A New Combined Local and Non-Local Boundary Layer Model: ACM2

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Outline

- Model development
- 1-D testing and evaluation
  - Large Eddy Simulation (LES)
  - GABLS Experiment (CASES99)
- MM5 testing and evaluation
- WRF implementation will soon be ready

Purpose

- Develop a simple PBL model that:
  - Produces realistic profiles in CBL
  - Accurate PBL heights
  - Appropriate for all stability conditions w/ minimal discontinuities
  - For both meteorology and chemistry models
  - Computationally efficient

Background

- Local flux-gradient proportionality (i.e. Eddy diffusion) is not appropriate for Convective Boundary Layers
  1. Upward heat flux penetrates to ~80% of *h* while potential temperature gradients are very small through most of the PBL
  2. Eddies in CBL are larger that vertical grid spacing (violates subgrid-scale assumption)
- Two common alternative approaches:

  1. Gradient adjustment term:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K_h \left(\frac{\partial \theta}{\partial z} - \gamma_h \right) \right)$$

Deardorff 1966,Troen and Mahrt 1986, Holstlag and Boville 1993, Noh et al. 2003

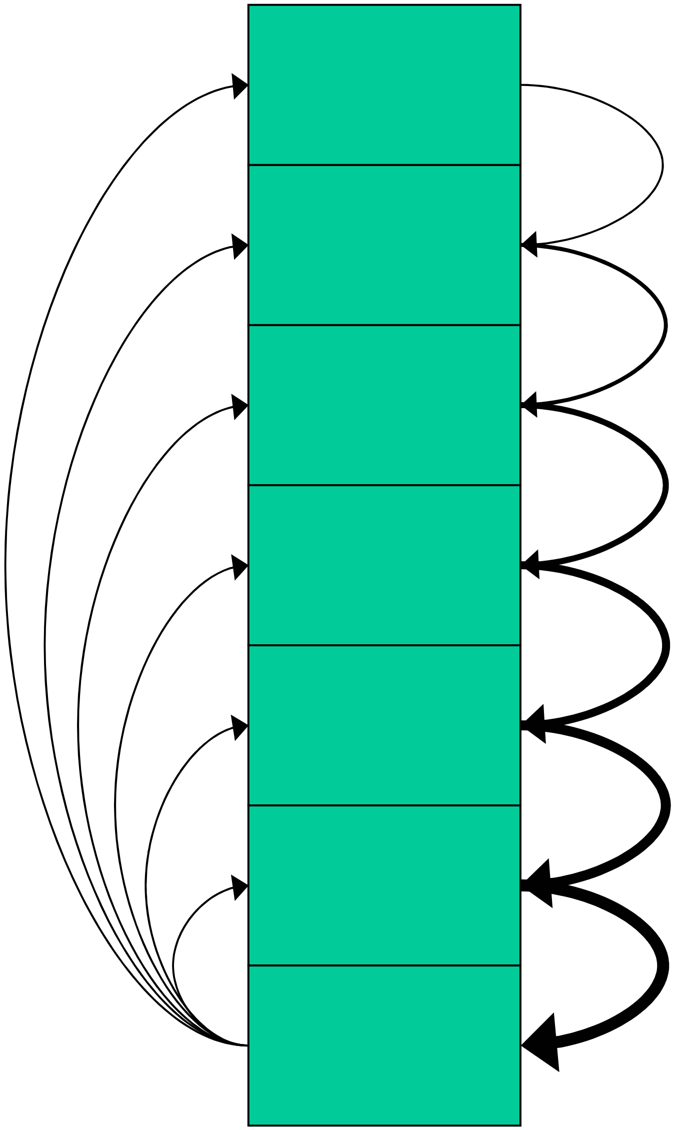
  2. Transilent or non-local closure:

$$\frac{\partial \theta_i}{\partial t} = M_{ij} \theta_j$$

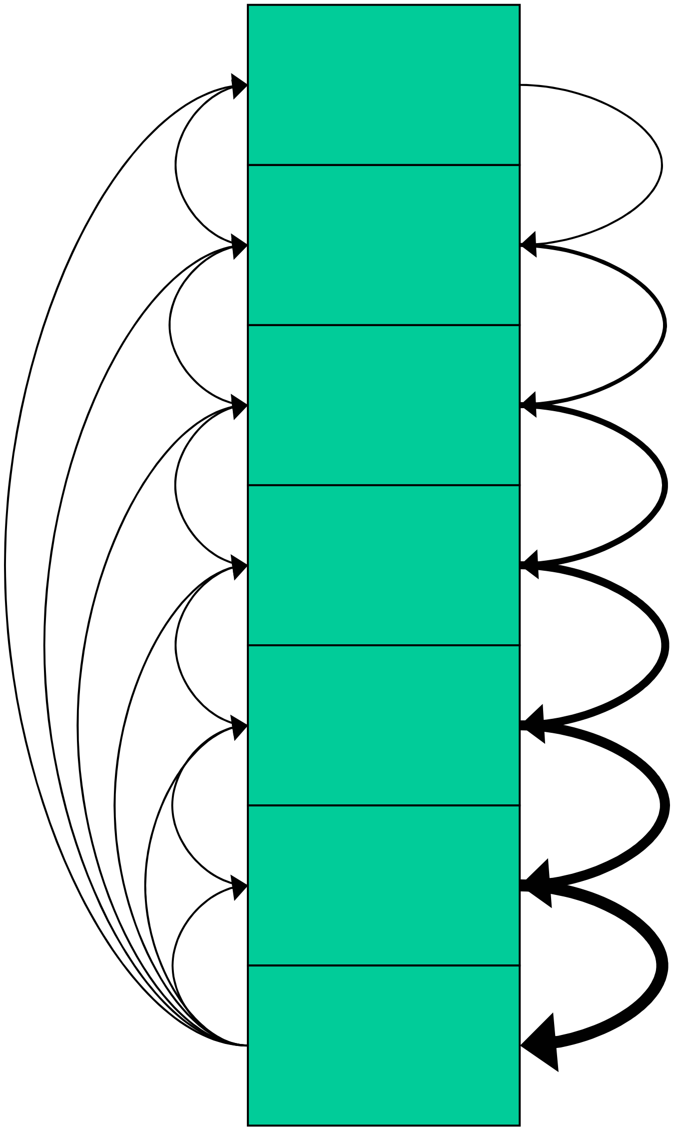
Stull 1984, Blackadar 1976, Pleim and Chang 1992

Asymmetric Convective Model (ACM)

- Original ACM
  - Simple Transilient model
  - Rapid upward transport by convectively buoyant plumes
  - Gradual downward transport by compensatory subsidence
  - Part of the PX-LSM in MM5
- ACM2
  - Added eddy diffusion to ACM
  - Allows local mixing at all levels
  - More realistic (continuous) profiles in lower layers
  - Smooth transition from stable to unstable



ACM

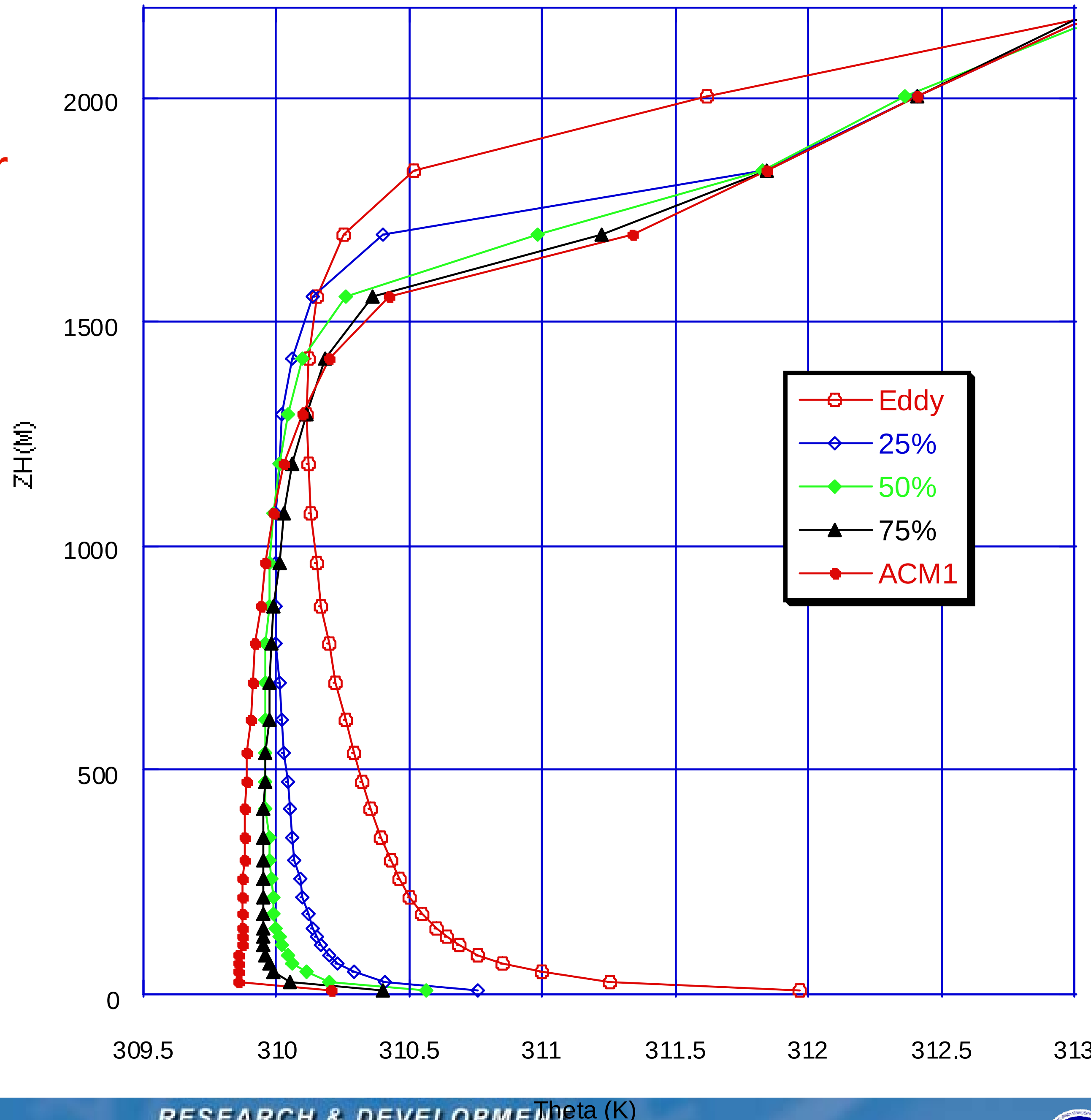


ACM2

Need to define a partitioning factor (f_{conv})

1-D experiments –

Variations in partitioning of local and non-local transport

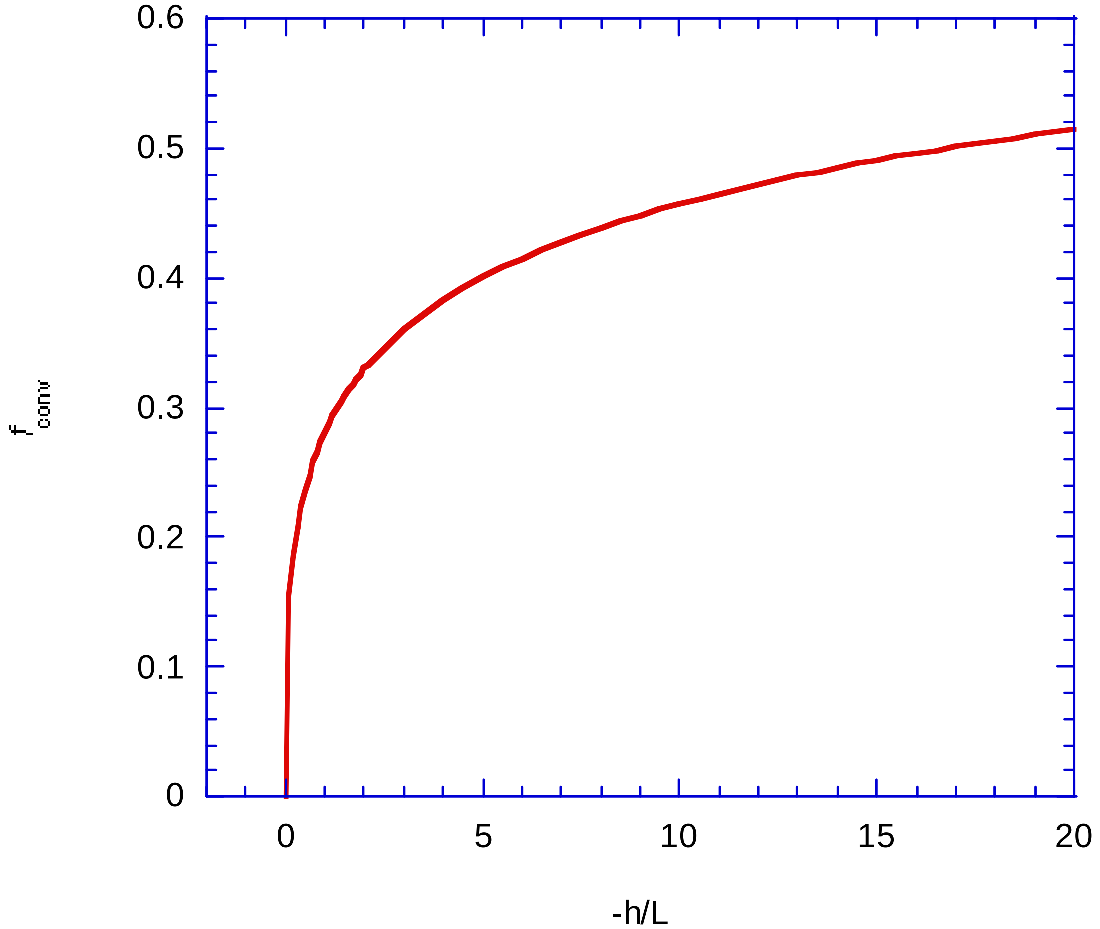


Non-local partitioning

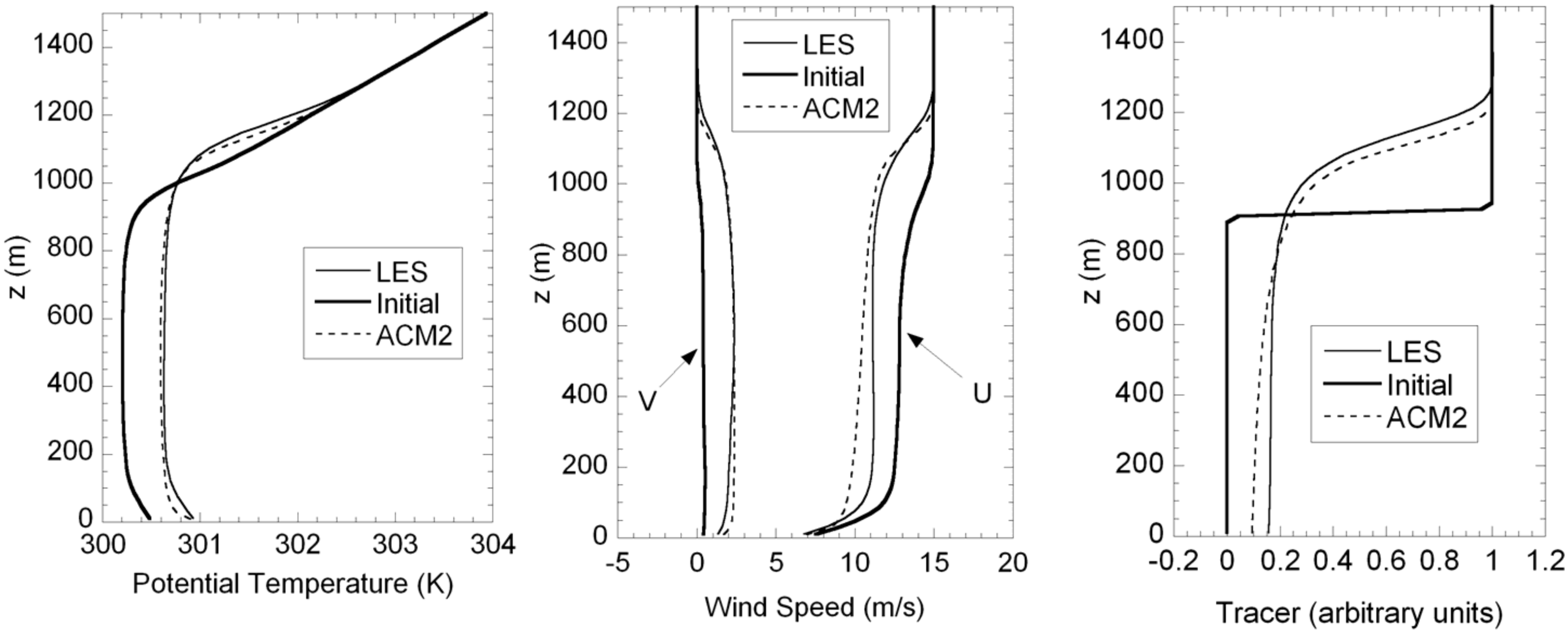
- These tests suggest that the upper limit of f_{conv} should be about 50%
- An expression for f_{conv} can be derived from gradient adjustment models (e.g. Holstlag and Boville 1993) at top of surface layer:

$$f_{conv} = \left(1 + \frac{k^{-2/3}}{0.1a} \left(-\frac{h}{L} \right)^{-1/3} \right)^{-1}$$

Non-local fraction (f_{conv}) as function of stability



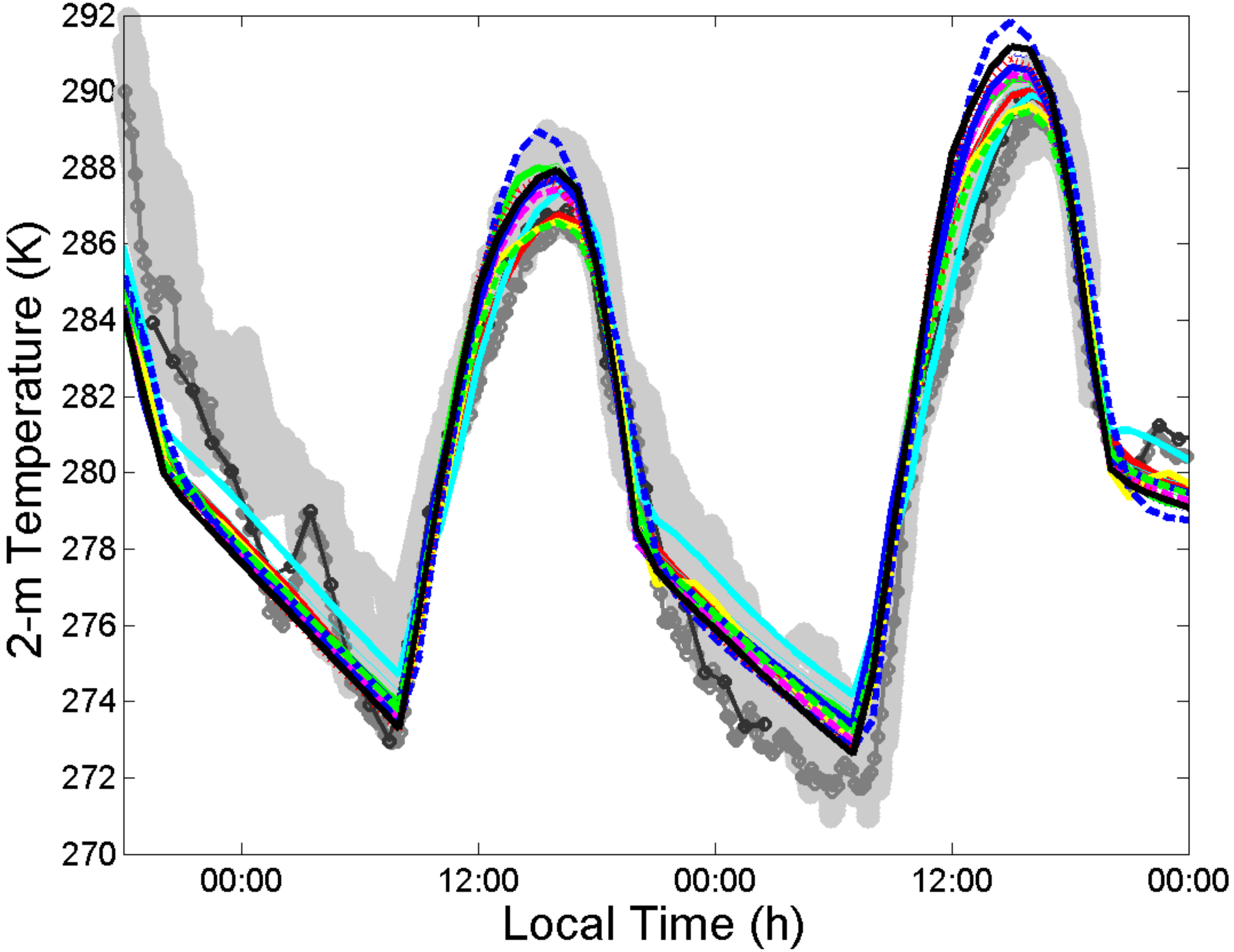
LES experiment low heat flux (Q* = 0.05 K m s-1), weak cap



The second GABLS model intercomparison

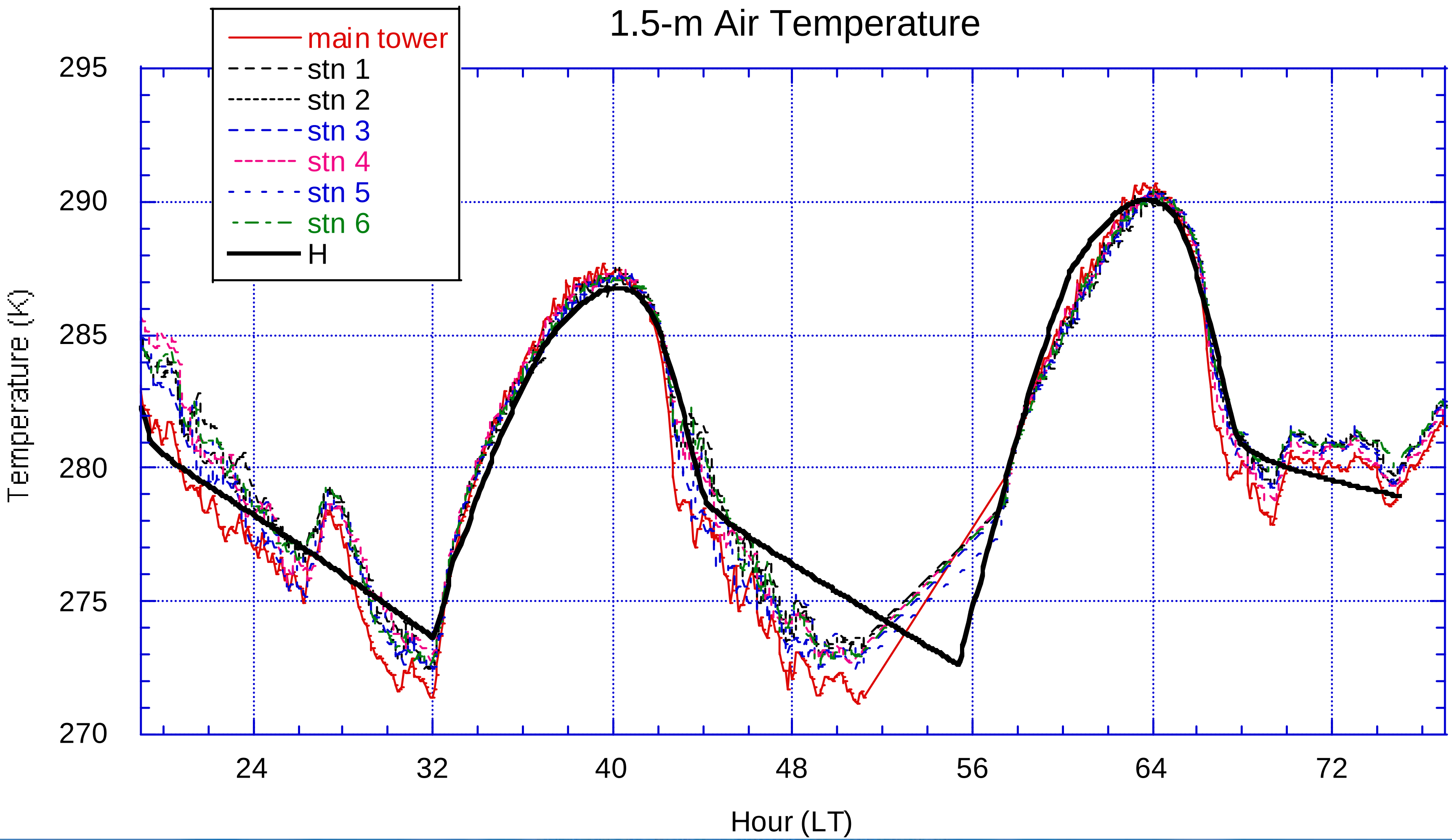
- Multi-day Intercomparison of 23 PBL models for CASES99 field study
  - Given initial profiles
  - T_g time series
  - Constant geostrophic wind
  - Large scale subsidence
  - 2.5% of potential evaporation
  - P, z_o, z_T

GABLS T-2m Intercomparison

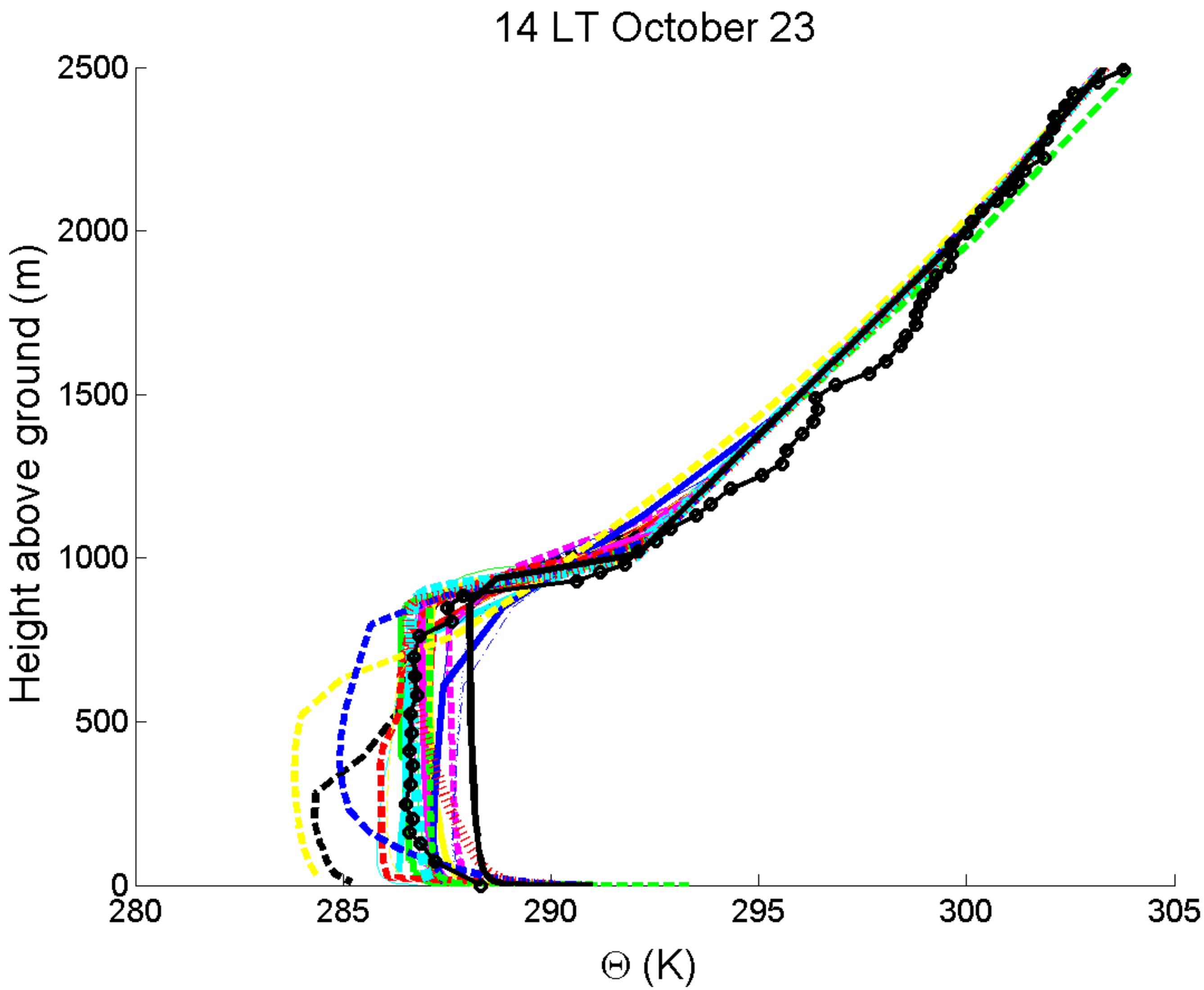


GABLS Experiment – Simulation of CASES99

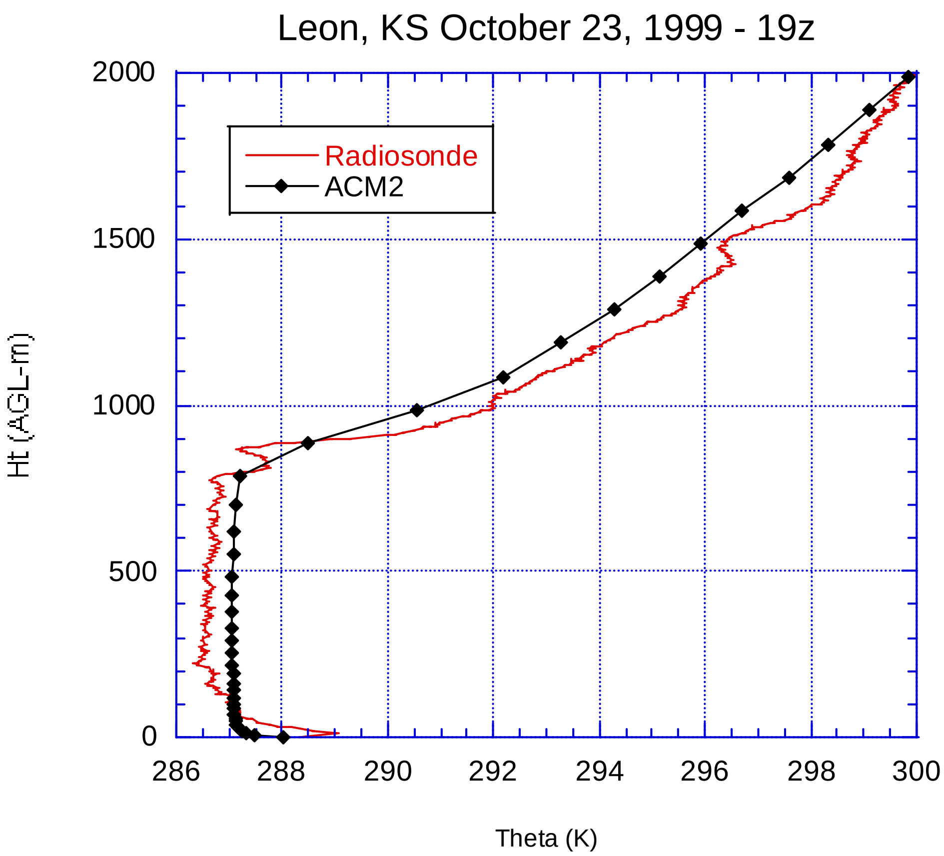
October 22-24, 1999

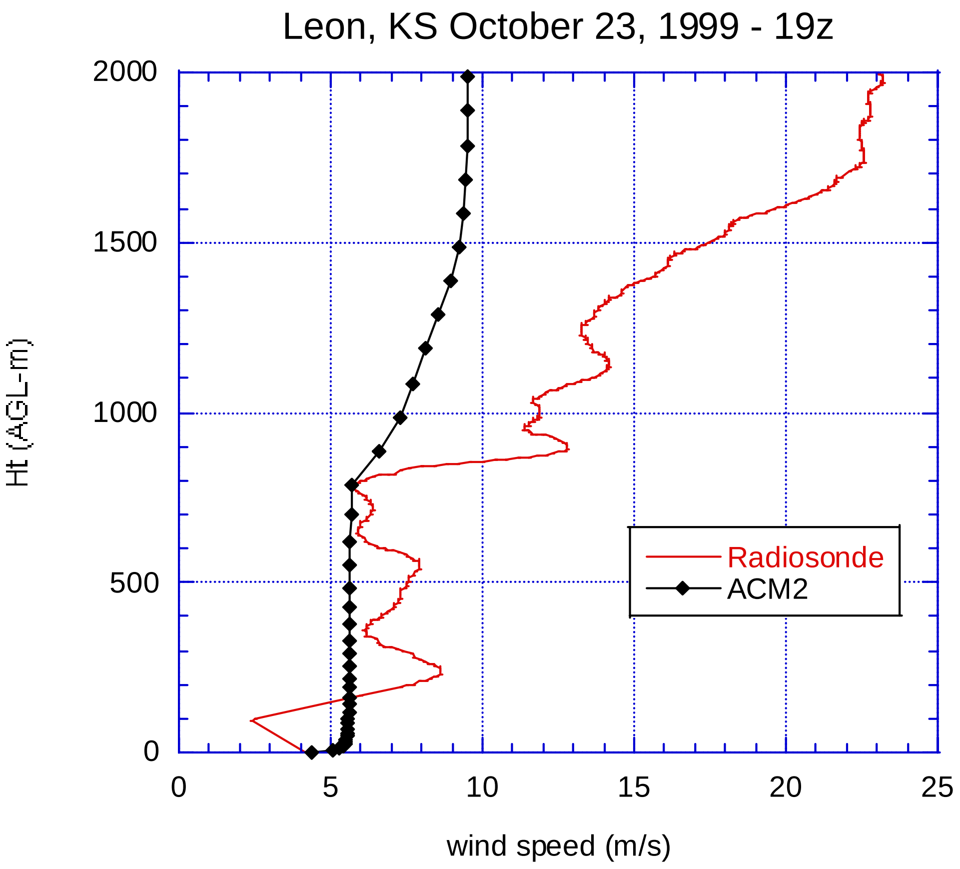


GABLS Profile intercomparison



CASES99 profiles

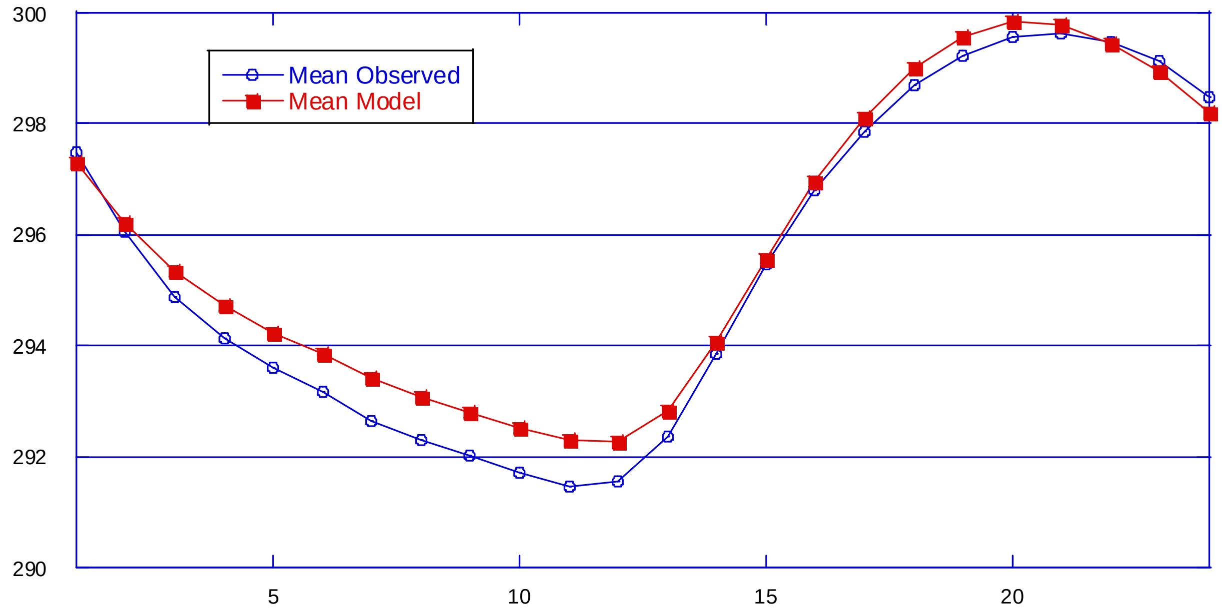




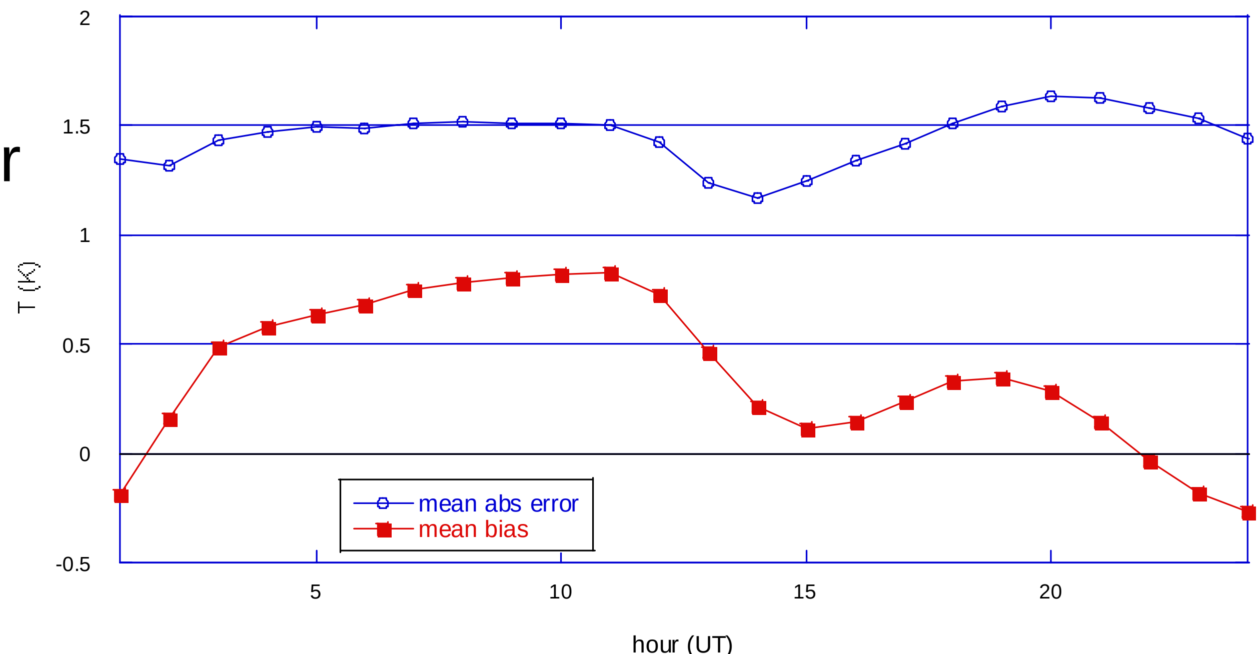
MM5 Evaluations

- Domain: 202 x 208 x 34 @ 12 km res
- Physics:
  - ACM2
  - PX LSM
  - KF2
  - Reisner 2
  - RRTM w/ Dudhia SW
- Data Assimilation:
  - Winds at all levels, T and q_v above PBL
  - Indirect soil moisture nudging
- July 13 – August 18, 2004

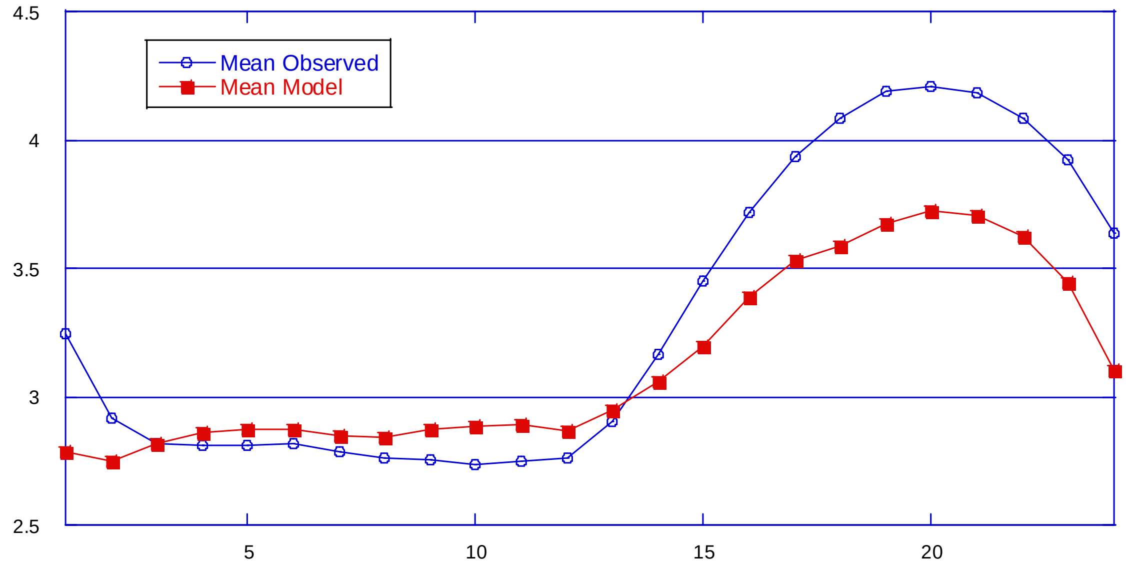
2 m Temperature Averaged over all NWS/FAA sites 7/15 – 8/18 2004

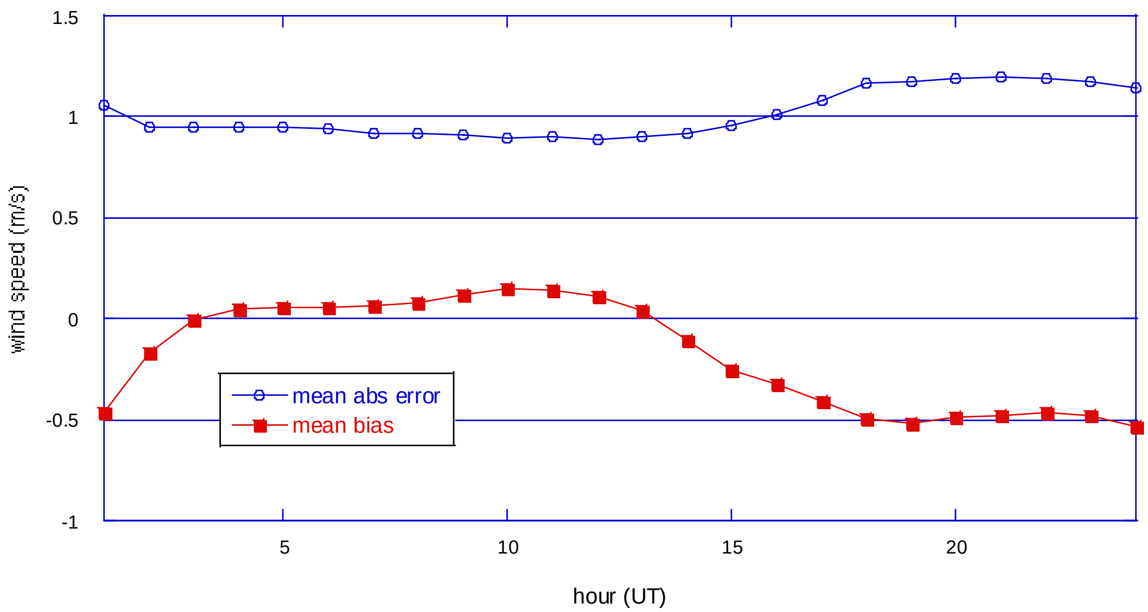


Mean Absolute Error
Mean Bias



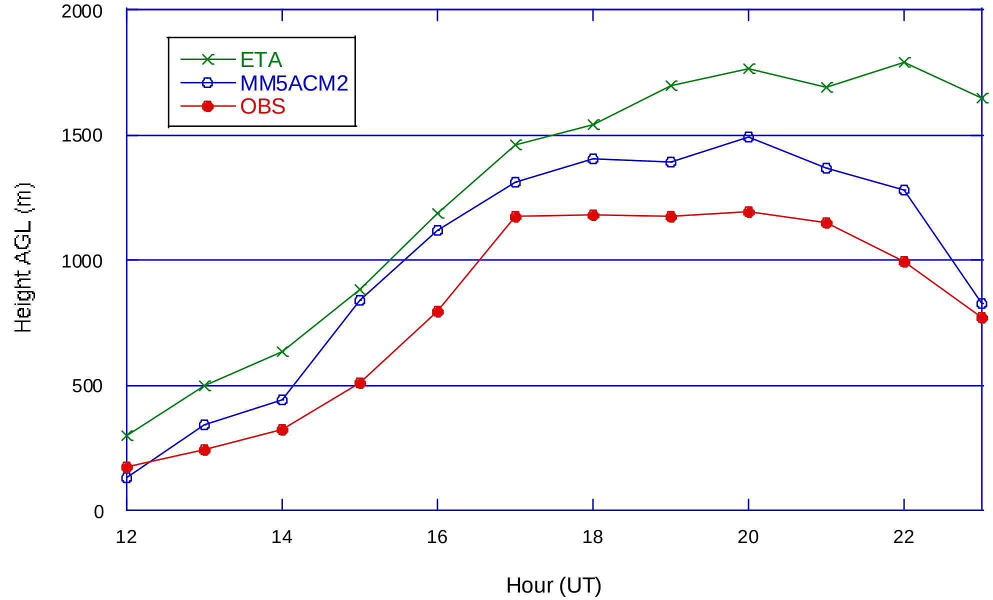
10 m Wind speed Averaged over all NWS/FAA sites 7/15 – 8/18 2004



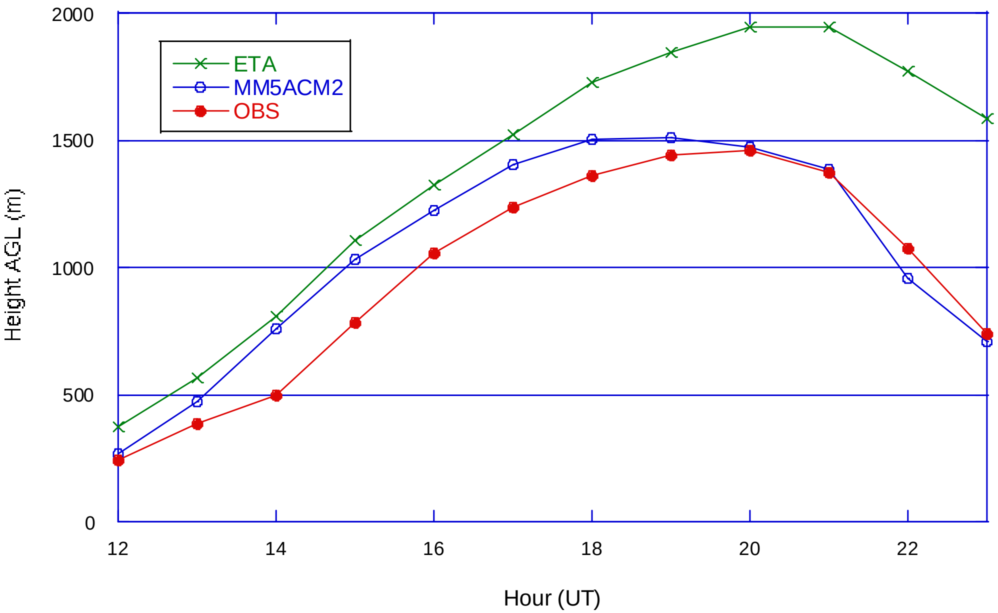


Mean Absolute Error
Mean Bias

PBL Height from Radar wind Profilers (from Jim Wilczak)



Pittsburgh, PA



Concord, NH

Conclusions

- ACM2 is a combination of local and non-local closure techniques
  - Similar capabilities to eddy diffusion w/ counter-gradient adjustment but more readily applicable to any quantity (e.g chemistry)
  - ACM2 produces more realistic near-ground profiles than ACM1
- LES and 1-D tests show accurate simulation of vertical profiles and PBL heights
- MM5 tests show good ground level performance and accurate PBL heights

Non-local Mixing rates

Convective mixing rate derived by conservation of buoyancy flux:

$$\overline{M} = B_{1+\frac{1}{2}} / \left[\left(h - z_{1+\frac{1}{2}}\right)\left(\theta_{v1} - \theta_{v2}\right)\right]$$

Buoyancy flux at top of first layer defined by eddy diffusion:

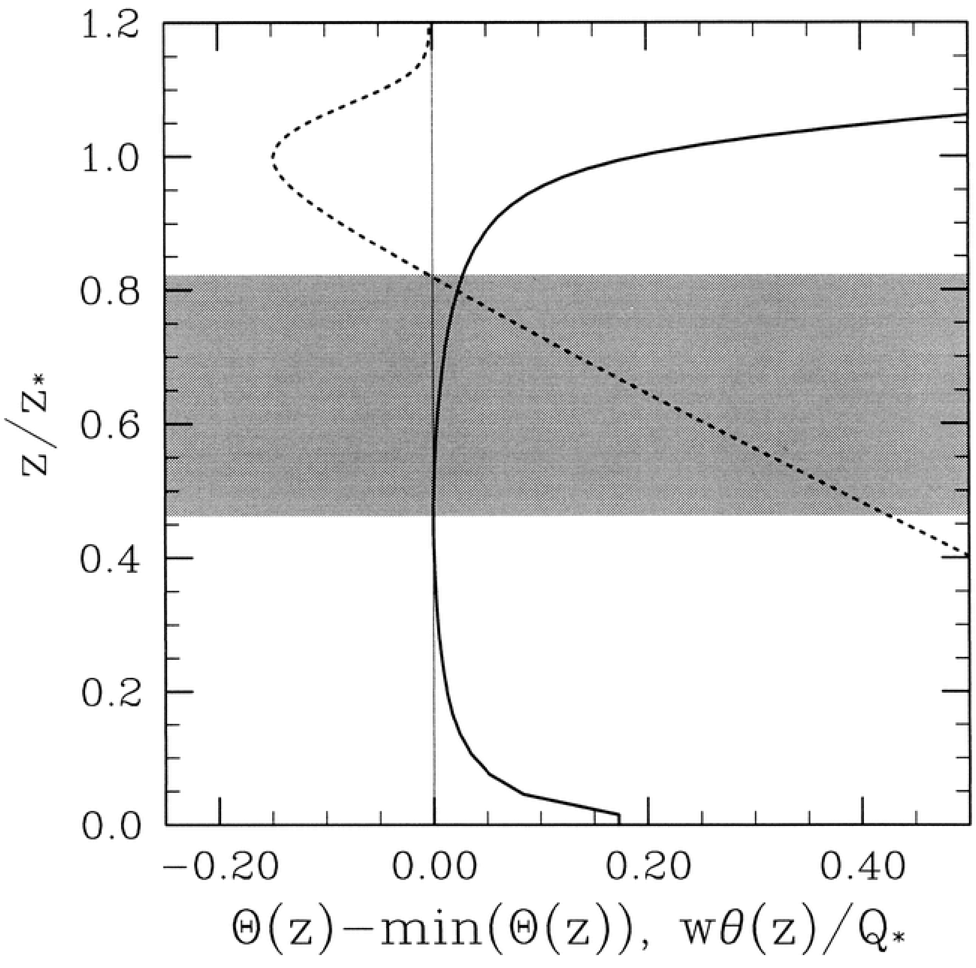
$$B_{1+\frac{1}{2}} = K_z(z_{1+\frac{1}{2}}) \frac{\left(\theta_{v2} - \theta_{v1}\right)}{\Delta z_{1+\frac{1}{2}}}$$

Where: $$K_z = k \frac{u_*}{\phi(\frac{z_s}{L})} z\left(1 - z/h\right)^2; z_s = \min\left(z, 0.1h\right)$$

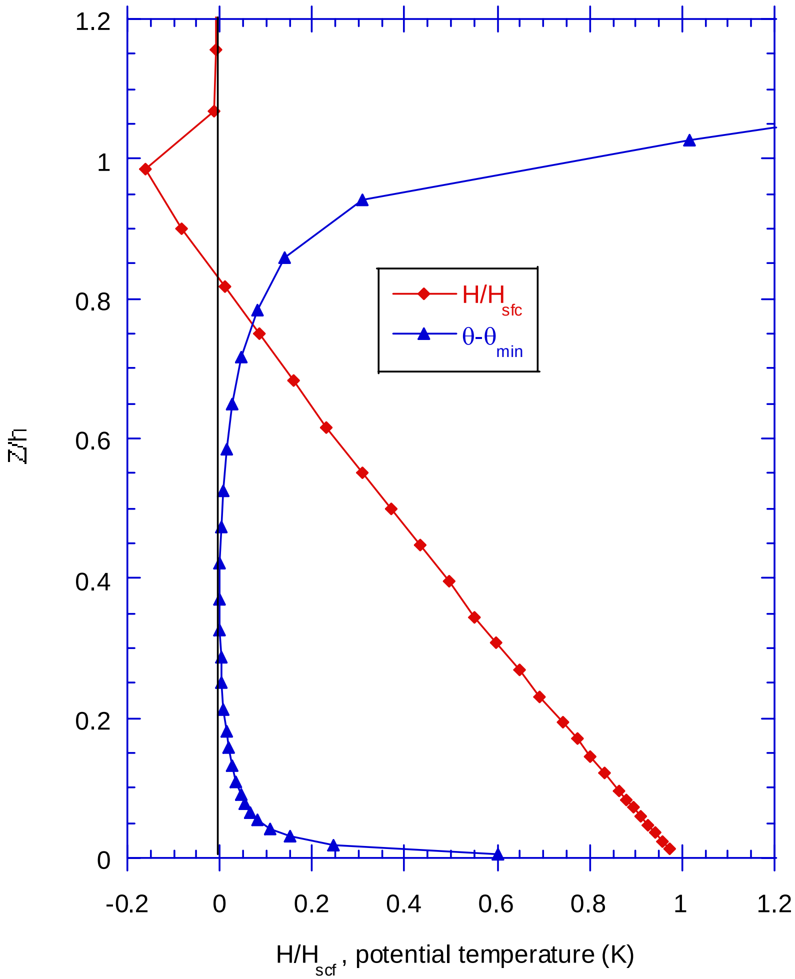
Thus, Convective mixing rate is a function of K_z but not a function of potential temperature gradient:

$$\overline{M} = \frac{K_z(z_{1+\frac{1}{2}})}{\Delta z_1\left(h - z_{1+\frac{1}{2}}\right)}$$

Normalized heat flux and potential temperature profiles

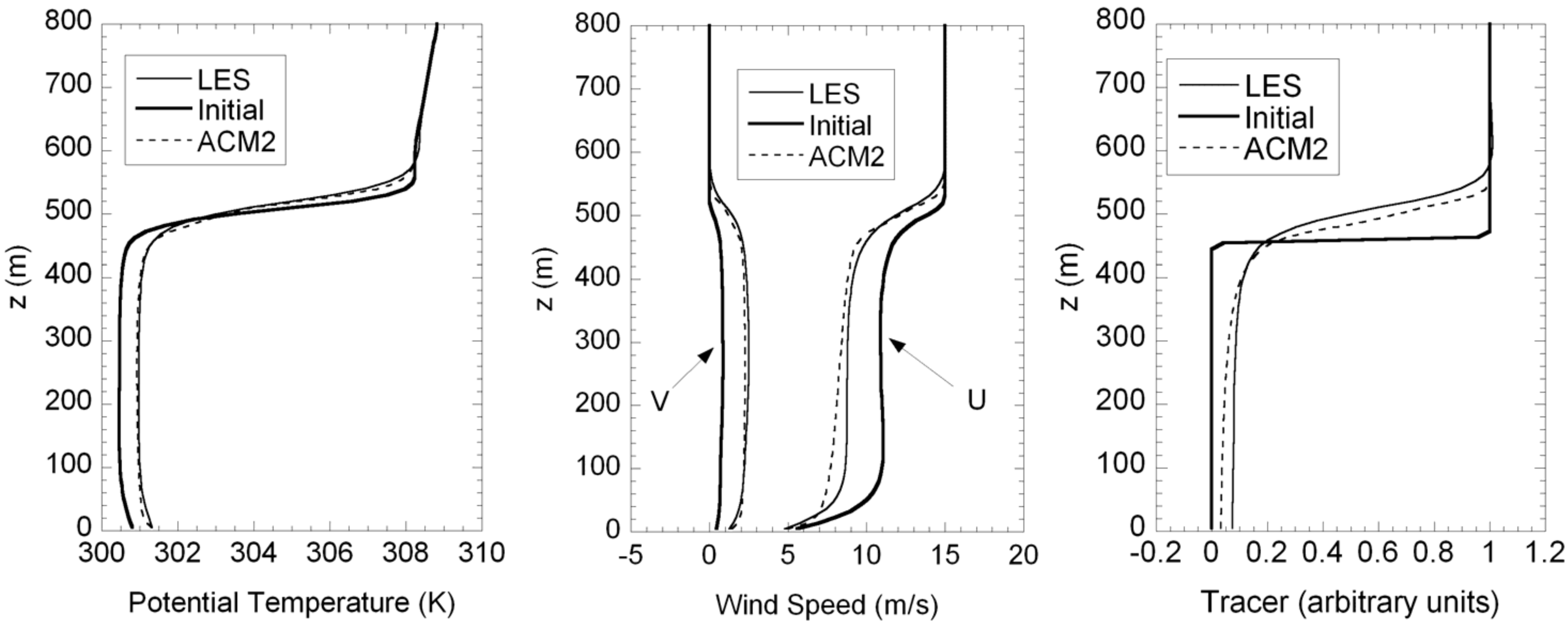


LES (Stevens 2000)

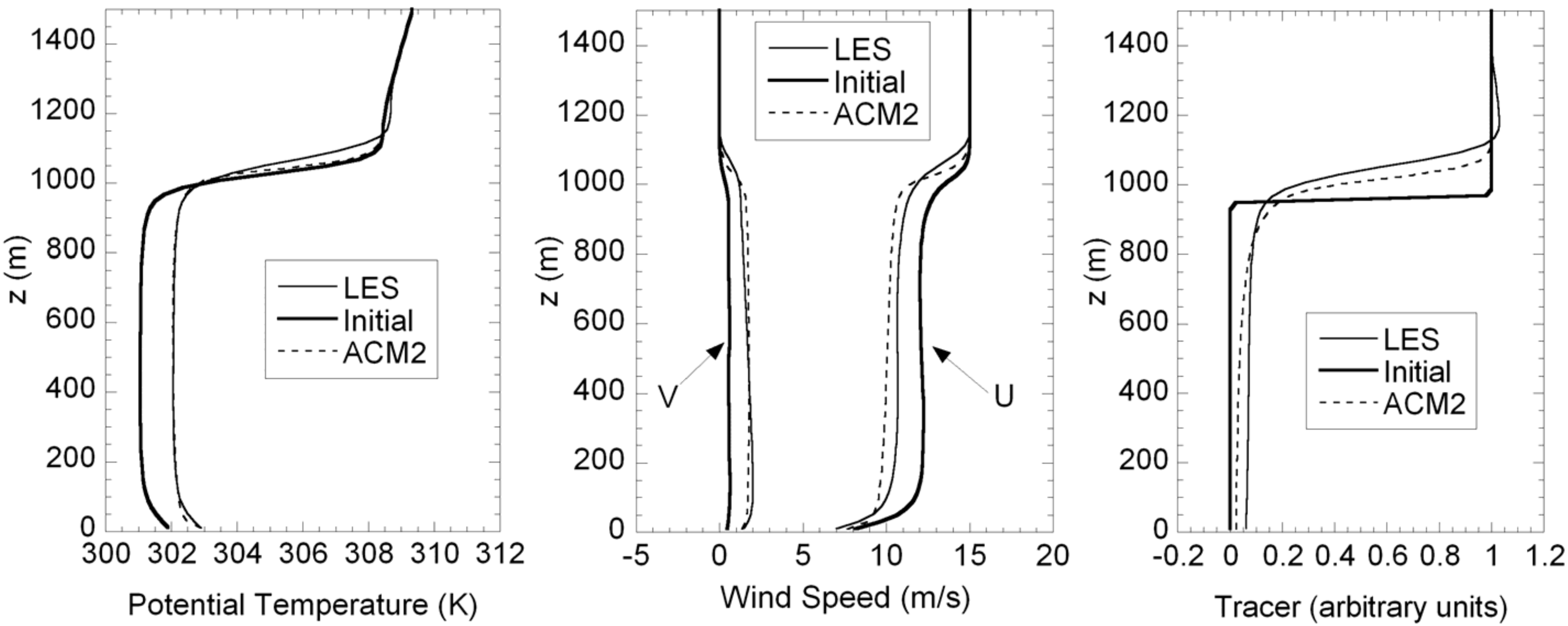


ACM2

LES experiment low heat flux
(Q* = 0.05 K m s-1), strong cap



LES experiment high heat flux (Q* = 0.24 K m s-1), strong cap



Model equations

$$\frac{\partial \mathrm{C_i}}{\partial t} = \mathrm{Mu\,C_1 - Md_iC_i + Md_{i+1}C_{i+1}}\frac{\Delta z_{i+1}}{\Delta z_i}$$

$$+\ \frac{1}{\Delta z_i}\left(\frac{K_{i+\frac{1}{2}}(C_{i+1}-C_i)}{\Delta z_{i+\frac{1}{2}}}+\frac{K_{i-\frac{1}{2}}(C_i-C_{i-1})}{\Delta z_{i-\frac{1}{2}}}\right)$$

where, $Md_i = Mu\left(h - z_{i-\frac{1}{2}}\right)/\Delta z_i$

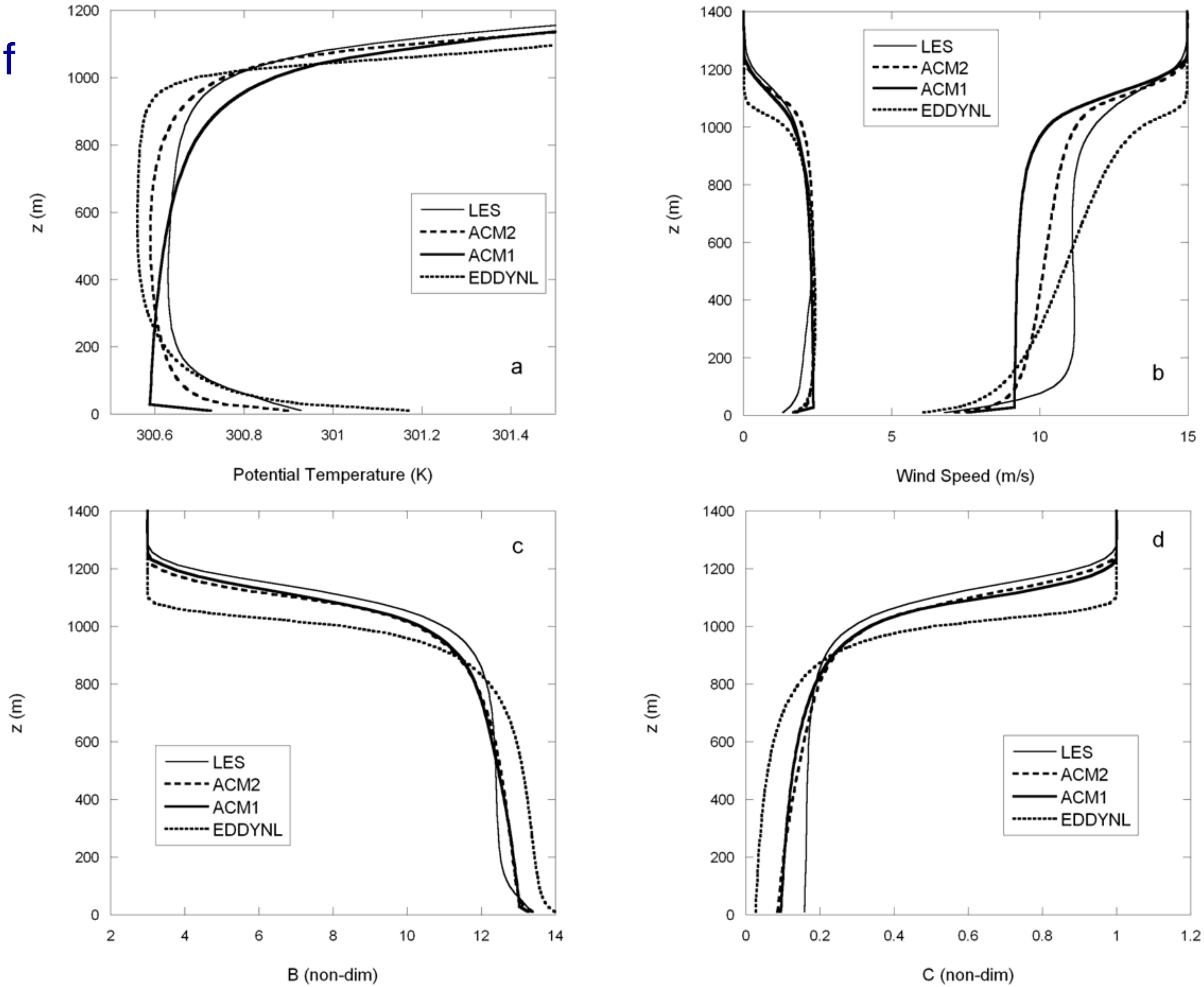
Mixing rates, all defined in terms of K_z *and* h, are partitioned into local and non-local components (f_{conv})

$$Mu = \frac{f_{conv}K_z(z_{1+\frac{1}{2}})}{\Delta z_1\left(h - z_{1+\frac{1}{2}}\right)}$$

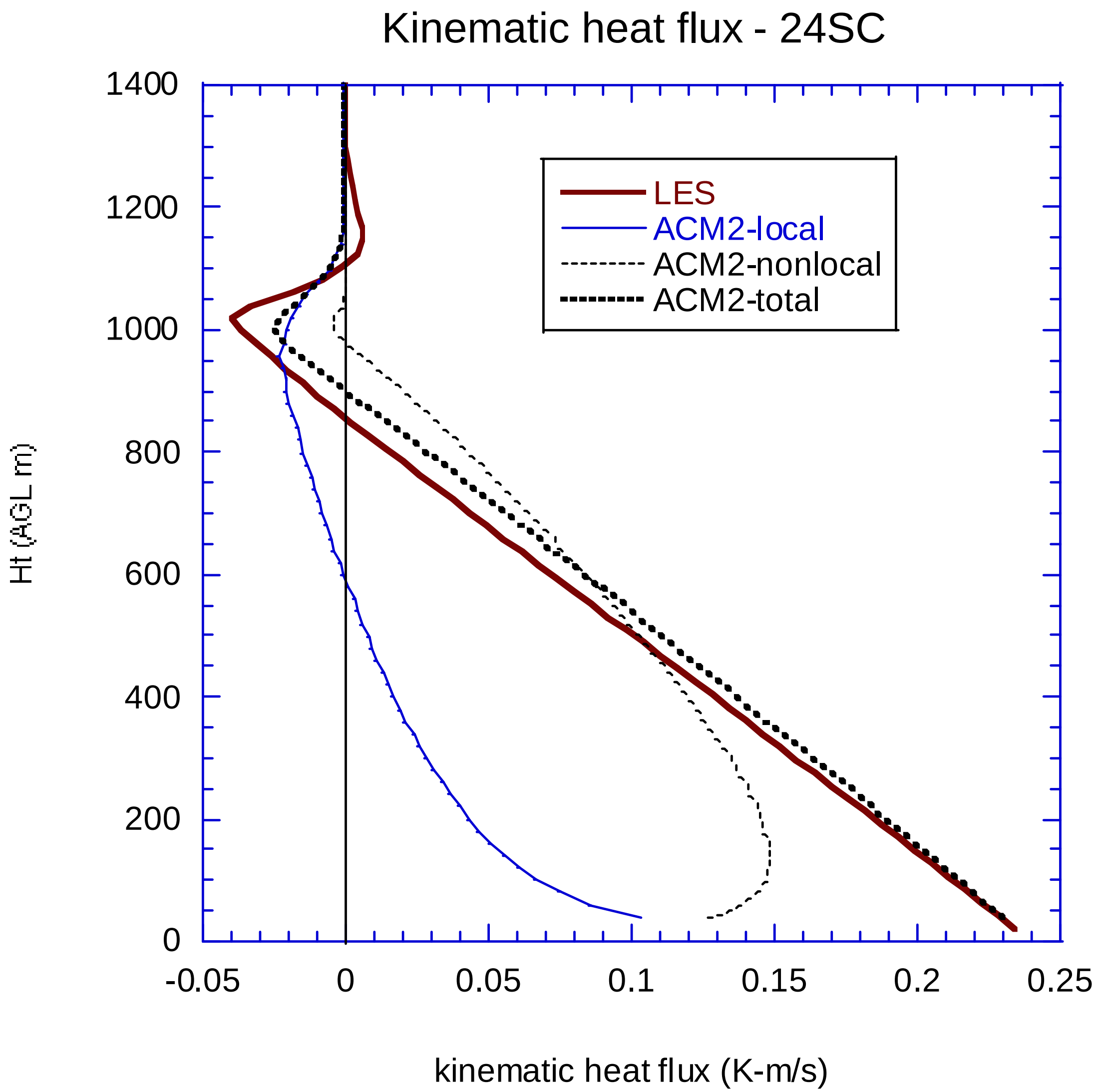
How to define f_{conv} ?

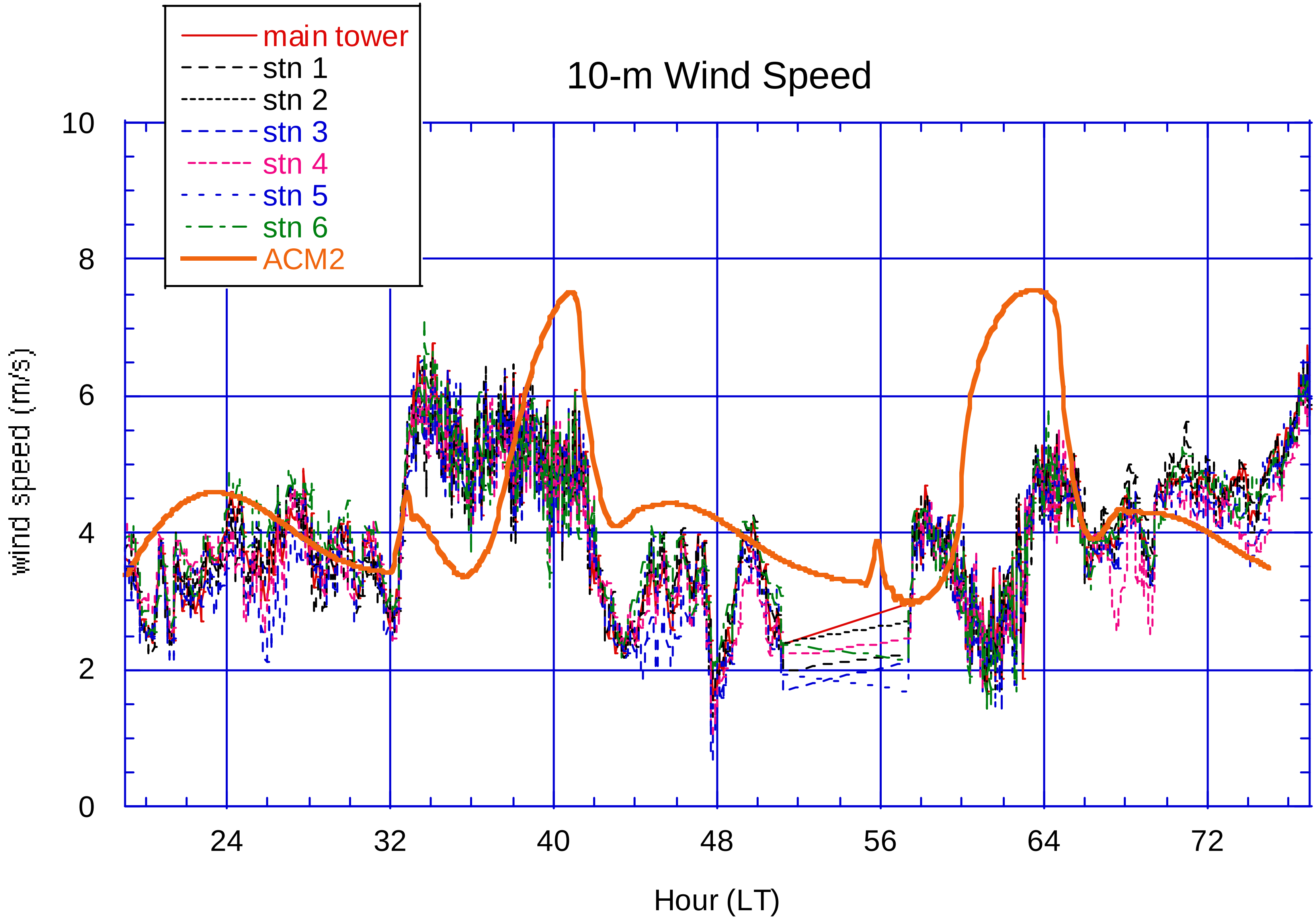
$$K_i = K_z(z)\left(1 - f_{conv}\right)$$

Comparison of ACM2, ACM1 and EDDYNL (based on HB93) for 05WC case



Profiles of sensible heat flux. Local, non-local, and total sensible heat flux compared to LES



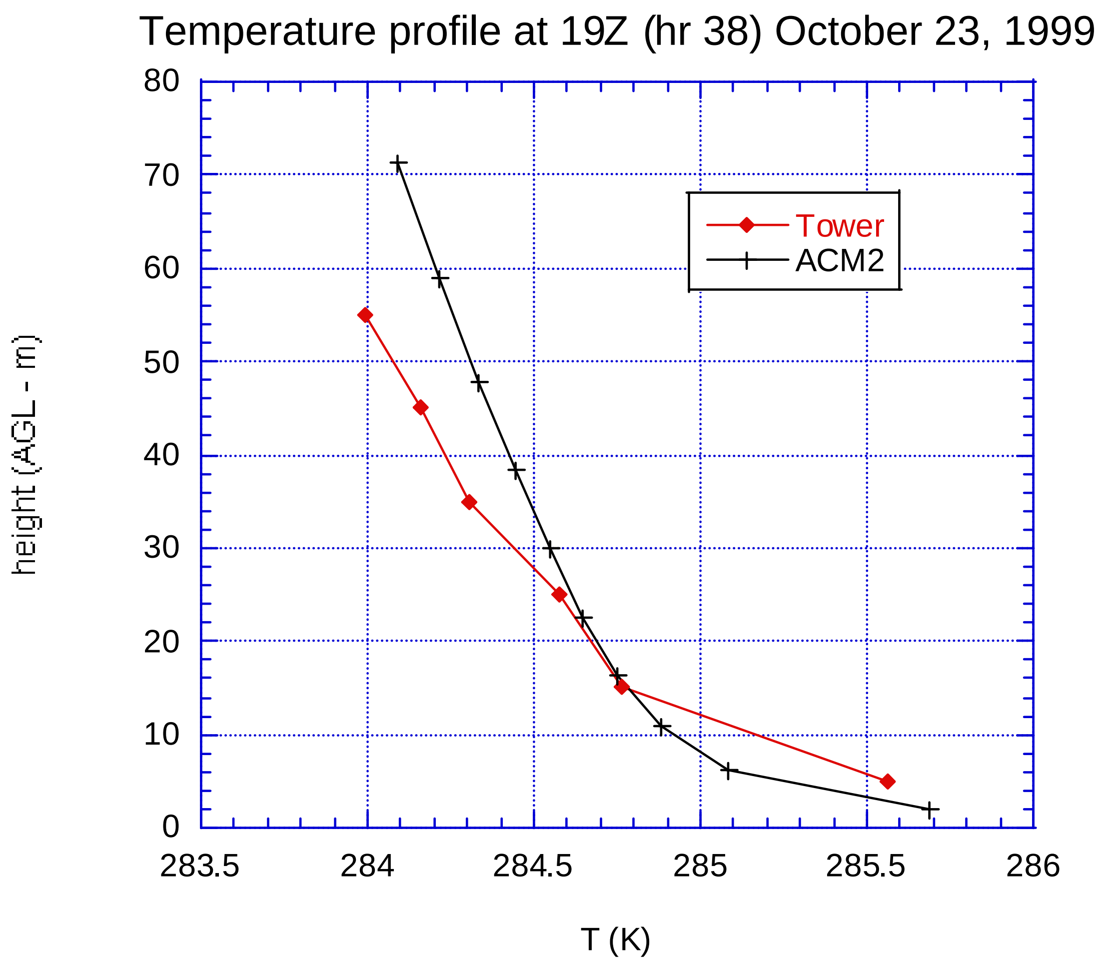


10-m Wind Speed
main tower
stn 1
stn 2
stn 3
stn 4
stn 5
stn 6
ACM2
wind speed (m/s)
Hour (LT)
0
2
4
6
8
10
24
32
40
48
56
64
72

Model performance statistics for the 12 km MM5-ACM2 simulations over the period of July 13 – August 18, 2004

	T	q_v	ws	wd
Data count	398848	398848	398848	398848
Correlation	0.934	0.915	0.612	---
MAE	1.42 K	1.14 g/kg	1.026 m/s	31.8 deg
MB	0.369 K	0.109 g/kg	-0.211 m/s	10.2 deg
Index of Ag	0.931	0.911	0.606	---

Near surface Temperature profile from CASES99 main tower



Wind speed bias segregated by Landuse