Wind turning in the boundary layer - observations, reanalysis and CMIP5 models

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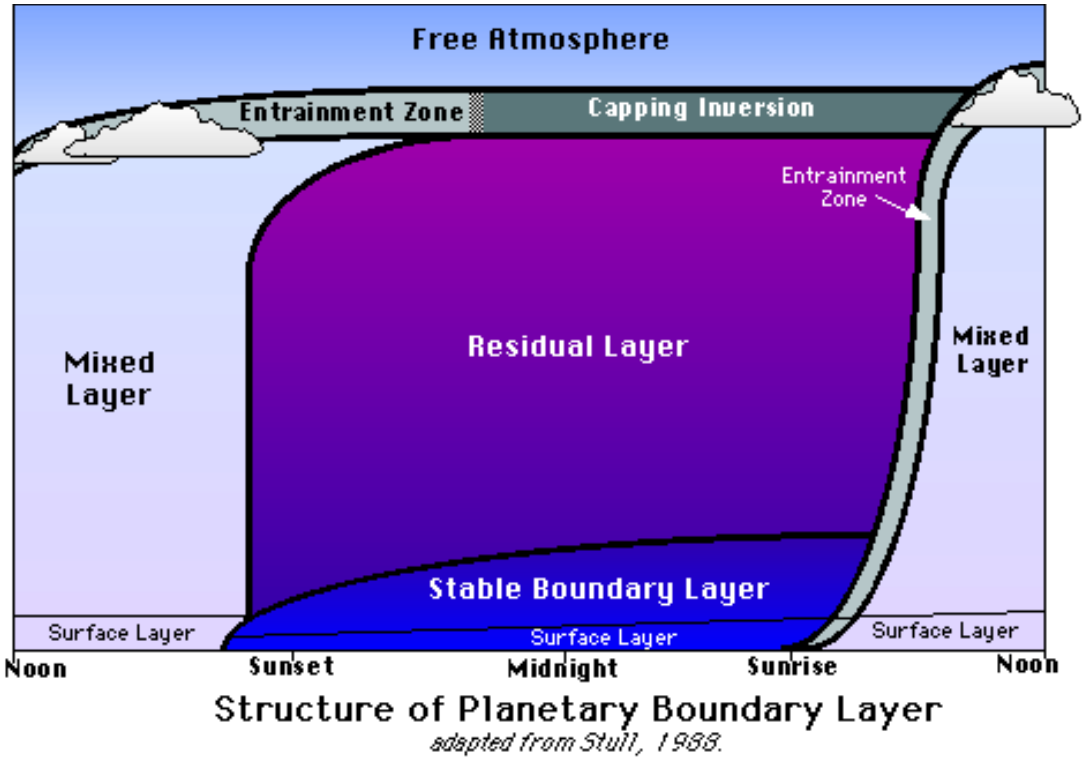
The atmospheric boundary layer

Lowest part of the atmosphere that controls the exchange of heat, moisture, **momentum** etc. at the surface interface

Depth varies between m and km

Always turbulent

Characteristic of diurnal cycles and strong vertical gradients

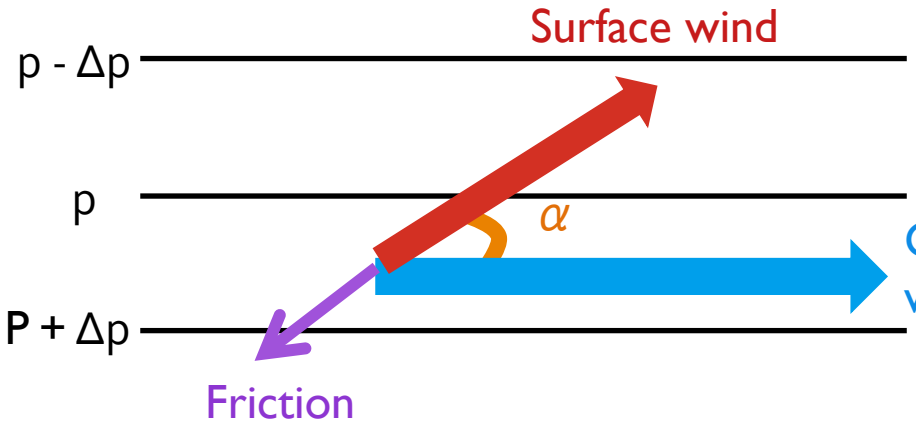


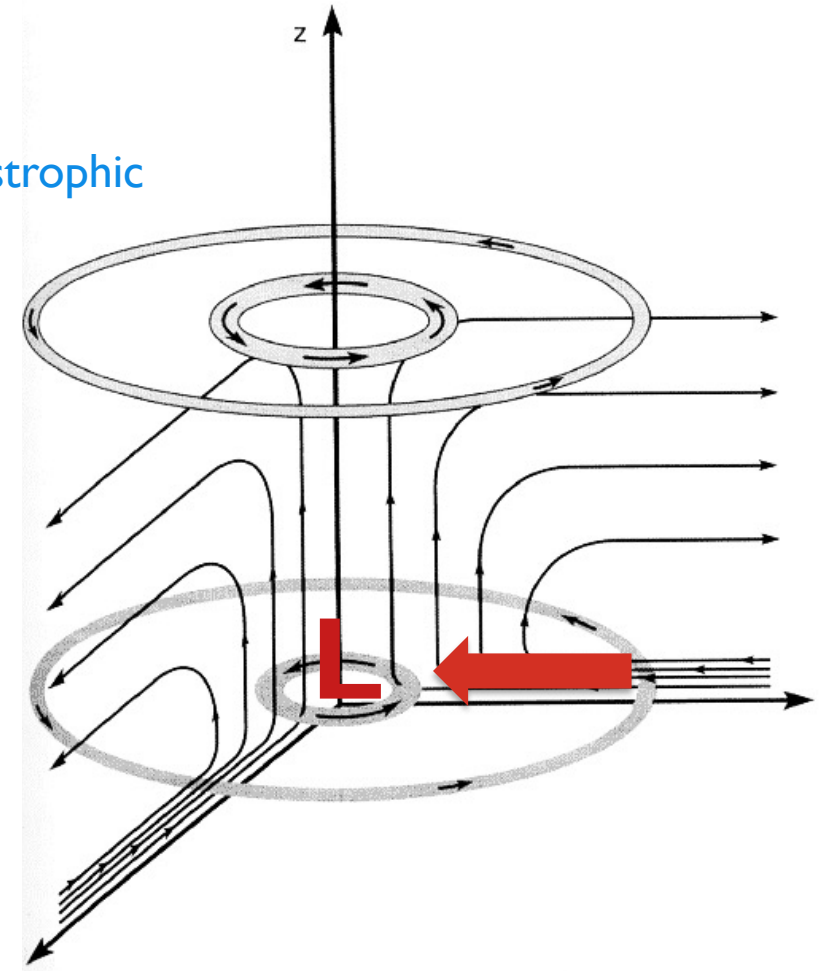
Structure of Planetary Boundary Layer
adapted from Stull, 1988.

Boundary layer processes are still not very well represented in global climate models

Holtslag et al (BAMS 2013)

Wind turning in the boundary layer





- The wind turns towards lower pressure in the PBL due to surface drag
- The angle of wind turning is closely related to the cross-isobaric flow which is important for cyclone development and the large-scale flow
- The wind direction in the PBL matters for weather forecasts, air pollution and the wind energy industry

Wind turning in the boundary layer

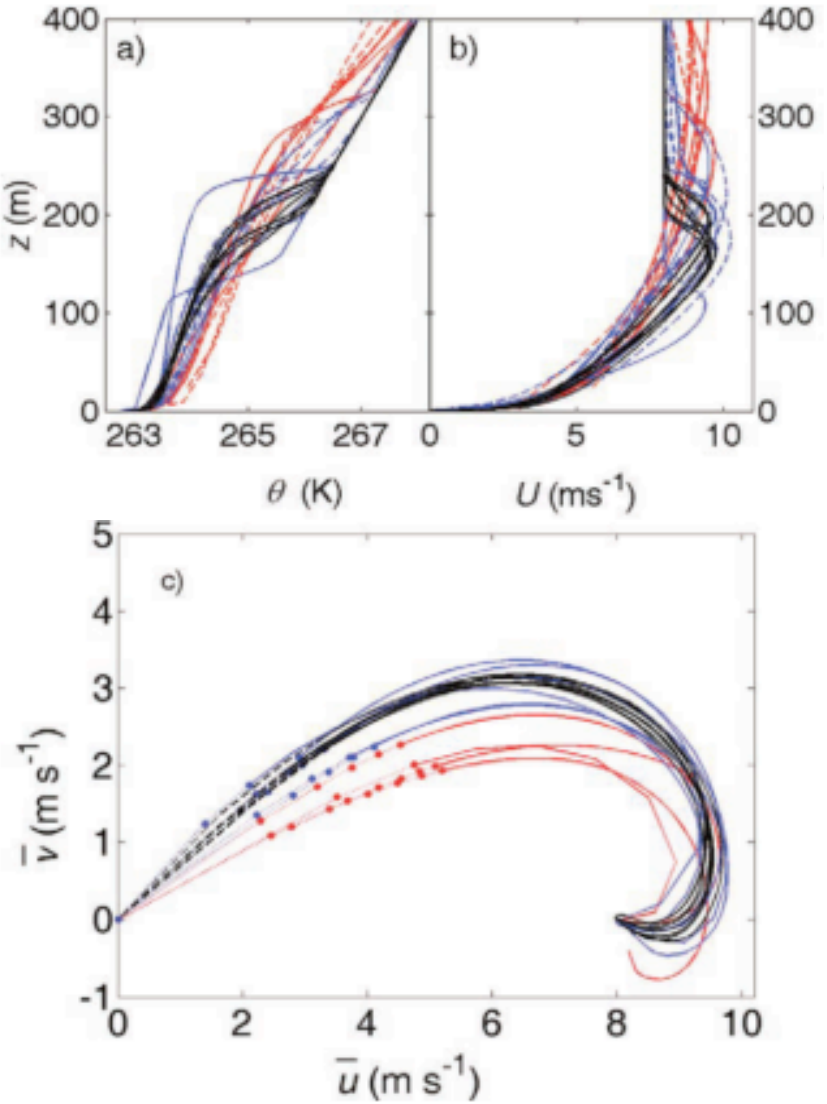
NWP models and some GCMs employ enhanced mixing in stably stratified conditions in order to avoid too much synoptic activity and reduce nighttime cold biases.

Known problems:

- Too large cross-isobaric flow
- Too small wind turning angles
- Too deep stable PBLs

The evaluations are generally based on a few point studies or LES comparisons

Recently climatologies of PBLH has emerged. Can we do something similar for the wind turning?



(Holtslag et al 2013, adapted from Beare et al. 2006, Cuxart et al. 2006 and Svensson and Holtslag 2009)

Data

IGRA

- Soundings at over 1000 locations (681 included)
- Limited vertical resolution
- PBLH from Seidel et al, 2010 (1971-2010) – based on Ri_{bulk}

IGRA stations

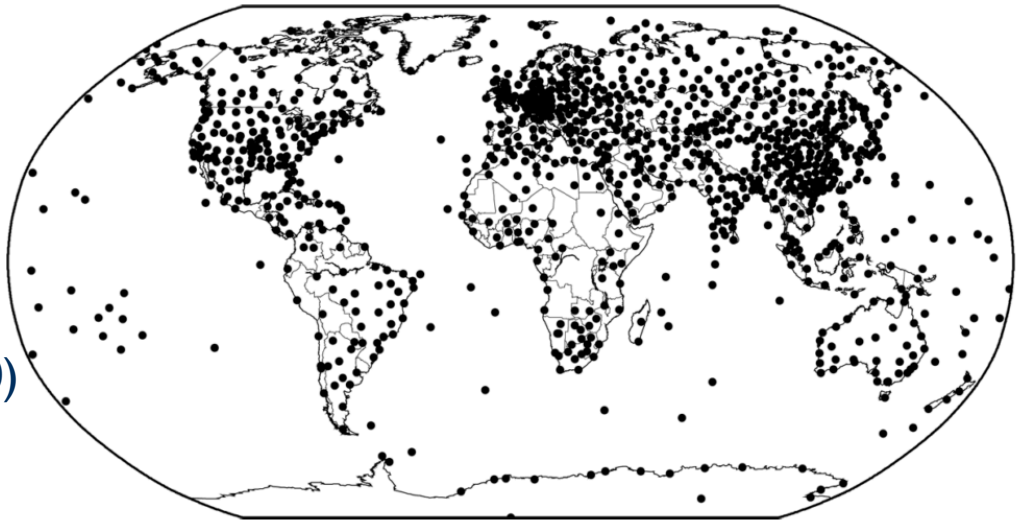
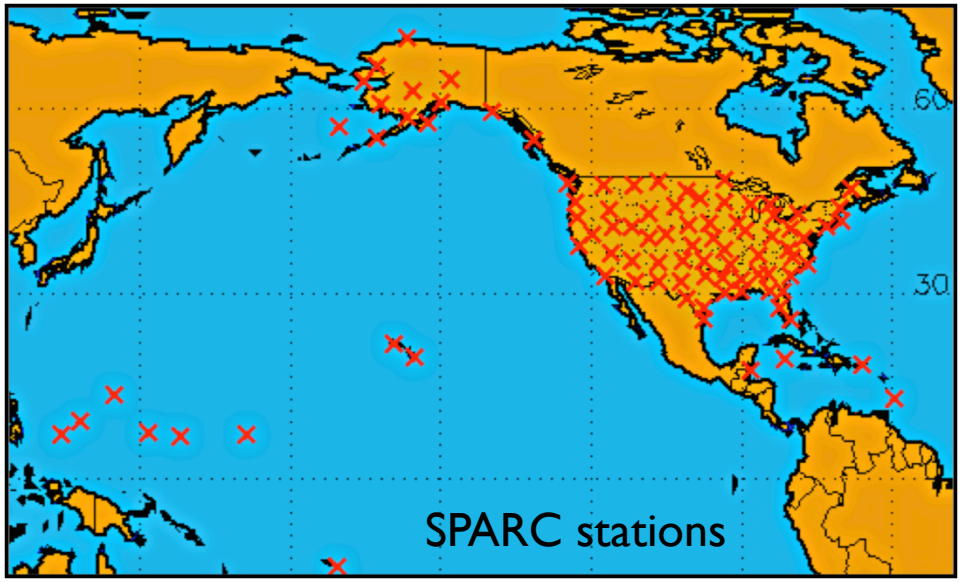


FIG. 1. Map of the locations of stations with derived IGRA data.

SPARC

- High vertical resolution (6 or 1 s)
- Fewer points (US only)
- 1998-2011

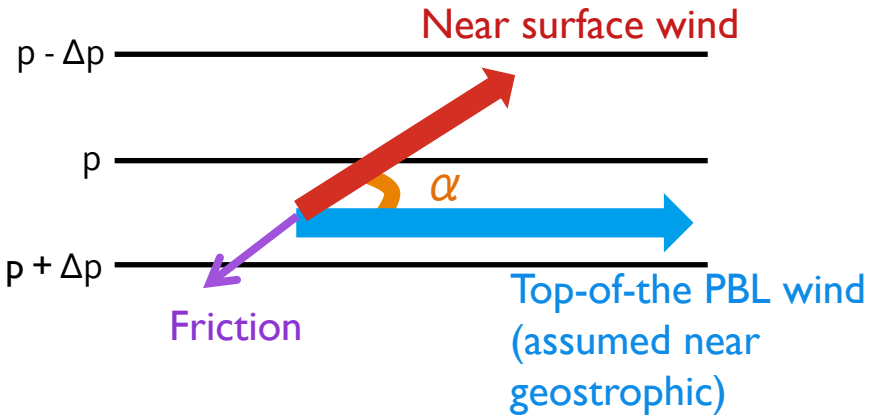


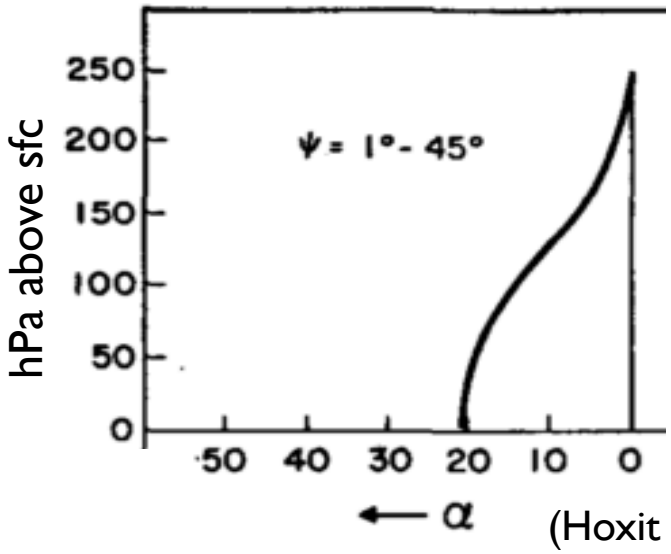
Models

- 6-hourly, global data
- 5 years and 10 models
- CMIP5 data + CESM(CLUBB)
- ERA-Interim

Method

Wind turning angle (approximately the cross-isobaric angle)



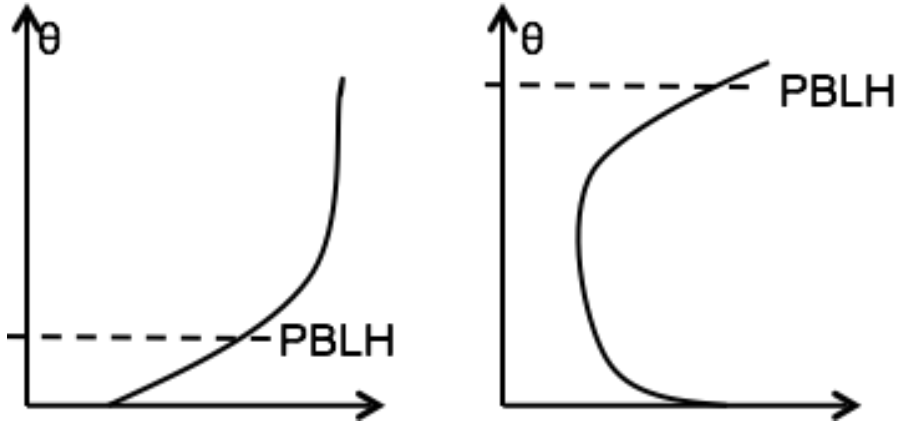


(Hoxit 1974)

PBLH:

Diagnosed using a bulk Richardson number (finding first level where $Ri_{bulk} > 0.25$)

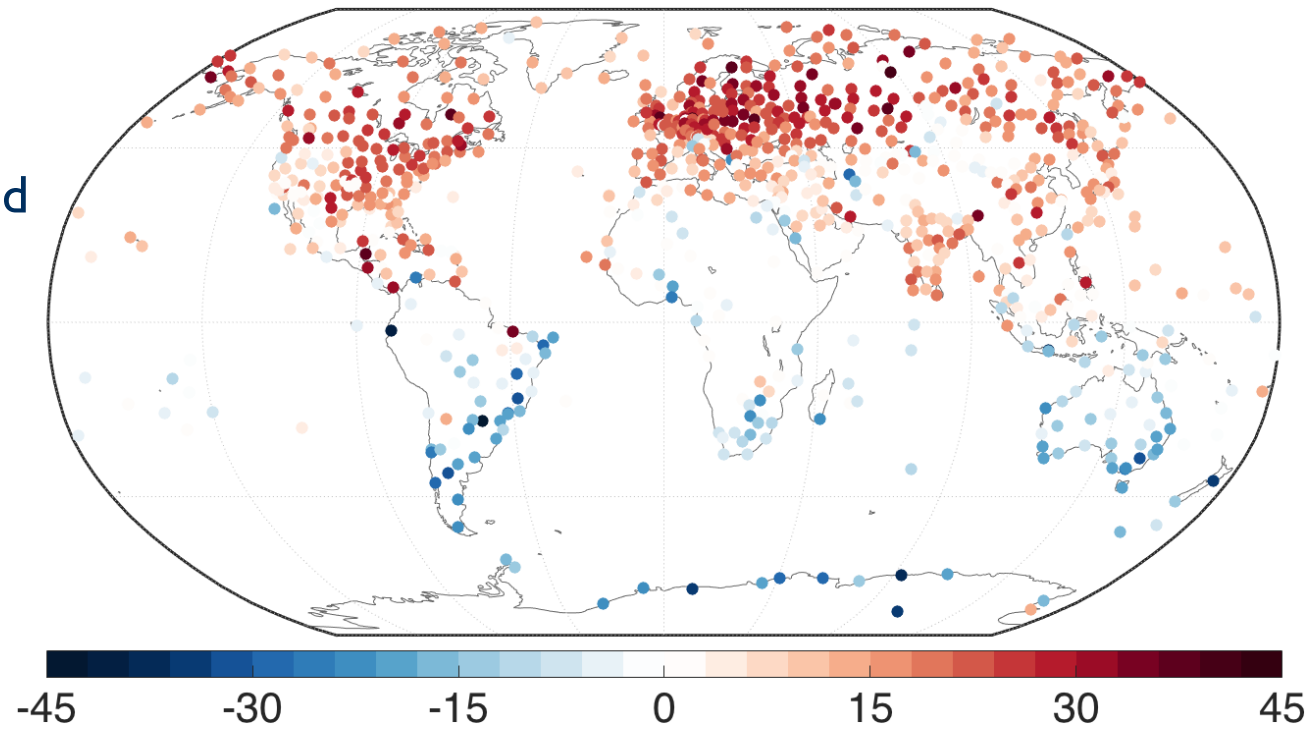
For a fair comparison, the same method is used to calculate the PBLH in the models and observations



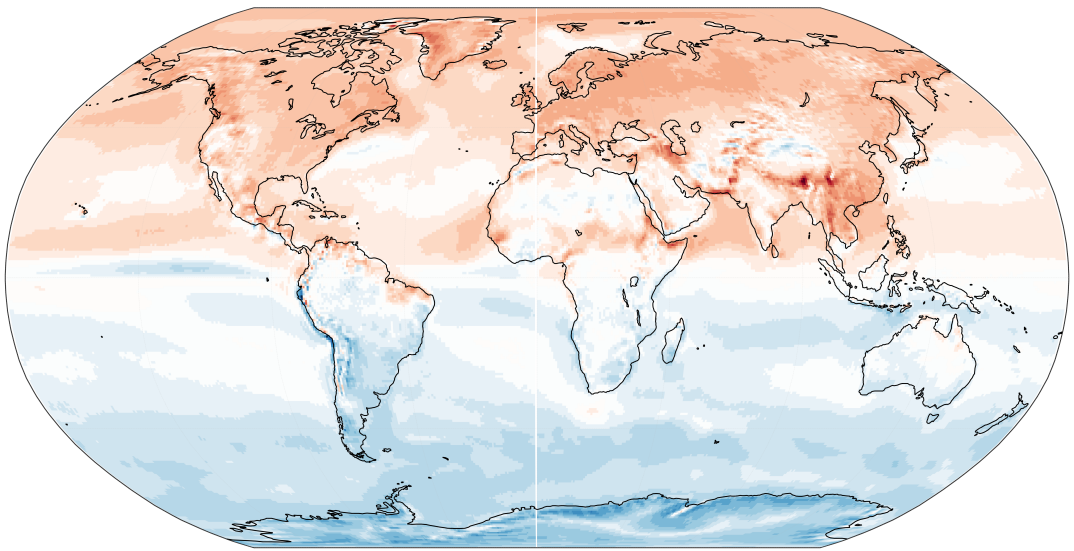
Windturning

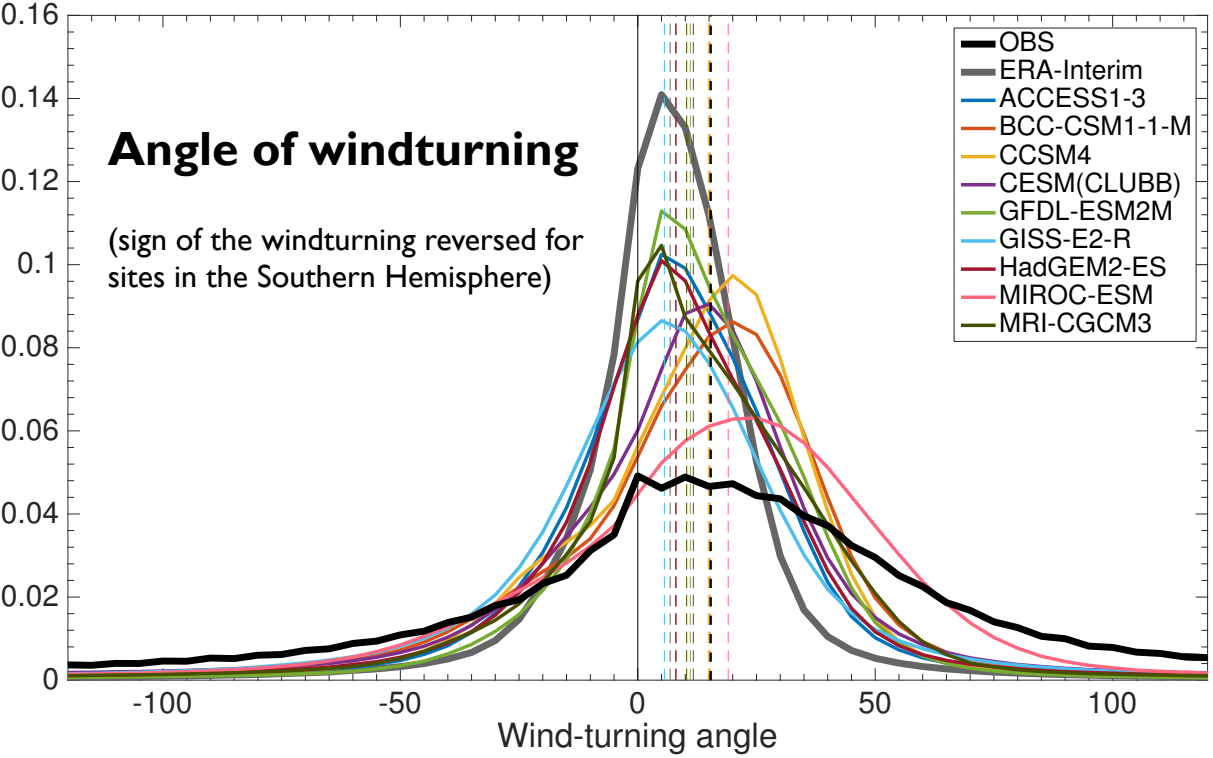
- the angle between surface wind and the wind above the PBL

Observations – annual mean

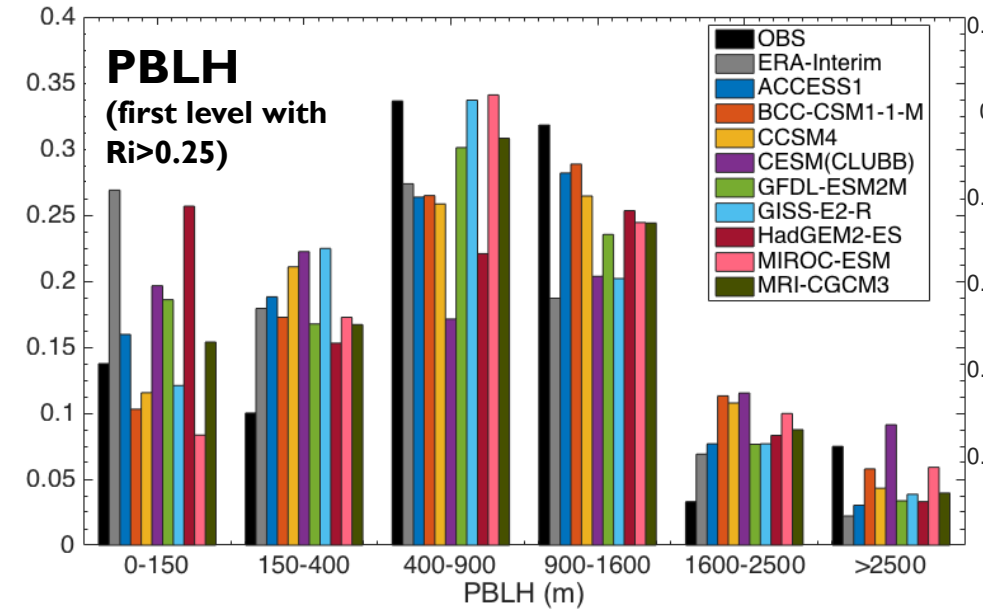


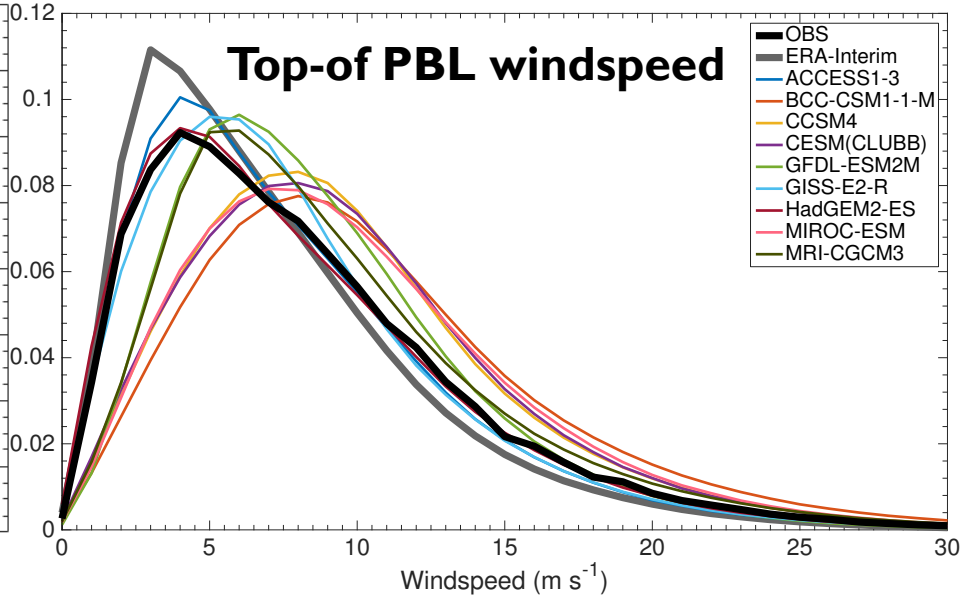
ERA-Interim – annual mean



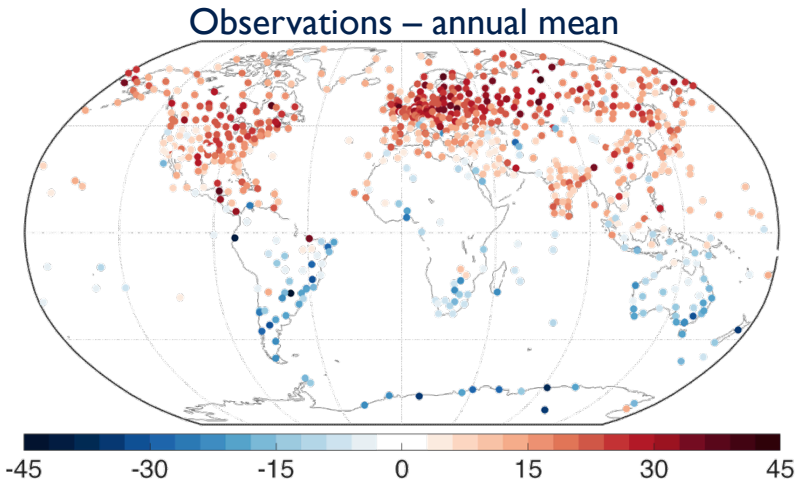


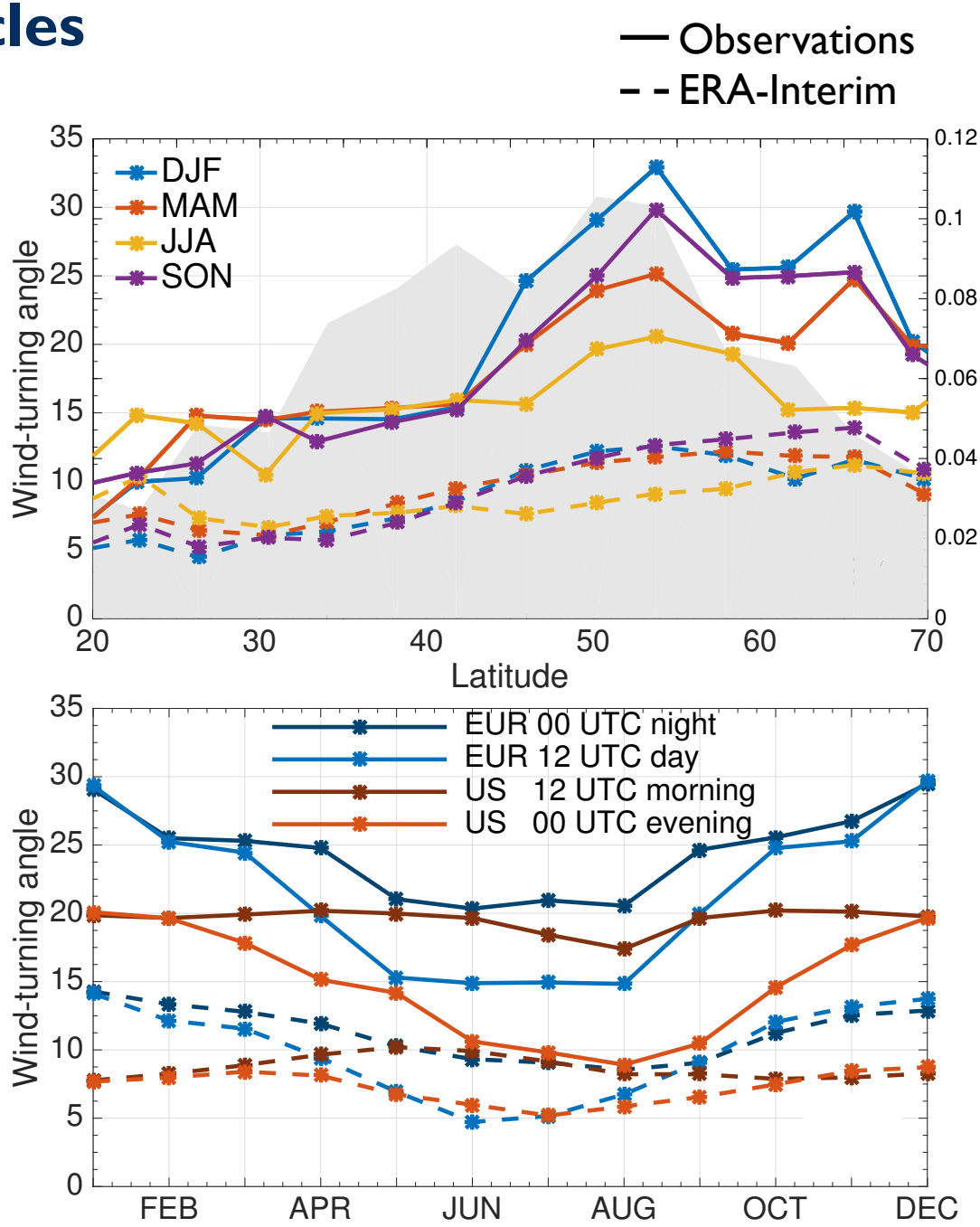
- Models show a narrower PDF and generally smaller angles of windturning
- The models with the largest wind turning tend to have the highest wind speeds





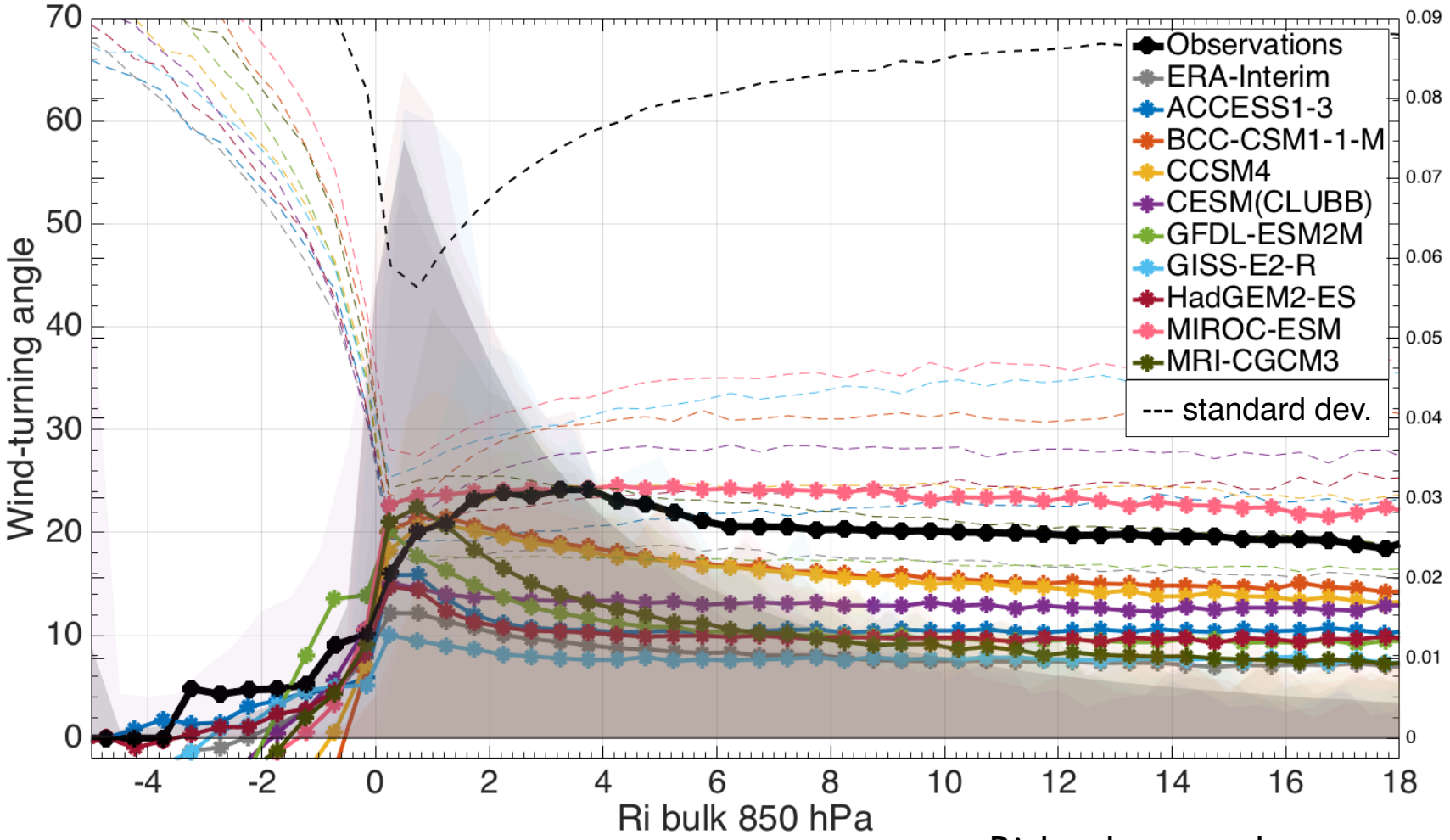
Diurnal and seasonal cycles





What determines the size of the wind turning angle?

– Bulk Richardson number



Wind turning increases with stability

Richardson number:

$$Ri(z) = \frac{(g/\theta_{vs})(\theta_{vz} - \theta_{vs})(z - z_s)}{(u_z - u_s)^2 + (v_z - v_s)^2}$$

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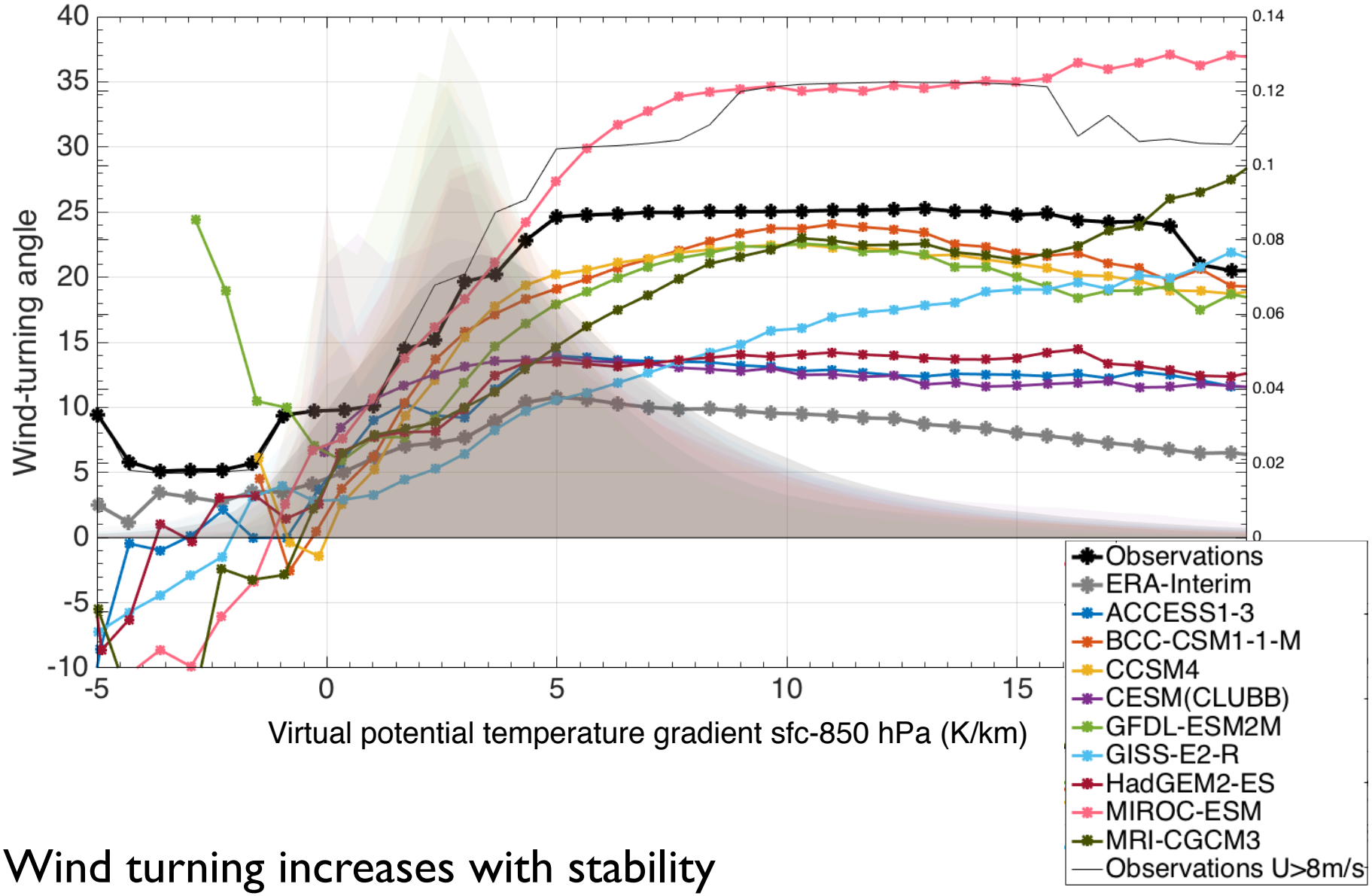

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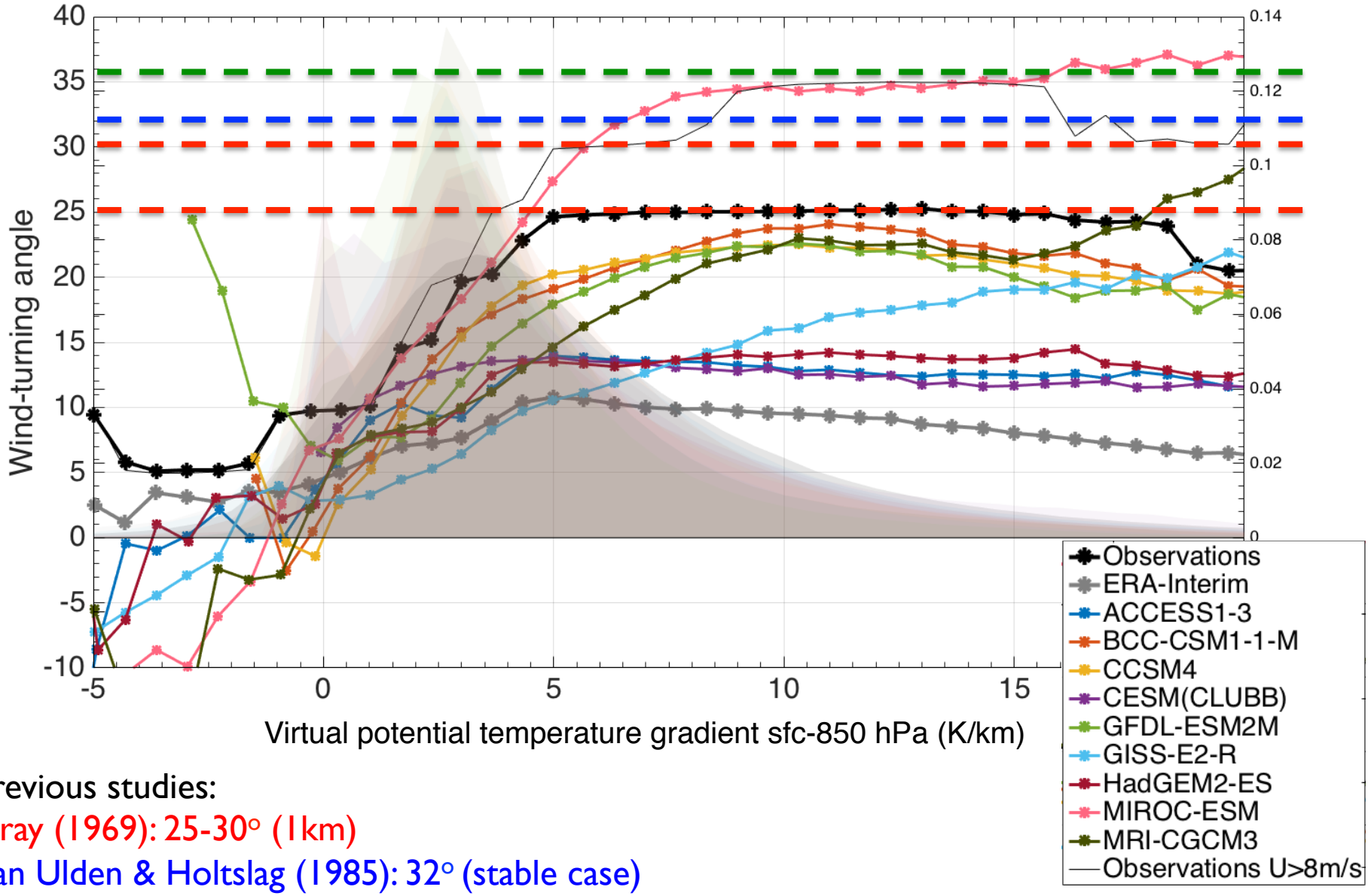


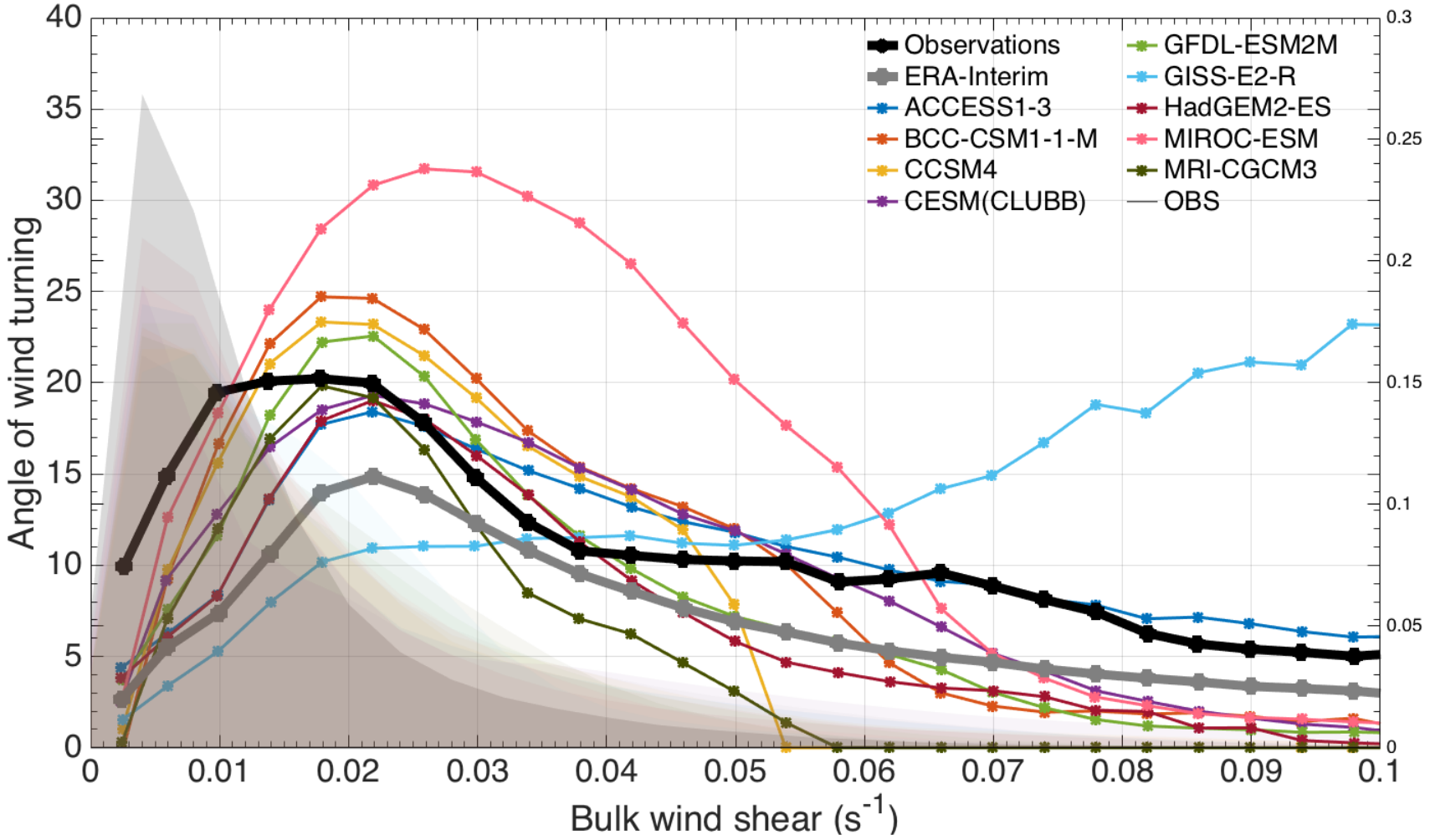
Previous studies:

Gray (1969): 25-30° (1km)

Van Ulden & Holtslag (1985): 32° (stable case)

GABLS1: 36° (LES)

What determines the size of the wind turning angle?



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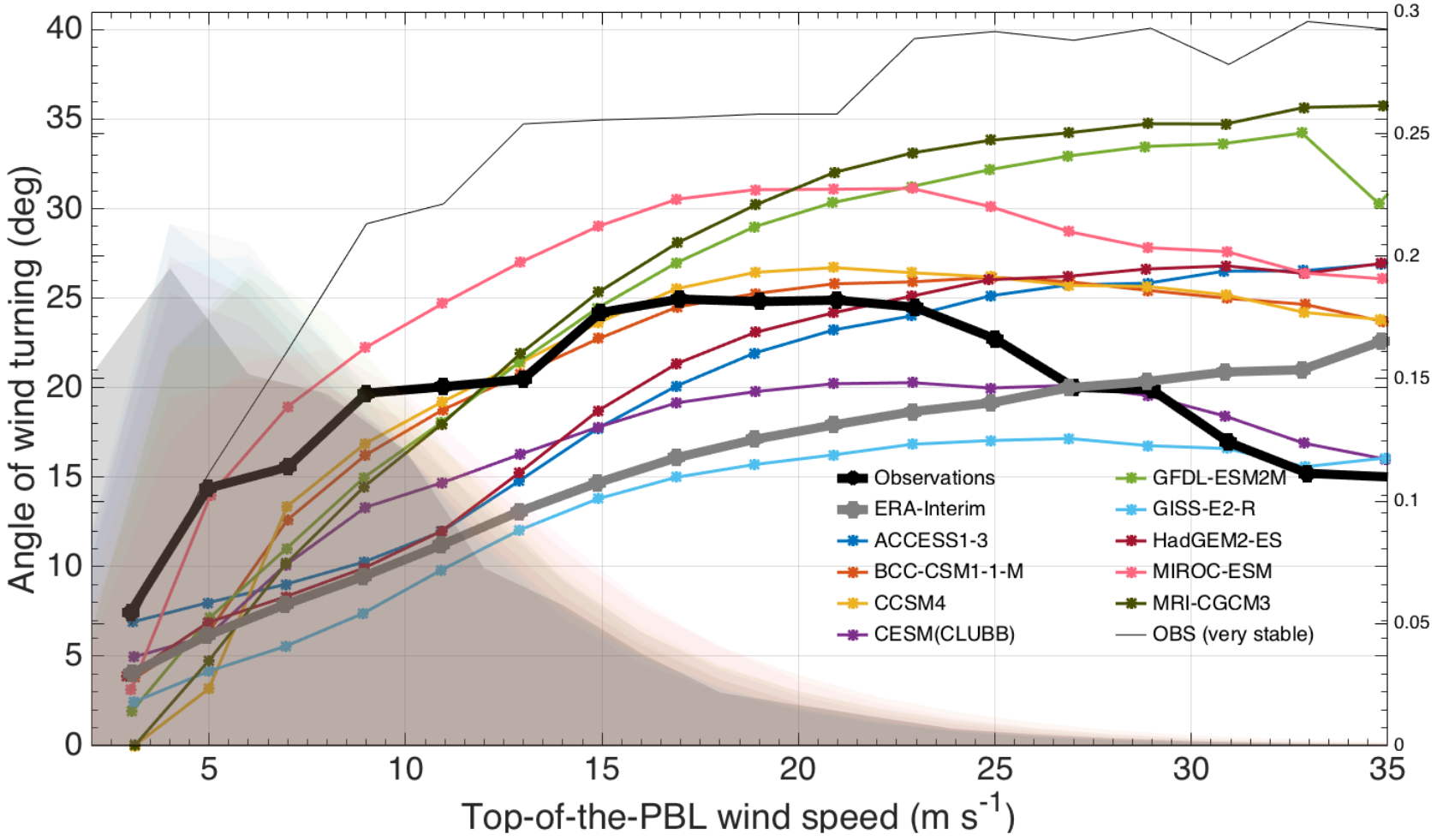
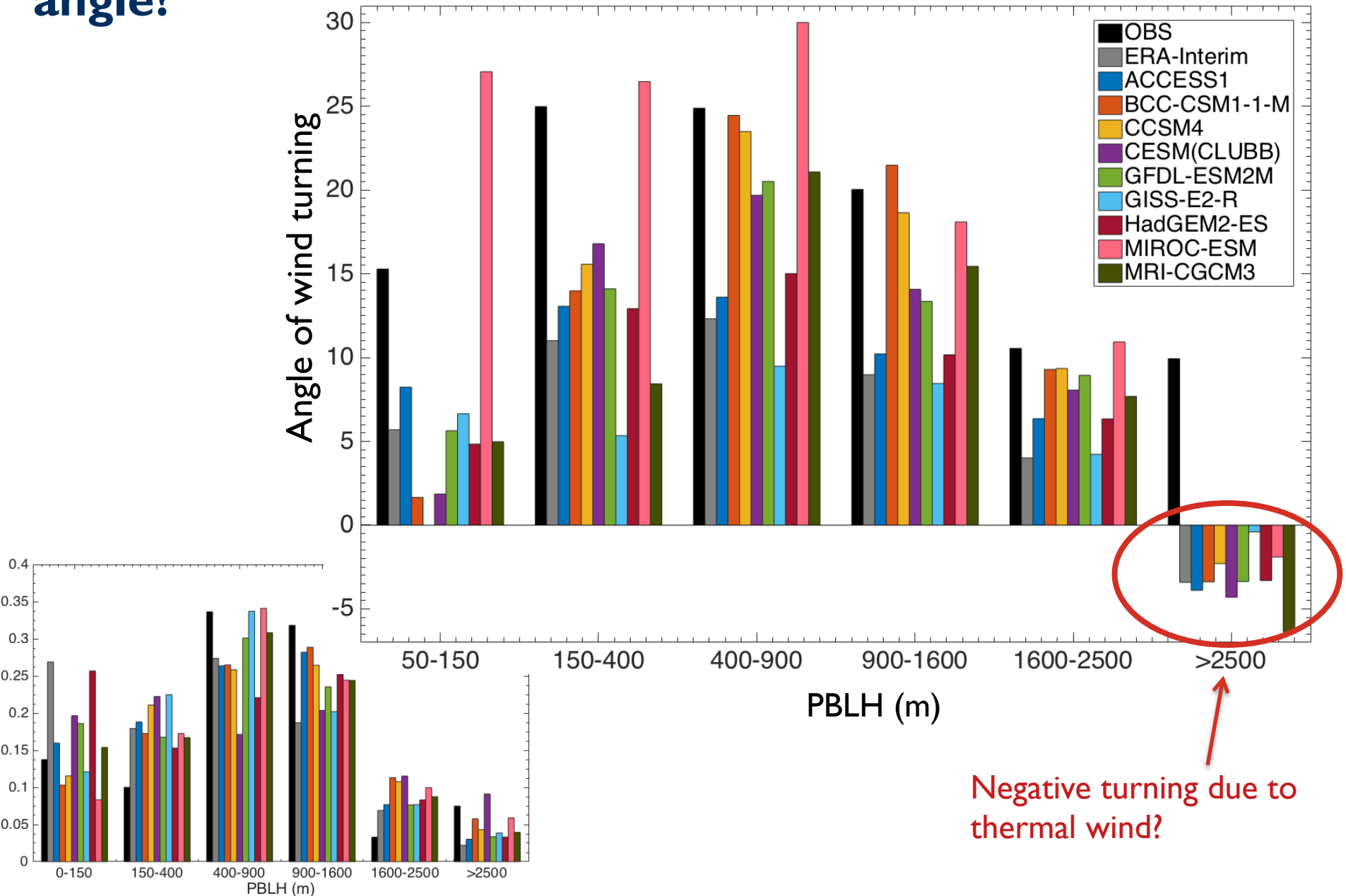


Wind turning tends to mostly increase with wind speed

What determines the size of the wind turning angle?



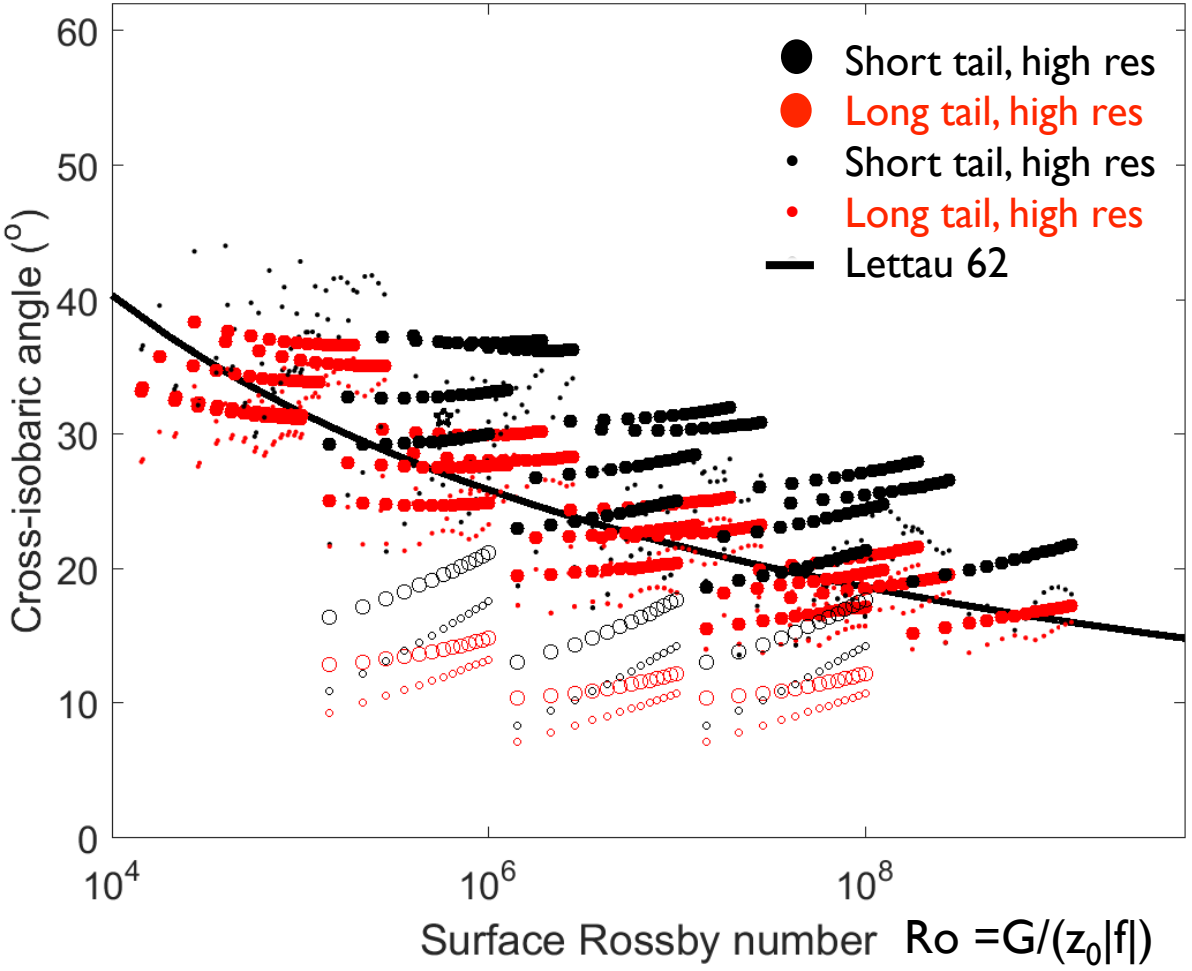
Negative turning due to thermal wind?

Summary

- Radiosondes have been used to derive a climatology of the wind turning in the atmospheric boundary layer
- The wind turning is important for the large-scale flow as well as for getting the right wind direction in the PBL (air pollution, wind energy etc)

- Both the windturning angles and the variations in the windturning are generally smaller in the models than what is observed
- There is a clear diurnal and seasonal cycle as well as a latitudinal dependence
- The angle of windturning increases with stability and with wind speed. This is (more or less) captured by the models
- From what we see right now there is no systematic dependence on the type of PBL scheme or the height of the first model level
- For the cross-isobaric mass flux, wind turning plays only one part, the size of the surface stress is also very important

Idealized model



The wind turning in the model is very sensitive to:

- vertical resolution
- the stability functions

See Svensson and Lindvall poster for further details

Stockholm University

Thank you!