Report on the Progress and Status of Cloud Motion Vector Retrieval by MISR on the Terra Satellite

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Abstract

This report covers progress in the MISR standard products for height-resolved cloud motion vectors since the previous winds workshop in Helsinki. Notable improvements have occurred due to the implementation of sub-pixel co-registration that allows all cameras to be used with confidence. This has improved the accuracy of individual CMVs, and, importantly, allowed much better quality control by independent use of the forward and aft triplets. Comparison with the Global Modeling and Assimilation Office 6-hour forecast winds shows essentially zero bias and an rms vector speed difference of 5 m/s for low-level winds. Comparison of improved versions of the MISR product shows that it can achieve an rms consistency in CMV speeds < 2 m/s, independent of height. With this study, the latest version (4.1) of the MISR wind product appears to have reached maturity, and older data will be reprocessed to provide a consistent climate data record of geometrically derived, height-resolved winds from the Terra satellite, from early 2000 to present.

INTRODUCTION

The full text of this work has been submitted for publication as a journal article (Davies et al., 2006), so this report is a summary of the key points of the presentation made at the 8th International Winds Workshop. The Multiangle Imaging SpectroRadiometer (MISR) has been operational on the Terra satellite with negligible loss of data since February 2000 (Diner et al. 2002). It measures reflected solar radiances from nine fixed viewing directions, of which five are typically used to obtain the CMV product. These are used in triplets, one forward looking, the other aft, each with nadir, 45° and 70° viewing angles. The passage of one triplet of views in the satellite's orbit takes about 3.5 minutes, sufficient for cloud advection to be measurable. Cross-track motion can be measured relatively easily, whereas along-track motion must be separated from the disparity due to cloud height and a consensus result obtained by analysis of individual high resolution retrievals over a mesoscale domain of size 70.4 km. The technique for doing this was first described by Horváth and Davies (2001a), with the first results using the technique given by Horváth and Davies (2001b).

The initial operational results confirmed the viability of the technique, but there were early problems with quality control. The results are very sensitive to navigation errors that affect the co-registration of the multiangle views, and occasionally the stereo matching makes mistakes. Featureless clouds and complex multilayered clouds should give no retrieval, but occasionally a retrieval for these slips through the operational processing as a bad wind. Solutions to both these problems have now been implemented. The co-registration is done dynamically at the sub-pixel level on an orbit-by-orbit basis, (Jovanovic et al. 2006) using a combination of land features and sea-ice patterns. The mesoscale statistics are also analyzed at the sub-pixel level, permitting the intrinsic rms error to vary continuously (previously it was discrete at ~6 m/s). The improved co-registration also solved a problem with the most oblique aft camera (Da) that had been preventing use of the aft triplet. With both triplets available, comparison between the two CMVs retrieved provides a powerful measure of quality control.

Two levels of products are produced: the basic operational CMV product, termed 'good winds', and an enhanced data set, termed 'better winds', that is targeted more at the research community. The thresholds in the quality control of these products, and the statistical differences between the fore and aft wind products are discussed in the next section. Comparison has also been made with the 6-hour forecast winds from the Global Modeling and Assimilation Office (GMAO), but using a slightly earlier version (4.0) of the product that produced an rms difference that increased with height. Much of this difference appears to be removed in version (4.1).

FORE–AFT DIFFERENCES IN CMV RETRIEVAL

The consensus mesocale CMV retrieved by the forward triplet can be compared against that from the aft triplet in terms of its North-South wind speed component, its East-West wind speed component, its direction, and its height assignment. For much of the orbit, the North-South wind component corresponds to the across-track component. Since the directionality of low speed vectors is of less significance, the directionality test is applied only to wind speeds > 2 m/s. Errors in these can be correlated, and there is a deliberate element of redundancy in the quality control to ensure that the outliers are excluded. Table 1 shows the basic and enhanced thresholds adopted for version 4.1.

	Basic Thresholds (all must be satisfied for 'good' winds)	**Enhanced Thresholds** (two or more must be satisfied for 'better' winds)
NS wind component	10 m/s	3 m/s
EW wind component	3 m/s	1 m/s
Height assignment	1000 m	300 m
Direction	45°	not used

Table 1. **Quality control thresholds applied to the component differences between mesoscale CMV retrievals obtained separately using forward triplet views (An-Bf-Df) and aft triplets (An-Ba-Da).**

A randomly chosen 10-orbit data set was chosen for analysis of the fore–aft CMV differences using these thresholds, and the resulting distributions of the differences in wind speed and direction are shown in Figs. 1 and 2, respectively, with the overall statistics summarized in Table 2. Included in Table 2 is the summary for version 4.0 'good' winds that were used in the GMAO comparison.

	All	**'good'**	**'better'**	**'good' (GMAO)**
Number	10,237	6,866	4,602	6,295
Coverage	100%	67%	45%	61%
Speed bias (m/s)	–0.10	–0.20	–0.14	–0.17
Speed rms (m/s)	19.1	2.4	1.5	2.7
Direction bias	3.1°	0.9°	0.5°	2.2°
Direction rms	55°	17°	14°	24°
Vector rms (m/s)	23.2	3.7	2.2	3.9
Height bias (m)	133	38	18	30
Height rms (m)	2,102	291	165	649

Table 2**. Summary statistics for the differences between fore and aft CMV retrievals using the current basic and enhanced thresholds, as well as for the earlier basic thresholds used in the GMAO comparison.**

Note that the quality control comes at the price of coverage. For the 'good' winds the coverage is about 67% of all possible mesoscale domains. Some of the excluded regions would be clear featureless ocean, featureless cloud, or complex multilevel cloud for which the stereo approach fails. Some of the included region is cloud free land or sea-ice, for which stereo works well, but for which the retrieval is typically a zero wind speed at the surface altitude. Without quality control, the blunders dominate the error statistics. These could be partially removed by other techniques, but the fore-aft quality control is the simplest and most reliable.

Both distributions are relatively symmetric and unbiased, with the 'better' winds showing a narrower error distribution, as expected. The overall summary statistics between versions 4.0 and 4.1 are not greatly different, except in the rms difference of assigned height, because of the dominant abundance of low-level winds. Better control of the height assignment between the two versions turns out to be significant, as shown in the next section.

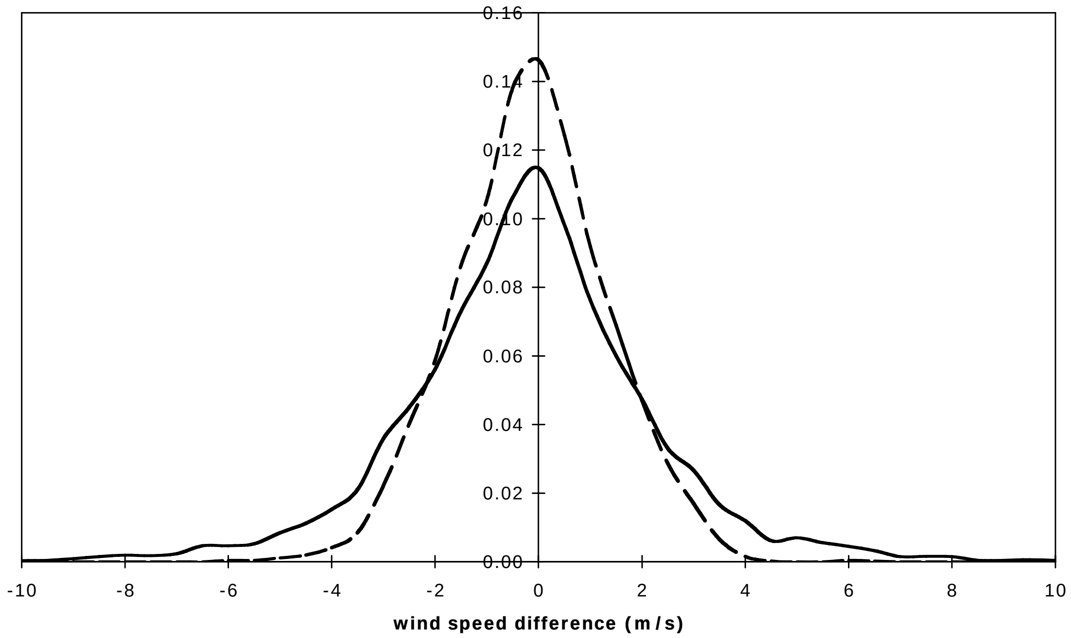

***Figure 1*. Frequency distribution of CMV speed differences between the forward and aft triplet retrievals, for cases that satisfy the quality control at a level of 'good' (solid) or 'better' (dashed).**

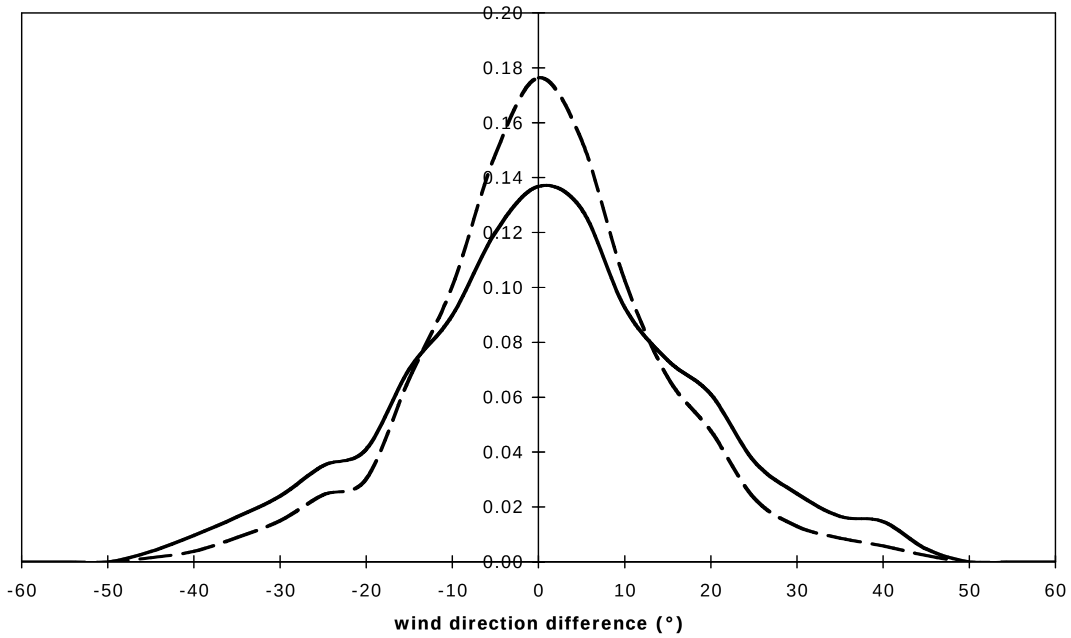

***Figure 2*. Frequency distribution of CMV direction differences between the forward and aft triplet retrievals, for cases that satisfy the quality control at a level of 'good' (solid) or 'better' (dashed).**

COMPARISON WITH FORECAST WINDS

A 6-week data set starting 1 September 2003 was used to compare MISR version 4.0 operational 'good' winds with 6-hour forecast winds from version 4.03 of the GEOS data assimilation and forecast system of the GMAO. The results are summarized in Table 3. Note that the bias error is very low, that the rms vector speed difference is about 5 m/s for low-level winds, and that this rises with height. The rise in difference with height was initially perplexing because the MISR retrieval error should not be very sensitive to height. This led to better quality control of the height assignment in version 4.1, and the results are shown in Fig. 3.

	low-level (>700 hPa)	mid-level (400-700 hPa)	high-level (<400hPa)
speed bias (m/s)	0.09	-0.02	1.01
rms vector difference (m/s)	5.1	7.4	10.5
mean speed (m/s)	8.6	12.1	24.3
normalized rms vector difference (m/s)	0.59	0.62	0.43
number of observations	70,091	12,442	2,631

Table 3. **Comparison of MISR wind retrievals with forecast winds from the Global Modeling and Assimilation Office.**

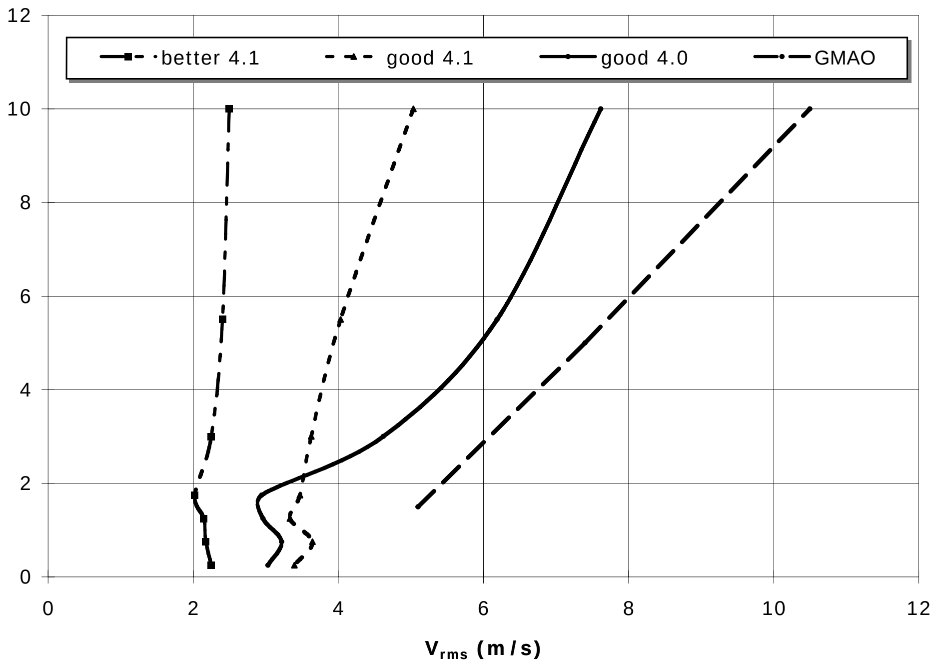

Figure 3. **Vector rms speed differences as a function of height. From left to right: 'better' fore–aft differences for version 4.1; 'good' fore–aft differences for version 4.1; 'good' fore–aft differences for version 4.0; differences between MISR 'good' version 4.0 and GMAO forecast winds.**

Much of the increase in vector rms wind speed difference with height has been reduced in going from version 4.0 to 4.1. The 'better' winds product shows a steady value of ~2.2 m/s rms vector speed error with height, consistent with expectations for this technique.

SUMMARY

Version 4.1 of the MISR wind product appears to have reached maturity, and the 'good winds' can be used with confidence for unbiased CMVs with a mesoscale horizontal resolution of 70.4 km. The rms differences in between internal estimates of these CMVs are 3.7 m/s in vectors speed, 2.4 m/s in speed, 17° in direction and 291 m in height assignment. The operational products are averages of the two triplets, with an expected rms error that is $1/\sqrt{2}$ of these values, or 2.6 m/s, 1.7 m/s, 12° and 206 m, respectively. Coverage by 'good winds' is about 67% of the possible mesoscale domains. Even lower errors are possible using the 'better winds' product, if a lower coverage (~45%) is acceptable.

The errors in the MISR wind, especially the 'better winds' do not appear to rise with assigned height, so that the normalized wind error goes down with height. The differences between MISR CMVs and forecast winds does appear to increase with height, even when differences in the versions compared are accounted for. This may point to a physical difference between CMV and wind that increases with assigned height.

The MISR data will be reprocessed with the version 4.1 software to provide a uniform climate data record of CMVs measured from Terra. Given the geometric nature of this retrieval, that is insensitive to radiometric calibration, interannual-to-decadal variations can usefully be studied.

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