Comparison of Field Test Data with Numerical Weather Modeling for Characterization of Atmospheric Refractive-Index Structure Coefficient, C_n^2, Under 100 Meter Altitude

Authors: Alex Clark, Christopher Phillips, Levi Smolin, Dr. Udaysankar Nair, Jaclyn E. Schmidt

Introduction: Comparison of field test data collected from differential temperature, temperature, pressure, and a Differential Image Motion Monitor (DIMM) placed on the Santa Rosa Island 100 meter tower to numerical weather modeling predictions from a one dimensional temperature diffusion equation model, and Laser Environmental Effects Definition and Reference (LEEDR) model, which utilizes Global Forecast System data(GFS). Comparisons are an effort to select the best tool for estimating lower earth vertical temperature profiles, from 0 to 100 meters, and then to estimate the Refractive-Index Structure Coefficient, Cn^2, or optical turbulence, for use in estimations of High Energy Laser system effectiveness. The use of Santa Rosa 100 meter tower for collection of field test vertical temperature profile data is a prelude to future research which will utilize a small Unmanned Aerial Vehicle (UAV) with a meteorological sensor set for the collection 100 meter vertical temperature profile data, which can then be used for numerical weather model initialization.

What is the Atmospheric Refractive-Index Structure Coefficient?

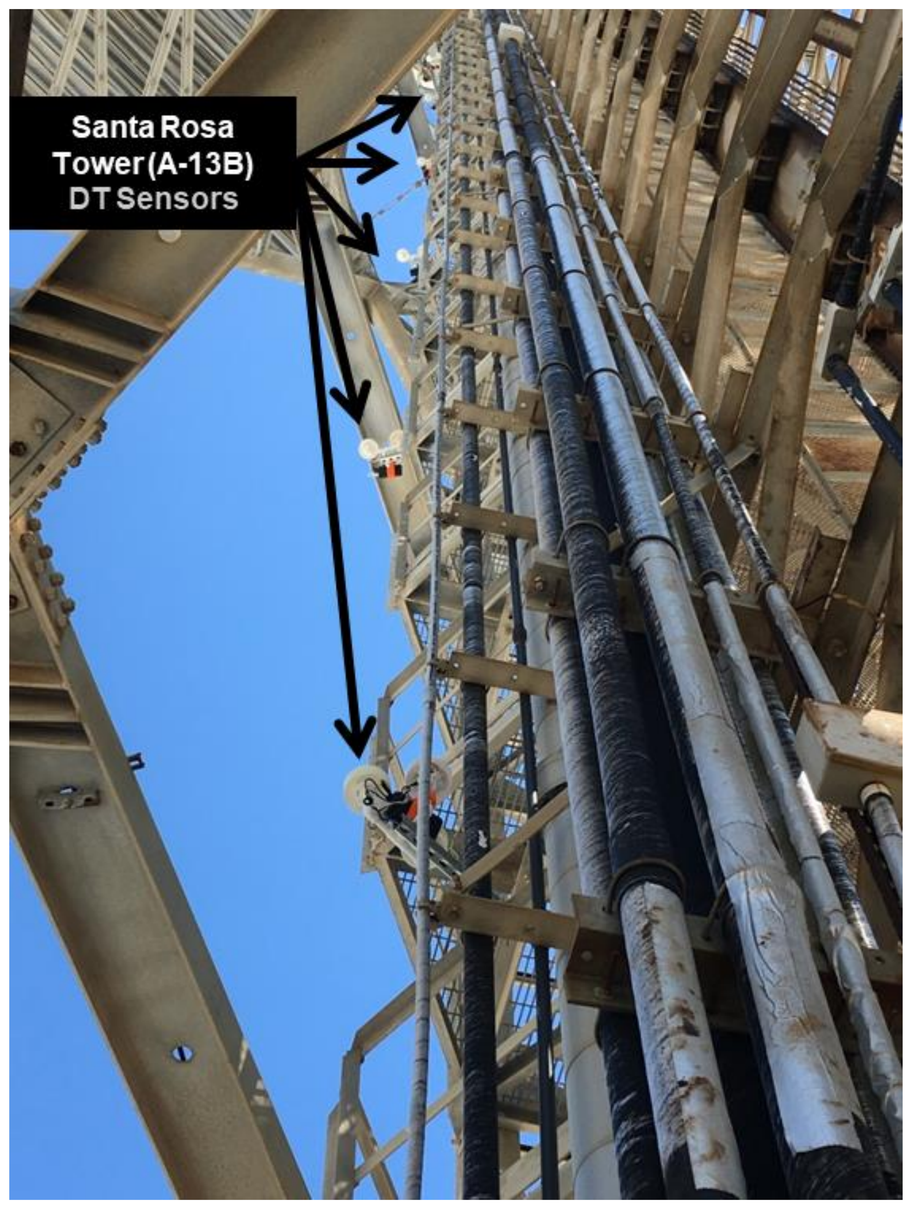
Micro changes in the base index of refraction of air caused by temperature differentials form the bulk of the Refractive-Index Structure Coefficient. This phenomena can been seen on hot days over pavement.

Questions:

Can current tools forecast C_n^2 vertical profiles accurately?

How to forecast C_n^2 vertical profiles in real time?

Data Collection:



To answer these questions a field experiment using an instrumented 100 meter tower was undertaken. The tower had high resolution temperature sensors installed at roughly 10 meter increments where data was collected at 1hz for roughly 14 days. The goal was to simulate a profile similar to a sounding but within FAA Part 107 requirements for a sUAS.

Method:

Utilizing differential temperature measurements to estimate the temperature structure coefficient, C_T^2, estimations of C_n^2 are possible through the use of empirical equations as seen in Roadcap 2009.

$$C_T^2 = \frac{\langle |T_1 - T_2|^2 \rangle}{r^{2/3}}$$

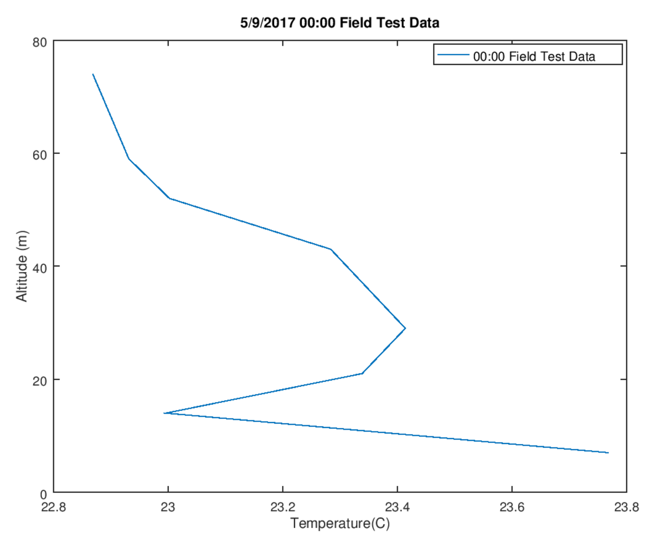
$$C_n^2 = \left(79 \times 10^{-6} \frac{p}{T^2}\right)^2 C_T^2 \left(m^{-2/3}\right)$$

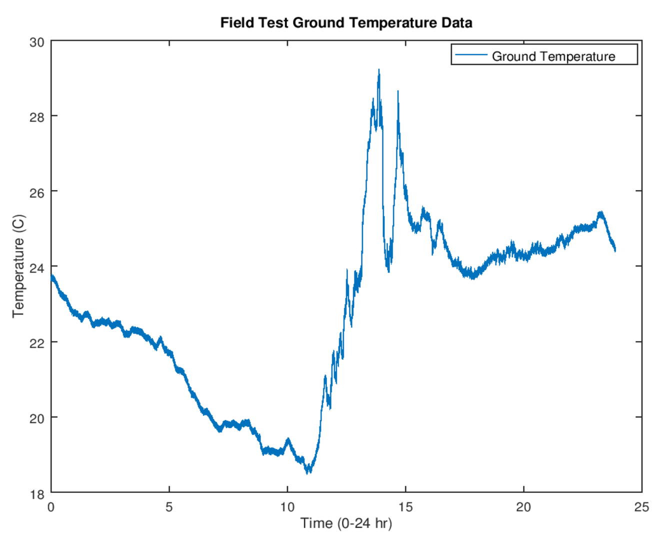
To estimate C_n^2 using a numerical weather model a simple one dimensional temperature diffusion model was created. The model will forecast the vertical temperature profile from an initialization sUAS sounding and then use a ground sensor to drive the model in real time. From a forecasted vertical temperature profile differential temperature can be extracted. Model output was then compared to profiles generated by LEEDR using local GFS data.

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} K \frac{\partial \theta}{\partial z} \qquad \theta = T\left(\frac{1000}{p}\right)^{0.286}$$

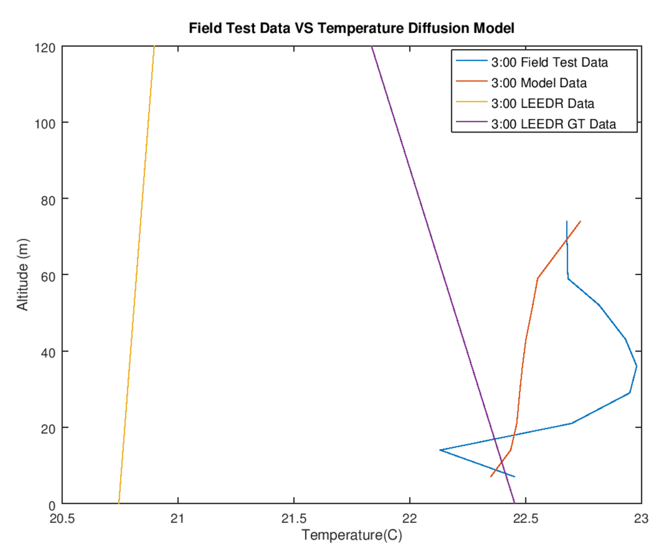
Simulation Data:

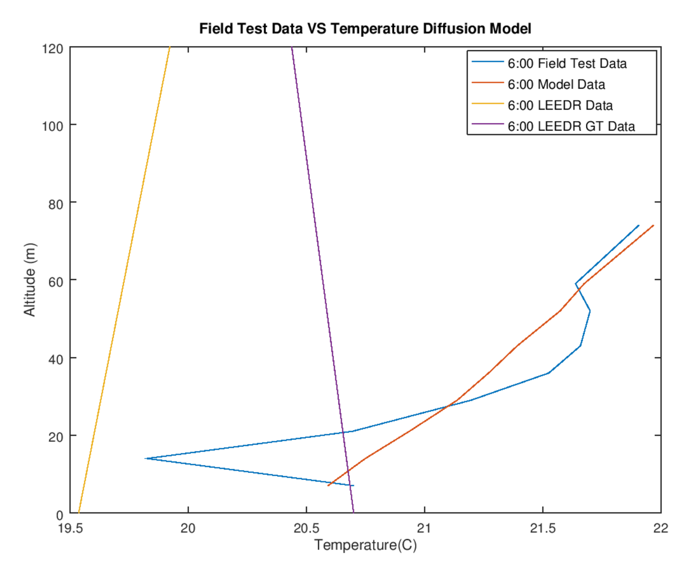
Simulation Input

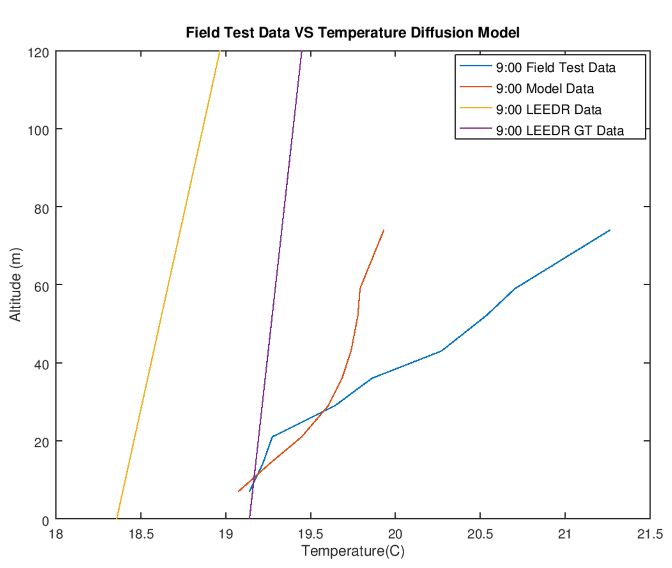


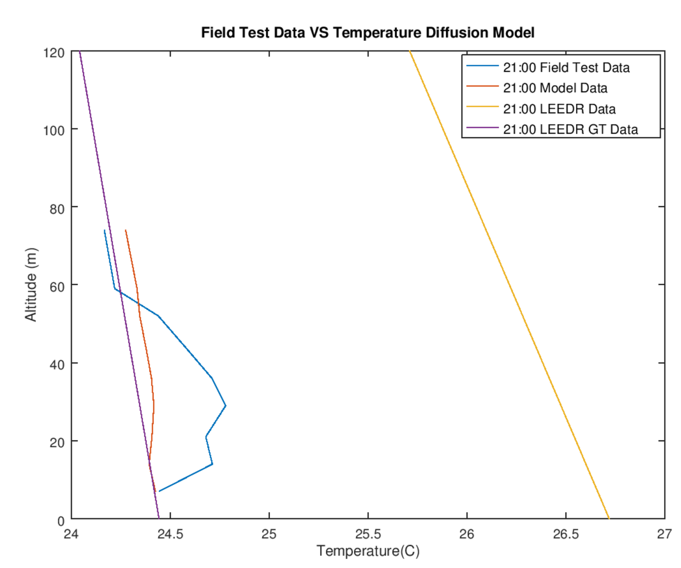


Simulation Output









Conclusions:

The utilization of a one-dimensional temperature diffusion model, in combination with a 100 meter meteorological sounding for initial conditions and meteorological sensor for boundary conditions with the ground, showed good agreement with field sensor data for estimating a vertical temperature profile. Vertical temperature profile output comparisons with LEEDR highlight the advantage of having micro-meteorological data available for locations that are between grid spacing steps of the GFS data used for analysis. As shown in vertical temperature profile comparisons, LEEDR's accuracy of estimating the area vertical temperature profile also increases with the availability of ground temperature and pressure measurements.

Future research is targeting the use of a small UAV to collect 100-meter vertical meteorological data profiles for use in initialization of numerical weather models. The use case for this system is to collect vertical profile data once every 12 hours and, in combination with a ground meteorological sensor suite, provide real time estimates of the vertical temperature profile and refractive-index structure coefficient to dismounted operators of High Energy Laser systems.

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