Stable Boundary Layers

Branko Grisogono

Dept. of Geophysics, Faculty of Sci., Univ. of Zagreb

TNX to: Danijel Belušić, Iva Kavčič, Amela Jeričević, Željko Večenaj, Leif Enger, Dale Durran, Thorsten Mauritsen, Larry Mahrt, Sergej Zilitinkevich, etc.

OUTLINE

- **INTRO**: background, overview & motivation

  - Modeled SABL often over-diffused or collapsed -

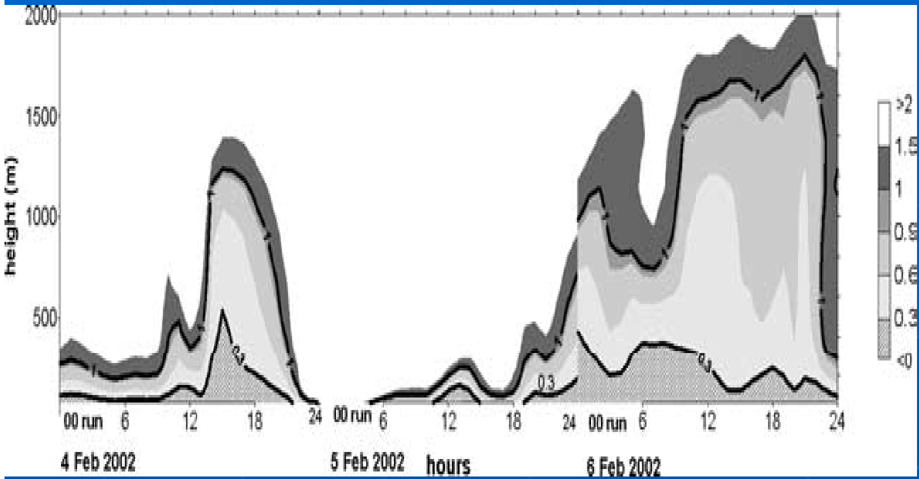
- **RECENT FINDINGS**: comparing various models…

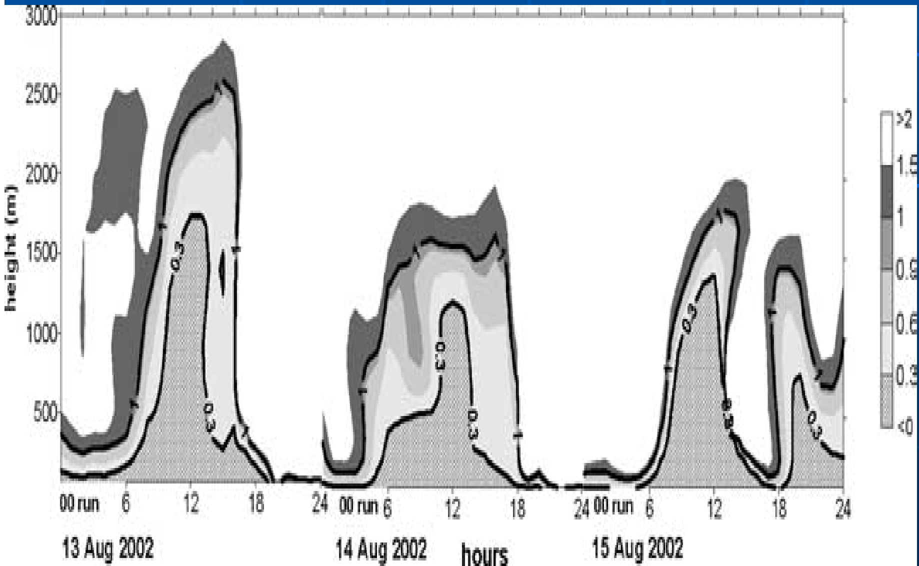
  - An improved "z-less" Mixing Length-Scale, Λ_{ML} -

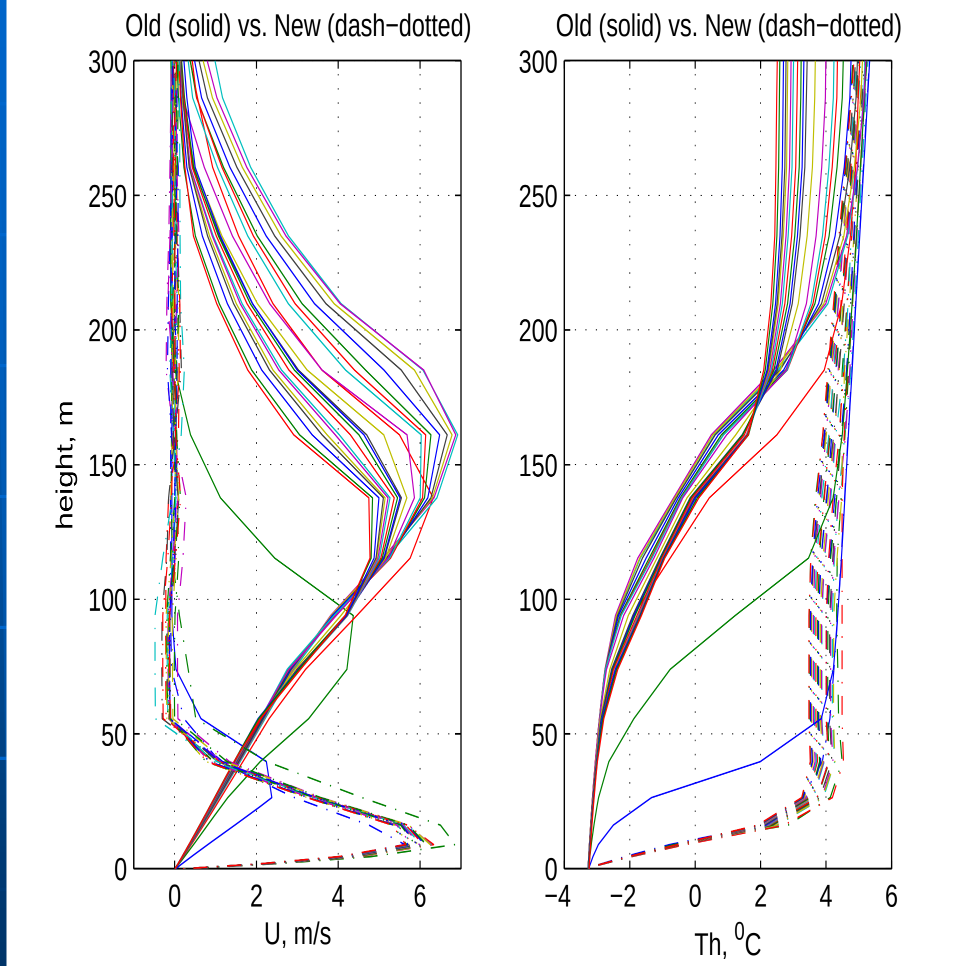
- **GENERALIZED RESULTS**

  - Λ_{ML} for 1^{st} & H.O.C. turbulence parameterization schemes -

- *COLLAPSED SABL*
- *OVER-DIFFUSED SABL*







A.J. & B.G.,Tellus '06

Same model but mixing length Λ: typical Λ (e.g. Blackadar, etc) over-diffusive!

Background & overview

- Mahrt, TCFD'98,..: SABL treated poorly...
- Zilitinkevich et al. QJ'08,... strong & weak mixing regimes
- Fernando, Ph Fl'03,...: turbulent patches in stratified shear flows
- Steeneveld '07 PhD thesis
- Mauritsen et al. JAS'07,... TTE
- Banta, Act.Geoph.'08: LLJ

- Nieuwstadt F.T.M. '84 x 2

BLM & JAS - local scaling

* Ozmidov length-scale:

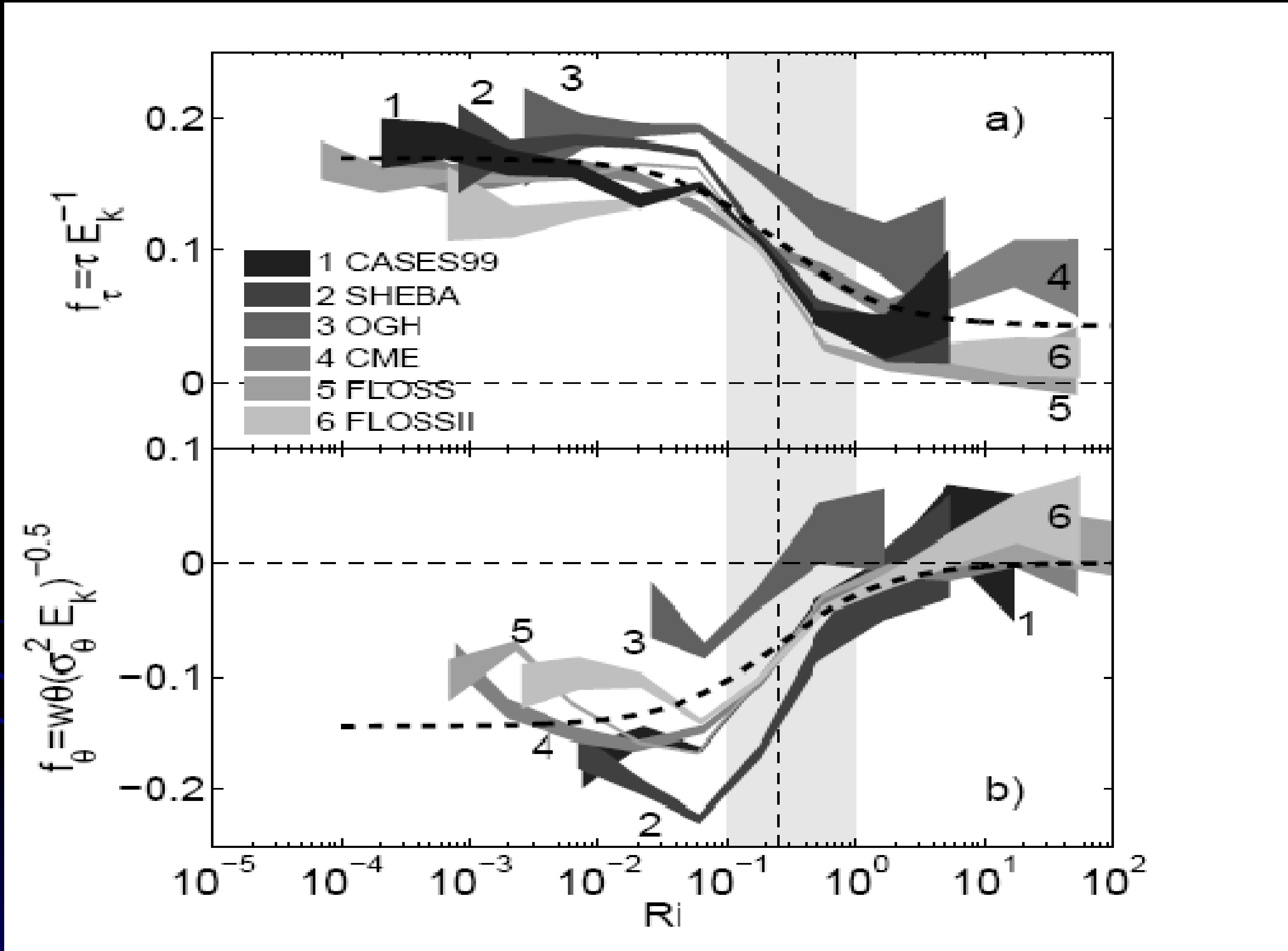
$$\Lambda_{OZ} \sim (\varepsilon / N^{3})^{1/2}$$

=>

$$\Lambda_{ML} \sim (TKE)^{1/2} / N$$

- *Hunt et al. '88, Tjernström '93, Schumann & Gerz '95, Grisogono & Enger '04:*
- *involve Shear in Λ_{ML} !*
- Other works: Fedorovich & Shapiro, Cuxart, Whiteman...

- Mauritsen et al. JAS 2007 ← →|



- *← weak mix. --->*

- *"z-less" Mix. Length, Λ_{ML} …modified*

- **PRANDTL MODEL & TKE eqn.**

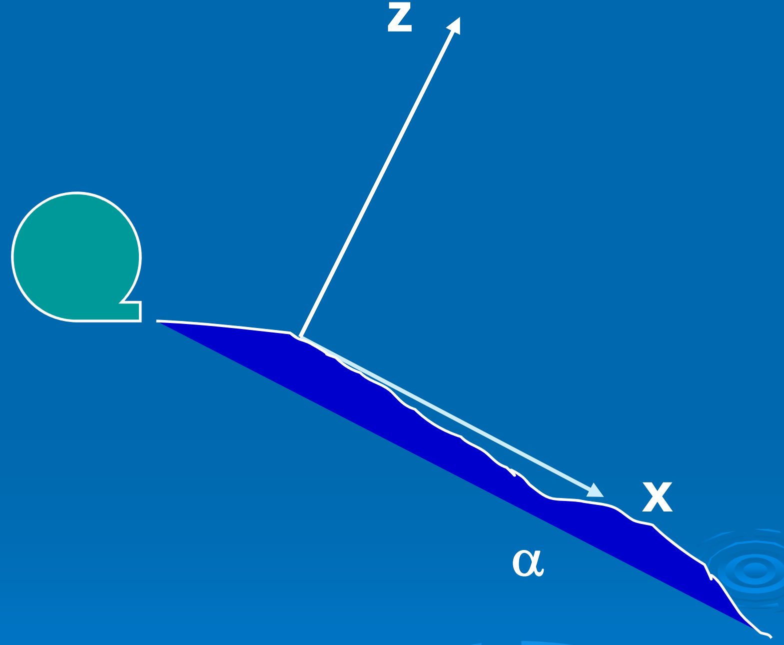
or TTE eqn.- *Nauman Awan*

- ***L*** *$_{MONIN\text{-}OBUKHOV}$ modified – Julia Palamarchuk*

(if a sfc. layer exists)

PRANDTL MODEL

- Analytical model for the "pure" katabatic flow
- Balance between the negative buoyancy & turbulent diffusion
- $\alpha < 0$
- Other improvements…



PRANDTL: CLASSICAL ANALYTICAL MODEL

- Stationarity for ***U*** & θ after t > **1-1.5*T***, ***T* = 2π/(Nsin(α))**,
- Later on: improved & calibrated Prandtl model, K(z),…

U:

$$0 = \frac{g}{\theta_0}\sin(\alpha)\theta + \Pr\frac{d}{dz}\left(K\frac{dU}{dz}\right)$$

θ:

$$0 = -\gamma\sin(\alpha)U + \frac{d}{dz}\left(K\frac{d\theta}{dz}\right)$$

MIUU MODEL & Simulation Parameters

- nonlinear, hydrostatic, *f*-plane
- 2.5-turbulence closure level
- 5 progn. eqns: ***U, V, Θ, q, TKE*** (e.g. *QJ '98, '04*)
-
- $\Delta x \approx 1.9$ km = const, $\alpha = -2.2°$, $C \approx -6.5°C$
- 211 × 7 × 201 gridpoints (*y=const*), total(nk)=402
- $\Delta t = 13$ s, $z_{TOP} = 5.6$ km (***"sponge"*** for $z \geq 4.4$ km)
- **1 m < Δz < 30 m**, ***"staggered, terrain influenced"***
- Initialisation: ***U*** & ***V*** ≈ 0, $\gamma = 5 \cdot 10^{-3}$ Km^{-1}, B.G. & D.B., *QJ'08*

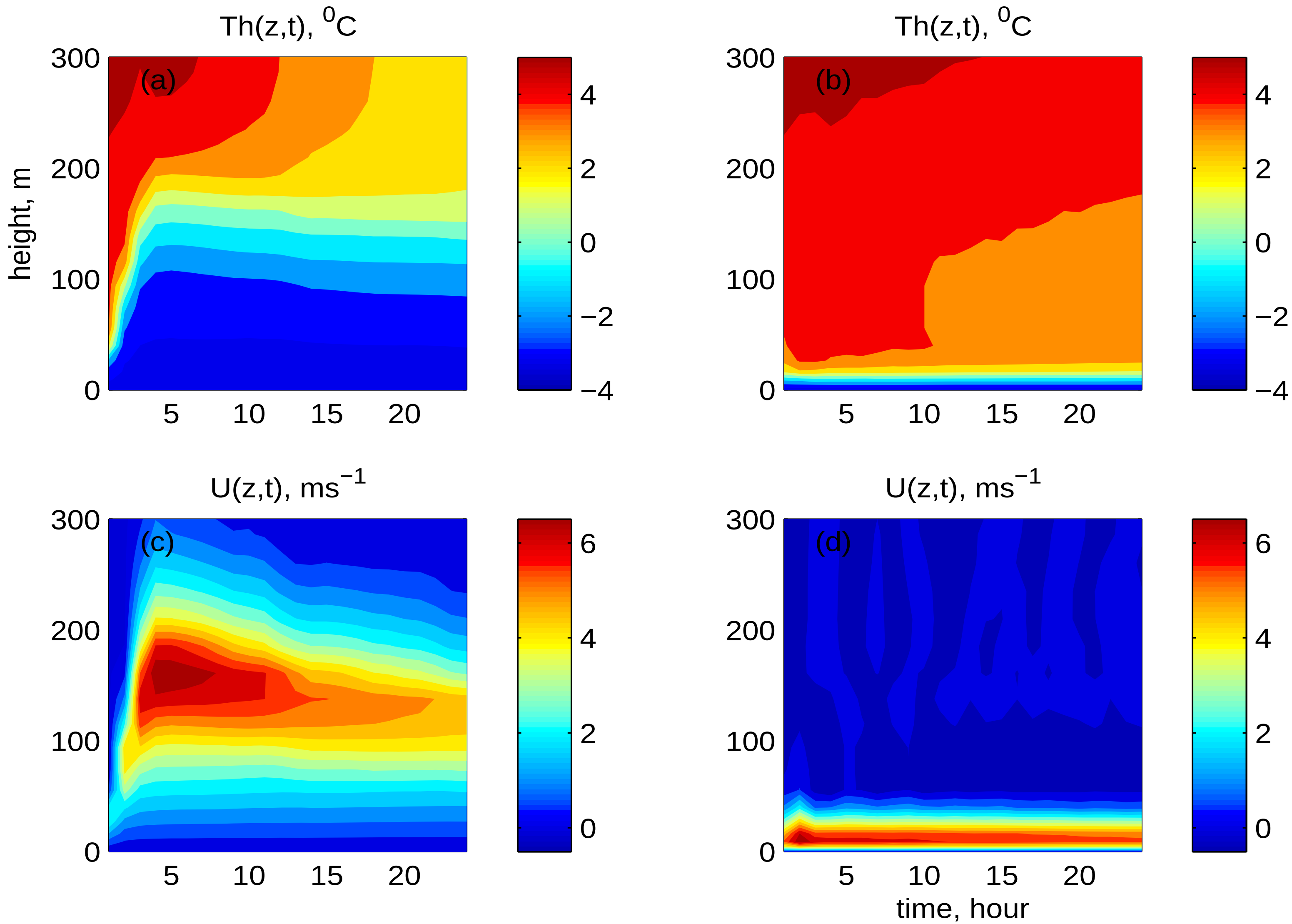
MIUU model's single change

- $\Lambda_{ML} = a\,(TKE)^{1/2} / N$
- Replaced by
- $\Lambda_{ML} = min(\Lambda_{ML},\, b(TKE)^{1/2}/\$)$

$\$ = |S|$; *in B.G. & D.B., QJ'08*

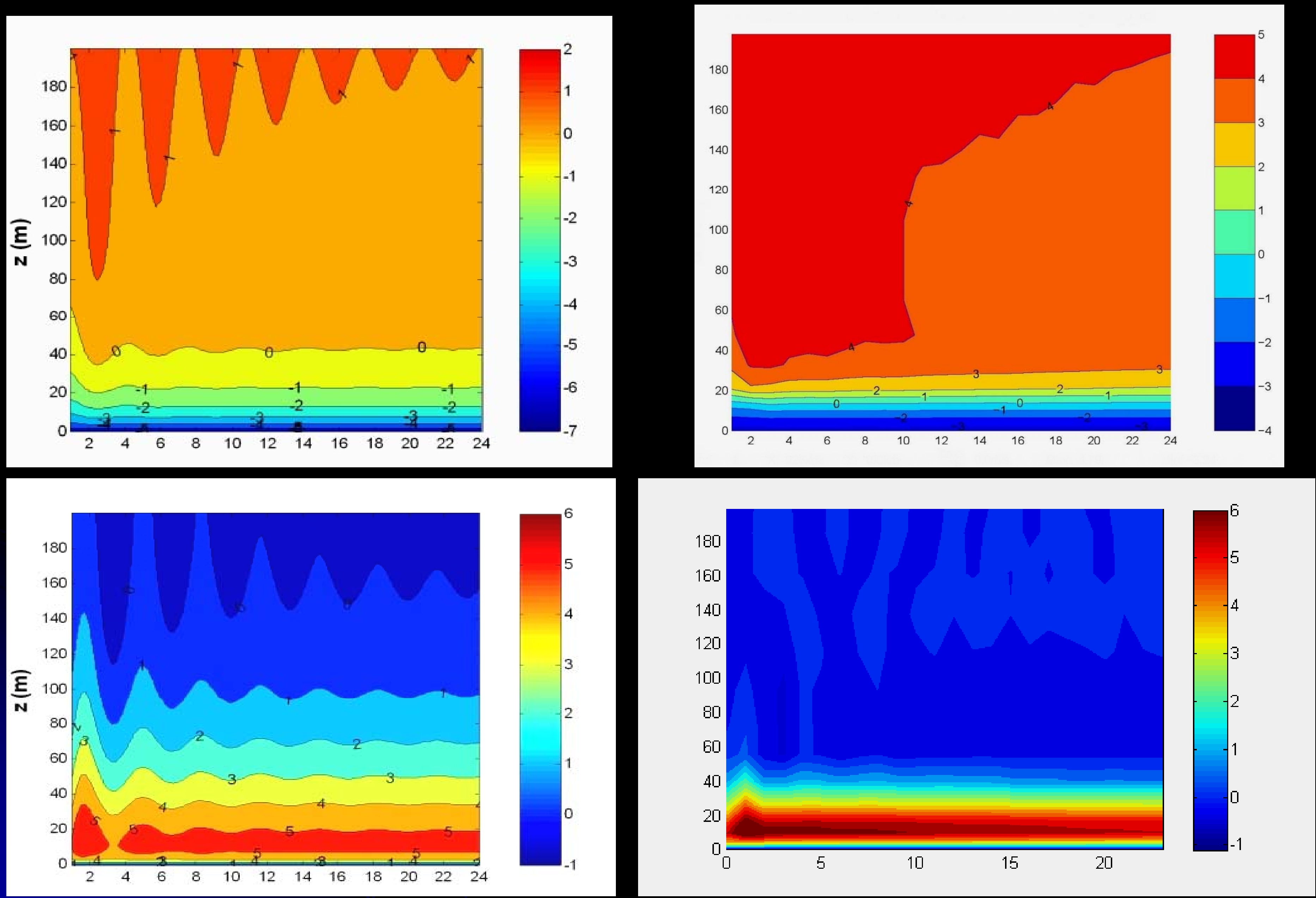
- Results vs. 1) old Λ_{ML}
- Results vs. 2) Prandtl model solution, got '*b*'
- => 3) Generalized Λ_{ML}

Over-diffusive (traditional: a, c) SABL | VSABL (very stable: b, d)



Prandtl model (θ, U)

MIUU model (θ, U)



time, h

Simplified TKE eqn & new generalized Λ

$$\frac{\partial(TKE)}{\partial t} = -\overline{u'w'}\frac{\partial \overline{u}}{\partial z} + \frac{g}{\theta}\overline{w'\theta'} - \frac{\partial}{\partial z}\left[\overline{w'(\frac{p'}{\rho_0} + TKE)}\right] - \varepsilon$$

- If steady, horiz. homog., insignificant transport terms (*3rd on the RHS*), K-parameteriz., Kolmogorov small-scale isotropy where dissipat. takes place:

$$0 = K_m \$^2 - K_h N^2 - \frac{b}{\Lambda}(TKE)^{3/2}$$

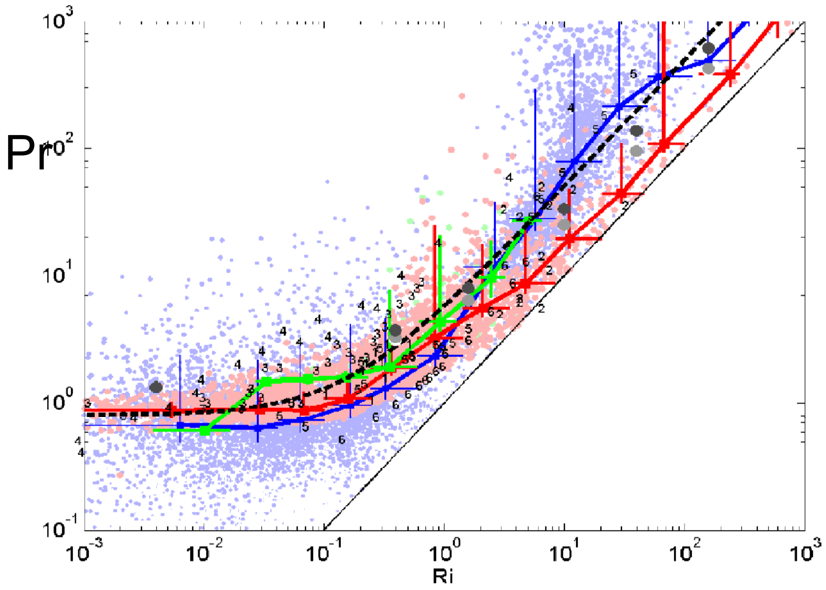
- $K_m = a_1 \Lambda^2 \$$; $= a_2 \Lambda (TKE)^{1/2}$, or $a_3 (TKE/N)$; $K_h = K_m / Pr$

=>

$$\Lambda = const \left(\frac{(TKE)^{1/2}}{\$}\right) f(Ri, \Pr)$$

$$\Lambda = \Lambda_0 \cdot const \cdot f(Ri, \Pr); \quad \Lambda_0 = \sqrt{TKE} \Big/ \$$$

- Zilitinkevich et al., QJ'08: Pr ≈ *0.8 + 5 Ri, f(Ri,* Pr*)* above easy to expand



<- SHEBA & CASES99 (blue), lab (green),

LES (red), DNS (large grey)

- Generalized Mixing-Length Scale, Λ:

$$\Lambda = \Lambda_0 \cdot const \cdot f(Ri, \Pr); \Lambda_0 = \sqrt{TKE} \big/ \$$$

K_m	Λ/Λ_0
$a_1 \Lambda^2 \$$	$(b/a_1)^{1/3} (1 + Ri/(3Pr))$
$a_2 \Lambda(TKE)^{1/2}$	$(b/a_2)^{1/2} (1 + Ri/(2Pr))$
$a_3 (TKE/N)$	$b/a_3 (Ri)^{1/2}(1 + Ri/Pr)$

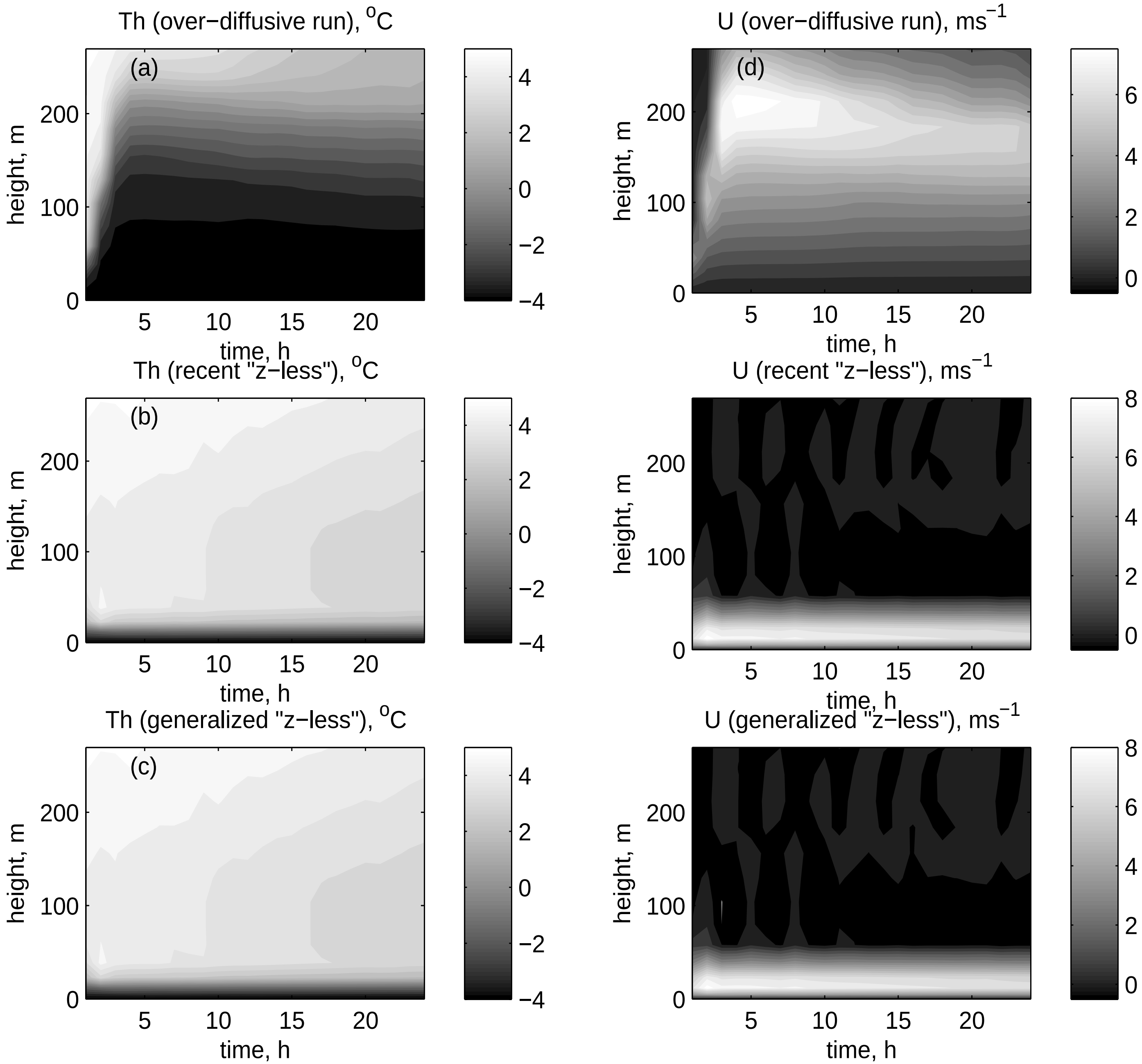
- Advantages: $\delta\$ >> \delta N$, 3-term balance in TKE (instead of only 2 or given a priori)...

Usual:

B.G. & D.B.

QJ'08:

Here:



Further generalization of Λ?

- Trying to include pressure- & turbulence transport terms (the 3rd term in the TKE)

- These terms are notoriously difficult to handle. At this point, we don't have much hope but to treat them with caution – as minor, corrective terms to the already obtained $\Lambda_0 = (TKE)^{1/2} /\$$

(work in progress,.. looking good,.. BW OK too…)

SABL & *Λ* - Conclusions

- Way to improve & generalize "z-less" mixing length *Λ*, maybe L_{MO} too, is offered …

- *Λ* sensitive to minute flow variations, smooth & finite for SABL, even sensitive to waves…

- Refined SABL simulations (for e.g. T_{min}, fog, wind energy, air-pollution studies...; climate scenarios) now more accessible…