Development at the University of North Dakota of a Digital Thermosonde Instrument for the Study of Atmospheric Optical Turbulence

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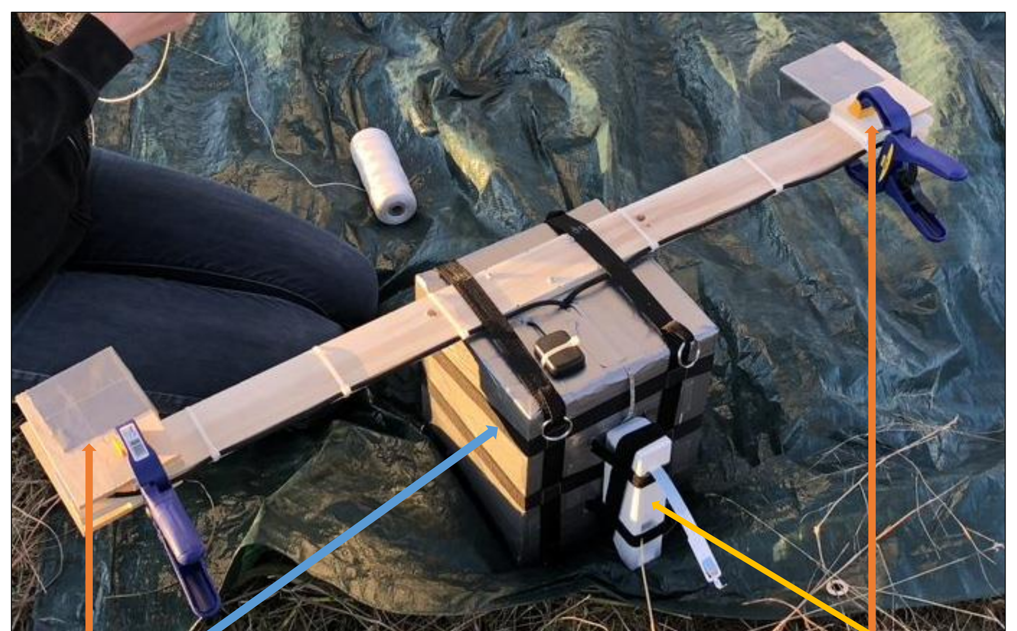
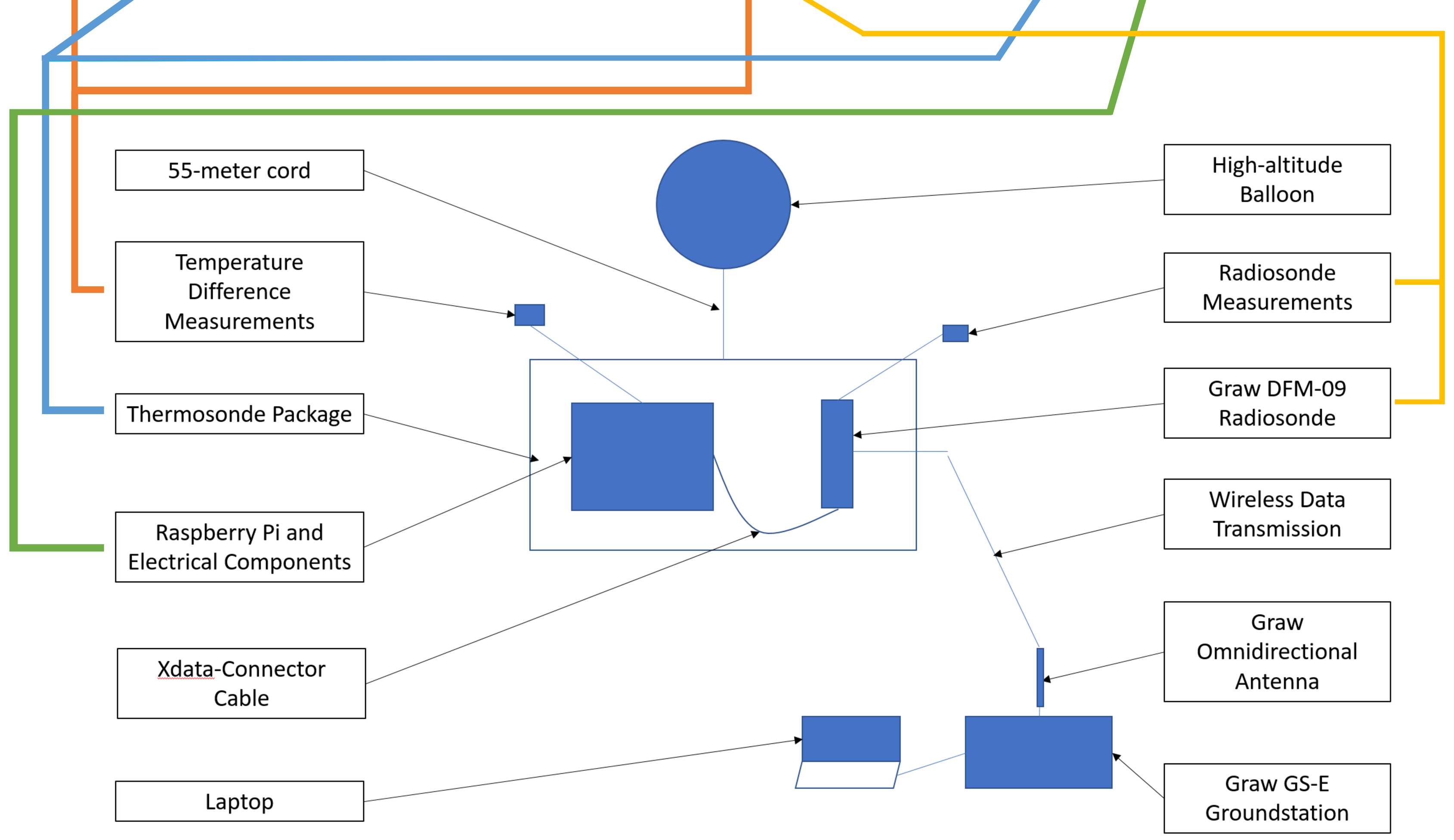
Objective

Atmospheric optical turbulence affects the transmission of electromagnetic waves between the Earth's surface and orbit. High optical turbulence results in noisier ground to satellite communication and degraded satellite images. Optical turbulence profiles can increase the quality of Earth surface images obtained from satellites and stellar object images taken from ground telescopes. A NASA Undergraduate Student Instrument Project (USIP) at the University of North Dakota constructed a balloon-borne digital thermosonde instrument to measures high-resolution temperature differences using fine-wire platinum thermocouples. The digital thermosonde designs are based on the design originally developed by NASA in the 1970s and improved on by the Air Force Research Laboratory.

Thermosonde

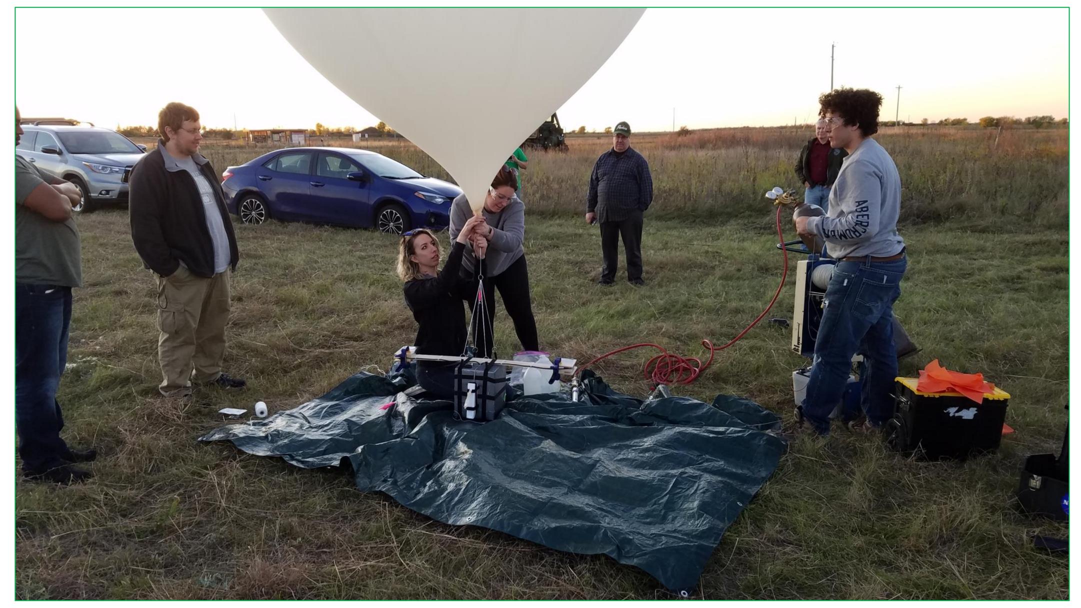
The digital thermosonde as it was at the launch site at the Glacial Ridge Field Site before the first tethered flight on 29 September 2017. The grey duct tape-covered box (blue arrow) at the center houses the thermosonde electrical components (green arrow), the Raspberry Pi and a GPS receiver. At each end of the one-meter wood board, covered by protective wood blocks, are the two 2 um-diameter platinum wire temperature difference probes (orange arrow). The white Styrofoam instrument on the back of the thermosonde is a Graw DFM-09 radiosonde (gold arrow), which is connected to the inside of the thermosonde by the XDATA connector cable.



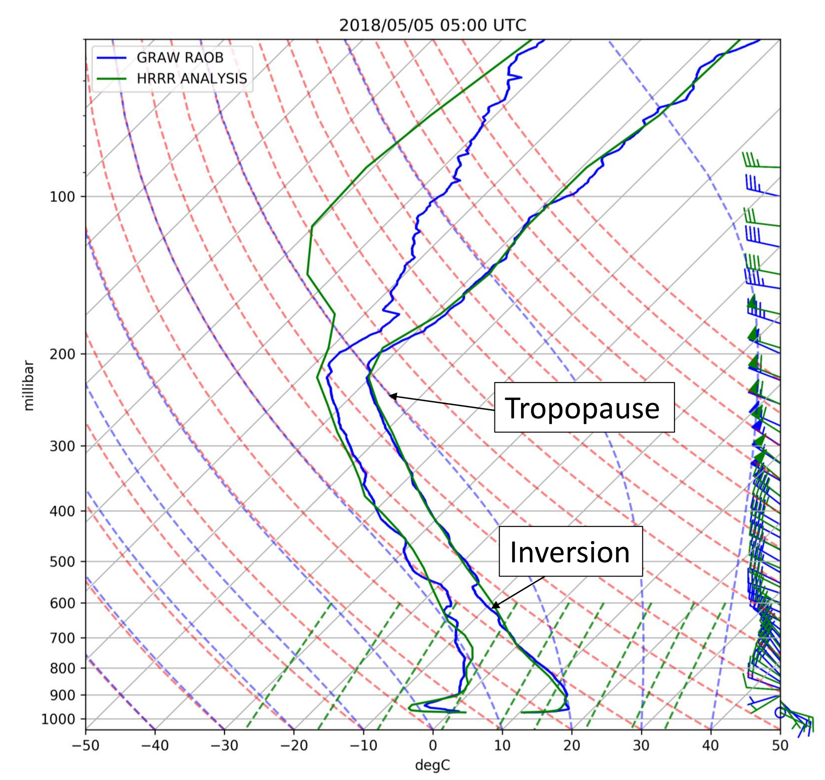


The thermosonde is connected to a high-altitude balloon by a 55-meter cable. Voltage from the temperature differences probes are sampled at 5 Hz by electrical components inside the thermosonde package. The voltage signal is smoothed, digitalized, averaged (to 1 Hz), and combined into a single voltage value. The Raspberry Pi send the averaged voltage to the Graw DFM-09's data stream using the X-data connector cable. The voltage measurement is combined with the radiosonde's standard meteorological measurements and sent down to the Graw GS-E groundstation.

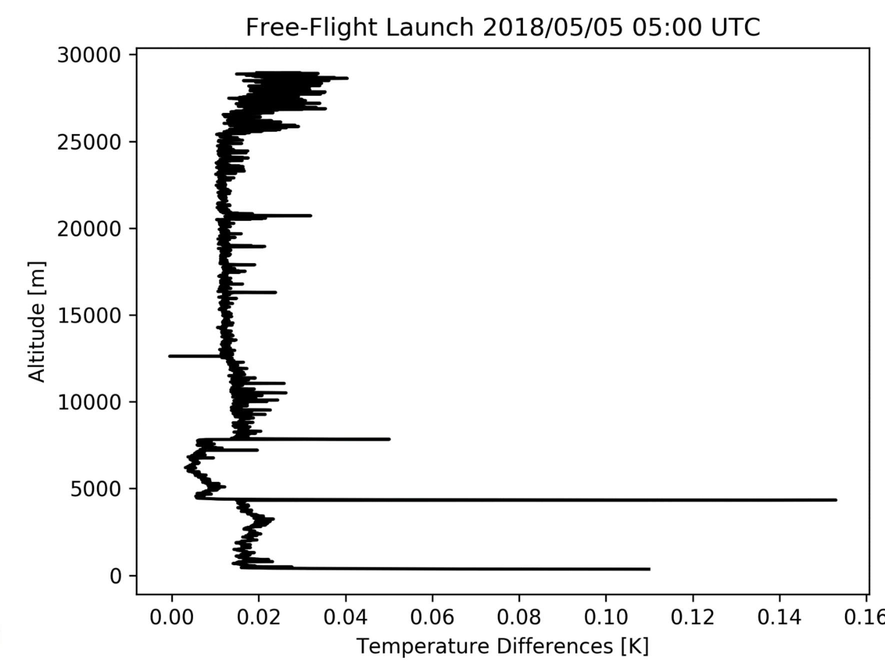
Flight Data



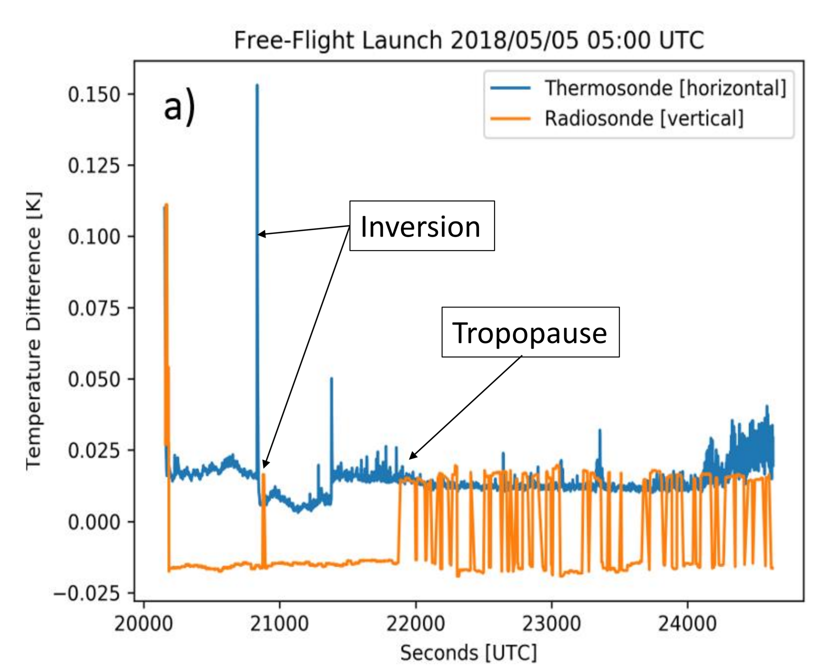
The thermosonde being attached to the balloon during the first tethered flight test. For the free-flying launch, the thermosonde was not attached directly to the balloon as in these pictures; it was attached to a 55-meter cord hanging below the balloon.

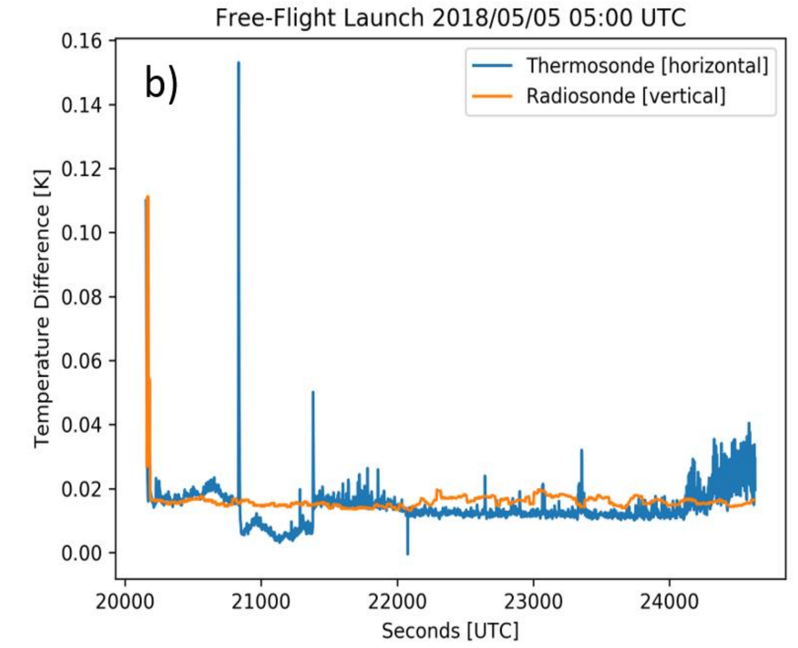


The temperature and dew point measurements from the Graw DFM-09 radiosonde in the thermosonde package (blue) and a HRRR model forecast sounding for the closest time and location to the launch site (green) for the free-flying launch on 5 May, 2018. The tropopause and an inversion in the middle of the troposphere are features that can be found in the thermosonde measurements.



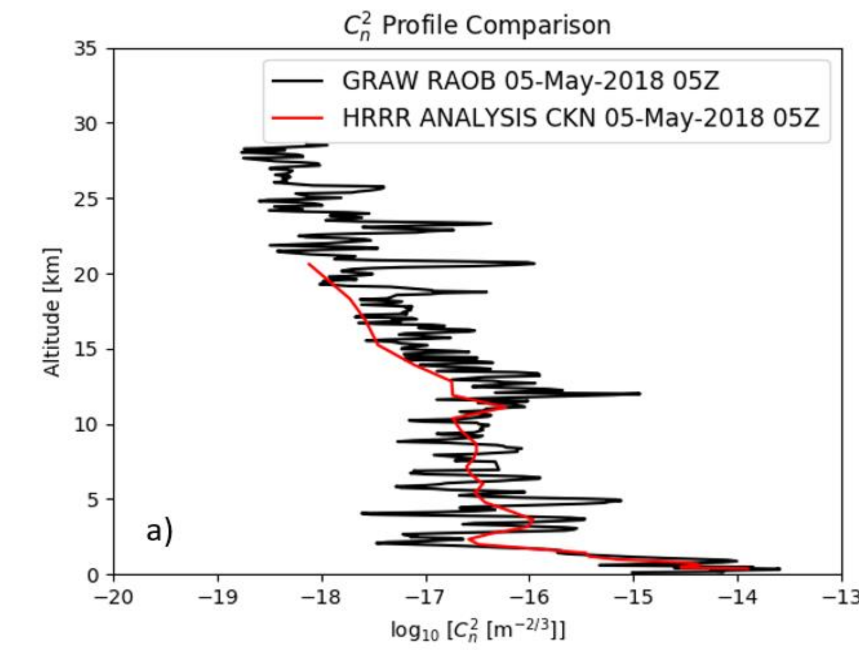
The horizontal temperature differences measured by the thermosonde throughout the ascent. The larger differences at the top of the profile are likely due to increased turbulence behind the enlarged balloon shortly before balloon burst. The large spike at the bottom of the profile is a result of initializing the instrument in a heated trailer and moving the instrument outside into the cold to launch.

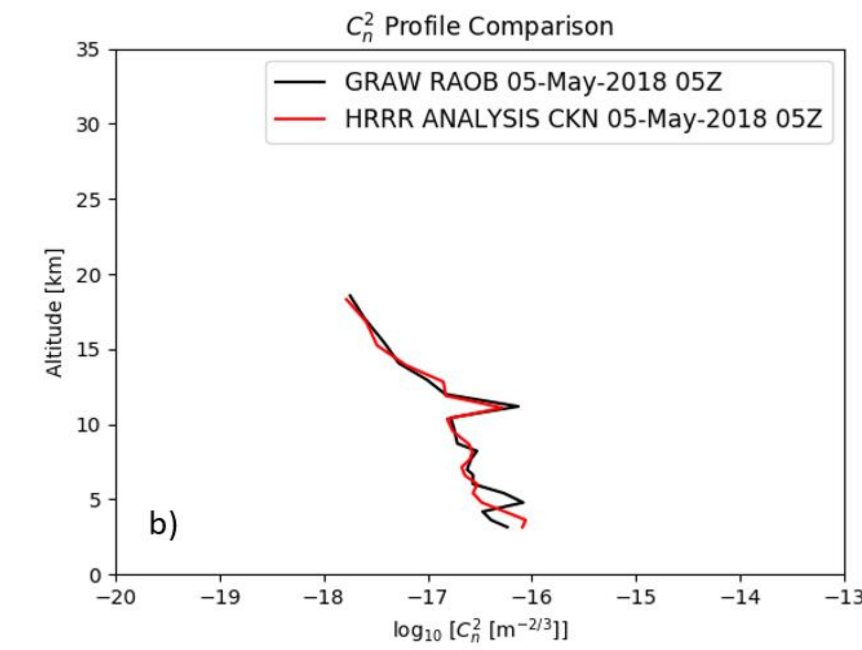




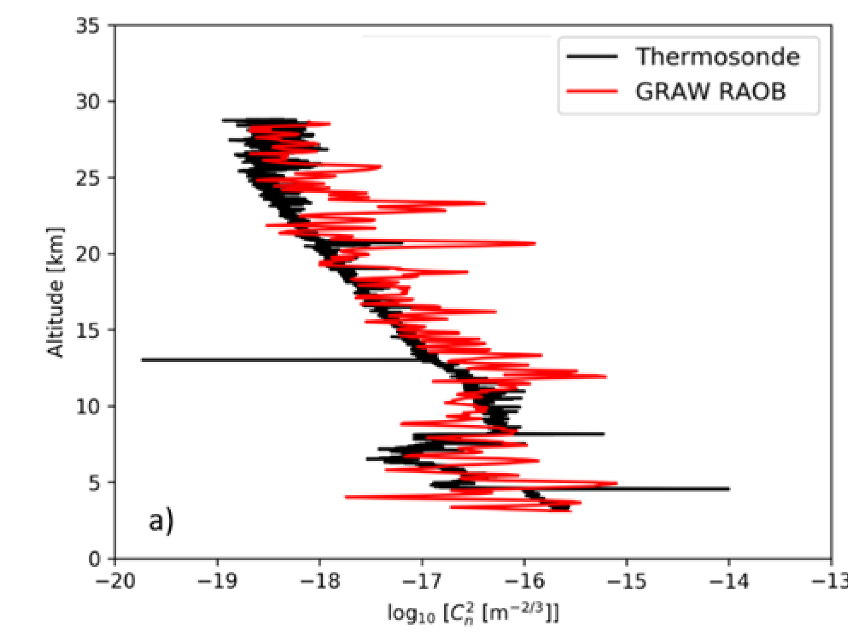
The thermosonde measures (below) of horizontal temperature differences (blue) and the vertical temperature differences from consecutive radiosonde temperature measurements (orange). The vertical and horizontal temperature difference show similar features, including the tropopause and the inversion near 550 mb. The absolute value of the radiosonde vertical temperature differences (right, orange) has a similar magnitude as the thermosonde horizontal temperature differences.

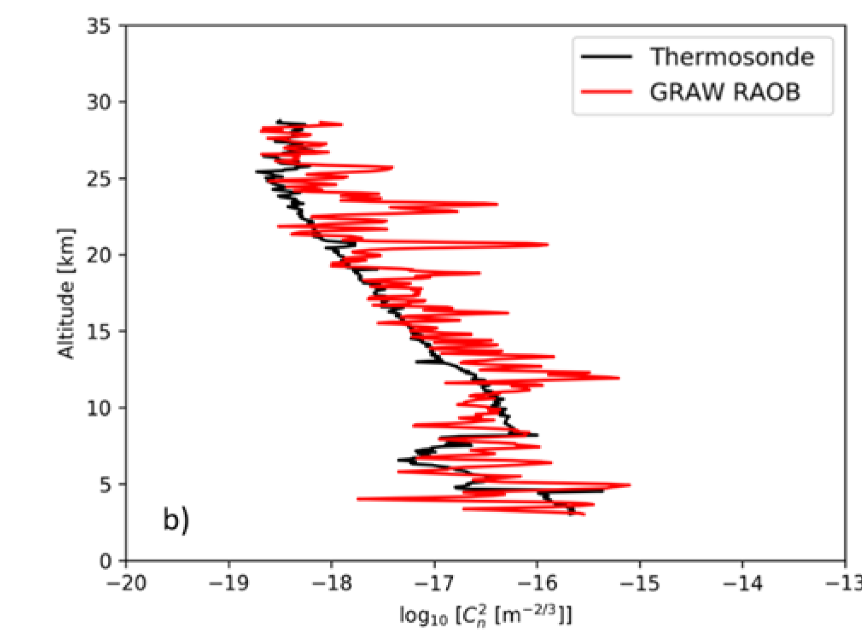
Results





The estimated refractive index structure parameter (C_n^2) profiles from the radiosonde data (black) and the HRRR model sounding (red). On the left, the 11-point running averaged radiosonde data is compared to the HRRR data. On the right, the 11-point smoothed radiosonde data are smoothed to match the resolution of the HRRR sounding.





The refractive index structure parameter (C_n^2) profile calculated from the thermosonde-measured temperature differences (black) and the estimated radiosonde C_n^2 profile (red). On the right, the thermosonde values are smoothed slightly to match the resolution of the radiosonde estimated values.

To compare the thermosonde and Graw radiosonde profiles, the average differences between the logarithms of each profile are compared with values from a similar study (Friehlich et al, 2010) to test the validity of the results.

Source	Troposphere	Stratosphere
Target values (Friehlich et al)	0.065 +/- 1.236	0.116 +/- 0.359
Radiosonde vs. Model	0.017 +/- 0.183	0.024 +/- 0.073
Thermosonde vs Radiosonde	0.058 +/- 0.628	0.410 +/- 0.441

Conclusions

- The thermosonde was successfully built and flown
- Atmospheric features are detectable by thermosonde and radiosonde temperature differences
- Horizontal temperature differences (thermosonde) and vertical temperature differences (radiosonde) are similar
- Comparison results fit within range found by previous study

Acknowledgements

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References

Friehlich, R., Sharman, R., Vandenberghe, F., Yu, W., Liu, Y., Knievel, J., and Jumper, G. (2010). Estimates of Cn2 from Numerical Weather Prediction Model Output and Comparison with Thermosonde Data. *Journal of Applied Meteorology and Climatology*, ***49***, 1742–1755. https://doi.org/10.1175/2010JAMC2350.1