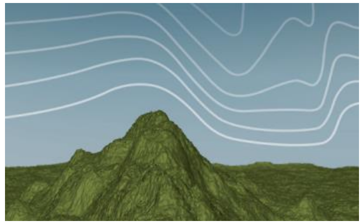
On the importance of and uncertainties in parametrizations of surface drag and momentum exchanges in weather and climate models

Part II – Impact of various sources of inter-model spread on short/medium range forecasts

Irina Sandu (ECMWF)

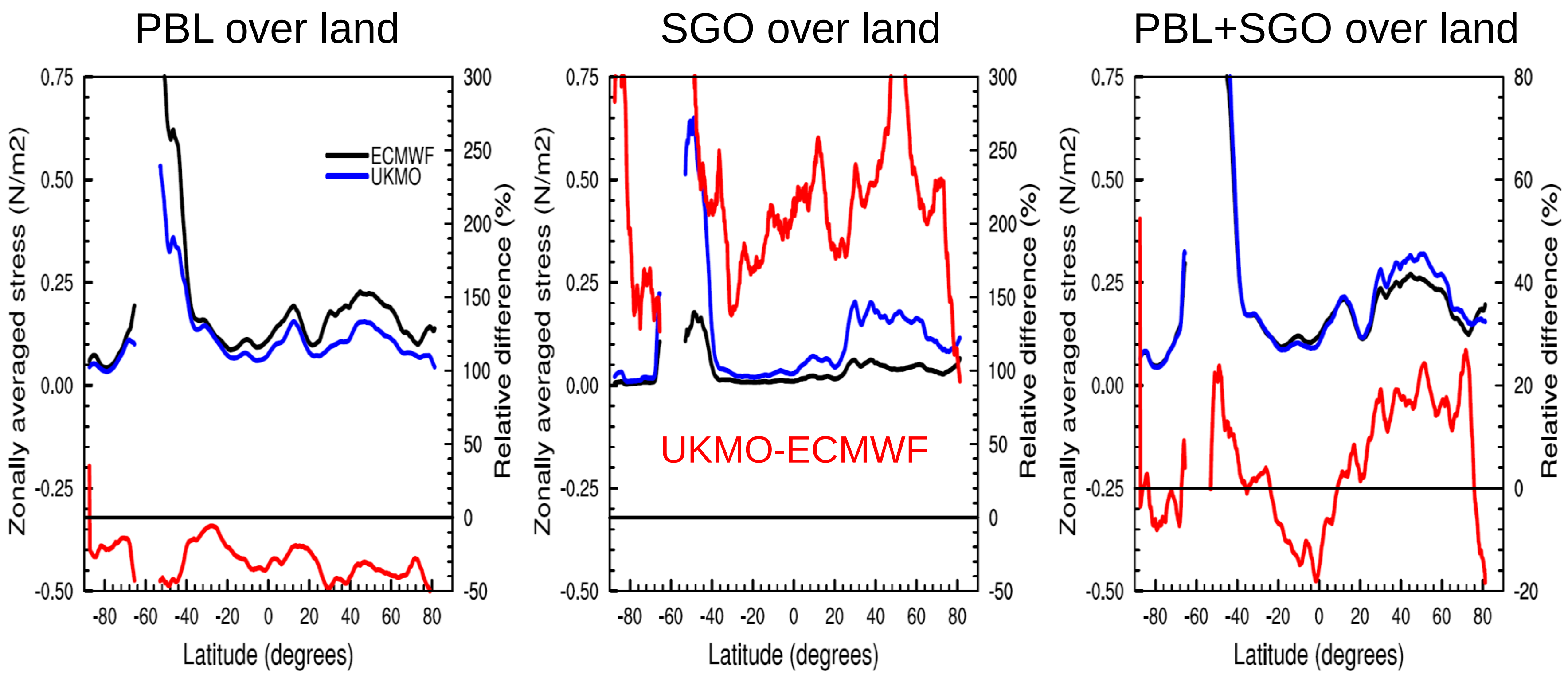
Thanks: Anton Beljaars, Peter Bechtold, Sylvie Malardel, Annelize van Niekerk, Felix Pithan, Ted Shepherd, Simon Vosper, Nils Wedi, Ayrton Zadra



Drag processes and their links to large-scale circulation
12-15 September 2016
ECMWF, Reading, UK

A zoom on the differences between ECMWF and UKMO

WGNE Drag project: ECMWF vs UKMO



The partition among the schemes is very different!

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

The diurnal cycles are very different as well!

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First order questions

- What causes these differences? parameterizations, underlying subgrid orography ?
- Do these differences matter for the large-scale circulation? If yes how much and on what timescales?
- Do only differences in total stress matter, or does the partition between different schemes matter as well?

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

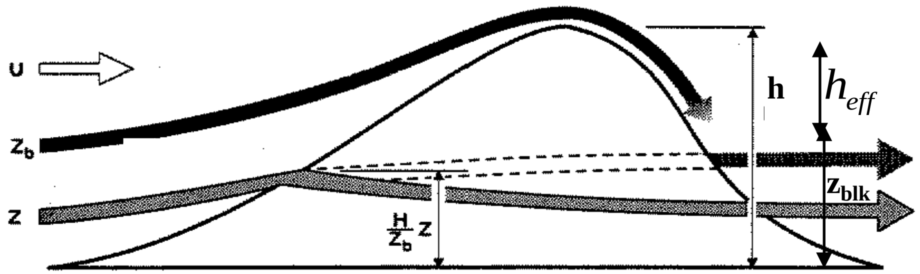
b) **Turbulent Orographic Form Drag -TOFD** : drag from small scale orography (*Beljaars et al. 2004*); Other models use orographic enhancement of roughness.

2. Sub-grid orography scheme for horizontal scales between 5 km and model resolution (*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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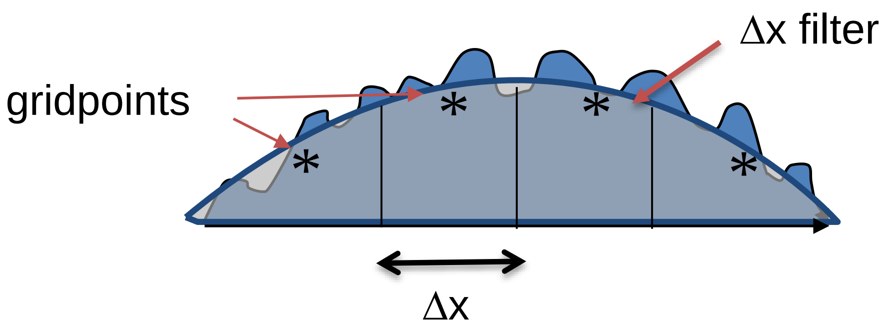
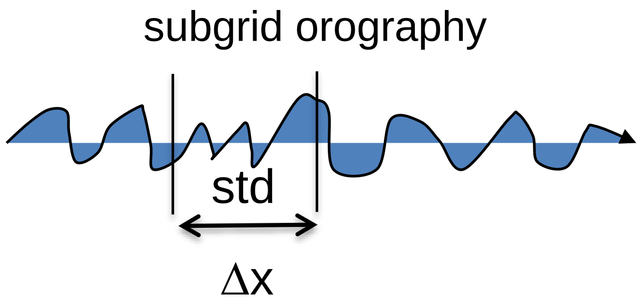
Questions stemming from the WGNE Drag project looked at so far:

- What is the impact of two of these schemes (TOFD and BLOCK) on the NH winter circulation, and does the partition of orographic surface drag between them matters for NWP and climate? (*Sandu et al, JAMES, 2015, Pithan et al, GRL, 2016*)

- Handover from parameterized to resolved drag & drag grey zone (*Vosper et al 2015,2016, Van Niekerk et al 2015*) – the subgrid orography should not represent scales smaller than the grid box but than the effective resolution

- What is the impact of constructing the subrid orography on 4 Δx, 6 Δx, 8 Δx instead of Δx?





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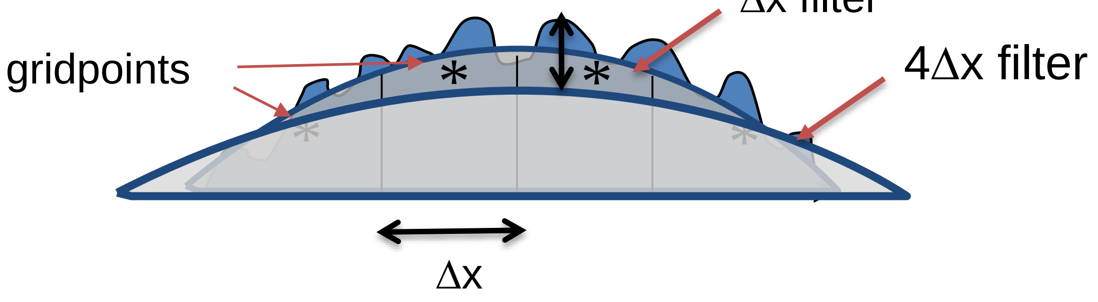

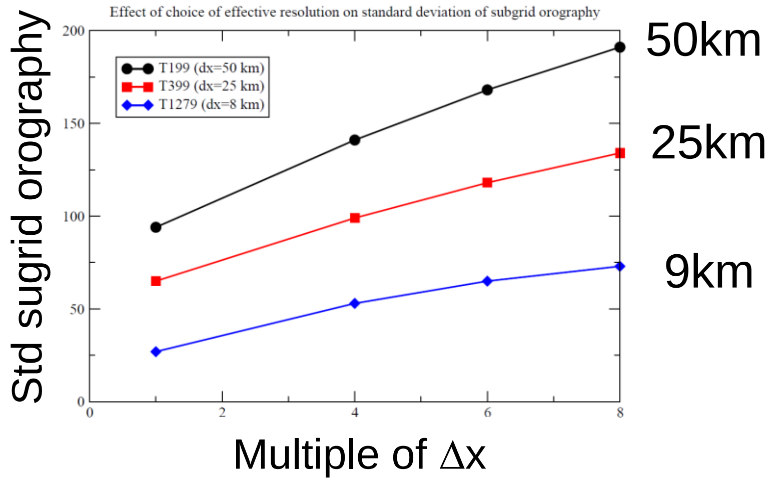

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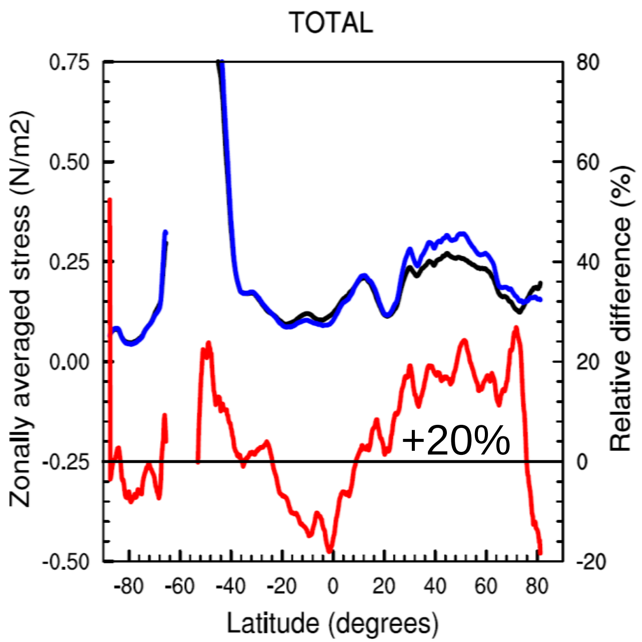
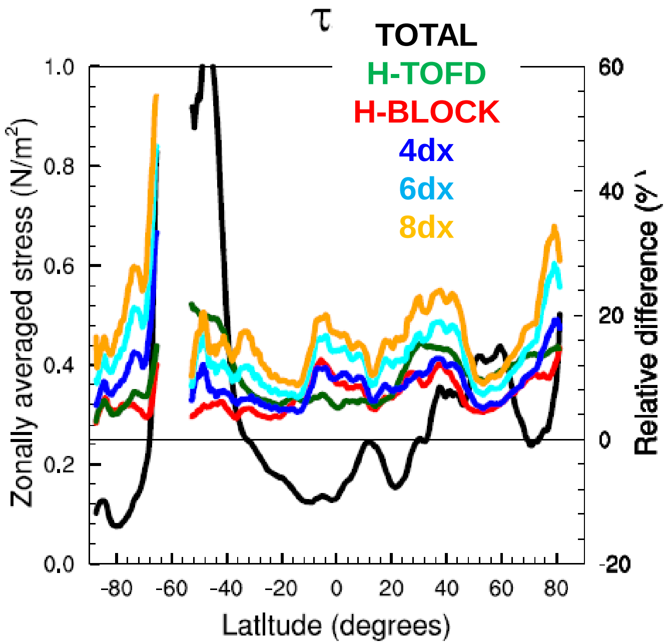
Mimicking inter-model differences in IFS

Similarly to Sandu et al, JAMES, 2015, but also for different subgrid orographies





(Daily 10 days forecast only runs, for December 2015, at TCO399 ~ 25 km at the Eq.)

at TCO199 ~ 50 km at the Eq.

at TCO1279 ~ 9 km at the Eq.

What is the impact on short/medium range forecasts?
Handover between parameterized and resolved drag

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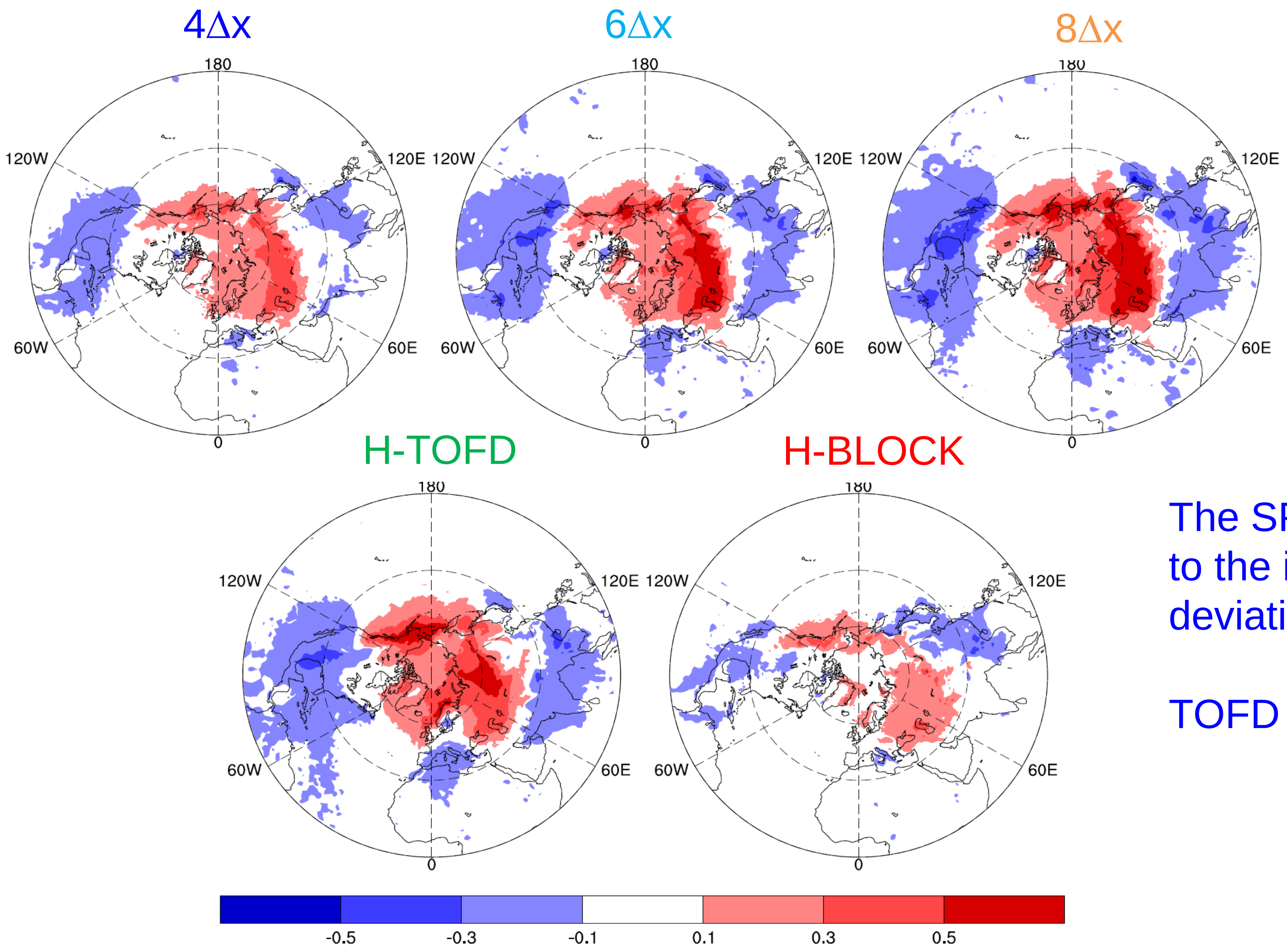
Do these differences in stress matter in short range forecasts ?

Change in SP
+24h

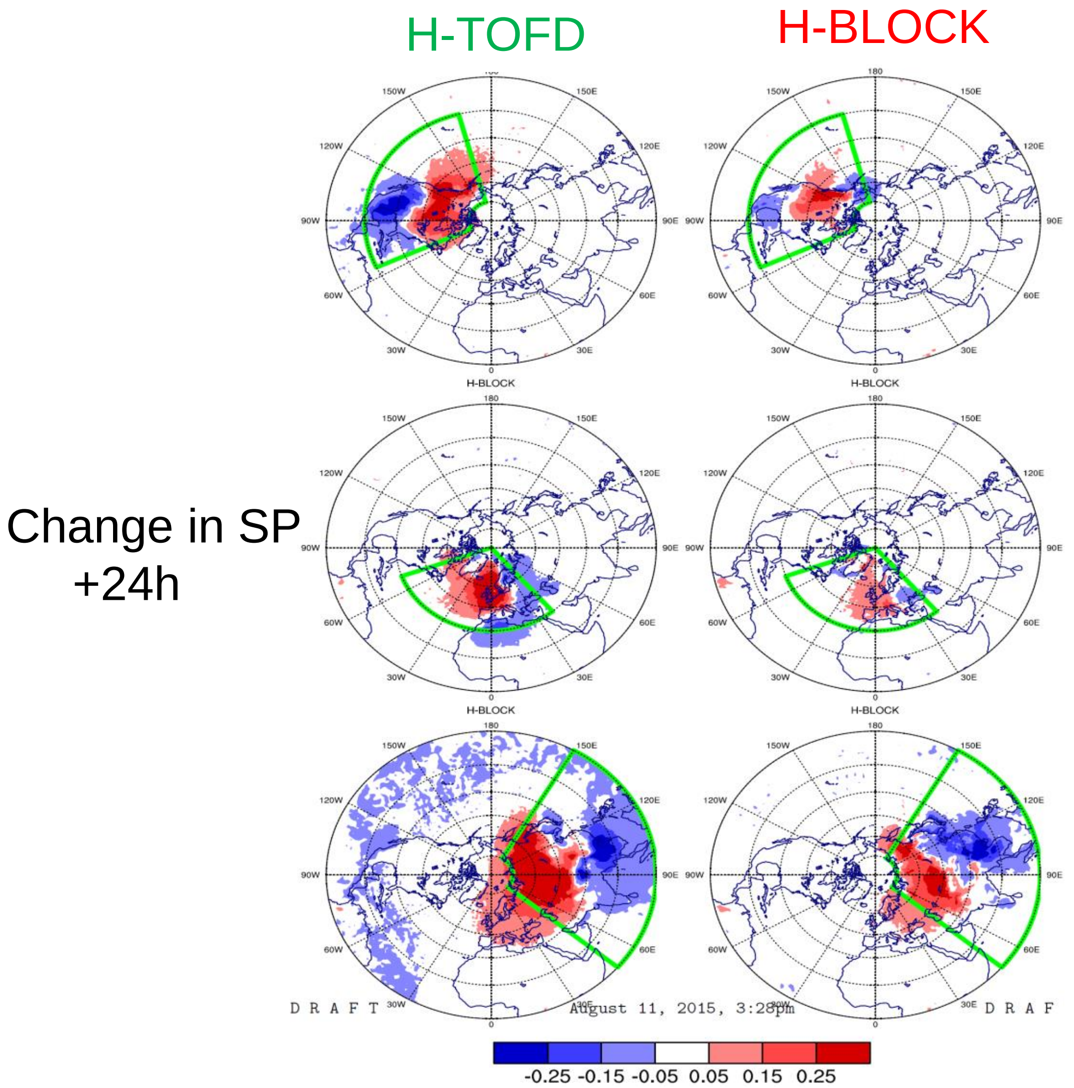


TCO399
25km

The SP change is proportional to the increase in standard deviation of subgrid orography

TOFD has similar effects

Are these effects local?



Local response in SP, through geostrophic balance. The meridional pressure gradient is induced by a deceleration of the mid-latitude westerlies (*Sandu et al. 2015*)

corroborates Zadra et al 2003

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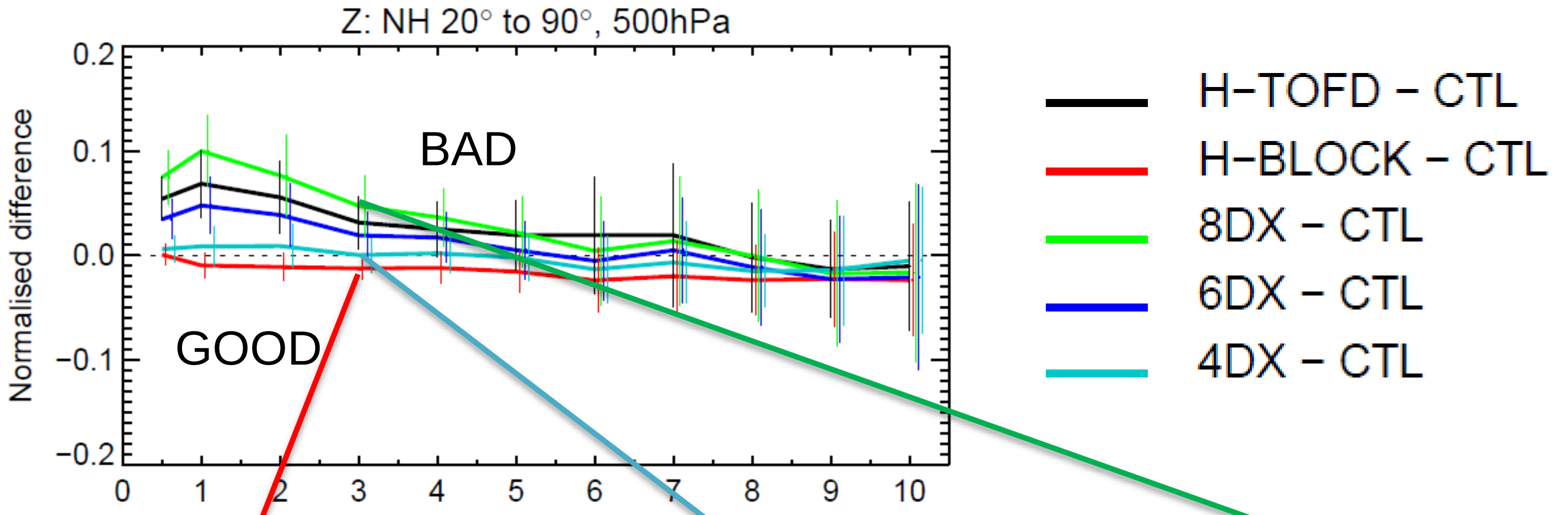
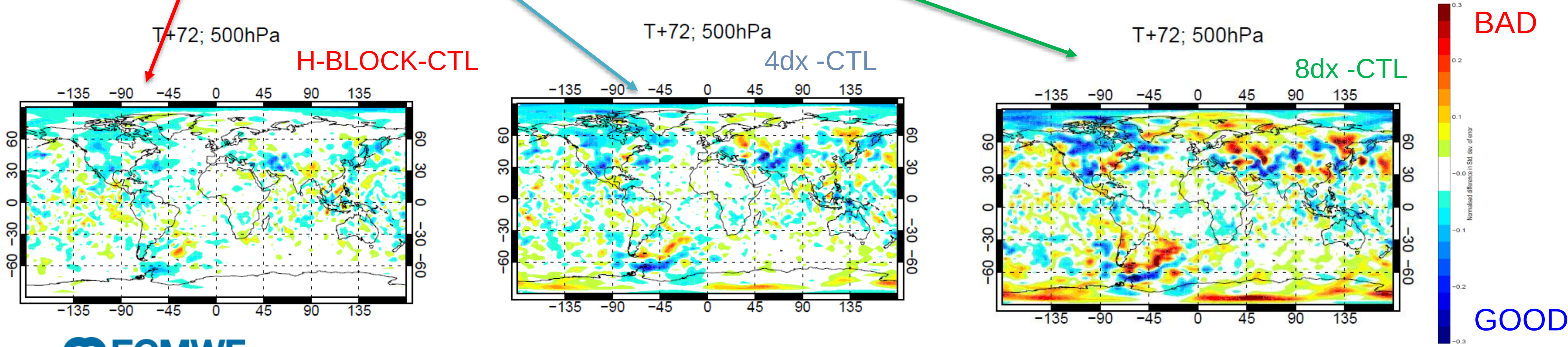
Impact on medium range forecasts: change in STD Z500

TCO399
25km

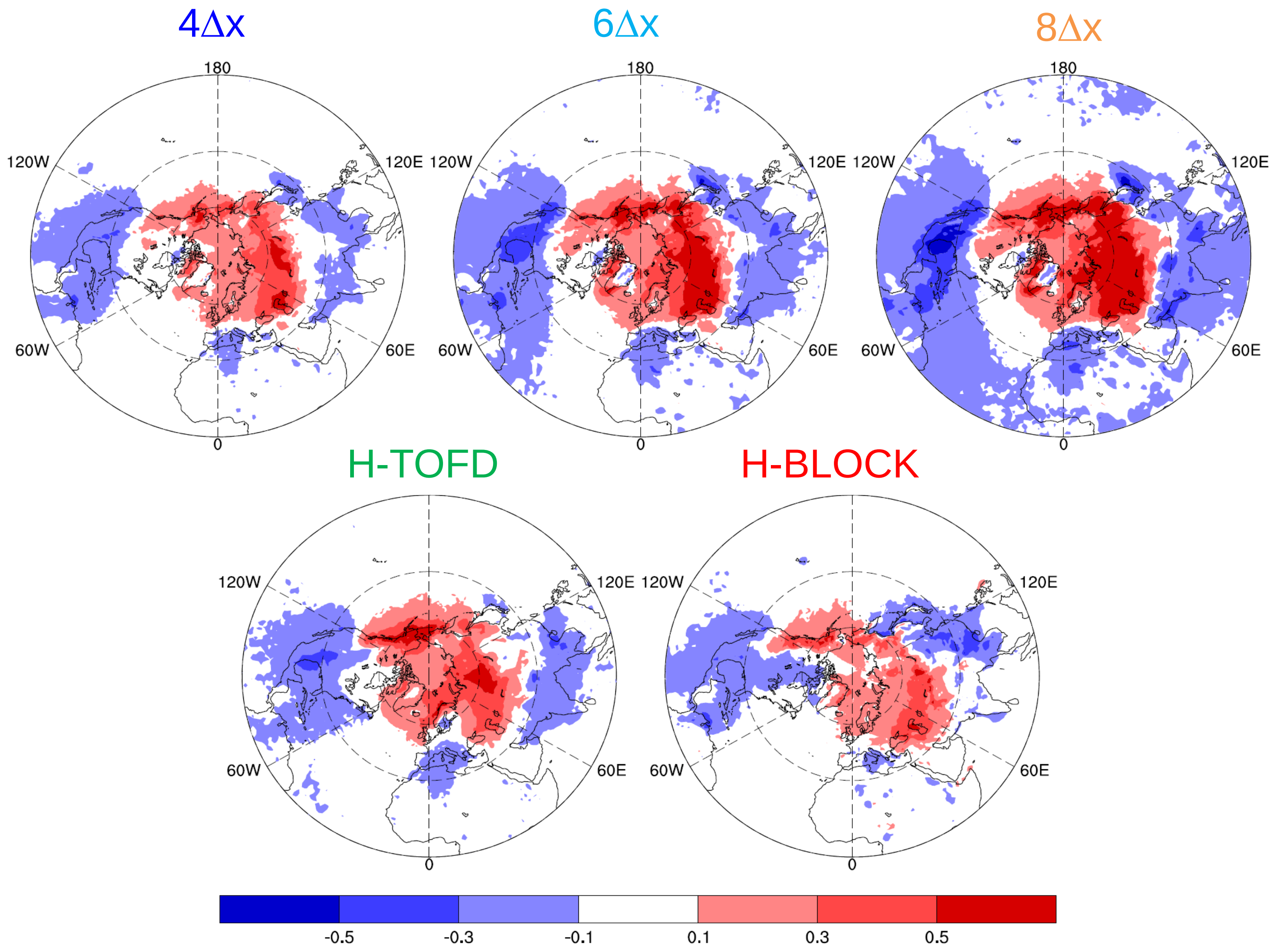


Fine balance between improving and degrading the forecast skill



Are these differences resolution dependent ?

Change in SP
+24h



TCO199
50km

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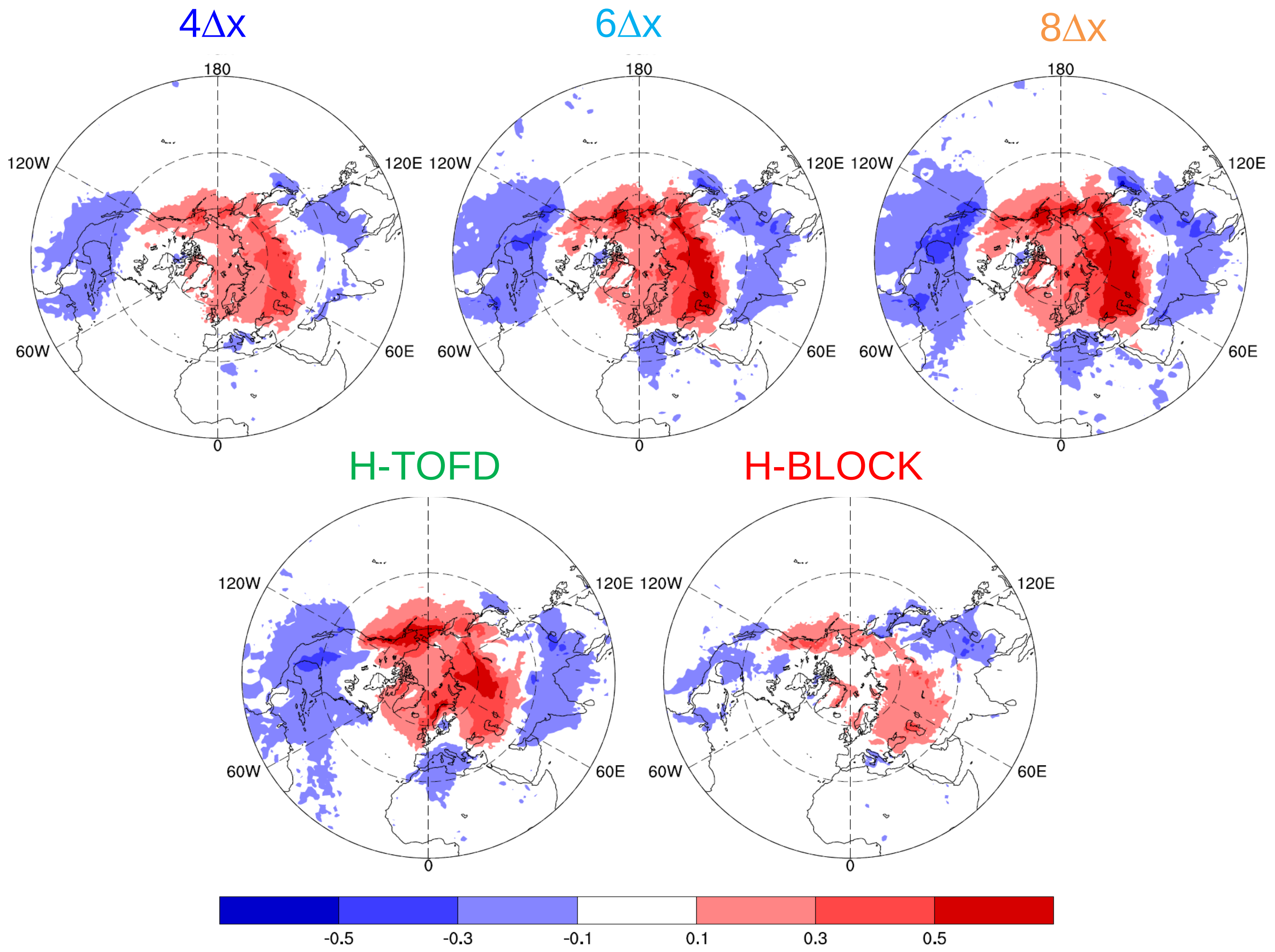
Are these differences resolution dependent ?

TCO399
25km

Change in SP
+24h



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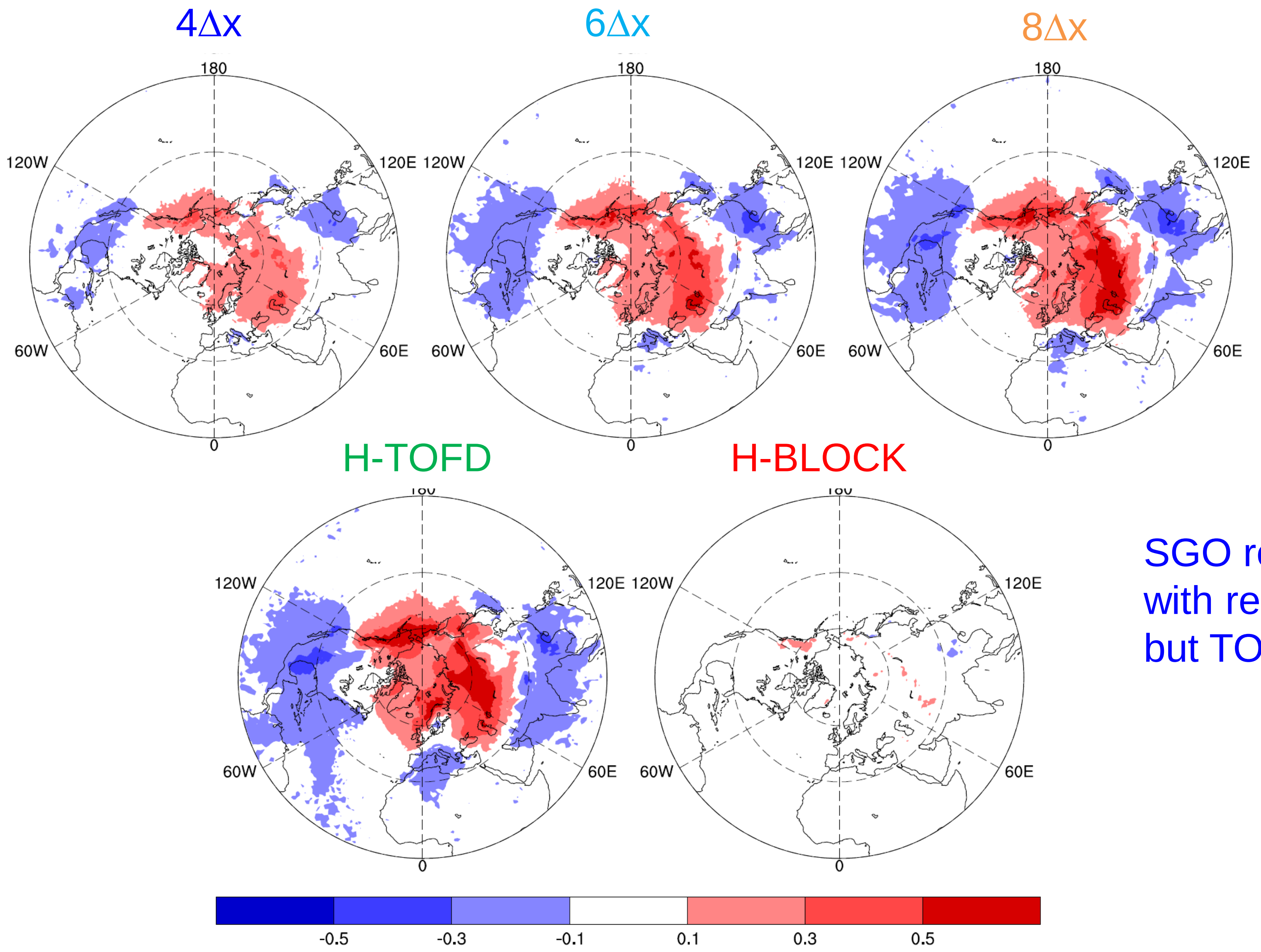

TCO1279
9km

Change in SP
+24h

SGO related impacts decrease with resolution as expected but TOFD impacts are similar

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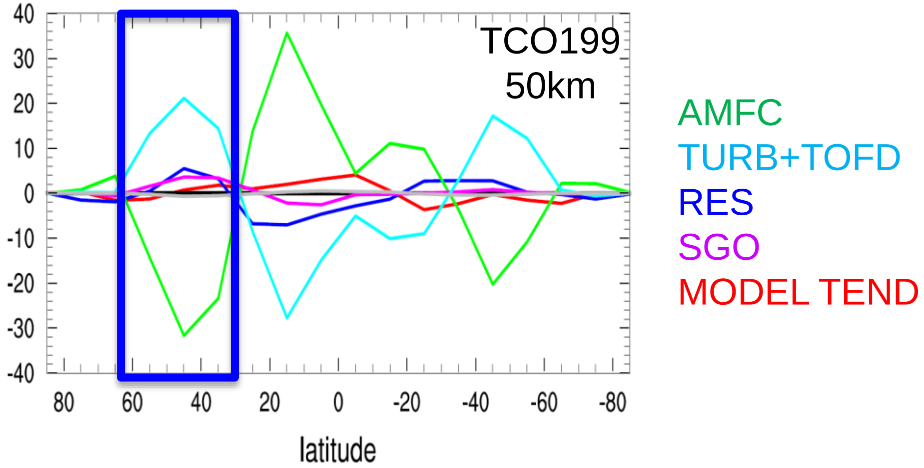
Angular momentum budget (*Brown et al. 2004, Van Niekerk et al. 2015*)

Difference between 9 and 50 km (Δx)

What we would expect:

- ✓ Increase in RES and decrease in SGO should compensate
- ✓ TOFD and TURB should not change much
- ✓ TOTAL should be constant

See Annelize's talk for more details



Angular momentum budget (*Brown et al. 2004, Van Nierkerk et al. 2015*)

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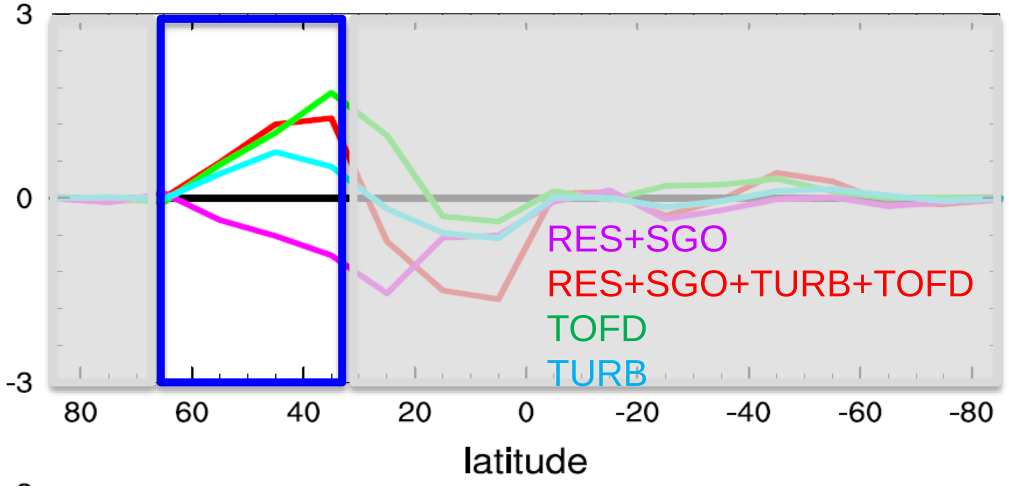

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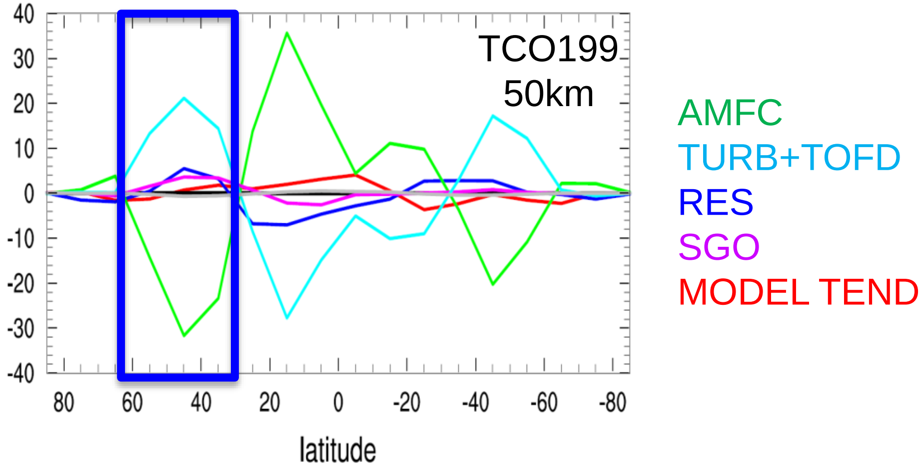
What happens:

- ✓ RES increases less than SGO decreases – so RES+SGO decreases, wind speed increases, hence TOFD and TURB increase (the wind speed increase is due to the change in SGO not the change in resolution – or mean orography)
- ✓ TOTAL increases

See Annelize's talk for more details



Angular momentum budget (Brown et al. 2004, Van Nierkerk et al. 2015)

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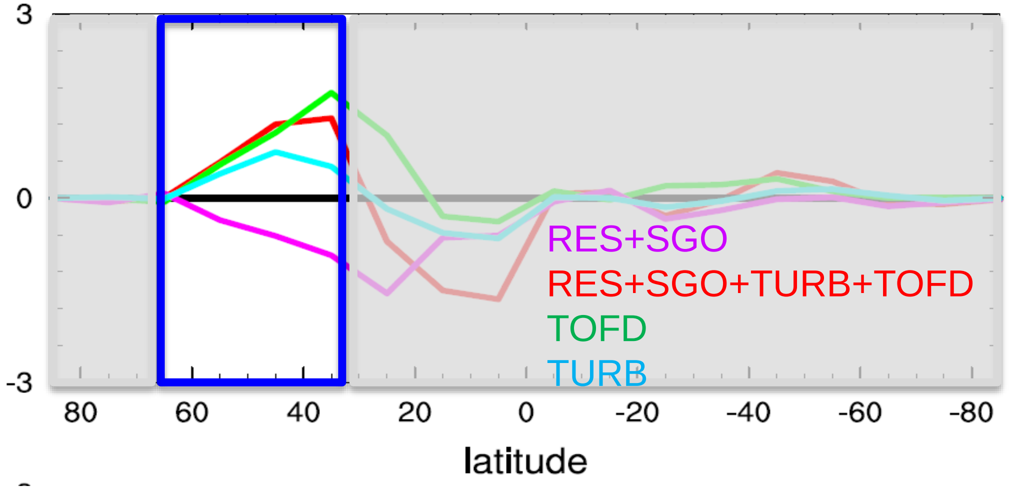
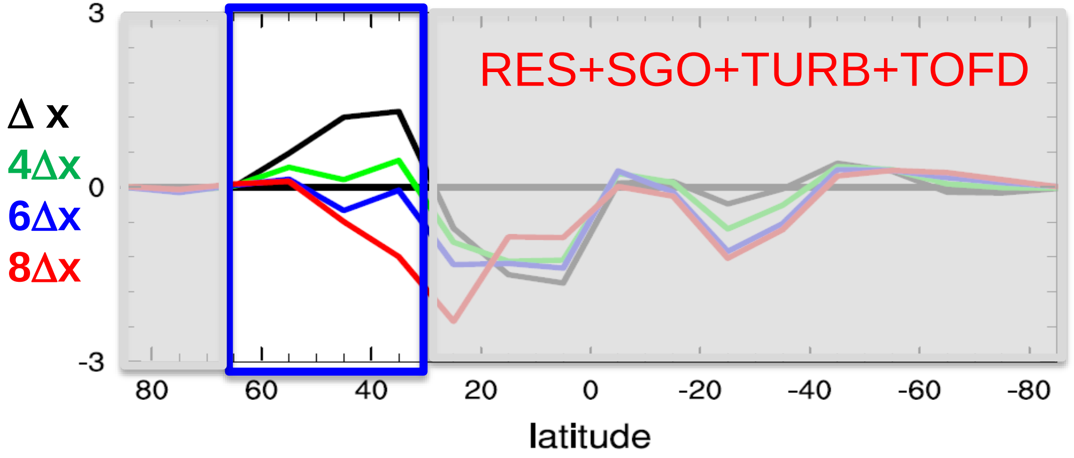


Difference between 9 and 50 km



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Change in TOTAL smallest for 4dx, which suggests that the effective resolution is 4 dx (corroborates what we expected for the TCO grid)

Summary

- Both the schemes themselves and way the subgrid orography is constructed affect the forecast skill
- If the impact of the blocking schemes fades away with increasing resolution, this is not true for form drag schemes. Both schemes are still important for climate for the foreseeable future
- Determining the effective resolution and constructing the subgrid orography to represent scales inferior to it seems the right thing to do (?) – care must be taken of islands (which we did not do here)
- Studying the resolution dependency of the momentum budget seems a way to determine the effective resolution
- The handover between parameterized and subgrid happens in an unexpected way (response in TOFD)
- Subgrid and resolved orography affect wind profiles in a different way

Lots of food for thought and debate during the working groups ☺

Open questions – Working groups

1. Theoretical aspects of drag impacts on the large-scale circulation

What do we and don't we theoretically understand about how drag affects the large-scale circulation? Which frameworks, specific questions or approaches can yield the largest progress? Is there recent theoretical work on the effects of complex orography on the flow, when various processes (turbulence, gravity waves, form drag, etc.) occur simultaneously?How does the surface orographic drag affect the flow on different time scales? Do we really know why enhanced drag leads to weaker cyclones/model activity in GCMs? If not, how can we find out? What is the impact of the wind dependence of ocean drag on the large scale circulation?

2. Representation in models (parameterizations, anciliary files)

Would we expect different models with the same ancillaries and drag schemes to produce the samecirculation? To what extent do the dynamical cores and physics-dynamics coupling influence the circulation? What is the best strategy for exploring the stability and wind dependence of orographic drag? How do different modelling centres construct their resolved and sub-grid orography datasets (at different resolutions)? Is the pre-processing of the subgrid orography to separate the forcing data between different schemes (e.g. scales > 5km for flow blocking and GWD; smaller scales for PBL scheme) still used? What would be a meaningful way of comparing different techniques? If the unresolved stress involves scales larger than the subgrid scale (as suggested by the recent studies of Vosper et al 2015,2016), how could the parametrizations take that into account? And how can we unambiguously define the resolved component of the stress of a model? Do we expect parameterizations to be scale-adaptive, or should model tuning be resolution-specific? How can we better understand inter-model differences, both in terms of total drag and the partition of drag between the different schemes? What are the next steps for the 'WGNE Drag project'?

3. Constraining drag

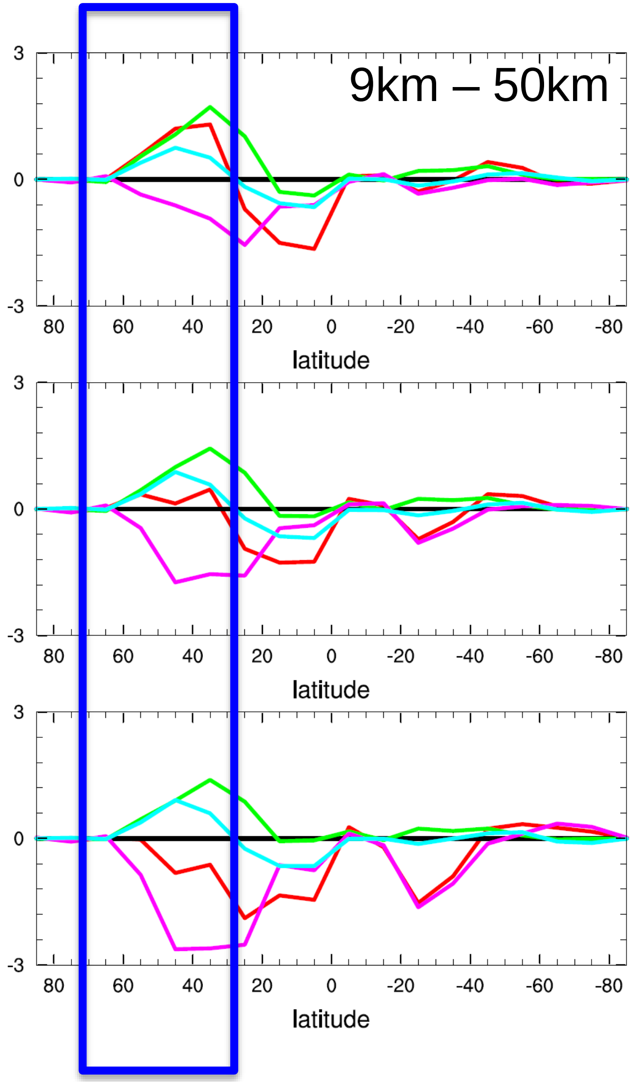
Momentum fluxes are very difficult to observe at spatial and temporal scales relevant to large-scale models. What observable bulk quantities could be used as metrics instead, and what is the fingerprint of individual drag processes in changes of these metrics? How do changes in model settings and parameters impact these metrics in GCMs? How to optimize poorly known parameters entering the parameterizations (e.g. land surface roughness)? Can 'inverse modelling' using data assimilation techniques help? Can we use observations, reanalysis and high-resolution simulations as 'ground truth' to constrain the total amount of drag and/or the contributions from individual processes (both over land and oceans)? Are high resolution simulations the best way to go forward? What can we gain from existing datasets such as the DEEPWAVE results? What new observations or model experiments are required?

Angular momentum budget (Brown et al. 2004, Van Nierkerk et al. 2015)

Δx

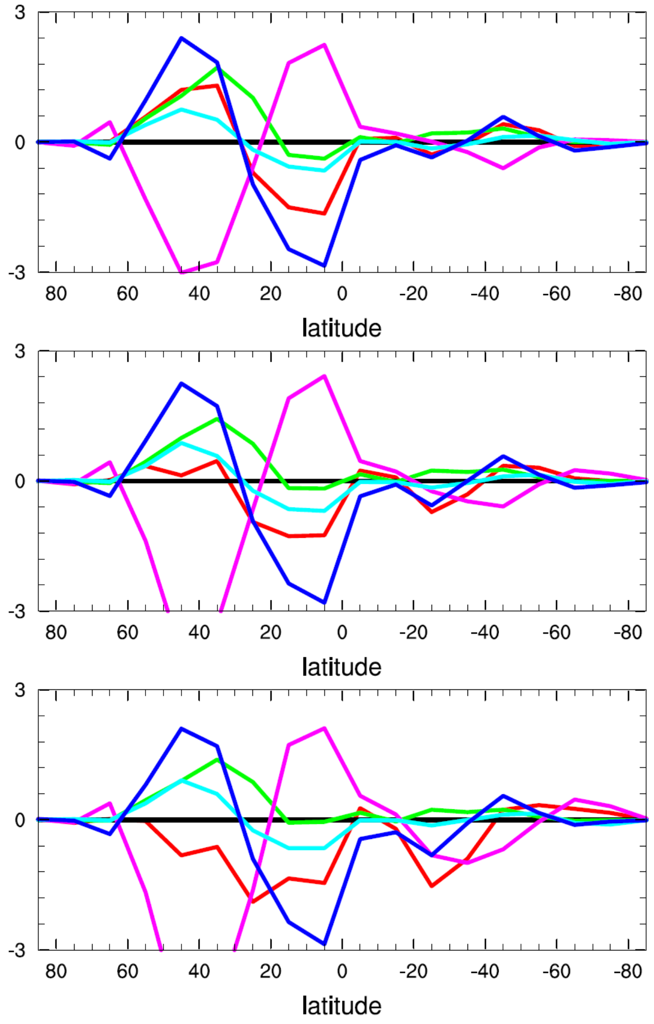
4Δx

8Δx



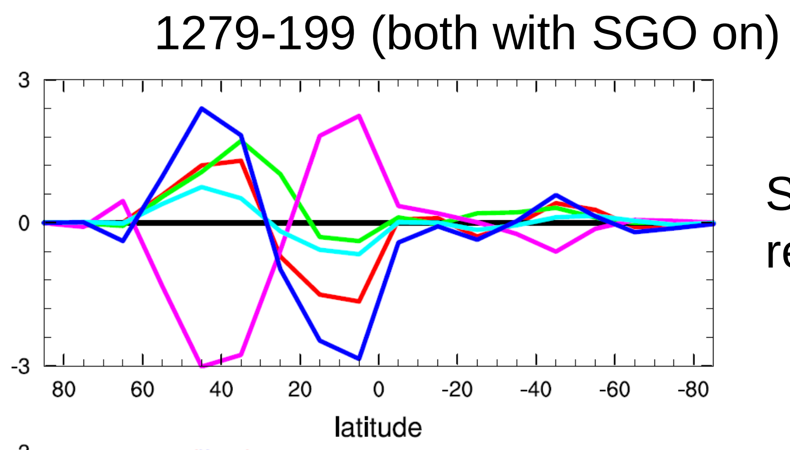
RES+SGO
RES+SGO+TURB+TOFD
TOFD
TURB

RES
SGO
TOTAL ~cst
TOFD
TURB

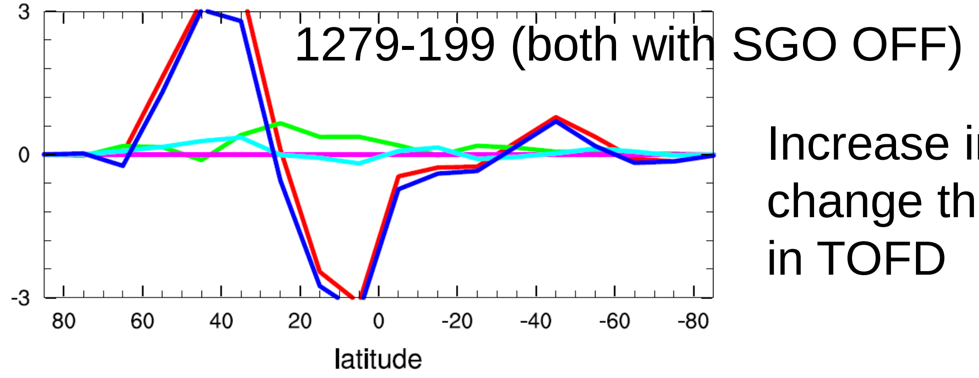


RES
SGO
RES+SGO+TURB+TOFD
TOFD
TURB

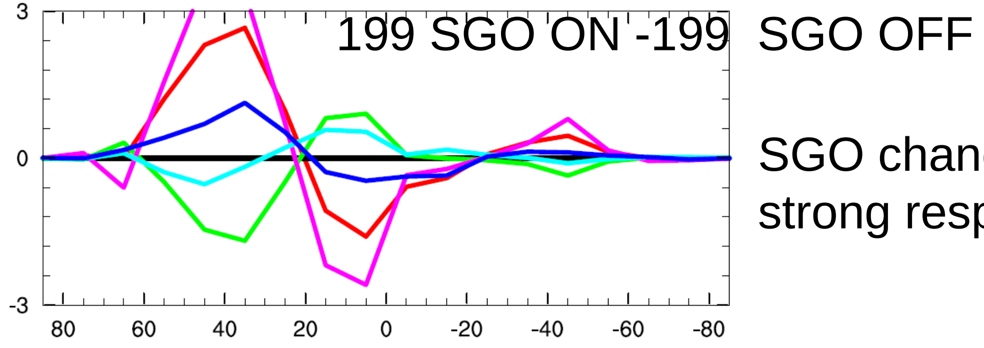
RES
SGO
RES+SGO+TURB+TOFD
TOFD
TURB



SGO decreases more than RES increases, response in wind hence TOFD

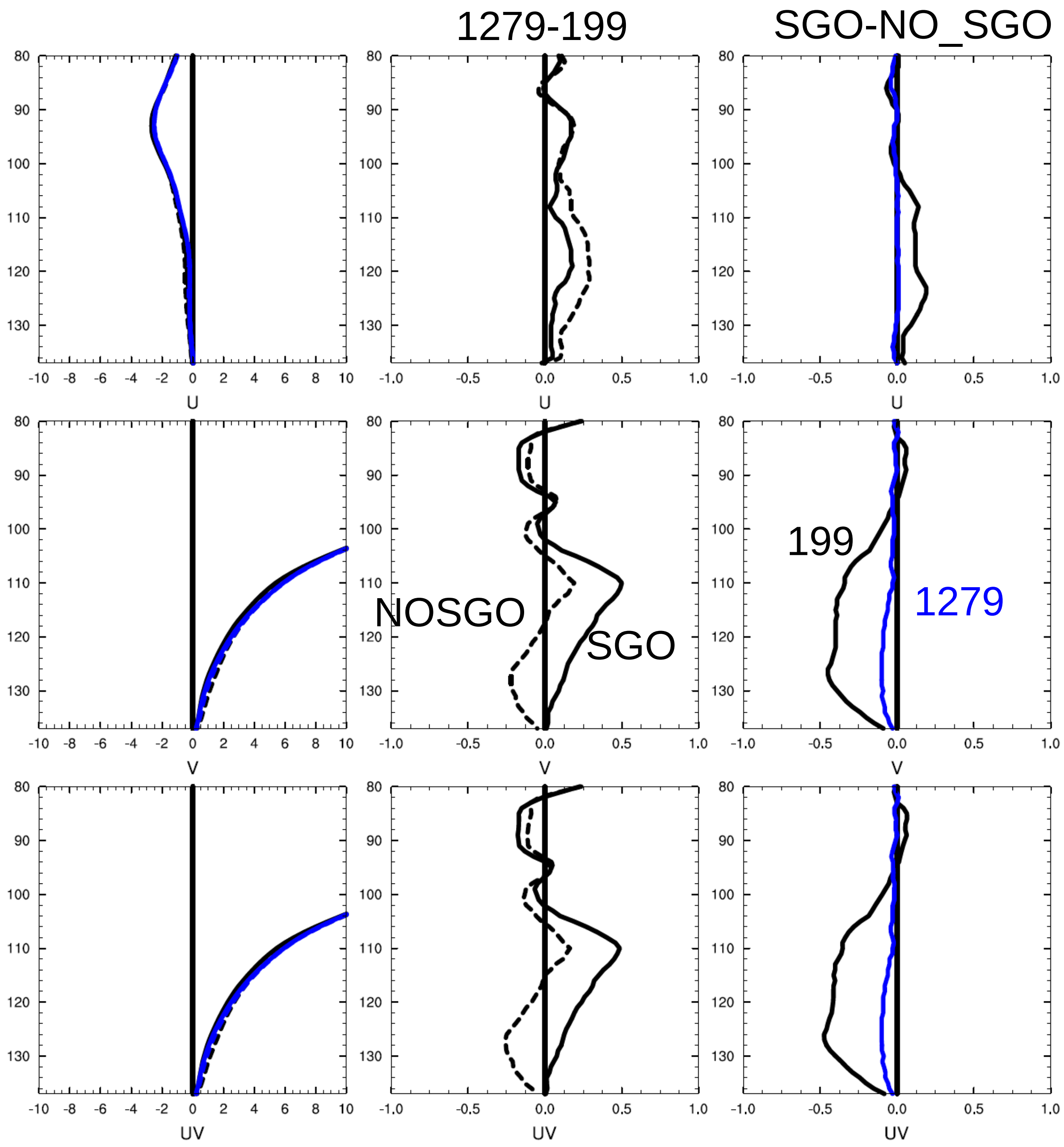


Increase in resolution does not change the winds, hence little change in TOFD



SGO changes the winds, hence strong response (change) in TOFD

extra



Preparation of the data sets to characterize the sub-grid orography

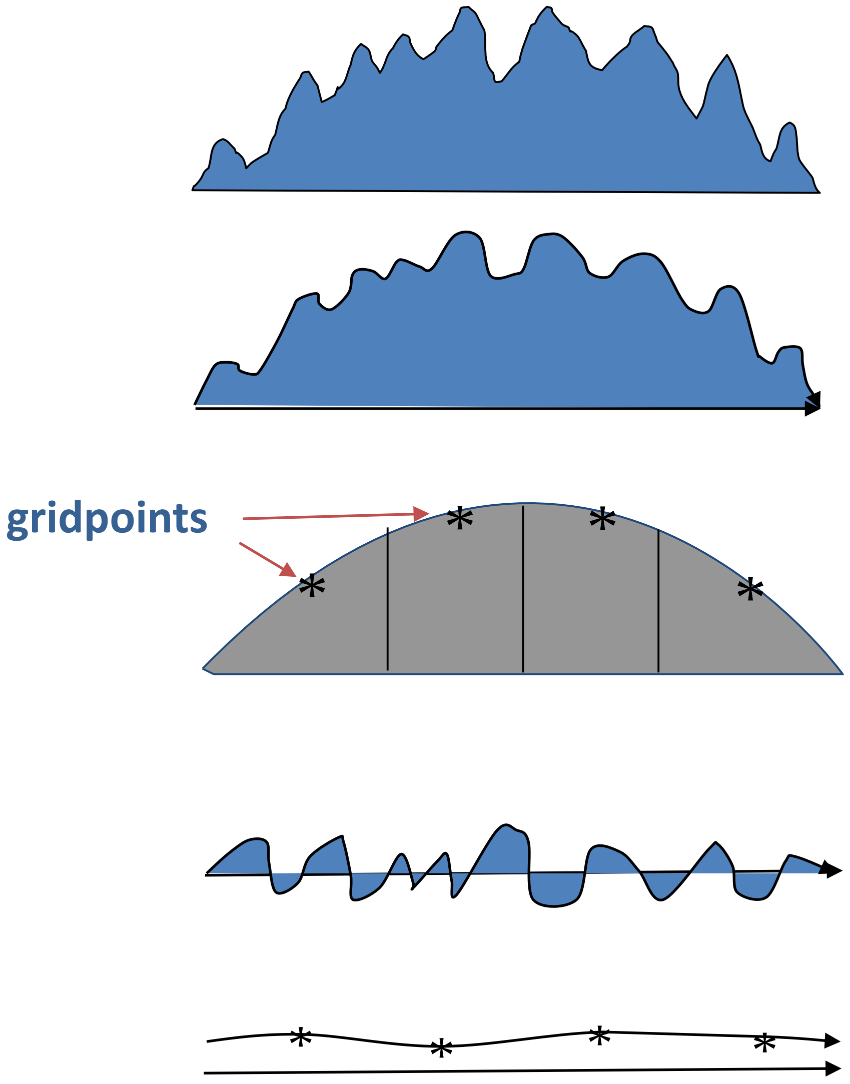
1. Global 1km resolution surface elevation data

2. Reduce to 5 km resolution by smoothing

3. Compute mean orography at model resolution

4. Subtract model orography (3) from 5km orography (2)

5. Compute standard deviation, slope, orientation and anisotropy for every grid box



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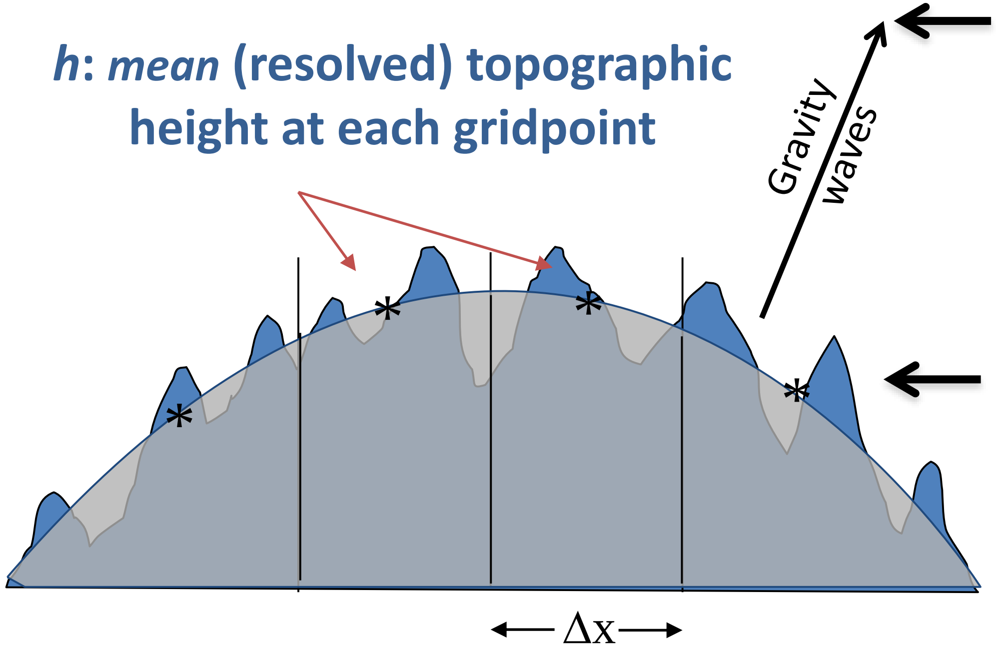
Sub-grid orography

***h*: *mean* (resolved) topographic height at each gridpoint**

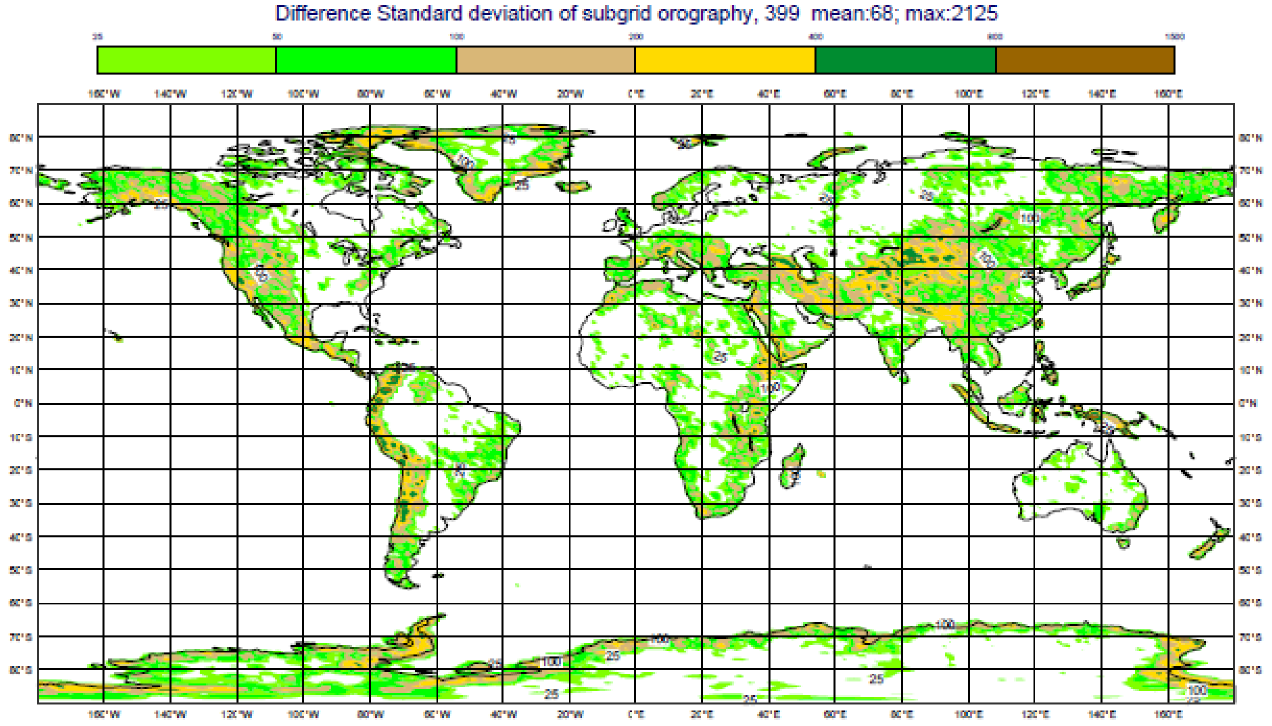
Effect: upper air drag due to gravity wave breaking



Effect: Near surface drag

h: topographic height above sea level (from global 1km data set)

Varying the filter scale: Stdev difference 8 Δ - ctrl



TCo399