

Advancing Storm Surge Modelling in the northern Indian Ocean

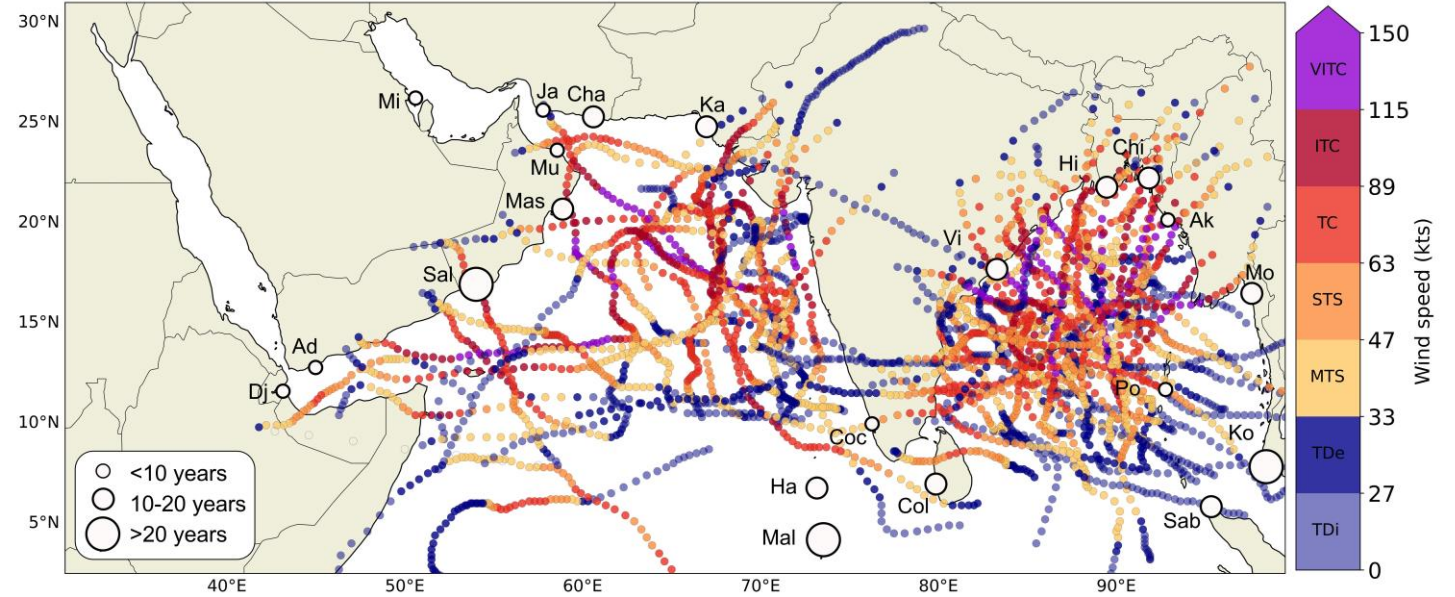
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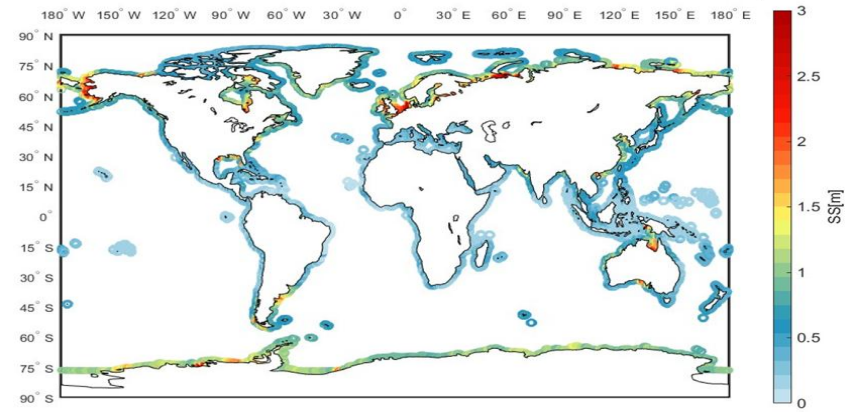
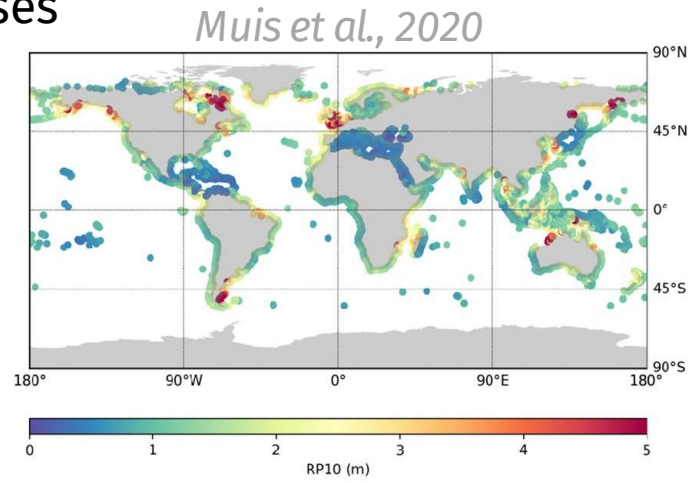
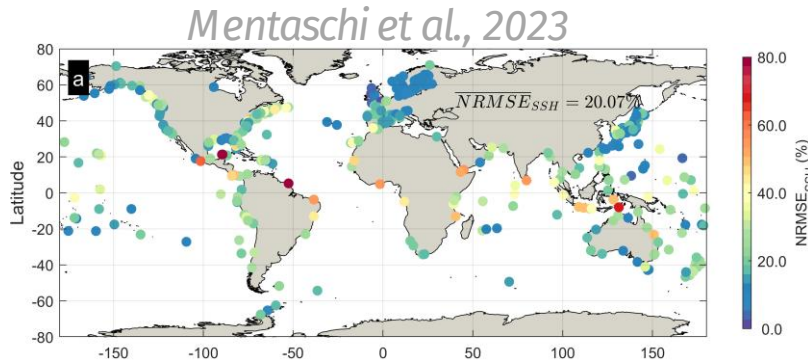
**International Workshop on Waves,
Storm Surges and Coastal Hazards
Santander
23/09/2025**

MOTIVATION

- Northern Indian Ocean experiences intense tropical cyclones and associated storm surges (*Khan et al., 2022, Leijnse et al., 2022, Sreeraj et al., 2022, Blakely et al., 2025*)
- Tide gauge records are scarce, often short in duration, and sometimes missing, highlighting the need for ocean modelling (*Haigh et al., 2023*)
- Existing global storm surge databases using 2-D barotropic models :

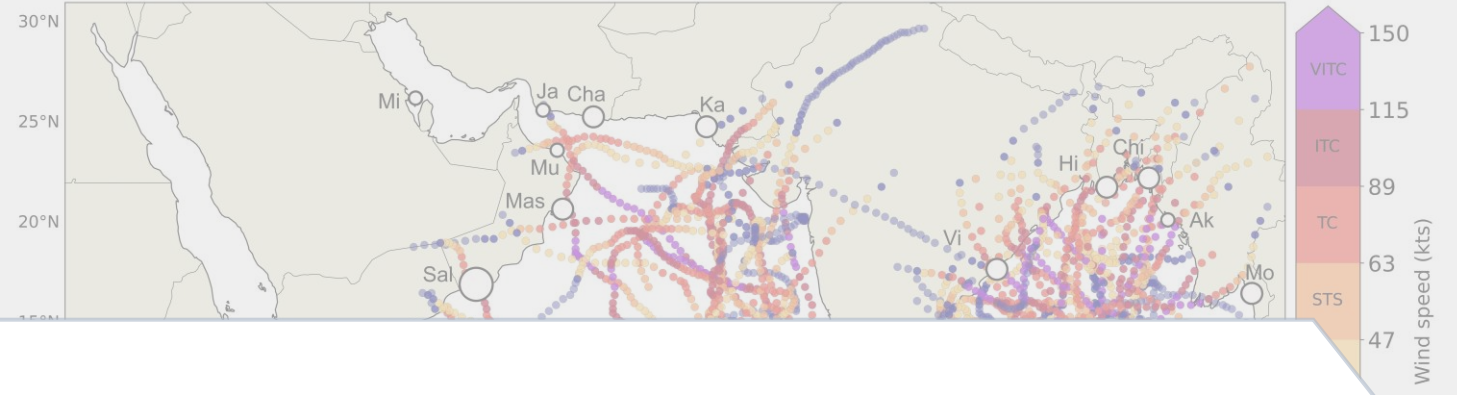


Elsy Ticse et al., — Waves (Presentation, Tuesday 23 Sept. 2025)



MOTIVATION

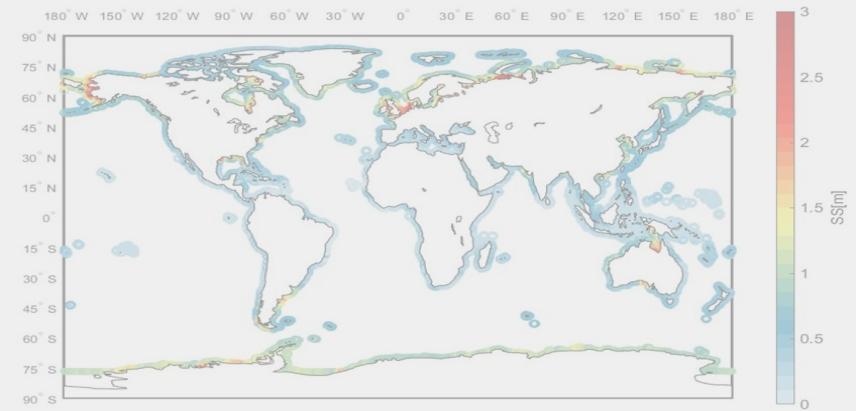
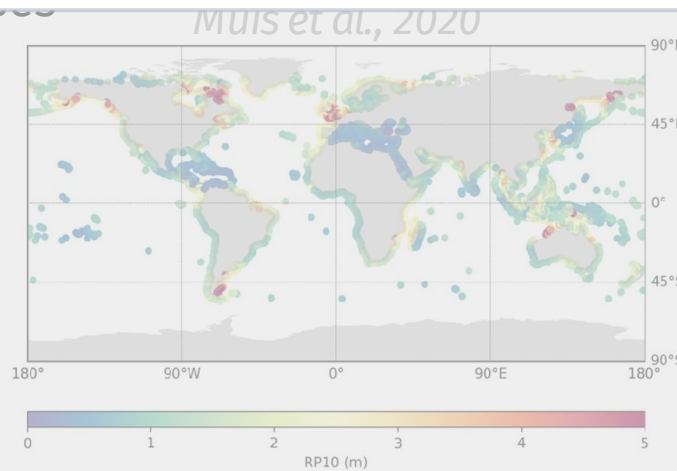
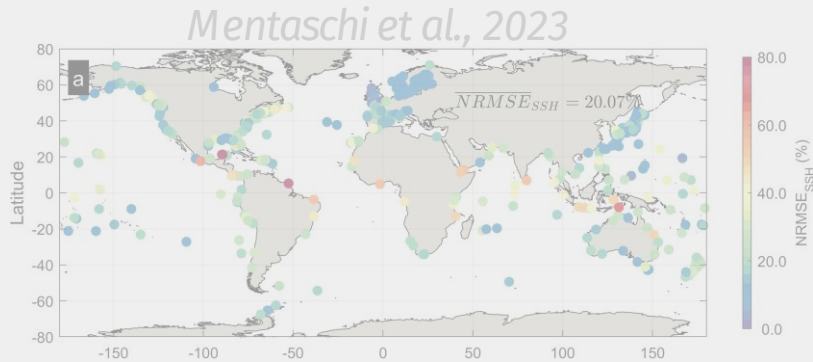
- Northern Indian Ocean experiences intense tropical cyclones and associated storm surges (*Khan et al., 2022, Leijnse et al., 2022, Sreeraj et al., 2022, Blakely et al., 2025*)



QUESTION:

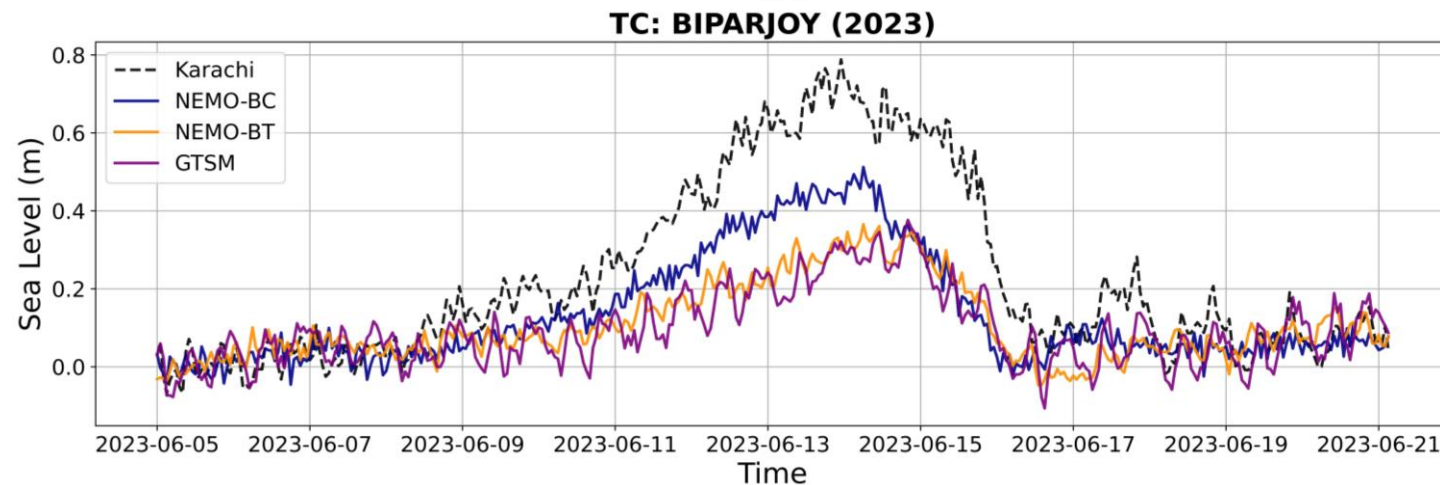
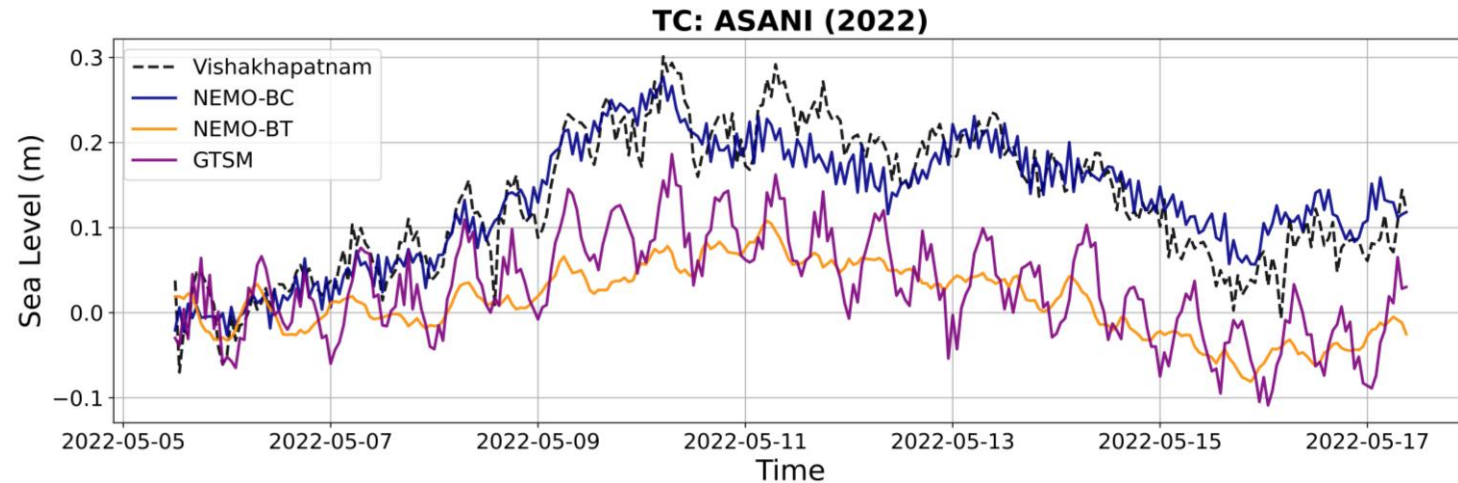
Importance of baroclinic dynamics for storm surge modelling in the northern Indian Ocean ?

Existing global storm surge databases using 2-D barotropic models :



NEW REGIONAL 3-D BAROCLINIC DATABASE FOR THE NORTHERN INDIAN OCEAN

- Time period: 1993-2023
- Model/configuration: NEMOv4.2, ~8-9 km, 75 vertical levels
- Forcings: ERA5 for atm., GLORYS2v4 for 3-D ocean, and FES2014 for tides
- Hourly sea level outputs including: storm surges, tides, mean sea level



CONTEXT AND MOTIVATION

- Northern Indian Ocean experiences intense tropical cyclones (TCs) and associated storm surges^[1-4].

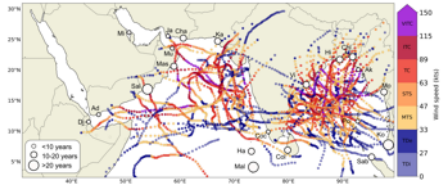


Fig. 1 | Historical TCs from IBTrACS^[5,6] (1993-2023). Circles indicate tide gauge stations from University of Hawaii Sea Level Center (UHSLC)^[7] used for storm surge validation.

- Existing storm surge hindcast databases using 2-D barotropic models, allowing high spatial resolution while maintaining computational efficiency^[8-10].
- 3-D baroclinic ocean general circulation models are state-of-the-art, but remain limited for assessing TC-induced storm surges^[11].

Question: Importance of baroclinic dynamics for storm surge modelling in the northern Indian Ocean?

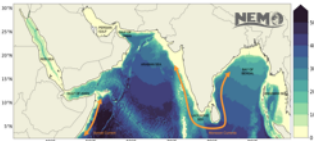
DYNAMICAL DOWNSCALING

Existing storm surge hindcasts used in the study:

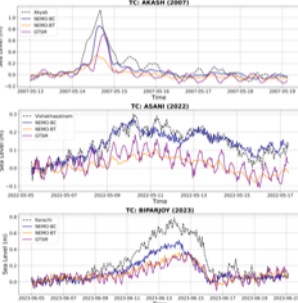
- GTSM:** Reanalysis GTSMv3.0^[12-14] (1950-2024) from Copernicus Climate Change Service, 3-D barotropic, forced by winds and pressure from ERA5^[12], global irregular grid up to 2.5 km.
- NEMO-BT:** (GOS, Global Ocean Surge)^[15] by Xiao et al., — Waves (Presentation, Tuesday 23 Sept. 2023)^[16] (1993-2025) from IH-Data based on NEMOv4.0.6^[17], 2-D barotropic, forced by winds and pressure from ERA5^[12], global curvilinear grid, up to 12 km.

NEMO-BC, our new database:

- Time period: 1993-2023 (hourly outputs)
- Model: NEMOv4.2.2^[18], regional configuration, ~8-9 km (curvilinear grid 1/12⁵), 3-D baroclinic (75 vertical z-levels)
- Forcing: 8 atmospheric variables from ERA5^[12] at the surface, CLORYS2v4^[19] for 3-D ocean (T,S,U,V,SSH) and FES2014^[14] for tides.

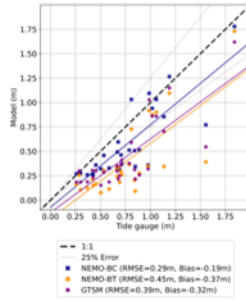


COASTAL IMPROVEMENTS OF THE NEMO-BC BAROCLINIC HINDCAST



- Selection of storm surges with an amplitude > 25 cm and within a 500 km radius from the TC track.
- Improvement not only in the amplitude of the maximum storm surges but also in the overall shape of the surge peak.

Fig. 2 | Time series of observed and modelled storm surges at 3 tide gauges locations for 3 TCs.



- Validation of maximum storm surges from TCs at all tide gauge stations.
- NEMO-BC shows improvement in RMSE by 18 cm (10 cm) and in bias by 15 cm (13 cm) compared to NEMO-BT (GTSM).
- Improvement observed across all amplitudes.

Fig. 3 | Scatter plot comparing modelled maximum storm surges from TCs with tide gauges^[7]: in blue NEMO-BC, in yellow NEMO-BT, and in purple GTSM.

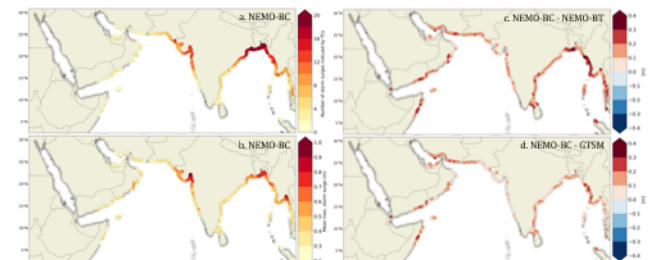


Fig. 4 | a) Number of modelled storm surges due to TCs. b) Mean of maximum of storm surges due to TCs in the NEMO-BC baroclinic hindcast. c), d) Differences with NEMO-BT and GTSM barotropic datasets.

The coast of Myanmar is identified as the most affected region, with an average surge amplitude increase of up to +40 cm across 12 tropical cyclones.

KEY POINTS

- In general, the baroclinic hindcast shows larger storm surge amplitudes induced by tropical cyclones.
- There is a significant improvement in reducing underestimations when compared with tide gauge observations.

REFERENCES

[1] Khan et al., 2022 [9] Dullaart et al., 2020
 [2] Leijse et al., 2022 [10] Mentaschi et al., 2023
 [3] Sreeraj et al., 2022 [11] Chaigneau et al., 2024
 [4] Blakely et al., 2025 [12] Hersbach et al., 2020
 [5] Knapp et al., 2010 [13] O'Neill et al., 2016
 [6] Galban et al., 2024 [14] Madec et al., 2023
 [7] Caldwell et al., 2015 [15] Garric et al., 2017
 [8] Muis et al., 2020 [16] Lyard et al., 2020

COME AT THE POSTER SESSION !!

+ validation against tide gauges
 + impact for all simulated tropical cyclones

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