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Atmospheric Motion Vectors (AMVs) and their forecasting significance

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ABSTRACT

Temporal and spatial variability of atmospheric processes play a significant role shaping the weather activities. Majority of space remain unsampled without considering the remote sensing observations from satellites. Forecasting the events in short term prediction (few hours to 3 days) of the weather events needs the vertical information of atmosphere. The automatic extraction of Atmospheric Motion vectors (AMV's) from geostationary satellites (Kalpana -1 or Meteosat -7) helps in predicting better the short lived weather events. Authors in this paper highlight the significance of AMV's in a user defined domain for real time weather applications.

Key words: Atmospheric motion vectors, wind shear, cyclones and passive remote sensing

Introduction:

Satellite division of India Meteorological Department (IMD) generated atmospheric motion over a wide area by tracing the movement of individual cloud or water vapor patterns in successive INSAT images. This product is called Atmospheric Motion Vector (AMV), and also includes information on wind speed and direction. AMVs derived at every half an hour on operational basis from geostationary satellite (Kalpana -1). The very high resolution radiometer (VHRR) payload on Kalpana -1satellite provides the half an hour images in three spectral bands, Visible, Infra –red (IR) and Water vapour (WV) with 2.0, 8.0 and 8.0 km spatial resolution respectively. In a recent technological advancement, INSAT -3D will have better resolution (VIS- 1 km, IR- 4.0 Km and WV -8.0 Km) and sensitivity in estimation of AMV's . As the atmosphere is divided into various layers which are thermally stratified and each layer can emit the radiation which is absorbed by the next layer and radiated back downward. In this way, infra red spectral band which is thermally active emits the radiation in 10.2µm to- 12.5 µm atmospheric window region. Visible spectral band reflected the radiation in 0.50µm to 0.75µm window region with a resolution of 2.0 km. Similarly, the water vapour spectral band, 5.7 µm to 6.7 µm absorbs the emitted radiation by upper layers of the atmosphere in 8.0 km resolution. As the contribution of each spectral band depends the transmitivity in the atmosphere and this is known as weighting function of each layer in the atmosphere. As the shape of the weighting function is bell type and peak contribution vary for each spectral band in the atmosphere. The winds generated by the satellite images in IR and WV sequence of images have several steps. Initially, three consecutive set of half hourly images is taken and pattern is identified in back and forth either by cross correlation or gradient thresholds methods. We call it tracer selection and once tracer is identified then it is optimized either with Numerical Weather Prediction (NWP) model output wind fields or statistically regressed wind fields (Genetic algorithm approach). After identification of the tracer its height is assigned via NWP forecast fields or statistically regressed fields. The height at different pressure level is assigned by IR intercept (25 % of coldest pixel height) method or Water Vapour intercept methods. Once height is assigned then the quality of each wind vector derived from the sequence of images checked by using various consistency checks. After assuring the quality of each wind vectors, this data is utilized as diagnostic tool for very short to short range forecasting or assimilated in high resolution NWP models to improve the moisture as well as initial conditions of the at\atmosphere. All this information is derived by passive remote sensing of satellite as the sun is the actual source of radiation. Later, other related products of winds like vorticity, convergence, divergence and wind shear etc. can be utilized to understand better the mechanism or processes involved in the atmosphere. In this paper, authors high lights the use of AMVs in weather forecasting. AMV is the combined name of Cloud Motion Vectors (CMVs) and Water Vapour Winds (WVWs). WVWs are derived in cloud free areas by tracking the moisture fields at upper layers of the atmosphere. The accuracies primarily depend on the proper calibration and navigation of the images before identifying the tracers. The extracted cloud motion winds are the invaluable tool in data sparse oceanic region and better in comparison to the conventional observations those having the problems in measuring the speed and height simultaneously (Horvath and Roger, 2001). The removal of errors is important because the data is used in real time data assimilation systems for the benefit of operational now casting or near casting system and other Numerical Weather Prediction (NWP) systems.

1. Data and Methodology:

The INSAT /Meteosat -7 derived AMV data is used for the prediction of weather events. INSAT derived winds data has been taken from Satellite Division of India Meteorological Department, Lodi Road, New delhi-3 and Meteosat-7 derived winds products are available on global web site: (http://tropic.ssec.wisc.edu/real-time/). These products are utilized in monitoring the movement of clouds, especially cumulus clouds which form the basis of convection. The speed and directions at various levels of the atmosphere is estimated by consecutive satellite images. The other related winds products like convergence and divergence and deep layered mean vorticity is also derived which provides the important information about the circulations within the atmosphere and extents of the weather systems.

Winds assimilation for tropical cyclone PHET:

Tropical cyclones are synoptic scale systems and the most vulnerable to the society. The genesis of such systems requires short range forecasting to save the life and property. Its forecasting of genesis and landfall requires the observation data in data sparse regions. Satellite remote sensing data provides a valuable source for diagnose and analyze the storm correctly or with optimum preciseness. Optimum preciseness means the resolution of the satellite data used and limits the accuracy. Winds assimilation showed small but positive results in cyclone track, regional and global prediction (Velden, 1996). The assimilation of satellite derived wind data can improve the landfall forecasting also. In this paper, a case study of Arabian Sea Cyclone PHET (31st May -06 June 2010) along with its assimilation in Weather Research Forecast (WRF) model is presented. In this case the effect of assimilation of Kalpana -1 satellite derived winds is not so prominent this is because the density of winds data over the cyclonic area is very less. The actual assimilated winds are very less as most of the winds are rejected in quality checks. Figure 1 below shows the Aqua satellite imagery view of the cyclone PHET. Figure 2 shows the actual track of the PHET cyclone. Figure 3 shows the positive vorticity (red color) at 850 hPa pressure level (maximum value of 140; unit:$10^{-5}s^{-1)}$ which indicates the lower level convergence which is required to sustain the intensity of the cyclone. Figure 4 signifies that minimum amount of low level wind shear is required to build the environment (up to 10 knots or $5.144ms^{-1}$) for the occurrence of the TC and a wind shear up to 20 knots (~$10.28ms^{-1}$) will help to maintain the cyclonic system. This rapid decrease supports the notion that tropical cyclones cannot sustain themselves in environments where the vertical shear is greater than 12.5 m s21 (Zehr 1992). Table 1 shows the model configuration used for the assimilation of AMV and Oceansat -2 winds. Control experiment in figure 5 shows the track positions of PHET cyclone without assimilation of satellite winds observations. Other track position with the assimilation of AMV and Oceansat -2 winds are also shown in figure -5. AMV assimilation does not show any significant improvement from control experiment due to the less density of quality controlled winds. Although the Ocean surface winds derived from Oceansat-2 shows positive impact on the track of the tropical cyclone.

Mesoscale activities:

With a better INSAT-3D Imager resolution of atmospheric observing systems our ability to monitor and forecast aspects of mesoscale weather phenomena increases. One aspect that has gained increased interest is the short-term prediction of rainfall events, especially those that evolve on meso–time scales (≤ 3h), which certainly include thunderstorm convection. Because thunderstorms are accompanied by rapidly changing weather on spatial and temporal scales important to public and aviation interests, and produce weather hazards and phenomena that often adversely impact professionals ranging from farmers to pilots, there is a critical need to accurately predict their development, evolution, and movement. In particular, hazards related to thunderstorms (lightning, hail, strong winds, and wind shear) cost the aviation industry many tens of millions of dollars annually in lost time, fuel, and efficiency through delayed, canceled, and rerouted flights, as well as accidents (Mecikalski et al. 2002; Murray 2002). Fig 6 below shows the shear tendency product at 03:00UTC on 10 March 2014. This product shows decreasing shear (10 -20 knots) over Himalaya and neighbored region and indicates the increase of convective clouds over the area. This time rain or snow occurred at most places of J & K area. Hence, by seeing the shear or its tendency we can infer about the increase or decrease of convective activities.

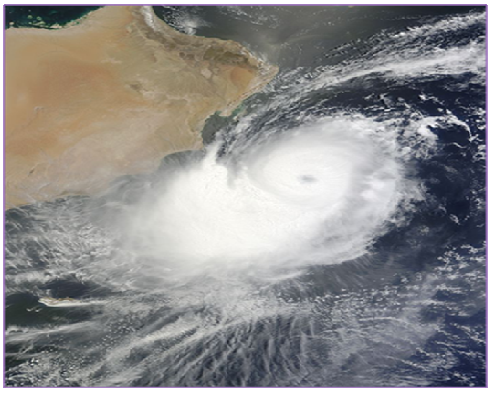

Figure 1: NASA's Aqua satellite imagery of the spatial coverage of cyclonic storm PHET (June 2010) over Arabian Sea (Courtesy of National Aeronautics and Space Administration, USA)

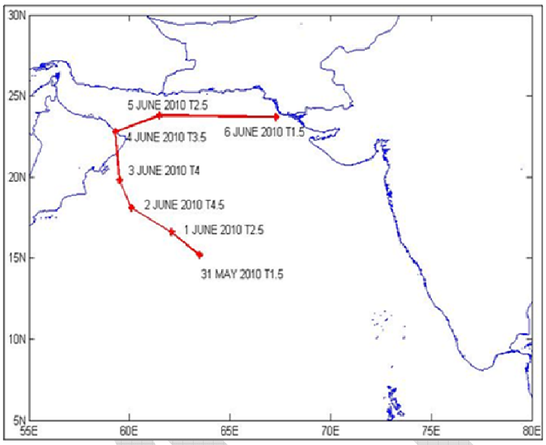

Figure 2: Observed track of cyclone PHET (1200UTC). The x-axis indicates the longitudes (in degree) and y-axis indicates the latitudes (in degree).

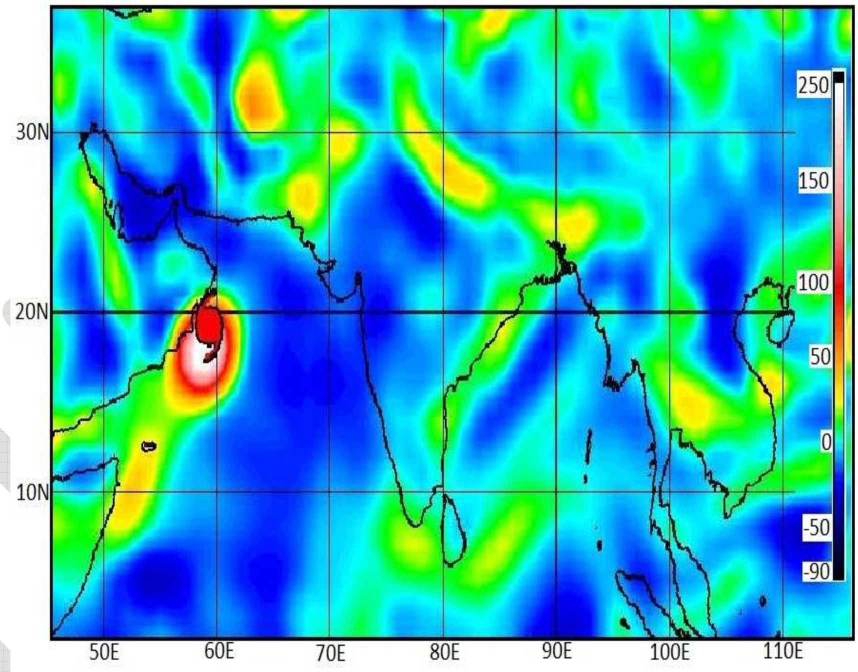

Figure 3: 850 hPa (mb) relative vorticity at 0900 UTC of 03 June 2010

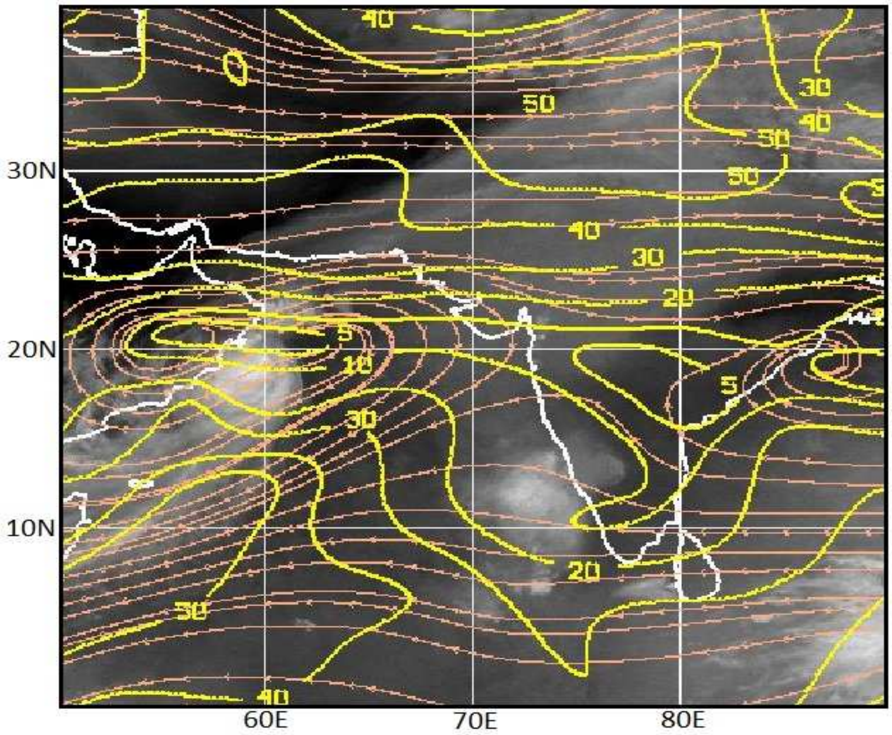

Figure 4: CIMSS-McIDAS generated wind shear (in Knots; 1 knot ~ $0.5144 ms^{-1}$) between surface and upper troposphere from METEOSAT-7 in north Indian Ocean at 0900 UTC on June 03, 2010 (Courtesy of CIMSS, University of Wisconsin, USA)

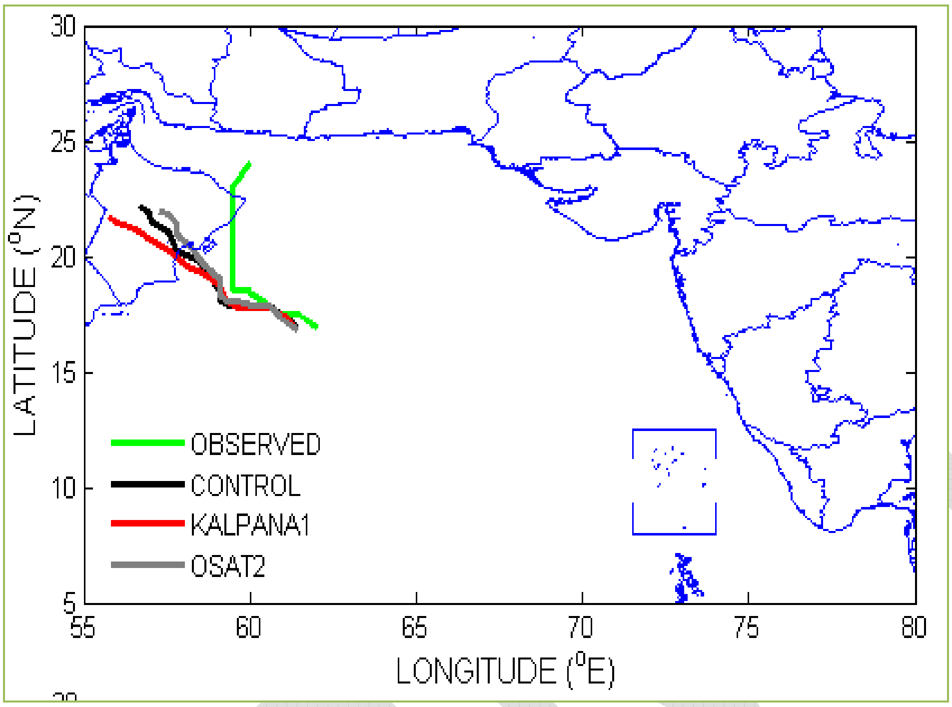

Figure 5: Satellite winds and Oceansat -2 Winds assimilation in WRF model

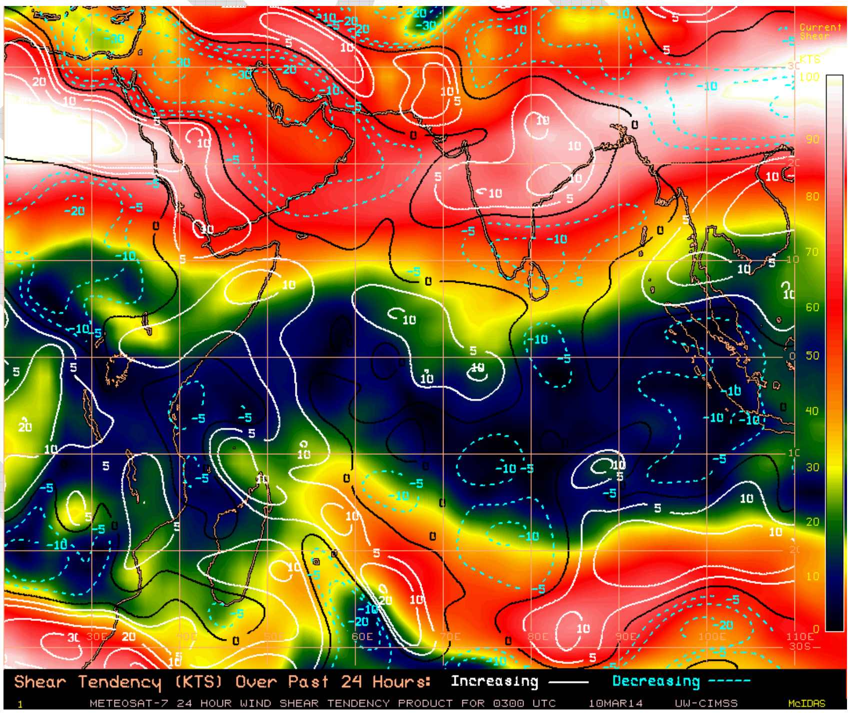

Fig 6: Shear tendency at 03:00 UTC of 10 March 2014

Table 1: Model configuration and experimental design

Horizontal grid distance	27 km
Integration time step	90s
Number of grid points	131 in both west-east as well as south north directions
Number of met grid levels	27
Number of vertical model eta levels	38
Model top	50 hPa
Microphysics	WSM 3-class simple ice scheme
Radiation scheme (long wave)	RRTM scheme
Radiation scheme (short wave)	Dudhia's short wave radiation
Surface layer physics	Monin-Obukhov scheme
Land-surface physics	Unified Noah land-surface model
Boundary layer physics	Yonsei University (YSU) scheme
Cumulus convection	(i) Grell-Devenyi (GD) ensemble scheme (CONTROL, KAL1AMV (**uses KALPANA-1 AMV for assimilation**) & OSAT2SF (**uses OCEANSAT-2 surface winds for assimilation**) experiments) (ii) Kain-Fritsch (KF) scheme (SENKF experiment) (iii) Betts-Miller-Janjic (BMJ) scheme (SENBMJ experiment) (iv) Grell -3D cumulus parameterization (SENGR3D experiment)
Dynamic option	Eulerian mass
Time integration	3rd order Runge-Kutta
Diffusion	2nd order diffusion in coordinate surface
Mode of simulation	Non-hydrostatic
Map projection	Mercator
Number of domain	Single
Central point of the domain	Central latitude: 17.50N Central longitude: 61.50E
Initial and boundary conditions	3-dimensional real data (FNL:1^{O}X1^{O})
Simulated hours	78 hours starting from 1800 UTC June 01, 2010

1. Concluding remarks:

From the series of satellite images the, the evolution of meteorological phenomena can be studied. It is essential to track the meteorological objects throughout the whole life time of the event. The observation of the temporal evolution of clouds at different space and time scales could improve our understanding of the physical processes involved in their formation, their persistence and dissipation. INSAT Geostationary satellite has the advantage to provide images to short time intervals. The evolution of clouds can be observed on them with a far better temporal resolution (1/2 hour, Kalpana -1/INSAT -3D images) than the resolution provided by classical measurements (6 hour or 12 hour). In this paper PHET cyclone is analyzed with the satellite derived winds and winds derived products and their assimilation in WRF model. The satellite wind derived products shows the capability of short range forecasting the movement and direction of the tropical storms and mesoscale activities. Although some of the problems associated with the satellite derived winds and products are broken clouds, Multilayered cloud,Semi-transparent cloud and Underlying surface features.

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