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A quantitative assessment of KALPANA-1 derived water vapour winds and their improvement from the use of NCEP first guess forecast fields

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सार – भारत मौसम विज्ञान विभाग के उन्नत इनसेट–2 ई. के मौसम विज्ञान से संबंधित आँकड़ा संसाधन प्रणाली का उपयोग करते हुए भारत मौसम विज्ञान विभाग, नई दिल्ली में भारत के भूस्थिर मौसम उपग्रह कल्पना–1 के अतिउच्च विभेदन रेडियो मीटर (वी. एच. आर. आर.) पेलोड के जलवाष्प चैनल (5.7 म्यू. एम.–7.1 म्यू. एम.) का उपयोग करते हुए भारत मौसम विज्ञान विभाग के नेमी प्रचालनात्मक आधार पर मार्च 2008 से जलवाष्प पवन के आँकड़े प्राप्त किए जाने लगे हैं। हाल ही में इस उत्पाद को प्राप्त करने के लिए प्रयोग में लाए गए एलगोरिथ्म में संशोधन किए गए हैं। भारत मौसम विज्ञान विभाग के प्रचालनात्मक समिति क्षेत्र निदर्श (एल. ए. एम.) के पूर्वानुमानों के स्थान पर 1°×1° के विभेदन पर राष्ट्रीय पर्यावरण प्रागुक्ति केन्द्र (एन. सी. ई. पी.) भूमंडल पूर्वानुमान प्रणाली (जी. एफ. एस.) से प्राप्त किए गए प्रथम अनुमानित पूर्वानुमान फील्डों का उपयोग व्यवहार में मूलभूत परिवर्तन करने के लिए किया गया है। इस अध्ययन में 40 डिग्री पूर्व – 129 डिग्री पूर्व और 40 डिग्री दक्षिण – 40 डिग्री उत्तर के क्षेत्र के अतंर्गत ई. सी. एम. डब्ल्यू. एफ. निदर्श पूर्वानुमान के आँकड़ों का उपयोग करते हुए प्रचालनात्मक जलवाष्प पवन के आँकड़ो की गुणवत्ता की जाँच की गई है इनसे प्राप्त हुए परिणामों से यह पता चला है कि जलवाष्प पवन के अच्छी गुणवत्ता वाले आँकड़ो की संख्या में उल्लेखनीय रूप से वृद्धि हुई है। ई. सी. एम. डब्ल्यू. एफ. प्रथम अनुमानित पूर्वानुमान फील्ड की तुलना में कल्पना – 1 के आर. एम. एस. ई. से प्राप्त किए गए जलवाष्प पवन के आँकड़ो में 5 एम./एस. की वृद्धि हुई है। जिनकी तुलना सामान्यतः विश्व के अन्य भूस्थिर मौसम विज्ञानकि उपग्रहों से उसी प्रकार के प्राप्त किए गए परिणामों के साथ की जाती है। अंततः एस. ए. टी. ओ. बी. के साथ साथ बी. यू. एफ. आर. दोनो फोरमेट में उपयोगकर्ताओं के प्रचालनात्मक उपयोग के लिए उन्नत गुणवत्ता वाले ये जलवाष्प पवन जी. टी. एस. पर प्रेषित किए जाते हैं।

मई 2008 से जुलाई 2009 तक की अवधि के क्रमवार रेडियोसौंदे प्रेक्षणों और अक्तूबर से दिसम्बर 2008 की अवधि के यूरोपीय मीटियोसेट – 7 आँकड़ों से प्राप्त किए गए मध्य उपरितन स्तर की पवनों के उपलब्ध आँकड़ो का उपयोग करते हुए जलवाष्प पवन की प्रमाणिकता के लिए त्रुटिपूर्ण विश्लेषण भी विस्तार से किए गए है। रेडियोसौंदे आँकड़ों के साथ किए गए विश्लेषण से पता चला है कि कल्पना – 1 जलवाष्प पवन के प्रभाव में संशोधन से पहले –2 से लेकर +4 एम./एस. तक की परिवर्तनशीलता थी और संशोधन के पश्चात् यह 4 एम./एस. का मान लगभग स्थितर हो गया। रेडियोसौंदे पवनो के संदर्भ में 100–500 हेक्टापास्कल स्तरों के मध्य उत्पन्न पवनों के आर. एम. एस. ई. संशोधन से पहले 4.2 से 9.2 एम./एस. की परिधि में थे। तथापि अक्तूबर, 2008 से जब संशोधन किए गए तो ये लगभग 4 एम./एस. के करीब स्थिर मान तक कम हो गए। इसकी तुलना जी. एम. एस. (जापान) और मीटियोसेट (यूरोपीय) नामक अन्य उपग्रह प्रचालकों द्वारा सामान्यतः उसी रूप में प्राप्त किए गए परिणामों के साथ की गई ह। तथापि अन्य उपग्रहों की तुलना में इसका प्रभाव कुछ अधिक है। प्रेक्षित किए गए उच्च प्रभाव (बियास) का एक कारण यह है कि निदर्श जनित प्रथम अनुमानित पूर्वानुमान फील्ड में कई बार तापमान संरचना के परिष्कृत विवरण सही तरीके से प्रस्तुत नहीं किए जाते हैं। इस दिशा में प्राप्त हुए सभी परिणामों से यह पता चला है कि एल. ए. एम. के स्थान पर एन. सी. ई. पी. के निदर्श प्रथम अनुमानित पवन फील्ड का उपयोग करने के बाद कल्पना –1 से प्राप्त किए गए जलवाष्प पवन के आँकडों में अनुकूल सुधार हुआ है। विशिष्ट चक्रवातों के मामलों के अध्ययन भी किए गए हैं और यह पाया गया है कि कल्पना –1 से प्राप्त किए गए जलवाष्प पवन के आँकडे चक्रवातों के भावी पथ का पूर्वानुमान लगाने के लिए उपयोगी होते हैं। इसमें यह भी पता चला है कि सामान्यतः उन्नत कल्पना –1 जलवाष्प पवन के आँकड़ों (डब्ल्यू. वी. डब्ल्यू.) मीटियोस्टेट –7 से प्राप्त पवनों के आँकड़ों के अनुरूप है क्योंकि ये सिनॉप्टिक मापक्रम प्रवाह पैटर्न को सही तरीके से प्रस्तुत करते हैं।

ABSTRACT. Derivation of Water Vapor Winds (WVWs) using water vapor channel (5.7µm- 7.1µm) of Very High Resolution Radiometer (VHRR) payload onboard India's KALPANA-1 geostationary meteorological satellite started in March, 2008 on a routine operational basis at India Meteorological Department (IMD), New Delhi using upgraded INSAT-2E meteorological data processing system of IMD. Recently a modification has been introduced in the algorithm used for derivation of this product. The primary change introduced is making use of first guess forecast fields obtained from National Center for Environmental Prediction (NCEP) Global Forecast System (GFS), at a resolution of 1º × 1º instead of forecasts of operational Limited Area Model (LAM) of IMD. In the present study, the quality check of operational WVWs has been carried out using ECMWF Model forecast data, covering the area 40ºE-129ºE and 40ºS-40ºN. Results show a significant increase in the number of good quality WVWs. The RMSE of KALPANA-1 derived WVWs, as compared to ECMWF first guess forecast field has improved to 5 m/s which are generally comparable with the similar results of other geostationary meteorological satellites in the world. Finally, these WVWs of improved quality are transmitted on GTS for operational use by the end users in both SATOB as well in BUFR formats.

Detailed error analysis has also been carried out for validation of WVWs using collocated radiosonde observations for the period from May 2008 to July 2009 and the available mid-upper level winds derived from European METEOSAT-7 data for the period from October to December 2008. The analysis with radiosonde data shows that before modification the bias of KALPANA-1 WVWs was variable between -2 and +4 m/s and after modification it has become almost steady to a value of 4 m/s. The RMSE of derived winds between 100 and 500 hPa levels with reference to the radiosonde winds ranged from 4.2 to 9.2 m/s before modification. However, from October 2008 onwards when modifications were made it has reduced to almost steady value of approximately 4 m/s. This is comparable with similar results generally obtained by the other satellite operators such as GMS (Japan) and METEOSAT (European). However, the bias is slightly higher as compared to that of other satellites. One of the reasons for observed high bias is the fact that fine details of temperature structure are sometimes not brought out properly in the model generated first guess forecast field. The overall results show consistent improvements in KALPANA-1 derived WVWs after using model first-guess wind field from NCEP instead of LAM. Case studies of specific cyclones have also been done and it is found that the KALPANA-1 derived WVWs are useful for predicting the future track of the cyclones. It is also found that the improved KALPANA-1 WVWs are in general in good agreement with METEOSAT-7 derived winds as they bring out the synoptic scale flow patterns very well.

Key words – VHRR, WVW, RMSE, BUFR, NCEP

1. Introduction

Wind is a key parameter for weather forecasting, meteorological studies and climate related applications. As a result of persistent efforts by the scientists and operational community world over, sufficiently reliable techniques have been developed for using the imagery data from geostationary meteorological satellites in order to derive Atmospheric Motion Vectors (AMV) by tracking movement of clouds and moisture features in successive half hourly images. The globally derived Atmospheric Motion Vector (AMV) fields are now well established and constitute an essential product especially for Numerical Weather Prediction (NWP) related applications. These data are now being routinely assimilated in operational models by many NWP centers in the world. Water vapor imagery from geostationary meteorological satellites has been available over the Indian region for more than a decade. These data were used extensively by operational analysts and forecasters mainly in a qualitative way (Weldon and Holmes, 1991). For many applications the upper troposphere atmospheric winds estimated from successive half hourly water vapor images of any geostationary meteorological satellite are very important product because of their proven operational use in NWP model world over. Early attempts to quantify the accuracy level of these winds based on manual methods to track moisture features in animated image sequences met with modest success (Stewart *et al.*, 1985; Hayden and Stewart, 1987). The water vapor images from geostationary satellites have allowed the estimation of both upper-level moisture flow and the flow that corresponds to water vapor layers. The resulting product or water vapor wind (WVWs) has generally an improved coverage with respect to the CMV product, the major advantage being the availability of many more targets in the image. However, there are indications of some problems in the height assignment of WV winds when extremely dry atmospheric conditions prevail and the quality of first guess forecast field from NWP over the cloudy areas is not reliable.

In particular, the upper level winds derived from METEOSAT-7 have proved to be very useful for predicting the future track position of depressions and well marked low pressure areas with deep vertical extent. On the basis of their potential use for better future track predictions it is possible to give more accurate heavy rainfall warnings to the areas likely to be affected by these weather systems. It is possible to give more precise warnings to the affected areas at least 24 to 48 hours (Bhatia *et al.* 2008) in advance since these types of weather systems are generally steered by the upper level winds.

The current Indian geostationary satellite KALPANA-1 has a payload called Very High Resolution Radiometer (VHRR) with three channels *viz*., Visible (0.55µm-0.75µm), Infrared (10.5µm-12.5µm) and Water Vapour (5.7µm- 7.1µm) with their ground resolutions of 2 km, 8 km and 8 km respectively. After KALPANA-1

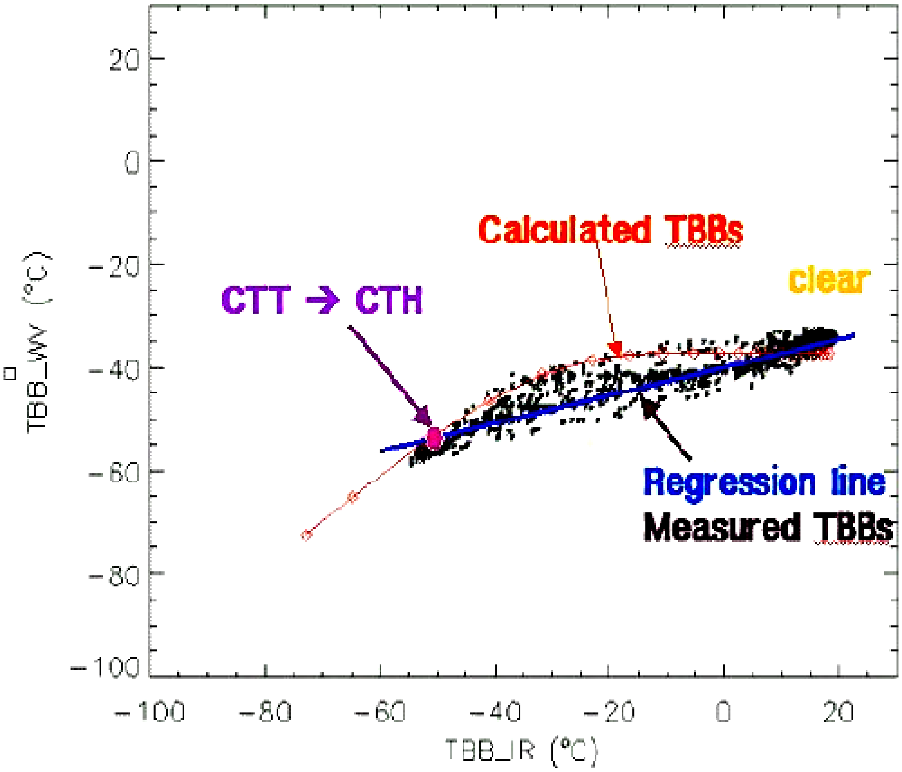


Fig. 1. Conceptual diagrams for IR/WV intercept method

satellite became operational in the month of October, 2002, IMD first began deriving Cloud Motion Vectors (CMVs) from the Infrared data twice a day using triplets scanned at 2330, 0000 and 0030 hrs UTC and 0700, 0730 and 0800 hrs UTC. CMV derivation was started on an operational basis in IMD in early 1980`s after the launch of first satellite of INSAT-1 series. Subsequently, Kelkar and Khanna (1986) introduced a new technique based on pattern matching by searching equality in pixel to pixel between tracer and target images. With the inception of new INSAT Meteorological Data Processing System (IMDPS) in 1992 under the INSAT-II project, cross correlation technique was introduced for derivation of CMVs by pattern matching. Thereafter, several improvements have been carried out by various scientists (Bhatia *et al.* 2002, Khanna and Prasad 1998, Khanna and Bhatia 2000, Mitra *et al.* 2008*)* leading to better results and reduced rms errors and biases.

Derivation of Water Vapor Winds using water vapor channel (5.7µm- 7.1µm) data of KALPANA-1 satellite with a new method, based on CIMSS Satellite Derived Wind Algorithm, had been introduced in the IMDPS on a routine operational basis from March 2008 at IMD. In this method height assignment is being done by the H2O-IRW Intercept method (Nieman *et al*., 1997) for CMV and WVW computations. Fig. 1 shows the concept of IR/WV intercept method which is based on the fact that single layer cloud with different cloud amount has a linear relationship between observed Infrared and water vapor brightness temperatures. The height of AMV is assigned from cloud top temperature at the intersection point between the calculated curve line and observed regression line. The advantage of this method is very well seen for WVWs as compared to the CMVs because water-vapour track winds can be derived even in an area free from clouds. The H2O-intercept method is generally not useful for clouds lower in the atmosphere than above 500 hPa because upwelling radiation comes primarily from the atmosphere above the cloud. Low clouds cannot be detected with the commonly-used water vapor channels centered near 6.7 µm.

Currently all operational AMV extraction centers make use of appropriate Automatic Quality Control (AQC) schemes. Traditional schemes (Le Marshall *et al.* 1994; Nieman *et al.* 1997) are usually based on vector acceleration checks and simple thresholding techniques that compare the derived vectors to their surrounding vectors or to the collocated forecast fields. All vectors that show an acceleration, directional deviation, or discrepancy compared to other observations larger than a predefined value are rejected. This thresholding approach is fairly successful as a gross error check, but it does not provide further information on the quality of the vectors passed on to the user. Therefore, advanced methodologies have been developed for AQC at the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and the University of Wisconsin–Cooperative Institute for Meteorological Satellite Studies (UW–CIMSS). The EUMETSAT scheme utilizes tests similar to those applied in the thresholding techniques; they are, however, implemented as normalized continuous functions, providing test results that can be combined into a final quality indicator (Holmlund 1998). At UW–CIMSS, the AQC is controlled by a series of quality checks and a three-dimensional objective analysis scheme referred to as the auto-editor (AE; Hyden; 1993, Hayden and Purser 1995; Hyden & Nieman, 1996,Velden *et al*. 1998), which results in the assignment of vector quality flags. In our operational AMV schemes of IMD, being used in the upgraded INSAT-2E Meteorological Data Processing System, we adopted the combined EUMETSAT and UW-CIMSS approach for automated quality control (AQC).

All height assignment techniques for CMV/WVW derivation mainly depend upon numerical model forecast data. It is therefore important to have good quality NWP forecast fields such as temperature, moisture, *u, v* and pressure fields which are finally converting satellite brightness temperature measurements into pressure height estimates. India Meteorological Department has been using a Limited Area Model (LAM) on an 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 schemes. 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 variables analyzed in this scheme are geopotential (z), u and v components of wind and specific humidity. Temperature (T) field is derived from geopotential field hydrostatistically. 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 a 1° × 1° horizontal lat./long. grid is used for a regional or limited horizontal domain covering Lat. 30° S to 60° N and Long. 0° to 150° E.

Global Data Assimilation System (GDAS) operational at NCEP is a six hourly intermittent three dimensional scheme. Main components of GDAS are (*i*) Data reception and quality control (*ii*) Data analysis and (*iii*) the NWP model. Meteorological observations of various observing platforms from all over the globe are received through GTS. The data are assimilated four times a day at, 0000, 0600, 1200 and 1800 hrs UTC. 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 through Internet in the GRIB format at the grid resolution of 1° × 1°. 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 in the model resolution but also due to assimilation of an extensive range of satellites and other conventional and non conventional observations. This motivated us to modify the current satellite derived wind processing algorithm for use of NCEP GFS as the first guess in place of LAM forecasts. The modification has been introduced in the month of October, 2008. The quality check procedure of WVW was carried out with NCEP Model forecast data, which covers the area 40° E - 129° E and 40° S - 40° N.

The focus of this study is mainly on the improvement and assessment of KALPANA-1 WVWs derived from two different forecast fields *i.e.*, NCEP GFS and LAM forecast. The quality of WVWs was assessed on the basis of statistics derived by using guidelines generated by the well known and internationally recognized Coordination Group for Meteorological Satellite (CGMS). The error analysis has been done by comparison of WVWs with the available collocated radiosonde observations for the period May 2008 to July 2009 and with METEOSAT-7 derived winds for the period October to December 2008. Quality of WVWs has also been assessed using a method similar to the one used for ECMWF for analysis of WVWs generated by the other satellite operators. Further, to assess the quality of the winds from the point of view of their use for general synoptic analysis, a qualitative comparision of water vapor upper level winds derived from KALPANA-1 and METEOSAT-7 has been done for particular case of cyclones (NISHA 2008 and PHYAN 2009).

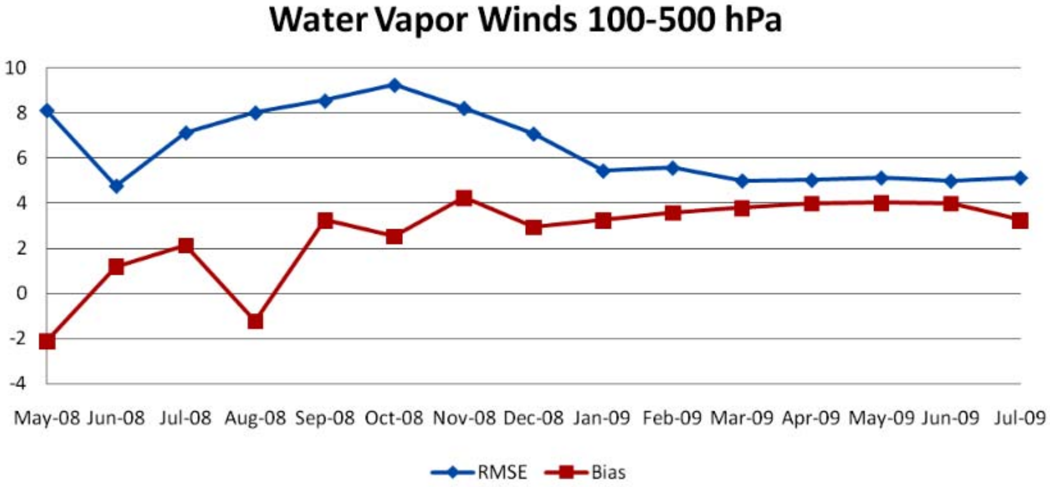


Fig. 2. Comparison of WVW with radiosonde observation for the period of May 2008 to July 2009

2. Data and methodology

Effects of using 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 the winds derived from METEOSAT-7 data. Their impact is estimated in quantitative terms using the statistical formula as given in CGMS wind evaluation reporting guidelines (Report of CGMS Activities, 2001).

The WVW data are compared with the collocated radiosonde observations (RS) for the period from May 2008 to July 2009. The collocation criteria for selecting WVW measurement with RS data are based on the following: (*i*) The absolute distance between the position (latitude and longitude) of the RS and the WVW data has been considered as 2° and (*ii*) The observational time of RS and WVW measurements was same, *i.e.*, 0000 and 1200 UTC.

The mean vector difference (MVD) is given by

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

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

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

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

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

The speed bias is given by

$$(\mathrm{BIAS})\mathrm{i} = \frac{1}{N}\sum_{i=1}^{N} \left[\left(\mathrm{Ui}^2 + \mathrm{Vi}^2\right)^{1/2} - \left(\mathrm{Ur}^2 + \mathrm{Vr}^2\right)^{1/2}\right]$$

where the subscript ‘r’ refers to the radiosonde report. These statistics can provide a fixed measure of product quality over a long period of time and can also be employed in determining the observation weight in objective data assimilation.

3. Results and discussions

3.1. *Validation of water vapor winds with radiosonde observations*

To achieve a reliable estimate of the quality of derived vectors, a reference dataset is required. For validation, WVWs are mainly used as single-point measurements equivalent to radiosonde measurements. It is therefore natural to use the radiosonde data for verification purposes. It is, however, important to recognize that the radiosonde measurements also contain

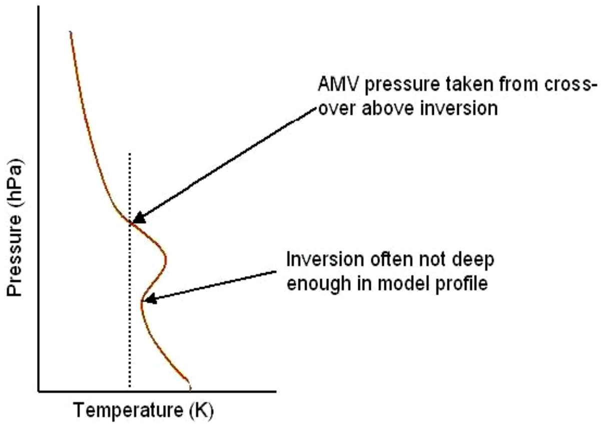
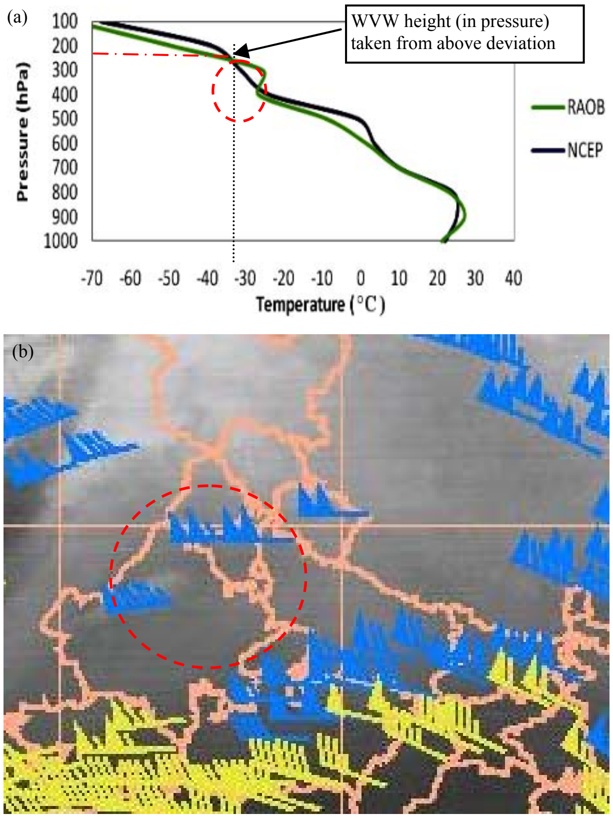


Fig. 3. Illustration of how a high height bias can occur in inversion regions

errors and do not provide an absolute truth. The KALPANA-1 derived WVWs were compared quantitatively with collocated radiosonde observations for the period May 2008 to July 2009. The quality of KALPANA-1 derived WVWs product was checked before and after incorporating the above mentioned changes in the algorithm. It may be seen from Fig. 2 that before incorporating changes in the algorithm, the RMSE of KALPANA-1 WVWs between 100-500 hPa levels generally ranged from 4.2 to 9 m/s. The bias of KALPANA-1 WVWs ranged from -2 to +4 m/s. It is also to be noted that these are not absolute accuracies, as radiosondes themselves are known to have errors ranging from roughly 2 m/s (low levels) to 4 m/s (high levels) (Tomassini *et al.*, 1999). However, it can be seen from Fig. 2, that from October 2008 onwards there is a reduction in the RMSE which has reduced from 9.2 m/s to almost steady value of 4.1 m/s. Bias has also become steady to a value of about +4 m/s. These improvements have been sustained for a considerably long period of time after making changes. Therefore, it can be stated that there is an improvment in the RMSE after replacing the LAM model forecast by NCEP forecast. The larger bias for WVWs could be caused by lower wind altitude estimates. Another possible reason for high bias may be due to errors in assigning heights in inversion regions. Assigning height in inversion region can be difficult because the results are very much dependent on the resolution and quality of the forecast data and there can be multiple cloud top height solutions. In particular, low water vapor amounts, atmospheric temperature inversions, and thin clouds can significantly impact the height assignment with infrared window, CO_2-slicing and H_2O intercept methods (Key *et al*. 2004). The MODIS cloud top height product was also found to have a high height bias relative to Calipso data (Robert Holz personal communication, September 2007). One situation that can give rise to a high height bias is when the inversion is not deep enough in the model profile as shown in Fig. 3 (Forsythe and Saunders, 2008). Similar kind of investigation has also been done with KALAPANA-1 derived WVWs. It has been found in this study that the high bias (+4 m/s) is generally observed from March to June 2009 (Fig. 2) and every year, during these months, short duration thunderstorms, dust storms occur mainly over the North and North-West parts of India. One of the reasons for occurrence of storm is the formation of low pressure area in summer seasons in these regions. The height of the vector is derived by first calculating the brightness temperature with the water vapor channel and then finding out the height at which this temperature occurs with the aid of a model forecast temperature profile. Model guess forecast fields must be valid for a time period within nine hours of the satellite imagery being used for wind computation. At the end of the processing, the editing of wind vectors is kept at a minimum in order to include significant deviations from the model 'guess' field. But sometimes the detection of



Figs. 4(a&b). (a) Comparison of radiosonde profile with NCEP profile 03 March 2009 (0000 UTC), (26.3° N / 76.01° E).Red circle indicates the deviation not captured deep enough in the NCEP model profile and (b) The high wind speed around 100 to 110 knots between 100-250 hPa observed by KALPANA-1 derived WVW over the same region

TABLE 1

A comparison statistics between NCEP and LAM with ECMWF model as reference at 100 -500 hPa

Parameters	NCEP	LAM
October 2008		
MEAN VECT. DIFF.	5.12	7.12
NUMBER OF CO-LOC.	653	650
RMSE	5.16	7.57
BIAS	1.18	2.58
November 2008		
MEAN VECT. DIFF.	5.60	7.24
NUMBER OF CO-LOC.	705	711
RMSE	5.11	7.29
BIAS	1.49	2.01

Legends :

MEAN VECT. DIFF. = Average Vector Difference WVW – ECMWF wind
NUMBER OF CO-LOC. = Amount of collocated WVW`s
RMSE = Average RMS error WVW – ECMWF wind
SPD BIAS = Average Speed Difference WVW – ECMWF wind

perturbed flow aloft due to thunderstorms and other small-scale features are not correctly captured by forecast models. These situations can give rise to the higher wind speed. For example, on a particular day, Figs. 4(a&b) shows the vertical temperature structure over Jodhpur (26.3° N / 76.01° E) observed by radiosonde and model profile on 3rd March 2009 and KALPANA-1 derived WVW over the same region. It is clearly seen from this Figure that a small perturbation in the upper atmosphere due to a particular synoptic situation can cause a mismatch between observed and model atmosphere profile in the middle and upper levels. This can cause a bias in radiative transfer calculations which may cause height bias in AMV computations. The above explanation is one of the possible reasons for the high height bias observed in the WVWs. The number of collocated data sets on the basis of which above error characteristics have been arrived at in each month is approximately 400- 500 points.

3.2. C*omparison of water vapor winds with two different forecast files (NCEP GFS & LAM) with ECMWF model*

To asses the quality of winds quantitatively, KALPANA-1 derived WVWs which are generated with LAM and NCEP GFS models as separate inputs were compared with the forecast field generated from the ECMWF model. Results are shown in the Table 1. The comparison statistics on RMS errors and biases computed with both datasets is for the period October to November 2008. The criterion used to estimate the wind quality is root mean square error between satellite wind vector and the reference wind vector (*i.e.*, ECMWF). The bias is defined as satellite wind vector speed minus reference wind speed. Results are shown for all the winds after applying Automatic Quality Control (AQC) procedure for 100 to 500 hPa levels. It is seen that smaller RMS errors (approximately 5 m/s) and bias (less than 1.5 m/s) have resulted using first guess forecast field from NCEP rather than LAM. These statistics are generally comparable with similar results produced by other centers in the world. According to METEOSAT satellite AMV verification statistics, the RMS and bias errors over the tropics are about 4.48 m/s and 1.82 m/s respectively. Similarly for MTSAT-1R satellite of Japan Meteorological Agency, these errors are 5.89 m/s and 0.44 m/s respectively over the tropics.

In order to make optimal use of the operational KALPANA-1 WVWs, it is necessary to accurately assess the quality and representativeness of individual wind vectors (after AQC) and to provide this information to the NWP centers as an integral part of the observations in near real time. In the AQC algorithm, quality checks are made based on vector acceleration checks and simple threshold techniques that compare the derived vectors to their surrounding vectors or to collocated forecasts fields. All vectors that show an acceleration, directional deviation or discrepancy larger than a predefined threshold value are rejected. The AQC statistics for WVW has been obtained using NCEP and LAM data between 02 December 2008 & 08 December 2008 at 0000 UTC. Fig. 6 shows a statistical representation of inter-compared quality-controlled wind vectors (using the identical quality-control criteria) produced by using two different first guess fields. It is clear that the middle and higher level vector density generated by NCEP is higher than that generated with LAM and there are more number of consistent wind vectors with NCEP forecast file. This may be due to the quality control of the wind vectors using the Recursive Filter analysis (Hayden and Pursor, 1995). This process involves a two stage, three−dimensional objective analysis (Hayden and Pursor, 1995) of the wind field using background information from a numerical forecast field. The overall analysis provides a final quality estimate for each vector based on the local quality of the analysis and the fit of the observation to that analysis. Vectors that do not possess a final quality value exceeding an empirically defined threshold are flagged and rejected based on the quality of numerical model background field.

TABLE 2

A comparison statistics of KALPANA-1 WVWs against METEOSAT-7 WVWs using NCEP and LAM forecast fields. Percentage improvement by NCEP data with respect to LAM is only shown. Numbers in percentage indicate the extent of improvement compared to METEOSAT-7 winds. Use of NCEP data results in better agreement (by indicated numbers in the table) with METEOSAT-7 winds

Time (UTC)	Wind Speed between 10-20 (kt)	Wind Speed between 25-50 (kt)	Height Assignment between 100 to 350 (hPa)	Height Assignment between 350 to 500 (hPa)	Direction difference
0000	30%	16%	17%	14%	28%
1200	22%	19%	21%	19%	21%

3.3. *Quantitative analysis of KALPANA-1 WVWs with METEOSAT-7 data using first guess forecast field from NCEP and LAM*

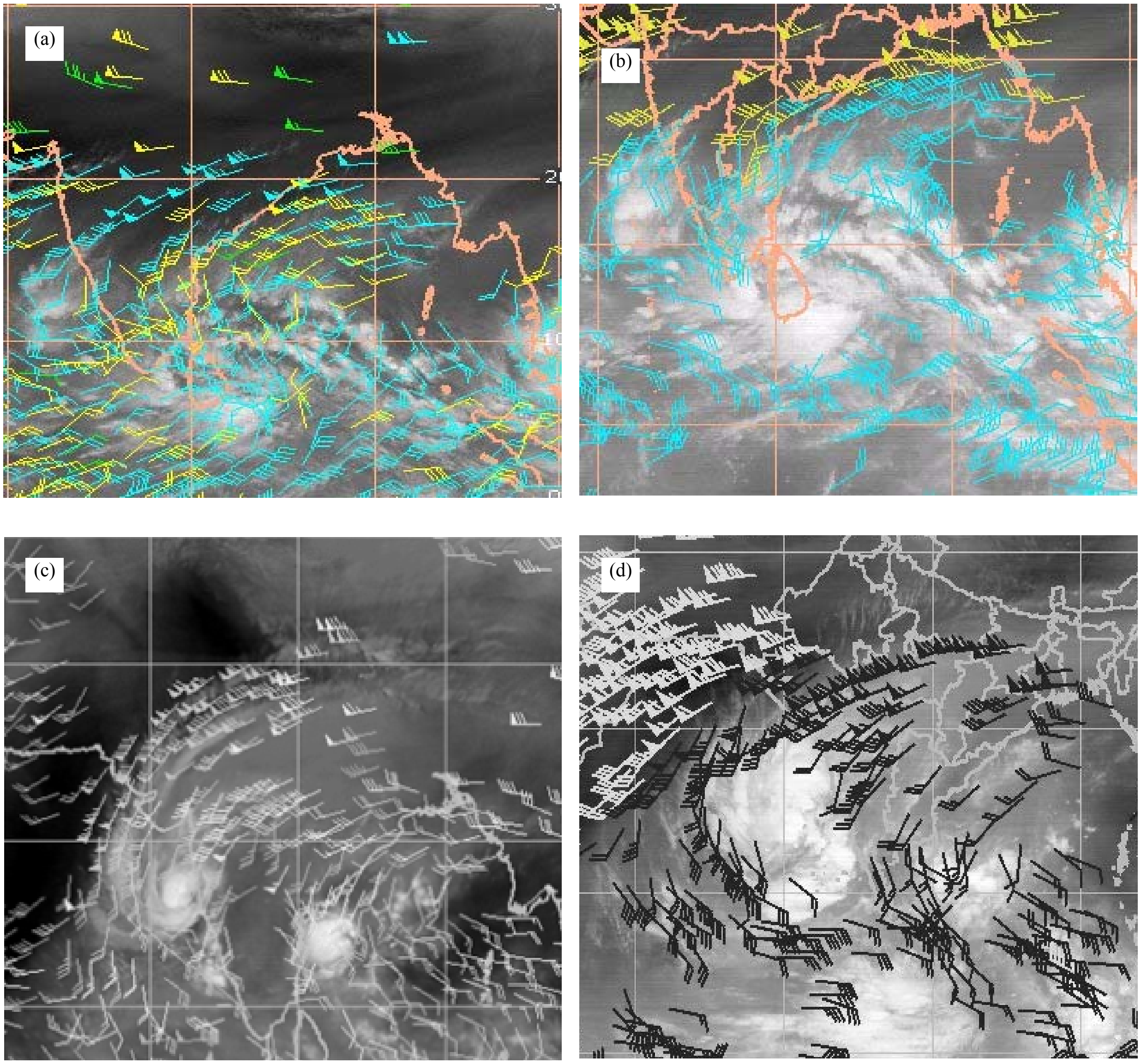
Further assessment of the quality of WVWs has been done by comparison of KALPANA-1 derived WVW (using NCEP and LAM data) with METEOSAT-7 derived WVWs over the same period since both satellites have fairly large common areas of coverage. Quantitative analysis has been done by comparing the WVWs generated from first guess forecast field of NCEP and LAM with operationally derived WVWs from METEOSAT-7 data at 0000 and 1200 hrs UTC for the period October to December 2008. Table 2 shows the results of statistical comparison and the improvement noticed by using NCEP dataset instead of LAM is also depicted. In the Table 2, 2nd and 3rd columns show the wind speed (between 10 to 20 kt and 25-50 kt) comparison from first guess forecast field of NCEP and LAM generated winds with collocated METEOSAT-7 WVWs. The collocation match radius does not exceed 2 degrees. It is found that very few winds in the above range have been produced by LAM dataset as compared to METEOSAT-7. However quantitatively in the same range, overall 30%, 22% and 16%, 19% of winds generated by NCEP dataset were agreeing with METEOSAT-7 winds at 0000 and 1200 UTC respectively. The percentage (%) depicted in the Table 1, shows the increase in the number of valid winds reported from NCEP dataset as compared with LAM.

In the 4th and 5th columns of Table 2, the METEOSAT-7 winds between 100-500 hPa levels have been compared with NCEP and LAM generated WVWs. In most of the cases when a high level wind at specific levels such as 100-350 hPa and 350 to 500 hPa is observed with corresponding NCEP and LAM generated winds, METEOSAT-7 and NCEP generated winds were found to be in good agreement in terms of level assigned whereas LAM generated winds do not appear to be matched and consistent with METEOSAT-7. The level assigned by LAM generated WVWs are somewhat (about 100-150 hPa) below the level assigned by METEOSAT-7 winds.

The 5th column of Table 2 shows the direction difference in comparison with METEOSAT-7 assigned wind direction at 100-500 hPa. The threshold between METEOSAT-7 and NCEP and LAM generated wind direction was 45°. The points where the difference of direction was more than 45° were considered erroneous points (either due to wrong retrieval or due to errors in forecast field). It was observed that the number of winds whose direction was within the threshold in comparison with METEOSAT-7 was more (by 28%) in NCEP generated winds than LAM. The overall statistical comparison in Table 2 shows that the use of NCEP data as first guess forecast field brings WVWs closer to the METEOSAT-7 derived winds by 16-30%, 15-20% and approximately 30% for wind speed, height assignment and wind direction respectively.

3.4. *Case Studies* : *Vortex ('Nisha') over Bay of Bengal and N/Hood during the period 24th to 26th November, 2008 and cyclone 'Phyan' during November 2009*

A low level circulation developed over southwest Bay of Bengal and N/hood in the morning on 24th Nov, 2008. It organized into a vortex with centre 8.0° N / 83.5° E 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-7 derived wind shear (between layers 150-300 and 700-925 hPa) 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 lay over sea centred near 9.7° N / 80.5° E at 0900 UTC of 25th and



Figs. 5(a-d). WVW derived from (a) METEOSAT-7, (b) Kalpana-1 at 0600 UTC of 24 November 2008 for NISHA and (c) METEOSAT-7 and (d) Kalpana-1 at 0300 UTC of 11 November 2009 for PHYAN. The height of these vectors are lying in between 500 – 100 hPa

intensity of the system at this time was T1.5. Because of favourable conditions for further intensification of the system and water vapour winds at 100-250 hPa level as indicated in Figs. 5(a&b), the system was expected to move in a north-north-westerly direction during next 24 hours. It intensified by 2100 UTC of 25th Nov, 2008 and also move in a north-north-westerly direction with its centre 10.4° N / 80.1° E and intensity T2.0. After 0200 UTC of 26th Nov, 2008 it moved slightly southwards and intensified further at 0300 UTC of 26th Nov, 2008 with centre 10.1° N / 80.1° E intensity T2.5. The system had very little movement in the NW-ly direction; it intensified further at 0800 UTC of 26th Nov,2008 with centre10.3° N/ 79.9° E and crossed the coast near centre 10.5° N / 79.8° E with intensity T3.0. Similar feature has also been observed during 'Phyan' cyclone in November 2009. In association with active northeast monsoon surge, a low pressure area formed over Comorin on 7th November, 2009. It became well marked over Lakshadweep on 8th. It concentrated in to a depression and lay centered at 1430 hrs IST of 9th November, 2009 over southeast and adjoining east central Arabian Sea near Lat. 11.0° N and

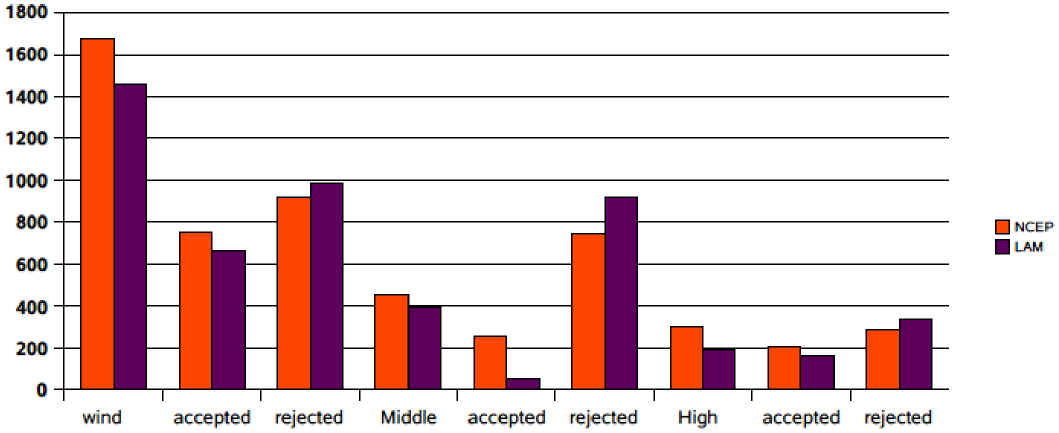


Fig. 6. Quality-controlled wind vectors (using AQC) produced by NCEP and LAM first guess fields

Long. 72.0° E, about 70 km west of Amini Divi. Further it intensified into a deep depression at 0830 hrs (IST) and into a cyclonic storm 'Phyan' at 2330 hrs (IST) of 10th November, 2009. From Figs. 5 (c&d), the KALPANA-1 derived WVWs pattern is clearly depicting the north-northeastward outflow pattern on 11th November, 2009 at 0300 UTC.

The qualitative comparision of water vapor upper level winds derived from KALPANA-1 and METEOSAT-7 has been shown in the Figs. 5(a-d). KALPANA-1 derived WVWs clearly show the outflow pattern and likely movement of the storm in west-north-westerly direction on METEOSAT-7 images of 0600 UTC on 24 November 2008 and north-northeastward direction on 0300 UTC of 11 November 2009 with METEOSAT-7. These winds clearly show the steering effect on weather system and likely movement of the depression/cyclone over land. From the figures it is seen that the KALPANA-1 derived WVW has shown fairly good agreement with the METEOSAT-7 winds and in general almost similar wind flow patterns are brought out. However, at times slight differences can be noticed between these two datasets. This may be due to the difference of spatial resolution and the sub-satellite points of Kalpana-1 and Meteosat-7. The horizontal resolution of Kalpana-1 is 8 km (Sub satellite point 74° E), while in Meteosat-7 it is 5 km (Sub satellite point 57° E).

Winds from water vapor channel data are generally found to be useful in depicting upper-level features and their evolution, which can play a crucial role in tropical cyclone movement particularly in the vicinity of cyclone. It was also shown by Velden (1996) that the inclusion of high-density satellite-derived water vapour wind information into the analyses of tropical cyclone environmental wind fields can effectively reduce the error of objective track forecasts.

4. Summary and conclusions

A quantitative assessment of improvements in KALPANA-1 derived water vapor winds based on the use of NCEP first guess forecast fields, in place of LAM model, has been done. The modifications were made in the currently operational WVW derivation scheme in use at IMD during the month of October 2008. An analysis of results of inter comparison of KALPANA-1 WVW with collocated radiosonde observations for the period May 2008 to July 2009 has been carried out. The analysis shows that before modification the bias of KALPANA-1 WVW was variable between -2 & +4 m/s and RMSE of derived winds between 100-500 hPa levels ranged from 4.2 to 9.2 m/s. However, from October 2008 onwards when modifications were made there is a reduction in the RMSE. It has reduced from 9.2 m/s to almost a steady value of approximately 4 m/s. The high bias is due to the fact that fine details of temperature structure are sometimes not brought out properly in the first guess forecast field. The improvements are prominently noticeble after replacing the first guess forecast field from LAM to NCEP from October 2008 onwards. The RMSE and bias of these winds are also found to sustain for a considerably long time after making changes. It has also been observed that the vector density with consistency in the middle and higher level of KALPANA-1 WVWs generated by NCEP is higher as compared to winds generated by LAM with more number of wind vectors generated using NCEP data. To assess the quality of the derived winds, KALPANA-1 derived WVWs which are generated with LAM model and NCEP GFS model as separate inputs, were compared with the first guess forecast field from the ECMWF model. The comparison of winds between 100 & 500 hPa levels of ECMWF model and operationally derived WVWs from KALPANA-1, shows that RMS errors of approximately 5 m/s and bias less than 1.5 m/s have been produced while using first guess forecast field from NCEP instead of LAM. Case studies of particular cyclones (NISHA 2008 and PHYAN 2009) have also been done and it was found that the KALPANA-1 derived WVWs show fairly good agreement with the METEOSAT-7 derived water vapor winds. Even though the wind speed at 100-350 hPa in KALPANA-1 is slightly higher but the synoptic scale flow patterns have been very well brought out in the KALPANA-1 WVWs and these are comparable to those of METEOSAT-7 winds. This shows that upper level water vapor winds derived from KALPANA-1 satellite with the upgraded INSAT-Meteorological Data Processing system of IMD are of good quality and could be very useful for predicting the future track position of intense cyclones, depressions and well marked low pressure areas.

Use of NCEP first guess forecast field instead of LAM, in the algorithm for WVW computation has certainly resulted in lot of improvement in the quality of operational WVWs derived from KALPANA-1 satellite. Inspite of the little high bias in the WVWs even after use of NCEP first guess, these winds are found to be useful for operational purposes of at least depicting the general synoptic scale flow patterns in the upper air winds. To a certain limited extent they could also be useful for NWP applications since the RMSE of KALPANA-1 derived WVWs with reference to the first guess forecast field of ECMWF model, is comparable to the similar data obtained from other International satellites.

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