Land Surface Climate and the role of the Stable Boundary Layer

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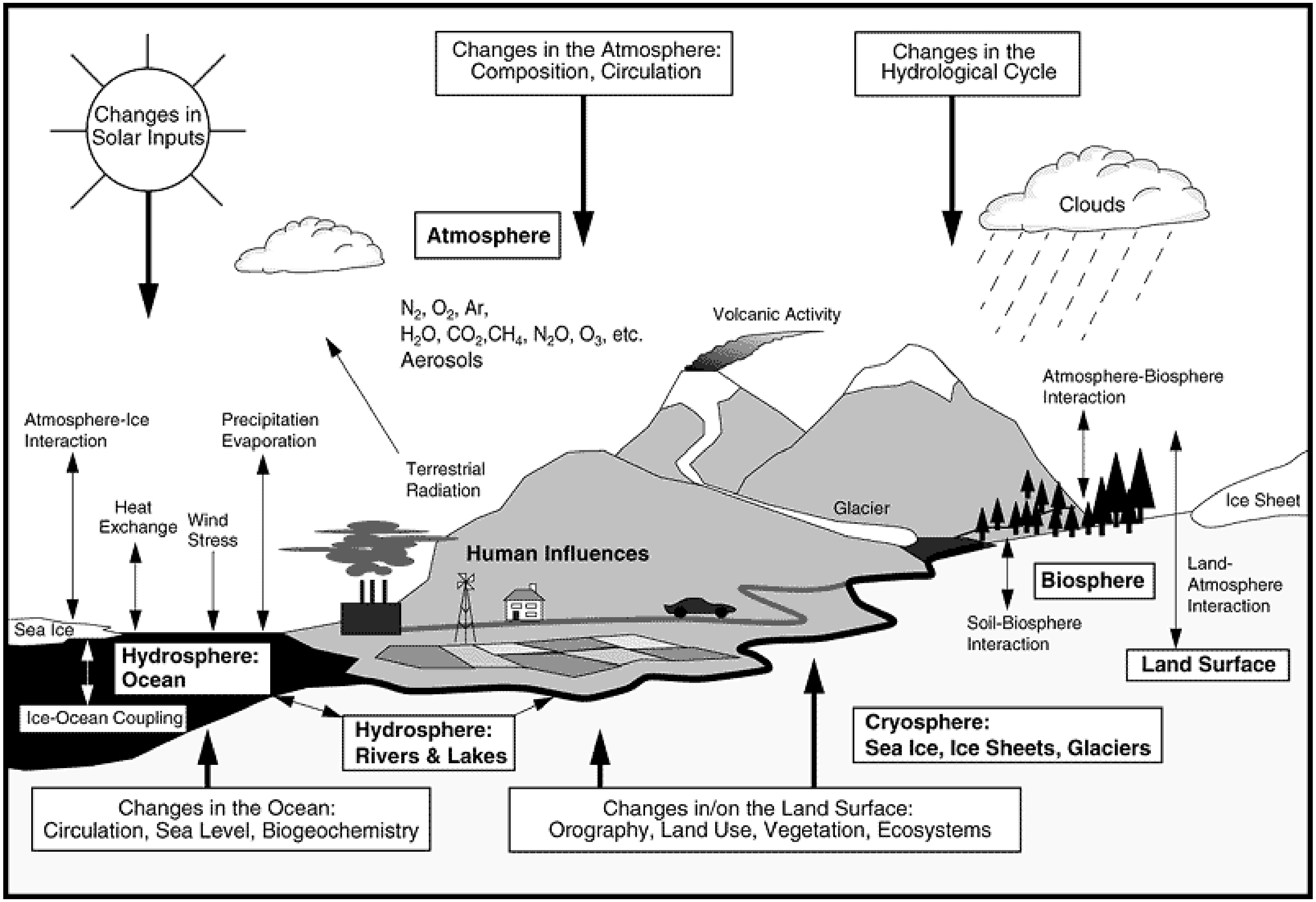
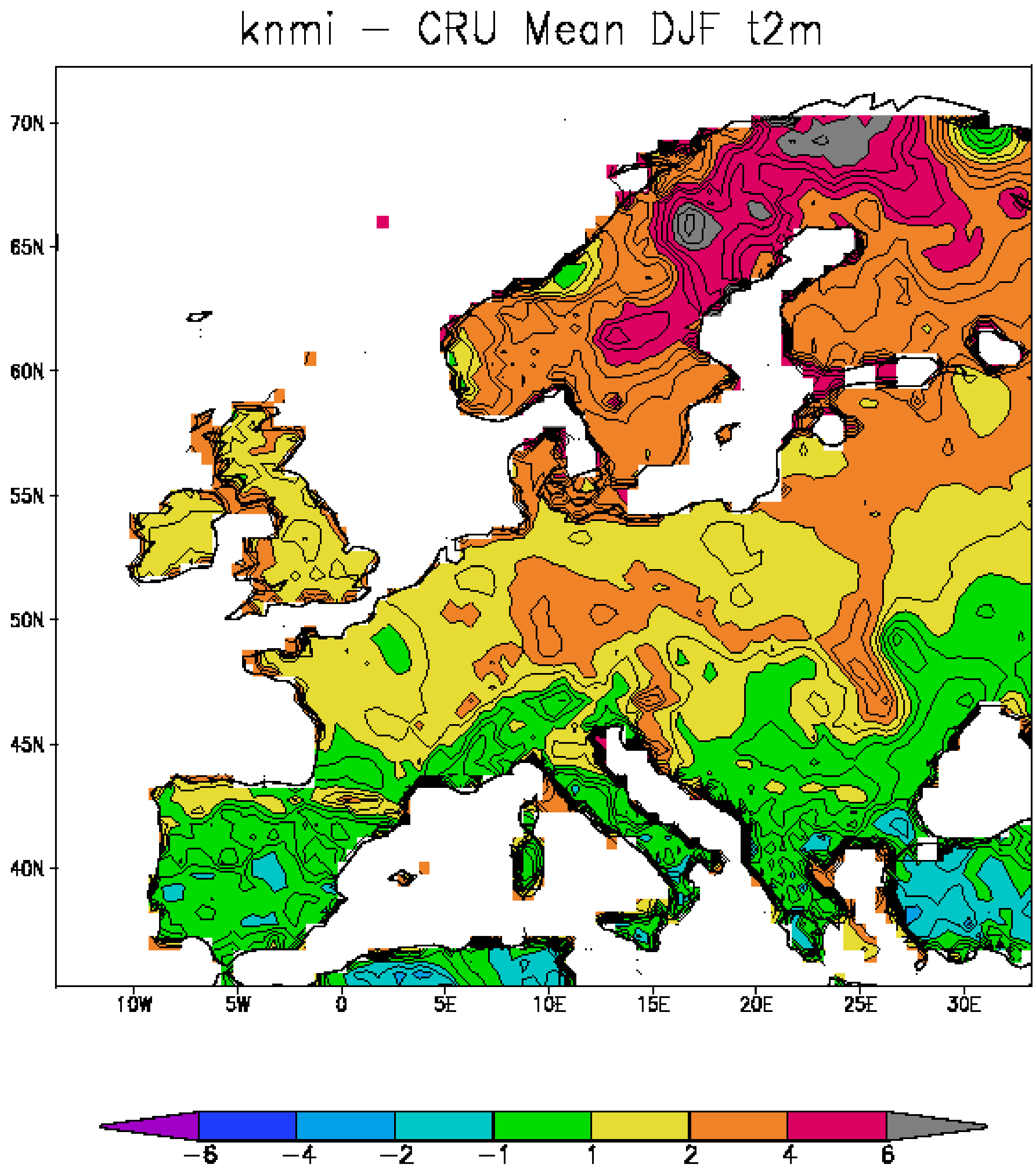
Towards a better representation of the Atmospheric Boundary Layer in Weather and Climate models

Climate: Many factors



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 concentrations at night...



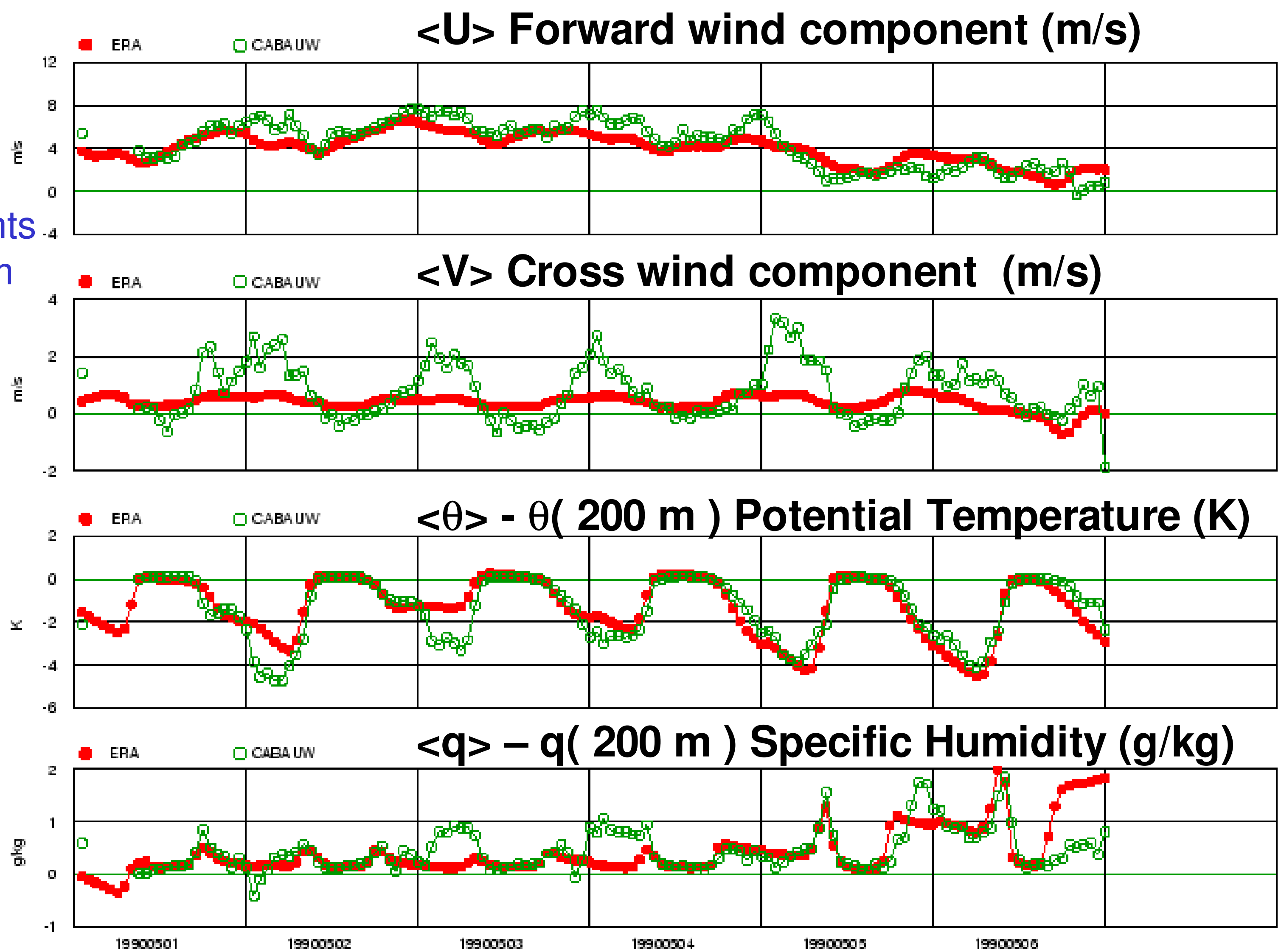
Mean model bias for the 2 meter temperature in present winter climate (30 years)

Courtesy, Geert Lenderink, KNMI

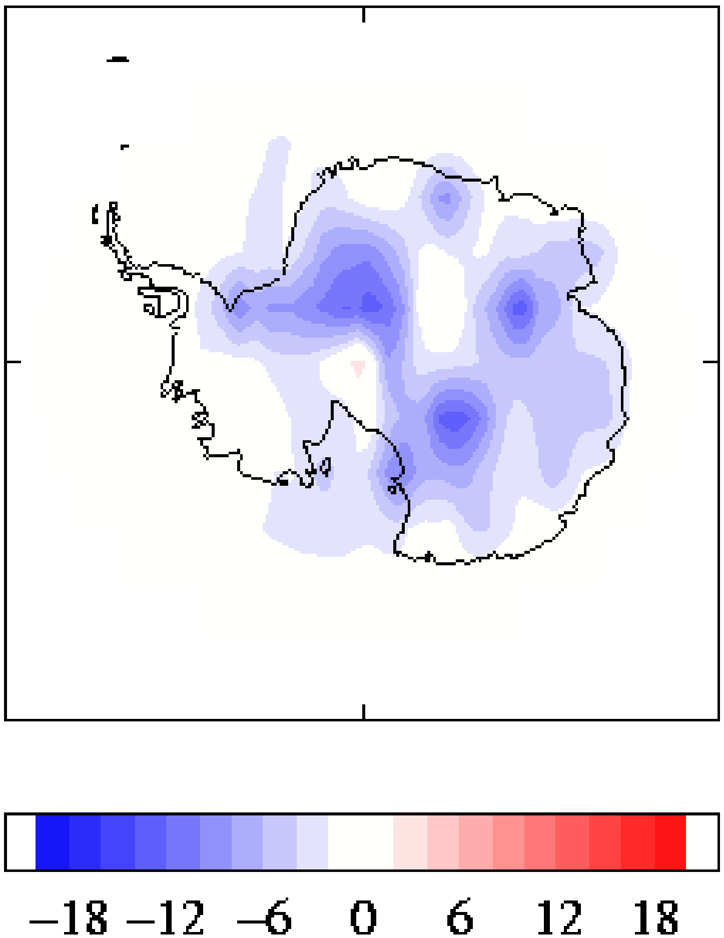
Also impact on diurnal cycle

Comparing ERA40 and Cabauw mean values over lowest 200 m
clear nights, 1-6 may 1990 (Courtesy F. Bosveld, KNMI)

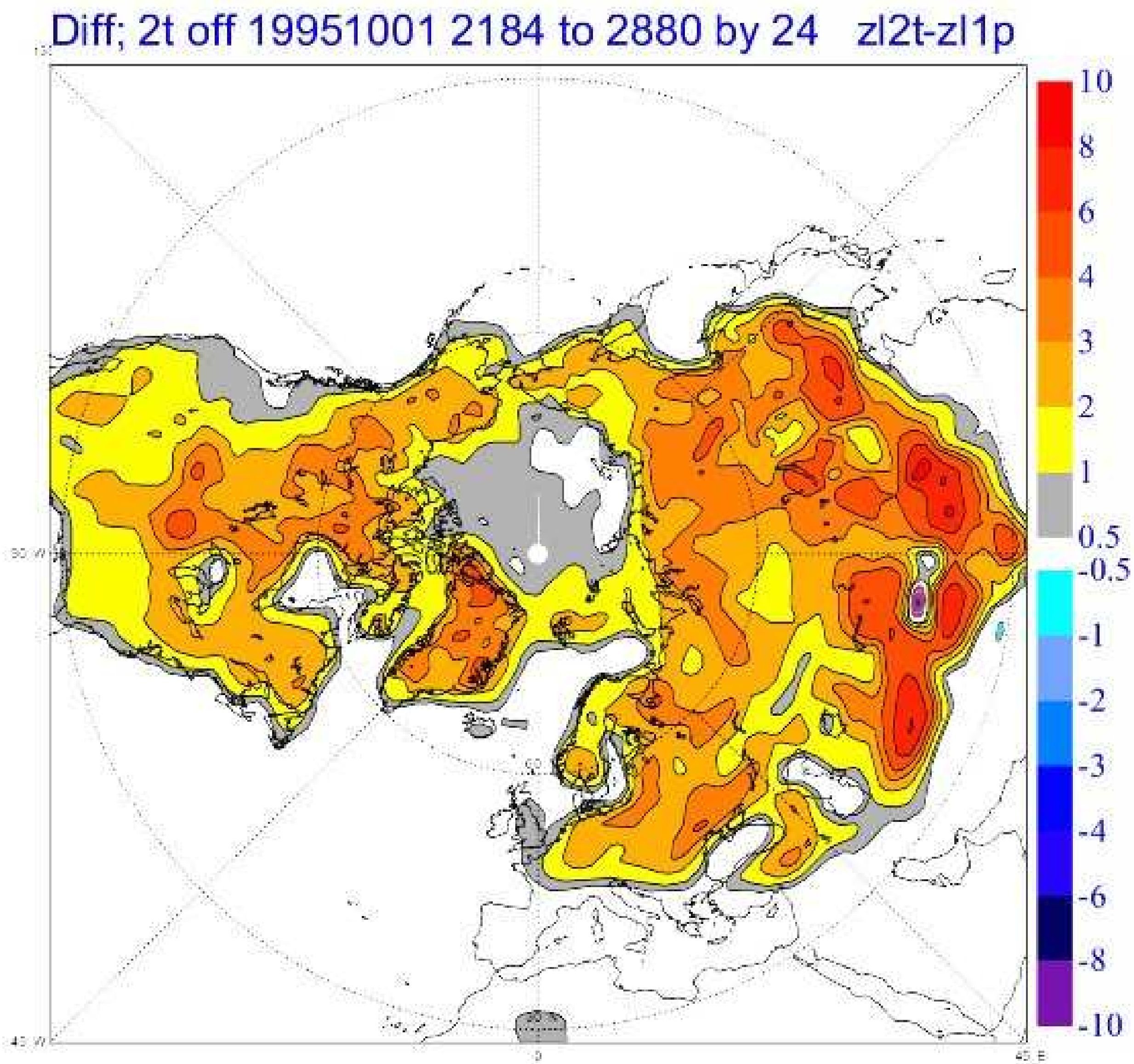
Wind components relative to 200 m wind vector



Sensitivity to SBL parameterization in Hadley Centre Climate Model, over Antarctic



Difference between new (2nd order closure) and current scheme (1st order closure) for 1.5m Temperature (K), JJA season, 5 year mean (King et al. 2001, QJRMS)



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

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

Flux-gradient Relationship

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

$$Ri = \frac{g}{\theta}\frac{\partial \theta}{\partial z}\left|\frac{\partial U}{\partial z}\right|^{-2}$$

Richardson number

Specification needed for length scale l and F(Ri)

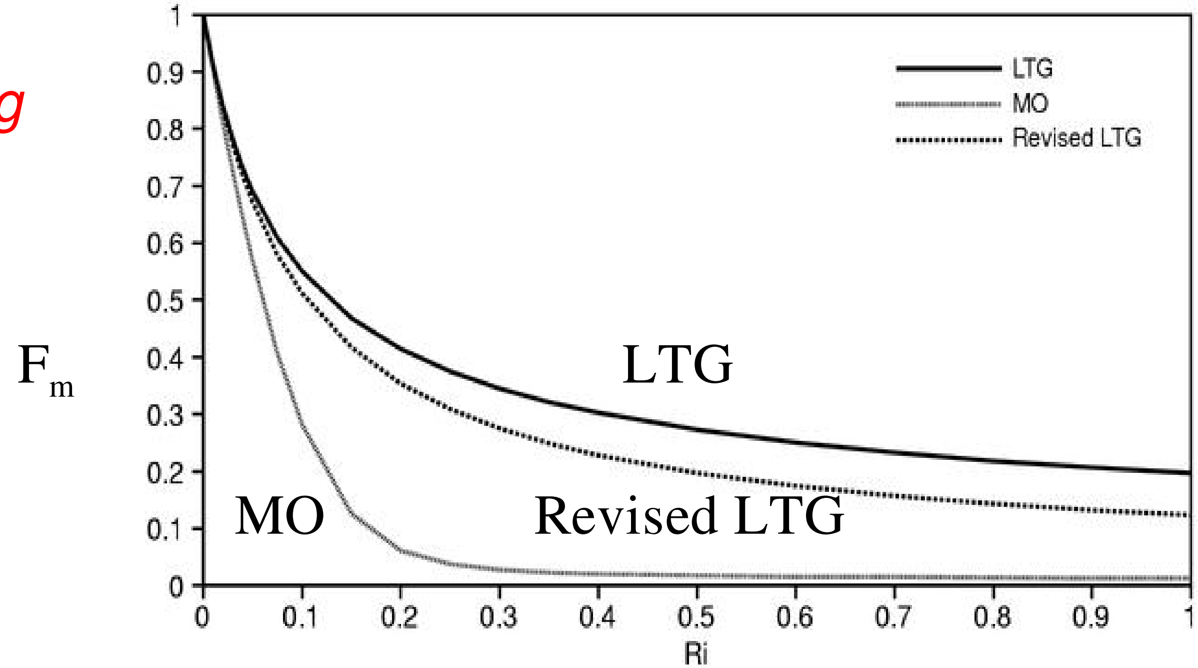
Stable boundary layer mixing

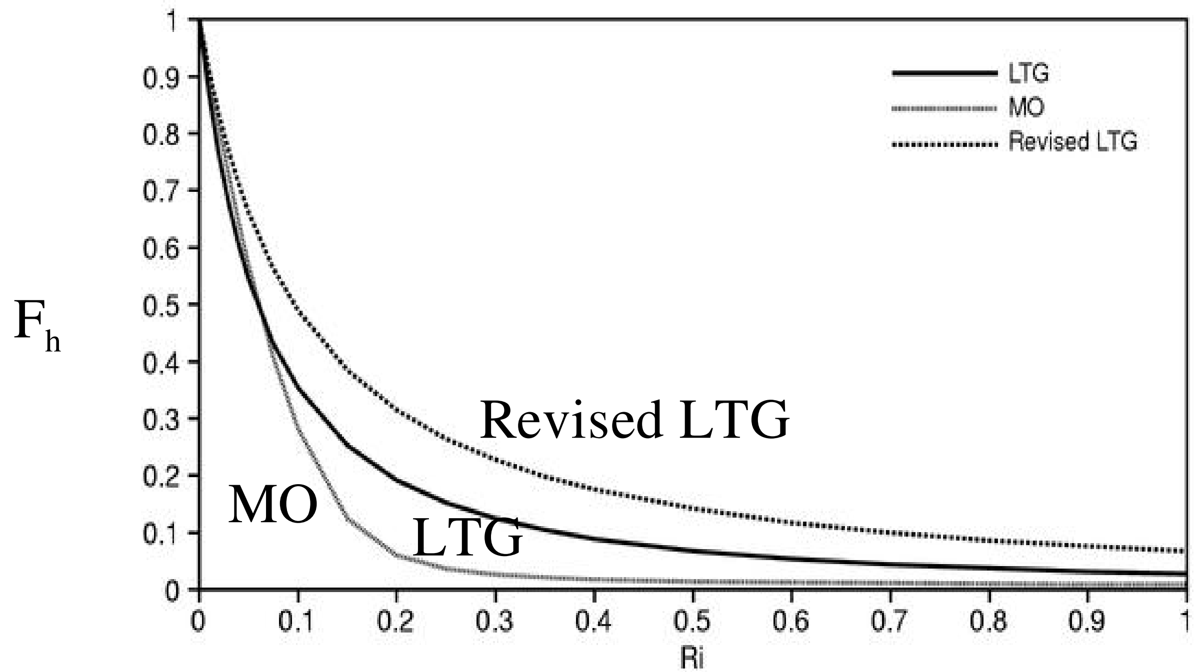
Diffusion coefficients by updated 'Monin-Obukhov (MO)' versus alternatives (LTG)

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

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

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





State of the Art

Great Sensitivity to Stable ABL formulation!

Operational models typically like enhanced mixing in stable cases

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

How do models compare?

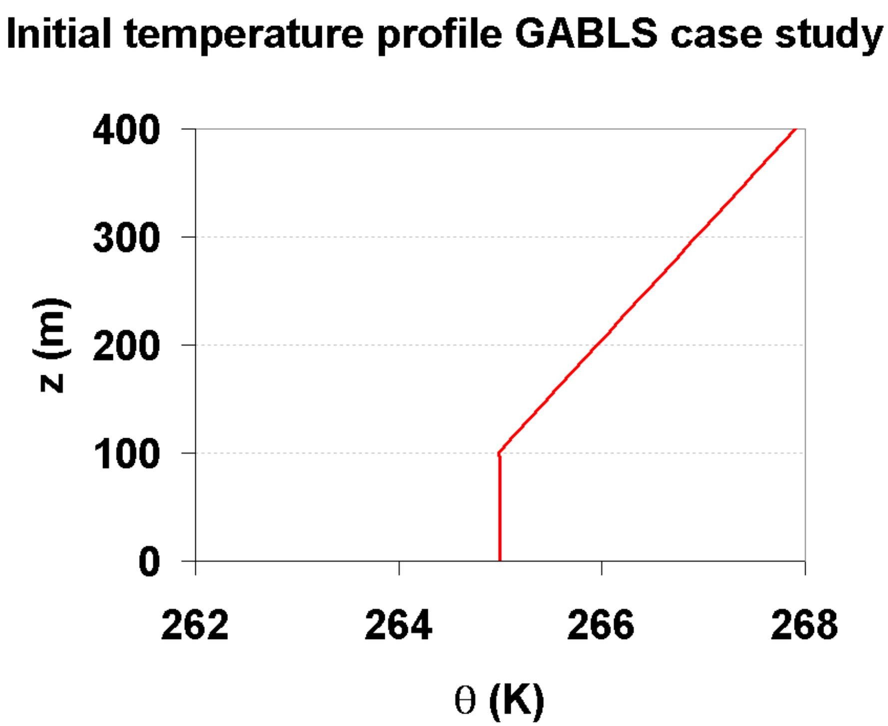
How important is vertical resolution?

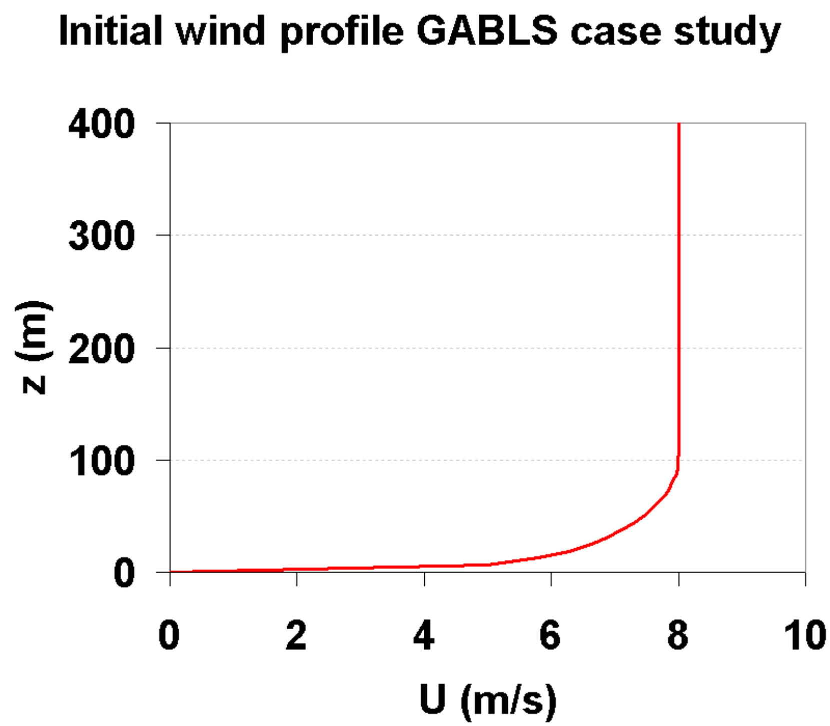
Strong recommendation of participants at GABLS meeting in Wageningen (about 80 attendees):

Start with simple CASE for Stable Boundary Layer!

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

An intercomparison of large-eddy simulations of the stable boundary layer

Coordinated by

Bob Beare, Malcolm MacVean, Anne McCabe

Met Office, UK

- Domain 400m x 400m x 400m
- Resolutions: 12.5m, 6.25m, 3.125m, 2m, 1m

10 results sets, 17 investigators

See: http://www. gabls.org

Large Eddy Simulation (LES) of stable boundary layers

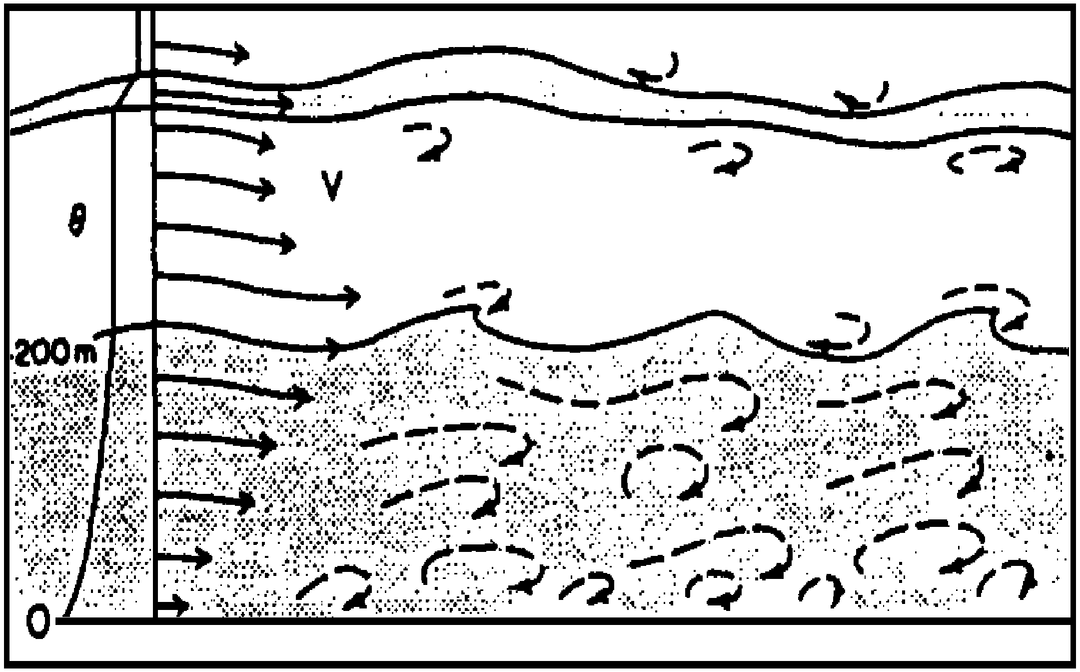
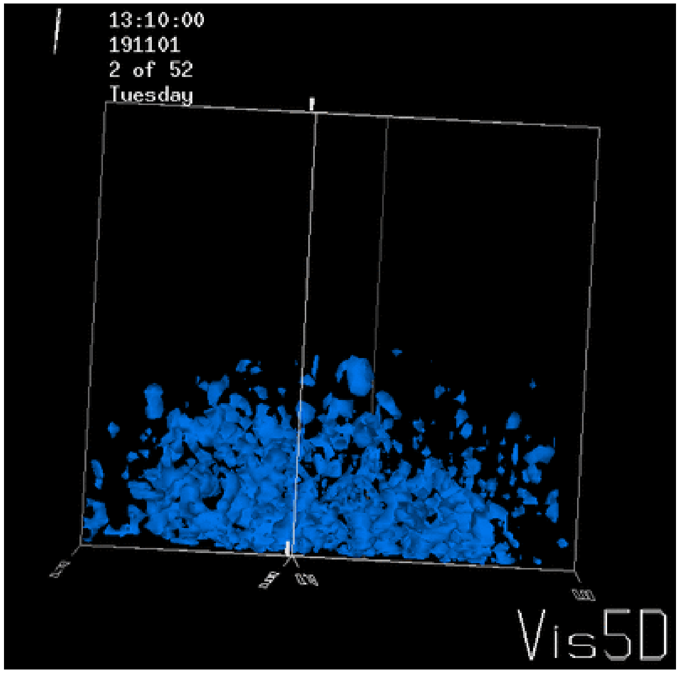


Image of the 0.2 m/s vertical velocity iso-surface



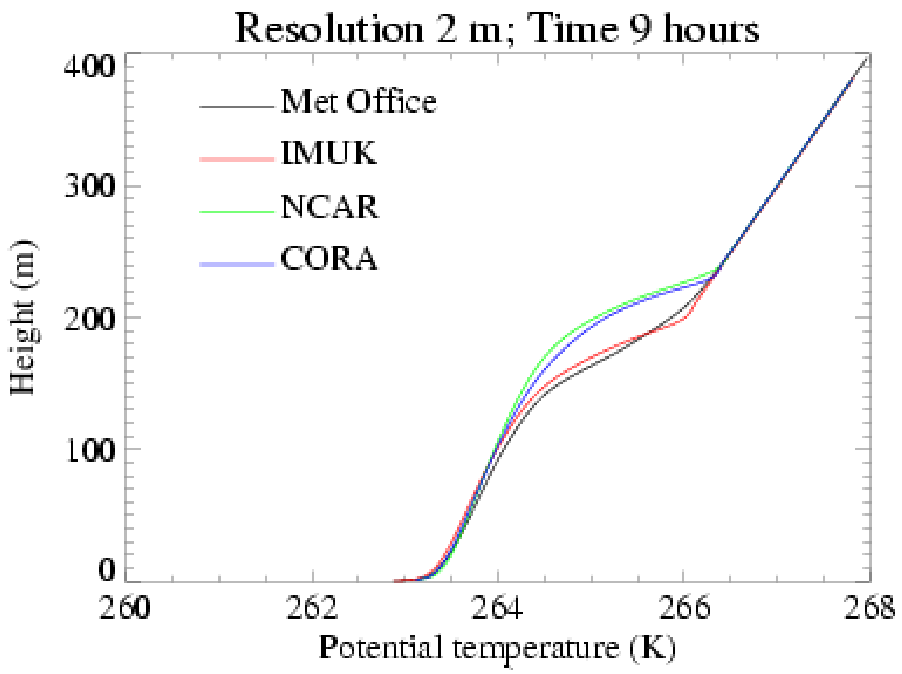
Use very high resolution to solve the turbulent flow on numerical grid

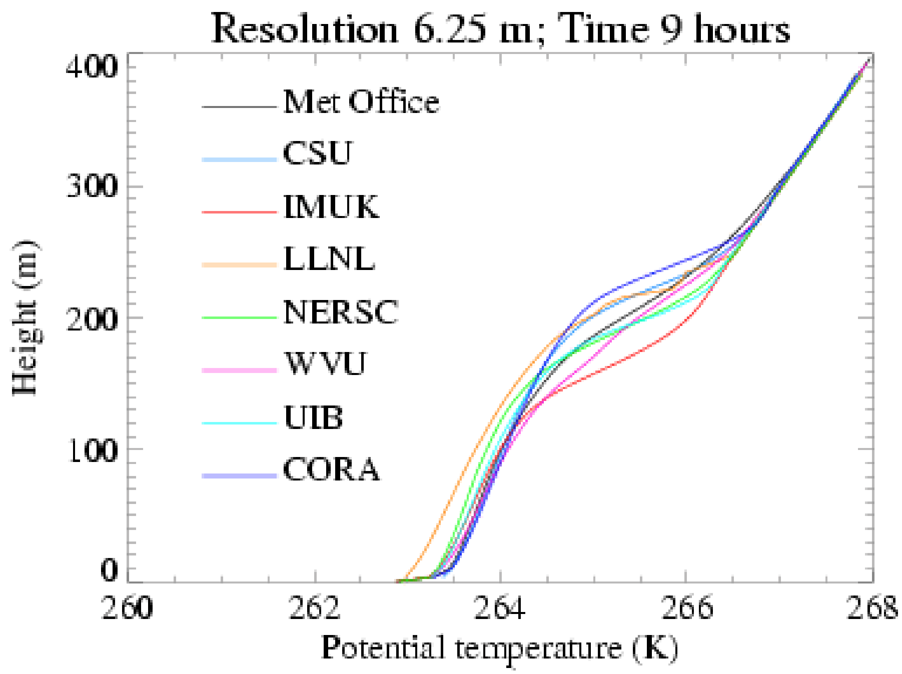
LES Participants

- Met Office, UK (Beare, MacVean, McCabe)
- CSU, USA (Khairoutdinov)
- IMUK, Germany (Raasch and Noh)
- LLNL, USA (Lundquist and Kosovic)*
- NERSC, Norway (Esau)
- WVU, USA (Lewellen)
- NCAR, USA (Sullivan)
- UIB, Spain (Cortes and Cuxart)
- CORA, USA (Lund and Paulos)
- Wageningen University, NL (Moene and Holtslag)

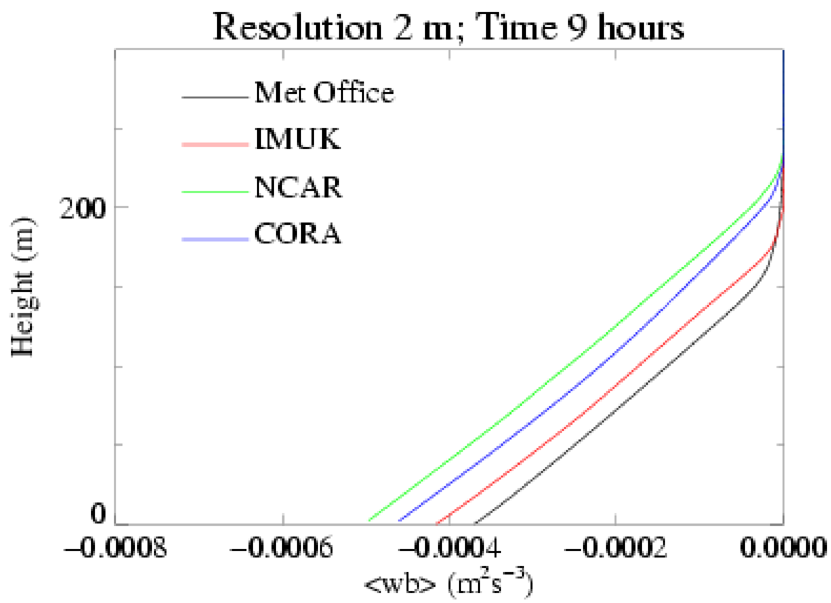
*Work performed under auspices of US Dept of Energy by Univ. of California, Lawrence Livermore National lab., Contract W-7405-Eng-48

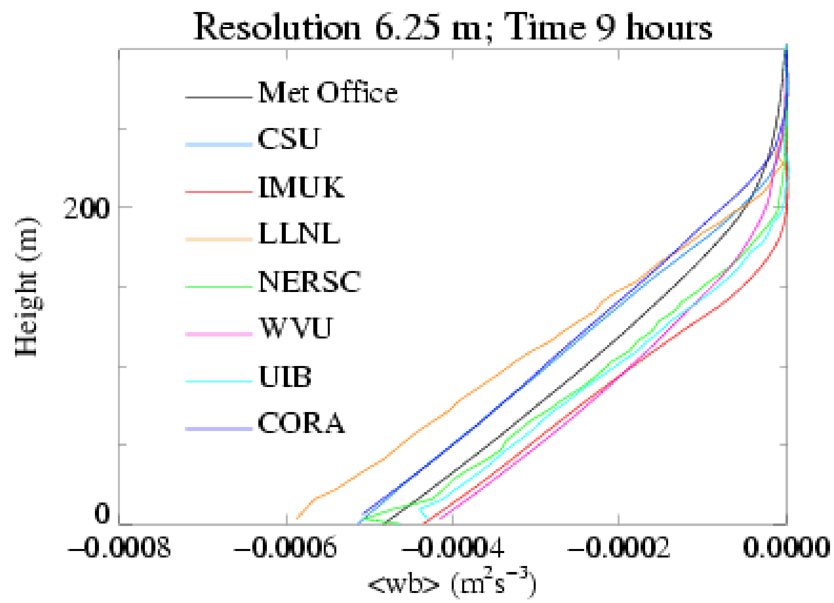
Mean potential temperature





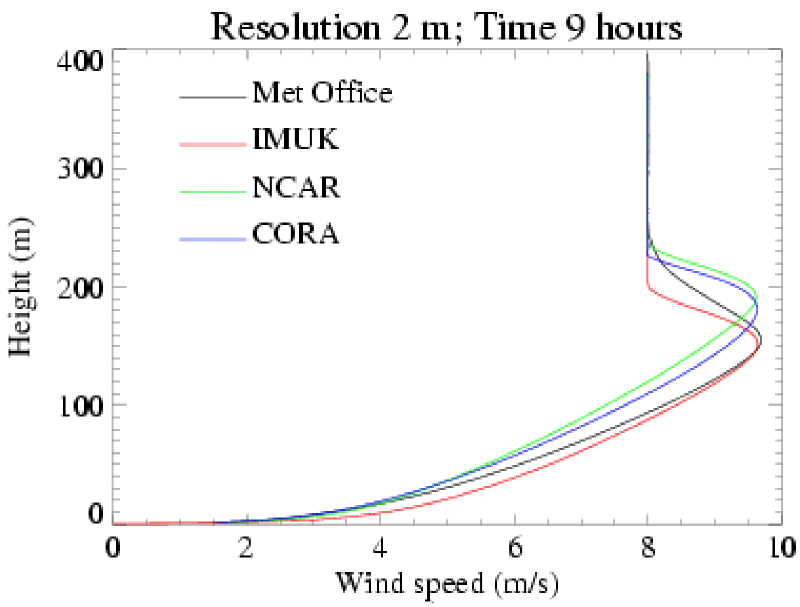
Mean heat fluxes

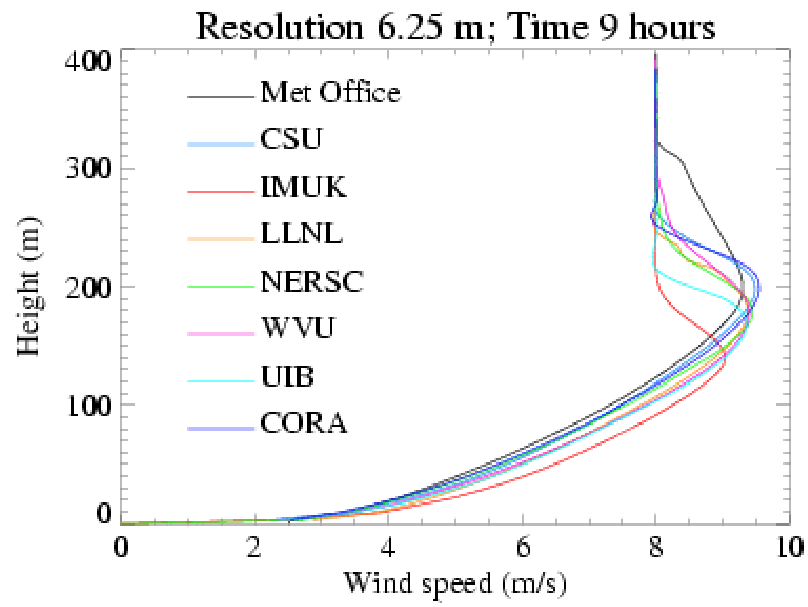




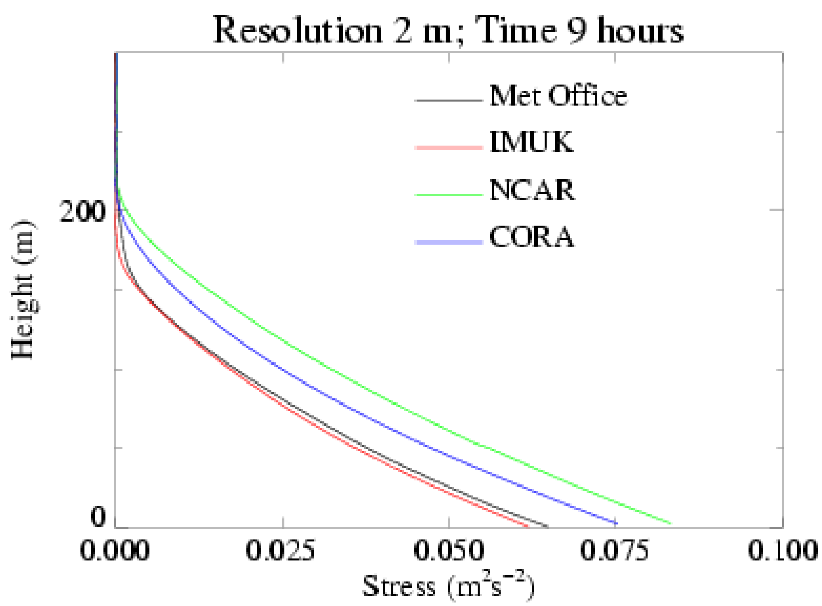
cf linear heat flux profile derived by Nieuwstadt (1984).

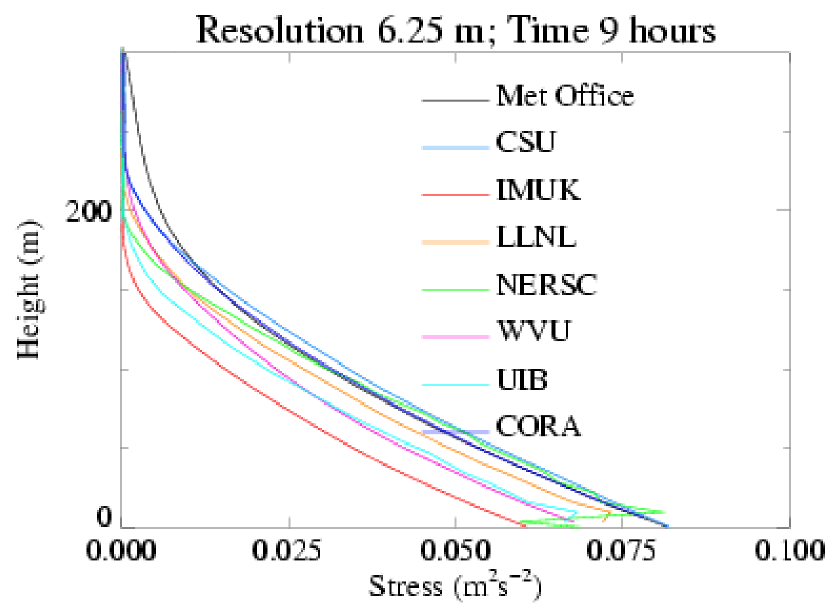
Mean wind


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

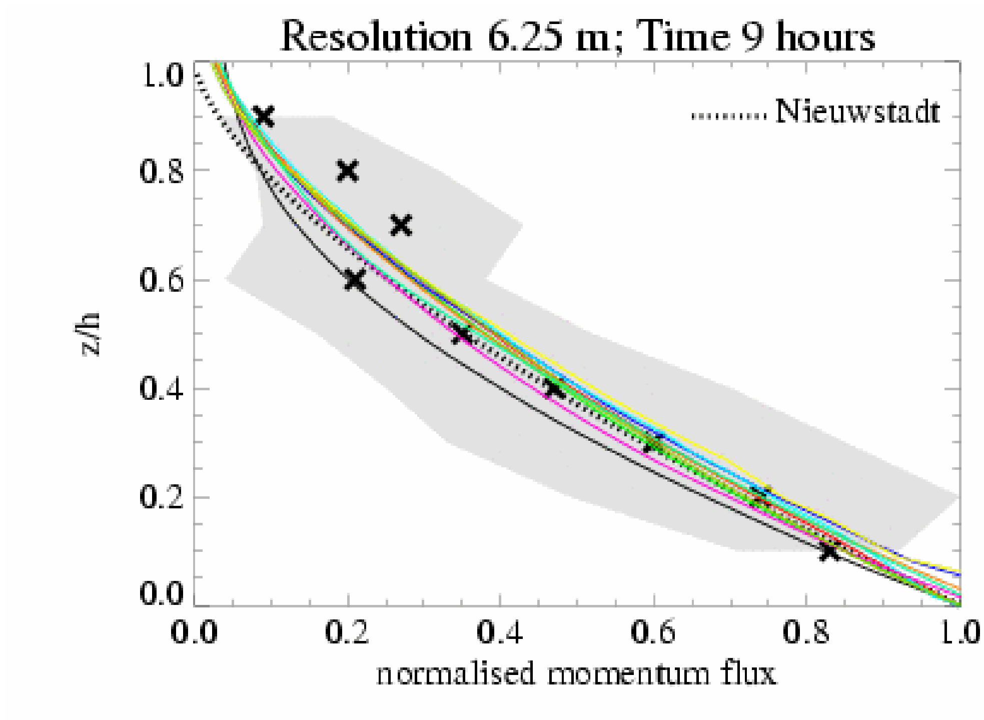

Resolution 6.25 m; Time 9 hours
Height (m)
Wind speed (m/s)
Met Office
CSU
IMUK
LLNL
NERSC
WVU
UIB
CORA
0
2
4
6
8
10
100
200
300
400

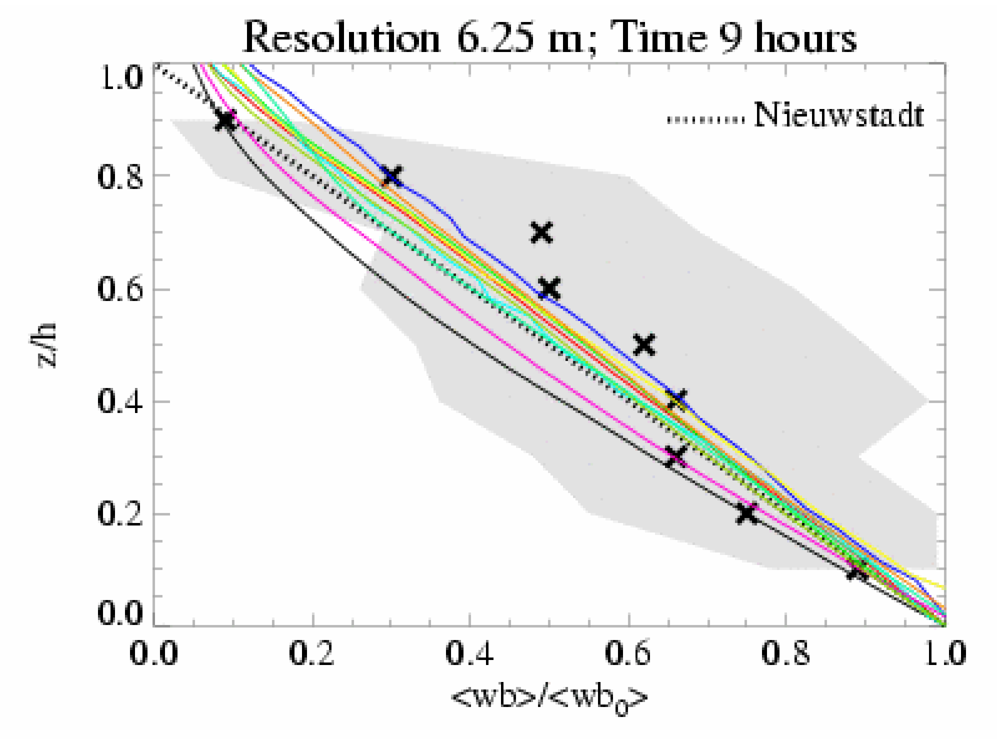
Mean stress


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})

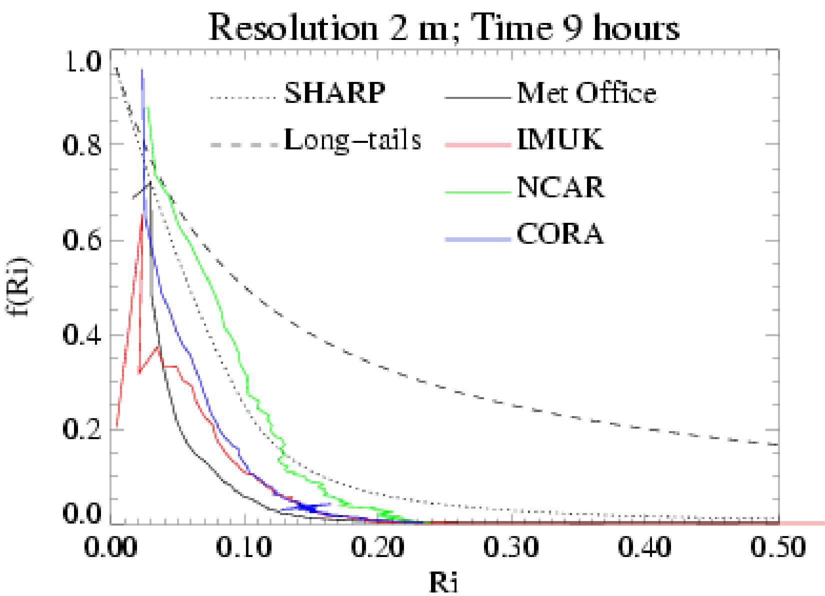
Normalized fluxes

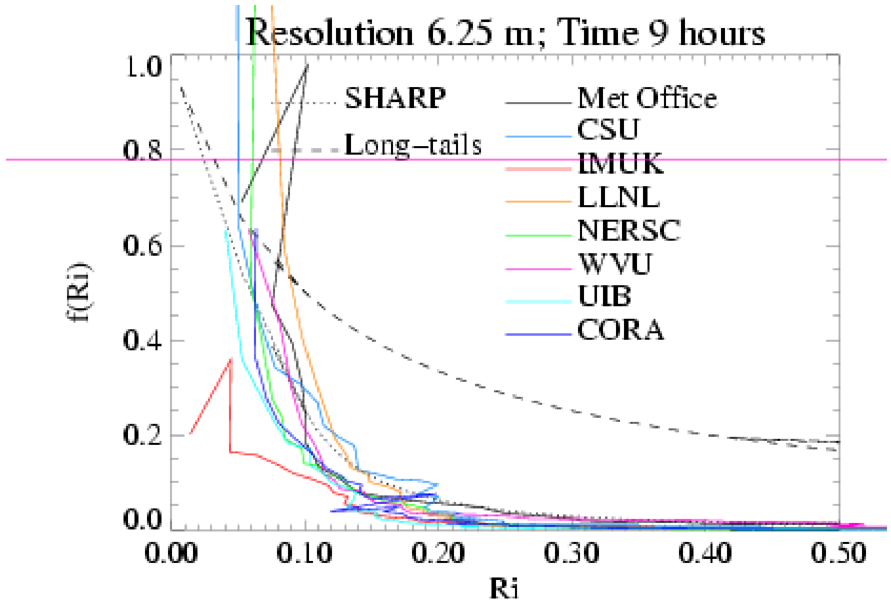




Crosses are based on Cabauw observations (Nieuwstadt 1984), with the standard deviation of the means shown by the shaded regions.

Momentum stability functions





LES is in equilibrium, flat terrain,
'Sharp tail' corresponds to observations!

Summary LES results

- Significant spread in results, but convergence at high resolution
- Sensitivity to sub-grid model
- Overall agreement with observations is fair!

Effective stability functions in agreement with observations and sharper than those typically used in Operational Models!

Intercomparison of Single-Column Models

Coordinated by
Joan Cuxart i Rodamilans, Maria Jiménez , *Laura Conangla*
Universitat de les Illes Balears (Mallorca, SP)
http://turbulencia.uib.es/gabls/

At present, results of 25 models
(many of them with sensitivity tests)
8 Operational, 17 Research models (including
10 with 'higher order' turbulence)

Various SBL parameterizations and resolutions:
Focus on operational models

The participants with operational models

- ECMWF: (OP,1st)
- *Anton Beljaars*
- NCEP: (OP, 1st)
- *Frank Freedman*

* Canadian MS: Environment Canada (OP, 1.5)

Jocelyn Mailhot

- KNMI-RACMO: Regional Atmospheric Climate model (OP,1.5) *Geert Lenderink*
- * French Meso-NH and the Spanish HIRLAM (OP,1.5),
- *Laura Conangla and Joan Cuxart*

The participants with research models

*GSPZ: Group *Galperin, Sukoriansky, Perov and Zilitinkevich* (R,1-5 k-e)

*WUR: Wageningen Univ. using Duynkerke's (1991) model (R, 1^{st})
Gert-Jan Steeneveld and Bert Holtslag

*WVU: West Virginia Univ (R, 1.5); *David Lewellen*

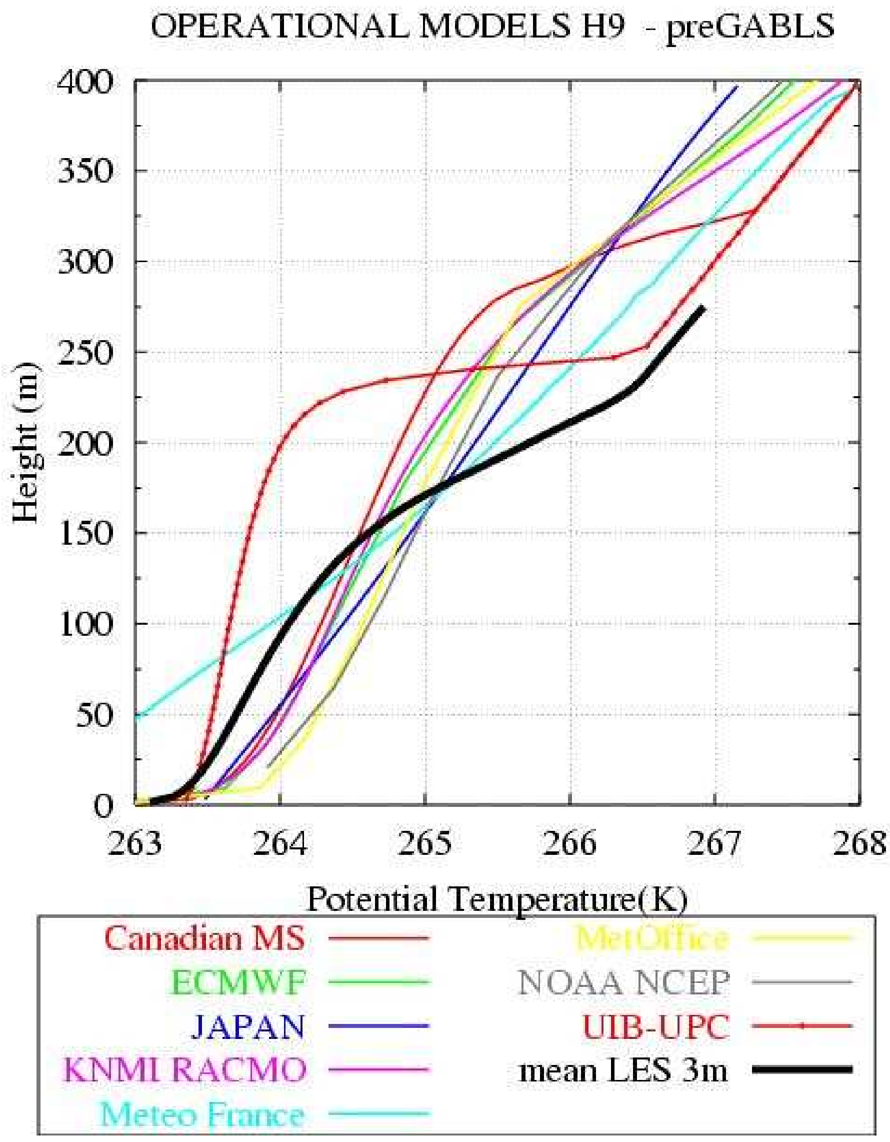
*York Univ, Canada: (R, 1.5); *Wensong Weng*

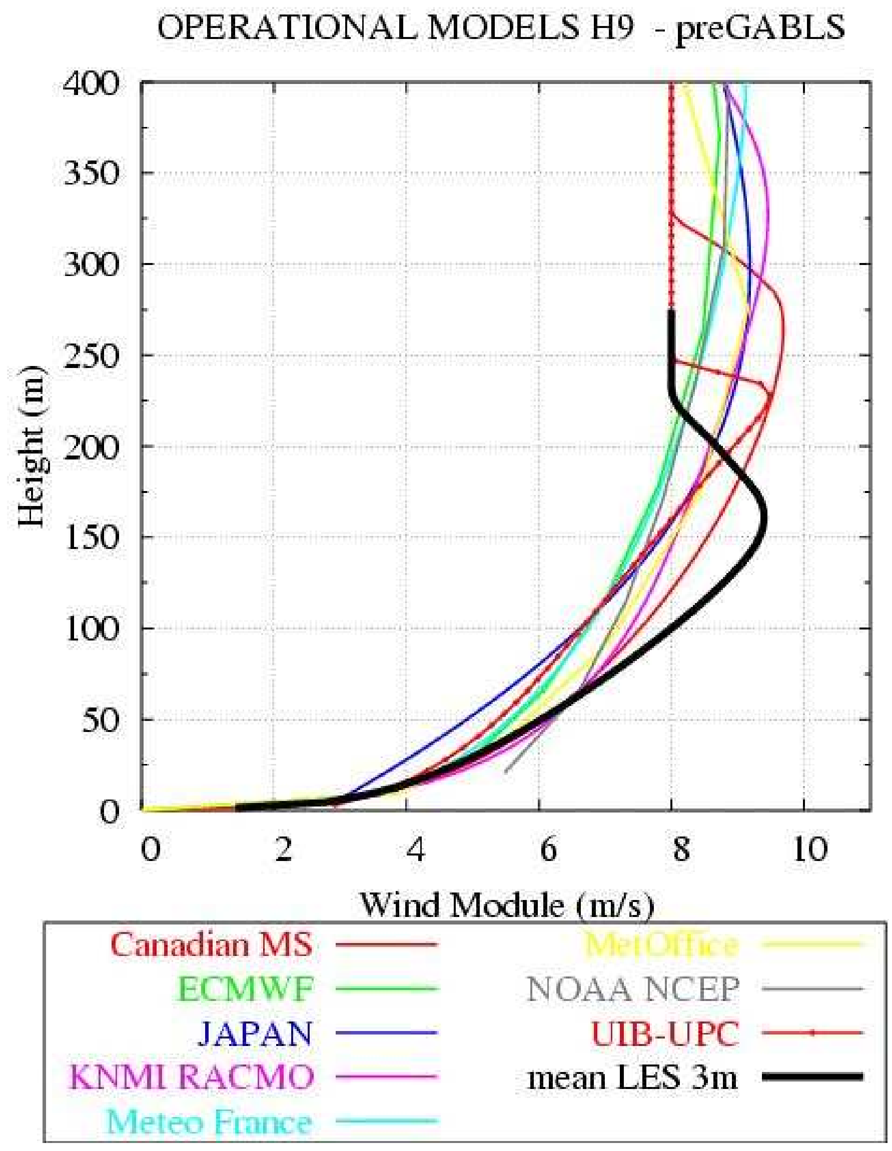
*University of Stockholm-Group 1 (R, 1.5) *Gunilla Svensson*

*University of Stockholm-Group 2 (R, 1.5 +EST)
Thorsten Mauritsen, S. Zilitinkevich, L.Enger,B.Grisogono,G.Svensson

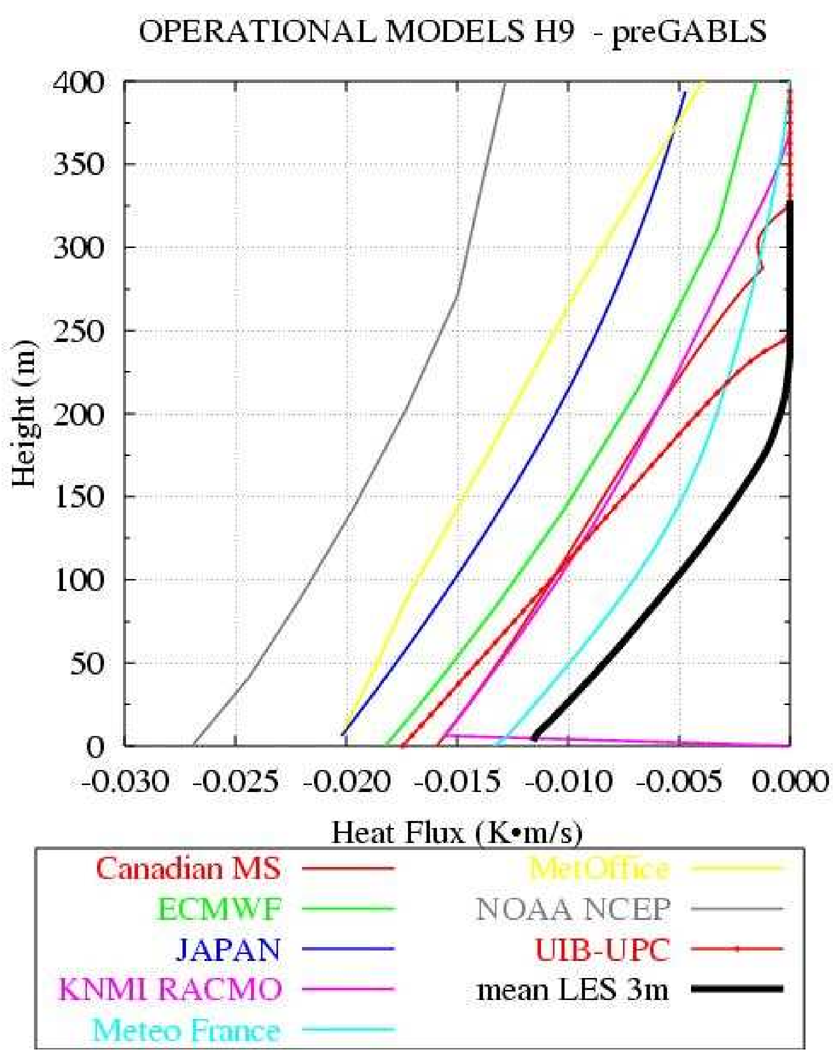
*Univ. Cat. Louvain, Belgium (R, 1.5) *Guy Schayes*

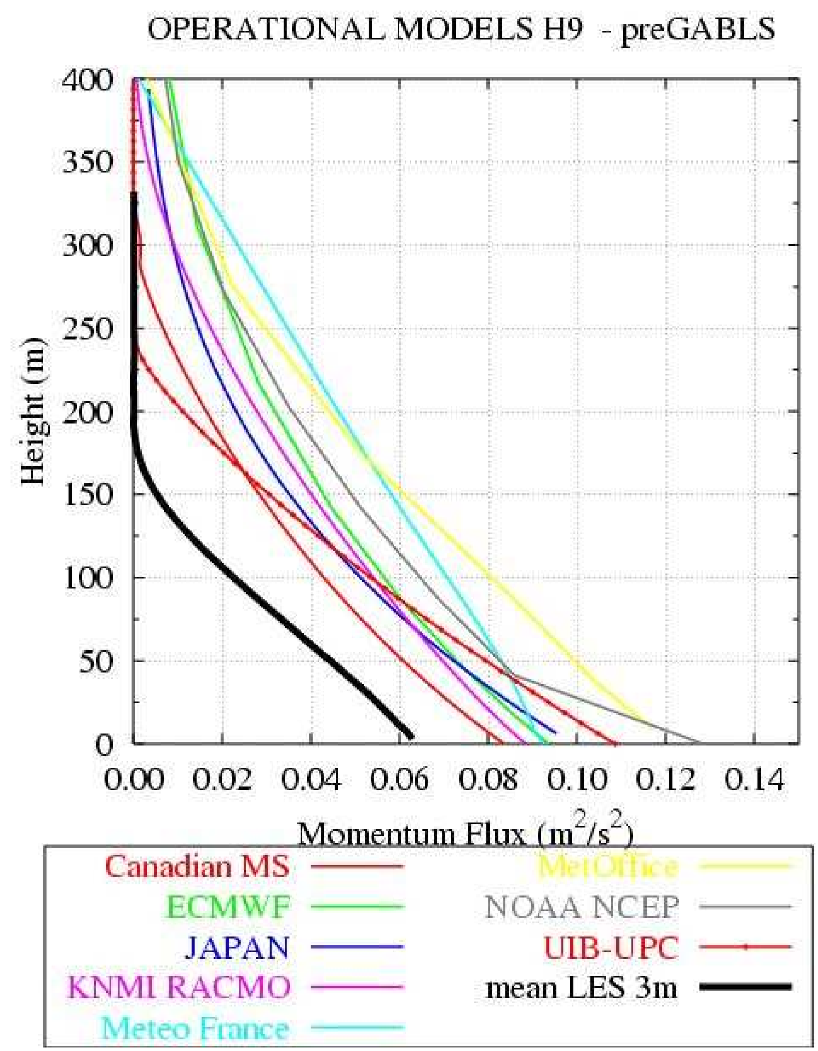
*Sandia Laboratories, California (R, ODT) *Scott Wunsch, Alan Kerstein*
*NASA (R,1.5) *Kuan-Man Xu, Anning Cheng*

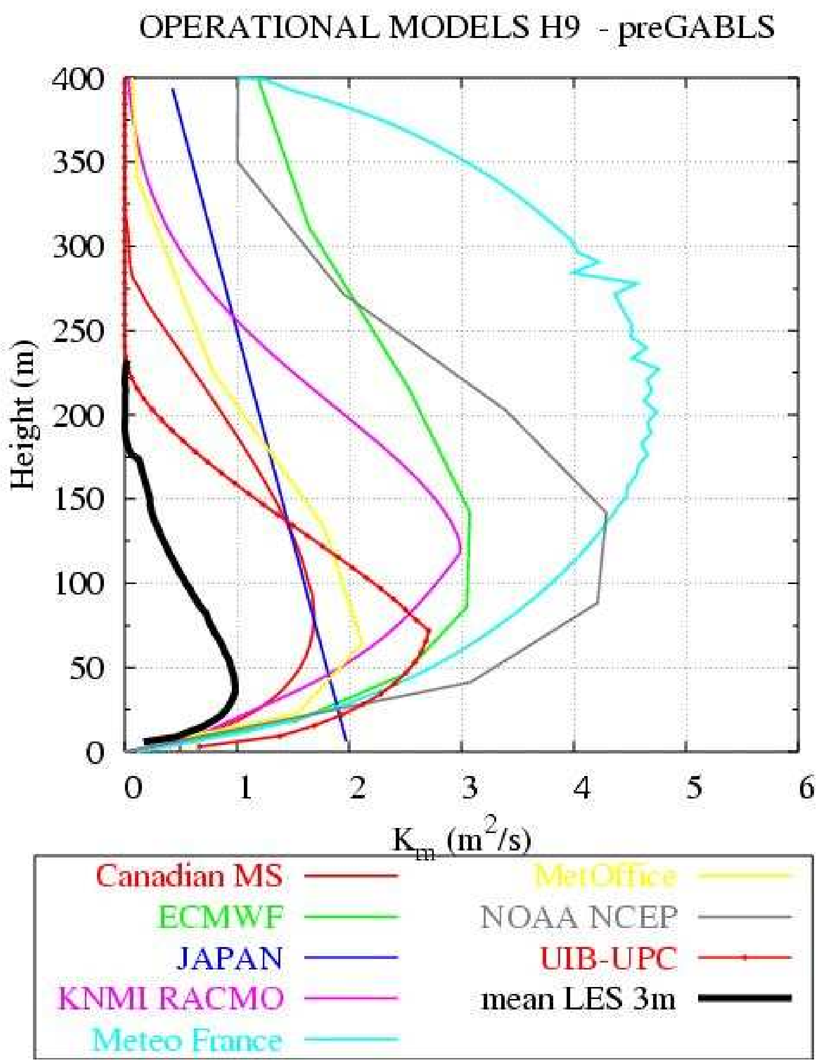


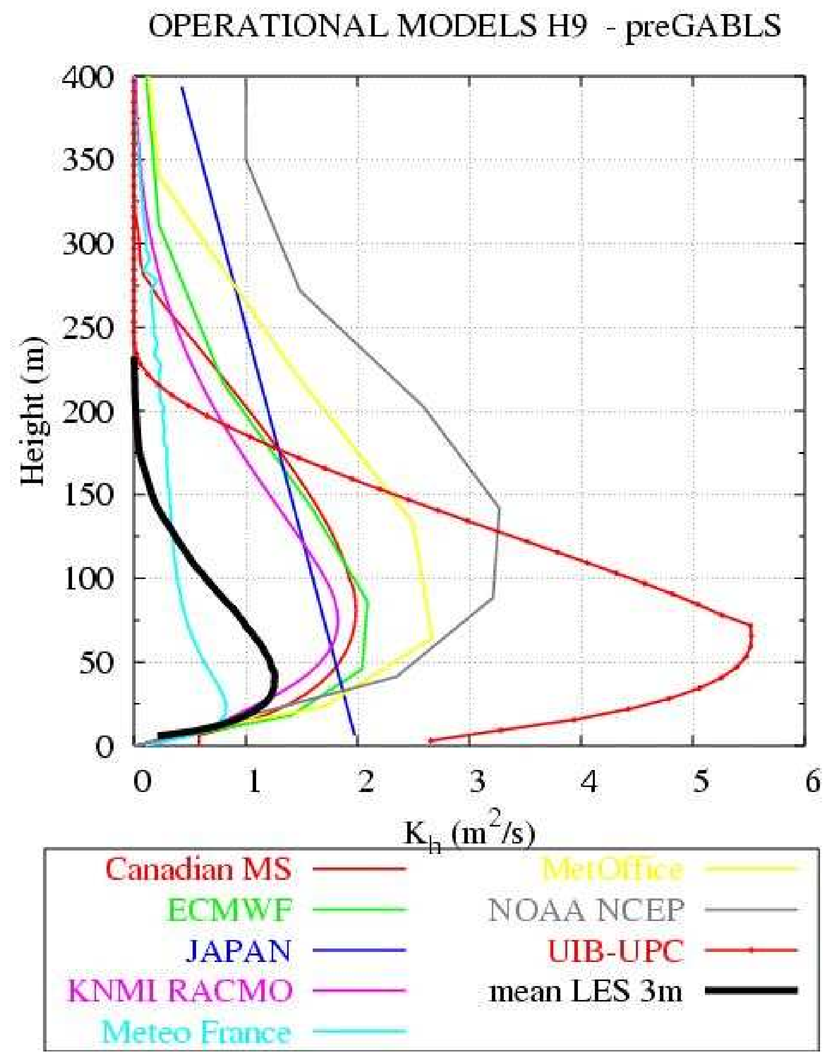


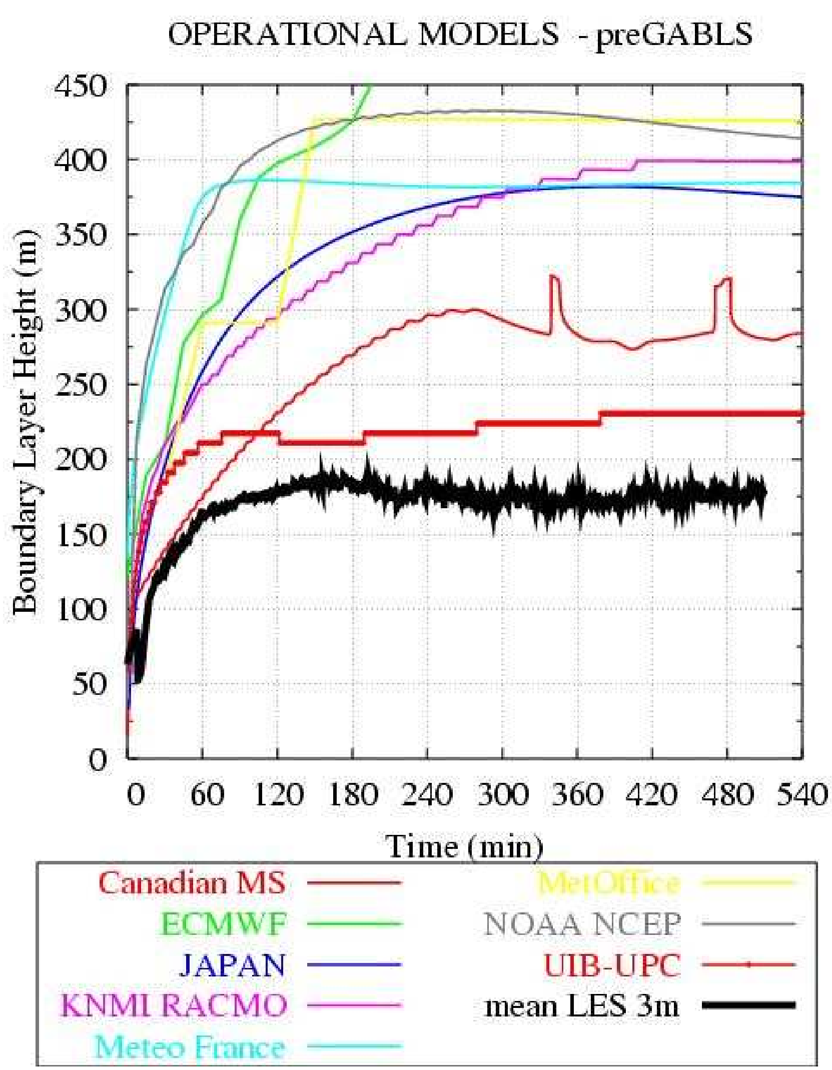
Resolution (most) operational models is set to 6.25 m!


OPERATIONAL MODELS H9 - preGABLS
Height (m)
Heat Flux (K•m/s)
Canadian MS
ECMWF
JAPAN
KNMI RACMO
Meteo France
MetOffice
NOAA NCEP
UIB-UPC
mean LES 3m

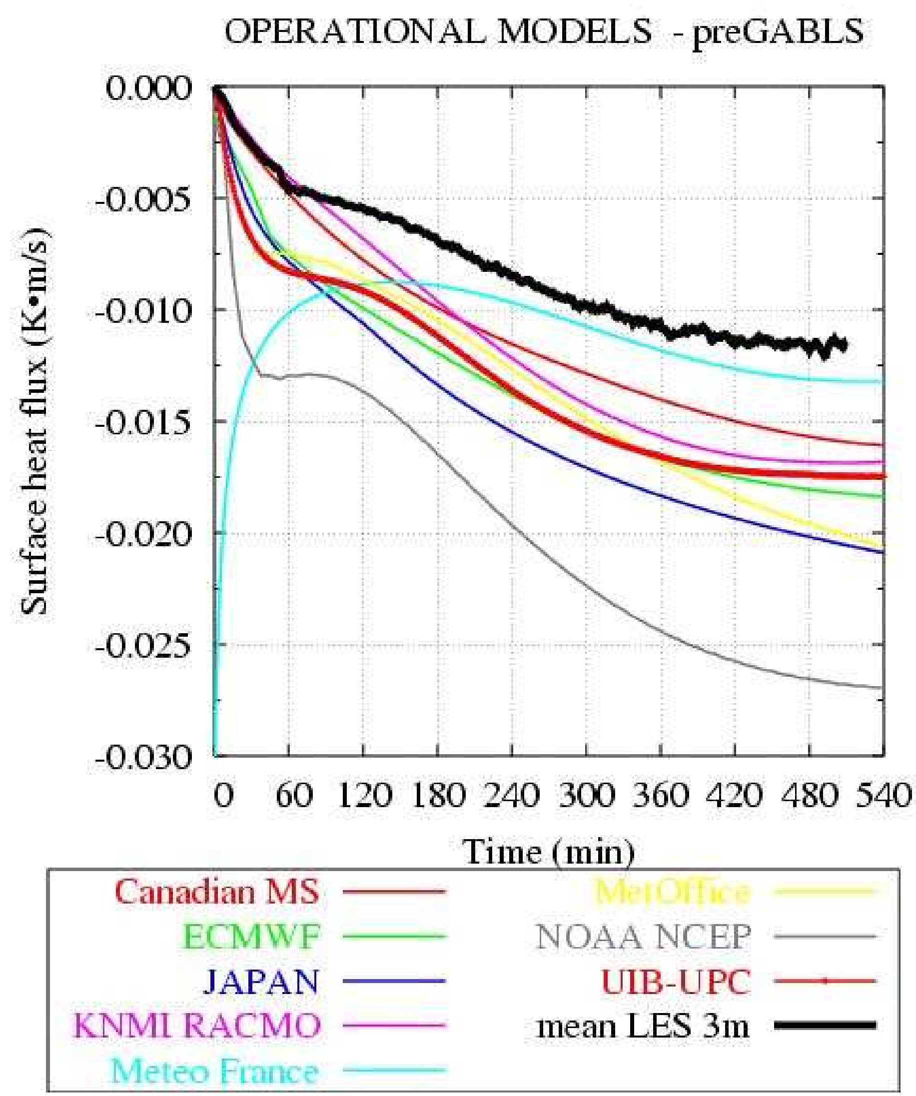

OPERATIONAL MODELS H9 - preGABLS
Height (m)
Momentum Flux (m²/s²)
Canadian MS
ECMWF
JAPAN
KNMI RACMO
Meteo France
MetOffice
NOAA NCEP
UIB-UPC
mean LES 3m


OPERATIONAL MODELS H9 - preGABLS
Height (m)
K_m (m^2/s)
Canadian MS
ECMWF
JAPAN
KNMI RACMO
Meteo France
MetOffice
NOAA NCEP
UIB-UPC
mean LES 3m


OPERATIONAL MODELS H9 - preGABLS
Height (m)
K_h (m^2/s)
Canadian MS
ECMWF
JAPAN
KNMI RACMO
Meteo France
MetOffice
NOAA NCEP
UIB-UPC
mean LES 3m

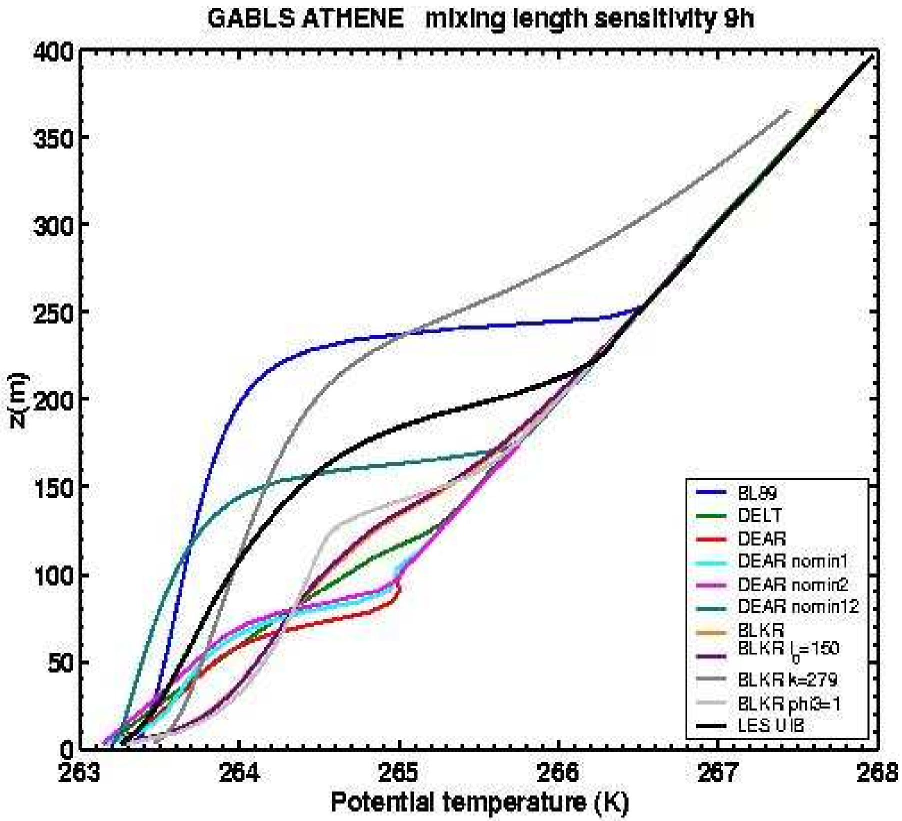


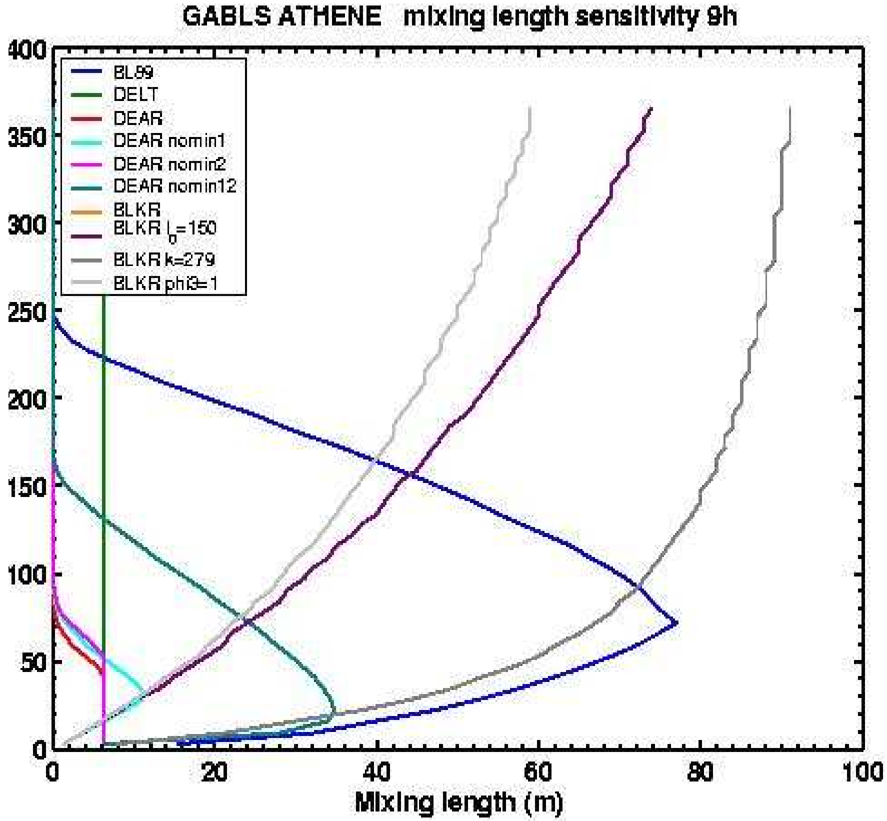
OPERATIONAL MODELS - preGABLS
Boundary Layer Height (m)
0
50
100
150
200
250
300
350
400
450
0
60
120
180
240
300
360
420
480
540
Time (min)
Canadian MS
ECMWF
JAPAN
KNMI RACMO
Meteo France
MetOffice
NOAA NCEP
UIB-UPC
mean LES 3m



OPERATIONAL MODELS - preGABLS
Surface heat flux (K•m/s)
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
0
60
120
180
240
300
360
420
480
540
Time (min)
Canadian MS
ECMWF
JAPAN
KNMI RACMO
Meteo France
MetOffice
NOAA NCEP
UIB-UPC
mean LES 3m

Test with one model (UIB-UPC) changing the mixing length





Summary 1D models

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

Length scale and stability function matter,
atmospheric resolution not so much!

Comparison with observations
and with scaling results needed

Coupling to surface energy budget
will be further explored (Steeneveld, Holtslag)

Open questions

How do models compare with the observations in more complex situations?

Which role for Atmosphere - Land Surface coupling, heterogeneity aspects?

How to classify the available data?

Do we overlook an atmospheric process?

Future work

New *simple* cases for LES and 1D models

Further exploration of data!

More studies with 1D and Mesoscale models
inspired by observations, e.g. select cases for
CASES-99, Cabauw, Lindenberg (coupling to land)
Halley (Antarctica), Sweden (strong inversions),
SABLES98 (elevated turbulence),
et cetera

Inclusion of full diurnal cycle

Activities 2004

GABLS session at AMS/BLT16, Portland, Maine, August 2004

Special GABLS issue in Boundary-Layer Meteorology