Turbulent Fluxes and Air Pollution in Cold Air Pool Events (Meteorology-Chemistry Coupling)

Heather Holmes, Xia Sun

Atmospheric Sciences Program, University of Nevada, Reno

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Salt Lake City, UT, USA

University of Nevada, Reno

Key Unanswered Questions

- What role does the boundary layer structure have on PM formation and the chemical processes?
- What role do stratiform clouds have on the atmospheric chemistry and boundary layer mixing?
- Can NWP models simulate near-surface meteorological conditions during stable PBL? **No!**
- Is it time to move on from existing dimensionless flux-gradient parameterizations to simulate the PBL mixing? **Yes!**
- Do we have enough turbulence data to make new empirical formulations for the RANS closure? **No!**

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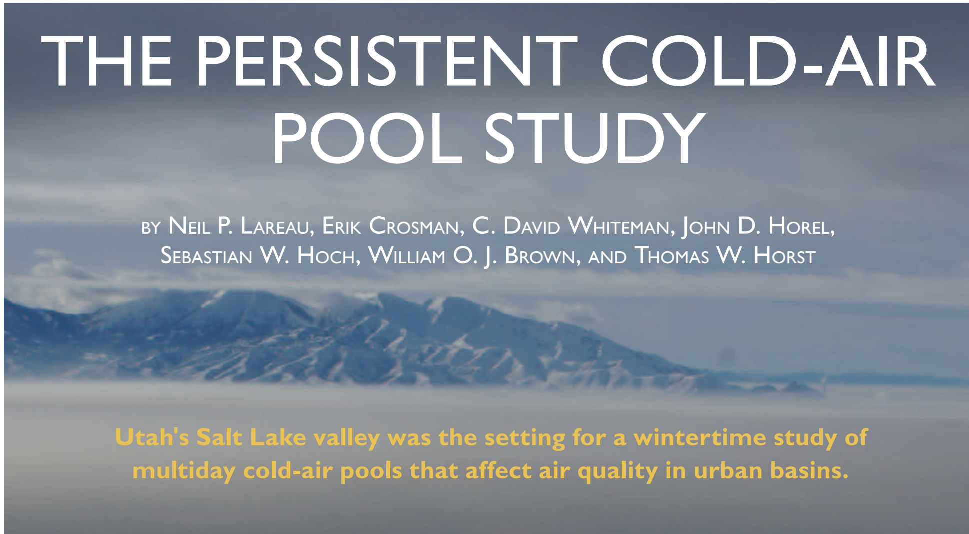
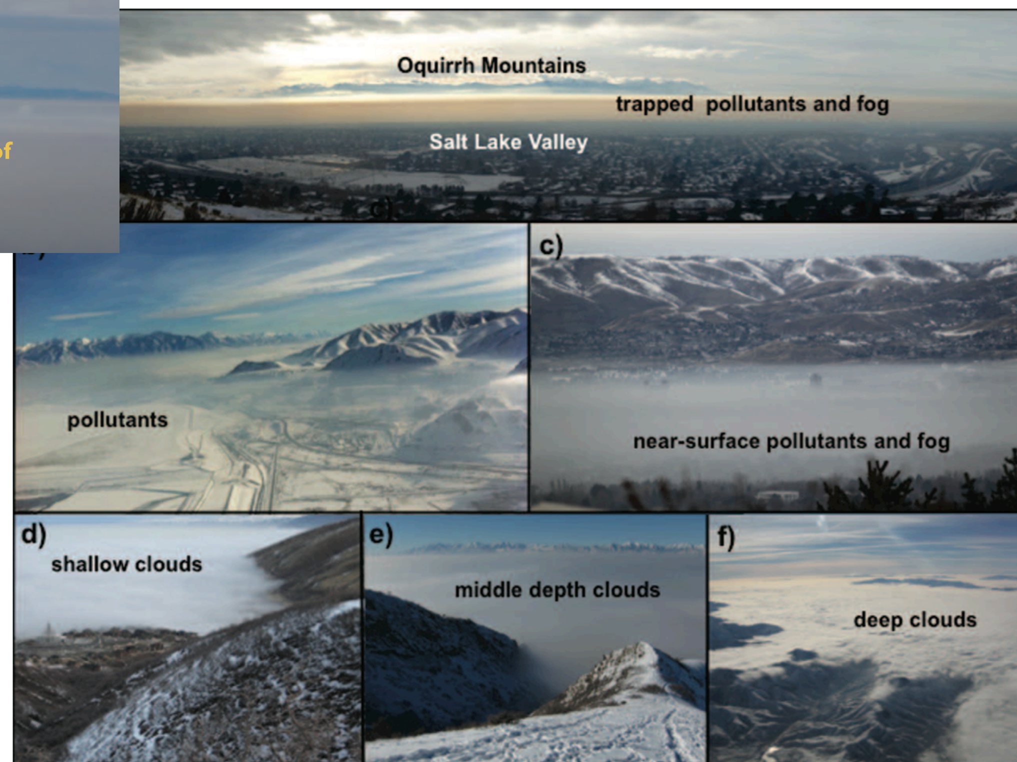
Persistent Cold-Air Pool Study



PCAPS field campaign (NSF: 0938397)

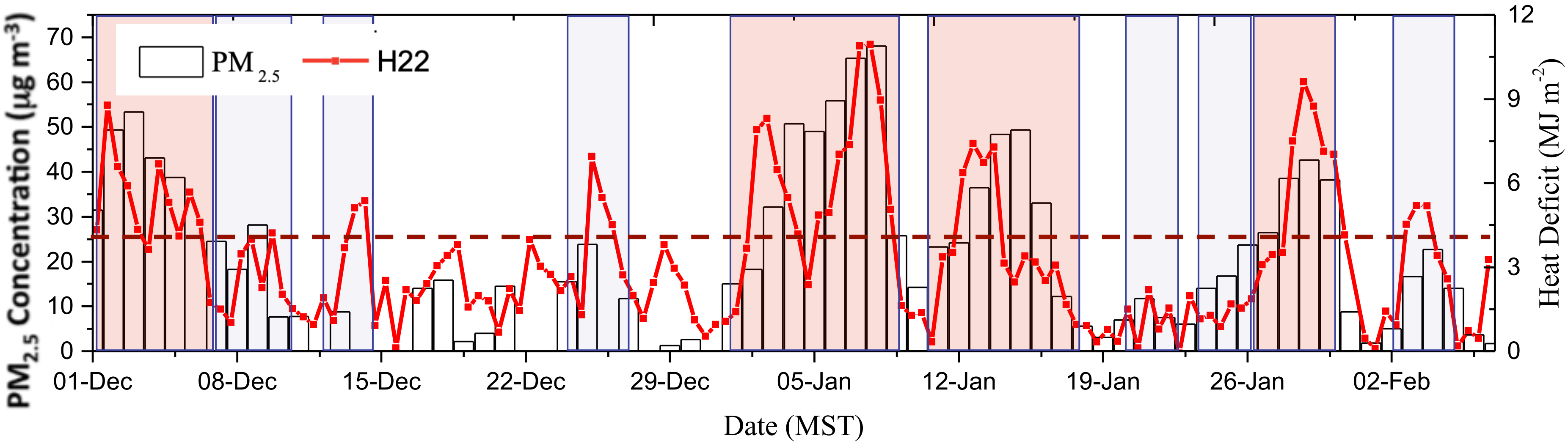
C. David Whiteman (U. of Utah)
John Horel (U. of Utah)
Sharon Zhong (Michigan State)

- Field Experiment
- Wintertime
- 2 ½ Months
- Salt Lake Valley, Utah
- Multiple Upper Air and Surface Sites



(Figures from: Lareau et al., BAMS 2013)

PCAPS Study Time Period: Winter 2010-2011



- 10 Intensive Observation Periods (IOPs)
- Brief and weak CAPs throughout ***Weak CAPs***
- 4 IOPs with ***Strong Multiday Persistent CAPs***
- NWP Modeling – IOP3 & IOP5
- Air Quality Modeling − January 2011 (IOP5 − IOP9)

Monitoring Locations: Turbulence Data

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NCAR EOL

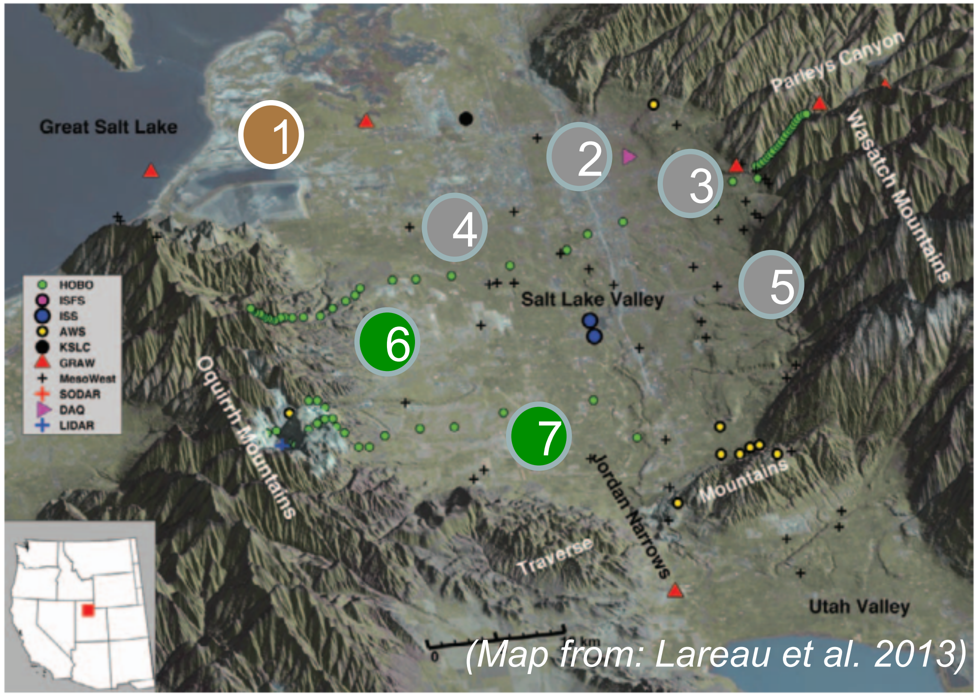
Integrated Surface Flux System (ISFS)

Observation period:

Dec 2010 – Feb 2011

Sensor height:

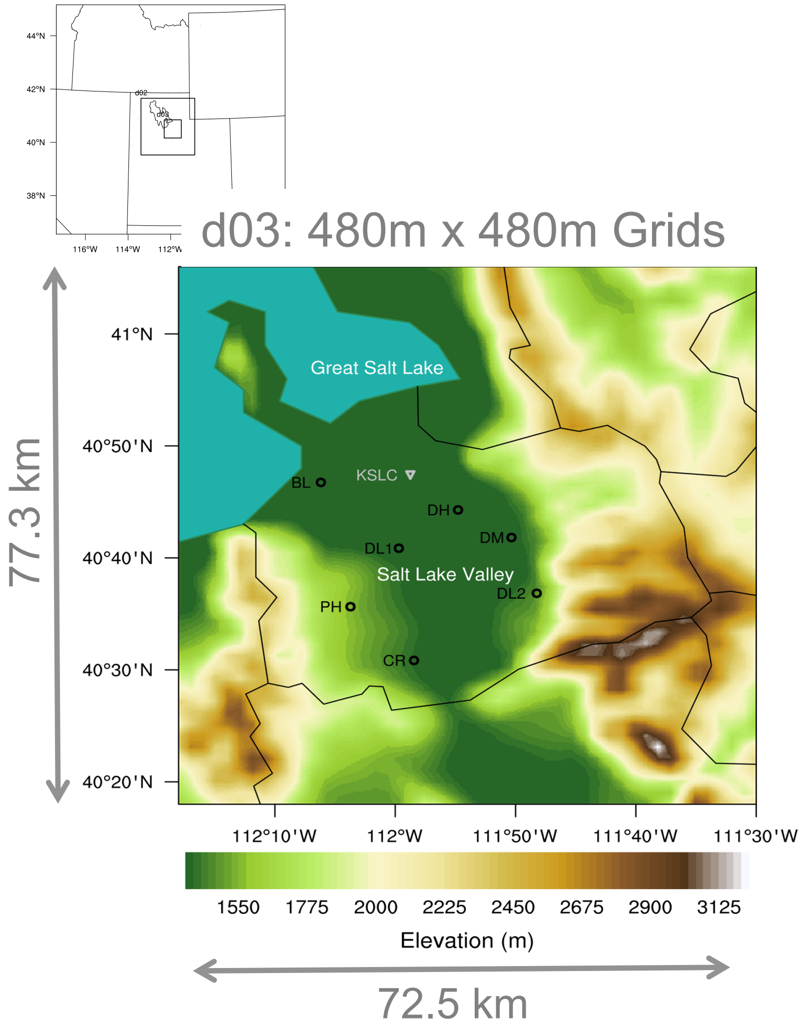
3m or 10m



No.	Site	Sensor Height (m)	Land Use (National Land Cover Database, NLCD)
1	Playa	3	Barren land
2	ABC Urban	10	Developed, high intensity
3	Highland	10	Developed, medium intensity
4	West Valley	10	Developed, low intensity
5	East Slope	10	Developed, low intensity
6	West Slope	3	Pasture/Hay
7	Riverton	10	Cultivated Crops

Numerical Weather Prediction Model

Weather Research & Forecasting (WRF) v3.7.1



Configurations

- NAM 12-km analysis dataset
- 3 Two-Way Nested Domains (finest: 480m)
- 30 Vertical Levels (10 in first 1,000m AGL)
- Surface and Upper Air Nudging (OBSGRID)
- NLCD Land Use Classification

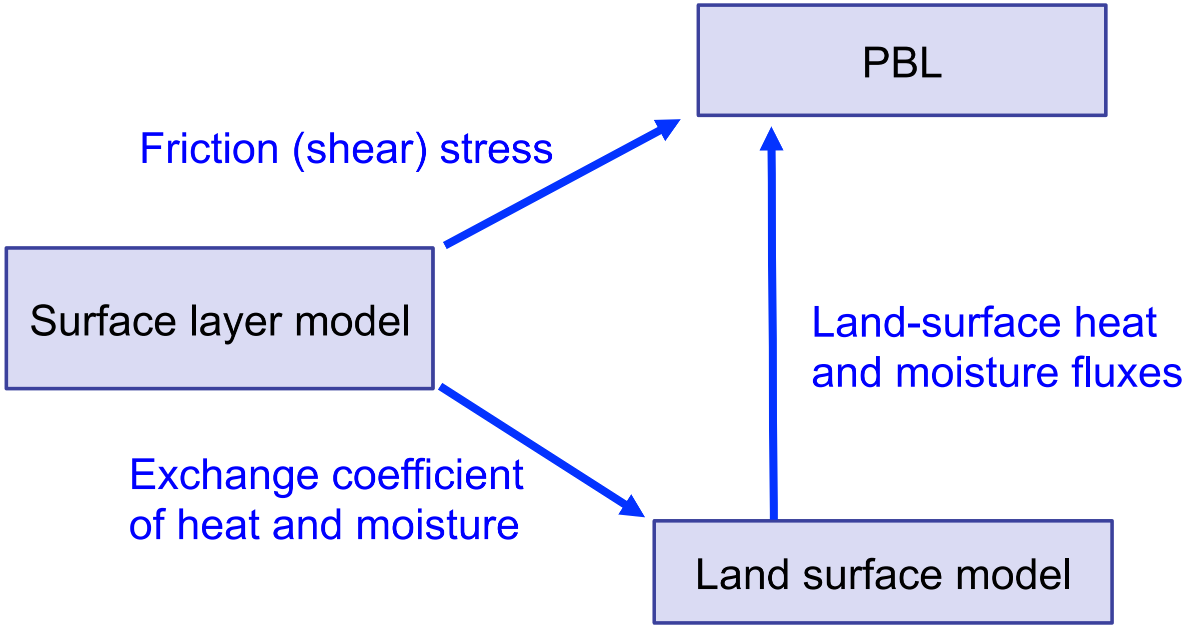
Common Physics

- **Cloud Microphysics:** Lin
- **Longwave Radiation:** Rapid Radiative Transfer Model
- **Shortwave Radiation**: Dudhia
- **Cumulus Parameterizations**: Kain-Fritsch
- **Cloud Fraction Option:** Xu-Randall

Sensitivity Testing: PBL, Surface Layer, LSM

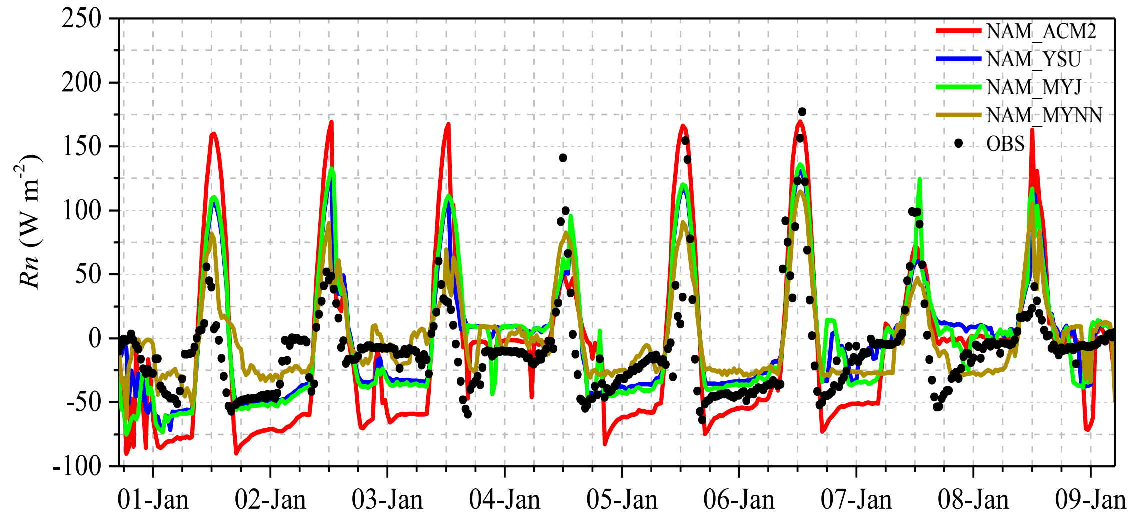
Planetary Boundary Layer, Surface Layer, Land Surface

1. ACM2, Pleim-Xiu, Pleim-Xiu (with soil nudging) [ACM2]
2. YSU, Revised MM5, Noah [YSU]
3. MYJ, Eta Similarity, Noah [MYJ]
4. MYNN, MYNN, Noah [MYNN]

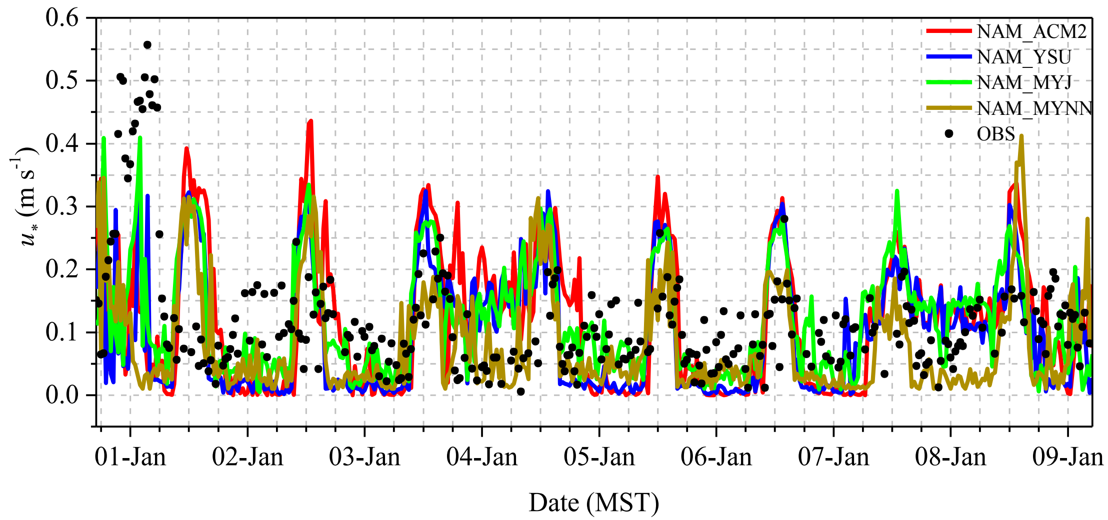


Simulated Net Radiation and Friction Velocity (Strong CAP – IOP5)

Net Radiation (W/m^2)



Friction Velocity (m/s)



Sun et al., *(in prep)*

Simulated Surface Fluxes (Strong CAP - IOP5)

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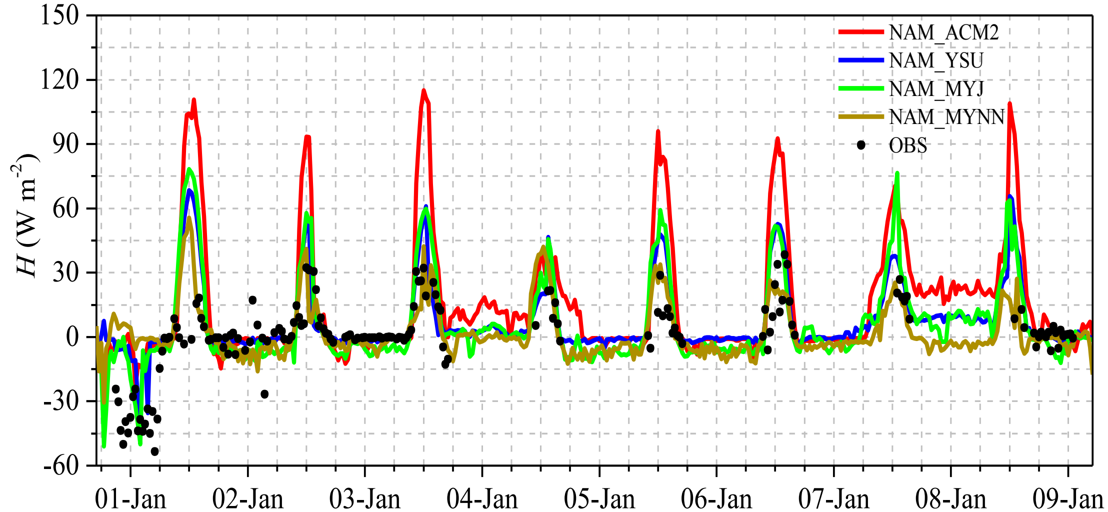
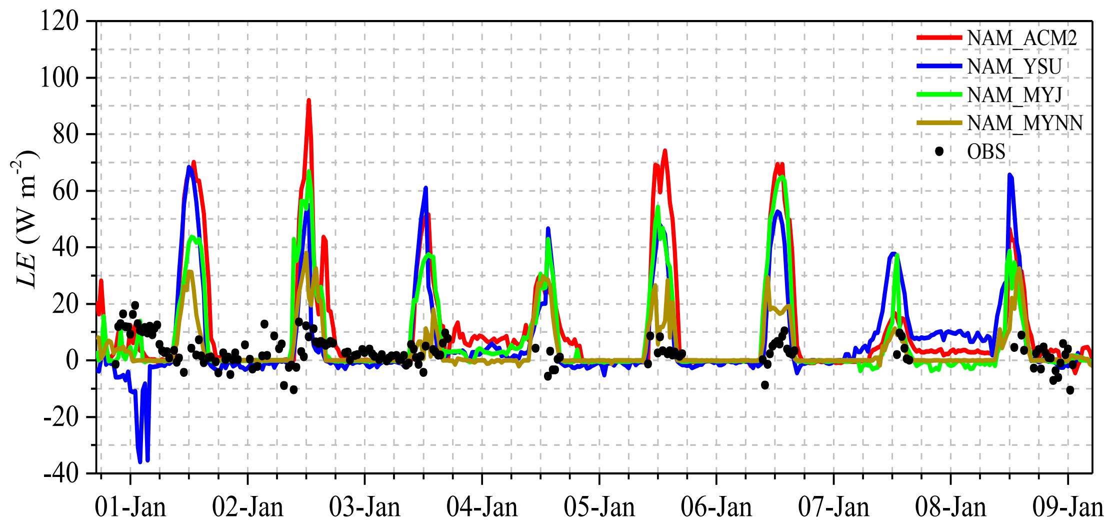
Sensible HF (W/m²)



Latent HF (W/m²)



Sun et al., ***(in prep)***

Spatial Variability of Surface Fluxes

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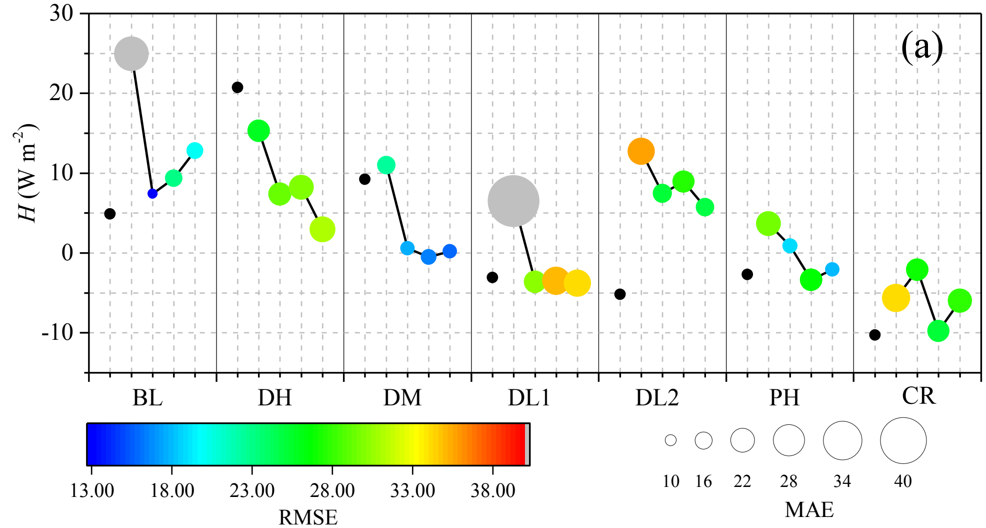
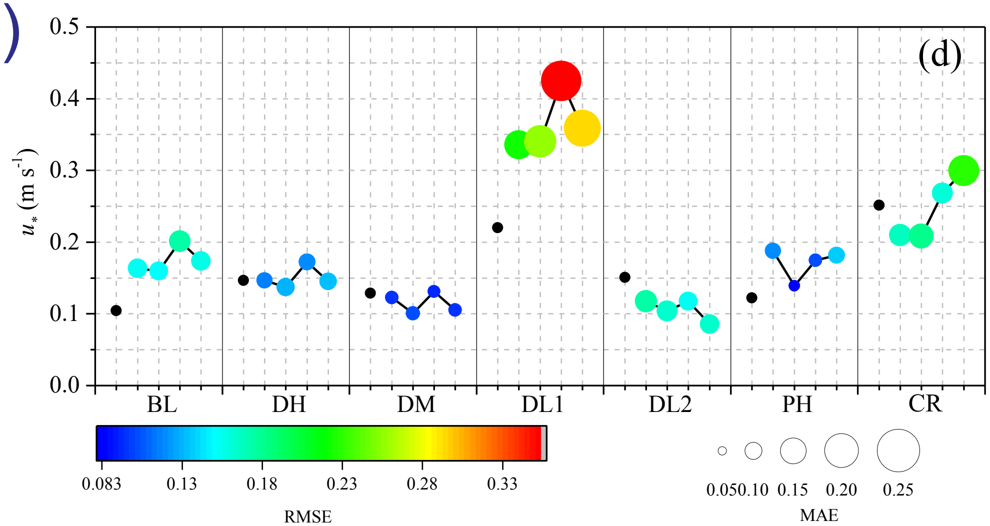
Sensible HF (W/m^2)



① ACM2
② YSU
③ MYJ
④ MYNN

Friction Velocity (m/s)



Sun et al., *(in prep)*

Spatial Variation of Surface Transfer Coefficient

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Sensible Heat Flux Calculation

$$H = \rho c_p C_h U_a (T_s - T_a)$$

Where:

ρ = density

c_p = specific heat capacity

C_h = surface transfer coefficient

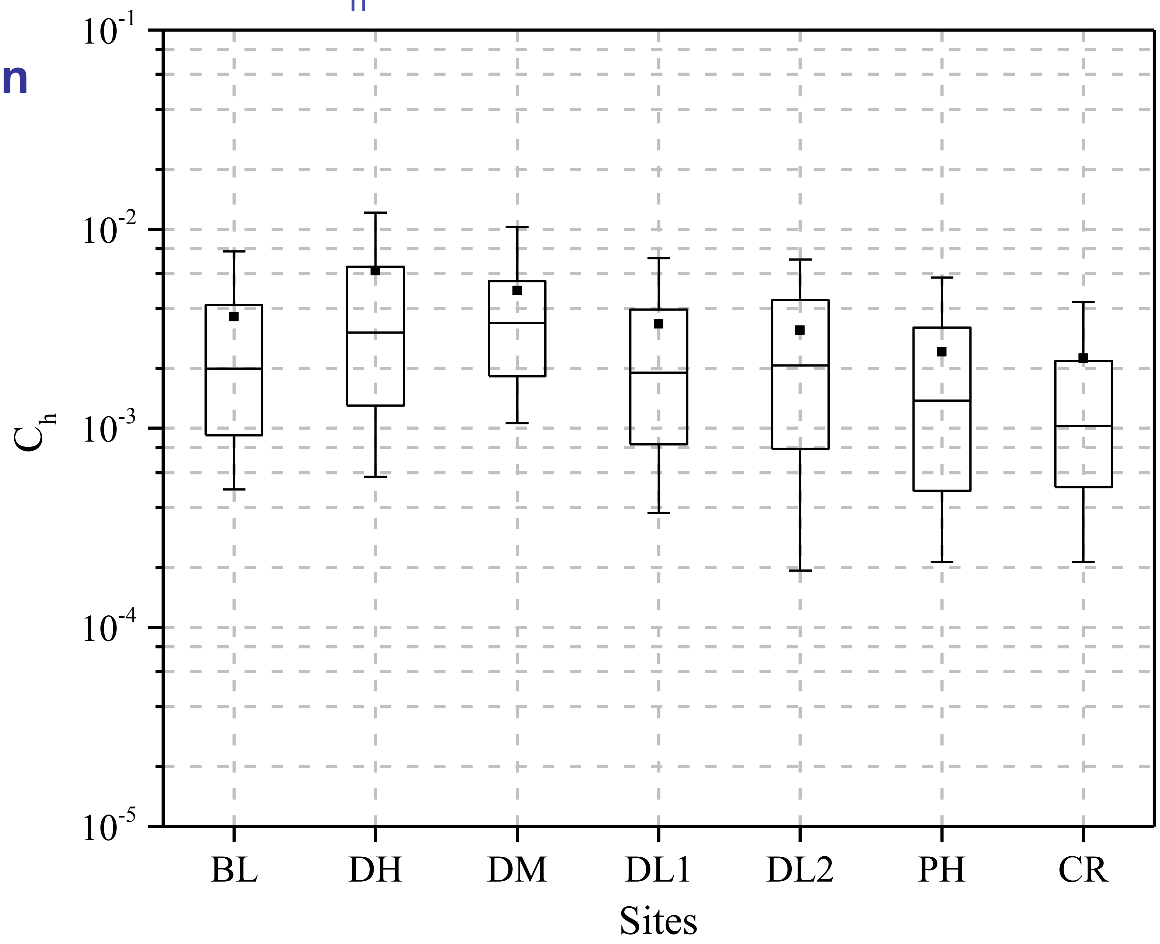
U = wind speed

T = temperature

s = surface

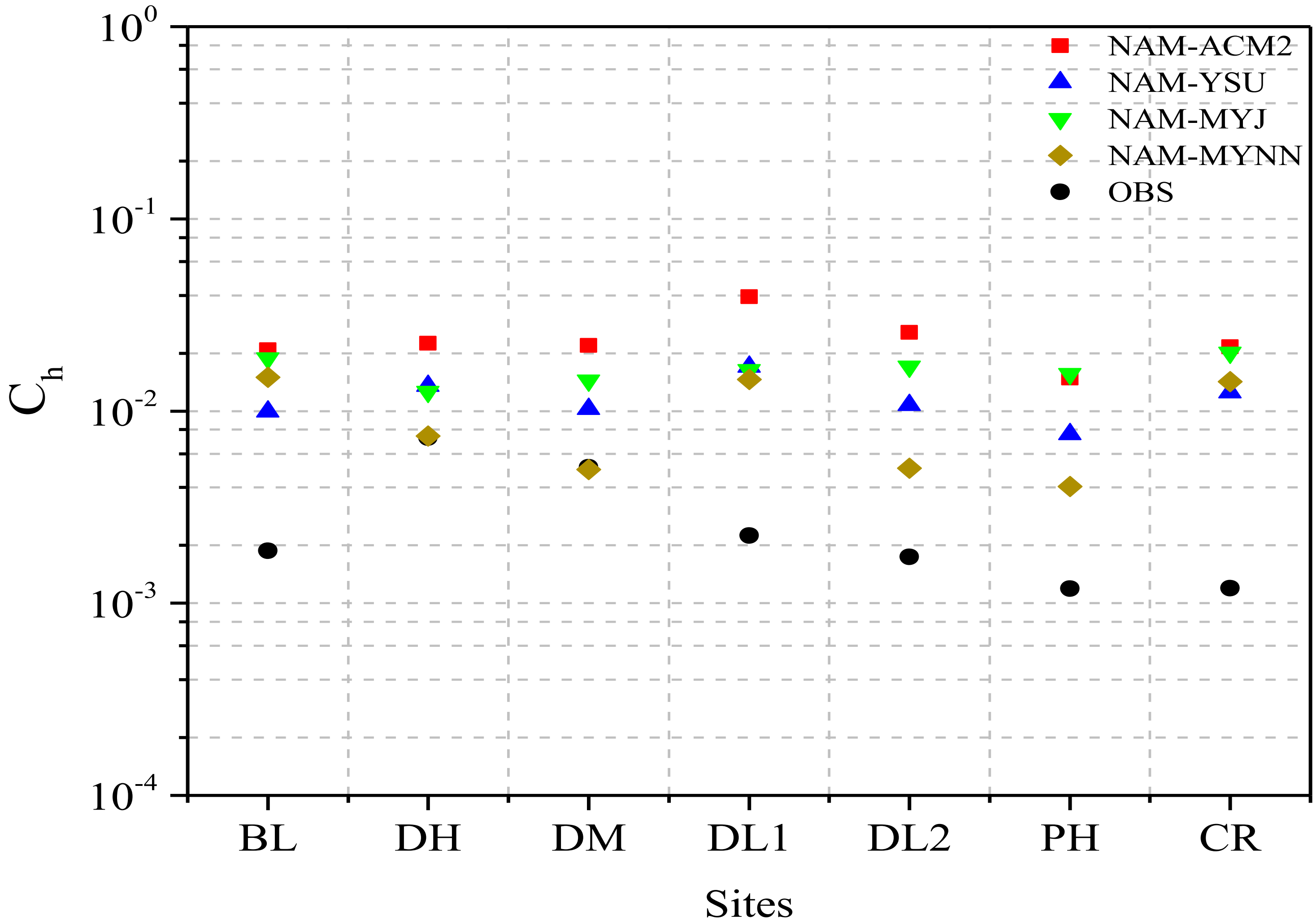
a = 2m above surface

C_h Calculated from Observations



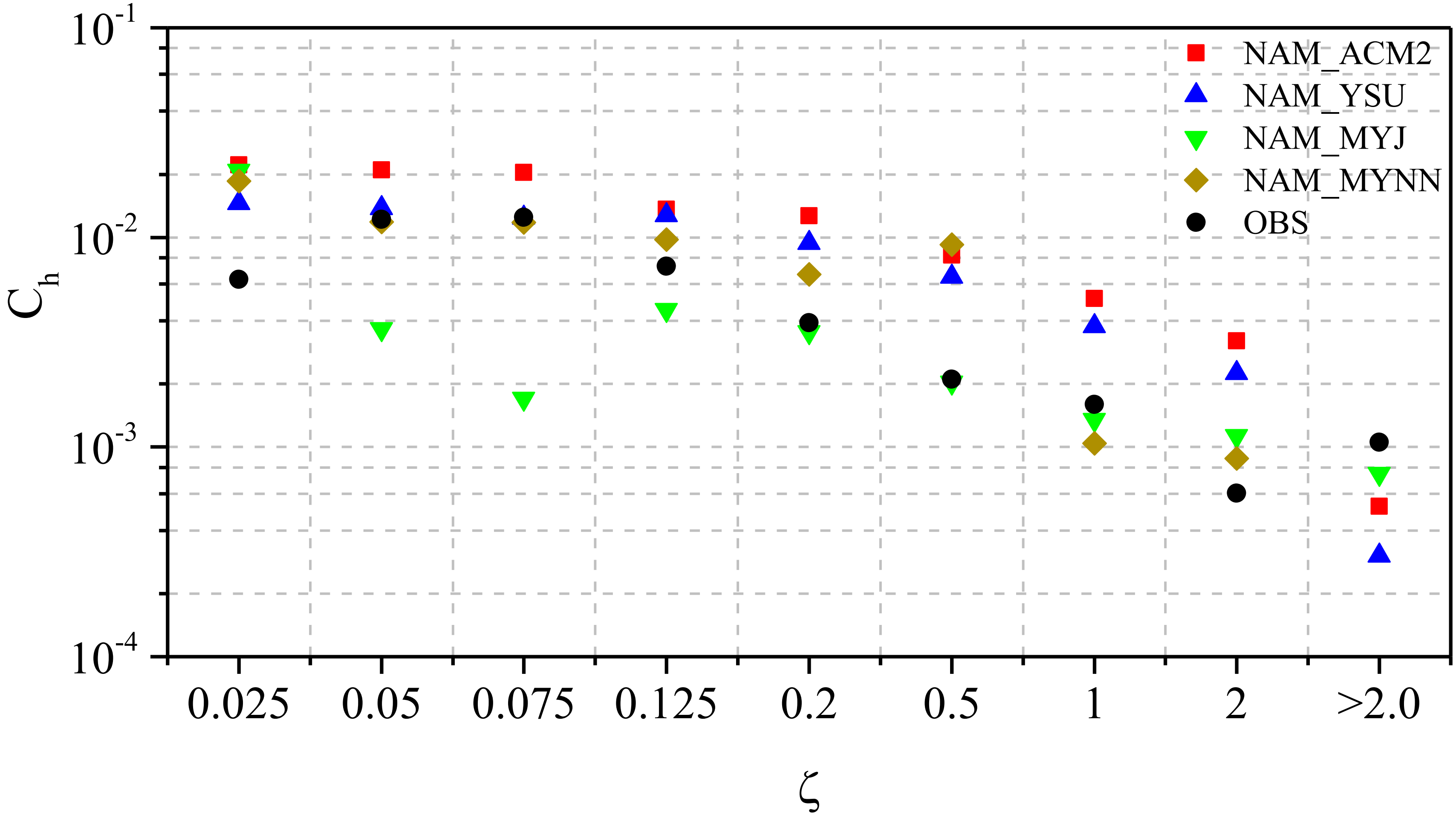
Sun & Holmes, *(in review)*

Average WRF Simulated Surface Transfer Coefficient



Sun et al., *(in prep)*

WRF Surface Transfer Coefficient and Stability

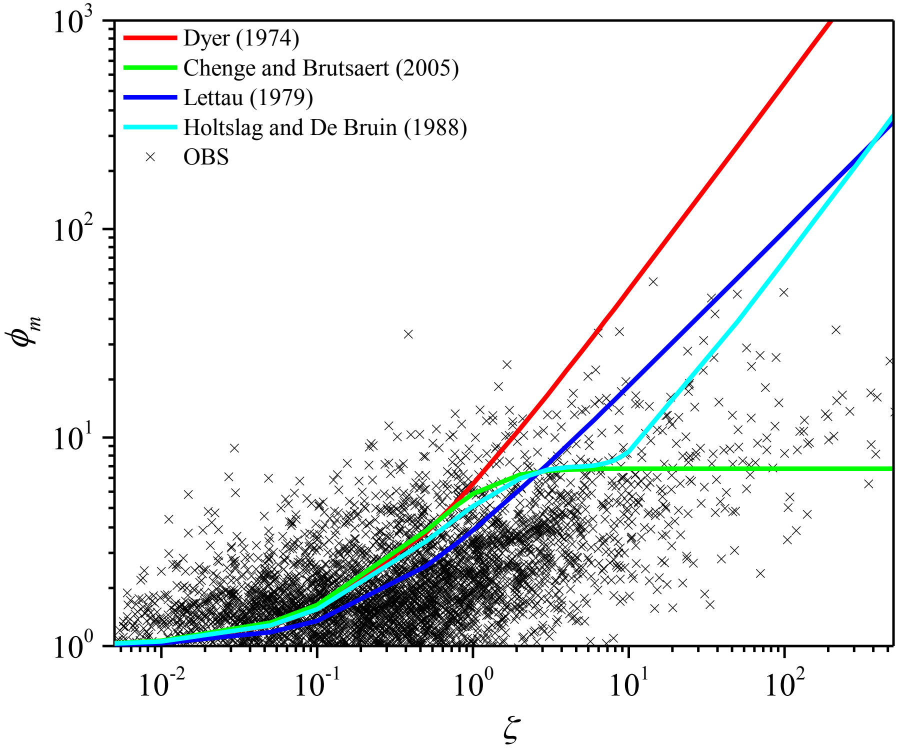


Sun et al., *(in prep)*

Flux-profile Stability Functions

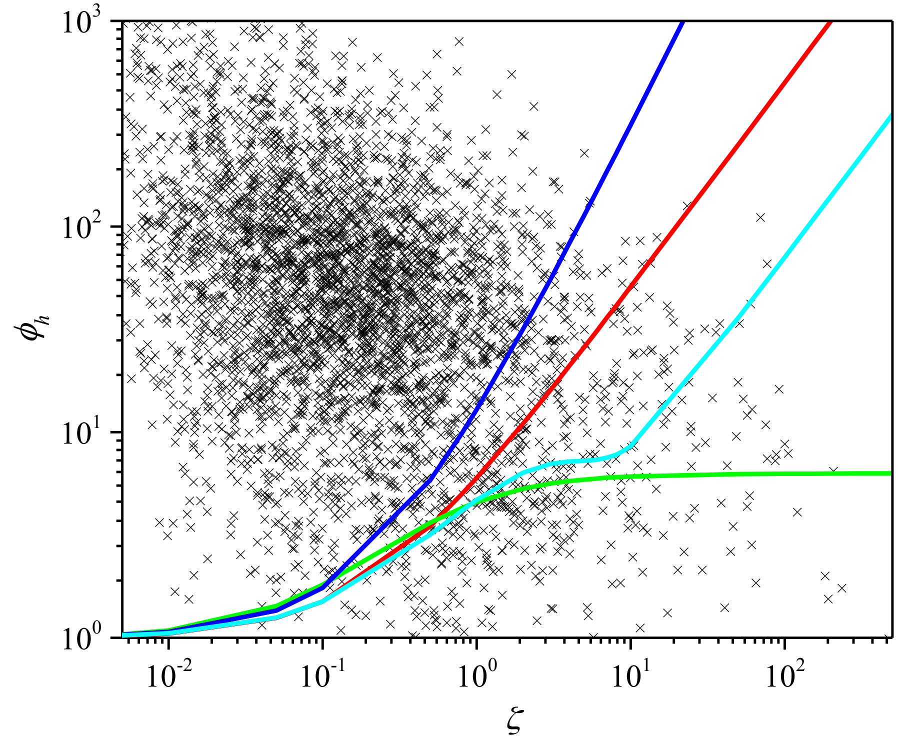
Dimensionless Wind Shear

$$\phi_M(\zeta) = \frac{\kappa z}{u_*}\frac{\partial U}{\partial z}$$



Dimensionless Temp Gradient

$$\phi_T(\zeta) = \frac{\kappa z}{\theta_*}\frac{\partial \theta}{\partial z}$$



(Sun et al. 2019, in prep)

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Summary

- In general, WRF performance depends on CAP strength and degrades for strong CAPs
- Surface exchange coefficient is typically overestimated by WRF
- Further investigation of flux-gradient relationship in complex terrain needed to improve surface layer model parameterizations
- *Can NWP models simulate near-surface meteorological conditions during stable PBL?* **No!**
- *Is it time to move on from existing dimensionless flux-gradient parameterizations to simulate the PBL mixing?* **Yes!**
- *Do we have enough turbulence data to make new empirical formulations for the RANS closure?* **No!**

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Field Experiment Wish List

- Surface energy balance; SHF, LHF, u_* @ many locations
- Surface skin temperature and moisture @ many locations
- Vertical profiles of SHF, LHF, and TKE
- Vertical profiles of aerosols and nitrogen chemistry
- Cloud thermodynamics and mixing (entrainment)