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GEWEX Atmospheric Boundary Layer Model Inter-comparison Studies

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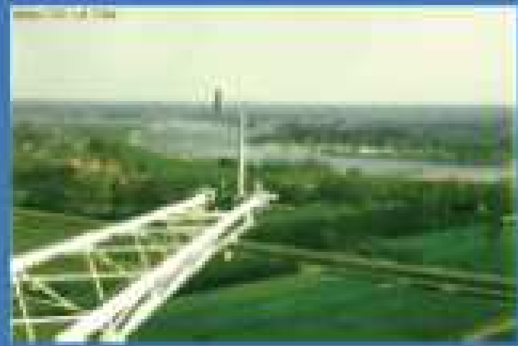
Motivation

Numerical weather prediction and climate models continue to have large errors for stable boundary layers (SBL). To understand and to improve on this, so far three atmospheric boundary layer model inter-comparison studies have been organised within the Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP).

Previous GEWEX ABL Studies (GABLS)

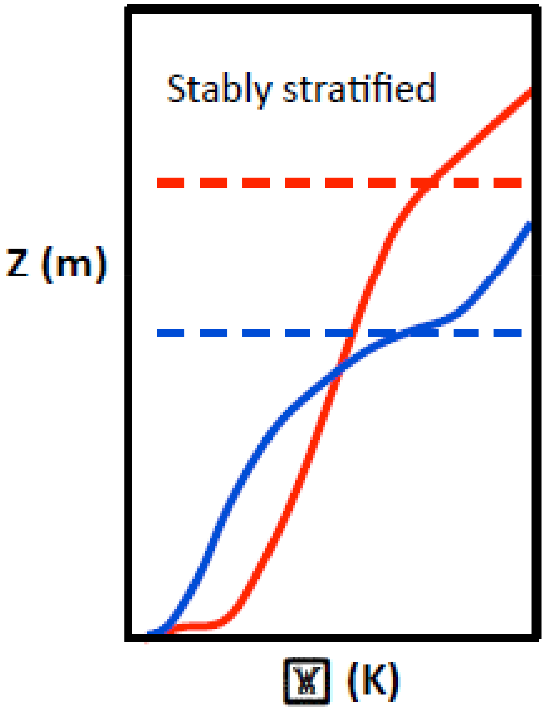
have joined about 20 research groups to model:

- the SBL (GABLS1)
- the diurnal cycle (GABLS2, GABLS3), and
- the nocturnal low-level jet (GABLS3).

GABLS1	GABLS2	GABLS3
		
LES as reference	Data (CASES99)	Data (CABAUW)
Academic set up	Idealized forcings	Realistic forcings
Prescribed T_s	Prescribed T_s	Full coupling *(SCM)* Prescribed T_s *(LES)*
No Radiation	No Radiation	Radiation included
Turbulent mixing	Diurnal cycle	Low levet jet + transitions

LES: Large Eddy Simulation; *SCM:* Single Column Model

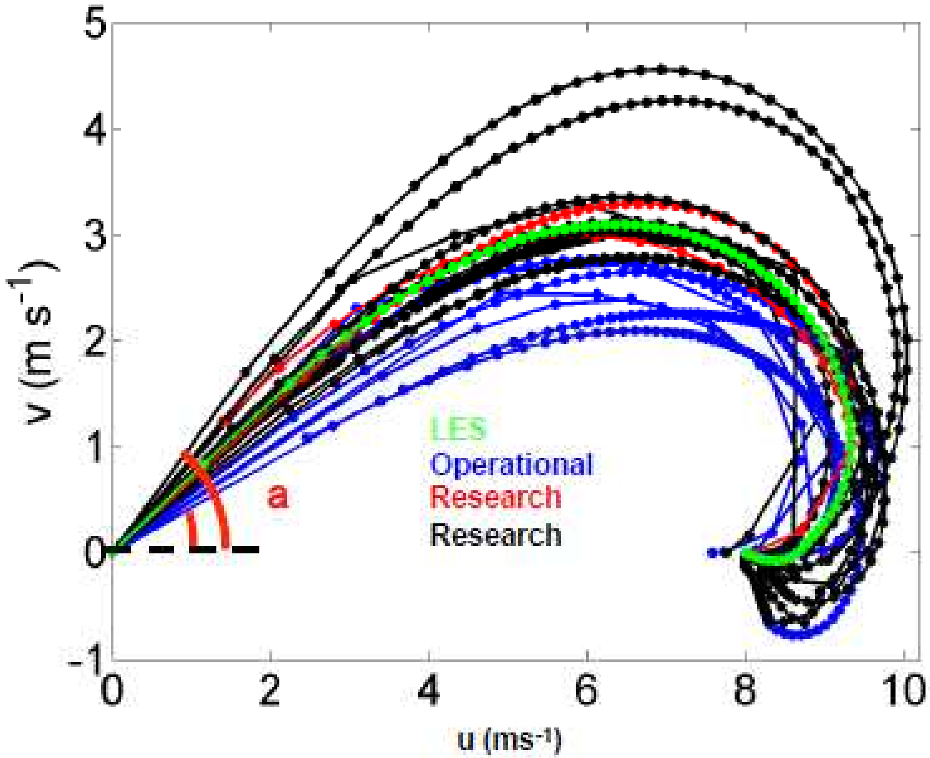
GABLS1
NWP too strong night-time mixing



NWP models
(boundary layer up to factor 2 too deep!)

LES
Research models
(boundary layer height order 180 m)

Too small near-surface wind direction



GABLS1

LES models are able to simulate a weakly stably stratified boundary layer

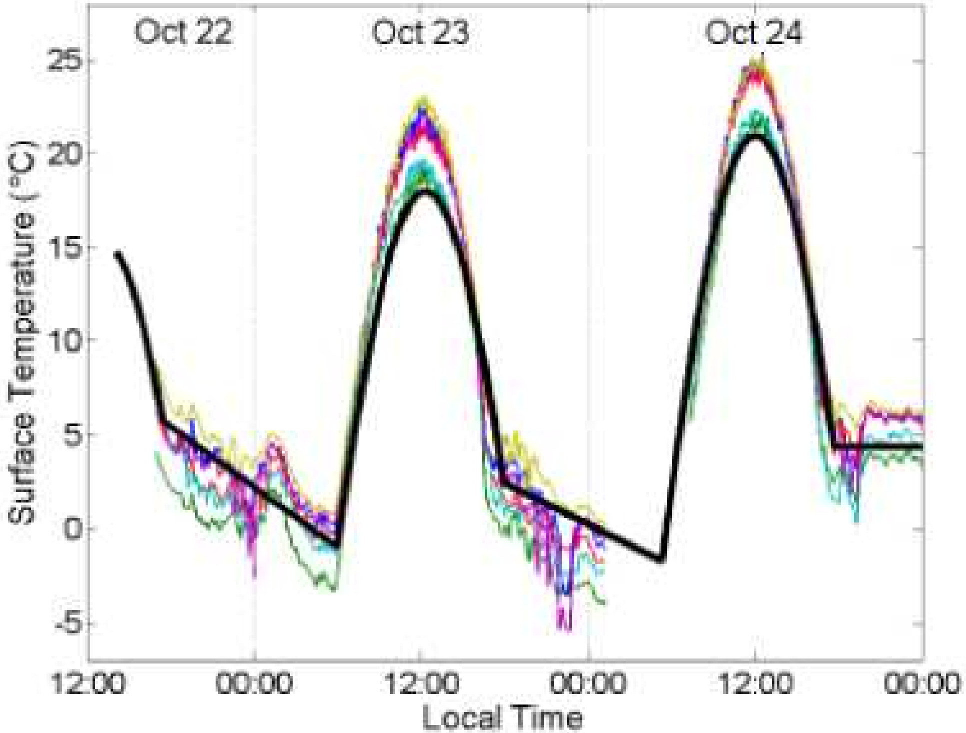
Large variation among 1D models, but all operational models show too strong mixing!

Many tests and new formulations in NWP models were initiated after this study but the general problem is not solved!

Special issue of Boundary-Layer Meteorology, 2006
(e.g. Beare et al., Cuxart et al., Holtslag and 5 other papers)
Wind turning issue discussed by Svensson and Holtslag (2009)

GABLS2 (coordinated by Gunilla Svensson):

Intercomparison of 19 SCM models on basis of CASES99 observations for a period of 2.5 days (after Steeneveld et al 2006);
Also LES run by Kumar et al (2010)



Prescribed surface temperature using the local observations
Also same initial conditions and forcings for wind and humidity

Summary GABLS2 (Svensson et al, 2011)

Within GABLS2 we find large variation for diurnal cycle among different boundary layer schemes, and typically underestimation of morning wind magnitude

More complexity does not really help

It seems that the variety of model results is influenced by using a prescribed surface temperature

Including surface temperature feedback can compensate for some of the variety introduced by changing model parameters (Holtslag et al, 2007)

GABLS3: SCM and LES model studies

GABLS3-SCM

12 Z 01 July 2006 → 12 Z 02 Jul

GABLS3-LES

00 Z 02 Jul → 09 Z 02 Jul

Cabauw tower (KNMI, NL)

Initialization Profiles

Cabauw tower, Profiler, De Bilt Sounding

Geostrophic Wind (time-height dependent)

Similar for both SCM and LES

Large-scale Advection (time-height dependent)

Similar for both SCM and LES

Surface Boundary Conditions

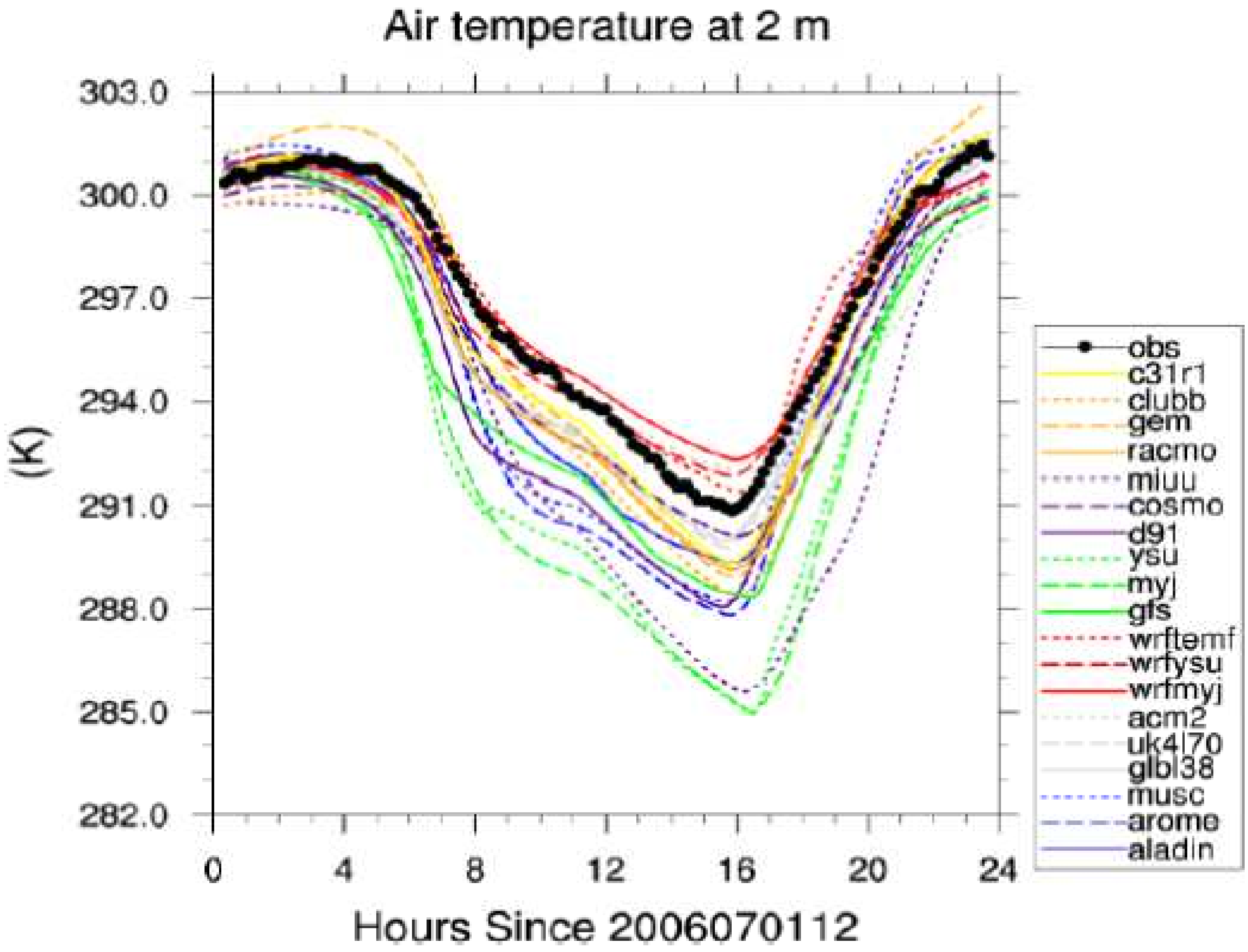
Cabauw tower

GABLS3 Single-column model experiments

GABLS3 intercomparison of Single Column versions (SCM) of operational and research models (Coordinated by Fred Bosveld, KNMI)

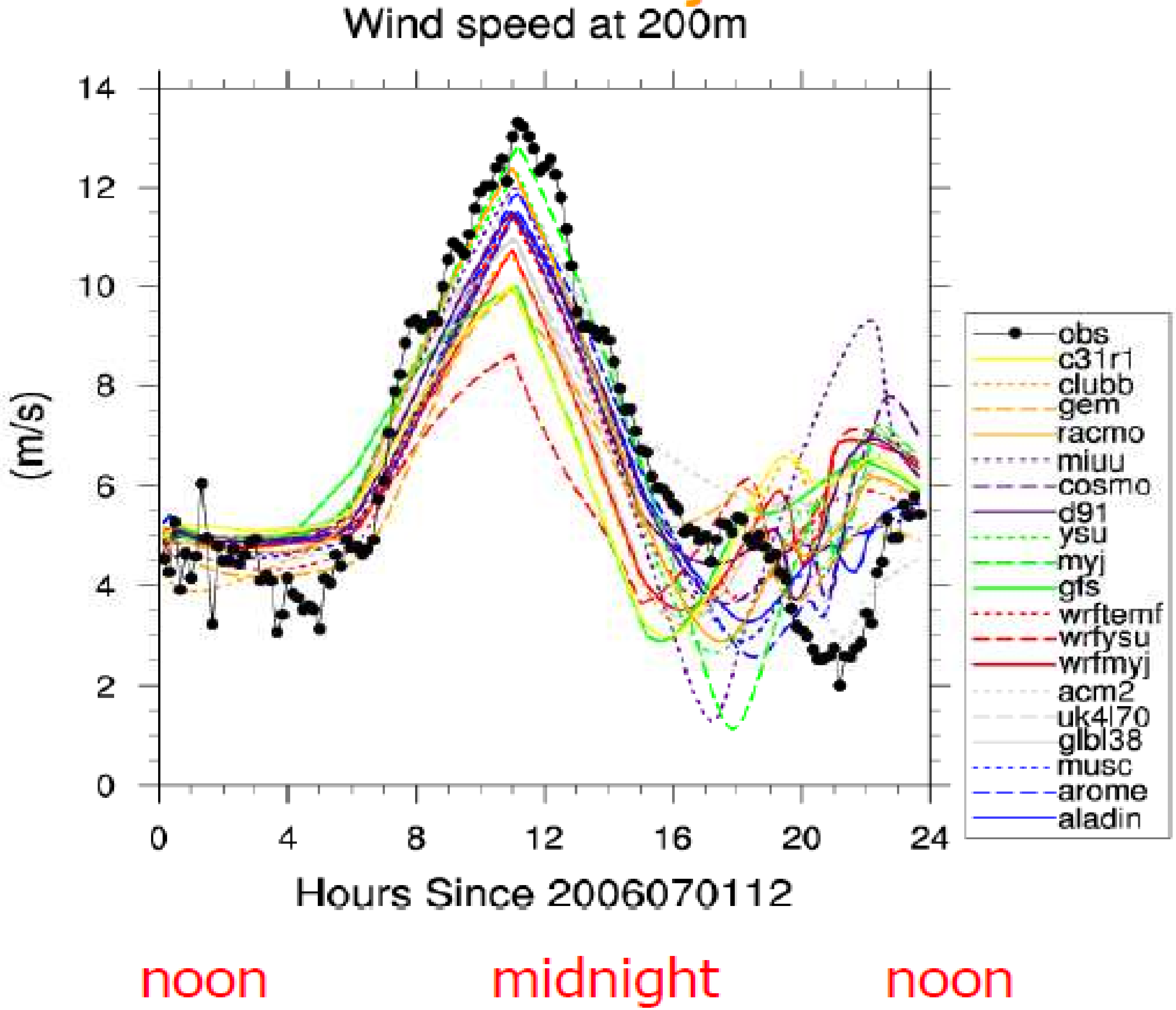
Note:
Each SCM uses its own radiation and land surface scheme interacting with the boundary layer scheme on usual resolution! (Nlev is number of vertical levels in whole atmosphere)

Name	Institute	Nlev	BL.Scheme	Skin
ALADIN	Meteo France	41	TKE	No
AROME	Meteo France	41	TKE	No
GLBL38	Met Office	38	K (long tail)	Yes
UK4L70	Met Office	70	K (short tail)	Yes
D91	WUR	91	K	Yes
GEM	Env. Cananda	89	TKE-l	No
ACM2	NOAA	155	K+non-local	No
WRF YSU	NOAA	61	K	No
WRF MYJ	NOAA	61	TKE-l	No
WRFTEMF	NOAA	61	Total E	No
COSMO	DWD	41		
GFS	NCEP	57	K	Yes
WRF MYJ	NCEP	57	TKE-l	Yes
WRF YSU	NCEP	57	K	Yes
MIUU	MISU	65	2nd order	
MUSC	KNMI	41	TKE-l	No
RACMO	KNMI	80	TKE	Yes
C31R1	ECMWF	80	K	Yes
CLUBB	UWM	250	Higher order	No



noon midnight noon

Low level jet



Conclusions from GABLS 1-3

- Diurnal cycles of temperature and wind continue to be a challenge for NWP and climate models

- inter-model scatter is large for all SBL variables

- sensitive processes in SBL include turbulent mixing, surface-interactions, and longwave radiation divergence

- GABLS experiments suggest that operational models typically overestimate mixing in SBL. This is supported by several 3D experiments and validation studies (Louis et al, 1982; Beare, 2007; Steeneveld et al, 2010; Lüpkes et al., 2010; Tastula and Vihma, 2011; Jakobson et al., 2012; Atlaskin and Vihma, 2012)

So far not addressed in GABLS

- long-lived very stable stratification
- ABL over polar regions with validation against observations

  Actual topic because of:
  - decrease of Arctic sea ice cover vs. increase in the Antarctic
  - collapse of Antarctic ice shelves
  - rapid melting of continental glaciers and permafrost

Plan for GABLS4

We explore the set-up of GABLS4 over the Brunt Ice Shelf, Antarctica, where the British Antarctic Survey carries out measurements at the Halley station

Halley station

75°35'S, 26°34'W, since 1956

Halley observations

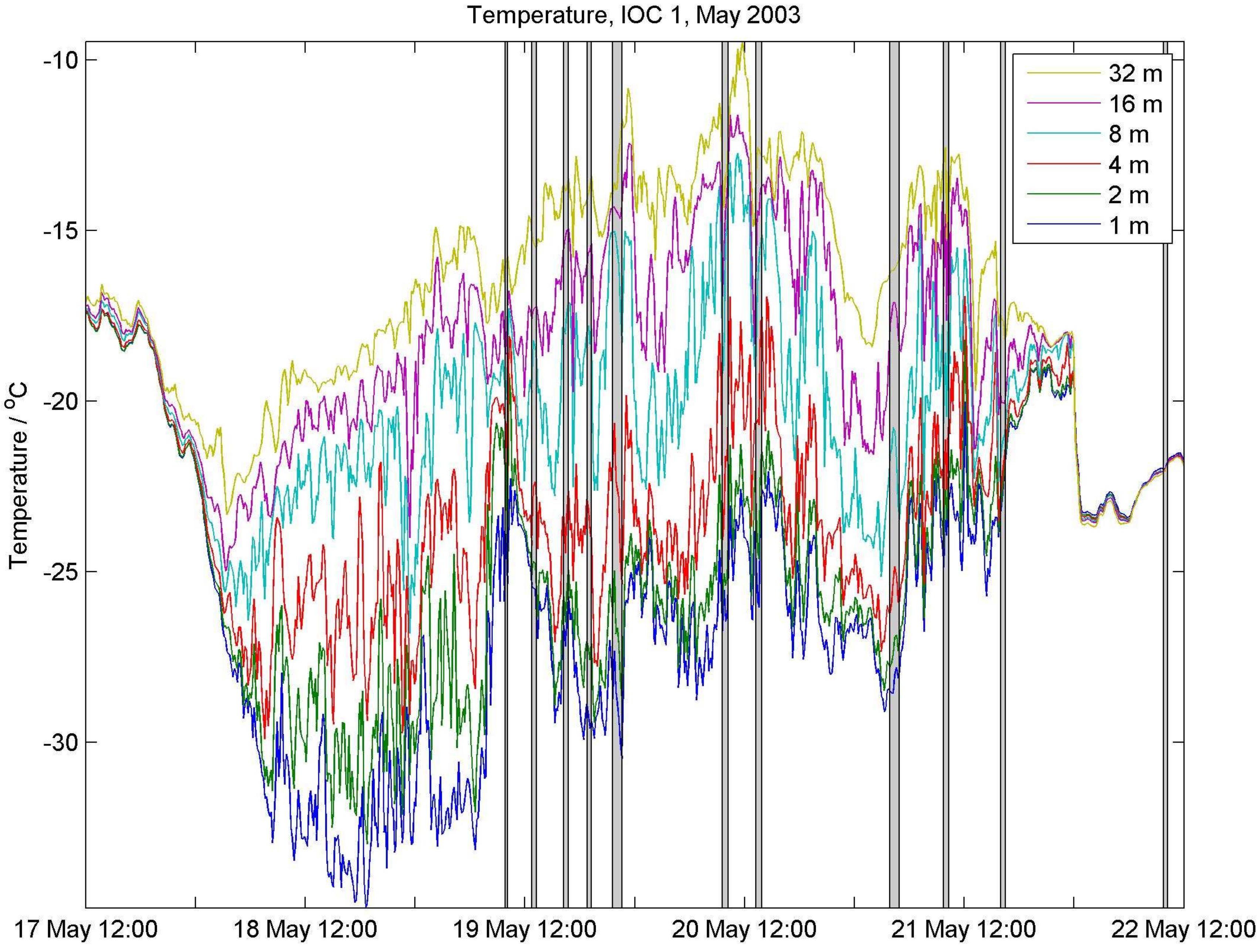
- 32-m-high mast

- Air temperature, relative humidity, wind speed and direction at 1, 2, 4, 8, 16, and 32 m

- 3D sonic anemometers at 4, 16, and 32 m → turbulence statistics and fluxes of momentum and sensible heat

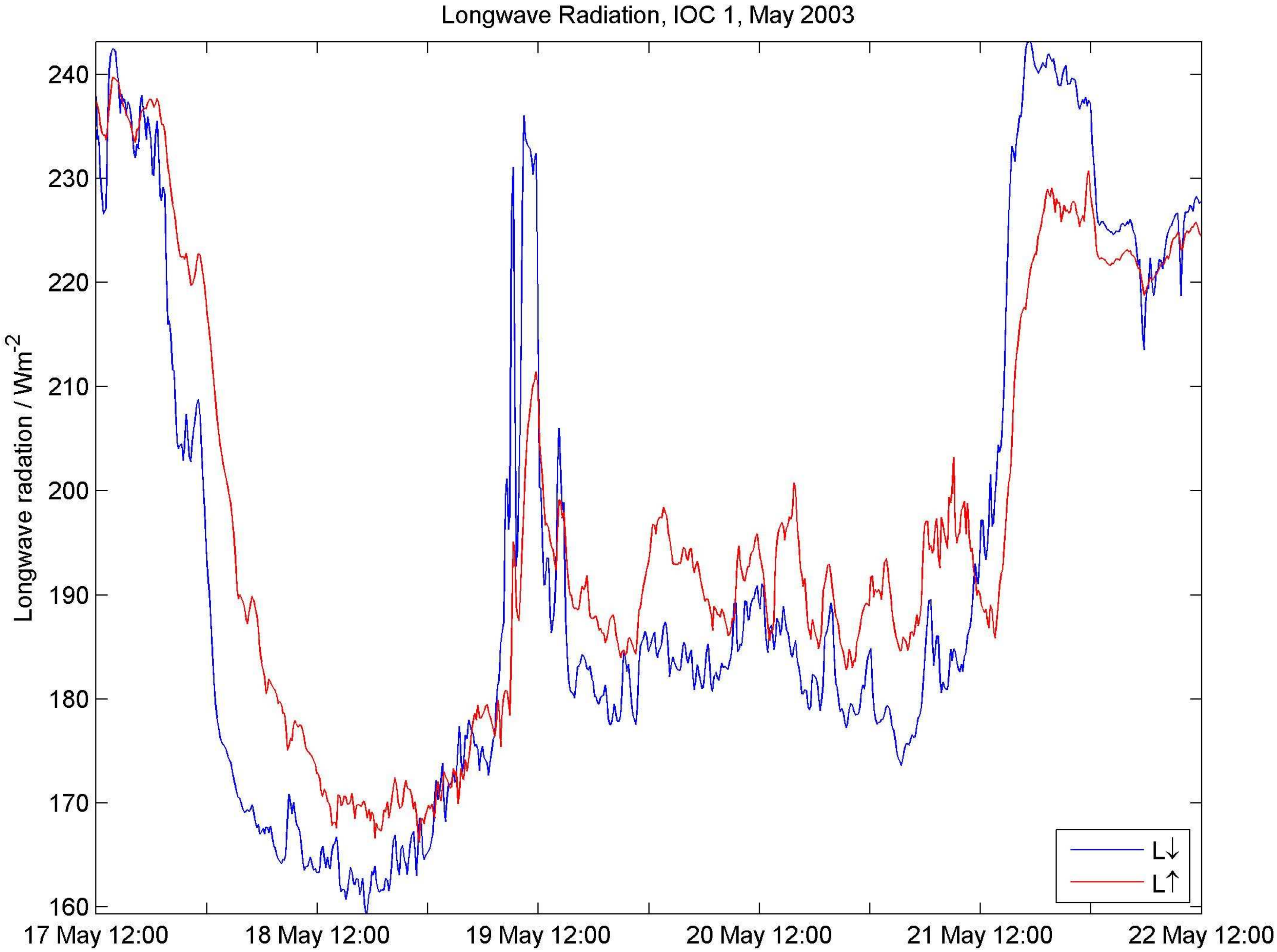
- Snow temperatures at 10 cm intervals: 20 sensors at depths which gradually change due to accumulation
- Rawinsonde soundings once a day at 10-12 UTC
- Tethersonde soundings during campaigns
- upward and downward shortwave and longwave radiation
- Sodar
- microbarograph array
- visual cloud observations

May 2003



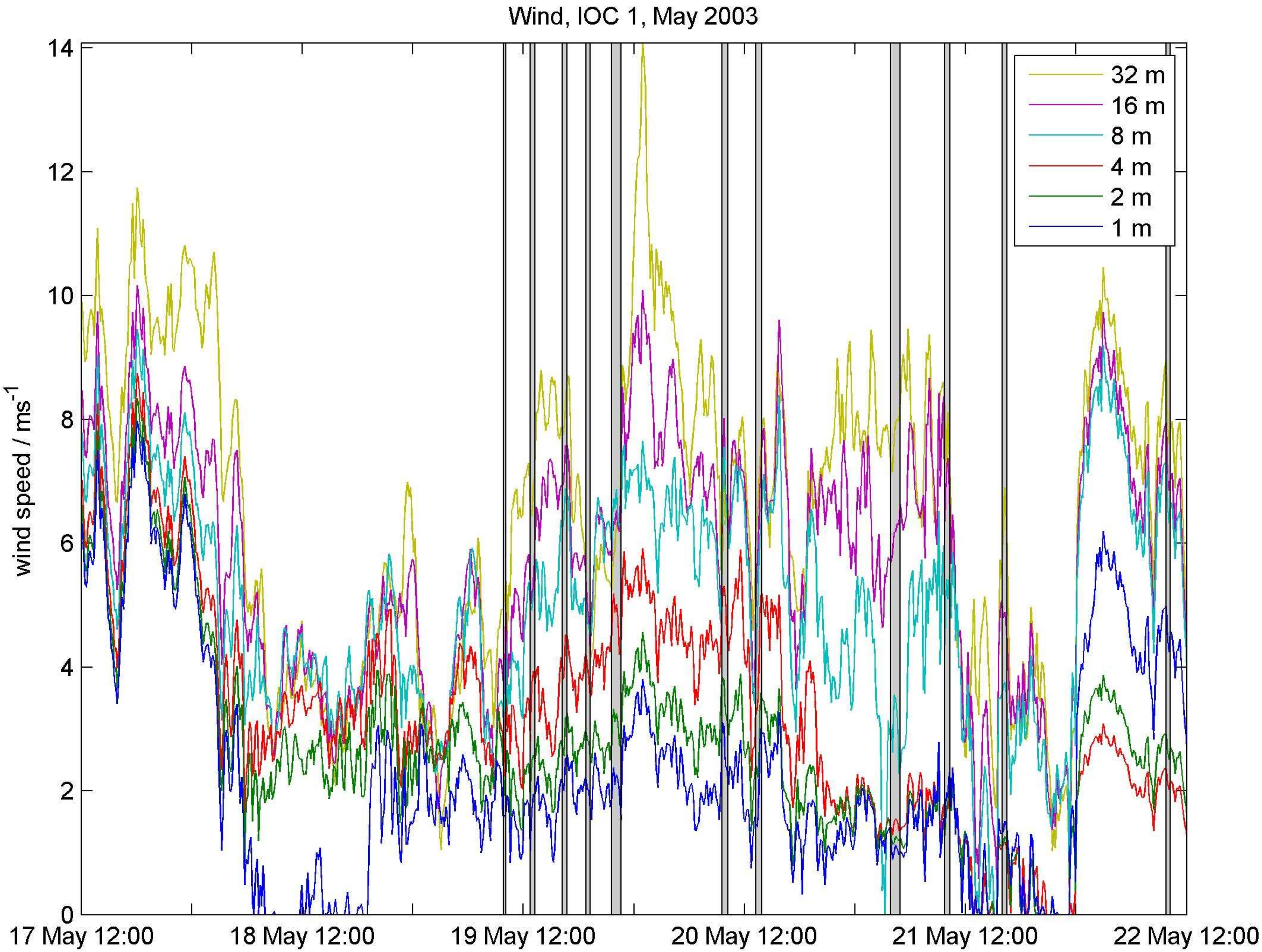
Temperature, IOC 1, May 2003
-10
-15
-20
-25
-30
Temperature / °C
17 May 12:00
18 May 12:00
19 May 12:00
20 May 12:00
21 May 12:00
22 May 12:00
32 m
16 m
8 m
4 m
2 m
1 m

May 2003



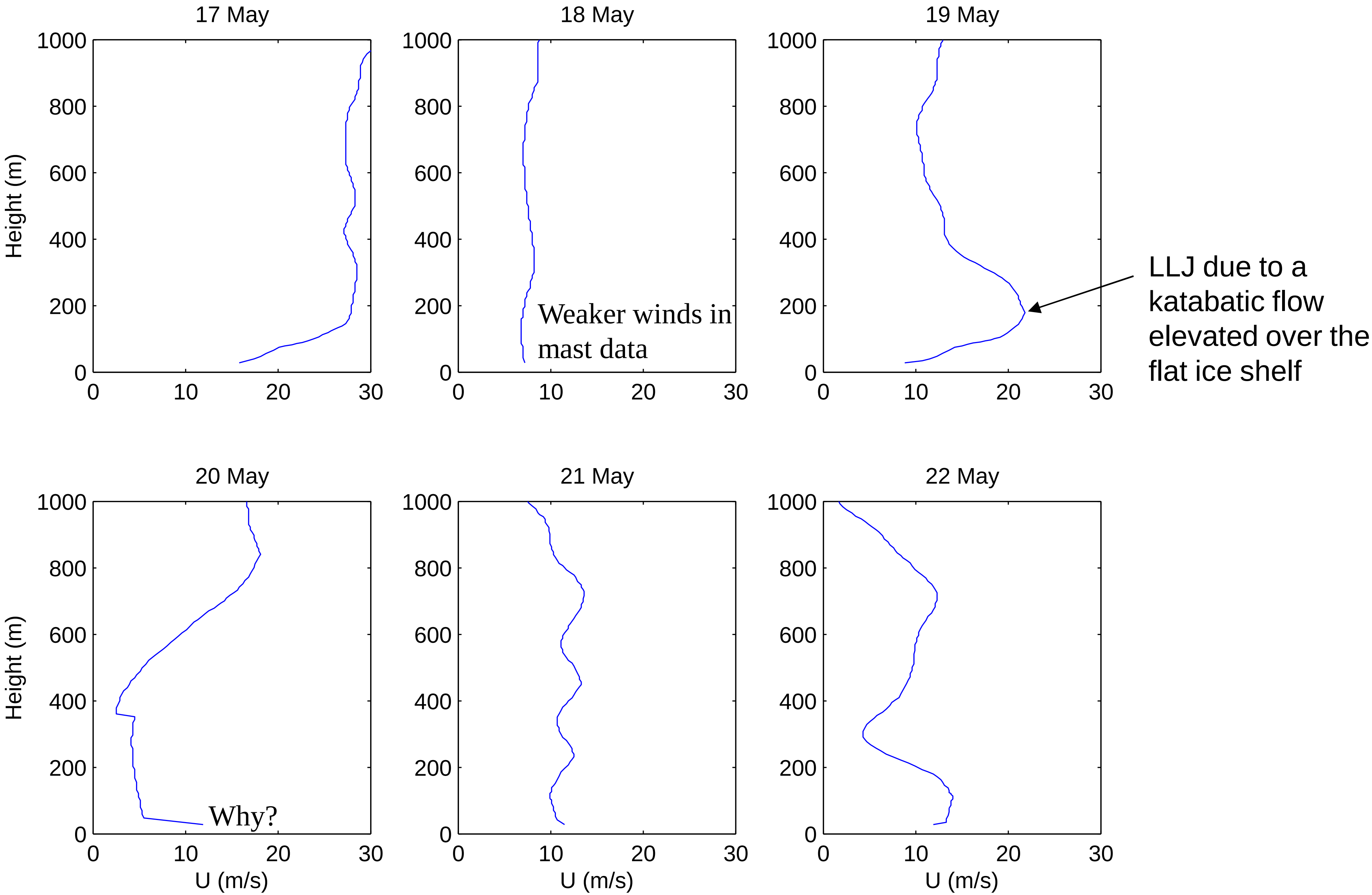
Longwave Radiation, IOC 1, May 2003
Longwave radiation / Wm-2
240
230
220
210
200
190
180
170
160
17 May 12:00
18 May 12:00
19 May 12:00
20 May 12:00
21 May 12:00
22 May 12:00
L↓
L↑

May 2003


Wind, IOC 1, May 2003
wind speed / ms^{-1}
0
2
4
6
8
10
12
14
17 May 12:00
18 May 12:00
19 May 12:00
20 May 12:00
21 May 12:00
22 May 12:00
32 m
16 m
8 m
4 m
2 m
1 m

May 2003

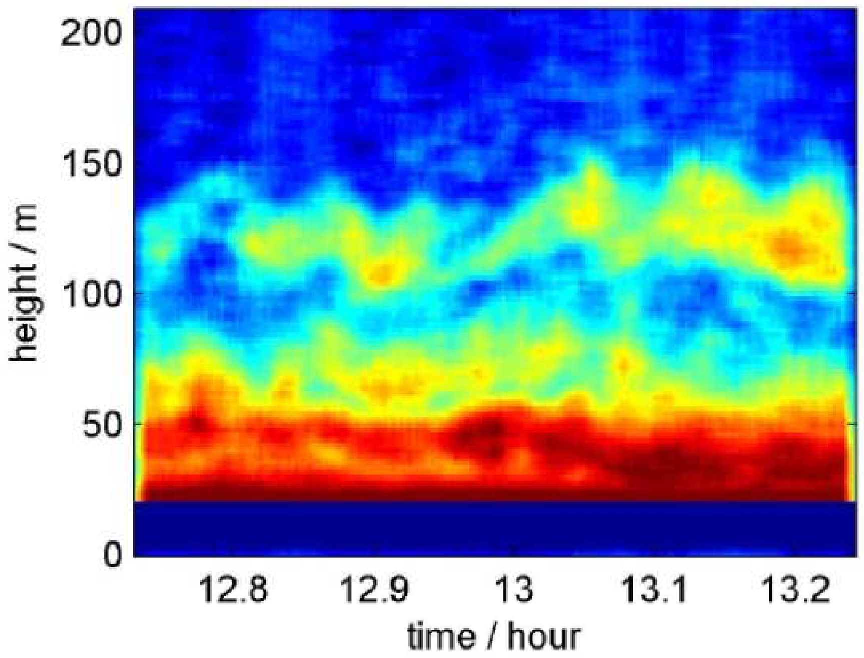
Rawinsonde wind profiles



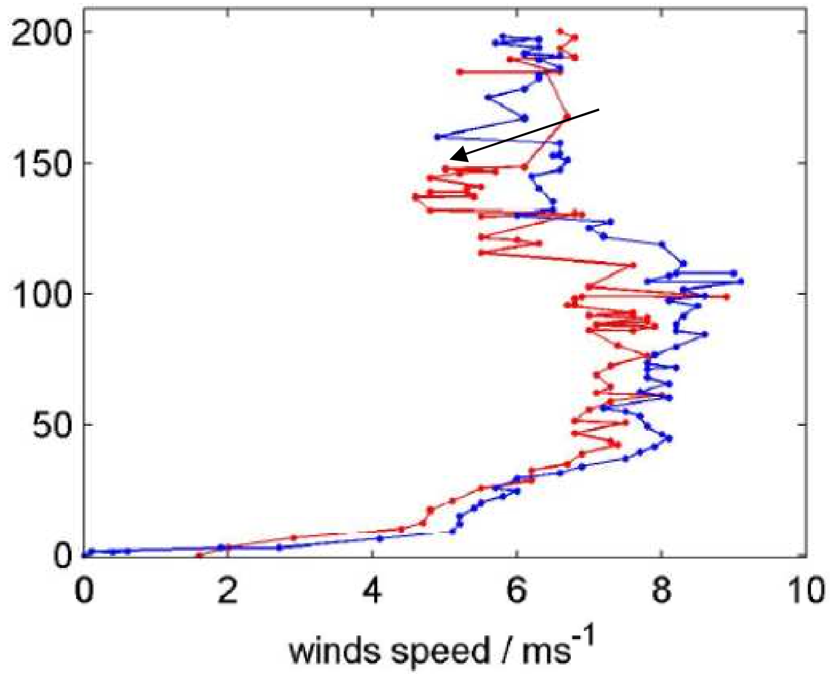
May 2003

19 May: LLJ core height varied (200 m in previous slide), and affected the vertical profile of turbulence

Sodar backscatter



Tethersonde



3D Model Experiments

Objective

- to find out if the May 2003 case is suitable for GABLS4 column modelling?

Look for:

- Horizontal homogeneity
- lack of significant advective effects
- lack of major changes in cloud cover

Models applied

- Polar WRF, by FMI
- Unified Model, by BAS
- HIRLAM, by FMI & Met Eireann
- HARMONIE, by FMI & Met Eireann

Next we focus on Polar WRF and HIRLAM results

Polar WRF Experiments

Study period: 18 May 2003 00 UTC–21 May 2003 00 UTC

Spin-up time: 9 days

Domains: 3 two-way-nested domains with 36, 12, and 4 km resolutions

Vertical levels: 70 (lowest full model level at 9 m, top at 10 hPa)

Initialization and lateral boundary conditions: ERA-Interim at 6-h intervals

Sea ice: fractional sea ice from ERA-Interim

Parameterizations: (following AMPS)

Boundary layer: Mellor-Yamada-Janjic TKE scheme

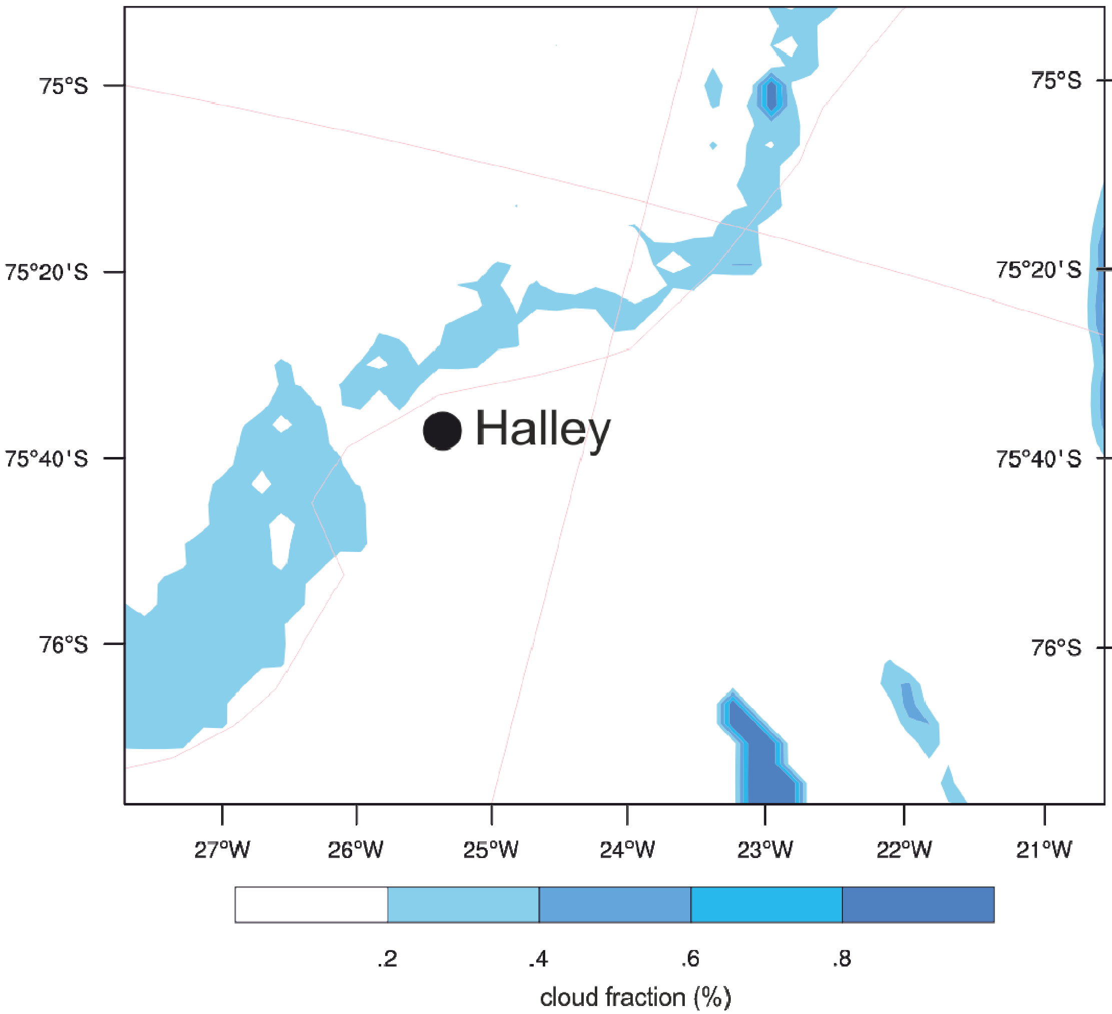
Longwave radiation: RRTMG Longwave radiation scheme

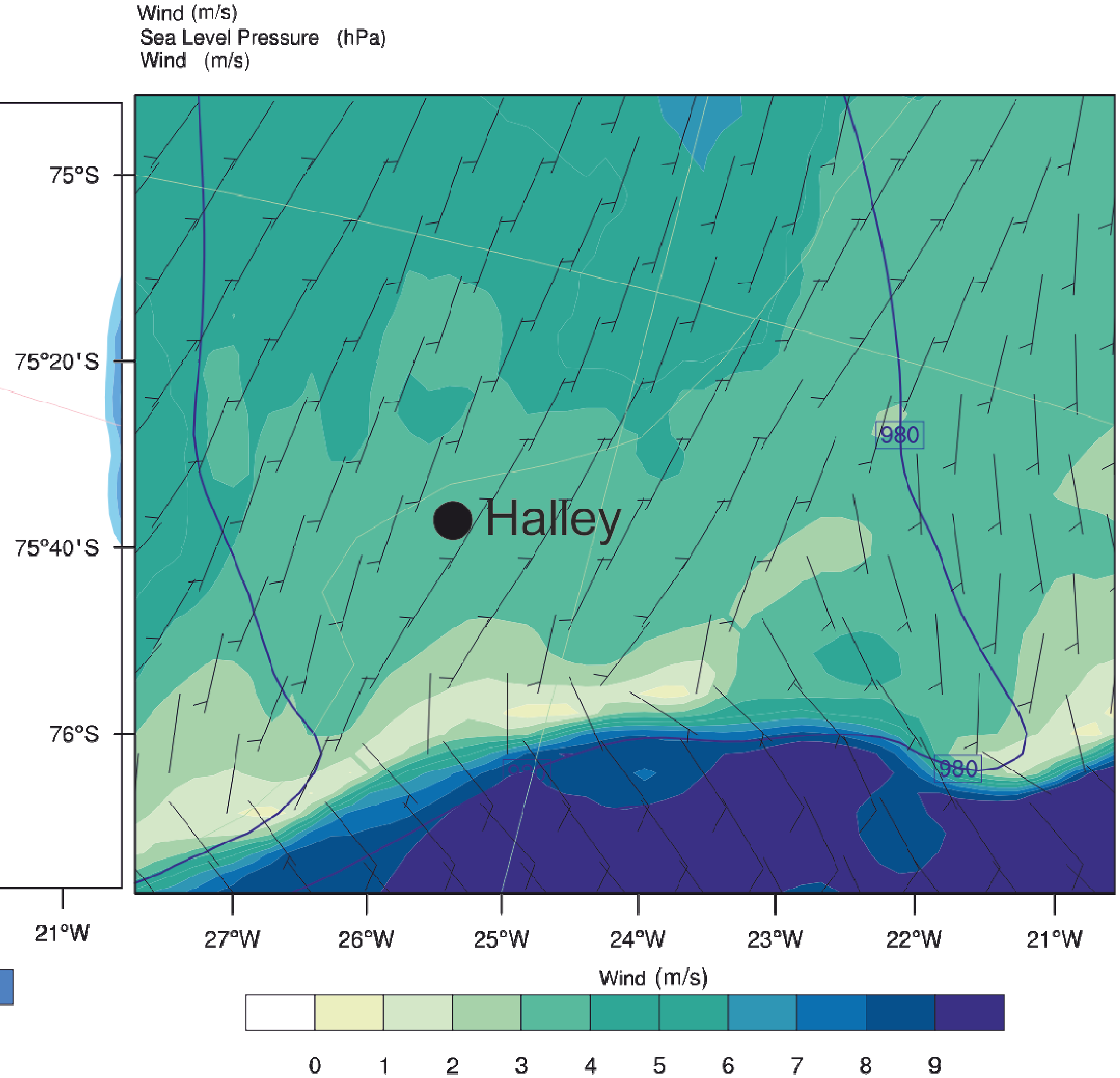
Land-surface: Unified Noah

Shortwave radiation: Goddard shortwave radiation scheme

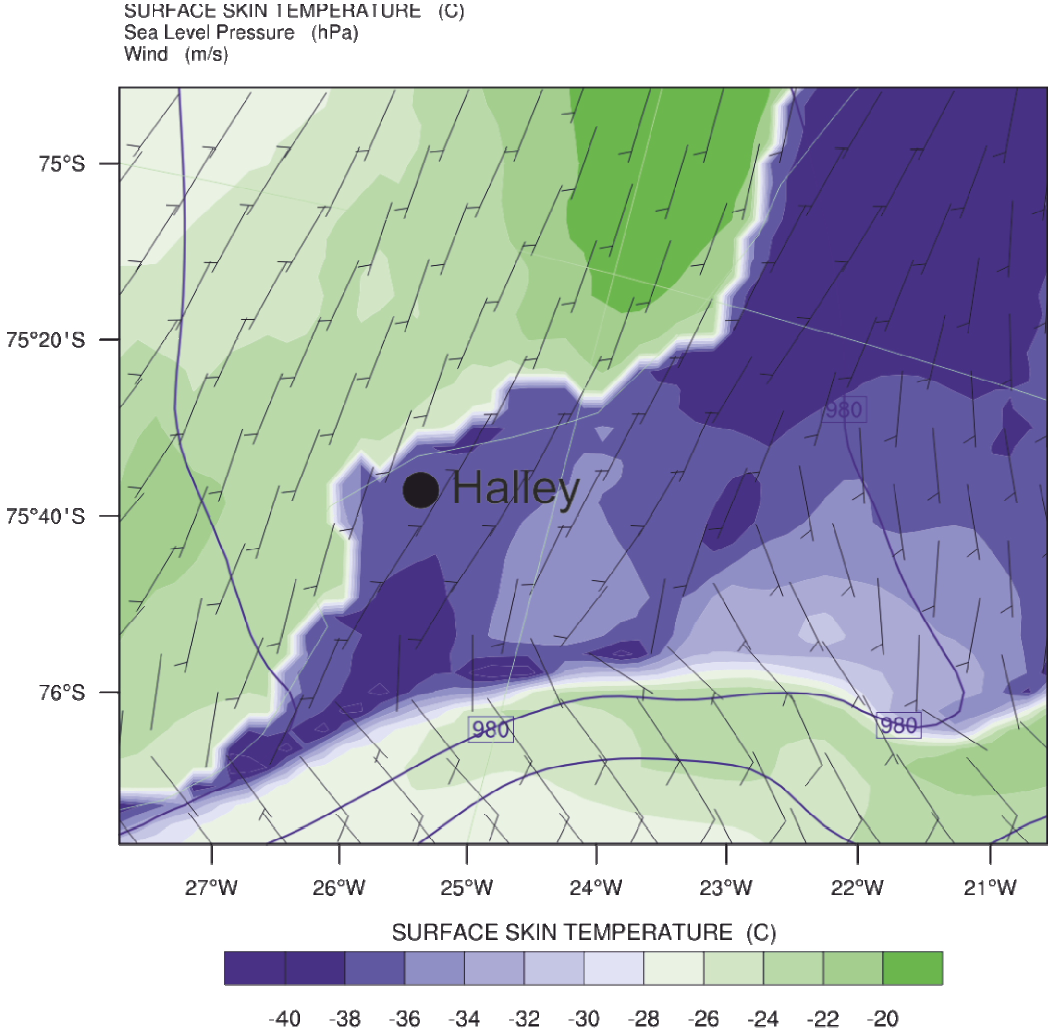
Microphysics: WSM 5-class scheme

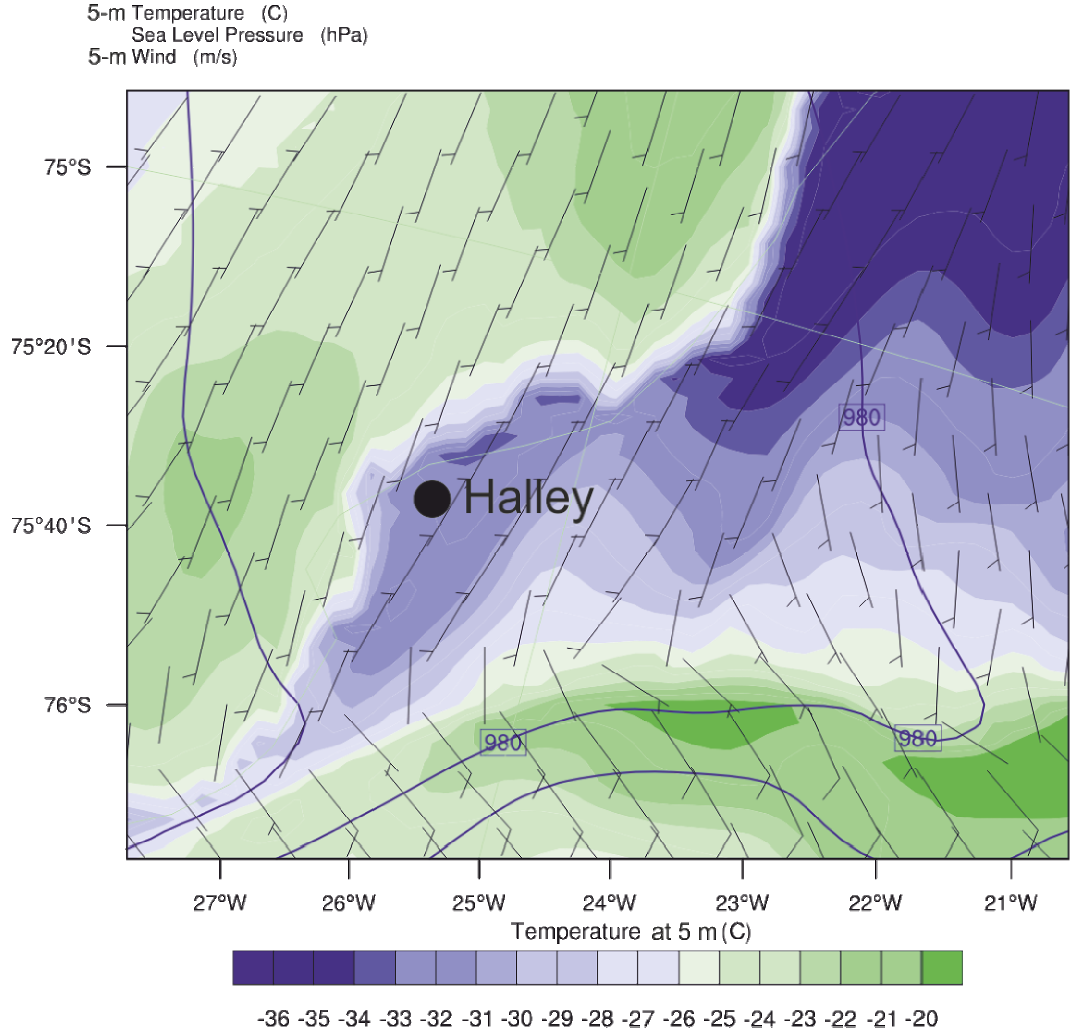
Polar WRF results



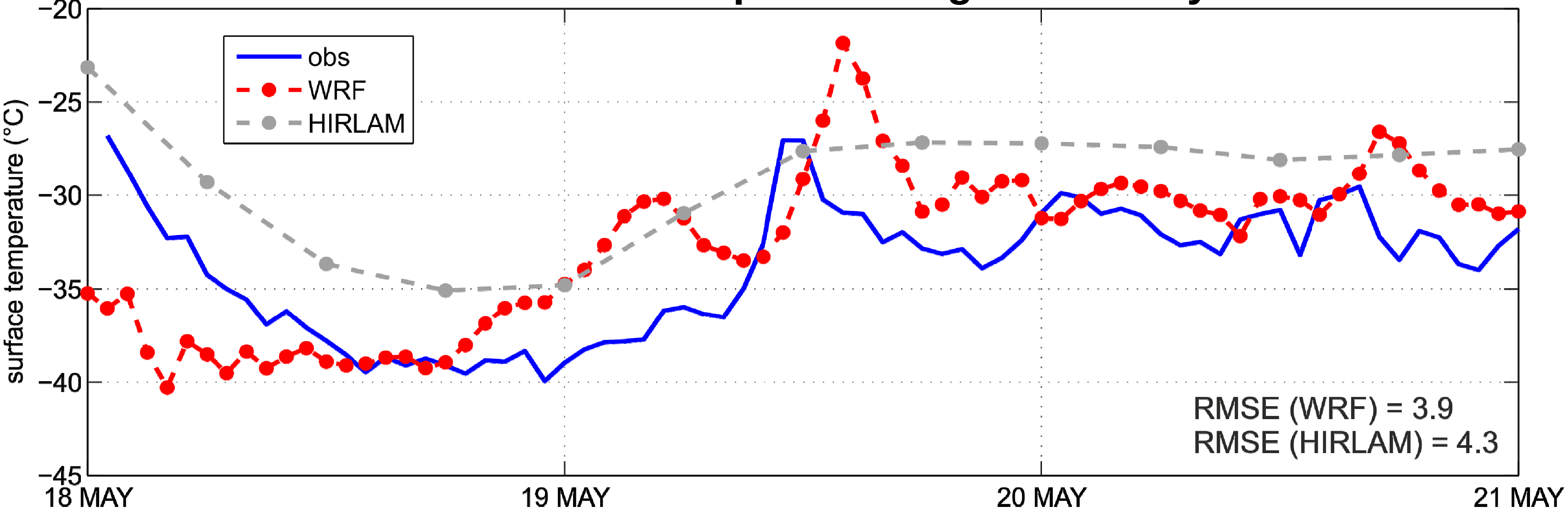


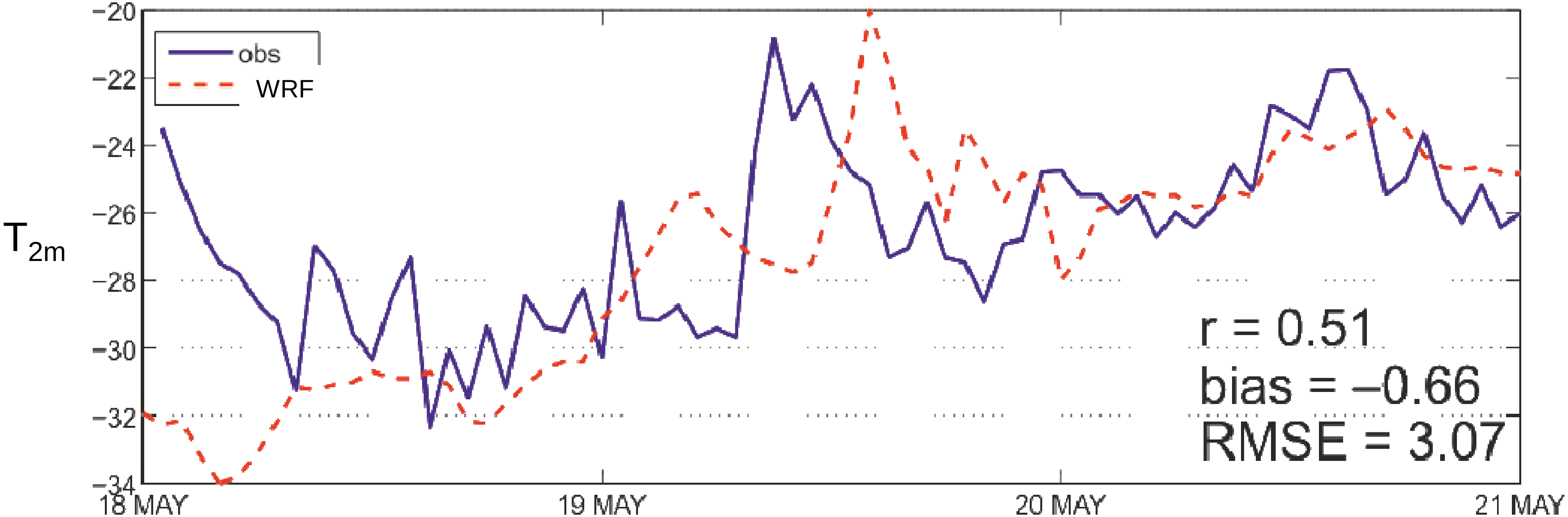
Polar WRF results

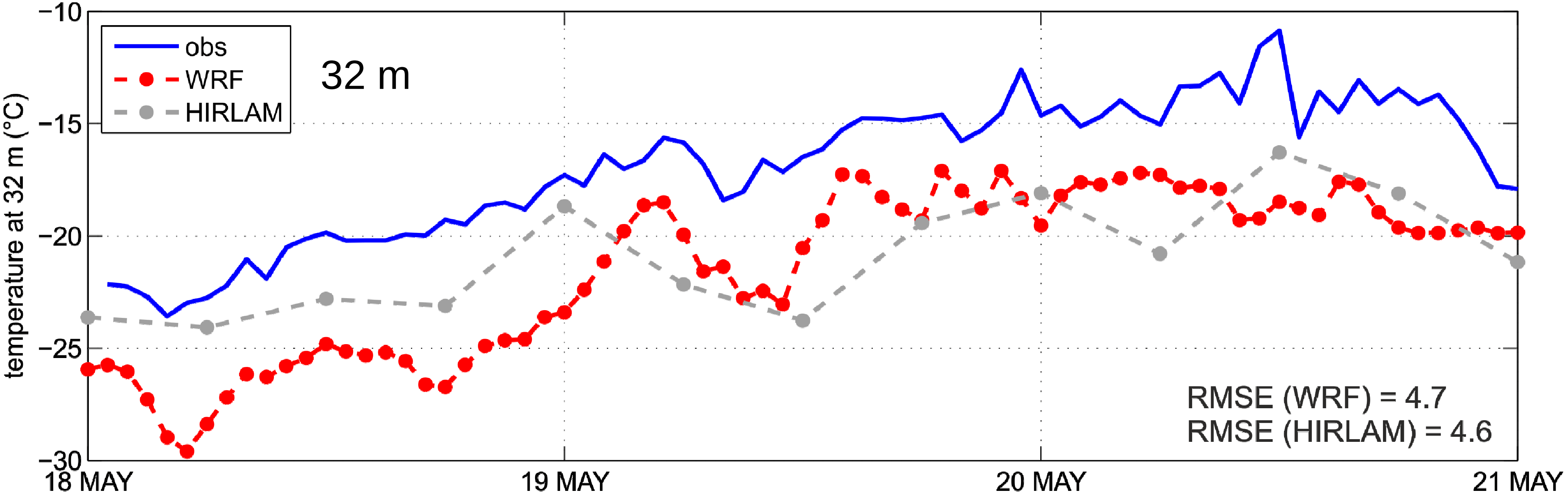




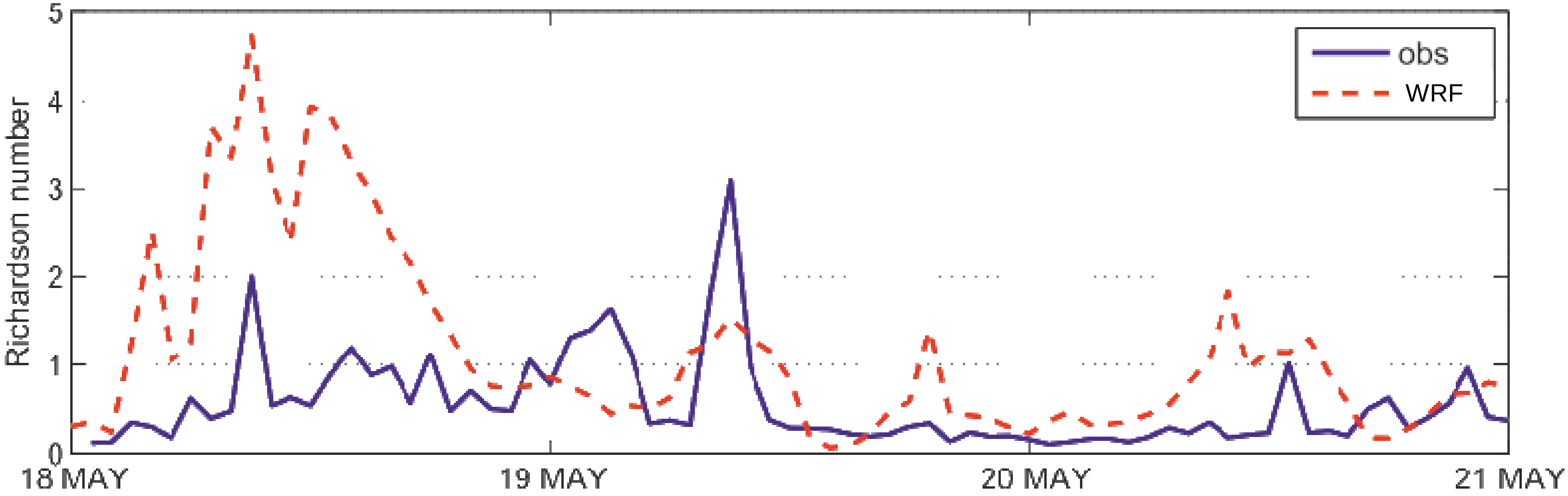
Polar WRF and HIRLAM results: Comparisons against Halley observations



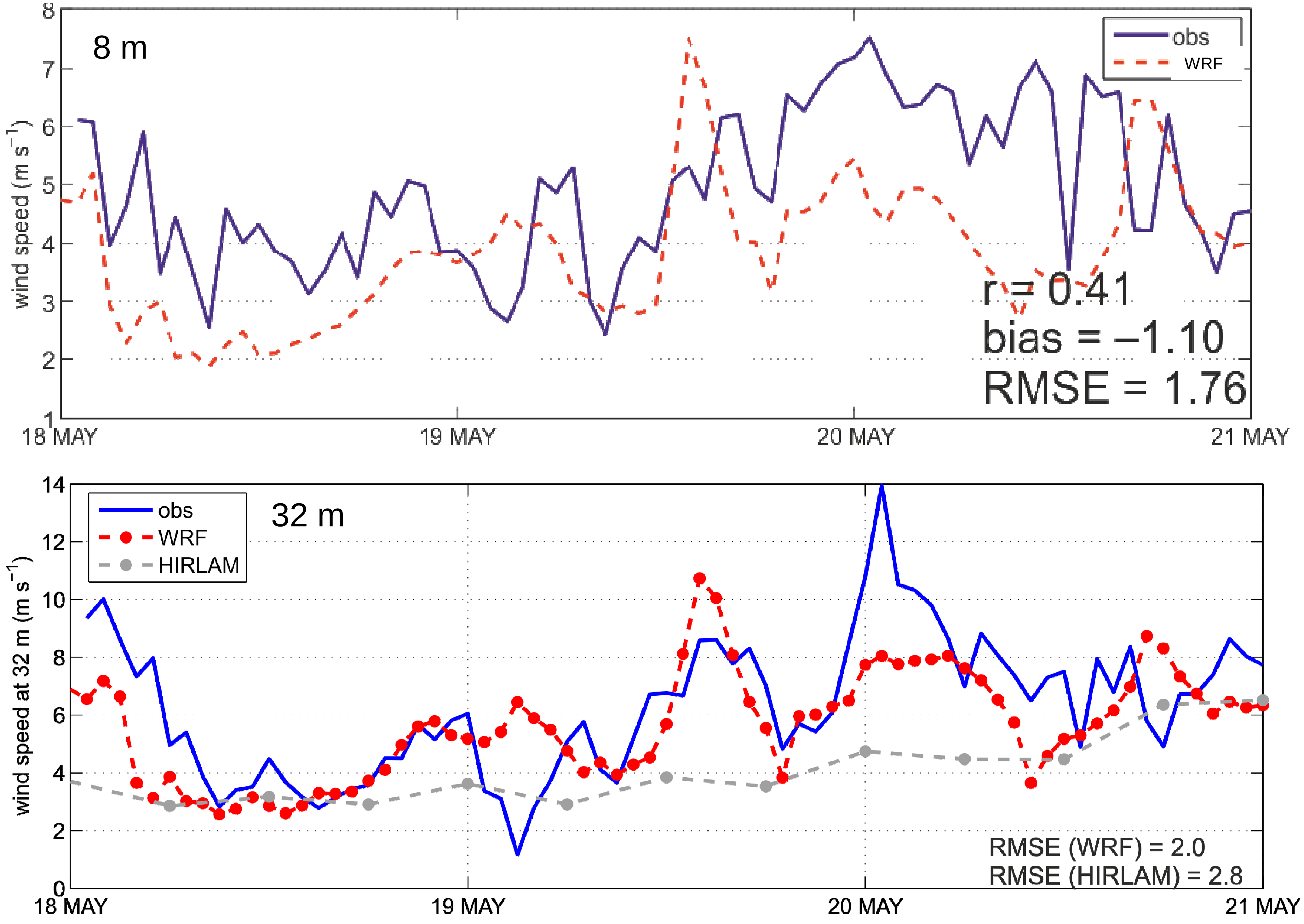


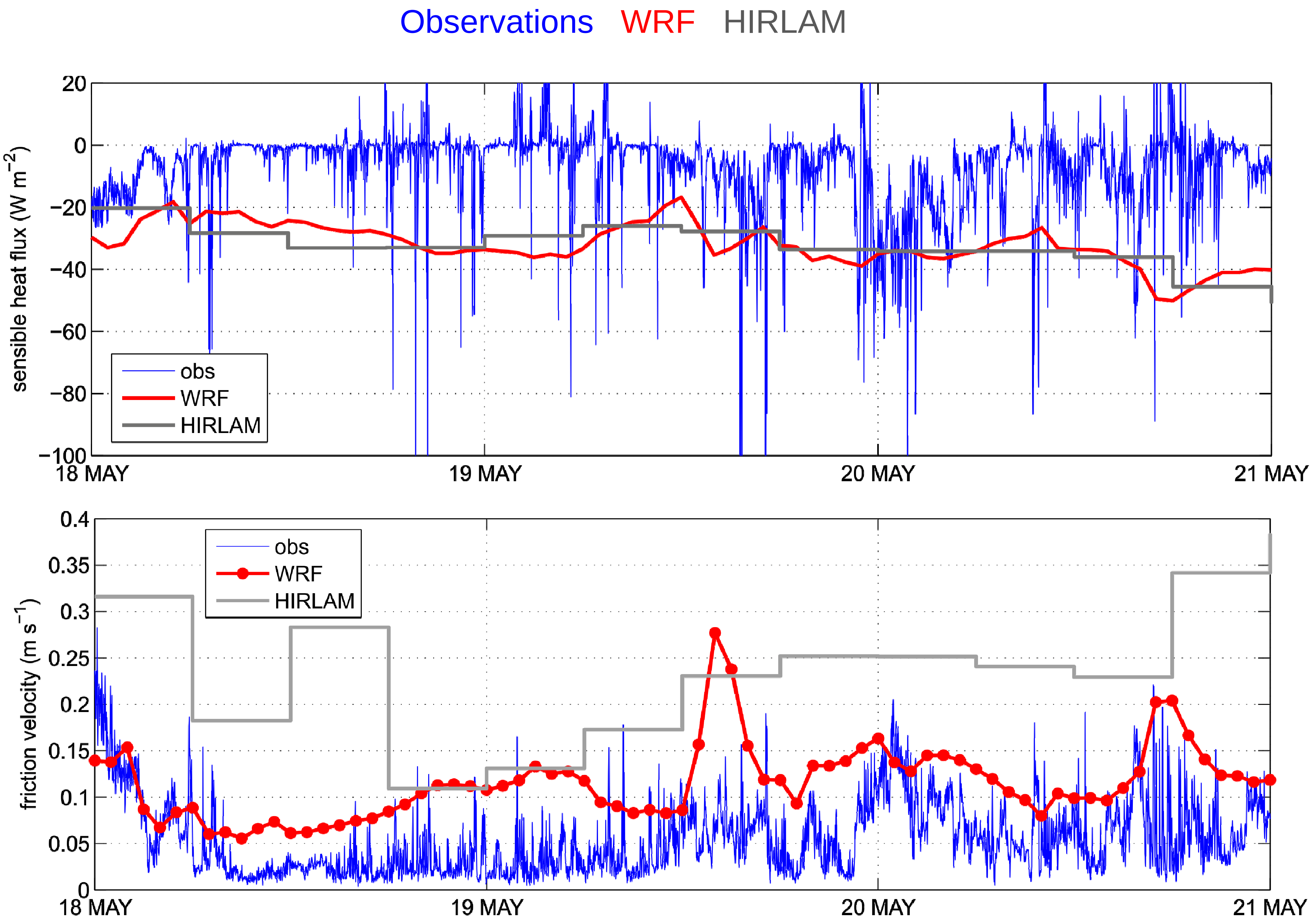


obs
WRF
HIRLAM
32 m
temperature at 32 m (°C)
−10
−15
−20
−25
−30
RMSE (WRF) = 4.7
RMSE (HIRLAM) = 4.6
18 MAY
19 MAY
20 MAY
21 MAY



obs
WRF
Richardson number
5
4
3
2
1
0
18 MAY
19 MAY
20 MAY
21 MAY


8 m
obs
WRF
r = 0.41
bias = −1.10
RMSE = 1.76
wind speed (m s^{-1})
18 MAY
19 MAY
20 MAY
21 MAY
32 m
obs
WRF
HIRLAM
wind speed at 32 m (m s^{-1})
RMSE (WRF) = 2.0
RMSE (HIRLAM) = 2.8
18 MAY
19 MAY
20 MAY
21 MAY



Observations WRF HIRLAM
sensible heat flux (W m^-2)
20
0
−20
−40
−60
−80
−100
obs
WRF
HIRLAM
18 MAY
19 MAY
20 MAY
21 MAY
friction velocity (m s^-1)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
obs
WRF
HIRLAM
18 MAY
19 MAY
20 MAY
21 MAY

Discussion

• Halley observations represent one of the best data sets available from flat polar areas (others are Dome C and SHEBA)

• the May 2003 case fairly well meets the requirements of lack of advection of heat and clouds

• more detailed analyses on the vertical profiles of heat and momentum advection under work. Can we trust the 3D model fields?

•the vicinity of the sloping glacier makes the environment rather challenging (LLJs related to elevated katabatic flows)

• wave patterns in the observations

• Polar WRF and HIRLAM experiments for the May 2003 case:

- systematic cold bias at 32 m, but mostly warm bias at snow surface

- far too large turbulent fluxes when decoupling in the observations

- initialization of snow temperature profiles requires attention

• The observed turbulent fluxes dropped almost to zero, but this was not the case in WRF. Due to such problems, it is important to study a case with very stable stratification. The validation is, however, more challenging as a lot of attention needs to be paid on radiation and snow schemes as well.

Plan

1. Continue 3D model experiments for the Halley 2003 case

   - detailed analyses on the vertical profiles of heat and momentum advection

   - the study period should start already on 17 May 12 UTC to also include hours with larger fluxes, which allow to study the evolution towards very stable stratification

2. Include in GABLS4 both the Halley 2003 case and a summer case from Done C, where the environment is homogeneous over larger spatial scales

3. Intercomparison of column models:

- coupled atmosphere – snow experiments
- atmosphere only, with (a) prescribed Ts or (b) prescribed conductive heat flux from snow
- Possibly: snow only, with (a) prescribed Ts or (b) prescribed longwave radiaton, Ta, RH, and U

GABLS basic publications
(plus many conference and invited presentations)

GABLS1:
Special issue Feb 2006, Boundary Layer Meteorology (7 papers)
Svensson and Holtslag, 2009, BLM (wind turning issue)

GABLS2:
Steeneveld et al, 2006, JAS (SCM) and 2008, JAMC (Mesoscale study)
Holtslag et al, 2007, BLM (Coupling to land surface)
Kumar et al, 2010, JAMC (LES study)
Svensson et al, 2011, BLM (SCM intercomparison)

GABLS3:
Baas et al 2010, QJRMS (set up case and SCM tests)
New special issue of BLM planned for 2013, including intercomparison papers by Bosveld et al (SCM), Basu et al (LES), Edwards et al (LES + Radiation scheme)....

GABLS overview paper in 2012 (Holtslag et al, BAMS, submitted)

GABLS 1. Beaufort Sea Arctic Stratus

- 10 LES + 20 1D models participated
- each had the same vertica domain, resolultion, time step, geostrophic wind, no radiation, surface cooling rate, and simulation time (9h).
- ABL schemes: both 1st order and higher order closures; both operational and reseacth schemes
- for all, pre- and post-GABLS results presented
- operational schemes mix over a deeper layer than the research schemes
- special issue of Boundary Layer Meteorology (Feb 2006)

GABLS 2: CASES-99

- again both LES and 1D
- three-day model runs
- models forced by Ts, Vg, and large-scale subsidence.
- diurnal cycle in focus: Ts range > 20K (October in Kansas).
- models produced very different results for all parameters, all differed substantially from the observations, and underestimated the diurnal cycle of wind speed.
- coordinator: Gunilla Svensson

GABLS 3. Low-level jet and diurnal cycle at Cabauw

- 24 h period simulated
- processes studied: decoupling around sunset, inertial oscillation, low level jet, and the morning time transition to convective conditions.
- cloud free conditions and a relatively constant Easterly geostrophic wind of approximately 8 m/s over Cabauw, decresing with height.
- prescribed forcing; evaporation, roughness, initial conditions, advection; the last one based on both local observations and hind-casts of several 3D NWP models.
- coordinated by Fred Bosveld, Cisco de Bruijn and Bert Holtslag.