EUMETSAT / ECMWF

Fellowship Programme

Research Report No. 11

Impact of solar stray-light effects on Atmospheric Motion Vectors from METEOSAT

by

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February 2002

Abstract

This study examines Atmospheric Motion Vectors derived from METEOSAT imagery for anomalies during the second eclipse period 2001. During eclipse periods, data from geostationary sensors are prone to anomalies caused by solar stray-light entering the radiometer around local midnight. As a result, imagery from geostationary satellites exhibit local anomalies for certain time slots and these anomalies can change considerably from one time slot to the next. The effect of these anomalies on Atmospheric Motion Vectors is characterised in this study by investigating the temporal consistency of the data itself and by careful monitoring of the winds against short-term forecasts from the ECMWF global model.

Atmospheric Motion Vectors from the METEOSAT WV channel exhibit spuriously fast winds for certain timeslots around local midnight for extended periods around the eclipse. The anomalies are caused primarily through tracking problems, but height assignment is also affected. Less severe anomalies are found for IR winds. The EUMETSAT as well as the ECMWF quality control are capable of reducing the problem, but anomalous characteristics can still be found in the quality-controlled sub-samples. The implications of these findings on the use of Atmospheric Motion Vectors in the ECMWF system are discussed.

1 Introduction

Anomalies caused by solar stray-light are a known problem of data from geostationary satellites, arising from the geostationary viewing geometry (e.g., EUMETSAT 2001). When the radiometer is facing the sun around local midnight, solar light can reach the sensors, either directly or through reflections within the radiometer. This happens mainly around the eclipse seasons (March/April; September/October). The anomalies in the METEOSAT (MET) clear-sky radiance (CSR) product for the water-vapour channel have been characterised in detail by Köpken (2001). The anomalies include “hot spots” and “warm bows” (probably a result of reflected sunlight reaching the sensor for parts of the image), as well as “bright (cold) bands” (caused by an incorrect stray-light-affected offset applied to some scan-lines). Köpken (2001) reports such anomalies throughout the year for the 1:00 UTC MET-7 CSR data, and up to a couple of months before and after the eclipse for other times around midnight.

This study characterises the effect of solar stray-light anomalies on Atmospheric Motion Vectors (AMVs) from METEOSAT. These “satellite winds” are derived by tracking clouds in half-hourly image sequences from the infrared (IR), visible (VIS), and water vapour (WV) channel, or clear-sky WV structures (e.g., Schmetz et al. 1993). Height assignment is performed based on characteristic IR or WV brightness temperatures and a forecast temperature profile. In principle, eclipse effects can affect the tracking of targets in image sequences as well as the height assignment. It is worth mentioning that derived data do not necessarily need to exhibit anomalies present in the raw input data, as long as the algorithm used is robust against such anomalies (e.g., Merchant and Le Borgne 2001).

Quality control of AMVs plays an important role within the winds derivation. In the 1980s and the early 1990s, winds producers themselves decided which winds pass quality control based on automated or manual methods. Recent years saw a shift towards disseminating almost all winds produced, and providing automated quality estimates for each wind, so that users can quality control the data themselves to their own specifications (e.g., Holmlund 1998, Rohn et al 2001). These quality estimates summarise a number of consistency checks on the AMV data. In the current study it is of particular interest to characterise how solar stray-light anomalies influence AMVs and to examine how AMV quality control mechanisms perform with eclipse affected imagery.

The structure of this report is as follows. We first describe the data and monitoring used in this study. We then present the results of our characterisation of eclipse-related AMV anomalies, paying particular attention to the nature and occurrence of the anomalies, the mechanisms which cause them, and to the performance of quality control with respect to detecting the anomalies. The results and conclusions are summarised in the last section.

2 Data

The AMVs considered in this study are EUMETSAT's operational WV, IR, and VIS cloud track winds from MET-5 and MET-7, provided 1 ½ hourly from 160 km (at sub-satellite point) processing segments (e.g., Schmetz et al. 1993). These winds are assimilated routinely at ECMWF, subject to geographical and layer-dependent blacklisting based on quality indicator (QI) thresholds (Rohn et al. 2001). A tight asymmetric check against the First Guess (FG) eliminates outliers and rejects more of the slower winds, thus addressing the common speed bias of AMVs (e.g., Järvinen and Undèn 1997). Furthermore, the winds are thinned to 1.25° (≈140 km) resolution within specified layers in the vertical, with higher QI winds taking precedence (Rohn et al. 2001).

The METEOSAT AMVs have been monitored in detail around the September/October 2001eclipse season. This monitoring includes the assessment of the temporal consistency of the data itself, as well as comparisons against the operational ECMWF FG used in the assimilation. During this time, the operational configuration of the ECMWF model used cycle 23r4 of the Integrated Forecast System (IFS) at a spatial model resolution of T511 (40km) and 60 levels in the vertical. Incremental 12h-4DVAR analyses were performed at T159 (125km).

3 Results

3.1 Occurrence

We will first characterise the occurrence of eclipse effects seen in *all* MET-7 AMVs disseminated operationally. Monitoring of all winds (rather than a quality controlled sub-sample) is best suited to identify anomalies in the data. It should be stressed, that this approach ignores quality control and therefore exaggerates potential problems. The performance of the quality control procedures implemented at EUMETSAT and ECMWF with respect to the eclipse effects is investigated in a later section.

Three-hourly time series of the average speed of WV cloud track winds show substantial fast peaks for the 0—3 UTC time period during the eclipse season, with the largest values around 20 September 2001 (Fig. 1). These fast wind speeds coincide with fast speed biases against the ECMWF FG (up to 12m/s) and clearly show that eclipse effects also affect the generation of AMVs. The number of disseminated winds drops markedly during the eclipse season, partly reflecting that EUMETSAT does not produce winds for 0:30 UTC during 31 August—15 October 2001 in an attempt to avoid eclipse problems. For the same period, 22:30 UTC winds are produced instead of the 23:00 UTC ones. It is worth mentioning that it is very difficult to spot the above mentioned anomalies in time series with coarser temporal resolution as the problem is restricted to very short periods of the day.

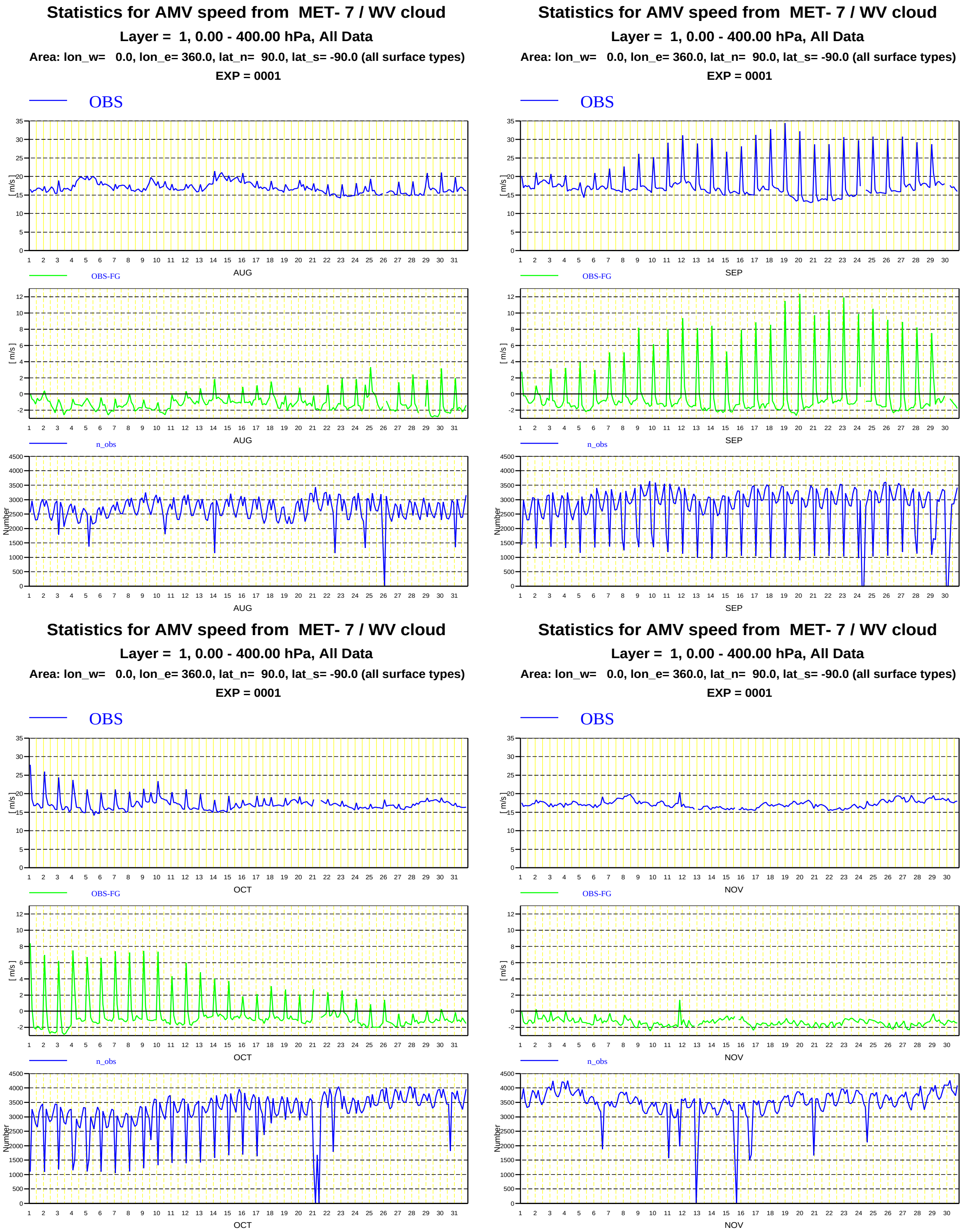

Fig. 1: 3-hourly time series of the AMV wind speed ("OBS"), the speed bias against the FG ("OBS-FG"), and the number of AMVs for all high level (above 400 hPa) MET-7 WV cloud track winds. The panels show monitoring results for August (top left panels), September (top right), October (bottom left), and November 2001 (bottom right).

Separate time series of the mean departures between the AMV and the FG wind speed for each time slot show that 0:30 and 2:00 UTC data are affected most severely (Fig. 2). Anomalies can be detected for the 2:00 UTC winds as early as beginning of July and until beginning of November 2001. The periods with noticeable data anomalies are summarised in Table 1. These agree favourably with the typical periods of CSR anomalies for MET-7 given in Köpken (2001).

All data

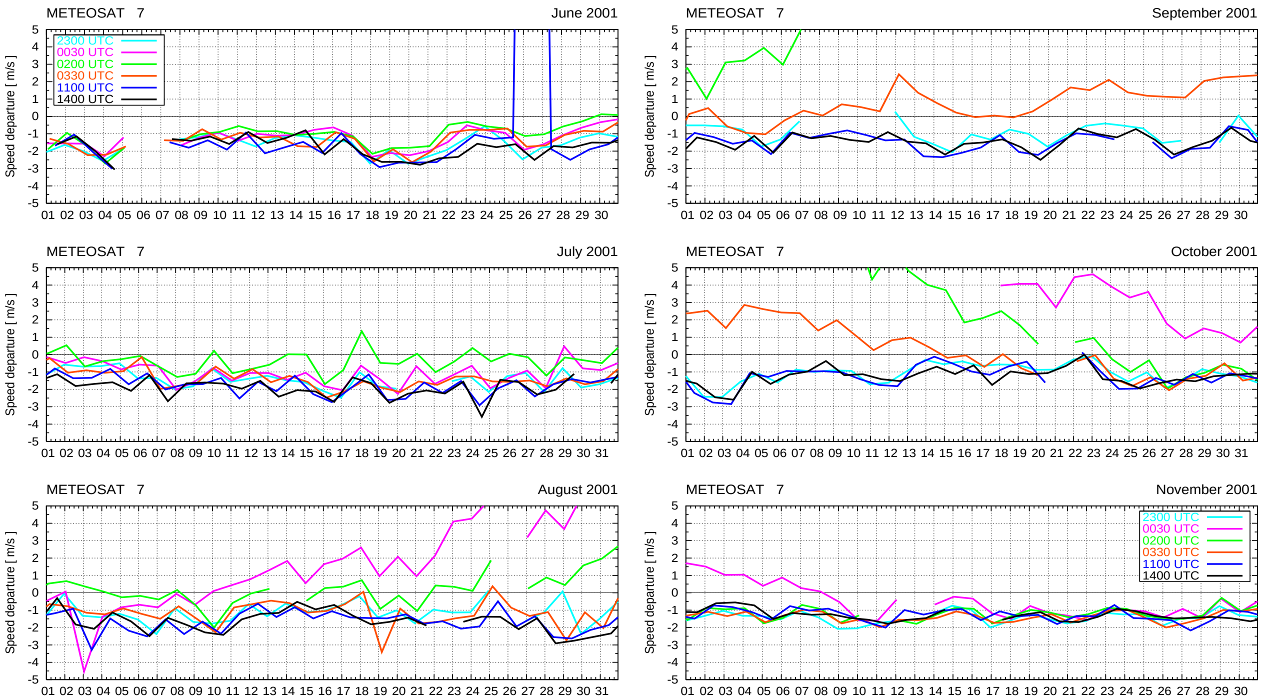

Fig. 2: Separate time series of the AMV speed departures for all MET-7 high-level WV cloud AMVs for selected time slots (see legend). Note that the winds labelled 23:00 UTC here are 22:30 UTC winds between 31 August—15 October 2001.

AMV time slot	Period of anomalies
0:30 UTC	28 July—22 November 2001
2:00 UTC	7 July—1 November 2001
3:30 UTC	24 August—23 October 2001

Table 1: Time slots for which some anomalies could be detected in all MET-7 WV AMVs during the September/October 2001 eclipse season.

For this eclipse period, spuriously fast winds first appear over the Northern Hemisphere, and later are observed further South. This is highlighted in Fig. 3 whose upper panel shows alternately the affected 2:00 UTC and the unaffected 14:00 UTC time slot in a Hovmoeller plot of the AMV speed. The affected zonal regions coincide with regions where spuriously cold clear-sky WV radiances occur (lower panel of Fig. 3), providing a link between the solar stray-light effects described in Köpken (2001) and the ones observed here.

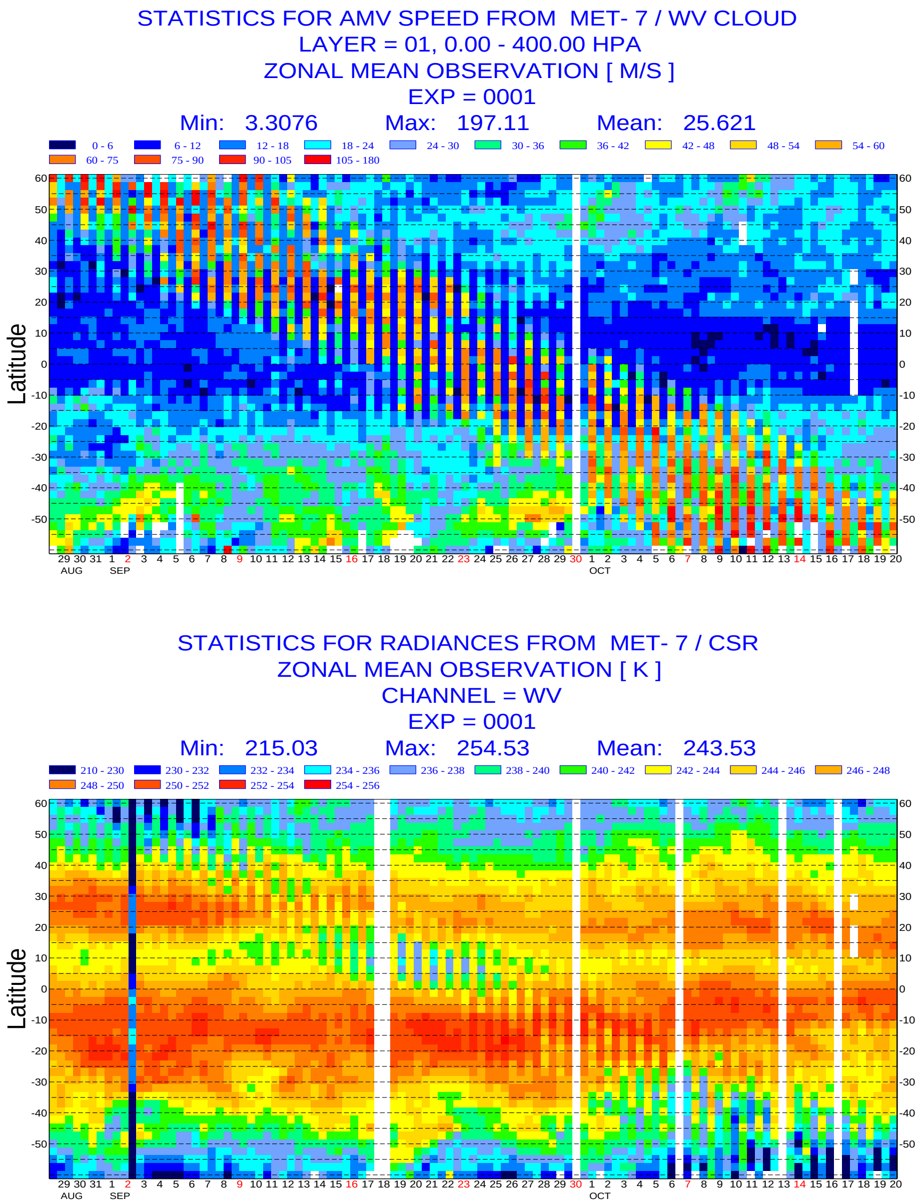

Fig. 3: Hovmoeller plot of the AMV wind speed for high level (above 400 hPa) MET-7 WV cloud track winds (upper panel) and MET-7 clear-sky WV radiances (lower panel). Only the data for 2:00 UTC and 14:00 UTC are shown to stress the differences in affected and unaffected time slots.

Time series for the IR cloud track winds also show spurious fast peaks for 0—3 UTC, but the magnitude is much smaller and the anomalies can be identified for the 2:00 UTC time slot and the period 10 September – 7 October 2001 only (Fig. 4). No eclipse-specific problems can be identified for VIS winds, as the effects are restricted to night-time.

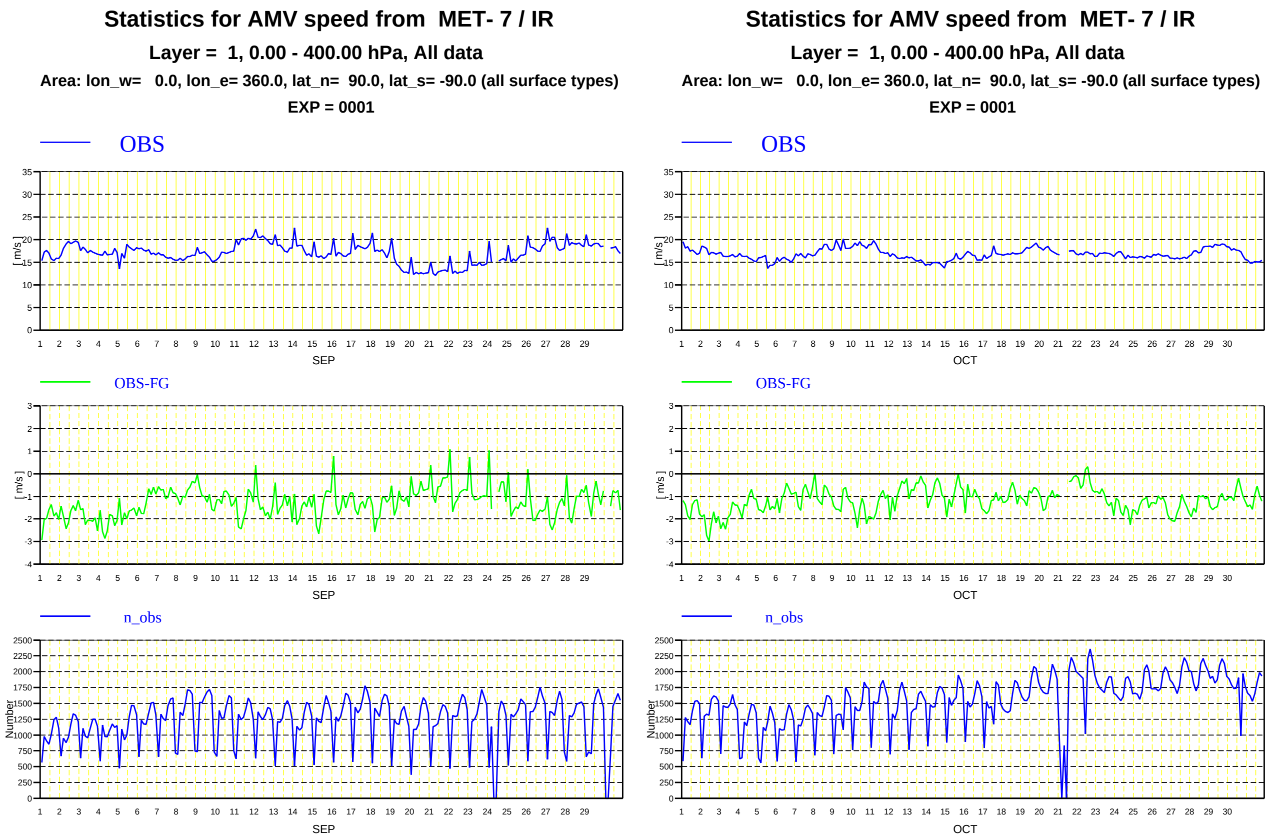

Fig. 4: 3-hourly time series of the AMV wind speed ("OBS"), the speed bias against the FG ("OBS-FG"), and the number of AMVs for all high level (above 400 hPa) MET-7 IR cloud track winds. The period shown is 1 September – 31 October 2001.

3.2 Mechanisms

Further investigations suggest that the main reason for the fast winds for WV cloud track winds are problems in the tracking. For these winds EUMETSAT uses a least-squares tracking procedure, in contrast to the cross-correlation methods used for IR or VIS winds (Elliott 2001, pers. communication). The least-squares procedure is sensitive to the actual image count values of the tracked target rather than just its structure. It will thus lead to incorrect results if image anomalies change between the images used in the tracking.

An example for changing image anomalies and resulting tracking problems is shown in Fig. 5. The first row shows the first and the last image of a triplet used to derive the 2:00 UTC WV winds for 27 September 2001. The first image exhibits unusually bright bands; one hour later, this anomaly is much weaker. The extent of the anomaly is most clearly seen in the difference between the two images. In and around this anomaly, spurious AMVs occur (see lower right plot in Fig. 5). Starting from a target within the bright band, the least-squares tracking procedure tried to find a matching similarly bright target in the subsequent images, where the area is now darker. The matched target is unlikely to be the same cloud (which will appear darker), and the resulting wind does not represent the atmospheric flow. The occurrence of such spurious winds is highlighted further by comparing the wind speed distribution for affected and unaffected times (e.g., 2:00 and 14:00 UTC, respectively, Fig. 6a). During the peak of the eclipse, fast winds are much more frequent at 2:00 UTC than at 14:00 UTC.

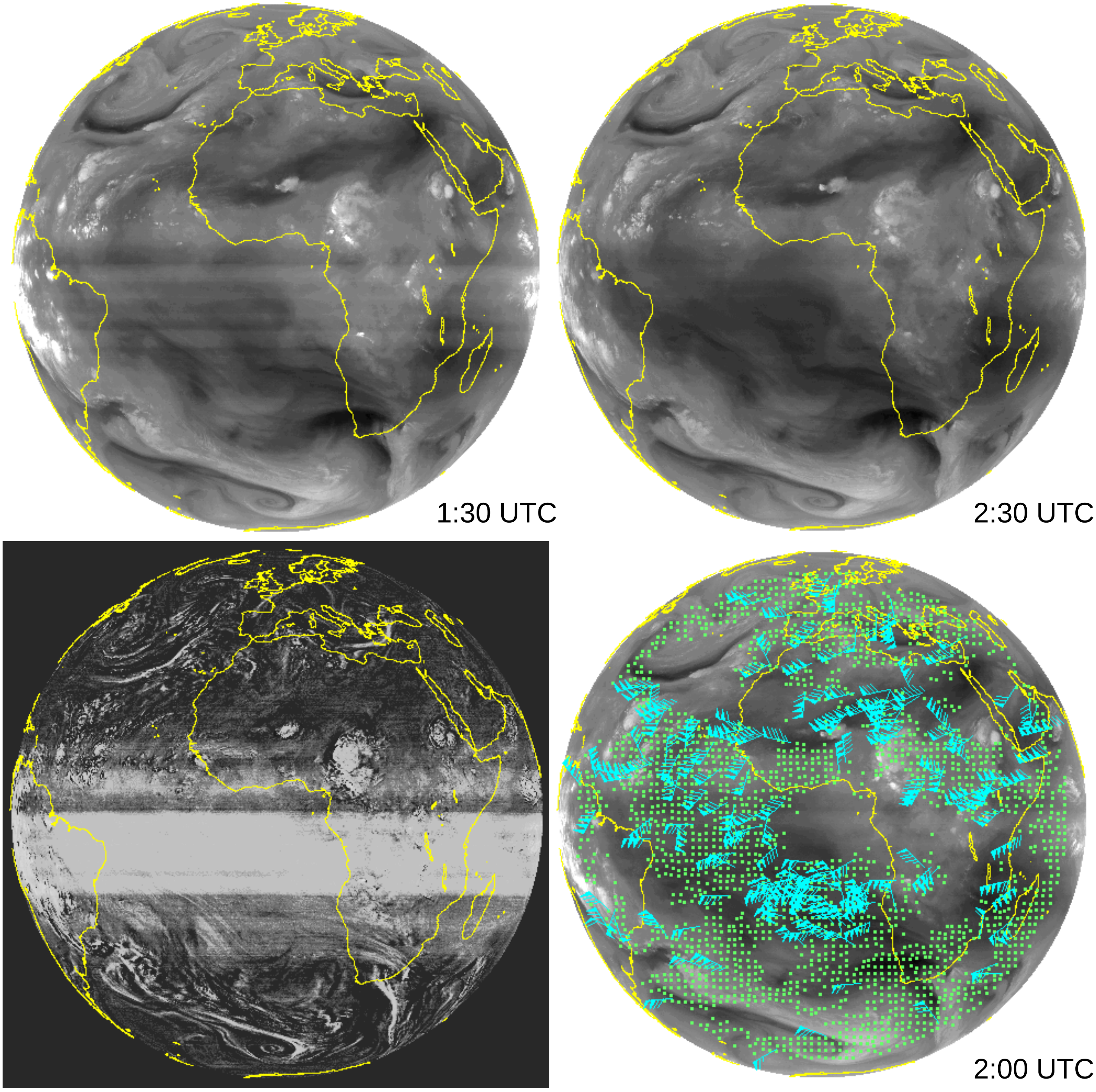

Fig. 5: Example of anomalies in AMVs. The upper row shows the 1:30 and 2:30 UTC MET-7 WV images for 27 September 2001. In the lower row, the difference between the upper two images is shown on the left. On the right, blue wind barbs indicate difference vectors between MET-7 cloudy WV AMVs and the ECMWF FG, where the length of this difference vector exceeds 30m/s. Positions of all WV winds are indicated by green dots.

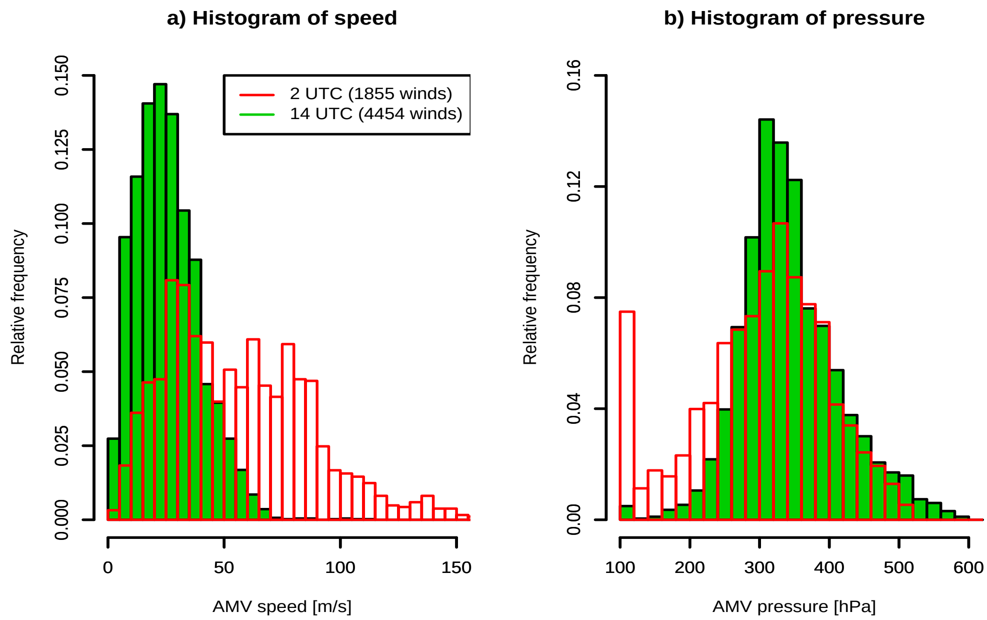

Fig. 6: a) Histograms of wind speed for Southern Hemisphere MET-7 WV cloud track winds for selected times of the day during the period 1—10 October 2001 (peak of the eclipse over the Southern Hemisphere). Red shows affected 2 UTC data, green 14 UTC data. b) As a), but for the assigned pressure.

Most of the spurious winds found in this study occurred around the “bright bands”, as shown in Fig. 5. Köpken (2001) also found more localised “warm bows” and “hot spots” in the CSR product, and this type of stray-light anomaly is expected to lead to similar tracking problems. However, as these anomalies are more localised (thus also leading to smaller tracking errors), such problems could not be detected.

The height assignment is also affected through eclipse anomalies, but not as drastically as the tracking. A comparison of the distribution of the assigned pressure for affected and unaffected times shows that there are more very high level winds in the eclipse-affected than in the unaffected data (Fig. 6b). In particular, many more winds have been assigned to 100 hPa, the minimum pressure allowed in the EUMETSAT processing. The height assignment for the EUMETSAT WV cloud track winds is based on the WV-intercept method (e.g., Schmetz et al. 1993). Assignment to lower pressure is consistent with the cold bands in the CSR data which frequently occur for this time slot. Some variations in the pressure distributions are also observed between daytime and night-time winds outside the eclipse season, but the unusually large number of 100 hPa winds is a feature specific to the eclipse season. A shift towards higher level winds, and peculiar numbers of 100 hPa winds can also be reported for IR winds (not shown). As we found stray-light anomalies to be less severe in IR imagery, tracking errors are less likely to be the main reason for anomalous IR winds. Instead, height assignment in combination with selective sampling through the QI appears to be the main reason for anomalies in the IR winds.

3.3 Quality control

The EUMETSAT automatic quality control is capable of reducing the eclipse anomalies in the data considerably, but it does not identify all spurious winds. So far, we have included all winds in our investigations, regardless of the QI value assigned to them. The QI threshold recommended for quality control by EUMETSAT is 80% for WV cloud track winds. Time series of the wind speed for cloudy WV AMVs after this quality control still show anomalous wind speeds during September and the first half of October (Fig. 7a). In contrast to the characteristics without quality control, this period is much shorter, and the fast speed bias against the FG is considerably reduced (cf Fig. 1). The better agreement with the FG is likely to reflect the use of the ECMWF FG within the calculation of the QI, and is thus hardly surprising. As can be seen in Fig. 8a, spurious fast peaks are mainly confined to 2:00 UTC data after applying the 80% QI threshold.

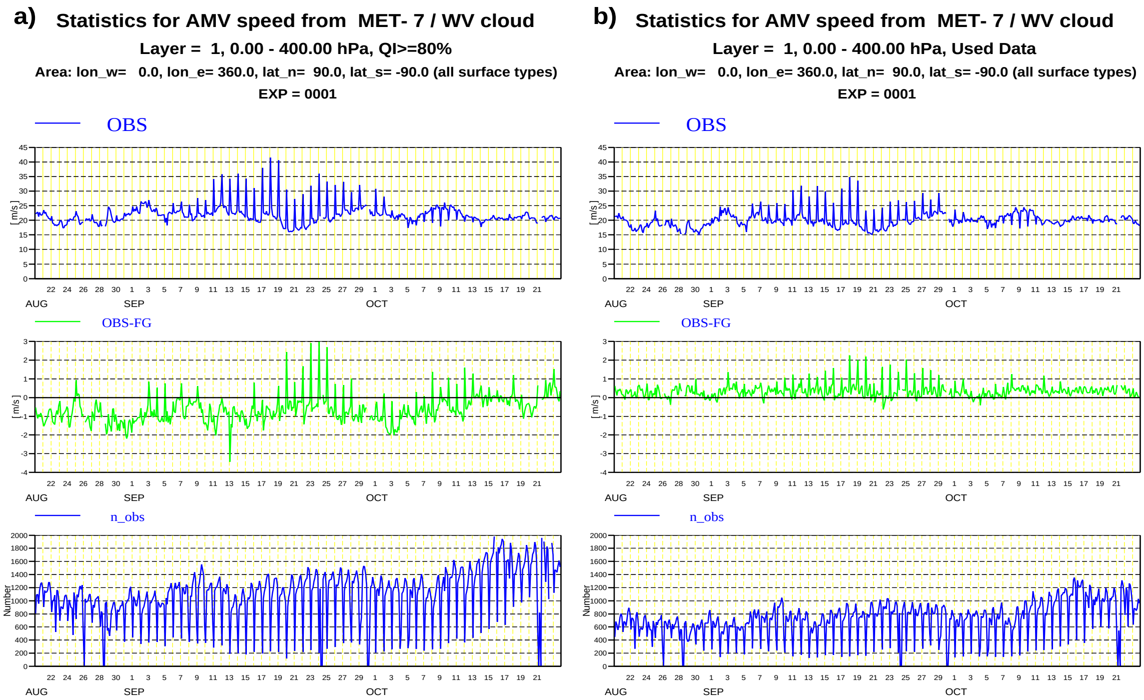

Fig. 7: As Fig. 1, but for winds with QI>= 80% (a) and for winds used in the ECMWF analysis (b).

Monitoring statistics against the QI further highlight the performance of the EUMETSAT quality control (e.g., Fig. 9). For the unaffected time slot, the mean AMV wind speed tends to increase with QI towards better agreement with the associated FG wind speed. In contrast, for the affected time slot the mean AMV wind speed *decreases* from spuriously fast winds to more reasonable values for QI > 90%. The latter winds are again in better agreement with the FG. Assuming the FG wind speed is more appropriate, the QI thus identifies better quality data for both time slots. In this context it is also reassuring, that for the stray-light affected time slot relatively fewer winds have higher QI than in the unaffected data, reducing the number of poor winds after quality control. The associated mean FG speed is, on average, larger than normal for all QI values in the affected data. This partly reflects the assignment of the winds to higher levels, and the tendency of the QI to favour faster winds and those in agreement with the FG. It is worth mentioning that the quality control threshold used at ECMWF is 60% for the winds shown, and Fig. 9 shows to what extent this threshold is unable to eliminate eclipse affected winds.

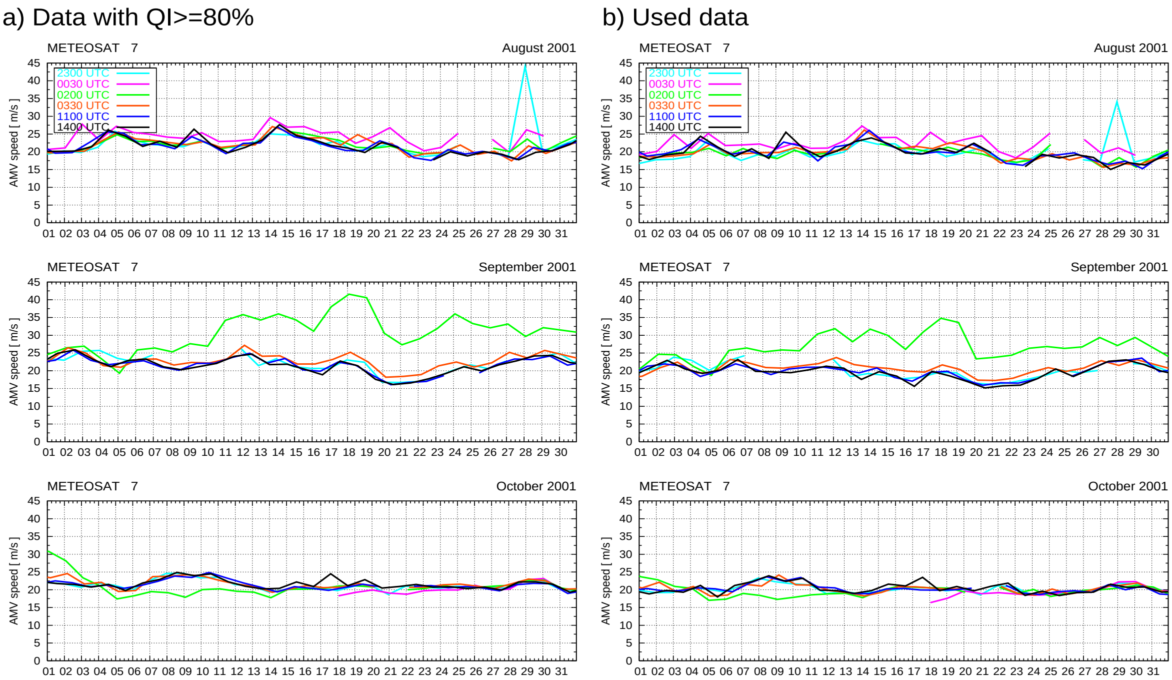

Fig. 8: Mean AMV wind speed for high level (above 400 hPa) WV cloud track winds for selected time slots (see legend). a) Data with QI>=80% . b) Data used in the ECMWF analysis.

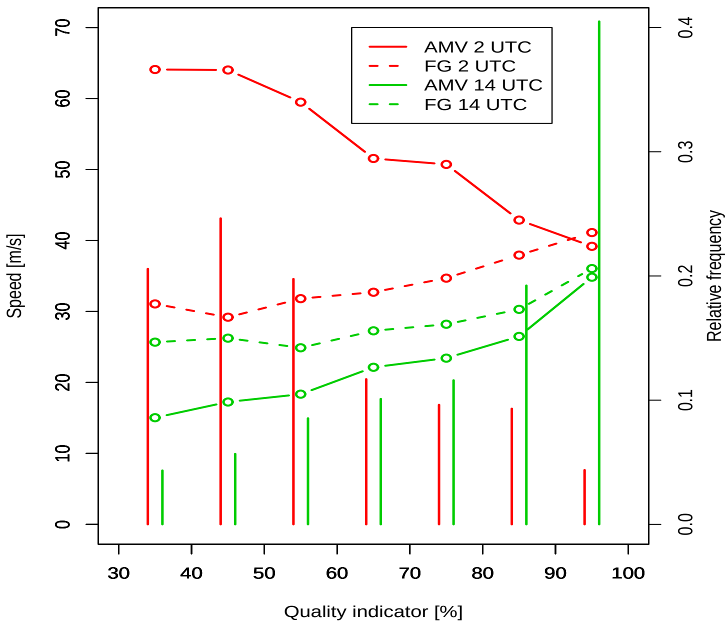

Fig. 9: Statistics of Southern Hemisphere MET-7 WV cloud track winds above 400 hPa against the EUMETSAT quality indicator (QI) for selected time slots during the period 1—10 October 2001. Solid lines with circles represent mean AMV wind speed (left y-axis), dashed lines with circles corresponding mean FG wind speeds (also left y-axis). The relative frequency of winds per QI bin is shown as vertical lines (right y-axis). Red indicates 2:00 UTC data, green shows 14:00 UTC data.

The additional tight quality control against the FG applied to AMVs before the assimilation in the ECMWF system does also not entirely remove the eclipse problems. Spurious peaks in the AMV wind speed and the speed bias can still be clearly identified in the sample of used winds for most of September 2001 and the first half of October (Figures 7b and 8b). However, very few winds pass the ECMWF quality control procedures for the affected times, limiting the impact of these spurious observations on the analysis.

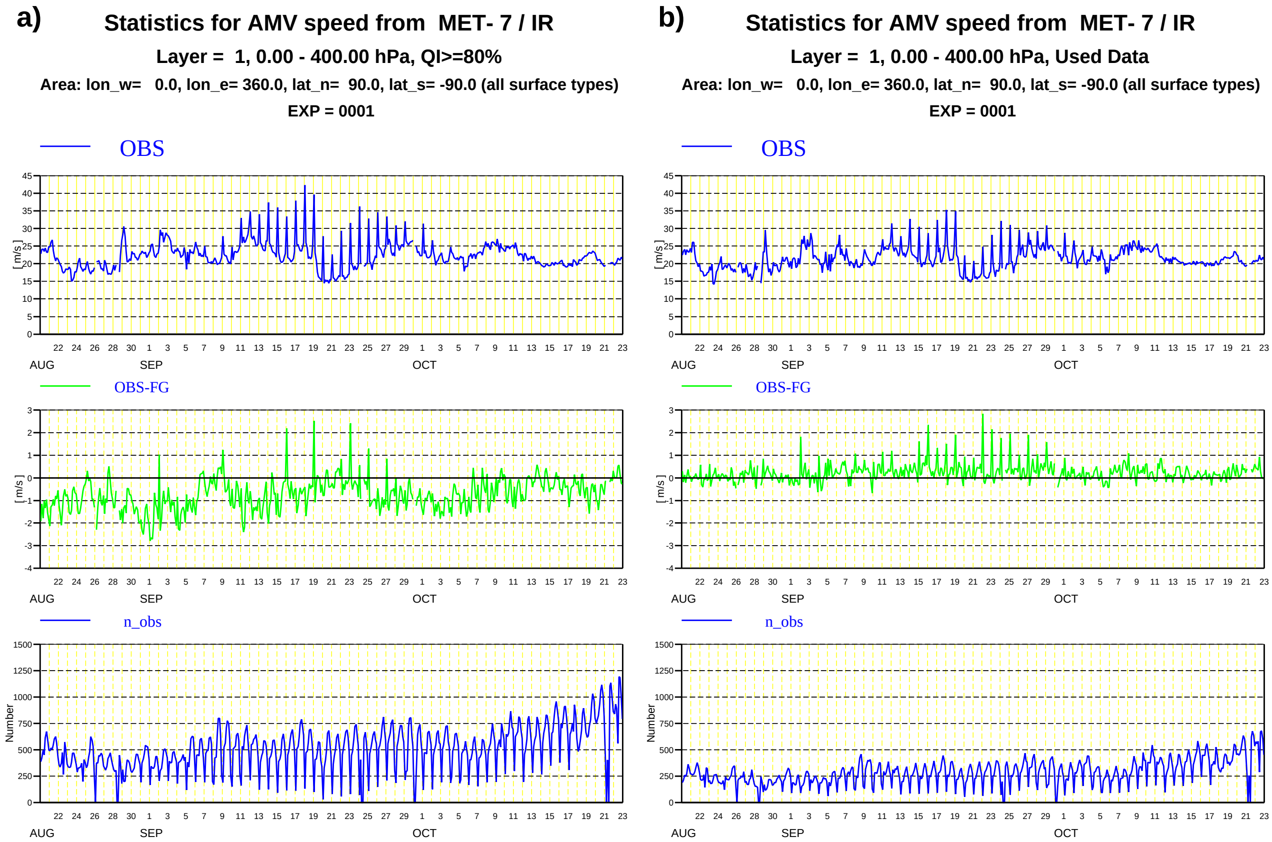

Fig. 10: As Fig. 7, but for IR winds from MET-7.

The eclipse anomalies for the IR winds are more apparent in the quality controlled sub-samples than in all data (Fig. 10). The most likely reason for this is the shift in the height assignment towards higher heights in combination with the selective sampling of winds which agree better with the FG wind speed. The FG wind speed tends to be higher at larger heights.

3.4 MET-5 winds

We found similar anomalies in MET-5 WV cloud track winds. Spuriously fast winds appear for the 20:00, 21:30, and 23:00 UTC time slot between beginning of August and mid-October with a peak around 12 September 2001, slightly earlier than for MET-7 data (Fig. 11, Table 2). The effect is smaller than in the MET-7 data, consistent with a smaller effect in the CSR product from the MET-5 WV channel. As a precautionary measure, EUMETSAT does not disseminate 20:00 UTC (midnight for MET-5) winds between 17 August and 5 October 2001.

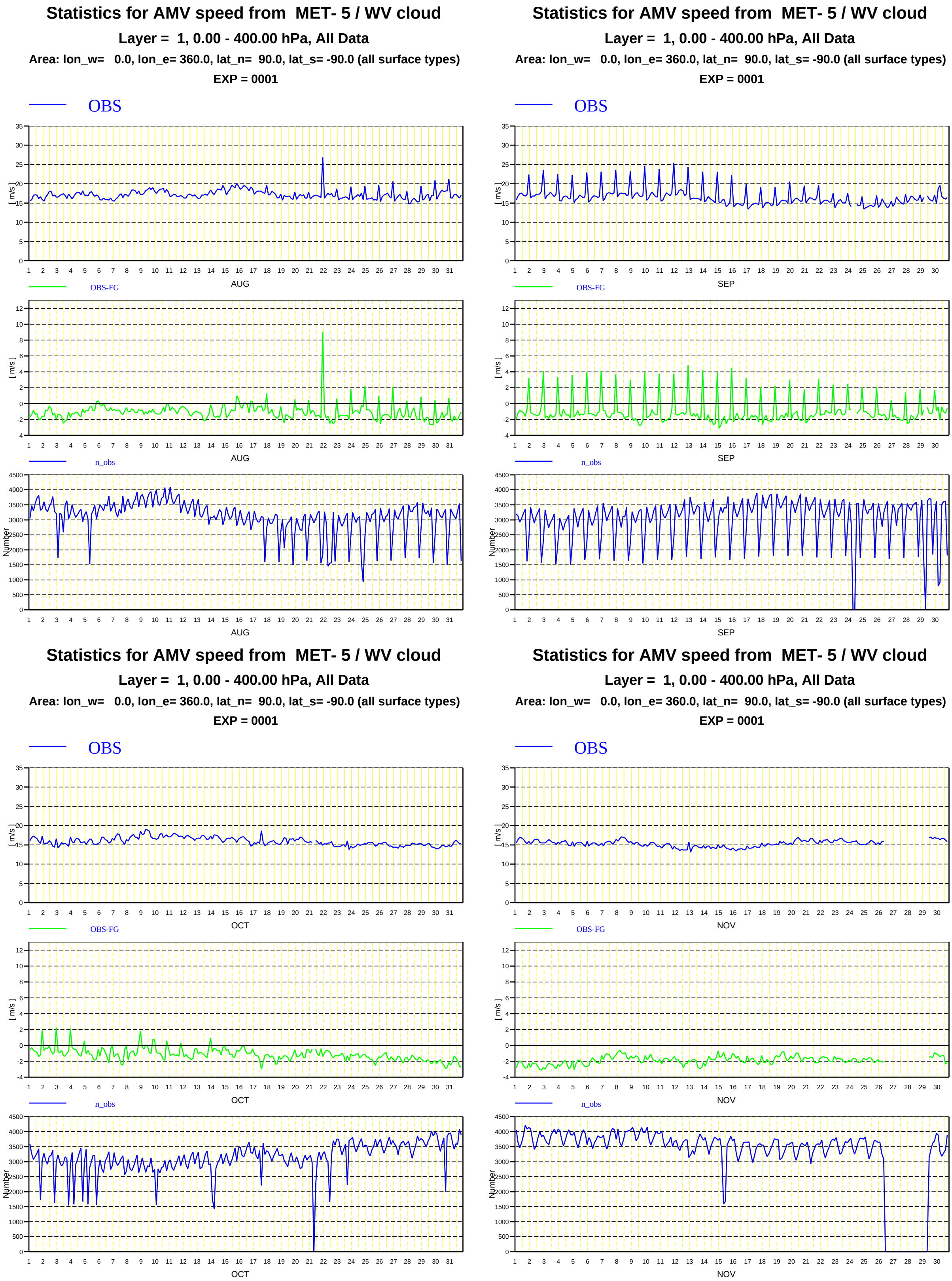

Fig. 11: As Fig. 1, but for WV cloud track winds from MET-5.

AMV time slot	Period of anomalies
20:00 UTC	24 July—15 November 2001
21:30 UTC	20 July—25 October 2001
23:00 UTC	18 August—7 October 2001

Table 2: Time slots for which some anomalies could be detected in all MET-5 WV AMVs during the September/October 2001 eclipse season.

There is little evidence for eclipse problems in MET-5 IR AMVs. The speed bias against the FG shows some diurnal signal, with stronger slow biases occurring after local midnight. However, such patterns occur throughout the year, and can thus not easily be attributed to solar stray-light effects (Fig. 12).

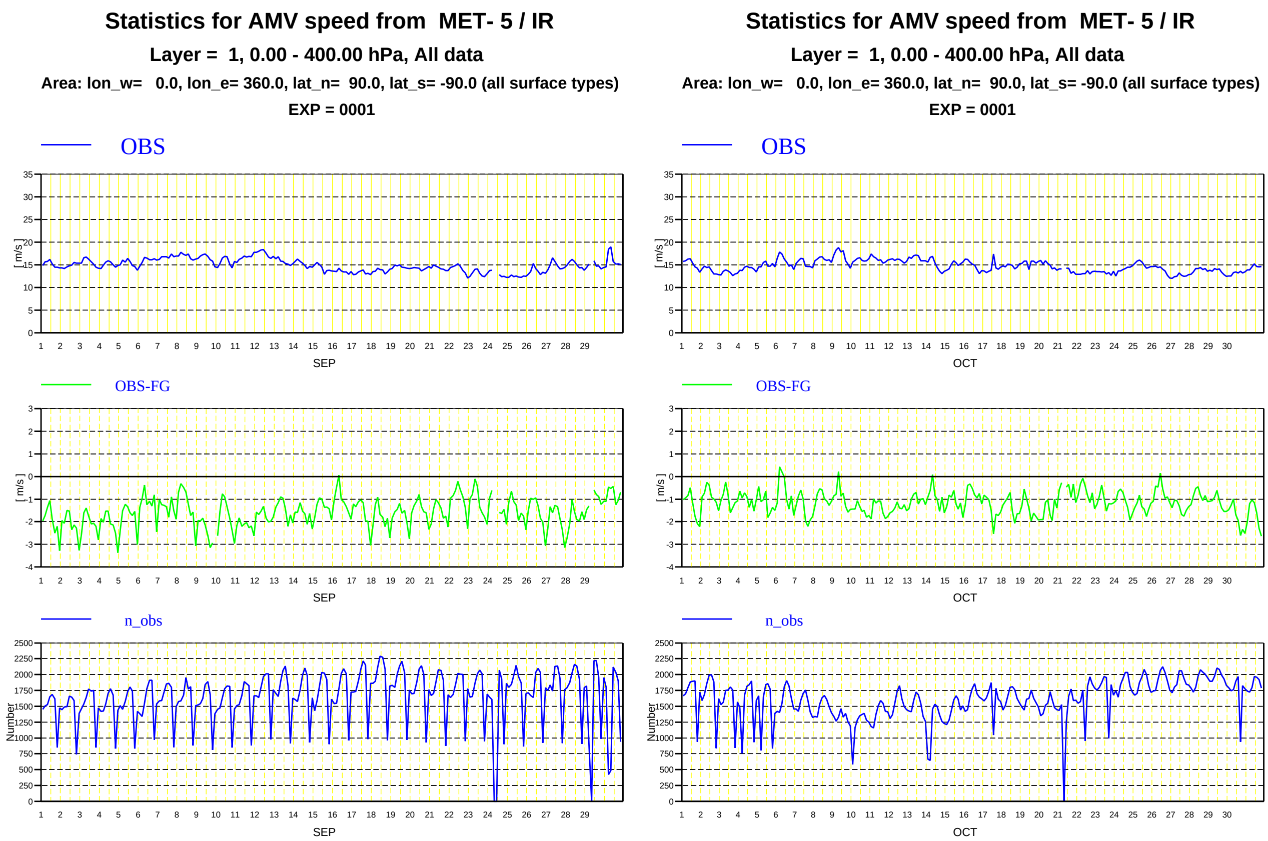

Fig. 12: As Fig.11, but for IR cloud track winds.

4 Conclusions

In this study we characterised solar stray-light effects in EUMETSAT's AMVs for the September/October 2001 eclipse season. The main findings are:

- During the eclipse season, EUMETSAT's cloudy WV AMVs exhibit spuriously fast winds and exceptional fast biases against the ECMWF First Guess for certain time-slots. The effect is stronger for MET-7 winds, but it is also present in MET-5 winds. IR winds show smaller anomalies.

- MET-7 winds for 2:00 UTC are affected most strongly during extensive periods around the eclipse season, and some anomalies are also noticeable in the 0:30 and 3:30 UTC data. For the September/October 2001 eclipse season, anomalies in the data are observed as early as July 2001, and until beginning of November 2001. For MET-5 AMVs, the winds at 21:30 UTC are most strongly affected, and the peak of the eclipse anomalies is somewhat earlier than for MET-7.

- There is evidence that the eclipse anomalies for WV AMVs are mainly caused by problems in the tracking, but the height assignment is also affected. The main reason for spuriously fast winds are tracking problems related to changing image anomalies in subsequent images. The main effect in the height assignment is an overall shift towards higher heights.

- The EUMETSAT as well as the ECMWF automatic quality control are capable of reducing the problem, and the number of affected winds passing quality control is relatively small. However, significant anomalies are still noticeable in the sample of winds passing the EUMETSAT quality control thresholds as well as in the sample of winds used in the ECMWF analysis.

It is encouraging that the automated quality control at EUMETSAT is capable of reducing the problems seen in stray-light affected data. This is particularly true, as the QI is based only on consistency checks on the derived wind field without any further information on typical eclipse-specific anomalies. However, given the remaining problems, improved eclipse-specific quality control at EUMETSAT is desirable. Work is underway at EUMETSAT to identify and exclude the stray-light affected areas (Elliott 2001, pers. communication). As a *complete* removal of eclipse image anomalies is difficult and therefore unlikely, a cautious approach is still necessary for quantitative analyses of these data.

The considerable anomalies in the AMV data used in the ECMWF system during the eclipse season suggest a revision of the blacklisting in the ECMWF system for AMVs for the affected time slots. In agreement with the approach for clear-sky radiances, AMVs for the affected times should be excluded from the analysis.

As all geostationary satellites are in principle prone to solar stray-light effects, it is likely that the effects described here can also be found in AMVs from other present or future geostationary sensors. Further investigations are necessary to determine the best approach to protect analysis systems from these spurious observations.

Acknowledgements

This study benefited significantly from many comments and software tools provided by Christina Köpken. Other monitoring tools used have been a combined effort by Christina Köpken, Antje Dethof and the first author.

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