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Towards the Fourth GEWEX Atmospheric Boundary Layer Model Inter-Comparison Study (GABLS4)

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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

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

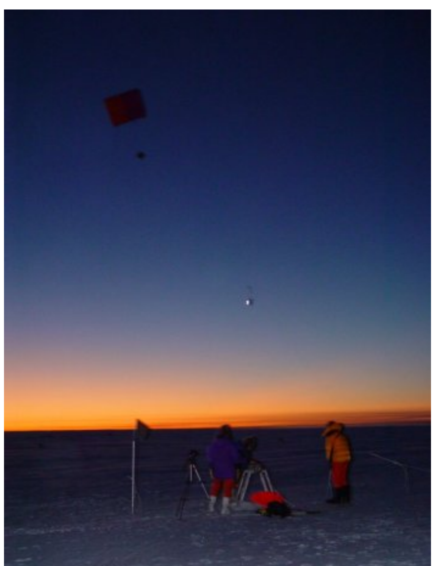
  Actual topic because of:
  - decrease of Arctic sea ice cover vs. increase in the Antarctic
  - collapse of Antarctic ice shelves
  - rapid melting of continental glaciers and permafrost

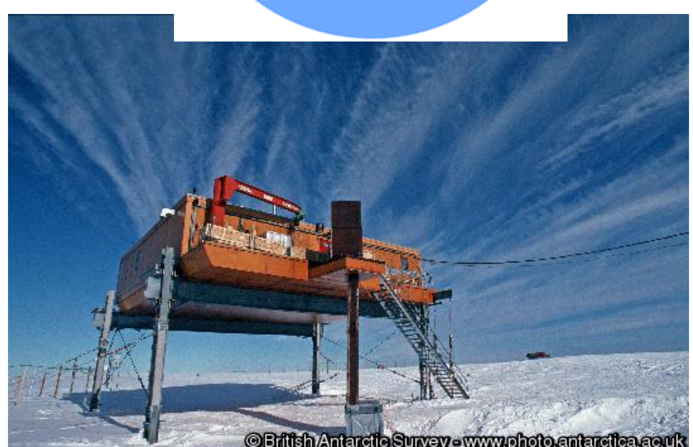
Plan for GABLS4

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

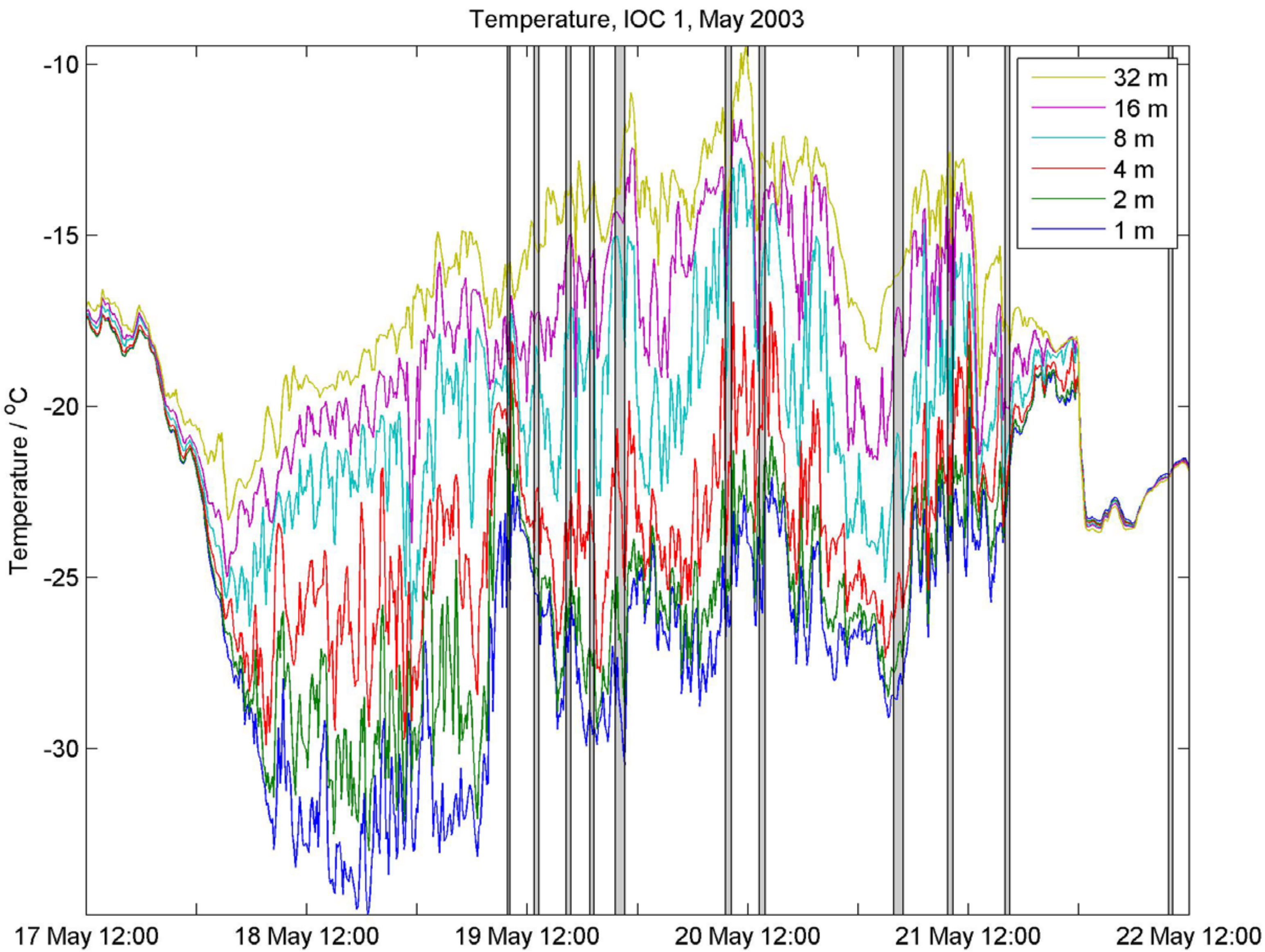
• upward and downward shortwave and longwave radiation

• Sodar

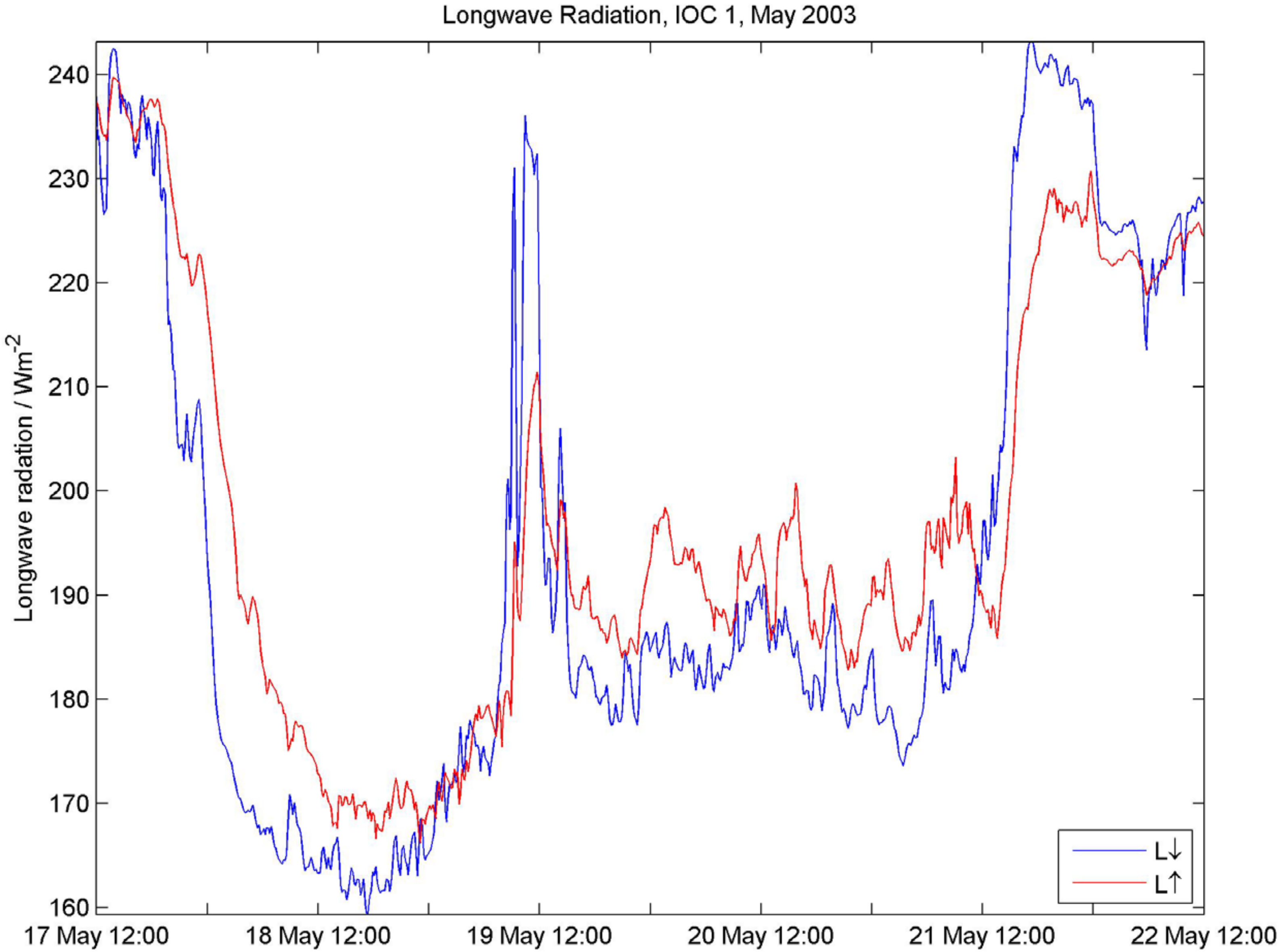
• microbarograph array

• visual cloud observations

May 2003

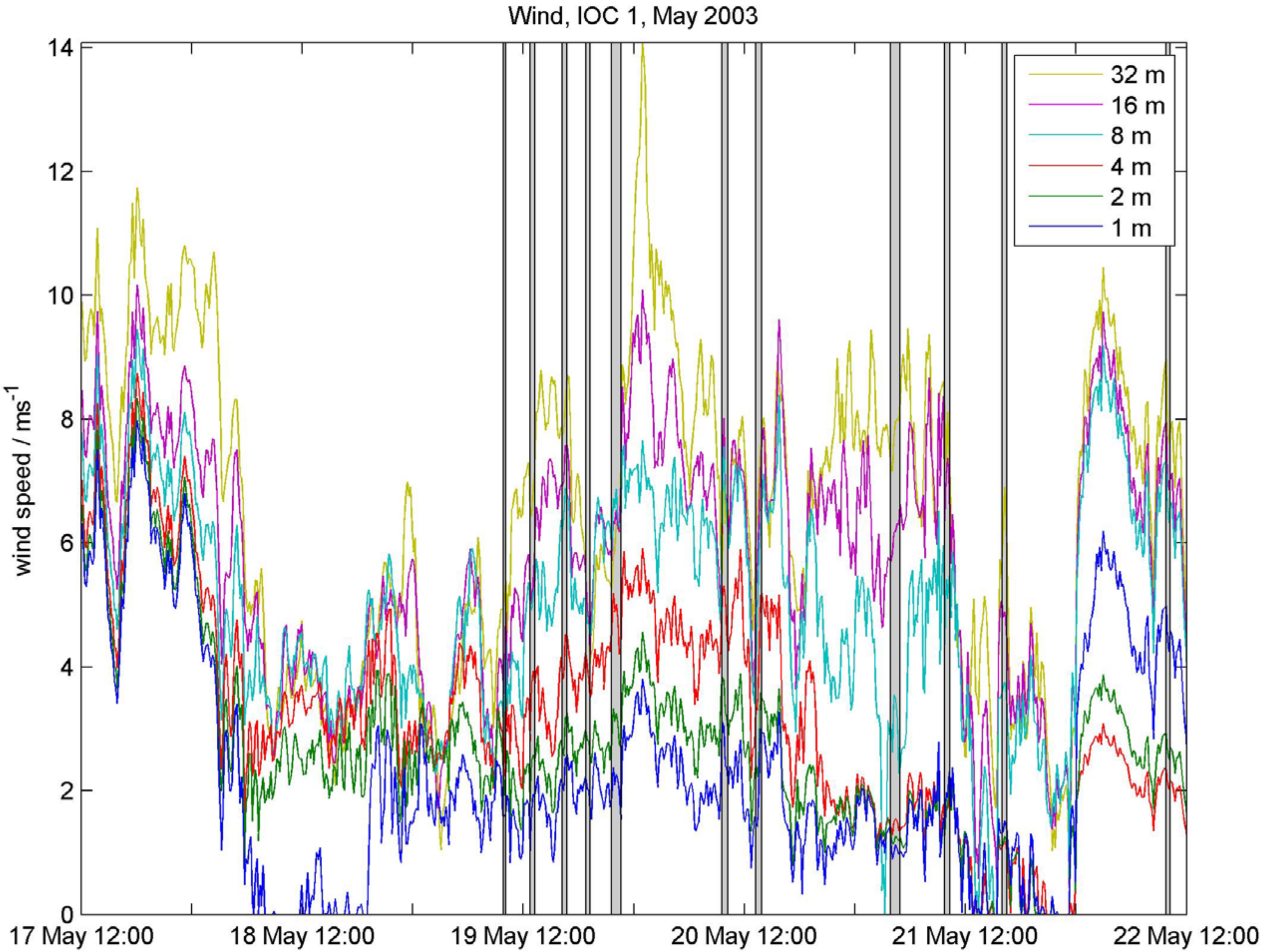

Temperature, IOC 1, May 2003
-10
-15
-20
-25
-30
Temperature / °C
17 May 12:00
18 May 12:00
19 May 12:00
20 May 12:00
21 May 12:00
22 May 12:00
32 m
16 m
8 m
4 m
2 m
1 m

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↑

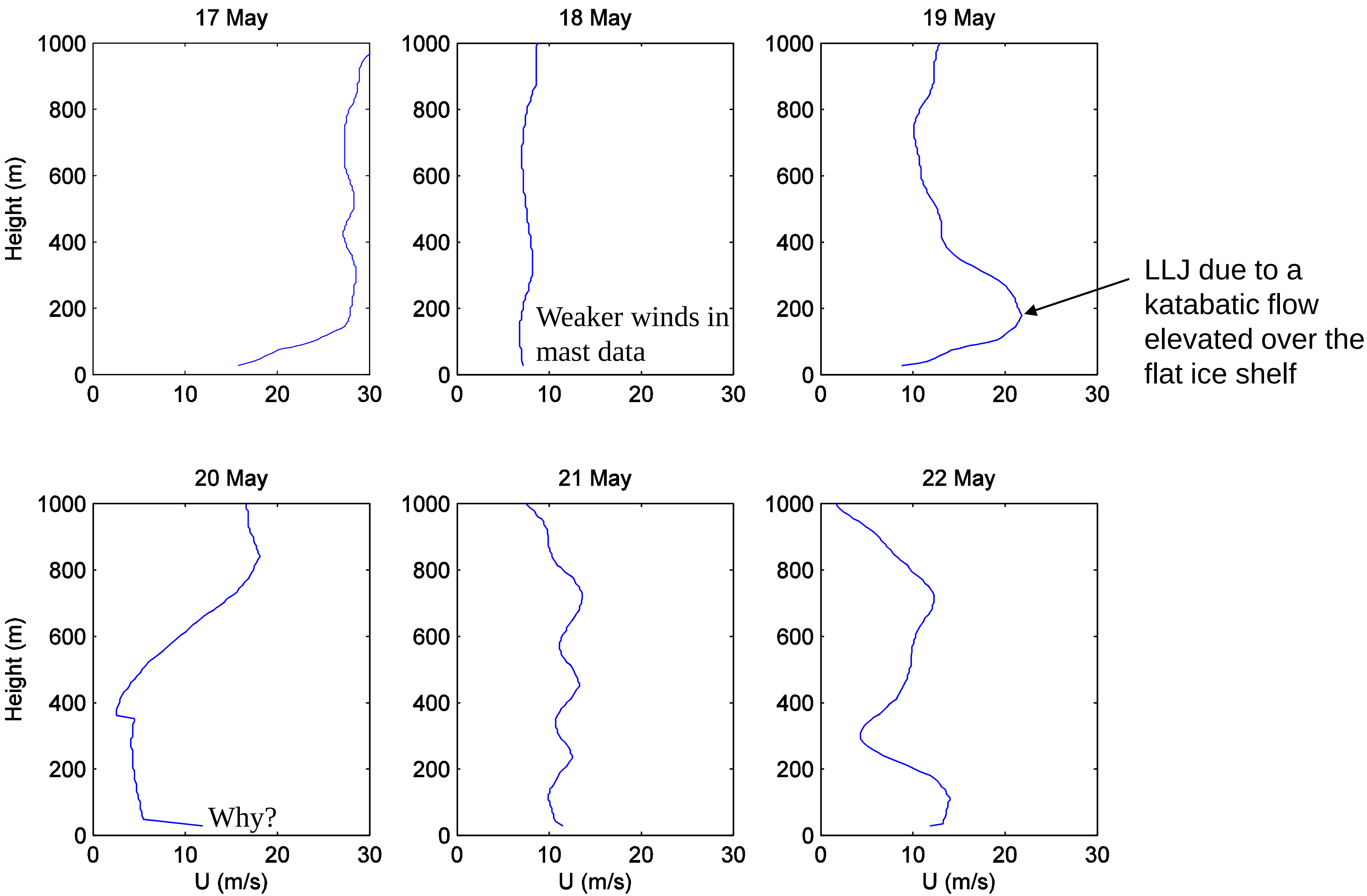
May 2003



Wind, IOC 1, May 2003
wind speed / ms-1
14
12
10
8
6
4
2
0
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

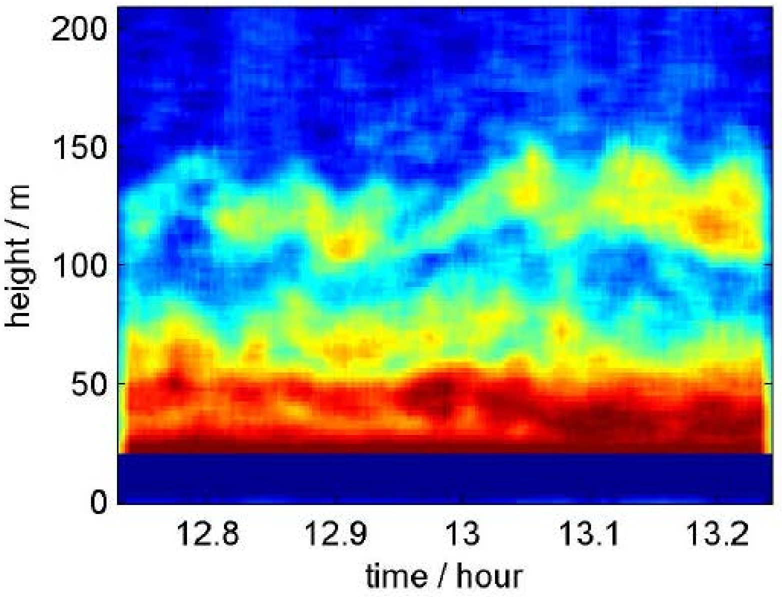
Rawinsonde wind profiles



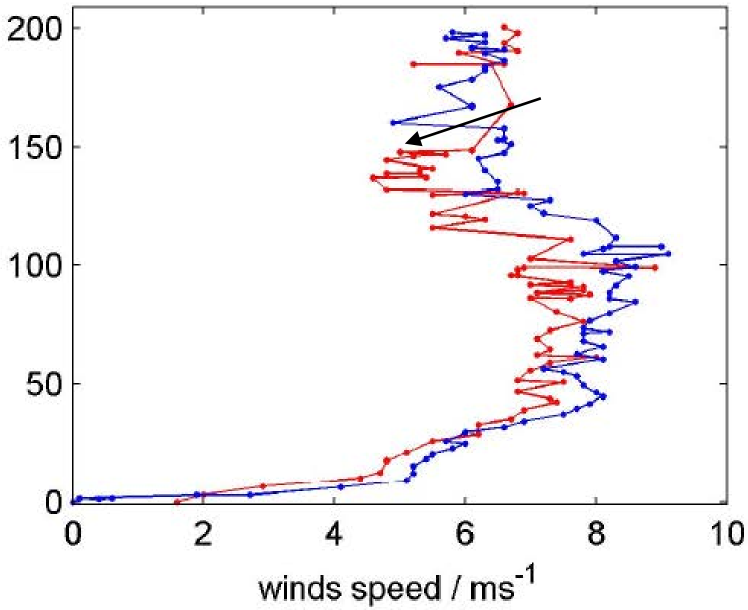
May 2003

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
- HIRLAM, by FMI & Met Eireann
- HARMONIE, by FMI & Met Eireann (under work)
- Unified Model, by BAS

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

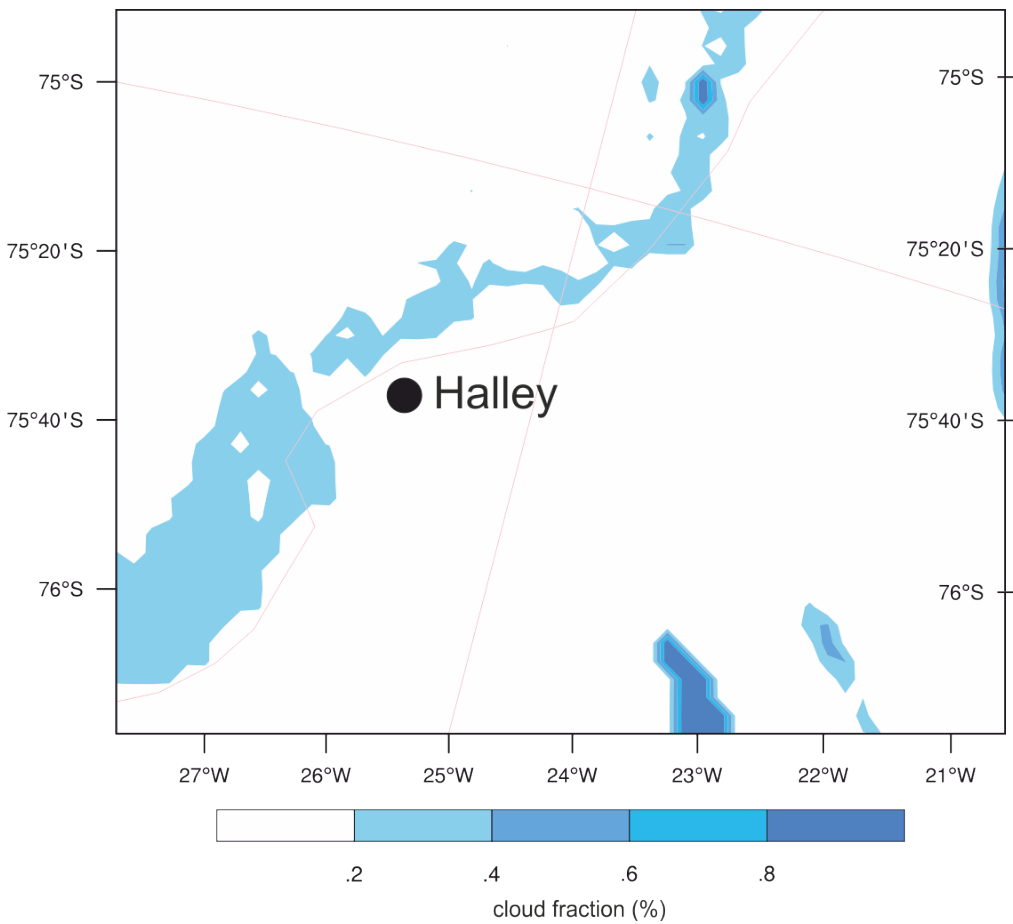
Longwave radiation: RRTMG Longwave radiation scheme

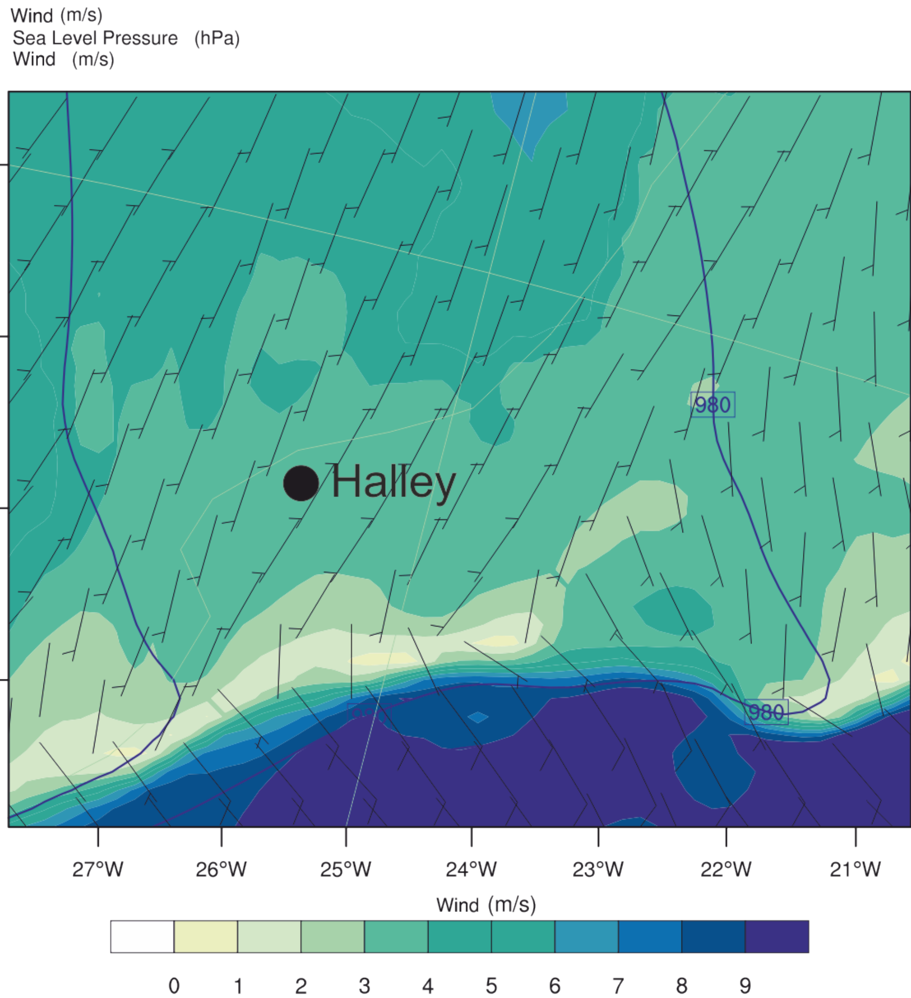
Land-surface: Unified Noah

Shortwave radiation: Goddard shortwave radiation scheme

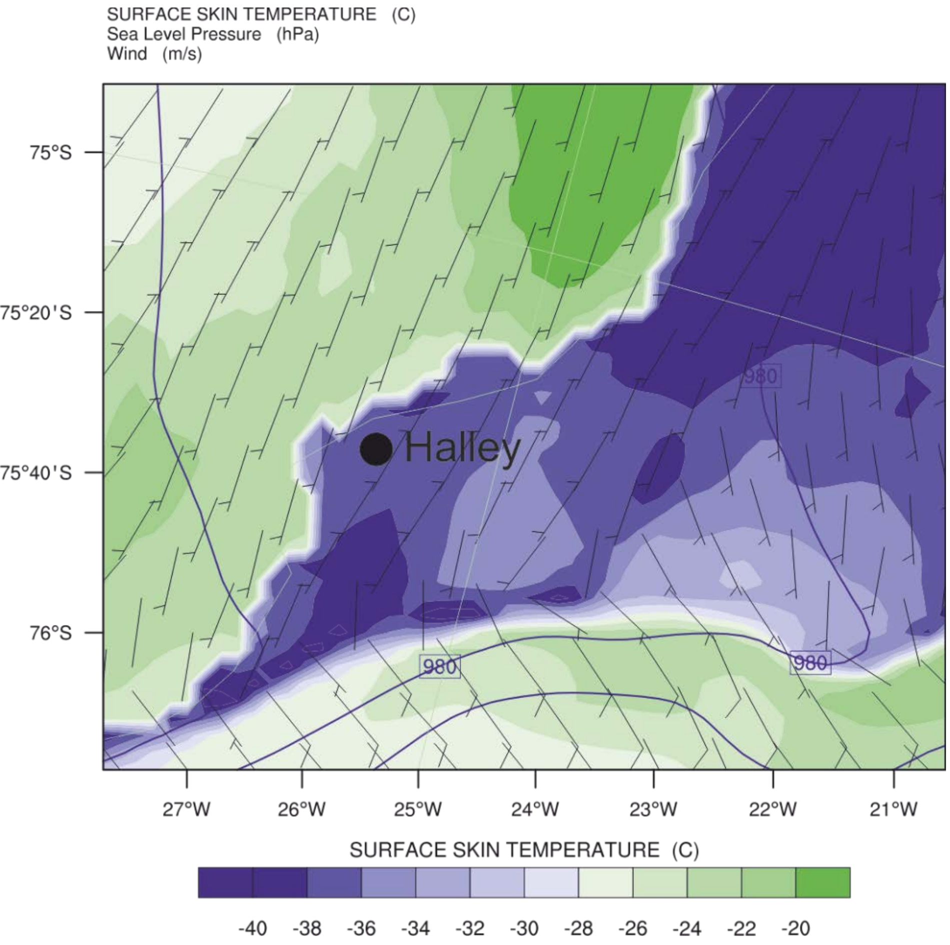
Microphysics: WSM 5-class scheme

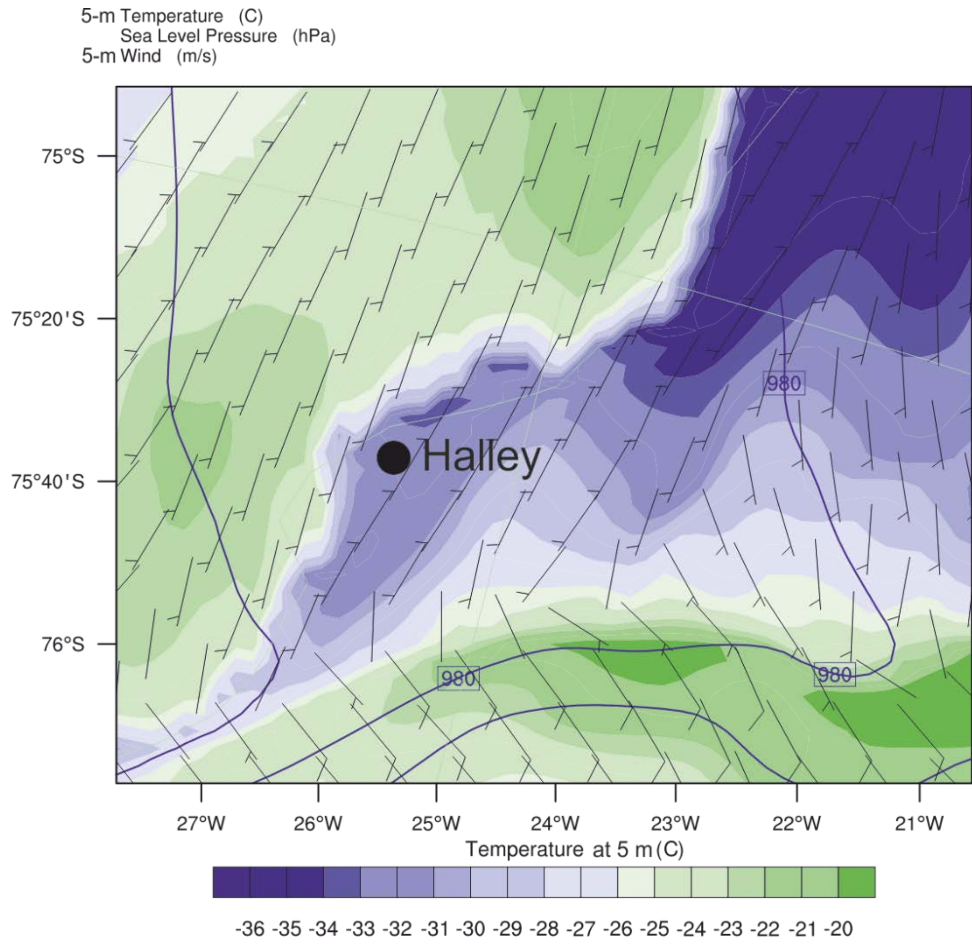
Polar WRF results





Polar WRF results





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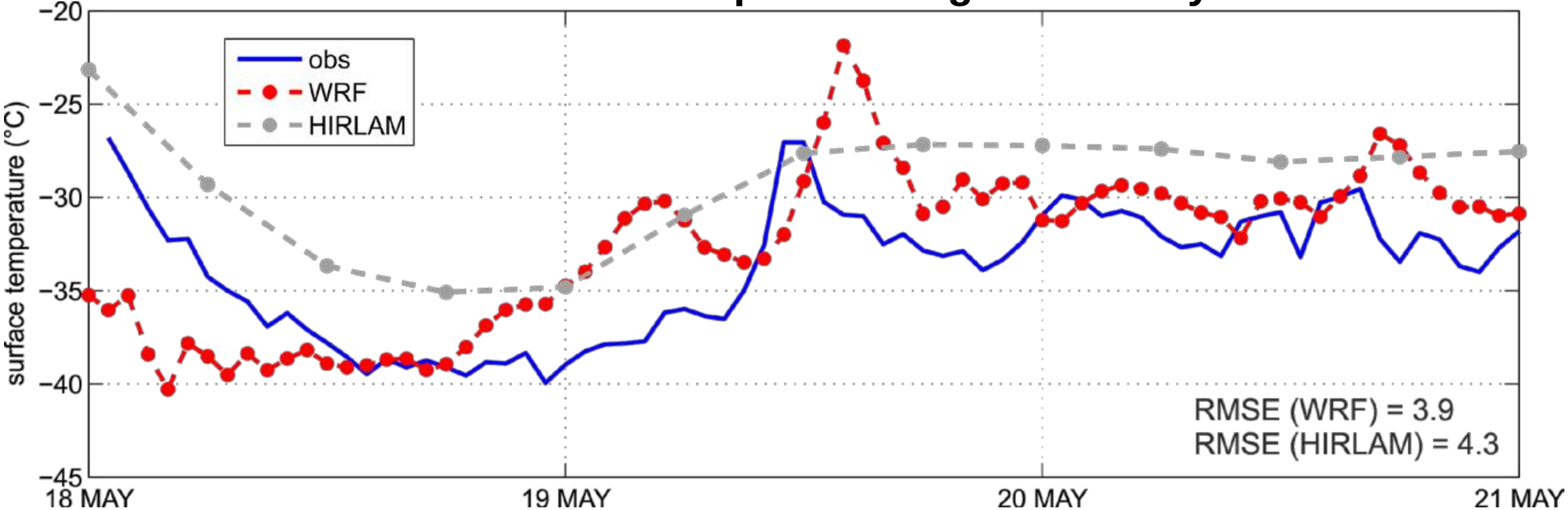
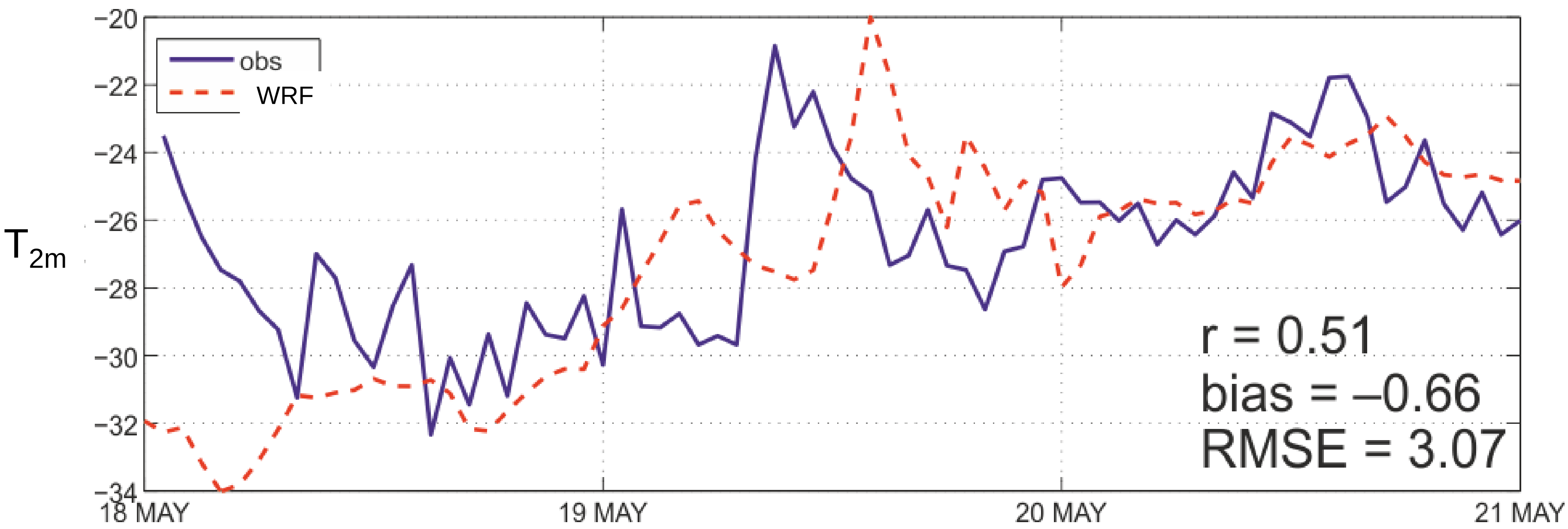
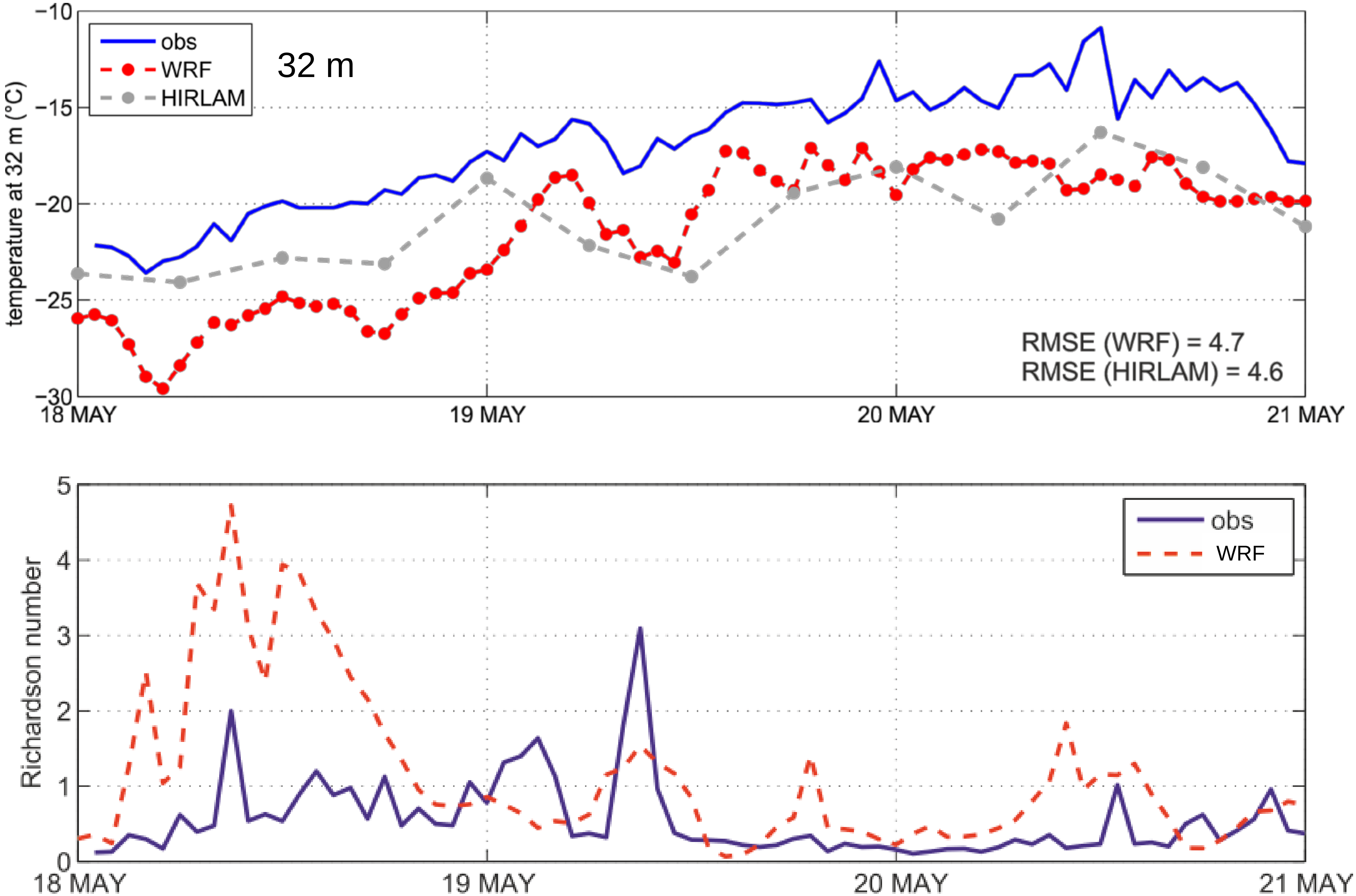
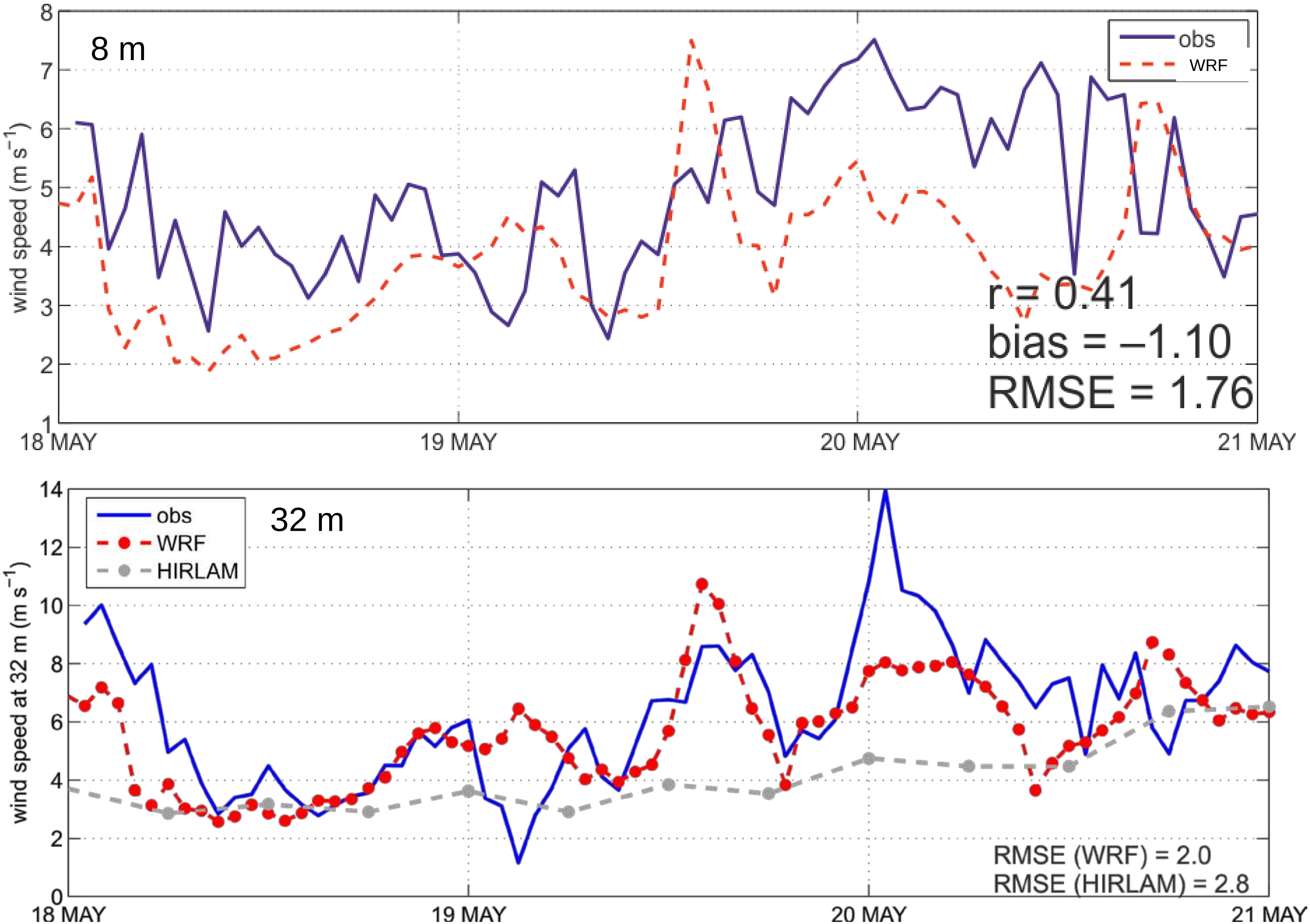
Polar WRF and HIRLAM results: Comparisons against Halley observations

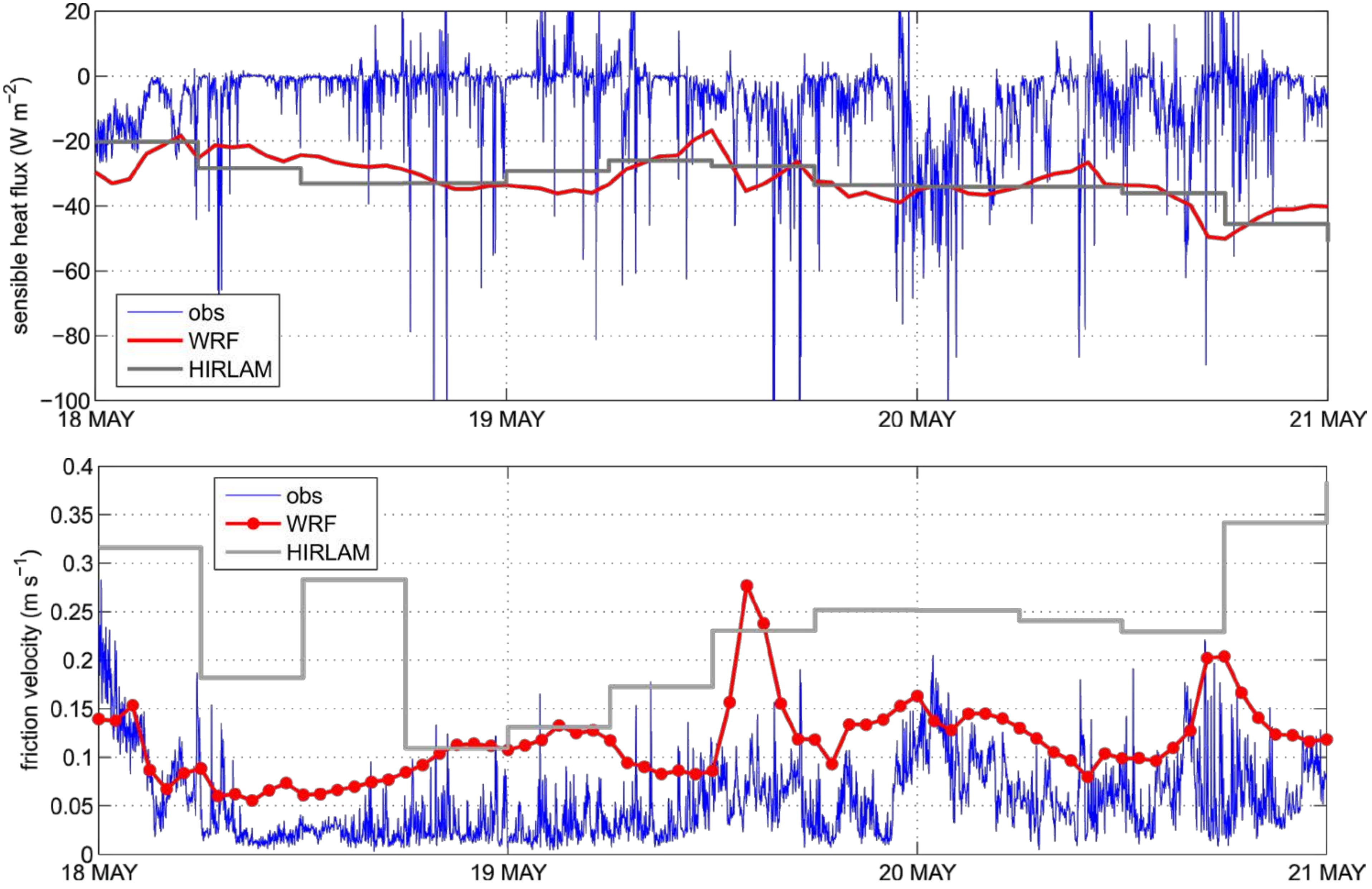





obs
WRF
HIRLAM
32 m
RMSE (WRF) = 4.7
RMSE (HIRLAM) = 4.6
temperature at 32 m (°C)
−10
−15
−20
−25
−30
18 MAY
19 MAY
20 MAY
21 MAY
Richardson number
obs
WRF
5
4
3
2
1
0
18 MAY
19 MAY
20 MAY
21 MAY


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
RMSE (WRF) = 2.0
RMSE (HIRLAM) = 2.8
wind speed at 32 m (m s⁻¹)
18 MAY
19 MAY
20 MAY
21 MAY

Observations WRF HIRLAM

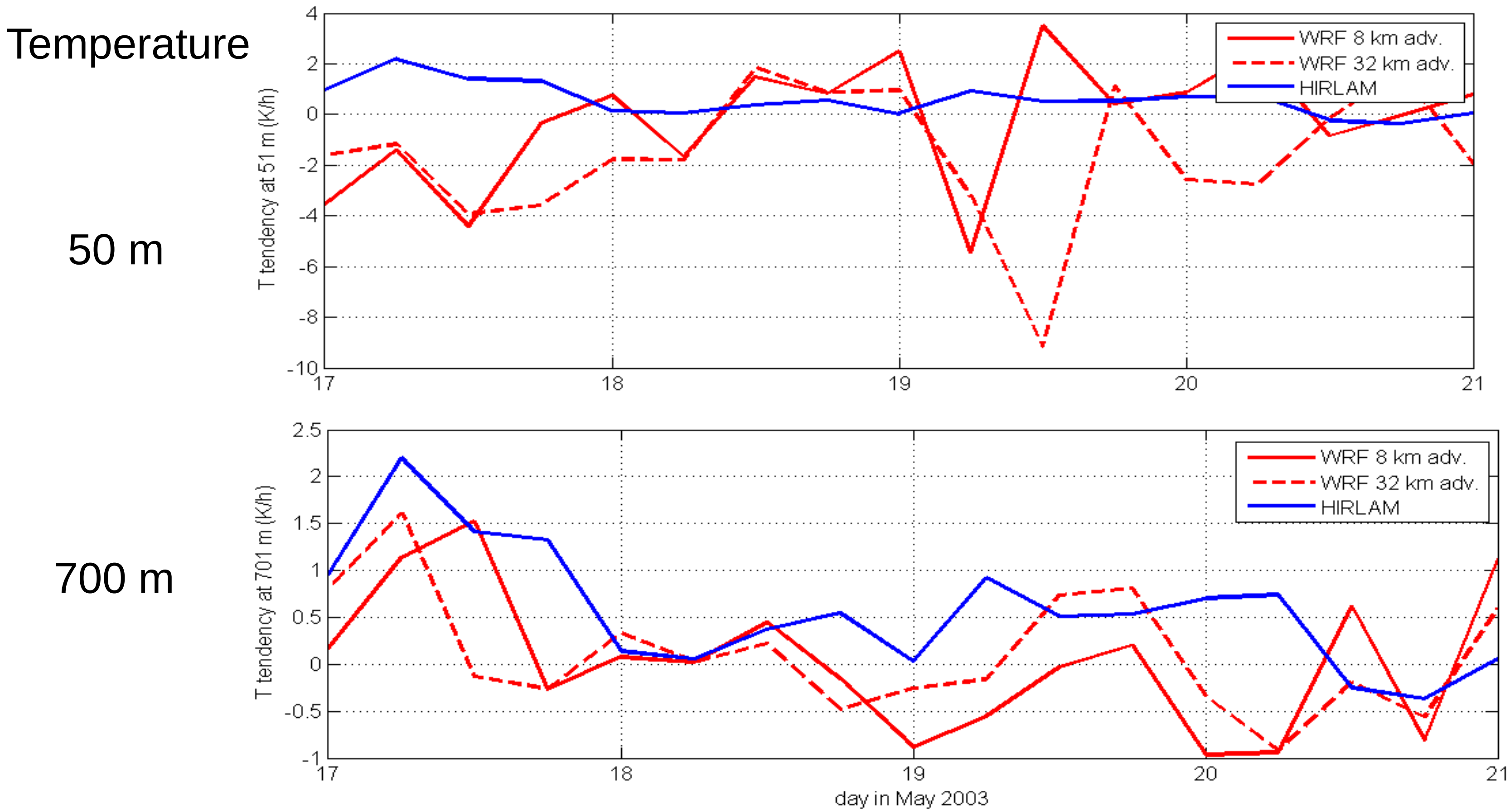


We need to find a period when there is little uncertainty in the effects of advection

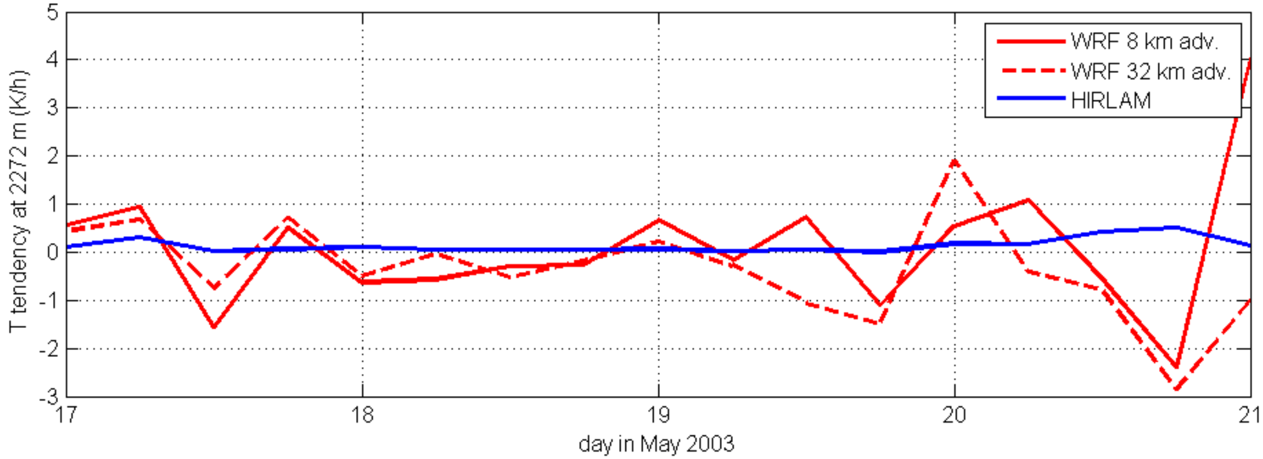
Advection of HIRLAM and Polar WRF was compared.

HIRLAM: adiabatic tendencies, including the effects of horizontal and vertical advection and horizontal diffusion

WRF: advection was calculated using horizontal grid points located 8/32 km apart.

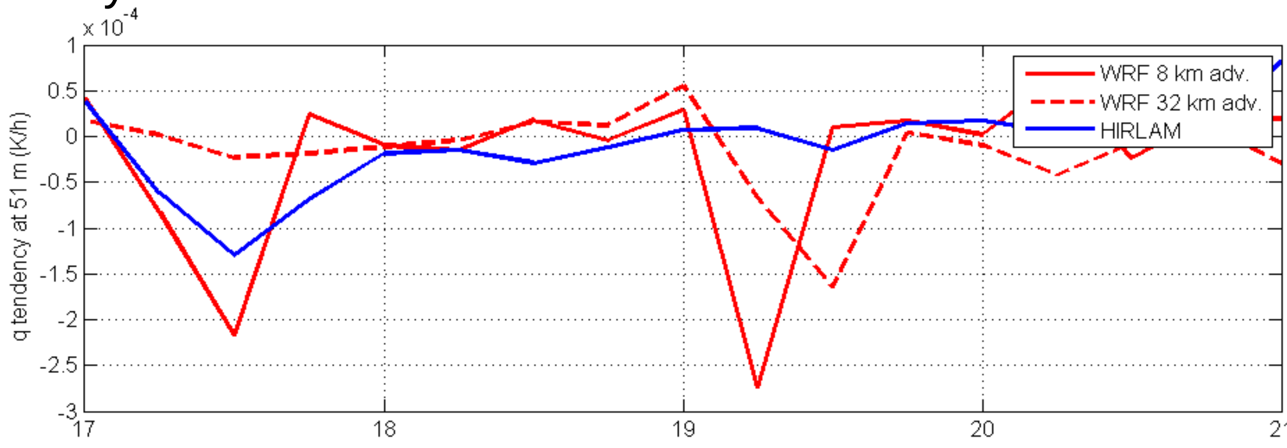


2270 m

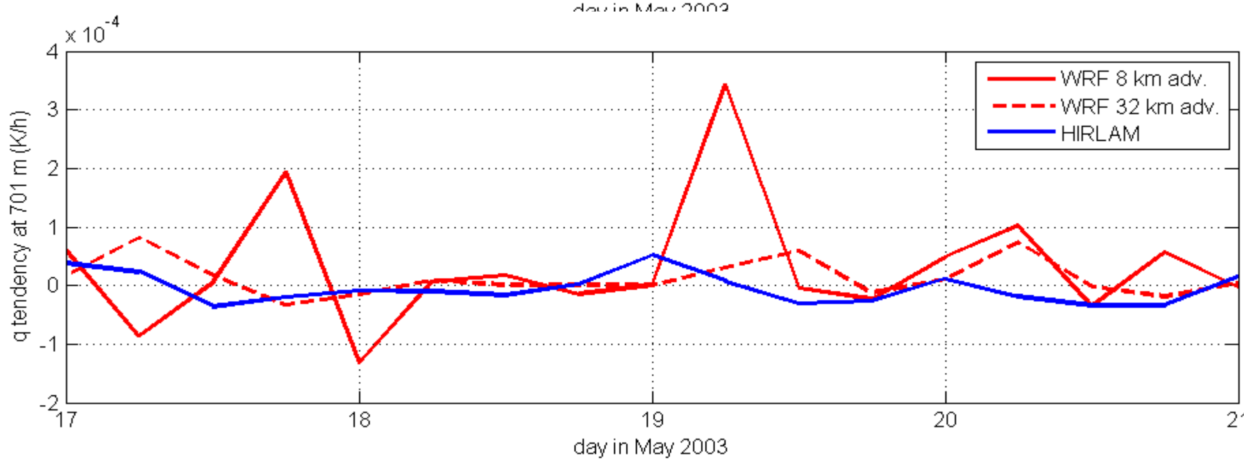


Specific humidity

50 m



700 m



Discussion

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

- 18 May 2003 is the most suitable period (24 h) for single column modelling:

- not much uncertainty about advection of heat and moisture

- very stable stratification, including the development from slightly stable to very stable

- momentum advection still needs to be calculated

- 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 analyses of 3D model fields for the Halley 2003 case
   - vertical profiles of momentum advection
2. Initial experiments with 1D models: MUSC and WRF

- optimal start time? 17 May 12 UTC would allow 12 h spin-up time, but includes more uncertainty in advection
- Comparison of 3D runs and 1D runs with prescribed dynamical tendencies

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

GABLS4 itself:

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