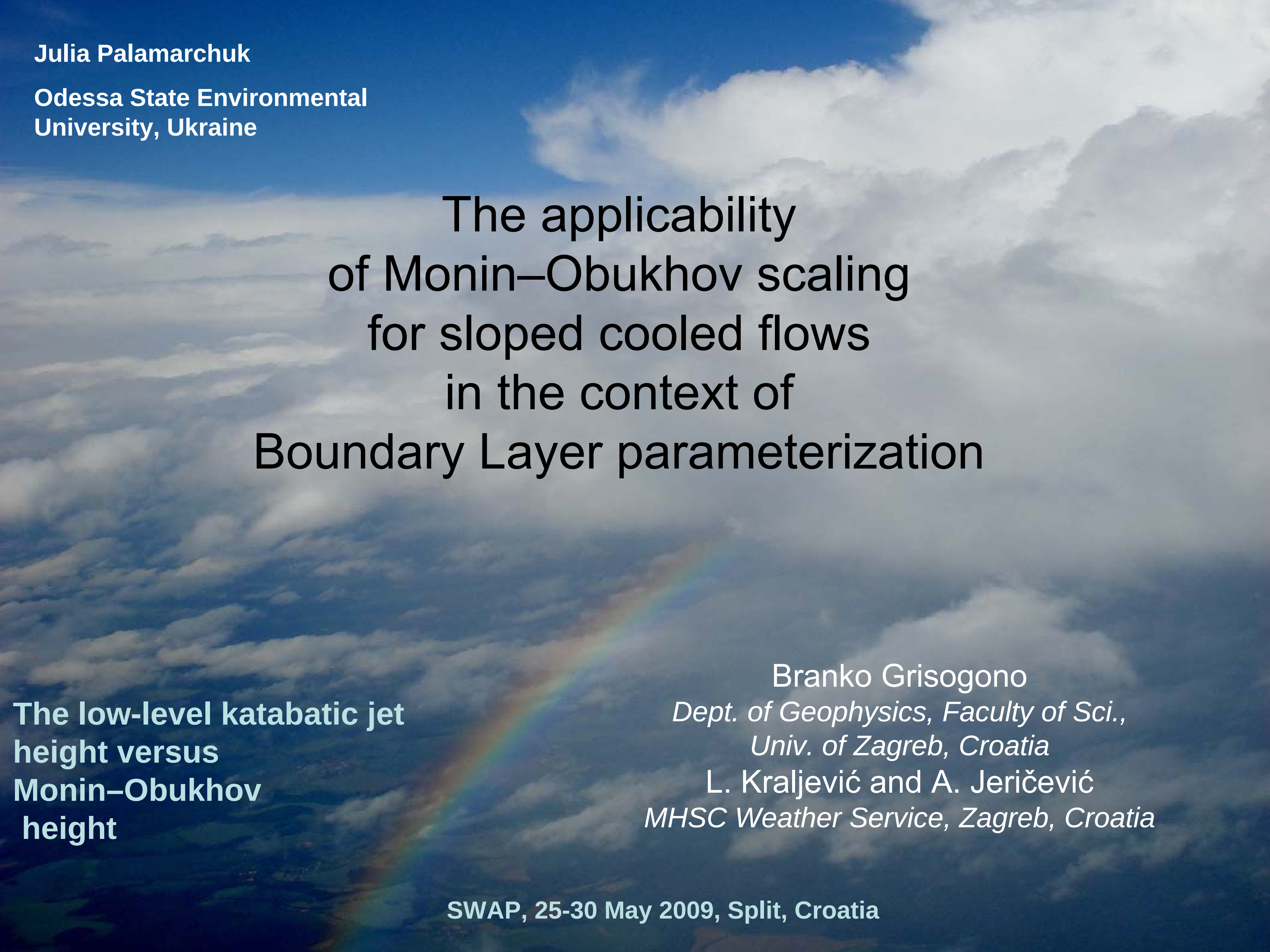

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The applicability of Monin–Obukhov scaling for sloped cooled flows in the context of Boundary Layer parameterization

The low-level katabatic jet height versus Monin–Obukhov height

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SWAP, 25-30 May 2009, Split, Croatia

Outline

Overview of ABL(PBL) parameterization :

- importance for describing ABL
- general approaches in modeling
- problems

SABL (VSABL)

- nature and modeling features
- Monin-Obukhov height (*L)* and the low-level jet (LLJ) height

Conclusions

Background & overview

stable boundary layers are still not well understood.

turbulence can be of different nature and properties than that generated over nearly-horizontal surfaces.

Monin-Obukhov length, *L*,
for parameterizing near-surface turbulent fluxes is widely used in NWP etc.,
but still questionable for katabatic flows.

for estimating z_j used the Prandtl model (Prandtl, 1942; Defant, 1949).

Baklanov and Grisogono, 2007
Banta, 2008
Cuxart and Jiménez, 2007;
Grisogono and Belušić, 2008
Grisogono and Oerlemans, 2001;
Jeričević and Grisogono, 2006
Kim and Mahrt, 1992;
King et at., 2001;
Mahrt,1998, 2007, 2008;
Mauritsen et al., 2007;
Steeneveld et al., 2007;
Söderberg and Parmhed, 2006;
Van der Avoird and Duynkerke, 1999;
Zilitinkevich et al., 2008
Zilitinkevich and Esau (2007)
. . . .

The sources of errors in NWP

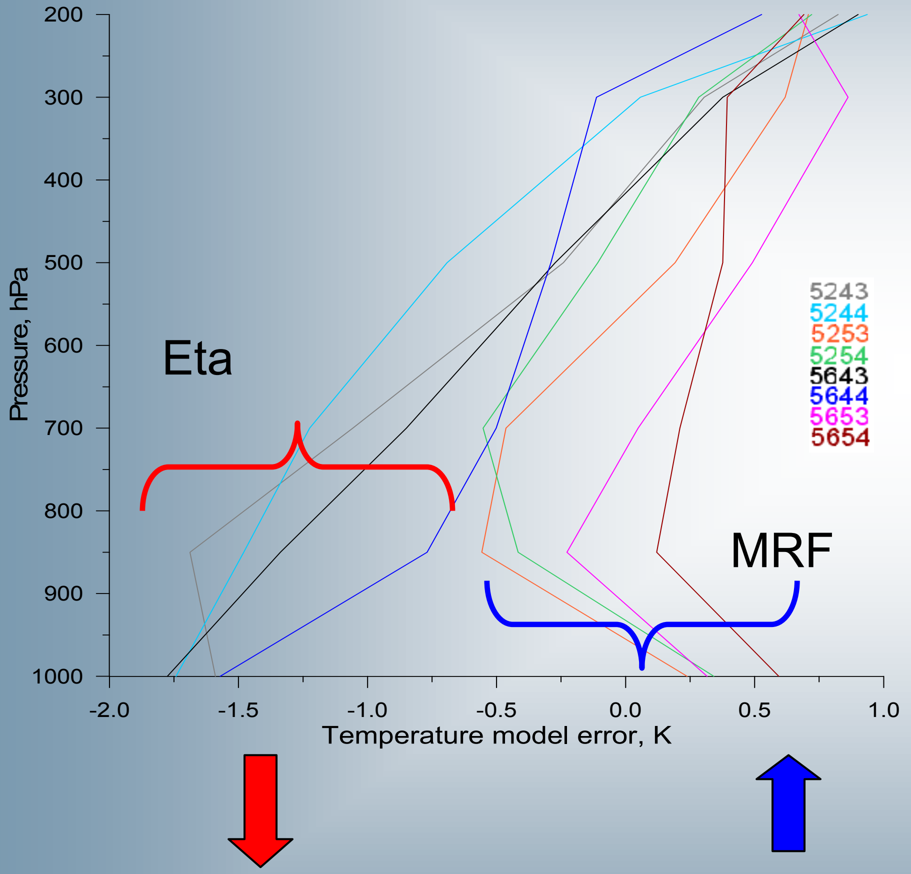
1. The initial conditions
- Observations
  - Instrumental errors
  - Representativeness errors
- Data assimilation
  - Observational operators
  - Assimilation methods

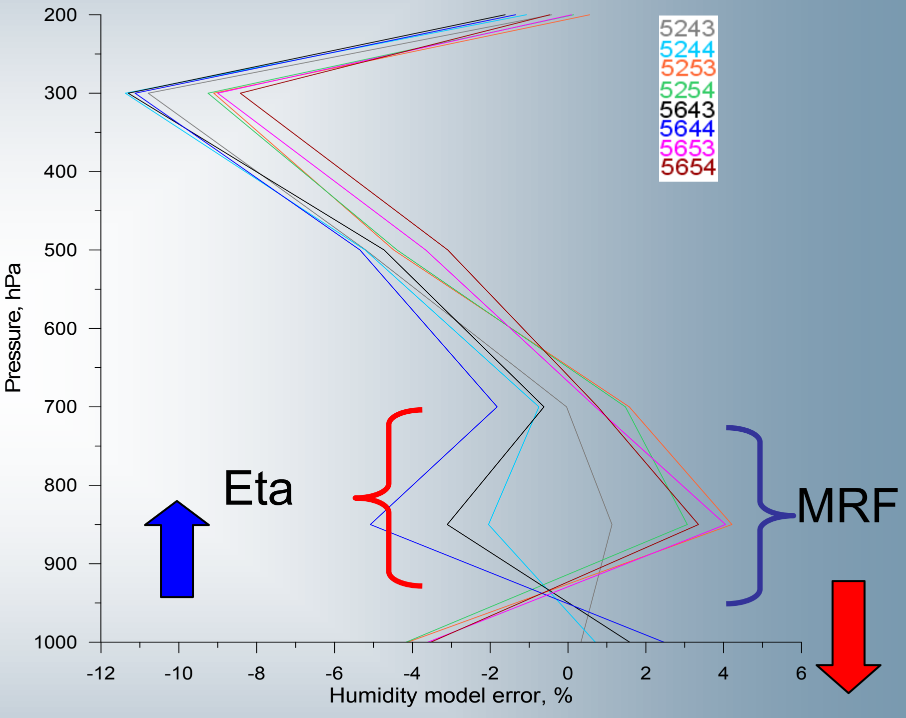
2. **The model formulation**
- Physical and dynamical options
  - Governing equations
  - Parameterization schemes
- Technical options
  - Numerical schemes
  - Resolution

* A big challenge to separate a contribution from each source

Vertical profiles of the systematic error

of temperature and relative humidity

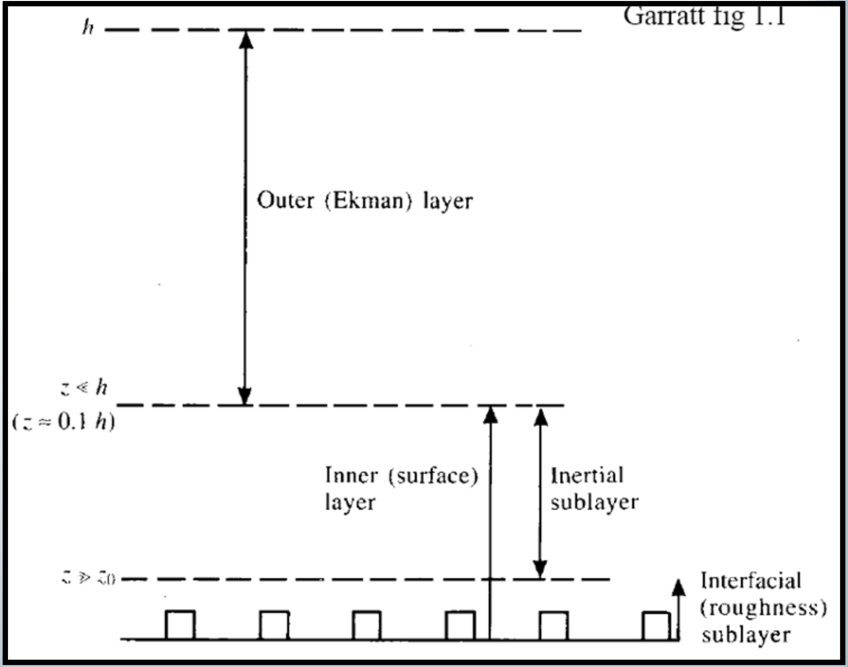




Here compared model (MM5*v3.7)* fields against reanalysis ERA40 for the winter season of 2002 over the North Atlantic and Europe on a coarse resolution grid (81 km).

Atmospheric (Planetary) Boundary Layer

Large diurnal temperature variations
Turbulence (owing to thermal forcing,
vertical/horizontal wind shear)
Gravity waves
Spiraling Winds
Katabatic (drainage) Winds
Nocturnal Jet
Clouds (Fair weather cumulus, trade cumulus
stratocumulus clouds)
Fog


Garratt fig 1.1

Kinds of ABL

Convective	[Ri < 0]
Near-Neutral	[Ri ≈ 0]
Stable (very stable BL)	[Ri >> 1]

Marine/continental ABL
(according to surface properties)

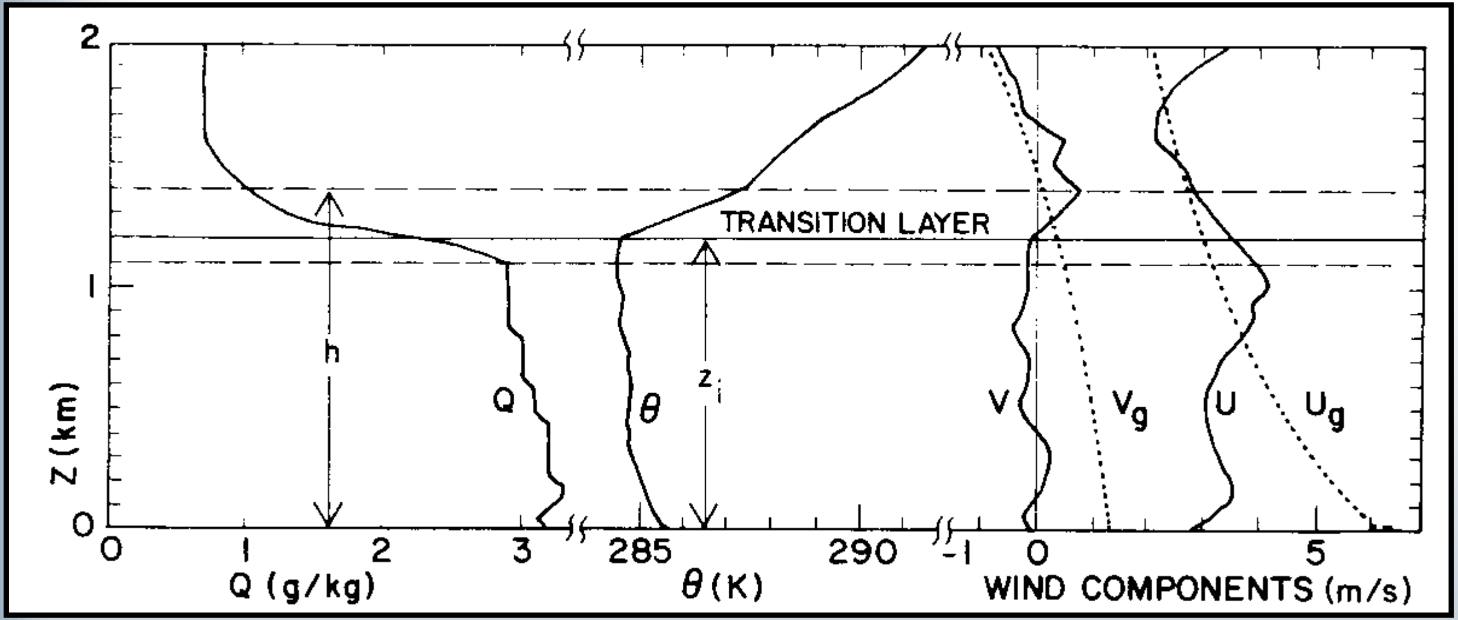
Zilitinkevich and Esau (2007)

- truly neutral (TN) ABL: $F_* = 0$, $N = 0$,
- conventionally neutral (CN) ABL: $F_* = 0$, $N > 0$,
- nocturnal stable (NS) ABL: $F_* < 0$, $N = 0$,
- long-lived stable (LS) ABL: $F_* < 0$, $N > 0$.

$\boldsymbol{F_*}$ - potential temperature flux at the surface,
$\boldsymbol{N}$ - Brunt-Väisälä frequency

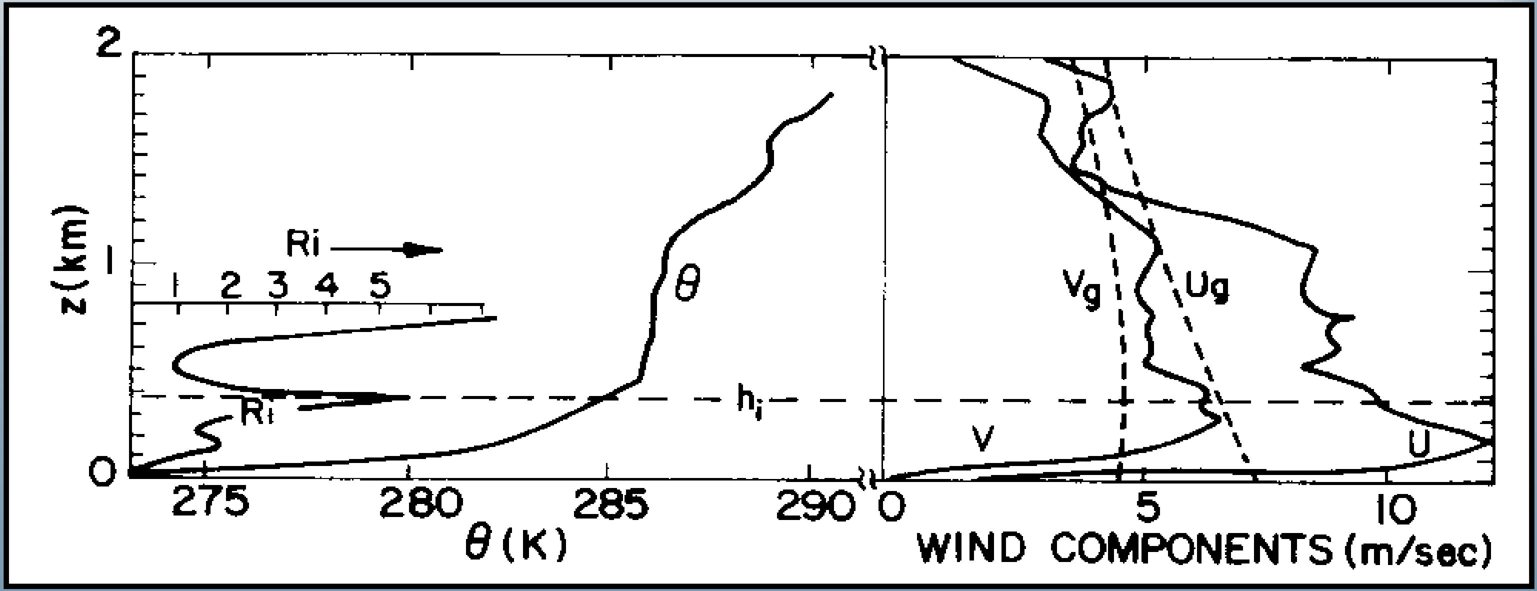
Measured profiles in PBL under convective (a) and very stable (b) conditions

from Deardoff (1978)



a)

b)



Reynolds averaging

$$a = \overline{a} + a'$$

a' fluctuating part or perturbation

$\overline{a}$ ensemble mean

$$\overline{\frac{Da}{Dt}} = \overline{\frac{\partial a}{\partial t}} + \nabla \cdot \overline{\mathbf{u}a}$$

$$= \frac{\partial}{\partial t}\bar{a} + \frac{\partial}{\partial t}\overline{a'} + \frac{\partial}{\partial x}\overline{(\bar{u} + u')(\bar{a} + a')} + \frac{\partial}{\partial y}\overline{(\bar{v} + v')(\bar{a} + a')} + \frac{\partial}{\partial z}\overline{(\bar{w} + w')(\bar{a} + a')}$$

$$= \frac{\partial}{\partial t}\bar{a} + \nabla \cdot \bar{\mathbf{u}}\bar{a} + \frac{\partial}{\partial x}\overline{u'a'} + \frac{\partial}{\partial y}\overline{v'a'} + \frac{\partial}{\partial z}\overline{w'a'}$$

General approaches in parameterization of ABL

Mixed layer models

$\bar{u}, \bar{v}, \bar{\theta}$ → uniform

'Local' closures based on eddy diffusivity (K-theory)

$$\overline{w'a'} = -K_a \frac{d\bar{a}}{dz}$$

- **First-order closure**, K_a is specified from the vertical shear and static stability, or by prescribing ***a***
- **1.5-order closure** or **TKE closure**, TKE is predicted with a prognostic energy equation, and K_a is specified using the TKE and some lengthscale.
- ***K*-profiles**, a specified profile of K_a is applied over a diagnosed turbulent layer depth.

'Nonlocal' closures

explicit model the effects of boundary layer filling eddies in some way.

Horizontal turb. fluxes neglected

TKE budget equation

De/Dt = S + B + T+ D

S = shear production;
B = bouyancy flux;
T = transport + pressure work;
D = dissipation

$$S = -\overline{u'w'}\frac{\partial \bar{u}}{\partial z} - \overline{v'w'}\frac{\partial \bar{v}}{\partial z}$$

$$B = \overline{w'b'}$$

$$T = -\frac{\partial}{\partial z}\left(\overline{w'e'} + \frac{1}{\rho_0}\overline{w'p'}\right)$$

$$D = -\ \nu\overline{|\nabla\times\mathbf{u}|^2}$$

The **flux Richardson number**

$Ri_f = -B/S$

characterizes whether the flow is
stable ($Ri_f > 0$), neutral ($Ri_f \approx 0$), or unstable ($Ri_f < 0$).

Problems in description of PBL

- PBL datasets (impacts of vertical advection, averaging time, stationarity, measurement height, site homogeneity, vertical alignment of the sensors, flow distortion).

- Spatial averaging of turbulent fluxes.
- In CABL cells and rolls in the shea rfree and sheared regimes, (respectively not well understood).

- Marine ABL constrained waters, coastal areas and lakes.
- Surface turbulent fluxes of momentum,heat and water vapour over the sea.
- The gas and particle exchange between the atmosphere and ocean

- Complex (sloping) surfaces
- Monin–Obukhov similarity theory unsatisfactory

(over complex terrain, inadequately strongly stable and strongly unstable stratification regimes)

General definition of L_{MO} and z_j

$$L_{MO} = -\frac{\overline{\theta}}{gk} \cdot \frac{u_*^3}{\overline{w'\theta'}} \qquad z_j = \frac{\pi}{4}\left(\frac{4K^2 \Pr}{N^2 \sin^2(\alpha)}\right)^{1/4}$$

$$Ri = \frac{N^2}{\left(\partial U / \partial z\right)^2}$$

near-surface momentum flux

$$u_*^{\,2} = K \Pr \frac{\partial U}{\partial z}$$

heat flux

$$-\overline{w'\theta'} = K \frac{\partial \Theta}{\partial z}$$

Pr – Prandtl number

Ri – Richardson number

g – gravity acceleration

k – von Karman const.

N – buoyancy frequency

U – mean wind spead

K – eddy heat conductivity

$\overline{w'\theta'}$ - near-surface heat flux

u_* - friction velocity

$\overline{\theta}$ - relevant potential temperature

α - const. slope angle

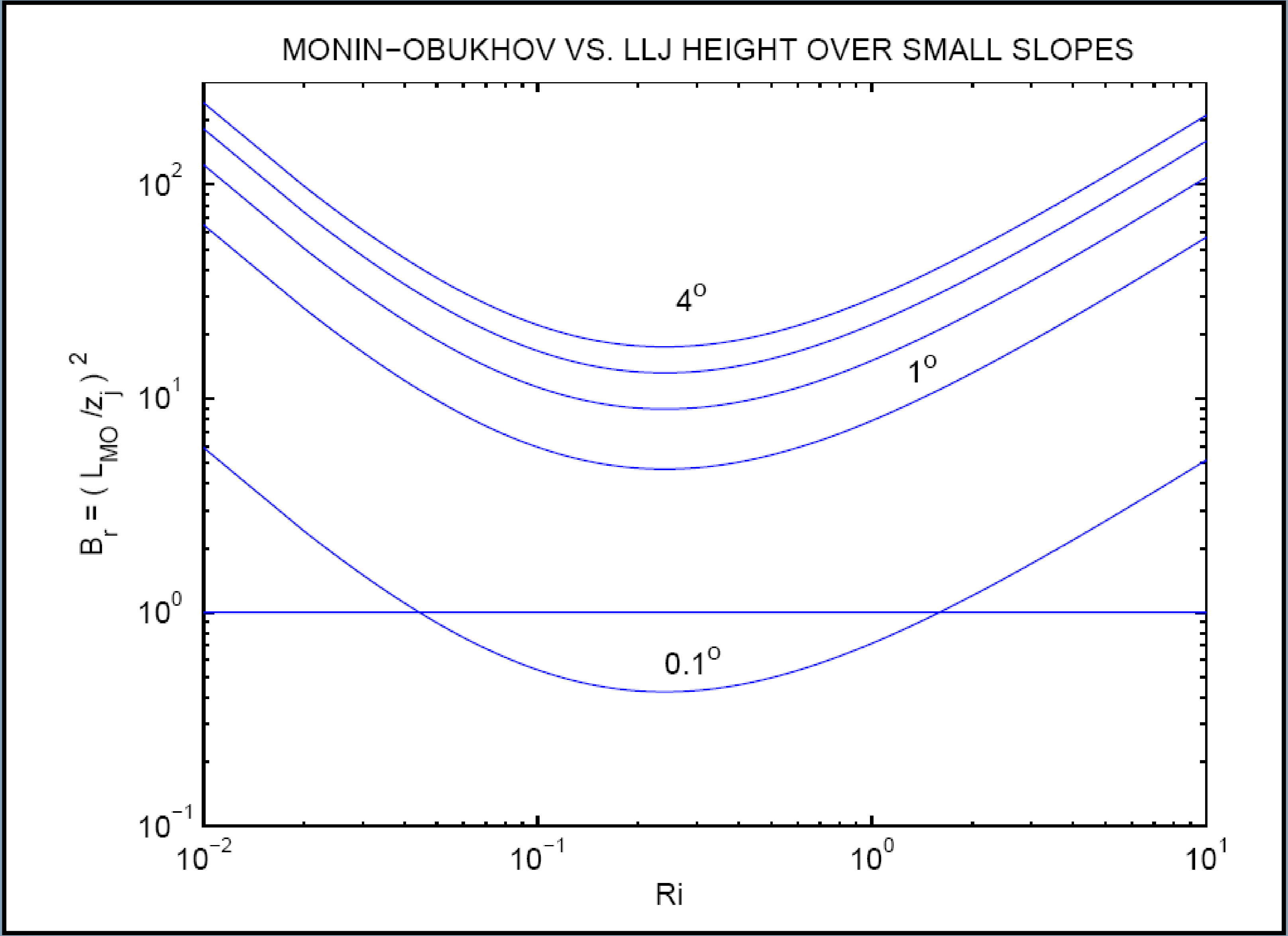
1

$$\left({}^{L_{MO}}\!\!\Big/_{z_j}\right)^2 = br = \frac{8}{(k\pi)^2}\,|\sin(\alpha)|\,\left(\frac{\Pr^5}{Ri^3}\right)^{1/2}$$

$$Pr \approx 0.8 + 5\ Ri$$

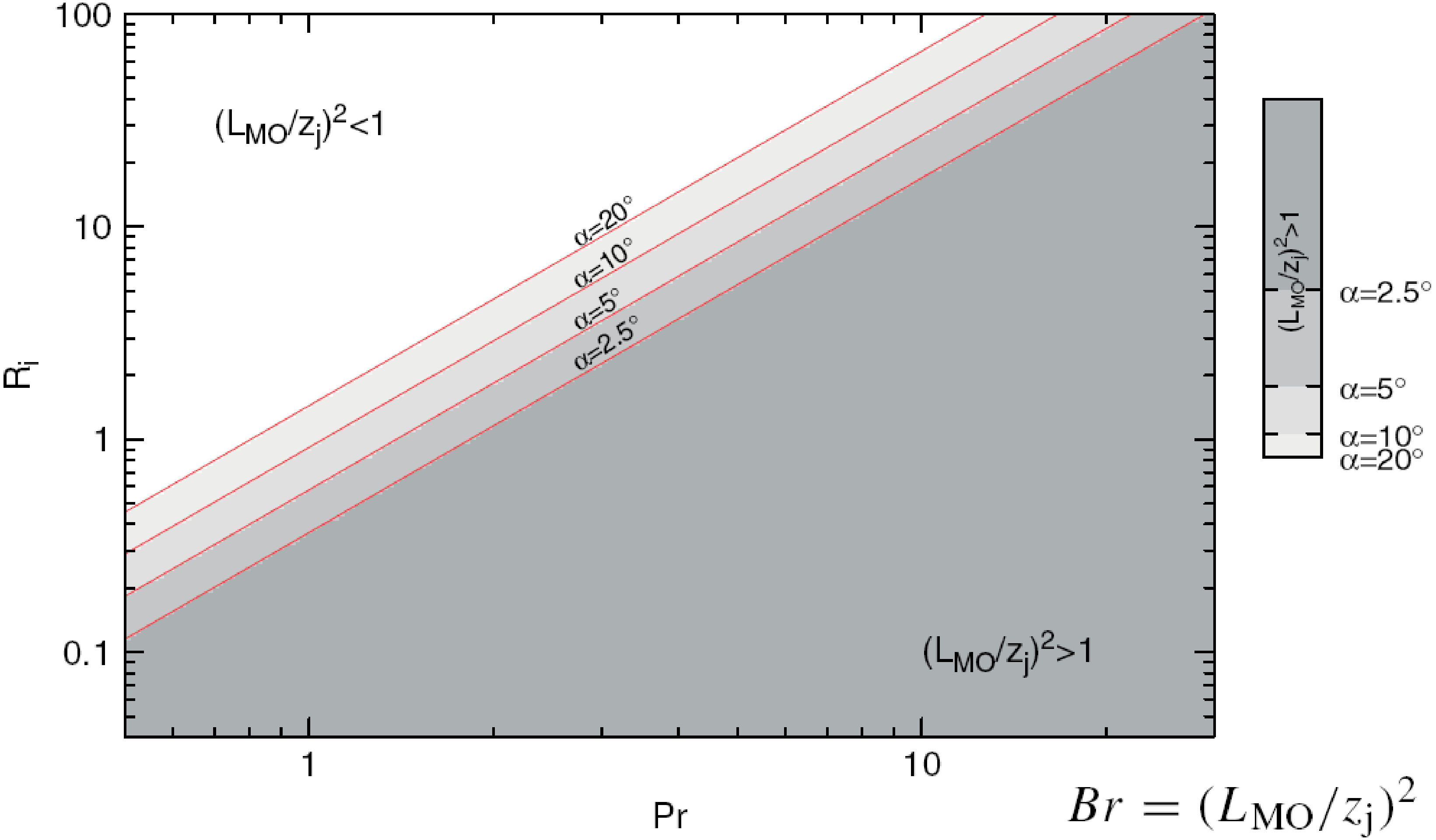
2

$$\left({}^{L_{MO}}\!\!\Big/_{z_j}\right)^2 = br = \frac{8}{(k\pi)^2}\,|\sin(\alpha)|\,\left(\frac{(0.8+5Ri)^5}{Ri^3}\right)^{1/2}$$


MONIN−OBUKHOV VS. LLJ HEIGHT OVER SMALL SLOPES
$B_r = (L_{MO}/z_j)^2$
10^{-1}
10^{0}
10^{1}
10^{2}
Ri
10^{-2}
10^{-1}
10^{0}
10^{1}
4°
1°
0.1°

k = 0.4, *L* = L_{MO}

LOW-LEVEL KATABATIC JET HEIGHT



$$Br = (L_{\text{MO}}/z_{\text{j}})^2$$

Possible including L_{MOD}

3

$$L_{MOD} = min(L,\ C_0\, z_j)$$

4

$$\frac{1}{L_{MOD}} = \frac{c}{L} + \frac{d}{z_j}$$

c, d should be obtained from measurements

$0.7 < C_0 \leq 0.9$

Conclusions

The Monin-Obukhov scaling becomes inadequate to describe the lower part of sloped stably-stratified boundary layers dynamics.

For refining horizontal resolution in numerical models, *L* should accommodate slope effects on the near-surface turbulent fluxes.

It requires more testing and model comparisons using very high vertical resolution against various data sets.

Thanks

for your
attention !