Radiation in high-resolution mesoscale models - what can be done?

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1. Scheme development

The HIRLAM radiation scheme is very fast and crude but nevertheless reasonably accurate (Niemelä et al. 2001a,b, Mejgaard et al. 2001). It can be easily tuned, e.g. the aerosol SW coefficients and LW continuum handling could be updated.

The clear-sky SW scheme appears to be particularly useful. The cloud SW scheme is based on a fit to an 'average' two-stream solution. Therefore e.g. the cloud SW absorptivity curve can be easily changed, should the 'anomalous absorptivity' discussion lead to something practical. The cloud SW reflectivity appears to agree with other works, see below.

The LW scheme is perhaps too simple, and clumsy in the cloudy case. A new fast two-stream approach has recently been suggested by Li (2002). This includes also methods for cloud LW scattering and overlapping. Perhaps someone could try that for HIRLAM.

2. Clear sky, flat ground

Observed high-resolution radiative fluxes (SW up and down, LW up and down) from aircraft campaigns such as NOPEX, WINTEX, ARTIST,..., show that in clear air over flat ground these fluxes do not show systematic small-scale horizontal variations along the flight tracks, except for:

1) surface albedo -related variations in the reflected solar radiation

2) surface temperature -related variations in the upwelling LW flux

3) weak air temperature (and perhaps air moisture) -related variations in the downwelling LW flux

The rest appears to be random small-amplitude turbulent-like variation and is not important.

The above effects can be handled in the FISBA-type tile approach by:

- Albedo: Define a representative albedo for each tile, and a realistic snow cover at all times. The albedo should depend on forecast time (midday albedo is the lowest) and on current surface wetness (wet ground, forest etc. is darker than dry). Snow albedo should depend on snow age, wetness and dirtiness (old, wet and dirty snow is dark). Average tree density and treetop height may also matter for the effective forest albedo: Dark treetops absorb direct sunbeams especially during low sun. A lot of sensible heat flux may result, even in winter.

- LW fluxes up: predict and use ground temperature for each tile type separately; i.e. have LW flux profiles up and perhaps also down (see below) separately for each tile.

- LW flux down: this is less studied but perhaps one could make use of the different tile surface temperatures (hence slightly different 2m temperatures and moistures) somehow (e.g. via Swinbank's rule). This may be less important, though. Could be tested.

3. Clear sky, nonflat ground:

As everyone knows, southern slopes tend to be warmer than northern slopes, as the former get more of direct solar radiation (i.e. their effective solar height angle is higher). Snow melts away first from the southern slopes. These also activate more thermals and convection in general during daytime.

When gridlengths get small, individual ridges and slopes are being resolved in high-resolution mesoscale models. At some point, these slope effects should be considered for SW radiation.

A version for HIRLAM has been tested. It uses the present HIRLAM global radiation scheme together with a simple scheme for diffuse radiation. It reproduces fairly well some measurements made on N-, E-, S-, W- and 60° south-facing walls made in South Finland during all seasons. It also reproduces and explains the systematic diurnal "effective albedo" variations reported in Antarctican SW observations made over even gentle slopes.

The slope effect is being tested in the Mars-HIRLAM two stream SW scheme (in Mars, steep small-scale slopes like crater systems are common). The slope angle and its direction (for the grid square or preferably for each tile) is needed as extra input. For Mars these are obtained from the Mars Orbiter Laser Altimetry (MOLA) observations onboard Mars Global Surveyor.

4. Clouds

Clouds are often inhomogeneous and the plane-parallel homogeneous framework (PPH, used also in HIRLAM) is in trouble in these cases. Because of the exponential dependence of SW absorption and LW emittance on the cloud condensate amount, horizontally inhomogeneous (for instance broken) clouds typically behave radiatively as if they had less cloudwater than the PPH-based schemes indicate. Vertical inhomogeneity is less of a problem.

Therefore in homogeneous stratus-like cases the HIRLAM and other PPH schemes cope quite well with aircraft radiation observations. In broken cloud cases, however, one should reduce the cloudwater input for both SW and LW radiation. In the ECMWF model a 25% reduction for SW is made routinely. Cahalan et al. (1994) have given a more strict quantitative and physical interpretation of this. (The SW reflectance function they used for their clouds appears to agree exactly with the one adopted in HIRLAM).

A quick solution: Do as in ECMWF: reduce cloudwater by a constant factor (25-50%) for radiation input in SW and perhaps also in LW, in all cases.

A more scientific approach: Develop a predictive or diagnostic equation for the cloud spatial variance, i.e. their brokenness. This can then be used to estimate the reduction needed in the radiation calculations. Cloud cover is not informative enough as the radiation field is very different if half of the sky is covered by a big cloud (small variance, small inhomogeneity) or by small clouds scattered all over the sky (large variance, large inhomogeneity).

(A general prediction equation for any temporal variance is derived in Savijärvi 1988)

Another 3D effect is that small gridvolumes will receive important radiation and shading effects also from the sides (reflected sunshine and LW emission from the sides of clouds in the neighbouring gridvolumes; shading if nearby clouds block the sun).

Research is made on this using Monte Carlo models. This may lead to simple parameterizations, but even there, variance of the cloud field would be helpful and perhaps necessary.

5. Summary

Barker (2002a,b) has made a good review of the subject in the ECMWF 2001 Seminar Proceedings. He concludes:

"...The hard reality is that one could have a line-by-line 3D Monte Carlo radiative transfer code in an atmospheric model and see little improvement in the simulation of weather and climate if the representations of water vapour and cloud water were poor. Thus, it is imperative that cloud routines keep in step with radiation codes and supply them with essential pieces of information that are presently completely lacking."

References:

Barker, H. W., 2002a: An overview of methods for handling, and issues facing, subgridscale radiative transfer in large-scale atmospheric models. ECMWF Seminar 2001 Proceedings, ECMWF, 1-23.

Barker, H. W., 2002b: Radiative transfer and cloud variability: from remote sensing to climate variability. ECMWF Seminar 2001 Proceedings, ECMWF, 305-325.

Cahalan, R. F., W. Ridgeway, W. J. Wiscombe, T.L. Bell, and J. B. Snider, 1994: The albedo of fractal stratocumulus clouds. J.Atmos.Sci., 51, 2434-2455.

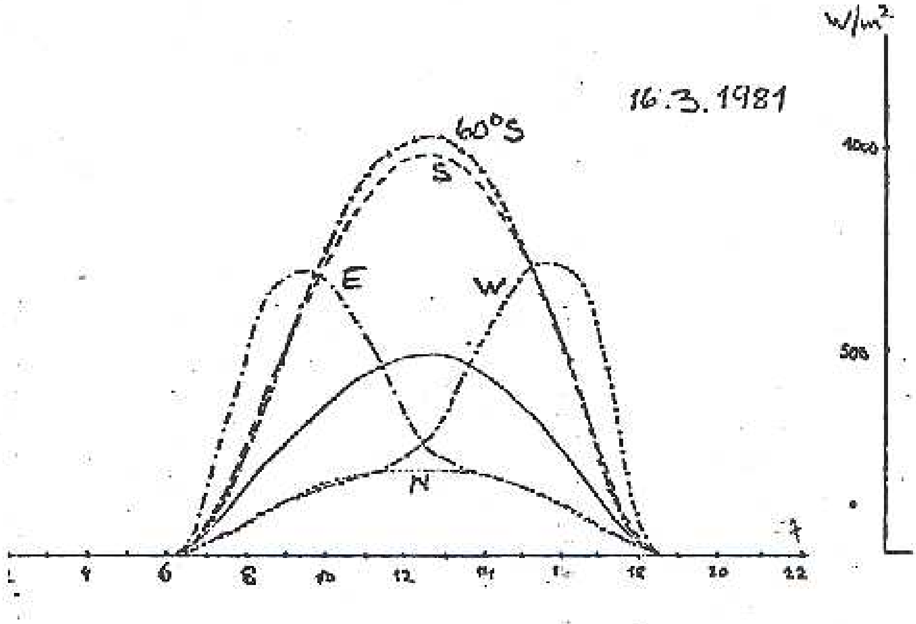
Li, J., 2002: Accounting for unresolved clouds in a 1D infrared radiative transfer model. Part I: Solution for radiative transfer, including cloud scattering and overlap. J.Atmos.Sci., 59, 3302-3320.

van Mejgaard, E., U. Andrae, and B. Rockel, 2001: Comparison of model predicted cloud parameters and surface radiation fluxes with observations on the 100 km scale. meteor.Atmos.Phys., 77, 109-130.

Niemelä, S., P. Räisänen, and H. Savijärvi, 2001a: Comparison of surface radiative flux parameterizations. Part I: Longwave radiation. Atmosph.Res., 58, 1-18.

Niemelä, S., P. Räisänen, and H. Savijärvi, 2001b: Comparison of surface radiative flux parameterizations. Part II: Shortwave radiation. Atmosph.Res., 58, 141-154.

Savijärvi, H., 1988: The maintenance mechanisms of transient large-scale variations in the atmosphere. J.Atmos.Sci., 45, 29-40.



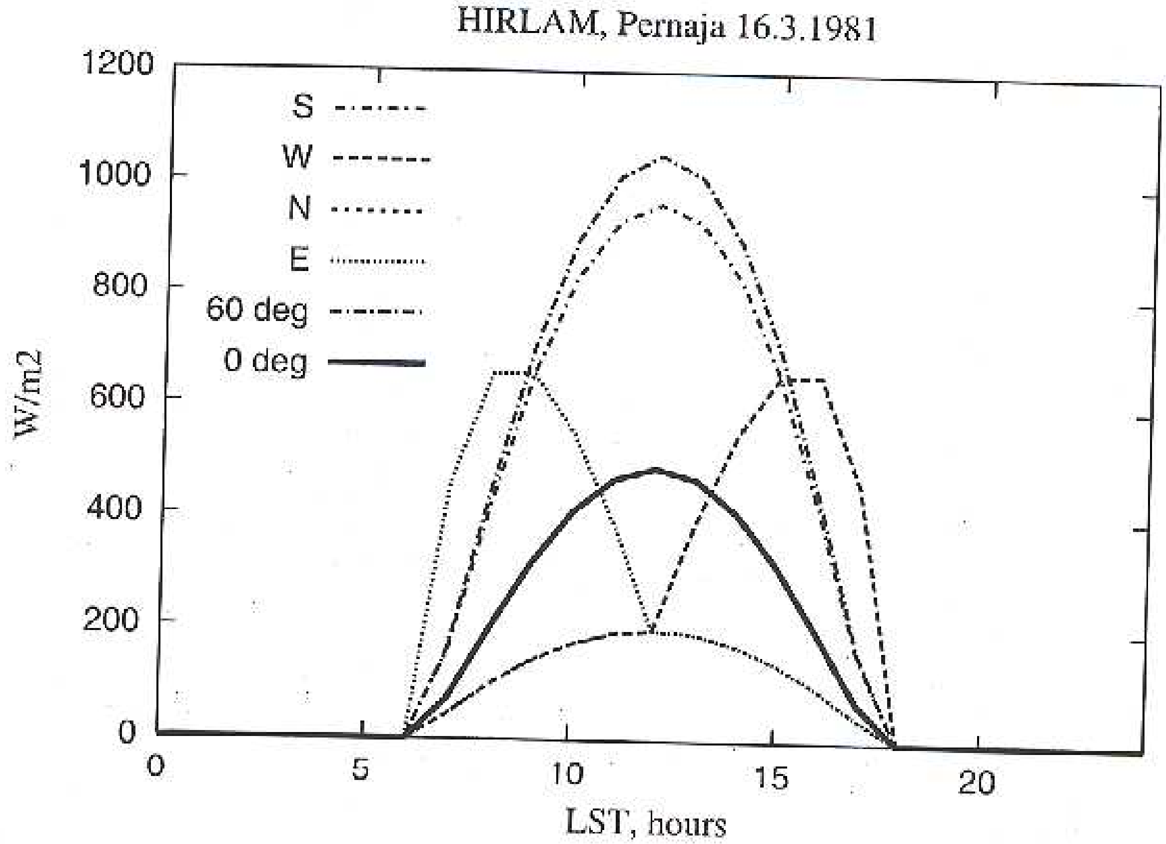


Figure 1. Top: FMI pyranometer-observed solar irradiation during 16 March 1981 (a cloudless day with snow on ground) at Pernaja, South Finland, on horizontal level (continuous line), on North-, East-, West- and South-facing walls and on a wall inclined at 60° from horizontal to the south as marked (From Maija Pietarinen's M.Sc. thesis).
Bottom: The top case simulated by the HIRLAM SW scheme extended by slope effects as described in the text.

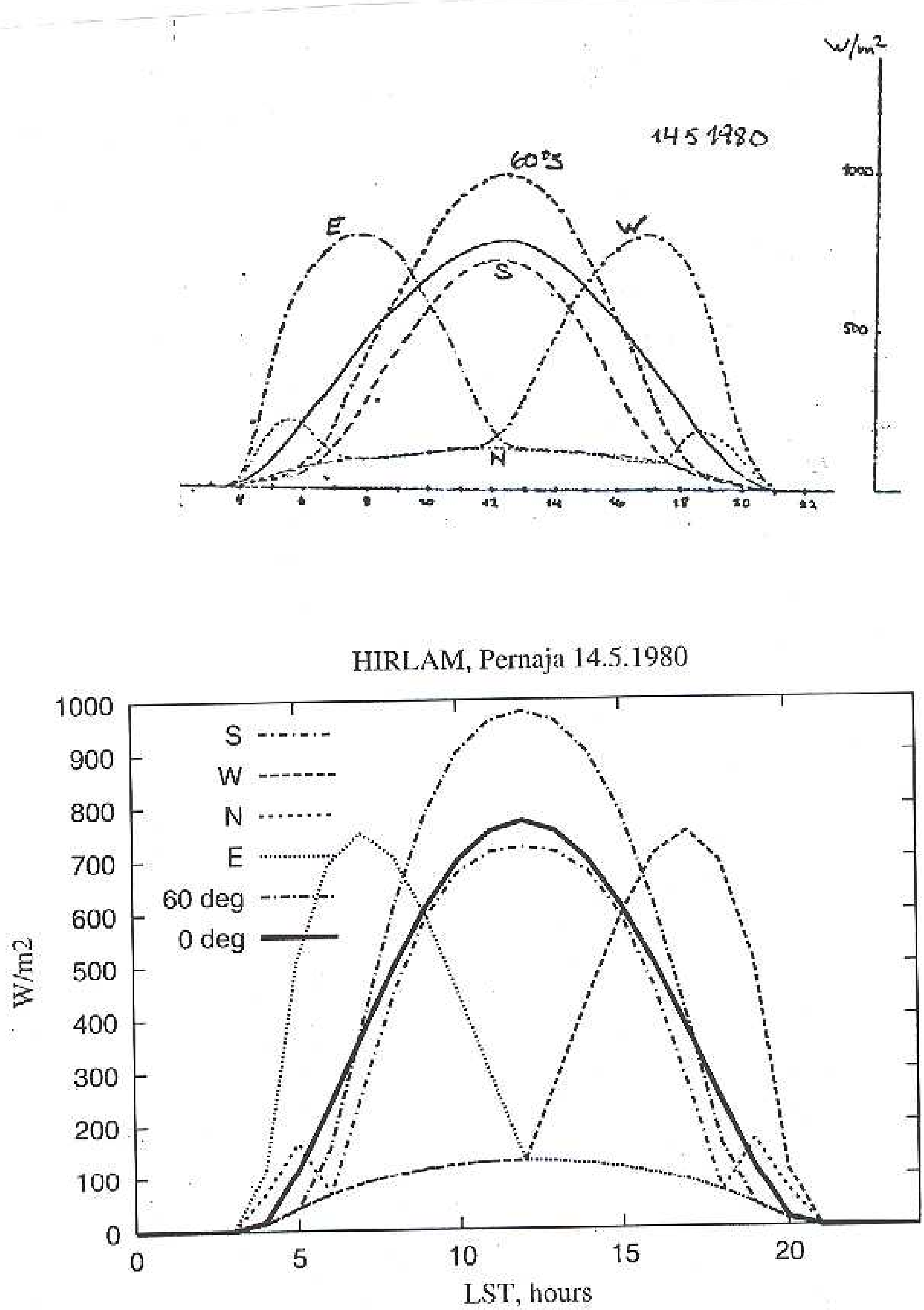


Figure 2. As Fig.1 but for 14 May 1980, a cloudless day with no snow on ground.