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Introduction

Unmanned aircraft (UA) systems have been used to collect basic atmospheric data since the 1970s (Konrad et al. 1970). However, more recent advancements in electronic technology allows for easier utilization of UA systems for meteorological purposes. These systems can be used in the planetary boundary layer (PBL) to detect spatial fluctuations in meteorological variables which are usually a direct product of turbulence. Understanding the turbulent mixing processes within the PBL can help to improve parameterization schemes used in numerical forecasts, fundamental understanding of pollutant transport, and calibrate remote sensors.

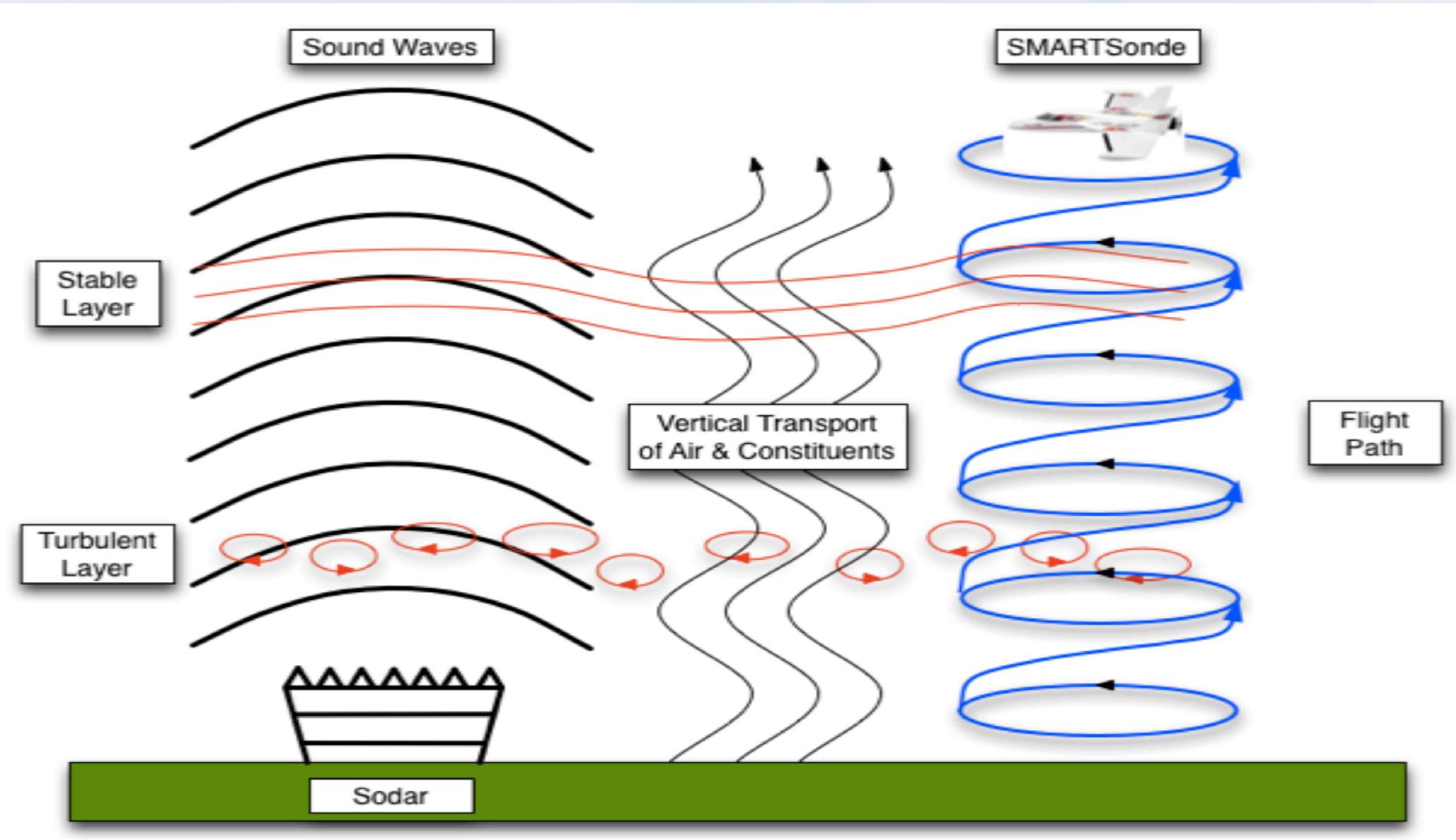


Figure 1: Helical step-wise flight plan of the SMARTSonde along with sodar sampling the lower atmosphere.

This project used the UA platform called SMARTSonde (Small Multifunction Autonomous Research and Teaching Sonde) which was developed in 2009 at The University of Oklahoma (Chilson et al. 2009). A small, fixed-wing, pusher-prop aircraft has been equipped with temperature, pressure, and humidity sensors and is controlled by the Paparazzi autopilot system via a ground control station.

Under the first civilian CoA (Certificate of Authorization) in the state of Oklahoma, this project collected its first data set on March 14, 2013. The three flights on that day were conducted in accordance with FAA regulations required to operate UA within the National Airspace. Because of a manned aircraft intruding the airspace and GPS issues, useful data were not collected above 100 m. Since then, reliable data have been collected on March 28, April 11, and April 24, 2013 up to 800 m.



Acknowledgements

We wish to thank Robert Huck and James Grimsley for organizing the CoA that made this project possible. We greatly appreciate Ken Carson and the OU Aviation Department for their mission support during flights. We also want to thank Charlotte Wainwright for providing us with sodar data. We are forever indebted to Phillip Chilson and Tim Bonin for their tremendous leadership and insight that made this project a success.

Method

Data were collected on days with weather suitable for flying a lightweight radio controlled aircraft. Therefore, mean wind speeds at flight level needed to be less than 15 m s^{-1} . For data collection, a helical flight path was chosen using a step-wise ascent with varying 50 m and 100 m increases in altitude. Here, we present an example of a fully autonomous flight trajectory using a flight on 4/11/2013. Each height was maintained for roughly three minutes with data collected every second.

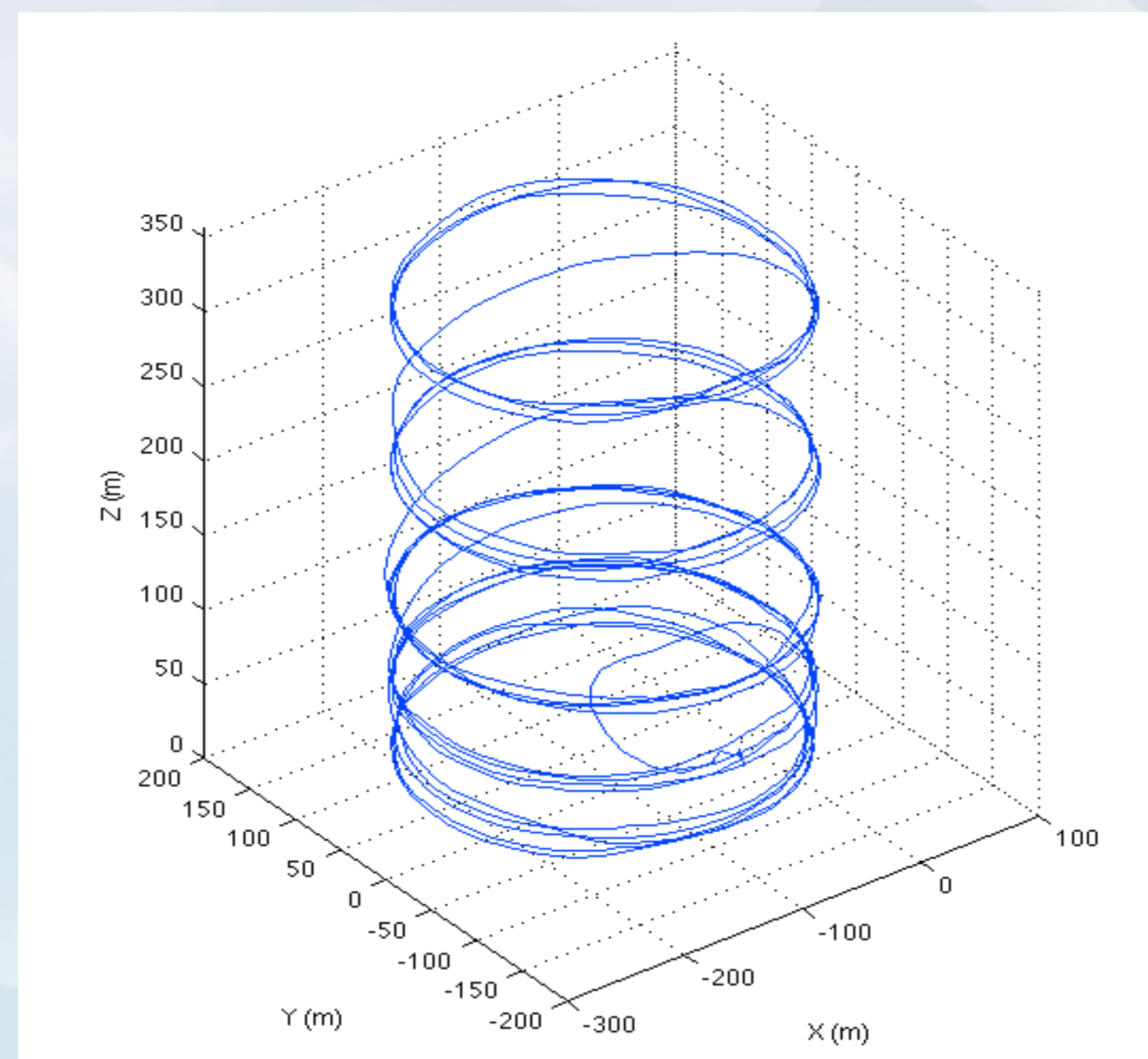


Figure 2: SMARTSonde trajectory plot for a flight on 4/11/2013.

Data were then quality controlled to eliminate erroneous values due to sensor malfunction. Once reliable data were obtained, the structure function parameter C_T^2 was estimated based on average temperature variations at a given height. To our knowledge, C_T^2 has only been calculated using UA once before (van den Kroonenberg et al. 2011). The following equation was used to calculate the structure function parameter. The variable $\langle(\Delta T)^2\rangle$ is the average of the squared temperature differences between data points of similar separation distances, while R is the separation distance between the data points.

$$C_T^2 = \frac{\langle(\Delta T)^2\rangle}{R^{2/3}}$$

Utilizing the step-wise ascent flight plan, the SMARTSonde circled at multiple heights, each for about three minutes, allowing for C_T^2 to be estimated at each height. Hence, a vertical profile of the structure function parameter can be achieved.

Because the structure function parameter is associated with the Bragg scattering conditions of the sampled turbulence (Gossard et al. 1982), sodar and other remote sensing return power can then be compared to the SMARTSonde simulated return power.

References

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Data

Here, we present an example of raw data collected on 4/11/2013 at 100 m. The height plot exemplifies the usual height fluctuations during most flights. Erroneous pressure data is also evident around 18:20:30 CDT.

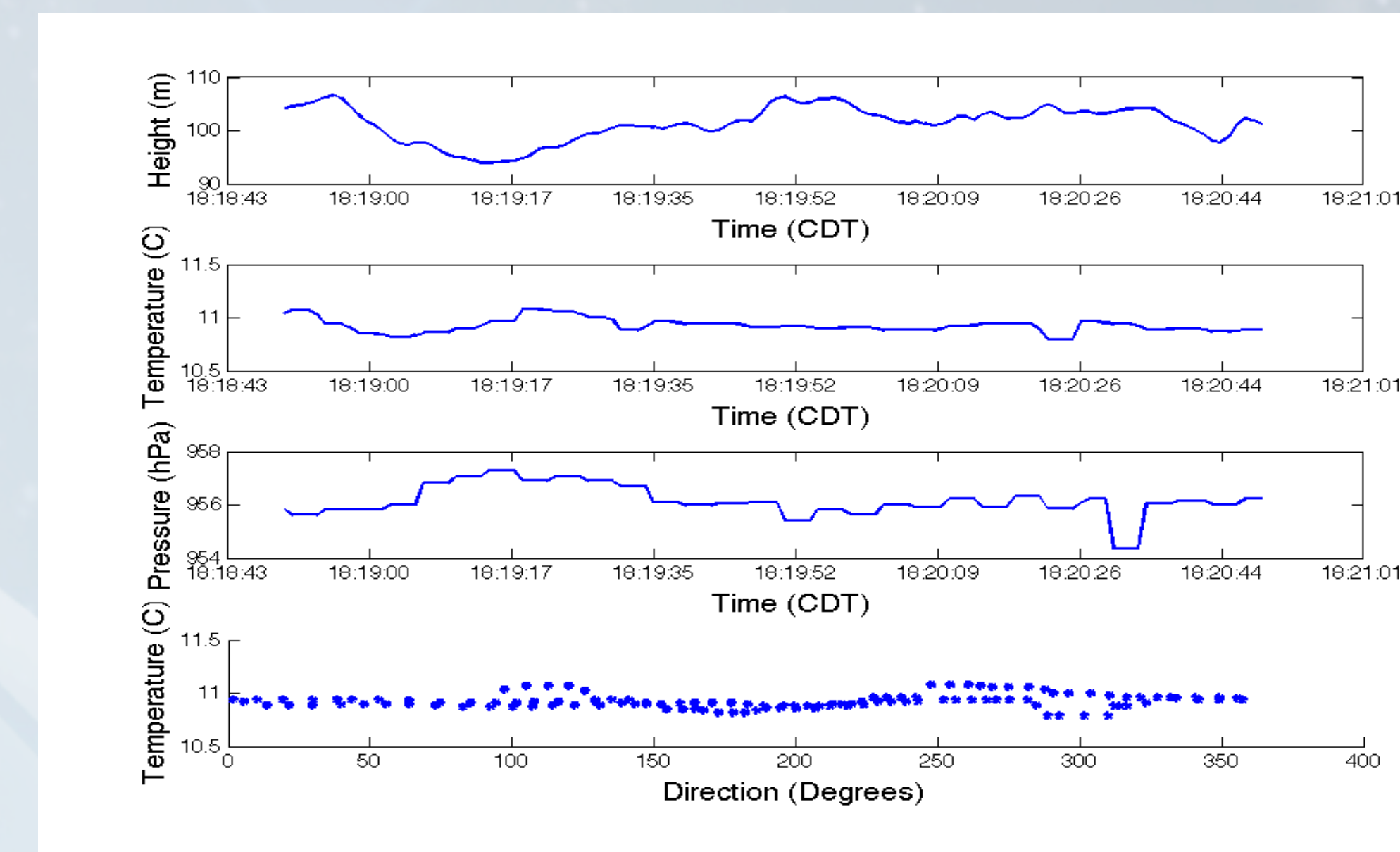


Figure 3: Height, temperature and potential temperature data collected from the SMARTSonde on 4/11/2013 at 100 m.

For an example, below are plots of the structure function (D_T^2) and the structure function parameter (C_T^2) from 4/11/2013 at 100 m. D_T^2 is the average squared temperature difference and C_T^2 is the proportionality factor in the 2/3-law expression for the structure function (Kolmogorov 1941). Results shown in rightmost panels were calculated using Taylor's hypothesis of frozen turbulence using mean wind velocity collected by the on-site lidar. Taylor's hypothesis lets us assume the eddies are unchanging, or "frozen", as they are advected across the sample space (Taylor 1938).

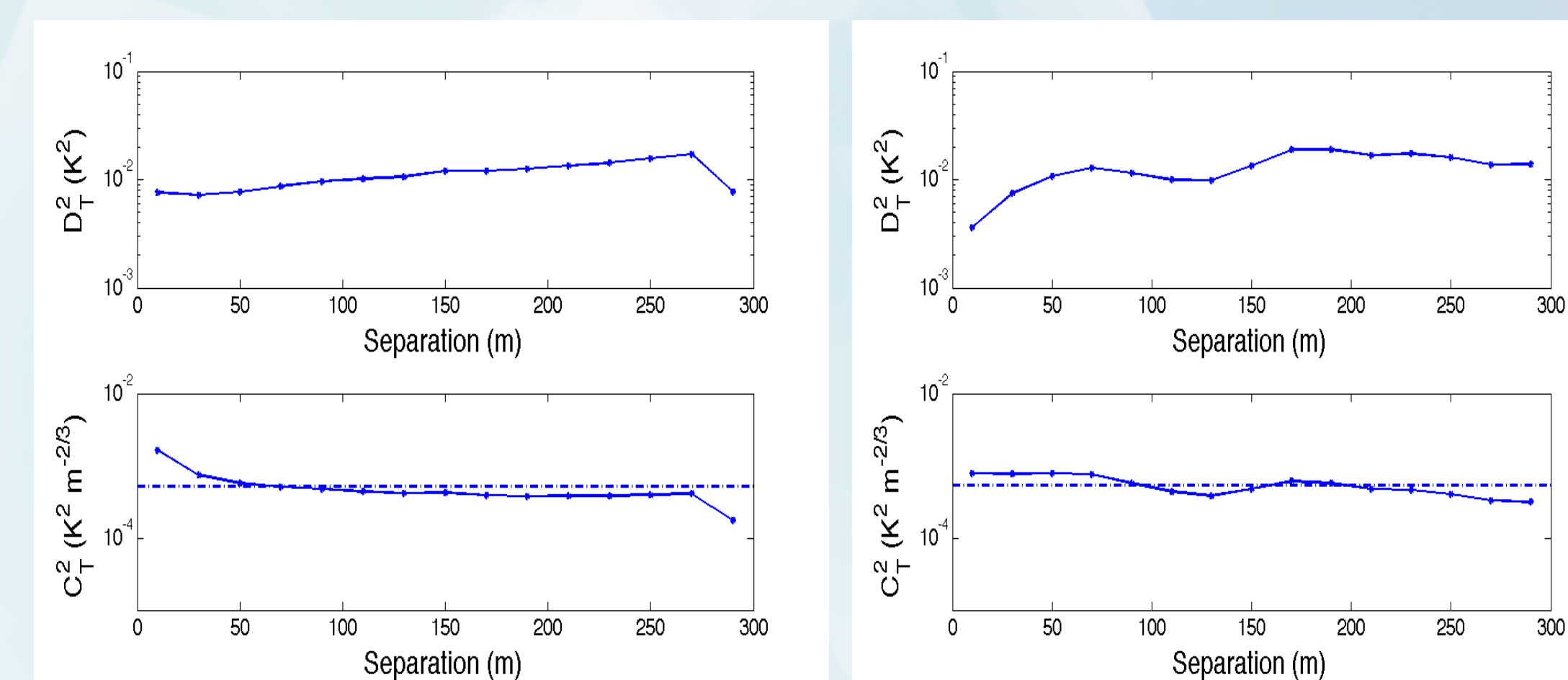


Figure 4: C_T^2 vs. R for 4/11/2013 at 100 m with Taylor's hypothesis utilized (right) and without (left).

Profiles of temperature, potential temperature and wind speed were also created using data from the SMARTSonde. These profiles illustrate the unique variability in the different atmospheric conditions from which data were collected.

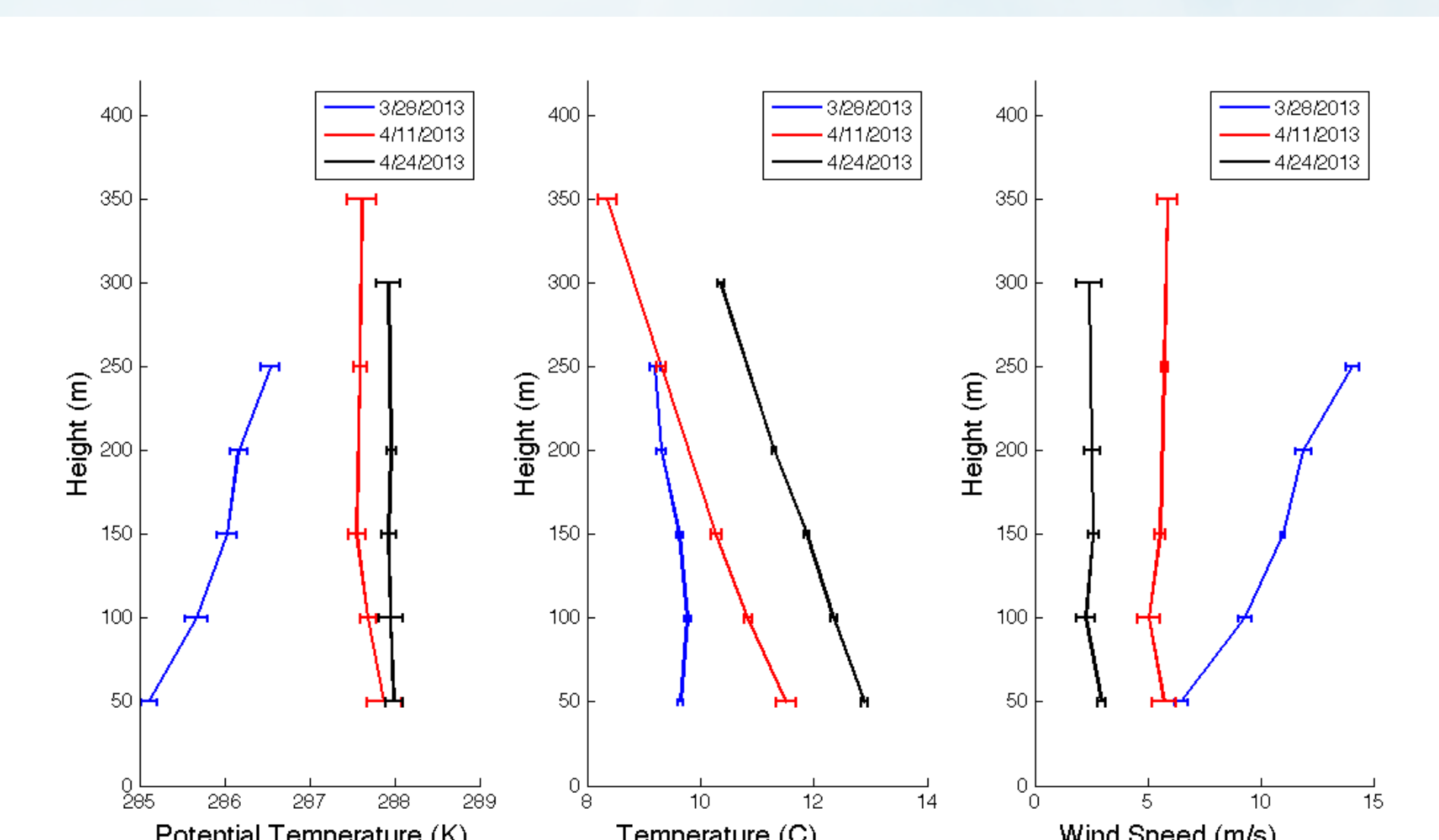


Figure 5: Atmospheric profiles for each day of data collection.

Discussion

Below is a figure isolating C_T^2 with respect to height for the same flights that were shown in Figure 5 which allows for a direct comparison of turbulence data for various atmospheric conditions. The values obtained are reasonable for the observed conditions. However, thermal updrafts, which can be detected with the on-site lidar, may have an impact on assumptions needed to compute C_T^2 and relate it to Bragg scattering.

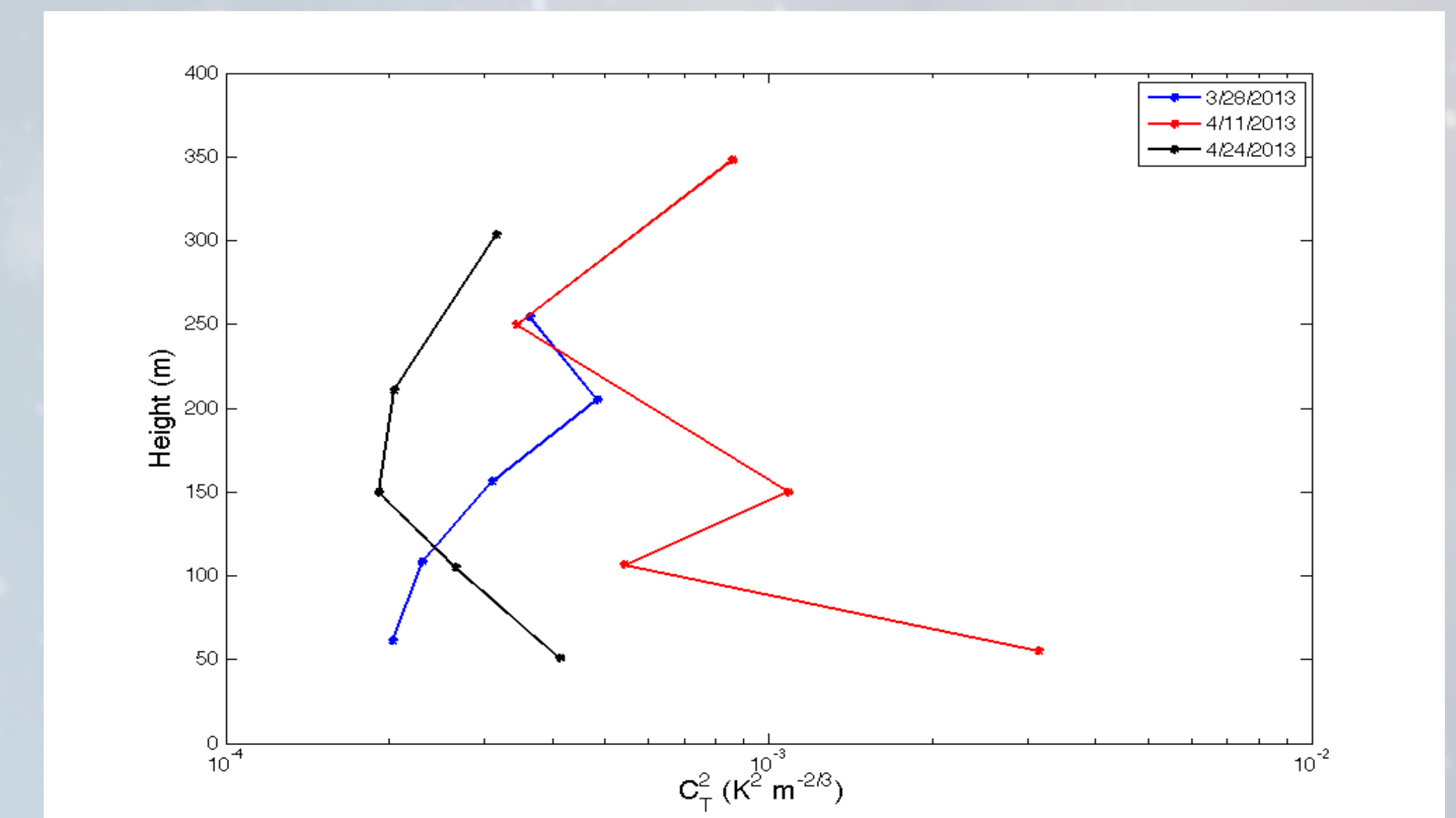


Figure 6: C_T^2 profiles for each day of data collection.

Below is a plot showing sodar return power alongside SMARTSonde simulated return power. Thermal updrafts were most prevalent during the flight on 4/24/2013 which may explain the lower values of the SMARTSonde simulated return power that day. Though no direct validation can be made, return power from the sodar should be directly proportional to the range corrected SMARTSonde simulated return power, which is calculated using the following equation:

$$\eta = \frac{C_T^2/T^2}{z^2}$$

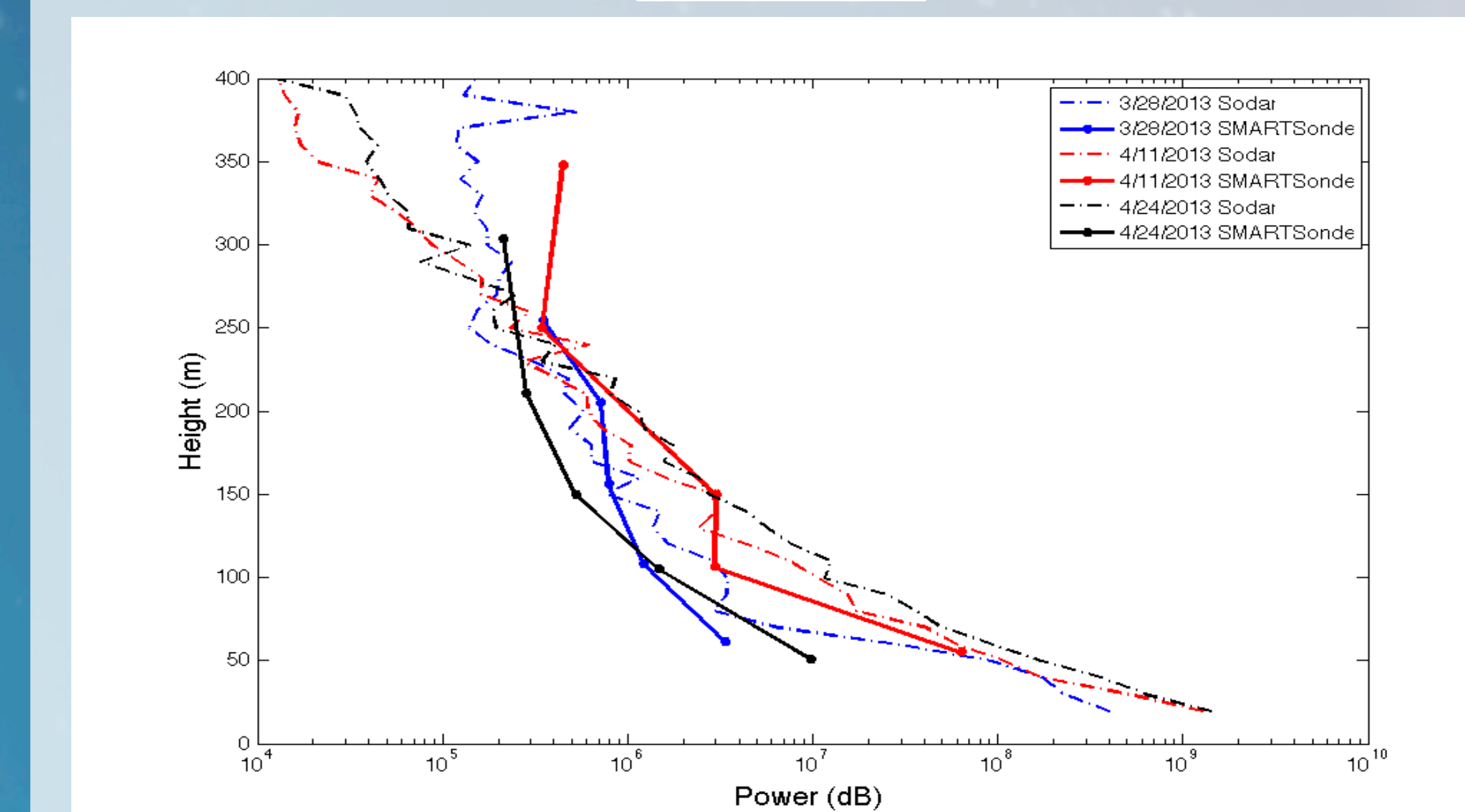


Figure 7: Sodar return power vs. SMARTSonde simulated return power for each day of data collection.

Conclusion

- Using UA for meteorological studies requires complex coordination and compliance with FAA regulations.
- Taylor's hypothesis of frozen turbulence is necessary to compensate for the advection of turbulence.
- C_T^2 can be calculated using a helical flight pattern with a UA and is dependent on atmospheric conditions.
- Fluctuations in height need to be accounted for, but using theta instead of temperature is not useful.
- Thermal updrafts may reduce the ability to calculate reliable C_T^2 values and more study is needed in this area.