International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-10 Issue-1, October 2020

A Comparative Study of Weather Forecasting Simulation Models through Sensors for Accurate Monsoon Predictions in the Indian Ocean

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Abstract*: When Monsoon depressions form over the seas, the Moderate Resolution Imaging Spectroradiometer (MODIS) provides humidity and high-horizontal resolution temperature details about the depressions. These high-resolution satellite data related to temperature and humidity can improve the poor predicting rate of depressions [1]. Using three-dimensional variational data assimilation (3DVAR) and with the help of humidity profiles along with MODIS temperature. We can achieve an advanced prospect of detection and a larger value of (ETS) equitable threat score observed over 48 hours collected precipitation with respect to the control run. The 3DVAR assimilation of Doppler Weather Radar wind data associated with Indian Meteorological Department (IMD) surface data and upper air data helped in the improvements in the simulation of strong gradients associated with horizontal wind speed ,higher warm core temperature , high vertical velocity & better precipitation and spatial distribution.[2]. The effect of Spectral sensor microwave imager (SSM/I), humidity profiles, use of Advanced TIROS Vertical Sounder (ATOVS) temperature and total precipitable water (TPW) helped in improving the ''forecast impact'' parameters of ''bias score'' and ''equitable threat score'' with respect to the assimilation of satellite observation[3]. In this paper we have discussed a comparative study of different proposed techniques to analyze its effects in improving the low prediction rates of depressions.

Keywords: MODIS, 3DVAR, ATOVS, TPW, monsoons depressions, prediction rates

I. INTRODUCTION

Agriculture is the most significant sector of the Indian Economy. The agricultural sector provides 18 per cent of the India's GDP & offers employment to around 50% of the country's workforce. So, rainfall and tropical cyclones have a major impact upon the agricultural sector. The Indian summer monsoon rainfall is dependent on the longevity and frequency of monsoon disturbances or depressions which form over the Arabian Sea and the Bay of Bengal. Hence depressions play a vital and important role in the time and space distribution of the rainfall and need to be simulated and examined in a better way. An accurate numerical prediction requires very accurate initial parameters and conditions. Some common drawbacks in the forecast of tropical cyclone are mainly related to the deficit of observational data, and incorrect assimilation of available data in an existing numerical model. We can get accurate and improved initial conditions by assimilating and ingesting high resolution meteorological observations with respect to the initial analysis using Three-Dimensional Variational data assimilation [1][6][7]. Mostly these monsoon depressions are formulated in the data sparse oceanic areas, so it is highly important to assimilate the satellite observations processed into the numerical model to calculate better forecasts with better analysis. The basic goal of this approach is to calculate the impact of ingestion and assimilation of input parameters in MODIS observation in the forecast of a monsoon depression formed over India with the use of a meso-scale approach. The main aim of the 3DVAR system is to calculate an optimal estimate of the correct state of the atmosphere at any specific time with the help of the cost function [4]. Another method to enhance the initial parameters is by ingesting and assimilating non-conventional high-resolution observations like satellites along with DWR observations successfully processed into the numerical implemented model. Because of the absence of input parameters, it may lead to the fact that the strength and the centre of the cyclonic vortex are not properly signified. By modifying the initial weak cyclonic vortex along with a synthetic vortex, which is specified at the correct location later on, the initial parameters can also be enhanced. In 1990, Stauffer and Seaman proposed Newtonian relaxation or nudging methods and in 1992, Parrish and Derbe proposed variational (VAR) data assimilation methods, which are the frequently used techniques for data assimilation to enhance the initial parameters. Despite its simplicity, the nudging method has limitations such as the inability of directly incorporating variables such as rainfall, radar reflectivity and radiance. These parameters can be utilized into the numerical model by the Three-dimensional methods and Four-dimensional Variational methods (3DVAR, 4DVAR). In recent years, several studies have used the 3DVAR assimilation methods to get more accurate predictions of weather conditions.

Revised Manuscript Received on October 10, 2020.
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[8][9][10].By decoding the impact of the assimilation of the ATOVS temperature with its, humidity profiles , SSM/I ,TPW on the simulation of a depression using 3DVAR and Forecast (WRF) model , it is found that the ‘‘forecast impact’’ parameter which is calculated for the wind speed offers a good evidence of the optimistic impact.

In this paper we have compared the results of the impacts of the assimilation of multiple proposed techniques. The rest of the paper is prepared as follows: Section 2 is a review of the existing techniques, Section 3 explains the model descriptions and numerical experiments, Section 4 discusses the results, Section 5 is a comparative study and Section 6 is the conclusion.

II. A REVIEW OF EXISTING TECHNIQUES

3DVAR AND 4DVAR APPROACHES:

During the past years, both 3DVAR and 4DVAR variational data assimilation methodologies have been utilised more and more to get improvised initial analysis (Lorenc et al. 2000, Parrish and Derber 1992). The common aim of the 3DVAR data assimilation system is to make an optimization estimate of the current state of the atmosphere at any specific analysis time with respect to the iterative solution of the recommended cost function J(x) (Ide et al. 1997).

$$J(x) = J^b + J^o = \tfrac{1}{2}(x - x^b)^T B^{-1}(x - x^b) + \tfrac{1}{2}(y - y^o)^T (E + F)^{-1}(y - y^o)$$

where

E: Observation (instrumental)

B: Background

F: Representivity error of covariance matrices.

H is used for transformation of the grid-point analysis ‘x’ mapped into observation space y ¼.

H_x is used for comparison with respect to observations.

x^b is the background forecast or previous forecast and y^o is the observations.

The 3DVAR technique gives an analysis of the actual state x that optimizes the function J(x). Minimization of cost function J(x) is done though an iteration process, which represents an a posteriori maximum likelihood estimate of the actual state of the atmosphere [4],[5].

Satellite data for assimilation

SSM/I total precipitable water:

SSM/I experiment receives the total precipitable water details from the SSM/I satellite for the data. The SSM/I, which is a polar orbiting satellite with a period of around 102 min, and swath width of about 1,400 km and a mean altitude of approximately 830 km. it is a four-frequency and conical scanning passive microwave radiometer having resolution of 25 km. The details of the description of the SSM/I instrument is available in Hollinger (1989) [3]. For the reclamation of SSM/I data products the version-five multiple stages regression algorithm used .

Advanced TIROS vertical sounder:

ATOVS is a sounding instrument package, and in the method validation by Rajan et al. (2002) they found that the associated root means square error (RMSE), when validated against near radiosonde observations, was less than ten percentage.The data from ATOVS has undergone quality-control and has been assembled into discrete data sets. The calibration information and the information of the location on Earth are appended to this data.

III. MODEL DESCRIPTION AND NUMERICAL EXPERIMENTS

The results of the three assimilation models are explained here. The First model [1] was related with WRF Version 2.2 and NCAR. For a single domain, this model configured having 28 layers (vertical) and with 36 km grid spacing (horizontal).The grid dimension related with 119 x 129 grid cells in the north-south and east-west directions.

The NCEP-FNL data presented at a time resolution of 6 hours horizontal resolution with 1^o x 1^o latitude/longitude used to improve the initial with lateral boundary conditions .With the help of MODIS data implemented over of simulation of monsoon depression in Bay of Bengal development on September 2006 was examined through two numerical control and 3DVAR experiments. One of them used MODIS humidity profiles and temperature at 14 standard pressure levels. During the time interval between Sept’27 2006 to Sept’30 2006 the control experiment employed the NCEP-FNL analysis associated with the boundary and the model simulations were examined.

In this proposed study the 2^{nd} model [2] used MM5 model. For 30km single domain, the model was configured with twenty-three layers(vertical) with a horizontal grid spacing with 130 * 118 grid cells in the east-west and north-south directions respectively. The NCEP FNL data helped to improve the boundary conditions. For assimilated wind data form DWR and upper air and surface data from IMD, effect of 3DVAR has been observed and calculated for Nov 2002 Cyclone. The first experiment which is called Control (CTRL) which used the NECP FNL data only. This data integrated with MM5 model without any observational data assimilation during time interval Nov 10^{th} 2002 to Nov 13^{th} 2002.Because the initial vortex of the cyclone was poor and initially placed wrong. The initial vortex then replaced with a synthetic vortex with correct location and intensity 10^{th} Nov 2002. The IMDVAR experiment utilized the IMD upper and surface air data. The DWRVAR experiment utilized the wind data from DWR along with upper air and surface data from IMD The third model [3] used the NCAR and WRF model. This model configured of 24 vertical levels. The model is having a horizontal resolutions of 36 and 12 km grid spacing. For the coarser domain this model is having a two-way nesting mode with 118*130 grid cells north–south and east–west directions. For finer domain 271 * 271 grid cells in the north–south and east–west directions respectively. The CTRL experiment utilized the NCEP -GFS for generating the boundary conditions. This simulations associated with this model were performed from 13^{th} Sept 2005 to 17^{th} Sep 2005. In the 2^{nd} experiment SSM/I model integrated from 13^{th} Sept 2005, 18 UTC to 14^{th} Sep 2005, 00 UTC. This experiment was having without any assimilation associated with observations. From 14^{th} Sept. 00 UTC SSM/I TPW observation has been calculated at every twelve hour interval up to 15^{th} Sept 2005, 00 UTC. The 3^{rd} numerical experiment (ATOVS) is like SSM/I experiment except that it utilized humidity profiles and temperature instead of TPW.

IV. RESULTS AND DISCUSSION

The root mean square error is calculated for dew point, temperature and wind speed associated with all radiosonde station data available over the Indian domain.

Model I:

Figure 1 show that 3DVAR run having higher spatial correlation of SLP comparison to the control run .Due to assimilation of humidity profiles and MODIS temperature this model displays a noticeable improving in the space correlation of the SLP field. Because of assimilating of the MODIS observations there is a reduction in the RMS error related to SLP field.

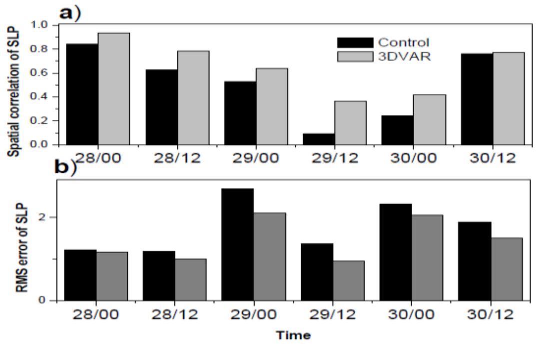

Figure 1: Time series of SPL and RMS error [1].

For further analysis upon quantitative measure like equitable threat score (ETS) and bias scores calculated depending upon the effect of the assimilation of MODIS observations. Figure 2 clearly shows that the values associated with ETS which are generated by the 3DVAR larger than those in the control run.

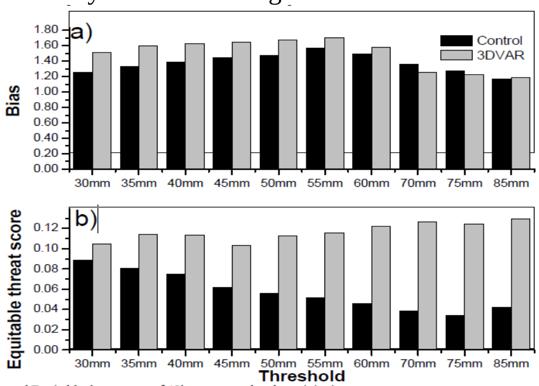

Figure 2: Bias and ETS for accumulated precipitation. [1]

The model examined using the FAR with the probability of detection with respect to FAR gives a measure of the false alarms. Figure 3, shows that the FAR associated with control run is more than3DVAR run for all threshold values. However, the difference between FAR in control and 3DVAR runs with the increase in threshold values shows an increase in magnitude.

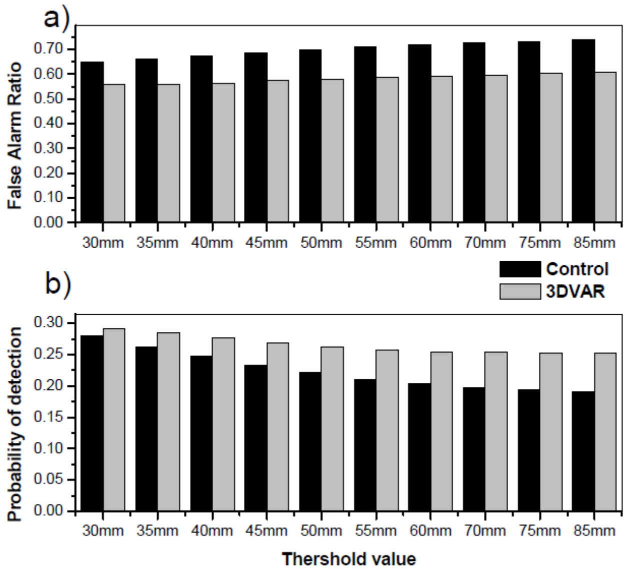

Figure 3: FAR and POD of precipitation [1].

Model II:

Bias and ETS are supportive for estimating non-probabilistic, gridded precipitation forecasts. From the 24 hour accumulated precipitation, in this model both observation and model, bias and ETS are calculated. The contingency table used for calculating the equitable threat score and bias values. Figure 4 depicts that the ETS values populated by the DWRVAR are larger than those of the IMDVAR and CTRL runs. Figure 5 provides the bias values with respect to all runs. The bias values populated by DWRVAR are much greater than that of the CTRL run and closer to 1. This indicates that the DWRVAR run has upgraded the precipitation forecast of the model associated to the control run. The IMDVAR run shows lower bias values compared to the other two runs over all the times. Figure 6 explains the false alarm ratio which calculates the number of the false alarms.

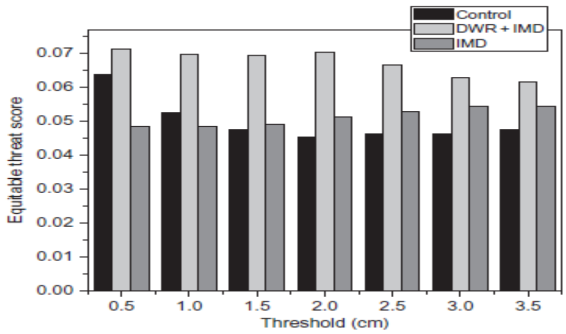

Figure 4 - ETS of control for runs [2].

Retrieval Number: 100.1/ijeat.F1502089620
DOI:10.35940/ijeat.F1502.1010120
Journal Website: www.ijeat.org

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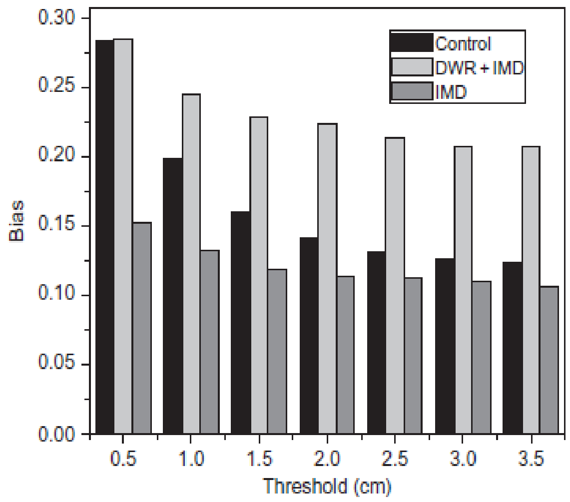

Figure 5 - Bias with respect to threshold. [2]

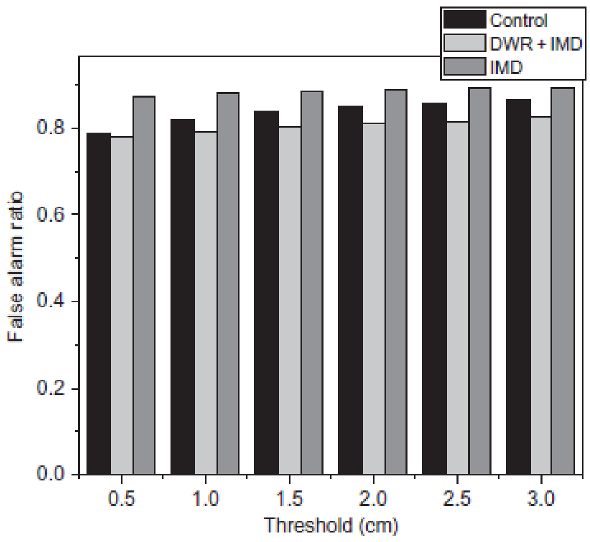

Figure 6 – FAR of all models.[2]

4.3 Model III

Figure 7 demonstrates the ETS and bias scores calculated for experiments depending upon the 48-hour accumulated precipitation related to TRMM observations. For the lower threshold rainfall values, it can be concluded that the ATOVS experiment shows greater skill of forecast with respect to the SSMI and CTRL experiments. When the threshold rainfall value increases, it can be clearly seen that the forecast skill associated with ATOVS experiment decreases. The experiment that related to assimilation of SSM/I parameters, total precipitable water shows greater ability in precipitation forecast at lower threshold values with respect to the CTRL run.

In Figure 7 the bias scores disclose that the CTRL, SSMI, and ATOVS experiments are over predicting the strength of rainfall associated with all the threshold values of rainfall.

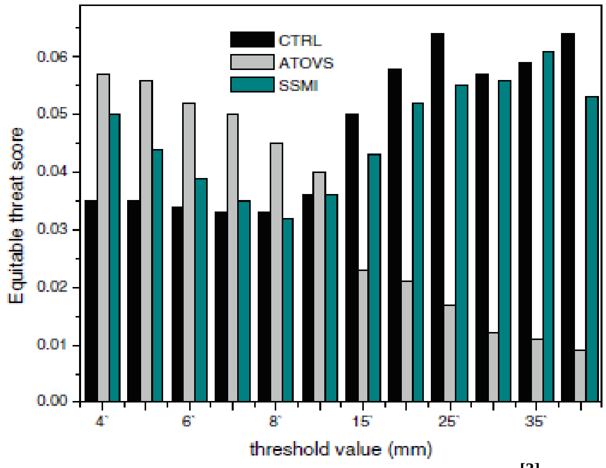

Figure 7 - ETS of the three experiments[3]

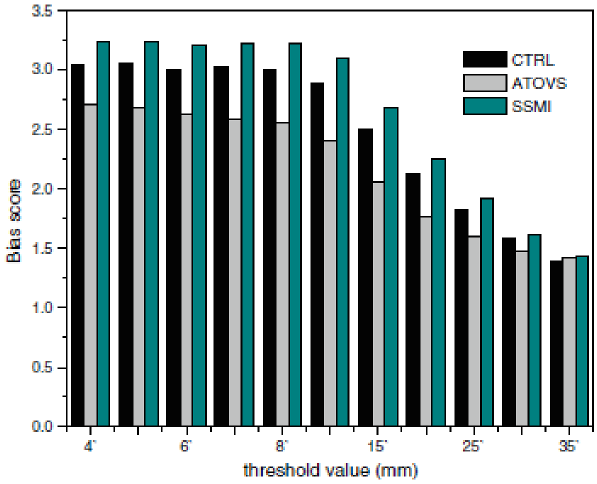

Figure 8 - Bias score[3]

Retrieval Number: 100.1/ijeat.F1502089620
DOI:10.35940/ijeat.F1502.1010120
Journal Website: www.ijeat.org

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V. A COMPARATIVE SUMMARY

Model	Dataset	Geographical Locations	Advantages	Disadvantages	Parameters
Model I	□ National Center for Atmospheric Research Weather Research and Forecast Model 2.2 □ 28 Vertical Layer □ 36 horizontal grid □ 129*119 grid space. □ MODIS satellite data. □ 14 Standard pressure points.	North East Bay Of Araca n coast 18.0^0 N and 89.0^0 E.	ETS shows higher values for run with MODIs temperature. POD of precipitation also increases with 3DVAR run	For pressure 200hPa, RMS error of dew point temperature is high.	3DVAR run has higher spatial correlation of SLP compared to the control run False alarm ratio for control run is greater in comparison to the 3DVAR run for all the threshold values. Time average rms value reduced due to assimilation of the MODIS observations
Model II	□ MM5 Model □ 23 Vertical Layer □ 30KM horizontal Grid □ 118*130 GRID Cell. □ DWR used for WIND data with IMD used for surface and upper air surface.	750 Km South and south west of Kolkata. Date: 10th Nov. 2002	Improvements in simulations of: □ Velocity □ Temperature. □ Wind speed. □ Spatial distribution. □ Precipitations.	Spatial Limitation of assimilated DWR data	**SLP:** CTRL: 0.6872 IMDVAR: 0.6947 DWRVAR: 0.7620 **False Alarm Ratio:** CTRL, IMDVAR > DWRVAR **RMSE:** CTRL:2.21 hPa IMDVAR: 2.86 hPa DWRVAR: 2.31 hPa
Model III	NCAR–WRF model. 24 Vertical Layer. 130*118 grid cells coarser domain. 271*271 grid cells finer domain.	September 2005. Arabian Sea.	□ CTRL and SSMI experiments have simulated a relatively more active system compared to the central pressure of the ATOVS experiment □ It has relatively stronger north easterlies, north of depression center at the initial time when compared to the ATOVS experiment. □ The rainfall intensity improved by using proposed model □ For day one of the forecast, improvement parameter is more positive over the regions of maximum precipitation for both the SSMI and ATOVS experiments. □ Intense warm core at mid-tropospheric levels	ATOVS experiment shows slightly lower values for ‘‘bias score’’ as compared to the CTRL, SSMI experiment. CTRL and SSMI runs had clearly overestimated the relative vorticity values associated with the depression when compared to the ATOVS run.	Mean sea level pressure: CTRL and SSMI (996 hPa) more accurate ATOVS (998 hPa) RMSE Error in wind speed: ATOVS reducing the error values as compared to other runs ETS: ATOVS experiment demonstrates slightly lower values for ‘‘bias score’’ as compared to other runs Relative vorticity: CTRL and SSMI runs shows overestimated the relative vorticity values of depression when compared to the other run

Table- I: Comparison of three models.

VI. CONCLUSION

In this paper, we have compared the results of the impact of assimilation of multiple proposed techniques with use of 3DVAR assimilation using MODIS temperature, Doppler Weather Radar (DWR), Advanced TIROS Vertical Sounder (ATOVS) temperature and total precipitable water (TPW). The comparison has been performed on the basis of rain fall, wind speed, Mean sea level pressure, ETS, Relative vorticity and false alarm ratio. In the future study we will propose an efficient model, for accurate prediction of cyclones with less error rates.

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Retrieval Number: 100.1/ijeat.F1502089620
DOI:10.35940/ijeat.F1502.1010120
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