

INVESTIGATING ERRORS IN LOW LEVEL AMV HEIGHT ASSIGNMENT

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Abstract

Height assignment is considered to be one of the main error sources for Atmospheric Motion Vectors (AMVs) and better understanding the associated error has been a long standing area of research undertaken by both the data providers and users. AMVs have been traditionally treated with a single layer observation operator in assimilation and the height estimated at the cloud top (or sometimes cloud base for low level clouds). Recent work at ECMWF and the Met Office highlighted potential issues with the height assignment in the low level winds over the Indian Ocean and Atlantic Ocean. In these regions, the change in wind speed with height for the AMVs is much smaller than the equivalent profile in the model. Data from Multi-angle Imaging SpectroRadiometer (MISR) stereoscopic winds and limited profiles from radiosondes in the Indian Ocean suggest that the AMVs are too fast in the range of 850-700hPa. This may be due to some AMVs being assigned pressures that are too low. However, positive speed biases, but of smaller magnitude, in MISR compared to Met Office model data intimate that some speeding up of the model winds may be beneficial.

The work in the Indian Ocean inspired more detailed analysis of errors in the height assignment of which the initial focus has been on the low level AMVs. AMVs have been collocated with model estimates of boundary layer height and cloud parameters to investigate connections with the assigned heights. A significant number of AMVs have been found to be at very high pressures and much lower than the model boundary layer top at levels where clouds are not expected. In the tropics, there is contrast of positive speed bias above the boundary layer and negative speed bias for AMVs within the boundary layer suggesting that there is a detrimental impact of the AMVs being too low or high relative to the boundary layer top. Preliminary results from profiles of model variables such as cloud cover fraction, temperature and humidity show that it may be possible to develop a systematic correction to the height in the future.

INTRODUCTION

AMVs have traditionally been treated with a single layer observation operator in the process of computing the model equivalent of the observation in assimilation. The height is estimated at the cloud top or sometimes cloud base in the case of low level clouds (e.g. LeMarshall et al. 1994). However, studies have indicated that this technique of height assignment is a significant source of error for the AMVs (e.g. Velden and Bedka, 2009). To better represent the bulk motion of the cloud, promising results have been found by treating the height as a layer average or reassigning the AMV to be at a single level within the cloud (Velden and Bedka, 2009; Hernandez-Carrascal and Bormann, 2014; Folger, 2016).

On 2nd March 2017, Meteosat-8 succeeded Meteosat-7 as the new provider of AMV coverage in the Indian Ocean in the ECMWF operational forecast system. During assimilation experiments for the new data, forecast impacts were largely neutral or showed small improvements (Lean and Bormann, 2018). However, an area of apparent degradation in short range forecasts around 850hPa was seen in a localised region over the Indian Ocean. The AMVs were found to be increasing the wind speed of the analysis in the region. Further analysis using other satellites with good Indian Ocean coverage (the Chinese FY-2E and Indian INSAT-3D satellites) showed that, although to a lesser extent, a faster analysis wind speed was supported in this region. In the first part of these proceedings we will discuss

the influence of the AMVs on the model wind field and investigate potential height assignment issues using wind speed profiles from other independent wind observations to include nearby radiosondes and stereoscopic winds from MISR.

This work motivated a wider study into height assignment characteristics which initially addresses the placement of AMVs around the top of the boundary layer. With the exception of fog, boundary layer clouds tend to form near the top of the boundary layer (Hartmann, 2015). However, AMVs can be found closer to the surface - this was recently noted as affecting many low level AMVs from Himawari-8 (Lean and Bormann, 2016). As the basis of AMVs is tracking cloud features, we aim to investigate whether some assigned heights are unphysically low for the existence of clouds and whether this has a detrimental impact on the statistics of these AMVs. The analysis of the low level winds (which are defined here as having an assigned pressure $> 700\text{hPa}$) was carried out using collocation of AMVs with ECMWF model variables to include the boundary layer height and profiles of wind speed, cloud liquid water, cloud cover, temperature and humidity. The height of the boundary layer is determined in the model by a threshold on the bulk Richardson number (Vogelezang and Holtslag, 1996). Maps of the boundary layer height (not shown) suggest that the pressure at the top of the layer over ocean might typically be around 900hPa in the tropics and up to 800hPa in the extra-tropics. The second part of these proceedings will present analysis from Meteosat-8 and Himawari-8. Potential connections between the assigned heights and model cloud parameters and boundary layer height are explored with the aim of identifying a systematic correction. In the future, this technique could be extended to winds at higher levels and to probe the Indian Ocean region at 850hPa also discussed here.

CHALLENGE AT 850HPA

During the testing for the switch from Meteosat-7 to Meteosat-8, an area of apparent forecast degradation was seen in a localised region over the Indian Ocean in the Meteosat-8 assimilation experiments. During the period of consideration, 21st October 2016 - 30th June 2017, the signal was stronger at first then lessens into February/March before resuming again such that over a long experiment time the feature persists (figure 1a). In the affected region of the Indian Ocean there is a general westward flow which is strengthened by the addition of the AMVs (figure 1b). This signal is seen consistently, although more weakly, in other Indian Ocean Data Coverage (IODC) satellites such as INSAT-3D and FY-2E (not shown). After the initial change applied at the analysis time, the strengthening influence of the AMVs here propagates very little into the short range forecast.

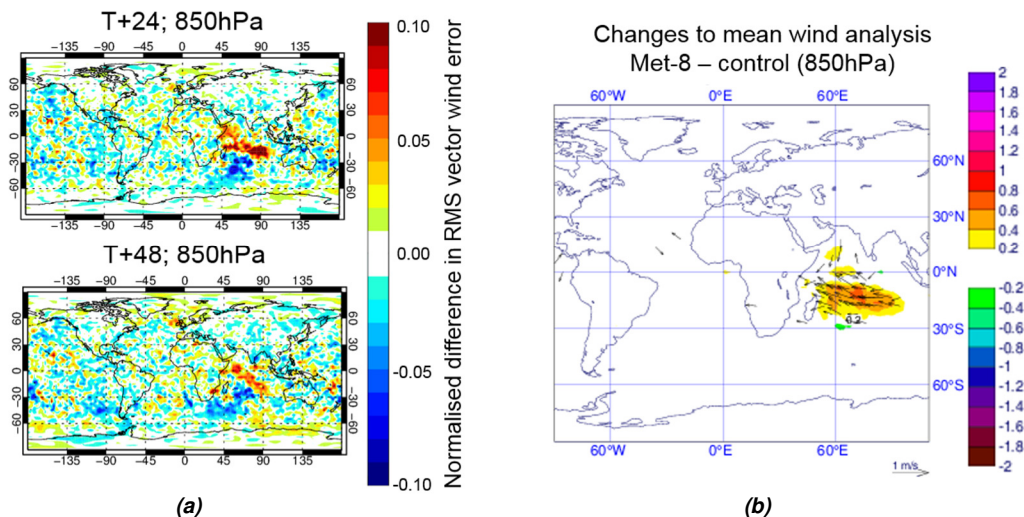


Figure 1 (a) Change in vector wind error at 850hPa at forecast lead times 24 and 28 hours (1st Dec 2016 - 30th Jun 2017) where red colours indicate an increase in error and (b) Map showing the change to the mean wind analysis (21st Oct - 18th Dec 2016) between the experiment containing Meteosat-8 AMVs and control.

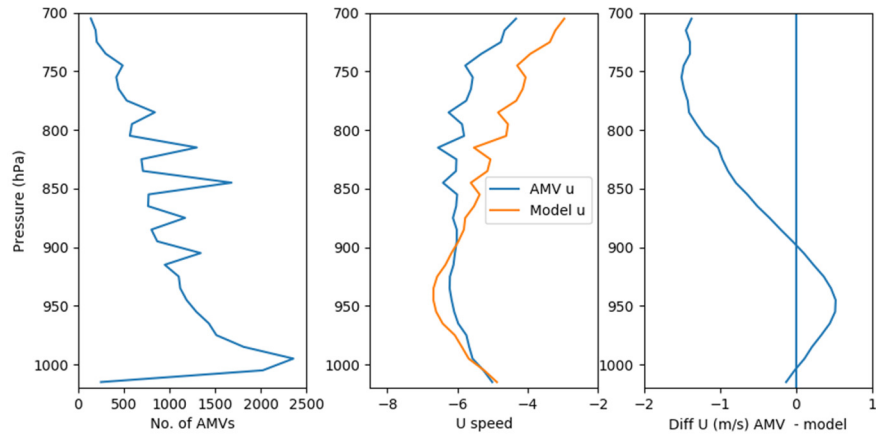


Figure 2 Mean of the daily profiles of number of observations (left), U component of wind for infrared and visible AMVs and ECMWF model background wind sampled at AMV locations (middle) and U bias (right) for Meteosat-8 within the area 50-100°E, 5-25°S, screened by QI and first guess check, using 10hPa averaging bins and for 1-31st Dec 2016. The model background had no IODC AMVs assimilated

Further investigations show that during October - December 2016, mean analysis increments act to strengthen the westward flow in the area also in the absence of the AMVs. This is indicative of a bias in the forecast model, leading to short-range forecasts that are too slow, and observations hence act to reduce this bias during the analysis. However, in the latter half of the experiment, such mean analysis increments are only present when AMVs are assimilated, so an AMV-specific bias is also possible.

The possibility of AMV biases was also investigated. To better understand the structure of the low level AMVs, vertical profiles of the mean wind speed and number density were studied using data only from a box covering the affected area (50-100°E, 5-25°S). The mean Meteosat-8 AMV wind profile (figure 2) shows very little variation in height while the ECMWF model background winds (provided by a short range T+12 forecast from the previous model cycle), sampled at the AMV locations, suggests more wind shear. Small spikes in the profiles of Meteosat-8 correspond to inversion levels where many more AMVs are assigned, as shown in the number density plot. FY-2E has a very similar pattern (not shown) but with comparatively very few winds in the region which may have resulted in any signal being too weak to show in the verification. INSAT-3D (not shown) agrees more with the model however this is likely due to the increased Numerical Weather Prediction (NWP) dependence in the height assignment part of the derivation process (Deb, 2012).

Unfortunately, this area of the ocean is very sparsely covered by conventional wind observations. Profiles from two radiosonde sites (Cocos Island and Réunion Island) on the periphery of the affected area were considered and these both supported some variation with height. Figure 3a shows the profiles of the mean wind speed for the Cocos Island radiosonde (12.2°S, 96.8°E) and the AMVs using data averaged in a 2°x2° box centred on the radiosonde location. Note that these plots now use the Met Office model background (T+6 forecast from the previous model cycle) but the presence of more wind shear is common to both models. Further discussion of the Met Office analysis can be found in Warrick and Cotton, 2018. The radiosonde shows good agreement with the model analysis and small speed biases in the first guess (around 1m/s). Meanwhile, the speed bias for Meteosat-8 is just over 1m/s at 850hPa but quickly increases to 4-5 m/s by 750hPa (figure 3b).

As the radiosondes are towards the edge of the affected area and only two in number, another independent check was sought using stereoscopic winds from MISR. Figure 4 shows the wind speed profiles, difference in speed and number of winds for MISR and Meteosat-8 over a wider area covering the whole degradation feature (5-25°S, 50-100°E). The MISR winds suggest a level of wind shear that is somewhere between the radiosonde and the AMVs. This supports the hypothesis that the AMVs do not fully capture the correct variation but hints that the model winds may contain too much wind shear. The distribution of the winds shows peaks in the number of MISR winds around 800hPa and just below 900hPa. Meanwhile Meteosat-8 has one broader peak centred around 800-850hPa which further suggests that some of the lower AMVs may be placed too high.

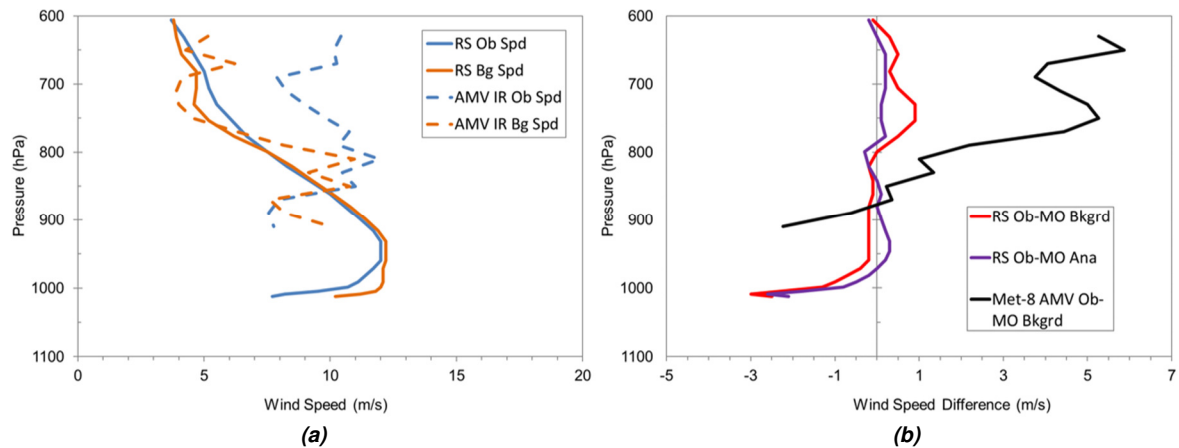


Figure 3(a) Mean profiles of wind speed for the Cocos Island radiosonde (12.2°S, 96.8°E), Meteosat-8 AMV and Met Office model background wind sampled at radiosonde and AMV locations. **(b)** Difference in wind speed for radiosonde - Met Office model background, radiosonde - Met Office model analysis and Meteosat-8 - Met Office model background. AMV data are from a 2°x2° box centred on the radiosonde site and both are from the period 31st July - 31st August 2018.

In summary, the comparisons suggest consistently that there is distinct vertical variation of the mean wind regime at lower levels, which is not captured by the AMVs and results in AMVs that are too fast above around 850hPa. This may be the result of a height assignment error where the faster winds are being placed too high, or it may suggest that the height assignment cannot reliably distinguish different levels between 700 and 950hPa. However, there are also indications of model bias, and the area is otherwise poorly constrained in terms of wind, particularly in terms of the vertical structure. Other routes to gaining information about the AMVs could include comparing the cloud heights to Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and with the recent launch of Aeolus (August 2018), providing wind profile information, this could give a valuable independent insight into the area.

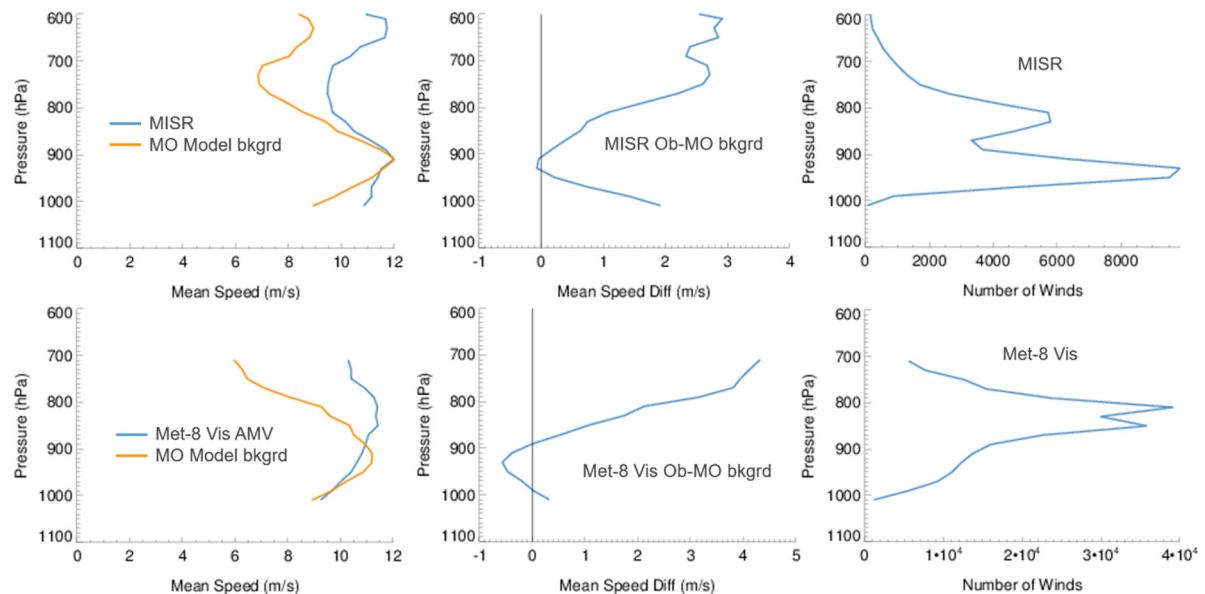


Figure 4 Mean profiles of wind speed (left column), difference in wind speed (observation - Met Office model background) (centre column) and number of winds (right column) for MISR winds (top row) and Meteosat-8 visible winds (bottom row). Data are from the region 5-25°S, 50-100°E, using 20hPa averaging bins and from the period 1st - 31st August 2018.

LOW LEVEL HEIGHT ASSIGNMENT

Considering the low level AMVs more generally (focusing over the ocean as low level winds over land are not assimilated due to poor data quality), AMVs from Meteosat-8 and Himawari-8 were matched to model estimates of the boundary layer height produced from very short range (up to T+11) hourly forecasts on a high resolution reduced gaussian N640 (~16km) grid. At ECMWF, the boundary layer height is determined as the lowest level at which the bulk Richardson number reaches a critical threshold (Vogelezang and Holtslag, 1996). AMVs were collocated to a model estimate at the nearest grid point and within 30 minutes of the observation time. Statistics for the matches were split into the tropics and extra-tropics (using 25°N/S as the boundary).

Figure 5(a) reveals that for Meteosat-8 the proportion of AMVs below the model boundary layer top is significant. For Himawari-8, not only are there are lot more winds available, in fact now the majority are within the model boundary layer. The corresponding bar chart of mean speed bias in figure 5(b) shows that in the tropics there is a clear division in values above and below the boundary layer top. For both satellites the AMVs within the boundary layer exhibit a negative speed bias of around 0.4m/s but show a positive bias for the low level winds above the boundary layer top. In the case of Meteosat-8, this positive bias is even larger, around 0.5m/s, which links in with the positive speed bias around 850-700hPa discussed in first part of these proceedings. In the extra-tropics, the difference in bias is smaller and is actually more negative for the Himawari-8 AMVs above the boundary layer.

The AMVs located within the boundary layer are distributed across much of the disk for Himawari-8 whereas for Meteosat-8 these very low AMVs tend to be less evenly spread (Figure 6). With the large coverage extent, it is not immediately clear that the placement of very low AMVs is related to a specific synoptic condition. Throughout the week of 3rd - 9th January these very low AMVs were found in a similar distribution. However, preliminary results using data from a week in July 2018 showed a higher density of very low winds in the southern hemisphere for both satellites (not shown) suggesting there is potentially an element of seasonality.

To investigate further the circumstances in which these very low level AMVs arise, profiles of model variables (wind speed, temperature, humidity, cloud liquid water and cloud cover fraction) taken at the grid point collocated to the AMV were produced. Figure 7 and 8 show example profiles from two 10°x10° boxes, one each from the tropics and extra-tropics, for Meteosat-8 infrared AMVs assigned more than 50hPa below the boundary layer top. In both cases the higher levels of cloud fraction and cloud liquid water occur around the boundary layer top, and the placement of the AMVs is not consistent with the model clouds.

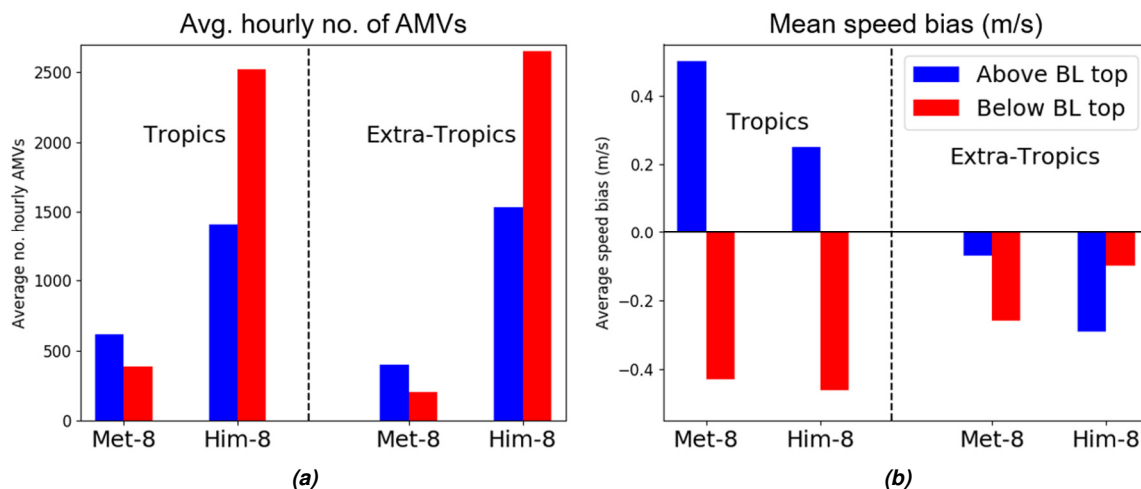


Figure 5 Bar charts of (a) the average hourly number of AMVs and (b) the mean speed bias for low level ($P > 700\text{hPa}$) infrared channel AMVs from Meteosat-8 and Himawari-8 with the winds separated by placement above (blue) or below (red) the boundary layer (BL) top and by tropics and extra-tropics. Data are from 3rd - 9th January 2018 and have been subject to screening by Q1 and first guess check.

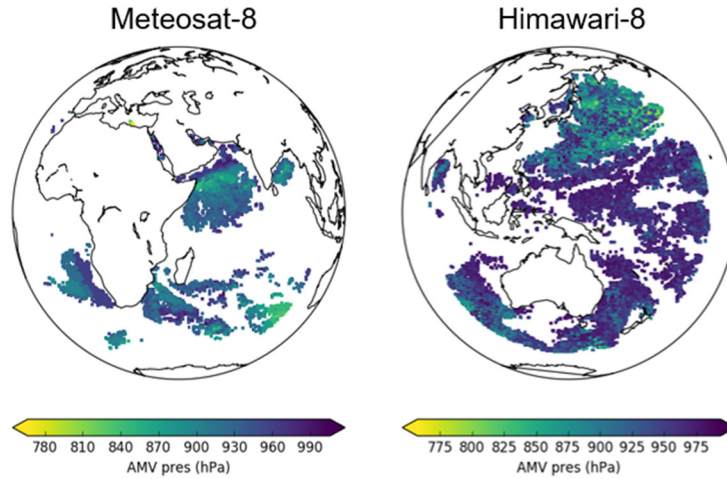


Figure 6 Maps showing the location and assigned pressure of infrared AMVs below the model boundary layer top for Meteosat-8 (left) and Himawari-8 (right). Data are between 12Z 4th - 00Z 5th January 2018 and have been subject to screening by QI and first guess check.

For the tropics examples, there is quite an abrupt transition around or just above the boundary layer top with a temperature inversion and sudden decrease in humidity and wind speed. The error in the assigned height may be linked with the treatment of the inversion. There may also be contamination in the cloud radiance from the warm ocean surface during the height assignment calculation which causes the cloud to appear warmer and closer to the surface. With more robust statistics from larger areas and longer time periods, it may be possible to identify a height correction procedure using model information. There is clearly a difference between the model and observation in the placement of the cloud but it is possible that the model clouds also may not be at the correct height. However, even if the model clouds are not always accurately placed, there may be benefit from reassigning the heights of the AMVs to reduce the speed error caused by height assignment issues.

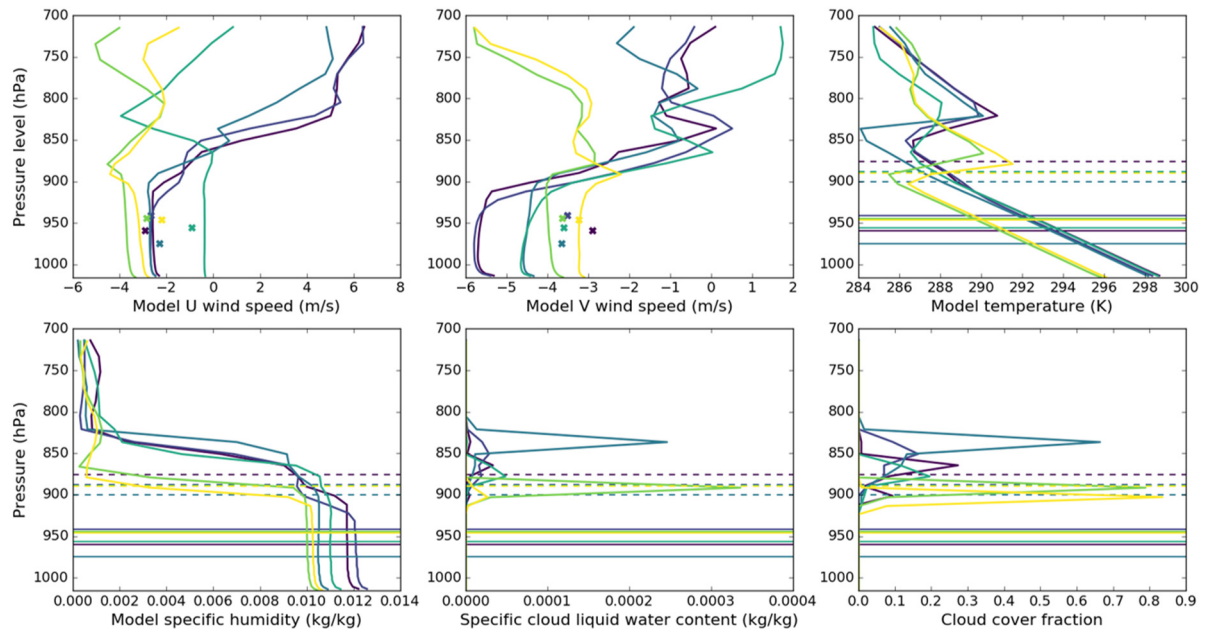


Figure 7 Profiles of model variables (clockwise from top left): U wind component, V wind component, temperature, cloud cover fraction, specific cloud liquid water content and specific humidity. In addition, the infrared Meteosat-8 AMVs are marked with crosses on the wind speed plots and as solid lines at their assigned pressure for other variables. Dotted lines show the model boundary layer tops. Different colours are used to differentiate each pairing of model profile with the corresponding matched AMV and boundary layer height. Data are from 10-20°N, 65-75°E 5-6Z 4th January 2018 where the AMV is more than 50hPa lower than the model boundary layer top and screened by QI and first guess check.

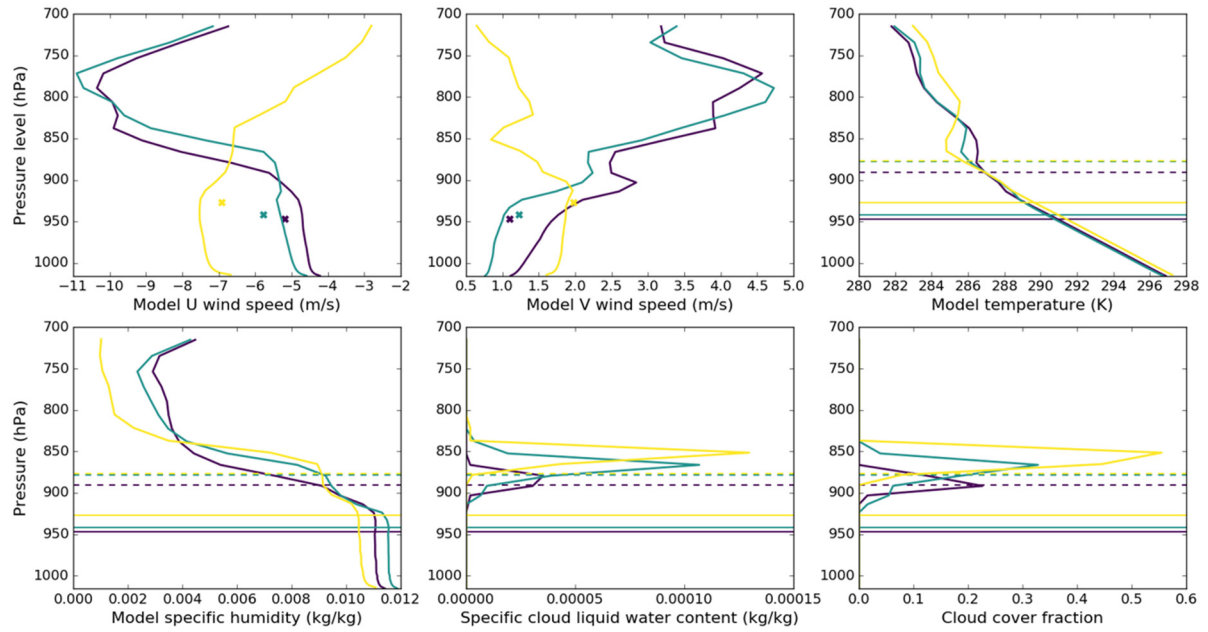


Figure 8 As for figure 7 but data are from 20-30°S, 75-85°E 5-6Z 4th January 2018 where the AMV is more than 50hPa lower than the model boundary layer top and screened by QI and first guess check.

Moving towards the very low winds in the extra-tropics, the sharp transition in the variables was less frequently seen, as in the examples in figure 7. Here, although the cloud is diagnosed at a lower pressure to the AMVs, proposing a more suitable level for a corrected height is less intuitive. This occurrence of smoother profiles likely explains why there is less contrast in the speed bias for the winds within and above the boundary layer as there is less sensitivity of the error in the wind speed due to an error in the height.

While the analysis here primarily considers the very low AMVs, figure 5 indicates that low level AMVs above the boundary layer may in fact be too high and statistics might be improved if the assigned heights were closer to the boundary layer top. The profiles of figure 7 and 8 also suggest the presence of more wind shear in the region 700-900hPa such that errors in height could lead to larger errors in wind speed. The situation dependent observation error model employed at ECMWF (Salonen and Bormann, 2013) incorporates information about wind shear at the location of the AMV. Therefore, if the AMVs are in a strong shear region, they should be given less weight in the assimilation. Conversely, those AMVs within the boundary layer, where there is less shear, would not receive a reduction in weighting in the same way.

SUMMARY AND FUTURE WORK

Key outcomes from this work are:

- The use of low level AMVs over the Indian Ocean poses some challenges. AMVs from Meteosat-8 act to speed up the low level westward flow and show less variation of wind speed with height than the equivalent ECMWF or Met Office model profiles. Nearby radiosondes suggest more wind shear whereas profiles using MISR over the region of degradation give an indication in the Met Office model that while there is more variation with height present than the AMVs, the model may be too slow.
- A general analysis of low level AMVs with model data shows that a significant number of AMVs are below the model boundary layer top, and the percentage of AMVs assigned below the top of the model boundary layer is very different for AMVs from different satellites/producers. This may point to differences in height assignment biases from different producers.
- In the tropics, there is a clear split in the speed bias above and below the boundary layer top with negative biases for those within the boundary layer. Height assignment for low level AMVs in these regions is frequently affected by inversion conditions, or may be too low due to surface

contamination in the pixels used for cloud height assignment. Strong wind shear associated with inversion conditions makes height assignment more critical.

The results presented here are from an investigation that is still in progress. Data from the recently launched Aeolus mission is anticipated to provide a valuable independent source of wind profile data for comparison to the AMVs. It will hopefully be possible to probe the Indian Ocean region as part of wider validation activities. The technique of using model profiles to diagnose systematic offsets in the AMVs could also be extended to consider the same region in addition to high level winds. Where possible, potential correction procedures will be developed and assessed in the future.

ACKNOWLEDGEMENTS

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