

Turbulence in the Stable Boundary Layer

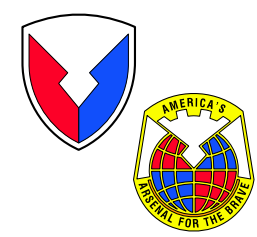
Chemical-Biological Information Systems
Austin, TX

11 January 2006

Walter D. Bach, Jr. and Dennis M. Garvey

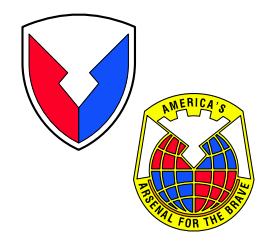
AMSRD-ARL-RO-EV & -CI-EE

JSTO Project: **AO06MSB00x**



Outline

- Acknowledgments
- Objectives
- Approach
- Early results
- Outlook for future
- Conclusions



Acknowledgments

JSTO Program Office

Army Research Laboratory colleagues

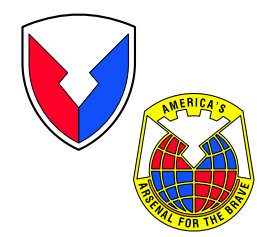
Army Research Office sponsored
investigators

Graduate students



Objectives

Improve basic understanding of atmospheric turbulence and dispersion in the stable boundary layer (SBL), by developing fundamental understanding of the dynamic processes and evolving structures of the SBL across multiple scales.



Approach

Conduct fundamental (6.1) research

Leverage existing research

Develop new initiatives

Academic

Army lab



Extramural Research



- International Workshop on Stable Atmospheric Boundary Layers
- Leverage existing SBL research activities
- Initiate new SBL research efforts



Intramural Research

- Generation of gravity waves by the nocturnal low-level jet
- Analyses of modeled and observed wind behavior during the Terrain-Rotor Experiment
- Analyses of Mid-IR propagation scintillation, turbulence and stability in SBL's using a new, local scaling approach
- Theoretical analyses of urban and rural SBL's using multi-resolution decomposition methods
- Examination of the differences in aerosol size, orientation, and composition in evolving SBL's, and
- Investigation of differences in stability patterns over complex heterogeneous surfaces



Workshop on Stable Atmospheric Boundary Layer

www.sedonasable.com

Sessions

- *Turbulence in Stratified Environments*
- *Observations - observed structure of SBL's*
- *Modeling the SBL*
- *Heterogeneity in the SBL*
- *R&D Needs, Capabilities and Opportunities*
- *Applications*



Workshop on Stable Atmospheric Boundary Layer

- Parameterizations of SBL must include
 - Gravity waves and wave drag
 - Stability as a function of scale
 - Variable turbulent Prandtl number
 - Refined concept of a critical gradient Richardson number
 - Both turbulent kinetic energy and turbulent thermal energy
 - Rotation
 - Radiation
- Spatial measurement capabilities must be developed or improved
 - Measure temperature and humidity through BL (H&V)
 - Measure BL height – aerosol, temperature, turbulence intensity
 - Resolve lateral motions on larger scales
 - Meandering in low wind conditions
- Surface Heterogeneity
 - A major component of SBL
 - Importance grows with stability
- Scale is Everything



Extramural Contributions



- ***QNSE - A New SBL Closure*** -- B. Galperin, U. South Florida
- ***Dual Doppler lidar in TREX*** -- R. Calhoun, Arizona State
- ***Stable Boundary Layer Evolution*** -- R. Frehlich, CIRES (New)
- ***JORNADA Data Analysis*** -- D. Miller, UConn (New)

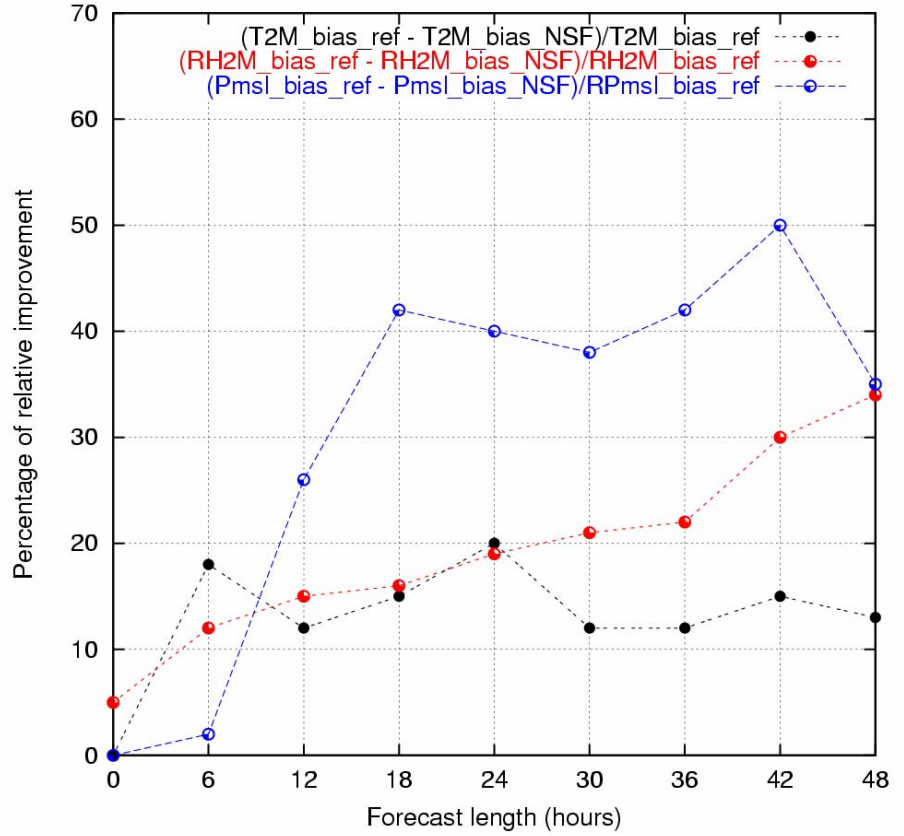
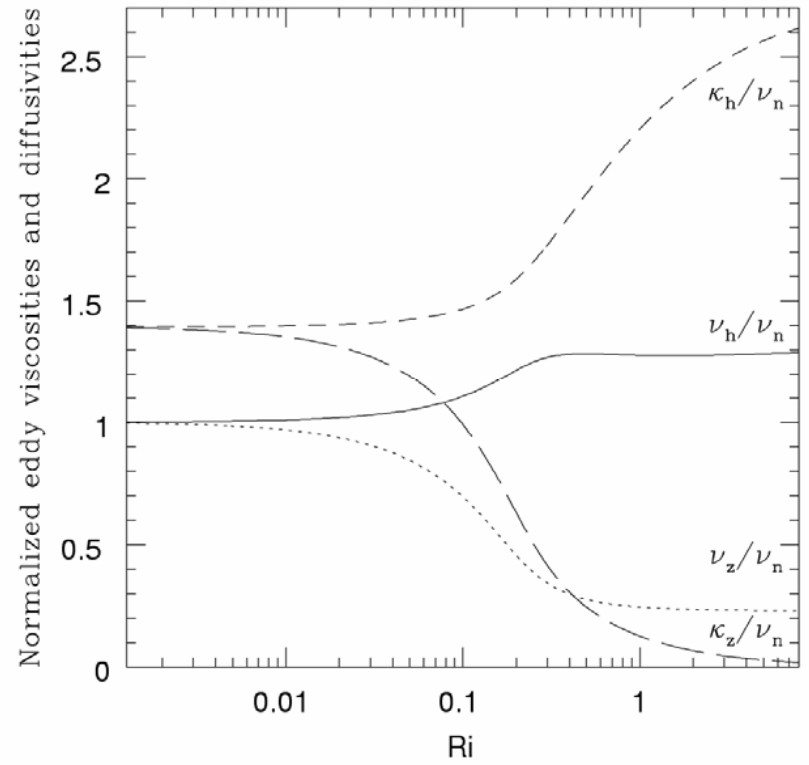


QNSE - A New SBL Closure

Includes turbulent kinetic energy and turbulent thermal energy

Eddy viscosity and eddy thermal diffusivity are coupled laterally & vertically

Application in HIRLAM 12 km grid shows ~15% reduction in bias of surface T, P, RH





QNSE - A New SBL Closure

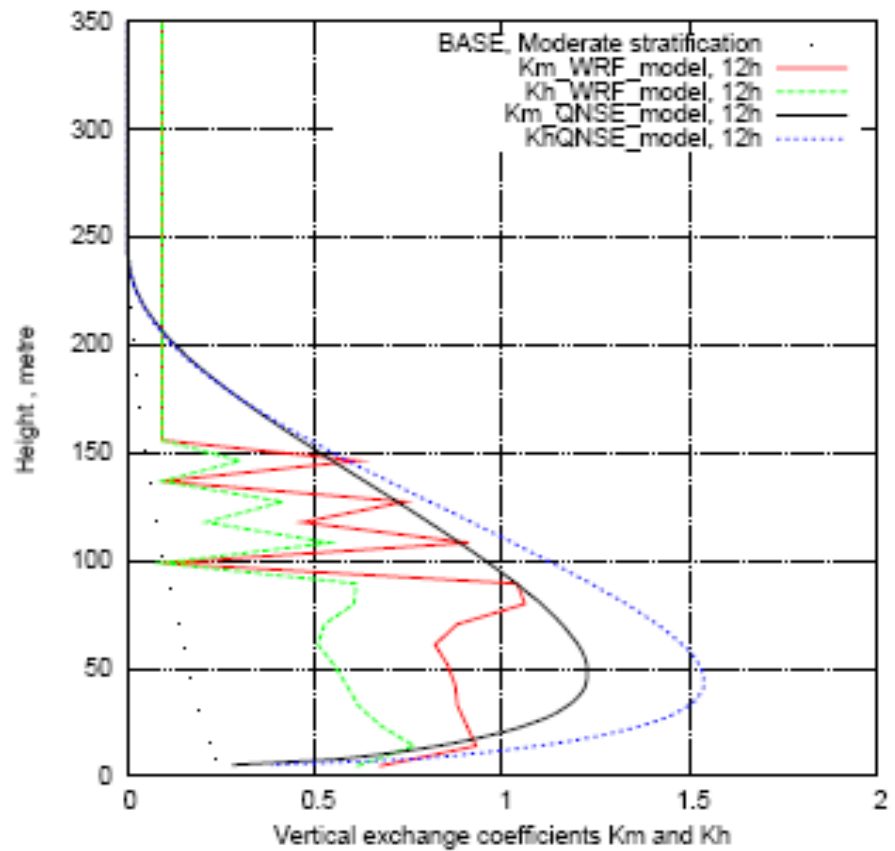
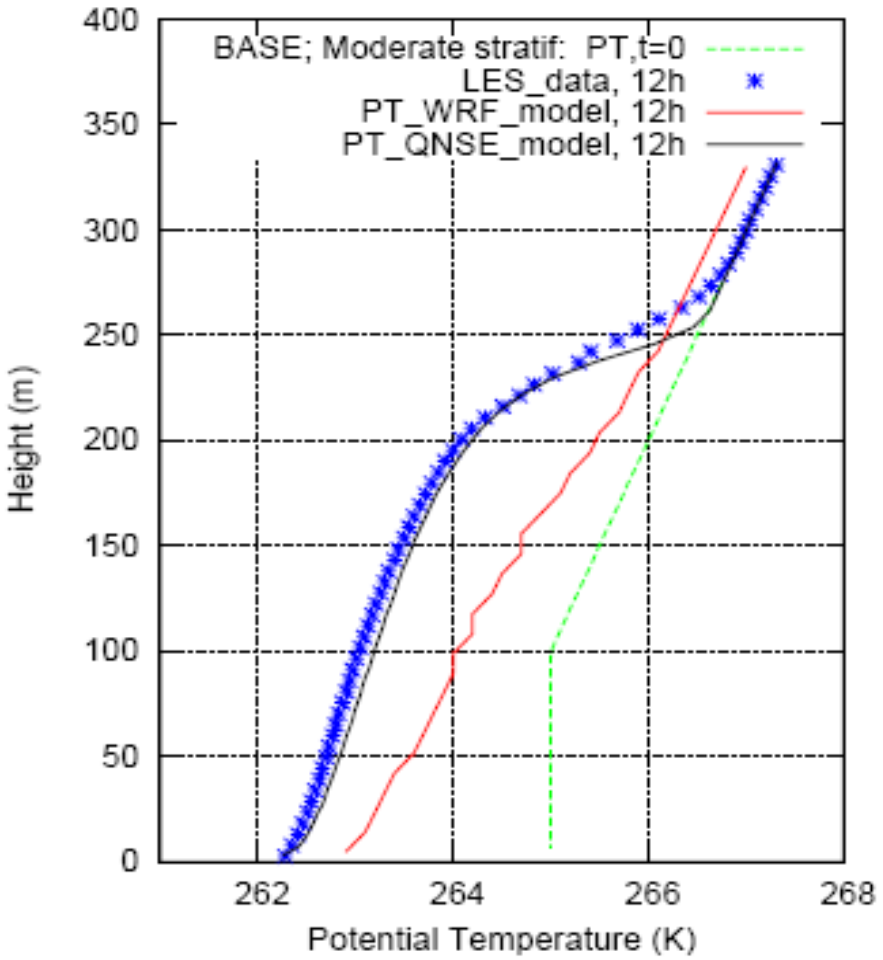


- Introduce, test and evaluate closure in WRF PBL model.
- Test and evaluate in high-res HIRLAM
 - Effects of grid size – lateral & vertical
 - Helsinki winter data for wind profiles, mixing height(s), heat flux, surface friction
- Test and evaluate in high-res WRF
 - Using NCAR test scenarios
 - T-REX simulations and observations
 - Incorporate into WRF PBL options



QNSE - A New SBL Closure

Single column intercomparison with WRF (PRELIMINARY)



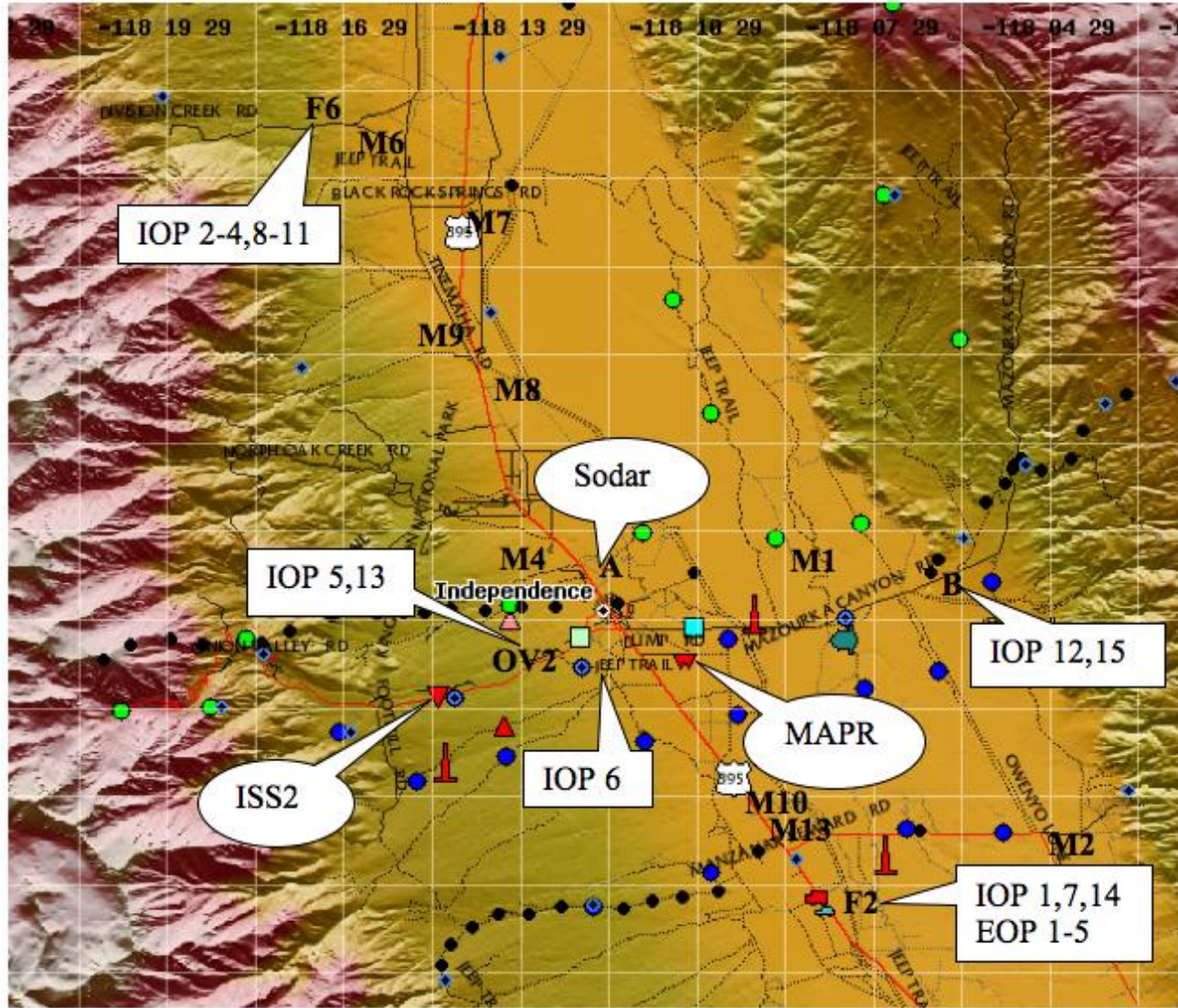


Analyses of Modeled and Observed Winds during T-REX

**Terrain -
Rotor
Experiment**

**Owens
Valley, CA**

**March-April
2006**





Analyses of Modeled and Observed Winds during T-REX



- ARL & AHPCRC supporting a 1 km ΔX version of WRF in real time for T-REX studies.
- Analyses of WRF-ARW forecasts during T-REX by examining data at surface and aloft
 - Evaluate Inherent Uncertainty of forecast quantities and their dependence on height AGL.
 - Representation of PBL wind scales through spectral and multi-scale decomposition techniques.
 - Representation of observed vertical and horizontal wind shear by forecasts.

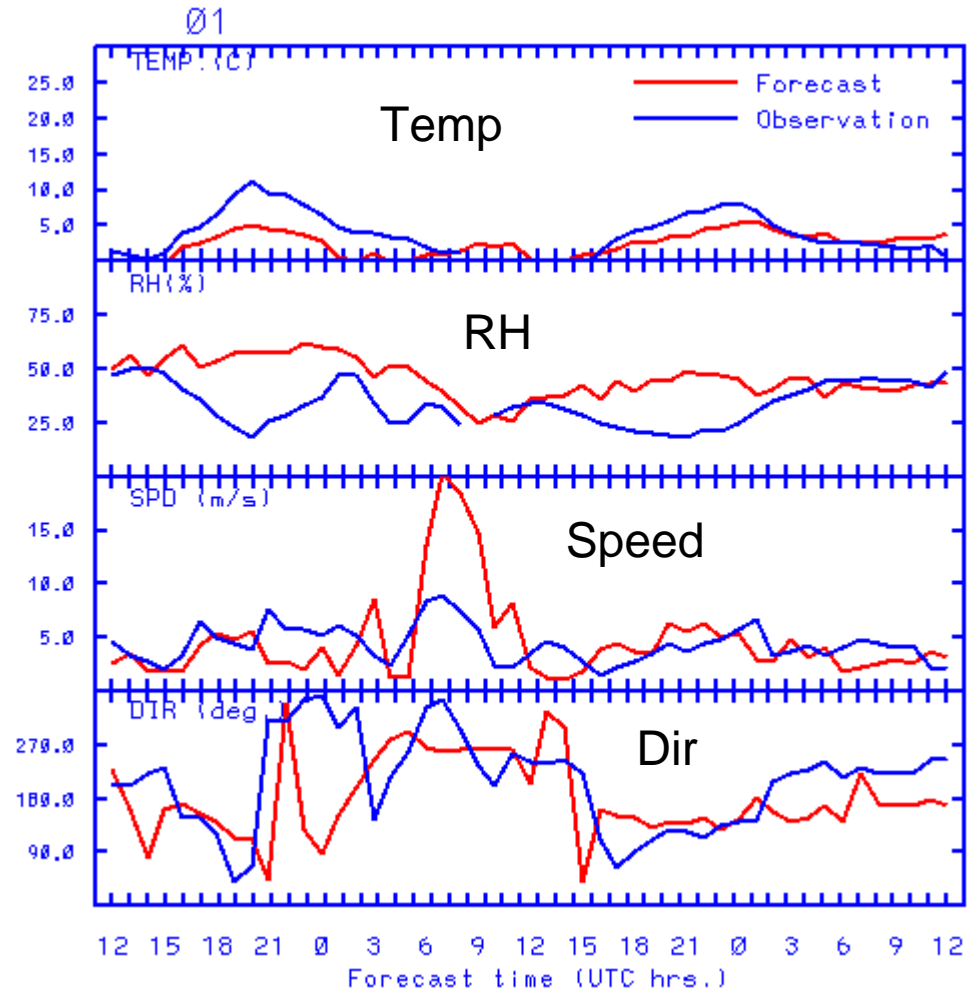


Analyses of Modeled and Observed Winds during T-REX

48 hour forecast verification beginning 12 March 1200 GMT at DRI surface station #1

Forecast is too cool in day, too warm at night (affects RH)

Wind speed / direction miss significant changes at night.



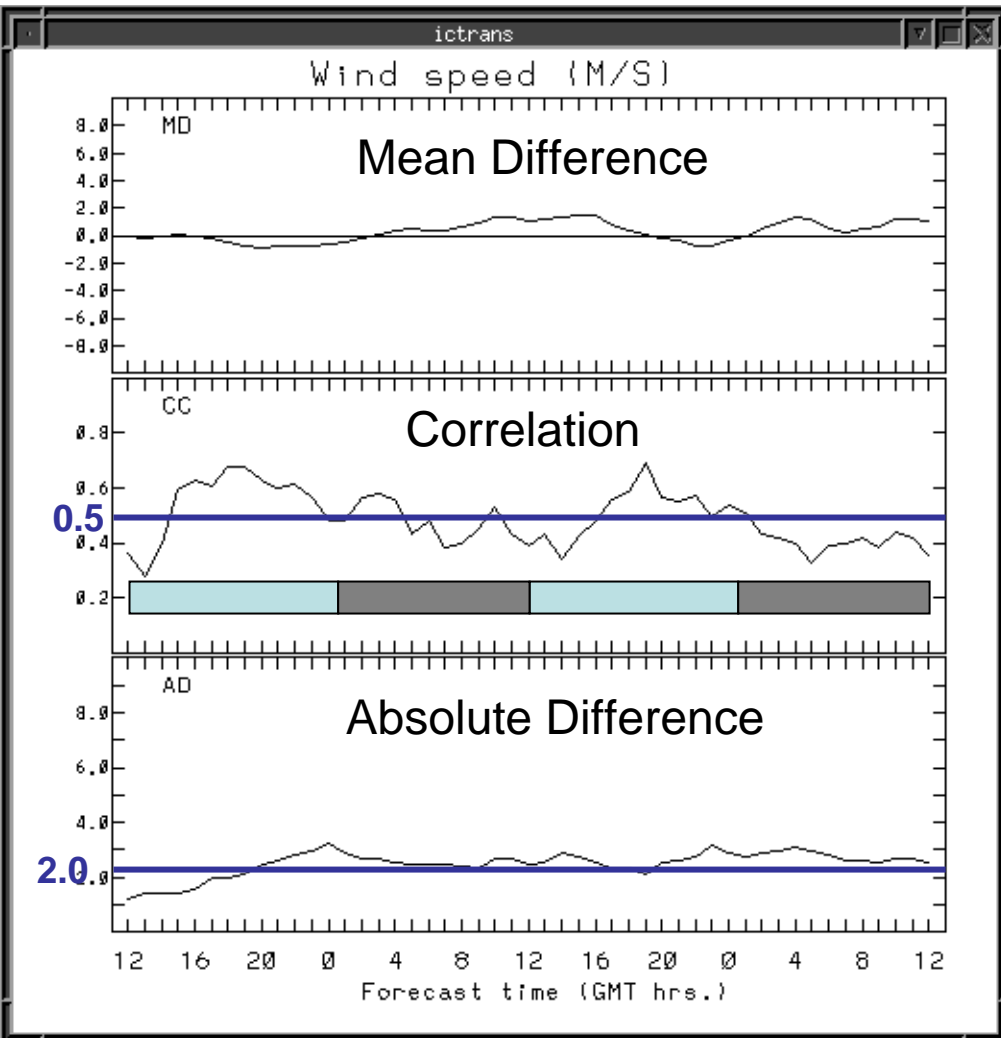


Analyses of Modeled and Observed Winds during T-REX

Error Analyses of hourly averaged WRF forecast winds with observed DRI surface station winds for cases considered to date.

- Mean F-O differences are small
- Correlation is small (~0.4 – 0.6) and declines in 20 to 12 GMT periods
- Mean absolute difference is ~ 3.0 m/s through forecast period.

Wind Speed m/s

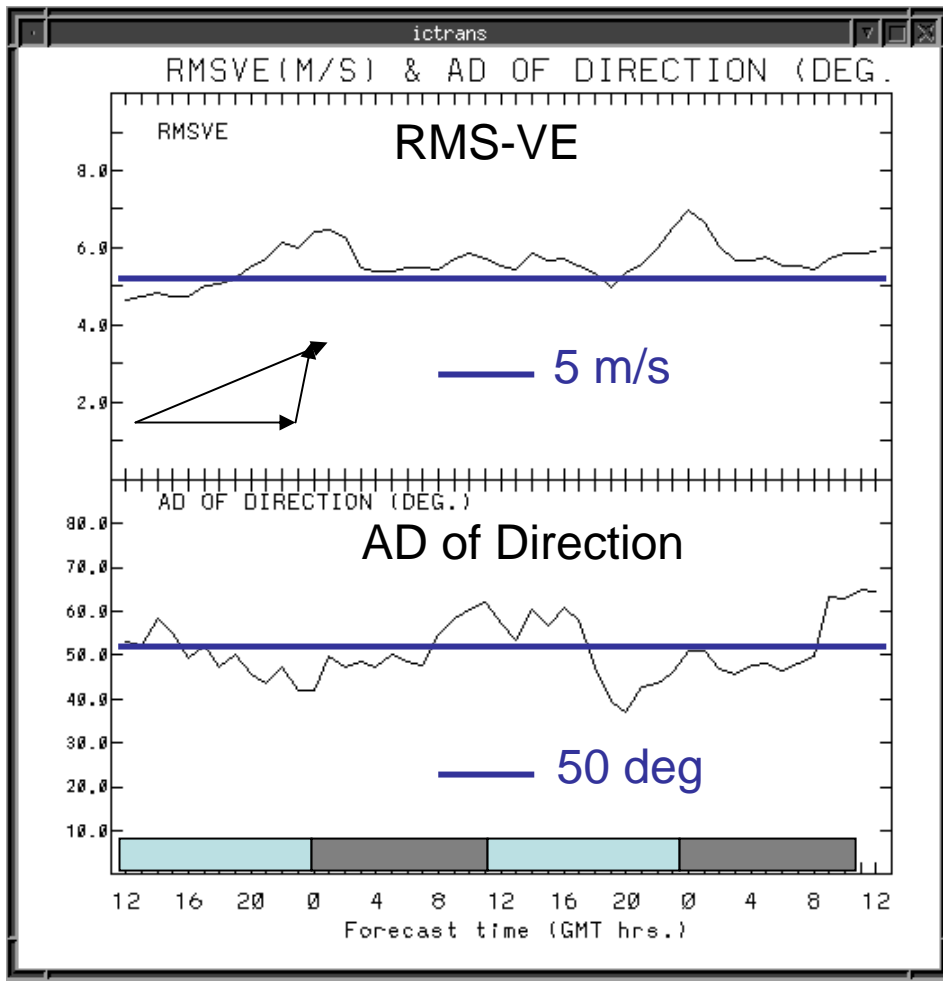




Analyses of Modeled and Observed Winds during T-REX

Error Analyses of hourly averaged WRF forecast winds with DRI surface station winds for cases considered.

- Large RMS vector speed error
- Large Absolute error of wind direction – typical of other studies.





Local Scaling for Mid-IR Scintillation and Turbulence

Stable Layer Analyses of RTG-40 and EOVAF Data Sets

David Tofsted

Sean O'Brien

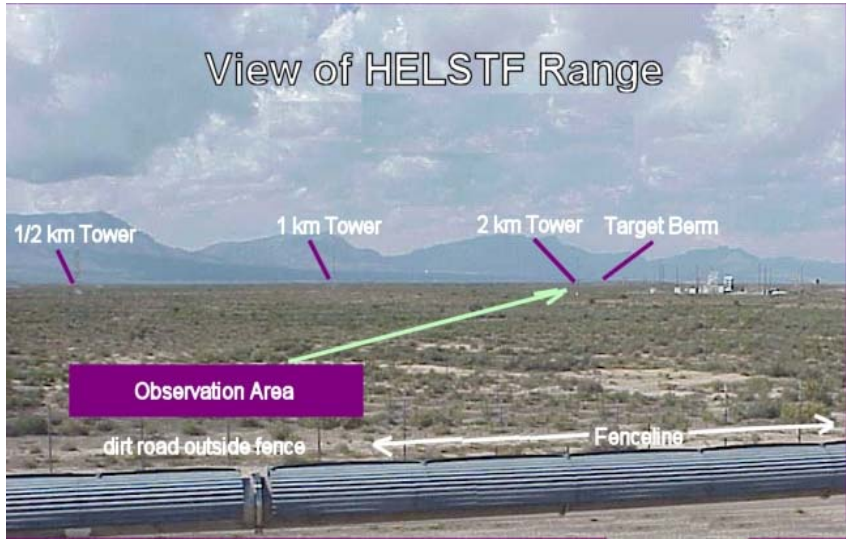
David Quintis

Jimmy Yarbrough

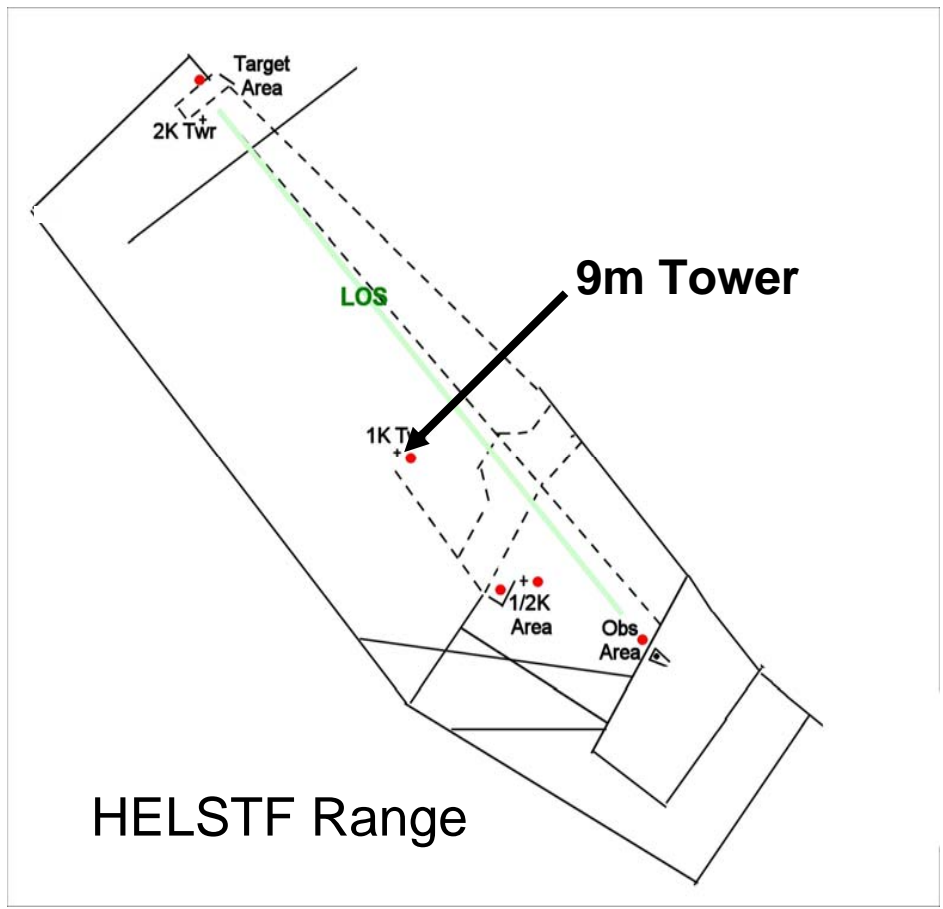
U.S. Army Research Laboratory
Computational & Information Sciences Directorate
Battlefield Environment Division



Local Scaling for Mid-IR Scintillation and Turbulence



Tularosa Basin. Roughly 10% foliage cover. Terrain *nearly* flat. November (dry). No precipitation.





Local Scaling for Mid-IR Scintillation and Turbulence



Gradient-based scaling:

$$\left\{ \begin{aligned} u_n(z) &= \sigma_w \\ L_n(z) &= \sigma_w / (\beta dT/dz)^{1/2} \\ T_n(z) &= L_n dT/dz \\ q_n(z) &= L_n dq/dz \end{aligned} \right.$$

Flux-based scaling:

$$\left\{ \begin{aligned} U_*(z) &= \tau_w^{1/2} \\ L_*(z) &= \tau_w^{3/2} / [\kappa\beta H(z)] \\ T_*(z) &= H(z)/U_*(z) \\ q_*(z) &= Q(z)/U_*(z) \end{aligned} \right.$$

Sorbjan Approach

$$\frac{X}{U_n^a T_n^b Q_n^c L_n^d} = f_x(Ri)$$

Monin – Obukov Approach

$$\frac{X}{U_*^a T_*^b Q_*^c L_*^d} = f(z/L_*) = const$$

in a “z-less” regime



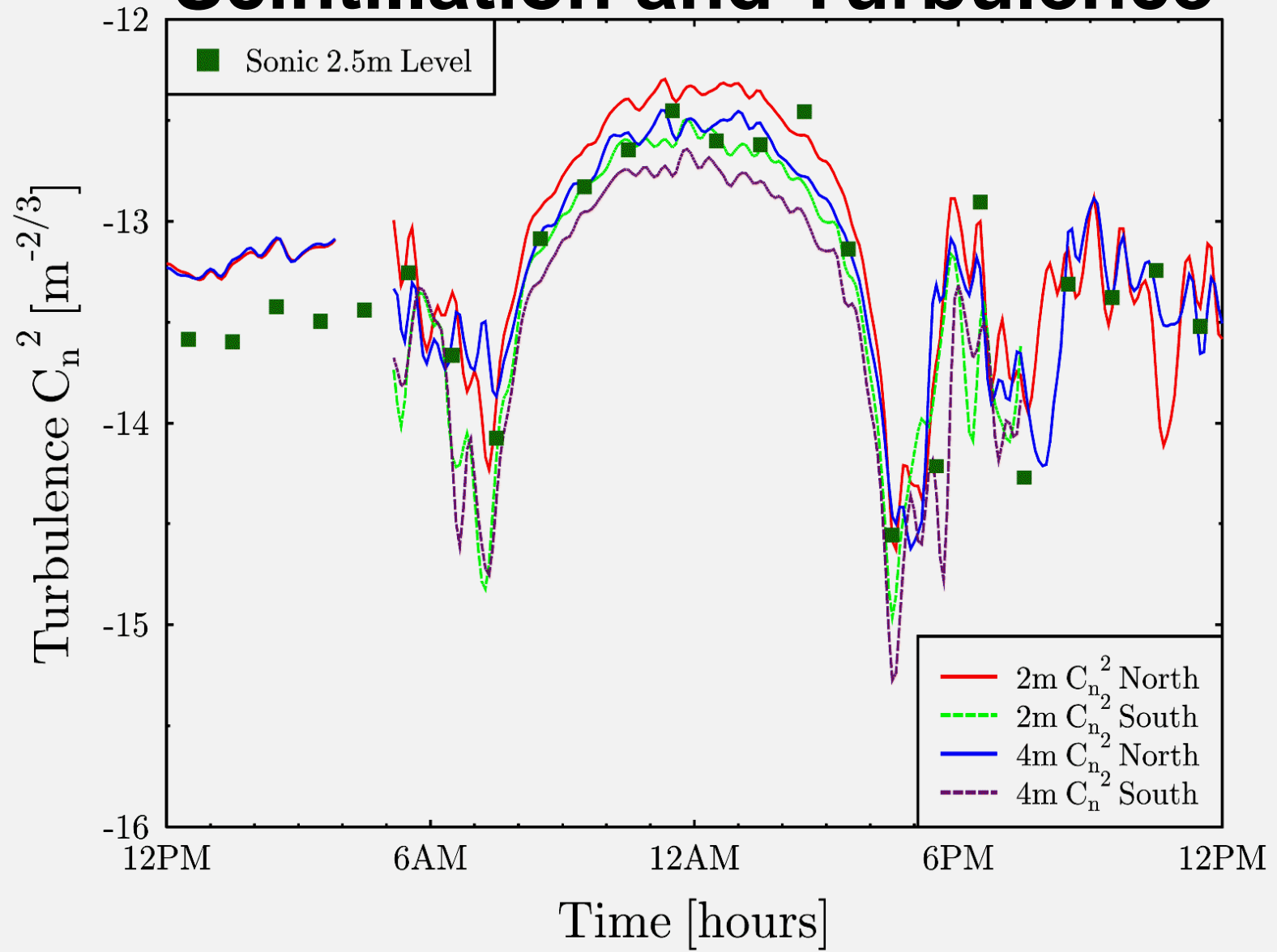
Local Scaling for Mid-IR Scintillation and Turbulence Objectives



- Use Sorbjan's alternative scaling concepts for the SBL using EOVAF and HELSTF scintillation and micrometeorology tower data to evaluate scaling parameters and their representation of scintillation (C_n^2) in the SBL.
- Assess the differences in local and flux-bases scaling at representing vertical wind, temperature and moisture profiles
- Assess the presence of gravity waves through temporal analyses of the wind and temperature signals
- Extend an analysis of radiative flux divergence in the first few meters into a model of radiative cooling in near-surface dynamics of the SBL.



Local Scaling for Mid-IR Scintillation and Turbulence





Outlook for the Future



- Workshop report on stable boundary layers should provide extensive recommendations for research directions and opportunities.
- Strong interaction with NCAR-WRF PBL community through Army and NSF actions.
- Report on prospects for physical modeling of SBL



Conclusions

- Developed a diversified study of basic processes in stable boundary layers using theory, models, and observations.
- Very reasonable progress in 8 months.
- Too soon to tell the final outcomes.

