STATUS OF MISR CLOUD-MOTION WIND PRODUCT

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ABSTRACT

Near-simultaneous multi-angle imagery from the Multi-angle Imaging SpectroRadiometer (MISR) forms the basis of a unique method able to simultaneously retrieve cloud motion and height from a polar orbiter platform. The method is fully automated and determines the characteristic horizontal wind for a mesoscale domain of 70.4×70.4 km^2. Provided the co-registration of the multiangle views is accurate to a pixel, the theoretical retrieval uncertainty can be as small as ±3 ms^{-1} for wind and ±400 m for height.

In this paper, we give a brief summary of the retrieval scheme, demonstrating its capabilities with two examples. In addition, we discuss product validation efforts and suggest two possible improvements: (1) providing quality indicators for wind vectors, and, (2) increasing the spatial coverage of the retrievals.

1. Introduction

The Multi-angle Imaging SpectroRadiometer (MISR) was successfully launched on the Terra satellite on 19 December 1999 and has been continuously providing data since February 2000. The instrument's high spatial resolution and unique multiangle capability allow the simultaneous retrieval of cloud height and motion using a purely geometric stereoscopic technique (Horváth and Davies 2001a). Knowledge of the mesoscale horizontal cloud motion field is required in order to accurately compute high level MISR products, such as small scale cloud top height variations. Cloud motion retrievals, however, have performed better than expected and thus have been included in the operational product file as a separate field.

2. Retrieval method

2.1 Instrument overview

MISR is a pushbroom scanner that measures spectral radiances reflected in nine different directions and four spectral bands (446, 558, 672, and 866 nm). The nine different directions (0, ±26.1°, ±45.6°, ±60°, and ±70.5°) are labeled by their cameras, An, Af/Aa, Bf/Ba, Cf/Ca, and Df/Da, respectively. The signal can be resolved up to 14 bits, allowing a wide dynamic range to be measured, and aiding the stereo matching of subtle reflectivity patterns. The combination of instrument geometry and orbital characteristics (sun-synchronous, 705 km altitude, near polar orbit) allows each point within a 360 km-wide orbital swath to be observed from all nine directions within an interval of approximately

7 min. In the red spectral band, which is used for wind retrieval, the cross-track ground-projected field of view and sample spacing are 275 m for the off-nadir cameras and 250 m for the nadir camera. The instantaneous along-track field of view ranges from 214 m at nadir to 707 m at the most oblique angle (±70.5°). The along-track sampling remains at 275 m for all cameras.

2.2 Algorithm Description

The algorithm used for operational retrieval is described in detail, together with an error analysis, by Horváth and Davies (2001a). In summary, it uses a stereo matcher to match solar reflectivity patterns within a 70.4 km square mesoscale domain for three appropriate view angles (typically An, B and D cameras). A minimum of three near-simultaneous multiangle views is required because there is an ambiguity between along-track cloud motion and cloud height above the ground. The measurements are then solved for the wind and height of each match by performing a least squares fit. It is assumed that vertical cloud motion can be neglected and horizontal cloud motion is constant during the 7-min observing period. Because the individual results can be noisy, the velocity vectors within a mesoscale domain are sorted into a 2D histogram and the two most common average velocities are determined.

For stereo matching, two different techniques have been tested: the nested max (NM) and the multipoint matcher (M2) algorithms [see Diner et al. (1999) for a detailed description]. Operational wind retrievals employ NM only. It is a very efficient feature-based matcher that quickly matches relatively few features, typically 1% of all pixels within a mesoscale domain, with a fairly even spatial distribution. The M2 is an area-based matcher, which is used solely for research purposes. It is considerably slower than NM but has larger coverage (theoretically almost every pixel can be matched), and yields more accurate results. Neither technique, however, has an automated blunder detection and/or subpixel matching capability.

3. Retrieval Examples

3.1 High Level Clouds over the Southern Argentinean Coast

Figure 1 shows MISR wind retrievals for blocks 123 to 130 of path 227, orbit 6964. The data were obtained at 1347Z on 9 April 2001. Each block contains two rows with eight mesoscale domains in each row. The winds are overlaid on the nadir image and are color coded according to their height. Notice that there are no retrievals over the dark featureless ocean and that the “winds” over clear land are within the expected uncertainty of 3 ms^{-1}. The high level northwesterly flow, showing a north-south gradient in wind speed, is picked up nicely.

The fact that there is no residual motion over clear land indicates the high accuracy of the automated co-registration of the multiangle views. In fact, the wind retrieval is so sensitive to navigation errors that it can be used to check the accuracy of, and calculate a correction to the image co-registration (Moroney et al. 2002). For data processed with version 4 of the Camera Geometric Model (prior to August 2000), the more oblique cameras (D and C) were significantly misregistered by up to 15 pixels due to a rotation of the swath. The situation improved dramatically once version 5 (and later 6) of the camera model went into production. The observed rotation of the swath in version 4 has been solved, and the vast majority of the data now has a misregistration error of 1 pixel or less.

3.2 Mature Cyclone in the Northeastern Pacific

The novelty of the MISR technique is to assign near-continuous geometric heights to the retrieved motion. This is demonstrated in Figure 2, where cloud top heights cover a large range. The data,

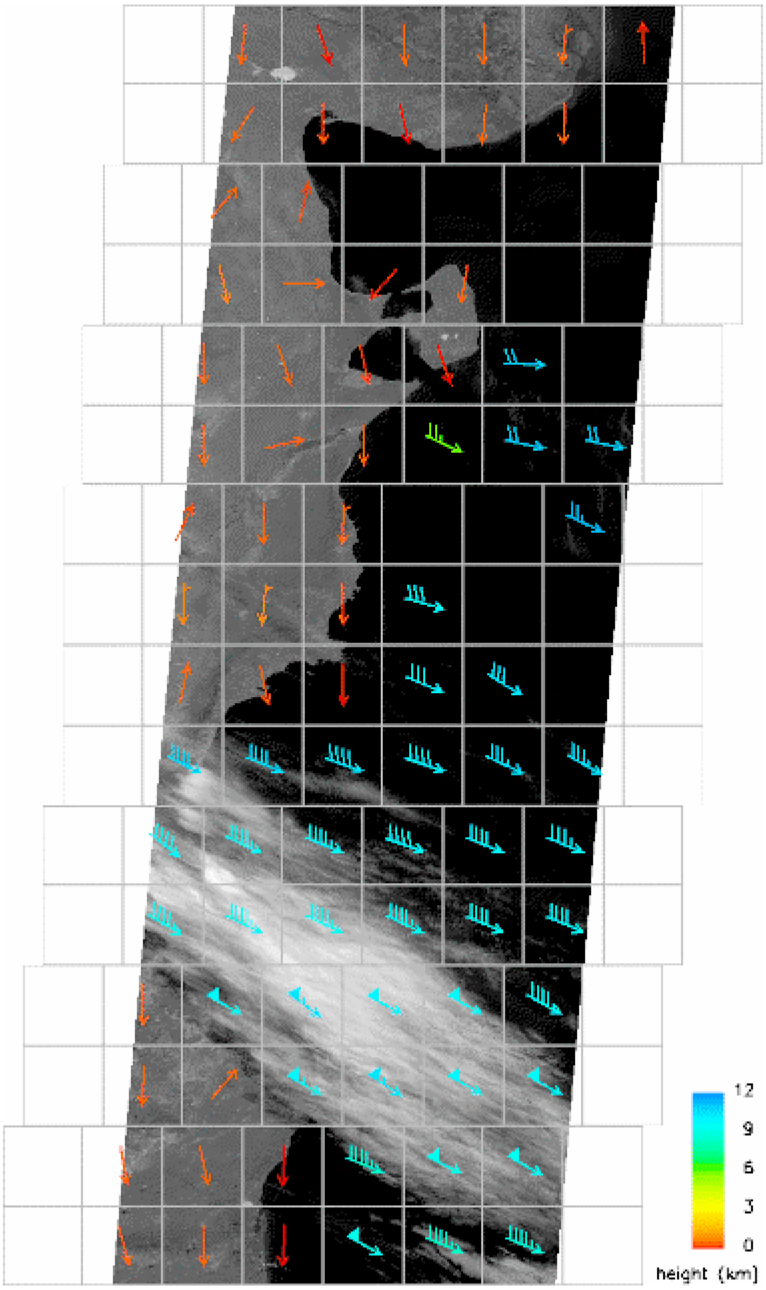

Figure 1. MISR cloud-motion winds for blocks 123 to 130 of path 227, orbit 6964. Winds are given in ms^{-1} and are color coded according to their height.

showing a mature extratropical cyclone off the west coast of North America, correspond to blocks 50 to 70 of path 54, orbit 1900, and were obtained at 2015Z on 26 April 2000. Notice that many different colors and shades can be discerned indicating a relatively fine vertical resolution. Obviously erroneous wind vectors were manually removed (for quality control issues see section 5.1).

The above results were compared to the corresponding GOES-W cloud motion winds obtained from NOAA/NESDIS (Horváth and Davies 2001b). In general, MISR and GOES were in good agreement in terms of both wind speed and direction. Comparison of the pressure heights revealed a negative GOES pressure bias for low-level winds, which was most likely due to a reduced brightness temperature caused by thin cirrus. The rms height difference between the two data sets was approximately 1 km.

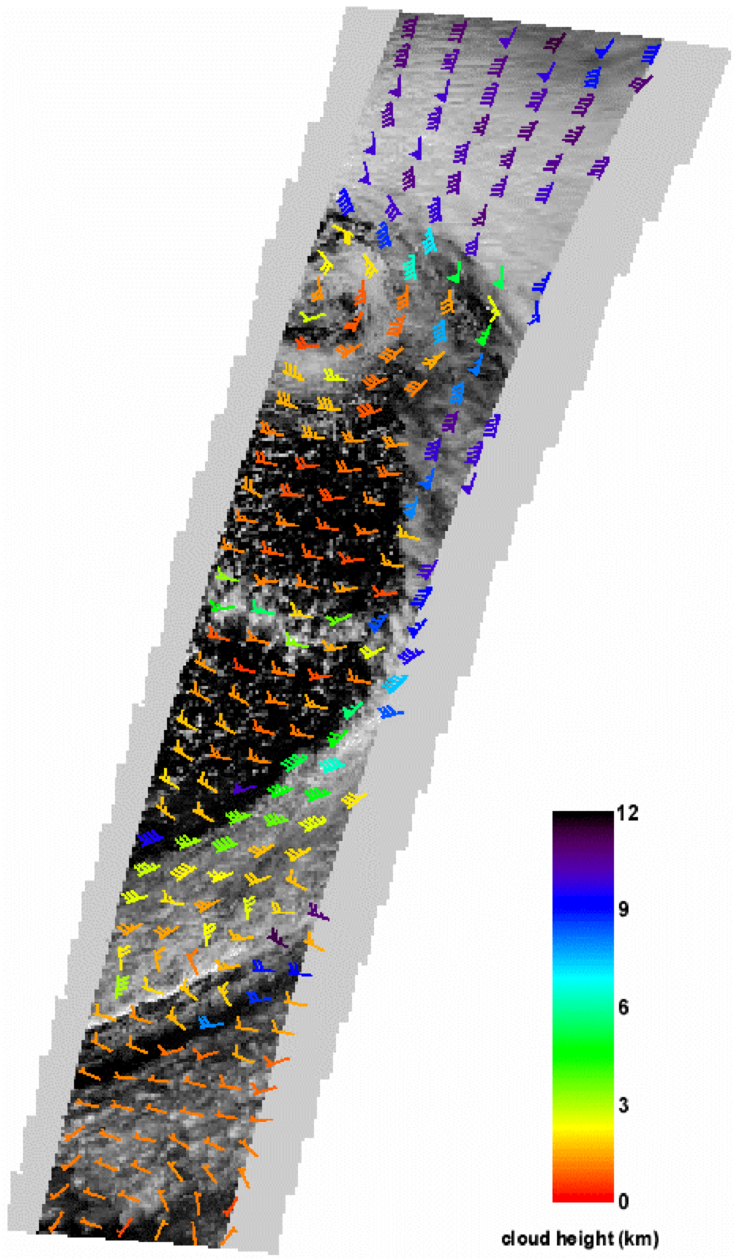

Figure 2. MISR cloud-motion winds for blocks 50 to 70 of path 54, orbit 1900. Winds are given in ms^{-1} and are color coded according to their height.

4. Validation Efforts

The MISR wind product has not been thoroughly validated yet. The prelaunch uncertainty estimate was 3 ms^{-1} for wind and 400 m for height. When applied to clear-sky surface data the algorithm was able to retrieve the zero wind and height of topography with at least the above accuracy. Independent tests are now being conducted to see whether this expected accuracy is also achieved by the cloud motion retrievals.

A systematic geophysical validation process is currently under way at NASA's Data Assimilation Office (DAO). MISR winds are evaluated against geostationary cloud track winds, rawinsondes, and aircraft measurements, and their impact on short and long term forecasts is also investigated (see Donald Frank's paper in this volume).

A separate comparison and validation effort is being undertaken by ETH, Institute of Geodesy and Photogrammetry, as part of the EU-project CLOUDMAP2 (Cloudmap2 2002). A unique dataset of cloud top heights and cloud-motion winds from coincident MISR, ATSR2, METEOSAT-6 Rapid Scan, and radiosounding measurements, as well as the regional-scale NWP model output data of MeteoSwiss are being compiled for an August 2000 case study over Switzerland. This project also evaluates the MISR stereo matching strategy with the help of a robust, high-precision stereo algorithm based on Least-Squares-Matching (Grün 1985). Preliminary results suggest that the use of the most oblique D cameras is not necessarily the best solution for all cloud situations. The matching statistics of the various MISR camera combinations indicate that the correspondence between non-adjacent cameras can be quite tricky, because the cloud objects have changed their shapes or even disappeared in the delay between the two views. While the matching success rate is about 95% for adjacent cameras, it decreases to about 78% between the nadir and the most oblique D cameras (Seiz and Baltsavias 2001). Therefore, in multi-layered or fast moving/changing cloud situations, the use of a more compact triplet (e.g. An-Af-Cf) should be evaluated.

5. Current and Future Improvements

5.1 Quality Control

One of the main factors limiting the usefulness of MISR cloud-motion winds is the lack of an automated quality assessment (QA) scheme. Although the wind retrieval itself is fully automated, erroneous wind vectors have to be removed manually. Currently, a major effort is directed towards the implementation of wind quality assessment flags in the stereo product (Moroney 2002). Quality indicators will be generated both on the swath-level and on the domain-level. Swath-level flags will evaluate the accuracy of image co-registration, while domain-level flags will assess the quality of each individual wind vector.

Swath-level parameters. Throughout processing, histograms will be gathered of the misregistration retrievals for each cross-track domain and summaries of these histograms will be reported at the swath-level. Additionally, the magnitude and direction of the individual wind vectors and their domain-to-domain differences will be histogrammed for each cross-track domain and summaries again reported in the swath QA. Both of these parameters are designed to reveal a swath-rotation problem. The first one makes use of misregistration retrievals over clear land. In the absence of clear-sky land, the rotation problem may be picked up by looking for a bias in the wind retrievals corresponding to domain number. This is based on the observation that the earlier rotation of the swath also showed itself through a systematic change in the wind vectors from the left edge of the swath to the right.

Domain-level parameters. Currently, three methods are under consideration for generating the domain-level wind QA flags. They are listed in descending order of their perceived importance and usefulness. First, the disparities (parallaxes) that are used in the wind retrievals can be looked at to make sure that they form a nice clear peak. If the stereo matching fails to find a strong signal and only returns noise for the disparities, the winds are going to be of very poor quality. The shape of the wind histogram will also be looked at in this method. Second, the jumps in the stereo heights across the domain boundaries can be looked at. Third, the deviation of each wind vector from an “average” of its neighbors can also be calculated. This last technique is assigned the smallest weight because of several difficulties inherent in the algorithm, such as the scarcity of points to work with, and the problem in differentiating between a wind that is different from its neighbors due to retrieval problems or an actual change in the cloud layer.

5.2 Higher Density Winds

Another factor limiting the practical usefulness of MISR winds is their relative scarcity. Operationally, the characteristic horizontal wind is calculated on a scale of 70 km. Due to the narrow MISR swath width, this results in merely 6-7 wind vectors across the swath enabling only a relatively crude representation of the atmospheric flow field. A large domain is also more likely to contain multiple cloud layers, which may pose difficulties for the retrieval algorithm. Therefore, winds would be desired on a finer scale

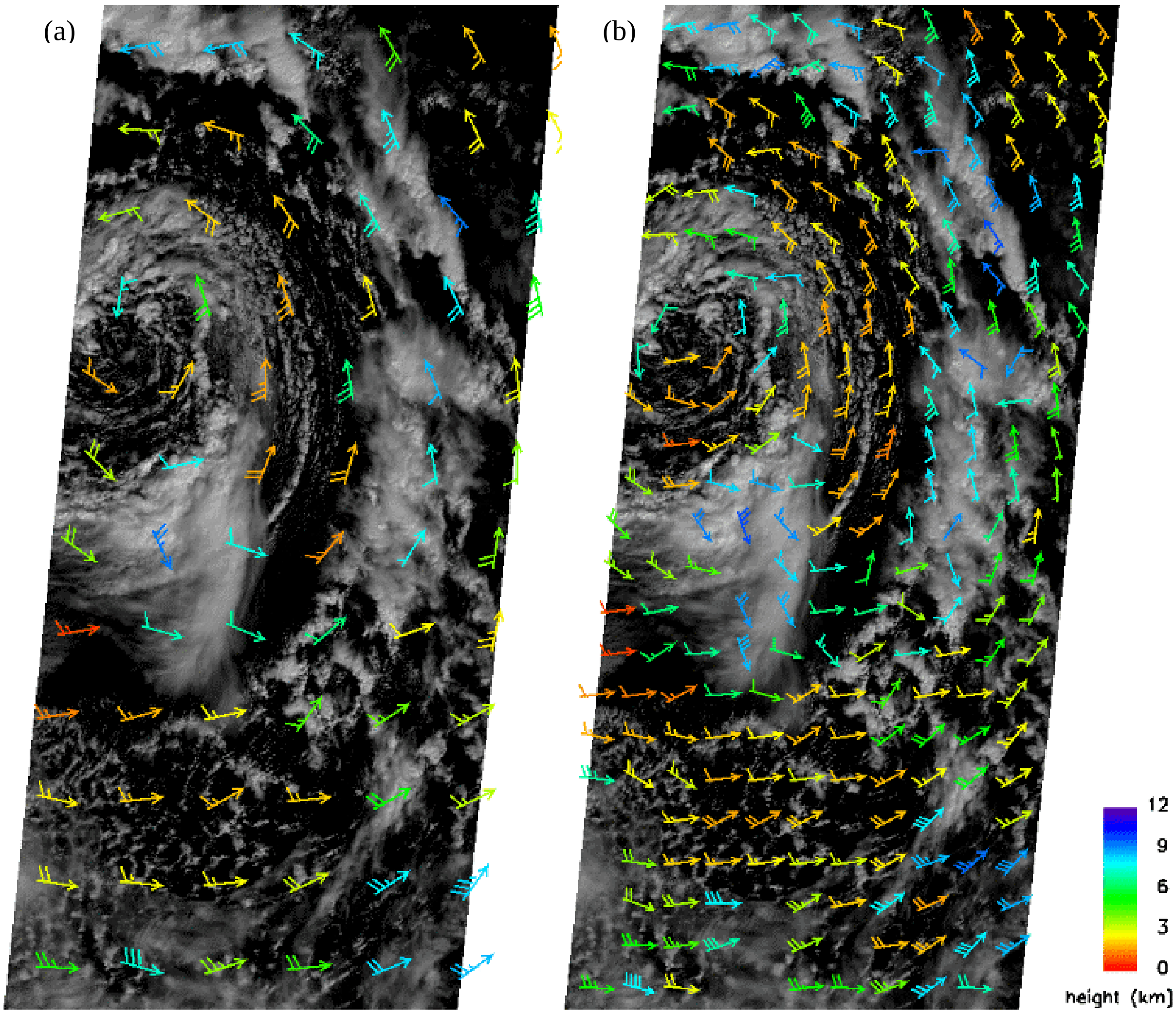

Figure 3. MISR cloud-motion winds for blocks 55 to 60 of path 227, orbit 6964: (a) standard 70 km resolution, and (b) enhanced 35 km resolution. Winds are given in ms^{-1} and are color coded according to their height.

The feasibility of higher density winds is demonstrated in Figure 3. The data, obtained at 1347Z on 9 April 2001, correspond to blocks 55 to 60 of path 227, orbit 6964 and show a mature cyclone in the North Atlantic. Figure 3a depicts the associated flow field retrieved on a 70 km scale, while Figure 3b shows that on a 35 km scale. The higher density winds were generated by dividing a MISR domain into four equal subdomains and by running the retrieval algorithm separately on each of these subdomains. Clearly, the circulation is better resolved especially around the surface low. It is noted here that the results shown in Figure 3b were calculated with the M2 area-based stereo matcher. The operational NM feature-based matcher does not provide enough targets to be able to pick up a clear signal at 35 km resolution. The M2 yields a much larger number of matches but this comes at the price of significantly increased computing time.

6. Summary

As recognized earlier by Horváth and Davies (2001b), the demonstration that accurate, height-resolved cloud winds could be obtained from MISR's near simultaneous multiangle measurements of reflected solar radiance raises the question whether this might have future operational significance. Height-resolved winds are likely to have more impact as inputs to NWP than those from coarsely categorized (low, middle or high) cloud levels. The wind retrieval technique may also be applied equally well to all latitudes from pole to pole. It is aided by the measurement characteristics of MISR, especially its spatial resolution and (14-bit) dynamic range, which facilitate feature matching from the different views. To explore the operational potential more seriously, we have successfully tested the retrieval technique at higher spatial resolution, and are currently implementing a number of objective tests to provide quality assurance.

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