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Earth Observing System

Multi-angle
Imaging
Spectro-
Radiometer

MISR Cloud Motion Vector Product Algorithm Theoretical Basis

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Multi-angle Imaging SpectroRadiometer (MISR)

Cloud Motion Vector Product Algorithm Theoretical Basis

Approval:

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MISR Principal Investigator

The MISR web site should be consulted to determine the latest released version of this document (http://www-misr.jpl.nasa.gov).
Approval signatures are on file with the MISR Project.

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GLOSSARY OF ACRONYMS

A

ASDC (Atmospheric Sciences Data Center)
ATB (Algorithm Theoretical Basis)

C

CCD (Charge-Coupled Device)
CF (Climate and Forecast)
CMV (Cloud Motion Vector)
CMVp (Cloud Motion Vector product)

E

ECI (Earth Centered Intertial)
ECR (Earth Centered Rotational)
EOS (Earth Observing System)

G

GDQI (Geometric Data Quality Indicator)
GOES (Geostationary Operational Environmental Satellite)

I

IFOV (Instantaneous Field of View)

L

L2TC (Level 2 Top-of-Atmosphere/Cloud)
LaRC (Langley Research Center)

M

MISR (Multi-angle Imaging SpectroRadiometer)
MODIS (Moderate Resolution Imaging Spectroradiometer)

N

NetCDF (Network Common Data Form)

P

PCMDI (Program for Climate Model Diagnosis and Intercomparison

PGS (Product Generator System)

S

SOM (Space Oblique Mercator)

W

WGS84 (World Geodetic System of 1984)

1 INTRODUCTION

1.1 PURPOSE

The Multi-angle Imaging SpectroRadiometer (MISR) Cloud Motion Vector product (CMVp) contains retrievals of cloud motion determined by geometrically triangulating the position and motion of cloud features observed by MISR from multiple perspectives and times during the ~7 minute overpass of the Terra platform over each cloud scene. Estimates of cloud motion, here labeled cloud motion vectors (CMVs), are a valuable proxy observation of the horizontal atmospheric wind field at the retrieved altitude of the cloud. MISR CMVs have been and continue to be operationally produced as part of the publicly available Level 2 Cloud product, whose record dates from February 2000 to the present. The CMV product provides users a complete global list of the highest quality CMVs extracted from the standard Level 2 Cloud product, distributed as monthly, seasonal, and annual NetCDF files that are neither gridded nor averaged. The annual files, the largest of these, are a manageable 160MB, facilitating scientific applications requiring CMV information spanning multiple months or years. The parameters encoded within each MISR CMV and recorded by the CMVp are summarized in Table 1. Distributed NetCDF files follow Climate and Forecast (CF) conventions established by the Program for Climate Model Diagnosis and Intercomparison (PCMDI).

The intent of this document is to identify and describe sources of CMVp input data required for parameter retrievals, provide the physical theory and mathematical background underlying parameter derivations, include implementation details, and describe key assumptions and limitations of the adopted approach. This document is used by the MISR Science Data System Team to establish requirements and functionality of the data processing software.

Table 1: CMV Parameters in the Cloud Motion Vector Product

CMV parameters		
Parameter name	**Units**	**Description**
Time	s	Specified as "seconds since 1970-01-01, 00:00:00 UTC"
Latitude	degrees	Latitude of center of 17.6 km SOM grid cell of retrieval
Longitude	degrees	Longitude of center of 17.6 km SOM grid cell of retrieval
CloudMotionEast	ms^{-1}	Apparent eastward motion of cloud features
CloudMotionNorth	ms^{-1}	Apparent northward motion of cloud features
CloudTopAltitude	m	Apparent altitude of cloud features relative to Earth ellipsoid
QualityIndicator	-	Integer between 0 and 100 estimating retrieval quality

InstrumentHeading	degrees	Earth-relative heading of Terra satellite at retrieval time, which influences retrieval error characteristics (degrees clockwise from North)
Orbit	-	Terra orbit in which retrieval occurred
Block	-	SOM grid block number of retrieval grid cell
DomainIndex	-	SOM grid index within block of retrieval grid cell
Year	-	Year in which retrieval occurred (UTC)
DayOfYear	Days	Julian day of year when retrieval occurred (UTC)
HourOfDay	Hours	Hour of the day when retrieval occurred (UTC)

1.2 SCOPE

This document covers the algorithm theoretical basis for the CMVp that will be routinely generated at the Langley Research Center (LaRC) Atmospheric Sciences Data Center (ASDC).

Chapter 1 describes the purpose and scope of the document. Chapter 2 provides a brief overview. The processing concept and algorithm description are presented in Chapter 3. Chapter 4 summarizes assumptions and limitations. Literature references are indicated by a number in italicized square brackets, e.g.,*[1]*.

1.3 MISR DOCUMENTS

Reference to MISR Project Documents is indicated by a number in italicized square brackets as follows, e.g.,*[M-1]*. The MISR web site (http://www-misr.jpl.nasa.gov) should be consulted to determine the latest released version of each of these documents.

[M-1] Experiment Overview, JPL D-13407, Rev. A.

[M-2] Data Product Description, JPL D-11103.

[M-3] Level 1 Georectification and Registration Algorithm Theoretical Basis, JPL D-11532, Rev. D.

[M-4] Level 1 Ancillary Geographic Product Algorithm Theoretical Basis, JPL D-13400, Rev. A.

[M-5] Level 2 Cloud Product Algorithm Theoretical Basis, JPL D-73327, Rev. A.

1.4 REVISIONS

The original version of this document was released July 23, 2010. This version is Revision B. Revision B describes the second version of the CMV product software. Whereas the first product version used the MISR Level 2 Top-of-Atmosphere/Cloud (L2TC) Stereo product as input, the second version uses the newer MISR Level 2 Cloud product.

2 EXPERIMENT OVERVIEW

2.1 OBJECTIVES OF MISR CLOUD MOTION VECTOR PRODUCT

The operational MISR Level 2 Cloud product is available from February 2000 onward and provides altitude-resolved, cloud motion vectors representing proxy wind observations extending nearly pole to pole on the sunlit side of the Earth *[M-5]*. Unlike CMVs produced by other satellite systems, such as the Geostationary Operational Environmental Satellites (GOES) and the Moderate Resolution Imaging Spectroradiometer (MODIS), MISR's altitude assignments do not rely on knowledge of the temperature structure of the atmosphere, and the retrieved winds are controlled for quality through redundant checking, without reliance on forecast model guidance.

2.2 INSTRUMENT CHARACTERISTICS

The MISR instrument consists of nine pushbroom cameras. It obtains global coverage every nine days, and flies in a 705-km descending polar orbit on the EOS-Terra platform. The cameras are arranged with one camera pointing toward the nadir (designated An), one bank of four cameras pointing in the forward direction (designated Af, Bf, Cf, and Df in order of increasing off-nadir angle), and one bank of four cameras pointing in the aftward direction (using the same convention but designated Aa, Ba, Ca, and Da). Images are acquired with nominal view zenith angles, relative to the Earth surface reference ellipsoid, of 0°, 26.1°, 45.6°, 60.0°, and 70.5° for An, Af/Aa, Bf/Ba, Cf/Ca, and Df/Da, respectively. Each camera uses four Charge-Coupled Device (CCD) line arrays in a single focal plane. The line arrays consist of 1504 photoactive pixels plus 16 light-shielded pixels per array. Each line array is filtered to provide one of four MISR spectral bands. The spectral band shapes are approximately Gaussian and centered at 446, 558, 672, and 866 nm.

MISR contains 36 parallel signal chains corresponding to the four spectral bands in each of the nine cameras. The zonal overlap swath width of the MISR imaging data (that is, the swath seen in common by all nine cameras along a line of constant latitude) is 380 km, which provides global multi-angle coverage of the entire Earth in 9 days at the equator, and 2 days near the poles. The cross-track instantaneous field of view (IFOV) and sample spacing of each pixel is 275 m for all of the off-nadir cameras, and 250 m for the nadir camera. Along-track IFOVs depend on view zenith angle, ranging from 214 m in the nadir to 707 m at the most oblique angle. Sample spacing in the along-track direction is 275 m in all cameras.

Additional background on the instrument design is provided in *[M-1]*.

2.3 MISR CLOUD MOTION VECTOR PRODUCT STRATEGY

The MISR CMVp is designed to provide conveniently organized, readily accessible, high quality retrievals of cloud motion due to advection. The CMVp does not contain any new retrievals of cloud motion, but instead reorganizes the information already available in the MISR Level 2 Cloud product. The CMVp notably excludes retrievals from that product whose retrieval parameters suggest poor quality and whose altitude and speed are unlikely to be associated with true cloud advection, as described below. These exclusions allow CMVp users to more readily employ MISR CMV data as a source of proxy wind observations. They also allow the retrievals to be conveniently packaged and distributed as monthly, seasonal, and annual NetCDF files of manageable size.

A few CMVp parameters are not direct corollaries of parameters contained in the MISR Level 2 Cloud product. They have been included to provide more convenient geolocation and to allow more detailed analysis of cloud motion retrieval error characteristics:

- *Latitude*: the geographic latitude of the retrieval 17.6 km × 17.6 km SOM domain center

- *Longitude*: the geographic longitude of the retrieval 17.6 km × 17.6 km SOM domain center

- *InstrumentHeading*: the heading of the ground track of the MISR instrument at time of CMV retrieval

The *InstrumentHeading* is relevant to the expected error of the CMV retrieval because the component of cloud motion along the instrument ground track is less accurately retrieved than the component across the ground track.

ALGORITHM DESCRIPTION

2.4 PROCESSING OUTLINE

Routine in-flight standard processing at the LaRC ASDC, to generate the MISR CMVp occurs in six stages, is described below.

(1) Reorganize month of Level 2 Cloud input into a list of retrievals

(2) Remove retrievals not associated with advection

(3) Remove low quality retrievals

(4) Concatenate monthly products into seasonal CMVp product

(5) Concatenate seasonal products into annual CMVp product

Processing flow concepts are shown diagrammatically throughout the document. The convention for the various elements displayed in these diagrams is shown in Figure 1.

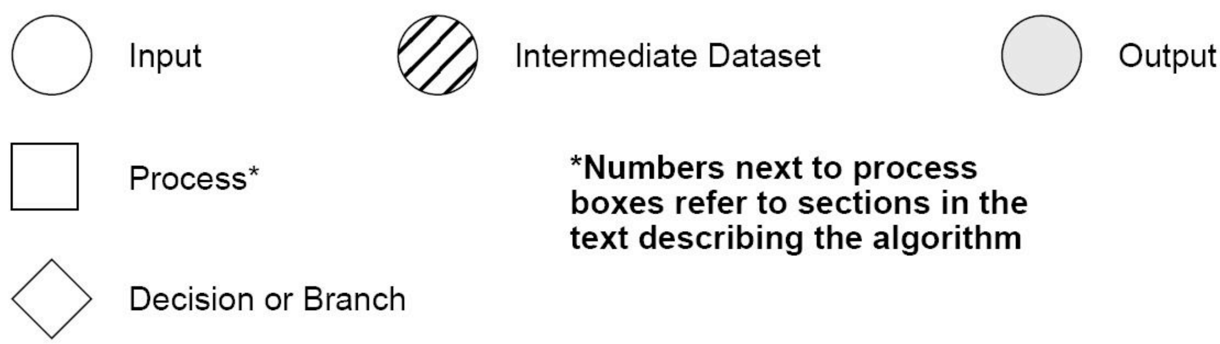

Figure 1. Conventions used in processing flow diagrams

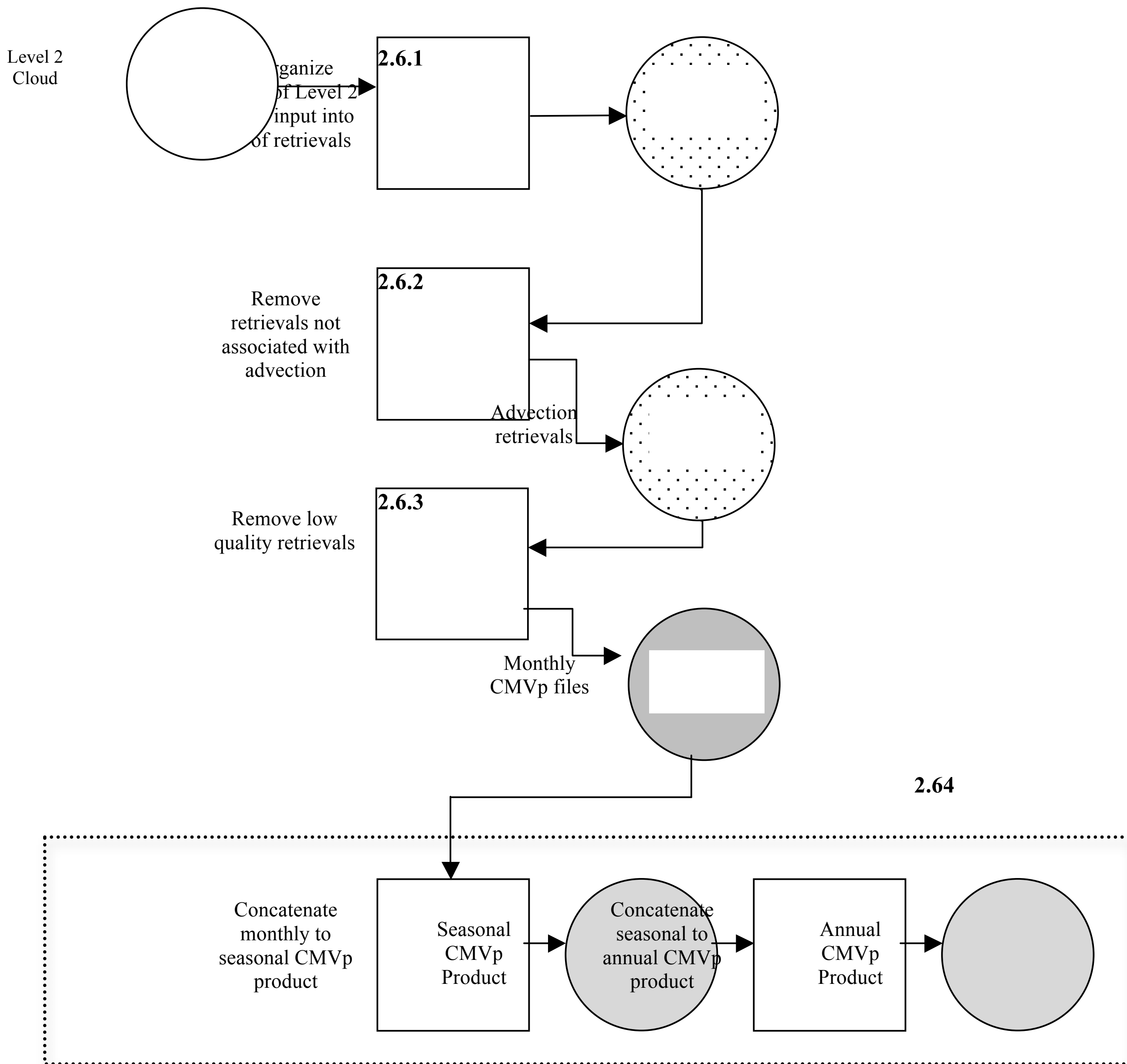

Figure 2. CMVp processing overview

2.5 ALGORITHM INPUT

The required inputs for the CMVp come from MISR and non-MISR sources and are summarized individually in the following paragraphs.

2.5.1 MISR data

Required inputs for the CMVp obtained from other MISR data products are summarized in Table 2. Further information on each of the inputs is provided below.

Table 2: CMVp inputs

Input data	Source of data	Reference
CloudTopHeightOfMotion	Level 2 Cloud product	*[M-5]*
CloudMotionEastward	Level 2 Cloud product	*[M-5]*
CloudMotionNorthward	Level 2 Cloud product	*[M-5]*
MotionDerivedCloudMask	Level 2 Cloud product	*[M-5]*
MotionQualityIndicator	Level 2 Cloud product	*[M-5]*
BlockCenterTime	Level 2 Cloud product	*[M-5]*

2.5.1.1 Level 2 Cloud inputs

Level 2 Cloud inputs are derived for each 17.6 km SOM grid retrieval domain by triangulating the mean altitude and horizontal motion of clusters of identifiable features appearing in L1B2 ellipsoid projected 672 nm (red band) camera images captured at a nominal 275 m resolution over a ~7 minute time span. Each parameter is then obtained from a synthesis of redundant determinations operating on the forward camera triplet (An, Bf, and Df) and the aft camera triplet (An, Ba, and Da).

The *Orbit_QA* input is a flag calculated during MISR L1B2 processing and included within the Level 2 Cloud product. Orbits for which the georectification and ellipsoid projection of raw MISR camera measurement have proceeded successfully report an *Orbit_QA* value of 0. Otherwise, the value of *Orbit_QA* is non-zero.. See *[M-4]*.

The *Orbit_qa_winds* input is a flag intended to indicate potential georectification issues that may not have been captured by the *Orbit_QA* flag. It is set to a non-zero value when the absolute value of the along-track, cross-track or height component of the forward-aft differences exceeds pre-determined thresholds. See *[M-5]*.

2.6 THEORETICAL DESCRIPTION:

CMVp processing reorganizes cloud motion vector information contained within per-orbit Level 2 Cloud files into monthly collections of CMV information (see 2.6.1), removes motion vectors not likely to be associated with advection (see 2.6.2), assigns quality indicator values to each motion vector, and removes low quality vectors (see 2.6.3). Monthly datasets are then concatenated into seasonal and annual products (see 2.6.4).

2.6.1 Reorganize a month of Level 2 Cloud input into a list of retrievals

The purpose of this stage is to read, reorganize, and accumulate raw CMVp parameters from the Level 2 Cloud input data associated with a given day.

2.6.1.1 Detailed description of the algorithm

CMVp product parameters are determined for each per-orbit Level 2 Cloud file and stored as a list of sets of parameter values transferred directly, without modification, from the Level 2 Cloud inputs. Each set of parameter values constitutes a single "retrieval," and each day of data consists of a list of retrievals collected from multiple Level 2 Cloud files. For orbits spanning a time period crossing a day boundary, only the retrievals whose calculated *Time* parameter is within the specific UTC day are included. All stored retrievals include their associated orbit number, SOM block, and SOM grid index, recorded in the *Orbit*, *Block*, and *DomainIndex* parameters. This allows users to relate the retrievals to the original Level 2 Cloud file from which the retrievals were extracted.

Table 3: Directly translated Level 2 Cloud fields

CMV product parameter	Level 2 Cloud Inputs
CloudMotionEast	CloudMotionEast
CloudMotionNorth	CloudMotionNorth
CloudTopAltitude	CloudTopHeightOfMotion
QualityIndicator	MotionQualityIndicator

The *Time* parameter is derived from the *BlockCenterTime* input provided at block resolution (140.8 km × 563.2 km) within the Level 2 Cloud product. Time values at 17.6 km domain centers are linearly interpolated in the SOM x-dimension (along track direction) from *BlockCenterTime* input values, yielding an effective precision of ~15 seconds. The *Year*, *DayOfYear*, and *HourOfDay* are readily determined from *Time*.

The *Latitude* and *Longitude* CMVp parameters are derived from the L2 SOM grid indices using the MISR Toolkit.

The *InstrumentHeading* CMVp parameter is determined using the PGS Toolkit call *PGS_EPH_EphemAttit*. Given the CMVp parameter *Time*, this returns the velocity vector for the Terra platform in ECI coordinates. Using CMVp parameters, *Latitude* and *Longitude*, this vector is transformed into geographic coordinates by transformations from ECI to ECR to geographic coordinates, following mathematics detailed in *[M-5]*. The *InstrumentHeading* value (λ) in degrees is then a simple function of the eastward (u_{Terra}) and northward (v_{Terra}) velocity vector components:

$$\lambda = 90 - 2 \cdot \arctan\left(\frac{v_{Terra}}{\left(\sqrt{u_{Terra}{}^{2} + v_{Terra}{}^{2}} \right) + u_{Terra}} \right) \quad (1)$$

2.6.2 Remove retrievals that are not associated with cloud advection

The purpose of this stage is to screen retrievals identified by Level 2 Cloud algorithms as unlikely to be associated with actual cloud motion. The Level 2 Cloud product includes the *MotionDerivedCloudMask* flag that differentiates between features associated with terrain or orographic clouds and features associated with advecting clouds. Only those CMV specified as *High Confidence Cloud* are included in the CMVp.

2.6.3 Remove low quality retrievals

The purpose of this stage is to exclude low quality CMV within the Level 2 Cloud product from the CMVp. Low quality CMV are identified and excluded by low values of the Level 2 Cloud flag *MotionQualityIndicator* or by large wind speeds that might be spurious.

The CMV product excludes CMV whose *MotionQualityIndicator* does not exceed $QI_{THRESHOLD}$ = 50. The *MotionQualityIndicator* specifies a numeric estimator of quality (from 1 to 100) based upon two metrics: (1) agreement between redundant determinations of cloud motion altitude, eastward velocity, and northward velocity retrieved independently from the forward (An, Bf, and Df) and aft (An, Ba, and Da) camera triplets; and (2) agreement between CMV in one grid cell relative to CMV in neighboring grid cells.

The CMV product excludes Level 2 Cloud CMV with speeds greater than $W_{THRESHOLD}=50ms^{-1}$. These retrievals are not excluded because they are inaccurate, but because they are subject to sampling bias. The ability of Level 2 Cloud algorithms to retrieve CMV beyond this speed is dependent on the heading of the cloud motion relative to the heading of the MISR instrument.

2.6.4 Concatenate monthly into seasonal and annual CMVp products

Seasonal CMVp files contain lists of CMV retrievals for three month periods: winter (December of previous year, January, February), spring (March, April, May), summer (June, July, August), and fall (September, October, and November). These files are generated by concatenating CMV lists from three associated monthly CMVp files into one larger list.

Annual CMVp files contain lists of cloud motion retrievals for twelve month periods extending from December of the previous year through November of the given year. These files are generated by concatenating CMV lists from four associated seasonal CMVp files into one larger list.

No averaging of retrievals is performed during this stage.

2.7 ALGORITHM VALIDATION

Evaluation of the Level 2 Cloud product used as input to the CMVp can be found at http://eosweb.larc.nasa.gov/PRODOCS/misr/Quality_Summaries/misr_qual_stmts.html.

3 ASSUMPTIONS AND LIMITATIONS

3.1 ASSUMPTIONS

The following assumptions are made when deriving CMV retrievals within the CMVp:

(1) Image features appearing to move or exist above the terrain altitude are labeled as clouds, but may represent various phenomena including, for example, optically thick aerosol plumes.

(2) Vertical cloud motions are ignored for the purposes of making wind displacement corrections. This may affect the accuracy of the along-track component of cloud motion estimates in situations where updraft speeds are very large.

(3) Horizontal wind is assumed constant for a given altitude over distances of 17.6 km. This may affect the accuracy of cloud motion estimates where the horizontal wind has significant variance at finer spatial scales.

(4) Standard nomenclature defines the altitude of each cloud motion retrieval as the "top" of the cloud, but retrieval altitude may be lower for optically thin, geometrically thick clouds.

(5) Collocated forward and aft cloud motion retrieval parameter estimates are assumed to constitute effectively independent measurements.

3.2 LIMITATIONS

The following limitations apply to the CMV retrievals within the CMVp:

(1) Despite screening, a number of CMV retrievals may be associated with terrain rather than cloud, yielding a low speed bias near the surface.

(2) Despite screening, a number of CMV retrievals may be associated with orographic clouds whose apparent motion is not due to advection. These cloud motion vectors are unlikely to be representative of the wind field.

(3) CMV retrievals are constrained to speeds below $W_{THRESHOLD}$=50ms^{-1}.

(4) Cloud motion due to advection may have a low speed bias relative to wind and may therefore not represent an accurate proxy in certain situations. It is difficult to imagine a situation in which a cloud moves faster than the surrounding air. In contrast, the surrounding air can clearly move faster than the cloud.

(5) Motion associated with true advection of actual clouds, particularly near the surface, may be screened inappropriately, leading to a potential bias in the wind climatology in the opposite sense to (3) above. The relative contributions of these opposing effects have not been quantified.

(6) The position and motion of clouds, having optical depth nominally less than 0.3 or lacking distinguishable texture, is unlikely to be detected by the Level 2 Cloud algorithm. This was a documented limitation of the L2TC Stereo product

[2].

4 REFERENCES

[1] Atlas, R. (1997), Atmospheric observations and experiments to assess their usefulness in data assimilation, *J. Meteorol. Soc. Japan, 75*, 111–130.

[2] Marchand, R. T., T. P. Ackerman, and C. Moroney (2007), An assessment of Multiangle Imaging Spectroradiometer (MISR) stereo-derived cloud top heights and cloud top winds using ground-based radar, lidar, and microwave radiometers, *J. Geophysical Res., 112*, D06204, doi:10.1029/2006JD007091.

5 APPENDIX

5.1 Constant thresholds

Table 4: Threshold values

Threshold name	Value	Description
$QI_{THRESHOLD}$	50	Minimum *MotionQualityIndicator* value for CMV to be included in CMV product
$W_{THRESHOLD}$	50 ms^{-1}	Maximum CMV speed to be included in CMV product