Mini-workshop

ABL - Current Problems & Advancements:

The angle of the near-surface wind-turning in weakly stable boundary layers

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OUTLINE

- **INTRO**: motivation/importance & background

  - Cyclones filling, Air-sea interaction, Air-pollution &

  transport, Wind energy estimates, Model validation..

- **RECENT FINDINGS**: research models, LES

  - In idealized conditions: $\alpha_0 \approx 35^0$

- ***NEW ANALYTIC RESULT:*** *in 2 steps α_0 retrieved*

INTRO – Modeling problems

- SBL depth, H, often too high in models
- LLJ often too weak
- excessive cross-isobaric mass flux
- angle between the near-surface & geostrophic wind, α_0, too small;

*Nielsen & Sass'04, Beare et al.'06, Cuxart et al.'06, B.G. & Belušić'08, Svensson & Holtslag'09 (**SH09**), B.G.'10,…*

Background

- **WSBL** ~ stratified **Ekman layer** cooled from below – convenient approach to **WSBL**

Holton, textb.'92:

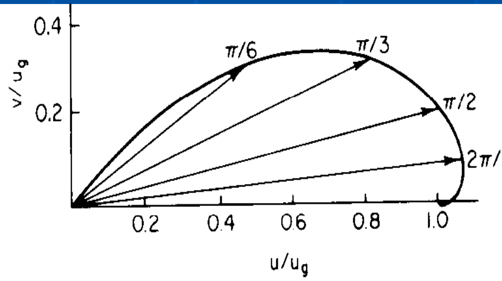
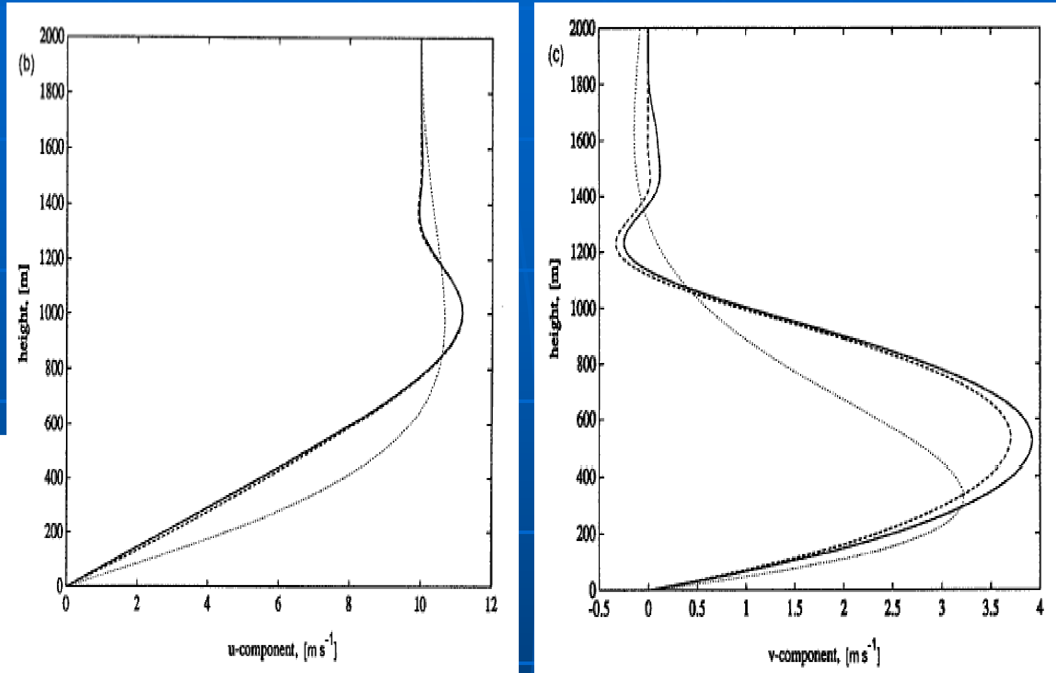


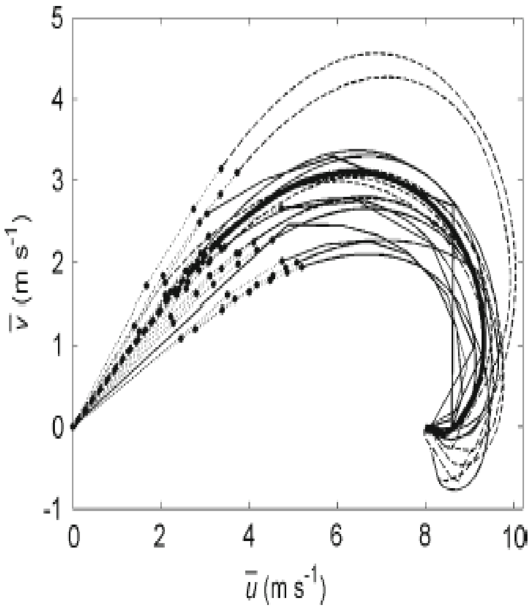
Fig. 5.4 Hodograph of the wind components in the Ekman spiral solution. The arrows show the velocity vectors for several levels in the Ekman layer, while the spiral curve traces out the velocity variation as a function of height. Points labeled on the spiral show the values of γz, which is a nondimensional measure of height.



- *Pedlosky'87, Holton'92, Zilitinkevich et al.'02, Nielsen & Sass'04, SH09*

Numerical modeling of WSBL

Fig. 2 Hodographs for the operational models (*solid lines*), research models (*dashed lines*) and averaged results for LES (*thick solid line*). The surface-layer part (lowest 10%) of the boundary layer is shown as dotted lines and here the larger black dots indicate the various model levels



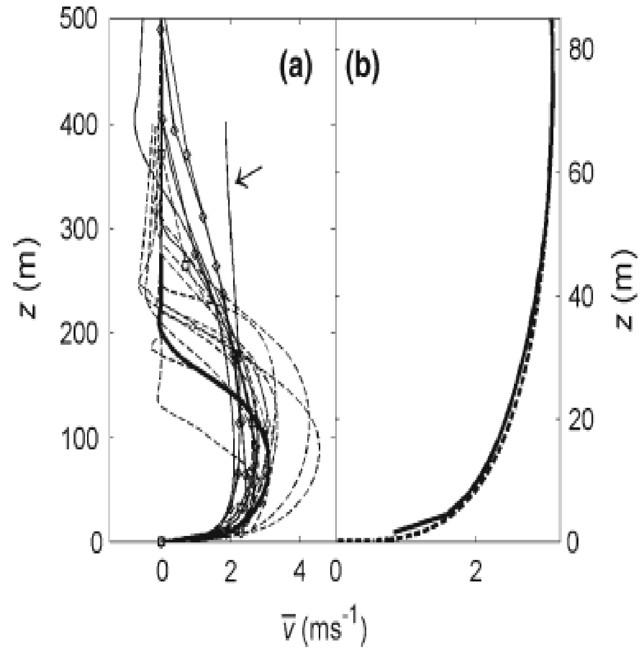


Fig. 5 Cross-isobaric wind component (ms^{-1}) as a function of height (m) for **a** the models in the inter-comparison study, operational models (*thin solid lines*), research models (*dashed lines*) and, averaged LES results (*thick solid line*); **b** Profiles of averaged LES results (*thick solid line*) and by expression (8) (*dashed line*) for the lower part of the SBL. Most models are run with a grid resolution of 6.25 m but a few used their operational grid (grid levels shown with symbols for these models). One of the model results discussed in the text is indicated with an *arrow*

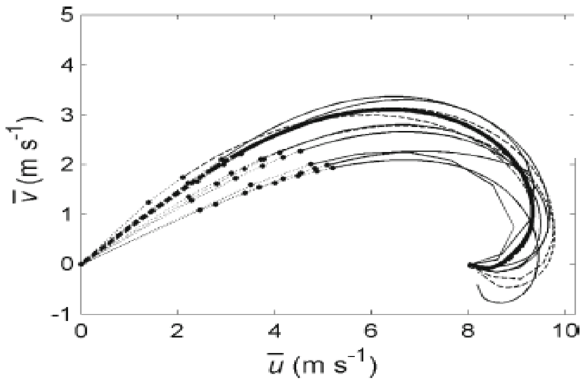


Fig. 10 Similar as in Fig. 2 for the models after selection

- ***SH'09*** ← *Cuxart et al.'06; 19 models in GABLS inter-comparison study*

Modeling of WSBL – cont'd

Fig. 6 The angle between the surface wind and the geostrophic wind plotted against the boundary-layer height (m, for definition see the text). Symbols as in Fig. 4

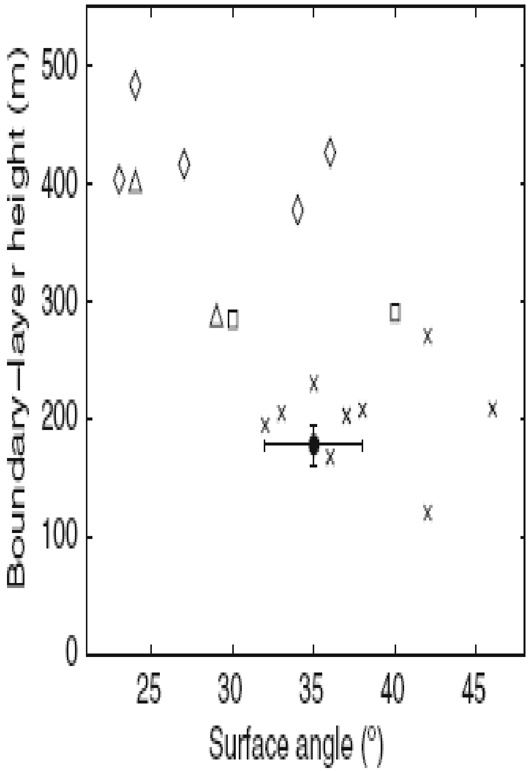
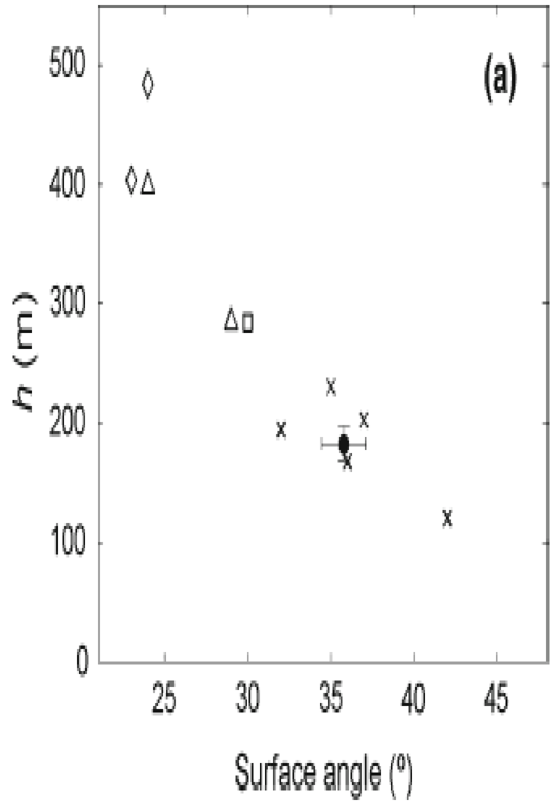


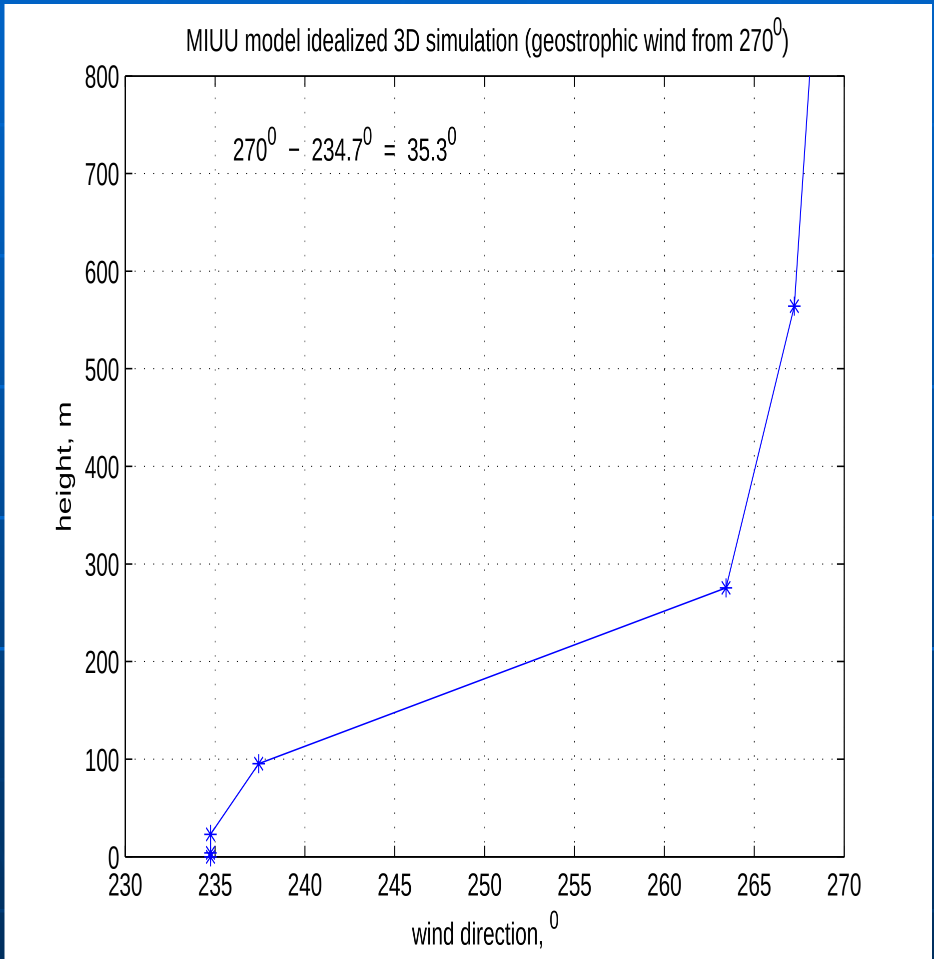
Fig. 9 a Similar as Fig. 6 for the models after selection. b Similar as Fig. 9a but boundary-layer depth normalised by the Obukhov length. See text for further discussion



- ***SH'09*** *← Cuxart et al.'06 ⇔ $\alpha_0 \approx 35^0$ based on* ***LES:***

Operational with 1st order closure = diamonds, with HOC = triangles; res. models 1st ord. closure = squares, with HOC = x; averaged LES (with st.dev.) = filled circle with error bars

Models, limited obs. & classic Ekman layer:



$H_{WSBL} \approx 250m$

(finer z-resol. → $H_{WSBL} \approx 200m$)

- *van Ulden and Holtslag'85 from* ***Cabauw tower data*** *got $a_0 \approx 35^0$*
- *Classic Ekman layer ⬄ Limit: z → 0 yields … $a_0 \approx 45^0$! (too large)*
- *Here goes this contrib. to the subject*

CLASSIC EKMAN LAYER (CEL)

$$0 = f(v - v_g) - \frac{\partial}{\partial z} < u'w' >$$

$$0 = -f(u - u_g) + \frac{\partial}{\partial z} < v'w' >$$

$$\ldots \Rightarrow \; fv = \frac{\partial}{\partial z} < u'w' > \ldots \Rightarrow$$

$$fH\bar{v} = - < u'w' >_0 = u_*^{\,2} \cos(\alpha_0)$$

$$\Rightarrow H = \frac{u_*^{\,2} \cos(\alpha_0)}{f\bar{v}} = BL_{TOP}$$

$$\ldots y - dir \ldots mass - flux :$$

$$\rho_0 \int_0^H v dz = \rho_0 u_*^{\,2} \cos(\alpha_0) \Big/ f$$

* *Small modeled α_0 => (too) large H, (excessively) large cross-isobaric mass flux (note <u'w'> shouldn't ~ (-z) ⬄ mean(v)=const!)*

* *Meanwhile, **CEL's** $\alpha_0 = 45^0$ (too large)*

Improve the Ekman layer analytic estimate for α_0 - 2 steps used -

$z_{=0} \rightarrow z_S$; $K \rightarrow K(z)$

before:

$$\tan(\alpha_0) = \frac{v_0(z_S)}{u_0(z_S)} =$$

$$= Lim_{z\to 0} \frac{e^{-I(z)}\sin(I(z))}{1-e^{-I(z)}\cos(I(z))}$$

$$= Lim_{z\to 0}[1 - I(z) + \ldots] = 1$$

$$with\ : I(z) = z\left(\frac{f}{2K}\right)^{1/2}$$

$$\Rightarrow \alpha_{0,CEL} = 45^0$$

- Now:

$$\tan\alpha_0 = Lim_{z\to z_S} \frac{e^{-I(z)}\sin I(z)}{1-e^{-I(z)}\cos I(z)}$$

$$\tan\alpha_0 \approx 1 - I(z_S) + \frac{2}{3} I(z_S)^2 + \ldots$$

$$\tan\alpha_0 \approx P_2(I(z_s))$$

$$I(z_S) = \sqrt{f}\int_0^{z_S}\frac{dz}{\sqrt{2K(z)}}$$

$$Min: P_2(I(z_s)) = ? \Rightarrow 45^0 \rightarrow \ldots \sim 35^0$$

Choice of K(z) … Sfc. Layer Thickness: $l(z_S)$ … relate h & z_S

$$K(z) = K_0 \frac{z}{h} \exp[-0.5(z/h)^2]$$

$$\Rightarrow \ldots D - less:$$

$$l(z) = \sqrt{\frac{fh}{2K_0} \int_0^z \frac{\exp(\frac{z}{2h})^2 dz}{\sqrt{z}}}$$

$$l_a(z_S) \approx \sqrt{\frac{2af}{K_0}} z_S$$

$$with$$

$$h \approx az_S, \sim 4 \le a \le 6$$

- *Minimized $P_2(l(z_S)) \rightarrow \alpha_0$*

$\approx 32^0$ …

$$use:$$

$$mean(H) \approx 200 - 300m,$$

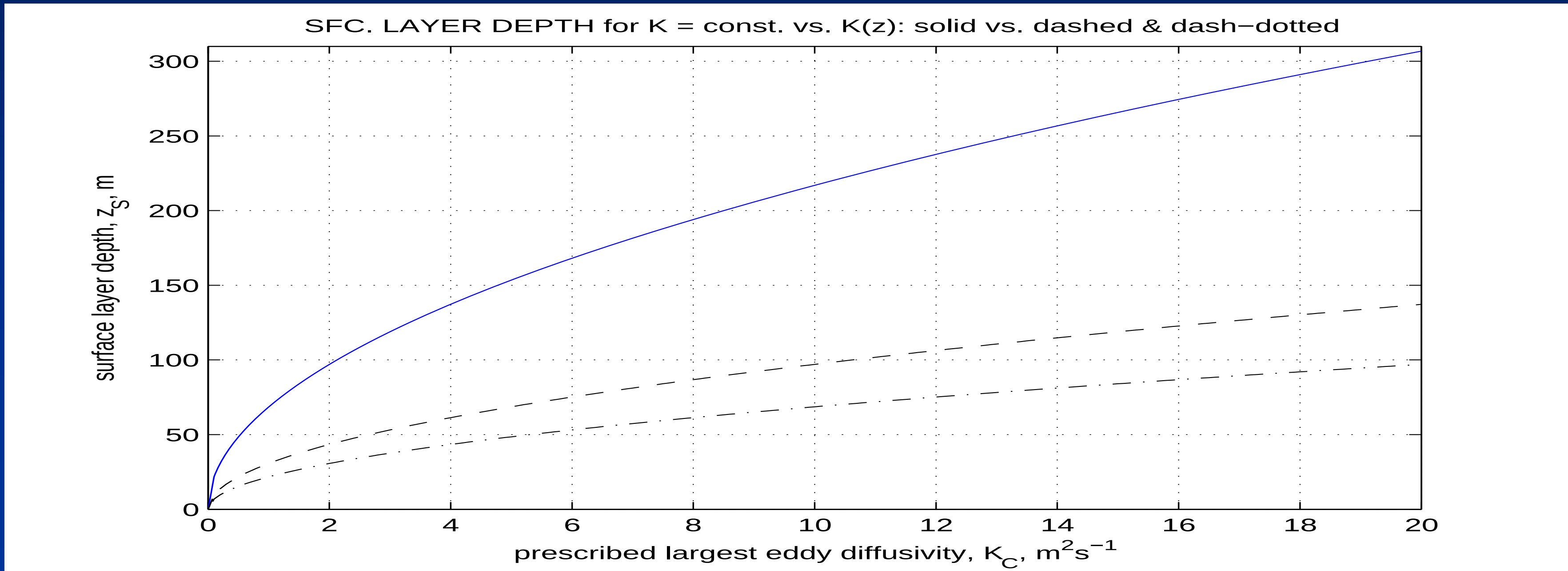
$$z_S < h < H \Rightarrow h \approx 100 - 150m$$

$$1 \le K_0 \le 20m^2 s^{-1}$$

EXAMPLES:

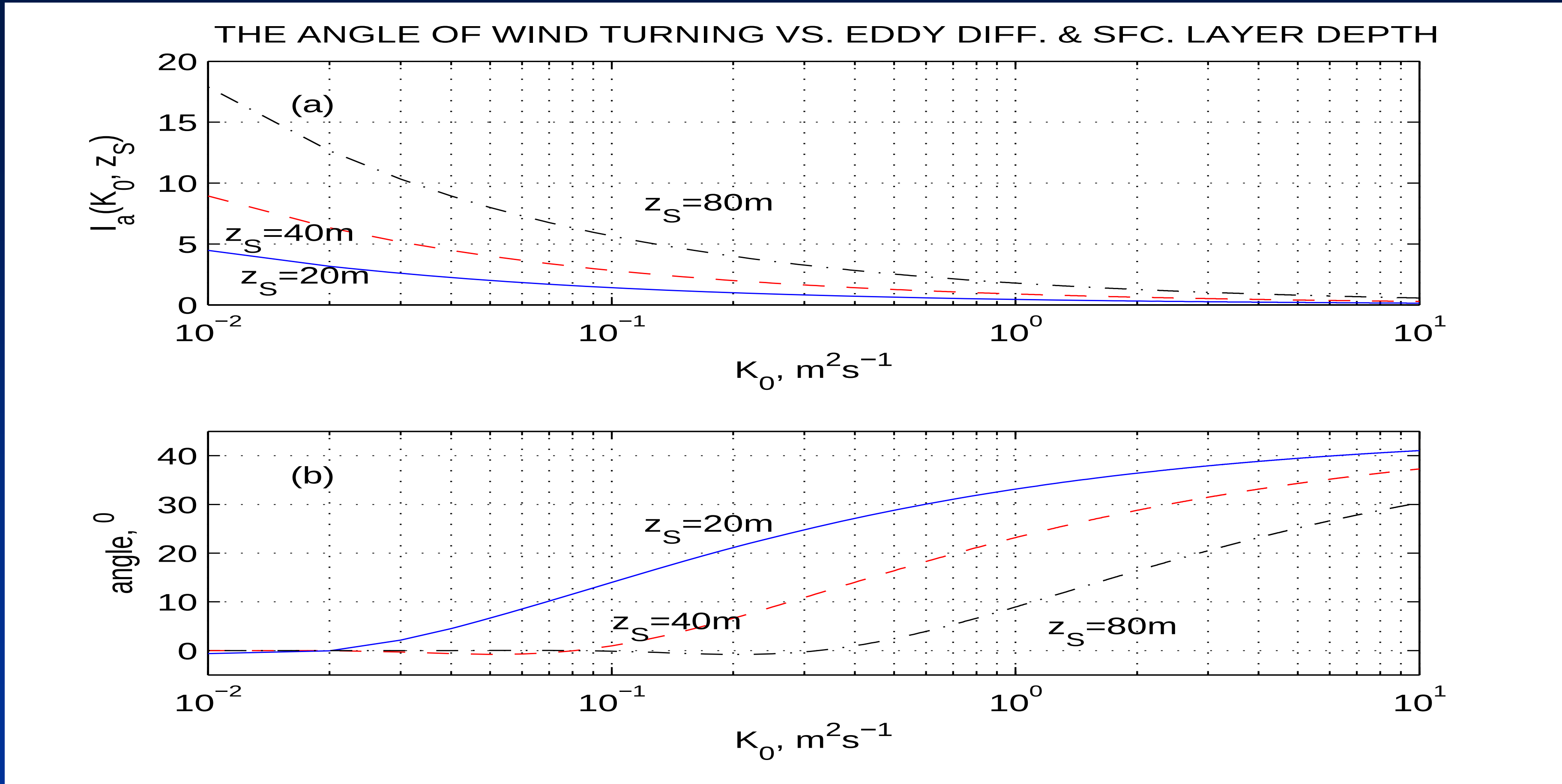
- $(f, K_0, h, z_S) = (10^{-4}\ s^{-1}, 5\ m^2s^{-1}, 150\ m, 30\ m), I(z_S) \approx 0.75$

$\Rightarrow \alpha_0 = \alpha_{0,NEW\ ANALYTIC} \approx 32^0$



$I_{MIN}(z_S) = 0.75 = [f/(2K_C)]^{1/2}z_S$ (const., solid), $I_{MIN}(z_S) = 0.75 \approx I_a(z_S) \approx [2af/K_0]^{1/2}z_S$

=D-less sfc. layer depth (dashed & dash-dotted), $h = az_S$, $a = 5$, $K_0 = 4K_C$ (dashed), $K_0 = 2K_C$ (dash-dotted)



$I_a(K_0,z_S)$ and α_0 plotted for 3 different sfc. layer depths: *20*, *40* and *80 m* (solid, dashed and dash-dotted); $I_a(K_0,z_S)$ → *exact* $tan(\alpha_0) = v(z_S)/u(z_S)$, *not the approx.* $P_2(I(z_S))$.

References (without 2 textbooks, *main ref's in yellow*):

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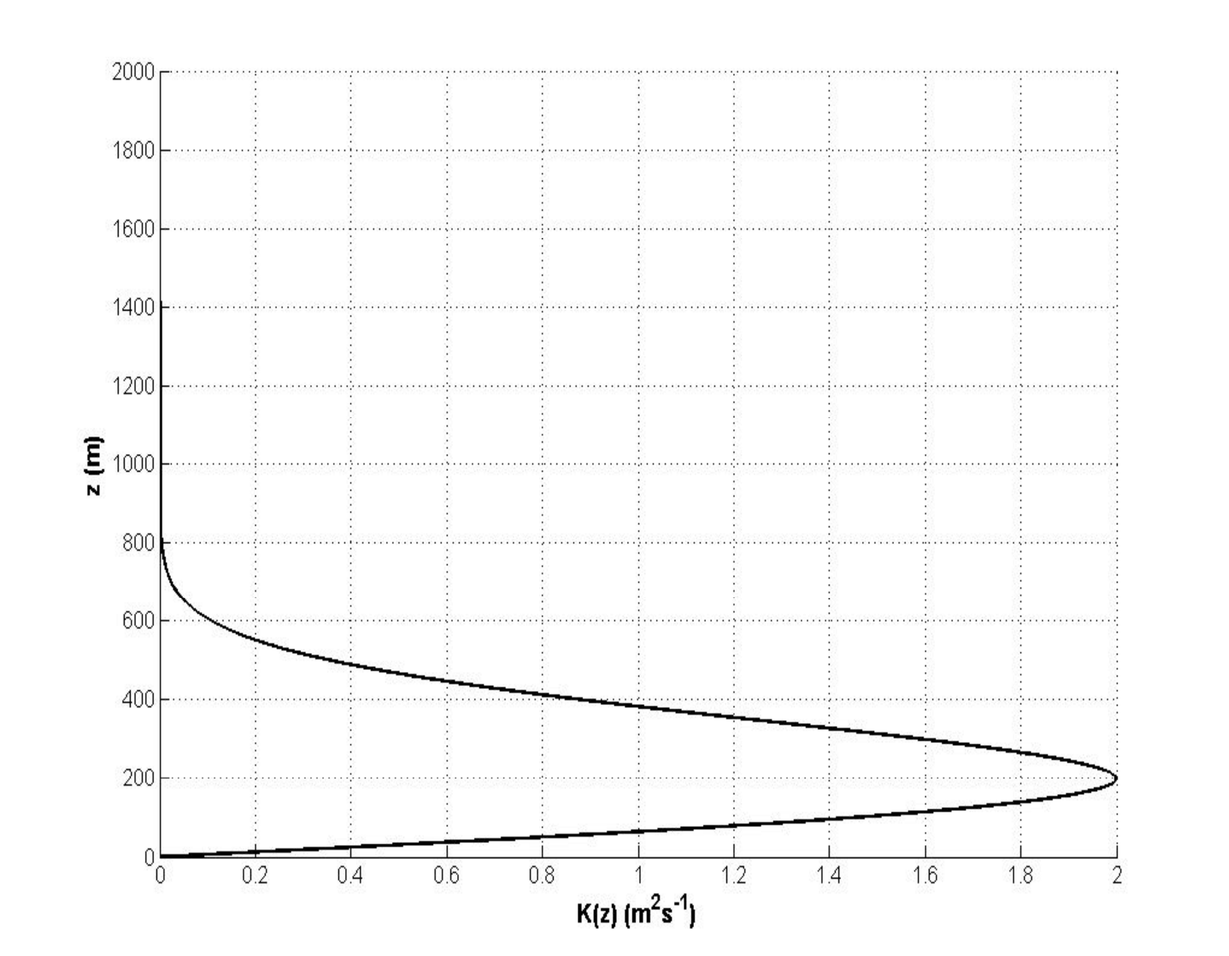
APPENDIX-DISCUSSION?

- *If discussion desires, continue …*
- *Otherwise, take on Larry's smile…*
- *& Let the others continue …*
- *Who said 'lunch'.?..*

- ***K(z)* profile:**

$$K(z) = K_{max}\sqrt{e}\,\frac{z}{h}\exp\left(-\frac{z^2}{2h^2}\right)$$



K(z) for numerical & analytical solutions, only 2 parameters!

e.g.

$\boldsymbol{K_{max} = 2\ m^2s^{-1}}$,

$\boldsymbol{h = 200\ m}$,

(JAS 2001, QJ2001,...)