Radiation and orography in weather models

Laura Rontu

ILMATIETEEN LAITOS

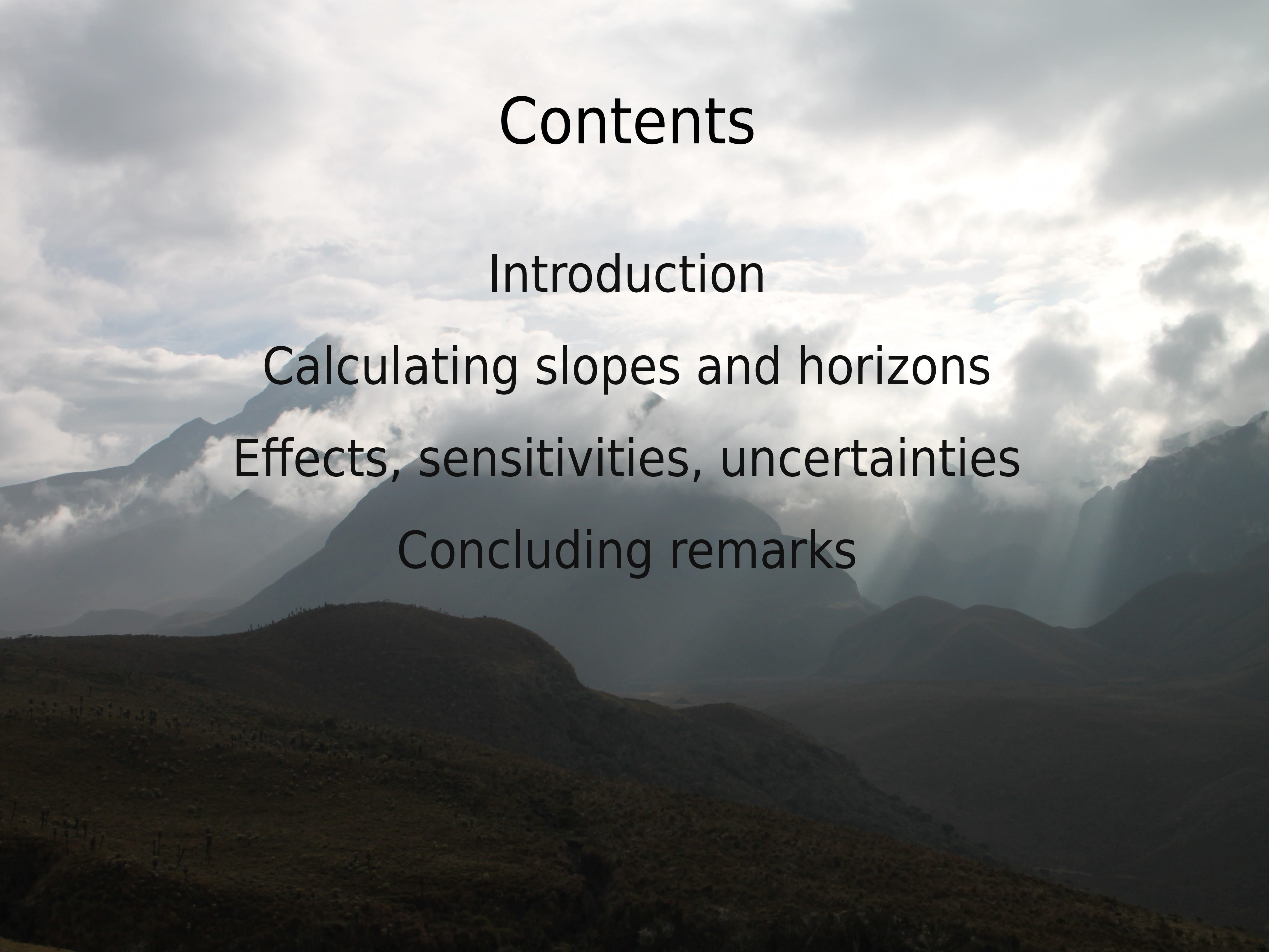
with thanks to

Alexandre Mary Clemens Wastl

Yann Seity Anastasia Senkova

Workshop on Radiation in the Next Generation of Weather Forecast Models

21 - 24 May 2018, ECMWF, Reading, U.K.



Contents

Introduction

Calculating slopes and horizons

Effects, sensitivities, uncertainties

Concluding remarks

Slope, terrain shadow and sky view effects on short- and longwave radiation at the surface

1) influence on atmospheric radiation transfer

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

2) influence on the surface energy balance

$LE + H + SW_{net} + LW_{net} + G$

Parametrization of the radiative transfer

Solar (SW) radiation: scattering and absorption
Terrestrial (LW) radiation: emission, absoption, scattering

Physico-chemical properties:
Mass concentration
Size
Shape
Composition

In the air:
Gas molecules
Cloud droplets and crystals
Aerosol particles

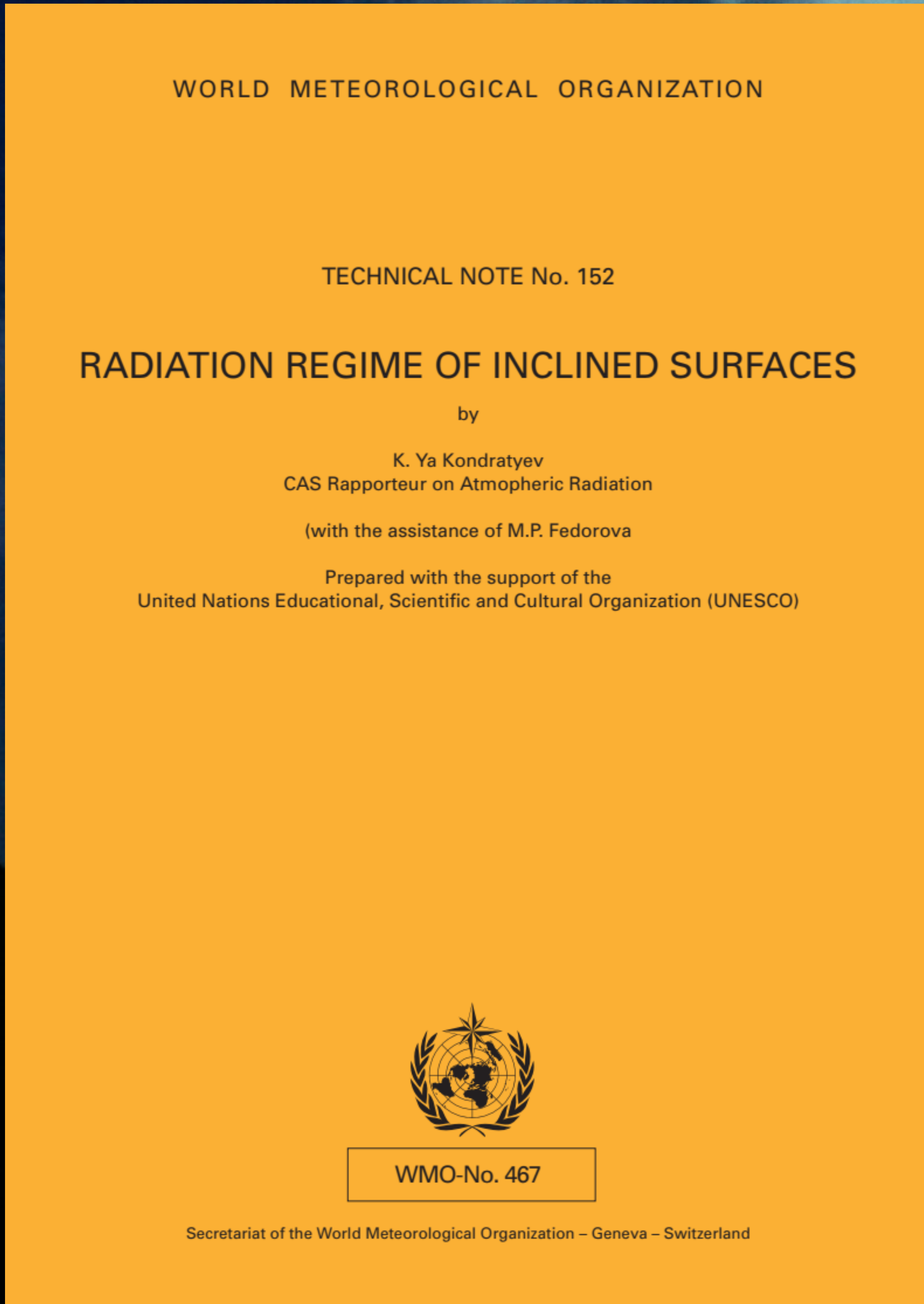
Grid-scale variables:
T, qv, qi, ql, qs, qg
Aerosol (concentration)
Radiative fluxes

Optical properties:
Optical depth
Single scattering albedo
Asymmetry factor

Surface-atmosphere radiative interactions

Surface albedo and emissivity
Orographic radiation effects

Characteristics of surface types
Surface elevation


WORLD METEOROLOGICAL ORGANIZATION

TECHNICAL NOTE No. 152

RADIATION REGIME OF INCLINED SURFACES

by

K. Ya Kondratyev
CAS Rapporteur on Atmopheric Radiation

(with the assistance of M.P. Fedorova

Prepared with the support of the
United Nations Educational, Scientific and Cultural Organization (UNESCO)

WMO-No. 467

Secretariat of the World Meteorological Organization – Geneva – Switzerland

Starting point: The early review by Kondratyev, 1977

NWP applications by

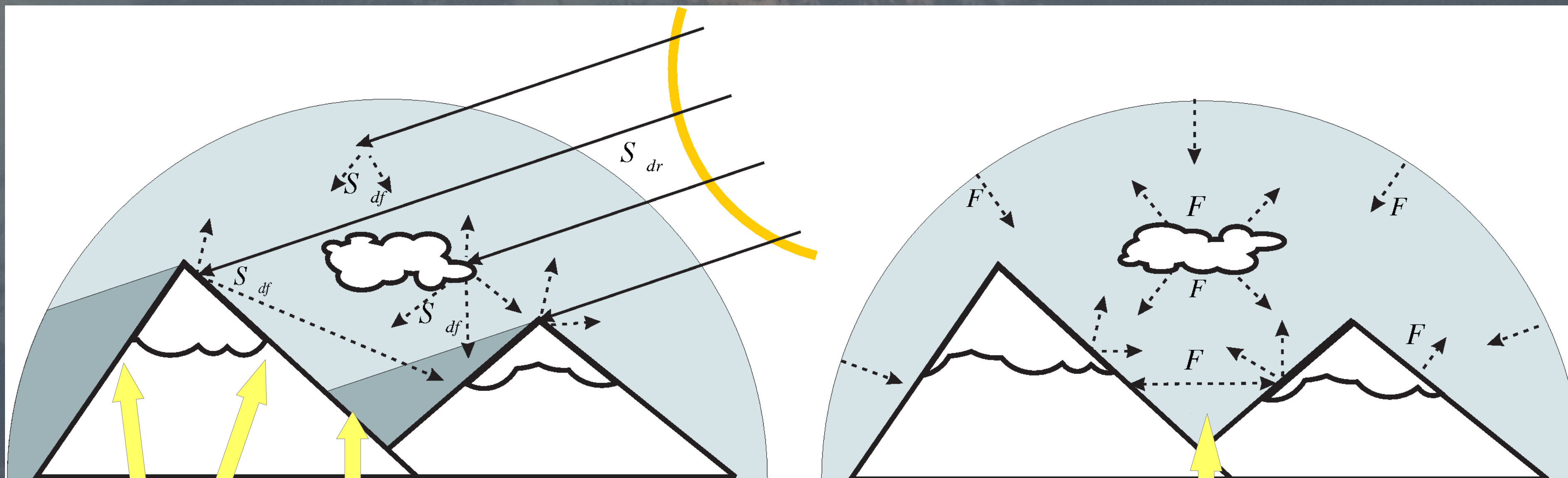
Müller, M. D., and D. Scherer (2005) 10.1175/MWR2927.1

Senkova, A. V., L. Rontu, and H. Savijärvi (2007) doi:10.1111/j.1600-0870.2007.00235.x

Helbig, N., and H. Löwe (2012) doi:10.1029/2011JD016465

Manners, J., S. B. Vosper, and N. Roberts (2012) doi:10.1002/qj.956

Rontu, L., C. Wastl and S. Niemelä (2014), doi: 10.3389/feart.2016.00013



slope shadow

sky view effects

Trigonometry ...

but how to describe the subgrid-scale orography properties in a NWP model grid?

Principles

1. Average the fluxes, not orography

e.g. net SW radiation

$$S_{\text{net}} = [\delta_{sl}\delta_{sh} - \alpha\delta_{sv}\sin(h_s)]S_{\downarrow dr,0} + [(1-\alpha)\delta_{sv}]S_{\downarrow df,0}.$$

- small-scale orography features have been condensed to grid-scale slope, shadow and sky view factors

How to derive them optimally for NWP?

Variables

Table 1. Orography-related parameters within grid resolution

parameter	description	unit	usage	remarks
$H_{\Delta x}$	mean surface elevation	m	dynamics	smoothed
σ_{sso}	subgrid-scale scale standard deviation	m	momentum	
s_{sso}	mean subgrid-scale slope angle	rad	not applied	eigenvalue of gradient correlation tensor
$h_{m,i}$	slope angle in direction i	rad	radiation	
f_i	fraction of slope in direction i	-	radiation	
$h_{h,i}$	local horizon in direction i	rad	radiation	
δ_{sv}	sky view factor	-	radiation	derived, runtime
δ_{sl}	slope factor	-	radiation	derived, runtime
δ_{sh}	shadow factor	-	radiation	derived, runtime

Variables

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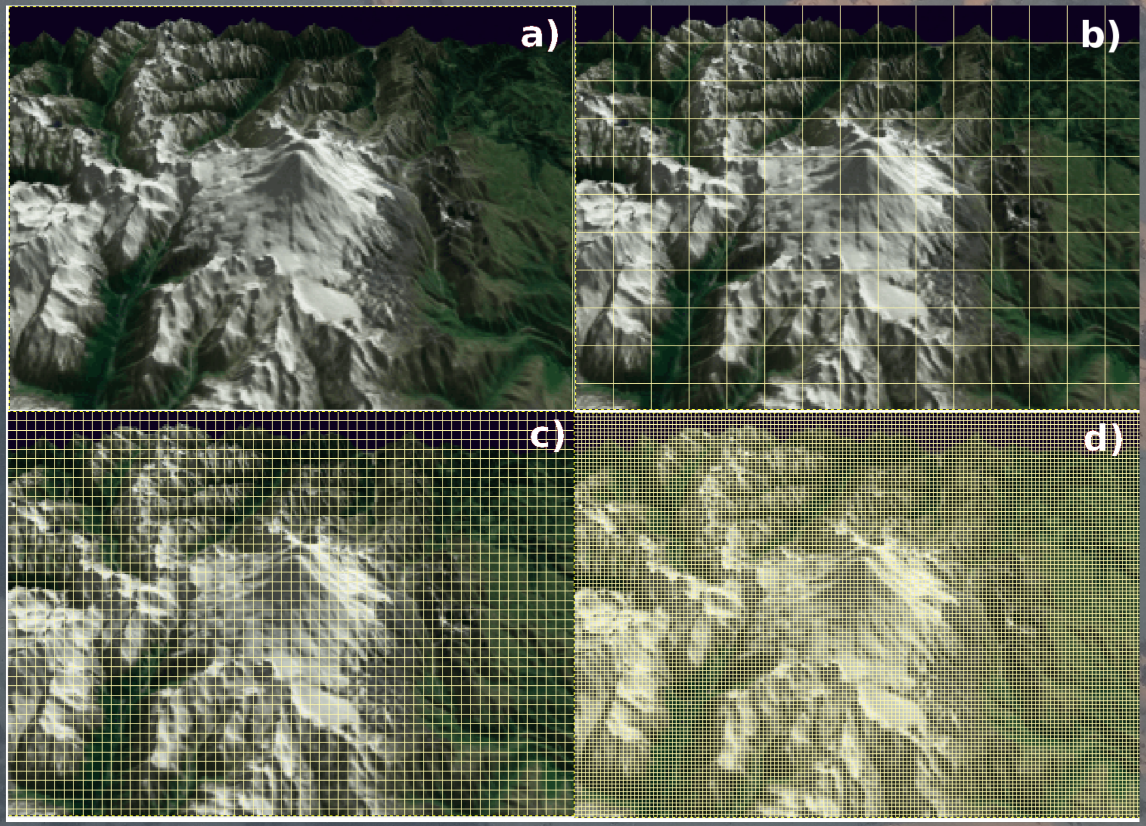
δ_{sl}	slope factor	-	radiation	derived, runtime
δ_{sh}	shadow factor	-	radiation	derived, runtime

nonlocal!

Principles

2. Mind the physics of scales



Grid-scale
> Subgrid-scale
< Supergrid-scale

Scale of the surface elevation source data
<< Grid-scale

We know a lot of details - how to do statistics for the parametrizations?

Subgrid-scale orography >
vegetation/urban canopy scale (trees and buildings on slopes)

Principles

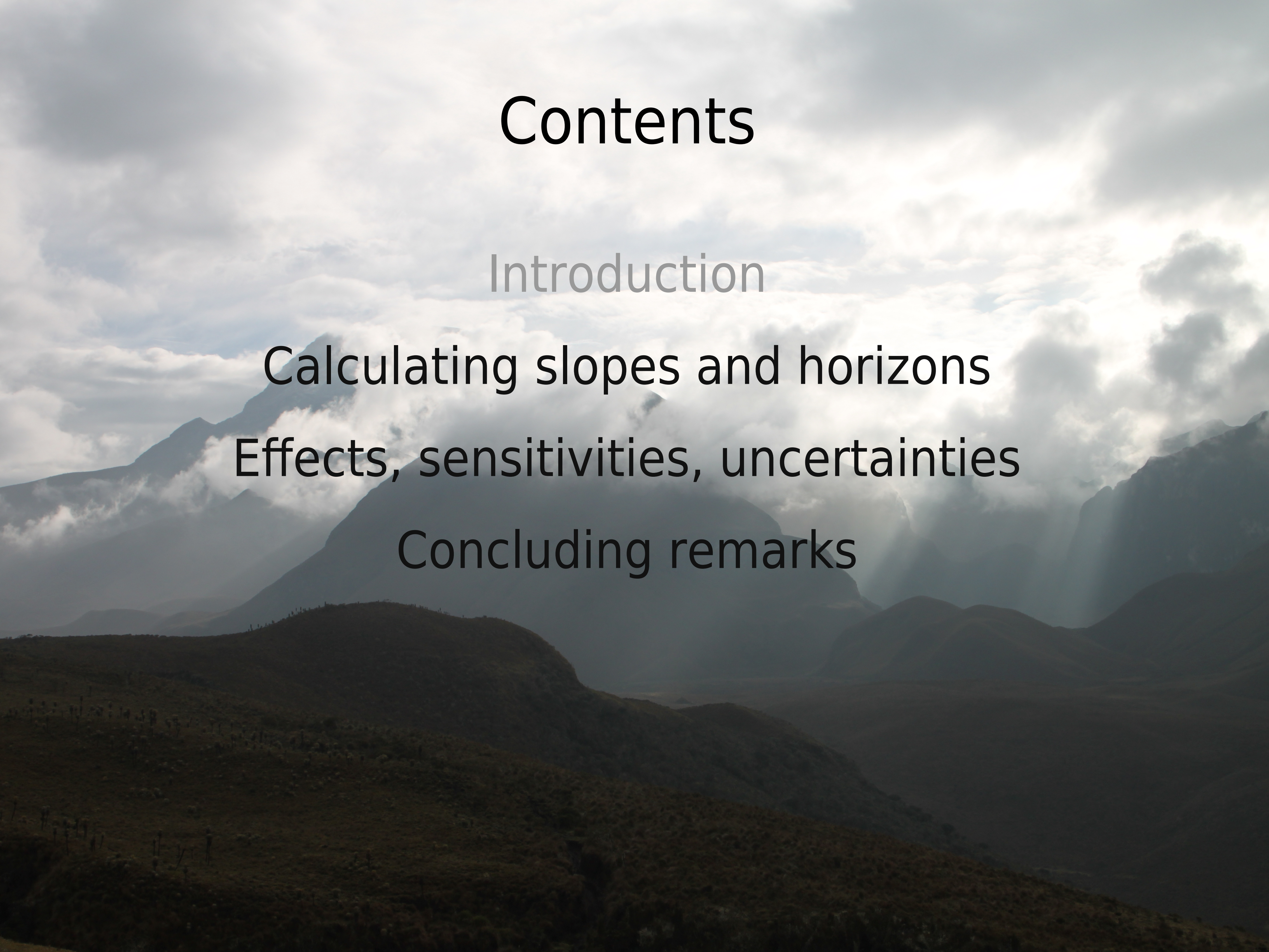
3. KISS: keep it simple, stupid

Integrated into the NWP model in runtime?

How much do the surface-radiation interactions influence the forecast via atmospheric radiative transfer and surface energy balance?

Local effects via postprocessing?

What can be preprocessed?



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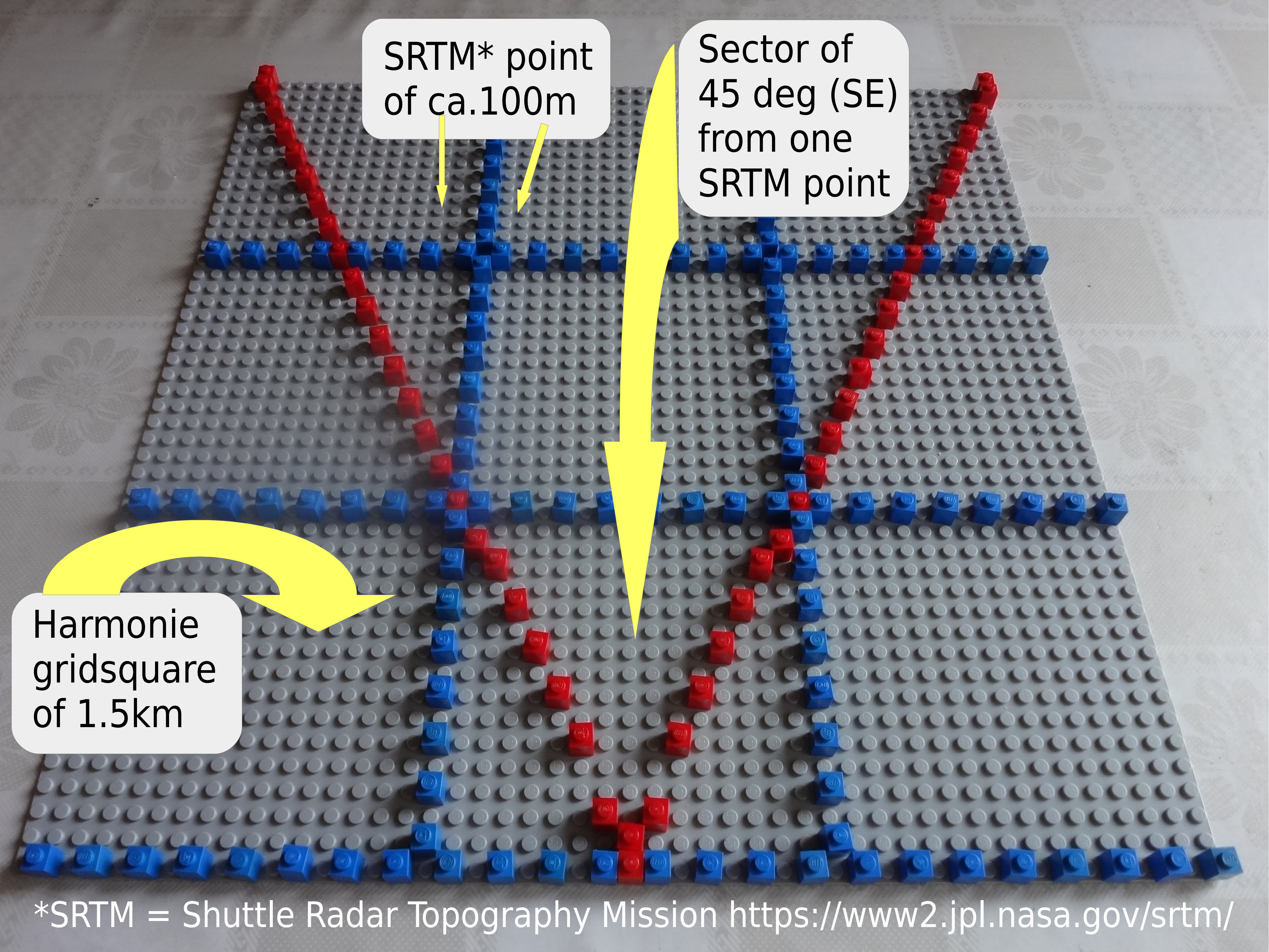
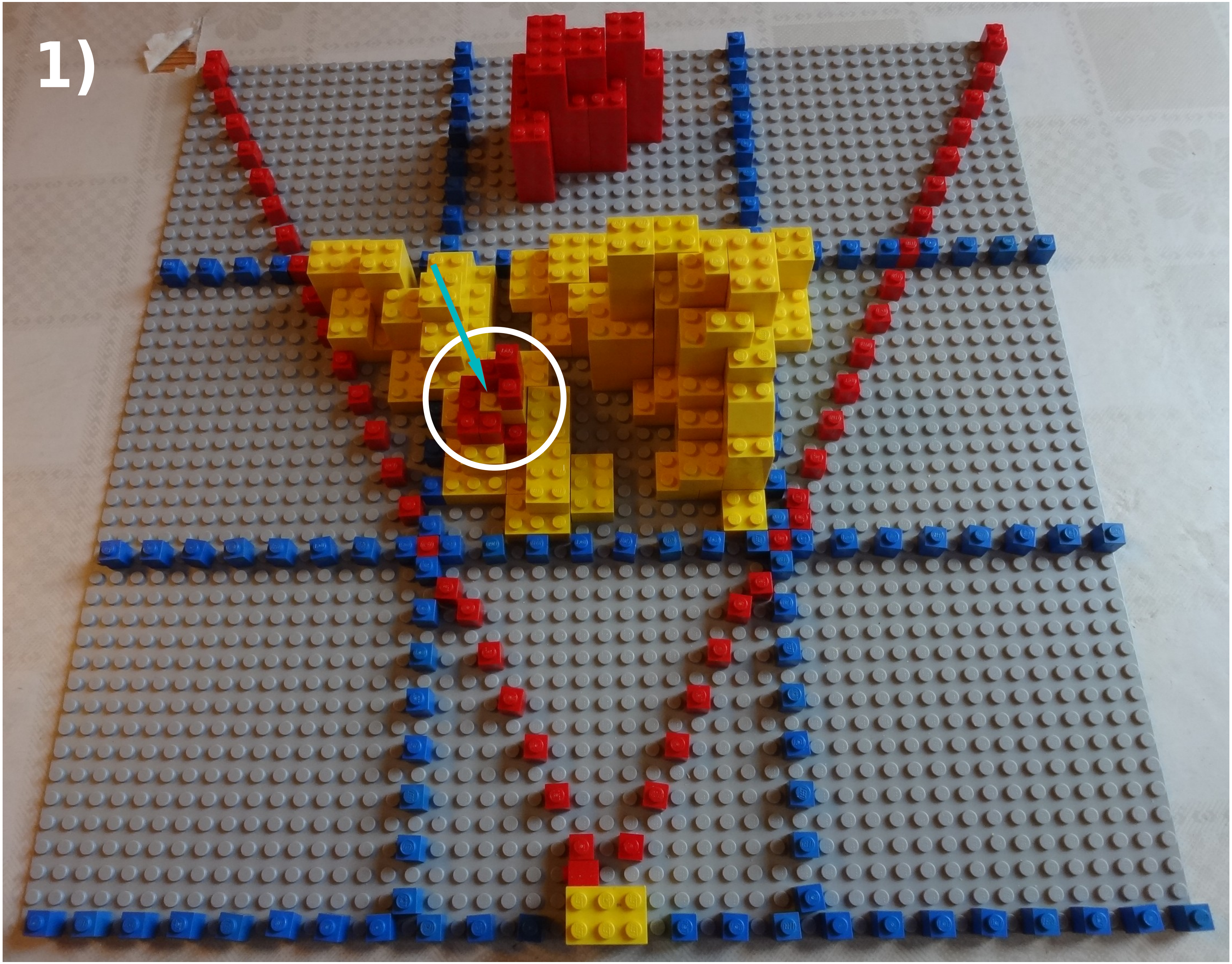


SRTM* point
of ca.100m
Sector of
45 deg (SE)
from one
SRTM point
Harmonie
gridsquare
of 1.5km
*SRTM = Shuttle Radar Topography Mission https://www2.jpl.nasa.gov/srtm/

Slopes for each SRTM point, statistics for each gridsquare

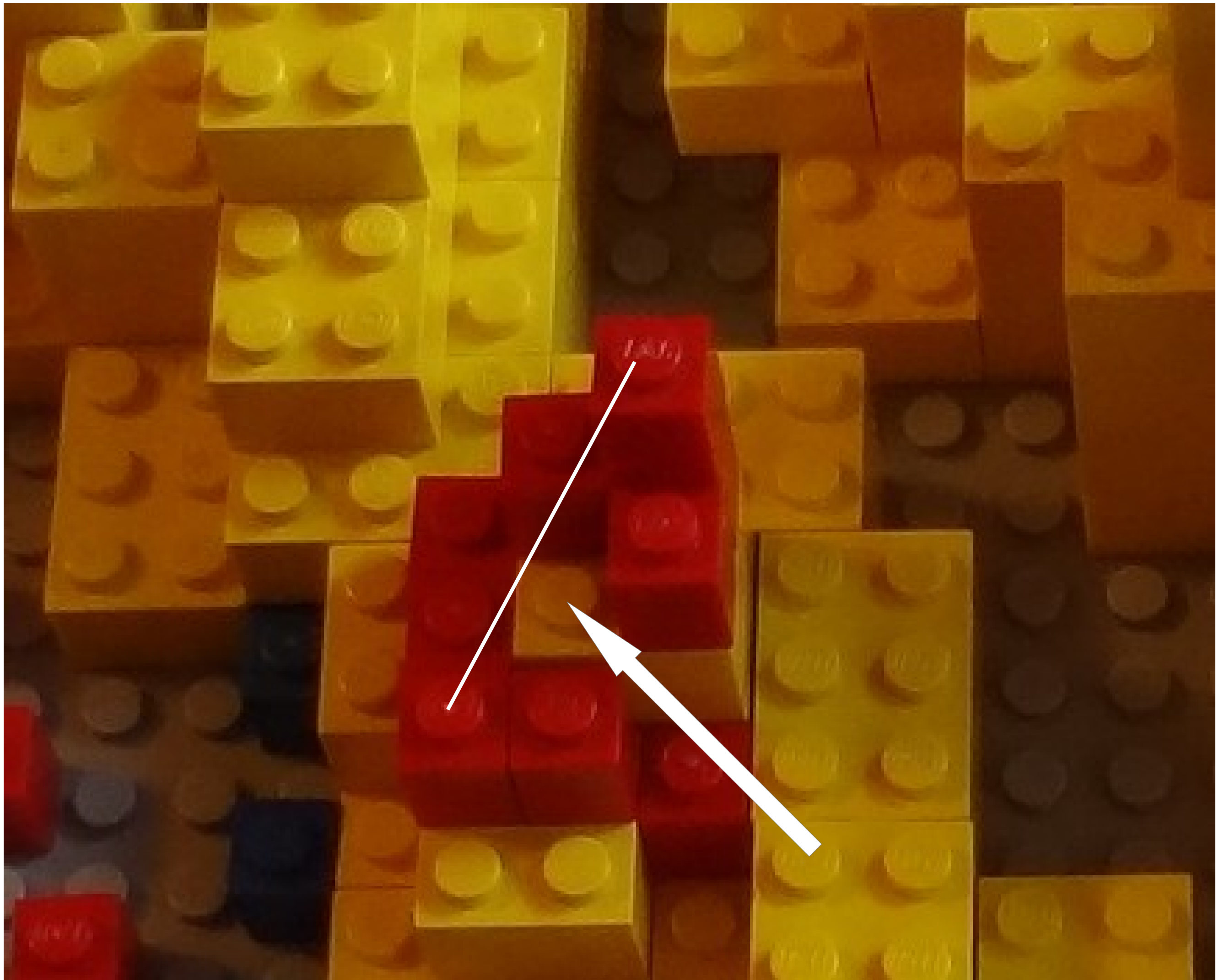


Calculations for each SRTM point, statistics for each gridsquare

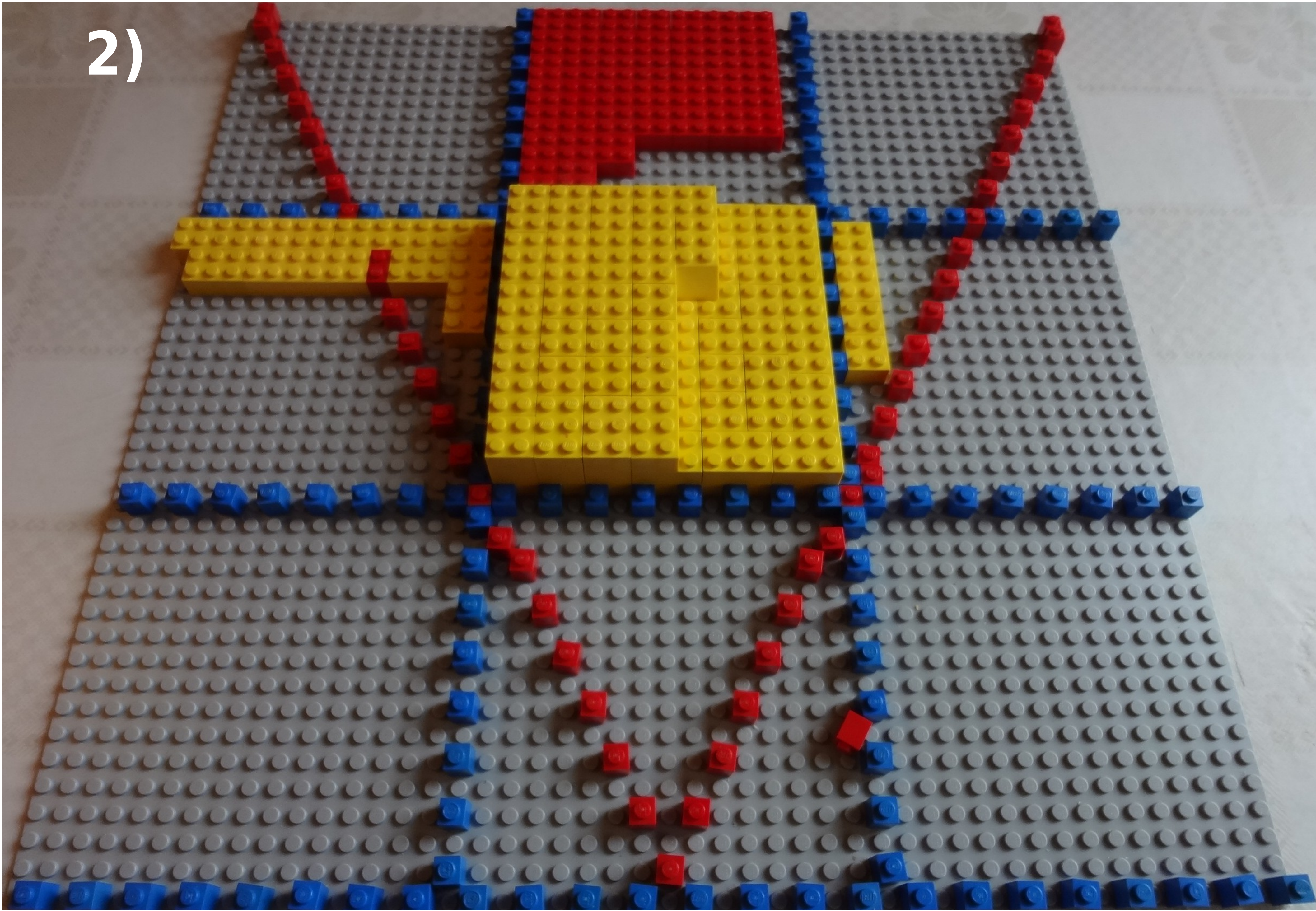
Maximum slope among 8 neighbours for each SRTM point:

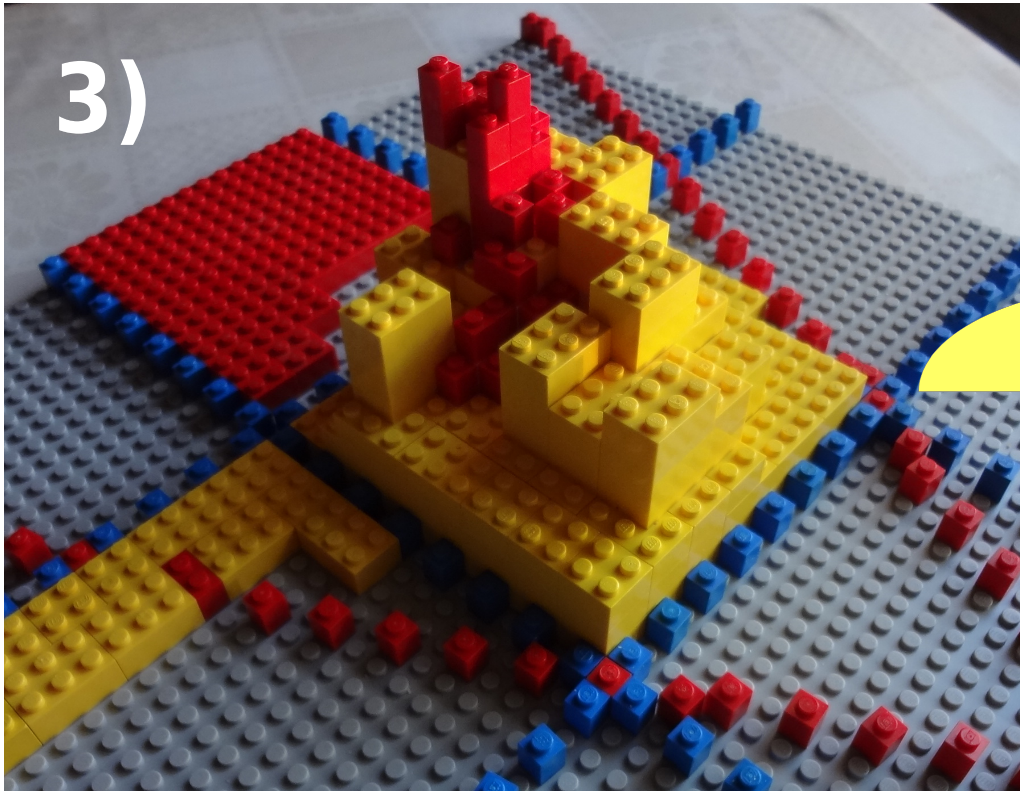
- slope direction → pick to own direction sector (e.g. SE) within each gridsquare

- slope angle → calculate mean maximum slope of each sector within gridsquare



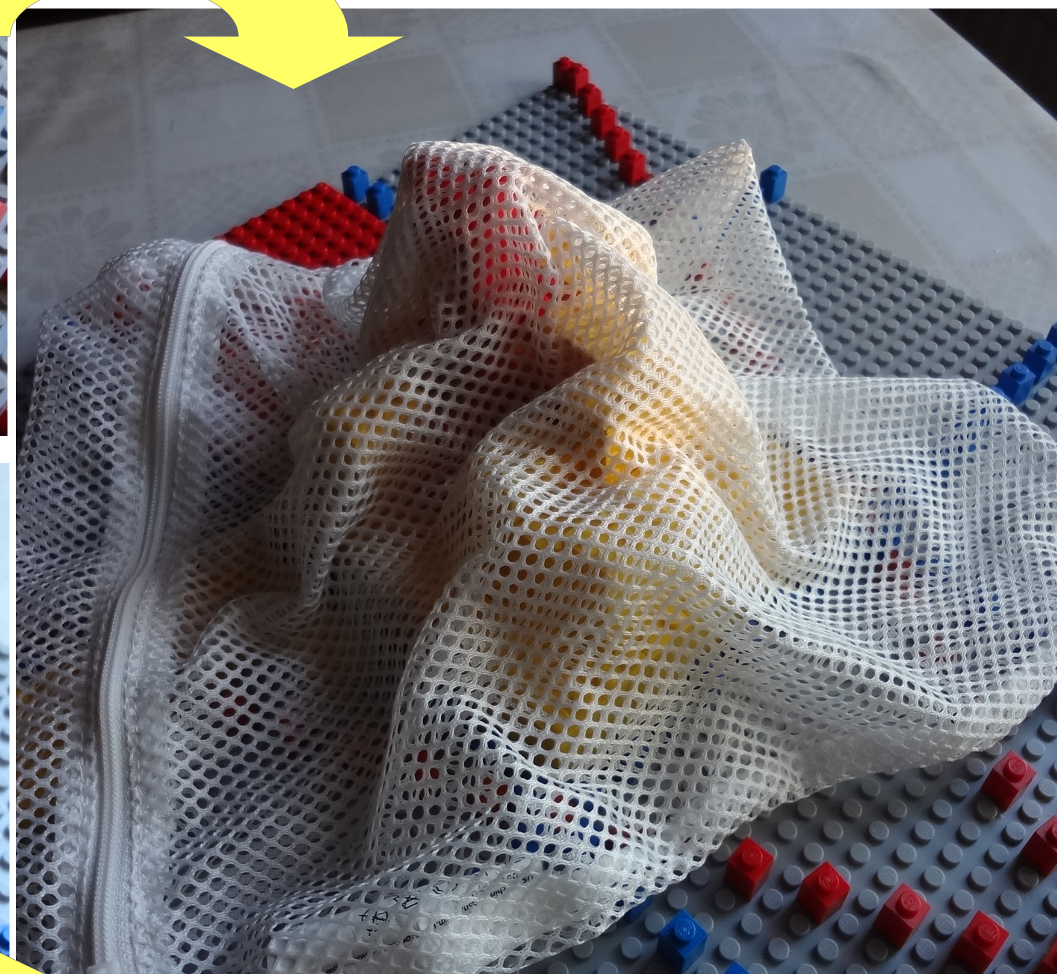
Using gridsquare average *h* results in a different variable, explicit slope

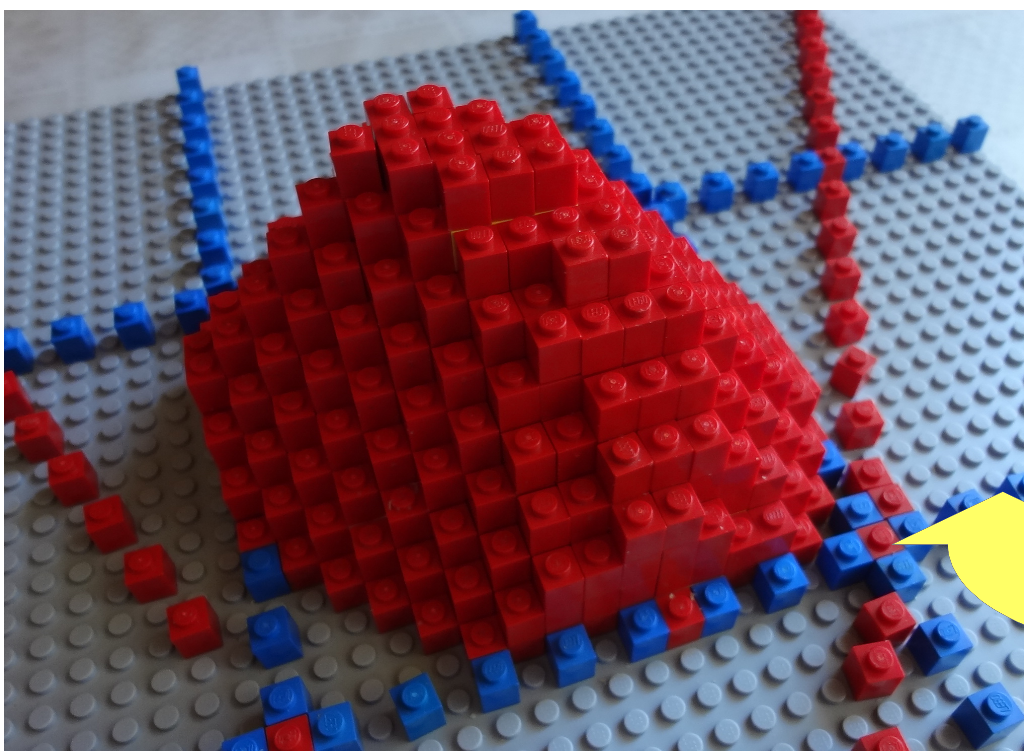




Orography gradient correlation tensor

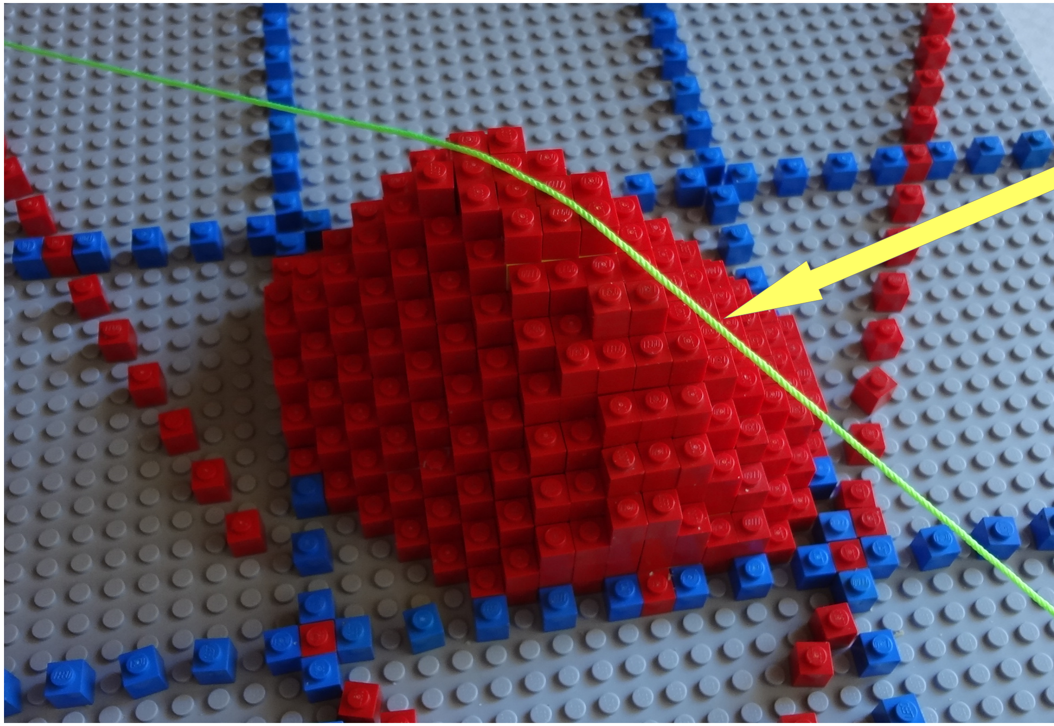
$$H_{ij} = \overline{\frac{\partial h}{\partial x_i}\frac{\partial h}{\partial x_j}}$$



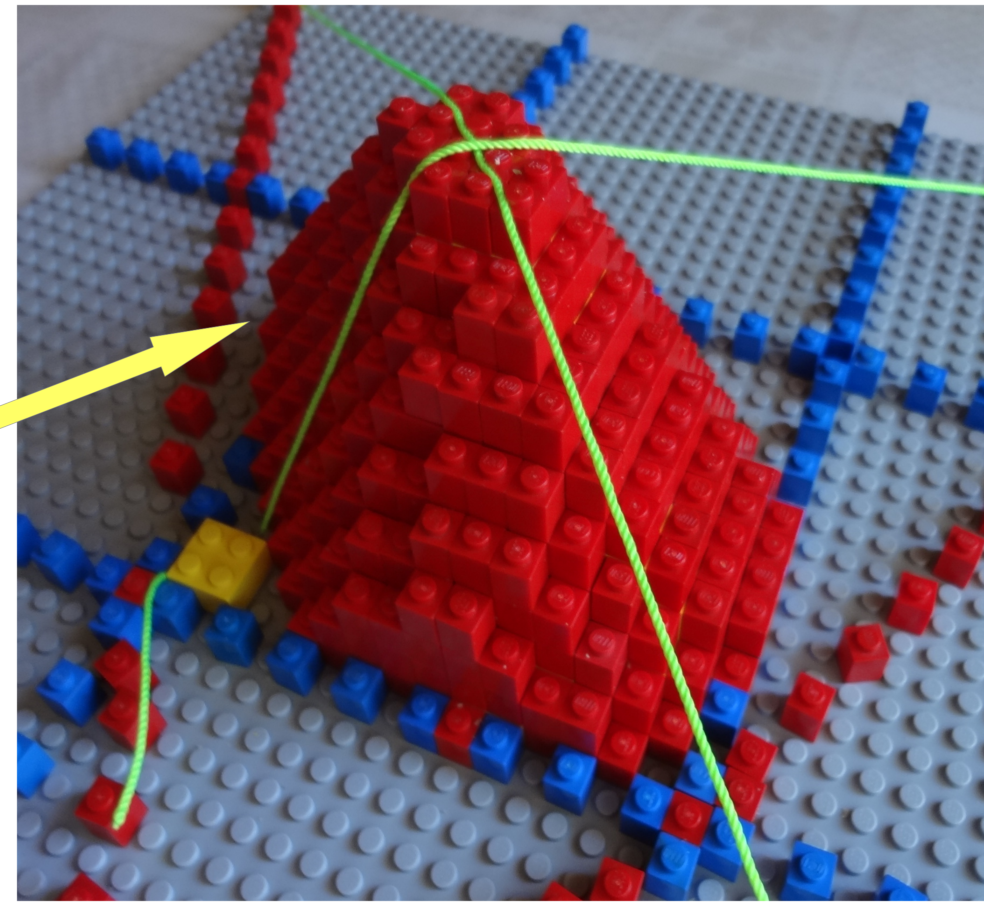


ellipsoid within each gridsquare

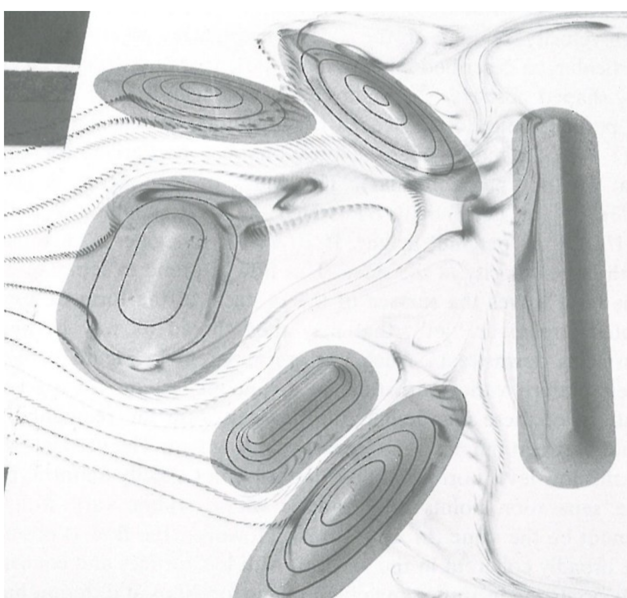
Eigenvalues of the tensor

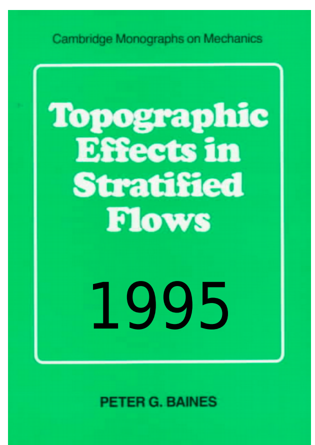


Principal axis → direction with respect to model grid

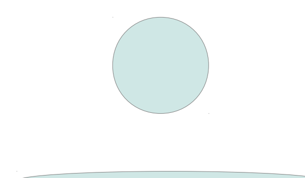


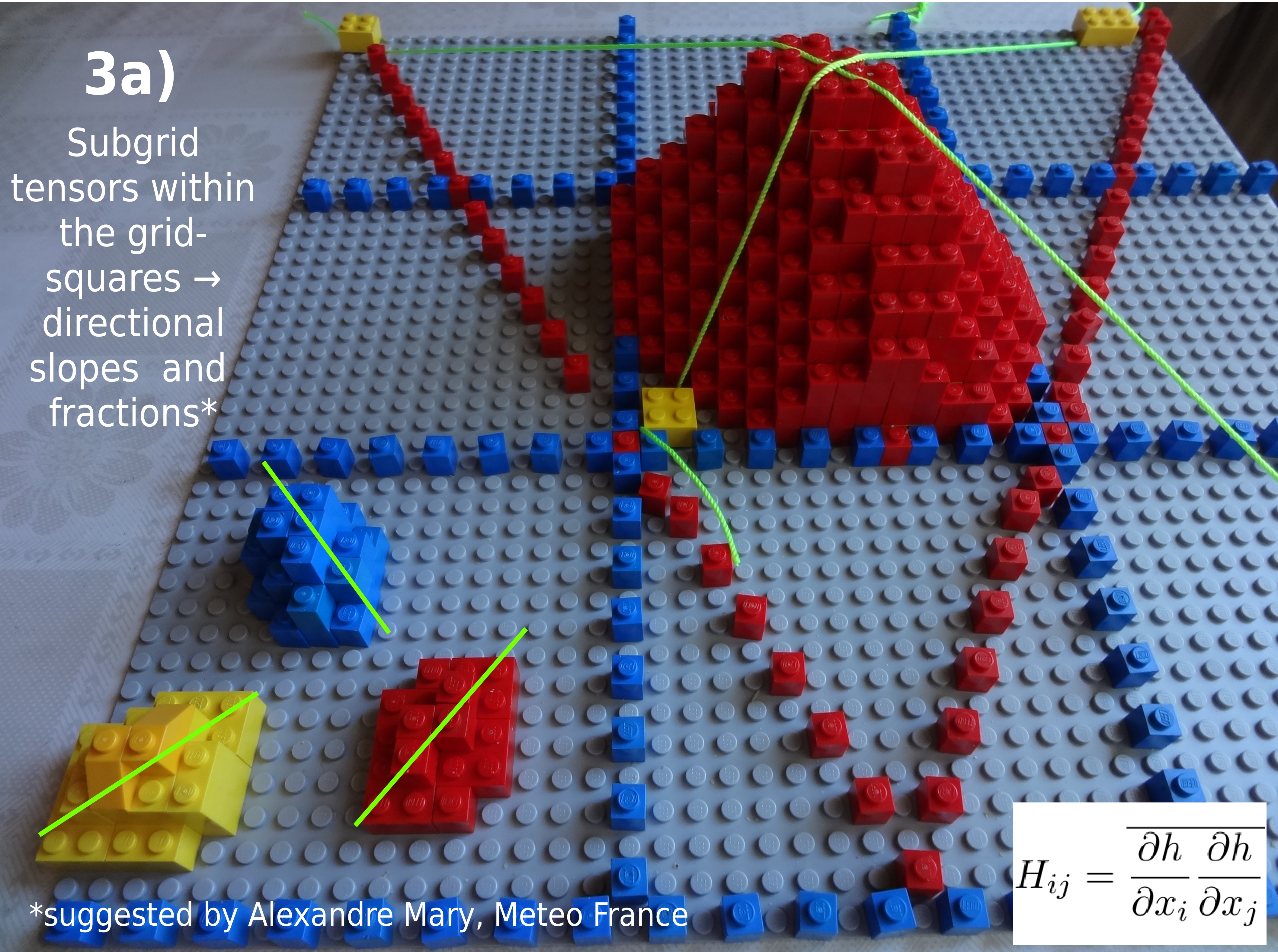
Mean subgrid-scale slope

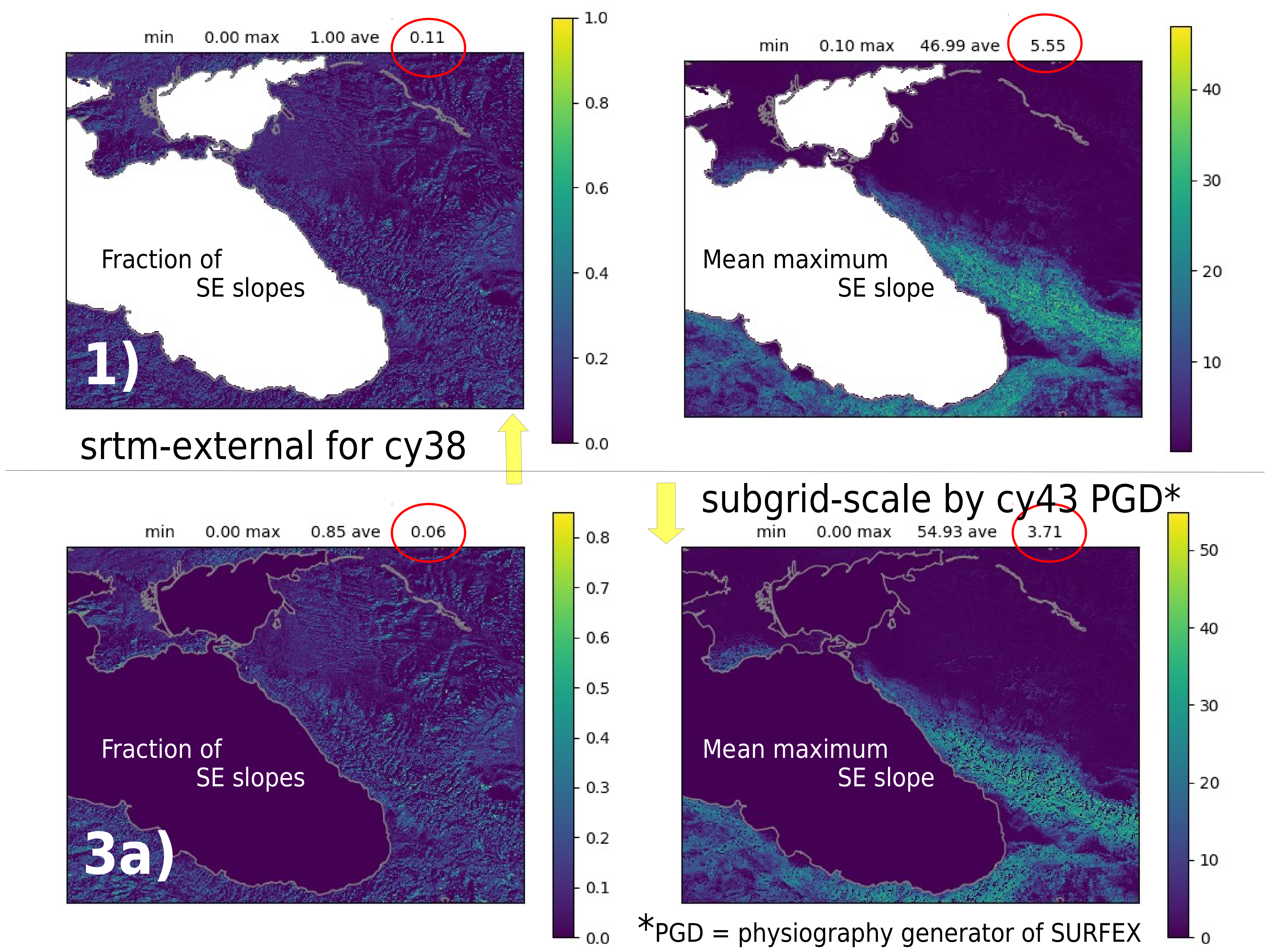


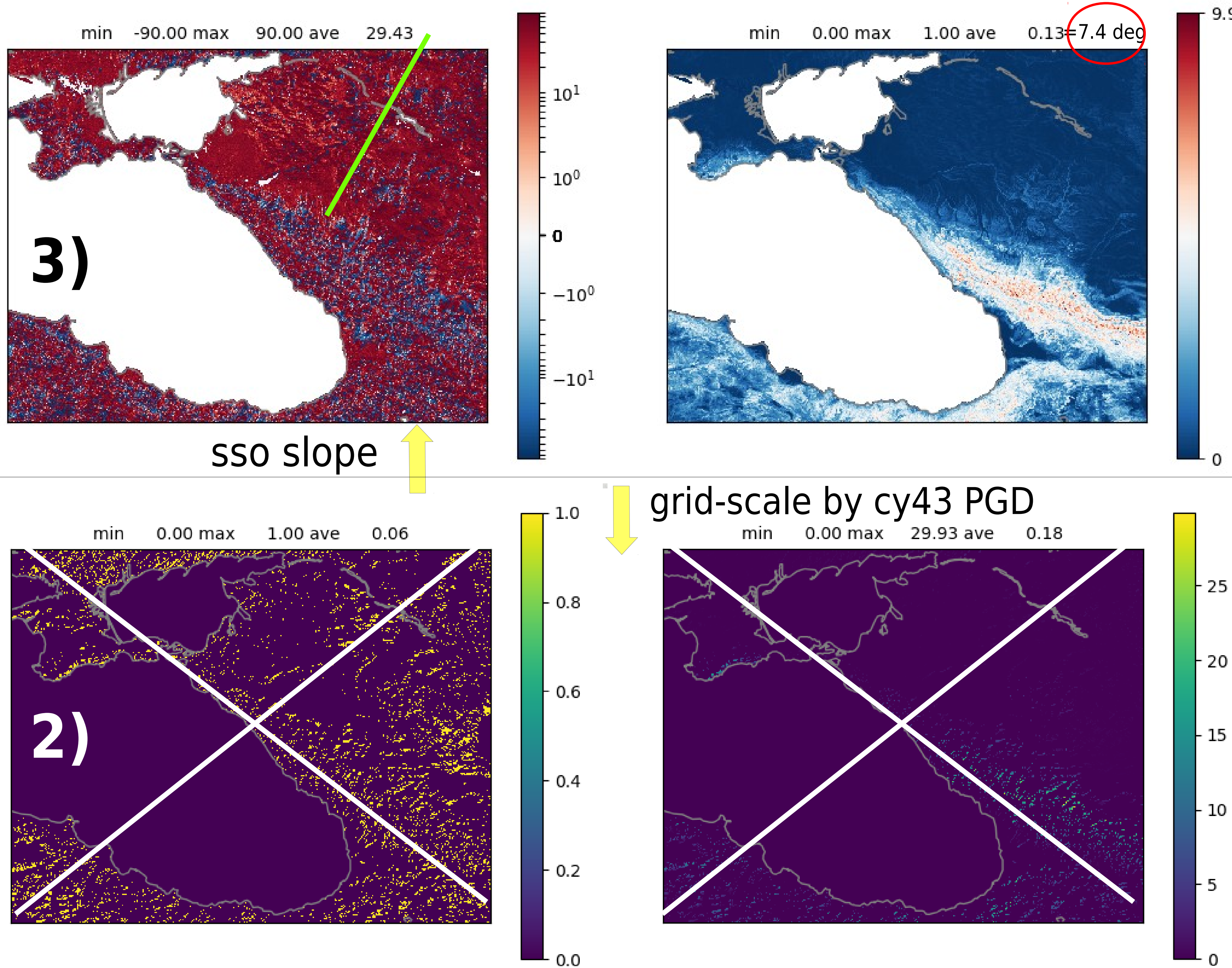


Asymmetry factor (form of the ellipsoid)

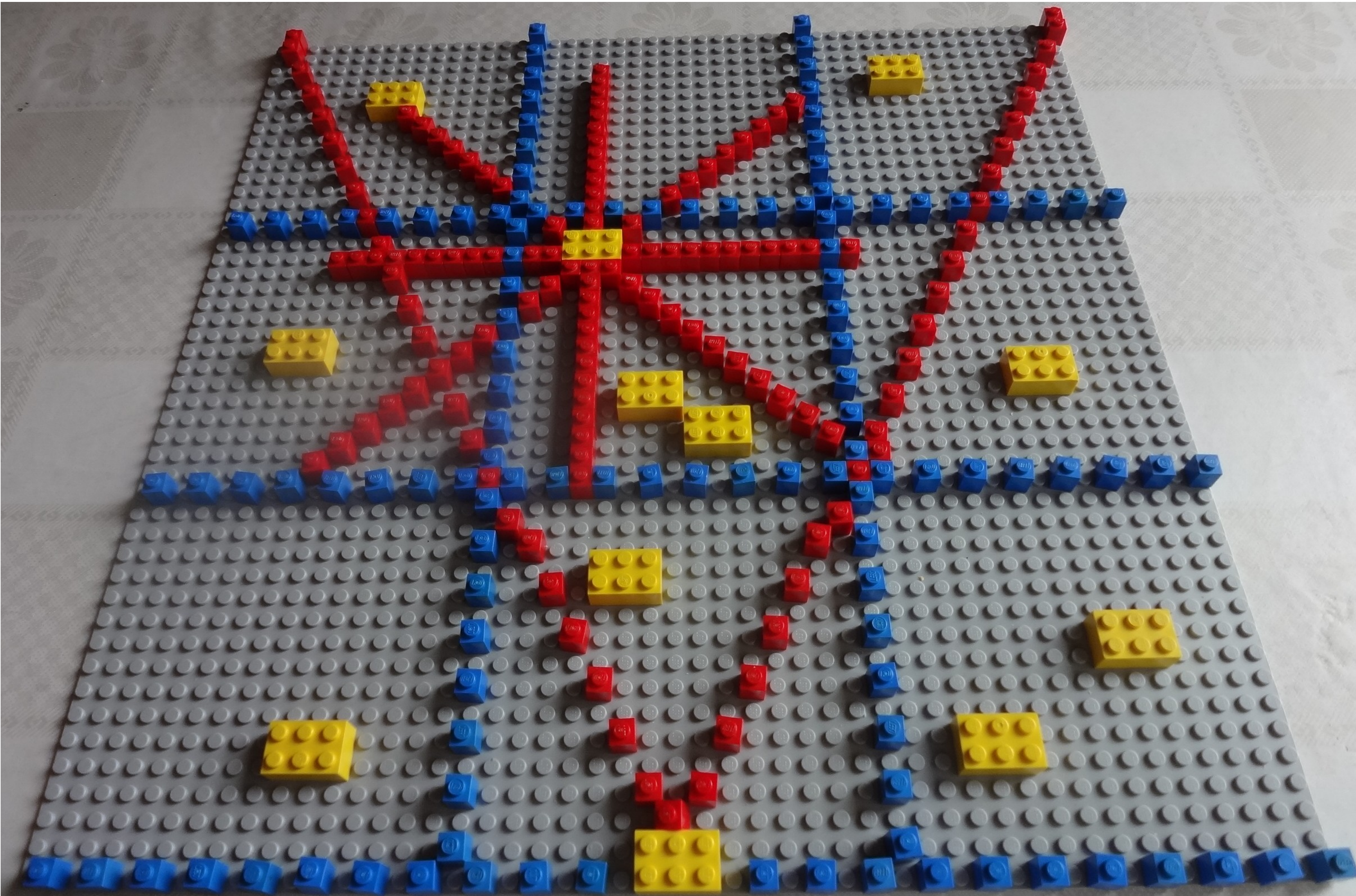



3a)
Subgrid tensors within the grid-squares → directional slopes and fractions*
*suggested by Alexandre Mary, Meteo France
$H_{ij} = \overline{\frac{\partial h}{\partial x_i}\frac{\partial h}{\partial x_j}}$

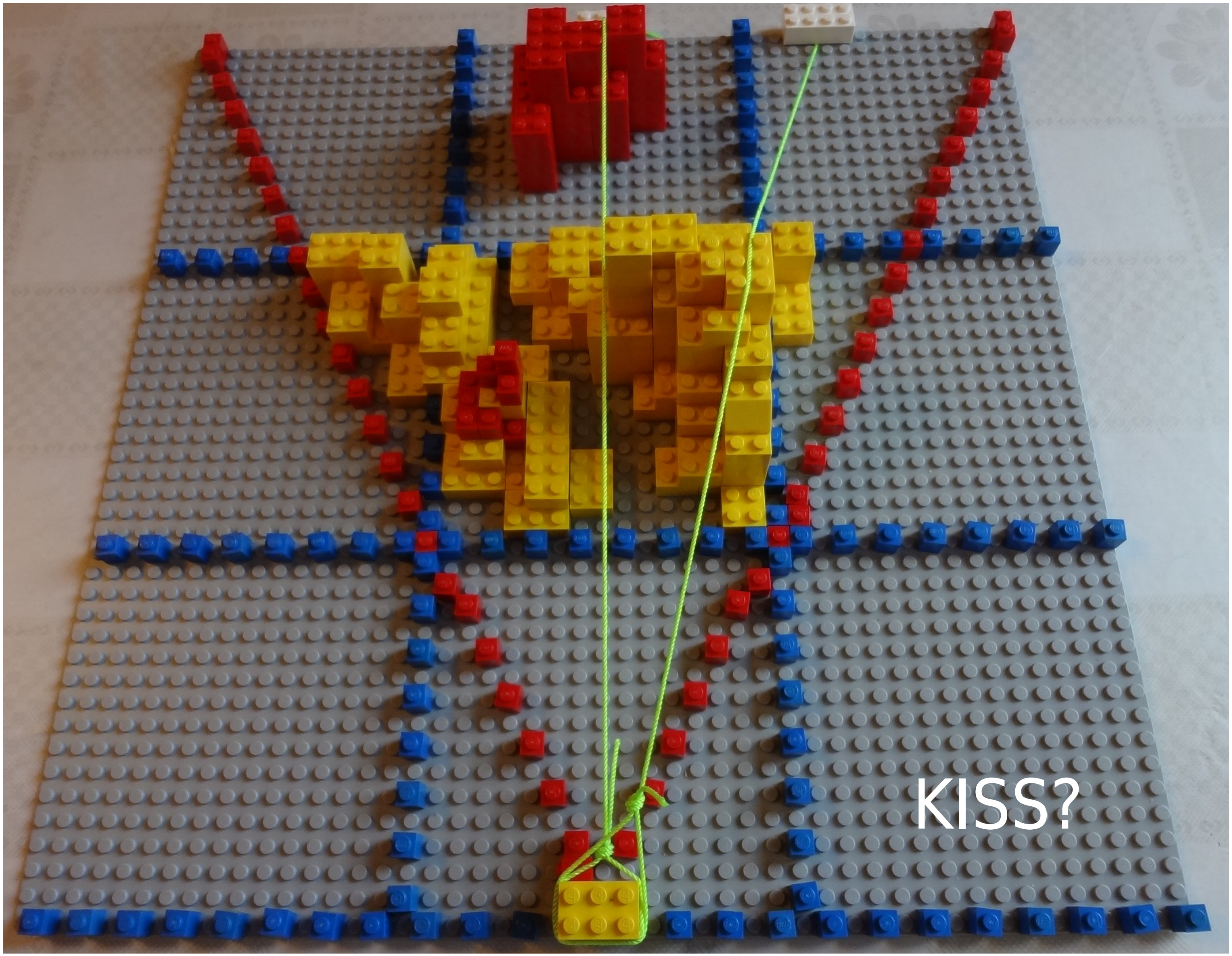

min 0.00 max 1.00 ave 0.11
Fraction of SE slopes
1)
min 0.10 max 46.99 ave 5.55
Mean maximum SE slope
srtm-external for cy38
subgrid-scale by cy43 PGD*
min 0.00 max 0.85 ave 0.06
Fraction of SE slopes
3a)
min 0.00 max 54.93 ave 3.71
Mean maximum SE slope
*PGD = physiography generator of SURFEX


min -90.00 max 90.00 ave 29.43
3)
10^1
10^0
0
-10^0
-10^1
sso slope
min 0.00 max 1.00 ave 0.13=7.4 deg
9.9
0
grid-scale by cy43 PGD
min 0.00 max 1.00 ave 0.06
2)
1.0
0.8
0.6
0.4
0.2
0.0
min 0.00 max 29.93 ave 0.18
25
20
15
10
5
0

Calculation of local horizon around each SRTM point, statistics for each gridsquare



Calculation of local horizon angle around each SRTM point by scanning one-degree direction angles in 8 sectors. Statistics for grid-scale sky-view and shadow factors

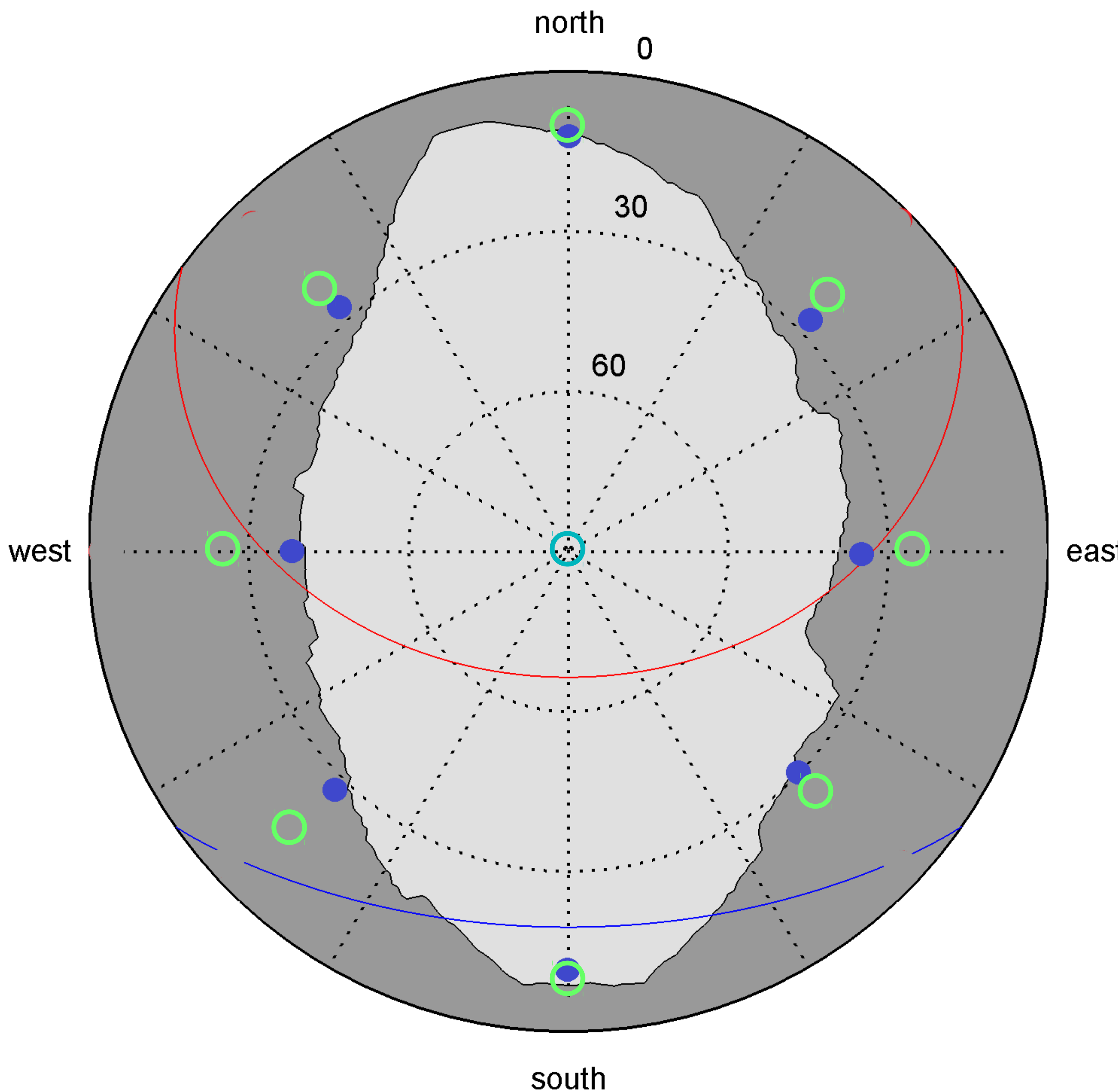


Result: local horizon around each SRTM point

Observed horizon (grey shaded area) and calculated local horizon angles (blue dots and green circles) around the Alpine station St. Leonhard/Pitztal, Austria.

Blue dots are in SRTM grid, green circles estimated for NWP gridpoint (2500m)

Red and blue lines show the path of the sun at the winter (blue) and summer (red) solstice.



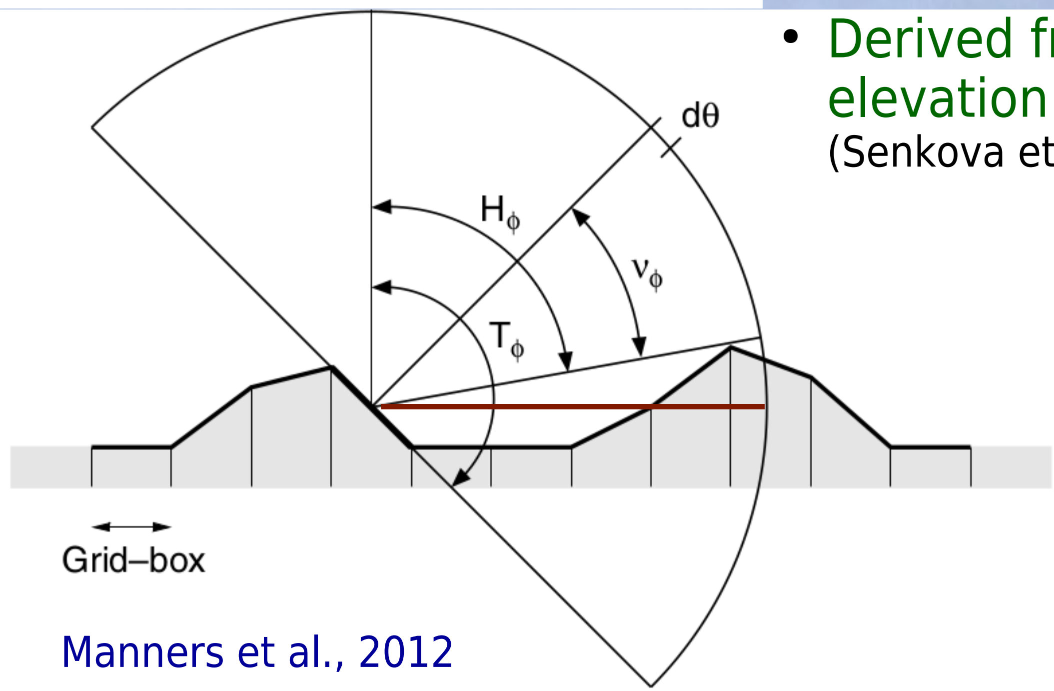
Sky view factor based on subgrid/grid-scale local horizon

- Parametrized as a function of mean squared slope and standard deviation of the surface elevation in grid-square (based on Gaussian covariances)
(Helbig and Löve, 2014, doi:10.1002/2013JD020892)

- Calculated from grid-scale surface elevation
(Manners et al., 2012 and Muller and Scherer, 2005)

- Derived from statistics of fine-resolution surface elevation data in each grid-square and around
(Senkova et al.,2007)

$$V \approx \frac{1}{16} \sum_{N=1}^{16} \sin^2 \left(H_{\phi_N} + \frac{\pi}{2} - T_{\phi_N} \right)$$



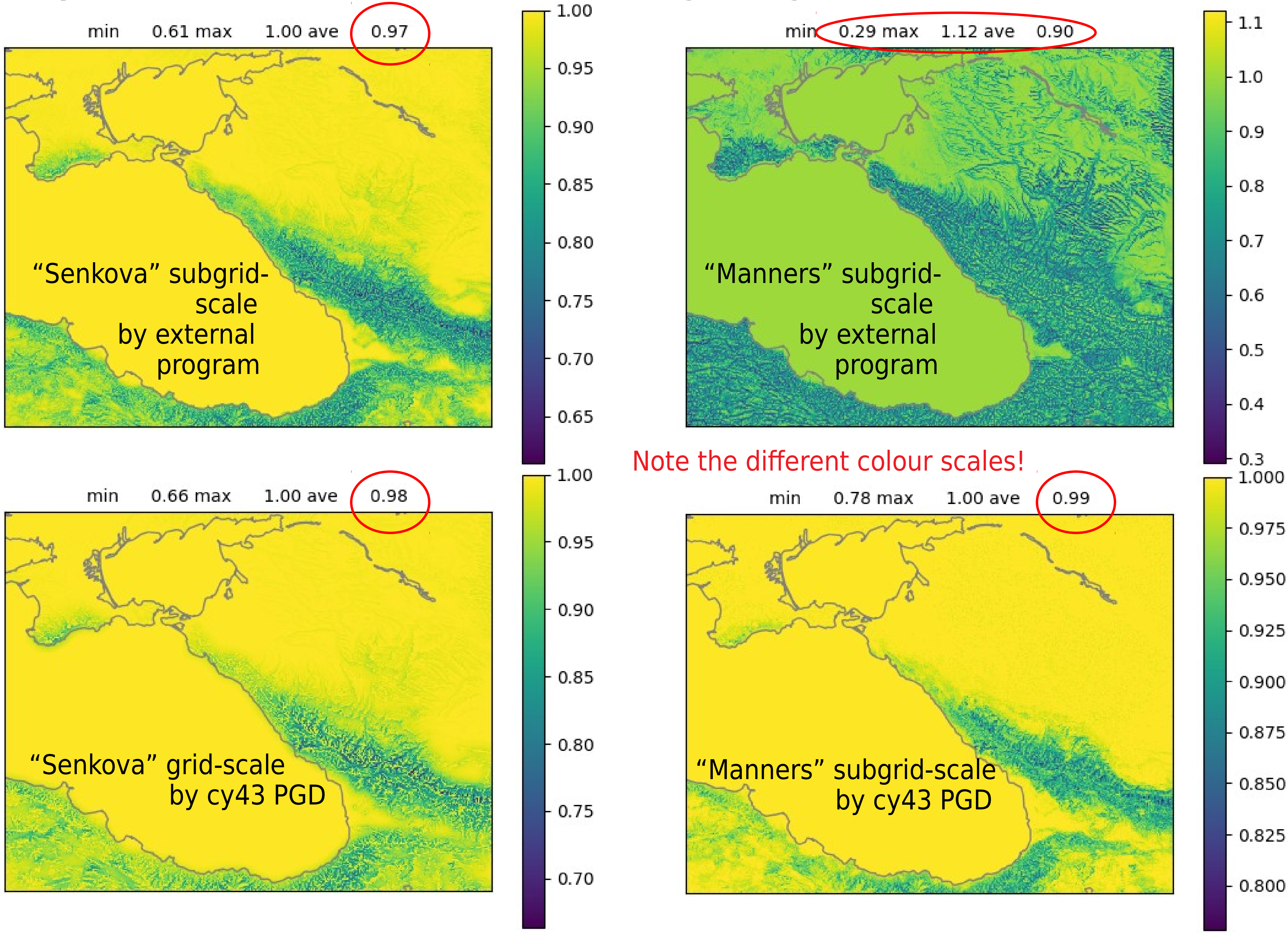
Manners et al., 2012

Figure 5. Calculation of sky-view factor from an inclined surface. Angles are shown for the azimuthal direction ϕ.

Sky view factor is an integrated local horizon angle, taking into account the slope at the viewpoint

- but how to define and calculate the slope in NWP grid and how much do the results differ and influence the model?

Sky view factor based on subgrid/grid-scale local horizon



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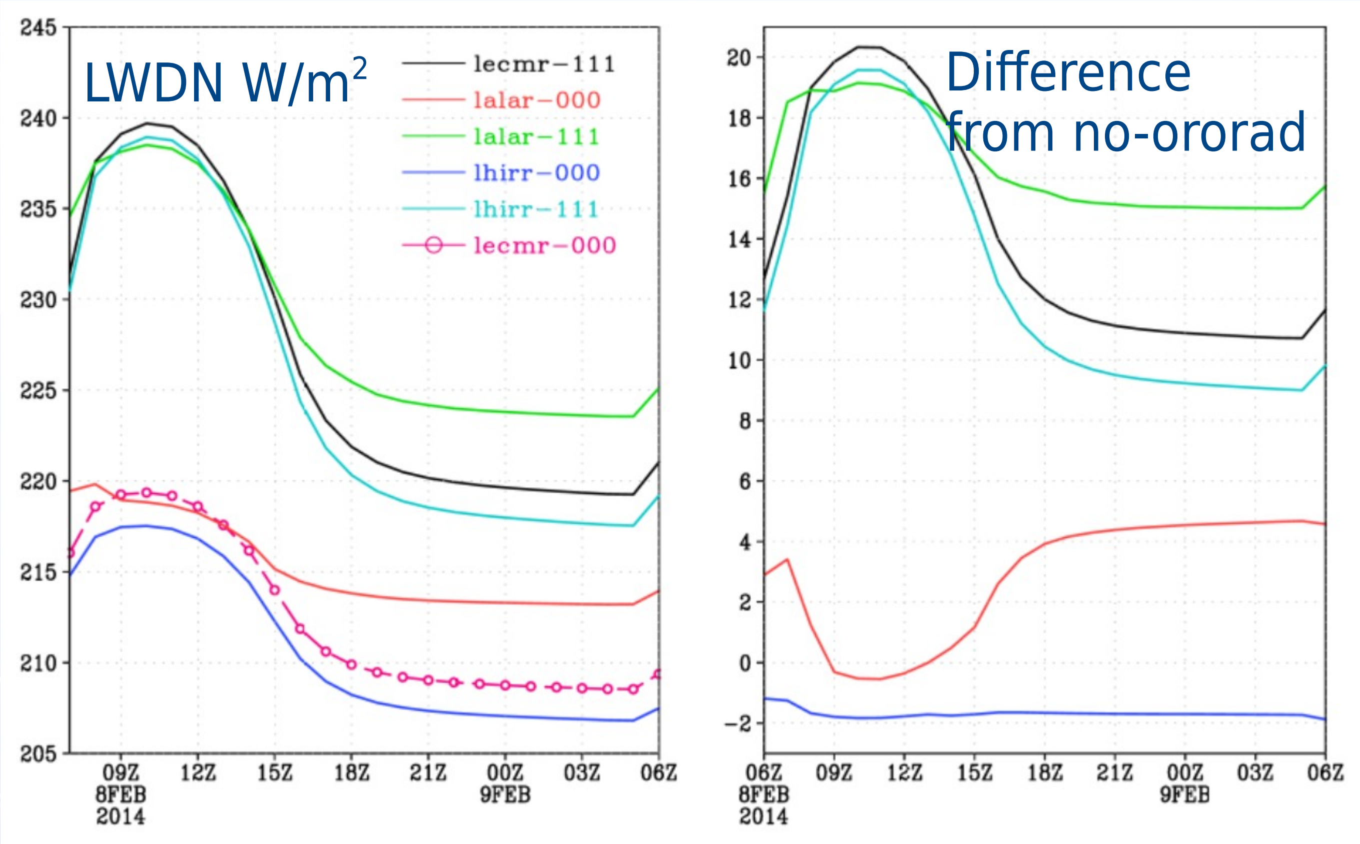
Ororad sensitivities

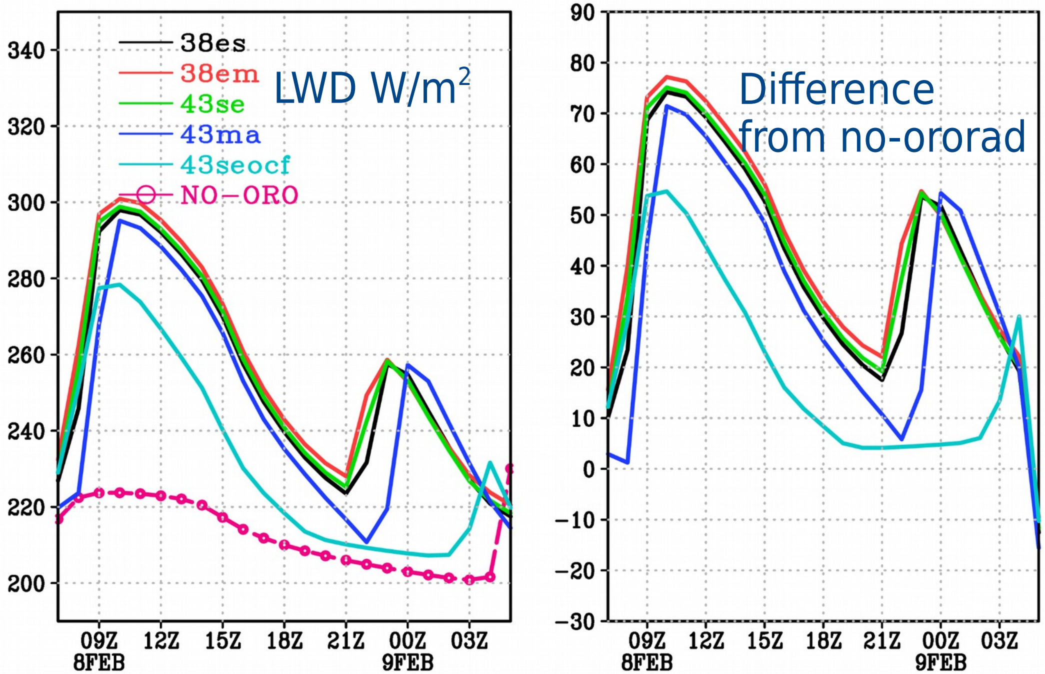
Single-column Harmonie experiments over Krasnaya Polyana, Sochi

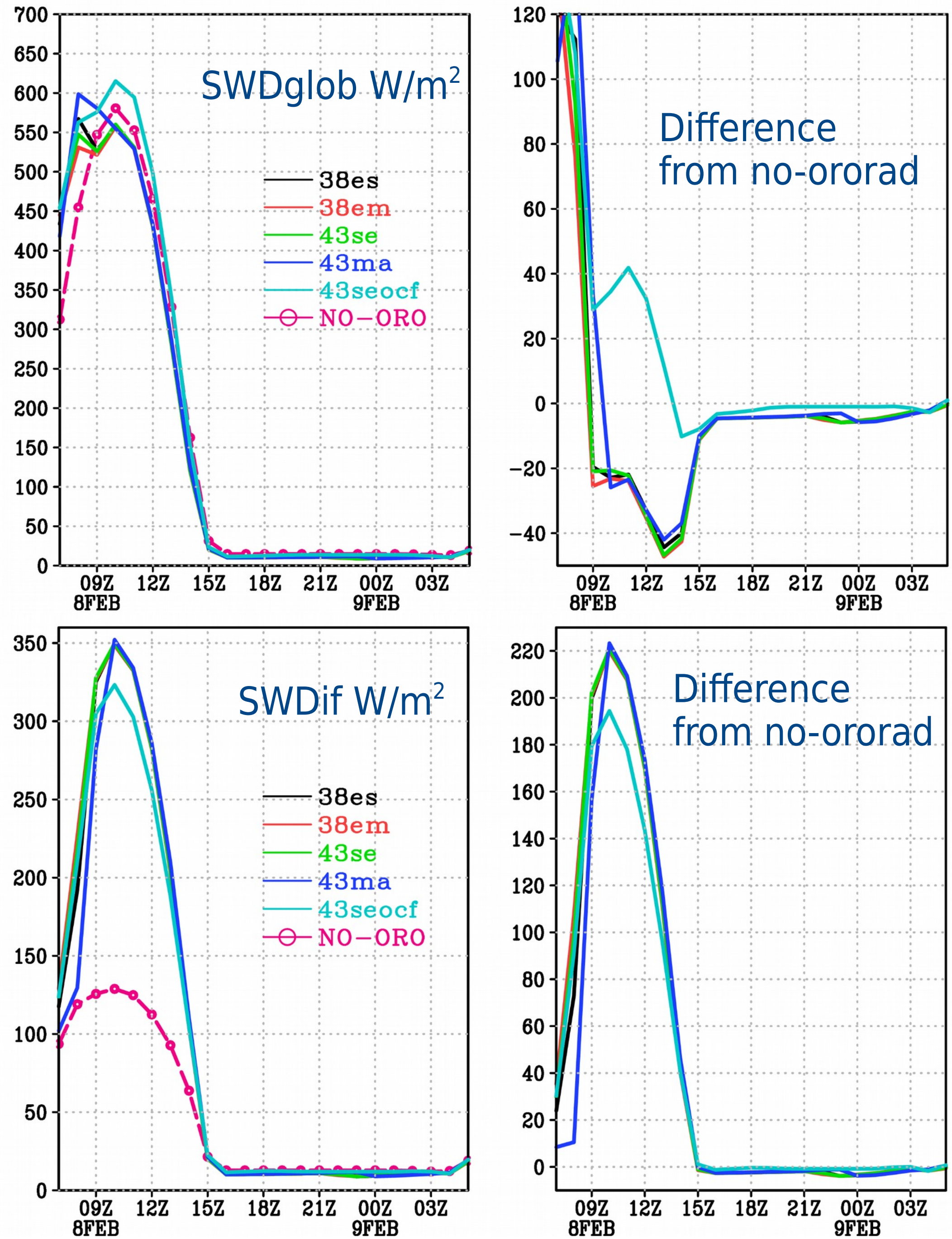


A longwave example: the effect of orography is larger than the difference between radiation schemes

Rontu Laura, Wastl Clemens, Niemela Sami, 2016: Influence of the details of topography on weather forecast – evaluation of HARMONIE experiments in the Sochi Olympics domain over the Caucasian mountains, Frontiers in Earth Science,4,(13). doi: http://dx.doi.org/10.3389/feart.2016.00013

MUSC* cy43 experiments over Krasnaya Polyana: influence of different orofields





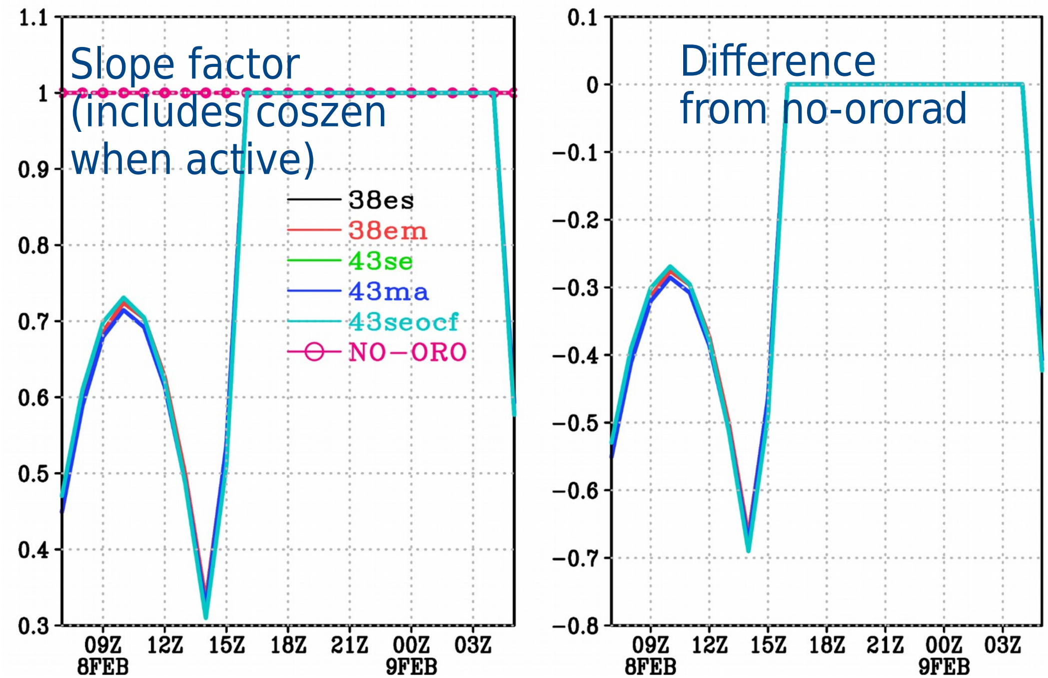
- LWD differences seem to be larger than in the cy38 experiments (different input atmosphere, too)
- SWD (global radiation) differences are due to the diffuse radiation
- 43seocf and 43se use same orofields but the results differ (to be explained soon ...)

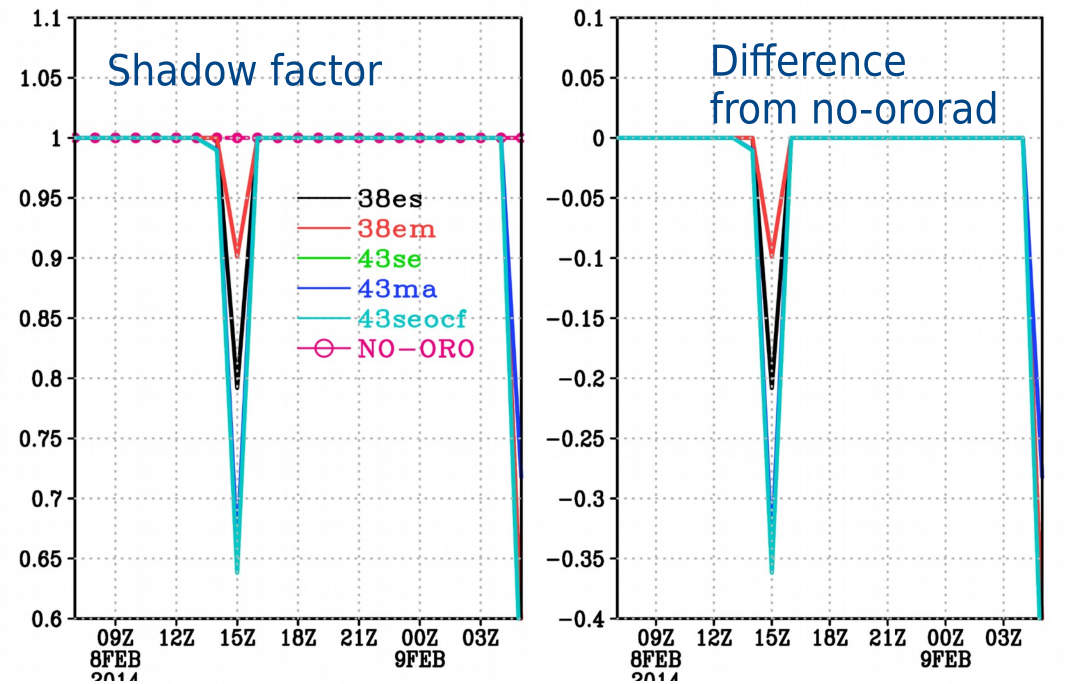
Orofields come from:

38es:	external senkova, cycle38
38em:	external manners, cycle38
43se:	explicit slopes in PGD, cycle 43
43ma:	subgrid slopes in PGD, cycle 43
43seocf:	explicit slopes in PGD, cycle 43

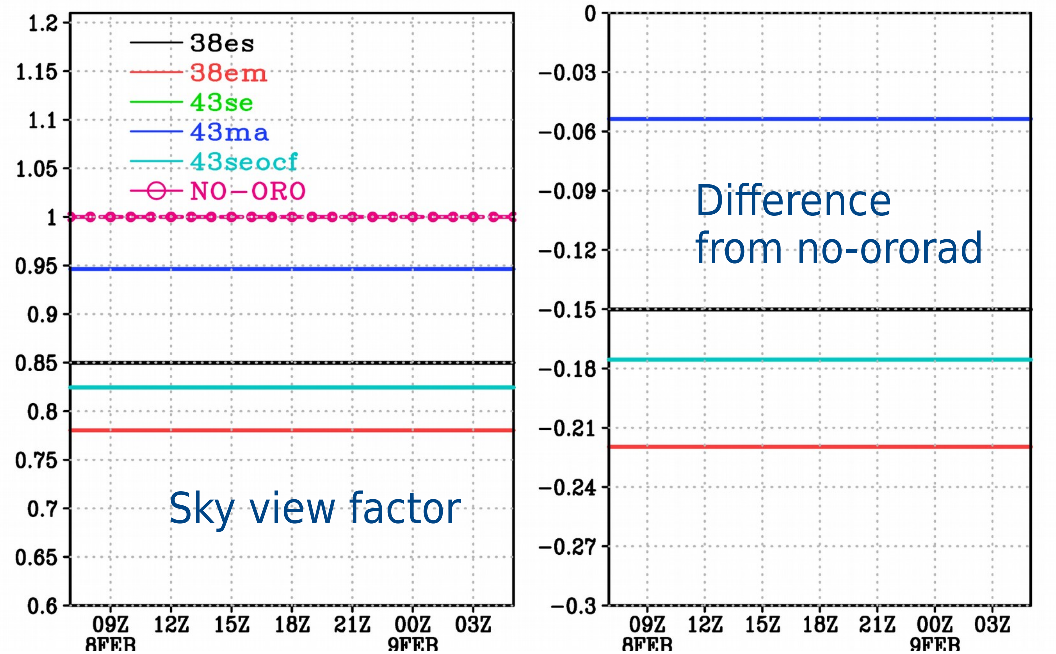
*MUSC = single-column AROME

MUSC cy43 experiments over Krasnaya Polyana: influence of different orofields





- Minor differences in slope factor
- Shadow factor influences in the afternoon/early morning only
- Sky-view factors differ except between 43se and 43seocf



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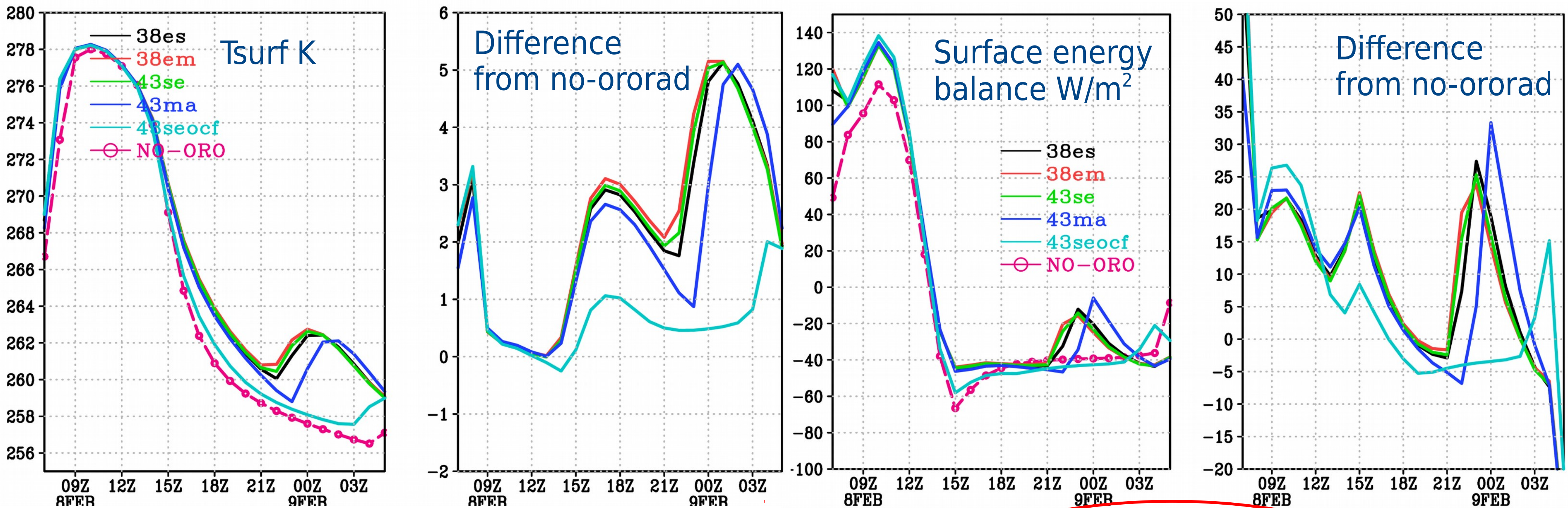
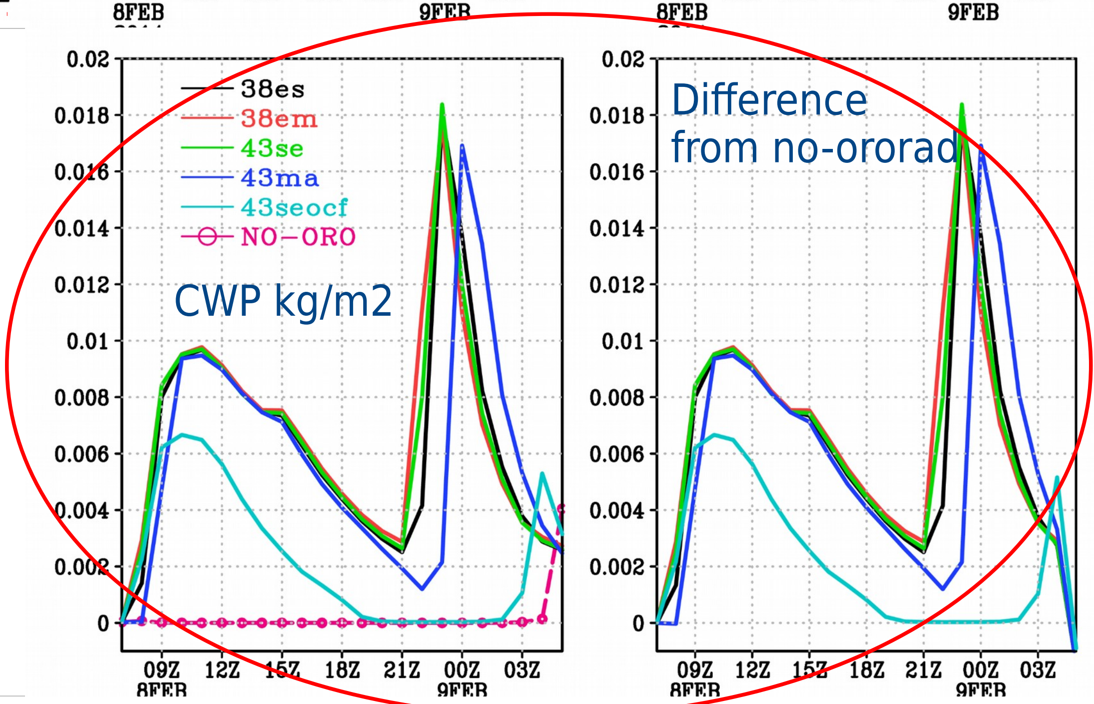
MUSC cy43 experiments over Krasnaya Polyana: influence of different orofields



- Tsurf and energy balance differences are correlated (as expected)
- Cloud interactions! 43Seocf uses different microphysics than the others– no OCND2
- Low clouds may be unrealistic in MUSC but such sensitivities may appear also in 3D!

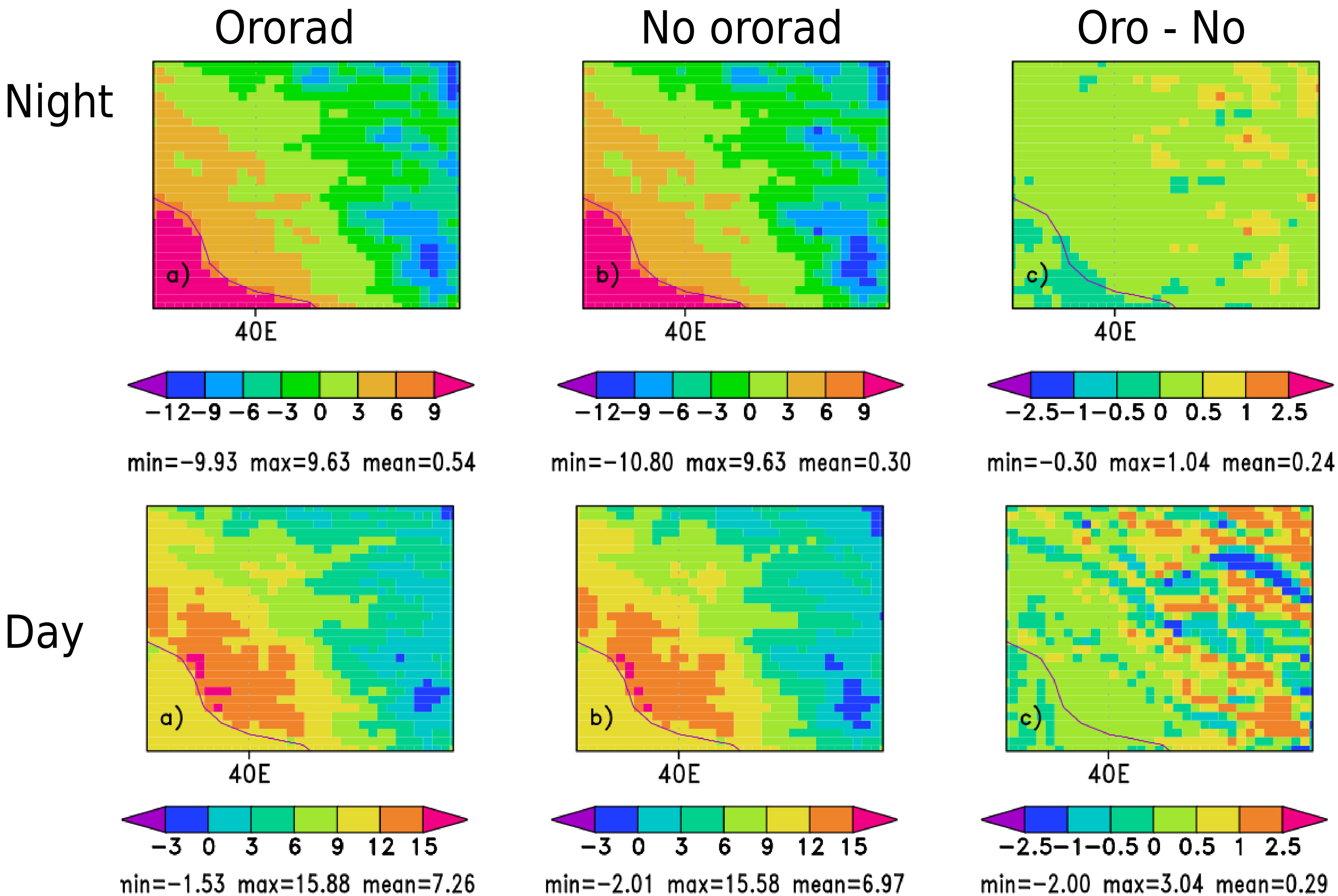
Orofields come from:

38es:	external senkova, cycle38
38em:	external manners, cycle38
43se:	explicit slopes in PGD, cycle 43
43ma:	subgrid slopes in PGD, cycle 43
43seocf:	explicit slopes in PGD, cycle 43



AROME ororad impact over Olympic Sochi 2014

February 2014 mean surface temperature



Sources of uncertainty

Derivation of the fields of basic orographic variables in NWP grid

Cloud-radiation interactions close to the surface

Simplified treatment of the non-local surface properties -
e.g. we assume that the albedo, emissivity and surface temperature of the gridpoint represent also the near neighbourhood

$$S_{\mathrm{net}} = [\delta_{sl}\delta_{sh} - \alpha\delta_{sv}\sin(h_s)]S_{\downarrow dr,0} + [(1-\alpha)\delta_{sv}]S_{\downarrow df,0}.$$

The devil is in the details -
Are the fluxes modified by ororad correctly passed through the chain of physical parametrizations to the atmospheric and surface prognostic equations and from a time step to another?

From the NWP radiation fluxes to point values

How to use NWP output radiation fluxes
for downstream models like road weather or urban or solar energy applications when the NWP results already contain ororad effects?

- Question of scales: grid-scale v.s. high-resolution point values

How to validate ororad effects or radiation fluxes
over complex orography by using point observations?

- Observed v.s. forecast SWDN and LWDN represent the same scales better than e.g. the observed v.s. forecast screen-level temperature but do we still need intelligent downscaling?

Contents

Status of ororad in HIRLAM, AROME (and IFS?)

Ororad parametrizations have been applied in the operational HIRLAM NWP model since October 2010, within model resolutions of 15 km/60L and 7km/65L, shadow effects excluded

- no harm detected but impact of ororad has never been systematically validated in the operational framework

A first version of AROME-SURFEX ororad runs within IFS-ARPEGE cycles 40 and 41 in ZAMG (Austria) and Meteo France, in the latter with the sky view effect excluded (in order to avoid increasing the already existing night-time warm bias of the model as LWDN increases due to decreasing δ_{sv}).

AROME resolutions 2.5km/65L and 1.3km/90L

– plans to validate against radiation and surface temperature observations over Alps

Consider implementation of ororad in the IFS model?

Thank you for your attention!

Paramo of Quindio, Colombia December 2017. Photo Laura Rontu