TECHNICAL MEMORANDUM

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Description of the ECMWF model post processing system

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POST PROCESSING

1. INTRODUCTION

The post processing package provides an interface between the forecast model and the Centre's databases for dissemination and archiving. It manipulates the model output in order to present it in a more convenient and standard format for the data users. Within the post-processing package, data can be interpolated vertically from the model's hybrid co-ordinates to constant pressure surfaces, and horizontally from the Gaussian grid to a regular latitude/longitude grid. Data are converted from line to field form, and from Cray to either a Cyber format or to WMO GRIB code for archiving under MARS. As well as providing grid point data the post-processing produces sets of spherical harmonics, which are a compact data form, suitable for long-term storage within the ECMWF archives.

Sections 2, 3 and 4 below describe the derivation of those post-processed fields which are not model dependent variables, and the vertical and horizontal interpolation systems. Section 5 provides details of the code organisation and file structures The contents of the ddr's is described in detail in the Appendix.

2. DERIVED FIELDS

The following fields which are not model dependent variables can be calculated by the post-processing. Reference should be made to ECMWF Research Manual 2 for the definition of symbols and the values of constants.

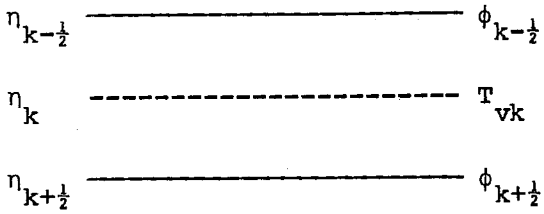
2.1 Geopotential

The geopotential is calculated at the model's half-levels, using

$$\phi_{NLEV+\frac{1}{2}} = \phi_s \tag{2.1}$$

$$\phi_{k-\frac{1}{2}} = \phi_{k+\frac{1}{2}} + R_d\, T_{vk} \ln\left(\frac{p_{k+\frac{1}{2}}}{p_{k-\frac{1}{2}}}\right) \qquad 1<k\leqslant NLEV \tag{2.2}$$

$$\phi_{\frac{1}{2}} = \phi_{1\frac{1}{2}} + R_d\, T_{v1}\, 2\ln(2) \tag{2.3}$$



2.2 Vertical velocity

The vertical velocity, ω, is calculated in two parts;

$$\omega = \omega_H + \omega_F \tag{2.4}$$

where
$$\omega_H = -\int_0^1 \nabla\cdot\left(\underset{\sim}{v}_h \frac{\partial p}{\partial \eta}\right) d\eta \tag{2.5}$$

and
$$\omega_F = \underset{\sim}{v}_h\cdot\nabla p \tag{2.6}$$

The ω_H is calculated at the model half levels. Using the model's finite difference scheme, the half-level part becomes:-

$$\omega_{\frac{1}{2}} = 0 \tag{2.7}$$

$$\omega_{k+\frac{1}{2}} = \omega_{k-\frac{1}{2}} - D_k\,\Delta p_k \qquad \text{for pure pressure layers} \tag{2.8}$$

or
$$\omega_{k+\frac{1}{2}} = \omega_{k-\frac{1}{2}} - D_k\,\Delta p_k - \left(\underset{\sim}{v}_h\cdot\nabla p_s\right)\Delta B_k \quad \text{for hybrid layers} \tag{2.9}$$

where $\underset{\sim}{v}_h$ and D_k are the horizontal wind and divergence at level k

$$\Delta p_k = p_{k+\frac{1}{2}} - p_{k-\frac{1}{2}}$$

$$\Delta B_k = B_{k+\frac{1}{2}} - B_{k-\frac{1}{2}}$$

$$p_{k+\frac{1}{2}} = A_{k+\frac{1}{2}} + B_{k+\frac{1}{2}} \, p_s$$

The ω_F is calculated on the model full levels and the finite difference representation is given by:

$$\omega_k = 0 \qquad (2.10)$$

for pure pressure levels, or

$$\omega_k = p_k \left(\underset{\sim}{v}_h \cdot \nabla p_s\right) \frac{1}{\Delta p_k} \left(\Delta B_k + C_k \frac{1}{\Delta p_k} \ln \left(\frac{p_{k+\frac{1}{2}}}{p_{k-\frac{1}{2}}}\right)\right) \qquad (2.11)$$

for hybrid levels (cf Eq. 2.2.26 of Research Manual 2) or

$$\omega_k = p_k \left(\underset{\sim}{v}_h \cdot \nabla p_s\right) \frac{1}{\Delta p_k} \Delta B_k \qquad (2.12)$$

for pure sigma levels where

$$C_k = A_{k+\frac{1}{2}} B_{k-\frac{1}{2}} - A_{k-\frac{1}{2}} B_{k+\frac{1}{2}}$$

2.3 Relative humidity

The relative humidity is calculated at the full model levels using:

$$RH_k = \left(\frac{q_k}{q_{sk}}\right) \times 100 \qquad (2.13)$$

where q_s, the saturation specific humidity, is defined as:

$$q_{sk} = \frac{\dfrac{R_D}{R_V} \dfrac{e_s(T_k)}{p_k}}{1 - \left(\dfrac{R_V}{R_D} - 1\right) \dfrac{R_D}{R_V} \dfrac{e_s(T_k)}{p_k}} \qquad (2.14)$$

and $e_s(T)$, the saturation vapour pressure, is defined as:-

$$e_s(T_k) = C_1 \exp \left(\frac{C_3 \, (T_k - T_o)}{T_k - C_4}\right) \qquad (2.15)$$

with $T_0 = 273.16$

$C_1 = 610.78$

$$C_3 = \begin{cases} 17.269 & \text{for } T_k \geqslant T_o \\ 21.875 & \text{for } T_k < T_o \end{cases}$$

$$C_4 = \begin{cases} 35.86 & \text{for } T \geqslant T_o \\ 7.66 & \text{for } T_k < T_o \end{cases}$$

This formulation takes account of both the ice and water phases.

2.4 Mean sea-level pressure

The calculation of mean sea-level pressure is based on assumption of a dry, hydrostatic subterranean atmosphere and a uniform lapse rate of 6.5×10^{-3} Km^{-1}. This lapse rate is modified for warm surface temperatures to approximate the formulation developed at the US National Weather Service (Technical Procedure Bulletin No. 57). It is invoked at points where the magnitude of the surface geopotential exceeds 10^{-3} $m^{-2}s^{-2}$, otherwise the mean sea-level pressure, p_{msl}, is set equal to the surface pressure, p_s.

First, a surface temperature T_* is computed:

$$T_* = T_{NLEV} + .0065 \frac{R_d}{g} T_{NLEV} \left(\frac{p_s}{p_{NLEV}} - 1\right) \tag{2.16}$$

Assuming a uniform lapse rate $\alpha g/R_d$, and a hydrostatic equation

$$\frac{\partial\phi}{\partial p} = - \frac{R_d T}{p} \tag{2.17}$$

with $$T = T_* + \frac{\alpha}{R_d}(\phi_s - \phi) \tag{2.18}$$

the following formulae for T, ϕ and p_{msl} are obtained:

$$T = T_* (p/p_s)^{\alpha} \tag{2.19}$$

$$\phi = \phi_s - \frac{R_d T_*}{\alpha} ((p/p_s)^{\alpha} - 1) \tag{2.20}$$

$$p_{msl} = p_s \left(1 + \frac{\alpha\phi_s}{R_d T_*}\right)^{(1/\alpha)} \tag{2.21}$$

The actual calculation of p_{msl} in the post-processing uses an approximation valid for small α:

$$p_{msl} = p_s \exp\left\{\frac{\phi_s}{R_d T_*}\left(1-\tfrac{1}{2}\left(\frac{\alpha\phi_s}{R_d T_*}\right)+1/3\left(\frac{\alpha\phi_s}{R_d T_*}\right)^2\right)\right\} \qquad (2.22)$$

It uses the value

$$\alpha = .0065\ R_d/g \qquad (2.23)$$

but this is reduced to

$$\alpha = R_d(290.5-T_*)/\phi_s \qquad (2.24)$$

if $T_* \leqslant 290.5$ and $T_o > 290.5$, where

$$T_o = T_* + .0065\phi_s/g \qquad (2.25)$$

If $T_* > 290.5$ and $T_o > 290.5$, $\alpha=0$ and T_* is replaced by $\frac{1}{2}(290.5 + T_*)$. These modifications inhibit low extrapolated pressures under hot elevated terrain. In a similar spirit, to inhibit high pressures under cold terrain, T_* is replaced by $\frac{1}{2}(T_* + 255)$ when it falls below 255K.

3. VERTICAL INTERPOLATION AND EXTRAPOLATION

By default, tension splines are used for the interpolation in the vertical from the model coordinates to constant pressure levels. Optionally, the user may choose to use instead linear or cubic spline interpolation or to do no vertical interpolation, leaving the data on the model coordinates. Regardless of the method selected by the user, linear interpolation is used for humidity variables (specific humidity, relative humidity) because the spline methods may overshoot if the input data vary too rapidly in the vertical.

3.1 Tension Spline Interpolation

Following Cline (1974), tension splines are defined as follows:

Given (i) a set of knots, $\{x_i\}$ for $1 \leq i \leq n$, with $x_i < x_{i+1}$

(ii) a corresponding set of functional values, $\{u_i\}$

(iii) a non-zero constant, t, the tension factor

then the tension spline, f, is a real-valued function such that

(i) $f(x_i) = u_i$ $\quad 1 \leq i \leq n$ (3.1)

(ii) f, f', f'' are continuous (3.2)

(iii) $f'' - t^2 f$ varies linearly on each of the intervals $[x_i, x_{i+1}]$ for $1 \leq i < n$ (3.3)

As $t \rightarrow o$, f becomes a cubic spline. As $t \rightarrow \infty$, f becomes linear interpolation. Within the post-processing t=1.

3.2 Cubic spline interpolation

Cubic splines are fitted using the NAG library's normalised B-splines. They are evaluated on pressure levels using an ECMWF vesion of the NAG code, which has been specially written to vectorise on the Cray.

3.3 Vertical coordinate system

$\ln(\eta)$ is the vertical coordinate used for interpolating geopotential, while η is used for all other variables. Before data can be interpolated with respect to η or $\ln(\eta)$ to pressure p, the value of η which corresponds to p has to be determined for each grid point. Since in the forecast model η is defined only at half levels, this is done by linear interpolation:

(i) find k such that $p_{k-\frac{1}{2}} \leq p < p_{k+\frac{1}{2}}$ for $1 \leq k \leq NLEV$ (3.4)

$$\text{(ii)} \quad \eta = \eta_{k-\frac{1}{2}} + \frac{(p-p_{k-\frac{1}{2}})\,(\eta_{k-1} - \eta_{k+\frac{1}{2}})}{p_{k+\frac{1}{2}} - p_{k-\frac{1}{2}}} \qquad (3.5)$$

Geopotential and part of the vertical velocity are input to the vertical interpolation on model half levels, while all other variables are supplied on full model levels.

3.4 Extrapolation

The general rule for extrapolation is that fields are given a constant value, which is equal to the value at the highest model level for all points above that level, and which is equal to the value at the lowest model level for all points below. Exceptions to this rule are given below:-

(i) u and v velocity are extrapolated linearly above the highest model level.

(ii) the full level part of the vertical velocity is set to 0 below the earth's surface.

(iii) geopotential is extrapolated linearly above the highest model level. For cubic spline interpolation, the geopotential is also interpolated linearly inside the highest model layer, ie above $p_{1\frac{1}{2}}$, to avoid any overshooting problems.

(iv) geopotential is extrapolated downwards in the same way as specified in Section 2.4 for mean sea level pressure. Equation 2.20 is approximated by

$$\phi = \phi_s - R_d T_* \ell n \frac{p}{p_s} [1+\tfrac{1}{2} \alpha \ell n \frac{p}{p_s} + \frac{1}{6} (\alpha \ell n \frac{p}{p_s})^2] \tag{3.6}$$

(v) between the lowest model level and the surface, the temperature is interpolated linearly, using:

$$T = \frac{(p_s - p) T_{NLEV} + (p - p_{NLEV}) T_*}{p_s - p_{NLEV}} \tag{3.7}$$

where T_*, the surface temperature, is defined as in (2.16).

(vi) To extrapolate temperature below the earth's surface, 2.19 is approximated by

$$T=T_*(1+\alpha \ell n p/p_s + \tfrac{1}{2}(\alpha \ell n p/p_s)^2 + \frac{1}{6} (\alpha \ell n p/p_s)^3) \tag{3.8}$$

with T_* as defined by (2.16). α is defined by

$$\alpha = .0065 R_d/g \quad \text{for } \phi_s/g < 2000 \text{ m} \tag{3.9}$$

but is modified for high orography to limit the extrapolated mean sea-level temperature. The formulae used are

$$\alpha = R_d (T'_o - T_*)/\phi_s \tag{3.10}$$

where, defining

$$T_{plat} = \text{Min} \{T_o, 298\} \tag{3.11}$$

T'_o is given by

$$T'_o = T_{plat} \quad \text{for } \phi_s/g > 2500 \text{ m} \tag{3.12}$$

and

$$T'_o = .002 \left\{(2500-\phi_s/g)\, T_o + (\phi_s/g-2000)T_{plat}\right\} \tag{3.13}$$

for $2000 \leqslant \phi_s/g \leqslant 2500$.

T_o is given by 2.25. If $T'_o < T_*$, α is reset to zero.

3.5 Interpolation for 10m wind, 2m temperature and 2m dewpoint

In the model the surface fluxes of momentum, heat and moisture are computed as follows:

$$|\tau| = u_*^2 = CDN^2\, F\left(R_i, \frac{h}{Z_o}\right) |V_{NLEV}|^2$$

$$H = u_*\, S_* = CDN^2\, G\left(R_i, \frac{h}{Z_o}\right) |V_{NLEV}| \left(S_{NLEV}-S_s\right)$$

$$L = u_*\, q_* = CDN^2\, G\left(R_i, \frac{h}{Z_o}\right) |V_{NLEV}|\; E\; \left(q_{NLEV}-q_{SAT}(T_s)\right)$$

where:

h is the height of the lowest model level (NLEV)

$|V_{NLEV}|$ is the horizontal wind speed at level NLEV

$s = g\,z + C_{pd}(1+(\delta-1)q)T$ is the dry static energy,

$q_{sat}(T_s)$ is the saturation mixing ration at surface temperature and pressure,

E is the evapotranspiration efficiency coefficient,

$R_i = \dfrac{gh\Delta S}{C_{pd}T_v|V_{NLEV}|^2}$ is the Richardson number

$CDN = \dfrac{k}{\ln\left(\dfrac{h+Z_0}{Z_0}\right)}$ is the drag coefficient for the neutral case,

and the subscript NLEV refers to values at the lowest model level, while the s subscript refers to the surface values.

The analytical expression for F, G and E can be found in Research Manual 3, Chapter 3.

The 10m wind, 2m temperature and 2m dew point temperature are post-processed in the subroutine *SURPAR* with the following method.

The values for each variable u, v, $gZ+C_pT$ and q are interpolated between the lowest model level and the surface according to the logarithmic profile, based on modified values of the roughness length. These modified values are the ones that would create in the neutral case the same drag coefficient, as those obtained with the real roughness length and the stability conditions of the atmosphere used for the interpolation.

Any change in the flux computations in the model should be implemented into *SURPAR* so that the drag coefficients are computed in exactly the same way as in the model.

The following basic relations are required to be fulfilled:

$$\begin{aligned} |V_{NLEV}| &= \frac{u_*}{k}\,\ell n\left(1+\frac{h}{z_o^{*M}}\right) \\ (S_{NLEV}-S_s) &= \frac{s_*}{k}\,\ell n\left(1+\frac{h}{z_o^{*H}}\right) \qquad (3.14) \\ (q_{NLEV}-q_s) &= \frac{q_*}{k}\,\ell n\left(1+\frac{h}{z_o^{*H}}\right) \end{aligned}$$

So that

$$\begin{aligned} |V_{10}| &= \frac{u_*}{k}\,\ell n\left(1+\frac{10}{z_o^{*M}}\right) \\ (S_2-S_s) &= \frac{S_*}{k}\,\ell n\left(1+\frac{2}{z_o^{*H}}\right) \qquad (3.15) \\ (q_2-q_s) &= \frac{q_*}{k}\,\ell n\left(1+\frac{2}{z_o^{*H}}\right) \end{aligned}$$

where $|V_{10}|$ is the horizontal wind speed at 10m with corresponding wind components u_{10} and v_{10}.

Accordingly, the 10m wind and 2m parameters may be written as:

$$\begin{pmatrix} u_{10} \\ v_{10} \end{pmatrix} = \begin{pmatrix} u_{NLEV} \\ v_{NLEV} \end{pmatrix} \ell n\left(1+\frac{10}{h}\,\frac{h}{Z^{*M}_{o}}\right)/\ell n\left(1+\frac{h}{Z^{*M}_{o}}\right)$$

$$(S_2 - S_s) = (S_{NLEV} - S_s)\ \ell n\left(1+\frac{2}{h}\,\frac{h}{Z^{*H}_{o}}\right)/\ell n\left(1+\frac{h}{Z^{*H}_{o}}\right) \qquad (3.16)$$

$$(q_2 - q_s) = (q_{NLEV} - q_s)\,\ell n\left(1+\frac{2}{h}\,\frac{h}{Z^{*H}_{o}}\right)/\ell n\left(1+\frac{h}{Z^{*H}_{o}}\right)$$

The quantities $\frac{h}{Z^{*M}_{o}}$ and $\frac{h}{Z^{*H}_{o}}$ can be deduced from the surface fluxes.

The following relations are required at the surface:

$$u_*^2 = \left(\frac{k}{\ell n(1+h/Z_0)}\right)^2 F\,|V_{NLEV}|^2 = \left(\frac{k}{\ell n\left(1+\frac{h}{Z^{*M}_{o}}\right)}\right)^2 |V_{NLEV}|^2 \qquad (3.17)$$

$$u_*S_* = \left(\frac{k}{\ell n(1+h/Z_0)}\right)^2 G\,|V_{NLEV}|\,(S_{NLEV}-S_s) = \left(\frac{k}{\ell n\left(1+\frac{h}{Z^{*H}_{o}}\right)}\right)^2 |V_{NLEV}|\,(S_{NLEV}-S_s) \qquad (3.18)$$

Setting $ZCFM = \frac{F^{\frac{1}{2}}}{\ell n(1+h/Z_0)} = \frac{1}{\ell n\left(1+\frac{h}{Z^{*M}_{o}}\right)}$ leads to $\frac{h}{Z^{*M}_{o}} = \exp(1/ZCFM)-1$

$$\text{and } u_* = k\ ZCFM\,|V_{NLEV}| \qquad (3.19)$$

Using (3.14) and (3.19), (3.18) can be written:

$$kZCFM\,|V_{NLEV}|\,S_* = \left(\frac{k}{\ell n(1+h/Z_o)}\right)^2 G\,|V_{NLEV}|\,\frac{S_*}{k}\,\ell n\left(1+\frac{h}{Z^{*H}_{o}}\right) \qquad (3.20)$$

So that $ZCFH = \frac{1}{\ell n(1+h/Z^{*H}_{o})} = [(k/\ell n(1+h/Z_o))^2 G]/(k^2 ZCFM)]$

which gives $h/Z^*_{oH} = \exp(1/ZCFH)-1$. Finally, it may be written

$$\begin{pmatrix} u_{10} \\ v_{10} \end{pmatrix} = \begin{pmatrix} u_{NLEV} \\ v_{NLEV} \end{pmatrix} ZCFM\ \ell n[(1+\frac{10}{h}(\exp(1/ZCFM)-1)]$$

Following the same method, it can be defined:

$$ZCFH = \frac{G^{\frac{1}{2}}}{\ell n(1+\frac{h}{Z_o})}$$

$$S_2 = S_s + (S_{NLEV} - S_s)\ ZCFH\ \ell n[(1+\frac{2}{h}(\exp(1/ZCFH)-1]$$

The effective mixing ratio at the surface is such that

$$q_{NLEV} - q_s = E\left(q_{NLEV} - q_{sat}(T_s)\right)$$

and then

$$q_s = Eq_{sat} + (1-E)\ q_{NLEV}$$

The mixing ratio at 2m can be expressed as

$$q_2 = q_{NLEV} + E\left(q_{sat}(T_s) - q_{NLEV}\right)\left(1 - ZCFH * \ell n[1+\frac{2}{h}\exp(1/ZCFH)-1]\right)$$

The value of the 2m temperature is obtained by

$$T_2 = (S_2 - 2g)/[C_{pd}\left(1+(\delta-1)q_2\right)] \qquad (3.21)$$

By definition, the dew point temperature at 2m is such that

$$q_2 = q_{sat}(Td_2)$$

Defining

$$q_{sat}(Td_2) \approx \left(a_1 \exp(a_3 \frac{Td_2 - T_0}{Td_2 - a_4})\right)\left(1+(\frac{1}{\varepsilon} - 1)q_2\right)/p_s$$

Td_2 can be obtained:

$$Td_2 = (T_o - a_4 ZFRAC)/(1-ZFRAC) \qquad (3.22)$$

with

$$ZFRAC = \left(\ell n\left\{[p_s q_e]/[a_1 x(1+(\frac{1}{\varepsilon}-1)q_2)]\right\}\right)/a_3$$

and the condition

$$Td_2 < T_2$$

4. HORIZONTAL INTERPOLATION

After the vertical interpolation has been done, the data is fitted spectrally, and then evaluated on the required output horizontal grid.

4.1 Spectral coefficients of non-velocity fields

The calculation of spectral coefficients (see Machenhauer and Daley 1972) within the post-processing resembles the corresponding calculation in the forecast model for all fields apart from the velocities.

For a non-velocity field F, the spectral coefficients F_n^m are defined as:

$$F_n^m = \frac{1}{4\pi} \int_{-1}^{1} \int_{0}^{2\pi} F(\mu,\lambda)\, P_n^m(\mu)\, e^{-im\lambda}\, d\mu\, d\lambda \tag{4.1}$$

$$= \frac{1}{2} \int_{-1}^{1} F_m(\mu)\, P_n^m(\mu)\, d\mu, \tag{4.2}$$

where $F_m(\mu)$ is the m'th Fourier coefficient

Since the input data is given on Gaussian latitudes, this can be evaluated using Gaussian quadrature:-

$$F_n^m = \tfrac{1}{2} \sum_{j=1}^{NGL} F_m(\mu_j)\, P_n^m(\mu_j)\, w_j \tag{4.3}$$

where NGL is the number of Gaussian latitudes and the w_j are the Gaussian weights.

Using the symmetry properties of the Legendre polynomials this can be reduced to:

$$F_n^m = \sum_{j=1}^{NGL/2} F_m^S(\mu_j)\ P_n^m(\mu_j)\ w_j \qquad \text{for m+n even} \qquad (4.4)$$

$$= \sum_{j=1}^{NGL/2} F_m^A(\mu_j)\ P_n^m(\mu_j)\ w_j \qquad \text{for m+n odd} \qquad (4.5)$$

where $F_m^S(\mu_j)$ and $F_m^A(\mu_j)$ are the symmetric and antisymmetric Fourier coefficients such that:

$$F_m^S(\mu_j) = \left(F_m(\mu_j) + F_m(-\mu_j)\right)*\tfrac{1}{2}$$

$$F_m^a(\mu_j) = \left(F_m(\mu_j) - F_m(-\mu_j)\right)*\tfrac{1}{2}$$

4.2 Spectral coefficients of velocity fields

The spectral coefficients required as output from the post-processing for the velocity fields are those of the pressure-level divergence and vorticity. These are calculated from the pressure level wind fields using:

$$\xi_n^m = \frac{1}{4\pi a} \int_{-1}^{1} \int_{0}^{2\pi} \left(\frac{1}{1-\mu^2} \frac{\partial V}{\partial \lambda} - \frac{\partial U}{\partial \mu}\right) P_n^m(\mu) e^{-im\lambda}\ d\mu\ d\lambda \qquad (4.6)$$

$$D_n^m = \frac{1}{4\pi a} \int_{-1}^{1} \int_{0}^{2\pi} \left(\frac{1}{1-\mu^2} \frac{\partial U}{\partial \lambda} + \frac{\partial V}{\partial \mu}\right) P_n^m(\mu) e^{-im\lambda}\ d\mu\ d\lambda \qquad (4.7)$$

with U = u cos(lat) and V = v cos(lat)

Integrating by parts gives:

$$\xi_n^m = \frac{1}{2a} \int_{-1}^{1} \left(imV_m(\mu)\ p_n^m(\mu) - U_m(\mu)\ H_n^m(\mu) \right) \frac{d\mu}{1-\mu^2} \qquad (4.8)$$

$$D_n^m = \frac{1}{2a} \int_{-1}^{1} \left(imU_m(\mu)\ p_n^m(\mu) + V_m(\mu)\ H_n^m(\mu) \right) \frac{d\mu}{1-\mu^2} \qquad (4.9)$$

with U, V and $H_n^m(\mu)$ defined by

$$U = \sum_{m=-M}^{M} U_m(\mu) e^{im\lambda}$$

$$V = \sum_{m=-M}^{M} V_m(\mu) e^{im\lambda}$$

$$H_n^m(\mu) = -(1-\mu^2) \frac{dP_n^m(\mu)}{d\mu}$$

Since the input data is given on Gaussian latitudes, this can be evaluated using Gaussian quadrature:

$$\xi_n^m = \frac{1}{2a} \sum_{j=1}^{NGL} \left(imV_m(\mu_j)\ P_n^m(\mu_j) - U_m(\mu_j)\ H_n^m(\mu_j) \right) \frac{w_j}{1-\mu_j^2} \qquad (4.10)$$

$$D_n^m = \frac{1}{2a} \sum_{j=1}^{NGL} \left(imU_m(\mu_j)\ P_n^m(\mu_j) + V_m(\mu_j)\ H_n^m(\mu_j) \right) \frac{w_j}{1-\mu_j^2} \qquad (4.11)$$

Using the symmetry properties of the Legendre polynomials, this can be reduced to:

$$\xi_n^m = \frac{1}{a} \sum_{j=1}^{NGL/2} \left(imV_m^S(\mu)\ P_n^m(\mu_j) - U_m^A(\mu_j)\ H_n^m(\mu_j) \right) \frac{w_j}{1-\mu_j^2} \text{ for } (m+n) \text{ even} \qquad (4.12)$$

$$\xi_n^m = \frac{1}{a} \sum_{j=1}^{NGL/2} \left(imV_m^A(\mu_j)\, P_n^m(\mu_j) - U_m^S(\mu_j)\, H_n^m(\mu_j) \right) \frac{w_j}{1-\mu_j^2} \text{ for } (m+n) \text{ odd} \tag{4.13}$$

$$D_n^m = \frac{1}{a} \sum_{j=1}^{NGL/2} \left(imU_m^S(\mu_j)\, P_n^m(\mu_j) + V_m^A(\mu_j)\, H_n^m(\mu_j) \right) \frac{w_j}{1-\mu_j^2} \text{ for } (m+n) \text{ even} \tag{4.14}$$

$$D_n^m = \frac{1}{a} \sum_{j=1}^{NGL/2} \left(imU_m^A(\mu_j)\, P_n^m(\mu_j) + V_m^S(\mu_j)\, H_n^m(\mu_j) \right) \frac{w_j}{1-\mu_j^2} \text{ for } (m+n) \text{ odd} \tag{4.15}$$

where $U_m^S(\mu_j)$, $V_m^S(\mu_j)$ are the symmetric Fourier coefficients of U and V and $U_m^A(\mu_j)$, $V_m^A(\mu_j)$ are corresponding antisymmetric coefficients.

4.3 Spectral truncation

For the forecast model, the spectral truncation is defined (as described in Section 2.1.1 of Research Manual 2) by 3 parameters M,J,K allowing a flexible pentagonal truncation. With this notation, a field F is described by the spectral coefficients:

$$\sum_{m=0}^{M} \sum_{n=m}^{\min(m+J,K)} F_n^m$$

In order to maintain consistency with earlier data formats, only triangular truncation (M=J=K) is permitted for the spectral fields output from the post-processing. However, the same generalised arrays as in the forecast model are used to control all the spectral transformations within the post-processing code, so this restriction to triangular truncation could be lifted if desired.

4.4 Inverse spectral transforms for non-velocity fields

In the final part of the post-processing, inverse spectral transforms are performed and the data is evaluated on the output regular latitude/longitude grid. For all fields except u and v (but including divergence and vorticity) this is done in the following steps:

(i) the symmetric and antisymmetric Fourier coefficients are formed using:

$$F^S_m(\mu_j) = \sum_{n=m}^{T}{}^{2} F^m_n P^m_n(\mu_j)$$
$$F^A_m(\mu_j) = \sum_{n=m+1}^{T}{}^{2} F^m_n P^m_n(\mu_j) \qquad (4.16)$$

for all latitudes μ_j between the pole and the equator:

where $\sum_{n=m}^{T}{}^{2}$ means n=m, m+2, m+4, ... $\begin{cases} T & \text{if } (m+T) \text{ is even} \\ T-1 & \text{if } (m+T) \text{ is odd} \end{cases}$ (i.e. m+n even)

and $\sum_{n=m+1}^{T}{}^{2}$ means n=m+1, m+3,... $\begin{cases} T-1 & \text{if } (m+T) \text{ is even} \\ T & \text{if } (m+T) \text{ is odd} \end{cases}$ (i.e. m+n odd)

and T is the triangular truncation

(ii) the full Fourier coefficients are formed:

$$F_m(\mu_j) = F^S_m(\mu_j) + F^A_m(\mu_j) \text{ for northern hemisphere}$$
$$F_m(-\mu_j) = F^S_m(\mu_j) - F^A_m(\mu_j) \text{ for southern hemisphere} \qquad (4.17)$$

(iii) an inverse Fourier transform is done

4.5 Inverse spectral transforms for u and v

First the spectral coefficients of U and V are calculated from the coefficients of vorticity and divergence, using:

$$U_n^m = a \left\{ -\frac{1}{n}\left(\frac{n^2-m^2}{4n^2-1}\right)^{\frac{1}{2}} \xi_{n-1}^m - \frac{im}{n(n+1)} D_n^m \right.$$

$$\left. + \frac{1}{n+1}\left(\frac{(n+1)^2-m^2}{4(n+1)^2-1}\right)^{\frac{1}{2}} \xi_{n+1}^m \right\} \qquad (4.18)$$

$$V_n^m = a \left\{ \frac{1}{n}\left(\frac{n^2-m^2}{4n^2-1}\right)^{\frac{1}{2}} D_{n-1}^m - \frac{im}{n(n+1)} \xi_n^m \right.$$

$$\left. - \frac{1}{n+1}\left(\frac{(n+1)^2-m^2}{4(n+1)^2-1}\right)^{\frac{1}{2}} D_{n+1}^m \right\} \qquad (4.19)$$

Except at the poles, the symmetric and antisymmetric fourier coefficients of U and V are formed using:

$$U_m^S(\mu_j) = \sum_{n=m}^{T+1} {}^2 \; U_n^m P_n^m(\mu_j)$$

$$U_m^A(\mu_j) = \sum_{n=m}^{T+1} {}^2 \; U_n^m P_n^m(\mu_j) \qquad (4.20)$$

with similar expressions for $V_m^S(\mu_j)$ and $V_m^A(\mu_j)$. Note that the summation limit is (T+1), while for non-velocity fields it was T.

So far it is the fourier coefficients of U and V which have been calculated and these will have to be divided by cos(lat) at a later stage in order to obtain u and v. At the poles, the symmetric and antisymmetric fourier coefficients of u and v are obtained directly.

At the poles,

$$\frac{P_n^m(\Theta)}{\cos(\Theta)} = 0 \quad \text{for } m > 1, \quad \Theta = \pm\frac{\pi}{2}$$

and $$\lim_{\Theta \to \pm\frac{\pi}{2}} \left[\sum_{n=0}^{T+1} U_n^0 \frac{P_n^0(\Theta)}{\cos(\Theta)} \right] = 0$$

so $$U_1^S\left(\frac{\pi}{2}\right) = \sum_{n=1}^{T+1}{}^2 \; U_n^1 \left(\frac{P_n^1(\frac{\pi}{2})}{\cos(\frac{\pi}{2})}\right) \qquad (4.21)$$

$$U_1^A\left(\frac{\pi}{2}\right) = \sum_{n=2}^{T+1}{}^2 \; U_n^1 \left(\frac{P_n^1(\frac{\pi}{2})}{\cos(\frac{\pi}{2})}\right)$$

$$U_m^S\left(\frac{\pi}{2}\right) = 0$$

for $m \neq 0$

$$U_m^A\left(\frac{\pi}{2}\right) = 0$$

Similar expressions define $V_m^S(\frac{\pi}{2})$ and $U_m^A(\frac{\pi}{2})$

$\dfrac{P_n^1(\frac{\pi}{2})}{\cos(\frac{\pi}{2})}$ is evaluated from a recurrence relation.

The full Fourier coefficients are then formed, the inverse Fourier transform is performed and, except at the poles, the resulting grid point values are divided by cos(lat).

5. POST-PROCESSING ORGANISATION

5.1 Introduction

Starting from model history files (or pressure level analysis files), the post-processing produces four different types of output file for CYBER processing and two for MARS.

5.1.1 CYBER Files

(i) Grid point files

These contain data on a regular latitude/longitude grid, which has been interpolated horizontally from the model grid by a spectral fitting technique. The data may also have been interpolated vertically from the model co-ordinates to constant pressure levels.

(ii) Spectral files

These contain sets of spherical harmonic coefficients for the same fields as those on the grid point files. The spherical harmonic coefficients are a compact form for long term data storage, and they can be used to evaluate the data on any output grid. However, each time the user requires data in grid point form from these files, he must pay for the cost of the inverse spectral transform.

(iii) Uninterpolated

These contain data on the model's Gaussian grid. They are used for physics fields, where grid point values are more meaningful than spectrally-fitted fields.

(iv) Diagnostic files

These contain fields of zonal diagnostics.

5.1.2 MARS Files

(i) Spectral files

These contain sets of spherical harmonic coefficients for the same fields as those for the CYBER spectral files, with the following differences.

(a) The spherical harmonic coefficients become of the same normalisation as in the model, i.e. they have been multiplied by $(-1)^m \frac{1}{\sqrt{2}}$

(b) The WMO GRIB code packing algorithm has been adopted.

(c) They have the structure of the WMO bit-oriented code (see ECMWF Tech.Memo. No.102).

(ii) Uninterpolated Files

These contain data on the model's Gaussian grid, for the same fields as for the CYBER except that the WMO GRIB code packing algorithm is used and the structure is in accordance with the WMO bit-oriented code. At the beginning of each output uninterpolated file there is a record of length 750 Cray words (6000 octets) which is called the MARS model switch record.

A detailed description of the format and content of each of these files is given in Section 5.2 for the CYBER files and 5.3 for the MARS files. Sections 5.4 and 5.5 describe aspects of the use of the post-processing. The user must specify which file types are required as output from the post-processing together with their contents and resolution. Codes used to specify output fields are defined in Section 5.6. Section 5.7 describes the organisation of the post-processing code. The scanning strategy is explained and the data structures are defined.

5.2 CYBER files

5.2.1 File format for CYBER files

The four post-processed file types all conform to the model history file format, described in Research Manual 2 Appendix 4. Each file consists of a set of data description records (ddr's) described in the Appendix to this memorandum, followed by packed data records. Word 15 of the first ddr of each file contains the total number of ddr's. The length of each ddr is given in its first word, while word 3 contains the length of the next ddr if there is one, or 0 if it is the last ddr. It is recommended that all programs which read these post-processed files should use this information to determine the numbers and lengths of the ddr's.

Each data record consists of a 16 word unpacked preliminary array, followed by a packed data field. The contents of the preliminary array are described in Table 1. (These are the same as in the original ECMWF format post-processed files).

Word	Meaning	Contents
1	Total length of unpacked data record	data dependent
2	Length of preliminary array	16
3	Length of next data record	data dependent
4	Maximum subscript of first data dimension	NLON (number of longitude points) for grid point or uninterpolated file or NTOUT+1 (triangular truncation +1) for spectral file or NLEV (number of levels) for diagnostic file
5	Maximum subscript of 2nd data dimension	NLAT (number of latitude rows) for grid point or uninterpolated or diagnostics file for NTOUT+1 for spectral file
6	Data type	1 (uninterpolated file) or 2 (grid point file) or 3 (spectral field packed 4 values/word) or 4 (diagnostics file) or 5 (spectral field packed 3 values/word)
7	Field code	See Table A6.5
8	Level	Pressure (in pascals) or -100 (for surface fields) or -200 (for mean sea level) or model level number (if there is no vertical interpolation)
9 10 11	Minimum value of field	See Section 5.2.2
12	Scaling factor for packing routines	See Section 5.2.2
13 14 15	Real m=0, n=0 spectral coefficient	See Section 5.5.2 for spectral or 0 for other file types.
16	Record number	

Table 1 Preliminary array

5.2.2 Data packing for CYBER files

Spectral coefficients of geopotential and height for CYBER files packed with 3 values/60 bit CYBER word. All other spectral fields, and all fields for the other file types, are packed with 4 values/word. Note that in the case of MARS fields the geopotential fields are represented by 24 bit integers, and the other fields by 16 bit integers.

The packing algorithm for a CYBER field is as follows:

(i) Find the minimum (ZMIN) and maximum (ZMAX) values of the field.

(ii) Store ZMIN in words 9, 10 and 11 of the preliminary array using

$\text{ZMIN} = (\text{K1}*2^{\text{IP}} + \text{K2})*(10**\text{AND}(\text{K3, MASK}))$

Where K1 = word 9 of preliminary array

K2 = word 10 of preliminary array

K3 = word 11 of preliminary array

IP = number of bits used to pack each value

(i.e. IP = 15 for 4 values/word packing

IP = 20 for 3 values/word packing)

MASK = 17777B for 4 values/word packing

777777B for 3 values/word packing

The sign of ZMIN is held in the IP'th bit of K3, and the sign of the exponent is held in the (IP-1)'th bit of K3.

(iii) Find the scaling factor ZSCAL, where

$S = (u - \mathrm{ZMIN}) * \mathrm{ZSCAL}$

with S = scaled integer with $0 \leqslant S < 2^{IP}$

U = unscaled real data element.

Let $IN' = \mathrm{INT}\ (\mathrm{Log}_2\ (\mathrm{ZMAX}-\mathrm{ZMIN}) + \varepsilon)$

and $\mathrm{ZSCAL}' = 2^{(IP-1-IN')}$

with ε = machine precision,

then if $S' = (u - \mathrm{ZMIN}) + \mathrm{ZSCAL}'$ we have

then $0 \leqslant S' < 2^{IP}$, since $(u - \mathrm{ZMIN}) < 2^{IN'+1}$

In order to keep IN, the word stored in word 12 of the preliminary array, positive, the equations are shifted:-

$$IN = \mathrm{INT}\ (\log_2\ (\mathrm{ZMAX} - \mathrm{ZMIN}) + \varepsilon + \mathrm{IBIAS})$$

and

$$\mathrm{ZSCAL} = 2^{(\mathrm{IBIAS}+IP-1-IN)}$$

with

$$\mathrm{IBIAS} = 2^{IP-1}+1$$

then

$$-2^{IP-1} - 1 \leqslant \log_2\ (\mathrm{ZMAX}-\mathrm{ZMIN}) < 2^{IP-1} - 1$$

so

$$0 \leqslant S < 2^{IP}$$

For spectral fields, the real (m=0, n=0) spectral coefficient (which represents the mean value of the field) may be much larger than the other coefficients. By finding the values of ZMIN and ZSCAL for all coefficients except the real (m=0, n=0) coefficient, their variation can be more accurately represented. The real (m=0, n=0) coefficient is stored in words 13, 14 and 15 of the preliminary array, with the same method as is used to store ZMIN in words 9, 10 and 11.

5.2.3 Grid point CYBER file

The grid point file has 5 ddr's: a first ddr, a spatial representation record, a model grid descriptor record, a model switch record and a data index record. These are described in detail in the Appendix.

The ddrs are followed by 1 packed data record for each grid point field. The fields are ordered with all the multi-level fields first, followed by all the single level fields (where multi-level fields, as their name implies, are fields which are required at more than one level). The multi-level fields are ordered with all the fields at the first level, followed by all the fields at the second level, and so on. At each level, the fields are given in the order specified by the array NFDML in the namelist POSTIN, specified in Section 5.5.

5.2.4 Spectral CYBER file

Like the grid point file, the spectral file has 5 ddr's. These parallel those of the grid-point files and are detailed in the Appendix.

The fields are given in the same order as in the grid point file, except that u velocity in the grid point file is replaced by vorticity in the spectral file, and v velocity is replaced by divergence. If the grid pint file contains only one of u and v, then both vorticity and divergence are given at the corresponding position in the spectral file.

All spectral fields apart from geopotential and height are packed with 4 values/word. Geopotential and height are packed with 3 values/word, since for these 2 fields the packing errors are unacceptably large with 4 values/word packing.

5.2.5 Uninterpolated CYBER file

The uninterpolated file similarly has 5 ddr's, described in the Appendix. The data fields are given in the order specified by the array NGPCL in namelist POSTIN (See Section 5.5). The data is given on the model's Gaussian grid, with the latitude rows ordered in straight-forward fashion from north to south. (The model history files, on the other hand, have alternate rows from the northern and southern hemispheres).

5.2.6 Diagnostics CYBER file

The diagnostics file has 5 ddr's, described in the Appendix. There is one data record, packed with 4 values/word for each zonal diagnostics field. Each field has the number of model levels in the vertical as its first dimension, and the number of model Gaussian latitudes as its second dimension. The latitudes are ordered simply from north to south.

5.3 File Format for MARS

5.3.1 Basic fields

The MARS file types all conform to the WMO bit-oriented code format. This format describes processed data in the form of either grid-point values or spherical harmonic coefficients, expressed in binary form.

A data record consists of 6 blocks named, the indicator block (block 0), the product definition block (block 1), the Grid description block (block 2), the bit map block (block 3), the data block (block 4), and the end block (block 5) of length four octets, character-coded as "7777". As noted earlier, the geopotentials are packed with 24-bit integer accuracy, while the other fields are packed with 16-bit integer accuracy.

For details about the structure of the MARS files, users are referred to ECMWF Tech.Memo.No.102.

5.3.2 MARS model switch record

At the beginning of each uninterpolated output file there is one record of length 750 Cray words (6000 octets), which is called the "Mars model switch record".

This record contains information of model switch settings and parameter values. It consists of: (see Table 2).

(a) block 0 (1-4 octets),

This simply has the contents "BUDG"

(b) block 1 (1-24 octet)

Its structure is similar to block 1 of AF 82 grib (see ECMWF Tech.Memo. No.102). Octet 8 is always zero, which indicates the absence of block 2 and 3, while octet 9 is always 128, which is an identification of the Mars model switch record.

(c) Block 4

Octets 1 up to 9 contain the length of the data block, the starting address of logical section, the starting address of the integer section, the starting address of the real section, and the length of the real section. The logical variables are started from octet 38, followed by the integer and then by the real variables.

The logical variables are coded as 1 in case of .TRUE., as 0 in case of .FALSE., and they occupy one octet each. The integer variables are coded in two octets, while the reals are coded in four octets, using the scheme for representing floating point numbers described in AF 82 grib (see ECMWF Tech. Memo. No.102). The content of the end of the message block is 7777 and it is located in octets 5997, 5998, 5999, and 6000.

The sequence of data is shown in Table 3. Reference should be made to the internal documentation of the model code for definitions of these variables. It should be noted that the precise contents of this record may change as new options and statistics are added to the model, and that fewer variables may be saved for earlier model cycles. The first word of the integer section, NCYCLE, contains the cycle number of the model used to produce the MARS model switch record, and reference should be made to the internal model documentation for the relevant cycle for a precise specification of the contents of the switch record for that cycle.

BLOCK	Position of octet starting from the beginning of each block	Position of octet starting from the beginning of MARS MODEL SWITCH RECORD		VALUE
0	1-4	1-4		BUDG
1	1-3	5-7	Length of block 1(octet)	24
	4	8	Reserved	
	5	9	Identification of Centre	98
	6	10	Model Identification	
	7	11	Grid definition	
	8	12	Flag (blocks 2 and 3 omitted) see code Table 1	0
	9	13	Parameter indicating the existence of MARS MODEL SWITCH RECORD	128
	10	14	Indicator of type of level	1
	11	15	Value 1 of level	0
	12	16	Value 2 of level	0
	13	17	Year of century	
	14	18	Month	
	15	19	Day	
	16	20	Hour	
	17	21	Minute	
	18	22	Indicator of unit of time range (code Table 4)	
	19	23	Time range 1	
	20	24	Time range 2	
	21	25	Time range flag (Table 5)	
	22-24	26-28	Reserved	

Table 2 MARS Model Switch Record

BLOCK	Position of octet starting from the beginning of each block	Position of octet starting from the beginning of MARS MODEL SWITCH RECORD		VALUE
4	1-3	29-31	Length of data block (octet)	5968
	4	32	Starting address of logical section (octet)	38
	5	33	Starting address of integer section (octet)	
	6-7	34-35	Starting address of real section (octet)	
	8-9	36-37	Length of real section (octet)	
	10-	38-5996	DATA BLOCK	
5	1-4	5997-6000	End of message block	7777

Table 2 MARS Model Switch Record
(Continued)

LOGICALS

From common COMDIZ:

LZLS

From common COMMSK*:

LMASK

From common COMDSW:

LSIMDT, LSIMZQ, LVTMPC1, LVTMPC2

From common COMNMI:

LLDIFF, LLROSS, LLPROJ, LLZA, LLPSRS, LLTEND, LLDIAB, LLFILT

From common COMPSW:

LPHYS, LVDIFF, LKUO, LCOND, LQNEGAT, LSURF, LSCV, LKUO0, LESFT, LEVAP, LSNRN

From common COMRSW:

LRAD, LDIUR

INTEGERS

From common COMDOC:

NCYCLE, NVERS

From common COMCTL:

NM, NN, NK, NGL, NLON(NGL), NLEV NVCLEV

From common COMDIZ:

NUMZLS, NFRZLS, NDTSCVL, NDTSCVS, NDQSCVL, NDQSCVS, NDUSCVL, NDUSCVS, NDVSCVL, NDVSCVS, NDESCVL, NDESCVS, NLANDP(NGL), NSEAP(NGL)

From common COMMSK:

NMASKA, NMASKV, NFRMSK, NFRMSKP, NRSLT

From common COMNMI:

NITNINI, NDIFFST, NVM

From common COMRSW:

NRADFR, NRINT

From common COMTRU:

NTRM(NLEV), NTRN(NLEV) NTRK(NLEV)

*from CY=25 onwards

Table 3

REALS

From common COMCTL:

DTIME, EPS, VCT(2*NVCLEV)

From common COMDIA:

CDIATS, CDIATD, CDIAWD, GPEO, GKEO, GQMO, GTSO, GTDO, GWSO, GWDO, GSNO, DSRADO, DTRADO, DSRADS, DTRADS, DVDIS, DHFS, DEVAP, DCVFR, DCVQAC, DCVMOI, DCVGR, DCVGS, DCVMS, DCVER, DCVES, DLSGR, DLSGS, DLSMS, DLSER, DLSES, DSSRAD, DSTRAD, DSHFL, DSDTFL, DSLSR, DSLSS, DSCVR, DSCVS, DSEVW, DSEVI, DSDWFL, DSSNMT, DDCTFL, DDCWFL, DSROS, DSROD, DADCON

From comon COMHDI:

DIFVO, DIFD, DIFT, DIFQ, CDRAG

From common COMMSK:

ALATN(32), ALATS(32), ALONE(32), ALONW(32)

From common COMNMI:

DTINIT, DTDIFF, PHYFIL

From common COMPSW:

VSMAX

From common COMSIM:

BETADT, BETAZQ, APR, TR, VCRIT, HDAMP

From common COMSTA:

GVO, GD, GQ, GT, GPS, GKE, GPE, GTE, GLQ, GTPE, GQM, GTS, GTD, GWS, GWD, GSN

Table 3 Continued

5.4 Input and Output files

The post-processing package can run

(i) From F1-F4 (FT21-FT24) and G3-G4 (FT20 and FT29) history files. The G4 file is only required if the diagnostic post-processed file is required. The F1-F4 Fourier files can be calculated by procedure SPEC2F from the spectral files.

(ii) From the input pressure analysis file (FT20).

The spectral constant files can either be pre-created and read from FT15 and FT16 or can be calculated within execution (LCALC=.T.).

The output fields are specified in the namelists POSTIN (for CYBER files) or POSTINM (for MARS files).

The output post-processed files are on the following units:

a. CYBER files

FT17: grid point file

FT18: spectral file

FT19: uninterpolated

FT64: Diagnostics file.

b. MARS files

FT38: spectral file

FT39: uninterpolated file

5.5 Namelists

5.5.1 Namelist POSTIN for CYBER

The namelist POSTIN is used to control the production of CYBER output fields. Its contents, together with their default values, are listed in Table 4. Further explanations for some of the variables are given below:

NLATO: the number of latitude rows for output grid point fields. For model files, the default value for NLATO is MAXROW+1, where MAXROW is the number of latitude rows on the model grid. The Gaussian grid has an even number of rows with no polar or equatorial rows. The default output grid has an odd number of rows, starting at the pole. For analysis files, which already start at the pole, the default value for NLATO is MAXROW.

GNLAT: the latitude of the northern boundary of the output grid, in degrees. The output grid point file is produced on a regular lat/long grid which is symmetric about the equator, and which has complete latitude circles. Once the user has specified the northern boundary, the number of latitude rows and the number of longitude points, the output grid is completely defined.

LPOSTINM: If LPOSTINM=.T. an additional namelist for MARS follows.

NTIN: the triangular truncation of the spectral fit. For model files, the default value is the maximum Fourier wave number used in the model. For analysis files, NTIN must be specified explicitly, since there is no suitable default value.

NTOUT: the triangular truncation of fields on the output spectral file, with 0 ≤ NTOUT = NTIN. If the user specifies a value greater than NTIN for NTOUT, the program sets NTOUT=NTIN. If NTOUT=0, no fields wil be written to the spectral file.

NAMELIST POSTIN

NAME	MEANING	DEFAULT
NLATO	*NUMBER OF LATITUDE ROWS IN OUTPUT GRID	MAXROW +1
NLONO	*NUMBER OF LONGITUDE POINTS IN OUTPUT GRID	NLON
GNLAT	*LATITUDE (DEGREES) OF NORTHERN BOUNDARY OF OUTPUT GRID	90.0
NTIN	*TRIANGULAR TRUNCATION OF SPECTRAL FIT	NMP1 -1
NTOUT	*TRIANGULAR TRUNCATION OF OUTPUT SPECTRAL COEFFICIENTS	NMP1 -1
NVINT	*VERTICAL INTERPOLATION CODE	2
NMFD	*NUMBER OF FIELDS AT MULTIPLE LEVELS	0
NFDML(20)	*CODES OF MULTI-LEVEL FIELDS	20*0
NMLV	*NUMBER OF LEVELS FOR MULTI-LEVEL FIELDS	0
NLVML(30)	*LEVELS OF MULTI-LEVEL FIELDS (PASCALS)	30*0
NSFD	*NUMBER OF SINGLE LEVEL FIELDS	0
NFDSL(30)	*CODES OF SINGLE LEVEL FIELDS	30*0
NLVSL(30)	*LEVELS OF SINGLE LEVEL FIELDS	30*0
N2D	*NUMBER OF UNINTERPOLATED FIELDS	0
NGPCL(2,50)	*CODES AND LEVELS OF UNINTERPOLATED FIELDS	100*0
LCALC	*TRUE* IF SPHERICAL HARMONIC CONSTANT FILES ARE TO BE CALCULATED	FALSE
LDIA	*TRUE* FOR DIAGNOSTICS FILES	FALSE
LMAXPPN	*TRUE* FOR FIXED MAX TO SCALE PRECIPITATION	FALSE
LPOSTINM	*TRUE* IF MARS POSTIN IS PROVIDED	FALSE

Table 4

NVINT: vertical interpolation code

NVINT=0 for no vertical interpolation, with fields given on model vertical co-ordinate surfaces

=1 for linear interpolation

=2 for tension spline interpolation

=3 for cubic spline interpolation

For model files, tension splines are the default vertical interpolation method. For analysis files, there is no vertical interpolation, and NVINT is ignored.

NMFD: number of multi-level fields on the grid point and spectral files.

NFDML(20): codes of multi-level fields. Table 5 lists the code number for each field type, and explains which fields may be requested for each file type.

5.5.2 Namelist POSTINM for MARS

The namelist POSTINM is used to control the post-processing output fields for MARS and it is exactly the same as the namelist POSTIN except that the parameter LPOSTINM is not included.

The parameters NTIN, NVINT, LCALC, LDIA and LMAXPPN must be the same in both namelists.

5.6 Post-processing field codes

5.6.1 Post-processing CYBER codes

Table 5 contains a complete list of field codes for CYBER post-processing. An entry in the table shows whether the field is available on forecast history files or on pressure analysis files or on both. A second entry shows for

CODE	FIELD (*denotes field accumulated since start of forecast)	Input file type F=forecast A=analysis	Post-processed file type s=spectrally fitted u=uninterpolated file	UNITS
1	Geopotential	F,A	S (u-surface geopotential only)	m^2s^{-1}
2	Temperature	F, (A-surface temperature only)	S	K
3	u-velocity: grid point fields vorticity: spectral fields	F,A	S (u-surface velocity analysis only)	u ms^{-1} vorticity s^{-1}
4	v-velocity: grid point fields divergence: spectral fields	F,A	S (v-surface velocity analysis only)	v ms^{-1} divergence s^{-1}
5	Specific humidity	F	S	kg/kg
6	Pressure	F,A	S (mean sea level pressure) u (surface pressure)	Pa
7	Vertical velocity	F	S	Pas^{-1}
9	Precipitable water content	A	S	m(water)
10	Vorticity	F,A	S	s^{-1}
11	Surface temperature	F,A	u	K
12	Surface soil wetness	F	u	m(of water)
13	Snow depth	F	u	m
14	Large scale rain*	F	u	m
15	Convective rain*	F	u	m

Table 5 Post-processing field codes

CODE	FIELD (*denotes field accumulated since start of forecast)	Input file type F=forecast A=analysis	Post-processed file type s=spectrally fitted u=uninterpolated file	UNITS
16	Snow fall*	F	u	m
17	Boundary layer dissipation*	F	u	Jm^{-2}
18	Surface sensible heat flux*	F	u	wm^{-2}
19	Surface latent heat flux*	F	u	wm^{-2}
23	Pressure at mean sea level	F	u	pa
24	$\ell n(p_s)$	F	s	-
27	Divergence	F,A	s	s^{-1}
28	Height	A	s	m
29	Relative humidity	F,A	s	%
30	Surface pressure tendency	F	s	Pas^{-1}
36	Cloud cover	F	u	[0-1]
37	10 m u	F	u	ms^{-1}
38	10 m v	F	u	ms^{-1}
39	2m temperature	F	u	K
40	2m dew point temperature	F	u	K
42	Deep soil temperature	F	u	K
43	Deep soil wetness	F	u	m(of water)
44	Land/sea mask	F	u	[0,1]
45	Surface roughness	F	u	m

Table 5 Post-processing field codes
Continued

CODE	FIELD (*denotes field accumulated since start of forecast)	Input file type F=forecast A=analysis	Post-processed file type s=spectrally fitted u=uninterpolated file	UNITS
46	albedo	F	u	-
48	Surface solar radiation*	F	u	Wm^{-2}
49	Surface thermal radiation*	F	u	Wm^{-2}
50	Top solar radiation*	F	u	Wm^{-2}
51	Top thermal radiation*	F	u	Wm^{-2}
52	u-stress*	F	u	Nm^{-2}
53	v-stress*	F	u	Nm^{-2}
54	Evaporation*	F	u	ms^{-1} (of water)
55	Climatological deep soil temperature	F	u	K
56	Climatological deep soil wetness	F	u	m(of water)
57	Convective cloud cover	F	u	[0-1]
58	Low cloud cover	F	u	[0-1]
59	Medium cloud cover	F	u	[0-1]
60	High cloud cover	F	u	[0-1]
62	EW component of sub-grid scale orographic variance	F	u	m^2
63	NS component of sub-grid scale orographic variance	F	u	m^2
64	NWSE component of sub-grid scale orographic variance	F	u	m^2
65	NESW component of sub-grid scale orographic variance	F	u	m^2

Table 5 Post-processing field codes
Continued

CODE	FIELD (*denotes field accumulated since start of forecast)	Input file type F=forecast A=analysis	Post-processed file type s=spectrally fitted u=uninterpolated file	UNITS
67	Latitudinal component of gravity wave stress *	F	u	Nm^{-2}
68	Meridional component of gravity wave stress *	F	u	Nm^{-2}
69	Gravity wave dissipation *	F	u	Jm^{-2}

Table 5 Post-processing field codes
Continued

which output file types the field may be requested. Some fields may only be requested on the uninterpolated files, while others may only be requested on the spectrally fitted files (ie the grid point and spectral files).

5.6.2 Post-processing field codes for MARS

Table 5 is valid as well for the post-processing field codes for MARS except that the field codes used in the product description block (block 1) are different. The convention adopted is that the field codes used by MARS are equal to the field codes for CYBER post-processing plus 128. For example, for CYBER fields code 2, the equivalent code for MARS becomes 130.

However, the same codes as given in Table 5 are used in the namelist input to the MARS post-processing, and internally in the post-processing code.

5.7 Code organisation

Detailed program documentation is contained within the source code, and can be extracted using DOC, the documentation extraction utility. The source code is included in the model update library and each subroutine is contained in as separate deck of the same name.

The post-processing code can logically be divided into 4 sections:

- start up
- spectral scan
- uninterpolated fields scan
- diagnostics scan

Each of these sections will be described in more detail below.

5.7.1 Start up

Fig. 1 shows a skeleton flow diagram for the start up of the post-processing.

(i) Use of memory manager

The memory manager controls the use of space within the post-processing. At the beginning of the start-up sequence, in subroutine BASINI, a small quantity of memory is requested as work space. This provides sufficient space to process the input and output ddr's, and initialise the common blocks and interpolation constants.

Once the input ddr's, defining the resolution of the input history files, and the namelist POSTIN, defining the resolution and contents of the output files, have been read, the program has sufficient information to calculate how much space will be required to process the data in the remaining scans. This is done in subroutine MEMINI, and the exact amount of extra space needed is requested. As a result, the post-processing always runs in the minimum space necessary.

(ii) I/O device numbers

The I/O device numbers, which are stored in the common block COMPP1, are defined at the beginning of the start-up sequence in subroutine BASINI. Where possible, the device numbers are the same as in the original ECMWF post-processing system. Table 6 shows all the I/O units used in the post-processing, and indicates whether data is input to or output from the particular device.

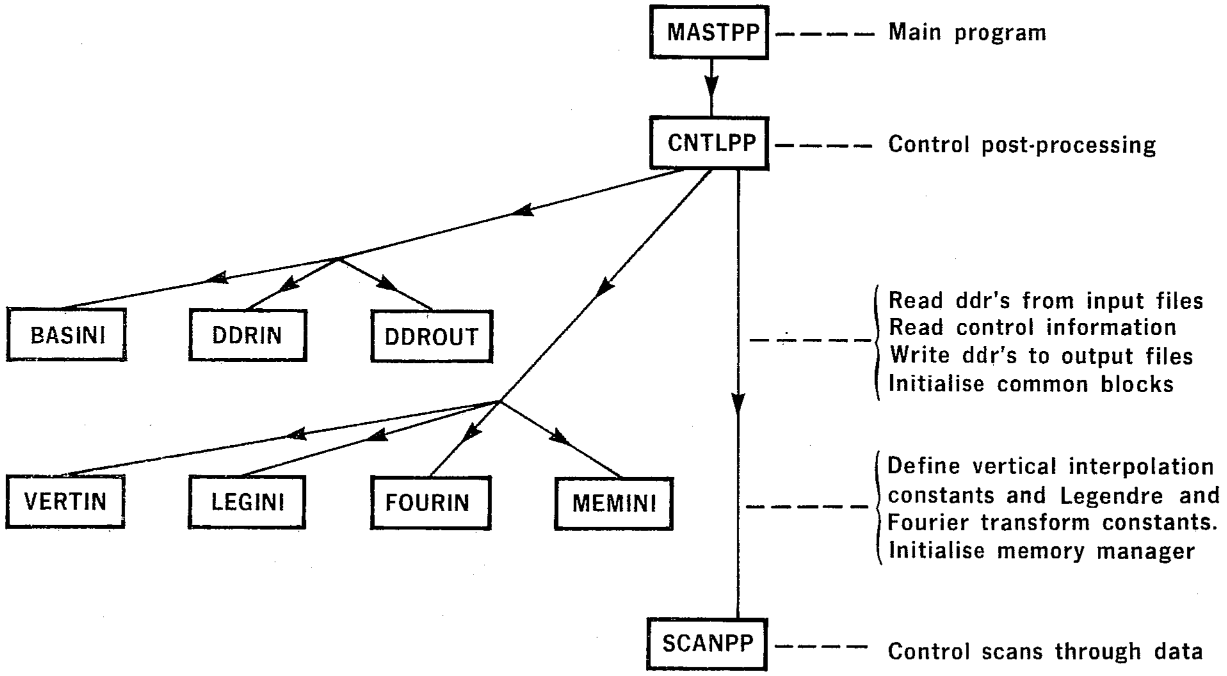


Fig.1 Skeleton flow diagram for the start up of the post processing.

Name	Unit Number	Input (I) or Output (O)	Meaning
NIN	5	I	Card input
NOUT	6	O	Print output
NGIN	20	I	G3 history file (forecast model (or pressure analysis file)
NF1IN	21	I	F1 history file
NF2IN	22	I	F2 history file
NF3IN	23	I	F3 history file
NF4IN	24	I	F4 history file
NFIIN	25	I	G4 history file
NGPOUTC	17	O	Grid point post-processed file for Cyber
NSHOUTC	18	O	Spectral post-processed file for Cyber
N2DOUTC	19	O	Uninterpolated post-processed file for Cyber
NDIOUT	64	O	Diagnostics post-processed for Cyber
NSHOUMF	38	O	Spectral post-processed file for Mars
N2DOUMF	39	O	Uninterpolated post-processed file for Mars
NLEGI	15	I(O)	Constant file for direct spectral transforms
NLEGO	16	I(O)	Constant file for inverse spectral transforms
NFWORK	71	I,O	Work file for 2-scan spectral fit
NSWORK	72	I,O	Work file for 3-scan spectral fit

Table 6 I/O device numbers

(iii) Constant files

If grid point or spectral files are being made, a constant file for the direct spectral transforms is required on unit 15. If grid point files are being made, a constant file for the inverse spectral transforms is also required on unit 16. If the variable LCALC in namelist POSTIN (see Table 4) is TRUE, these constant files are created in subroutine LEGINI during the start-up sequence.

Since it is relatively expensive to calculate these constant files, it is recommended that they be created only once and saved for each resolution. The file for the direct spectral transform depends on the resolution of the input grid and the spectral truncation. The file for the inverse spectral transform depends on the resolution of the output grid and the spectral truncation.

Pressure analysis files, which are given on a regular latitude/longitude grid rather than a gaussian grid, need a different set of constants for the direct spectral transform. These are calculated in subroutine MAKEZZ, which is called from subroutine LEGINC, which is in turn called from CNTLPP.

5.7.2 Spectral scan for non-multitasked version

Fig. 2 shows a skeleton flow diagram of the spectral scan, which is controlled by subroutine SCANPP.

(i) Scanning Strategy

The flow diagram illustrates the simplest possible scanning strategy for the spectral fit, the single scan version, in which no intermediate work files are required. In this case, the spectral scan

can be divided into two major loops. In the first, over the input rows, the spectral coefficients are built up, while in the second, over the output fields, the inverse spectral transforms are done and the fields are packed and written to the grid point and spectral files.

With the single scan version, it is necessary to have sufficient space to hold all the spectral coefficients in memory simultaneously. For higher resolutions, the 2 scan strategy requires sufficient space to hold all the spectral coefficients of at least 1 level in memory simultaneously. The first scan, which is only done once, consists of the single scan version's loop over the input latitude rows, but omitting the direct spectral transform. Instead, the symmetric and antisymmetric fourier coefficients calculated in subroutine SYM1P are written to the fourier work file, unit NFWORK. The second scan consists of 2 major loops. In the first, over the input rows; the fourier coefficients are read from the fourier work file, and the direct spectral transform is done for as many levels as possible. In the second, over the output fields, the inverse spectral transforms are done and the fields are written out. The second scan is repeated until all the levels have been processed.

For very high resolutions, a 3 scan strategy might be required. The first scan would be the same as for the 2 scan version. The second scan would read the fourier work files, do the direct spectral transforms for one field at a time, and write the spectral coefficients to the spectral work file, unit NSWORK. The third scan would read the spectral coefficients from the spectral work file and do the inverse spectral transforms. Space would be required for at least 3 spectral fields, because in order to calculate the spectral coefficients of u or v, the coefficients of both divergence and vorticity are required. If the resolution is so great that the 3 scan version is required, the program halts with an error message, since the 3 scan version has not yet been coded.

Subroutine MEMINI, in the start-up part of the post-processing, uses information about the input and output resolutions, the spectral truncation and the number of fields selected in order to decide which scanning strategy is required.

(ii) Data structures

(a) Input data

Surface geopotential and surface pressure are read from the start of the G3 history file.

GEOS(NLP2), APS(NLP2)

where NLP2 = number of longitude points + 2

There is 1 record/row, and the rows come alternately from the northern and southern hemispheres.

Symmetric and antisymmetric fourier coefficients are read from the F1-F4 history files.

eg FSQ (NLEV, 2, NMP1), FAQ(NLEV, 2, NMP1)

where NLEV = number of levels

NMP1 = max Fourier wave number + 1

i.e. the fields are ordered first by level, then by real or imaginary post, then by wave number.

There is 1 record for each pair of rows.

(b) Full fourier coefficients on input grid

In SYM2P, the full Fourier coefficients of divergence, specific humidity, temperature, ucos(θ), vcos(θ), $\frac{1}{\alpha\cos\theta}\frac{\partial\rho u p_s}{\partial\lambda}$, $\frac{1}{\alpha}\frac{\partial\rho u p_s}{\partial\mu}$ are constructed for each latitude row:

D(NLP2,NLEV), Q(NLP2,NLEV), T(NLP2,NLEV), U(NLP2,NLEV), V(NLP2,NLEV), DALPSL (NLP2), DALPSM (NLP2)

The fields are ordered first by wave number, then by level, so they are now in the correct order for the Fast Fourier Transform.

(c) Grid point fields on input grid

The inverse fourier transforms in subroutine FFTIP give grid point values on the input model grid. The grid point fields occupy the same arrays as the full fourier coefficients.

e.g. (NLP2, NLEV)

At each level, the first NLON elements contain the value at each longitude point, while the last 2 contain dummy values.

(d) Grid point fields output from vertical interpolation

The grid point fields output from the vertical interpolation in subroutine INTVER are arranged in the order required by the spectral transforms:

GPVERT (NLP2, MFDIN), where MFDIN=NMFD*NMLV+NSFD

and NMFD = number of multi-level fields

NMLV = number of levels for multi-level fields

NSFD = number of single-level fields

The fields are ordered as follows:

(i) all non-velocity fields processed on first pass through spectral transforms

(ii) all velocity fields processed on first pass through spectral transforms

(iii) all non-velocity fields processed on second pass through spectral transforms

(iv) all velocity fields processed on second pass through spectral transforms

etc.

For the single scan version of the spectral fit, there will only be one pass through the spectral transforms. The multi-level fields are given first, then the single level fields. The multi-level fields are ordered first by field, then by level. The velocity fields consist of u and v at all requested levels.

The array NTAB1 in common COMPP3 is used to determine the order of the fields. This array, together with other control arrays in COMPP3, was initialised in subroutines MKCNTR and MKCNT2, called from DDROUT, in the start-up part of the post-processing.

(e) Full Fourier coefficients of vertically interpolated data

The direct Fourier transforms in subroutine FFTDP give full fourier coefficients in array GPVERT.

(f) Symmetric and antisymmetric fourier coefficients of vertically interpolated data

The symmetric and antisymmetric parts of the fourier coefficients are constructed in subroutine SYM1P:-

FS(2,MFDIN,NTINP1), FA(2,MFDIN,NTINP1)

where NTINP1 = triangular truncation of spectral fit + 1.

The coefficients are ordered with real and imaginary components as the first index, field type as the second index and wavenumber as the third index. There is one set of FS and FA for each pair of latitude rows (where the pair has one row from each hemisphere).

(g) Input grid spectral constant file

The input grid spectral constant file is originally calculated and written in subroutine LEGINI. Within the spectral scan, it is read in SCANPP and used in LEGDIR. It has 1 record for each pair of input grid rows, containing

NPMW(NSPNM), PMRAW(NSPNM), HRAW(NSPNK)

with NSPNM = (T+1)*(T+2)/2

and T is the triangular truncation of the spectral fit.

Note that the legendre functions used by the post-processing for CYBER files have a different normalisation to those used by the forecast model. The post-processing normalisation for CYBER files has been kept consistent with the normalisation used originally at ECMWF.

Specifically, if $P_n^m(\mu)$ = post-processing legendre function

and $\tilde{P}_n^m(\mu)$ = model legendre function

then $P_n^m(\mu) = \tilde{P}_n^m(\mu) * \sqrt{2} * (-1)^m$

The fields on the input grid Legendre constant file are defined as follows:

$$\mathrm{PNMW}_n^m(\mu) = \tilde{P}_n^m(\mu)*\sqrt{2}*(-1)^m*2*\mathrm{GW}(\mu)$$

$$\mathrm{PMRAW}_n^m(\mu) = \tilde{P}_n^m(\mu)*\sqrt{2}+(-1)^m*2*\mathrm{GW}(\mu)*\frac{m}{a\cos^2\theta}$$

$$\mathrm{HRAW}_n^m(\mu) = \tilde{H}_n^m(\mu)*\sqrt{2}*(-1)^m*2*\mathrm{GW}(\mu)*\frac{1}{a\cos^2\theta}$$

where θ = latitude

$\mu = \sin(\theta)$

$\mathrm{GW}(\mu)$ = Gaussian weight

The constants are stored in the order $\sum\limits_{m=0}^{T}\ \sum\limits_{n=m}^{T} P_n^m(\mu)$

Forecast model subroutines PHCS and GAUAW are used to calculate $\tilde{P}_n^m$, $\tilde{H}_n^m$ and GW

Spherical harmonic coefficients output for MARS are rescaled to have the same normalisation as in the forecast model. In this normalisation the m=0, n=0 component is the global mean of the field in question.

(h) Spectral coefficients

The spectral coefficients are calculated in subroutine LEGDIR and stored in the array

SP(2,NDSPTR,NSPNM)

when NDSPTR = number of spectral files processed in this pass.

For the single scan version NDSPTR=MFDIN

The spectral coefficients are ordered first by real or imaginary part, then by field, then by wavenumber. Vectorisation of the direct spectral transform is over field and complex type.

If INV = number of non-velocity fields processed in this scan, then the inner vector loops in which the row's contributions to the spectral coefficients are added are of the form:

$$\sum_{\mathrm{JF=1}}^{\mathrm{INV+2}} \left\{\mathrm{SP(JF,1,IS)}\right\} = \sum_{\mathrm{JF=1}}^{\mathrm{INV+2}} \left\{\begin{array}{l}\mathrm{SP(JF,1,IS)} \\ \mathrm{+PNMW(IS)*FS(JF,1,JM)}\end{array}\right\} \quad \begin{array}{l}\text{for } (m+n) \\ \text{even}\end{array}$$

$$\sum_{\mathrm{JF=1}}^{\mathrm{INV+2}} \left\{\mathrm{SP(JF,1,IA)}\right\} = \sum_{\mathrm{JF=1}}^{\mathrm{INV+2}} \left\{\begin{array}{l}\mathrm{SP(JF,1,IA)} \\ \mathrm{+PNMW(IA)*FA(JF,1,JM)}\end{array}\right\} \quad \begin{array}{l}\text{for } (m+n) \\ \text{odd}\end{array}$$

where IS = position of $\binom{m}{n}$'th spectral coefficient with (m+n) even IA = position of $\binom{m}{n}$'th spectral coefficient with (m+n) odd JM = position of m^{th} zonal wave number

These loops are repeated for all wave numbers (see equations 4.4 and 4.5)

If IVE= number of velocity fields processed in this scan, then the corresponding inner vector loops for the velocity fields are:

$$\sum_{J=1}^{IVE/2}\left\{\begin{array}{ll}
\text{SP(1,IZ,IS) = SP(1,IZ,IS)-FS(2,IV,JM)*PMRAW(IS)} & \\
\qquad\qquad\qquad\qquad \text{-FA(1,IU,JM)*HRAW(IS)} & \\
\text{SP(2,IZ,IS) = SP(2,IZ,IS)+FS(1,IV,JM)*PMRAW(IS)} & \\
\qquad\qquad\qquad\qquad \text{-FA(2,IU,JM)*HRAW(IS)} & \\
\text{SP(1,ID,IS) = SP(1,ID,IS)-FS(2,IU,JM)*PMRAW(IS)} & \\
\qquad\qquad\qquad\qquad \text{+FA(1,IV,JM)*HRAW(IS)} & \\
\text{SP(2,ID,IS) = SP(2,ID,IS)+FS(1,IU,JM)*PMRAW(IS)} & \\
\qquad\qquad\qquad\qquad \text{+FA(2,IV,JM)*HRAW(IS)} & \\
\text{IU=IU+2} \qquad \text{IZ=IZ+2} & \\
\text{IV=IV+2} \qquad \text{ID=ID+2} &
\end{array}\right. \quad \begin{array}{c}\text{for}\\ (m+n)\\ \text{even}\end{array}$$

and

$$\sum_{J=1}^{IVE/2}\left\{\begin{array}{ll}
\text{SP(1,IZ,IA) = SP(1,IZ,IA)-FA(2,IV,JM)*PMRAW(IA)} & \\
\qquad\qquad\qquad\qquad \text{-FS(1,IU,JM)*HRAW(IA)} & \\
\text{SP(2,IZ,IA) = SP(2,IZ,IA)+FA(1,IV,JM)*PMRAW(IA)} & \\
\qquad\qquad\qquad\qquad \text{-FS(2,IU,JM)*HRAW(IA)} & \\
\text{SP(1,ID,IA) = SP(1,ID,IA)-FA(2,IU,JM)*PMRAW(IA)} & \\
\qquad\qquad\qquad\qquad \text{+FS(1,IV,JM)*HRAW(IA)} & \\
\text{SP(2,ID,IA) = SP(2,ID,IA)+FA(1,IU,JM)*PMRAW(IA)} & \\
\qquad\qquad\qquad\qquad \text{+FS(2,IV,JM)*HRAW(IA)} & \\
\text{IU=IU+2} \qquad \text{IZ=IZ+2} & \\
\text{IV=IV+2} \qquad \text{ID=ID+2} &
\end{array}\right. \quad \begin{array}{c}\text{for}\\ (m+n)\\ \text{odd}\end{array}$$

where IU = position of Fourier coefficients of u

IV = position of Fourier coefficients of v

IZ = position of spectral coefficients of vorticity

ID = position of spectral coefficients of divergence

(i) Output grid spectral constant file

The output grid spectral constant file is originally calculated and written in subroutine LEGINI. Within the spectral scan, it is read in SCANPP and used in LEGIND. It has a single record containing OUTPNM(NHLATO,NSPNMO) with NHLATO the number of rows between pole and equator in the output grid and NSPNMO= (T+1)*(T+4)/2.

The number of spectral wave numbers, NSPNMO, is greater than for the input grid constant file, because extra wavenumbers are required to derive grid point values of u and v from their spectral coefficients.

The Legendre functions have the same normalisation as the input grid constants, i.e.

$$\mathrm{OUTPNM}_n^m(\mu) = \tilde{P}_n^m(\mu) * \sqrt{2} * (-1)^m$$

where $\tilde{P}_n^m(\mu)$ = model Legendre function

The spectral coefficients are stored in the order

$$\sum_{m=0}^{T} \sum_{n=m}^{T+1}$$

(j) Spectral coefficients of u and v

If grid point values of u and/or v are required, then the spectral coefficients of u and v are calculated from the vorticity and divergence and stored in the arrays

UCF(2,NSPNMO), VCF(2,NSPNMO)

(Note that, whereas the spectral coefficients of vorticity and divergence are given at all the vertical levels in the current scan, only a single level of u and v coefficients is ever held at one time).

u and v coefficients are calculated in subroutine UVCOEF, using equations 4.17 and 4.18.

(k) Symmetric and antisymmetric output grid fourier coefficients

In subroutine LEGIND, the symmetric and antisymmetric Fourier coefficients are calculated for a single field at a time, and stored in the arrays

FSO(2,NHLATO,NTINP1), FAO(2,NHLATO,NTINP1)

The Fourier coefficients are ordered with real or imaginary components as the first index, latitude as the secod and wavenumber as the third. Vectorisation of the inverse spectral transform is over latitude and complex type.

(l) Full Fourier coefficients on the output grid

Full Fourier coefficients on the output grid are calculated from their symmetric and antisymmetric parts in subroutine FFTIO, and stored in the array

GPO(NLONO+2,NLATO)

where NLONO = number of longitude points in output grid

NLATO = number of latitude rows in output grid

(m) Grid point fields on output grid

The inverse Fourier transform in subroutine FFTIO gives grid point values in the array GPO.

(n) Packed output grid point field

The output grid point field is packed in subroutine OUTGP. Together with the preliminary arrays it is then converted to CYBER format and stored in the array

GPB(NSPGPB)

Where NSPGPB = (MPRELO+(NLONO+NLATO+3)/4+1)*15/16

and MPRELO = length of preliminary array

The expression for NSPGPB uses integer arithmetic throughout. Division by 4 represents the data packing, while multiplication by 15/16 represents the difference between CRAY and CYBER word lengths. The data record is buffered out from OUTGP.

(o) Packed output CYBER spectral field

The subset of spectral coefficients with triangular truncation NTOUTC (where NTOUTC≤NTIN, the truncation of the spectral fit) is extracted for a single field at a time in subroutine OUTSHC, packed with 3 or 4 values/word depending on the field type, converted to cyber format and stored in the array

SPB(NSPSHB)

where NSPSHBC=(MPRELO+((NTOUTC+1)+(NTOUTC*2)+2)/3+1)*15/16

Division by 3 in the expression for NSPSHB represents the largest possible packed length. The packed data field is buffered out from OUTSHC.

(p) Packed output spectral field for MARS

A subset of spectral coefficients with triangular truncation NTOUTM is extracted for each spectral field at a time in subroutine OUTSHM. Although for the CYBER spectral file the original ECMWF post-processing normalisation has been adopted, the Mars files have been kept consistent with the model normalisation (see A5.1.2(i)).

This subset of spectral coefficients is then packed into 16 bit or 24 bit integer accuracy depending on the field type and converted to WMO GRIB format in MARS subroutine CODEGB and stored in the array

MSPBM(IL1),

where for T106, IL1=4350 for geopotentials, and IL1=2910 for the other fields. Header block information is supplied to CODEGB from COMMON blocks COMBLI and COMBS2.

In the case of T63, IL1=1575 for geopotentials and IL1=1050 for the other fields.

5.8 Spectral scan for multitasked version

The most time consuming part of the post-processing involves the calculations in subroutines SPEC1 (see Fig. 2). A dualtasked version of this part has been developed in research mode and is shown in Fig. 3. It includes the formation of full fourier coefficients from their symmetric and antisymmetric part, the inverse fourier transform, the vertical interpolation and the direct fourier transform.

Calculations for the northern hemisphere line are carried out in task-0, while the calculations for the corresponding southern line are done in task-1.

There is a synchronisation point at the end of the direct fourier transform (FFTDP), and after that the symmetric and antisymmetric fourier calculations are formed. Generalisation to more than two tasks can be carried out in a way similar to that developed for the forecast model.

5.9 Uninterpolated fields scan for CYBER and MARS

Processing of the uninterpolated fields is controlled by subroutine SCANPP. The G3 history file (or the pressure analysis file) is read for each row. Then in subroutine UNIN (or UNINAN for the analysis file), selected variables are extracted and built up into fields in the array.

WK2D (NLON, NGL, NUM2D)

where NLON = number of longitude points

NGL = number of latitude rows

NUM2D = number of variables processed on this pass through the uninterpolated fields.

In the G3 history file, the data is ordered with successive rows coming from alternate hemispheres. The output post-processed fields are reordered so that the rows go from north to south. When all the rows have been processed, all the fields in the current scan are packed and written in subroutine OUT2D, or OUT2DM. The above sequence is repeated if necessary until all the fields have been processed.

If any of the fields of surface pressure, mean sea-level pressure cloud cover, 2 metre temperature or dew point temperature or 10 metre u or v is requested, then data is also required from the F1-F4 history files. If so, these files are read in SCANPP, and the appropriate dynamics fields are built up in subroutine GETDYN. Cloud cover is calculated in subroutine CLCOV, while the other 4 variables are calculated in SURPAR. The output packed uninterpolated fields are produced in OUT2D or OUT2DM which are called by (for forecast data) UNIN and UNINAN (for analysis data). In front of the uninterpolated file for MARS there is the MARS model switch record (Section 5.3.2).

5.10 Diagnostics scan

Processing of the diagnostics fields is controlled by subroutine SCANPP. The G4 history file is read for each row, and in subroutine DIACTL the diagnostics fields are extracted and built up in the array.

WKDI (NLEV, NGL, NDIFDS)

where NLEV = number of vertical levels

NGL = number of latitude rows

NDIFDS = number of diagnostic fields.

Rows of data are reordered to go from north to south. When all the rows have been read, the fields are packed and written in subroutine OUTDIA.

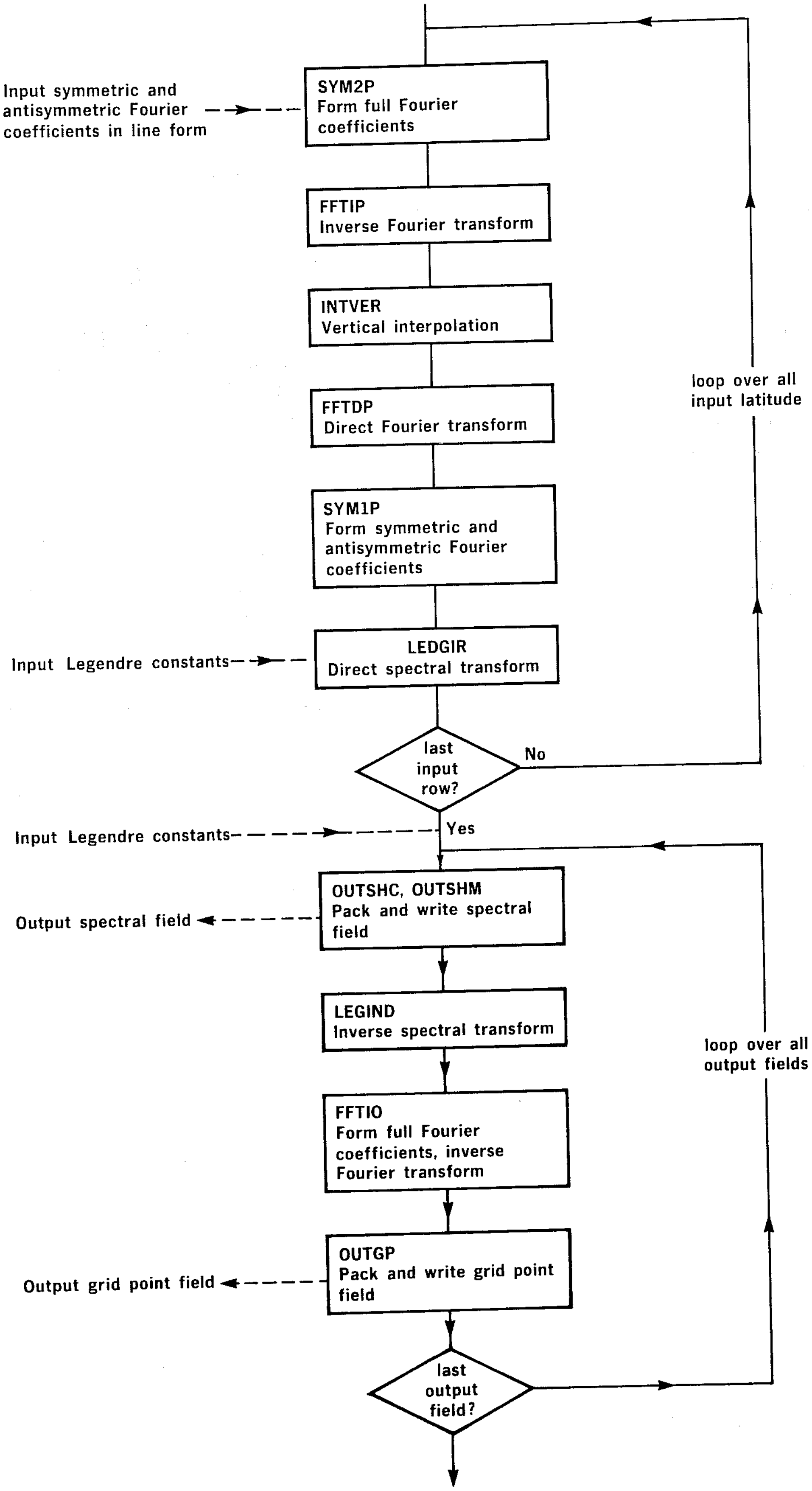


Fig.2 Outline of the main calculation sequence of the post-processing of spectrally-fitted fields.

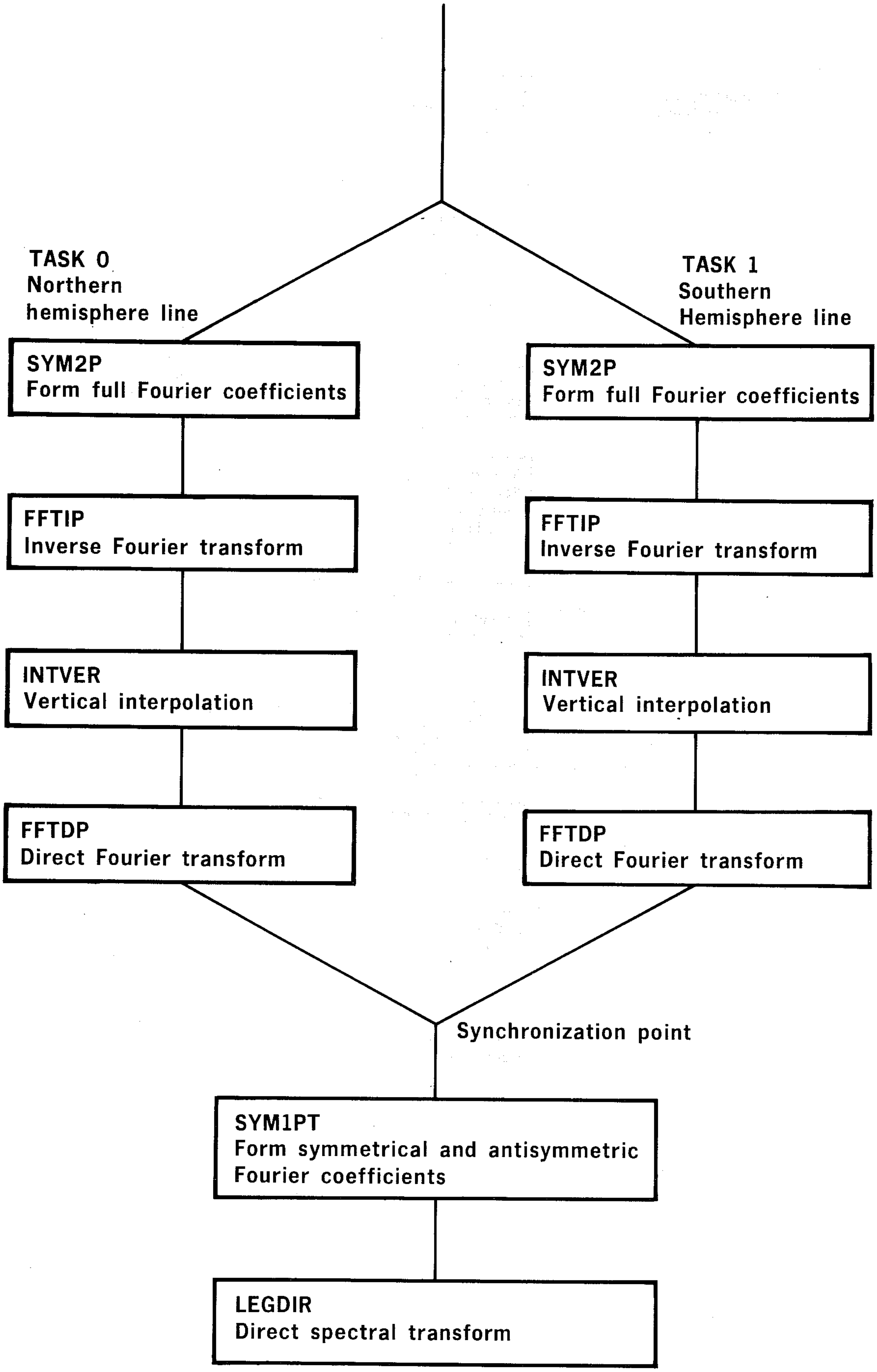


Fig.3 A dual-tasked version of the calculation of spectral fields.

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APPENDIX

DATA DESCRIPTOR RECORDS

In the current post-processing implementation, up to five data description records are used:

(i) First data description record

(ii) Spatial representation record

(iii) Model grid descriptor record

(iv) Special information record (model switch record)

(v) Data index record

FIRST DATA DESCRIPTOR RECORD

WORD	CONTENTS	PPG-post-processed grid point file	PPS-post-processed spectral coefficient file	PPU-post-processed uninterpolated file	PPD-post-processed diagnostics file
1	Length of 1st DDR	630	630	630	630
2	Length of INTEGER section	30	30	30	30
3	Length of next DDR	540+4*NMFD+5*NSFD+NLATO*4 +NMLV	543+4*NMFD+5*NSFD+NMLV	540+5*N2D+4*MAXROW	548+MAXROW+2*NLEV
4	No.of non-INTEGER sections	1	1	1	1
5	Type of next section	3 ('char')	3	3	3
6	1st word of next section	31	31	31	31
7	Creation time	HHMMSS	HHMMSS	HHMMSS	HHMMSS
8	Creation date	YYMMDD	YYMMDD	YYMMDD	YYMMDD
9	Initial data time	HHMMSS	HHMMSS	HHMMSS	HHMMSS
10	Initial data date	YYMMDD	YYMMDD	YYMMDD	YYMMDD
11	Forecast data time	HHMMSS	HHMMSS	HHMMSS	HHMMSS
12	Forecast data date	YYMMDD	YYMMDD	YYMMDD	YYMMDD
13	No.of history files	1/2/3/4	1/2/3/4	1/2/3/4	1/2/3/4
14	Data type	2	11	2	13
15	No.of DDR's	5	5	5	5
16	No.of data records	MFDOUT=NMFD*NMLV+NSFD	MFDOUT=NMFD*NMLV+NSFD	N2D	NDIFDS

where NMFD = no. of multi-level fields
NMLV = no. of levels
NSFD = no. of single level fields

FIRST DATA DESCRIPTOR RECORD ctd (1)

WORD	CONTENTS	PPG-post-processed grid point file	PPS-post-processed spectral coefficient file	PPU-post-processed uninterpolated file	PPD-post-processed diagnostics file
17	Max DDR length	Max(630;540+4*NMFD +5*NSFD+NLATO*4+NMLV; 249+ 7*MAXROW/3+2*NLEV; 10+4*(NMFD*NMLV+NSFD)	Max(530;543+4*NMFD +5*NSFD+NMLV;249+ 7*MAXROW/3+2*NLEV; 10+4*(NMFD*NMLV+NSFD)	Max(630;540+5*N2D +4*MAXROW;249+ 7*MAXROW/3+2*NLEV; 10+4*N2D	Max(630;548+MAXROW +2*NLEV; 249+7*MAXROW/3 +2*NLEV; 10+4*NDIFDS)
18	Max data record length	MPRELO+NLATO*NLONO/4	MPRELO+(NTOUT+1)*(NTOUT+2)/3	MPRELO+NLON*MAXROW/4	MPRELO+NLEV*MAXROW/4
		where MPRELO=length of prelimary array (16) NLATO=no. of output latitude row NLONO no. of output longitude points NTOUT=output truncation of spectral coefficients NLON=no. of longitude points of model grid MAXROW=no. of latitude rows of model grid NLEV=no. of vertical levels of model grid			
19-30	Not yet assigned				
31-40	Character descriptor of experiment				
41-630	Character descriptor section				

SPATIAL REPRESENTATION RECORD

WORD	TYPE	CONTENTS	PPG-post-processed grid point file	PPS-post-processed spectral coefficient file	PPU-post-processed uninterpolated file	PPD-post-processed diagnostics file
1	I	Length of spatial representation record	540+4*NMFD+5*NSFD+NMLV+NLATO*4	543+4*NMFD+5*NSFD+NMLV	540+5*N2D+4*MAXROW	548+MAXROW+2*NLEV
2	I	Length of INTEGER section (NILEN2)	40+NPVAL*NPARM+NHLEN+NVCLEV*NUMVC=40+4*NMFD+5*NSFD+NMLV+NLATO	40+NPVAL*NPARM+NHLEN+NVCLEV*NUMVC=40+4*NMFD+5*NSFD+NMLV+3	40+NPVAL*NPARM+NHLEN+NVCLEV*NUMVC=40+N2D*5+MAXROW	40+NPVAL*NPARM+NHLEN=40+4+1
3	I	Length of next DDR	249+7*MAXROW/3+2*NLEV	249+7*MAXROW/3+2*NLEV	249+7*MAXROW/3+2*NLEV	249+7*MAXROW/3+2*NLEV
4	I	No.of non-INTEGER sections	2	2	2	2
5	I	Type of next section	1 (=REAL)	1	1	1
6	I	Type of 3rd section	3 (='CHAR')	3	3	3
7	I	1st word of 2nd section	NILEN2+1	NILEN2+1	NILEN2+1	NILEN2+1
8	I I	1st word of 3rd section (NWCHAR)	NILEN2+NHLEN*NUMLL+NVCREF+1=NILEN2+NLATO*3+1	NILEN2+NHLEN*NUMLL+NVCREF+1=NILEN2+1	NILEN2+NHLEN*NUMLL+NVCREF+1=NILEN2+MAXROW*3+1	NILEN2+NHLEN*NUMLL+NVCLEV*NUMVC+NVCREF+1=NILEN2+MAXROW+2*(NLEV+1)+2
9-10	I	Not allocated				
11	I	Data type	1	3	1	4
12	I	Grid type	1	21	2	31
13	I	Grid order	1	20	1	1
14	I	Data order	14	1	14	34

SPATIAL REPRESENTATION RECORD ctd (1)

WORD	TYPE	CONTENTS	PPG-post-processed grid point file	PPS-post-processed spectral coefficient file	PPU-post-processed uninterpolated file	PPD-post-processed diagnostics file
15	I	Data section order	23	23	2	2
16	I	Data spacing type	2	2	2	2
17	I	Data spacing length	16	16	16	16
18	I	Data packing code	1	3	1	1
19-20	I	Not allocated				
21	I	No.of data sections	NMFD*NMLV+NSFD	NMFD*NMLV+NSFD	N2D	NDIFDS
22	I	No.of fields in fields descrip.array (NPARM)	NMFD+NSFD	NMFD+NSFD	N2D	1
23	I	No.of entries/field in fields description array (NPVAL)	4	4	4	4
24	I	1st word of fields description array	41	41	41	41
25	I	No.of entries in horizontal resolution table (NHLEN)	NLATO	3	MAXROW	1
26	I	1st word of horizontal resol. table (NWHOR)	41+NPVAL*NPARM=41+4*(NMFD+NSFD)	41+NPVAL*NPARM=41+4*(NMFD+NSFD)	41+NPVAL*NPARM=41+4*N2D	41+NPVAL*NPARM=45

SPATIAL REPRESENTATION RECORD ctd (2)

WORD	TYPE	CONTENTS	PPG-post-processed grid point file	PPS-post-processed spectral coefficient file	PPU-post-processed uninterpolated file	PPD-post-processed diagnostics file
27	I	No.of entries/field in lat/long table (NUMLL)	3	0	3	MAXROW
28	I	1st word of lat/long table (NWLTLN)	NWVCT+NVCLEV*NUMVC=41+5*NSFD+4*NMFD+NMLV+NLATO	NWVCT+NVCLEV*NUMVC=44+5*NSFD+4*NMFD+NMLV	NWVCT+NVCLEV*NUMVC=41+5*N2D+MAXROW	NWHOR+NHLEN=46
29-30	I	Not allocated				
31	I	No.of model levels	NMLV+NSFD	NMMLV+NSFD	N2D	NLEV
32	I	Vertical representation type	1	1	4	3
33	I	Vertical interpolation code	1 or 2 or 3	1 or 2 or 3	0	0
34	I	No.of vertical coordinate levels (NVCLEV)	NMLV+NSFD	NMLV+NSFD	N2D	NLEV+1
35	I	No.of coordinates/level (NUMVC)	1	1	1	2
36	I	No.of reference values (NVCREF)	0	0	0	1
37	I	1st word of vertical coordinate table (NWVCT)	NWHOR+NHLEN=41+4*(NMFD+NSFD)+NLATO	NWHOR+NHLEN=44+4*(NMFD+NSFD)	NWHOR+NHLEN=41+4*N2D+MAXROW	NWLTLN+NHLEN*NUMLL=46+MAXROW

SPATIAL REPRESENTATION RECORD ctd (3)

WORD	TYPE	CONTENTS	PPG-post-processed grid point file	PPS-post-processed spectral coefficient file	PPU-post-processed uninterpolated file	PPD-post-processed diagnostics file
38	I	1st word of reference values (NWVCR)	NWLTLN+NHLEN*NUMLL=41+5*NSFD +4*NMFD+NMLV+NLATO*4	NWLTLN+NHLEN*NUMLL=44+4*NMFD +5*NSFD+NMLV	NWVCT+NVCLEV*NUMVC=41+5 *N2D+MAXROW*4	NWVCT+NVCLEV*NUMVC=46+ MAXROW+2*(NLEV+1)
39-40	I	Not allocated				
41	I	Fields description array (length NPVAL*NPARM)	NFDML(1),NMLV,1,NMLV,... NFDML(NMFD),NMLV,1,NMLV, NFDSL(1),1,NMLV+1,NMLV+1,... NFDSL(NSFD),1,NMLV+NSFD, NMLV+NSFD	NFDML(1),NMLV,1,NMLV,... NFDML(NMFD),NMLV,1,NMLV, NFDSL(1),1,NMLV+1,NMLV+1,... NFDSL(NSFD),1,NMLV+NSFD, NMLV+NSFD	NGPCL(1,1,),1,1,1,NGPCL(1,2), 1,2,2,...NGPCL(1,N2D),1, N2D,N2D	23,NLEV,1,NLEV

SPATIAL REPRESENTATION RECORD ctd (4)

WORD	TYPE	CONTENTS	PPG-post-processed grid point file	PPS-post-processed spectral coefficient file	PPU-post-processed uninterpolated file	PPD-post-processed diagnostics file
NWHOR	I	Horizontal resolution table (length NHLEN)	NLONO,NLONO,...,NLONO	NTOUT,NTOUT,NTOUT (i.e.M=N=K= NTOUT, where spectral coeffs are held in order $\sum_{m=0}^{M}\sum_{n=m}^{\min(m+N,K)} S_{mn}$)	MLONG(1),MLONG(2),...MLONG (MAXROW)where MLONG(J)=no.of longitudes in Jth model latitude row	MAXROW
NWVCT	I	Vertical coordinate table (length NVCLEV*NUMVC) (integer form)	NLVML(1),NLVML(2),...NLVML (NMLV),NLVSL(1),... NLVSL(NSFD)	NLVML(1),NLVML(2),...NLVML (NMLV),NLVSL(1),... NLVSL(NSFD)	NGPCL(2,1),NGPCL(2,2),... NGPCL(2,N2D)	-
NWLTLN	R	Latitude/longitude table (length NHLEN*NUMLL)	LAT(row 1),START LONG (row 1), END LONG (row 1),...LAT(row NLATO),START LONG (row NLATO) END LONG (rowNLATO)	-	LAT(row 1),START LONG (row 1), END LONG (row 1),...LAT(row NLATO),START LONG (row NLATO) END LONG (row NLATO)	LAT(row 1),LAT(row 2),LA (row MAXROW)
NWVCT	R	Vertical coordinate table (length NVCLEV*NUMVC) (real form)		-	-	$a_{\frac{1}{2}}, a_{1\frac{1}{2}},\ldots a_{NVCLEV-\frac{1}{2}}$ $b_{\frac{1}{2}}, b_{1\frac{1}{2}},\ldots b_{NVCLEV-\frac{1}{2}}$
NWVCR	R	Vertical reference values (length NVCREF)	-	-		p_o
NWCHAR	B	'character' section (length 500)				

MODEL GRID DESCRIPTOR RECORD

WORD	TYPE	CONTENTS	VALUE
1	I	Length of model grid descriptor record	249+9*MAXROW/2+2*NLEV
2	I	Length of INTEGER Section	46+3*MAXROW/2
3	I	Length of next DDR	
4	I	Number of non-INTEGER Sections	2
5	I	Type of 2nd section	1 (= real)
6	I	Type of 3rd section	3 (= 'char')
7	I	First word of real section	47+3*MAXROW/2
8	I	First word of 'character' section	50+9*MAXROW/2 +2*NLEV
9-10	I	Not allocated	
11	I	Grid point space grid type	2 (Gaussian lat/long)
12	I	Number of latitude rows	MAXROW
13	I	Order of latitude rows	2(=NS/NS/..)
14	I	Code for regular grid	1
15	I	First word of table containing no. of longitude points/row (NWLONS)	47
16	I	First word of lat/long table (NWTLN)	47+3*MAXROW/2
17-20	I	Not allocated	

MODEL GRID DESCRIPTOR RECORD ctd (1)

WORD	TYPE	CONTENTS	VALUE
21	I	Fourier space grid type	11 (symmetric + antisymmetric fourier coefficients on Gaussian lats)
22	I	Order of Fourier coeffs	1 (real, m=0, imag, m=0; real, m=1, imag, m=1;...)
23	I	Number of latitude rows	MAXROW/2
24	I	Code for regular grid	1 (constant no. of fourier wave nos/row)
25	I	First word of table containing highest fourier wave number for each row (NWFOUR)	47+MAXROW
26-28	I	Not allocated	
29	I	Spectral space normalization code	$1\ (\frac{1}{2}\int_{-1}\left\|P_o\right\|^2 d\mu = 1)$
30	I	Order of spectral coeffs	$1\ (\sum_{m=o}^{M}\ \sum_{n=m}^{\min(m+N,K)} C_{mn})$
31	I	M	M=63
32	I	N spectral truncation $\sum_{m=o}^{M}\ \sum_{n=m}^{\min(m+N,K)}$	N=63 for T63)
33	I	K	K=63
34-36	I	Not allocated	
37	I	Number of model levels	NLEV
38	I	Vertical representation type	3 (hybrid)

MODEL GRID DESCRIPTOR RECORD ctd (2)

WORD	TYPE	CONTENTS	
39	I	No. of vertical coordinate levels (NVCLEV)	NLEV+1
40	I	No. of variables to define a coordinate level (NUMVC)	2
41	I	No. of reference values (NVCREF)	1
42	I	1st word of vertical coordinate table (NWVCT)	47+9*MAXROW/2
43	I	1st word of vertical reference values (NWVCR)	47+9*MAXROW/2+2*(NLEV+1)
44-46	I	Not allocated	
NWLONS	I	Table containing no. of longitude points/row (length MAXROW)	NLON,NLON,...NLON
NWFOUR	I	Table containing max Fourier wave no. in each row (length MAXROW/2)	M,M,M,...M
NWLTLN	R	Table containing latitude, + start and end longitudes of each row (length MAXROW*3)	Lat 1, start long 1, end long 1; lat 2, start long 2, end long 2;..lat MAXROW, start start long MAXROW, end long MAXROW
NWVCT	R	Vertical coordinate table (length NVCLEV*NUMVC)	$a , a ,...a_{NLEV+} , b , b_{1} ,...b_{NLEV+\frac{1}{2}}$
NWVCR	R	Vertical reference values (length NVCREF)	p_o
NWCHAR	B	'Character' description, length 200	

SPECIAL INFORMATION RECORD (Model Switch Record)
(strongly dependent on the version of the model)

WORD		CONTENTS	VALUE	TYPE
1		Length of model switch record		I
2		Length of integer section		I
3		Length of next DDR		I
4		Number of non-integer sections	3	I
5		Type of second section	1 (Real)	I
6		Type of third section	2 (Logical)	I
7		Type of fourth section	3 (Character)	I
8		First word of second section		I
9		First word of third section		I
10		First word of fourth section		I
11	COMSDS	First word of INTEGER section	101	I
12		Number of words in integer section	500	I
13		First word of Real section		
14		Number of words in real section		
15		First word of Logical section		
16		Number of words in Logical section		
17	COMDOC	First word of INTEGER section	101	I
18		Number of words in integer section	500	I
19		First word of Real section		
20		Number of words in real section		
21		First word of Logical section		
22		Number of words in Logical section		
23-28	COMCTL	Same as COMDOC		

SPECIAL INFORMATION RECORD (Model Switch Record)
(strongly dependent on the version of the model)

WORD	CONTENTS	VALUE	TYPE
29-34	COMDIA		
35	COMDIZ first word of INTEGER SECTION		
36	Number of words in integer section		
37	First word of Land/Sea table		
38	Number of word of Land/Sea table		
39	First word of Logical section		
40	Number of word of Logical section		
41-46	COMDSW same as in COMSDS		
47-52	COMHDI same as in COMSDS		
53-58	COMMSK same as in COMSDS		
59-64	COMNMI same as in COMSDS		
65-70	COMPSW same as in COMSDS		
71-76	COMRSW same as in COMSDS		
77-82	COMSIM same as in COMSDS		
83-88	COMSTA same as in COMSDS		
89-94	COMTRU same as in COMSDS		
95-100	Reserved		
101 -	Integers from COMSDS, COMDOC, COMCTL, COMDIZ Land/Sea table from COMDIZ, Integers from COMMSK, COMNMI, COMPSW, COMTRU Reals from COMCTL, COMDIA, COMHDI, COMMSK, COMNMI, COMPSW, COMSIM, COMSTA Logicals from COMSDS, COMDIZ, COMDSW, COMNMI, COMPSW, COMRSW		

DATA INDEX RECORD

WORD	TYPE	CONTENTS	PPG-post-processed grid point file	PPS-post-processed spectral coefficient file	PPU-post-processed uninterpolated file	PPD-post-processed diagnostics file
1	I	Length of data record	10+4*(NMFD*NMLV+NSFD)	10+4*(NMFD*NMLV+NSFD)	10+4*N2D	10+4*NDIFDS
2	I	Length of INTEGER part	10+4*(NMFD*NMLV+NSFD)	10+4*(NMFD*NMLV+NSFD)	10+4*N2D	10+4*NDIFDS
3	I	Length of next DDR	0	0	0	0
4	I	No.of non-INTEGER Sects.	0	0	0	0
5-10	I	Not allocated				
11	I	Data record containing data sect.1	1	1	1	1
12	I	Record length	16+NLATO*NLONO/4	16+((NTOUT+1)*(NTOUT+2)-1)/p where p=packing density; p=3 for height,geopotential; p=4 for all other fields	16+MAXROW*NLON/4	16+NLEV*MAXROW/4
13	I	1st word of data section 1 within record	1	1	1	1
14	I	Length of data sect.1	16+NLATO*NLONO/4	16+((NTOUT+1)*(NTOUT+2)-1)/P	16+MAXROW*NLON/4	16+NLEV*MAXROW/4

DATA INDEX RECORD ctd.(1)

WORD	TYPE	CONTENTS	PPG-post-processed grid point file	PPS-post-processed spectral coefficient file	PPU-post-processed uninterpolated file	PPD-post-processed diagnostics file
N*4+7	I	Data record containing data section N	N, where 1≤N≤NMFD*NMLV+NSFD	N, where 1≤N≤NMFD*NMLV+NSFD	N, where 1≤N≤N2D	N, where 1≤N≤NDIFDS
N*4+8	I	Record length	16+NLATO*NLONO/4	16*((NTOUT)*(NTOUT+2)-1)/P	16+MAXROW*NLON/4	16+NLEV*MAXROW/4
N*4+9	I	1st word of data section N within record	1	1	1	1
N*4+10	I	Length of data section N	16+NLATO*NLONO/4	16+((NTOUT+1)*(NTOUT*2)-1)/P	16+MAXROW*NLON/4	16+NLEV*MAXROW/4