HEIGHT ASSIGNMENT WITH METEOSAT-8: OUR EXPERIENCE SO FAR

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ABSTRACT

On 29th January 2004 the first Meteosat Second Generation satellite MSG-1, renamed to Meteosat-8, commenced routine operations. The generation of atmospheric motion vectors (AMVs) and the subsequent dissemination of AMV BUFR products over the GTS are part of these operations.

AMVs are currently derived from four Meteosat-8 channels: one visible channel (VIS-0.8, channel 2), one infrared channel (IR-10.8, channel 9), and two water-vapour channels (WV-6.2 and WV-7.3, channels 5 and 6). High resolution visible winds, derived from the HRVIS channel (channel 12), will be introduced later this year, whereas the feasibility to generate winds with the IR-3.9 channel (channel 4) are under investigation.

The AMV algorithms benefit from a number of improvements over the algorithms that are used for the first generation of Meteosat satellites. These include better quality control, a better spatial coverage of the AMV product and an improved height assignment for semi-transparent cloud tracers.

This paper describes our experience with the height assignment of Meteosat-8 cloud and clear-sky tracers. It compares the Meteosat-8 winds both with Meteosat-7 winds and radiosonde wind observations. In addition it compares the various Meteosat-8 height assignment methods against each other.

1. INTRODUCTION

The quality of atmospheric motion vectors (AMVs) derived from geostationary satellite imagery has increased gradually. AMVs contribute significantly to the data assimilated by all major numerical weather prediction (NWP) centres and have a proven positive impact on forecast quality. In spite of this, it has been recognised for a long time that the height assignment is still an area of concern. This is in the first place due to the complex nature and diversity of the tracers. Are we dealing with multi-layered clouds? Is the cloud opaque or semi-transparent, or maybe broken? Does this cloud coincide with a temperature inversion? These and other questions require attention in the process of assigning heights to cloud targets.

For the first generation of Meteosat satellites, of which currently Meteosat 5 to Meteosat 7 are still in use, the height assignment of cloud targets was basically limited to one method for opaque clouds (EBBT method) and one for semi-transparent clouds (the Semi-Transparency Correction, or STC, method). With the second generation of Meteosat satellites more spectral channels are available and as a direct consequence a wider range of height assignment methods. These methods will be subjected to constant validation and scrutiny in the next coming years, gradually optimising the algorithms and fine-tuning the set-up parameters, leading to an improved height assignment of the AMVs.

2. CURRENT OPERATIONAL SETUP

Table 1 lists the Meteosat 8 channels for which AMVs are derived operationally. Four 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 range	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

Table 1. Meteosat 8 spectral channels used for AMV derivation.

At the basis of the wind derivation is a one hour sequence of four consecutive images, starting at the top of each hour. The selection of cloud or clear-sky targets takes place for the first image only, using a target area window of 24 by 24 pixels for cloud targets, and 32 by 32 pixels for clear-sky targets. With the use of cross-correlation techniques, each target is then matched with the next image, leading to a displacement vector. The majority of targets can be traced in this way until the fourth image; only a small number will drop out because of poor vector quality. At the end of the hour there will be three intermediate wind components for each target. The information of the components will then be combined to derive a final atmospheric motion vector.

A large number of height assignment methods is available for deriving target heights, a sub-set of which is currently operational, see Table 2. The semi-transparency correction (STC) and infrared water-vapour ratioing (IR/WV) methods are available for semi-transparent clouds only, whereas the various CO_2 ratioing methods are applicable to all cloud types.

The height assignments are derived for each intermediate wind component. The final height is simply an arithmetic average of each successfully applied height assignment method of the individual wind components.

Section 3 describes the operational methods in some detail.

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	no
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	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	yes (four variants)
CO_2 12.0	IR 13.4 + IR 12.0	all clouds	no
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 and operational height assignment methods.

Cloud targets that have heights lower in the atmosphere than 600 hPa and are within a temperature inversion layer, will be assigned a new height that coincides with the bottom of the inversion layer. Low-level clouds that have not been subjected to this so-called inversion height assignment but whose heights are close to the forecasted top of the boundary layer, will be assigned a height that corresponds with the cloud base, rather than the cloud top.

3. HEIGHT ASSIGNMENT METHODS

The equivalent blackbody brightness temperature (EBBT) method is the classical method for deriving a height of a cloud. We use it for opaque clouds only, or for semi-transparent clouds if all other methods have failed.

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 1.

The infrared water-vapour ratioing (IR/WV) method is similar to the STC method, the main difference being that the cloud is sampled by a three by three pixel window, resulting in a cluster of cloud radiances. The line slope and offset are obtained by fitting a straight line through the cloud samples, this time not taking into account the cloud-free scene.

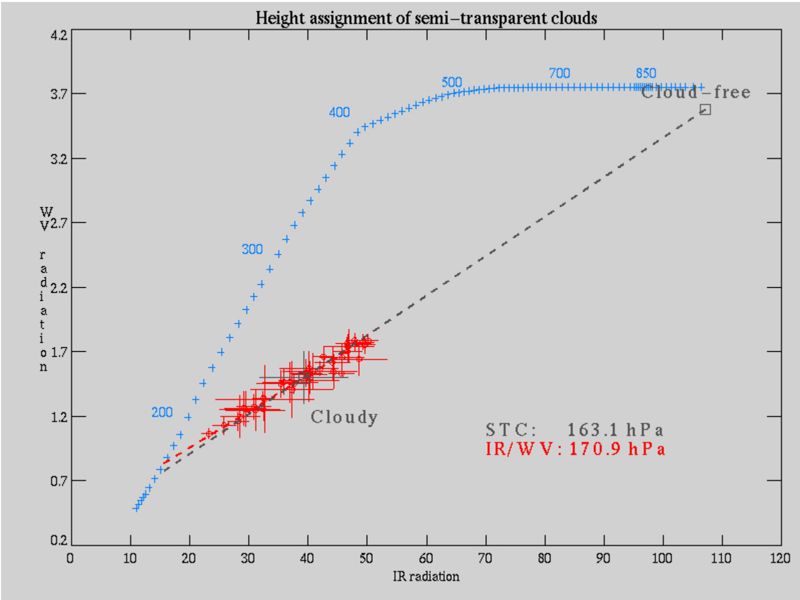

Figure 1. Height assignment with the semi-transparency correction (STC) method and the infrared water-vapour ratioing (IR/WV) method.

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.

The CO_2 ratioing method is based on the assumption that cloud emissivities are equal in the CO_2 channel and in the 10.8 and 12.0 infrared channels (Niemann et al., 1993). It can be applied both to opaque and semi-transparent clouds, although it performs poorly for low-level broken clouds and very thin cirrus, as in those cases the difference between the cloud target radiance and the cloud-free radiance becomes equal to or less than the instrument noise.

For the WV 6.2 and WV 7.3 channels the height estimation of clear-sky heights is based on the normalised total contribution (NTC) and the normalised total cumulative contribution (NTCC) tables, which are provided by the radiative transfer model. These tables indicate for a large number of atmospheric levels how much these levels contribute to the total amount of radiation measured by the satellite radiometer. The first clear-sky height assignment method derives the height at which the NTCC value is 50% of its maximum value. The second method calculates the height at which the NTC curve has a maximum. The third method is a simple EBBT method, calculating the EBBT for the actual water-vapour channel, using the 25% coldest pixels of the clear-sky target.

For a further discussion of the Meteosat 8 height assignment methods, see Borde and Arriaga (2004).

How useful are these height assignment methods in practice? That depends not only on their quality, in terms of bias and standard error, but in the first place on the method's failure rate. Each method has its limitations and can not be expected to be applicable to all cloud tracers under all circumstances. If a method is unsuccessful, e.g. the method's algorithm fails to yield a realistic solution, or the associated standard error is huge, this indicates either that the method is not suitable for the very cloud target being processed or that the algorithm itself is flawed.

The success rates of the operational height assignment methods for one full day of AMVs derived with the IR 10.8 spectral channel are as follows:

1) EBBT method 100%
2) STC 6.2 method 46%
3) IR/WV 6.2 method 30%
4) CO2 10.8 method (variant 1) 78%
5) CO2 10.8 method (variant 2) 75%

The poor success rates of the semi-transparent methods are currently under investigation and seem to be partly explained by tuning parameters that are too strictly set.

4. COMPARISON STUDIES

The quality of the final height assignment depends largely on the quality of the individual height assignment methods. It is therefore important to assess the behaviour of these methods, finding out how often and under which circumstances they fail, and how they compare to other height estimates. We used AMV information from Meteosat 7 and radiosonde profile data to compare the Meteosat 8 AMV heights with. For all channel winds we applied a quality threshold of 0.90, only in the case of clear-sky water-vapour winds we lowered the threshold to 0.70.

The advantage of using Meteosat 7 winds is that it covers the same geographical area, as the sub-satellite longitudes of Meteosat 7 and Meteosat 8 are only 3.3 degrees apart. The number of winds is large, resulting in a vast amount of useful AMV collocations. Moreover, it is fairly easy to identify winds, derived from Meteosat 7 and Meteosat 8 images, that relate to the same cloud target. This enables a direct comparison of Meteosat 7 and Meteosat 8 AMV heights. On the other hand, the quality of Meteosat 7 AMV heights is itself limited and the AMVs from both satellites are not completely independent, since the height assignment algorithms are partly based on the same physics and the same assumptions.

The advantage of radiosonde profiles is that the data are of high quality and constitute a really independent source of information. The disadvantage is the relatively poor distribution of radiosonde profiles, especially over the oceans, yielding a limited number of collocations.

Figure 3 shows a comparison between the Meteosat 7 and Meteosat 8 height assignments of opaque clouds for the IR 10.8 channel. The horizontal axis represents the heights of the Meteosat 7 infrared winds, whereas the vertical axis represents the Meteosat 8 IR 10.8 winds. From left to right the plots show the following heights: final height, EBBT height, and CO_2 10.8 height.
There is a lot of scatter in these plots, especially between the surface and the 650 hPa level, and the correlations are not impressive. Above 650 hPa, the CO_2 10.8 heights are more consistent with the Meteosat 7 heights. Part of the scatter can be explained by differences in cloud target analysis, implying that the Meteosat 7 targets do not always match with the Meteosat 8 targets.

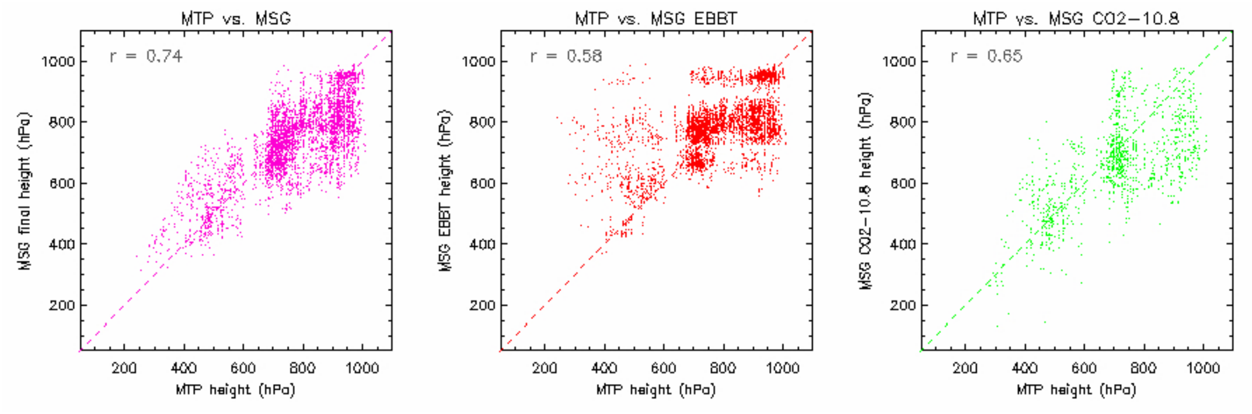

Figure 3. Collocations between Meteosat 7 heights (horizontal axis) and Meteosat 8 heights for opaque clouds, derived from IR 10.8 channel images.

Figure 4 is similar to Figure 3 but represents semi-transparent clouds rather than opaque clouds. From top left to bottom right it shows the following heights: final height, STC 6.2 height, and CO_2 10.8 height. The last plot compares the IR/WV 6.2 height against the STC 6.2 height.

In this case the correlations are better. The STC 6.2 method shows a bias compared to the Meteosat 7 heights, putting the AMVs approximately 50 hPa higher in the atmosphere. It is currently not understood what is the cause of this discrepancy.

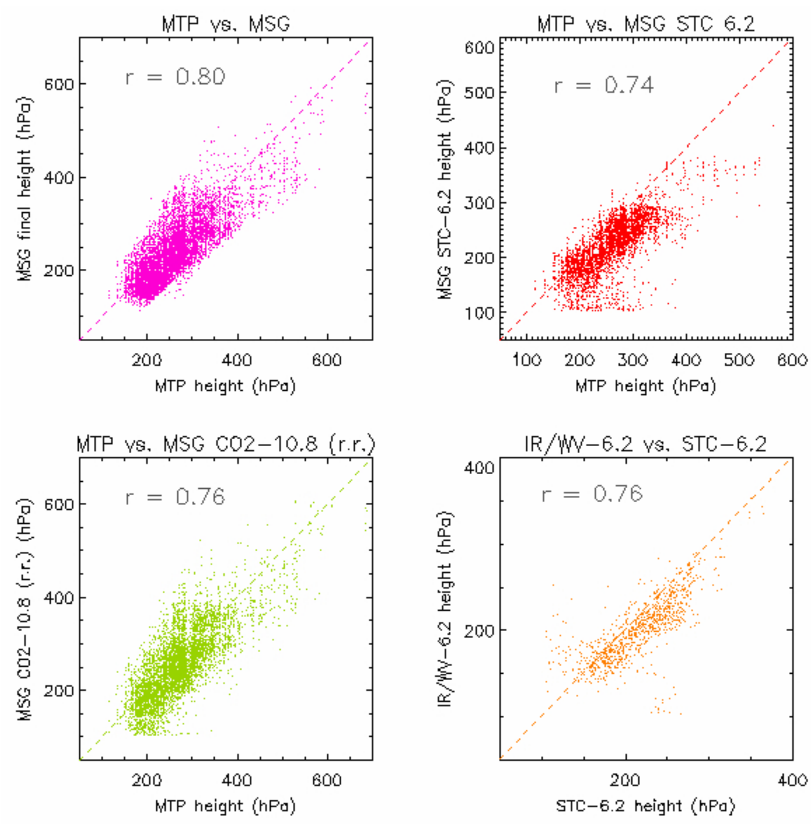

Figure 4. Collocations between Meteosat 7 heights (horizontal axis) and Meteosat 8 heights for semi-transparent clouds, derived from IR 10.8 channel images.

Figure 5 shows a comparison between the Meteosat 7 and Meteosat 8 height assignments of opaque and semi-transparent clouds for the WV 6.2 channel. The horizontal axis represents the heights of the Meteosat 7 high-resolution water-vapour winds, whereas the vertical axis represents the Meteosat 8 WV 6.2 winds.

From left to right, top to bottom, the plots show the following heights: final height, STC 6.2 height, and CO_2 10.8 height. The last plot compares the IR/WV 6.2 height against the STC 6.2 height.

The correlations are poor but the overall picture is roughly consistent with the IR 10.8 winds. The Meteosat 8 final height, which is an average of the individual height assignment methods, is mainly determined by the CO_2 10.8 method, since the semi-transparent methods have such a high failure rate. Above 300 hPa the CO_2 method shows a strong positive pressure bias. This is possibly related to thin cirrus which is known to cause difficulties for the CO_2 method, as the contrast between cloudy and clear-sky radiances becomes very small in that case.

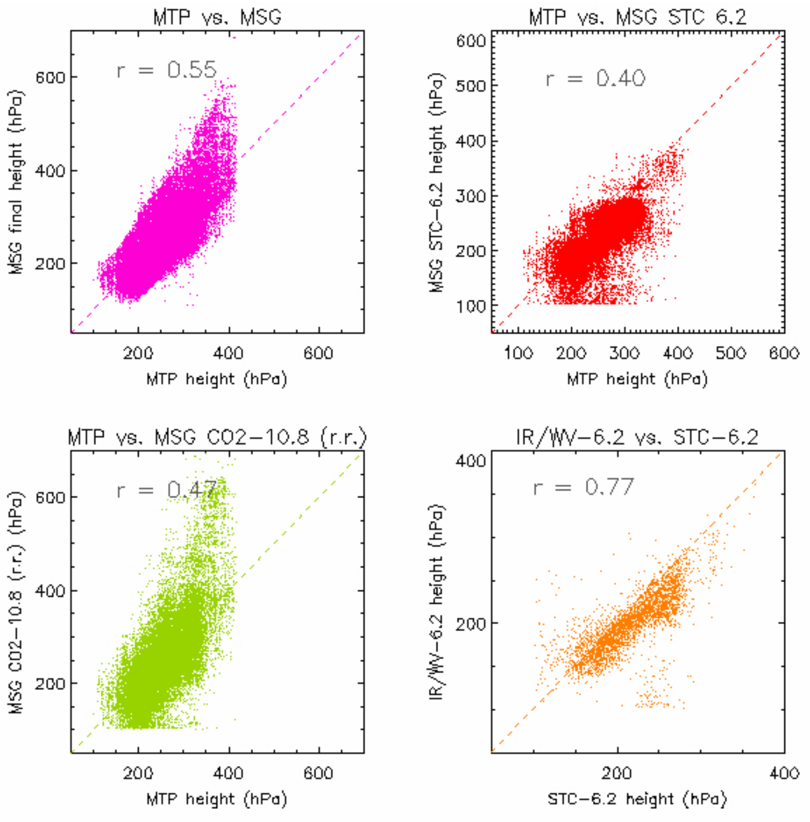

Figure 5. Collocations between Meteosat 7 heights (horizontal axis) and Meteosat 8 heights for clouds, derived from WV 6.2 channel images.

Figure 6 compares the Meteosat 7 and Meteosat 8 height assignments of clear-sky targets for the WV 6.2 channel. The horizontal axis represents the heights of the Meteosat 7 water-vapour winds, whereas the vertical axis represents the Meteosat 8 WV 6.2 winds. From left to right the plots show the following heights: NTCC 50% height, NTC peak height, and EBBT height.

The NTCC 50% method shows a negative pressure bias of 50 hPa. Since this method relies mainly on forecast data being fed into a radiative transfer model, which is very similar for Meteosat 8 and Meteosat 7, this bias is probably due to differences in spectral channel characteristics.

The NTC peak heights are in general consistent with the Meteosat 7 heights. The EBBT method, which uses the 25% coldest pixels of the clear-sky target, has a negative bias of 100 hPa, which indicates that the threshold of 25% is too low.

Radiosonde profile data are very useful in assessing satellite derived AMVs. In this case we compare wind speeds at the pressure level corresponding with the AMV height assignment. Figure 7 compares radiosonde wind speeds with VIS 0.8 Meteosat 8 wind speeds, for the EBBT height and the CO_2 10.8 height.

The level of correspondence is in general high and especially the CO_2 10.8 method is in this respect very successful.

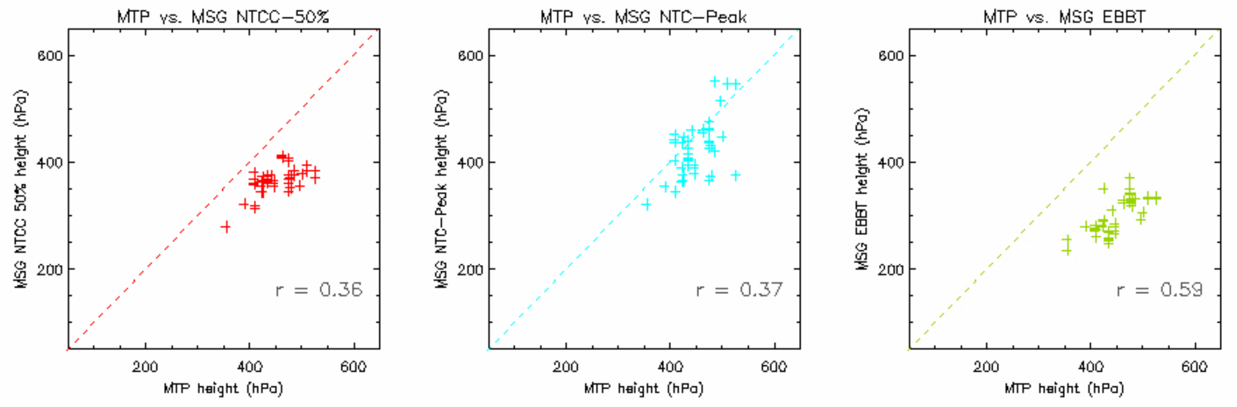

Figure 6. Collocations between Meteosat 7 heights (horizontal axis) and Meteosat 8 heights for clear-sky targets, derived from WV 6.2 channel images.

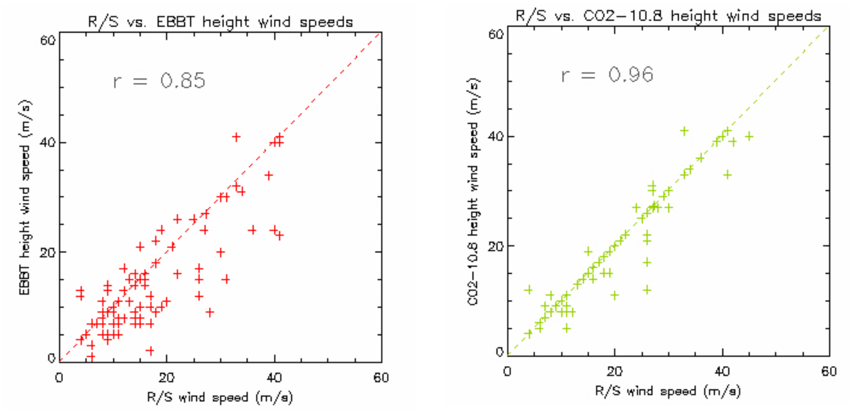

Figure 7. Collocations between radiosonde wind speeds (horizontal axis) and VIS 0.8 Meteosat 8 wind speeds at the following atmospheric levels: (left) EBBT height, and (right) CO_2 10.8 height.

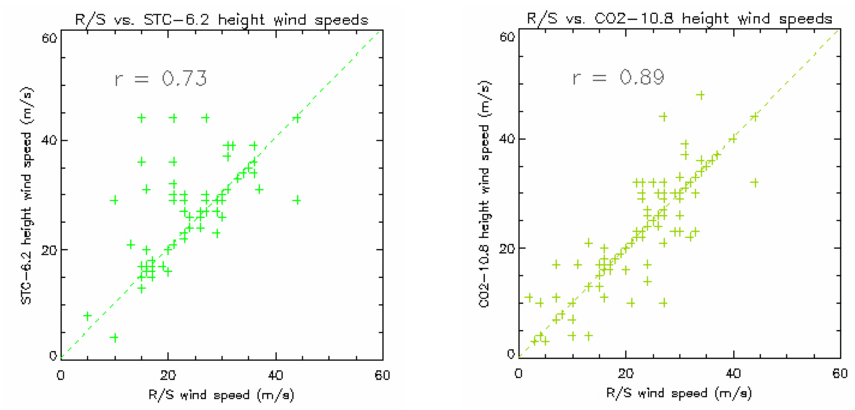

Figure 8. Collocations between radiosonde wind speeds (horizontal axis) and IR 10.8 Meteosat 8 wind speeds at the following atmospheric levels: (left) STC 6.2 height, and (right) CO_2 10.8 height.

Figure 8 compares radiosonde wind speeds with IR 10.8 Meteosat 8 wind speeds, for the STC 6.2 height and the CO_2 10.8 height. The Meteosat 8 wind speeds at the STC 6.2 heights are in general higher than the radiosonde ones. This indicates that the STC 6.2 heights are too high in the atmosphere, confirming our conclusions about the STC 6.2 method when making comparisons with Meteosat 7 heights (Figures 4 and 5).

5. CURRENT AND FUTURE ACTIVITIES

After four months of operational Meteosat 8 wind derivation, the first signs are that a significant proportion of winds is of good quality and compares well with independent measurements. At the same time it is clear that there is ample scope for improvement of the height assignment. The first priority is to improve the success rates of the individual height assignment methods, especially those of the STC and IR/WV methods, which currently fail in the majority of cases.

We also feel that the current approach to derive a final height, by simply taking the average of all successful height assignment methods, is not good and should be replaced by a so-called sequential approach. This implies that the final height is in principle equal to the CO_2 10.8 height. If the CO_2 10.8 height is not available, then the STC 6.2 height should be used. If this height is not available, then the EBBT height should be used. This sequence is just an example, alternative sequence definitions may also be considered.
Tuning of set-up parameters is an on-going activity that will gradually pay off in improved wind quality.

In the course of 2004 we will start trials with the other available, but not yet operational, height assignment methods:

1) The STC 7.3 method,
2) The IR/WV 7.3 method,
3) The IR two-WV method,
4) CO_2 methods using the IR 12.0 channel.

An important contribution to height assignment validation will come from an external study, performed by a consortium of the Free University of Berlin (Germany), the Institute of Geodesy and Photogrammetry in Zürich (Switzerland), and the Appleton Rutherford Laboratory (United Kingdom). The aim of the study is to compare the Meteosat 8 AMV heights with independent observations and methodologies, including MODIS and MERIS data (CO_2 slicing, oxygen A-band), MISR and AATSR data (stereo heights), as well as data from Lidar, Radar and radiosonde instruments.

6. CONCLUSIONS

First results with Meteosat 8 wind extraction and height assignment are encouraging. Comparisons between the Meteosat 8 winds on the one hand and Meteosat 7 winds and radiosonde winds on the other hand show in general a good level of agreement. But there is certainly room for improvement. The failure rate of the semi-transparent methods is currently between 50 and 70% and this must clearly be improved.

The CO_2 absorption method is a new method that was not available before to Meteosat AMVs. It shows very promising results for medium and high level clouds.

The final AMV height is currently the average of all successful individual height assignment methods. This approach is not appropriate, as too much useful information is lost in the averaging process, putting too many winds in the middle of the atmosphere.

7. REFERENCES

Borde, R., A. Arriaga, 2004. Atmospheric Motion Vector Height Assignment Techniques with Meteosat 8. Proc. 7^{th} International Winds Workshop, EUMETSAT (This publication).

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.