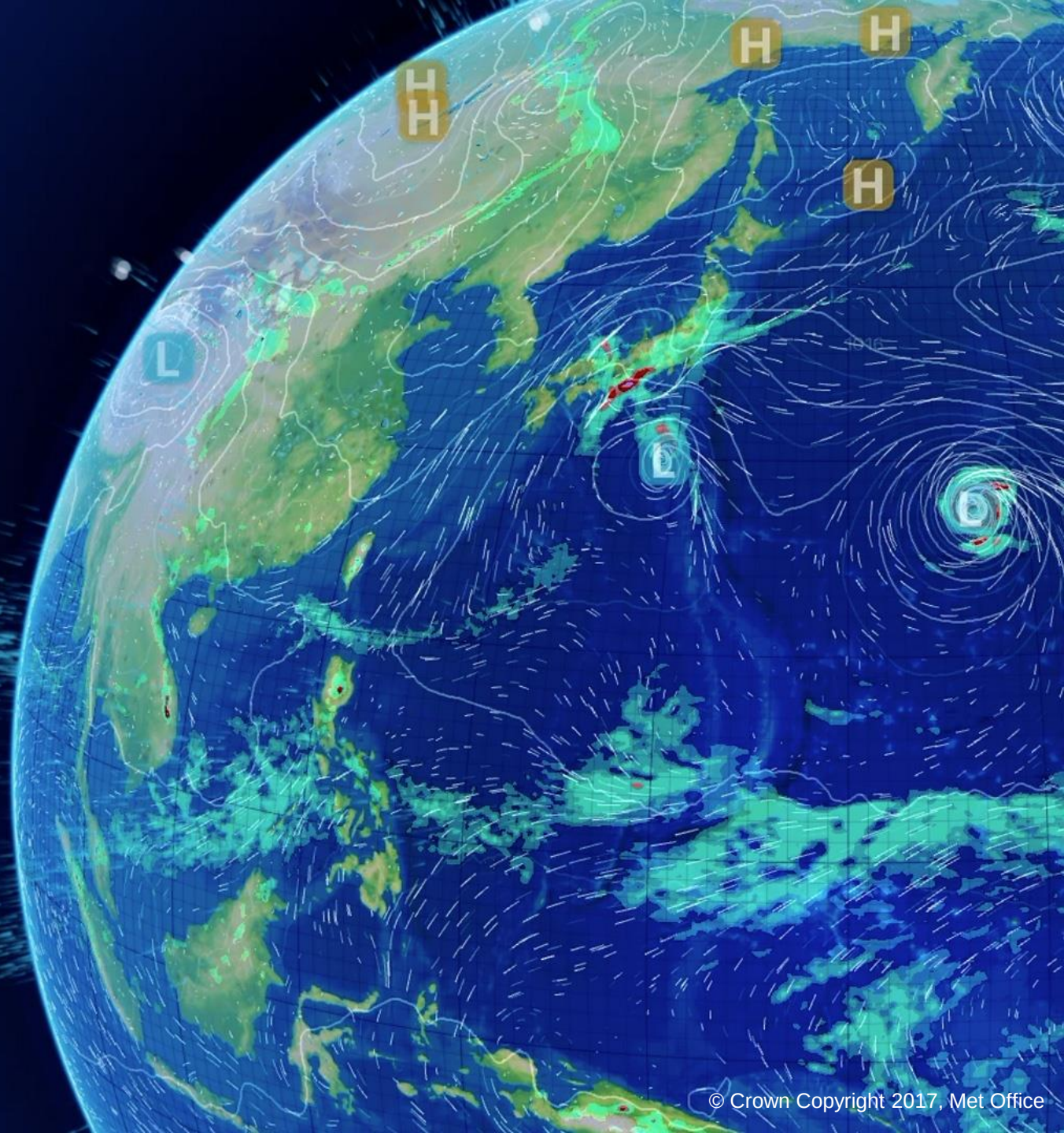
Mode-S temperature introduction

November 2020

Dr Edmund Stone

Expert Scientist - Observations R&D

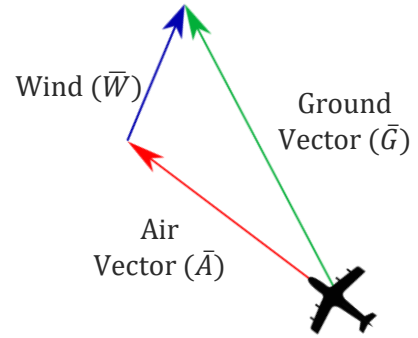


Contents

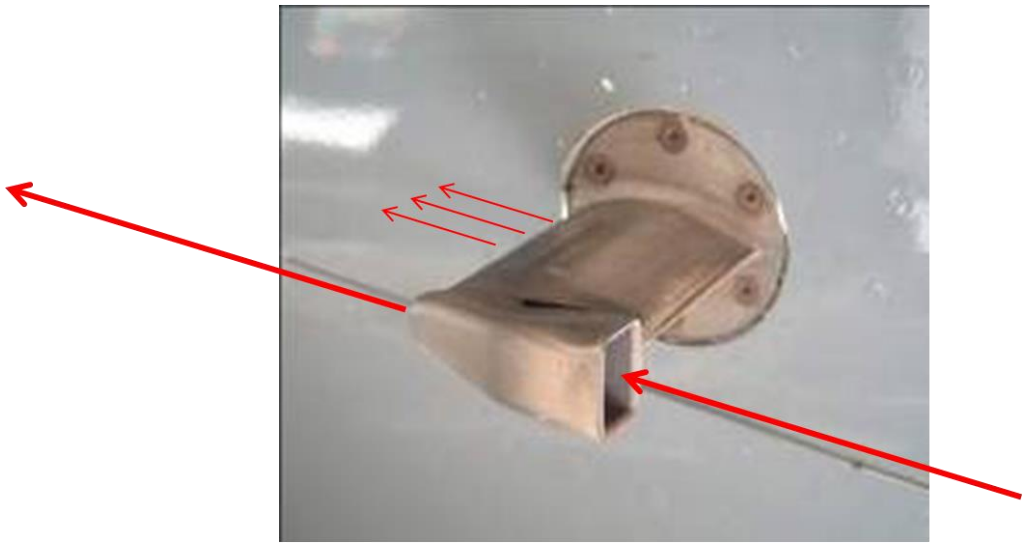
- AMDAR Temperature
- Mode-S, EHS and ADS-B
- Mode-S EHS temperature
- Mode-S EHS temperature corrections and improvements

AMDAR temperature

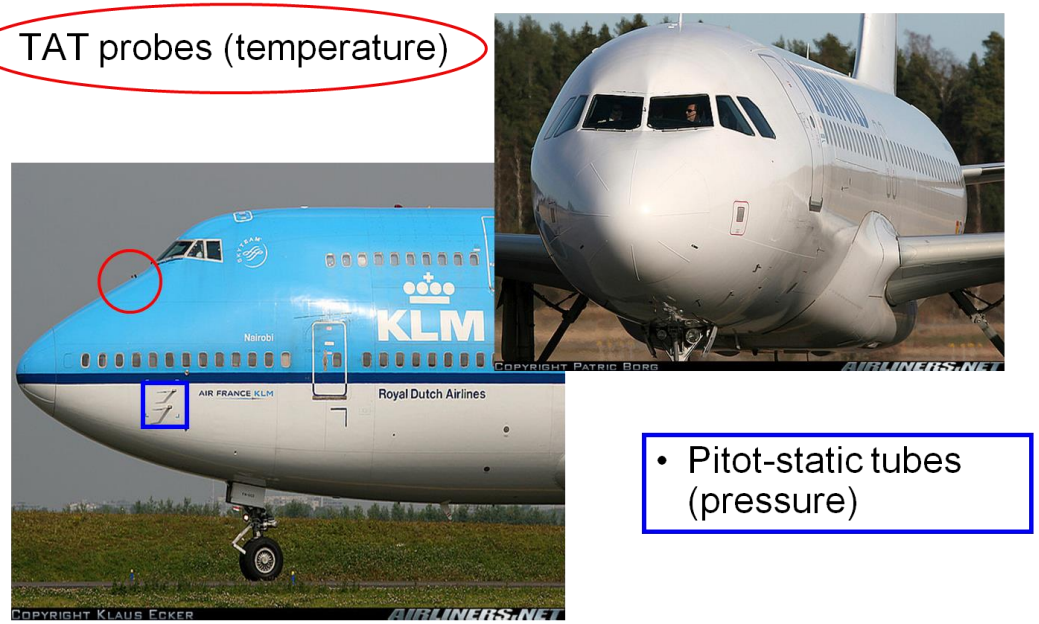
Aircraft measurements



- Sample the air around the aircraft, “temperature” and “pressure”.
- Measure the movement of the aircraft relative to a reference frame.



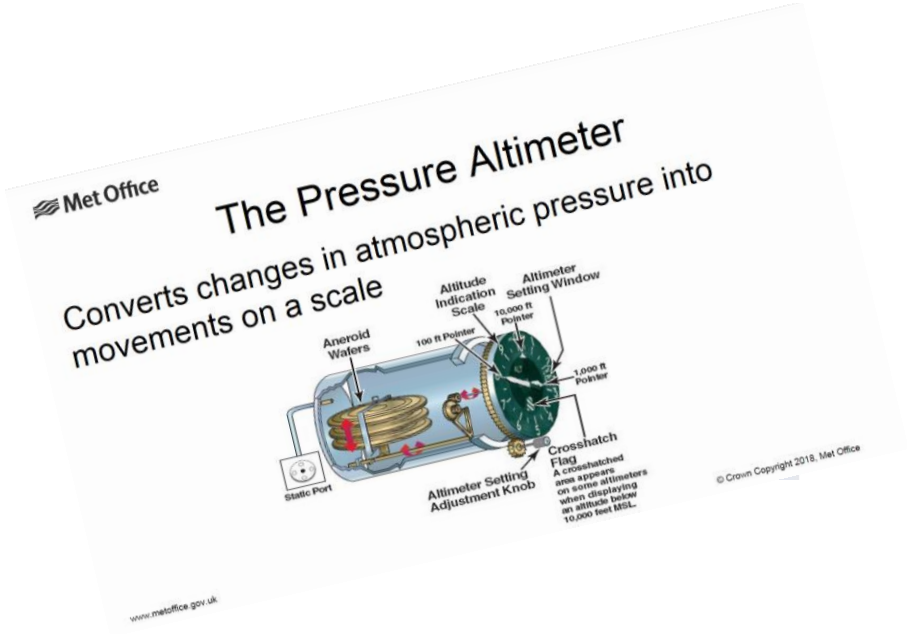
- TAT probes (temperature)

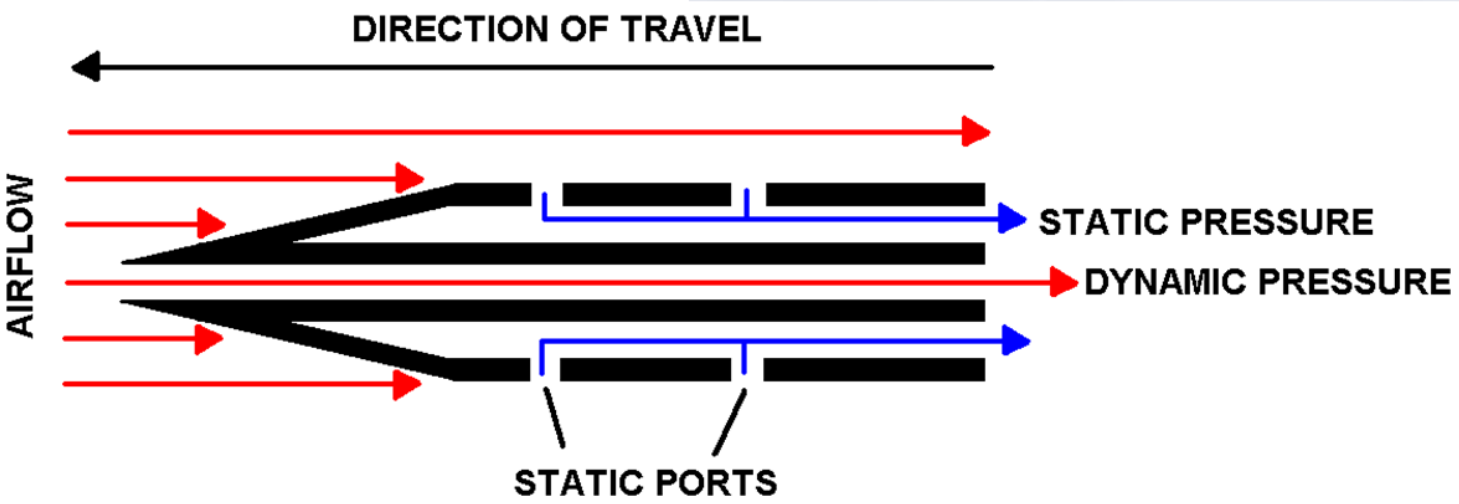


- Pitot-static tubes (pressure)

What does it measure?

Pressure (Altitude)

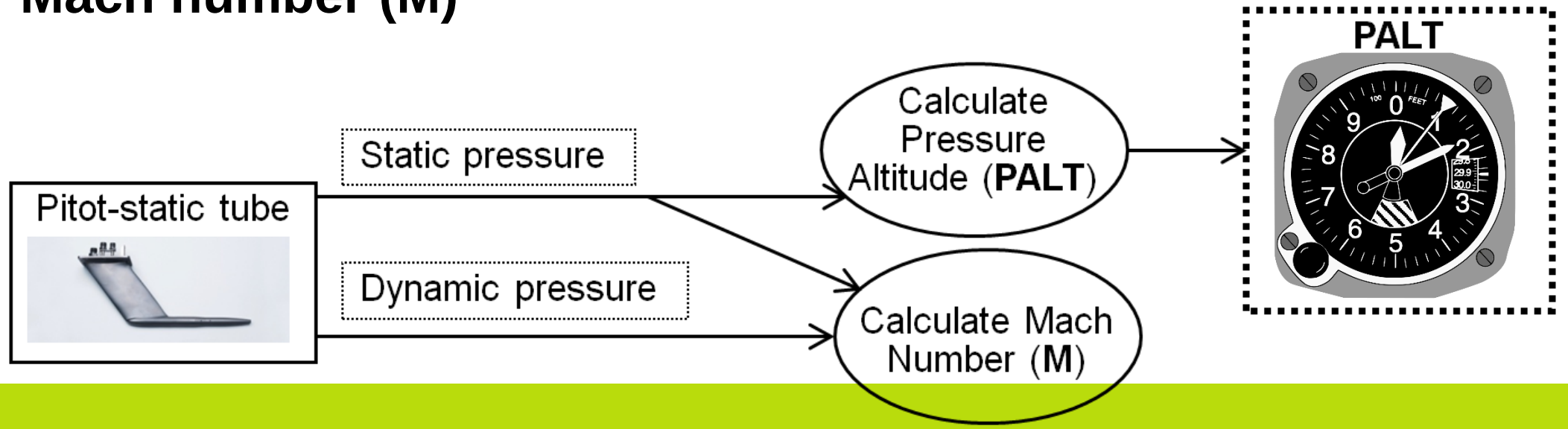




Pressure (and speed) is measured by standard aircraft sensors known as Pitot-static tubes

What does it measure?
Pressure (Altitude)

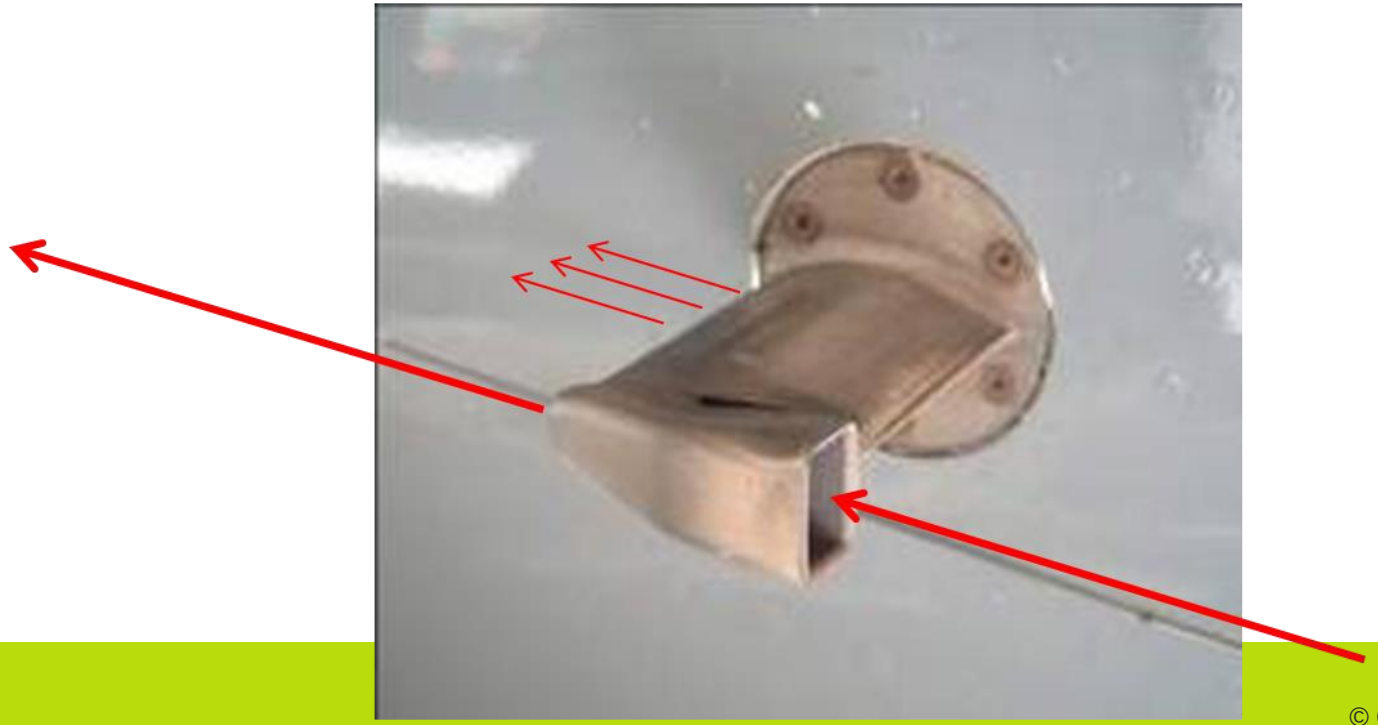
- Static pressure is used to calculate pressure altitude (**PALT**) by comparing to a standard atmosphere.
- Static pressure (normal air pressure) and dynamic pressure (caused by flight) can be used together to calculate the aircraft's speed as a **Mach number (M)**



What does it measure

Temperature - Sensor

- Temperature is measured by a Total Air Temperature (**TAT**) probe
- Sensor faces into the airflow and brings air to a stop inside the sensor where its temperature is measured

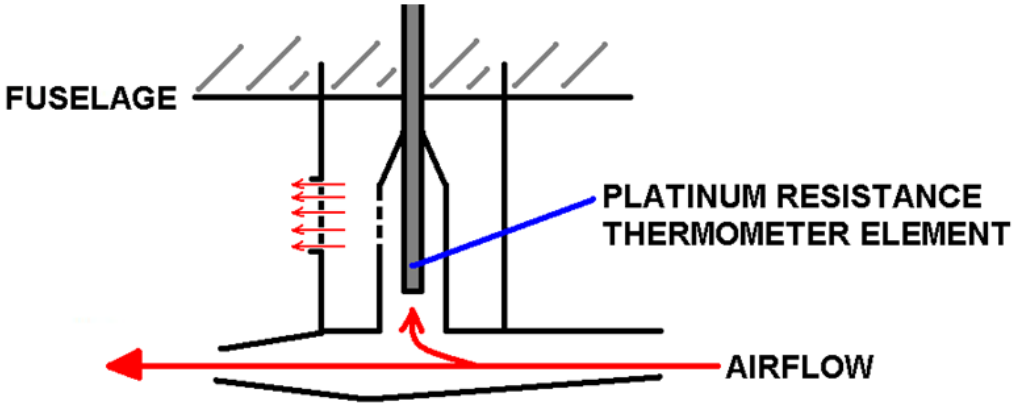


What does it measure

Temperature - Sensor

This halting effect causes the air to warm.

This warmer value is known as the **T**otal **A**ir **T**emperature (**TAT**)



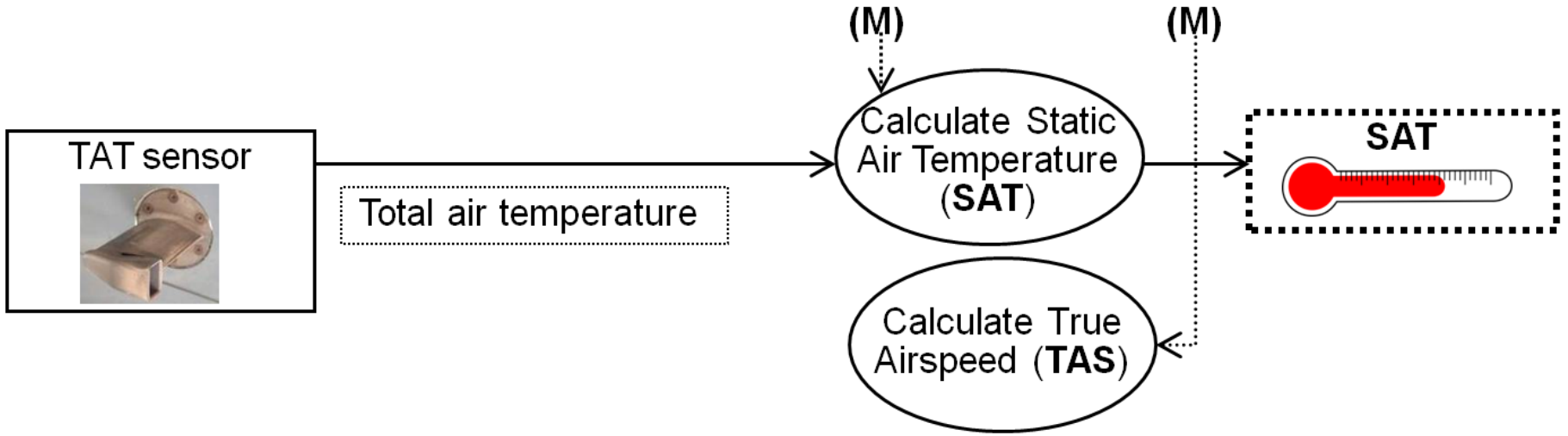
This is then converted into **S**tatic **A**ir **T**emperature (**SAT**) by onboard software, which is equivalent to the true external air temperature. This uses an assumed airflow model for the particular aircraft.

What does it measure

Temperature – Linking to pressure

Static **A**ir **T**emperature (**SAT)** is a function of sensor probe and **Mach Number** (aircraft speed relative to the speed of sound).

Mach Number is derived from total and static pressures



Met Office

- Mode-S, EHS and ADS-B

So what is Mode-S?

Mode-Selective (S) is an ICAO authorised aviation standard for the two way communication between aircraft and secondary surveillance radar.

- Provides a standard way for
  - Air Traffic Management (ATM) to send data to aircraft.
  - ATM to request information from aircraft and for them to send it.
  - A standard way for aircraft to broadcast information.

So what about EHS?

Mode-Selective (S) Enhanced Surveillance (EHS).

- A subset of the Mode-S standard, which is mandated for aircraft over certain limits to have to respond to in Europe.
- An agreed interrogation regime.

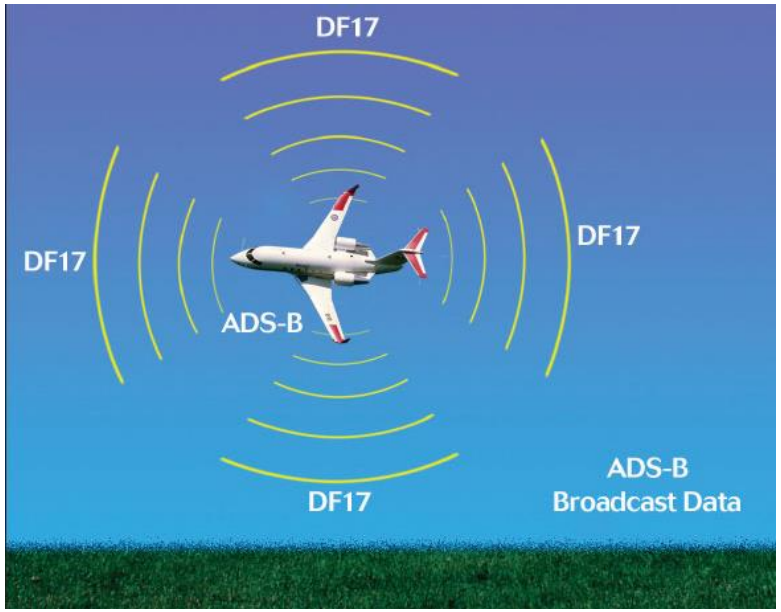
And ADS-B?

Automatic Dependent Surveillance-Broadcast (ADS-B)

- Another subset of the Mode-S standard, which is mandated for aircraft over certain limits to operate in Europe.
- No interrogation required.
- The data is “squittered”, i.e. routinely broadcast. Up to twice a second!

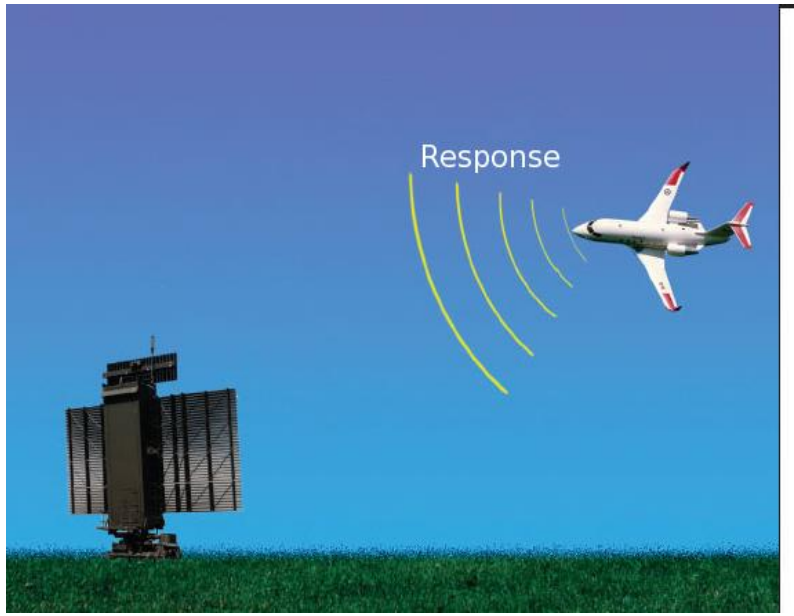
ADS-B data

- DF17s are broadcast at 2Hz but there are different types.
  - We've detected DF17 Aircraft Identifier, DF17 Airborne Position and DF17 Airborne velocity.
  - These include the aircraft type, unique identifier, altitude, ground speed, and position of the aircraft.

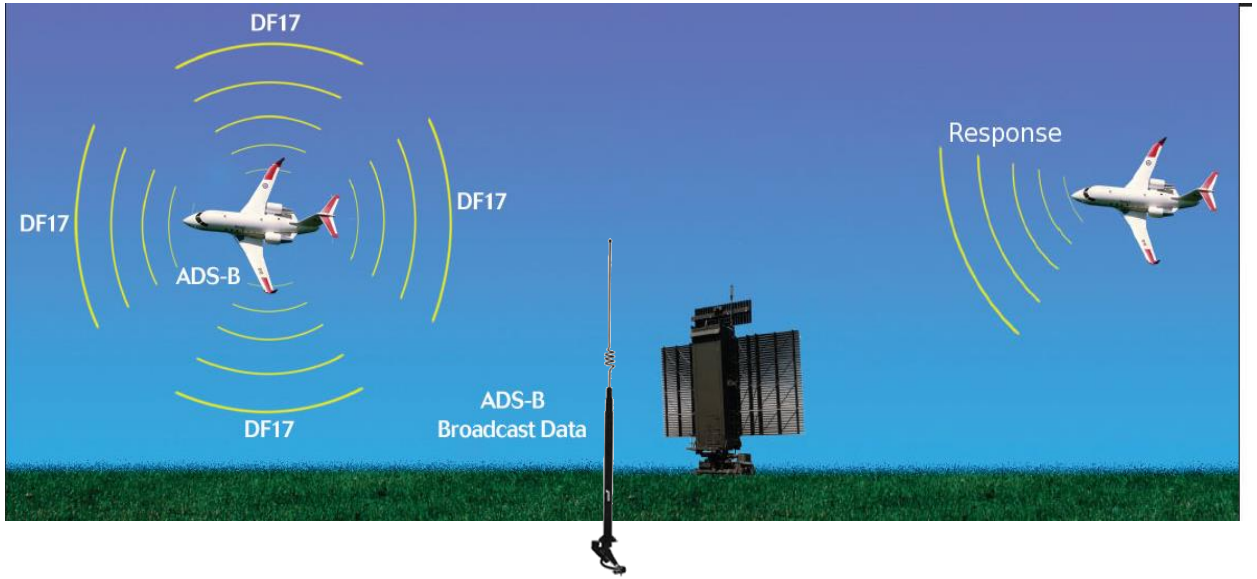


Mode-S EHS data

- DF20s and DF21s contain requested data.
  - The unique identifier of the aircraft and the data type are not included in the message but must be inferred by other means.
  - We've detected and require two types of these data broadcasts.
  - BDS5,0 which contains maneuvering information.
  - BDS6,0 which contains the indicated airspeed and magnetic heading.
  - A BDS definition exists for meteorology data but these have not been observed.



Mode-S EHS and ADS-B data



- Navigational data broadcast from aircraft for ATC and other aircraft.
- Freely intercepted using equipment designed for and by aircraft enthusiasts.
- Met Office uses their own network of receivers to collect DF17 (ADS-B) and DF21/22 (Mode-S EHS) messages.

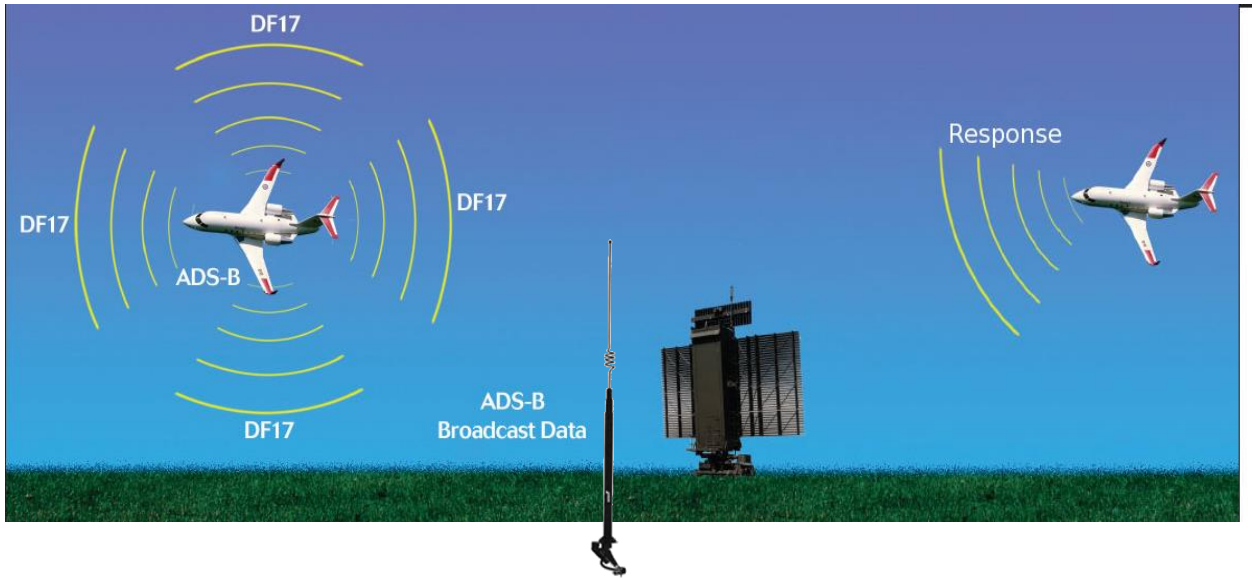
- We now have:
  - Mach number
  - True Air Speed
  - Ground track
  - Magnetic head

What does this tell us about the atmosphere?

Stone, E.K. and Pearce, G., 2016. A Network of Mode-S Receivers for Routine Acquisition of Aircraft-Derived Meteorological Data. *Journal of Atmospheric and Oceanic Technology*, *33*(4), pp.757-768.

- Mode-S EHS temperature

Mode-S EHS and ADS-B data



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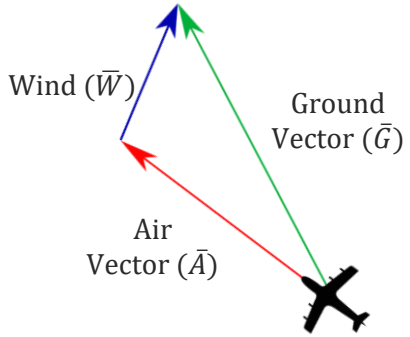
- We now have:
  - Mach number
  - True Air Speed (TAS)
  - Ground track
  - Magnetic head



$$\bar{w} = \bar{G} - \bar{A}$$

$$T = \left(\frac{v_{\mathrm{TAS}}}{38.975M} \right)^2$$

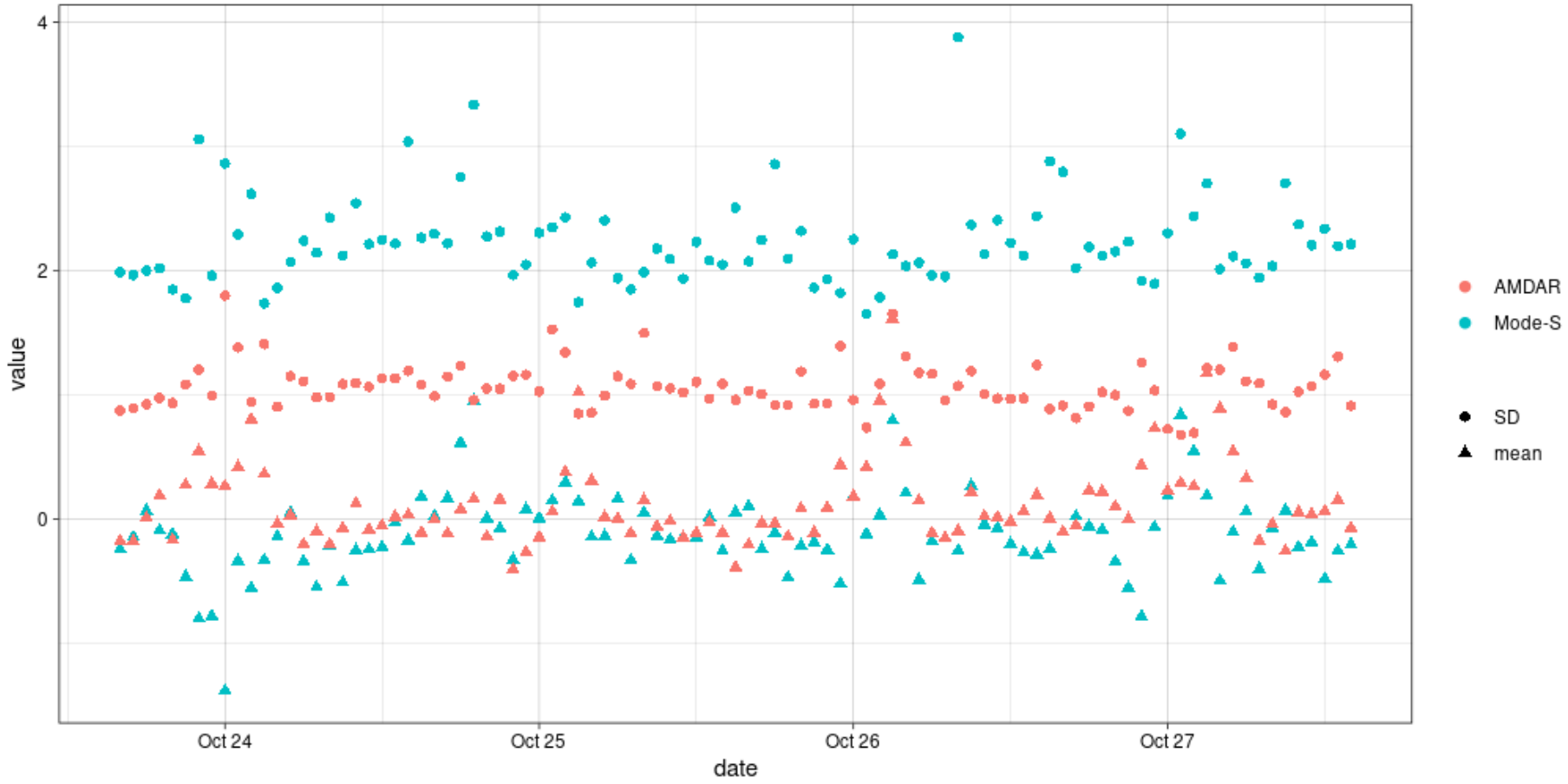
T temperature
v_{TAS} true air speed
M mach number

Stone, E.K. and Pearce, G., 2016. A Network of Mode-S Receivers for Routine Acquisition of Aircraft-Derived Meteorological Data. *Journal of Atmospheric and Oceanic Technology*, *33*(4), pp.757-768.

Data Quality – Obs - Background

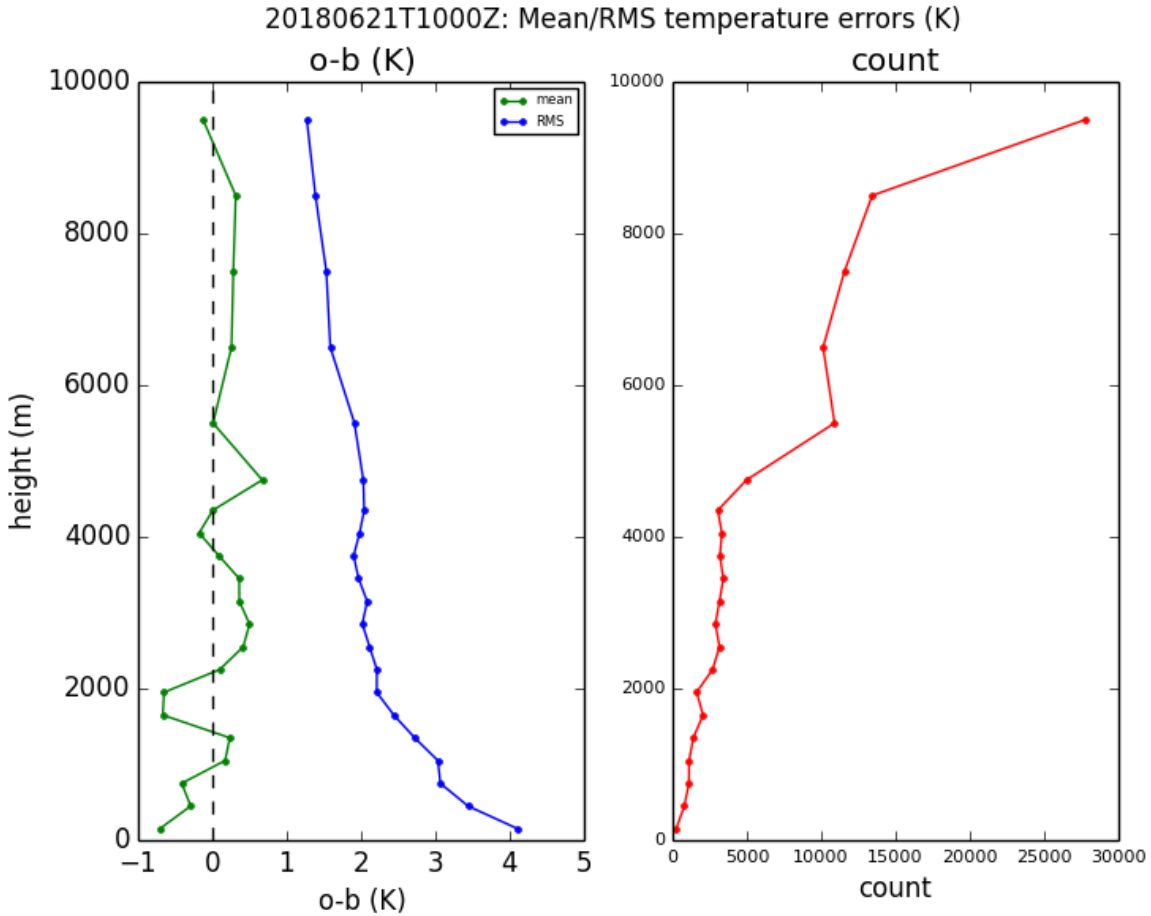
Temperature, observation minus background (o-b) for AMDAR and Mode-S EHS derived temperatures. Model is the hourly cycling UKV (1.5 km, 4DVAR).

AMDAR temperatures are assimilated.
Mode-S temperatures are NOT assimilated.



Stone EK. A comparison of Mode-S Enhanced Surveillance observations with other in situ aircraft observations. Q J R Meteorol Soc. 2018;1–6. https://doi.org/10.1002/qj.3238

Data Quality – temperatures



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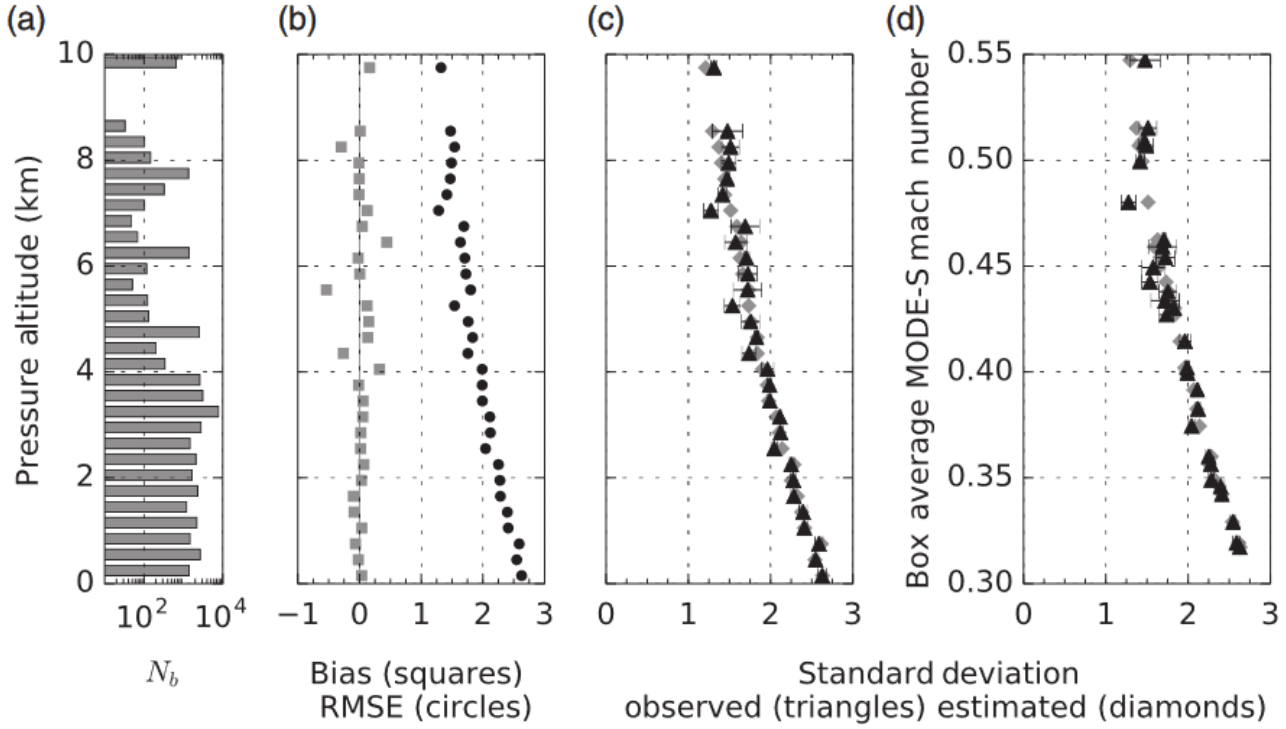
Data Quality – temperatures



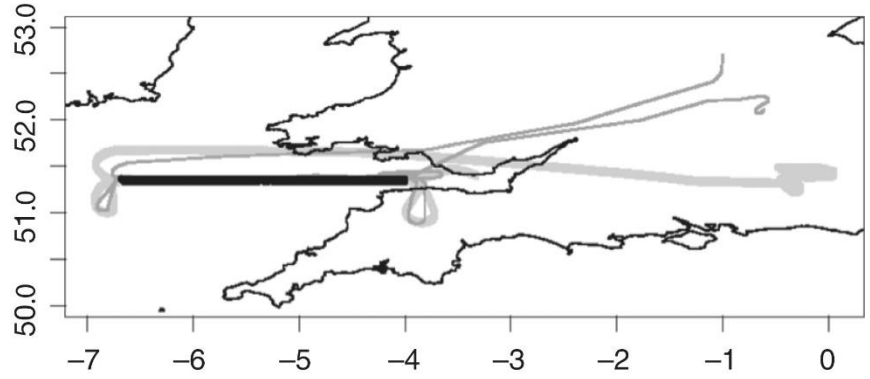
$$\Delta T = \pm \frac{T_0}{A_0^2} \frac{2V_A}{M^2} \sqrt{\left(\Delta V_A^2 + \frac{V_A^2}{M^2} \Delta M^2 \right)},$$

Figure 11. Box-average statistics for temperature for all case-studies listed in Table 6. Results are binned by altitude, with bin heights at 0.3 km intervals. Panel (a) is the number of reports per altitude bin, N_b, expressed using a $\log_{10}$ scale. (b) Vertical profile of temperature difference ($T_{MACH} - T_{REF}$) mean bias (MB) (squares) and RMSE (circles). (c) Vertical profile of the box-average observed σ (triangles) (using Eqs (12) and (15)) and the box-average estimated ΔT (diamonds) due to the quantization error (using Eqs (16) and (17)). Panel (d) depicts the results of (c) against the box-average M reported by Mode-S EHS.

Mirza, A. K., Ballard, S. P., Dance, S. L., Maisey, P. , Rooney, G. G. and Stone, E. K. (2016), Comparison of aircraft-derived observations with in Situ research aircraft measurements. Q.J.R. Meteorol. Soc., 142: 2949-2967. doi:10.1002/qj.2864

Data Quality – BA flight

Parameter	Source	Mean	RMS
u	Mode-S minus FAAM	0.5	1.5
u	Mode-S minus FDR	0.3	1.8
u	FDR minus FAAM	0.2	0.6
v	Mode-S minus FAAM	0.6	0.9
v	Mode-S minus FDR	−0.1	0.9
v	FDR minus FAAM	0.6	1.4
T	Mode-S minus FAAM	−0.3	1.6
T	Mode-S minus FDR	−0.3	1.5
T	FDR minus FAAM	−0.1	0.5



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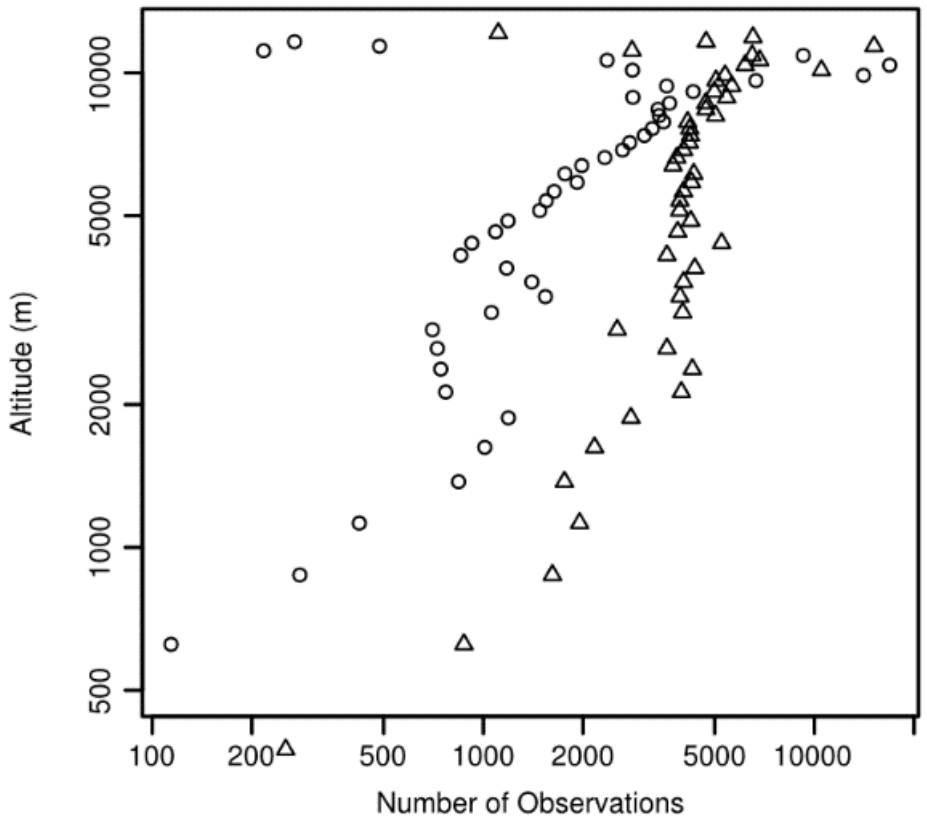
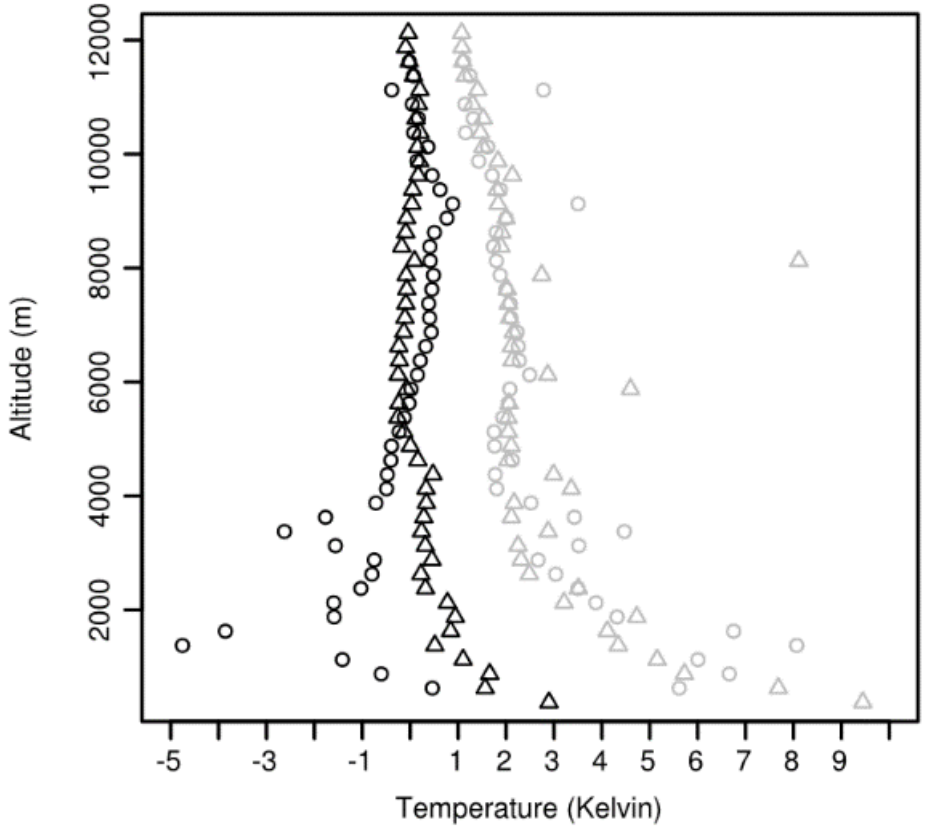
Data Quality – BA flight





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https://doi.org/10.1002/qj.3238

- Corrections and Improvements

Smoothing, corrections, etc…

- KNMI have demonstrated that smoothing of the parameters and correcting the True Airspeed can significantly improve the error statistics.

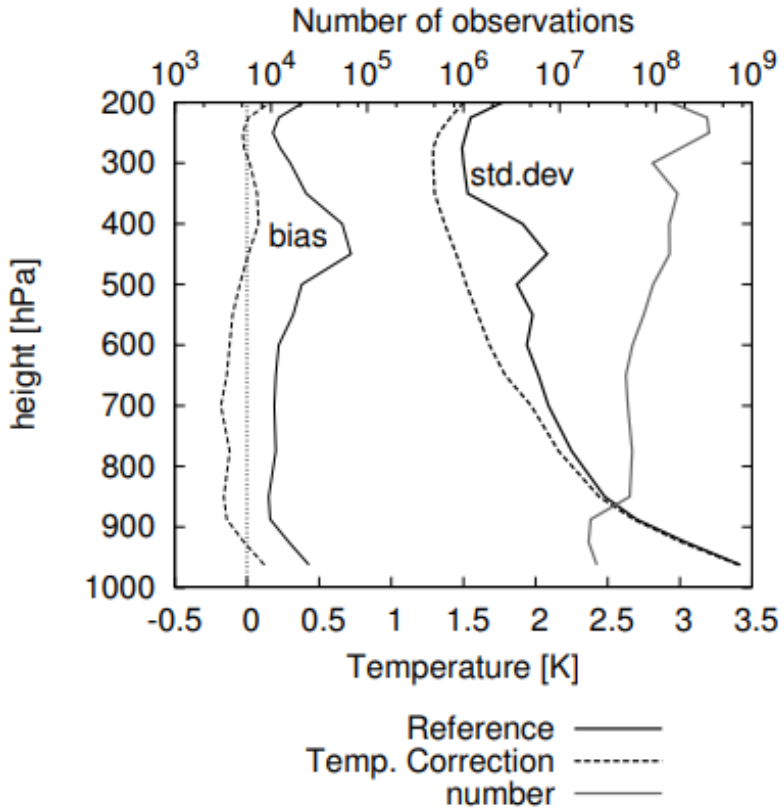
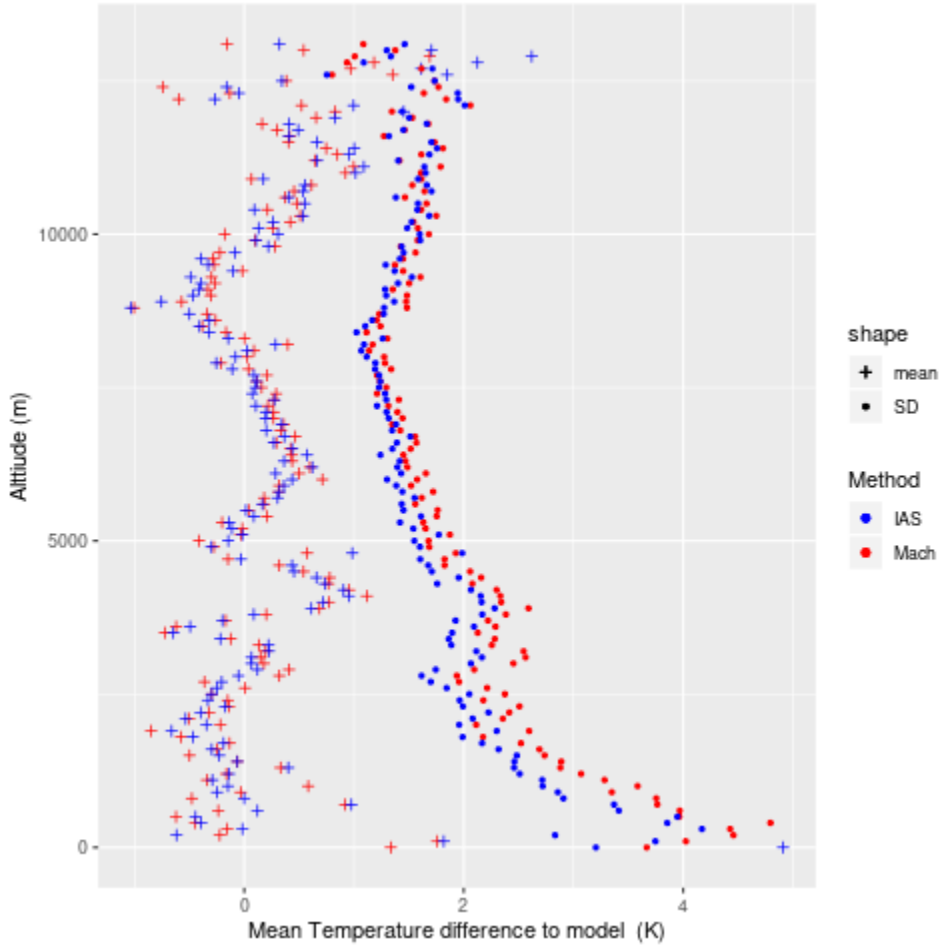


Figure 6.1: Temperature mean difference between ECMWF and observation and standard deviation of the difference for all quality controlled Mode-S EHS aircraft observations for which a temperature correction is available. The reference (no correction) is depicted as a solid black line (thin is bias, thick is standard deviation). The dashed line shows the bias and standard deviation for temperature corrected observations. The number is shown by the gray line (top axis).

Haan, S. de, *An improved correction method for high quality wind and temperature observations derived from Mode-S EHS* KNMI publication: TR-338, 2013. http://mode-s.knmi.nl

Recalculating the MACH number…

- Aircraft report their Indicated Airspeed (IAS) as well, we can therefore use the TAS and IAS to calculate a MACH number…
- O-B data from a single hourly run of the UKV.
- We see a small improvement, KNMI have reported that doing this, smoothing and a model comparison error correction that they see a “significant” improvement close to AMDAR quality.



- Conclusions

Conclusions

- AMDAR temperatures are derived from temperature and pressure measurements. On board the aircraft.
- Mode-S EHS temperatures are derived from air speed and Mach number on the ground. The True Air Speed and Mach number are derived from temperature and pressure measurements onboard the aircraft. They're reported to a limited precision
- Mode-S EHS temperature errors are dominated by the Mach number reporting resolution.
- Correcting or averaging the data should provide some further value from the data.
- Not shown here but there is a significant amount of data available in many airspaces.

Thank you for listening

www.metoffice.gov.uk

enquiries@metoffice.gov.uk

from the UK: 0370 900 0100 From outside the UK: +44 1392 885680