STEREO RETRIEVALS OF CLOUD AND SMOKE WINDS AND HEIGHTS FROM EO PLATFORMS: PAST, PRESENT AND FUTURE

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Abstract

The justification for the use of stereo motion vectors (SMVs) derived from instruments such as the NASA MISR (Multiangle Imaging Spectro-Radiometer), ESA AATSR (Advanced Along Track Scanning Radiometer) and future Sentinel-3 SLSTR is given. Examples are shown of cloud-top heights and winds (Stereo Motion Vectors, SMVs) using the M2/3 stereo matching system described by (Muller et al., 2002) and its modification, M4, for AATSR (Muller et al., 2007). Examples are also shown of the application of a modified scheme, M6 for smoke-plume injection height (Fisher et al., 2012) and its validation using CALIPSO. A new algorithm for better discrimination of clouds over snow/ice based on the census algorithm is also described (Fisher and Muller, 2012) along with results applied to wind retrieval over Greenland from overlapping AATSR data.

A description of the proposed ESA WINDS mission using the MISRlite instrument concept (Muller et al., 2010) is given along with results on an evaluation of systemic biases using a triple collocation technique. This indicates that current MISR data have similar error characteristics to existing AMVs but superior quality along-track performance. As data assimilation of Doppler Lidar winds is unidirectional, this suggests that only small modifications to the DA schemes developed for Doppler Lidars would be required for ingestion of MISR-like winds to NWP models in the future.

CONTEXT AND INTRODUCTION

Presently, knowledge of the 3D wind field over large parts of the tropics, near-polar and major oceans is incomplete. This leads to major difficulties both in studying key processes in the coupled climate system and in further improving operational numerical weather forecast systems towards mesoscale dynamical processes. Progress in climate modelling is intimately linked to progress in numerical weather prediction (NWP), since the synthesis of the global observing system through NWP reanalyses has become an important vehicle for climate modelling.

EUMETSAT Post-EPS planning for 2018-2033 and the US NRC Earth Sciences Decadal Survey for 2010-2025 noted in 2005 that "Tropospheric winds are the number one unmet measurement objective for improving weather forecasts...Reliable global analyses of three-dimensional tropospheric winds are needed to improve the depiction of atmospheric dynamics, transport of air pollution, and climate processes." IWW10 also recommended that We strongly encourage renewed efforts to evaluate MISR winds in NWP and support proposed initiatives to develop MISR follow-ons which consider the timeliness and coverage requirements of NWP.

Most of our knowledge of the 3D wind-field comes from radiosondes (primarily in the northern hemisphere over land), from cloud motion vectors on geostationary satellites (mostly from thermal IR channels and restricted to the range ±55º of latitude). Such systems suffer from poor height assignment, especially from MODIS thermal (water vapour) channels over polar regions (≥70º of latitude). In addition, for thermal-channel derived AMVs, pressure (height) assignment relies on the use of NWP models to provide brightness temperature look-ups of cloud-top pressure (CTP) as well as assumptions of cloud-top emissivities. However, GEO-AMVs have been shown to have positive impacts on NWP including tropical cyclone forecasts (Berger et al., 2011; Langland et al., 2009; Rohn et al., 2001). Polar winds from MODIS and AVHRR (Dworak and Key, 2009; Key et al., 2003) have also been shown to have positive impacts on winds including on ERA-40 as well as have positive
effects on lower latitude weather systems (Santek, 2010). However, there are gaps in the coverage, especially of the region from 55-70º of latitude where many mid-latitude storms originate and the sampling of low-level clouds, which are important to better represent trade wind Cumulus, as well as improve representation of entrainment processes in marine cloud systems.

In contrast, stereo photogrammetric retrievals of cloud-top heights do not depend on any external information such as Objective Analysis (OA) fields. They were first demonstrated with geostationary images from the GOES-East and West satellites (Hasler, 1981; Hasler and Morris, 1986; Hasler et al., 1998; Rodgers et al., 1983) and proposed for use with the ATSR (Along Track Scanning Radiometer) instrument onboard the European ERS-1 satellite in 1985 (Lorenz, 1985). They were first demonstrated with ATSR data by (Prata and Turner, 1997; Shin and Pollard, 1996). The MISR (Multi-angle Imaging SpectroRadiometer) instrument was launched in December 1999 and for more than twelve years has been operationally producing Stereo Motion Vectors (SMVs) using the computer vision methods described by (Moroney et al., 2002; Muller et al., 2002). These have recently been modified to obtain better coverage of winds (K. Mueller et al., this workshop) including the potential of near real-time winds within 5 hours of data acquisition by MISR. For a limited time period, it was shown that ATSR2-AATSR so-called tandem observations could be employed to derive two-component wind-fields (across and along-track) as well as separate CTHs (Muller et al., 2010).

MISR CTH AND SMV ASSESSMENT AFTER 12 YEARS

As MISR uses visible (red channel) wavelengths, the near-nadir views often do not have any detectable signal due to high-level Cirrus or hazes. Such a signal is often present at the most off-nadir views (C and D) but the motion field cannot be unambiguously retrieved, as this requires correlation with nadir views. Recently, (Wu et al., 2009) analysed the height distribution of cloud layer tops (expressed as a cloud fraction % per km) and found that MISR preferentially samples low-level clouds which are often the poorest quality with MODIS due to emissivity issues. Figure 1, taken from Wu’s paper shows this distribution compared against a spaceborne lidar (CALIPSO) and mm-radar (CLOUDSAT) as well as sounders such as AIRS. The impact of such preferential sampling of low-level clouds is yet to be determined.

Long-term trends in the CTH field has recently been reported by (Davies and Molloy, 2012) but no such report on the wind-fields have recently been reported on.

Figure 1. January 2008 zonal mean CFs for (a) MISR wind-corrected CTH, (b) AIRS CTP, (c) MODIS CTP, (d) OMI effective cloud pressure, (e) CALIPSO daytime CTH, (f) CALIPSO daytime multi-layer clouds, (g) CloudSat CTH, and (h) CloudSat multi-layer clouds. All observations, except for MISR, were acquired from the NASA A-Train, which have slightly different local time
from MISR on Terra varying from ≈10 minutes near the north pole to several hours near the south pole. A 7.2 km scale height is used to convert CTP to CTH. Taken from Wu et al. (2009)

Assessments have also been made of the differences between contemporaneous SMV and AMV (from METEOSAT-9) winds for 2008 (Lonitz and Horvath, 2011). These indicate that SMVs have weaker westerlies and southerlies than CMVs at all latitudes and levels and that meridional winds have poorer quality than zonal and that their quality degrades significantly as higher altitudes are reached. SMV CTHs are usually higher than corresponding ones from AMVs and some of this difference can be accounted for through errors in the thermal retrievals used to retrieve CTPs of the AMVs. Sampling and typical differences are shown in Figure 2. These results have focused our efforts on the MISR science team to seek improvements in the new products to reduce these biases.

Figure 2. Figures taken from Lonitz & Horvath (2011). Upper Left: number of cotemporaneous samples which meet the joint quality conditions; Upper Right: 2D scatterplots showing the location of different clusters; rose diagrams of AMV-SMV showing along-track biases in SMV.
MISR SMV ASSESSMENT USING TRIPLE COLLOCATION

As part of an ESA bid to develop a demonstration MISR-lite as part for a global WINDS technological demonstrator mission, a joint study was performed by Ad Stoffelin (KNMI), Iliana Genkova (KNMI) and Akos Horvath (Liebnitz university). To characterize the error properties of SMVs, AMVs and ECMWF winds, a triple collocated (Stoffelen, 1998) data set for January-July 2008 was analysed based on a collocation criteria of MISR SMVs and Meteosat AMVs to be within 50 km horizontally, 25 hPa vertically, and 30 minutes, respectively. The ECMWF short-range forecast NWP winds are interpolated to the AMV and SMV locations and times for ocean-only winds.

With respect to the AMVs, the linear regression biases in the across-track wind components were found to be less than 2%. The bias in the SMV along-track component is about 4% with respect to ECMWF and AMV, which are mutually unbiased. The estimated random errors are given in Table 1. The results for an AMV quality indicator (QI; not using forecast information) above 85%, which is the threshold for quality control MSG AMV screening in the ECMWF data assimilation system.

<table>
<thead>
<tr>
<th>SD [m/s]</th>
<th>AMV</th>
<th>SMV</th>
<th>NWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Across track</td>
<td>1.3</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Along track</td>
<td>0.9</td>
<td>3.3</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Table 1: Random error estimates (SD) of triple collocated AMV, SMV and NWP winds (after Stoffelin, Genkova & Horvath).

This table shows good across-track component AMVs and SMVs, but poorer NWP winds across track. Most likely, because of the correlated along-track SMV wind component and height error, the estimated SMV along-track error is relatively large. It is expected that an evaluation of the along-track wind component with cloud-top height errors will result in much improved comparison statistics.

Validating SMVs globally is very challenging and no published reports have yet appeared on intercomparison with radiosondes, such as those which have been performed for AMVs (Holmlund, 1998; Holmlund et al., 2001). A notable exception is the study performed by (Hinkelman et al., 2009) which used Doppler wind data records from 23 of the US NWS Doppler wind profilers for the time period from March 2000 through September 2006 to assess the MISR wind retrievals and found agreement of -0.27±3.61 m/s with better agreement for the zonal component compared with the meridional component. Figure 4 shows a map of the locations of the Doppler wind stations employed for this analysis and the corresponding 2D scatterplots of the winds. The Doppler wind data are accurate to 1.1-4.5 m/s depending on the study site. Intercomparisons with MISR indicate that the biases are very small and the standard deviations in the 4-6 m/s are comparable to those from intercomparison studies with radiosondes (loc.cit.).

Figure 4: Map showing distribution of NOAA Doppler wind profilers employed (filled circles) and corresponding comparison of MISR and NOAA profiler winds at "Best Winds" heights for 23 locations. Ground return filtering applied. (a) W–E (u) wind
component. (b) S–N (v) wind component. (c) Wind speed. (d) Wind direction. Taken from Hinkelman et al. (2009)

MISR & AATSR SMVs FOR CHEMICAL TRANSPORT MODELS

Another area in which MISR provides unique products is the dispersal of forest fire and desert dust including smoke-plume digitised boundaries (Smoke Plume Masks) and Smoke Plume Injection Heights (SPIH). Currently, such features are only extracted manually using the MINX tool. However, after a number of years of student labour a significant resource for modelling the dispersal of aerosols and atmospheric greenhouse gases and pollutants has been created (Val-Martin et al., 2010) as well as a valuable web resource (http://misr.jpl.nasa.gov/getData/accessData/MisrMinxPlumes/index.cfm).

More recently, a new automated method for retrieving SPM/SPIHs from AATSR multispectral stereo has been developed (Muller et al., 2011) using a new variant of the M4 matcher (Muller et al., 2007) called M6 (Fisher et al., 2012). This has been applied to the processing of 4 years of AATSR observations over the Russian federation (loc.cit.) to yield SPIHs/SPMs. In addition, SPIH across-track winds have been calculated but as no validation has yet been able to be carried out, these are not shown here. Instead, an example SPM and SPIH is shown in Figure 3 with superimposed MODIS derived fire locations. Such data is being employed to assess its impact on chemical transport models and initial experiments indicate that for larger events, they can have a significant impact (M. Krol, 2012, private communication) on CO forecast predictions.

![Figure 3](image_url)

Figure 3. Example false colour composite (0.55, 0.87, 1.6µm as red, green, blue) AATSR subset for 7/7/2010 showing SPM boundaries in yellow and MODIS fire data in red.

AATSR SMVs FOR POLAR REGIONS FROM OVERLAPS

In (Muller et al., 2010) ATSR2-AATSR tandem data was demonstrated to be able to retrieve two-component (along and across-track) winds. A study was therefore performed to investigate how this could be applied to narrow-swath AATSR overlaps in polar regions, specifically for the whole of Greenland. (Muller et al., 2007) showed that Greenland included the strongest meridional wind components due to the jet-stream. In Figure 4 the overlap of AATSR swaths is shown for a single day which demonstrates that most of Greenland is covered. Taking a collocated pair, and applying the census matcher (Fisher and Muller, 2012), cloud-top winds were retrieved in addition to CTHs from each AATSR image-pair separately. This is shown in Figure 4 where most retrievals can be observed to have taken place over the diagonal cloud bank. Such results suggests that overlapping AATSR may be a fruitful source of wind data at this latitude range which has the significant advantage that thermal retrievals can be performed during austral night.
Figure 4. AATSR-AATSR SMVs showing areas of overlap (uppermost) taken from the CEOS Orbital Visualisation Environment at [http://www.ceos-cove.org](http://www.ceos-cove.org), AATSR nadir overlapping pair, orbits 38283/4 on 12/7/08; (middle) and derived wind vectors (lowest)
SENTINEL-3 SLSTR SMVs FOR POLAR REGIONS FROM OVERLAPS

The ESA Sentinel-3a, due to be launched in 2013/14 will have a stereo swath-width of 700km (cf. 512km from AATSR) so the opportunities for wind retrievals will be more plentiful as well as more accurate due to the sub-1km pixel size. However, the absolute accuracy will still be limited by the large time difference (~90 minutes). Once Sentinel-3b is launched the possibility will exist for sideways overlap and for subsequent stereo wind retrievals with only 30 minutes between orbits. Such a possibility will also exist for METOP-2/3 but clearly not in stereo. The future therefore looks encouraging for SMVs and their potential impact on operational NWP forecasts.

References Cited
Fisher, D., Muller, J.-P., Yershov, V., 2012. Automated Retrieval of Smoke Plume Injection Heights (SPIH) and Smoke-Plume Masks (SPM) from AATSR stereo for mapping aerosol and trace gas injection into the free troposphere. Journal of Applied Earth Observation and Geoinformatics submitted 5/12.


