

**U.G.A.M.P.
INTERNAL REPORT**

UK Universities Global Atmospheric Modelling Programme

UGAMP Internal Report No. 39

The SLIMCAT Offline Transport Model

Martyn Chipperfield

January 1996

**This paper has not been published and is for internal circulation
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Martyn Chipperfield
Centre for Atmospheric Science
University of Cambridge

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Version 1.0

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1 Introduction

SLIMCAT is an off-line three-dimensional (3D) chemical transport model (CTM). The model is a development of the TOMCAT model which was initially written by Pascal Simon and Martyn Chipperfield at the Centre National de Recherches Météorologiques at the French Met. Office in Toulouse.

SLIMCAT can use winds and temperatures from a variety sources such as meteorological analyses or GCM output. The model uses an isentropic vertical coordinate (surfaces of constant potential temperature, θ) and can be used as a single level model or a multi-level model with or without vertical transport. Tracer transport is achieved using the scheme of Prather [1986]. This can be used with the conservation of second order moments, conservation of first order moments or conservation of zero order moments. SLIMCAT can be used to simply advect passive tracers or can be coupled with a chemistry scheme. The SLIMCAT `nupdate` library contains a stratospheric chemistry scheme which can be used with SLIMCAT. Alternatively the user can supply his/her own.

Another related model is TOPCAT. This is a model which calculates 3D particle trajectories again using the same forcing files as TOMCAT. The vertical motion of the trajectories can be calculated using the vertical winds derived from the divergence (as in TOMCAT) or using a radiation scheme (as in SLIMCAT). The TOMCAT chemistry scheme can also be used to calculate chemistry along these trajectories (see UGAMP internal report no. 37).

Section 2 briefly describes the formulation of the model. Section 3 lists the sources of winds and temperatures than can be used to force SLIMCAT. Section 4 describes how to access standard job decks and how to run the model.

2 Formulation of SLIMCAT

This section briefly describes the formulation of SLIMCAT. A lot of the code of SLIMCAT is common to TOMCAT.

2.1 Horizontal Transport

The horizontal winds are obtained directly from the forcing files that are read in. These forcing files can either contain spectral coefficients of streamfunction and velocity potential (e.g. from the ECMWF) or gridpoint values of u and v from the UKMO.

The model uses regularly spaced longitudes but the spacing of latitudes can be completely irregular. This is no problem when using the gridpoint UKMO winds but with the spectral ECMWF fields the model will need the files of Legendre coefficients to perform the spectral transform to the required grid. For this reason, when using ECMWF (or GCM) spectral data it is easiest to use one of the standard Gaussian grids (e.g. T10, T15, T21, .. T213) for which the necessary coefficients have already been set up.

2.2 Vertical Transport

For multilevel runs of SLIMCAT the vertical (diabatic) transport can be calculated using the MIDRAD radiation scheme. MIDRAD was originally written by K.P. Shine and the version used in SLIMCAT is almost identical to the code implemented in the UGAMP Stratosphere Mesosphere Model (USMM) by J. Thuburn. For multilevel runs the vertical motion can be turned on and off using the switch `IVER`.

SLIMCAT is coupled with the MIDRAD radiation scheme to calculate heating rates for the vertical transport in isentropic coordinates. In the standard code the bottom boundary for the radiation code is specified as 700

hPa. There are dummy levels for the radiation scheme above and below the SLIMCAT isentropic levels. The bottom boundary infra-red fluxes are a latitudinally varying climatology, and have been provided by K.P. Shine.

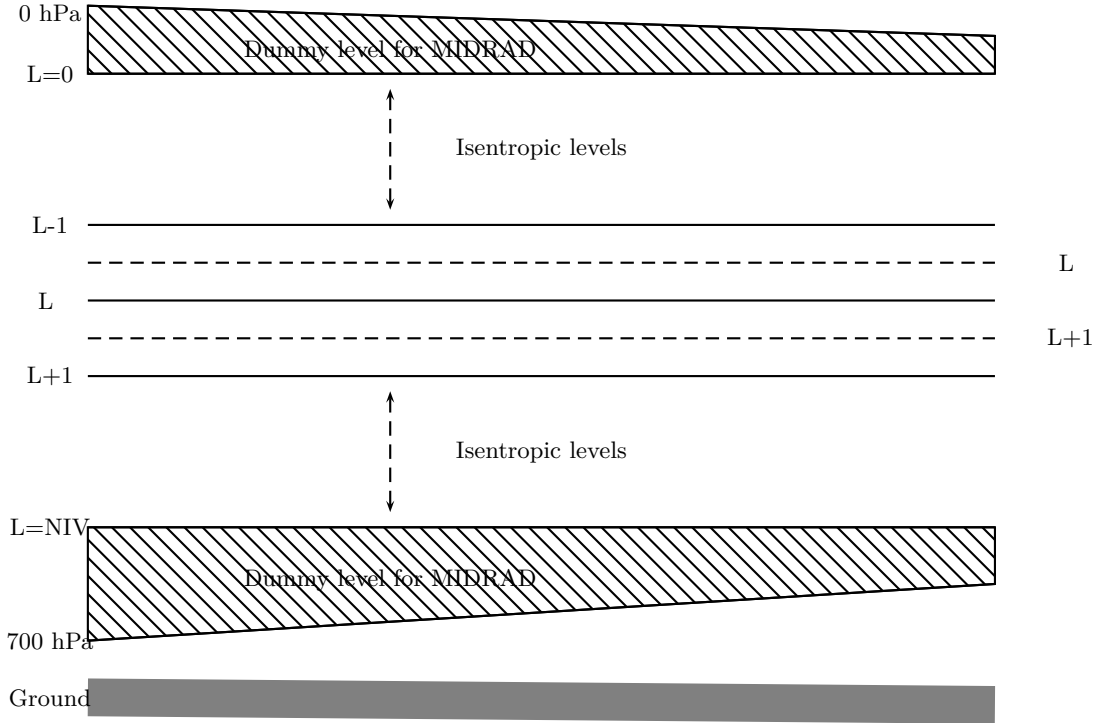
The MIDRAD radiation scheme gives the diabatic heating rate (dT/dt) at the centres of the model levels. This is converted to the change in θ and then to the vertical mass flux (vmf in kg/s) between 2 boxes of area **SURF** as follows:

$$vmf = \frac{dT}{dt} \left(\frac{XP00}{p} \right)^{RASCp} \left(-\frac{1}{g} \frac{dp}{d\theta} \right) \text{SURF}$$

where p is pressure and the other symbols have there usual meaning (see section 4.6).

2.3 Model Grid

The SLIMCAT model grid is illustrated below. The model isentropic levels are labelled downwards from 1 to NIV. Between the top of the top isentropic level and 0 hPa, and between the bottom of the bottom isentropic level and 700 hPa are two dummy levels used by the MIDRAD scheme to account for the atmosphere outside of the model domain.



2.4 Mass Balance

In the current standard version of SLIMCAT described here (UNISLIMC) there is no constraint on the horizontal and vertical motions to ensure that the net mass transport into (or out of) a box equals the evolution of the box mass on the basis of the specified temperature fields through the changing isentropic density. To overcome this, a fairly crude correction is applied to the tracer masses on each timestep. Firstly, the total mass of a gridbox is reset to what it should be on the basis of the analysed temperature fields. Then, the tracer mass after the advection step is scaled in proportion to this correction of the total mass (i.e. the tracer mass is reset by keeping the volume mixing ratio constant). It is planned that a future version of the model will constrain the horizontal winds to balance the calculated vertical winds.

3 Forcing Winds and Temperatures

This section describes the various sources of winds and temperatures that can be used to force SLIMCAT. These forcing files are identical to those used in the TOMCAT 3D model and the TOPCAT 3D trajectory model.

3.1 ECMWF Analyses

The ECMWF analyses that can be used to force SLIMCAT are stored on Green/Fermat/Wrenn in the directories `/v/1rkd/ECMWF/T42` (operational T42) and `/v/1rkd/ECMWF/T42E40` (ERA 40 T42). The files contain the spectral coefficients of the streamfunction, velocity potential, temperature and specific humidity on the original 60 ECMWF model levels as well as the surface pressure. The table lists the periods that are currently available:

Product	Period
T42 Operational	
T42 ERA 40	89, 90, 98

3.2 UK Meteorological Office UARS Analyses

SLIMCAT can also be run using the gridpoint analyses of the U.K. Meteorological Office produced for the UARS mission. These analyses are produced on 22 isobaric levels from 0.3 hPa down to 1000 hPa. The analyses are produced on an Arakawa ‘B’ grid so that the wind fields (u and v) are not given at the same location as temperature and geopotential. SLIMCAT reads the data on this staggered grid; the fields are interpolated to a Gaussian grid and converted to spectral coefficients. They are then treated like the ECMWF winds (above). This data is stored in `/v/1rkd/UKMO`. The table lists the periods that are currently available:

Period	Resolution
21/10/91 to 31/8/2002	2.5 x 3.75

3.3 (E)UGCM Output

SLIMCAT can equally be forced using winds from any (E)UGCM experiment. The winds need to be converted into a similar spectral or gridpoint form to the ECMWF or UKMO analyses.

4 Running the Model

The standard version of the model is 'unislmc' which is contained in the directory `/sanhp/lrkd/unicat/BIBLI`. The processed nupdate decks are in `UNISLIMC` and there is a listing (with linenumbers) in `unislmc_list`.

4.1 Jobdecks

Example jobdecks for SLIMCAT can be found on the Cray in the directory `/sanhp/lrkd/unicat/JOBS`. At present the following standard jobdecks are there:

- None!

4.2 Initial Data and Restart Runs

A file containing the initial tracer fields will need to be set up before SLIMCAT is run. An example initialisation job is `inimod_job` (see above). In this job the user needs to define the horizontal grid required for the model run, the vertical levels of the forcing files (using `FLT` and `GLT`) and the SLIMCAT levels (using `THI` and `THM`). The file `grid_data` in on the web page contains `fortran` data statements which define common horizontal and vertical grids. These can be cut and pasted into the initialisation job.

A SLIMCAT run creates two output files: a PDG file which contains the 3D tracer distributions at specified intervals throughout the run and a REST file which contains the tracer fields at the end of the run. This REST file can be used as 'initial data' for a restart run (see below).

4.3 Parameters

The table lists some of the main parameters in SLIMCAT.

Parameter	Meaning
LAT	number of latitudes
LEV	number of levels in forcing files
LON	number of longitudes
MIO	spectral truncation of winds after conversion
MI1	spectral truncation of winds read in
MLAT	number of latitudes in gridpoint forcing file
MLON	number of longitudes in gridpoint forcing file
NIV	number of isentropic SLIMCAT levels

4.4 Model Switches and Variables

The following switches can be set in the model jobdeck:

Switch	Meaning
IFOR	=1 for spectral (ECMWF) forcing
IFOR	=3 for gridpoint (UKMO) forcing
IVER	=1 to include vertical motion

The length of the SLIMCAT model run is controlled by the variables read in on channel 94

```

cat <<'eof'> fort.94
240  NO OF FILES TO JUMP IN FORCING FILE
0    =0 INITIALLY, =1 RESTART
40   NCYCLT (NDAYS * NO FORCING FILES/DAY)
48   NFFILE (NO FORCING OUTPUTS PER FILE)
eof

```

The first line is no longer used. The second line indicates whether the start data comes from an initial data file or from a restart file. The third line specifies the length of the run in numbers of analysis times. NFFILE is no longer used.

```

#
# file at forcing resolution
cp $MARTYN/UTIL/TRONxx fort.2
# files at model grid resolution
cp $MARTYN/UTIL/TRONyy fort.1
cp $MARTYN/UTIL/LEGCyy fort.20
cp $MARTYN/UTIL/LEGIyy fort.21
#

```

The above data files need to be correctly set (if spectral forcing files are being used) according to the values of MI0 and MI1. xx=MI1 and yy=MI0.

The model outputs 2 files. On channel 9 the model output a PDG file which contains the 3D tracer arrays at intervals specified by the variable NS01. On channel 30 the model outputs REST file which can be used to restart a continuation run.

```

#
# jour=n results
cp fort.9  $WORK/xx.PDGxx
cp fort.30 $WORK/xx.RESTxx
#

```

The following lines in the subroutine INIEXP control the length of the model timestep and frequency of output.

DT0=3600.0	INIEXP.62
NITERT=24	INIEXP.63
NDYN=1	INIEXP.64
NS01=24	INIEXP.65
NS02=24	INIEXP.66
NS03=24	INIEXP.67

DT0 is the basic model timestep. This is split into NDYN dynamical subtime steps. NITERT is the number of iterations in one cycle, i.e. the time between the forcing files divided by DT0. Output is written to the PDG file every NS01 iterations.

The Prather advection scheme can use a limiter to prevent negative mixing ratios, as described by Prather [1986]. This limiter can be switched on by setting the variable LIMIT to TRUE. Note that the use of this limiter can destroy tracer correlations (as the advection is no longer independent of the tracer distribution) and so should be used with care.

LIMIT=.FALSE.

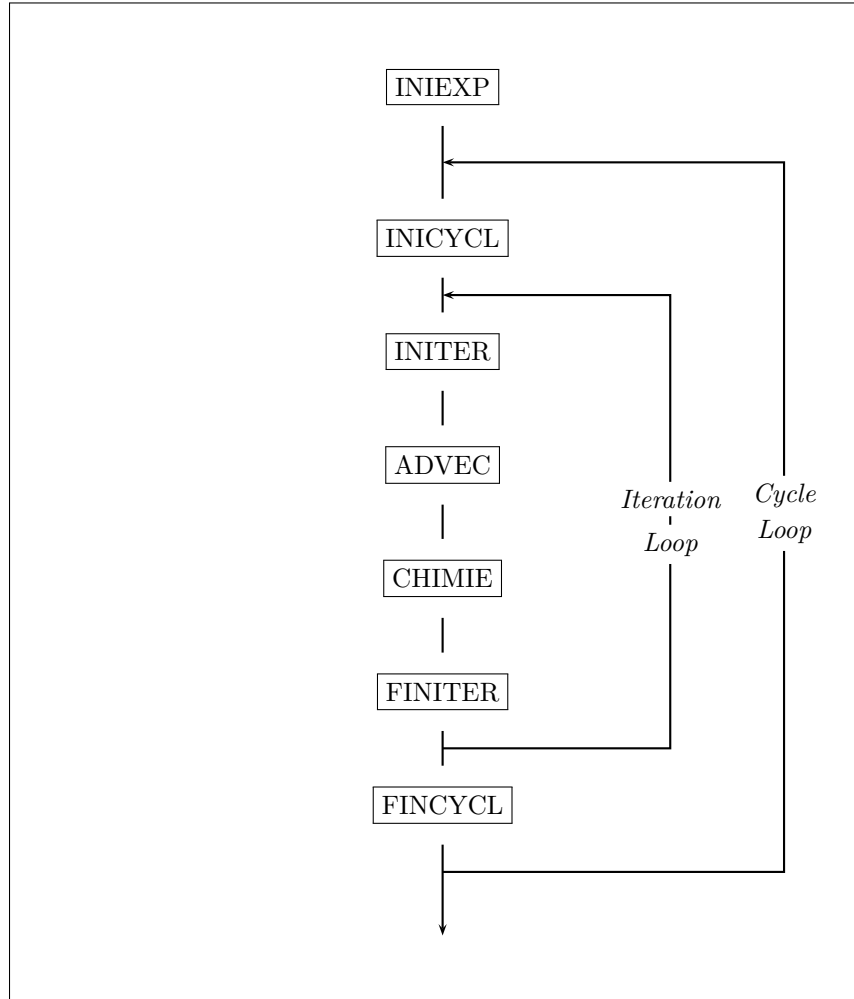
ADVEC.19

The following table lists some of the main model variables and the Fortran common decks in which they are stored.

Variable	Common Deck	Meaning	units
FLT	GRILLE	defines interlevel pressure	none
GLT	GRILLE	defines interlevel pressure	none
DLAT	GRILLE	latitude of box centre	radians
DLAT2	GRILLE	latitude of box edge	radians
DLON	GRILLE	longitude of box centre	radians
DLON2	GRILLE	longitude of box edge	radians
PL	FOR3D	centrelevel pressure	Pa
PLT	FOR3D	interlevel pressure	Pa
Q3D	FOR3D	specific humidity at box centre	kg/kg
SM	MOMENTS	total mass of box	kg
S0	MOMENTS	zero order moment	kg*vmr
SX	MOMENTS	first order moment in x direction	kg*vmr
SXX	MOMENTS	second order moment in xdirection	kg*vmr
SURF	GRILLE	surface area of grid cell	m ²
THI	GRILLE	θ at SLIMCAT level interfaces	K
THM	GRILLE	θ at SLIMCAT level centres	K
T3D	FOR3D	temperature at box centre	K
U3D	FOR3D	velocity in x direction at box centre	ms ⁻¹
U3DI	FOR3D	velocity in x direction at box edge	ms ⁻¹
V3D	FOR3D	velocity in y direction at box centre	ms ⁻¹
V3DI	FOR3D	velocity in y direction at box edge	ms ⁻¹
H3D	FOR3D	heating rate at box centre	Ks ⁻¹

4.5 Subroutines

The following diagram shows the structure of the model. The cycle loop corresponds to the frequency of the forcing winds and temperatures (typically 6 or 24 hours). The iteration loop corresponds to the basic model timestep (set by DT0).



- **ADVEC** calls the subroutine to perform advection with Prather scheme in three directions.
- **ADVX0** advection in x direction with conservation of 0 order moments
- **ADVX1** advection in x direction with conservation of 1st order moments
- **ADVX2** advection in x direction with conservation of 2nd order moments
- **CHIMIE** interface between the chemical model and the SLIMCAT dynamical model.
- **INIEXP** Initialise experiment. Reads initial/restart data and first set of forcing winds and temperatures
- **INICYCL** Called at start of cycle. Reads forcing files.
- **FINCYCL** End of cycle
- **ITER** Start of iteration (DT0 seconds)
- **FINITER** End of iteration. Writes output to PDG file.
- **PCMDRD** Interface subroutine with MIDRAD radiation scheme.
- **CONFOR** Interpolates forcing files to θ levels.

4.6 Universal Constants

The following table lists the variable names of the universal constants in SLIMCAT. They are contained in the `fortran` common block `CSTES` which is in the `nupdate` common deck `CSTUNI`.

Variable	Description	
CONV	180/XPI	
CP	Specific heat capacity of dry air at constant p	1005.46 JK ⁻¹ kg ⁻¹
CPSG	CP/GG	
CPSL	CP/XL	
CPV	Specific heat capacity of water vapour at constant p	1869.46 JK ⁻¹ kg ⁻¹
CPVMCP	CPV - CP	
DEUOMG	2*OMEGA	
ECPH	CPV/(CP-1)	
ETV	RVSRA -1	
ETVQ	1 - RASRV	
GG	acceleration due to gravity	9.80665 ms ⁻²
GSCP	GG/CP	
GSRA	GG/RA	
OMEGA	Earth's speed of rotation	7.292x10 ⁻⁵ rad s ⁻¹
RA	gas constant for dry air	287.05 JK ⁻¹ kg ⁻¹
RASCP	RA/CP	
RASCP2	RA/(2CP)	
RASL	RA/XL	
RASRV	RA/RV	
RTER	radius of the earth	6371229 m
RTER2	RTER*RTER	
RV	gas constant for water vapour	461.51 JK ⁻¹ kg ⁻¹
RVSRA	RV/RA	
STEFAN		5.6697x10 ⁻⁸ ms ⁻²
TMERGL		271.23K
TOO	ice melting temperature	273.16K
UNSCP	1/CP	
UNSG	1/GG	
VKARMN	von Karman constant	0.4
XL	Latent heat of condensation at 0°C	2.5008x10 ⁶ Jkg ⁻¹
XLF	XLI -XL	
XLI	latent heat of sublimation	2.83456x10 ⁶ Jkg ⁻¹
XLISCP	XLI/CP	
XLISG	XLI/GG	
XLSCP	XL/CP	
XLSG	XL/GG	
XLSRV	XL/RV	
XPI	π	3.14159..
XPOO	reference pressure	10 ⁵ Pa

4.7 User Supplied Chemistry

SLIMCAT can be used simply as a model to advect passive tracers with the user supplying code to calculate chemistry. The simplest way to do this is to name the top level subroutine of the new chemistry as CHIMIE and not use the SLIMCAT subroutine of this name. An example subroutine would be as follows:

```
SUBROUTINE CHIMIE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C      User supplied chemistry interface
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
*CALL PARADI
*CALL MOMENTS
C
C      Modify advected tracers
      DO 1 JV=1,NTRA
      DO 1 L=1,NIV
      DO 1 K=1,LAT
      DO 1 I=1,LON
          S0(I,K,L,JV)=0.5*S0(I,K,L,JV)
1      CONTINUE
C
C      Store advected tracers in output array
      DO 2 L=1,NIV
      DO 2 K=1,LAT
      DO 2 I=1,LON
          ST(I,K,L,1)=S0(I,K,L,1)
          ST(I,K,L,2)=S0(I,K,L,3)
          ST(I,K,L,1)=S0(I,K,L,1) + S0(I,K,L,2)
2      CONTINUE
C
      RETURN
      END
```

4.8 Analysing SLIMCAT Output

A number of programs exist for looking at SLIMCAT data. These can generate UTF files for use with UPLOT. Jobs also exist so that the UMAP program can be used. It is best to contact me (martyn@atm.ch.cam.ac.uk) directly if you need help with this.

5 Tests

5.1 Compiler Tests

- The model compiles with no ERRORS or WARNINGS.
- The model runs with variables initialised indefinite (`-f indef`).
- The model was checked for arrays going out of bounds (`-Rbc` in `cft77`).

5.2 Model Runs

SLIMCAT has been used in a large number of successful model runs.

6 Acknowledgements

I am grateful to Pascal Simon for many helpful discussions. I would like to thank John Thuburn and Keith Shine for their help with the MIDRAD radiation scheme.

References

- [1] Chipperfield, M.P., J. Kettleborough and A. Pardaens, The TOPCAT offline trajectory model, UGAMP internal report no. 37, November 1995.
- [2] Prather, M. J., Numerical advection by conservation of second-order moments, *J. Geophys. Res.*, *91*, 6671-6681, 1986.

7 Appendix 1. Flowtrace

Below is a flowtrace from a 10 day single level run with NIV=1, LON=128, LAT=64 with (24-hourly) UKMO winds and LVERT=.FALSE..

+ flowview -Luc

Flowtrace Statistics Report
Showing Routines Sorted by CPU Time (Descending)
(CPU Times are Shown in Seconds)

Routine Name	Tot Time	# Calls	Avg Time	Percentage	Accum%	
-----	-----	-----	-----	-----	-----	
ADVX2	1.86E+01	960	1.94E-02	32.77	32.77	*****
ADVY2	1.53E+01	960	1.60E-02	26.95	59.72	*****
CALUVI	4.66E+00	11	4.24E-01	8.20	79.53	**
CHTRUV	2.60E+00	11	2.36E-01	4.57	84.10	*
CHTRTG	2.26E+00	11	2.06E-01	3.98	88.09	
CONUKM	1.71E+00	11	1.56E-01	3.02	91.10	
INITER	1.53E+00	480	3.19E-03	2.70	93.80	
ADVEC	1.51E+00	480	3.15E-03	2.66	96.46	
INICYCL	1.20E+00	10	1.20E-01	2.11	98.58	
FINCYCL	2.35E-01	10	2.35E-02	0.41	98.99	
SLIMCAT	1.56E-01	1	1.56E-01	0.28	99.27	
FINITER	1.53E-01	480	3.19E-04	0.27	99.53	
INIEXP	1.38E-01	1	1.38E-01	0.24	99.78	
CHIMIE	7.49E-02	480	1.56E-04	0.13	99.91	
CALFLUK	5.17E-02	11	4.70E-03	0.09	100.00	

FINEXP	8.27E-05	1	8.27E-05	0.00	100.00
CALNUM	8.05E-05	1	8.05E-05	0.00	100.00
GENGRID	3.49E-05	1	3.49E-05	0.00	100.00
INICSTE	3.35E-06	1	3.35E-06	0.00	100.00

=====

Totals	5.08E+01	6321			
--------	----------	------	--	--	--

The 2 Prather advection routines (x and y directions) are the most expensive. The next 3 most expensive routines (CALUVI, CHTRUV, CHTRTG) simply interpolate the UKMO winds to the SLIMCAT grid. These could probably be made more efficient.

Below is a flowtrace from a 5 day multilevel run with NIV=3, LON=128, LAT=64 with (6-hourly) ECMWF winds and LVERT=.TRUE..

+ flowview -Luc

Flowtrace Statistics Report
Showing Routines Sorted by CPU Time (Descending)
(CPU Times are Shown in Seconds)

Routine Name	Tot Time	# Calls	Avg Time	Percentage	Accum%	
-----	-----	-----	-----	-----	-----	
ADVX2	2.73E+01	480	5.70E-02	22.92	22.92	*****
ADVY2	2.28E+01	480	4.76E-02	19.15	42.07	****
INCIRA	1.40E+01	21	6.68E-01	11.76	53.83	**
ADVZ2	1.32E+01	480	2.74E-02	11.03	64.86	**
CONFOR	1.29E+01	21	6.12E-01	10.78	75.63	**
CALFLU	1.08E+01	21	5.15E-01	9.06	84.69	**
HRTC02	5.03E+00	1344	3.75E-03	4.22	88.91	*
SOLAR	2.46E+00	1344	1.83E-03	2.06	90.97	
HRT03	2.17E+00	1344	1.61E-03	1.82	92.79	
INITER	2.07E+00	240	8.61E-03	1.73	94.52	
FINCYCL	1.41E+00	20	7.04E-02	1.18	95.71	
INTRAN	1.30E+00	1	1.30E+00	1.09	96.80	
HTRH20	8.10E-01	1344	6.03E-04	0.68	97.47	
ADVEC	7.84E-01	240	3.27E-03	0.66	98.13	
SETUSS	7.61E-01	1344	5.66E-04	0.64	98.77	
INIEXP	2.85E-01	1	2.85E-01	0.24	99.01	
FINITER	2.72E-01	240	1.13E-03	0.23	99.24	
CHIMIE	2.38E-01	240	9.92E-04	0.20	99.44	
INICYCL	2.17E-01	20	1.08E-02	0.18	99.62	
THERML	1.11E-01	1344	8.27E-05	0.09	99.71	
PCMDRD	9.76E-02	21	4.65E-03	0.08	99.79	
CHTRON	7.54E-02	4071	1.85E-05	0.06	99.86	
SOLANG	6.68E-02	1344	4.97E-05	0.06	99.91	
SLIMCAT	6.03E-02	1	6.03E-02	0.05	99.96	
PCMRAD	3.84E-02	1344	2.86E-05	0.03	99.99	

CORPOLE	5.65E-03	21	2.69E-04	0.00	100.00
ORBIT	2.25E-04	21	1.07E-05	0.00	100.00
WCALEN	8.23E-05	21	3.92E-06	0.00	100.00
CALNUM	8.18E-05	1	8.18E-05	0.00	100.00
FINEXP	8.15E-05	1	8.15E-05	0.00	100.00
GENGRID	3.55E-05	1	3.55E-05	0.00	100.00
INICSTE	3.64E-06	1	3.64E-06	0.00	100.00
=====					
Totals	1.19E+02	17417			

Again the Prather advection schemes account for about 53% of the total cost. The subroutine INCIRA is relatively expensive as it just interpolates the CIRA O₃ and T fields onto the SLIMCAT model levels. In general the MIDRAD scheme is well coded and cheap. Overall the above job ran at 72 Mflops.

Considering the number of calculations involved in the Prather second order moment advection scheme the subroutines ADVX2 etc. are coded efficiently. These are the most computationally intensive routines and should dominate the total cost of the model. As can be seen from the flowtraces above they do. The rest of the model is also sufficiently efficient. Of course, when a chemistry scheme is coupled to the model this will then dominate the total cost.