

# Numerical Weather Prediction

## MSG wind height assignment problems



Forecasting Research Technical Report No. 469

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A decorative wavy line that starts on the left, dips down, rises up, and then dips down again towards the right.

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### Document History

Date	Version	Action	Approval
31/8/2005	1.0	First version of the report	R. Saunders
1/12/2005	2.0	Amended version of the report	J. Eyre
5/1/2006	3.0	Amended version of the report	M. Forsythe

## 1. Introduction

A proper specification and analysis of winds is an important prerequisite to accurate numerical model forecasts. Winds have been derived from satellite imagery since the 1960s when the first TIROS polar orbiting satellites gave cloud pictures which showed the potential of inferring atmospheric motion (Fujita, 1968). Since then, atmospheric wind vectors have been derived operationally (Menzel, 2001, Velden et al. 2005). The basic elements of wind vector production have not changed since their inception. These are: (a) selecting a feature to track; (b) tracking the target in a time sequence of images to obtain a relative motion; (c) assigning a pressure height (altitude) to the vector; and (d) assessing the quality of the vector.

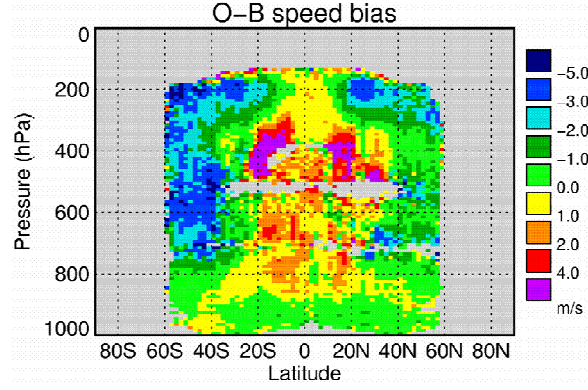
The basic concept behind the cloud drift winds is that some clouds are passive tracers of the atmosphere's motion in the vicinity of the cloud. However, clouds grow and decay with lifetimes which are related to their size. To qualify for tracking, the tracer cloud must have a lifetime that is long with respect to the time interval of the tracking sequence. The cloud must also be large compared with the resolution of the images. This implies a match between the spatial and temporal resolution of the image sequence. It must be recognized that cloud winds represent a limited and meteorologically biased data set. The cloud winds generally yield measurements from only one level (the uppermost layer of the cloud) and from regions where the air is going up (and producing clouds). Schmetz and Nuret (1993) gave the following postulate: "cloud motion wind (CMW) could give an unbiased estimate only if clouds were conservative tracers randomly distributed within and floating with the airflow". Obviously this postulation is hardly fulfilled. Some clouds do not move with the wind while others follow the wind at a level lower than cloud top (convective cloud system, wave clouds). The wind height assignment remains the most challenging task in the wind processing task. As winds are routinely assimilated in numerical weather prediction (NWP) models it is very important to understand where the potential errors are in the height assignment.

Meteosat second generation (MSG) is a new generation of European geostationary meteorological satellites (Schmetz et al. 2002), the first of which is known as Meteosat-8. The purpose of this report is to evaluate and better understand the new MSG cloud motion winds height assignment. We first describe the technique used to derive a wind vector with MSG. In the following section we compare these winds with other atmospheric motion vectors (AMV) and compare the AMV pressures with two other cloud top pressure datasets: a Met Office cloud top pressure product derived from MSG images and a MODIS cloud top pressure product.

## 2. Motivation

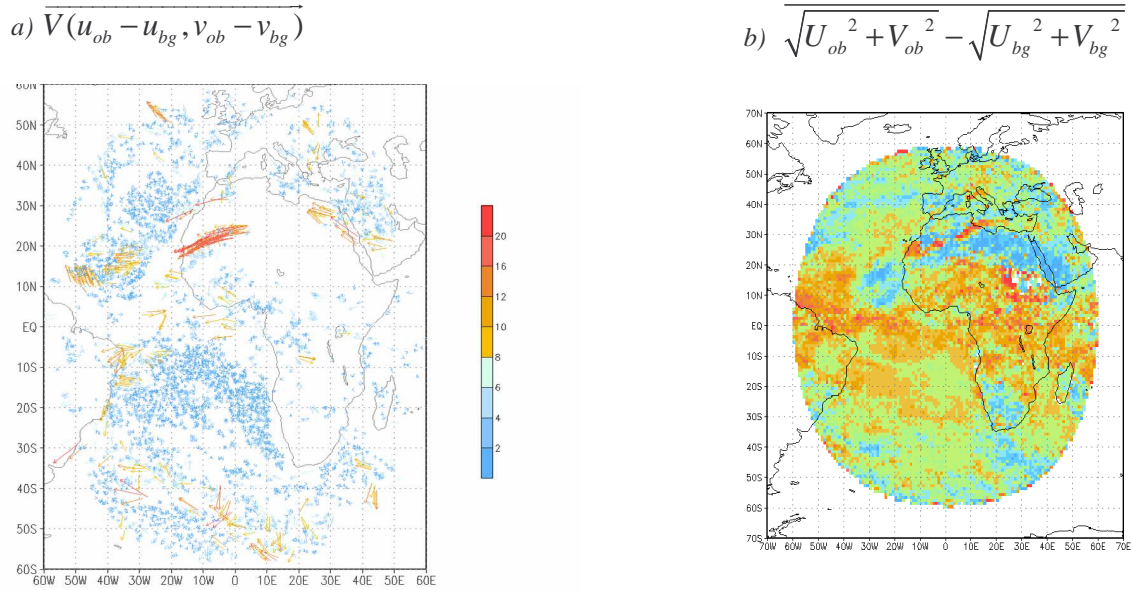
To be able to get more impact from AMV data in NWP it is essential to improve our understanding and representation of the errors, which are hard to characterise and are typically non-Gaussian and correlated. The main source of error in the data is thought to be from the vector height assignment. This study aims to investigate the height assignment of a new AMV dataset from Meteosat-8

Figure 1 shows an example of an observation-background statistics plot for Meteosat-8 IR compared with the Met Office model background.



**Figure 1:** Zonal mean of Meteosat 8 IR observed minus background wind speeds for May 2005.

We can clearly see that there are problems. Some pressure-latitude regions show mean monthly differences between observations and background of more than  $5 \text{ ms}^{-1}$ . When the difference between observation and background speeds is high, it may mean that the wind has not been assigned at the right atmospheric level. There are fast (positive difference) or slow (negative difference) speed biases depending on the region. Some, for example a fast bias observed at mid level over the Sahara desert, may be due to high level faster AMVs being wrongly assigned to mid level where the wind speeds are lower (see Figure 2).



**Figure 2:** a) 13 April 2005, 10:30UTC, MSG wind speed (m/s) Observation – Background. The colour represents the norm of the difference. Note the large differences over the Sahara. b) 8-day mean of observation-background wind speed on a 1x1 degree resolution grid.

In this report we will produce an assessment of the accuracy of the height assignment of the MSG wind product before its assimilation into the Met Office NWP suite. Throughout this report, we consider only the MSG winds with quality indicators greater than 80, unless otherwise specified.

### 3. Target selection and height assignment

This section describes how the winds are produced based on the EUMETSAT system. Wind vector determination is performed routinely from a sequence of consecutive satellite images. For MSG four images are used and for the first Meteosat generation three images are used. The resolution of the MSG AMV product is  $72 \text{ km}^2$  at sub-satellite point. The winds are produced hourly. The processing which leads to the production of the winds is divided into three parts: i) determination of

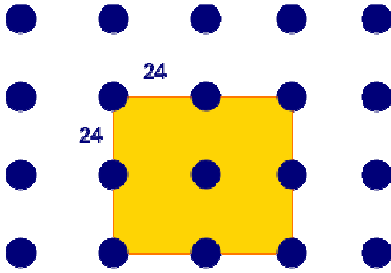
the wind corresponding to the displacement of a cloud, ii) height assignment and iii) quality control. The first two steps will be described here.

### 3.1. SCE and CLA

Before the winds are produced, a scenes (SCE) and cloud analysis (CLA) are run. These are pixel-based. The SCE labels each pixel as cloudy or clear. The CLA takes the SCE as input and generates some more information in the cloudy areas, primarily the cloud phase (water, ice, mixed or unknown) and the cloud top pressure. The output from the CLA is used at various stages of the atmospheric motion vector (AMV) production.

### 3.2. Target selection

The first step is to find a target at a selected grid point. The grid points are evenly spaced every 24 image pixels. For each grid point, a search is made in a 48x48 pixel box (see Figure 3). For each 3x3 pixel within this search box, the local mean and standard deviation are computed. The target location is selected to be the 24x24 target box which has the maximum contrast (difference between maximum and minimum local means). No overlap of more than 50% is allowed between adjacent targets. Initially the scheme will try to find a cloudy target (greater than 50 pixels classed as cloudy based on CLA output). If this is not found, a clear sky target will be sought.



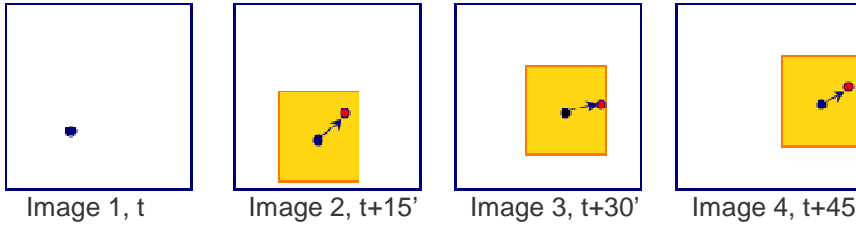
*Figure 3: Representation of a target search box around each grid point*

### 3.3. Deriving displacement

The next step is to locate the position that best corresponds to this target in the image 15 minutes later.

The search is done on the second image in an 80x80 pixel box centred around the target. A cross-correlation in the Fourier domain is used for cloud tracking and Euclidean Distance is used for clear sky WV tracking. The matching compares only the individual pixel counts of the target with all possible locations of the target in the search area to find the best match. Regions of strong contrast (e.g. cloud edges) will probably dominate in the decision of best final target location.

This is repeated for each of the next three images (four images used in total to derive three displacement vectors – see Figure 4). The final vector is an average of the three component vectors. Currently the final vector is assimilated, but in theory the component vectors could be assimilated instead. Using them directly could avoid possible errors introduced at the averaging step. However, there are temporal error correlations in the AMV data and it is not clear how assimilation of data at 15 minute intervals would affect the assimilation.



**Figure 4:** The three wind vectors components derived every 15 minutes. The final wind vector is an average of these three components.

Note that an image enhancement is made for the IR 10.8 $\mu$ m channel to help the targeting.

### 3.4. Height assignment

The cloud analysis (CLA) output is used to bin each pixel in the target into different cloud scenes or clusters based on its phase (ice, water, mixed, unknown) and cloud top pressure (200h Pa bins). Note that the CLA for image 2 is used for the first vector, the CLA for image 3 is used for the second vector, etc.

There are many possible methods for height assignment that will be briefly described in the following subsections. The height assignment is applied to the cloud scenes determined using the CLA. Some scenes with less than a threshold number of pixels are not considered for height assignment. At the time of the investigations reported here, only the Equivalent Black Body Temperature (EBBT) and CO<sub>2</sub> slicing (13.4/10.8  $\mu$ m) methods were used operationally, with an inversion correction applied to low level vectors (below 600 hPa) when an atmospheric inversion is present in a vertical profile model forecast from the European Centre for Medium-Range Weather Forecast (ECMWF). Generally speaking, EBBT is a reliable method for low-level clouds and CO<sub>2</sub> is a good one for high-level clouds.

#### 3.4.1. Problem of relationship of tracking to height assignment

There seems to be a conceptual problem for the height assignment method of the winds because the tracking and the height assignment are not necessary done on the same group of pixels. The cross-correlation used in the tracking will be dominated by regions of strong contrast. The height assignment is carried out independent of that information and relies on the CLA product to group the pixels into different cloud scenes (can be as many as 6-8). The final height assignment is taken as that of the coldest scene. It seems there are no studies showing that the tracking is dominated by the coldest cluster/scene. There could be some cases where the tracking is dominated by lower cloud, but the height assignment is based on the coldest cloud. In some cases this could lead to large errors in height assignment.

#### 3.4.2. Equivalent Black Body Temperature (EBBT) method

This method compares measured brightness temperatures to forecast temperature profiles from ECMWF to find the level of best agreement. The comparison starts at the top of the forecast temperature profile and so if there is more than one level of agreement the one higher in the atmosphere will be selected.

The main limitation of this method is that for semi transparent or sub-pixel clouds, where the observed radiance contains contributions from below the cloud, this technique assigns the height to too low a level (as the scene looks “warmer”).



### 3.4.3. IR/WV intercept methods

This method is not currently used operationally for Meteosat 8, but there are plans to use it in the future. It is a multi-channel method that allows a correction for semi-transparent cloud. It is based on the fact that the radiance in one spectral band observing a single cloud layer varies linearly with the radiances in another spectral band as a function of cloud amount in the field of view (Schmetz et al, 1993; Nieman et al., 1993). The correction method uses two simultaneous pairs of radiance observations in the water vapour (WV) and infrared (IR) channels, where one pair of radiances is from semi-transparent cloud and a second pair from an adjacent cloud free area. These data are used in conjunction with calculations of the radiances of both spectral channels for opaque clouds at different levels in a given atmosphere produced using forecast profiles of temperature and humidity (blue curve on Figures 5 and 6). The intersection of measured and calculated radiances will occur at clear sky and opaque cloudy radiances. The cloud top temperature is extracted from the cloud radiance intersection. Figure 5 represents an idealised plot. This method can be applied using the Meteosat WV channel  $6.2\ \mu\text{m}$  or  $7.3\ \mu\text{m}$ . This is a good technique for cloud with uniform transparency but requires a clear sky value.

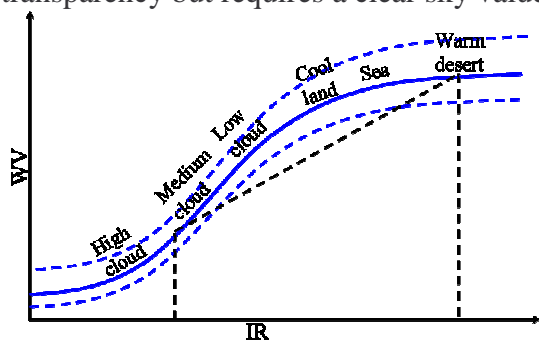


Figure 5: An idealised plot of IR against WV radiances from MIEC report 1987.

A new technique is under development at EUMETSAT (de Smet and Borde, 2005) which fits a line through all cloud sample radiances for a particular cloud scene (but not using the cloud-free radiances at all). This IR/WV method is successful for cloud scenes with a non-uniform transparency, i.e. when the range of pixel radiances is large. In practice, when the traditional IR/WV method (also called Semi-Transparency Correction STC at EUMETSAT) is successful, the IR/WV is not successful, and vice versa. The methods complement each other well. Figure 6 shows examples of these two variant IR/WV methods.

a) Good technique for cloud with non-uniform transparency. Does not rely on clear sky value. The line is the best fit through all points.

b) Good technique for cloud with uniform transparency. Requires clear sky value (indicated by a green square).

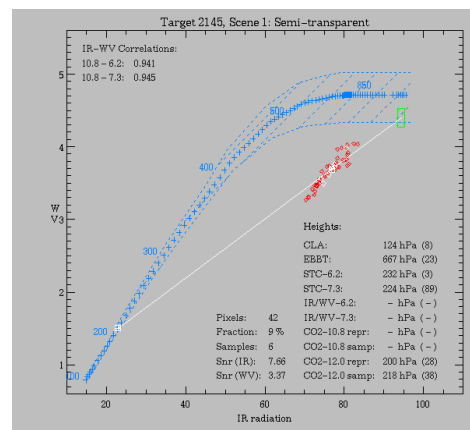
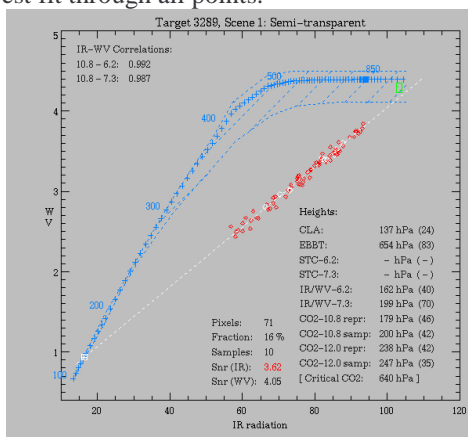


Figure 6: Example of IR/WV semi-transparency methods for a) the “new” technique and b) the traditional IR/WV intercept method (STC).

### 3.4.5 CO<sub>2</sub> slicing method

This method is also used for semitransparent clouds. Corrections for the semi-transparency of the cloud are possible with the carbon dioxide (CO<sub>2</sub>) slicing technique (Menzel et al. 1983) where radiances from different layers of the atmosphere are ratioed to infer the correct height. Existence of a CO<sub>2</sub> absorption channel at 13.4 μm on the SEVIRI instrument enables the use of the IR/CO<sub>2</sub> ratioing method. The cloud pressure is inferred from ratios of radiance differences between clear-sky and cloudy regions at two nearby wavelengths.

The general equation for the CO<sub>2</sub> slicing method is:

$$\frac{R_{cs}(CO_2) - R_{cld}(CO_2)}{R_{cs}(IR) - R_{cld}(IR)} = \frac{\varepsilon(CO_2) [R_{surf}(CO_2) - R_{bb}(CO_2, P_c)]}{\varepsilon(IR) [R_{surf}(IR) - R_{bb}(IR, P_c)]}$$

where  $R_{cs}$  and  $R_{cld}$  are the cloud free and cloudy radiances which are measured in the CO<sub>2</sub> and IR bands by the SEVIRI instrument.  $R_{surf}$  and  $R_{bb}(P_c)$  are the calculated surface radiance and Planck black body radiances for a cloud at the level  $P_c$  in the atmosphere.  $\varepsilon(CO_2)$  and  $\varepsilon(IR)$  are the emissivities in the two bands. Assuming the emissivities in the two spectral bands are the same, the cloud top pressure within the field of view can be specified as the ratio of cloudy and clear sky radiance differences. The observed ratios of differences are compared to various calculated ones (varying  $P_c$ ). The cloud pressure is assigned to the pressure,  $P_c$ , which fit best the observations.

During these investigations, the 10.8 and 13.4 μm channels were used, but the 12.0-13.4 μm CO<sub>2</sub> slicing method replaced the 10.8-13.4 CO<sub>2</sub> slicing as the operational method on 1<sup>st</sup> December, 2005. Studies have shown that this puts the cloud pressure around 20 hPa lower in the atmosphere where the winds agree better with radiosonde measurements. Note that this improvement may be confined to the extra-tropics, as comparisons with the ECMWF background suggest the fast bias in the tropics becomes worse.

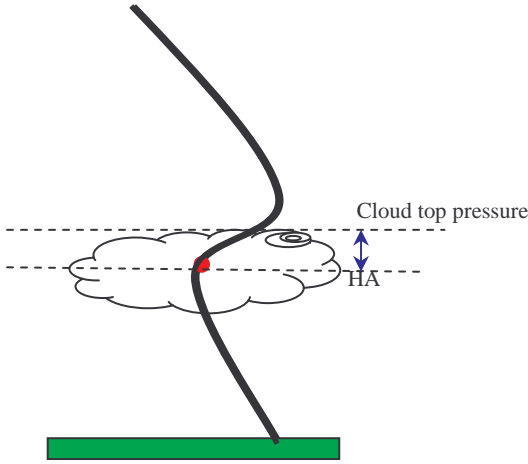
There are some limitations to the CO<sub>2</sub> slicing method. For optically thin cirrus, when the cloud signal, i.e., the difference in radiance between the cloud and clear-sky is low, and thus comparable to instrument noise, it is difficult to assess cloud pressure (thought to be partly responsible for poor mid level winds in the Sahara). In the case of multilayered clouds, specifically when thin cirrus overlies a lower-level water cloud, the cloud height assessment is performed operationally under the assumption that only a single cloud layer exists in the field of view. Biases occur in cloud height when more than one cloud layer exists and the uppermost layer is optically thin. For lower level clouds, because of signal-to-noise considerations, the CO<sub>2</sub> slicing method does not work well.

### 3.4.6. Inversion

Note that this method and the following one (Cloud base height assignment) are not used on each individual scene but after scene merge. The method is described in this section only for clarity.

The inversion method (Elliott et al., 1999) is used to assign a height to a vector when the vector is low (below 600 hPa) and when an ECMWF forecast profile shows an inversion. The wind vector is relocated to the minimum temperature of the inversion. This is the simplest technique to apply, although it is generally accepted that the real cloud top height is normally located above this point (see Figure 7). This will lead to a systematic bias to place the cloud too low in the atmosphere.





**Figure 7:** Idealised view of cloud height assignment in case an inversion occurs in the atmosphere.

In the Southern Atlantic Ocean, height assignment is purely a forecast one because there is always an inversion and in this case the algorithm will take the forecast (background) value. It leads to a large zone where we find the same height for many vectors.

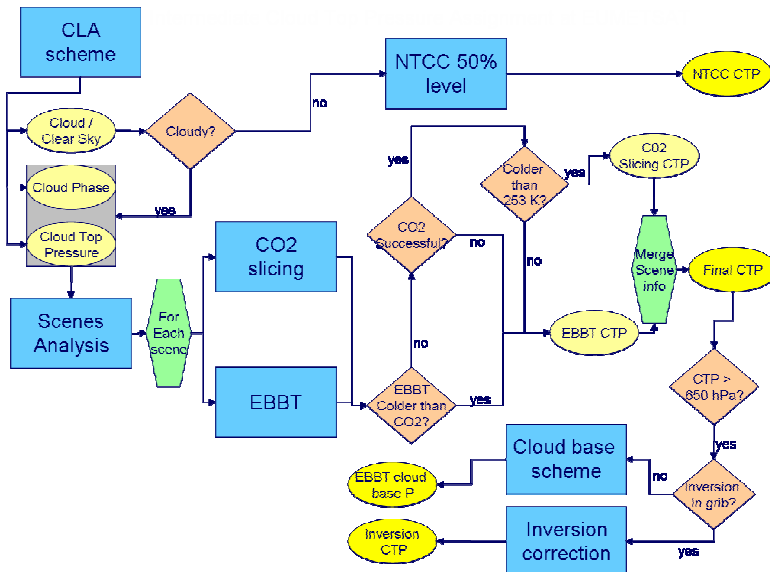
#### 3.4.7. Cloud base height assignment (CBH) method

It has been shown that the motion of low level cumuli type clouds agrees better with the wind at cloud base. To assign a cloud cluster to the level of the cloud base, an estimation technique has to be applied. To find the temperature of the cloud base the standard deviation of the cloud cluster is used.

$T_{base} = T_{cloud} + K * \sigma_{cld}$ , where  $T_{base}$  is the cloud base temperature,  $T_{cld}$  is the cluster mean temperature and  $\sigma_{cld}$  is the standard deviation of the cloud cluster. If the selected cloud target pressure is lower in the atmosphere than 600 hPa and if there is no inversion in the atmospheric temperature profile, the CBH method is applied to that vector. To apply CBH results in an average lowering of the vector by 40 hPa.

#### 3.4.8. Choice of final height assignment

Figure 8 illustrates the process by which the final height assignment for each component vector is decided.



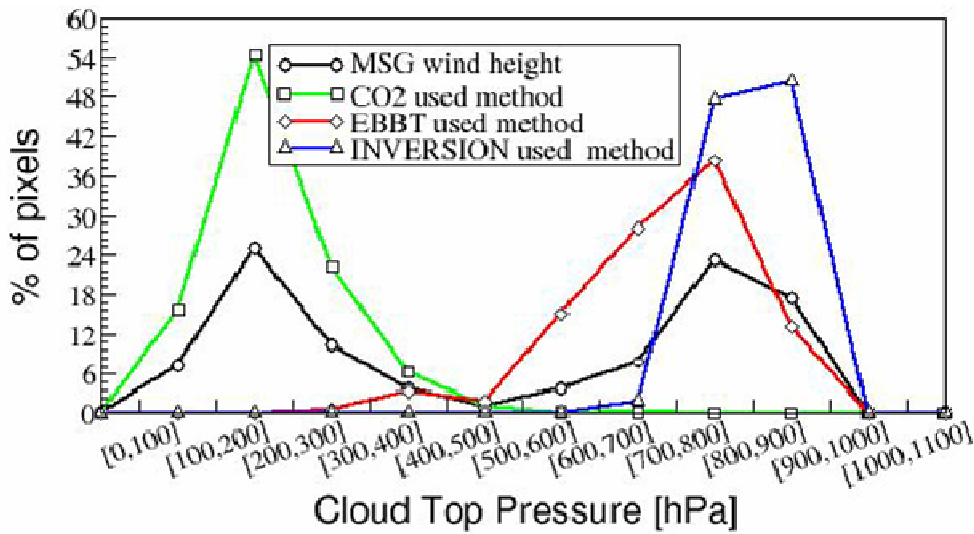
**Figure 8:** Intermediate operational cloud top pressure determination.

In the first step, all possible height assignments for each scene are calculated and a decision tree used to determine the final height assignment for each scene. In the next step, the information from the different scenes needs to be merged to generate a final height assignment for the target. Currently the coldest scene is selected for the final height assignment. If this final target height assignment is below 600 hPa in the atmosphere, the inversion or cloud base techniques are used.

The final stage is to combine the final target height assignments for each of the three component vectors. The approach used operationally is to average all components with heights within 50 hPa and two components are required as a minimum.

#### 4. Some initial investigations

Figure 9 shows the distribution in wind vector height according to each MSG operational height assignment method. High-clouds are mainly retrieved using the CO<sub>2</sub> method while low-level clouds are retrieved using the EBBT and inversion methods.



**Figure 9:** Example of vertical distribution of MSG wind vectors for 13 April 2005 according to the height assignment method used.

One point that is immediately apparent from Figure 9 is how few mid level winds are produced. This is a common observation for AMV data.

Table 1 shows some height assignment statistics for the winds produced from the IR and two WV channels. The example is for a particular time but similar results are obtained for other periods.

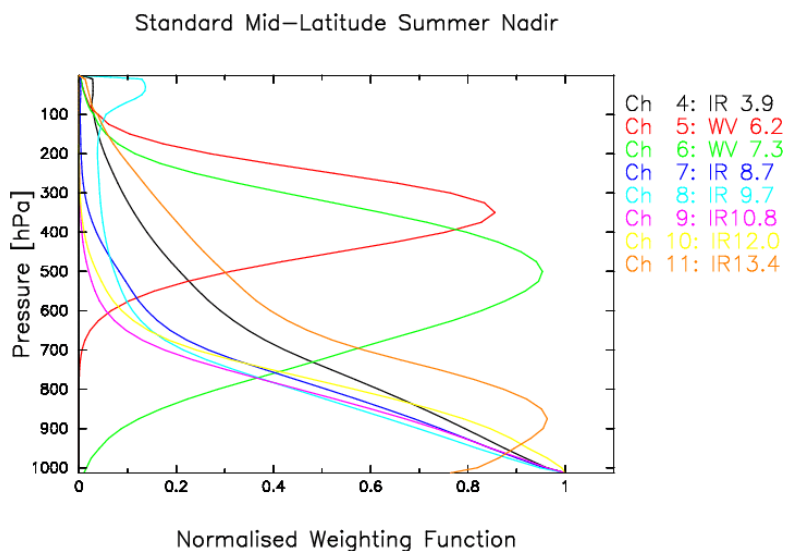
	Average pressure	Number	Percentage
<i>IR winds</i>			
<i>Total winds</i>		11041	100
<i>Number of winds with QI1 and QI2 &gt;80</i>		4833	43.7
<i>Method used is CO<sub>2</sub>, when QI &gt;80</i>	258.6 hPa	3040	62.9
<i>Method used is EBBT, when QI &gt;80</i>	885.0 hPa	643	13.3
<i>Method used is inversion, when QI &gt;80</i>	880.7 hPa	1150	23.8
<i>P<sub>CO2</sub> &gt; P<sub>EBBT</sub></i>		120	2.5
<i>P<sub>CO2</sub> &lt; P<sub>EBBT</sub></i>		4146	85.8

<b>WV62 winds</b>			
<b>Total WV62 winds</b>		7222	100
<b>Number of winds with <math>QI1</math> and <math>QI2 &gt; 80</math></b>		3829	53.02
<b>Method used is <math>CO_2</math>, when <math>QI &gt; 80</math></b>	209.8 hPa	1983	51.8
<b>Method used is EBBT, when <math>QI &gt; 80</math></b>	268.7 hPa	1846	48.2
<b>Method used is inversion, when <math>QI &gt; 80</math></b>	-	0	0
<b><math>P_{CO2} &gt; P_{EBBT}</math></b>		1779	46.5
<b><math>P_{CO2} &lt; P_{EBBT}</math></b>		1983	51.8
<b>WV73 winds</b>			
<b>Total WV73 winds</b>		7431	100
<b>Number of winds with <math>QI1</math> and <math>QI2 &gt; 80</math></b>		3995	53.8
<b>Method used is <math>CO_2</math>, when <math>QI &gt; 80</math></b>	249.2 hPa	3614	90.4
<b>Method used is EBBT, when <math>QI &gt; 80</math></b>	389.8 hPa	381	9.6
<b>Method used is inversion, when <math>QI &gt; 80</math></b>	-	0	0
<b><math>P_{CO2} &gt; P_{EBBT}</math></b>		367	9.2
<b><math>P_{CO2} &lt; P_{EBBT}</math></b>		3614	90.4

**Table 1:** Statistics for 19 April 2005, 15:30 UTC for three of the MSG channel wind product.

Table 1 shows the percentage of winds with  $QI > 80$  which use each height assignment technique. The  $CO_2$  height assignment method is the main method for the IR and WV7.3 winds, but is only used half the time for the WV6.2 winds. This is due to the WV6.2 EBBT pressures being frequently higher in the atmosphere than the  $CO_2$  pressures. In these circumstances the EBBT method is used as the final height assignment (see Figure 8). The average pressures for each height assignment method show the expected pattern from Figure 9 of higher pressures for the EBBT and inversion methods and lower pressures for the  $CO_2$ .

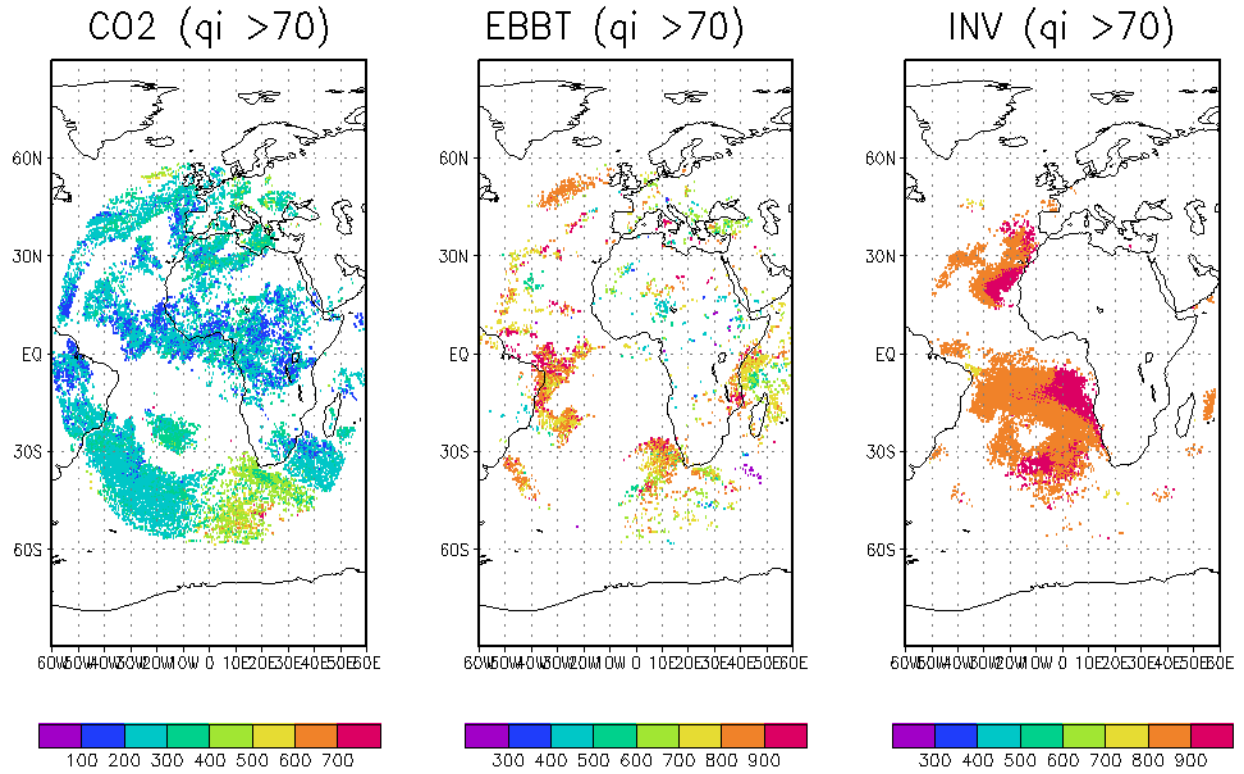
The WV and IR channels peak at different levels in the atmosphere as illustrated in Figure 10. The WV6.2 channel produces mostly high level AMVs, the WV7.3 channel produces high and mid level AMVs and the IR channel produces AMVs at all levels.



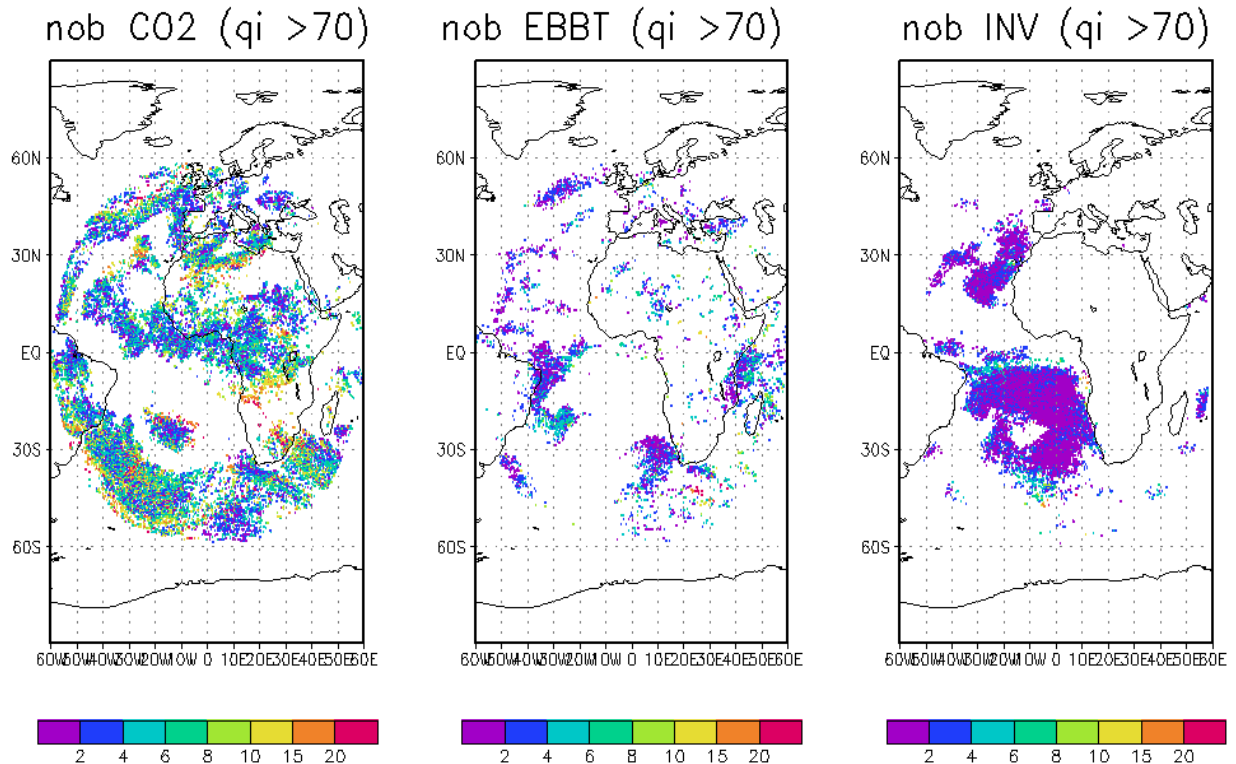
**Figure 10:** Normalised weighting functions for different MSG channels.

Figure 11 shows the geographical distribution of where each height assignment method is applied for one hour of Meteosat-8 IR data. Also shown are the cloud top pressures retrieved with each technique and the norm of the wind speed difference.

a) Cloud top pressure (hPa) retrieved using different height assignment methods



b) Norm of the difference of MSG wind speed Observation – Background (m/s).



**Figure 11:** 26 Sept 05, 00:00 until 21:00 UTC, MSG IR 10.8 winds for which  $QI$  are larger than 70.

In terms of geographical distribution, the inversion method is used where we expect atmospheric inversions to appear (e.g. over large part of the southern Atlantic). When looking at the norm of the

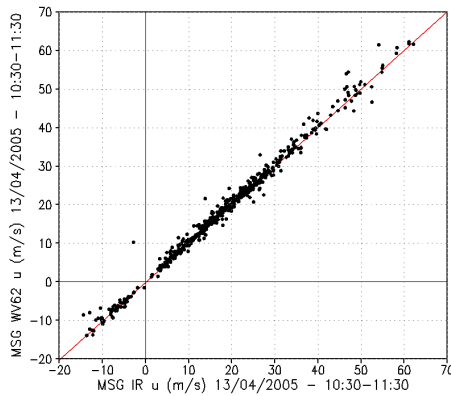
wind speed difference between observation and background, there is a good agreement where the inversion method is used except south of Africa and near the equator.

When the CO<sub>2</sub> method is used the agreement between observation and background is more variable. This partly reflects the higher wind speeds of the higher level vectors retrieved with this method.

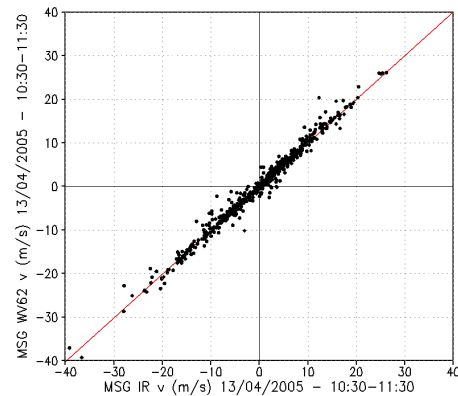
Figure 12 shows collocated IR and WV winds for a particular time on a 0.2 x 0.2 degree grid. The  $u$  and  $v$  wind components scatter plots show pretty good agreement for the collocated IR and WV (6.2 and 7.3) winds. There could be little vertical wind shear in some cases, but the good agreement might suggest that the channels are normally tracking the same feature.

Unlike the  $u$  and  $v$  scatter plots, the pressure scatter plot comparing the IR and WV (6.2 and 7.3) pressures shows some big differences. The IR and WV heights compare well at high levels (above ~230 hPa for WV6.2 and above ~350 hPa for WV7.3). Below this the heights start to diverge with the WV winds located systematically higher in the atmosphere. The difference is most marked for the WV6.2 channel and could be linked to the greater use of the WV6.2 EBBT height assignment method (as described earlier). The divergence at different levels for the two WV channels could reflect a height assignment problem which is most pronounced when the winds are located lower down their respective WV weighting functions (see Figure 10). This could reflect problems with allowance for WV absorption above the cloud top in the radiative transfer calculations (no correction for atmospheric absorption above cloud top was applied operationally to the Meteosat-8 data until 1<sup>st</sup> December, 2005 - after this investigation was carried out).

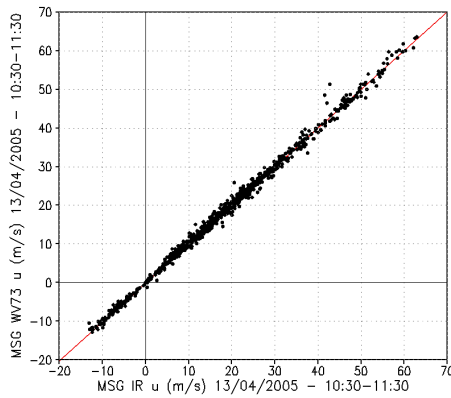
a) MSG WV6.2



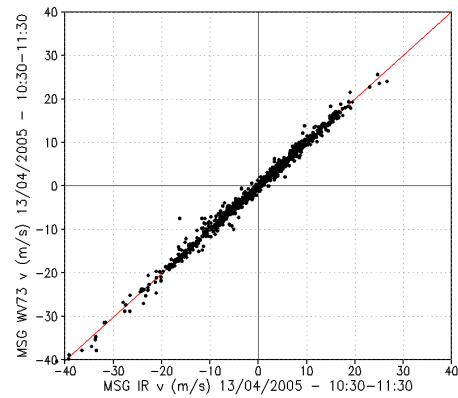
b) MSG WV6.2



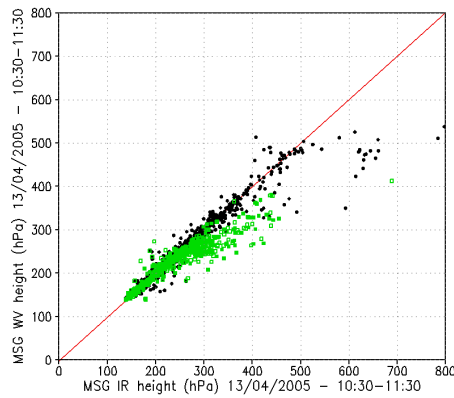
c)MSG WV7.3



d)MSG WV7.3



e)MSG WV6.2 (green) and WV7.3(black) as a function of IR



**Figure 12:** 13 April 2005, 10:30 – 11:30 UTC collocated IR and WV winds.

## 5. Validation of cloud top pressure

In order to understand and evaluate the MSG wind height assignment, we should have other datasets to compare with. We have decided to use other AMV datasets and two cloud top pressure products: the Met Office Autosat cloud top pressure and the MODIS CTP.

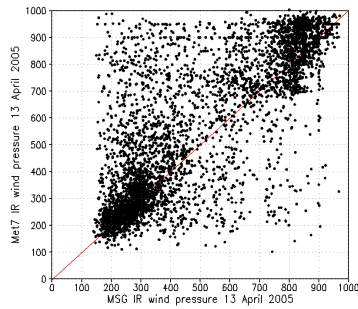
### 5.1. Comparison of Meteosat-8 winds with other AMVs

#### 5.1.1. Comparison with Meteosat-7 winds

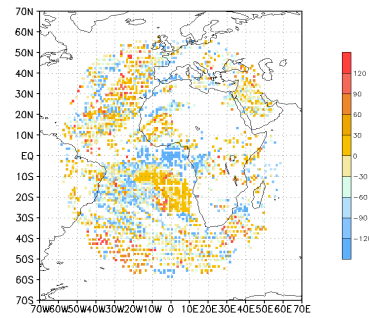
EUMETSAT are producing winds from Meteosat-7 and Meteosat-8 in parallel. Both satellites provide imagery over the Europe-Africa region. There are some important differences between Meteosat-7 and Meteosat-8. Meteosat-7 has coarser horizontal resolution (2 times smaller) and the image interval is 30 minutes rather than 15 minutes. There are also fewer channels. For these reasons the number of AMVs produced is less. Additionally there are differences in the image target selection and height assignment. We show here some results of comparisons for the 13th April 2005. Meteosat 7 and Meteosat 8 winds have been regridded on a 1x1 degree grid (Figure 13). Similar results were observed for a comparison on a 0.2x0.2 degree grid. We show the results for daily averaged data as well as data from 10:30UTC. There is a good correlation in the  $u$  and  $v$  components (and therefore also in wind speed) with no obvious bias between the two datasets. There is more variability in the height assignment of the AMVs from the two satellites. This is probably to expected given the different height assignment methods used, particularly for high level winds where Meteosat-7 normally uses the WV intercept method and Meteosat-8 the CO<sub>2</sub> slicing method.



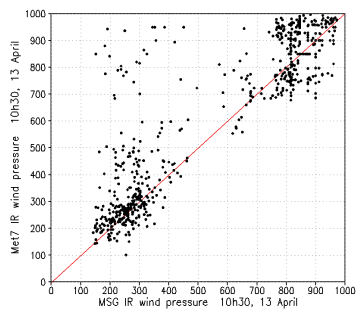
a) Met7 IR wind pressure (hPa) as a function of Met8 IR wind pressure. 13 April 2005, average over the whole day



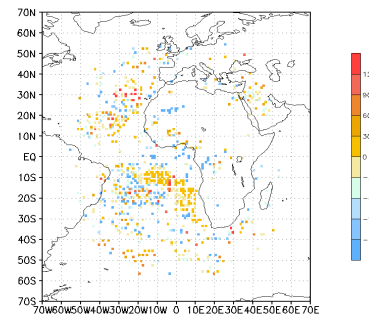
b) Meteosat wind height assignment difference (hPa) Met8 - Met7. 13 April 2005, average over the whole day



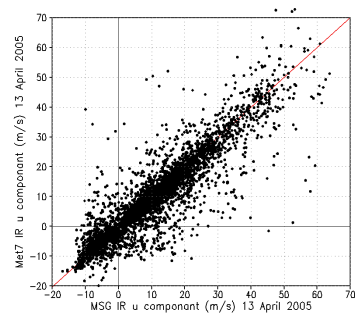
c) Met7 IR wind pressure (hPa) as a function of Met8 IR wind pressure. 13 April 2005, 10:30UTC



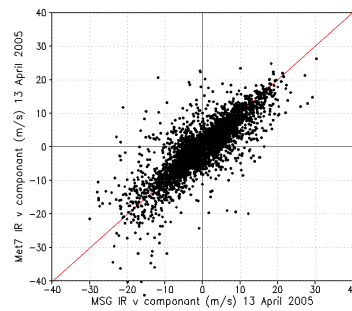
d) Meteosat wind height assignment difference (hPa) Met8 - Met7. 13 April 2005, 10:30UTC



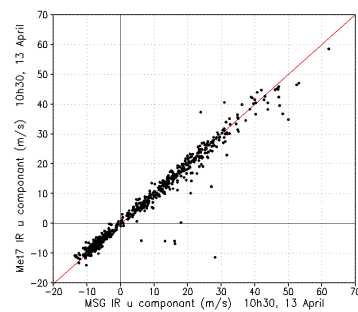
e) 13 April 2005, u component (m/s)



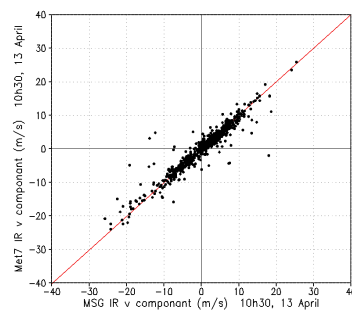
f) 13 April 2005, v component (m/s)



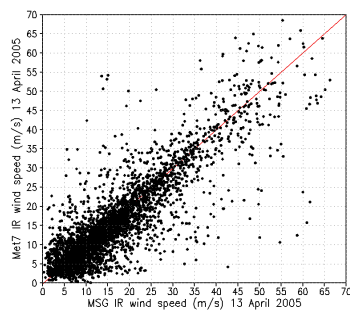
g) 10:30UTC u component



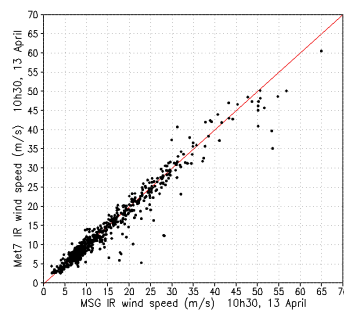
h) 10:30UTC v component



i) 13 April 2005 wind speed (m/s)



j) 10:30UTC wind speed (m/s)



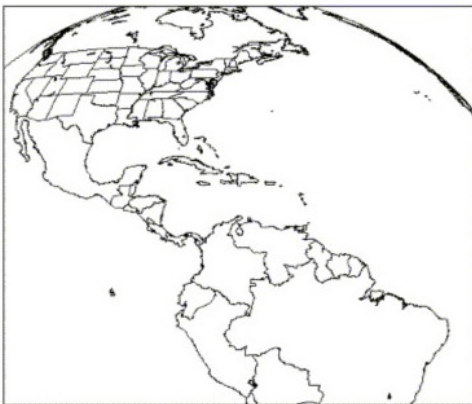
**Figure 13:** *Meteosat 7 as a function of Meteosat 8 wind height.*

### 5.1.2. Comparison with GOES 12 winds

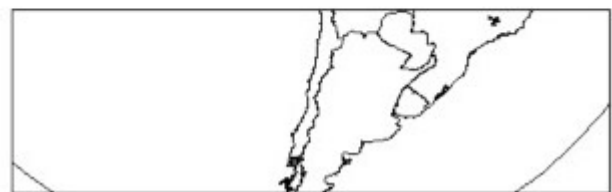
It is possible to compare the Meteosat-8 winds with the GOES-12 winds in the region of overlap between the two satellites (strip over the Atlantic Ocean).

The GOES scan is more complicated than the Meteosat one. It allows multiple scan sectors (see <http://www.oso.noaa.gov/goes/schd-sector/index.htm>). Figure 14 shows two of the scan sectors used to derive winds with GOES 12. Due to the scheduling time, GOES 12 winds are daily available for the following time periods: 01-02UTC, 04-05UTC, 07-08UTC, 10-11UTC, 13-14UTC, 16-17UTC, 19-20UTC, and 22-23UTC. We have retrieved Meteosat 8 winds for the same time periods.

GOES-12 N. HEMISPHERE EXT. SCAN SECTOR



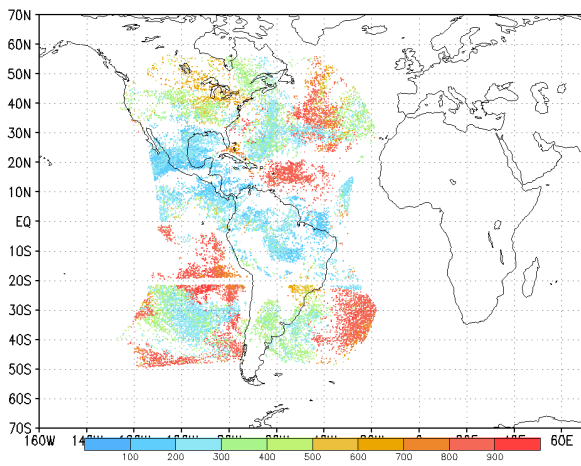
GOES-12 IMAGER S. HEMISPHERE SCAN SECTOR



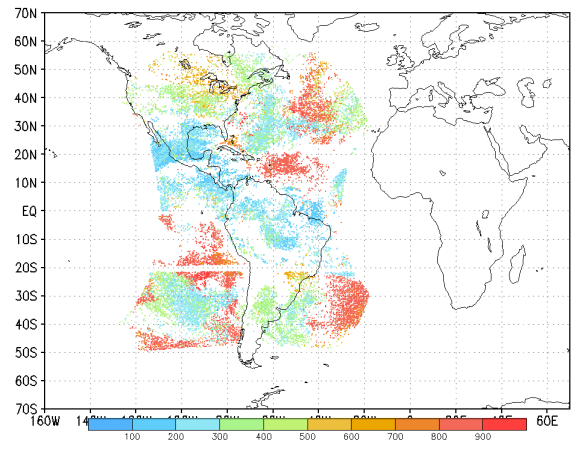
**Figure 14:** *Two out of the eleven GOES scan areas used to extract the GOES 12 winds.*

The basic principles of wind retrieval using GOES data are the same as those for METEOSAT wind derivation. All details of GOES wind retrieval can be found in a technical note by Olander (2001) or a paper by Nieman et al (1997). An autoeditor is used to improve the quality of the GOES AMVs. This works by adjusting the pressure assignment to better fit a model background and surrounding winds and increasing the wind speed of a subset of winds to counteract the slow bias in the jet (Hayden et Purser, 1995). These post-autoeditor winds are referred to here as GOES edited winds. The pre-autoeditor wind speeds and pressures are also included in the BUFR and we have also considered them here. These are referred to as GOES unedited winds. The main difference between the edited and unedited GOES 12 winds appears for high level clouds where GOES 12 edited winds can be assigned up to 200hPa higher in the atmosphere (see Figure 15).

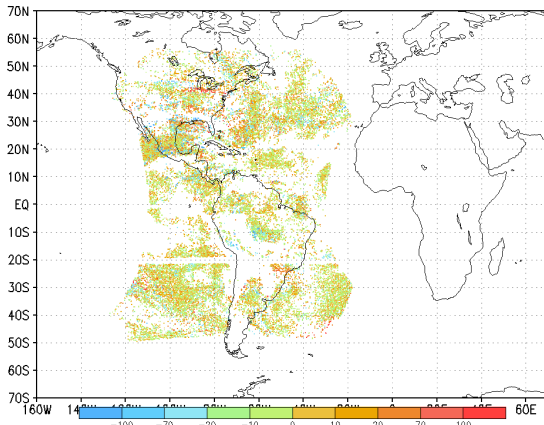
a) GOES 12 edited winds (hPa)



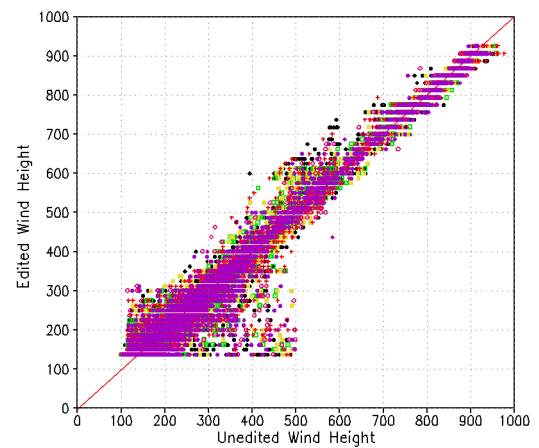
b) GOES 12 unedited winds (hPa)



c) GOES 12 edited – unedited winds (hPa)



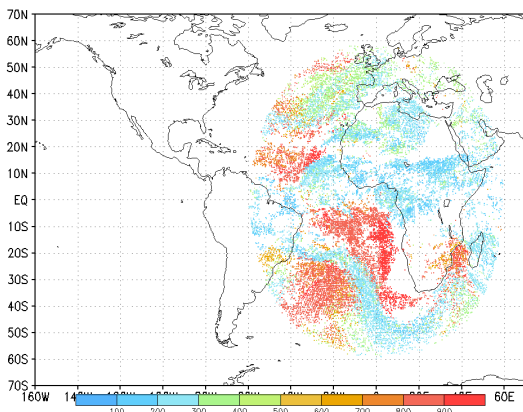
d)



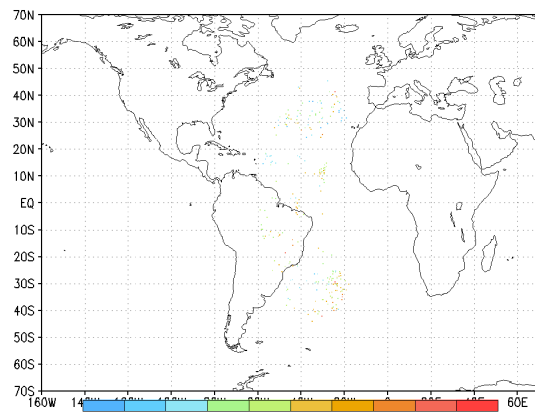
**Figure 15:** GOES 12 wind height for the 28<sup>th</sup> of April 2005.

When there is spatial and temporal coincidence Meteosat 8 and GOES 12 winds agree quite well as shown in Figure 16. There is no bias between the 2 datasets. There is unfortunately only a few coincident winds every day. When there is a difference, the winds retrieved by GOES seem slightly lower in the atmosphere.

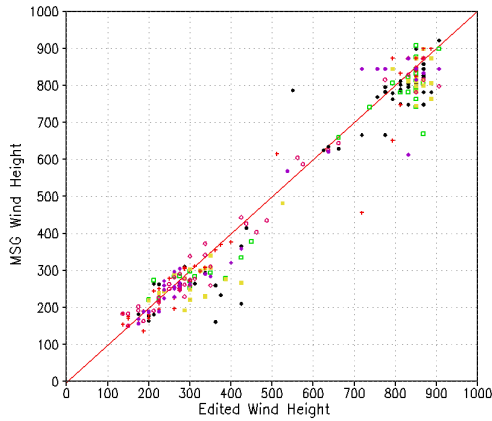
a)



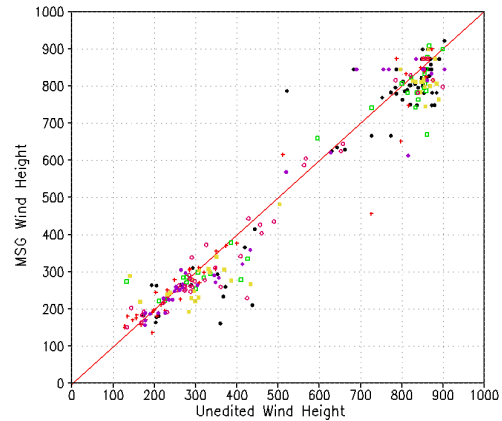
b)



c) Met 8 as a function of edited GOES12



d) Met 8 as a function of unedited GOES12



**Figure 16:** Comparison between GOES 12 and Meteosat 8 wind height for the 28<sup>th</sup> of April 2005. On the scatter plots c) and d) the different colours represent different time of the day.

## 5.2 Comparisons with other cloud top pressure products

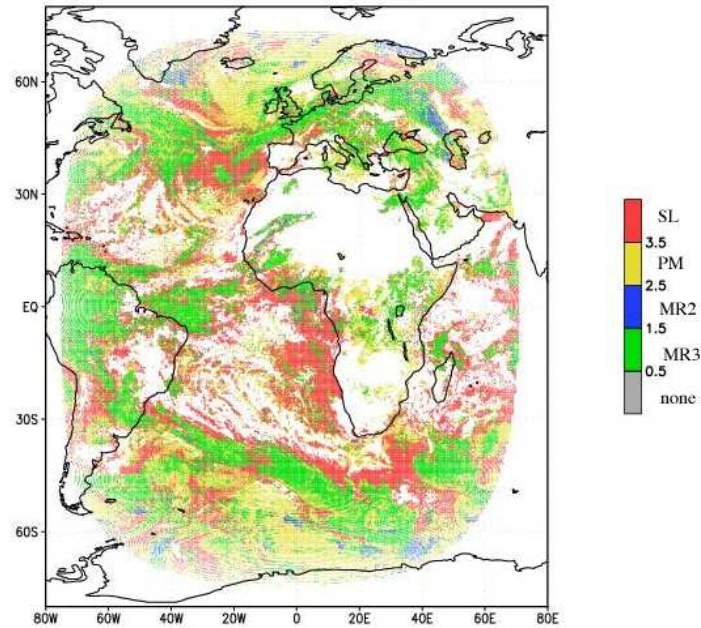
Before describing the results of comparisons, a brief introduction to the Autosat and MODIS cloud top pressures is provided.

### 5.2.1. Autosat cloud top pressure determination

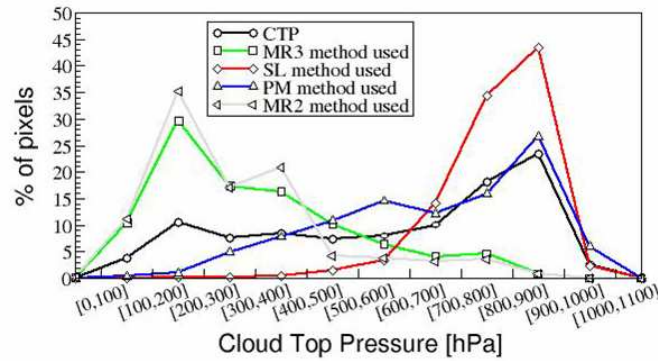
In this section we briefly describe the Met Office Autosat cloud processing in particular the determination of cloud top temperature. The cloud top temperature determination is based on three MSG infrared channels at wavelengths of 10.8, 12.0 and 13.4  $\mu\text{m}$ . It is derived for every image which means every 15 minutes, for one in every 4 pixels. Three different retrieval methods are available for each pixel a) the Minimum residual method (Eyre and Menzel, 1989) using two (MR2, 12.0 and 13.4  $\mu\text{m}$ ) or three channels (MR3, 10.8, 12.0 and 13.4  $\mu\text{m}$ ), b) the profile matching method (PM) and c) the stable layer method (SL). The minimum residual method uses data from NWP model profiles to perform radiative transfer calculations in order to simulate radiances in all three channels for different cloud top heights and effective cloud amount. The method then attempts to find the solution which minimises the differences between the measured and simulated radiances in all three channels. A check is also made so as not to place the cloud top at the bottom of an unstable layer which would cause vigorous convection if subsequently assimilated into the NWP model. If an acceptable solution is found, i.e. if a well defined minimum is obtained, the value of cloud top temperature corresponding to this height is accepted as a solution. This is typically the case for most mid- and high-level clouds. If a solution is not found, a single channel approach is used, the so-called SL method, which attempts to match the measured brightness temperature at 10.8  $\mu\text{m}$  with the simulated value, reducing the weighting of any solution which would put the cloud top at the base of an unstable layer. The majority of low-level clouds is processed using this method. Finally, if an acceptable solution is not found, the third method (PM) is used, which simply finds the best match between measured and simulated 10.8  $\mu\text{m}$  brightness temperatures, working from the surface upwards, with no account taken of atmospheric stability. Figure 17 illustrates which of the three methods is used to retrieve the cloud top pressure in the Autosat processing. We can see that the MR3 method is used to retrieve most of the high level clouds. The MR2 method is almost never used. Low-level clouds are generally retrieved using the SL method. The PM method is generally used at high latitudes.



a) Method used to retrieve the cloud top pressure in the Autosat processing



b) Vertical distribution of wind according to the method used



**Figure 17:** 13 April 2005, a) an example of the method used to retrieve the cloud top pressure in the Autosat processing and b) vertical distribution of wind according to the method used.

### 5.2.2. MODIS cloud top pressure

The Moderate Resolution Imaging Spectroradiometer (MODIS) cloud top pressure methodology builds on a long history of operational analyses performed with sounding data from the High Resolution Infrared Radiometer Sounder (HIRS) and the Geostationary Operational Environmental Satellite (GOES) sounder. The technique to infer cloud-top pressure has been discussed in detail by Menzel et al. (1983) and Wylie and Menzel (1999). A detailed description of this product can be found in the Algorithm Theoretical Basis Document (ATBD) (Menzel and Strabala 2002). MODIS cloud top pressure is retrieved using mainly the CO<sub>2</sub> slicing method. The method takes advantage of differing partial CO<sub>2</sub> absorption in several of the MODIS infrared bands located within the 15-micron CO<sub>2</sub> band, with each band being sensitive to a different level in the atmosphere. The bands located closer to the centre of the CO<sub>2</sub> band at 15 microns are sensitive to high clouds only, while the bands away from the CO<sub>2</sub> band centre are sensitive to mid level clouds. So this technique is most accurate for high- and mid-level clouds. Due to signal-to-noise issues, cloud heights inferred from this method must be in the range from approximately 700 hPa to the tropopause. If no valid retrieval is found in this pressure range, the 11µm band is used to infer cloud pressure assuming the cloud is opaque. In the MODIS operational processing, cloud top pressures are calculated for the following ratio pairs 14.2/13.9, 13.9/13.6, 13.6/13.3, 13.9/13.3, and 13.3 /11 µm.

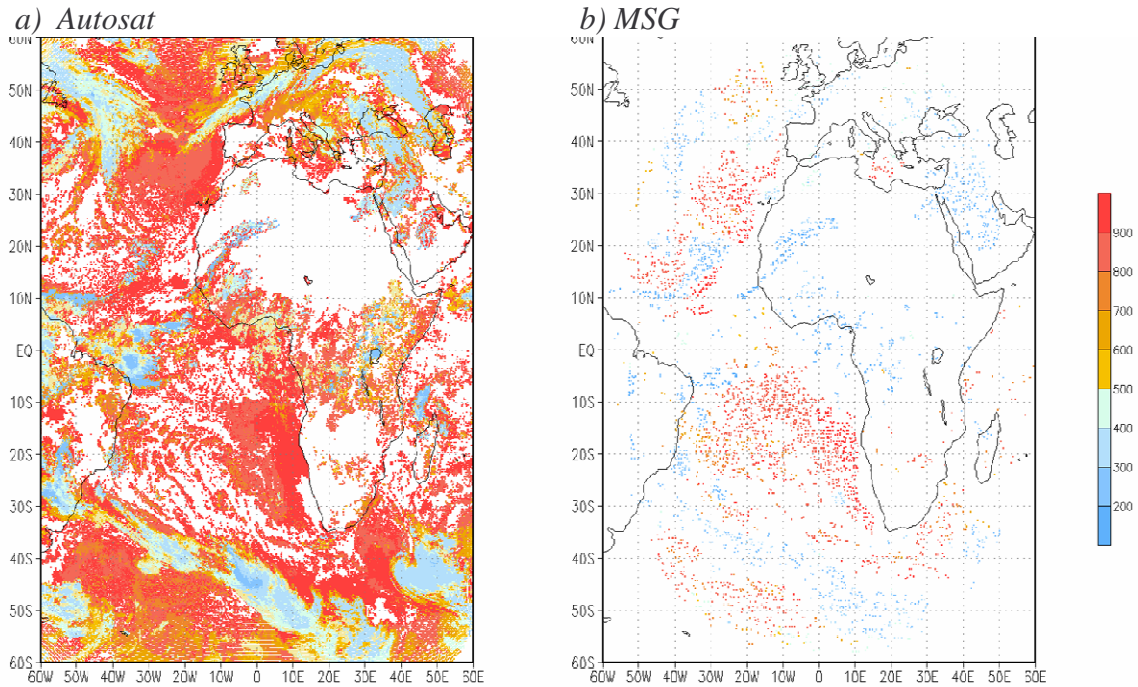
Given the fact that each band pair may return a different cloud pressure, a choice must be made as to the most representative cloud pressure. The final cloud pressure is chosen by minimizing the difference between the observed cloud signal (i.e., the difference between the clear-sky and measured radiance) and the simulated cloud signal calculated from a forward radiative transfer model (Menzel et al. 1983).

In this work we have used two MODIS products. The first product is the full resolution product referenced MOD08\_L2. The cloud top temperature is produced both day and night at 5 x 5, 1km-pixel resolution. The second one is MOD08\_D3 where the CTP is produced daily at a 1x1 degree resolution.

### 5.2.3 Full resolution comparison

#### 5.2.3.1. Autosat versus MSG wind height

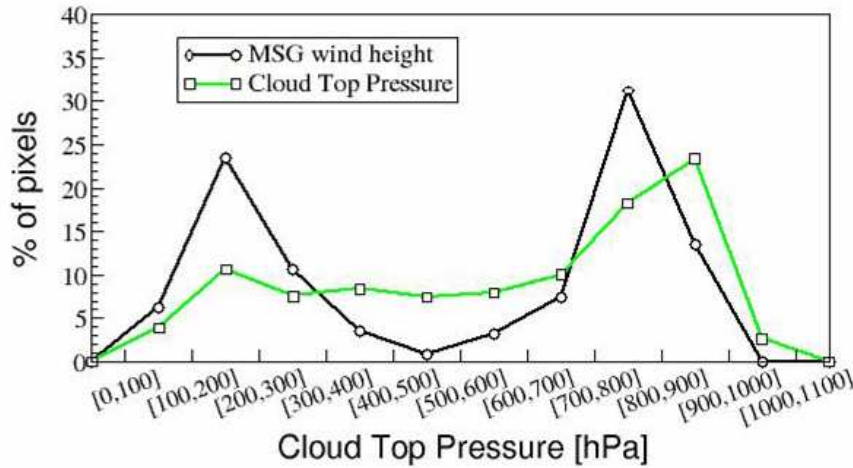
We start with a full resolution comparison. We focus on one particular day of April 2005 (Figure 18).



**Figure 18:** 13 April 2005, 10:30UTC, a) Autosat CTP and b) MSG wind height (hPa).

The Autosat cloud top pressure shows a more complete coverage of the region. It shows much more spatial variability than the MSG wind pressure. The distribution of MSG winds within the atmosphere is bimodal, while clouds are more spread in the atmosphere in the Autosat product (Figures 9 and 19).

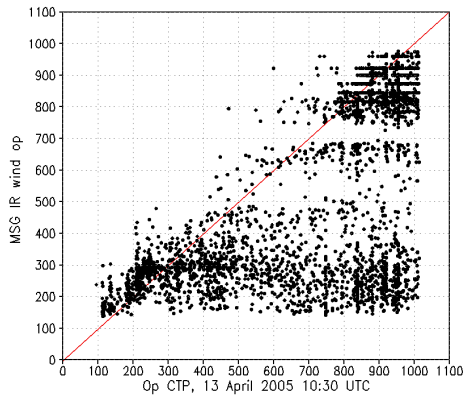




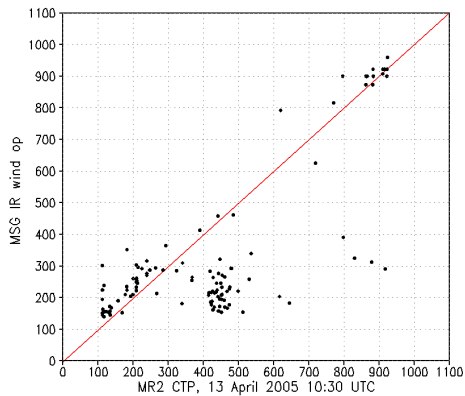
**Figure 19:** distribution of cloud top pressure within the atmosphere.

Figure 20 shows how the MSG AMV cloud top is nearly always higher in the atmosphere than the Autosat one. Note that this is not obvious in Figure 19 as the sample is different. We can try to understand which height assignment method contributes more to the observed difference. We show in Figure 20 a scatter plot of MSG IR wind height as a function of the CTP retrieved using different Autosat methods. When the MR3 method is employed the agreement is quite good between the wind height and cloud top pressure. This is not true when it is the PM method which is used.

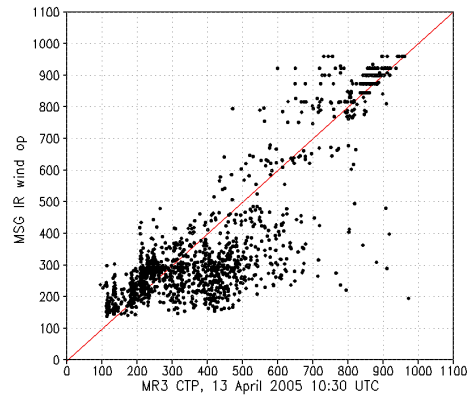
a)



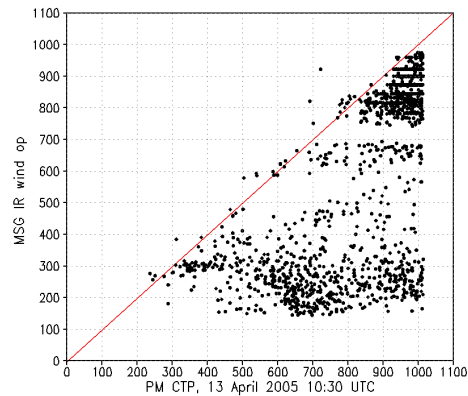
c)



b)

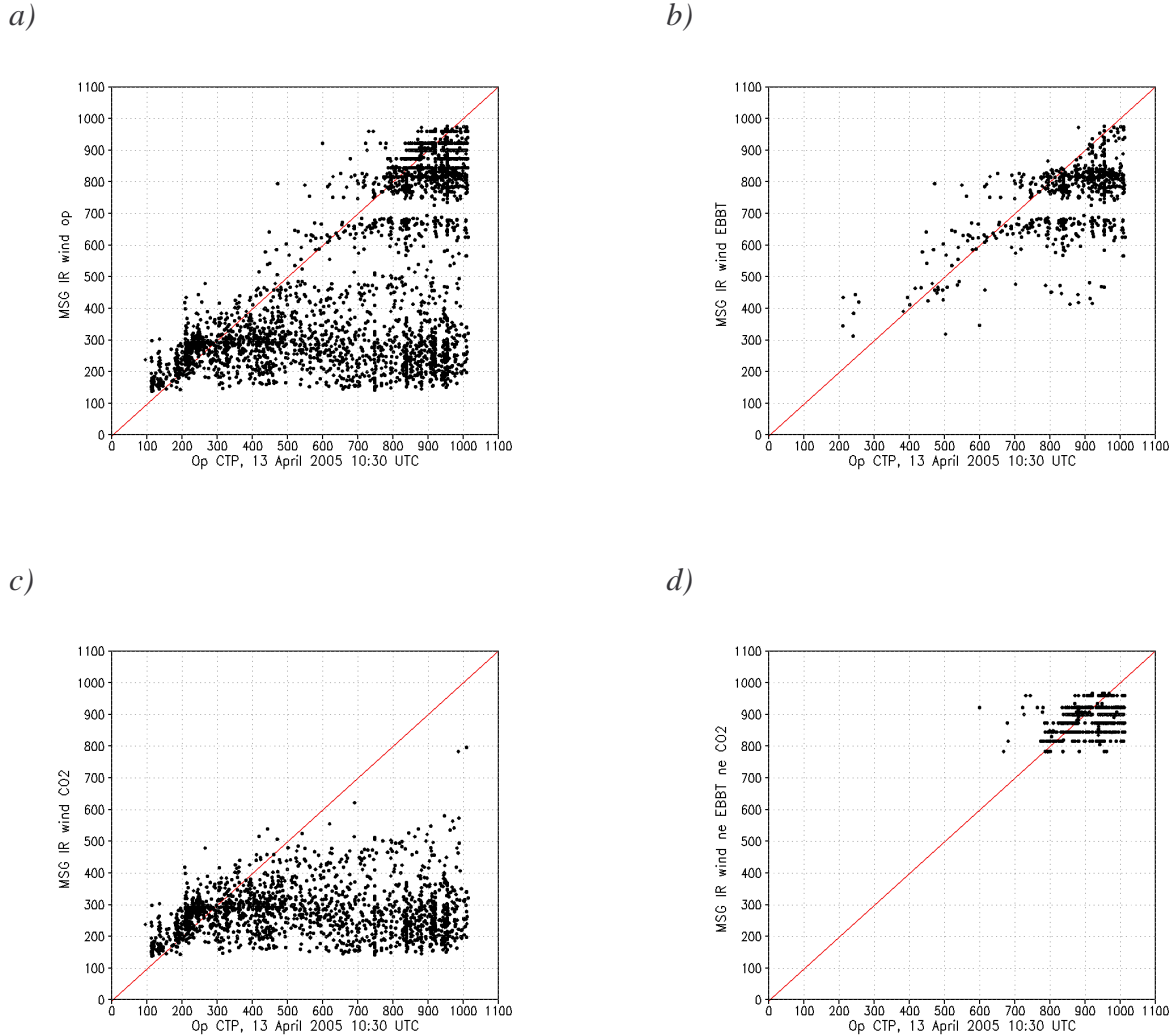


d)



**Figure 20:** Scatter plot of MSG IR wind height as a function of Autosat cloud top pressure retrieved with a) all methods b) MR3 method, c) MR2 and d) PM. Only winds with QI1 and QI2 higher than 70 are retained.

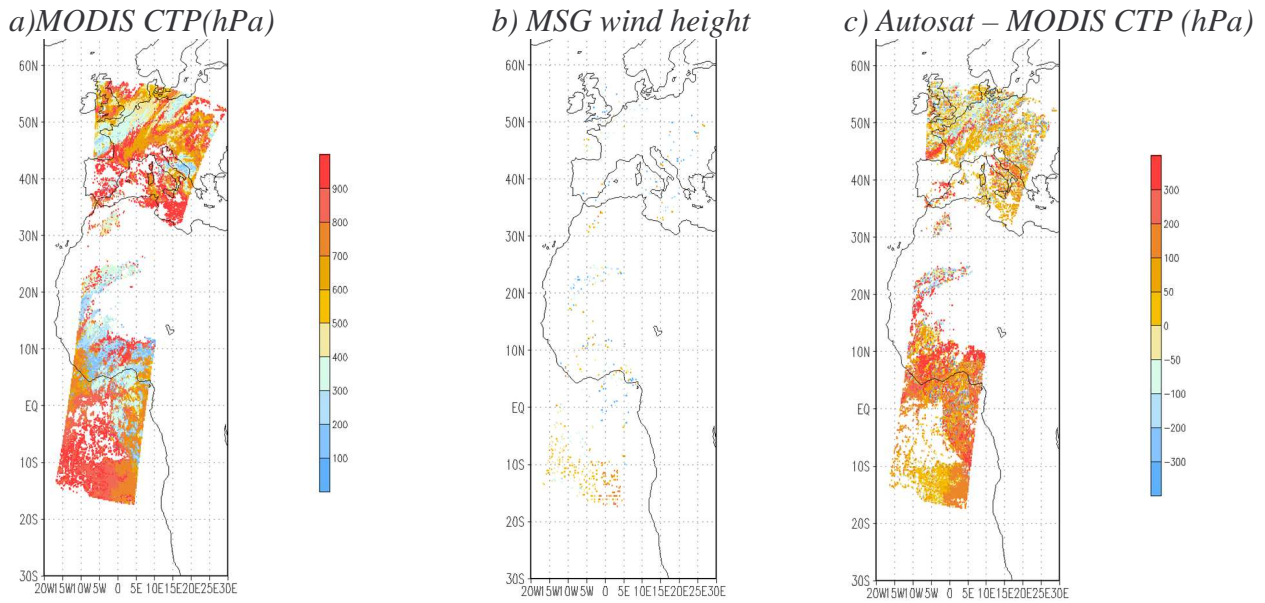
Figure 21 shows the different MSG methods as a function of the operational Autosat CTP. The Autosat CTP tends to assign clouds lower in the atmosphere whatever the method used. The main difference between MSG and Autosat CTP (Figure 21a) is found when the CO<sub>2</sub> method is used for the MSG wind height assignment.



**Figure 21:** Same as Figure 20 but MSG wind height retrieved using a) all methods, b) EBBT method, c) CO<sub>2</sub> slicing method and d) inversion method as a function of Autosat cloud top pressure.

#### 5.2.3.2. MODIS versus MSG wind height

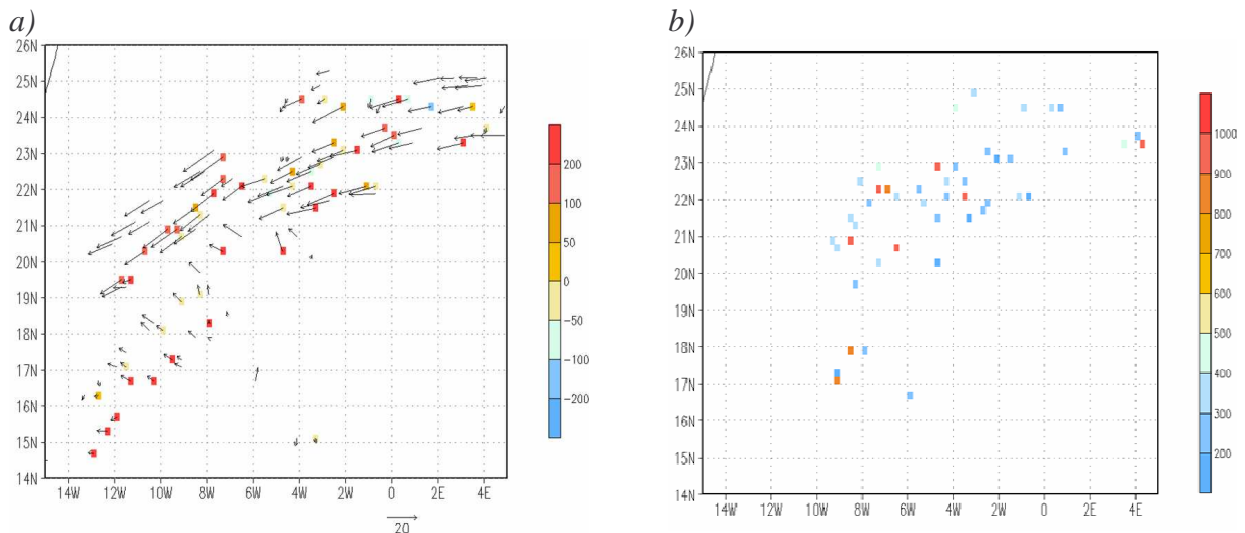
As we do not really know which of these two cloud top pressures is right, we also compared with the MODIS cloud top pressure which forms an independent dataset (Figure 22)



**Figure 22:** 13 April 2005, 10:30UTC

Usually, the Autosat cloud top is lower in the atmosphere than the MSG wind or MODIS cloud top. MSG winds are almost always assigned pressures higher in the atmosphere. This is consistent with the fact that the height assignment method is based on the coldest scene in the target and that they work from top down.

Generally when the cloud situation is complex the wind height assignment is more likely to be wrong. Figure 23 shows an example of a situation where MODIS reports clouds as liquid whereas they are very high (could be a dust event making the MODIS phase restitution misleading). For this particular case, the difference between the observed AMV and the model background wind speeds was very high.

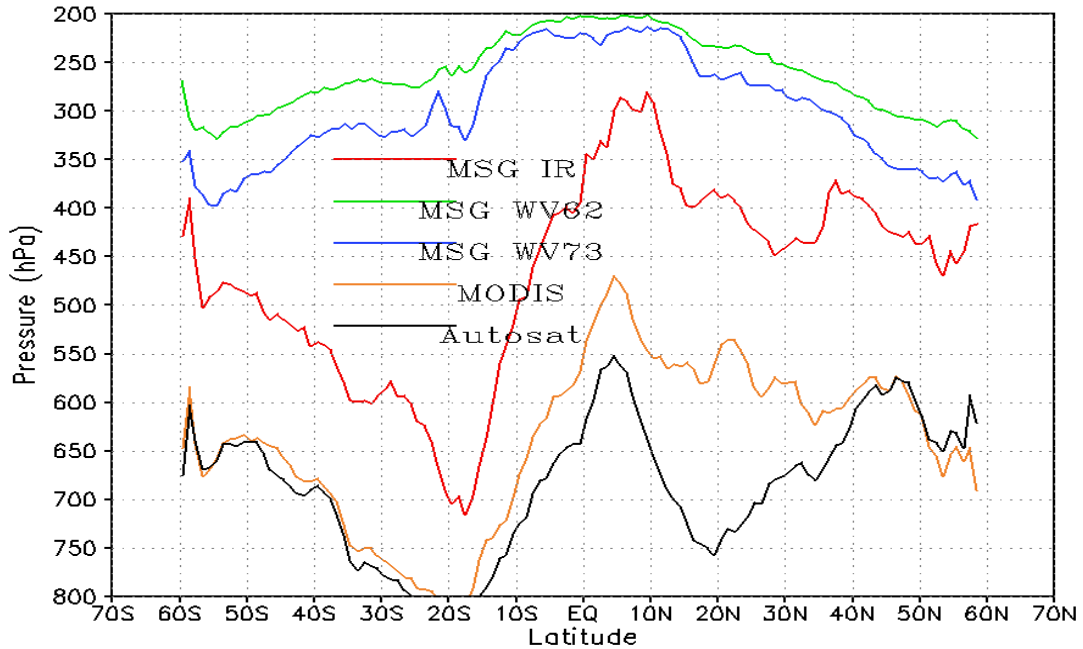


**Figure 23:** 13 April 2005, 10:30UTC a) arrows represent differences in wind speed (observation – background) while the colour stands for the pressure difference between the wind and Autosat cloud tops b) MODIS cloud top pressure for liquid clouds.

At this stage it is difficult to draw any strong conclusions. To try to better understand the differences we will compare the three products on a longer time averaged period and on a lower resolution.

#### 5.2.4. Low resolution comparison

We also ran a comparison at 1x1 degree resolution. The zonal mean of the cloud top distribution is shown in Figure 24.

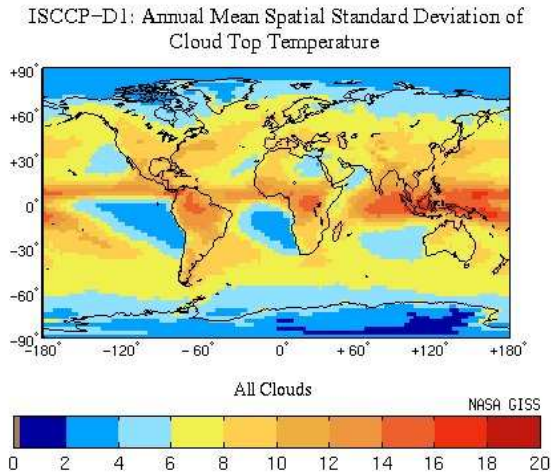


**Figure 24:** Zonal average (over the MSG longitudes) of the cloud top distribution retrieved from MSG (wind and Autosat) and from MODIS for 13-20 April 2005. The blue, red and green lines represent MSG 7.3, 6.2 and 10.8  $\mu\text{m}$  channels respectively. The orange line represents MODIS cloud top pressure and the black line represents the Autosat cloud top pressure.

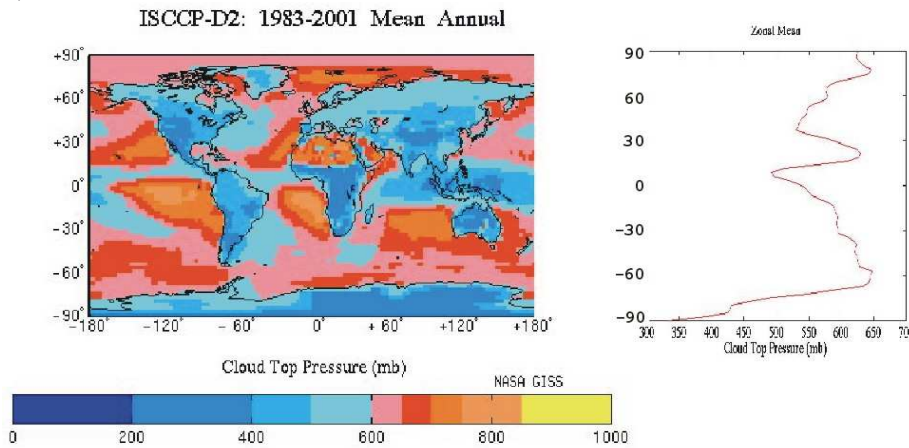
Areas of maxima and minima agree in all datasets. The water vapour wind height is higher than the infrared due to the sensitivity of this channel to a higher part of the atmosphere. Cloud top pressure retrieved from Autosat is lower in the atmosphere than the others. The discrepancies between different datasets are more pronounced in the northern hemisphere. MODIS and Autosat cloud top pressure agree very well at latitudes south of 20S and north of 40N.

Cloud top temperature (or pressure) is quite variable during the year. Figure 25 shows the annual mean standard deviation of cloud top temperature variability for all clouds obtained from ISCCP data (Rossow et al. 1996). The variability is caused by mixtures of different cloud types. The occurrence of upper-level clouds produces the larger effects.

a)



b)

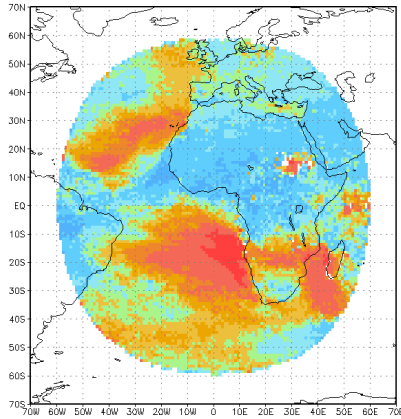


**Figure 25:** a) ISCCP D1 annual mean spatial standard deviation of cloud top temperature and b) cloud top pressure 1983-2001 annual mean. See <http://isccp.giss.nasa.gov/climanal2.html>.

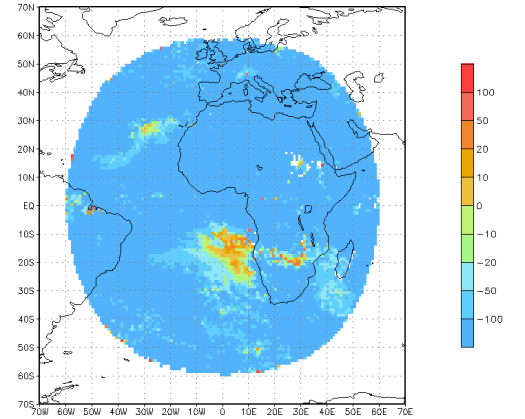
Figure 26 shows the cloud top pressure retrieved from the MODIS and MSG satellite data for eight days of the month of April 2005. We can see that the Autosat and MODIS cloud top pressures are always lower in the atmosphere than the MSG wind heights except over areas where there is always a temperature inversion in the atmosphere. For these particular areas, the wind vector is relocated to the minimum temperature of the inversion. This is the simplest technique to apply, although it is generally accepted that the real cloud top height is normally located above this point (see Figure 7). This leads to a systematic tendency to place the cloud too low in the atmosphere. This systematic low bias is not thought to be a problem as the wind shear below the inversion is typically low. It is much more important to avoid putting the cloud above the inversion where the wind regime can be very different.



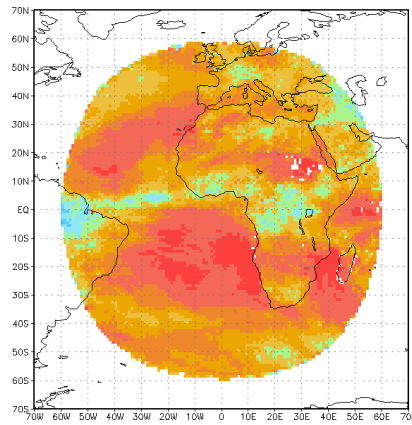
a) MSG IR wind height



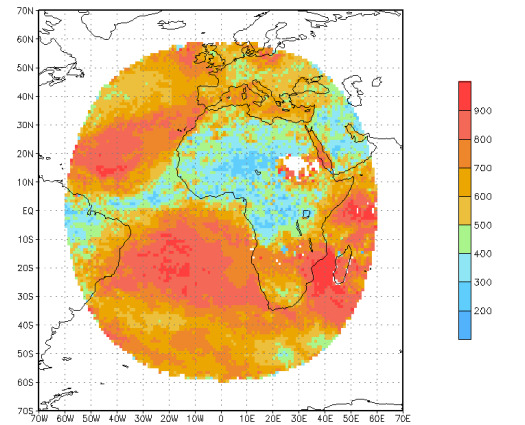
b) Autosat – MSG wind height



c) Autosat CTP



d) MODIS cloud top pressure



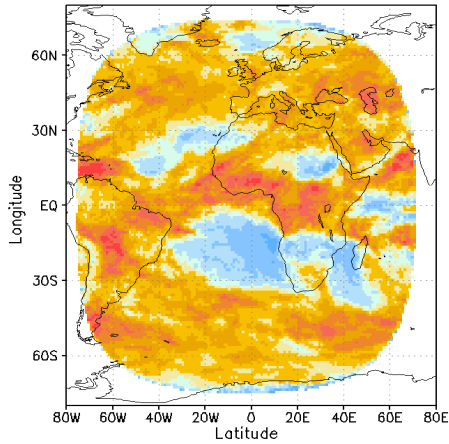
**Figure 26:** 13-20 April 2005, a) MSG IR wind height, b) difference between Autosat cloud top pressure and wind height, c) Autosat CTP, and d) MODIS CTP.

Between MODIS and Autosat, there is generally quite a good agreement for the southern hemisphere. In the northern hemisphere and in particular over the Sahara it seems that the Autosat clouds are too low. This could be due to either very thin cirrus that MSG can detect but which are assigned wrongly to a lower level or to a problem of surface emissivity which can be wrong and leads the Autosat cloud mask to detect clouds where there are none. Over the Sahara, there is a big variation of surface temperature. The model may not be good enough to detect it and in the cloud mask, the temperature difference threshold can detect a fake cloud.

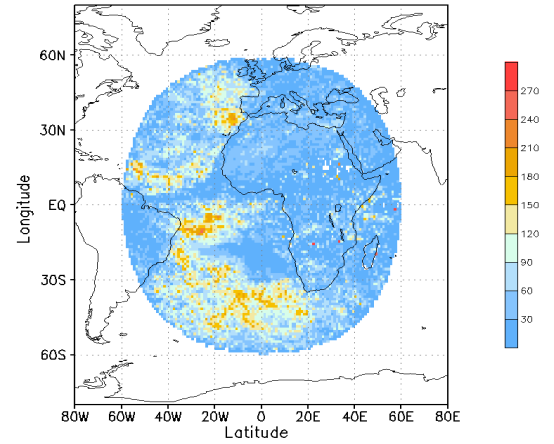
Figure 27 shows the spatial standard deviation of the Autosat cloud top pressure for 8 days periods. The spatial standard deviation ( $\sigma$ ) is compute on each 1x1 degree grid point using the following formula  $\sigma = \sqrt{\frac{1}{N} \sum (x_i - \bar{x})^2}$ , where  $N$  is the number of wind in a grid point,  $x_i$  is the wind height, and  $\bar{x}$  is the wind height mean.



a)

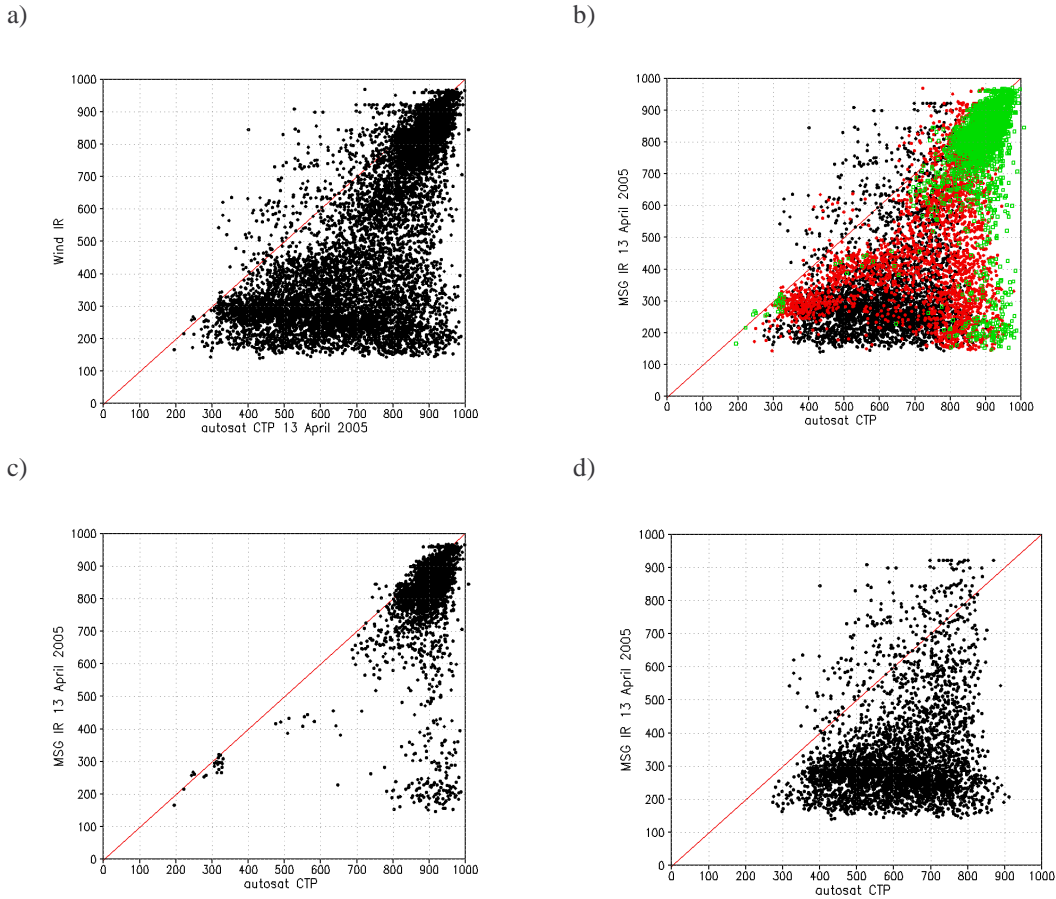


b)



**Figure 27:** Spatial standard deviation of a) Autosat CTP for 13-20 April 2005, and b) Autosat CTP-MSG wind height absolute height difference.

The difference between the Autosat CTP and the MSG wind heights increases with the spatial variability of the Autosat cloud top pressure (see Figure 28). When the spatial standard deviation is smaller than 100 hPa the difference with the wind height is small. These cases are likely to reflect simple cloud situations where the wind height assignment is less problematic. However, it is difficult to use this correlation as a test for discarding winds before assimilation as almost all high-level clouds would be rejected. These results do, however, suggest that much of the big height assignment differences between the Autosat and MSG AMV datasets are related to more complex cloud situations. It is possible that an indicator of multi-level cloud may be beneficial for adjusting AMV errors (raising them in regions of complex cloud).



**Figure 28:** 13 April 2005, scatter plot of Autosat CTP as a function of MSG IR wind height for a) all pixels, c) pixels where the Autosat spatial standard deviation is higher than 100hPa, d) pixels where Autosat CTP standard deviation are higher than 200hPa. Figure b) is the same as Figure c) (in green) and d) (in black). Red dots are pixels where Autosat CTP standard deviation are between 100 and 200 hPa.

## 6. Conclusion

The comparisons of Meteosat-8 AMVs with other AMV datasets were quite encouraging. In general there was good agreement, although there is still some spread in the heights, particularly in the comparison with Meteosat-7. The comparison of Meteosat-8 AMVs with other cloud top pressure products shows that the AMVs are often higher in the atmosphere, except in the inversion regions. It is difficult to draw too much from this result since some differences are expected due to the way the AMV system is designed. The AMV method is specifically concerned with assigning a height that best represents the motion of the tracer. The brighter features, often higher in the atmosphere, will probably dominate in the tracking and therefore we might expect a high bias of the AMVs compared to the normal cloud top pressure products.

The larger observed differences between MSG AMV heights and Autosat heights in regions of greater spatial variability in the Autosat product probably reflects a greater chance of height assignment error in complex multi-level cloud situations. Investigations into O-B AMV statistics confirm that problems with AMV height assignment are observed in multi-level cloud situations, and additionally there are known problems with thin cloud particularly over the desert. There are some known weak points in the EUMETSAT AMV derivation and height assignment. Some ideas for improvement include (i) identifying and using the pixels that dominate in the tracking for the

height assignment (currently use the coldest cloud scene in the target box), (ii) improving the differentiation of cloudy and clear sky targets and (iii) introducing height quality indicators.

In summary, this is preliminary work. It has to be continued to reach stronger conclusions. Height assignment is a difficult task and there are differences from one dataset to another. More work is required to continue investigations into AMV errors in general. Other cloud top pressure products could be used for validation such as POLDER/Parasol (Vanbaume et al., 2003) or MISR cloud top pressures. It is hoped that an improved approach to AMV error setting can be designed, which takes into account factors such as multi-level cloud and vertical wind shear to adjust the observation errors. The results of this study should also feed into improvements to the Autosat CTP product. For example, improvements can be made to the Autosat CTP in some areas such as the Sahara where the cloud detection is not working very well.

In terms of assimilation, it remains some questions:

- How does the forecast change if the wind height assignment is done with 10 or 100hPa potential bias?
- Will doubling the number of winds change the forecast? Do we really need more winds?
- What is the vertical wind shear in the atmosphere? In areas with little vertical wind shear, we should not care too much about the height assignment.

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## Acknowledgements

M. Doutriaux-Boucher was a visiting scientist at the Met Office during the period of this work. She was funded by the Laboratoire d'Optique Atmosphérique, University of Lille, France.