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Image registration and atmospheric motion vectors retrieval from Geo-stationary satellite

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Abstract

In the determination of atmospheric motion vectors (AMVs) from sequential images obtained from geostationary satellites, registration of the images play a primary and important role**.** Image registration is an essential and fundamental component in the retrieval of AMVs from triplet consecutive images of Kalpana -1 satellite is done by suitable matching of valid tracers in back and forth from middle image. If the triplet is not properly registered than it may lead to errors in wind speed and direction**.** The inaccuracy of registration (N-S or E -W shift) in one set of triplet images will generate the errors in wind speed and direction this will affect in other images if available in sequence also. Image registration maintains the spatial relationship between the pixels within images and between images. Improper registration results due to the deviation in orbital parameters, spacecraft attitude, thermal distortions and earth sensor biases. If we need continuous train of images like, sometimes we need morphing in images to get continuous AMVs which can be a potential source of errors for the input of Numerical Weather Prediction (NWP). But in this framework the other issues will also need further investigation like cloud evolution, height assignment and thickness biases, etc. in AMVs. In this paper, authors will deal only the registration issue. It has been shown from daily registration shift in Kalpana -1 satellite images during the year 2008 between 0000UTC to 0200 UTC in Northern Hemisphere that, the errors introduced in wind speed varies from 10 m/sec to 45 m/sec at nadir due to registration only. Few cases have been shown appreciable improvement after applying the interactive correction of registration errors.

Keywords: AMV, Image registration, NWP, Weather

Introduction

The Atmospheric Motion Vectors (AMVs) winds are derived by passive tracers in triplet image sequence of half an hour difference. The accuracy of satellite derived AMVs primarily depend on the proper registration of the images followed by navigation. Currently, INSAT images are registered to a 'fixed grid' so that each pixel in a given frame always views the same point on the earth. The proper registration means that the successive images should be completely aligned. The registration of images pixels in a fixed grid is accomplished during instrument scanning and adjust the instrument detectors during East West (EW) swath so that detector output samples points always the same fixed grid pixels level locations on the earth. Normally the registration inaccuracy affects the navigation process which have attitude and orbit time varying variables and none of them is known perfectly. The time variation occurs due to instrument thermal deformations, spacecraft attitude, orbital position and control system disturbance torques which affect the registration accuracy. This paper deals with the registration issues involved in AMV's retrieval process. Currently in AMVs retrieval, all N images are in sequence and optimized matching is applied to subsequent N-1 images and the suitable candidate (tracer) is saved along with its score. The optimization is achieved by spatial-coherence analysis (Coakeley & Bretherton, 1982) to identify the highest (brightest) cloud in the scene, and find the region of strongest brightness gradient. The suitability of the tracer is decided by minimizing the norm between the candidates and neighboring pixels. This difference is saved as a buffer and later it will be utilized for other candidates to decide perfect match of cloud features by the minimum cost function. In the absence of any image, morphing of image will generate the new image and it will be used for AMVs computation. Then height is assigned by using the estimate of cloud top temperature for higher level cloud and the cloud base for lower level clouds. Similar, type of simulation (Bremen *et al.*, 2009) by using the high resolution European Centre for Medium Range Weather Forecast (ECMWF) forecast fields over a 6 hour (at T2047, ~10 Km) period is tried and then AMVs is derived at Cooperative Institute of Meteorological Satellite Studies (CIMSS). But apart from all, the image registration part of the sequence of images is of prime importance. Because registration error once introduced then it will flow for all winds and will produce spurious winds also, even where there is no cloud. Image registration accuracy in AMV computation should be of the order of one pixel, if it is more than it will introduce an error in the wind speed. Christopher *et al.* (2001) showed in Visible and IR calculated registration errors exceed 2 km. However, the accuracy of the correction depends on the number and distribution of landmarks, which can vary considerably. Thus, errors exceeding 2 km may be fairly common. In addition, rotational and non-linear errors cannot be eliminated fully due to time varying nature of the parameters used in registration process. Since a 2 km shift in 30 minutes introduces a wind speed error of 1.1 m/s at nadir (and more near the edge of the image), this is obviously a significant source of correlated error that must be included in simulated CMV. The main difficulty in simulating these errors is the spherical nature of the earth. A simple west-east registration shift will introduce only zonal wind errors, though the magnitude of the error will increase toward the edges of the image. However, a north-south shift will introduce both longitudinal and zonal wind components, with the ratio of the components changing depending on latitude and longitude (Christopher *et al.,* 2001). Registration is a measure of the consistency in navigation between successive images. The winds production process is much more sensitive to changes in registration than to errors in absolute earth location (i.e., navigation). For acceptable registration, land features such as coastlines must remain stationary from image to image within a certain tolerance (Menzel & Purdom, 1994). Automated registration quality control relieves the burden of manual intervention by pattern matching land features with the same techniques used in the automated cloud tracking algorithm (Merrill, 1989).

Initial landmark locations are screened for cloud contamination using a spatial coherence analysis (Coakley & Bretherton, 1982). Each resulting landmark is sought in subsequent imagery within a small spatial tolerance using extremely tight correlation thresholds for determining successful matches; the tight correlation thresholds act to further screen landmarks for cloud contamination. Undetected cloudy landmarks are eliminated by an analysis of the mean registration deviations suggested by all successfully correlated landmarks. Up to one-fourth of this landmark sample can be eliminated if gross differences from the originally suggested mean deviation in registration occur and a new mean is derived from the remainder. This check also guards against cases in which the registration exhibits varying shifts in different regions of the image. If more than one-fourth of the landmarks show a large amount of scatter, less than five landmarks remain, or the diagnosed registration deviations are less than a predetermined tolerance, no correction is applied. INSAT satellite is a three axis stabilized system which made the navigation more challenging. Nieman *et al.* (1997) showed that, non-rotating satellites are subject to differential heating, especially near local midnight, and the result is a reduced ability to consistently navigate the imagery. Around local midnight navigation are worsened during the periods just before and just after satellite eclipse, which occur near the time of solar equinox and registration quality were apparent in early experimental GOES-8/9 winds processing, prompting NESDIS to perform manual registration corrections (Nieman *et al.,* 1997).

Data and methodology

The Level -1B imagery data of Kalpana -1 satellite is taken from India Meteorological Department, Lodi Road, New Delhi. The registration issue of the consecutive images (triplet in this case) is solved by the interactive software program in which translational, rotational and vibrational mode of the pixels parameters also taken into account by adjusting suitable North South (N-S) or East West (E-W) shift. The translational shift is based on the registration shift algorithm developed by Christopher *et al.* (2001). The brief description of the algorithm used is given below. The translational equation of in equatorial azimuthal orthographic projection is given by:

x = cos(lat)sin(lon) (A)

and y = sin(lat) (B)

The procedure used, in the present paper is based on Christopher et al. (2001) in which the random shift (δx, δy) in x and y is assigned. Then, from the given true landmarks the true position is determined as x_{true} and $y_{true.}$ Next, the shifted longitude position x_{shift} is determined from $x_{true} + \delta x$, and a new longitude is back-calculated from equations (A) and (B). This is repeated for latitude, resulting in a new (or apparent) latitude and longitude for the location. Finally, the differences between the true and apparent latitudes and longitudes are used to determine the distance shifts in km, which yields a wind speed which corresponds to the image registration error. (or)

In matrix form, we generally use affine transform shown below in Eq -(C)

$$\begin{bmatrix} u \\ v \end{bmatrix} = A\begin{bmatrix} x \\ y \end{bmatrix} + T + scaling + rotation \quad \text{(C)}$$

Where, u, v are new latitude and longitude and T is translation vector. Final image is obtained by reprocessing the image after the corrections of translational shift and attitude parameters.

Results and discussions

Registration is a measure of consistency of navigation and landmark features (like coastline) must remain stationary from image to image. In three axes stabilized system like Kalpana -1 satellite is much more difficult due to the time varying nature of attitude variables (like roll, pitch and yaw). Prakash and Bhandari (1996) developed an algorithm which is based on geometric scheme and works well with when there is a poor contrast between the images. Satellite derived winds are much more sensitive to registration; hence an interactive sub-program of registration correction is applied to the satellite imageries or triplet under consideration for the AMVs retrieval. Due to the dynamical nature of the meteorological phenomena, an image time sequence analysis is more appropriate, which can be used for AMVs detection. Because the response of the every pixel is important, as it is the representative of the average temperature of the objects present in the underlying surface. Proper registration of the image facilitates the proper segmentation of the clouds. Due to the non-linear phenomena of cloud formation, the shift in the registration of images may lead to mismatch of different cloud segments, which in turn will provide the wrong AMVs or

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Fig. 1 (a). Kalpana -1 (IR 00:00 UTC) (Without correction, on 20-05-11)

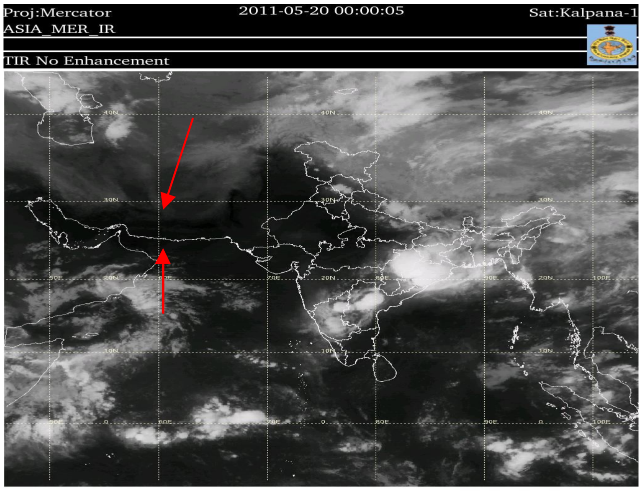

Fig. 1 (b). Kalpana -1 (IR 00:00 UTC) (With correction, on 20-05-11)

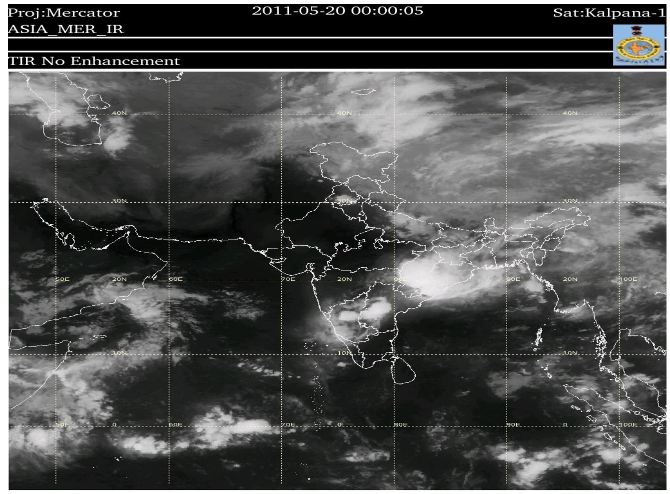

Fig.2(a). Kalpana -1 WV image at 0100 UTC on 06-01-2011(Before registration correction)

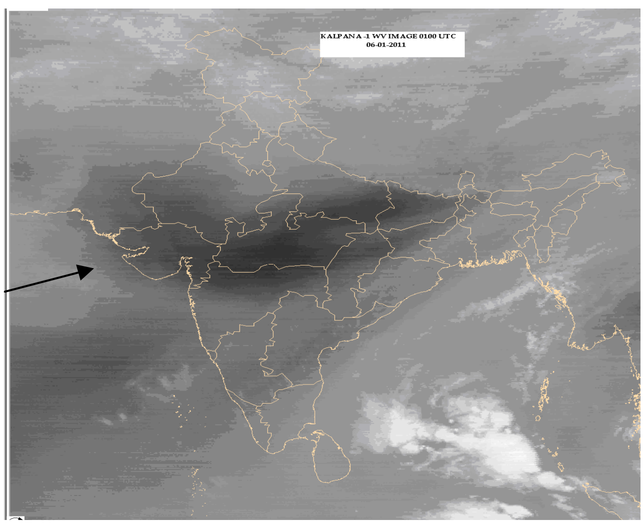

Fig. 2(b). Kalpana -1 WV image at 0100 UTC on 06-01-2011(after registration correction)

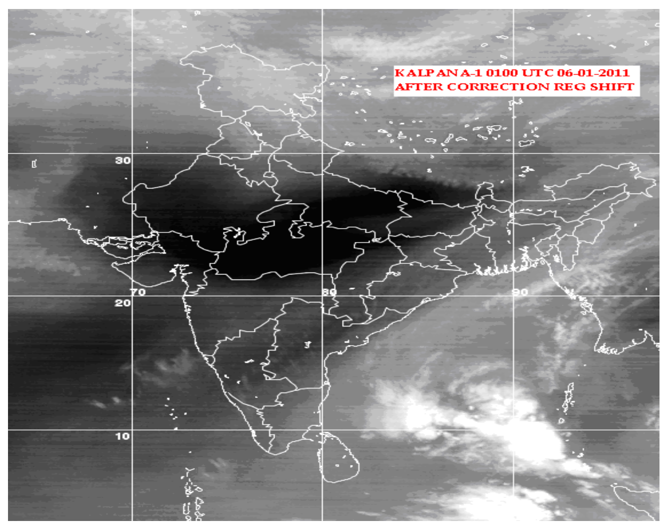

Fig. 2(c). Kalpana -1 WV image at 0130 UTC on 06-01-2011 (Before registration correction)

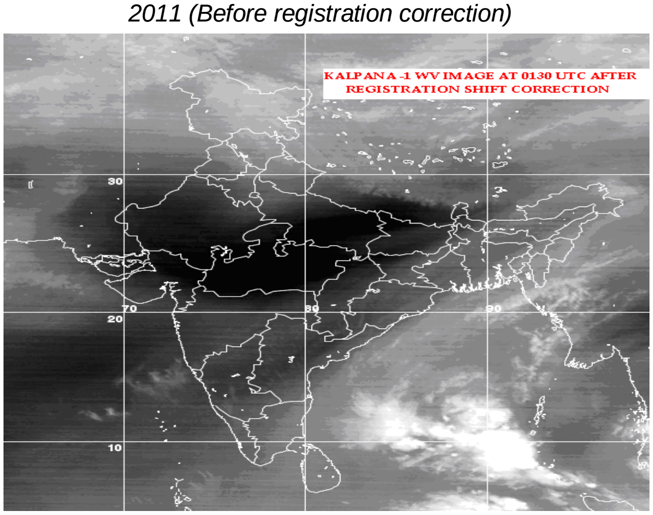

Fig. 2(d). Kalpana -1 WV image at0130 UTC on 06-01-2011(After registration correction)

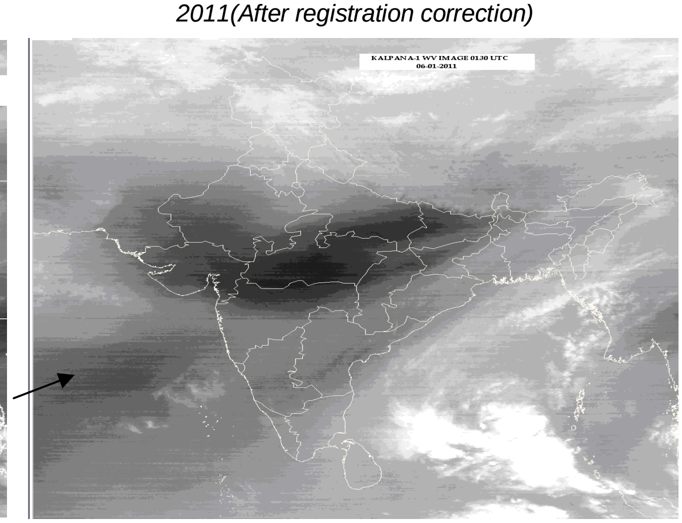

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Fig.3(a).Kalpana -1 IR image at0100 UTC on 06-01-2011(Before registration correction)

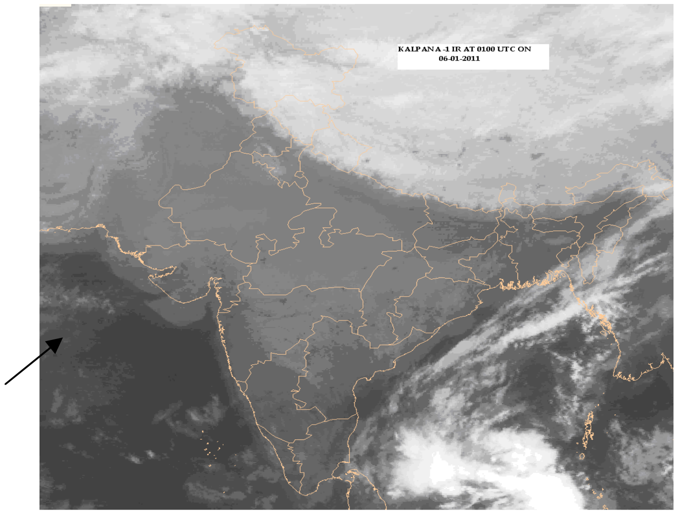

Fig. 3(b).Kalpana -1 IR image at0100 UTC on 06-01-2011(After registration correction)

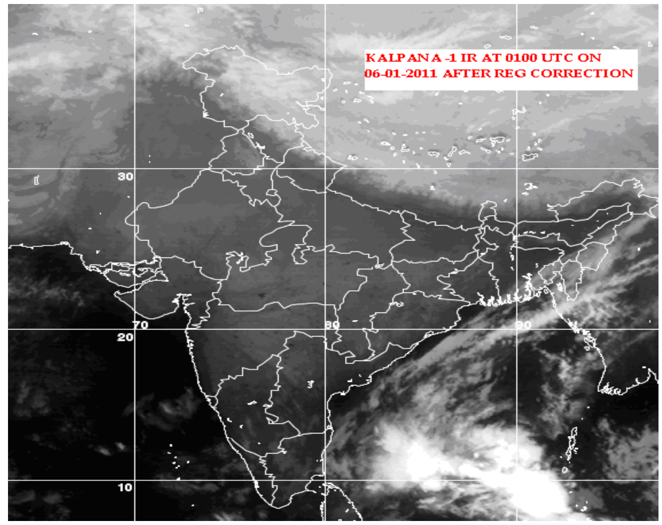

Fig. 4 (a). WVW at 0130 UTC on 01-06--11

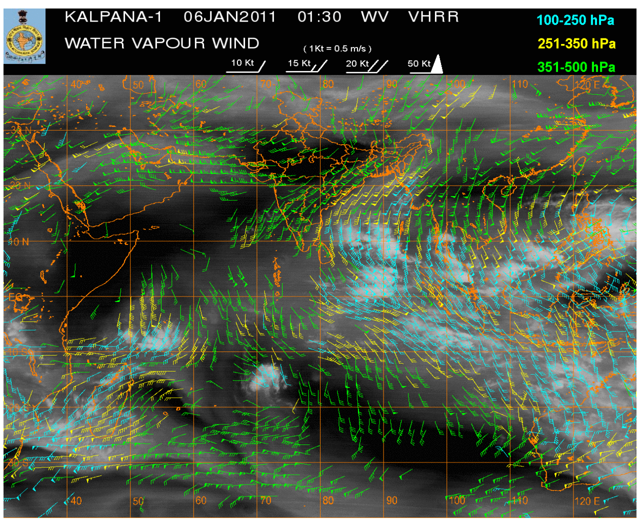

Fig. 4(b). CMV at 0130 UTC on 01-06-11

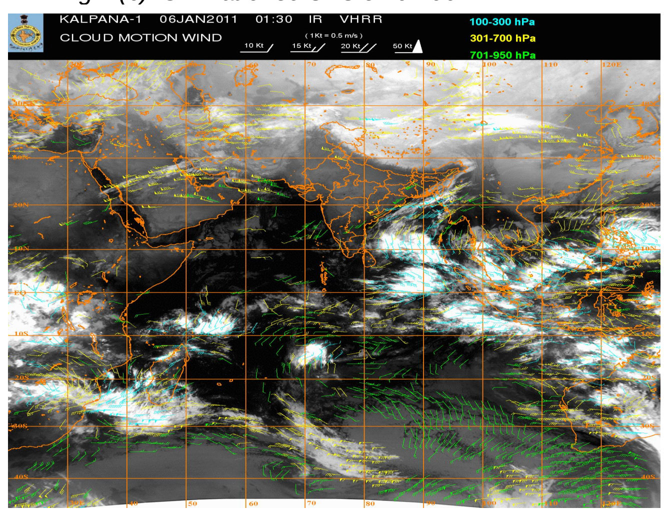

Fig 5 (a). IMD GFS (382 analyses for 0000 UTC of 06-01-2011 (925 hPa)

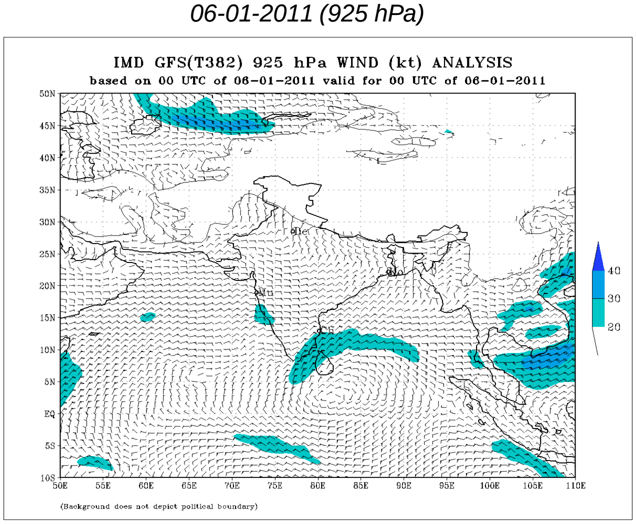

Fig 5(b).IMD GFS (382) forecast (24 hour)based on 0000 UTC valid up to 07-01-2011(925 hPa)

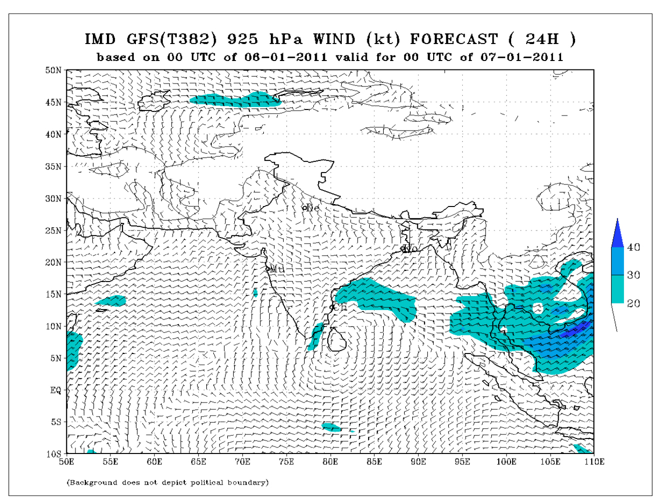

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Fig 6. (a). Image registration shift 2 kmNorth in 30 minute (Christopher O'Handley, et al., 2001)

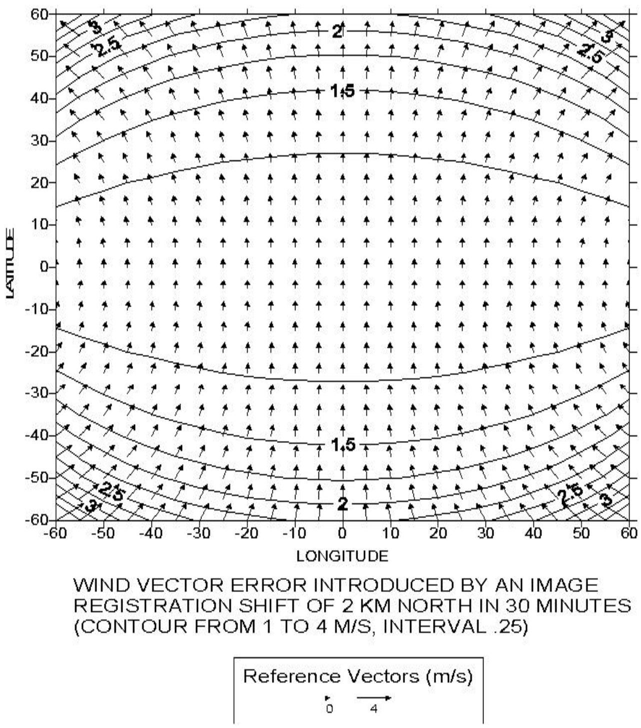
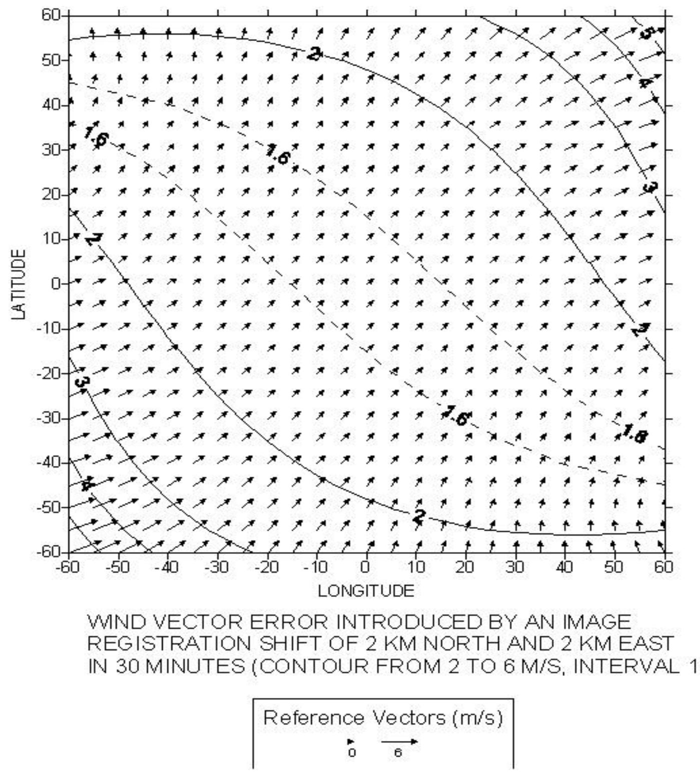


Fig. 6(b). Image registration shift 2 km East and 2 km North in 30 minute.



even in areas where there is no signature of either moisture or cloud. In the current operational algorithm the registration is performed by the cross correlation and minimum lag coefficient analysis of the selected landmarks in the imagery to ensure proper alignment. Any error in registration translates into additional vector thereby resulting in poor quality of CMVs (Daniels *et al.,* 1998).

At 00:00 UTC the poor contrast of landmarks leads to poor correlation and alignment in the imagery. In Fig.1 (a) of Kalpana -1 satellite on 20 -05-2011 the red arrows shows the misalignment or mismatch of landmarks. This improper alignment of the images is responsible for registration inaccuracy in the images. Fig.1 (b) is the reprocessed image after applying interactively the E-W and N-S translational shift of 120 km. Normally the tolerance limit or accuracy of navigation is 1 pixel (8.0 Km in IR and WV) but in this case it is of the order of 15 pixels. This is the case of more inconsistent registration and it will generate the error in wind speed up to the order of 60 m/sec and direction also significant change due to the variation of attitude parameters of the spacecraft. This will generate the poor quality of winds and after applying the quality check the valid winds will be very less in quantity and will produce very small impact on numerical weather perdition models. This paper highlights the requirement of automated iteration of registration and navigation on each and every image to sustain the consistency in the images. Similarly, Fig.2 (a-d) shows WV images before and after the correction applied. The images taken 01:00 and 01: 30 UTC of 06 January, 2011 respectively, which will be used as triplet in 00:00 UTC operationally derived products of WVWs. The correction applied in this case E-W =100 km and N-S = 80 km as a translational shift to ensure the proper alignment or registration of the images. Fig.3 (a-b) is for IR images of Kalpana -1 satellite and their alignment is ensured by the same correction as applied in the case of WV imagery above. After the registration correction the image is properly navigated and valid tracers are selected for AMVs computation and after ensuring the quality of AMVs, these winds to be used for day to day weather forecasting or numerical weather prediction models to improve the forecast and disseminated in global telecommunication system (GTS) or BUFR code to the end users. Fig.4 (a-b) shows the derived CMV and WVW winds both after the registration correction at 01:30 UTC. Similar procedure is applied for all the subsequent set of images and finally the winds used in day to day applications or to study any synoptic or mesoscale systems**.** Proper registration of images will generate appropriate representativeness of the weather events by these satellite derived winds**.** The consistency and optimization of the winds is also ensured by the global forecast system (GFS) derived analysis and forecast fields Fig.5 (a-b). Once this is finalized then the satellite derived winds will further used in NWP models for assimilation and it will modify the observation domain and output fields also affected. Sometimes it will produce negative impact also if the qualities of the winds are not proper or not properly registered. In brief we can say that registration correction involves an examination of as many landmarks as possible on the images; the individual shifts are then averaged to produce a single correction in *x* and *y* for the image set. Fig.6 (a) shows the wind vector error introduced by an image registration shift of 2 km in North in 30 minutes. It is clear from the figure that as we go towards higher latitudes the contour interval gap gets smaller and smaller. This may be due to the fact that registration inaccuracy towards higher latitude is more significant or needs more attention. Similarly, Fig.6 (b) shows the wind vector introduced by an image registration shift of 2 km North and 2 km East direction.

Daily registration shift

The daily registration shift for Kalpana- 1 satellite data in Northern Hemisphere for the year 2008 at 0000-0200 UTC for both E-W and N-S directions is shown in the Fig.7. The inaccuracy in registration process increases with the ageing of the satellite. The correction is essential because winds production process from the satellite is very sensitive for image registration shift and consistency of navigation between the images. The daily variation for North -South and East -West direction is zigzag manner (Fig.7). This irregular variation is due to the deviation in the registration of correlated landmarks. At 0000 UTC the contrast or matching of the landmarks is poor and it is more prone to inaccuracy in image registration process. In this present work we have noted the daily registration shift between 0000UTC and 0200 UTC images of Northern Hemisphere for the year, 2008 of Kalpana -1 satellite. The imageries during this time do not have acceptable registration like land features such as coastlines not remain stationary from one image to other within a certain tolerance (one pixel ~8.0 km in IR and WV).

Fig.7 clearly shows that the registration shift will reached up to 80 Km, and this will cause the error in wind speed measurement up to 45 m/sec at nadir and more near the edge of the image. The maximum permissible inaccuracy is up to the order of 4 to 5 m/sec (one pixel). To maintain the consistency of wind in space and time and suitable for NWP applications the translation shift play an important role in correcting the registration. The water vapour winds are seems to be inferior in comparison to the IR winds because as they are representative average of deep layers rather than a single level wind. This is also a limitation in most of the time in NWP models data assimilations as they the schemes inbuilt in the model accept AMVs as single level observations. The accurate wind observations are generally preferable to mass observations (Baker, 1991) because it is easily acceptable in NWP models. Another point winds observations of low latitudes cannot be inferred from the mass filed and upper air sounding are scare. Due to varying nature the spacecraft attitude parameters (roll, pitch and yaw) the image is distorted and the ground control points (GCP) in this distorted image should match reasonably with their true positions in ground coordinates (latitude & longitude). With the help of suitable transformation which include translational scaling and rotation parameters the satellite images in the triplet made consistent navigation. This will be very important in the case of the animation of images or derived AMVs in a mesoscale or cyclonic flow. If the images are not properly registered then there will be flipping of the images in between the series of images and this can mislead the movement of the storm or flow pattern kinematics.

Daily registration shift for the year 2009

The daily registration shift for the year 2009 at 0600, 0900, 1200 and 1800 UTC are shown in Fig.8-11 respectively. From Fig.8 & 9 it is clear that the N-S and E-W shift are more during monsoon season followed by post-monsoon, pre-monsoon and winter season respectively. The shift reaches up to 75 km which lead the inaccuracy in wind speed up 22 m/sec. From Fig.10 at 1200 UTC it is clear that the during the December month the shift reaches up to 90 km (50 m/sec) in N-S direction. During monsoon season at 1200 UTC both the shifts (N-S or E-W) shows the variation up to 60 km or of the order of 30 m/sec while January to March its order about 10 km. At 1800 UTC the shifts is more and reaches up to 100 km (or 50 m/sec), this may be due to poor contrast between land and continental boundaries (Fig.11). The data gaps in between, shows that ingest was not received during that time. Fig.7 of the year 2008 between 0000-0200 UTC shows more variation in (N-S or E-W) shifts during the monsoon season as compared to the year 2008. This indicates that inaccuracy results more when the sky is full of clouds or during night time when the contrast of boundaries are poor. During the time of poor contrast cubic B-spline interpolation are used to acquire the accurate position of corners on coastline; arc length restriction is applied in the corner matching algorithm and corner matching confidence is calculated.; accurate transformation parameters are obtained adopting the least squares method with arc-length as weight. This entails the location of the pixel within an image or between the subsequent images should be uniform with respect to their earth referenced latitude and longitude by adjusting by auto-computing the satellite attitude parameters using traditional linear translation methods suggested by Equation (C) above.

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Fig. 7. Daily registration shift of the year 2008 for Kalpana -1 Satellite between 0000UTC -0200UTC (bold line for N-S Shift and dotted line is in E-W direction)

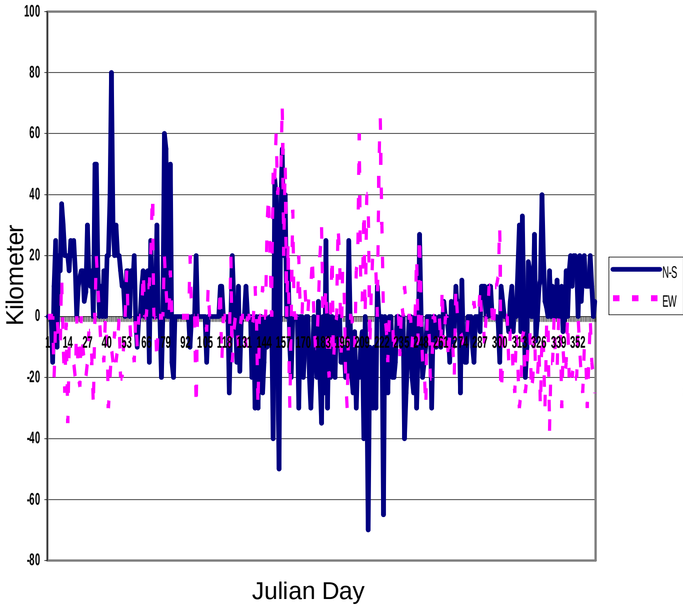


Fig. 8. Daily registration shift of the year 2009 for Kalpana -1 Satellite at 0600 UTC (bold line for N- S Shift and dotted line is in E-W direction)

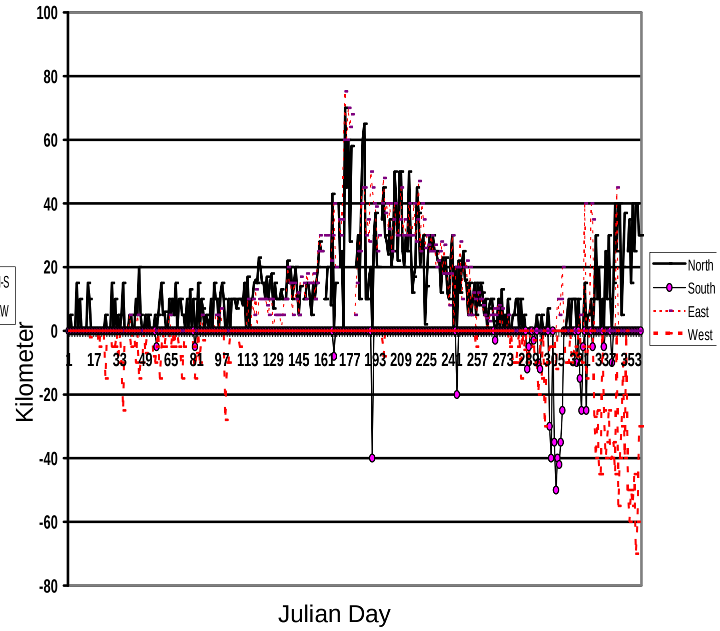


Fig. 9. Daily registration shift of the year 2009 for Kalpana -1 Satellite at 0900 UTC (bold line for N-S Shift and dotted line is in E-W direction)

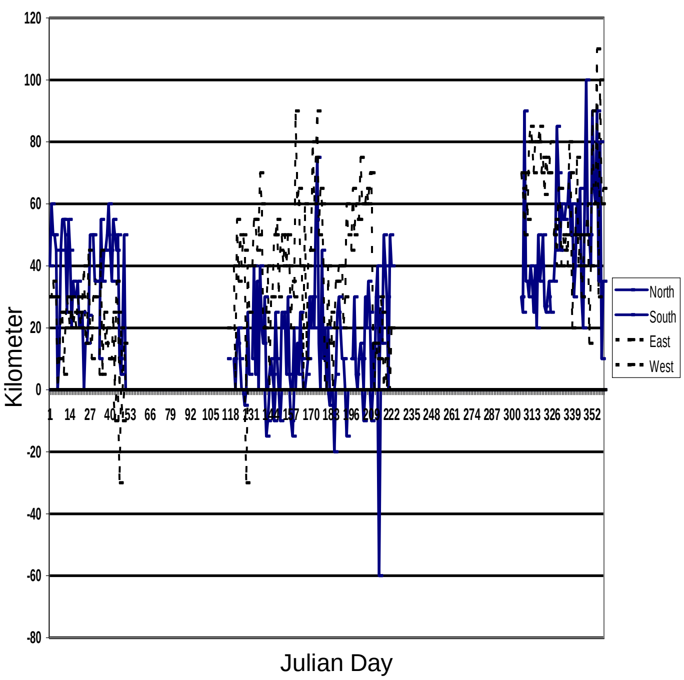


Fig. 10. Daily registration shift of the year 2009 for Kalpana -1 Satellite at 1200 UTC (bold line for N-S Shift and dotted line is in E-W direction)

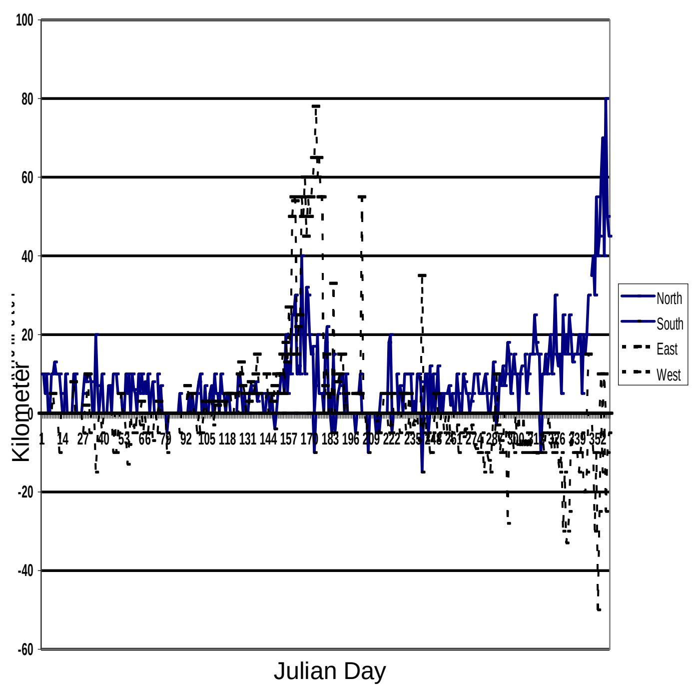
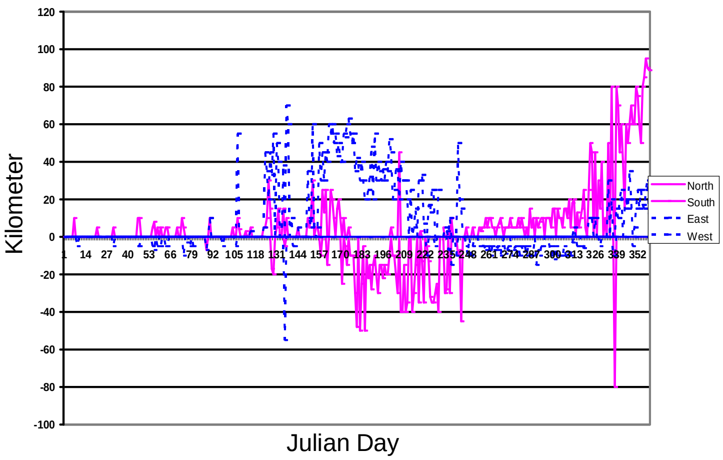


Fig. 11. Daily registration shift of the year 2009 for Kalpana -1 Satellite at 1800 UTC (bold line for N-S Shift and dotted line is in E-W direction)



New approach

The geographical locations of each pixel can be achieved by proper registration of the recognizable features of land and ocean boundaries. The continental boundaries may not be accurately determined if the brightness contrast between land and ocean is not sharp and clouds also obscure the satellite image. These limitations haven been worked out in the new algorithm proposed by Indian Space Research Organization (ISRO) based on the scheme of overlying world map boundaries and a latitude longitude grid on the grid based purely on spherical geometric considerations. Initially, start with the orthographic projection which assumes the perspective point at infinity. Let us assume the geoid is the most appropriate suitable representation of the earth. In this method two transformations is used one is geodetic to geocentric and then sphere projection to plane surface. In this algorithm the idea given by Barton and Tarlowski (1991) has been implemented. The software code developed by Prakash and Bhandari (1996) is utilizing the worldmap.dat file for geodetic coordinates. Other supporting sub-routines are used for geodetic coordinates to geocentric coordinate's transformation, latitude/longitude latitude/longitude grids and the map boundaries from the intermediate unit plane on to the VHRR image and finally plot a line between calculated coordinates using a brute-force algorithm. In this way, the algorithm will taking care the poor contrast between ocean and continental boundaries nearly up to desired accuracy (one pixel). Grids and map boundaries on to the intermediate unit plane.

Conclusions

The registration inaccuracy leads the errors in the wind measurement, which varies from 10 m/sec to 80 m/sec during the year 2008 and 2009. The interactive registration correction sub -program works fairly well in adjusting a suitable bias in registration of the images used operationally 10 % of the time and further work in progress to fully automate it with all time of day and night. AMVs are directly use as winds in data analysis for numerical weather prediction (NWP) will show improvement after the removal of registration errors. New approach based on spherical geometric considerations will be useful when the contrast is between the ocean and continental boundaries are not sharp. The wind flow also helps in future prediction of storm track also by knowing the kinematics of the wind like the tendency of convergence and divergence at lower and upper levels respectively.

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References

1. Baker W (1991) Utilization of satellite measurements for climate and global change studies in operational satellites. In: Sentinels for the monitoring of climate and global change. Ohring G, McClain EP and Ellis JO (Eds.). Special issue: *Global & Planetary Change*. 4, 157-163.
2. Barton CE and Tarlowski CZ (1991) Geomagnetic, geocentric and geodetic coordinate transformations. *Compu. & Geosci.* 17(5), 669-678.
3. Bremen LV, Bormann N, Wanzong S, Hortal M, Salmond D, Thepaut JN and Baur P (2009) Evaluation of AMVs derived from ECMWF model simulations. *ECMWF News Lett.* 121, 30-33.
4. Coakley JA and Bretherton FP (1982) Cloud cover from high-resolution scanner data. Detecting and allowing for partially filled fields of view. *J. Geophys. Res.* 87, 4917-4932.
5. Christopher O'Handley, Emmitt Steven GD and Greco S (2001) Simulating cloud motion vectors from global circulation model data For Use in OSSEs. A Preliminary, But Useful, *Algorithm Appl. Curr.* NASA/NOAA OSSE Projects.
6. Daniels JM, Bresky W, Velden C and Wanzong S (1998) Recent advances to the operational. GOES Wind Processing System at NESDIS, *Proce.* 4th Intl. wind workshop. Oct 20 -23 Saanenmoser, Switzerland. pp: 29-39.
7. Menzel WP and Purdom JFW (1994) Introducing GOESI. The first of a new generation of geostationary operational environmental satellites. *Bull. Am. Meteorol. Soc.* 75, 757-781.
8. Merrill R (1989) Advances in the automated production of wind estimates from geostationary satellite imaging. *Proc. 4th Conf. Satellite Meteorol. San Diego, CA, Am. Meteorol. Soc*. pp: 246-249.
9. Prakash WJ and Bhandari SM (1996) An algorithm to overlay continental boundaries and latitude -longitude grids over INSAT-VHRR images. *Compu. & Geosci.* 22(4), 433-440.
10. Steven J, Nieman W, Paul Menzel, Christopher M, Hayden, Donald Gray, Steven T, Wanzong, Christopher S, Velden and Jaime Daniels (1997) Fully Automated Cloud-Drift Winds in NESDIS Operations. *Bull. Am. Meteorol. Soc.* 1121-1133.