Presentation at GABLS4 workshop, Toulouse, 12 September 2018

Background and Overview of the GEWEX Atmospheric Boundary Layer Study (GABLS)

Bert Holtslag

(thanks to Gert-Jan Steeneveld and GABLS community)

GABLS
GEWEX Atmospheric Boundary Layer Study

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Meteorology and Air Quality

Bulletin of the American Meteorological Society (BAMS), November 2013

STABLE ATMOSPHERIC BOUNDARY LAYERS AND DIURNAL CYCLES

Challenges for Weather and Climate Models

BY A. A. M. HOLTSLAG, G. SVENSSON, P. BAAS, S. BASU, B. BEARE, A. C. M. BELJAARS, F. C. BOSVELD, J. CUXART, J. LINDVALL, G. J. STEENEVELD, M. TJERNSTRÖM, AND B. J. H. VAN DE WIEL

The atmospheric boundary layer impacts strongly the model performance for temperature and wind, yet stable situations, such as in clear, calm conditions at night or over ice, remain problematic.

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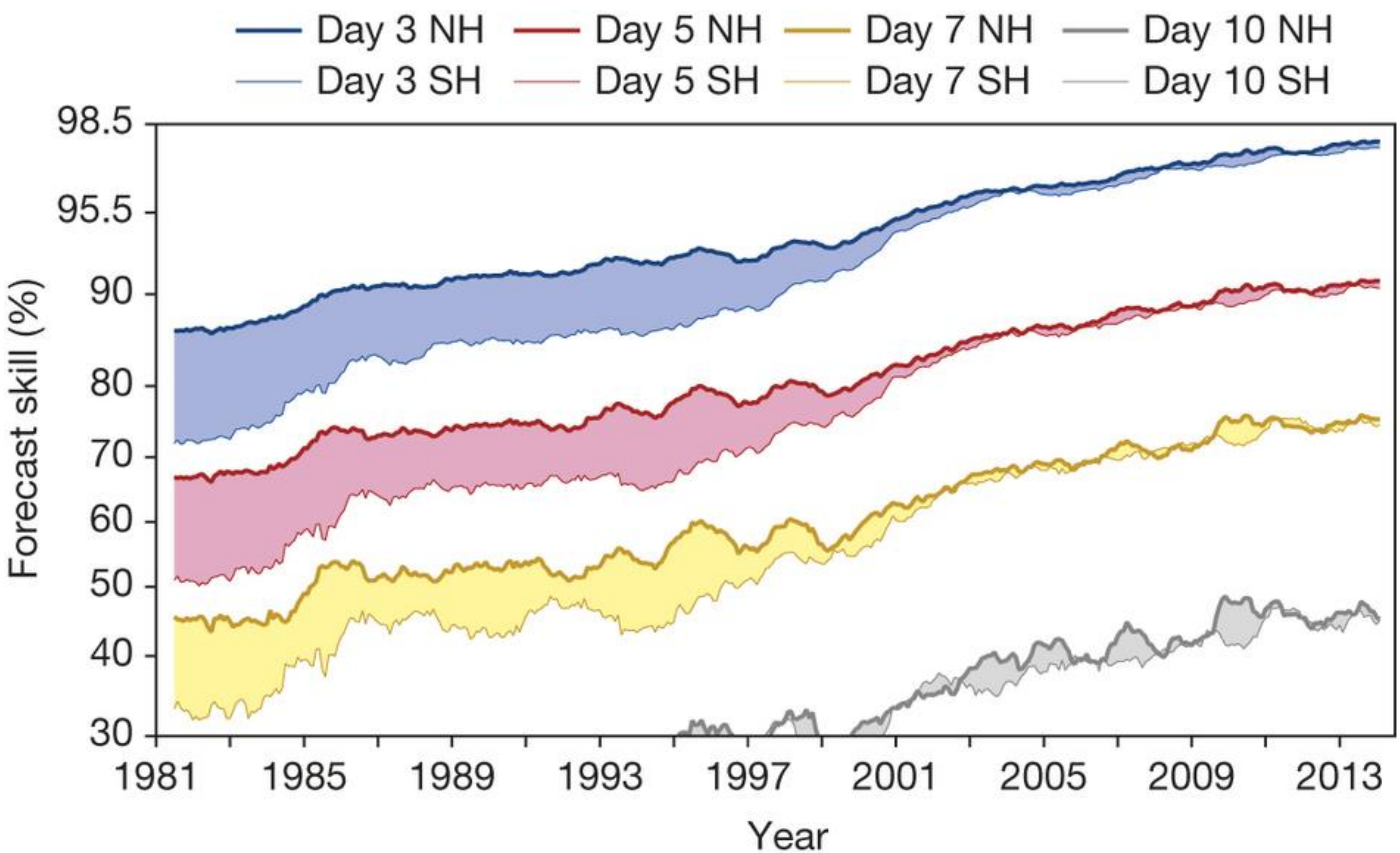
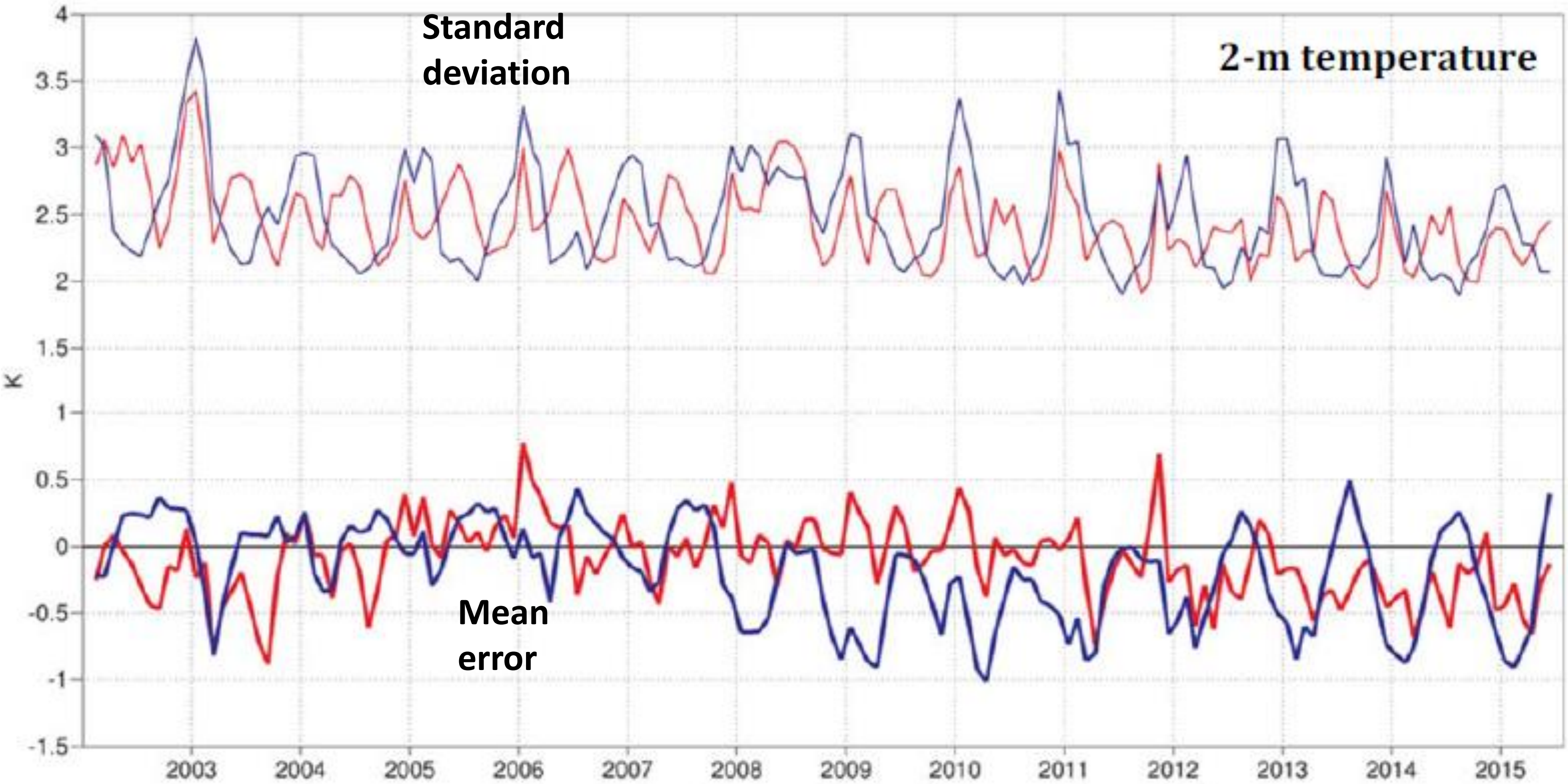
Improvement of forecast skill during the years

as the correlation between the forecasts and the verifying analysis of the height of the 500-hPa level, expressed as the anomaly with respect to the climatological height. Values greater than 60% indicate useful forecasts, while those greater than 80% represent a high degree of accuracy



(Bauer et al., 2015)

Still significant day (+72 h) and night (+60h) temperature errors in weather forecasts (Monthly averages over Europe by ECMWF)



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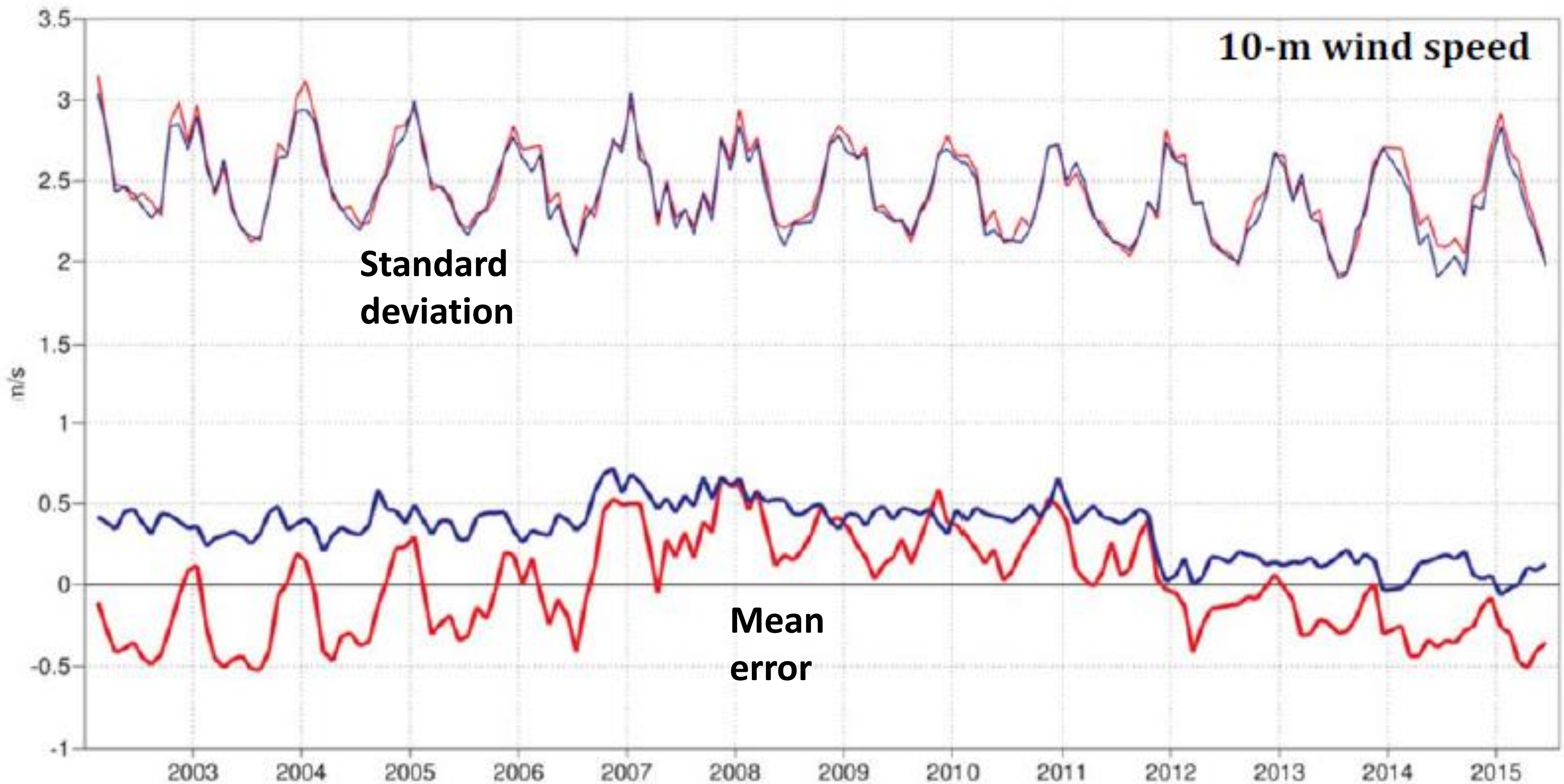
(Haiden et al, 2015, ECMWF, Tech.Memo 765)

Still significant day (+72 h) and night (+60h) wind errors in weather forecasts (Monthly averages over Europe by ECMWF)



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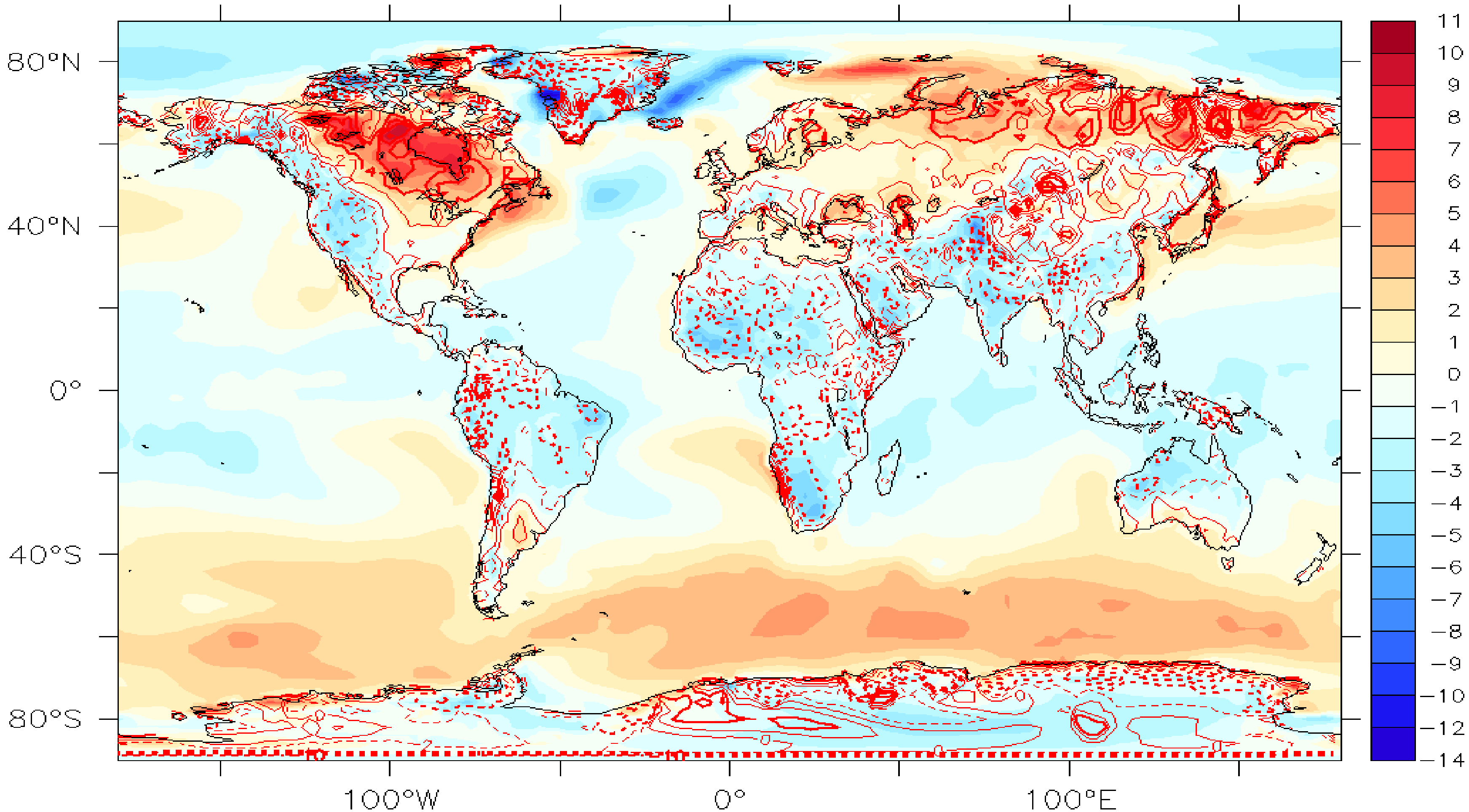
(Haiden et al, 2015, ECMWF, Tech.Memo 765)

Bias of 2 m temperature in DJF

EC-Earth climate model – ERA-Interim (Jan 1989-Jan 2009)



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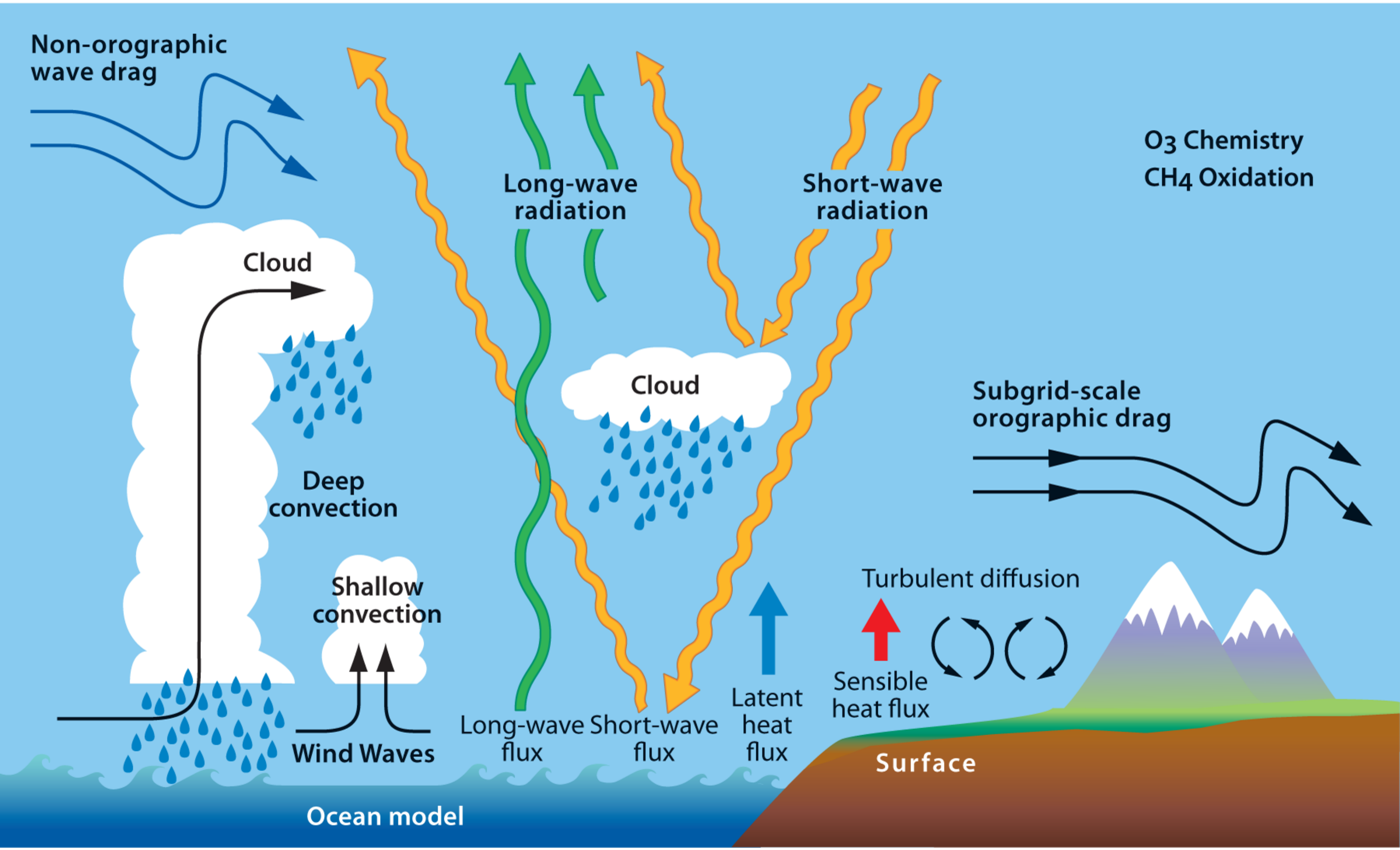
(Hazeleger et al., 2011)

Small-scale processes relevant for weather and climate



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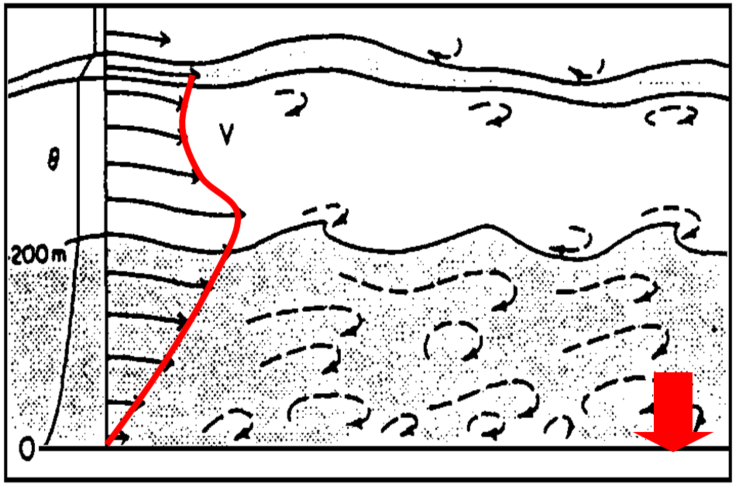
Courtesy ECMWF

Stable Atmospheric Boundary Layers



(Figure by
John Wyngaard, 1985)

Long history of research and applications

(e.g., Zilitinkevich, 1972; Brost and Wyngaard, 1978; Nieuwstadt, 1984,...)

Progress in understanding through observations, simulations and modelling, in particular for cases with stronger turbulence

Stable boundary layers with weak and intermittent turbulence still very challenging (e.g., vd Wiel et al., 2002; Mahrt, 2014,...)

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Understanding and Modeling Atmospheric Boundary Layers:

It is still a challenge!

Atmospheric models do have difficulties in representing the stable boundary layer in particular

Sensitivity to details in turbulence mixing formulations and interaction with other small scale processes

Strategy

GABLS

GEWEX Atmospheric Boundary Layer Study

Enhance understanding by benchmark studies over land and ice in comparison with observations and fine scale numerical model results

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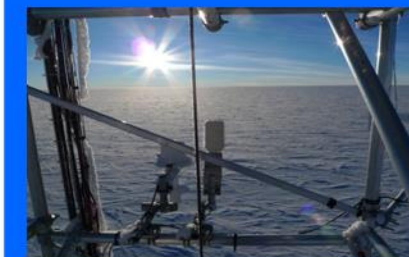
GEWEX Atmospheric Boundary Layer Study (GABLS) provides platform for model intercomparisons

GABLS1	GABLS2	GABLS3	GABLS4
			
LES as reference	Data (CASES99)	Data (CABAUW)	Data (DOME-C)
Academic set up	Idealized forcings	Realistic forcings	Realistic forcings
Prescribed T_s	Prescribed T_s	Full coupling *(SCM)* Prescribed T_s *(LES)*	Full coupling Prescribed T_s
No Radiation	No Radiation	Radiation included	Radiation included
Turbulent mixing	Diurnal cycle	Low levet jet + transitions	Very Stable

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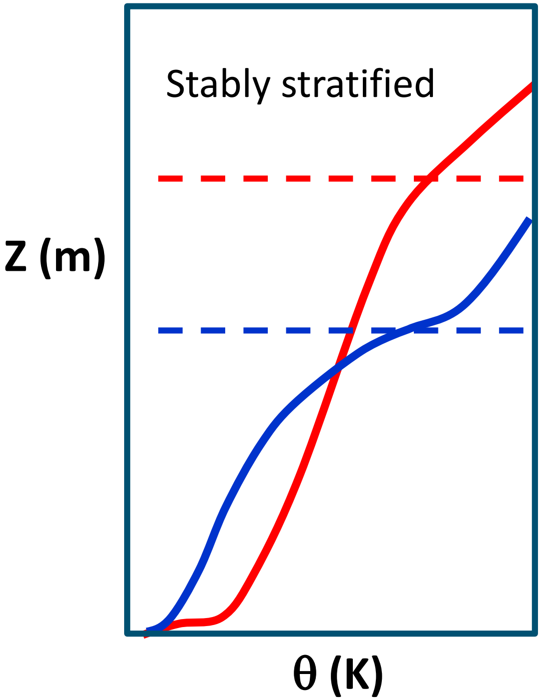
LES: Large Eddy Simulation; *SCM:* Single Column Model

GABLS1
NWP models show too strong night-time mixing

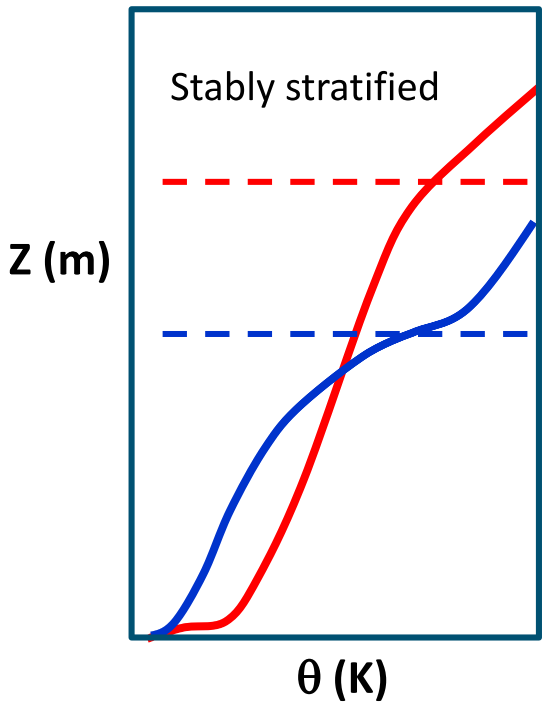


NWP models
(boundary layer up to factor 2 too deep!)

LES
Research models
(boundary layer height order 180 m)

(Beare et al. 2006; Cuxart et al. 2006; Svensson and Holtslag, 2009)

GABLS1
NWP models show too strong night-time mixing



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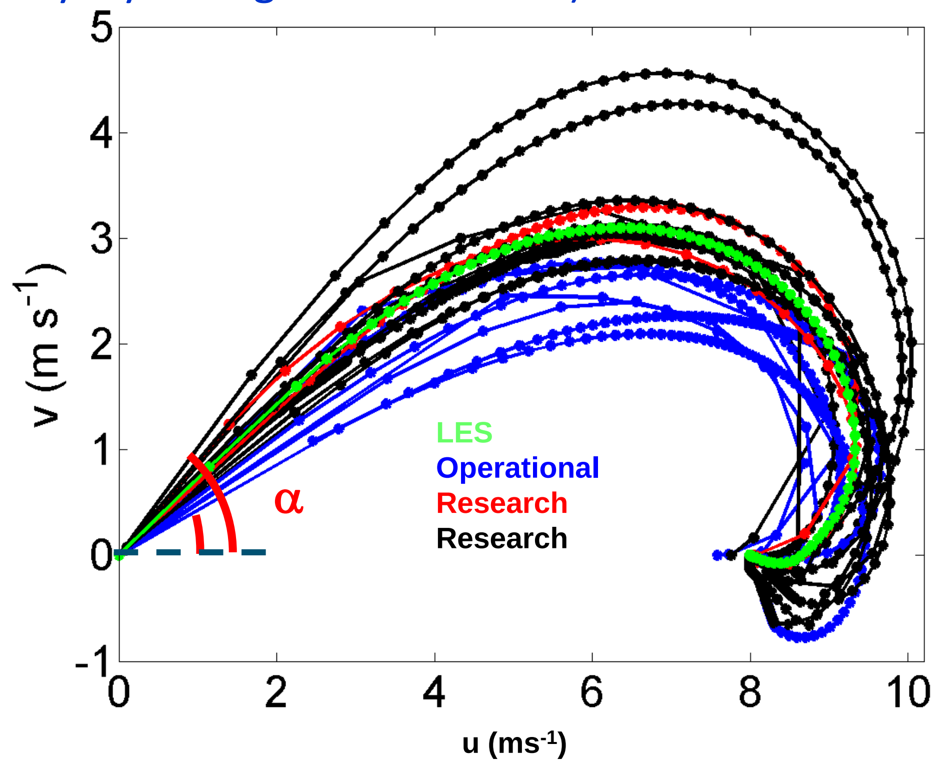

Too small variation of wind direction with height in operational NWP models

(Beare et al. 2006; Cuxart et al. 2006; Svensson and Holtslag, 2009)

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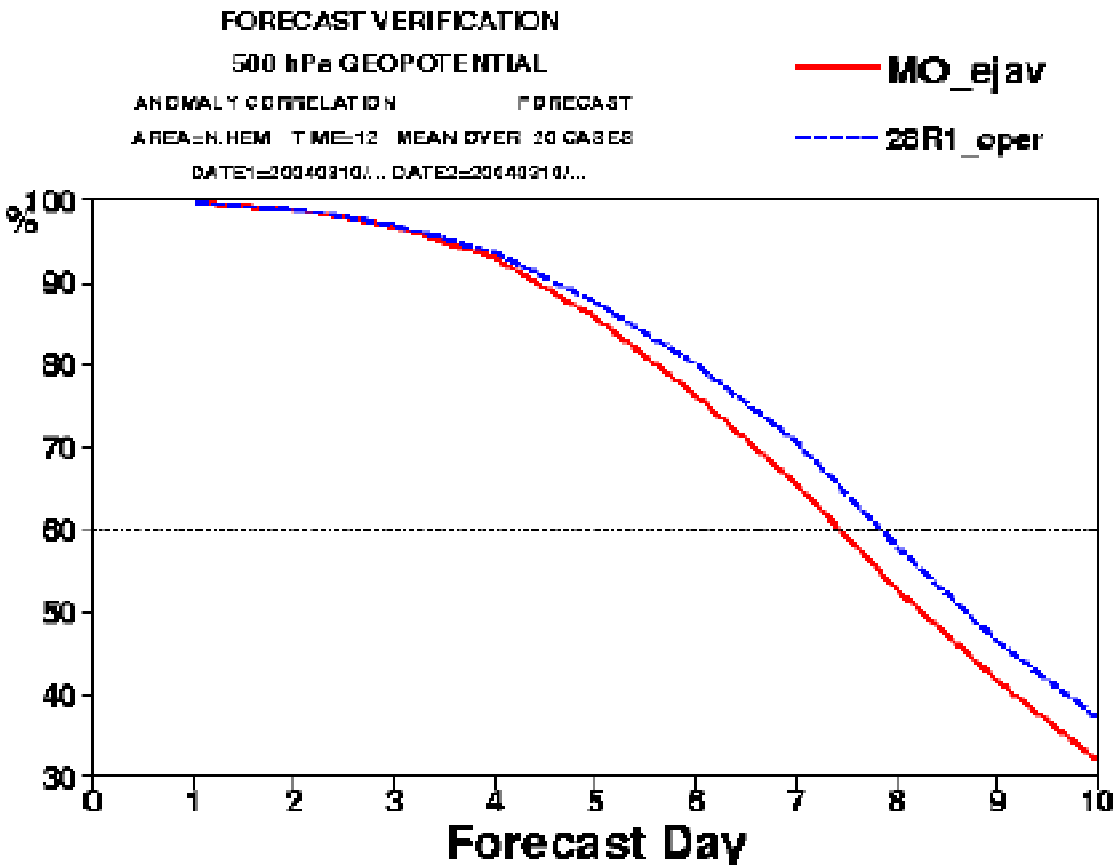
Stable boundary layer diffusion affects large scale scores



Effect of MO-stability functions (reduced diffusion) instead of operational formulation, on 500hPa NH height scores

Model somehow needs larger drag over land than can be obtained from schemes that produce reasonable stable boundary layer structure.

Ground truth for drag over land does not exist.

Courtesy
Anton Beljaars

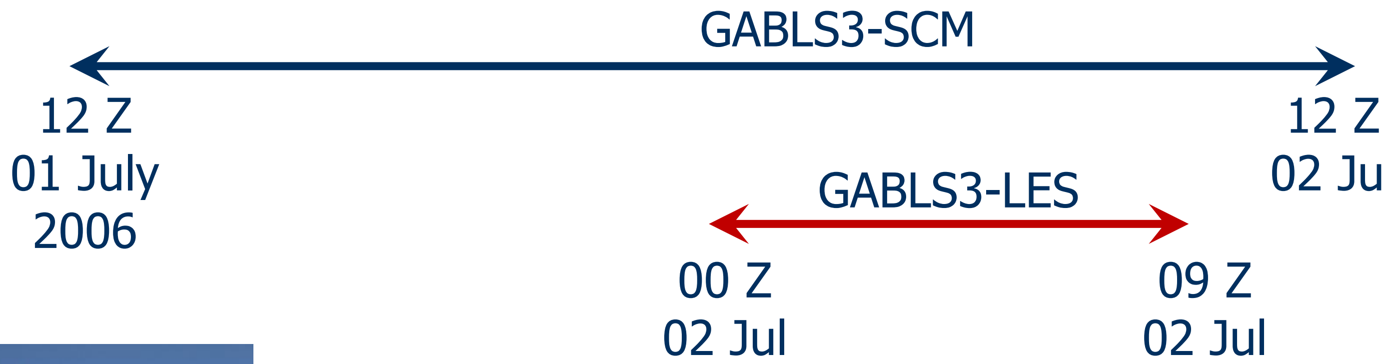
ECMWF

Can small-scale orographic gravity waves provide the missing drag in the stable boundary layer?

Aristofanis Tsiringakis, Gert-Jan Steeneveld, and Bert Holtslag
Meteorology and Air Quality
Wageningen University, NL

See paper in QJRMS, 2017

GABLS3: SCM and LES model studies



Cabauw tower
(KNMI, NL)

Initialization: Cabauw tower, Profiler, Nearby De Bilt Sounding

Geostrophic Wind (time-height dependent)

Large-scale Advection (time-height dependent)

LES: Prescribed Observed Near Surface Temperature (0.5 m)

SCM: Full interaction with Land Scheme and Radiation

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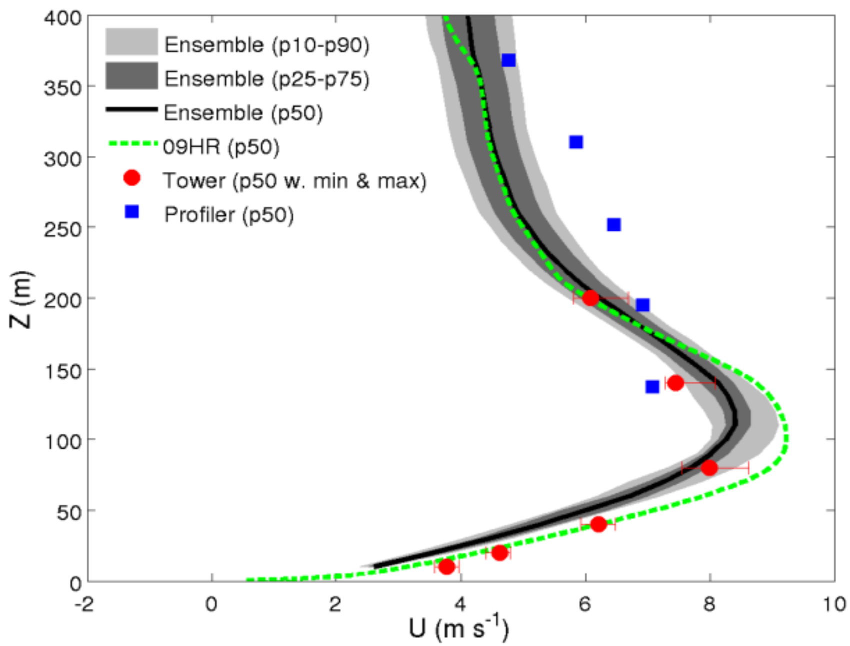
(Bosveld et al., 2014)

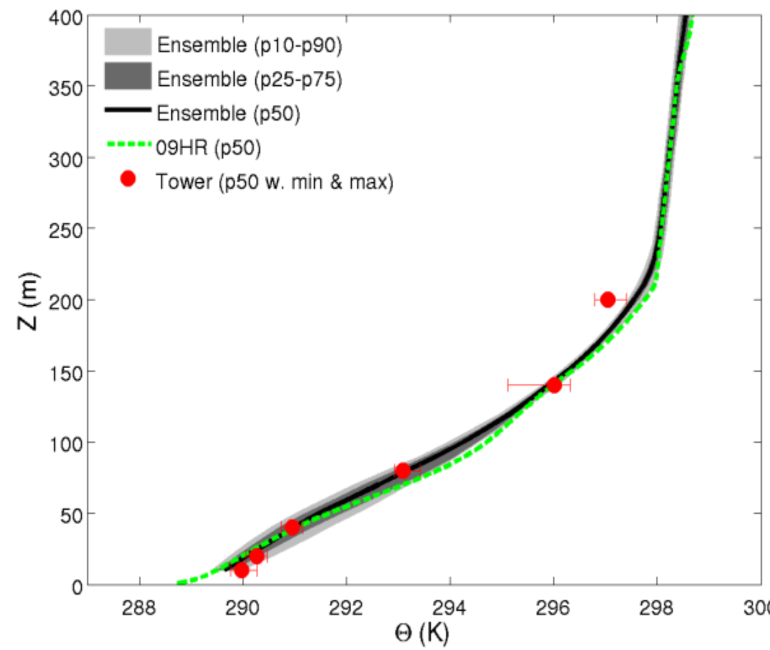
GABLS3 Large Eddy Simulation intercomparison

(coordinated by Sukanta Basu)

Wind magnitude (m/s)



Potential Temp (K)



Ensemble of 11 LES models for mean profiles 03-04 UTC (6.25 m resolution)
Green dashed line: 1m vertical resolution LES run (Courtesy Siegfried Raasch)
Red dots: Tower observations; Blue squares: Wind Profiler

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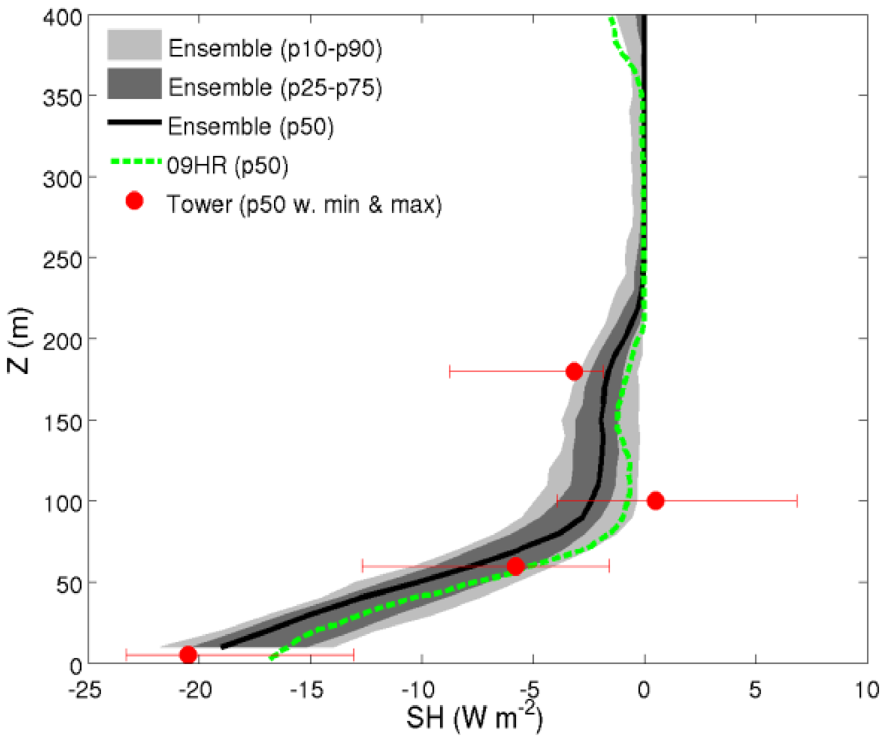
(Holtslag et al., 2013)

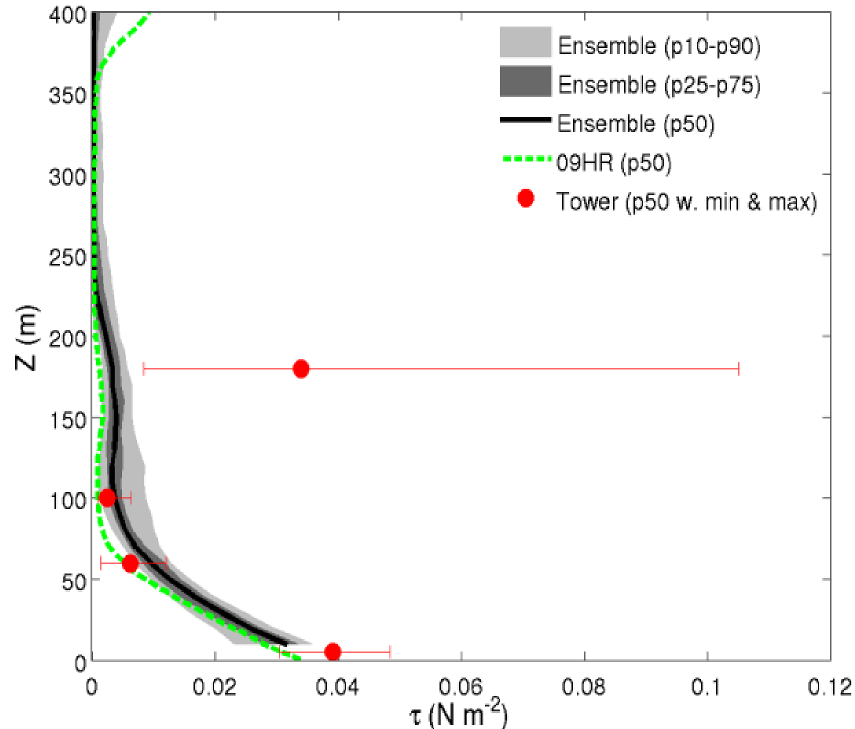
GABLS3 Large Eddy Simulation intercomparison

(coordinated by Sukanta Basu)

Sensible Heat flux (W/m2)



Momentum flux (N/m2)



Flux profiles 03-04 UTC

Green dashed line: 1m LES run (Courtesy Siegfried Raasch)

Red dots: Cabauw Tower observations

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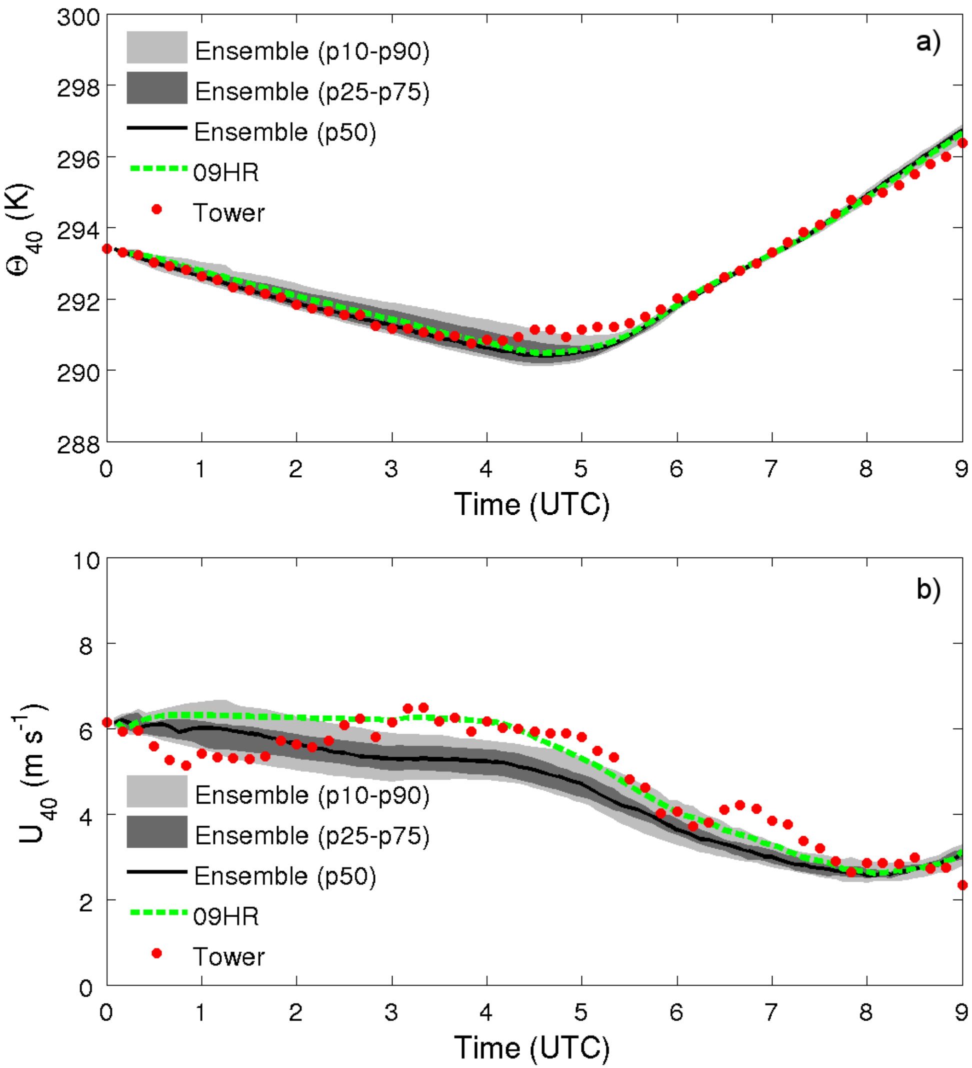
(Holtslag et al., 2013)

GABLS3 Large Eddy Simulation intercomparison



Temporal evolution

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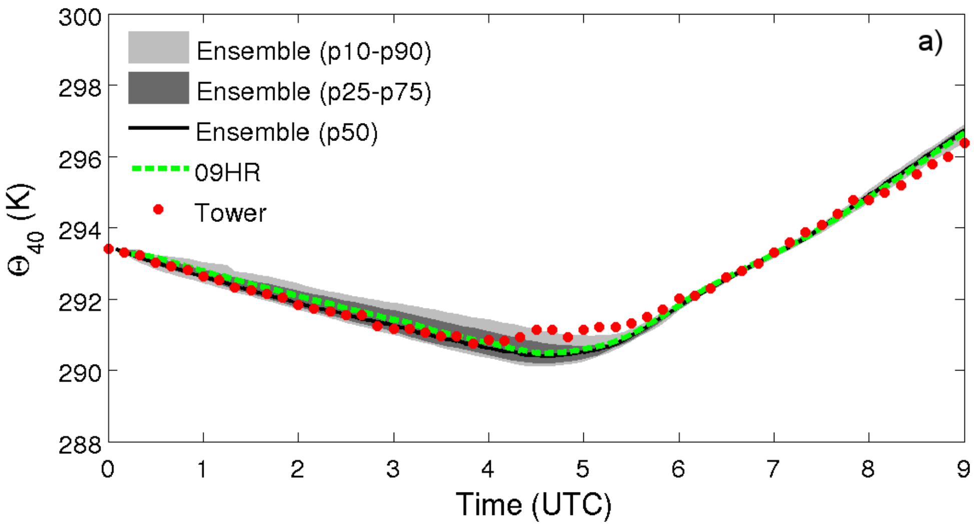
(Holtslag et al., 2013)

GABLS3 Large Eddy Simulation intercomparison



Temporal evolution

Overall LES results in good agreement with Cabauw mean and turbulent flux profiles

(using observed near surface temperatures)

But there are issues...

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(Holtslag et al., 2013)

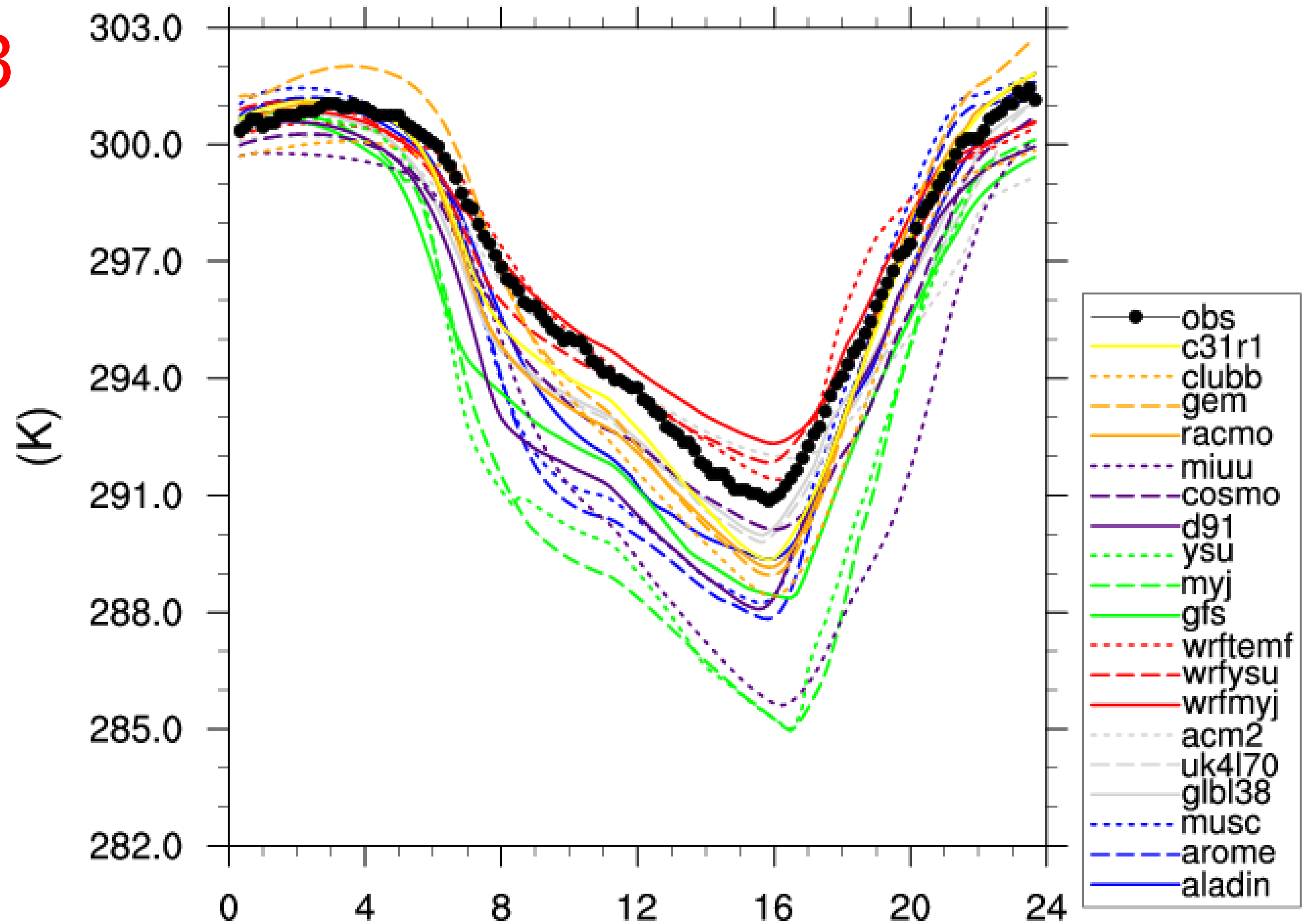
GABLS3 intercomparison of 19 Single Column versions (SCM) of operational and research models (Coordinated by Fred Bosveld, KNMI)

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

Models show large range of results for 2 m temperature

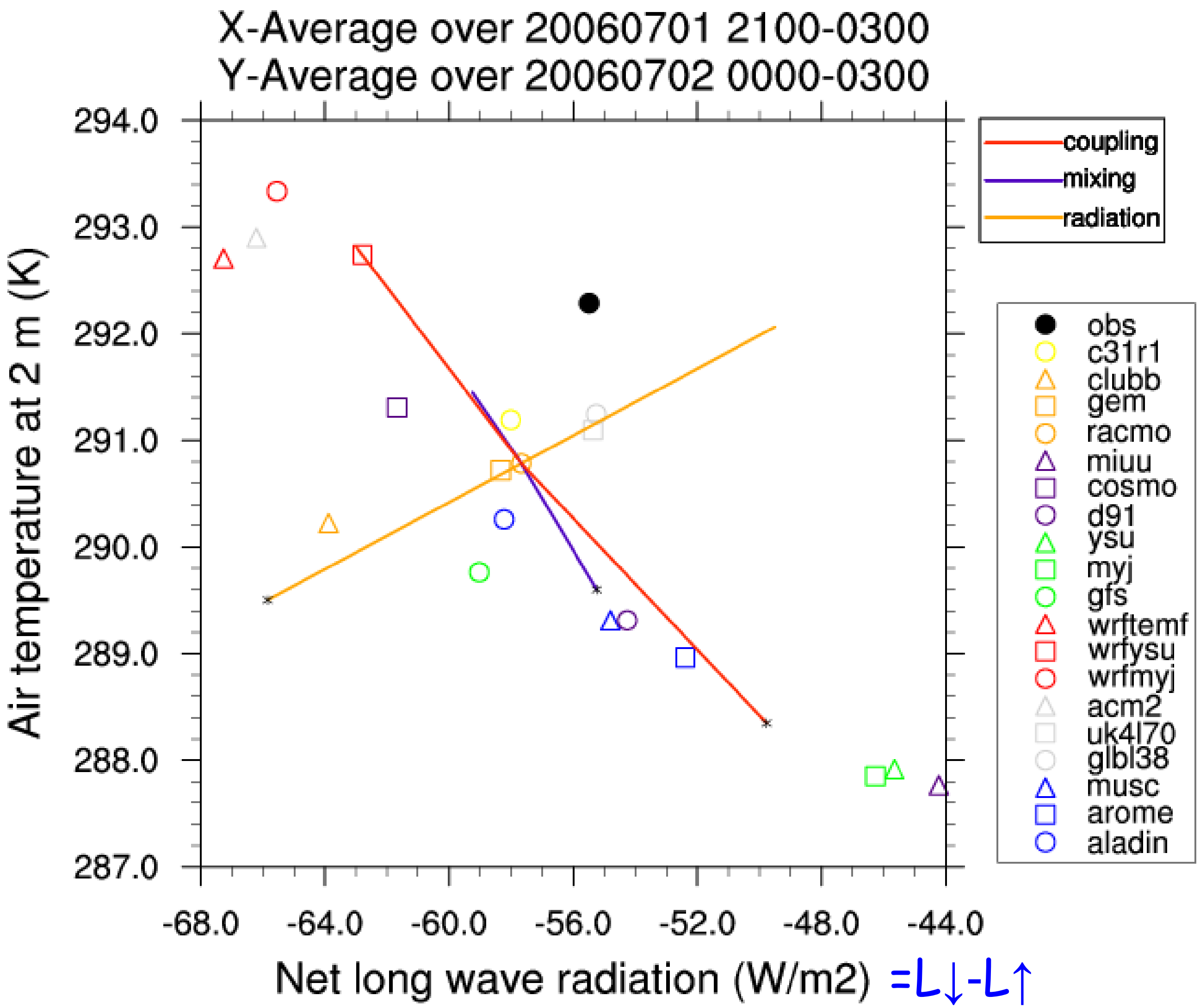
GABLS3



noon midnight noon

(Bosveld et al., 2014)

Process diagram: Influence of surface radiation



=L↓-L↑

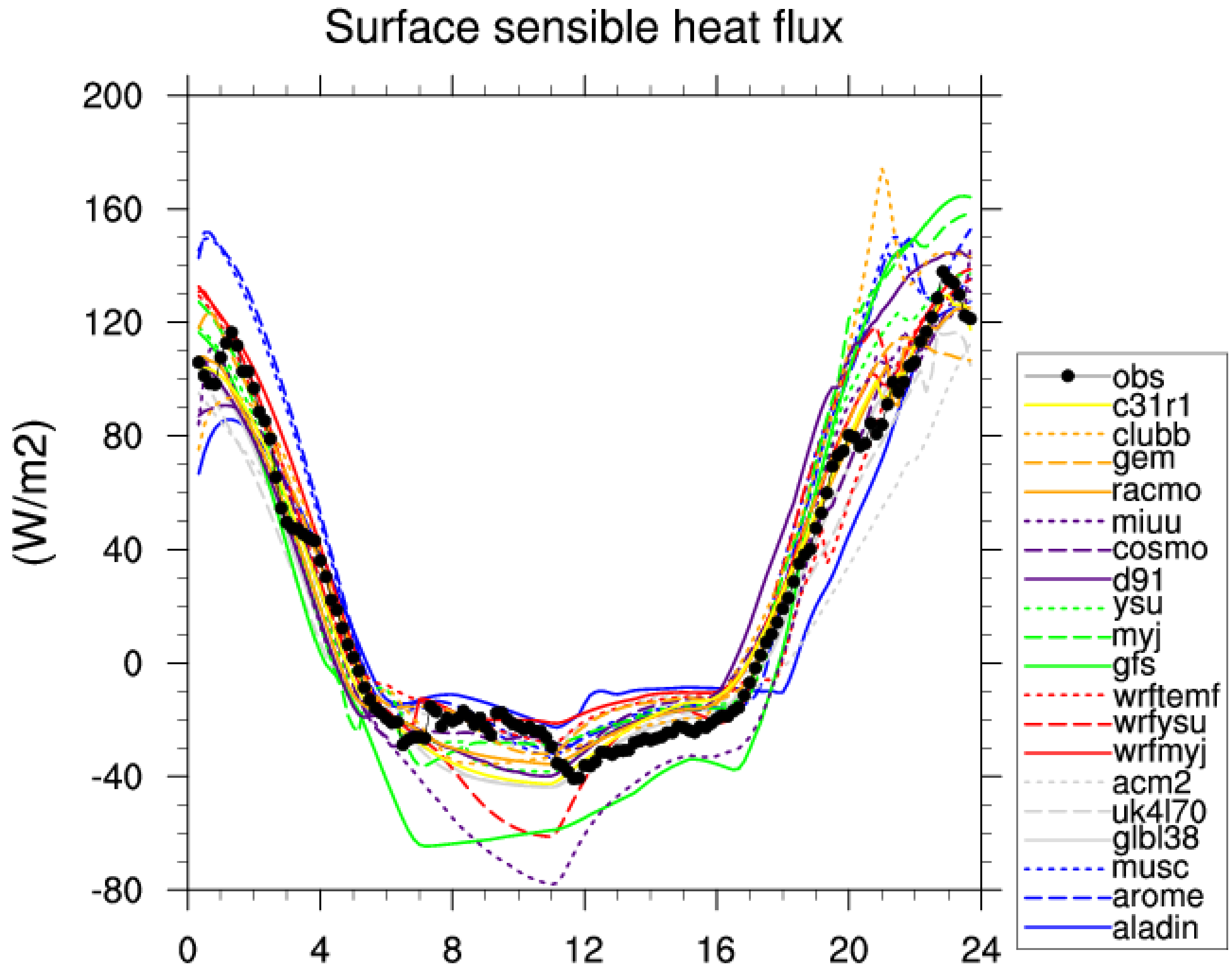
Note:
L↑ is strong function of surface temperature

Warmer surface

Colder Surface

(Bosveld et al, 2014)

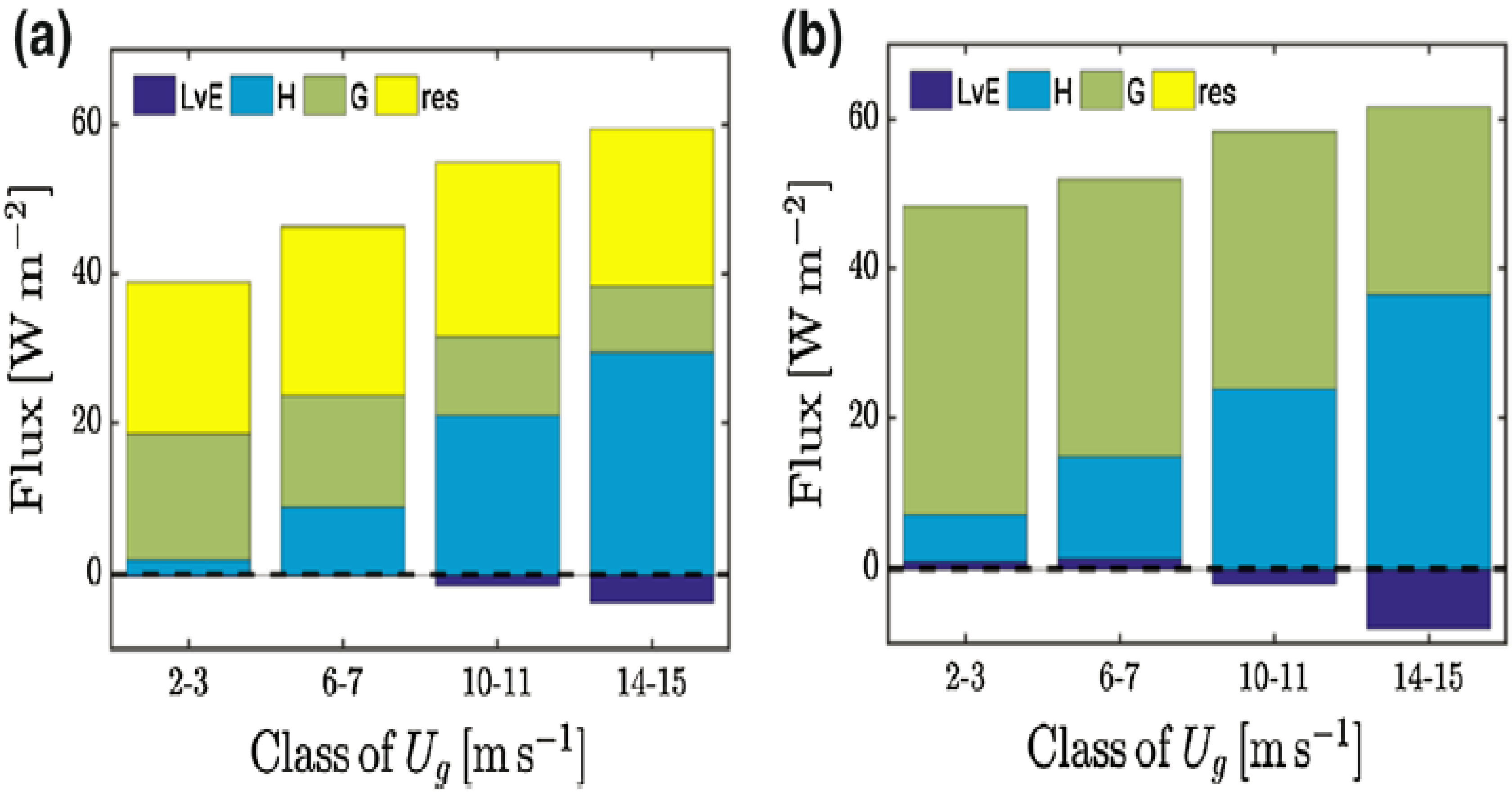
GABLS3



noon midnight noon

(Bosveld et al., 2014)

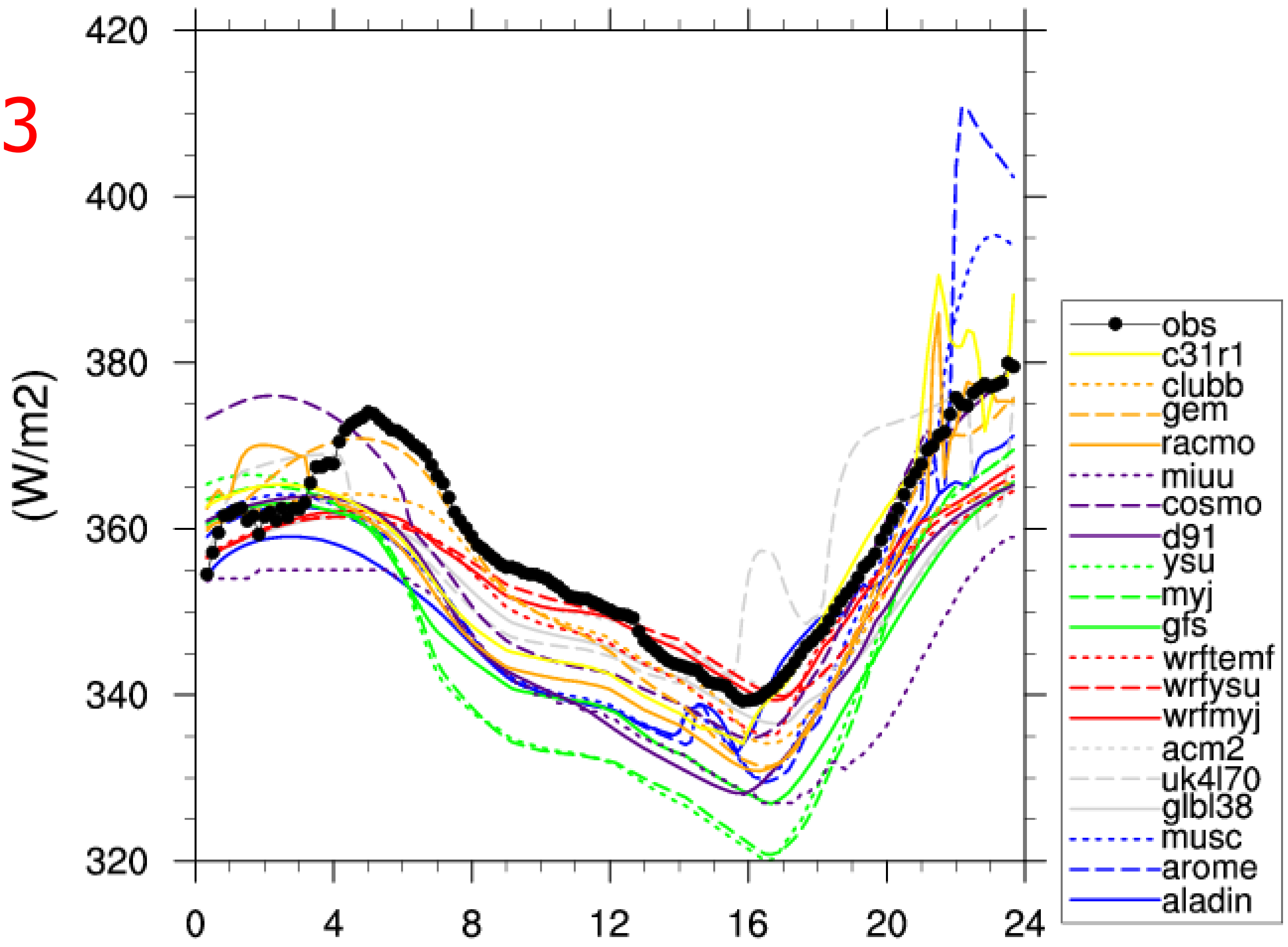
Observed (a) and modelled (b) components of the surface energy balance for four classes of geostrophic wind speed Ug using 11 years (2005–2015) of daily SCM simulations vs Cabauw observations (for Qnet < -30 W/m2). *The residual term is indicated by 'res' (after Baas et al., BLM, 2018)*



Models underestimate downward longwave radiation at surface

(positive feedback with temperature)

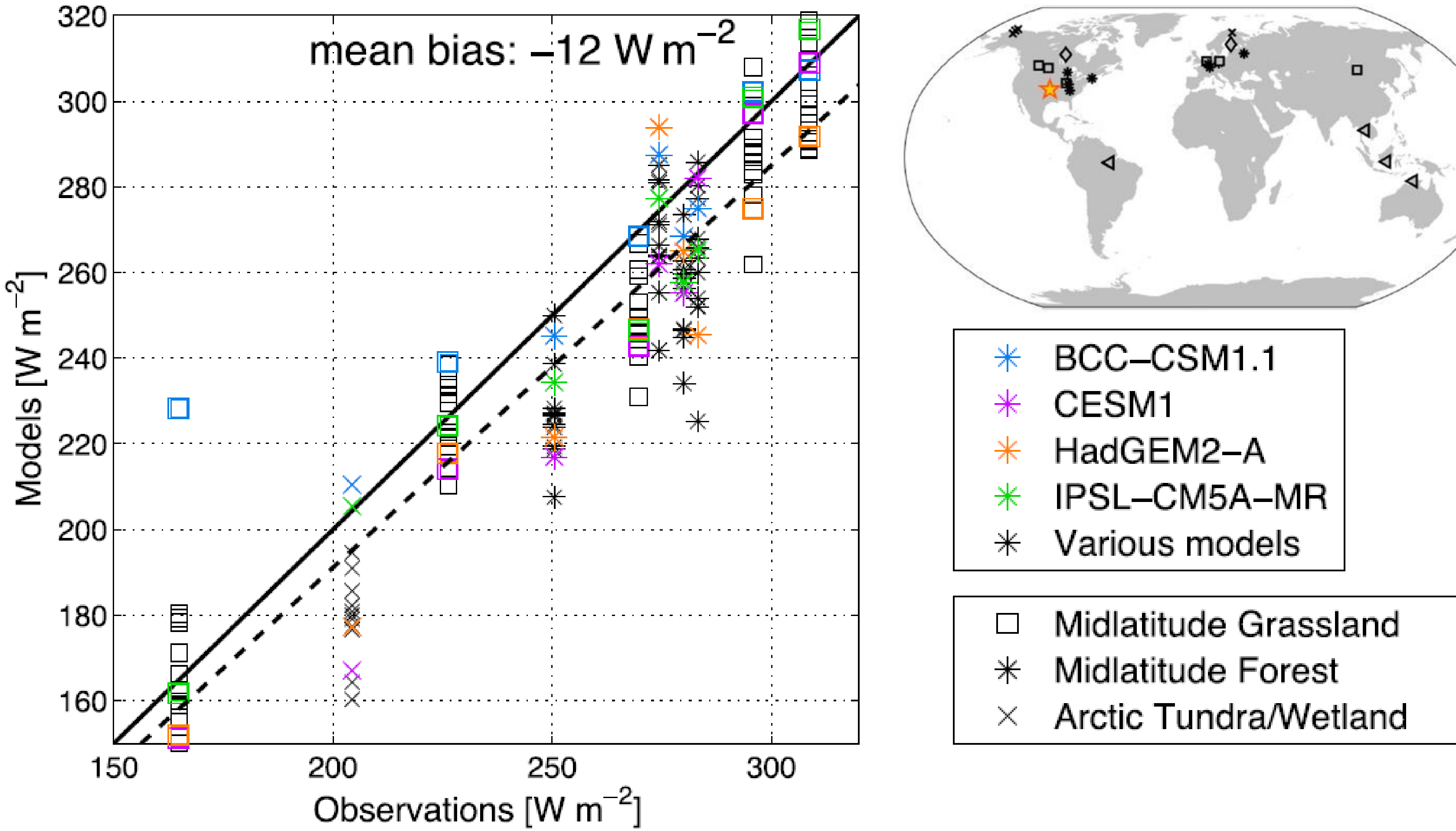
GABLS3



noon midnight noon

(Bosveld et al., 2014)

Downward longwave radiation typically underestimated by climate models on various locations (10 year averages)



(Svensson and Lindvall, 2015)

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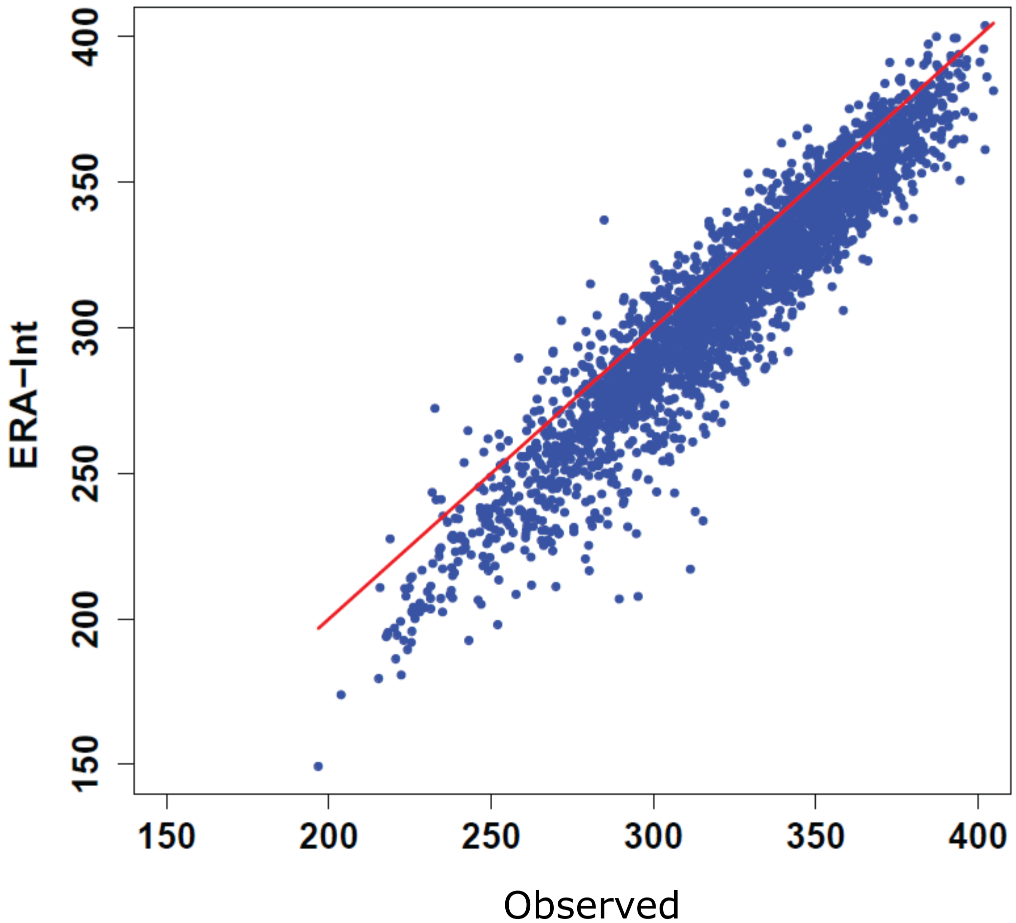
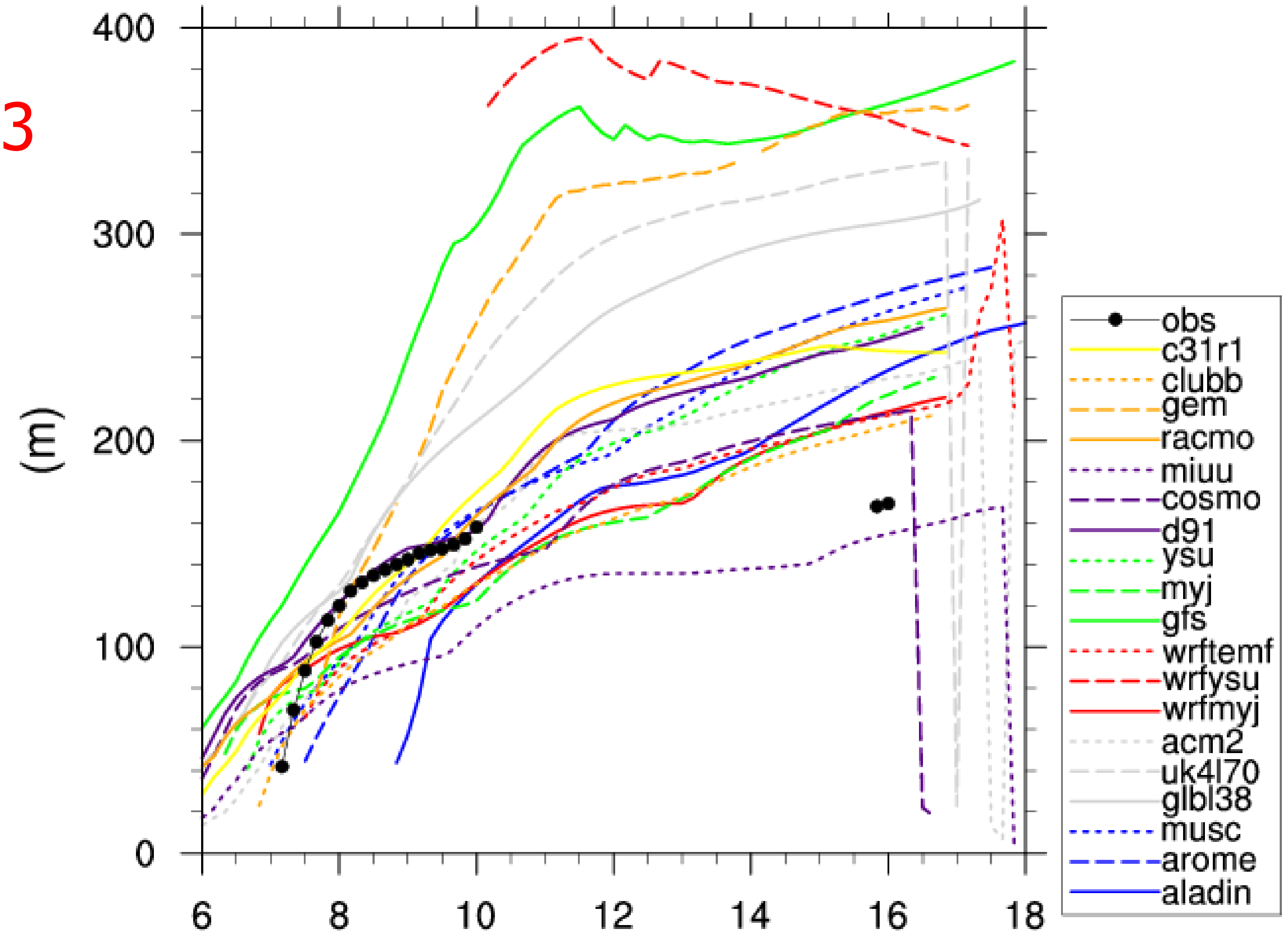
Average values of incoming long-wave radiation measured in Wageningen versus ERA-Interim (period 2001-2012)



Courtesy Hartogensis and Anton Beljaars (De Bruin, 2016)

Models show typically too deep boundary layers

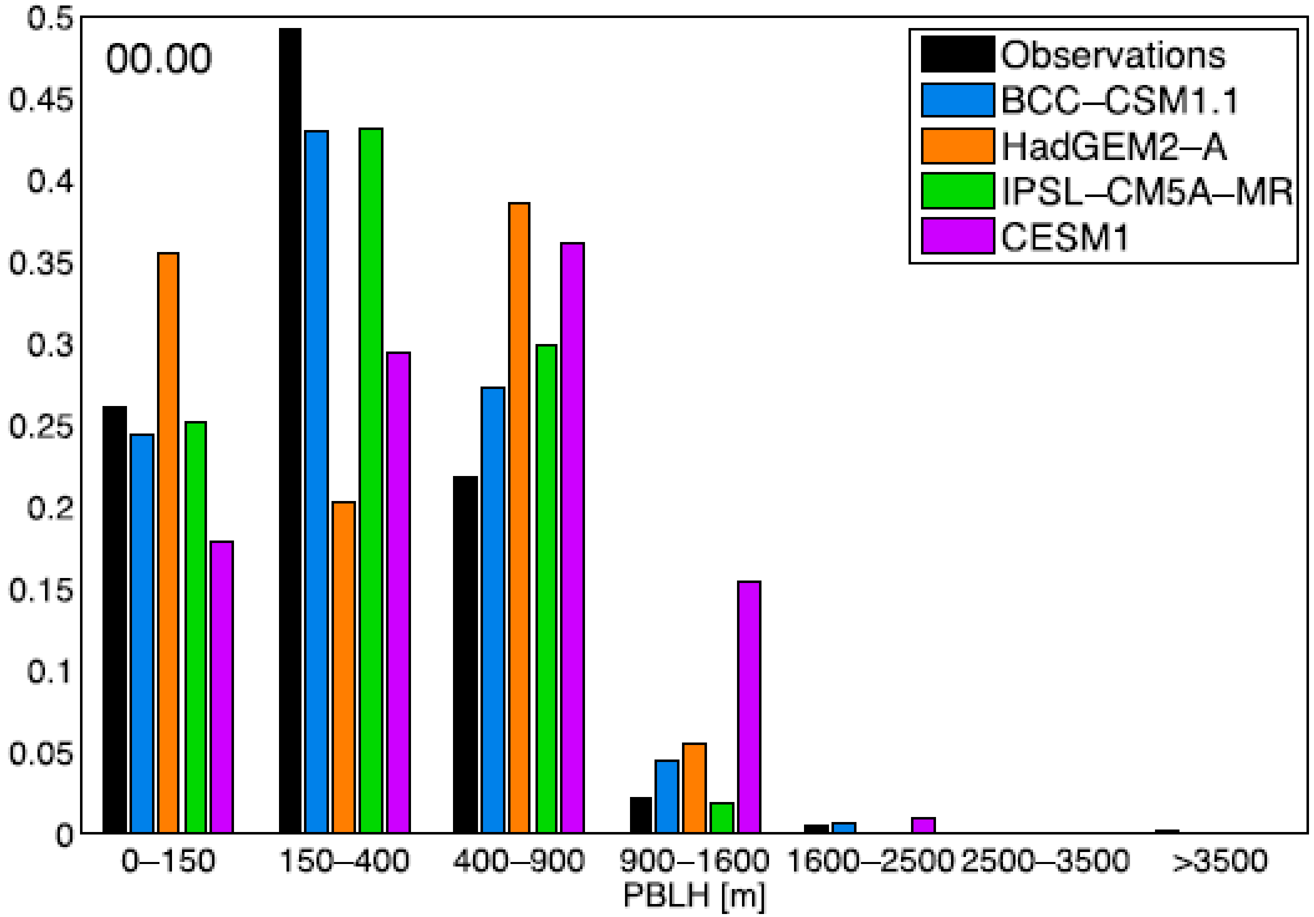
GABLS3



evening midnight morning

(Bosveld et al, 2014)

Also deeper stable boundary layer depths in climate models (10 year averages for ARM Southern Great Plains site, USA)



(Svensson and Lindvall, 2015)

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Why so difficult to represent stable boundary layers?

Many small scale processes and non-linear interactions not fully understood

Realistic turbulence schemes improve the representation of low-level jet, wind turning, pbl depth, diurnal cycle...

But, result in negative impact on larger scale model performance (e.g., filling of cyclones)

Connection to land-atmosphere coupling, sloping terrain, (small-scale) orographic wave drag, et cetera

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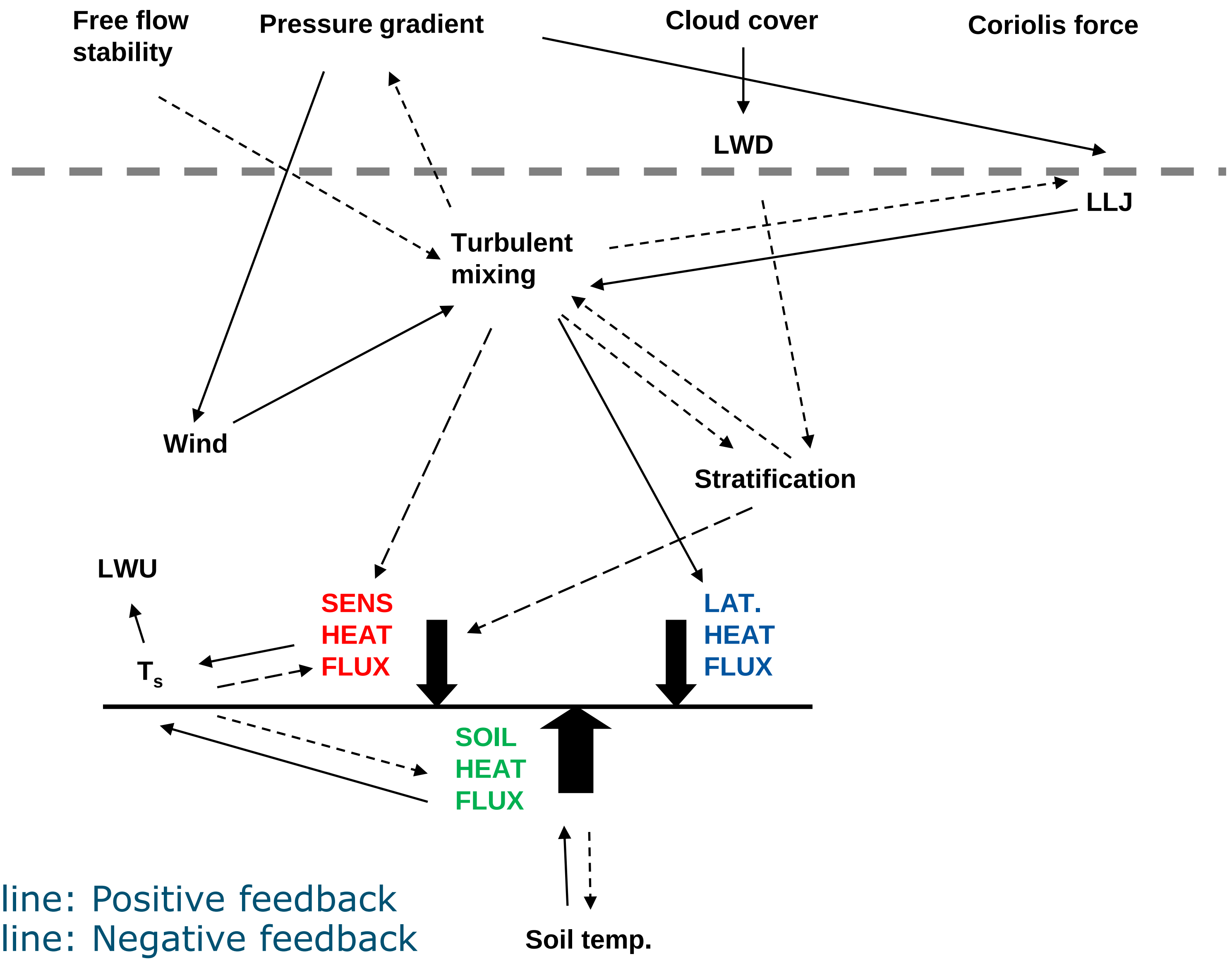
(Louis, 1979; Mahrt, 1987; Steeneveld et al., 2008; Sandu et al., 2013; Holtslag et al., 2013 among others)

Stable Atmospheric Boundary Layer Processes and Feedbacks



Full line: Positive feedback
Dashed line: Negative feedback

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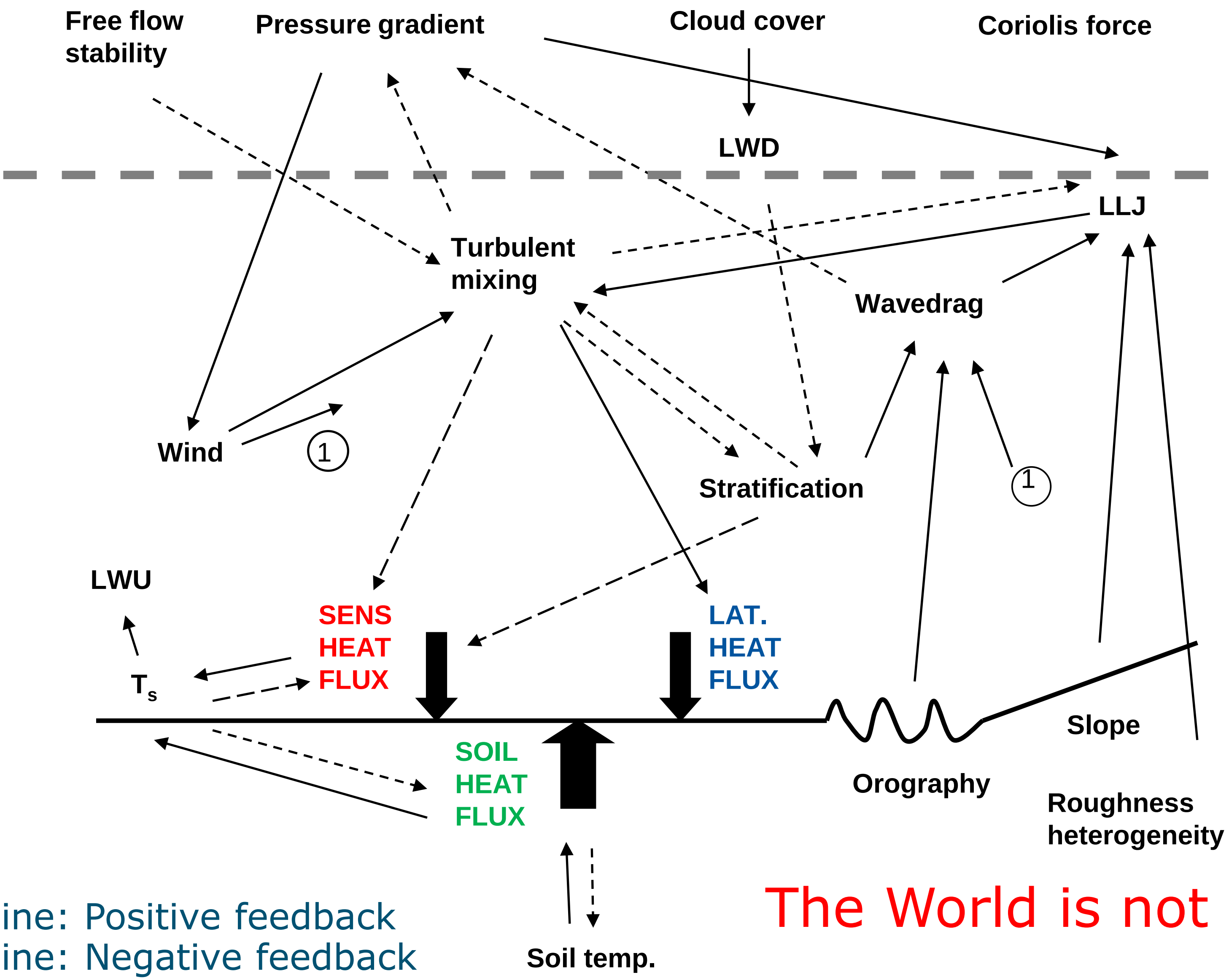
(after Steeneveld, 2014)

Stable Atmospheric Boundary Layer Processes and Feedbacks



Full line: Positive feedback
Dashed line: Negative feedback

The World is not Flat

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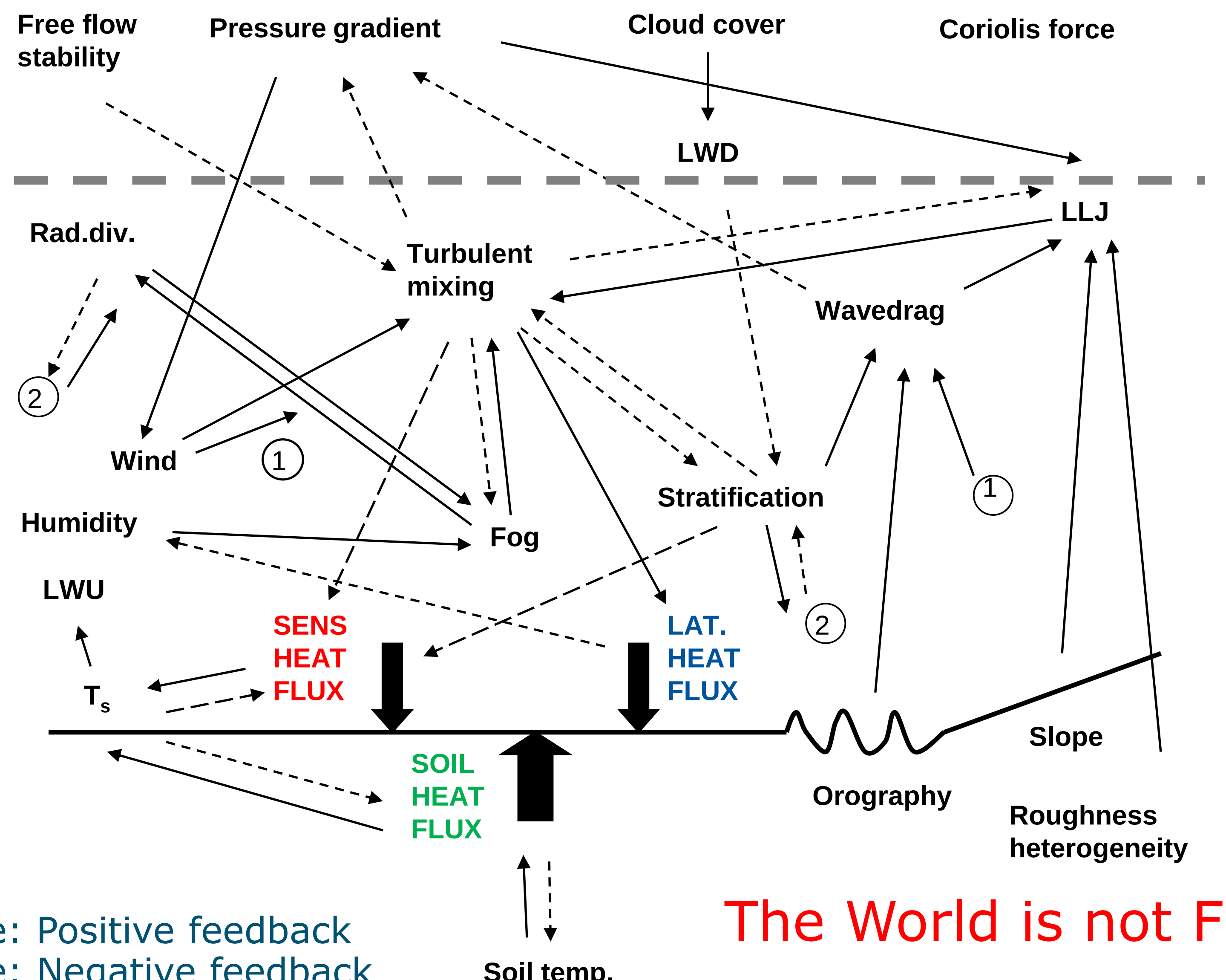
(after Steeneveld, 2014)

Stable Atmospheric Boundary Layer Processes and Feedbacks



The World is not Flat

Full line: Positive feedback
Dashed line: Negative feedback

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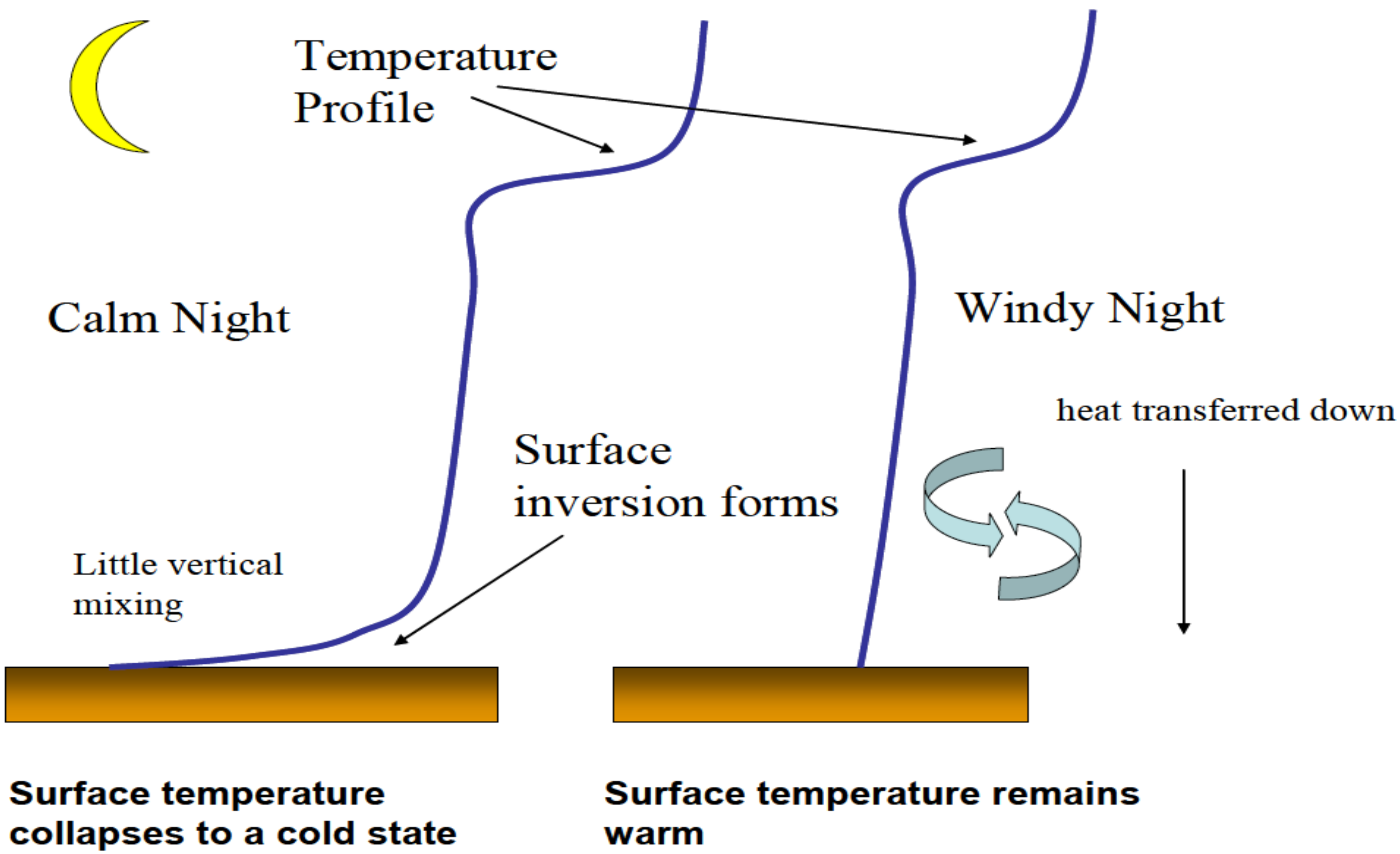
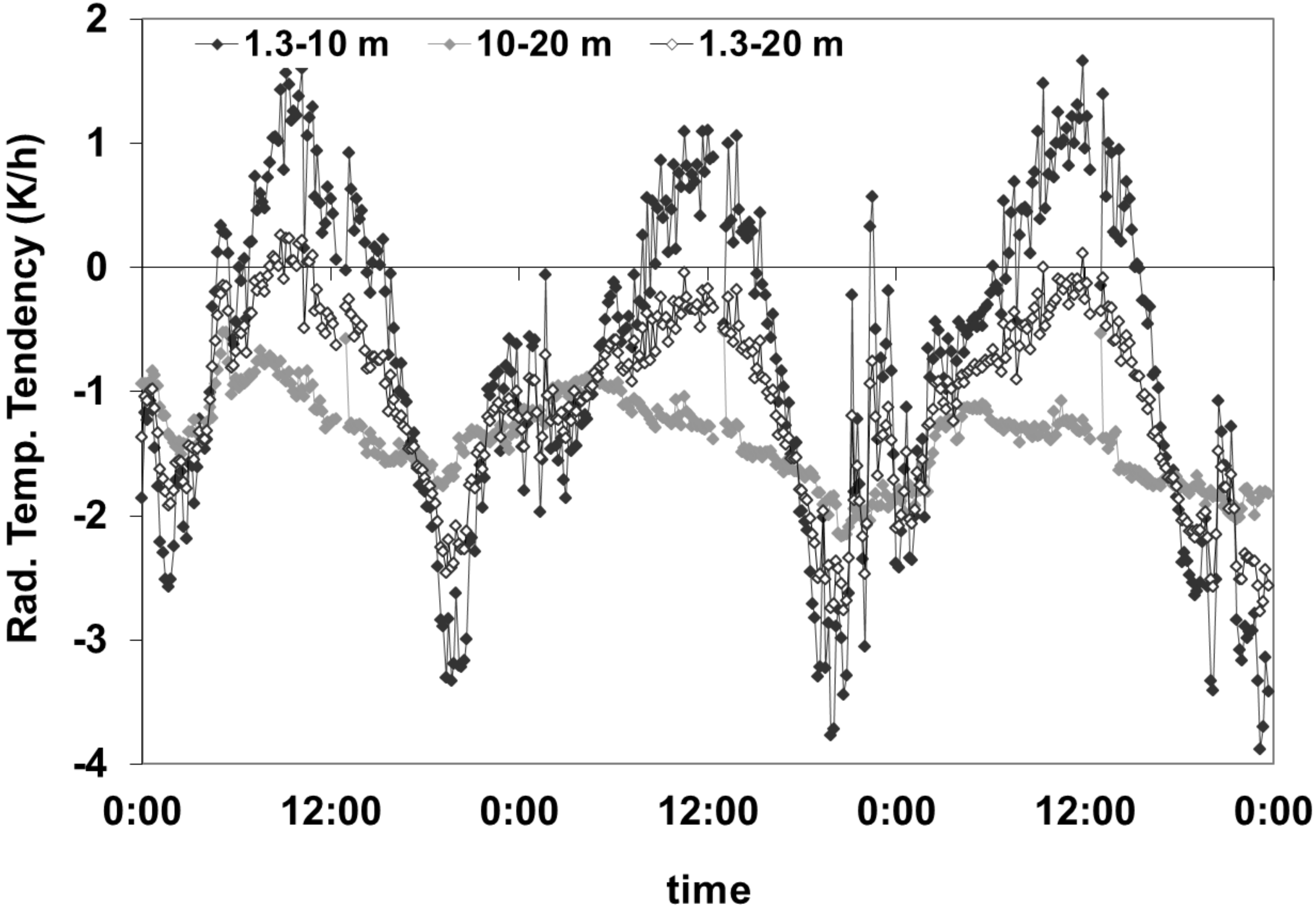
(after Steeneveld, 2014)

Contrast between the temperature profiles in calm and windy nights under clear skies (adapted from McNider et al, 2010)



Near surface longwave heating rates

(Three clear calm days, June 2006, Wageningen, NL)



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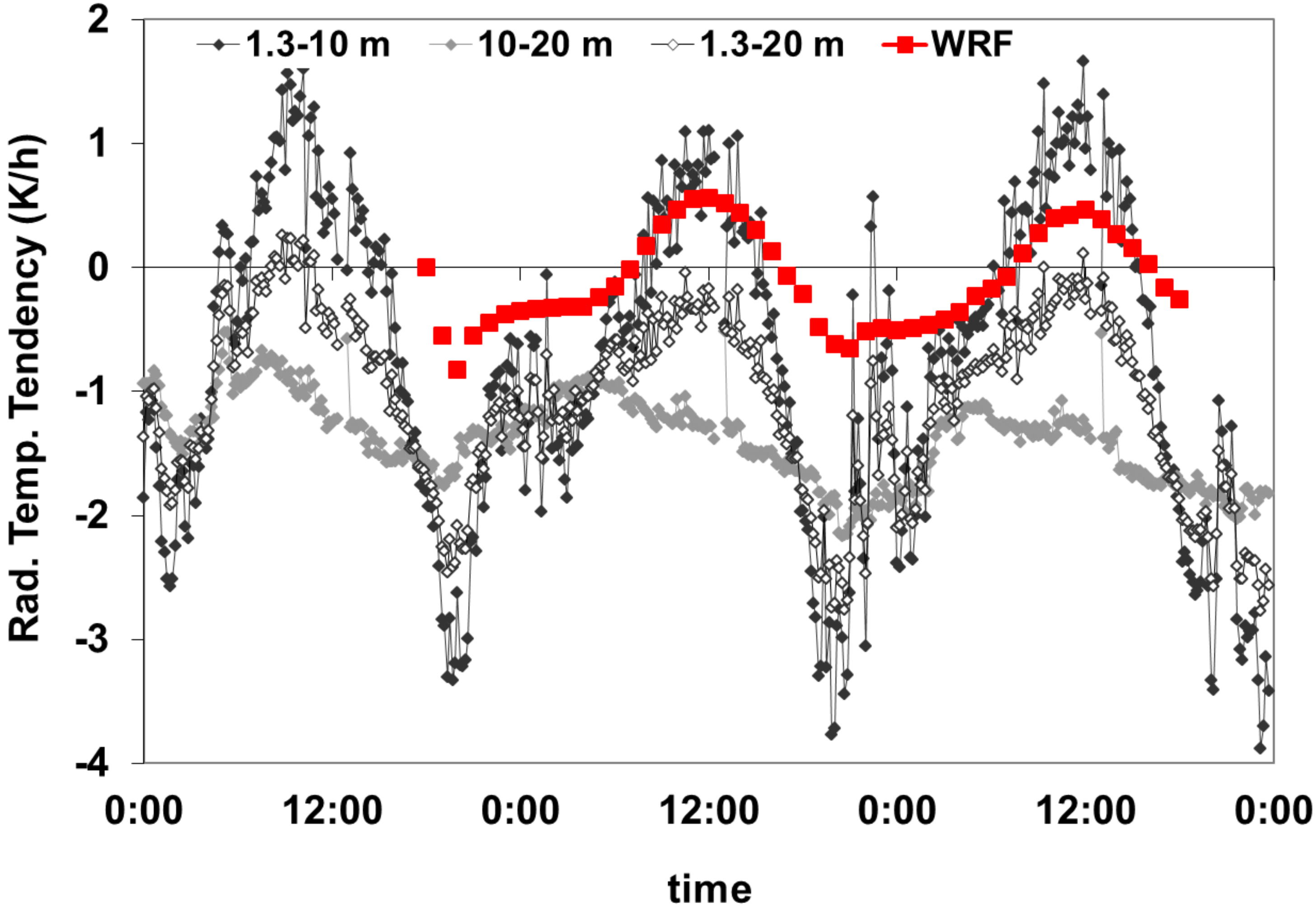
(Steeneveld et al., 2011; Gentine et al., 2018)

Near surface longwave heating rates:

Typically underestimated in models (like in WRF, here at ~10 m)



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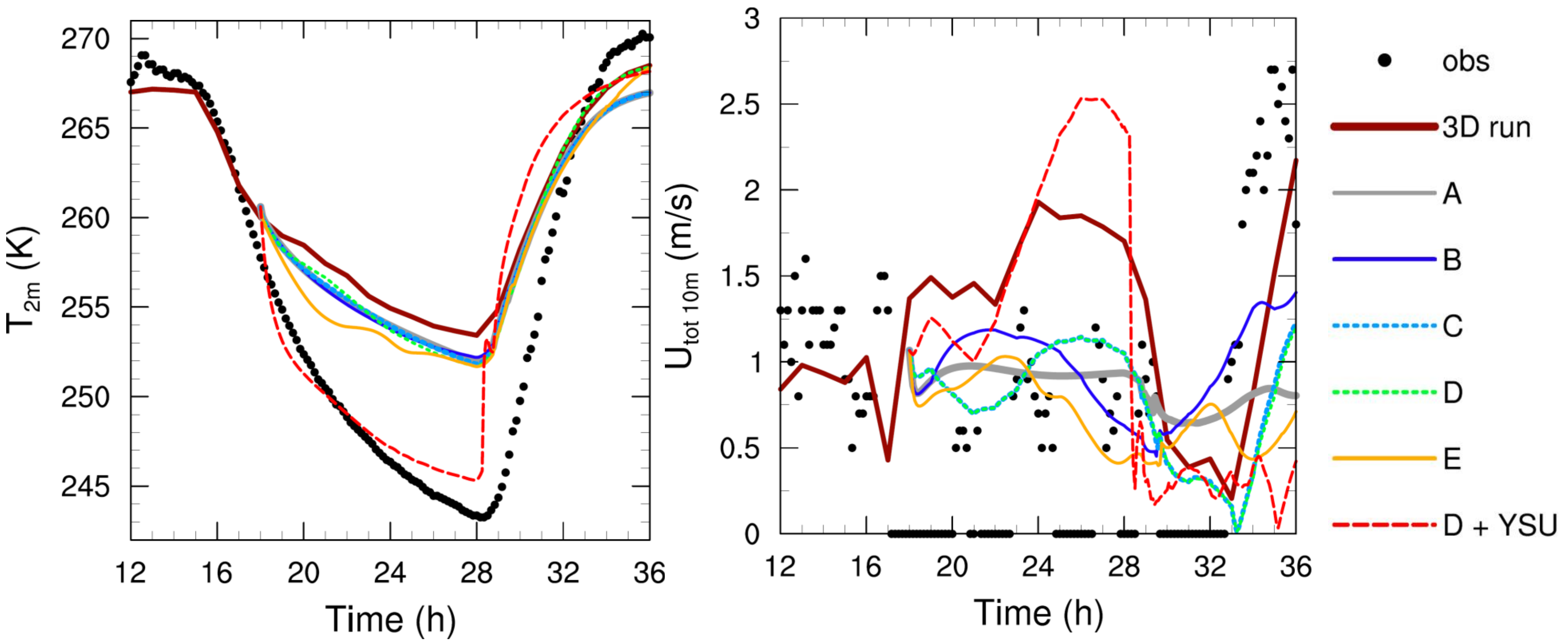
(Steeneveld et al., 2011; Gentine et al., 2018)

Modelling stable boundary layers over snow and ice are still very challenging as well!



Example for Södankyla (Finland) for various WRF single column model set ups in comparison with obs and 3D

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(Sterk et al, 2015)

Stable Boundary Layers: Still a challenge!

We know a lot already, but still need to better understand the many small scale processes and their non-linear interactions

Develop and test parameterizations for the very stable boundary layer when turbulence is not the dominant driver

Need for further model benchmark studies over land, sea, and ice under various atmospheric conditions
(including radiation, advection,
surface heterogeneity and coupling, fog,...)

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(Holtslag et al., 2013)

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Stable boundary layers, more than turbulence

© Vincent van Gogh

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