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The impact of real time global SST update on the Hudhud Tropical cyclone track simulation over the Bay of Bengal region using the Advanced Mesoscale Weather Research and Forecasting Model

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Abstract: In the present study, an attempt is made to explore the influence of Sea surface temperature (SST) update on the tropical cyclone track using the advanced mesoscale weather research and forecasting model. Very severe tropical cyclones over the Indian Ocean region Hudhud were considered to study high resolution Real Time Global SST influence over cyclone track. Two nested domains are considered for the model simulation with the horizontal resolution of domain-1, and domain-2, are 27 km, and 9 km respectively. The simulated track, sea level pressure and intensity of tropical cyclones were compared with the real-time data provided by the Indian Meteorological Department (IMD). WRF model Simulations were carried out by fixing the Kessler microphysics parameterization (MP) scheme, Kain-Fritsch convective cumulus parameterization (CU) scheme and Yonsei University planetary boundary physics scheme. It was observed that SST ingest to wrf model simulations has impact on cyclone track sea surface level pressure and cyclone intensity.

Keywords: Sea Surface Temperature ARW Model, Cyclone track, Track error, cyclone Intensity

Introduction

There are a number of uses for sea surface temperature analysis data in Numerical weather prediction. The Marine Modelling and Analysis Branch of the Environmental Modeling Center at the National Centers for Environmental Prediction (NCEP) responsible for the development of SST analysis data. NCEP develops two types of SST analysis data are the Real Time Global (RTG) and the Optimal Interpolation (OI) or aka Reynolds SST. The RTG data is high resolution SST analyses data developed for the weather prediction and weather modelling applications. 2DVAR data assimilation technique is used to develop the RTG SST analyses data. The OI data is a lower resolution SST analyses data developed for the long range weather prediction and climatology studies. RTG SST analyses data is used in the present study. Very severe tropical cyclone Hudhud simulated with SST update option using Advanced Research WRF (ARW) v 3.9.1 mesoscale model developed by NCAR.

The Very Severe Cyclonic Storm HUDHUD developed from a low pressure area over North Andaman Sea in the morning of 6th October 2014 and turned into a depression in the morning of 7th October over the north Andaman Sea. It intensified into a Cyclone Strom in the morning of 8th October and further intensified into a Very Severe Cyclonic Storm (VSCS) in the afternoon of 10th October. Hudhud tropical cyclone crossed north Andhra Pradesh coast over Visakhapatnam (17.7°N 83.3°E) between 0630 and 0730 UTC of 12th October 2014.

The numerical weather prediction (NWP) and statistical dynamical models provided good guidance with respect to its genesis, track and intensity. It is considered to be very important to examine the synoptic features of cyclones to RTG SST update to Advanced Research Weather Research and Forecasting (ARW-WRF, hereafter WRF) mesoscale model developed at National Center for Atmospheric Research (NCAR) because of its superior performance in generating fine-scale atmospheric structures as well as its better forecast skill.

Data and Methodology

Numerical Weather Prediction (NWP) model used in cyclone simulation is the Advanced Research WRF (ARW) v 3.9.1 mesoscale model developed by NCAR. NWP is a method of weather forecasting that uses governing equations, different numerical methods, parameterization schemes, different domains and Initial and boundary conditions. The MODIS based terrain topographical data have been used for domain-1, and domain-2 in the WRF Preprocessing system (WPS). The NCEP GFS data is used as the initial conditions to WRF simulations at an interval of 6 hours, Kessler microphysics parameterization (MP) scheme, Kain-

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Fritsch convective cumulus parameterization (CU) scheme and Yonsei University planetary boundary physics schemes are fixed throughout the model simulation.

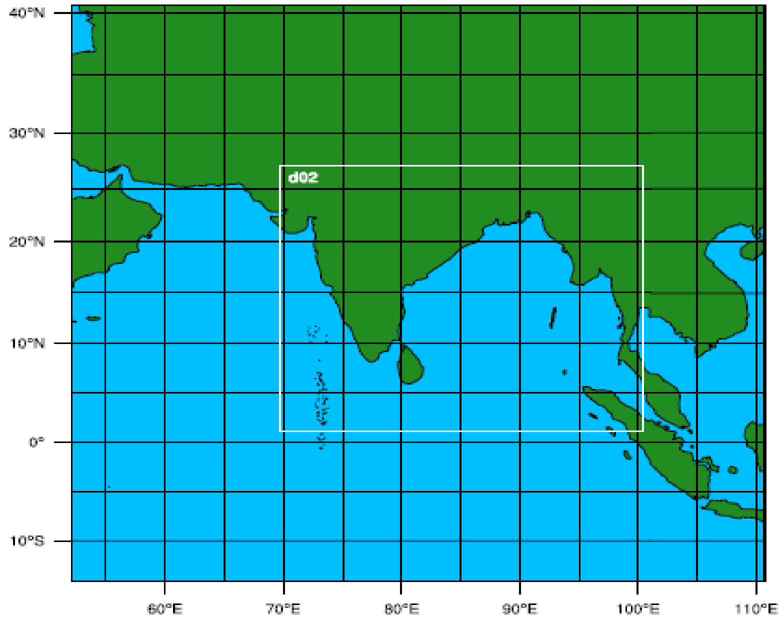

Figure 1. WPS Domain Configuration

The Initial and boundary conditions are obtained from the UCAR & NCAR Research Data Archive https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs.

These NCEP GFS Operational Global Analysis data are on 1-degree by 1-degree grids prepared operationally every six hours. For all the three TC simulations the model output is generated for every six hours were taken into consideration for track position.

Table 1: Model microphysics parameterization schemes

Name of the microphysics scheme	Acronyms
Thompson graupel scheme 2 moment (mp option=8)	THOM2

The WPS domain configuration is generated using NCL (NCAR Command Language). The microphysics, cumulus and planetary boundary layer parameterization schemes used in the present simulation to investigate the track of the tropical cyclones were listed in Table 1, Table 2 and Table 3.

Table 2: Model cumulus parameterization schemes.

Name of the cumulus scheme	Acronyms
Grell 3D Ensemble Scheme (cu Option=5)	G3D

Table 3: Model Planetery Boundary layerarameterization schemes.

Name of the cumulus scheme	Acronyms
Yonsei University Scheme	YSU

WRF Model dynamics and domain details are listed in Table 4 and the HPC Cluster details are given in Table 5.

Table 4: WRF Model dynamics and domain details

Model dynamics details	
Equation	Non-hydrostatic
Time integration scheme	Third-order Runge-Kutta scheme
Horizontal grid type	Arakawa-C grid
Model Domain details	
Map projection	Mercator projection
Central point of the domain	81.4°E, 15°N
No. of domains	2
No. of vertical layers	27
Horizontal grid distance	27 km & 9 km for domain 1 & 2 respectively
Time step	90 sec & 30 sec for domain 1 &2 respectively
No. of grid points	210 (EW), 210 (SN) in domain-1 328 (EW), 292 (SN) in domain-2

Table 5: HPC Cluster facility Specifications

HPC Cluster Specifications	
Master nodes	Fujitsu PRIMERGY RX200 S8 Servers (02)
Compute Nodes	Fujitsu PRIMERGY RX200 S8 (08)
Compute Nodes (MIC nodes)	Fujitsu PRIMERGY CX400 S2 (02)
Communication with all internal cluster	D Link 24 port Gigabit ports with the manageable Ethernet switch
Fast Interconnects	Mellanox 18 port switch (01)
I/O display	KVM 16port switch (01)
Fujitsu DX 60 Storage	40 TB

Results and Discussions

The initial state and representation of the physical process in the model decide the accuracy of numerical prediction of tropical cyclones. The Simulations for the Hudhud Tropical cyclone were carried out in order to determine the influence of high resolution RTG SST update on the cyclone track, SLP and Maximum sustained wind speed.

Results from domain-2, considered for the analysis of tropical cyclone Hudhud. In all the simulation experiments the planetary boundary layer (PBL) scheme is fixed to Yonsei-University (YSU) scheme [9], cumulus physics parameterization fixed to Grell 3D Ensemble Scheme and microphysics parameterization fixed to Thompson graupel microphysics scheme. The simulated track of Hudhud Tropical cyclone with and without RTG SST update was plotted using Grid Analysis and Display System (GrADS) for visualization of the wrf model output. GrADS an interactive desktop tool used for the analysis and display of satellite remote sensing data. GrADS support different data formats and data models. GrADS can handle regular, non-linearly spaced, Gaussian resolution grids. GrADS allow graphically overlay of different data sets with the correct time and spatial registration. The wrf model output and the IMD observed track were compared concurrently. The track errors for Hudhud TC with different initial conditions are plotted. Track error is calculated using haversine formula.

$$a = sin^2\left(\frac{\Delta\varphi}{2}\right) + \cos\varphi * \cos\varphi * sin^2\left(\frac{\Delta\lambda}{2}\right) \quad (1)$$

$$c = 2 * \tan^{-1}\left(\frac{\sqrt{a}}{\sqrt{(1-a)}}\right) \quad (2)$$

$$D = R * c \quad (3)$$

$$\Delta\varphi = \varphi_{JTWC} - \varphi_{wrf} \quad (4)$$

$$\Delta\lambda = \lambda_{JTWC} - \lambda_{wrf} \quad (5)$$

Where D is Track error, φ is latitude, λ is longitude.

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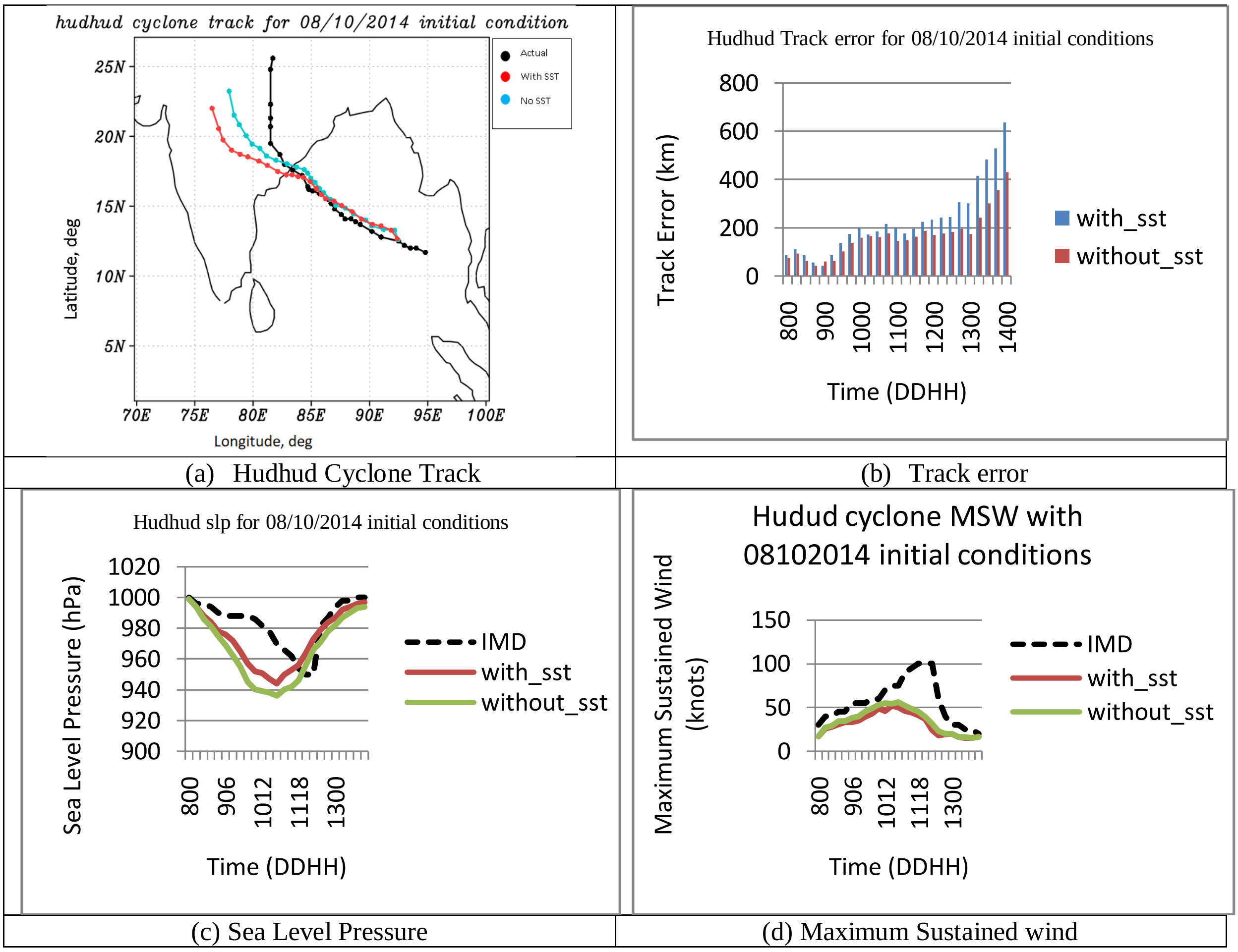
Hudhud Cyclone Track Simulation

Hudhud TC Simulations were initiated with different initial and lateral boundary conditions and were carried up to 14th October 2014, 0000 UTC. The model run up to 144hr, 120hr, 96hr, 72hr, and 48hr the simulated track of Hudhud cyclone with and without SST update were plotted separately. The Hudhud cyclone track for 08/10/2014 initial conditions with and without SST update is plotted in the Figure 2.



(a) Hudhud Cyclone Track (b) Track error

(c) Sea Level Pressure (d) Maximum Sustained wind

Figure 2. The Hudhud cyclone Simulation for 08/10/2014 initial conditions

Time variation of model simulated cyclone track and central sea level pressure (CSLP) with IMD observations for Hudhud TC in hPa is plotted in Figure 2(a) & 2(c). Both with and without RTG SST update well simulated the initial position of the storm. With SST update Sea Level Pressure is better simulated compared with with-out SST update. SST update has no influence on the intensity prediction of the Hudhud Tropical cyclone. Both under estimated the Maximum Sustained Wind of the Hudhud Tropical Cyclone. The Hudhud cyclone track for 09/10/2014 initial conditions with and without SST update is plotted in the Figure 3.

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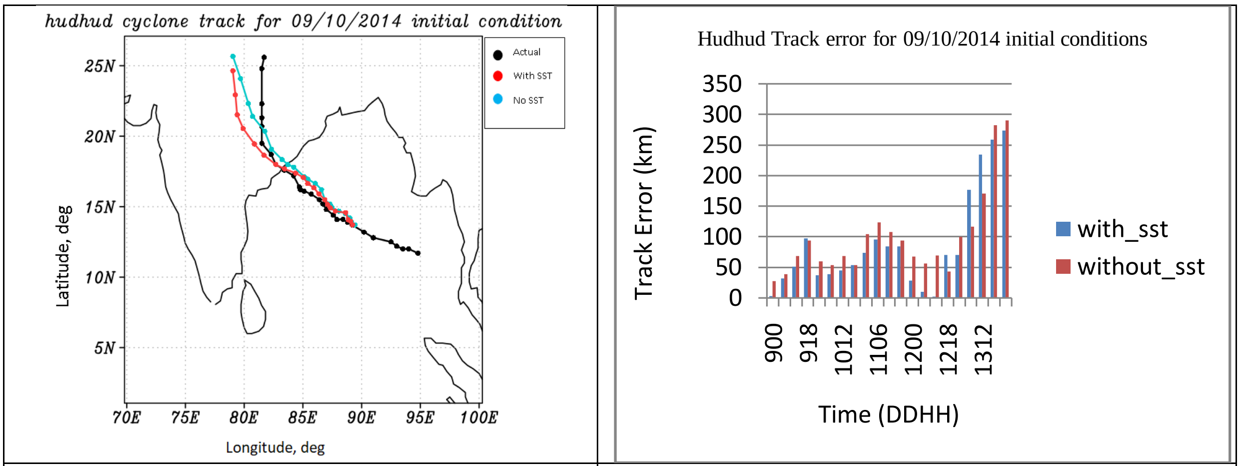
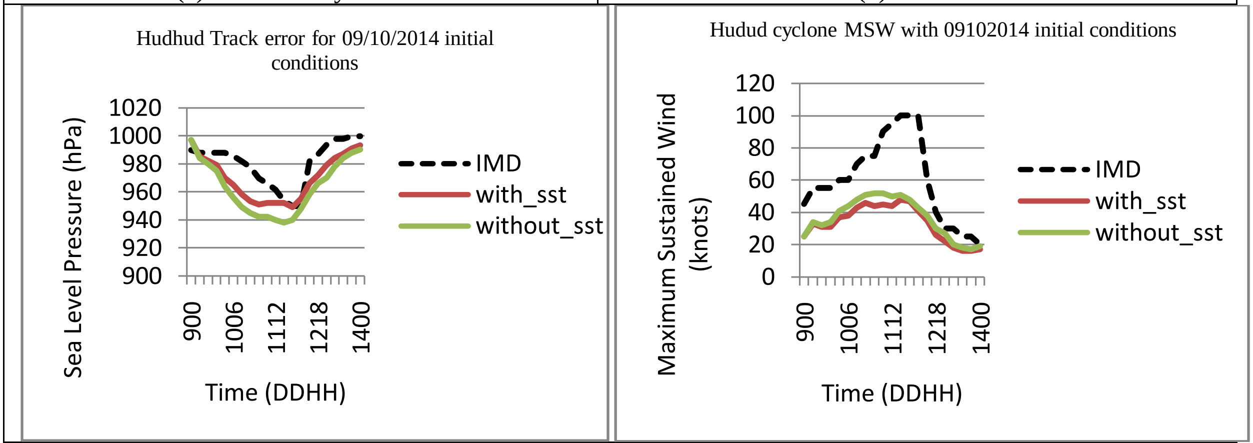


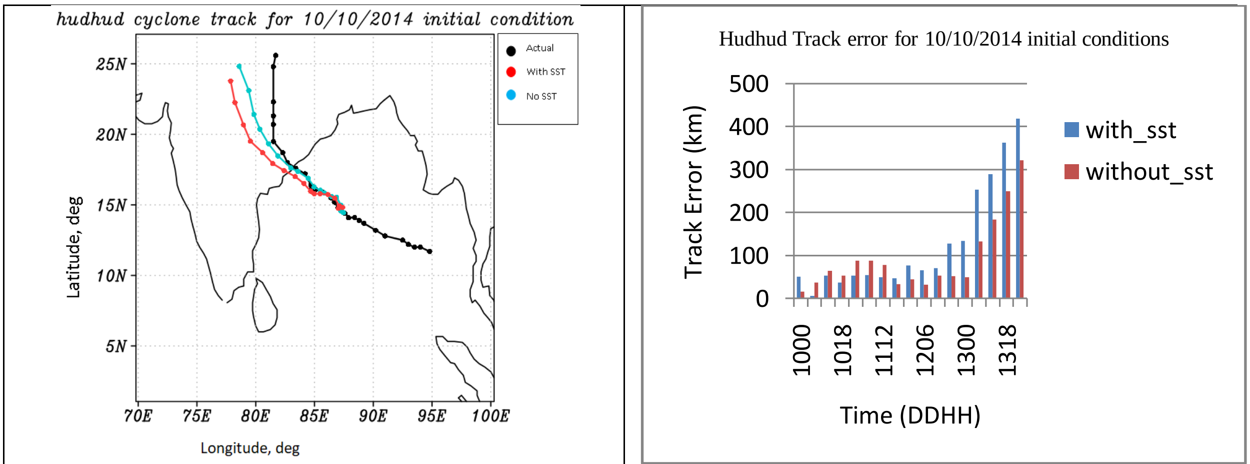
(a) Hudhud Cyclone Track (b) Track error



(c) Sea Level Pressure (d) Maximum Sustained wind

Figure 3. The Hudhud cyclone Simulation for 09/10/2014 initial conditions

Time variation of model simulated cyclone track and central sea level pressure (CSLP) with IMD observations for Hudhud TC in hPa is plotted in Figure 3(a) & 3(c). Both with and without RTG SST update well simulated the initial position of the storm. The RMSE of track for with SST is 117 km and without SST is 120km. The Hudhud cyclone track for 10/10/2014 initial conditions with and without SST update is plotted in the Figure 4.



(a) Hudhud Cyclone Track (b) Track error

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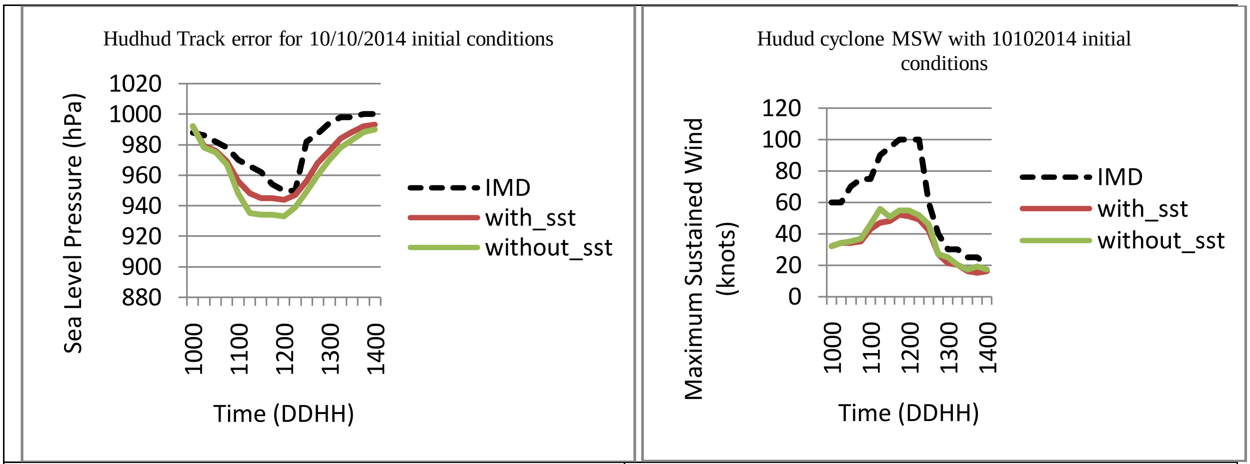
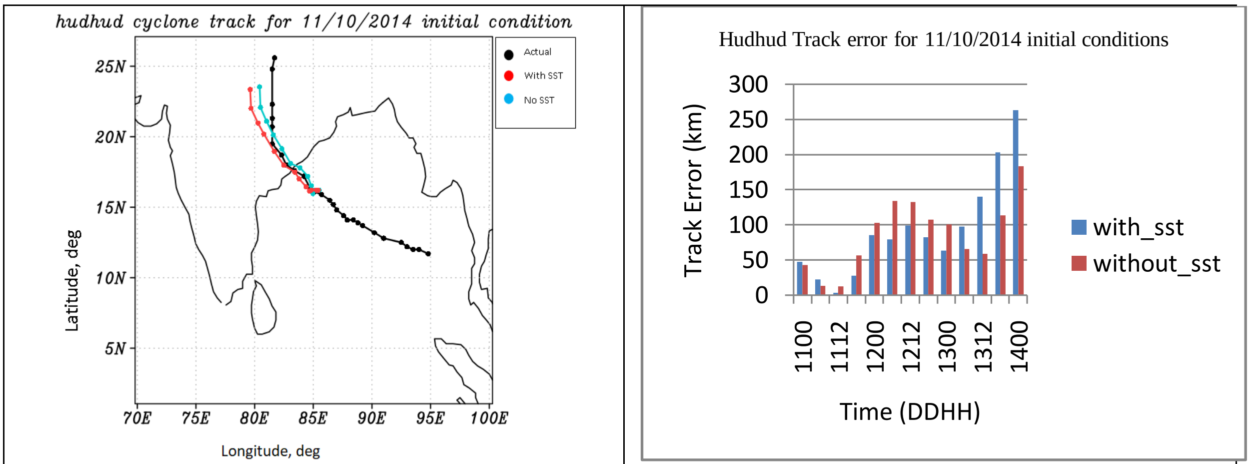


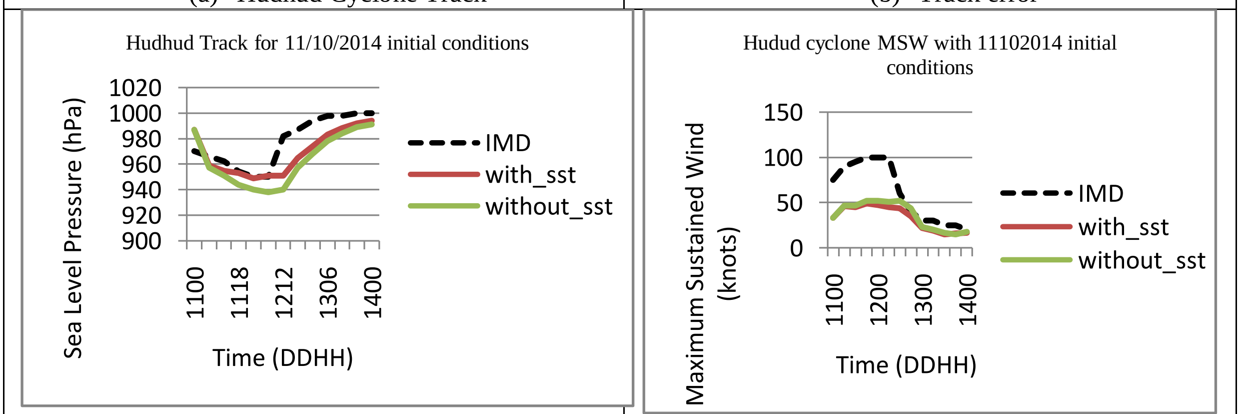
(c) Sea Level Pressure | (d) Maximum Sustained wind

Figure 4. The Hudhud cyclone Simulation for 10/10/2014 initial conditions

Time variation of model simulated cyclone track and central sea level pressure (CSLP) with IMD observations for Hudhud TC in hPa is plotted in Figure 4(a) & 4(c). Both with and without RTG SST update well simulated the initial position of the storm. The Hudhud cyclone track for 11/10/2014 initial conditions with and without SST update is plotted in the Figure 5.



(a) Hudhud Cyclone Track | (b) Track error



(c) Sea Level Pressure | (d) Maximum Sustained wind

Figure 5. The Hudhud cyclone Simulation for 11/10/2014 initial conditions

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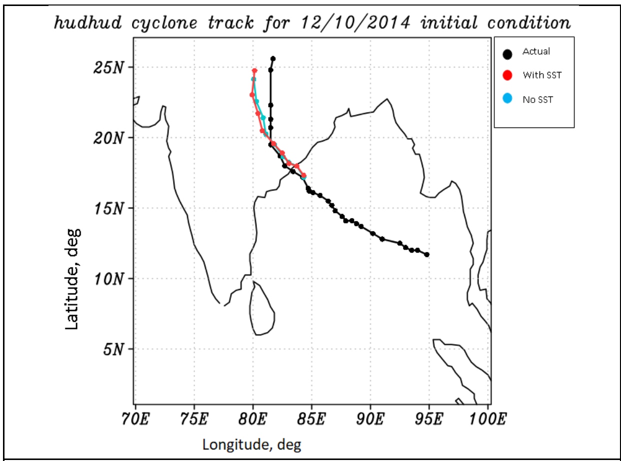
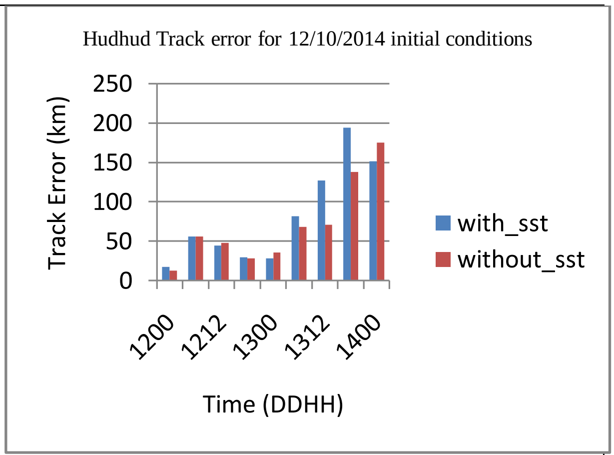
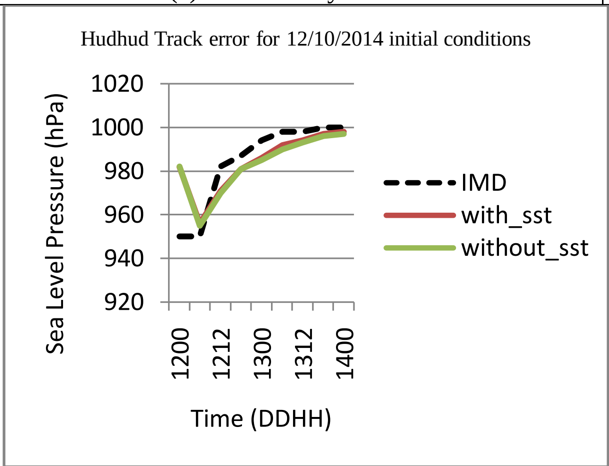
Time variation of model simulated cyclone track and central sea level pressure (CSLP) with IMD observations for Hudhud TC in hPa is plotted in Figure 5(a) & 5(c). Both with and without RTG SST update well simulated the initial position of the storm. The Hudhud cyclone track for 12/10/2014 initial conditions with and without SST update is plotted in the Figure 6.



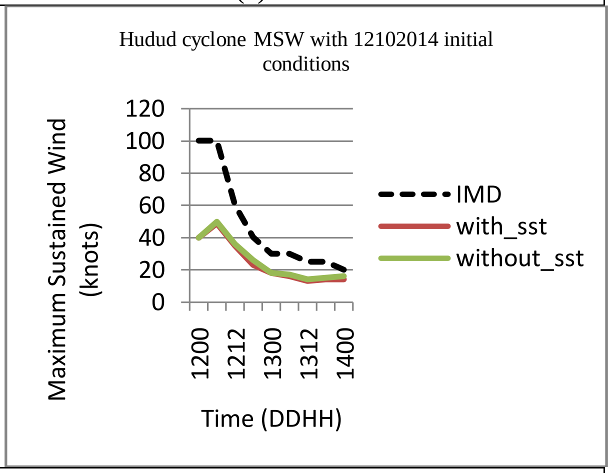
(a) Hudhud Cyclone Track



(b) Track error



(c) Sea Level Pressure



(d) Maximum Sustained wind

Figure 6. The Hudhud cyclone Simulation for 12/10/2014 initial conditions

Time variation of model simulated cyclone track and central sea level pressure (CSLP) with IMD observations for Hudhud TC in hPa is plotted in Figure 6(a) & 6(c). Both with and without RTG SST update well simulated the initial position of the storm. But both over estimated the SLP and under estimated the MSW. The Hudhud tropical simulation with 09/10/2014 initial conditions, the RTG SST update better predicted the cyclone track and SLP.

Conclusion

The sensitivity analyses of model performances have mainly focused on model physics, and initial conditions. The analysis associated with inner domain-2 is considered. In this paper, Hudhud cyclone is simulated over the coast of Bay of Bengal and presented the influence of SST update on the Hudhud cyclone track. For Hudhud TC simulations THOM2 microphysics scheme in combination G3D cumulus scheme with SST update and 09/10/2014 initial conditions gives out the best results which closely matches with the IMD track. The track error for this combination is the minimum.

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