# Impacts of diffusion in stable boundary layers and orographic drag

Irina Sandu

Thanks: Anton Beljaars, Ted Shepherd, Ayrton Zadra, Felix Pithan, Alessio Bozzo, Peter Bechtold

# Outline

Context: drag and its (uncertain) representation in models

Diffusion in stable boundary layers – example of impacts

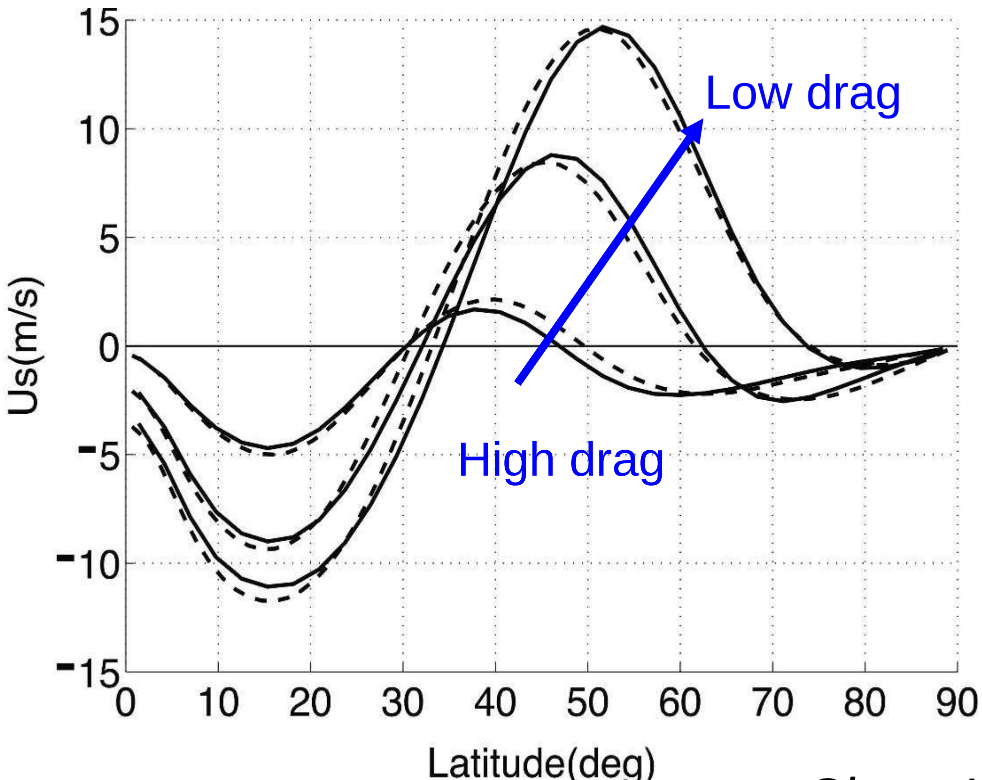
Orographic drag – example of impacts

Compensating errors

Conclusions

# Surface drag/stress/friction

*Surface stress* = force parallel to the surface, per unit area, as applied by the earth's surface on the wind




In idealized AGCMs, surface jet strength and latitude are highly sensitive to surface drag, via feedback on baroclinic eddies

*Chen, Held & Robinson (2007 JAS)*

# Representation of stress in models

$$\vec{\tau} = \vec{\tau}^{res} + \vec{\tau}^{phy}$$

$\vec{\tau}^{res} = p_s \vec{\nabla} \mathrm{h} =$ resolved orographic stress

$\vec{\tau}^{phy} = \vec{\tau}^{pbl} + \vec{\tau}^{sgo} =$ subgrid (physics) stress

Stress from boundary layer (or turbulence) scheme

Stress from subgrid orographic scheme

$$\vec{\tau} : (\tau_x, \tau_y) = (\overline{u'w'}, \overline{v'w'})$$

$$\tau = \sqrt{\tau_x^2 + \tau_y^2}$$

# Subgrid drag (stress) mechanisms in the ECMWF model

1. Turbulence scheme for horizontal scales below 5 km

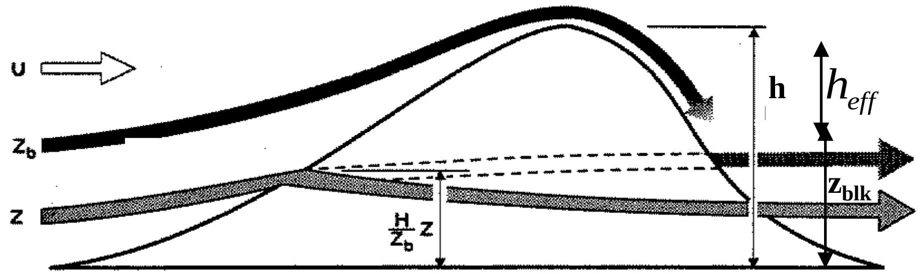
**PBL**

- **a) Turbulent Drag - TURB**: Traditional MO transfer law with roughness for land use and vegetation
- **b) Turbulent Orographic Form Drag -TOFD** : drag from small scale orography (Beljaars et al. 2004); Other models use orographic enhancement of roughness.

2. Sub-grid orography scheme for horizontal scales between 5 km and model resolutio (Lott and Miller 1997)

**SGO**

- **a) Gravity Wave Drag - GWD** : gravity waves are excited by the "effective" sub-grid mountain height, i.e. height where the flow has enough momentum to go over the mountain
- **b) Orographic low level blocking - BLOCK** : strong drag at lower levels where the flow is forced around the mountain



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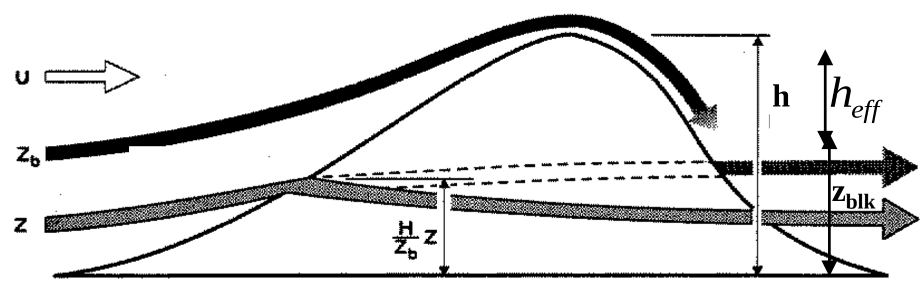
TURB TOFD GWD BLOCK

PBL (TURB, TOFD) SGO (GWD, BLOCK)



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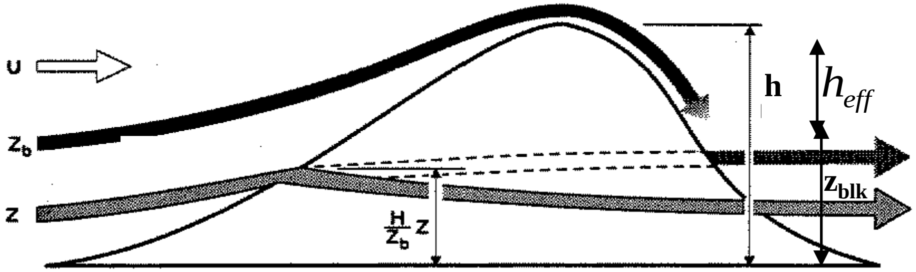
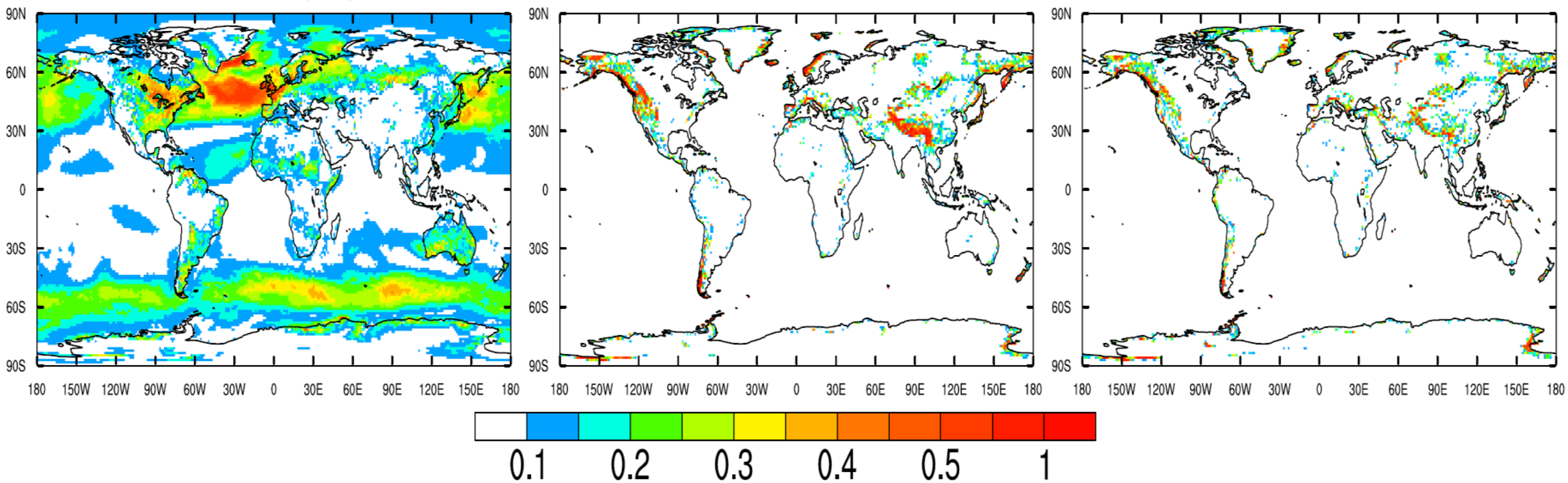
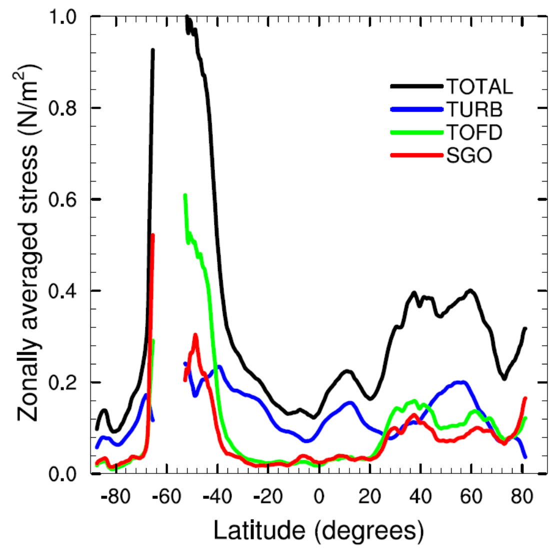


# Surface stress components in the ECMWF model

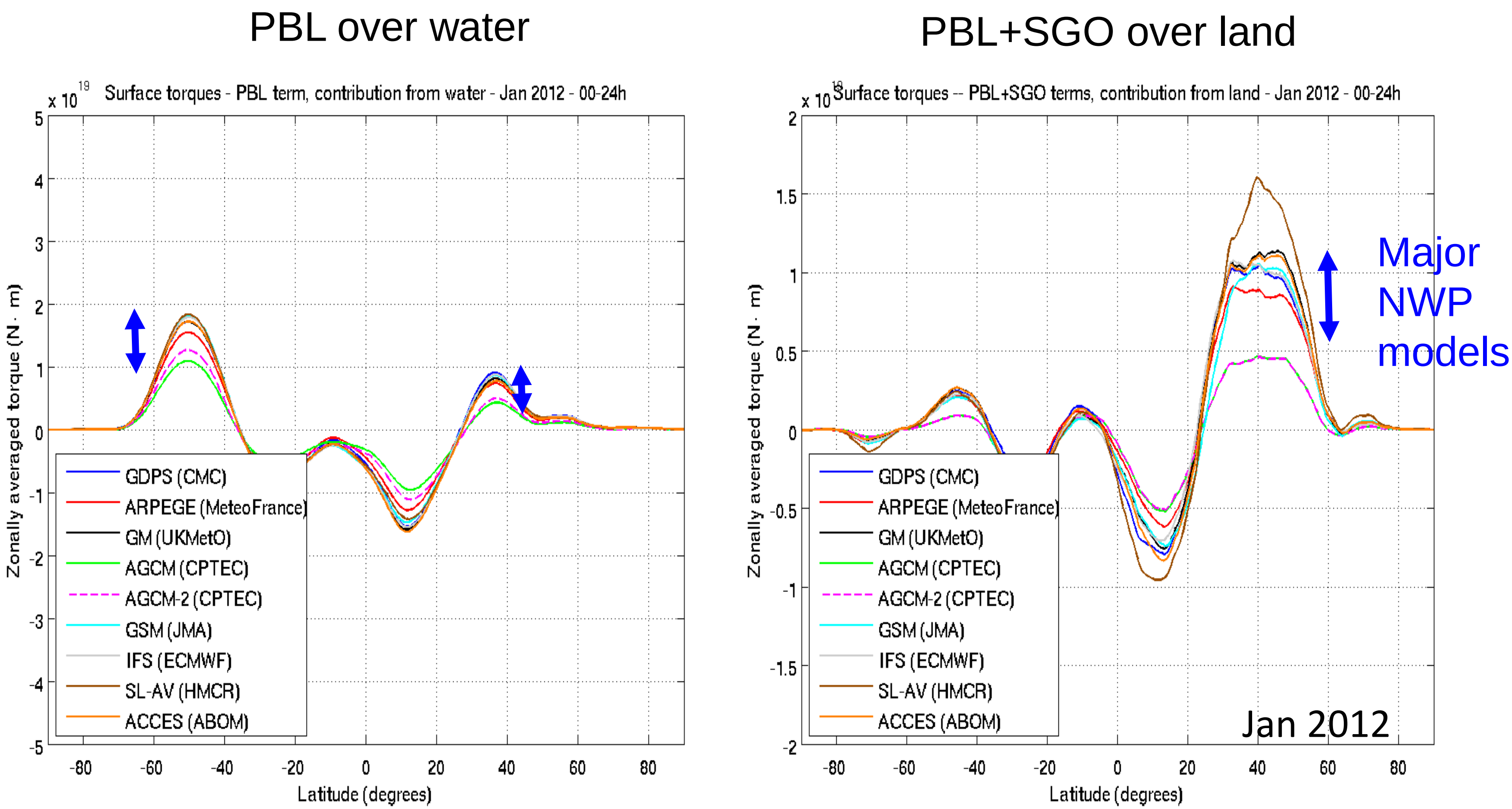
TURB Stress (N/m2) TOFD Stress (N/m2) SGO Stress (N/m2)




Similar zonal average but different distribution

# WGNE Drag project – comparison of surface stress




Much better agreement over water than over land !

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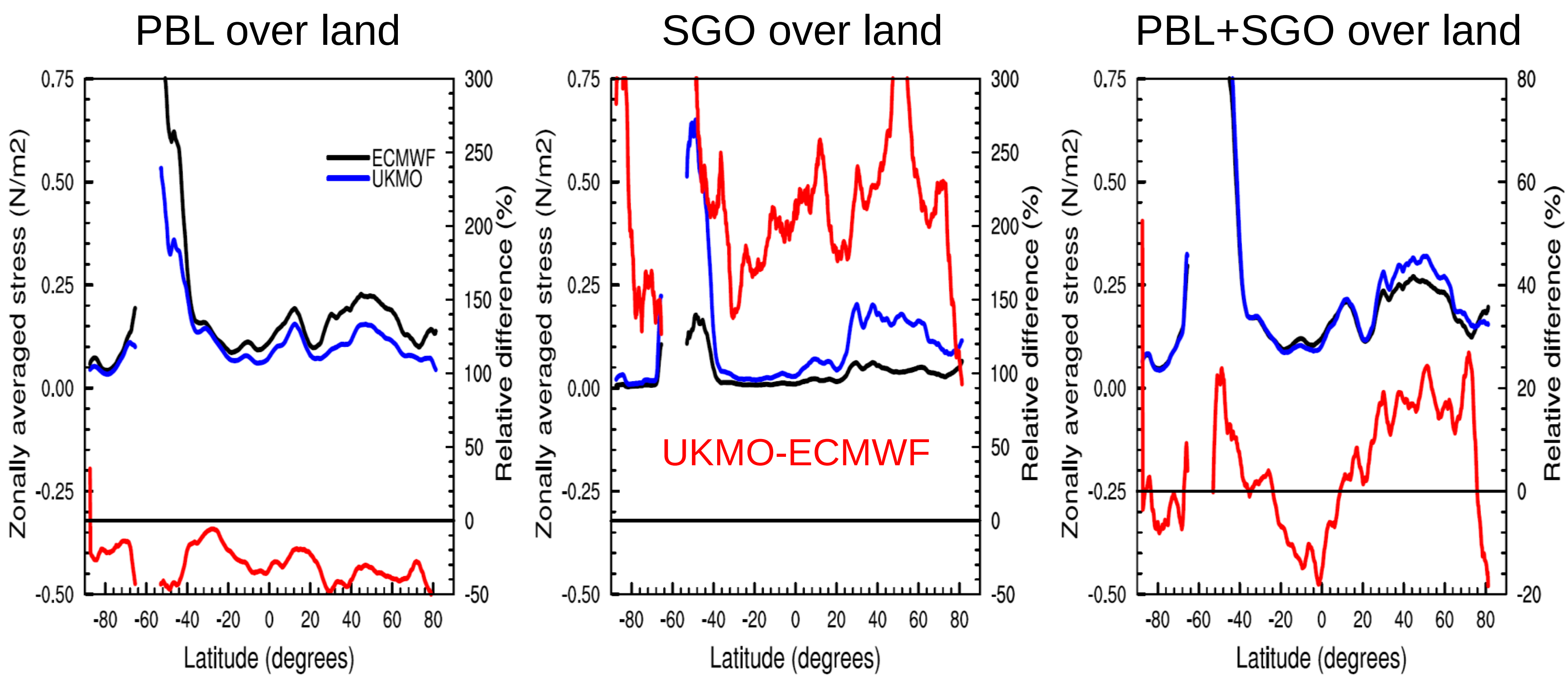
Link to Drag Project website* (A. Zadra and J. Bacmeister):

*http://collaboration.cmc.ec.gc.ca/science/rpn/drag_project/index.html*

# WGNE Drag project

## ECMWF vs UKMO

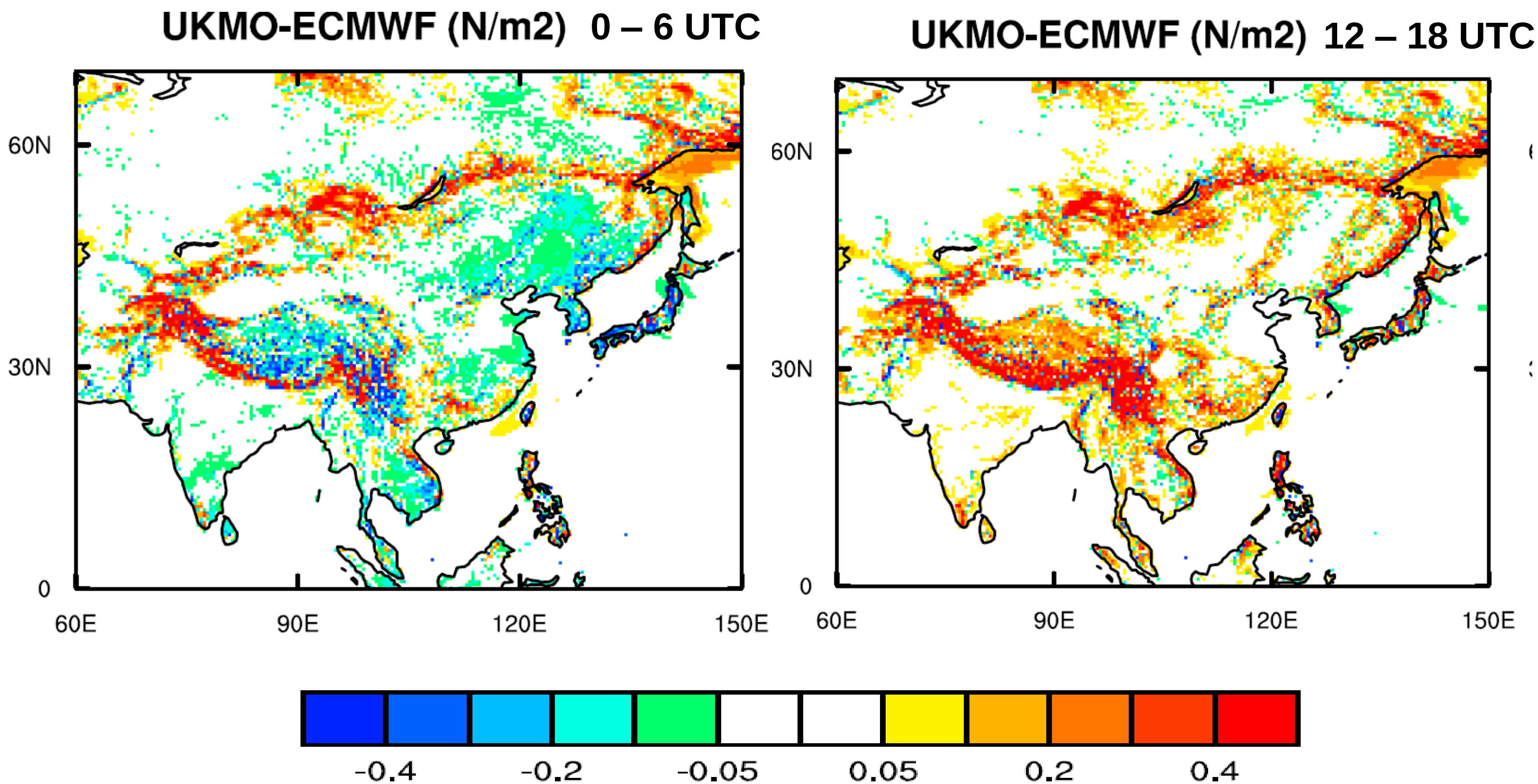



The partition among the different schemes is very different!

UKMO PBL term < EC PBL term, but SGO term >> EC SO term

# WGNE Drag project

## ECMWF vs UKMO: total surface stress




The diurnal cycles are very different as well!

# Take-home messages so far:

- Surface stress is represented through different schemes
- Models don't agree in the amount of total stress, partition between schemes, diurnal cycle over land
- Clear need to better constrain surface drag, especially over orography
- But also to understand

1. the impacts of the different schemes
2. whether only differences in total drag matter for NWP and climate or the partition among the different schemes is also important?

TURB TOFD GWD BLOCK

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Turbulent diffusion in stable boundary layers

Orographic drag

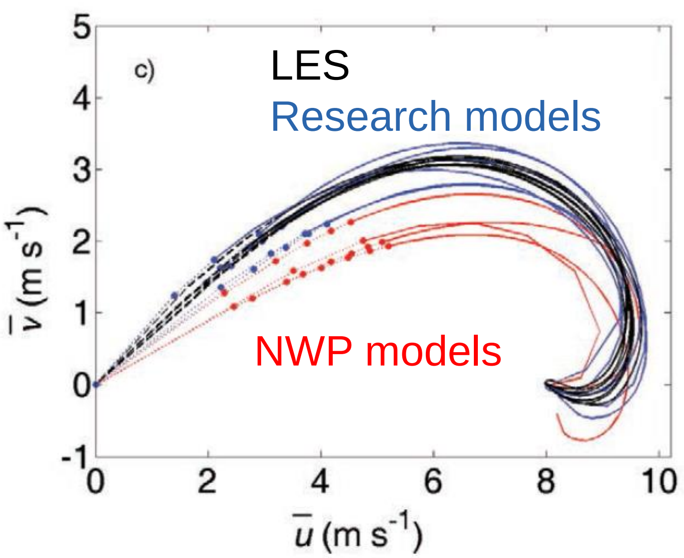
- They are (still) poorly represented in global models
- Their representation depends on a large number of parameters which are highly uncertain, and which are often tuned to obtain the desired answer (NWP skill, or model climate)
- No consensus on the processes that need to be parameterized (in particular for orographic drag)

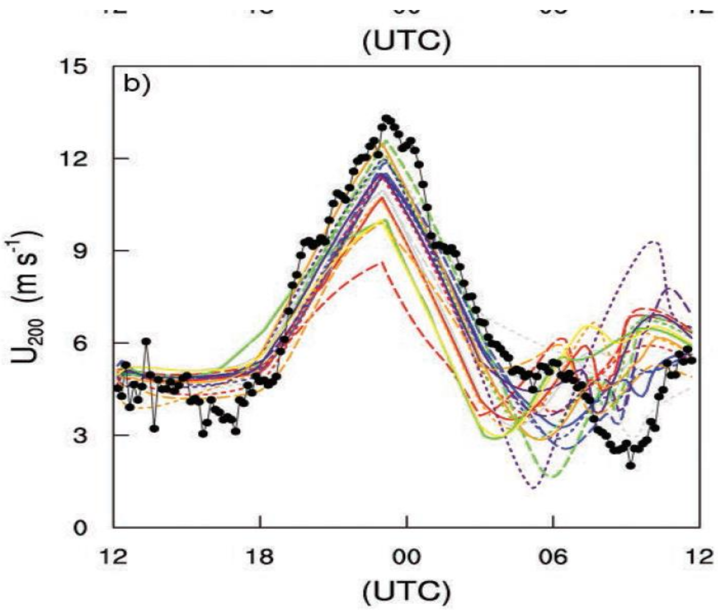
# Diffusion in stable boundary layers

- ✓ Impacts on near surface variables
- ✓ Impacts on NH winter circulation

# 10+ years of GABLS: Hostlag et al., 2013

Excessive diffusion in stable conditions still common practice in NWP : ECMWF, MetOffice (over land), GFS, although it is known to deteriorate crucial features of stable boundary layers



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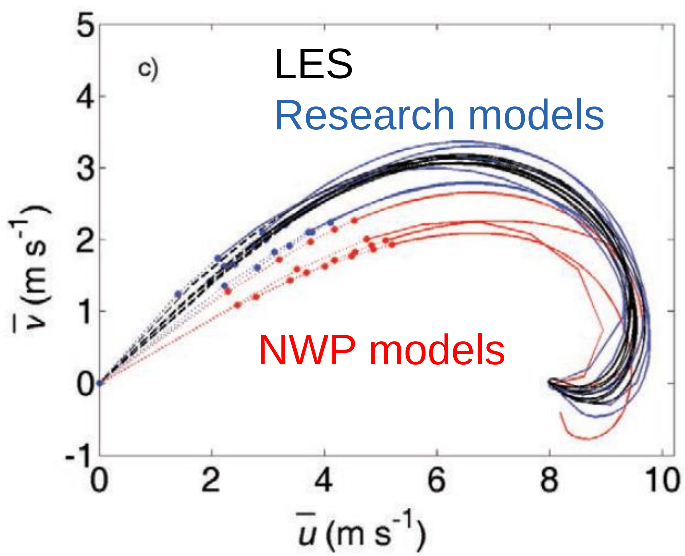
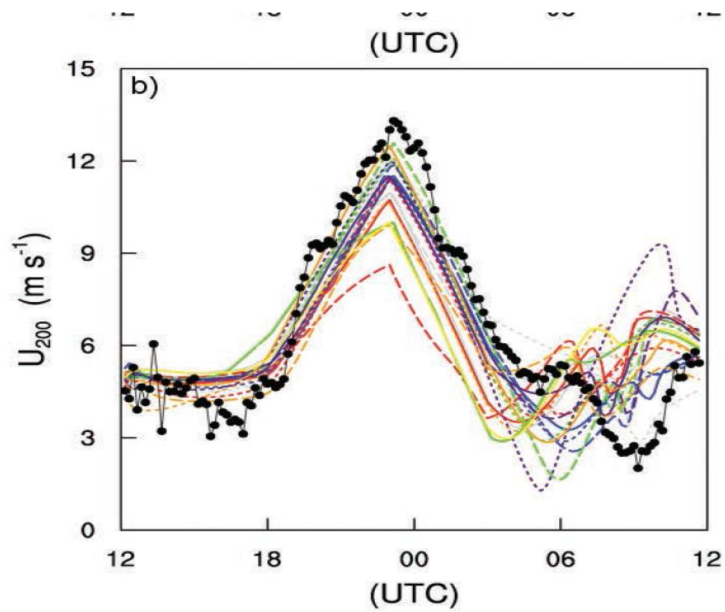
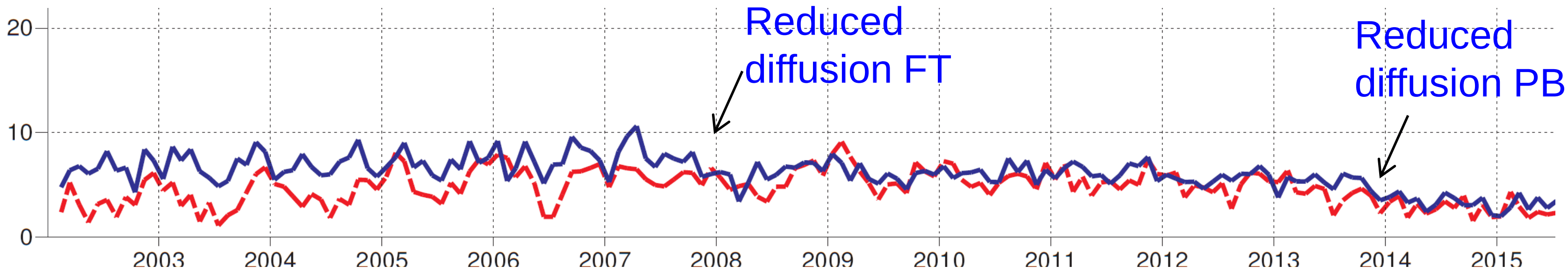


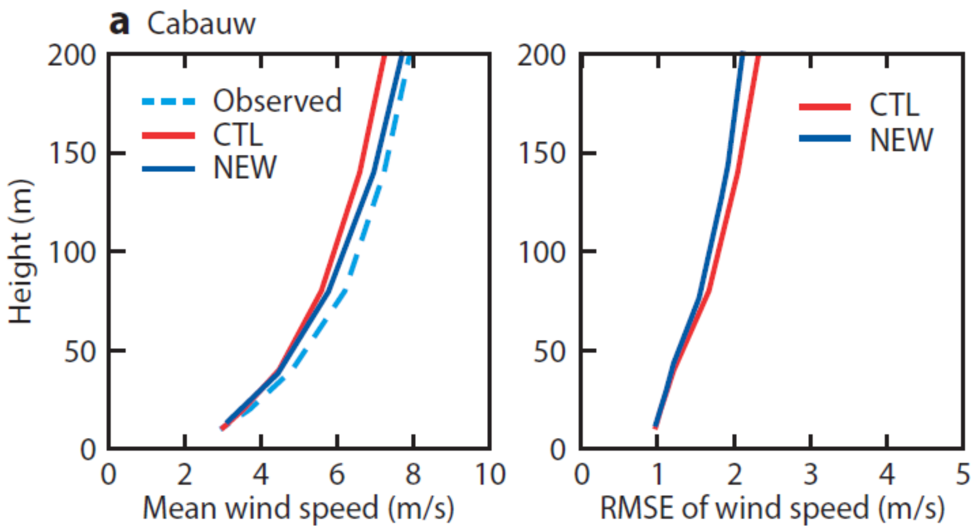




Why? : It offsets model biases in key aspects of weather forecast (cold near-surface biases in stable boundary layers, development of synoptic cyclones, circulation in NH winter, Beljaars&Viterbo 1998, Sandu et al. 2013)

# Longstanding near-surface wind (short-range) forecast errors diminished when diffusion is reduced

10m wind direction error in the ECMWF system (°) - Europe



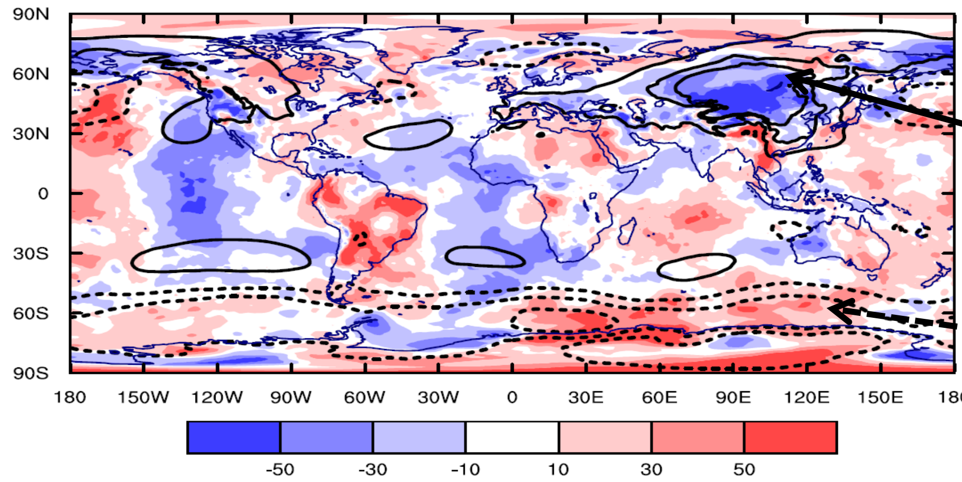

Improvement in both mean and RMSE in the upper part of stable boundary layers



*Sandu et al, ECMWF Newsletter 138*

# Reduced diffusion also impacts NH winter circulation

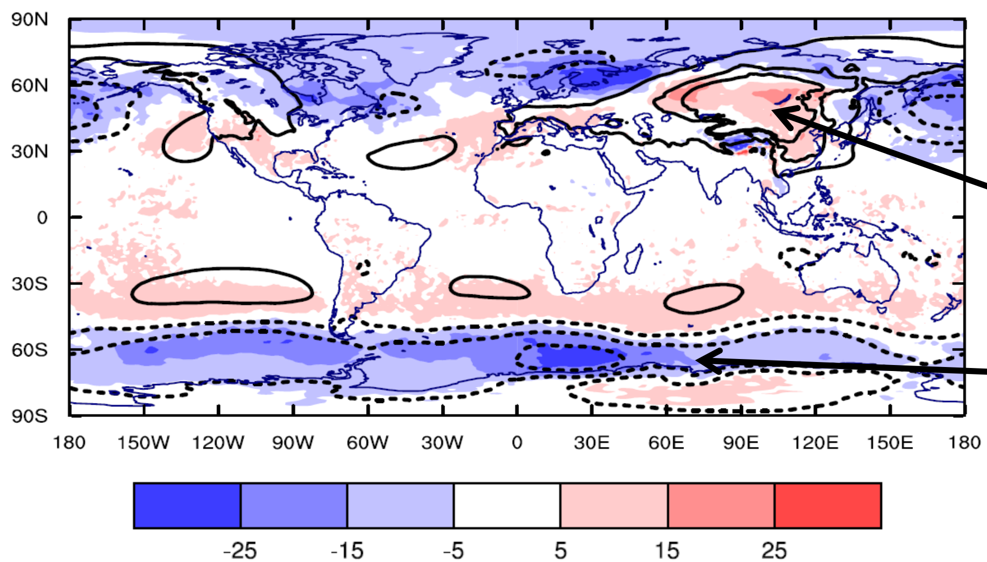
Bias Z CTL




High pressure

Low pressure

Z LOWDIFF - Z CTL




Stronger high pressure systems

Deeper low pressure systems

ECMWF

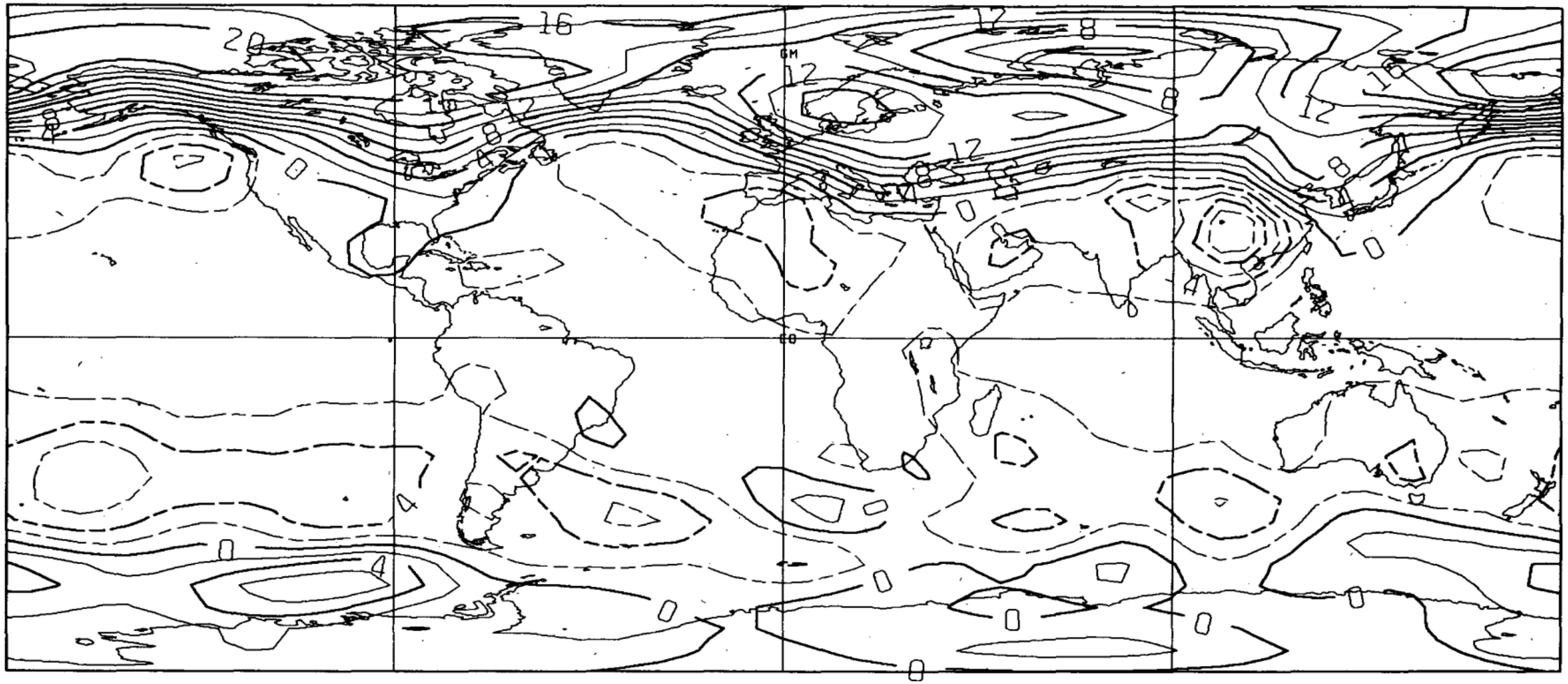
*Sandu et al, 2013, Beare 2007, Svensson et al 2009*

# Orographic drag

- ✓ A few example of impacts of GWD
- ✓ The importance of low level blocking for NWP
- ✓ Does the partition of orographic surface drag between the TOFD and BLOCK matters for NWP and climate?

# Impact of GWD drag

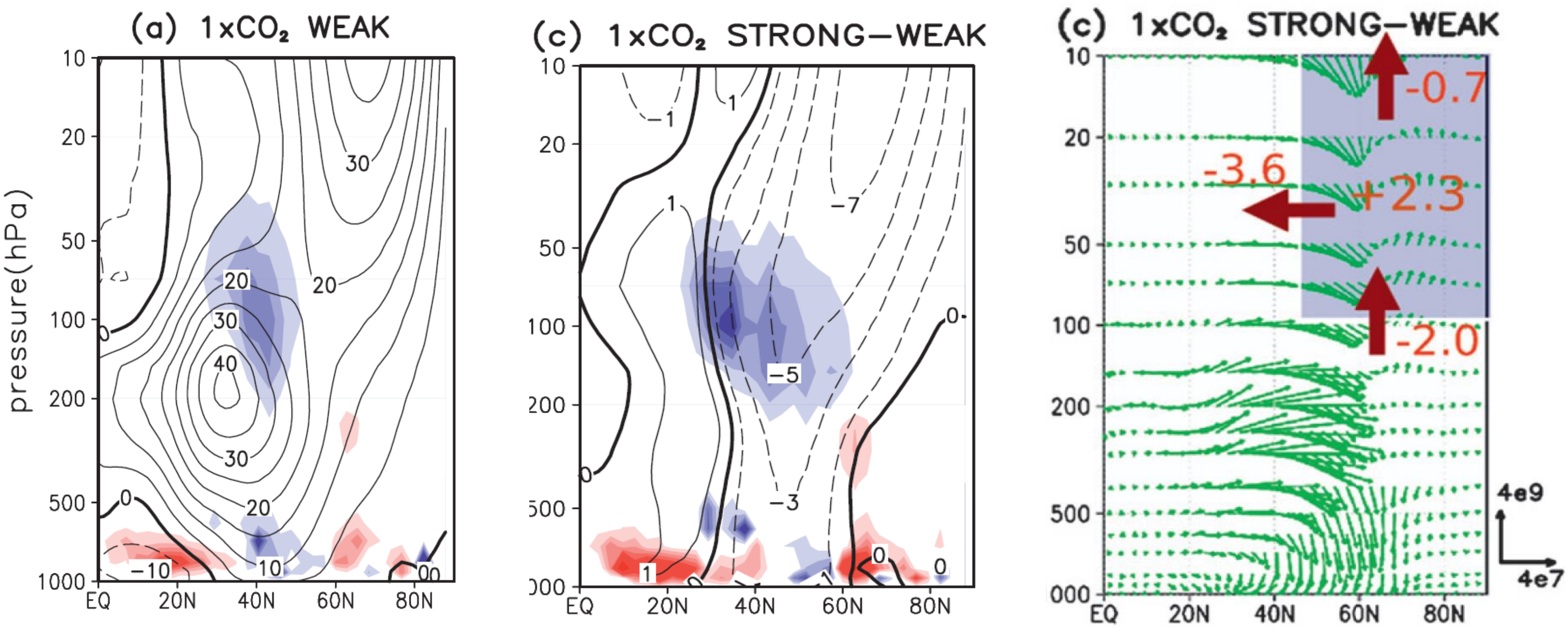
Effect of parameterized orographic GWD on mean sea level pressure in the Canadian GCM (January conditions, C.I. 2 hPa)




*McFarlane (1987 J. Clim.)*

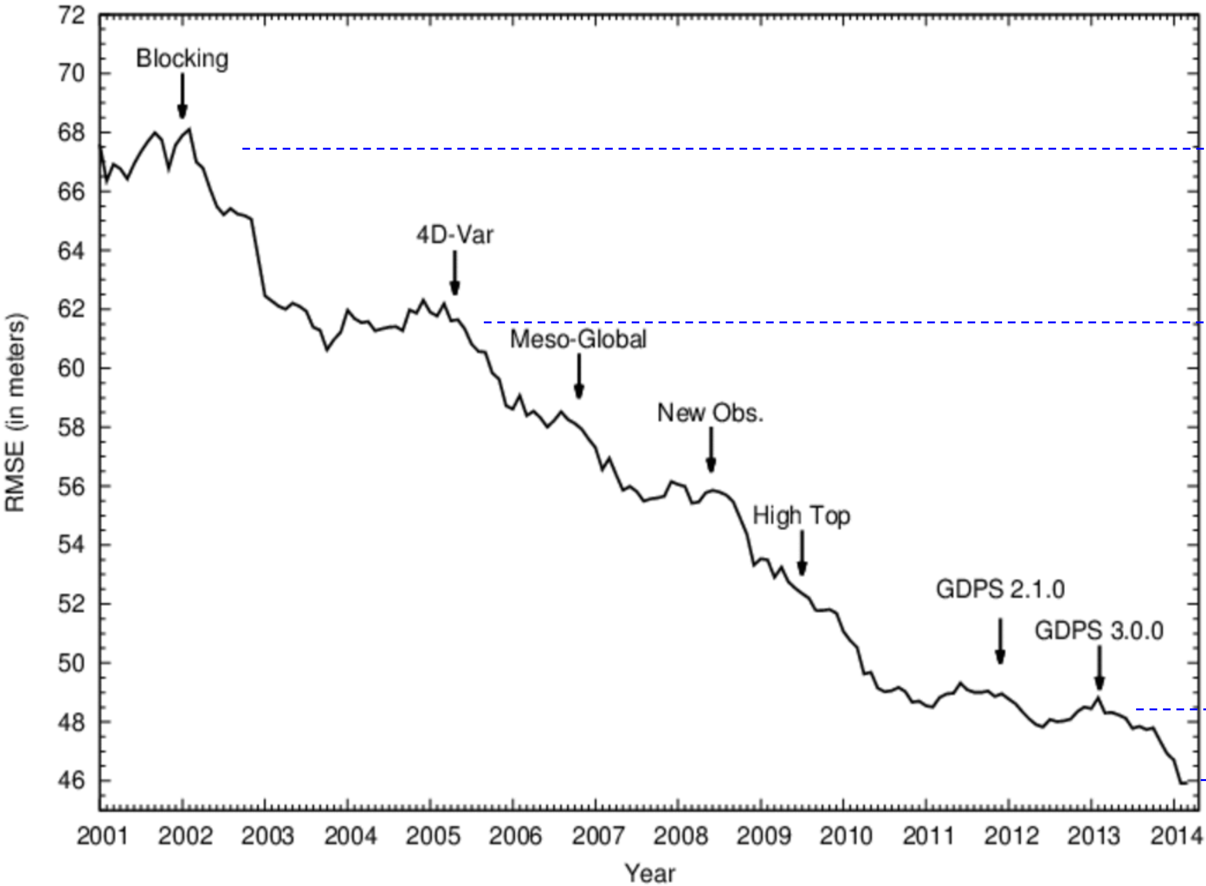
# Impact of GWD drag

Stronger drag leads to a deceleration of the polar vortex, through impact on planetary waves, and their equatorwards propagation




*Sigmund and Scinocca, 2010*

# Impact of changes to drag-related schemes at the Canadian center



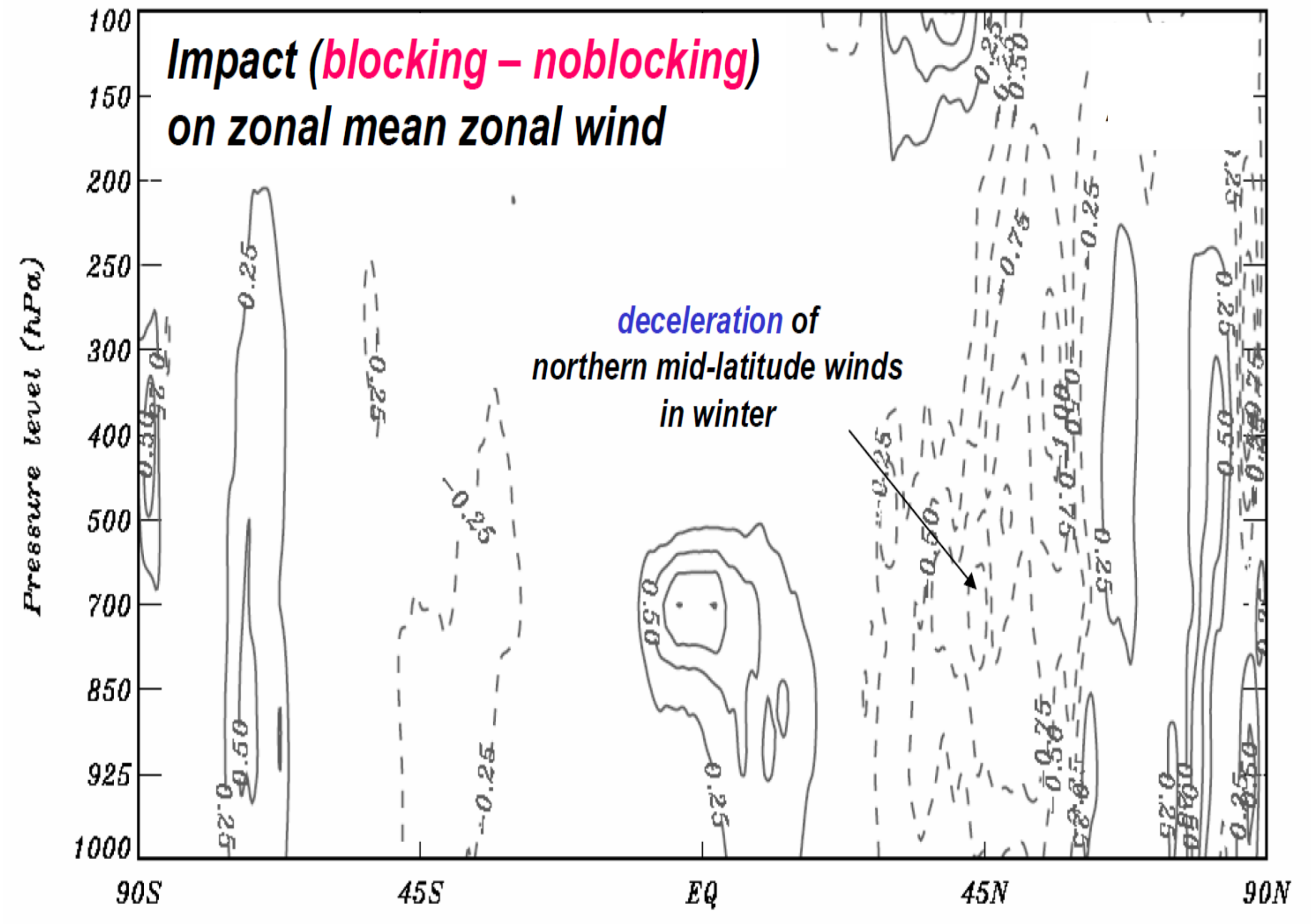

***~ 7m***
***mostly due to introduction of orographic blocking scheme***

***~ 2m***
***mostly due to adjustments in orographic blocking and PBL schemes***

***Fig.: Evolution of 500-hPa RMS errors over the N. Hemisphere: 12-month running mean, from 2001 to 2014.***

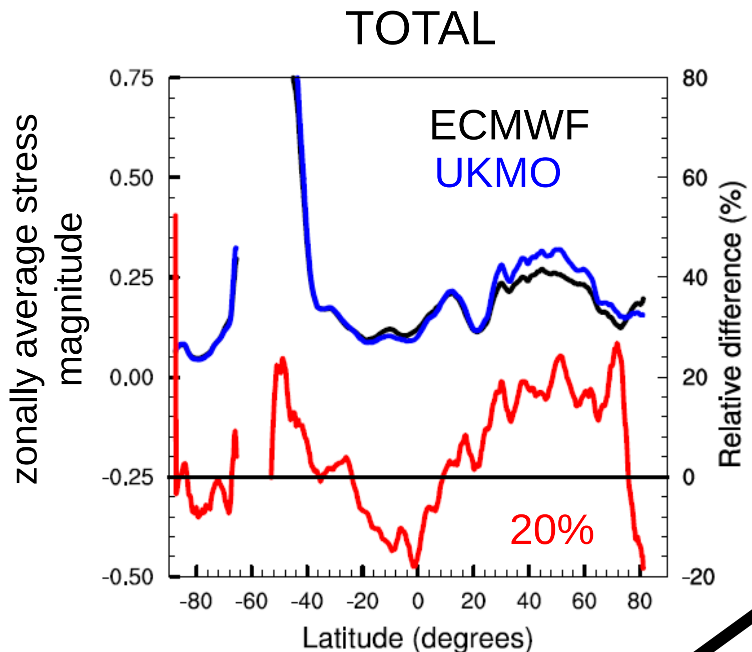
*Courtesy A. Zadra*

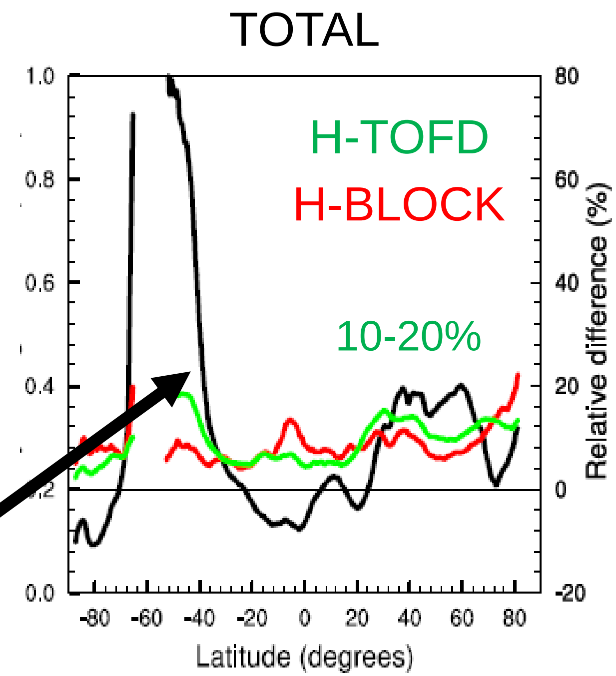
# Impact of low level blocking at the Canadian Center




*Zadra et al, 2003*

# Does the partition between TOFD and BLOCK matter in short range forecasts?




*(Daily 10 days forecast only runs, for February 2014, at T639 ~ 32 km at the Eq.)*

Easy to change the magnitude of the stress by an amount comparable to inter-model differences

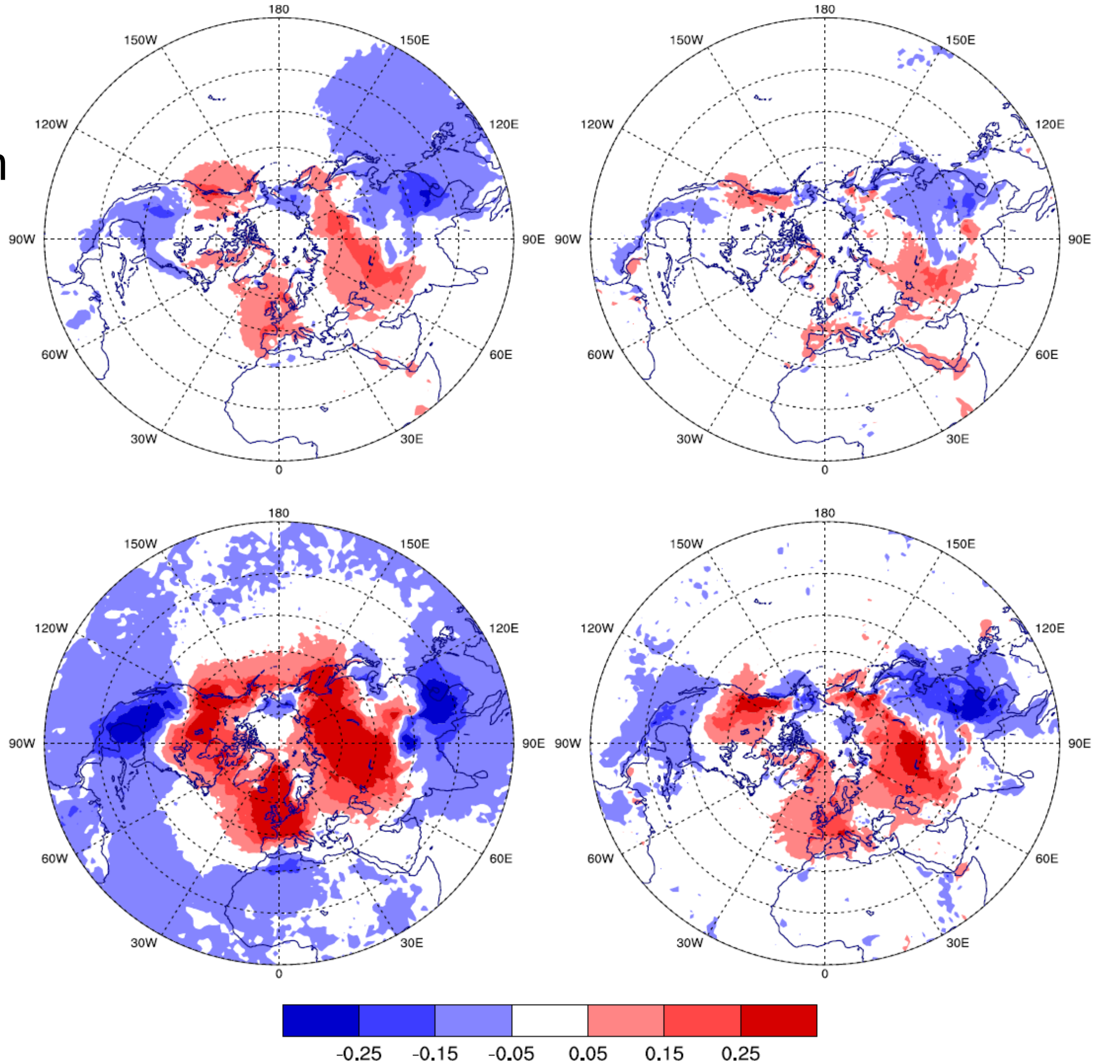
*Sandu et al, in preparation*

# Does the partition matter in short range forecasts?

H-TOFD | H-BLOCK

Mean change in SP +6h

Mean change in SP +24h



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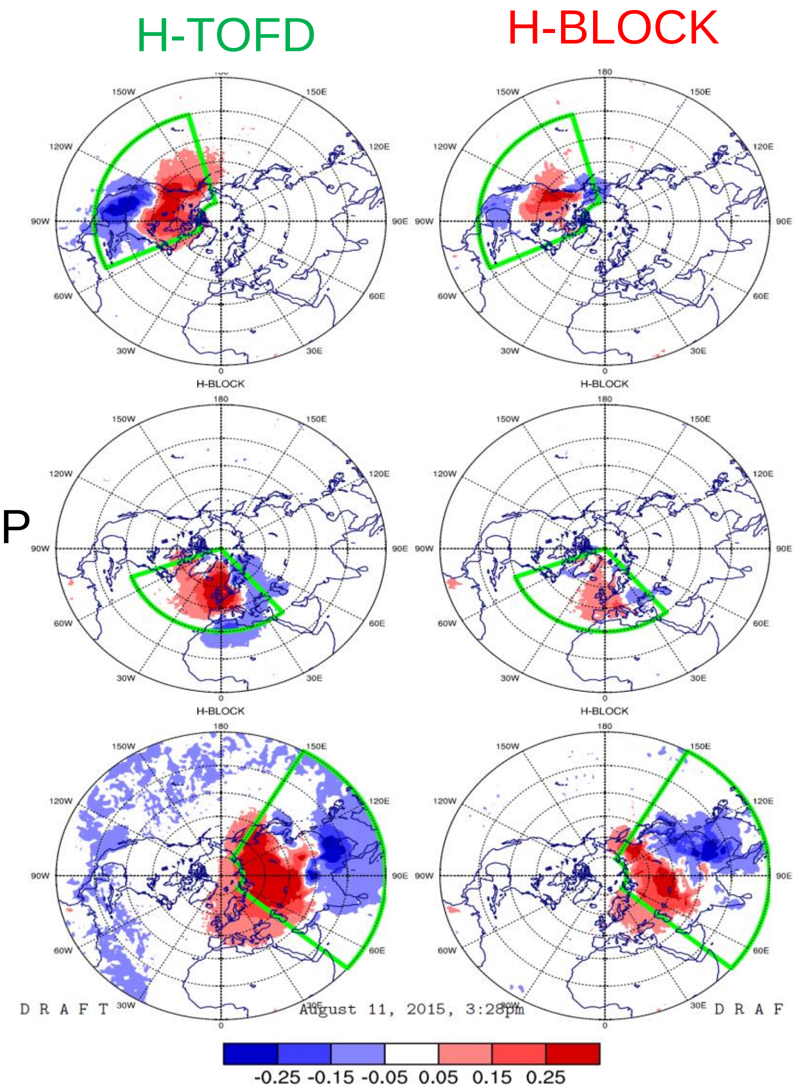


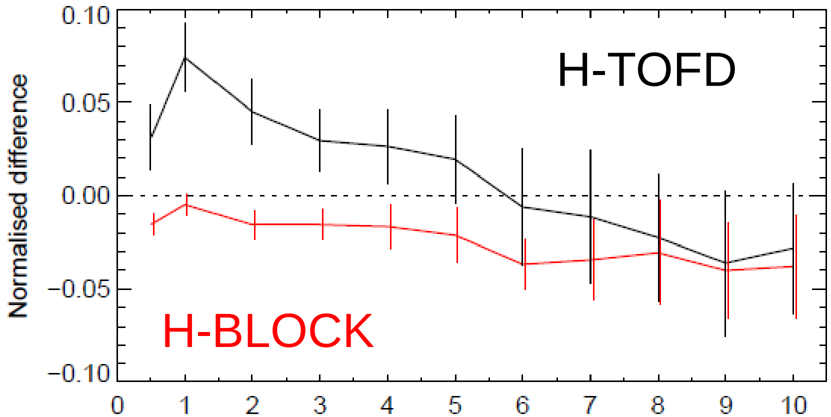

Change in SP +24h

Local response in SP, through geostrophic balance. The meridional pressure gradient is induced by a deceleration of the mid-latitude westerlies

*corroborates Zadra et al 2003*

# Does the partition matter in medium range forecasts?

Change in RMSE Z 500hPa




Lead time (days)

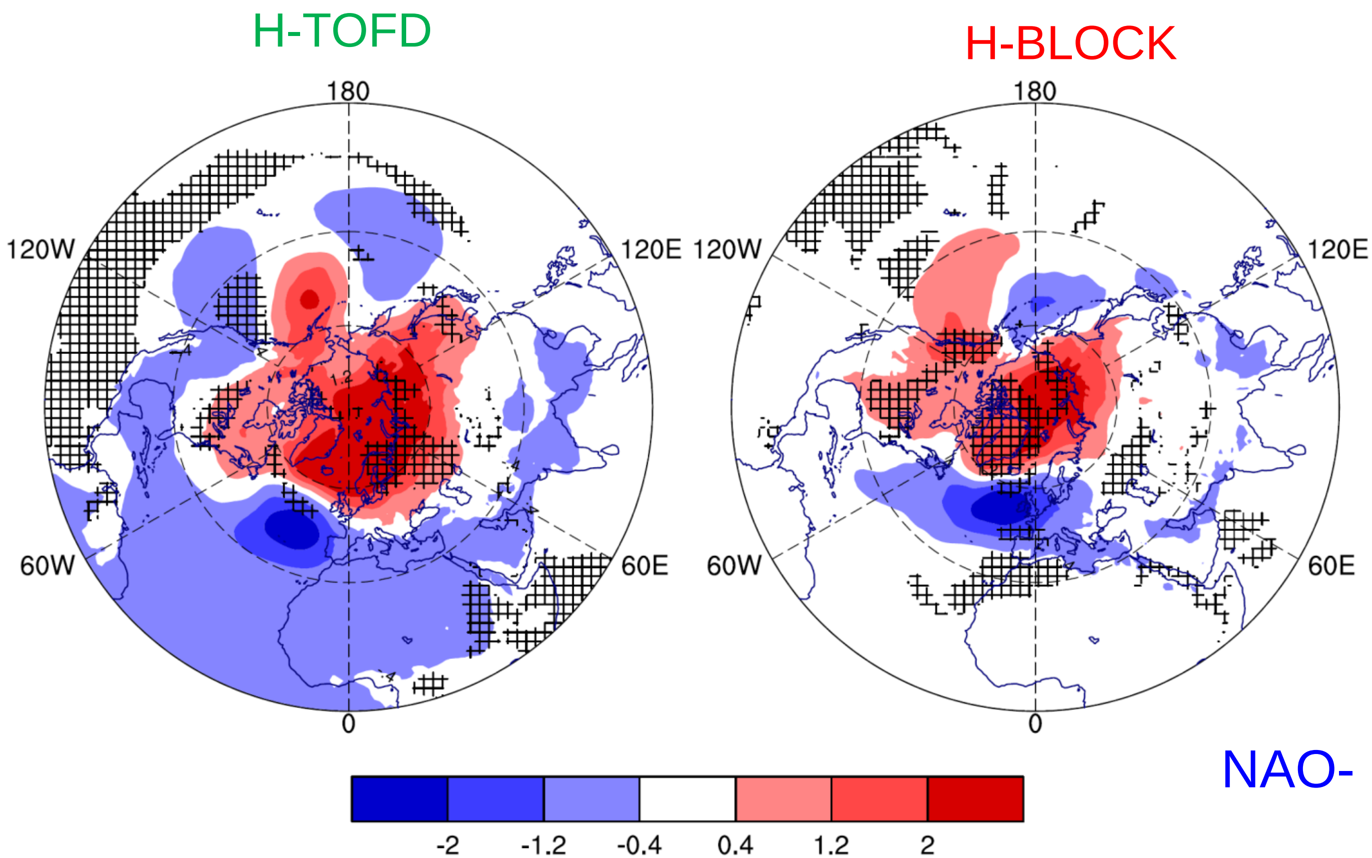
Fine balance between improving and degrading the forecast!

Quasi-indentical response for H-TOFD at T1279!

The trouble won't go away with high resolution anytime soon!

# Does the partition matter in long integrations?

Mean change in surface pressure

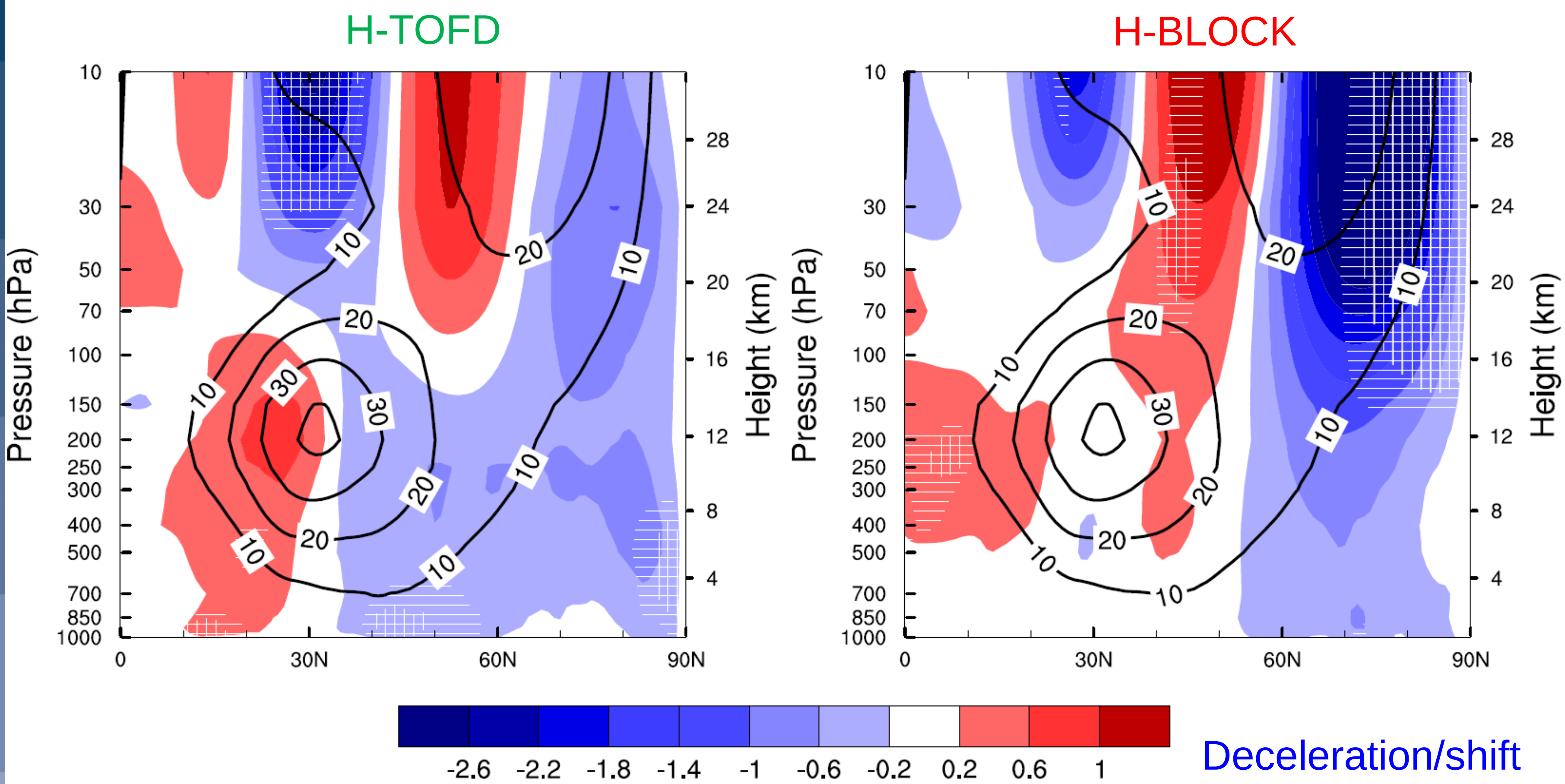



NAO- like pattern

*(30 year-long forecast runs, 1984-2014, at T255 Looking at DJF season)*

# Does the partition matter in long integrations?

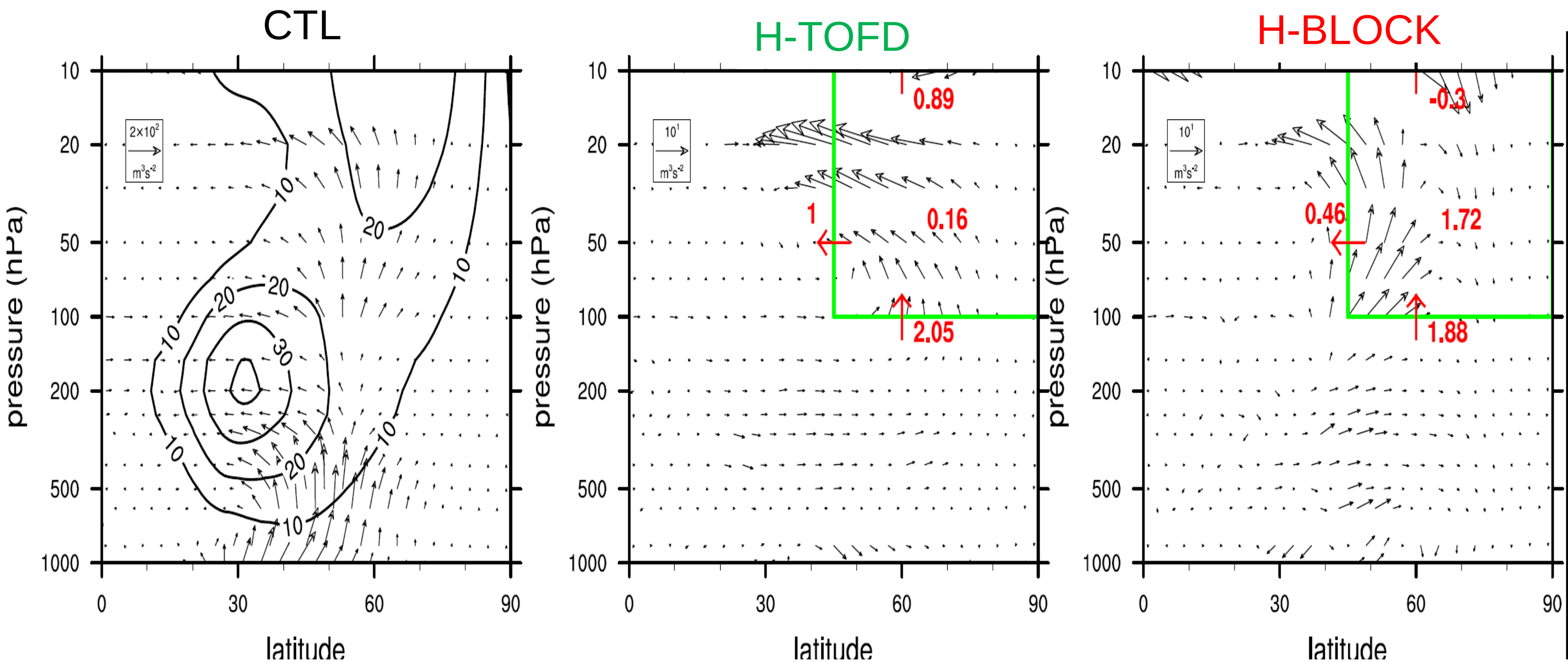
Change in zonal mean zonal wind




Deceleration/shift of the polar vortex

# Does the partition matter in long integrations?

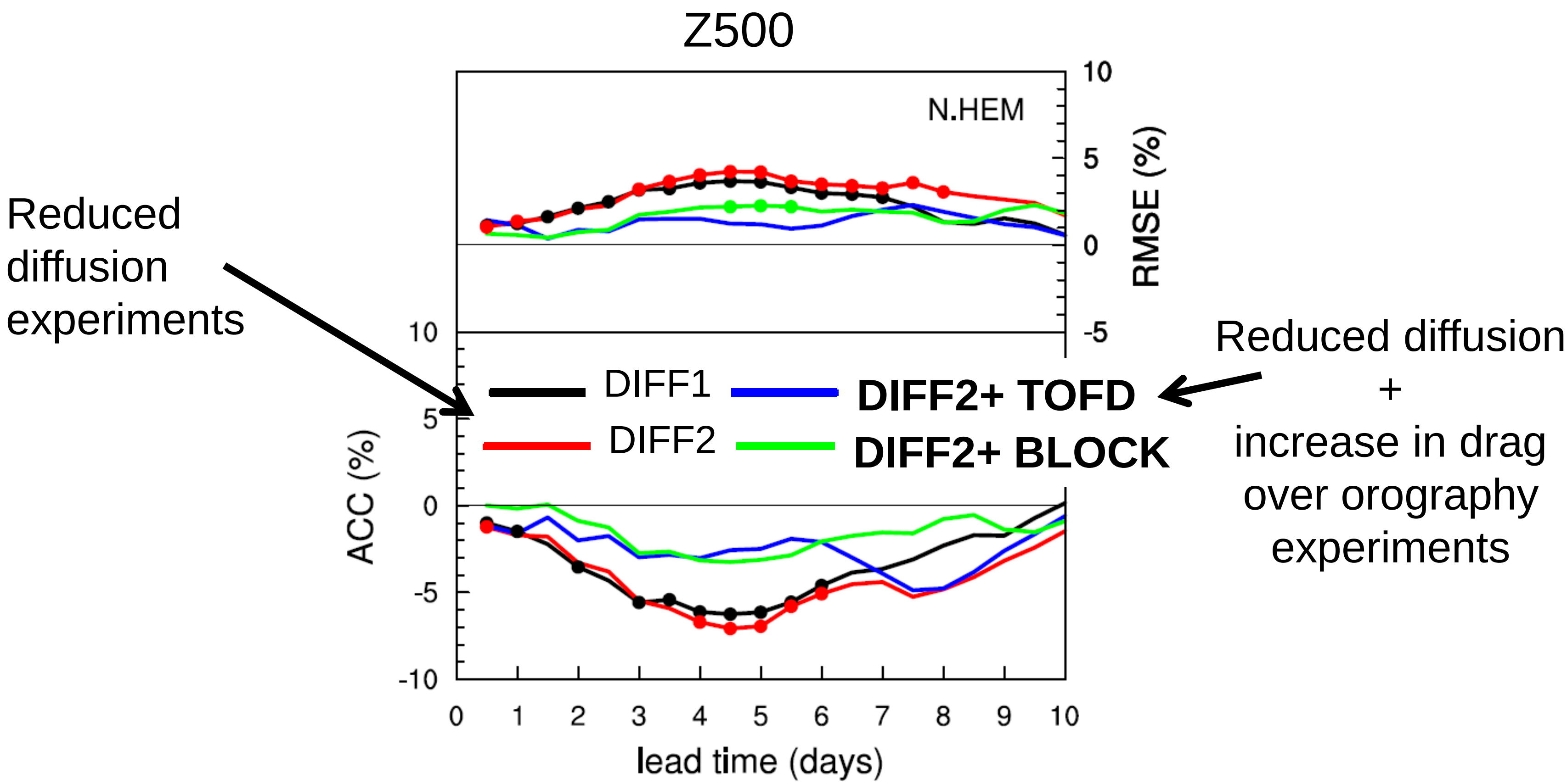
EP-flux analysis




change in the resolved wave driving integrated over the box leading to deceleration of the polar vortex in H-BLOCK, corroborates Sigmund and Scinocca, 2010

# Compensating errors in NWP and climate

# Compensating errors in NWP




- reduced diffusion in stable layers = deterioration of forecast performance
- the deterioration due to reduced diffusion is outweighed by an increase in orographic drag

ECMWF

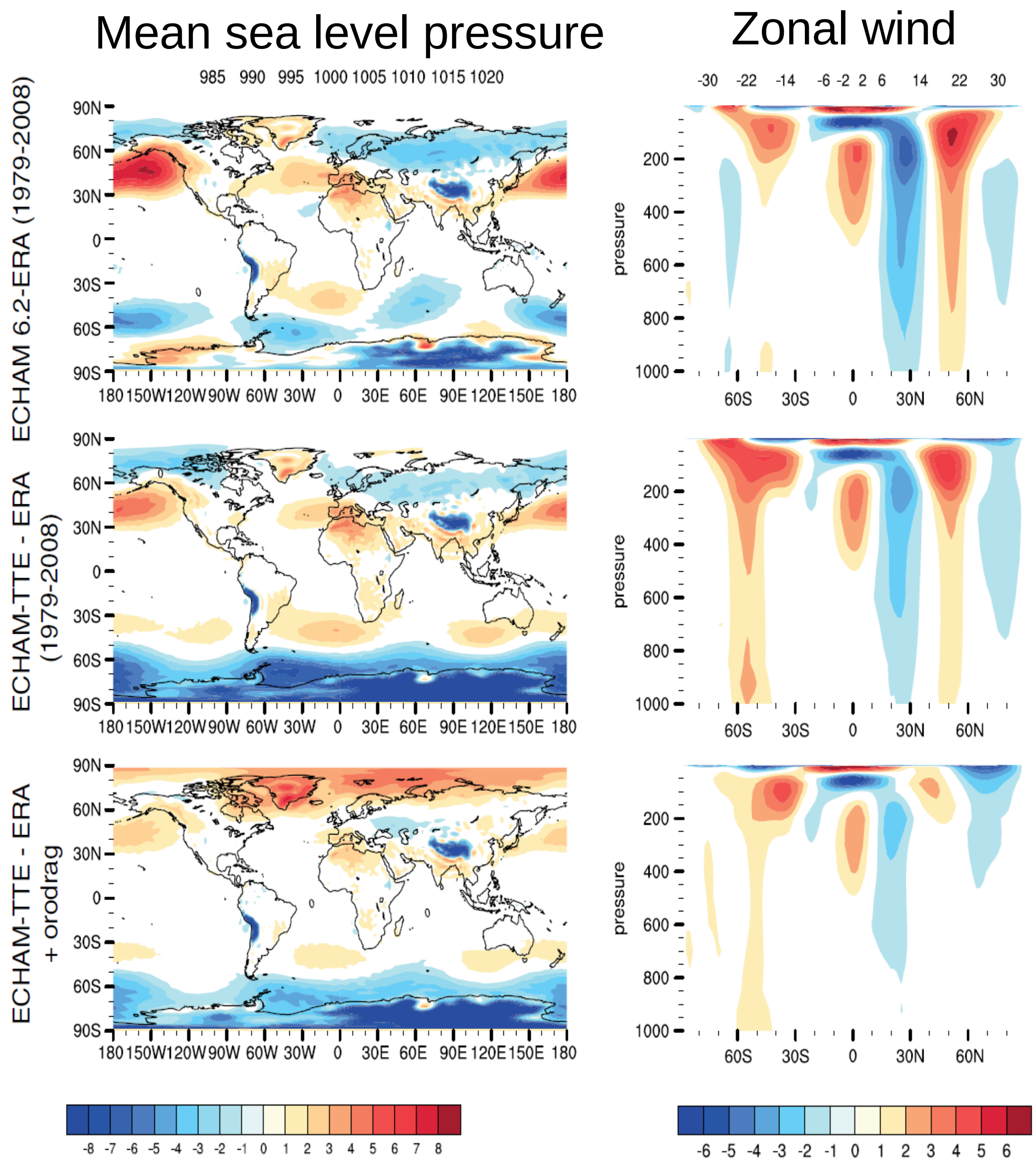
*Sandu et al, 2013*

# Compensating errors in climate simulations

reference- ERA

low diffusion - ERA

low diffusion + increased block - ERA




*Pithan et al, 2014*

# Conclusions

- The schemes used to represent subgrid drag impact the zonal mean flow in NH winter in similar ways
- The partition of drag among these schemes seems to matter at all scales
- Yet, no straightforward how one should make this partition, nor how to constrain poorly known parameters entering these schemes
- Need for better understanding of processes, existing parameterizations
- Need to constrain surface drag: one option is to use high resolution models