Objectively-Determined Fair-Weather NBL Features in the ARW-WRF Model and their Comparison to CASES-97 Observations[a]

Peggy LeMone[1], Mukul Tewari[2], Fei Chen[2], Jim Dudhia[1]

With Acknowledgments to:

Alberto Martilli (BouLac), Zavisa Janjic (MYJ), Esa-Matti Tastula (QNSE), Joe Olsen (MYNN2), and Songyou Hong (YSU)

[1]NCAR/MMM[b]
[2]NCAR/RAL

[a]Much of content soon to appear in Monthly Weather Review

[b]NCAR is sponsored by the National Science Foundation

DATA: CASES-97 Array
(NSF/NCAR, Argonne National Labs ABLE)

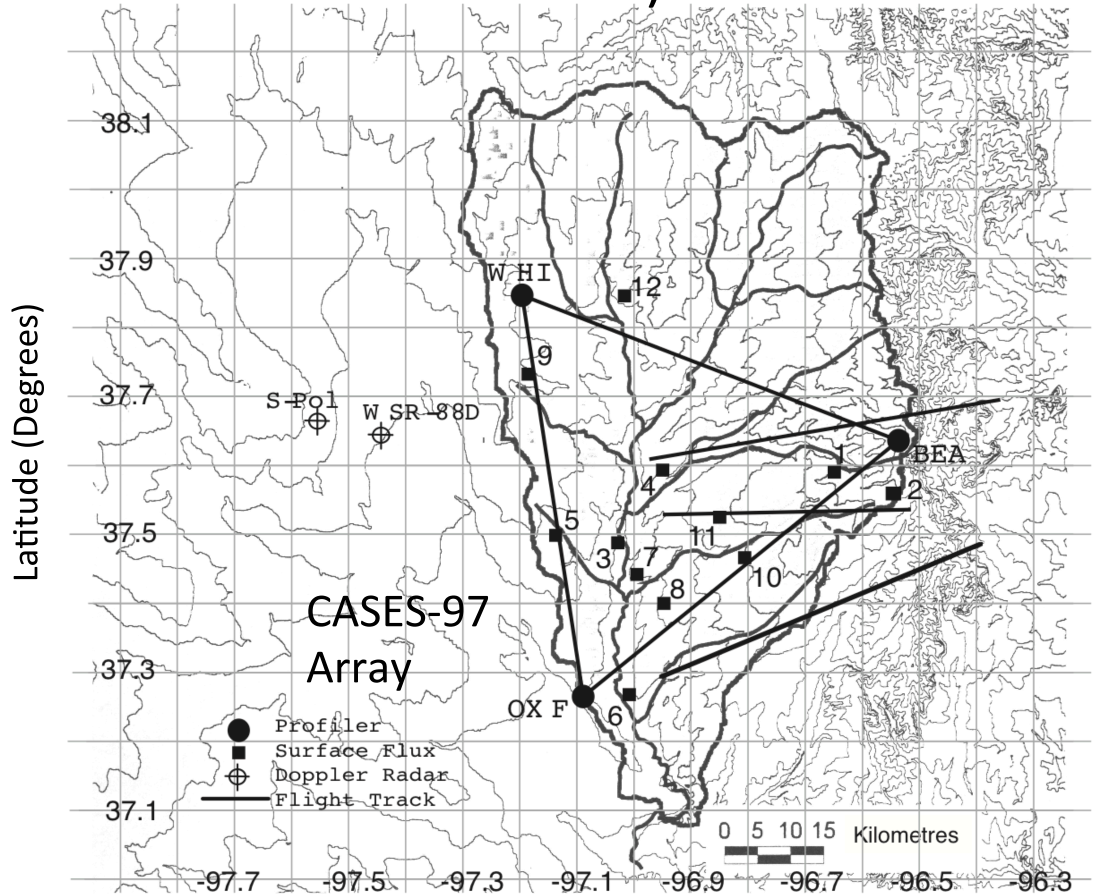
<u>PBL WIND PROFILES</u>

At: Beaumont (BEA)
Whitewater (WHI)
Oxford (OXF)

Hourly (consensus):
Radar Wind Profilers (150 – 2000 m)
Minisodars (5 – 200 m)

90-minute samples
Radiosondes

<u>SURFACE FLUXES, WINDS, etc</u>
30-minute averages
Numbered sites



Longitude (Degrees)

<u>NIGHTS</u>
4-5 May 1997
10-11 May 1997
20-21 May 1997

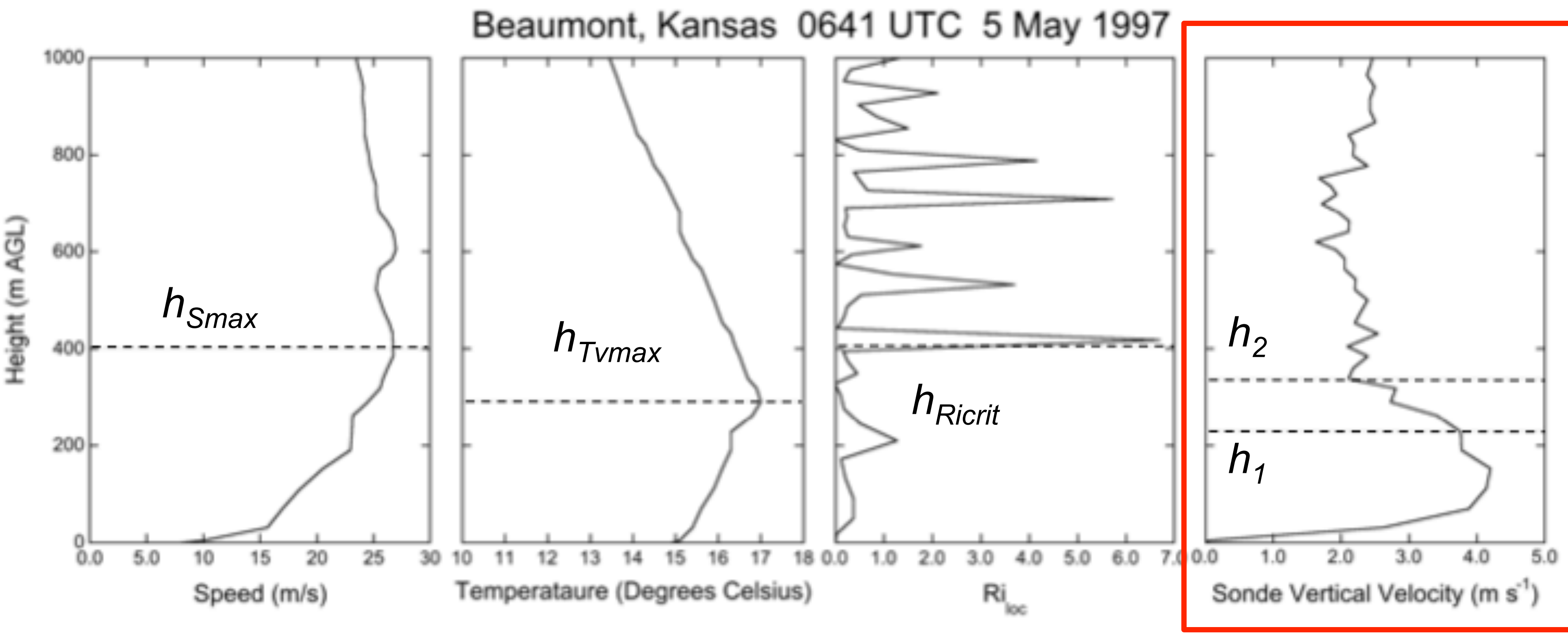
<u>Sample Size per night</u>
RWP+Sodars: hourly → 12 samples (when working)
Model: hourly → 12 Samples
Radiosondes: 90 min → 6) samples (obs stop at 0930 UTC

Weather for the three nights in the study (note: All have strong radiative cooling)

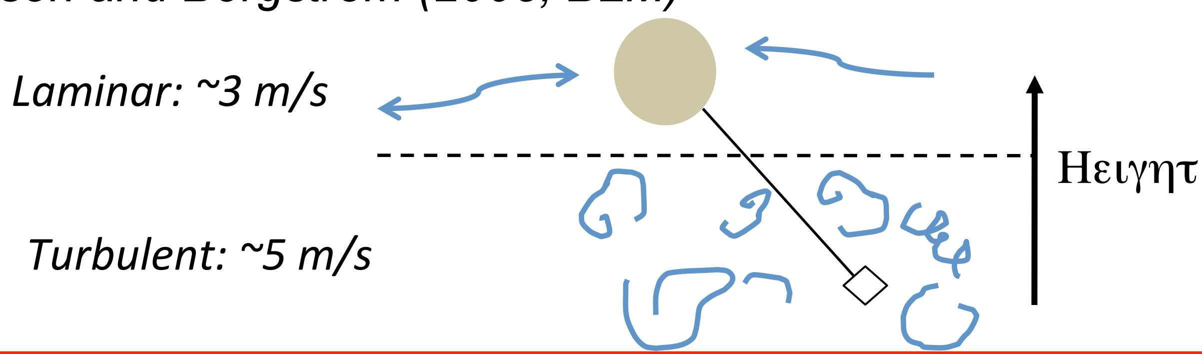
Night	48-m wind	Near-surface flow	Turbulence
4-5 May	7.8 – 14 m/s	Parallel to synoptic flow	Continuous
10-11 May	4.5 – 11.5 m/s	Some drainage flow, across synoptic flow	Intermittent; intermittent to continuous by 0930 UTC
20-21 May	4.3 – 7.6 m/s	Drainage forcing against synoptic wind direction → weak winds at Whitewater	Intermittent

References: Sun et al. 2012, Van de Wiel et al. 2012, LeMone et al. 2003.

Methods for Determining NBL Depth from Observed Soundings

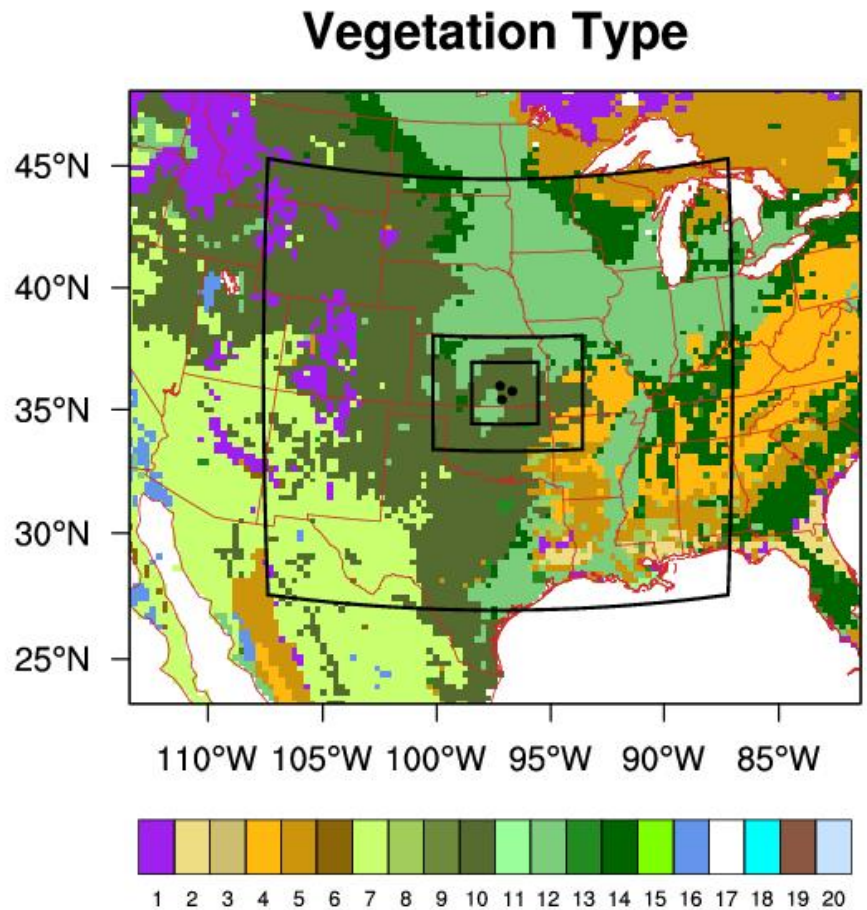


Johansson and Bergstrom (2005, BLM)



The Model: Simulate days with WRFv3.2*

- Domains (27, 9, 3, 1km)
  - e_we = 127, 235, 229, 304,
  - e_sn = 107, 223, 175, 283,
- Landuse (MODIS, 20 Cats), modified z_0
- WRF Runs initialized with NARR data
- 24-h starting at 12 UTC (6 a.m. LST)
- Noah LSM
- PBL Schemes:
  - MYJ PBL
  - QNSE PBL
  - BouLac PBL
  - YSU PBL
  - MYNN2 (for this talk)
- Levels
  - 44 levels
    15 levels below 1 km
    21 levels below 2 km



*Except for YSU, for which we also ran v3.4.1.

PBL Schemes solve for changes due to turbulence flux divergence

$$\frac{\partial C}{\partial t} = -\frac{\partial \left(\overline{w'c'}\right)}{\partial z} = \frac{\partial}{\partial z}\left(K_C \frac{\partial C}{\partial z} \right)$$

For schemes that solve the TKE (*e*) equation (BouLac, MYJ, MYNN, QNSE)

$$K_C = S_C L_{mix} e^{0.5}$$

For YSU

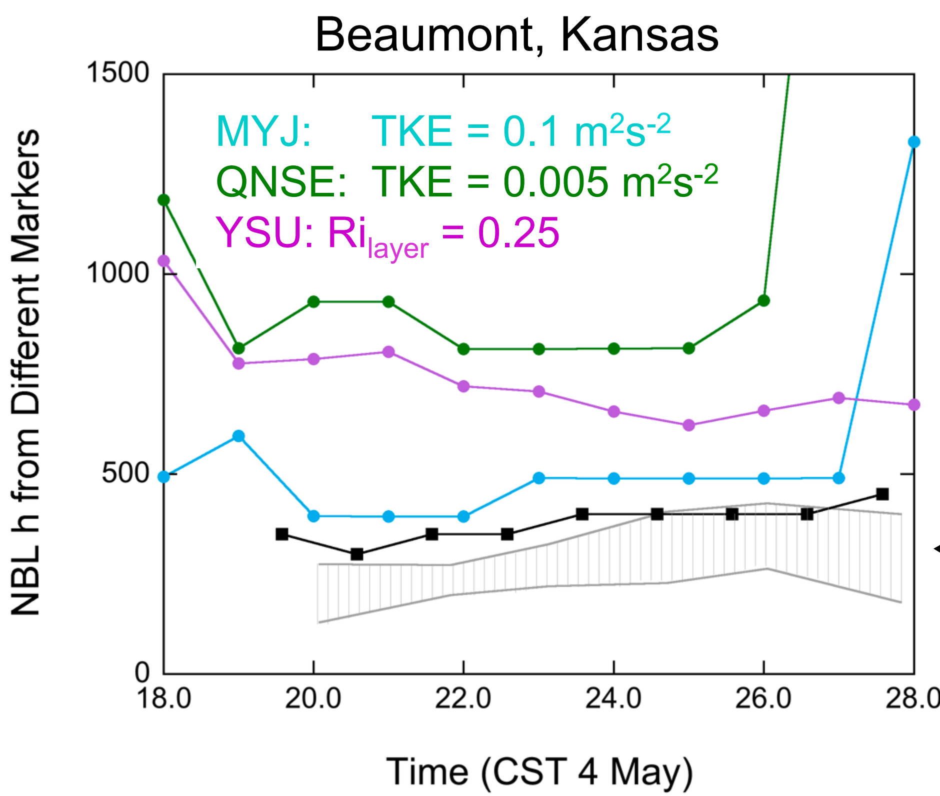
$$K = w_s kz \left(1 - \frac{z}{h_{NBL}} \right)^2$$

$w_s = u_*$ v 3.2

$w_s = u_* / (1 + 5z/L)$ v 3.4.1

Other things that change;
-- $Pr_t = K_M/K_H$
-- surface-layer formulation

NBL in WRF Simulations: “Official” Depths use different criteria

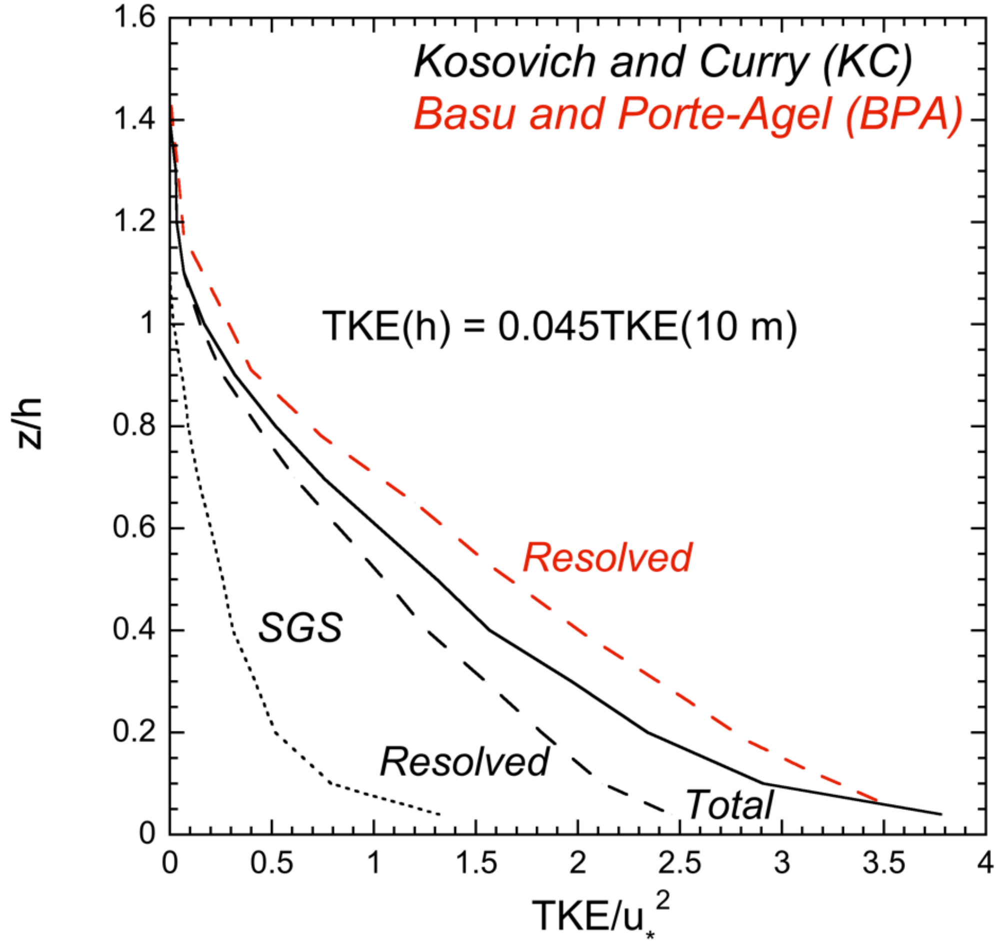


Shading = Range observed estimates

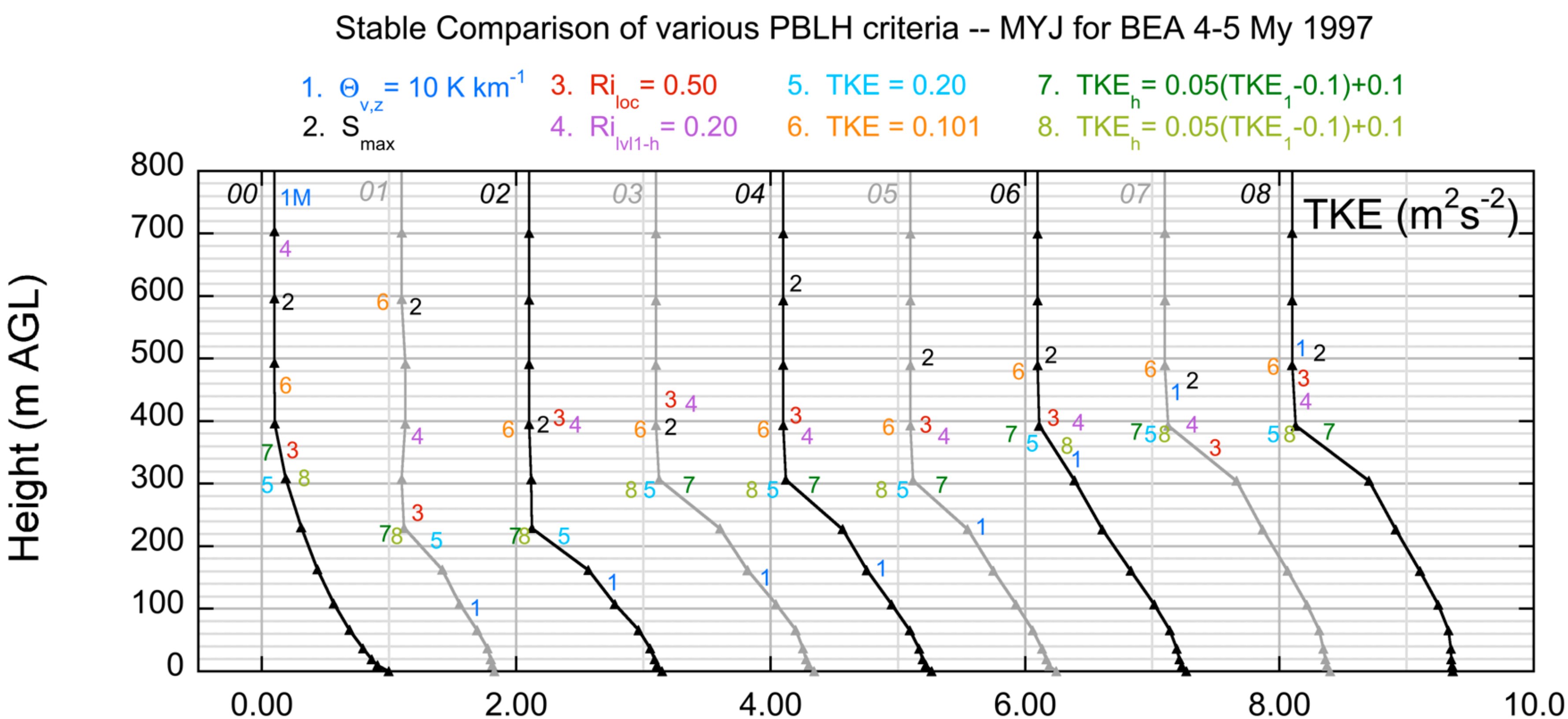
Need for “universal” criterion

Since turbulence and K profiles drop off at roughly same height as TKE, TKE is used to determine subjective NBL depth from simulations for TKE schemes; K for YSU

Profiles at right for near neutral NBL (L ~ 100 m) at equilibrium



Evaluation of criteria for model profiles– uses TKE profiles as truth



(offset by 1 m^2s^{-2} each hour)

Results: (1) TKE excess as fraction of TKE maximum most reliable (use 5%)

NOTE: For MYJ must subtract 0.1 m^2s^{-2} first

(2) max T_v and Speed work only after several hours

(3) No Ri works reliably (Ri for "good" *h* varies with time)

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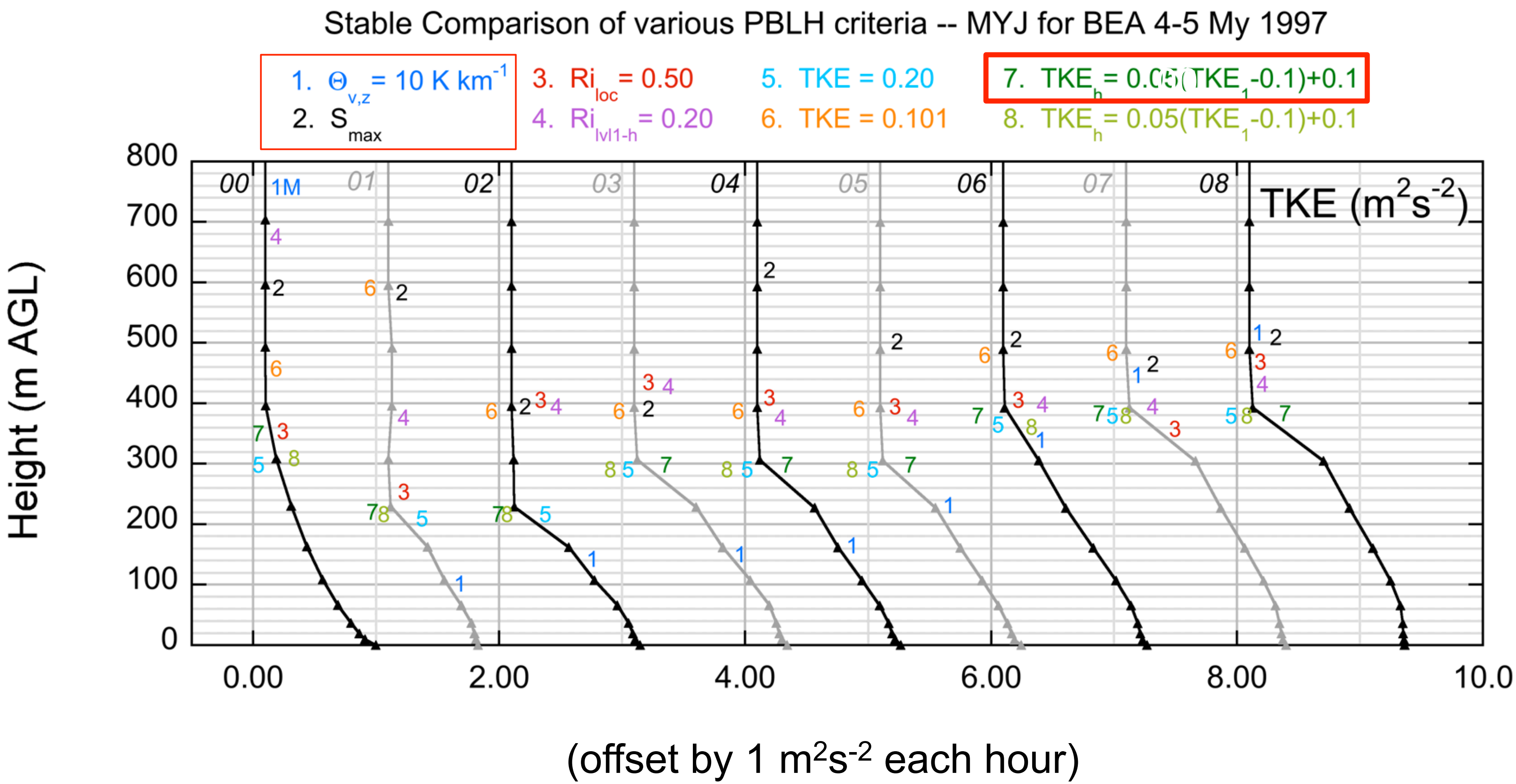

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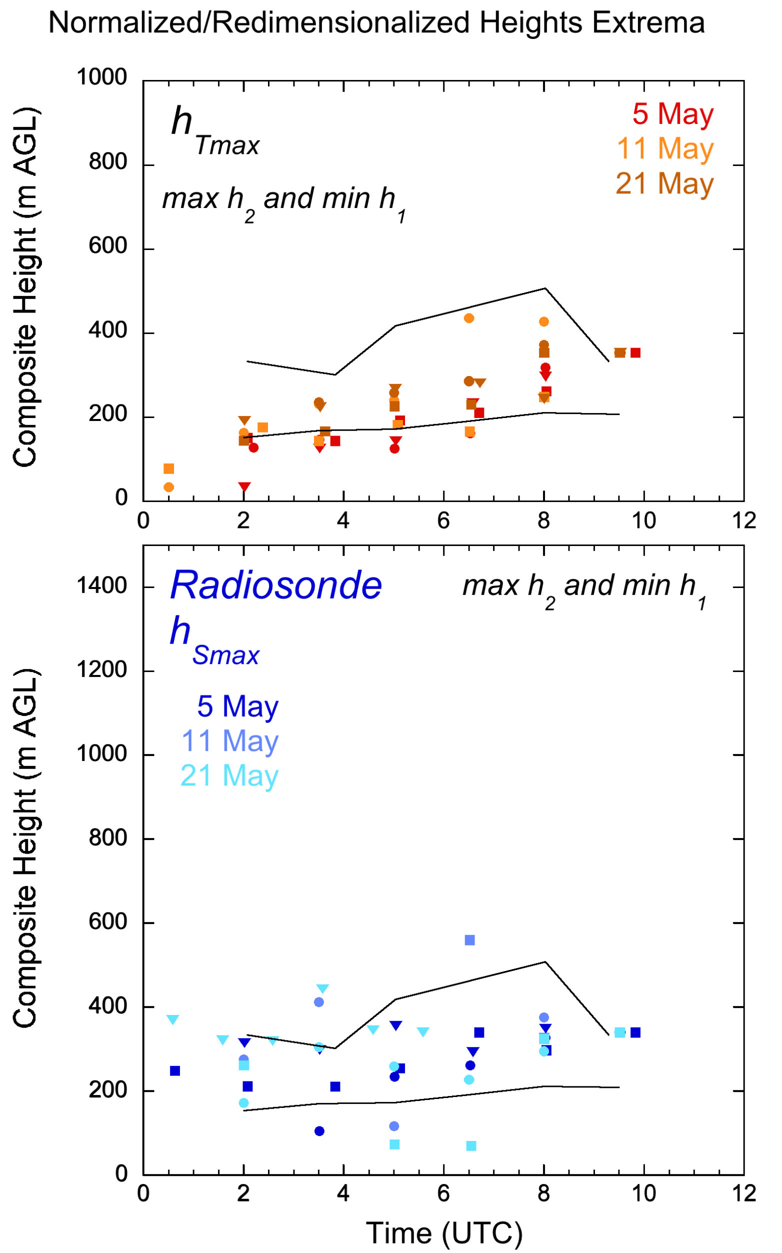
Observations: Composite PBL behavior for evaluation of models: “convergence”

Steps:

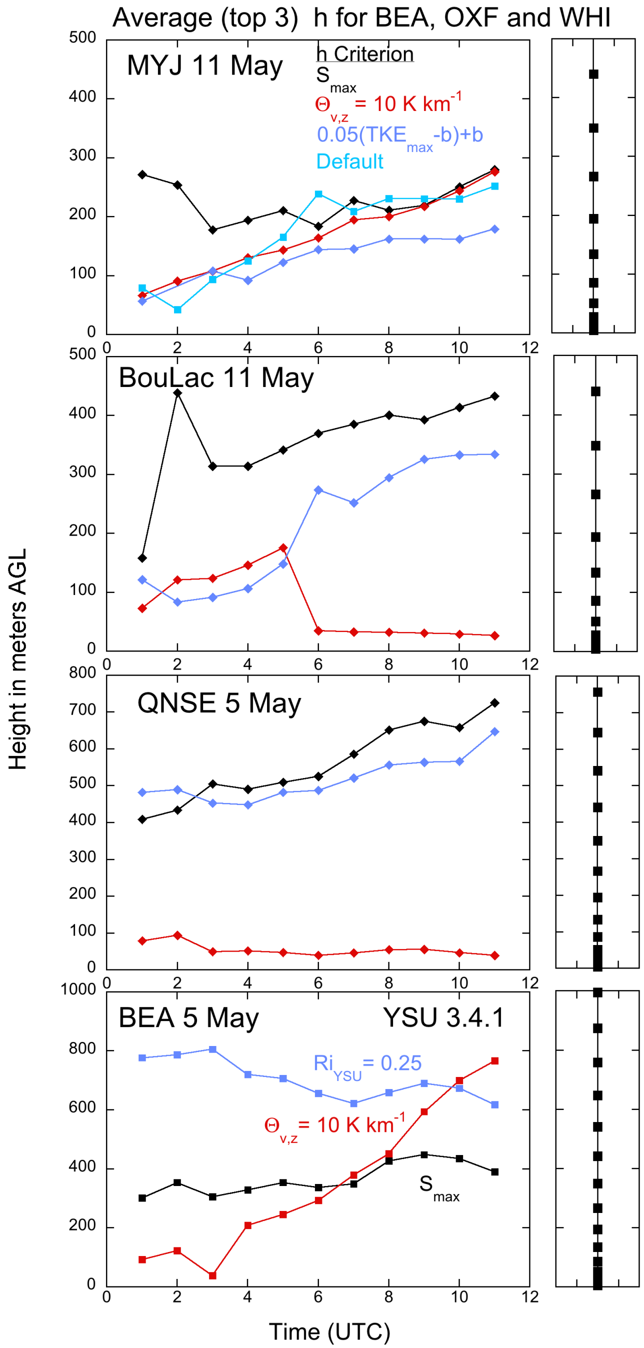
1. Take 0930 UTC value
2. Divide earlier heights by value
3. Average 0930 UTC values for all days
4. Multiply normalized values by average

Note:

1. All three are close at 0930



Model



"Convergence" Behavior" – closest to observations

<u>Two "Pathologies" (windy nights)</u>

"Collapse" of height of max T_v

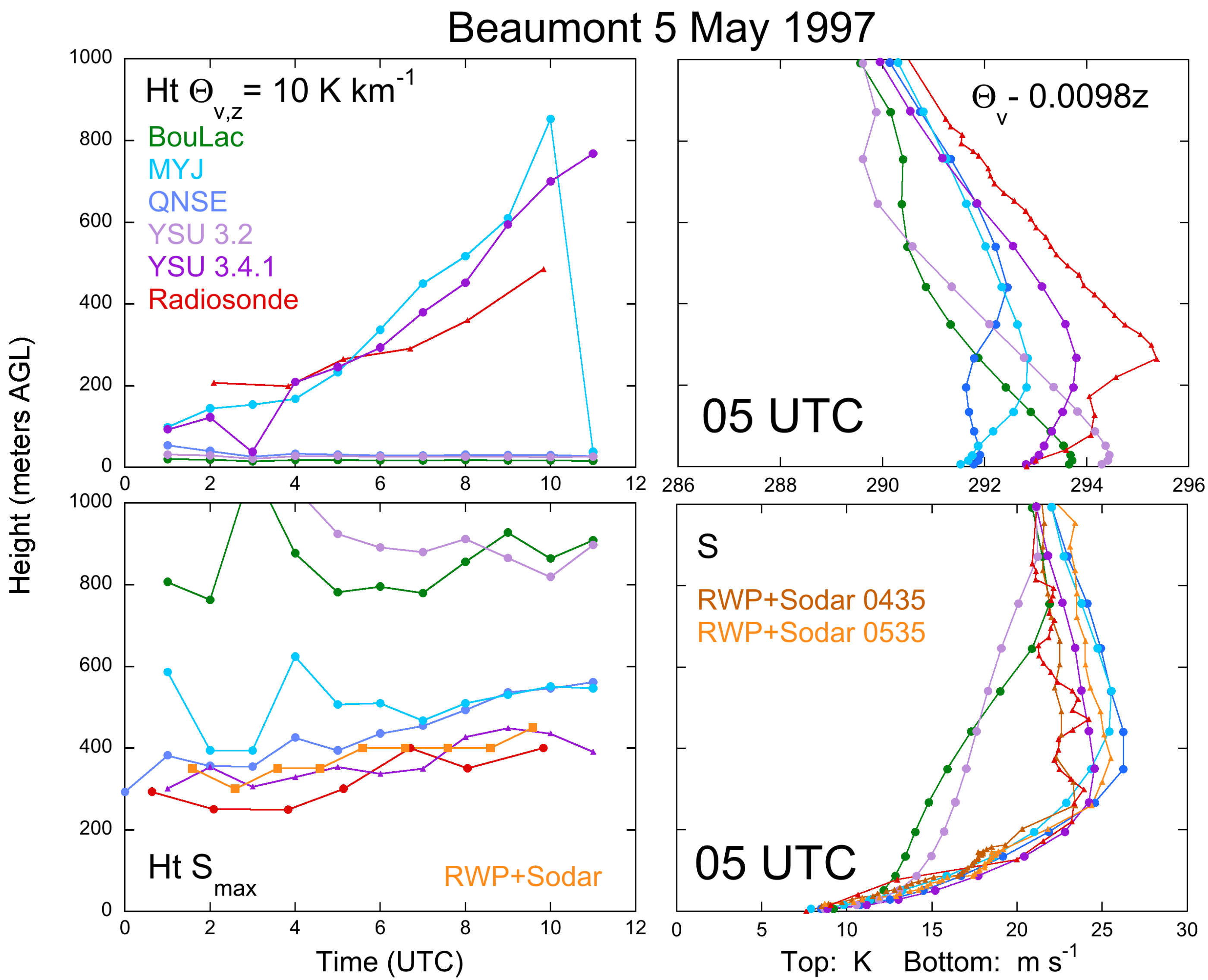
PBL SCHEME	Frequency
YSU 3.2:	67%
BouLac:	55%
QNSE:	33 %
YSU 3.4.1:	8 %
MYJ	7 %

"Too High" height of max T_v

PBL SCHEME	Frequency
YSU 3.4.1	7%
MYJ	4 %

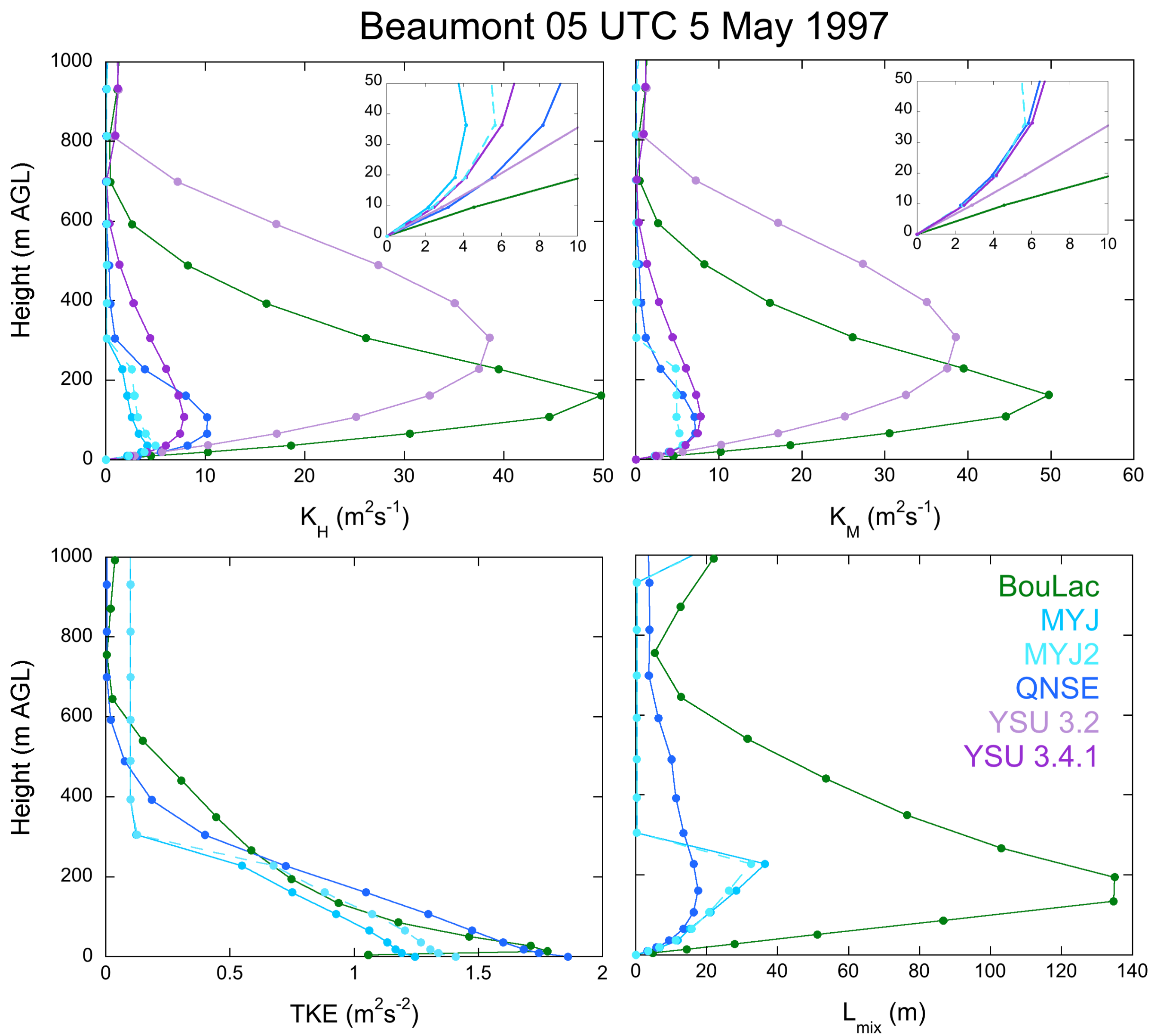
<u>BouLac and</u>
<u>YSU 3.2</u>:
Too much
Mixing

<u>QNSE</u>:
Too much
Mixing – but
For T_v only



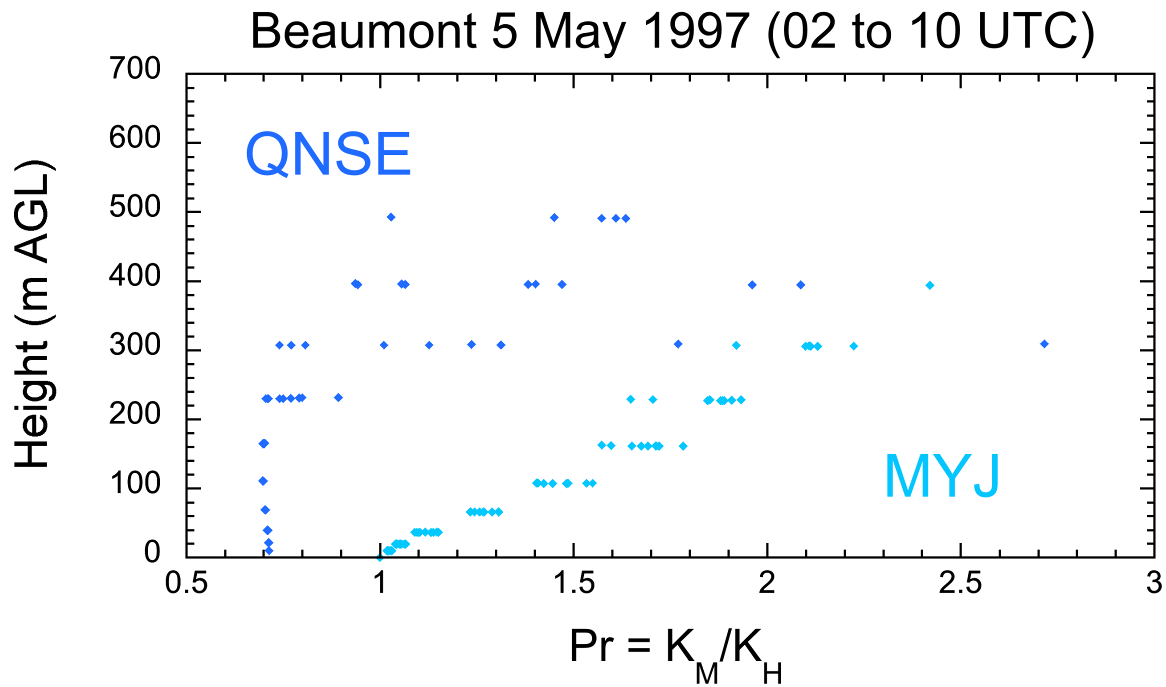
<u>BouLac and YSU 3.2</u>:
Too much Mixing: Big K

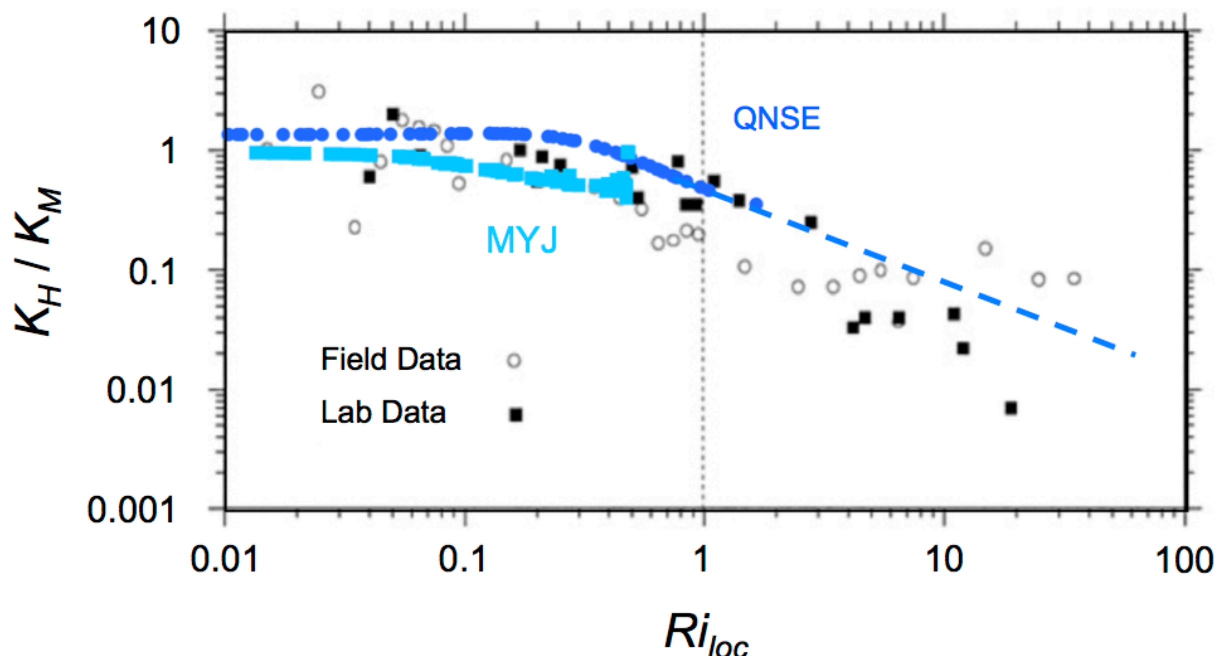
<u>QNSE</u>:
Too much Mixing – Big K_H
But O.K. K_M



Link to Prandtl number?

(K_M / K_H)





data superimiposed on plot from Monti et al. (2002, JAS), see also Sukoriansky et al. (2006. Nonlin. Proc. Geophys.*)*

Not just Pr -- Tastula et al. (2014, QJRMS submitted)

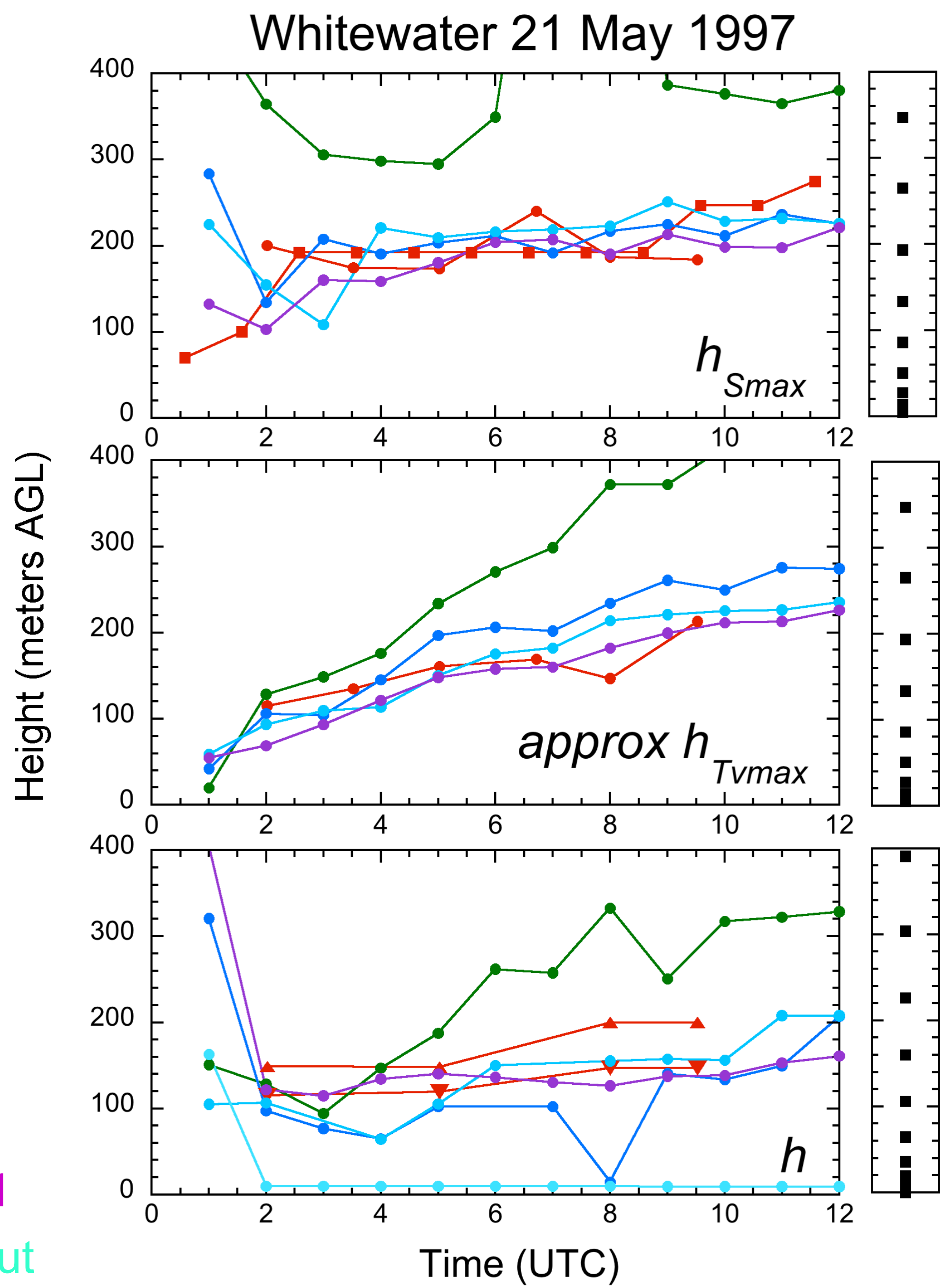
NBL “Collapse”?

when observations suggest otherwise…

From MYJ output value h_{MYJ} (due to small TKE), yet

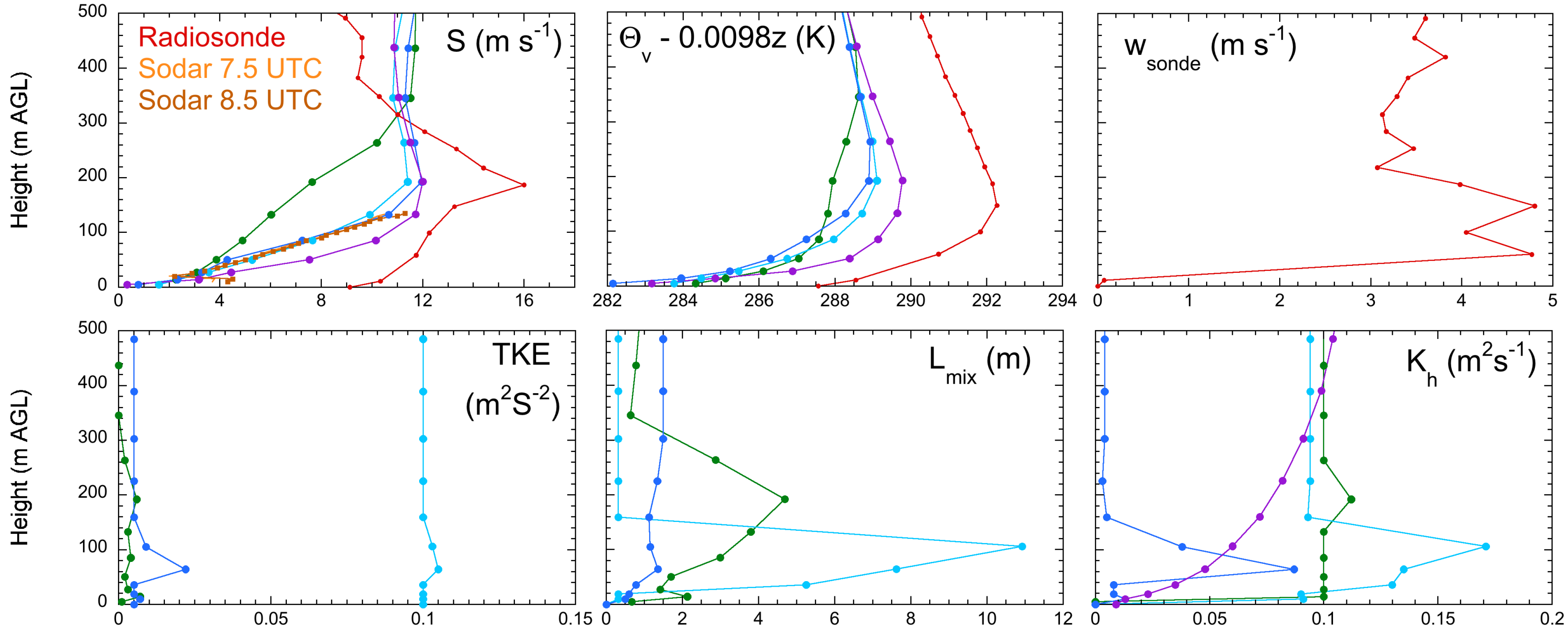
h from TKE'_{max} criterion look good except for 08 UTC QNSE

Max T_v and S heights look good except for BouLac



BouLac
MYJ
QNSE
YSU 3.4.1
MYJ output

Whitewater – 08 UTC 21 May 1997



Heights of maxima in T_v and *S* not bad

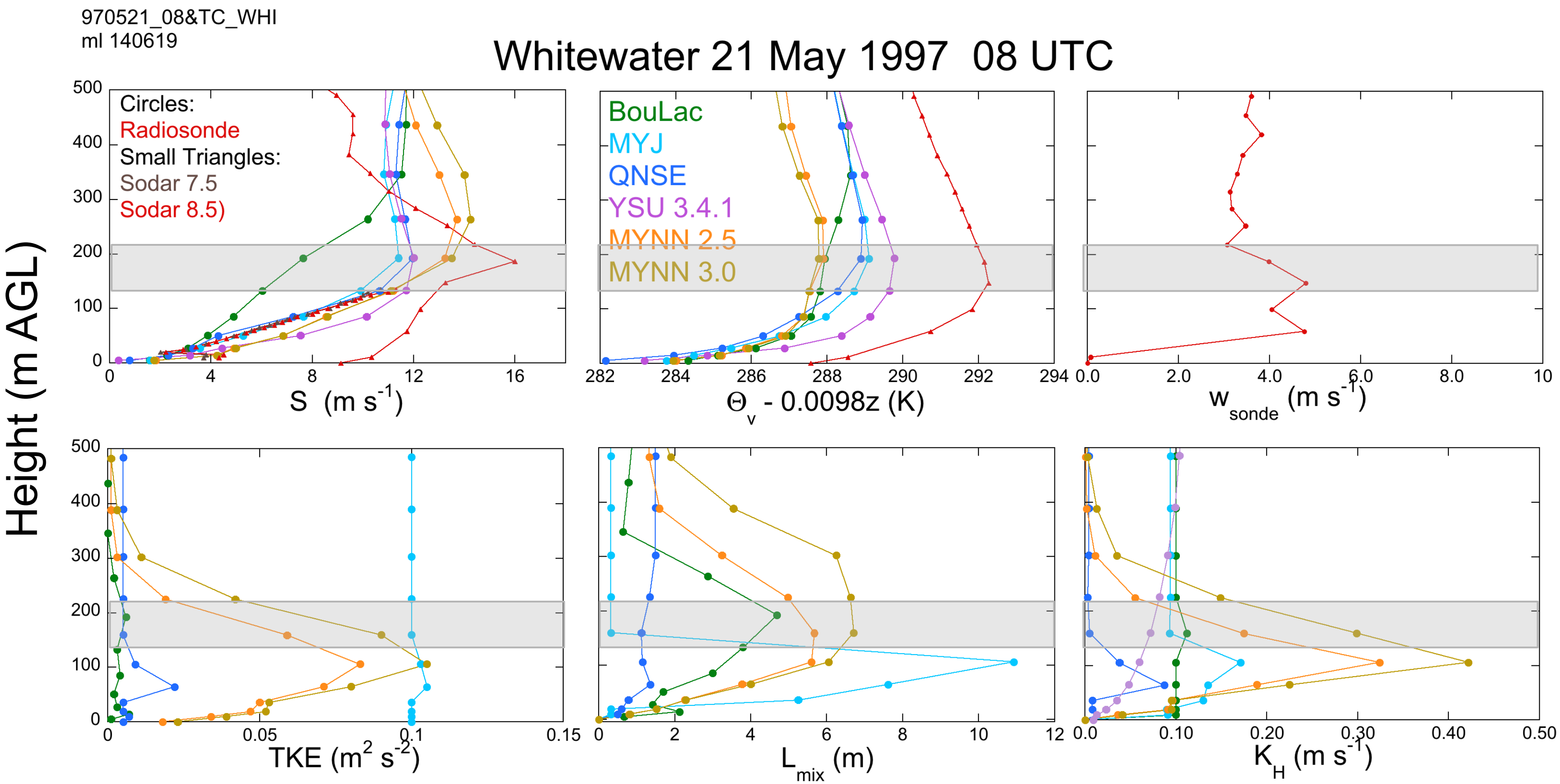
Well-defined NBL top (above surface) from balloon rise rate, but tiny modeled TKE

Why?

--Guess 1: Larger TKE upstream advected (not in schemes)

--Guess 2: TKE equation inadequate here

More complete turbulence equations (MYNN2.5, MYNN3) → larger TKE (also deeper, but by 1 grid point)



Conclusions

Turbulence parameters best indicate PBL depth (we use TKE).
This ambiguous if there is turbulence above NBL.

Max *S* and T_v "work" only once both coincide with TKE criterion, in the early morning.
(Parallel with time taken for NBL LES to reach equilibrium)

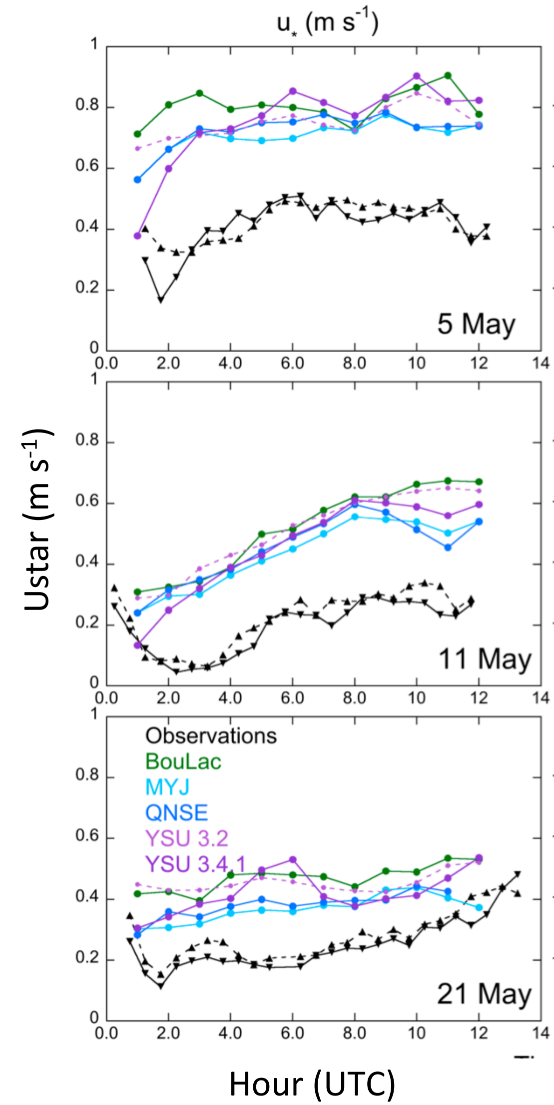
Comparisons:
MYJ perform best of four schemes compared
For YSU 3.2 and BouLac, too much mixing → height max T_v too low
For QNSE, too much thermal mixing → height max T_v too low,
Tastula et al., QJRMS, submitted) confirm role Pr but L_{mix}, TKE, $S_{H,M}$ important.
NBL depth and PBL profiles of *S* and T_v for most stable night surprisingly good
though TKE looked too small.
Need better turbulence equations? Horizontal advection TKE?

Careful examination of small (but detailed) sample enables insights into model behavior

Schemes work well despite large discrepancy in ustar

-- Profiles consistent

-- S at 10 m (S_{10}) close (model average average 3% lower than obs)



WHY?

Assume S_{10M} (Model) = S_{10O} (Observations)
Assume neutral
Use ratio of ustars = 1.5 for 5 May (L = 400 m model, 100 m obs)

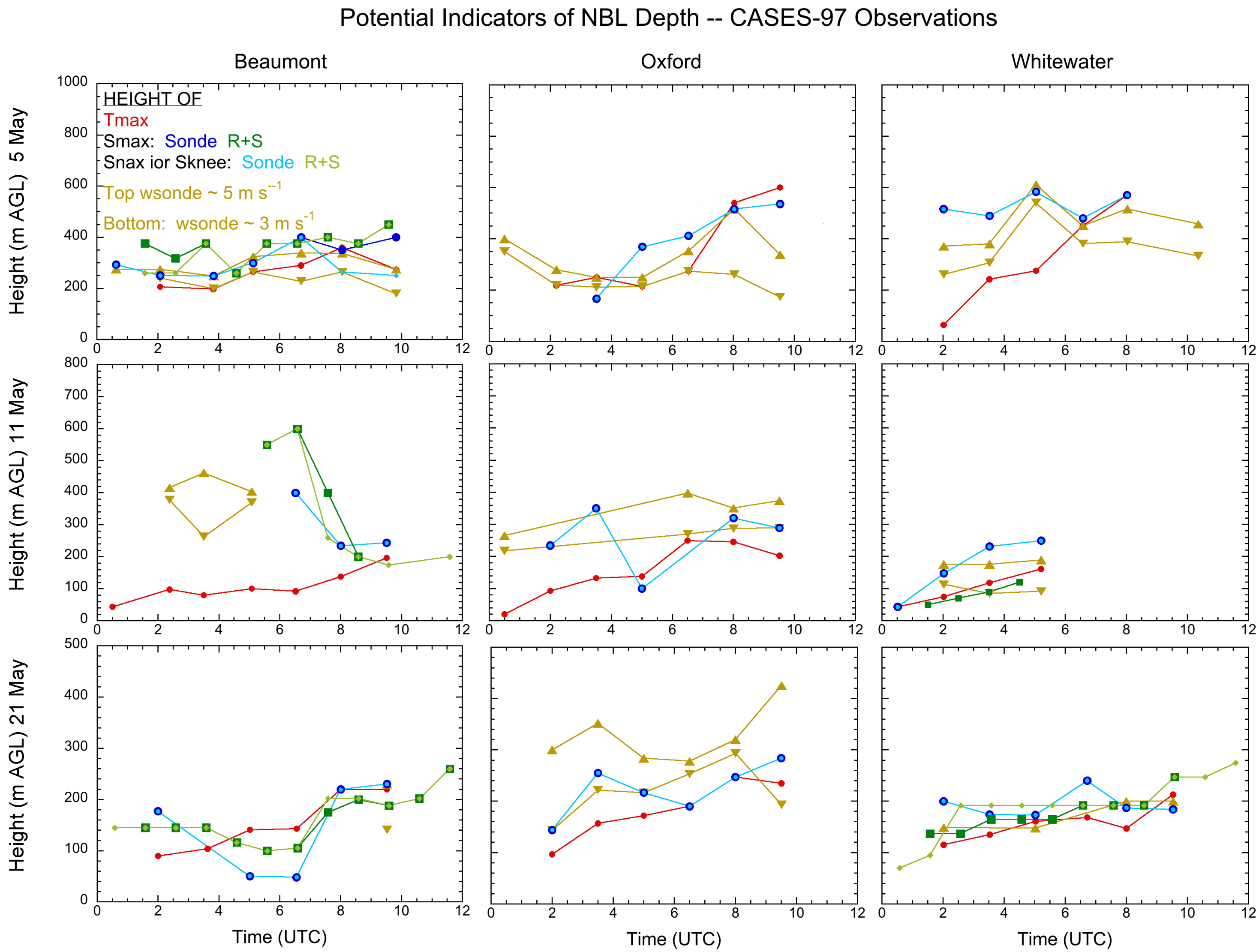
$$S_{10} = \frac{u_{*M}}{k}\ln\frac{10}{z_{0M}} = 1.5\frac{u_*}{k}\ln\frac{10}{z_{0M}} = \frac{u_*}{k}\ln\frac{10}{z_{0O}}$$

Rearranging,

$$\ln z_{0O} = 1.5(\ln z_{0M} - \ln 10) + \ln 10$$

z_{0O} = 0.0035 m, close to estimated values (0.006 and 0.002 for Sites 1 and 2) using observations.

Observations



PBL Schemes for changes due to turbulence flux divergence

Scheme	Basic Physics for stable conditions	NBL depth
BouLac (Level 1.5)	Solve for TKE (or *e*) $K_H = K_M = K_E = 0.4\, L_{mix}\, e^{0.5}$, **Big L_{mix} !** L_{mix} vertical travel distance traveled with initial vertical velocity = $(2e)^{0.5}$	Not for NBL
MYJ (level 2.5)	Solves for e, θ'^2 **Complicated!** $(K_{H,M}=L_{mix}e^{0.5}S_{H,M}(L_{mix},e,U_z,V_z,\Theta_z))$ $\frac{1}{L_{mix}} = \frac{1}{L_T} + \frac{1}{kz}, L_T = \alpha \int_0^{hnbl} qz\,dz / \int_0^{hnbl} q\,dz, q = (2e)^{0.5}$ L_{mix} adjusted if necessary to satisfy an equation for L_{mix}/q	Lowest level at which e = 0.1
MYNN2 (level 2.5 or 3)	Solves for e Adds buoyancy effects of pressure fluctuations for Level 2.5 version, flux and variance for level 3 Advection of TKE $K_{H,M}$ as in MYJ but $S_{H,M}$ changed $\frac{1}{L_{mix}} - \frac{1}{L_S} + \frac{1}{L_T} + \frac{1}{L_B}$ where L_S modifies kz for stability; $L_B = q/N$, L_T as in MYJ except for α value	Lowest level for which TKE falls to $0.025{*}TKE_{max}$ for TKE > $0.025\ m^2s^{-2}$,
QNSE (level 2.5)	TKE equation similar to MYJ (solved differently) (a) $\frac{1}{L_{mix}} - \frac{1}{kz} + \frac{1}{\lambda} + \frac{1}{.75e^{0.5}N^{-1}}$ (b) $K_{H,M}=0.55\alpha_{H,M}(Ri)$, α from spectral model, $\lambda=0.0063u^*/f$.	Lowest level at which e = 0.005
YSU	(a) $K_{M,H} = kw_s z(1-z/h)^2$ V3.2: $w_s = u_*$ V3.4.1: $w_s = u_*/(1+4.7z/L)$ (b) $\frac{1}{L_{mix}} - \frac{1}{kz} + \frac{1}{\lambda}$ $\lambda = 30$ m	Ri_{crit} = 0.25 (interpolated), with wind at lvl1=0