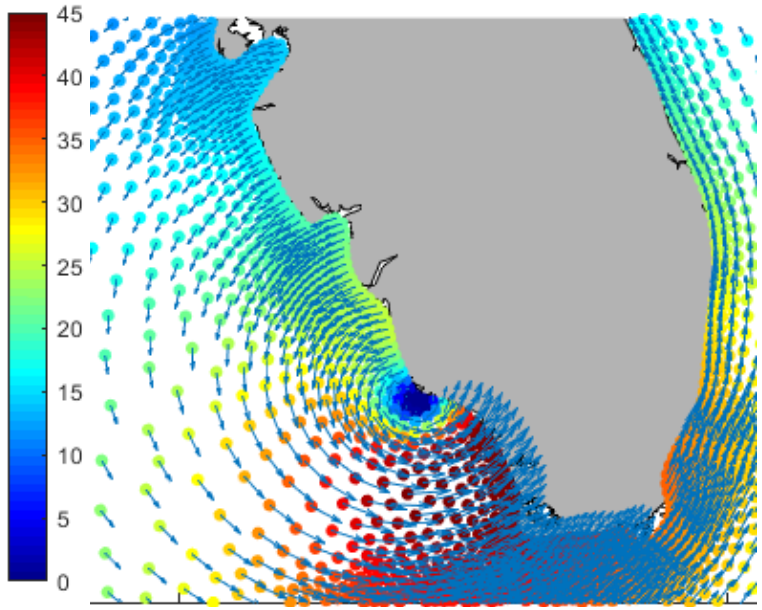


# Sensitivity of hurricane-induced storm surge to the atmospheric forcing input

25th September 2025

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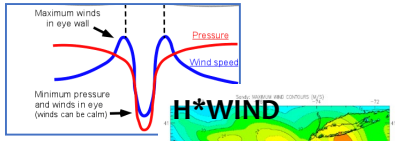
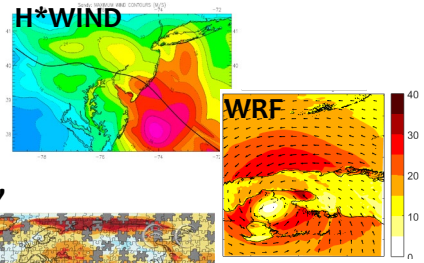
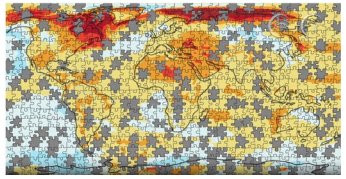
# 1. INTRODUCTION

- Accurate characterization of Tropical Cyclones (TCs) induced marine hazards essential for effective risk assessment, coastal management and related applications.
- The reconstruction of the associated winds is a key element. Wide range of approaches:
  - Parametric models,
    *Symmetric and asymmetric*
  - Kinematic methods,
    *H*WIND, IOKA*
  - Mesoscale weather models,
    *WRF, GFDL, MM5*
  - Reanalysis databases
    *ERA5, CFS, MERRA-2, JRA-55*

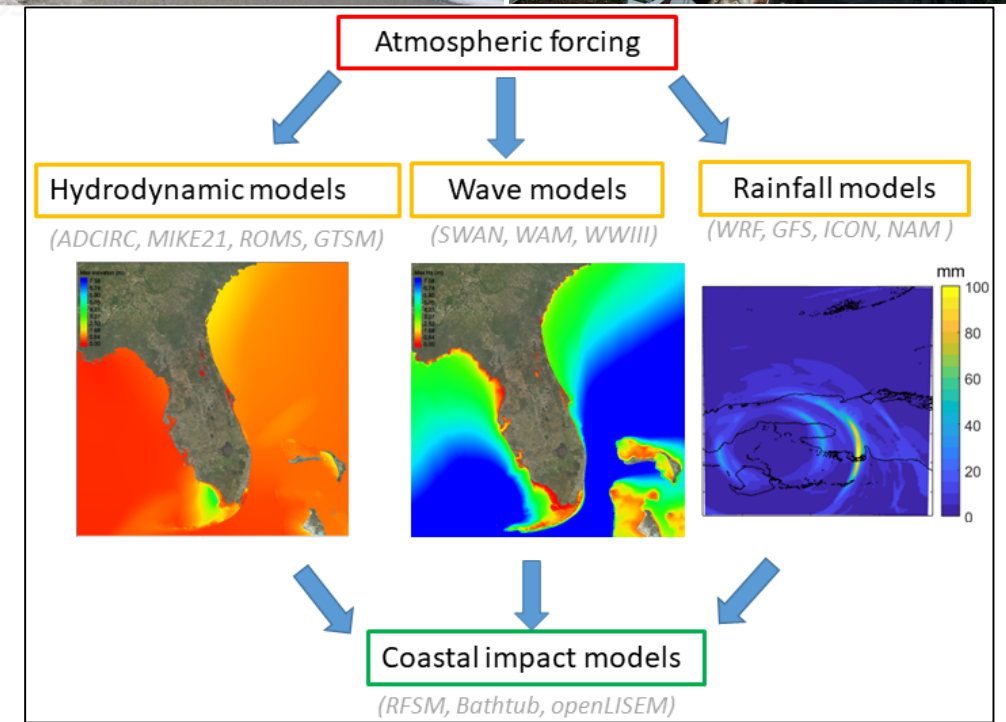


- The rapid advancements in computational capabilities, the growing availability of observational data, and the extensive number of published models and studies demand an update on the state-of-the-art in TC wind field reconstruction and its applicability to storm surge simulations.

**Goal:** Evaluating multiple approaches to characterize the TC wind field and the induced storm surge



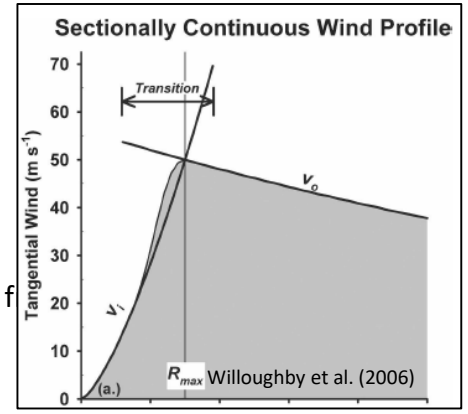
# 2. METHODS

## 1.- Wind and pressure fields reconstruction:

Best track data

**PARAMETRIC MODELS**

- **Dynamic Holland Model**
  - Holland model with the modifications f
  - Accounts for the translational speed
- **Willoughby et al. (2006)**
  - Sectionally continuous parametric profile (empirical functions)
  - Promising results (Ramsay et al., 2009; Kepert, 2006; etc).
- **Chavas et al. (2015)**
  - Physics-based model
  - **Emanuel (2004)** (inner region) + **Emanuel&Rotunno (2011)** (outer region)




**ERA5 Reanalysis**

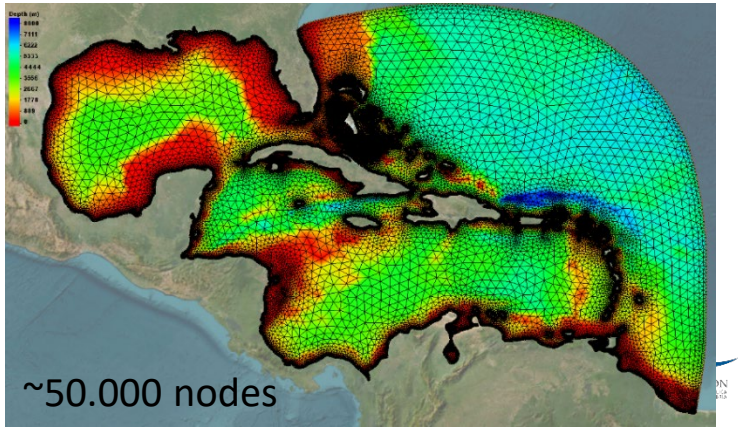
- Institution: ECMWF
- Spatial resolution: 0.25º x 0.25º
- Hourly temporal resolution
- From 1950 – present
- Reference: Herbasch et al. (2020)

| | Parametric models | Reanalysis databases |
|---|---|---|
| Pros | Simplicity, low computational cost, flexible resolution<br>Simulation of large number of synthetic events | Long and homogeneous dataset, more realistic<br>Simulation of the background wind field |
| Cons | Only approximations. Do not simulate the background wind field | Coarse resolution to resolve the TC characteristics |

## 2.- Hydrodynamic model:

ADvanced CIRCulation (Luettich et al., 1992)

- 2D barotropic mode.
- Unstructured grid with ~3 km resolution along the coastline.
- Set-up model similar as Chaigneau et al. (2024)
- Commonly applied for hurricane storm surge and flooding



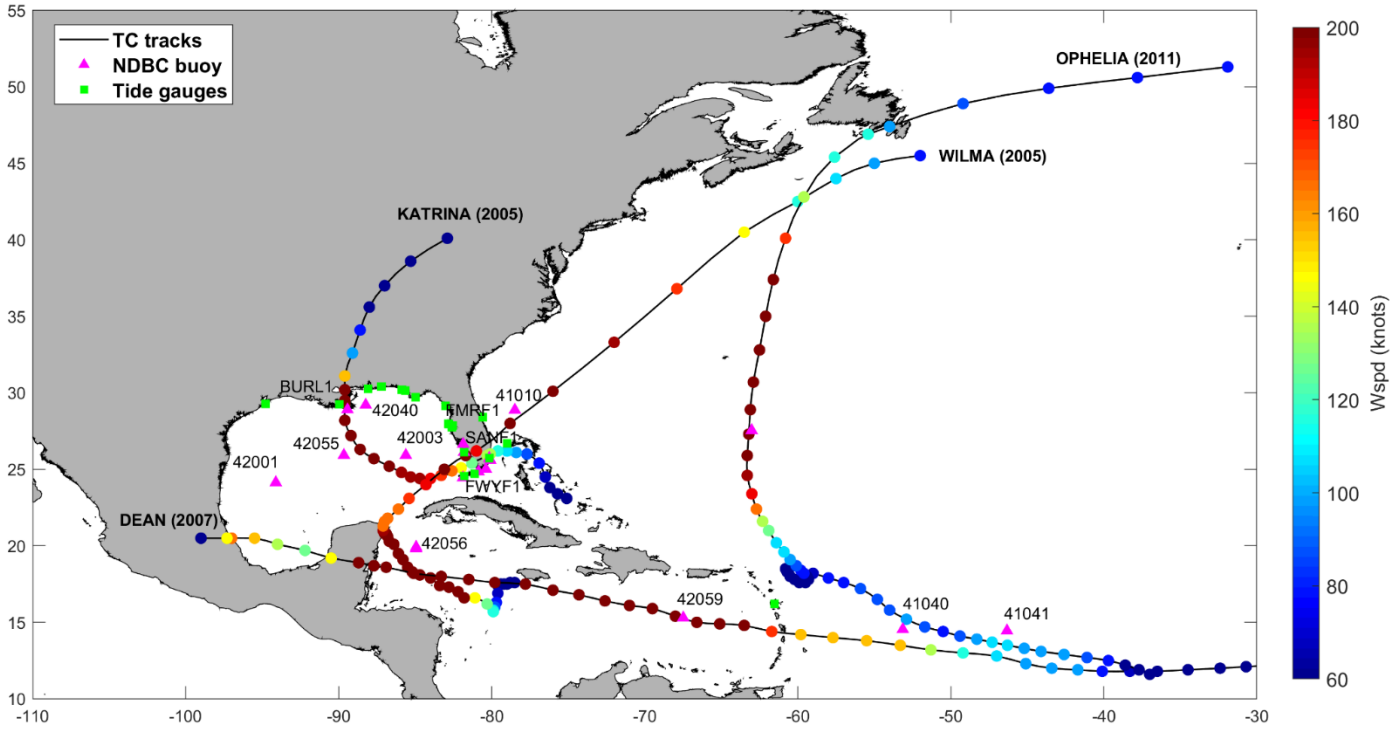
# 2. METHODS

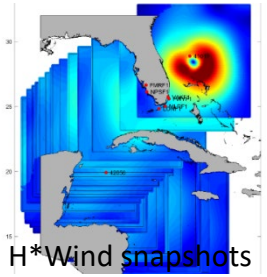
## 3.- Historical hurricanes:

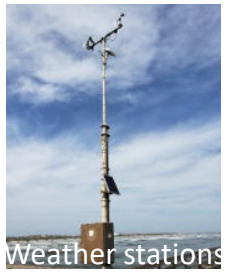
| Hurricane | Date | Wmax (km/h) | Pmin (mbar) |
|---|---|---|---|
| Katrina | 23-30 August 2005 | 278 | 902 |
| Wilma | 15 - 25 October 2005 | 296 | 882 |
| Dean | 14 - 23 August 2007 | 278 | 905 |
| Ophelia | 20-Sep to 3-Oct 2011 | 222 | 940 |

## 4.- Instrumental data:

| Source | Variable | Data type | Nº |
|---|---|---|---|
| NDBC | Wind speed and direction | Hourly time series | 21 |
| H*Wind | Wind speed and direction | Spatial wind fields on an 8º x 8º grid, ~6 h temporal resolution. | |
| GESLA3 | Storm surge | Hourly time series | 31 |

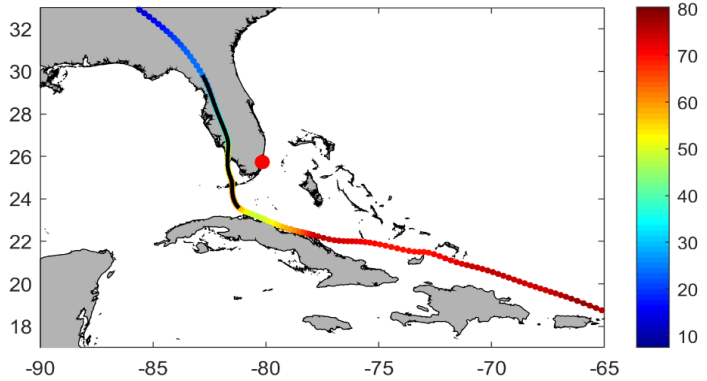


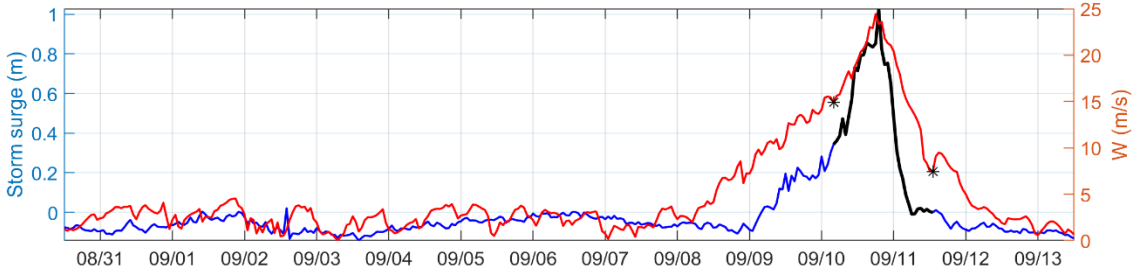


H*Wind snapshots


Weather stations


Tide gauges

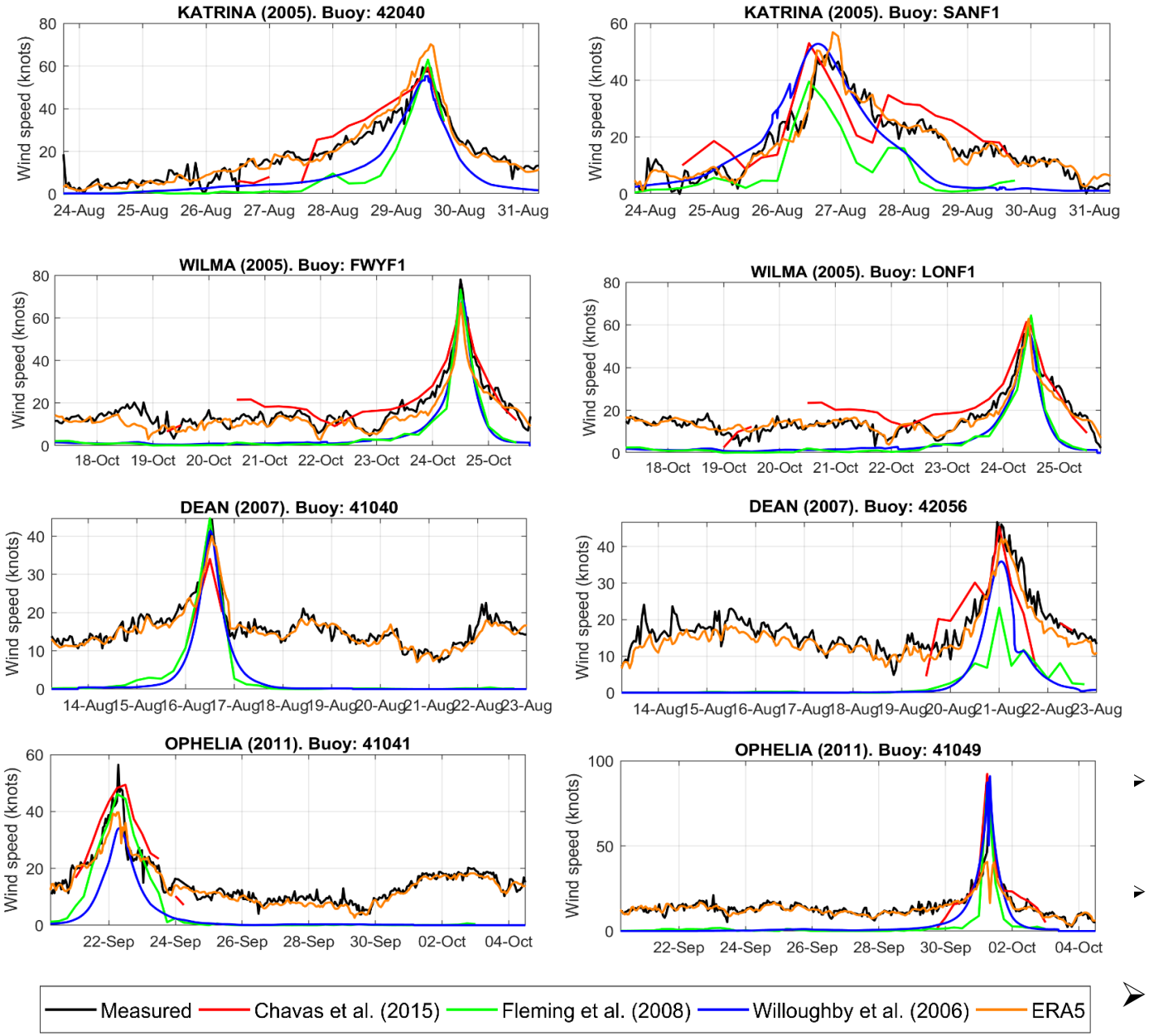
## 5.- Extreme Event Definition:

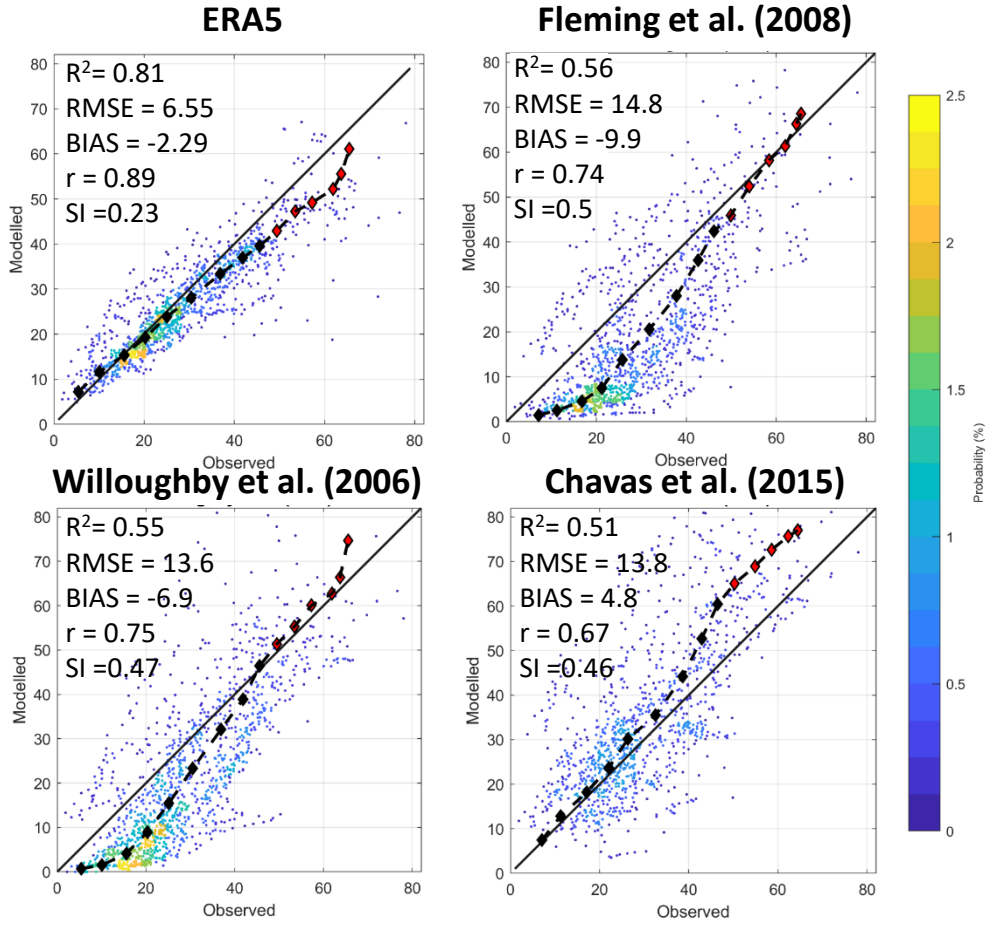





**Definition of Extreme Event**: Based on the wind speed time series, using values above the 95$^{th}$ percentile around the peak.

# 3. RESULTS – Temporal series of Wind speed




- **ERA5** provides the **best results** (r=0.89, RMSE= 6.5 knots) although underestimates Wmax.
- **No** significant **differences** among the **parametric models** (r=0.68-0.75; RMSE= 13.5 – 14.8 knots).
- Highly **variable performance** depending on the event and the distance from TC center.

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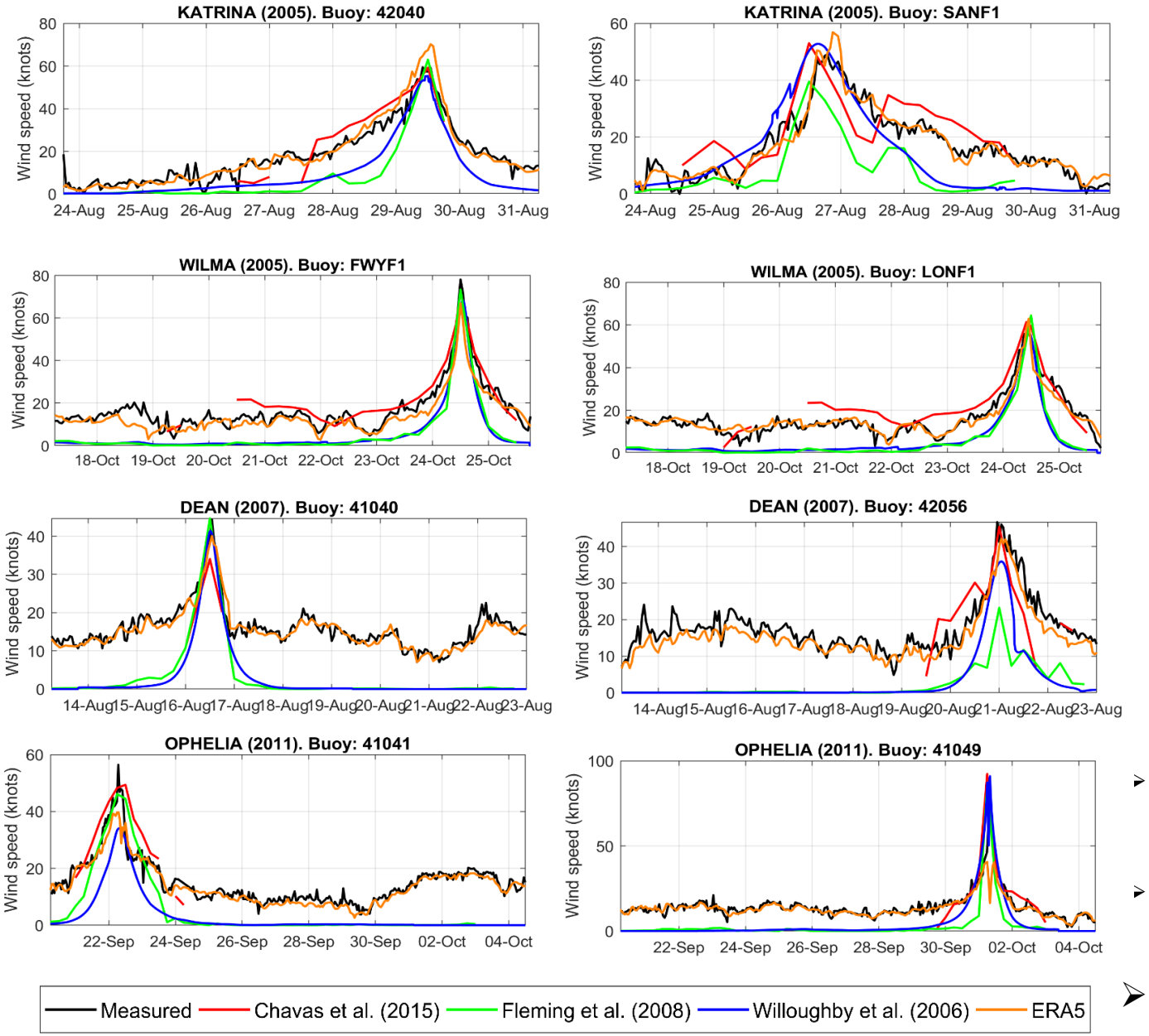


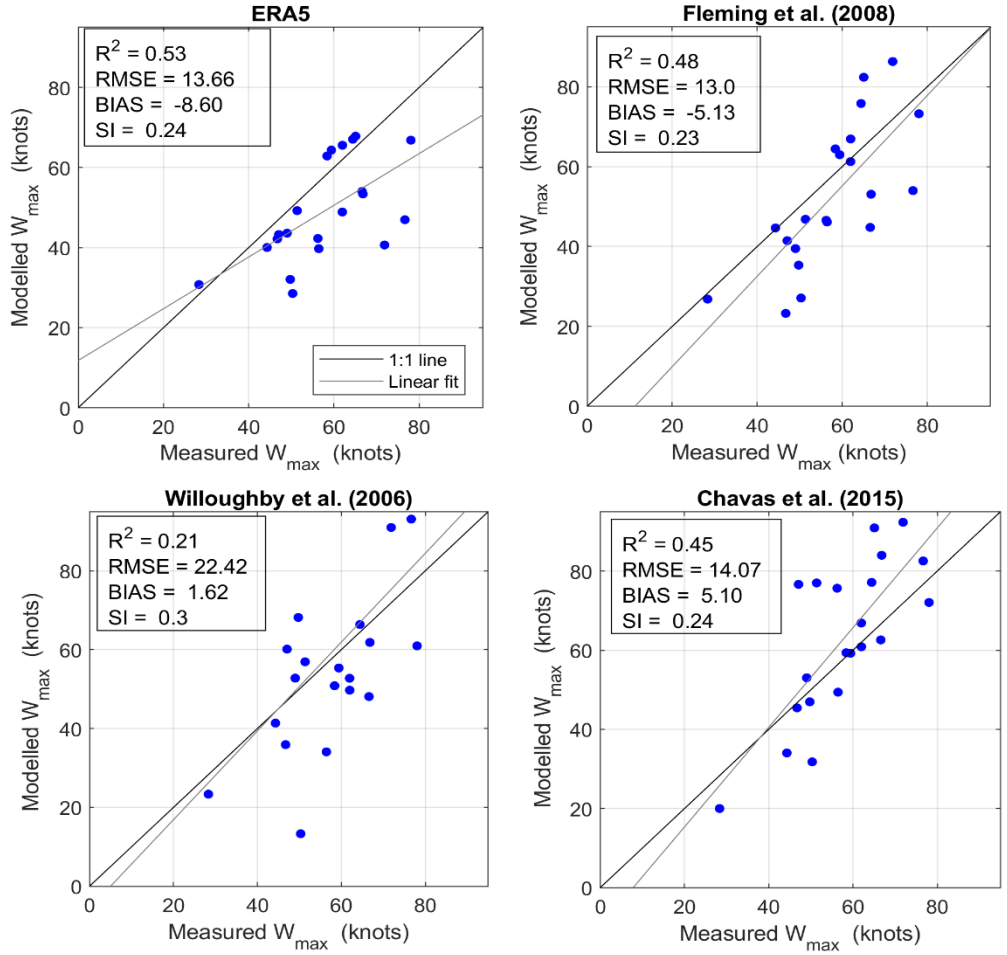


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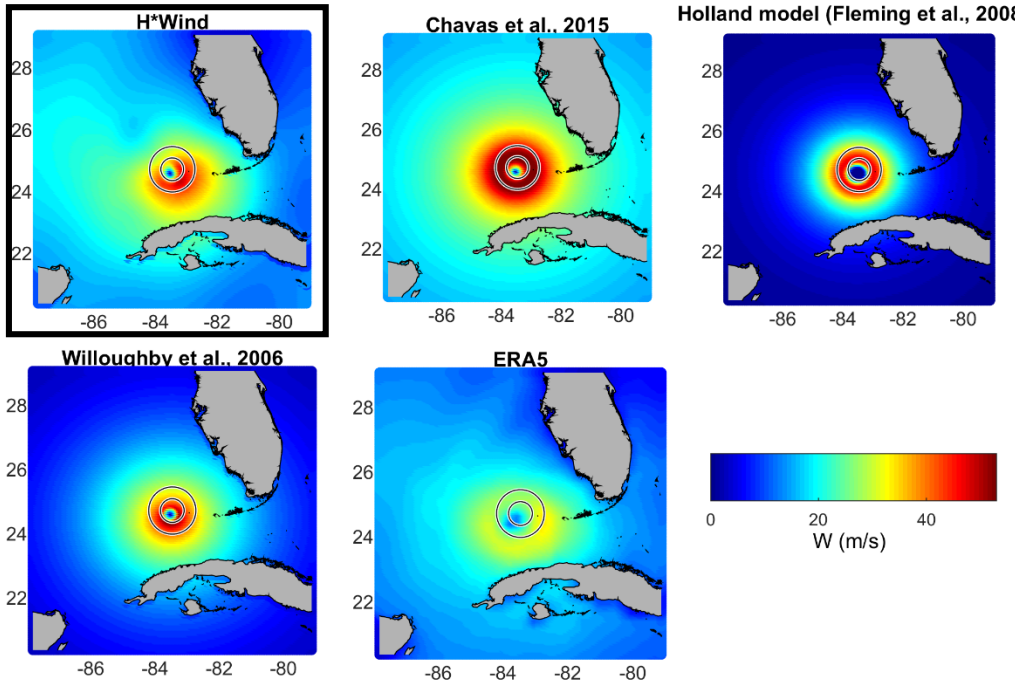
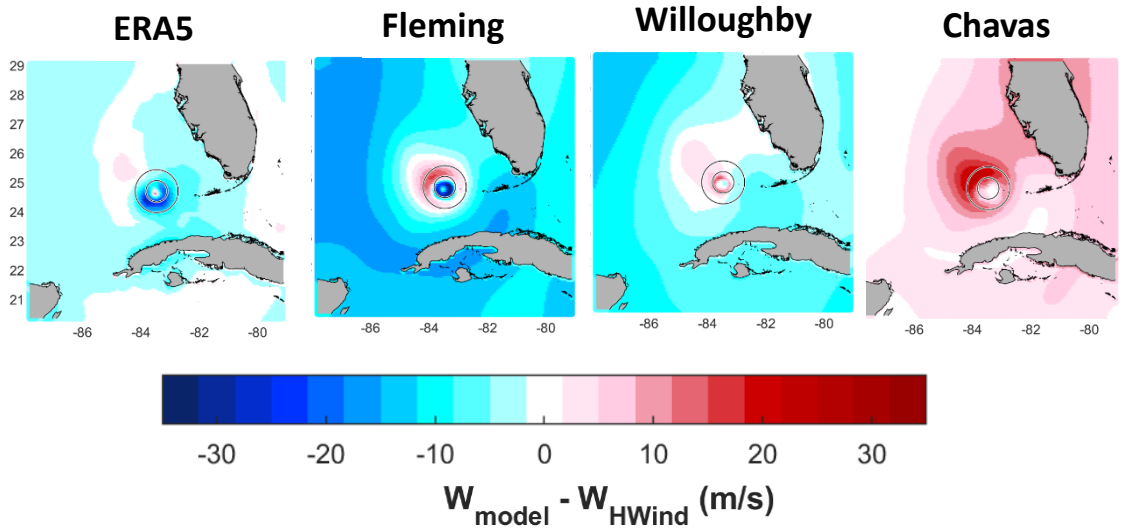
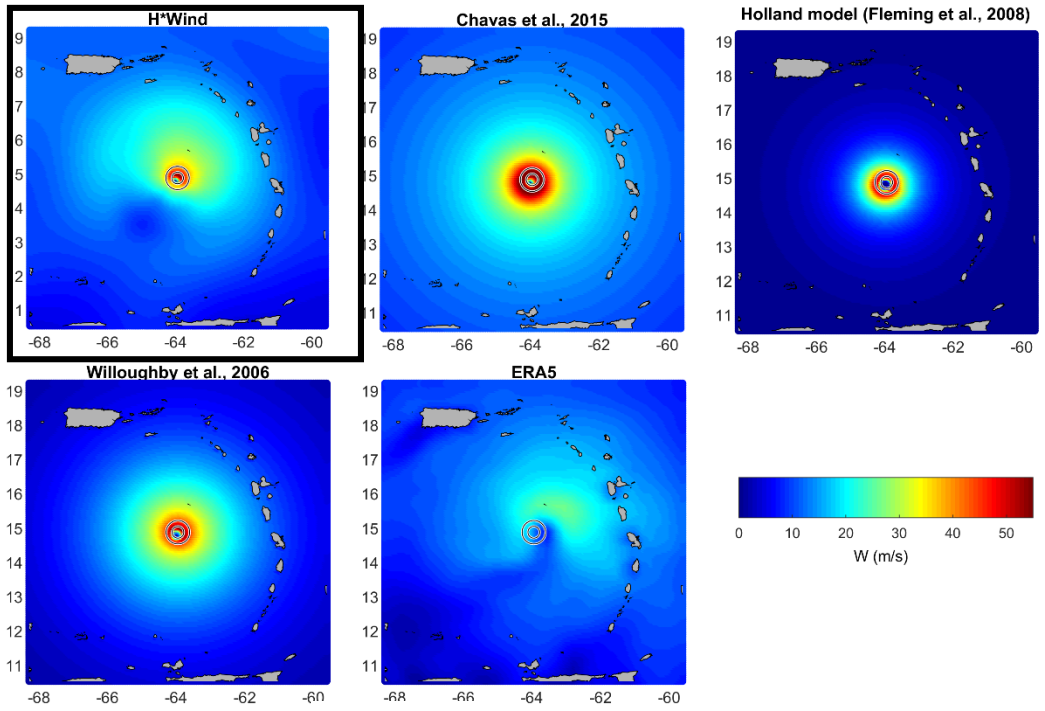
# 3. RESULTS– Spatial Wind field

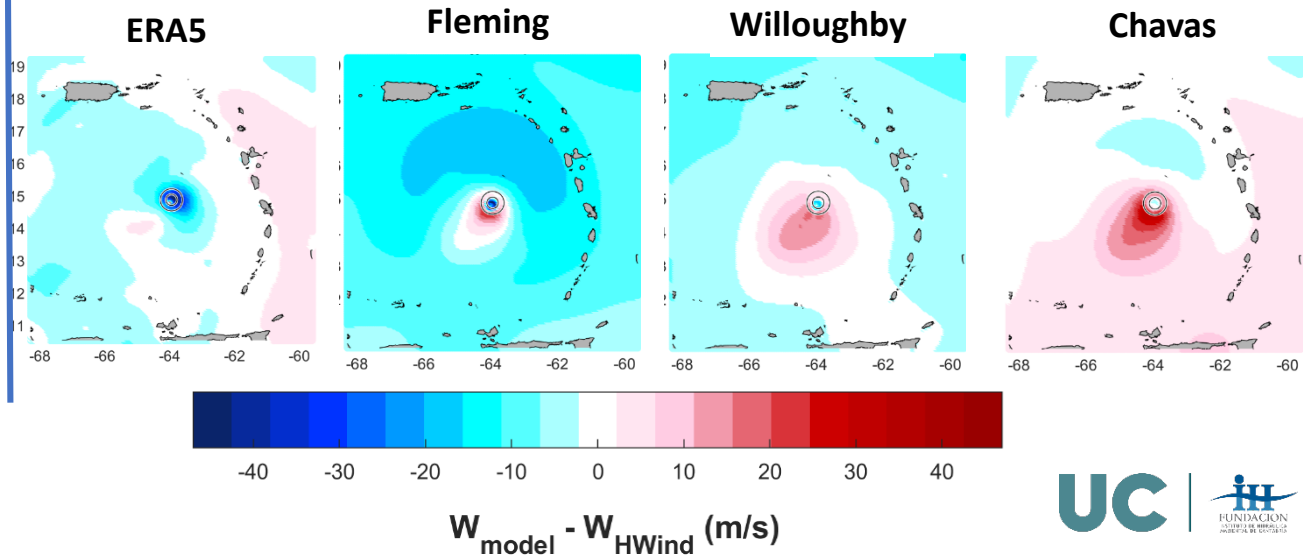
## Wilma hurricane. 24 Oct 2005, 04:30 UTC




## Dean hurricane. 17 August 2007, 19:30 UTC



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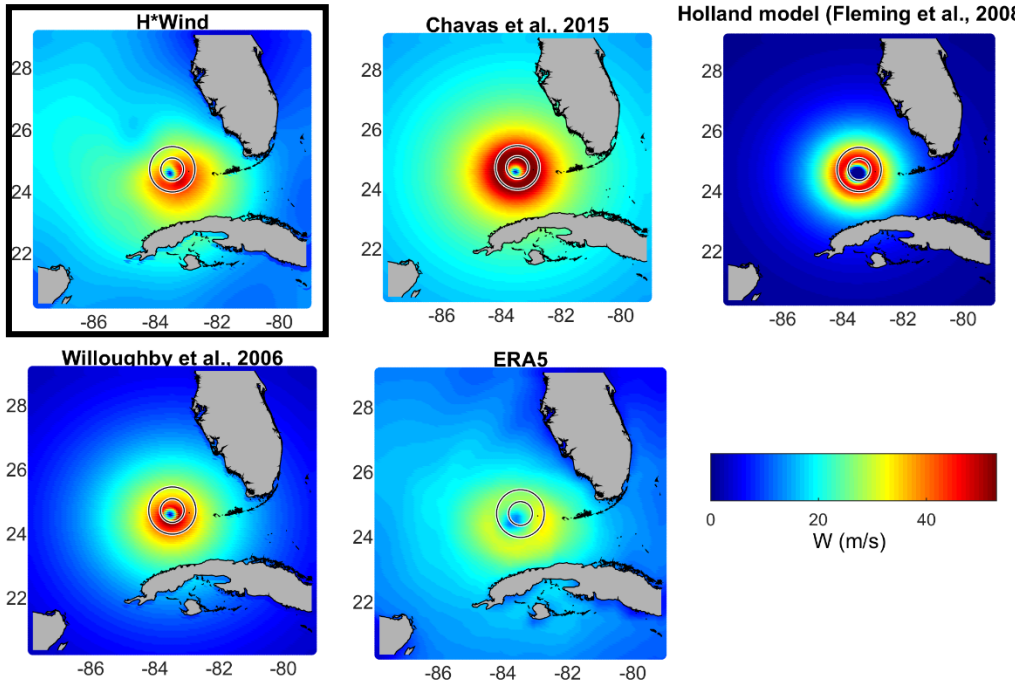


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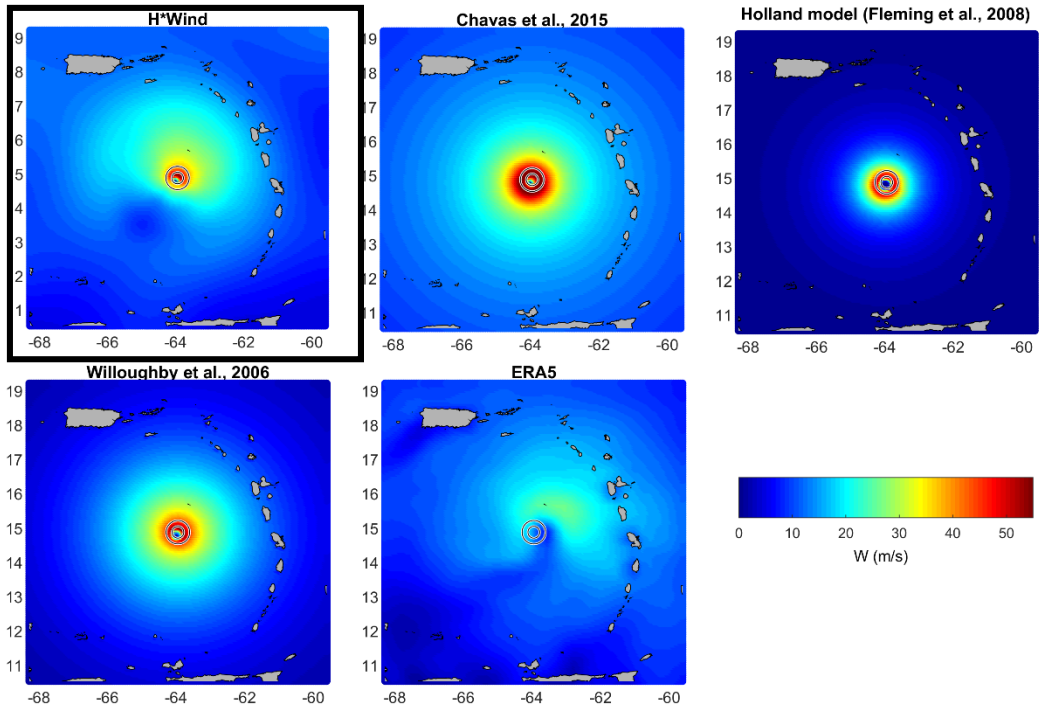
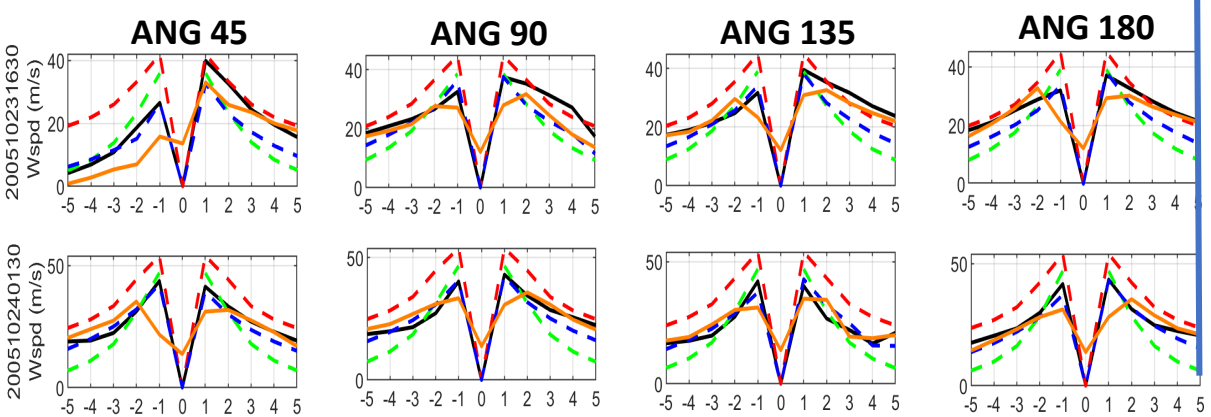
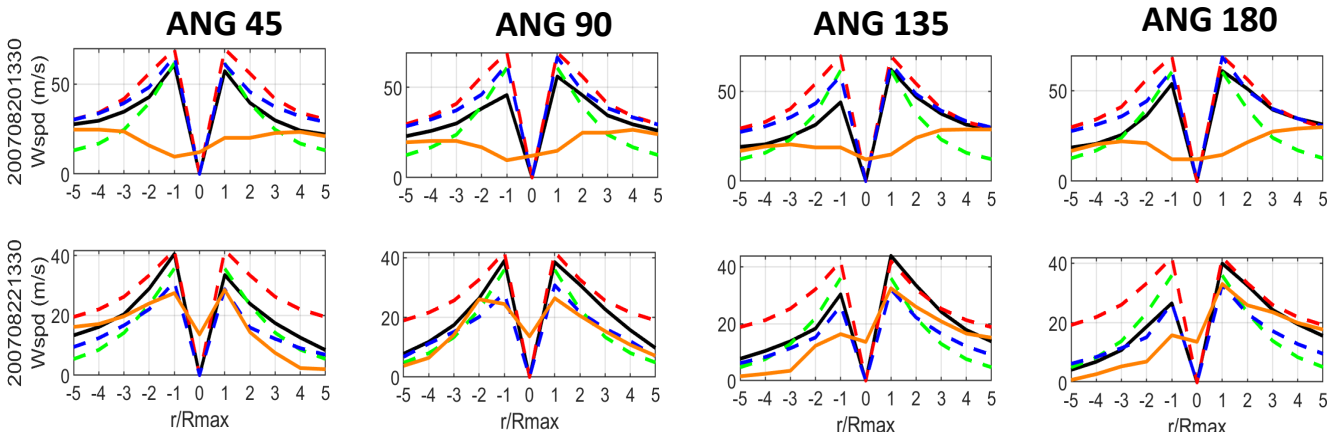


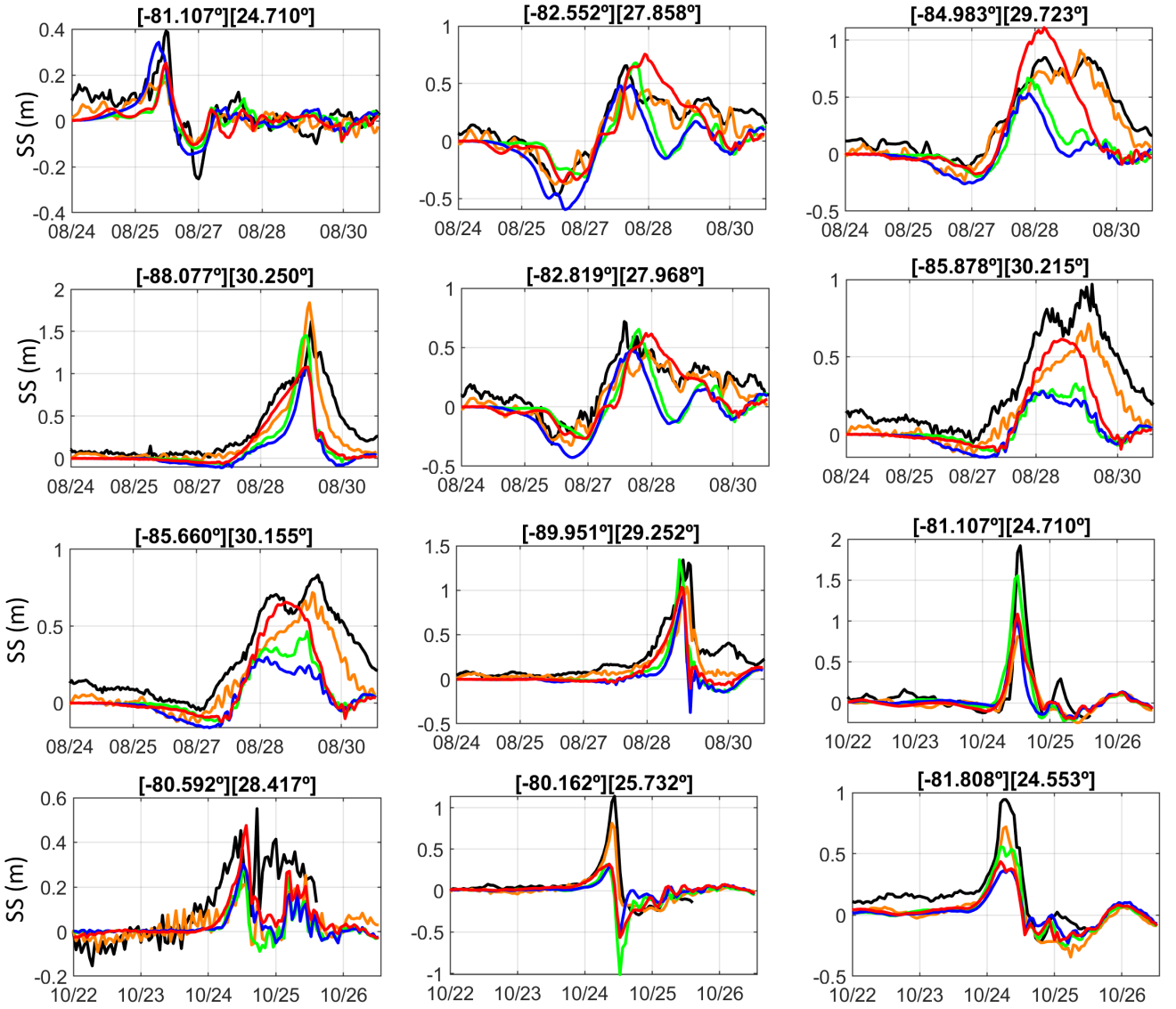



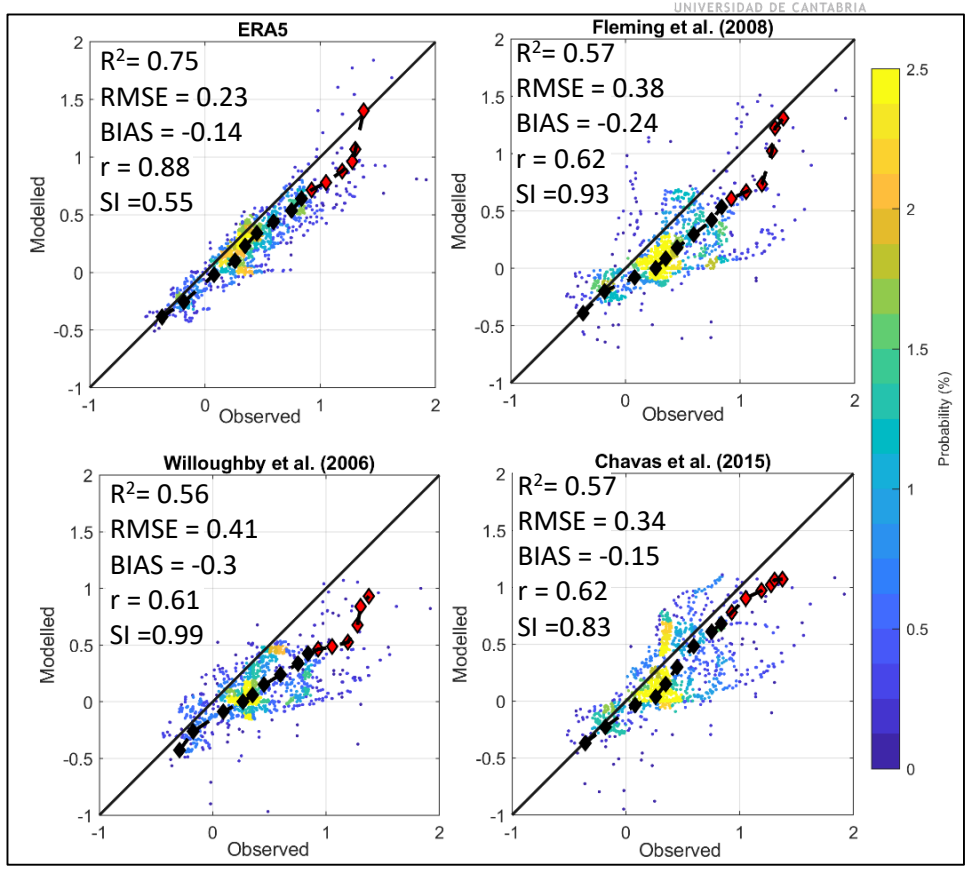

H*Wind — Chavas (2015) — Fleming (2008) — Willoughby (2006) — ERA5

# 3. RESULTS – Time Series of Induced Storm Surge

Katrina (2005)

Wilma (2005)




- **ERA5** demonstrates **strong skill** in reproducing the extreme event ($R^2$ = 0.75, BIAS = −0.14 m).
- **Highly variable accuracy** of the **parametric models** depending on several factors, such as distance to TC center, location of the tide gauge relative to the storm...

# 3. RESULTS – Time Series of Induced Storm Surge

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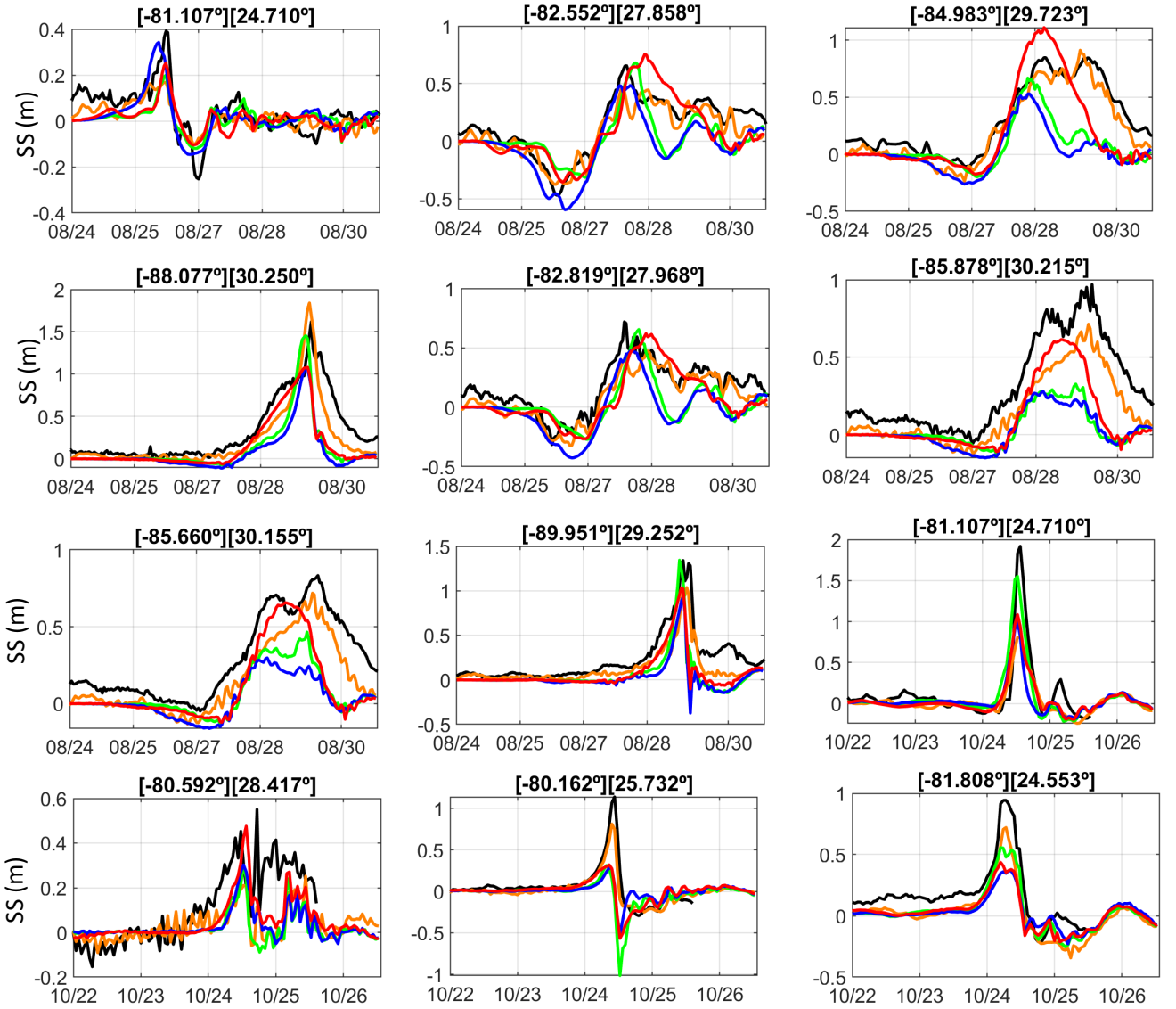
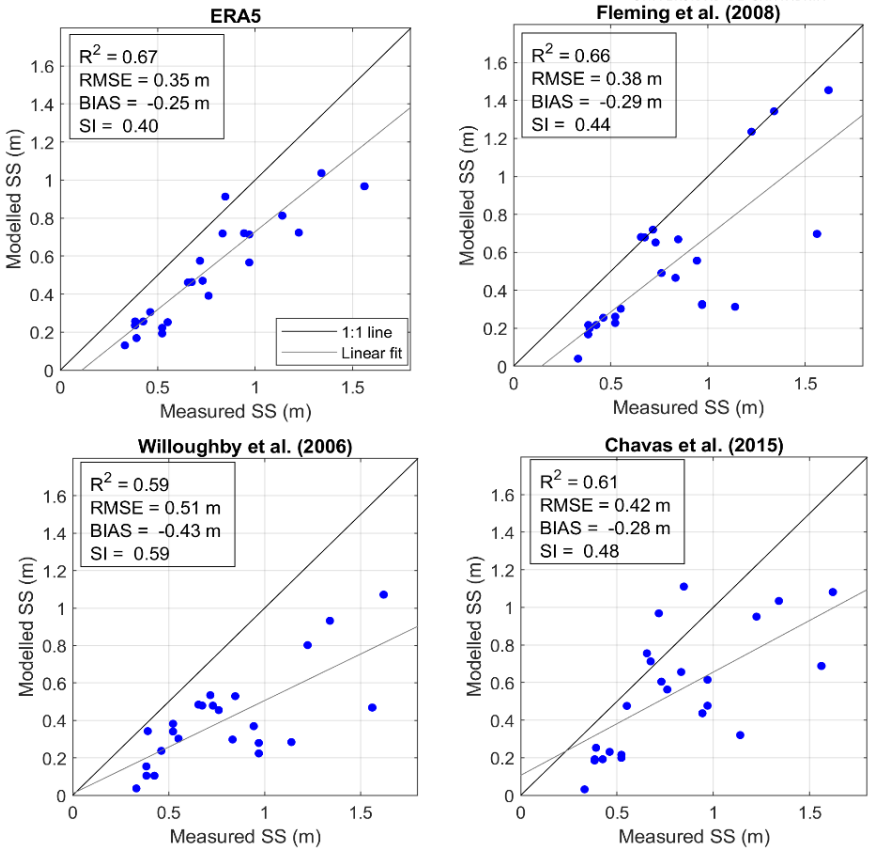
Katrina (2005)

Wilma (2005)

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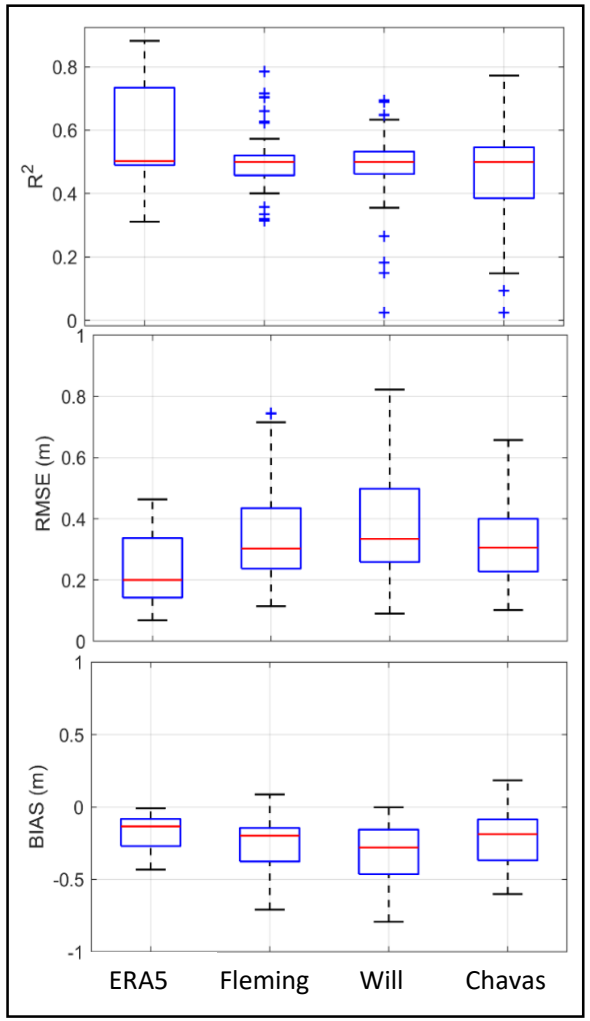
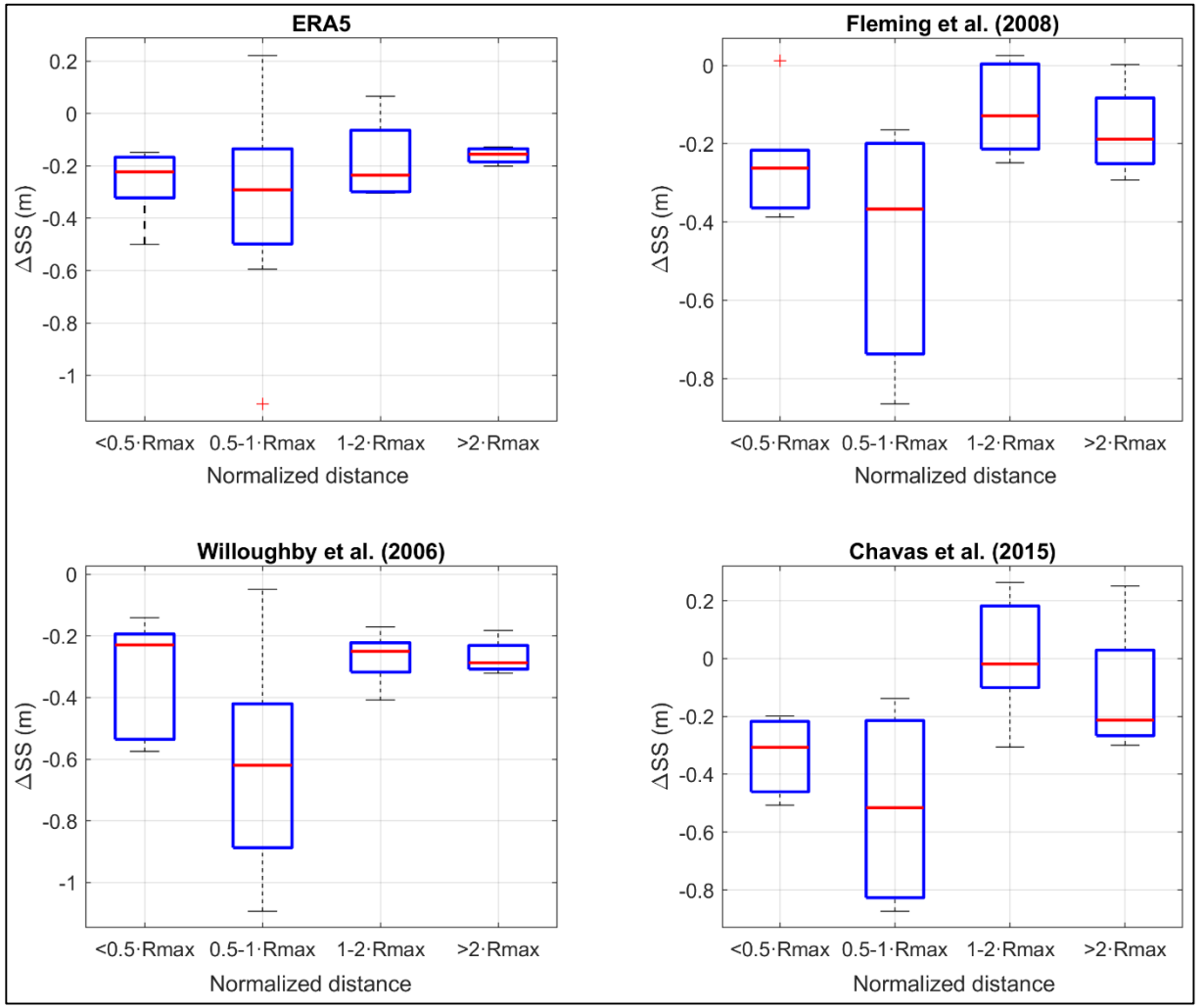
# 3. RESULTS – Error in Storm Surge simulations

## Summary



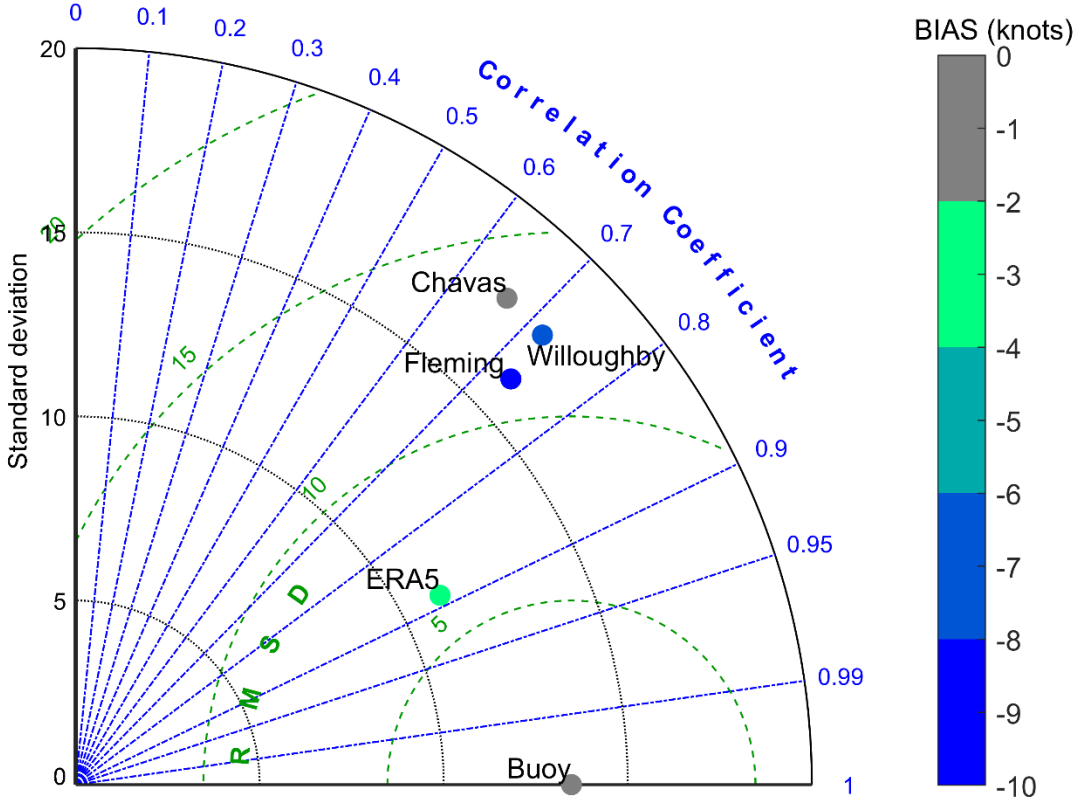

## Error *vs* Distance to TC center



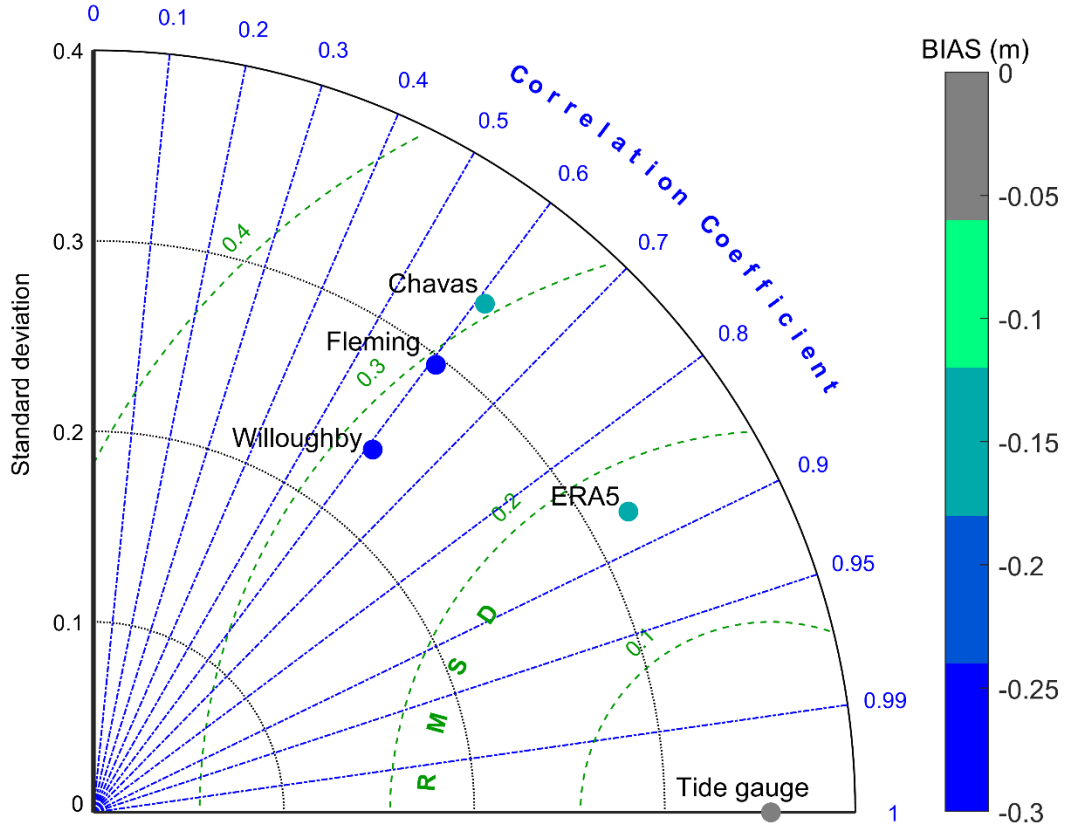

- Minor differences observed among the error metrics for the various parametric models. **Chavas** et al. (2015) shows the **smallest bias** (−0.15 m), while **Willoughby** et al. (2006) exhibits the **largest** (−0.3 m).
- Poorest parametric model performance at **r < Rmax** and best between **Rmax < r < 2·Rmax**

# 3. RESULTS – Summary of model performances

## Wind speed




## Storm surge




- **ERA5** shows **highest correlation** and **lowest RMSD** for both wind speed and storm surge.
- Similar correlation and RMSD values for the parametric models, although **Chavas et al. (2015)** shows the **lowest bias** and a standard deviation closely matching that observed in the tide gauge records.

# 4. CONCLUSIONS

→ A sensitivity analysis was conducted of different methods for reconstructing the TC-associated wind field in the Tropical Atlantic region, and their suitability as forcing in storm surge models.

→ The best results were obtained with the ERA5 reanalysis, due to its better representation of the analyzed historical hurricanes and the large volume of assimilated data.

→ Although ERA5 does not fully capture the TC radial wind profile and tends to underestimate the maximum wind speed, it still provides the most accurate results when compared with wind and storm surge measurements.

→ No single parametric model consistently outperforms the others. Their performance varies depending on the specific event and the location relative to the storm track.

→ Future work:

- Extend the analysis with additional hurricanes
- Conduct a similar analysis in other oceanic basins where ERA5 assimilates less data, and where these parametric models have yet to be evaluated.

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# Thank you

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