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Parametrization of Subgrid-Scale Orographic Drag in the COSMO Model: An Alpine Perspective

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MeteoSwiss

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Overview

- Introduction
- SSO Scheme (Lott and Miller, 1997)
- Improvements
- Case Study
- Verification
- Conclusions & Outlook

Motivation

Deutscher Wetterdienst

Conclusions

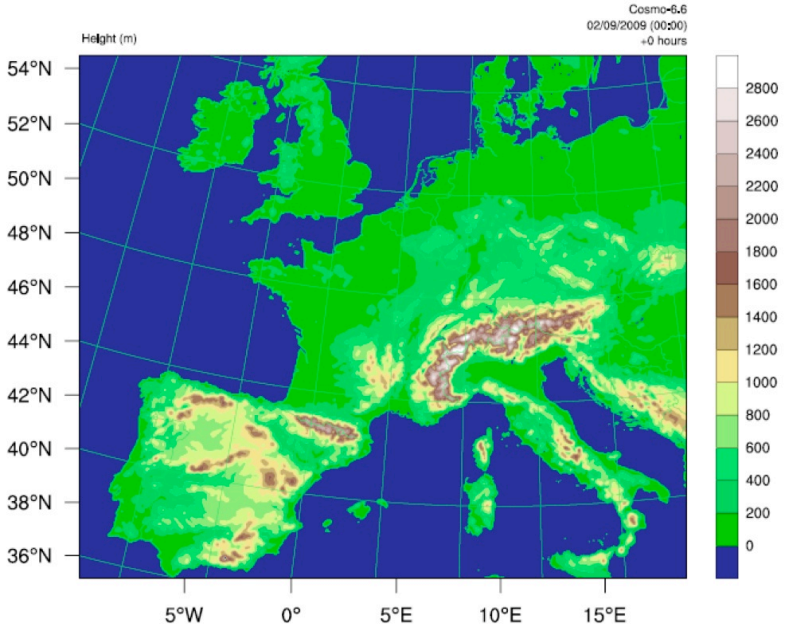
The sub-grid scale orography scheme by Lott and Miller (1997) was implemented in the COSMO model. It shows the following improvements in COSMO-EU in the period 26 Feb. – 17 Mar. 2008:

- The positive bias of the surface wind speed is removed.
- The positive bias of the surface wind direction and the RMSE of the vector wind are reduced.
- The negative bias of the mean sea level pressure is reduced.
- The RMSE of the mean sea level pressure is significantly reduced, the variance of the pressure is substantially reduced by more than 13%. This means that the pressure patterns are much better captured by the model. A similar improvement of this quantity has not been achieved by any other model modification during the last years.
- Upper air verification shows a similar improvement.

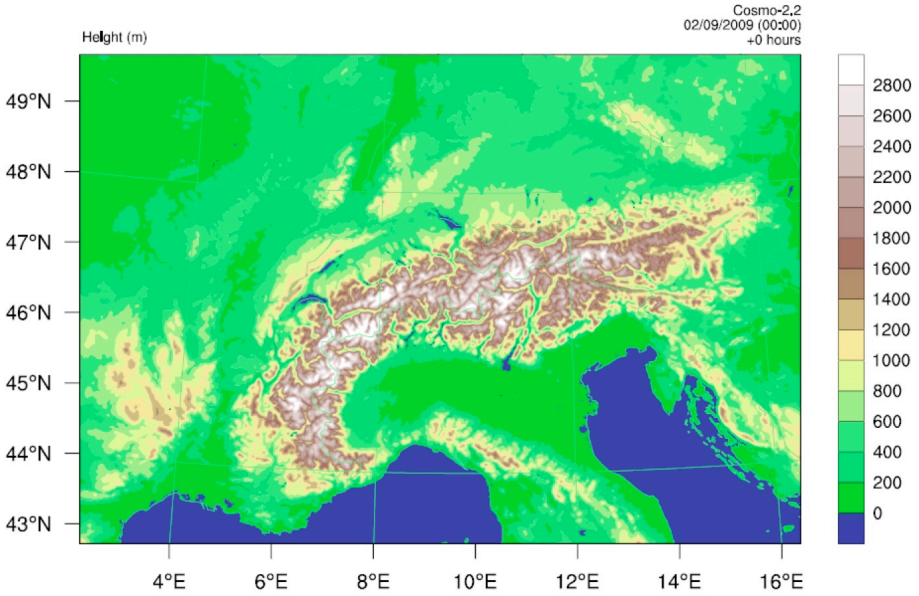
Thanks to Ulrich Damrath and Ulrich Pflüger, DWD, for their verifications.

Model domains

COSMO-7



COSMO-2



Subgrid-Scale Orography

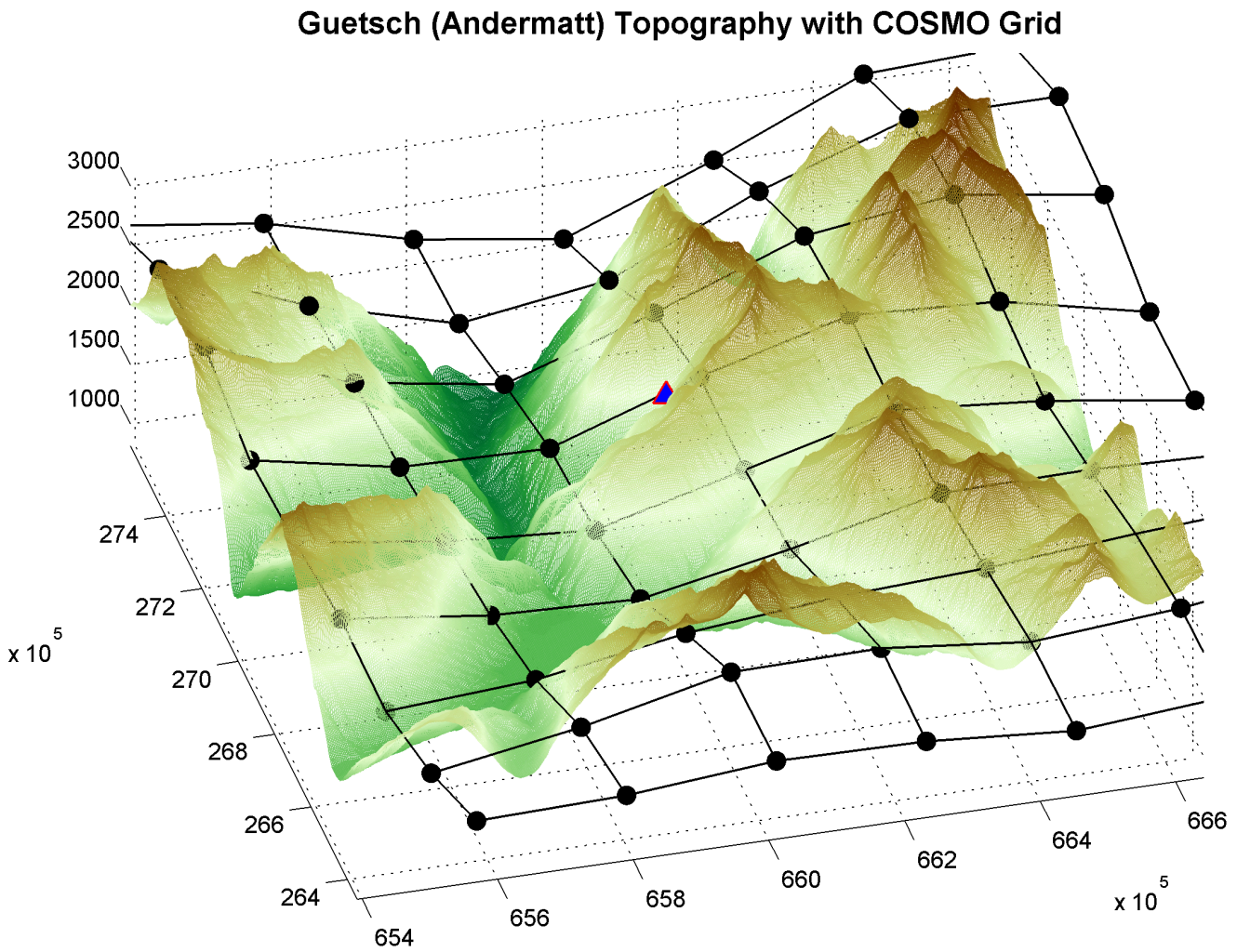


Image: Christophe Hug

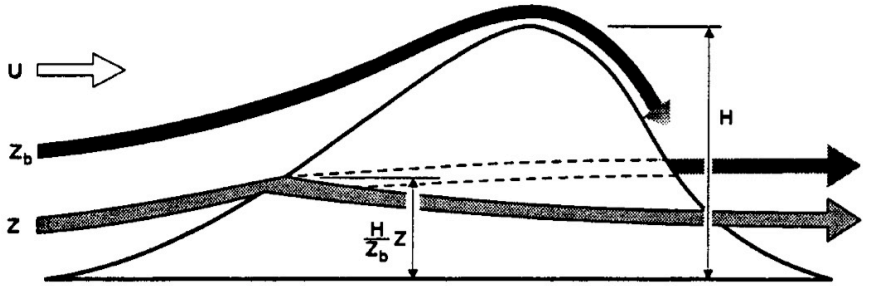
Motivation

- Hope for similar improvements in COSMO-7
- Performance over the Alps unclear
- Usefulness in COSMO-2 unclear

Lott and Miller (1997) scheme

- Elliptic mountain
- Split flow

$$Z_b = H \max\left(0, \frac{H_n - H_{nc}}{H_n}\right)$$



- Gravity wave drag (e.g. Philipps 1984)

$$\tau_w = \rho_0 \, bGB(\gamma) NU H^2$$

Ri_c

- Blocked-flow drag (e.g. Kirchhoff 1867)

$$\tau_b \approx C_d \pi b \rho_0 Z_b \frac{U|U|}{2}$$

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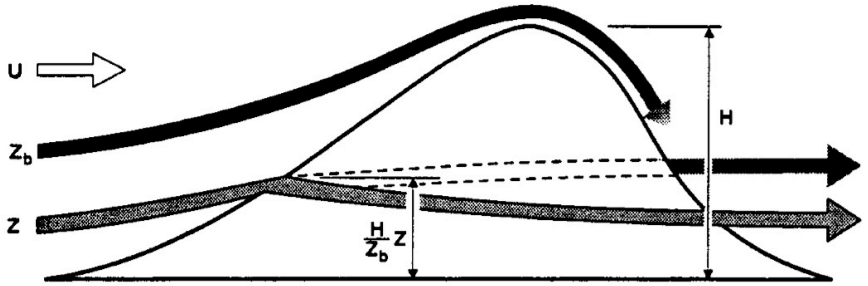

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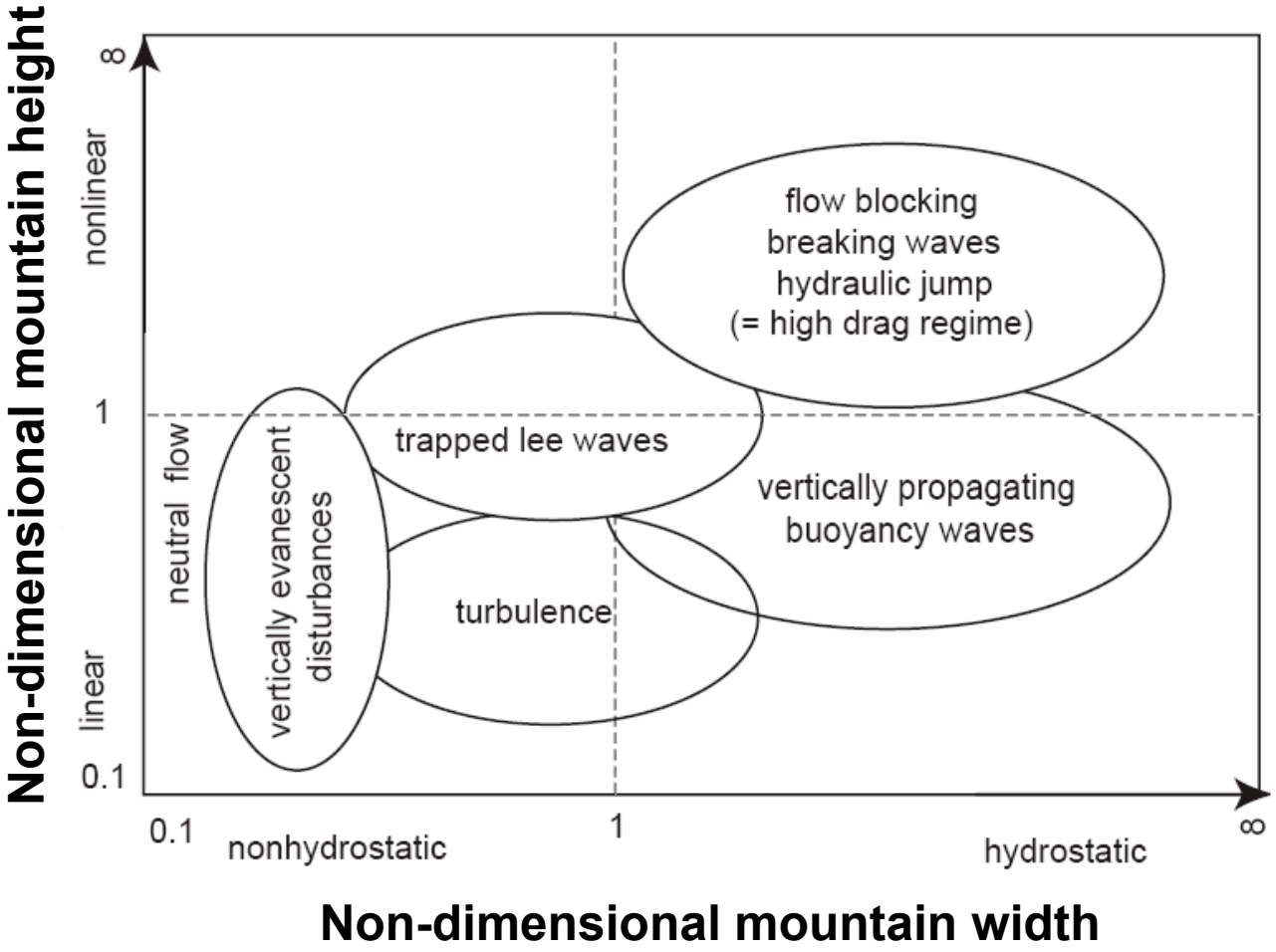
Input field
Tuning parameter

Processes

- Not all scales are relevant for processes parametrized by the SSO scheme



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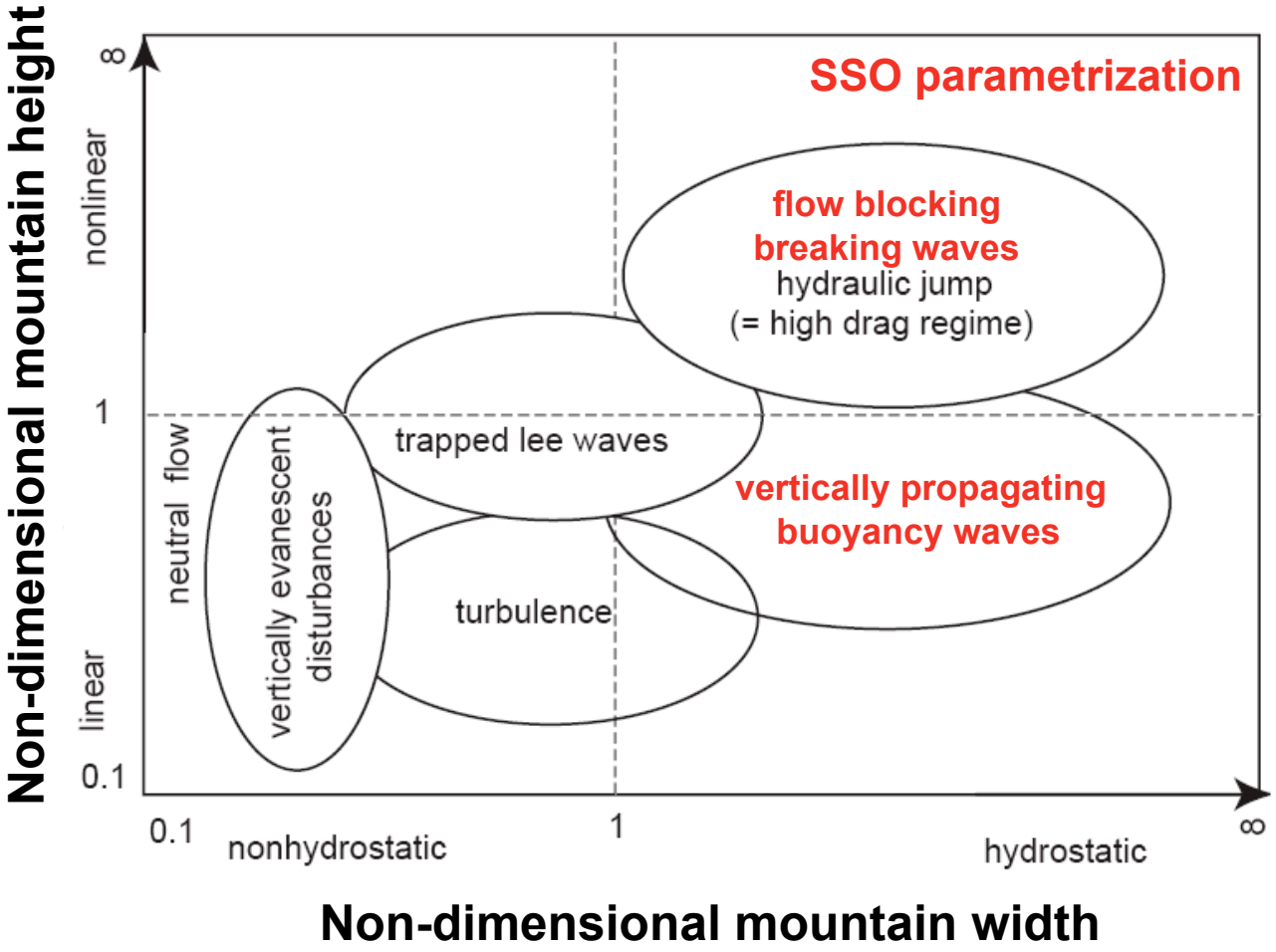

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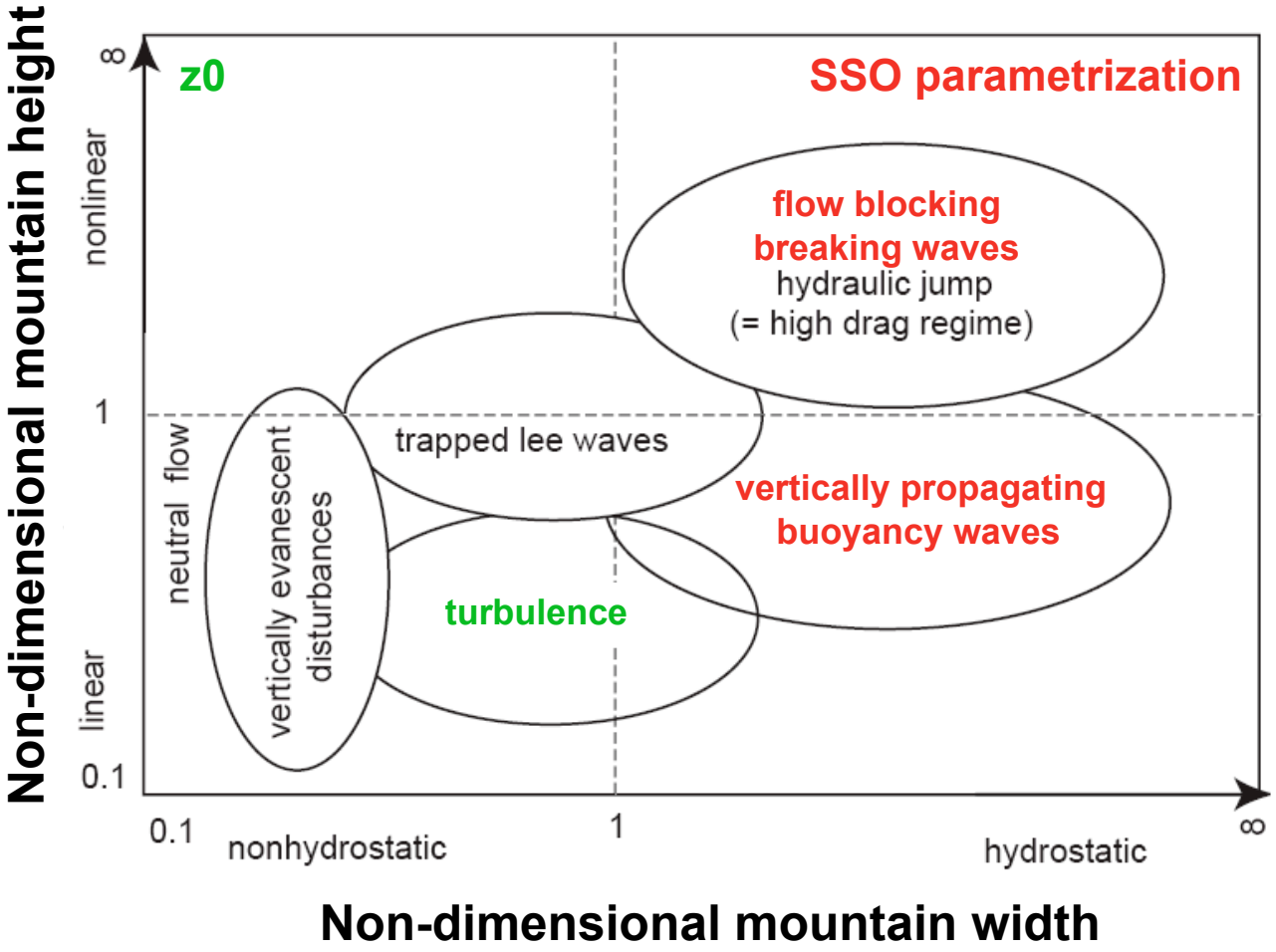
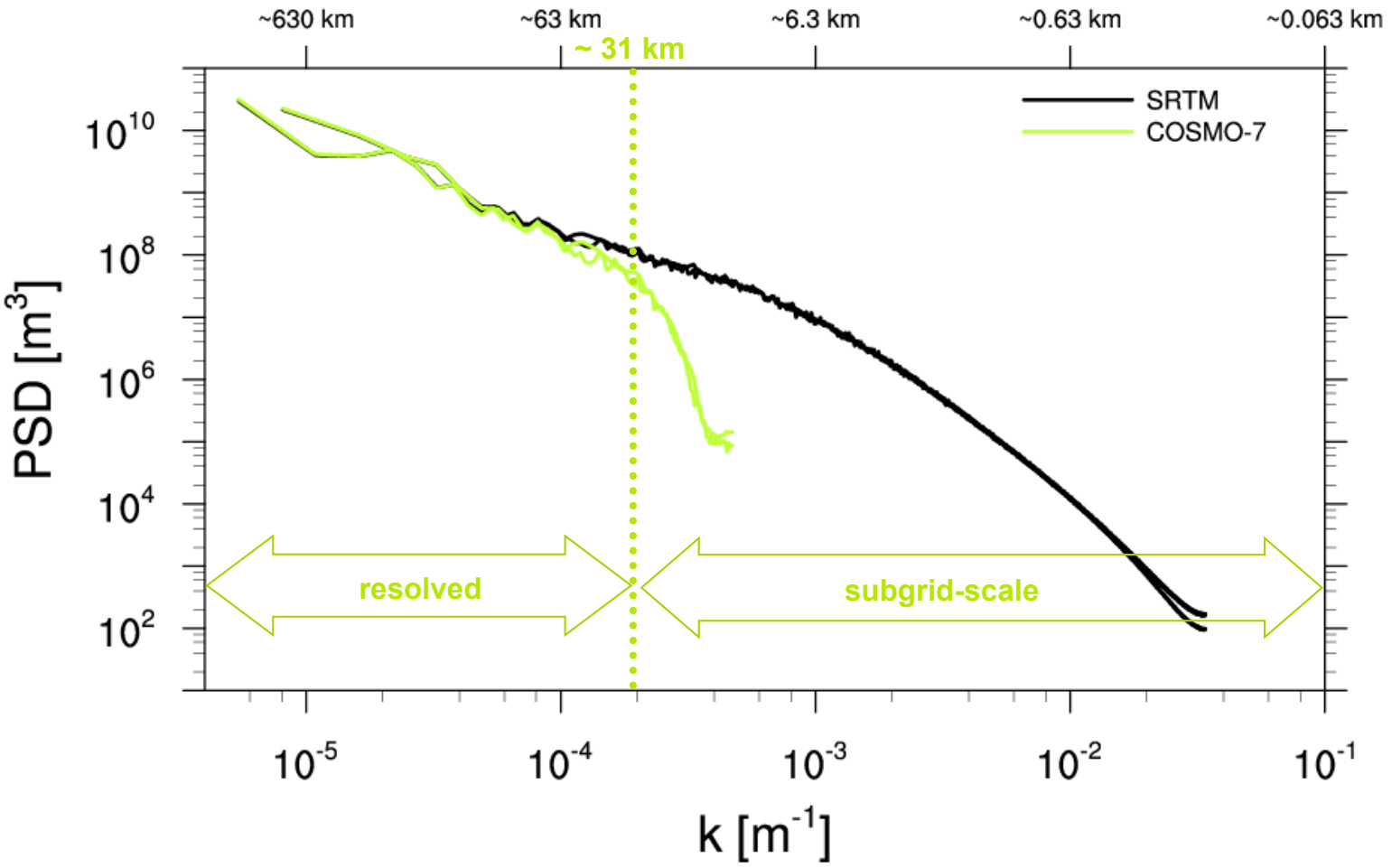


Scale-separation

- Need to separate turbulent and mesoscale unresolved drag



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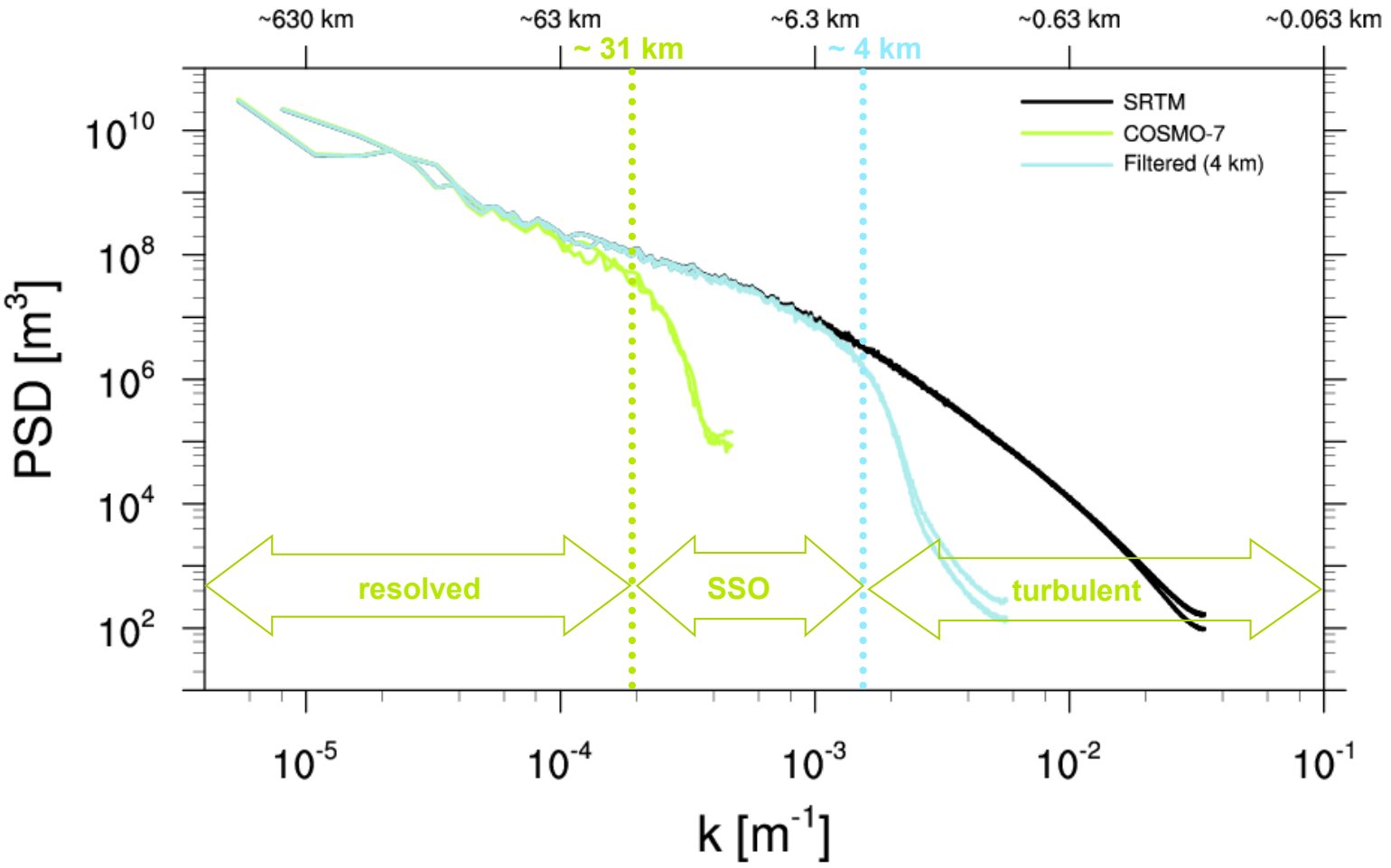

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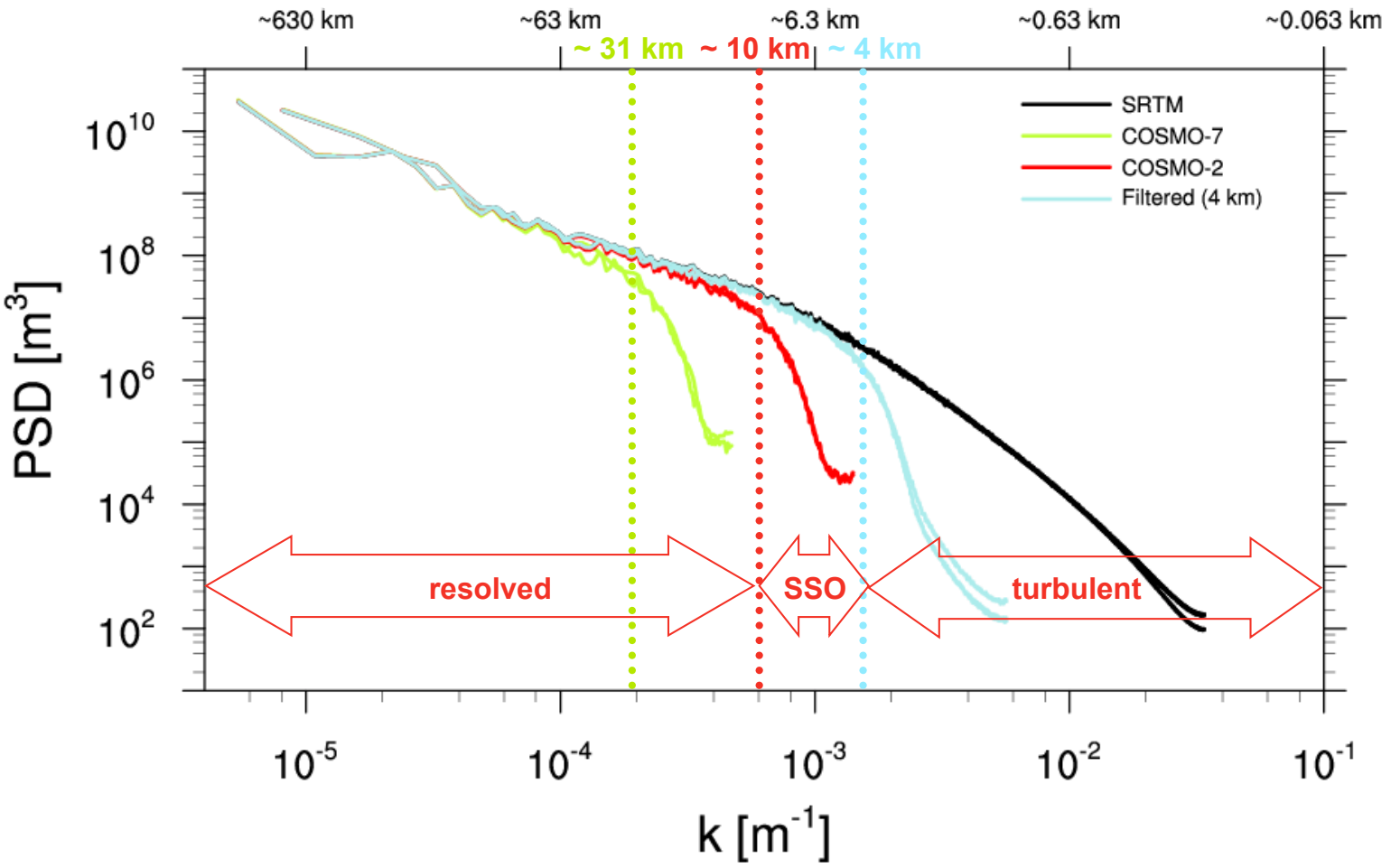
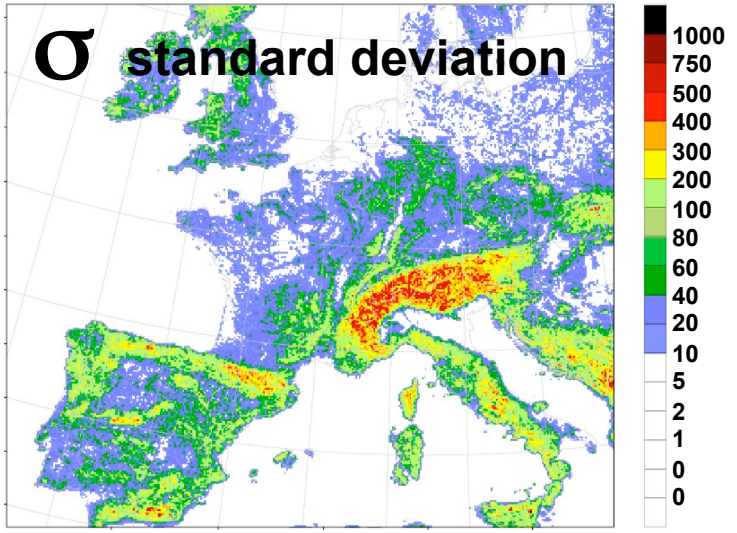
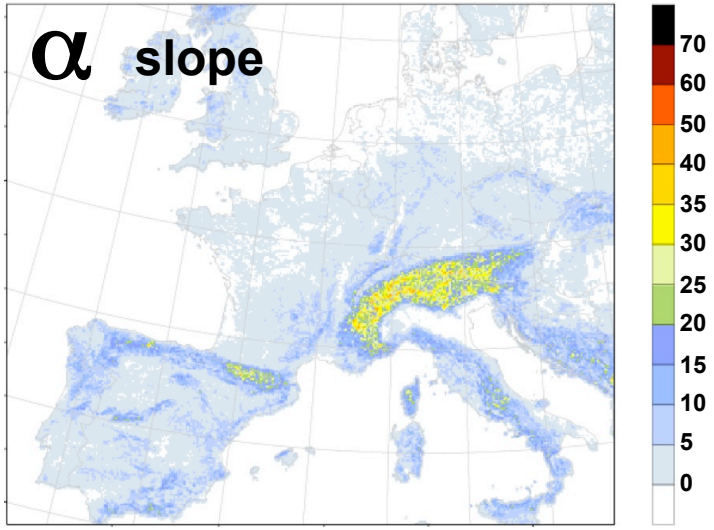
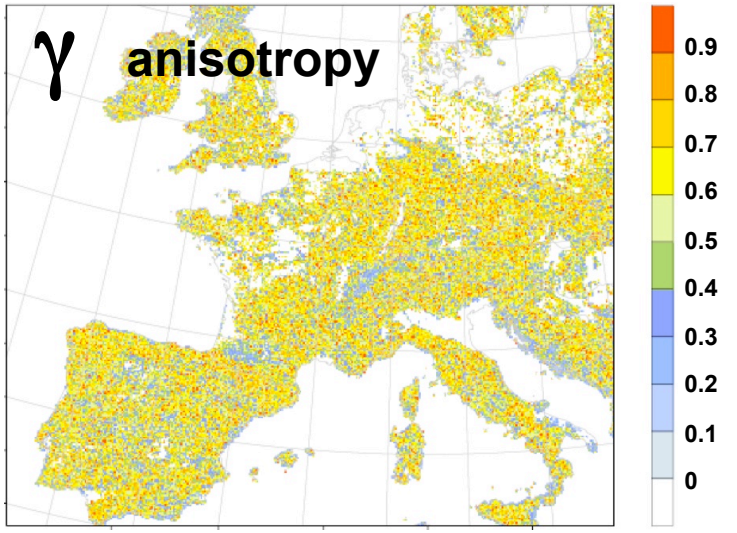
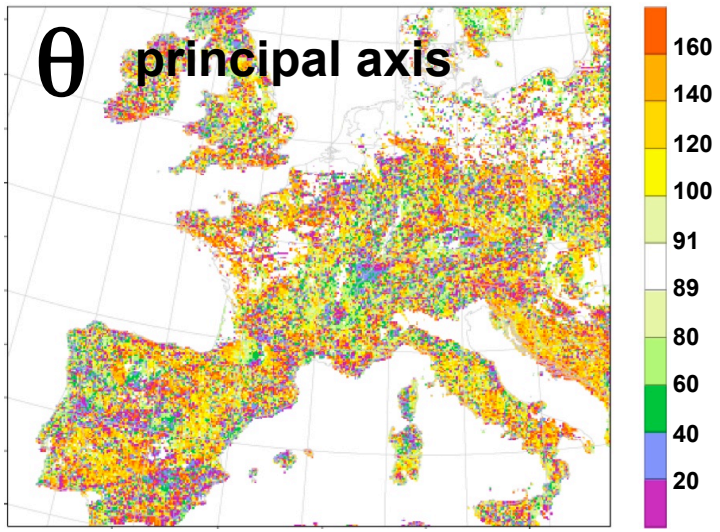


Input parameters





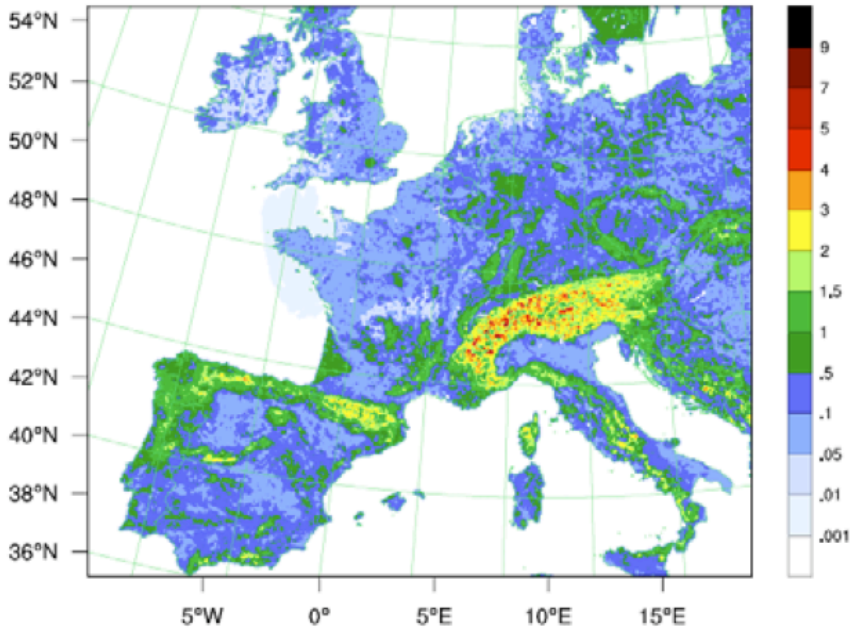




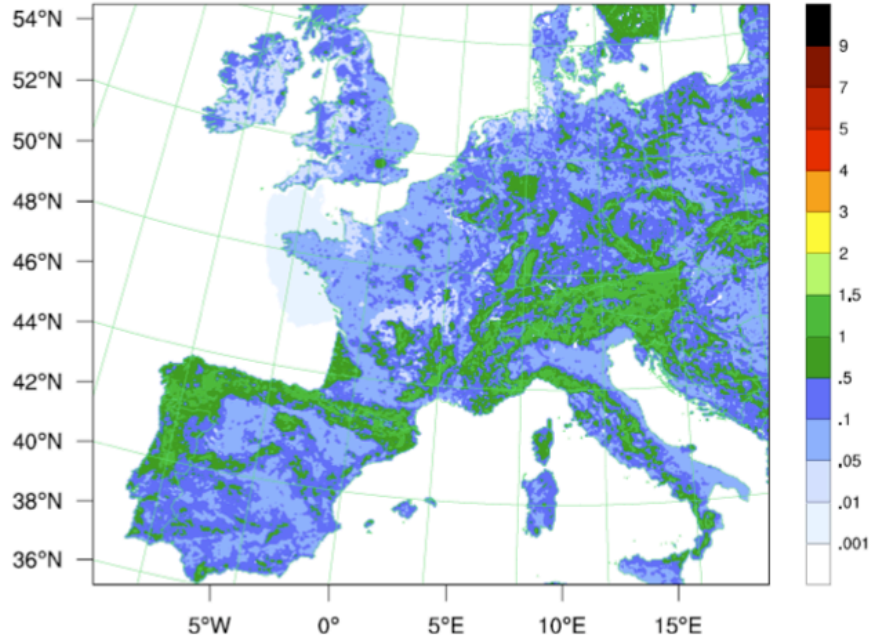
Roughness length z0

- Substantial decrease in roughness length over topography
- Large z0 inconsistent with BL-scheme assumptions

OLD z0

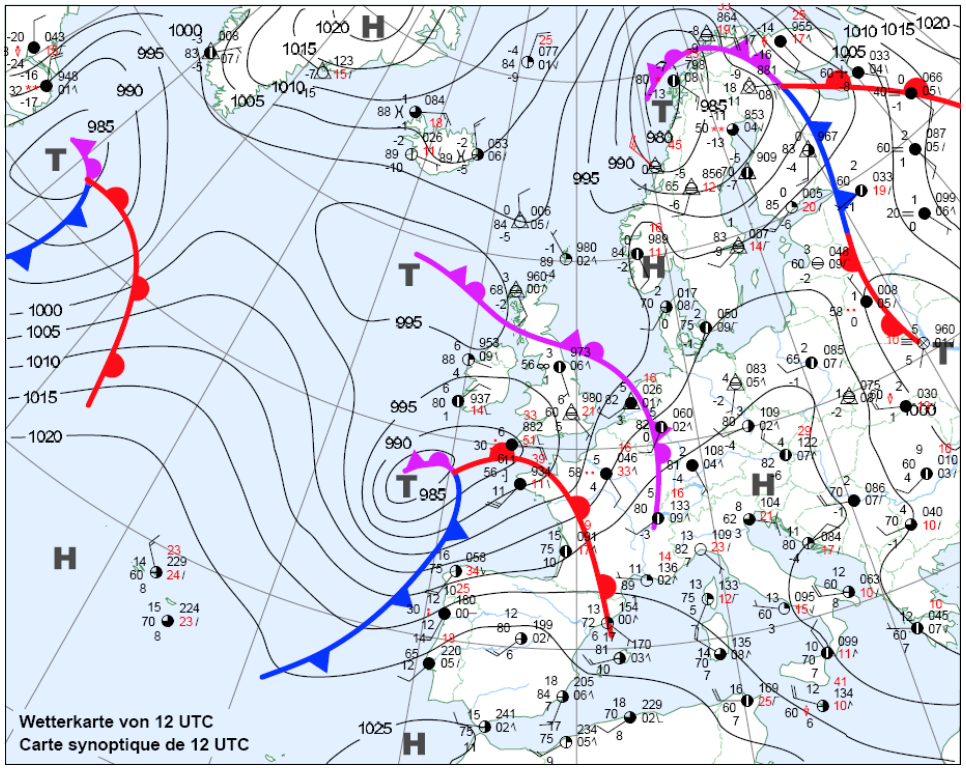


NEW z0



Case Study

- Winter storm Quinten (10.2.2009)
- Cold start
- ECMWF
  → COSMO-7 +72h
  → COSMO-2 +24h



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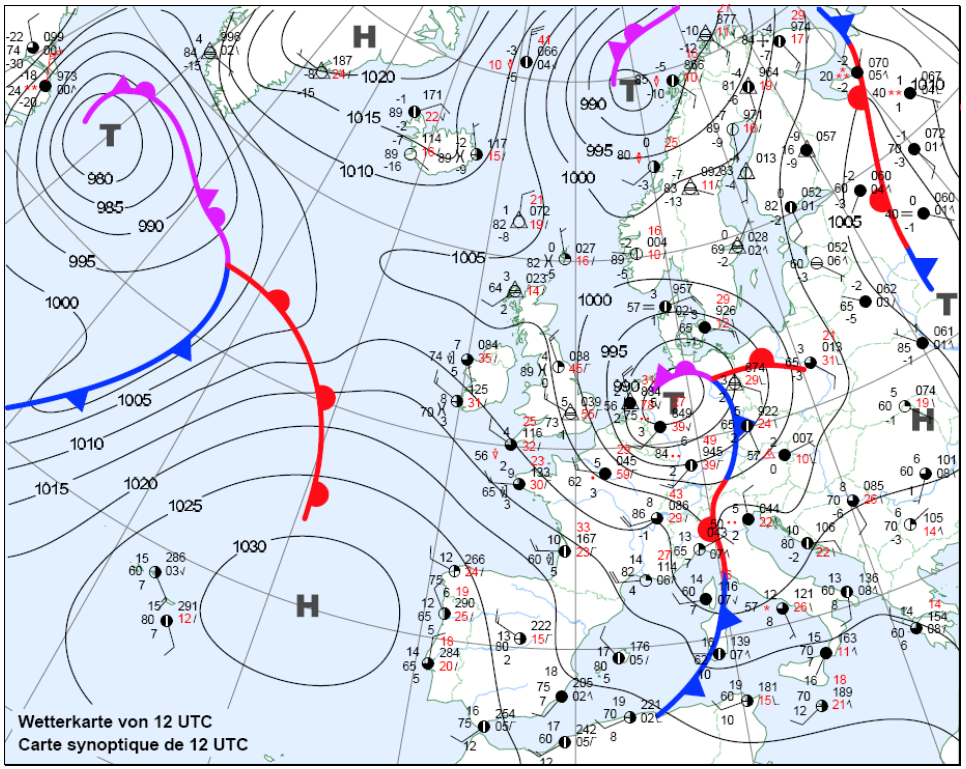

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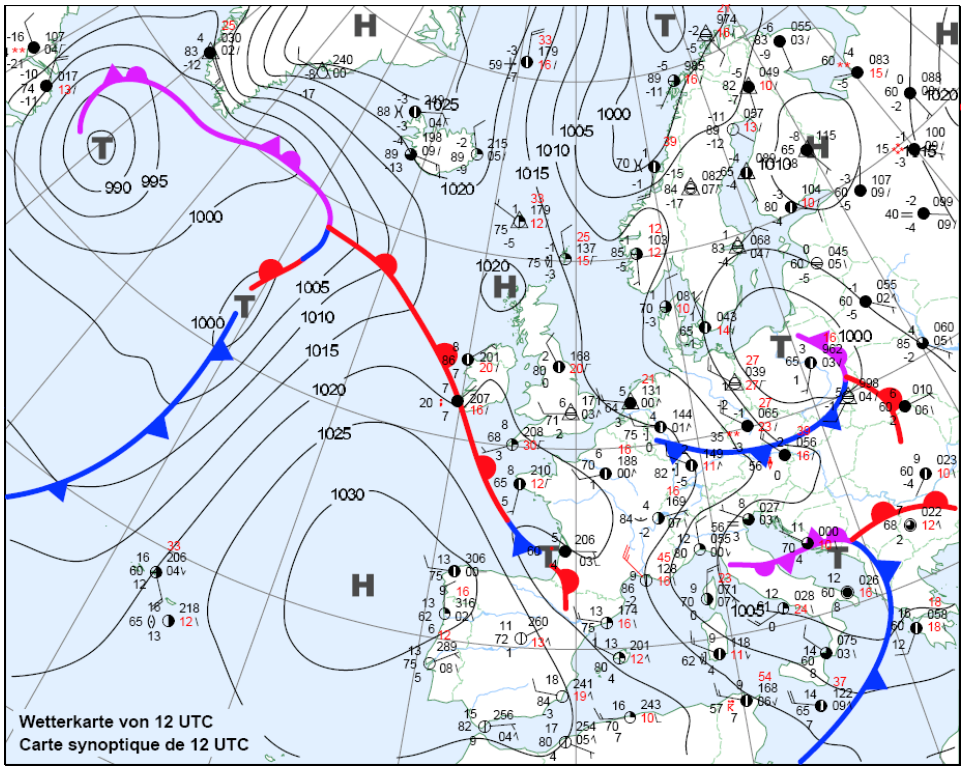
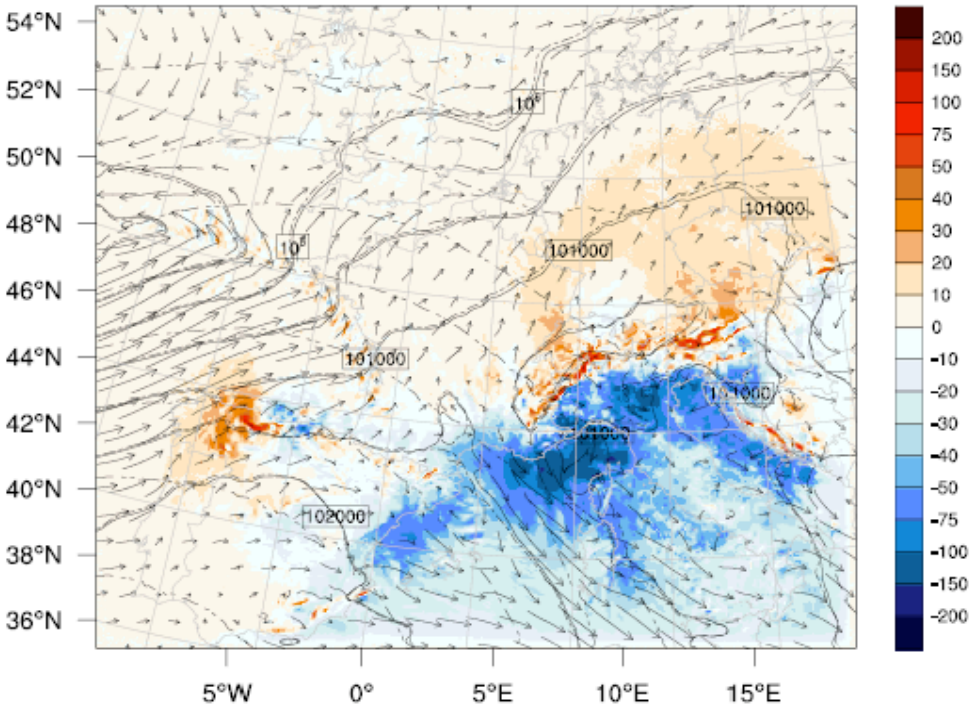


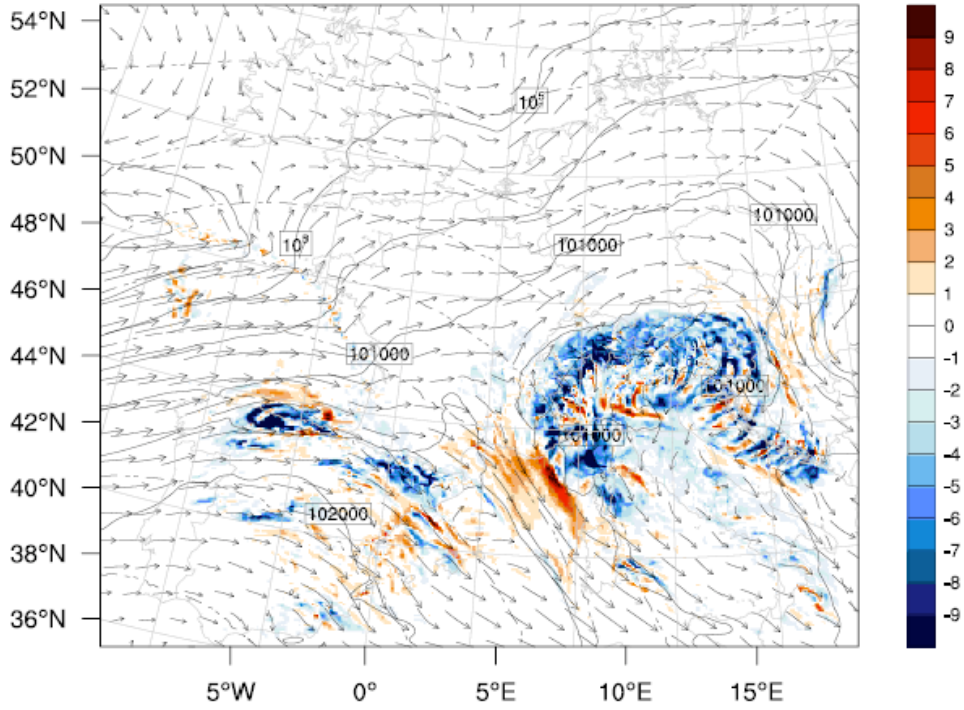
Impact of SSO parametrization (1 of 3)

- Enhanced flow blocking
  - fast process (already after +1h)
  - local + large scale effect over orography
  - changes in pressure of 0.15 hPa and wind up to 10 m/s

Surface Pressure +6h SSO - REF



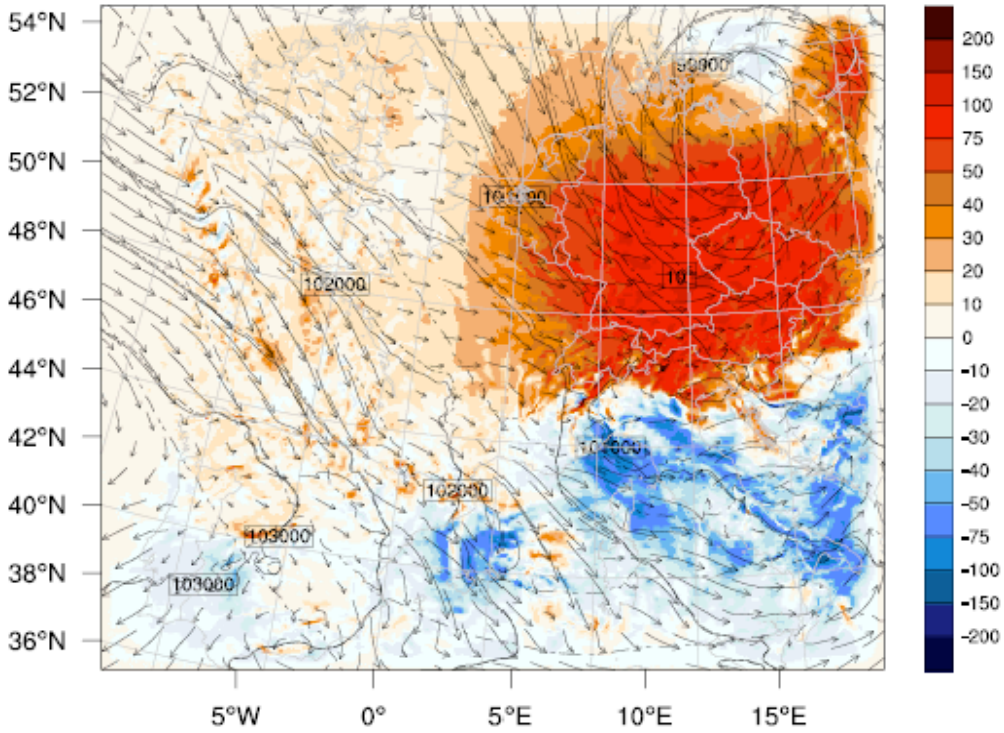
Wind @ 2km +6h SSO - REF



Impact of SSO parametrization (2 of 3)

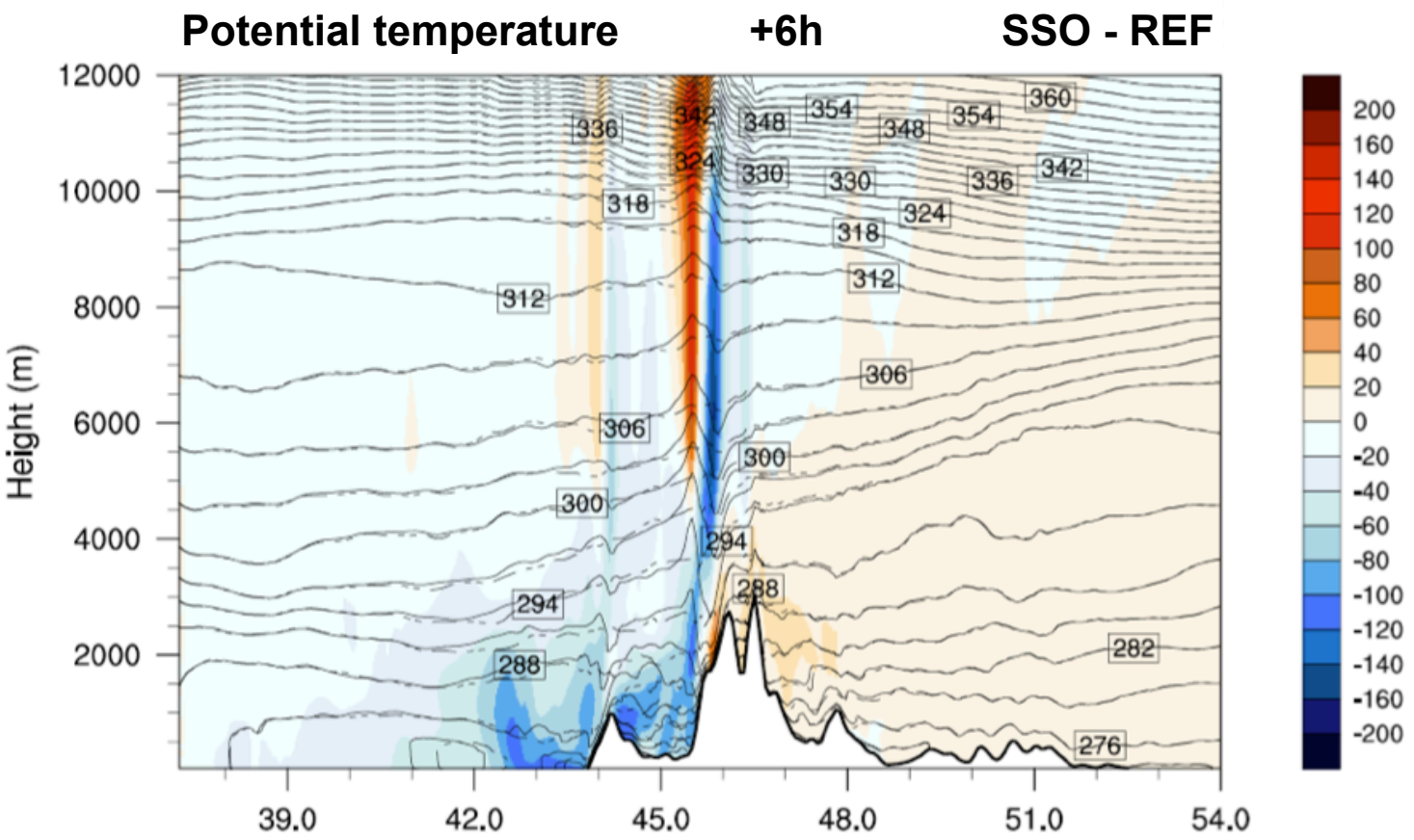
- Enhanced cross-isobar flow
  - slow process (significant after +24h)
  - limited in importance by domain size
  - difference in core pressure of ~ 0.4 hPa

Surface Pressure +48h SSO - REF



Impact of SSO parametrization (3 of 3)

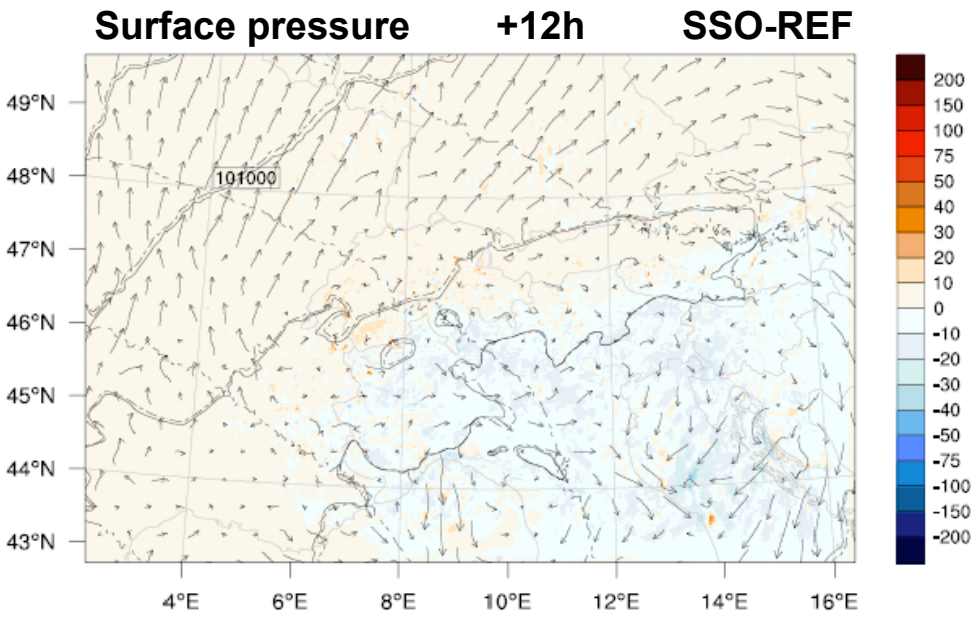
- Reduction of resolved gravity wave activity
  - fast process
  - local and large scale effect over orography



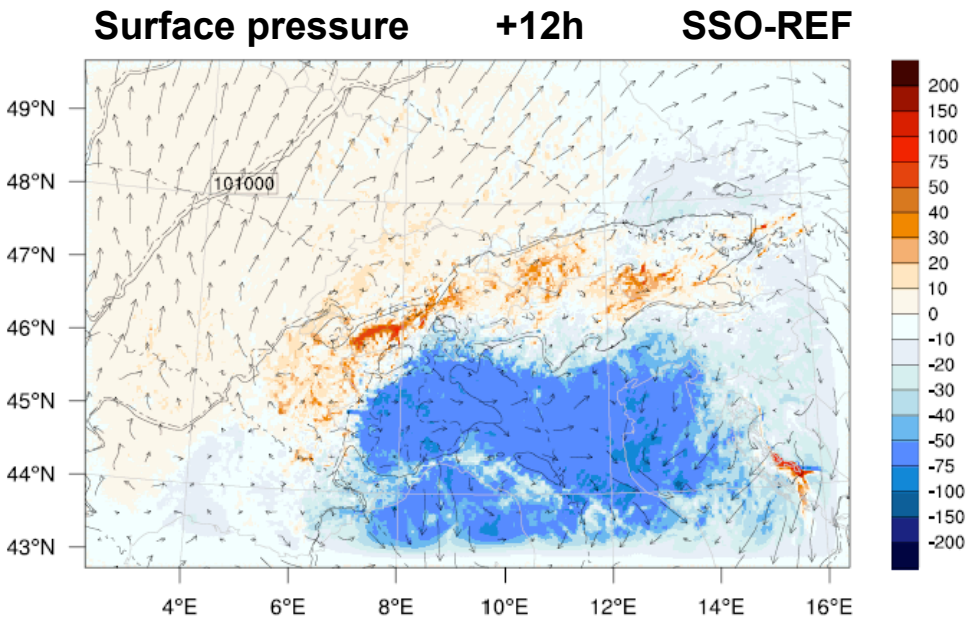
Relevance of SSO for COSMO-2

- Amplitude of sub-grid scale orography reduced by ~ 35%
- Impact of enhanced cross-isobar flow negligible due to small domain and short integration time (+24h)
- Impact of sub-grid scale GWD negligible
- **Nevertheless, non-negligible impact!**

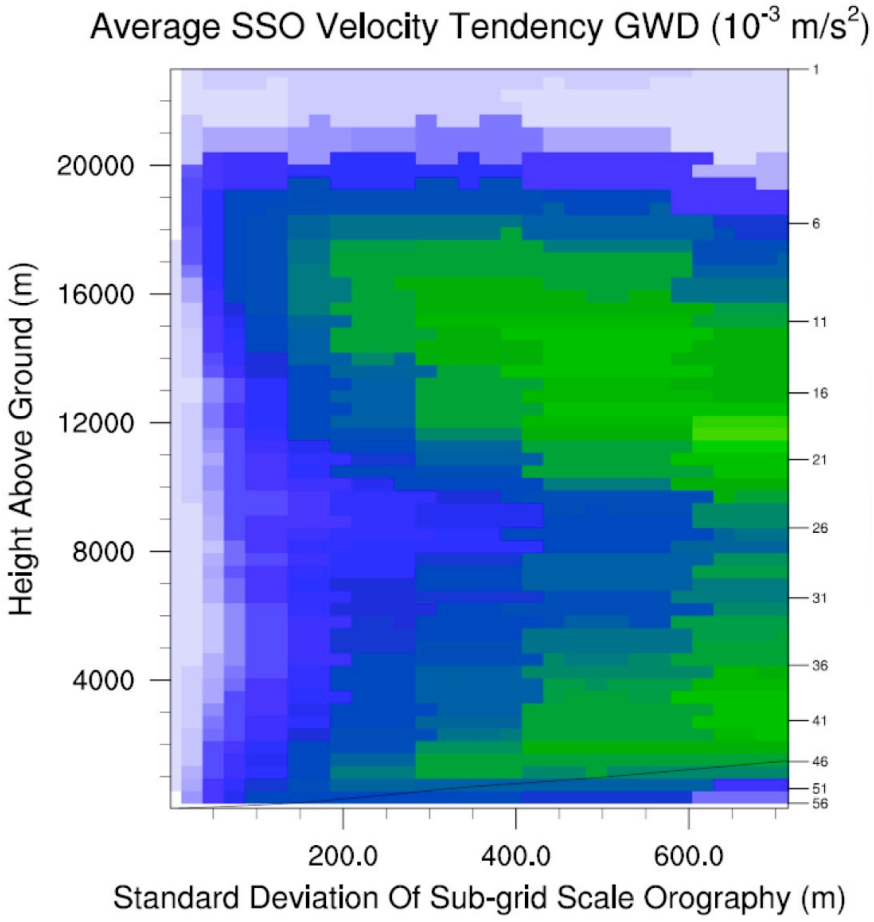
only GWD

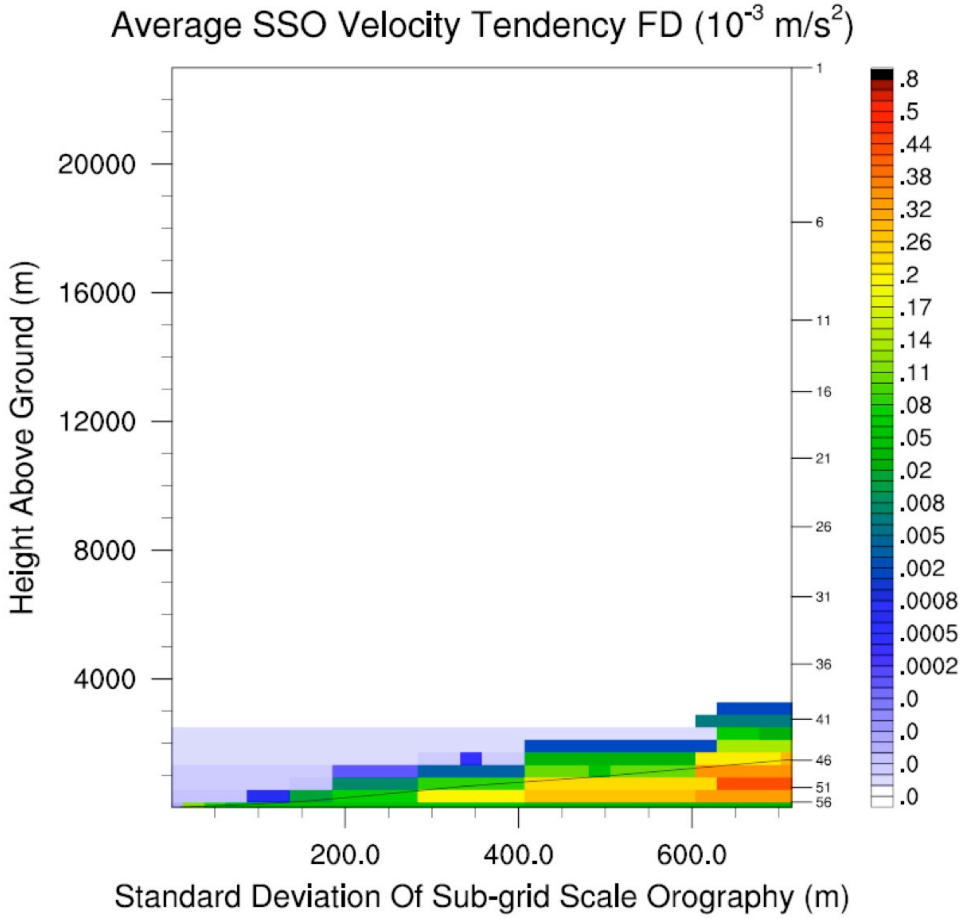


only FD

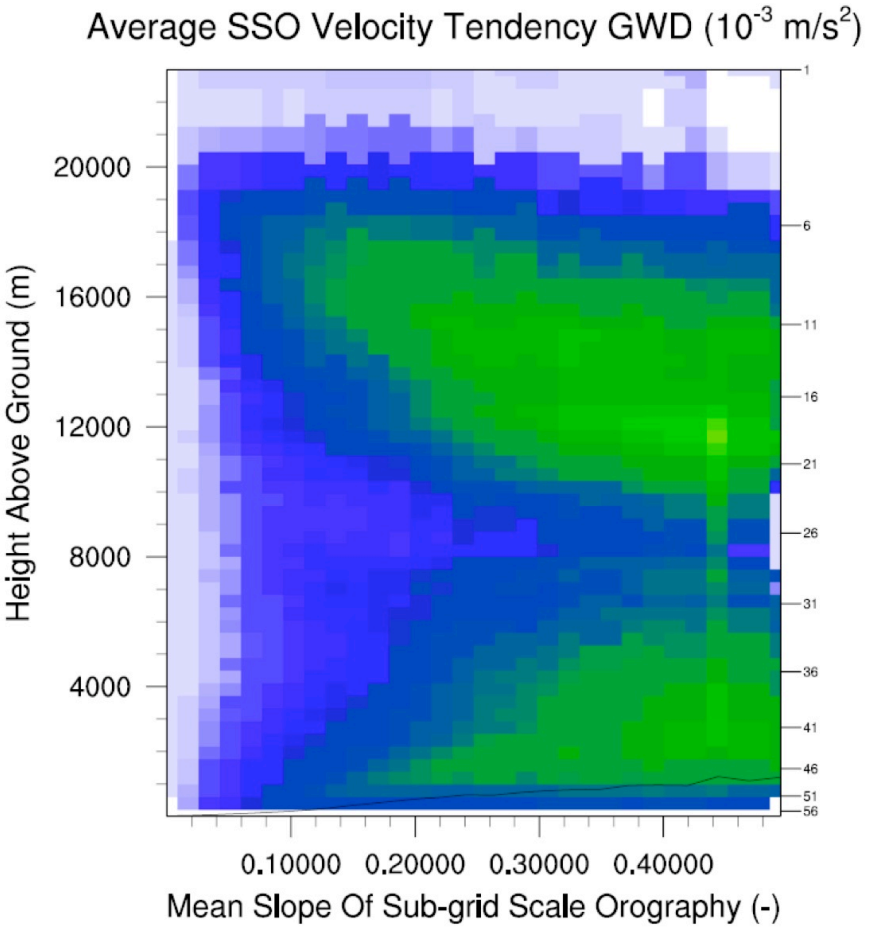


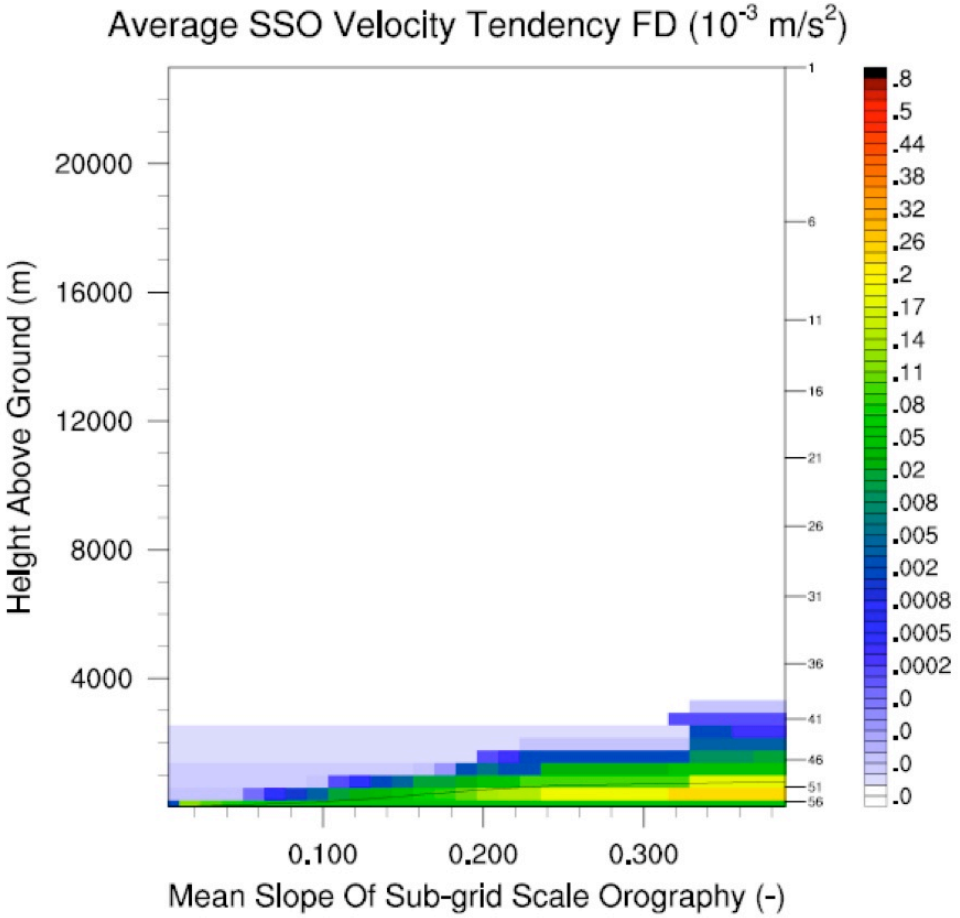
Sensitivity: Standard deviation σ



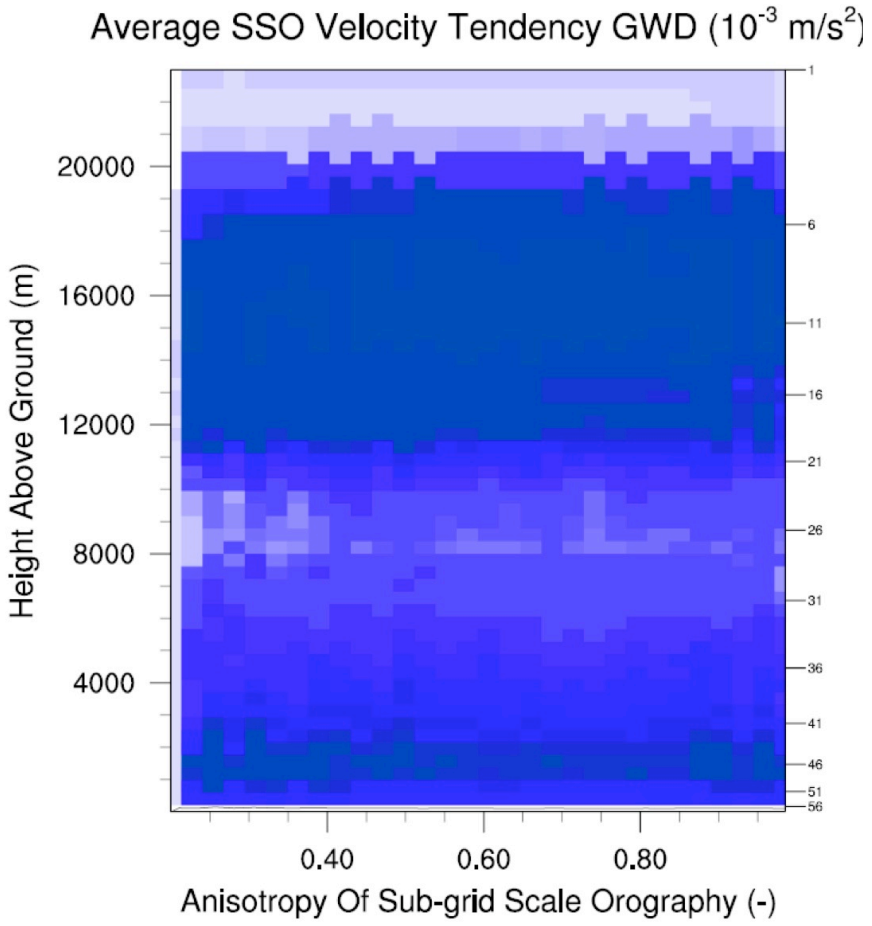


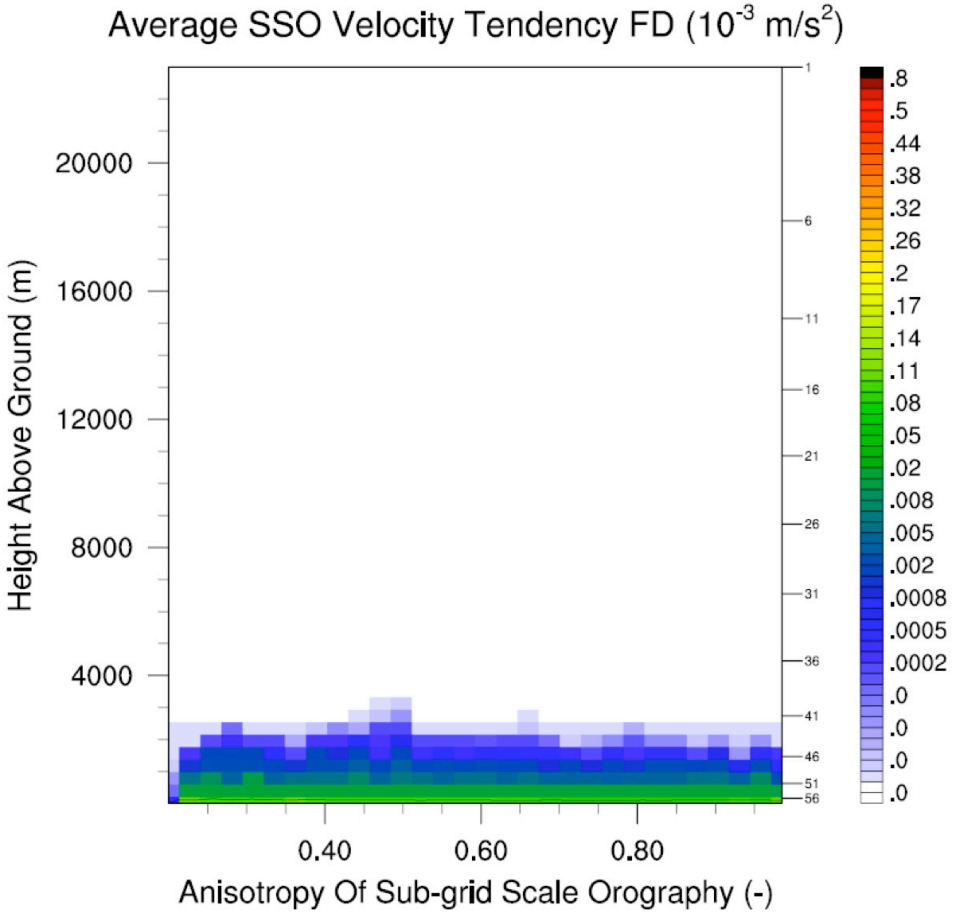
Sensitivity: Slope α



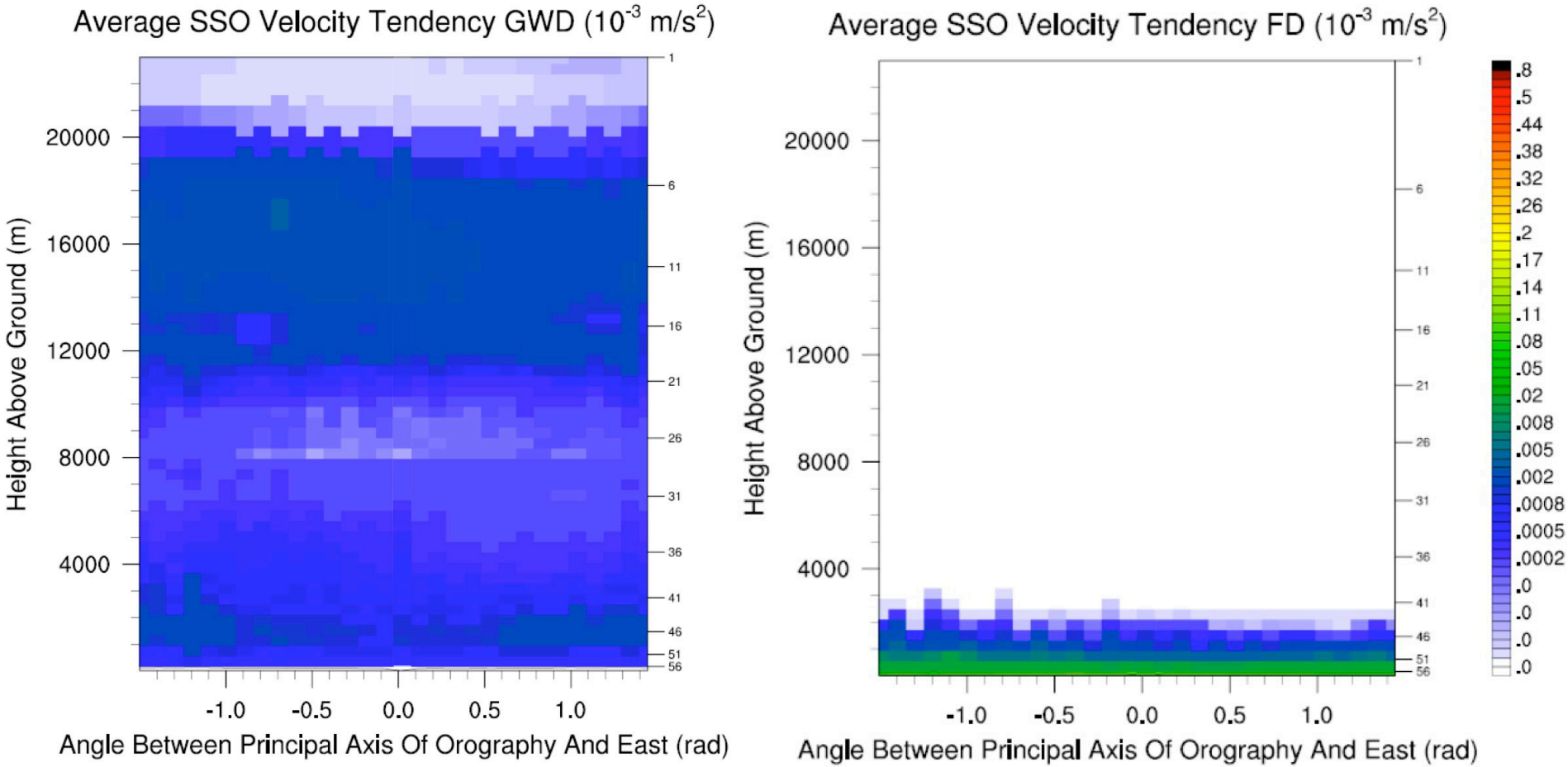


Sensitivity: Anisotropy γ





Sensitivity: Principal axis θ



Verification

- Testchain with full assimilation cycle of COSMO-7 and COSMO-2 running with SSO parametrization
- Winter period: 29.2.2008 to 19.3.2008 (20 days)
- Summer period: 27.7.2008 to 19.8.2008 (24 days)
- Evaluation over EU, ALPS, and CH domain
- SYNOP and Upper-air verification

Verification (COSMO-7, EU domain)

- Positive impact in almost all parameters, especially 10m wind speed and direction as well as total precipiation
- In contrast to DWD, no significant reduction in pressure bias

Parameter	Score	Winter	Summer
PS	ME	~	-
	STD	+	+
PMSL	ME	~	-
	STD	+	+
T_2M	ME	~	-
	STD	~	~
TD_2M	ME	~	~
	STD	+	+
DD_10M	ME	++	++
	STD	+	~
FF_10M	ME	+++	+++
	STD	+	+

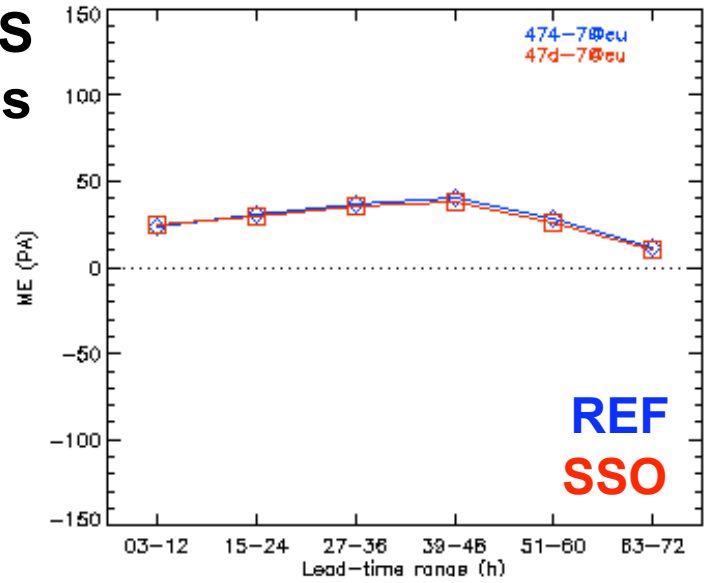
Parameter	Score	Winter	Summer
CLCT	ME	~	~
	STD	~	~
	FBI 30%	~	~
	FBI 80%	~	~
TOT_PREC	ME	++	+*
	STD	~	~
	FBI 0.1 mm/12 h	~	~
	FBI 1 mm/12 h	~	~
	FBI 10 mm/12 h	+	+
VMAX_10M	ME	+	+
	STD	-	-

--- a lot worse -- significantly worse - worse ~ same

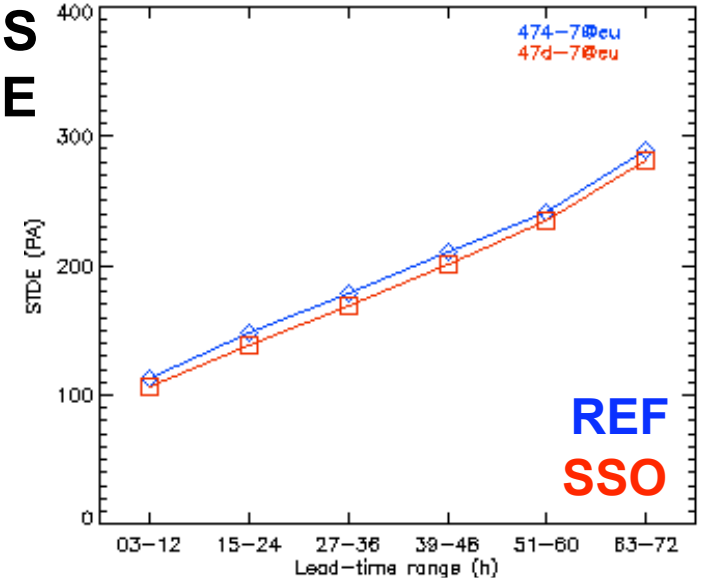
+++ a lot better ++ significantly better + better

Verification (COSMO-7, EU domain)

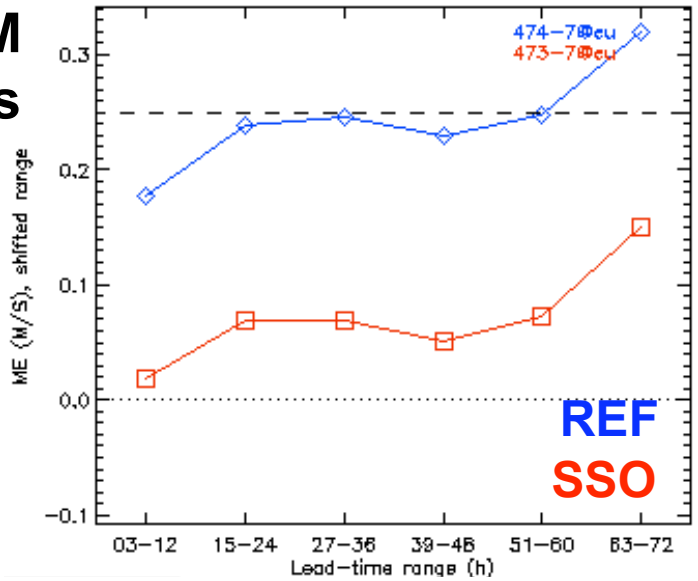
PS bias



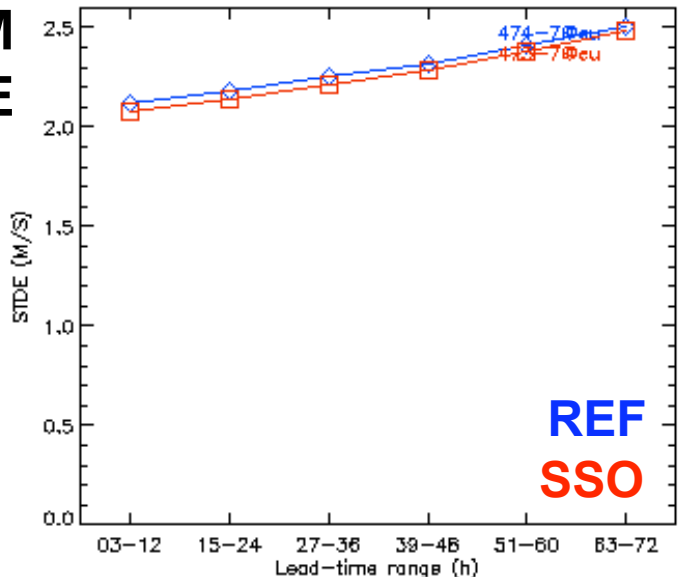
PS STDE



FF10M bias



FF10M STDE



Verification (COSMO-7/2, CH domain)

- Increase of negative bias of wind speed and direction over the Alps
- Other parameters generally positive results

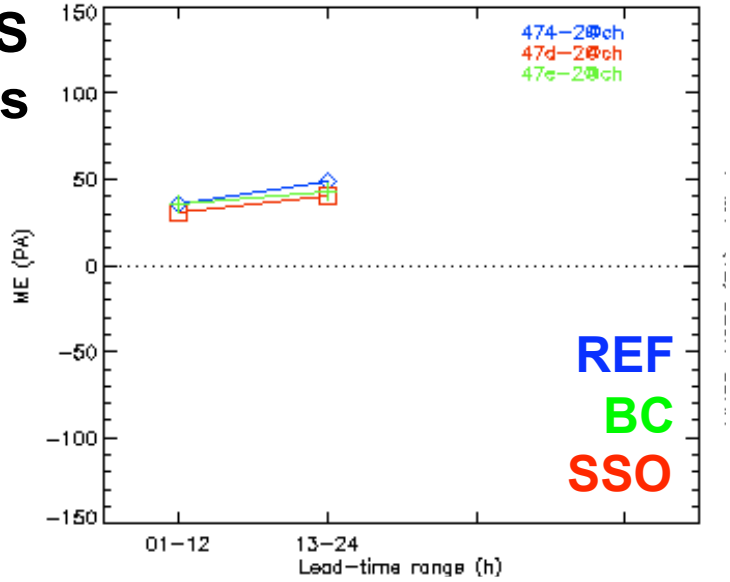
Parameter	Score	Winter		Summer	
PS	ME	~	+	-	-
	STD	~	~	~	~
PMSL	ME	+	+	+	+
	STD	+	+	+	+
T_2M	ME	+	~	--*	-
	STD	+	~	+	~
TD_2M	ME	+	~	++	+
	STD	+	~	+	~
DD_10M	ME	--*	-	-	--
	STD	+	~	~	~
FF_10M	ME	-*	--*	--*	---*
	STD	~	~	~	~

Parameter	Score	Winter		Summer	
CLCT	ME	++	-	~	++
	STD	~	~	~	~
	FBI 30%	+	~	~	~
	FBI 80%	++	~	~	+
TOT_PREC	ME	-**	~	+++	~
	STD	+	~	-	~
	FBI 0.1 mm/12 h	++	~	-	~
	FBI 1 mm/12 h	+	+	~	~
	FBI 10 mm/12 h	-**	~	++	~
VMAX_10M	ME	--*	-*	-	-
	STD	+	~	~	~

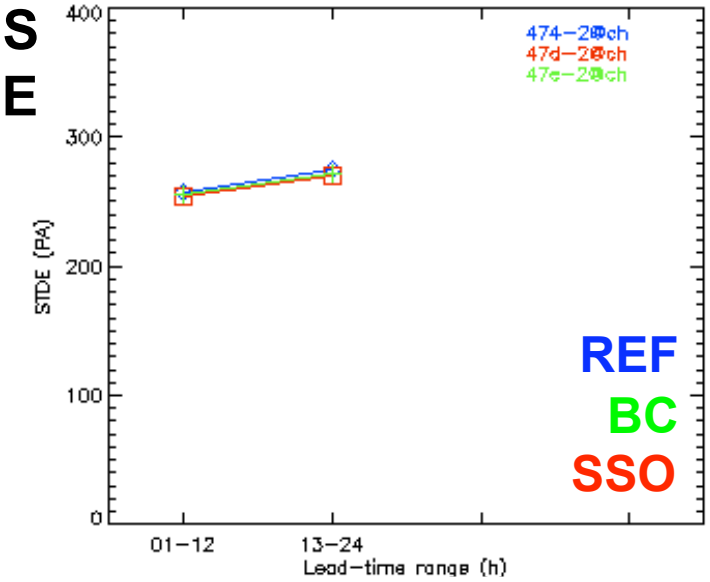
--- a lot worse
-- significantly worse
- worse
~ same
+++ a lot better
++ significantly better
+ better
* contrasing bias/STDE

Verification (COSMO-2, CH domain)

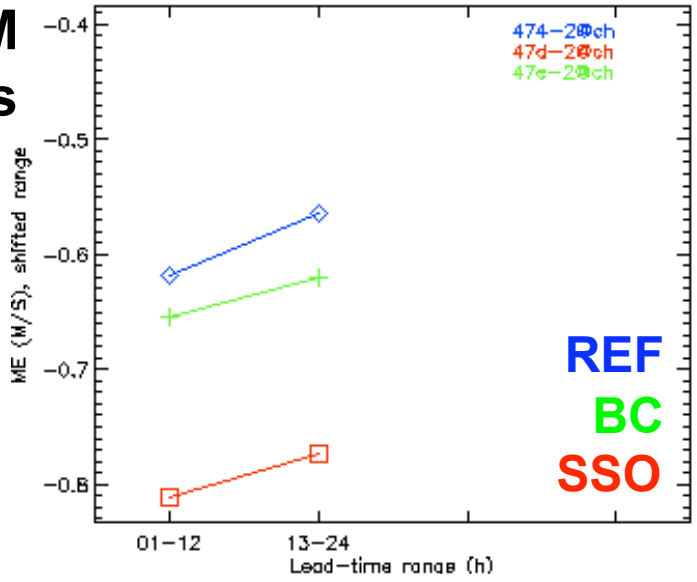
PS bias



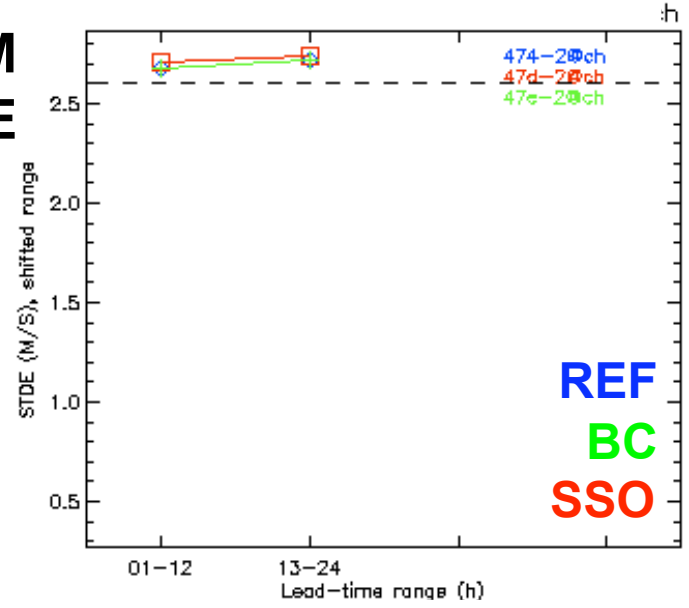
PS STDE



FF10M bias



FF10M STDE



Verification (Summary)

- In **general positive impact** for both COSMO-7 and COSMO-2 for stations outside of significant topography
- Within the Alps, **wind speed and direction bias is further increased**, but verification is questionable
- Impact in COSMO-2 is roughly 1/3 over boundary conditions and 2/3 due to SSO parametrization

Conclusions

- Consistent implementation of SSO drag scheme
  - Scale separation of SSO
  - Reduction of z0
- Significant impact via several processes...
  - Enhanced local + large-scale flow blocking
  - Enhanced cross-isobar flow
  - Reduction in resolved gravity wave activity
- Relevance for COSMO configurations...
  - COSMO-7: positive impact, GWD and FD relevant
  - COSMO-2: positive impact, only FD relevant, cross-isobar flow irrelevant
- Verification over significant topography problematic!

Outlook

- Comparison against non-conventional measurements

  → e.g. investigate a MAP case with flight measurements

- Investigate self-consistency by idealized simulations at different resolutions