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Characterization of AMDAR temperature bias

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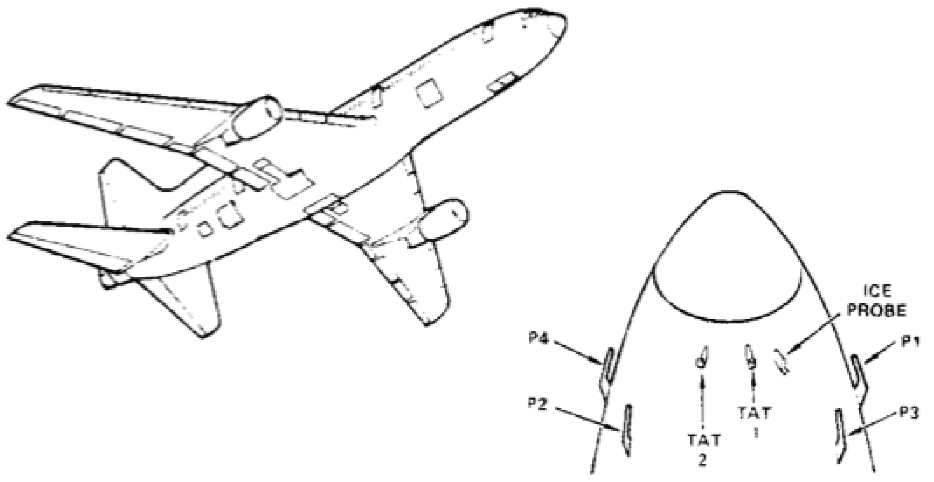
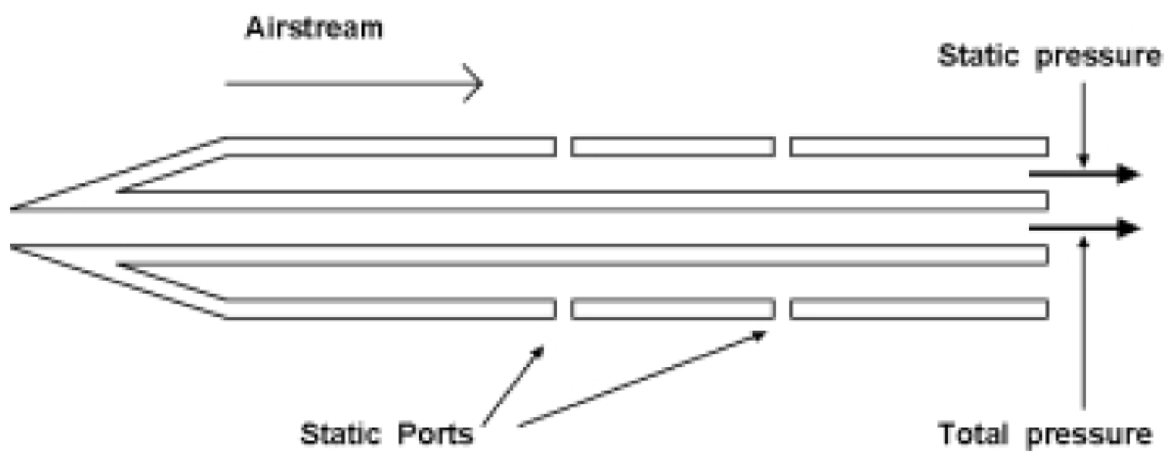
(warm) AMDAR bias

Studies show that AMDAR temperature exhibits a bias

We suspect/assume that the main cause is related to the “pressure defect” caused by the pitot-probe

Exploiting downlinked Mode-S EHS information, we are able to reduce the bias to almost zero





Temperature

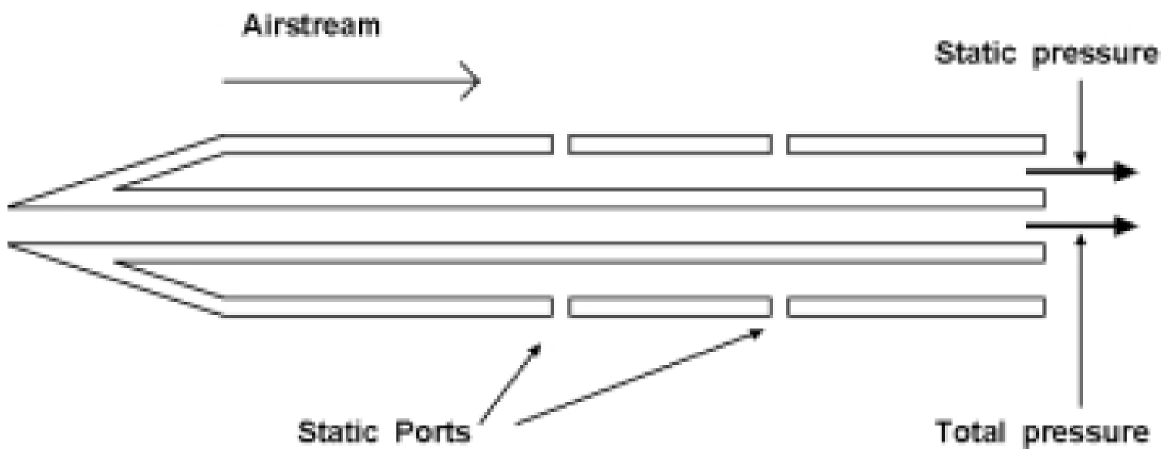
An thermometer probe measures the (stagnation) temperature T_i.
The static air temperature, is related to the measured temperature by

$$T_a = T_i \left(1 + \lambda \frac{\gamma - 1}{2} M^2\right)^{-1}$$

where the Mach-number is measured by a pitot-probe

$$M = \sqrt{\frac{2}{\gamma - 1}\left(\left(\frac{q_i}{p_s} + 1\right)^{\frac{1}{\gamma}(\gamma-1)} - 1\right)}$$

with $q_i = p_t - p_s$



biases

Knowledge of presence of biases is crucial for use

bias = observation - truth

Here we assume we can characterise the AMDAR bias by
1 timing difference
2 internal updates (related to pressure defect)

The first process depends on the flight phase of the aircraft and relates to difference of timing, as it appears that the time of measurement of height and temperature differ.

The second process is related to internal corrections applied to pressure altitude without feedback to temperature observation measurement.

Flight phase dependent bias

aircraft exhibit a different bias when descending and ascending.

cause?: by time mis-synchronization between height message and the temperature message due to atmospheric temperature lapse rate ($\Gamma \approx -6.5$K/km)

When observation time of the temperature and the height differ a bias will be introduced with opposite sign for descending and ascending flight paths.

Suppose the time difference is τ:

T is observed at t_T and height at t_h, with $t_T = t_h - \tau$

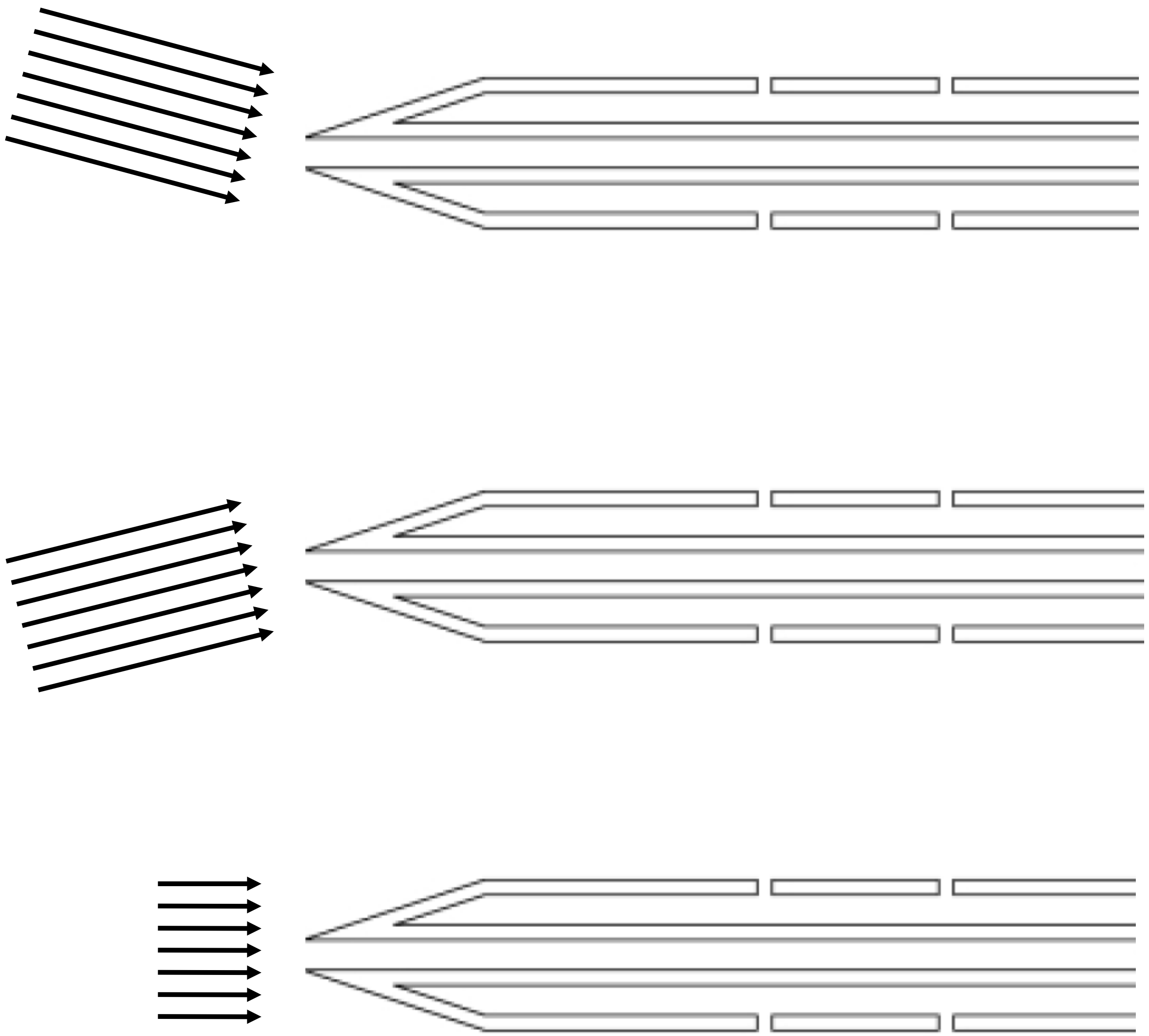
thus a bias will be present, that is

$$T(t_h) = T(t_T + \tau) \approx T(t_T) + \tau\, v\, \Gamma$$

where v is the aircraft vertical speed

we estimated τ by comparing AMDAR temperature with NWP temperature using the temperature lapse rate from the model

pressure defect



Accuracy of pressure observations are influenced by the magnitude and relative direction (angle-of-attack) of the airstream

$$p_t = \tilde{p}_t + \Delta_{p_t}(V_a, \alpha)$$

$$p_s = \tilde{p}_s + \Delta_{p_s}(V_a, \alpha)$$

Assume now that

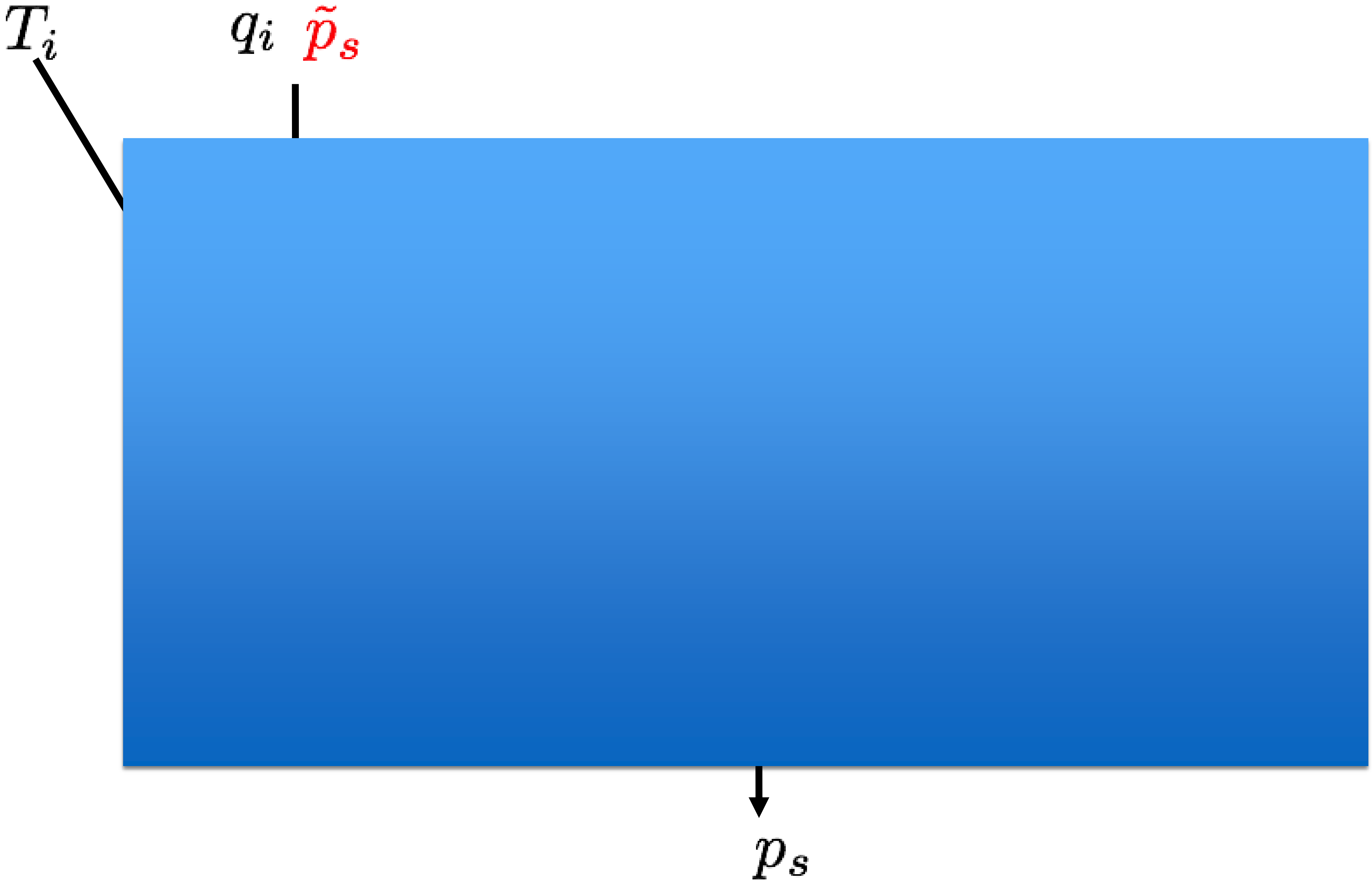
$$\Delta_{p_s} \approx \Delta_{p_t}$$

then the impact pressure is accurate

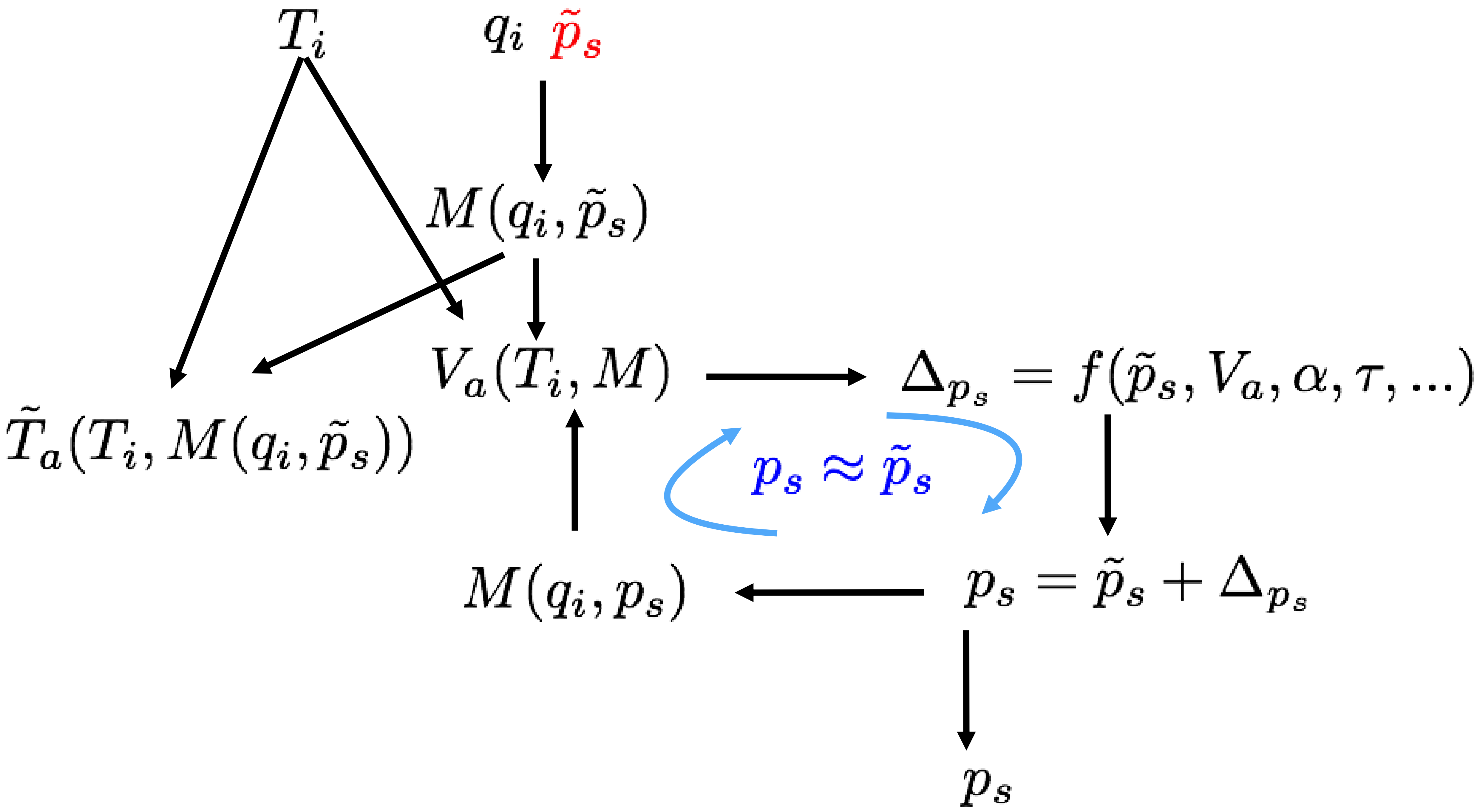
$$q_i = p_t - p_s$$

Corrections

http://mode-s.knmi.nl



Corrections



inversion using Mode-S EHS and model data

http://mode-s.knmi.nl

$$T_a = T_i \left(1 + \lambda \frac{\gamma - 1}{2} M^2\right)^{-1}$$

$$IAS = \sqrt{\frac{p_0}{\rho_0} \frac{2}{\gamma - 1} \left(\left(\frac{q_i}{p_0} + 1 \right)^{\frac{1}{\gamma}(\gamma - 1)} - 1 \right)}$$

obtain q_i from Mode-S EHS IAS

Observed: $p_s \; \tilde{T}_a \; q_i$

Assume we know f^{-1}

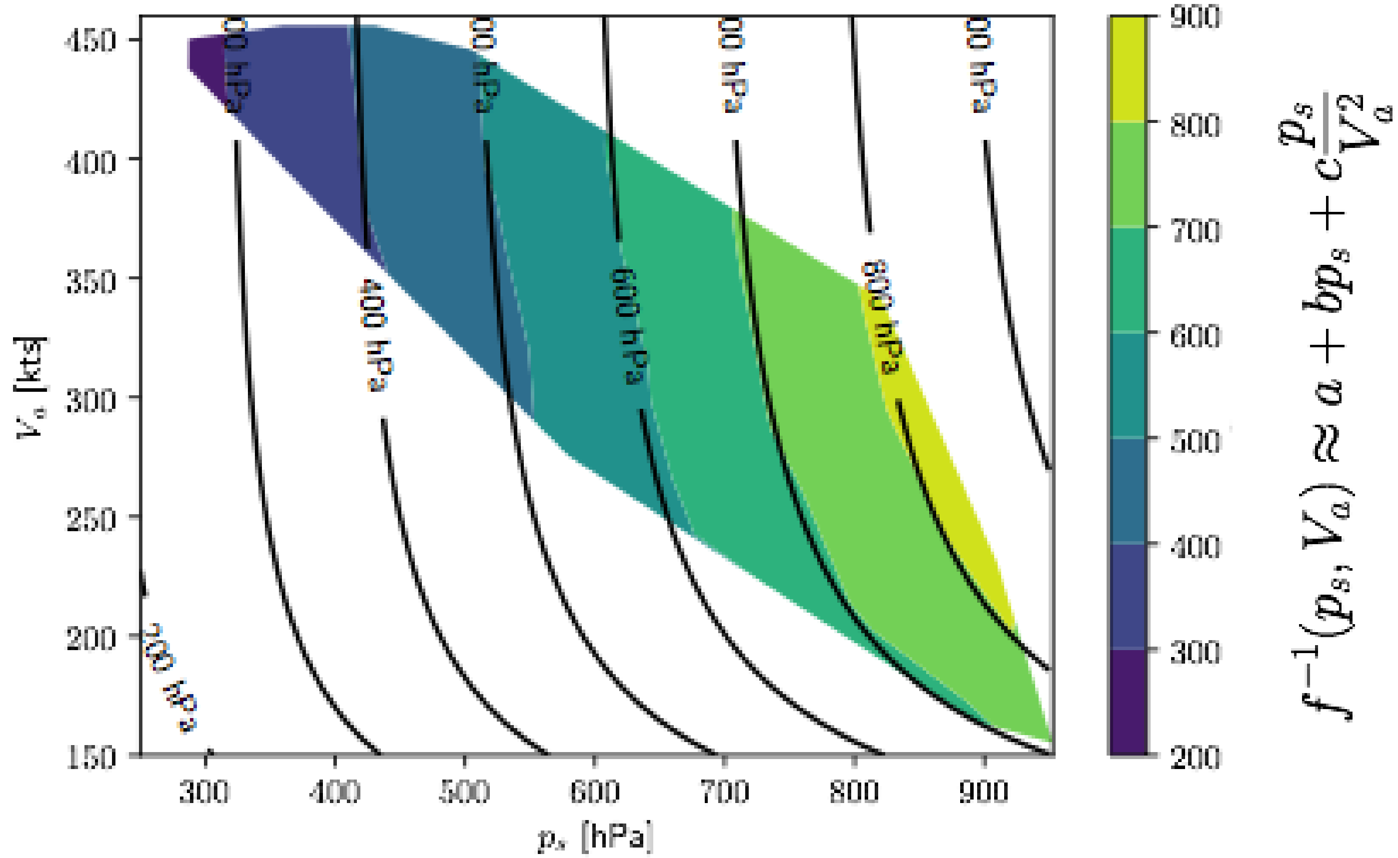
then we can estimate $\tilde{p}_s$

using $M(q_i, \tilde{p}_s)$ $\tilde{T}_a$ then we can find T_i and finally we find the corrected temperature T_a using $M(q_i, p_s)$

$$T_a = \tilde{T}_a \left(1 + \lambda \left(\left(\frac{q_i}{f^{-1}(p_s, V_a, \ldots)} + 1 \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right) \right) \left(1 + \lambda \frac{\gamma - 1}{2} M^2\right)^{-1}$$

Estimate of corrections

- *truth* : numerical weather prediction model temperature
- IAS, airspeed : Mode-S EHS observations
- period : January 2017 to July 2018.



The above figure shows the value of f^{-1} as a function of p_s and V_a for a selected aircraft (filled contours) using NWP data over an 18 month period. The fit was constructed by binning both p_s and V_a in 10 separate bins, and use the median value of f^{-1} in a least squares fit.

the corrections were applied on AMDAR observations over the period from September 2018 to mid December 2019

Note: corrections January 2017 to July 2018

verification against radiosonde temperatures

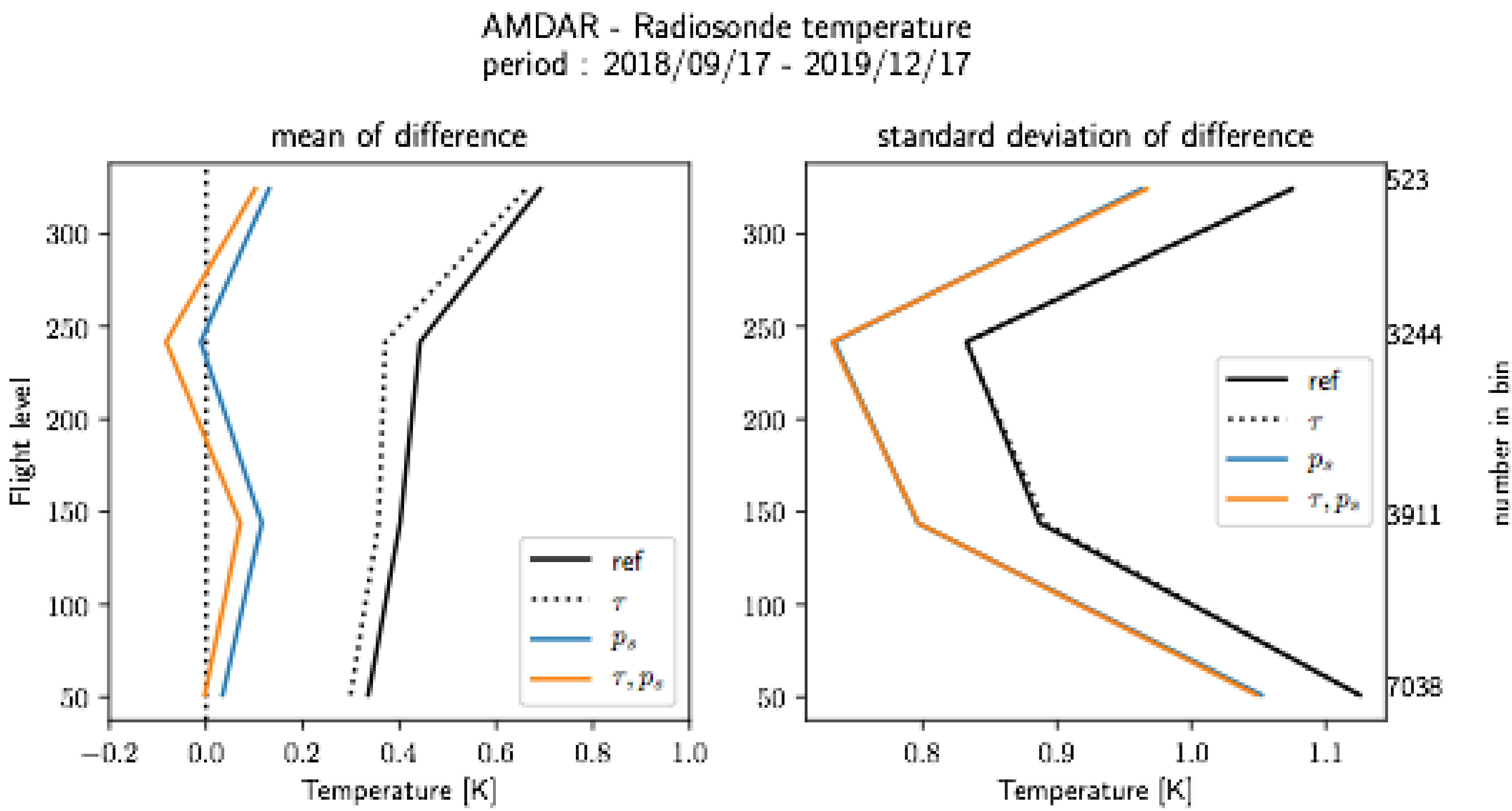
AMDAR observation is collocated with a radiosonde observation
- distance is smaller than 50 km,
- time difference is smaller than 30 minutes
- height difference is less than 15 m.

For each AMDAR observation, a nearby radiosonde observation, if exists, was found. This implies that a radiosonde observation could have multiple matching AMDAR observations.

Comparison against Radiosonde

correction	number	mean	standard deviation
ref	14716	0.389	1.007
τ	14716	0.343	1.007
p_s	14716	0.049	0.923
τ, p_s	14716	0.003	0.921

Comparison against Radiosonde



Conclusions

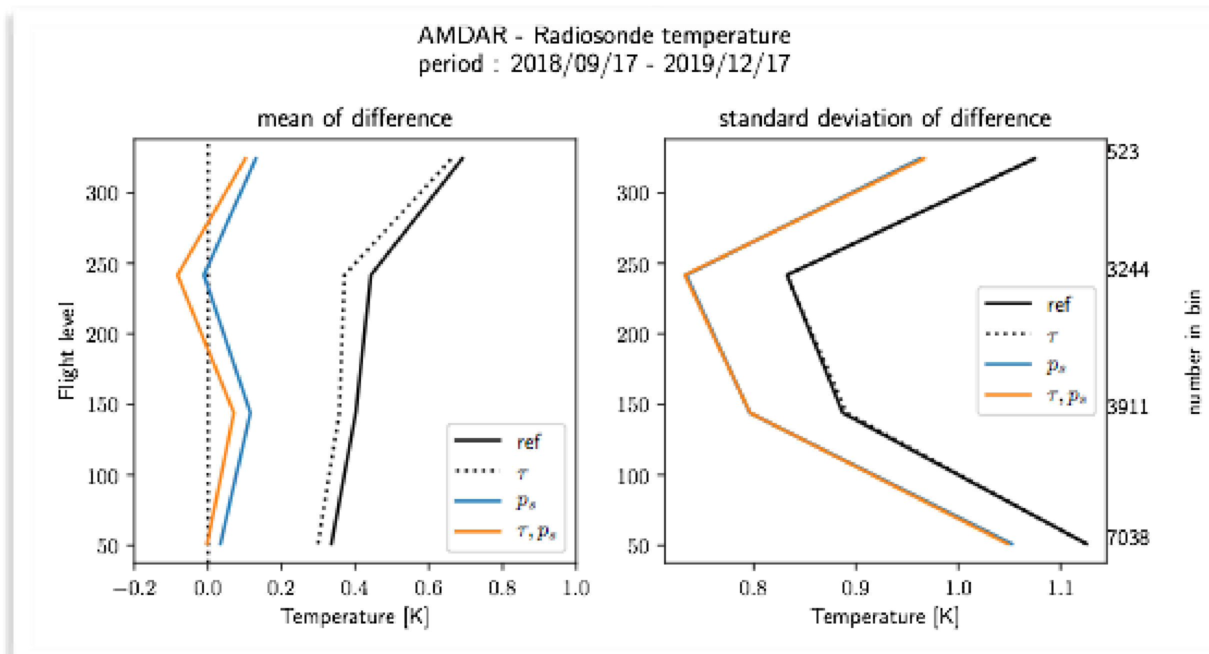
AMDAR bias is characterized by two corrections:
- timing related correction,
- accuracy related correction.

$$T_a = \tilde{T}_a \left(1+\lambda\left(\left(\frac{q_i}{f^{-1}(p_s, V_a, \ldots)}+1\right)^{\frac{\gamma-1}{\gamma}}-1\right)\right)\left(1+\lambda\frac{\gamma-1}{2}M^2\right)^{-1}$$

Both corrections can be found using an external source of temperature information;

The second correction requires additional parameters, such as true airspeed, indicated airspeed and Mach

The corrected AMDAR temperatures were compared to radiosonde observations from a different period



The resulting bias was diminished by the correction, while the standard deviation improved by almost 10 %.

Mode-S EHS information could be used to correct the AMDAR temperature bias, for those airspaces where Mode-S EHS information is available.

thanks and stay safe!

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