Estimates of $C_n^2$ from numerical weather prediction model output

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Estimates of Cn2 from Numerical Weather Prediction Model Output and Comparison with Thermosonde Data.

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Motivation for Forecasting $C_n^2$

- Defines image quality for optical and infrared sensors
- Describes laser beam distortion
- Investigate new turbulence estimates in the troposphere (where traditional metrics based on vertical gradients perform poorly)
- Evaluate usefulness of turbulence metrics in evaluating the skill of forecast models
- Radio $C_n^2$ describes GPS signal distortion
Operational high-resolution WRF over ATEC* ranges, updated continuously with latest observations (4DWX)

- Aberdeen (ATC)
- Dugway Proving Grounds (DPG)
- Electronic Proving Grounds (EPG)
- Ft. Greely, AK (CRTC)
- Redstone Arsenal (RTTC)
- Yuma Proving Ground (YPG)
- White Sands Missile Range (WSMR)

*ATEC=U.S. Army Test and Evaluation Command
3 nested grids customized to each range

D1=30km, D2=10km, D3=3.33 km

(YPG, CRTC, RTTC not shown)
WRF Model Setup

- Initialized with GFS
- Nested in 3 domains 30/10/3.3km
- 80 levels with top at 30 km
- Rayleigh sponge starting at 15 km
- MYJ, YSU PBL schemes
Model Estimates

- Compute $C_n^2$ based on 2nd order structure functions by accounting for model filtering at small scales
- Related to turbulence estimates for aviation safety
- First case study uses WRF with 3 km grid
- Compared to “thermosonde” measurements of $C_n^2$ at Holloman AFB, NM
- Nighttime – SBL
- Complex terrain

![Graph showing $D_T(s)$ vs. Separation $s$ with model deficit indicated.](image)
\( C_n^2 \) Estimates

- Compute \( C_n^2 \) around each grid point using 5x5 point domain
- Calculate best-fit model
- Best-fit level is \( C_n^2 \)
Thermosonde Profiles

• Rawinsonde platform
• Average temperature difference squared at 1 m ($C_T^2$)
• Convert $C_T^2$ to $C_n^2$
• Intermittency of turbulence

2 profiles 1 hr apart
Thermosonde launch (flight 15 July 19 2004 0200 UTC – “The Good”)
Thermosonde launch (flight 7
July 16  2004 0400 UTC – “The Bad”)
Thermosonde launch (flight 22 July 21 2004 0400 UTC)
Sensitivity to PBL Scheme (flight 21 July 21 2004 0400 UTC)

- MYJ and YSU
- PBL scheme modifies surface winds
- Changes gravity wave evolution
Rapid Changes in Time (flight 21 July 21 2004 02-03 UTC)

- MYJ scheme
- Reduction in upper tropspheric turbulence
- Gravity wave evolution
Vertical Cross-sections (flight 21
July 21 2004 02 UTC)
Example WSMR output

u, w cross section 12 Jul 2007 10 UTC
Forecast Maps of $C_n^2$

- Constant altitude (10 km) calculation
- Spatial variability of turbulence
- Low and high turbulence regions
Summary

• Structure function-based estimates of $C_n^2$ are promising
  – Produces good agreement over full altitude range for forecast lead time out to 18 hrs
  – Easy to compute
  – Does not require vertical gradients

• Area averaged estimates have less statistical variability than thermosonde data

• Sensitive to PBL scheme

• An excellent NWP model verification metric since it is very sensitive to NWP model errors