The need for unbiased aircraft temperature and pressure data

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1. Introduction

In some regions aircraft reports (many of them AMDARs) make up a large proportion of the data available for operational weather forecasting and reanalyses, such as ERA5 (Hersbach et al, 2020). Ballish and Kumar (2008) showed that aircraft temperatures tend to be biased high (typically between 0.5 and 1.5 K). NWP and reanalysis centres perform bias correction of temperatures for individual aircraft - this reduces the problem but does not eliminate it. There are still issues over airports in the USA for example. Bias corrections are also needed for satellite soundings but for aircraft we can envisage improved processing so that they are essentially unbiased. In that case aircraft temperatures would be part of the solution rather than part of the problem.

Aircraft measurements are described in WMO (2018) and Wendisch and Brenguier (2013), however the raw temperature, pressure and wind measurements are all interrelated.
Because aircraft travel at high speed the measured temperature can be 20 K higher than the air temperature, this contribution is estimated from the airspeed and subtracted. However, the airspeed also depends on the temperature and it appears that the processing is not iterated to convergence (de Haan et al, 2022). There is some dependence on aircraft type/avionics.

The advantage of aircraft measurements is that they are made anyway for aircraft operations and their cost to meteorological services is small. However, the arms-length relationship means that meteorologists have little control or metadata about the measurements.

2. Temperature bias correction and residuals

Numerical Weather Prediction (NWP) combines information from a forecast model and the latest observations (data assimilation) to provide new initial conditions and then a new forecast. Pauley and Ingleby (2022) review the assimilation of in situ observations, including aircraft data. Bias correction schemes were originally designed for satellite soundings, but have since been applied to aircraft temperatures (e.g Zhu et al, 2015). They work moderately well but are affected by (inevitable) biases in the forecast model. Eyre (2016) showed that bias correction schemes work best when there is a large proportion of uncorrected 'anchor' observations – essentially radio occultation and radiosonde data for temperature. Because aircraft data can be very dense there is a danger that partially corrected aircraft temperatures will affect the resulting (re)analyses. This can be seen in figure 1: the difference in analysis and 12-hour forecast temperatures with and without aircraft temperatures (see Ingleby et al, 2021). The largest, most widespread difference is at cruise levels (200 or 250 hPa) where many of the reports are. The differences are 'only' about 0.15°, but this is large enough to be a problem for climate and NWP. At lower levels differences are localised over airports. The information that we have shows that the bias corrections tend to be larger for Boeing than Airbus aircraft (Figure 2).

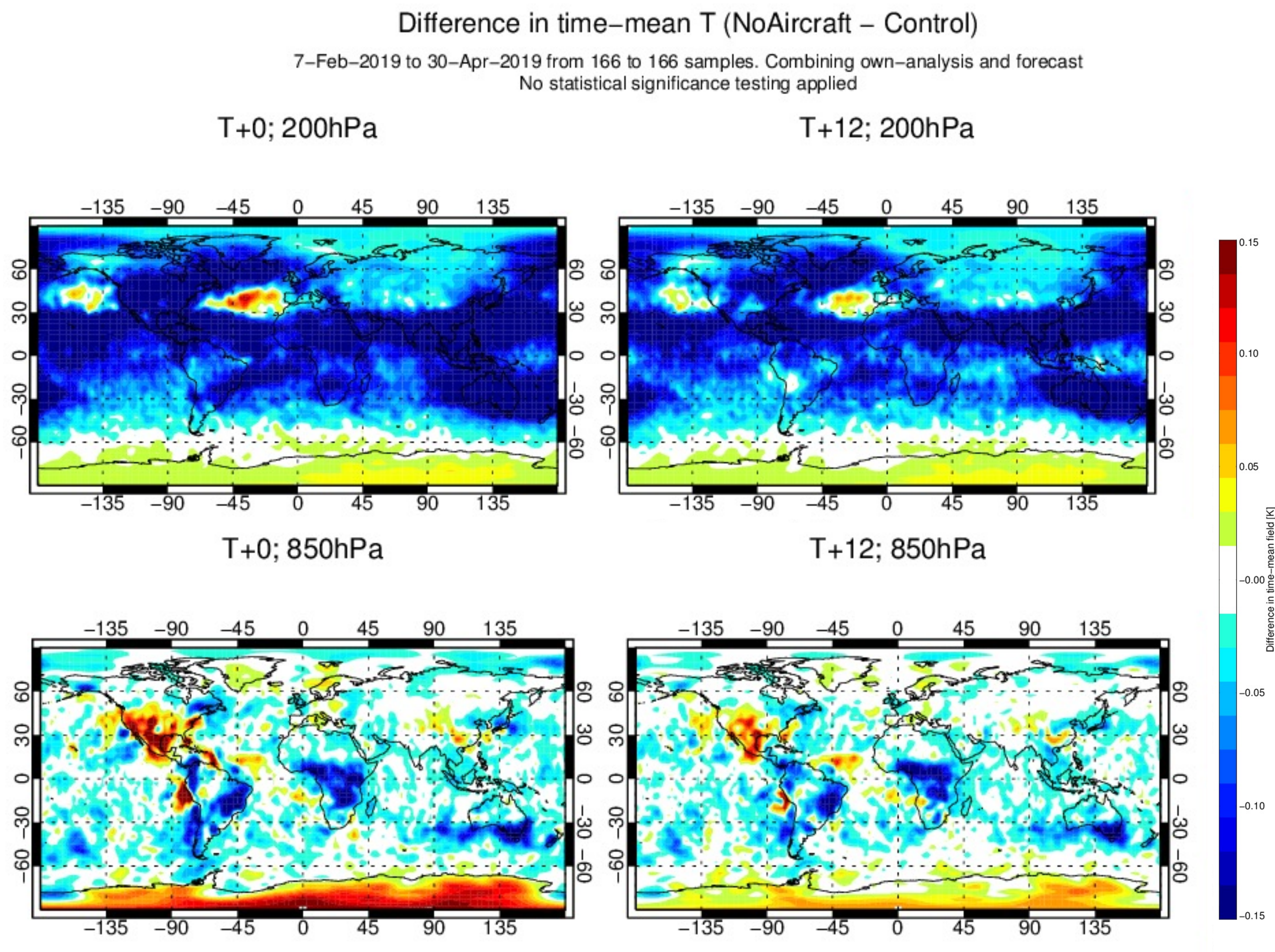

Figure 1. Differences in analysis (T+0) and 12-hour forecast temperatures at 200 and 850 hPa between a control (using all data) and an experiment without aircraft temperatures (other aspects shown in Ingleby et al, 2021).

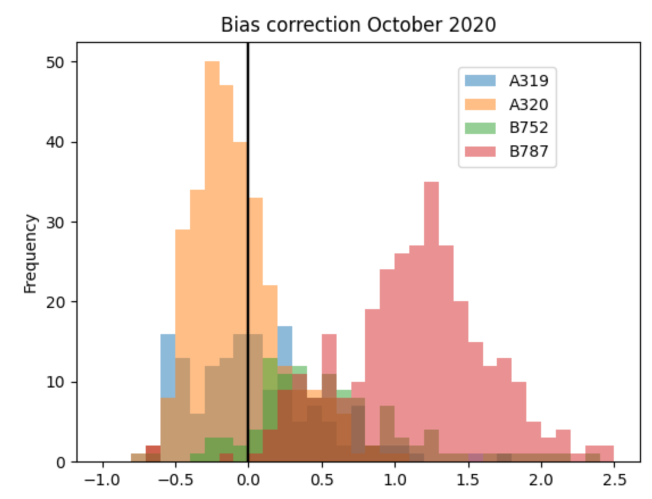

Figure 2. Histograms of aircraft temperature bias correction by aircraft type applied in the ECMWF system, October 2020. The aircraft type information that we have only covers about half of AMDAR identifiers, results are shown for the four most common types.

3. GNSS altitude data

All aircraft have sophisticated navigation systems, including GNSS to give accurate horizontal and vertical positions. So far GNSS altitude has not been used in NWP: there is an empty slot for it in AMDAR reports. Some TAMDAR systems do report GNSS altitude and recent work has compared it with ECMWF forecast heights (using pressure as coordinate), figure 3 gives results for two aircraft. The standard deviation of the differences is 10-15 m but the biases are larger and sometimes height dependent (this may be due to 'uncompensated errors on the aircraft static pressure ports', P Brown, pers. comm. Pressure errors would degrade the usefulness of other variables.)

The altitude data would be an independent piece of data and if assimilated would give a temperature dipole: with opposite sign of increment above and below the aircraft report.

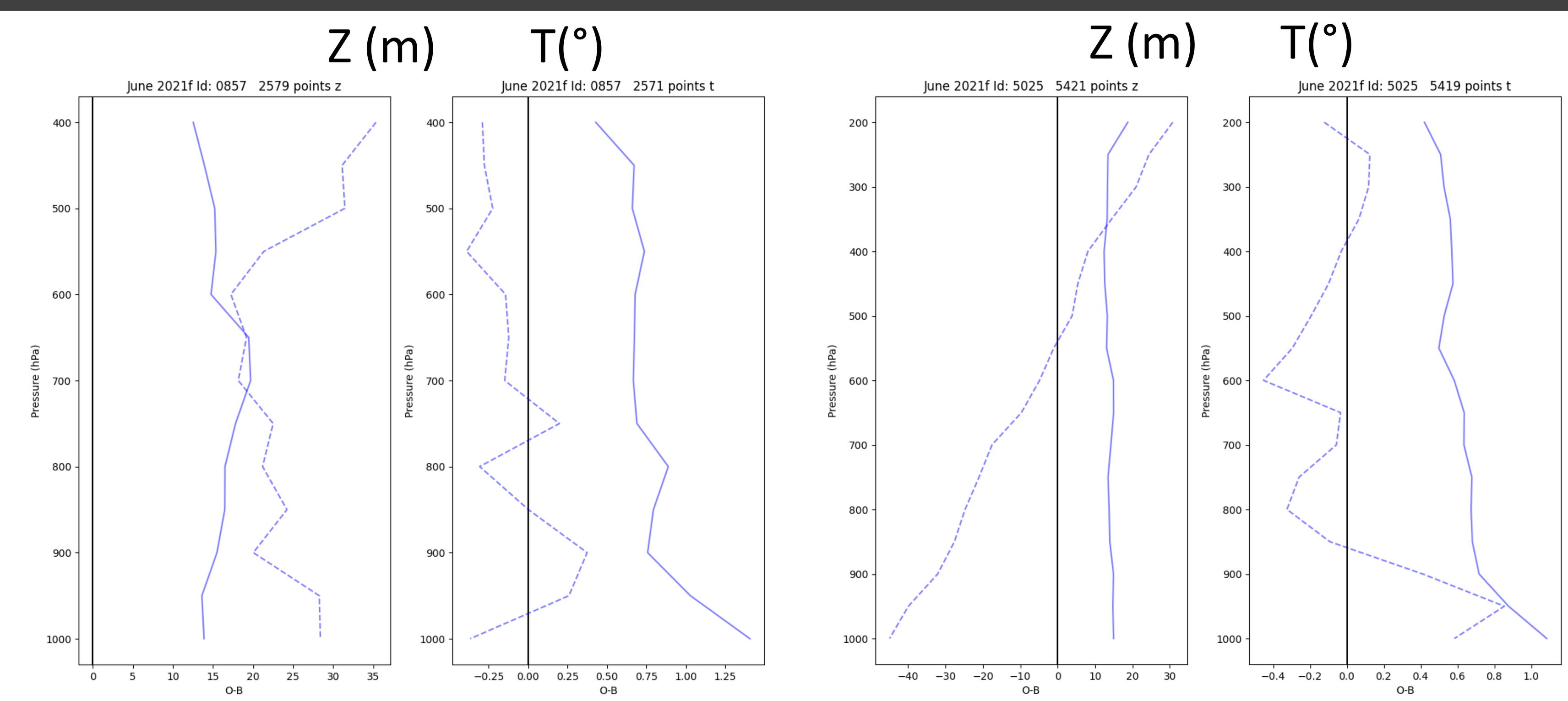

Figure3. Altitude (Z) and temperature (T) differences from ECMWF background values as a function of pressure, for two TAMDAR aircraft, June 2021. Standard deviation – solid lines and mean – dashed lines.

Summary

- Because of the aircraft speed the raw measurements of temperature, pressure etc all need substantial adjustment, and it seems that the adjustments may not be iterated to convergence (de Haan et al, 2022).
- Most aircraft report temperatures that are too warm, some by more than 1 degree.
- Bias corrections within the data assimilation reduce the biases, but cannot eliminate them (Figure 1).
- There is some hope that avionics could be improved to the point where the output temperature biases are negligible – aircraft could then be anchor observations and part of the solution to bias problems.

References

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