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IMPROVED DERIVATION OF WATER VAPOR WIND PRODUCT FROM KALPANA-1 SATELLITE FROM THE USE OF NCEP FIRST GUESS FORECAST FIELDS AND ITS APPLICATION: A QUANTITATIVE ASSESSMENT

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Abstract

The coverage of satellite derived winds over the data gap Indian Ocean region has improved with the operation of India's first dedicated satellite for meteorology KALPANA-1 since 12 September 2002. Availability of these data has opened up a new possibility to examine the impact of these data on the NWP system for simulation of Indian summer monsoon and analysis of tropical cyclones. Derivation of Water Vapor Winds (WVW) using water vapor channel (5.7µ- 7.1µ) from Kalpana-1 geostationary satellite has been started and being used operationally at India Meteorological Department (IMD), New Delhi since March 2008.

To improve the quality of AMVs (CMV and WVW), recently some vital changes and modification are made on current satellite derived wind processing algorithm at IMD. The changes include a new height assignment scheme using H_2O/IR interception method based on Cooperative Institute for Meteorological Satellite Studies (CIMSS) Satellite Derived Wind Algorithm was introduced into computing WVW.Second, the making use of National center for environmental prediction (NCEP) GFS at the resolution of 1º X1º as the first guess in place of forecasts of operational limited area model (LAM) of IMD. Third, the quality check procedure of WVW was carried out with NCEP Model forecast data, which covers the area 40ºE-129ºE and 40ºS-40ºN. The introduction of the NCEP first guess improved the qualities of WVWs against sonde observation and METEOSAT-7 winds. This results a significant increase in the number of good quality WVW. Finally, these WVW are put on GTS for end users in both SATOB as well in BUFR format. The error analysis has been carried out for the validation of WVW with radiosonde observations and the available mid-upper level winds derived from METEOSAT winds for the period from May 2008 to July 2009. The results show consistent improvements in the quality of the model first-guess wind field from NCEP and have significant improvement on mid-upper level winds compare to LAM data. Further, in this paper, a cyclone case study has been examined and it is found that the Kalpana-1 derived WVW has fairly good agreement with the METEOSAT-7 winds.

Keywords:- CMV, WVW, RMSE, BUFR,NCEP,AQC

1. INTRODUCTION

The current Indian geostationary satellite Kalpana-1 has a payload called Very High Resolution Radiometer (VHRR) with three channels viz. Visible (0.55µ-0.75µ), Infrared (10.5µ-12.5µ) and Water Vapor (5.7µ- 7.1µ) with a ground resolution of 2 km,8 km and 8 km respectively. After Kalpana-1 satellite became operational in the month of October 2002, IMD began first deriving Cloud Motion Vectors (CMV) from the Infrared data, twice a day from the triplets at 2330, 0000 and 0030 UTC and 0700, 0730 and

0800 UTC. The derivation of Water Vapor Winds (WVW) using water vapor channel (5.7μ- 7.1μ) from Kalpana-1 satellite has been started and being used operationally at IMD, New Delhi since March 2008. The history of CMV derivation in IMD from INSAT data started with Kelkar and Khanna (1986) using pattern matching by searching equality in pixel to pixel between tracer and target images. With the inception of IMDPS, cross correlation technique is being used for pattern matching. Several improvements have been carried out by various scientists (Khanna and Bhatia 2000*)* with better results and reduced rms errors and biases.

A new method, based on *CIMSS Satellite Derived Wind Algorithm,* has been upgraded in the INSAT Meteorological Data Processing System (IMDPS) in which height assignment is being done by the H2O-IRW Intercept Method (Neiman et al, 1997) for CMV and WVW computation. The H2O intercept is predicted on the fact that the radiances from a single-level cloud deck for two spectral bands vary linearly with cloud amount. Radiances from the infrared window and H2O absorption band (WV Channel) are measured and compared to Plank body radiances as a function of cloud top pressure. A numerical forecast of temperature and humidity profile in the region is used for the necessary radiative transfer calculation for measured and opaque cloud conditions. The automated quality control (AQC) used in the algorithm is based on EUMETSAT approach (Hayden 1993; Hayden and Nieman 1996).

All height assignment techniques for CMV/WVW derivation mainly depends on numerical model forecast data. So it is important to have good NWP forecast fields such as temperature, moisture, *u,v* and pressure fields which is finally converting satellite brightness temperature measurements into pressure height estimates. India Meteorological Department has been using a Limited Area Model (LAM) on operational basis for the short range forecasting (forecasts up to 48 hours) since 1995. The operational LAM of IMD consists of real time processing of data received from Global Telecommunication System (GTS) and objective analysis by three dimensional multivariate optimum interpolation scheme. The input data used for the analysis consists of : Surface -SYNOP/SHIP; Upper air-TEMP/PILOT, SATOB; Aircraft reports-AIREP,AMDAR,CODAR. The methodology applied for objective analysis scheme is the statistical 3-dimensional multivariate scheme which is based on applying correction to a first guess (from global model forecast of NCEP), the corrections being the weighted average of (observation-first guess) residuals at the observation location. The variable analyzed in this scheme is geopotential (z), u and v components of wind and specific humidity. Temperature (T) field is derived from geopotential field hydro statistically. Analysis is carried out on 12 sigma (pressure- divided by surface pressure) surfaces 1.0,0.9,0.8,0.7,0.6,0.5,0.4,0.3,0.2,0.1,0.07,0.05 in the vertical and 1ºX1º horizontal lat./long. grid for a regional or limited horizontal domain covering lat. 30ºS to 60ºN and long. 0º to 150º E.

Global Data Assimilation System (GDAS) operational at NCEP is a six hourly intermittent three dimensional scheme. Main component of GDAS are (i) Data reception and quality control (ii) Data analysis and (iii) the NWP model. Meteorological observations of various observing platform from all over the globe is received through GTS. The data is assimilated four times a day viz, 0000,0600,1200 and 1800 UTC everyday. A six hour prediction from the model with a previous initial condition valid for the current analysis time is used as the background field or the first guess field for the subsequent analysis. The analysis scheme used is the Spectral Statistical Interpolation (SSI) technique developed at NCEP (Parish and Derber 1992). The global forecast system (GFS) at NCEP is a spectral global model. The resolution of NCEP GFS is T-254/L64 and the outputs of the model are available in the Internet in the GRIB format at the grid resolution of 1ºX1º. The NCEP global model forecasts of wind and pressure fields are based on the Global Forecast System (GFS). The superiority of the NCEP GFS is not only the model resolution, it uses an extensive range of satellites and other conventional and non conventional observations. This made motivated to modify the current satellite derived wind processing algorithm from the use of NCEP GFS as the first guess in place of LAM forecasts. The modification has been done in the month of October 2008. The quality check procedure of WVW was carried out with NCEP Model forecast data, which covers the area 40E-129E and 40S-40N.

The focus of this study is mainly on the performance and assessment of NCEP GFS forecast on derivation of WVW against the LAM forecast. The WVW were evaluated with the statistics given on CGMS wind evaluation reporting guidelines. The error analysis has been carried out for the validation of WVW with the available available radiosonde observations for the months of May 2008 to January 2009 and METEOSAT-7 for the months of October to December 2008. Further, a cyclone case study has been examined.

2. DATA AND METHODOLOGY

Effects of NCEP GFS as the first guess to the Kalpana-1 satellite wind extraction scheme are reviewed by inter-comparing verification data of water vapor winds (WVW) with collocated radiosonde wind measurements and METEOSAT-7. Their impact is estimated in quantitative terms using the statistical formula given on CGMS wind evaluation reporting guidelines.

The WVW data are matched with the radiosonde observations(RS) for the period of May 2008 to January 2009. The criteria for selecting WVW measurement with collocated RS data are based on the following: (*1*) The absolute distance between the position (latitude and longitude) of the RS and the WVW data has considered for 2º (*2*) The observational time of RS and WVW measurements was 00 and 12 UTC.

The mean vector difference (MVD) is given by

$$(\mathrm{MVD}) = 1/N \sum_{i=1}^{N} (\mathrm{VD})i$$

Where the vector difference (VD), between an individual CMV report (i) and collocated first-guess fields of LAM (m) used for verification is,

$$(\mathrm{VD})i = [\ (Ui - Um)^2 + (Vi - Vm)^2\ ]^{1/2}$$

The root-mean-square error (RMSE) traditionally reported is the square root of the sum of the squares of the mean vector difference and the standard deviation about the mean vector difference,

$$(\mathrm{RMSE}) = [\ (\mathrm{MVD})^2 + (\mathrm{SD})^2\ ]^{1/2}$$

where the standard deviation (SD) about the mean vector difference is

$$(\mathrm{SD}) = 1/N \sum_{i=1}^{N} [(\mathrm{VDi}) - (\mathrm{MVD})]$$

The speed bias is given by

$$(\mathrm{BIAS})\ i = 1/N \sum_{i=1}^{N} [(Ui^2 + V\,i^2)^{1/2} - (Ur^2 + Vr^2)^{1/2}]$$

These statistics can provide a fixed measure of product quality over time and can be employed in determining the observation weight in objective data assimilation.

3. RESULTS AND DISCUSSION

3.1. *Validation of Water Vapor Winds with radiosonde observation*

The Kalpana-1 derived WVW were compared quantitatively with radiosonde observation for the period of May 2008 to January 2009. After the incorporating above mentioned changes in the algortihm, quality of WVW derived product was checked. It may be seen from the Fig-1, the RMSE of Kalpana-1 WVW between 100-500 hPa level ranges from 4 to 8 m/s. Similarly the bias of Kalpana-1 WVW is also quite higher *i.e.*, 2 to 4 m/s. It is to be noted that these are not absolute accuracies, as radiosondes themselves have errors ranging from roughly 2 m/s (low levels) to 4 m/s (high levels) (Tomassini et al., 1999). However it can also be seen from the Fig-1, October 2008 onwards there is a reduction in the RMSE and it has reduced from 8 m/s to almost steady value of 4 m/s. Similary bias has also not incresed. Therfore it can be stated that there is an improvment in the RMSE after replacing the LAM model forecast by NCEP forecast from October 2008. However the bias is little higher compared to radiosonde observations. The reason for high hight bias may be due to errors in assigning heights in inversion regions. Assigning height in inversion reason can be difficult because the results are very dependent on the resolution and quality of the forecast data and there can be multiple cloud top height solutions. The water vapor winds from geostationary satellites are not the only product to have difficulty in inversion regions. The MODIS cloud top height product was also found to have a high height bias relative to Calipso data (Robert Holz personal communication, Sep 2007). One situation that can give rise to a high height bias ,if the inversion is not deep enough in the model profile as shown in Fig-2 *(*Forsythe and Saunders, 2008*).*

3.2. *Quantitative analysis with METEOSAT-7 data using first guess forecast field from NCEP*

In order to better understand the features observed in the WVW pattern and to identify possible causes, it has been informative to make use of additional statistics. One of the statistics that can be very useful is a comparison of the Kalpana-1 derived WVW (using NCEP forecast and LAM data) with METEOSAT derived WVW for the period of October to December 2008, since both satellites have fairly large common areas of coverage. Qualitative checks on the quality of Kalpana-1 derived WVW were also done by visual examination of their matching with the large scale and synoptic scale flow patterns obtained from conventional upper air charts and the supporting satellite pictures which normally indicate the position of troughs and ridges. Quantitative analyses have been done by comparing first guess forecast field of NCEP and LAM with METEOSAT-7 data. The statistics generated by the data used from first guess forecast field of LAM and NCEP for the same time period and then compared with METEOSAT-7 WVW. The improvement noticed by NCEP data with respect to LAM is only shown in the Table-1. It may be seen from the Table-1 that significant improvements have been noticed by NCEP data when both the datasets (NCEP & LAM) compared with METEOSAT-7. The height assignment has improved on an average of 18% and 16% at 100-350 hPa and 350-500 hPa respectively in comparison with METEOSAT-7. Similar result has also been noticed in the field of wind direction.

3.3 Case Study : *Vortex (NISHA) over Bay of Bengal and N/Hood during the period 24th to 26th November , 2008.*

A low level circulation developed over south west Bay of Bengal and N/hood at 0600 UTC of 24th Nov, 2008. It organized into a vortex with centre 8.0N/83.5E and intensity T1.0 at 0600 UTC of 24th November, 2008. Sea surface temperature over the region at this time was 29.0 degree Celsius, which is normal and meteosat derived wind shear between layers (150-300 to 700-925) was about 15-20 knots and there was no change in wind shear tendency during past 24 hours. So conditions were favourable for further intensification of the system during next 24 hours. Moving in a West-North-Westerly direction, it crossed Srilanka Coast in the morning of 25th November, 2008 and thereafter moving towards north again it lies over sea centred near 9.7N/80.5E at 0900UTC of 25th and intensity of the system at this time was T2.5. Becouse of favourable condition for the further intensification of the system and water vapour winds indicate shown in Fig4(a-b) ,the system is likely to move in a north-north-westerly direction during next 24 hours. As expected It intensified further at 2100 UTC of 25th Nov, 2008 with centre 10.4N/80.1E Intensity T2.0. After 0200 UTC of 26th Nov, 08 it moved slightly southwards and intensified further at 0300 UTC of 26th Nov, 08 with centre 10.1N/80.1E intensity T2.5 shown in Fig-5(a-b). The System had very little movement in the NW-ly direction; it intensified further at 0800 UTC of 26th Nov, 08 with centre 10.3N/79.9E and crossed the coast near centre 10.5N/79.8E with intensity T3.0.

For comparison , the Kalpana-1 and Meteosat-7 derived water vapor upper level winds have shown in the study (Figure 3). Kalpana-1 derived WVW clearly shows the steering effect on weather system and likely movement of the storm in west-north-westerly direction on 06 UTC of 24-11-2008. From the figures it is seen that the Kalpana-1 derived WVW has shown fairly good agreement with the Meteosat-7 winds and the synoptic scale flow pattern has very well brought out in the Kalpana-1 WVW. This case study indicates that the data are useful in depicting upper-level features and their evolution, which can play an important role in tropical cyclone formation and motion.

4. SUMMARY AND CONCLUSION

A quantitative assessment of KALPANA-1 derived water vapor winds from the use of NCEP first guess forecast fields in place of LAM model has been done. The modifications are made on current satellite derived wind processing scheme at IMD in the month of October 2008. The error analysis has been carried out for the validation of Kalpana-1 WVW with radiosonde observations for the period of May 2008 to January 2009. The error analysis shows that the bias of Kalpana-1 WVW is quite higher i e, 2 to 4 m/s and RMSE between 100-500 hPa level ranges from 4 to 8 m/s but October 2008 onwards there is a reduction in the RMSE and it has reduced from 8 m/s to almost steady value of 4 m/s, which is in acceptable range, similarly bias has also not incresed. Therefore improvments are noticeble after replacing the first guess forecast field from LAM to NCEP from October 2008. A cyclone case study has also been examined and it has found that the Kalpana-1 derived WVW has shown fairly good agreement with the METEOSAT-7 winds. Even though the wind speed is slightly higher but the synoptic scale flow pattern has very well brought out in the Kalpana-1 WVW and comparable to those of METEOSAT winds. This shows that upper level water vapor winds derived from Kalpana-1 satellite are quite improved and could be very useful for predicting the future track position of intense cyclones, depressions and well marked low pressure areas.

The performance of Atmospheric Motion Vectors (CMV/WVW) reflects the overall effect of satellite and NWP system. The coverage and quality of WVW will vary depending on atmospheric factors such as moisture availability and structure, vertical shear and instrument characteristics such as detector precision and resolution. To have high quality WVW to be produced, the image navigation, calibration and NWP output should be well performed because the wind retrieval is so sensitive to navigation errors that it can be used to check the accuracy and calculate a correction to the image co-registration. Further down the road, it is hoped that the accuracy of the height assignment of AMVs will be greatly improved with the forthcoming INSAT-3D IR sounders that will fly on geostationary orbit Future work will also be focusing on applying flexible search area by using NWP wind data at the level corresponding to AMV height and analyzing the model best-fit pressure comparisons.

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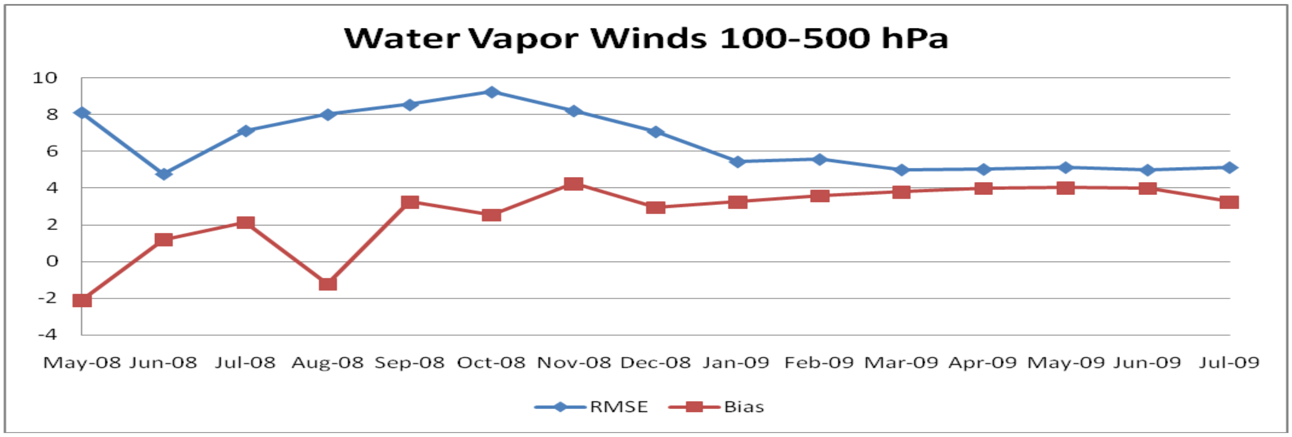


Figure 1**: Comparison of WVW with radiosonde observation for the period of May 2008 to July 2009**

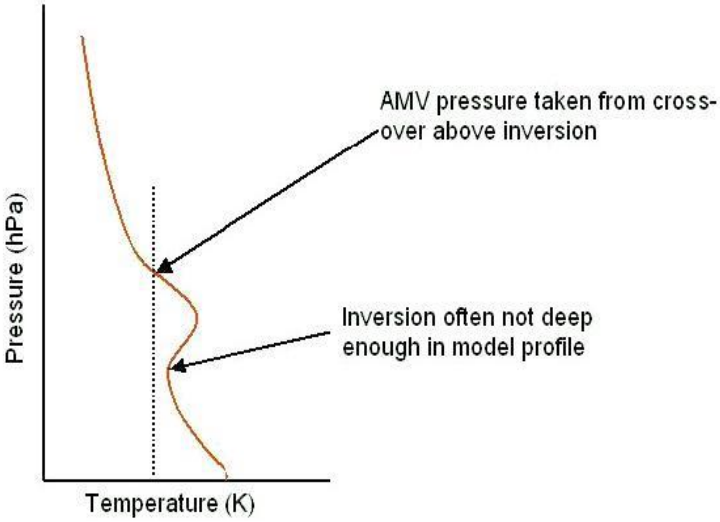
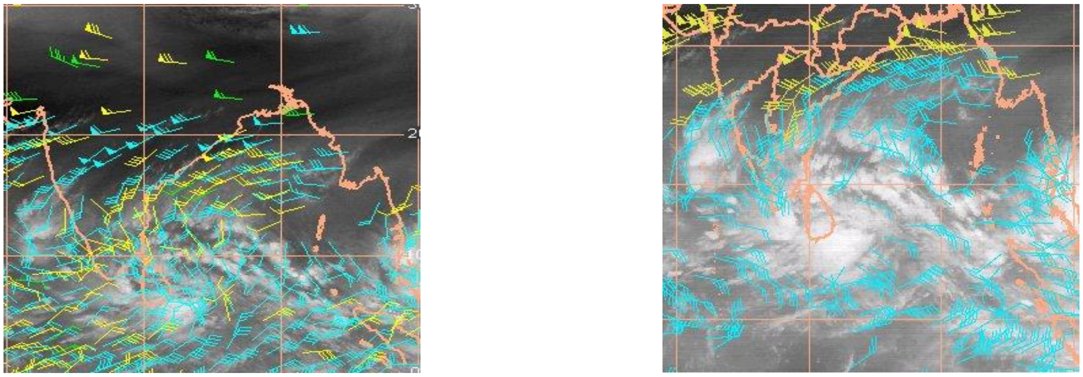


Figure 2: **Illustration of how a high height bias can occur in inversion regions. (*Forsythe and Saunders, 2008)***



(a) (b)

Figure 3(a-b): **WVW derived from (a) METEOSAT-7 and (b) Kalpana-1 at 06 UTC of 24-11-2008**

Time	Wind Speed B/w 10-20 Kt	Wind Speed B/w 25-50 Kt	Height Assignment Between 100 to 350 (hPa)	Height Assignment Between 350 to 500 (hPa)	Direction difference
00 UTC	30%	16%	17%	14%	28%
12 UTC	22%	19%	21%	19%	21%

Table 1: **The comparison statistics of KALPANA-1 WVWs against METEOSAT-7 WVWs using NCEP and LAM forecast fields. The improvements by NCEP data with respect to LAM are only shown.**