Multiplet based technique to derive atmospheric winds from Kalpana-1

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Abstract

The atmospheric motion vectors (AMVs) are generally derived from three successive images (called as Triplet based algorithm) in most of the operational centers in world. However, in this study a new approach for the retrieval of atmospheric motion vectors from the infrared and water vapor channels of Indian geostationary satellite Kalpana-1 has been demonstrated. The new algorithm uses previous eight images during the retrieval. The tracers are selected by calculating local image anomaly and tracked in the subsequent images using Nash-Sutcliff model efficiency function. The tracer’s height assignments are done using widely used the Infrared-window (WIN) technique/Water vapor histogram technique, the H2O intercept and the cloud base method based on either infrared or water vapor channel. A completely new quality control procedure is adopted in this algorithm. The winds retrieved from the new and the earlier Triplet based algorithms are compared with collocated radiosonde data. The new algorithm significantly improves the statistics of the retrieved winds. The spatial pattern comparison also shows improvement in all levels in the new algorithm.

1. Introduction:

Indian Space Research Organization (ISRO) started to produce AMV from three successive Kalpana-1 infrared and water vapor images (called as triplet based method) with two times a day (00 & 12 UTC) over full disk area in June 2007 by its own developed software package (Deb et al. 2008, Kishtawal et. al. 2009). The triplet method was adopted because during a day only two triplets (i.e. two sets of three 30-minute images) were generated centered at 00 UTC and 12 UTC for the purpose of wind retrieval. The 30-minute image acquisition from Kalpana-1 started in June 2009 and subsequently AMV’s from Kalpana-1 are being generated every half an hour. In the triplet algorithm, one criteria to accept a vector during quality control is to test its consistency with neighborhood vectors. The vector in question is rejected if the movement of a tracer at some location is detected in one pair of images but not in the other. On the other hand, the spatial consistency of a vector is disturbed if not enough vectors are present in its neighborhood. Availability of more frequent winds (every 30-minute) allows one to use larger amount of information to make statistically more robust judgement on the quality of a vector at the time of retrieval. This information can be obtained from a reasonable spatial neighborhood or from the retrieved wind observation during the recent past. However, the size of the spatial and temporal windows critically depends upon the decorrelation scale of the wind observation. The study by Kaur et al (2012) shows that long decorrelation timescales of atmospheric wind allow one to use more number of images to extract maximum information from a continuous stream (every 30-minute interval) of satellite images and is found with one year of Meteosat-7 AMVs that the minimum decorrelation timescale in Asia Monsoon region is about 4-hour with average decorrelation timescale ranging between 16-24 hours depending upon the time as well the region. The present study proposes to modify the Triplet based AMV retrieval algorithm (Kishtawal et al. 2009) at SAC by considering a wind buffer generated using multiple images (i.e. previous eight half hourly successive images) for a particular point of time for quality control. The last eight images were considered for wind buffer generation to maintain the minimum 4-hour decorrelation timescale during retrieval, as reported by Kaur et al. (2012). This wind buffer is used later for quality control of wind retrieved using two subsequent 30-minute images.
2. ISRO AMV retrieval Algorithm

The current AMV algorithm at ISRO composed of four parts, image registration, features selection and tracking, wind buffer generation and quality control and finally height assignment. A separate procedure is adopted for validation exercise. As preprocessing numerical weather prediction (NWP) model wind, temperature and humidity profile data are required as ancillary data for height assignment algorithm. All the steps except wind buffer generation and quality control are described very briefly, while wind buffer based quality control process is discussed in more details.

The image registration is performed using infrared images as landmarks can be identified at the surface using this channel and during this process the registration error in consecutive images is eliminated using cross-correlation analysis at user defined landmark points. Cloud-free landmarks are identified within the first infrared image and matching of these landmarks is searched for in the subsequent infrared image.

The features are selected by computing local image anomaly (Deb et al. 2008) in a 20 x 20 template window, both in cloudy and cloud free regions. The anomaly-based tracers are generally produced by a smooth feature field in comparison to the gradient-based features. The degrees of matching between two successive images are calculated by the Nash-Sutcliffe model efficiency (Nash and Sutcliffe 1970) coefficient ($E$). The application of this tracking method in estimation of water vapor winds has shown some improvement over Indian Ocean region (Deb et al. 2008).

The height assignments of the selected tracers corresponding to each retrieved vectors are derived using the widely used methods viz. such as the infrared window (WIN) technique or the water vapor histogram method (HIST), the H$_2$O intercept method (Nieman et al. 1993) and the cloud base method (LeMarshall 1993). Once final height is selected a few gross error checks are also applied. The height assignment component of ISRO’s AMV algorithm is updated to height assignment component of AMV retrieval algorithm of NOAA/NESDIS with scientific collaboration with Co-operative Institute for Meteorological Satellite studies (CIMSS), University of Wisconsin, Madison, USA.

2.1 Wind buffer generation and quality control

In most of the operational centers the quality control technique used during AMV generation are either through Automatic Quality Indicator (Holmlund 1998) followed at EUMETSAT or through 3-dimensional recursive filter function followed at NESDIS (Nieman et al. 1997) or both the algorithms together. In the present study a wind buffer generation and quality control procedure is proposed and implemented first time in AMV (i.e. both infrared and water vapor winds) retrieval. The wind buffer is created using eight images between a pair of images (viz. the winds retrieved between 1-2, 2-3, 3-4, 4-5, 5-6, 6-7 and 7-8) and stored in a file. For infrared winds the buffer is generated using infrared images, while for water vapor winds the buffer is generated using water vapor images. Here each vector wind is represented by a complex number $V_{i,j} = u_{i,j} + iv_{i,j}$. For every new vector under consideration, (from current image-pair), its vector difference from the buffer is computed at the same as well as 3 X 3 neighborhood ($V_{diff}$) at the centre of first box represents the current vector under consideration and O (circle sign) represents spatial and temporal neighborhood vectors. The vector differences (magnitude of complex numbers) are calculated as $|V_{diff}| = |V_{i,j,t} - V_{i,j,t'}|$. Here $V_{i,j,t}$ represents the current vector at (i, j) point and $V_{i,j,t'}$ neighborhood vectors with $-1 \leq i \leq 1$, $-1 \leq j \leq 1$ and temporal scale $t$ varies from 1 to 8. If all spatial and temporal neighborhood vectors are present, then the difference set will contain 72 vectors (9 spatial neighborhoods with 8 temporal scales). However, all vectors may not be there all the times. The quality control process begins if at least 10 vector
differences $V_{\text{dif}}$, excluding the difference corresponding to current $(i, j)$, are present in the set. In the next step, set of vector differences $|V_{\text{dif}}|$ is arranged in ascending order, if the mean wind magnitude of first 10-vectors is less than 1.1 pixels, then the vector under consideration is accepted, otherwise rejected and the final vector is computed by taking weighted mean of first 10 sorted vectors and current vector. In the conventional triplet based methodology requires that a vector is available in both sets (i.e. in 1-2 and 2-3), if not so, such vectors are rejected, because they don’t get “support”. Hundreds of “isolated” vectors thus get eliminated, even though they represent the real situation. In the current method, the vector under consideration receives support from the past eight images.

![Figure 1](image-url)

Figure 1: A schematic diagram of wind buffer based quality control process.

To explain this more explicitly, if we take eight satellite images each with 30-minute interval stating at 12:00 UTC to 15:30 UTC, then winds retrieved using each-image pair are stored as buffer in a file and represented as wind buffer generated at 15:30 UTC. The buffer generated at 15:30 UTC is used for quality control for wind retrieved using 15:30 UTC and 16:00 UTC images and the second image time is given as actual observation time of retrieved wind. For example winds retrieved using 15:30 UTC wind buffer and 15:30 UTC and 16:00 UTC images is given as 16:00 UTC observation time. As a whole to complete the process once it requires nine images. Similarly the buffer is updated at every 30-minute with the latest available image and process is repeated for next cycle of wind retrieval. This method produces higher number of valid retrieval in all levels and captures upper-level meridional flow very prominently.

3. Validation results:

The validation of the retrieved winds is calculated according to the Coordination Group for Meteorological Satellites (CGMS) guidelines (Tokuno, 1998). It is suggested to report the mean vector difference (MVD), the root-mean-square vector difference (RMSVD), the standard deviation (SD), along with the mean radiosonde speed (SPD) and number of collocations (NC) with radiosonde data. Here the unit of MVD, RMSVD, SD, SPD and BIAS is m/s.
Figure 2: Time series of RMSVD and BIAS from Kalpana-1 and Meteosat-7 infrared winds for: a) High Level, b) mid Level and c) Low Level. (Black and Blue lines represent Kalpana-1 winds using multiplet and triplet method while green lines represent Meteosat-7 winds)
The following Fig 2(a-c) shows the RMSVD and BIAS for HIGH (100-400 hPa), MID (401-700 hPa) and LOW (701-950 hPa) level infrared wind for Kalpana-1 from triplet (blue lines) and multiplet based techniques (black lines) starting from July 2010 to December 2011 (January 2011 is missing) and Meteosat-7 (green lines) starting from February 2011 to December 2011. The statistical analysis is done here with respect to collocated radiosonde profile two times a day (i.e. for 00 UTC and 12 UTC) for each month. The Kalpana-1 winds are retrieved using ISRO’s triplet based and multiplet based algorithm at SAC Ahmedabad while Meteosat-7 winds are retrieved at CIMSS using NOAA/NESDIS operational algorithm. It is clearly visible from the figures that the Kalpana-1 BIAS with multiplet based algorithm (black lines) is almost in same order of magnitude with Meteosat-7 in all the levels, however, the RMSVD values is higher by 1-1.5m/s in all levels. The statistical analysis shows both RMSVD and BIAS has improved in Kalpana-1 winds when multiplet based technique is used during quality control.

Though RMSVD and BIAS has improved using multiplet technique, however the Kalpana-1 RMSVD values are still 1-1.5 m/s away from corresponding Meteosat-7 values. It is not wise to compare the statistical analysis of Meteosat-7 and Kalpana-1 as both the retrieval algorithm are different so as the horizontal resolution, however, it is shown here just to see where the Kalpana-1 winds are stand in the global scenario.

![RMSVD and BIAS: HIGH Level WV winds](image)

**Figure 3: Time series of RMSVD and BIAS from Kalpana-1 and Meteosat-7 water vapor winds. (Black and Blue lines represent Kalpana-1 winds using multiplet and triplet method while green lines represent Meteosat-7 winds)**

Similar to the infrared winds, Fig 3 shows the RMSVD and BIAS for HIGH level water vapor wind for Kalpana-1 triplet method (blue lines) and multiplet method (black lines) starting from July 2010 to December 2011, with missing in January 2011 and Meteosat-7 (green lines) starting from February 2011 to December 2011. The statistical analysis is done here with respect to collocated radiosonde profile two times a day (i.e. for 00 UTC and 12 UTC) for each month. It is visible from the figure that the Kalpana-1 BIAS is almost in same order of magnitude with respect to Meteosat-7, however, the RMSVD values is higher by approximately 1.5m/s in all months. However there is a slight improvement, though not significant, in RMSVD values when multiplet based technique is used in quality control during the retrieval.
References:


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