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

\[
\frac{\partial T}{\partial t} = -\mathbf{v} \cdot \nabla \zeta T - \zeta \frac{\partial T}{\partial \zeta} - \frac{1}{c_p} \left( \frac{g}{p_s} \frac{\partial F_r}{\partial \zeta} + \frac{g}{p_s} \frac{\partial F_l}{\partial \zeta} + F_c \right)
\]

2) influence on the surface energy balance

\[
\text{LE} + H + \text{SW}_{\text{net}} + \text{LW}_{\text{net}} + G
\]
Parametrization of the radiative transfer

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

Physico-chemical properties:
- Mass concentration
- Size
- Shape
- Composition

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

Optical properties:
- Optical depth
- Single scattering albedo
- Asymmetry factor

Grid-scale variables:
- $T$, $q_v$, $q_i$, $q_l$, $q_s$, $q_g$
- Aerosol (concentration)
- Radiative fluxes

Surface-atmosphere radiative interactions

Surface albedo and emissivity
- Orographic radiation effects

Characteristics of surface types
- Surface elevation
Starting point: The early review by Kondratyev, 1977

NWP applications by

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


Trigonometry ...

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

1. Average the fluxes, not orography

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

- 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

<table>
<thead>
<tr>
<th>parameter</th>
<th>description</th>
<th>unit</th>
<th>usage</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_{\Delta x}$</td>
<td>mean surface elevation</td>
<td>m</td>
<td>dynamics</td>
<td>smoothed</td>
</tr>
<tr>
<td>$\sigma_{{sso}}$</td>
<td>subgrid-scale scale standard deviation</td>
<td>m</td>
<td>momentum</td>
<td></td>
</tr>
<tr>
<td>$s_{{sso}}$</td>
<td>mean subgrid-scale slope angle</td>
<td>rad</td>
<td>not applied</td>
<td>eigenvalue of gradient correlation tensor</td>
</tr>
<tr>
<td>$h_{m,i}$</td>
<td>slope angle in direction $i$</td>
<td>rad</td>
<td>radiation</td>
<td></td>
</tr>
<tr>
<td>$f_i$</td>
<td>fraction of slope in direction $i$</td>
<td>-</td>
<td>radiation</td>
<td></td>
</tr>
<tr>
<td>$h_{h,i}$</td>
<td>local horizon in direction $i$</td>
<td>rad</td>
<td>radiation</td>
<td></td>
</tr>
<tr>
<td>$\delta_{sv}$</td>
<td>sky view factor</td>
<td>-</td>
<td>radiation</td>
<td>derived, runtime</td>
</tr>
<tr>
<td>$\delta_{sl}$</td>
<td>slope factor</td>
<td>-</td>
<td>radiation</td>
<td>derived, runtime</td>
</tr>
<tr>
<td>$\delta_{sh}$</td>
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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?
Contents

Introduction

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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/](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

\[ H_{ij} = \frac{\partial h}{\partial x_i} \frac{\partial h}{\partial x_j} \]
Eigenvalues of the tensor

Principal axis → direction with respect to model grid

Mean subgrid-scale slope

Asymmetry factor (form of the ellipsoid)

1995
3a) Subgrid tensors within the grid-squares → directional slopes and fractions*

*suggested by Alexandre Mary, Meteo France

\[ H_{ij} = \frac{\partial h}{\partial x_i} \frac{\partial h}{\partial x_j} \]
1) Fraction of SE slopes

srtm-external for cy38

3a) Fraction of SE slopes

Mean maximum SE slope

subgrid-scale by cy43 PGD*

*PGD = physiography generator of SURFEX
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)

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?

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

\[
V \approx \frac{1}{16} \sum_{N=1}^{16} \sin^2 \left( H_{\phi N} + \frac{\pi}{2} - T_{\phi N} \right)
\]
Sky view factor based on subgrid/grid-scale local horizon

“Senkova” subgrid-scale by external program

“Manners” subgrid-scale by external program

“Senkova” grid-scale by cy43 PGD

“Manners” subgrid-scale by cy43 PGD

Note the different colour scales!
Contents

Introduction
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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

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

Orofields come from:

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

Night

Ororad

No ororad

Oro - No

Day

Ororad

No ororad

Oro - No

min=-9.93 max=9.63 mean=0.54

min=-10.80 max=9.63 mean=0.30

min=-0.30 max=1.04 mean=0.24

min=-1.53 max=15.88 mean=7.26

min=-2.01 max=15.58 mean=6.97

min=-2.00 max=3.04 mean=0.29
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

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

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?
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 nighttime warm bias of the model as LWDN increases due to decreasing $\delta_{sv}$).

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?