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Parameterization of orographic effects on surface radiation in AROME

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1. Introduction & Motivation

Topographic features like slope angle, slope aspect, sky view factor or shadowing by surrounding obstacles have a significant influence on radiation fluxes at the earth's surface. As a consequence, these characteristics can also alter temperature fields, the local circulation, the formation of clouds or the triggering of convection in such areas.

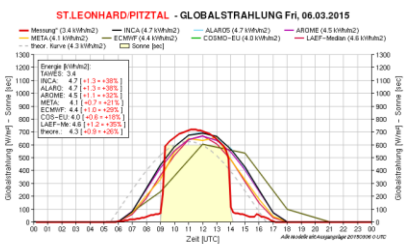


Figure 1: Measured (thick red line) and modelled (thin lines) global radiation flux [Wm^{2}] at the station St. Leonhard/Pitztal on March 06, 2015.

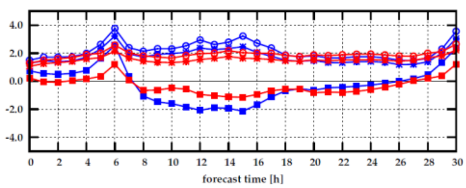
Figure 1 shows the influence of topographic effects on solar radiation measurements at the station St. Leonhard/Pitztal which is located in a narrow south-north orientated valley in Tyrol. For several hours in the morning and evening this station is shadowed by surrounding mountains (thick red line).

With increasing spatial resolution of NWP models these effects gain also importance for numerical modelling.

However, in most current NWP models this shadowing is not considered - the grid boxes are supposed to be flat and effectively homogeneous (thin coloured lines in Figure 1).

As a consequence the predicted model temperatures of e.g. ALARO and AROME at the station St. Leonhard/Pitztal (Figure 2) are at sunrise about 2 - 3 °C higher (averaged over 3 months) than the observations. The effect in the evening at sunset is not significant because of thermal mixing.

Figure 2: Temperature BIAS (squares, model – observation) at the station St. Leonhard/Pitztal for the operational models at ZAMG (ALARO, 4.8km, red; AROME, 2.5km, blue). Crosses show the corresponding MAE, RMSE is denoted by circles. Values are averaged over 3 months in summer 2013.



For a better representation of such topographic influences and with the aim to improve the performance of numerical models in areas with complex topography, a respective radiation parameterization scheme has been introduced to the High Resolution Limited Area Model AROME. The scheme called *ororad* is based on the parameterizations introduced by Müller and Scherer (2005) and adapted to HIRLAM by Senkova et al. (2007). The present scheme for AROME has been developed in a collaboration between ZAMG, Météo France and the Finnish Meteorological Institute.

2. Methodology I - Preprocessing

The *ororad* radiation parameterization scheme is based on high resolution topography data and takes into account following effects on the short-wave (SW) and long-wave (LW) radiation fluxes at the surface (Figure 3):

- SW direct: shadowing of direct solar radiation by orography
- SW direct: angle/direction of slope with respect to sun
- SW diffusive: reduced fraction of sky visible
- LW: reduced fraction of sky visible

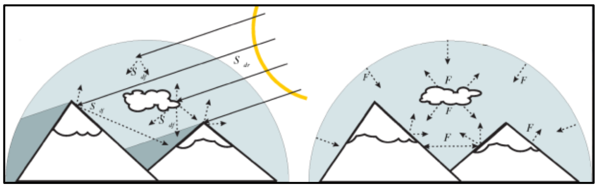


Figure 3: Orographic effects on the short-wave (left) and long-wave (right) surface radiation fluxes (Senkova et al., 2007).

Slope, aspect and local horizontal angles have been calculated on the digital elevation model raster of the Shuttle Radar Topography Mission (SRTM, Jarvis et al., 2008) with 3-arcseconds (~90m in Central Europe) horizontal resolution. To reduce computational requirements, the local horizontal angles have been defined in 45° sectors (namelist setting) centered at the main geographical directions N, NE, E, SE, etc.

All these angles have originally been calculated by external scripts. In a further development of *ororad* by Météo France they can now be derived together with other physiographic data (e.g. land cover) directly within the preprocessing step of SURFEX-PGD. SURFEX stands for Surface Externalisée and is a surface model developed at Météo France (Masson et al., 2013).

3. Methodology II – Model Integration

In a further step this information is aggregated to the model grid by SURFEX-PGD (PhysioGraphic Data). Within the actual model integration when the current postition of the sun is known, the 3 factors δ_{SV}, δ_{SL} and δ_{SH} are introduced by following equations:

- δ_{sv} (sky view factor) is defined by a simple sum of local horizontal angles ($h_{h,i}$) over all sectors.
  $$\delta_{sv} = 1 - \frac{\sum_{i=1}^{8}(sin(h_{hi}))}{8}$$
- δ_{sl} (slope and aspect factor) is defined by solar height (h_s) and azimuth (α_s) and the fraction (f_i) of subgrid slopes in each sector.
  $$\delta_{sl} = \sin(hs) + \cos(hs)\sum_{i=1}^{8}(f_i tan(h_{mi})\cos(\alpha_s - \alpha_{mi}))$$
- δ_{sh} (shadow factor) is defined by solar height (h_s) and A, B factors which are depending on the maximum and minimum horizontal angles in each sector.
  $$\delta_{sh,i} = A_i \sin(h_s) + B_i$$

All 3 factors are applied to the respective radiation fluxes in the actual model integration. Figure 4 is an example for the sky view factor δ_{sv} on the model grid of 1km in the target area surrounding Innsbruck. Highest values can be found in flat areas and on mountain peaks (~1.0) while in narrow valleys δ_{sv} reaches values < 0.6.

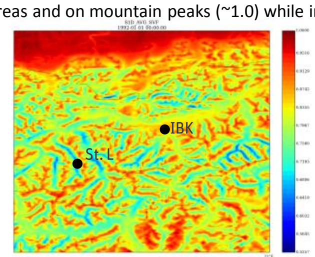
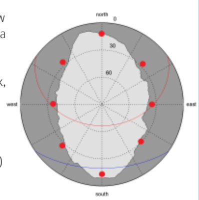


Figure 4: (Left) Sky view factor δ_{sv} in the test area of Tyrol. IBK is the abbreviation for the capital city of Innsbruck, St. L stands for St. Leonhard/Pitztal. (Right) Comparison of measured (grey area) and modelled (red dots) δ_{sv} at the station St. Leonhard/Pitztal.



4. Results and Verification

The *ororad* scheme is now in a test phase at ZAMG and Météo France. The evaluation of several case studies has already indicated a strong benefit of this scheme. A long-term verification with a parallel E-Suite run is planned for autumn 2015.

The *ororad* scheme shows in Figure 5 a significant decrease of global radiation flux in the morning and evenening hours, when the station is shadowed by surrounding mountains. The slope and aspect effect becomes obvious when looking at the 2m-temperature plot in Figure 6. Sunny slopes are heated (< 3°C) while shaddy slopes are cooled up to -4°C compared to the reference run without *ororad*.

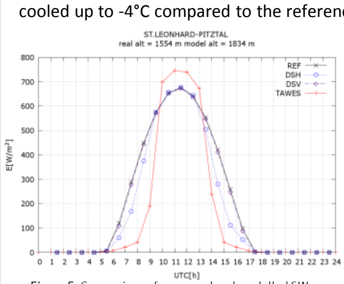


Figure 5: Comparison of measured and modelled SW radiation flux (hourly mean values) at the station St. Leonhard/Pitztal for March 12, 2014. Red curve shows the station observation (TAWES), black curve the reference AROME run without *ororad* (REF), blue one is for shadow effect only (DSH), magenta one for sky view effect (DSV).

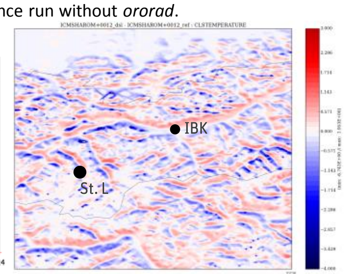


Figure 6: 2m temperature difference *ororad* – REF for 12 UTC at March 12, 2014 in the area of Tyrol (12 hour forecast). Black dots show the location of the capital city of Innsbruck (Ibk) and of the station St. Leonhard/Pitztal (St. L).

The effect of sky view factor (DSV) is very small in Figure 5 because we are here looking at SW radiation fluxes on a clear sky day when the diffuse fraction is negligible. During the night sky view is the dominating effect since it enhances the downwelling longwave radiation flux significantly and as a consequence also increases minimum temperatures in narrow valleys (not shown).

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Masson, V., et al.,, 2013: The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variables and fluxes, Geosci. Model Dev., 6, 929-960,

Müller, M. D. and D. Scherer, 2005: A grid- and subgrid-scale radiation parameterization of topographic effects for mesoscale weather forecast models. Mon. Wea. Rev. 133, 1431-1442.

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