Scale-dependent parametrization of orographic momentum fluxes in HIRLAM

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FINNISH METEOROLOGICAL INSTITUTE

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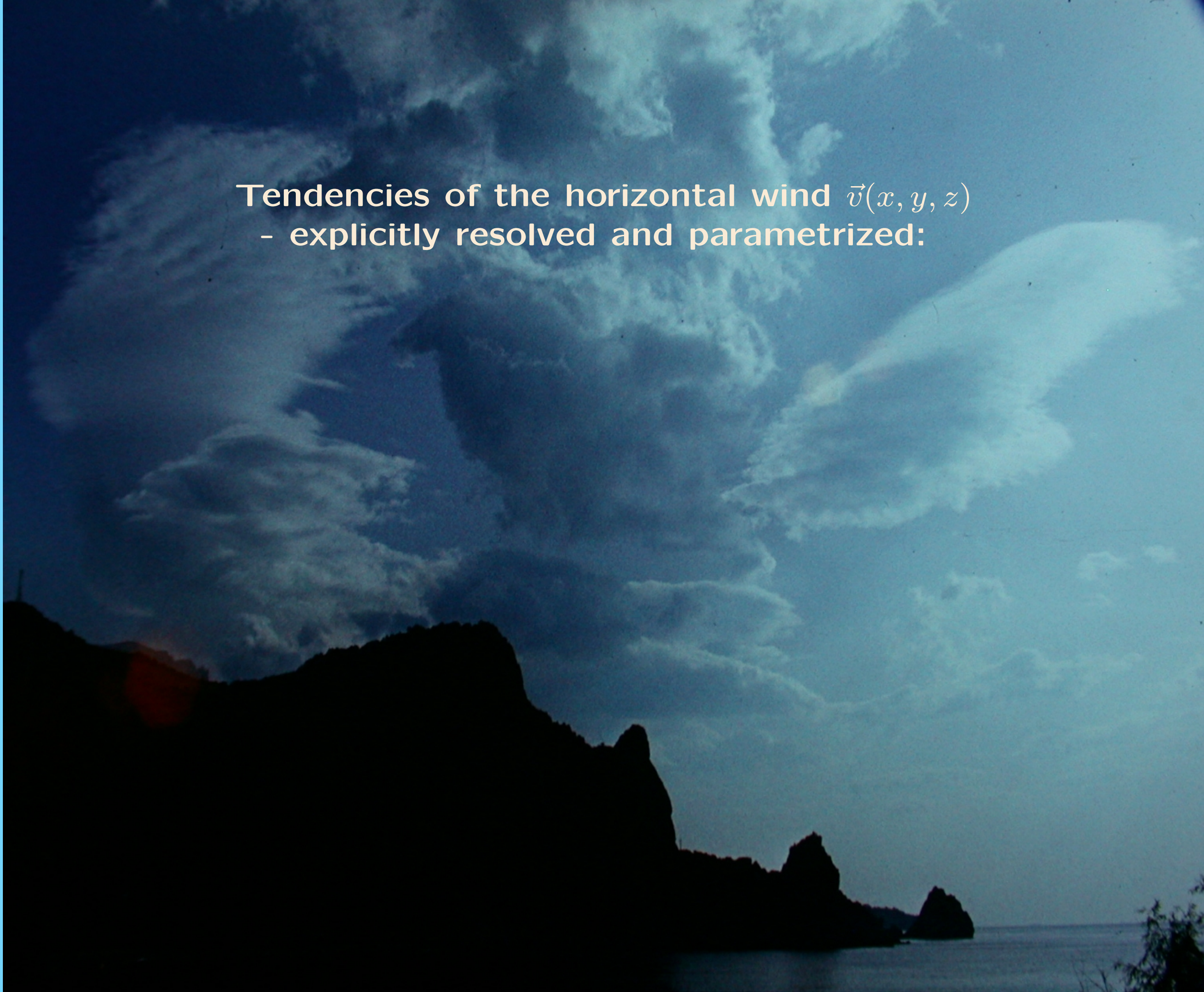
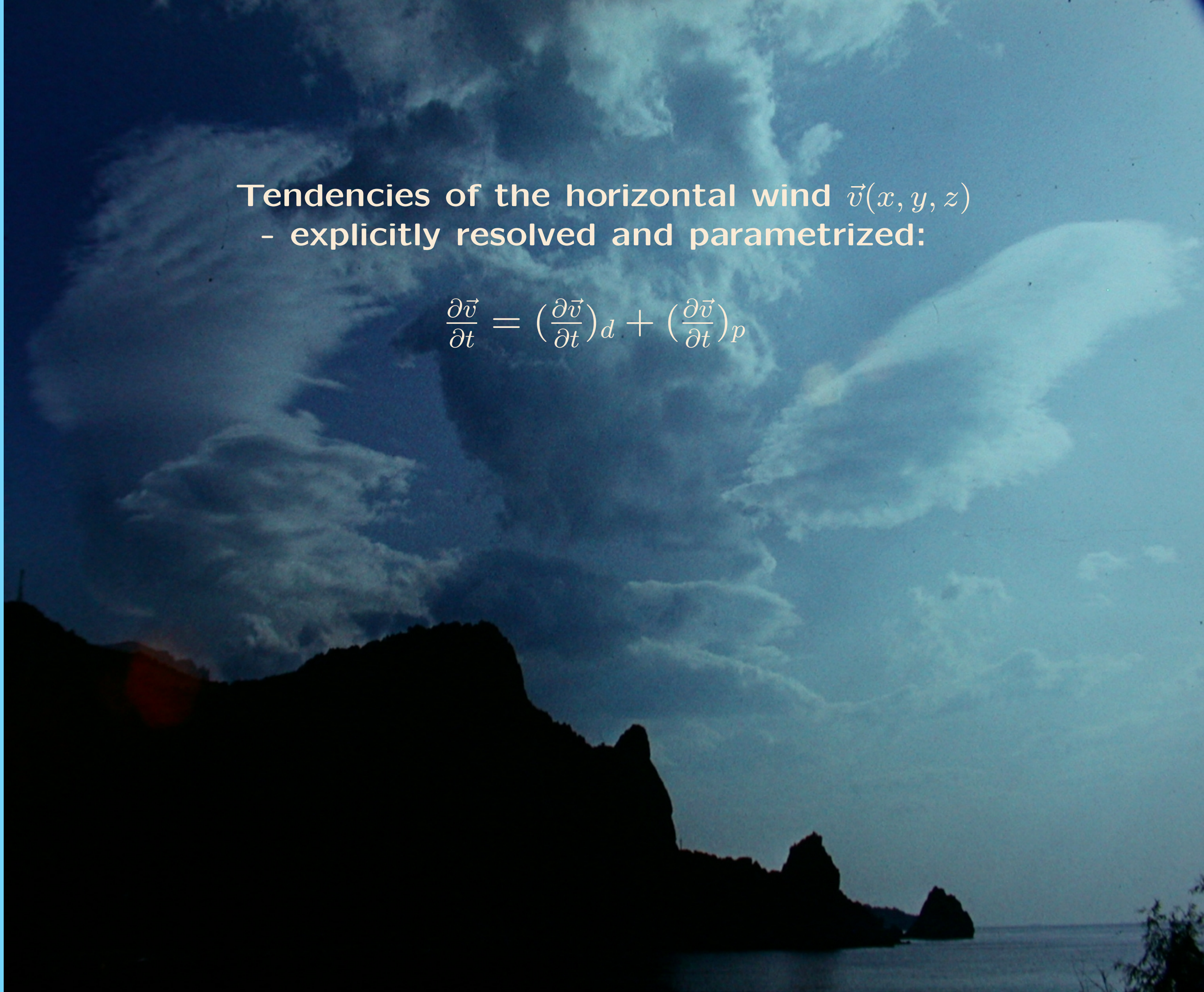
Tendencies of the horizontal wind $\vec{v}(x, y, z)$ - explicitly resolved and parametrized:



Tendencies of the horizontal wind $\vec{v}(x,y,z)$ - explicitly resolved and parametrized:

$$\frac{\partial \vec{v}}{\partial t} = (\frac{\partial \vec{v}}{\partial t})_d + (\frac{\partial \vec{v}}{\partial t})_p$$



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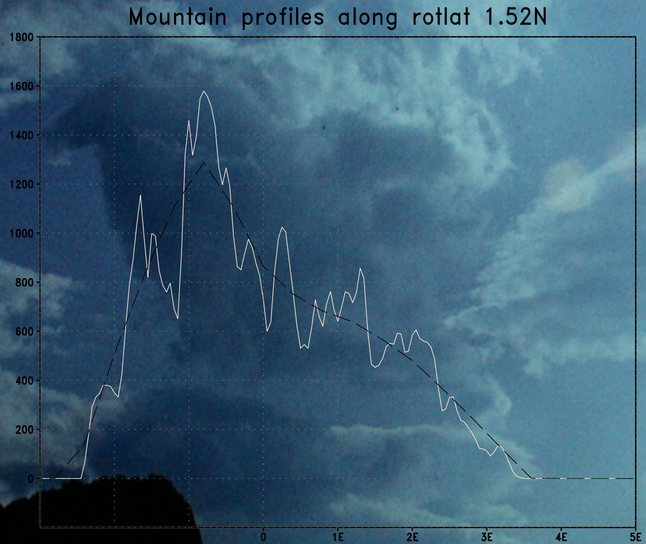
$$(\frac{\partial \vec{v}}{\partial t})_p = \frac{1}{\rho}\frac{\partial \vec{\tau}}{\partial z}, \vec{\tau} = -\sum_{j=1}^{n} \rho(\overline{\vec{v}' w'})$$

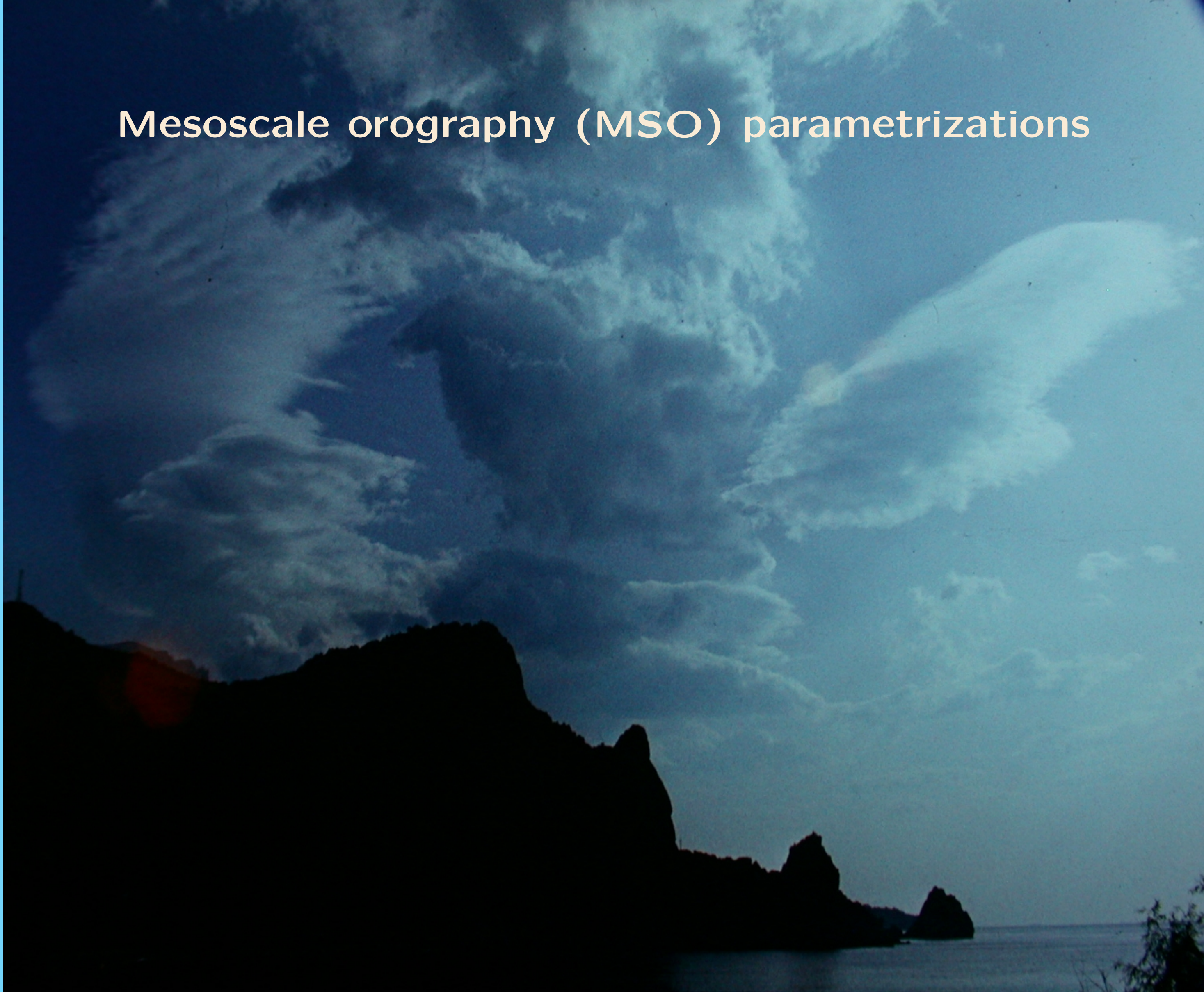
Several sub-grid scales of orography



Components of the parametrized drag

drag	related to	momentum sink	scale
$\vec{\tau}_{ts}$	turbulent drag due to surface roughness	surface (2D)	micro
$\vec{\tau}_{o}$	drag due to unresolved small-scale orography	internal (3D)	small
$\vec{\tau}_{m}$	blocked flow drag due to mesoscale orography	internal (3D)	meso
$\vec{\tau}_{w}$	drag due to breaking buoyancy waves	internal (3D)	meso
$\vec{\tau}_{t}$	turbulence (vertical diffusion)	internal (3D)	$< \Delta x$

Mesoscale orography (MSO) parametrizations



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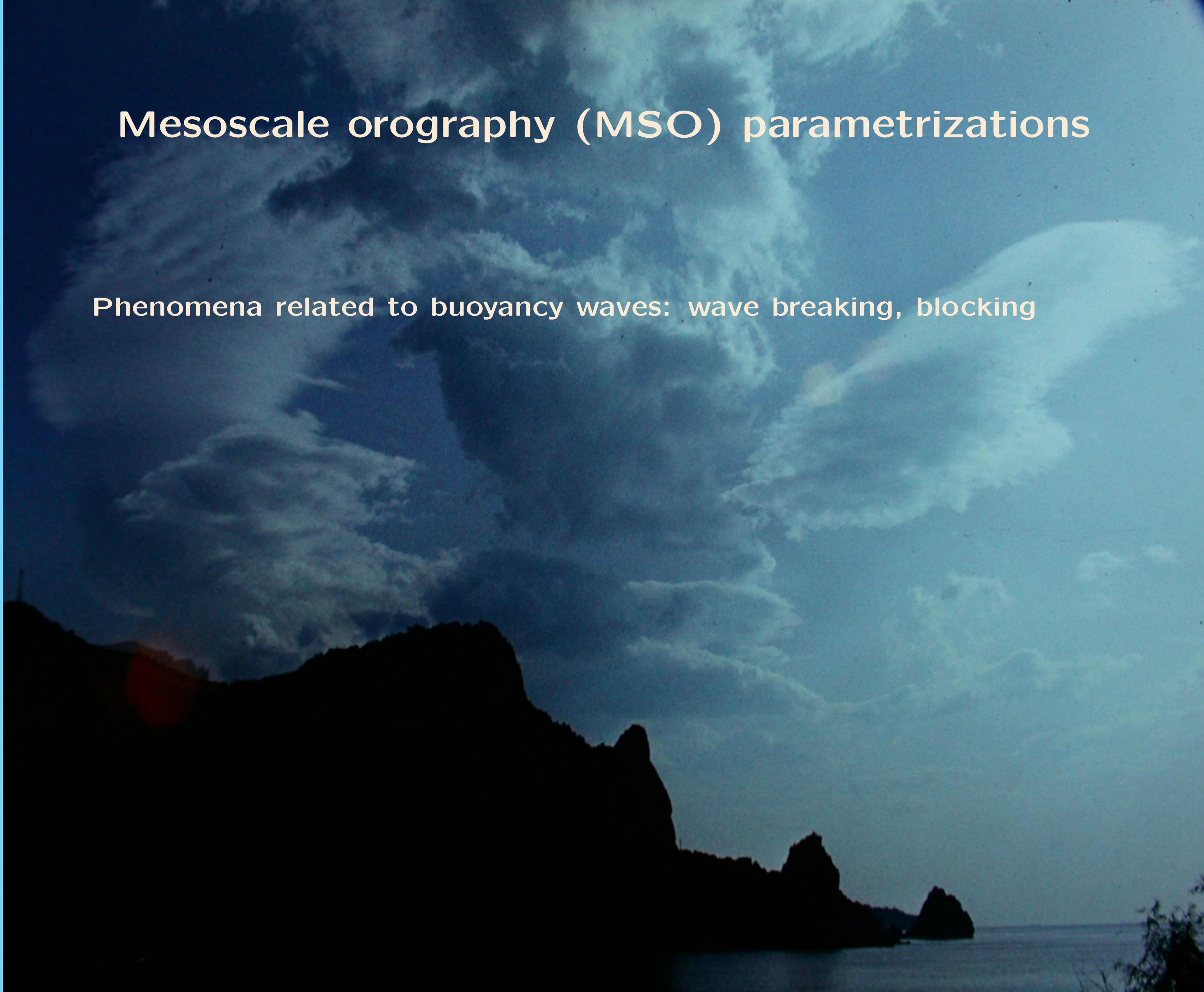
Mesoscale orography (MSO) parametrizations

Phenomena related to buoyancy waves: wave breaking, blocking



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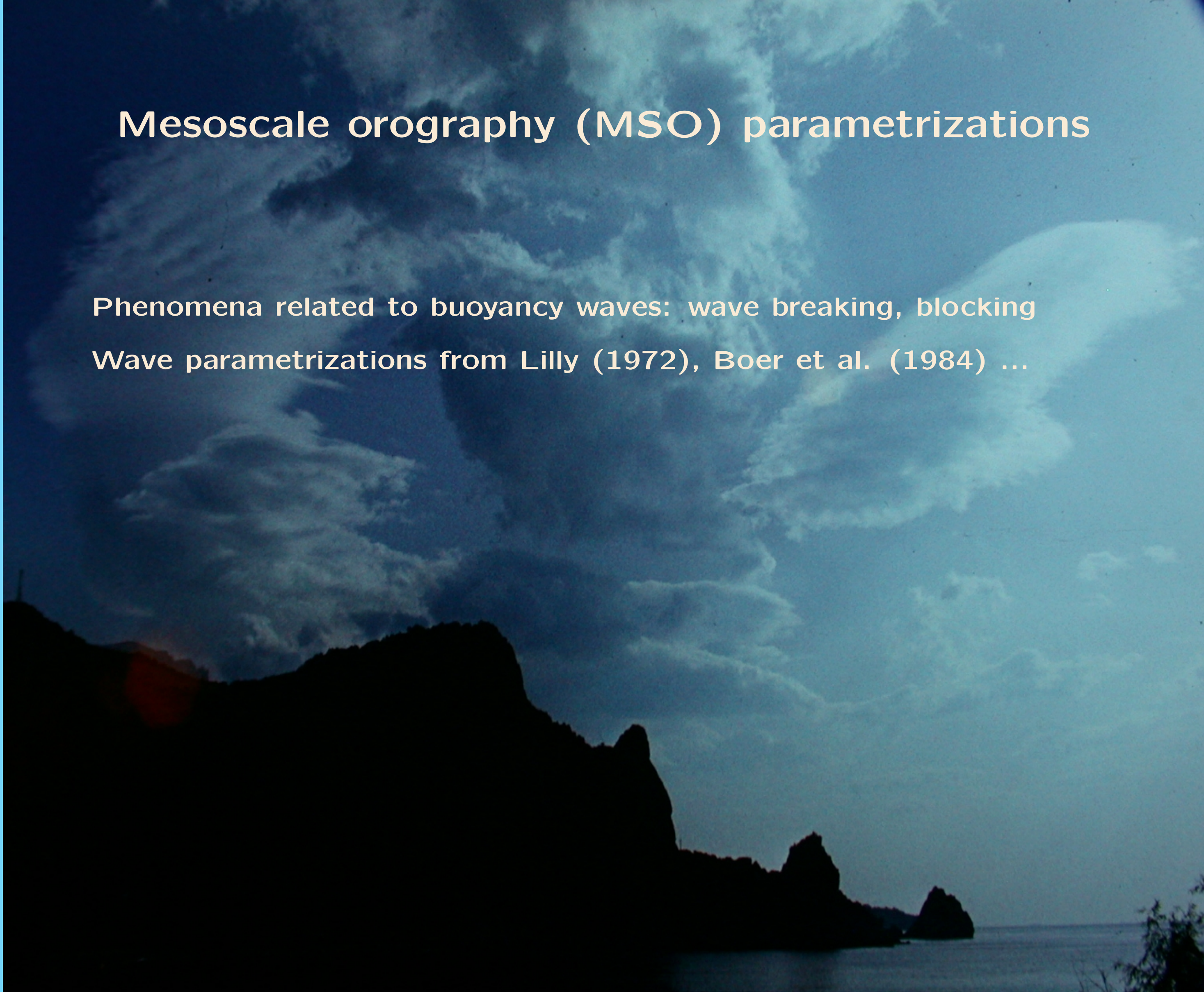
Wave parametrizations from Lilly (1972), Boer et al. (1984) ...



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In HIRLAM: simple and classical scheme from Meteo France

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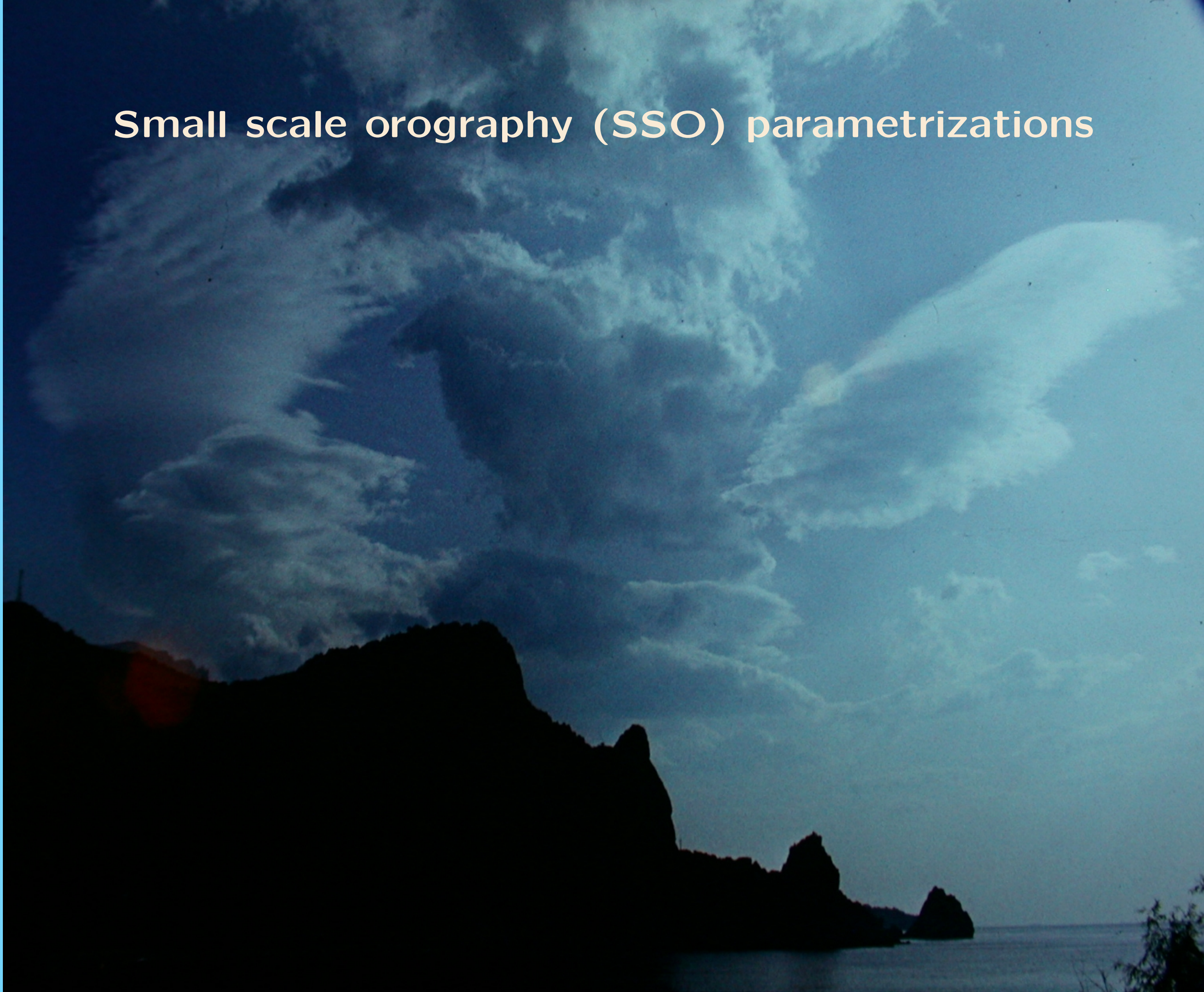
* blocked flow drag = form drag according to Lott and Miller

Small scale orography (SSO) parametrizations



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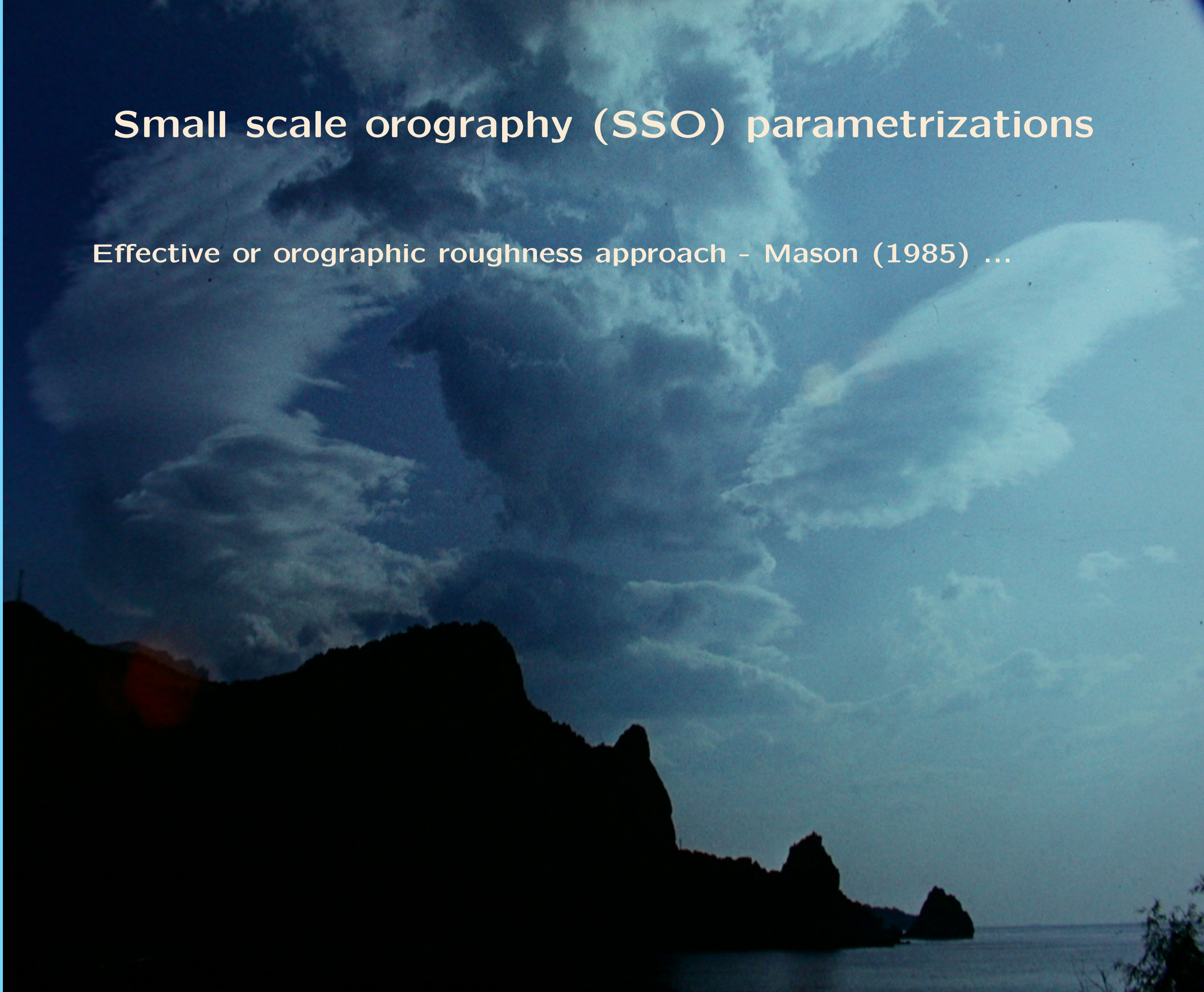
Effective or orographic roughness approach - Mason (1985) ...



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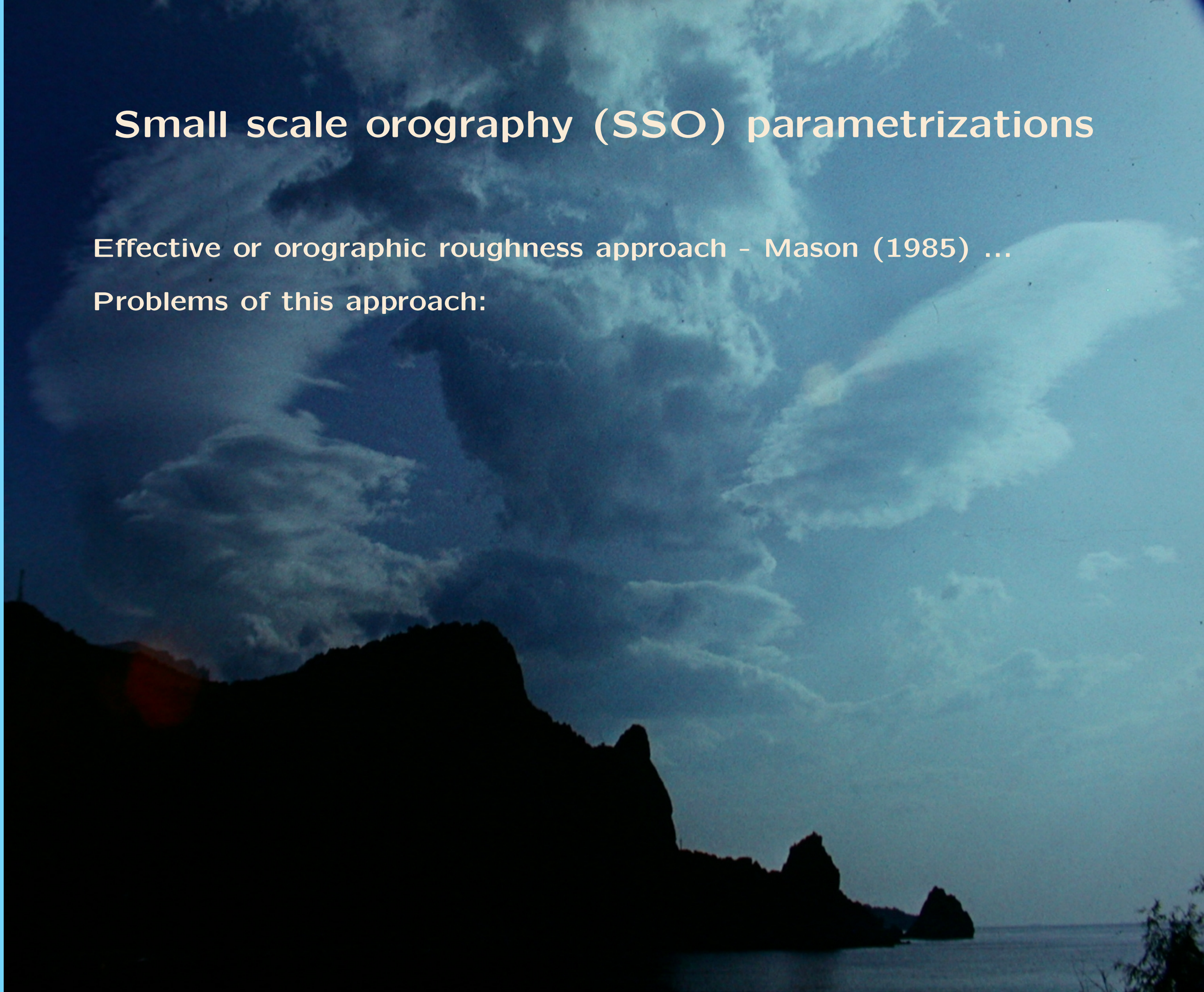

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In HIRLAM: z_{oro} used, alternative approach tested

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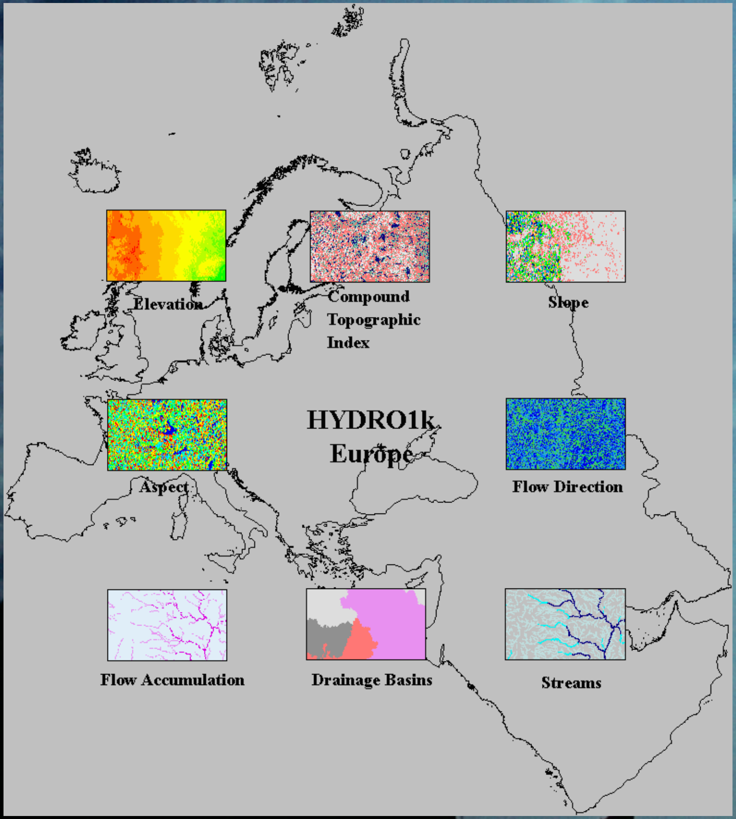
Orography parameters and scales

variable	definition	scale of orography
	For resolved dynamics	
$H_{2\Delta x}$	mean height	$> 2\Delta x$
	For mesoscale orography parametrization	
σ_m	standard deviation of mesoscale orography	3 km - 2Δx
α	anisotropy of the mesoscale orography	3 km - 2Δx
θ	angle between mesoscale ridges and model's x-axis	3 km - 2Δx
	For small-scale orographic stress	
($z_{0,oro}$	orographic roughness	$<$ 3 km)
s_t	averaged maximum slope s_{max}	$<$ 3 km
σ_t	smallest scale standard deviation	$<$ 3 km
	For turbulence over flat rough surface	
z_0	roughness	$<<$ 1 km

Source: digital elevation map



Old experiments and verification pictures

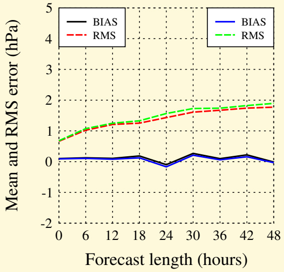
experiment	description
RC33	reference HIRLAM with technical corrections
NO33	RC33 but SSO parametrization instead of $z_{oro,0}$
NM33	NO33 but MSO parametrization added
NT33	NM33 but with rotated turbulent stress vector

European area with Δx=33 km/40 levels, 00 UTC only + 48h HIRLAM v.6.3.3, boundaries from 33 km/40 level HIRLAM reanalysis 6.2.2 run at ECMWF for the year 2000, observations from ECMWF archive.

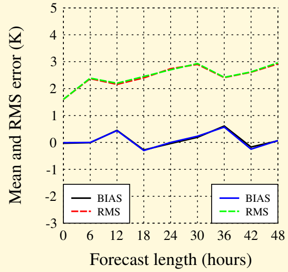
Station verification

against EWG observations
RC33 (left) NO33 (right)
Period: 20000119 - 20000129

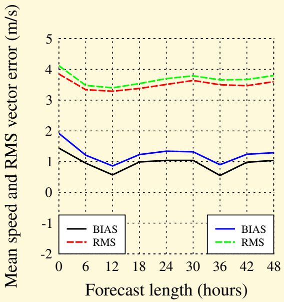
Surface pressure



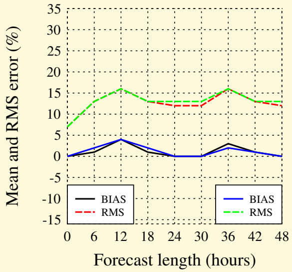
Two metre temperature



Ten metre wind



Two metre relative humidity



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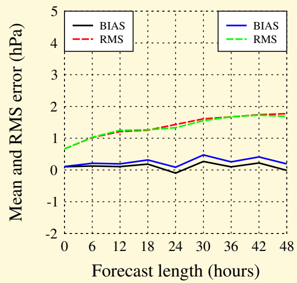

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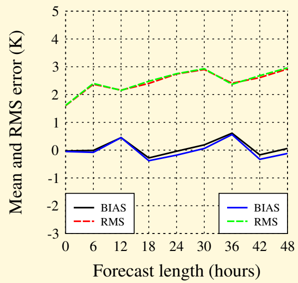
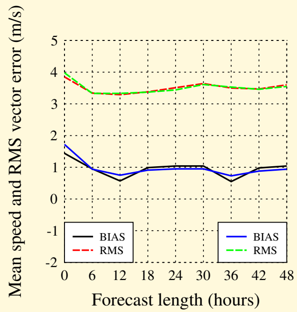


Ten metre wind



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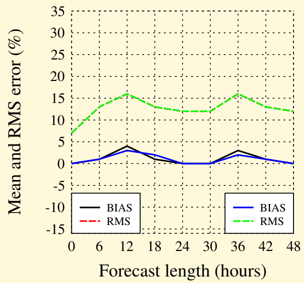
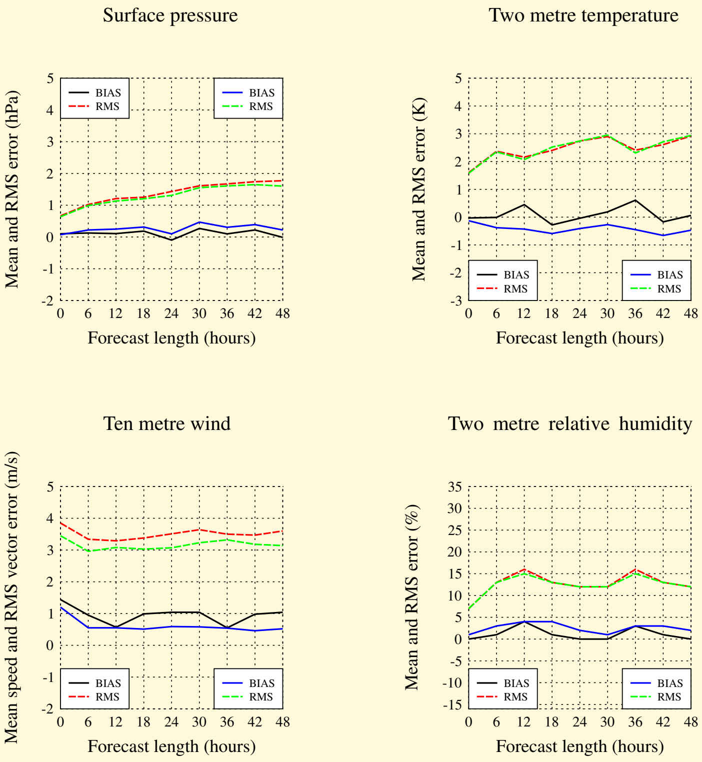


against EWG observations
RC33 (left) NT33 (right)
Period: 20000119 - 20000129



Hirlam

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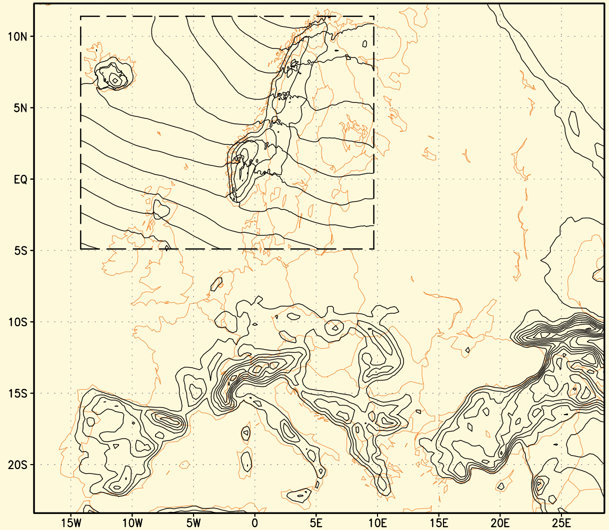
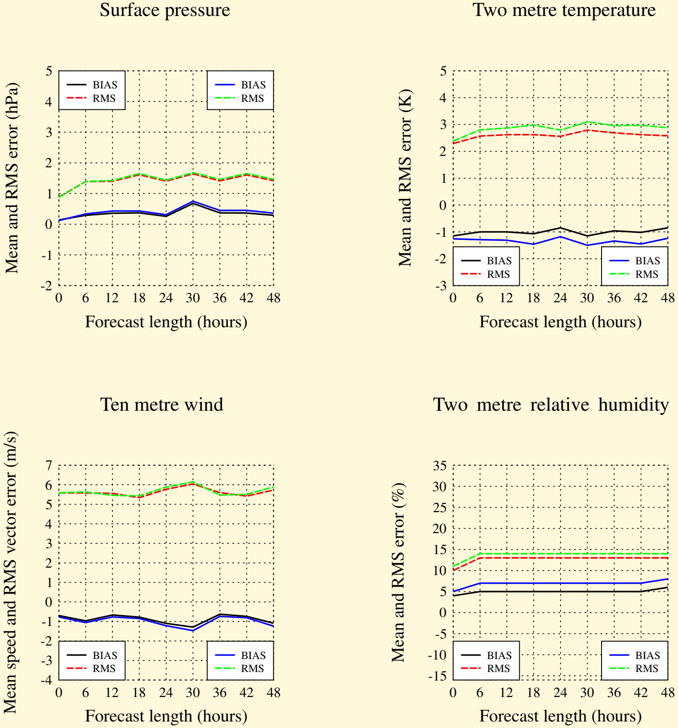
New experiments and verification pictures

R33 and R11	**reference HIRLAM ≈ 6.3.5**
O33 and O11	**MSO + SSO parametrizations**
B33 and B11	**MSO + ECMWF SSO parametrizations**



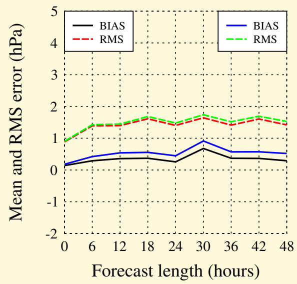
Integration areas of the 33 km (full area of the map) and 11 km (box outlined by dashed line) experiments. Shown in the figure are isolines of the surface elevation (whole area, isoline spacing 300 m) and mean sea level pressure averaged over January 2000 (small area, given by the +48h forecasts of the experiment O33, isoline spacing 5 hPa).

against Isl observations
R33 (left) O33 (right)
Period: 20000101 - 20000131

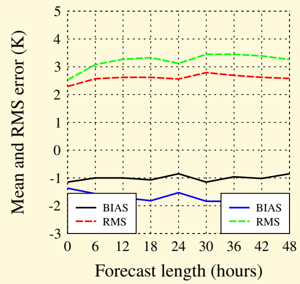


against Isl observations
R33 (left) BB33 (right)
Period: 20000101 - 20000131

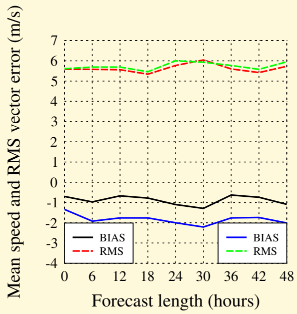
Surface pressure



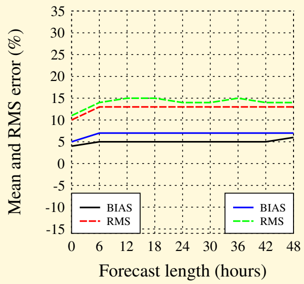
Two metre temperature



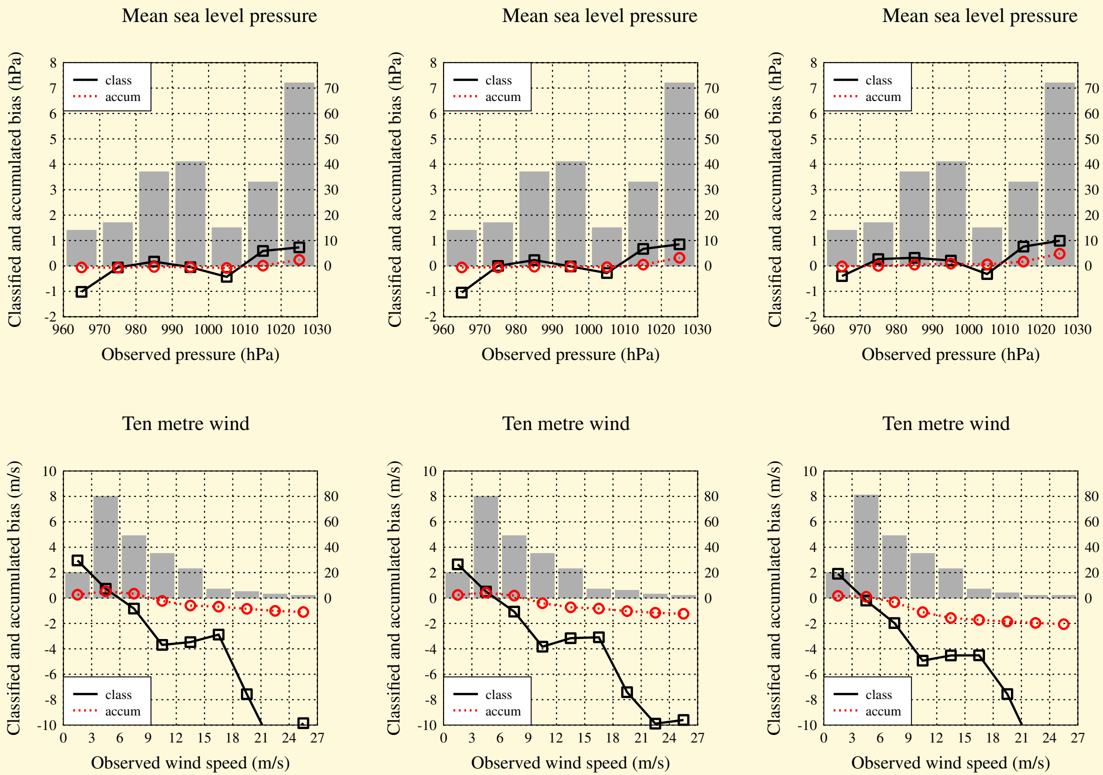
Ten metre wind



Two metre relative humidity

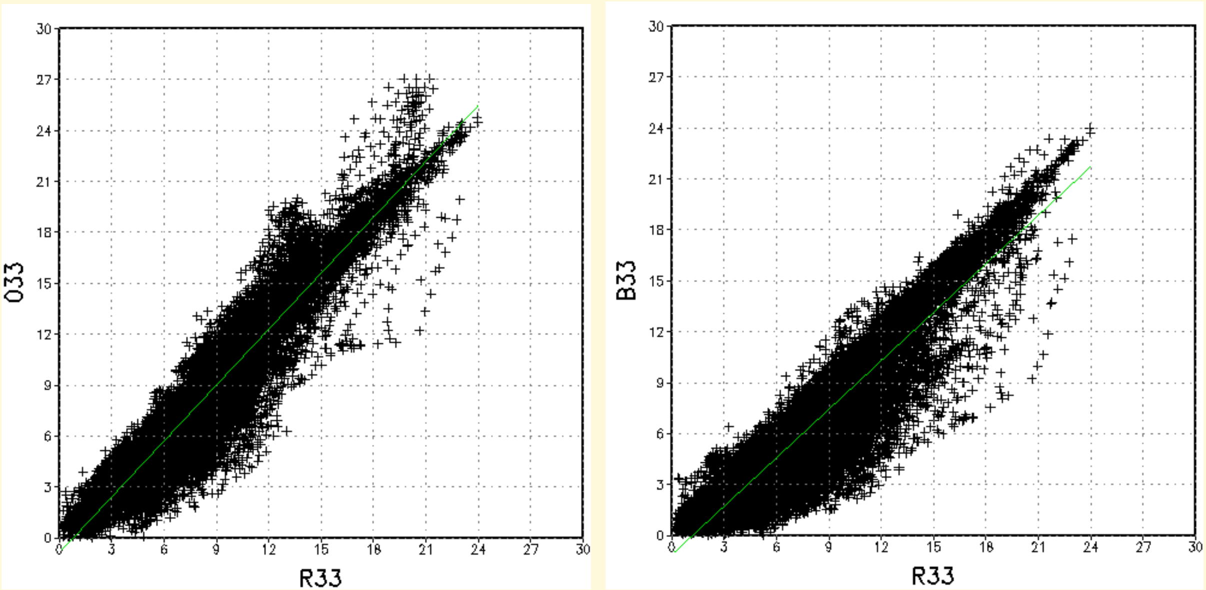


More verification pictures, with explanations



Experiments from left to right: R33, O33, B33.

Lowest model level wind speed January 2000 00UTC+48h



R33=Reference experiment, O33=MSO+Hirlam style SSO, B33=MSO+ECMWF style SSO. Unit: m/s, area: Iceland.

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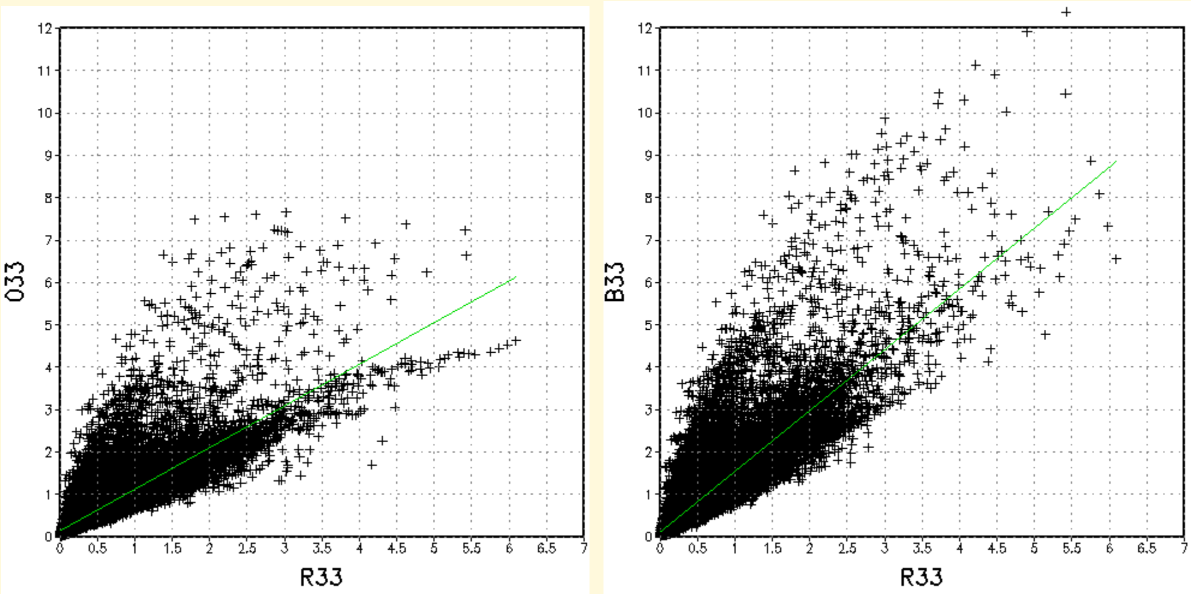
Total surface stress, January 2000 00UTC+48h



R33=Reference experiment, O33=MSO+Hirlam style SSO, B33=MSO+ECMWF style SSO. Unit: Pa, area: Iceland. Note different scales of the axes!

Summary and conclusions

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Summary and conclusions

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- The needed scale-dependent orography variables were derived from high-resolution digital elevation map.
- Parametrization schemes representing different sub-grid scales interact and partly compensate each other. New parametrizations increase the total drag only a little.
- Careful verification and use of diagnostic tools to analyse kinetic energy and vorticity budget are needed to understand the effects and interactions of the parametrizations.

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