ECMWF use of Mode-S winds and changes to aircraft thinning

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Overview

High resolution Mode-S aircraft data over Europe were introduced in August 2020, earlier than planned because of the Covid pandemic. Their use was switched off in Nov 2022, because we found that locally the density was too high making the forecasts worse.

The problem was first noted via poor observation fit to analysis statistics over central Europe. The 'track thinning' used was not sufficient with the many 100s of flights over Europe. Instead 'box thinning' was adapted for aircraft use and tested, initially for Mode-S data and then for all aircraft data. The results are encouraging and the short-range benefits of using Mode-S winds over Europe are again clear in the T+12 fit to European radiosondes. The benefit is largest (up to 6 or 7%) for upper tropospheric wind, but is also substantial for temperatures. We hope to reintroduce Mode-S data operationally soon.

Aircraft numbers

Figure 1 shows the numbers of aircraft reports assimilated from January 2020 onwards. Numbers dropped by about 75% in mid-March 2020 (Ingleby et al, 2021) and have largely recovered since, although this hides regional variations: see black and blue lines, excluding Mode-S. The Mode-S data are processed by EMADDC, part of KNMI, in the Netherlands (de Haan, 2011). ECMWF started using about 5% of the Mode-S winds in late July 2020, the numbers have fluctuated (green line) but soon exceeded all other aircraft data, especially in summer 2022. Figure 2 shows the coverage of used data over Europe for a 30-minute period, even with revised thinning it is dominated by Mode-S data where the receivers exist.

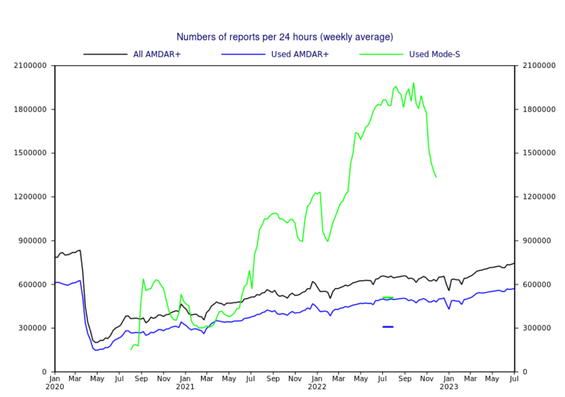


Figure 1. Global aircraft numbers reported (black) and used (blue), excluding Mode-S. Used Mode-S numbers in green.

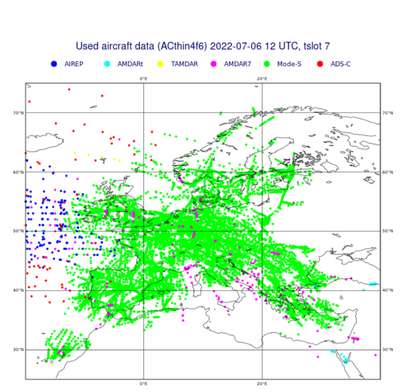


Figure 2. Locations of used aircraft data for a 30-minute period in July 2022.

Changes to aircraft thinning

Figure 3 shows a map of SD(O-A) for Mode-S in August 2022. Instead of the values being relatively constant, as expected there is a marked maximum in central Europe where the density is highest. This triggered an investigation. Profiles of rms(O-A) and rms(O-B) for this region are shown in figure 4. We should have rms(O-A) < rms(O-B) but this is violated for the research experiment (top right) and to a lesser extend in operations (top left) which has higher horizontal resolution and an extra outer loop. With the revised thinning (bottom right) the system becomes well behaved again.

The original thinning was performed on individual aircraft tracks, but this became completely inadequate when faced with 100s of flights over central Europe. It was replaced by box thinning that considers all aircraft data together. After trying various values the boxes used for Mode-S and AMDAR are 0.6 deg horizontally and 20 hPa in the vertical. For other aircraft data, mainly at cruise level over the ocean 0.4 deg boxes are used

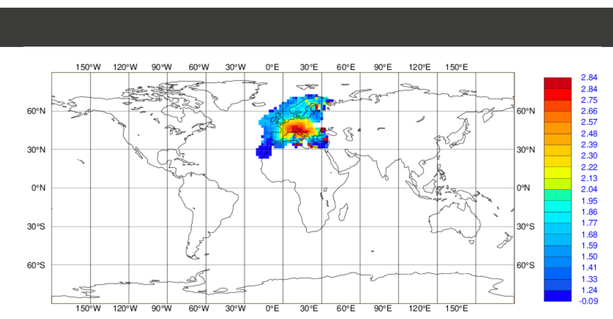


Figure 3. The standard deviation of windspeed analysis departure (O-A) for Mode-S at ~200 hPa, August 2022. (From ECMWF monitoring website.)

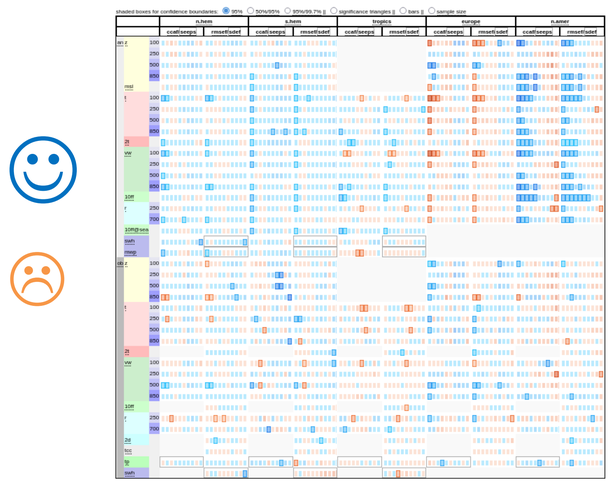


Figure 5. Scorecard June-August 2022. Revised thinning vs noModeS. Each row of rectangles represents scores for days 1 to 10.

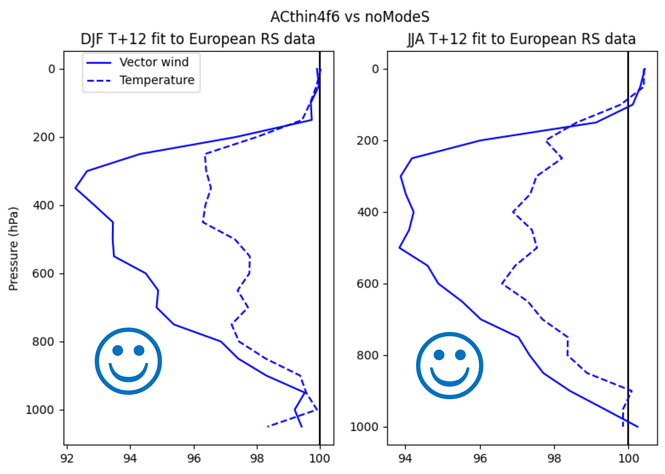
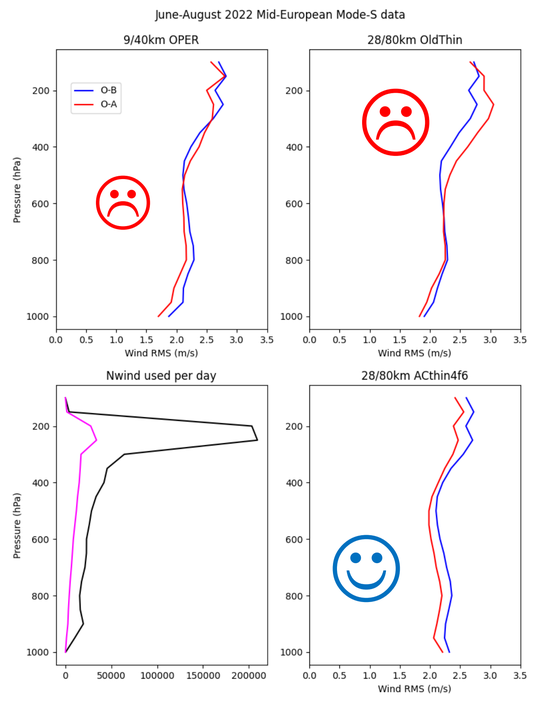


Figure 6. RMS T+12 fit to radiosonde data over Europe for two three-month periods (winter/summer).

Figure 4. Mode-S rms(O-B) blue) and rms(O-A) red for 43-50N and 0-20E for three different experiments (forecast and analysis grid spacing in header). Revised thinning bottom right.

The bottom left panel shows the number of used observations for this area in the original and revised thinning.



Results

Figure 5 shows a scorecard for the revised thinning against noModeS, Against own analysis (top) we mainly see improvements (blue) but there are apparent detriments (orange) at short-range over Europe, this is a feature often seen against own analyses when adding data. Over North America large numbers of observations have been excluded by the thinning and the large blue signal at short range is also over exaggerated.
Against radiosonde and surface observations (bottom half of Figure 5) the signal is more mixed, but more blue than orange. Against European radiosondes at T+12 (Figure 6) the signal is strongly positive especially in the upper

With either Mode-S switched off or the revised thinning the number of inner iterations (and cost) decreased by ~10% and forecast performance improved. The improvements over Europe are stronger and longer lasting than seen in previous LAM studies (eg Li, 2021) due to the much wider coverage now.

Outlook

Given the improved short-range forecasts over Europe we plan to reintroduce Mode-S shortly along with the revised thinning (to be confirmed). This is given more urgency by a) in 2024 the Met Office will buy global Mode-S data (where available) from flightradar24 and provide the data to EMADDC for processing giving the potential for improvements elsewhere and b) at some point E-AMDAR collection will be cut back in areas with good Mode-S coverage.

As a separate development we intend to try assimilation of GNSS height from aircraft. There are currently small amounts of data but efforts are in hand to obtain more. The attractions are the good accuracy of GNSS height – already available on all aircraft – and it should not be affected by the biases that plague aircraft temperatures.

References

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Ingleby, B., et al, 2021: The impact of COVID-19 on weather forecasts: a balanced view. *Geophys. Res. Let.*, https://doi.org/10.1029/2020GL090699.
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