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Radiative transfer in atmospheric models — why do we still have to work on it?

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In principle, radiative transfer is a well-known piece of atmospheric physics. Given (1) an accurate characterization of the spatial distribution of atmospheric radiatively active constituents and their optical properties, and the surface radiative properties, (2) and sufficient computer resources to use a rigorous radiative transfer solver, radiative fluxes can be computed very accurately. Yet, issues remain in the specification of surface radiative properties and optical properties of atmospheric constituents, such as single-scattering properties of non-spherical ice crystals, snow flakes or aerosol particles. Furthermore, computing time considerations impose severe restrictions on how precisely, and how frequently, radiation calculations can be performed in a climate model or a numerical weather prediction (NWP) model.

The assumption of a plane-parallel horizontally homogeneous (PPH) atmosphere allows the radiative transfer to be treated as a 1-D problem dependent only on the vertical coordinate. Subject to the PPH assumption, fast radiation schemes applicable to NWP and climate models can be calibrated quite succesfully against much more costly reference schemes. However, the PPH assumption is a major simplification. Some aspects of the non-PPH world, such as cloud overlap and subgrid-scale cloud horizontal variability, can be treated with techniques like the Monte Carlo Independent Column Approximation (McICA). The impacts of 3-D radiative transfer are harder to deal with, although very recently, techniques for this have been suggested. The increasingly high horizontal resolution of NWP models makes the neglect of 3-D effects increasingly questionable. In particular, a largely neglected issue is that when the horizontal extent of atmospheric columns is comparable to, or even much smaller than, the depth of the troposphere, the exchange of radiative energy between neighboring atmospheric columns can be important.

Compromises between the speed and accuracy of radiation computations will be needed in the foreseeable future. Then which should be prioritized; for example, more accurate calculations for the PPH world, parameterization of 3D effects, or a shorter radiative time step to allow for faster cloud-radiation interaction? The answer may well depend on the application. Ideally, such choices should be based on comprehensive testing of how various approximations in the treatment of radiative transfer impact the climate or NWP simulation, compared to reference runs with more rigorous / more frequent radiative transfer calculations.