Handling of orography in NWP models - topics for discussion

Laura Rontu
Finnish Meteorological Institute, HIRLAM-B

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WHY SURFACE ELEVATION IN NWP?

Basis of the vertical coordinate in model dynamics

Data assimilation and validation
using observations at some elevation from surface

Parametrisation of momentum and radiation fluxes
depending on orography

WHY SURFACE ELEVATION IN NWP?

Basis of the vertical coordinate in model dynamics

- smoothness

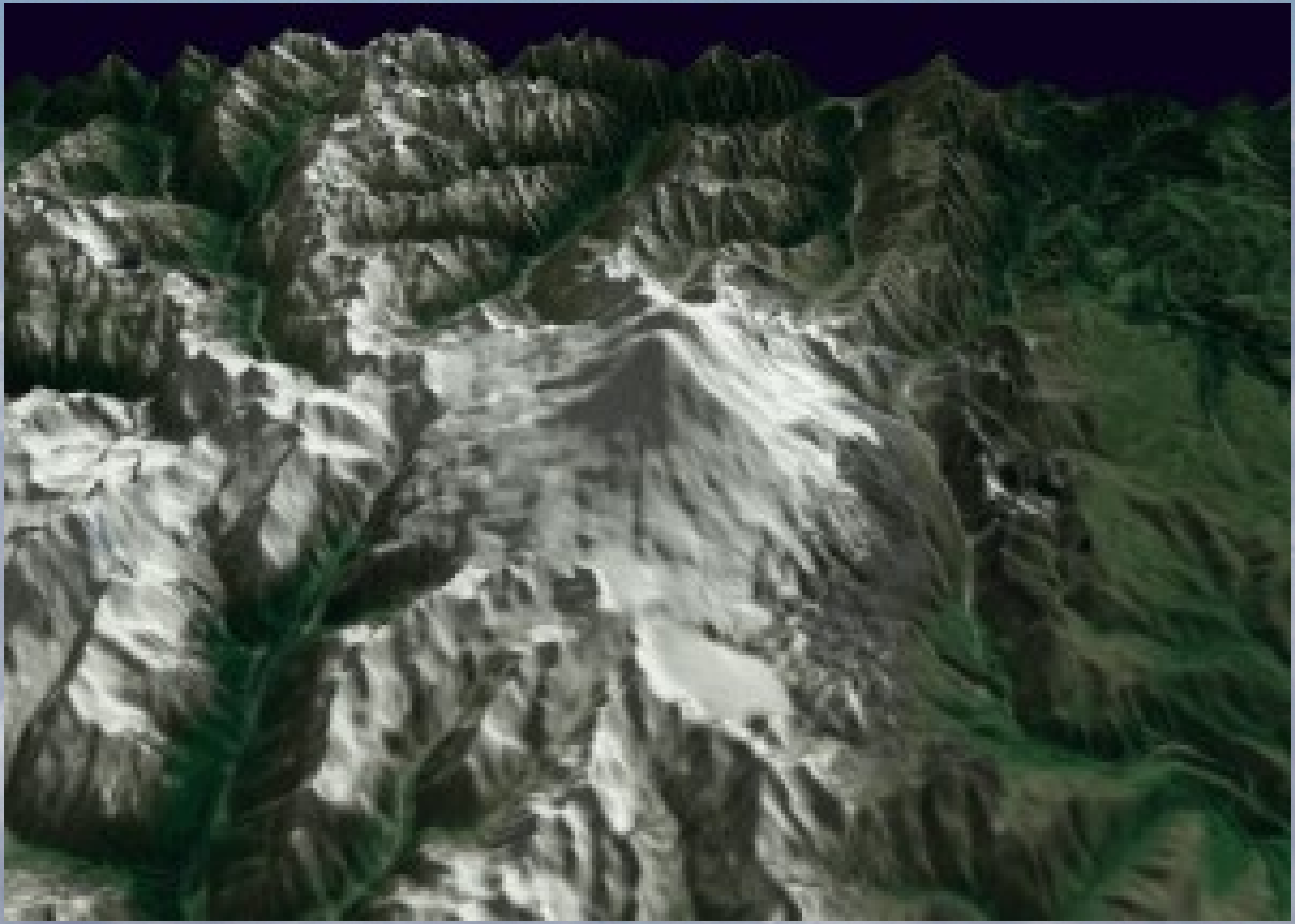
Data assimilation and validation
using observations at some elevation from surface

- details, consistency

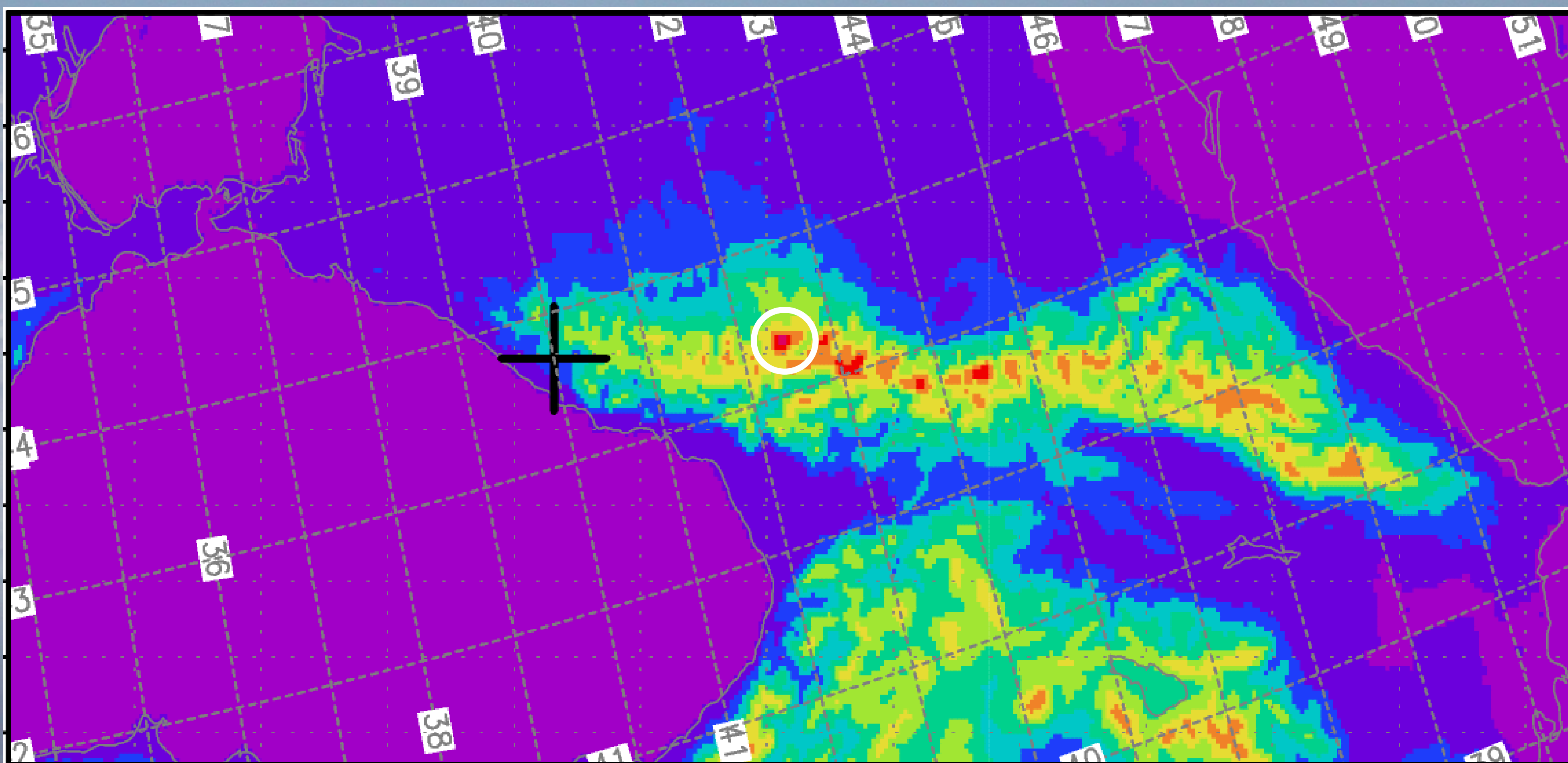
Parametrization of momentum and radiation fluxes
depending on orography

- (statistical) parameters, consistency of scales and surface types

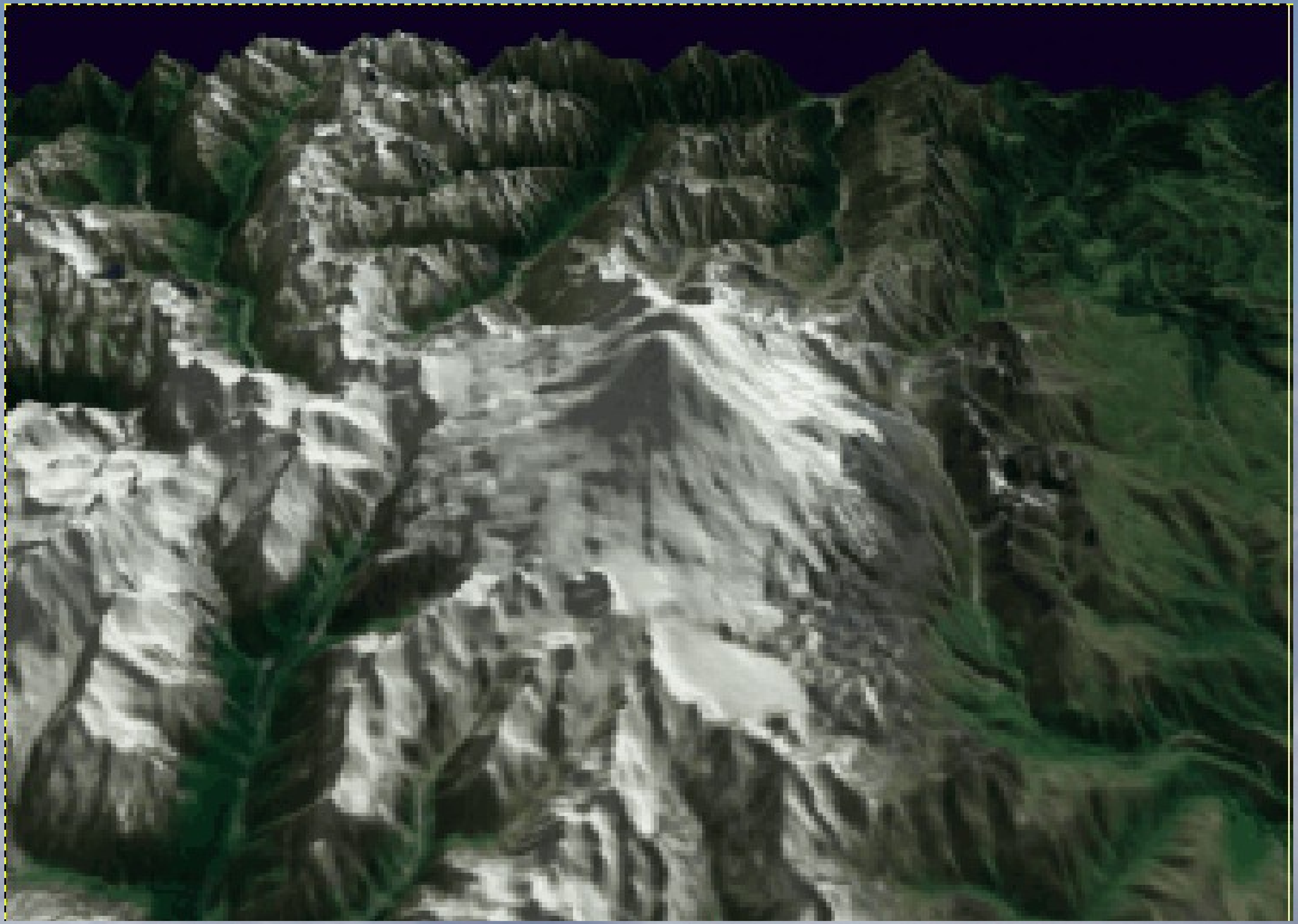
What do we know about the surface elevation?



Caucasian mountains, Mount Elbrus and Sochi Olympics venue Krasnaya Polyana



Only one variable: surface elevation



Try a grid there: ECMWF, deltax 15 km
(this here is one gridbox!)

Only one variable: surface elevation

Mean elevation

Measure of variance:

standard deviation > roughness

Slopes and slope directions

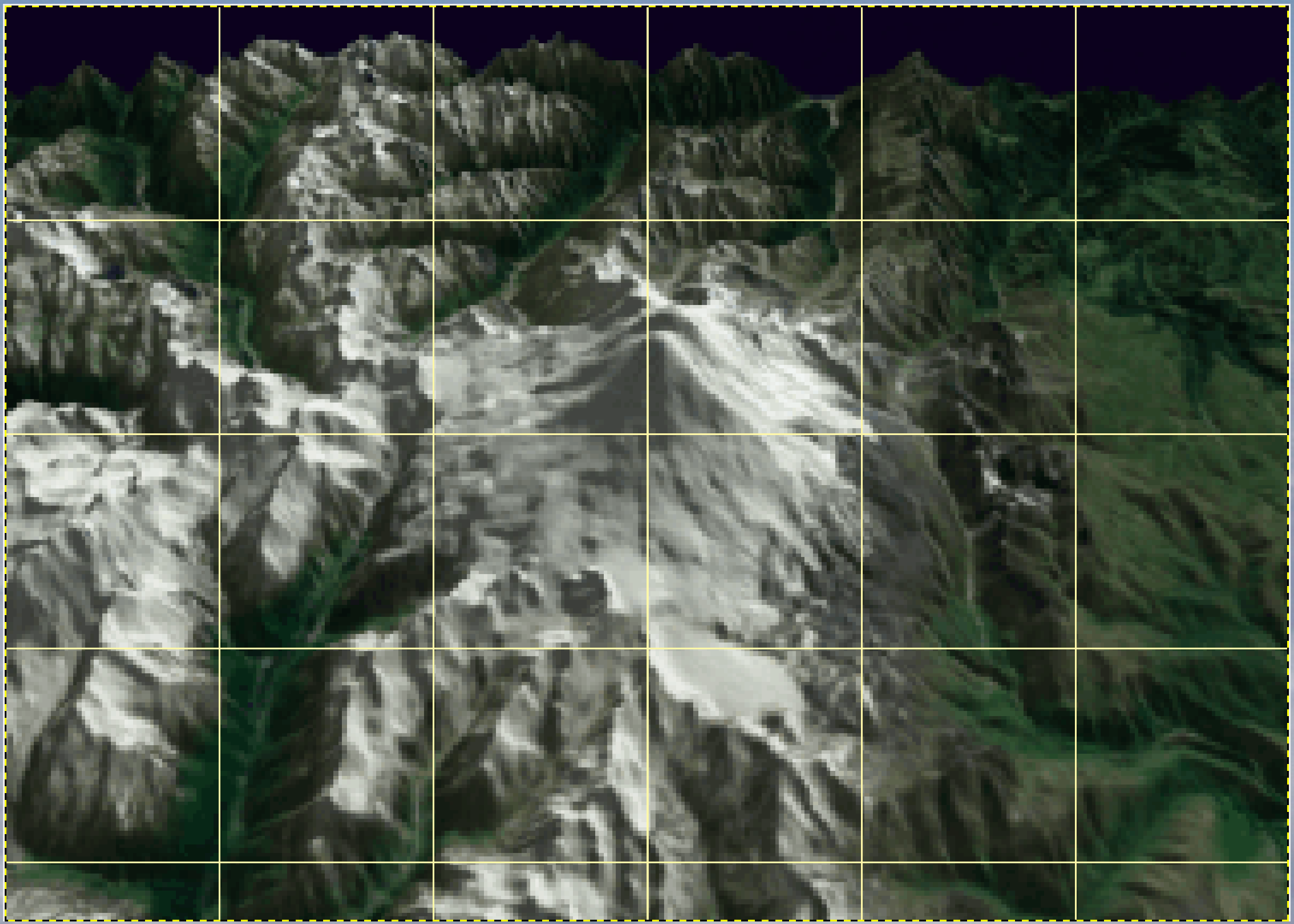
Description of the surface:

orography gradient correlation tensor

$$H_{ij} = \overline{\frac{\partial h}{\partial x_i} \frac{\partial h}{\partial x_j}}$$

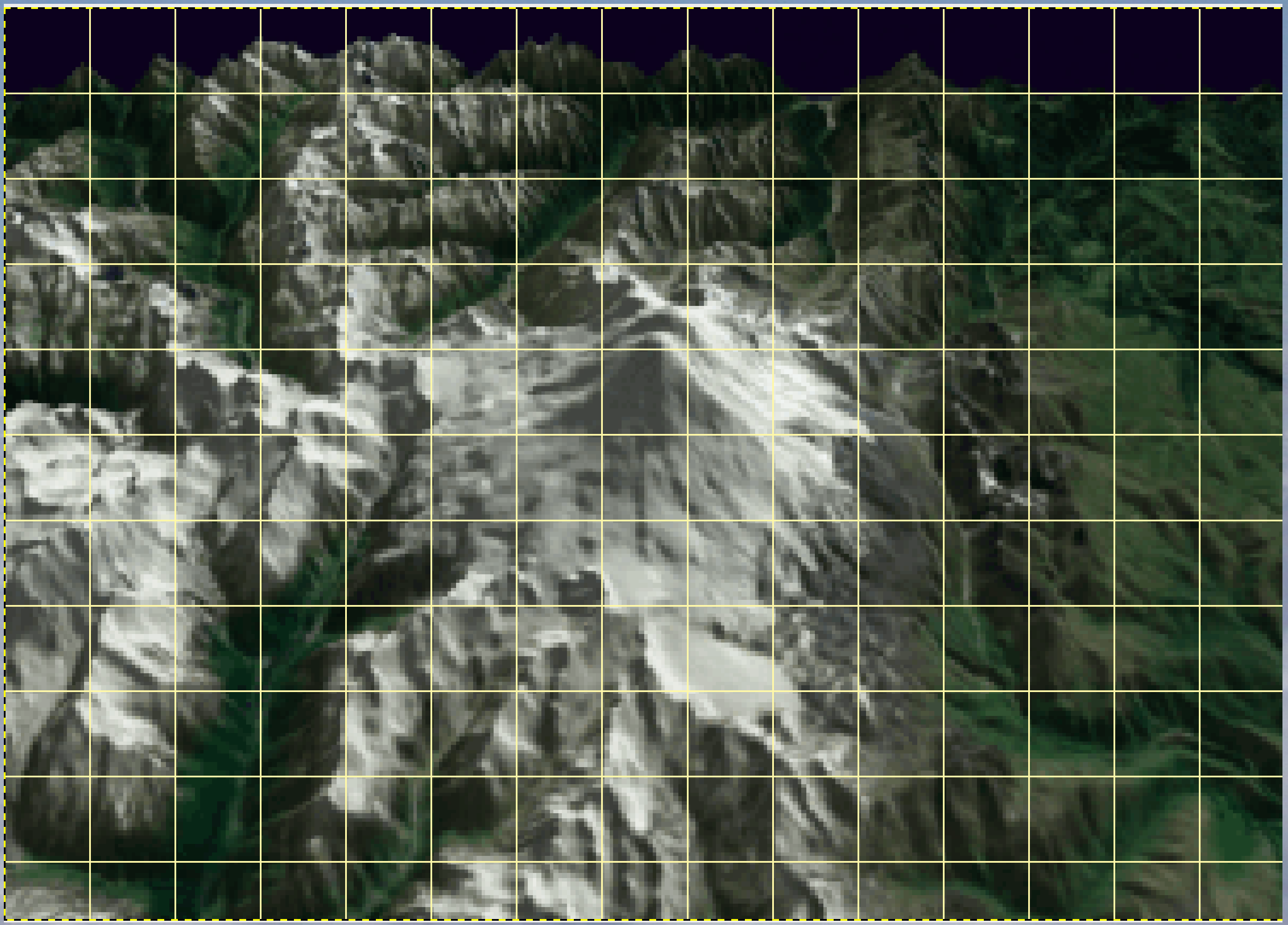
+ statistical measures in sub-grid scale, to be applied by parametrizations

Only one variable: surface elevation



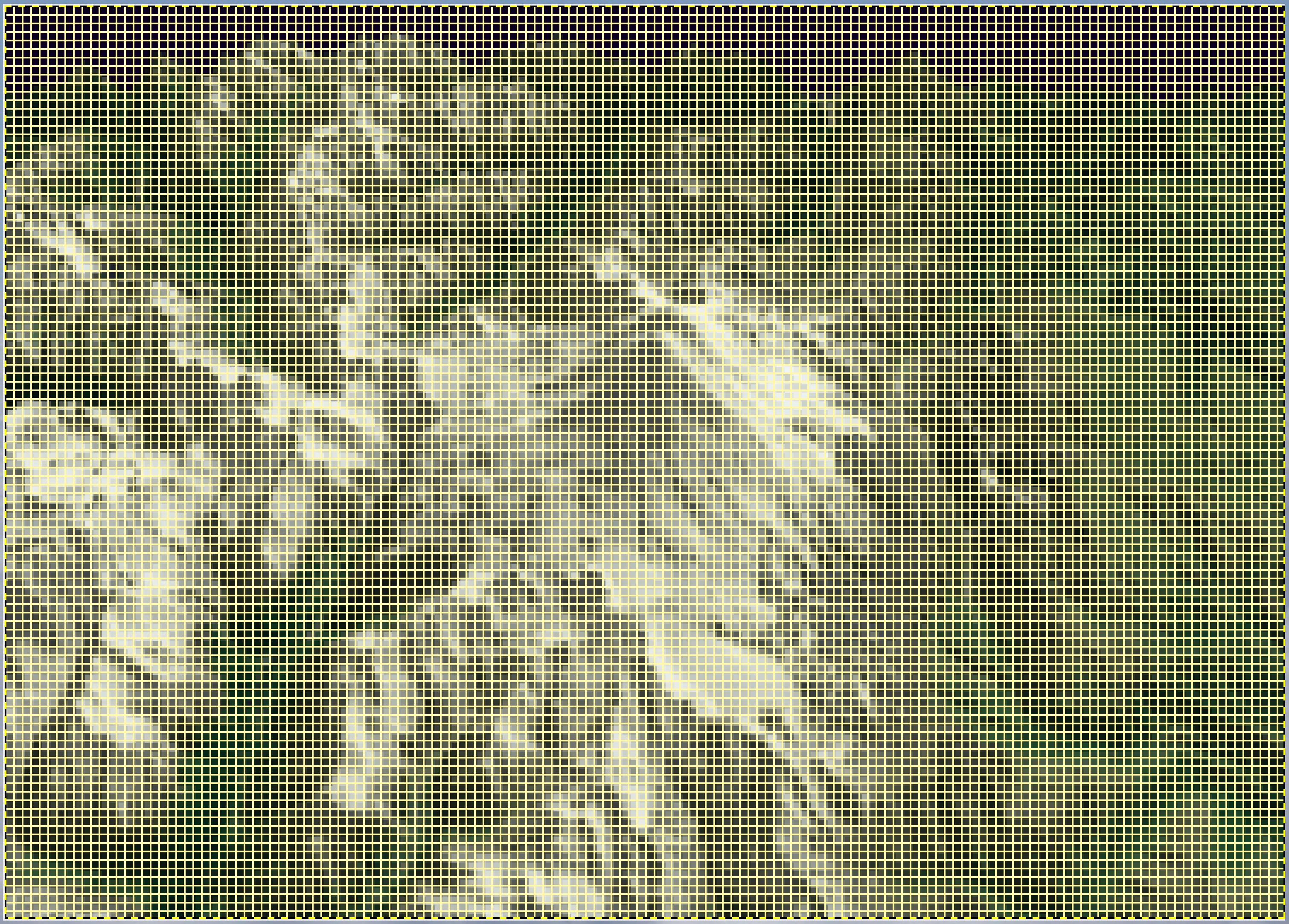
AROME, deltax 2.5 km

Only one variable: surface elevation



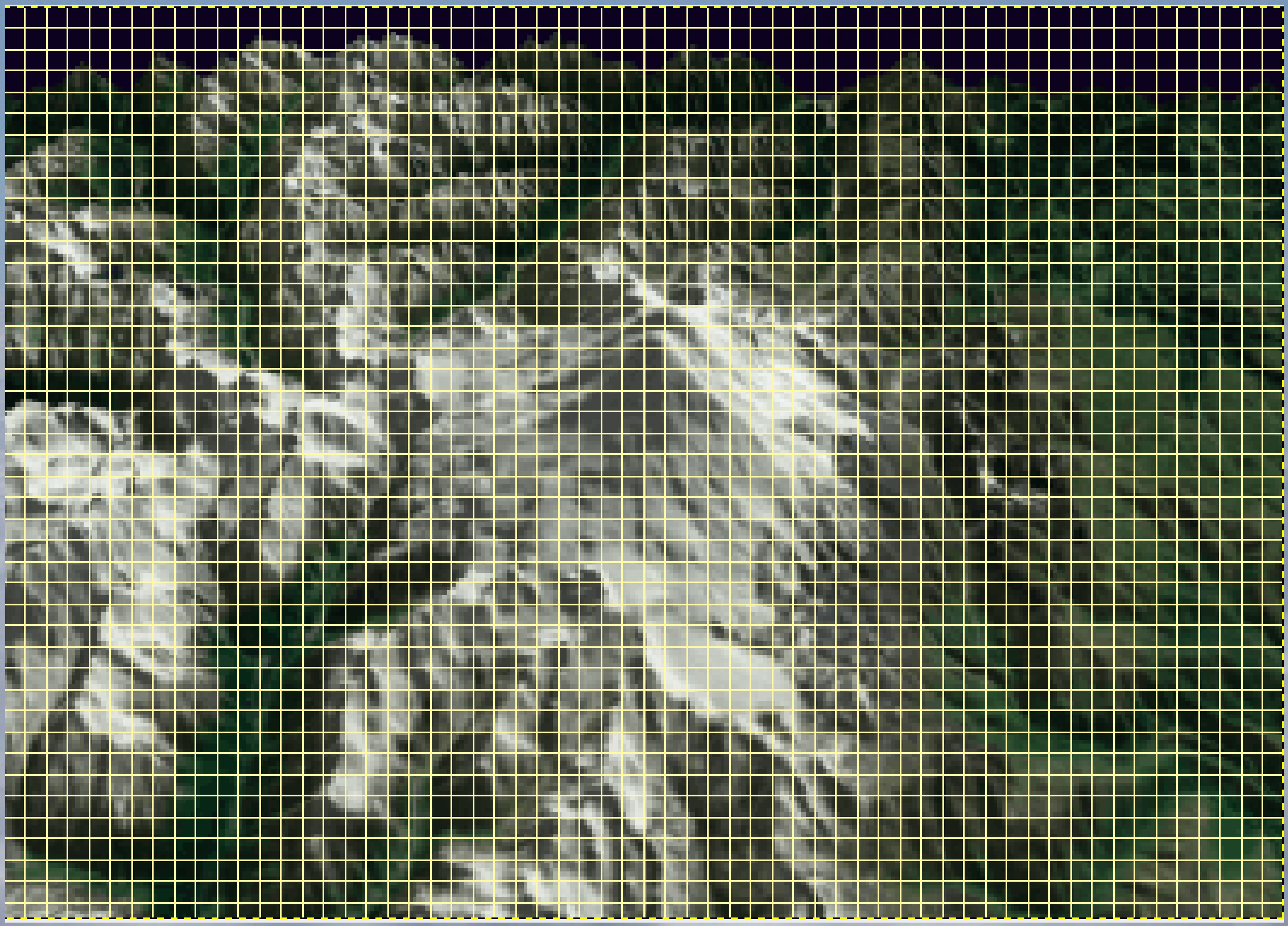
We know this from gtopo30, deltax 1 km

Only one variable: surface elevation



... or this from SRTM, deltax < 100 m

Only one variable: surface elevation



... or this from GMTED2010, deltax 250 m

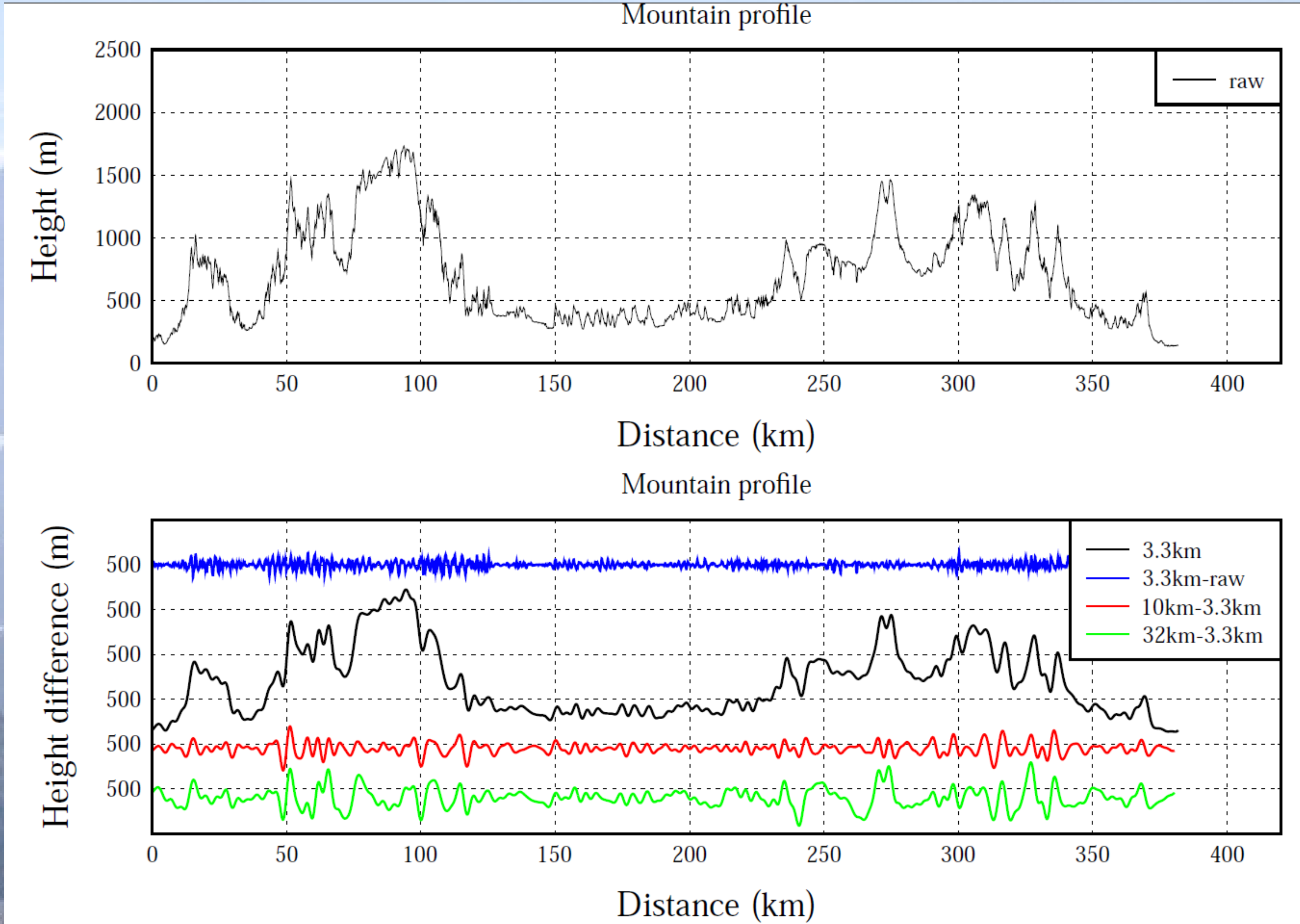
Renewal of the oroparameters

Derivation of parameters for dynamics and parametrisations, based on the highest resolution global digital elevation data

WHY?

- Consistency within the models
- Understanding the sensitivities of atmosphere-orography interactions
- Revision of the orography-related parametrizations
- Very fine resolution (VFR) modelling

Dynamics: smooth enough mean elevation for the vertical coordinate



Parametrizations

$$\frac{\partial \vec{v}}{\partial t} = -\vec{v} \cdot \nabla_\zeta \vec{v} - \dot{\zeta}\frac{\partial \vec{v}}{\partial \zeta} - \frac{1}{\rho}\nabla_\zeta p - \nabla_\zeta \Phi - f\vec{k} \times \vec{v} - \frac{g}{p_s}\frac{\partial \vec{\tau}}{\partial \zeta}$$

$$\frac{\partial T}{\partial t} = -\vec{v} \cdot \nabla_\zeta T - \dot{\zeta}\frac{\partial T}{\partial \zeta} - \frac{1}{c_p}\left(\frac{g}{p_s}\frac{\partial F_r}{\partial \zeta} + \frac{g}{p_s}\frac{\partial F_t}{\partial \zeta} + F_c\right)$$

$\vec{\tau}_s \sim f_1$(orography(x,y)), f_2(flow(x,y,z,t))

$F_{rs} \sim g_1$(orography(x,y,t)), g_2(radiation flux(x,y,z,t))

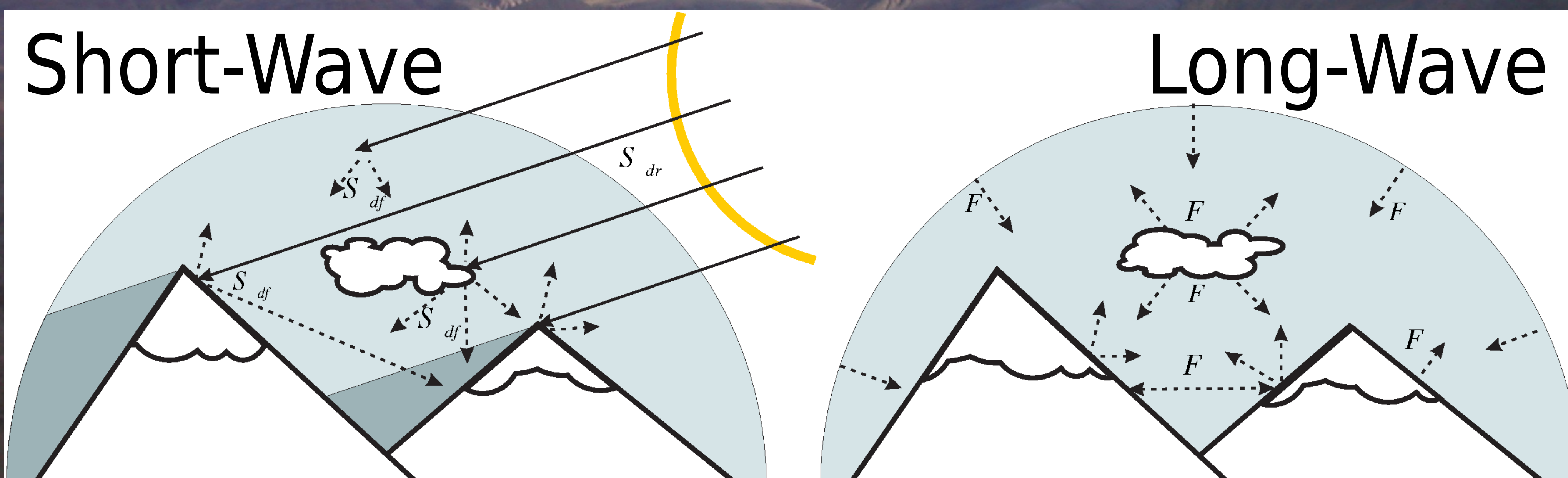
How to determine the orography-dependent functions?

VARIABLES DERIVED FROM THE FINEST-RESOLUTION SOURCE DATA: There is more than the mean elevation!

parameter	description	unit	usage	scale (km)	filtering
$H_{k\Delta x}$	mean surface elevation	m	dynamics	$> k\Delta x$	low-pass
s_t	mean maximum small-scale slope	rad	SSO	< 1 km	high-pass
σ_t	small scale standard deviation	m	SSO	< 1 km	high-pass
σ_m	mesoscale standard deviation	m	MSO	1 km . . . $k\Delta x$	band-pass
α	coefficient of anisotropy	-	MSO	1 km . . . $k\Delta x$	band-pass
Θ	x-angle of orography gradient	rad	MSO	1 km . . . $k\Delta x$	band-pass
s_m	mean maximum mesoscale slope	rad	MSO	1 km . . . $k\Delta x$	band-pass
$h_{m,i}$	slope (in direction i)	rad	radiation	full resolution	none
f_i	fraction of slope (in direction i)	-	radiation	full resolution	none
$h_{h,i}$	local horizon (in direction i)	rad	radiation	full resolution	none

Typically, the empirical coefficient k in kΔx could be given a value 1 . . . 3 in mesoscale models.

HOW TO USE OROPARAMETERS FOR PARAMETRIZATIONS: RADIATION



Slope, shadow and sky view factors

$$\delta_{sl} = \sin(h_s) + \cos(h_s) \sum_{i=1}^{8} f_i \tan(h_{m,i}) \cos(a_s - a_{m,i}), \qquad (13)$$

where f_i is the fraction and $h_{m,i}$ the mean height angle of the slopes in each sector i, centred at (8) azimuth angles $a_{m,i} = 0^\circ$, $45^\circ, \ldots, 270^\circ, 315^\circ$ (N, NE, E, SE, S, SW, W, NW-note that the

slope factor for direct solar radiation

For the calculation of the shadow factor, minimum and maximum values of $h_{h,i}$ are found in each sector. Direction-dependent coefficients A_i and B_i are determined so as to fulfil a linear relationship

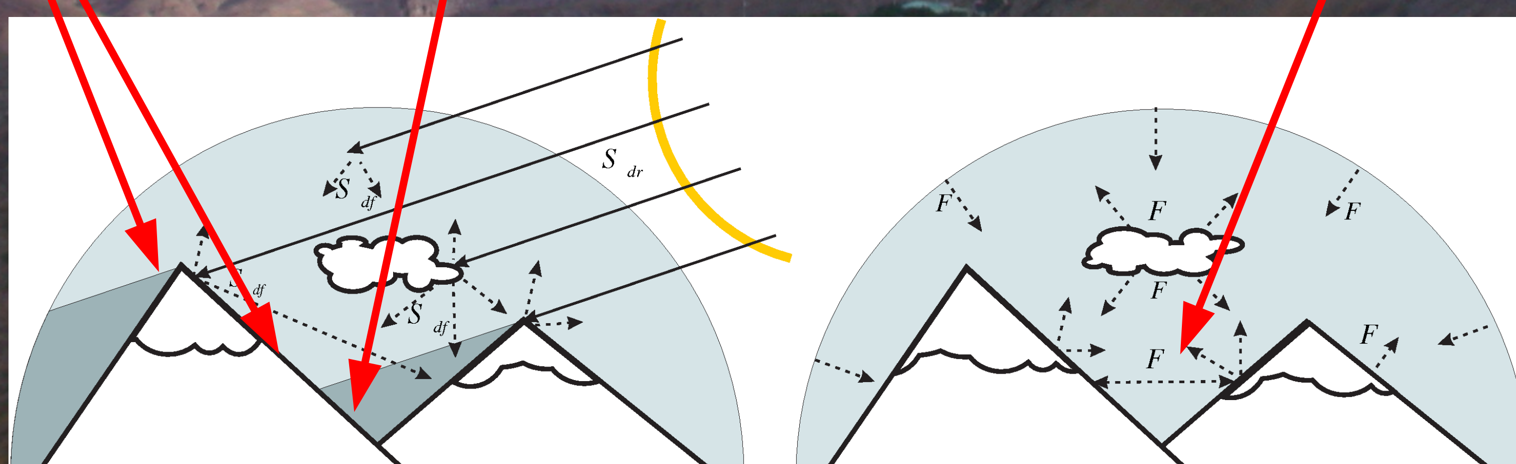
$$\delta_{sh,i} = A_i \sin(h_s) + B_i,$$

shadow factor for direct solar radiation

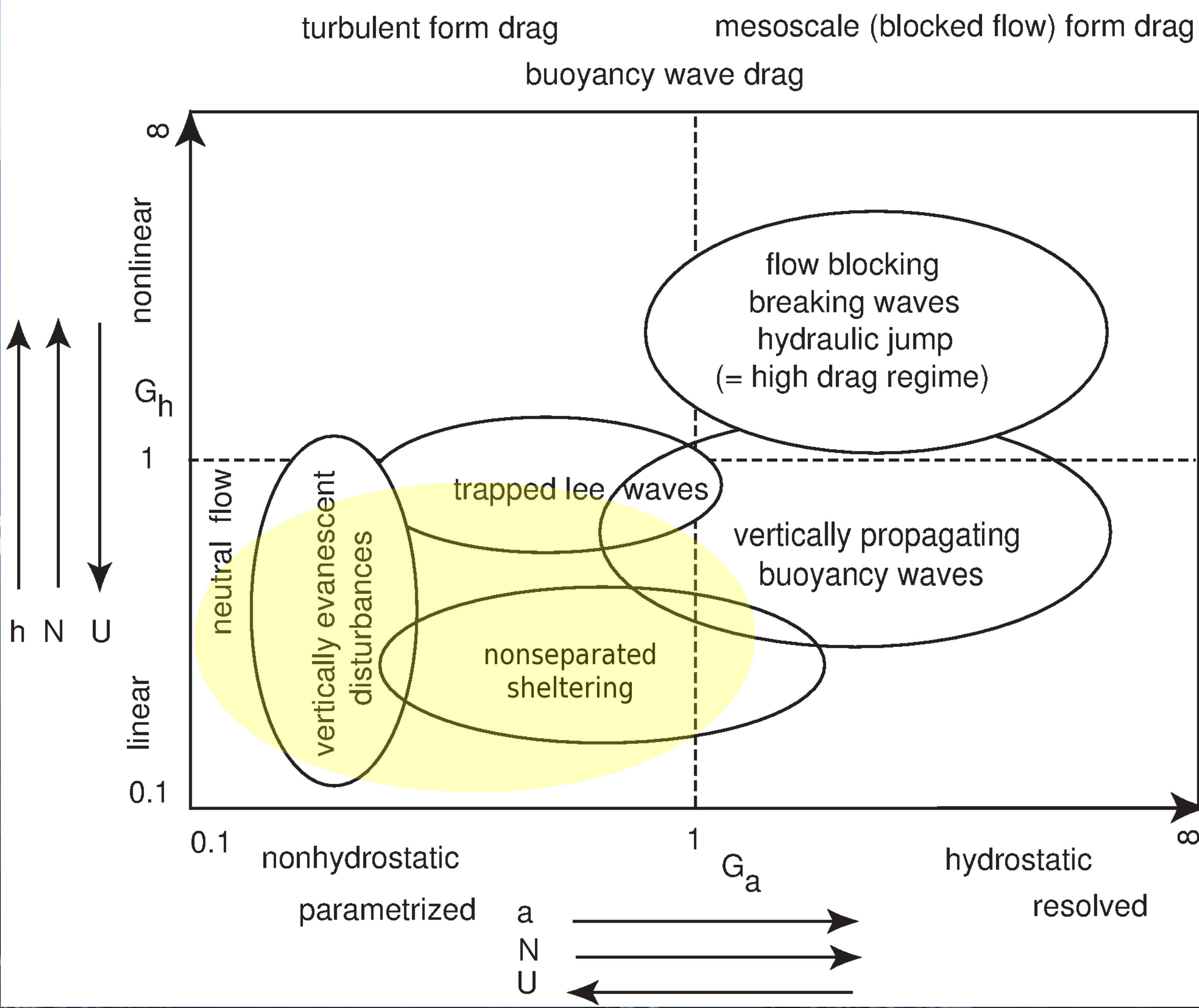
summation of the sectorial local horizon values $h_{h,i}$,

$$\delta_{sv} \approx 1 - \frac{\sum_{i=1}^{8} \sin(h_{h,i})}{8}.$$

sky view factor for LW and diffuse SW



About resolved and parametrized waves and momentum fluxes



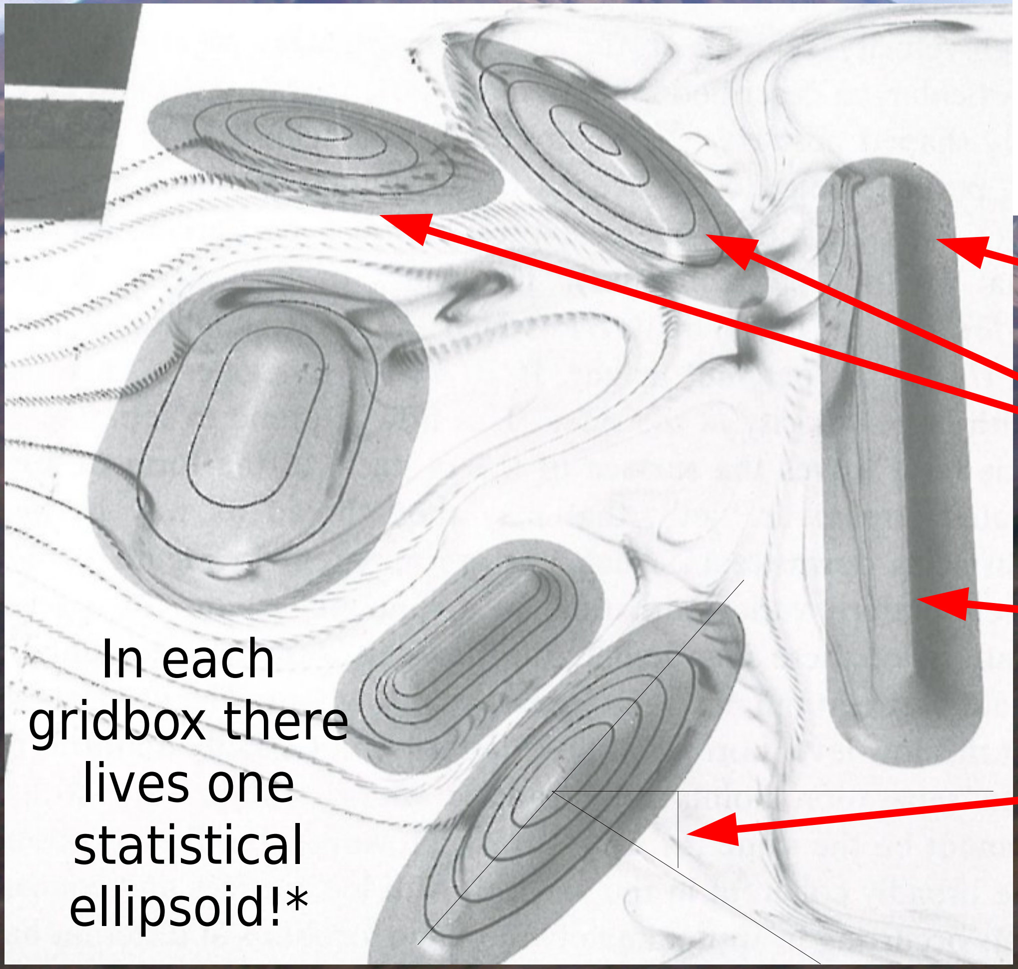
HOW TO USE OROPARAMETERS FOR PARAMETRIZATIONS: MESOSCALE MOMENTUM FLUXES

3.1.1 Generation of the wave stress

The generation of wave stress $\vec{\tau}_s$ [Pa] at the surface is calcu

$$\vec{\tau}_s(x,y) = K_g \cdot \rho_s \cdot N_s \cdot \vec{v}_{fs} \cdot h_m^2,$$

where the index s refers to the effective near-surface values



MSO slope = steepness

anisotropy = round or long

MSO standard deviation = height

xangle = slope direction

In each gridbox there lives one statistical ellipsoid!*

$$* \quad H_{ij} = \overline{\frac{\partial h}{\partial x_i}\frac{\partial h}{\partial x_j}}$$

HOW TO USE OROPARAMETERS FOR PARAMETRIZATIONS: SMALLEST-SCALE MOMENTUM FLUXES

Wood et al. (2001) and Brown and Wood

HIRLAM and used instead of the orograp

to the small scale orographic features is es

$$\vec{\tau}_o(z) = C_o \frac{\vec{\tau}_{ts}}{\rho_s} s_t^2 \rho(z) e^{-z/l_o} = \vec{\tau}_{os} f(z)$$

where C_o is an orographic drag coefficient,

SSO slope = steepness in the sub-kilometre-scale

Two small changes were made to the SSO parametrizations compared to Rontu (2006). First, the parametrized surface orographic stress $\vec{\tau}_{os} = C_o \frac{\vec{\tau}_{ts}}{\rho_s} s_t^2$ (where C_o is SSO drag coefficient, $\vec{\tau_{ts}}$ denotes surface turbulent stress, ρ_s is surface air density and and s_t is the SSO slope parameter) is added to the surface turbulent stress and transmitted to the vertical diffusion (CBR) scheme, instead of using a simple exponential decay of the stess suggested by Wood et al. (2001) and used

RENEWAL OF OROGRAPHY PARAMETERS

Take the most detailed global digital elevation data (SRTM – ASTER – Pan-Arctic DEM ...), improve & convert into needed by NWP input

Do (spectral) filtering in order to separate scales for derivation of variables for

- Model dynamics
- Orographic buoyancy wave parametrisations (MSO)
- Smallest scale orographic effects on momentum fluxes (SSO)
- Orographic radiation parametrisations

SRTM – ASTER -
PANARCTIC DEM - VIEWFINDER...
In GeoTIFF

High resolution digital elevation sources
ca. 100 m horizontal / 20 m vertical

Processing with
GDAL tools

Combined, cleaned, processed
by available tools to get

CORRECTED
SURFACE ELEVATION
and SLOPE ANGLES
In unformatted integer (gtopo)

Correct surface elevation and slopes in
the original high resolution grid and format

Spectral filtering
of elevation

Derivation of
scale-dependent
oroparameters

Filtered and processed with the tools
used in NWP models (e.g. SURFEX PGD and
AROME spectral dynamics) to get

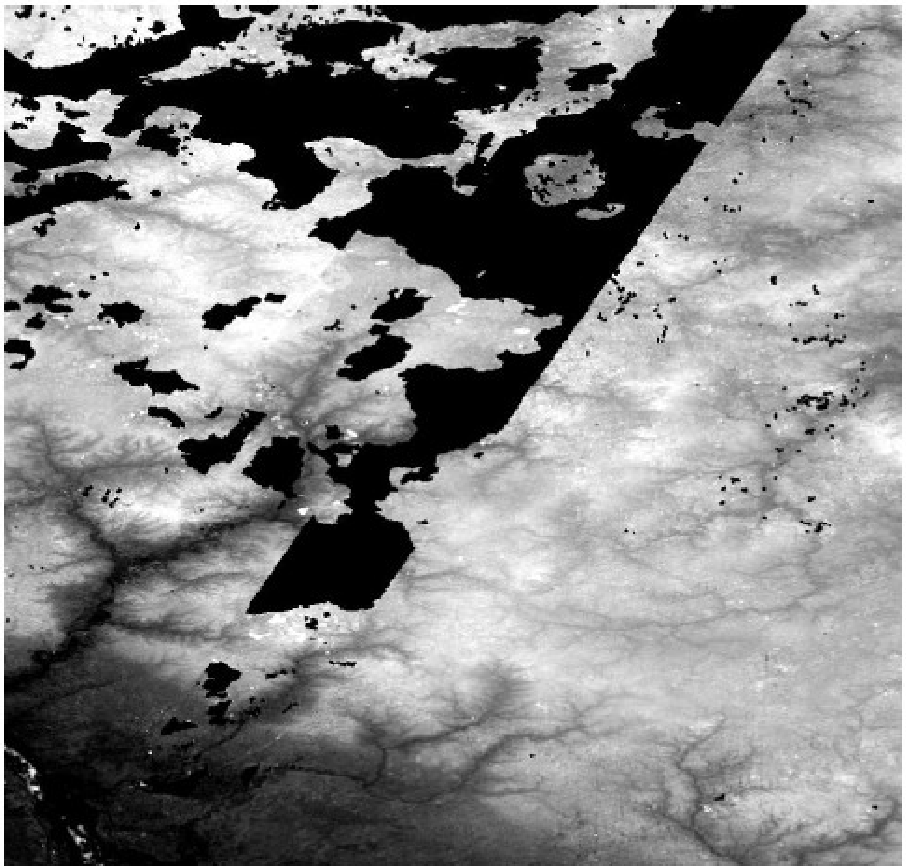
OROPARAMETERS
FOR NWP DYNAMICS
AND PARAMETRISATIONS
In model grid

Needed oroparameters in the NWP model
coordinates, resolution and file formats,
also coordinated with land-sea mask etc

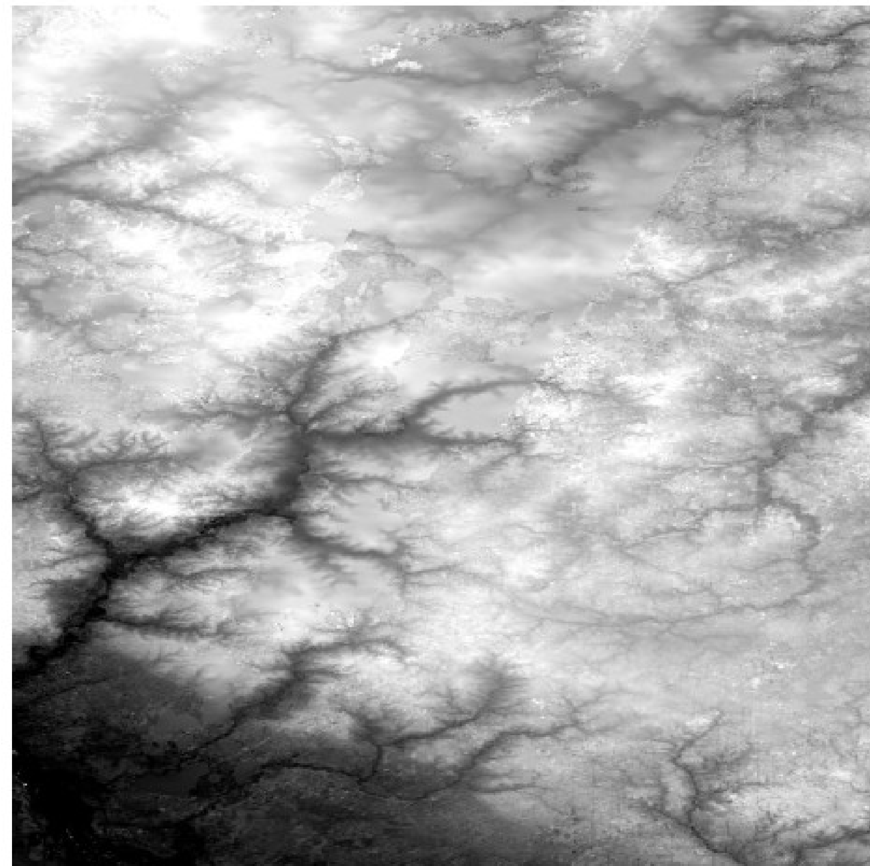
PROBLEMS OF (GLOBAL) DEM SOURCES

Limited geographical extent 55 S – 60 N (max 82 N)

Gaps, artifacts, errors



Raw ASTER tile : N62E045

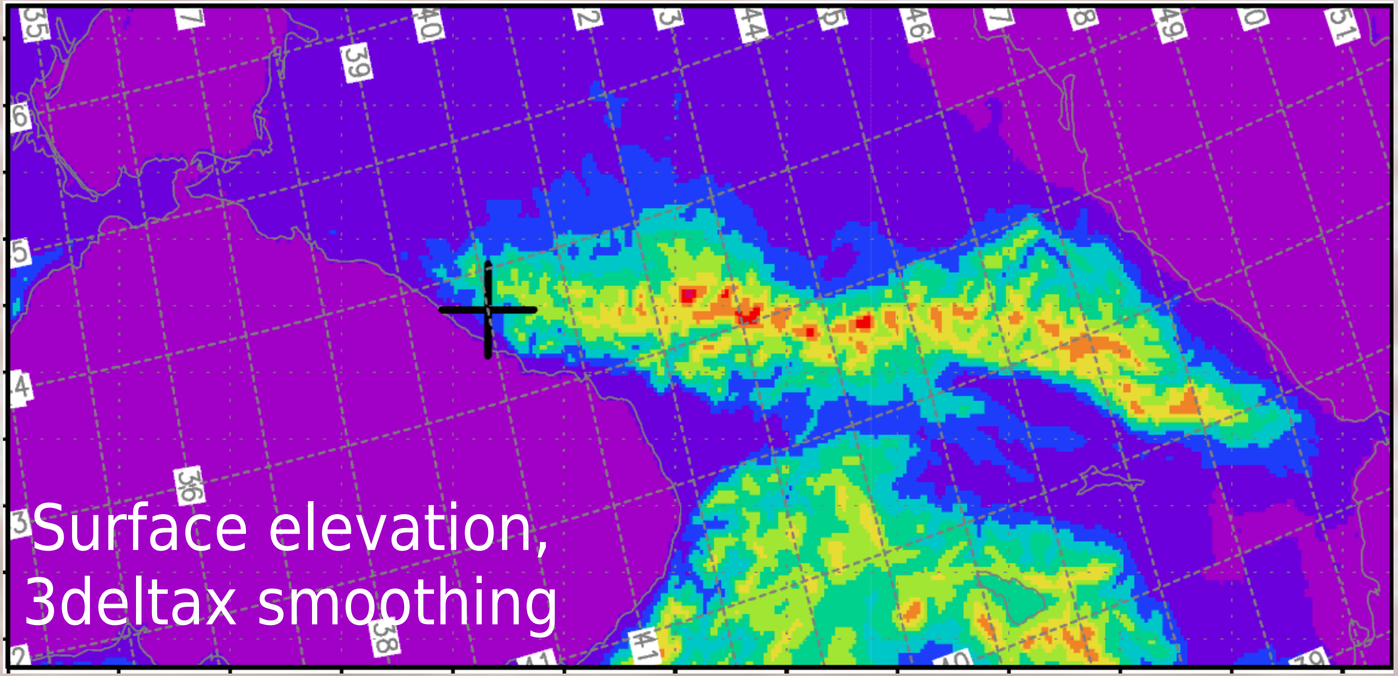


ASTER tile N62E045 corrected

Nicolas Bauer, FMI, 2012

HIRLAM experiments over Caucasia

Hydrostatic, deltax 3.5 km, January 2013
Oroparameters prepared from SRTM (100m), compared with those from hydro1k (1km) sources and reference HIRLAM with gtopo30 mean elevation



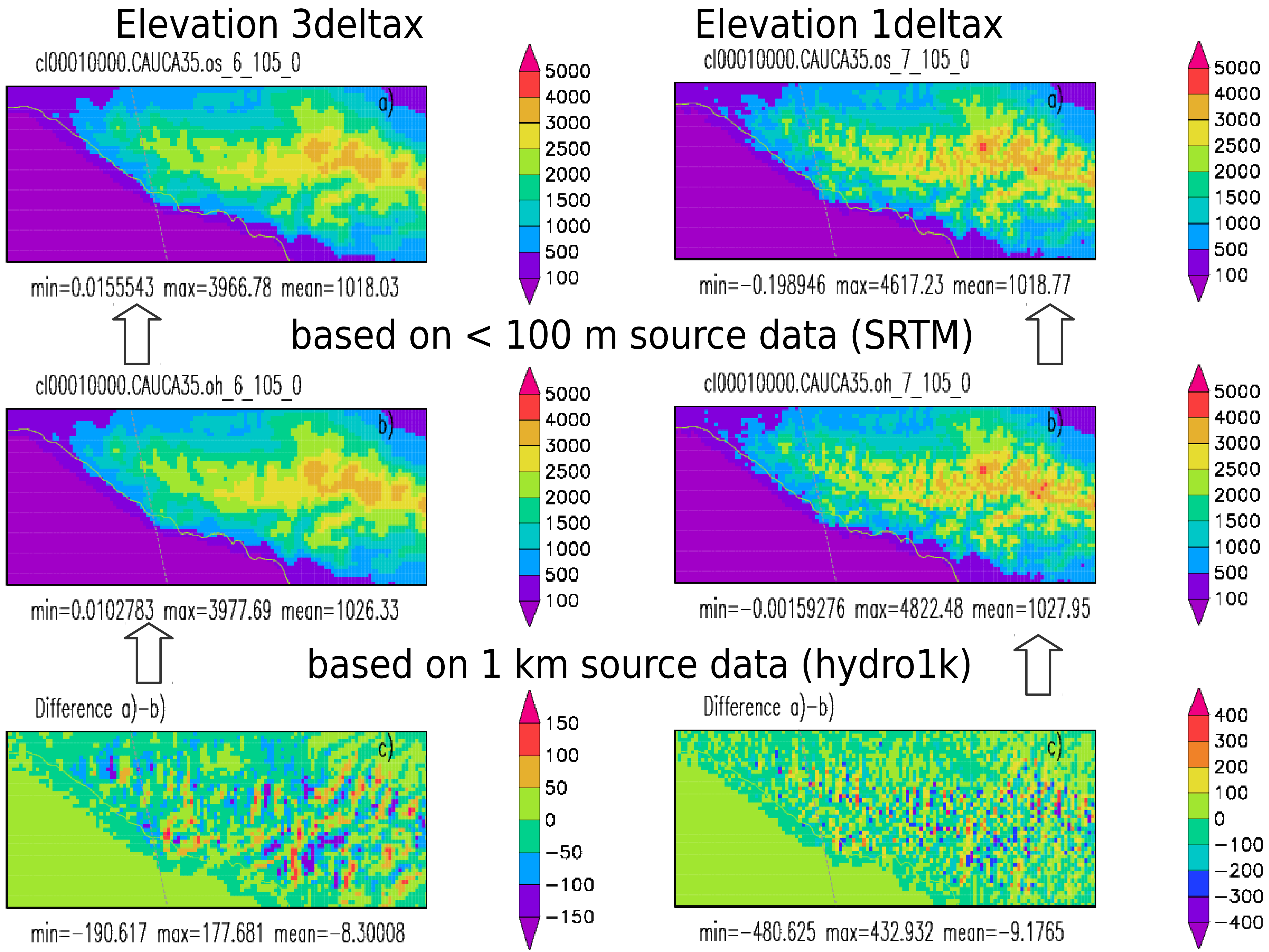
Experiments

hircau0
– reference HIRLAM, but no oroparametrizations

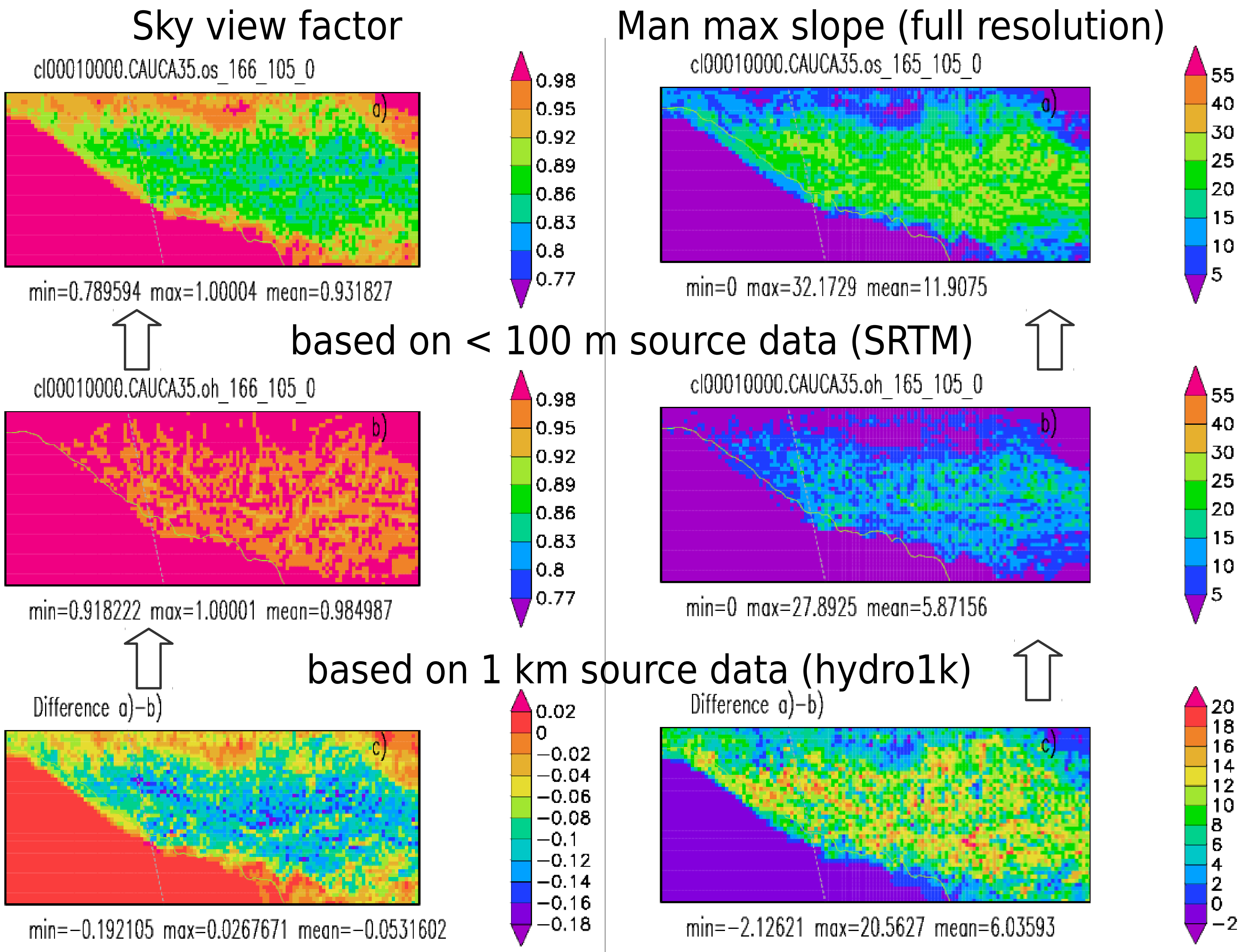
hircau1
- all oroparametrizations, old hydro1k parametres

hircau2
- all oroparametrizations, SRTM with 3deltax smoothing for dynamics

hircau3
- all oroparametrizations, SRTM with 1deltax smoothing for dynamics



Elevation 3deltax
Elevation 1deltax
cl00010000.CAUCA35.os_6_105_0
cl00010000.CAUCA35.os_7_105_0
min=0.0155543 max=3966.78 mean=1018.03
min=-0.198946 max=4617.23 mean=1018.77
based on < 100 m source data (SRTM)
cl00010000.CAUCA35.oh_6_105_0
cl00010000.CAUCA35.oh_7_105_0
min=0.0102783 max=3977.69 mean=1026.33
min=-0.00159276 max=4822.48 mean=1027.95
based on 1 km source data (hydro1k)
Difference a)-b)
Difference a)-b)
min=-190.617 max=177.681 mean=-8.30008
min=-480.625 max=432.932 mean=-9.1765



Sky view factor
Man max slope (full resolution)
cl00010000.CAUCA35.os_166_105_0
a)
min=0.789594 max=1.00004 mean=0.931827
0.98
0.95
0.92
0.89
0.86
0.83
0.8
0.77
cl00010000.CAUCA35.os_165_105_0
a)
min=0 max=32.1729 mean=11.9075
55
40
30
25
20
15
10
5
based on < 100 m source data (SRTM)
cl00010000.CAUCA35.oh_166_105_0
b)
min=0.918222 max=1.00001 mean=0.984987
cl00010000.CAUCA35.oh_165_105_0
b)
min=0 max=27.8925 mean=5.87156
based on 1 km source data (hydro1k)
Difference a)-b)
c)
min=-0.192105 max=0.0267671 mean=-0.0531602
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
Difference a)-b)
c)
min=-2.12621 max=20.5627 mean=6.03593
20
18
16
14
12
10
8
6
4
2
0
-2

Ten-metre wind speed contingency table

3.5km resolutionHIRLAM

over Caucasian mountains in January 2012

Contingency table for U10m (m/s)
Selection: ALL 55 stations
Period: 20130101-20130131
Used {00,12} + 12 18 24
Limits 1.500000000 3.299999952 5.500000000 8.000000000 10.80000019 13.89999962 24.50000000
Each class is data <= limit, the very last > last limit
Total number of values 9047

No orographic parametrizations (HIRLAM ref.run) — 3024

	OBSERVATION								
	1731	593	100	25	0	1	1	0	2451
	1776	1271	314	107	12	5	3	0	3488
	390	864	360	156	27	10	8	0	1815
hircau0	90	255	249	184	40	23	11	0	852
	14	69	101	121	43	20	9	0	377
	0	6	8	19	14	8	5	0	60
	0	0	0	1	3	0	0	0	4
	0	0	0	0	0	0	0	0	0
SUM	4001	3058	1132	613	139	67	37	0	9047

SRTM, more smoothing (k=3) — 3645

	OBSERVATION								
	2130	1000	281	86	14	8	12	0	3531
	1484	1022	246	103	6	2	1	0	2864
	326	779	297	163	34	8	9	0	1616
hircau2	50	200	213	145	27	15	6	0	656
	10	49	75	80	39	20	5	0	278
	1	7	16	22	12	12	4	0	74
	0	1	4	14	7	2	0	0	28
	0	0	0	0	0	0	0	0	0
SUM	4001	3058	1132	613	139	67	37	0	9047

SRTM, less smoothing (k=1)

	OBSERVATION								
	2106	991	268	88	13	8	10	0	3484
	1479	1033	263	99	16	2	2	0	2894
	356	764	290	159	27	7	8	0	1611
hircau3	50	215	214	147	27	17	7	0	677
	10	46	79	89	36	16	6	0	282
	0	8	14	21	12	15	4	0	74
	0	1	4	10	8	2	0	0	25
	0	0	0	0	0	0	0	0	0
SUM	4001	3058	1132	613	139	67	37	0	9047

HIRLAM experiments over Caucasia

Very first conclusions

Some orographic parametrizations are needed both for radiation and momentum fluxes

•

Try to resolve as much with dynamics and smooth as little as possible

•

Derivation of oroparameters from the fine-resolution SRTM sources is useful especially for the radiation parametrizations

•

The methods and data from HIRLAM are available for HARMONIE and other models for application and further development

Experiments

hircau0
– reference HIRLAM, but no oroparametrizations

hircau1
- all oroparametrizations, old hydro1k parametres

hircau2
- all oroparametrizations, SRTM with 3deltax smoothing for dynamics

hircau3
- all oroparametrizations, SRTM with 1deltax smoothing for dynamics

PERTURBING THE OROGRAPHY?

... from the Midsummer discussions in the SRNWP EPS WS in Madrid, 2013:

3. Are there untouchables, e.g. perturbing orography, gravity constant or other fundamentally known functions?
   - Do not touch what makes our planet's atmosphere what it is (Ω, g, R (not R_d alone though, of course), L_v/s, c_p)
   - Orography can be seen from two sides:
     - For the resolved (dynamical) part it may be changed but in a multi-model spirit (not randomly, so to say)
     - For the sub-grid and residual (physical) part, perturbing parameterisation input (variance, z_0, …) should be preferable to touching the resolved part. Neva can repeat her tests and see the differences/convergences, this will be instructive.

PERTURBING THE OROGRAPHY?

We know the details of orography far better than we are presently able to use: let us not disturb the true information but try to apply it in the models, instead of making virtue of our present ignorance

- In the atmosphere – orography interactions there are two partners: a different (perturbed in any way) air flow over the same mountains leads to different weather, even without perturbing the elevation of the Earth's surface

- We can make conscious choices: how much to resolve, what to parametrize, how to handle the effects due to the different scales of orography - there is a need to understand more, plenty of space for sensitivity studies and alternative solutions which could benefit also EPS developments

A CAUCASIAN TESTBED?

Semi-finished source data, based on SRTM, are available: elevation, smoothed elevation, slopes ...

- Methods for calculation and aggregation of orographic variables into model resolution grids exist for HIRLAM, could be tried and developed further in other models
- There is a need, possibilities and ongoing activities for mesoscale model studies over the Caucasian area related to the winter Olympic games 2014
- Perhaps we could launch a cross-consortium mountain group (within the SRNWP Surface Expert Team?), to plan Caucasian orographic experiments and comparisons?


Thank you!