Why is it so difficult to represent stably stratified conditions in NWP models?

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Stable conditions: a longstanding issue for NWP models

GABLS: Operational NWP models have less skill in reproducing stable boundary layers than research models or large-eddy simulations

The reason: their turbulence closures for stable conditions are much more diffusive than what can be justified from LES or observations

The outcome:

- ✓ too deep stable boundary layers
- ✓ smearing out of low level jets
- ✓ underestimation of the wind turning in the boundary layer
- ✓ too much diffusion of warm and dry air from above into the boundary layer, resulting in underestimation of stratocumulus decks

So why enhancing the diffusion in stable conditions?

Still common practice in NWP : ECMWF, MetOffice (over land), GFS

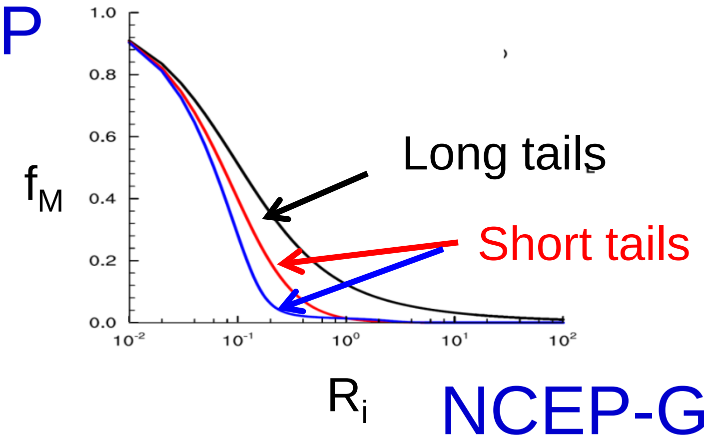
Justification (poor evidence – McCabe and Brown, 2007):
To account for surface heterogeneity, unresolved sources of gravity waves, or meso-scale contributions to vertical transport

In practice: It offsets model biases in key aspects of weather forecast (Beljaars et al. 1998, Viterbo et al. 1999)

- ✓ cold near-surface biases in stable boundary layers
- ✓ development of synoptic cyclones

First order closures used in NWP

$$K_{M,H} = \left|\frac{\partial U}{\partial Z}\right| l^2 f_{M,H}(R_i), \quad \frac{1}{l} = \frac{1}{kz} + \frac{1}{\chi}$$



IFS	UKMO	NCEP-GFS
long tails near surface, short tails above PBL	Ocean: short tails Land: long tails near surface, short tails above PBL	Long tails
λ =150m	λ=40m	λ=30m
		background diffusivity for momentum only, and reduced diffusion coefficients in inversions capping the PBL

Questions

Is it still necessary to prescribe an artificially enhanced diffusion in stable conditions ?

Have the other components of the model improved enough or has the increase in resolution helped to overcome the need for such a compromise, that is clearly detrimental for the representation of near surface parameters?

Approach

Forecast experiments with reduced diffusion in stable conditions:

ST: long tails ⟶ short tails
LT30: λ=150m ⟶ λ=30m

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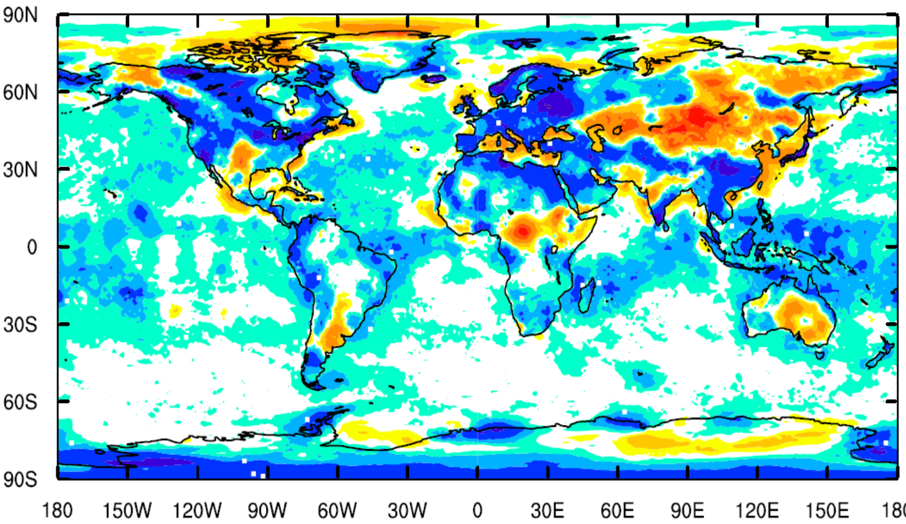
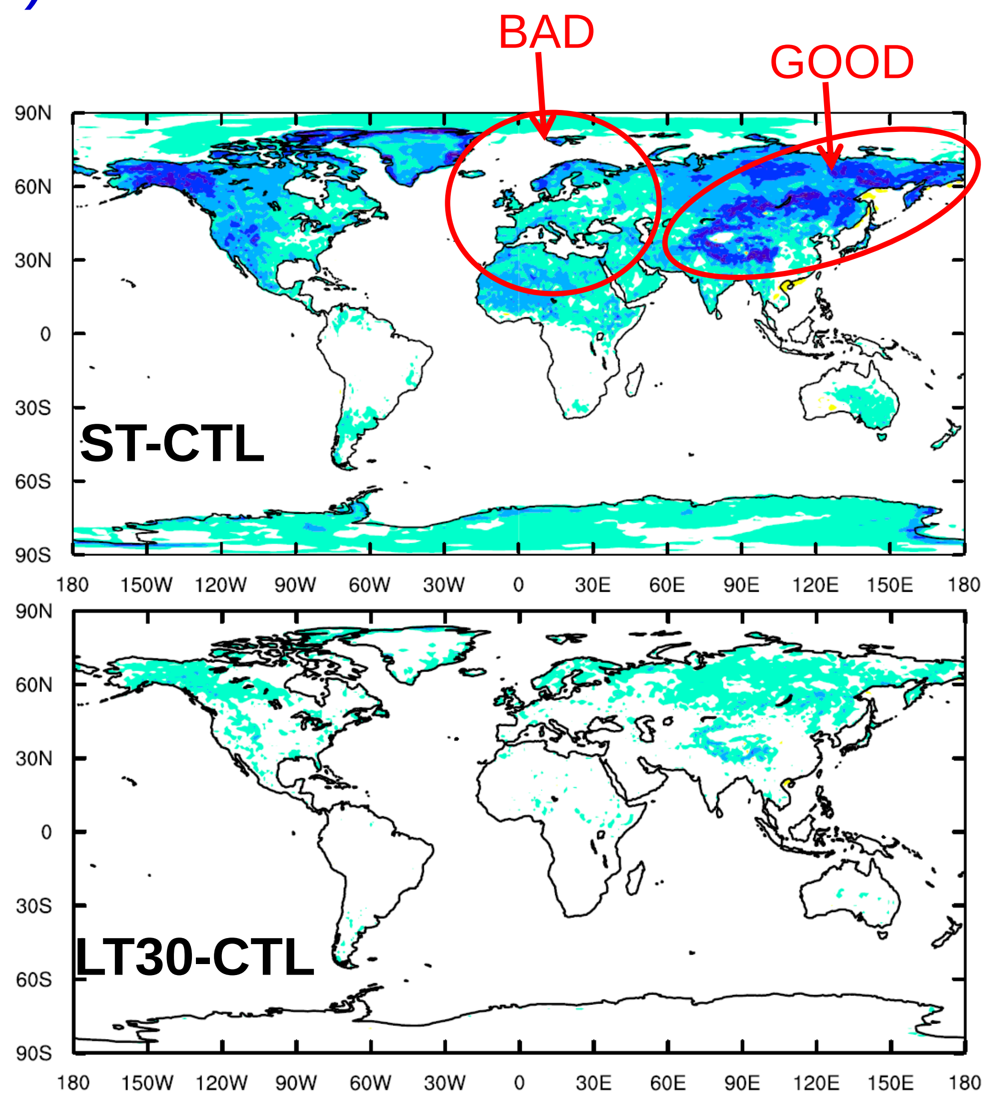
✓ what are the impacts on the model performance?
- near the surface
- free-troposphere
- large-scale dynamics

✓ can we do such a change as a stand alone change? Or do we need to improve the parameterisation of other processes? If so which ones?

Near the surface: T2m (day 1)

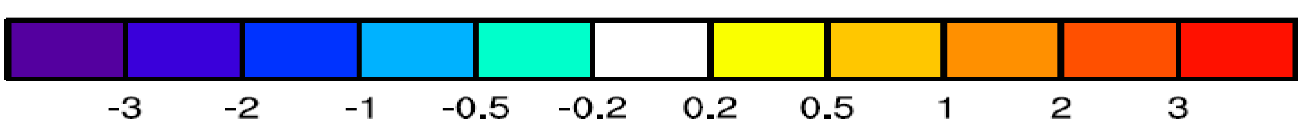
Bias (FC-AN) T2m CTL



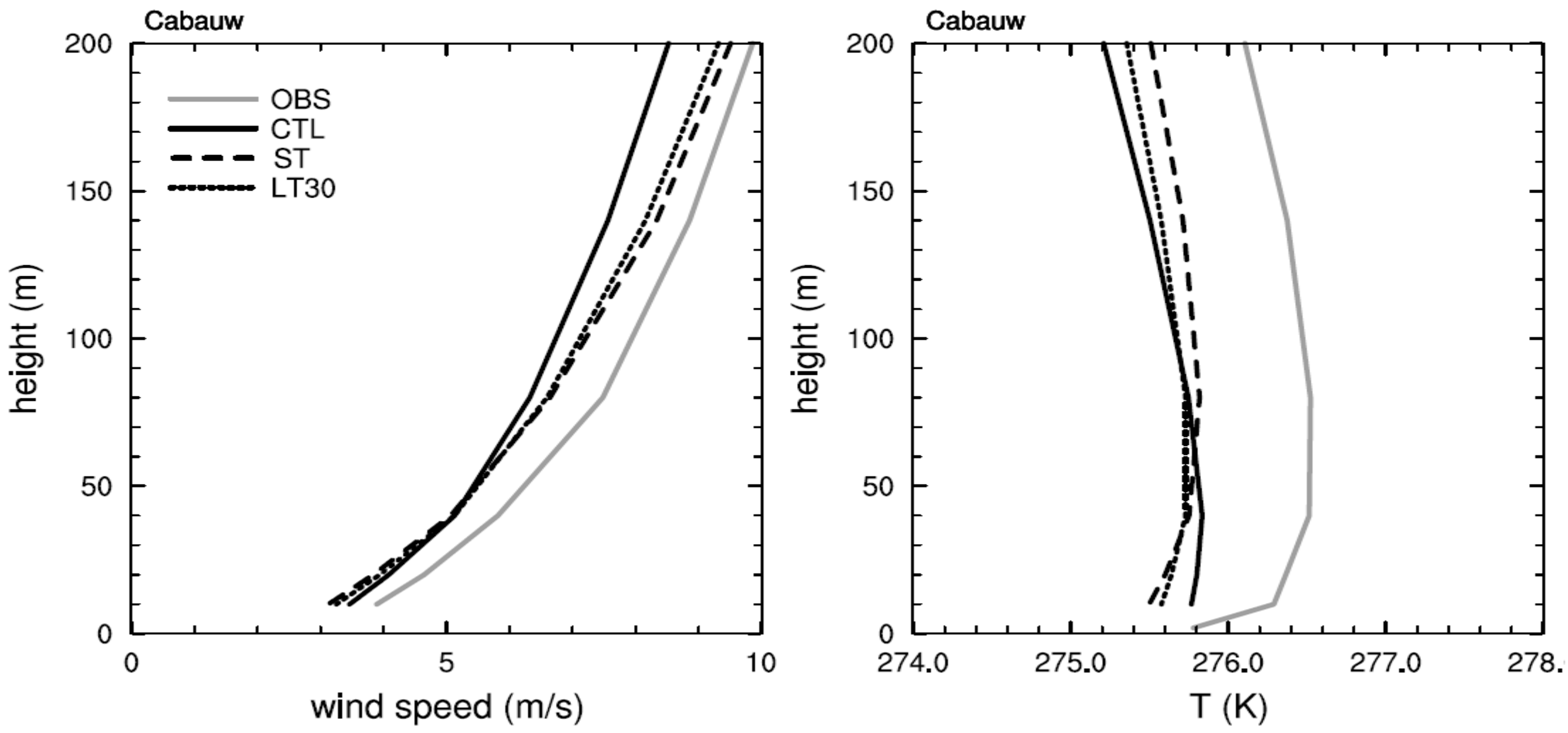


ST: long tails ⟶ short tails

LT30: λ=150m ⟶ λ=30m



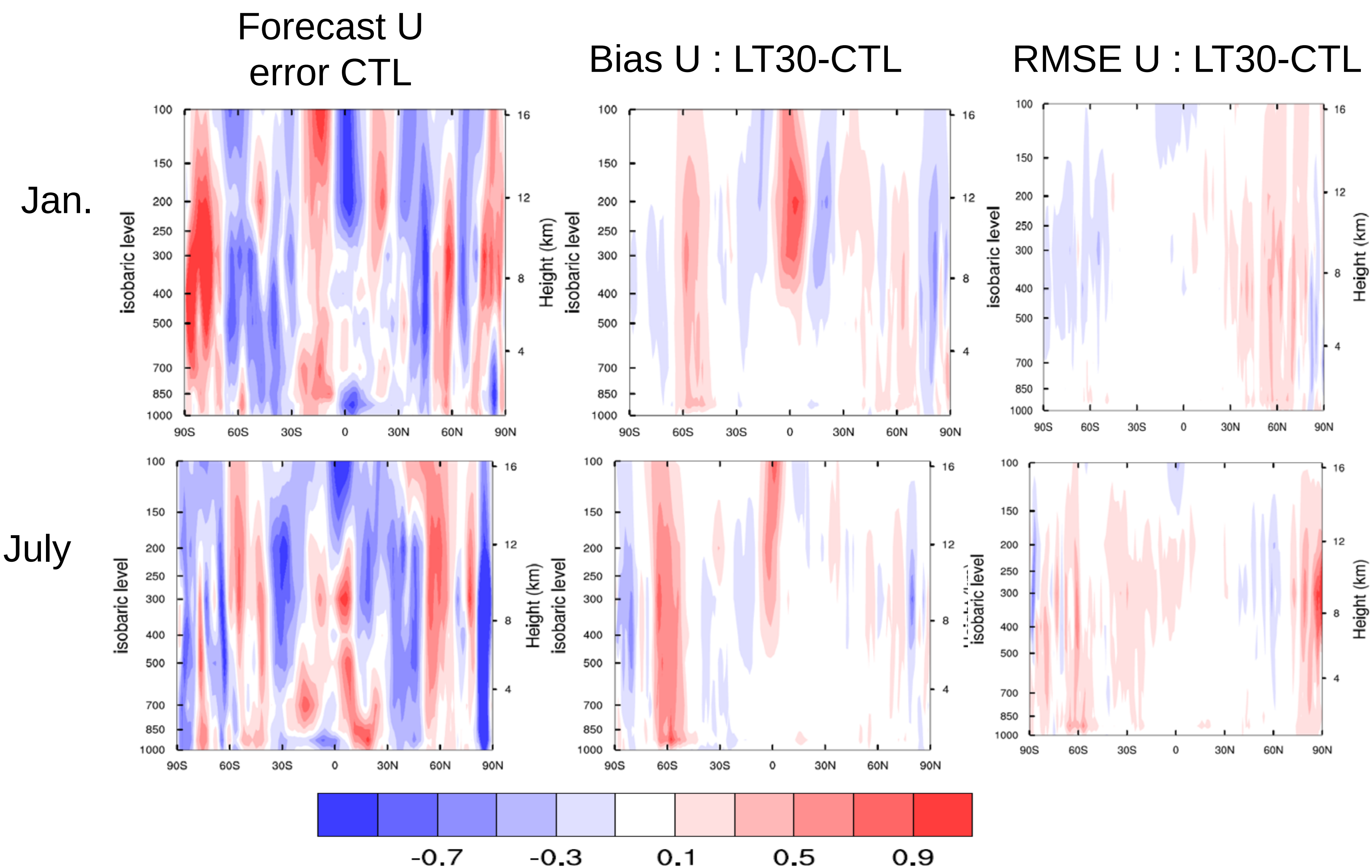
Near the surface: profiles U,T (day 1)



Almost halves the errors in low level jet, also increases the wind turning

ECMWF

Higher up: The upper tropospheric jets (day 5)



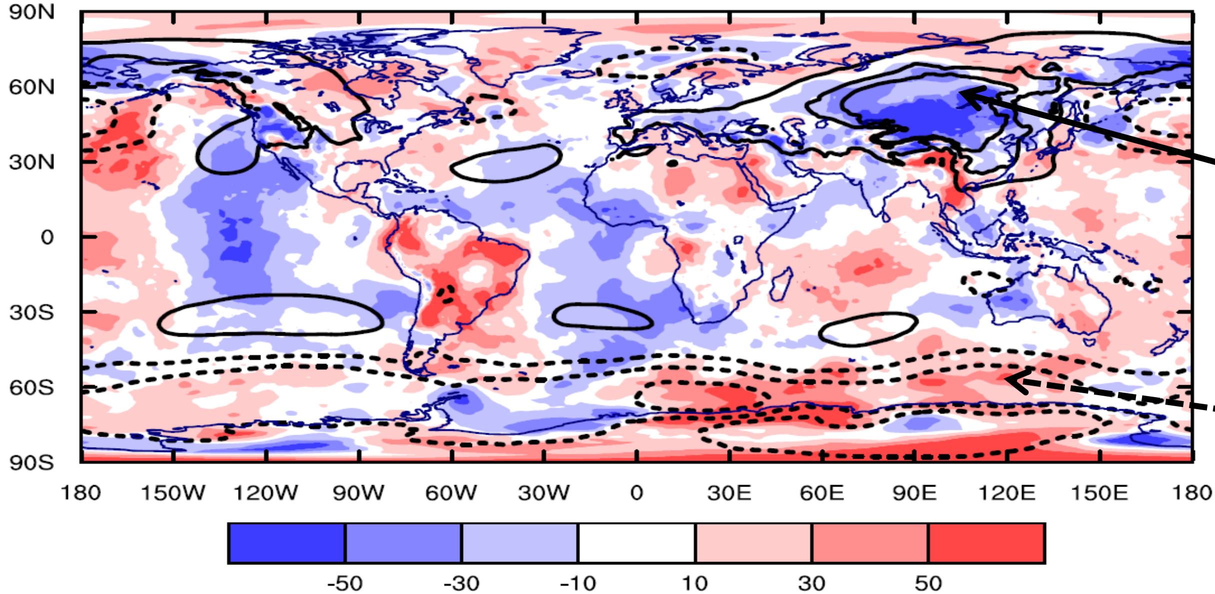
The large-scale flow

Hypothesis made by previous studies

Reduced diffusion implies less drag close to the surface hence increased ageostrophic angles, but also less mixing in the boundary layer, hence shallower turbulent layers. It results thus in decreased cross-isobaric flow, weaker spin down effect, hence stronger cyclones (Holton, 2004, Beare, 2007, Svensson&Holtslag, 2009)

The large-scale flow: 1000hPa geopotential height (day 1)

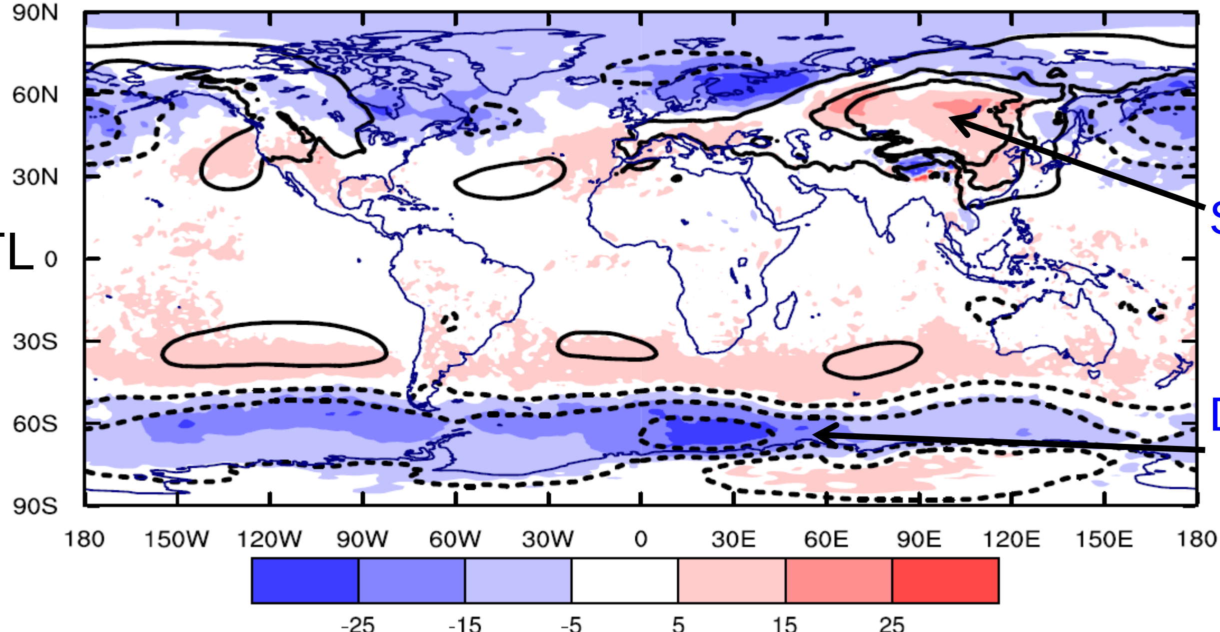
Bias Z CTL



High pressure

Low pressure

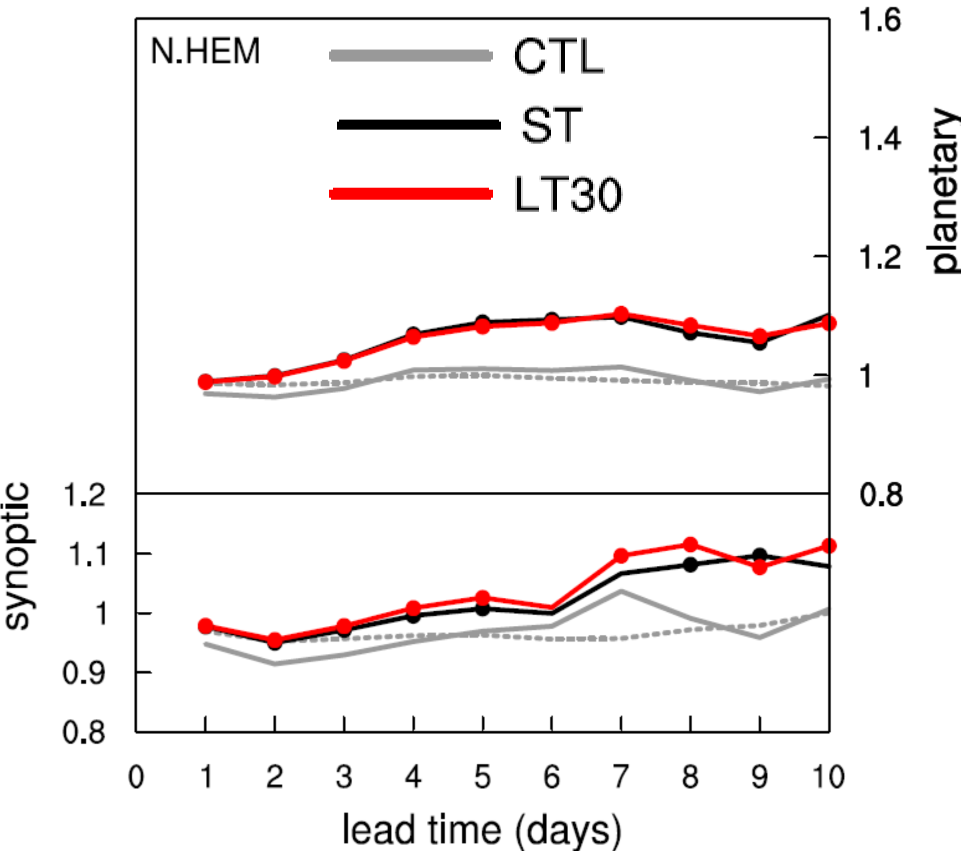
Z LT30- Z CTL

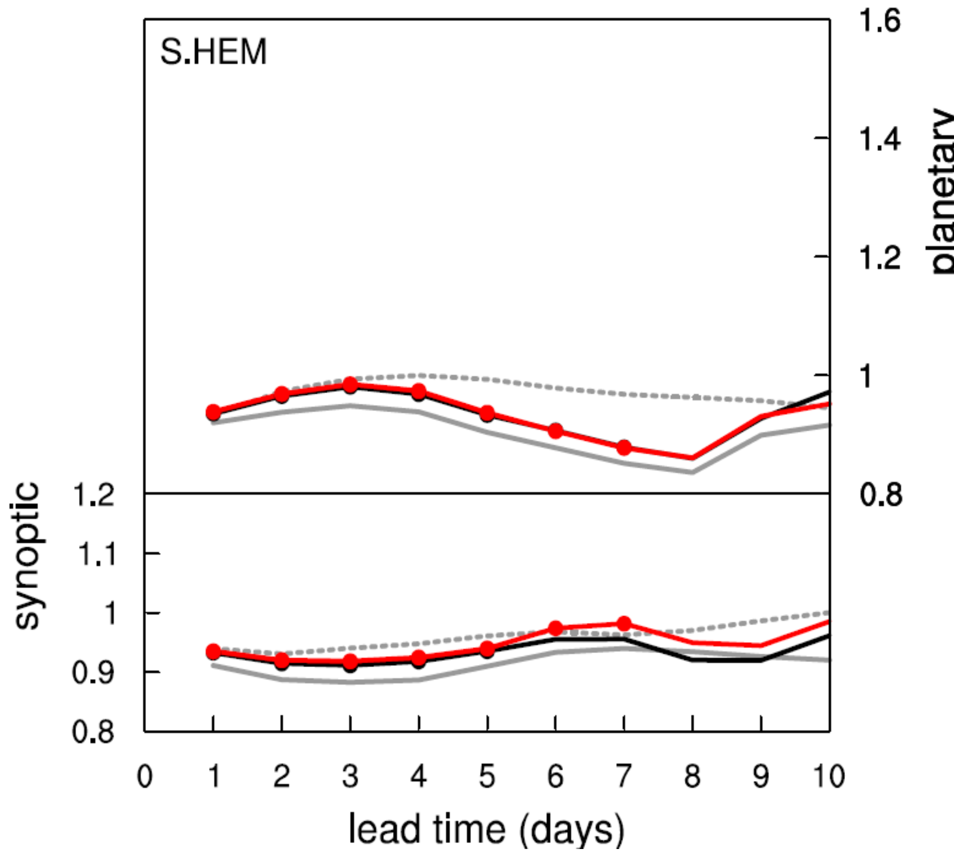


Stronger high pressure systems

Deeper low pressure systems

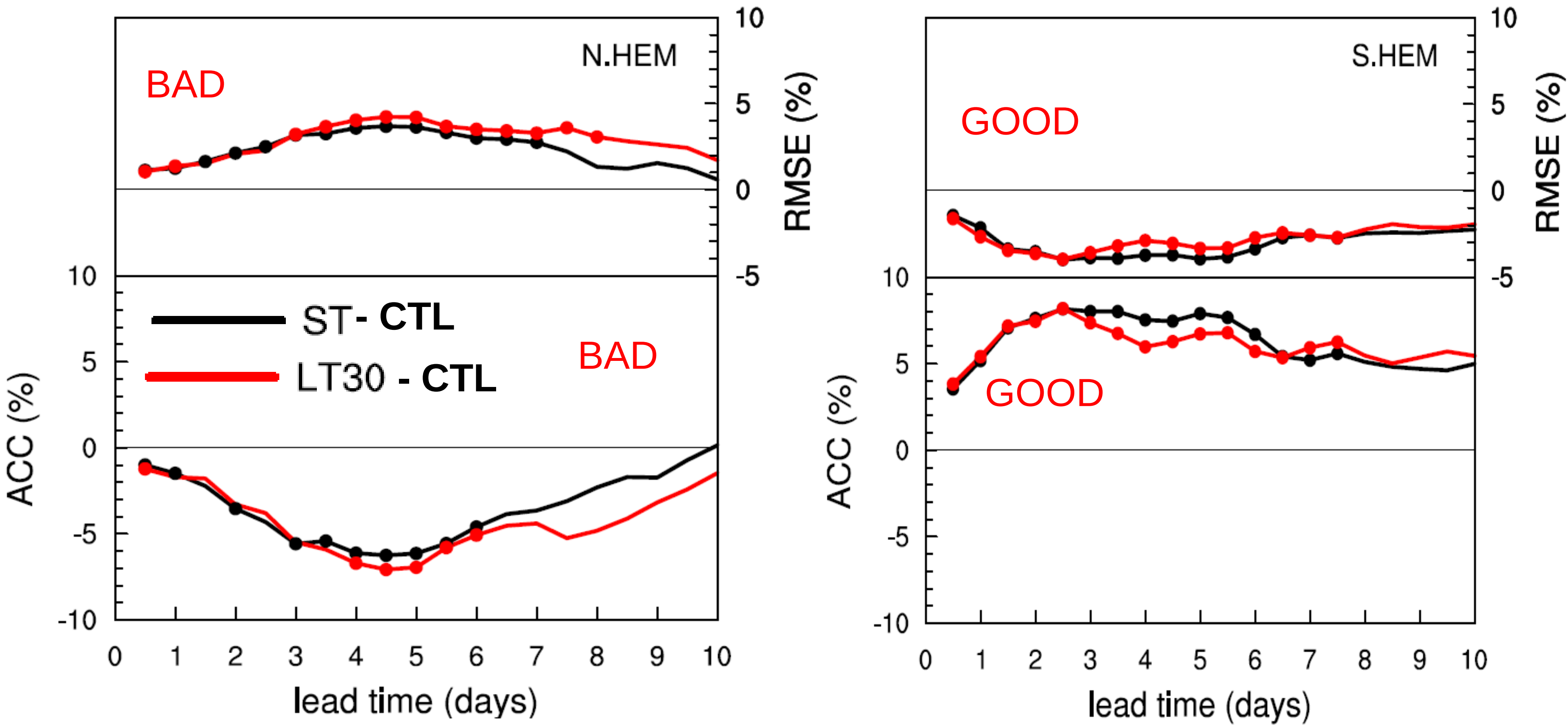
The large-scale flow: Model activity 1000hPa





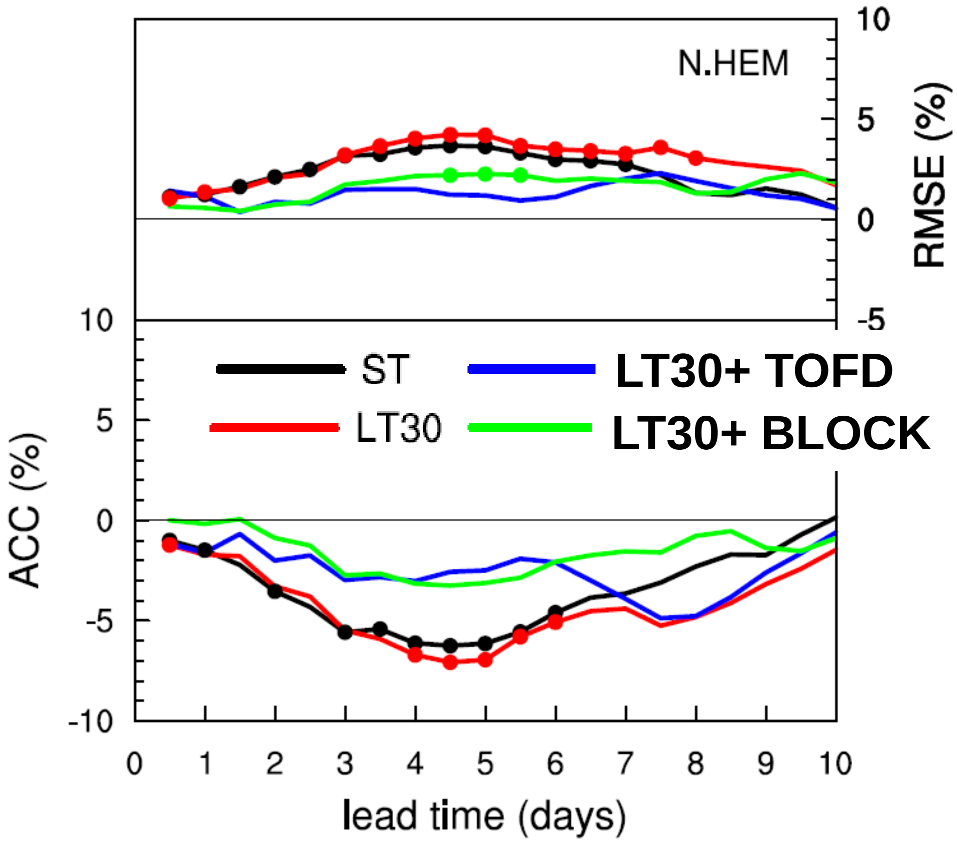
reduced diffusion increases the activity both at synoptic and planetary scales, with mixed effects on model performance

The large-scale flow: geopotential scores 500hPa



reduced diffusion cannot be implemented as a stand alone change, because it deteriorates crucial aspects of model large-scale performance

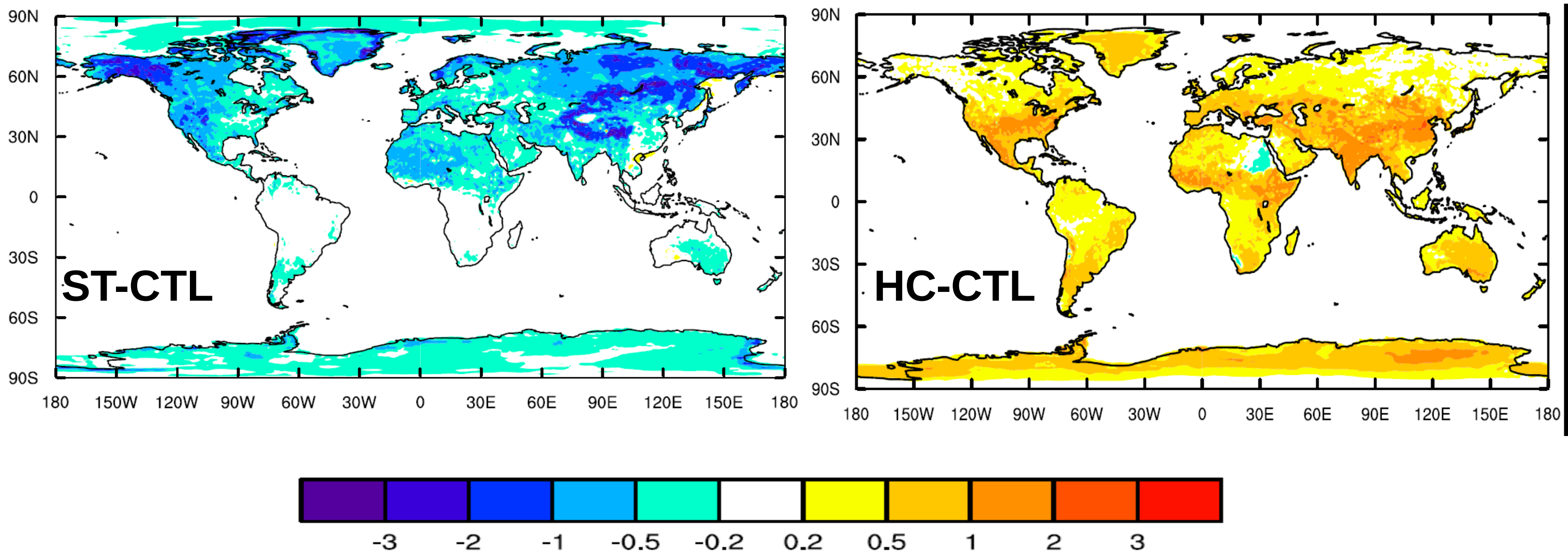
The large-scale flow: geopotential scores 500hPa



the deterioration due to reduced diffusion is outweighed by an increase in orographic drag

ECMWF

Increased coupling with the surface: T2m (day 1)



The deterioration of near-surface temperatures is partially compensated by doubling the land-atmospheric coupling coefficients

Conclusions

✓ The turbulent diffusion in stable conditions impacts not only the near-surface properties, but also the large-scale dynamics, namely:

- synoptic cyclones/anticyclones
- planetary standing waves
- upper tropospheric jets

✓ A reduction of the diffusion cannot be implemented as a stand-alone change, because it currently compensates for effects of poorly represented processes as:

- ✓ the drag over orography
- ✓ the land-atmosphere coupling