UCRL-TR-205281

Testing Impact's Radiation Code

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July/2004

U.S. Department of Energy

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Testing IMPACT's Radiation Code

Taner Edis, Philip Cameron-Smith,
Keith Eric Grant, Dan Bergmann, Catherine C. Chuang

July 9, 2004

This is a summary of work done over an 8 week period from May to July 2004, which concerned testing the longwave and shortwave radiation packages in IMPACT. The radiation code was initially developed primarily by Keith Grant in the context of LLNL's 2D model, and was added to IMPACT over the last few summers. While the radiation code had been tested and also used in some aerosol-related calculations, its 3D form in IMPACT had not been validated with comparisons to satellite data. Along with such comparisons, our work described here was also motivated by the need to validate the radiation code for use in the SciDAC consortium project. This involved getting the radiation code working with CAM/WACCM met data, and setting the stage for comparing CAM/WACCM radiation output with IMPACT results.

A detailed description of the comparisons follows; another person looking to do similar work—which will be necessary in further phases of SciDAC—should be able to follow similar procedures.

1 ERBE comparisons

The initial testing compared the radiation calculated in a full year's run of the "TS6" compact sulfur-ozone chemistry mechanism to ERBE (Earth Radiation Budget Experiment) satellite data.

1.1 ERBE data sets

ERBE data can be obtained either from PCMDI (Program for Climate Model Diagnosis and Intercomparison, at LLNL) or from NASA Langley ASDC. To

get the data straight from NASA, visit

`http://eosweb.larc.nasa.gov/PRODOCS/erbe/table_erbe.html`

The procedure is simple; setting up an account at Langley is easy, and once done, data can be obtained by ftp or on the Web.

There are a number of ERBE data sets available. We chose "s4gn_wnf5". This is wide field, non-scanner data; its prime virtue is that it it includes a wide variety of top-of-the-atmosphere radiation data organized by monthly files. According to Jay Hnilo of PCMDI, this should be a good data set for comparison purposes. This data set also comes in HDF (Hierarchical Data Format) files instead of ERBE's native format. HDF files can be directly used on VCDAT, the climate data visualization tool, provided a version built to be able to read HDF is installed on the users' computer. Currently one is on the machine `passatt`, invoked by `/home/pjc/CDAT/cdat/bin/vcdat`. Note that the files from Langley will not have `.hdf` attached; the files will have to be renamed to add `.hdf`. For example, see the files `s4gn_wnf5._9401_2.hdf` and others in the directory ~`edis/ERBE`.

For the IMPACT comparison, we used the 1994 data set from ERBE, which is the latest S-4GN set available from the mid-90's, and is closest to the met data available for our IMPACT run (1998). These include longwave and shortwave flux data on a $5^\circ \times 5^\circ$ grid.

Visualizing the HDF data sets properly with VCDAT requires some more work:

- ERBE does not cover the poles, so data from latitudes $> 60^\circ$ or $< -60^\circ$ are missing. Missing data are flagged as values ≈ 32000. There are also cases, especially with shortwave fluxes, where the satellite has missed more than just the poles, and a couple of bad patches are flagged with negative flux numbers. So on VCDAT, masking out ERBE flux data which are > 20000 and < -10 was used on all occasions.

- VCDAT dimension aliases need to be set from the Preferences menu, in order to recognize latitude and longitudes. Add *fakedim15*, *fakedim17*, *fakedim37* and *ii* to the list of longitude aliases. Add *fakedim14*, *fakedim16*, *fakedim36* and *jju* to the latitude aliases.

- The variable names in the HDF files are remarkably uninformative. Fortunately fuller descriptions are available in the long names and annotations for the variables—easily obtained by clicking on the "i" icon

next to the variable name in VCDAT. The variables we used in our comparisons were:

- *Data-Set-17*: Monthly mean longwave flux up, top of the atmosphere.
- *Data-Set-19*: Monthly mean shortwave flux up, TOA.
- *Data-Set-35*: Monthly mean of longwave flux up, TOA, for 24 *local* hours—for time 0:00, 1:00, 2:00, ... locally all over the planet etc.
- *Data-Set-37*: Monthly mean of hourly shortwave flux up, TOA.

All units are W/m^2.

- The latitudes in ERBE data go from 90° to −85°. To plot properly, VCDAT requires the centers of latitude bands to be specified. Possibly due to a bug in VCDAT, this has to be fixed externally. The steps are:

  - Save the properly masked data to a NetCDF file from VCDAT. For example, see `ERBE_lw_apr94_5x5.nc` in the ~`edis/ERBE` directory.
  - Create a temporary text file by issuing a command like "`ncdump ERBE_lw_apr94_5x5.nc > temp`".
  - In a text editor, edit the file `temp`, getting rid of all variables and attributes having to do with *bounds*. Then replace the data for the latitude—*fakedim14*, *fakedim16*, or *fakedim36*—with "−87.5, −82.5, −77.5, ...". See the file `temp_example` for an example of a properly edited file.
  - Create a fixed NetCDF file by using a command like "`ncgen -o ERBE_lw_apr94_5x5_latfix.nc temp`".

  After the fixing is done, the new NetCDF files can be used directly. See the directory ~`edis/ERBE` for examples.

Looking into how ERBE data might be obtained from PCMDI might be useful if any further comparisons of this sort are to be made. If PCMDI has the kind of data we need, it will at least be in NetCDF format, saving some trouble. We do not know whether other issues listed would still need to be dealt with.

1.2 Impact runs

For the initial tests, two IMPACT runs of the TS6 mechanism using $4° \times 5°$ 1998 MACCM3 met fields were generated. One was a full year's worth, with monthly mean radiation results output, and the other was a run of January only, with instantaneous radiation output every three hours.

The full-year run had to be broken into two segments due to run-time restrictions on seaborg. The first part did the first 7 months of the year, and the second part used the restart file from the first run to get the remaining 5 months. The results are in `TS6_rad.rad.nc` and `TS6_rad_rst7.rad.nc` in the ~`edis/ERBE` directory. The namelist files for these runs are `TS6_rad.in` and `TS6_rad_rst7.in`.

The *radiation* dimension for the flux fields in these files corresponds to sulfur being included (1) or turned off (0) for the radiation calculations. The presence of sulfur affects only the shortwave radiation, and the difference is usually 2–3 W/m^2. An example difference between monthly mean top of the atmosphere shortwave fluxes calculated with sulfur and without is given in Figure 1. (*Note:* IMPACT's radiation code computes top of the atmosphere values in the shortwave, but top of the model in the longwave.) All runs used in the comparisons following are for the sulfur turned on.

The hourly run produced instantaneous radiation results every three hours for the full month of January. These are in `TS6_hourlyrad.rad.nc`; note that to save time, only one radiation calculation, that including sulfur, was performed in this case. The namelist file is `TS6_hourlyrad.in`.

1.3 ERBE-Impact comparisons

1.3.1 Monthly mean comparisons

The first comparison was of monthly mean shortwave and longwave radiation fluxes at the top of the atmosphere. We compared both the regional patterns and the zonal averages for each month.

For the regional comparisons, the procedure was as follows. ERBE data from files such as `ERBE_lw_apr94_5x5_latfix.nc` were regridded onto the $4° \times 5°$ IMPACT grid. Then the regridded ERBE data (longwave or shortwave), the corresponding data slice from the IMPACT radiation file (either `TS6_rad.rad.nc` or `TS6_rad_rst7.rad.nc`, depending on the month), and a field consisting of [IMPACT − ERBE]/ERBE for each grid point were written to files such as `apr_lw_4x5.nc` and `apr_sw_4x5.nc`. Then the [IMPACT −

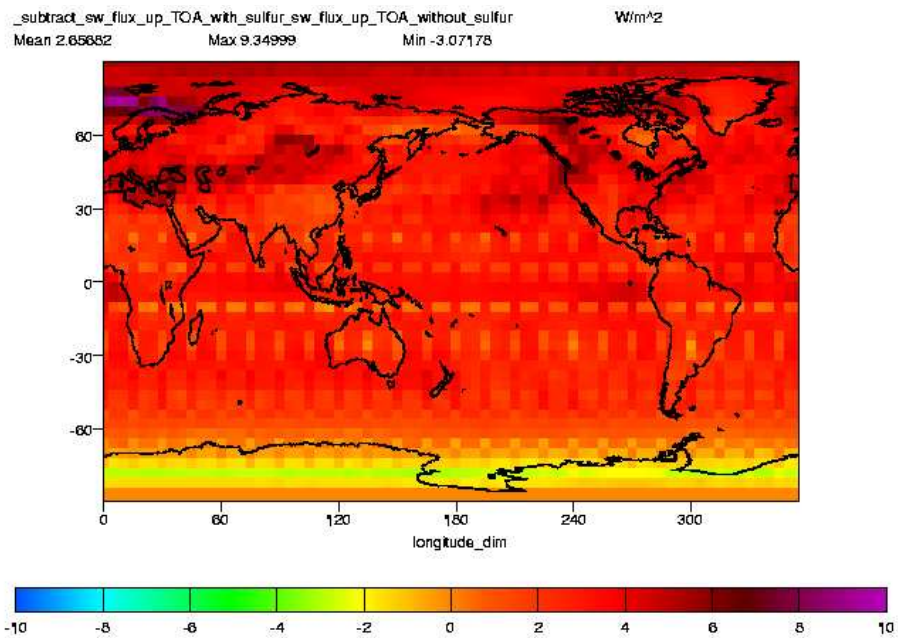

Figure 1: Difference between monthly mean shortwave radiation at the top of the atmosphere with sulfur and without, for May 1998, as calculated by IMPACT. Units of W/m^2. The hourly features are probably due to IMPACT's monthly averaging of shortwave calculations performed at the same hours, so the day-night terminator effects do not get smoothed out over the month.

ERBE]/ERBE was plotted for each month, to give a relative comparison for regional variations between ERBE and IMPACT results. These plots are stored in files such as `apr_lw_4x5_compare.gif`. Some, but not all, have PDF and EPS equivalents as well.

A sampling of these regional comparisons are shown in Figures 2 and 3. Plots for other months can be found in the ~`edis/ERBE` directory. The patterns for longwave radiation match relatively well, due to the major determinant of longwave flux being surface temperatures. The local patterns in the shortwave vary more strongly, but that can be expected as clouds in particular have a stronger effect on the shortwave radiation reflected upward.

Zonal comparisons involve integrating fluxes over longitudes for ERBE

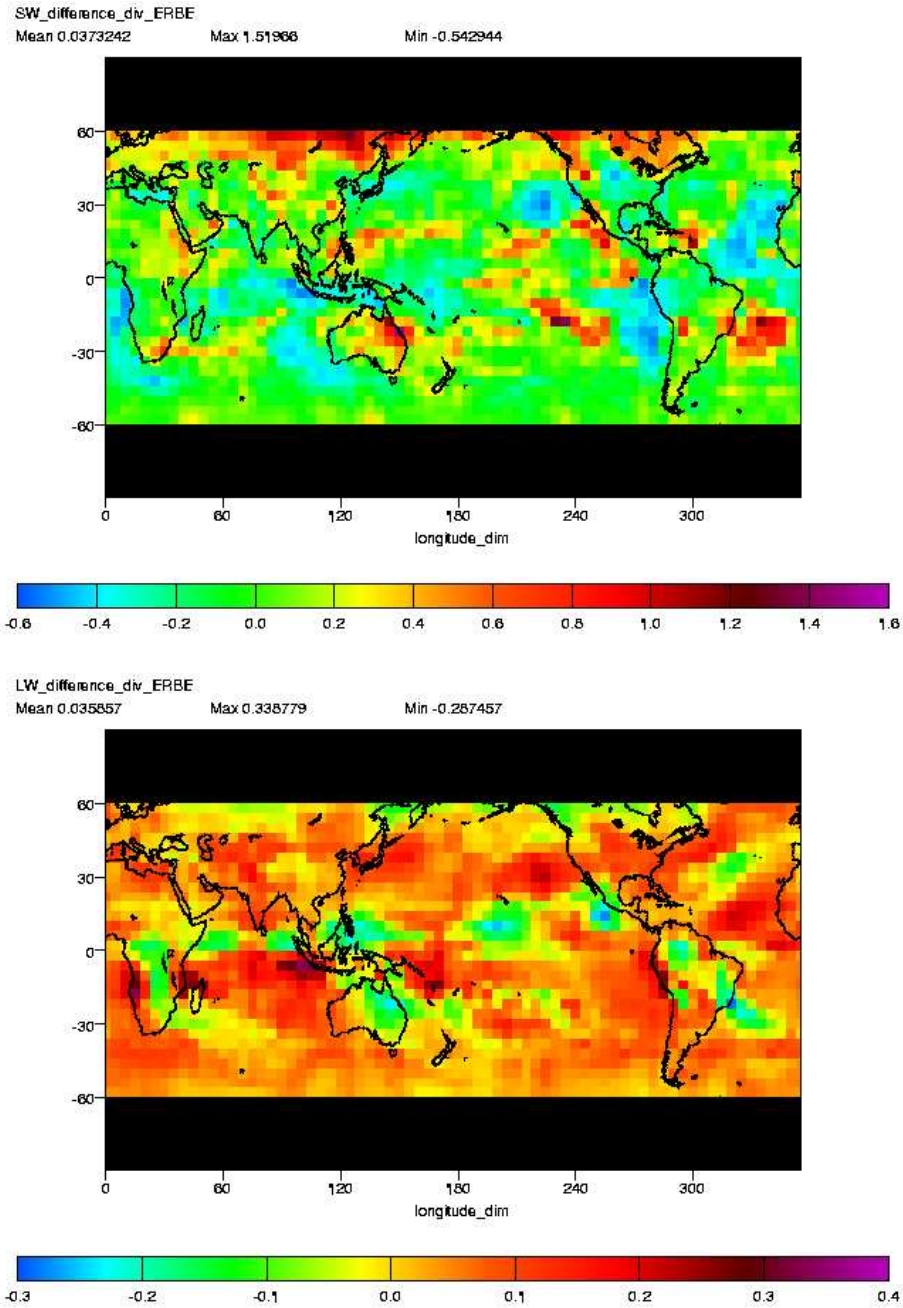

Figure 2: January shortwave TOA comparisons (top), longwave TOM (bottom). Scale: 1 = 100%.

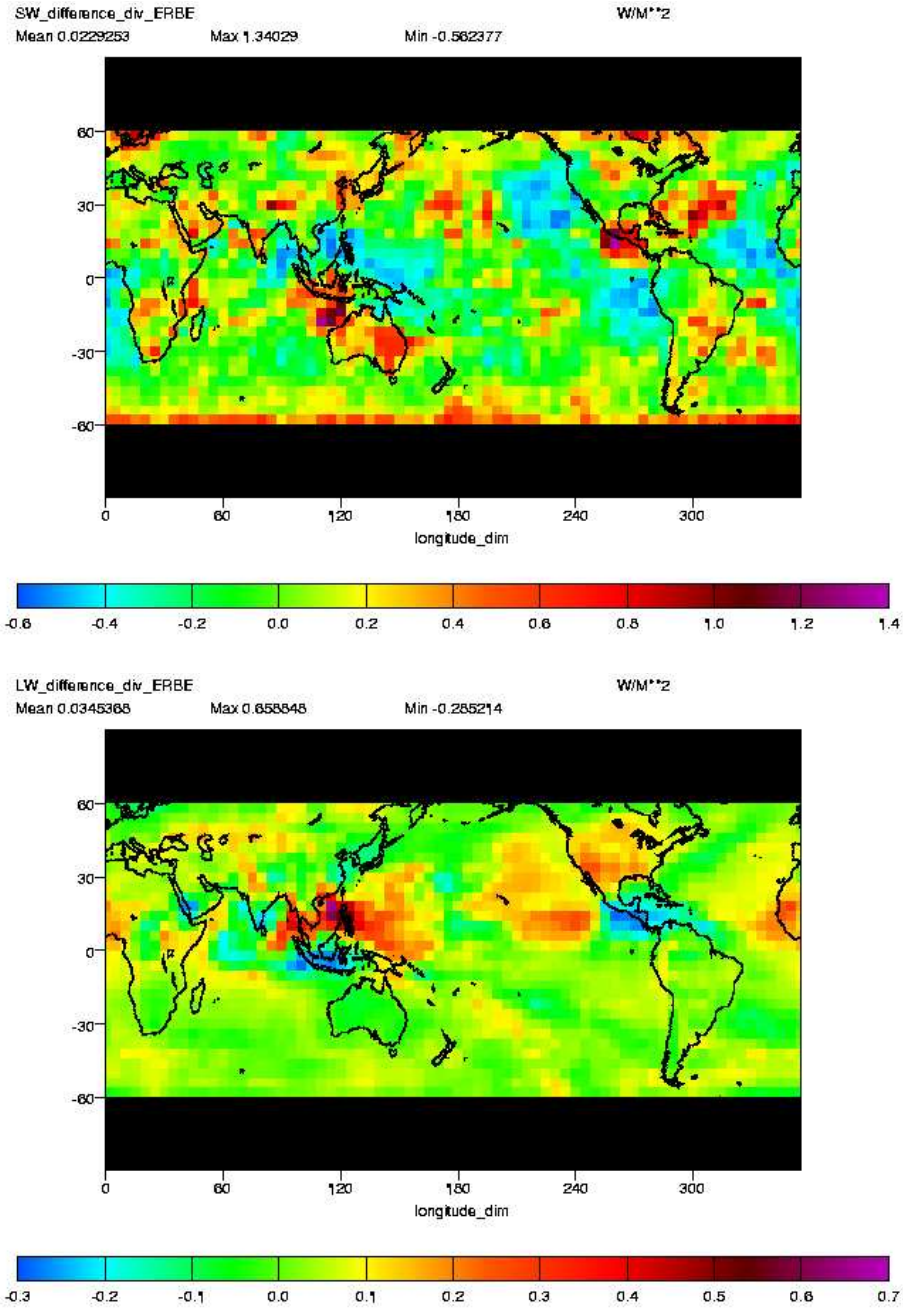

Figure 3: July shortwave TOA comparisons (top), longwave TOM (bottom). Scale: 1 = 100%.

and for IMPACT results. The zonal averaging smooths out some of the regional variation due to clouds, presenting a better overall comparison. These graphs are in files such as `jan_sw_zonal.gif`; many have EPS and PDF equivalents. Note that these are overlay graphs. The horizontal axes are labeled by some "fakeDim" which really means latitude. The vertical axis is average flux, in W/m^2. The black line is ERBE data, and the red line is the result of the IMPACT run in each. Figures 4 and 5 present some zonal comparisons for short- and longwave fluxes.

These comparisons show some general trends.

- For shortwave radiation, regional and zonal fluctuations do not exactly correspond, but this is no great surprise. The global average fluxes compare pretty well. Discrepancies are likely due to differences in cloud cover, plus concerns with surface albedos in the MACCM3 met data being used. The albedos are read in from a separate file, and were originally generated from CCM3 for Cathy Chuang's use. Given all these imperfections in the met data, our match is very reasonable in the shortwave.

- The longwave radiation from IMPACT matches regional and zonal patterns from ERBE well, as it should. However, the IMPACT calculation appears on our graphs to overestimate the longwave fluxes by about 4–5 W on average. Now, about a 2% overshoot is not bad, but it's systematic. We cannot expect much better from this test, however, because of shortcomings of the MACCM3 met data. The largest problem is that MACCM3 does not provide ground temperatures, so we use the lowest air layer temperature as the best approximation available. It is hard to judge the exact effects of this, but due to blackbody emission being proportional to T^4, offhand we would expect this approximation to slightly depress the calculated longwave fluxes. So our actual error might be larger than 2%.

  On the other hand, another source of error comes from the different boundaries between long- and shortwave radiation in IMPACT and ERBE. The wavelength range of 0.175–3.85 μm is the shortwave for IMPACT's radiation code, while for the ERBE instruments shortwave is listed as 0.2–5.0 μm. The overlapping 4–5 μm range is included in IMPACT's longwave calculation but not in ERBE's longwave range; this is an area on the tail of the blackbody curve, but it still could contribute

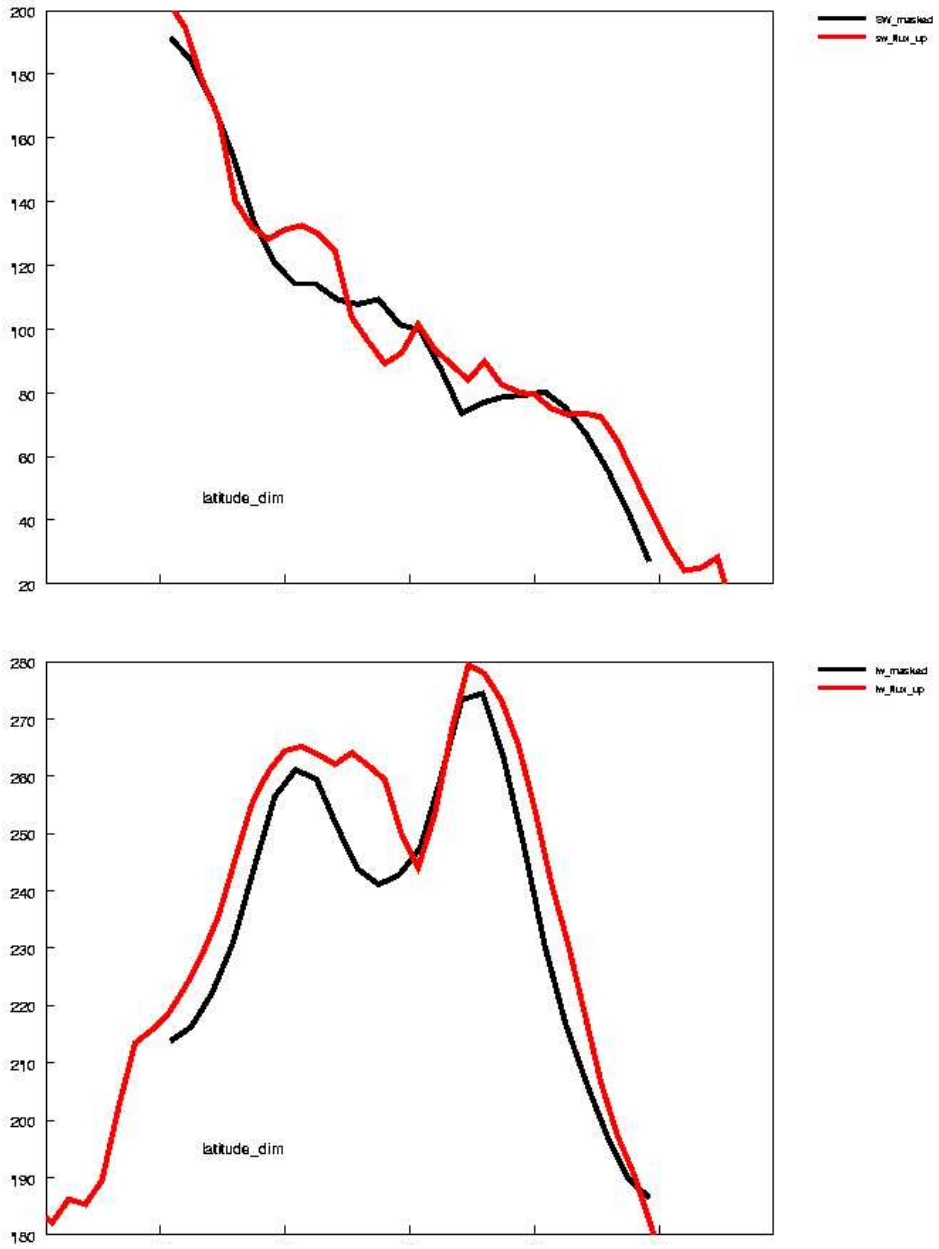

Figure 4: January, zonal shortwave TOA (top) and longwave TOM (bottom). Red: IMPACT, black: ERBE. "latitude_dim" is a VCDAT artifact. Units: W/m^2.

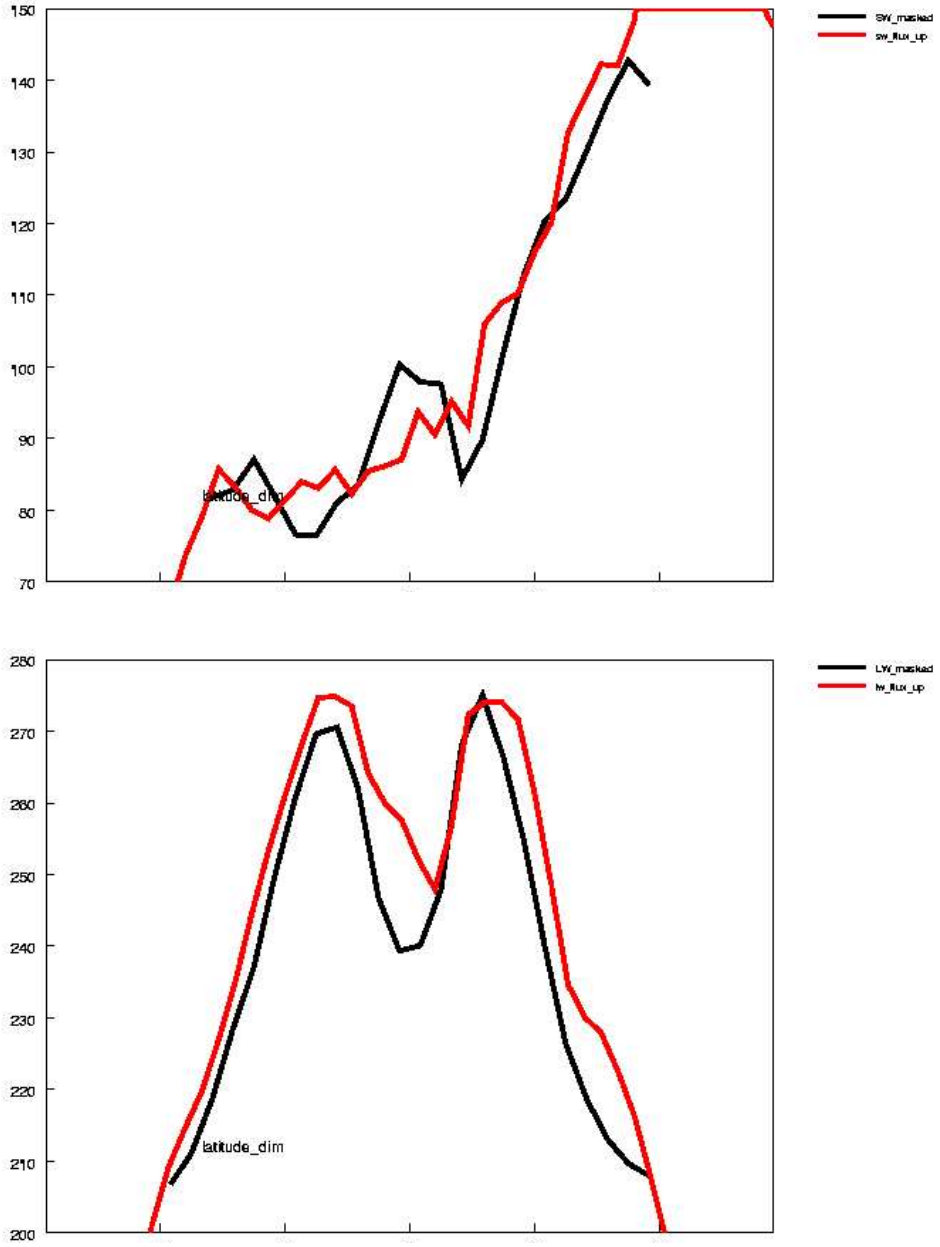

Figure 5: April, zonal shortwave TOA (top) and longwave TOM (bottom). Red: IMPACT, black: ERBE. "latitude_dim" is a VCDAT artifact. Units: W/m^2.

a percent or two. It is possible to alter the radiation code to test this by altering a loop in `irrad.F` to not sum the 8th spectral band corresponding to $\sim$ 4–5 μm when calculating the total flux. However, this is probably not worth the time as we are clearly playing with a few percent errors comparable to what we expected from imperfections in the met data.

In short, the monthly means compare well for both short- and longwave radiation fluxes. We consulted with Jay Hnilo from PCMDI to confirm our judgment, and he agreed; our zonal comparison graphs look very much like those PCMDI produces, and he says that getting within 4–5 W is good.

1.3.2 Total annual flux

We also checked that the annual integrated flux at the top of the atmosphere (top of the model for longwave) as calculated by IMPACT balanced out properly. The results are in Table 1.

longwave upward yearly average	=	242.86 W/m^2
shortwave upward yearly average	=	103.53 W/m^2
shortwave downward yearly average	=	339.96 W/m^2
net flux difference (down − up)	=	−6.43 W/m^2
difference / downward flux	=	−1.9 %

Table 1: Annual average fluxes at the top of the atmosphere.

This table was calculated by an IDL program, `flux_avg.pro`, located on the directory ~`edis/ERBE` as with all else.

1.3.3 Hourly flux comparisons

We also checked the monthly averages of local hourly fluxes for longwave radiation. ERBE includes regional data for hourly fluxes, but IMPACT produces output at regular intervals. So the data from the IMPACT runs had to be converted to monthly averages of local hourly data.

The IMPACT run for hourly radiation output results every 3 hours. The averaging and rearranging to local hourly form was done through a pair of IDL programs.

- `lw_mm.pro` was used to create separate files for the longwave top of the atmosphere upward flux for GMT 3, 6, 9, . . . , 21, 24 hours. The current form is for generating hour 24. Each hour's file, such as `lw_h09.nc`, was generated by altering the IDL program—changing the *mmo* variable to the appropriate offset in the last element of the array (0 for hour 3, 1 for hour 6, etc.), and changing the name of the new file created—and then recompiling and rerunning it. All flux data in each of the hourly files is stored in the variable *lwup_top_h3* even for hours other than 3.

- The hourly files such as `lw_h09.nc` were then processed to create a file called `lw_local.nc`, containing local hourly flux data that can be compared with ERBE data. This was done with the IDL program `local_hours.pro`, which took each longitude which had the appropriate local hour of 3, 6, 9, . . . , 21, 24 from the hourly files, together with an 1.5 hour-wide strip on its east and west sides, and glued them all together to make an approximation to global hourly results for local hours 3, 6, etc. This program needs to be compiled and run just once, without repeated alterations.

When zonal averages are compared, the hourly flux data show a similar pattern to what was the case with monthly zonal means: the longwave results from Impact are a slight overestimate. Comparisons for hours 3, 6, etc. can be found in files named `jan_lw_h12_zonal.gif` and so forth; some have EPS and PDF equivalents. Two are reproduced in Figure 6.

Another relevant comparison is between local hours 3 and 15 (cold and hot part of day); plotting the flux differences calculated by Impact and obtained from ERBE data. These are presented in Figure 7, from files `jan_lw_ERBE_15-3h.gif` and `jan_lw_Impact_15-3h.gif` (or `.pdf` or `.eps`). The overall patterns make sense and compare well, with one exception. For Impact, over Australia and North America the longwave flux is *less* at 15 hours local than at 3 hours local. This is puzzling. It is possible that some cloud features may lead to this behavior, but they would have to be pretty persistent, since these are month means. Jay Hnilo suggested that the Australian case may be understandable because it is at high latitudes in January, but that would not apply to North America. Though not a huge concern, this is something to look at, perhaps when comparisons with calculations based on better met data can be done.

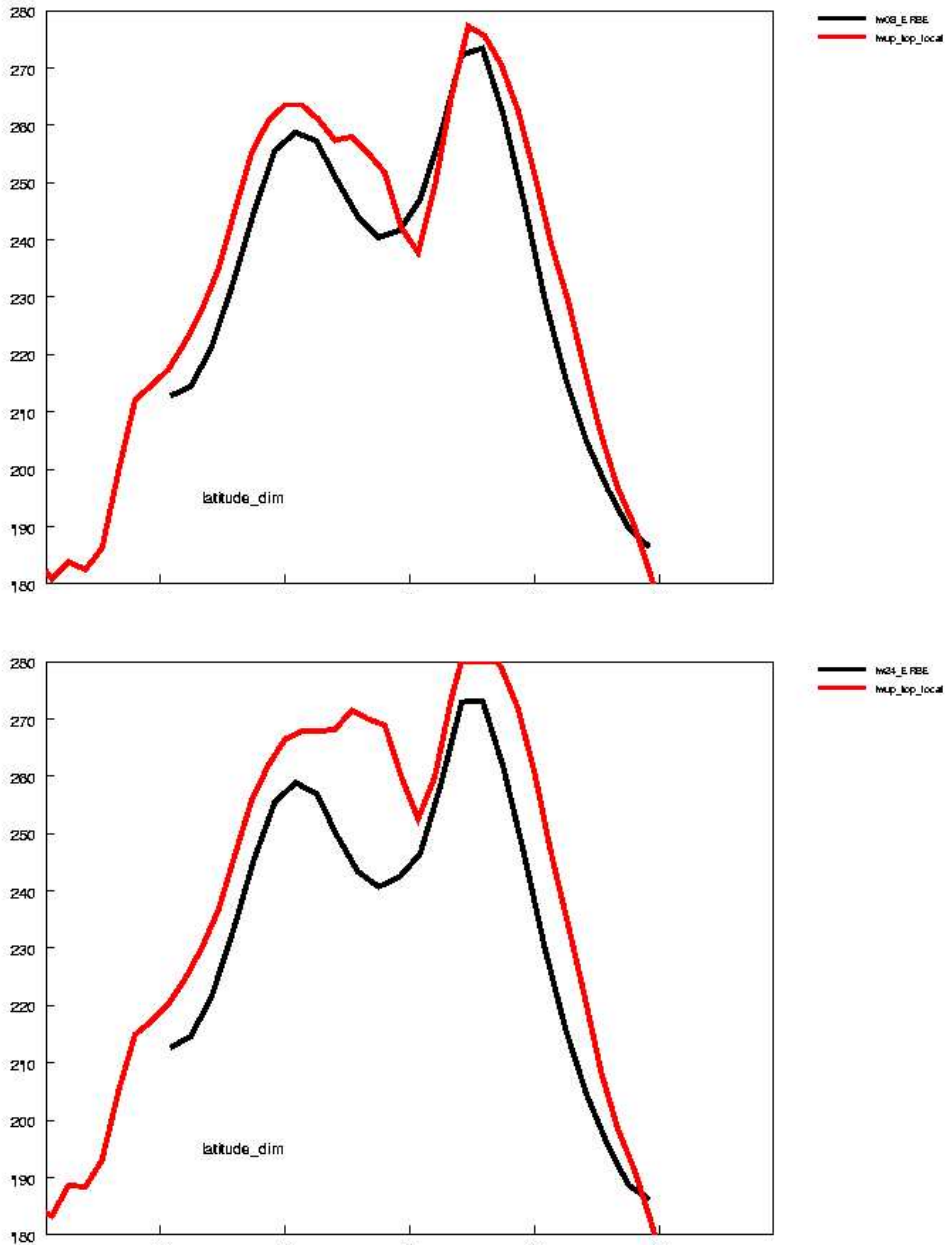

Figure 6: January, zonal longwave TOM, local hour 3 (top) and 15 (bottom). Red: IMPACT, black: ERBE. "latitude_dim" is a VCDAT artifact. Units: W/m^2.

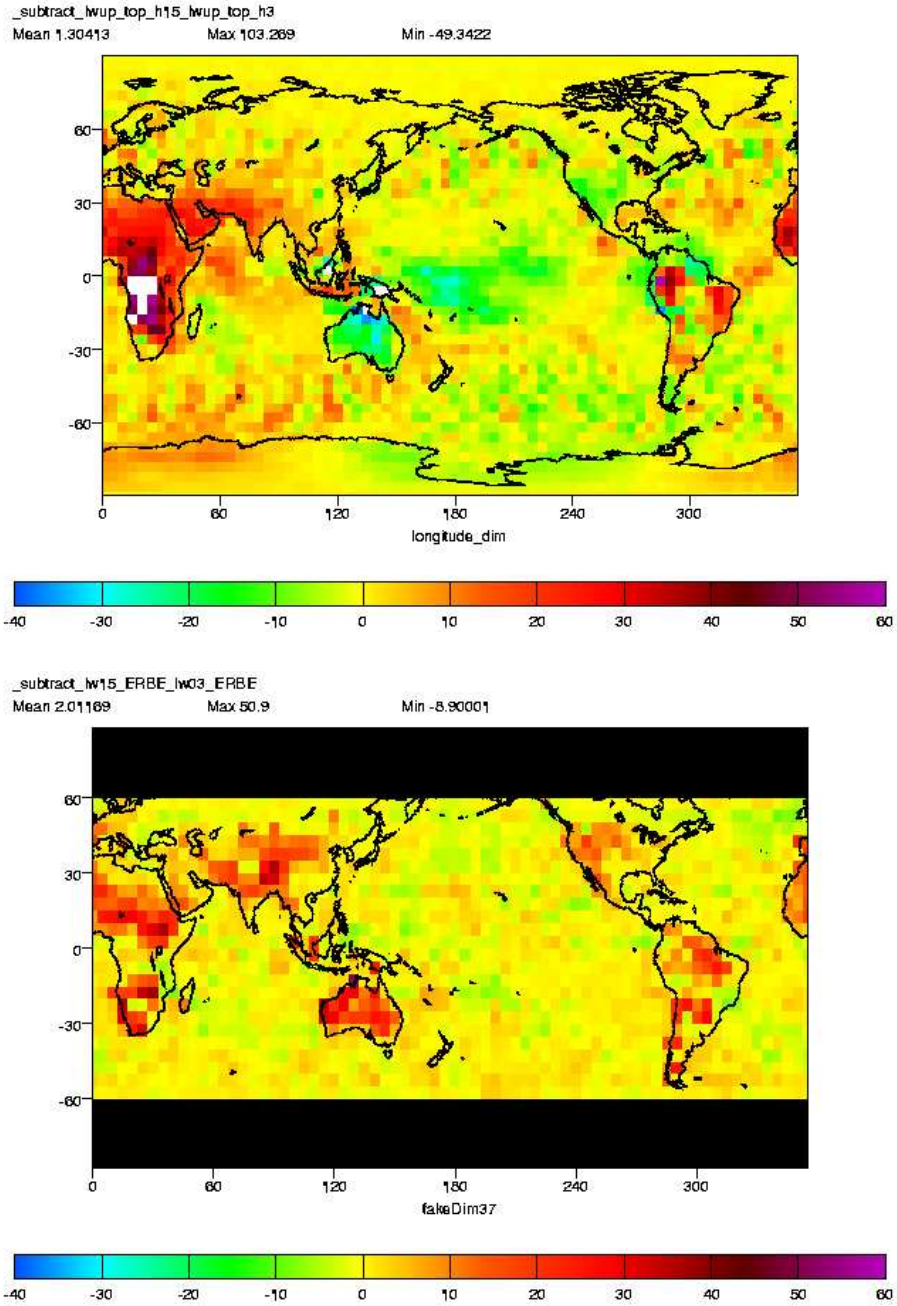

Figure 7: Difference between 15 and 3 hours local, IMPACT (top) and ERBE (bottom).

2 CAM3 testing

Given the imperfections of MACCM3 met data, and our goal of using IMPACT radiation calculations in the SciDAC project which relies on CAM3/WACCM, the next step was to begin testing the radiation code by using CAM3 met data.

2.1 Brief CAM3 runs

Our initial effort was to test the radiation code with CAM/WACCM met data generated for 1978 September 1-6. This was a crude run, just to shake some bugs out and confirm that IMPACT was running properly with the CAM3 met fields. This appeared to give reasonable results.

One of the major issues with CAM3 met fields is the surface albedo values which are needed for the radiation calculations. In the met data files themselves, a three-hourly average is used. This, however, gives peculiar values close to the day-night terminator, due to CAM3 representing land with an albedo of 1 and sea with an albedo of 0 on the dark side. So reading albedos in along with other met fields will lead to significant errors, especially in shortwave radiation computations. The partial solution we adopted was to read in albedo values hourly, as a separate stream from different files. This will be much more accurate.

Once IMPACT was running with CAM3 met data, two different radiation runs were made to test the difference made by reading albedos as met data and as a separate stream. Both runs were on CAM3 met fields and associated albedo files for January 1 and 2, 1979. The file `TS6_CAM3_alb3test.rad.nc` contains a straight run with albedos obtained from met fields—*sfalbedo_opt = 3* in the namelist file. Radiation results from a run which was identical in all respects but for reading in albedos separately, every hour, (*sfalbedo_opt = 4*) is in `TS6_CAM3_alb4test.rad.nc`. Their respective namelist files in ∼`edis/ERBE` are `TS6_CAM3_alb3test.in` and `TS6_CAM3_alb4test.in`.

The runs were done with *do_timinterp_met* = *F* in the namelist files, so met data were not time-interpolated. The results obtained make the best sense if they are based on the albedos read in previously to the time of radiation output. In Figure 8, the surface shortwave direct albedo values being used to calculate the radiation output at hour 18 are displayed. For the albedos read in with the met data, this is the albedo from hour 15. For the albedos read in separately, they are for hour 17. Note the problematic terminator for

the met data version. The files for these plots are `sasdir_met_h15.eps` and `sasdir_hourly_h17.eps` (and `.pdf`).

Figure 9 gives the upward shortwave flux at the bottom of the atmosphere for the run with albedos taken with the met data, and for the run with albedos read in separately. Both are at 18 hours model time. Note that the run using the met data significantly overestimates the reflected flux; this was a general pattern with other hours as well. To interpret the graphs, consult Figure 8 for the albedos used at that point. The line of where the reflection terminates in the Pacific ocean tracks the corresponding albedo terminators in Figure 8 well. The North American albedo gets overestimated for the run using met file albedos, as the sun has already moved westward and is picking up the land areas with albedo set ≈ 1. Why there is an overestimation over spots of South America is not clear, however. The files for these plots are `sw_surf_h18_metrun.eps` and `sw_surf_h18_hourlyrun.eps` (and `.pdf`).

For a more reliable shortwave calculation, it would be best if the albedo values read in were better synchronized with the time the radiation is computed. Since hourly read-ins of the albedo from separate files is done largely for radiation purposes, it would be a good idea to look at where they are read-in in the IMPACT code and use the closest appropriate time albedos in the radiation calculations.

2.2 WACCM radiation variables

Our motivation for this work is to compare IMPACT-calculated radiation with WACCM radiation in the context of the SciDAC project. We have therefore also identified the WACCM fields which need to be output for comparison purposes.

These fields were compared to the monthly mean radiation output of IMPACT to check what combination of IMPACT variables should be compared to WACCM. The comparison is far from exact, as the only complete TS6 IMPACT run we have on hand is for 1998 with MACCM3, and the test data from WACCM we used was for a 2100 run. The relevant WACCM variables and IMPACT equivalents are presented in Table 2.

Among the WACCM variables, *FLUT* ($\uparrow$ longwave flux at TOM) probably should be omitted because it is practically identical to *FLNT*; similarly, *FSNTOA* (Net $\downarrow$ shortwave flux at TOA) is almost identical to *FSNT*. Note that the heating rates in WACCM are given in K/s while IMPACT uses K/day and should be divided by 86400 to compare.

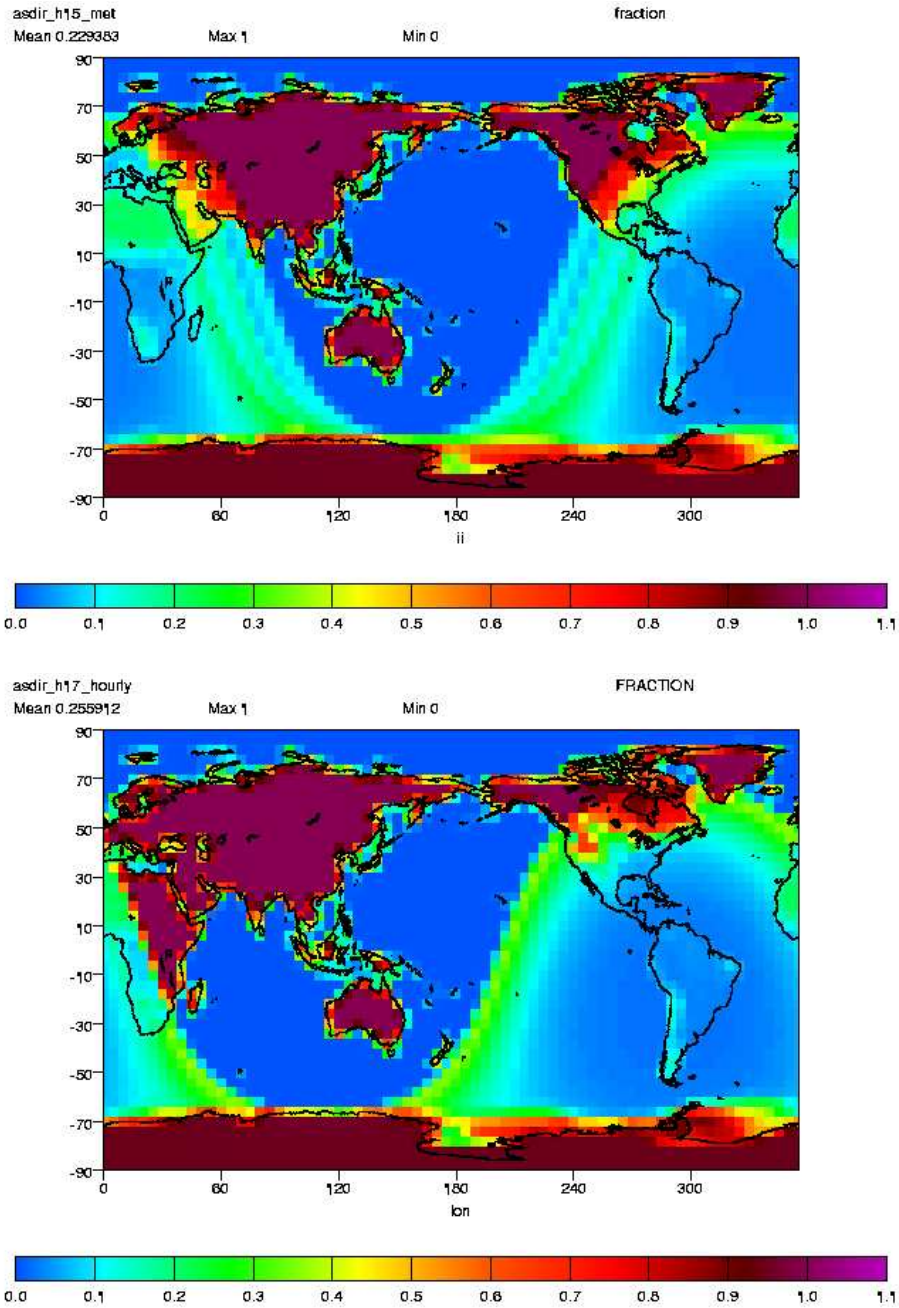

Figure 8: Direct shortwave albedos; met data (top) and hourly (bottom).

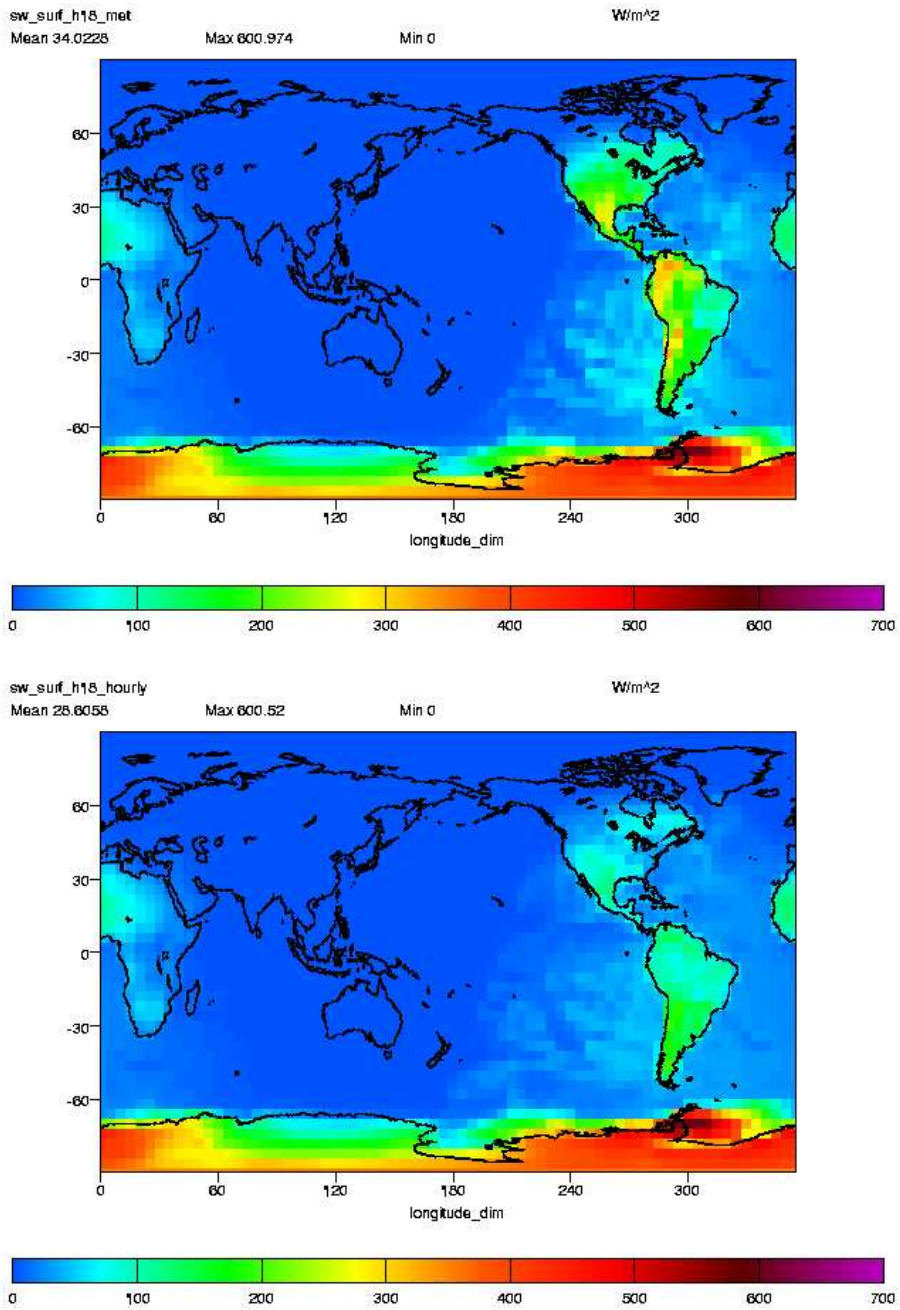

Figure 9: Upward shortwave flux at the surface using met and hourly albedos.

WACCM	Description	Impact
FSNS	Net ↓ SW, surface	*sw_flux_down* − *sw_flux_up* (surface)
FLNS	Net ↑ LW, surface	*lw_flux_up* − *lw_flux_down* (surface)
FLNT	Net ↑ LW, TOM	*lw_flux_up* − *lw_flux_down* (top)
FSDS	SW ↓, surface	*sw_flux_down* (surface)
FSNT	Net ↓ SW, TOM	*sw_flux_down* − *sw_flux_up* (top)
QRS	SW heating rate	*sw_heat_rate* (3D)
QRL	LW heating rate	*lw_heat_rate* (3D)

Table 2: WACCM variables and corresponding IMPACT radiation variables.

Even the crude 2100 vs. 1998 comparisons are generally fine, with global mean differences not exceeding 10–15%, and the regional patterns being very similar. The exception is the shortwave heating rate, which has the right order of magnitude, but the mean is off due to some extreme values dominating. For both short- and longwave heating rates, the discrepancies arise in the stratosphere. We are not completely sure of the reason or significance of this; however, the IMPACT runs were done using TS6, which is inaccurate at just those altitudes where the heating rates seem too high. For example, TS6 has too much ozone higher than about 3 mbar, which would lead to overheating. This should not be a concern for SciDAC runs with CAM3, as the CAM3 atmosphere only goes up to about 3.5 mbar. In any case, the high latitude heating rates bear looking at again when proper runs for comparisons are available. Figures 10 and 11 give the zonally averaged heating rate plots for WACCM year 2100 and IMPACT with MACCM3 year 1998, both monthly means for January. The vertical scale is logarithmic, to highlight the divergences high in the atmosphere. The files plotted are `qrs_zonal.eps`, `swhr_zonal.eps`, `qrl_zonal.eps`, `lwhr_zonal.eps` (and `.pdf`).

Some details of WACCM should also be found out. WACCM makes some near-IR variables available; we need to know whether the near-IR is treated separately or folded into the shortwave fluxes as in IMPACT. It would also be useful to know precisely what wavelength ranges WACCM considers shortwave and what is longwave.

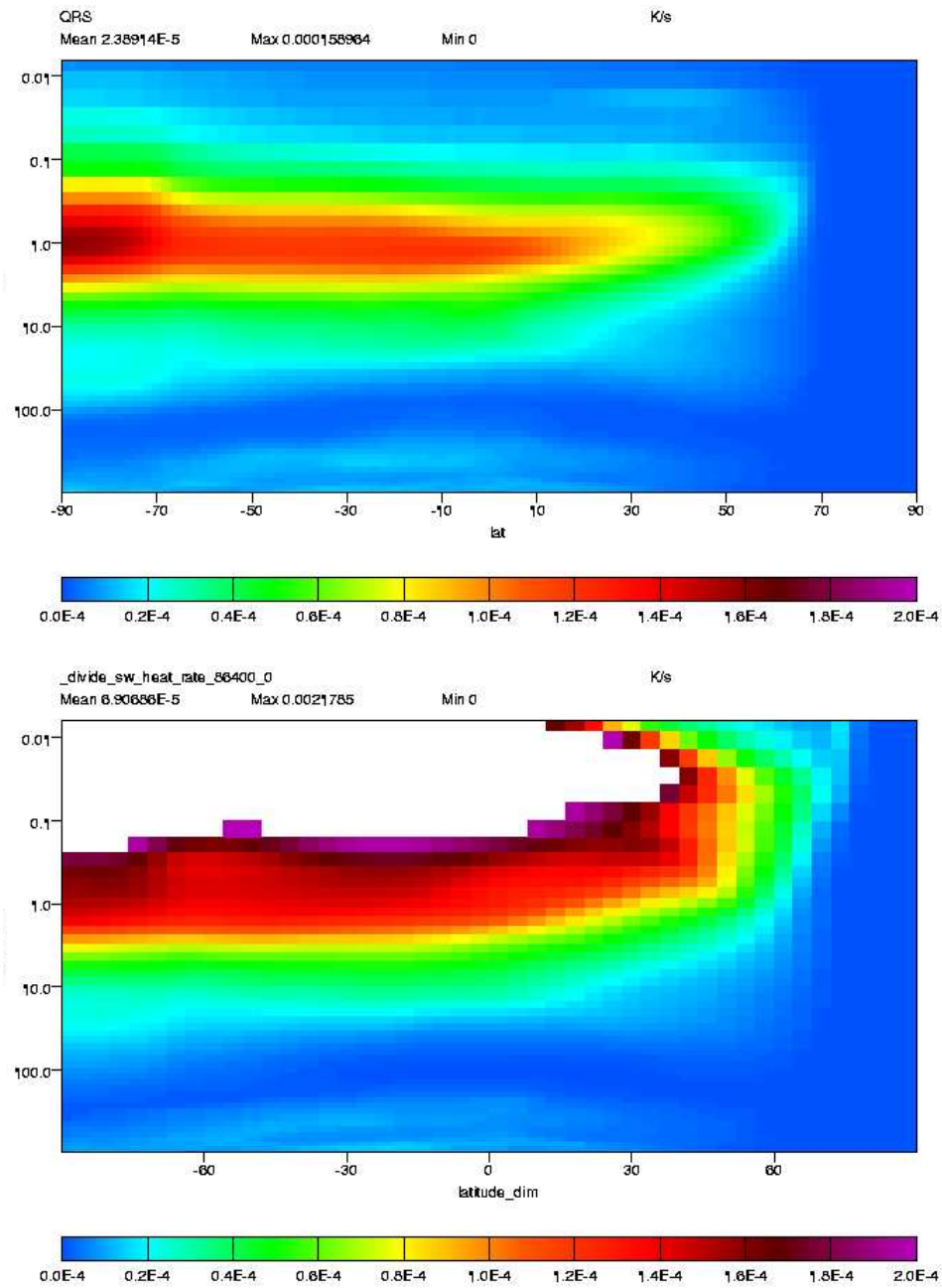

Figure 10: January shortwave heating rates, WACCM year 2100 (top) and TS6 IMPACT year 1998 (bottom). Units: K/s. Whitespace: offscale.

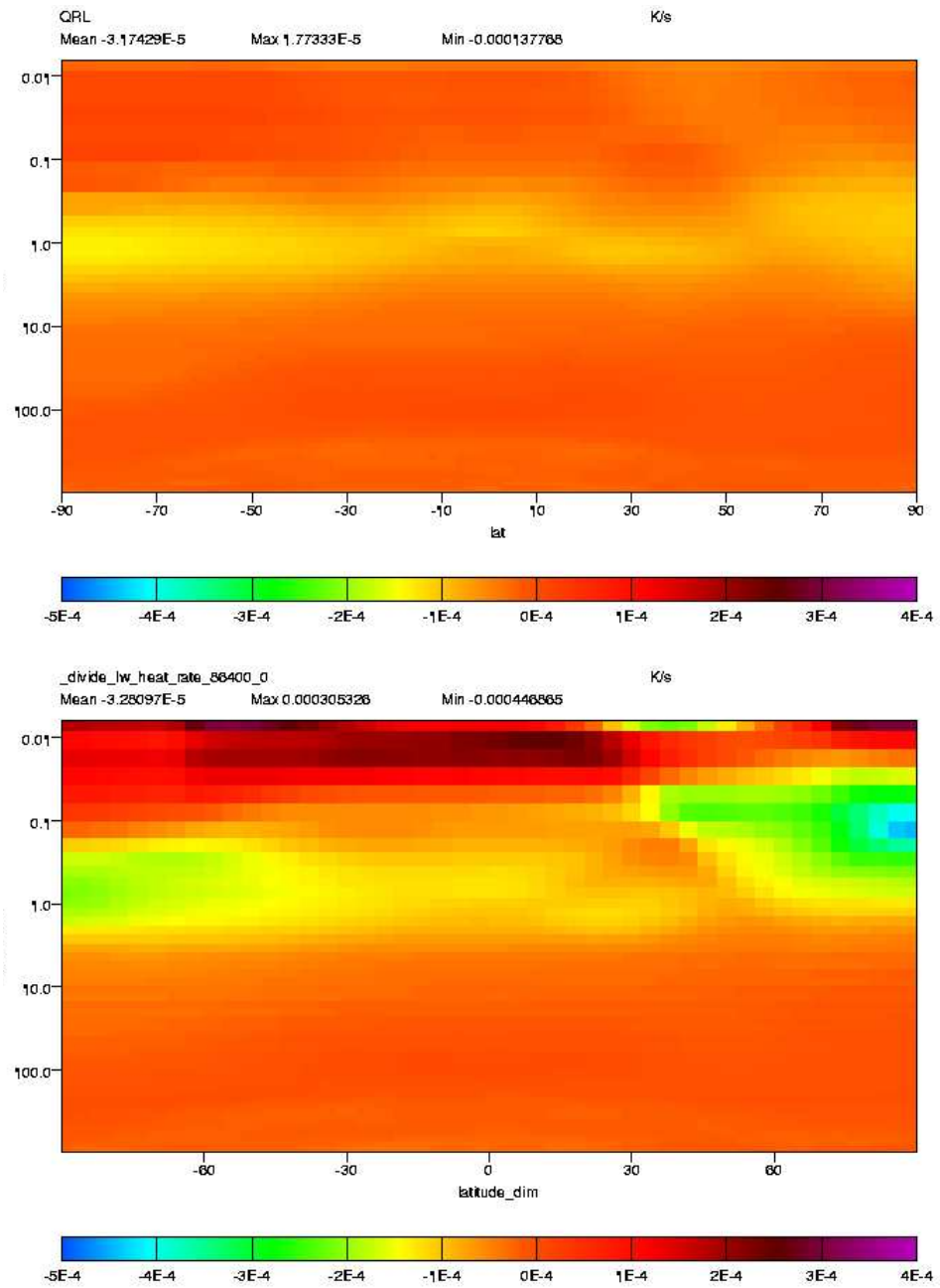

Figure 11: January longwave heating rates, WACCM year 2100 (top) and TS6 IMPACT year 1998 (bottom). Units: K/s.