COMPARISON OF AMV CLOUD TOP PRESSURE DERIVED FROM MSG WITH SPACE BASED LIDAR OBSERVATIONS (CALIPSO)

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Abstract

Cloud top heights (CTHs) of atmospheric motion vectors (AMV) derived from METEOSAT-8 are compared against collocated CALIOP lidar cloud tops. Comparisons have been performed using METEOSAT-8 AMV intermediate product and intermediate Cloud Analysis (CLA) product for 21 days period in spring 2007. An overall good agreement has been found between all CTHs from MSG (CLA box and AMV) and CALIOP. However, the AMV pressure allocation is systematically higher than CALIOP retrieval for semi-transparent clouds. The correction methods applied for dense low level clouds are identified to have a positive impact on AMV pressure. Detailed comparisons for various cloud types are presented and discussed in this paper.

I Introduction

Height Assignment (HA) is currently the most challenging task in the operational Atmospheric Motion Vectors (AMV) extraction schemes. Several sources of error are associated with the height assignment step, including the sensitivity of the HA methods to several atmospheric parameters. Meteosat Second Generation (MSG) provides many new opportunities to improve height assignment of AMVs. The existence of a CO_2 absorption channel at 13.4 μm on the SEVIRI instrument enables to use simultaneously the IR/CO_2 ratioing method in addition to the semi-transparency technique (based on IR window/WV channels) for height assignment.
The objective of this study is to investigate the various height assignment methods used at EUMETSAT for Atmospheric Motion Vectors (AMV) derived from METEOSAT-8 image data in comparison with direct lidar observations from CALIPSO. Study has been funded by EUMETSAT in the framework of CGMS Rec.34-14 **Recommendation 34.14:** Comparison of standard methods for the height assignment of AMVs with the new measurements from instruments on the A-Train (e.g. with the cloud lidar)

All the HA methods used to set AMV heights have been compared to the CALIOP lidar data. The analyzed dataset represents 20 days between February and March 2007, for which the AMV and CLA intermediate products (EUMETSAT ATS) and the CALIOP data (Winker et al, 2007) have been collected and co localized. This dataset,described in section II, allows to cover a large set of cloud type situations. The lidar data gives vertical profiles observations only on very small portion of the AMV target box. How these data are representative of the whole target box is studied in section III. Results of the comparison of the AMV cloud top pressure with the CALIOP data are presented in section IV, considering three different groups of AMV situations: the AMV with a cloud top pressure corrected for semi-transparency, the AMV with a cloud top temperature smaller than 253K and not corrected for semi-transparency and the AMV with a cloud top temperature larger than 253K. For this last group, the low level AMV, the efficiency of the inversion height method and the cloud base assignment is estimated.

II. PRESENTATION OF THE OBSERVATIONS

II.1 CALIOP

The lidar CALIOP is on board the CALIPSO platform flying in the A-train Constellation. The AQUA-train overpasses are close to 13:30 pm and 1:30 am equator crossing times. The lidar CALIOP delivers observations along the satellite track. The laser beam diameter at surface is about 70m. Footprints are produce every 333m. The vertical resolution is 30m from the surface to 8.2km. For altitudes higher than 8.2km it is 60m (Winker et al. 2007). Space lidars provide unambiguous cloud top height (CTH) retrieval of the uppermost layer in nearly all situations and the CTH of the lower layers in case of upper optically thin (optical thickness <3) or broken dense layers. They are able to detect very small cumulus and thin cirrus (optical thickness down to about 0.01, McGill et al, 2007). However, thin cloud layer detection depends on the signal to noise ratio. Lidar signals are usually required to be averaged to increase signal-to noise ratio to better detect optically thin clouds. The cloud and aerosol CALIOP operational products (CALIPSO ATBD, 2005) are given at different scales (333m, 1, 5, 20 km)(Vaughan et al. 2004).

In this study, the operational Level 2 V2.01 cloud layer boundary product available at the French ICARE data centre (http://www.icare.univ-lille1.fr) with 5km resolution along track (~ 70m across-track) comparable to the size of the SEVIRI pixels is used. With this resolution, an elevated 1km depth ice cloud should be detected by the CALIOP lidar provided its optical thickness is greater than 0.03 (daytime). The cloud layer top and bottom altitude extracted from this product have been converted to pressure using the meteorological profiles given in the CALIOP products.

II.2 SEVIRI AND DERIVED PRODUCTS FOR WINDANALYSIS

The spatial resolution of the SEVIRI channels used to retrieve the cloud to height is 3km at sub-satellite point. The repeat cycle (RCY) is 15 minutes. The target size used for the derivation of the AMV is currently of 26 pixels by 26 pixels, that is 80x80km^{2}at sub-satellite point. Nine HA retrieval methods have been provided by EUMETSAT for comparison: the equivalent black body temperature (EBBT) method, (1) the equivalent black body temperature (EBBT) method, (2 and 3) the semi-transparent correction (STC) (Schmetz et al., 1993) method using the mean radiance of this pixels and a clear sky reference for a combination of one WV channel and one IR channel, IR10.8 and WV6. or WV 7.3, (4 and 5) the IR/WV ratioing method using also a combination of one WV channel and one IR channel, IR10.8 and WV6.2 or WV7.2, without requiring the determination of a clear radiance, (6 to 7) the CO2 absorption representative radiance method (Menzel et al., 1993) using a combination the CO2 channel and one IR channel, IR10.8 and IR12., (8 and 9) the CO2 absorption sampled radiance arithmetic mean method using also a combination the CO2 channel and one IR channel, IR10.8 and IR12. EBBT method is mostly suited for dense opaque clouds, whereas all the methods 2 to 5 are used for semi-transparent clouds. Methods 6 and 7 can be used for both cloud types. The current CTP choice of the operational AMV product is done between the EBBT and CO2 methods using a Cloud Top height Temperature(CTT) threshold of 253 K.
A specific treatment is done for low level clouds, (pressure > 650 hPa), the AMV HA is then set to the temperature inversion level when exists, or to cloud base height (Le Marshall et al., 1993).

All these methods were in the AMV intermediate files provided by EUMETSAT, and 51 CTP values are available for each AMV. They correspond to the use of 6 thresholds to define the cold part of the CTH distributions (10%, 15%, 20%, 25%, 50% and 100%), for all the methods in addition to.the operational method, for which 9 CTP retrievals are given. For the alternative method, CTH only for 6 retrievals are reported in the AMV product. The operational (OP) CTP and alternative (ALT) CTP are chosen among these 51 CTP .

In the following, the AMV are classified in 3 types according to the method used for the operational CTP: (1) the STC AMV with a CTP corrected for semi-transparency, (2) when the EBBT has been used as final CTP despite its CTT <253K and (3) when CTT is larger than 253K.

II.3 SELECTED PERIOD AND DATA COLLOCATION

21 days during the 2007 February 23 to March 19 period have been selected. This corresponds to 192 CALIOP half orbits. 24966 AMV close from the CALIOP track and in a time coincidence of +/- 7.5' have been analyzed. This has required intermediate AMV product and CLA (Cloud Analysis) product for 979 SEVIRI cycles (RCY). Each day, at the most 10 CALIOP half orbits have been be retained for comparison with SEVIRI: 5 during night time and 5 during day time. Figure 2.a gives examples of CALIOP observations under the track projected on the SEVIRI grid for the 14th of August at 0130 local time. In this figure, the composite CTH of the AMV given over the globe are in time coincidence with CALIOP. CALIOP profiles for small parts of these orbits are given in Figure 1.b.

For each of the selected 24966 AMV, the 27x27 SEVIRI pixel box centered on the AMV location (close from 80kmx80km at sub-satellite point.) representative of the target box used to estimate the AMV speed, direction and CTH is defined. For that box are retained, the number of CALIOP profiles falling in the box, the top, the bottom pressure and the optical thickness of the cloud layers of each profile, the SEVIRI CLA CTP of each pixel, the operational AMV CTP and the 9 CTP associated with the operational choice of representative pixels and the 42 CTP associated with the alternative method.

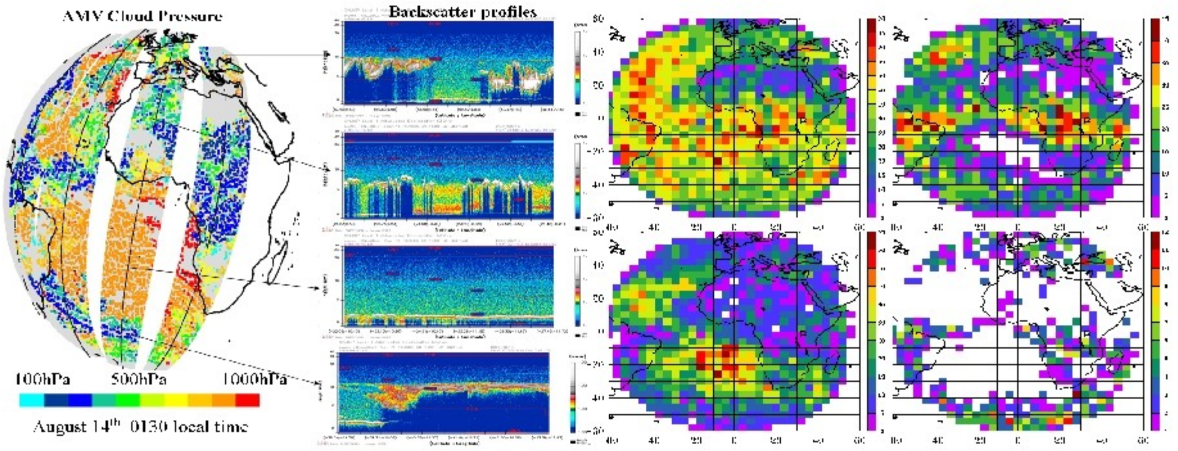

Figure 1: (a) SEVIRI AMV CTP composite with superimposed the CALIOP orbit tracks for August the 14th 2006 and (b) quick-look of CALIOP profiles for several CALIOP under track segment. (c) Geographical distribution of the AMV: all AMV (left,top) ; STC AMV (right,top) ,the EBBT <253K (right,bottom), EBBT >253K(left bottom).

The distribution of the number of profiles per AMV (not shown) shows a peak at 17 profiles. This value is linked to the average size of AMV box and the horizontal resolution of the CALIOP profiles. As the size of the box increases with increasing SEVIRI viewing angle, the number CALIOP profile increases. Due to the pole to pole orientation of the CALIOP orbit track, the increase observed corresponds mainly to an increase with latitude (about 25 profiles at 50N or 50S). In the following study, in order to kept the number of AMV as large as possible for the comparison with CALIOP, the number of CALIOP profiles by AMV can be as low as 3. Increasing this minimal number of profiles does not change the overall results of this study.

III RESULTS

III.1 REPRESENTATIVENESS OF OBSERVATIONS

CLA UNDER THE TRACK AND IN THE BOX CTP – CALIOP ALL LAYER AND UPPEST LAYER CTP

For CLA, two distributions are built, the under track (TRA) distribution using only the SEVIRI pixels under the CALIOP track and the whole box (BOX) distribution using all the target box pixels. For CALIOP two distributions can be used, the top pressure distribution of all the cloud layer (AllTOP) and the top pressure distribution of the uppest cloud layer (TopTOP). From these distributions a classification of the AMV in 10 cloud types (high, high over high, high over middle, high over low, middle, middle over middle, middle over low, low, low over low, clear) is performed using the lowest CTP value and the largest CTP value. From figure 2 (left panel) we infer that for CLA, Box to Track reduces the detection of multi cloud layers. CLA under track there is more low clouds and less high cloud than CALIOP due to the larger sensitivity of the lidar instruments. For CALIOP, the distribution of cloud layer tops on the vertical allows to catch a large part of the spatial variability in the target box. For a classification in 3 main types taking into-account only the highest cloud TOP, the degree of agreement between CALIOP and the CLA BOX reaches 78%. In figure 2 (middle panel), the shapes of the CAL ALLTOP and CLA BOX CTP distributions are similar with a peak at low pressure and a peak at high pressure. But at low pressure the CALIOP peak shifted toward smaller pressure is larger.

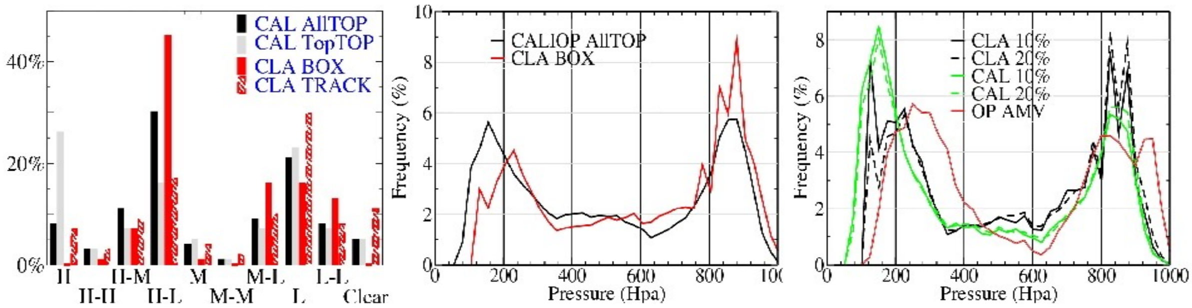

Figure 2: distribution of the 10 cloud types for CLA BOX , CLA track, CAL TopTOP and AllTOP (left), CLA BOX and CAL ALLTOP CTP distributions (middle) etect).

CALIOP AND CLA REPRESENTATIVE CTP COMPARED TO THE AMV CTP

The AMV CTP retrieval is designed to derive the mean pressure of the coldest cluster in the target box, For each AMV, CALIOP and CLA provide distributions of CTP. For a given distribution, we define a representative value as the pressure value at a certain percentil of the distribution. Percentil 0 is equivalent to the highest cloud top in the AMV box, percentil 100 is equivalent to the lowest cloud top in the AMV box. In order to take into account the coldest part of the cloud cover but not the extreme, CTP value at percentil 20 (CTP at 20) is retained has representative value for CALIOP CTP and CLA CTP in this section.

Figure 2 (right panel) gives the distributions of the CLA BOX CTP at 20 and at 10 and similary, the CALIOP AllTOP CTP at 20 and at 10 distributions. All these curves have similar shapes with a peak at low pressure and a peak at high pressure. In that figure, is also given the AMV operational CTP distribution curve. Compared to the CLA curve and the CALIOP curve, the peak at low pressure is shifted toward larger pressure in the AMV curve and more spread between 300hPa and 400hPa. There is a very high pressure peak (above 950hPa). For a classification in the 3 high, middle and low levels, in 74% of the cases, the CALIOP CTP and AMV CTP agree. To change the CALIOP distribution percentil value from 20 to 10 or 0 does not change the agreement frequency. For the 26% which are not in agreement, 13% correspond to CALIOP multi layered situations. In these cases, the possibility to derive a representative CALIOP CP to compare with the AMV CTP is not excluded. (see section IV.4). To apply a threshold on CALIOP cloud layer with optical thickness smaller than 0.2, do not increase the overall agreement between the AMV and CALIOP high cloud cover.

III.2 HIGH LEVEL, SEMI-TRANSPARENCY CORRECTION APPLIED, CTT<253

Respectively 86% and 9% of the AMVs corrected for semi-transparency (STC AMV), are observed by CALIOP at high and middle levels. In figure 3.c, the peak at high pressure in the CALIOP CTP at 100 distributions indicates the high frequency of multi-layered high plus low clouds (47%). CALIOP CTP distribution using percentil 1 and percentil 20 are similar.

The proportions of high and middle level CTPs for STC AMV are 92% and 8% respectively. The frequency of CTP above 300hPa is large (34%). As already noted in section III, the peak at low pressure is shifted toward larger pressure in figure 3 left-top panel. This is no more the case when AMV IR/WV6.2 ratioing method is used. (fig 3 (left-top panel) dotted red curve). The shapes of the CTP distributions for the other semi-transparent correction methods are close to the OP CTP shape, except for the STC WV6.2/IR CTP (figure 3, left and right top panel).

The peak of occurrence for CALIOP, the AMV alternative method height (AMV ALT) (figure 3 right-top panel) and the AMV operational height (AMV OP), is respectively close to 150, 200 and 250 hPa.
The WV6.2/IR ratioing method has been used to set the final AMV height for only 2% of the STC AMV operationally, and for 62% of the STC AMV using alternative methods. This could partly explain the differences observed between the OP and the ALT CTP distributions.

Figure 3.d represents the difference of AMV CTP and CALIOP CTP at 20 for OP CTP, operational WV6.2/IR ratioing method CTP, AMV ALT and the alternative WV6.2/IR ratioing method CTP for the 10% percentage of coldest. The bias with CALIOP is slightly smaller with the alternative method; but the RMS is smaller with the operational method. Considering CALIOP as the reference, the WV6.2/IR ratioing method, gives the best agreement. However, for 14% of the case, this method failed to estimate correctly the CTP.

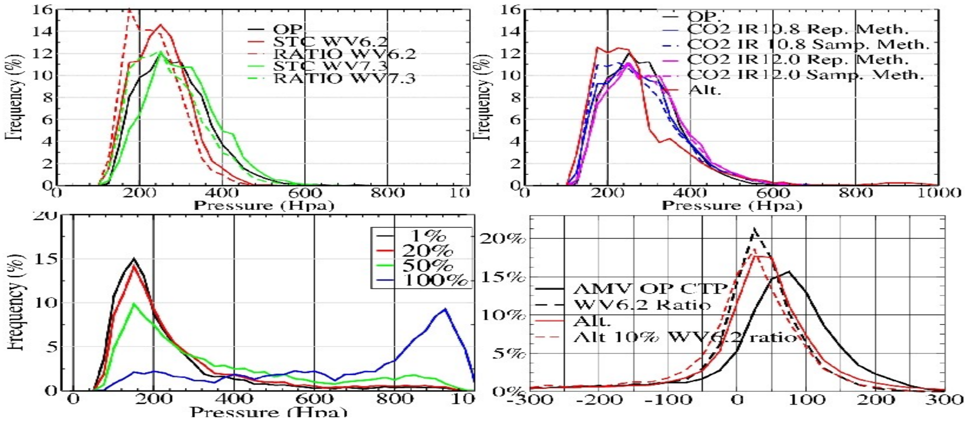

Figure 3: CTP distribution for (left top panel) the four WV/IR retrievals, (right top) the four CO2/IR retrievals, (left bottom panel) for several CALIOP representative CTP's. In top panels are also given the operational CTP curve (black curve), in right-top panel is given the alternative CTP (red curve). In the bottom-right panel, distribution of AMV CTP minus CALIOP CTP (percentil 20) for the AMV OP meth., the AMV IR/WV6.2 ratio meth, the AMV ALT meth., the AMV Alt at 10% IR/WV6.2 ratio meth.

The bias between AMV CTP and CALIOP CTP for the CALIOP high cloud class cases is as low as 28hPa with a RMS of 86hPa when considering WV6.2/IR ratioing method. For the 9% of CALIOP midlevel clouds, the bias is larger if a semi-transparent correction method is applied. For the EBBT method, the biais is only 27hPa but the RMS is large. Filtering CALIOP cloud layers with optical thickness smaller than 0.2 , the bias between CALIOP and the AMV CTP decreases but the RMS increases. Table 1 gives the frequency of AMV minus CALIOP differences smaller than 75hPa for several AMV CTP.

	OP	ALTER.	WV6.2 rat.	CO2	WV6.2 10%	EBBT
CAL High	45%	65%	73%	44%	71%	17%
CAL Mid.	27%	36%	14%	38%	14%	42%

Table 1: occurrence frequency of AMV CTP minus CALIOP CTP at 20 for CALIOP high cloud top and middle cloud top cases.

The difference between the high level and midle level clouds is obvious in this table. The best agreement with CALIOP is found for the WV6.2 ratioing method for high clouds and for EBBT method for the middle level clouds.

III.3 HIGH LEVEL, SEMI-TRANSPARENCY CORRECTION NOT APPLID, CTT<253K

The amount of AMV's for which no correction for semi-transparency has been applied and having a CTT smaller than 253K is small, 4.5% of the total AMV population. CALIOP identified 80% of this group as high clouds and 18% as middle level clouds, when AMV software identified, 75% as high clouds and 25% as mid-level clouds. As for the STC case, the frequency of multi-layered situation observed by CALIOP is large. However as shown by the CTP distribution of the lowest layer CTP in figure 3 (left-bottom panel), the percentage of high above middle level clouds is larger (31% against 19%).

The shapes of the AMV and CALIOP CTP distributions given in figure 4 (left-top panel) and 4 (left-bottom panel) are similar with a peak at 150hPa, another peak between 250hPa and 350hPa and then a smooth decrease toward larger pressure. They are quite different to distributions observed for the STC cases. The occurrence of middle level clouds is larger.

As for the STC AMV case, the distribution of WV6.2/IR CTP in figure 4 (left-top panel) gives smaller pressure than OP and CO2/IR or WV7.3/IR CTP distributions in figure 4 (left-right panel). Alternative CTP distribution at high level is closer from the WV6.2/IR CTP than from the AMV OP CTP distribution. The alternative CTP has been estimated using the WV6.2/IR retrieval 47% of the time.

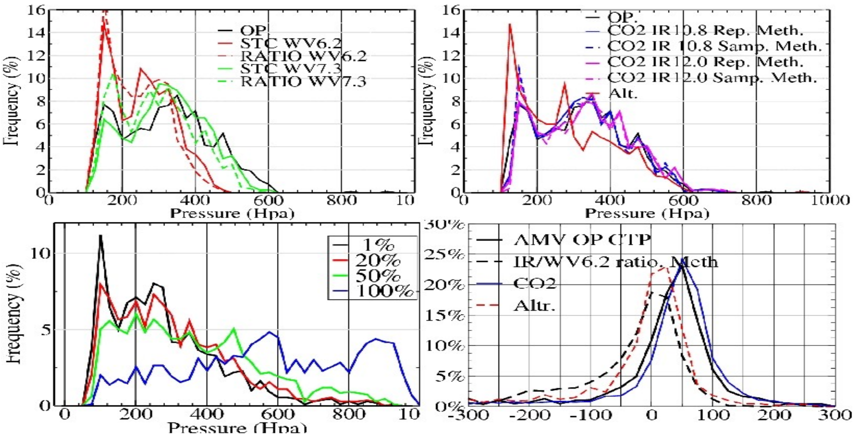

Figure 4: CTP distribution for (left top panel) the four WV/IR retrievals, (right top) the four CO2/IR retrievals, (left bottom panel) for several CALIOP representative CTP's. In top panels are also given the operational CTP curve (black curve), in right-top panel is given the alternative CTP (red curve). In the bottom-right panel, distribution of AMV CTP minus CALIOP CTP (percentil 20) for the AMV OP meth., IR/WV6.2 ratio meth, CO2 meth., ALT meth.

In the CALIOP CTP distribution, the magnitude of the peak at 100hPa is smaller when using the pressure value at 20% instead of using the upper layer CTP at 1% (figure 4 left-bottom panel).

The WV6.2/IR and alternative method CTP distributions are closed from the CALIOP upper layer CTP distribution. Figure 4 right-bottom panel illustrates that the agreement between CALIOP and alternative method is better than the agreement between CALIOP and the operational AMV CTP. The negative values, obtained when AMV CTP is smaller than CALIOP CTP, are in large part due to cases for which CALIOP sees middle level clouds and AMV software identified high level feature. That can be due to problem of CALIOP track representativeness within the target box.

If the CALIOP layers OD <0.2 are removed, the bias of operational AMV with CALIOP CTP decreases together with the RMS. This indicates the presence of very thin clouds above a thick high or middle level clouds.

	OP	ALTER.	WV6.2 stc.	WV6.2 10%	CO2	CO2 10%	EBBT 10%
CAL High	70%/46%	82%/69%	80%/61%	80%/68%	66%/38%	77%/54%	80%/66%
CAL Mid.	63%/48%	55%/47%	26%/17%	29%/19%	61%/46%	67%/49%	59%/50%

Table 2: occurrence frequency of AMV CTP minus CALIOP CTP at 20 smaller than 75hPa/50hPa for CALIOP high cloud top and middle cloud top cases.

Table 2 shows the occurrence of AMV CTP minus CALIOP CTP differences smaller than 75hPa or 50hPa for CALIOP high and middle level clouds. The alternative method gives again the best results for high clouds observed by CALIOP. For the mid-level clouds, the alternative at 10% CO2 gives the best agreement with CALIOP.

III.4 Mid level, EBBT applied, CTT>253K

The threshold on CTT used to apply or not a correction of semi-transparency is 253K (~ 600hPa). In this section, we analyse the CALIOP cloud cover corresponding to these cases and investigated the improvement what could bring the application of a correction when CALIOP detect high or middle cloud layers.

Figure 5 gives the distribution of the CTP for CALIOP and the AMV. A large peak of occurrence is present between 850 and 900hPa in the AMV and in the CALIOP top distributions. However some high and middle level cloud layers are also observed with CALIOP.

For 35% of the AMV classified low clouds, CALIOP has detected at least one layer with a middle (15%) or high (20%) level CTP. For these AMV , the OP CTP is smaller than 600hPa and 700hPa in 23% and 29% of the cases respectively.

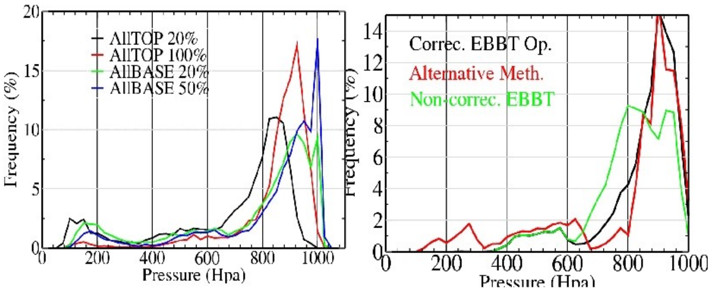

Figure 5: Distributions of CTP for : (left panel) CALIOP AllTOP at percentil 20 and 100 and CALIOP All BASE at percentil 20 and 50 CTP , (right panel) the AMV and the operational method, the alternative method and the operational AMV before correction for low clouds.

When CALIOP detects high cloud, at least 25% of these cases could be retrieved in +/-75hPa of the CALIOP CTP if the alternative method CTP is used. That percentage reaches almost 40% when the WV6.2/IR ratioing method is used (that represents only 970 cases over 2209).

For the CALIOP midlevel clouds, the use of the EBBT and alternative method at 10% or the CO2/IR12 method allows to be as close as 75hPa of the CALIOP pressure in almost 70% of the cases.

III.5 Low level correction methods

Below 650 hPa, different methods are used to set the AMV height. When temperature inversion occurs in the forecast profile, the height is set to the inversion level. For other cases, a cloud base height method is used to set the height of the AMV to the cloud base instead of the cloud top (Le Marshall et al. 1993). When several clusters are present at low level, they are merged together to estimate the altitude. Inversion and Cloud base height methods including or not this merging process have been compared to CALIOP measurements.

Figure 6 right panel shows the geographical distribution of the Inversion (left) and Cloud base (right) methods, using (up) and not including (bottom) merging process. Height inversion method applied with scene merging represents 213 AMVs which corresponds to 0.8% of the cases, cloud base method applied with scene merging represents 3554 cases (14.5%), height inversion applied without scene merging represents 2241 cases (9.2%), and cloud base applied without scene merging represents 2648 cases (10.8%).

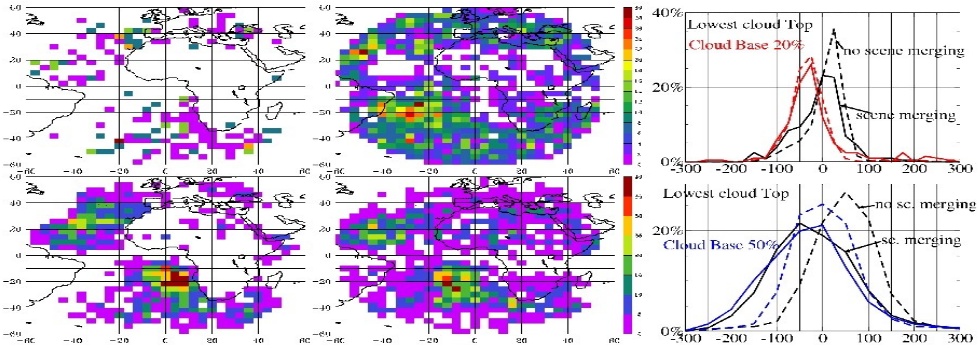

Figure 6: Spatial distribution of low cloud cases as a function of the correction method (right-panel) and distribution of differences between AMV OP and CALIOP for the Height inversion method and the base assignment method (left panel).

For 34% of the AMVs detected at low level, high or mid-level layers are also observed in the box by CALIOP. In figure 6 right panel, AMV CTPs are compared to CALIOP lowest cloud layer CTP for inversion method, and lowest cloud layer base for cloud base method.

Both bias and RMS are smaller for corrected CTP, applying inversion or cloud base methods, than for uncorrected cases: (cor. 24/120hPa, uncor. -34/206hPa). The best agreement is obtained with the CALIOP lowest cloud top and the inversion methods (biais of 18hPa bias and RMS of 75hPa). No bias between AMV CTP and CALIOP exists when scene merging process is applied for cloud base method. However, the RMS for the cloud base correction is larger than from inversion correction method. Results from methods cloud base assignment are in good agreement with CALIOP cloud base observations.

IV CONCLUSION

This paper summarizes the results of the comparison of AMV HA against CALIOP measurements, using a set of 24966 AMVs collocated with CALIOP observations. Several methods have been compared against CALIOP measurements, including semi-transparency correction methods generally applied to high level clouds, EBBT method used for opaque clouds, and low level correction methods applied below 650 hPa.

Significant differences have been noted between AMV CTPs and CALIOP pressure levels for high level clouds. CO2 slicing method is in good agreement with CALIOP cloud top only for the highest layer (100-200 hPa). The bias is degraded to about 100 hPa at 300 hPa

Alternative configurations of semi-transparency correction methods using several percentages of coldest pixels are in a general better agreement with CALIOP observation. The best agreement is realised for IR/WV methods, which is generally the method that gives the lowest pressure. Then, the comparison of AMVs HA with CALIOP observations for semi-transparent clouds may be limited by the different characteristics of the two instruments. The Lidar is able to detect very thin cirrus not seen by SEVIRI, and it may generally bias the comparisons towards upper altitude. The fact that the best agreement of semi-transparent methods occurs for the one which gives the smallest pressure is then not a surprise and does not constitute a proof of the reliability of this method.

There is a small number of AMVs detected at mid level (400-700 hPa) and the agreement with CALIOP measurements is poor. That is partly due to multilayer situations where SEVIRI and CALIOP do not consider the same layer, and/or cases for which CALIOP track does not catch the part of the pixels used for HA calculation within the target area.

Inversion correction method used at low level to set the AMV height at the level of the temperature inversion is in very good agreement with the lowest cloud top observed by CALIOP. Results from cloud base assignment methods which aimed to set the height of the AMV to the cloud base are also very close to CALIOP cloud base observations. These last results are very important and demonstrate that these correction methods must be applied to set the height of the AMVs at low level.

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Acknowledgements

The authors would like to thanks the NASA, CNES and ICARE data center for giving access to CALIOP data and the EUMETSAT MOD for providing the SEVIRI AMV product.