Tropospheric Error Bounding:

Nominal and Anomalous Tropospheric Conditions

Parameter Calculation and Consistency

Presented to: CAAC Team

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Overview

- **Tropospheric Error Bound**
- **Presentation of samples of calculated tropospheric parameters for GBAS.**
  - Tropospheric parameters and calculations are reviewed.
- **Examples for Memphis and Atlantic City are included.**
- **Tropospheric Storm Bounding**

Thanks to Julian Babel for gathering and processing the data.

Tropospheric Parameters

- **Areas of Concern/Responsibility**
  - Determine nominal and maximum observed variation of temperature and humidity at selected locations
  - Determine values for tropospheric parameters which provide integrity for all users
    - Process defined in the HMI document and Algorithm Description Document
  - Gather additional verification data from available public sources
    - Requires historical observations of the region's weather activity

Determination of TC and σ_{tropo}

In computing the tropospheric correction and its estimated error the LGF computes these three following parameters.

- **Refractivity Index (N_r)**
- **Scale Height (h_0)**
- **Refractivity Uncertainty (σ_n)**

Determination of TC and σ_{tropo} (Con't)

$$TC = N_R h_0 \frac{10^{-6}}{\sqrt{0.002 + \sin^2(\theta)}} \left(1 - e^{-\Delta h / h_0}\right) \qquad \sigma_{tropo} = \sigma_N h_0 \frac{10^{-6}}{\sqrt{0.002 + \sin^2(\theta)}} \left(1 - e^{-\Delta h / h_0}\right)$$

The total refractivity index is defined as

$N_r = N_{Rdry} + N_{Rwet}$ which can also be expressed as

$N_R = 77.6P_s/T_s + N_{Rwet}$

Where

T_s: Surface Temperature

P_s: Surface Static Pressure

N_{Rwet}: Wet component of the Refractivity Index

Calculating Refractivity Index (N_r)

To determine N_{Rwet}

$$N_{Rwet} = N_S \left(\frac{13000 - h}{13000 - h_s} \right)^4 \quad h \le 13000\ m$$

$$N_s = 2.2777 x 10^4 \frac{(RH)}{T_s^2} 10^{\left(\frac{7.4475(T_s - 273)}{T_s - 38.3} \right)}$$

Where

h: User height (meters)
h_s: Surface height (meters)
N_s: Surface Refractivity
RH: Relative Humidity (%)

Calculating Scale Height (h_0)

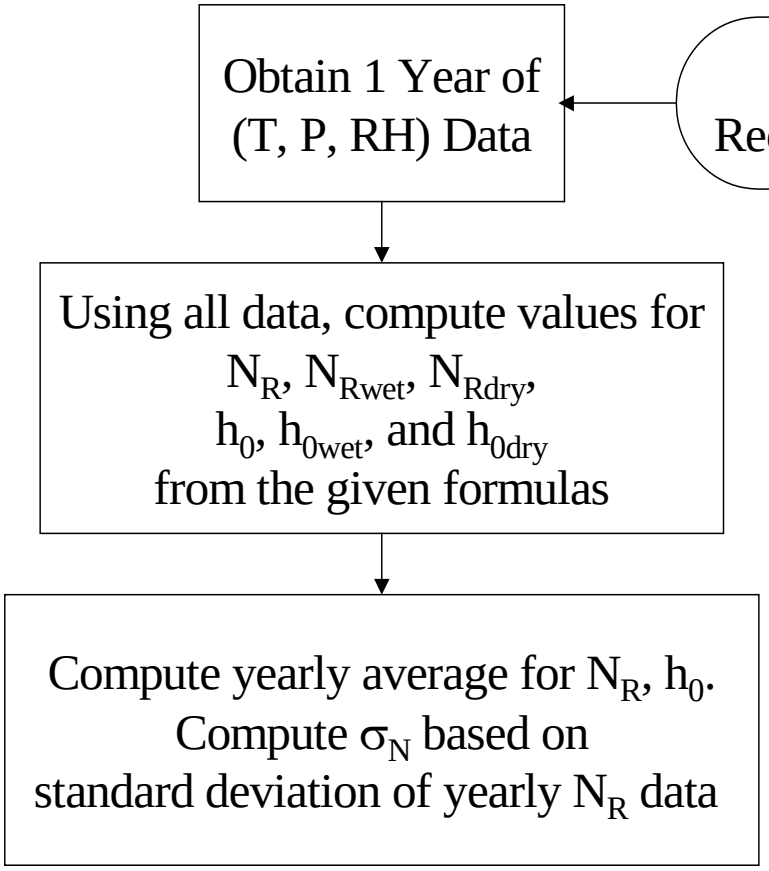
In order to determine scale height (h_0), it must be separated into two parts, wet and dry components

$$h_{0\,dry} = \frac{42700 - h_s}{2} \quad \textbf{and} \quad h_{0\,wet} = \frac{13000 - h_s}{2}$$

Using these in conjunction with the wet and dry components of the Refractivity Index (N_r), we are now ready to find the scale height (h_0) as follows:

$$h_0 = \frac{N_R \, h_{0\,wet} \, h_{0\,dry}}{N_{R\,dry} \, h_{0\,wet} + N_{R\,wet} \, h_{0\,dry}}$$

Diagram for Determining N_r, h_0, and σ_N



Remember that Temperature, Pressure, Relative Humidity, and Height are all different based on location

Weather data were obtained from the National Climatic Data Center (NCDC), using the Integrated Surface Hourly data found on:

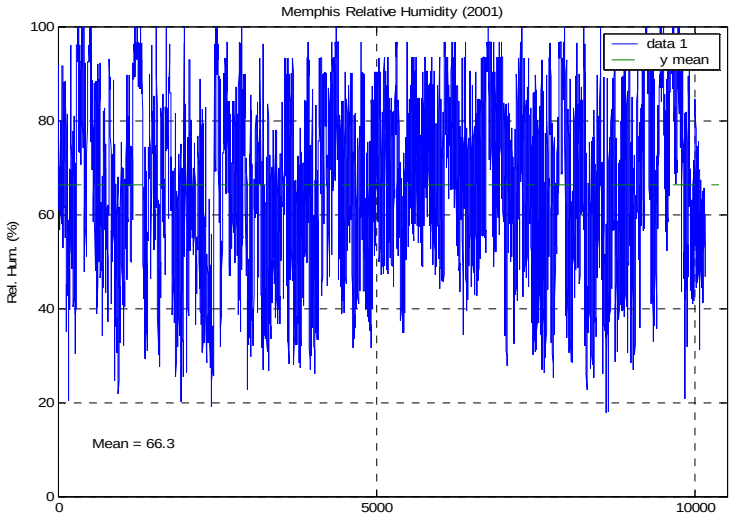
http://www.ncdc.noaa.gov/oa/ncdc.html

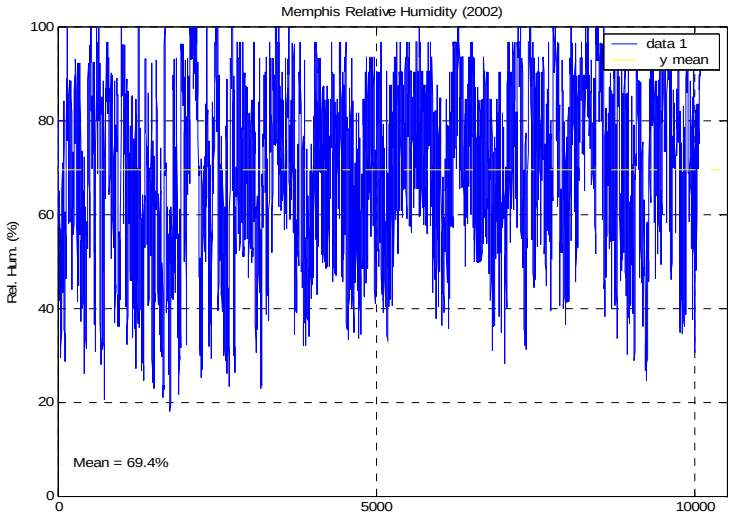
For the sake of this analysis all data obtained were assumed valid.

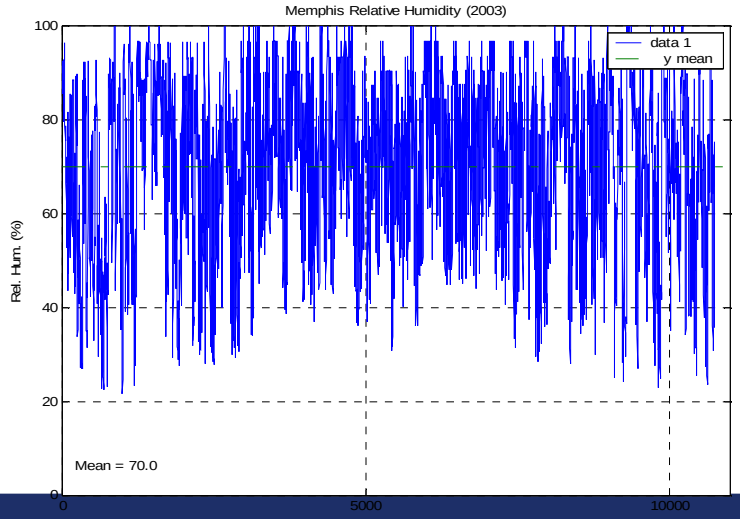
Calculation Method

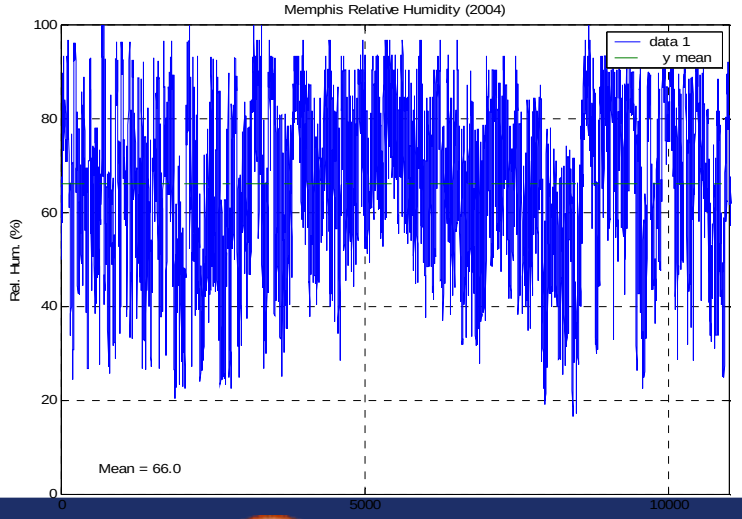
- **The first four years (2001-2004) are shown for Memphis.**
- **The measurement index begins on January 1 and ends December 31, and nominally indicates a mixture of hourly and extra observable data which were recorded.**
- **All data were processed using both Excel and Matlab.**

Memphis Relative Humidity

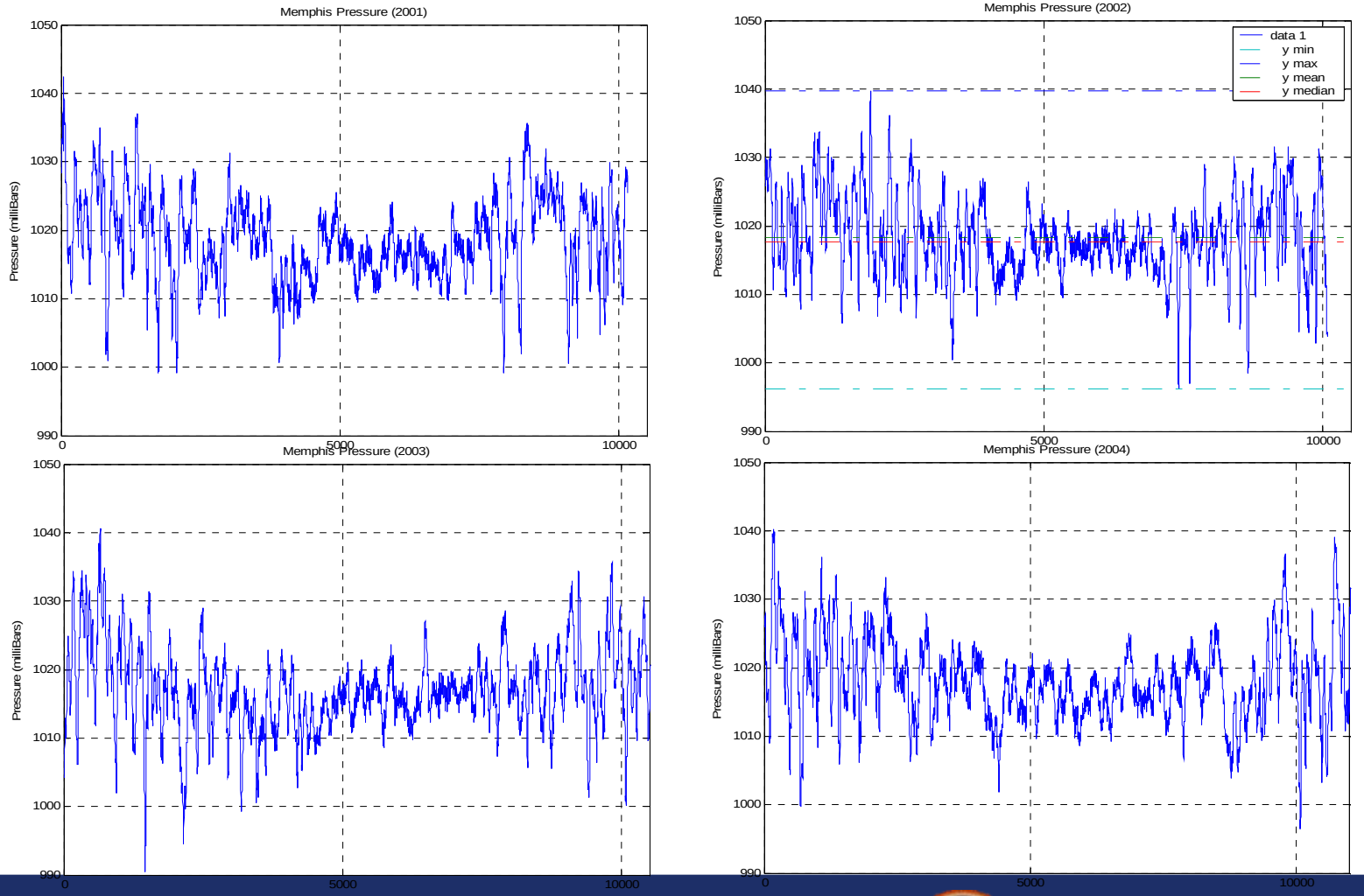




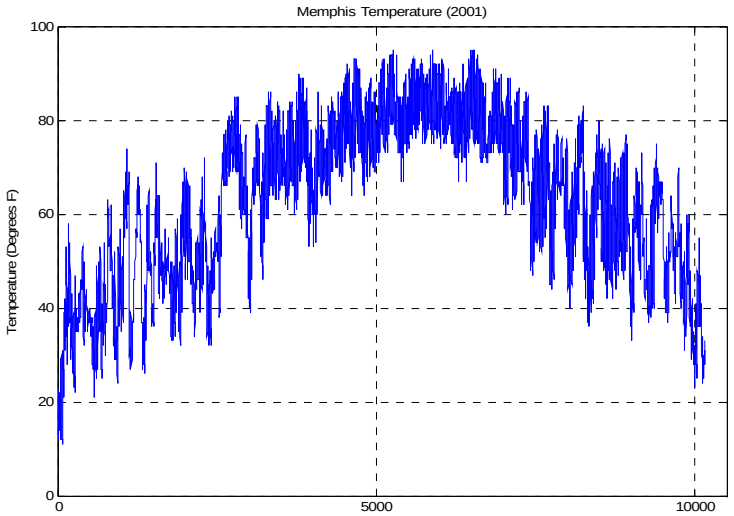


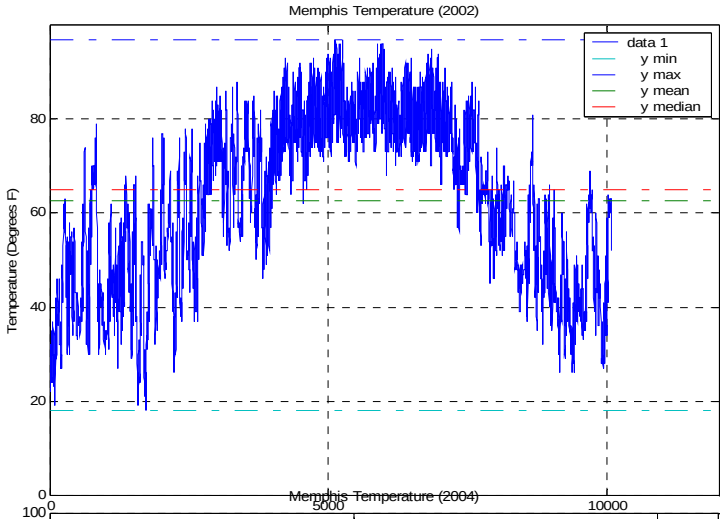


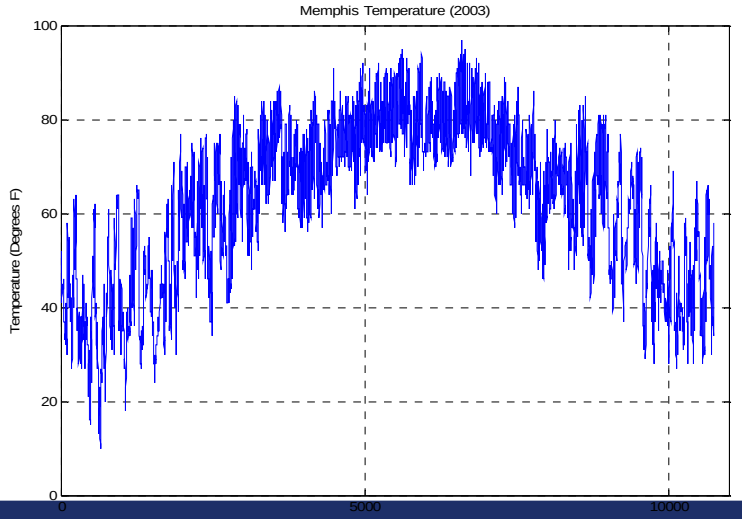
Memphis Pressures

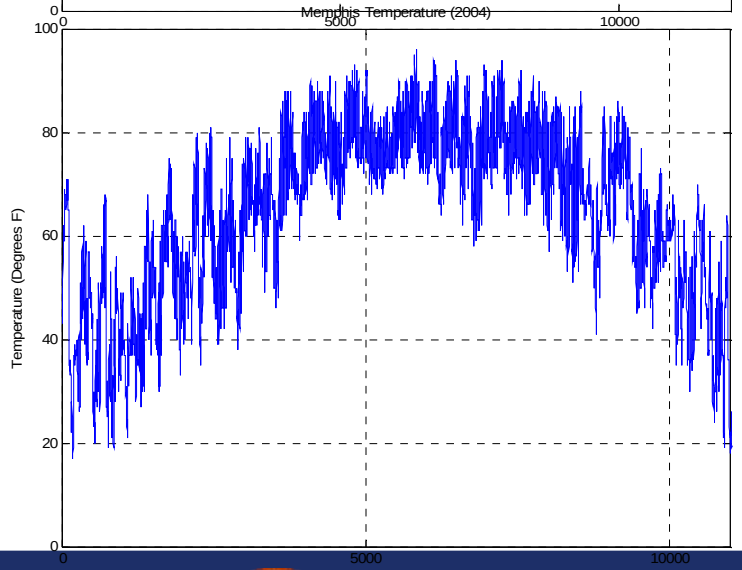


Memphis Temperature (FAA)









Mean and Standard Deviation

Memphis 2002	Honeywells Computed		FAAs Computed	
	Mean	Standard Deviation	Mean	Standard Deviation
Refractivity Index	340.70	25.3	340.73	26.4
Scale Height	15006.2	2095.5	15029.8	2146.79

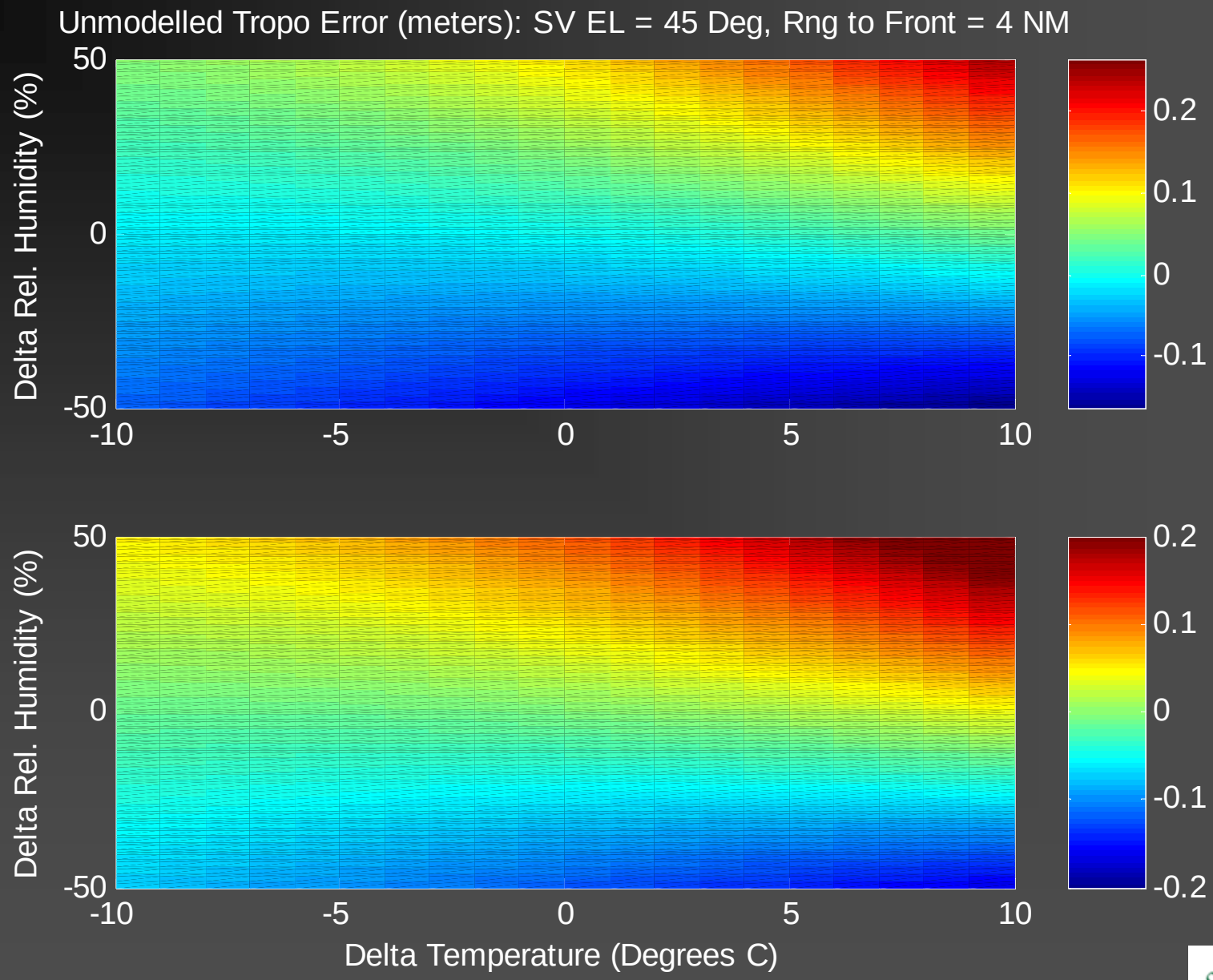
Calculations (Con't)

For our location ACY, 8 years were chosen (2001-2008). Where the following results are shown:

Year and Location	Refractivity Index	Refractivity Uncertainty	Ref. Scale height
ACY 2001	331	23	15809
ACY 2002	332	22	15682
ACY 2003	339	26	15353
ACY 2004	333	23	15753
ACY 2005	334	25	15635
ACY 2006	329	22	15841
ACY 2007	330	24	15862
ACY 2008	332	21	15613

Tropospheric Storm Bounding

- **A parameterized version of the LAAS tropospheric model was developed to explore the magnitude of range-domain model error**
  - Characterized the expected errors due to differences in the observed weather at the LAAS and user locations
  - The tropospheric range domain errors due to storms were shown to be bounded by inflation of the ionospheric divergence parameter
    - Distance factor in the protection level equation aids bounding


Unmodelled Tropo Error (meters): SV EL = 45 Deg, Rng to Front = 4 NM
Delta Rel. Humidity (%)
50
0
-50
-10
-5
0
5
10
0.2
0.1
0
-0.1
Delta Rel. Humidity (%)
50
0
-50
-10
-5
0
5
10
0.2
0.1
0
-0.1
-0.2
Delta Temperature (Degrees C)

Summary

- **Tropospheric broadcast parameter determination requires only the processing of historical data collected in the region of interest in accordance with the installation guidance**
- **Multiple data sources were located to supply the needed data for CONUS tropospheric calculations.**
  - National Climatic Data Center (NCDC) data was used
- **Memphis and Atlantic City data and parameters were presented**
- **Some variation is observed in different yearly results.**
  - Identified in the Integrity Risk Compliance Argument (IRCA)
- **Tropospheric Storm errors are bounded**

Questions