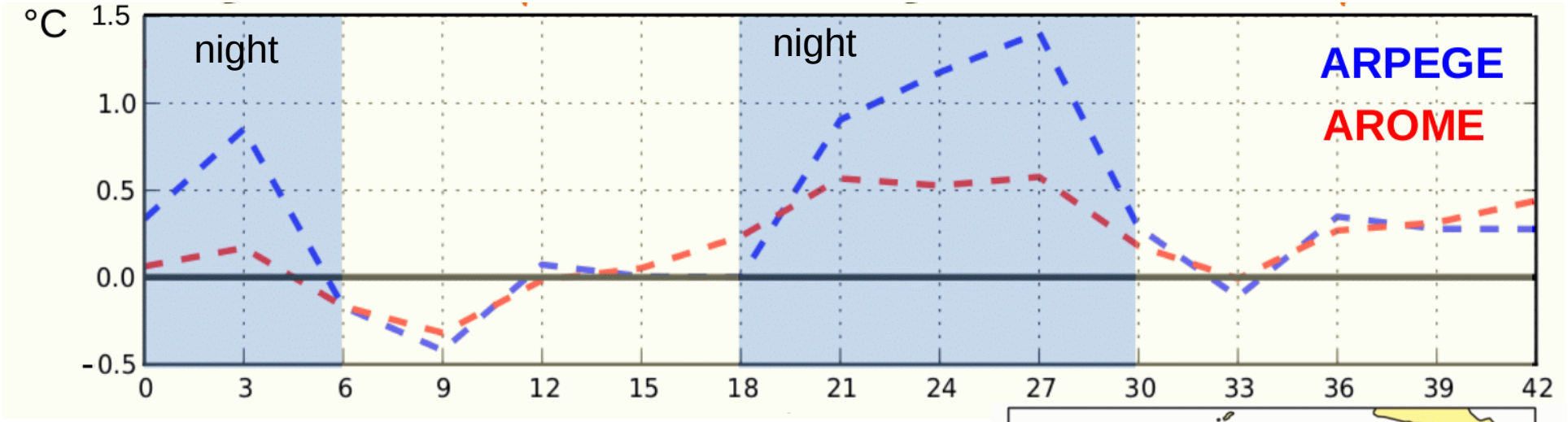
The GABLS4-LES exercise : a challenging intercomparison for LES in very stable conditions

Fleur Couvreux, E Bazile, 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, G Canut, E. Vignon

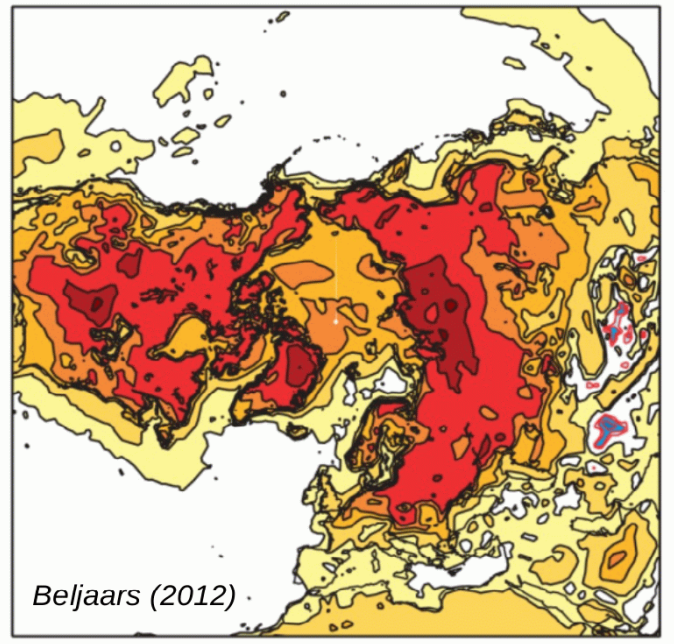
GABLS4 Workshop 12-14 September 2018

Motivations

A larger bias at night in operational models



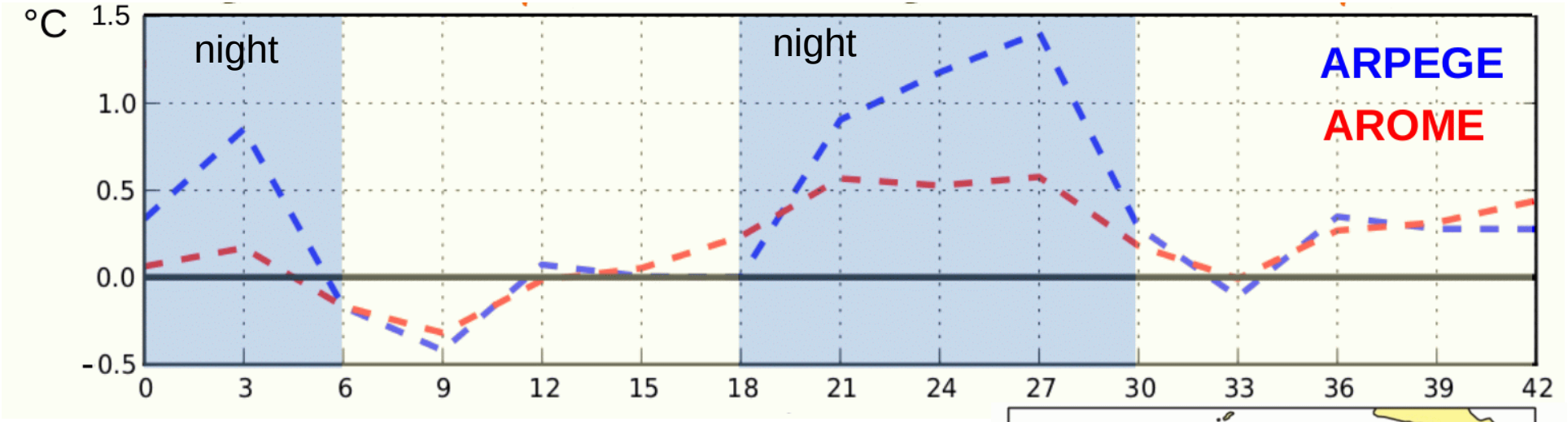
Sensitive results to the turbulence scheme



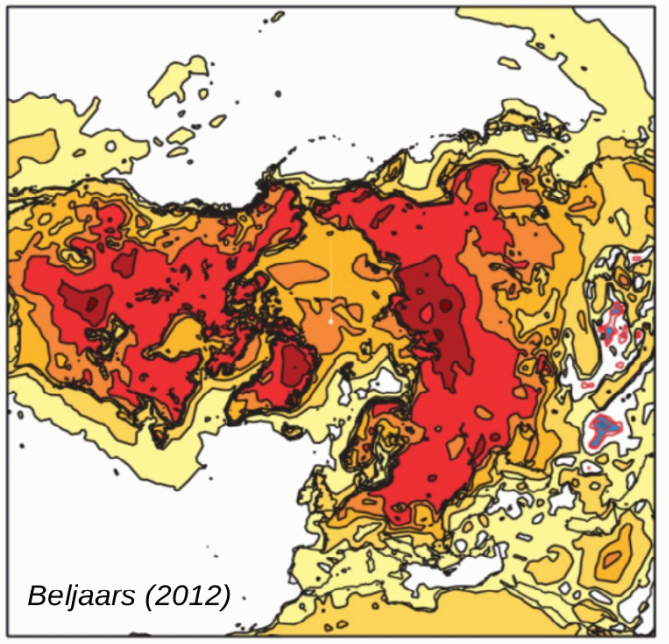
Difference in Temperature between two ECMWF simulations with different turbulence schemes (Beljaars, 2012 ; Holtslag et al, 2013)

Motivations

A larger bias at night in operational models



Sensitive results to the turbulence scheme



Need of LES as a reference
For parameterization development

Difference in Temperature between two ECMWF simulations with different turbulence schemes (Beljaars, 2012 ; Holtslag et al, 2013)

Motivations

Stable BL : « *still in a state of discovery as the couplings between large-scale forcings, internal waves, and weak turbulence ... in the presence of strong stratification » (Sullivan et al, 2016) also Mahrt 2014*

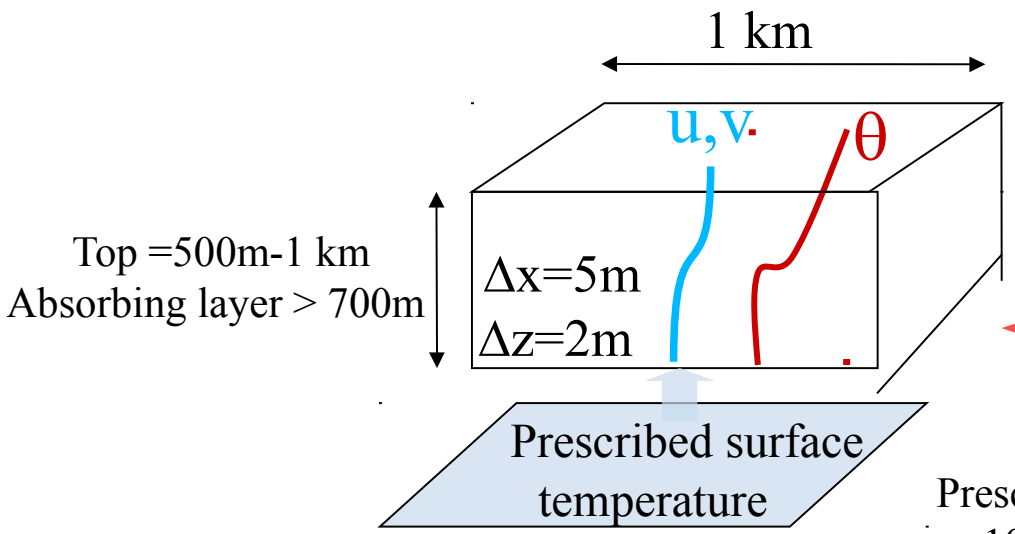
No LES intercomparison at very stable conditions

GABLS4 case: challenging for LES because entire diurnal cycle but at the same time relatively strong stable conditions (10 K in the 1st 20m)

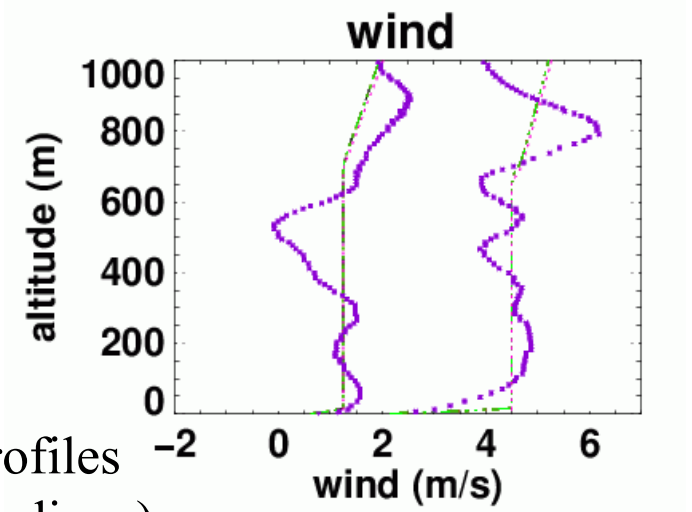
- At such high stability, we tackle the limit of validity of the LES => **what is the variability among LES at such stability?**
- **What is the necessary resolution** to resolve the main processes in such stable case?
- How the results **depend on turbulence scheme and surface parameterizations**?

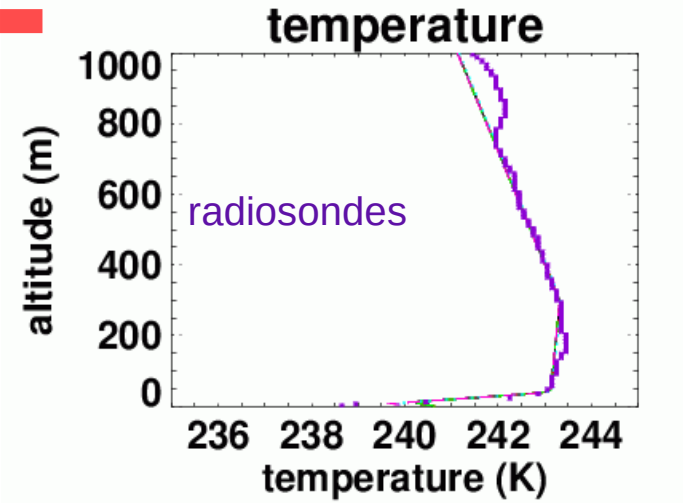
I. Models and Experiments

Stage 3 : a simplified set-up

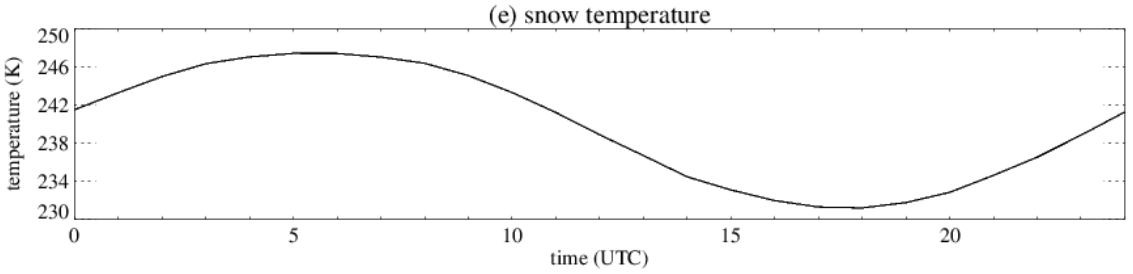


Initial profiles (from soundings)





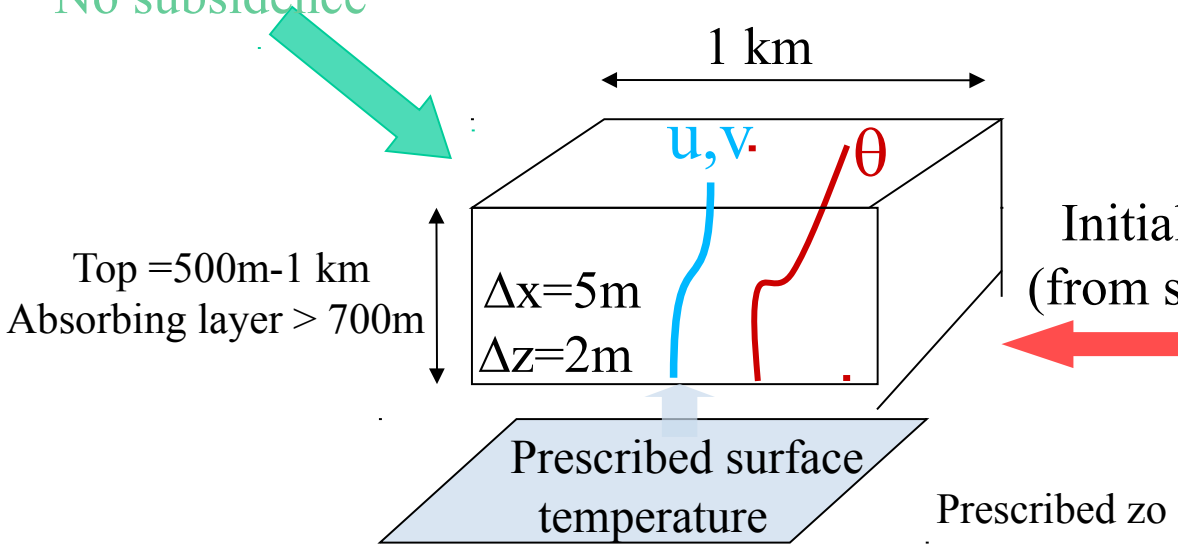
Prescribed zo
zom=10^{-2}/zoh=10^{-3}
zom=10^{-3}/zoh=10^{-4}



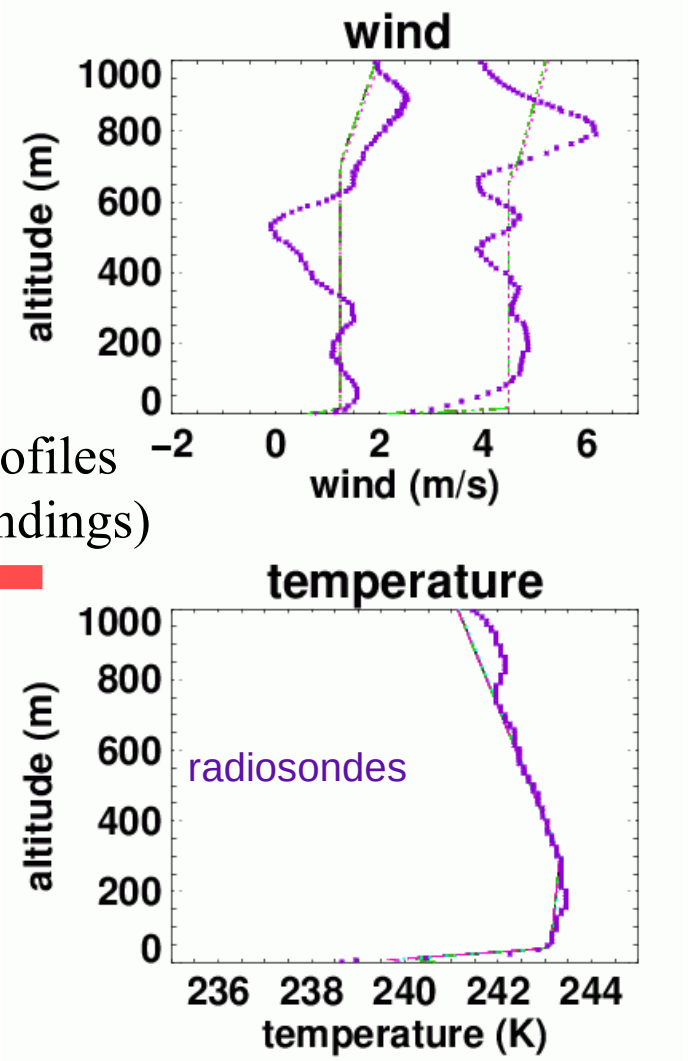
No moisture (qv <3.10-4kg/kg)

Stage 3 : a simplified set-up

LS forcing :
No T & q advection
Cst geostrophic wind
No subsidence



Initial profiles (from soundings)

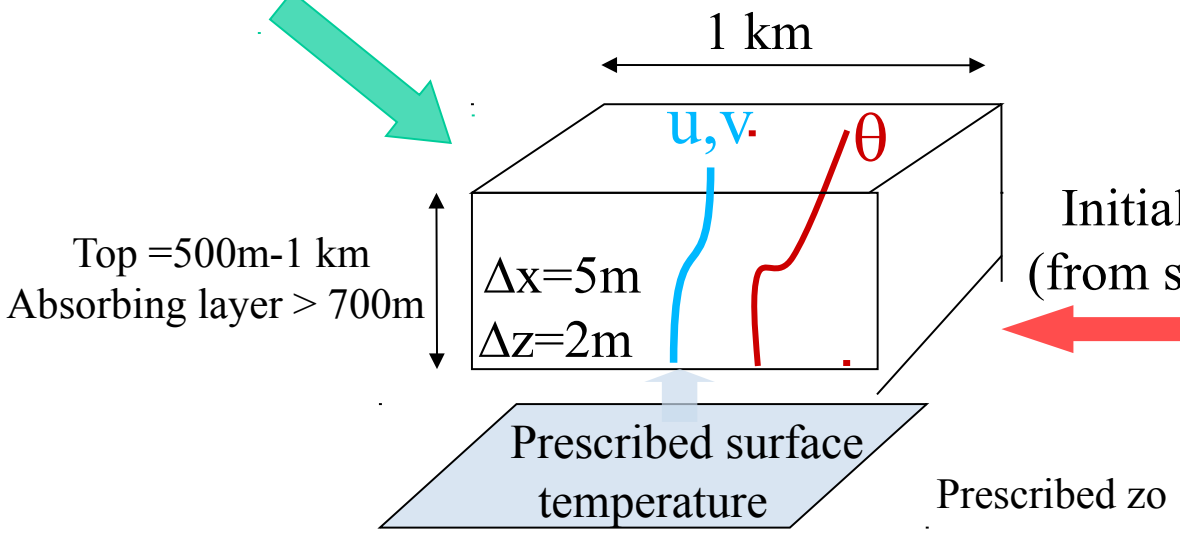


No moisture

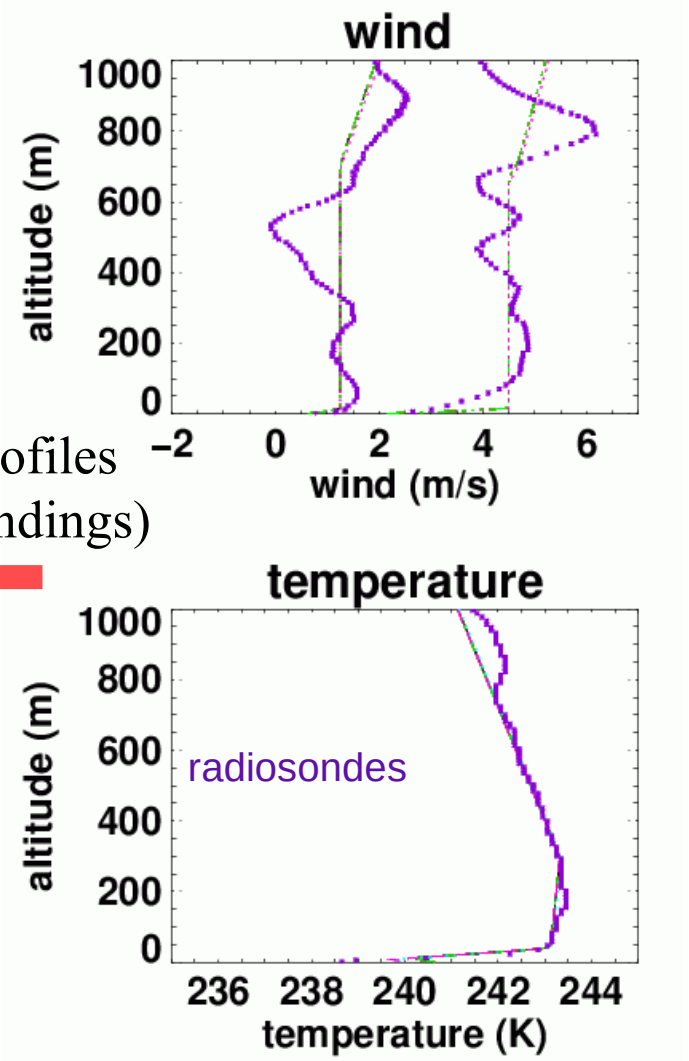
Stage 3 : a simplified set-up

LS forcing :
No T & q advection
Cst geostrophic wind
No subsidence

Parametrizations:
- turbulence scheme
-surface flux formulation
- **NO** radiative scheme



Initial profiles
(from soundings)

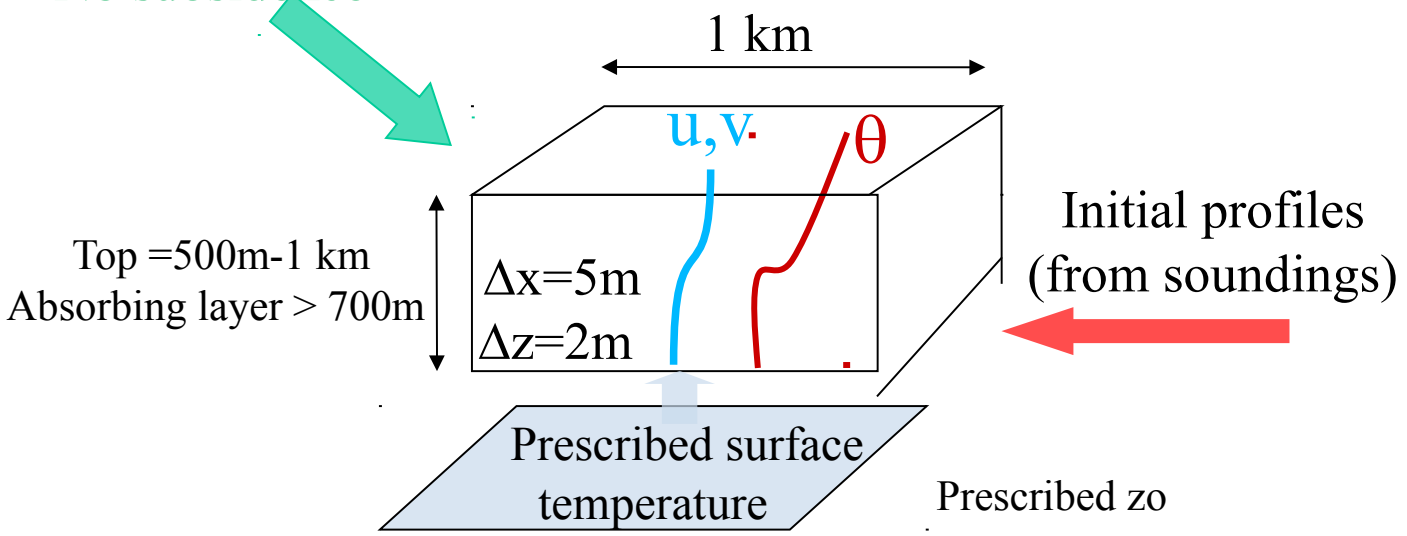


No moisture

Stage 3 : a simplified set-up

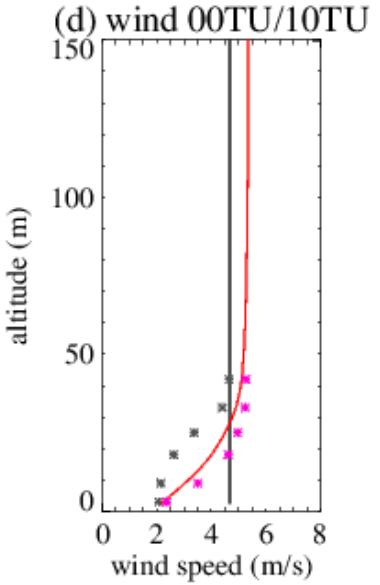
LS forcing :
No T & q advection
Cst geostrophic wind
No subsidence

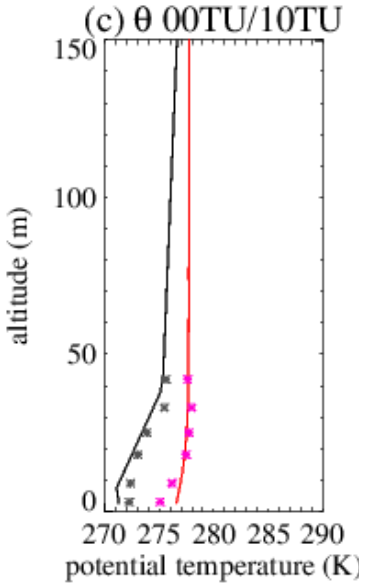
Parametrizations:
- turbulence scheme
- surface flux formulation
- **NO** radiative scheme



From 00 UTC, 24h; Δx=5m,
Δz=2m, Lx=1km

From 10UTC (LES mean), 10h;
Δx=1m, Δz=1m, Lx=500m, Lz=150m





Stage 3 : 10 LES models

LES	Subgrid turbulence scheme	Surface scheme	Advection scheme	Temporal scheme
MesoNH (Lac et al. 2018)	1.5 order scheme after Deardorff (1980)	Monin-Obukhov similarity theory, fluxes computed iteratively (Noilhan and Planton 1989)	Scalars : monotonic Piecewise Parabolic Method Momentum : 4th order centered	3rd order Runge Kutta
PALM (Maronga et al. 2015)	1.5 order scheme after Deardorff (1980)	Monin-Obukhov similarity theory (bm=bh=5)	Scalars & momentum : 5th order advection scheme (Wicker and Skamarock 2002)	3rd order Runge Kutta
Uconn (Matheou and Chung 2014)	Buoyancy adjusted stretched vortex model (Chung and Matheou 2014) – sensitivity test to a Smagorinsky type	Monin-Obukhov similarity theory	Scalars and momentum : sixth-order fully conservative scheme	3rd order Runge Kutta
MicroHH (van Heerwaarden et al. 2017)	Smagorinsky-Lilly stability Fixed Prandtl number (1/3) wall-damping near the surface	Monin-Obukhov similarity theory with stability functions from Wilson (2001) for unstable and Hogstrom (1988) for stable conditions	Scalars and momentum : 2nd order with 4th order interpolations	3rd order Runge Kutta
CLMM (Fuka and Brechler 2011)	Sigma sgs model with an experimental stability correction	Monin-Obukhov similarity theory applied locally, fluxes computed iteratively	Scalars : k=1/3 scheme momentum : 2nd order symetric centered differences	3rd order Runge Kutta
NCSU (Basu and Porte-Agel 2006)	Locally-averaged scale-dependent dynamic model (LASDD)	Monin-Obukhov similarity theory	*pseudo-spectral (spectral in horizontal ; 2nd-order finite difference in vertical)*	2nd order Adams-Bashforth
SAM-IPHOC (Khairoutdinov and Randall 2003)	IPHOC (intermediately prognostic higher-order turbulence closure) : progn eq° for 2nd & 3rd moments + Joint double gaussian pdf for thl, rt,w	Monin-Obukhov similarity theory	Scalars and momentum : 5th order ULTIMATE-MACHO for non-uniform vertical grid	3rd order Adams-Bashforth
DALES (Heus et al. 2010)	1.5 order scheme after Deardorff (1980)	Monin-Obukhov similarity theory	Scalars and momentum : 5th order or 6th order	3rd order Runge Kutta
UKMO-LES (Edwards et al. 2014)(	Smagorinsky subgrid scheme (neutral mixing length 1.15m)	Monin-Obukhov similarity theory	Flux-based conservative	Centred scheme
CSIRO-LES (Bou-Zeid et al. 2005)	scale-dependent lagrangian dynamic model (Huang and Bou-Zeid 2013)	Monin-Obukhov similarity theory (bm=4.8 ; bh=4.7)	pseudo-spectral (cf NCSU)	2nd-order Adams-Bashforth

Stage 3 : 10 LES models

LES	Subgrid turbulence scheme	Surface scheme	Advection scheme	Temporal scheme
MesoNH (Lac et al. 2018)	1.5 order scheme after Deardorff (1980)	Monin-Obukhov similarity theory, fluxes computed iteratively (Noilhan and Planton 1989)	Scalars : monotonic Piecewise Parabolic Method Momentum : 4th order centered	3rd order Runge Kutta
PALM (Maronga et al. 2015)	1.5 order scheme after Deardorff (1980)	Monin-Obukhov similarity theory (bm=bh=5)	Scalars & momentum : 5th order advection scheme (Wicker and Skamarock 2002)	3rd order Runge Kutta
Uconn (Matheou and Chung 2014)	Buoyancy adjusted stretched vortex model (Chung and Matheou 2014) – sensitivity test to a Smagorinsky type	Monin-Obukhov similarity theory	Scalars and momentum : sixth-order fully conservative scheme	3rd order Runge Kutta
MicroHH (van Heerwaarden et al. 2017)	Smagorinsky-Lilly stability Fixed Prandtl number (1/3) wall-damping near the surface	Monin-Obukhov similarity theory with stability functions from Wilson (2001) for unstable and Hogstrom (1988) for stable conditions	Scalars and momentum : 2nd order with 4th order interpolations	3rd order Runge Kutta
CLMM (Fuka and Brechler 2011)	Sigma sgs model with an experimental stability correction	Monin-Obukhov similarity theory applied locally, fluxes computed iteratively	Scalars : k=1/3 scheme momentum : 2nd order symetric centered differences	3rd order Runge Kutta
NCSU (Basu and Porte-Agel 2006)	Locally-averaged scale-dependent dynamic model (LASDD)	Monin-Obukhov similarity theory	*pseudo-spectral (spectral in horizontal ; 2nd-order finite difference in vertical)*	2nd order Adams-Bashforth
SAM-IPHOC (Khairoutdinov and Randall 2003)	IPHOC (intermediately prognostic higher-order turbulence closure) : progn eq° for 2nd & 3rd moments + Joint double gaussian pdf for thl, rt,w	Monin-Obukhov similarity theory	Scalars and momentum : 5th order ULTIMATE-MACHO for non-uniform vertical grid	3rd order Adams-Bashforth
DALES (Heus et al. 2010)	1.5 order scheme after Deardorff (1980)	Monin-Obukhov similarity theory	Scalars and momentum : 5th order or 6th order	3rd order Runge Kutta
UKMO-LES (Edwards et al. 2014)(	Smagorinsky subgrid scheme (neutral mixing length 1.15m)	Monin-Obukhov similarity theory	Flux-based conservative	Centred scheme
CSIRO-LES (Bou-Zeid et al. 2005)	scale-dependent lagrangian dynamic model (Huang and Bou-Zeid 2013)	Monin-Obukhov similarity theory (bm=4.8 ; bh=4.7)	pseudo-spectral (cf NCSU)	2nd-order Adams-Bashforth

Please check the information for your model

Stage 3 : 10 LES models

LES	Subgrid turbulence scheme	Surface scheme	Advection scheme	Temporal scheme
MesoNH (Lac et al. 2018)	1.5 order scheme after Deardorff (1980)	Monin-Obukhov similarity theory, fluxes computed iteratively (Noilhan and Planton 1989)	Scalars : monotonic Piecewise Parabolic Method Momentum : 4th order centered	3rd order Runge Kutta
PALM (Maronga et al. 2015)	1.5 order scheme after Deardorff (1980)	Monin-Obukhov similarity theory (bm=bh=5)	Scalars & momentum : 5th order advection scheme (Wicker and Skamarock 2002)	3rd order Runge Kutta
Uconn (Matheou and Chung 2014)	Buoyancy adjusted stretched vortex model (Chung and Matheou 2014) – sensitivity test to a Smagorinsky type	Monin-Obukhov similarity theory	Scalars and momentum : sixth-order fully conservative scheme	3rd order Runge Kutta
MicroHH (van Heerwaarden et al. 2017)	Smagorinsky-Lilly stability Fixed Prandtl number (1/3) wall-damping near the surface	Monin-Obukhov similarity theory with stability functions from Wilson (2001) for unstable and Hogstrom (1988) for stable conditions	Scalars and momentum : 2nd order with 4th order interpolations	3rd order Runge Kutta
CLMM (Fuka and Brechler 2011)	Sigma sgs model with an experimental stability correction	Monin-Obukhov similarity theory applied locally, fluxes computed iteratively	Scalars : k=1/3 scheme momentum : 2nd order symetric centered differences	3rd order Runge Kutta
NCSU (Basu and Porte-Agel 2006)	Locally-averaged scale-dependent dynamic model (LASDD)	Monin-Obukhov similarity theory	*pseudo-spectral (spectral in horizontal ; 2nd-order finite difference in vertical)*	2nd order Adams-Bashforth
SAM-IPHOC (Khairoutdinov and Randall 2003)	IPHOC (intermediately prognostic higher-order turbulence closure) : progn eq° for 2nd & 3rd moments + Joint double gaussian pdf for thl, rt,w	Monin-Obukhov similarity theory	Scalars and momentum : 5th order ULTIMATE-MACHO for non-uniform vertical grid	3rd order Adams-Bashforth
DALES (Heus et al. 2010)	1.5 order scheme after Deardorff (1980)	Monin-Obukhov similarity theory	Scalars and momentum : 5th order or 6th order	3rd order Runge Kutta
UKMO-LES (Edwards et al. 2014)(	Smagorinsky subgrid scheme (neutral mixing length 1.15m)	Monin-Obukhov similarity theory	Flux-based conservative	Centred scheme
CSIRO-LES (Bou-Zeid et al. 2005)	scale-dependent lagrangian dynamic model (Huang and Bou-Zeid 2013)	Monin-Obukhov similarity theory (bm=4.8 ; bh=4.7)	pseudo-spectral (cf NCSU)	2nd-order Adams-Bashforth

Please provide for each model when possible the value of the coeff in MOST

$$\frac{\partial u}{\partial z} = \frac{\partial v}{\partial z} = \frac{u_*}{\kappa z}\left(1 + \beta_m \frac{z}{L}\right),$$

$$\frac{\partial \theta}{\partial z} = \frac{\theta_*}{\kappa z}\left(1 + \beta_h \frac{z}{L}\right),$$

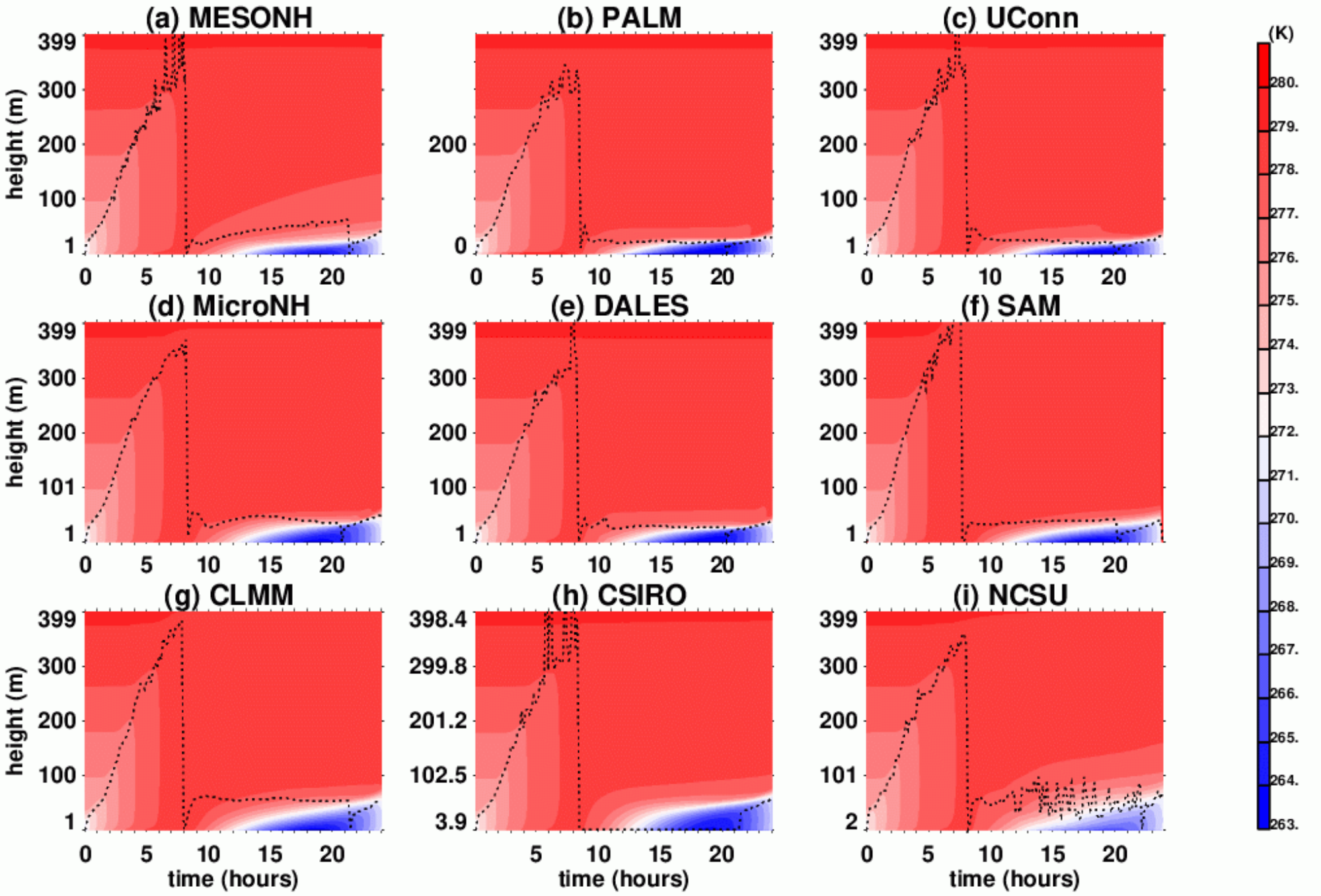
Stage 3 : List of experiments for each model

Model	Experiment	Horizontal resolution	Vertical resolution	Top of the domain	Domain size	Momentum roughness length (m)	Heat Roughness length (m)
MesoNH	M1E1	5m	2m :streched z>400m	Sponge : z> 700m K=10^{-3}	1x1x1 km³	10^{-2}	10^{-3}
	M1E2	5m	2m :streched z>400m	Sponge : z> 700m K=10^{-3}	1x1x1 km³	10^{-3}	10^{-4}
	M1E3	1m	1m	Sponge : z> 130m K=10^{-3}	500x500x150 m³	10^{-3}	10^{-4}
	M1E3R105	1m	0.5m	No damping	250x250x75 m³	10^{-3}	10^{-3}
	M1E3R05	0.5m	0.5m	No damping	250x250x75 m³	10^{-3}	10^{-3}
	M1E3R025	0.25m	0.25m	No damping	250x250x75 m³	10^{-3}	10^{-3}
PALM	M2E1	5m	2m	Sponge : z> 700m K ??	1x1x1km³	10^{-2}	10^{-3}
	M2E2	5m	2m	Sponge : z> 700m K ??	1x1x1km³	10^{-3}	10^{-4}
	M2E2D2	5m	2m	Sponge : z> 700m K ??	2.5x2.5x1km³	10^{-3}	10^{-4}
	M2E2R2	2m	2m	Sponge : z> 700m K ??	1x1x1km³	10^{-3}	10^{-4}
	M2E2R105	1m	0.5m	Sponge : z> 700m K ??	1x1x1km³	10^{-3}	10^{-4}
	M2E3 (MOST/sf)	1m	1m	Sponge : z> 120m	500x500x150 m³	10^{-3}	10^{-4}
UConn	M3E1	5m	2m	Sponge : z> 700m t=600s	1x1x1km³	10^{-2}	10^{-3}
	M3E2	5m	2m	Sponge : z> 700m t=600s	1x1x1km³	10^{-3}	10^{-4}
	M3E2R22 (Sm/Vo)	2m	2m	Sponge : z> 700m t=600s	1x1x1km³	10^{-3}	10^{-4}
	M3E2R11	1m	1m	Sponge : z> 700m t=600s	1x1x1km³	10^{-3}	10^{-4}
	M3E3 (MOST/Sf)	1m	1m	Sponge : z> ??	500x500x150 m³	10^{-3}	10^{-4}
	M3E3R05(MOST/Sf)	0.5m	0.5m	Sponge : z> ??	500x500x150 m³	10^{-3}	10^{-4}
	M3E3R025(MOST/Sf)	0.25m	0.25m	Sponge : z> ??	500x500x150 m³	10^{-3}	10^{-4}
MicroHH	M4E1	5m	2m	Sponge : z> 700mK ??	3x3x0.5km³	10^{-2}	10^{-3}
	M4E3	1m	1m	Sponge : z> ??	3x3x0.5km³??	10^{-3}	10^{-4}
CLMM	M5E1	5m	2m	Sponge : z> 600m K ??	1x1x1km³	10^{-2}	10^{-3}
NCSU	M6E1	10m	5m	Sponge : z> 600m K ??	1x1x1km³	10^{-2}	10^{-3}
	M6E2			Sponge : z> 600m K ??	1x1x1km³	10^{-3}	10^{-4}
SAM-HR	M7E1	5m	2m	???	1x1x1km³	10^{-2}	10^{-3}
DALES	M8E1	5m	2m	Sponge : z> 750m K= ??	1.08x1.08x0.5 km³	10^{-2}	10^{-3}
	M8E3	1m	1m	Sponge : z> 120m K= ??	512x512x150 m³	10^{-3}	10^{-4}
UKMO-LES	M9E2	5m	2m	No damping	1x1x1km³	10^{-3}	10^{-4}
	M9E3	1m	1m	??? No damping ??	500x500x150 m³	10^{-3}	10^{-4}
CSIRO-LES	M10E1	7.8m	3.9m	Sponge : z> 700m K= ??	1x1x1km³	10^{-2}	10^{-3}
	M10E2	7.8m	3.9m	Sponge : z> 700m K= ??	1x1x1km³	10^{-3}	10^{-4}
	M10E3	3.9m	1.17m	Sponge : z> 120m K= ??	500x500x150 m³	10^{-3}	10^{-4}

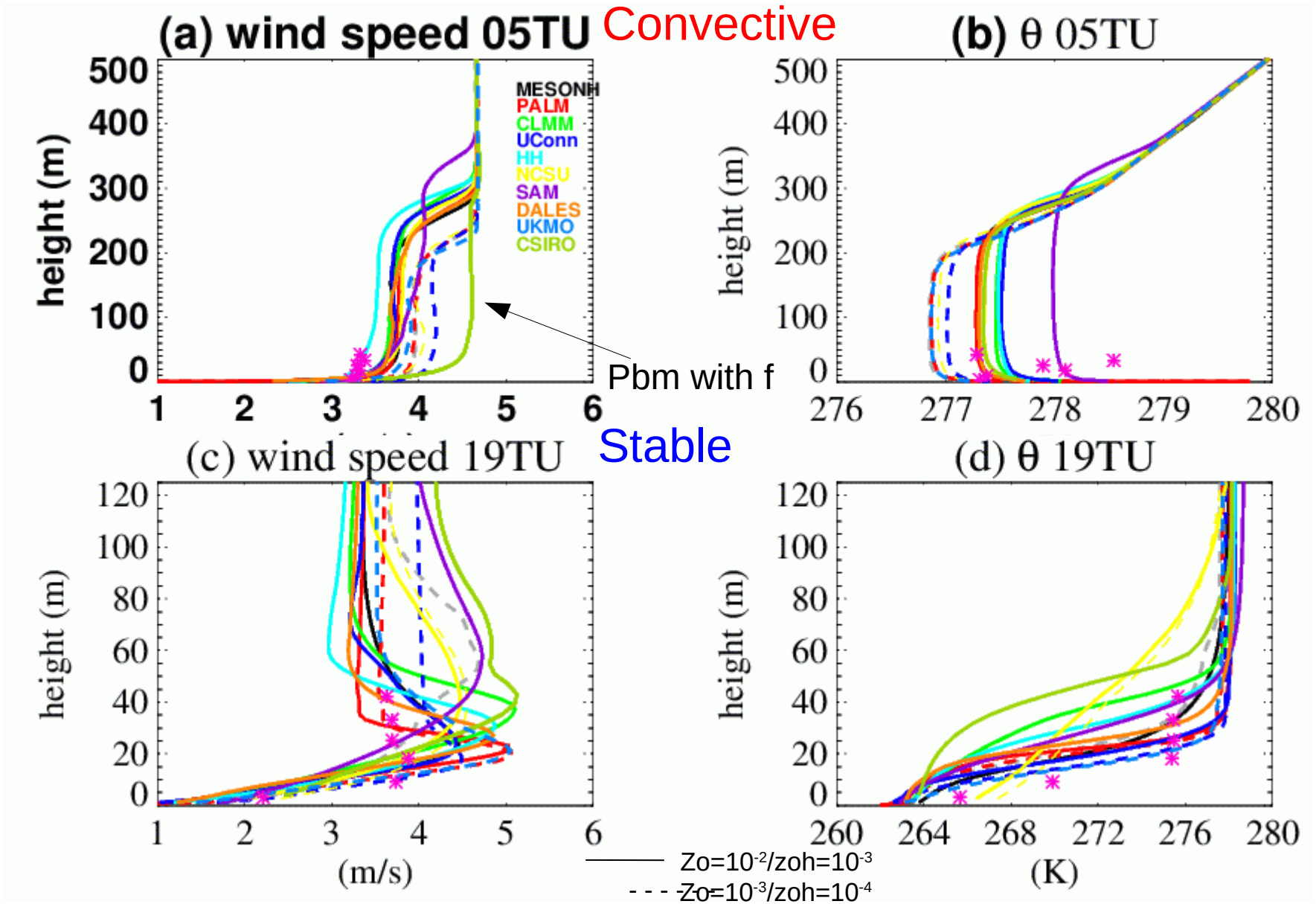
Still need infos on :- damping layer

II. Results : entire diurnal cycle & focus on stable conditions

Diurnal cycle evolution (models with zo=10^{-2}m)

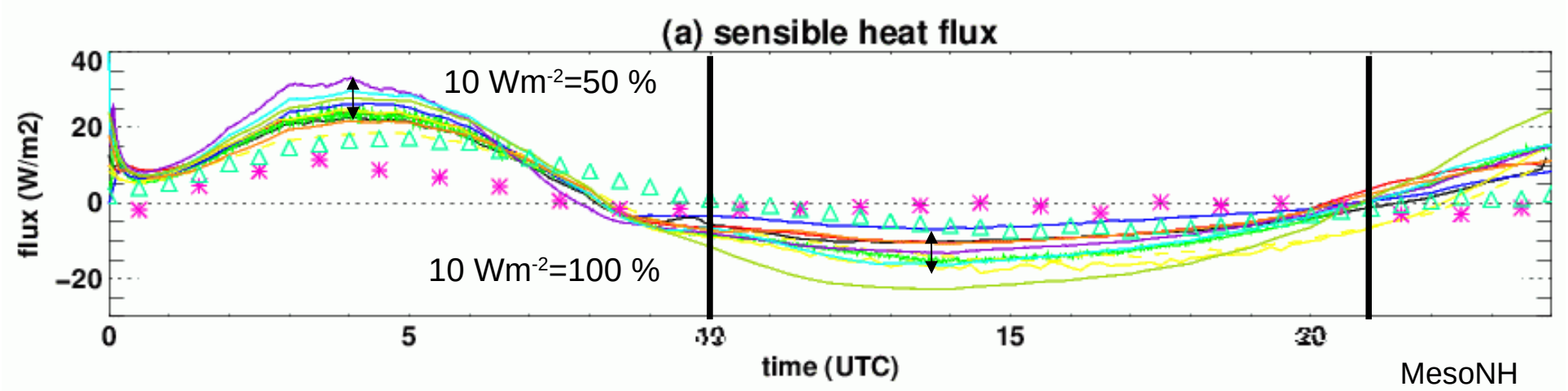


Vertical profiles : convective/stable conditions

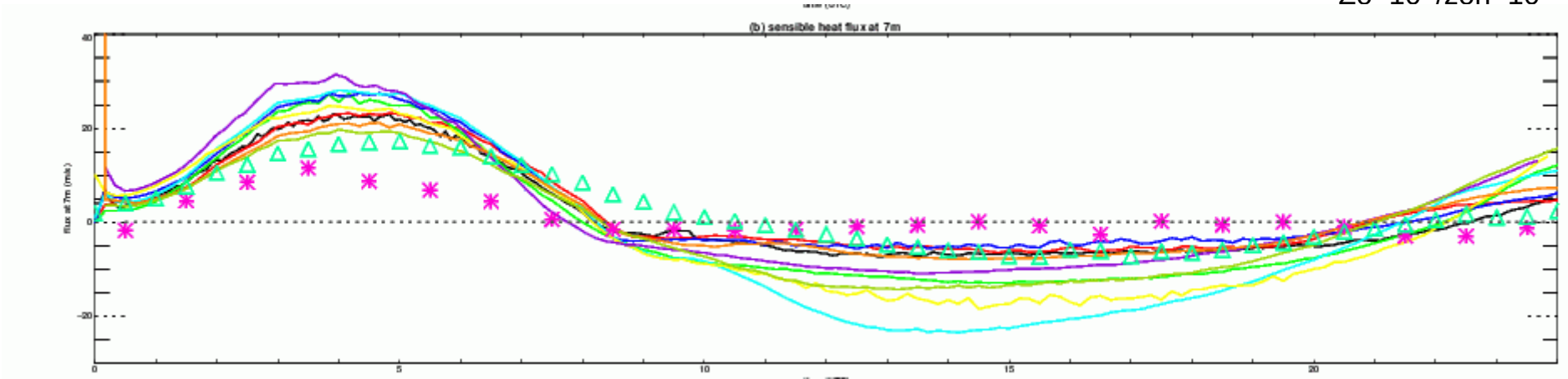


Do we want to show each individual models or just as a grey shading
The spread among the different models ?

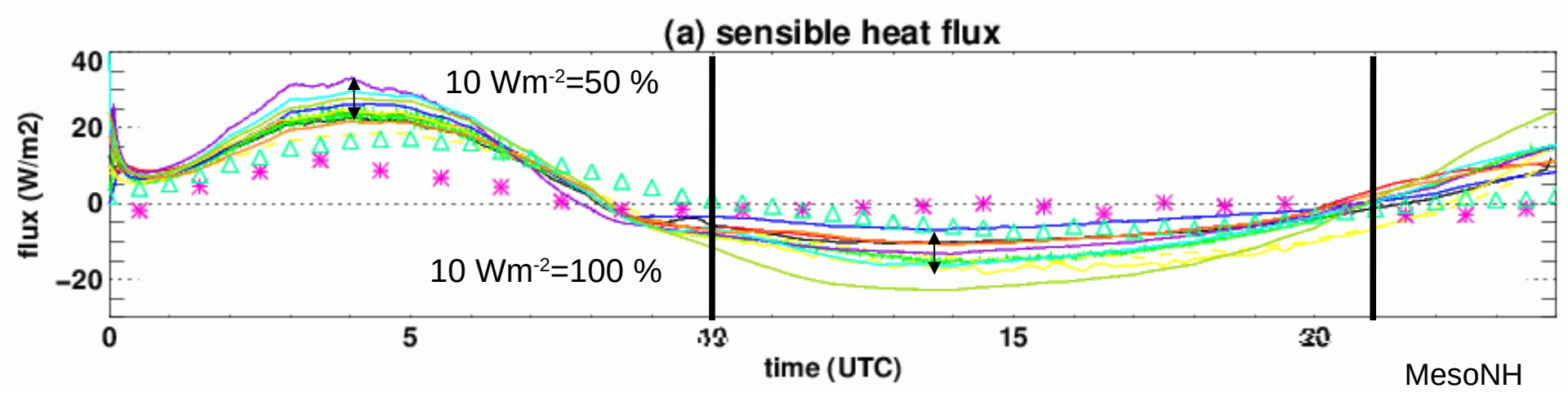
Time series :



MesoNH
PALM
CLMM
MicroHH
UConn
NCSU
SAM
DALES
CSIRO
Eddy-correl° obs
Gradient obs
Zo=10^{-2}/zoh=10^{-3}



Time series :



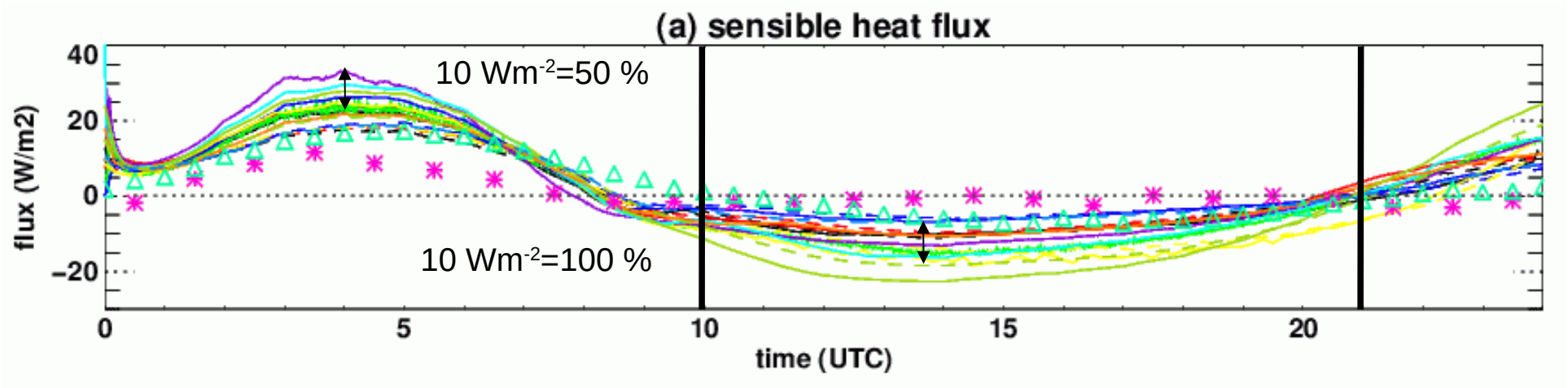
Large variability among LES at day and night time ~ mean flux values as relatively small

LES uncertainties ~ observation estimation uncertainties

<u>Remind:</u>

- surface temperature prescribed from observations
- because simplified setup, Dome C observations here just for a qualitative assessment

Time series :



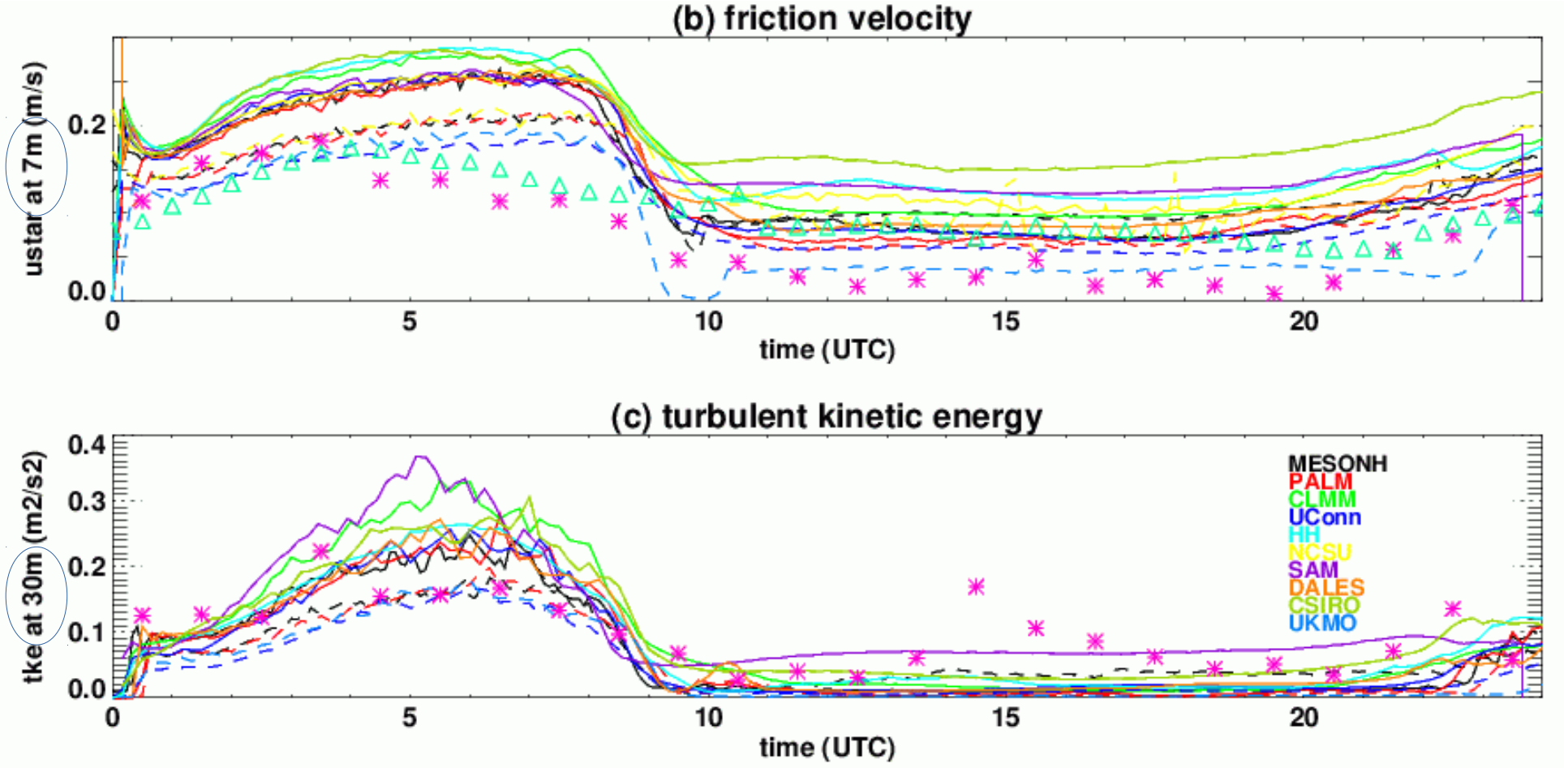
PALM
CLMM
MicroHH
UConn
NCSU
SAM
DALES
CSIRO
Eddy-correl° obs
Gradient obs
——— Zo=10^{-2}/zoh=10^{-3}
- - - - - - Zo=10^{-3}/zoh=10^{-4}

Large variability among LES at day and night time ~ mean flux values as relatively small
LES uncertainties ~ observation estimation uncertainties

<u>Remind:</u>

- surface temperature prescribed from observations
- because simplified setup, Dome C observations here just for a qualitative assessment

Time series :



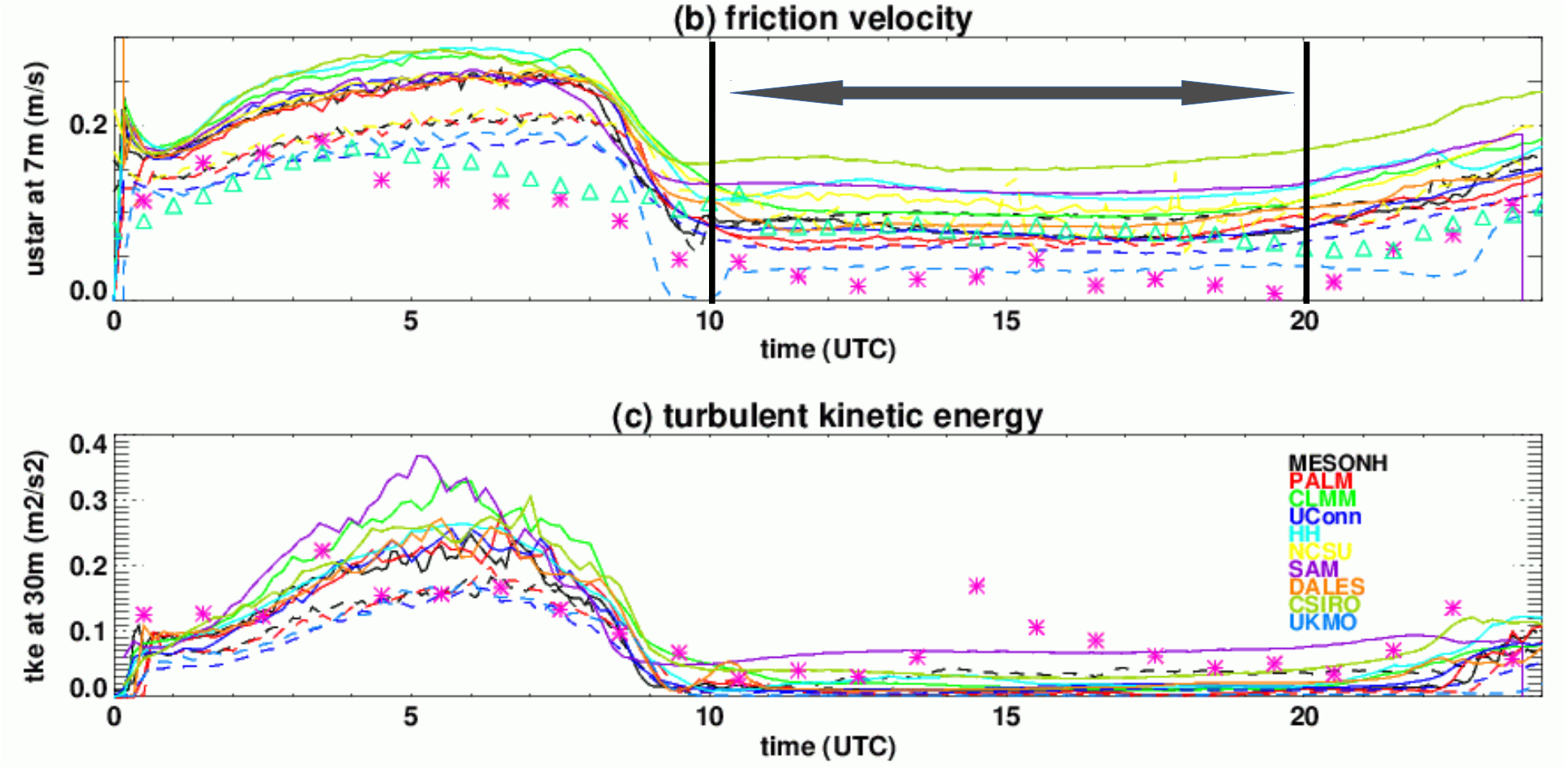
Zo=10^{-2}/zoh=10^{-3}

Zo=10^{-3}/zoh=10^{-4}

Better agreement with observations when using zo=10^{-3}m (also value expected from observations)

=> concentrate on simulations with zo=10^{-3} m

Time series :



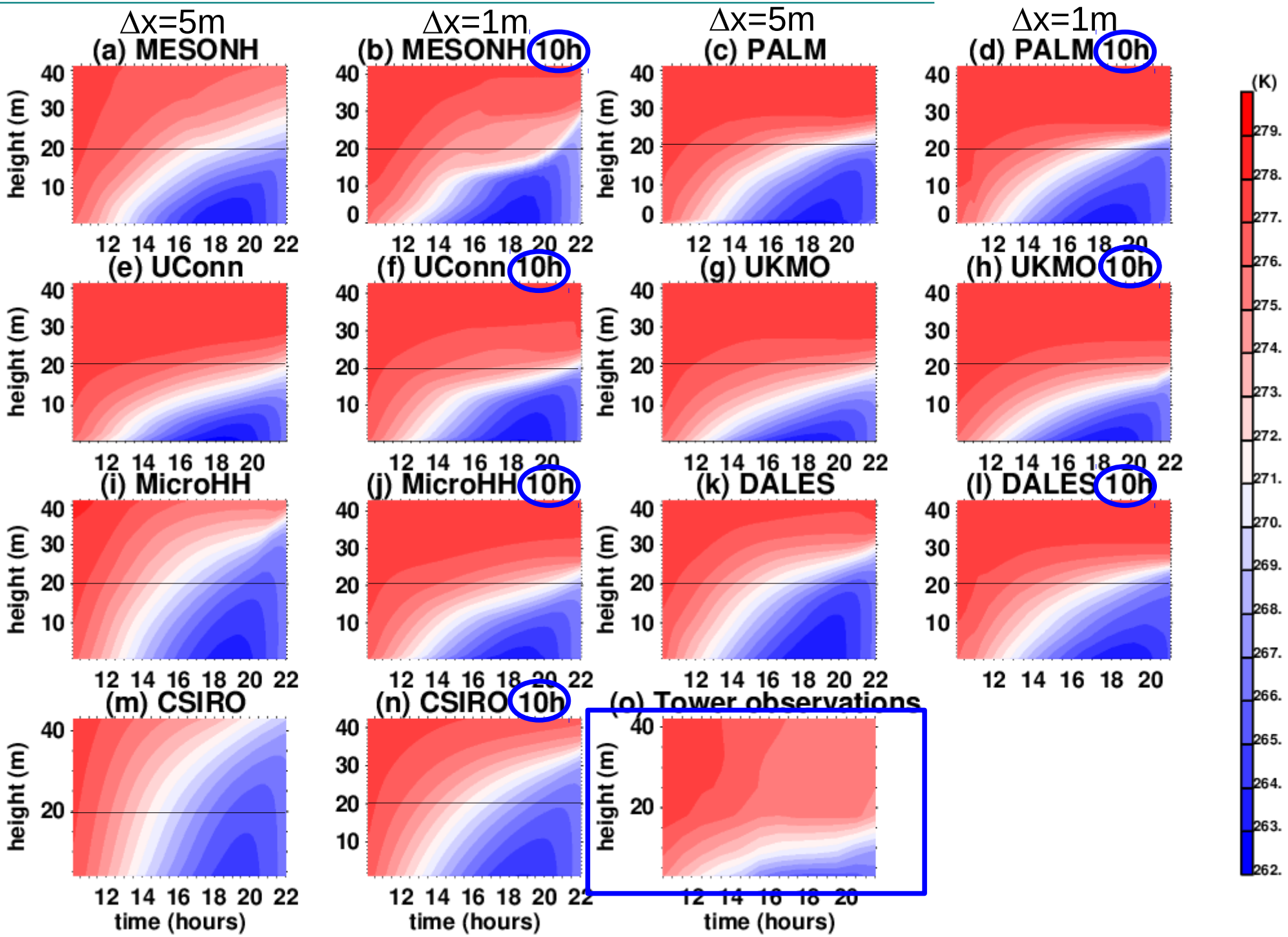
Zo=10^{-2}/zoh=10^{-3}

Zo=10^{-3}/zoh=10^{-4}

Better agreement with observations when using zo=10^{-3}m (also value expected from observations)

=> concentrate on simulations with zo=10^{-3} m

Focus on stable conditions :

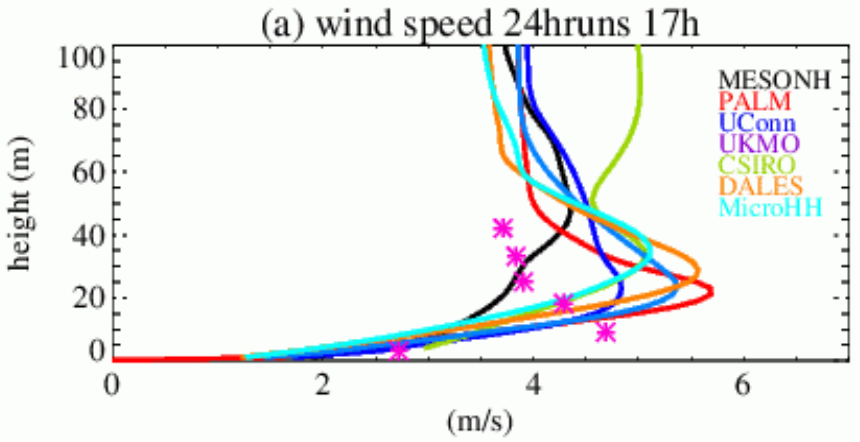


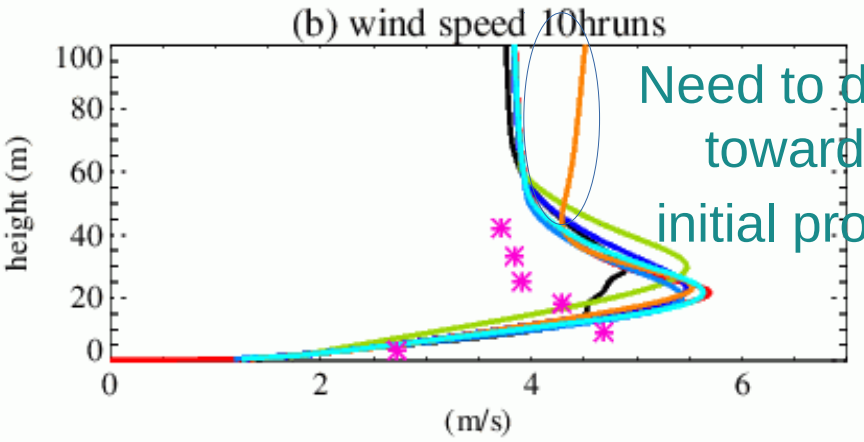
Focus on stable conditions :

At 17TU

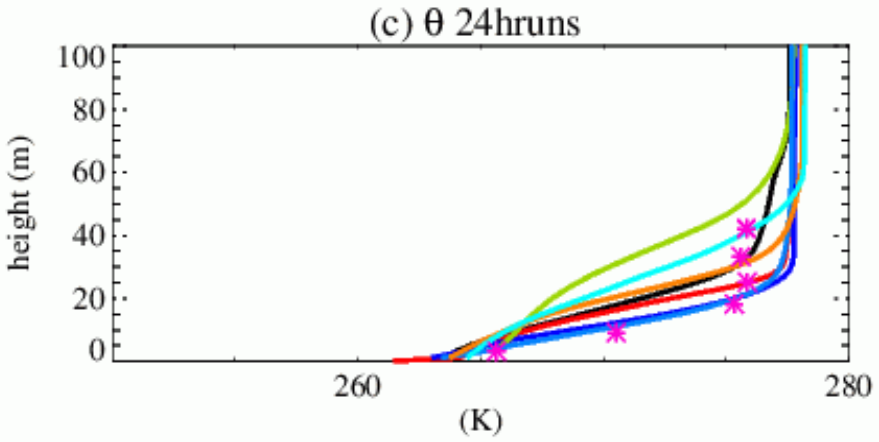
Δx=5m

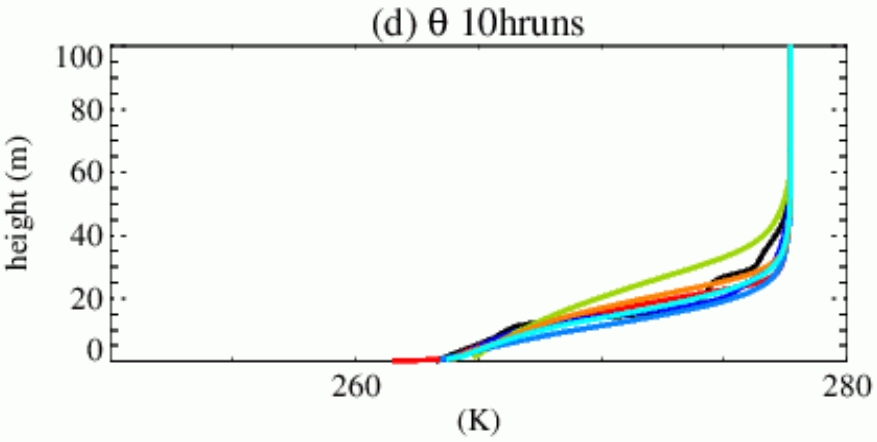
Δx=1m

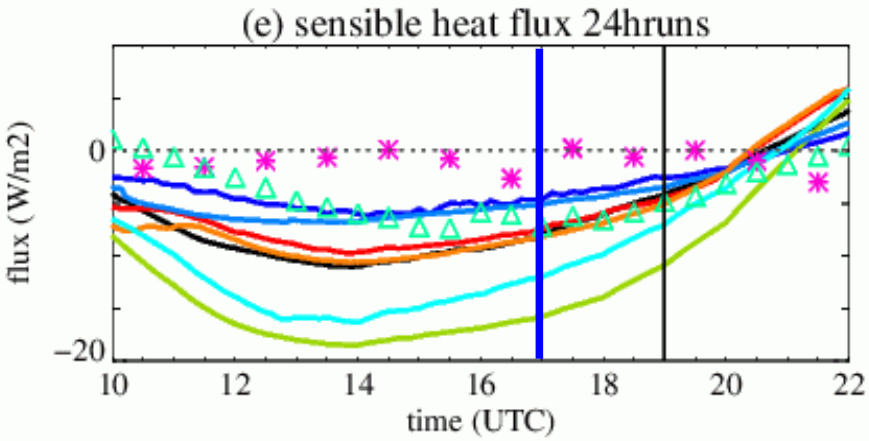


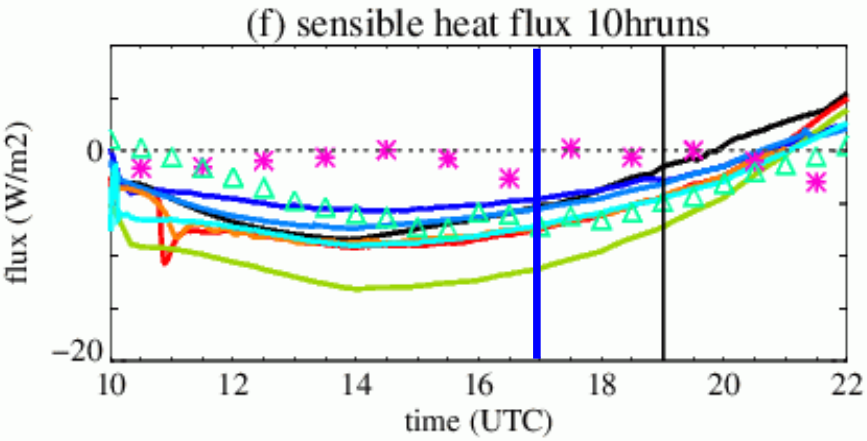


Need to damp towards initial profile



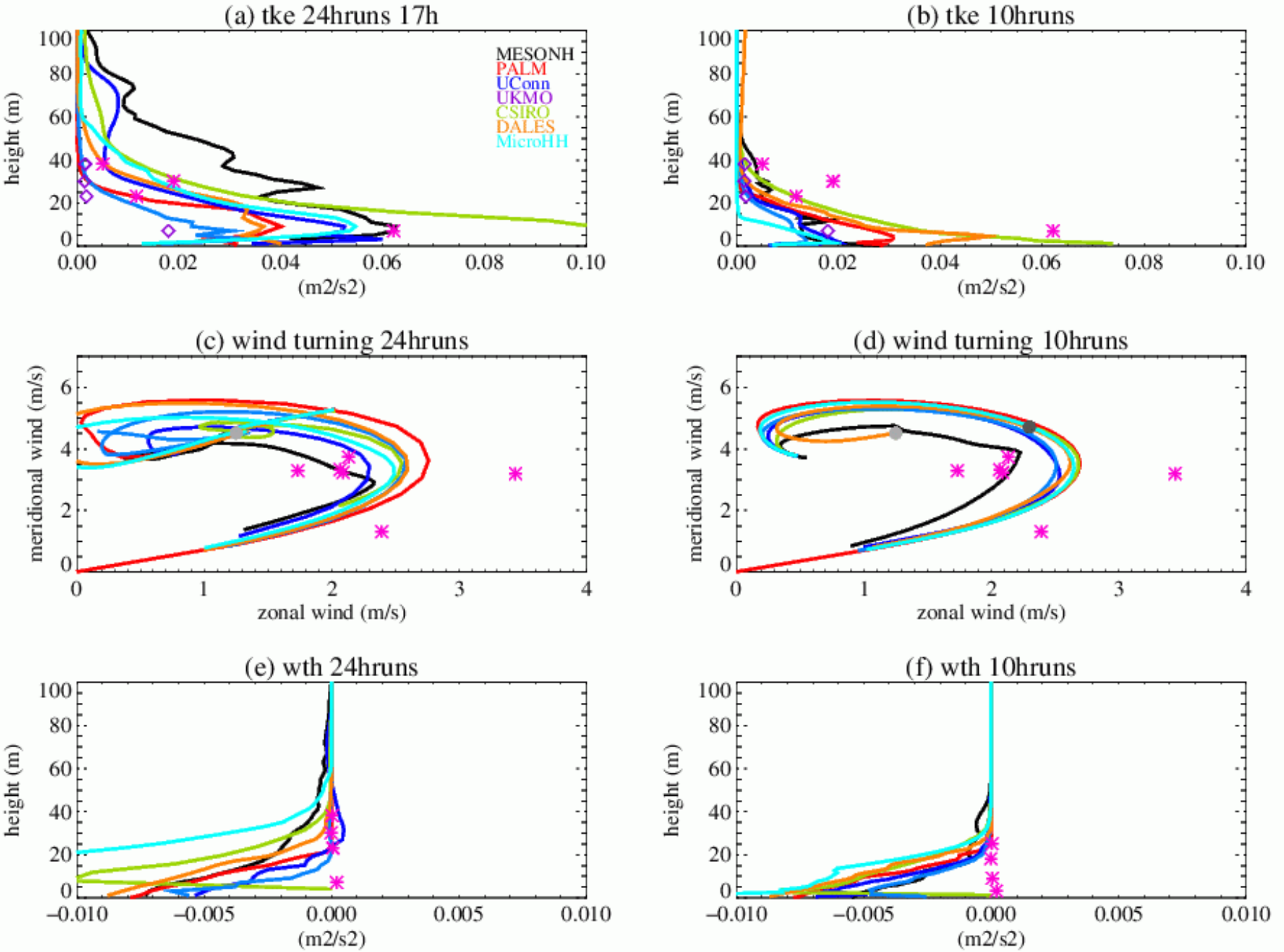






Focus on stable conditions :

Contributions from Waves ?

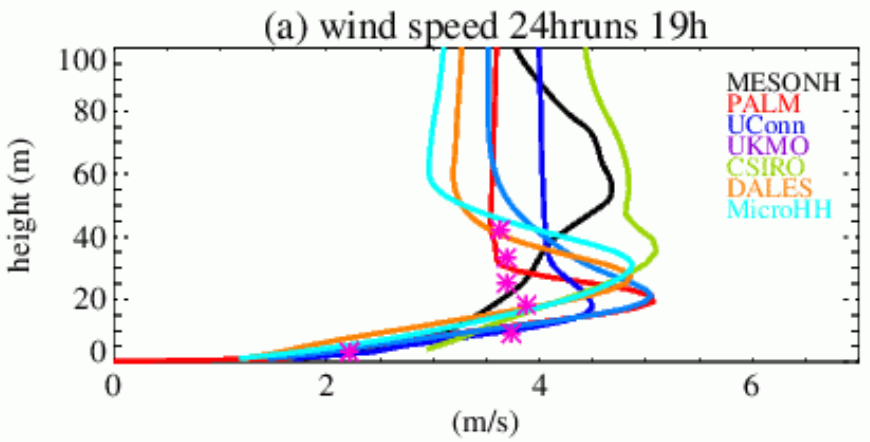


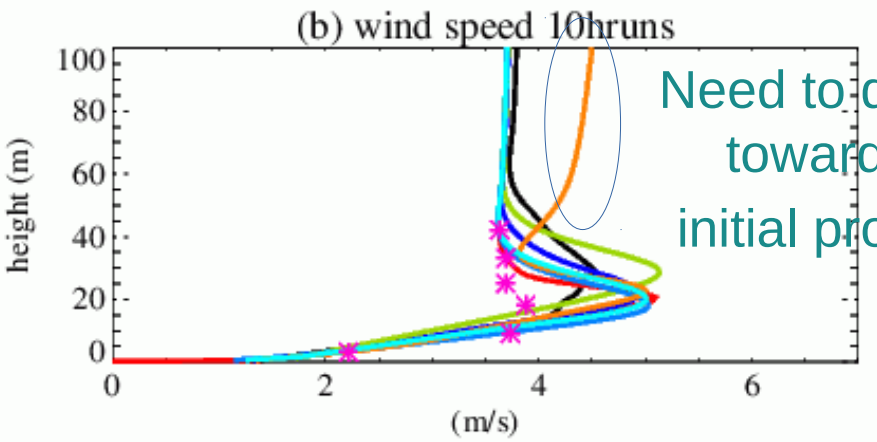
Focus on stable conditions :

At 19TU

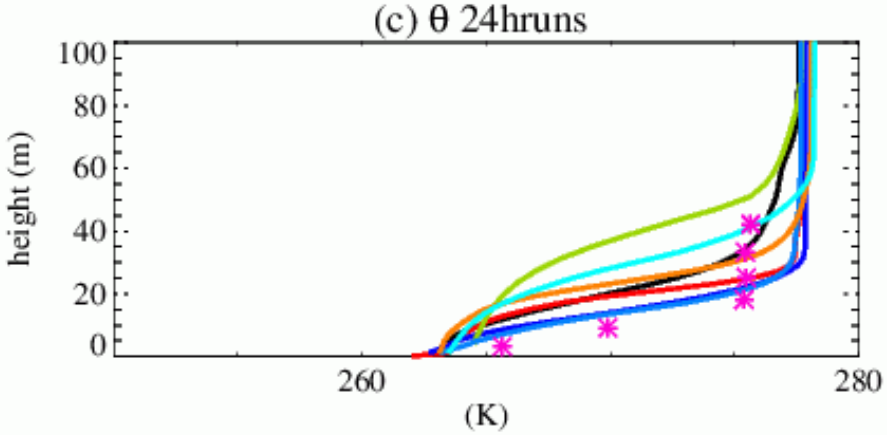
Δx=5m

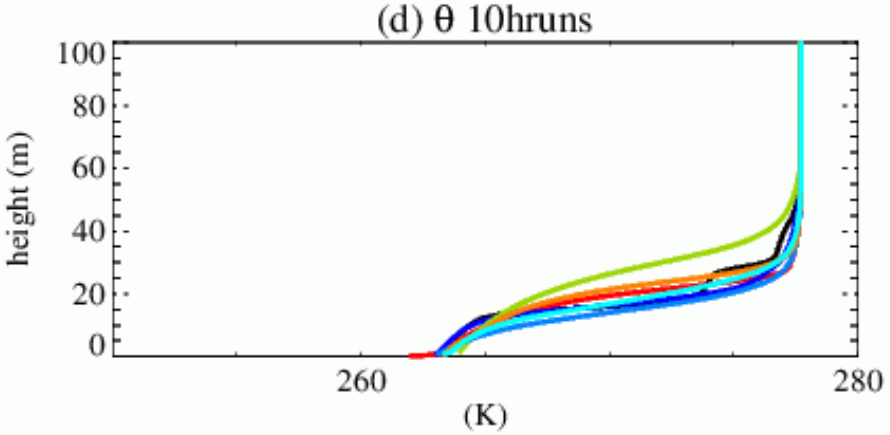
Δx=1m

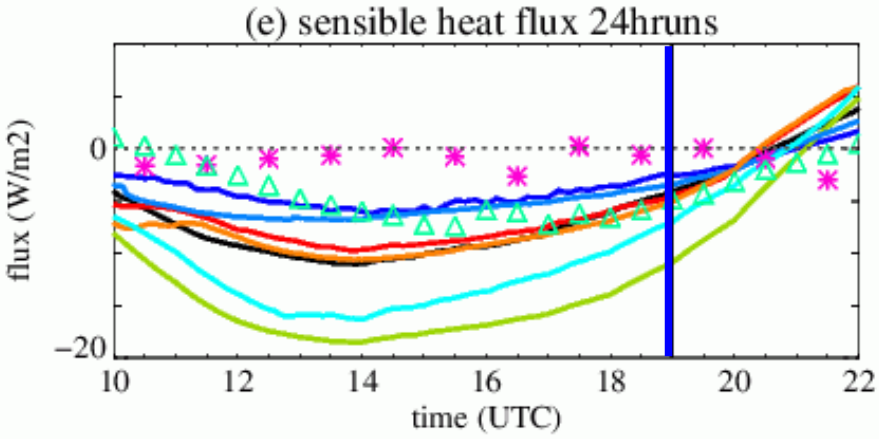


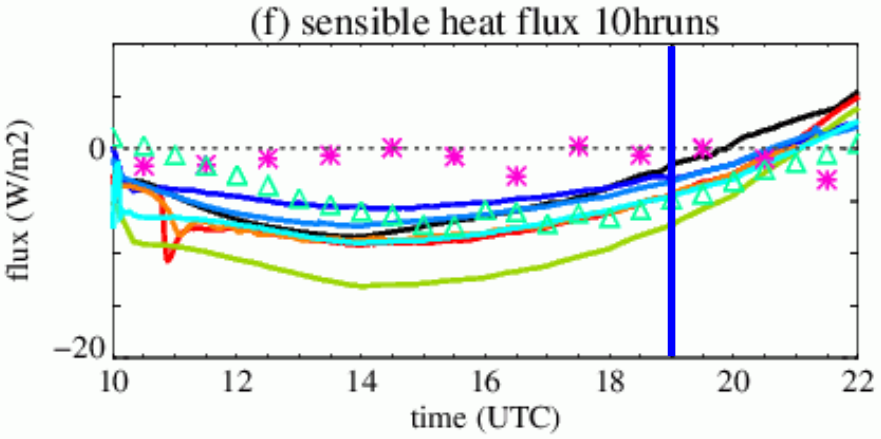


Need to damp towards initial profile



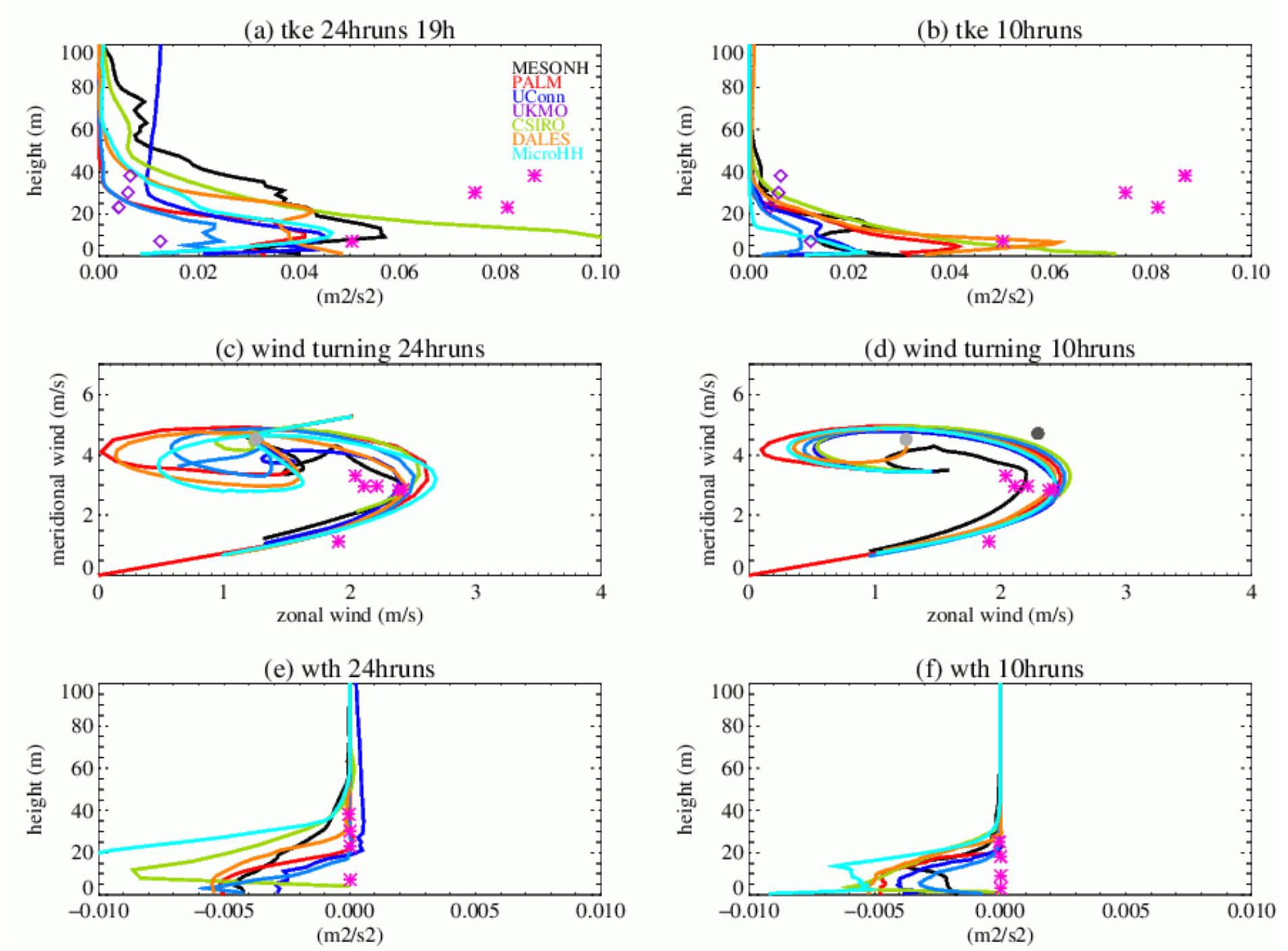






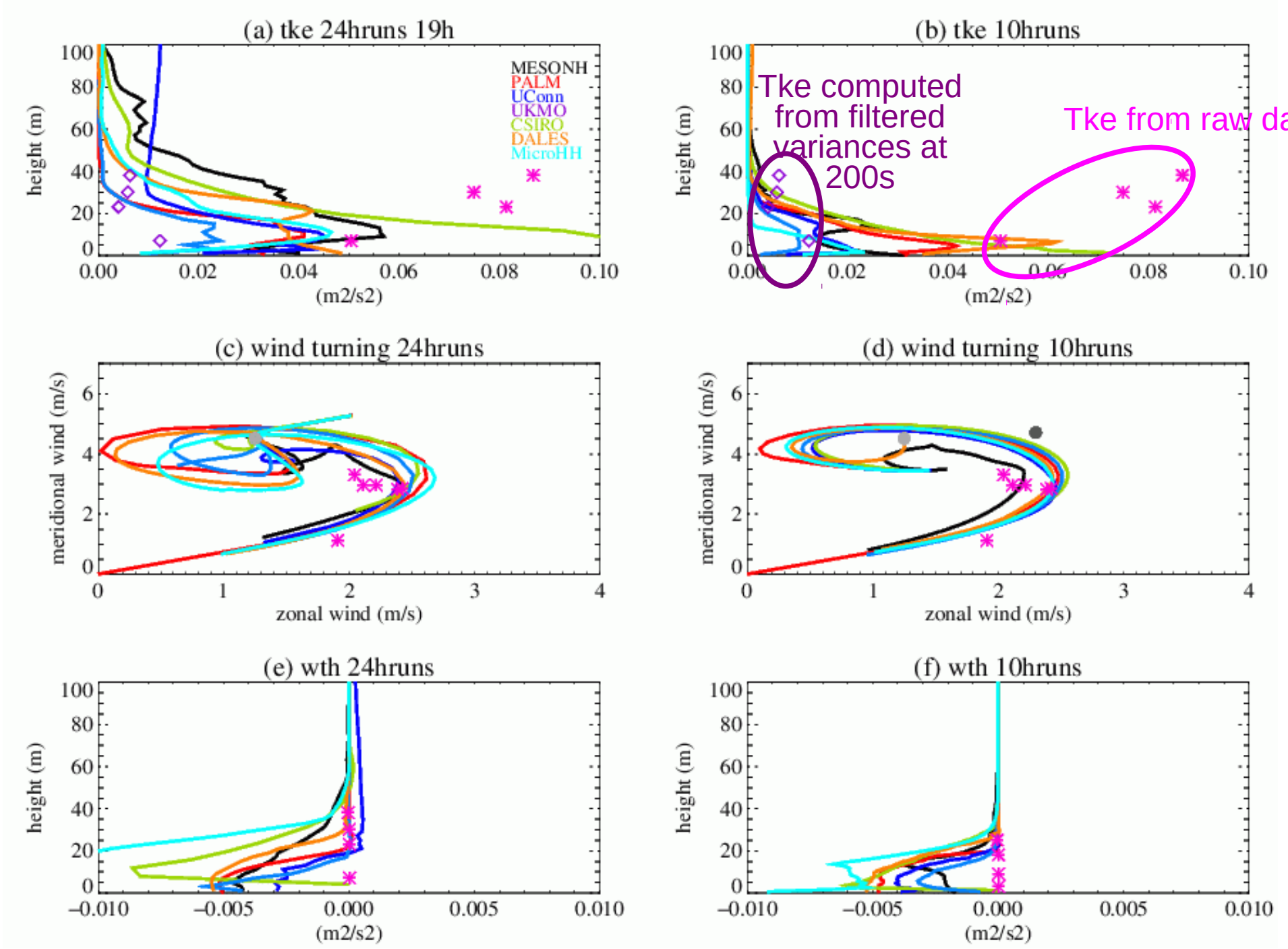
Focus on stable conditions :

Contributions from Waves ?

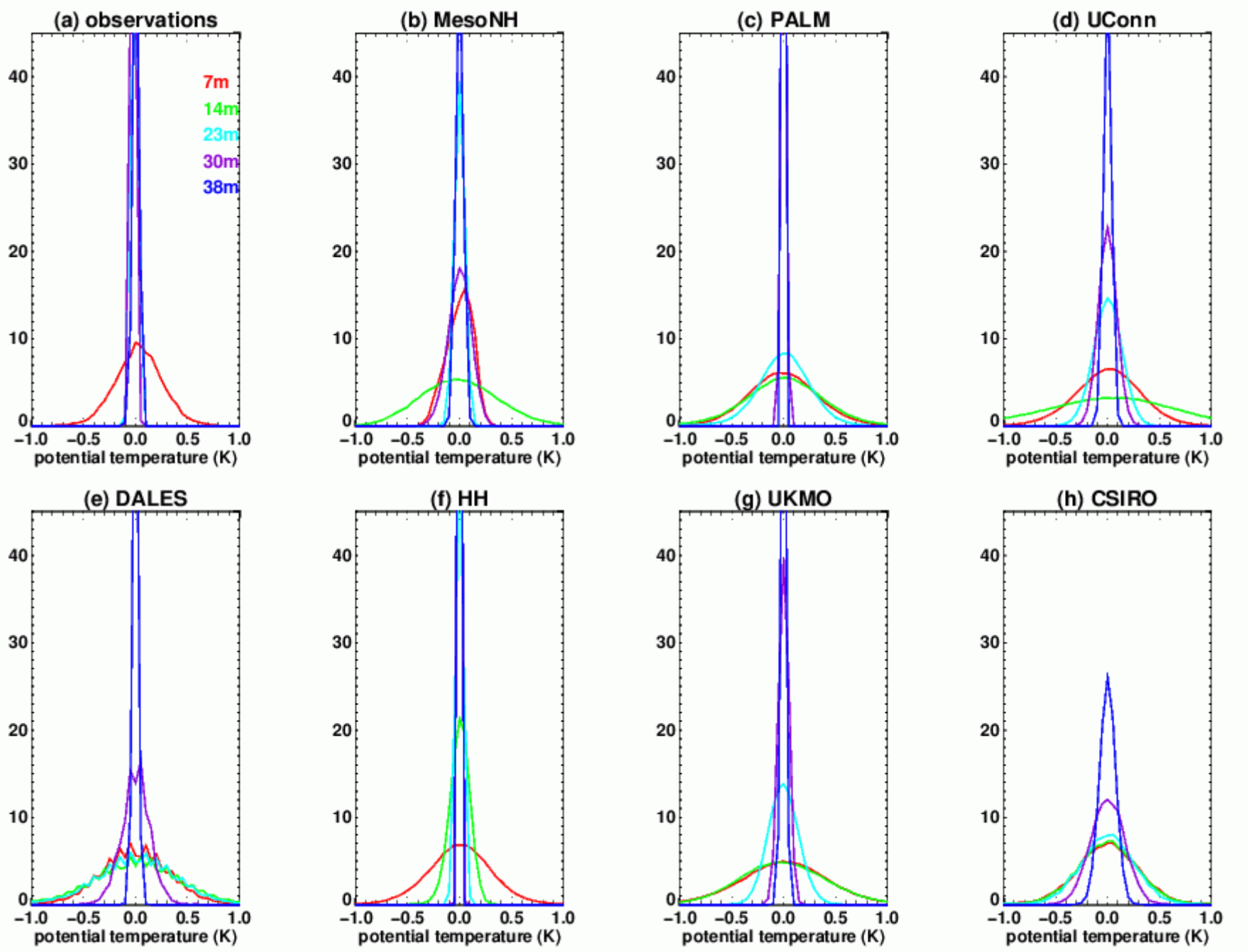


Focus on stable conditions :

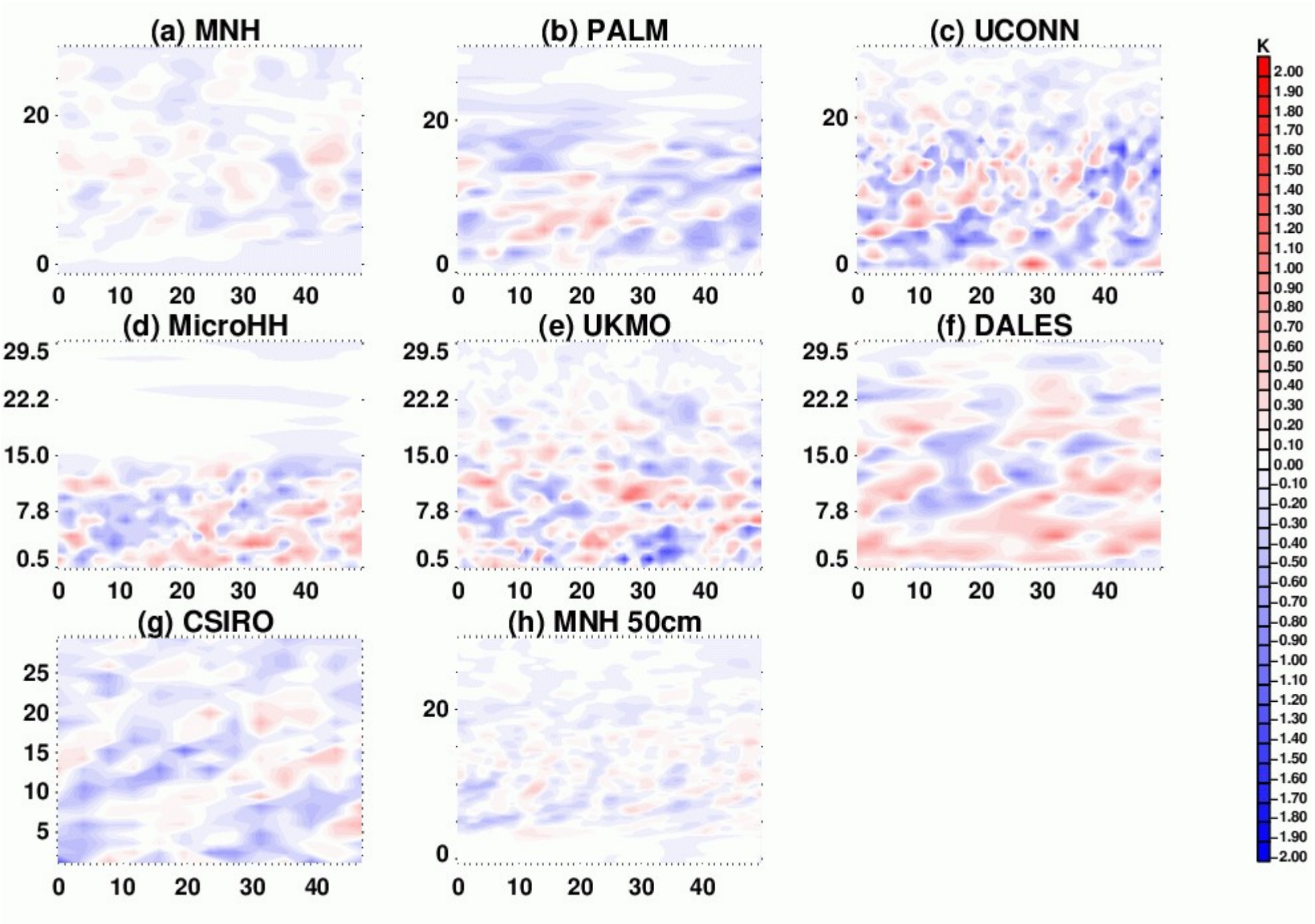
Contributions from Waves ?



Example of distributions of potential temperature at 17h :

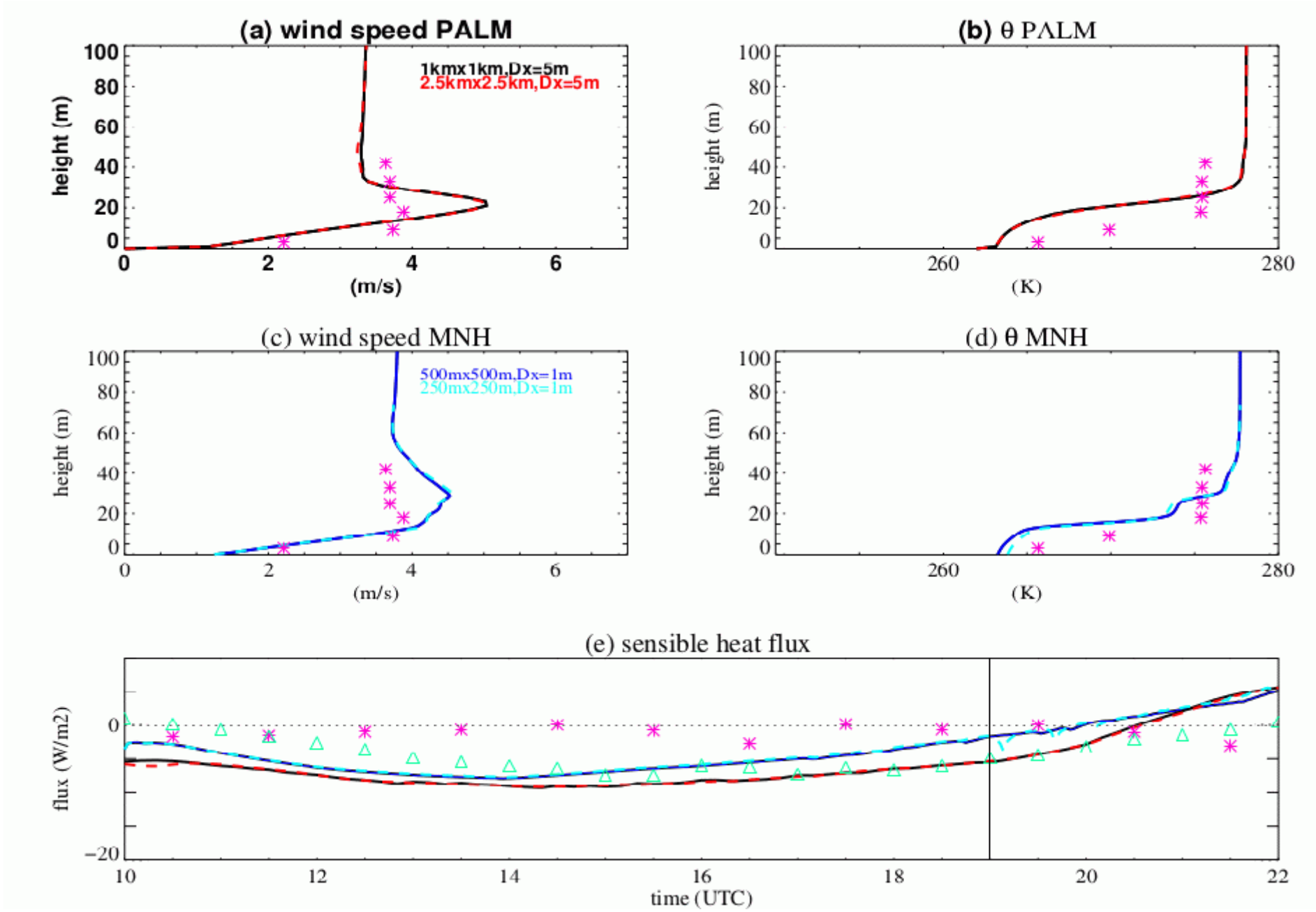


Vertical cross sections at 15h :

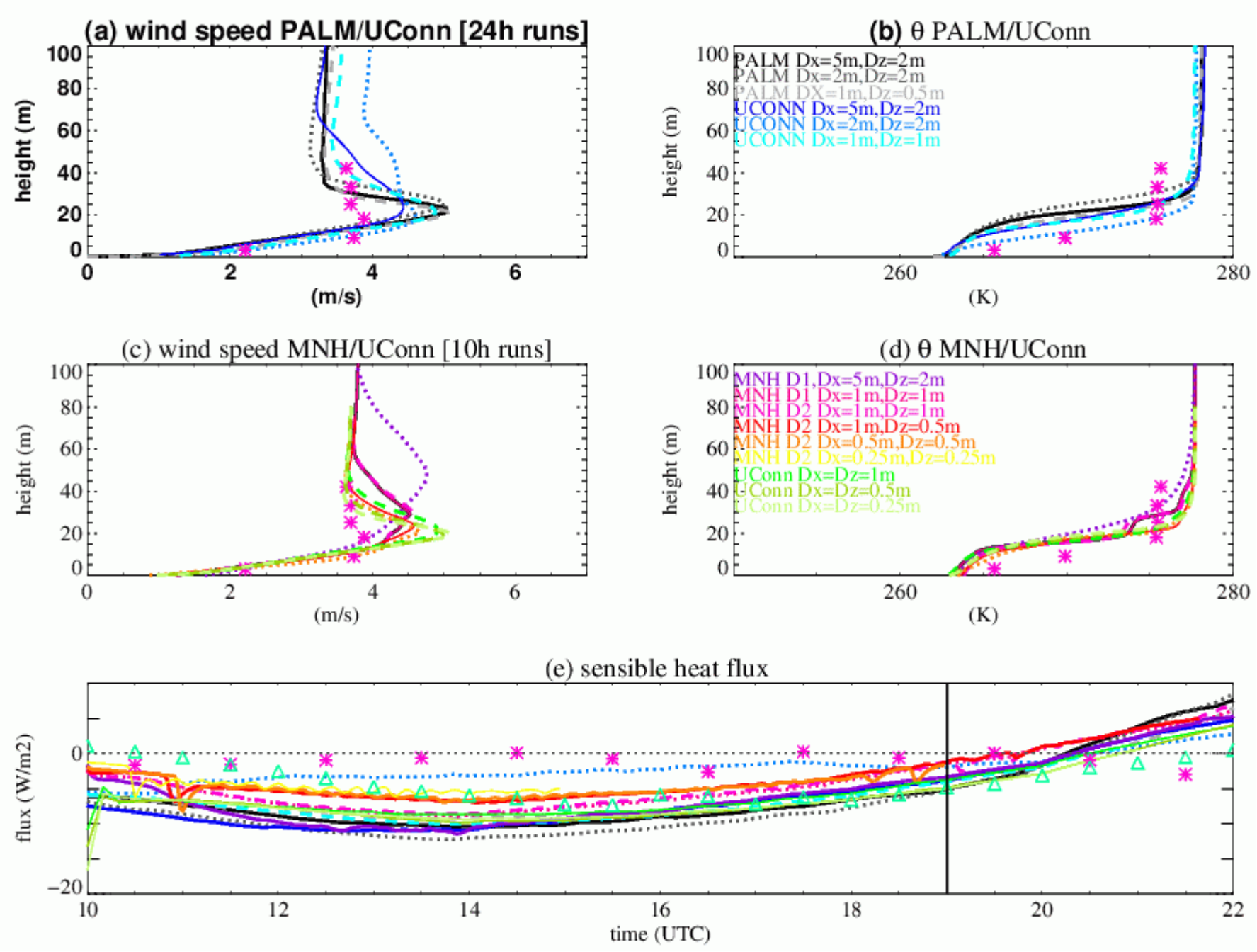


III. Sensitivity experiments

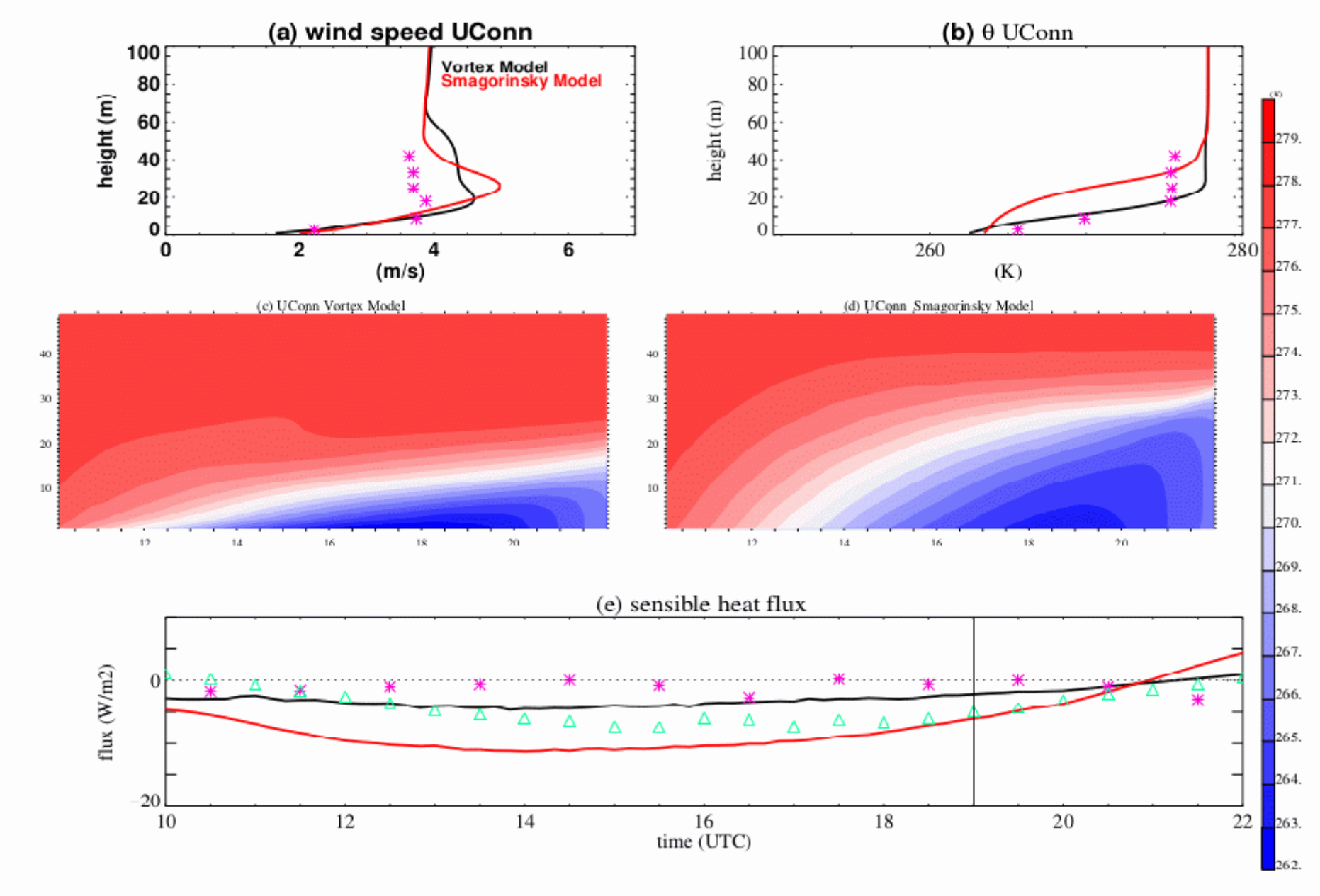
Some sensitivity tests : to the domain size



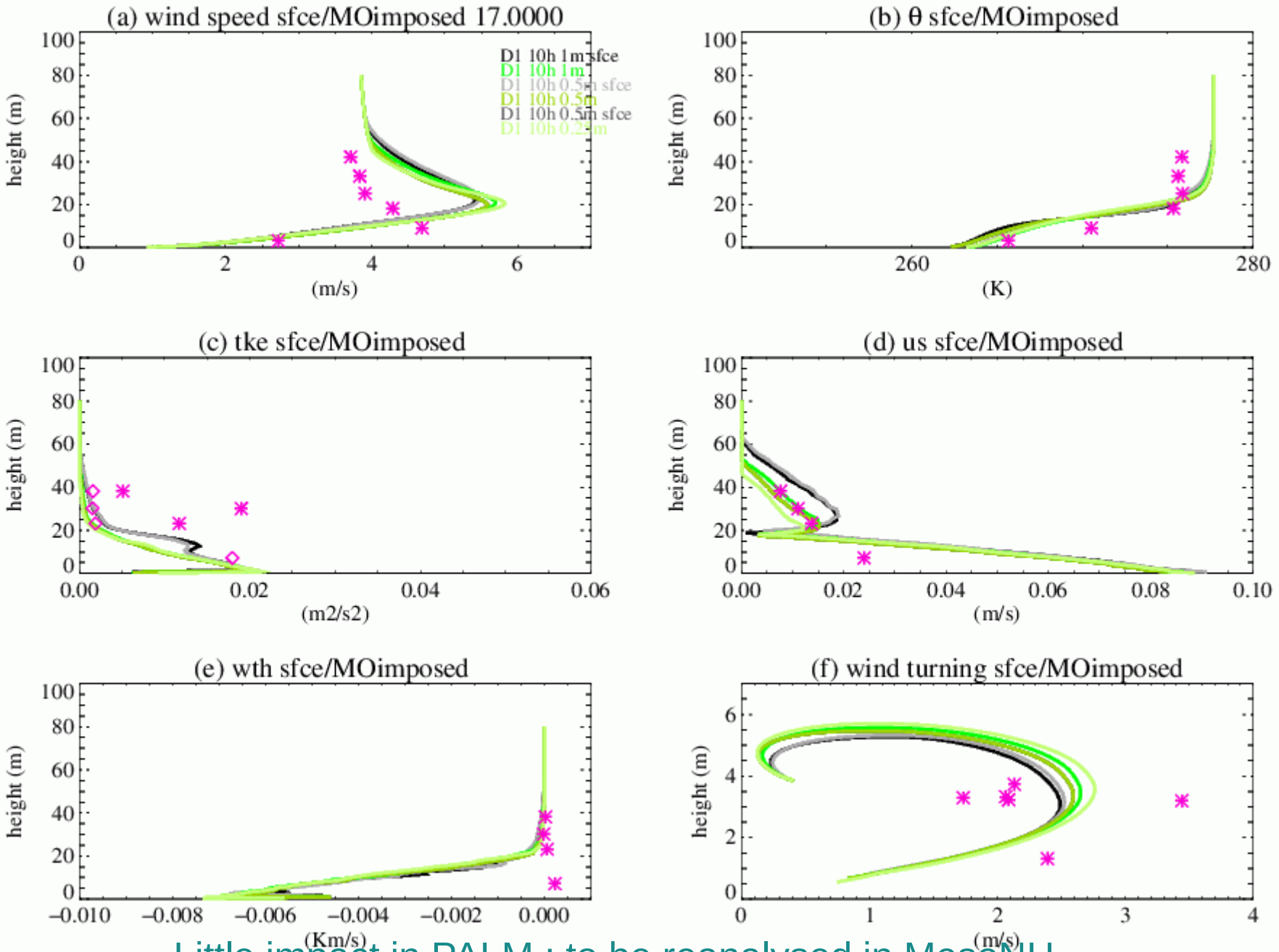
Some sensitivity tests : to the resolution



Some sensitivity tests : to the subgrid scheme



Some sensitivity tests : to the surface parameterization (NS)



Little impact in PALM ; to be reanalysed in MesoNH

Still to be analysed ; z/L => to check for validity of the formulation

Conclusions :

- GABLS4 full diurnal cycle = demanding in term of domain & resolution

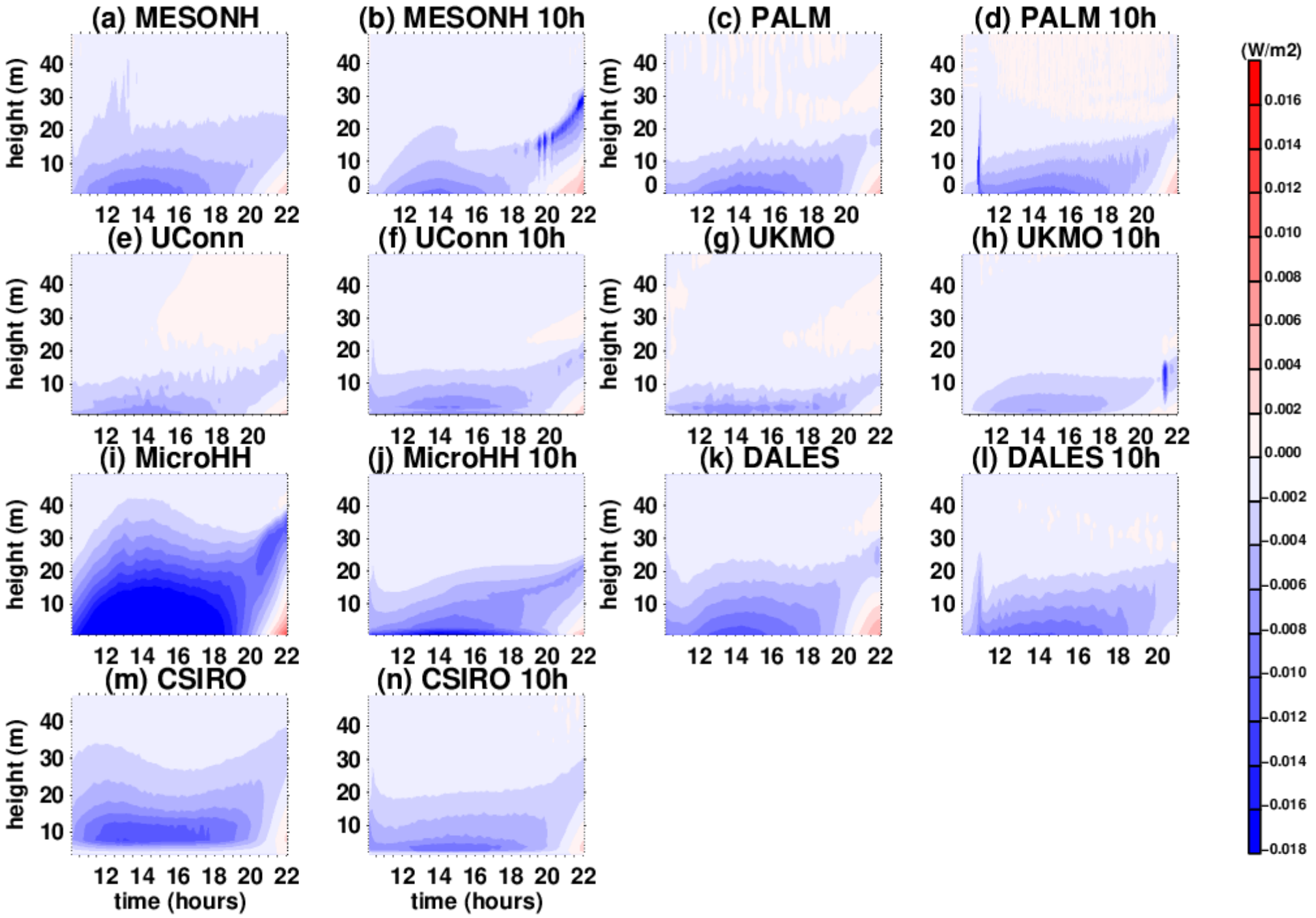
- Agreement btw LES for 1st 8 hours = convective BL although Tre ~-30°C

- Large spread for the stable conditions => new set-up
- Reduction of the spread for Dx=Dz=1m but still differences for 2nd order
- Existence of micro-fronts (as in Sullivan et al 2016)

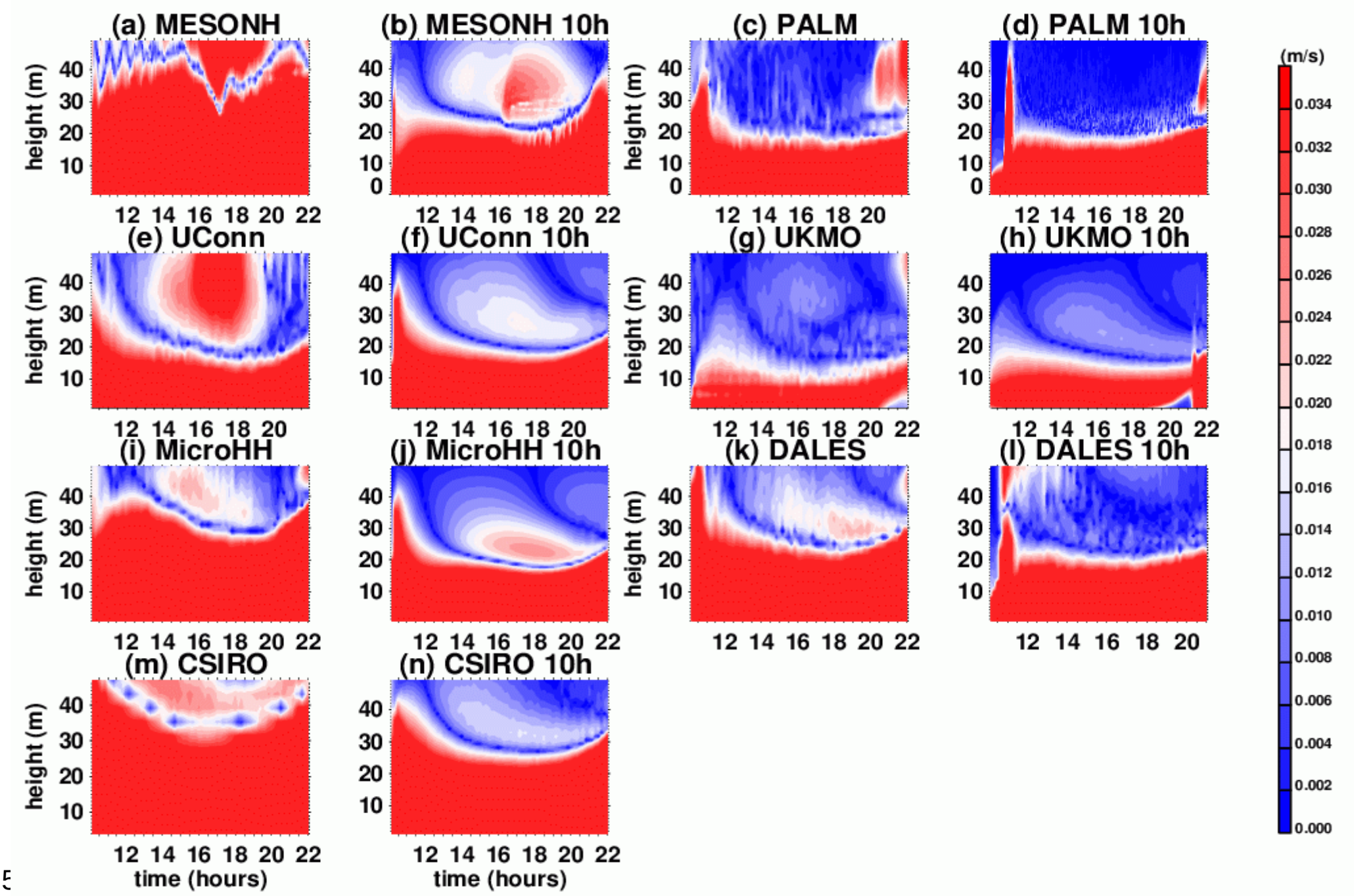
- Several sensitivity tests (resolution, domain, zo, subgrid turb scheme) :
  - Not sensitive to initial conditions & domain
  - Strong sensitivity to subgrid turbulence scheme (cf G Matheou talk)
  - Seems to converge around Dx=25cm/Dz=25cm (cf Q Rodier talk)
  - Sensitivity to the surface flux to be more analysed

- Not tackled but maybe a focus for next GABLS cases:
  - interaction between radiation/turbulence
  - Interaction between surface scheme/turbulence
  - Interaction between turbulence/waves

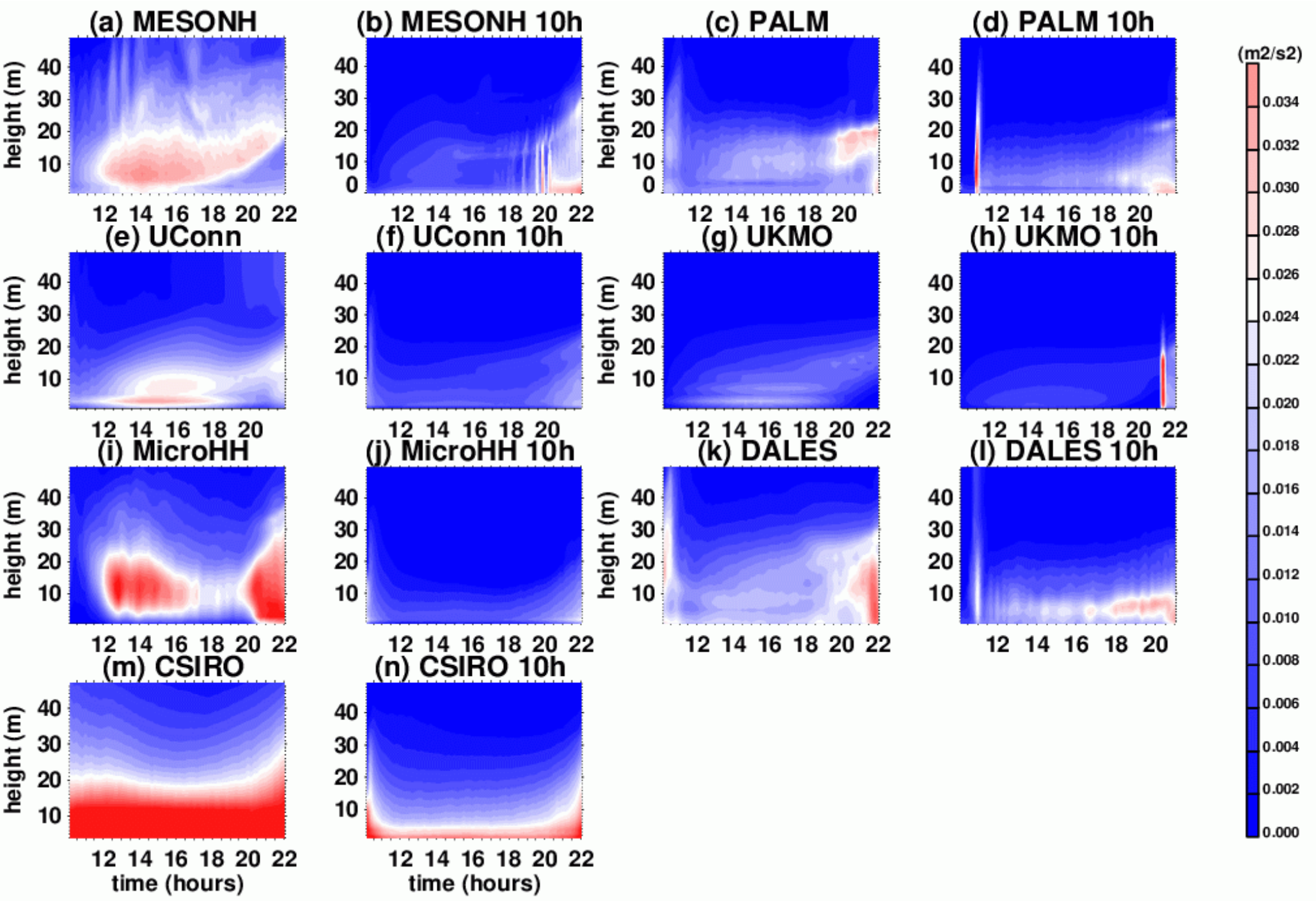
Supplementary : <wthl>



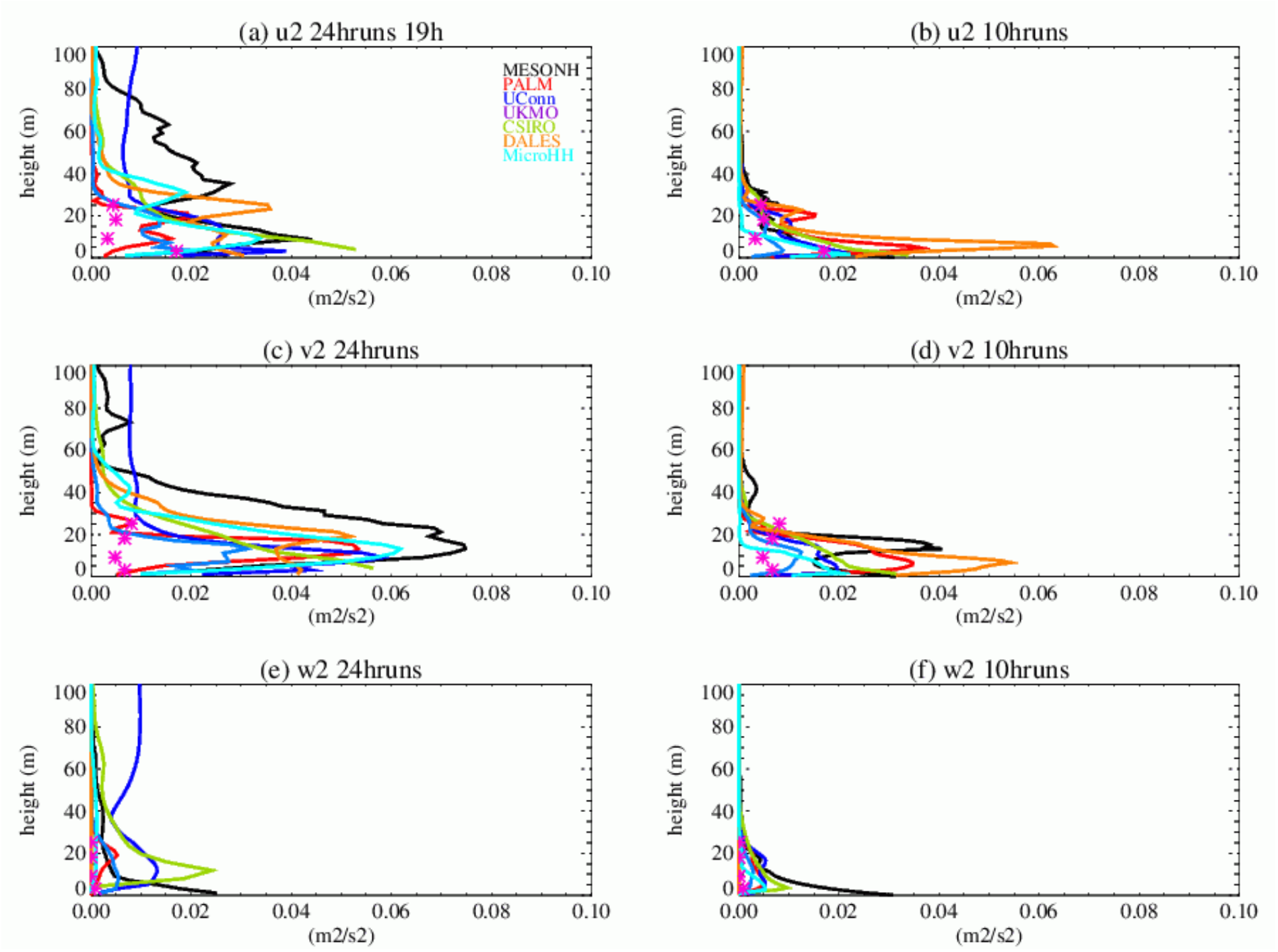
Supplementary : friction velocity



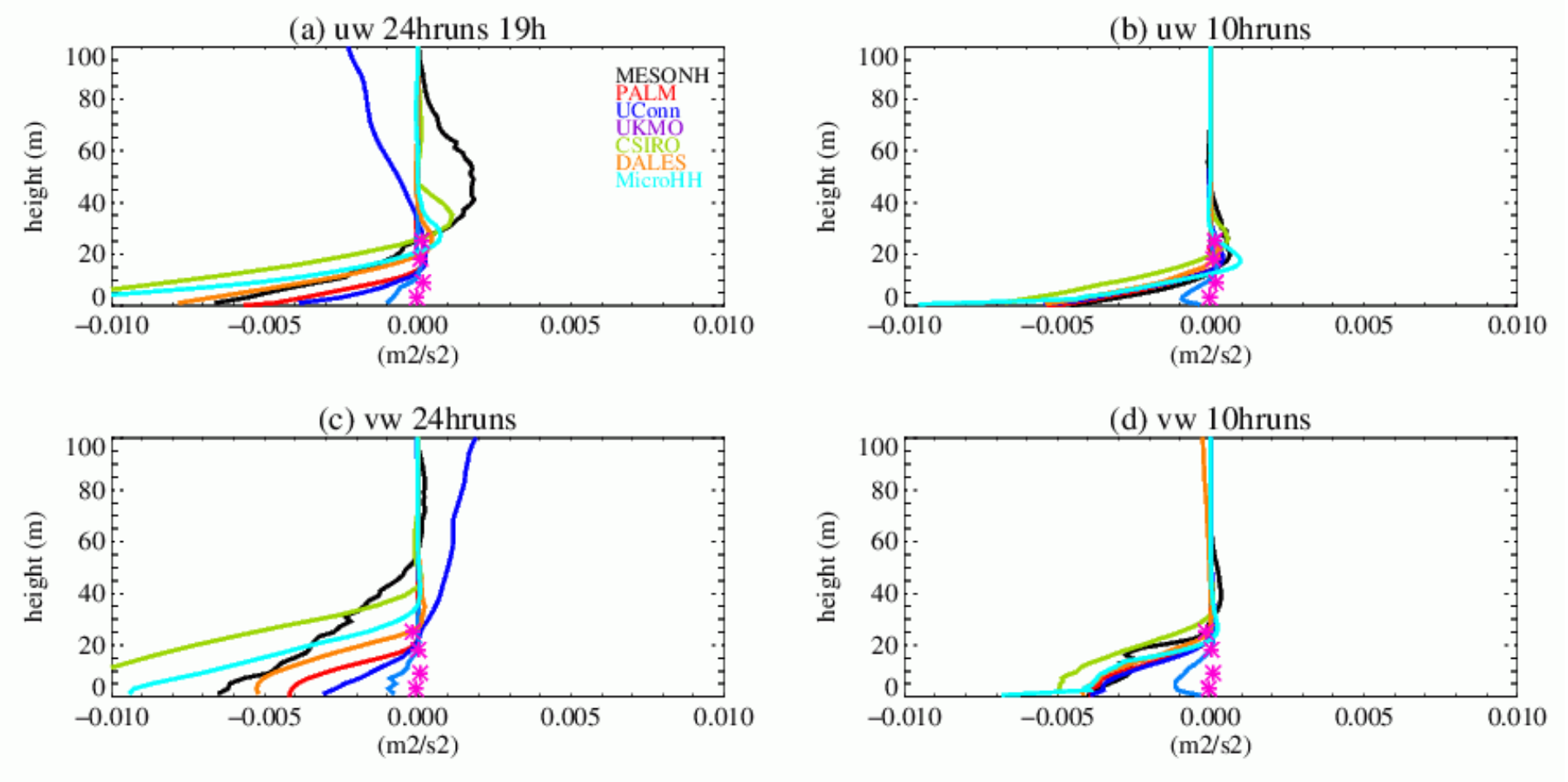
Supplementary : turbulent kinetic energy



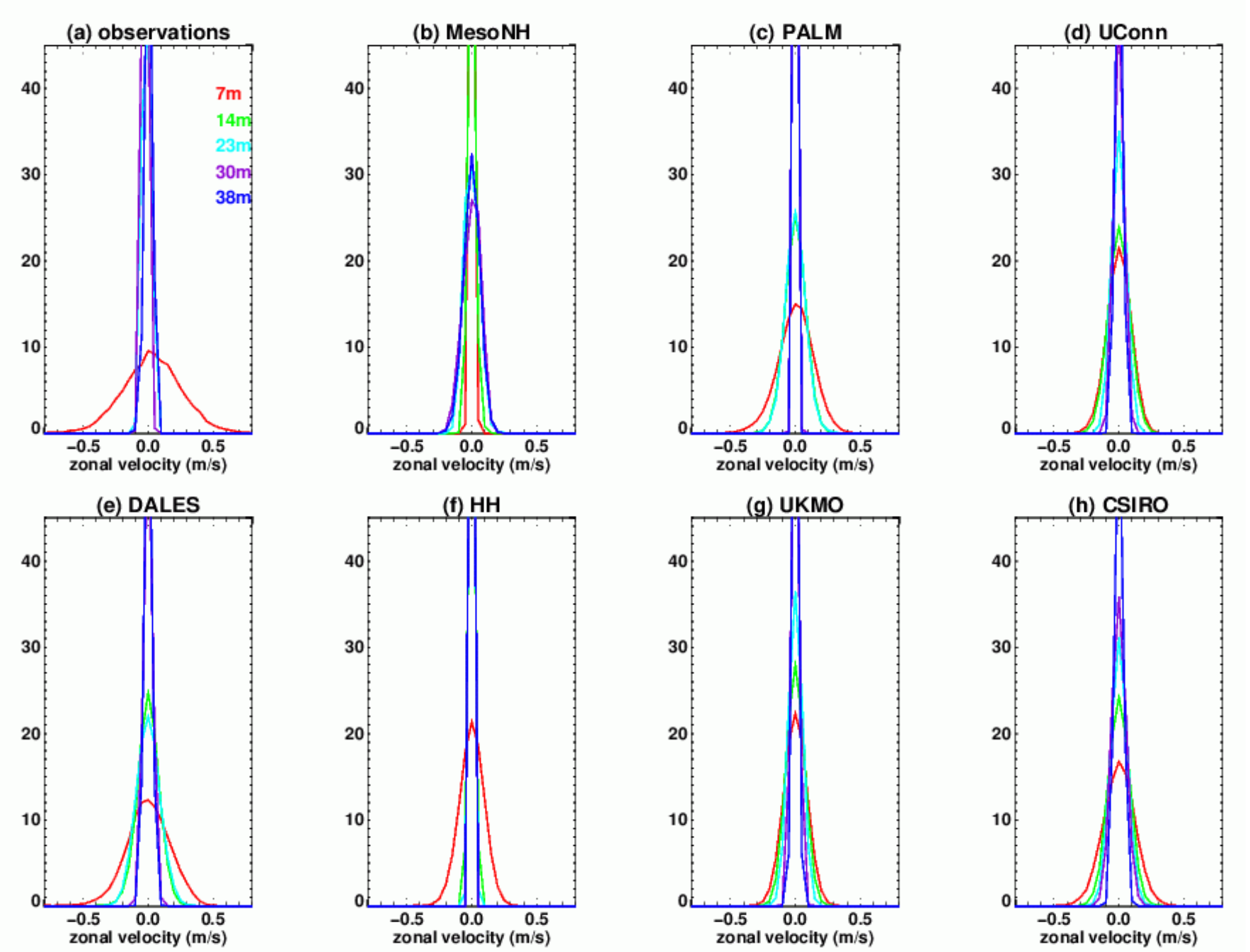
Supplementary : 2nd order moment at 19TU



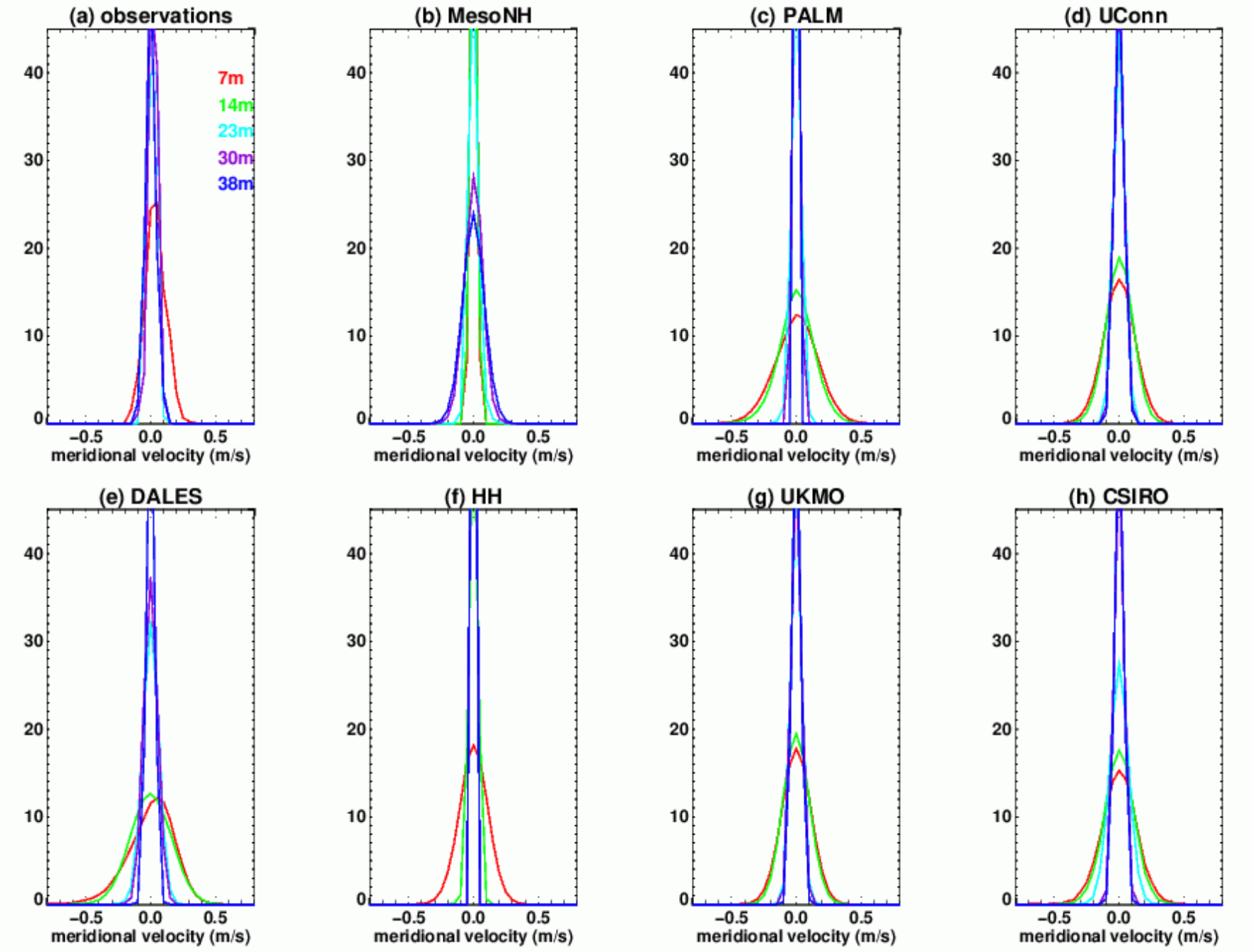
Supplementary : 2nd order moment at 19TU



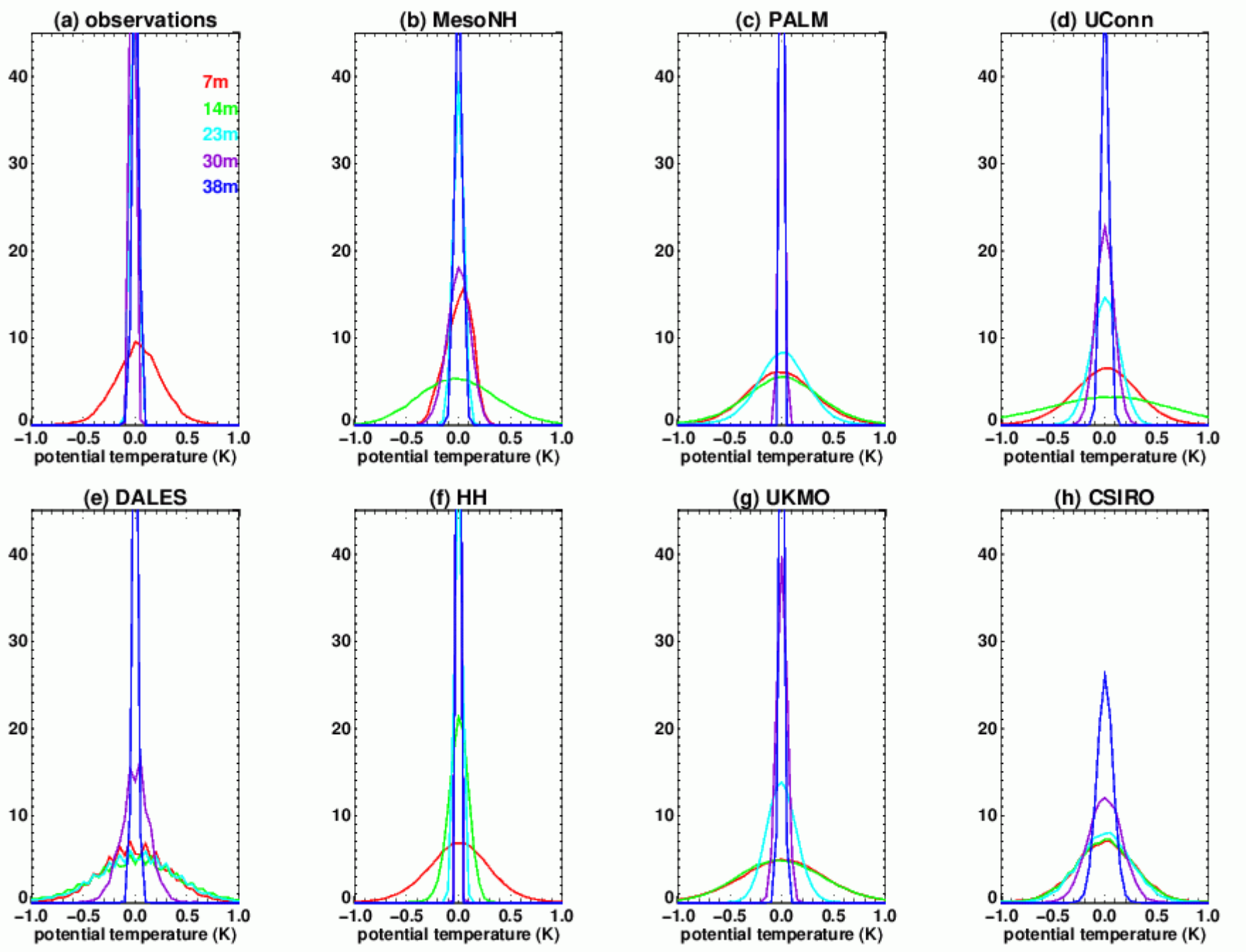
Example of distributions of zonal wind at 17h :



Example of distributions of meridional wind at 17h :

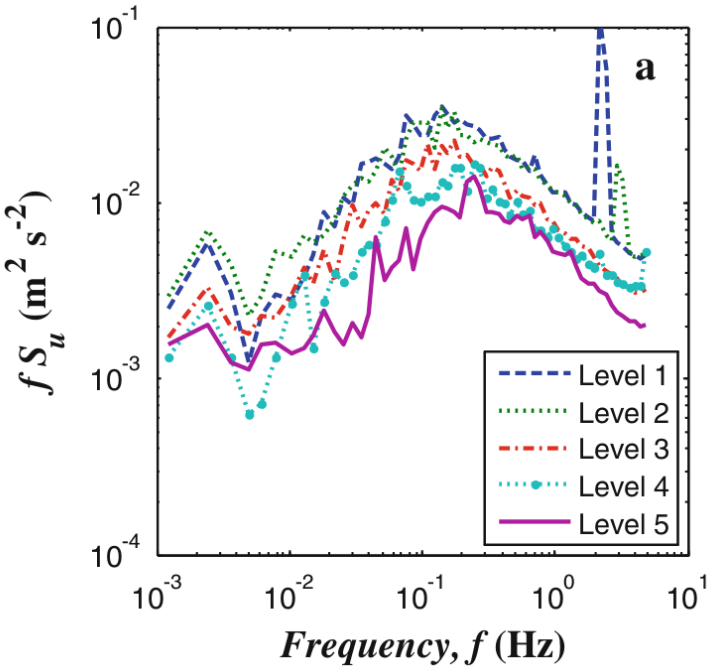


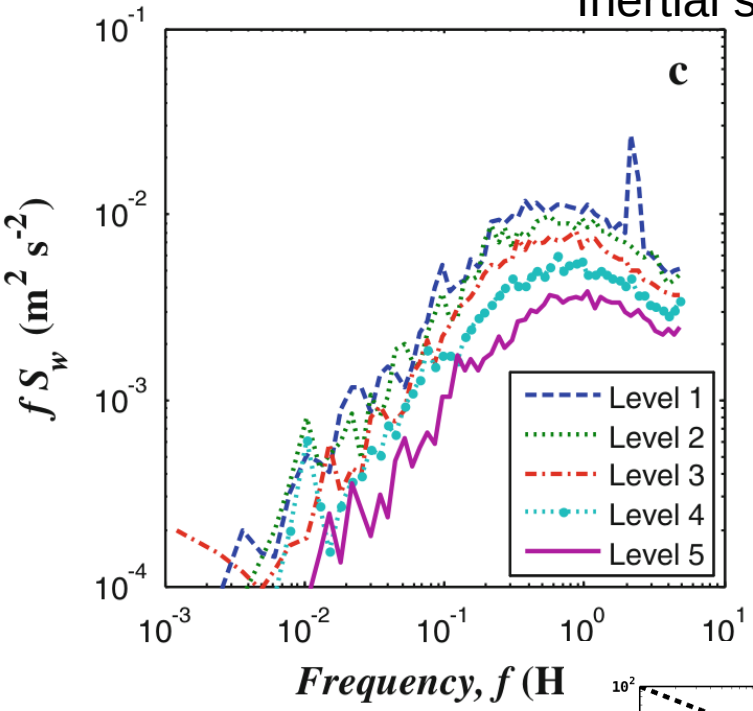
Example of distributions of vertical velocity at 17h :



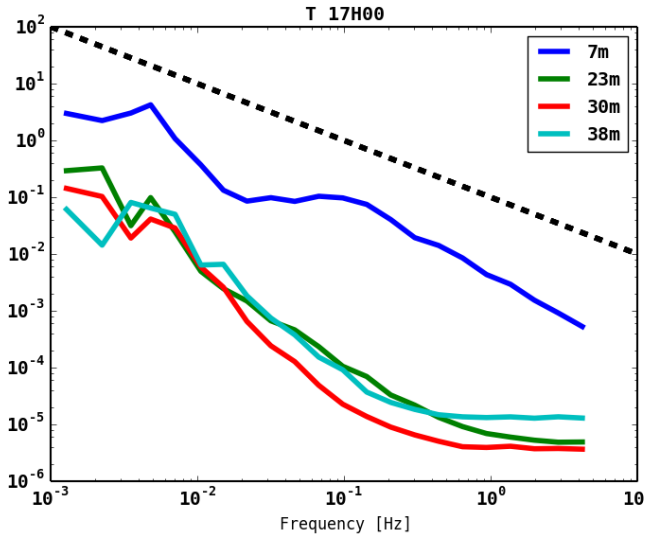
Campagne SHEBA : 20m tower (5 levels) over Arctic sea ice [Grachev et al 2013]

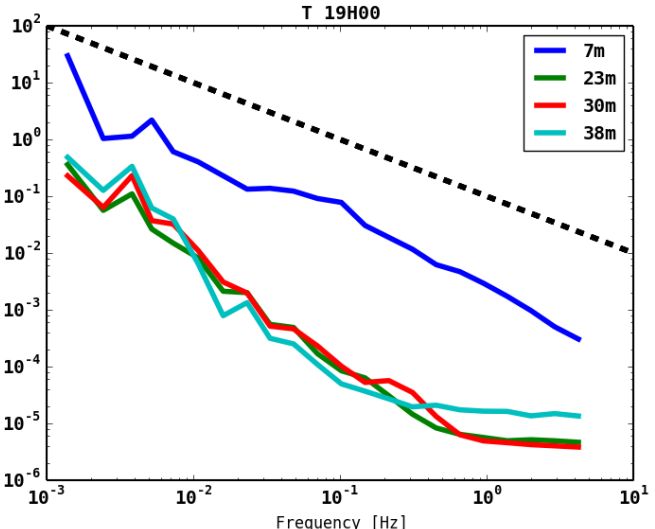
Inertial subrange = 1-3Hz

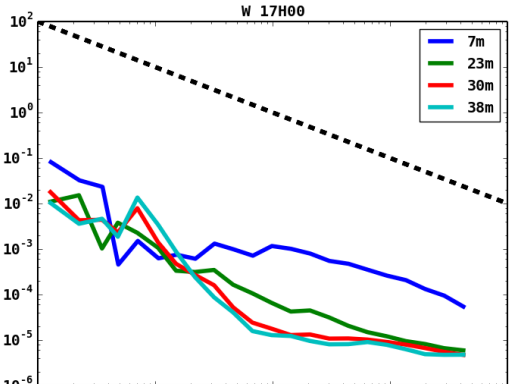


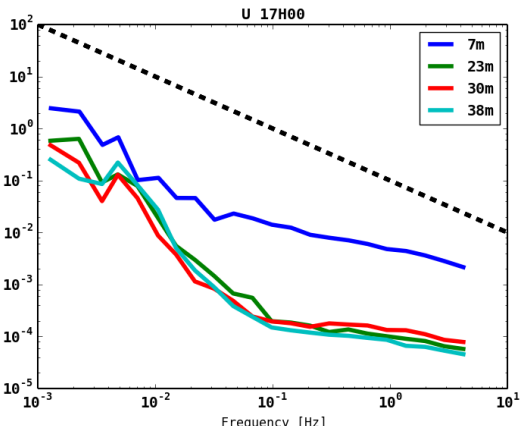


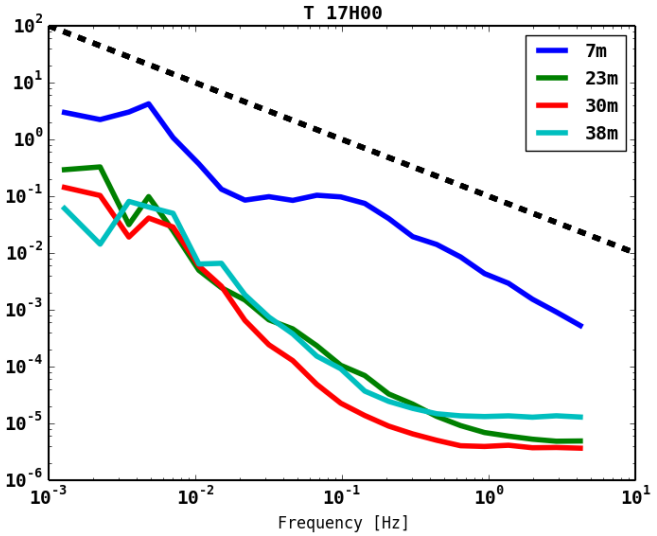
Dome C observation : 42m tower (5 levels) over Antarctica

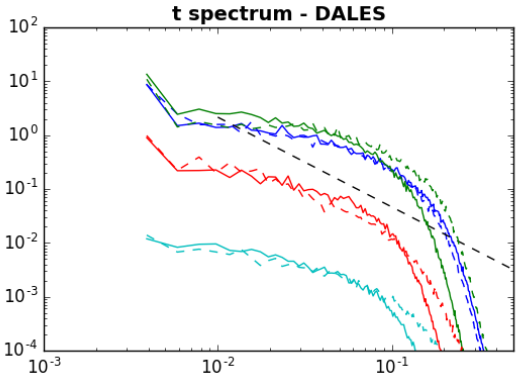


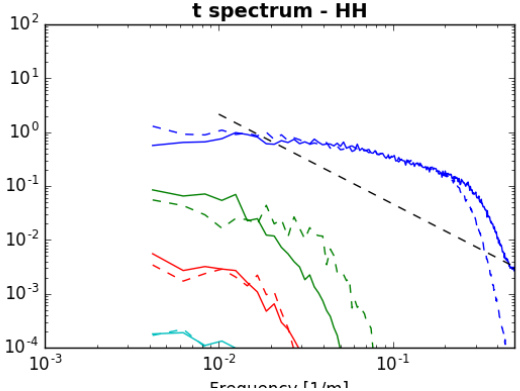


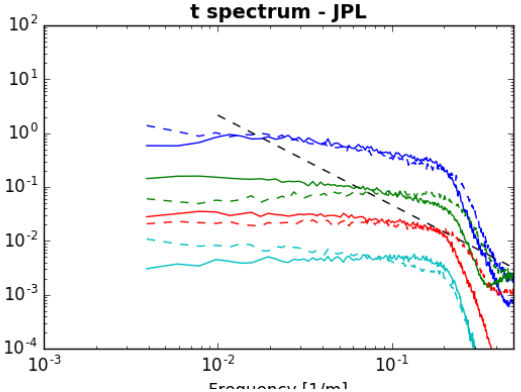


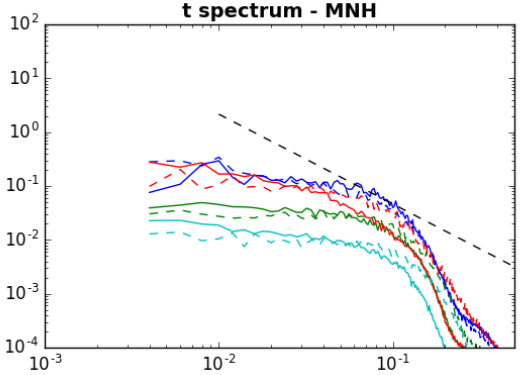


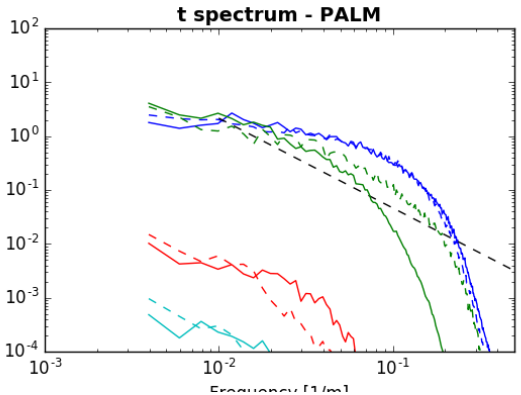

T 17H00
7m
23m
30m
38m
Frequency [Hz]

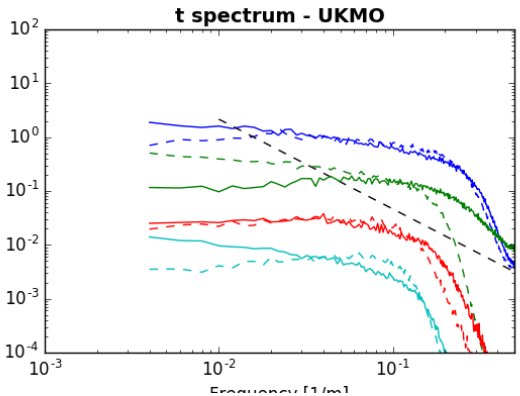

t spectrum - DALES

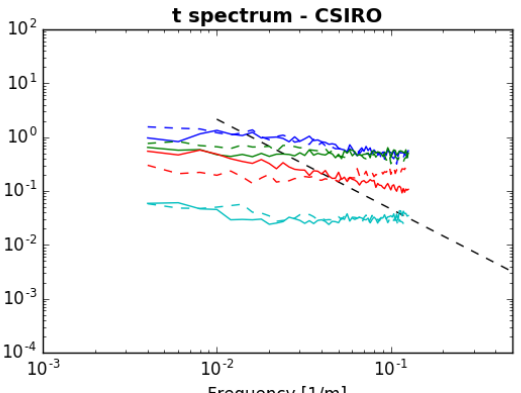

t spectrum - HH


t spectrum - JPL


t spectrum - MNH


t spectrum - PALM


t spectrum - UKMO


t spectrum - CSIRO

Some sensitivity tests : to the surface parameterization (NS)