AMV HEIGHT ASSIGNMENT WITH METEOSAT-9: CURRENT STATUS AND FUTURE DEVELOPMENTS

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ABSTRACT

Meteosat-9 was declared the prime satellite on 11 April 2007, taking over routine operations from Meteosat-8, which had been the prime satellite since 29 January 2004. Meteosat-8 became backup satellite to Meteosat-9. The transition was smooth and caused only a one hour interruption in the operational generation of meteorological products at EUMETSAT.

Several changes in the algorithms responsible for the derivation of atmospheric motion vectors (AMVs) were introduced in March 2007. The main modification was in the identification of cloud scenes. The previous approach, relying on static pressure layers, frequently led to ill-defined cloud targets. The new approach applies a histogram analysis to the individual pixel's cloud top pressure values and yields better cloud scenes. A detailed analysis by the ECMWF led to the conclusion that the impact of the algorithm changes on the forecast quality was 'neutral'.

This paper describes the results of two internal collocation studies, one comparing the AMVs against forecast data, the other comparing them against Lidar observations by the CALIOP instrument on-board the CALIPSO satellite. The aim of the collocations was two-fold: (1) to investigate the impact of the algorithm changes, and (2) to identify potential problems in the AMV height assignment.

The studies indicate that the modifications in the algorithms had in general a small but beneficial effect. On the other hand, a large positive bias was found in the pressure values of high level AMVs above 200 hPa, which was not affected by the algorithm changes. The comparison with CALIPSO data led to some very interesting results, which clearly indicate that it is not easy to tell which height assignment method yields better results than other methods under which circumstances.

1. INTRODUCTION

EUMETSAT derives atmospheric motion vectors (AMVs) from five channels of the Meteosat-9 satellite, which is currently the prime operational satellite. The number of height assignment methods that is operationally applied for cloudy targets, increased from two to six in 2007. This enhancement was part of a large number of (mainly minor) changes in the AMV algorithms. Section 2 contains an overview of the current operational set-up, whereas Section 3 describes the algorithm changes introduced in March 2007.

There are basically two different methods of assessing the impact of algorithm changes on the AMV quality. The first is to perform a so-called forecast impact study. This is done, in our case, by ECMWF, which collects statistics for at least one month on the impact of AMVs on the forecast quality. The second method is to compare the AMVs with independent observations of atmospheric motion. There are several ways to do this, with a variety of observation platforms and various techniques to obtain useful statistics. Section 4 contains results of a best-fit analysis of AMVs against forecast data, and Section 5 discusses several collocation cases of AMV and CALIPSO data.

2. CURRENT OPERATIONAL SET-UP

Table 1 lists the Meteosat-9 channels for which AMVs are derived operationally. Five channels are currently operational for AMV generation. Each of these extracts motion vectors from the displacement of cloud targets, whereas the two water-vapour channels derive clear-sky winds as well.
The AMV derivation system generates, for each of the five channels, three intermediate AMV products per hour, as well as one final AMV product, which is an average of the intermediate ones. The BUFR product contains all AMVs from the five channels that have a quality better than 0.30 and pass some other criteria as well (e.g. speed must exceed 1 m/s and visible channel AMVs must have a pressure larger than 700 hPa).

Channel number	Channel name	Wavelength	Target types
2	VIS 0.8	0.74 - 0.88 µm	cloud
5	WV 6.2	5.35 - 7.15 µm	cloud, clear-sky
6	WV 7.3	6.85 - 7.85 µm	cloud, clear-sky
9	IR 10.8	9.8 - 11.8 µm	cloud
12	HRVIS	0.75 µm	cloud

Table 1 Meteosat-8 spectral channels used for AMV derivation

Six height assignment methods are used operationally for cloudy targets, see Table 2. The CO_2-12.0 method is the prime method, whereas the EBBT, STC and IR/WV methods are only applied in special cases. More specifically, the pressure value obtained by the CO_2-12.0 method (let's call it P-CO_2) is selected when it meets the following criteria:
(a) The temperature at P-CO_2 is lower than 253 K.
(b) P-CO_2 is lower than the EBBT pressure.
Otherwise, either the EBBT or one of the STC methods is selected. The STC pressure (P-STC) results are not considered, however, when the temperature at P-STC is higher than 243 K.

Method	Channels involved	For which targets ?	Operational ?
EBBT	wind channel	opaque clouds	yes
STC 6.2	IR 10.8 + WV 6.2	semi-transparent clouds	yes
STC 7.3	IR 10.8 + WV 7.3	semi-transparent clouds	yes
IR / WV 6.2	IR 10.8 + WV 6.2	semi-transparent clouds	yes
IR / WV 7.3	IR 10.8 + WV 7.3	semi-transparent clouds	yes
IR two WV STC	IR 10.8 + WV 6.2 + WV 7.3	semi-transparent clouds	no
IR two WV IR/WV	IR 10.8 + WV 6.2 + WV 7.3	semi-transparent clouds	no
CO_2 10.8	IR 13.4 + IR 10.8	all clouds	no
CO_2 12.0	IR 13.4 + IR 12.0	all clouds	yes
CO_2 10.8 - 12.0	IR 13.4 + IR 10.8 + IR 12.0	all clouds	no
NTCC 50%	water-vapour wind channel	clear-sky	yes
NTC peak level	water-vapour wind channel	clear-sky	yes
clear-sky EBBT	water-vapour wind channel	clear-sky	yes

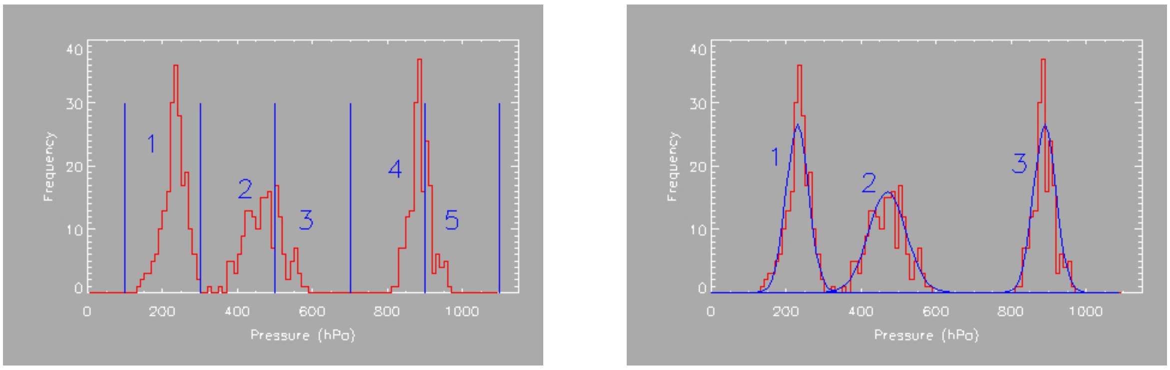
Table 2 Available height assignment methods

3. RECENT ALGORITHM CHANGES

A new version of the AMV algorithms was introduced in March 2007. It contained a relatively large number of major and minor modifications in various aspects of the wind derivation. The most important changes were the following:

(a) Scenes analysis: introduction of dynamic clustering instead of ‘layering’,
(b) AMV location moved to position with maximum local standard deviation (in the radiance values),
(c) CO_2 height assignment methods: improved handling of forecast temperature inversions,
(d) Use Semi-Transparency Correction (STC) methods for a narrow selection of AMVs
(e) Do not apply Cloud Base Height Assignment if this places the AMV higher in the atmosphere,
(f) Do not apply Inversion Height Correction if this places the AMV higher in the atmosphere.

The introduction of dynamic clustering as a technique to identify cloud scenes inside the target area was the most important change of all. Both this technique and the previous technique are based on the cloud top pressure values of the individual pixels, which are provided by the so-called Cloud Analysis (CLA) product. The CLA product applies itself a ratioing method involving the IR-10.8 and the WV-6.2 channels to derive cloud top pressure values for each pixel.
The old clustering method relied on static pressure boundaries. The obvious disadvantage of that method was that it frequently split well-defined scenes into separate scenes. Figure 1-a visualizes this problem for a sample case. The frequency distribution of the cloud top pressure values clearly indicates the presence of three separate cloud layers inside the target area. Because of the fixed pressure boundaries (at 100, 300, 500, 700, and 900 hPa), the old algorithm results in five separate cloud scenes.
The new clustering method tries to fit Gaussian curves through the cloud top pressure frequency distribution and is, by its nature, completely dynamic. Figure 1-b shows how this results in cloud scenes that are better defined.
Each cloud scene will be subjected to the complete suite of height assignment methods. But in the end there is only one of them that can be selected as the scene that represents the tracked feature. Both the old and the new methods calculate for each scene the average equivalent blackbody temperature (EBBT) and selects the coldest one.



(a) (b)

Figure 1 Frequency distribution of the cloud top height pressure values of all pixels inside a sample target area. The left figure (a) shows how the static layering results in five separate cloud scenes. The right figure (b) shows the result of the new ‘dynamic clustering’ approach, yielding three scenes.

Low level cloud scenes always need some special attention. The new clustering methodology uses a new approach to handle cases with multiple low level cloud scenes, which eventually leads to the definition of a single scene representing all low level cloud pixels. If there are exactly two low level scenes, these will be merged to a single scene. If there are more than two of them, the lowest one (i.e., having the highest EBBT) will be ignored and the others will be merged.

4. BEST-FIT ANALYSIS

Comparisons with independent sources of information are indispensable to obtain a feeling for the quality of the AMVs. A very useful comparison technique is the so-called *best-fit analysis*, which relies on vertical wind profile data from, for example, radiosondes or wind profilers. The technique is based on the fact that the uncertainty in the tracking, i.e. the speed and direction of the AMVs, is small in comparison to that in the height assigned to the tracked cloud features. It works basically as follows:

1) Find pairs of AMVs and independent wind profiles that are close to each other, both in a temporal and in a spatial sense. These are the so-called collocation pairs.
2) Perform the following steps for each collocation pair:
   (a) Compare the AMV speed and direction to all wind profile levels and identify the best-fit level, i.e. the level at which the AMV and the profile wind vector are closest to each other.
   (b) Compare the AMV pressure to the best-fit pressure.

In the current study I have used a best-fit analysis that compares AMV data to forecast profile data. The advantage of using forecast data is the large number of collocation pairs that can be found. Radiosonde and wind profiler observations are indeed much more cumbersome as a source of information, since the number of collocation pairs is so much smaller.
The actual implementation of the best-fit technique depends on how the AMV is compared to the profile wind. I introduced a measure that is very similar to the forecast consistency, which is one of the components that make up the Quality Index (QI) value. The consistency value is calculated for each profile level, as follows:

$$Consistency \;=\; 1 \;-\; \left(\tanh \left(\frac{\left| \vec{S} - \vec{F} \right|}{MAX\ (0.2 \cdot \left| \vec{S} + \vec{F} \right|, 0.01) + 1} \right) \right)^2$$

where *S* is the AMV wind vector and *F* is the forecast wind vector.
Consistency values are between 0 and 1, with 0 representing a very poor consistency and 1 an excellent one.
The peak in the consistency profile tells us at which level the AMV matches the profile winds best, or in other words: what is the best-fit level. But the identification of this level is not sufficient. The question remains if the information at the best-fit level is useful. This is not always the case, for several reasons:

(a) *Best fit* does not necessarily mean *good fit*. The maximum consistency in the profile must exceed a threshold value, C_{peak}, to be useful at all.
(b) There are cases in which an AMV matches the profile winds nicely over a deep atmospheric layer. This is not interesting for a best-fit analysis, because it will not result in a well-defined best-fit height.
(c) There may be more than one well-defined peak in the consistency profile, making the best-fit level ambiguous and not useful for the analysis.

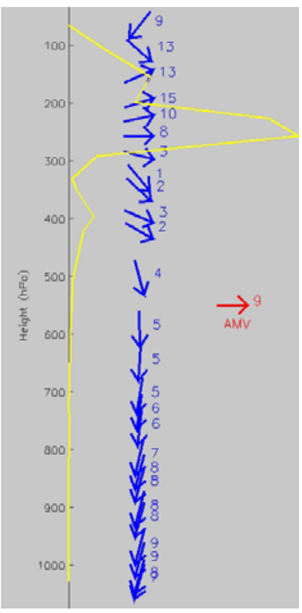


Figure 2 The consistency between the AMV (in red) and the profile winds (in blue) can be displayed as a curve (in yellow). If the peak of the curve exceeds a threshold value C_{peak} and, at the same time, all consistency values outside the best-fit layer are smaller than C_{base}, we accept this case as a well-defined best fit collocation.
The best-fit layer is defined as the layer of P_{BFL} thickness that is centred around the maximum consistency level.
This study is based on the following values:

C_{peak} = 0.85
C_{base} = 0.35
P_{BFL} = 110 hPa

The best-fit analysis was based on intermediate AMV products (IR-10.8 channel) around midnight (23.30 and 00.30 UTC) and around noon (11.30 and 12.30 UTC) on the one hand, and ECMWF forecast data (+12 hours period) for midnight and noon, on the other hand. The forecast profiles contain 25 pressure levels between the surface and 100 hPa. Only AMVs with a final quality of at least 0.85 were considered.

The aim of the best-fit study was two-fold: (1) to investigate the impact of the algorithm changes, and (2) to identify potential problems in the AMV height assignment. The study was therefore done for both February 2007 and November 2007, using approximately five weeks of data in each case.
Figure 3 shows results for the final AMV heights, for both February and November 2007. Because of the stringent criteria that were applied in the best-fit analysis, the number of cases is limited: an average of 10 best-fit cases was found per AMV product. An overwhelming majority of the best-fit heights is within the 100-300 hPa layer.

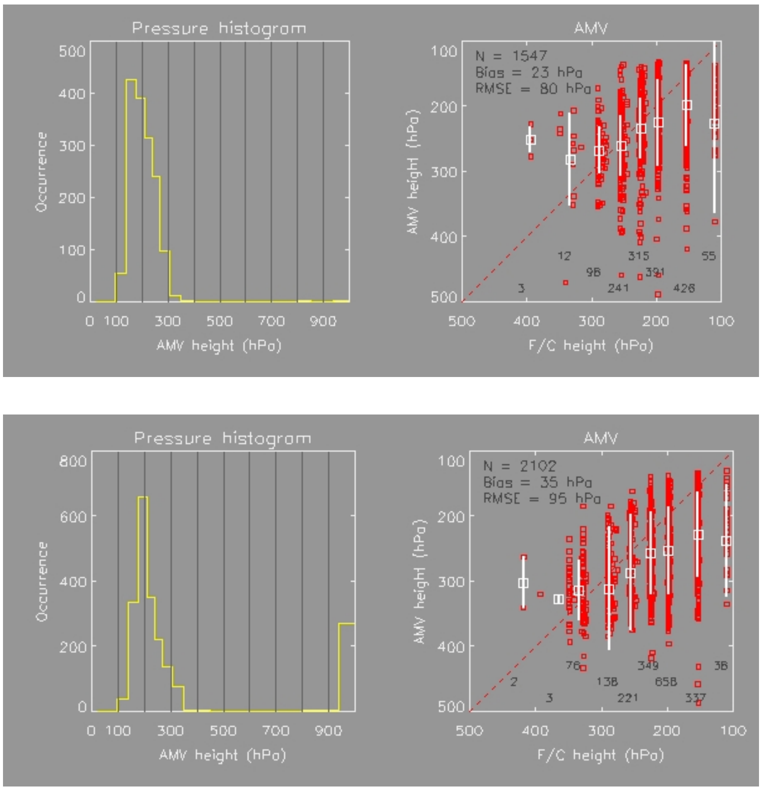


Figure 3 Frequency distribution of the final AMV heights and scatter plots of AMV heights against best-fit forecast heights. The top panel represents February 2007, the bottom panel represents November 2007.
There are not many cases outside the 150-300 hPa layer.

Figure 4 shows the bias of the AMV heights as a function of the atmospheric level, not just for the final height but also for several individual height assignment methods. One can conclude that there is a small to moderate positive bias between 200 and 250 hPa that has become slightly worse in the November 2007 analysis. There is a general shift to higher pressure values for the November 2007 case compared to the February 2007 case. This can mainly be attributed to the dynamic clustering and is really an improvement. The previous clustering frequently led to high level cloud scenes to be split into two separate scenes, one with a pressure value below 300 hPa and another one above 300 hPa (because of the static boundary at 300 hPa). The final AMV height was then derived from the highest scene. The new clustering, on the other hand, would not split this cloud scene and therefore yield a larger pressure value.
The strong negative bias below 300 hPa has improved considerably after the introduction of the algorithm changes. This is not true though for the Semi-Transparency Correction (STC) methods, which still generate heights that are too low in the atmosphere. It is not possible to make any statements about the heights below 350 hPa, as the number of cases for these levels is too small.
An interesting feature is the strong positive bias above 200 hPa. All height assignment methods show the same feature and it has not changed after the algorithm modifications. The cause of this is not clear, but it seems to be related to an incorrect handling of the atmospheric correction tables near tropopause levels.

One could state that because of the very stringent criteria applied to this best-fit analysis only very special cases will be selected, which might not be representative for the entire global atmosphere. This concern is fair but is not supported by any evidence. Firstly, the results are independent of geographical location: separate analyses for the Tropics and the Northern and Southern hemispheres yield very similar results. Secondly, a strong relaxation of the best-fit criteria hardly affects the biases found with the stringent criteria.

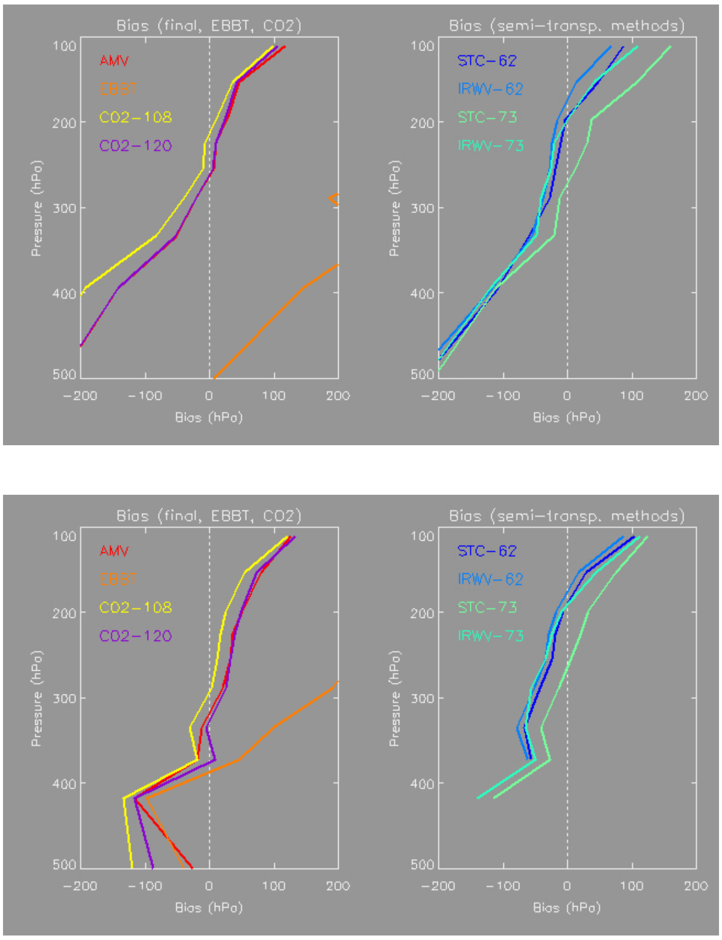


Figure 4 Biases between AMV heights and best-fit heights. The top panel represents February 2007, the bottom panel represents November 2007.
The plots show the bias as a function of best-fit height for both the final AMV height and several AMV height assignment methods.

Final height: red,
EBBT height: orange,
CO_2-10.8 height: yellow,
CO_2-12.0 height: purple,
STC-6.2 height: dark blue,
IRWV-6.2 height: blue,
STC-7.3 height: green,
IRWV-7.3 height: cyan.

5. CALIPSO COLLOCATIONS

CALIPSO is a polar satellite that is part of the so-called A-train constellation. It carries a Lidar instrument (CALIOP) that measures backscatter from aerosols and clouds. The backscatter profiles can be used to estimate cloud-top heights. Sèze et al. (2008) carried out an extensive study to compare AMV heights produced by EUMETSAT to cloud-top heights detected by CALIPSO.
We looked at several collocation cases and compared the heights of high-quality AMVs (QI at least 0.85) directly to the CALIPSO cross-section plots, which are published on the Internet (url: http://www-calipso.larc.nasa.gov/products).

Figure 5 shows an example of a cross-section plot, which was used to collocate two AMV cases at approximately 9° N, 26° E, on the 21^{st} of October 2007, around 11:45 UTC. The cloud-top height observed by CALIPSO is roughly at 140-190 hPa. The corresponding cloud target was a high level, semi-transparent cloud. The various height assignment methods report quite interesting values for the two AMVs (The CO_2-12.0 method yielded the final height for both cases):

Method	AMV-1 heights	AMV-2 heights
EBBT	400 hPa	405 hPa
STC-6.2	210 hPa	150 hPa
IR/WV-6.2	165 hPa	140 hPa
STC-7.3	255 hPa	195 hPa
IR/WV-7.3	190 hPa	180 hPa
CO_2-10.8	150 hPa	240 hPa
CO_2-12.0	**175 hPa**	**260 hPa**

The *infrared water-vapour ratioing* (IR/WV) and CO_2 heights for the first AMV are consistent with each other and match the CALIPSO height well. The situation is different for the second AMV: the STC and IR/WV heights match each other and the CALIPSO height, but the CO_2 heights are this time too low in the atmosphere.

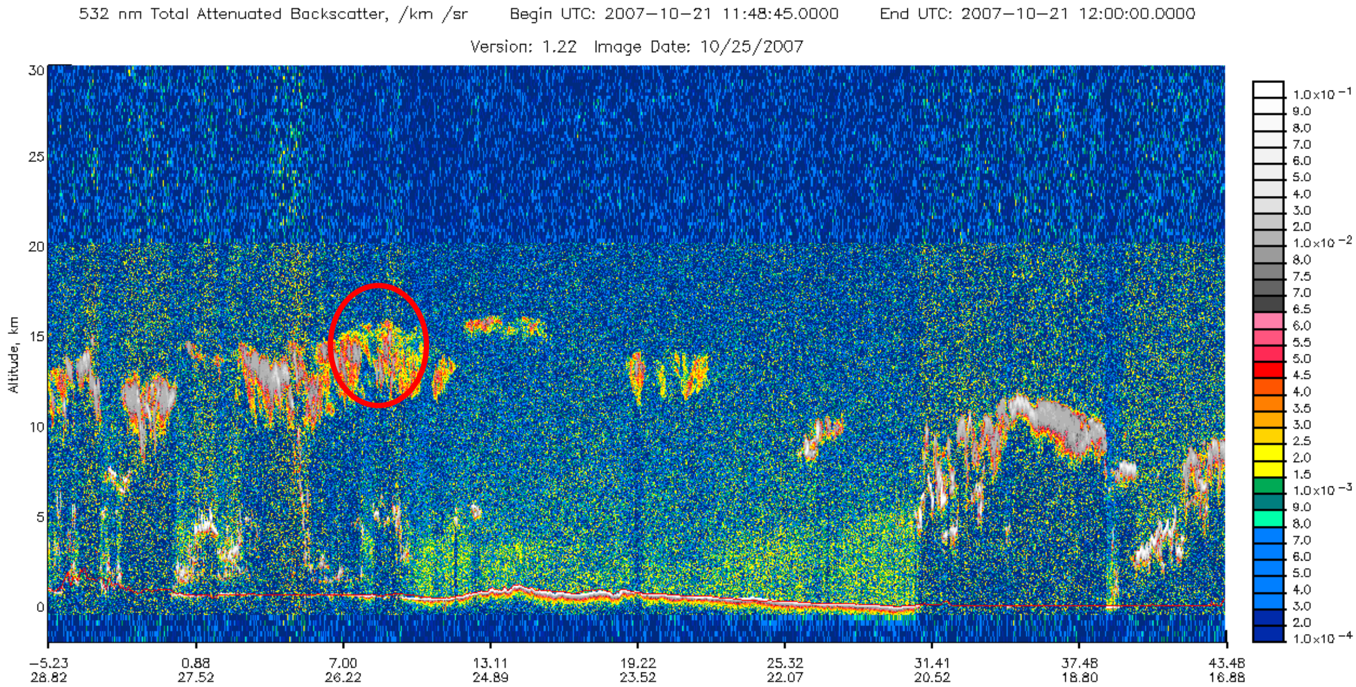
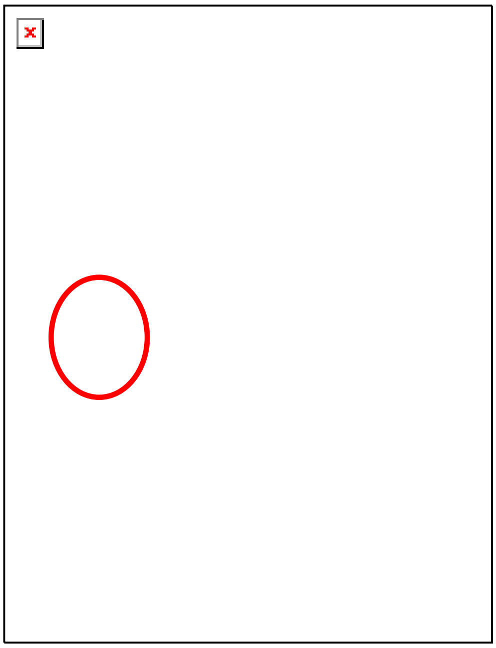


Figure 5 Cross-section of CALIPSO backscatter values. The cloud target inside the red ellipse is discussed in the text.

Figure 6 shows another example of two AMV cases, this time located at approximately 2° S, 28° E, on the 21st of October 2007, around 11:45 UTC. The CALIPSO data suggest a cloud-top height around 190 hPa. The first AMV shows very mixed results: the two CO_2 methods failed, whereas most STC methods are in reasonable agreement with the CALIPSO height. But the AMV decision tree selects the EBBT pressure as the final height, which is too low in the atmosphere. The second AMV, which represents the more opaque parts of the cloud feature, yields heights that are mutually very consistent, albeit too low in the atmosphere. In this case the CO_2-12.0 method provides the final AMV height.

These and other cases give useful information about the reliability and robustness of the various height assignment methods. The results were rather unsatisfactory though, because no clear pattern arose about which methods perform better under certain circumstances than other methods. The case study, on the other hand, confirmed the positive bias, found by the best-fit analysis for high level clouds.



Method	AMV-1 heights	AMV-2 heights
EBBT	**270 hPa**	260 hPa
STC-6.2	175 hPa	245 hPa
IR/WV-6.2	175 hPa	230 hPa
STC-7.3	135 hPa	255 hPa
IR/WV-7.3	185 hPa	235 hPa
CO_2-10.8	-	240 hPa
CO_2-12.0	-	**250 hPa**

Figure 6 Cross-section of CALIPSO backscatter values. The AMV heights in the table above correspond with the cloud target inside the red circle.

6. FUTURE DEVELOPMENTS

AMV derivation is mainly a task of tracking cloud features and assigning a height to the tracked feature. It is therefore important to base the height assignment on those pixels that actually contribute to the tracking. Borde and Oyama (2008) have shown that the identification of the pixels that contribute most to the peak in the cross-correlation surface is straight-forward and that the heights derived with these pixels are more consistent. This method will be investigated at EUMETSAT in 2008.
A height consistency check will also be introduced in 2008. This will be based on an inter-comparison of the individual height assignment results.
Meteosat-8 will provide rapid scan images from its new position at 9.5° E, starting in Spring 2008. EUMETSAT will disseminate AMVs derived from these images, with a frequency of three products per hour.

7. CONCLUSIONS

Algorithm changes were introduced in early 2007, leading to a small improvement of the wind quality. The introduction of the so-called dynamic clustering as a means of defining cloud targets increased the number of well-defined targets and led to a small increase in the pressure values associated to these targets.
A best-fit analysis with forecast data showed a large positive pressure bias for high level clouds. This feature was evident for all height assignment methods.
A comparison of the AMV heights with cloud-top heights detected by CALIPSO yielded some interesting, but not altogether satisfactory results. The main conclusion is that it is difficult to tell which height assignment method is more reliable under certain circumstances than other methods.

8. BIBLIOGRAPHIC REFERENCES

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