A new 'bracketing' technique for a flexible and economical computation of thermal radiative fluxes, scattering effects included, on the basis the Net Exchanged Rate (NER) formalism.

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The Net Exchanged Rate (NER) formalism (Green, 1967) offers several theoretical advantages with respect to other competing methods for thermal radiative computations: simplicity, since it allows to neglect the paths of all photons symmetrically exchanged between two atmospheric layers or between the surface and one of them, the interest being focussed only on those photons without counterpart; realism, since the warmer part of the exchange always looses energy to the colder one, whatever approximations may be used for computing transmissivities; accuracy, since it ensures energy conservation principles for the whole atmospheric column taken together with its underlying surface.

But, from a more practical point of view, NER allows stratifying the N(N+1)/2 thermal exchange terms between primary and secondary ones, N being the number of discretised layers along the vertical. Experience shows (Eymet et al., 2005) that, in the absence of cloud screening, the primary terms are threefold: cooling to space (CTS), exchange with surface (EWS) and exchange with the adjacent layers (EAL).

In this study we are treating the scattering effects (and in fact all cloudy effects) for these primary terms through a technique already introduced in 1992 in the operational models of Meteo-France: the gaseous optical thicknesses under which any given layer is seen from (A, the top of the atmosphere -CTS-, B, the surface -EWS- and C, either of its edges) are first computed as exactly as possible in a gas-only idealised atmosphere. These computations are of the band-model type. The obtained optical thicknesses are then injected back locally in two-stream + adding computations including all non-gaseous effects. One can readily show that this allows treating with an excellent accuracy the long-wave radiative interaction between multiple scattering and the very high spectral dependency of gaseous absorption rates, for those three cases (CTS, EWS and EAL) where the source/sink of the photons exchanged with the considered layer is unambiguously known. In these particular cases, there is in fact an analogy with the solar radiative computations, especially for the CTS case, where the thermal photons are following a kind of return path with respect to the solar ones (see for instance Ritter and Geleyn, 1992).

But this treatment leaves aside the majority of the exchange terms, which, although smaller than the primary ones, cannot be neglected. If one would like to reach the same relative accuracy than for the primary ones, it would be necessary to do a full 'emissivity-like' computation of all paired optical thicknesses and to then solve the two-stream & adding system N+1 times rather than something like 4 times. Needless to say, this destroys all the economy advantages of NER and of our advocated technique for the inclusion of scattering effects. Coming back to the above-mentioned stratification of the NER terms, we are however seeking absolute accuracy rather than relative accuracy and we may thus admit a more approximate treatment of these additional terms.

The method advocated here for this purpose relies on a simple fact. When knowing the CTS, EWS and EAL gaseous-only optical thicknesses relative to one given layer, **we already have the minimum and maximum optical thicknesses under which this layer is seen from any part of the gas-only atmosphere**. Indeed the former is the minimum of the CTS and EWS values and the latter is the EAL value. Hence, without any additional expensive computation of gaseous transmissions functions and with only a doubling of the number of two-stream + adding solvers, we are able to bracket the truth between computations with maximum and minimum estimated optical thicknesses for the terms other than CTS, EWS and EAL.

This way of dealing with the 'multiple source - multiple sinks' core problem of thermal radiative transfer shifts the problem to the search of an adequate set of interpolation coefficients for retrieving the best possible estimate of the truth, starting from its two 'bracketing values'. We first verified that the accuracy of such an interpolation is far better when applying it to the fluxes rather than to the cooling rates (both methods were a priori possible).

Arrived at this point, two strategies are possible:

To aim at an intermittent type of expensive radiative computations: the above-mentioned full pairing of layers is done from time to time, together with the max and min calculations, the interpolation weights are inferred and kept constant over several model time steps while recomputing only the cheap part of the procedure. This has not yet been tried but is one of our next goals to do it.

To search for a statistical parameterisation of the local values of the weighting coefficient α between min (0) and max (1). Stratifying a big amount of data, we found that α increases when the local gas absorption potential increases, i.e. lower down in the atmosphere as well as when there are strong changes of the basic vertical temperature gradient, i.e. in inversions. These are of course two expected behaviours since high alpha values means taking relatively more into account the local exchanges of photons.

Encouraged by the apparently wide validity of these findings we tried the following purely heuristic parameterisation:

$$\alpha = 0.3(p / p_s) + 0.1C_p(\partial\theta / \partial\Phi)$$

Even with this very simple fitting, results show a lot of improvements of the new parameterisation with respect to its old counterpart (where EAL was treated as a secondary process and α was consequently implicitly set to zero). Except for small problems in the stratosphere, the statistical fit withy only two tuning constants works very well (see below the dispersion diagram of fluxes between their exact and retrieved values in one example). In the ARPEGE NWP model of Meteo-France, use of the new parameterisation leads to scores equal or slightly better than those of the old version of the ECWMF scheme with still a tenfold reduction in cost when both are compared in stand-alone mode for models with about forty levels. The scheme is already operational at CHMI and in the ALADIN contribution to the Europroject MFSTEP. Our goal is now to fit as closely as possible the RRTM transmission functions with the needed band-model-type calculation, in order to see which better cost-accuracy balance might be achieved with the 'statistical' version of the new scheme, before attacking the intermittency issue.

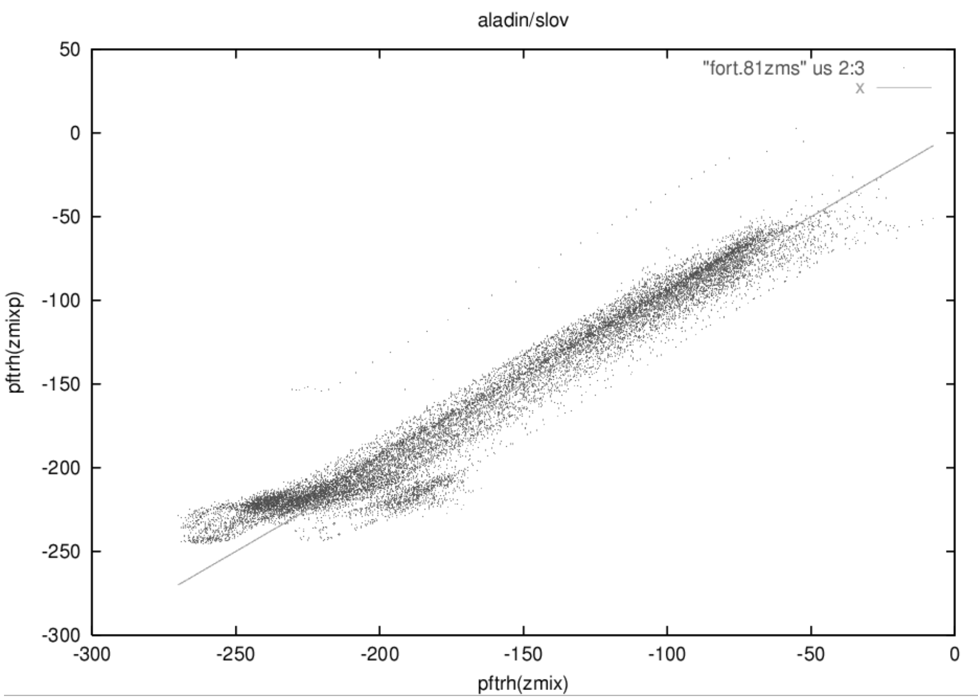

Figure: Dispersion diagram of thermal fluxes. X-axis: exact values. Y-axis : retrieved values from the parametrisation.

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