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Synoptic assessment of AMV errors

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Synoptic assessment of AMV errors

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1. Introduction

The statistical analysis routinely produced as part of the NWP SAF atmospheric motion vector (AMV) monitoring and analysis reports is excellent at identifying systematic bias, but may be less effective at relating this to underlying meteorology. The aim of this study is to use case studies to get a better insight into the relationship between observation-model speed bias and features in the satellite imagery or synoptic meteorology.

The work was undertaken by Renato Galante (CPTEC) during a 3 week NWP SAF-funded visiting scientist mission to the Met Office. Three case studies were selected, focusing on the tropics. Met Office AMV monitoring tools and McIDAS were used to produce the plots for the analysis. The study primarily used AMV data available in operational monitoring files at the Met Office, but cases were additionally compared to AMVs generated at CPTEC.

This study aims to demonstrate the potential of a case study approach for better understanding the source of AMV errors. If successful, the approach will be pursued further as part of the 4th NWP SAF AMV analysis to be undertaken during 2009. Understanding the cause of errors is ultimately beneficial both for identifying improvements to the AMV derivation and improving AMV usage in NWP.

2. Methodology

The selection of case studies was based on the following approach:

1. The NWP SAF AMV monthly monitoring available at http://www.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/monthly_mon.html was used to select suitable months to pursue further with case studies. The main focus was on tropical bias features described in the 3rd NWP SAF AMV analysis report available from: http://www.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/analysis.html.

2. Hovmoeller plots were produced for the satellite-channel-month of interest, using additional filtering (e.g. latitude-longitude) as necessary to narrow down a specific 6-hour run for further examination.

3. Map and vector statistics plots were produced for the 6-hour run to check the bias feature is located where expected.

After the cases were selected, the following approach was used to better understand the bias:

1. Map plots were produced for the region of interest showing a range of parameters e.g. AMV pressure, AMV height assignment method, model best-fit pressure etc. The model best-fit pressure is taken as the pressure with the minimum vector difference between the observed vector and background model vector profile. Some additional pre-filtering is applied to remove:
    - minimum vector difference > 4m/s (to remove cases where there is no good agreement)
    - vector difference < the minimum vector difference + 2m/s outside of a band +/- 100hPa (to remove poorly constrained cases)

2. McIDAS was used to display the observed and background wind vectors overlain on the satellite imagery and to display the background wind field at different levels. The model background refers to the short period (3-9 hour) forecast. For comparisons to the observation, this is interpolated in time and space to the observation location.

3. Where relevant MODIS cloud top pressure and CALIPSO profiles were viewed to further evaluate AMV height assignment errors.

4. The cases were compared to AMVs generated at CPTEC. In Cases 1 and 2 this involved generation of AMVs from Meteosat-9 imagery. For Case 3 the comparison was performed against the CPTEC GOES-10 AMV product.

5. The plots were analysed and case study summaries put together for inclusion in this report.

Case studies

Unless otherwise specified, all plots were produced after pre-filtering the data using a model-independent quality indicator (QI) threshold of 80. For more background on AMV tracking and height assignment see Schmetz et al. (1993) and Nieman et al. (1997). For more information on features identified in the AMV O-B monitoring, see the NWP SAF analysis reports (link provided earlier).

Case 1: 18 October 2008, near to 25N; 25W, Meteosat9 channel 7.3µm.

Case 1 focuses on the commonly observed high level tropical fast bias (AMVs faster than model background), which tends to be most prominent in the WV AMVs (see Feature 2.13 in the 3rd analysis report). Figure 1 shows statistics for Meteosat-9 WV 7.3 high level (above 400 hPa) winds compared with the Met Office model background for the month of October 2008. Of interest are the linear fast speed bias features (> 5 m/s) situated around 25N and 15S in the Atlantic Ocean. The same features are observed in the WV 6.2 high level plot, but to a much lesser extent in the IR 10.8 high level plot (not shown). These linear fast bias features are seen in some other months of the NWP SAF monitoring and are currently not well understood.

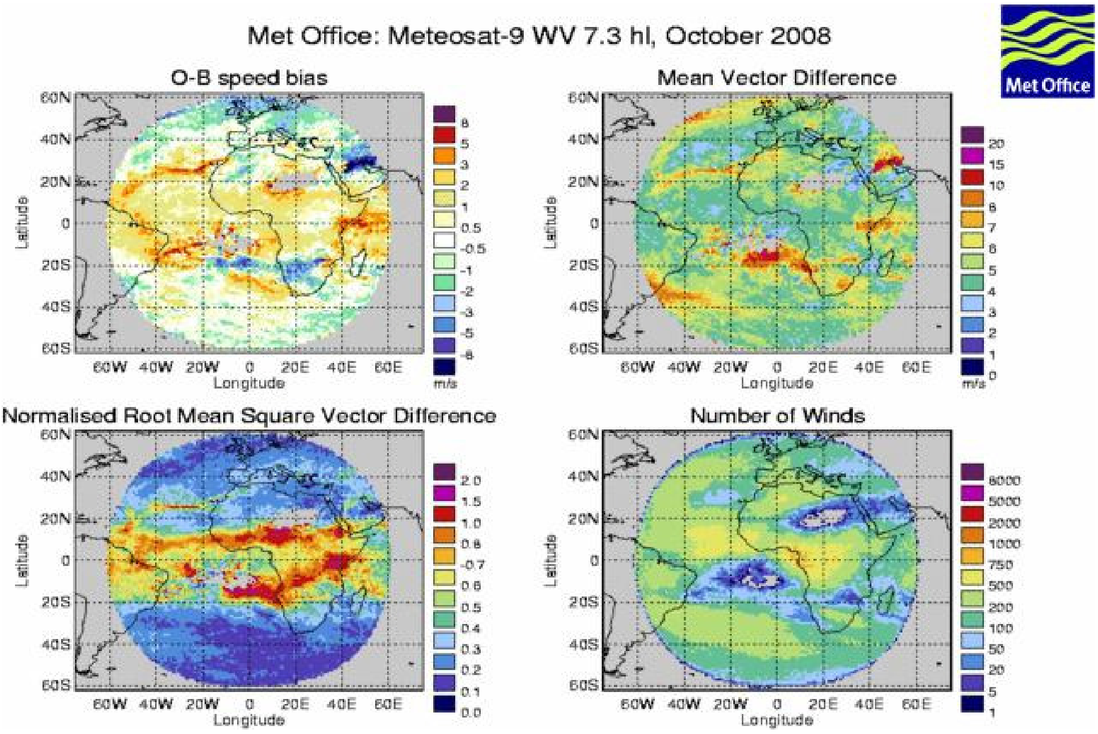

Figure 1: *Map plots showing statistics for the Meteosat 9 WV 7.3µm AMVs compared with the Met Office model background for October 2008.*

Hovmoeller plots were used to better understand the temporal variation in speed bias and to identify a suitable case study. The case chosen was 1130 UTC on 18 October 2008, when the fast bias around 25N is particularly prominent.

Figure 2 shows the Meteosat-9 WV 7.3 AMVs (in blue), together with the model background winds interpolated to the AMV locations (in yellow), overlain on the 11:30 UTC Meteosat-9 WV 7.3 image. Of interest are the group of AMVs highlighted by the red ellipse where the observed and background winds have inconsistent speeds and directions. The circled group of AMVs show a westerly flow consistent with surrounding observations and are associated with the same high level cloud feature in the imagery. Most of the AMVs associated with this cloud are assigned pressures (yellow numbers in Figure 2) of ~180 hPa. At this level the AMVs and model background show good agreement. By contrast the circled group of AMVs are assigned pressures much lower in the atmosphere at ~390 hPa, where the background wind field is very different (more northerly flow).

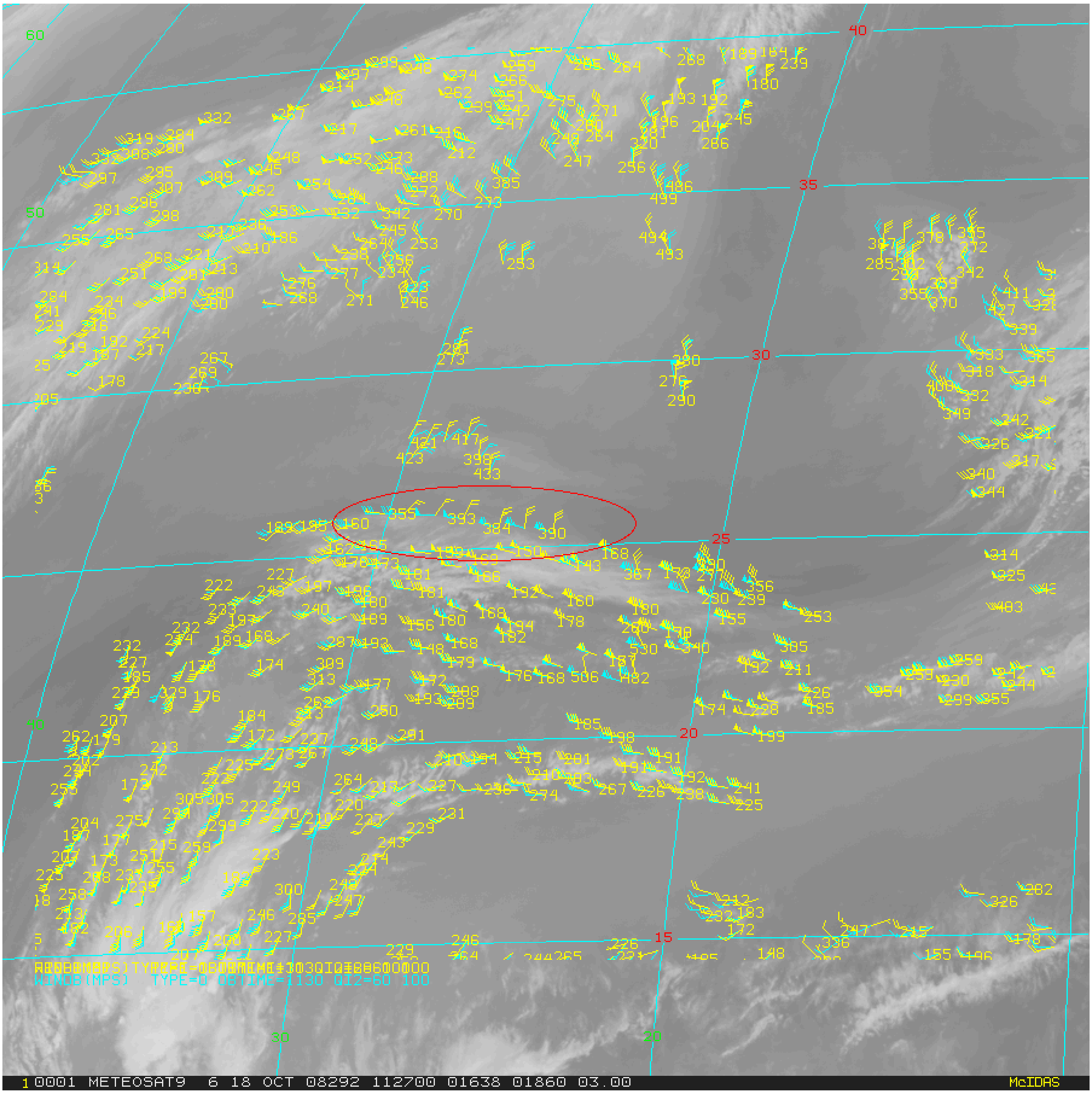

Figure 2: *Meteosat-9 WV 7.3 AMVs (blue) and NWP model background vectors (yellow) for 18 Oct 2008 1130UTC overlain on the Meteosat-9 WV 7.3 imagery (QI threshold of 60).. Numbers in yellow indicate the AMV assigned pressure in hPa.*

The most likely explanation for the speed and direction bias is that the circled AMVs have been wrongly assigned ~200 hPa too low. This leads to a significant speed and direction bias due to wind shear in this region (evident from viewing the model background wind field at different levels).

What is interested about this case is that many of the observations associated with the high level cloud are assigned to a pressure level where the AMVs agree well with the background. It is only a small subset of the AMVs close to the edge of the cloud that appear to be put too low. Figure 3 shows that those AMVs being assigned lower heights have an equivalent black-body temperature (EBBT) height assignment method (green dots in Fig 3c), in contrast to the majority of observations in this area that have CO_2 slicing heights (orange dots in Fig 3c). It is not surprising that the EBBT approach will assign the AMVs too low for high level semi-transparent cloud due to contributions from below the cloud. The more interesting question is why the CO_2 slicing method was not applied for this group of AMVs.

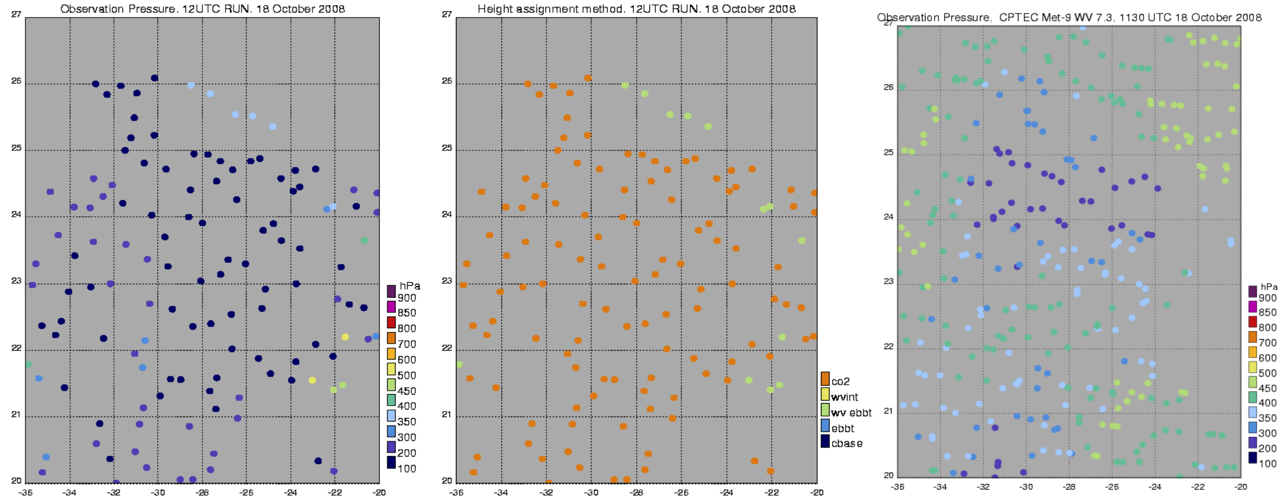

Figure 3: *(a) AMV assigned pressure and (b) height assignment method for the Meteosat 9 WV7.3 AMVs for data valid at 11:30 UTC on 18th October 2008. (c) AMV assigned pressure for Meteosat-9 WV7.3 AMVs generated using the CPTEC derivation scheme.*

The CPTEC-derived AMV pressures are shown in Figure 3c. The plot shows a more extensive low height bias than seen for the EUMETSAT AMVs, which is consistent with the height assignment being based only on the EBBT approach.

Case 2: 8 October 2008, region near to 20S; 14W, Meteosat 9 WV 7.3µm

Case 2 is aimed at better understanding the slow speed bias feature at ~20S seen in Figure 1. The Hovmoeller plots in Figure 4 show how this bias feature lasts for several days from 8 to 11 October 2009. 8 October was selected for further investigation.

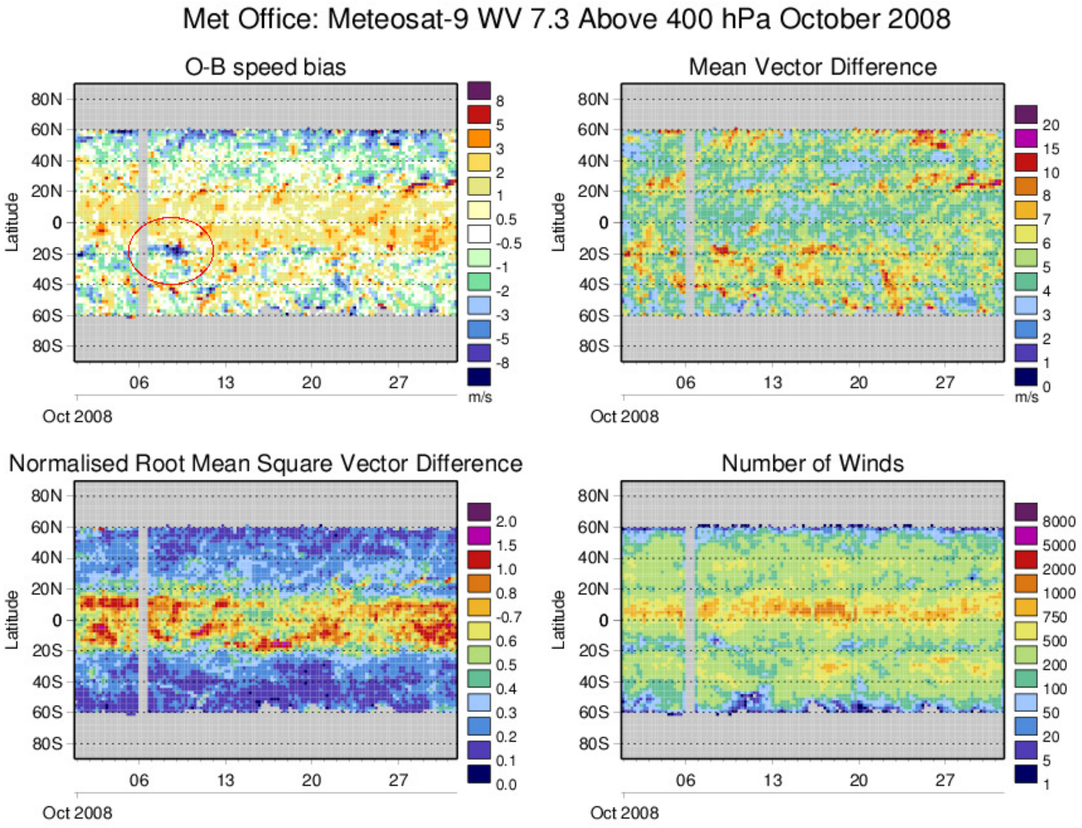

Figure 4: *Hovmoeller plots showing statistics for Meteosat 9 WV 7.3µm AMVs compared with the Met Office model background for October 2008. The red circle highlights the slow bias of interest in this case study.*

The red arrow in Figure 5 indicates the location of this slow speed bias feature for the 8 October case. The bias is seen for AMVs produced from both WV channels and the IR 10.8µm channel.

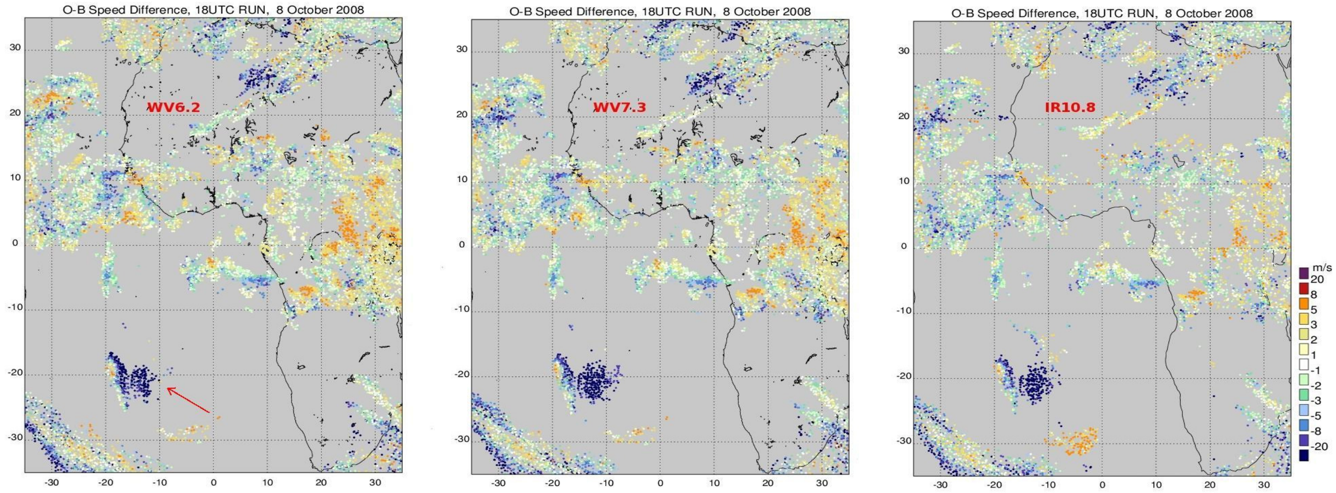

Figure 5: *Speed difference between Meteosat-9 (a) WV 6.2, (b) WV 7.3 and (c) IR 10.8 AMVs and the Met Office model background for data valid between 1500-2100 UTC on 8 October 2008*

Figure 6 shows the WV 7.3µm AMVs overlain on a Meteosat-9 IR 10.8µm image for data valid at 1330 UTC on 8 October 2008. Of particular interest is the area of AMVs close to 20S (top half of Figure), which corresponds to the slow speed bias feature in Figure 5.

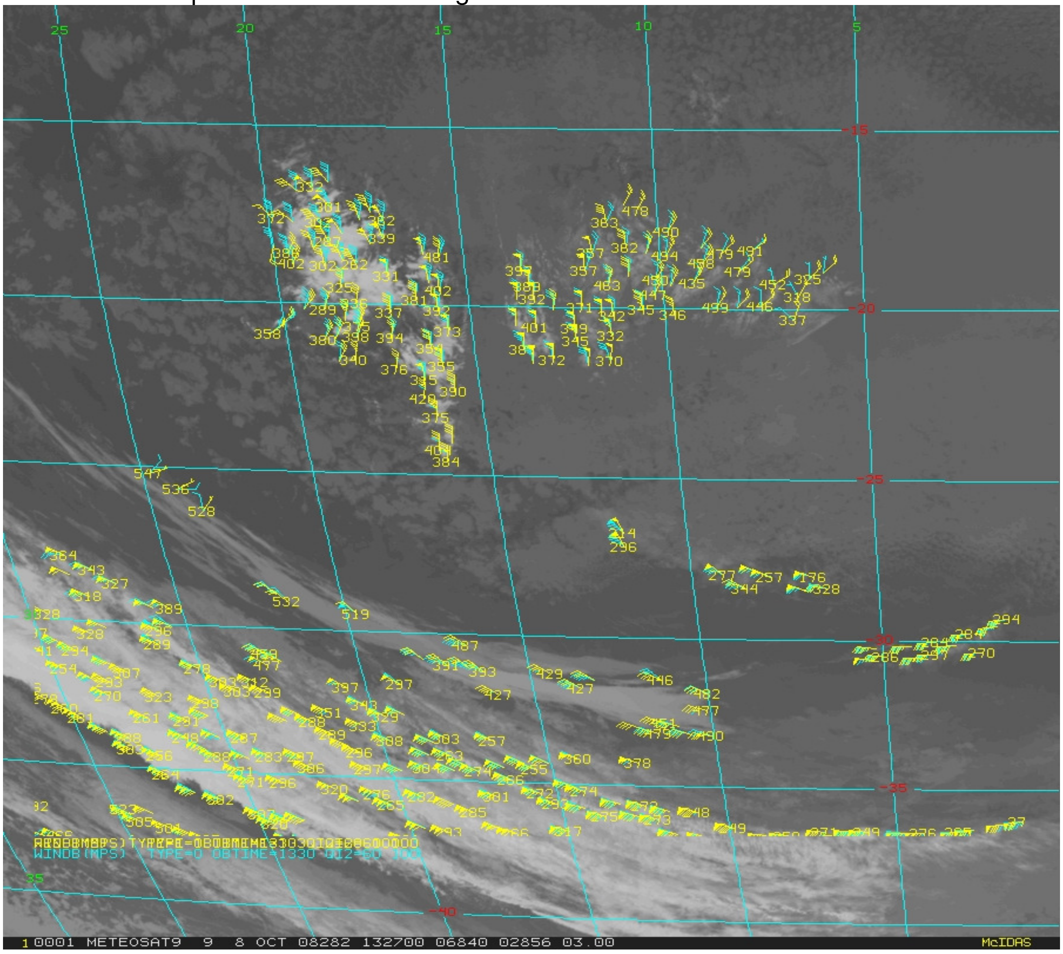

Figure 6: *Meteosat-9 WV 7.3 AMVs (blue) and background wind vectors (yellow) valid at 1330 UTC on 8 October 2008 overlain on the 1330 UTC Meteosat-9 IR 10.8 image (QI threshold of 60).*

The AMV assigned heights in this region vary between 300 and 500hPa (shown by yellow numbers). There is some difference in vector direction, but the main difference between observed and background vectors is in the wind speed; the AMVs shown in blue are slower than the background in yellow by, in some cases, more than 20 m/s. To better understand the cause of the slow bias we examined the background wind field on various levels surrounding the AMV assigned heights (see Figure 7).

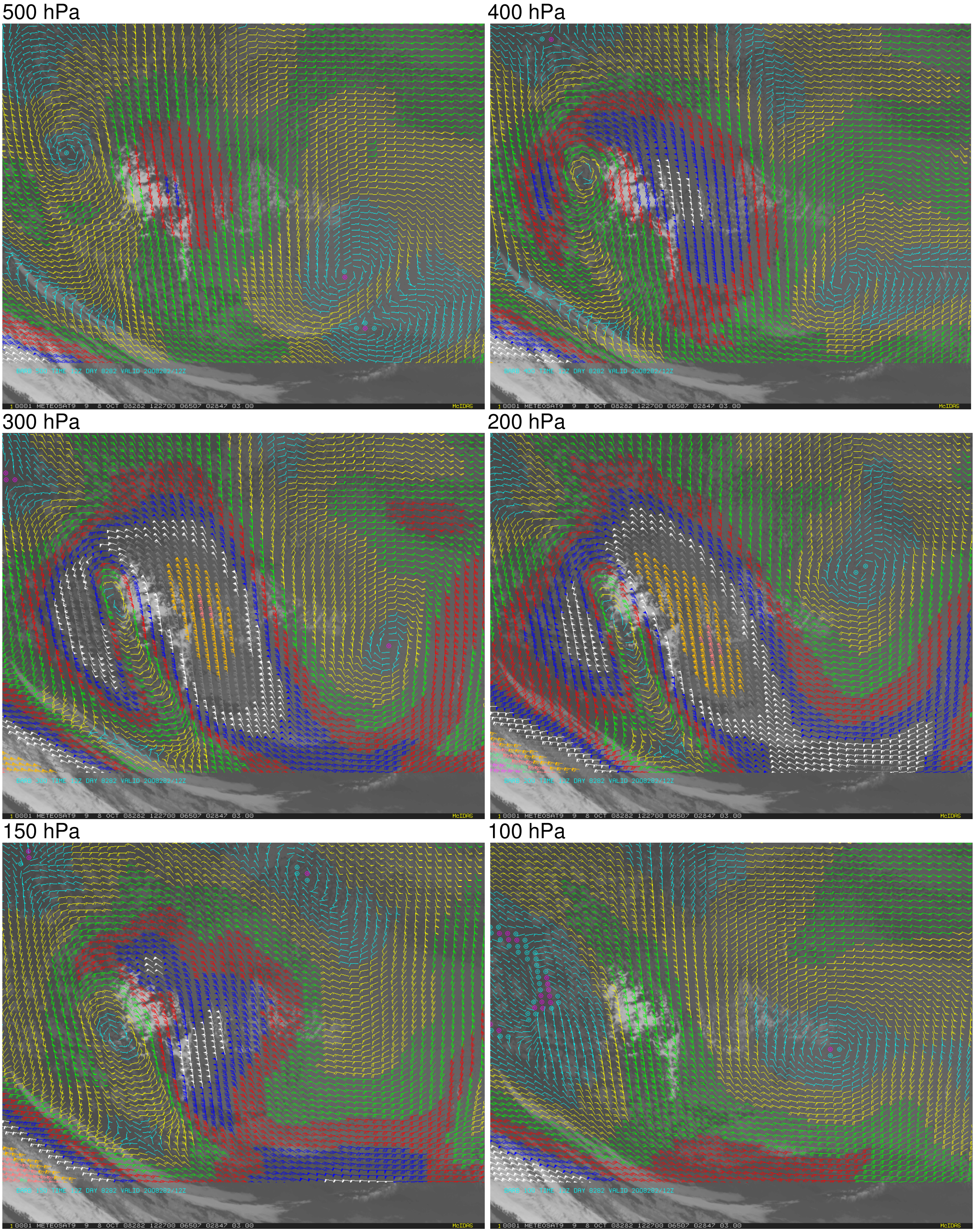
500 hPa
400 hPa
300 hPa
200 hPa
150 hPa
100 hPa

Figure 7: *Plots showing Met Office global model background wind field at different levels for 1200 UTC on 8 October 2008 (pale blue 1-5 m/s, yellow 5-10 m/s, green 10-15 m/s, red 15-20 m/s, dark blue 20-25 m/s. white 25-30 m/s, grey 30-35 m/s, orange 35-40 m/s, peach 40-45 m/s)*

Figure 8 shows a high speed flow peaking at ~45 m/s at 200-300 hPa close to the clouds of interests. The speed 100 hPa above and below this level is significantly slower. At this stage we cannot rule out an error in the background wind field, but a possible explanation for the bias is that the AMVs are derived from tracking clouds closer to either 500 hPa or 150 hPa where the background wind speeds agree better with the AMVs.

In order to confirm, or otherwise, the likelihood of an AMV height assignment bias we looked for CALIPSO overpasses to provide an independent assessment of the cloud top heights in the region of interest. There are no CALIPSO overpasses close to 1330 UTC, but the clouds are visible, although to a lesser extent, in the imagery at 0200 UTC when there is an overpass (see Figure 8a). The CALIPSO data (Figure 8b) suggests that the clouds of interest are at about 14 km (~150 hPa), but that there is also a layer of more continuous low level cloud close to 1 km (~900 hPa). The CALIPSO overpass the following day at 0240 UTC on 9 October 2008 (not shown) also shows some high level cloud at ~14 km above a bank of low level cloud giving some confidence that the cloud pattern is similar for our case, part way between the two.

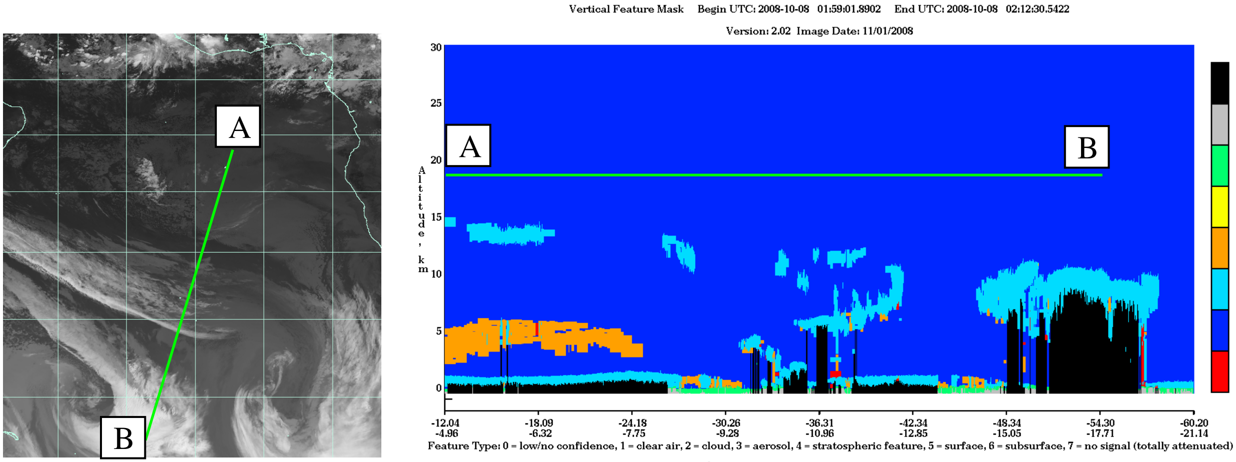

Figure 8: *(a) Meteosat-9 IR 10.8 image valid at 0200 on 8 October 2008 with approximate location of CALIPSO overpass marked; (b) CALIPSO feature mask for 08 Oct 2008 02:00UTC*

There may be some differences between CALIPSO cloud top and IR observed cloud top, but not enough to account for the difference between 150 hPa (CALIPSO) and 300-500 hPa (AMV assigned heights). As shown earlier there is also better agreement between the AMVs and model background at 150 hPa. It, therefore, seems likely that the speed bias is due to AMVs at higher levels (above 200 hPa) being wrongly assigned lower in height (300-500 hPa) where the background wind speeds are faster. The CPTEC-derived AMVs (not shown) have heights in the same range as those from EUMETSAT suggesting they are affected by a similar height assignment problem.

The satellite imagery and CALIPSO profile show two layers of cloud. In these situations cloud top pressure assignment is known to be harder, with the cloud top pressure often being put between the two layers (examples shown at the EUMETSAT cloud workshop in 2009). Figure 9a shows that the AMV heights are a combination of EBBT heights (green dots) and CO_2 slicing heights (orange dots). There is a slight tendency for the EBBT heights to be lower in the atmosphere (Figure 9b), but both are inconsistent with the CALIPSO very high cloud feature, except for a few AMVs close to 18S, 18W. Interestingly the model best-fit pressure (Figure 9c) gives inconsistent results. Mostly the preferred level is close to 500 hPa or above 200 hPa. We suspect the variability is due to the similar wind field pattern at these two levels (as seen in Figure 9) leading to some ambiguity in best-fit. Filtering of the model best-fit pressure is applied in an attempt to remove ambiguous cases, but may benefit from further refinement. The biggest O-B speed differences (Figure 9d) unsurprisingly occur in the region with strongest wind shear in the area close to 20S, 12W.

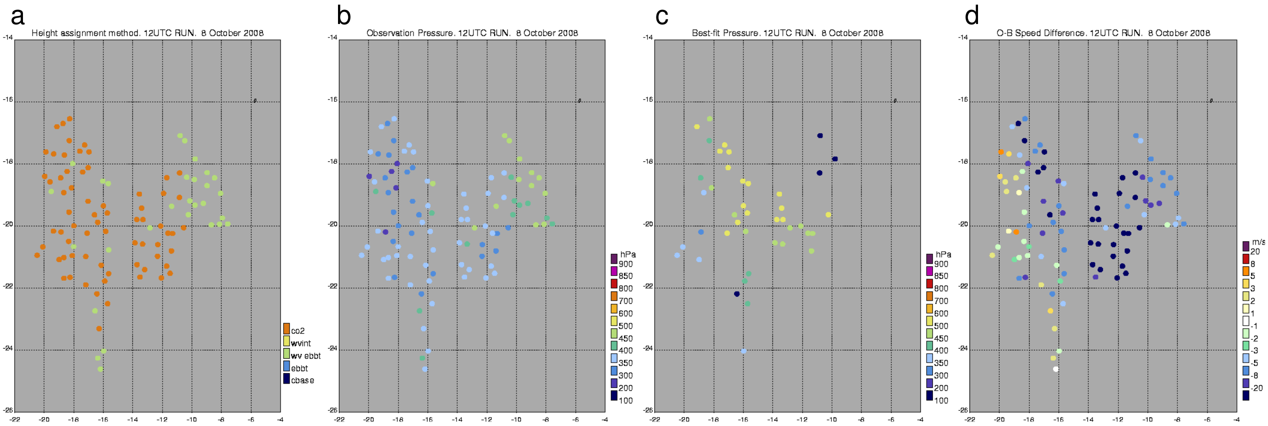

Figure 9: *(a) height assignment method, (b) observed pressure, (c) model best-fit pressure level and (d) O-B speed difference for Meteosat 9 channel 7.3µm valid at 1330 UTC on 08 October 2008*

Case 3: GOES-12, low levels IR 10.2μm and Visible AMVs 16 October 2008, Pacific Ocean near to the west coast of South America.

Case 3 focuses on the fast speed bias seen at low level (below 700 hPa) off the west coast of South America (see Figure 10 and Feature 2.1 in the 3rd analysis report for more background). This feature is fairly well understood, but the case was selected for this study to enable comparison with the CPTEC-generated GOES-10 AMVs.

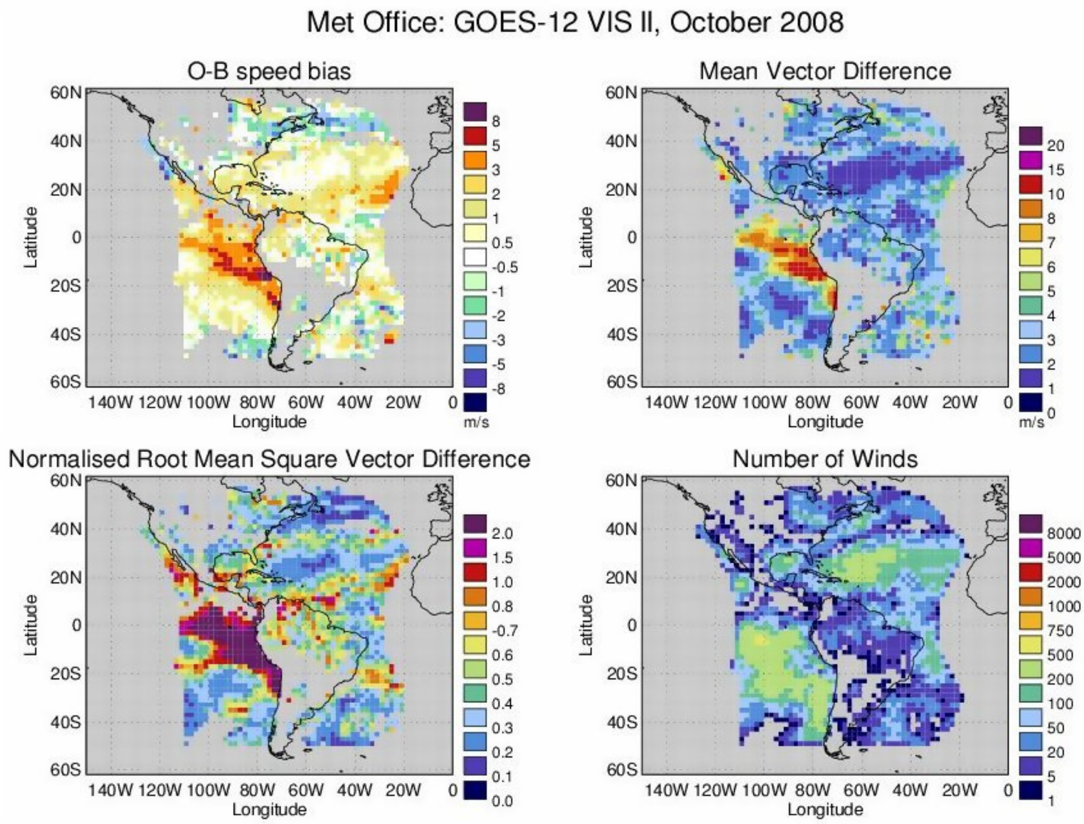

Figure 10: *Map plots showing statistics for GOES-12 visible AMVs compared with the Met Office model background for October 2008*

Hovmoeller plots were used to identify 16 October 2008 as a good case for further investigation (peak in the fast bias).

Figure 11 shows the O-B speed difference for GOES-12 visible AMVs on 16 October 2008.

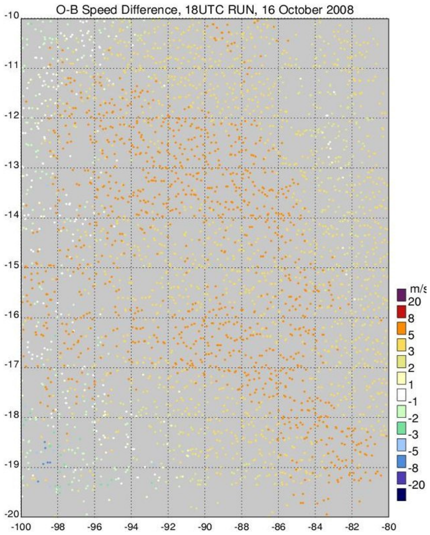

Figure 11: *Speed differences between GOES-12 visible AMVs and the Met Office model background for 16 October at 15 to 21UTC*

Where the speed differences are greatest the AMVs have mostly been assigned heights between 600 and 700 hPa (Figure 12a). Whereas, the model best fit pressures are below 850hPa in the atmosphere (Figure 12b). Figure 12c shows the GOES-10 IR pressures, which show a similar height range to the GOES-12 AMVs, suggesting they are affected by a similar height assignment error.

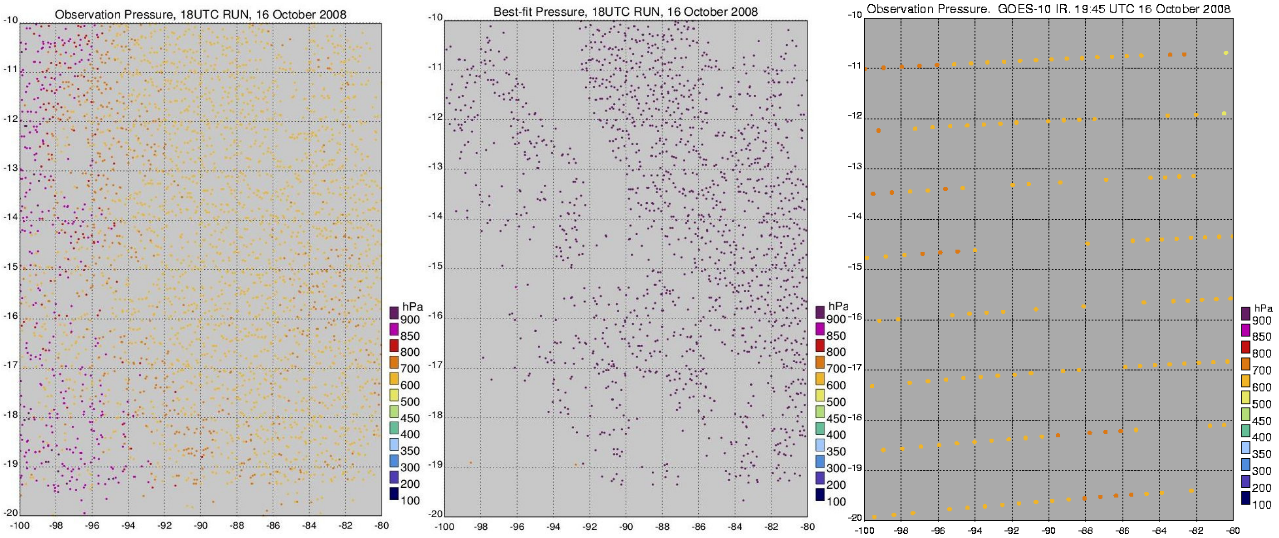

Figure 12: *(a) GOES-12 IR 10.2µm assigned pressure, (b) model best-fit pressure for GOES-12 IR AMVs and (c) CPTEC GOES-10 IR assigned pressure*

Comparisons can also be made with data from CALIPSO overpasses. Figure 13 shows an example for ~2000 UTC 16 October 2008. This data supports the model best-fit pressure with clouds located close to 1 km in altitude (right-hand part of plot).

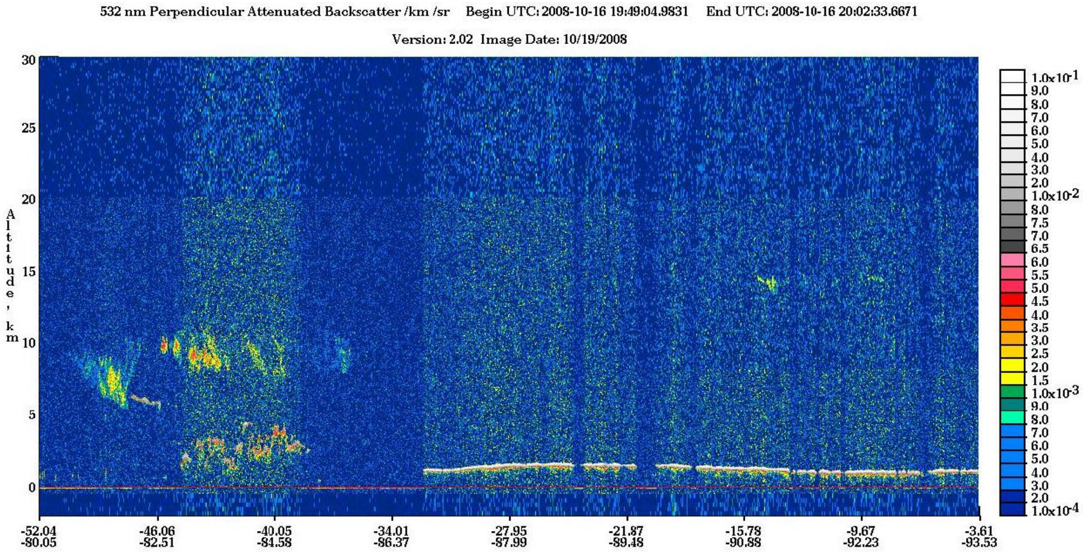

Figure 13: *CALIPSO profile of 532 nm perpendicular attenuated backscatter for 16 October 2008 at 2000 UTC*

It is generally accepted that this height error is due to difficulties with height assignment in temperature inversion regions. NESDIS are evaluating an improved approach in these cases. The similar error in the CPTEC winds, suggests that they should also consider introducing some form of inversion correction.

Conclusions

This study demonstrates how we can select and investigate case studies to learn more about some of the features observed in the NWP SAF monthly monitoring. Of particular interest is the relationship of the bias to clouds in the imagery and to synoptic flow patterns in the model background field. It was also useful to compare the AMV pressures to model best-fit pressure and MODIS and CALIPSO cloud products.

It is interesting that in all 3 cases described in this study, the speed bias is best explained by AMV height assignment errors, a known problem area for AMV extraction algorithms. In Case 1 a few AMVs towards the edge of a high level semi-transparent cloud are assigned heights using the WV EBBT method instead of the CO_2 slicing method, which puts the winds too low (by ~ 200 hPa). In Case 2 the AMVs are located in a region where CALIPSO data suggests there is some very high level clouds overlying a more continuous region of low level cloud. Height assignment can be a problem in these multi-level cloud regions. From the imagery the AMVs appear to relate to tracking of the high level cloud, but are assigned lower to 300-500 hPa. This height error combined with a large amount of vertical wind shear, gives rise to a sizeable speed bias. The 4-day duration of this event illustrates how AMVs can have temporal error correlations due to systematic error related to longer-lived cloud features and synoptic patterns. Finally, Case 3 is a re-look at the GOES-12 low level fast bias problem in inversion regions. Although this bias feature is fairly well understood the case was selected to enable comparisons with GOES-10. It was found that the CPTEC GOES-10 AMVs are affected by a similar high height bias. Work is ongoing at NESDIS to address the problem for the GOES-11 and 12 AMVs.

Acknowledgements

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