Balloon-borne Digital Thermosonde Instrument for Measurements of Atmospheric Optical Turbulence (C_n^2)

David J. Delene, Blake T. Sorenson[1], and James Casler

[1]Department Alumni 2018 and 2024

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Atmospheric Optical Turbulence

- Light waves are impacted by fluctuations in the air's refractive index, known as optical turbulence.
  - Optical turbulence causes stars to "twinkle" .
- The quality of electromagnetic signals is impacted by optical turbulence, leading to degraded images.
- Knowledge of the atmospheric optical turbulence helps to improve high-resolution image quality

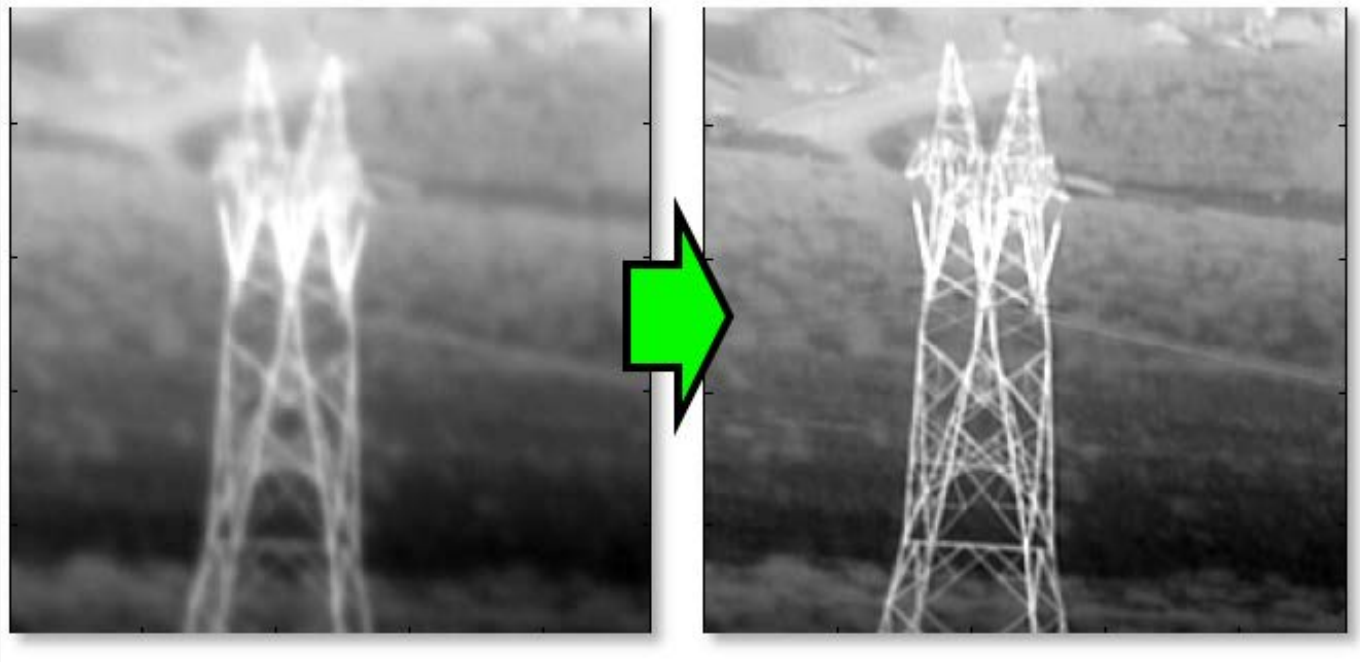

Image from University of Dayton Signal & Image Processing Lab (https://tinyurl.com/nhkcbn9k)

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Calculations using Thermosonde Temperature Measurements

- Optical turbulence is quantified by the refractive index structure parameter C_n^2, given in Bufton (1975) as:

- $C_n^2 = \left(76 \times 10^{-6}\left(\frac{P}{T^2}\right)\right)^2 \boldsymbol{C_T^2}$
  - P = *Pressure (mb)*
  - T = *Temperature (K)*
  - $C_T^2(h) = \frac{[\boldsymbol{T}(\boldsymbol{r_1}) - \boldsymbol{T}(\boldsymbol{r_2})]^2}{r^{\frac{2}{3}}}$
  - C_T^2 quantifies the thermal turbulence over a distance (r) resulting from **temperature** differences between points r_1 and r_2.

- Methods were developed to estimate C_n^2 from standard meteorological variables.
- One method, defined by Dewan et al., (1993)
  - $C_n^2 = 2.8\left(76 \times 10^{-6}\left(\frac{P}{T^2}\right)\left(\frac{\partial T}{\partial Z} + \gamma\right)\right)^2 \times (0.1)^{\frac{4}{3}} \times 10^{Y(z)}$
  - $Y(z) = \begin{cases} 1.64 + 42 \times S_{raw}, & Troposphere \\ 0.506 + 50 \times S_{raw}, & Stratosphere \end{cases}$
  - $S_{raw} = \sqrt{\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2}$
  - Estimates C_n^2 based on air temperature and pressure, as well as the vertical wind shear and vertical temperature gradient

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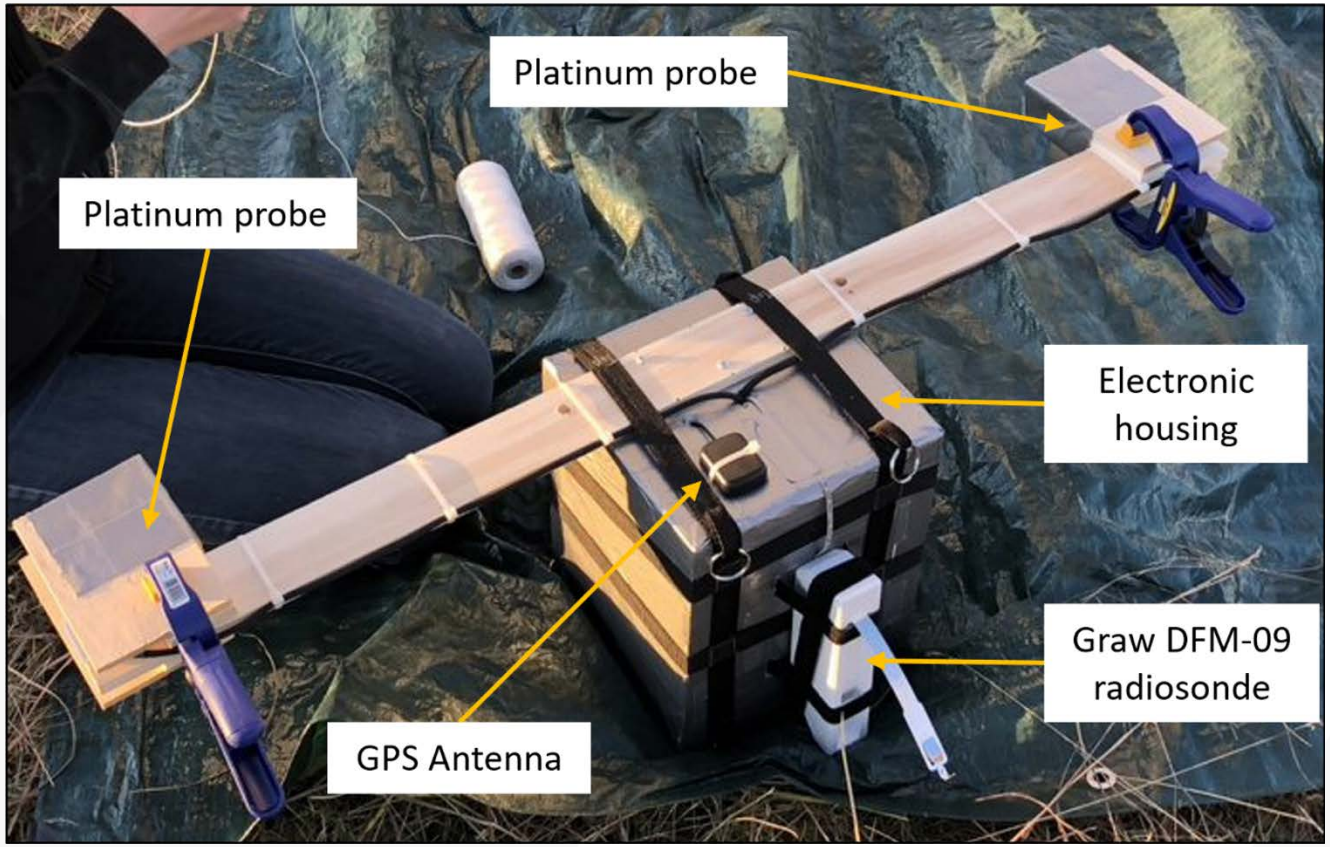
Thermosonde Instrument Design

- The thermosonde instrument, based on NASA designs, measures high-resolution temperature differences that can be used to calculate C_n^2.
- Major Components
  - 2 μm Diameter Platinum Wires
  - Graw DFM-09 Radiosonde (XDATA protocol)
  - Raspberry Pi Signal Processing Components
  - GPS Receiver
- Two thin-wire probes for Wheatstone Bridge legs.
  - Difference in resistance between the wires creates voltage difference at the bridge.
  - Voltage difference is a function of the difference in temperature between the probes.



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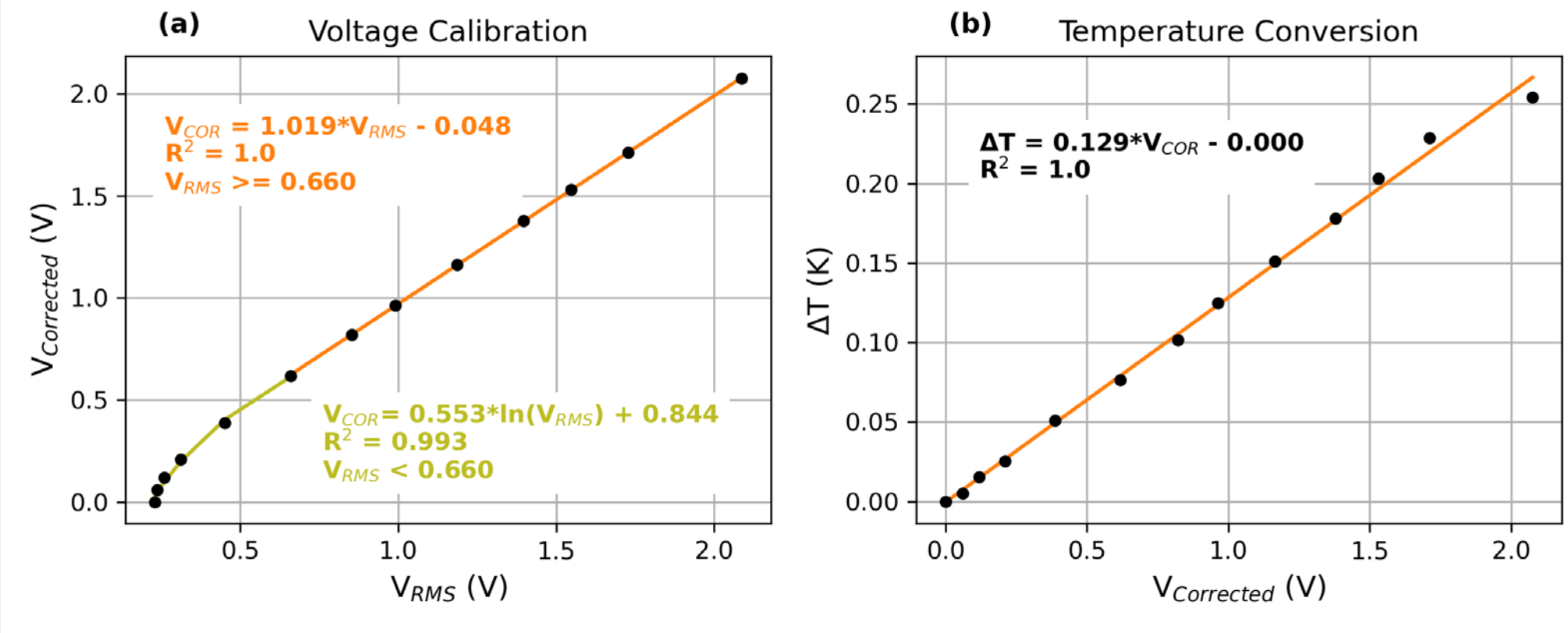
17 November 2017 Instrument Calibration



- Calibration conducted based on a November 2017 tethered balloon measurements.
- Root-mean-square voltages from instrument corrected to account for noise floor.
- Corrected voltages are converted to temperature differences.

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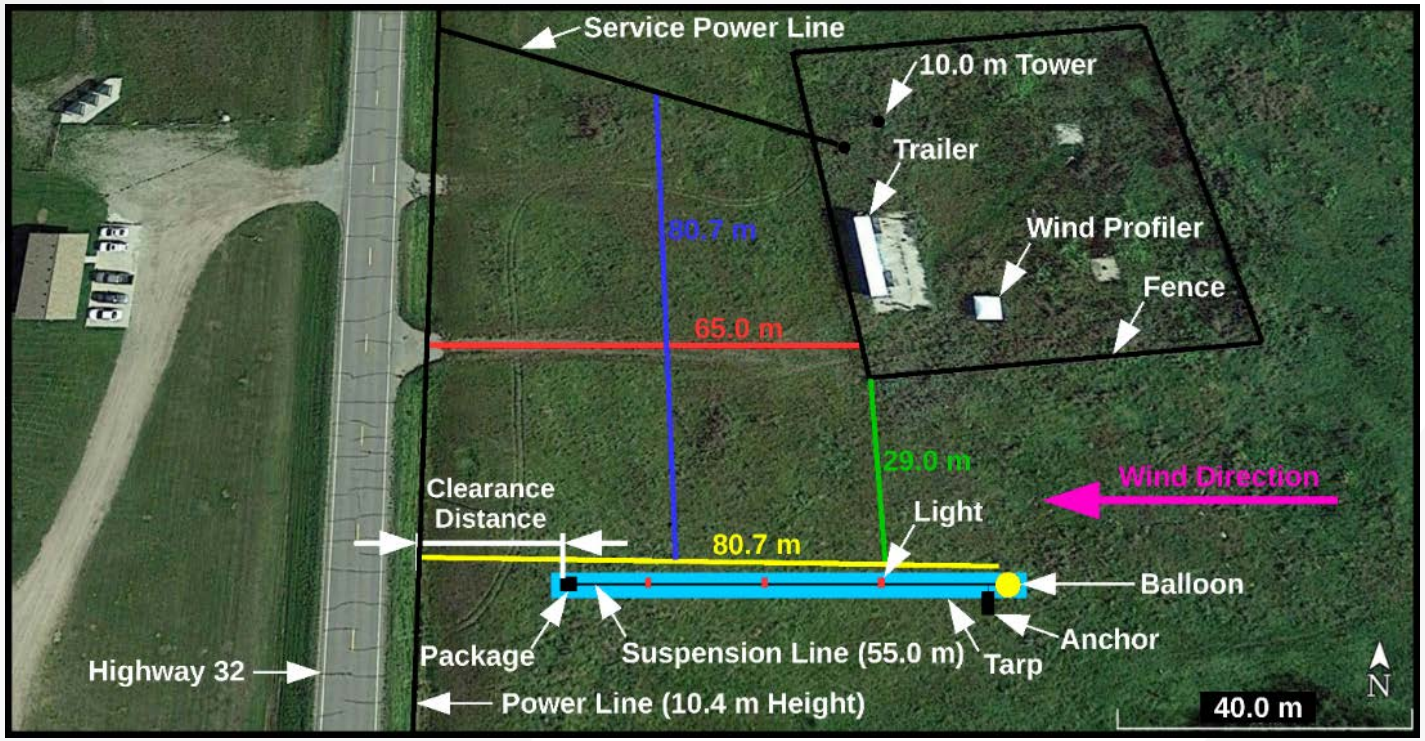
Balloon Flight Operations

- Thermosonde package suspended 55 m beneath a balloon.
  - Long tether used to reduce the effect of thermal balloon wakes on the measurements.
- High altitude balloon carries instrument through the atmosphere and descends after balloon burst.
- Initial flights testing conducted at the University of North Dakota Glacial Ridge Atmospheric Observatory



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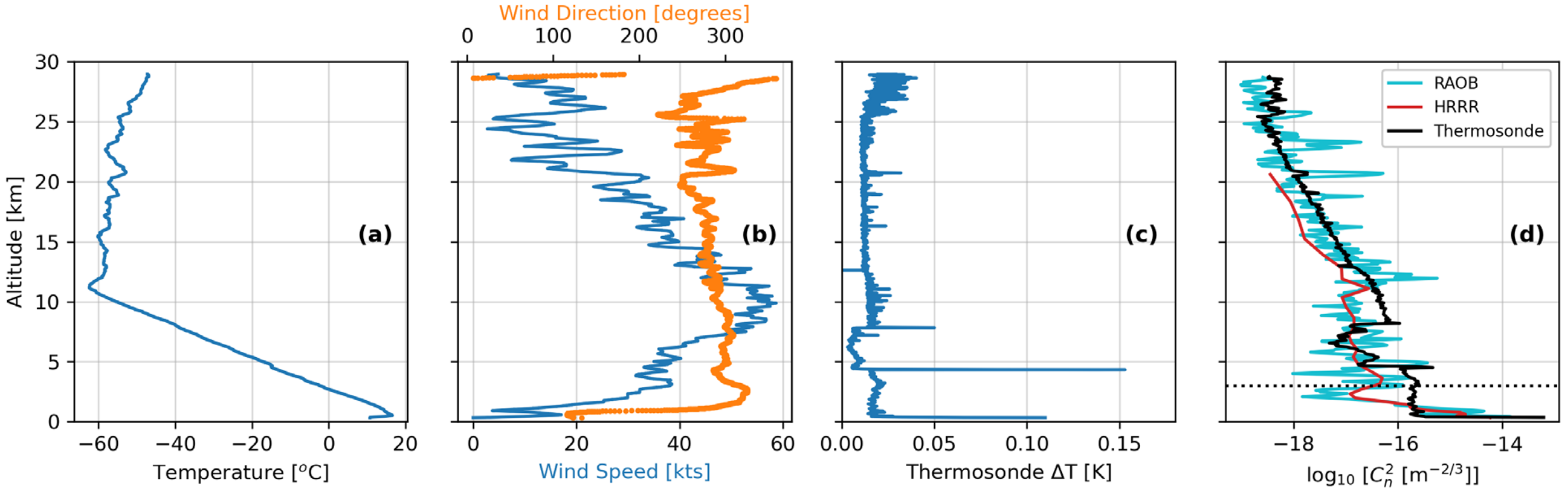
5 May 2018 Thermosonde Balloon Flight



- Thermosonde measured temperature differences with resolution of 0.02 K.
- Slight increase in temperature differences below the tropopause.
- C_n^2 from the thermosonde highest near the surface.
- Radiosonde-estimated C_n^2 compares well with thermosonde-observed C_n^2.

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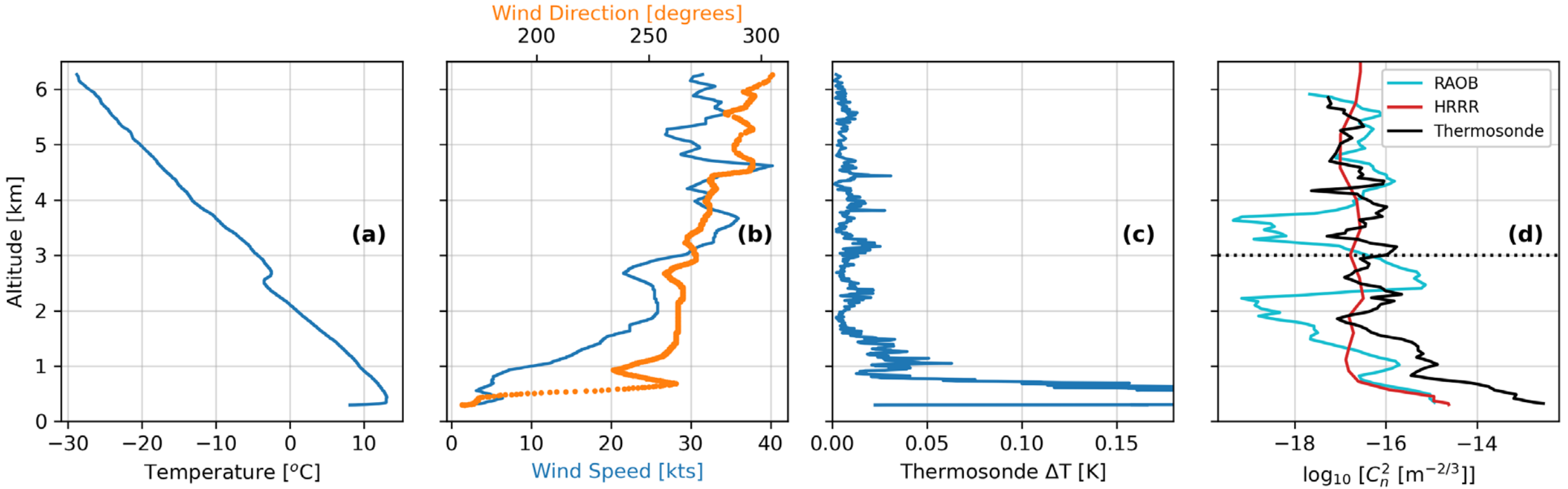
4 May 2019 Thermosonde Balloon Flight (Mayville)



- The thermosonde was restructured to increase measurements sensitivity.
- Instrument connection was lost at ~6 km.
- Larger temperature difference variations were observed compared to previous flight.
- Radiosonde-estimated and thermosonde-observed C_n^2 agree; however, radiosonde C_n^2 has higher variations.

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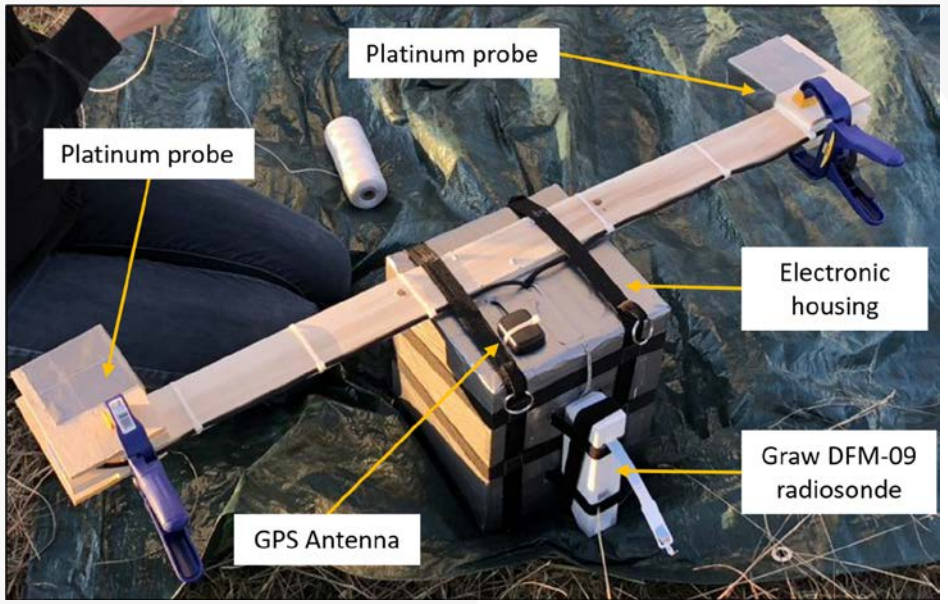
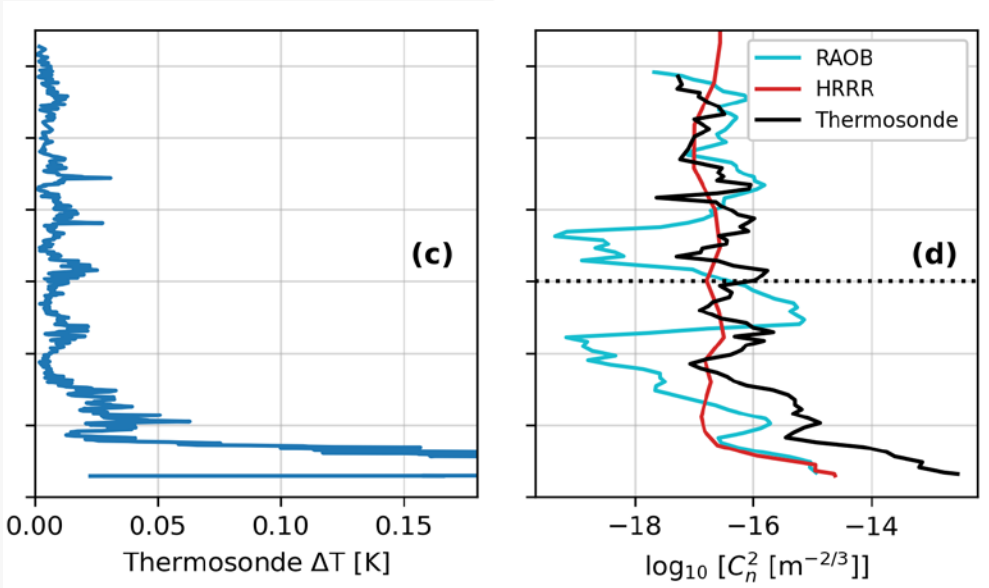
Conclusions

- A thermosonde instrument was built to study atmospheric optical turbulence
- Profiles of the refractive index structure parameter (C_n^2) observed by the thermosonde compare well with radiosonde-based estimates of C_n^2
- The instrument designed in this study can serve as a prototype for future systems to routinely observe atmospheric optical turbulence profiles when coupled with radiosondes





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Future Work

Sorenson, Blake, James Casler, and David Delene, Development at the University of North Dakota of a Digital Thermosonde Instrument for the Study of Atmospheric Optical Turbulence (Cn2), *American Journal of Undergraduate Research*, in public release review, 2025.

Proposal entitled “Expendable Air-Sea Profiling Observations Supporting Agency” , Department of Deference - ONR STTR; Dollar Value - $95,999; Project Duration 08/01/2025 - 10/31/2026; Support 2026-1.0, 2027-1.0; Proposal Submitted 02/05/2025

References

Bufton, J., 1975: A Radiosonde Thermal Sensor Technique For Measurement of Atmospheric Turbulence (No. NASA-TN-D-7867). NASA. Retrieved from https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19750008971.pdf

Dewan, E. M., Good, R. E., Beland, R., and Brown, J., 1993: A Model for Cn2 (Optical Turbulence) Profiles Using Radiosonde Data (Scientific No. ERP, No. 1121) (p. 52). PHILLIPS LAB HANSCOM AFB MA. Retrieved from http://www.dtic.mil/docs/citations/ADA279399

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