ESTIMATION OF CLOUD MOTION WINDS FROM KALPANA VHRR

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ABSTRACT

The operational derivation of Cloud Motion Winds (CMW) from infrared channels of three successive geo-stationary satellite images started in the early seventies. However, for the last decade the extraction of cloud motion vectors from satellite images has become the most important component for operational numerical weather prediction (NWP) and a significant contribution of both atmospheric wind information are derived from satellite observations that use the movement of cloud tracers to determine winds operationally several times a day. The present study focuses on our attempts of operational derivation of atmospheric winds from the observations from Indian geostationary satellite, KALPANA. With the availability of Infrared window channel (10.5-12.5 μm) on-board KALPANA Imager; an attempt has been made to derive cloud motion winds. The algorithms of cloud motion wind retrieval techniques basically depend upon the proper selection of appropriate cloud tracers and corresponding tracking of these tracers in the subsequent images. In the present work, cloud motion winds are derived from the IR images by considering 1) an efficient tracer selection procedure based on Image Thresholding Technique generated using histogram analysis, 2) tracking procedure of the selected tracer in the subsequent image based on cross-correlation procedure, 3) quality check based on vector acceleration checks and simple threshold techniques that compare the derived vectors to their surrounding vectors and 4) an empirically derived height assignment technique based on genetic algorithm. For validation of the algorithm, it is applied to METEOSAT5 VHRR images over Indian Ocean and validated with radiosonde data. The present algorithm shows some improvements over operational EUMETSAT wind retrievals algorithms. On average the new algorithm shows smaller mean vector difference and biases when collocated radiosonde observations were used as ground-truth. The present algorithm when applied to KALPANA VHRR shows reasonable resemblances with the corresponding radiosonde observations. However at lower levels, the KALPANA winds show slightly larger errors than corresponding EUMETSAT winds. This can be attributed to the lower resolution of KALPANA infrared imager.

1. Introduction

During seventies and early eighties, satellite winds were produced using a combination of automated and manual techniques (Leese et al. 1971; Young 1975; Green et al. 1975). Though the operational derivation of Cloud Motion Vector (CMV) from infrared channel of three successive geo-stationary satellite images started in the early seventies (Fujita 1968, Hubert and Whitney 1971), for the last decade the extraction of atmospheric motion vectors from satellite images has become most important component for operational numerical weather prediction (NWP). With the advancement of different numerical weather prediction techniques at different operational centers, a significant contribution of both middle and upper air wind information are derived from satellite observations that use the movement of cloud tracers to determine winds operationally several times a day. These satellite wind products are then assimilated in both regional and global-scale model and revealed its positive impacts on weather forecast (Kelly 2004, Bedka and Mecikalski 2005), especially over tropics. Though substantial progress have been made in derivation of operational satellite winds from geo-stationary operational environmental satellites (Neiman 1997, Veldon 1998, Schmetz et. al. 1993, Tokuno 1996) and their impacts in numerical weather prediction (both data assimilation and tropical cyclone studies) has been assessed. But not much work has been done for Indian meteorological geo-stationary satellite series (INSAT-3A/KALPANA). The present study focuses on our attempts of operational derivation of atmospheric winds from the observations from Indian geostationary satellites. With the availability of infrared window channel (10.5-12.5 μm) on-board Kalpana VHRR, an attempt has been made to derive cloud-tracked winds (900-100 hPa) from Indian geo-stationary satellites.

2. Algorithm for Cloud Motion Winds retrieval

Infrared images are used for detection and movement of clouds for estimation of winds at cloud levels. A procedure for the detection of cloud motion vector (CMV) winds using KALPANA IR data is being presented here. Detection of motion vectors is based on the assumption that clouds at different levels follow the atmospheric motion as rigid bodies. This assumption can be applied over a short interval of time, say, 30 minutes. Three consecutive KALPANA-IR images at 30-minute interval are needed to determine the CMVs. Following steps are involved in these estimations i) Image Thresholding, ii) Feature Selection and Tracking for CMV extraction, iii) Use of image-triplet and basic quality control and iv) Height assignment. These steps along with the description of algorithm is described below:

2.1 Image Thresholding

Grey level (digital number, or DN) thresholds are predetermined for the identification of land/ocean, low-level clouds (900-700 mb), and high-level clouds (100-300 mb). For a 10-bit resolution IR image, these values were determined by histogram analysis of several images. Threshold values for an inverted IR images from KALPANA are fixed as:

If DN < 520	Land/Ocean	No AMV extraction
521 < DN < 640	Low Clouds	
680 < DN < 880	High Clouds	

2.2 Feature Selection and Tracking for CMV extraction

Next step is to determine the features and their motion in two consecutive KALPANA/INSAT images. The features are determined sequentially in 20 X 20 pixel windows (called "template"). Maximum and average DN values of a template are used to determine the "class" of the template (e.g. low-cloud/high-cloud). Further, if the distribution of grey-levels is "coherent" within a template, it is assumed that it does not contain a traceable feature, and such templates are rejected. "Coherence" is measured in terms of the variance of DN values within the template. The match of this template is searched in second image within a "search window" of 40 X 40 pixels, centered at the same point as the template window. The 20 X 20 template in the second image, that lies within the search window, should have the same class as the template in first image, otherwise the template in second window is rejected as a potential match. The matching is done using the "cross-correlation" (CC) method, where the CC is defined as

$$CC = \frac{\sum (g(i,j) - \overline{g}) * (h(i,j) - \overline{h})}{\sigma_g * \sigma_h}$$

where g and h represent the grey values in the templates in first and second images respectively, over bars denote spatial averaging and σ is the standard deviation of DN values. Templates with CC < 0.8 are rejected. The center of the template with maximum value of CC is considered to be the location of feature in second image. This is the first set of the motion vector for the given template location. Sequentially the template is shifted in x and y directions and the motion vectors are determined using the procedure given above.

2.3 Use of image-triplet and basic quality control

Step (2) is repeated for second and third IR images, and a second set of motion vectors is generated. In both the above sets of CMVs there are several vectors that are spurious. This may occur due to several factors. For example, clouds may not always act as rigid bodies. Some clouds may dissipate, and other clouds may form. Also, with atmospheric motion, clouds may change shape, and maximum correlation may appear at some false location. Some rectification of this problem can be done using basic quality control measures. These are:

- AMV magnitude should not exceed a threshold that is predetermined for each level using climatology.
- Any vector should not deviate by more that 60^o from the average direction in a 3 X 3 neighborhood.
- Any vector magnitude should not exceed by more that 10 m/s from the average magnitude in a 3 X 3 neighborhood.
- Any vector direction should not deviate by more that 60^o from the direction of corresponding vector in second set of AMV.

- Any vector magnitude should not exceed by more that 10 m/s from the magnitude of corresponding vector in second set of AMV.
- If an image location produces 2 vectors in 2 sets and satisfies conditions (iv) and (v), both the vectors are averaged to produce the AMV at that location. If only one set contains a vector at the above location, that is retained, but has to pass tests (i),(ii), and (iii).

2.4 Height assignment

In this section the height assignment of derived cloud motion wind vector is done. The Genetic Algorithm (GA) is one of the best empirical techniques to determine best relationship between the independent and dependent parameters. The GA is used here to find the height of the corresponding vector. In this step, a function is generated for cloudy pixels using three image variables like coldest, warmest and cosine of latitude from randomly selected 95 METEOSAT5 images and corresponding product of EUMETSAT from one month data as training data sets. Later a mapping is defined between METEOSAT5 and KALPANA using the sensor response function of both the satellite, so that the function generated using METEOSAT5 can be used in KALPANA CMV. Finally the functions for cloudy regions are used to find the cloud tracer height in KALPANA through the mapping. Theoretically the maximum accuracy that can be attributed to the CMV is equivalent to the error of 1 pixel/30 minutes. This is 4-5 m/s for KALPANA/INSAT. There are several other sources of error, for example uncertainties about cloud thickness, and the validity of assumptions of rigidity of cloud shapes within a short time span.

3. Verification Procedure

The quantitative evaluation of derived atmospheric motion vectors are calculated according to the CGMS guidelines, where derived cloud motion winds are validated with collocated radiosonde data. According to CGMS guidelines, the Vector Difference (VD) between an individual wind (i) and the collocated Rawinsonde wind (r) used for verification is given by

$$VD = \left[(U_i - U_r)^2 + (V_i - V_r)^2 \right]^{1/2}.$$

The speed bias (BIAS) is calculated as

$$BIAS = \frac{1}{N} \sum_{i=1}^{N} \left[\left(U_i^2 + V_i^2\right)^{1/2} - \left(U_r^2 + V_r^2\right)^{1/2} \right]$$

Finally the mean vector difference (MVD) is reported as

$$MVD = \frac{1}{N} \sum_{i=1}^{N} (VD)_i \,.$$

These statistics can provide a fixed measure of product quality over time and can be employed in determining the observation weight in objective data assimilation. And the standard deviation (SD) about the mean vector difference traditionally reported is

$$SD = \left[\frac{1}{N} \sum_{i=1}^{N} (VD - MVD)^2 \right]^{\frac{1}{2}}$$

The root-mean-square error (RMSVD) 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,

$$RMSVD = \left[MVD^2 + SD^2 \right]^{\frac{1}{2}}.$$

It is suggested to report mean vector difference (MVD) and standard deviation (SD), along with mean radiosonde speed (SPD) and number of collocation with radiosonde data (NC). Here the unit of MVD, RMSVD, SD, SPD and BIAS is m/s. A typical example of cloud motion winds derived from KALPANA VHRR for 2nd January 2008 valid at 0730 UTC using the present technique is shown in the Fig. 1. It shows that the present technique is able to produce the wind with uniform coverage, large-scale and synoptic-scale features are well captured and vertical distribution of information is in between 100-950-hPa portion of the troposphere.

3.1 Validation with Radiosonde and Meteosat data

The cloud motion winds derived two times (00Z and 0730Z) a day at Space Applications Centre (SAC) Ahmedabad. The winds derived at SAC with all available acquisitions are validated with radiosonde data for the period of September, October and November 2007. To know the performance of the product generated at SAC from KALPANA, the EUMETSAT derived METEOSAT7 winds for September, October and November 2007 are also acquired and compared with radiosonde data for the same time when KALPANA winds are also derived at SAC. The validation is done for each day by calculating different statistical parameters as discussed above for the region 50^{o}N to 50^{o}S and 30^{o}E to 130^{o}E and making the average to get the monthly mean. During collocation 1.0 x 1.0 degree latitude/longitude grid point is considered, with speed and direction differences more than 30 m/s and 90 degree respectively are filtered out.

Table 1 shows the values of different statistical parameters calculated for cloud motion winds for the month of September 2007 as derived from Meteosat7 (Table 1a-b) and Kalpana (Table 1c-d) when both the sets are compared with radiosonde data independently. The parameters are calculated in three cases viz. i) by considering all acquisitions together, ii) considering all 00Z acquisitions and iii) all 0730 acquisitions respectively. During the validation of 00Z acquisitions all available 00Z radiosonde data are used, while for 0730Z acquisitions all available radiosonde data between 06Z and 09Z are used. It is seen from the Table 1 that in high and mid level, the statistical parameters for Meteosat7 and Kalpana are very close to each other, while in the low level RMSVD for Meteosat7 and Kalpana are 4.8 m/s and 7.3 m/s respectively. This may be due to the difference of horizontal resolution of Kalpana and Meteosat7. The horizontal resolution of Kalpana is 8 km, while in Meteosat7 it is 5 km. As similar to Table 1, the different statistical parameters calculated for cloud motion winds for the month of October 2007 is shown in Table 2(a-d). Similar to the month of September 2007, the statistical parameters for Meteosat7 and Kalpana are very close to each other in high and mid-level, while in the low level RMSVD for Meteosat7 and Kalpana are 5.3 m/s and 9.8 m/s respectively. Table 3(a-d) shows the different statistical values for the month of November 2007. Surprisingly at all three levels, the statistical parameters derived from Meteosat7 and Kalpana are very close each other, which was not case for September and October. Another interesting feature is that total number of collocations (NC) in Kalpana is larger in high level than the corresponding Meteosat7 derived winds in all the cases. However, low-level NC's of Kalpana is less when it is compared with low-level NC's of Meteosat7. This may be due to the difference of cloud tracers height in EUMETSAT derived Meteosat7 and SAC derived Kalpana cloud motion winds for the lower level winds. Another set of validation is also carried out by collocating Meteosat7, Kalpana and radiosonde data together. Table 4(a-c) shows the statistical parameters calculated in this collocation procedure for he three different cases viz. i) Meteosat7 vs. radiosonde, ii) Kalpana vs. radiosonde and iii) Kalpana vs. Meteosat7 respectively. It is also seen from the Table 4(a-b) that Meteosat7 and Kalpana values are very close to each other at all three levels when both are compared with radiosonde data. However, when Kalpana and Meteosat7 are compared RMSVD in the high, mid and low levels are coming out 5.7 m/s, 6.1 m/s and 3.5 m/s respectively.

4 Conclusion

The cloud motion winds derived from Kalpana at SAC for September, October and November 2007 are validated against radiosonde data. To know the performances of the derived product from Kalpana, the corresponding cloud motion winds derived at EUMETSAT using Meteosat7 are also acquired and validated. The Kalpana derived cloud motion winds in the high and mid levels have also good agreement with the corresponding winds from Meteosat7 over the Indian Ocean region. While comparing with radiosonde data the low-level cloud motion winds from Kalpana do not compare that closely as seen with Meteosat7. This may be because of the empirical height assignment technique used while deriving cloud motion winds from Kalpana. The present empirically derived height assignment has some discrepancies at low-level cloud motion winds derived by Kalpana, when they are compared with the corresponding radiosonde data as well as with EUMETSAT derived Meteosat7 winds. To remove these discrepancies, the numerical model forecasts will be used in the height assignment technique. Apart from the present height assignment technique, the height assignment algorithm used in different operational centers like CO2-slicing method, H2O-Intercept method and Cloud Base Method etc needs to be implemented.

5. Acknowledgement

Authors are thankful to EUMETSAT for providing one-month METEOSAT VHRR images and the corresponding derived winds, which were used for the development of height assignment algorithm and also the derived product of September, October and November 2007 from METEOSAT7 for validation. The Director, the Deputy Director, RESA and the Group Director MOG/RESA of Space Applications Centre (SAC), ISRO Ahmedabad are thanked for their encouragement and help.

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TABLE 1 : METEOSAT7 CMV & RADIOSONDE: SEPTEMBER 2007

a) Considering both 00Z & 0730Z acquisition together

Parameters	HIGH 100-399 hPa	MID 400-699 hPa	LOW 700-950 hPa
MVD	8.3	7.8	4.5
RMSVD	9.4	8.7	4.8
SD	4.2	3.1	1.2
BIAS	-3.5	-3.2	-2.3
SPD	16.2	10.3	5.0
NC	214	104	39

b) Considering 00Z & 0730Z acquisition separately

Parameters	HIGH (00 UTC) 100-399 hPa	HIGH (0730 UTC) 100-399 hPa	MID (00 UTC) 400-699 hPa	MID (0730 UTC) 400-699 hPa	LOW (00 UTC) 700-950 hPa	LOW (0730 UTC) 700-950 hPa
MVD	8.4	8.2	7.6	7.9	5.5	2.7
RMSVD	9.6	9.3	8.4	8.9	6.0	2.8
SD	4.4	4.0	3.1	3.2	1.9	0.08
BIAS	-2.8	-4.2	-2.0	-4.2	-2.8	-1.5
SPD	12.11	13.2	7.4	6.6	5.3	4.3
NC	103	111	57	47	30	9

KALPANA CMV & RADIOSONDE: SEPTEMBER 2007

c) Considering both 00Z & 0730Z acquisition together

PARAMETERS	HIGH 100-399 hPa	MID 400-699 hPa	LOW 700-950 hPa
MVD	9.1	7.8	7.1
RMSVD	10.3	8.4	7.3
SD	4.7	2.4	0.6
BIAS	-3.9	1.6	4.3
SPD	19.0	14.3	8.0
NC	551	100	20

d) Considering 00Z & 0730Z acquisition separately

Parameters	HIGH (00 UTC) 100-399 hPa	HIGH (0730 UTC) 100-399 hPa	MID (00 UTC) 400-699 hPa	MID (0730 UTC) 400-699 hPa	LOW (00 UTC) 700-950 hPa	LOW (0730 UTC) 700-950 hPa
MVD	8.7	9.5	7.8	7.8	10.7	5.0
RMSVD	10.0	10.6	8.4	8.4	11.1	5.0
SD	4.7	4.7	2.7	2.0	1.4	0.0
BIAS	-3.7	-4.1	2.5	0.8	6.8	2.8
SPD	16.3	21.6	10.5	14.6	8.3	7.9
NC	202	349	51	49	9	11

TABLE 2: METEOSAT7 CMV & RADIOSONDE: OCTOBER 2007

a) Considering both 00Z & 0730Z acquisition together

PARAMETERS	HIGH 100-399 hPa	MID 400-699 hPa	LOW 700-950 hPa
MVD	8.6	6.5	5.0
RMSVD	10.2	8.0	5.3
SD	5.0	4.1	1.0
BIAS	-4.1	-2.5	-0.7
SPD	17.1	10.2	5.2
NC	197	144	45

b) Considering 00Z & 0730Z acquisition separately

Parameters	HIGH (00 UTC) 100-399 hPa	HIGH (0730 UTC) 100-399 hPa	MID (00 UTC) 400-699 hPa	MID (0730 UTC) 400-699 hPa	LOW (00 UTC) 700-950 hPa	LOW (0730 UTC) 700-950 hPa
MVD	8.2	9.0	7.1	6.0	4.5	5.7
RMSVD	10.2	10.2	9.3	6.8	4.8	6.0
SD	5.7	4.4	5.3	3.0	1.1	0.9
BIAS	-3.0	-4.9	-1.9	-2.9	-1.2	-0.1
SPD	14.9	18.9	10.0	10.5	4.0	6.8
NC	114	83	74	70	28	17

KALPANA CMV & RADIOSONDE: OCTOBER 2007

c) Considering both 00Z & 0730Z acquisition together

PARAMETERS	HIGH 100-399 hPa	MID 400-699 hPa	LOW 700-950 hPa
MVD	8.1	8.1	9.7
RMSVD	9.8	8.6	9.8
SD	5.2	1.7	1.0
BIAS	-3.6	-0.4	5.1
SPD	17.4	15.9	7.0
NC	389	81	22

d) Considering 00Z & 0730Z acquisition separately

Parameters	HIGH (00 UTC) 100-399 hPa	HIGH (0730 UTC) 100-399 hPa	MID (00 UTC) 400-699 hPa	MID (0730 UTC) 400-699 hPa	LOW (00 UTC) 700-950 hPa	LOW (0730 UTC) 700-950 hPa
MVD	7.5	8.7	6.5	9.6	10.5	8.9
RMSVD	9.4	10.1	6.9	10.1	10.8	9.0
SD	5.4	4.9	1.5	1.9	1.0	0.9
BIAS	-2.7	-4.4	0.6	-1.4	6.0	4.3
SPD	14.3	20.2	11.6	19.9	6.3	7.7
NC	209	180	44	37	10	12

TABLE 3: METEOSAT7 CMV & RADIOSONDE: NOVEMBER 2007

a) Considering both 00Z & 0730Z acquisition together

PARAMETERS	HIGH 100-399 hPa	MID 400-699 hPa	LOW 700-950 hPa
MVD	9.0	8.9	5.5
RMSVD	10.8	10.2	5.6
SD	5.6	4.2	0.94
BIAS	-4.5	-4.7	-2.0
SPD	19.2	13.2	5.6
NC	188	177	36

b) Considering 00Z & 0730Z acquisition separately

Parameters	HIGH (00 UTC) 100-399 hPa	HIGH (0730 UTC) 100-399 hPa	MID (00 UTC) 400-699 hPa	MID (0730 UTC) 400-699 hPa	LOW (00 UTC) 700-950 hPa	LOW (0730 UTC) 700-950 hPa
MVD	8.4	10.1	9.3	8.7	5.6	5.2
RMSVD	10.4	11.6	11.1	9.5	5.9	5.3
SD	5.9	5.6	5.7	3.2	1.0	0.8
BIAS	-4.3	-4.8	-4.8	-4.4	-3.3	0.5
SPD	17.3	21.7	14.0	12.8	5.7	5.6
NC	112	76	99	78	26	10

KALPANA CMV & RADIOSONDE: NOVEMBER 2007

c) Considering both 00Z & 0730Z acquisition together

PARAMETERS	HIGH 100-399 hPa	MID 400-699 hPa	LOW 700-950 hPa
MVD	9.7	9.8	6.1
RMSVD	11.4	10.5	6.2
SD	5.5	2.9	0.3
BIAS	-3.7	-2.3	3.8
SPD	22.4	17.9	7.2
NC	376	114	17

d) Considering 00Z & 0730Z acquisition separately

Parameters	HIGH (00 UTC) 100-399 hPa	HIGH (0730 UTC) 100-399 hPa	MID (00 UTC) 400-699 hPa	MID (0730 UTC) 400-699 hPa	LOW (00 UTC) 700-950 hPa	LOW (0730 UTC) 700-950 hPa
MVD	8.8	10.6	7.6	10.3	5.4	6.3
RMSVD	10.8	12.0	8.2	10.9	5.4	6.6
SD	6.1	5.2	2.0	3.0	0	1.3
BIAS	-3.2	-4.6	-0.3	-1.8	2.6	4.3
SPD	16.4	25.9	14.9	18.2	6.6	5.7
NC	184	152	40	90	3	14

TABLE 4: SEPTEMBER, OCTOBER AND NOVEMBER 2007
(METEOSAT7, KALPANA CMV & RADIOSONDE collocated together)

a) METEOSAT7 VS RADIOSONDE

PARAMETERS	HIGH 100-399 hPa	MID 400-699 hPa	LOW 700-950 hPa
MVD	8.7	10.0	3.1
RMSVD	9.2	10.0	3.1
SD	1.6	0.02	0.0
BIAS	-4.9	-1.7	1.2
SPD	18.1	15.7	7.6
NC	118	14	5

b) KALPANA VS RADIOSONDE

PARAMETERS	HIGH 100-399 hPa	MID 400-699 hPa	LOW 700-950 hPa
MVD	9.2	7.5	3.5
RMSVD	9.7	7.5	3.5
SD	1.7	0.06	0.0
BIAS	-3.3	-1.7	3.2
SPD	18.1	15.7	7.6
NC	118	14	5

c) KALPANA VS METEOSAT7

PARAMETERS	HIGH 100-399 hPa	MID 400-699 hPa	LOW 700-950 hPa
MVD	5.7	6.1	3.5
RMSVD	6.0	6.1	3.5
SD	1.08	0.1	0
BIAS	1.5	0.0	2.0
SPD	18.1	15.7	7.6
NC	118	14	5

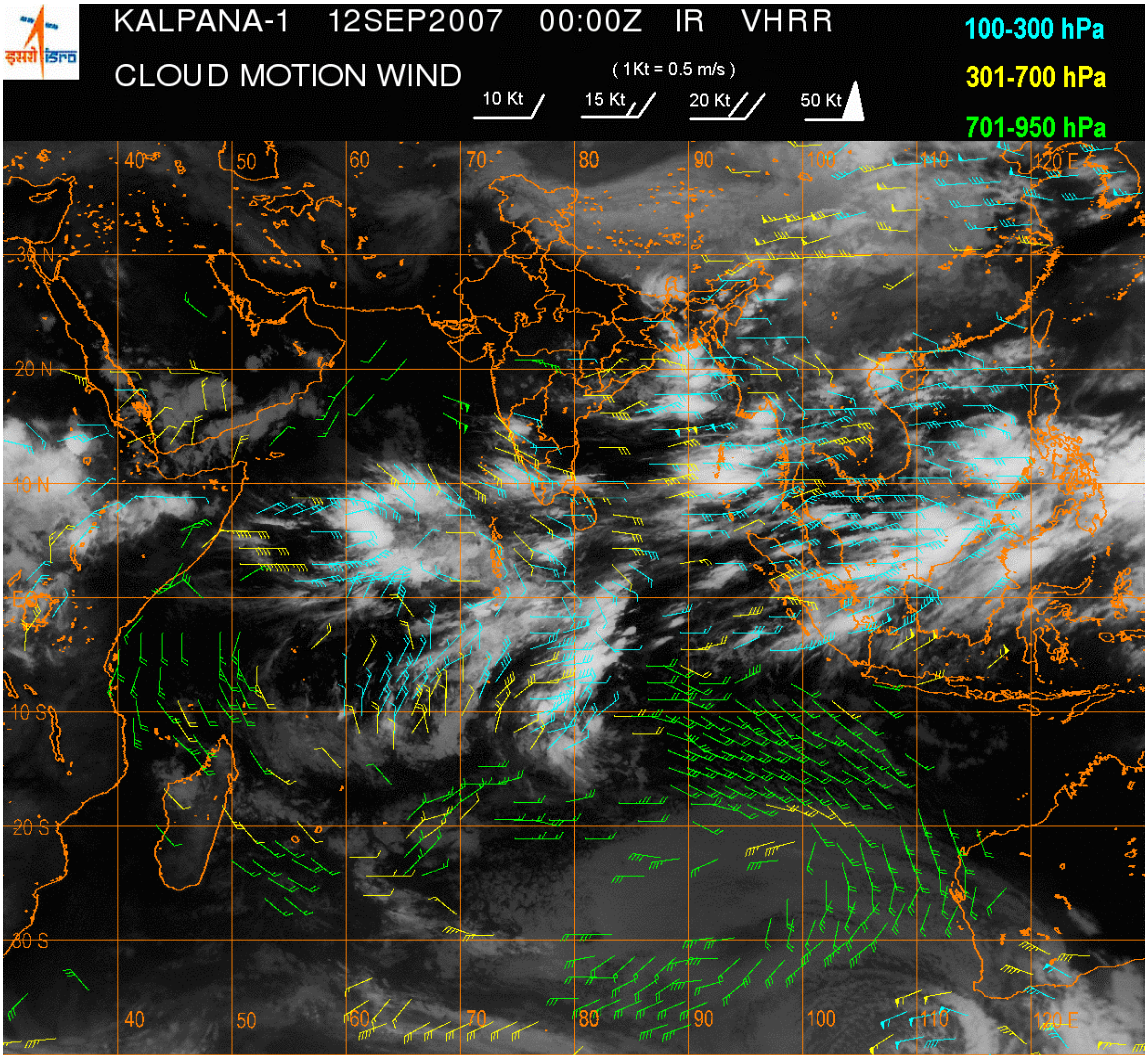

Figure 1: A typical example of cloud motion winds derived over Indian Ocean region (30E-130E, 50S-50N) from KALPANA VHRR derived at SAC using the present algorithm for 12 September 2007 valid at 00 UTC.