Stable Boundary Layers

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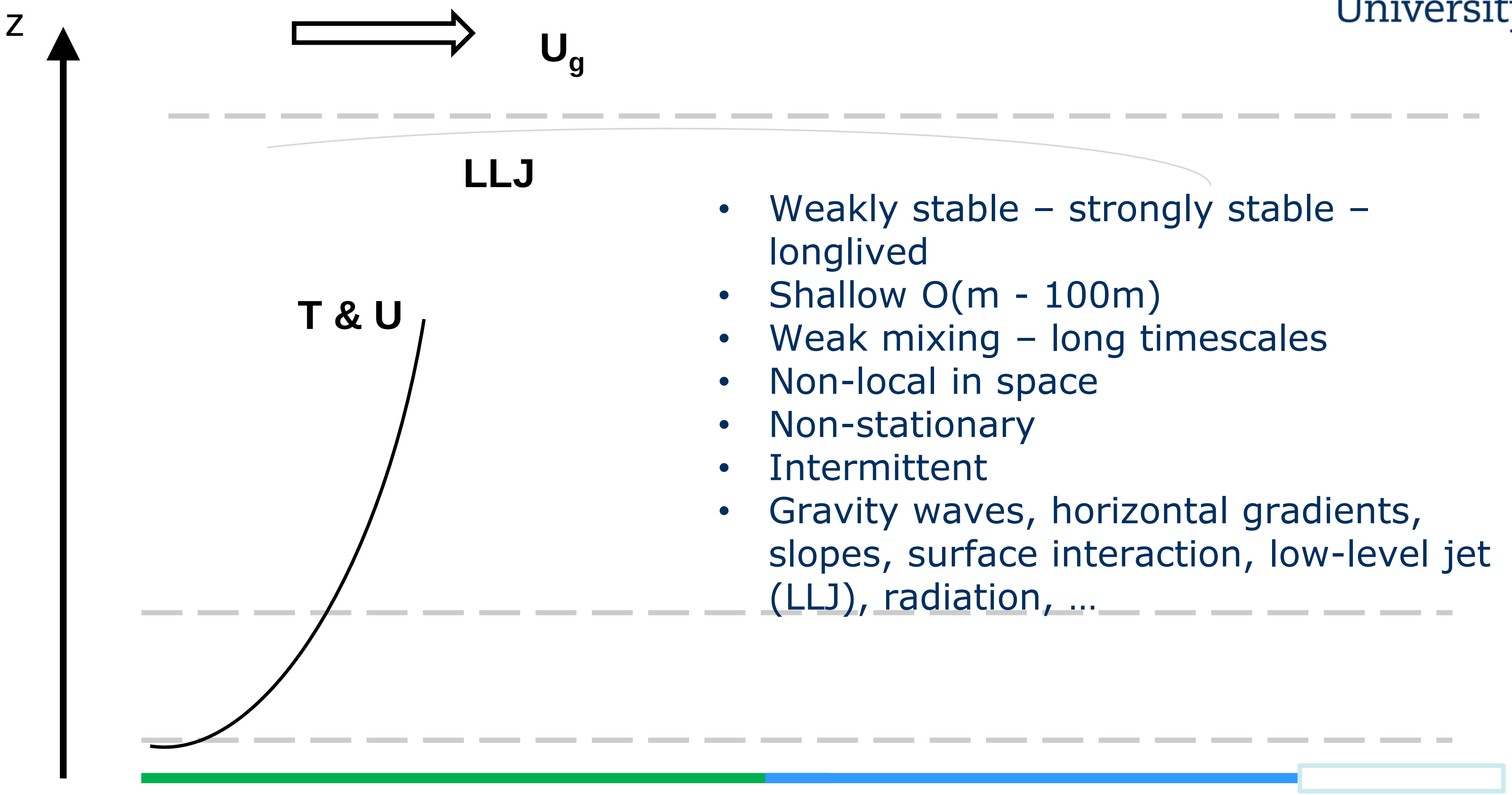
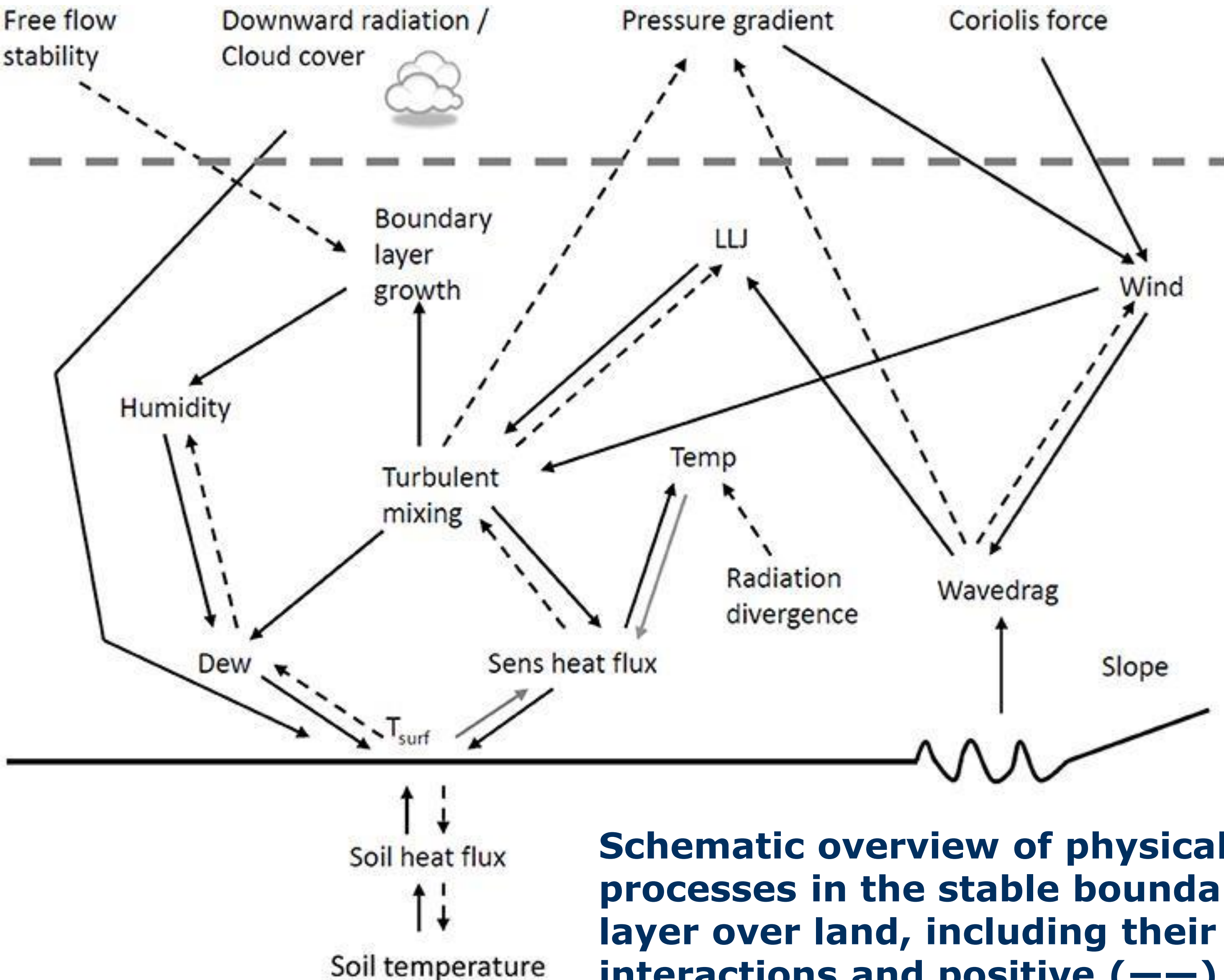
SBL over land and water & ice



- Weakly stable – strongly stable – longlived
- Shallow O(m - 100m)
- Weak mixing – long timescales
- Non-local in space
- Non-stationary
- Intermittent
- Gravity waves, horizontal gradients, slopes, surface interaction, low-level jet (LLJ), radiation, …

SBL



Schematic overview of physical processes in the stable boundary layer over land, including their interactions and positive (——) and negative feedbacks (-----)
(Steeneveld, 2015)

SBL in models

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$$\overline{w'c'} = -K\frac{\partial C}{\partial z}$$

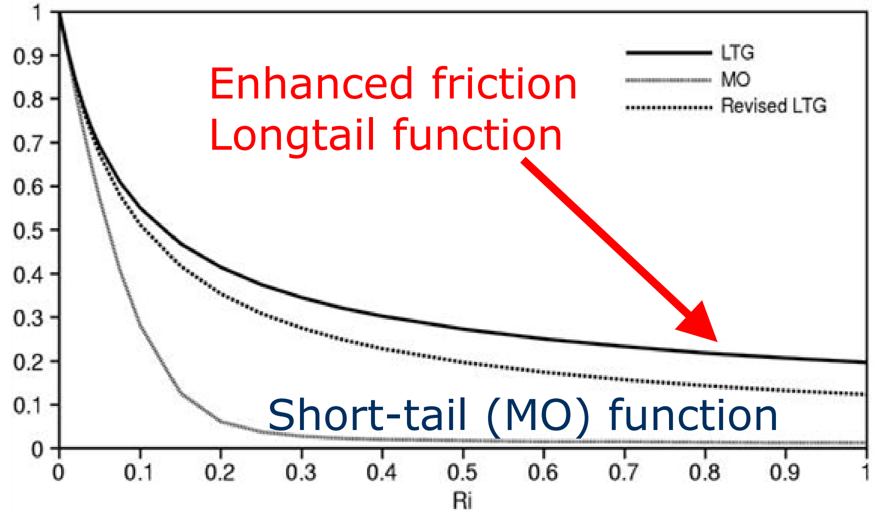
$$K = \left|\frac{\partial U}{\partial z}\right| l^2 F_{m,h}(Ri)$$

$$l : length\ scale$$

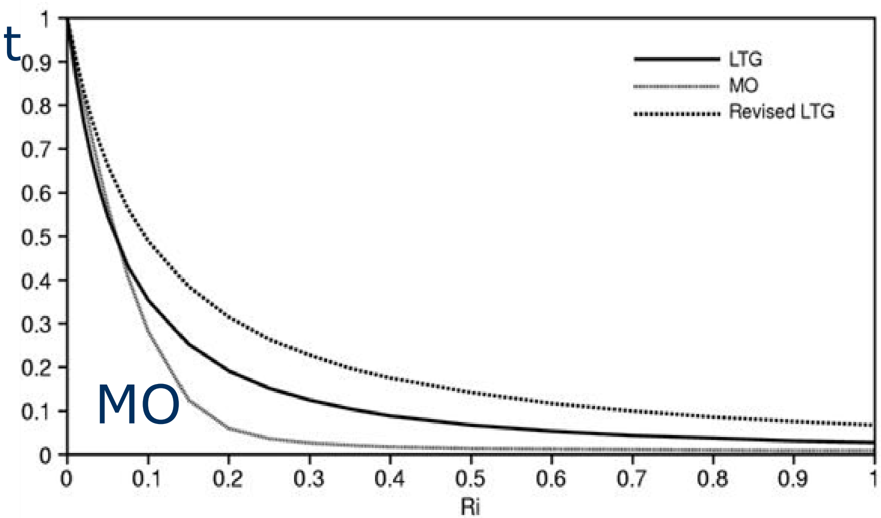
$$Ri = \frac{g}{\theta}\frac{\partial \theta}{\partial z} \Big/ \left|\frac{\partial U}{\partial z}\right|^2$$

NWP models
need a long tail
formulation to get the
synoptic scale right
(Louis et al. 1981)

Stability functions for momentum



and heat



SBL in NWP models

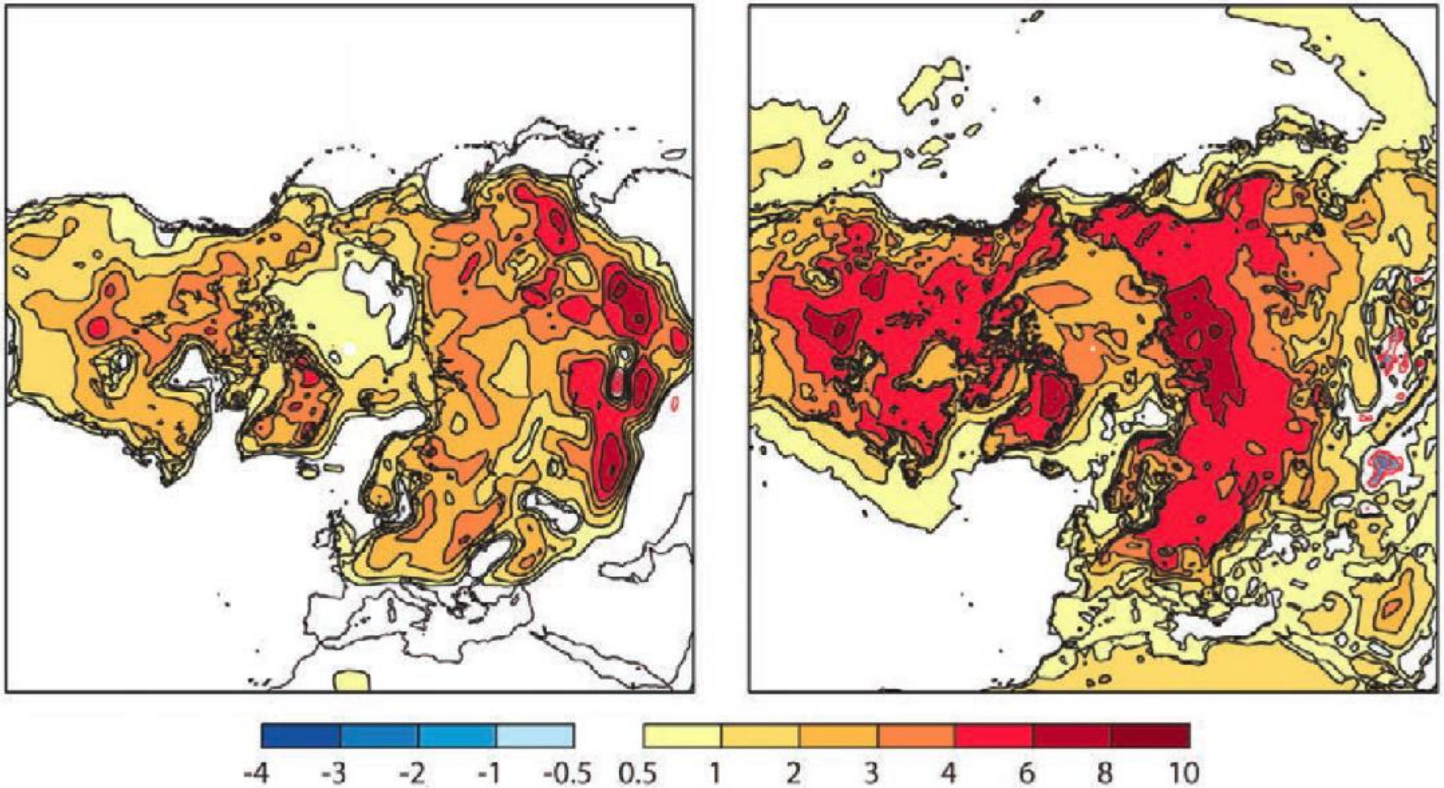


FIG. 4. Difference in 2-m temperature (°C) averaged over January 1996 between simulations with two different stability functions in the ECMWF model (Viterbo et al. 1999; Beljaars 2012). (left) Impact in the 1994 version of the ECMWF model and (right) impact of the same change in the 2011 model version. Color range in legend indicates temperature differences between −4° and 10°C.

Holtslag et al., 2013

Global forecast model

Stability functions affect the large scale forecast scores

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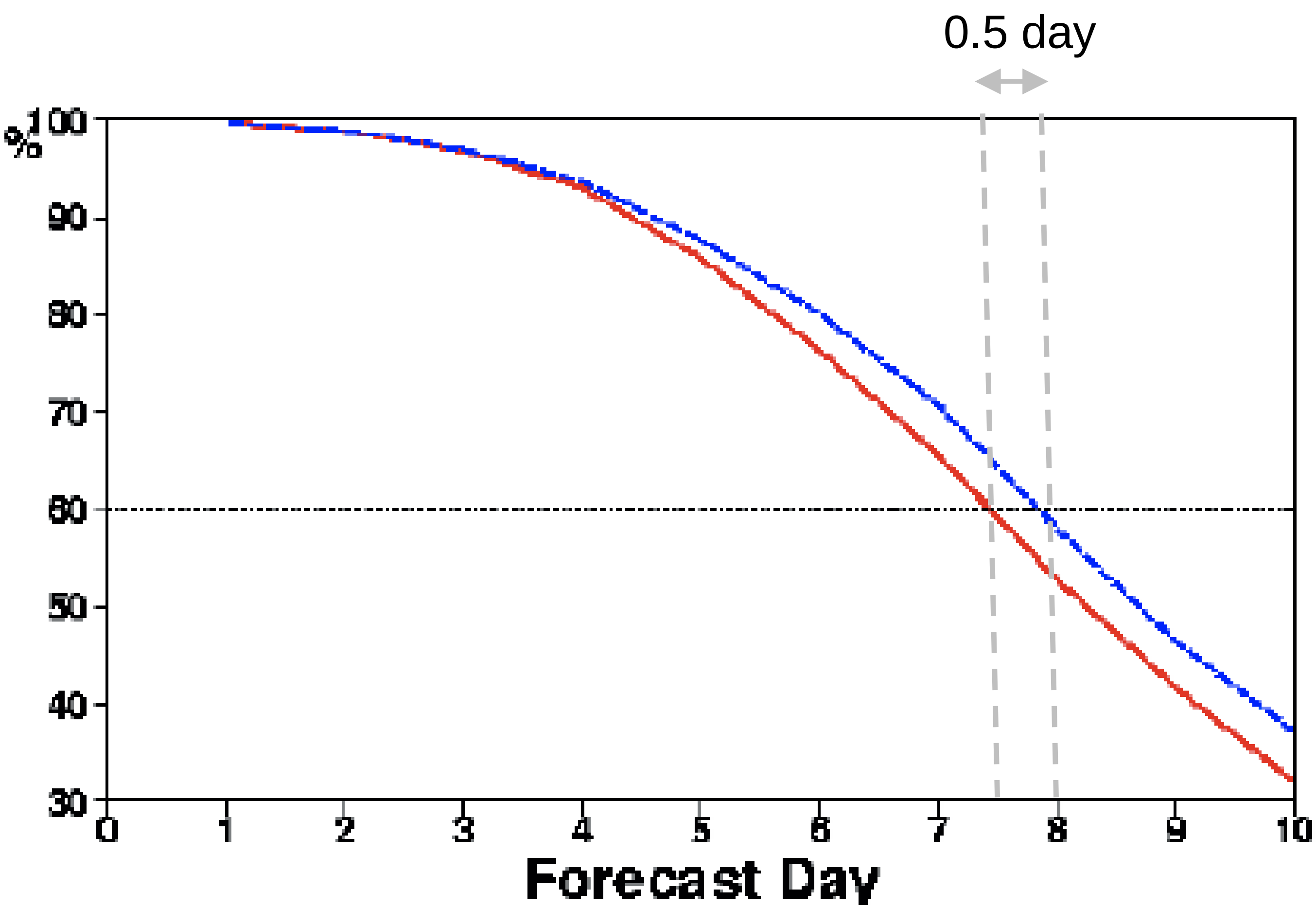
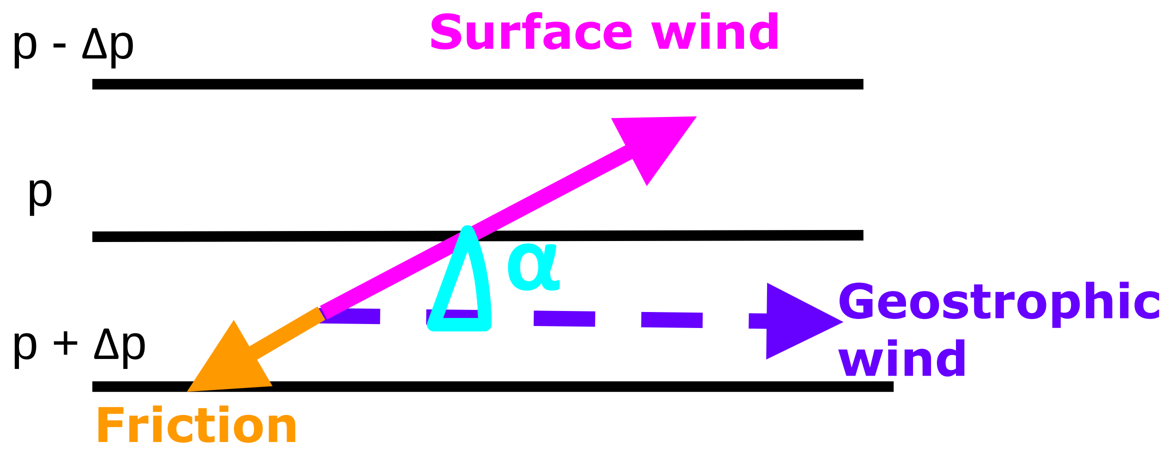
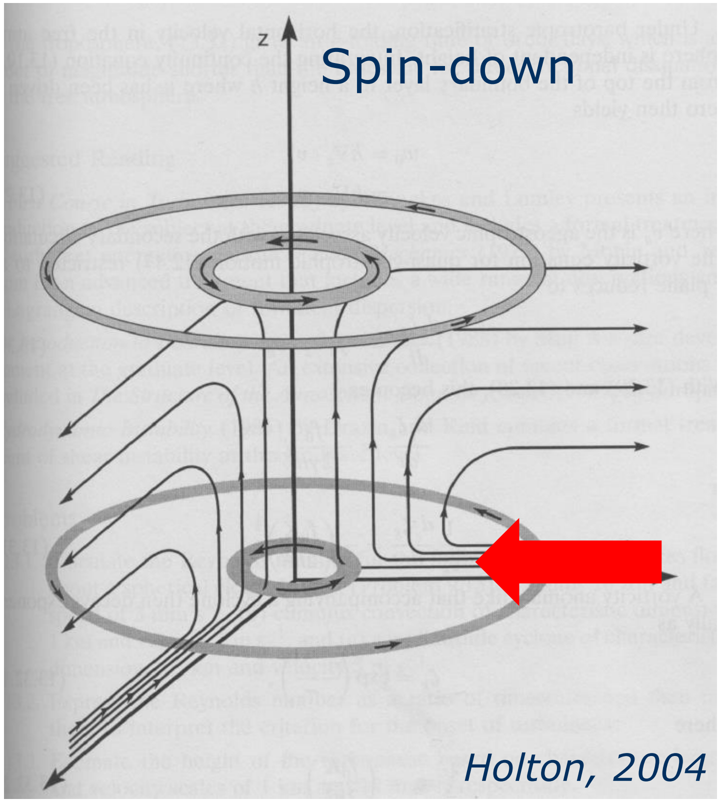


Effect of MO-stability functions (reduced diffusion) instead of operational formulation, on 500hPa NH height scores

ECMWF IFS Courtesy A. Beljaars

The ageostrophic flow





Deeper PBL gives larger friction velocity and larger total drag
Cross-isobaric angle provides a measure the of ageostrophic flow

PBL over ocean

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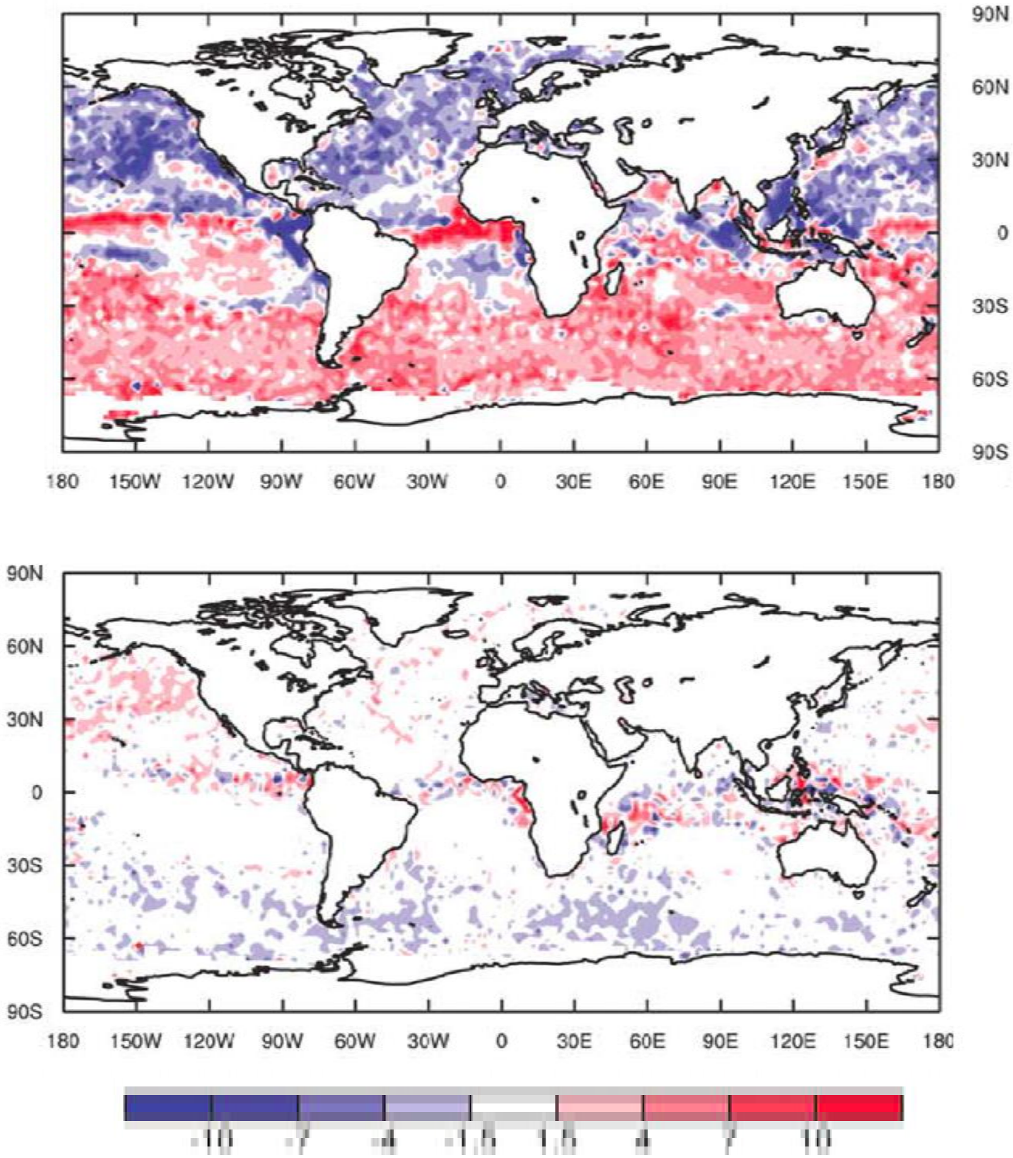
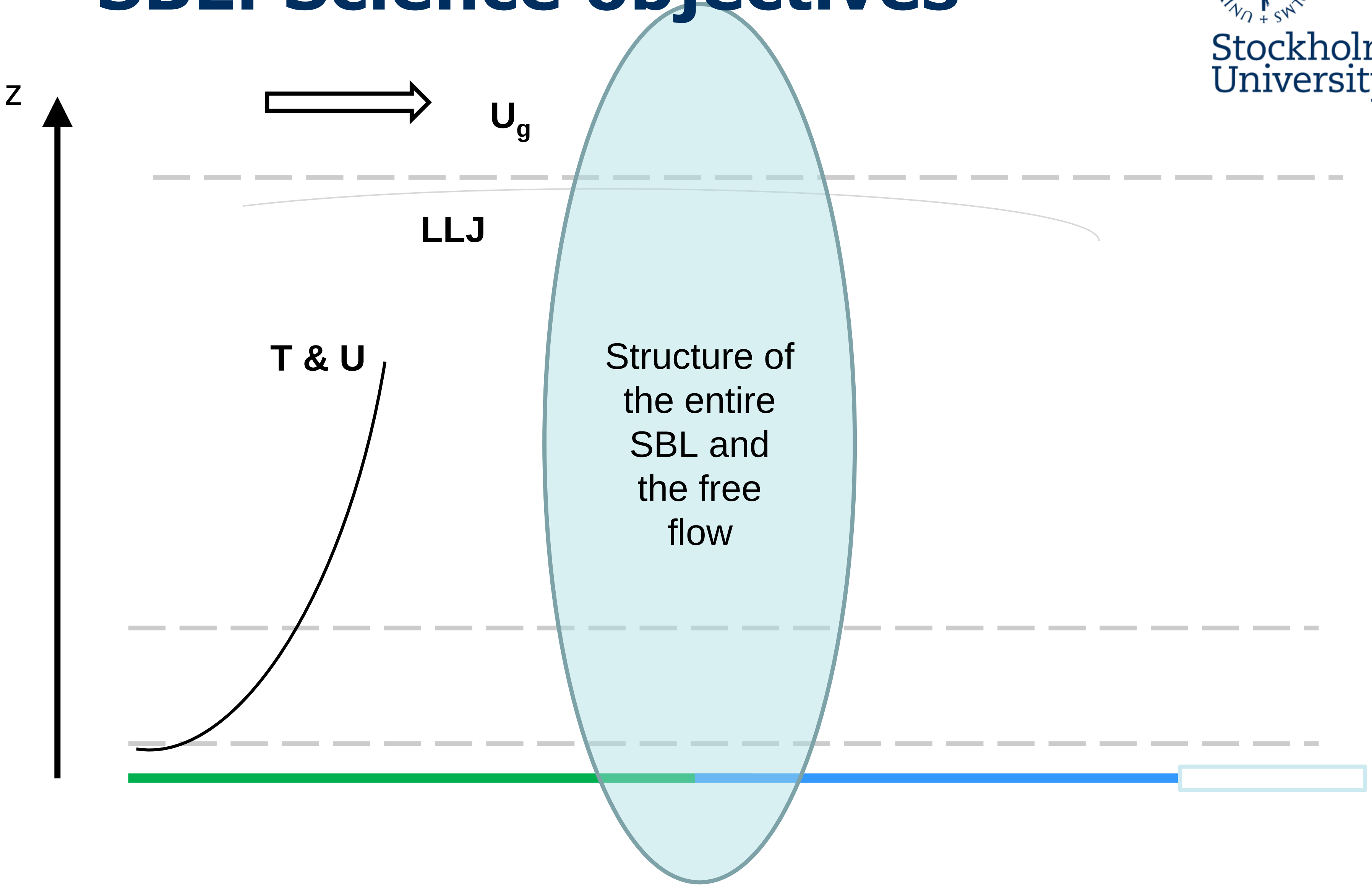


Mean first guess departure (ECMWF model – observation, ASCAT) of surface wind direction in degrees

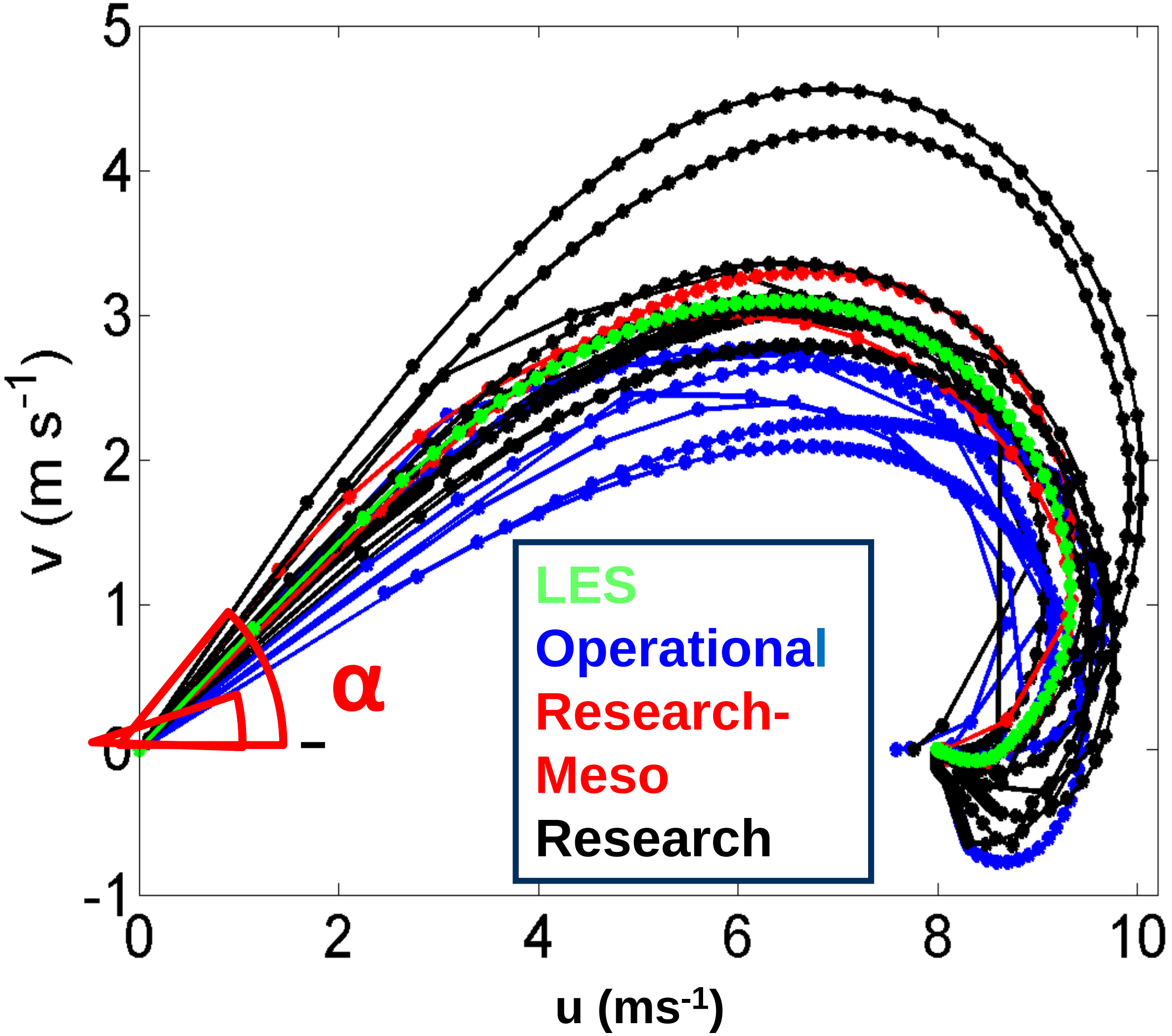
Improves a bit when short-tail (MO) functions are used

Sandu et al., 2013

SBL: Science objectives



GABLS1
PBL scheme intercomparison



LES: 36°

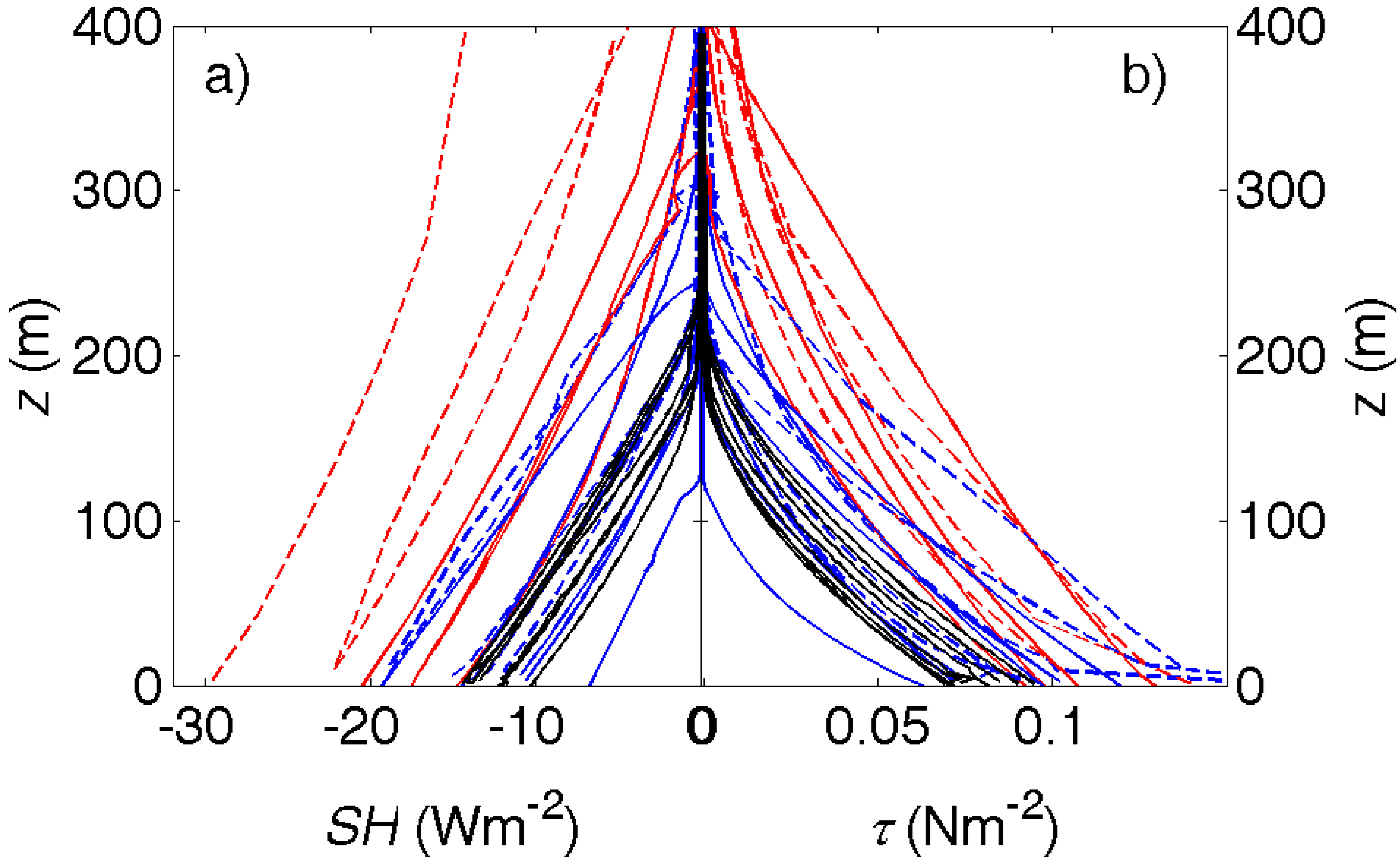
Operational models: 23 – 36°

Research models: 27 – 46°

(Ekman spiral: 45°)

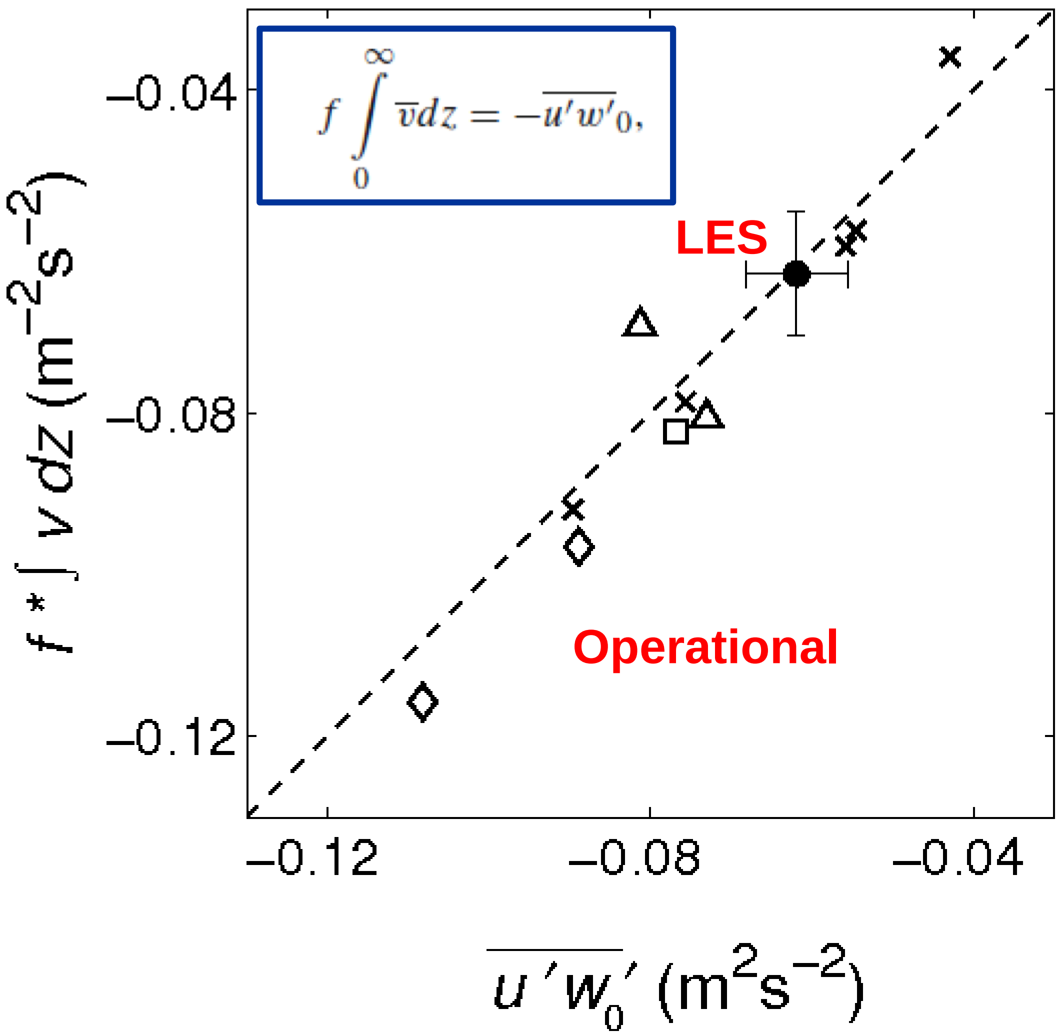
Cuxart et al.2006; Beare et al. 2006; Svensson and Holtslag 2009

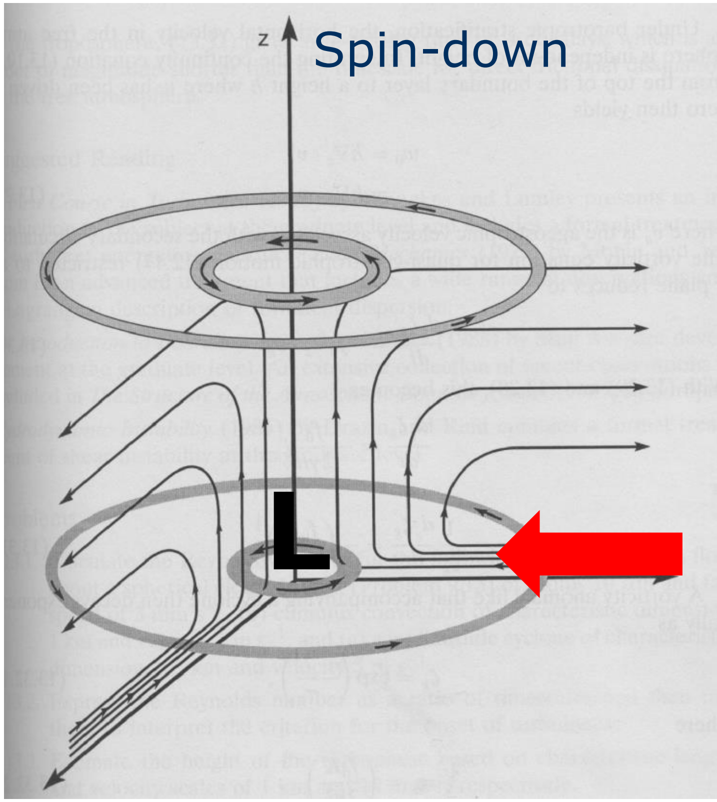
GABLS1
PBL scheme intercomparison



Holtslag et al. 2013

The ageostrophic flow

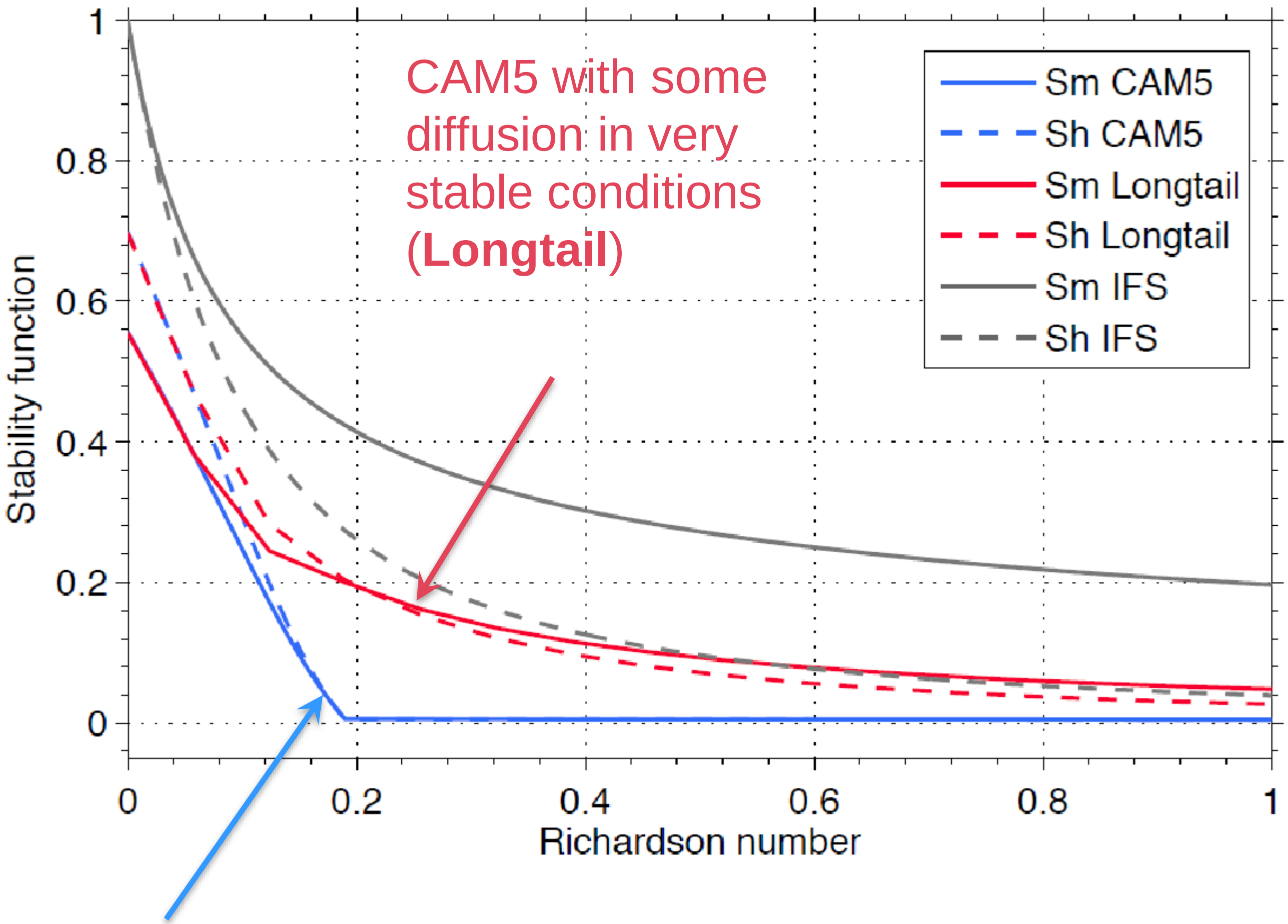




Svensson and Holtslag, 2009

Experiments in CAM5.3

10-year AMIP-type experiments



Default CAM5 (**CONTROL**)
No atmospheric turbulence when Ri > 0.19

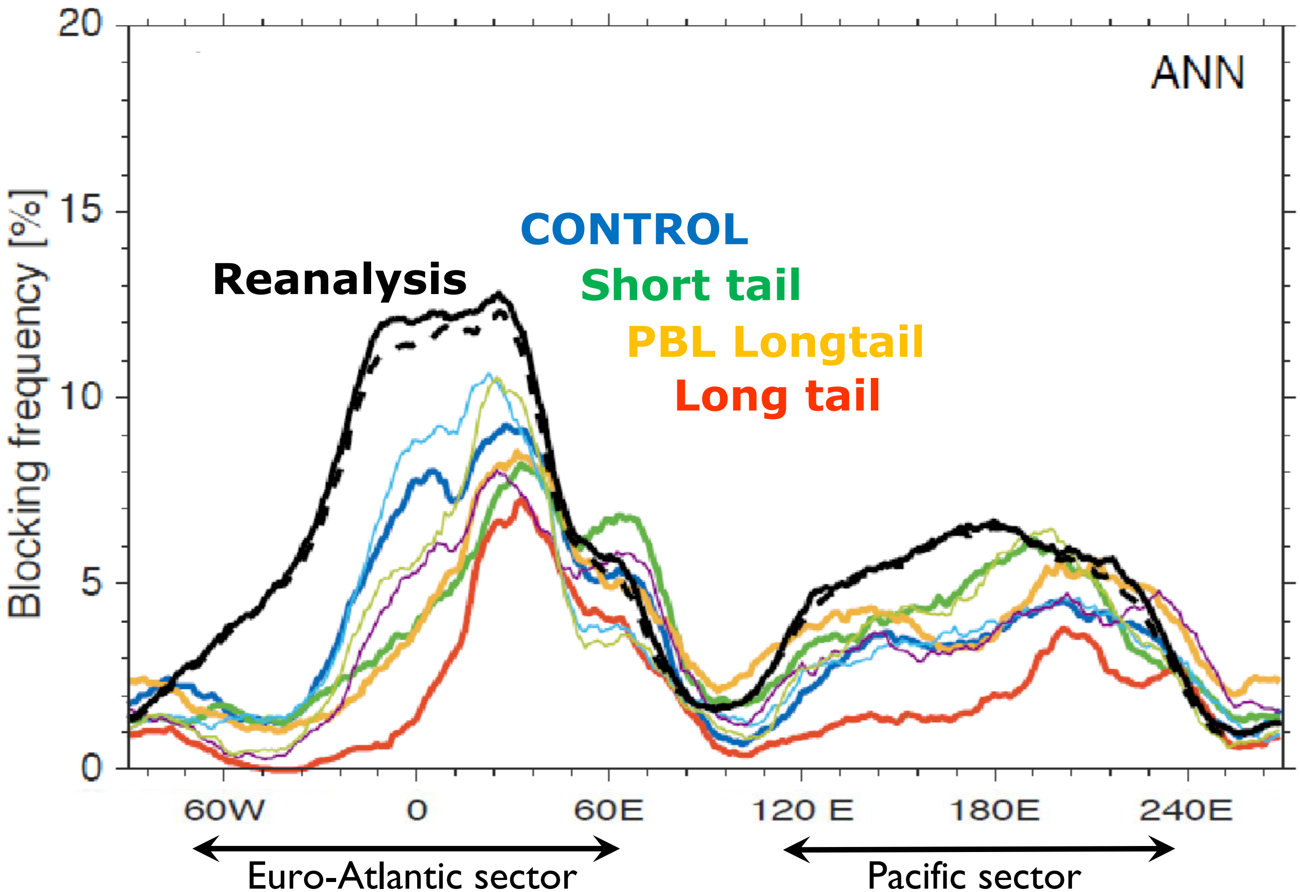
1 degree resolution
&
30 vertical layers

PBL scheme: *Bretherton and Park, (2009)*

Land model use long-tail functions

Lindvall, Svensson and Caballero, 2016

Atmospheric blocking frequency



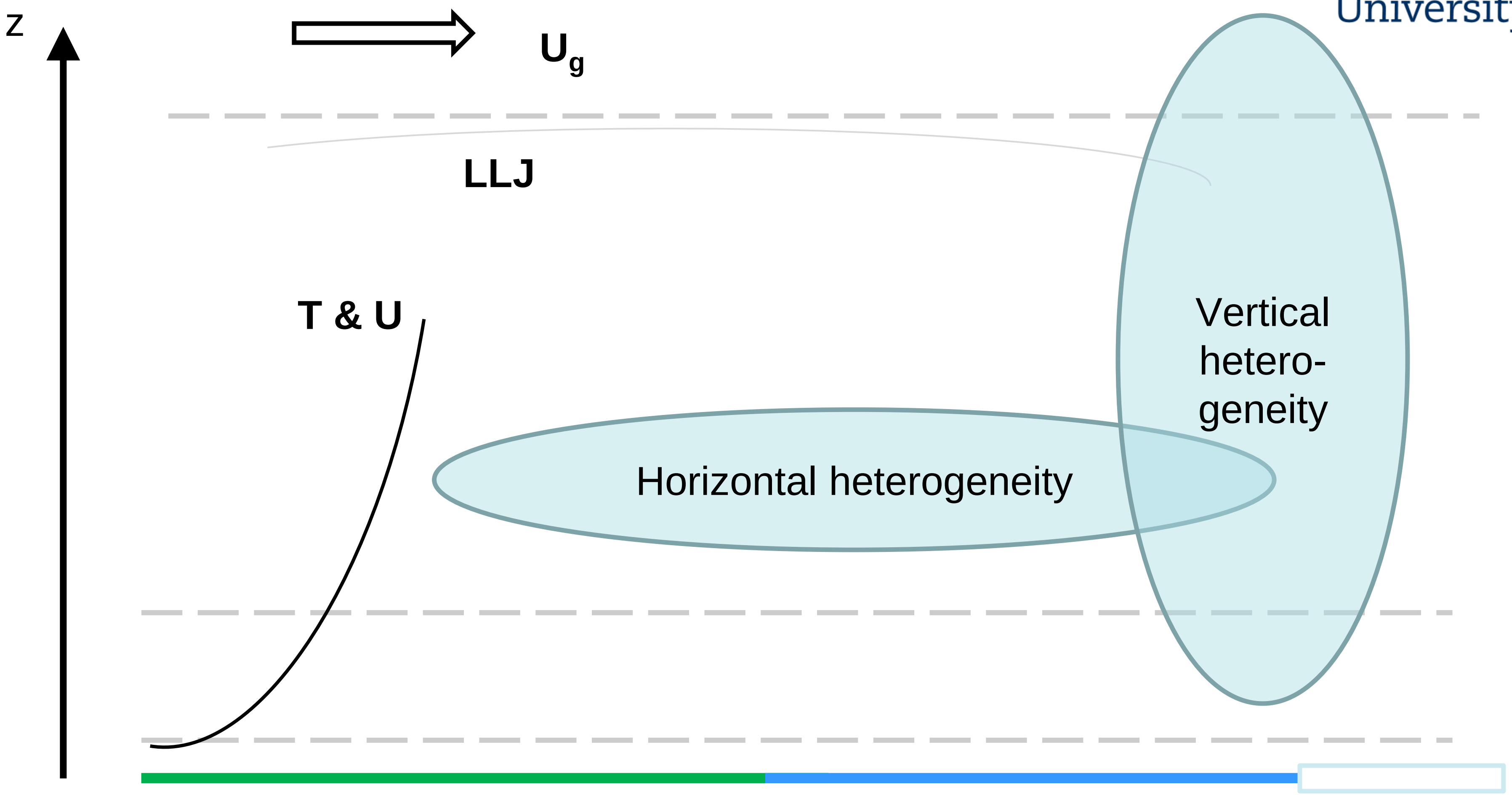
CAM5.3
All model versions have too few blockings, specially for the Euro-Atlantic sector

Control is closer to observations

Control: enhanced surface roughness based on subgrid scale terrain variability
Short tail: Critical Ri of 0.19, Longtail for surface fluxes
PBL Long tail: Only in PBL (and surface)
Long tail: SBL and above (and surface)

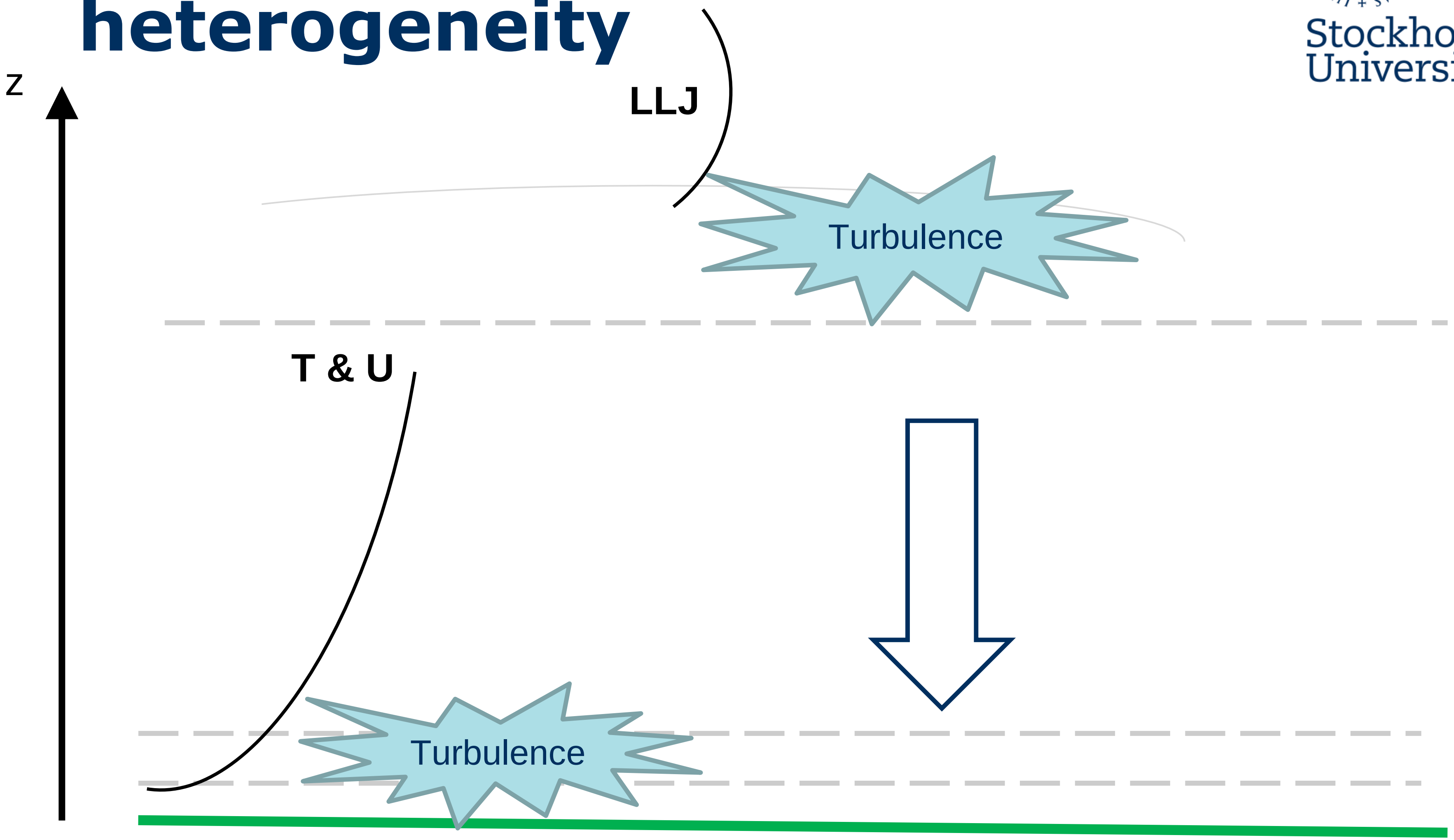
Lindvall, Svensson and Caballero, 2016

SBL: Science objectives



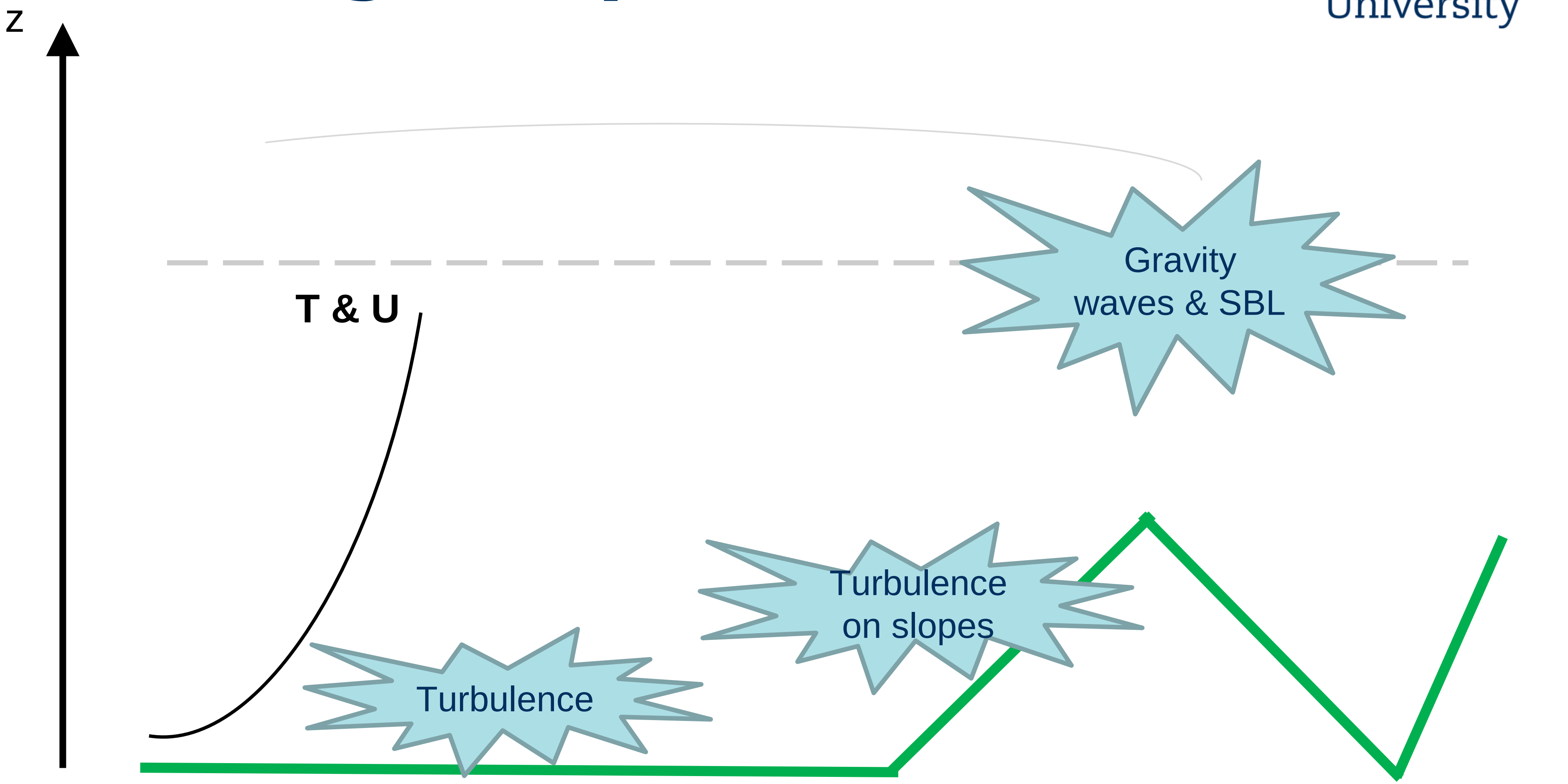
PBL in transition …

Horizontal and vertical heterogeneity

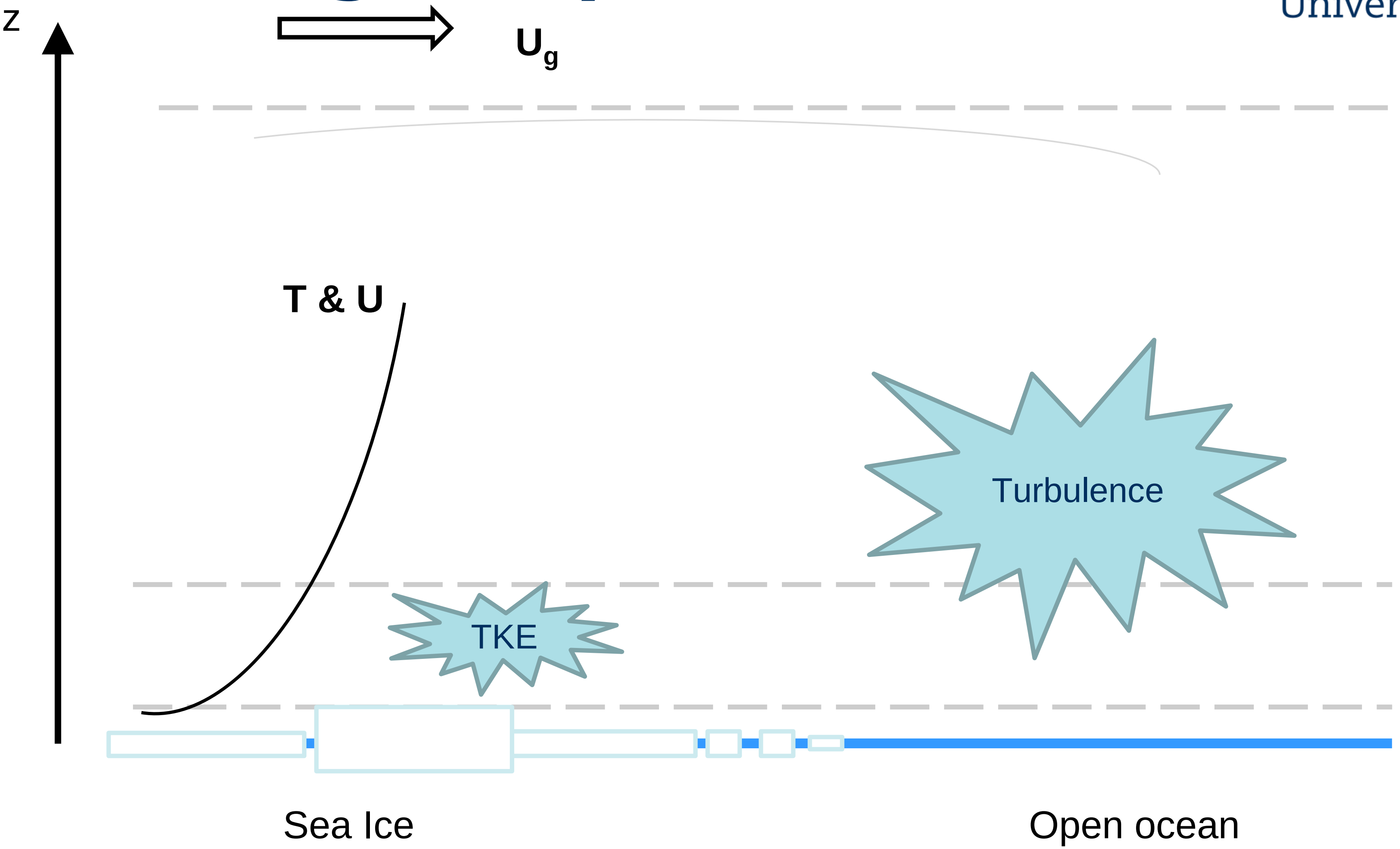


The atmosphere is always turbulent

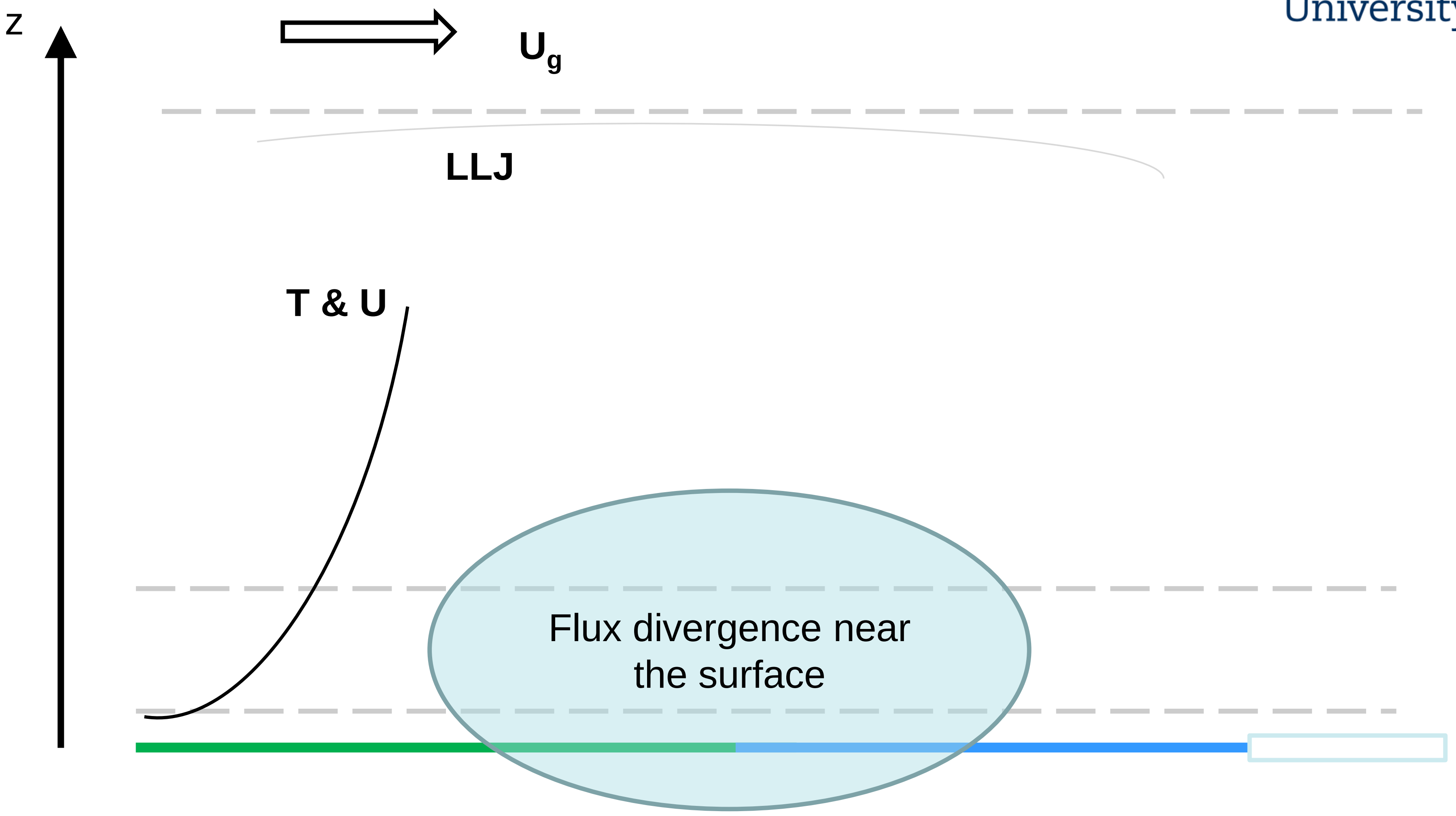
Horizontal and vertical heterogeneity



Horizontal and vertical heterogeneity



SBL: Science objectives



Systematically missing fluxes?
Preliminary analysis of observations and model simulations

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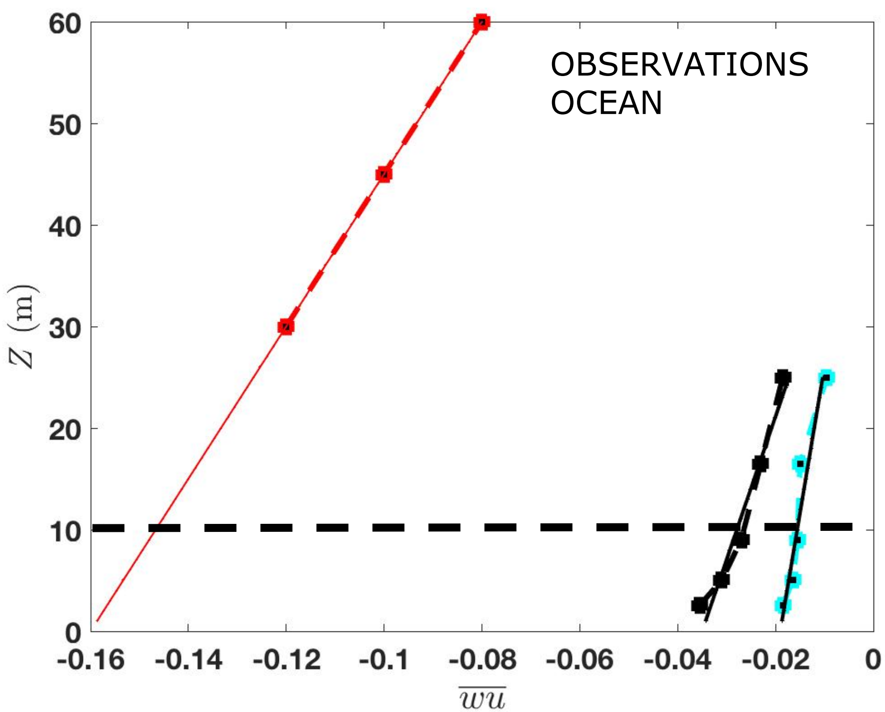
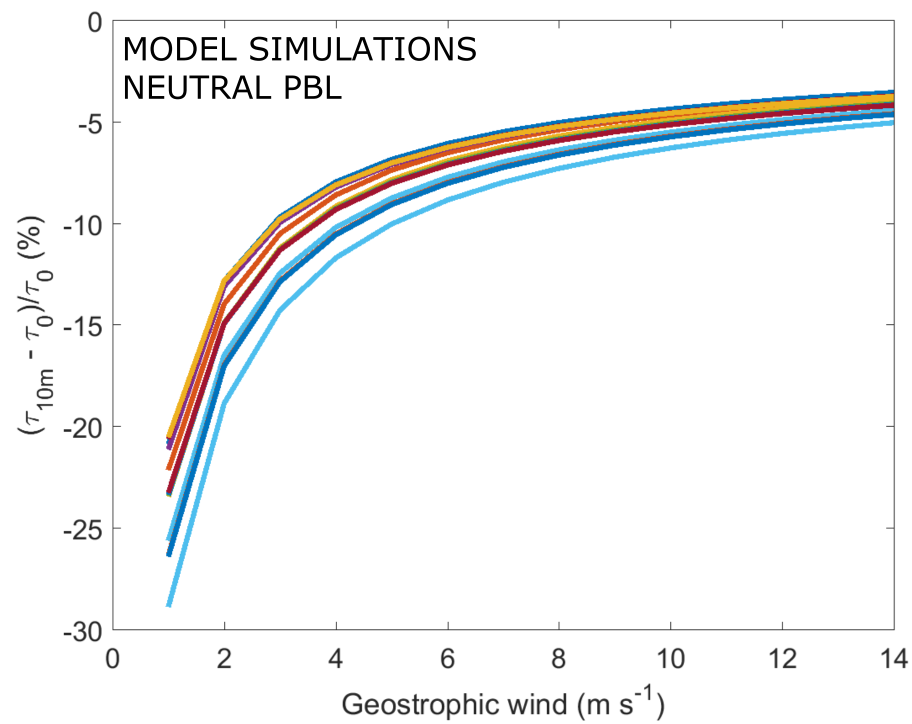
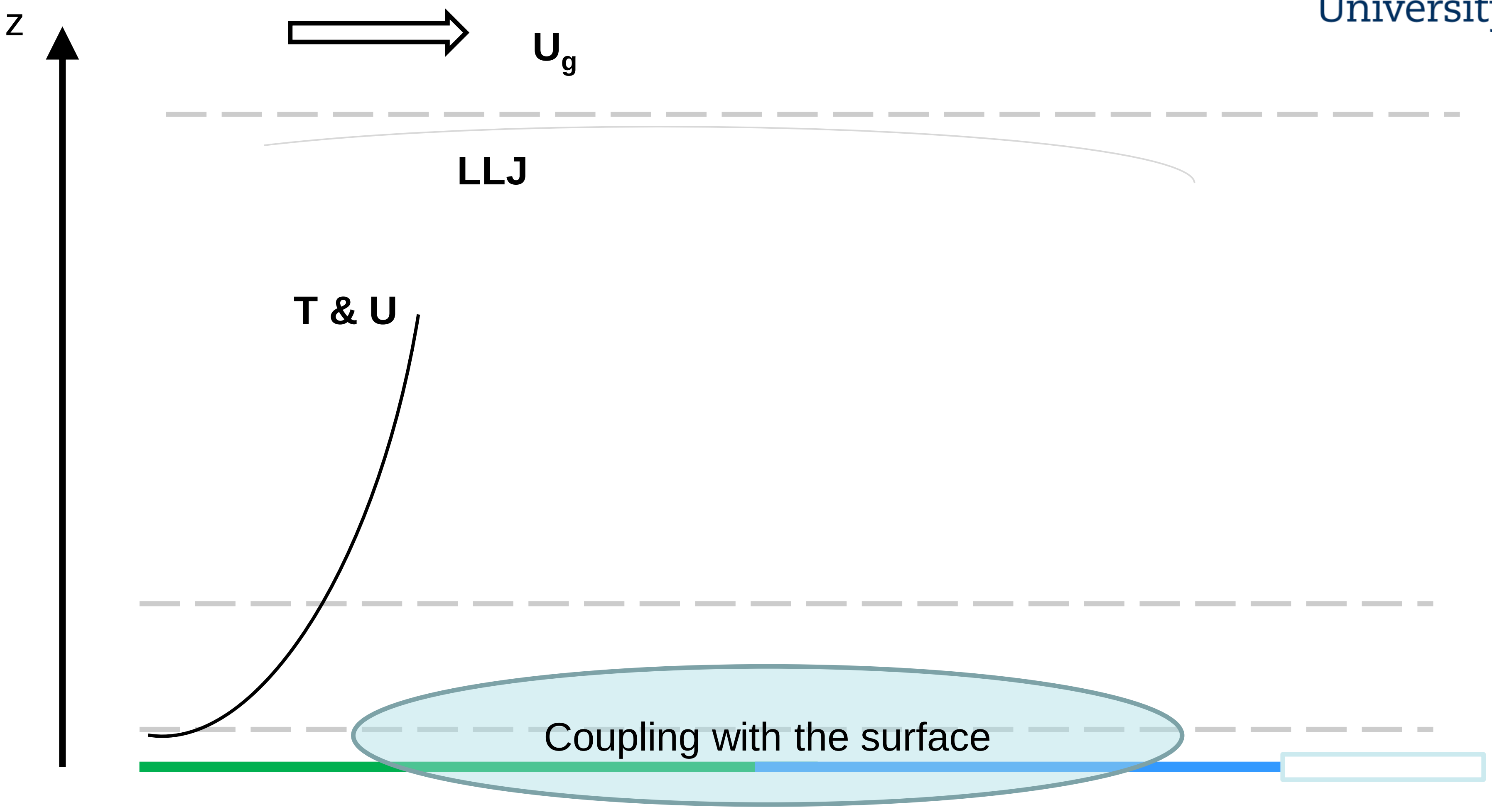


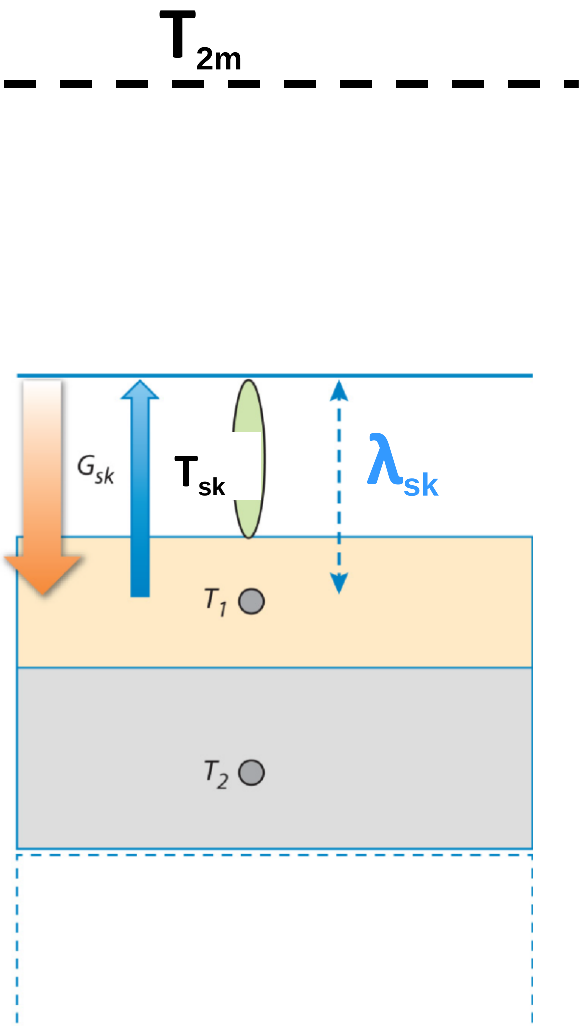


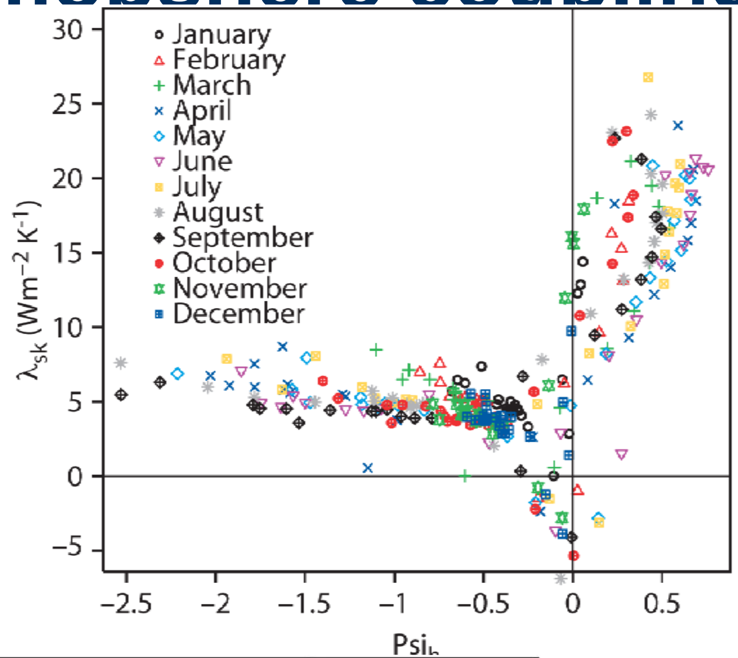
Monin-Obukhov theory assumes a constant flux layer
What about directional divergence?
Aligned stress and wind vectors?

SBL: Science objectives

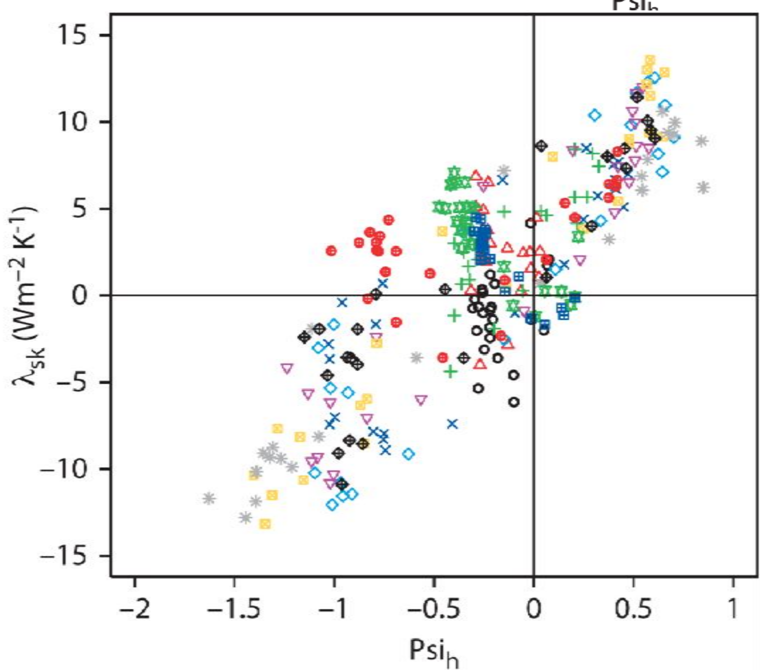


Strength of land-atmopshere coupling





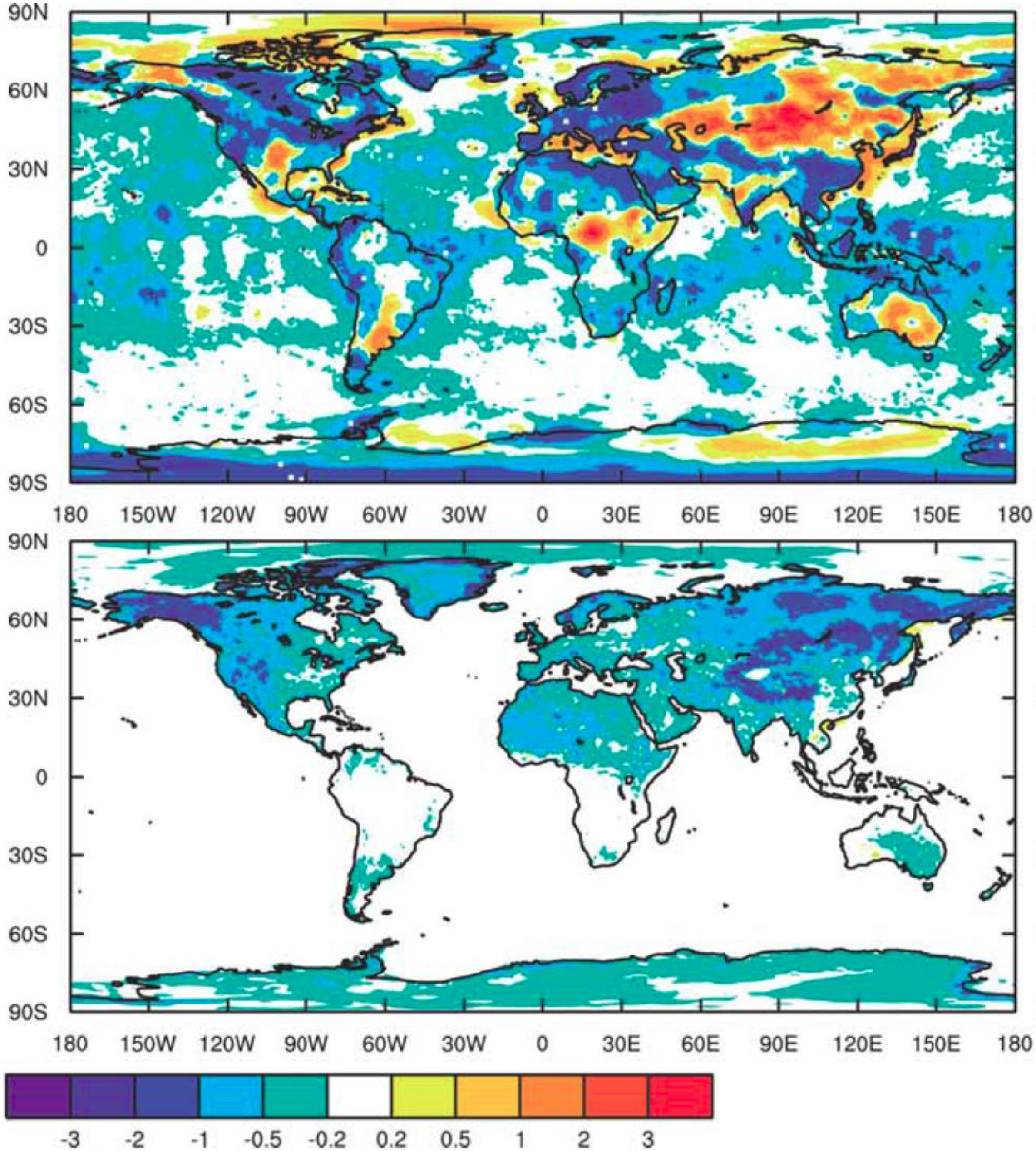
OBSERVATIONS
GRASS



OBSERVATIONS
FOREST

Verhoef and Vidale,
ECMWF report 2013

T_{2m} Short tail vs long tail



Jan 2011 Forecast - analysis

Jan 2011 Short tail – long tail

Doubling the **skin conductivity** on top of short tail increases the temperature with up to 2 degrees again

Sandu et al., 2013

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Concluding remarks

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- Improved understanding and modeling of SBL is important at all latitudes and all seasons
- Theory builds on horizontal homogeneity and stationarity – PBL is always in transition
- Model development is done with all processes interacting
- Observations are needed for model development, most useful if all important processes are observed e.g. SHEBA, CASES99
- Understand how momentum is extracted from the atmosphere (kinetic and thermal energy conservation)
    1. Structure of the entire SBL and the free flow
    2. Flux divergence near the surface
    3. Horizontal and vertical heterogeneity
    4. Coupling with the surface