Global Mode-S aircraft winds improving low latitude forecasts

Bruce Ingleby. *bruce.ingleby@ecmwf.int*

ex-Research Department, ECMWF, Reading, United Kingdom

ECMWF @ 50

December 2025, Reading

Overview

ECMWF started assimilating dense Mode-S aircraft winds over Europe in 2020. In October 2024 Global Mode-S data became available and they were tested over a 3.5 month period together with thinning changes. There are clear benefits between 60°S and 60°N especially at low latitudes and the change became operational on 8th May 2025.

Mode-S aircraft data

The Mode-S meteorological reports are produced from Air Traffic Control messages at EMADDC in the Netherlands as described by de Haan et al (2025). For EMADDC Met Office Global Mode-S data see https://www.emaddc.com/participate/data+users/emaddc-met-office-global/default.aspx. ECMWF started assimilating European Mode-S winds during the Covid lockdowns (Ingleby et al, 2021) and since then aircraft numbers have almost recovered. Two years later we found that the Mode-S density in central Europe was causing problems and the data were switched off for a year whilst the aircraft usage was changed to use box thinning (Ingleby, 2025). Figure 1 shows a timeseries of aircraft observation numbers over the last five years.

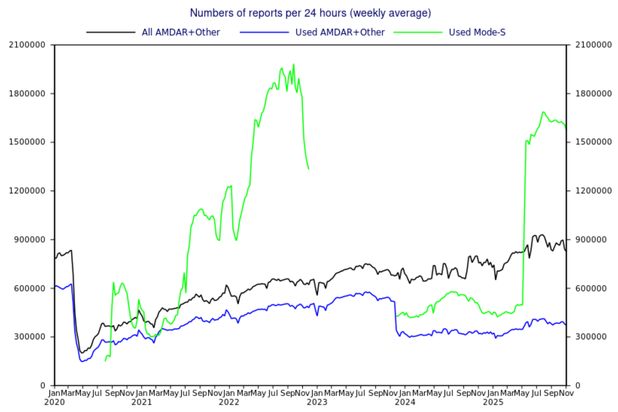


Figure 1. Numbers of aircraft wind reports per day at ECMWF. Black line: total number excluding Mode-S. Blue line: used number excluding Mode-S. Green line: used Mode-S (operational, from May 2025 both European and global Mode-S are used).

Figure 2 shows vector wind RMS observation-minus-background (O-B) at 200 hPa for European+Global Mode-S data in 1x1 degree boxes (there is less coverage in the lower troposphere, many profiles above airports do not extend to the ground depending on receiver distribution). There are points in Eastern Europe with large RMS due to GPS jamming and intermittent problems south-east of Iceland (now resolved). There are relatively large RMS values in parts of the tropics due to deep convection and also the sparsity of other wind observations. Figure 3 shows latitude-pressure cross sections, the RMS is largest at high levels in the tropics and is slightly larger in southern than northern mid-latitudes. Wind quality is similar to that of AMDARs although there are some subtle features due to a need for a heading correction in the processing (Ingleby, 2025).

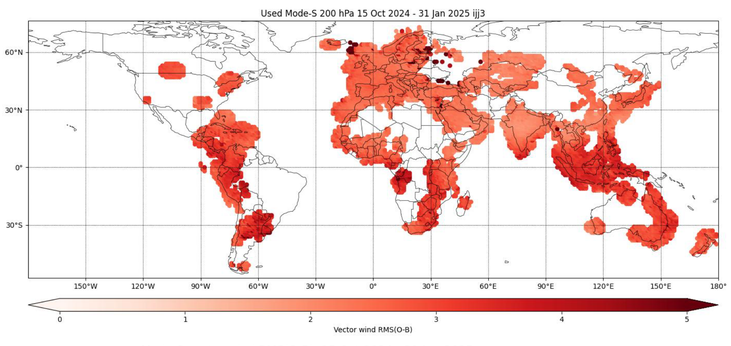


Figure 2. RMS vector wind O-B (m/s) at 200 hPa in 1 degree boxes, 15 Oct 2024 to 31 Jan 2025.

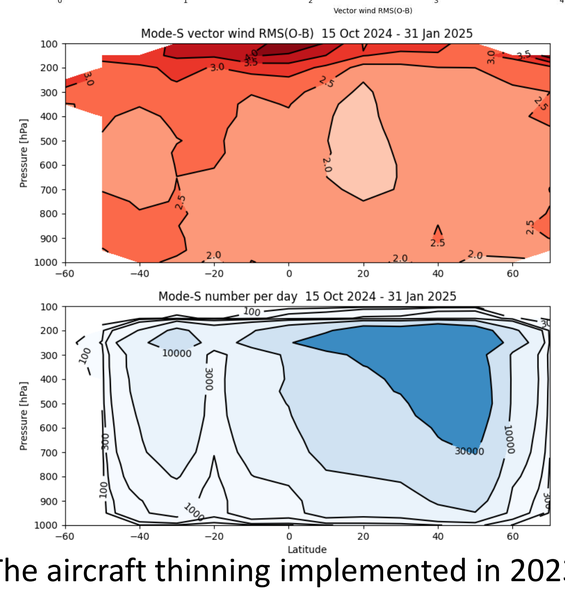


Figure 3. Top: RMS vector wind O-B (m/s) calculated in 50 hPa and 10 degree latitude boxes, 15 Oct 2024 to 31 Jan 2025.

Bottom: Mean number of used Mode-S reports per day calculated in the same boxes.

The aircraft thinning implemented in 2023 considers all aircraft types together, because the same aircraft can report in several different formats. There was an unsuccessful attempt to give highest preference to AMDAR and lowest to Mode-S. Since then a version has been written with preference selection working and also an option to have different box sizes at different pressure levels – based on diagnostic results in Ingleby (2025). For the Global Mode-S tests several versions were tested, the best has a low-level box size of 44 km increasing to 95 km at 200 hPa. This is the version implemented operationally. Changes were also made to allow the processing of WindBorne balloon reports (treated as aircraft data because they include level flight as well as ascents/descents).

Impacts

The trials were from 15 October 2024 to 31 January 2025 using IFS 49r1. Figure 4 shows a scorecard for different regions for this period. The results are overwhelmingly positive (blue). The negative scores vs own analyses at short range in the tropics are partly an artefact because the analyses are not independent (results against observations and operational analyses are positive in the tropics). The results for Europe are neutral because the control included European Mode-S data. The Asian results are very good.

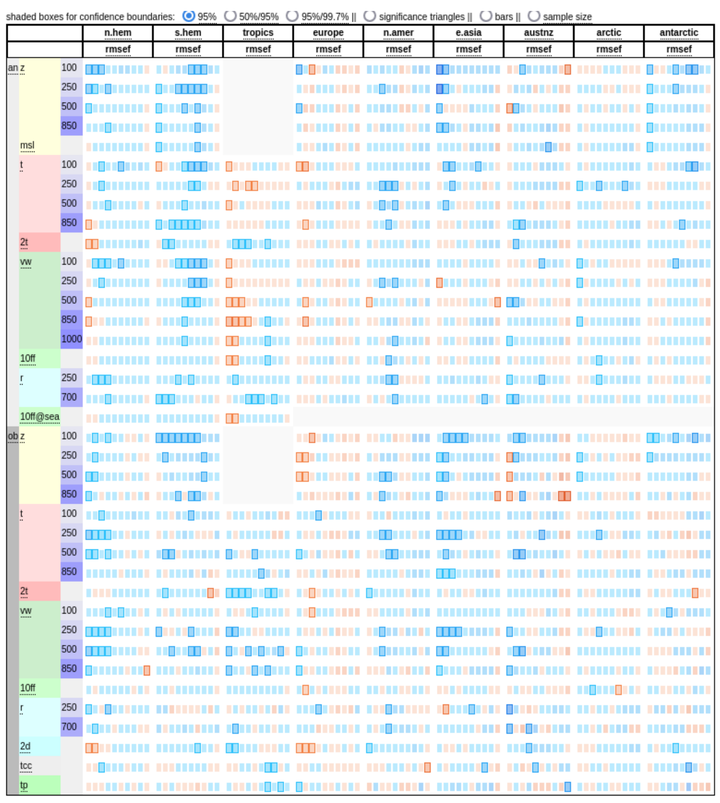


Figure 4. Scorecard for experiment assimilating Global Mode-S winds, plus aircraft thinning change. Blue indicates improvements, orange degradations. Top half vs own analyses, bottom half vs observations. Each row of 10 boxes represents days 1 to 10. Highlighted boxes are significant at the 95% level. The tropics covers 20S-20N; n.hem and s.hem cover 20-90°

Figure 5 shows the T+12 improvement in vector wind RMS fit to AMDAR aircraft winds: largest (up to 8%) in the tropics, but also up to 4% at 30°S. Figure 6 shows an estimate of operational forecast impact – the aircraft timeseries shows a large increase in May 2025.

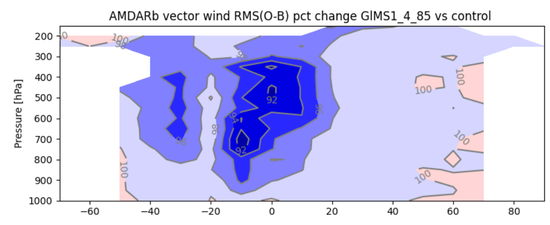
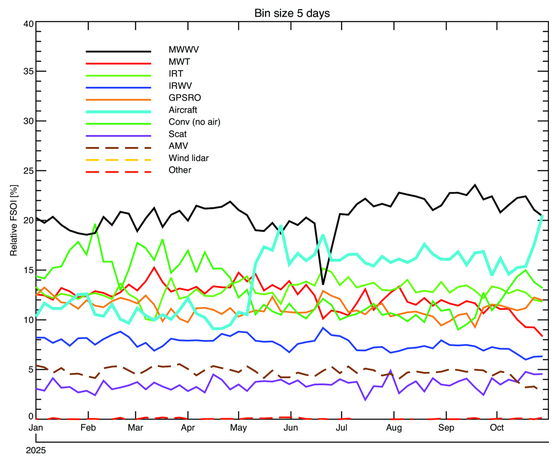


Figure 5. Percentage change in 12-hour forecast fit to AMDAR winds relative to control.

Figure 6. Operational FSOI timeseries for 2025 (courtesy A Geer). This provides an estimate of the impact of different observation types on 24 h forecasts. In May the aircraft FSOI jumped by 5 or 6% and aircraft are now ranked second.



Summary

Whilst not fully global the Global Mode-S data represent a huge opportunity, particularly the winds in the tropics, to improve weather forecasts. Thanks are due to the Met Office and EMADDC (KNMI) for making them available. With such dense data care is needed to thin the observations appropriately (and possibly in the future to model observation error correlations). The Met Office (Warren et al) and MeteoFrance are expected to start assimilating Global Mode-S operationally in 2026.

Ongoing longer-term work is looking at the possibility of using GNSS altitude data from aircraft (hardly reported at present in AMDAR) to improve the forecasts. Evidence suggests that GNSS altitude is more accurate than aircraft pressure altitude, so in principle it would be better to assimilate variables like wind and temperature as a function of height rather than pressure.

References

De Haan S. et al 2025: EMADDC: high volume, high quality and timely wind and temperature observations from aircraft surveillance data (Mode-S EHS) https://amt.copernicus.org/articles/18/3341/2025/

Ingleby, B. et al 2021: The impact of COVID-19 on weather forecasts: A balanced view. Geophysical Research Letters, 48, e2020GL090699. https://doi.org/10.1029/2020GL090699

Ingleby, B. 2025: The benefits and challenges of using dense Mode-S aircraft winds at ECMWF. QJRMS http://doi.org/10.1002/qj.70032

Warren et al 2025: Assimilation of European and Global Mode-S Observations into the Met Office Global Deterministic NWP Model (QJRMS, under review)

Also https://www.ecmwf.int/en/forecasts/quality-our-forecasts/monitoring-observing-system