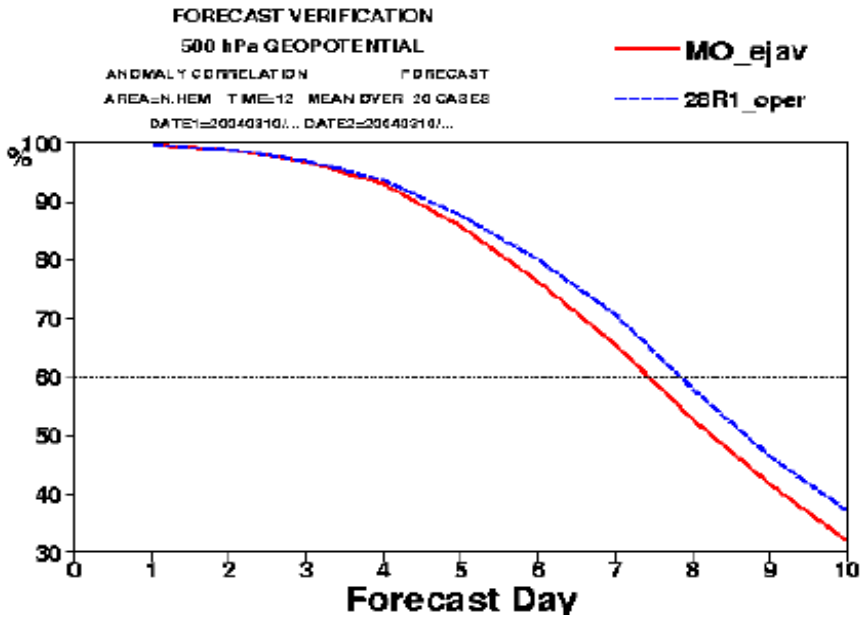
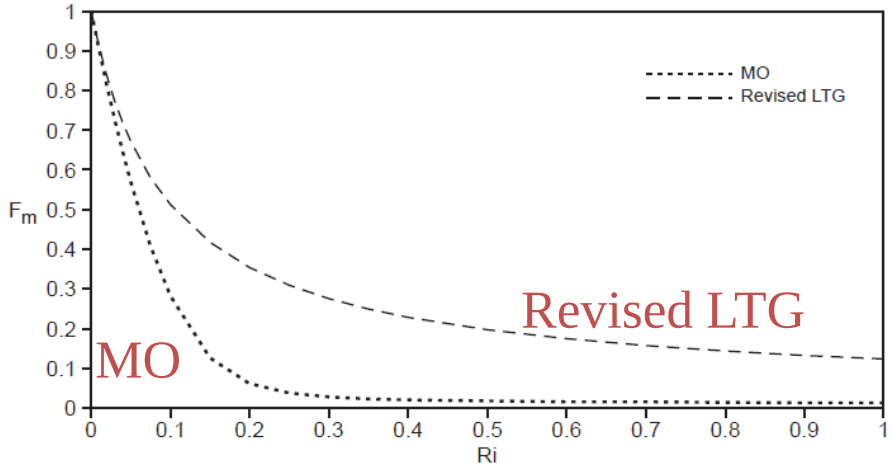
Are we facing “grey zone” issues in boundary layer parametrization?

Anton Beljaars, Irina Sandu and Linus Magnusson (ECMWF)

Turbulent diffusion in stable boundary layers





- Observations indicate MO stability function.
- ECMWF uses revised LTG, i.e. more diffusion than observed.
- The reason is that with MO stability functions:
  - Typically 0.5 day of forecast range is lost over NH in older versions of the ECMWF model. This is related to a reduction of drag over land.
  - Night-time surface temperatures become too cold at low wind.

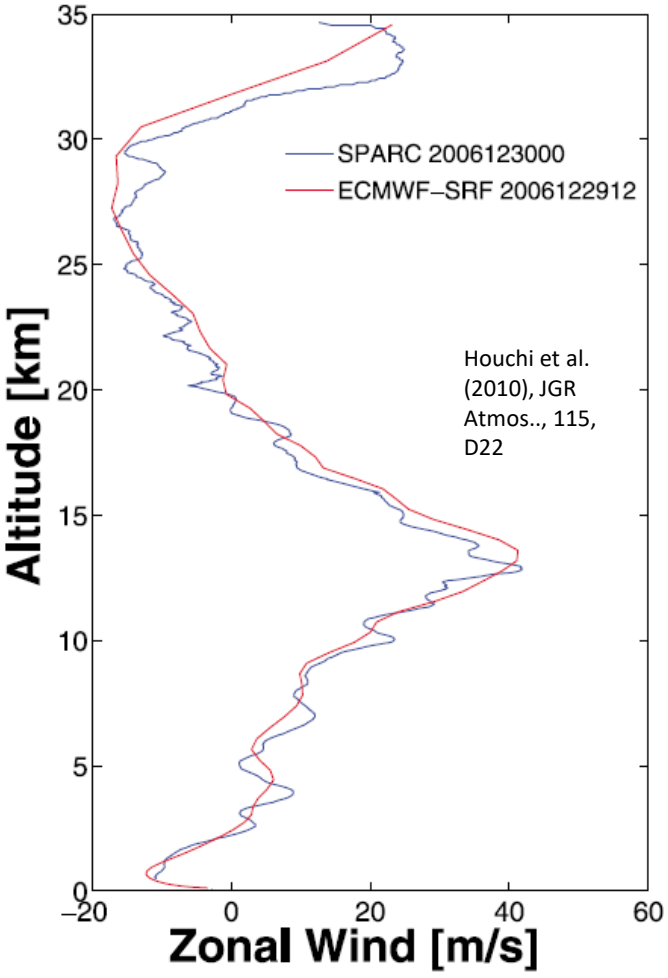
Why does MO not work? Are the observations wrong?

A possible explanation is that large scale models lack “meso-scale” variability which involves shear (e.g. gravity waves, inertial waves).

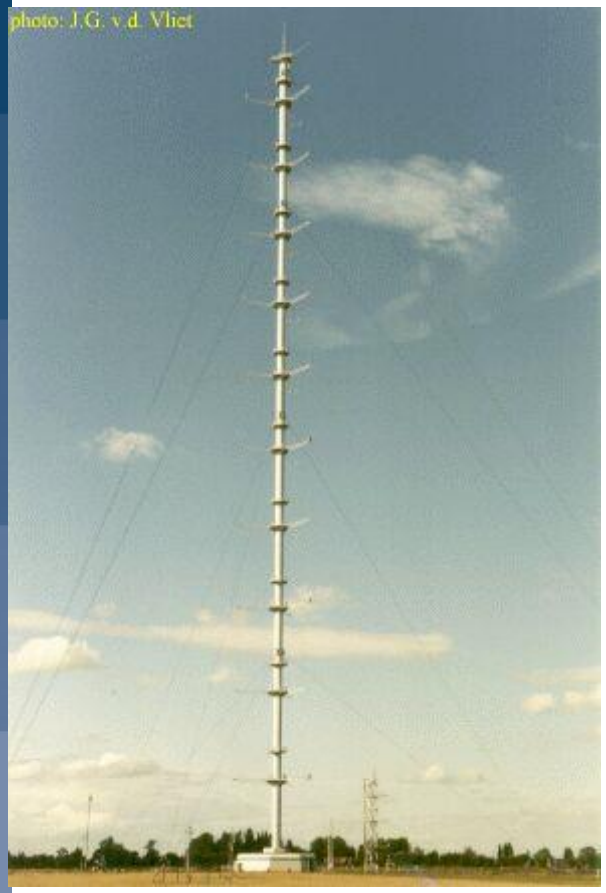
Houchi et al. (2010) analysed a large volume of high resolution radio sondes and concluded that the IFS underestimates the magnitude of vertical shear by more than a factor 2.

Hypothesis:

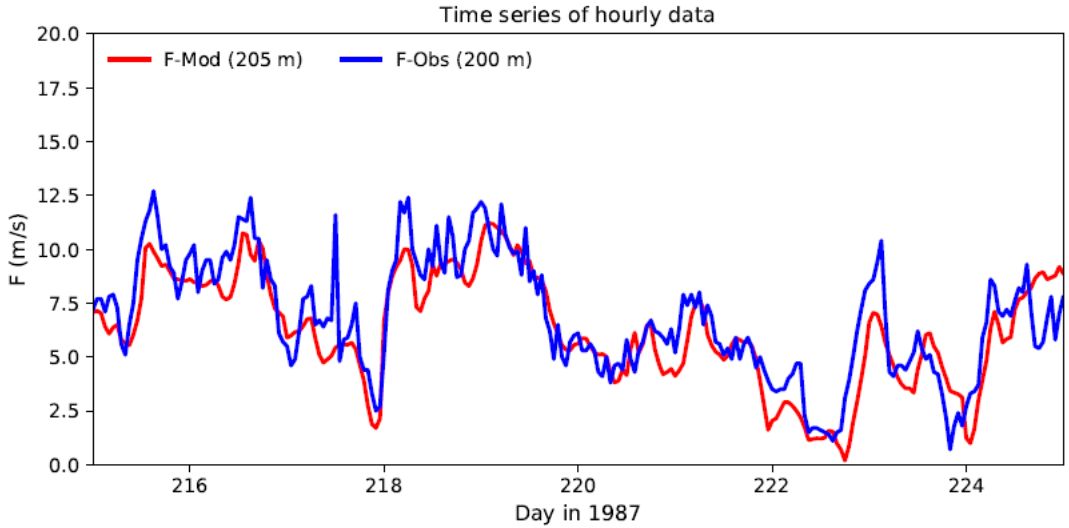
- The effect of meso-scale variability needs parametrization
- Such a parametrization should be resolution dependent



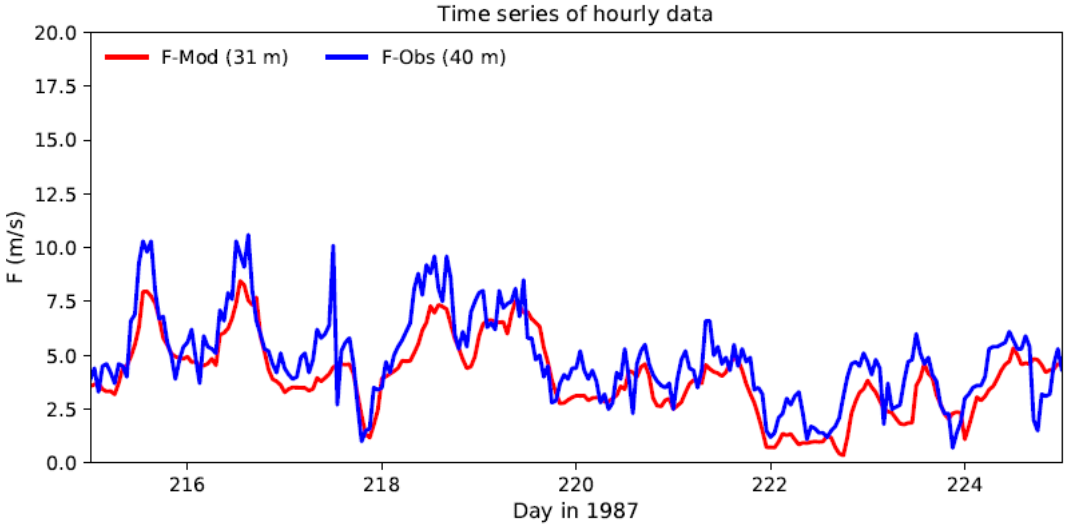
Time series of wind speed at Cabauw (Netherlands) for 10 days in August 1987: Observations (30 min averages) & ERA5



200 m above surface

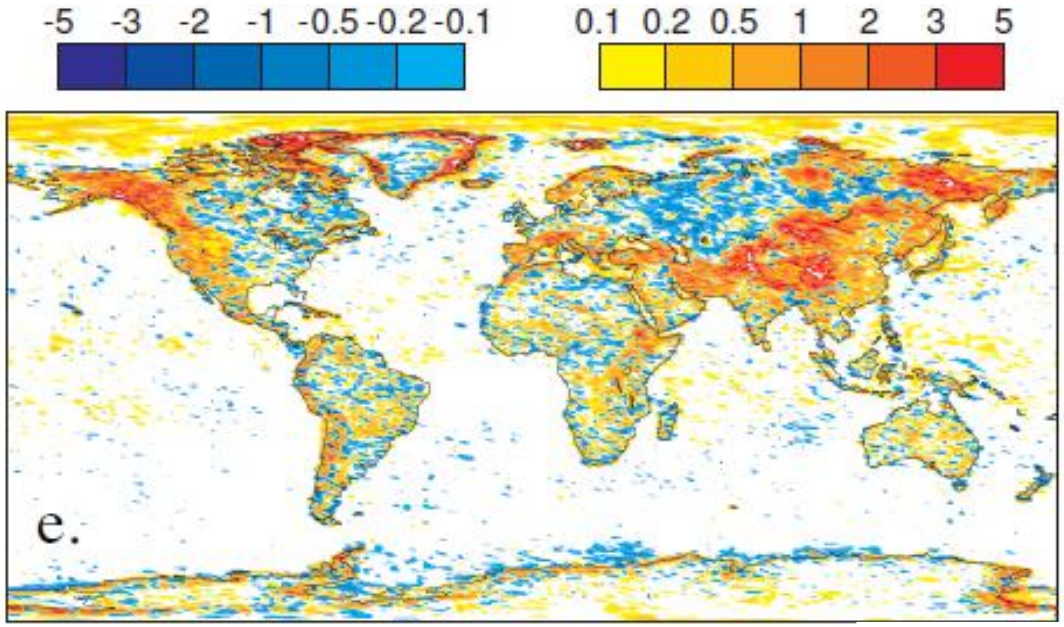


10 m above surface

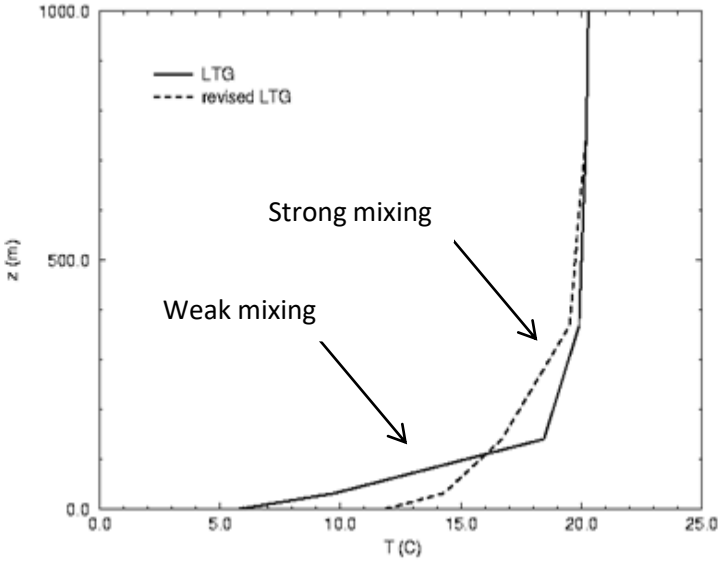


Data: Fred Bosveld, KNMI

Effect of orography resolution on 2T (T1279-T639)



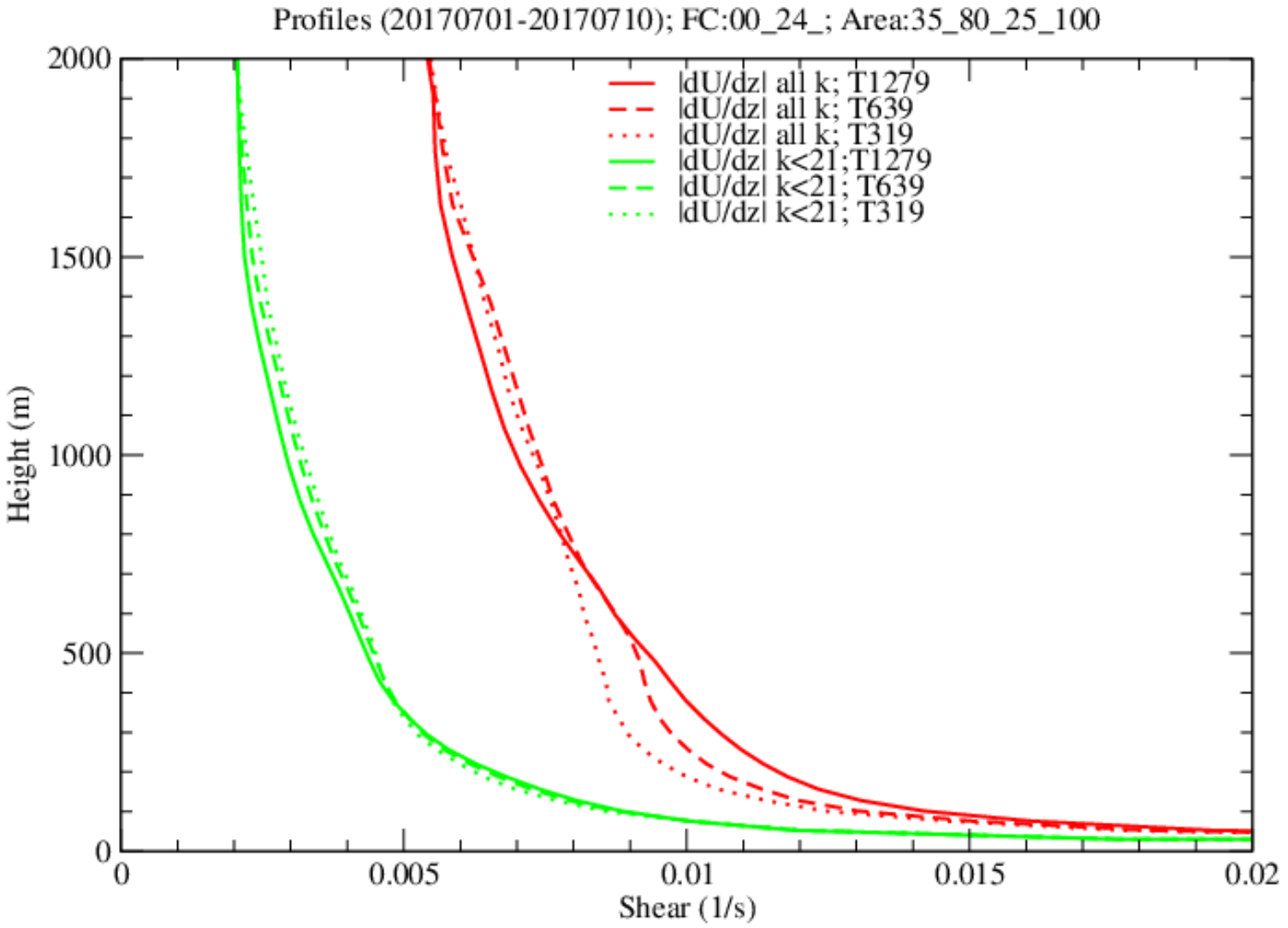
Cooling over 9 hrs with 50 W/m2



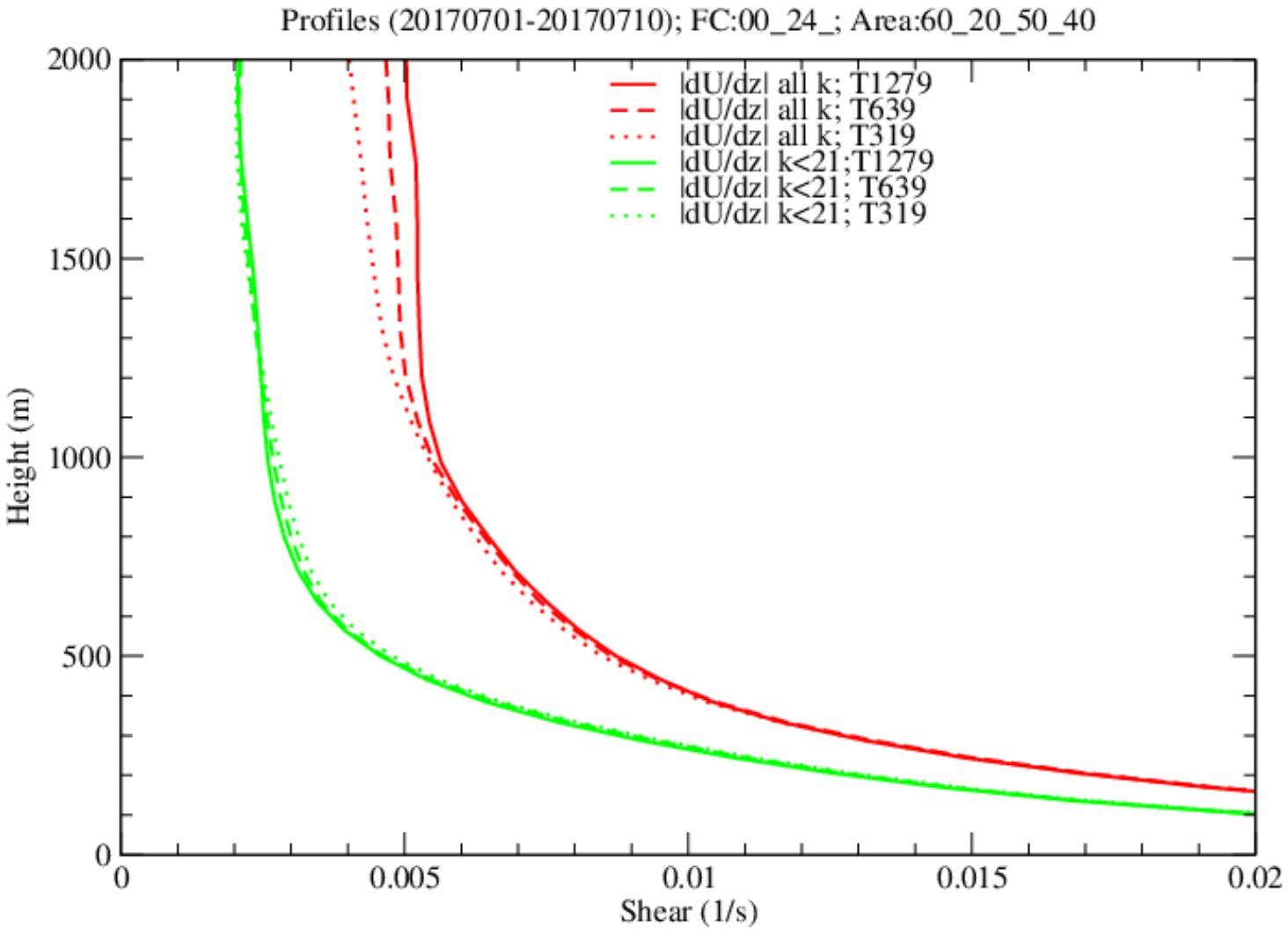
Hypothesis; with high resolution orography:

- Resolved gravity waves are stronger
- Local shear is increased
- Turbulent mixing is stronger
- Stable layers are deeper
- Near surface temperature is higher

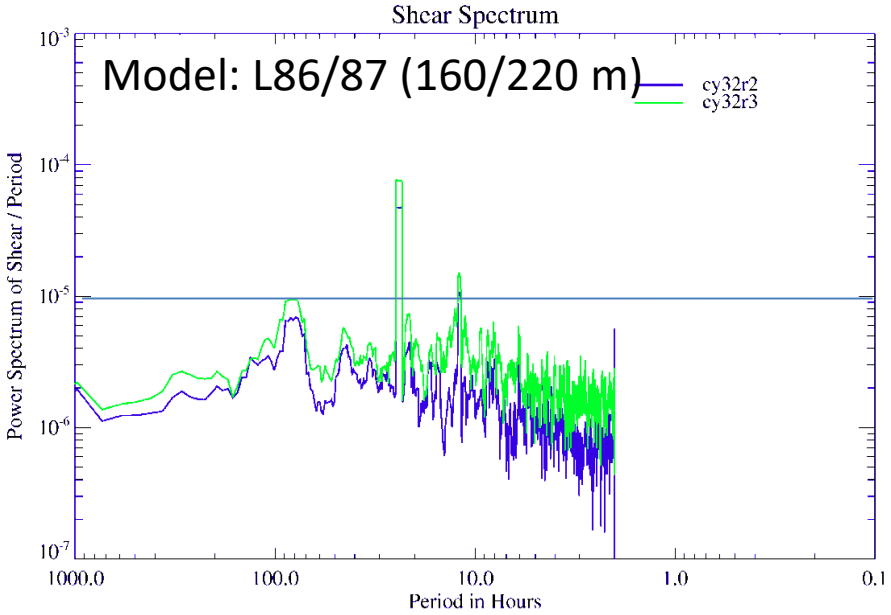
RMS of wind shear over Himalayas

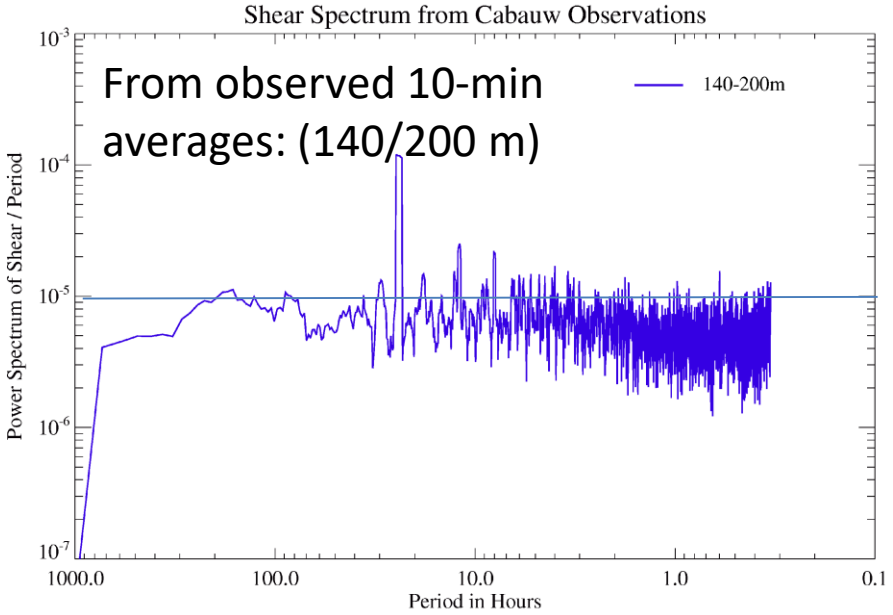


RMS of shear over fairly flat terrain (Russia)



Shear spectrum at Cabauw tower from 2-month time series of hourly data: observations and model output (concatenated daily forecasts)





Figures: Martin Koehler

Conclusion:
- Model lacks variability at all time-scales.
- Different model versions show different shear but are always too low.

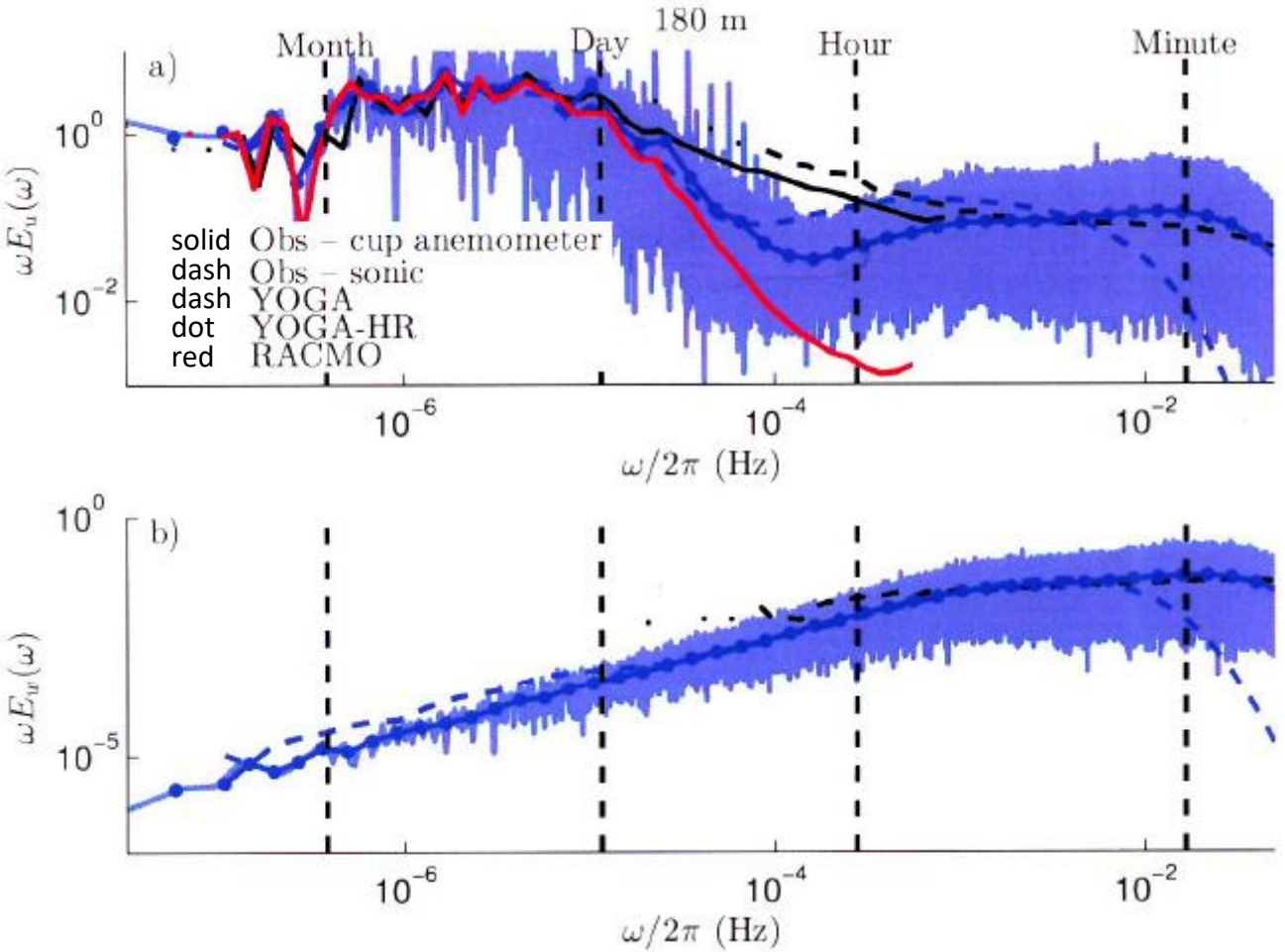
Is a meso-scale shear term needed and how does it scale?

$$K_m = l^2 \left\{ \left| \frac{dU}{dz} \right| + S_m \right\} f_m(Ri) \qquad Ri = \frac{g}{\theta} \frac{\frac{\partial \theta}{\partial z}}{\left\{ \left| \frac{\partial U}{\partial z} \right| + S_m \right\}^2}$$

To document shear: High resolution modelling is needed over large areas

Horizontal wind

Vertical wind

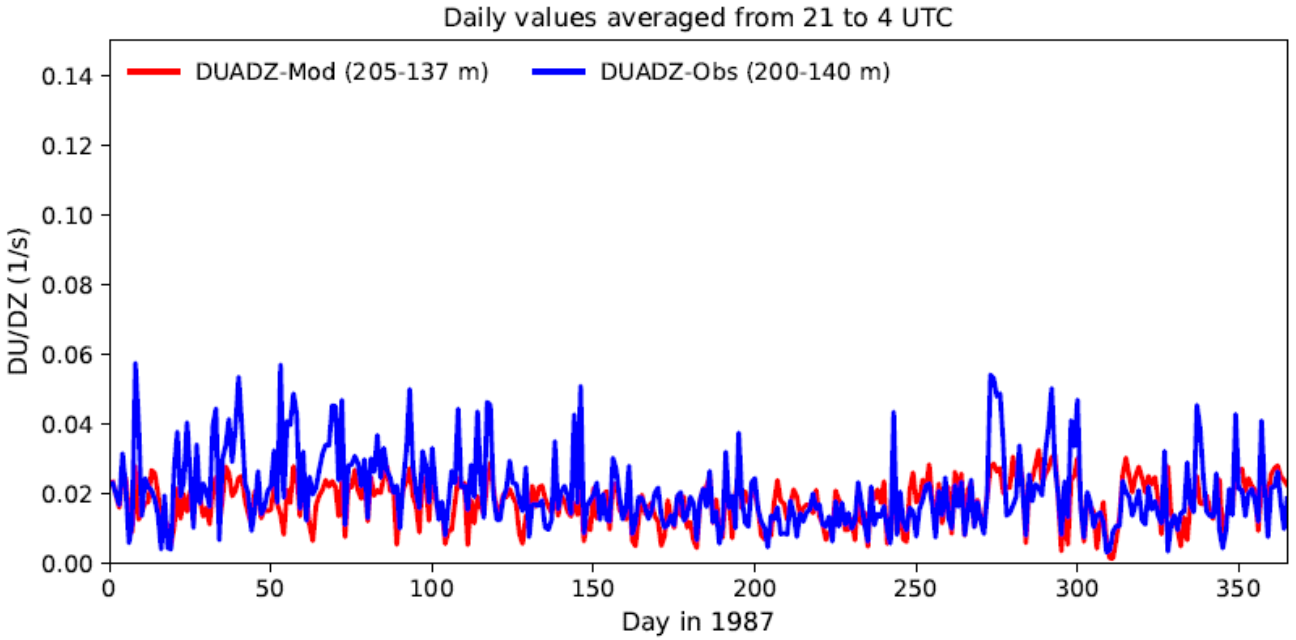


Schalkwijk et al. (2015) : A year-long large-eddy simulation of the weather over Cabauw: an overview, Mon. Weather. Rev., 143, 828-844.

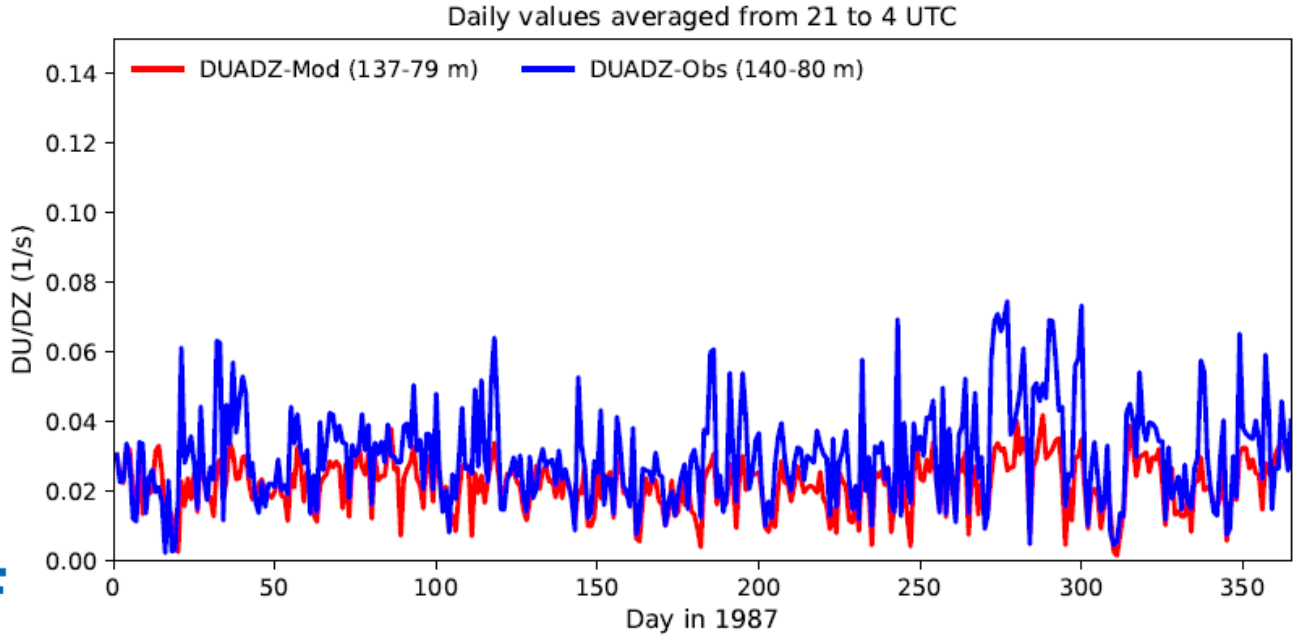
Embedding an LES in a large scale model is not sufficient to represent the energy in the meso-scale. LES simulations over large areas are needed. The meso-scale variability is missing in current parametrizations.

Daily absolute shear averaged every night from 21 to 4 UTC from 30-minute averaged wind observations

Z=170 m



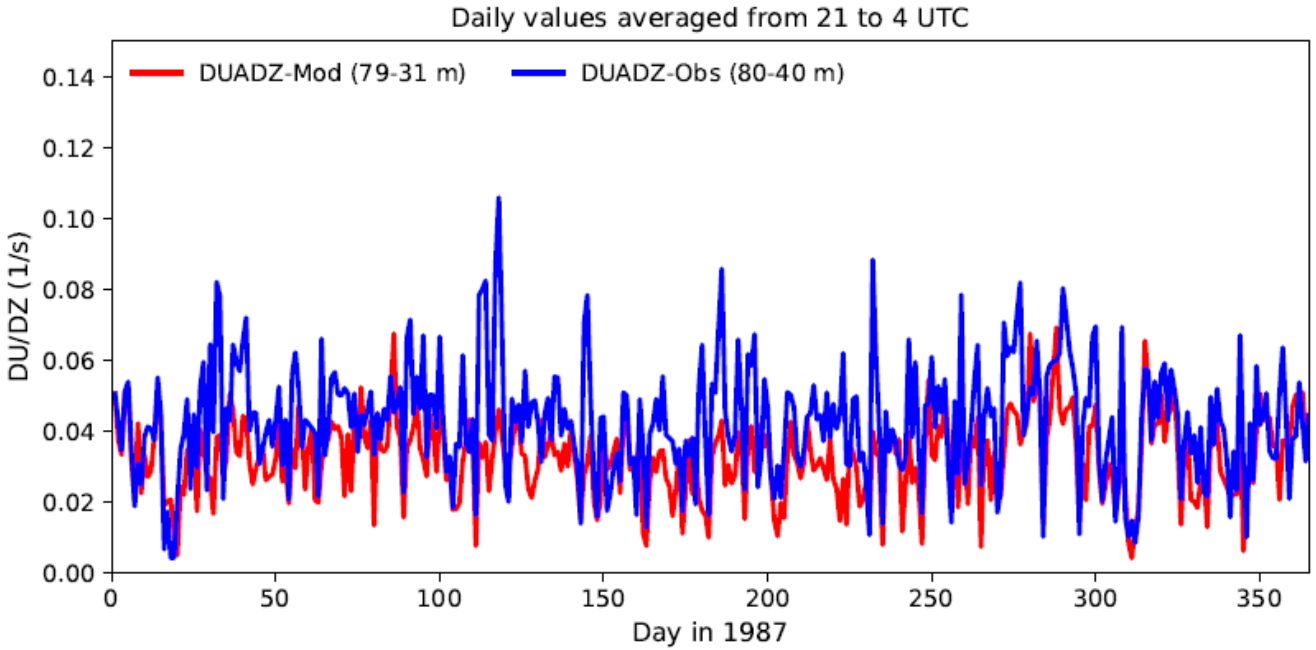
Z=110 m



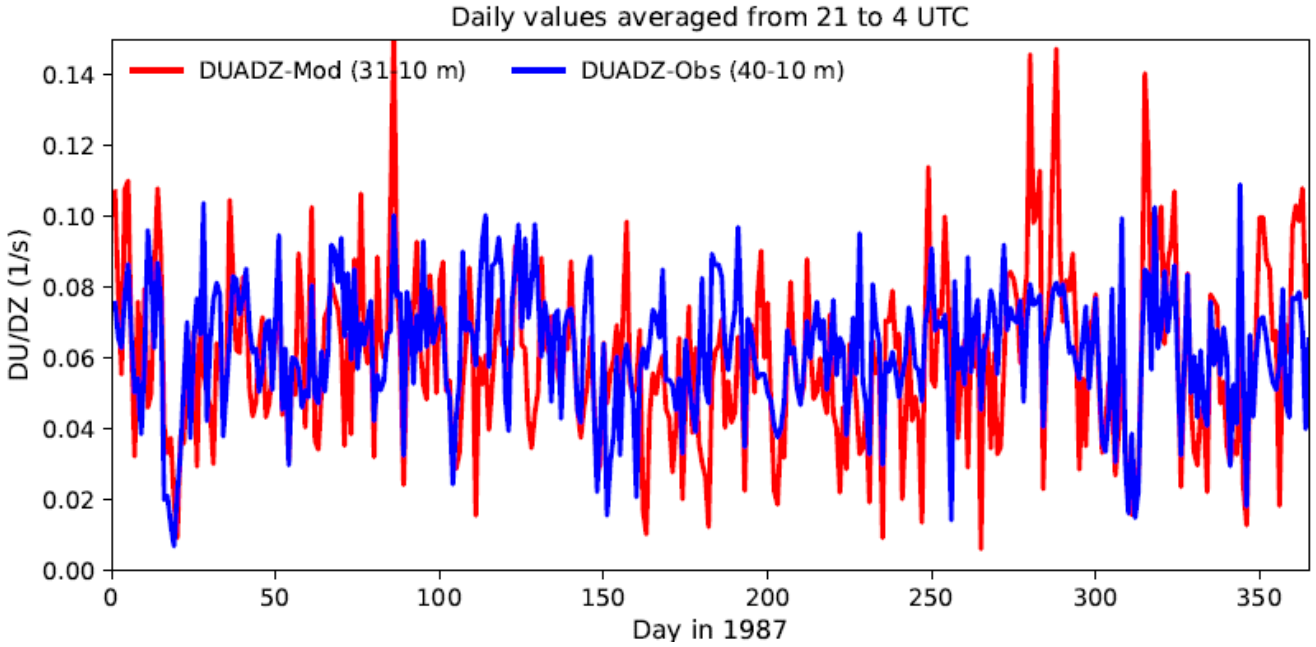
ECMWF

Daily absolute shear averaged every night from 21 to 4 UTC from 30-minute averaged wind observations

Z=60 m



Z=25 m



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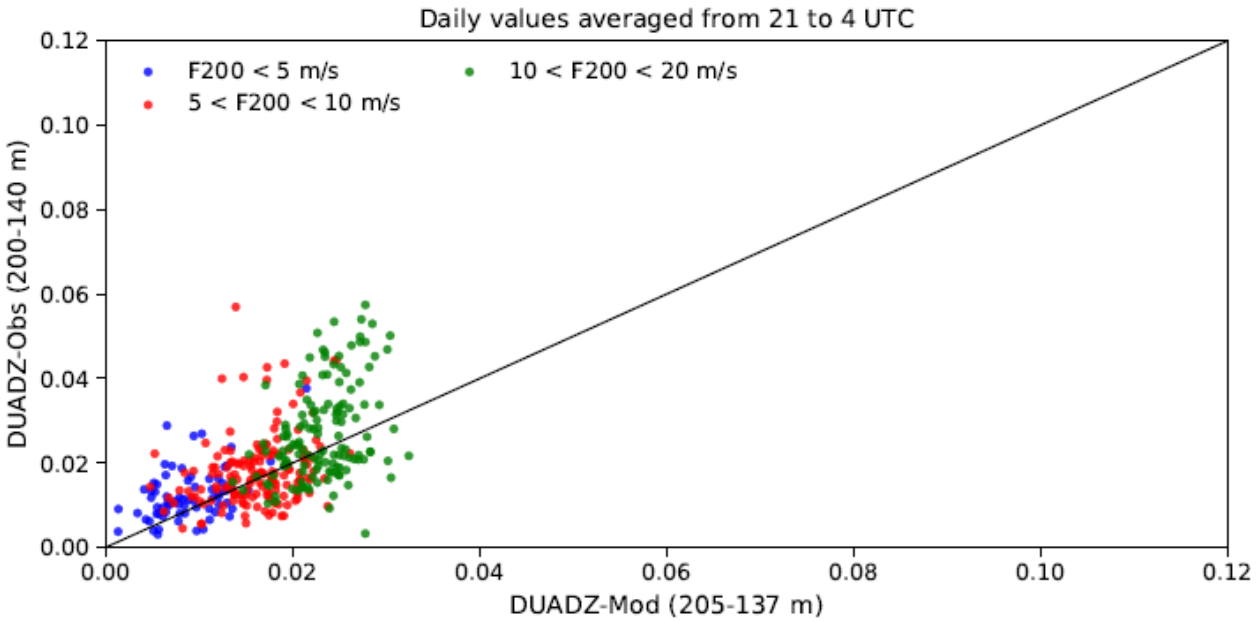
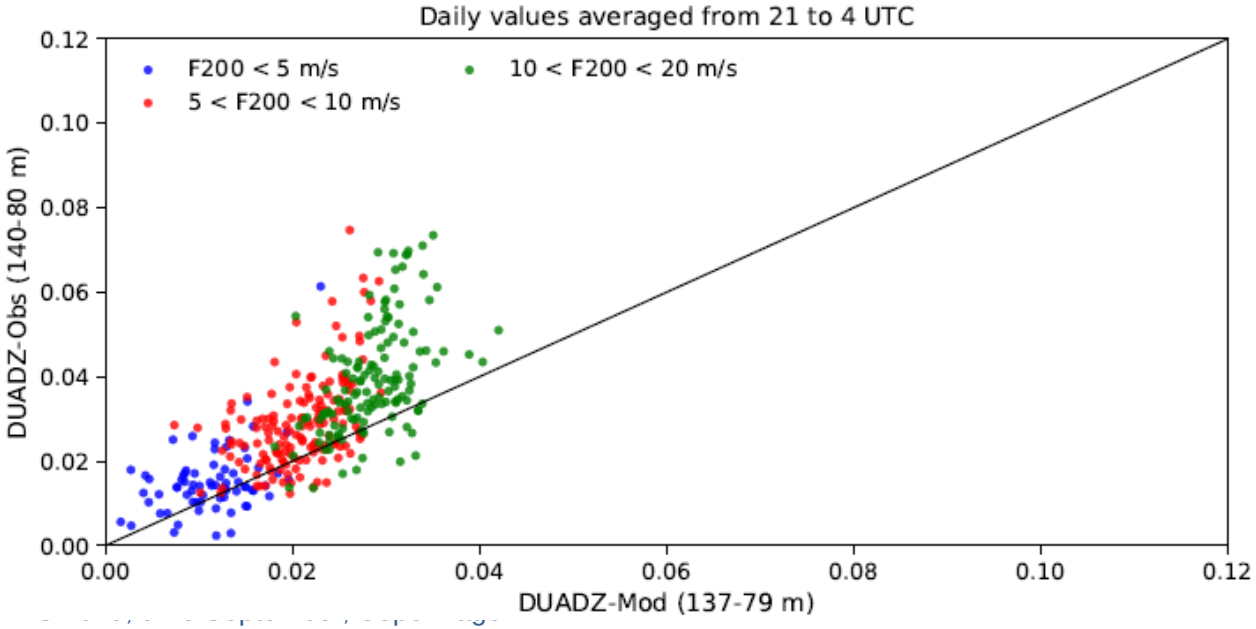


Z=110 m



ECMWF

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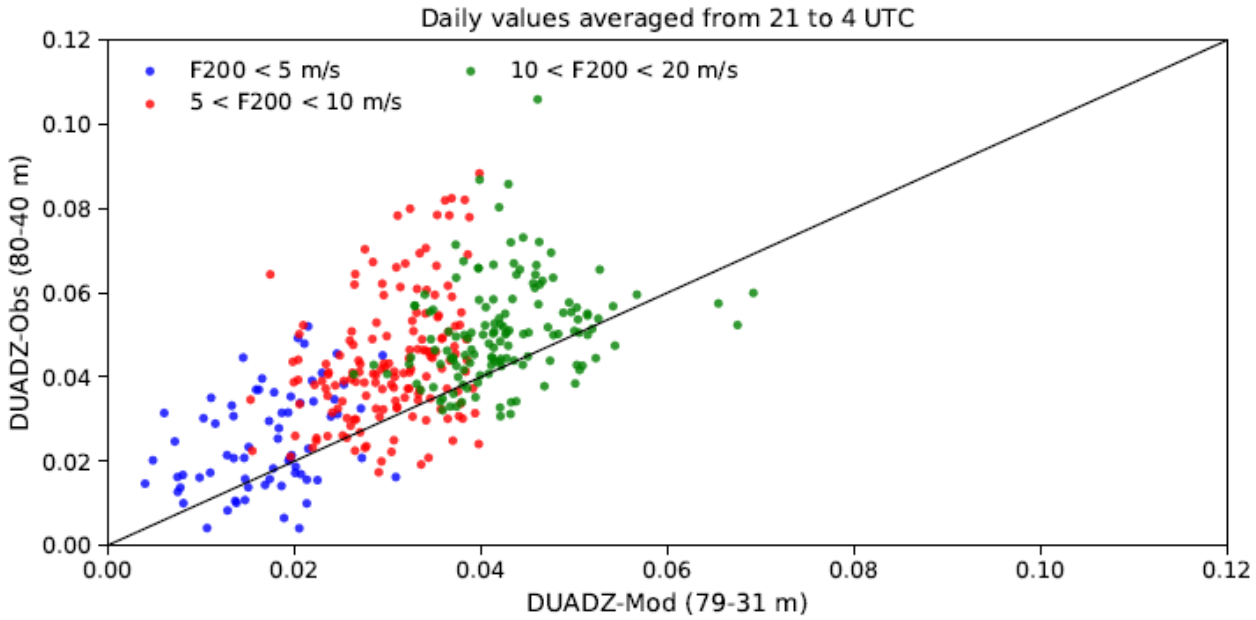

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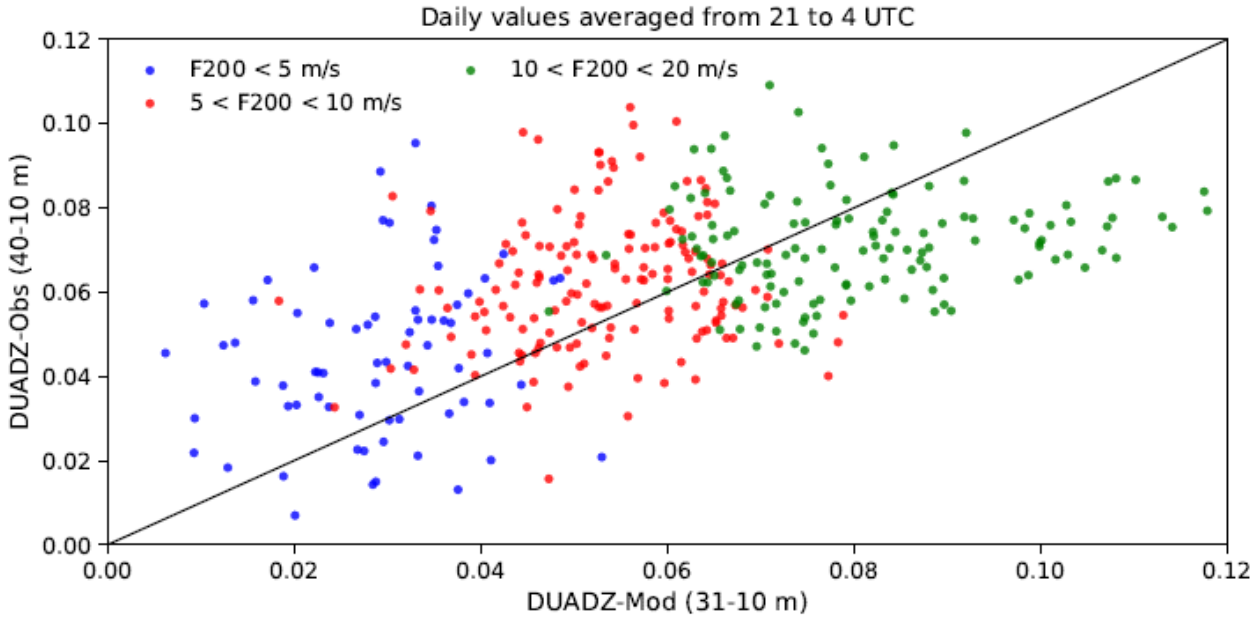
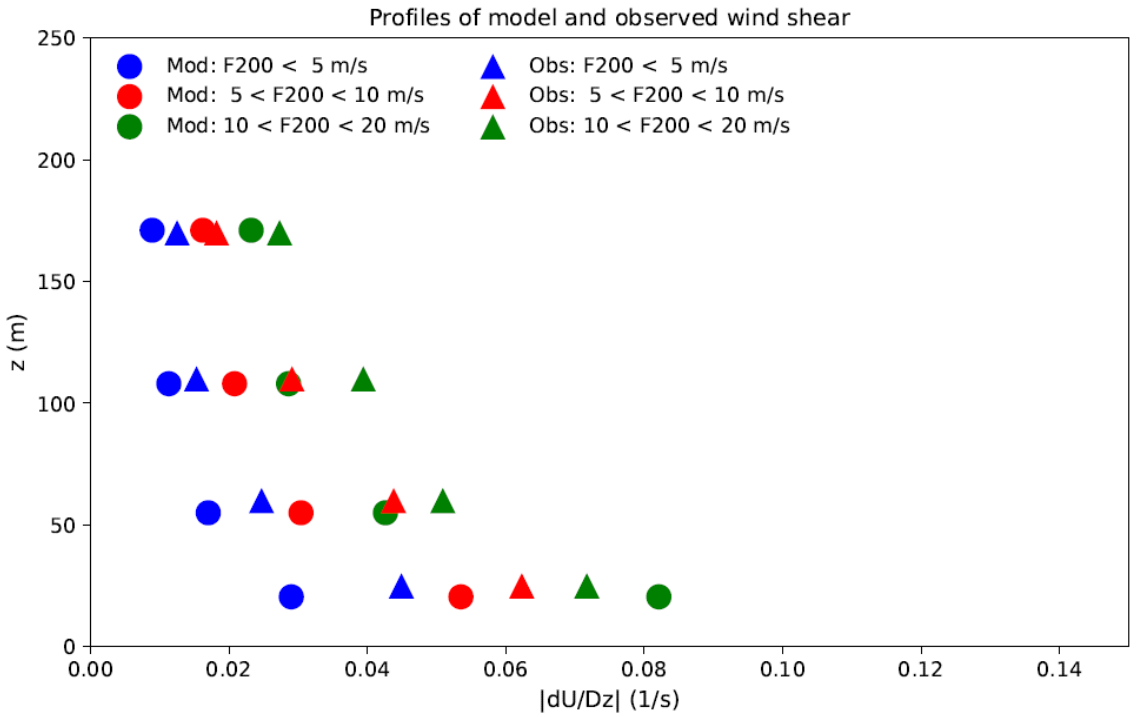
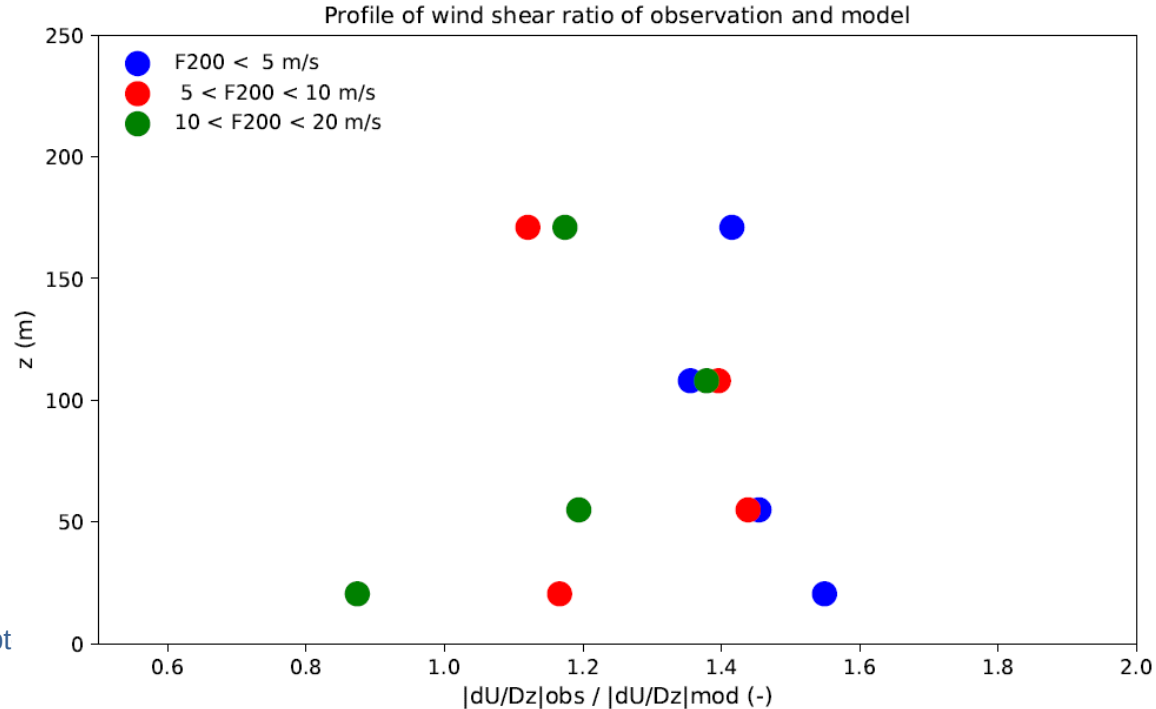


ECMWF

Modelled (dots) and
observed (triangles)
shear profiles
in different wind speed classes of
200m wind (colours)



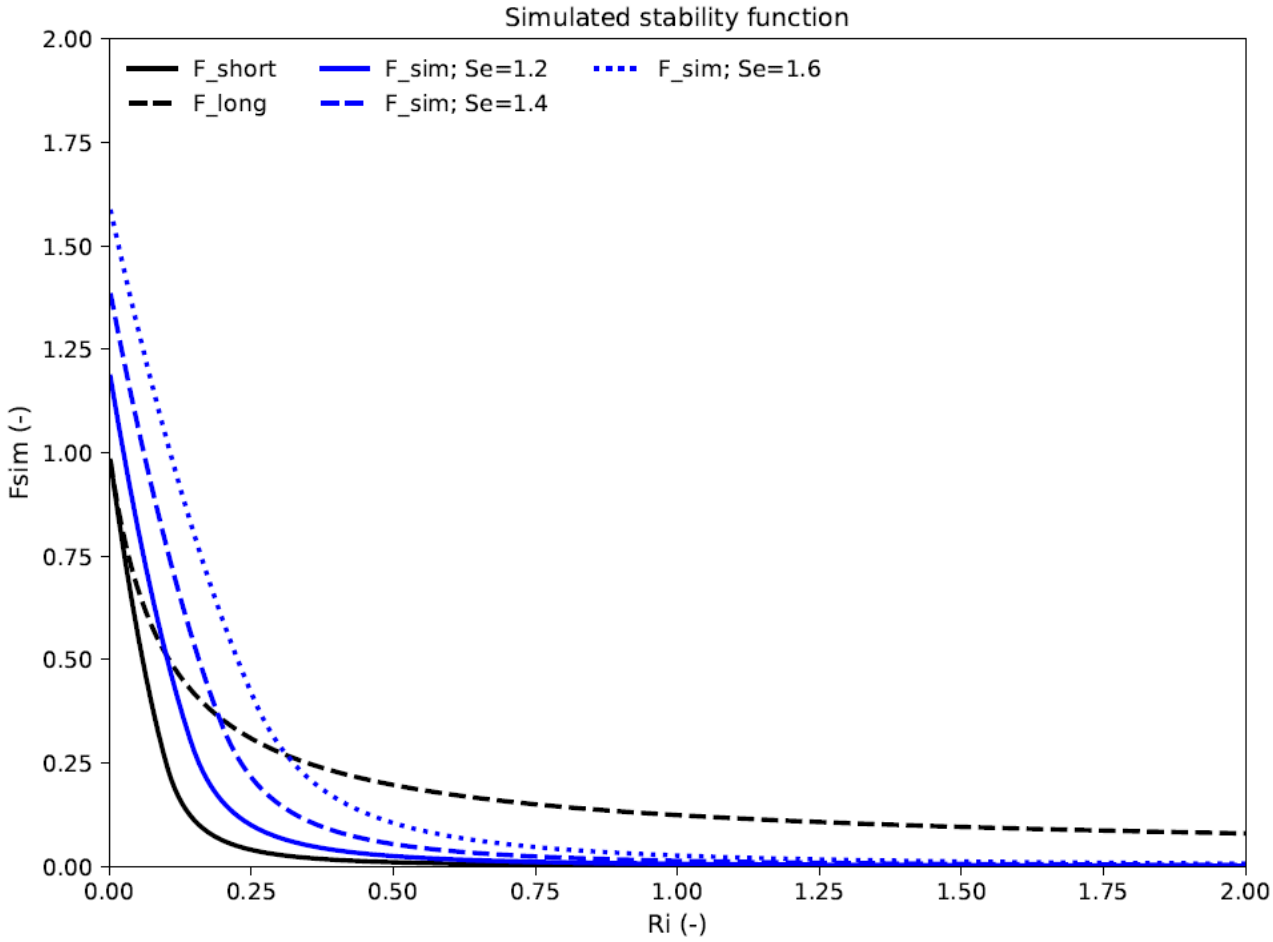
Profiles of
ratio of
observed and
modelled shear
in different wind speed classes of
200m wind (colours)



Simulated stability functions are derived from short tail functions (MO), by enhancing the model shear by a factor S_e according to observations.

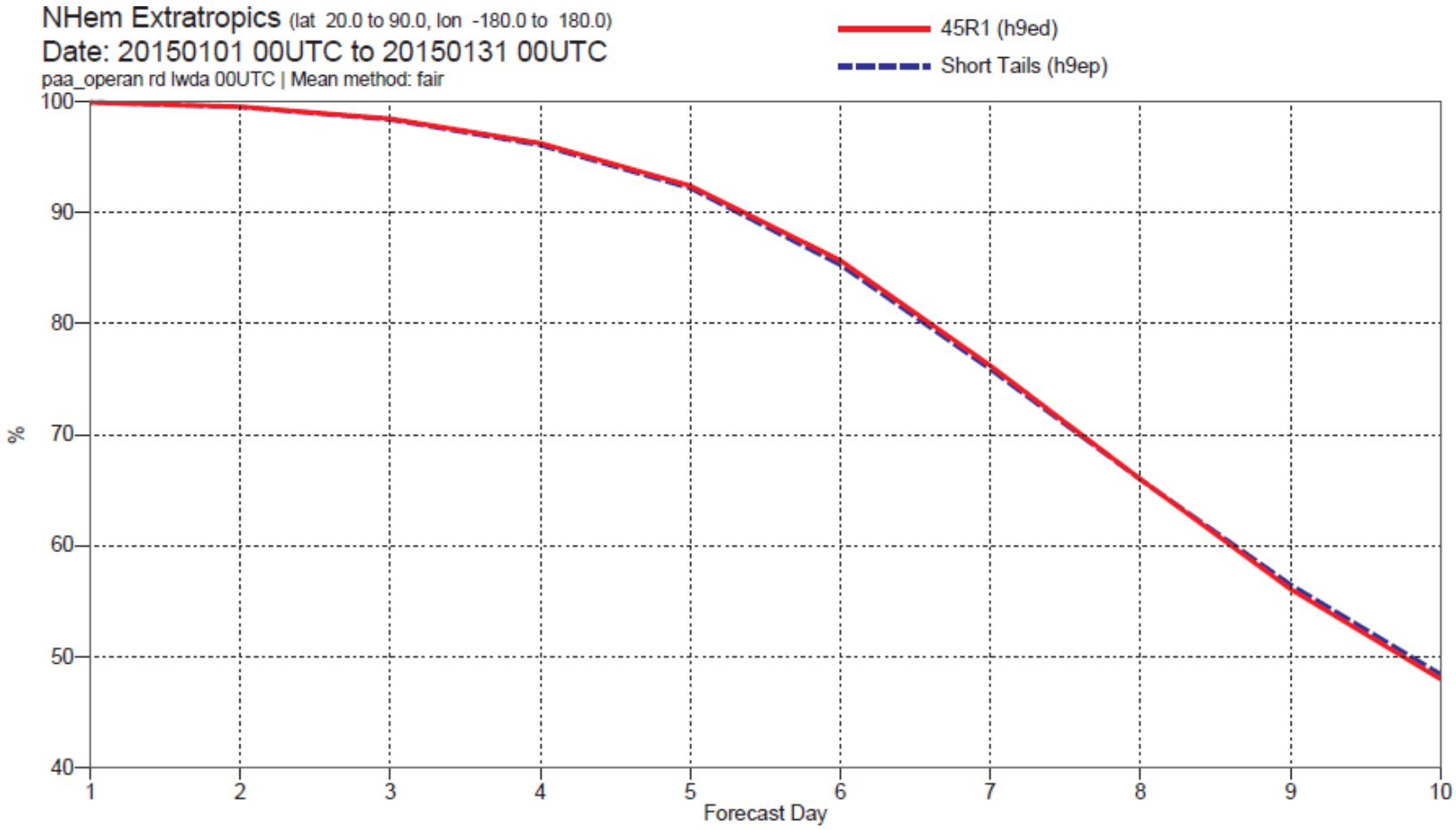
This divides the Richardson number by a factor S_e^2, and multiplies the stability function by a factor S_e

$$F_{sim} = S_e \, F\left(\frac{Ri}{S_e^2}\right)$$



500 hPa anomaly correlation with:

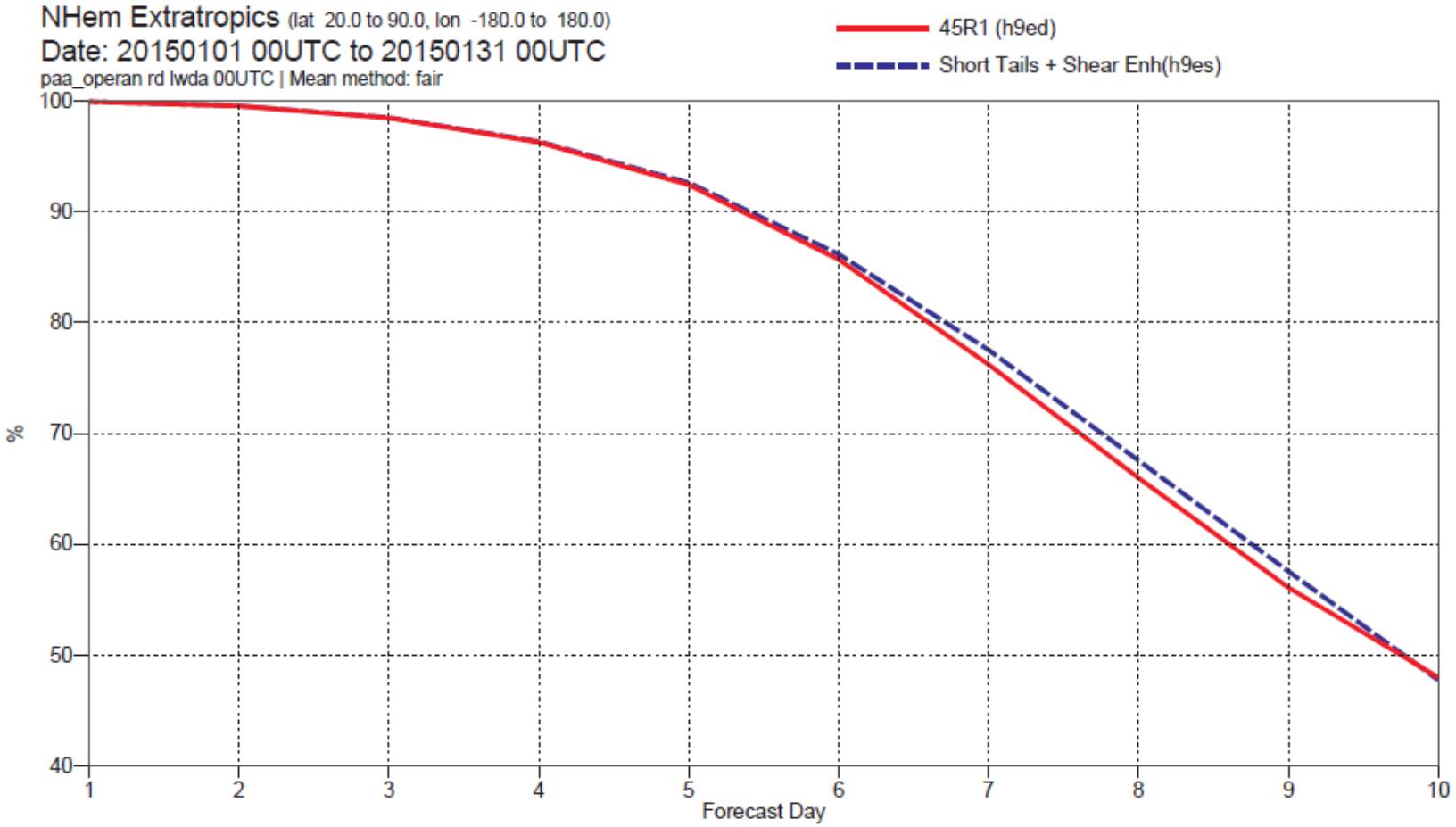
- short tails (dashed)
- long tails (solid)



In recent model version short tails are only slightly worse than long tails

500 hPa anomaly correlation with:

- short tails and shear enhancement factor 1.4 (dashed)
- long tails (solid)



Sort tails with enhanced shear improves with respect to long tails.

Summary

- **Models need more turbulent diffusion in stable situations than can be justified on the basis of observationally based Monin-Obukhov similarity.**
- **Models can use short tail functions over the ocean which suggests that heterogeneous land may be a dominant source of variability**
- **Models lack meso-scale variability and associated shear particularly over orography**
- **The source of meso-scale heterogeneity is not known (e.g. gravity waves, inertial waves?)**
- **Meso-scale variability can be studied by analyzing high resolution simulations, but a large domain is needed to cover large heterogeneous areas**