Radiation schemes: Some clear-sky off-line comparisons

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1 Introduction

A comparison of surface-measured and off-line-calculated radiative fluxes has been made in the former Department of Meteorology, University of Helsinki (note our new name above). This was Sami Niemela's M.Sc. thesis work. The comparison included several NWP model schemes as well as several simple schemes developed for applications such as agricultural and forest meteorology. One of the model schemes was HIRLAM; the others were ECMWF ('old' and 'new') and DWD. Comparisons were made for the shortwave (solar, SW) and longwave (thermal, LW) spectral regions separately. Niemela et al. (2001a,b) give more details. We report here those results which may be interesting for the HIRLAM community.

The comparisons for the NWP schemes included clear-sky 00 (for LW) and 12 UTC (for SW) situations during two years (1997 and 1999) at the Jokioinen and Sodankylä observatories of the Finnish Meteorological Institute. Input for the NWP schemes was provided by radio soundings, which were used to define the temperature and moisture profiles at 72 pressure levels (i.e. the same input and same high vertical resolution was provided for all schemes). The NWP schemes need the cloud water content and cloud cover profile in cloudy conditions so their comparison was restricted to clear-sky cases only. Conditions ranged from summer days into very cold and clear winter nights with surface temperatures reaching down to -49°C in Sodankylä.

The work thus highlights intercomparisons of the NWP and simpler schemes extended into the extremely cold conditions of the Northern Finland winter, where strong surface inversions are common, especially during the clear-sky conditions.

2 Longwave comparisons

In the longwave, the NWP schemes included the HIRLAM broadband scheme, the Morcrette 6-band 'old' ECMWF scheme, the 'new' ECMWF 16-band Rapid Radiative Transfer Model (RRTM), and the DWD 5-band scheme. HIRLAM is much faster than the multi-band schemes, so it could be less accurate. What was compared was the 00 UTC downwelling LW radiation (DLR) given by the schemes, and the 'observation', i.e. an estimate for DLR obtained from the 00 UTC net all-wave and shortwave flux observations plus information about the soil/snow surface temperature next to the radiometers (to obtain the upwelling LW flux). The total RMS error of our 'observed' DLR is estimated to be within 7-14 Wm^{-2}. The quality indicators for the DLR parameterizations were the mean difference to the observed values (i.e. bias), the standard deviation around the mean difference (SD), and the RMS difference.

The LW results from Sodankylä are collected into Table 1 below. They are separated for summer 1997 and for winters 1997 and 1999, both of which included many surface inversion cases. The average measured DLR was 262 W/m^2 for summer 1997 (17 clear-sky cases), 191 W/m^2 for winter 1997 (27 cases), and 162 W/m^2 for the very cold winter of 1999 (13 cases). Some simple schemes are included for reference, such as the Brunt, Swinbank and Brutsaert schemes. These only use screen-level temperature and moisture values as input.

Scheme	Summer 1997		Winter 1997		Winter 1999	
	bias	SD	bias	SD	bias	SD
Brunt	-24.9	8.5	-40.5	14.4	-51.9	8.3
Swinbank	-16.8	8.9	-34.8	19.1	-52.9	12.1
Brutsaert	-11.1	9.1	-42.6	20.7	-64.3	14.2
Prata	-5.0	8.4	-17.5	14.6	-30.1	8.2
EC-OLD	-5.3	5.5	-22.9	8.3	-21.7	7.9
DWD	-14.8	5.0	-27.6	7.8	-26.9	7.8
RRTM	-1.5	5.1	-15.4	8.2	-14.3	8.4
HIRLAM	-7.0	5.7	-24.6	8.3	-24.3	8.0

Table 1: Results of the LW comparison in cloudless situations: DLR bias and SD in W/m^2.

The LW results indicate that in summer 1997 all four NWP schemes are about equally good in that their standard deviation is in the range 5.0 - 5.7 W/m^2. They expectedly beat all the simple schemes, which have their SD in the range 8.4 - 9.1 W/m^2 . RRTM has the least bias of the NWP schemes (-1.5 W/m^2), DWD the largest (-14.8 W/m^2). Most schemes show negative bias during the summer. HIRLAM was about as good as the other NWP schemes.

In the clear-sky winter situations, all schemes substantially underestimate DLR. The negative bias is smallest for RRTM, around -15 W/m2; for the other NWP schemes the bias is -22...-28 W/m^2. The standard deviations of the NWP schemes are higher than in summer; i.e. 7.9 - 8.4 W/m^2. Simpler schemes now display much higher SDs and biases, especially for the winter 1997, when half of the clear-sky cases in Sodankylä were non-inversions.

The wintertime underestimation in all the NWP schemes is curious as they should have the correct temperature and humidity high-resolution input profiles, and varying amounts of ozone or aerosol cannot possibly explain systematic differences this large. All NWP schemes do in fact catch the DLR fairly well during the coldest surface inversions (unlike the simple schemes), but the scatter is larger for DLR in the range 150-240 W/m^2.

3 Shortwave comparisons

The NWP schemes include the HIRLAM broadband SW scheme, the ECMWF Morcrette 2-band scheme, and the DWD 3-band scheme. Simple schemes include some, which only use the solar height angle as input (e.g. Paltridge and Platt; Bennett). One simple scheme (Iqbal) is in fact a slightly more complex calculation, needing the screen level temperature and moisture as input. The 12 UTC 1997 observed global radiation is the 'truth' here; input for the models is the 12 UTC sounding plus the local albedo obtained from the reflected radiation. The aerosol optical depth was fixed to 0.1 for all schemes, which need this information; continental aerosol type was selected for the ECMWF and DWD schemes.

Scheme	Jokioinen 1997		Sodankylä 1997	
	bias	SD	bias	SD
Paltridge and Platt	-16.1	29.7	-41.1	21.5
Bennett	-5.2	20.7	-26.2	26.1
Shine	15.7	23.4	-10.5	17.8
Iqbal	-1.1	12.4	-19.9	8.3
EC-OLD	5.9	19.7	-16.3	14.1
DWD	2.9	13.7	-17.2	8.0
HIRLAM	13.6	13.1	-6.0	9.9

Table 2: Results of the SW comparison in cloudless situations: scheme bias and SD in W/m^2.

The results are given in Table 2 for the year 1997. Judging by small standard deviation, the DWD, HIRLAM and the Iqbal scheme were the best while the ECMWF scheme had slightly larger values of SD. In biases, the HIRLAM scheme was slightly more transparent than the others, but it is difficult to tell which scheme was the best in that respect. All schemes do underestimate the solar radiation in Sodankylä, so air there may be much cleaner than in Jokioinen. Indeed, when the aerosol optical depth was estimated crudely from visibility observations, its value was 0.1 on the average in Jokioinen, and 0.08 in Sodankylä in the cases of Table 2. However when the actual visibility-produced aerosol optical depths were fed into the ECMWF scheme, its bias became more positive by 3 W/m^2 only, and the standard deviation remained the same. Thus we believe that the variable aerosol content is not the key factor in the scheme errors. There may be small but systematic measurement errors in one or both stations.

When the differences are plotted against the solar height angle, all SW schemes tend to display positive correlation. Either this means a common fault in all schemes or it is another indication of small systematic measurement errors.

4 Summary

Off-line comparisons of the HIRLAM, ECMWF and DWD model radiation schemes were made against observed downwelling SW and LW radiation fluxes at Jokioinen and Sodankylä observatories, having as input the detailed radio soundings and actual surface albedo. The comparison covered clear-sky 00 and 12 UTC cases during two years. Also some simple methods were included. HIRLAM was about as good as the other NWP schemes by standard deviation, although it is much faster. The RRTM scheme of ECMWF had the lowest LW bias. The relatively simple Iqbal scheme surprisingly provided the best results in the SW. Otherwise the NWP schemes clearly outperformed the simple schemes, which only use surface information.

All schemes underestimated LW flux in cold conditions. All SW schemes also underestimated SW radiation in Sodankylä, indicating perhaps parameter values tuned for less clean air than is the norm at this northern observatory. Use of actual aerosol optical depth derived from visibility observations did not explain most of the differences however. All SW schemes also displayed correlation in their errors with the solar height angle.

Although the radiation measurements are made with well-maintained instruments in these two FMI observatories, they might still contain some small and unknown systematic and random errors, which are a nuisance in a very sensitive comparison, such as the present one. The comparisons (of the NWP schemes) were restricted to clear-sky cases only, as in cloudy cases the NWP schemes need the cloud water and cloud cover profiles, which are not provided by ordinary soundings. On-line comparisons using model-predicted data on the other hand would be dominated by the accuracy of the cloud forecast above the measurement site, rather than revealing errors in the radiation schemes.

5 References:

Niemela, S., P. Räisanen and H. Savijärvi, 2001a: Comparison of surface radiative flux parameterizations, Part I: Longwave radiation. Atmospheric Research, 58, 1-18.

Niemela, S., P. Räisanen and H. Savijärvi, 2001b: Comparison of surface radiative flux parameterizations, Part II: Shortwave radiation. Atmospheric Research, 58, 141-154.