MULTI-ANGLE MEASURES OF CLOUD TRACKED WINDS FROM MISR

R. Davies, C. Moroney and D. Nelson

Jet Propulsion Laboratory, California Institute of Technology,
4800 Oak Grove Drive, Pasadena, Ca 91109, USA

ABSTRACT

Stereo matching of cloud reflectivity patterns using two or more pairs of viewing directions can be used to obtain instantaneous cloud tracked winds and cloud heights from a polar orbiter. Under ideal conditions and using MISR measurements at a resolution of 275 m, the accuracy of cloud tracked winds for a 70 km domain is nominally 4 m/s rms, with a height resolution of 400 m. Comparisons by the NASA Goddard's Global Modeling and Assimilation Office of model-analyzed wind fields with the MISR operational products based on only two camera pairs yielded normalized uncertainties (i.e. rms/mean) of about 0.7, or 6.2 m/s for lower tropospheric winds, which were higher than expected.

Here we examine the lessons learned regarding the need for accurate co-registration, quality control of stereo matching (especially the treatment of multilevel clouds), and the merits of adding a second camera triplet. Provided co-registration can be guaranteed, addition of a second camera triplet appears to improve the wind product by about 2 m/s rms, motivating an additional round of comparison with the GMAO.

1. INTRODUCTION

This paper summarizes the status, at the time of the 7th International Winds Workshop, of the wind retrievals (i.e. cloud motion vectors) obtained by applying a hyper-stereo-photogrammetric technique to multi-angle spectrally reflected radiances measured by MISR. MISR is the Multi-angle SpectroRadiometer on the Terra satellite of NASA's Earth Observing System (Diner *et al*., 2002).

Elsewhere in these proceedings, Zhu *et al*. (2004) describe the status and impact of MISR winds on forecast anomalies based on the version of the operational product effective as of late 2003. They show an rms difference between MISR winds and model forecast winds of about 6 m/s for the bulk of the retrievals (i.e. low level clouds) with no positive impact on forecast skill. While the impact may be partially obscured by the nature of the data sampling used (the MISR data are sun-synchronous over relatively narrow orbital swaths) the rms wind errors were certainly higher than the expected pre-launch uncertainty of 3–4 m/s from Horváth and Davies (2001a). Subsequent investigation revealed that the navigation of the most oblique aft looking MISR camera (the Da camera) intermittently suffered from co-registration anomalies of one or more pixels, which affected the accuracy of the wind retrievals in the dataset used in the Zhu *et al*. (2004) study.

The following briefly describes the nature of this problem, an operational correction that has been implemented, and the results of a preliminary data analysis showing the differences between the corrected and uncorrected MISR winds. The impact of the improved winds on forecast skill will now be the subject of a future study.

2. ISSUES ASSOCIATED WITH MISR WIND RETRIEVALS

As described by Horváth and Davies (2001a) and Moroney *et al*. (2002), the MISR operational wind retrievals provide height-resolved cloud motion vectors at a mesoscale resolution (70.4 km). For a nominal overlap swath width for all cameras of about 350 km, this yields typically no more than six wind vectors across the swath. While this obviates the need to apply thinning, the narrow swath width limits the amount of data available for comparison and impact studies.

The Terra orbit is sun synchronous, with an equator-crossing local time at about 10:45 am, which typically misses many of the diurnally varying clouds over land. The wind retrieval technique is independent of latitude, however, giving uniform coverage from pole to pole, subject to cloud conditions. The multi-angle measurements are also nearly simultaneous, with a maximum time between measurements of about 7 min, so that changes due to mesoscale or synoptic scale cloud development are minimized.

Because the stereo matching technique requires contrast at high spatial resolution, results cannot be obtained over homogeneous clouds. Fortunately these are relatively rare on a global scale as noted by Genkova and Davies (2003). Similarly no retrievals are obtained over clear ocean. Clear retrievals over land typically indicate zero wind at an altitude consistent with the terrain height, and serve as a diagnostic check on the method.

The red band (670 nm) data used in the wind retrievals are sampled at a high spatial resolution of 275 m for each of the nine cameras. While this resolution makes nearly simultaneous wind retrievals possible, it results in a very high data volume incident to the wind-processing algorithm of about 3 Gbytes per orbit. This has led to the development of non-conventional stereo matchers that compromise between processing speed and degree of spatial coverage. Given the presence of heterogeneous cloud, a consensus wind vector is obtained for each mesoscale domain using a modal-histogram approach that is relatively tolerant of individual (i.e. 2.2 km resolution) stereo matching errors and sparseness in coverage. This is now helped by a redundancy technique that requires use of both fore and aft viewing triplets. [A triplet usually consists of the nadir view, a 45° view (B camera) and a 70° view (D camera)].

However, some cloud scenes remain too complex for the operational approach, as when thin cloud exists above a lower cloud deck. Here the nadir view is more affected by the low cloud, whereas the oblique views are more affected by the high cloud, making a consistent pattern match impossible. A number of quality checks are implemented to identify and exclude such cases. While the evidence of how well these checks work globally remains somewhat empirical, the so-called "best winds" operational product is thought to err on the conservative side, and likely excludes more cases than may be absolutely necessary.

Because the technique basically separates the total disparity in pattern locations into two components — one component due to cloud-top height above the reference surface (an ellipsoid defined by the World Geodetic System 1984) and another component due to along-track cloud motion (the across-track wind is obtained directly) — the consensus wind vector automatically comes with a geometrical height assignment. This also means that the along-track wind accuracy is tightly coupled with the cloud-top height accuracy. There is recent evidence (Sherwood *et al*. 2004) that the MISR cloud-top heights appear to be quite accurate and agree well with other geometrically based techniques (lidar). Interestingly, these geometrically based techniques differ systematically from thermally based cloud-top heights, which appear to be biased 1–2 km low. Similar occasional discrepancies between geometrically (MISR) and thermally (GOES) based cloud motion vector height assignments were noted by Horváth and Davies (2001b) and attributed to the influence of thin cirrus.

As noted above, the ability to retrieve wind vectors from nearly simultaneous multi-angle measurements requires high spatial resolution. The multi-angle measurements must thus be carefully co-registered. While the MISR camera navigation has generally been excellent, and this has been checked by manual inspection for specific case studies discussed earlier, problems with the navigation, especially that of the Da camera are known to have been present in data and to have propagated through to the operational wind products, at least those processed through 2003. The MISR data are currently undergoing a reprocessing that includes a number of related improvements to many of the standard products. The main issue addressed here, therefore, is the implementation of an operational correction of co-registration errors together with an analysis of the potential impact of this correction.

3. IMAGE CO-REGISTRATION

The new approach, which is in the form of an automatic algorithm involving optimal least squares matching, calculates any co-registration errors on a block-by-block basis, where a block refers to a region 140 km along the orbital track with a swath width of about 350 km. The most prominent features in the nadir view are found first and each oblique view of the same features is then compared with a tolerance of ±32 pixels about the assumed centre. The pixel offsets of the best-matched features are then tested to see whether the feature is a cloud. This is done by comparison of the offsets for each oblique view, noting their relative behaviour. If the feature is a cloud then this is excluded from further consideration. Otherwise, consistent offsets are found and used to calculate co-registration corrections for each camera, down to a sub-pixel resolution of 0.2 pixels.

In practice the technique applies to substantially clear scenes, when the underlying surface is either land or sea ice. The results of the automatic algorithm were also checked for a number of orbits by a visual inspection of 9-camera animations, indicating no discernible shifts. The resulting accuracy of the 9-camera co-registration for regions containing clear features is considered to be better than 0.5 pixels. In orbits containing one or more correctly co-registered blocks, confidence is high that the same corrections apply to the other blocks in the same orbit. However, the same cannot be said of different orbits, and an orbit for which no co-registration check can be made (due to too much cloud) is now deemed to be too uncertain for precision wind vector retrieval.

4. RE-PROCESSED WIND VECTORS

To explore the potential impact of the improved co-registration, a random subset of 30 orbits was extracted from the 6-week dataset used in the GMAO comparison. New co-registrations were found for 16 of these orbits, with corrections attempted down to the level of 0.2 pixels (with an expected final accuracy of 0.5 pixels). Ten orbits had corrections to the Da camera in excess of one pixel. While the main effect of the improved co-registration is on the Da camera, we note that 4 orbits had corrections in excess of 0.5 pixels to the Df camera. Wind retrievals are especially sensitive to the co-registration of the Bf and Ba cameras. These appeared well calibrated in general, but improvements were noted for at least two of these orbits.

The rms differences in the wind speeds and heights due to co-registration corrections can be summarized as follows:

across-track wind change	= 1.7 m/s
along-track wind change	= 5.9 m/s
total vector wind change	= 6.1 m/s
wind height change	= 550 m

Of these changes, about 1 m/s in the vector wind change can be attributed to detection of blunders in the stereo matching algorithm. By comparison, the effect of including the Da camera triplet in addition to the Df triplet had been noted earlier as contributing an rms change of about 2 m/s.

5. SUMMARY

The implementation of improved co-registration indicates a significant difference in the height-resolved cloud motion vectors obtained by MISR. The rms differences of 6 m/s are similar to the differences noted in the earlier GMAO study. Of course, this may be coincidental, and a further round of comparisons with the GMAO analysis is now planned to explore this further.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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