



2pNSb5

A procedure for obtaining forecast turbulence parameters in the atmospheric boundary layer for acoustic propagation

Will Doebler and Alexandra Loubeau
Acoustics 2023 Conference | 12/5/2023

Forecast turbulence parameters for acoustic propagation within the atmospheric boundary layer are available online for free!



Talk Outline

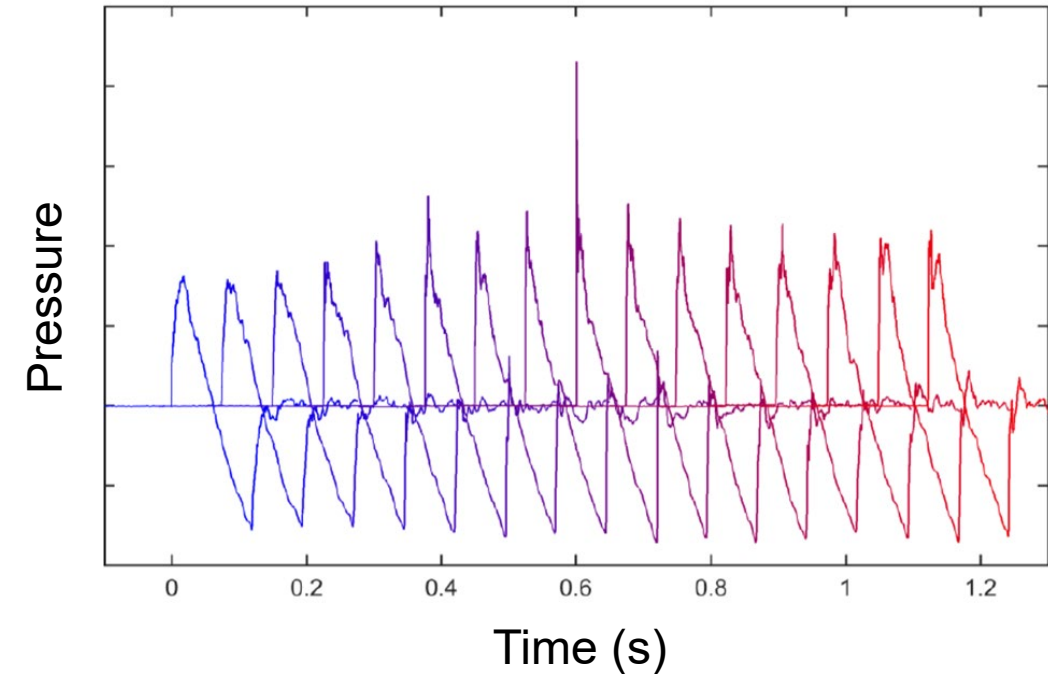
- Motivation
 - The importance of turbulence parameters for supersonic aircraft noise
- Obtaining forecast turbulence data from the Climate Forecast System model
- Illustration of spatial resolution
- Identification and derivation of turbulence parameters to run NASA sonic boom propagation software
- Comparison of turbulence model data and data measured during the NASA SonicBAT flight test campaign

Motivation for obtaining forecast turbulence data



- Turbulence within the atmospheric boundary layer impacts sound propagation
- The NASA Quesst mission has particular interest in turbulence effects on sonic booms
 - Turbulence forecast data is needed to estimate mean reduction in X-59 loudness level for community noise survey flight planning
 - Data is needed to exercise the PCBoom Turbulence Filter Module and the KZKFourier turbulence modeling software developed by Stout and Sparrow that uses the Ostashev and Wilson turbulence model
- Forecast turbulence data may be useful for new supersonic aircraft noise certification procedures and measurements
- Goal:
 - Raise awareness of modeled turbulence forecast data availability
 - Show small-scale assessment of forecast data accuracy at two locations

Variability in sonic boom recordings for microphones spaced 30 m apart





Forecast products for many models are available from NOAA



Index of /pub/data/nccf/com

Screenshot of this website:

<https://nomads.ncep.noaa.gov/pub/data/nccf/com/>

Name	Last modified	Size
Parent Directory		-
557ww/	23-Apr-2016 03:00	-
amsu_estimation/	13-Jun-2022 19:16	-
aqm/	06-May-2022 13:49	-
arch/	26-Feb-2016 16:00	-
blend/	17-Jan-2023 13:03	-
ccpa/	06-May-2022 13:51	-
cdas/	02-Jun-2022 20:14	-
cdas2/	14-Jun-2022 18:45	-
cfs/	06-May-2022 14:19	-
ens_tracker/	06-May-2022 14:37	-
estofs/	06-Feb-2023 15:20	-
etss/	06-May-2022 14:51	-
fnmoc/	01-Mar-2016 18:55	-
fnmoc_wave/	18-May-2022 15:29	-
gefs_legacy/	15-Sep-2022 21:06	-
gens/	25-Oct-2022 18:35	-
gfs/	10-Dec-2022 17:06	-
gfs_mos/	11-Apr-2023 16:32	-
glmp/	11-Apr-2023 16:50	-
glofs/	13-Jun-2022 19:16	-
glwu/	09-May-2023 11:06	-
hiresw/	06-May-2022 15:44	-
hmon/	13-Jun-2022 19:16	-
hourly/	26-Feb-2016 15:20	-
href/	13-Jun-2022 19:17	-
hrrr/	06-May-2022 15:45	-
hur/	26-Feb-2016 15:22	-
hwrf/	13-Jun-2022 19:18	-
hysplit/	07-Feb-2023 18:07	-
ingest/	02-Sep-2022 00:54	-
lmp/	11-Apr-2023 16:48	-
naefs/	06-May-2022 15:51	-
nam/	19-May-2022 14:28	-
nam_mos/	13-Jun-2022 19:18	-
narre/	06-May-2022 15:53	-
navgem/	08-Aug-2022 15:56	-
navo/	29-Jun-2021 14:36	-
ncom/	01-Mar-2016 13:48	-
ngac/	02-Mar-2016 08:31	-
nhc/	01-Mar-2016 14:05	-
nldas/	06-May-2022 15:57	-
nos/	25-Oct-2022 12:15	-
nos/	25-Oct-2022 12:15	-
nosofs/	25-Oct-2022 12:15	-
nsst/	13-Jun-2022 19:18	-
nwm/	06-May-2022 15:59	-
nwps/	06-May-2022 16:00	-
obsproc/	08-Dec-2022 17:16	-
omb/	15-Sep-2022 21:23	-
pcpanl/	06-May-2022 16:08	-
petss/	06-May-2022 16:09	-
psurge/	02-May-2023 16:20	-
rap/	06-May-2022 16:10	-
rtma/	21-Feb-2023 12:20	-
rtofs/	08-Aug-2022 13:49	-
seaice_analysis/	13-Jun-2022 19:19	-
seaice_drift/	13-Jun-2022 19:19	-
smartinit/	13-Jun-2022 19:19	-
spc_post/	01-Jun-2022 18:24	-
sref/	06-May-2022 16:15	-
stofs/	12-Jan-2023 15:20	-
swmf/	06-May-2022 16:16	-
ukmet/	03-Nov-2022 14:12	-
urma/	15-Feb-2023 15:20	-
uvi/	13-Jun-2022 19:19	-
wave/	19-May-2022 14:29	-
wave_nfcens/	13-Jun-2022 19:20	-
wfs/	06-May-2022 16:18	-
wsa_enlil/	09-Apr-2023 18:20	-



Indicates the model data shown for the rest of this presentation



Indicates other models that NASA has investigated as part of the Quesst mission



An automated process for obtaining CFSv2 forecast turbulence data

- Software:
 - Matlab 2020b
 - Python 3.8.8
 - Matlab nctoolbox <https://github.com/nctoolbox/nctoolbox>
- CFSv2 data location: <https://nomads.ncep.noaa.gov/pub/data/nccf/com/cfs/prod/>
- Python script to download the data
 - Inputs: reference time, valid time
 - Pseudocode:

```
import requests, sys
r = requests.get(myURL, allow_redirects=True)
save r.content to file
```
- Matlab wrapper to download and process the data
 - Pseudocode:

```
setup nctoolbox
choose reference time and valid forecast time
load data as ncgeodataset
populate a structure with the turbulence parameters
plot/analyze as needed
```



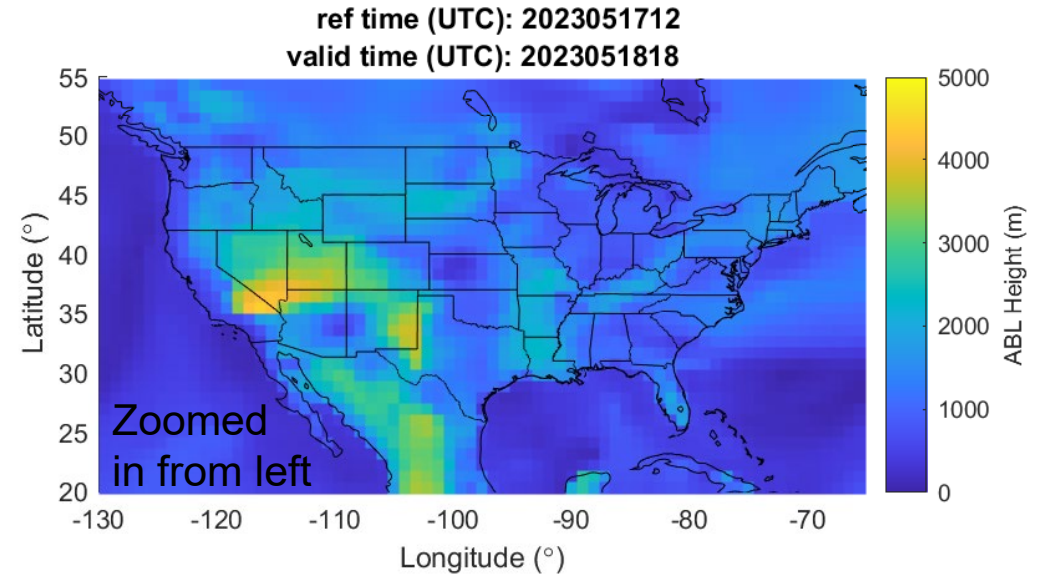
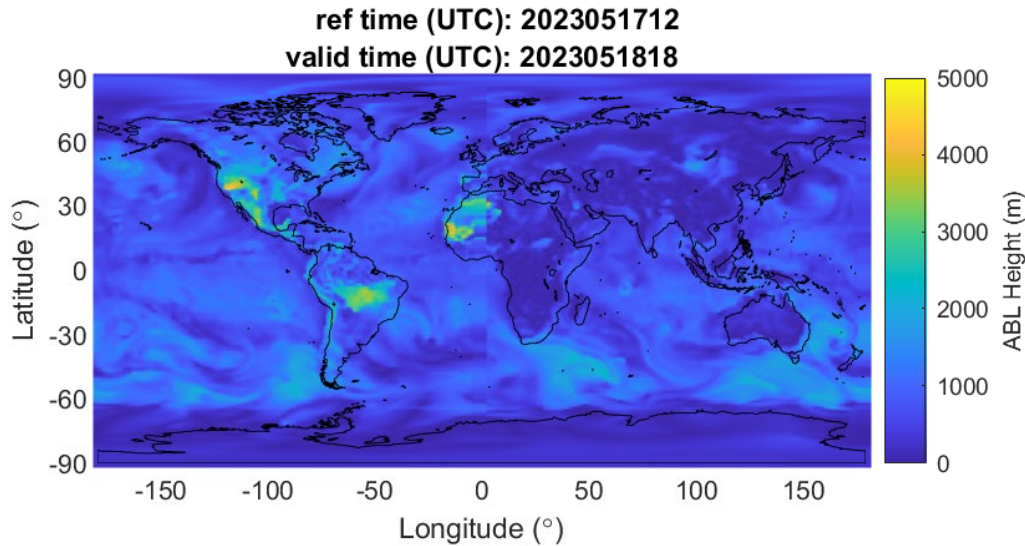
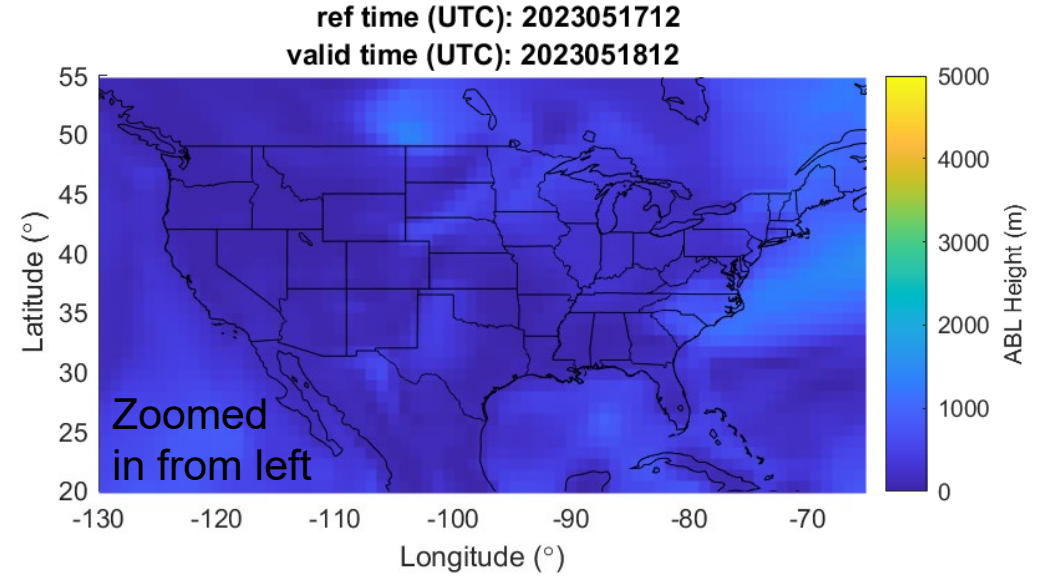
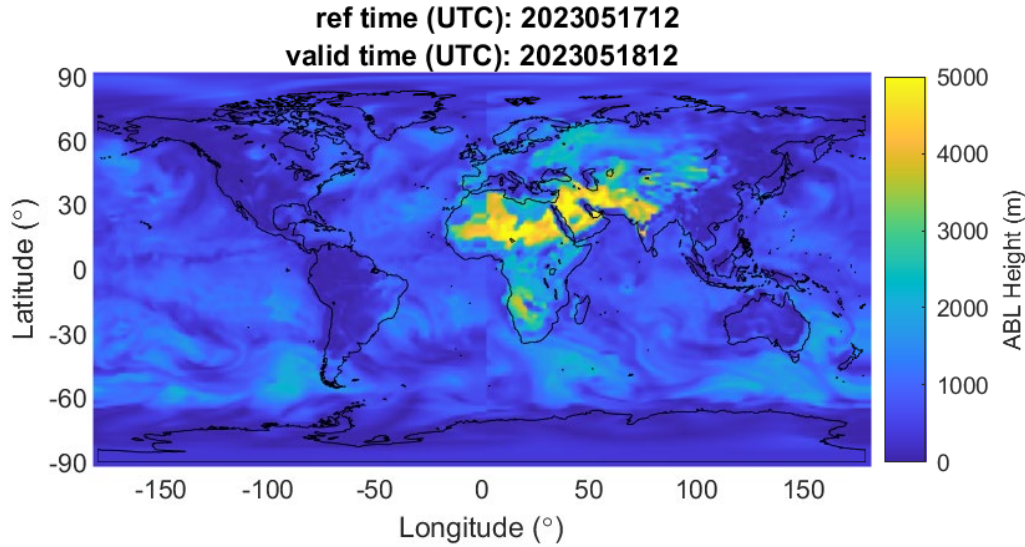
Example data: +24 and +30 hr atmospheric boundary layer height



Same Reference Time

+24 hr forecast
12:00 UTC = 8 AM EDT

+30 hr forecast
18:00 UTC = 2 PM EDT





Model data resolution

- CFSv2 data presented here
 - $\sim 1^\circ \times 1^\circ$ Lat/Lon
 - Forecast data available every 6 hours
- Future work: look at other available models with better spatial and temporal resolution



Useful Native CFSv2 Model Parameters

- Surface pressure p_s
 - Variable: "Pressure_surface"
 - Units: Pa
- Surface temperature θ_s
 - Variable: "Temperature_surface"
 - Units: K
- Specific humidity at 2 m AGL q
 - Variable: "Specific_humidity_height_above_ground"
 - Units: kg/kg
- Friction velocity u_*
 - Variable: "Frictional_Velocity_surface"
 - Units: m/s
- Atmospheric boundary layer height z_i
 - Variable: "Planetary_Boundary_Layer_Height_surface"
 - Units: m
- Sensible heat flux H
 - Variable: "Sensible_heat_net_flux_surface"
 - Units: W/m²
 - Note that the sign convention of this matters
- Surface geopotential height $Z_g = \Phi/g_0$
 - Variable: "Geopotential_height_surface"
 - Units: geopotential meters "gpm"

Additional derived parameters needed for PCBoom and KZKFourier software



- Relative humidity (%) at 2m AGL¹

$$h_r \approx 100 \frac{q}{0.622 \frac{e_s}{p_s}} = \frac{100 p_s q}{0.622 \left(611 \exp \left(\frac{17.67 (\theta_s - 273.16)}{\theta_s - 29.65} \right) \right)}$$

- Mixed-layer velocity scale² w_*

$$w_* = \left(\frac{g_0 H z_i}{\theta_s \rho c_p} \right)^{1/3}$$

- $\rho \rightarrow$ Density is derived using Ideal Gas Law

$$\rho = \frac{p_s}{R_{air} \theta_s}$$

$$R_{air} = 287.05 \text{ J/kg K}$$

- $g_0 \rightarrow$ gravity = 9.80665 m/s²

- $c_p \rightarrow$ specific heat at constant pressure $\approx 1.006 \text{ kJ / kg K}$

- Surface-layer temperature scale² T_*

$$T_* = - \frac{H}{u_* \rho c_p}$$

- Ground elevation from geopotential height³

$$z_0 \approx \frac{r_E Z_g}{r_E - Z_g}$$

- Radius of earth $r_E = 6378.1 \text{ km}$

1. C. Webster, <https://earthscience.stackexchange.com/questions/2360/how-do-i-convert-specific-humidity-to-relative-humidity>
2. D. K. Wilson, "A turbulence spectral model for sound propagation in the atmosphere that incorporates shear and buoyance forcings," *J. Acoust. Soc. Am.* **108**, pp. 2021-2038, (2000); doi: [10.1121/1.1311779](https://doi.org/10.1121/1.1311779)
3. R. Romond, "Meteorological reanalysis data inputs for improved aviation noise modeling," (2019); <https://etda.libraries.psu.edu/catalog/17792rar241>

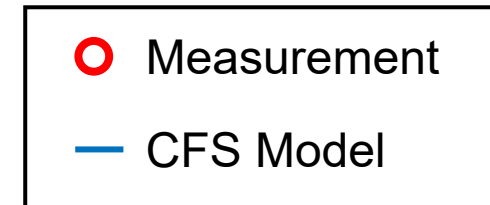
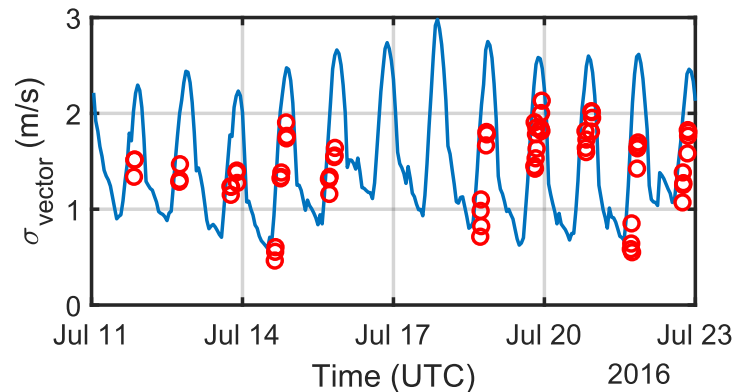
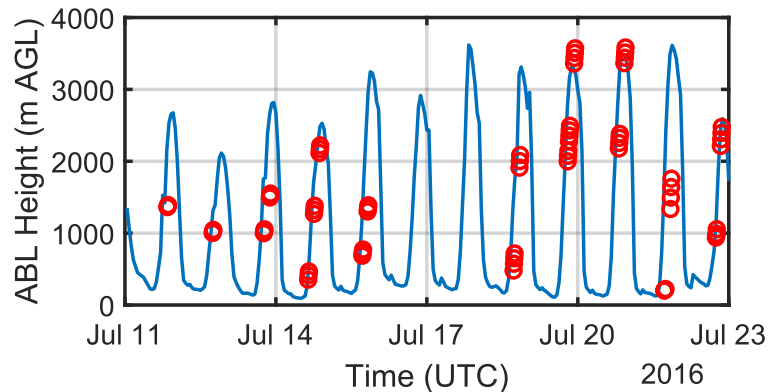
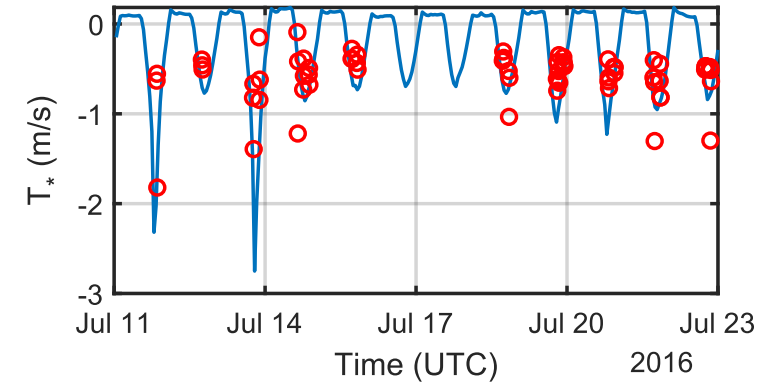
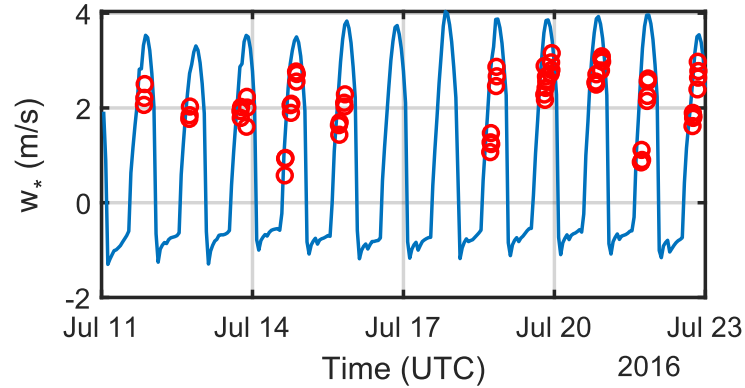
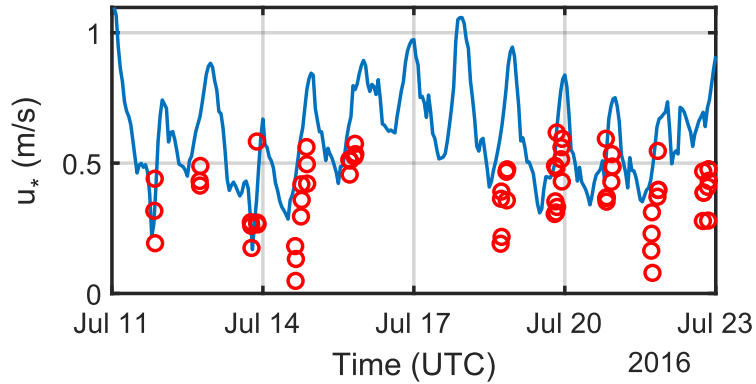
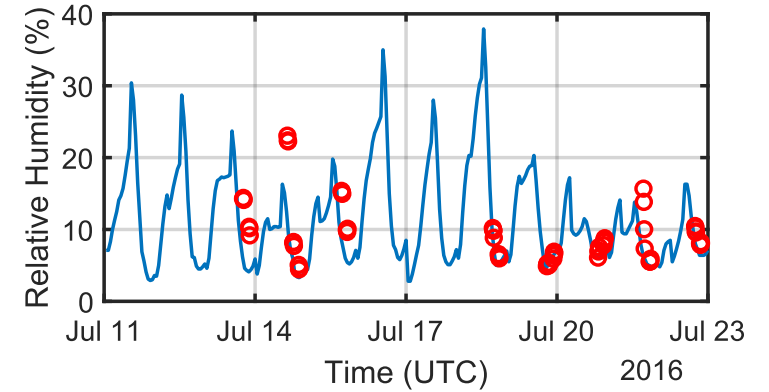
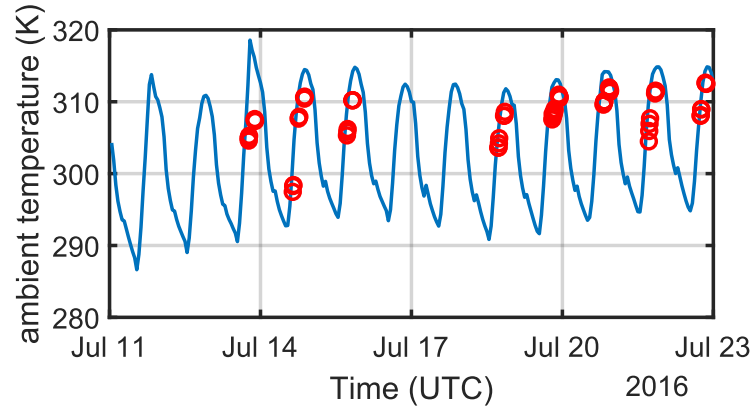
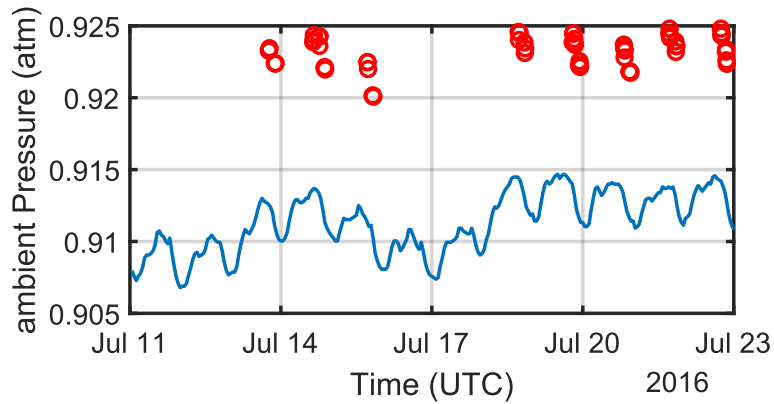
Comparison of forecast and measurement data

- Sonic Booms in Atmospheric Turbulence (SonicBAT) flight test and measurement campaign
 - Desert location near Edwards Air Force Base, California
 - Measurements taken over a ~2-week period in July 2016
 - Humid coastal location near Kennedy Space Center, Florida
 - Measurements taken over a ~2 week period in August 2017
- Turbulence parameters derived from a combination of measurements by
 - sonic anemometers
 - SODARs
 - surface weather towers
 - weather balloons



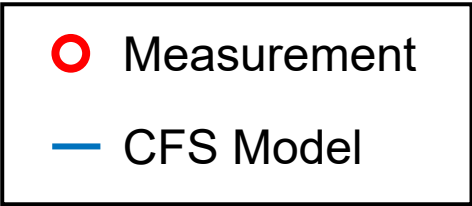
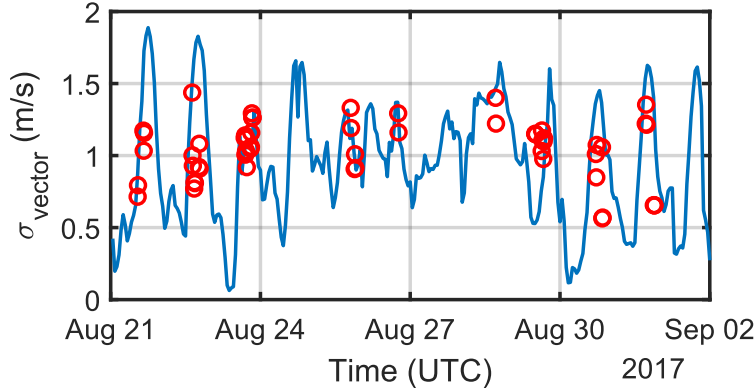
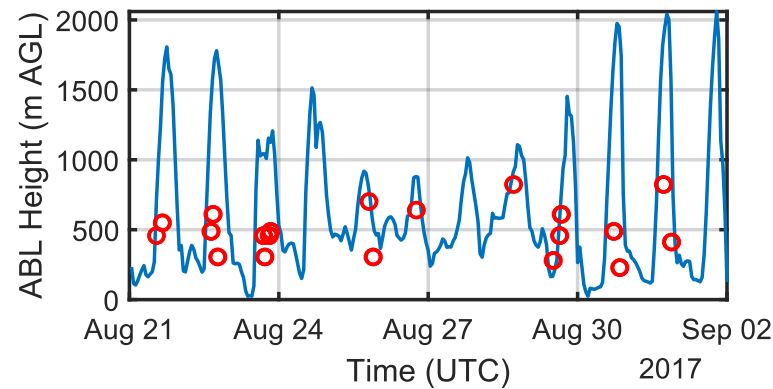
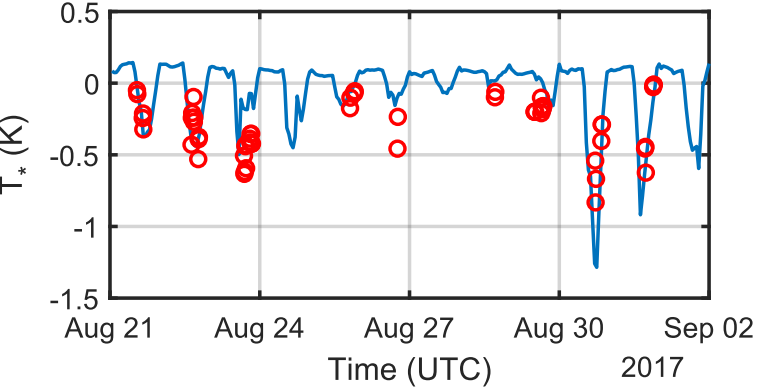
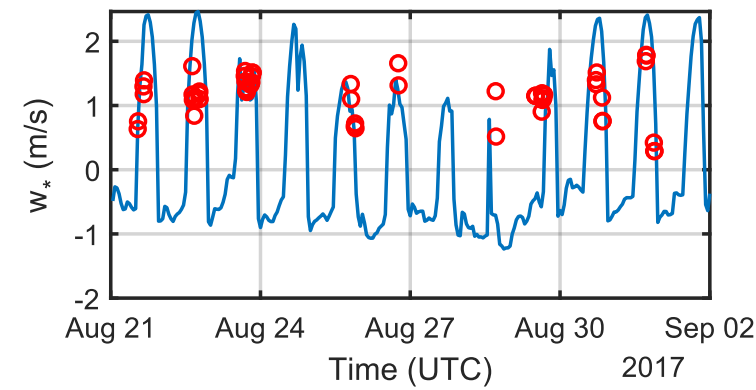
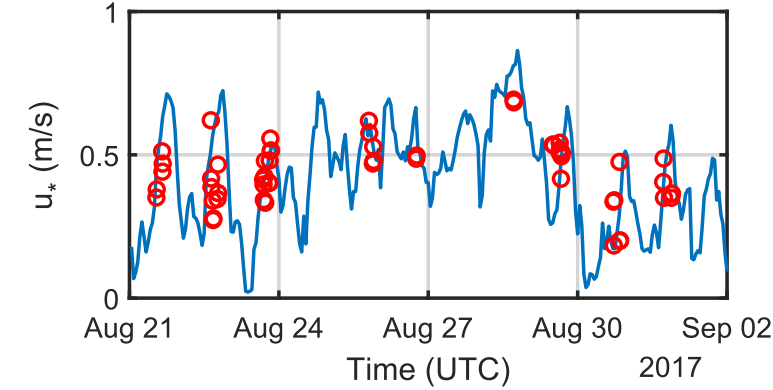
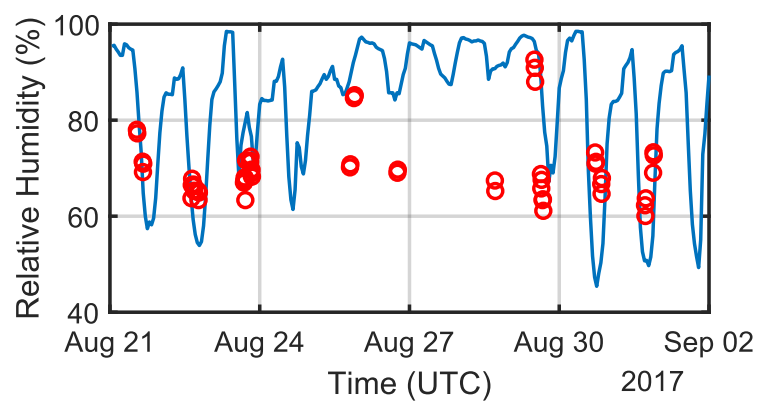
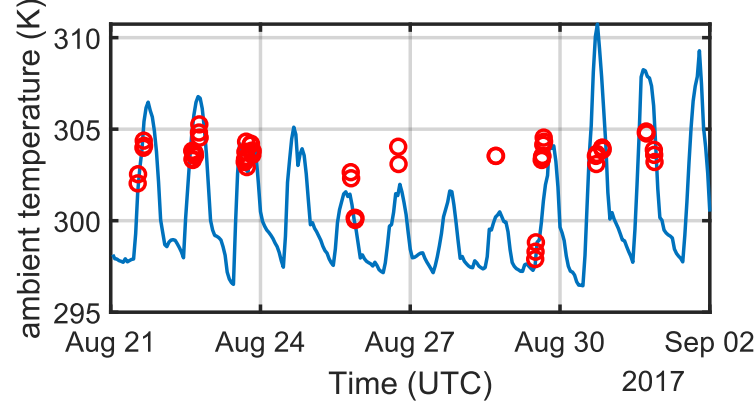
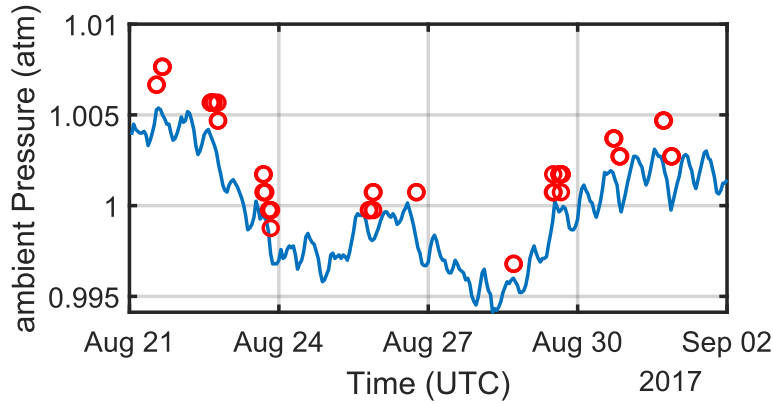


Comparison of forecast and measurement data (California)





Comparison of forecast and measurement data (Florida)



Summary and future work



- Turbulence forecast parameters are important for sonic boom propagation
- NASA Quesst mission needs forecast turbulence parameters for pre-flight planning of the X-59 aircraft as part of its community noise survey
- NOAA provides turbulence forecast data from the CFS and other models
- The turbulence parameters were obtained to run the NASA PCBoom and KZKFourier software
- Modeled turbulence parameters were compared to those measured during the NASA SonicBAT mission and have reasonable agreement
- Future work
 - Investigate other available turbulence models

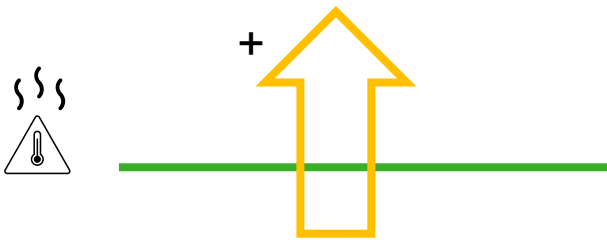
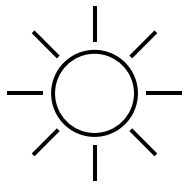
QUEST



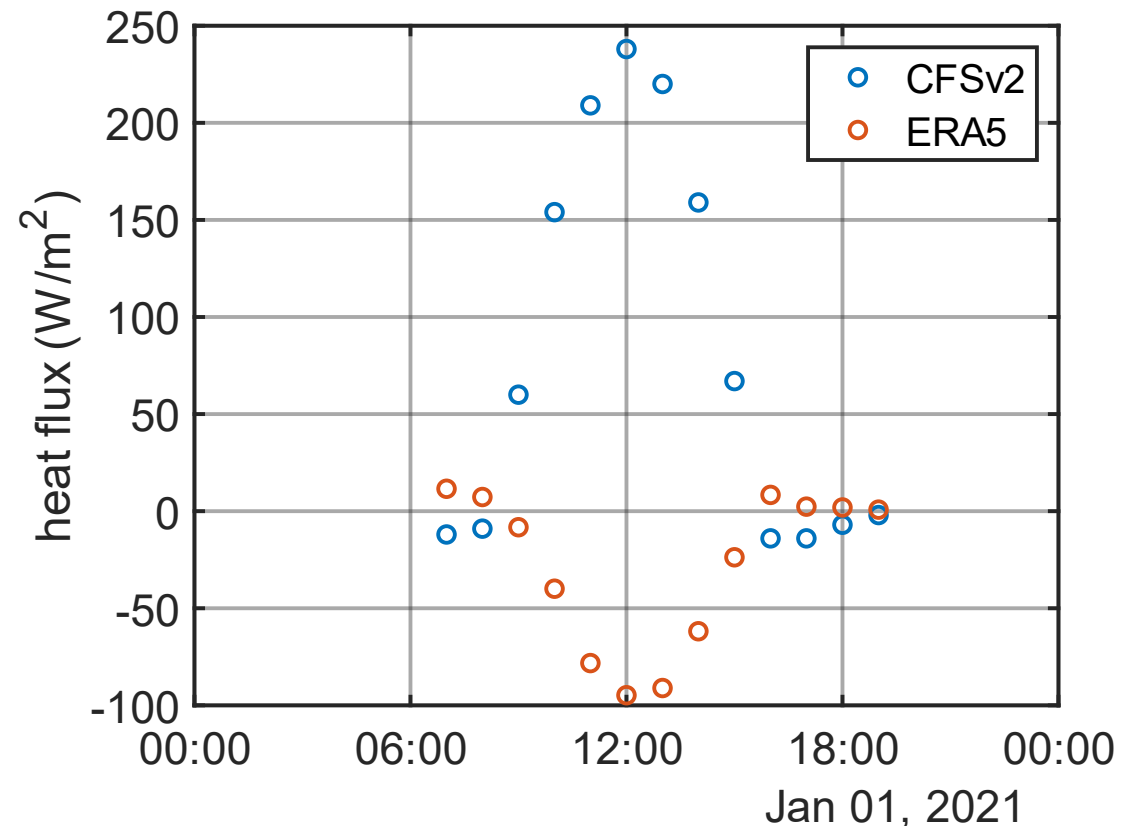
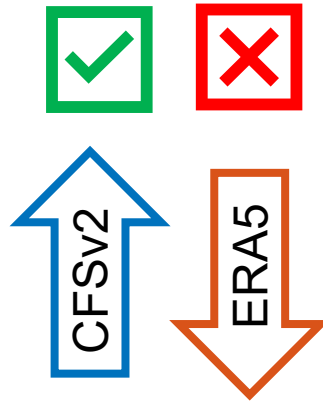
BACK-UP

Note on heat flux sign convention

- CFSv2 and ERA5 heat flux have opposite sign convention
 - “The ECMWF convention for vertical fluxes is positive downwards”
- Ostashev and Wilson (2016), “the sensible heat flux [is] from the surface to the overlying air”
- Need to multiply ERA5 heat flux by -1 to match Ostashev and Wilson model used in KZKFourier



KZKFourier sign convention:
Heat flux from the surface to the air



Abstract



- Propagation through turbulence causes a mean reduction in loudness of sonic booms and in some cases can cause significant fluctuations in loudness about that mean. Understanding these effects is important for accurately planning loudness levels during upcoming community noise tests with the X-59 aircraft as well as mitigating the risk for excessive loudness due to turbulence. Current methods for modeling acoustic propagation through turbulence require several atmospheric parameters including the atmospheric boundary layer (ABL) height, friction velocity, mixed-layer velocity scale, surface-layer temperature scale, as well as ambient pressure, temperature, and humidity within the ABL. Accurate forecasts of these parameters are needed for X-59 flight planning and may also be useful for planning future supersonic aircraft certification flight tests. This presentation showcases one method for obtaining the forecast turbulence and ambient atmospheric parameters from freely available Climate Forecast System Version 2 data. Forecast parameters are compared to measurements to assess accuracy and utility.