The 4th GABLS mode intercomparison: overview and 1D results

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GABLS4 workshop

12-14 September 2018 Météo-France, Toulouse

Outline:

- Introduction: History of GABLS, Why Dome C, Observation
- Case description
  - Climatology at DomeC / Criteria for the period
  - How the initial fields and forcings have been created
  - Why an ideal case ?
- Several intercomparisons
  - Snow model not detailled
  - 1D
  - And LES (see Couvreux et al. paper)
- Results
- Conclusions

Introduction (1):

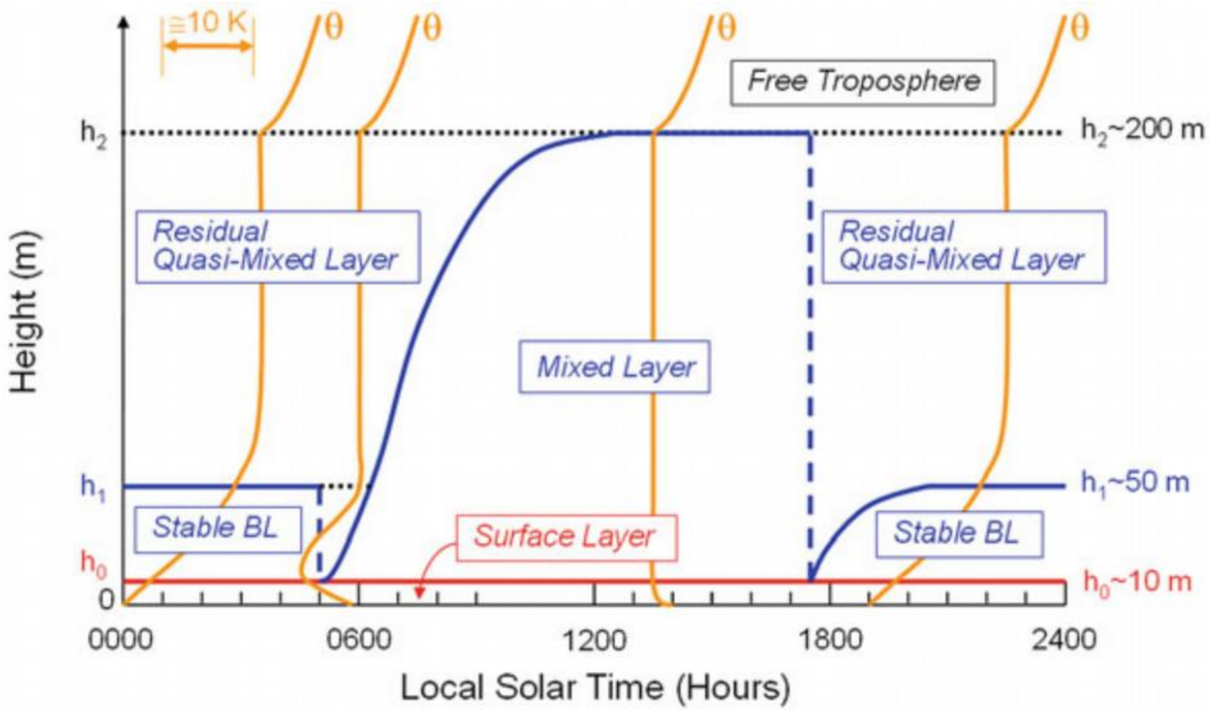
- Accurate surface fluxes and vertical profile in stable boundary layer are still a challenge for many NWP or climate models despite of several improvements done in the PBL parameterization since the first GABLS exercice (Cuxart et al 2006).
- Significant biases at the surface over land and especially over snow are often reported in many papers Holtslag et al 2013, Freville et 2014 …
- Atlaskin and Vihma (2012) evaluate several NWP models in wintertime IFS, GFS, HIRLAM and AROME and one of conclusions is : "This suggests that over an almost flat terrain horizontal resolution is not a major factor for the accuracy of T2m forecast at low T2m typically associated with temperature inversions".
- Antarctica and especially DomeC has many advantages versus other site:
  - Rather "Uniform" soil characteristics (snow), flat terrain, no catabatic wind, low conductivity and a high potential cooling, low roughness length
  - Mast data temperature, humidity and wind at 6 levels with sonic anemometer (Genthon 2010, 2013) snow temperature profile, radiative fluxes (BSRN, Lanconelli et al 2011) etc ..
  - Constant flux in the first layer and flux-profile relationship still valid ? Many formulation ...
  - Estimation of surface fluxes from the sonic (extreme condition), the roughness length for heat and momemtum is still a challenge for the very stable condition, problem with sastrugi
  - Z0h/m probably requires an dynamical parametrization over Antarctica (Vignon et al. 2016)

Introduction (2):

- The weak stratification has been studied in many studies especially with the previous GABLS intercomparison (Cuxart et al. 2006, Svensson et al. 2011 and Bosveld et al. 2014) and is rather well understood and parameterized.
- However for stronger stratification:
  - the turbulence is weaker and more chaotic or intermittent (Mahrt 1999, Mahrt 2014, Van de Wiel 2003)
  - The interaction between radiative processes and turbulence is more important during the transition (cooling) phase (Edwards 2009 part1) and even if in the SBL the radiative cooling dominates in mean, a radiative heating is present near the surface < 0.5m (compensated by the extreme cooling at the surface) Edwards 2009, part 2 , Savijarvi (2006)
  - Gopalakrishnan et al. 1998 suggest also that two types of SBL for strong wind with an equilibrium and weak wind with no limit (?) for the dT/dz (correlated also with the role of the radiation) .
  - Later this hypothesis has been confirmed by Van de Wiel (2012), with the minimum wind speed for sustainable turbulence in the nocturnal boundary layer. For DomeC Vignon et al 2017a based on observation from the tower found that the minimum wind speed for weak turbulence is about 5-6 m/s. Below this value the dT/dz can reach 3K/m

Climatology at DomeC / Criteria for the period

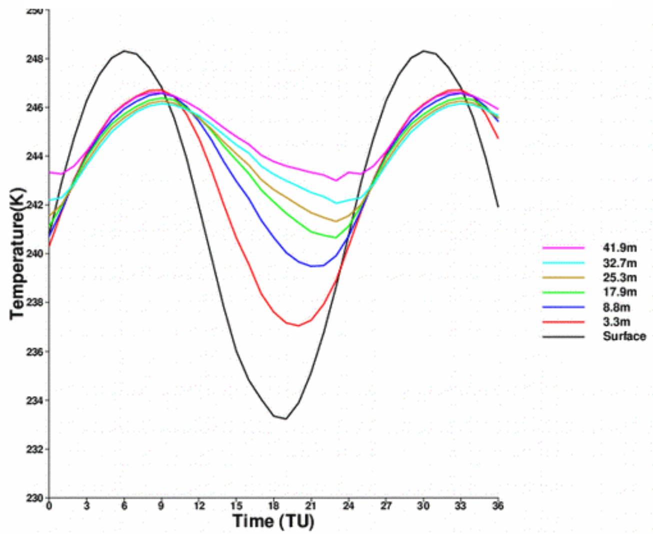
- DomeC : ideal for homogenous surface : flat snow desert with almost no wind greater the 12m/s (Argentini et al 2011). H. Barral during her PhD (2014) computes the mean diurnal cycle for the temperature and the wind for December (2009-2010-2011) showing even in summer strong stability with weak wind below the minimum value found by Vignon et al 2017.
- Ricaud et al 2011 with radiometric measurement have shown that typically the PBL height (mixed layer) varies from 200m during day time to 50m during night.



Climatology at DomeC / Criteria for the period

- The topic was to find a golden day with all the sonic available at 5 levels for the turbulent fluxes along the mast. Low wind, no clouds (to avoid the difficult aspect of ice cloud, humidity observation and sursaturation) and if possible during the Concordiasi (Rabier et al. 2010) field experiment to potentially have two soundings data instead of one as a re-analysis is necessary to compute the large scale forcing.

Climatological diurnal cycle: Temperature for December 2011-2016



GABLS4 11dec 2009 diurnal cycle: Temperature

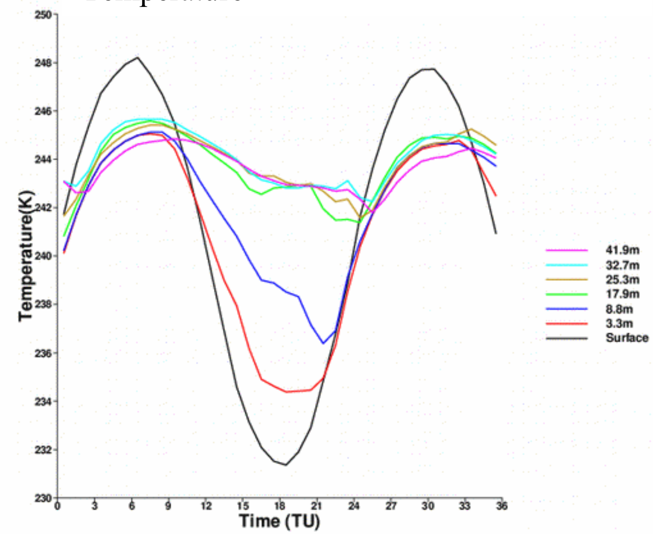


Fig1

Climatology at DomeC / Criteria for the period

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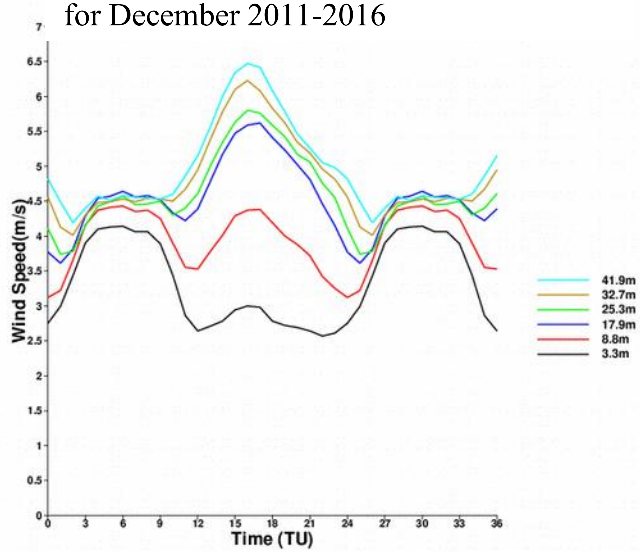
Climatological diurnal cycle: Wind speed for December 2011-2016



GABLS4 11dec 2009 diurnal cycle: Wind speed

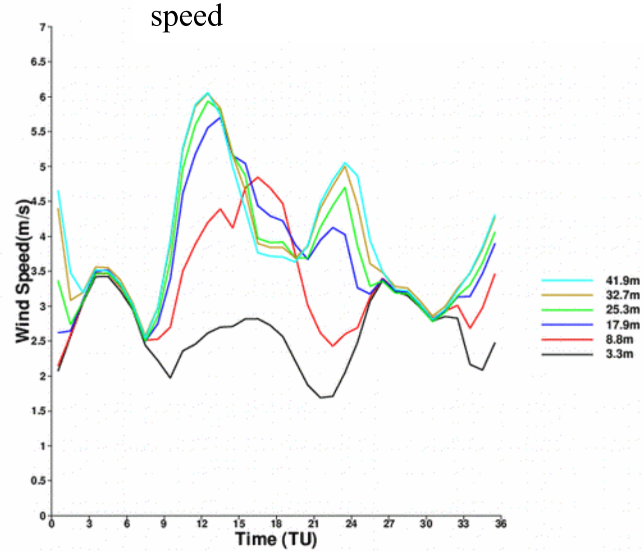
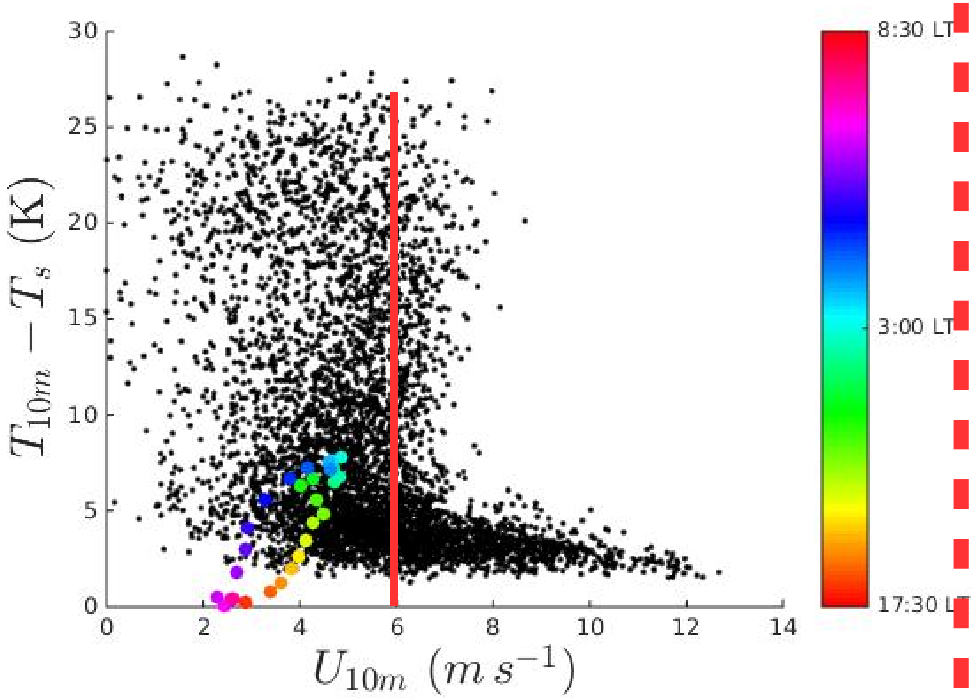
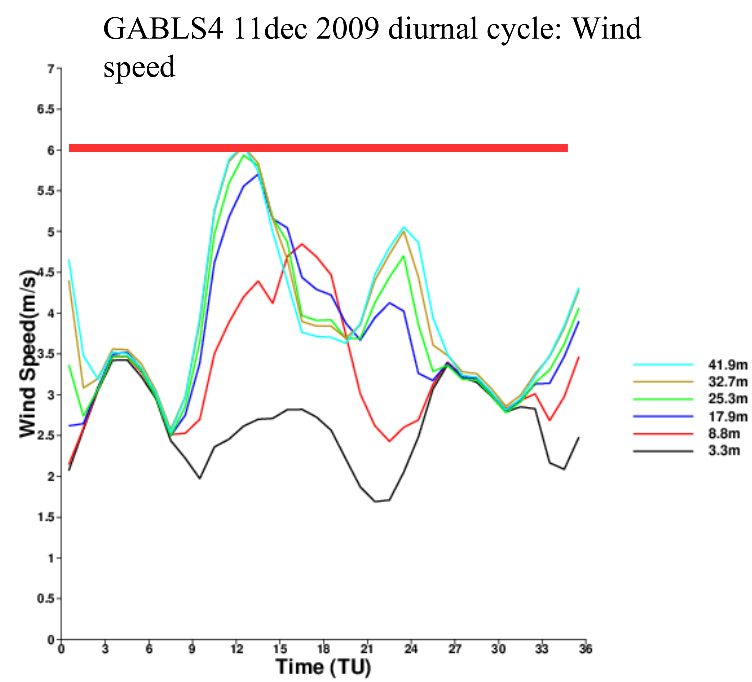


Fig1 ??

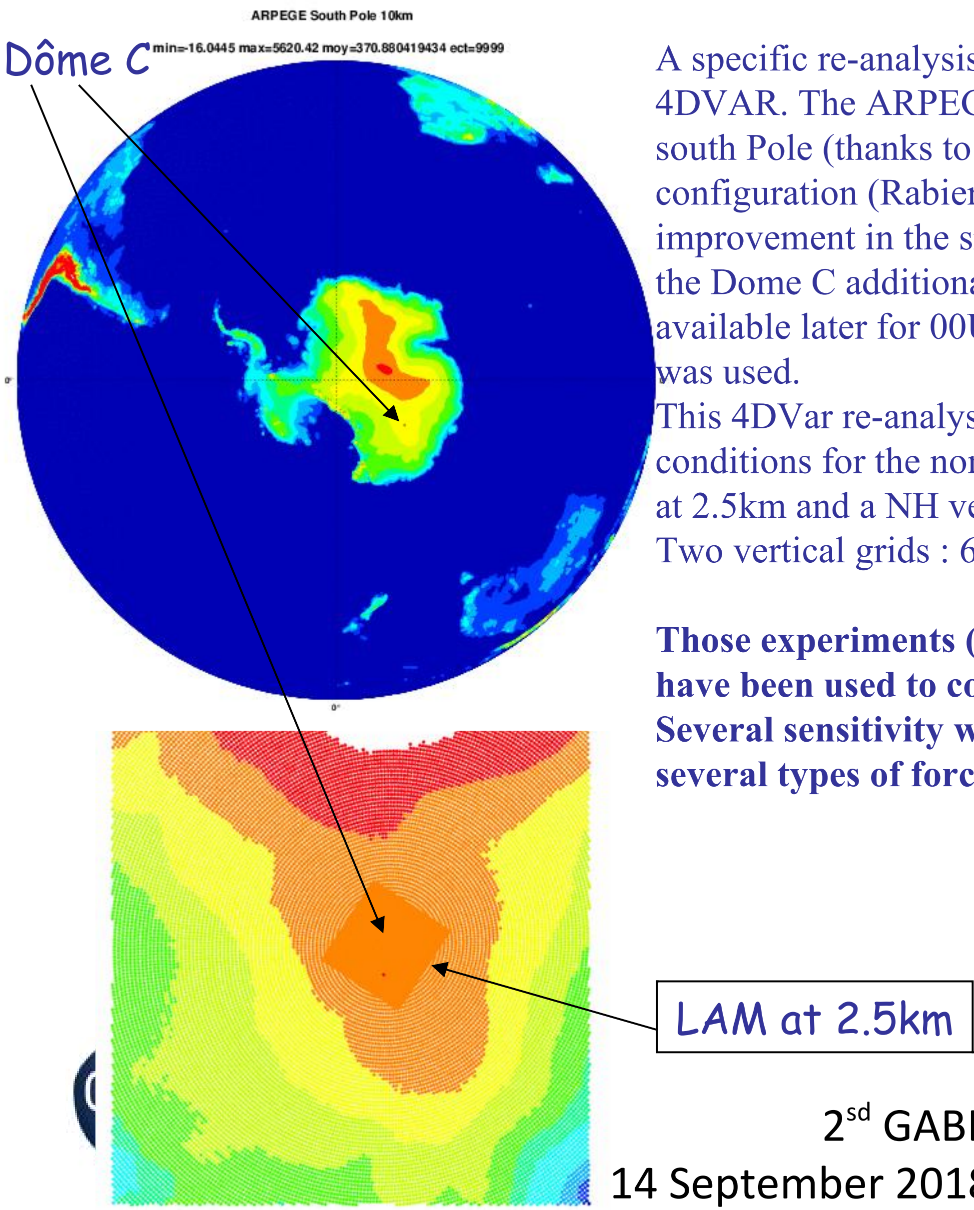
Climatology at DomeC / Criteria for the period





Thanks to E. Vignon

How the forcing have been created ?



A specific re-analysis was performed with the global model ARPEGE and a 4DVAR. The ARPEGE model was used with a high resolution (10km) over the south Pole (thanks to the variable mesh) similar to the ARPEGE Concordiasi configuration (Rabier et al. 2010, Bouchard et al. 2010). ARPEGE used an improvement in the snow scheme for a better diurnal cycle over Antarctica and the Dome C additional sounding data (not used in the operational ARPEGE) available later for 00UTC and 12UTC with the full vertical resolution (every 2m) was used.

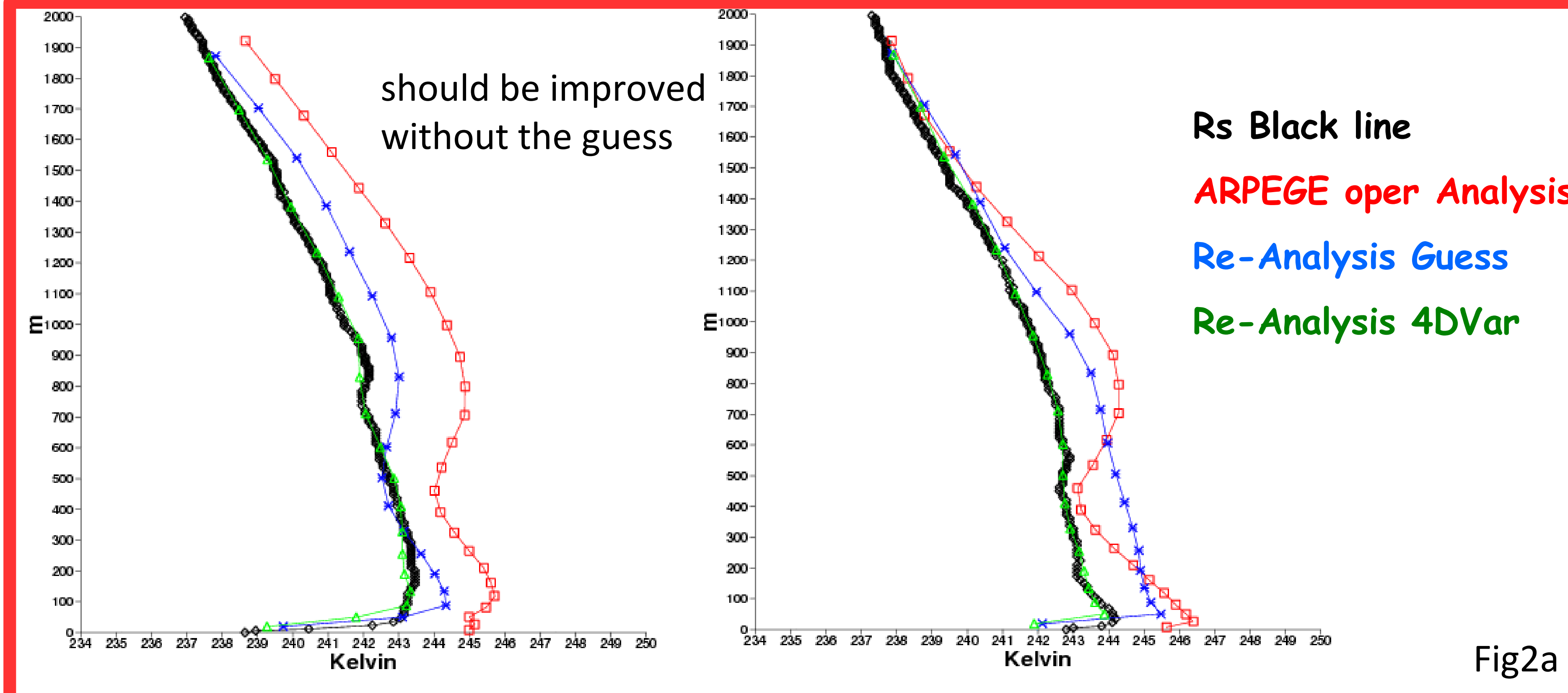
This 4DVar re-analysis was used to provide initial fields and Lateral Boundary conditions for the non hydrostatic limited area model AROME (Seity et al, 2011) at 2.5km and a NH version of ALADIN (ARPEGE physics) used also at 2.5km. Two vertical grids : 60 vertical levels with a time step=60s (SL) and 90 with 45s.

Those experiments (4) done at 2.5km, can be considered as an ensemble, have been used to compute the large scale advection, geostrophic wind etc … Several sensitivity with the 1D model (not shown) have been done with several types of forcings (advection, geostrophic, vertical velocity.

How the forcing have been created ?

20091211 at 00UTC

20091211 at 12UTC



Analyse oper (red line)

4DVar re-analysis done with ARPEGE stretched over the Antarctic Plateau (10km) with high resolution of RS

How the forcing have been created ?

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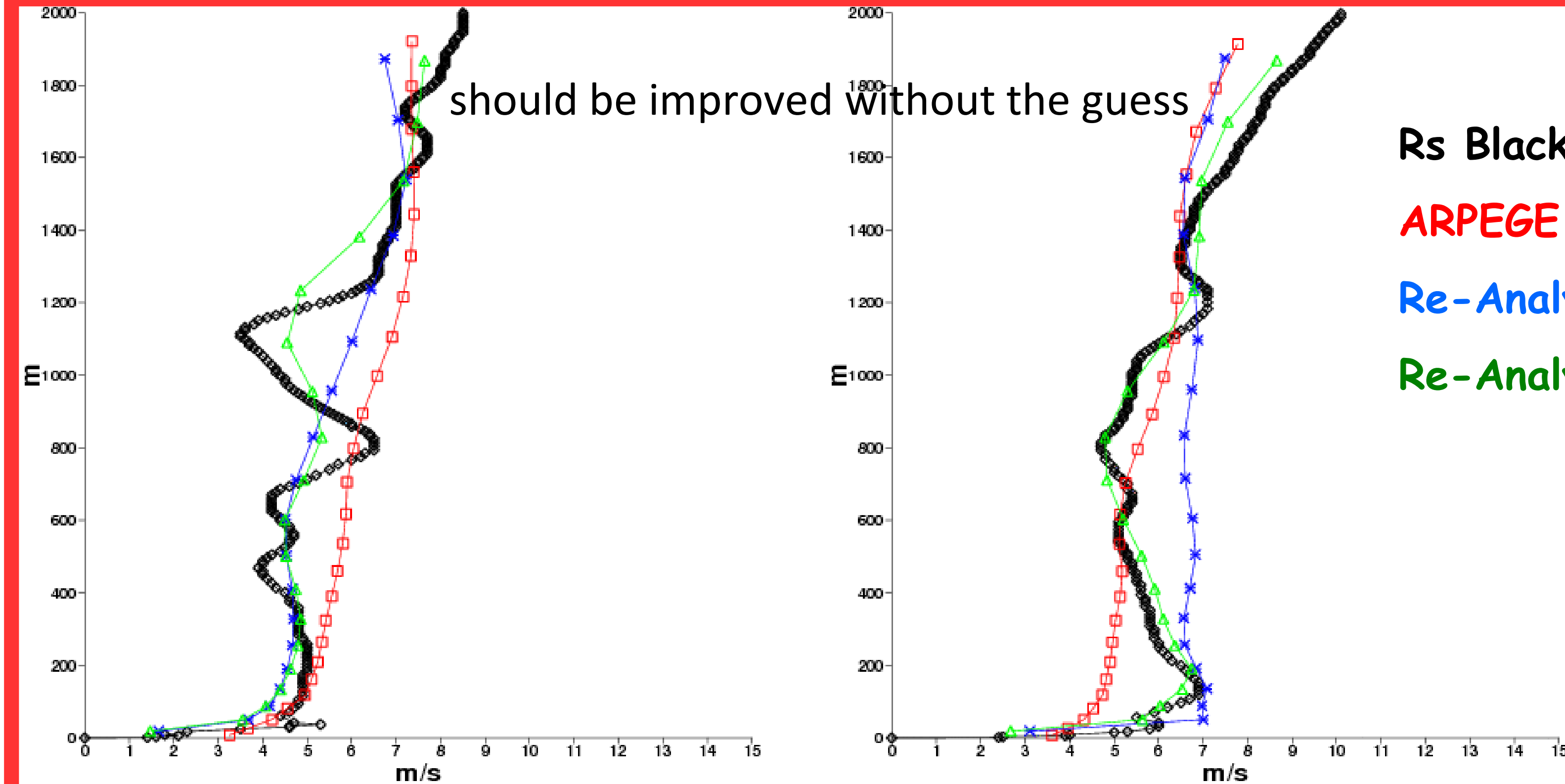


Rs Black line

ARPEGE oper Analysis

Re-Analysis Guess

Re-Analysis 4DVar

Fig2b

Analyse oper (red line)

4DVar re-analysis done with ARPEGE stretched over the Antarctic Plateau (10km) with high resolution of RS

How the forcing have been created ?

From a 3D experiment :

- Classical method: from horizontal fields at different level, dependency to the grid, instantaneous output, requires some time and space filtering. Scale = f(dx,dy,dz)

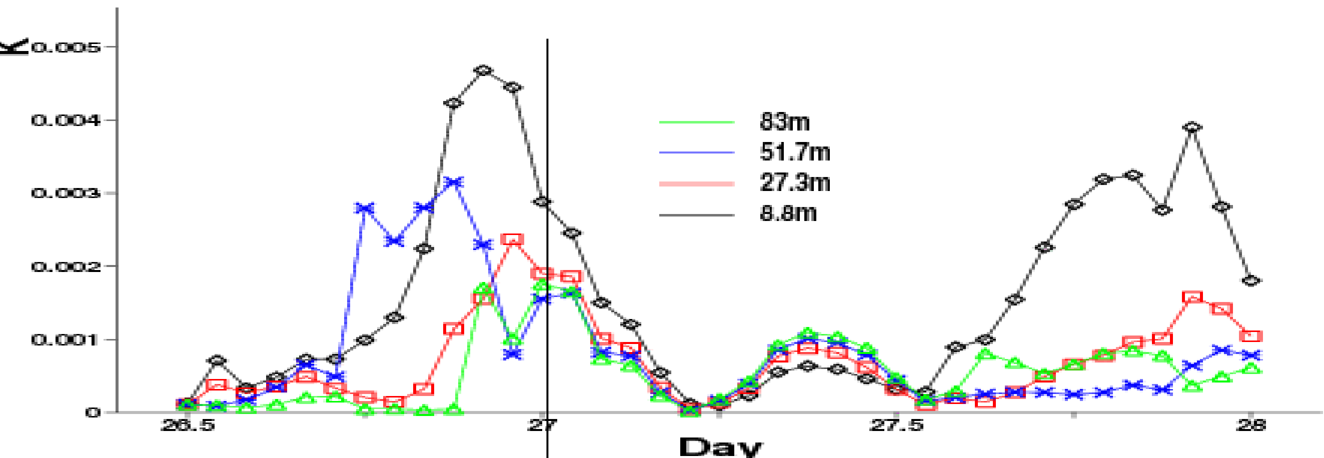
$$\frac{\partial T}{\partial t}_{forc} = -\frac{\partial uT}{\partial x} - \frac{\partial vT}{\partial y} \frac{1}{\rho} \frac{\partial \rho wT}{\partial z}$$

- Since the first version of the fully integrated 1D model of ARPEGE/ALADIN/AROME system 2005, the advection, vertical velocity, geostrophic wind are computed with an integrated tool (called DDH for Diagnostic Domaine Horizontal) during the 3D model integration. The principle is to use the budget equation for each variables and computes each terms for a single profile or a box and for different time periods. All the physical processes are available and dynamical forcing can be deduced from:

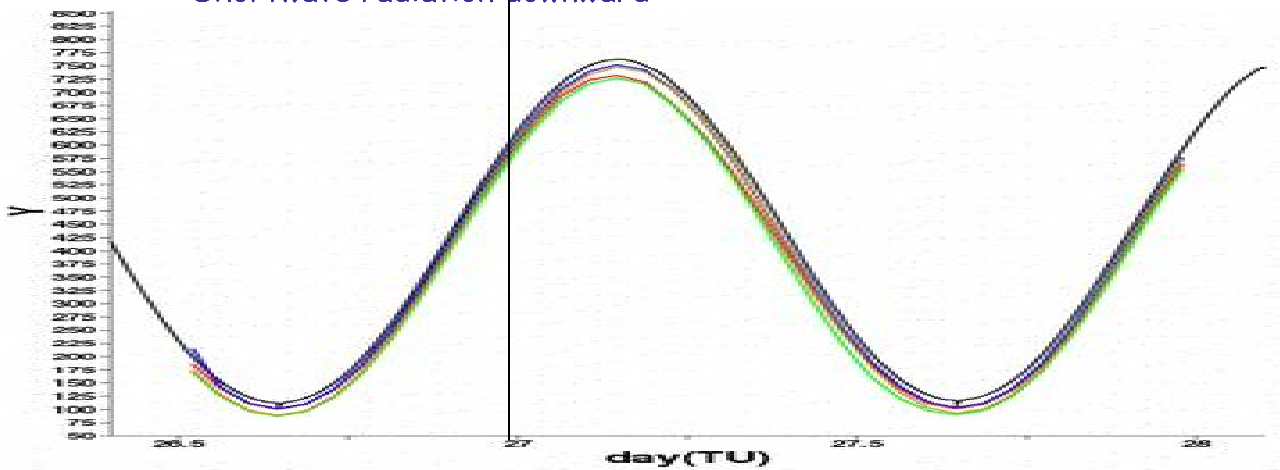
$$\frac{\partial T}{\partial t} = Dyn + \underbrace{\frac{\partial T}{\partial t}_{rayt} + \frac{\partial T}{\partial t}_{turb} + \frac{\partial T}{\partial t}_{shal} + \ldots}_{Physics_{parameterizations}}$$

Horizontal scale variability around DomeC seen by the AROME model

STD for temperature at different level



Shortwave radiation downward



The temperature STD is very small in the CRM model (< 5.10-3K) with a « shifted diurnal cycle »
So at least, for the model the site is homogeneous and it makes sense to compare the model directly to the observations BUT it does not mean that in the "reality" there is no more variability !

Case description and how ?

- Initial profile based on the radiosonde data but simplified (red)

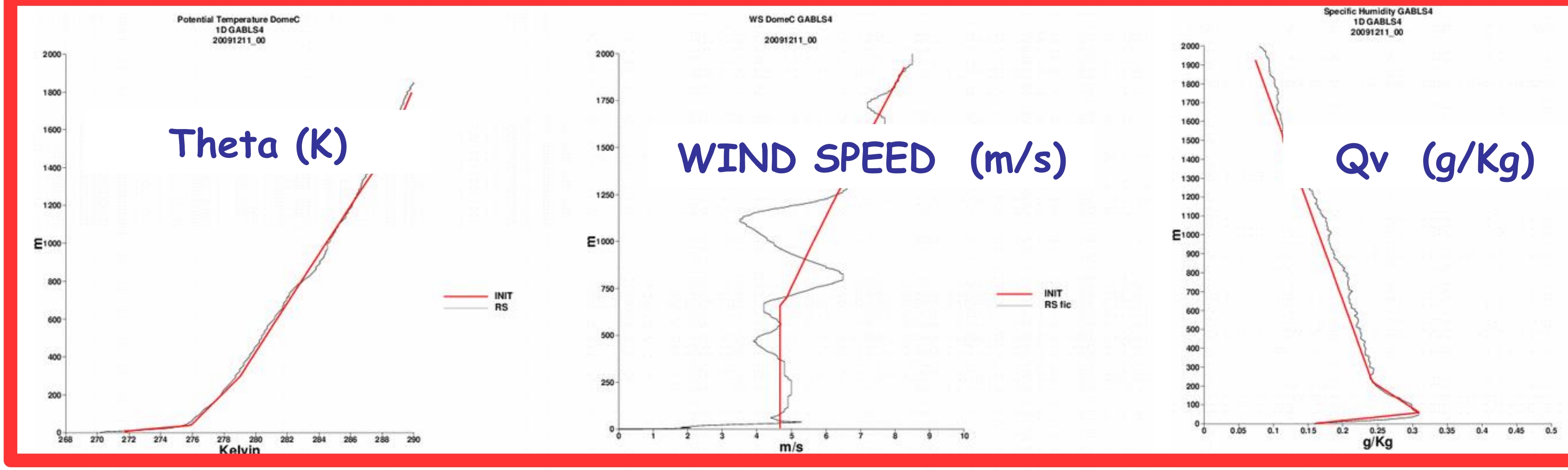
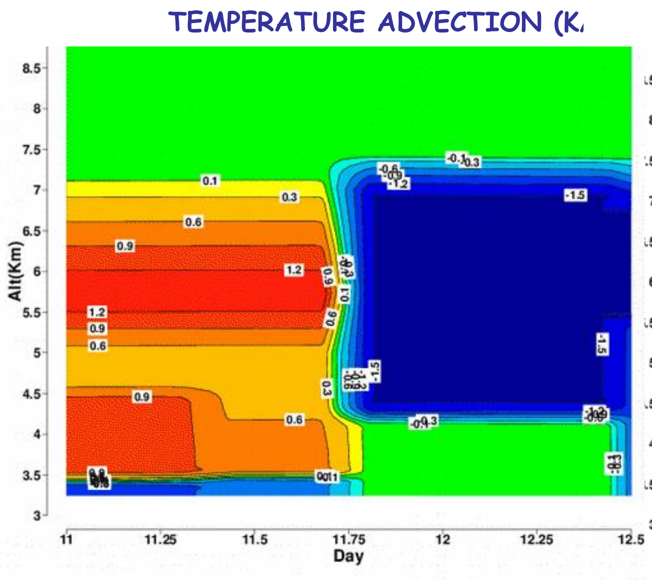
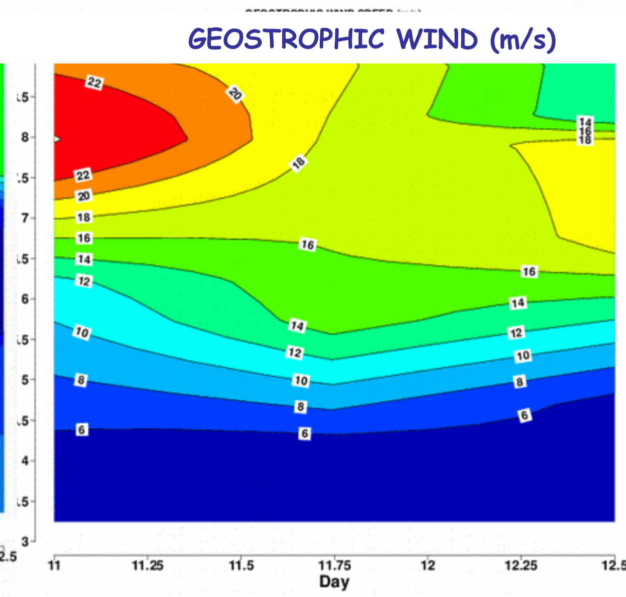


Fig3





It was decided to start the simulation during day time with the radiative forcing to reduce the impact of the spin-up when the decrease of the turbulence starts (after 6h). The initial conditions for the soil (snow pack) was given with a temperature profile however depending on the snow scheme used in the model, it was possible to use initial condition for the snow computed by an integration of the snow model driven by the observations

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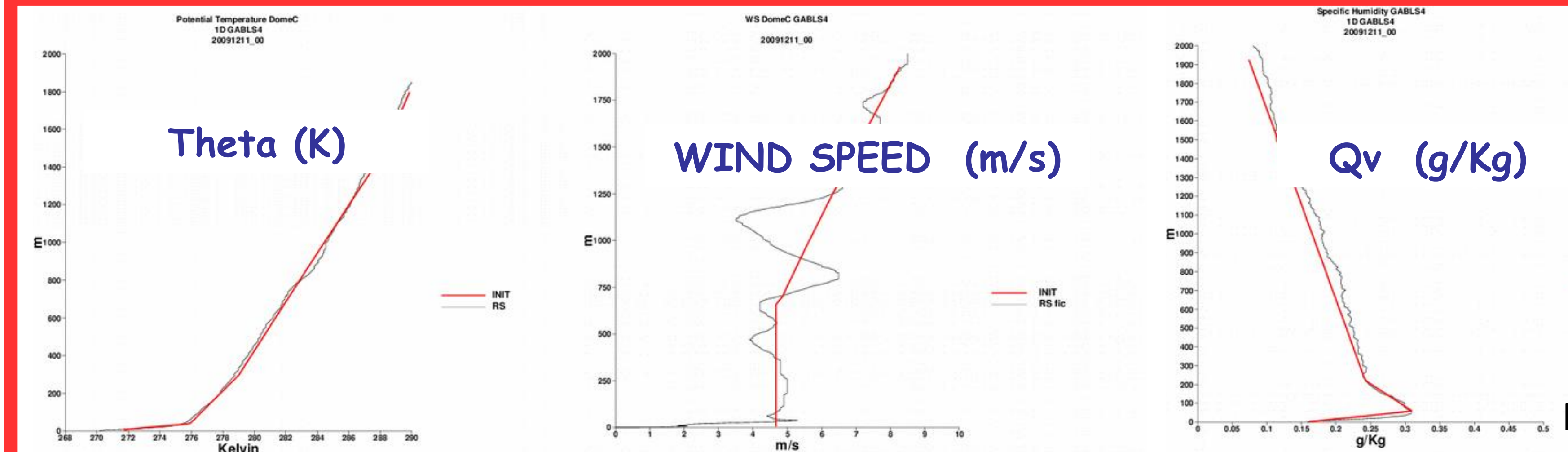
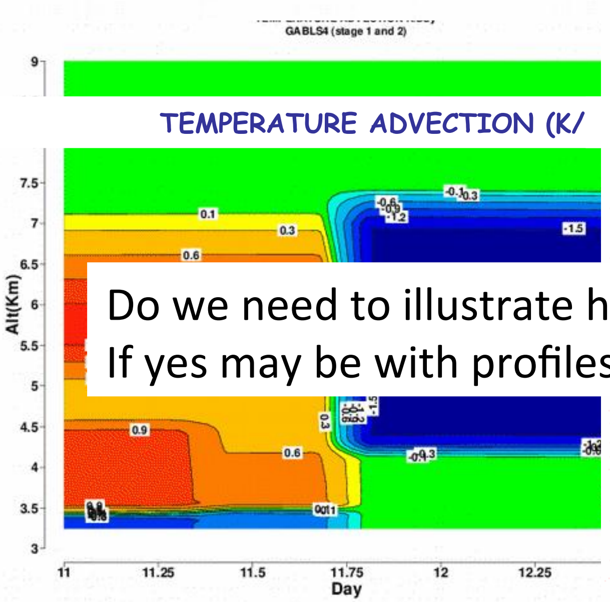
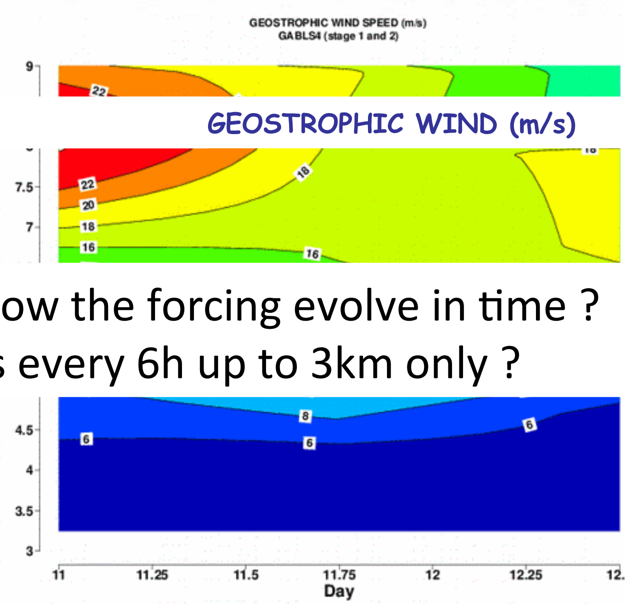


Fig3





Do we need to illustrate how the forcing evolve in time ?
If yes may be with profiles every 6h up to 3km only ?

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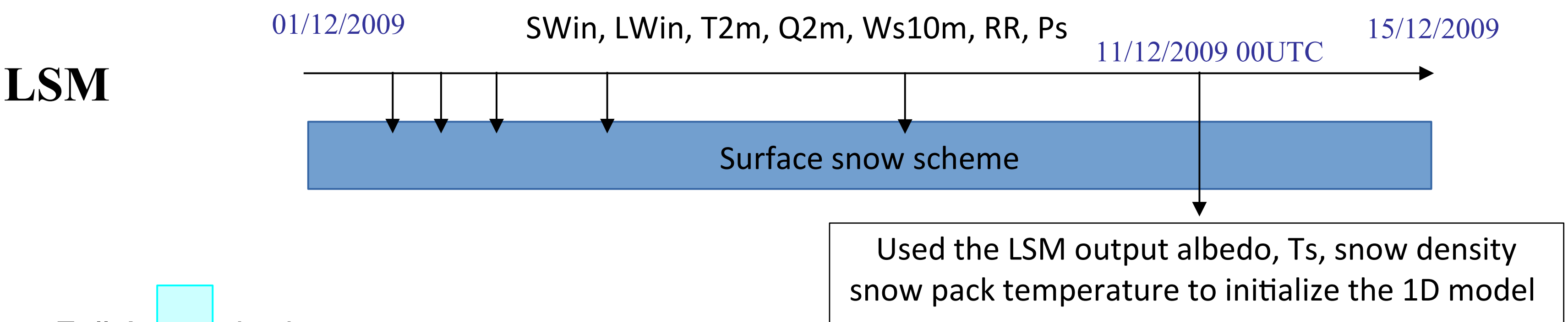
METEO FRANCE

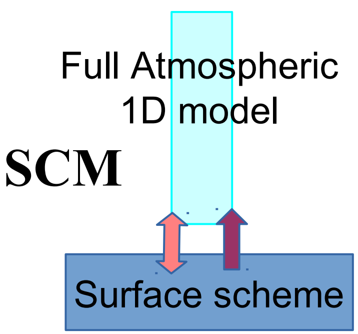
e, Toulouse

Case description and how ?

•To reduce or avoid the problem with the initialization of the soil (snow) characteristics albedo, emissivity density and temperature profile in the snow pack and to be as much as possible close to the operational model or climate model we follow the DICE (paper ?) protocol:

- **LSM forced by observations** = T,Rh,WS, SWd, Lwd,RR,Ps offline mode
    - comparison of snow models during 15 days vs observed temperature profile, surface fluxes





•For the SCM intercomparison two experiments will be performed :

•Stage 1 : 36h with a full interaction with the surface scheme to study the interaction and the feedback (response) of the atmosphere from the surface (Ts, albedo)

•Stage 2 : same as Stage1 but with a prescribed Ts to only evaluate the PBL parametrization

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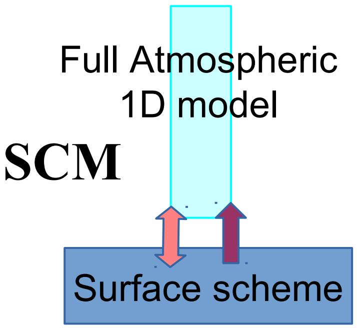
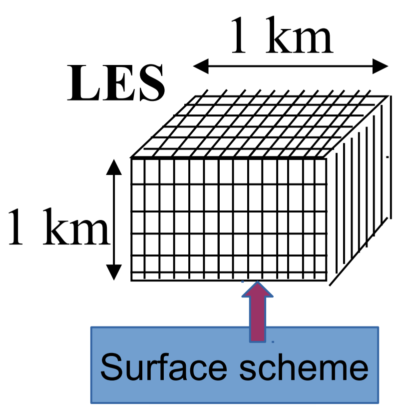


•For the SCM intercomparisons two experiments will be performed :

- •Stage 1 : 36h with a full interaction with the surface scheme to study the interaction and the feedback (response) of the atmosphere from the surface (Ts, albedo)
- •Stage 2 : same as Stage1 but with a prescribed Ts to only evaluate the PBL parametrization , surface flux formulation and radiation



• For the LES intercomparisons two experiments has been planned at the beginning similar to the SCM one. However, due to the simulation length (minimum 24h), the domain size (1kmx1kmx1km), minimum grid size 5m and the use of a radiation and a surface scheme → the number of LES-group able and interested to participate was extremely small → an ideal or simplified case was created stage3

•Stage3 : no radiation, no humidity, no advection, constant geostrophic wind, ts prescribed (same as stage2) in fact similar to GABLS1 except the diurnal cycle with a stronger stability

Table 1 : List of the different models, model type (O=oper, R=research, G=Global or L=limited Area) with a brief description of the parameterization used to represent the boundary layer and the radiation scheme

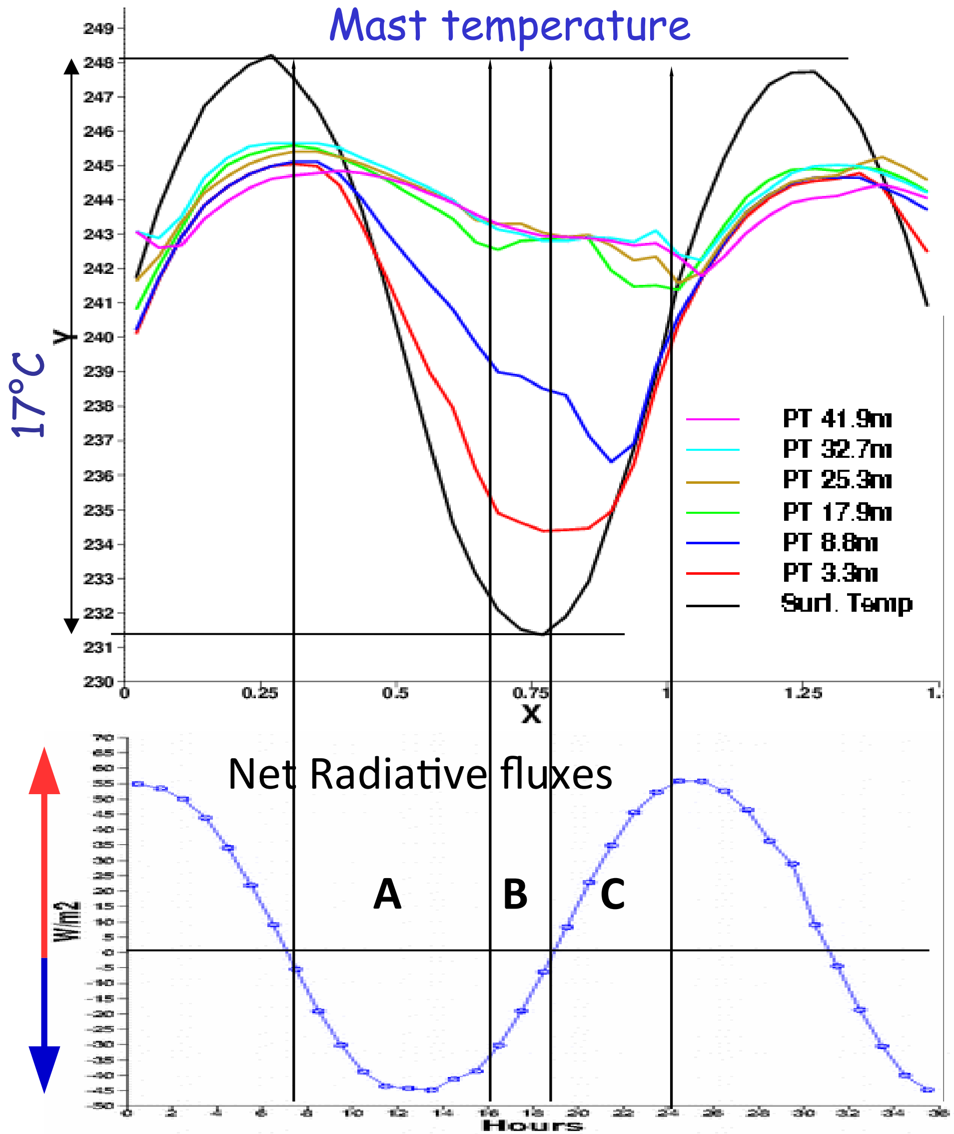
Model name	Model type	Participant(s)/Institute	Stage 1	Stage 2	Stage 3	Subgrid turbulence scheme	Surface layer scheme	Shallow convection	Radiation scheme
ARPEGE/ALADIN	O/G/L	Eric Bazile Météo-France	Y	Y	Y	TKE Cuxart et al (2000) with mixing length from Bougeault-Lacarrere (1989) interaction with shallow Bazile et al(2011)	Modified Louis stability function	Bechtold et al (2001)	
GDPS	O/G	Ayrton Zadra Environment and Climate Change Canada	Y	Y	Y	TKE-l 1.5 [Belair et al. (1999); Bougeault and Lacarrere (1989)]	ISBA, multilayer with 10 prognostics variables [Noilhan and Planton (1989); Belair et al. (2003a,b)]	Kuo-type closure (Kuo transient) [Belair et al. (2005)]	Correlated k distribution for gaseous transmission [Li and Barker (2005)]
GFS	O/G	Weizhong Zheng NOAA	Y	Y	Y				
IFS	O/G	Irina Sandu ECMWF	Y	Y	Y	K-diffusion for stable cases: LTG stability functions,		EDMF scheme for convective PBL	
MetUM	O/G/L	J. M. Edwards MetOffice	Y	Y	Y	K-profile/Richardson number	Louis and Beljaars and Holtslag	Mass-flux	Two-stream
AROME	O/L	Eric Bazile Météo-France	Y	Y	Y	TKE Cuxart et al (2000) with mixing length from Bougeault-Lacarrere (1989)	Modified Louis stability function	Pergaud et al (2009)	
HARMONIE-AROME	O/L	Wim de Rooj/KNMI	Y	No	No	TKE with mixing length (Lenderink and Holtslag 2004)	Masson et al,2013	EDMFm (Siebesma et al 2007; de Rooy and Siebesma, 2008; Neggers et al 2009)	ECMWF 2015, Nielsen et al. 2014,
CAM5-IPHOC	R/G	Anning Cheng EMC/NCEP/NOAA	Y	Y	Y	IPHOC (Cheng and Xu 2006,2011, 2015)	CLM4	IPHOC	RRTMG
WRF(1)	R/L	Wayne Angevine (CIRES/NOAA) & D. Veron and A. Schroth (University of Delaware)	Y	No	Y	MYNN-EDMF as in WRF v3.9 (Nakanishi and Niino 2006, BLM; Angevine et al. 2018, in review)	MYNN	EDMF built in	RRTMG SW & LW
WRF(2)	R/L	Wayne Angevine (CIRES/NOAA) & D. Veron and A. Schroth (University of Delaware)	Y	No	Y	TEMF(Angevine et al. 2010)	TEMF	EDMF built in	RRTMG SW & LW
CSIRO(1)	R/G	Jing Huang Australia	Y	Y	Y	K-profile/Richardson number Huang et al 2013	CABLE (Kowalczyk et al 2007)	McGregor 2003 convection for K-profile and Huang et al 2013	GFDL-CM2.1 (Freidenreich and Ramaswamy 1999, Schwarzkopf and Ramaswamy 1999)
CSIRO(3)	R/G	Jing Huang Australia	Y	Y	Y	TKE-epsilon and mass flux (Hurley 2007)	CABLE (Kowalczyk et al 2007)	EDMF	GFDL-CM2.1 (Freidenreich and Ramaswamy 1999, Schwarzkopf and Ramaswamy 1999)
LMDz	R/G	Etienne Vignon (IGE)/ Marie-Pierre Lefevre (LMD)	Y	Y	Y	Mellor & Yamada scheme			
MAR	R/G	Hubert Gallée (IGE)	Y	Y	No	TKE-epsilon scheme			
MesoNH	R/L	M.A. Jimenez Cortes and J. Cuxart Uni. des Illes Balears	Y	Y	Y	Prognostic equation for TKE Cuxart et al (2000) with mixing length from Bougeault-Lacarrere (1989)	SURFEX (Masson et al, 2013; ISBA for nature areas)	Edy-Diffusivity-Kain-Fritsch scheme (Kain-Fritsch 1990; Pergaud et al. 2009)	ECMWF radiation scheme: LW (RRTM, Mlawer et al. 1990) and SW (Fouquart and Bonnel 1980)
RACMO	R/L	Peter Baas / TuDelft	Y	Y	Y	TKE mixing length Lenderink and Holtslag 2004)	TESSEL(from IFS cy31r1)	EDMFm (Siebesma et al 2007; de Rooy and Siebesma, 2008; Neggers et al 2009)	RRTM
Wurd91	R	G.J. Steeneveld / Wageningen Uni.	Y	Y	Y	First order local closure with D91 f(Ri) functions	D91 f(Ri) functions	None	Broadband emissivity Scheme (Garratt and Brost, 1981)

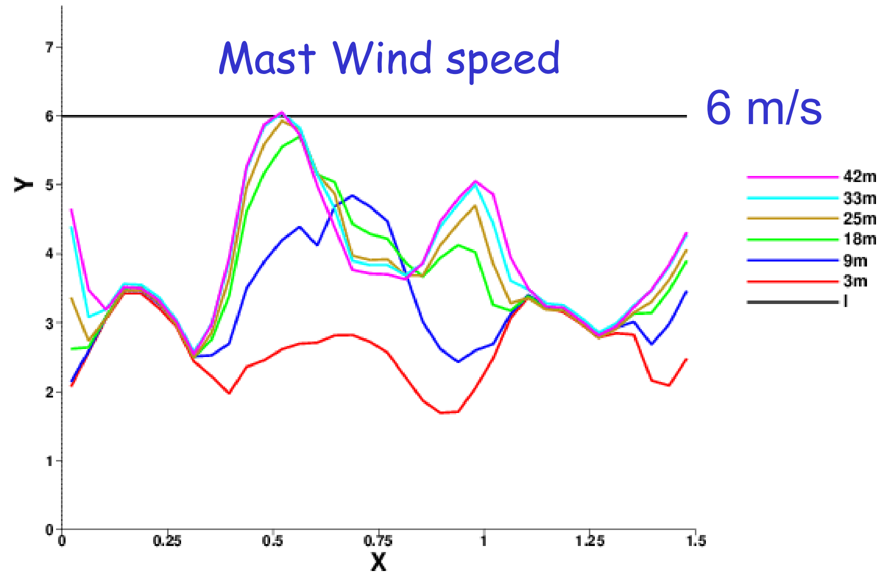
Some questions adressed in the paper

- For SCM:
- What is the status for the PBL parameterization used in GCM/NWP for SBL since GABLS1 ?
- How the surface interacts with the stable boundary layer ? Increases or compensates deficiencies from the PBL scheme ? Vertical resolution ? Height of the 1st level ?
- Are the results similar between stage2 and stage 3 for SCM ?
- Can we use stage3 with the LES results to understand the SCM deficiencies seen in stage2 and stage1

- For LES and Fleur ! :
  - At such high stability, do we reach the limit of the LES ? what is the variability among LES at such stability?
  - What is the necessary resolution to resolve the main processes in such stable case?
  - How the results depend on turbulence scheme and surface parameterizations?

GABLS4 : golden day 11th Dec 2009

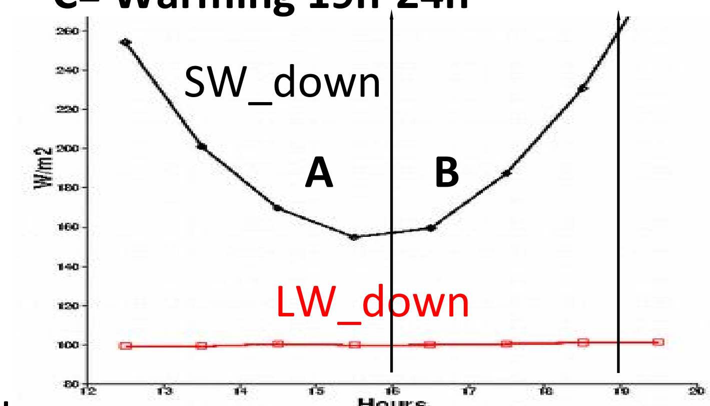




A= Cooling period 8h-16h

B= Less cooling with Swd ↗

C= Warming 19h-24h



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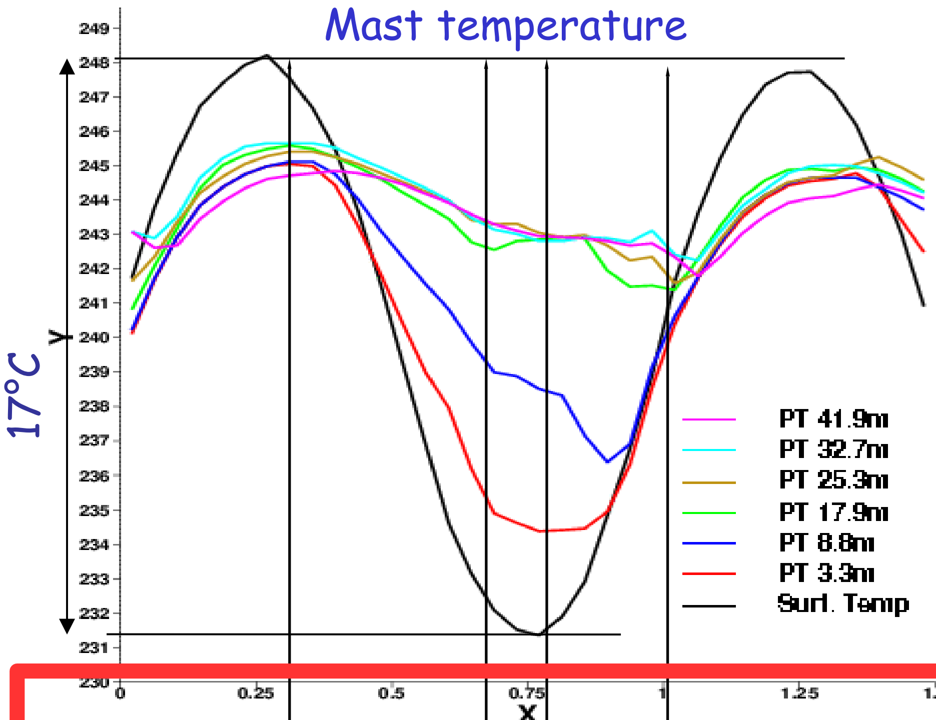

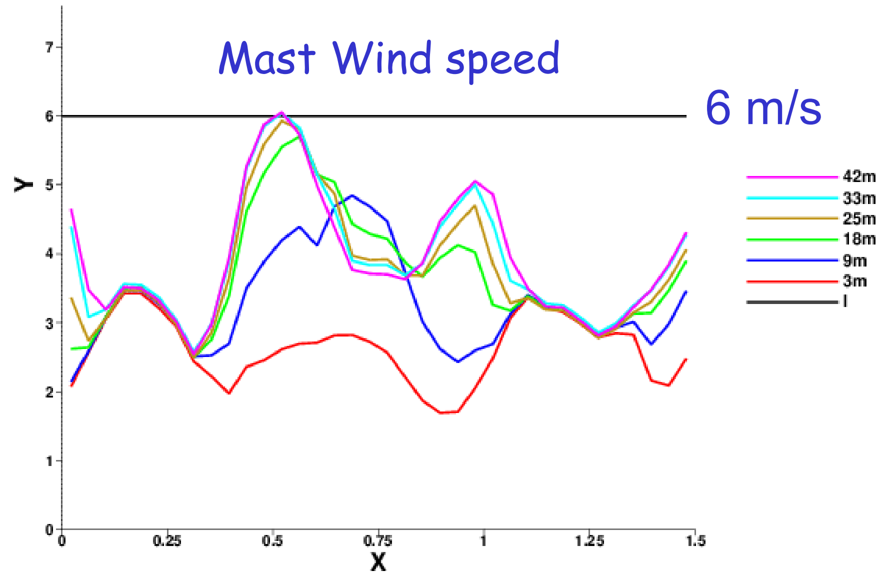

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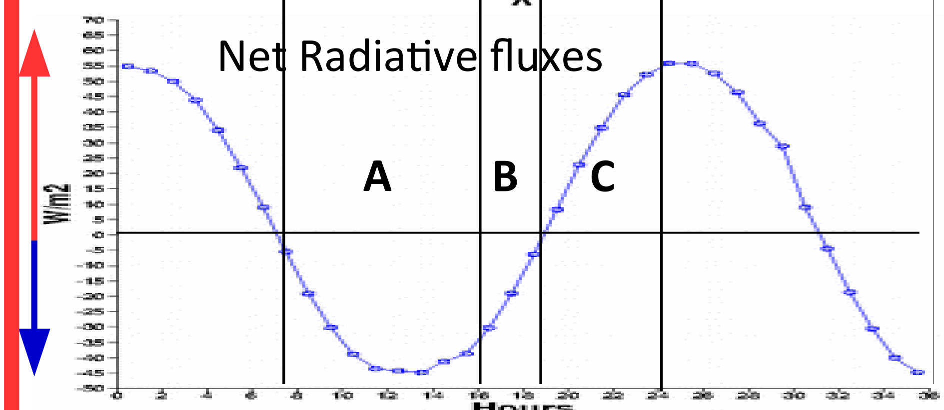


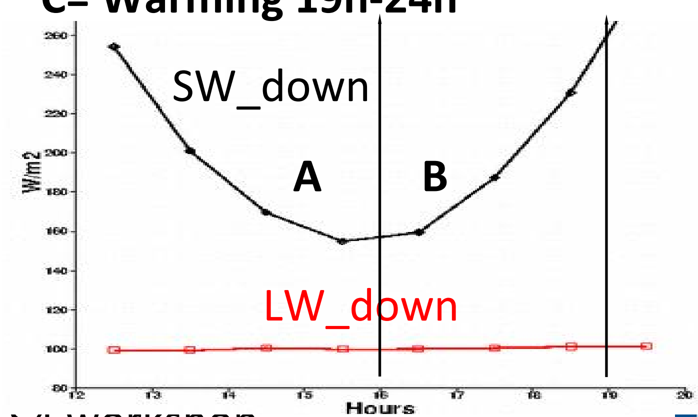
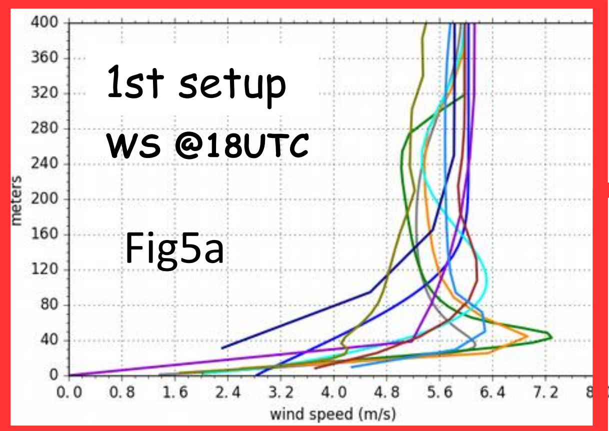
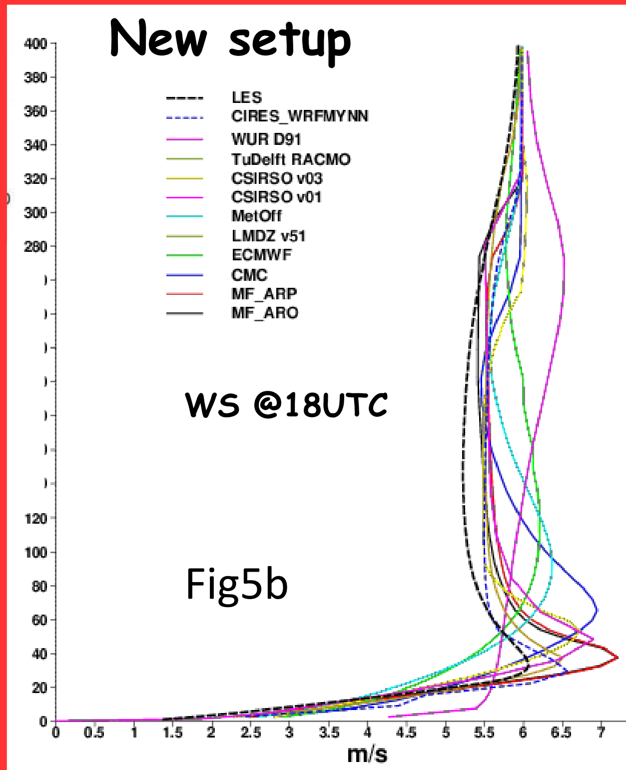


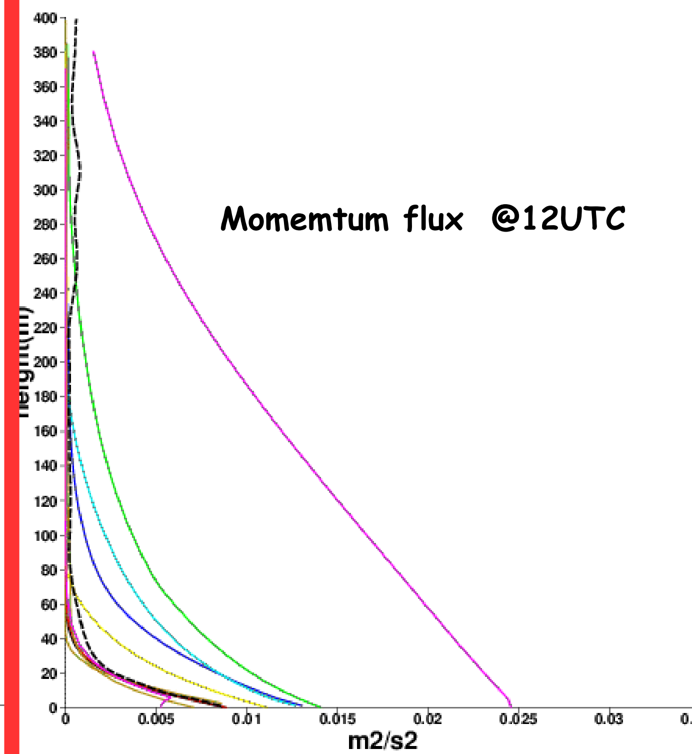
Fig4

Impact of the new setup stage 1 SCM:



New setup: given albedo=0.81, z0m=1mm, z0h/q=0.1mm, Emis=0.98, snow conductivity and a prescribed vertical grid with a first level at 2.5m and 17 levels below 100m (dz ~ 5m)

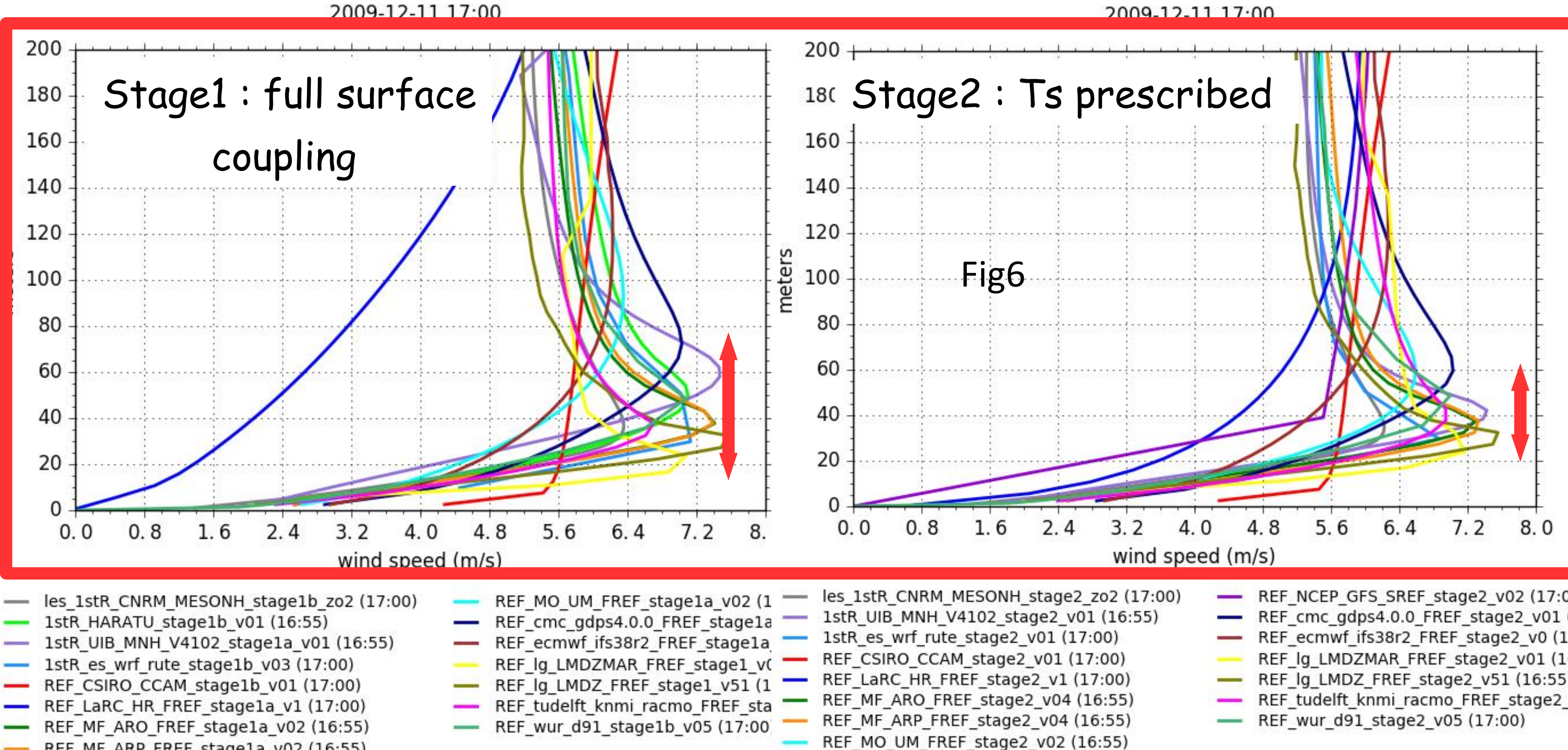




With the new setup less variability between SCM results. The LLJ is lower and improved for many models, mainly due to a finer vertical grid. → better framework for the inter-comparison to investigate models deficiencies. Sterk et 2014 aslo showed that in WRF an accurate surface description helps for a “good description” of stable bounadary layer over snow or ice.

The new vertical grid with the first level at 2.5m improves the height of the LLJ for many models however depending on the PBL scheme (ex in CSIRSO or ECMWF) the impact is very small.

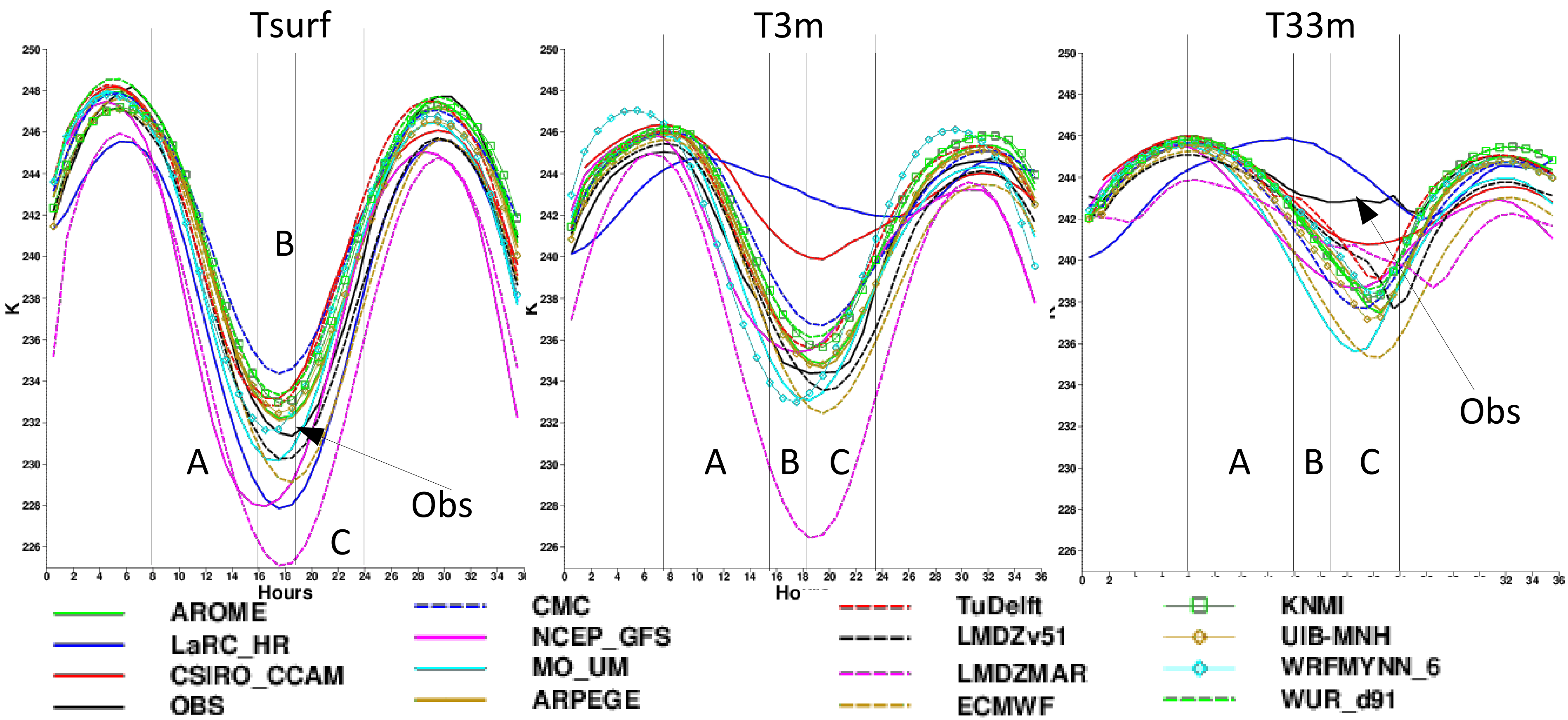
Impact of the prescribed Ts on the Ws @ 17TU



The prescribed Ts (stage2) in the SCM improves the height of the LLJ for several models due to a less surface interaction. Warm Ts --> higher LLJ ? Check sensible heat flux between stage 1 and stage2 ?

Stage 1 : Tsurf & T3m & T33m

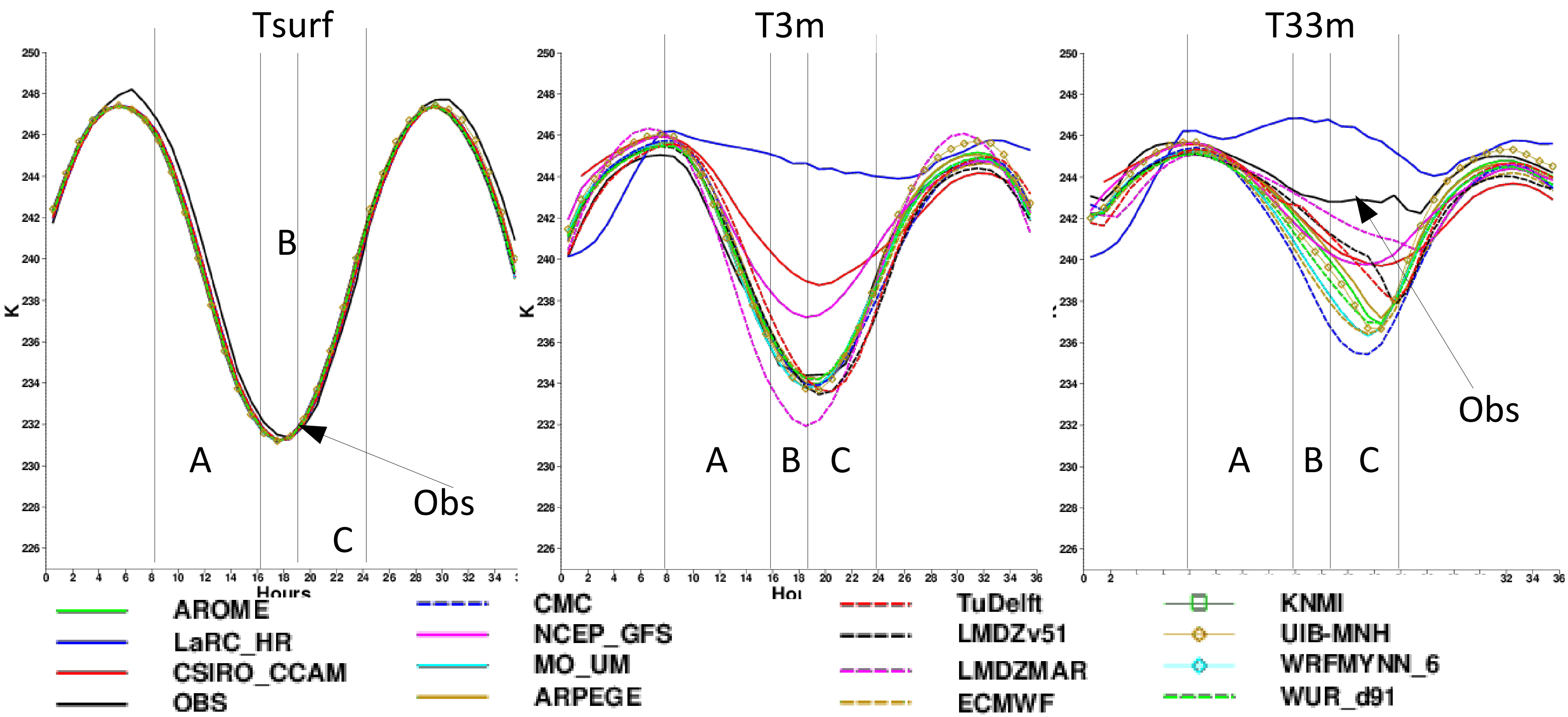
Phase A= Cooling Rn<0
Phase B= Mixte Rn<0 & Swd +
Phase C= Heating Rn>0



More variability during night for Tsurf with warm and cold bias. However for T33m all the models have a cold bias more increased during phase B & C

Stage 2 : Tsurf & T3m & T33m

Phase A= Cooling Rn<0
Phase B= Mixte Rn<0 & Swd +
Phase C= Heating Rn>0



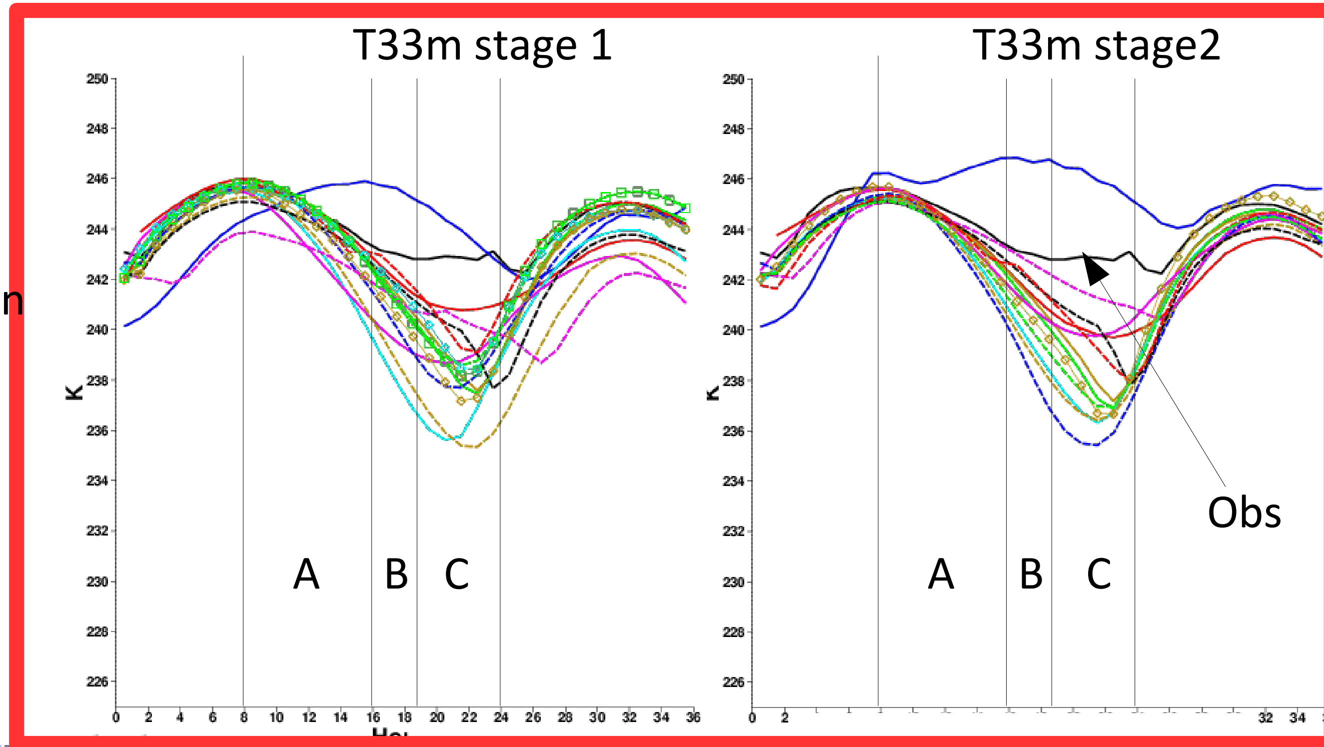
With the prescribed Ts, the cold bias at 33m still exists → problem of turbulence ? Lwd ? Swd ? Residual layer ?

T33m stage1 & stage2

Phase A= Cooling Rn<0
Phase B= Mixte Rn<0 & Swd +
Phase C= Heating Rn>0

May be add also T18m
To introduce the discussion
With the radiation or
Replace 33m by 18m

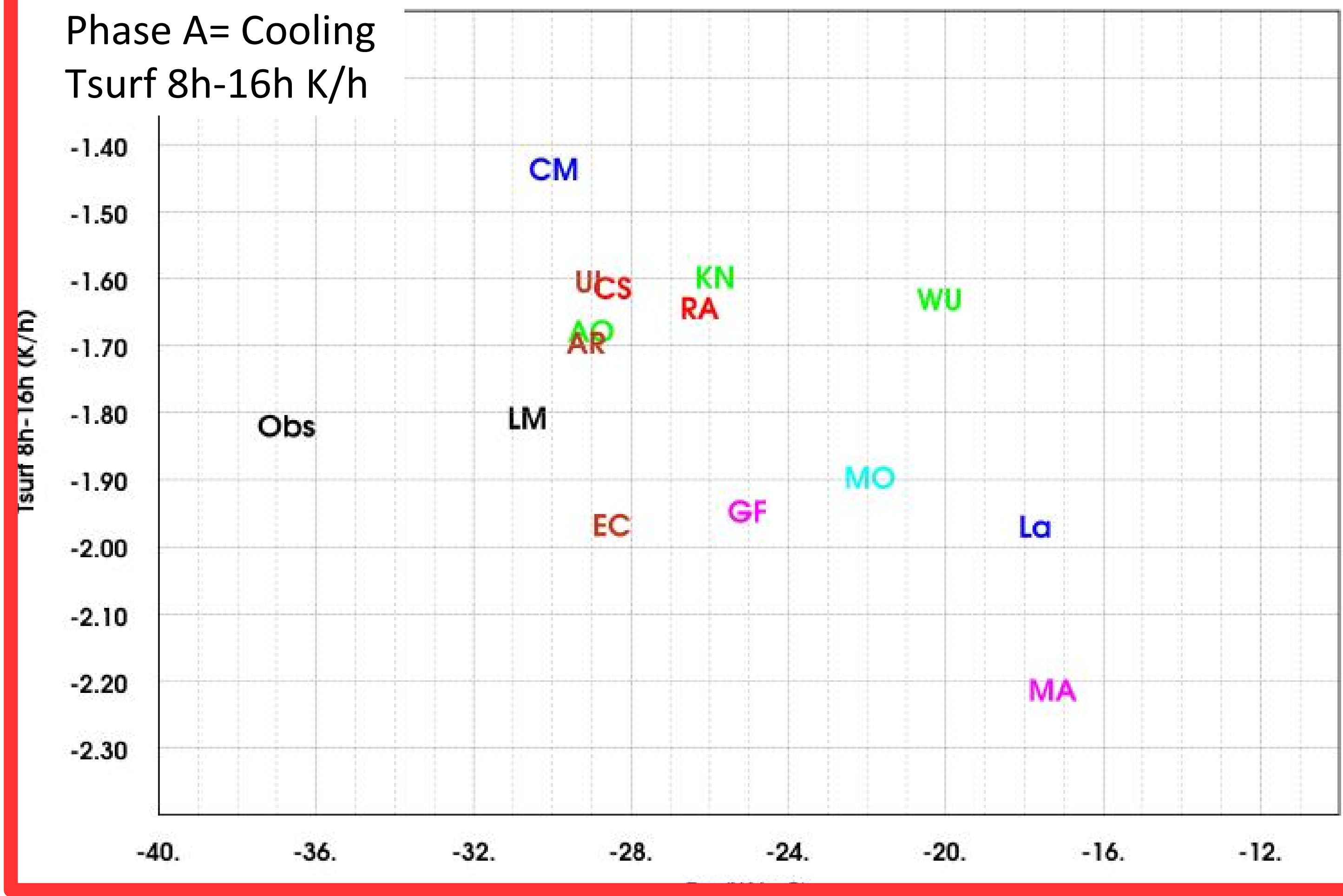
Fig7



With the prescribed Ts, the cold bias at 33m still exists → problem of turbulence ? Lwd ? Swd ? Residual layer ?

Tsurf tendency / Net Radiative Flux

Fig8

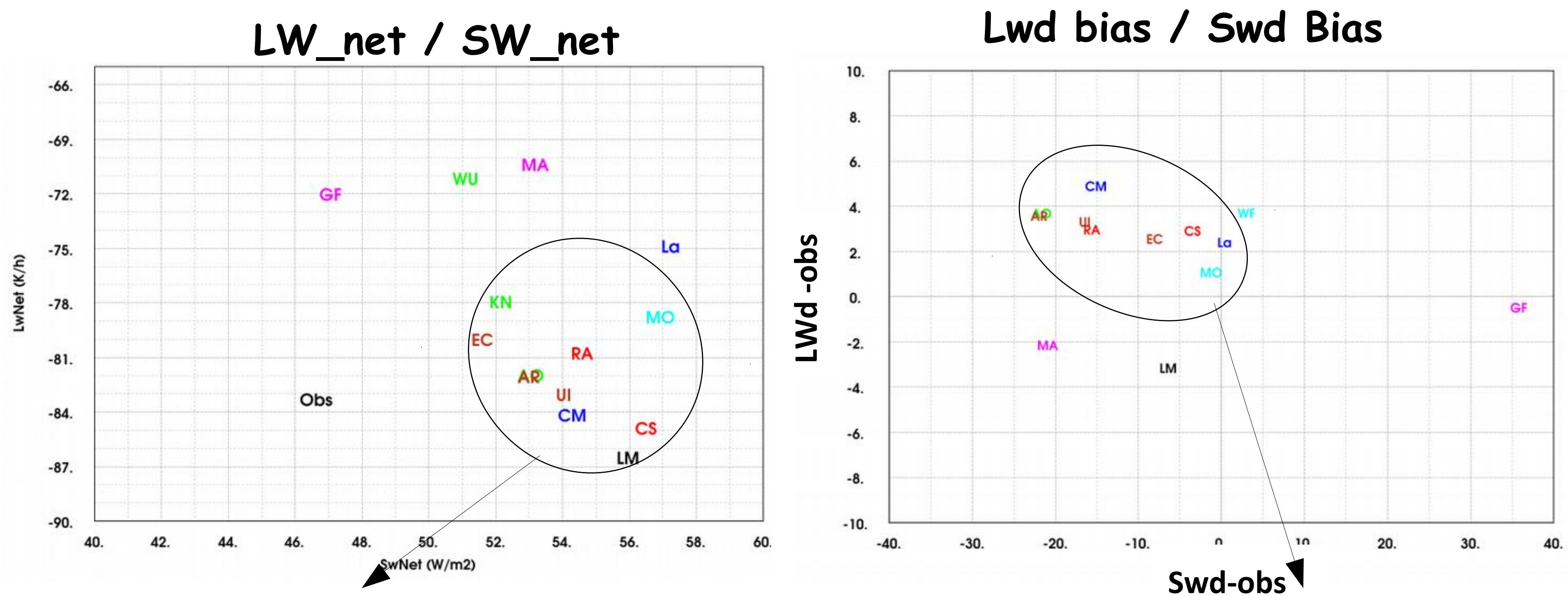


CSIRO_CCAM = CS
LaRC_HR= La
AROME = AO
ARPEGE = AR
UKMO = MO
NCEP_GFS = GF
CMC = CM
ECMWF = EC
LMDZMAR =MA
LMDZ = LM
RACMO = RA
WUR_D91 = WU
WRFMYNN6 = WF
UIB_MNH = UI
HARMONIE = KN

Not enough radiative cooling for all models

Underestimation of the radiative cooling

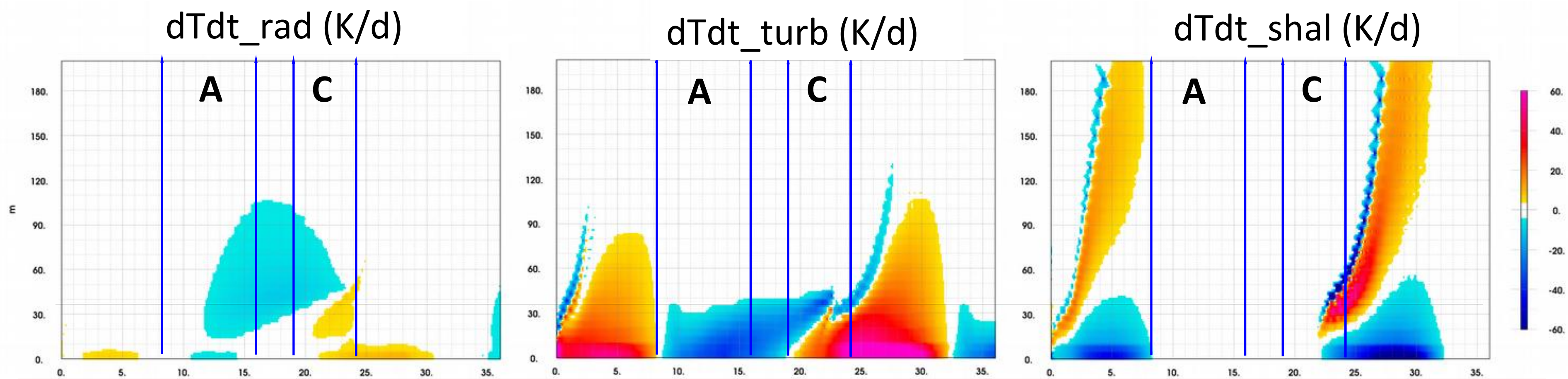
Phase A= Cooling period 8h-16h

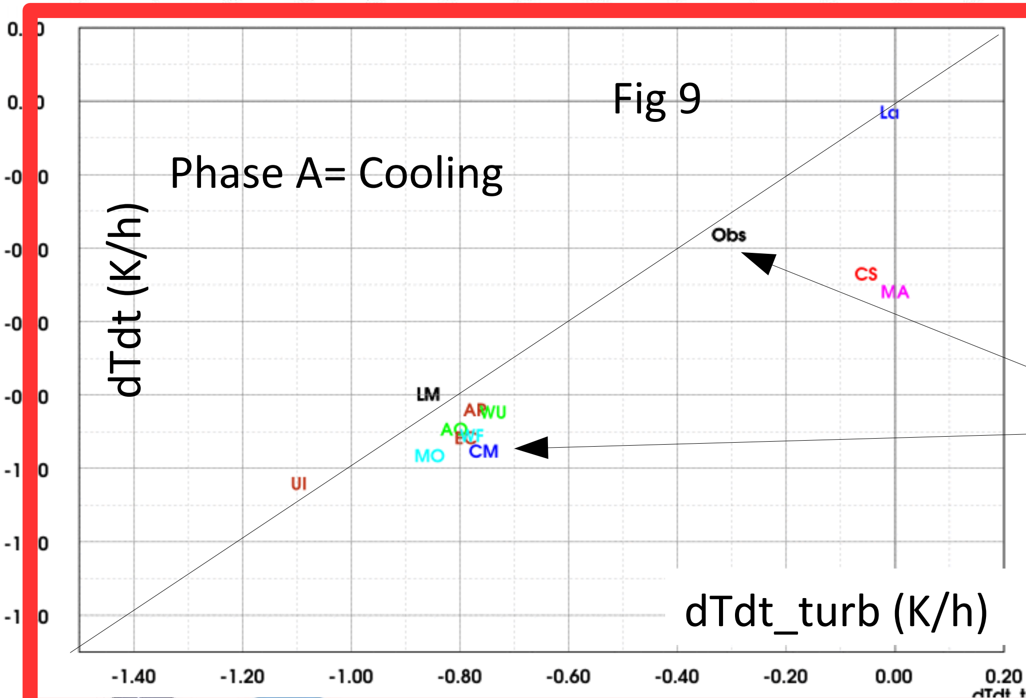


SW_net is overestimated by many models although the SWdw is underestimated !

→ snow albedo is a function of the solar angle and difficult to estimate especially with a low-angled sun

Cooling period ...





Phase A : above 30m only radiative cooling

Phase C : only due to the turbulence

@18m all the cooling is done by the turbulence 0.35K/h (Obs) however in the models it is 0.8K/h !

→ stage 3 without radiation will be probably very useful with the LES output

GABLS4 : comparison between stage2 & stage3

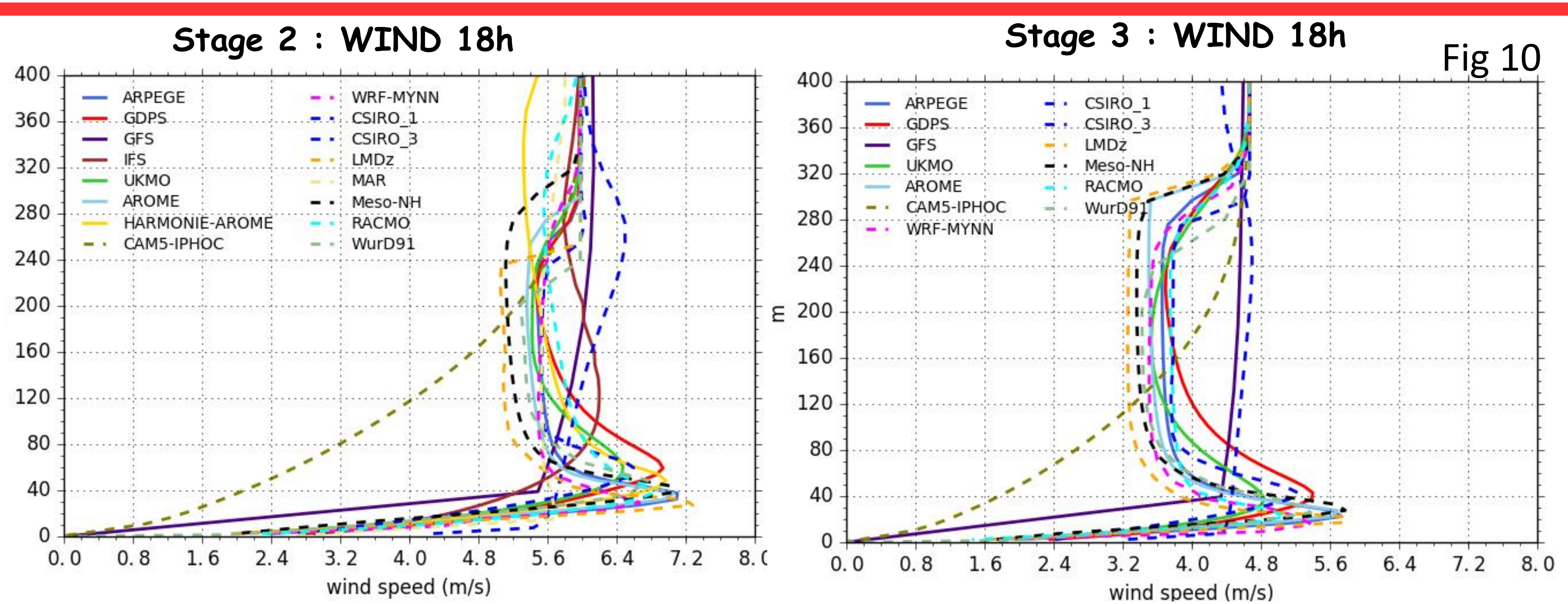


Fig 10

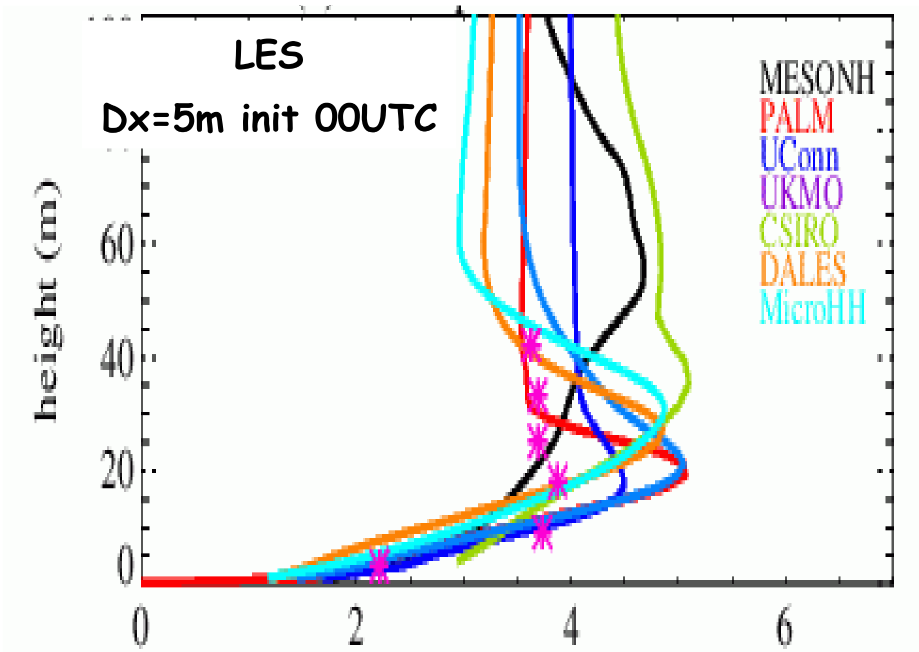
The « ideal case » or stage3 is representative to the real case and the differences between 1D models are similar comparison between SCM and LES on stage 3 will be very useful …

Max wind speed is reduced due to a lower geostrophic wind and LLJ height also.

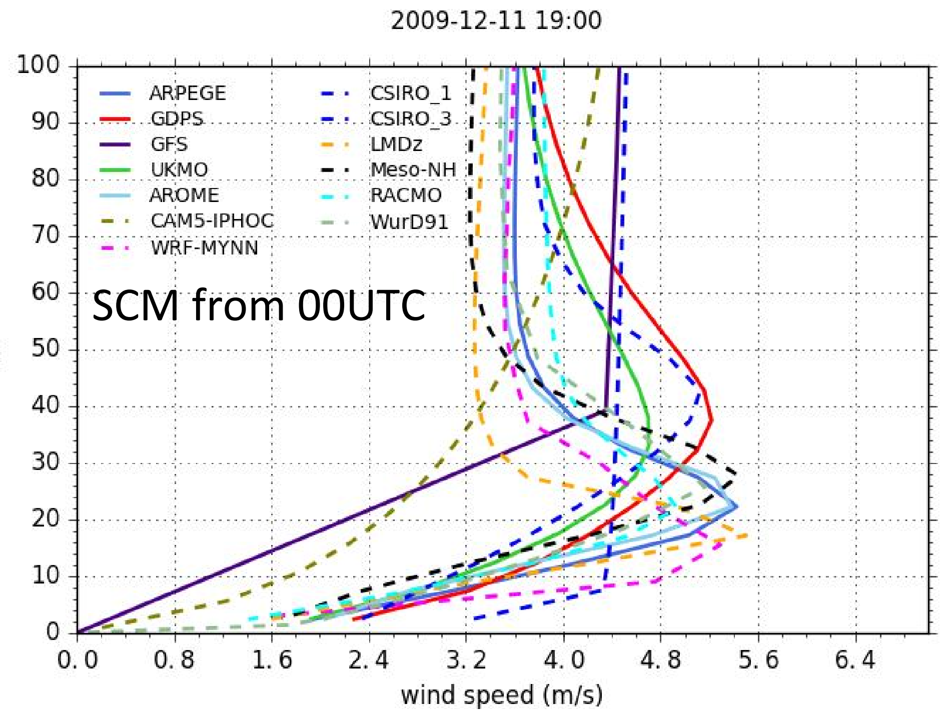
GFS not used the prescribed vertical grid (18m, 59m, 105m …) so …

CSIRO-1 : K-profile/Richardson number (Huang et al 2013) the best for various cases !
CSIRO-3 : TKE-epsilon and mass flux (Hurley 2007)

Stage 3: SCM results vs LES @ 19TU



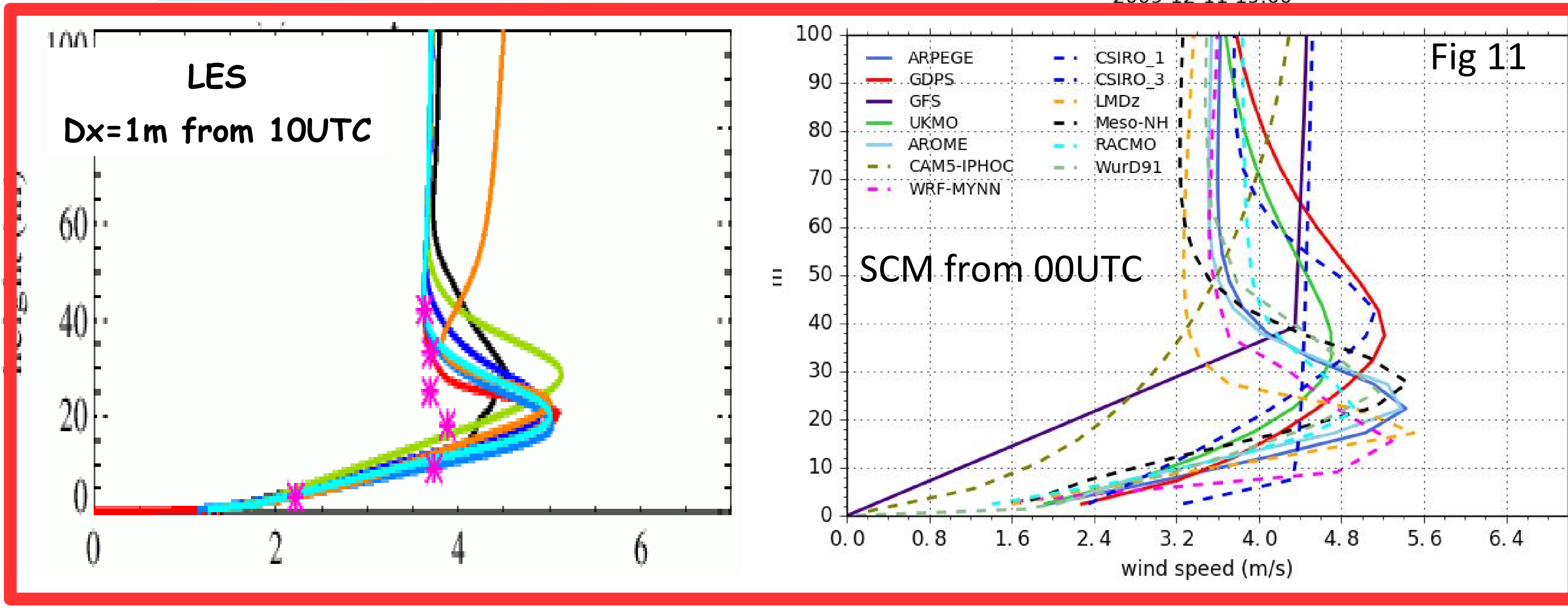
From F. Couvreux and LES participants :B Maronga, G. Matheou, M Chinita, J Edwards, B. Van Stratum, C. van Heerwaarden, J. Huang, A. F. Moene, V. Fuka, S. Basu, A Cheng, Q Rodier, E. Bou-Zeid



Some differences (!) (or uncertainties) between LES with a dx=5m

Several SCM have the LLJ around 20-30m so in good agreement with some LES

Stage 3: SCM results vs LES @ 19TU



From F. Couvreux and LES participants :B Maronga, G. Matheou, M Chinita, J Edwards, B. Van Stratum, C. van Heerwaarden, J. Huang, A. F. Moene, V. Fuka, S. Basu, A Cheng, Q Rodier, E. Bou-Zeid

With the new LES setup : « short ideal case » @ 1m → less variability among LES (at least for variables) --> LLJ ~ 20m. Several SCMs are in good agreement with LES mainly when a TKE scheme is used. For oper. NWP GDPS, LLJ height is about 30/40m and 20m for ARPEGE and AROME

For the stage3 SCM versus LES: to be done soon

- LES mean at 1m and LES STD (grey area) or grey line for all LES for wind profile, theta , w't' 2 pictures

- Time serie for SCM/LES T18m/T33m/w't'/TKE for stage3 : 2 pictures
- Have a look to the wind turning versus LES

Summary

- Compared to the GABLS1 results, now almost all the models are potentially able to create a LLJ even if the height of the LLJ is too high. Many NWP models now use a TKE scheme for the PBL with rather good results however instead of ECMWF, UKMO, ..
  - Do we need to add a fig showing the spread from GABLS1 ?

- Stage 2 vs Stage1 shows that a prescribed Ts, improves temperature near the surface, the LLJ reduces the variability among SCM but does not solve the negative biases above 20m (PBL height) .

Summary ...

Overestimation of the cooling below 20m (phase A) by a factor 2: turbulence too active

- Not enough radiative cooling at the surface for all the models.
  - Discussion : about the albedo estimation due to low-angled sun and the comparison with the models.
  - SW_dw is underestimated by 10-20W/m2 : sensitivity test done with no aerosol and no O3 --> impact on the SW_d about +20W/m2--> but almost no impact on profile, etc..