Development and use of thermistor sensors in a Rosemount 102 housing

12th November 2020

Hannah Price, FAAM Instrument Scientist

hannah.price@faam.ac.uk

FAAM

AIRBORNE LABORATORY

Measuring air temperature at FAAM

- FAAM has a team of instrument scientists looking after a suite of “core” instruments
- Data from these instruments is available to anyone using the aircraft

Measuring air temperature at FAAM

FAAM

- Indicated air temperature measured inside two Rosemount 102 housings
- Combined with pressure measurements and recovery factor to produce static air temperature

Measuring air temperature at FAAM

Non-de-iced housing is smaller, with smaller inlet

De-iced housing has optional heater, turned on manually in icing conditions

Improvements to air temperature at FAAM

	Present
Indicated temperature	PRT sensors calibrated regularly at National Physical Laboratory
Mach	Comes from static and dynamic RVSM pressure measurements
Recovery factor	Constant recovery factor for each housing measured via speed runs

Improvements to air temperature at FAAM

FAAM

	Present	Future
Indicated temperature	PRT sensors calibrated regularly at National Physical Laboratory	Thermistor sensors calibrated regularly at National Physical Laboratory
Mach	Comes from static and dynamic RVSM pressure measurements	Science static and dynamic pressure measurements, transducers calibrated regularly at Met Office
Recovery factor	Constant recovery factor for each housing measured via speed runs	A more refined recovery factor for each housing, uncertainty quantified

Improvements to air temperature at FAAM

FAAM

	Present	Improvements	Future
Indicated temperature	PRT sensors calibrated regularly at National Physical Laboratory	Thermistor calibration and processing to remove self-heating; New circuit to decrease susceptibility to noise	Thermistor sensors calibrated regularly at National Physical Laboratory
Mach	Comes from static and dynamic RVSM pressure measurements	Installation of new static pressure transducer; Position error calibration flight	Science static and dynamic pressure measurements, transducers calibrated regularly at Met Office
Recovery factor	Constant recovery factor for each housing measured via speed runs	Recovery factor measurement test flights; Conversations with Collins Aerospace	A more refined recovery factor for each housing, uncertainty quantified

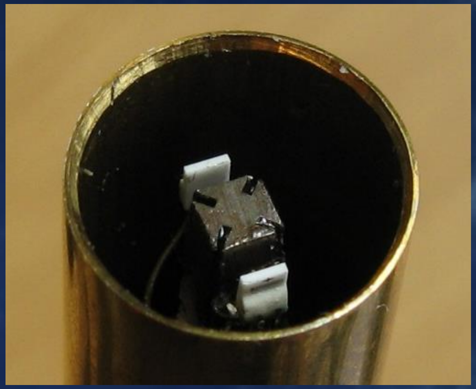
Improvements to air temperature at FAAM

FAAM

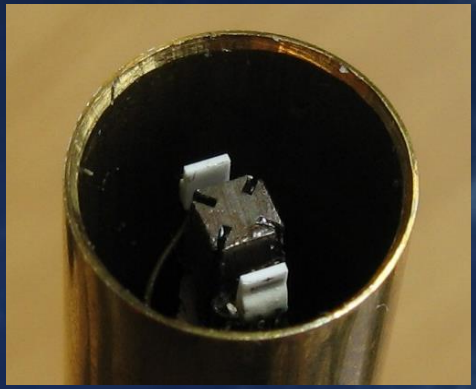
	Present		Future
Indicated temperature	PRT sensors calibrated regularly at National Physical Laboratory	Thermistor calibration and processing to remove self-heating New circuit to decrease susceptibility to noise	Thermistor sensors calibrated regularly at National Physical Laboratory
Mach	Comes from static and dynamic RVSM pressure measurements	Installation of new static pressure transducer Position error calibration flight	Science static and dynamic pressure measurements, transducers calibrated regularly at Met Office
Recovery factor	Constant recovery factor for each housing measured via speed runs	Recovery factor measurement test flights Conversations with Collins Aerospace	A more refined recovery factor for each housing, uncertainty quantified

Measuring air temperature: PRT sensors



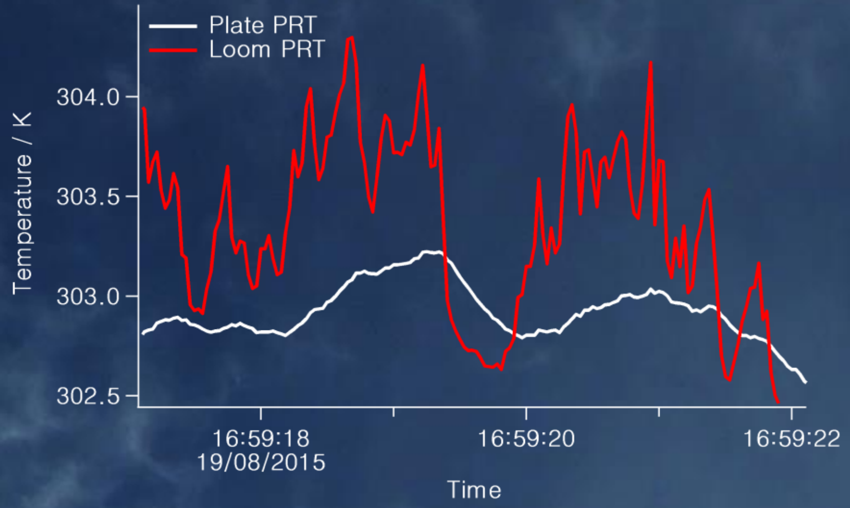



Measuring air temperature: PRT sensors



- Original sensors, “looms”, were thin platinum wire wound round mica support
- Fast response, but complex due to dual time constant
- Looms are fragile and can drift / fail suddenly
- Out of production, expensive to get one made
- Commercial thin-film PRTs can be mounted in an old holder
- Low-cost, robust and minimal calibration drift
- BUT slower (~1s) time response than loom

In-flight plate *vs* loom temperature response

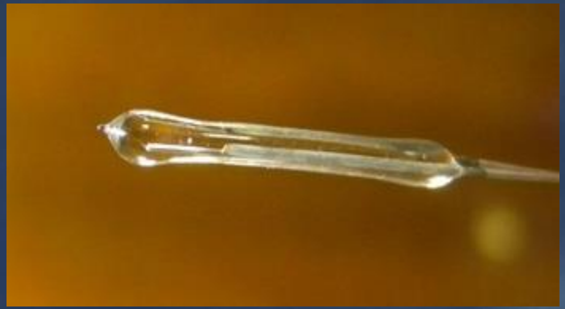


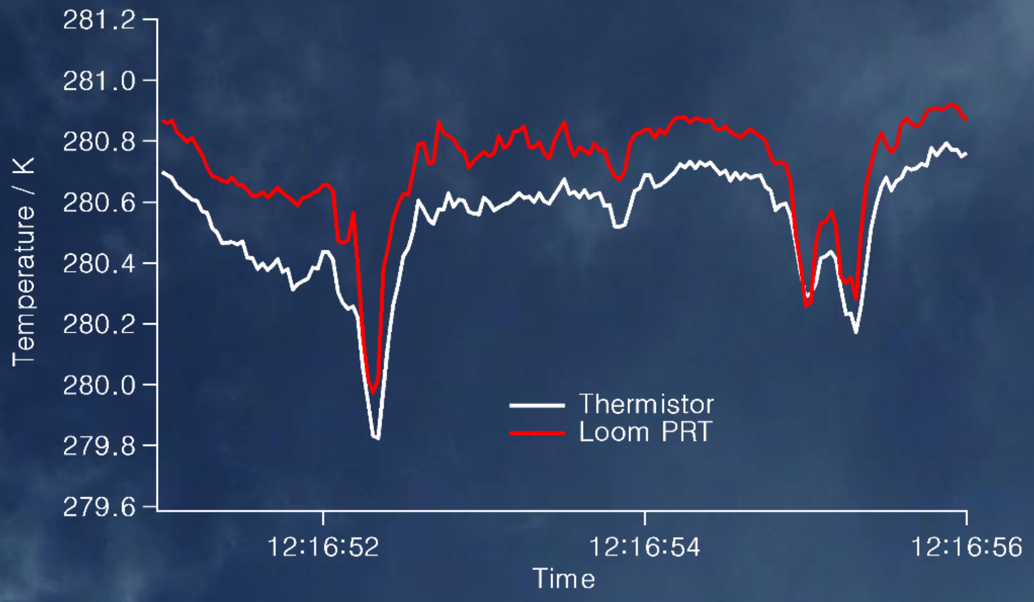
Measuring air temperature: thermistors

FAAM

- Commercially available (GE NTC Type FP07 Fastip Thermoprobes) fast response glass bead thermistors mounted instead of PRT in old holder
- Two of type FP07DA103N, 10 kΩ at 25 °C, and two of type FP07DB154N, 150 kΩ at 25 °C
  → Focussing here on FP07DA103N
- Initial tests indicate that response may be as fast as loom sensors, with minimal drift
- Thermistors currently susceptible to electronic noise

↳ New circuit being designed





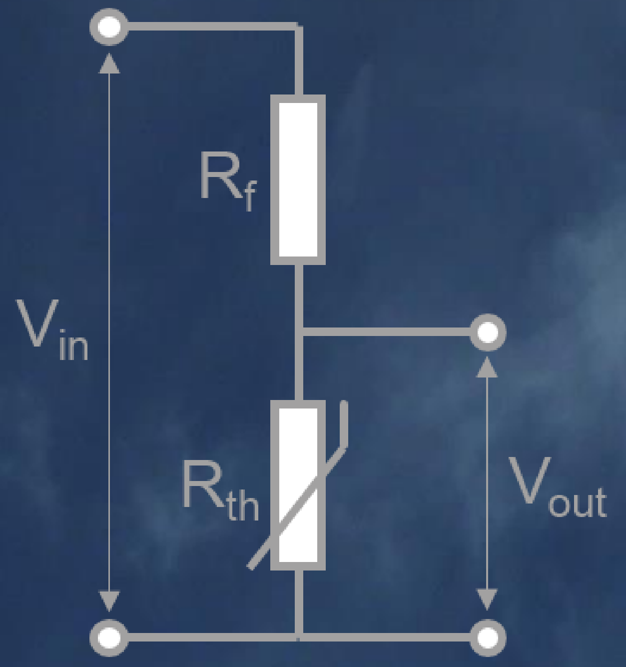
Calibrating FAAM's thermistors

FAAM

- Thermistors self-heat
  → needs to be handled carefully in calibration and processing
- Dissipation of heat depends on flow over sensing element
- Flow is small in the calibration lab, greater in-flight, how much?
- Need to correct for self-heating in calibration lab, and self-heating in-flight, without knowing the difference between flows
- Also, self-heating is temperature dependent:

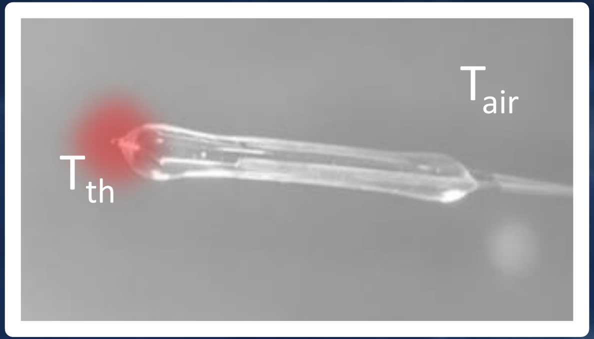
$$P = K\,(T_{th}-T_{air})$$

Power input to thermistor = dissipation constant x self-heating



Calibrating thermistors in the lab

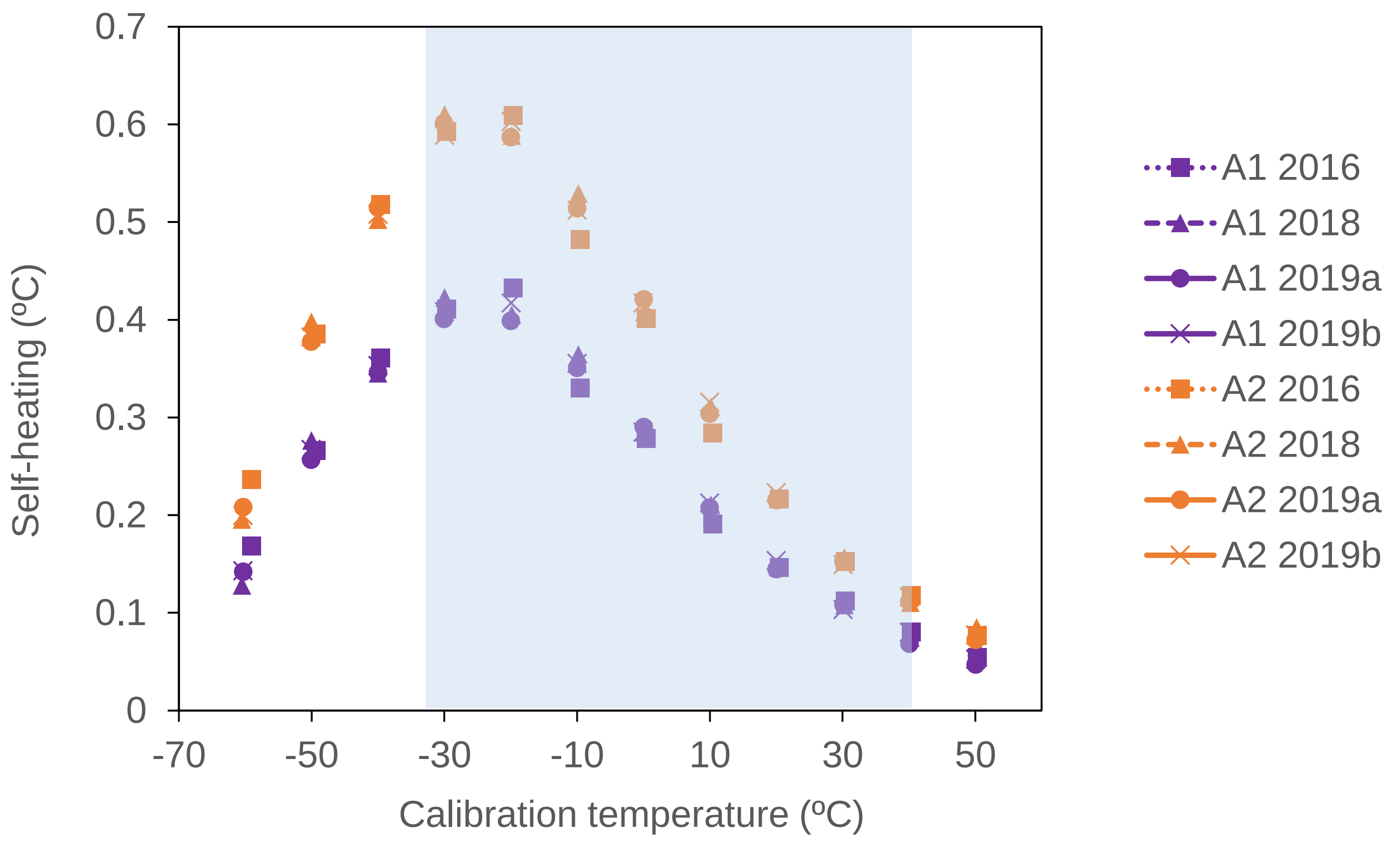
- Calibration happens in air, in chamber refreshed at 1 litre/minute
- Want to know how resistance relates to probe temperature (not air temperature)
- Need to measure self-heating as part of the calibration, in order to infer probe temperature
- To do this, calibrate at two voltages
- Reducing voltage by $1/\sqrt{2}$ reduces the self-heating by half
- Slight differences in resistance of thermistor measured for the two applied voltages at each calibration point allows us to calculate self-heating



Self-heating = T_{th} - T_{air}

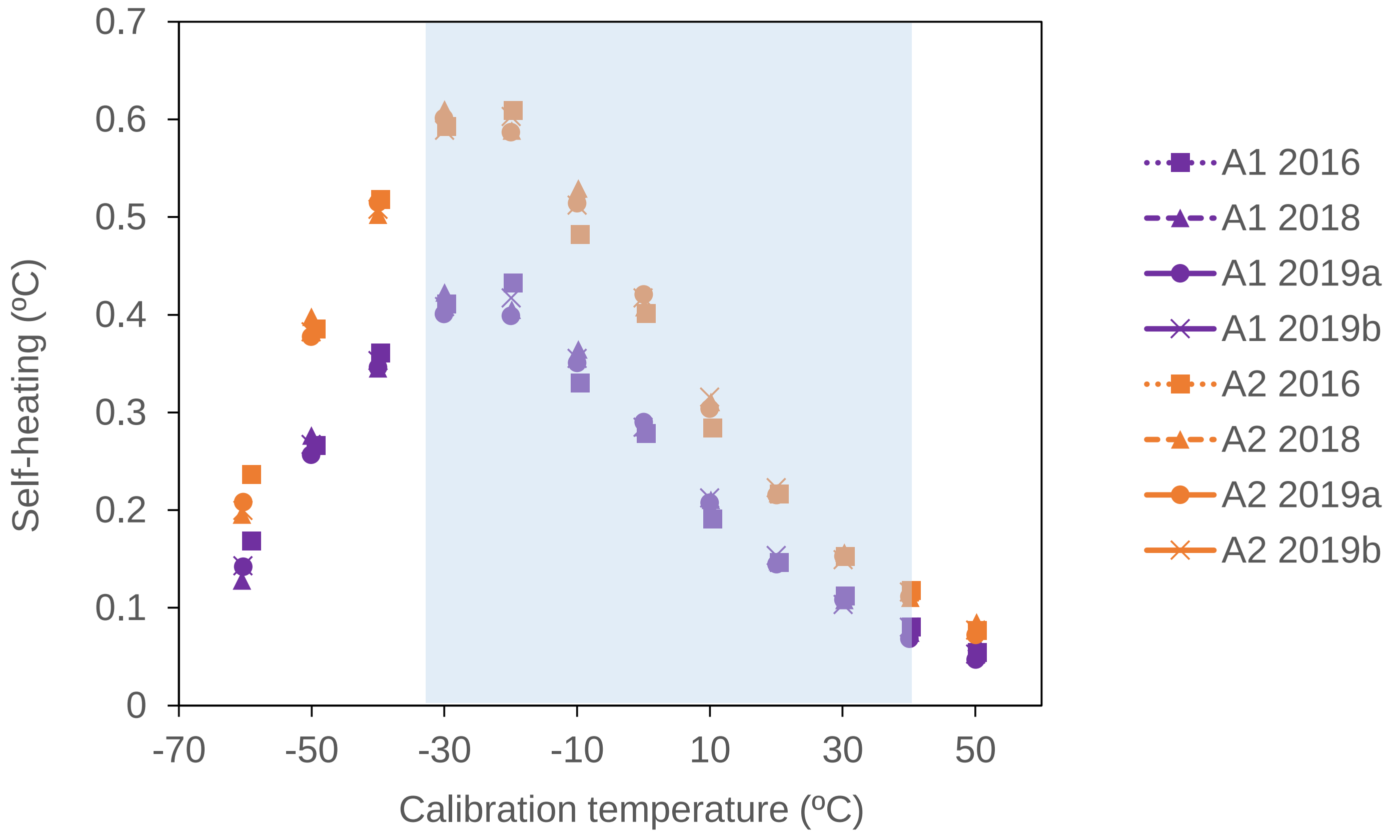
Calibrating thermistors in the lab

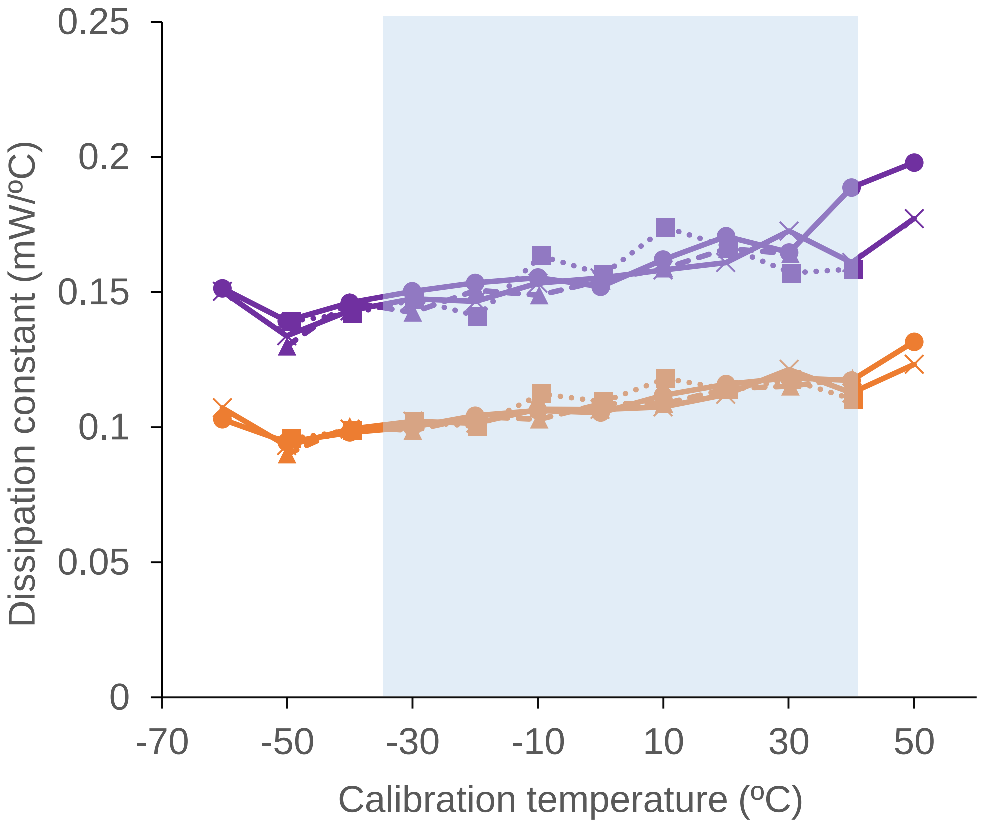
- Focussing on our two FP07DA103N thermistors, A1 and A2, each calibrated 4 times
- Both are the same type, but have different dissipation properties (glass thickness?)
- Self-heating and dissipation measurement is repeatable over 3 years



Calibrating thermistors in the lab

- Focussing on our two FP07DA103N thermistors, A1 and A2, each calibrated 4 times
- Both are the same type, but have different dissipation properties (glass thickness?)
- Self-heating and dissipation measurement is repeatable over 3 years





Using thermistors in flight

FAAM

- Now know how thermistor temperature relates to resistance ✓
- But how much self-heating is there in flight?
- Flow through housings will be greater in flight - no data (?) for how much

Using thermistors in flight

- Now know how thermistor temperature relates to resistance ✓
- But how much self-heating is there in flight?
- Flow through housings will be greater in flight - no data (?) for how much

  - Thermistors flown on 82 flights with applied voltage switched every 5 s (5 V and 5/√2 V)

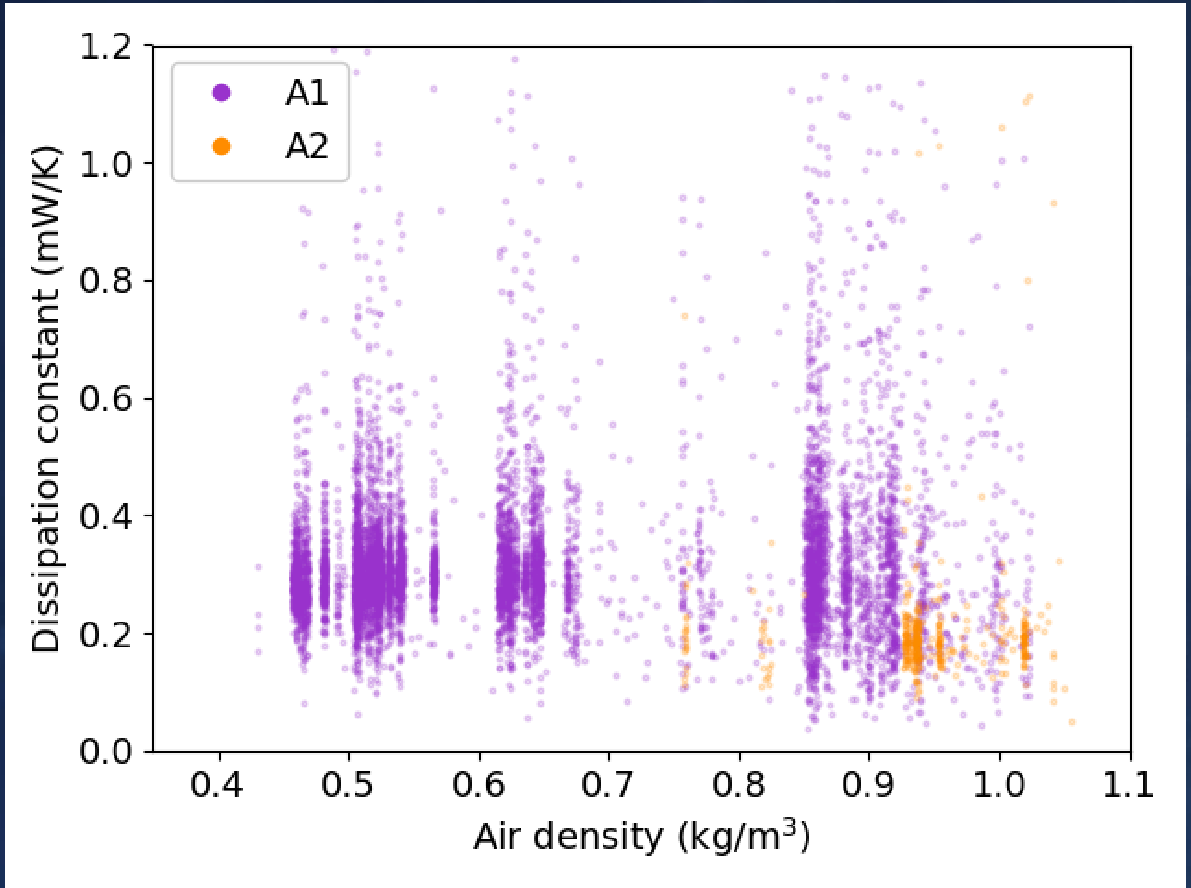
    ↳ >100,000 measures of self-heating (along with knowing power input to thermistor)

      ↳ >100,000 measures of dissipation constant

  - Tricky to analyse with temperature changing, so filtering required
  - Now need to look for any dependencies of dissipation on measured quantities

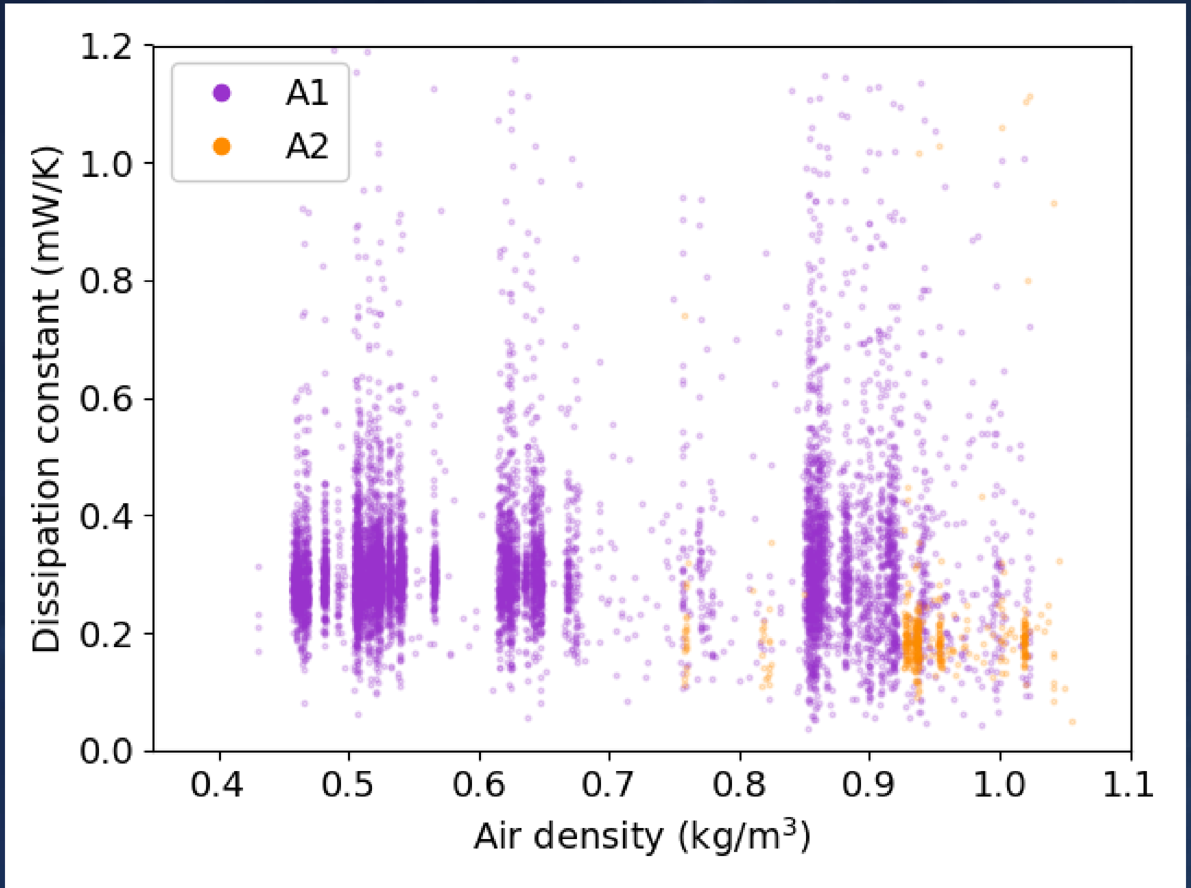
Thermistor self-heating in flight

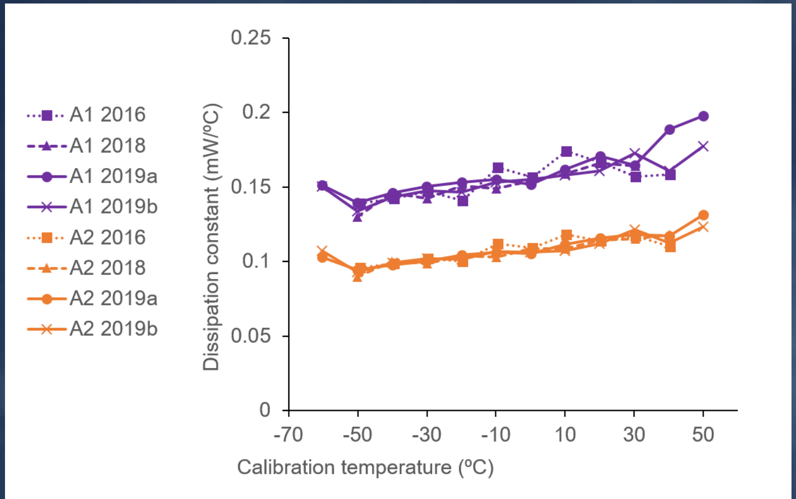
Example: does dissipation vary with air density?



Thermistor self-heating in flight

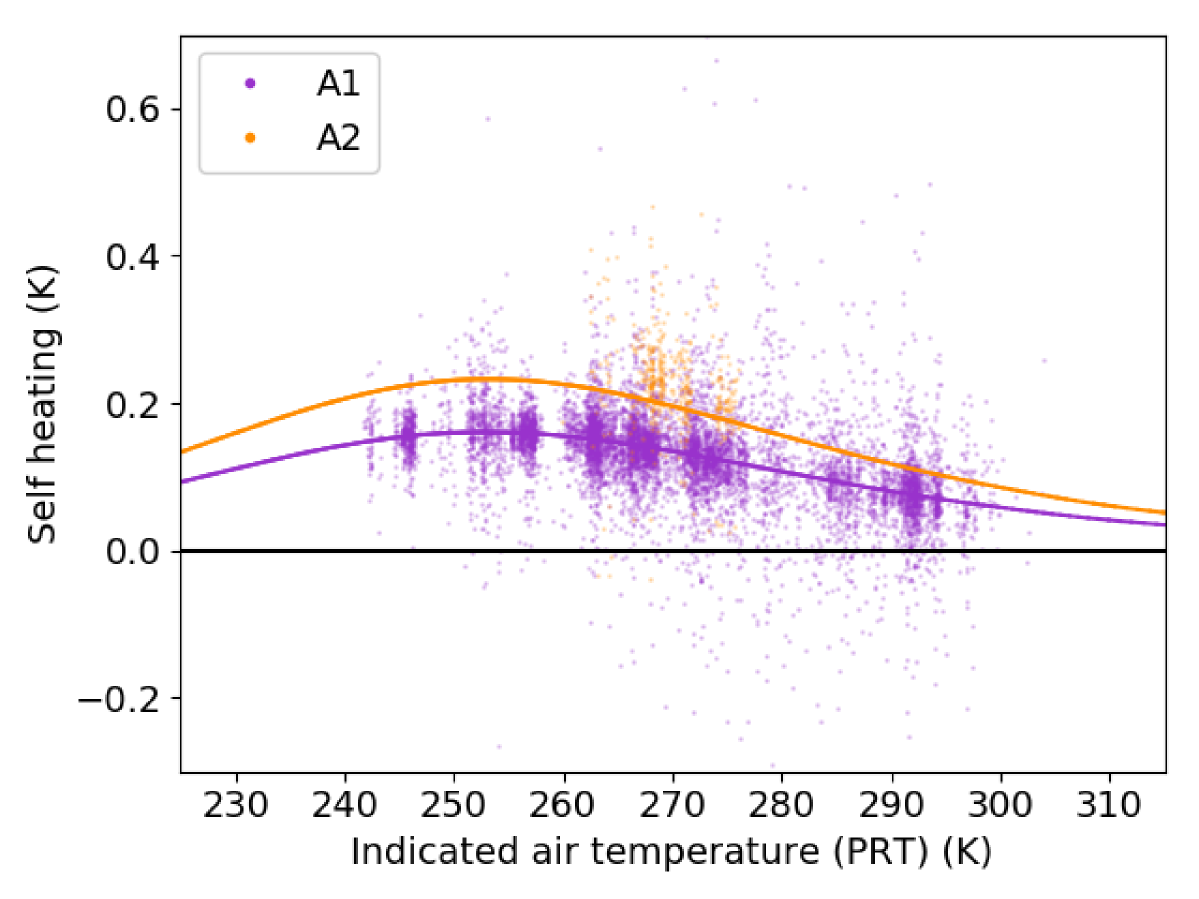
Example: does dissipation vary with air density?





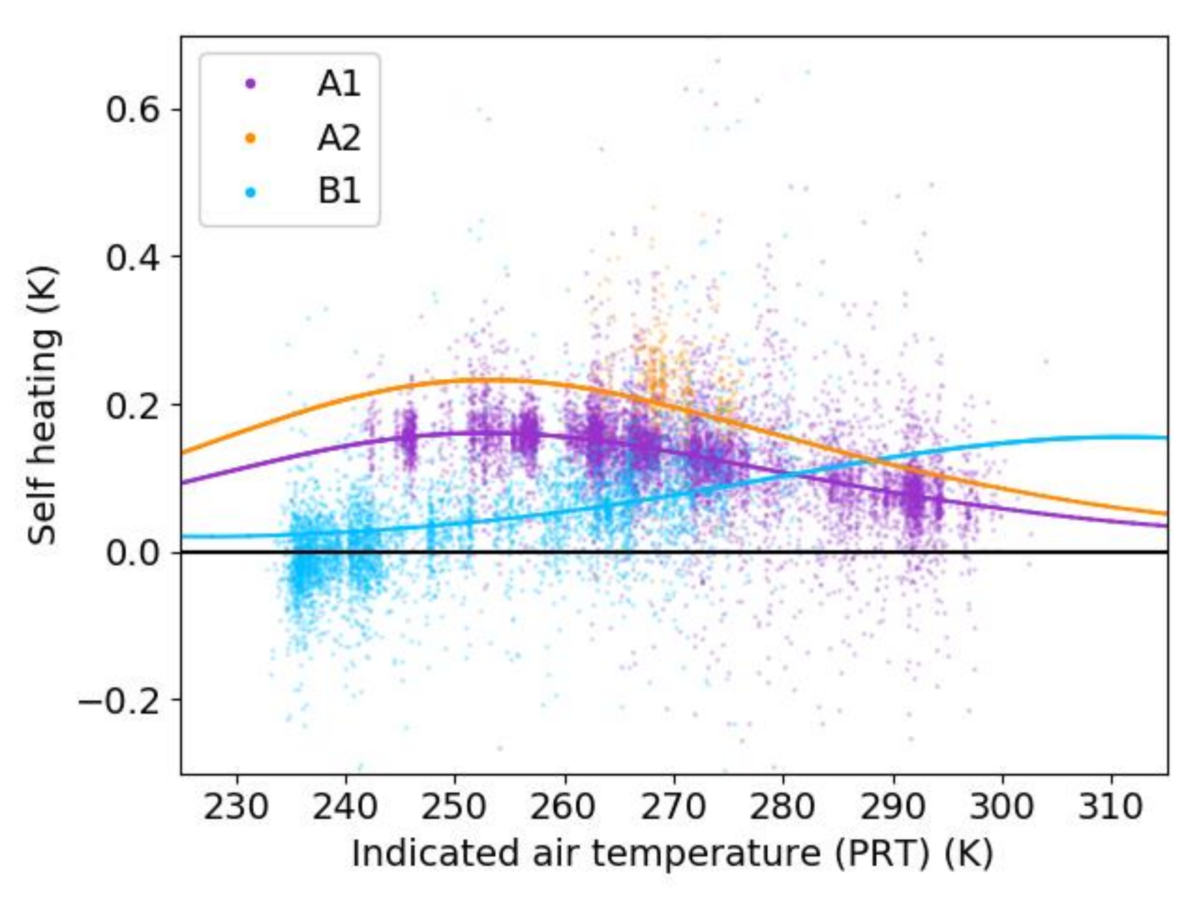
Thermistor self-heating in flight

- Sensor to sensor variation exists in flight
- Lines shown are for $k_{flight} = k_{lab} \times 1.97$

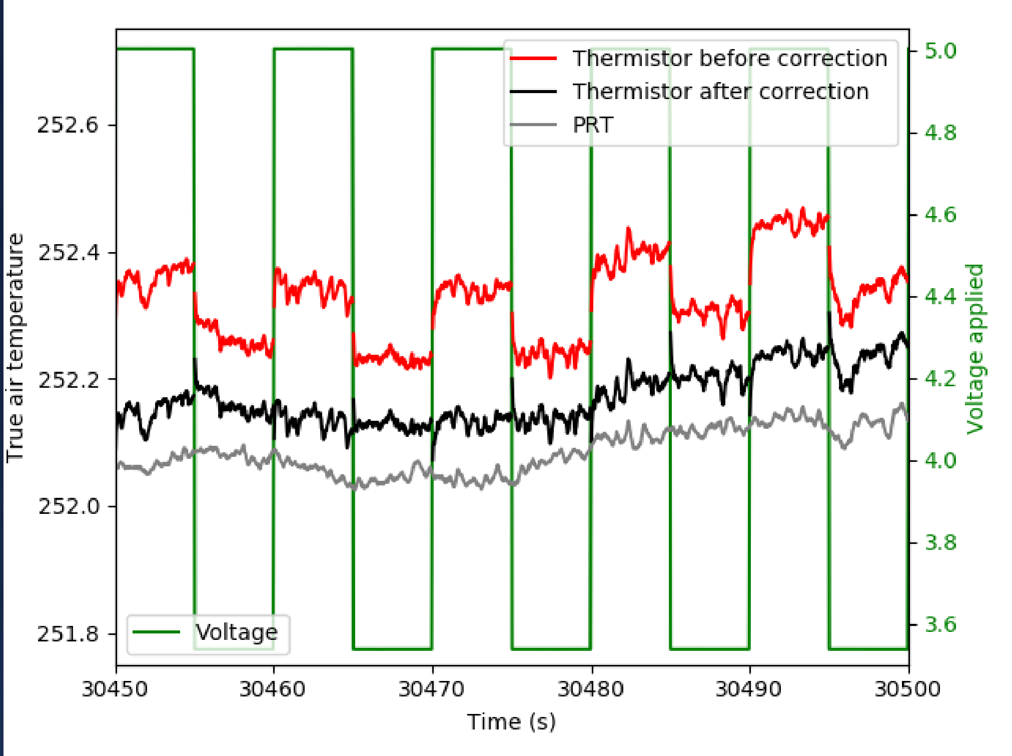


Thermistor self-heating in flight

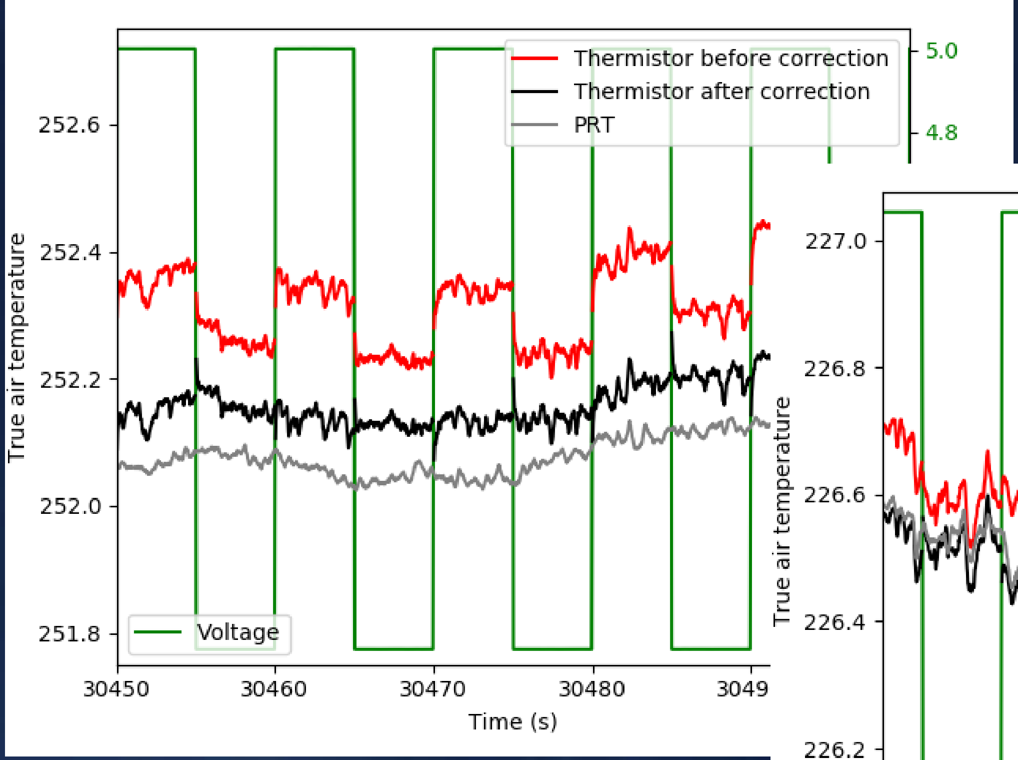
- Sensor to sensor variation exists in flight
- Lines shown are for $k_{flight} = k_{lab} \times 1.97$

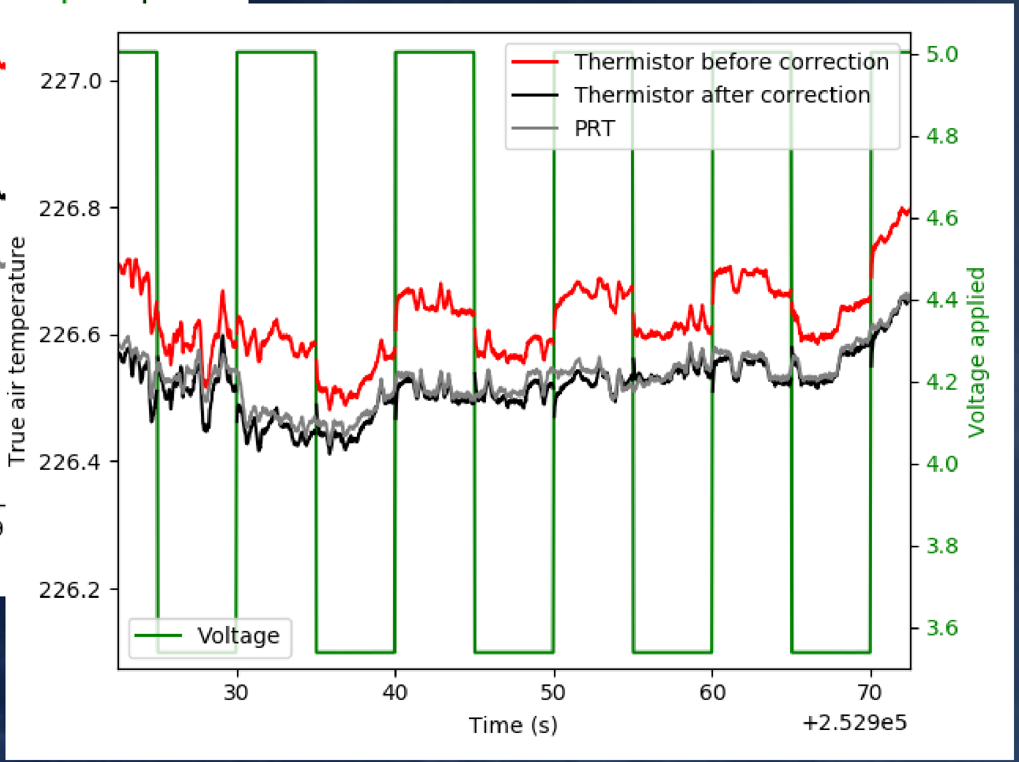


Measuring static air temperature: thermistors

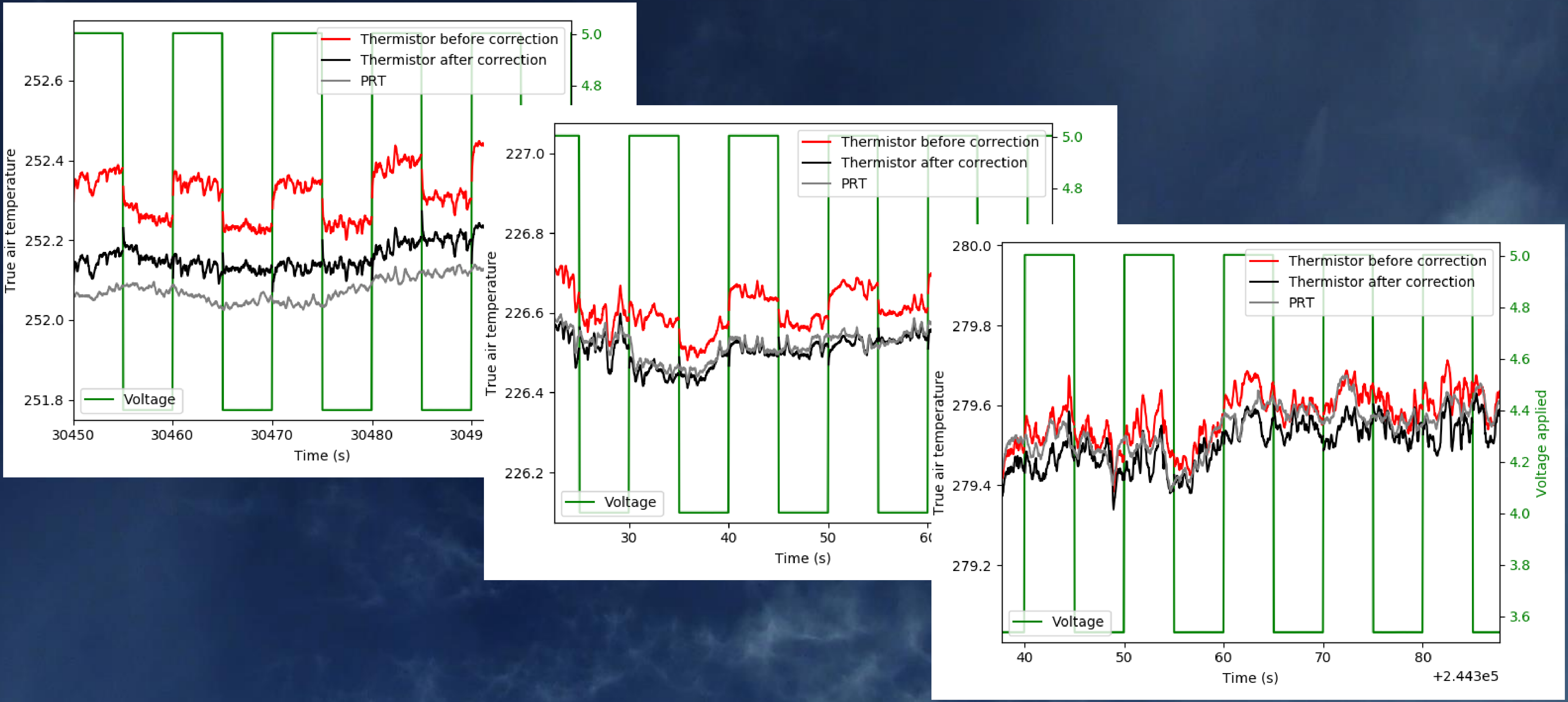


Measuring static air temperature: thermistors



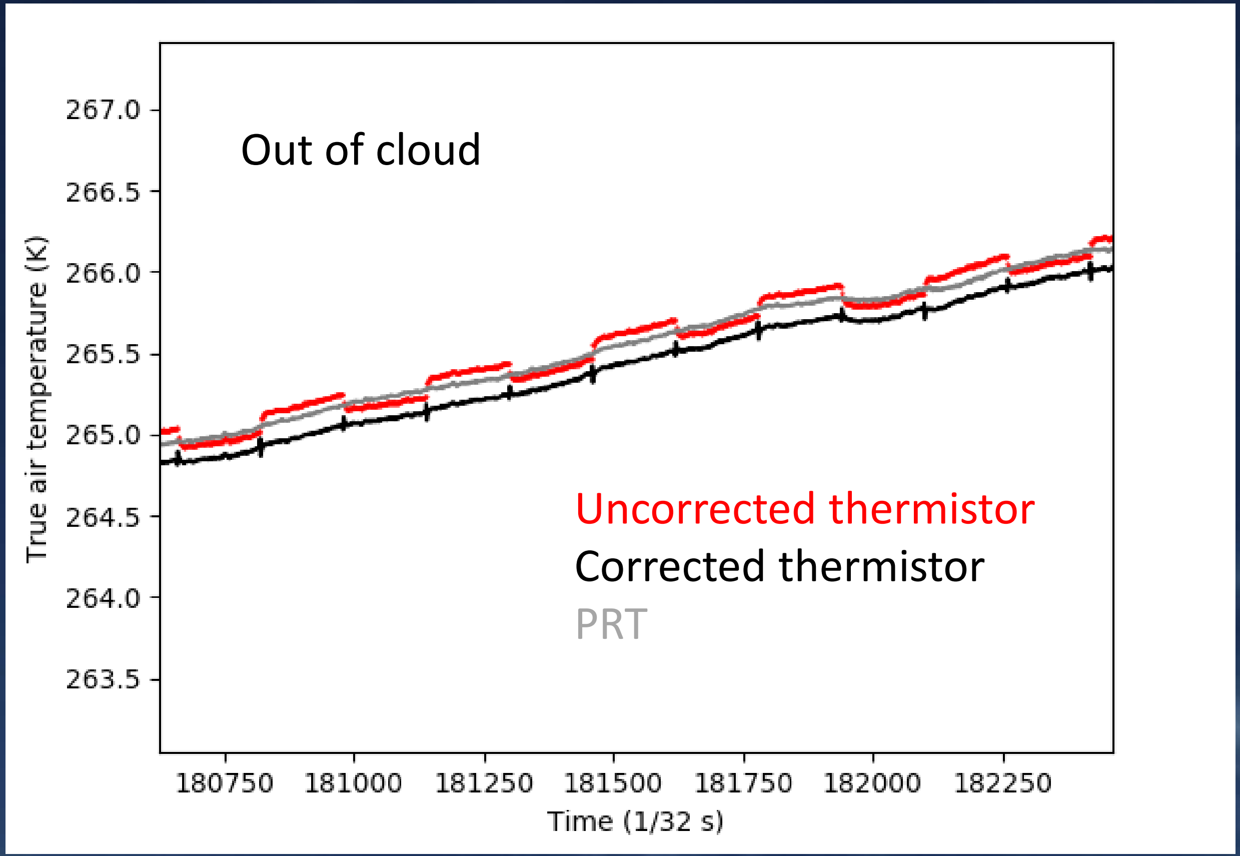


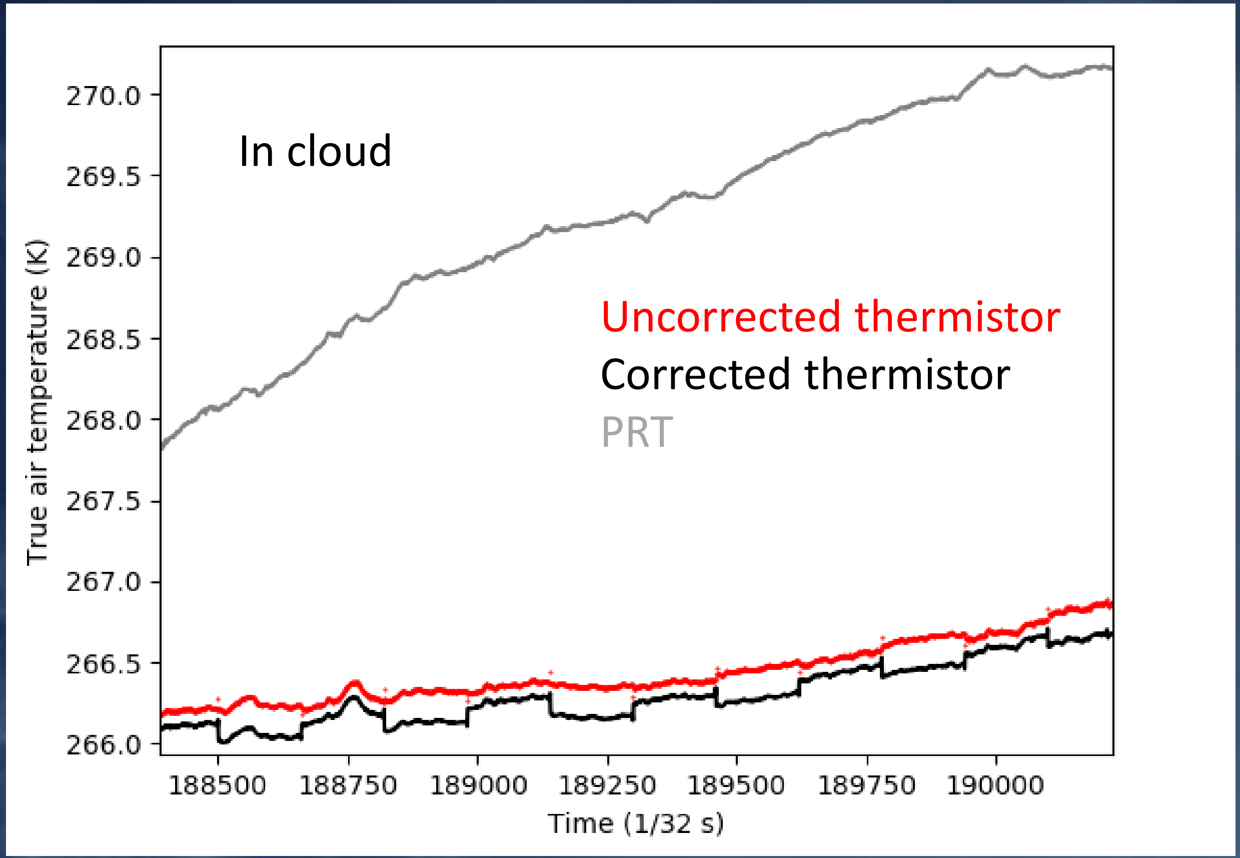
Measuring static air temperature: thermistors



What about when the sensor gets wet?

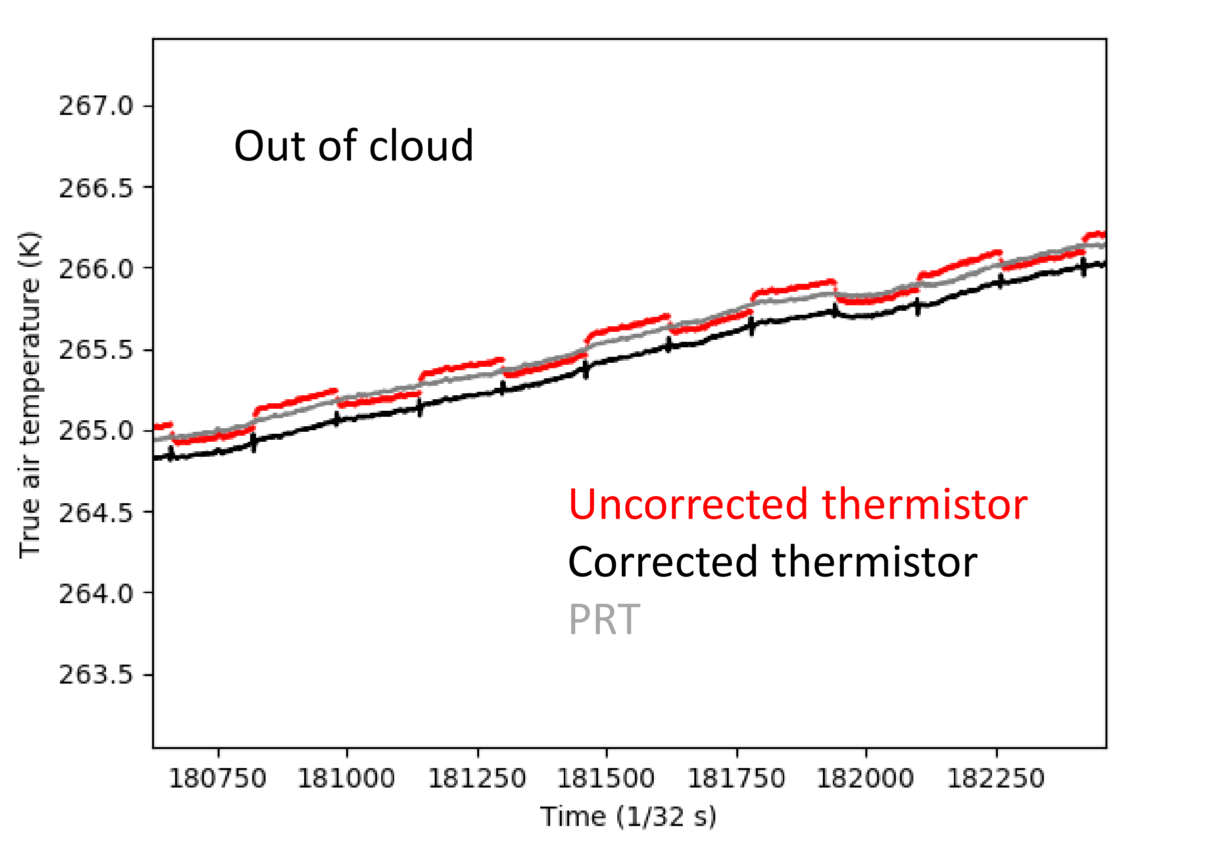
Correction doesn't work when sensor is wet
→ Different dissipation properties

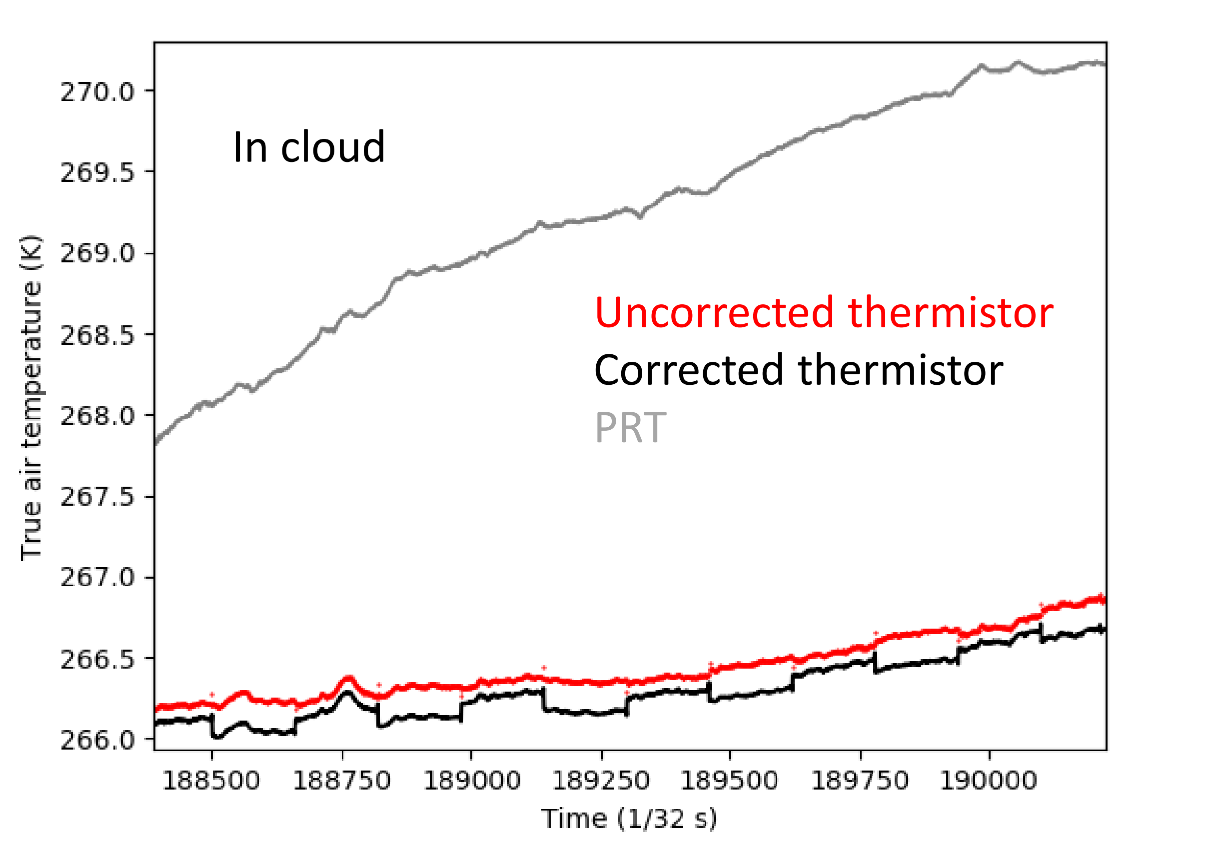




…now we can verify that a sensor isn't wetted

- Correction makes things worse, so this tells us sensor is wet
- So also tells us when sensor isn't wet
- We now know when we can trust temperature measurements in cloud
- Could investigate further – correlation between LWC and dissipation?





Summary

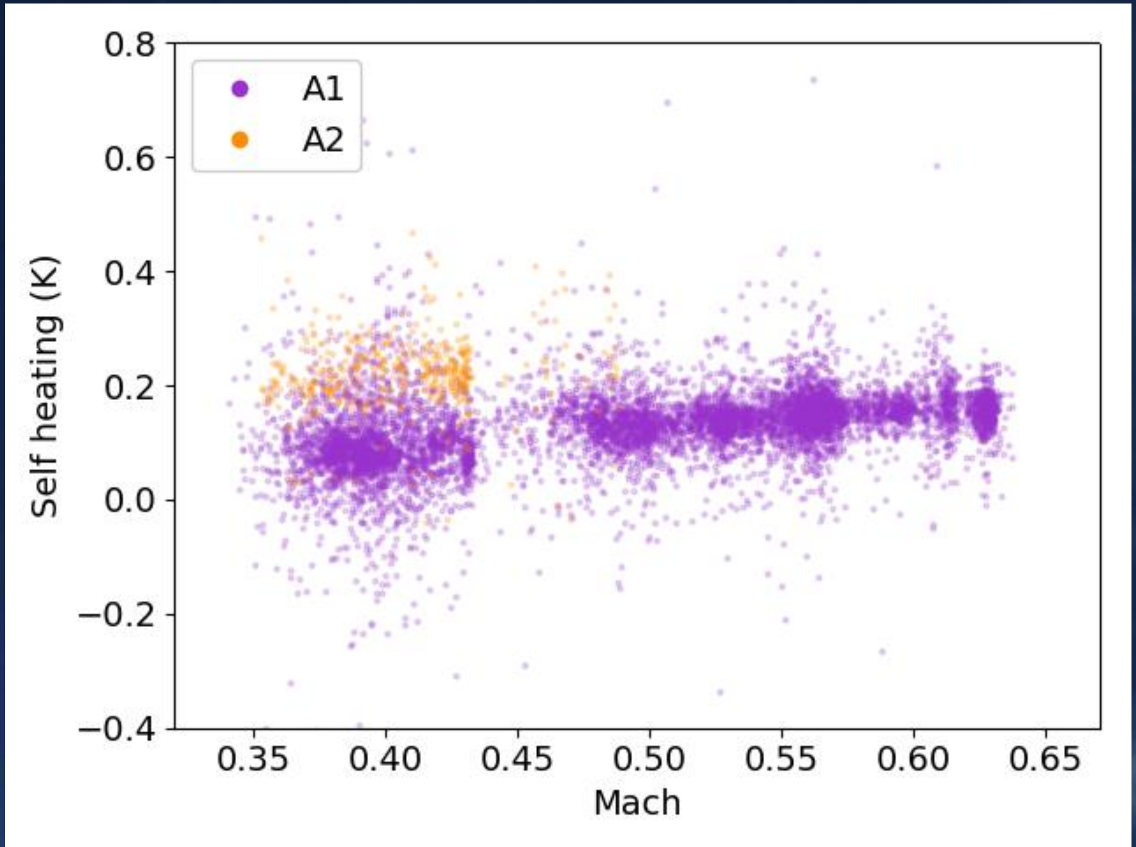
- New thermistor sensors provide a good alternative to original PRTs, flown on many flights
- Self-heating means calibration and processing isn't straightforward
  - → by switching voltages, we can measure self-heating and dissipation
- Dissipation properties evident from voltage switching in-flight tells us if sensor is wetted
  - → we can now know if a sensor is successfully measuring in-cloud air temperature

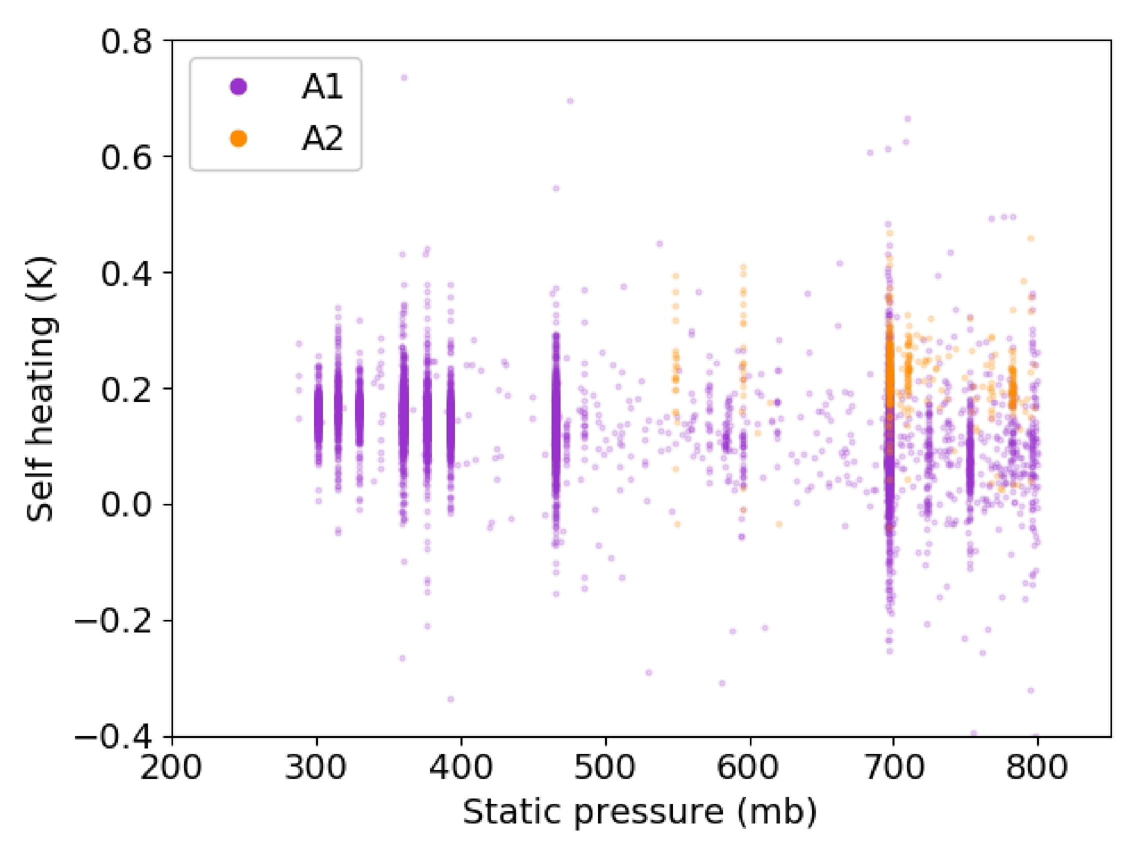
Hannah Price, FAAM Instrument Scientist

hannah.price@faam.ac.uk

FAAM
AIRBORNE LABORATORY

Thermistor self-heating in flight





(In-flight, Mach, temperature, pressure and air density are all tied to altitude)

temperature of the air as if we weren’t there disturbing things

Measuring static air temperature

Time response ↔ spatial resolution

- Sensor needs low thermal mass – delicate!
- Sensor also shouldn’t get wet

temperature of the air as if we weren’t there disturbing things

Measuring static air temperature

Time response ↔ spatial resolution

Sensor needs low thermal mass – delicate!
Sensor also shouldn’t get wet

Let’s put it in a housing

temperature of the air as if we weren't there disturbing things

Measuring static air temperature

Time response ↔ spatial resolution

Sensor needs low thermal mass – delicate!
Sensor also shouldn't get wet

Let's put it in a housing

Air flowing through the housing gets compressed and slows down…

temperature of the air as if we weren’t there disturbing things

Measuring static air temperature

Time response ↔ spatial resolution

Sensor needs low thermal mass – delicate!
Sensor also shouldn’t get wet

Let’s put it in a housing

Air flowing through the housing gets compressed and slows down…

Uh oh, that makes it warm up. By up to 15^{o}C! We wanted to know its temperature!

temperature of the air as if we weren't there disturbing things

Measuring static air temperature

Time response ↔ spatial resolution

Sensor needs low thermal mass – delicate!

Sensor also shouldn't get wet

Let's put it in a housing

Air flowing through the housing gets compressed and slows down…

Uh oh, that makes it warm up. By up to 15°C! We wanted to know its temperature!

Have to characterise how it warms up

$$\frac{T_i}{T_s} = 1 + \left(r \times \frac{\gamma - 1}{2} \times M^2 \right)$$

Temperature of the sensor (T_i)

What we want to know (T_s)

Recovery factor of housing (r)

Mach, comes from static and dynamic pressure (M)

temperature of the air as if we weren't there disturbing things

Measuring static air temperature

Time response ↔ spatial resolution

Sensor needs low thermal mass – delicate!
Sensor also shouldn't get wet

Let's put it in a housing

Air flowing through the housing gets compressed and slows down…

Uh oh, that makes it warm up. By up to 1[illegible]ºC! We wanted to know its temperature!

Have to characterise how it warms up

Getting temperature right depends on getting pressure right

Recovery factor of housing

Temperature of the sensor

What we want to know

$$\frac{T_i}{T_s} = 1 + \left(r \times \frac{\gamma - 1}{2} \times M^2 \right)$$

Mach, comes from static and dynamic pressure

temperature of the air as if we weren't there disturbing things

Measuring static air temperature

Time response ↔ spatial resolution

Sensor needs low thermal mass – delicate!
Sensor also shouldn't get wet

Let's put it in a housing

Air flowing through the housing gets compressed and slows down…

Uh oh, that makes it warm up. By up to 15ºC! We wanted to know its temperature!

Have to characterise how it warms up

Temperature of the sensor ✔

What we want to know

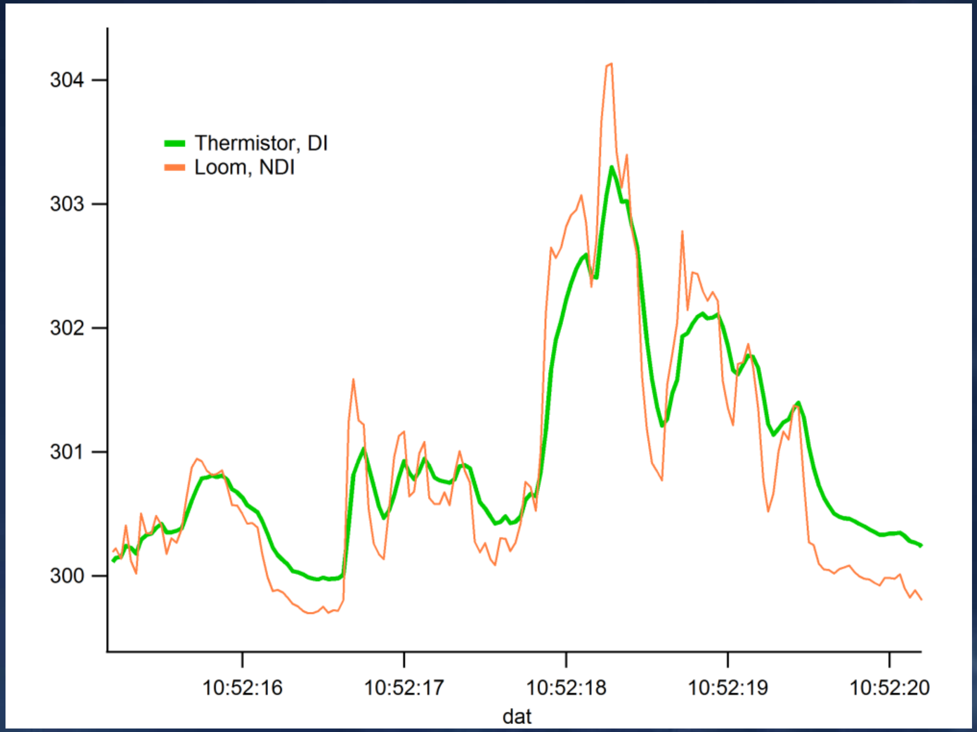
$$\frac{T_i}{T_s} = 1 + \left(r \times \frac{\gamma - 1}{2} \times M^2 \right)$$

Recovery factor of housing

Mach, comes from static and dynamic pressure

ROOM FOR IMPROVEMENT

Thermistors – example flight data 2019



Magnitude of variations in thermistor temperature less than for loom. Peaks and troughs occur at the same time though.

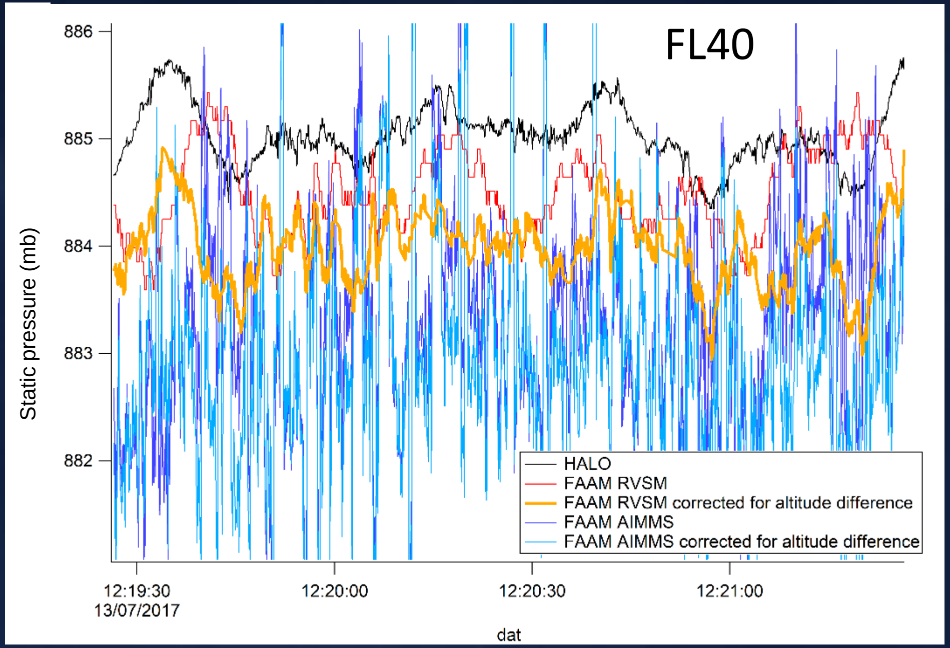
- Is the thermistor sensor slower to respond to changes in temperature?
- Does the loom overshoot?
- Is the thermistor signal over-damped by the sampling electronics?

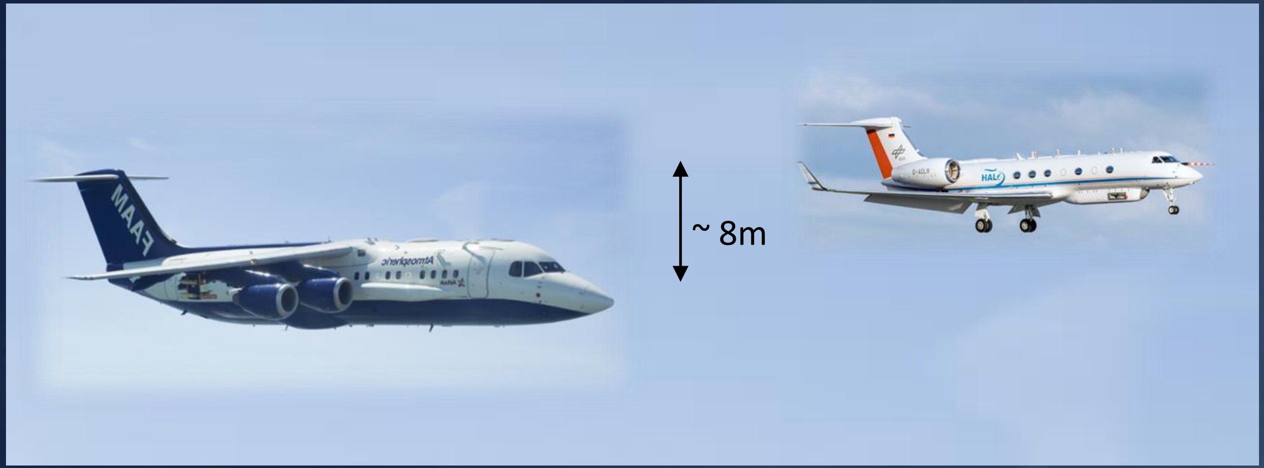
Measuring static air temperature: de-icing

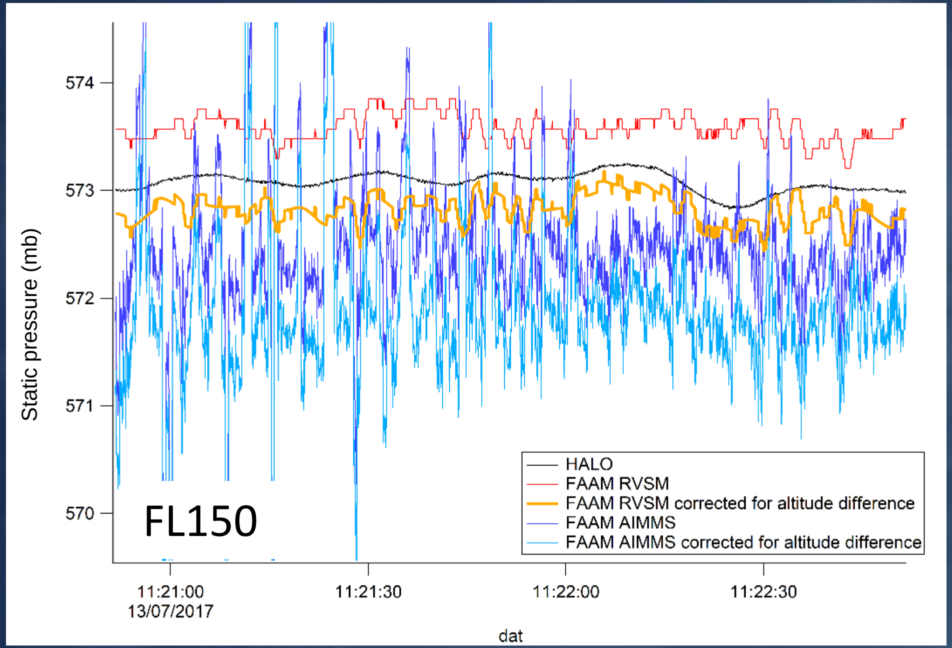
Measuring static air temperature: de-icing

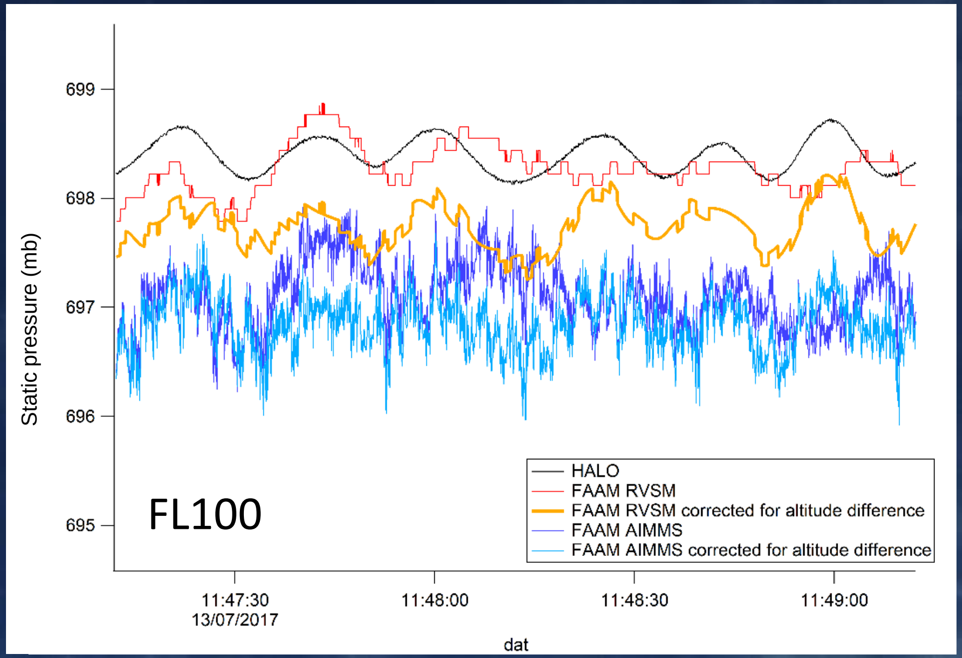
Measuring static air temperature: de-icing

- Housings can clog up with ice
- De-iced housing has optional heater
- More changing the temperature of the thermometer!
- Can be corrected for, but sensor wetting still an issue in both housings









RVSM Pressure