Wind-turning over the atmospheric boundary layer in observations and models

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Evaluation of CMIP5 models

Carbon flux network, 26 sites used here
Long-term surface flux observations

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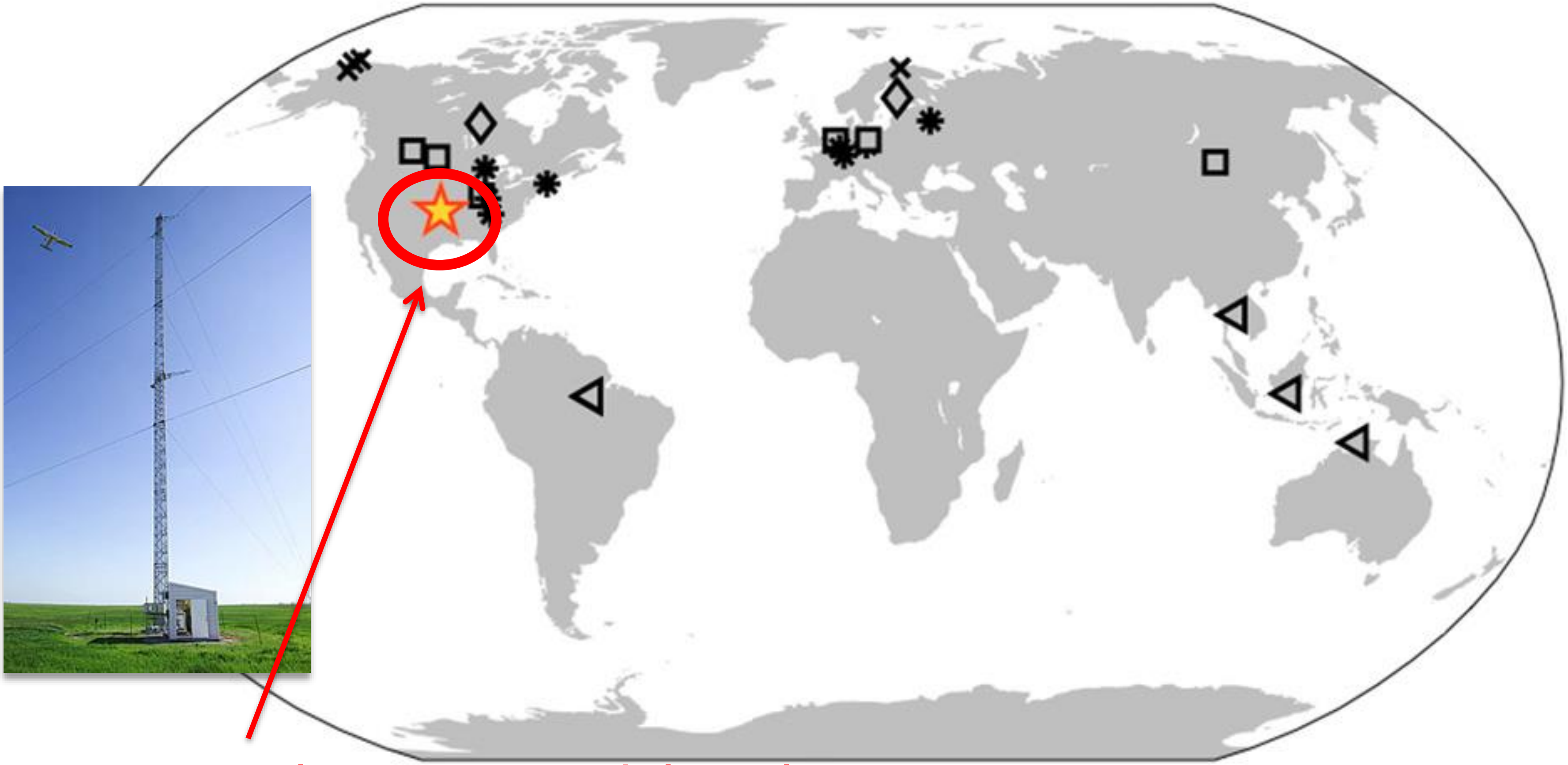


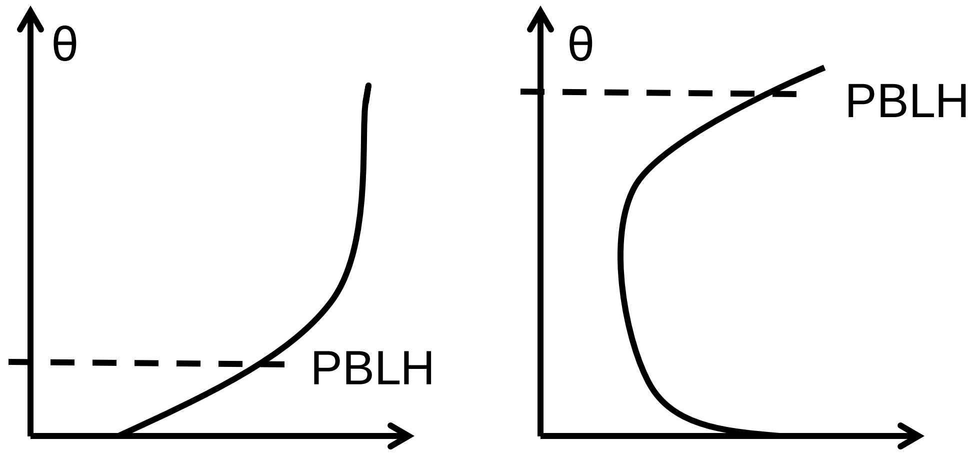
ARM Southern Great Plains site

Six years of measurements
Radiosondes are released four times daily

Svensson and Lindvall, 2015

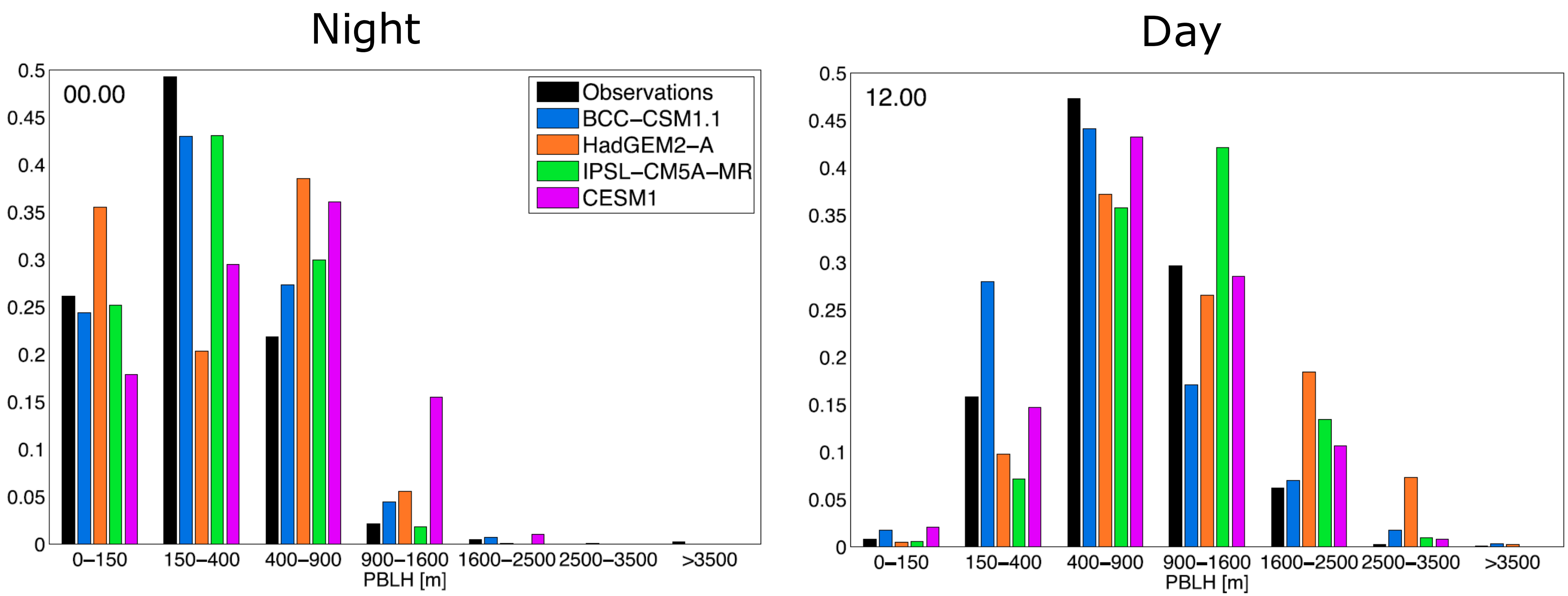
PBL depth estimation

- Diagnosed using a bulk Richardson number (finding first level where $Ri_{bulk} > 0.25$ or 0.30)
- When possible, use friction velocity to improve the estimate following Vogelezang and Holtslag (1996)
- For a fair comparison, the same method is used to calculate the PBLH in the models and observations



Evaluation of CMIP5 models

ARM Southern Great Plane

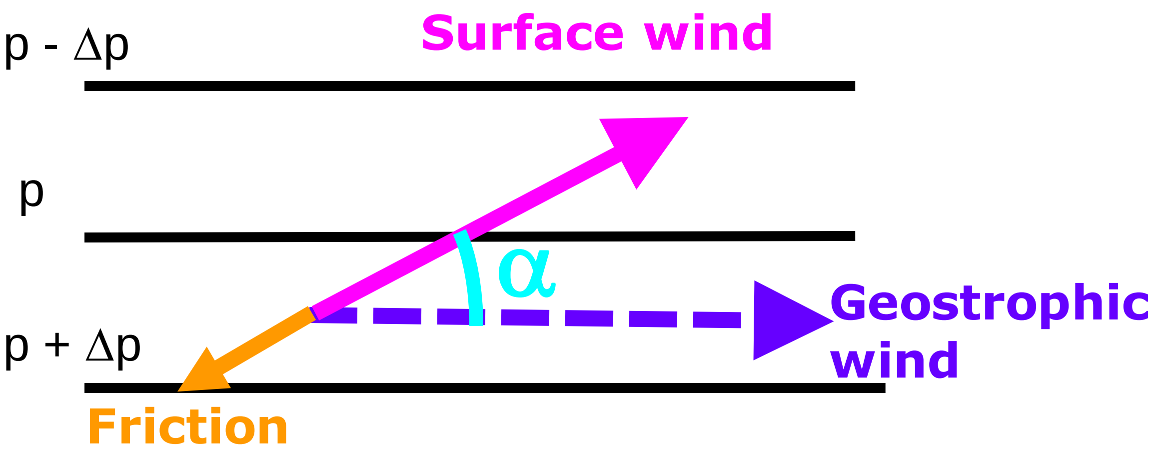


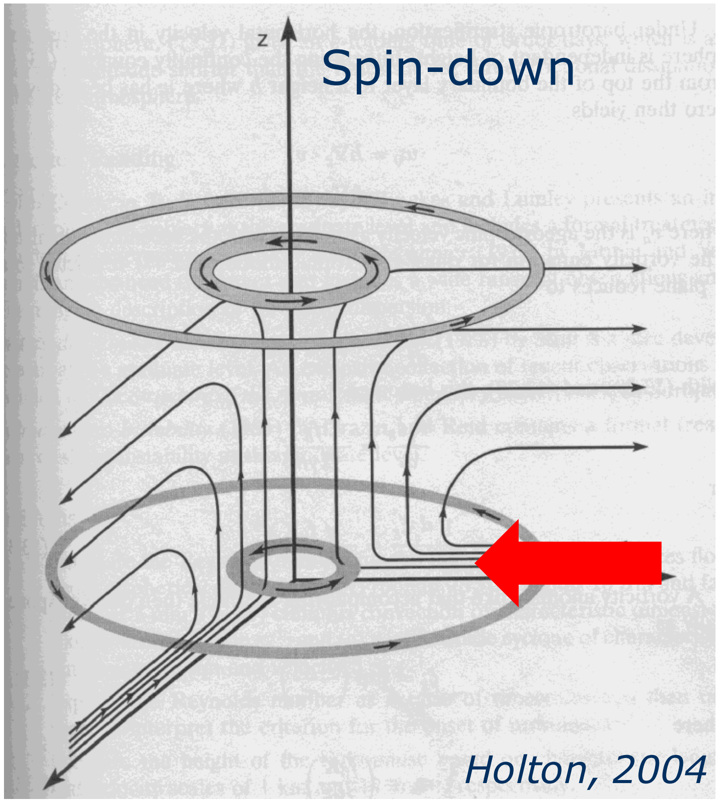
PBL height (m) overestimated by the models

⟹ friction is also overestimated

Svensson and Lindvall, 2015

The ageostrophic flow





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

Ekman layer equations

Provide a relation between the surface angle and the ageostrophic flow

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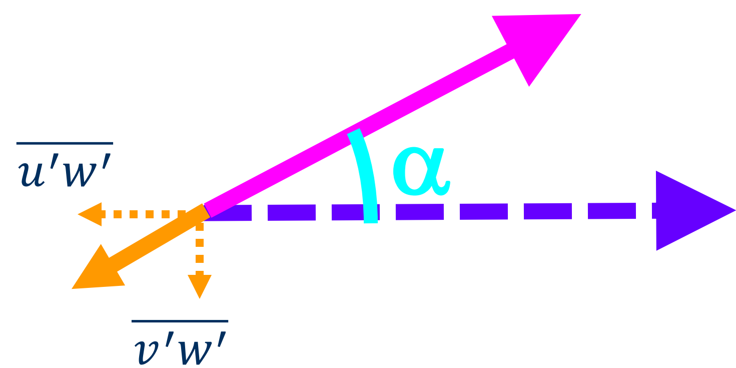
$$\frac{d\overline{u}}{dt} = f(\overline{v} - v_g) - \frac{\partial \overline{u'w'}}{\partial z},$$
$$\frac{d\overline{v}}{dt} = -f(\overline{u} - u_g) - \frac{\partial \overline{v'w'}}{\partial z},$$

Assume steady-state and v_g=0, then the cross-isobaric flow is given by:

$$f\overline{v} = \frac{\partial \overline{u'w'}}{\partial z}.$$

Integrating over the atmospheric column, note that $\overline{u'w'}$ =0 above the boundary layer:



$$\boxed{f\int_0^\infty \overline{v}dz = -\overline{u'w'}_0,}$$

Svensson and Holtslag, 2009

Evaluation of CMIP5 models

ARM Southern Great Plane

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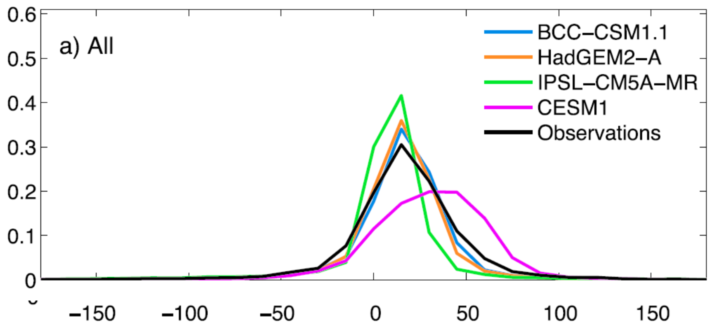


Wind turning over the PBL (°)

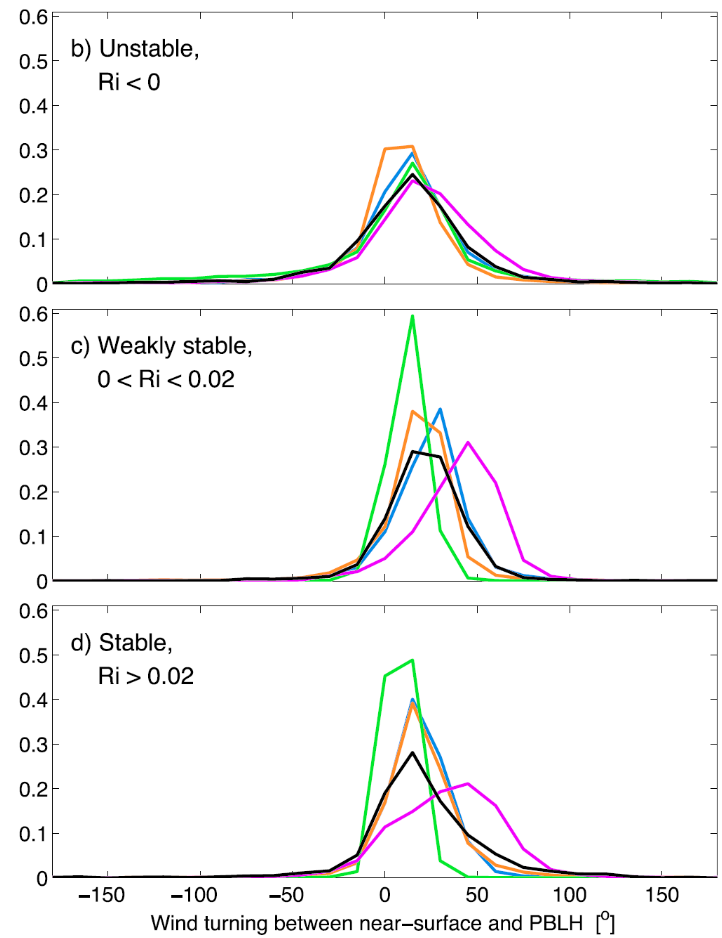


TABLE 5. Mean values of the surface stress in the direction opposite to the geostrophic wind ($-\overline{u'w'_0}$) for the different stratification categories. See text for details.

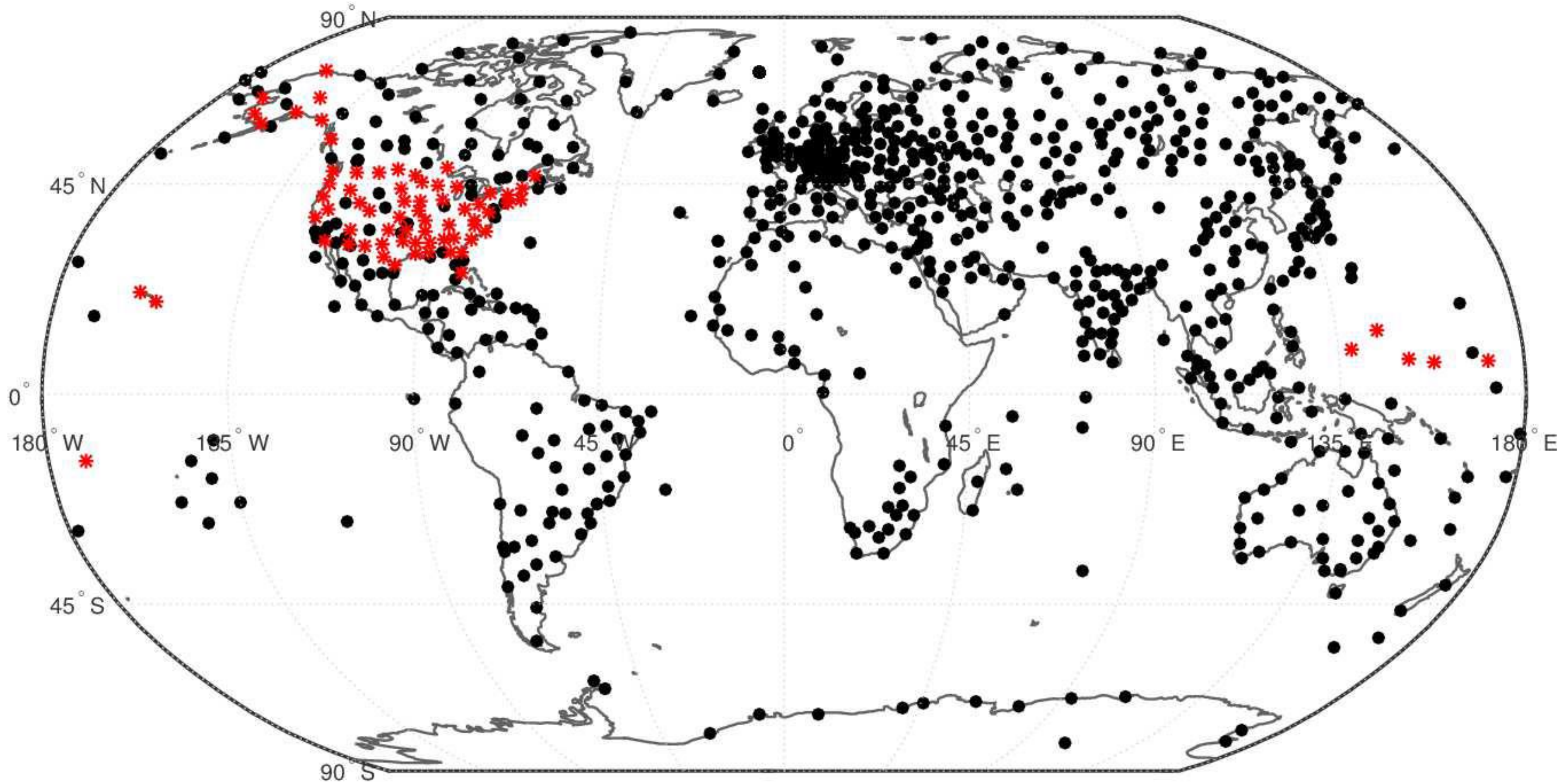
	All	Unstable	Weakly stable	Stable
Observations	0.11	0.15	0.16	0.03
BCC_CSM1.1	0.22	0.30	0.39	0.10
HadGEM2-A	0.22	0.33	0.31	0.08
IPSL-CM5A-MR	0.19	0.21	0.36	0.10
CAM5	0.22	0.35	0.35	0.09

Svensson and Lindvall, 2015

How can we use observations to better constrain models?

- Lack of direct global measurements of surface drag
- Over ocean, there are scatterometer data that providethe low-level winds, however, these observations rely on similarity theory to get the stress vector
- Over land there are local observations of the surface friction, but no area coverage – and there are more processes (surface heteorogeneity, orography, gravity waves, etc)
- Wind-turning over the boundary layer, the cross-isobaric angle, can be analyzed as a measure of the ageostrophic flow in the PBL

Observations



IGRA

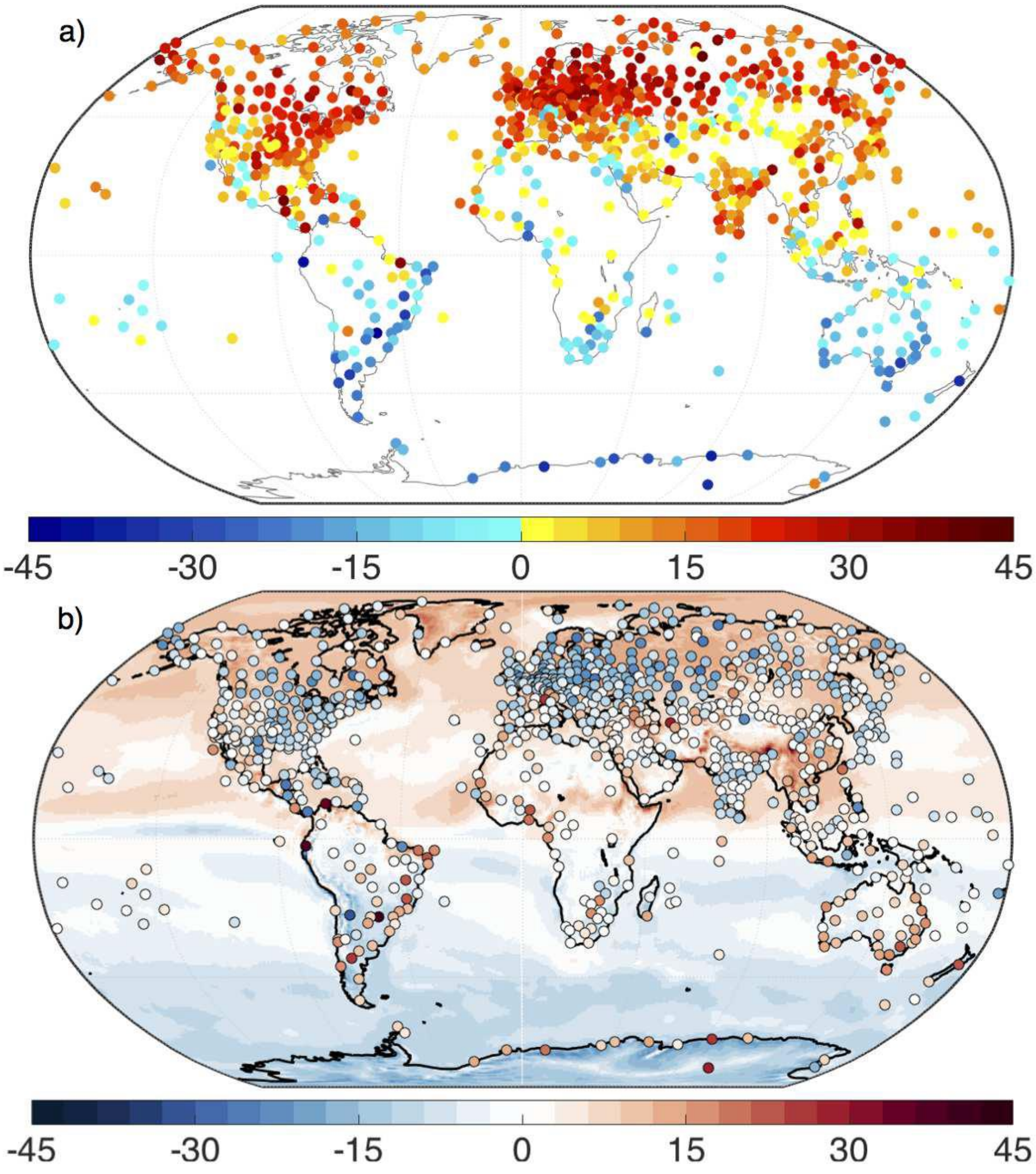
- Soundings at over 1000 locations (681 included)
- Limited vertical resolution
- PBLH from Seidel et al, 2010 (1971-2010)

SPARC

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

Lindvall and Svensson, 2019

Wind turning over PBL
Climatology



Observations

ERA-Interim

Lindvall and Svensson, 2019

Variation with latitude and time

Observations and ERA-Interim

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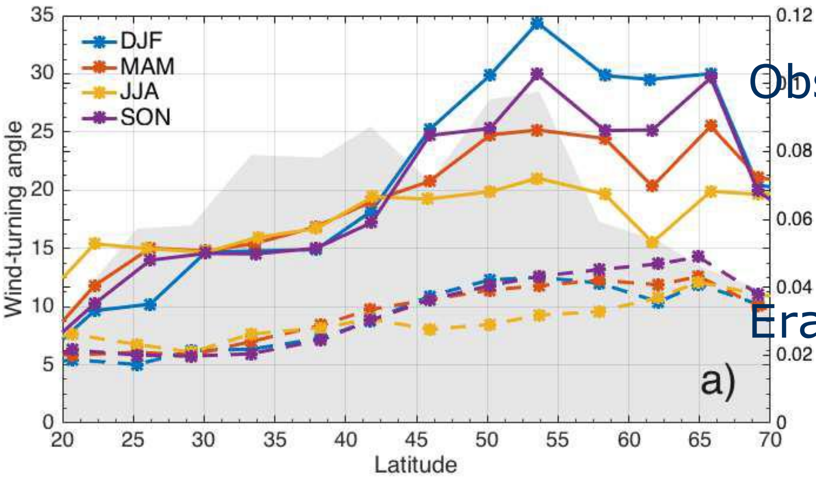
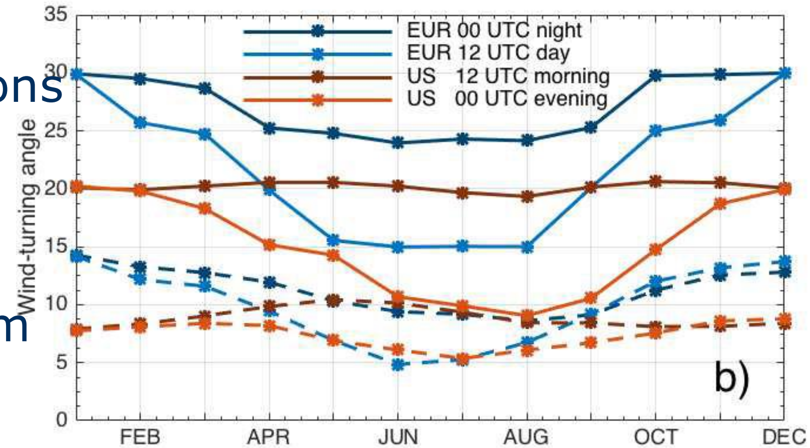


Observations

Era-Interim



Large difference between observations and ERA-Interim

Angle increases with latitude

Larger seasonal cycle in observations although ERA-Interim show the same behavior, much smaller angles

Lindvall and Svensson, 2019

Variation with stability and wind speed

Observations and ERA-Interim

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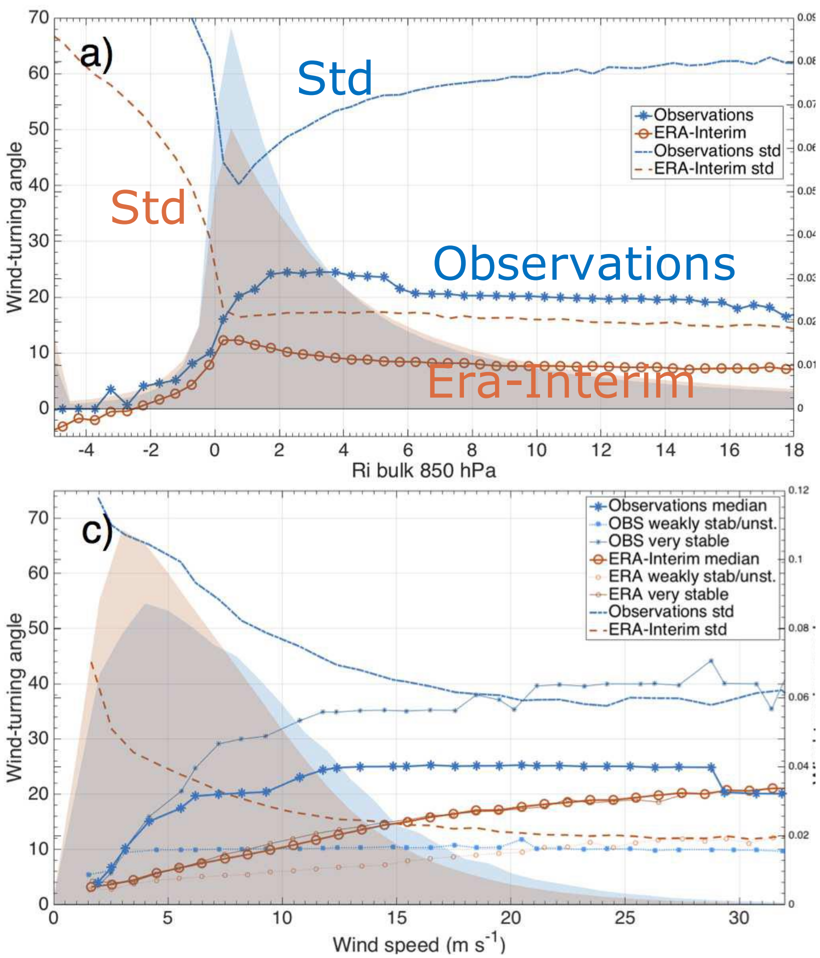

Angle increases with PBL bulk stability as expected, then decrease and level of

Angle increases unexpectedly with wind speed, over entire range in ERA interim while it levels of at higher wind speed in observations

Shaded areas show data distributions

Lindvall and Svensson, 2019

Conclusions

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- Wind turning over the boundary layer, or cross-isobaric angle, is generally smaller in ERA-Interim than observations show
- As the wind turning over the PBL is related to the surface drag processes, the presented wind-turning climatology may be used as a metric to evaluate NWP and global climate models
- Some expected and some unexpected dependencies are seen
- Evaluation of CMIP6 models are ongoing

Further reading:

- Svensson G. and J. Lindvall, 2015: Evaluation of near-surface variables and the vertical structure of the boundary layer in CMIP5 models. *Journal of Climate*, **28**, 13, 5233-5253
- Lindvall J., and G. Svensson, 2019: Wind turning in the atmospheric boundary layer over land. *Quarterly Journal of the Meteorological Society,* **145**, 3074-3088.