Stable Boundary Layers over Land

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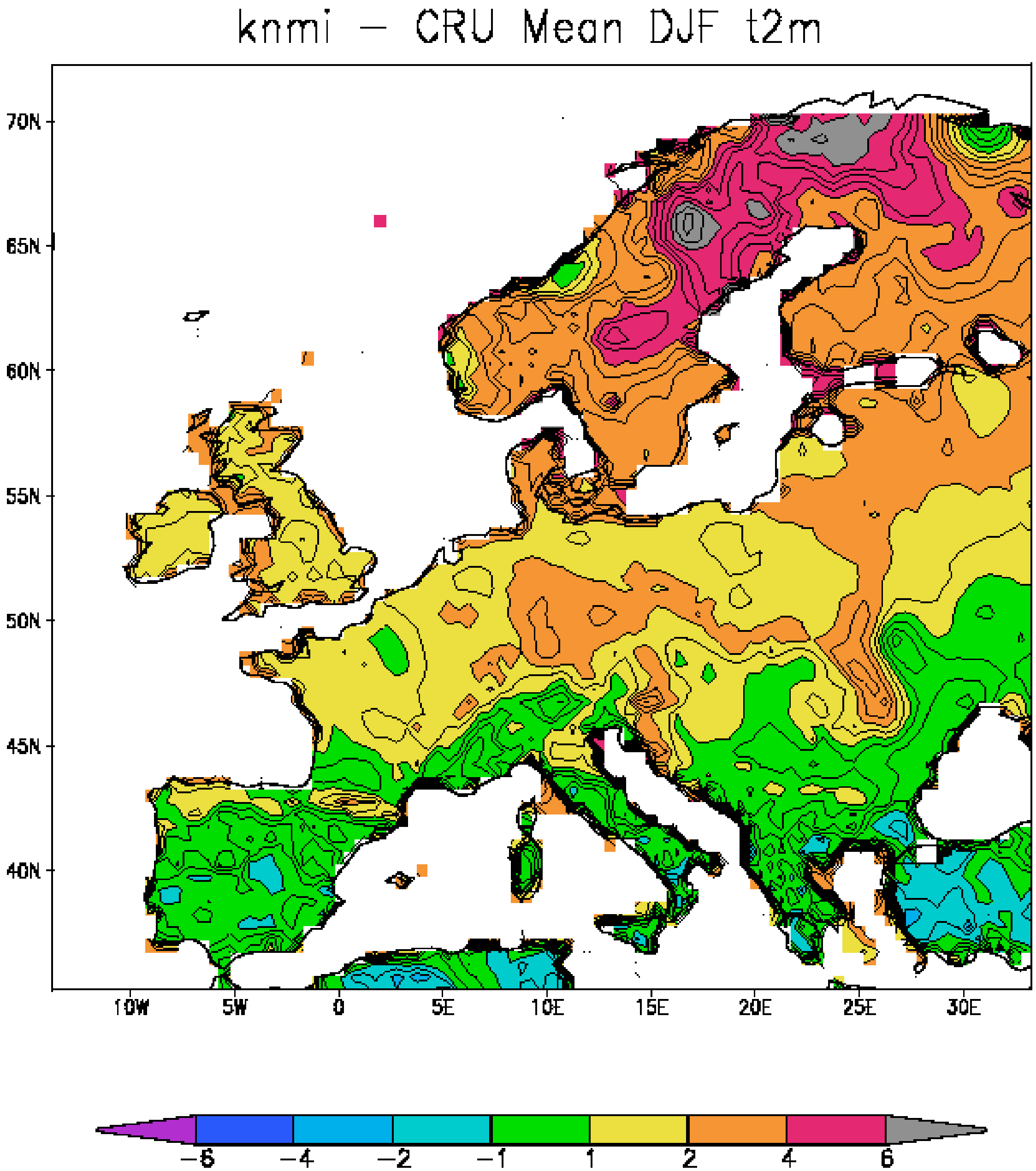
Presentation mostly based on achievements within GEWEX Atmospheric Boundary Layer Study (GABLS)

Towards a better representation of the Atmospheric Boundary Layer in Weather and Climate models

Why is the stable boundary layer (SBL) important?

- Surface temperature forecasting at night
- Fog forecasting
- Polar climate
- Land Climate (night and in winter)
- Dispersion studies
- Built up of high CO2 (and other scalar) concentrations at night over land...

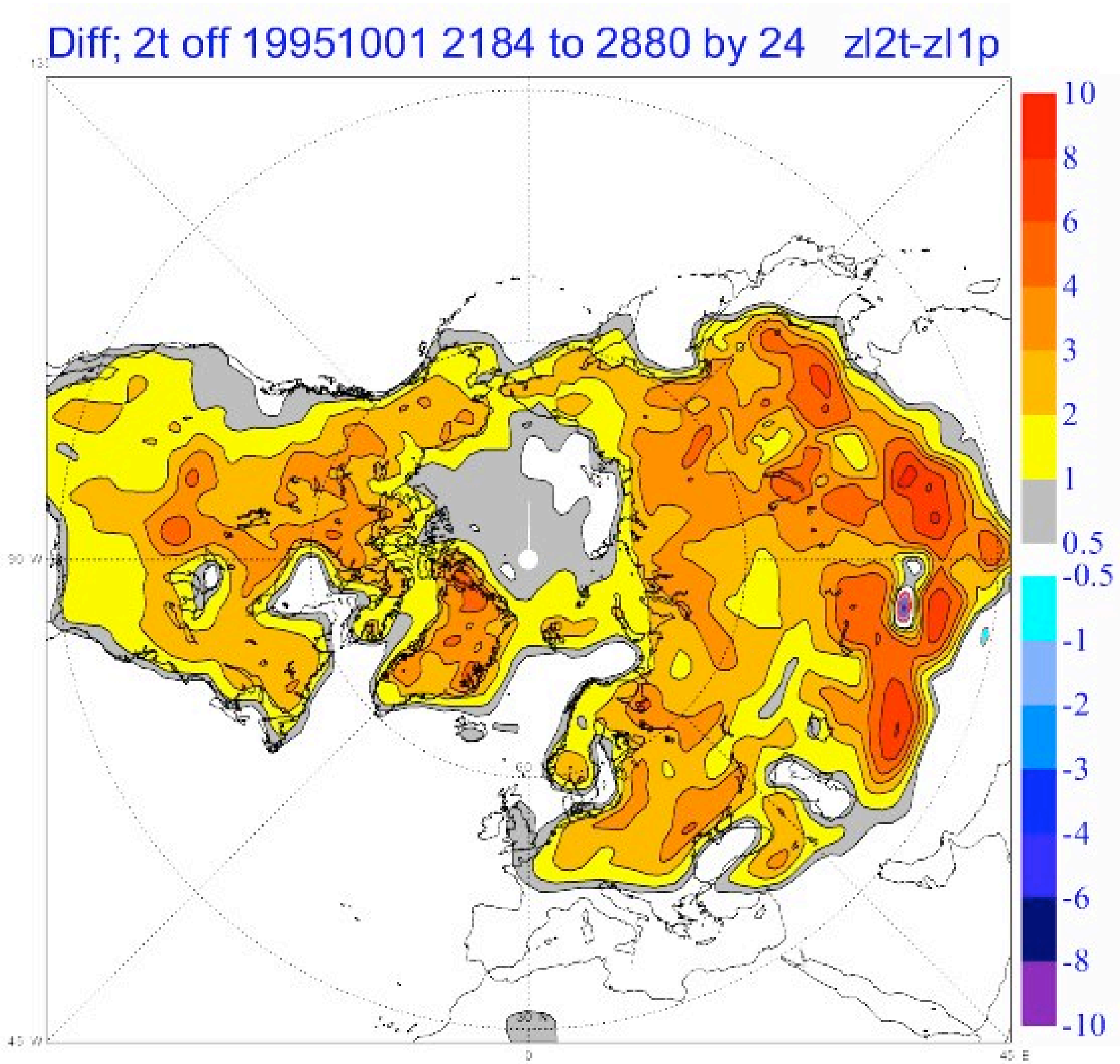


Example:

Mean model bias for the 2 meter temperature in present winter climate (30 years)

Courtesy, Geert Lenderink, KNMI

Also impact on diurnal cycle



Mean model difference in 2 meter temperature for January 1996 using two different stabilty functions in ECMWF model (Courtesy A. Beljaars)

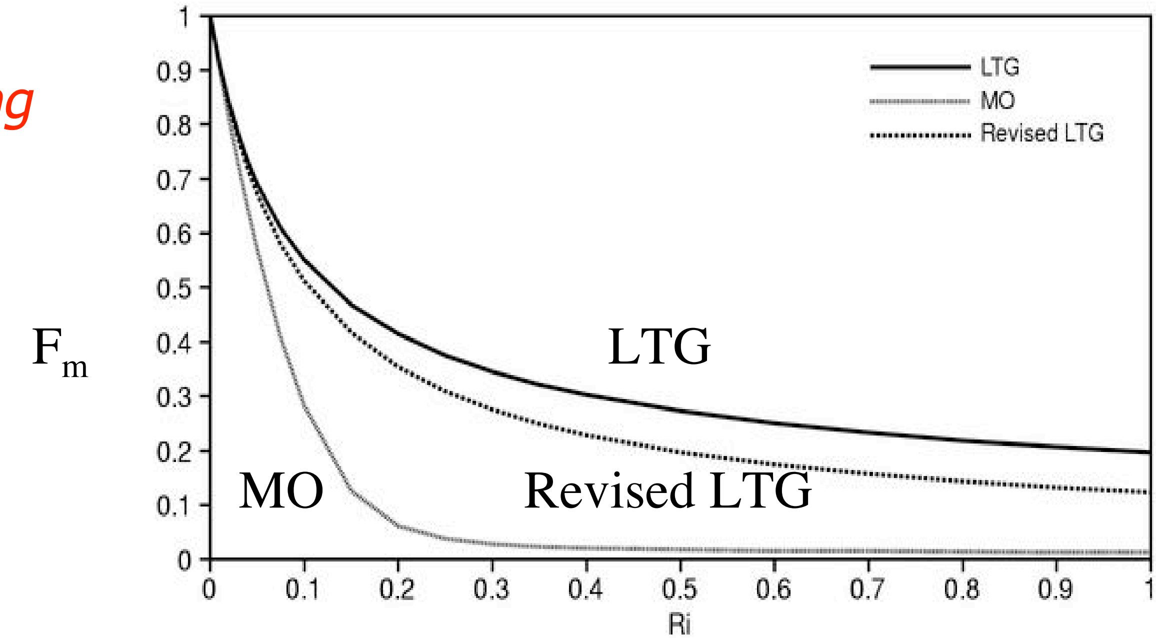
Stable boundary layer mixing

Diffusion coefficients by updated 'Monin-Obukhov (MO)' versus alternatives (LTG)

$$K = \left|\frac{\partial U}{\partial z}\right| l^2 F_{m,h}(Ri)$$

MO based on Cabauw data (Beljaars and Holtslag, 1991)

LTG 's used in ECMWF model (Louis et al; Beljaars et al)



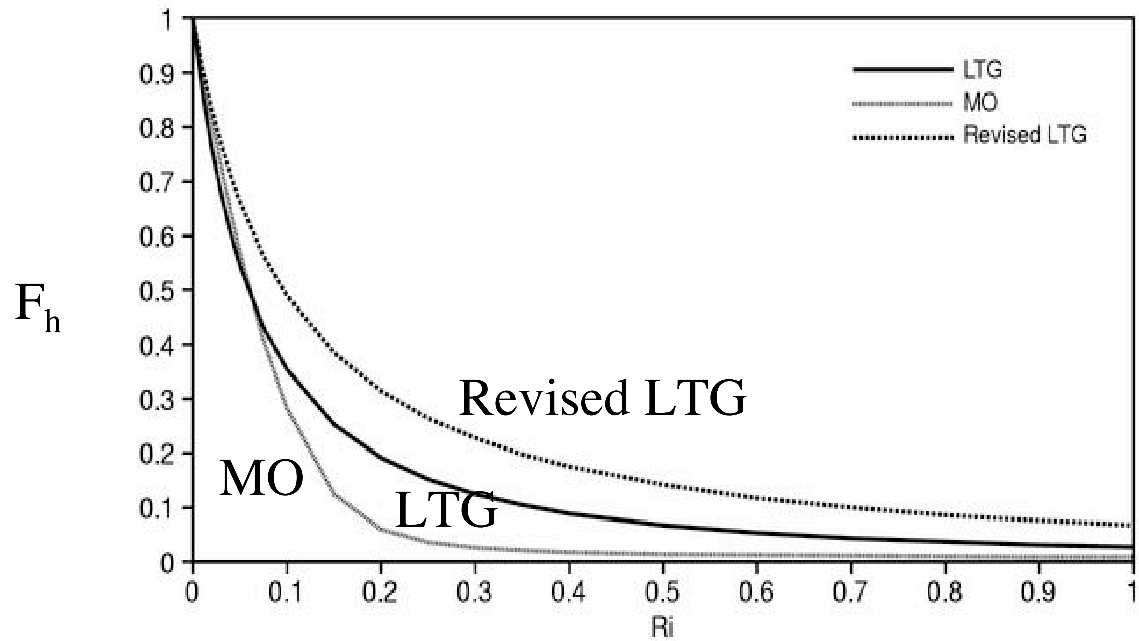
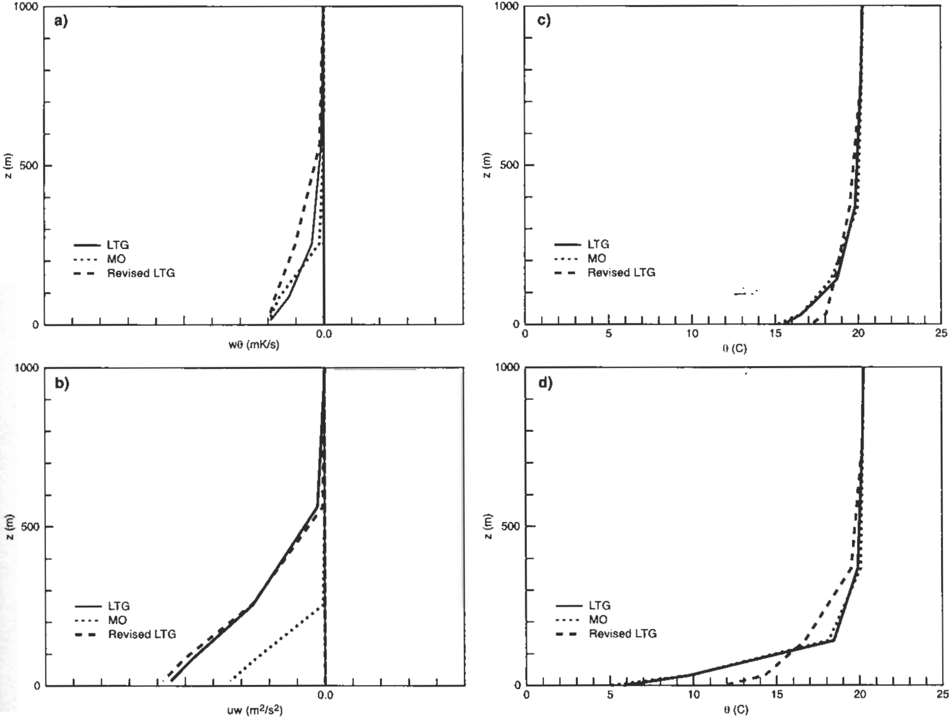


Fig. 8. Single column simulations where a neutral boundary layer is cooled by a downward surface heat flux of 25 W/m^2 over a period of 9 hours. The geostrophic wind is 10 m/s in the x-direction and the surface roughness length is 0.1 m. Three different schemes are used: The LTG scheme (Louis et al., 1982), the Monin Obukhov scheme (MO) and the revised LTG scheme. Profiles of kinematic heat flux (a), kinematic momentum flux in the direction of the geostrophic wind (b), the potential temperature profile (c) and the potential temperature profile with a surface heat flux of 50 W/m^2 (d) are shown.



a)
b)
c)
d)
LTG
MO
Revised LTG
z (m)
wθ (mK/s)
uw (m²/s²)
θ (C)
0
500
1000
0.0
0
5
10
15
20
25

Why do models need Enhanced Mixing?

To compensate for model errors and to prevent 'runaway' surface cooling

To have sufficient 'Ekman pumping'

State of the Art

Large Bias and Sensitivity to Stable ABL formulation (at least over Land and Ice!)

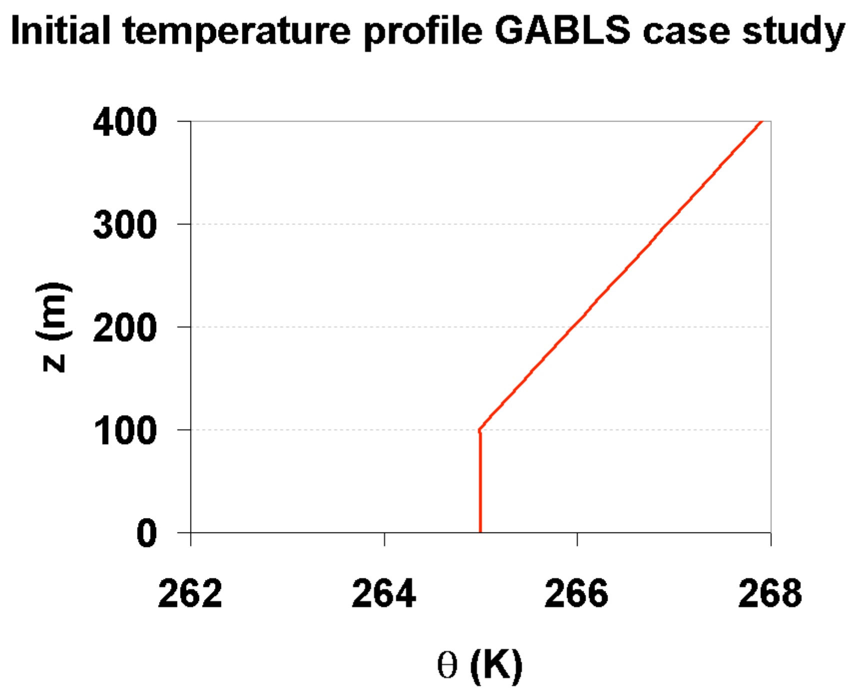
Operational models typically like enhanced mixing in stable cases

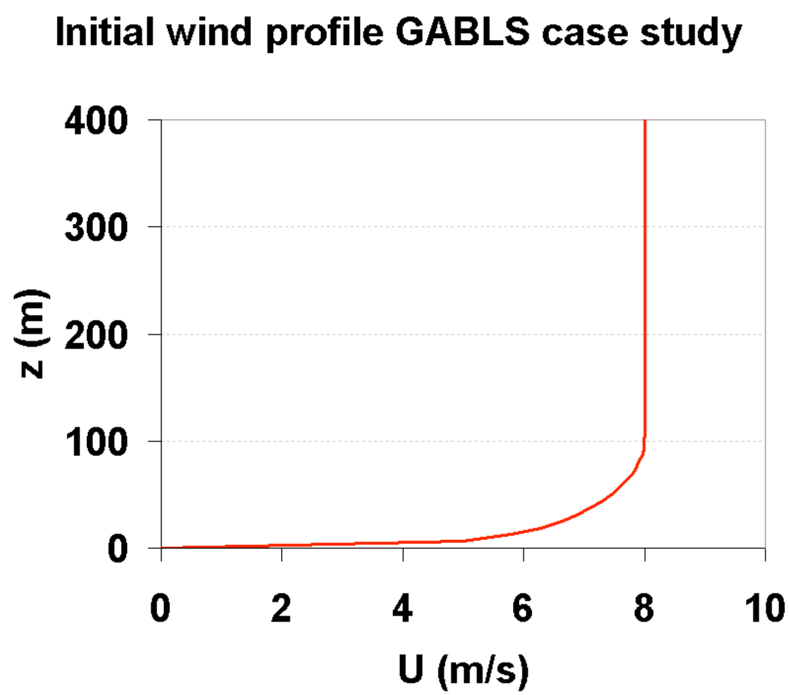
What can we learn from fine-scale modeling (LES)?

How do operational models compare?

GABLS first inter comparison case

Simple shear driven case *(after Kosovic and Curry, 2000)*

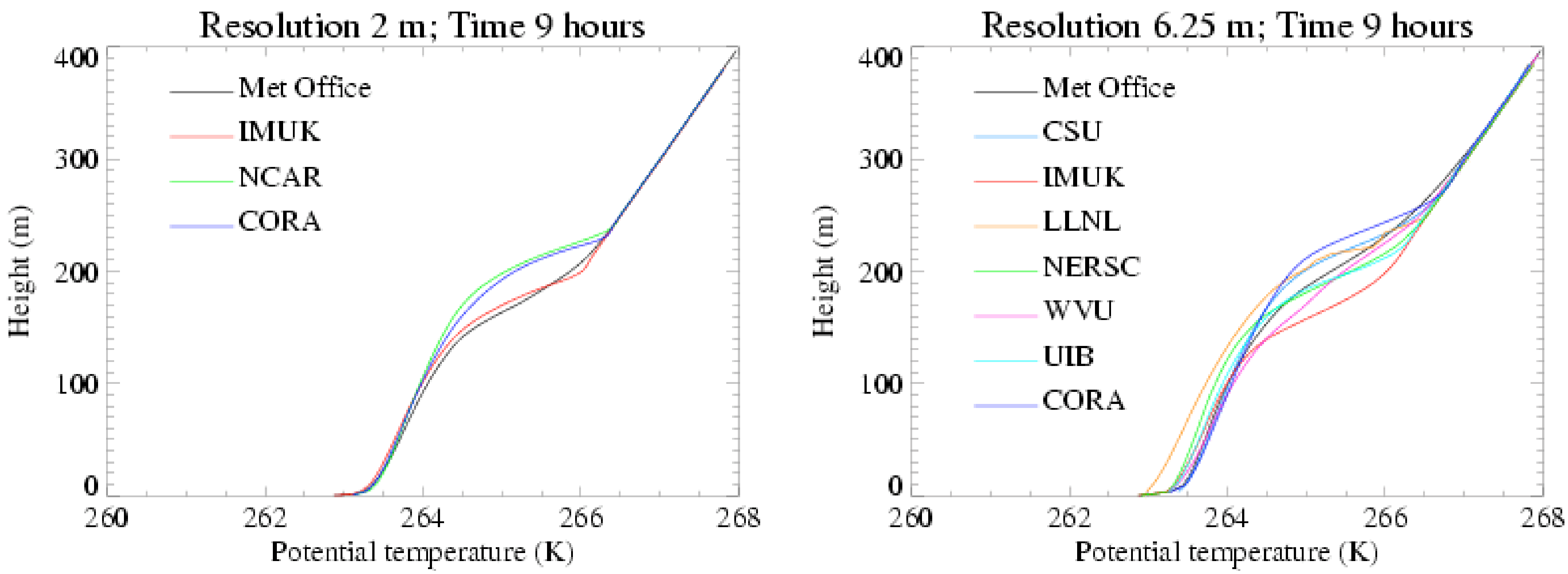




Prescribed surface cooling 0.25 K/h (over ice) for 9 hours to quasi- equilibrium; no surface and radiation scheme

Geostrophic wind 8 m/s, latitude 73N

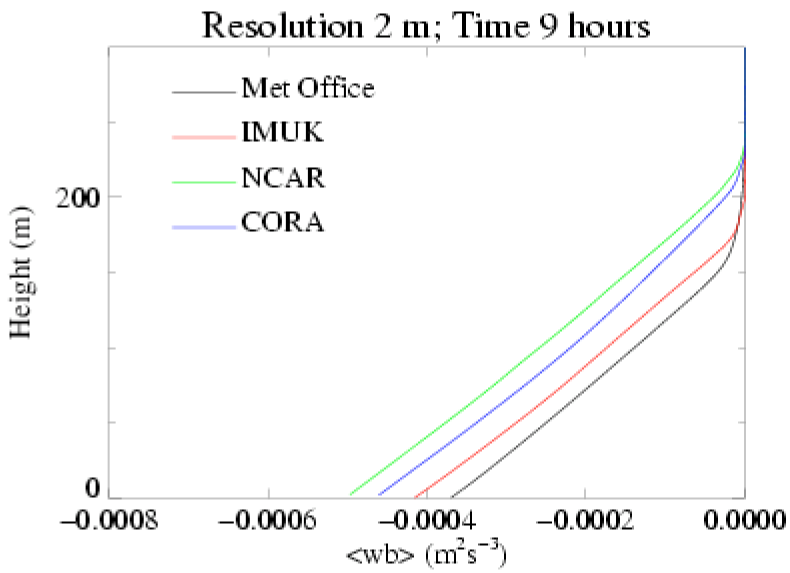
Mean potential temperature of LES models after nine hours of cooling

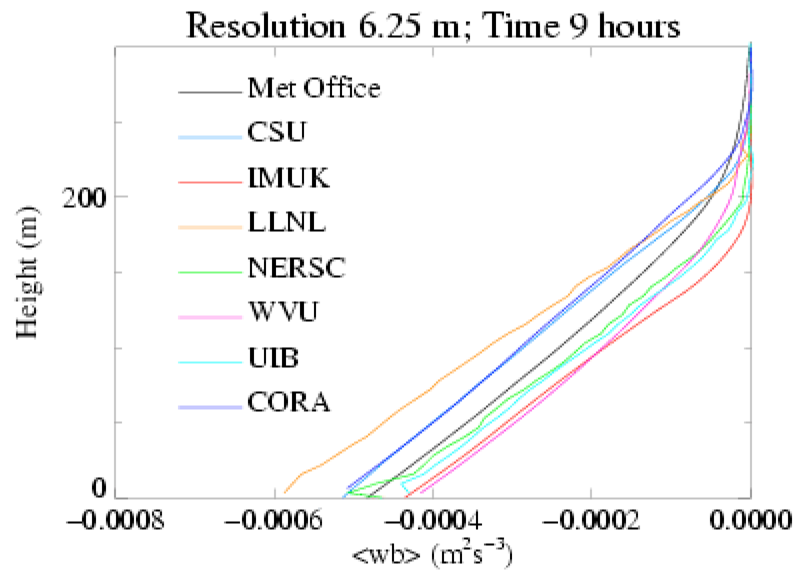


Significant spread in results, but convergence at high resolution (Sensitivity to sub-grid model)

Beare et al, 2005

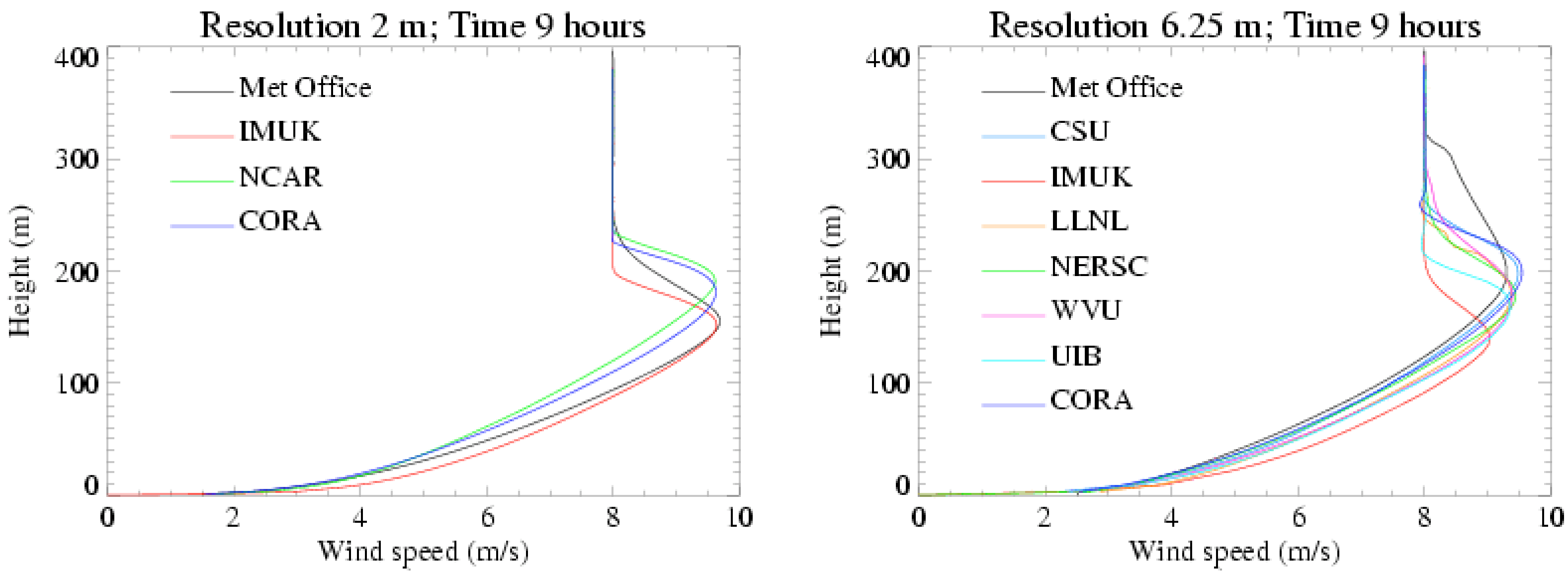
Mean heat fluxes





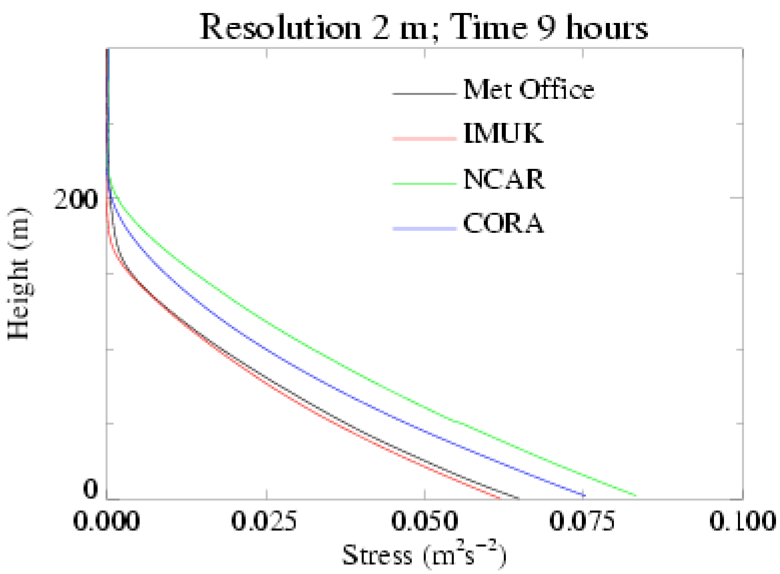
cf linear heat flux profile derived by Nieuwstadt (1984).

Mean wind

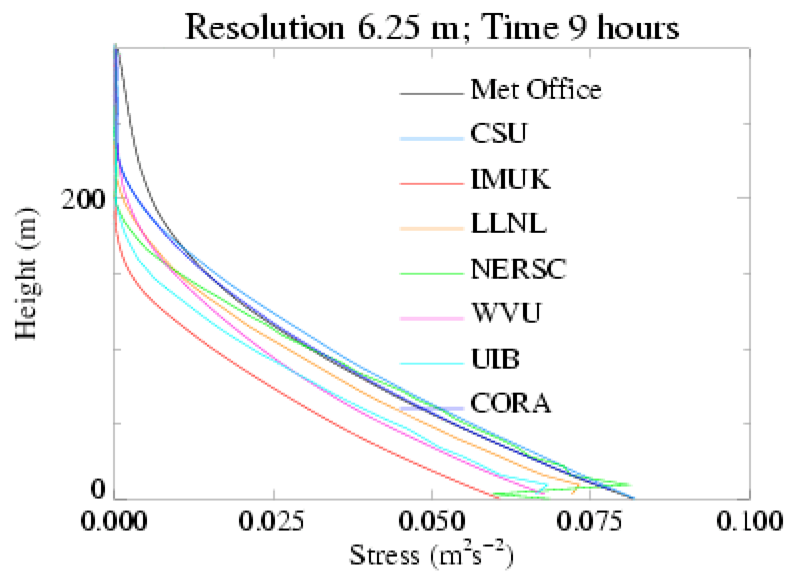


Resolution 2 m; Time 9 hours
Met Office
IMUK
NCAR
CORA
Height (m)
Wind speed (m/s)
0
100
200
300
400
0
2
4
6
8
10
Resolution 6.25 m; Time 9 hours
Met Office
CSU
IMUK
LLNL
NERSC
WVU
UIB
CORA
Height (m)
Wind speed (m/s)
0
100
200
300
400
0
2
4
6
8
10

Mean stress

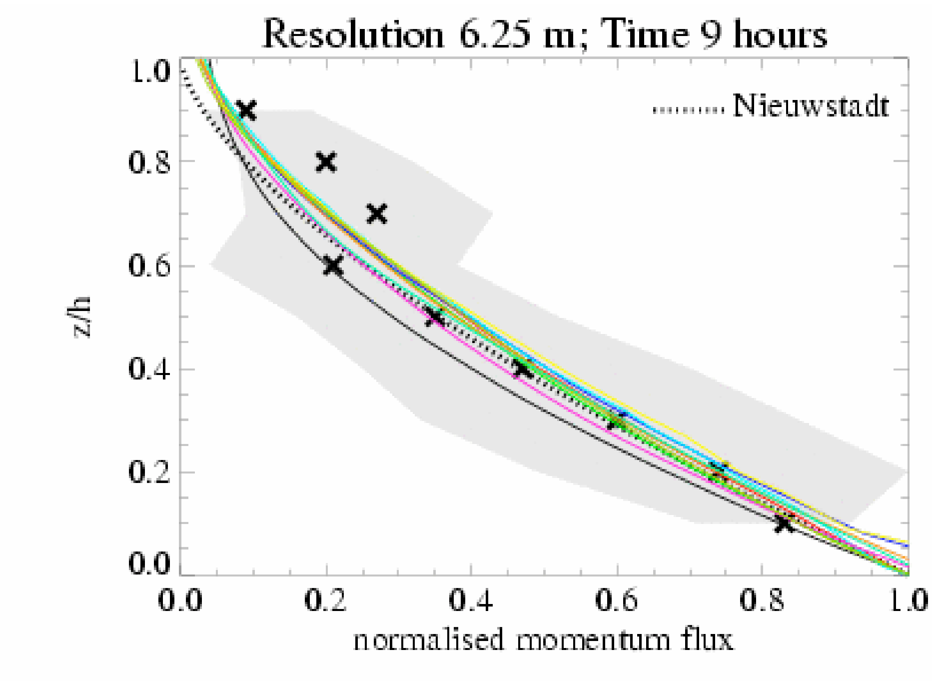


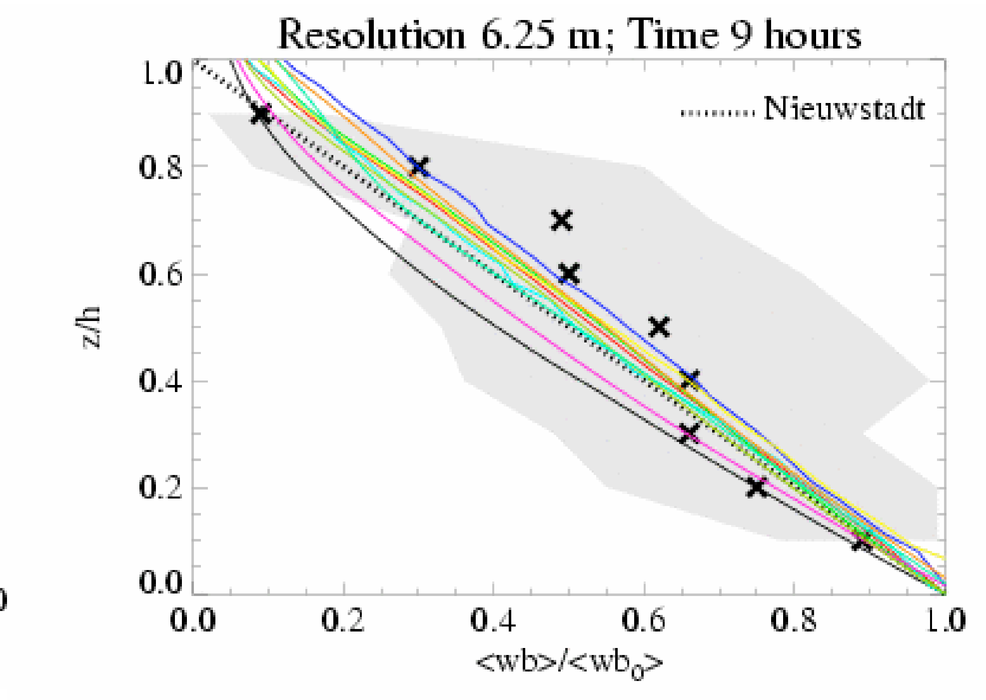
Resolution 2 m; Time 9 hours
Met Office
IMUK
NCAR
CORA
Height (m)
200
0
0.000
0.025
0.050
0.075
0.100
Stress (m^2s^{-2})



Resolution 6.25 m; Time 9 hours
Met Office
CSU
IMUK
LLNL
NERSC
WVU
UIB
CORA
Height (m)
200
0
0.000
0.025
0.050
0.075
0.100
Stress (m^2s^{-2})

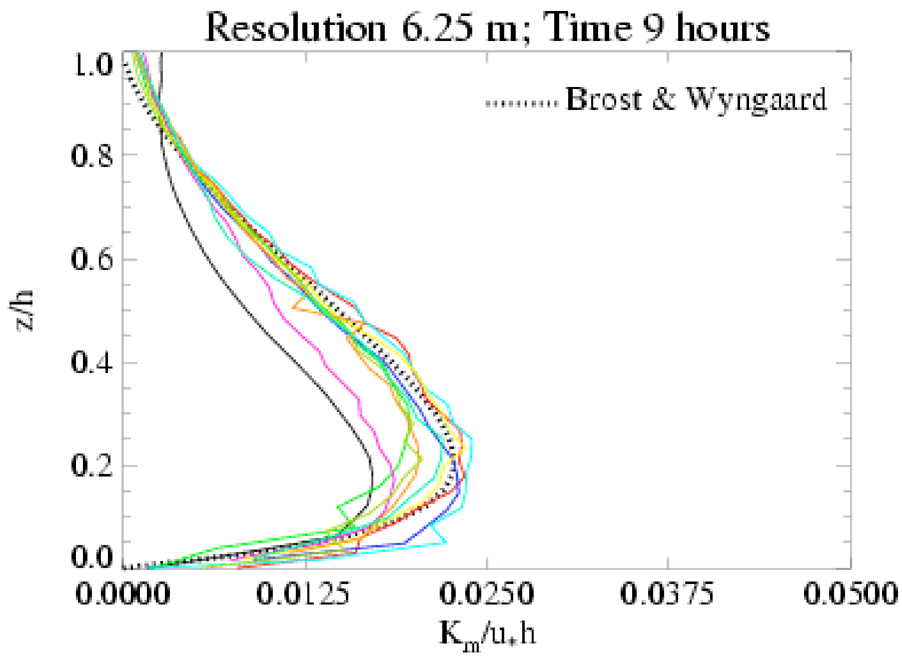
Normalized fluxes

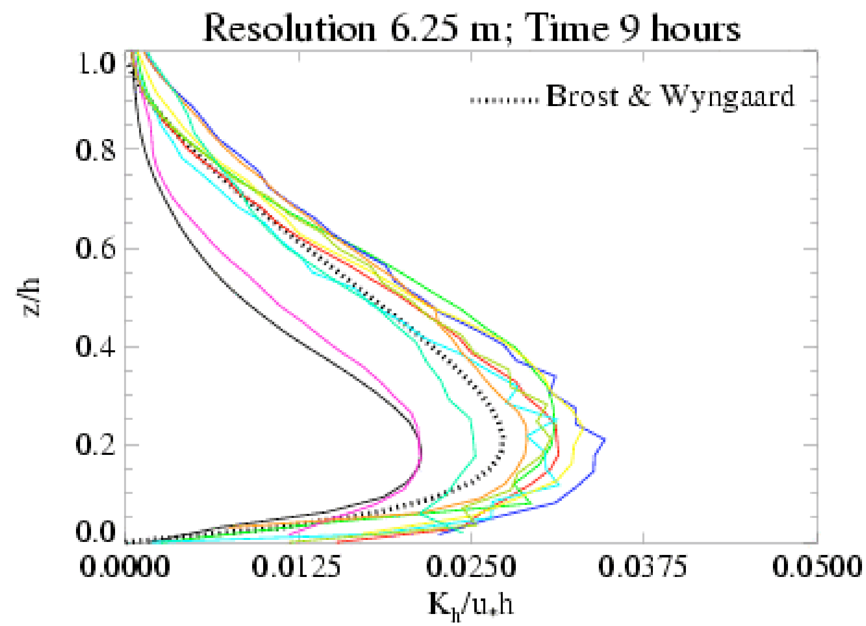




Crosses are based on Cabauw observations (Nieuwstadt 1984),
with the standard deviation of the means shown by the shaded regions.

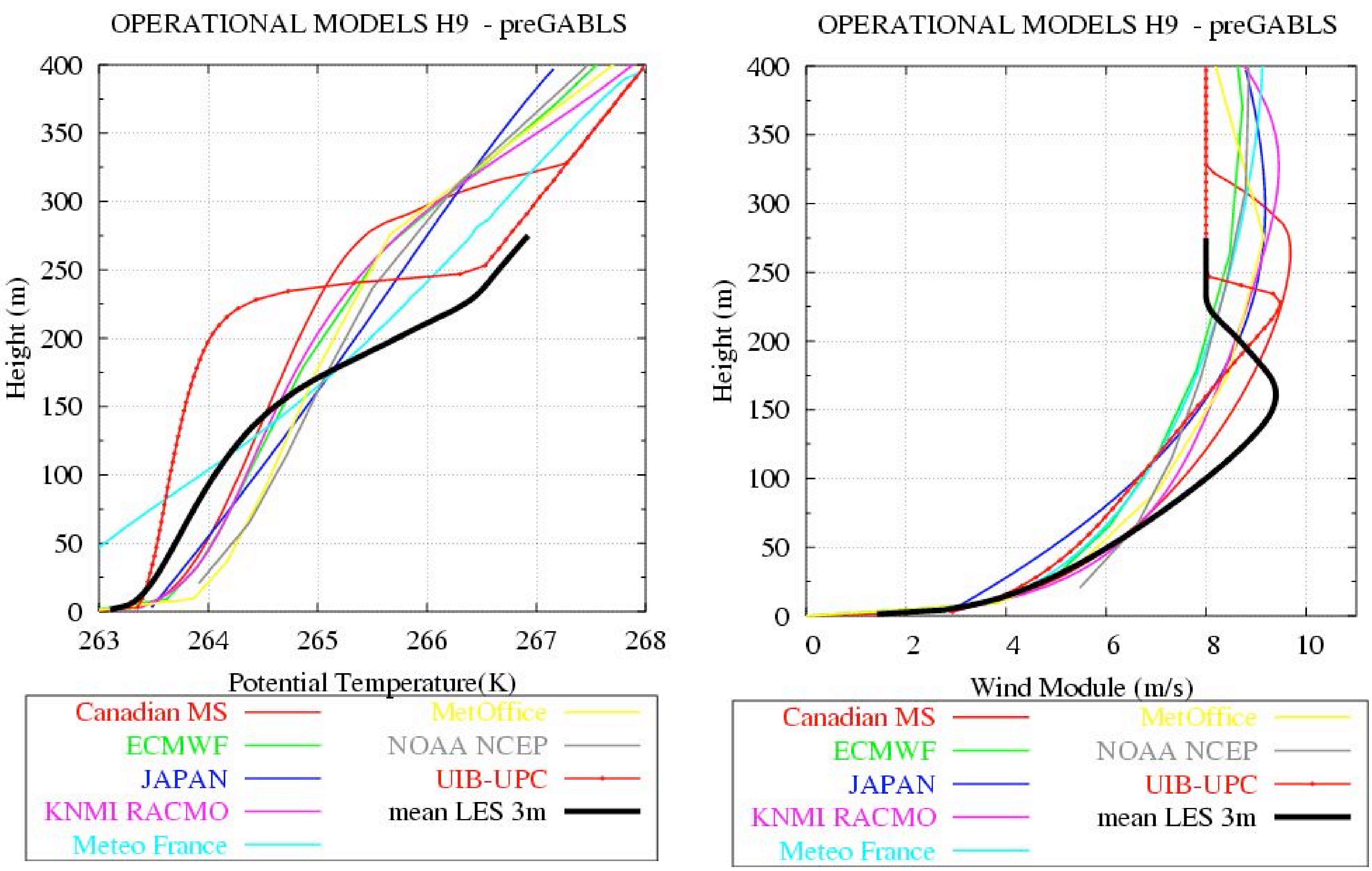
Eddy-Diffusivities



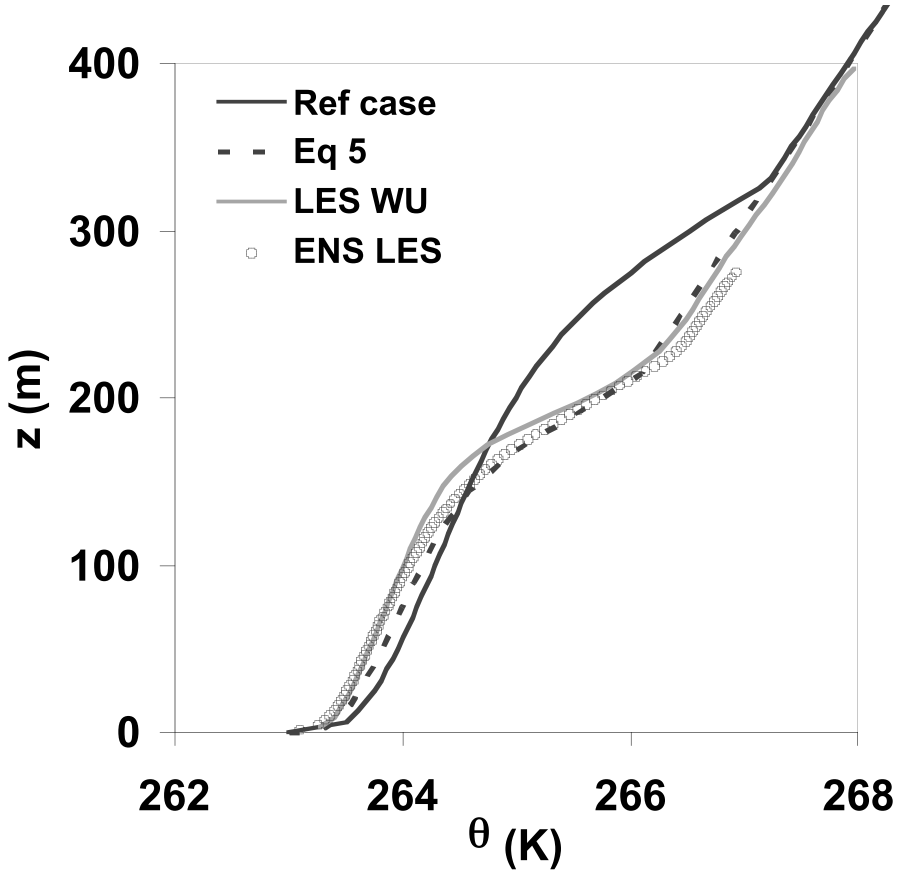


In LES: Pr = Km / Kh < 1,
but observations indicate Pr ~ 1 or > 1

‘Operational’ Single-Column Models versus LES (Cuxart et al, 2005)



Resolution (most) operational models is set to 6.25 m!

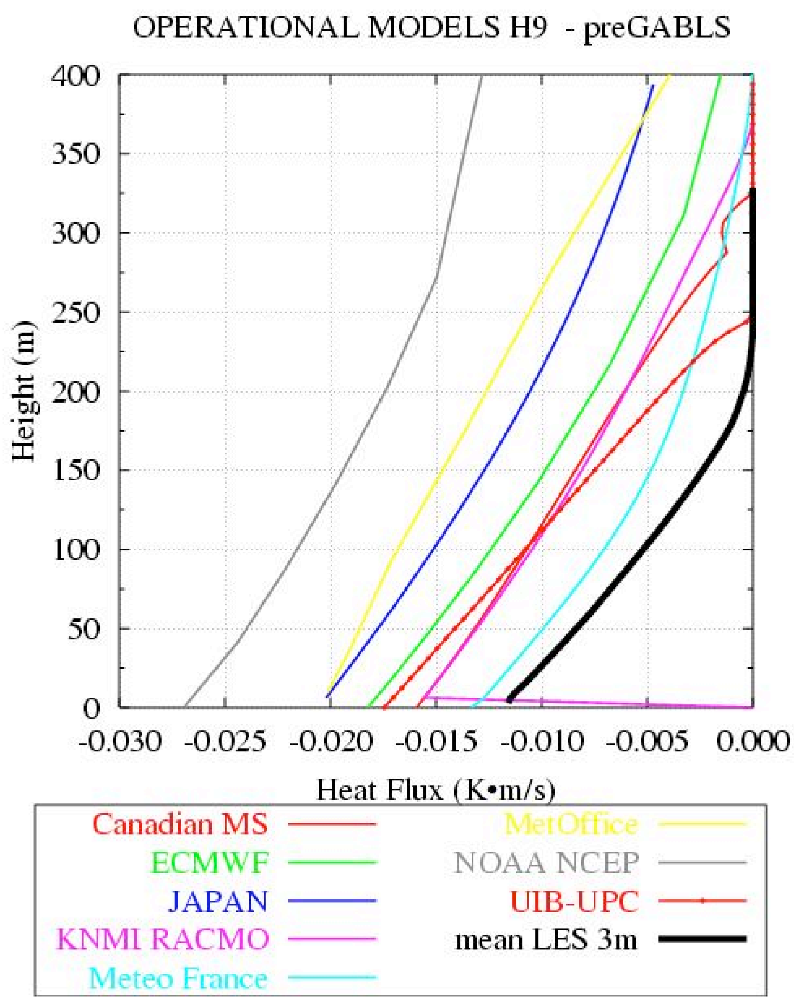


Models can represent main LES results after adjusting, e.g. length scale:

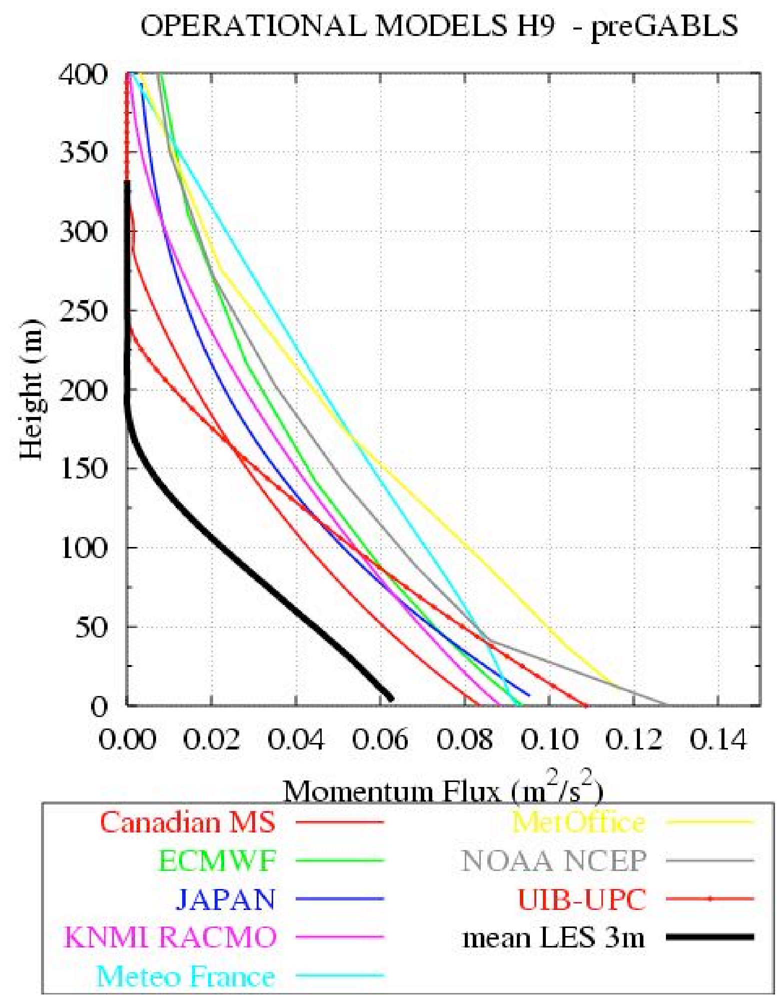
$$\frac{1}{l} = \frac{1}{kz} + \frac{N}{\sigma_w}$$

Steeneveld, Van de Wiel, Holtslag, 2005 (BLM, accepted)

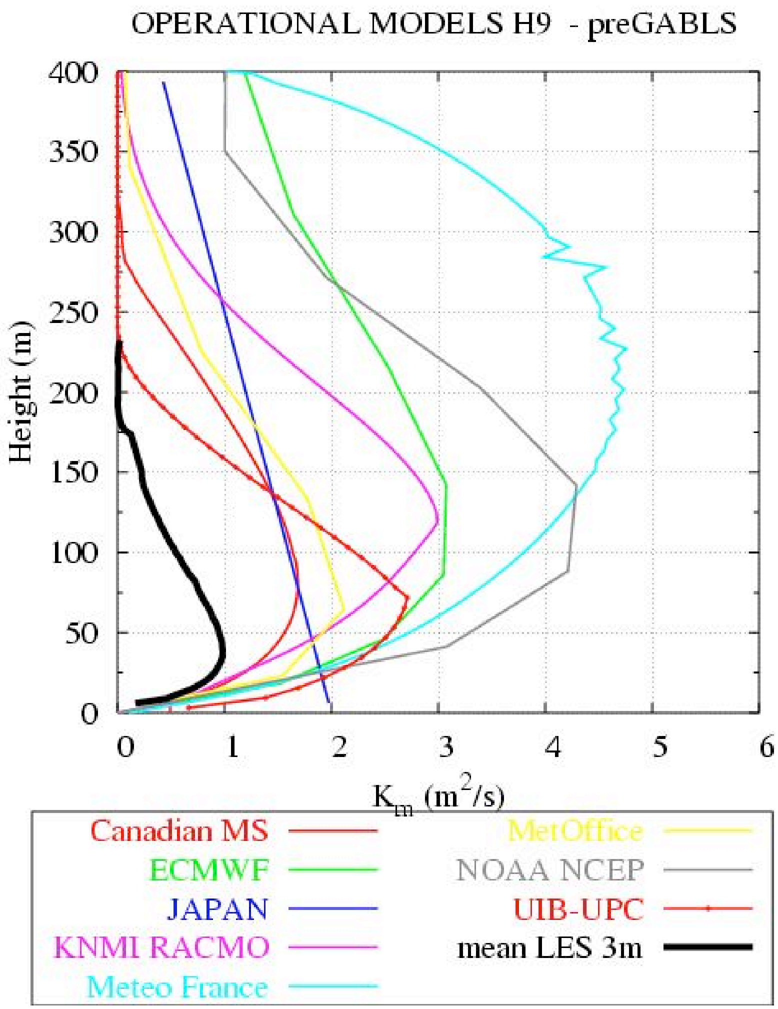
Heat Fluxes

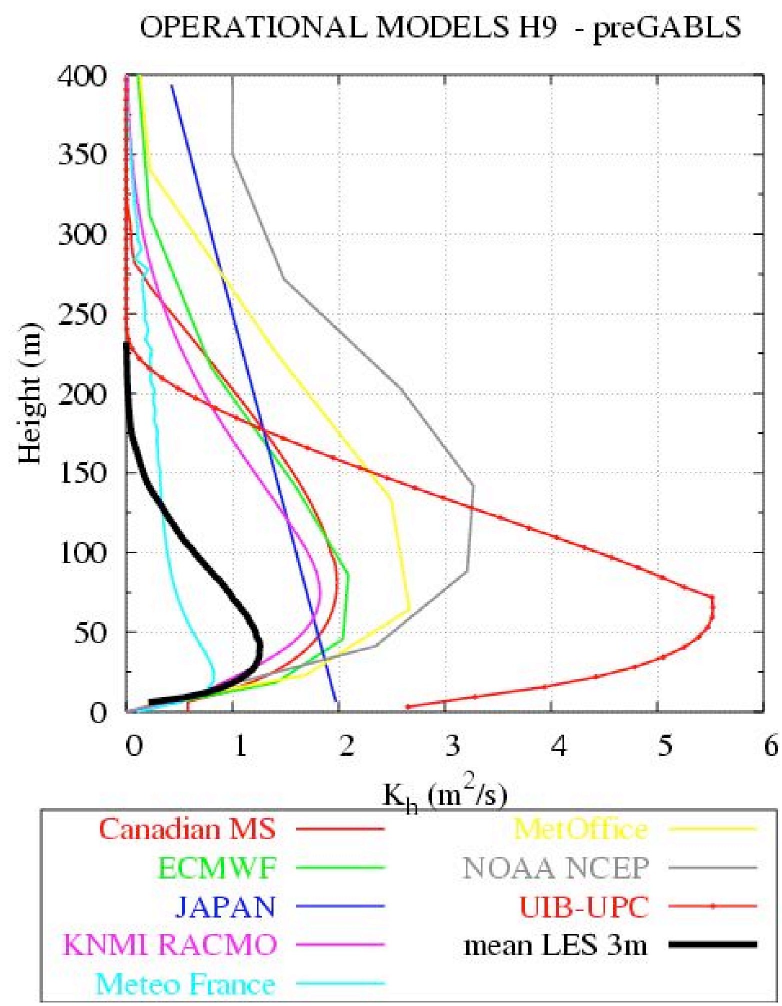


Momentum Fluxes



Apparent Diffusivities for Momentum and Heat





Summary

Large variation among 1D models,
but all operational models show too strong mixing!

Apparently the turbulence schemes are used to increase operational model performance but this decreases representation of ABL!