UNIVERSITY OF READING.

DEPT. OF METEOROLOGY

ATMOSPHERIC MODELLING GROUP

PROGRAM DESCRIPTION FOR THE MULTI-LEVEL GLOBAL SPECTRAL MODEL.

CONTENTS

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1 INTRODUCTION

This documentation describes the Fortran program for an adiabatic, multi-level, primitive-equation atmospheric model which uses a spherical geometry with representation of the fields at each level as a truncated series of spherical harmonics.

The version described here may be run on either the global or hemispheric domain, or a portion of the hemisphere by imposing symmetry restrictions in longitude. It uses a jagged triangular truncation of the spectral series.

The program described has been developed and run on the Cray 1S at the University of London Computer Centre (ULCC). It uses standard library functions and routines for matrix algebra which are available at ULCC, together with an efficient Fast Fourier Transform routine, written for the Cray at the European Centre for Medium-Range Weather Forecasts (ECMWF).

2. DEVELOPMENT HISTORY

- The theory for an adiabatic, multi-level model, using spectral representation in sigma surfaces, based on the vorticity and divergence equations, was described by Hoskins & Simmons (1975), Quart. J. R. Met. Soc., 101, 637-655, which shall be denoted HS.

- This original model incorporated a vertical finite difference scheme (the 'T-scheme') which conserves mass and total energy, but not angular momentum : see HS.

- An alternative vertical scheme was later incorporated which does also formally conserve angular momentum. It is based on the scheme used at ECMWF, described by Simmons & Burridge (1981), Mon. Wea. Rev., 109, 758-766. Note that, in that paper, the scheme is described in the context of a generalised vertical co-ordinate, whereas the Reading spectral model retains the basic sigma co-ordinate.

- The model program was originally written for a scalar processor but has since been adapted to run efficiently on a Cray 1S. The main Legendre transforms were completely rewritten to vectorise efficiently on the Cray.

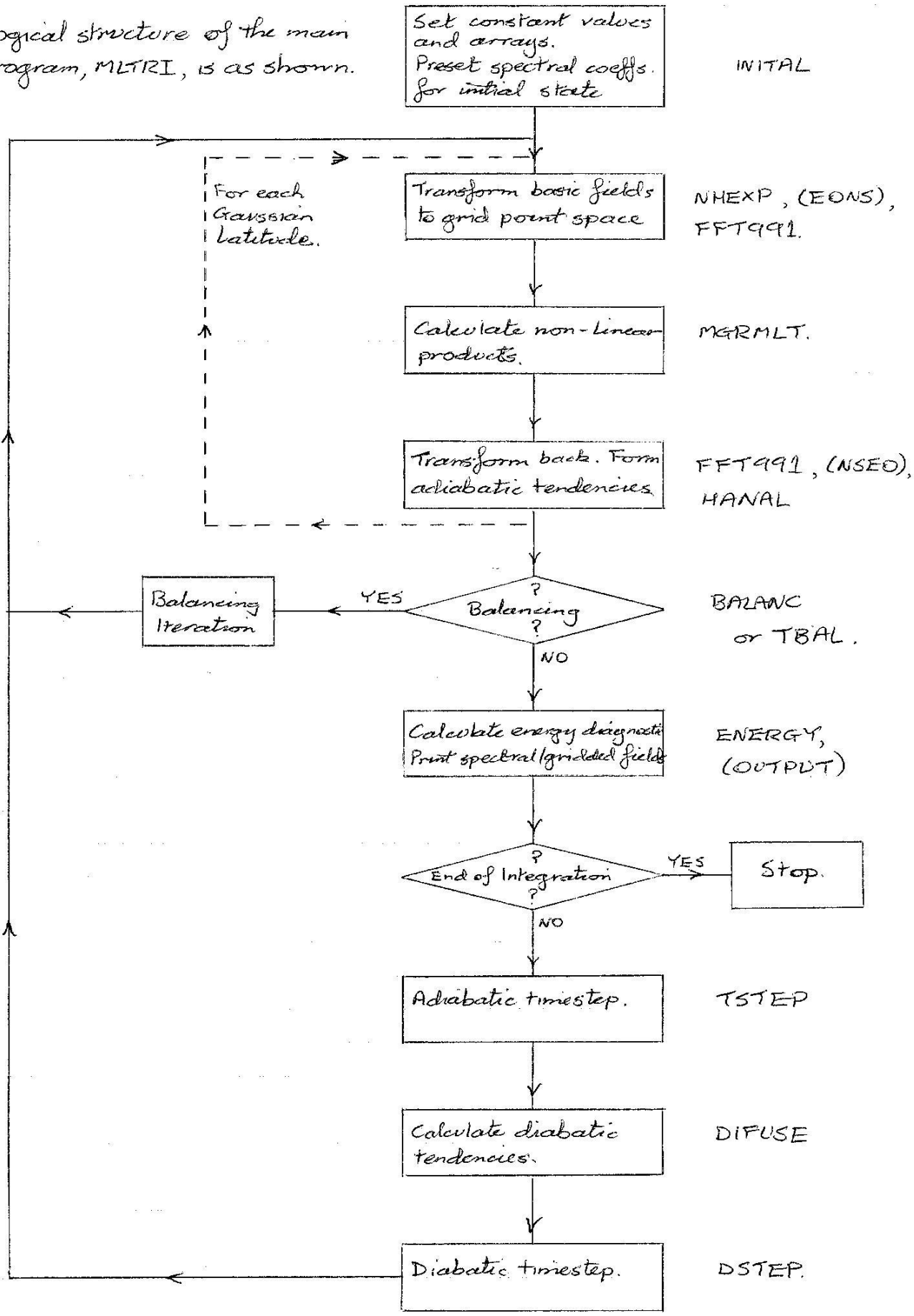
RSPUP, ED=7 — With the advent of the Fortran 77 standard, parameters have been used to define array sizes. This has greatly eased the task of changing the model's resolution: only ten parameters need to be manually altered.

RSGUP, ED=1, ED=2. — Until August 1983 the model was restricted to a hemispheric domain, the southern hemisphere flow being implicitly assumed to mirror that in the northern hemisphere, with no cross-equatorial flow. Thus only half the possible spectral coefficients were stored and used. The model now runs in either the hemispheric or full global domain, the choice being controlled by a single parameter.

RSGUP, ED=3. — The model is dry, the only diabatic processes being biharmonic diffusion and an optional restoration of the zonal mean state. The diabatic tendencies were passed through the semi-implicit scheme until it was found that this severely under-represented forcing/damping of high frequency gravity modes by these processes. In July 1984 a split time-step was introduced to overcome this problem. "Interim" fields are produced by an adiabatic semi-implicit step; these fields are then used to determine the diabatic tendencies which are added separately.

3 OVERALL MODEL STRUCTURE.

Logical structure of the main program, MLTRI, is as shown.



Organisation of Program Flow.

The model may be run in several different "modes", depending on the initial conditions and required results.
The possible choices are controlled by logical switches (see section 9o) which are supplied as data.

i) Initial Runs. (LRSTRT = <false>)

The model is to be integrated forward in time from a prescribed initial state and balancing of the initial flow is required.
The initial state is assumed to be zonally symmetric. Either the relative vorticity or the temperature and surface pressure spectral coefficients are read in as data, and a balancing procedure is used to set up the remaining coefficients in a non-divergent initial state with zero divergence tendency. (The balancing procedures are iterative so the initial state is never perfectly balanced. KBAL iterations are used).

LTBAL = <true> Input temperature and surface pressure to obtain vorticity coefficients by balancing

LTBAL = <false> Input relative vorticity to obtain temperature and surface pressure coefficients by balancing.

By default, a white noise perturbation is applied to the balanced surface pressure field before the integration, in order to initiate baroclinic instability. This is applied to the m>0 surface pressure coefficients and is normalised to 0.1mb amplitude.

The integration begins with KITS short timesteps, first an initial forward step, followed by centred steps each double the length of the preceding step.

If the zonal mean state is to be restored/damped during the integration, the restoration timescale RESTIM (in days) must be set. During the first timestep the initial, balanced zonal mean state is copied into the restoration state and also written to channel 13. This is done in a separate part of subroutine TSTEP before the actual timestep. Then the integration continues normally. The restoration state is computed here because, if the restoration was to be the forcing necessary to maintain a non-zonal initial-flow as a stationary solution throughout the integration, the initial adiabatic tendencies would be required rather than the initial zonal state.

ii) Restart Runs. (LRSTRT = <true>).

No balancing is assumed to be needed and the initial state is read in from a previous model run as a history or restart record, as written in the main program, containing the complete spectral fields of absolute vorticity, divergence, perturbation temperature and log of surface pressure. If the wrong record is read the program stops.

The integration may be begun with or without short timesteps. This is controlled by the logical switch LSHORT.

LSHORT = <false> No short timesteps.
Generally used to continue a long integration
A full restart record is read in, containing the (t) and (t-Δt) fields. Set KITS equal to the number of short timesteps at the beginning of the original run, to offset the counters correctly.

LSHORT = <true> KITS short timesteps are used.
Generally used to start a new integration from a previously model-generated state.
A history record is read in, containing the fields at a single time-level.
Counters begin again from zero.

If the zonal mean state is to be restored/damped during the integration, the damping timescale RESTIM must be set. The restoration state is then read in subroutine INITAL, as the spectral coefficients of the required zonal mean state. This will generally have been written from a previous model run.

iii) Normal Mode Perturbation Runs.

These are runs in which normal-mode baroclinic instability is initiated on an unstable zonal flow by applying a small perturbation which has the structure of (generally the fastest growing) unstable normal mode.
These runs are possibly best treated as restart runs, with the initial balanced zonal flow plus unbalanced perturbation set-up by the WMATRIX normal-mode program as a history or restart record.

Clearly other types of run and different forms of initial data will be needed in the future. The model is written and organised to handle the envisaged standard types of run described here without changes in the code.

4 ASSOCIATED FILES.

Channel no.	Description / Use.
7	Input
2	Output.
3	Default for output of execution-time diagnostics of the fields and regular spectral and gridded data. (For fiche). May be reset in namelist INPB as follows: NPC1 : spectral coefficients written by OUTPUT. NPC2 : gridded fields written by OUTPUT. NPC3 : RMS values and energies written by ENERGY, and KE spectra written by MSPECT.
9	a) Used as scratch file during balancing using TBAL only. b) History file is built up during the time-integration, containing the basic spectral arrays.
10	In a restart run only the initial state is read from this channel in INITAL. Not used in initial runs.
13	Used to store a restoration state if the flow is to be restored. In an initial run the restoration state is written from TSTEP. In a restart run it is read in INITAL.
24	a) Used as a scratch file during the integration for the grid point fields used in OUTPUT. b) At the end of the run the final state is written to this channel as a restart record, overwriting the data from (a). A continuation of the integration can be begun from this record.
25	Scratch file to store the Legendre functions and other arrays, one record per latitude. Only used when parameter JGL = 1. The the arrays ALP, DALP, DP, DQ are written to this channel from INITAL and subsequently read in one latitude at a time in the main program loop. This is a storage-saving device necessary for runs at T42, 15 level, global or greater resolution. Not used when JGL = JG. Then the arrays are stored in core for all latitudes simultaneously.

5 COUNTERS.

KOUNT — Number of timesteps completed.

a) KOUNT = -KIBAL
Preset in INITAL to minus the no. of balancing iterations, unless in a restart run.

b) KOUNT = KOUNT + 1
Incremented either at the end of a balancing iteration (just before BALANC or TBAL) or just before the calculation of the new spectral fields (just before TSTEP).

c) KOUNT < 0
Balancing occurs instead of a timestep. No diffusion.

d) KOUNT = 0
Initial balanced state.
OUTPUT called to write spectral and gridded fields.

e) KOUNT > 0
Normal timesteps are performed. KOUNT measures the number of timesteps completed (see (b)).

f) 0 < KOUNT ≤ KITS
Short timesteps are performed, one per value of KOUNT. First an initial forward step and then centred steps, each double the length of the preceding step. At the end of KITS short steps, time has been advanced by the equivalent of one full semi-implicit timestep.
NB. No short steps in a restart run with LSHORT false, irrespective of the value of KITS.

g) KOUNT > KITS
Full semi-implicit timesteps, one per value of KOUNT.

h) KOUNT = KTOTAL
End of run.

Comments: Let Δt be the length of a full semi-implicit timestep. The time from the beginning of the run is then

$$t = (KOUNT + 1 - KITS)\Delta t \quad \text{for } KITS > 0$$

or $$t = (KOUNT)\Delta t \quad \text{for } KITS = 0.$$

KTOTAL: Total number of timesteps.

a) KTOTAL = <value>
Set in INITAL in the namelist input INPB.

Comments: allowance must be made for the number of short timesteps. Number of full timesteps per day is TSPD and number of short steps is KITS. For the model to run to 'm' days we require

$$KTOTAL = (m \times TSPD) + \begin{cases} 0 & \text{, when } KITS = 0. \\ (KITS - 1) & \text{, when } KITS > 0. \end{cases}$$

$$t_{TOTAL} = n \Delta t_{FULL}$$
$$= (m \times TSPD) \Delta t_{FULL}.$$

KSTART: Starting timestep number.

a) KSTART = <value>
Set in INITAL in the namelist input INPB.
Should be zero for an initial run, although it is only used in INITAL when restarting the integration from a history or restart record when in a restart run. It is used to find the required record on channel 10.

KITS: Number of short timesteps.

a) KITS = <value>
Set in INITAL in the namelist input INPB.

KBAL: Number of balancing iterations.

a) KBAL = <value>
Set in INITAL in the namelist input INPB.

KOUNTP — Number of timesteps between successive writings of spectral and gridded fields.

KOUNTH — Number of timesteps between successive writings of history records, containing spectral fields at the present time level only.

KOUNTR — Number of timesteps between successive writings of restart records, containing spectral fields at the present and previous time levels.

These values are set in INITAL in the namelist INPB. If a value is zero (the default) then it is subsequently set to -999 and that particular type of output is not produced.

KOUTP, KOUTH, KOUTR are the counters for the three types of output mentioned above. Each counter is treated as follows:

a) $KOUT* = \begin{cases} 0 & \text{, for } KITS = 0 \\ 1-KITS & \text{, for } KITS \neq 0. \end{cases}$

Preset in INITAL, allowing for short timesteps.

b) KOUT* = KOUT* + 1

Incremented in main program just before the calculation of the new spectral fields in TSTEP. Not incremented during balancing.

c) KOUT* = KOUNT*

The required type of output is produced at this timestep Then KOUT* is reset to zero and counting begins again for this type of output.

KKOUT — Variable used when writing spectral and gridded fields from OUTPUT.

a) Set from other counters in main program loop at each timestep.

b) KKOUT ≠ 0. No output is required.

c) KKOUT = 0. Output is required and the grid point fields at each latitude are written to a scratch file, channel 24, ready for use by OUTPUT. This occurs for KOUNT = 0 (initial state) and when KOUTP = KOUNTP.

DAY — Number of days from beginning of integration, as a decimal. Used for history and restart records.

6 PARAMETERS.

The resolution of the model is controlled by a series of parameters. These determine:

i) Spectral resolution within sigma surfaces.
ii) Number of vertical levels.
iii) Use of a global or hemispheric domain.
iv) Optional imposition of m-fold symmetry in longitude.

The parameters are stored in common-decks on the same update-library as the rest of the model. The decks are called from each subroutine and inserted in-line before compilation, allowing the parameters to be used throughout the program.

In order to change the resolution of the model, as described above, it is necessary to change only the commondeck involved. This single change alters array dimensions consistently in all common blocks and subroutines without further work.

NB. This is only true for the jagged triangular truncation and vertical scheme described here. If structural changes are made to the model, all arrays must be checked to ensure that the parameters affect them consistently.

The parameters are stored in two commondecks:

PARAM1
PARAM2

Only the values in PARAM1 need to be changed when the model resolution is changed.

The values in PARAM2 are derived from those in PARAM1, or are invariant.

Commondeck PARAM1

MM — Highest zonal wavenumber retained in the spectral series. The jagged triangular truncation only retains $m \leq MM-1$.

NN — Highest total wavenumber retained in the spectral series.

NL — Number of levels in the vertical.

NHEM — Determines domain of integration:
= 1 : hemispheric, with flow symmetric about equator.
= 2 : full global domain.

MOCT — a) Symmetry imposed in longitude.
b) Portion of the sphere or hemisphere on which the calculations are performed.
c) Only the following zonal wavenumbers are included:
$m = 0, MOCT, 2\times MOCT, 3\times MOCT, \ldots, (MM-1)$ (or nearest m below this).

MG. — Number of longitudes in the transform grid. Assumed to be even. Must obey $MG \geq (3MM+1)/MOCT$ to prevent aliassing in the quadratic terms (see HS). Also must be of the form $(2^P \times 3^Q \times 4^R)$ where $P \geq 1$.

JG. — Number of Gaussian latitudes in the transform grid between pole and equator. Must obey $JG \geq (3MM+1)/4$ to prevent aliassing in the quadratic terms (see HS).

NWJ2 — Number of either even or odd spectral coefficients retained in the spectral series (they are equal for the jagged triangular truncation).

$$NWJ2 = \frac{MM+1}{2} + \frac{MM+1-MOCT}{2} + \frac{MM+1-2\times MOCT}{2} + \ldots \quad (\text{by integer division.})$$

NCRAY — = 64. Optimum number of Fast Fourier Transforms to be performed in parallel.

JGL. — Number of latitudes at which the Legendre functions and their derivatives are stored in core (see common /LEGAU/.)
= JG for runs at low resolution (eg T21 and also T42 except 15level global)
= 1 for runs at high (eg T42 15level) resolution, with values being read from disc at each latitude.

Common deck PARAM2

MH	= 2	Used in counting no. of odd or even coefficients.
PI	= 3.14159265359	
PI2	= 2 × PI	
NNP	= NN+1	
MGPP	= MG+2	Real dimension of a single level of the grid-point/half-transform arrays, for a single latitude or for just odd or even values.
JGP	= JG+1	
MJP	= NWJ2 × 2	Used for real equivalenced arrays.
NLM	= NL−1	
NLP	= NL+1	
NLPP	= NL+2	
NLA	= NL+3	
NLB	= NL+4	
NL2	= NL × NL	Array dimension used in vertical scheme.
IDA	= (3×MG)/2 +1	No. of trig. functions for FFT
IDB	= NWJ2 × NL	No. of odd or even coeffs. for NL levels.
IDC	= 2×IDB	Used for real equivalenced arrays.
IDD	= MGPP × NL	Dimension of grid point arrays: single latitude.
IDE	= NL2 × NN	Used for BM1 arrays. (NL × NL) matrix for each 'n'.
IDF	= NCRAY × (MG+1)	Size of work area for FFT.
IDG	= JG × NL	Hemispheric zonal average array dimension: in OUTPUT.
IDH	= JGP × (2×MG+1)	Grid point array dimension in OUTPUT.
IDI	= (NNP)/2	Max. no. of odd or even coeffs. for a single 'm'.
IDJ	= IDI × IDI	Matrix dimension for balancing using TBAL.
IDK	= NL × IDI	Used in TBAL.
IDL	= MGPP/2	Complex dimension of grid point array (see MGPP).
IDM	= NNP/2	No. of odd or even coeffs for m = 0 at single level.
IDN	= IDM × NL	No. of odd or even coeffs for m = 0 for NL levels.
NWW	= 1 + (MM−1)/MDT	No. of m-wavenumbers or half-transforms.

IGA	= NWJ2 × NHEM	No. of spectral coeffs. at a single level.
IGB	= IDB × NHEM	No. of spectral coeffs at NL levels.
IGC	= MGPP × NHEM	Real dimension of grid point array at single level
IGD	= IDD × NHEM	Real dimension of grid point array at NL levels.
IGG	= IDG × NHEM	Dimension of zonal average grid point array.
IGL	= IDL × NHEM	Complex dimension of ½-transform array at single level.
IGM	= IDM × NHEM	No. of m=0 spectral coeffs. at a single level.
IGN	= IDN × NHEM	No. of m=0 spectral coeffs at NL levels.
IGO	= IGA + IGA	Used for real equivalenced arrays.
IGP	= IGB + IGB	Used for real equivalented arrays.
NVRI	= 7×NL + 2	No. of single-level fields to be transformed in NHEXP, HANAL
IDPOL	= NVRI × IGA	Dimension of polynomial for Legendre transforms.

7 COMMON BLOCKS.

```
COMMON /SPECTR/ SP(IGA), SPDU(IGA), DDA(IGB), ZDA(IGB), ZDB(IGB)
                , DDB(IGB)
                , Z(IGB), D(IGB), T(IGB), SPA(IGA), VP(IGA)
                , TT(IGB), DT(IGB), ZT(IGB), GS(IGA)
All complex.    , ZMI(IGB), DMI(IGB), TMI(IGB), SPMI(IGA)
```

IGA → no. of coefficients at a single level = NWJ2 × NHEM
IGB → no. of coefficients at NL levels = NWJ2 × NHEM × NL

The order of storage is by level, beginning at the uppermost level, for each variable. Within each level storage is as follows:

i) Hemispheric: only the even or odd coefficients, depending on the symmetry of the field.

ii) Global : coefficients for the hemispheric domain, followed by those for the "non-hemispheric" domain.
ie Even preceding odd: SP, D, T, VP, GS etc.
Odd preceding even: Z, ZT, ZMI, ZDA, ZDB.

Using the jagged triangular truncation there are equal numbers (NWJ2) of odd and even coefficients for each field at each level.

Hemispheric:

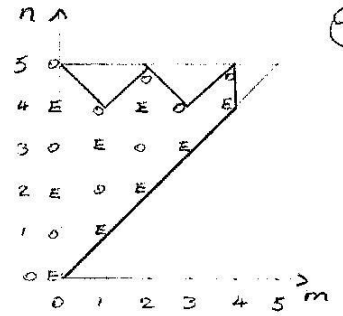
L=1 Hemispheric	L=2. Hemispheric	.....	L=NL. Hemispheric
NWJ2	NWJ2		NWJ2

Global:

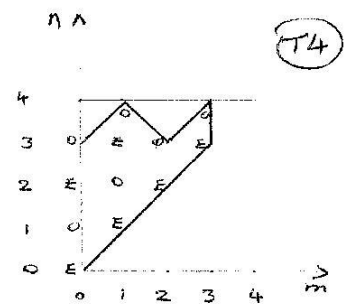
L=1 Hemispheric	L=1. Non-Hem	.....	L=NL Hemispheric	L=NL. Non-hem.
NWJ2	NWJ2		NWJ2	NWJ2

For each level, odd or even coeffs., storage is increasing n within increasing m.

(T5)



(T4)



For each n: equal numbers of odd and even coeffs.
Lowest n value: even.
Highest n value: odd.

(A_n^m)

Even : $A_0^0, A_2^0, A_4^0 \ldots\ldots, A_1^1, A_3^1, \ldots\ldots, A_2^2, A_4^2, \ldots\ldots, \ldots\ldots, A_{NN-1}^{NN-1}$.
Odd : $A_1^0, A_3^0, A_5^0 \ldots\ldots, A_2^1, A_4^1, \ldots\ldots, A_3^2, A_5^2, \ldots\ldots, \ldots\ldots, A_{NN}^{NN-1}$.

SP	$\ln p_*$	- log of surface pressure.
SPDU	Copy of $\ln p_*$	
DDA	$(-i) \times d$	- divergence.
ZDA	$(-i) \times \zeta$	- absolute vorticity.
ZDB	ζ	- " "
DDB	$-d$	- divergence.

} Copies to aid vectorisation.

Z	ζ	- absolute vorticity.
D	d	- divergence
T	T'	- deviation from basic state temperature ($T' = T - \bar{T}$)
SPA	p_*	- surface pressure.
VP	$-P = \sum_{r=1}^{NL} P_r \Delta\sigma_r = \sum_{r=1}^{NL} (\underline{U}_r \cdot \nabla \ln p_*) \Delta\sigma_r$	: contrib^n to $\ln p_*$ tendency.
TT	Temperature tendency; $d(T')/dt$.	
DT	Divergence tendency ; $d(d)/dt$.	
ZT	Vorticity tendency ; $d\zeta/dt$	
GS	Φ_*	- orography.
ZMI	ζ at previous timestep.	
DMI	d at previous timestep.	
TMI	T' at previous timestep.	
SPMI.	$\ln p_*$ at previous timestep.	

COMMON/GRIDP/ PJT(IGC), PLT(IGC), UGT(IGD), VGT(IGD)
, UG(IGD), VG(IGD), ZG(IGD), DG(IGD), TG(IGD)
, PMG(IGC), PJG(IGC), PLG(IGC), VPG(IGC), EG(IGD)
, VTG(IGD), VTG(IGD), UZG(IGD), VZG(IGD), TNLG(IGD)
Real dimensions , VZGT(IGD), UZGT(IGD)

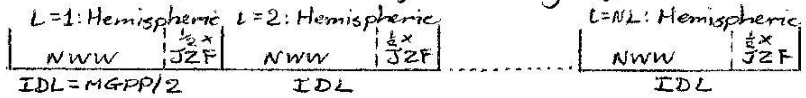
IGC → dimension for a single level = MGPP × NHEM
IGD → dimension for NL levels = MGPP × NHEM × NL.

Depending on the stage of the program, this block stores either real grid point values or complex half transforms (single latitude).

For each variable, storage is by level, beginning at the uppermost. Within each level the hemispheric part of the field precedes the "non-hemispheric" part. In hemispheric mode only the hemispheric part is included.

a) Half transforms: before reaching routine EONS and after routine NSEO, the half transforms are the odd and even contributions to the complete half transforms, for the northern hemisphere latitude, +μ, only. In hemispheric mode only the odd or even contribution is present, depending on the symmetry of the variable.

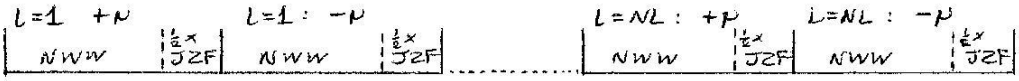
Hemispheric (dimensions complex):



Global:

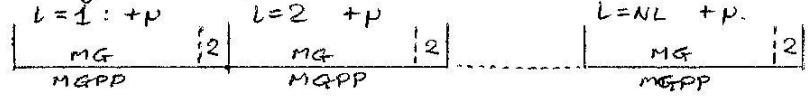
b) Half transforms: in global mode only, after routine EONS and before routine NSEO, the half transforms are the complete versions, but now for the northern and southern hemisphere latitudes, ±μ. (In hemispheric mode the arrays contain odd or even half transforms at +μ, still).

Global:



c) Grid point values: in hemispheric mode values are stored only for +μ. In global mode values at +μ precede those at −μ. Ordering is in increasing longitude, for $0 \leq \lambda \leq 2\pi/\text{MOCT}$.

Hemispheric (Real dimensions):



Global:

PJT	$(1-\mu^2)\frac{\partial \ln p_*}{\partial \mu}$
PLT	$\ln p_*$
UGT	U_χ (divergent wind)
VGT	V_ψ (rotational wind)
UG	U_ψ, then U (rotational wind)
VG	V_χ, then V (divergent wind)
ZG	ζ
DG	d
TG	T'
PMG	$\frac{\partial \ln p_*}{\partial \lambda}$
PJG	$(1-\mu^2)\frac{\partial \ln p_*}{\partial \mu}$
PLG	$\ln p_*$ or p_*
VPG	$-\dot{\sigma}$
EG	(U^2+V^2)
UTG	(UT')
VTG	(VT')
UZG	$\mathcal{F}_U$
VZG	$\mathcal{F}_V$
TNLG	$(\dot{\sigma}+\nabla.\underset{\sim}{U}T')$, then include $-\frac{\partial (UT')}{\partial \lambda}$
VZGT	$\frac{\partial \mathcal{F}_U}{\partial \lambda}$
UZGT	$\frac{\partial \mathcal{F}_V}{\partial \lambda}$.

} Wave to grid FFT. (PLG → $\ln p_*$, UG → U, VG → V)

} Grid to wave FFT. (PLG → p_*)

COMMON / /SQ(NNP), RSQ(NNP), RCS(JG), SIGMAH(NLM), SIGMA(NL)
, TΦ1S2(NLM), TΦ(NL), ALPHA(NL), DSIGMA(NL), RDSIG(NL)
, TKP(NL), C(NL2), SQH(NNP)
, MF, MFP, JZF, NF, NFP
, AKAP, RCSJ, GA, GASCON, RADEA, WW, PFAC
Complex → , E2, AIOCT
Logical → , LTBAL, LRSTRT, LSHORT
(others real)

Used to store constant arrays and variables for the vertical scheme and horizontal domain, plus constants and logical switches.

SQ(n+1) = $n(n+1)$ for $n = 0, NFP$.
RSQ(n+1) = $\frac{1}{n(n+1)}$ for $n = 0, NFP$, except $RSQ(1) = 0$ for $n = 0$.
RCS(j) = $1/(1-\mu_j^2) = 1/\cos^2\phi_j$ for $j = 1, JG$. Begins at north pole.
SIGMAH(r) = $\sigma_{r+\frac{1}{2}}$ for $r = 1, NL-1$.
SIGMA(r) = σ_r for $r = 1, NL$.
TΦ1S2(r) = $(\bar{T}_{r+1} - \bar{T}_r)$ for $r = 1, NL-1$.
TΦ(r) = $\bar{T}_r$ for $r = 1, NL$.
ALPHA(r) = $\begin{cases} \sigma_{r+\frac{1}{2}}^2/\sigma_r^2, & r = 1. \\ \ln(\sigma_{r+\frac{1}{2}}/\sigma_{r-\frac{1}{2}}), & r = 2, NL. \end{cases} = \alpha_r$.
Used to set up $\underset{\sim}{g}$ matrix and defines vertical scheme. The value for $r=1$ is not actually used in the ECMWF angular momentum conserving vertical scheme.
DSIGMA(r) = $\Delta\sigma_r = (\sigma_{r+\frac{1}{2}} - \sigma_{r-\frac{1}{2}})$ for $r = 1, NL$.
RDSIG(r) = $1/2\Delta\sigma_r$ for $r = 1, NL$.
TKP(r) = $\kappa\bar{T}_r$ for $r = 1, NL$.
C matrix. $C_{rs} = \left(\frac{\Delta\sigma_s}{\Delta\sigma_r}\right) \cdot g_{sr}$. This is set up in INITAL from the $\underset{\sim}{g}$ matrix and is used for the third component of the $\underset{\sim}{\Sigma}$ matrix. (See HS, Appendix 1).

$$r \downarrow \begin{pmatrix} & \overset{s}{\Rightarrow} & \\ & C_{rs} & \end{pmatrix}$$

for $r = 1, NL$, $s = 1, NL$.

SQH(n+1) = $\frac{1}{2}n(n+1)$ for $n = 0, NFP$.
MF = $MM - 1$
MFP = MM
JZF = $MGPP - 2 \times NWW$. Filler dimension for $\frac{1}{2}$-transform arrays. Number of blank real values between adjacent $\frac{1}{2}$-transforms.
NF = $NN - 1$.
NFP = NN.
AKAP = $\kappa = R/C_p$, for dry air.
RCSJ = $1/(1-\mu^2)$ at present latitude μ_j.

GA = g: gravitational acceleration (ms^{-2})
GASCON = R: gas constant for dry air ($Jkg^{-1}K^{-1}$).
RADEA = a: Earth's radius. (m).
WW = Ω: Earth's rotation rate (s^{-1}). Sidereal value

PFAC = $\frac{1}{2}(a\Omega)^2 p_0/g$, where $p_0 = 10^5$ Pa (1000 mb). Used in MSPECT.

EZ = $\sqrt{8/3}$ Spectral coeff. for planetary vorticity: $(EZ) \times P_1^0(\mu) = 2\mu$.

AIOCT = $(MOCT) \times (0,1) = i \times (MOCT)$.

LTBAL. Logical Switch { true : balancing from T', $\ln p_*$ to ζ.
false : balancing from ζ to T', $\ln p_*$.

LRSTRT Logical Switch { true : restart run from stored spectral data.
false : initial run with balancing.

LSHORT Logical Switch { true : restart with short timesteps.
false : restart without short timesteps.
Redundant in initial runs.

```
COMMON /BATS/ BM1(IDE), ALAT(JG), BFILT(NL), RGTΦ(NL), AK(NNP)
              , AQ(NL2), G(NL2), TAU(NL2), RG(NL2), EP1(IGA), EP2(IGA)
              , KOUNT, KITS, KTOTAL, ITSPD, PNU21
(All real)    , SRGTΦ, DELT, DELT2, CV, CG, CT, PNU, PNU2, DAMP, MWV1, MFTBAL
```

Used for constant arrays and variables mainly associated with the time scheme and vertical scheme. Also counters.

BM1 = Contains $\underset{\sim}{A}_n^{-1}$ matrix for each $n = 1, NN$. For semi-implicit scheme (see HS, section 3).

ALAT(j) = Φ_j in degrees for $j = 1, JG$. Begin at north pole.

BFILT(r) Binomial filter used in balancing from ζ to $T', \ln p_*$.

RGTΦ(r) = $(\underset{\sim}{g}^{-1}\overline{T})_r$ Used in balancing from ζ to $T', \ln p_*$.

AK(n+1) = $\tilde{AKK} \times [n(n+1)]^{k/2}$. Non dimensional dissipation factor for total wavenumber n. Dissipation is of form ∇^k.

AQ$_{rs}$ = $B_{rs} = \sum_{k=1}^{NL} g_{rk} \cdot \tau_{ks} + \overline{T}_r \Delta\sigma_s$. Used in time scheme.

G$_{rs}$ = g_{rs}. Defines vertical scheme. (See HS Appendix 1)

TAU$_{rs}$ = τ_{rs} Used for temperature tendency. (" " " ")

RG$_{rs}$ = $(\underset{\sim}{g}^{-1})_{rs}$. Used in balancing from ζ to $T', \ln p_*$.

EP1 = $2(1+\frac{1}{n})\varepsilon_n^m$: even followed by odd coeffs. } For TBAL set-up.

EP2 = $2(1-\frac{1}{n})\varepsilon_n^m$: " " " " " } $\varepsilon_n^m = \left(\frac{n^2-m^2}{4n^2-1}\right)^{\frac{1}{2}}$

KOUNT Number of timesteps completed.

KITS Number of initial short timesteps.

KTOTAL Total number of timesteps in integration.

SRGTΦ Normalising factor for use in balancing from ζ to $T', \ln p_*$.

DELT = Δt. Timestep.

DELT2 = $2\Delta t$.

CV = $a\Omega$. Non-dimensionalising factor for velocity. (ms^{-1})

CG = $(a\Omega)^2$. " " " " energy. (Jkg^{-1})

CT = $(a\Omega)^2/R$. " " " " temperature. (K)

PNU Factor for time filter.

PNU2 = $2 \times$ (PNU).

DAMP Constant for restoration/damping.

MWV1 = 1 + MOCT. Lowest zonal wavenumber with $m > 0$.

MFTBAL = 9 default. Highest zonal wavenumber in TBAL balancing.

ITSPD Integer number of timesteps per day.

PNU21 = (1.0 − 2 × PNU) Factor for time filter.

```
COMMON /LEGAU/ ALP(MJP,JGL),DALP(MJP,JGL), DP(MJP,JGL), DQ(MJP,JGL)
              , AW(JG), CS(JG), SI(JG)
              , WEIGHT, CSJ, MJPP, SIT, JL
(All real)    , ALPW(MJP), DALP(MJP), CALPW(MJP), SQALP(MJP)
```

Constant arrays and variables used for Legendre transforms.

ALP	P_n^m	Stored for JGL latitudes : JGL = JG or 1. For each latitude values are stored in ascending order of n within ascending order of m, with even and odd functions alternating.
DALP	$(1-\mu^2)\, dP_n^m/d\mu$.	
DP	$\frac{m}{n(n+1)}\, P_n^m$	
DQ	$\frac{1}{n(n+1)}(1-\mu^2) dP_n^m/d\mu$.	

AW(j) $= w_j'$. Gaussian weight for latitude μ_j, for j = 1, JG.

CS(j)	$= 1-\mu_j^2 = \cos^2\phi_j$	for j = 1, JG.	Begin near north pole, end near equator.
SI(j)	$= \mu_j = \sin\phi_j$	for j = 1, JG.	

WEIGHT	$= w'$. Gaussian weight for present latitude.
CSJ	$= (1-\mu^2) = \cos^2\phi$ for present latitude
MJPP	= MJP + NWW.
SIT	$= \mu = \sin\phi$ for present latitude.
JL	Subscript for ALAT, CS, SI etc arrays for present latitude.

ALPW	$w_j' \times P_n^m$	Set in HANAL at each latitude. Same ordering as ALP, DALP etc.
DALPW	$w_j' \times (1-\mu^2) dP_n^m/d\mu$.	
CALPW	$\frac{1}{1-\mu^2} \times w_j' \times P_n^m$	
SQALP	$\frac{1}{2} n(n+1) \times w_j' \times P_n^m$	

```
COMMON/OUTCON/RNTAPE,NCOEFF,NLAT,MGIN,INLAT,INLONG,NGOUT1,NGOUT2
             ,LSPO(NL),LGPO(NL),NPC1,NPC2,NPC3,INSPC
             ,KOUNTP,KOUNTH,KOUNTR,KOUTP,KOUTH,KOUTR,DAY
(LSPO,LGPO logical)  ,SQR2,RSQR2,EAM1,EAM2,TOUT1,TOUT2,RMG
(Rest real).
```

Constants and counters to control printed and other output.

RNTAPE	Identifying run number.
NCOEFF	Maximum wavenumber of printed spectral coeffs.
NLAT	No. of latitudes in printed grid point fields.
MGIN	= MG×INLAT. Used to skip through grid point array in OUTPUT.
INLAT	= JG/NLAT. Spacing in transform grid of printed latitudes.
INLONG	= MG/NLONG. Spacing in transform grid of printed longitudes.
NGOUT1, NGOUT2	To determine which hemispheres have printed gridded data. N. Hem. only : NGOUT1 = 1, NGOUT2 = 1; S. Hem only : NGOUT1 = 2, NGOUT2 = 2; Both Hems. : NGOUT1 = 1, NGOUT2 = 2. Only in global run, NHEM = 2.
LSPO	Logical switch for spectral output. True for a level implies
LGPO	Logical switch for gridded output. output at that level.
NPC1	Channel for printed spectral coeffs.
NPC2	" " " gridded data.
NPC3	" " " RMS and energy values and spectra.
INSPC	Number of odd or even coeffs. to be written out of NWJ2.
KOUNTP	Spacing in timesteps of printed output (spectral + grid)
KOUNTH	Spacing in timesteps of history records.
KOUNTR	Spacing in timesteps of restart records.
KOUTP	Counter for printed output.
KOUTH	Counter for history records.
KOUTR	Counter for restart records.
DAY	Number of days from beginning of integration.
SQR2	$= \sqrt{2}$.
RSQR2	$= 1/\sqrt{2}$.
EAM1	$= \sqrt{2}/3$.
EAM2	$= \sqrt{2/45}$.
TOUT1	$= \sum \bar{T}_r \Delta\sigma_r$.
TOUT2	$= \sum \bar{T}_r^2 \Delta\sigma_r$.
RMG	$= 1/(MG)$

COMMON /COMFFT/ NTGW, NRSTGW, NTWG, NRSTWG, NTOU, NRSTOU
(All real). , TRIG(IDA), WORK(IDF), IFAX(10)

Arrays and constants needed for the FFT, particularly to aid its vectorisation on the Cray.

The FFT performs several transforms between Fourier and grid-point space simultaneously. The vectorisation on the Cray means that it is most efficient to perform NCRAY = 64 simultaneously. Thus the transforms at a given latitude are performed in batches (of 64) with any remainder being performed in a final call.
The constants in /COMFFT/ control this batching. They are set-up near the beginning of INITAL.

NTGW, NRSTGW : grid to wave transforms.
NTWG, NRSTWG : wave to grid transforms.
NTOU, NRSTOU. : separate streamfunction transform.

Consider the main wave-to-grid transform.

NTRWG = (5×NL+3) × NHEM: no. of transforms.

NTWG = (NTRWG − 1)/NCRAY : no. of complete batches.
(integer arithmetic) One is subtracted in case NTRWG is an exact multiple of NCRAY, since the remainder is then also a full batch.

NRSTWG = NTRWG − (NCRAY × NTWG) : no. of transforms remaining after batching.

Logic is:
```
      IF(NTWG.=Ø) GO TO 12
      DO 1Ø I = 1, NTWG
1Ø    CALL FFT991 (correctly offset batch of transforms)
12    CALL FFT991 (correctly offset remaining transforms).
```

TRIG Trigonometric functions for the FFT.
WORK Workspace for the FFT.
IFAX Factors of two for the FFT.

COMMON/POLYNO/ POLY(IDPOL), CMPA(IGL)

POLY : real. CMPA : complex.

Polynomial to aid vectorisation of the Legendre transforms in NHEXP and HANAL.

POLY Polynomial. Dimension $(7\times NL+2)\times NWJ2\times NHEM$.
Reset in each pass through NHEXP and HANAL.

CMPA $\left(\frac{m}{NOCT}+1\right)$ = (im) for j = 1 to NWW.
= 0 for j = (NWW+1) to IDL.
(= (im) for j = (IDL+1) to (IDL+NWW) } NHEM = 2
= 0 for j = (IDL+NWW+1) to IGL } only).

COMMON/RESTOR/ZRES(IGN), DRES(IGN), TRES(IGN), SPRES(IGM)

Real arrays for the restoration state : to contain real parts of spectral coefficients of zonal mean state used for restoration.
Storage is same as for spectral arrays in /SPECTR/, by level, with even preceding odd coefficients at each level (reversed for vorticity, ZRES), and in order of increasing 'n'.

8. DESCRIPTION OF SUBROUTINES.

MLTRI

Main program which organises the counters and output, and calls the subroutines to perform the spectral transforms, balancing and timestepping. The structure is shown in section 3.

INITAL

Initialises the constant arrays for the time-scheme, vertical scheme, spectral transforms and balancing procedures (if used). Various constants and logical switches are read in the namelist INPB which, together with the parameters, are sufficient to define the characteristics of the run and set up the constant arrays and values.

The initial atmospheric state is preset to a horizontally stratified state (the basic state) and is then overwritten using spectral data. The format and amount of data needed depends on the type of run.

Details of the input data and initial state data are given in section 9, on running the model.

INITAL calls subroutine GWTLT to calculate the Gaussian latitudes and weights, QREIG and MINV for matrix algebra, and FAX and FFTRIG to set up arrays for the FFT.

NHEXP

Performs the Legendre transform from spectral space to produce the even and add contributions to the half transforms (Fourier coefficients) at the current northern hemisphere latitude, +μ:

eg. $\zeta^m_{ODD}(\mu) = \sum_n \zeta^m_n P^m_n(\mu)_{ODD}$, $\zeta^m_{EVEN}(\mu) = \sum_n \zeta^m_n P^m_n(\mu)_{EVEN}$.

In hemispheric mode, only $\zeta^m_{ODD}(\mu)$ is computed.

Spectral input : SP, SPDU, DDA, ZDA, ZDB, DDB, Z, D, T. $(7\times NL+2)$ single levels.
½-trans. ouput : PJT, PLT, UGT, VGT, UG, VG, ZG, DG, TG. " " " .
Then copies are made : PJT → PJG; PLT → PLG ; PLT × (im) → PMG.

In hemispheric mode this gives the "complete" half-transforms at +μ, ready for the FFT. Further work is required in global mode.

EONS.

Called only in global mode. Sums and differences the even and odd contributions to the half transforms at $+p$ to produce the "complete" half transforms at both $\pm p$, northern and southern hemisphere latitudes.

$$\text{eg.} \quad \mathcal{L}^{(m)}(+p) = \mathcal{L}^{(m)}_{EVEN}(+p) + \mathcal{L}^{(m)}_{ODD}(+p)$$
$$\mathcal{L}^{(m)}(-p) = \mathcal{L}^{(m)}_{EVEN}(+p) - \mathcal{L}^{(m)}_{ODD}(+p).$$

Fields used are UG, VG, ZG, DG, TG, PMG, PJG, PLG, giving $(5 \times NL + 3)$ sets of single level fields.

FFT991.

General routine for the simultaneous evaluation of (optimum) 64 Fast-Fourier-Transforms, from wave to grid or vice-versa. Vectorisation is achieved on the Cray by doing the FFT's in parallel. A single FFT corresponds to the half transforms for a single variable at a single level and single latitude, $+p$ or $-p$.

The number of longitudes in the transform grid, MG, is assumed to be an even number, and of the form $(2^p \times 3^q \times 4^r)$, where $p \geq 1$.

The main program MLTRI batches the fields to the FFT in batches of 64 plus any final remainder.

MGRMLT.

Evaluates grid point values of the non-linear contributions to the tendencies for the present latitude: $+p$ only in hemispheric mode: $\pm p$ in global mode.

Input from FFT : UG, VG, ZG, DG, TG, PMG, PJG, PLG.

Output to FFT : PLG, VPG, EG, UTG, VTG, UZG, VZG, TNLG.

ie $(5 \times NL + 3)$ single level fields are input, $(6 \times NL + 2)$ are output.

NSEO.

Called only in global mode. Sums and differences the "complete" half transforms at the current northern and southern hemisphere latitudes, $\pm p$, to produce the odd and even contributions to the half transforms at the northern hemisphere latitude, $+p$:

$$\text{eg } \mathcal{L}^{(m)}_{ODD}(+p) = \tfrac{1}{2}\left(\mathcal{L}^{(m)}(+p) - \mathcal{L}^{(m)}(-p)\right)$$

$$\mathcal{L}^{(m)}_{EVEN}(+p) = \tfrac{1}{2}\left(\mathcal{L}^{(m)}(+p) + \mathcal{L}^{(m)}(-p)\right).$$

Fields used are PLG, VPG, EG, UTG, VTG, UZG, VZG, TNLG, giving $(6 \times NL + 2)$ sets of single level fields.

HANAL

The contributions of the non-linear terms to the adiabatic spectral tendencies are evaluated by Gaussian integration, using only the northern hemisphere latitudes by making use of the symmetries of the various terms.

HANAL adds the contributions from the current Gaussian latitude to the tendencies.

The half transforms used are: PLG, VPG, EG, UTG, VTG, UZG, VZG, TNLG, yielding the spectral tendencies: SPA, VP, TT, DT, ZT.

BALANC

Performs one iteration of the balancing procedure from the vorticity to produce T', $\ln p_*$ as described in HS, Appendix II. Given the adiabatic spectral tendencies, BALANC evaluates the T', $\ln p_*$ coefficients necessary to make the (semi-implicit) divergence tendency zero, with the Binomial filter described in HS to minimise the 2-grid wave in the vertical.

This procedure leaves a large 2-grid wave if attempted with orography included. The program aborts in INITAL if attempted.

After the final iteration (KOUNT = 0), the initial forward timestep is set up by copying the present (t) fields into the previous ($t-\Delta t$) fields: Z, D, T, SP → ZMI, DMI, TMI, SPMI.

TBAL

Performs one iteration of a balancing procedure to obtain the vorticity from T', $\ln p_*$. Given the spectral adiabatic tendencies, TBAL evaluates the ζ coefficients necessary to give zero (semi-implicit) divergence tendency.

After the final iteration, (KOUNT = 0), the initial forward timestep is set up by copying the present (t) fields into the previous ($t-\Delta t$) fields: Z, D, T, SP → ZMI, DMI, TMI, SPMI.

NOISE

In an initial run with balancing, a white noise perturbation is applied to the balanced ($\ln$) surface pressure field, to initiate baroclinic instability. Not used in a RESTART run.

A random-number generator is used to add the perturbation to all the $m > 0$ (non-zonally-symmetric) spectral coefficients of $\ln p_*$. The perturbation is normalised to 0.1mb.

Split Time-Stepping Scheme.

This has been introduced to treat forcing/damping of gravity modes by diabatic processes accurately. The previous scheme, which used the $(t-\Delta t)$ time-lagged fields to evaluate the diabatic tendencies but passed these through the semi-implicit scheme, did not. The split-timestep involves first producing "interim" fields at $(t+\Delta t)$ from the adiabatic, semi-implicit tendencies. These fields are then used to evaluate the diabatic tendencies, which are added separately.

$$\text{eg} \quad \frac{\partial \zeta}{\partial t} = \left(\frac{\partial \zeta}{\partial t}\right)_{\text{ADIABATIC}} + \left(\frac{\partial \zeta}{\partial t}\right)_{\text{DIABATIC}} = \dot{\zeta}_A + \dot{\zeta}_D$$

becomes:

$$\zeta_*^{t+\Delta t} = \zeta^{t-\Delta t} + 2\Delta t\,(\dot{\zeta}_A^{t}) \quad \text{uses fields at } (t)$$

$$\zeta^{t+\Delta t} = \zeta_*^{t+\Delta t} + 2\Delta t\,(\dot{\zeta}_D^{t+\Delta t_*}) \quad \text{uses fields at } (t+\Delta t)_*$$

For $D, T', \ln p_*$, the adiabatic tendency is evaluated semi-implicitly, as before and described in HS.

The time filter: $\zeta_f^t = \zeta^t + \alpha\left[\zeta^{t-\Delta t} - 2\zeta^t + \zeta^{t+\Delta t}\right]$

becomes

$$\tilde{\zeta}_f^t = \zeta^t + \alpha\left[\zeta^{t-\Delta t} - 2\zeta^t\right]$$

$$\zeta_f^t = \tilde{\zeta}_f^t + \alpha\left[\zeta^{t+\Delta t}\right]$$

TSTEP

Performs the adiabatic step and explicit part of the time-filter.

Either: a) A centred semi-implicit step as described in section 3 of HS. Time filtering is included. (KOUNT > KITS)

or: b) A initial short timestep, either forward for KOUNT = 1, or centred for subsequent steps (1 < KOUNT ≤ KITS). Each step is double the length of the preceding step, so the matrix $B(\Delta t)^2$ is incremented after the step. The centred steps are semi-implicit but time-filtering is omitted.

For the first timestep in an initial run with restoration, the balanced zonal mean state is copied into the restoration state before the timestep.

DIFUSE

Calculates the diabatic spectral tendencies from diffusion and (if included) restoration. The "interim" $(t+\Delta t)_*$ fields are used for this.

DSTEP.

Performs the diabatic part of the timestep and completes the filter. Details as for TSTEP: for short steps, Δt and $2\Delta t$ are incremented.

LGNDRE

Called by INITAL, this routine calculates values of the Legendre functions $P_n^m(\mu)$ and their derivatives $(1-\mu^2)\,dP_n^m/d\mu$ for the current northern hemisphere latitude. Both odd and even functions are returned, interspersed, in order of increasing n within increasing m, for the jagged triangular truncation.

ENERGY.

Calculates and writes to channels 2 and NPC3 (if different from 2) the following diagnostics at each timestep:

RMS Relative vorticity : $\left[\frac{1}{4\pi}\int_0^1\int\!\!\int_S \zeta^2\,ds\,d\sigma\right]^{\frac{1}{2}} = \left[\sum_{r=1}^{NL}\sum_{m,n} Re(\zeta_{n,r}^m\,\zeta_{n,r}^{m*})\,\Delta\sigma_r\right]^{\frac{1}{2}}$

RMS Divergence : $\left[\frac{1}{4\pi}\int_0^1\int\!\!\int_S D^2\,ds\,d\sigma\right]^{\frac{1}{2}}$

RMS Temperature : $\left[\frac{1}{4\pi}\int_0^1\int\!\!\int_S (\bar{T}+T')^2\,ds\,d\sigma\right]^{\frac{1}{2}}$

PE + IE. $\frac{1}{4\pi}\int\!\!\int_S p_*\int_0^1 \left(\frac{T}{k}+\Phi_*\right)d\sigma\,ds.$

Mean p_*. $\frac{1}{4\pi}\int\!\!\int_S p_*\,ds.$

All values are non-dimensional.

MSPECT.

Computes the KE spectrum for output timesteps (ie every KOUNTP steps), except when KOUNT = 0. The half transform values of U and V are used and the approximation $p_* = 1000\,mb = \text{constant}$ is made.

(JG+2) calls are required to perform the analysis, so each call uses 1 of the 3 parts of the routine:

i) Initialise array RKE to zero.
ii) Add contributions from present latitude to the sums.
iii) Normalise and write out the results.

For zonal wavenumber m at level r:

$$\bar{K}_{m,r} = \frac{p_*}{4\pi g}\int\!\!\int_S \tfrac{1}{2}(U^2+V^2)_m\,ds$$

The values written are:

i) Total eddy KE.
ii) $\bar{K}_{m,r}$ for each zonal wavenumber and level.
iii) Vertical integral of each $\bar{K}_{m,r}$
iv) (iii) as a fraction of (i).
v) Log_{10} of (iii).
vi) Log_{10} of (iv).

The spectrum is written to channels 2 and NPC3 (if different from 2).

OUTPUT.

Writes the spectral coefficients up to m and n = NCOEFF on channel NPC1 and writes the grid point array (latitude-longitude plots and zonal sections) on channel NPC2. Levels to be written are defined by elements of the LSPO and LGPO arrays which are "true".

a) Spectral Coefficients.

Phases and non-dimensional amplitudes of the spectral coefficients of relative vorticity, divergence, perturbation temperature and log of surface pressure.

The amplitude and phase of each coefficient is calculated as follows:

For $m > 0$: $\mathcal{S}_n^m . Y_n^m(\lambda,\mu) + \mathcal{S}_n^{-m} Y_n^{-m}(\lambda,\mu) = 2P_n^m(\mu)\, Re\left[\mathcal{S}_n^m e^{im\lambda}\right]$
$= P_n^m(\mu) . Z \cos(m\lambda + \phi_n^m)$.

Then:

Amplitude $Z = 2\left\{[Re\,\mathcal{S}_n^m]^2 + [Im\,\mathcal{S}_n^m]^2\right\}^{\frac{1}{2}}$. Phase $\tan(\phi_n^m) = \frac{Im(\mathcal{S}_n^m)}{Re(\mathcal{S}_n^m)}$.

NB: For $m = 0$ the factor of 2 in the amplitude is omitted. Thus the amplitudes printed are double the values implied by the coefficients themselves in Z, D, T, SP for $m > 0$.

NB: The phase ϕ_n^m is normalised with the wavelength of zonal wavenb. m as 2π.

The actual longitude of the ridge is given by θ_n^m in $P_n^m(\mu) . Z . \cos m(\lambda - \theta_n^m)$, so the ridge longitude is:

$$\theta_n^m = -\phi_n^m / m .$$

b) Grid Point Fields.

Integer maps of the fields in the sigma surfaces and the zonally averaged arrays are written. NLAT and NLONG determine the resolution of the maps within the transform grid.

Variable	Units.
Streamfunction.	$10^{-4}(a^2\Omega)$
Divergence.	$10^{-3}(\Omega)$
Zonal velocity.	$0.1\ ms^{-1}$
Meridional velocity	$0.1\ ms^{-1}$
(Temp. − 273.16°)	0.1°C.
(Surf. Press. − 1000mb)	0.1mb.

In hemispheric mode, only northern hemispheric fields are mapped.

In global mode both hemispheres are mapped.

This can be controlled by altering NGOUT1, NGOUT2 in INITAL.

(Units of $1\ cm\,s^{-1}$ for the zonal average of meridional velocity.)

WRSPAIS

This routine is called from OUTPUT to write in compact form the amplitudes and phases of the spectral coefficients for one variable at a single level.

HXPOUT

When output is required this routine calculates the half transform values of the streamfunction for the present latitude from the spectral coefficients of vorticity.

In hemispheric mode the half transforms contain only odd contributions and are evaluated at +p.

In global mode the half transforms are first evaluated as odd and even contributions at +p. They are then summed and differenced as in EONS to obtain the "complete" half transforms at ±p.

OTHER ROUTINES: GWTLT, MINV, , BFAIL, FAX, FFTRIG, HESSEN, QREIG, QRT, the Fast Fourier Transform (FFT991) are all stored in binary form, precompiled, on a separate Cray dataset.

This page is out-of-date!

9 RUNNING THE MODEL.

a) Location.

The spectral model is stored at the University of London Computer Centre (ULCC) on the permanent file store of the Cray 1S. The major part of the program is stored in "update" program library format, as dataset RSGUP on ID = GBAR361. The FFT and several "black box" routines are stored precompiled on dataset SUBLIB, ID = GBAR361. There are also source versions of these routines on dataset MSUBS, ID = GBAR361, in program library format.

b) Sample Job-Deck.

```
JOB, US = <user id.>, JN = <job name>, MFL=100000, T=1Φ.        <comment>.
*. Reading atmospheric spectral model.
*. Test run.
ASSIGN, DN = $IN, A = FTΦ7.
ASSIGN, DN =$OUT, A = FTΦ2.
ASSIGN, DN = FT24, BS = 1Φ.
ACCESS, DN = $PL, PDN = RSGUP, ID = GBAR361.
UPDATE, F, IN, ID.
CFT, I =$CPL, L = Φ, ON =AZ, AIDS =LOOPALL.      (L = Φ suppresses listing,
ACCESS, DN =SUBLIB, PDN =SUBLIB, ID= GBAR361.     ~ 80 pages).
LDR, LIB =SUBLIB, MAP = PART.
EXIT.
DUMPJOB.
DEBUG.
/EOF
*IDENT CHANGE
*DELETE PARAM1.2,3
      PARAMETER(NN=21, MM=21, NHEM=1, NL=5, MOCT=7, MG=8, JG=16, NWJ2=22
     +   , NCRAY = 64, JGL = JG)
*DELETE INITAL.55Φ,557
      K = IDM + 2
      DO 8ΦΦ L = 1, NL
      Z(K) = ZDATN(1)
 8Φ Φ  K = K + IGA
*DELETE MLTCA.23
/EOF
 $INPB KTOTAL = 98, KBAL =5, KITS =3, KOUNTP = 48,
  NPC1 =2, NPC2=2, NPC3 =2, LSPO = .F., .T., 2*.F., .T., LGPO = .F., .T., 2*.F., .T.,
  NDEL = 6, TDISS = Φ.1666666666667 $
  $WVORT ZDATN = Φ.Φ1, 54* Φ.Φ $
/EOF
```

This job deck will run the model on a hemisphere with 7-fold symmetry in longitude, with T21 resolution and 5 vertical levels. The basic flow is stationary (at rest) with a roughly barotropic Rossby mode (a single vorticity coefficient, equal in amplitude at all levels) which should propagate westwards at about $6\frac{1}{2}^{\circ}$ per day.

The update alters the parameters which determine the model resolution and also alters a loop in INITAL which sets up the vorticity of the initial state from the WVORT namelist. This gives zero basic state flow plus $\vec{\zeta}_{10} = (0.01, 0.0)$ at all levels.

c) Required Data.

i) Parameters.

The horizontal and vertical resolution of the model is determined by the parameters in common-deck PARAM1. See section 6.

The default is for T21, 5level, hemispheric resolution, with MOCT=1. For other resolutions at MOCT=1 the following are appropriate:

	MM	NN	MG	JG	NWJ2
T21	21	21	64	16	121
T42	42	42	128	32	462
T63	63	63	192	48	1024

ii) Namelist INPB.

The remaining data necessary to set up all the constant arrays and variables is read in subroutine INITAL in namelist INPB. Defaults are provided for all these variables, so a value only needs to be provided in INPB if the default is inappropriate.

Name	Default	Meaning.
KSTART	0	Starting timestep number (restart runs)
KTOTAL	0	Total no. of timesteps in integration.
KBAL	0	No. of balancing iterations.
KITS	0	No. of short timesteps (except LRSTRT=.F., LSHORT=.F.)
TSPD	48.0	No. of timesteps per day.
KOUNTP	0	Spacing in timesteps of printed output.
KOUNTH	0	Spacing in timesteps of history records.
KOUNTR	0	Spacing in timesteps of restart records. Must be a multiple of KOUNTH!
RNTAPE	0.0	Identifying run number.
NPC1	3	Channel for printed spectral coeffs.
NPC2	3	Channel for printed grid point data.
NPC3	3	Channel for diagnostics at each timestep and for KE spectrum every KOUNTP timesteps.
NCOEFF	NN	Max. wavenumber of printed spectral coeffs.

Name	Default.	Meaning.
NLAT	JG	No. of latitudes in printed grid point data. (NLAT = Φ switches off all the grid point output). Should be factor of JG
NLONG	MG	No. of longitudes in printed grid point data. Should be factor of MG
LSPO(NL)	all False	Levels at which printed spectral coeffs. required.
LGPO(NL)	all False	Levels at which printed grid point data required. (with all LGPO values false, print only surface pressure)
GA	9.81	Gravitational acceleration (ms^{-2})
GASCON	287.Φ	Gas constant for dry air ($Jkg^{-1}K^{-1}$)
RADEA	6371ΦΦΦ.Φ	Earth mean radius. (m)
WW	7.292×10^{-5}	Earth's siderial rotation rate. (s^{-1})
AKAP	Φ.286	$K = R/C_p$ for dry air.
TDISS	Φ.Φ	Timescale in siderial days of biharmonic diffusion acting on the shortest retained length-scale (wavenumber NN).
NDEL	Φ	Order of biharmonic diffusion (∇^{NDEL}). Should be even
RESTIM	Φ.Φ	Timescale in siderial days of restoration.
PNU	Φ.Φ1	Factor for time filter.
TMEAN(NL)	all 25Φ.Φ	Level mean temperatures (K).
LRSTRT	False.	False: initial run with balancing. True: restart run from a history or restart record.
LSHORT	False.	False: no short timesteps. True: begin with short timesteps } Restart runs only.
LTBAL	False	False: balance from ζ to T', lnp* : BALANC. True: balance from T', lnp* to ζ : TBAL.

Stratification Set-Up.

The initialisation of the temperature stratification depends on the number of levels, NL.

NB The TΦ array is used for the basic state stratification $\bar{T}(\sigma)$ in the semi-implicit scheme.
The TMEAN array is used for the complete stratification — level mean temperature — of the initial state.

$\bar{T}(\sigma)$ should be isothermal for NL > 5 to ensure computational stability.

i) Preset defaults : TΦ = TMEAN = 250K at all levels.

ii) INPB override : read TMEAN as required.

iii) Special Case : for NL ≤ 5 set TΦ = TMEAN, to include the complete stratification in the basic state.

iv) Non-Dimensionalise : divide TΦ and TMEAN by CT.

v) Initial Fields : First preset all (t) and (t-Δt) fields to zero. Gives $(T')^{\circ}_{0} = 0$.

Then : BALANCing : $(T')^{\circ}_{0} = TMEAN - T\Phi$

or TBALancing : $(T')^{\circ}_{0} = (T')^{\circ}_{0} - T\Phi$. This assumes that $(T')^{\circ}_{0}$ read in the namelist TMPSP is non-dimensional but includes the level mean.

or ReSTaRTing : do nothing : assume that $(T')^{\circ}_{0}$ on the history or restart record is set up as needed.

Sigma Levels.

NL ≤ 5 : Sets up equispaced levels.

NL > 5 : Sets up non-equispaced levels using a formula originally intended for use with NL = 15.

iii) Initial State.

Finally, the initial state is set up in INITAL. The method used and data required depend on the type of run.

1 Initial Run : Balancing from ζ to T', lnp*.

Read zonal mean relative vorticity coefficients in namelist WVORT. This requires the real parts of all the m = 0 coefficients at NL levels, non-dimensionalised.

In a global run, all the odd coeffs. must precede all the even coeffs.

Within each level the coeffs. must be stored in increasing 'n':

Odd : n = 1, 3, 5, 7, ...

Even : n = 0, 2, 4, 6, ...

In all, IGN real values are needed.

2 Initial Run : Balancing from T', lnp* to ζ.

Read zonal mean temperature and log of surface pressure coeffs. in namelist TMPSP. This requires the real parts of all the m = 0 coeffs. at NL levels. The coeffs. are assumed to be non-dimensional and the temperatures to include the level means. Storage is as for WVORT above, with all the temperature coeffs preceding all the surface pressure coeffs.

3 Restart Run : No short timesteps.

Read in the spectral fields for two time levels (t, t-Δt) from a full restart record on channel 10. This must contain :

RKOUNT, RMTAPE, DAY, Z, D, T, SP, RMTAPE, ZMI, DMI, TMI, SPMI, RMTAPE.

4 Restart Run : with Short Timesteps.

Read in the spectral fields at a single time level only from a history record on channel 10. This must contain:

RKOUNT, RMTAPE, DAY, Z, D, T, SP, RMTAPE.

These fields are copied into the $(t-\Delta t)$ coefficient arrays ready for the initial forward timestep. The counters then begin from zero.

If the wrong record is read in, the program stops.

5 Restoration in Restart Runs.

The state towards which the zonal mean state is to be restored during the integration is read from channel 13.

It must contain : ZRES, DRES, TRES, SPRES.

Only the real parts of the coeffs. are useds in the arrays.

Ordering is by level for each variable, with the "hemispheric" part preceding the "non-hemispheric" part, at each level.

For each odd or even part at a level, storage is in increasing 'n'.

Even : $n = 0, 2, 4, 6, \ldots$ Odd : $n = 1, 3, 5, 7, \ldots$

d) Output Description.

The model produces printed output as follows:

i) Description of input data and type of model run on channel 2.

ii) Energy and RMS values at each timestep (a single line of output) on channels 2 and NPC3 (if different from 2).

iii) The spectral coefficients on channel NPC1 and gridded fields on channel NPC2, at KOUNT = 0 and every KOUNTP timesteps.

iv) The kinetic energy spectrum every KOUNTP timesteps on channels 2 and NPC3 (if different from 2).

By default NPC1 = NPC2 = NPC3 = 3 so that (ii), (iii) and (iv) are all written on channel 3. This is intended to be a microfiche file for long-term storage of the results.

Only the KE spectrum and RMS/energy values are written to channel 2, the output file.

By default (LSPO, LGPO all false) the spectral coefficient output is suppressed and only the surface pressure grid point field is written (for NLAT > 0).

10 TIMINGS AND STORAGE REQUIREMENTS.

The Cray job statement requires estimates of the CPU time in seconds and the total field length (program, arrays and buffers) in Cray words.

The following table gives the values needed for a one-day integration using 48 steps per day with MOCT = 1 and JGL = 1 in the parameter list. Valid for present operating system COS 1.12.

Horiz. Resolution	Vert. resol. (NL)	NHEM	Execution time (s)	T parameter (s)	MFL parameter
T21	5	1	4	10	120 000
		2	8	15	150 000
T21	15	1	11	20	180 000
		2	21	30	260 000
T42	5	1	22	30	200 000
		2	40	50	300 000
T42	15	1	55	70	500 000
		2	110	120	660 000

The contribution to the MFL parameter from common blocks is given in the following table.

Horiz. Resolution	Vertical Resolution (NL)	NHEM = 1 JGL = JG	NHEM = 1 JGL = 1	NHEM = 2 JGL = JG	NHEM = 2 JGL = 1	JGL = 1 Saving.
T21	5	50 000	35000	77 000	62 000	15 000
	10	77000	62 000	130000	115 000	
	15	105000	90 000	183 000	168 000	
T42	5	227 000	112000	321000	206000	115 000
	10	317 000	202000	497000	383000	
	15	409000	294000	676 000	561000	
T63	5	618000	223000	*819000	434000	385000
	10	*807000	425 000	*1 192000	* 807 000	
	15	*999000	614 000	*1568000	*1 183000	

The program, subroutines etc generally take an extra MFL ~ 50000. The buffers require roughly a further MFL ~ 30000, depending on resolution. Thus, to obtain an MFL parameter for a run, add roughly 80000 to the values in the table.

Maximum allowed value is MFL = 880000 and asterisks values denote resolutions likely or certain to overflow this.