UV radiation in a mountaineous terrain: comparison of accurate 3D and fast 1D calculations in terms of UV index

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Introduction

Modelling ultraviolet radiation in a mountaineous domain is a challenging task.
The rough topography involves:

- modifying gas and aerosols profiles according to the altitude of each site (**figure 1**)
- considering the real fraction of the sky covered by mountains (horizon correction)
- working with a high-resolution elevation model and simulation grid.

Moreover, the presence of snow on the ground complicates the calculation of the effective albedo (notoriously different from local albedo [1] and rapidly changing in space) and triggers 3D effects. These variables are absolutely relevant in an alpine environment like Aosta Valley (North of Italy, **figure 2**) with an average altitude of more than 2000 m asl.

3-d radiative transfer models can mostly take account of these factors, but they are still too time-demanding to be routinely used. On the contrary, 1-d codes are fast, but they cannot explicitly consider topology and snow distribution.

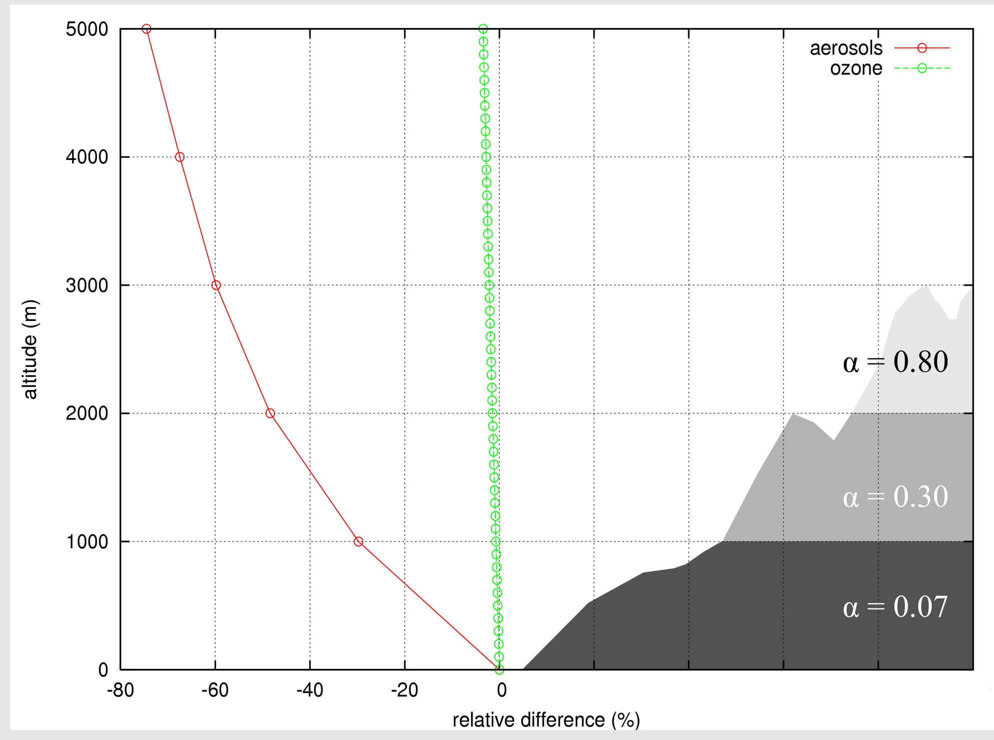


Figure 1. Total ozone (green line) and aerosol optical depth (red) variations with altitude, expressed as percentage differences relative to sea level. On the right, a mountain shape with the *local* albedo parameterization set for MYSTIC.

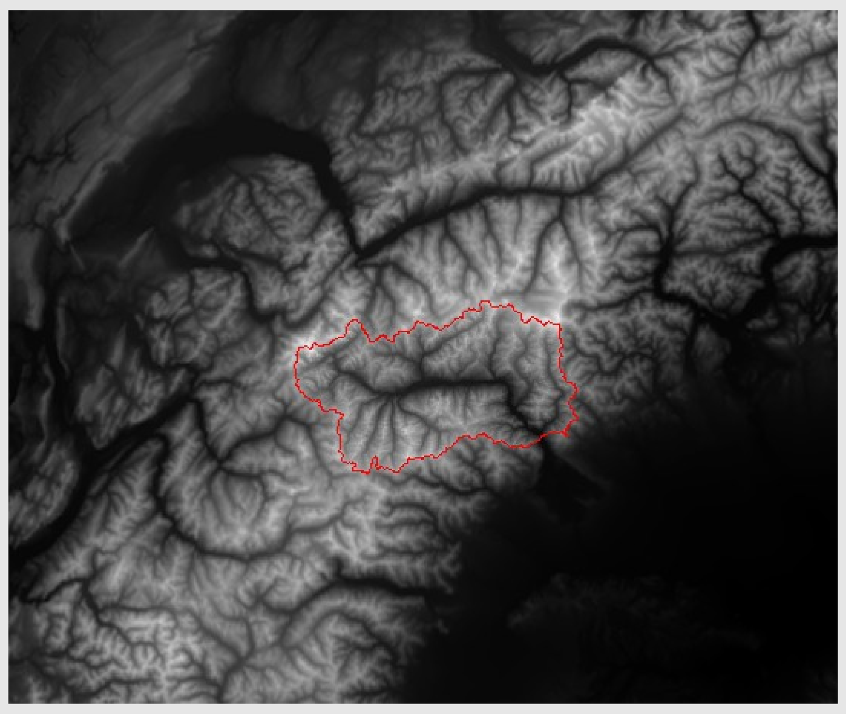


Figure 2. Aosta Valley (red line) in the context of Western Alps. The figure represents the elevation model over a 260x230 km^2 area. The borders of Aosta Valley demarcate the domain of study, about 80x40 km^2 wide.

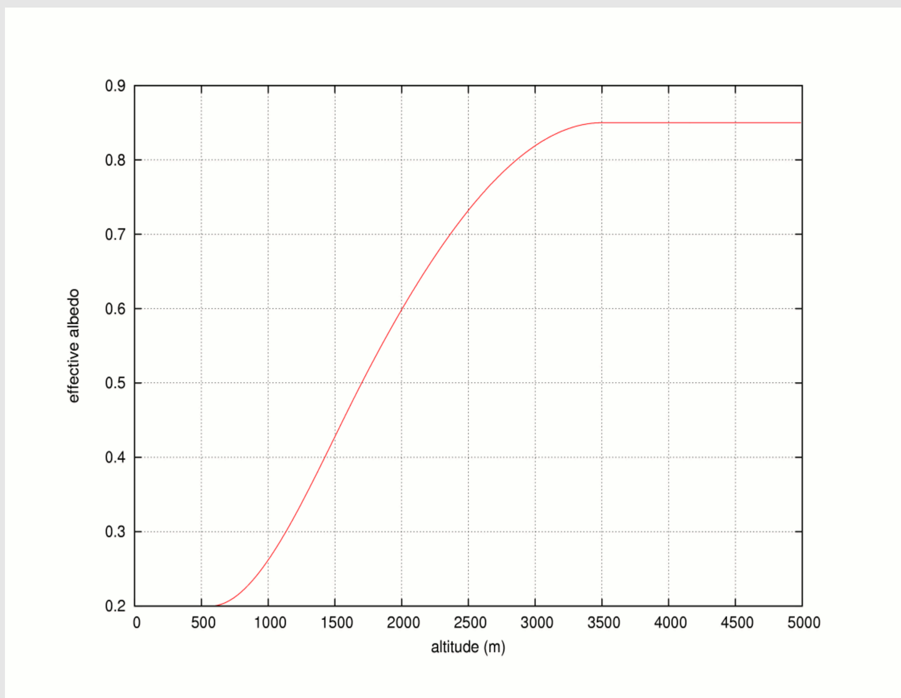


Figure 3. Parameterization of the *effective* albedo depending on altitude for the 1-d model.

Models description

This work presents a comparison of UV-Indexes calculated by an accurate 3-d code, MYSTIC [2] (Monte carlo code for the phYSically correct Tracing of photons In Cloudy atmospheres), and the 1-d DISORT code [3]. Both solvers are operated as part of the libRadtran package [4], the latter in a special version of libRadtran, modified and used by ARPA Valle d'Aosta for the forecast of the UV-index and validated by means of a broadband and spectroradiometric UV network in mountaineous terrain.

The ARPA Valle d'Aosta libRadtran variant:

- works on a high resolution elevation grid;
- "cuts" gas and aerosols profiles according to the altitude of each grid point;
- considers the horizon obstruction by mountains in each point (the diffuse radiance field is considered isotropic in first-order approximation).

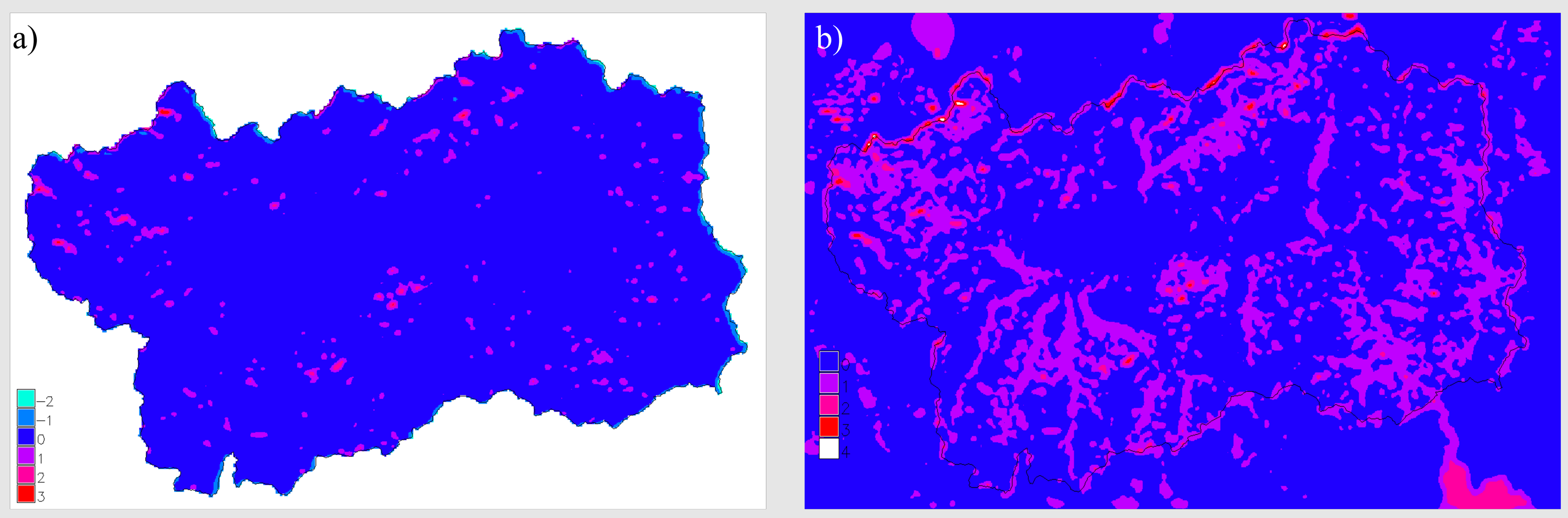
The effective albedo is varied as a function of altitude (**figure 3**) using a cubic spline fit of the effective albedo retrieved at three different altitudes through the comparison of the modeled irradiance and the irradiance measured by three radiometers (570, 1640 and 3500 m asl) during clear-sky days.

The results of the work also let us to check if the positioning of the three radiometers meets the requirements for this purpose.

Method

The models are first run without snow (summer) and then with a realistic snow distribution (winter) on the domain: the local albedo for the 3-d input is set to 0.07 for snow free surfaces, 0.30 for snow covered surfaces under the tree line (2000 m asl) and 0.80 above [5] (**figure 1**). A high resolution regional 100m x 100m DTM is used as input to both codes, to resolve distinct features such as strongly peaked mountains and deep narrow valleys. The two models were obviously run with the same gas and aerosols profiles. Simulations are accomplished for different solar zenith angles and with and without the horizon correction to estimate the importance (in summer and winter) of this improvement.

We calculated the absolute differencies of UV indexes estimated by the two models, then we georeferenced and plotted them by means of a GIS software (Grass GIS), for a visual analysis of the areas where the 1-d model fails. A 3D view is also presented.



Figures 4a and 4b. Absolute differencies between the 1-d approximation and the 3-d model in terms of UV index. The figures represent the case of summer, with horizon obstruction correction (a) and without it (b). In the latter case, the 1-d approximation clearly overestimates the radiation at the bottom of the valleys.

Results

The results are satisfying: the absolute differences mostly lie between ±1 UVI. That is, even if the effective albedo is assessed just at three well-chosen sites, the UV filed agrees quite well on the whole domain, too. In particular, we found out that the most crucial point is the choice (or retrieval from the UV measurements) of the effective albedo at an altitude of approximately 2000 m asl, where the local albedo abruptly changes because of the tree line.

It was found that in summer (dark mountains surfaces) the horizon correction is necessary to avoid an overestimation in the valleys and that with the correction the agreement between the models is very good (**figures 4a and 4b**) so that no 3-d code is required in summer. The situation is different in winter (**figures 5 and 6**) where bright slopes might actually enhance rather than reduce the irradiance. In fact, the presence of snow triggers differences between the models that are well correlated with topography and north/south exposition: the horizon correction shows some limits and probably the 1-d model still cannot take account of some topographical features and reflections between opposite mountainsides covered with snow.

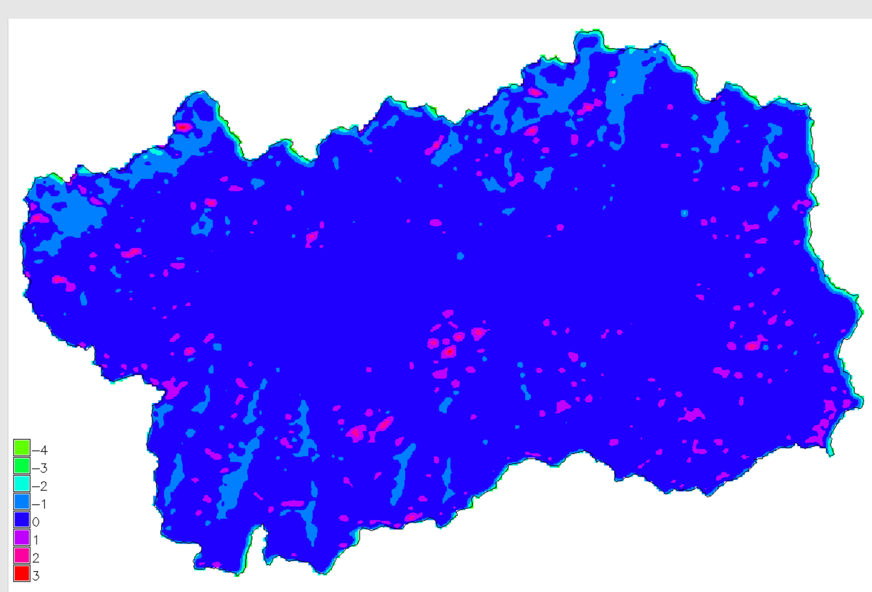


Figure 5. Winter, horizon correction. The presence of snow makes worse the model results.

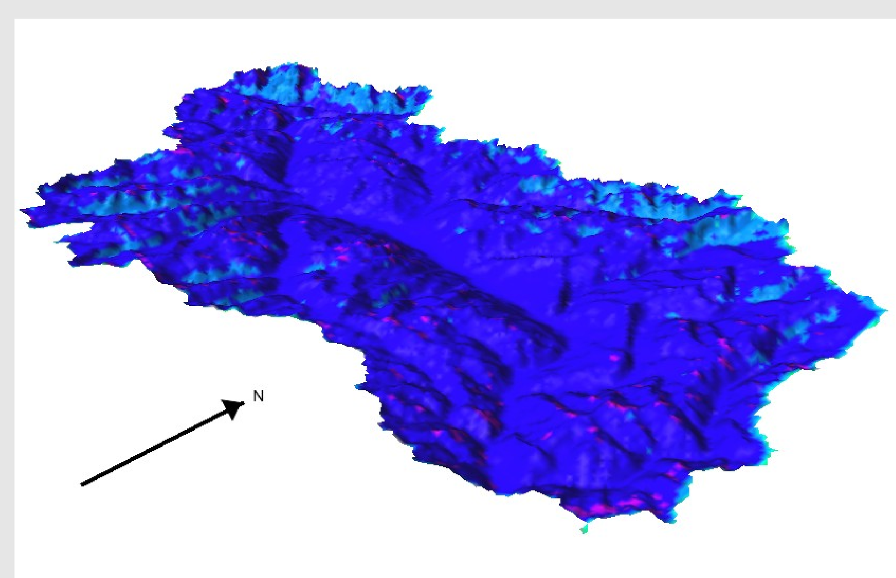


Figure 6. 3-d view of the previous image (the arrow indicates the North direction). This view clearly shows that the differences between the two models are well correlated with topography and North/South exposition of mountainsides.

References

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