SUMBMITED ABSTRACT:

Numerical modelling of the Bay of Bengal Tropical Cyclone Characteristics during 2001-20 and the impact of scatterometer winds

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ABSTRACT

The paucity of observational data over the North Indian Ocean (NIO) region poses significant challenges in effectively monitoring and forecasting extreme weather events such as tropical cyclones (or TCs). Since direct observational measurements of dynamic and thermodynamic variables at different atmospheric levels are insufficient to provide a deeper understanding of the interacting forces, a numerical modelling-based approach is needed to address the synoptic scale convective processes. The present study aims to investigate the characteristic features of the Bay of Bengal (BOB) TCs through the Weather Research and Forecasting (WRF) modelling framework that includes three-dimensional variational data assimilation (3DVAR). And intends to focus on various ocean, atmosphere, dynamics, thermodynamic, or physical characteristics to understand the TC characteristic differences pertaining to the distinct intensification, genesis locations, and seasonality. In the process, the impact of the assimilation of scatterometer winds is discussed for 36 BOB TCs during 2010-2020. To conduct the assimilation experiment, the TCs are categorised into three classs, i.e., Cyclonic Storm (CS, 34-47 kts), Sever Cyclonic Storm (SCS, 48-63 kts) that includes both SCS and Very Sever Cyclonic Storms (VSCS, 64-119 kts), and Highly Intensified Cyclonic Strom (HICS) including Extremely Severe Cyclonic Storm (ESCS, 90-119 kts) and Super Cyclonic Storm (SuCS, > 120 kts). Two sets of numerical simulations are conducted for each cyclone, i.e., the control or CTRL experiment without the data assimilation and the second one, considering the 3DVAR (DA simulation). CTRL simulations are initialized with NCEP-FNL and NOAA Sea surface temperature (SST) data sets, and DA simulation considers modified initial conditions prepared through the 3DVAR technique, where scatterometer winds are assimilated into the WRF model. Both simulations utilized the same set of physical parametrizations. The results show improvement in case of DA simulations compared to CTRL for different classes of tropical cyclones during the pre-monsoon, post-monsoon seasons, and sectorial analysis ensured through the Root Mean Square Error (RMSE) of minimum sea level pressure (MSLP) and maximum sustained wind (MSW). It was observed that during the genesis and intensification period, the DA simulation results exhibited more accurate estimates compared to CTRL in predicting MSLP and MSW. The wind shear analysis is done to determine the model's performance during the developing and strengthening stages. RMSE of the predicted wind shear from DA and CTRL run is compared to Indian Monsoon Data Assimilation and Analysis reanalysis (IMDAA), and the results reveal that the DA reduces error in the SCS and HICS classes compared during pre-monsoon season. Overall, DA shows improvement in forecast for MSLP by 12%, 17% and 21% for 24, 36 and 48 h compared to CTRL simulation. Similar improvement in the prediction of MSW is also observed with 53%, 37% and 25% in 24, 36 and 48 h of simulation for DA compared to CTRL simulation for all TCs analysed in a composite mode. These results indicate the potential effectiveness of 3DVAR with scatterometer wind data assimilation in improving the prediction accuracy of TC-related parameters, which can enhance the monitoring and forecasting of extreme weather events in the BOB region.

Keywords: Tropical cyclones, Scatterometer wind, WRF, Data assimilation, IMDAA

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Introduction

The paucity of observational data over the North Indian Ocean (NIO) region poses significant challenges in effectively monitoring and forecasting extreme weather events such as tropical cyclones (or TCs). Since direct observational measurements of dynamic and thermodynamic variables at different atmospheric levels are insufficient to provide a deeper understanding of the interacting forces, a numerical modelling-based approach is required to address the synoptic scale convective processes. The present study aims to investigate the characteristic features of the Bay of Bengal (BOB) TCs through the Weather Research and Forecasting (WRF) modelling framework that includes three-dimensional variational data assimilation (3DVAR).

Objective

- To investigate BOB TC characteristic features through WRF modelling framework that includes 3DVAR.
- To analyze various dynamics and thermodynamic characteristics based on distinct intensification, genesis locations, and seasonality.

Study Area

Fig 1. WPS domain configuration considered for simulating TCs over BOB

The study area considered for the simulation of 36 BOB TCs. The domain consists of parent domain of 30 km (d01) and nested domain of 6 km (d02) respectively. The vertical resolution of the model includes 35 eta levels.

Data and Methodology

- Two sets of numerical simulations are conducted including CTRL experiment and the second one, considering data assimilation with scatterometer wind data 3DVAR(DA simulation).
- CTRL simulations are initialized with NCEP-FNL and NOAA SST as input, and DA simulations consider modified initial conditions prepared through the 3DVAR technique, where scatterometer winds are assimilated into the WRF model.
- The scatterometer winds datasets consists of data from SCATSAT-1, OCEANSAT-2, RAPIDSCAT, QUIKSCAT, and ASCAT satellite for data assimilation.
- IMD Best track data is use to obtain cyclone's position and minimum sea level pressure values in 6 hourly duration https://rsmcnewdelhi.imd.gov.in/
- JTWC Best Track data used to validate the cyclone's position https://www.metoc.navy.mil/jtwc/
- Indian Monsoon Data Assimilation and Analysis reanalysis (IMDAA) https://rds.ncmrwf.gov.in/ consisting of 12km used to validate the simulated results.

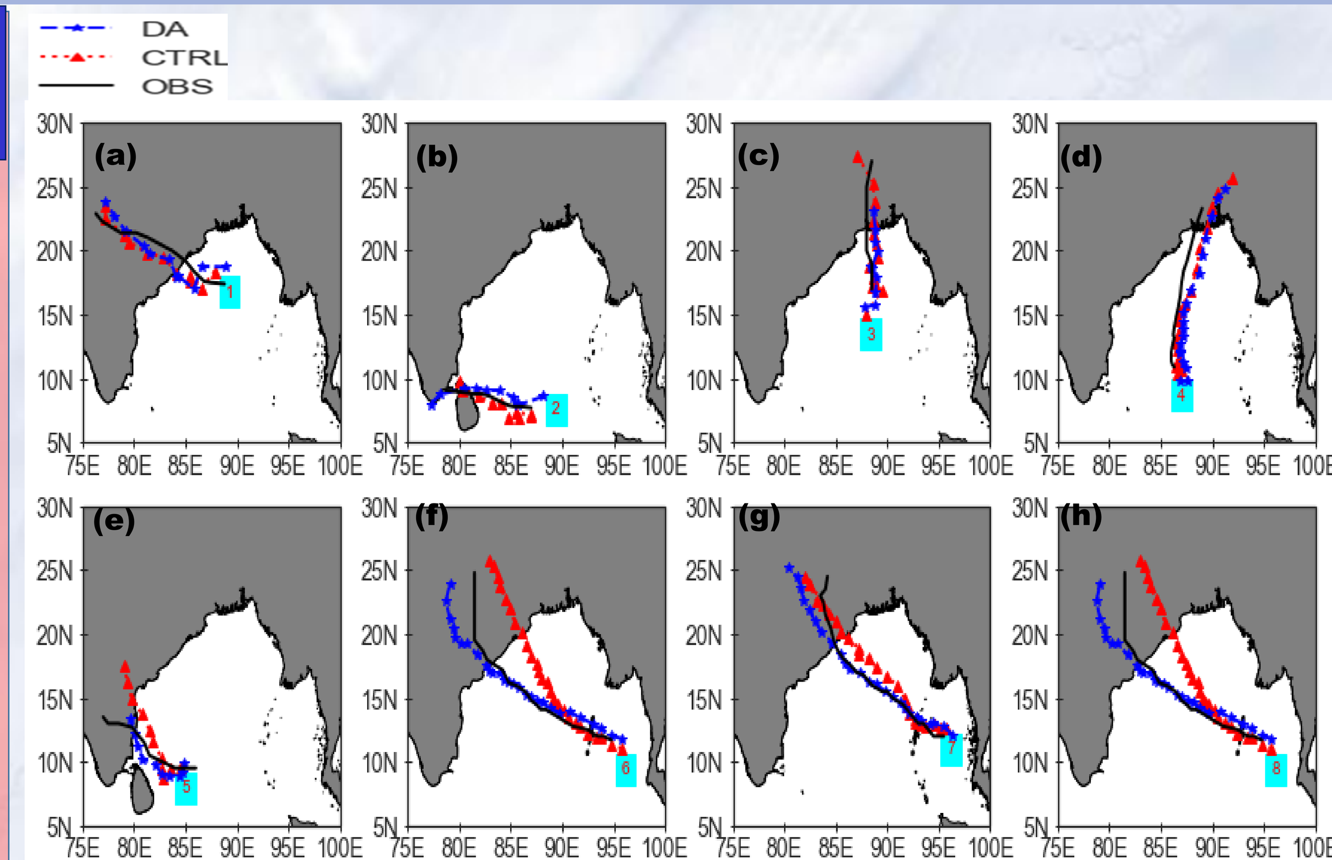

Fig 2. Track analysis of simulated TCs over BOB validated with observed IMD datasets. Top panel (a-d) Premonsoon Cyclones: (a)DAYE(CS), (b) BUREVI(CS), (c)AILA(SCS), (d) AMPHAN(SuCS). Bottom Panel (e-h) Postmonsoon Cyclones: (e)NILAM(CS), (f) PETHAI(SCS), (g) PHAILIN(ESCS), (h)HUDHUD(ESCS)

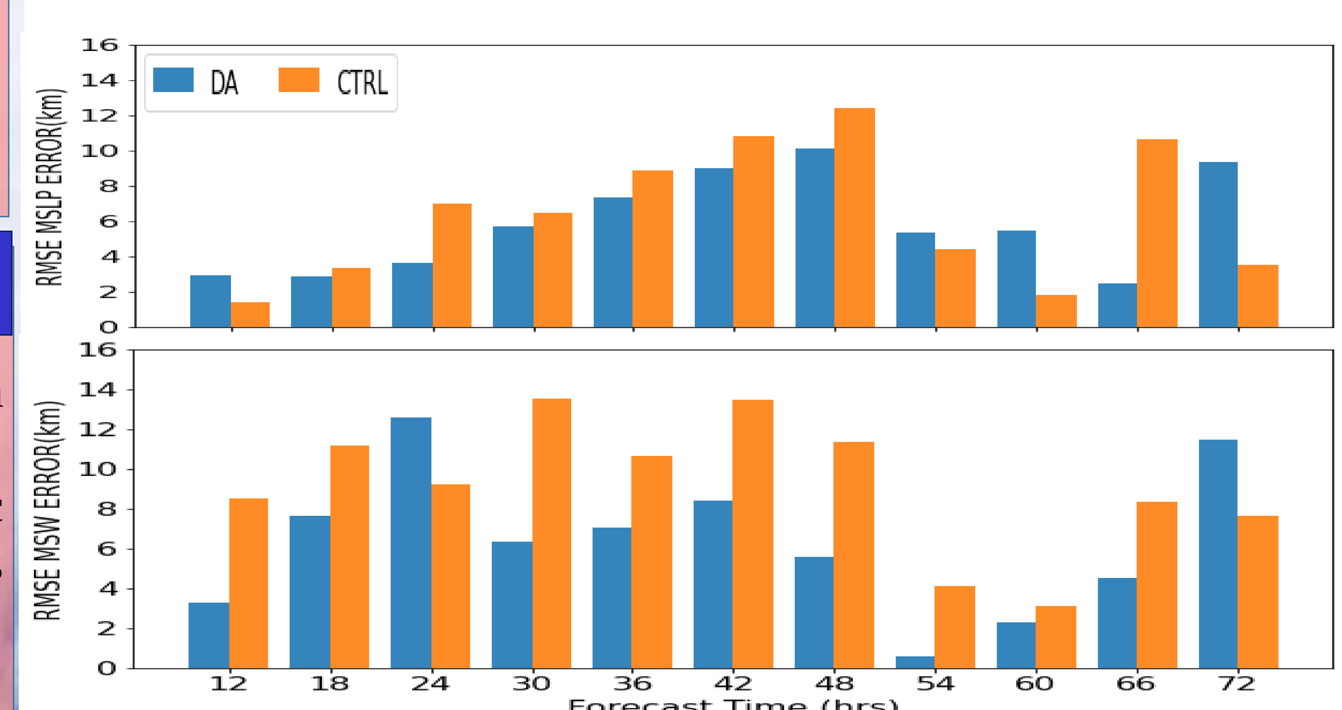

Fig 3. Composite RMSE error of minimum sea level pressure (mslp) and maximum sustained wind (msw) from 12-72 hours.

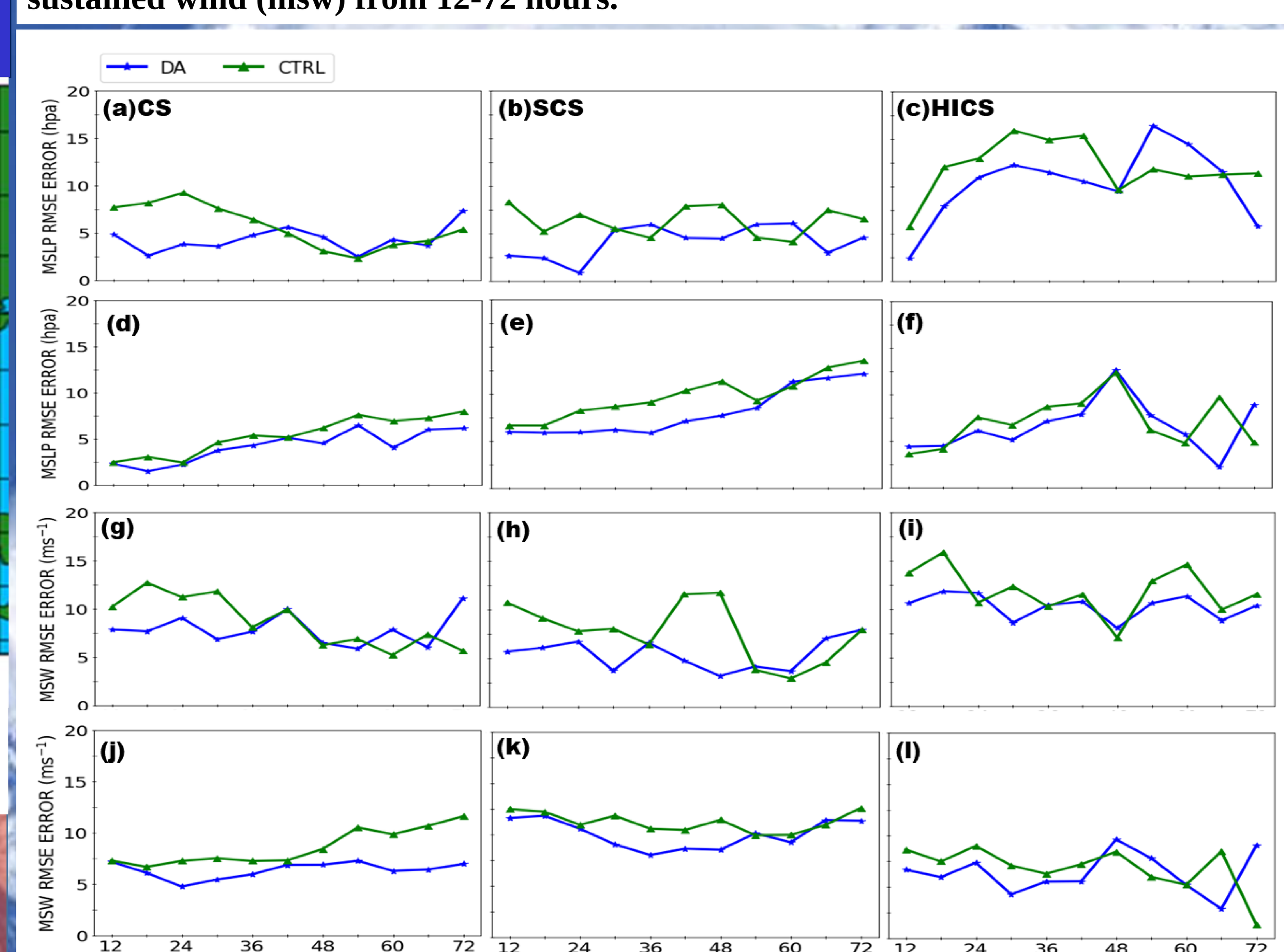

Fig 4.Composite analysis of RMSE error of MSLP (first and second row)and MSW (third and fourth row) with respect to IMD dataset for three categories of TCs from 12-72 hours. First(a-c) and third row(g-i) consist of premonsoon TCs and second(g-i) and fourth row(j-l) consist of post-monsoon TCs. The first column represents CS category, second column represents SCS category, and third column represent HICS category.

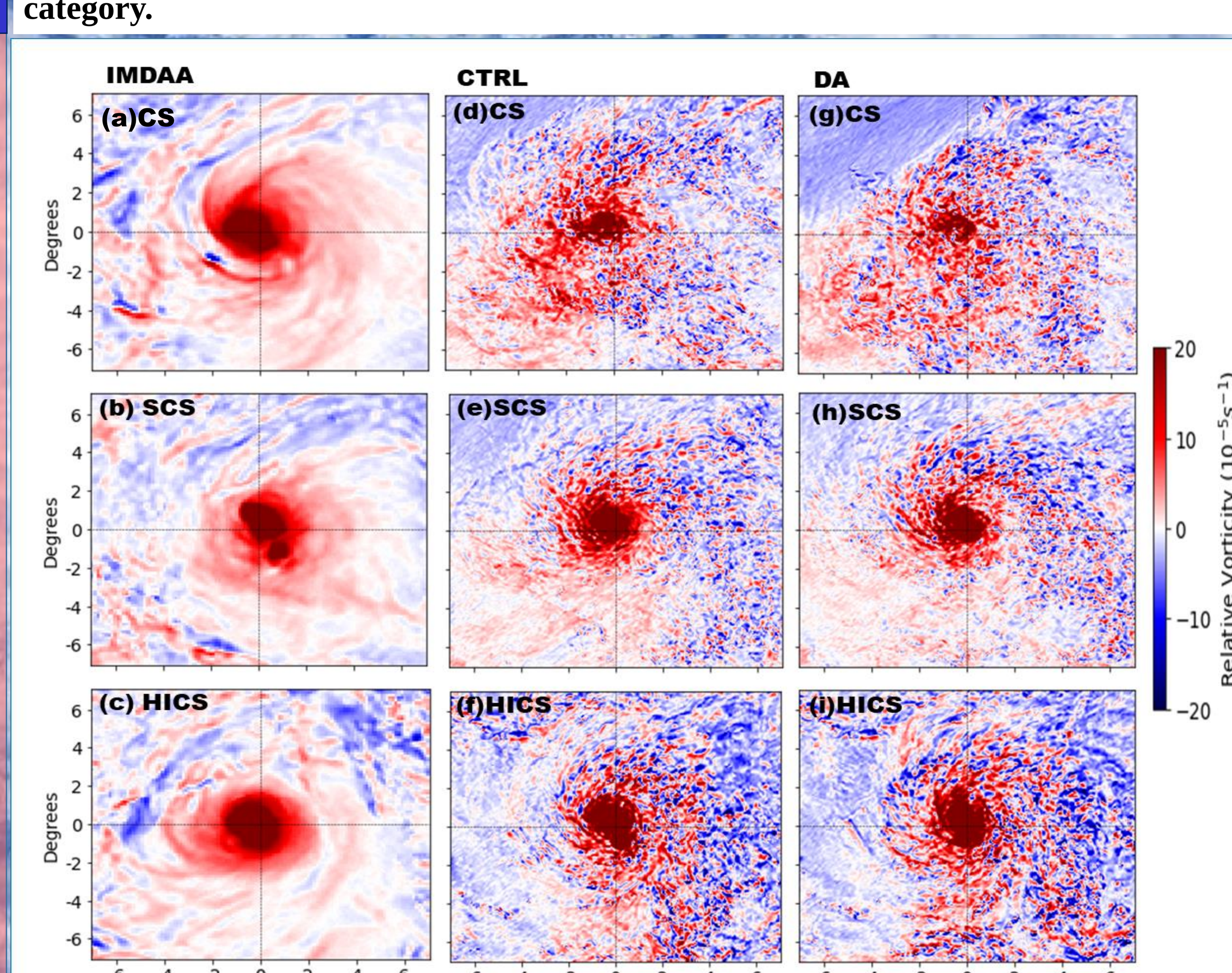

Fig 5. Composite of relative vorticity (850hPa) for CS category(top row), SCS category (middle row), and HICS category (bottom row). The first column (a-c)represent IMDAA datasets, the second column(d-f) represents CTRL and third column(g-i) represents DA.

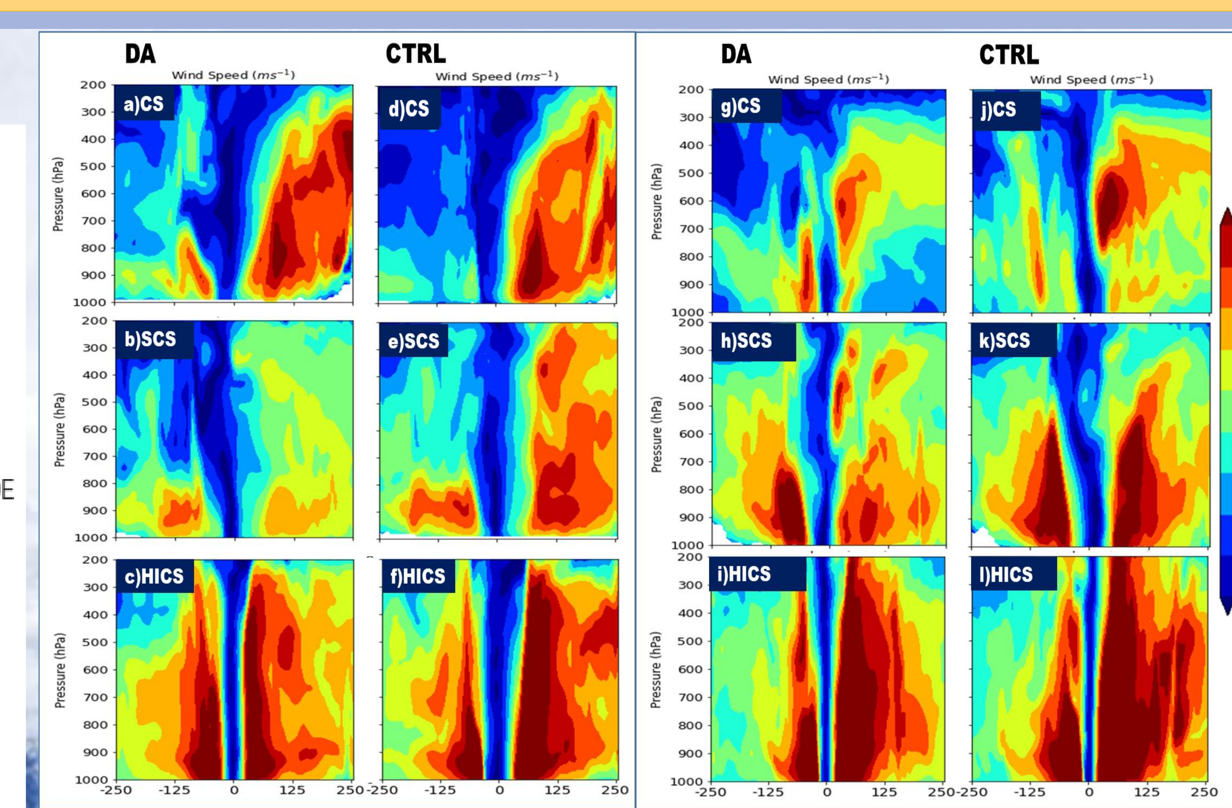

Fig 6. Composite vertical structure of wind speed (ms^{-1}) by considering three of TCs for premonsoon(a-f)and post-monsoon(g-l) based on various categories. First column(a-c) and third column(g-i) represents DA. Second column(d-f) and fourth column(j-l) represents CTRL run.

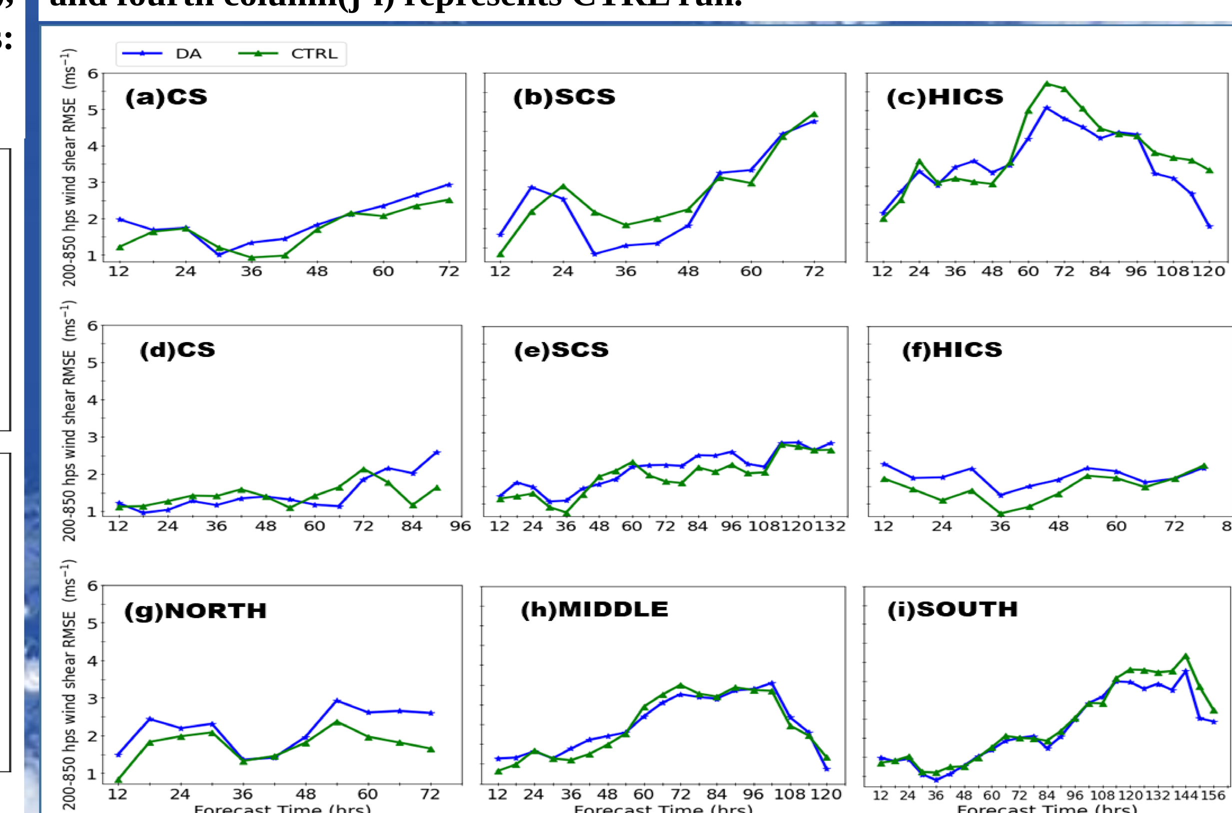

Fig 5. Composite RMSE error of wind shear (200hpa – 850pha) computed for premonsoon TCs(a-c), Postmonsoon TCs(d-f) and sectorial (g-i) evaluated using IMDAA datasets.

Conclusion

The key finding of the study are as follows:

- The simulation of 36 BOB TCs through the assimilation of scatterometer wind data in WRF 3DVAR modelling resulted in improved prediction of MSLP and MSW with reduce in RMSE error observed in DA compared to CTRL.
- Composite analysis of spatial relative vorticity represents small and well defined center of TCs with high relative vorticity value at obtained at center, the result is consistent on comparing with IMDAA datasets.
- A clear eye wall region is observed in the composite vertical structure analysis of wind speed. The vertical towering structure varies according to category.
- Postmonsoon TCs of HICS category display a comparatively smaller diameter in both DA and CTRL than the premonsoon TCs. It indicates the stretching of TCs during the stage.

Acknowledgment

The data sets obtained from scatterometer winds datasets consists of data from SCATSAT-1, OCEANSAT-2, RAPIDSCAT, QUIKSCAT, ASCAT satellite for data assimilation are dually acknowledged. The author are grateful for IMD best track data, JTCW best track data, and IMDAA datasets for providing high temporal and spatial resolution datasets to validate the results.

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