AMV HEIGHT ASSIGNMENT WITH METEOSAT-8: CURRENT STATUS AND FUTURE DEVELOPMENTS

A.C. de Smet

EUMETSAT
Am Kavalleriesand 31, 64295 Darmstadt, Germany

ABSTRACT

Meteosat-8 commenced routine operations on January 29th 2004. EUMETSAT currently generates atmospheric motion vectors (AMVs) from five Meteosat-8 channels: one visible channel (VIS-0.8, channel 2), one infrared channel (IR-10.8, channel 9), two water-vapour channels (WV-6.2 and WV-7.3, channels 5 and 6), and one high resolution visible channel (HRVIS, channel 12).

The CO_2 slicing method, using the IR 12.0 µm and the IR 13.4 µm channels, is the preferred height assignment method for Meteosat-8 winds. Despite its weaknesses the performance and quality of this method is successful for a large part of the AMVs. Clouds that are highly transparent however, like thin cirrus, are problematic for the CO_2 slicing method. Two separate methods are available to cover the height assignment of these cases. The Semi-Transparency Correction (STC) method assumes a linear relationship between the infrared and water vapour radiances of the pixels that represent the cloud scene. It tries to fit a line through the cloudy radiance on the one hand and a cloud-free radiance on the other hand. The intersection point of this line with the so-called opaque cloud curve, which represents imaginary, opaque clouds at different levels in the atmosphere, yields the cloud height.

The IR/WV ratioing method is very similar to the STC method, but it relies on fitting a line through the individual cloud pixel radiances, without using the cloud-free radiance. It turns out that this method is very successful in height derivation of clouds that show a large range of transparency. The method does not perform very well for clouds with a uniform transparency because the error margins become very large. But these are exactly the cases for which the STC method is successful. Experience has shown that the STC and the IR/WV ratioing methods are complementary, in the sense that when one of them fails to derive the height of a semi-transparent cloud successfully, the other will be successful, and vice versa.

This paper will discuss a number of AMV cases, showing the merits and shortcomings of the available height assignment methods. Plans for further improvement will also be presented.

1. INTRODUCTION

Discussions about the merits of atmospheric motion vectors (AMVs) to numerical weather prediction (NWP) tend to finish with two conclusions:

1) Yes, AMVs have a positive impact on forecast quality,
2) No, we still do not know enough about the errors in the AMV height assignment.

These statements have become the mantras of satellite wind derivation.

The NWP community is eager to obtain better error estimates for the heights assigned to the winds, not just to filter out poor winds but also to weight the individual AMVs against each other. There is an increasing pressure on wind providers to attach to the AMVs better estimates of the height error.

2. CURRENT OPERATIONAL SET-UP

Table 1 lists the Meteosat 8 channels for which AMVs are derived operationally. Five channels are currently operational for AMV generation. Each of these extract motion vectors from the displacement of cloud targets, whereas the two water-vapour channels derive clear-sky winds as well.

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

Although a large number of height assignment methods is available for deriving target heights, only two of them are used operationally for cloudy targets, see Table 2.

The CO_2-12.0 method is the preferred method. This implies that an AMV will be assigned the CO_2-12.0 pressure if it meets each of the following criteria:

a) The CO_2-12.0 method is successful,
b) The CO_2-12.0 pressure is lower than the EBBT pressure, and
c) The CO_2-12.0 temperature is lower than 253 K.,

In all other cases the AMV will be assigned the EBBT pressure.

Section 3 will discuss the CO_2-10.8 and CO_2-12.0 methods in detail, Section 4 will deal with the semi-transparency methods.

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	no
STC 7.3	IR 10.8 + WV 7.3	semi-transparent clouds	no
IR / WV 6.2	IR 10.8 + WV 6.2	semi-transparent clouds	no
IR / WV 7.3	IR 10.8 + WV 7.3	semi-transparent clouds	no
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. CO_2 SLICING METHOD

The CO_2 slicing method, also known as the CO_2 ratioing method, is based on the radiance ratio between two channels: one CO_2 absorption channel and one window channel. The method will only yield satisfactory results when the main assumption is met: that the emissivity of the tracked cloud is the same for the CO_2 channel and the window channel.
For Meteosat-8 the CO_2 channel has a central wavelength of 13.4 μm. There are two window channels available: the IR-10.8 and the IR-12.0 channel. This results in two CO_2 height assignment methods, the CO_2-10.8 and the CO_2-12.0 method. The latter is used operationally, the former is derived for comparison only.
The height derivation with this method consists of three steps.
The first step is to derive the ratio for the observed cloud target:

$$\mathrm{Ratio}_{\mathrm{obs}} = (R_{\mathrm{cf}} - R_{\mathrm{cld}})^{13.4\,\mu\mathrm{m}} \;/\; (R_{\mathrm{cf}} - R_{\mathrm{cld}})^{12.0\,\mu\mathrm{m}} \qquad [1]$$

where R_{cf} is the radiance of a cloud-free scene and R_{cld} is the radiance of our cloud target.

The second step is to derive ratios for a large number of atmospheric levels, based on forecast profile data:

$$\mathrm{Ratio}^{i}_{\mathrm{fc}} = (R_{\mathrm{surf}} - R^{i}_{\mathrm{bcld}})^{13.4\,\mu\mathrm{m}} \;/\; (R_{\mathrm{surf}} - R^{i}_{\mathrm{bcld}})^{12.0\,\mu\mathrm{m}} \qquad [2]$$

where R_{surf} is the radiance at the bottom of the atmosphere and R^{i}_{bcld} is the radiance of an imaginary, opaque cloud at level i (and which can be treated as a perfect black radiator).
The third and final step is to determine the pressure level at which the forecast ratio becomes identical to the observed ratio. Figure 1 is a visual representation of the method.

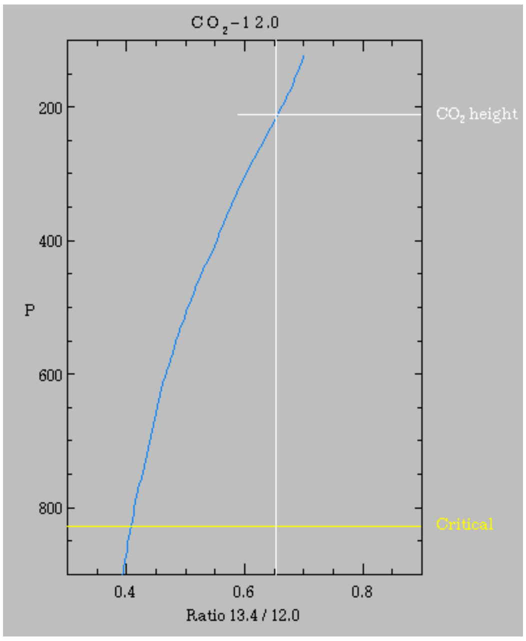


Figure 1 Visual representation of the CO_2 height assignment method, with ratio (between IR-13.4 and IR-12.0 channel radiances) on the x-axis and pressure on the y-axis. The vertical, white line indicates the observed ratio, whereas the blue curve represents the ratios derived from the forecast profile data. The intersection point between the white line and the blue curve yields the CO_2 height. Solutions below the critical level (the yellow line) are invalid, because of poor signal-to-noise ratios of the IR-13.4 channel.

CO_2-10.8 versus CO_2-12.0 method

The assumption that the cloud emissivity is the same in the CO_2 channel (IR-13.4) and the window channel is usually met, but can not be guaranteed for each individual cloud target. Violation of this assumption is more likely to occur with the IR-10.8 channel than with the IR-12.0 channel, as the latter is closer to the CO_2 channel in terms of wavelength. This is the main argument to apply the CO_2-12.0 method as the operational one.
I have studied many cloud targets, including opaque, semi-transparent and broken clouds, and compared the results of both CO_2 methods.
The CO_2-12.0 method has a slightly lower failure rate than the CO_2-10.8 method: 20 % against 25 % of all cases. There are two causes for potential failure of the CO_2 method:

1) either the radiance contrast between cloud target and cloud-free scene is too small, leading to invalid ratios,

2) or the pressure is larger than the critical pressure, in which case the result is rejected and the method is said to have failed.

The CO_2-10.8 method yields consistently lower pressure values than the CO_2-12.0 method. For opaque clouds the difference is around 10 hPa, for semi-transparent and broken clouds the difference is approximately 30 hPa. Larger pressure differences have been observed for cases with very thin cirrus.

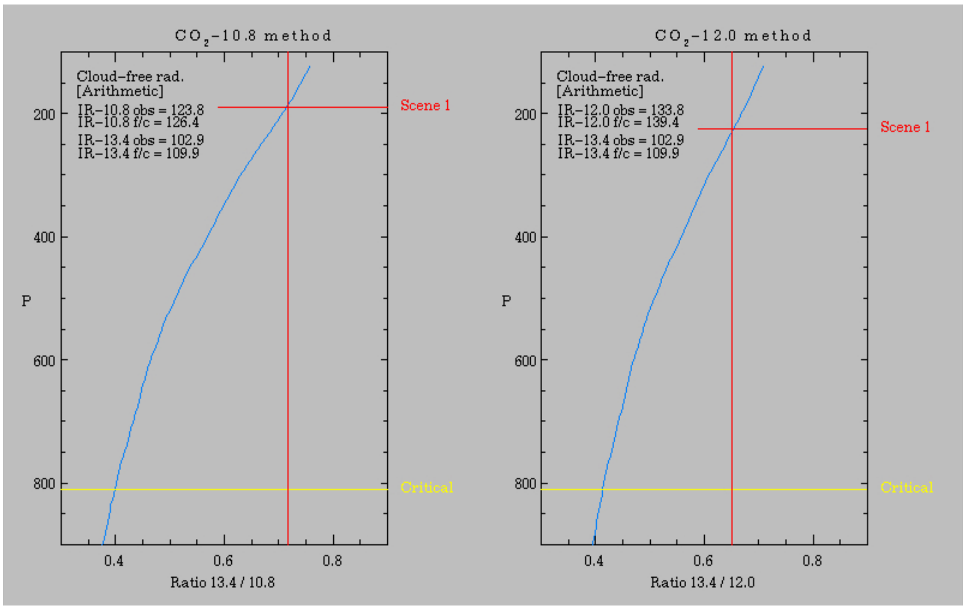


Figure 2 Comparison of the CO_2-10.8 and the CO_2-12.0 methods for a semi-transparent cloud.

Multiple-layer clouds

Cloud targets do not always represent well-defined, single cloud layers. They will often contain contributions from two or more cloud features at different levels in the atmosphere, some of them opaque, others semi-transparent or broken. They pose at least two problems.

Firstly, it is not always clear which part of the cloud target is being tracked: is it the higher cloud, which occupies only a small area of the total cloud target, but shows a large brightness contrast, or is the vast, low cloud, which is much bigger but has a relatively small brightness contrast? Tracking algorithms are not well-suited to identify unambiguously the cloud pixels that contribute to the tracking. It is therefore not always possible to select the proper pixels for the height assignment.

Secondly, even if the appropriate pixels are used for the height assignment they may contain radiance contributions from other cloud layers. In the worst case this will result in a pressure value that is somewhere in between two cloud layers.

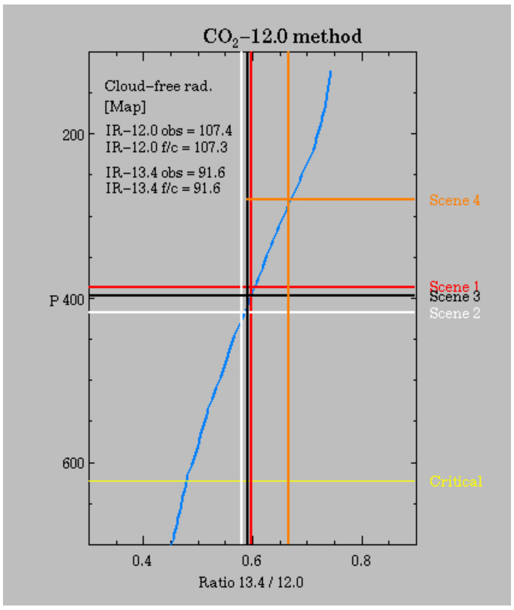


Figure 3 CO_2-12.0 results for a multiple-layer cloud. There are four different cloud scenes, but the CO2 height assignment puts them at two different levels, one at 280 hPa and an other one close to 400 hPa. In this very case that matched very well with the forecast profile.

Figure 3 shows an example of a multiple-layer cloud case. Animation of the visible and infrared channel images suggest the presence of two distinct cloud features. This is supported by the forecast data, which show two peaks in the local humidity profile, one at high level and another one at medium level. The EUMETSAT cloud analysis algorithm identifies four different cloud scenes, which are put at two different cloud levels by the CO_2-12.0 method, at 280 hPa and 400 hPa.

The consistency between the three scenes around 400 hPa is striking. This has been observed for many other cases as well. But it is not always as good as this. Other cases show less favourite results and it is not always possible to identify the circumstances that will lead to positive results. One important condition, that will be discussed in the next section, is the accurate definition of the cloud-free radiance.

A tale of two cloud targets

The CO_2 method gives in general satisfactory results. But in some cases the method fails or yields unrealistic pressure values, even for well-defined cloud targets that are neither too thin nor too low in the atmosphere. After studying many cases the conclusion is that the CO_2 method is very sensitive to the cloud-free radiance and that inaccurate values thereof will almost always lead to erroneous heights.

Consider the case of two cloud targets over Western Africa, which are only 85 kilometers apart and are representative of the same cloud system. The radiance scatter plots are very similar for both cloud targets, see Figure 4. There is one major difference: in one case the cloud-free radiances are derived from the cloud-free pixels within the target area, but in the other case these have been derived from the forecast data. The reason for this discrepancy is the number of cloud-free pixels in the target area; if this number is lower than a pre-defined threshold value (currently 20 pixels), the cloud-free radiances will be derived from the forecast data. If the forecast is too far off the results will be plain wrong.

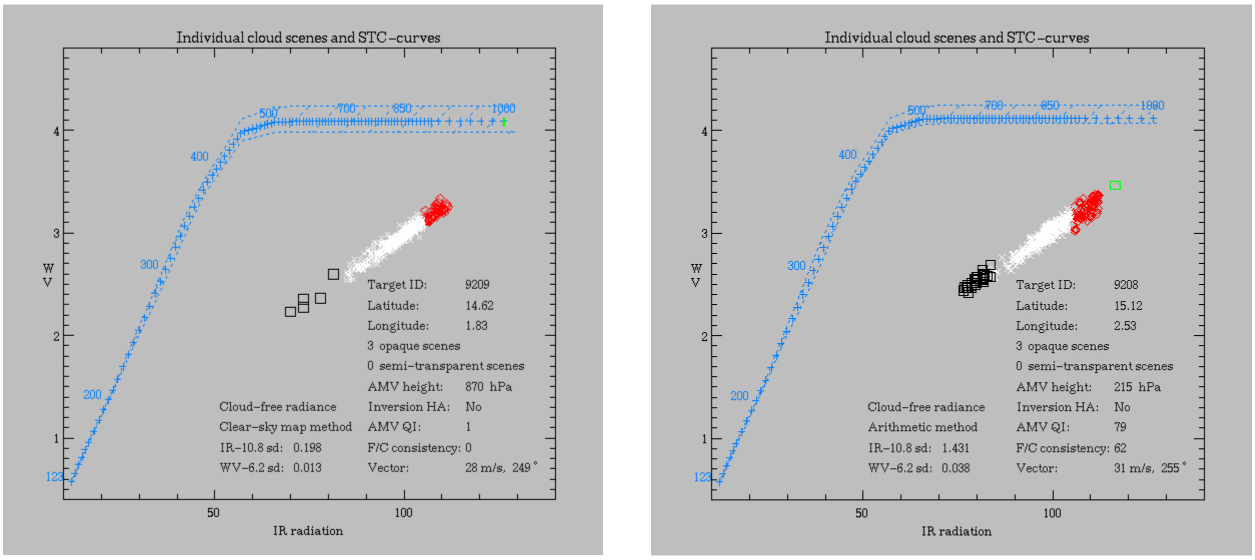


Figure 4 Radiance scatter plots, with IR-10.8 radiance (x-axis) versus WV-6.2 radiance (y-axis). The blue curve represents imaginary, opaque clouds at various atmospheric levels. The black, white and red symbols indicate cloud pixels for three different cloud scenes. The green rectangle represents the cloud-free radiance. The two plots refer to two different target areas, which were only 85 kilometers apart and contained cloud features from the same dynamic system.

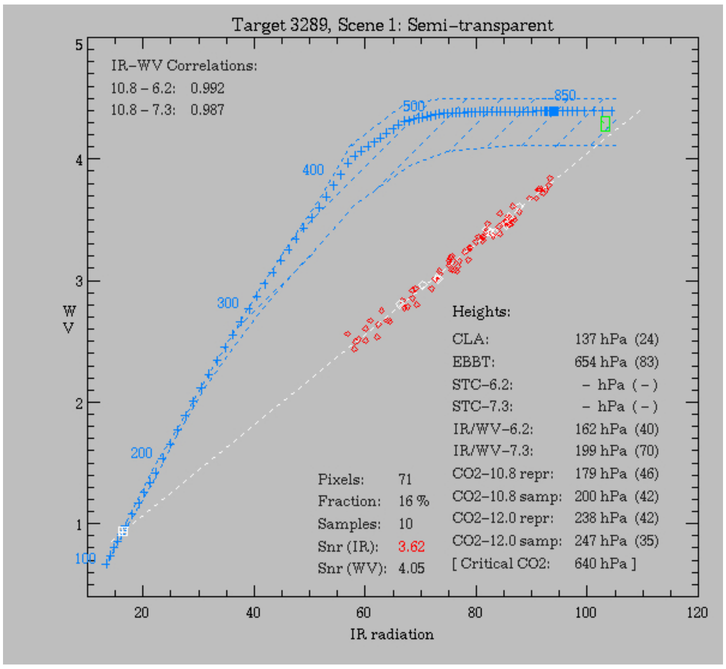
And that is exactly what happens. In the first case the CO_2 method relies on cloud-free radiances derived from forecast data. These do not even come close to the true values; as a result the height assignment algorithm fails to yield a valid solution. The second target contains enough cloud-free pixels to derive proper cloud-free radiances. This results in a CO_2 height around 220 hPa, in very good agreement with the forecast profile.

From this we can conclude that the CO_2 method is very sensitive to the cloud-free radiances and that satisfactory results can only be expected when accurate cloud-free radiance values are available.

4. SEMI-TRANSPARENCY METHODS

EUMETSAT applies two classes of semi-transparency height assignment methods: the semi-transparency correction (STC) methods and the infrared water-vapour ratioing (IR/WV) methods.
The semi-transparency correction (STC) method is based on the assumption that the relation between the water-vapour radiances (WV 6.2 or WV 7.3) and the infrared radiances (IR 10.8) of the cloud target are approximately linear (Schmetz et al., 1993). The actual cloud height can be found by calculating the intersection point between the line connecting a cloud-free scene and the cloud target on the one hand, and the semi-transparency curve on the other hand; see Figure 5.
The infrared water-vapour ratioing (IR/WV) method is similar to the STC method, the main difference being that a straight line is fitted through the cloud pixels, this time not taking into account the cloud-free scene.

Figure 5 Height assignment with the semi-transparency correction (STC) method and the infrared water-vapour ratioing (IR/WV) method



The STC and IR/WV methods are not yet operational at EUMETSAT. There are several reasons for this. In the first place, the methods show a relatively large rate of failure. The STC-6.2 method fails in 38% of all cases, for the IR/WV-6.2 method this figure is even 55%. In the second place, both methods have shown a clear bias, with pressure values that are much lower than the CO_2 methods.
There have been positive developments in both problem areas which will be discussed in the remainder of this section.

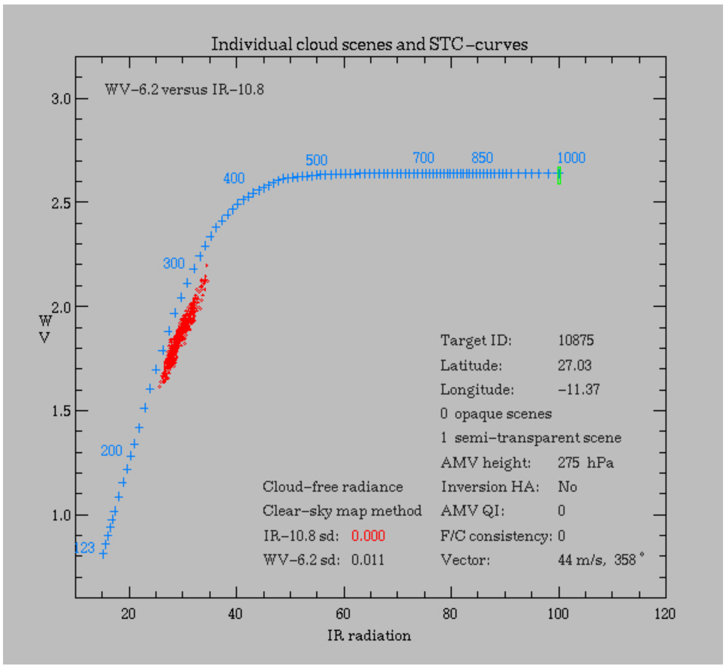
Success rates
Despite a lot of effort, including the tuning of several parameters and the relaxation of thresholds, it has not been possible to increase significantly the success rates of the STC and IR/WV methods. It is clear that when these methods fail they do so for good reasons. The STC method, for example, will fail when the radiance contrast, in either the infrared channel or the water-vapour channel, is larger than a predefined value. This is actually the case in Figure 5: the range of pixel radiances is very large, leading to an IR-10.8 signal-to-noise ratio of only 3.62, which is well below the lower threshold of 6.0. Relaxing this threshold is possible, but will very often lead to erroneous results or to very large error margins.
The IR/WV method is the counter part of the STC method. It needs a large range of pixel radiances to be able to fit a straight line through them. The smaller the radiance contrast the more likely it is to fail.
This leads to the conclusion that the STC and IR/WV methods complement each other: the former needs a small range of pixel radiances to be successful, the latter needs a large one. And a closer look at the success rates of both methods confirms this:

- in 62% of all cases the STC-6.2 method is successful,
- in 45% of all cases the IR/WV-6.2 method is successful,
- in 74% of all cases either the STC-6.2 or the IR/WV-6.2 method is successful.

This 74% success rate comes close to those of the CO_2-12.0 and CO_2-10.8 methods, which are 80% and 75%, respectively.
The deployment of the semi-transparency methods in an operational scheme requires a rather sophisticated decision tree.

Bias
After investigating many cloud cases it became clear that there must be a bias in the WV-6.2 channel radiances. Scatter plots for opaque cloud pixels showed a systematic discrepancy between the pixel radiances and the opaque cloud curve, as in Figure 6. Under ideal circumstances the pixel radiances should coincide with the opaque cloud curve. For the WV-7.3 channel they actually did for a large majority of the cases. But in the case of the WV-6.2 channel the pixel radiances were systematically below the curve, indicating a 'cold' bias.
There were at the same time indications that the WV-6.2 clear-sky radiances showed a 'warm' bias.

Figure 6 Radiance scatter plot displaying opaque cloud pixels, with IR-10.8 radiance (x-axis) versus WV-6.2 radiance (y-axis). The pixel radiances are systematically below the opaque cloud curve (blue).



In April 2006 engineers at EUMETSAT's Image Processing Facility (IMPF) had the bright idea to improve the algorithms that are responsible for the conversion of radiometer counts to radiance values. For most channels the impact was small, but not so for the IR-3.9 and the WV-6.2 channels. At the moment this paper went to press, validation of these changes was still ongoing. But the first results were very promising, with opaque cloud pixels nicely coinciding with the opaque cloud curve.

This should resolve a great part, if not all, of the observed biases in the STC-6.2 and WV-6.2 heights.

Added value
With the CO_2-12.0 method proving to be very successful at assigning heights to AMVs it is fair to ask what could be the added value of the semi-transparency methods. The CO_2 methods are obviously capable of handling all cloud types at medium and high level, whereas the STC and IR/WV methods can only cope with semi-transparent and broken clouds. There are however two reasons to consider these methods seriously.
First, the CO_2 methods are not too happy with very thin cirrus. As in these cases the contrast between cloudy radiance and cloud-free radiance becomes very small the CO_2 algorithm often fails to come up with a proper solution. The semi-transparency methods show a better skill for these cloud types.
Second, the STC and IR/WV methods are useful for comparison with the other height assignment methods. This is not just interesting for academic reasons, but in the first place to obtain a measure of the accuracy of the final AMV height.

The IR-2-WV methods
By combining the STC 6.2 and STC 7.3 methods the cloud top height can in theory be derived by calculating the intersection point between the two regression lines, completely by-passing the semi-transparency curve. This method has the advantage that it is less dependent on forecast profiles, since the semi-transparency curve itself is derived from forecast data. This so-called infrared two-water-vapour (IR two-WV) method comes in two variants: one based on the STC 6.2 and STC 7.3 methods and another one based on the

IR/WV 6.2 and IR/WV 7.3 methods. They are currently not in operational use, but plans to look into them are advanced.

5. CURRENT AND FUTURE ACTIVITIES

AMV height assignment depends in the first place on the accurate identification of cloud targets. Borde (2006) has shown that the current cloud classification scheme deployed by EUMETSAT regularly fails to identify the cloud feature that is actually tracked. This leads to inconsistent AMV heights.

This problem is already being tackled. Borde (2006) has proposed an alternative scheme to identify cloud targets, which is currently under investigation. This new scheme is planned to become operational and therefore take over the current scheme at the end of 2006.

In response to requests by the NWP community to provide better estimates of the height assignment error, EUMETSAT will put effort into deriving such estimates. It is clear that establishing accurate error margins for the AMV heights is not possible, since this would require a detailed knowledge of the contributions of all error sources, including calibration, radiative transfer model and forecast data, which is currently beyond our capabilities. By comparing the results of individual height assignment methods it will be possible to obtain a rough measure of the error margins.

The height assignment for Meteosat-8 winds is currently restricted to just two methods: the CO_2-12.0 and the EBBT method. The STC and IR/WV methods have some added value in that they are more successful at deriving heights for very thin cirrus. They will therefore be included in the operational scheme.

To further improve the CO_2 methods EUMETSAT will also look into a better handling of the cloud-free radiance, reducing the dependence on forecast data.

As an additional quality indicator EUMETSAT will introduce the Recursive Filter Flag (RFF) in the course of 2006 (Dew).

6. CONCLUSIONS

The CO_2 absorption methods show in general good results for medium and high level clouds. The CO_2-12.0 method has a lower failure rate than the CO_2-10.8 method and yields higher pressure values, with differences ranging from 10 hPa (for opaque clouds) to more than 30 hPa (for semi-transparent and broken clouds). One important feature of the CO_2 methods is their sensitivity to the cloud-free radiance. Case studies show that even slightly incorrect values for the cloud-free radiance may lead to completely wrong results. This will happen when insufficient cloud-free pixels are available and, consequently, the cloud-free radiance is derived from forecast data.

The CO_2 methods are sometimes successful at deriving heights for dual cloud layers. Even though this is not directly relevant for AMV height assignment, in which only the highest cloud layer is considered, it confirms the strengths of these methods.

The semi-transparency methods, including the STC and IR/WV ratioing methods, are currently not used in the operational height assignment scheme. Recent improvements in the conversion of radiometer counts to radiance values have removed the cold bias in the WV-6.2 channel, which was the main obstacle to using the semi-transparency methods. It is therefore recommended to re-instate these methods and include them in the operational scheme.

7. BIBLIOGRAPHIC REFERENCES

Niemann, S.J., J. Schmetz, W.P. Menzel, 1993. A Comparison of Several Techniques to Assign Heights to Cloud Tracers. J. Appl. Meteor., **32**, pp 1559-1568.

Schmetz, J., K. Holmlund, J. Hoffman, B. Strauss, B. Mason, V. Gärtner, A. Koch, L. van de Berg, 1993. Operational Cloud-Motion Winds from Meteosat Infrared Images. J. Appl. Meteor., **32**, pp 1206-1225.

Borde, R., 2006. AMV Height Assignment Methods with Meteosat-8. *Submitted to Proceedings of 8th International Winds Workshop*.

Dew, G., 2006. Introduction of the Recursive Filter Flag in MSG MPEF Environment. *Submitted to Proceedings of 8th International Winds Workshop*.