# NWP SAF AMV monitoring: the 11th Analysis Report (AR11)

Daniel Etheridge[1], James Cotton[1], Mohamed Dahoui[2], Meiko Volknandt[3] and Mary Forsythe[1]

Met Office[1], ECMWF[2], DWD[3]

This documentation was developed within the context of the EUMETSAT Satellite Application Facility on Numerical Weather Prediction (NWP SAF), under the Cooperation Agreement dated 7 September 2021, between EUMETSAT and the Met Office, UK, by one or more partners within the NWP SAF. The partners in the NWP SAF are the Met Office, ECMWF, DWD, and Météo France.



| Change record | | | |
|---|---|---|---|
| Version | Date | Author / changed by | Remarks |
| 0.1 | 24/12/24 | Daniel Etheridge | First draft |
| 0.2 | 30/01/25 | Daniel Etheridge | Incorporate feedback from James Cotton and Mary Forsythe |
| 0.3 | 12/02/25 | Daniel Etheridge | Incorporate additional feedback |
| 0.4 | 18/02/25 | Daniel Etheridge | Incorporate feedback from Fabien Carminati |
| 1.0 | 26/03/25 | Daniel Etheridge | Approved for publication |
| | | | |
| | | | |

**Contents**

## 1. Introduction

The NWP SAF (Satellite Application Facility for Numerical Weather Prediction) Atmospheric Motion Vector (AMV) monitoring (http://nwpsaf.eu/site/monitoring/winds- quality-evaluation/amv) provides tools to monitor, document, and investigate error characteristics of AMV data.

The NWP SAF provides a long-term archive of observation-minus-background (O-B) statistics where the AMVs are compared with short-range (T+6 hours) forecasts from an NWP model. Forecast model fields are interpolated in time and space to the observation location and used to calculate a model-equivalent of the observation, referred to as the "background" value. O-B are calculated against the Met Office, ECMWF, and DWD global models, to give insight into whether features seen in the monitoring are related to problems with the models or with the AMVs. Monitoring against the DWD global model has been included in the NWP-SAF archive from December 2023.

An extensive set of AMV products are actively monitored by the NWP SAF (Table 1). Previous generations of satellites/instruments can also be found in the archive. There have been several changes in datasets since the last report in 2023 (Table 2). Several satellites have retired or are no longer providing data ahead of retirement including INSAT-3D, Meteosat-8 (Indian Ocean Data Service (IODC)), and Aqua and Terra (MODIS). EUMETSAT have changed coverage for Meteosat-10 and Meteosat-11, so that Meteosat-10 is now the prime satellite at 0 degrees and Meteosat-11 has switched to rapid scanning the northern hemisphere. New data sets have been added to the monitoring for NOAA-21 and DWD backgrounds. Additionally, NOAA's new "Enterprise Winds Algorithm" has now been implemented for GOES-16, GOES-18, SNPP, NOAA-20, and NOAA-21. GK-2A data was unavailable from October 2022 – July 2024, due to an internal issue that has now been fixed and the data is being stored again.

Analysis reports are released at intervals of 2-years to help guide discussion on improvements to the AMV derivation and data assimilation. Results are presented at the workshops of the International Winds Working Group (IWWG). The analysis reports identify features from the monitoring statistics and document how these evolve over time. Where possible, attempts are made to diagnose the cause of the difference between the AMVs and the model.

This paper marks the eleventh in the series of analysis reports (AR11). Previous analysis reports are hereafter referred to by the order of their publication e.g., 10th Analysis Report (AR10), and are available to download from the NWP SAF website.

This paper is structured as follows. Section 2 provides a status summary of the current active features in the monitoring. Section 3 explores changes in datasets. Section 4 describes the impacts of NOAA's "Enterprise Winds Algorithm". Sections 5-7 provide updates on three existing features. Sections 8-9 investigate newly added features. Finally, a summary is provided in Section 10.

*Table 1. AMV datasets monitored by the NWP SAF. Channels are infrared (IR), short wave infrared (SWIR), visible (VIS), high resolution visible (HRVIS), cloudy water vapour (WV), clear sky water vapour (CSWV). DB stands for direct broadcast station.*

| **Geostationary AMVs** | **Producer** | **Channels** |
|---|---|---|
| Meteosat-9/10/11 | EUMETSAT | IR 10.8, WV 6.2, WV 7.3, VIS 0.8, HRVIS |
| Himawari-9 | JMA | IR, WV 6.2, WV 6.7, WV 7.3, VIS |
| GOES-16/18 | NOAA/NESDIS | IR, SWIR, WV, VIS |
| INSAT-3DR | ISRO | IR, SWIR, WV, VIS |
| GK-2A | KMA | IR, SWIR, WV, VIS |
| FY-2G | CMA | IR, WV |
| **Leo AMVs** | | |
| NOAA-15/18/19 | CIMSS, DB | IR |
| Metop-B/C | EUMETSAT | IR |
| Suomi NPP | NESDIS, DB | IR |
| NOAA-20/21 | NESDIS | IR |
| **Mixed AMVs** | | |
| LeoGeo | CIMSS | IR |
| Dual-Metop | EUMETSAT | IR |

*Table 2. Changes to the monitoring since AR10 (2023).*

| **Change** | **Type** | **Date** | **Description** |
|---|---|---|---|
| Direct Broadcast (DB) | Change | | Plots for the DB VIIRS winds are not currently available since they cannot be distinguished from the global data stream in the monitoring. Ideally CIMSS/NESDIS could provide a method to distinguish them. |
| Meteosat-8 | Retired | 01/07/2022 | Retired following Meteosat-9 taking over IODC coverage [1]. |

| | | | |
|---|---|---|---|
| Meteosat 10/11 | Switched coverage | 05/04/2023 | Prime operational satellite switched from Meteosat-11 to Metesat-10 at 0 degrees coverage. |
| DWD | Addition | December 2023 | DWD global model backgrounds have been added to O-B map and zonal AMV monitoring for several geostationary satellites. |
| Aqua and Terra | Data stopped | 29/01/2024 | The AMV products have been retired as the satellites are due to be retired soon. |
| GOES Enterprise | Derivation Update | 06/02/2024 | Affecting GOES-16 and GOES-18. |
| | | 06/03/2024 | Affecting SNPP, NOAA-20, and NOAA-21 VIIRS Polar Winds. |
| INSAT 3D | Data stopped | 18/06/2024 | To be replaced by data from INSAT-3DS once declared operational. INSAT-3DR is still operating. |
| NOAA-21 | Addition | August 2024 | Declared operational as of 8$^{th}$ November 2023. Monitored by NWP SAF since August 2024. |
| Meteosat-12 | Addition | 04/12/2024 | Monitored by NWP SAF since January 2025. |

## 2. Index of features identified in the monitoring

Table 3 documents the features that were active from AR10 and provides an update on their status within the monitoring. In some cases, features may have been renamed from previous reports to better reflect the pattern or cause. For each feature, the table indicates whether further details are provided in the following sections of this report.

Features are referenced in the format X.Y, where X is the number of the analysis report where that feature was first described, and Y is the example number.

Unless otherwise specified, the tropics refer to the area 20°N-20°S and the extra-tropics polewards of these boundaries. Upper-level, mid-level and low-level refer to AMV heights above 400 hPa, between 400-700 hPa and below 700 hPa respectively.

*Table 3. Status of the active features identified in the AMV monitoring. Green shading denotes a new feature. Blue denotes a feature than is fixed or considered closed. The AR column lists the analysis report numbers where the feature is discussed. The AR11 column indicates whether the feature is discussed in AR11.*

| Ref. number | Feature name | AR | Status | AR11 |
|---|---|---|---|---|
| **Geostationary: low-level (below 700 hPa)** | | | | |
| 2.3 | GOES winter negative bias over NE America | 2,3,6 | Still present but improved for GOES-16 for the Met Office and ECMWF, present for DWD.<br><br>Comparing IR low-level for GOES 13 and GOES 16, 2017/18 to 2023/24 respectively, this feature looks to have improved over the years. Mainly in the change from GOES 13 to GOES 16 in 2018. This is likely due to the new derivation method, GOES-R, used with GOES-16 as it was the first of the new generation of GOES satellites. The magnitude is less than it was before, but the negative bias is still present over land.<br><br>Feature background: AR3 highlighted observations over land with a high height bias relative to the level of best-fit. This was linked to low level winds assigned to cloud base over sea, but not over land. AR6 showed a negative bias also observed over the N. Atlantic during cold air outbreaks which is linked to model forecast bias and difficulties in tracking the breakup of cloud along the SST front. | |
| 2.6 | MSG positive bias over North Africa | 2,3,4,6,8,11 | Still present for the Met Office, ECMWF, and for DWD.<br><br>Feature background: A large positive wind speed bias is observed in the Meteosat Second Generation (MSG) IR and visible channels over North Africa and the Arabian Peninsula during winter. Although mainly over land, the bias extends over the Atlantic to the west of Africa in January/February and moves northwards into the Mediterranean by May. AR4 linked the bias to large height assignment errors when tracking cirrus clouds, leading to very fast winds being assigned around 500 hPa too low. The feature closely matches the location of the sub-tropical jet stream.<br><br>AR8 suggested that the diurnal variation of the bias in the IR channel is because the thin clouds associated with the large errors in height assignment are unable to be tracked in the hours either side of local midday and so the bias is not evident at these times. In a case study, CLA and OCA heights for a problematic area of cloud were found to be much lower in height compared to the Met Office cloud products, in this case the MO products appeared to be better than OCA. Lidar comparisons concluded that on average AMV heights are lower than lidar heights for AMVs assigned below 700 hPa height. Large discrepancies in height are found for visible channel winds at around 850 hPa.<br><br>AR9 investigated positive biases over the Arabian Peninsula in July 2018 and July 2019. Case for 27 July 2018: IR channel shows AMVs are easterlies whereas background is west or north- | Yes |

| | | | | |
|---|---|---|---|---|
| | | | westerlies. Observed pressures are typically 700-800 hPa, best-fit is 100-200 hPa. Imagery shows tracking thin cirrus moving from east to west. Appears to be a classic example of large height assignment error. Also noted lots of dust in the imagery but AMVs (600-700 hPa) for this appear to match the model well. | |
| 5.2 | MSG negative bias during Somali jet | 5,6,9 | Still present.<br><br>Feature background: SEVIRI AMVs from Meteosat-8/9 and Meteosat-11 show a large negative wind speed bias during July and August in the NW Indian Ocean, near the Gulf of Aden. This feature seems to vary in strength from year to year. This time period coincides with the strengthening of the Somali Low-Level Jet. Previous investigation has shown the bias is due to instances of height assignment error, with slow upper-level vectors incorrectly assigned within the fast, low-level wind regime, and the influence of an island (Socotra) causing semi-stationary wave cloud formations within the jet. | |
| 6.2 | FY-2 bias during NE winter monsoon | 6 | Still present to some degree for the Met Office and ECMWF, possibly less marked in winter 23/24. This is likely to be annual variability or AMV improvement.<br><br>Feature background: A marked negative speed bias in the northern hemisphere during the winter months from November to March. AR6 indicates that the negative-biased observations may have been assigned too high. | |
| 8.1 | MSG positive speed difference in the tropics over IODC and tropical Atlantic | 8,9,10 | Still present for the Met Office and ECMWF and seen in DWD plots. Slightly worse for ECMWF. Predominantly over IODC.<br><br>Feature background: Meteosat-8 low level winds show a positive speed O-B and high Root Mean Square Vector Difference (RMSVD) over the southern tropics of the Indian Ocean. Model and radiosonde profiles provide evidence for a lack of shear in the AMVs which leads to a positive speed bias above 900 hPa height. Best-fit pressure indicates this could be due to AMVs being assigned too high. See AR9.<br>Additionally, in AR10 it was noted that AMVs in the tropical Atlantic have been assigned too high above the top of the boundary layer for MSG. | |
| 9.2 | Large vector differences near the Southwest African coast for MSG | 9 | Still present in Met Office and ECMWF vector plots for Meteosat 9 and 10 for several months in 2023 and 2024. Area no longer covered by Meteosat 11 since April 2023.<br><br>Feature background: Meteosat-10 and Meteosat-9 (and previously 8 and 11) low level IR winds show an area of large vector differences along the Atlantic coast of Southern Africa for several months each year except for June and July. AR9 indicates that this is due to two reasons 1) AMVs tracking high clouds that are incorrectly assigned to heights of 960 hPa, and 2) sheets of fog or low cloud with well-defined breaks, which are not representative of the local wind, leading to large discrepancies in wind direction with the model and other nearby AMVs. The monthly O-B variations, notably the lack of this feature in June and July, can be explained by seasonal variations, with less | |

| | | | | |
|---|---|---|---|---|
| | | | fog and low cloud in this area at this time of year. | |
| 11.1 | Horizontal lines below 800 hPa in zonal plots for EUMETSAT satellites | 11 | New. Present for the Met Office, ECMWF, and DWD.<br><br>Feature background: Present for Meteosat 9, 10, and 11. IR 10.8, VIS 0.8, and HRVIS zonal plots. These lines are due to the inversion height correction applied in the EUMETSAT processing for MSG which remained present after the cross-correlation contribution (CCC) method was introduced. This results in the striping seen in the zonal plots of the counts, and to some degree in the O-B stats. | Yes |
| 11.3 | INSAT widespread positive bias | 11 | New.<br><br>Feature background: INSAT-3D and INSAT-3DR show widespread positive bias of 1-2 m/s in the IR channel in the tropics and southern hemisphere. This feature is clearly shown in O-B map statistics. Coordinate Group for Meteorological Satellites (CGMS) time series statistics indicate it has been present since 2020. In both regions the increased bias corresponds to a large increase in the number of winds which occurred in September 2020. RMSVD remains consistent throughout this time period. | Yes |
| **Geostationary: mid-level (400-700 hPa)** | | | | |
| 2.8 | Positive bias in the tropics for MSG, FY-2, GK-2A | 2,3,4,5,6,7, 8 | Still present for MSG and FY-2 for the Met Office, ECMWF, and DWD (Meteosat- 9 and 10 only).<br><br>GK-2A: Plots not available from October 2022 – July 2024, otherwise features are still present.<br>INSAT: Present, still showing small biases in extra-tropics. The negative biases are evident in the CGMS time series statistics.<br><br>Feature background: Previous reports have noted that mid-level AMVs tended to have a positive speed bias in the tropics and a negative speed bias in the extra-tropics. As new generations of satellites and derivation schemes have been introduced this has no longer been the case, e.g. for Himawari, and GOES. In general, there are far fewer AMVs extracted at mid-level and biases are thought to be largely the result of height assignment errors. | |
| 2.9 | Negative bias in the extra-tropics for MSG, FY-2, INSAT | 2,3,4,5,6,7, 8 | | |
| 11.2 | Change in O-B statistics above/below 500 hPa in GOES zonal plots | 11 | New. Present for the Met Office, ECMWF, and DWD.<br><br>Feature background: This is present for GOES 16 and 18 in the IR channel from February 2024 onwards. This looks to be due to NOAA's new "Enterprise" algorithm's cloud phase check during QC. If the AMV height assignment is above (below) 500mb and the dominant cloud type for the target scene is liquid water (ice/cirrus), the AMV is flagged as bad, leading to the change in O-B evident in the zonal plots at this level. | Yes |
| 11.5 | Positive bias in all | | New. Present for the Met Office and ECMWF. | |

| | | | | |
|---|---|---|---|---|
| | regions for MSG WV channels | | Feature background: The O-B stats tend to drop off at mid-level for WV, where there is a strong positive bias in the zonal plots. WV 7.3 can see deeper than WV 6.2. This has been an issue since MSG first launched. Noting as an AR feature for completeness. CGMS time series statistics also reveal that WV 6.2 and 7.3 show high positive bias for all regions for Meteosat. | |
| **Geostationary: high-level (above 400 hPa)** | | | | |
| 2.10 | Negative speed bias in extra-tropics for MSG, FY-2 and GK-2A | 2,3,4,5,6,8 | Still present.<br><br>Meteosat-11: No data for ECMWF. The Met Office plots show strong negative bias in northern hemisphere for IR, but less for WV7.3 and less again for WV6.2 as seen in AR10.<br>Meteosat-10: Similar between models, more prominent in winter. Strong negative bias for IR, less prominent for WV7.3 and less again for WV6.2.<br>Meteosat-9: Strong negative bias for IR, again there are minor differences between models, semi-permanent area of negative bias over Himalayan plateau as before.<br>FY-2G: Very strong negative bias in IR and WV.<br>GK-2A: Plots not available from October 2022 – July 2024, otherwise feature is still present.<br><br>Feature background: The dominant signal in the O-B monitoring statistics at high level is a negative speed bias located in the extra-tropics. The bias is usually associated with the position of the jet stream and hence peaks in the winter months. It is often more marked in the northern hemisphere. Previous analyses have suggested the main causes to be 1) height assignment error in high wind shear environments, 2) representative errors, and 3) errors in the tracking step (correlation poorly constrained where cloud features more linear e.g. AR4). Access to more information from the correlation surface (how well constrained the maxima is) could help to filter out cases where the tracking is problematic. | |
| 2.13 | Positive speed bias in tropics for MSG and FY-2 | 2,3,4,5,6,7, 8,11 | MSG: Positive bias is still present for IR and WV, though not that prominent, more scattered than the negative speed bias in the extra tropics.<br>FY-2G: Present for IR. WV barely present, only for the occasional month, often little or negative bias.<br>Similar between models.<br><br>Feature background: Most satellite-channel combinations show a positive speed bias at high level in the tropics, particularly for the WV channels. In previous ARs, this feature has been linked to tracking and assigning heights to linear cloud tracers, and to height assignment of cloud edges in regions of wind shear. Changes in derivation methods and transitions to newer satellites have altered and reduced this bias over time. In AR8, for MSG, OCA height assignments were shown to provide AMVs closer to the model best-fit pressure resulting in reduced O-B biases. | Yes |

| | | | | |
|---|---|---|---|---|
| 2.14 | High troposphere positive bias for MSG | 2,3,6,8 | Meteosat-11: Still present up to March 2023, after which the coverage changed.<br>Meteosat-10: Still present, though less prominent in 2024.<br>GOES: No longer present.<br>The positive bias looks to be seasonal (as noted in AR8), being most prominent in the winter hemisphere.<br><br>Feature background: A positive speed bias for MSG AMVs assigned heights high in the upper troposphere (>200 hPa). This was previously an issue for “unedited” GOES too. The bias may be due to a ‘high’ height assignment bias. There is a seasonal dependence affecting the EUMETSAT data: a positive bias can be observed between October-April, the rest of the year is dominated by a negative speed bias. Though the positive bias is present in both hemispheres, the most prominent is the winter hemisphere. In AR8 it was shown that OCA height assignments reduced this positive bias in O-B zonal plots for MSG in the winter hemisphere for IR. | |
| 2.15 | Differences between channels | 2,3,5 | Zonal plots suggest there are still differences between IR and WV for MSG, GOES, and Himawari. WV positive biases are much stronger than IR. Plots are generally similar between models except for Himawari where the DWD zonal plots have slightly less bias, and ECMWF plots have slightly stronger biases, see Feature 9.3.<br><br>For Himawari-9, over 2023 and 2024, the WV 7.3 long wave channel is of better quality, has wider coverage, and has a higher number of winds. We only have AMVs from the GOES WV 6.2 channel. AMVs from a longer wave WV channel might be of better quality, allowing use in operations.<br><br>Feature background: There are some notable differences between the IR and WV statistics for some satellites, including GOES, Himawari, and MSG. Previous ARs suggested that this could be due to systematic height assignment errors, which in some cases have been improved upon with derivation changes by JMA and EUMETSAT. | |
| 3.2 | Negative Speed bias for MSG in Tropical Easterly Jet (TEJ) strongest over the Indian Ocean | 3,6 | Present for Meteosat 9 and 10 in summer 2024. Not present in 2023. This feature still resembles the original feature in AR3 zonal plots, although the background wind speed and the magnitude of the speed bias are less this year.<br><br>The Met Office, ECMWF, and DWD O-B zonal IR plots look very similar for 2023 and 2024. ECMWF plots are missing for Meteosat 9 and 11 prior to August 2022.<br><br>Feature background: A negative speed bias for MSG winds in the high troposphere of the tropics between June and September. Historically the zonal O-B speed bias is worse for the Met Office than ECMWF. Previously shown to be a contribution from the Met Office model error linked to an excessive TEJ in the analysis. | |

| | | | | |
|---|---|---|---|---|
| 4.2 | GOES negative bias in tropical Pacific | 4,5,6,11 | There are small negative biases for December 2023 to February 2024 for GOES-18 IR, though there are more noticeable negative biases for December 2022 – April 2023. Similarly for WV. There is some missing data for DWD. There are small model differences, though generally they are well aligned in the pacific region for this feature.<br><br>Recent biases are smaller than those historically for GOES-17. While this could be interannual variability, the GOES Enterprise derivation changes look to have lessened this feature significantly since they came into effect (see the section on enterprise changes) over February – April 2024.<br><br>Feature background: GOES West exhibits a negative speed bias from December to April. Model errors are thought to contribute to the O-B signal which has also previously been shown to vary from year to year indicating some synoptic dependence. | Yes |
| 9.5 | Negative speed bias in tropics for GOES | 9,11 | Closed. While this was present for GOES 16 and 18 across ECMWF, the Met Office, and DWD plots, it lessened over 2023 and is not present for March 2024 – September 2024, IR and WV. This coincides with the GOES Enterprise derivation changes which came into effect in February 2024 (see the section on enterprise changes).<br><br>Feature background: A negative bias in both IR and WV channels in the tropics for GOES. | Yes |
| 11.4 | INSAT widespread positive bias in tropics and SH | 11 | New. Parallel feature to 11.3 but at high level.<br><br>Feature background: IR and WV channels for INSAT-3D and INSAT-3DR show widespread positive bias of 1-2 m/s in the tropics and southern hemisphere, occasionally extending into the northern hemisphere. This feature is clearly shown in O-B map statistics. CGMS time series statistics indicate it has been present since 2020. In most channel-region combinations the increased bias corresponds to a large increase in the number of winds which occurred in September 2020. RMSVD remains consistent through this time period. | Yes |
| **Leo and mixed AMVs** | | | | |
| 2.19 | Aqua WV high-level positive speed bias | 2,3,4,5 | Closed. Data no longer produced as mission approaches end of life. | |
| 2.20 | Low-level negative speed bias | 2,3,4 | Closed. CIMSS Metop data is no longer available, and NESDIS MODIS satellites have reached end of life.<br><br>Feature background: A general slow speed bias is seen below 900 hPa in the polar IR datasets from both NESDIS and CIMSS, tends to be worse for higher wind speeds. | |
| 4.3 | Near-pole mid-level negative bias | 4,5 | Closed. CIMSS Metop data is no longer available, and NESDIS MODIS satellites have reached end of life. | |

| | | | | |
|---|---|---|---|---|
| | | | Feature background: A slow speed bias was visible in zonal plots for mid-level IR AMVs polewards of ~80 N/S, mainly during the winter months, for CIMSS AVHRR and NESDIS MODIS winds. | |
| 7.1 | Dual-Metop high level positive bias in tropics | 7 | Still present.<br><br>Feature background: AMVs from EUMETSAT's Low-Earth Orbit satellites are known to have significant positive speed biases in the tropical band at most longitudes.<br>The relationship between O-B bias and Satellite Zenith Angle (SZA) was investigated in AR7 for Dual-Metop. The bias is thought to be linked to the differences in characteristics between the different image pairs in terms of time gap, overlap extent, and viewing geometries. Parallax and pixel size variation (1 km at nadir, 4 km at the edge of the swath) complicate the tracking step.<br>It has now been shown that the root cause of the tropical speed bias is the tracking algorithm [2] and is indeed linked to parallax correction. A lack of robustness of cross-correlation tracking, combined with an approximation made on the forecast vector, and the long temporal gap between consecutive images used from LEO satellites, is responsible for the positive bias observed in the tropics and the negative bias at mid-latitudes. A new derivation method is being developed which has been tentatively named "Feature Matching Consensus (FMC)" [3]. | |
| 7.2 | EUMETSAT Metop high level negative bias in midlatitudes | 7 | Still present.<br><br>Feature background: A negative speed bias affecting single and dual Metop winds between 60S-20S at upper levels. This followed derivation updates in May 2014, where this slow bias became larger and more extensive for Single-Metop and was present for Dual-Metop AMVs when they were introduced later in the year. | |
| 7.6 | VIIRS square distribution | 7,8 | Still present in Suomi NPP, NOAA-20 and NOAA-21.<br><br>Feature background: The VIIRS AMVs from Suomi-NPP and NOAA-20 for conventional IR channels have an unusual spatial distribution which is square-shaped on a polar projection. The cause of the square distribution is known to be the dimensions of a box used for the polar projection during the derivation process which imposes a hard limit on the coverage. It is likely we lose some usable data as a result of this hard limit. | |
| 9.4 | EUMETSAT Metop low level AMVs in winter hemisphere | 9 | Still present.<br><br>Feature background: Metop low level winds have a speed bias and large vector difference in the winter hemisphere. Imagery suggests the AMVs could be erroneously tracking surface features. | |
| 11.6 | VIIRS differences in northern hemisphere | 11 | New. See the section on NOAA-21 VIIRS AMVs for more detail.<br><br>Feature background: There are differences between NOAA-21, NOAA-20, and Suomi-NPP VIIRS MVDs in the northern hemisphere. Bias and RMSVD are well aligned, however. NOAA-20 has the smaller MVDs in this area. This discrepancy is potentially linked to the number of winds received for | Yes |

| | | | | |
|---|---|---|---|---|
| | | | each satellite, as more are received for NOAA-20. DB winds are not received for NOAA-21 and are typically received faster than non-DB winds for NOAA-20. Suomi-NPP typically has longer delays in data provision than NOAA-20 and has experienced outages in the past which may have impacted MVD. Delays in data receipt have a knock-on impact during processing, where cut off times can reduce the number of winds processed and thus used in the O-B statistics, potentially resulting in differences in MVD. | |
| **General issues** | | | | |
| 9.1 | Orographic effects | 9 | Still present.<br><br>Feature background: Meteosat have a semi-permanent area of negative bias over the Himalayan Plateau. Apparent in all 3 channels and all year, apart from JJA. Not seen in Himawari, INSAT or in dual Metop. There is a consistent 50 hPa height difference between Meteosat-8 and other AMVs in this area. This height bias has less of an impact in summer when the vertical wind shear is less. | |
| 9.3 | Differences between Met Office, ECMWF, and DWD statistics for Himawari | 9, 11 | Still present. However, the bias differences between ECMWF and the Met Office are not as significant or widespread. The MVD patterns also have less variation, with ECMWF having slightly larger MVDs in general.<br><br>There are differences between DWD and the Met Office. DWD has a smaller MVD in the tropics at mid-levels and generally a larger MVD in the extra tropics at low and high levels. DWD has smaller absolute biases at mid-levels in parts of the tropics, in the same areas as the MVD differences.<br><br>Feature background: Historically, ECMWF has smaller mean vector differences at upper levels, the Met Office has smaller mean vector differences at mid-level in the tropics. There are differences also in biases at mid-level. There are differences in the use of Himawari data in data assimilation between the centres, but biases probably reflect wider NWP model difficulties in this area. | Yes |
| 10.1 | Problems in regions of organized convection in the tropics | 10 | For Meteosat-10 this looks to be present in the medium and high-level IR map plots as positive speed biases West of central Africa in June - September 2023 and 2024. A larger standard deviation can generally be seen for the tropics at these times.<br><br>Feature background: In the tropics there are periods when there are strongly organized convective clusters. These clusters sometimes become large and develop their own mesoscale system and many AMVs are produced from their high-level clouds. Sometimes forecast models fail to capture these systems which leads to large O-B departures. | |
| 10.2 | Differences between NWC SAF and EUMETSAT UKV AMVs | 10 | New. Added after coverage in AR10.<br><br>Feature background: The Nowcasting Satellite Applications Facility (NWC SAF) provide software products for calculating AMVs based on Meteosat, GOES, and Himawari satellite imagery. The SAF package produces a larger data volume (AMVs provided every 15 minutes vs hourly for EUMETSAT) | |

| | | | | |
|---|---|---|---|---|
| | | | and uses up to three tracers for each segment compared to one for EUMETSAT. Calculating O-Bs in the UK region for Meteosat-11 AMVs results in NWC SAF producing larger volumes of AMVs with smaller bias and standard deviation. | |

# 3. Assessment of data changes

## NOAA-21 VIIRS AMVs

NOAA-21, the latest satellite in NOAA's Joint Polar Satellite System, was declared operational on the 8th November 2023 [4]. Statistics for NOAA-21 VIIRS AMVs have been added to the NWP SAF monitoring from August 2024 onwards. So far, for August to October 2024, NOAA-21 (Figure 2) is generally well aligned with NOAA-20 (Figure 1) in the O-B plots for bias and RMSVD. Depending on the height and month there are noticeable differences in MVD in parts of the northern hemisphere. NOAA-21 has lower MVD in August at all levels, but for September-October at high and low levels there is a slightly higher MVD, and at medium level there is little change. NOAA-21 has a smaller number of winds than NOAA-20 at all levels in the northern hemisphere which appears to correspond to the differences in MVD. Suomi-NPP (not shown) is more similar to the NOAA-21 data counts in recent months.

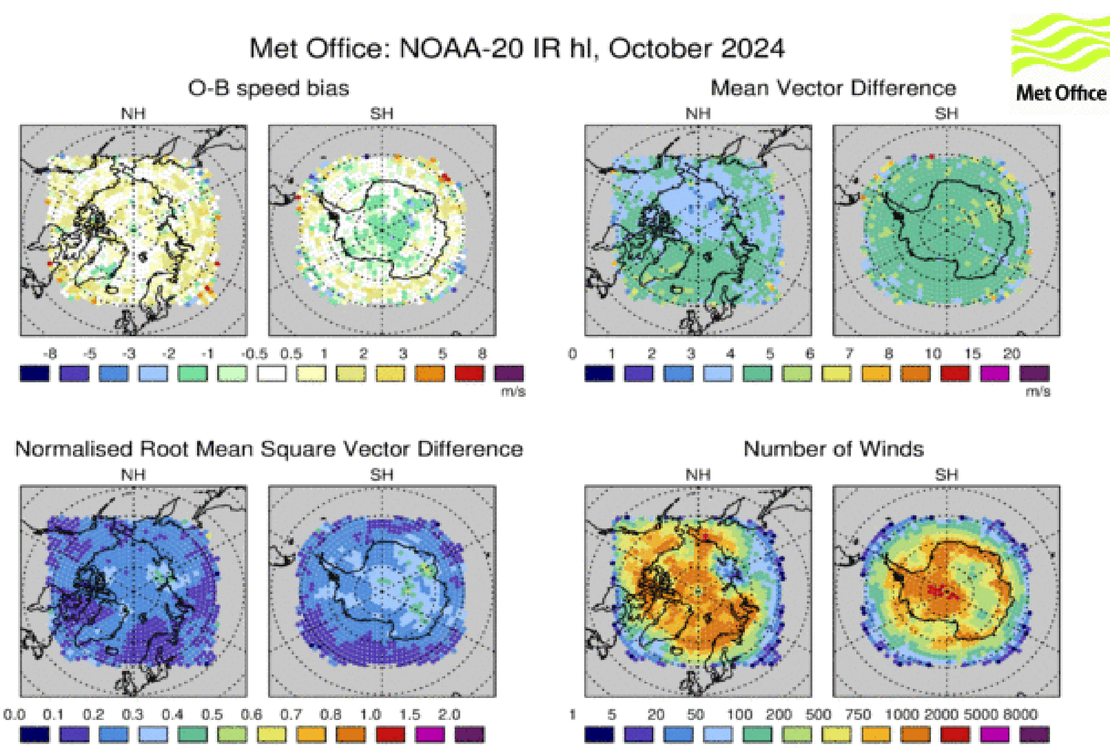


*Figure 1. Map of O-B speed bias, mean vector difference, root mean square vector difference, and AMV counts for NOAA-20 Infrared channel winds above 400 hPa in October 2024.*

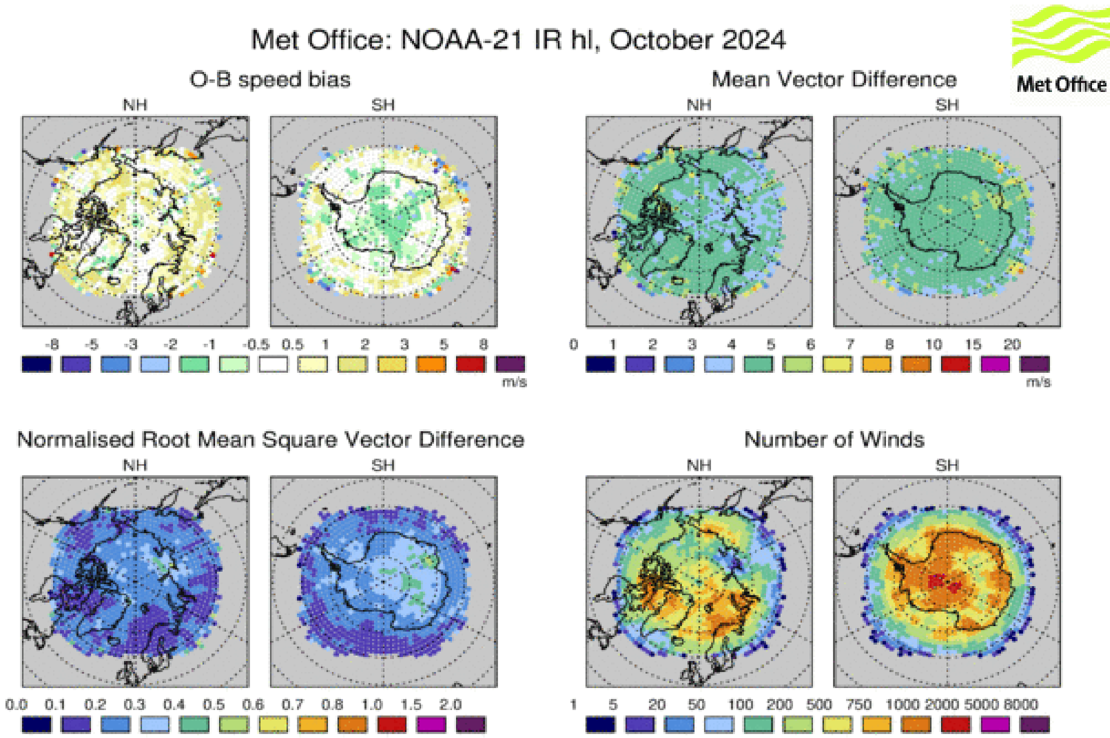


*Figure 2. The same plot as Figure 1, but for NOAA-21.*

The difference in the number of winds is likely linked to the differences in timeliness. There are a couple of reasons for the differences between the 3 NOAA platforms. (1) Direct Broadcast (DB) winds are not currently received for NOAA-21 while they are received for NOAA-20 and Suomi-NPP over the Arctic. (2) The timeliness of the non-DB Suomi-NPP winds is slower than the other two satellites as it is a lower priority mission. Some of the later arriving Suomi-NPP will miss the data inclusion cutoffs (Figure 3). This became more noticeable from February 2024 due to an internal change to the way AMVs are monitored at the Met Office. AMVs assimilated in operations are now monitored with a slightly earlier cutoff time which can impact data with longer delay times, i.e. Suomi-NPP. NOAA-21 winds are not yet assimilated and are currently monitored with a later cutoff.

Historically, there have been differences in MVD and the number of winds between NOAA-20 and Suomi-NPP that appear to correspond to either this data timeliness issue or due to data outages, both resulting in fewer winds for Suomi-NPP. During 2024, Suomi-NPP experienced several significant outages due to satellite geolocation issues.

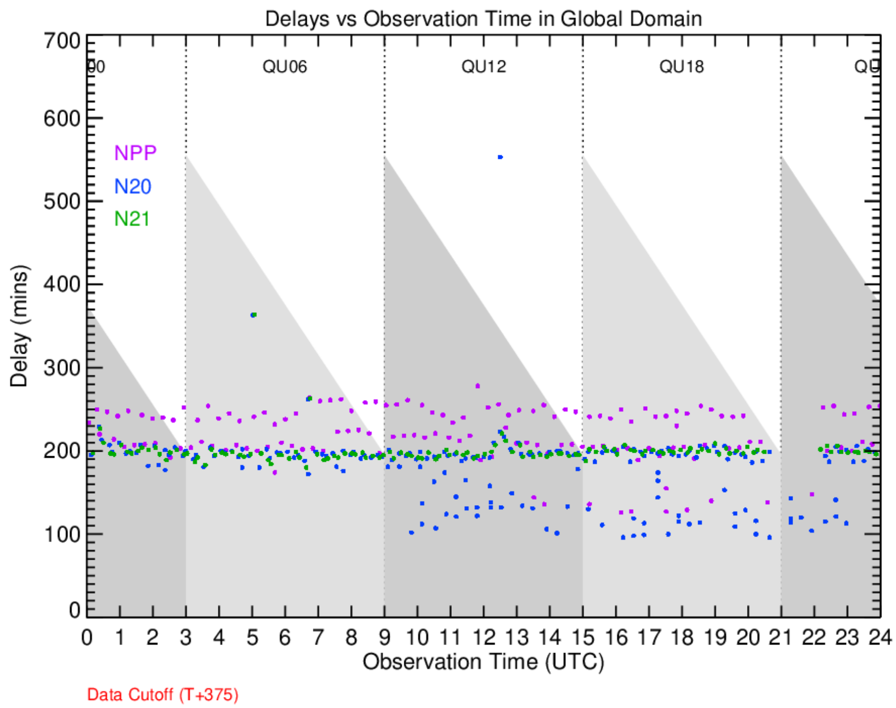


*Figure 3. Delay time (difference between observation time and reception at the Met Office) as a function of the observation time for VIIRS AMVs: Suomi-NPP purple, NOAA-20 blue, NOAA-21 green. Data extracted for 1-5 January 2025. Shaded grey polygons show the requirement to meet a data cutoff of T+375 mins from each analysis time T. If points lie in the shaded grey polygons they are received in time for the assimilation and monitoring. For NPP there are quite a few batches which fall just outside this so no longer make the monitoring. The DB winds are received much faster (~100 mins) and there are more for NOAA-20 than NPP.*

Figure 4 shows the mean bias and vector differences as a function of the delay time (the received time minus the observation time) for NOAA-20 for a single day. The winds delayed by less than 140 minutes (the DB winds) have lower MVDs. The first column has such low counts the overall mean of the MVD is still close to 3.4 m/s for the DB winds. This compares to ~4.0 m/s for the global data received later, so the MVD for the DB data is around 15% less. This may be the reason why NOAA-20 has lower MVDs in the northern hemisphere than NOAA-21 and Suomi-NPP.

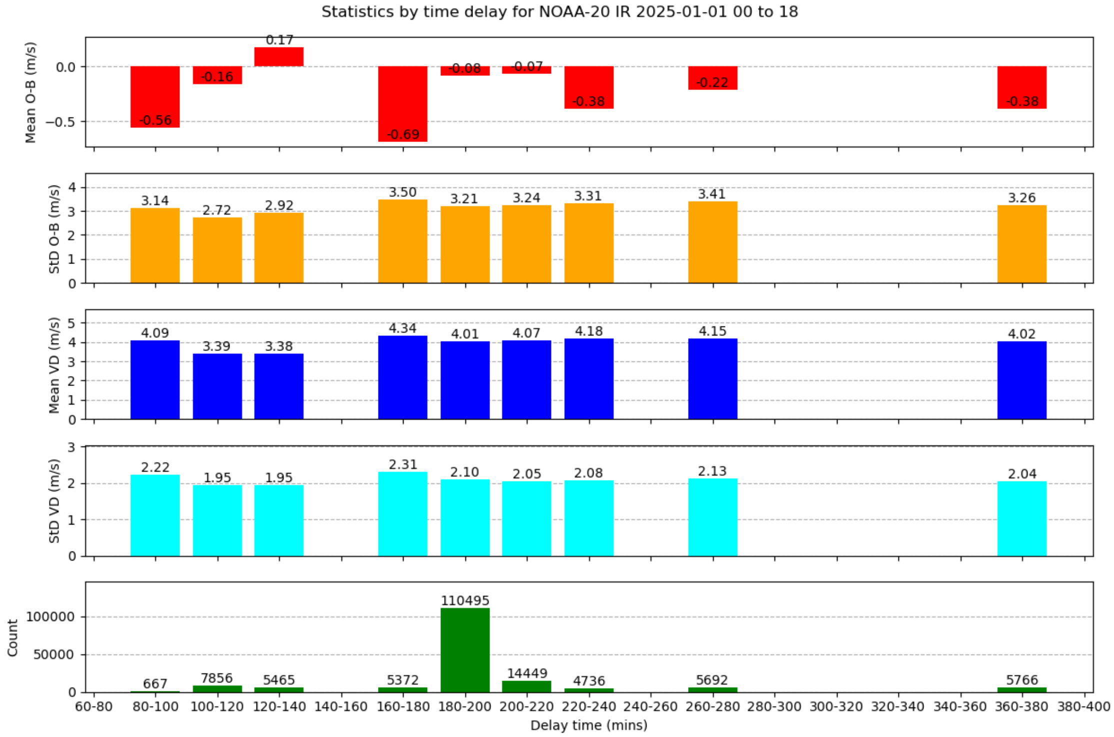


*Figure 4. A column plot of mean bias statistics as a function of time delay (= received time – observed time), with the time delay binned into 20-minute intervals, for NOAA-20 on the 01/01/2025 cycles 00 through 18 inclusive. From top to bottom: the mean bias, the standard deviation of the bias, the mean vector difference, the standard deviation of the vector difference, and finally the number of winds received.*

In summary, NOAA-21 bias and RMSVD is in line with that of NOAA-20 and Suomi-NPP. However, in the northern hemisphere NOAA-21 has a higher MVD and lower number of winds. This could potentially be remedied with the inclusion of DB winds for NOAA-21 and with adjustments to internal processing at the Met Office to account for the variations in data timeliness between satellites.

**DWD**

In addition to the Met Office and ECMWF, global model background statistics for the German Weather Service, Deutscher Wetterdienst (DWD), for geostationary AMVs have been added to the NWP SAF monitoring website. Map and zonal plots are available from December 2023 onwards.

DWD statistics are largely consistent with the Met Office and ECMWF except for Himawari IR. This is already a feature for ECMWF and Met Office differences and is investigated further for all modelling centres in the section on Feature 9.3 in this report.

**Meteosat-12**

The first satellite in the Meteosat Third Generation (MTG) programme, Meteosat-12, was delayed due to a calibration issue during its commissioning phase which lasted longer than anticipated. It became operational on the 4$^{th}$ December 2024 [5].

Onboard the MTG imager satellites is the Flexible Combined Imager (FCI), which continues and improves on the successful operations of the SEVIRI instrument on the current MSG satellites. The FCI has 16 channels over SEVIRI's 12 and can deliver a full image of Earth every 10 minutes with a spatial resolution of 1-2km [6]. Additionally, it can zoom in on smaller areas to deliver images more frequently at a higher resolution.

AMVs from Meteosat-12 are now being produced, though with some caveats on the data quality. Statistics have been added to the NWP SAF monitoring from January 2025 with data coverage from December 2024 onwards.

## 4. Impacts of NOAA Enterprise algorithms

NOAA have introduced new "Enterprise" versions of their wind and cloud height algorithms [7], with an aim to minimise the slow speed AMV bias and reduce errors in AMV height assignment. The "Enterprise Winds Algorithm" introduces several important updates for data handling and winds quality control and takes advantage of the improved cloud heights generated by the new "Enterprise Cloud Height Algorithm", similar to EUMETSAT's Optimal Cloud Analysis (OCA) product.

The new wind algorithm can retrieve AMVs from several different GEO and LEO instruments processed at NOAA/NESDIS. It replaces the current operational algorithm and was implemented for GOES-16 and GOES-18 on the 6$^{th}$ February 2024, and later for SNPP, NOAA-20 and NOAA-21 VIIRS Polar Winds on the 6$^{th}$ March 2024.

The new winds algorithm includes the following changes, details courtesy of Andrew Bailey personal communication 15th August 2023, and Hongming Qi personal communication 12th January 2024:

- Introduction of a check on the satellite zenith angle of each target scene. Any target scene where the satellite zenith angle exceeds 70 degrees is discarded.
- Tightened up the AMV-forecast wind thresholds associated with the vector difference test that compares retrieved Long Wave Infrared LWIR (ABI band 14) and Cloud-Top Water Vapour CTWV (ABI band 8) winds against the NCEP GFS forecast wind.
- Added verification for the input cloud phase in quality control, performing “reasonableness” checks on the dominant cloud type in the target scene. The AMV is flagged as bad (failed) where:
    - The cloud type is “overlap”.
    - The AMV height assignment is above 500 hPa and the dominant cloud type for the target scene is liquid water.
    - The AMV height assignment is below 500 hPa and the dominant cloud type for the target scene is ice or cirrus.
- Takes advantage of the improved cloud heights, particularly at upper levels (above 400 hPa), generated by the enterprise cloud height algorithm.

**Expected impacts**

For GOES, based on preliminary time-series and vertical AMV/radiosonde statistics analysis by NOAA of the first few weeks of the GOES Enterprise AMV test (personal communication, Andrew Bailey, 15th August 2023), the algorithm changes were expected to lead to notable impacts and reductions in “good” wind counts compared to operational counts, depending on the channel, and hopefully improve O-B bias, mainly affecting high and mid-level AMVs.

Test data for the new algorithm was provided as a parallel stream to the operational data covering April 2020 for GOES-16 and GOES-17. From the test data the following changes in O-B monitoring for the Met Office backgrounds were expected:

- A shift to a more positive windspeed bias for WV, IR high-level, and IR mid-level of the order 0.5-1.0 m/s.
- A generally higher RMSVD for all channels except IR at high-level, most impactful for IR and mid-level.
- Winds assigned to higher pressures at both upper and lower levels.

It was noted that the test data provided at the time may not be the same as the data provided operationally.

**Observed impacts**

Looking at the observed impacts since implementation, via comparisons of the O-B NWP SAF statistics for GOES-16 and GOES-18 from 2023 to 2024 over the months February-September, generally show that:

- High-level IR and WV show a change in bias, in some cases improving it where it was previously negative, accompanied by a reduction in RMSVD.
- Mid-level IR has little change, there are slight increases in bias and slight improvements in RMSVD.
- Low-level IR and VIS show no clear change in bias, nor RMSVD.

Figures 5 and 6 for March 2023 and March 2024 high-level IR for GOES-16, show the change in bias and decrease in RMSVD and MVD.

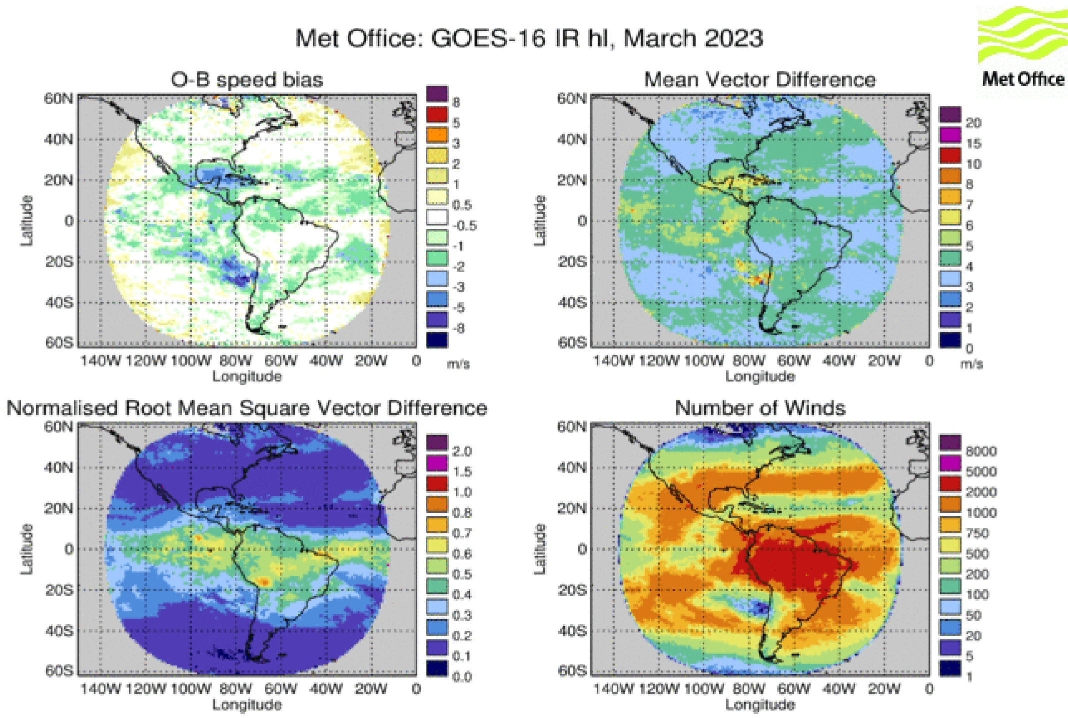


*Figure 5. Map of O-B speed bias, mean vector difference, root mean square vector difference, and AMV counts for GOES-16 Infrared channel winds above 400 hPa in March 2023.*

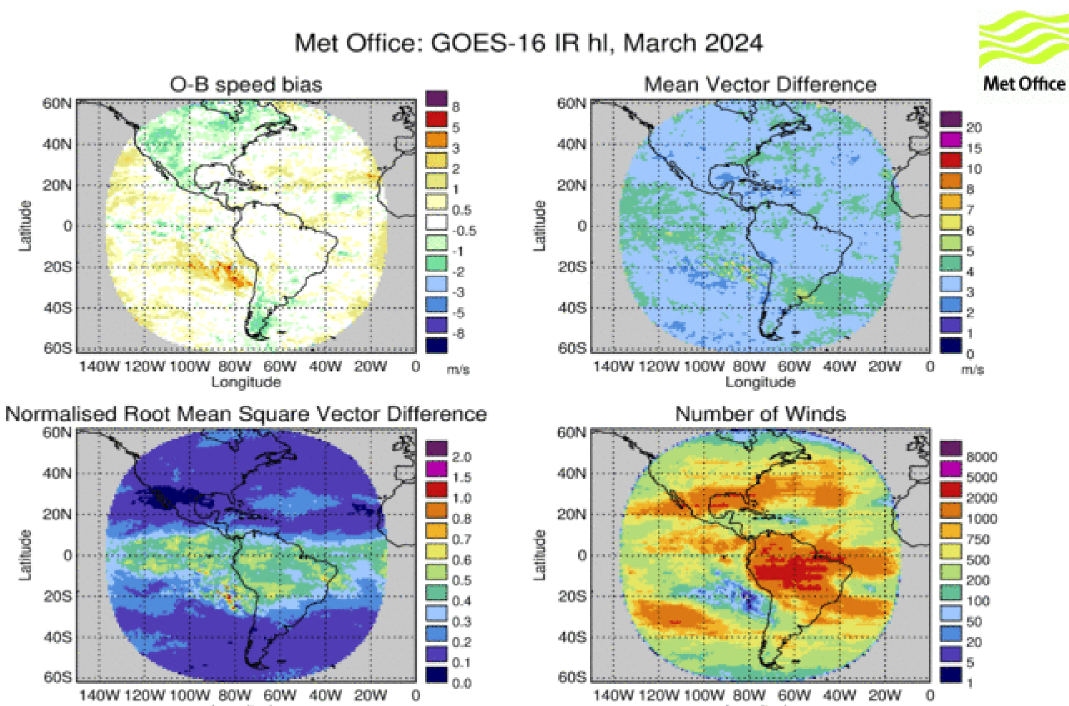


*Figure 6. The same plot as Figure 5, but for March 2024.*

The impacts on bias were largely expected from the test data, although they are most prominent for high-level IR and WV and not for mid-level IR. An unexpected impact at high level is that the RMSVD has decreased and improved overall, with little change at medium and low level.

The changes seen in the O-B statistics are supported by historical monthly time series statistics for AMVs compared with the Met Office background as defined (see appendices) by the Coordination Group for Meteorological Satellites (CGMS) (Figures 7-9). The statistics are significantly different since February 2024 when the Enterprise changes were introduced. In general, across all channels in the CGMS time series, the enterprise changes have led to a positive shift in bias and decreased the RMSVD, and the changes are most significant at high level (above 400 hPa) (Figure 7). Additionally, the bias and RMSVD overall are more consistent month to month. The number of winds has also decreased for mid and high-level IR and high-level WV 6.2 since February.

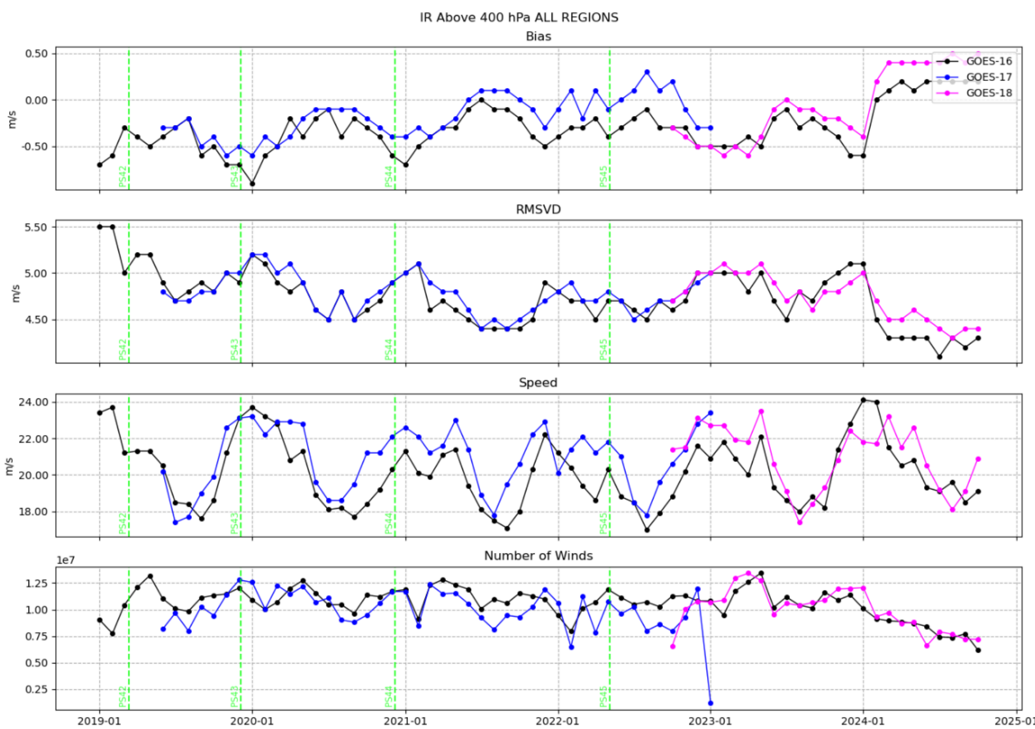


*Figure 7. Coordination group for meteorological satellites monthly time series statistics of O-B speed bias, root mean square vector difference, AMV speed, and AMV counts for GOES-16 (black), GOES-17 (blue), and GOES-*

*18 (magenta) high-level infrared channel winds above 400hPa, for all regions from January 2019 to October 2024 inclusive.*

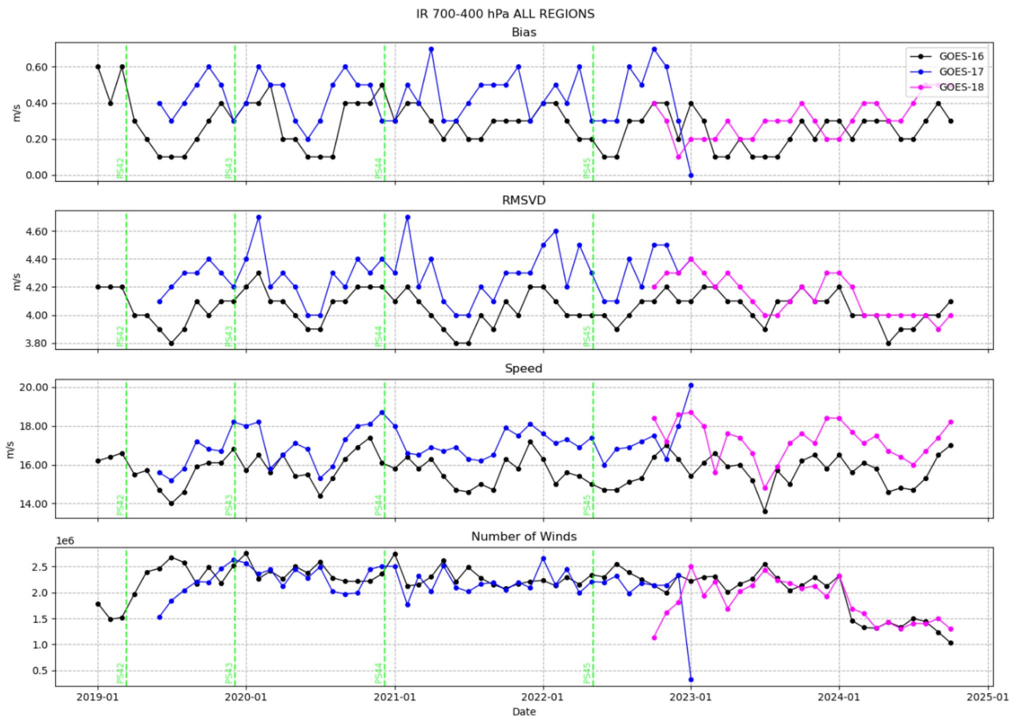


*Figure 8. The same plot as Figure 7, but for mid-level infrared channel winds between 700-400 hPa.*

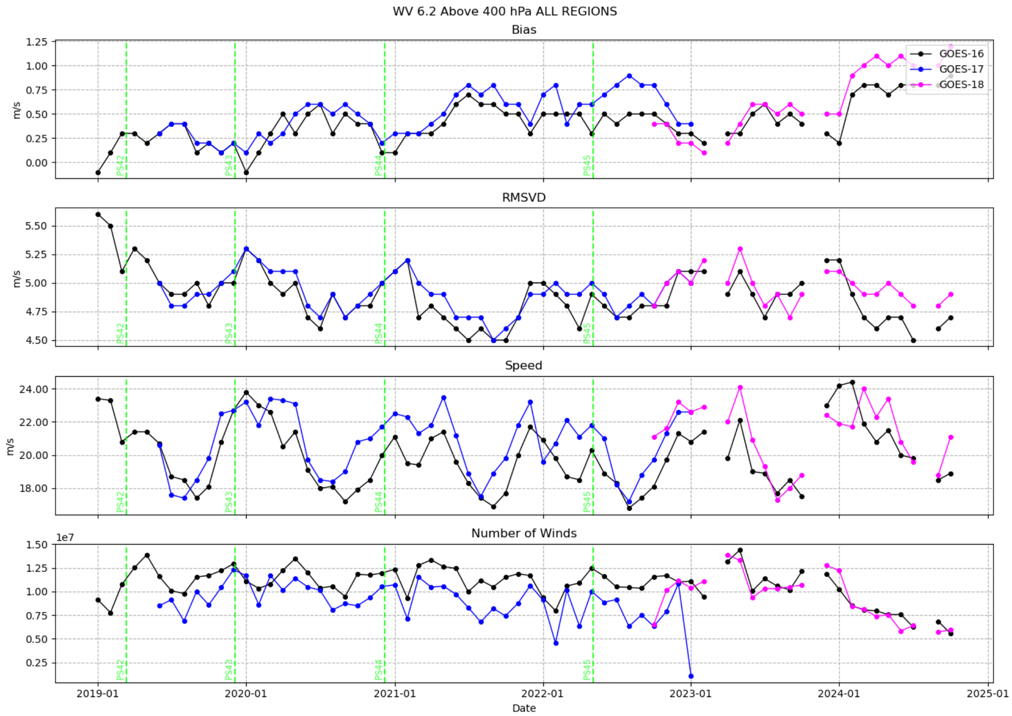


*Figure 9. The same plot as Figure 7, but for the 6.2 µm water vapour channel.*

### Changes in features

As a consequence of the Enterprise algorithm changes, a new mid-level feature has been identified, *Feature 11.2: Change in O-B statistics above/below 500 hPa in GOES zonal plots*. This is present for GOES-16 (Figure 10) and GOES-18 in the IR channel from February 2024 onwards for the Met Office, ECMWF, and DWD. It is more noticeable for GOES-16 than 18. This feature is most likely caused by the Enterprise algorithm's cloud phase check during quality control, where if the AMV height assignment is above (or below) 500 hPa and the dominant cloud type for the target scene is liquid water (or ice/cirrus) respectively, the AMV is flagged as bad, thus leading to the change in O-B evident in the zonal plots at this level (Figure 10).

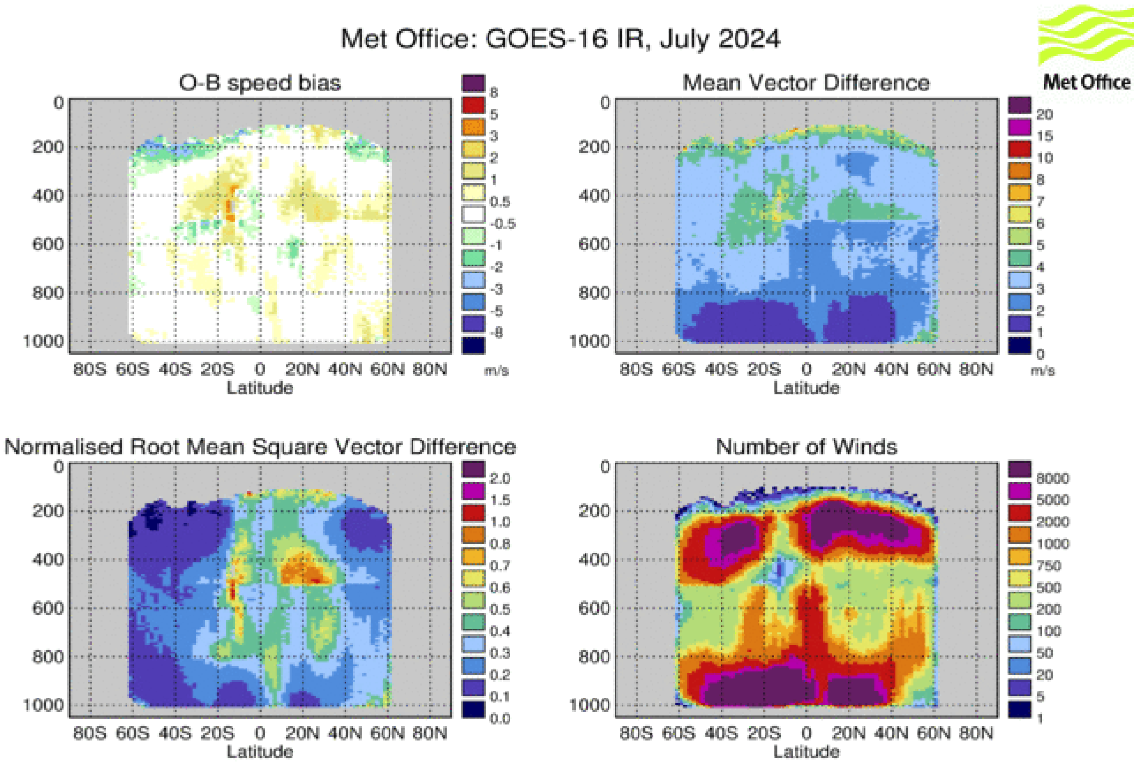


*Figure 10. Zonal O-B statistics as a function of latitude and pressure (hPa), showing speed bias, mean vector difference, root mean square vector difference, and AMV counts for the GOES-16 infrared channel in July 2024.*

Some GOES features have improved because of the new algorithm. At high level, the bias has improved for IR and WV, with windspeeds shifting to be more positive for GOES in the tropics since February 2024. This has led to an improvement for *Feature 4.2: GOES negative bias in tropical Pacific*, which is still present but lessened. And for *Feature 9.5: Negative speed bias in tropics for GOES*, which has been closed.

**Additional impacts**

The above analysis has only considered GOES. There are also impacts for the LEO VIIRS AMVs since the Enterprise implementation. NOAA-20 IR shows a reduction in MVD of the order ~1 m/s in the northern hemisphere, most notably above sea, at all levels since February 2024, though this could be annual variability (Figures 11 and 12). At low level there appears to be an accompanying smaller reduction in MVD in the southern hemisphere and in bias in the northern hemisphere. For Suomi-NPP, high level IR shows little to no impact but at medium and low level there are similar reductions in MVD of the order ~1 m/s, and a smaller reduction in bias in the northern hemisphere, with small reductions in the southern hemisphere.

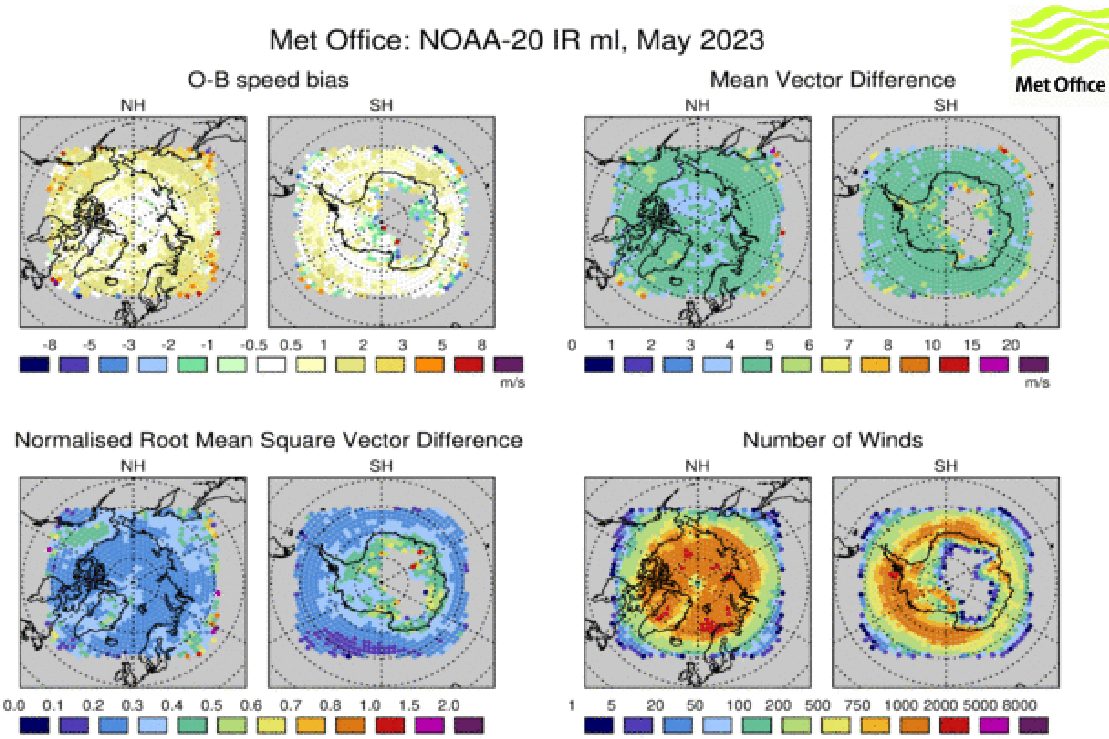


*Figure 11. Map of O-B speed bias, mean vector difference, root mean square vector difference, and AMV counts for NOAA-20 Infrared channel winds between 700-400 hPa in May 2023.*

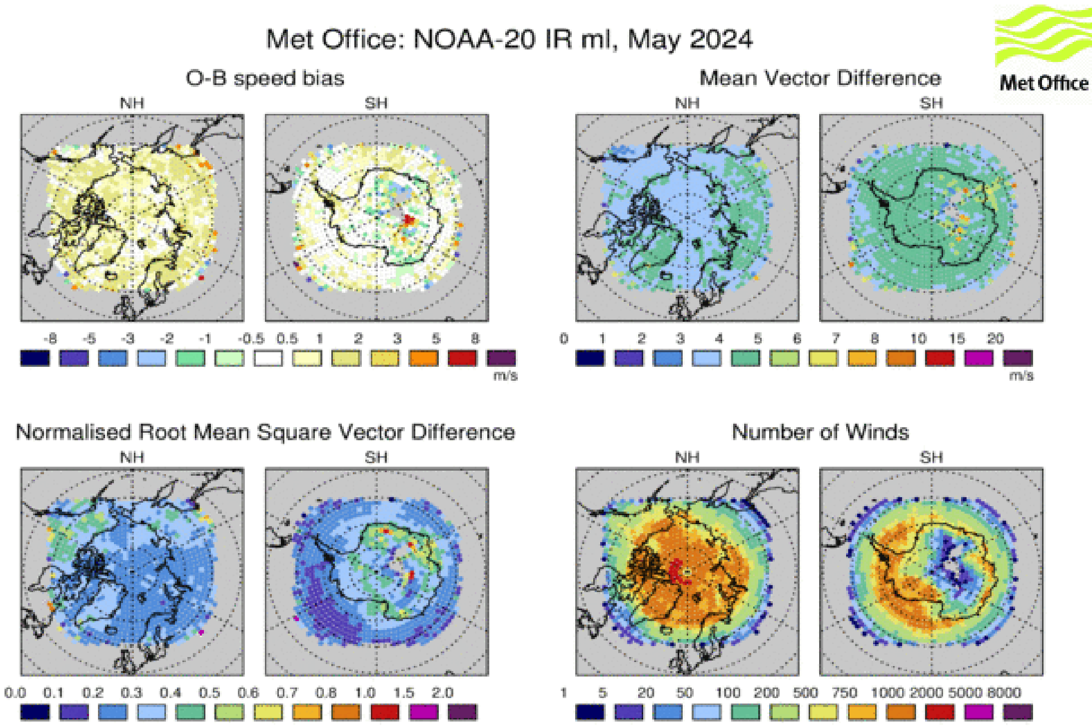


*Figure 12. The same as Figure 11, but for May 2024.*

## 5. Update on Feature 2.6: MSG positive bias over North Africa

*Feature background:*

A large, positive O-B wind speed bias is observed in the Meteosat Second Generation (MSG) IR and visible channels over North Africa and the Arabian Peninsula during winter. Although mainly over land, the bias extends over the Atlantic to the west of Africa in January/February and moves northwards into the Mediterranean by May. This feature closely matches the location of the sub-tropical jet stream and follows faster mid-upper-level winds. It is seen to exhibit a diurnal signal. Previous investigation has linked the bias to large height assignment errors when tracking cirrus or semi-transparent clouds, where winds are assigned ~500 hPa too low compared to the best-fit pressures. The diurnal signal is thought to be due to larger surface contributions to the measured cloud radiance in the hours surrounding midday, where IR AMVs might not be able to be extracted.

*Update:*

This bias has remained unchanged since the last report. Hovmoeller plots for the IR channel for Meteosat-10 over February 2024 show that the diurnal signal is still present. Similarly to Figure 1 in AR8, there is a clear positive speed bias with the largest signal from 1700 to 0000 for heights between 600-800 hPa (Figure 13).

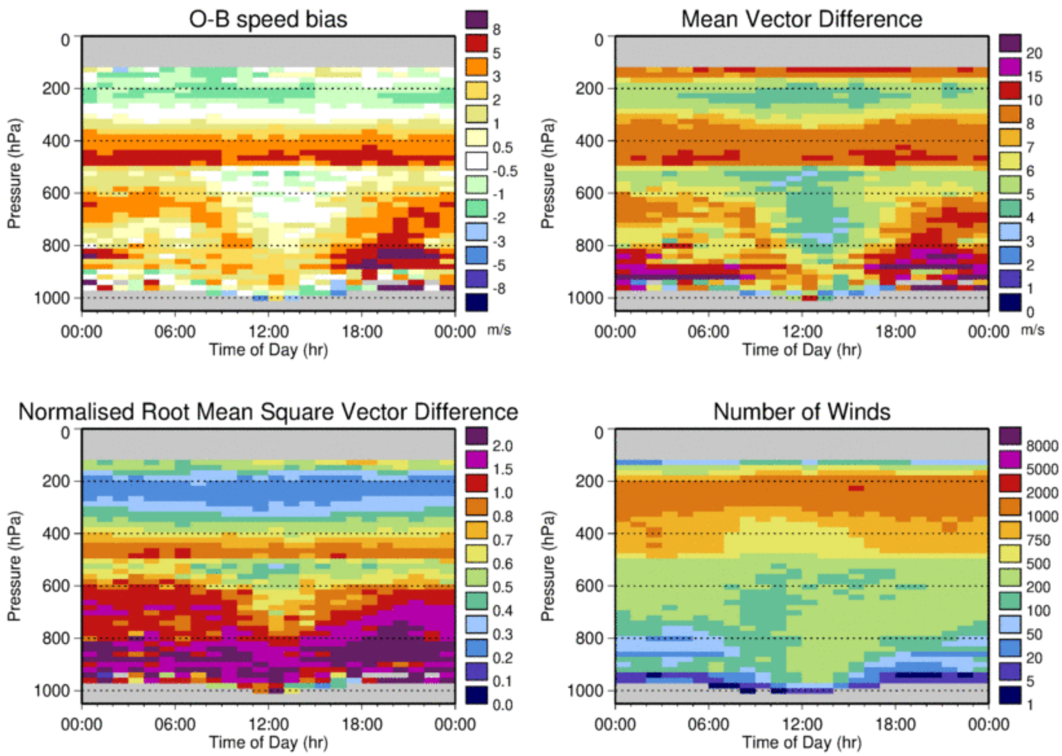


*Figure 13. Hovmoeller plots showing O-B statistics as a function of the time of day and pressure for speed bias, mean vector difference, root mean square vector difference, and AMV counts for Meteosat-10 infrared channel winds in February 2024.*

To gain a further understanding of the cause of this feature it is useful to look at alternative height assignment methods such as the heights assigned by EUMETSAT's Optimal Cloud Analysis (OCA).

In AR8, Met Office cloud products were found to be better than OCA heights for a problematic area of cloud. They produced higher cloud top heights and temperatures which looked more consistent with AMV best-fit pressures and Calipso lidar observations. One potential contributing factor to the Met Office cloud products performing better in this area that is worth mentioning is that the Met Office cloud product injected forecast profiles more frequently than EUMETSAT, better capturing the sharp diurnal variability in the surface temperatures. So, there may be a link to forecast frequency, which is a known limitation of the EUMETSAT setup.

Here we examine the OCA heights again, for Meteosat Second Generation (MSG) Meteosat-10, to see if they have improved, and as suggested in AR8, to try to understand why OCA is not as good as the Met Office or other cloud products in this area. This is useful to investigate because OCA heights are going to become the new operational method for assigning heights to Meteosat AMVs and may be considered with MSG as well as with the introduction of Meteosat Third Generation (MTG).

OCA heights are provided alongside the current CLA operational heights within the AMV products themselves. This allows us to use the OCA pressures in place of the current CLA pressures when calculating the backgrounds for the O-B Met Office bias statistics.

Low-level IR map statistics for February and September 2024 have been produced for Meteosat-10. Plots of these can be seen in Figures 14 and 16 with the current CLA height-based statistics for comparison. February shows a strong positive bias over North Africa as expected, while September shows only small areas of positive bias in comparison.

The O-B plots for February and September 2024 show a small improvement in bias over the Atlantic Ocean when using OCA heights (Figures 15 and 17), with areas of positive bias appearing to reduce. But the strong positive bias over North Africa has not improved significantly.

To some extent this is to be expected because OCA currently has a couple of limitations regarding thin high-level clouds. Firstly, it sometimes wrongly interprets cirrus as low-level cloud, or multi-level cloud with “very thin” cirrus. Secondly, it effectively filters out and ignores these thin upper layers (e.g. high-level cirrus) in height assignment, where it assumes that the tracers are unlikely to be linked to the high-level clouds [8]. These aspects of OCA are often an issue over bright surfaces like deserts, where radiation can pass through thin clouds from below. The cloud properties retrieved for use in assignment are representative of the level of the effective IR emission of the cloud, and with no extra information about the vertical profile of the cloud properties used, the height is thus assigned to the lower clouds [9]. Clearly, some thin high-level clouds are important, over the bright surface of the Sahara in this case, and ideally would be identified correctly as part of OCA to prevent the associated tracers from being erroneously linked to lower-level clouds, resulting in these large height assignment errors showing up in the O-B statistics.

We know the cause of this feature is the large height assignment error when tracers are picked up from high thin cloud, but the height assigned is for lower thicker cloud or due to the hot desert causing the cloud temperature to appear warmer than it is. As the OCA heights are not improving this feature, the only things that could potentially be done about it are either improvements to OCA (to better detect thin cirrus clouds), the AMV height assignment (to not ignore thin cirrus in multilayer cloud situations), or through quality controls based on the cloud optical thickness and cloud phase. However, not all data providers are providing cloud information in the BUFR files we receive. It would be good if they could add more, especially once OCA has been implemented, so that a solution could be explored.

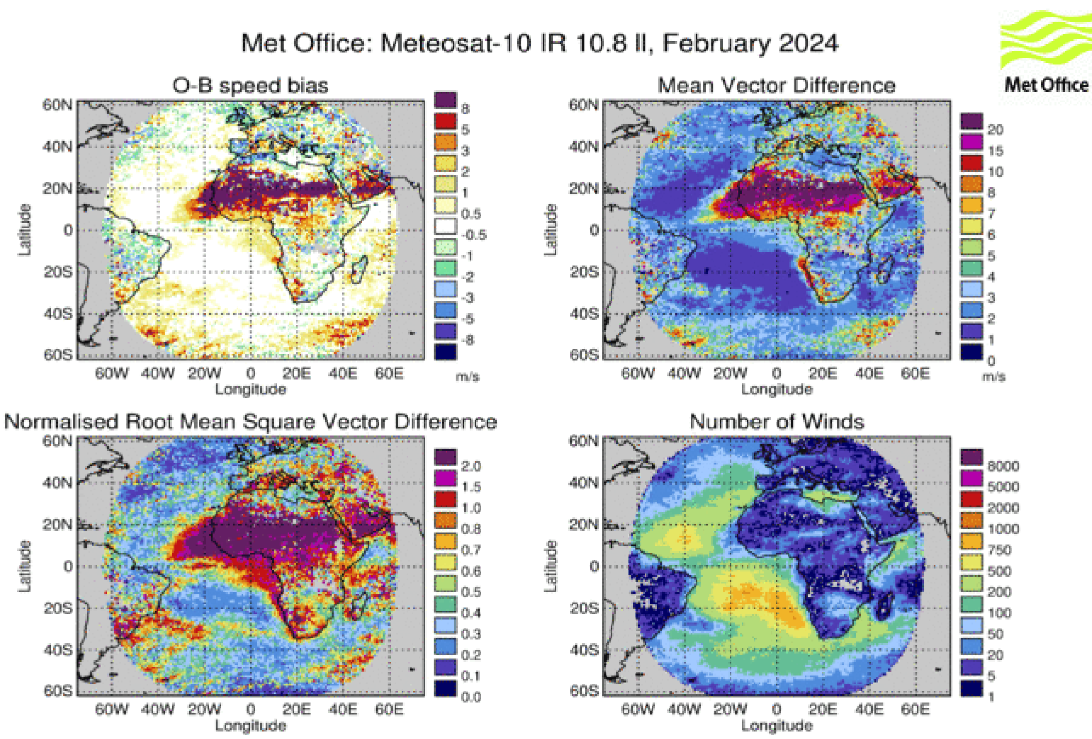


*Figure 14. Map of O-B speed bias, mean vector difference, root mean square vector difference, and AMV counts for Meteosat-10 10.8 µm infrared channel winds below 700 hPa in February 2024.*

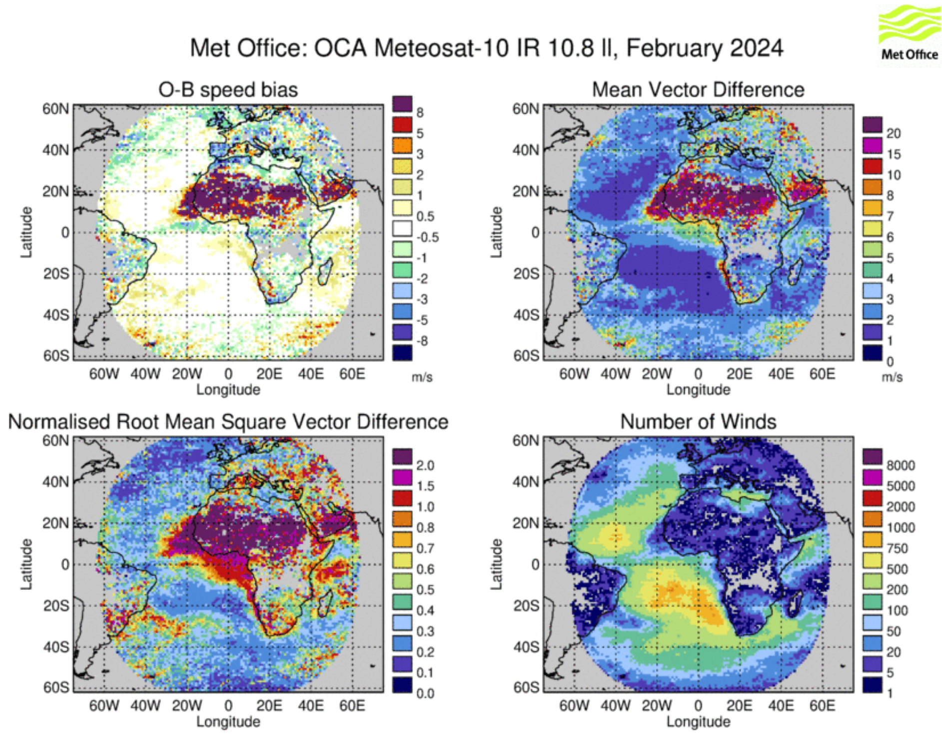


*Figure 15. The same as Figure 14, but using optimal cloud analysis AMV heights.*

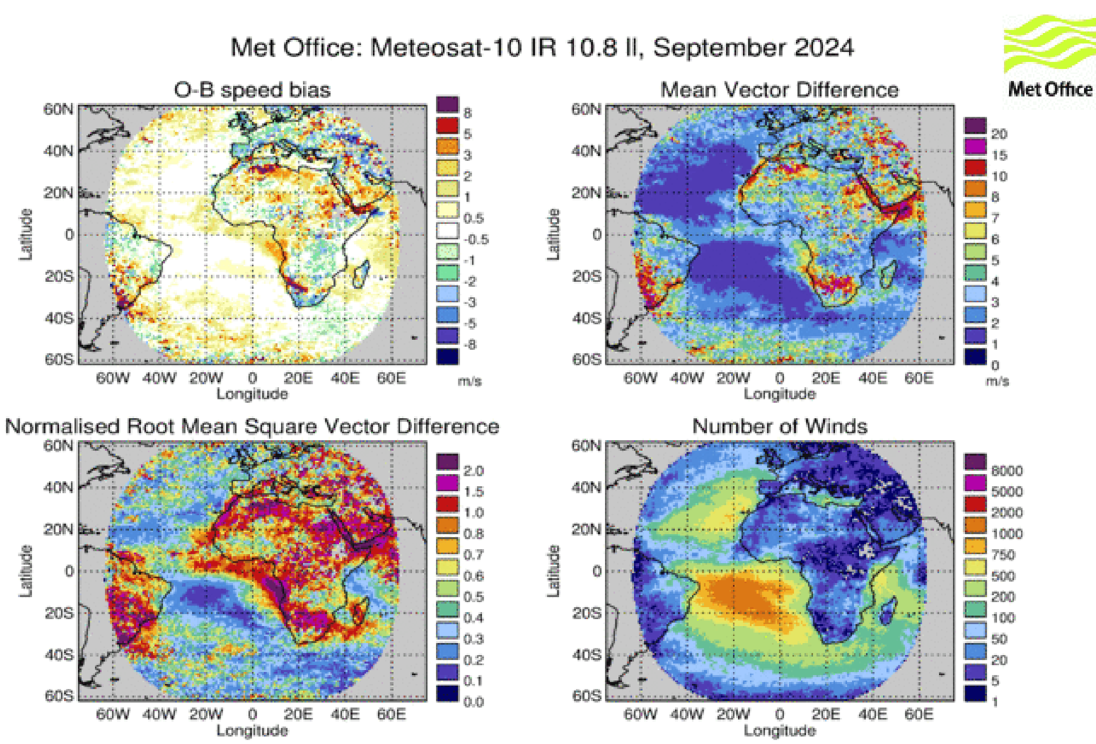


*Figure 16. The same as Figure 14, but for September 2024.*

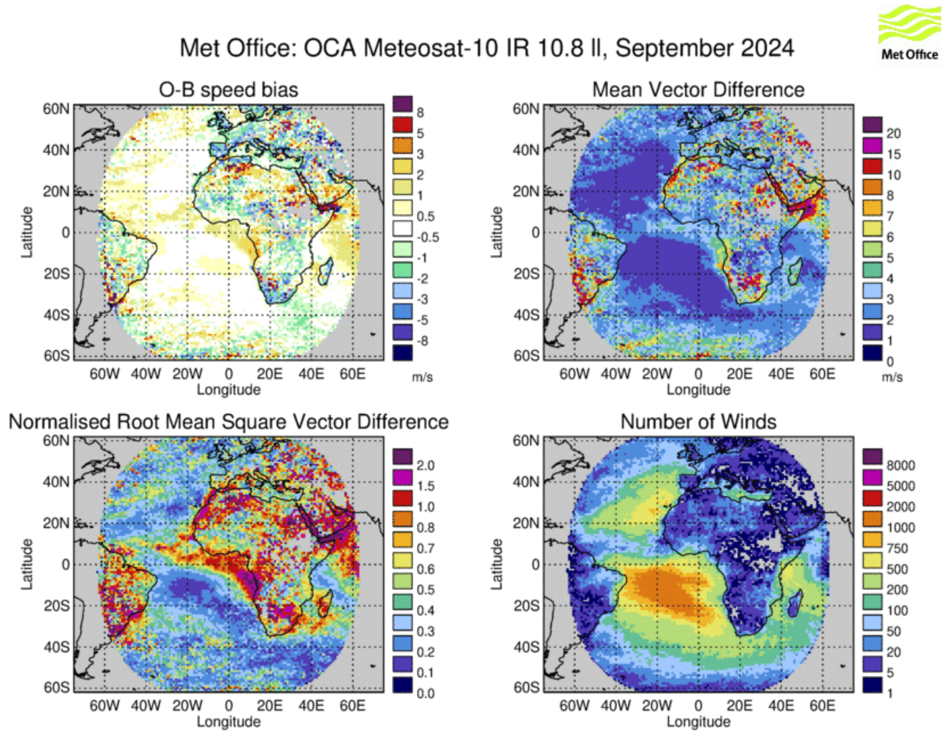


*Figure 17. The same as Figure 14, but using optimal cloud analysis AMV heights for September 2024.*

The impact of OCA can now be confirmed using Meteosat-12 AMVs (Figure 18). As expected from using OCA heights for Meteosat-10, there is a clear improvement in bias for Meteosat-12 over the Atlantic Ocean with an accompanying increase in the number of winds, except for over North Africa where the height assignment errors associated with high-level clouds persists.

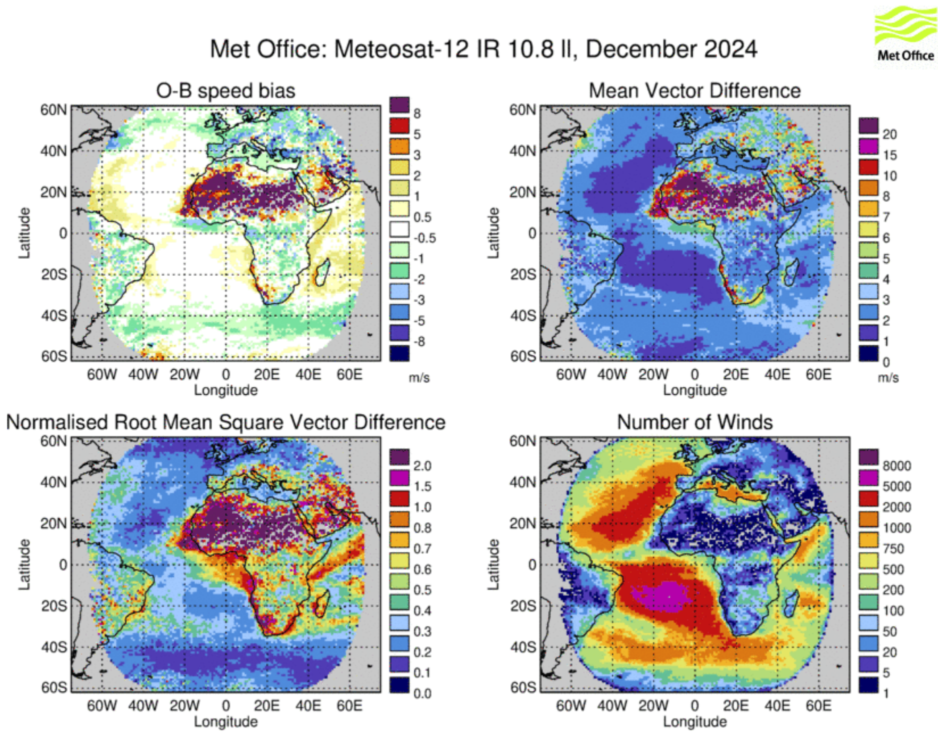


*Figure 18. The same as Figure 13, but for Meteosat-12 (which uses optimal cloud analysis AMV height assignment), for December 2024.*

## 6. Update on Feature 2.13: Positive speed bias in tropics for MSG and FY- 2

*Feature background*

Most satellite-channel combinations show a positive speed bias at high level in the tropics, particularly for the WV channels. In previous ARs, this feature has been linked to tracking and assigning heights to linear cloud tracers, and to height assignment of cloud edges in regions of wind shear. Changes in derivation methods and transitions to newer satellites have altered and reduced this feature bias over time. In AR8, for MSG, OCA height assignments were shown to provide AMVs closer to the model best-fit pressure resulting in reduced O-B biases.

*Update:*

For FY-2, the bias is barely present for WV at high level in the tropics. The bias is generally around zero or negative in the NWP SAF monthly statistics, with only sparse patches of small positive bias (Figure 19). For high-level IR, the positive bias varies month to month, some months are dominated by areas of negative bias with small positive patches, while other months show much stronger positive areas (Figure 20).

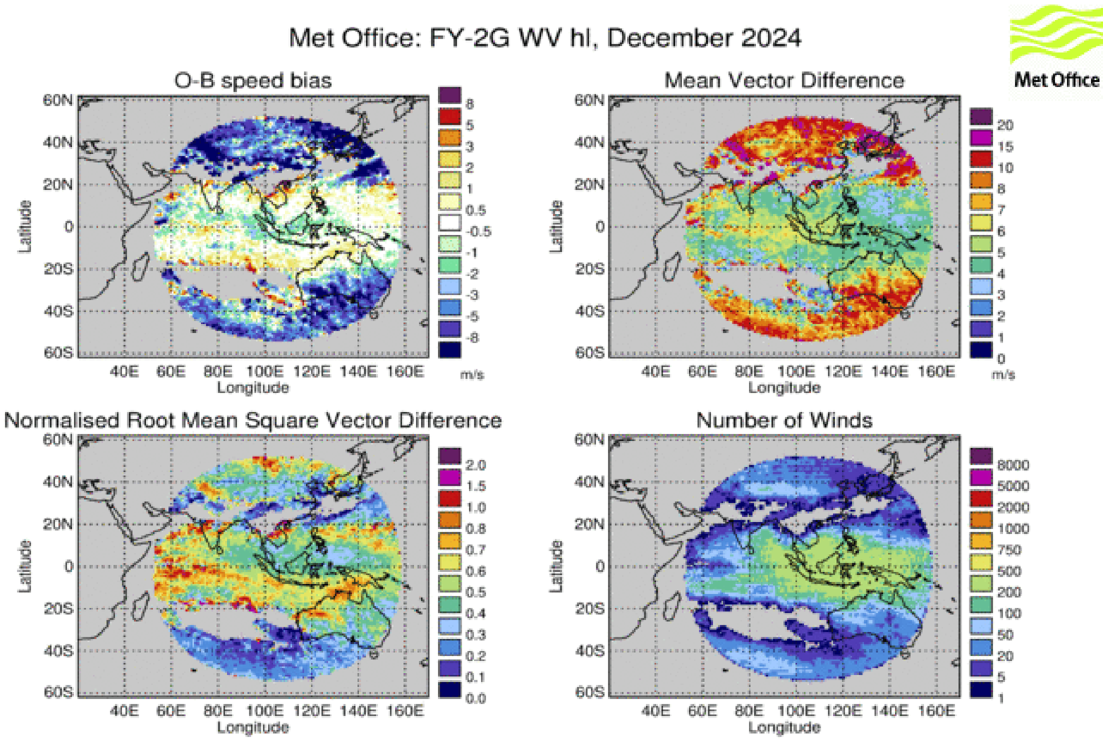


*Figure 19. Map of O-B speed bias, mean vector difference, root mean square vector difference, and AMV counts for FY-2G water vapour channel winds above 400 hPa in December 2024.*

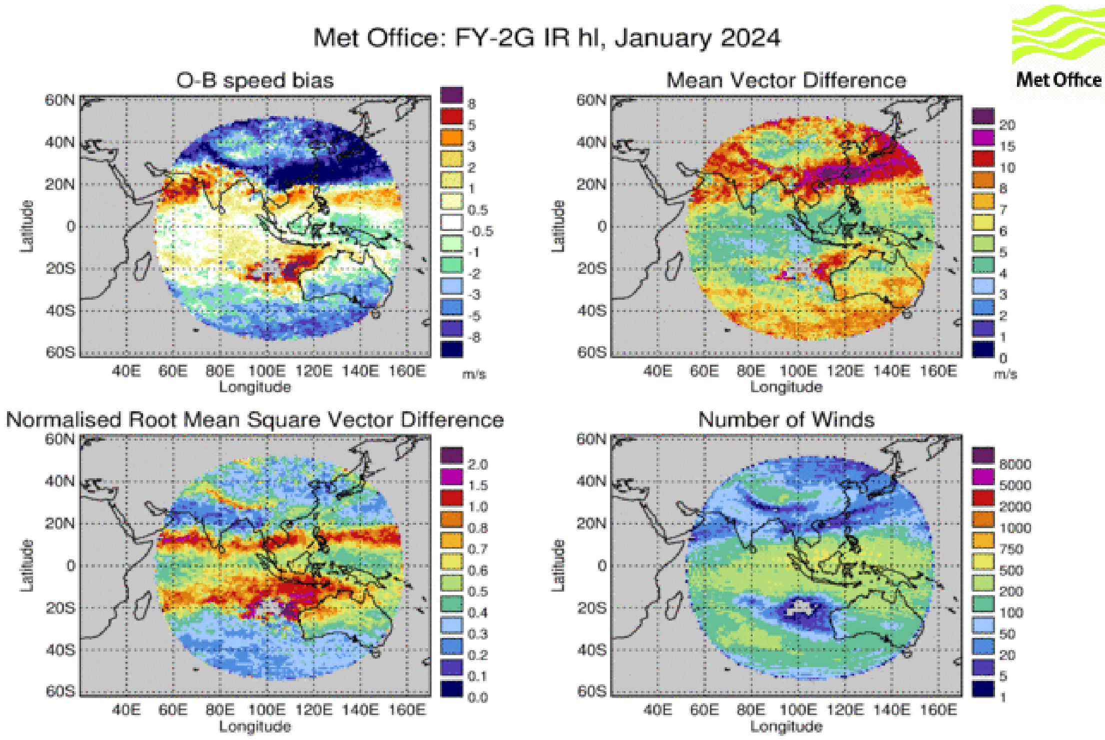


*Figure 20.The same as Figure 19, but for the infrared channel in January 2024.*

CGMS time series for FY-2G WV at high level since 2019 show that overall, the bias has steadily improved in the tropics where it was previously negative (Figure 21). Conversely, high-level IR in the tropics overall shows little change in the CGMS time series since 2019 (not shown).

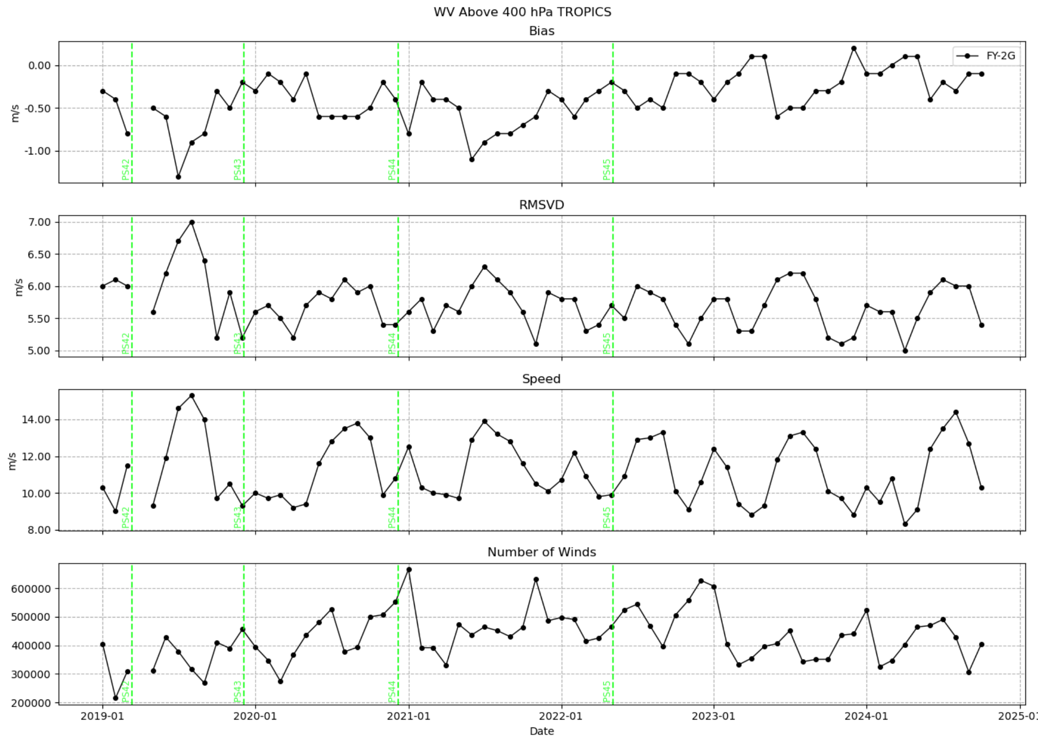


*Figure 21. Coordinate group for meteorological satellites monthly time series statistics of O-B speed bias, root mean square vector difference, AMV speed, and AMV counts for FY-2G (black) water vapour channel winds above 400 hPa, in the tropics from January 2019 to October 2024 inclusive.*

For MSG, the positive bias is still present in the NWP SAF monthly statistics, although the bias is more scattered and less prominent in recent years.

OCA heights were seen to provide an improvement in bias for this feature in AR8. The OCA algorithm has remained unchanged since AR8, but it is useful to examine it again to see if an improvement would still be seen over a longer time period. As for Feature 2.6, we can use the OCA pressures in place of the current CLA pressures when calculating the backgrounds for the Met Office O-B bias statistics.

For Meteosat-10, high-level WV and IR O-B map statistics for February and September 2024 have been produced. The WV statistics for February 2024 for CLA and OCA heights can be seen in Figure 22 and Figure 23 respectively, with additional figures in the appendices.

For the WV 6.2 channel, where this feature is most substantial, there is a noticeable improvement in bias for February and September 2024 when using OCA heights. The positive bias of this feature is reduced, though this is accompanied by a slight increase in areas of negative bias. Effectively reducing the overall bias, bringing it closer to 0. There is an accompanying improvement in the RMSVD.

For the IR 10.8 channel, while some areas of positive bias have reduced and improved this feature, the negative bias has increased more noticeably when using the OCA heights for both February and September 2024.

Overall, both channels show an improvement in bias but the strongest signals of positive bias in the tropics are still present when using OCA heights. There are two points to note on the remaining bias features. Firstly, they are all in areas with a smaller number of winds. Secondly, they are quite linear in shape. As this feature is thought to be partly caused by height assignment of cloud edges in areas of strong wind shear, it may be that OCA heights, while improving the bias, are still struggling in areas of high wind shear. Further investigation into specific instances of positive bias would be useful.

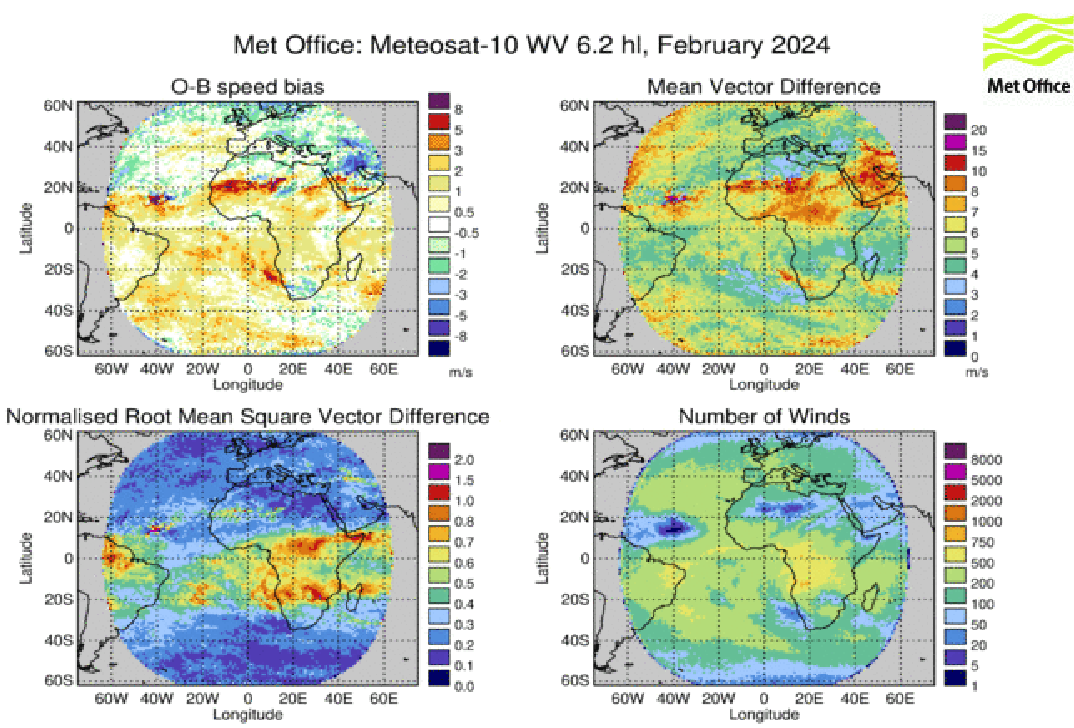


*Figure 22. Map of O-B speed bias, mean vector difference, root mean square vector difference, and AMV counts for Meteosat-10 6.2 µm water vapour channel winds above 400 hPa in February 2024.*

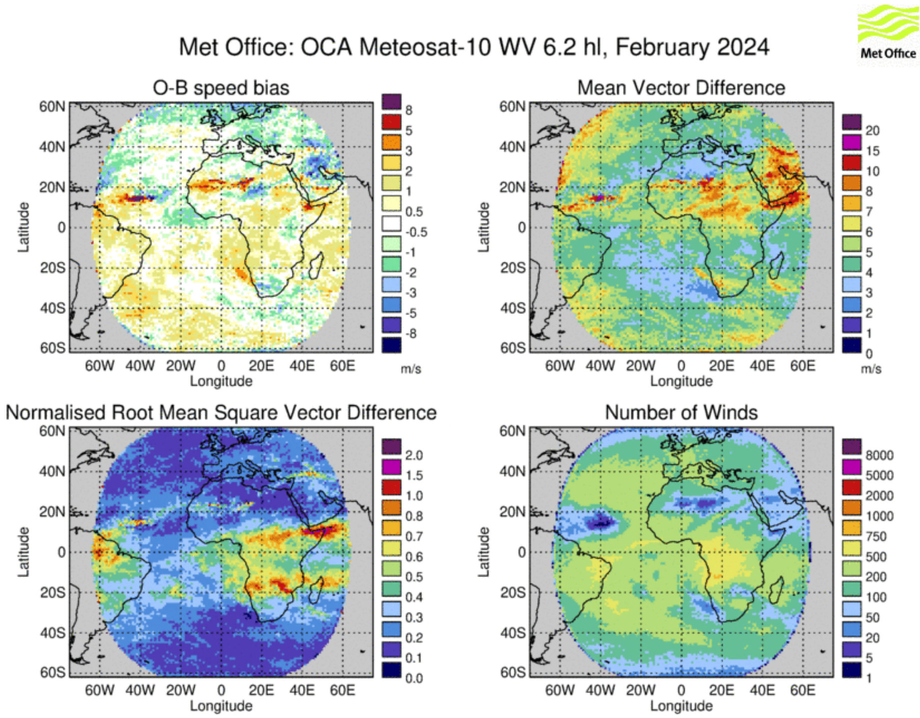


*Figure 23. The same as Figure 22, but using optimal cloud analysis AMV heights.*

## 7. Update on Feature 9.3: Differences between Met Office, ECMWF, and DWD statistics for Himawari

*Feature background:*

Zonal statistics for Himawari-8 have shown noticeable differences between O-B patterns of the ECMWF and Met Office models. ECMWF has smaller mean vector differences at upper levels, while the Met Office has smaller mean vector differences at mid-levels in the tropics. There are differences also in biases at mid-level. The previous investigation in AR9 suggested that while there are differences in the use of Himawari data in data assimilation between the centres, the biases probably reflect wider NWP model difficulties in this area.

*Update:*

The NWP SAF monitoring pages for Himawari-9 zonal statistics over 2023 and 2024 show smaller O-B pattern differences between the Met Office and ECMWF models compared to the differences seen previously for Himawari-8. This is seen for all channels.

The addition of DWD statistics to the monitoring pages shows that there are significant O-B pattern differences between the Met Office and DWD models.

To examine the differences between models more closely for Himawari-9 AMVs, MVD and absolute bias differences between ECMWF and the Met Office, and DWD and the Met Office, have been calculated and plotted for the months of January and July 2024 (Figures 24-27).

Previously, ECMWF in the tropics at mid-levels had larger MVDs than that of the Met Office, this difference now appears to have lessened and is less widespread, particularly for January 2024 (Figure 24).

At higher levels, ECMWF had smaller MVDs than the Met Office, now it has switched to have higher MVDs than the Met Office. Overall, the two models' MVD patterns are now more aligned for Himawari-9, with the Met Office having slightly lower MVDs in areas at higher levels, in parts of the tropics at mid-level, and at low level in the northern hemisphere in January 2024.

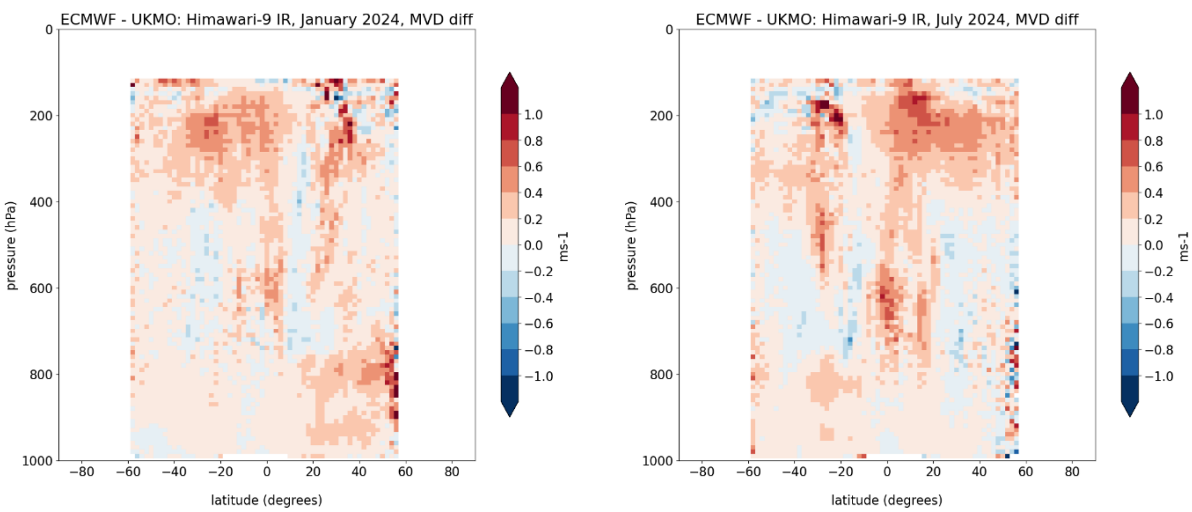


*Figure 24. Zonal O-B mean vector difference differences between ECMWF and the Met Office as a function of latitude and pressure, for Himawari-9 infrared channel AMVs in January 2024 (left) and July 2024 (right).*

Regarding absolute bias differences, similarly to the MVDs, the patterns between ECMWF and the Met Office are fairly aligned for Himawari-9. Unlike the MVDs, there are no clear significant areas where either model has a smaller bias (Figure 25). A small difference in the tropics at mid-level appears to depend on the month as to which model has a smaller bias. With potentially some seasonal dependence hemisphere to hemisphere.

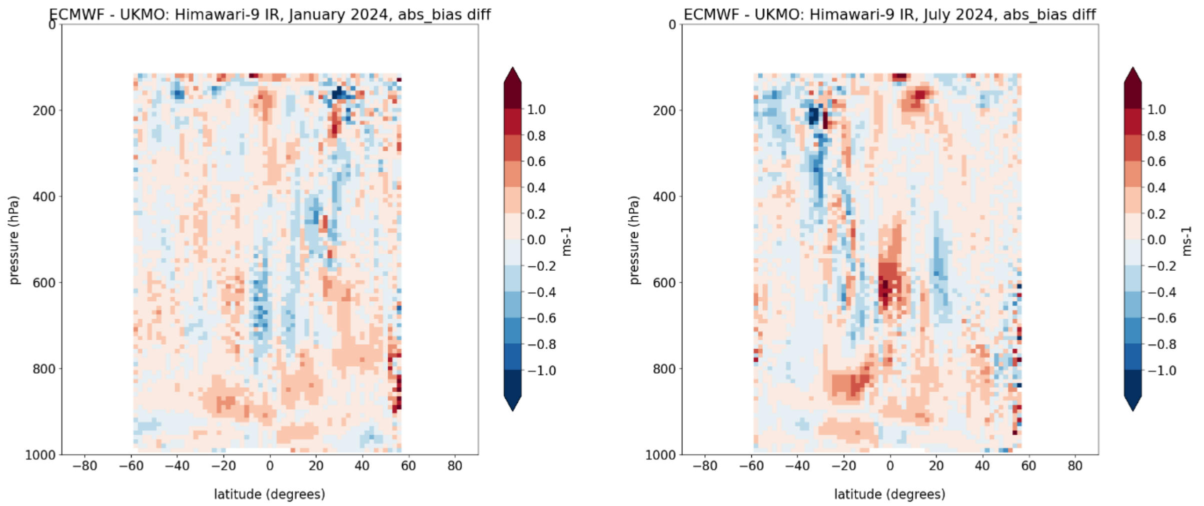


*Figure 25. Zonal O-B absolute speed bias differences between ECMWF and the Met Office as a function of latitude and pressure, for Himawari-9 infrared channel AMVs in January 2024 (left) and July 2024 (right).*

For DWD and the Met Office, the differences are larger and more widespread and are primarily seen in the tropics at mid-level in the IR channel. For monthly statistics in this area, the DWD backgrounds have smaller MVDs than the Met Office, by more than 1 m/s in places. At upper levels, DWD has larger MVDs in the extra-tropics than the Met Office, again by more than 1 m/s in places (Figure 26).

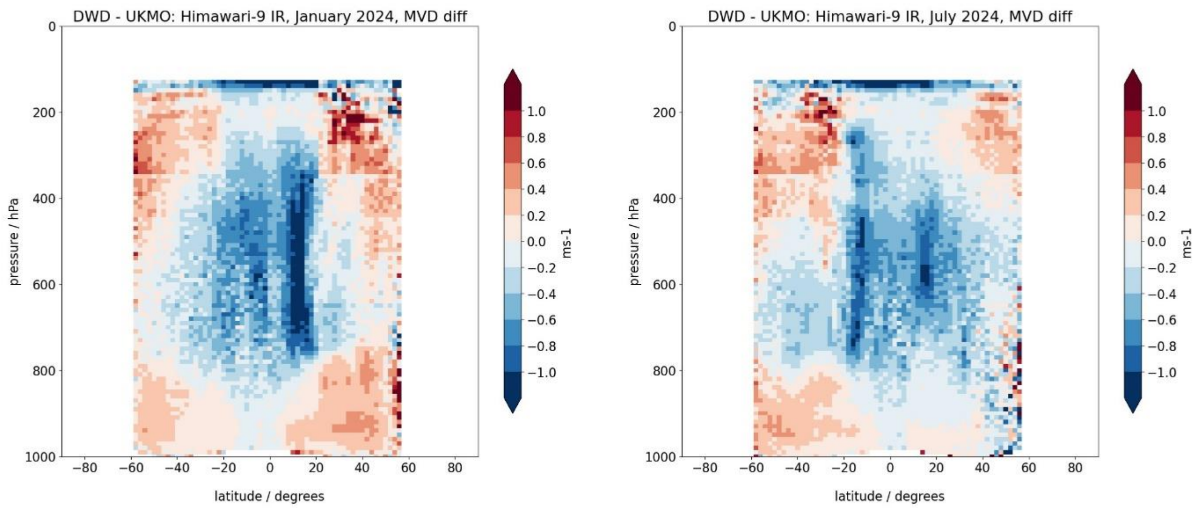


*Figure 26. Zonal O-B mean vector difference differences between DWD and the Met Office as a function of latitude and pressure, for Himawari-9 infrared channel AMVs in January 2024 (left) and July 2024 (right).*

DWD has smaller absolute biases at mid-levels in parts of the tropics, generally in the same areas as the MVD differences but with less coverage (Figure 27). There are well defined bands running through the mid-levels at around 20ºN and 20ºS, for both MVD and absolute bias differences, where the differences can exceed 1 m/s.

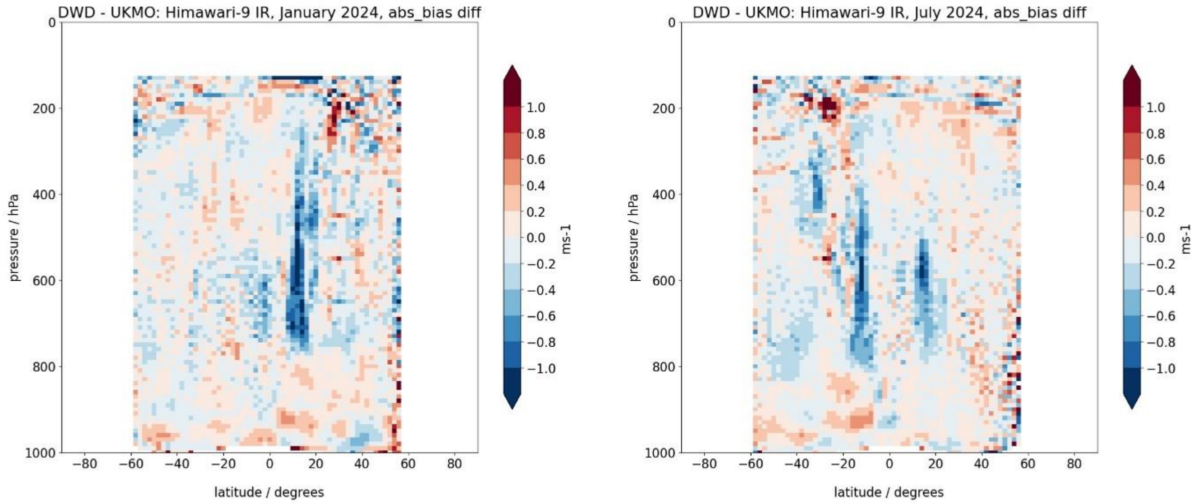


*Figure 27. Zonal O-B absolute speed bias differences between DWD and the Met Office as a function of latitude and pressure, for Himawari-9 infrared channel AMVs in January 2024 (left) and July 2024 (right).*

The presence and strength of the band correspond to the winter hemisphere and follow the divide between the tropics and extra tropics at a latitude of 20ºN/S. O-B map plots for Himawari-9 show some strong negative biases at these locations and months.

These MVD and bias differences could be due to differences in Quality Control (QC) for Himawari-9 data assimilation at the Met Office, ECMWF, and DWD. They could also be due to NWP modelling differences.

**NWP modelling differences**

Both the Met Office and ECMWF have made upgrades to the atmosphere components of their NWP models since AR9 in 2020 when this was previously investigated.

Since 2019, the Met Office have introduced Global Atmosphere (GA) model changes in 3 different Parallel Suites (PS). PS45 included the GC4 (Global Coupled) configuration which reduced smoothing in the orography and led to better near-surface winds. Prior to this, PS43 introduced the Global Atmosphere 7.2 model which saw significant improvements to tropical wind forecasts, among other improvements.

ECMWF made a notable change in 2021 in IFS cycle 47r3 where "Upper-air geopotential and wind in the first few days of the forecast are significantly improved" [10].

From previous Met Office investigations there are known NWP modelling differences in the tropics between ECWMF and the Met Office. Internally it was noted that the differences between ECMWF and Met Office forecast winds are in general largest in the tropics (e.g. MAM 2017 difference in analysed zonal mean u-wind) with the differences increasing with height. There are also temperature/geopotential height differences which are driving these wind differences.

Additionally, ECMWF's "The NWP Impact of Aeolus Level-2B Winds at ECMWF" report [11] compared ECMWF and Met Office analyses at several height levels for u-winds (Figure 12 within the report) which also supports differences in the tropics: "This indicates that systematic differences (and by assumption errors) are larger in the tropics and polar regions than elsewhere (reaching 2 m/s at smaller spatial scales)".

Thus, there are already known NWP modelling differences in the tropics for ECMWF and the Met Office, increasing with height, and we have seen improvements in modelling in the last few years due to NWP model upgrades that may have improved biases and brought the two centres more in line. This is indeed what we are seeing in the zonal plots for this feature since it was last examined.

**CGMS time series statistics**

Looking at the Met Office CGMS time series statistics for Himawari-8 and 9 show that only the tropics have significant trends in bias and RMSVD (Figure 28). Mid and low levels generally show small improvements, but high levels show degradations with increases in bias and RMSVD since 2021. The wind speeds and number of winds remain fairly consistent throughout this time.

Based solely on this increase in bias, one might expect the differences between the Met Office and ECMWF for Himawari to have become worse since 2021. This is not what is being observed in the zonal plots for bias and MVD in 2024, and therefore suggests other factors are of more importance than changes in modelling at the Met Office. The differences for Himawari between the Met Office and DWD are not known for 2021 nor historically as a point of comparison.

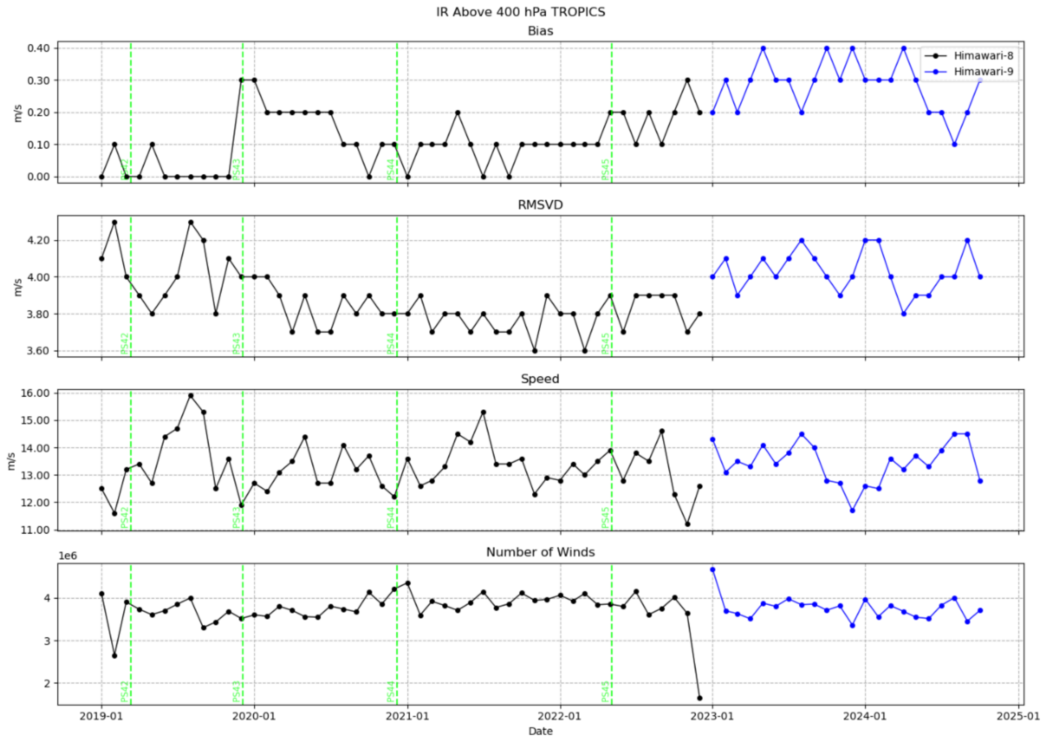


*Figure 28. Coordinate group for meteorological satellites monthly time series statistics of O-B speed bias, root mean square vector difference, AMV speed, and AMV counts for Himawari-8 (black) and Himawari-9 (blue) infrared channel winds above 400h Pa in the tropics, from January 2019 to October 2024 inclusive.*

In AR9, this feature was examined for March and October 2019. Comparing the CGMS RMSVD between 2019 and 2024, there is not much difference. There is as much variability throughout the year, so modelling changes at the Met Office may not have had a noticeable effect on this feature when compared between 2019 and 2024.

For the bias however, following the implementation of PS43 in November 2019 there is a large increase at high level in the tropics. This might suggest larger differences between the Met Office and ECMWF than there were in 2019, but this is not what we see in the zonal plots, again suggesting the differences in zonal statistics are not due to the Met Office model changes alone.

**Data assimilation experiment**

An experiment has been run using the Met Office deterministic model for the month of June 2021. Three experiments have been run with different quality control configurations for Himawari-8, emulating some of the key differences between modelling centres. This experiment provides some indication of the degree to which this feature is caused by differences in DA QC, while ignoring differences in the physical model.

*Differences applied in experiment*

The assimilation of Himawari winds at the Met Office and ECMWF is described on the NWP SAF pages at https://nwp-saf.eumetsat.int/site/monitoring/winds-quality-evaluation/amv/amv-use-in-nwp/. Information for DWD was provided by email.

In the control experiment, the Met Office configuration was used. Table 4 details the differences in QC that were considered in the ECMWF and DWD assimilation experiments.

*Table 4. The differences in quality control considered in the ECMWF and DWD data assimilation experiments, including the Met Office quality controls used in the control experiment. The key differences are highlighted in bold.*

| QC / *Experiment* | *Met Office* | *ECMWF* | *DWD* |
|---|---|---|---|
| Channels accepted | IR, VIS, cloudy WV 6.9 | IR, VIS, cloudy WV 6.9 | IR, VIS, cloudy WV **6.2/6.9/7.3** |
| QI2 threshold | 70 | 70 | **85** (simplification of actual thresholds which vary by height and location) |
| Upper limit | 160 hPa in tropics, 200 hPa in extra-tropics (polewards of 20N/S) | **150 hPa** | **None** |
| Land rejections | IR, VIS below 600 hPa over land north of 20N | All below 500 hPa over land<br><br>All over land in region north of 20 N and east of 100 E | All over land in the extra tropics (outside 20S-20N), |
| Tropics rejection | None | **IR winds below 300 hPa in the tropics (25N-25S)** | None |
| WV lower limit | 400 hPa | 400 hPa | 400 hPa (WV 6.2), **700 hPa** WV 6.9/7.3 |

*Reference zonal plots*

Figure 29 shows the existing zonal plots for June 2021, the month selected for the data assimilation experiment. The same pattern seen in historic differences (e.g. 2019) between ECMWF and the Met Office Himawari-8 zonal statistics can be seen with the higher MVD in the tropics at mid-level for ECMWF, and the lower MVD in the higher level and extra tropics. The band at very high level is also clearly visible in MVD differences.

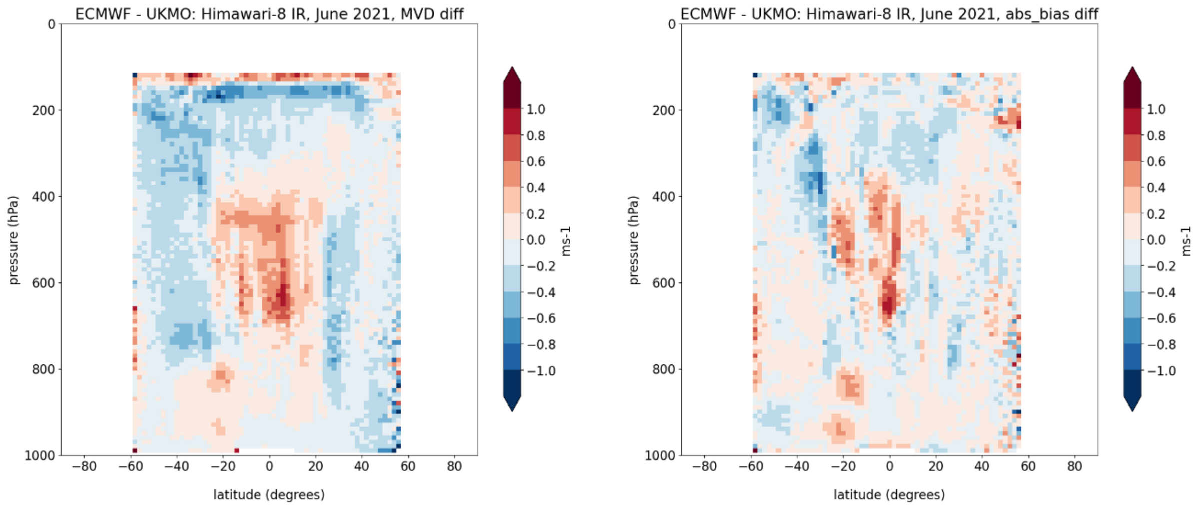


*Figure 29. Zonal O-B statistics differences between ECMWF and the Met Office as a function of latitude and pressure, for Himawari-8 infrared channel AMVs in June 2021. With mean vector difference (left) and absolute speed bias (right).*

The Met Office CGMS time series statistics for IR (all regions and levels) show that this month, June 2021, was very similar to January and July 2024 in terms of bias and RMSVD (time series statistics not shown).

*Experiment results*

The zonal plots of MVD and absolute bias difference have been produced from the experiments for the month of June 2021 (Figure 30). The first week of the month has been ignored to account for the model spinning up, so the plots are for the period 8$^{th}$ June 2021 – 30$^{th}$ June 2021 inclusive.

For the UKMO (ECMWF QC) – UKMO MVD difference plot, there is a positive difference in the tropics at mid-level. This would seem to confirm that the tropical rejection (removal of Himawari winds below 300 hPa in the tropics) by ECMWF leads to higher MVDs for ECMWF in this area. In the Met Office experiment, the assimilation of Himawari AMVs in this area result in an improved analysis fit, and the short-range forecast then fits closer to the Himawari AMVs in the next assimilation cycle (reducing the O-B). Thus, the QC differences in this area appear to lead to the corresponding differences observed in the O-B plots.

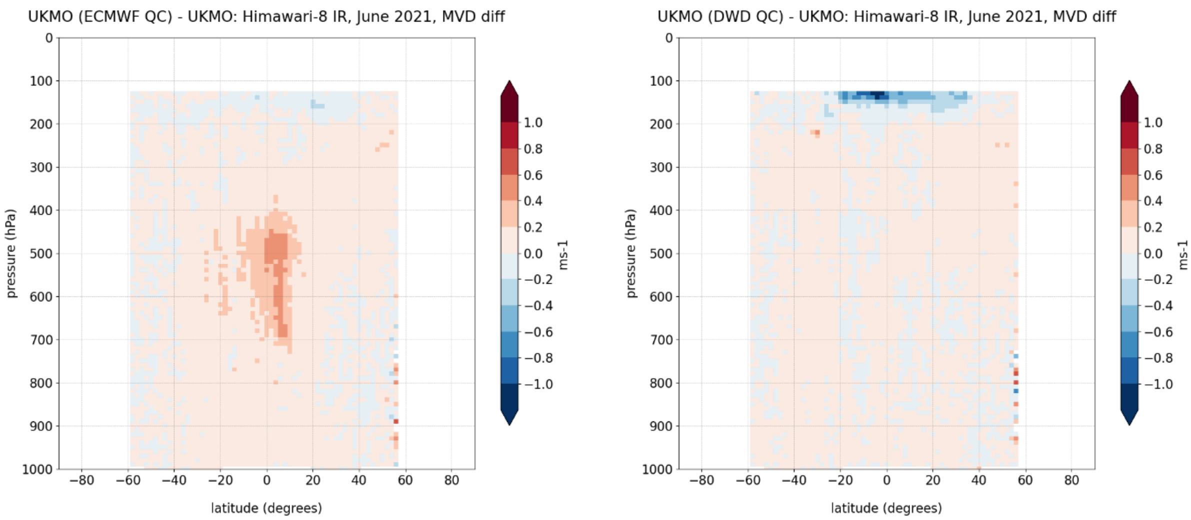


*Figure 30. Zonal O-B mean vector difference differences for QC experiments between ECMWF QC and the Met Office (left), and DWD QC and the Met Office (right), as a function of latitude and pressure, for Himawari-8 infrared channel AMVs in June 2021.*

For UKMO (DWD QC) – UKMO, the MVD difference plot has a negative difference at very high levels. This is expected and indicates that the lack of pressure limits for Himawari winds in DWD QC at high levels is causing smaller MVDs for DWD and is leading to the high-level differences in the O-B plots. However, it looks like the additional WV channels do not have an effect for DWD. So, the differences between the Met Office and DWD are more of a model difference.

Overall, QC differences between the Met Office and ECMWF look to be the cause of the O-B differences in the tropics for Himawari, but this does not explain the differences in the extra tropics at high level. The high-level and extra tropical differences between ECMWF and the Met Office have changed and improved since 2021 and are thus likely to be due to NWP modelling differences, which have also changed over the past few years. Similarly, for DWD, the main O-B differences look to be associated with differences in NWP modelling. If possible, it would be beneficial to repeat the experiments for a more recent time period, given that the ECMWF – Met Office MVD differences have changed significantly since 2021.

## 8. Feature 11.1: Horizontal lines below 800 hPa in zonal plots for EUMETSAT satellites

This feature is present in the Met Office, ECMWF, and DWD zonal plots for Meteosat 9, 10, and 11, in channels IR 10.8, VIS 0.8, and HRVIS. These lines are due to the inversion height correction applied in the EUMETSAT processing for MSG, both before and after the Cross-Correlation Contribution (CCC) method was introduced [12] [13]. This results in the striping seen in the zonal plots of the counts, and to some degree in the O-B stats (Figure 31 and Figure 32).

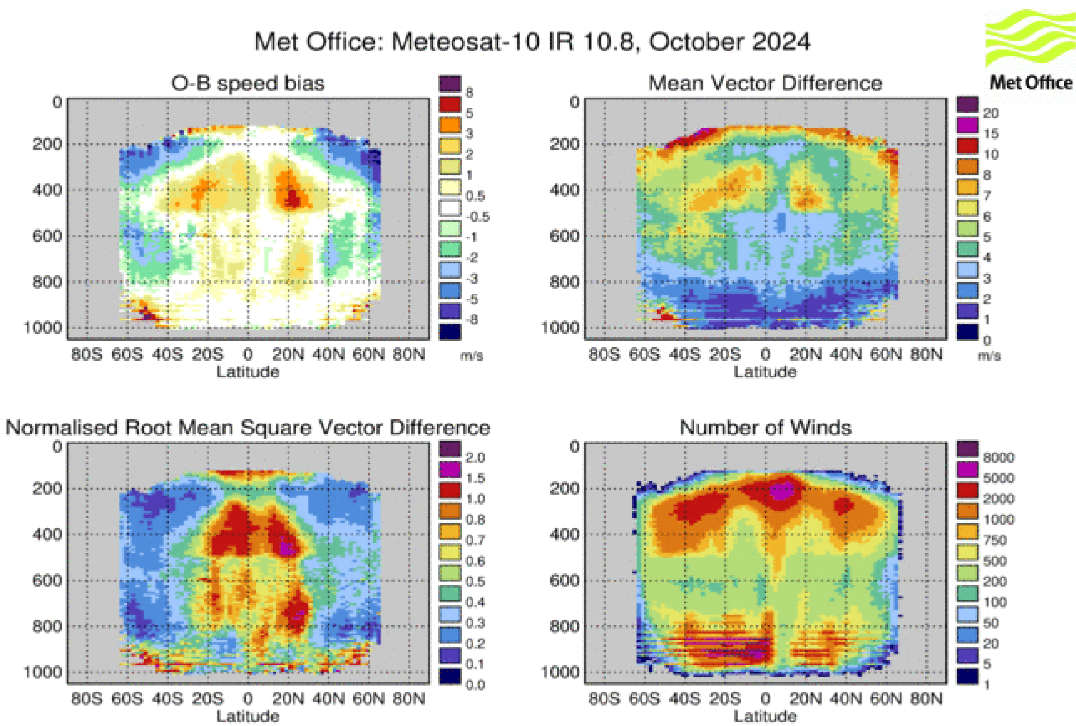


*Figure 31. Zonal O-B statistics as a function of latitude and pressure (hPa), showing speed bias, mean vector difference, root mean square vector difference, and AMV counts for the Meteosat-10 10.8 µm infrared channel in October 2024.*

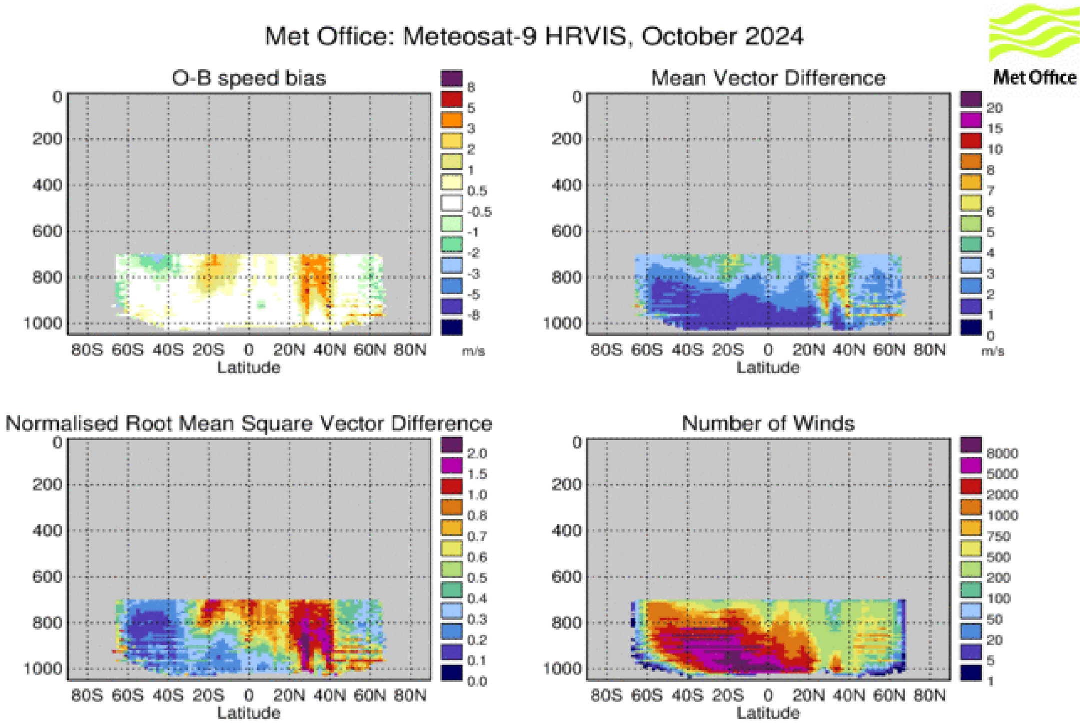


*Figure 32. The same as Figure 31, but for the Meteosat-9 high resolution visible channel.*

## 9. Features 11.3 and 11.4: INSAT widespread positive bias

INSAT-3DR, and INSAT-3D historically, show widespread positive bias at low and high levels, the features have been numbered as 11.3 and 11.4 respectively. The bias is most prominent for the IR channel over the Indian Ocean in the tropics and the southern hemisphere.

At low level, the widespread positive bias is of the order 1-2 m/s in the IR channel over the tropics and southern hemisphere. At high level, the bias is of the order 1-2 m/s in both the IR and WV channels over the tropics and southern hemisphere, occasionally extending into the northern hemisphere. The positive biases are clearly shown in the NWP SAF monitoring O-B map statistics (Figure 33 and Figure 34).

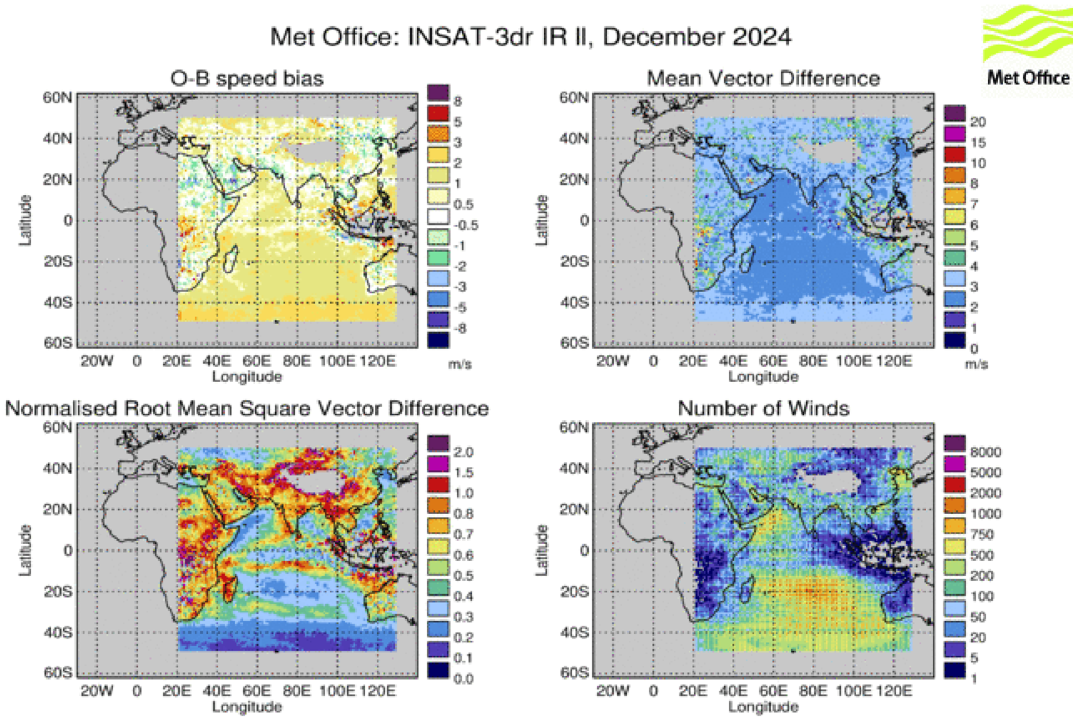


*Figure 33. Map of O-B speed bias, mean vector difference, root mean square vector difference, and AMV counts for INSAT-3dr infrared channel winds below 700 hPa in December 2024.*

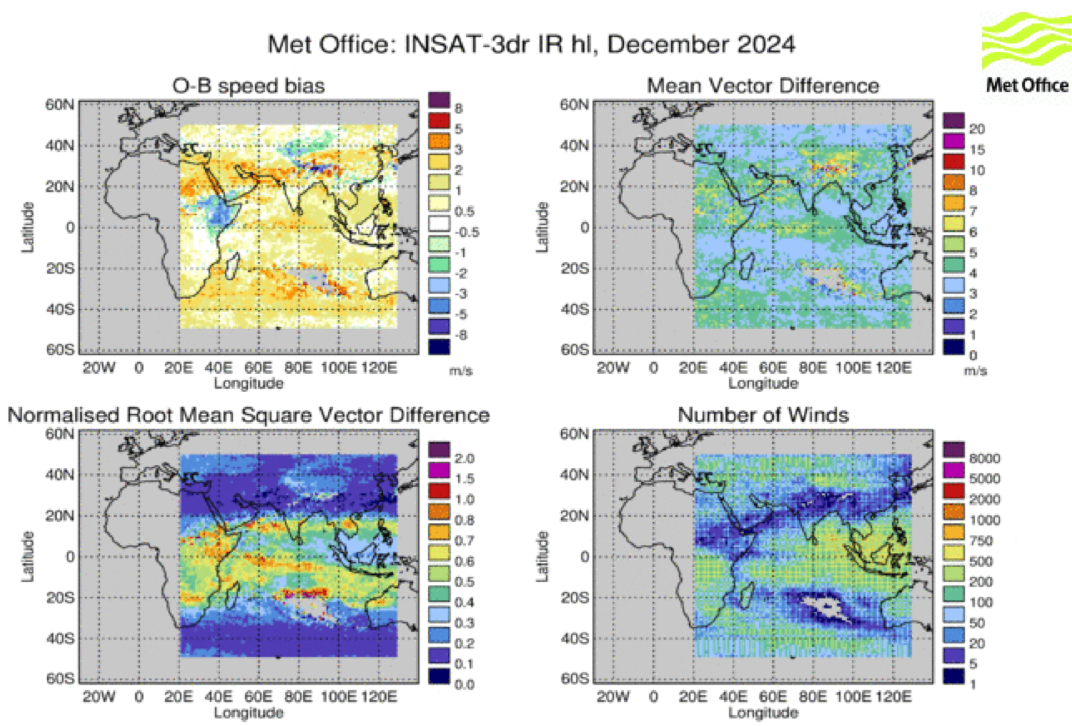


*Figure 34. The same as Figure 33, but for winds above 400 hPa.*

CGMS time series statistics indicate this positive bias has been present since 2020 (Figure 35). In most channel-region combinations the increased bias corresponds to a large increase in the number of winds which occurred in September 2020. The RMSVD remains consistent throughout this time.

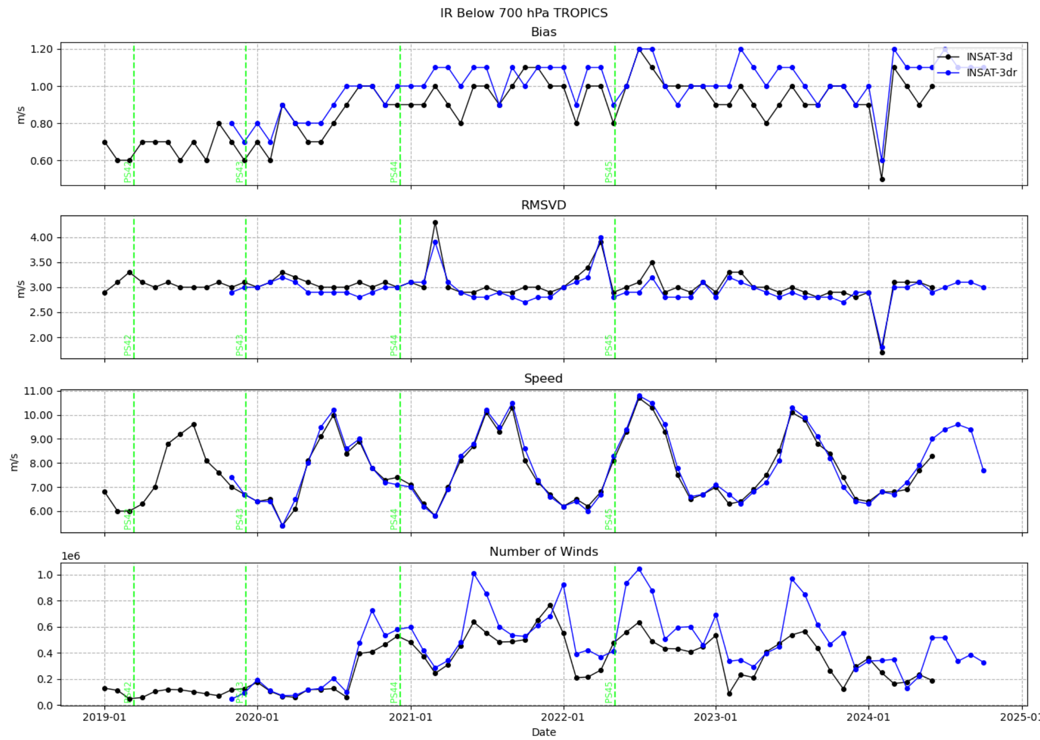


*Figure 35. Coordinate group for meteorological satellites monthly time series statistics of O-B speed bias, root mean square vector difference, AMV speed, and AMV counts for INSAT-3d (black) and INSAT-3dr (blue) infrared channel winds below 700 hPa in the tropics, from January 2019 to October 2024 inclusive.*

The reason for this historical increase in the number of winds is unknown. However, this feature and the increase in winds in 2020 has been communicated to INSAT and is under investigation.

## 10. Summary

This paper marks the eleventh iteration of the analysis reports for the NWP SAF AMV monitoring. The status of existing features identified in the monitoring has been updated to reflect changes in the past two years. Four previously active features are now considered closed, predominantly due to satellites reaching end of life.

Several new data sets have been added to the monitoring since AR10. These include the addition of DWD backgrounds, NOAA-21 VIIRS AMVs, and Meteosat-12 AMVs. Alongside these new data sets there have been changes in derivation methods including the rollout of NOAA's enterprise algorithms and the use of OCA heights and MTG algorithm with Meteosat-12. Additionally, EUMETSAT have rearranged their geostationary satellites, with Meteosat-9 taking over from Meteosat-8 for IODC coverage, and Meteosat-10 swapping with Meteosat-11 for 0 degrees coverage.

Further investigation for some existing and new features has expanded our understanding of the cause of the difference between the AMVs and the model:

*Feature 2.6: MSG positive bias over North Africa*

The use of OCA heights was explored for this feature but the bias over land remained present. This highlights the current limitations of OCA in correctly identifying thin high-level cirrus clouds, and filtering them out in multilayer cloud situations, especially over bright surfaces such as the Sahara.

*Feature 2.13: Positive speed bias in tropics for MSG and FY-2*

The bias for FY-2 is barely present now. The use of OCA heights was explored for MSG, which showed improvements in bias except for some small areas of strong positive bias where there are smaller numbers of winds, and potentially an issue in assigning heights for cloud edges in areas of high wind shear.

*Feature 9.3: Differences between Met Office, ECMWF, and DWD statistics for Himawari*

The addition of DWD statistics to the NWP SAF monitoring pages has shown that it also has differences from the Met Office O-B for Himawari as well as ECMWF. Zonal statistics show this feature has lessened for ECMWF and the Met Office. The impact on this feature from differences in QC were explored through data assimilation experiments. Differences between ECMWF and the Met Office in the tropics were found to be impacted largely by QC differences but less so in the extra tropics. Differences between DWD and the Met Office overall were not found to be impacted by QC differences other than at very high level. Differences that are not shown to be impacted by QC are likely to be caused by differences in NWP modelling between modelling centres.

*Feature 11.1: Horizontal lines below 800 hPa in zonal plots for EUMETSAT satellites*

This feature was added for completeness. These lines have been visible for many years and the cause is understood to be the inversion height correction applied in the EUMETSAT processing for MSG.

*Feature 11.2: Change in O-B statistics above/below 500 hPa in GOES zonal plots*

This feature is a consequence of NOAA's enterprise algorithm changes, despite many positive improvements. The feature appears to be caused by the enterprise algorithm's cloud phase check during quality control, where the dominant cloud type is checked above and below 500 hPa.

*Feature 11.3 and 11.4: INSAT widespread positive bias*

This feature occurs at both high and low levels and has been present for some time. CGMS time series statistics revealed that the increased bias corresponded to a large increase in the number of winds in September 2020. The cause of this increase is under investigation.

It is hoped the findings of this report will be useful to AMV producers seeking to improve aspects of the AMV derivation schemes, as well as for NWP centres in improving the assimilation and impact of the data. Feedback on the cases investigated in this report are welcome via the NWP SAF helpdesk.

**Acknowledgements**

ECMWF statistics are routinely provided thanks to Mohamed Dahoui.

DWD statistics are routinely provided thanks to Meiko Volknandt.

Thanks to James Cotton for routinely generating the monthly monitoring plots and maintaining the AMV section of the NWP SAF website.

Additional thanks to Francis Warrick, Mohamed Dahoui, and Meiko Volknandt.

## References

[1] "Meteosat series," 2024. [Online]. Available: https://www.eumetsat.int/our-satellites/meteosat-series.

[2] K. Barbieux and R. Borde, "An Investigation of the Reasons behind the Biases in the Tropical and Extratropical Atmospheric Motion Vectors Derived from EUMETSAT Low Earth Orbit Satellite Data," *Remote Sensing Letters,* vol. 14, no. 6, pp. 620-30, June 2023.

[3] K. Barbieux and R. Borde, "A New Paradigm for the Derivation of LEO AMVs Without Wind Guess," 9 May 2023. [Online]. Available: https://www.ssec.wisc.edu/meetings/iwwg/2023-meeting/presentations/a-new-paradigm-for-the-derivation-of-leo-amvs-without-wind-guess/.

[4] NOAA, "NOAA-21 satellite is now operational," 8 November 2023. [Online]. Available: https://www.noaa.gov/news-release/noaa-21-satellite-is-now-operational.

[5] "Europe's most advanced weather satellite is now fully operational," 4 December 2024. [Online]. Available: https://www.eumetsat.int/europes-most-advanced-weather-satellite-now-fully-operational.

[6] "Flexible Combined Imager," 2024. [Online]. Available: https://www.esa.int/Applications/Observing_the_Earth /Meteorological_missions/meteosat_third_generation/Flexible_Combined_Imager.

[7] J. Daniels, J. Key, W. Bresky, A. Bailey, R. Allegrino, S. Wanzong, J. Carr, H. Madani, C. Velden, D. Stettner, D. Santek, R. Dworak and J. Apke, "Status of the Development of Atmospheric Motion Vector (AMV) Capabilities at NOAA," 8 May 2023. [Online]. Available: https://www.ssec.wisc.edu/meetings/iwwg/2023-meeting/presentations/status-of-development-of-atmospheric-motion-vectors-amv-capabilities-at-noaa/.

[8] A. Bozzo, P. Watts, L. Spezzi, M. Carranza, R. Borde, J. Jackson, O. Hautecoeur, A. Lattanzio and M. Doutriaux-Boucher, "Improving the reliability of AMV height assignments: a study using ABI cases of the IWWG intercomparison and OCA cloud properties retrievals," in *Sixteenth International Winds Workshop*, Montréal, 2023.

[9] A. Bozzo, M. Doutriaux-Boucher, J. Jackson, L. Spezzi, A. Lattanzio and P. D. Watts, “First Release of the Optimal Cloud Analysis Climate Data Record from the EUMETSAT SEVIRI Measurements 2004–2019,” *Remote Sensing,* vol. 16, no. 16, p. 2989, 2024.

[10] ECMWF, “Forecast upgrade improves moist physics and use of satellite observations,” ECMWF, 12 October 2021. [Online]. Available: https://www.ecmwf.int/en/about/media-centre/news/2021/forecast-upgrade-improves-moist-physics-and-use-satellite .

[11] M. Rennie and L. Isaksen, “The NWP Impact of Aeolus Level-2B Winds at ECMWF,” ECMWF, 2024.

[12] M. Carranza, R. Borde and M. Doutriaux-Boucher, “Recent Changes in the Derivation of Geostationary AMVs at EUMETSAT,” in *Twelfth International Winds Workshop Presentation*, Copenhagen, 2014.

[13] M. Carranza, R. Borde and M. Doutriaux-Boucher, “Recent Changes in the Derivation of Geostationary Atmospheric Motion Vectors at EUMETSAT,” in *Twelfth International Winds Workshop*, Copenhagen, 2014.

[14] A. Bailey, ““GOES enterprise test data” NOAA email,” 2023.

# Appendices

## CGMS statistics

The CGMS statistics presented in this report are O-B differences, where the background is the Met Office global model. Statistics shown are for winds with QI > 80 for IR and WV winds, QI > 65 for visible winds, and QI > 50 for clear sky WV winds (EUMETSAT-recommended thresholds). Derivation of statistics are as outlined in Report from the Working Group on Verification Statistics, Proc. Conf. 3rd Int. Winds Workshop, p. 17, Ascona, Switzerland, 10-12 June 1996, EUMETSAT, Darmstadt.

## Feature 2.13 additional figures

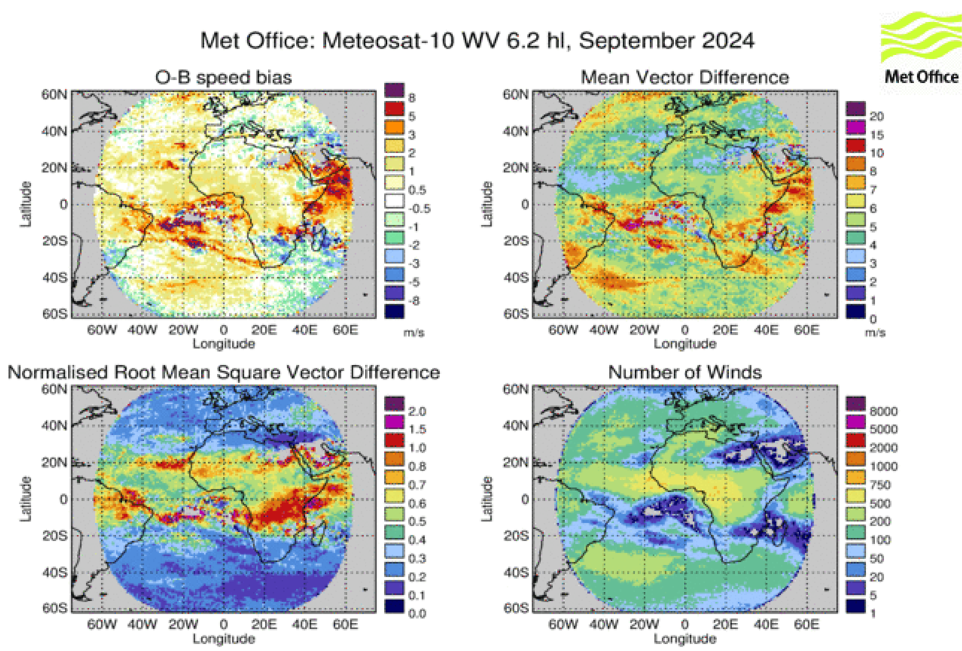


*Figure 36. Map of O-B speed bias, mean vector difference, root mean square vector difference, and AMV counts for Meteosat-10 6.2 µm water vapour channel winds above 400 hPa in September 2024.*

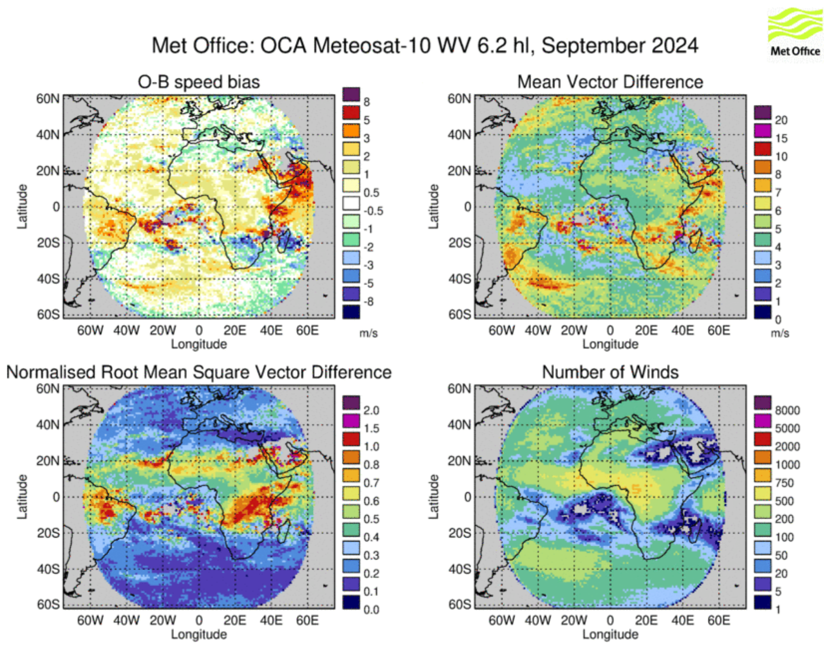


*Figure 37. The same as Figure 36, but using optimal cloud analysis AMV heights.*

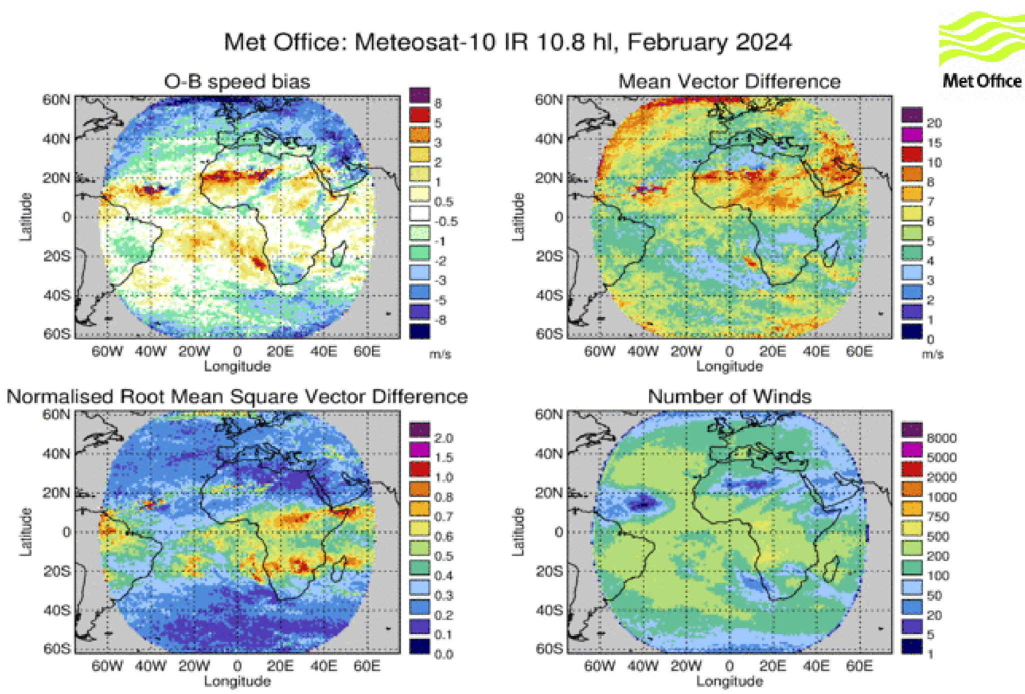


*Figure 38. Map of O-B speed bias, mean vector difference, root mean square vector difference, and AMV counts for Meteosat-10 10.8 µm infrared channel winds above 400 hPa in February 2024.*

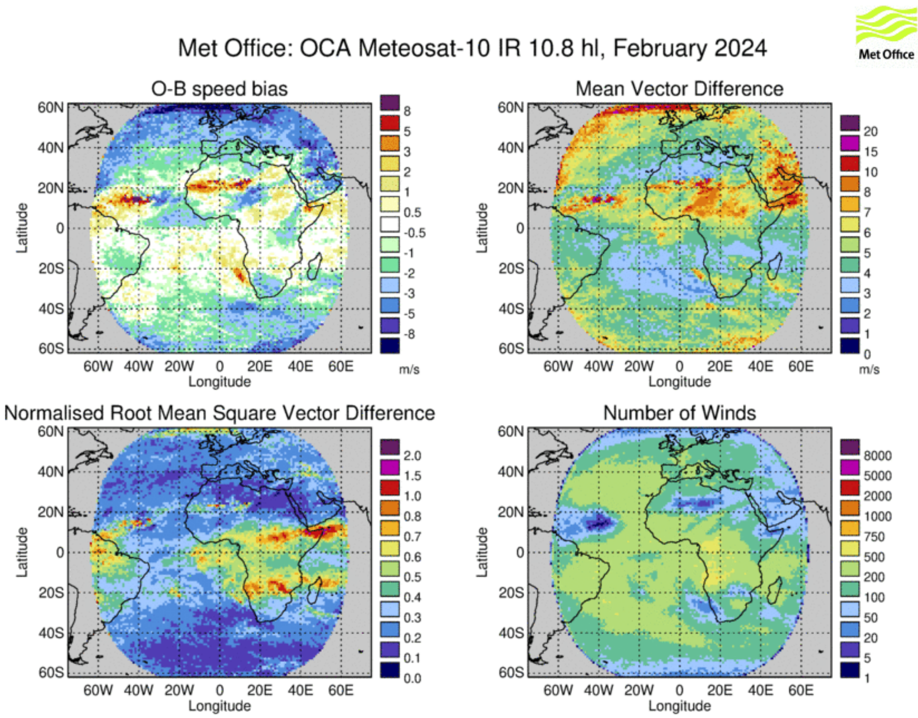


*Figure 39. The same as Figure 38, but using optimal cloud analysis AMV heights.*

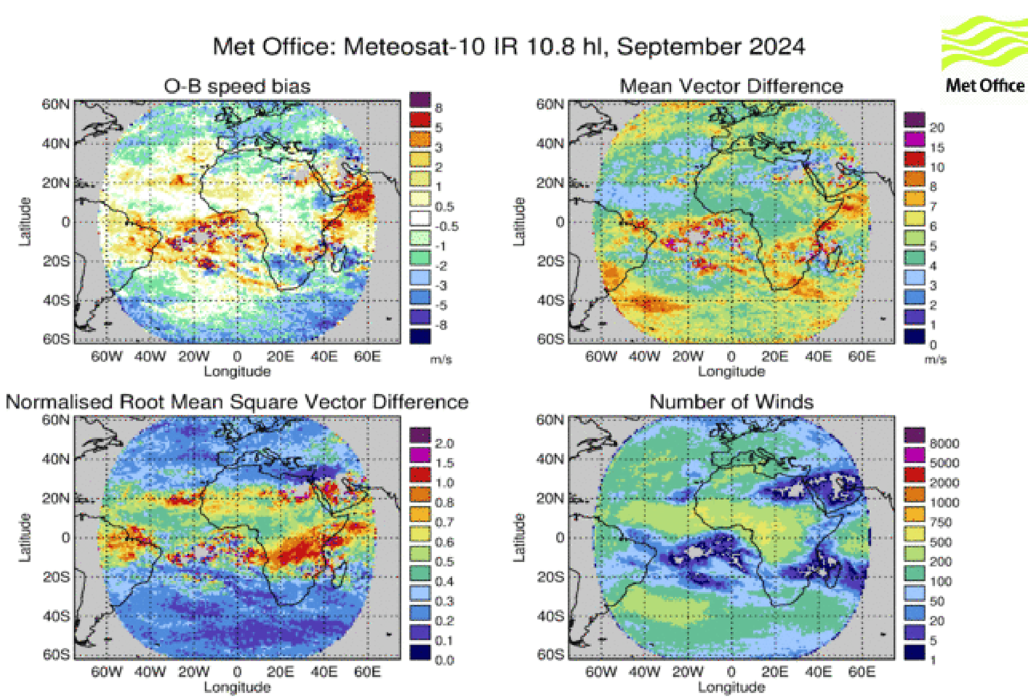


*Figure 40. The same as Figure 38, but for September 2024.*

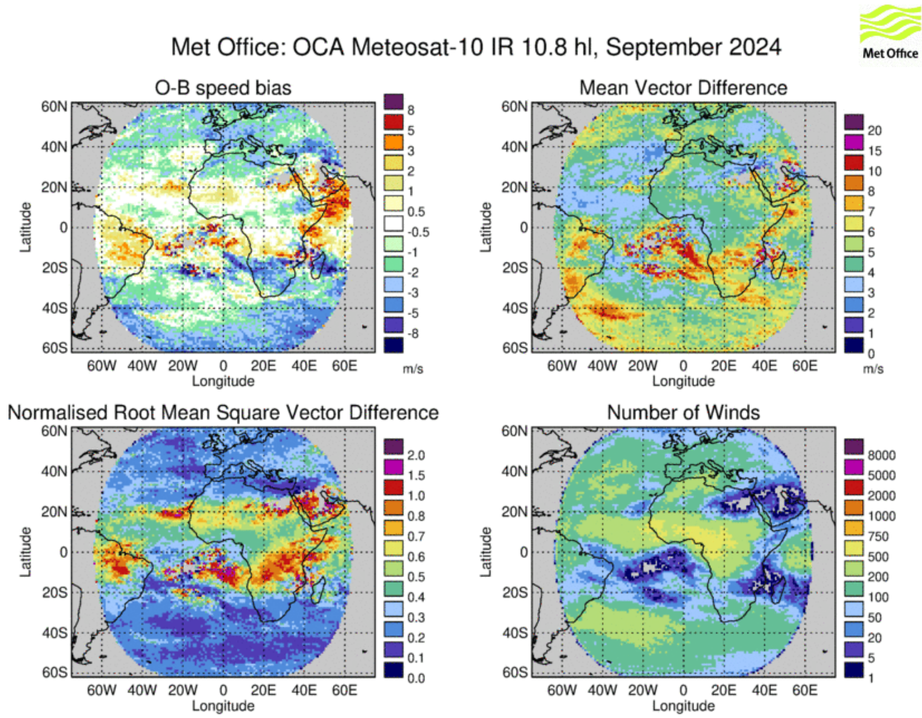


*Figure 41. The same as Figure 38, but for September 2024 using optimal cloud analysis AMV heights.*