# TECHNICAL MEMORANDUM

**2**

# The forecast and analysis post-processing package

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## 1.   Introduction

The post-processing package provides an interface between
the forecast model or the analysis system on the Cray and
the archiving and dissemination systems on the Cyber.
Selected fields are sent from the Cray, packed and in
Cyber format.  They may have been vertically interpolated,
using linear or cubic spline fits, and they may have
been horizontally interpolated, by fitting spherical
harmonics, and then interpolating back to a regular latitude/
longitude grid.

The post-processing package may be divided into 2 parts.
In the first part, a work file is generated, containing
selected fields in line form.  This part may either be
initialised at selected time steps while a forecast
model is running, or it may be a separate job, which takes
as input an analysis or forecast history file.  The second
part of the package is a separate job, which converts the
data from line to field format, and may interpolate it
horizontally before packing it and converting it to Cyber
format.

Section 2 describes the theory of the method used to cal-
culate the spherical harmonic coefficients for the hori-
zontal interpolation.  Section 3 describes the forecast-
called version of the first part of the post-processing
package, while Section 4 describes the stand-alone version.
Section 5 describes the way in which the fields are re-
arranged, so that they are in the most convenient order
for the spherical harmonic fitting routines.  Section 6
defines the format of the work file, which is the inter-
face between the first and second part of the post-process-
ing package.  Section 7 contains a description of the

second part of the package. Section 8 describes the space
layout used in the second part, and the algorithms used to
decide how many fields can be processed in each scan
through the data. Section 9 describes the format of the
3 types of output file which may be generated by the post-
processing package. Section 10 consists of tables
describing the common blocks used by the post-processing
package. Section 11 contains examples of the job control
language used to run different parts of the package.

## 2. Theory of the method of calculating the spherical harmonic coefficients

The spherical harmonic coefficients are calculated, using the method described by Machenhauer and Daley (1972). Given a function which may be represented by a truncated series of spherical harmonics:-

$$\psi(\lambda,\phi) = \sum_{m=-M^*}^{M^*} \sum_{n=|m|}^{N^*} \psi_{mn} Y_{mn}(\lambda,\mu) \qquad (1)$$

(where $0 \leqslant M^* \leqslant N^*$, $\lambda$ = longitude, $\phi$ = latitude, $\mu = \sin\phi$) then this method calculates the coefficients $\psi_{mn}$ exactly.

$$\psi(\lambda_k,\phi_j) = \sum_{m=-M^*}^{M^*} \sum_{n=|m|}^{N^*} \psi_{mn} P_{mn}(\mu_j) e^{im\lambda_k} \qquad (2)$$

$$= \sum_{m=-M^*}^{M^*} \psi_m(\phi_j) e^{im\lambda_k} \qquad (3)$$

$$= \psi_o(\phi_j) + \sum_{m=1}^{M^*} (\psi_m(\phi_j)e^{im\lambda_k} + \psi_m^*(\phi_j)e^{-im\lambda_k}) \qquad (4)$$

(since $\psi(\lambda_k,\psi_j)$ is real, $\psi_{-m}(\phi_j) = \psi_m^*(\phi_j)$
where $\psi_m^*(\phi_j)$ = complex conjugate of $\psi_m(\phi_j)$ )

Compare this with the format of the 'half-complex' Fourier transform

If $x_a = \sum_{b=0}^{B-1} C_b e^{2ia\pi b/B}$ and $C_{B-b} = C_b^*$ (i.e. $C_o$ and $C_{B/2}$

are real)

then $x_a = C_o + \sum_{b=1}^{\frac{B}{2}-1} \{C_b e^{2\pi iab/B} + C_b^* e^{-2\pi iab/B}\} + C_{\frac{B}{2}} e^{ia\pi}$

and

$$C_b = \frac{1}{B} \sum_{a=o}^{B-1} x_a e^{-2ia\pi b/B}$$

Given a field $\psi(\lambda_k, \phi_j)$ on a regular latitude/longitude grid, with

$$\lambda_k = \frac{2\pi k}{NLON} \text{ for } k = 0,1,\ldots NLON-1$$

NLON = number of longitude points

then the Fourier coefficients $\psi_m(\phi_j)$ may be exactly calculated by the transform

$$\psi_m(\phi_j) = \frac{1}{NLON} \sum_{k=o}^{NLON-1} \psi(\lambda_k, \phi_j) e^{-im\lambda_k}$$

$$\text{if } 0 \leq m \leq M^* \leq \frac{NLON}{2} - 1 \tag{5}$$

(Within the post-processing package, half-complex transforms are used, so that by exploiting the fact that $\psi_{-m} = \psi_m^*$, only the Fourier coefficients for $m \geq o$ need to be calculated explicitly).

The Fourier coefficients $\psi_m(\phi_j)$ may be divided into symmetric and antisymmetric parts with respect to the equator:-

$$\psi_m^S(\phi_j) = \frac{1}{2} (\psi_m(\phi_j) + \psi_m(-\phi_j))$$

$$\tag{6}$$

$$\psi_m^A(\phi_j) = \frac{1}{2} (\psi_m(\phi_j) - \psi_m(-\phi_j))$$

The Legendre functions $P_{mn}(\mu)$ may be represented as trigonometric polynomials with latitude $\phi$ as argument:-

$$P_{mn}(\mu) = \begin{cases} \sum_{r=\epsilon 1}^{n} 2 \; P_{mn}^{r} \cos(r\phi) \quad \text{for} \quad (m+n) \text{ even} \\[2em] \sum_{r=\epsilon 2}^{n} 2 \; P_{mn}^{r} \sin(r\phi) \quad \text{for} \quad (m+n) \text{ odd} \end{cases} \tag{7}$$

where $\displaystyle\sum_{r=\epsilon 1}^{n} 2$ means $r = \epsilon 1, \; \epsilon 1+2, \; \epsilon 1+4, \ldots, n$ or $n-1$

and

$$\epsilon 1 = \begin{cases} 0 & \text{for m even} \\ 1 & \text{for m odd} \end{cases} \qquad \epsilon 2 = \begin{cases} 1 & \text{for m even} \\ 2 & \text{for m odd} \end{cases}$$

So $P_{mn}(\mu)$ is symmetric with respect to the equator when $(m+n)$ is even, and antisymmetric when $(m+n)$ is odd.

From (2) $\quad \psi_m(\phi) = \displaystyle\sum_{n=|m|}^{N^*} \psi_{mn} P_{mn}(\mu) \tag{8}$

$$= \psi_m^S(\phi) + \psi_m^A(\phi)$$

Using (7) $\quad \psi_m^S(\phi) = \displaystyle\sum_{n=|m|}^{N^*} 2 \; \psi_{mn} P_{mn}(\mu) \tag{9}$

$$\psi_m^A(\phi) = \displaystyle\sum_{n=|m|+1}^{N^*} 2 \; \psi_{mn} P_{mn}(\mu)$$

since for $n=|m|, n=|m|+2$, etc., $(m+n)$ is even, and $P_{mn}(\mu)$ is symmetric.

Combining (9) and (7) gives

$$\psi_m^S (\phi) = \sum_{r=\epsilon 1}^{N^*} 2 \; \psi_m^r \cos (r\phi)$$

$$(10)$$

$$\psi_m^A (\phi) = \sum_{r=\epsilon 2}^{N^*} 2 \; \psi_m^r \sin (r\phi)$$

where $\psi_m^r = \sum_{n=r}^{N^*} 2 \; \psi_{mn} \; P_{mn}^r \qquad r=\epsilon 1, \ldots, N^*$  (11)

Using the orthogonality relations for trigonometric functions on (10) gives

$$\psi_m^r = \begin{cases} \dfrac{\delta}{\pi} \displaystyle\int_0^{2\pi} \psi_m^S (\phi) \cos (r\phi) d\phi \quad r=\epsilon 1, \epsilon 1+2, \ldots, N^* \text{ or } N^*-1 \\[3em] \dfrac{1}{\pi} \displaystyle\int_0^{2\pi} \psi_m^A (\phi) \sin (r\phi) d\phi \quad r=\epsilon 2, \epsilon 2+2, \ldots, N^* \text{ or } N^*-1 \end{cases}$$

$$(12)$$

where

$$\delta = 1 \quad \text{for } r \neq 0$$

$$\delta = \frac{1}{2} \quad \text{for } r = 0$$

The trapezoidal quadrature formula

$$\frac{1}{\pi} \int_0^{2\pi} f(\phi) \, d\phi = \frac{2}{k} \sum_{j=1}^{k} f(\phi_j)$$

$$(13)$$

(where $\phi_j = \alpha + (j-1)\dfrac{2\pi}{k}$ and $0 \leq \alpha \leq \dfrac{2\pi}{k}$ )

is exact for $f(\phi)$ being any trigonometric polynomial of degree $\leqslant$ k-1. The polynomials of equation (12) are of degree $\leqslant$ 2N$^{*}$, so they can be integrated exactly by:-

$$\psi_m^r = \begin{cases} \dfrac{2\delta}{B} \displaystyle\sum_{j=1}^{B} \psi_m^S(\phi_j) \cos(r\phi_j) & r=\epsilon 1, \epsilon 1+2, \ldots \\[2em] \dfrac{2}{B} \displaystyle\sum_{j=1}^{B} \psi_m^A(\phi_j) \sin(r\phi_j) & r=\epsilon 2, \epsilon 2+2, \ldots \end{cases} \tag{14}$$

where $B \geqslant 2N^{*}+1$, $\phi_j = \alpha + (j-1)\dfrac{2\pi}{B}$, $0 \leqslant \alpha \leqslant \dfrac{2\pi}{B}$

For the forecast model grid, $\alpha = 0$ will be used for all fields except v-velocity, which will use $\alpha = \dfrac{\pi}{B}$ .

With these values of $\alpha$, and if B is chosen to be a multiple of 4, i.e. B = 4*C, equation (14) can be further simplified:-

$$\psi_m^r = \begin{cases} \dfrac{2\delta}{C} \displaystyle\sum_{j=1}^{D} W_j\, \psi_m^S(\phi_j) \cos(r\phi_j) & r=\epsilon 1, \epsilon 1+2, \ldots \\[2em] \dfrac{2}{C} \displaystyle\sum_{j=1}^{D} W_j\, \psi_m^A(\phi_j) \sin(r\phi_j) & r=\epsilon 2, \epsilon 2+2, \ldots \end{cases} \tag{15}$$

where, if $\alpha = 0$,  $D = C + 1$

$W_j = \dfrac{1}{2}$  for j = 1 and j = D

$W_j = 1$  for j $\neq$ 1 and j $\neq$ D

and, if $\alpha = \dfrac{\pi}{B}$,  $D = C$

$W_j = 1$  for all values of j .

This simplification is possible because each term in (14) is a trigonometric polynomial of even degree, including only cosines or only sines.

Consider for example the case where $\alpha = 0$ and $m$ is odd. Then $\varepsilon 1 = 1$, and for $r$ odd

$$\cos(\frac{2\pi r}{B}) = -\cos(r\pi - \frac{2\pi r}{B}) = -\cos(r\pi + \frac{2\pi r}{B}) = \cos(2r\pi - \frac{2\pi r}{B})$$

and since $\psi_m^S(\phi_j) = \sum_{r=\varepsilon 1}^{\frac{N}{2}} \psi_m^r \cos(r\phi_j)$

$$\psi_m^S(\frac{2\pi r}{B}) = -\psi_m^S(r\pi - \frac{2\pi r}{B}) = -\psi_m^S(r\pi + \frac{2\pi r}{B}) = \psi_m^S(2r\pi - \frac{2\pi r}{B})$$

so

$$\psi_m^S(\frac{2\pi r}{B})\cos(\frac{2\pi r}{B}) = \psi_m^S(r\pi - \frac{2\pi r}{B})\cos(r\pi - \frac{2\pi r}{B})$$

$$= \psi_m^S(r\pi + \frac{2\pi r}{B})\cos(r\pi + \frac{2\pi r}{B}) = \psi_m^S(2r\pi - \frac{2\pi r}{B})\cos(2r\pi + \frac{2\pi r}{B})$$

Using the orthogonality relations for Legendre functions on (8)

$$\psi_m(\phi) = \sum_{n=|m|}^{N^*} \psi_{mn}(\mu) \, P_{mn}(\mu)$$

gives

$$\psi_{mn} = \frac{1}{2} \int_{-1}^{1} \psi_m(\phi) \, P_{mn}(\mu) d\mu \qquad (16)$$

Inserting (10) into (16) gives

$$\psi_{mn} = \begin{cases} \sum_{r=\epsilon 1}^{N^*} \psi_m^r \frac{1}{2} \int_{-1}^{1} P_{mn}(\mu)\cos(r\phi)d\mu & \text{for } m+n \quad \text{even} \\[3em] \sum_{r=\epsilon 1}^{N^*} \psi_m^r \frac{1}{2} \int_{-1}^{1} P_{mn}(\mu)\sin(r\phi)d\mu & \text{for } m+n \quad \text{odd} \end{cases} \tag{17}$$

And inserting (15) into (17) gives

$$\psi_{mn} = \begin{cases} \sum_{j=1}^{D} \psi_m^S(\phi_j)Z_{mn}(\phi_j) & \text{for } m+n \quad \text{even} \\[3em] \sum_{j=1}^{D} \psi_m^\Lambda(\phi_j)Z_{mn}(\phi_j) & \text{for } m+n \quad \text{odd} \end{cases} \tag{18}$$

where

$$Z_{mn}(\phi_j) = \begin{cases} \frac{W_j}{C} \sum_{r=\epsilon 1}^{N^*} \delta R_{mn}^r \cos(r\phi_j) & \text{for } m+n \quad \text{even} \\[3em] \frac{W_j}{C} \sum_{r=\epsilon 2}^{N^*} R_{mn}^r \sin(r\phi_j) & \text{for } m+n \quad \text{odd} \end{cases} \tag{19}$$

and

$$R_{mn}^r = \begin{cases} \int_{-1}^{1} P_{mn}(\mu)\cos(r\phi)d\mu & \text{for } (m+n) \text{ even,} \\ & r=\epsilon 1, \epsilon 1+2, \ldots \\[2em] \int_{-1}^{1} P_{mn}(\mu)\sin(r\phi)d\mu & \text{for } (m+n) \text{ odd,} \\ & r=\epsilon 2, \epsilon 2+2, \ldots \end{cases} \tag{20}$$

The coefficients $R_{mn}^r$ are evaluated using Gaussian quadrature, which is exact if $N^*$ Gaussian latitudes are used.

It has been shown so far that the spherical harmonic coefficients may be calculated exactly by this method, providing that the data fitted may be represented exactly by a truncated series of spherical harmonics of the form:

$$\psi(\lambda_k, \phi_j) = \sum_{m=-M^*}^{M^*} \sum_{n=|m|}^{N^*} \psi_{mn} P_{mn}(\phi_j) e^{im\lambda_k}$$

where        $0 \leqslant M^* \leqslant N^*$

and providing that certain relations between the grid and the truncation limits are satisfied.

On the model grid, data is given at the points

$\lambda_k$        $= (k-1)\Delta\lambda$ for k=1,2,..4Q    (for all fields except u)

        $= (k-\frac{1}{2})\Delta\lambda$ for k=1,2,..4Q    (u only)

$\phi_j$        $= \pm(j-1)\Delta\phi$ for j=1,2,..(Q+1)(for all fields except v)

        $= \pm(j-\frac{1}{2})\Delta\phi$ for j=1,2,..Q    (v only)

with $\Delta\lambda = \Delta\phi = \frac{\pi}{2Q}$

and    Q = NLON/4 where NLON = number of longitude points

        = (NOREC-1)/2 where NOREC = number of latitude rows

From (5), the Fourier transform will be exact if

        $M^* \leqslant 2Q - 1 = NLON/2-1$

Equation (18) will be exact if

$$2N^* \leq 4Q - 1$$

i.e. $N^* \leq (NLON-1)/2$ and $N^* \leq NOREC-1-\frac{1}{2}$

so we need

$$0 \leq M^* \leq N^* \leq \begin{cases} (NLON-1)/2 \\ NOREC-2 \end{cases}$$

In general, grid point fields will not satisfy the above restrictions, since the number of grid points will always be larger than the number of spherical harmonics used. Instead the function $\psi'(\lambda,\phi)$ will be fitted to the data, where

$$\psi'(\lambda,\phi) = \sum_{m=-M}^{M} \sum_{n=|m|}^{N} \psi_{mn} \, P_{mn}(\phi) e^{im\lambda}$$

with $M \leq M^*$, $N \leq N^*$ and $M, N \leq \begin{cases} (NLON-1)/2 \\ NOREC-2 \end{cases}$

$\psi'(\lambda,\phi)$ can be shown to be, in some sense, a least squares fit to the data.

Within the post-processing package, triangular truncation is used, i.e. $M = N = T$, say.

## 2.1 Velocity fields

The method described above is modified for the calculation of spherical harmonic coefficients for the velocities. First the coefficients for divergence, D, and vorticity, $\zeta$, are calculated from the grid point values of u and v. Both divergence and vorticity are well defined at the poles. The coefficients for u and v are then derived from the divergence and vorticity coefficients.

In the forecast model, the u-velocity components are
defined at the points $(\lambda_k^u, \phi_j^u)$, where

$$\lambda_k^u = (k-\frac{1}{2})\Delta\lambda \quad \text{for } k=1,2,\ldots 4Q$$

$$\phi_j^u = \pm(j-1)\Delta\phi \quad \text{for } j=1,2,\ldots(Q+1)$$

and $\quad \Delta\lambda = \Delta\phi = \dfrac{\pi}{2Q}$

The v-velocity components are defined at the points
$(\lambda_k^v, \phi_j^v)$,
where

$$\lambda_k^v = (k-1)\Delta\lambda \quad \text{for } k=1,2,\ldots 4Q$$

$$\phi_j^v = \pm(j-\frac{1}{2})\Delta\phi \quad \text{for } j=1,2,\ldots Q$$

Let $\quad U = u\cos(\phi) \quad \text{and} \quad V = v\cos(\phi)$, then

$$\zeta = \frac{1}{a(1-\mu^2)} \left\{ \frac{\partial U}{\partial\lambda} - (1-\mu^2)\frac{\partial V}{\partial\mu} \right\}$$

$$\hspace{10cm}(21)$$

$$D = \frac{1}{a(1-\mu^2)} \left\{ \frac{\partial U}{\partial\lambda} + (1-\mu^2)\frac{\partial V}{\partial\mu} \right\}$$

where $\quad a = $ radius of earth

Then $\zeta_{mn} = \dfrac{1}{2a} \displaystyle\int_{-1}^{1} \left\{ imV_mP_{mn} - U_mH_{mn} \right\} \dfrac{d\mu}{1-\mu^2}$

$$\hspace{10cm}(22)$$

$$D_{mn} = \dfrac{1}{2a} \displaystyle\int_{-1}^{1} \left\{ imU_mP_{mn} + V_mH_{mn} \right\} \dfrac{d\mu}{1-\mu^2}$$

where
$$H_{mn} = -(1-\mu^2)\frac{dP_{mn}}{d\mu}$$

The coefficients $D_{mn}$ and $\zeta_{mn}$ can be calculated using a modified version of (18).

$$D_{mn} = \begin{cases} \sum_{j=1}^{Q+1} imU_m^S(\phi_j^u)Z_{mn}^I(\phi_j^u) + \sum_{j=1}^{Q} V_m^A(\phi_j^v)Z_{mn}^{II}(\phi_j^v) & \text{for } m+n \text{ even} \\[4mm] \sum_{j=1}^{Q+1} imU_m^A(\phi_j^u)Z_{mn}^I(\phi_j^u) + \sum_{j=1}^{Q} V_m^S(\phi_j^v)Z_{mn}^{II}(\phi_j^v) & \text{for } m+n \text{ odd} \end{cases} \tag{23}$$

$$\zeta_{mn} = \begin{cases} \sum_{j=1}^{Q} imV_m^S(\phi_j^v)Z_{mn}^I(\phi_j^v) - \sum_{j=1}^{Q+1} U_m^A(\phi_j^u)Z_{mn}^{II}(\phi_j^u) & \text{for } m+n \text{ even} \\[4mm] \sum_{j=1}^{Q} imV_n^A(\phi_j^v)Z_{mn}^I(\phi_j^v) - \sum_{j=1}^{Q+1} U_m^S(\phi_j^u)Z_{mn}^{II}(\phi_j^u) & \text{for } m+n \text{ odd} \end{cases} \tag{24}$$

where

$$Z_{mn}^I(\phi_j) = \begin{cases} \dfrac{w_j}{aQ} \sum_{r=\varepsilon 1}^{N^*/2} \delta R_{mn}^{Ir} \cos(r\phi_j) & \text{for } m+n \text{ even} \\[4mm] \dfrac{w_j}{aQ} \sum_{r=\varepsilon 2}^{N^*/2} R_{mn}^{Ir} \sin(r\phi_j) & \text{for } m+n \text{ odd} \end{cases} \tag{25}$$

$$Z_{mn}^{II}(\phi_j) = \begin{cases} \dfrac{w_j}{aQ} \sum_{r=\varepsilon 2}^{N^*/2} R_{mn}^{IIr} \sin(r\phi_j) & \text{for } m+n \text{ even} \\[4mm] \dfrac{w_j}{aQ} \sum_{r=\varepsilon 1}^{N^*/2} \delta R_{mn}^{IIr} \cos(r\phi_j) & \text{for } m+n \text{ odd} \end{cases} \tag{26}$$

With

$$
w_j = \begin{cases} 1 \text{ for } j \neq 1 \\[2mm] \frac{1}{2} \text{ for } j = 1 \text{ at } \phi_j^u \\[2mm] 1 \text{ for } j = 1 \text{ at } \phi_j^v \end{cases} \quad \text{and} \quad \delta = \begin{cases} \frac{1}{2} \text{ for } r = 0 \\[4mm] 1 \text{ for } r \neq 0 \end{cases}
$$

The coefficients $R_{mn}^{Ir}$ and $R_{mn}^{IIr}$ are determined by Gaussian quadrature of the following integrals:-

$$
R_{mn}^{Ir} = \begin{cases} \displaystyle\int_{-1}^{1} \frac{P_{mn}(\mu)}{1-\mu^2} \cos(r\phi)d\mu & \text{for } m+n \text{ even,} \\ & r = \epsilon 1, \ \epsilon 1+2, \ldots, N^* \text{ or } N^*-1 \\[4mm] \displaystyle\int_{-1}^{1} \frac{P_{mn}(\mu)}{1-\mu^2} \sin(r\phi)d\mu & \text{for } m+n \text{ odd,} \\ & r = \epsilon 2, \epsilon 2+2, \ldots, N^* \text{ or } N^*-1 \end{cases} \tag{27}
$$

$$
R_{mn}^{IIr} = \begin{cases} \displaystyle -\int_{-1}^{1} \frac{dP_{mn}}{d\mu} \sin(r\phi)d\mu & \text{for } m+n \text{ even,} \\ & r = \epsilon 2, \epsilon 2+2, \ldots, N^* \text{ or } N^*-1 \\[4mm] \displaystyle -\int_{-1}^{1} \frac{dP_{mn}}{d} \cos(r\phi)d\mu & \text{for } m+n \text{ odd,} \\ & r = \epsilon 1, \epsilon 1+2, \ldots, N^* \text{ or } N^*-1 \end{cases}
$$

The coefficients $U_{mn}$ and $V_{mn}$ may be derived using the following relations:-

If $\zeta = \nabla^2 \psi$, then $\zeta_{mn} = \dfrac{-n(n+1)}{a^2} \psi_{mn}$

If $D = \nabla^2 \alpha$ then $D_{mn} = \dfrac{-n(n+1)}{a^2} \alpha_{mn}$

$U = \left( \dfrac{\partial \alpha}{\partial \lambda} + (\mu^2-1) \dfrac{\partial \psi}{\partial \mu} \right) \dfrac{1}{a}$

$$V \quad = -(\mu^2-1)\ \frac{\partial \alpha}{\partial \mu} + \frac{\partial \psi}{\partial \lambda}\ )\ \frac{1}{a}$$

$$H_{mn}(\mu) \quad = \quad (\mu^2-1)\ \frac{dP_{mn}}{d\mu}$$

$$\quad = \quad nF_{m,n+1}\ P_{m,n+1}\ -\ (n+1)\ F_{m,n}\ P_{m,n-1}$$

$$\text{with } F_{mn} = \left(\frac{n^2-m^2}{4n^2-1}\right)^{\frac{1}{2}} \qquad\qquad (28)$$

$$\text{and } G_{mn} = \frac{-m}{n(n+1)}$$

$$\text{so } U_{mn} = a\ (-\ \frac{1}{n}\ F_{mn}\zeta_{m,n-1} + G_{mn}D_{mn} + \frac{1}{n+1}\ F_{m,n+1}\zeta_{m,n+1})$$

$$(29)$$

$$V_{mn} = a\ (\frac{1}{n}\ F_{mn}D_{m,n-1} + G_{mn}\zeta_{mn} - \frac{1}{n+1}\ F_{m,n+1}D_{m,n+1})$$

If a subset of spherical harmonic coefficients are calculated, with triangular truncation T, i.e.

$$\hat{\zeta} \quad = \quad \sum_{m=-T}^{T}\ \sum_{n=|m|}^{T} \zeta_{mn} P_{mn}(\lambda,\mu)e^{im\lambda}$$

$$\hat{D} \quad = \quad \sum_{m=-T}^{T}\ \sum_{n=|m|}^{T} D_{mn}P_{mn}(\lambda,\mu)e^{im\lambda}$$

then the derived velocity fields are

$$\hat{u} \quad = \quad \frac{1}{\cos(\phi)}\ \sum_{m=-T}^{T}\ \sum_{n=|m|}^{T+1} U_{mn}P_{mn}(\lambda,\mu)e^{im\lambda}$$

$$(30)$$

$$\hat{v} \quad = \quad \frac{1}{\cos(\phi)}\ \sum_{m=-T}^{T}\ \sum_{n=|m|}^{T+1} V_{mn}P_{mn}(\lambda,\mu)e^{im\lambda}$$

where

$$U_{m,T+1} = a\left(-\frac{1}{T+1} F_{m,T+1} \zeta_{m,T}\right)$$

$$V_{m,T+1} = a\left(\frac{1}{T+1} F_{m,T+1} D_{m,T}\right)$$

and $U_{m,T} = a\left(-\frac{1}{T} F_{m,T} \zeta_{m,T-1} - \frac{im}{T(T+1)} D_{m,T}\right)$

$$V_{m,T} = a\left(\frac{1}{T} F_{m,T} D_{m,T-1} - \frac{im}{T(T+1)} \zeta_{mT}\right)$$

It can be shown that equation (29), defining u and v, is also valid at the poles.

For any value of m, the T-m+1 coefficients $D_{mn}$ and $\zeta_{mn}$ define T-m+2 coefficients of $U_{mn}$ and $V_{mn}$, so that by elimination of D and $\zeta$ coefficients from (28), relations between U and V coefficients may be derived. In particular, when m = 0 the following relations hold:-

$$U_{o,T+1} = -\frac{1}{\sqrt{(2T+3)}} \sum_{n=\epsilon 1}^{T-1} {}^{2} \sqrt{(2n+1)} U_{on}$$

$$V_{o,T+1} = -\frac{1}{\sqrt{(2T+3)}} \sum_{n=\epsilon 1}^{T-1} {}^{2} \sqrt{(2n+1)} V_{on} \qquad (31)$$

$$U_{o,T} = -\frac{1}{\sqrt{(2T+1)}} \sum_{n=\epsilon 2}^{T-1} {}^{2} \sqrt{(2n+1)} U_{on}$$

$$V_{o,T} = -\frac{1}{\sqrt{(2T+1)}} \sum_{n=\epsilon 2}^{T-1} {}^{2} \sqrt{(2n+1)} V_{on}$$

where, if T is odd, $\epsilon 1 = 0$ and $\epsilon 2 = 1$
   and  if T is even, $\epsilon 1 = 1$ and $\epsilon 2 = 0$

At the poles, $\dfrac{P_{mn}(\phi = \pm \frac{\pi}{2})}{\cos(\phi)} = 0$ for $m > 1$

It can be shown that $\lim\limits_{\phi \to \pm \frac{\pi}{2}} \sum\limits_{n=o}^{T+1} U_{o,n} \dfrac{P_{o,n}(\phi)}{\cos(\phi)} = 0$

i.e. $\sum\limits_{n=o}^{T+1} U_{on} \dfrac{\partial P_{o,n}(\phi)}{\partial \cos(\phi)} = 0$ when $\phi = \pm \frac{\pi}{2}$

$$\sum_{n=o}^{T+1} U_{on} \frac{\partial P_{on}(\phi)}{\partial \cos(\phi)} = \sum_{n=o}^{T+1} \frac{1}{\sin(\phi)\cos(\phi)} U_{on}$$

$$\times \left[ nF_{o,n+1}P_{o,n+1} - (n+1)F_{o,n}P_{o,n-1} \right] \quad (32)$$

Substituting the relations (30) into (31) and using

$$P_{o,n} = \frac{1}{F_{mn}} (\mu P_{o,n-1} - F_{o,n-1} P_{o,n-2})$$

it can be shown that each term in (32) is proportional to $\cos(\phi)$, and thus vanishes at the poles.

So at the poles

$$u(\phi) = \sum_{n=1}^{T+1} U_{1n} \frac{P_{1n}(\phi)}{\cos(\phi)} e^{i\lambda} \quad (33)$$

$$v(\phi) = \sum_{n=1}^{T+1} V_{1n} \frac{P_{1n}(\phi)}{\cos(\phi)} e^{i\lambda}$$

## 3.    Forecast-called version

This section describes in detail the forecast-called version of the first part of the post-processing package, in the order in which it is executed. Subroutines from the forecast model are marked (M), and are described in (Haseler and Burridge, 1977).

### 3.1    Subroutine PRESET (M)

<1.1> I/O unit numbers used by the post-processing package are preset (units 15,16,17,18,19,60).

<1.6> Logical switches are set

    NLANAL = false (forecast, not analysis, data is to
            be post-processed)

    NLSTAL = false (this is the forecast-called version,
            not the stand-alone version)

### 3.2    Subroutine DATA (M)

<7.1> Call INISTP to set post-processing parameters

### 3.3    Subroutine INISTP

<1>  Call PRESTP to preset post-processing parameters with
    default values

<2>,<3>,<4> Read data cards to enable default values to be
    overridden. Fig. 3.1 describes the data cards.

<7.2> Call INITXX.  This initialises parameters used in the
    vertical interpolation from sigma to pressure levels.

<7.4> Call HAFFT.  This initialises parameters used by the
    fast Fourier transforms in the second part of the
    package.

<7.4> Call MAKEDS. Calculate coefficients $F_{mn}$ and $G_{mn}$ (defined by equation 28 of Section 2, used in the generation of u and v spherical harmonic coefficients), and store them in the arrays DD and SS from COMSH1.

<7.4> If NLCALC= true, call MAKEZZ. Generate the following functions used in the calculation of spherical harmonic coefficients:

(a) $Z_{mn}(\phi_j^T)$ – defined by equation 19 of Section 2 and given at latitudes of T grid points.

(b) $Z_{mn}^I(\phi_j^u)$, $Z_{mn}^I(\phi_j^v)$ – defined by equation 25 of Section 2, and given at latitudes of both u and v grid points.

(c) $Z_{mn}^{II}(\phi_j^u)$, $Z_{mn}^{II}(\phi_j^v)$ – defined by equation 26 of Section 2 and given at latitudes of both u and v grid points.

These functions are expensive to calculate. They depend only on the resolution of the model grid and the triangular truncation used in fitting the spherical harmonics. The first time a particular resolution and truncation are used, NLCALC should be set to true, so that these functions are calculated, and they should be saved as permanent files. Thereafter, by setting NLCALC = false, they need not be recalculated.

<7.4> If NLCALC = true, call MAKELG. Calculate Legendre functions at the latitude of the output grid, to be used in extracting fields on the output grid from their spherical harmonic coefficients. Again, these functions are expensive to calculate, and need only be made once, for any output grid resolution and triangular truncation.

<7.5> Call REORDR to rearrange the fields selected for
post-processing by the user to the order most
convenient for the second part of the post-processing
package. Section 5 describes in detail how the
fields are rearranged, and how control arrays are
constructed to describe the new order of the data.

## 3.4   Subroutine LINEMS (M)

<2.9> call SITOPR if it is a post-processing time step,
then update the pointer to the next post-processing
step.

<3.2> If post-processing is requested at the first or
second time-step of a model run, call SITOPR, then
update the pointer to the next post-processing step.

## 3.5   Subroutine SITOPR

Generate the work file which will be used as input to the
second part of the post-processing package. Section 6
contains a detailed description of the work file.

The user may select 3 types of fields to be processed:-

(a) fields on multiple levels, to be interpolated
horizontally using spherical harmonics

(b) fields on single levels, to be interpolated
horizontally, using spherical harmonics

(c) fields on single levels on the model grid, which
are not to be interpolated either horizontally or
vertically. (These will usually be surface fields.
They will be referred to in future as uninter-
polated fields).

Field types (a) and (b) are interpolated vertically from
sigma to pressure levels, if the data comes from a forecast
model. Analysis data is already on pressure levels, and
is not vertically interpolated.

<1.01>Before the first row of data has been written, update
  the parameters describing the date and time of the
  data.

<1.03>Before the first row of data has been written, write
  6 common blocks, as separate records, to the work
  file on unit NPOUT.

<1.1> Find the first field to be processed. This will be
  the first multi-level field (type (a) above) if there
  are any, or the first single level field (type (b)
  above).

<1.2> If there are no fields of type (a) or (b), the first
  field to be processed will be the first uninterpolated
  field.

<2.1> The area of blank common starting from the displace-
  ment NLINE2(2) is used as work space by SITOPR. The
  work space is laid out with fields starting at the
  following displacements:-

  (i)    IPNVP1 - the area in which fields derived at
                  the (NLEV+1) sigma half-levels are
                  stored (e.g. geopotential, part of
                  the vertical velocity).

  (ii)   IOMEG  - work space used in the calculation of
                  vertical velocity and relative humidity
                  fields

  (iii)  IPC    - work space used by the vertical inter-
                  polation routines

(iv)  IWRITE - the fields which are to be written to the work file are built up in a buffer, starting at displacement IWRITE.

<2.27> The code of the field to be processed is stored in ICODE, and the level (converted to pascals) is stored in ILEVEL.

<2.4>  The start address of the highest level of the current field is stored in IPFLD.  If the field is relative humidity, it is calculated at all the model σ-levels by subroutine RELHMF.  If the field is vertical velocity, it is processed in 2 scans, on the first scan, part of it is calculated by subroutine OMEG1.  On the second scan, the rest is calculated by subroutine OMEG2.

<3>    If the field being processed is to be interpolated vertically from sigma to pressure levels, subroutine ANALYS is called.  If cubic splines are being used to fit the data in the vertical, ANALYS uses data at all the sigma levels to calculate the coefficients of the splines, and store them in the work array IPC. For multi-level fields, ANALYS need only be called once, since the same array of coefficients in IPC can be used to extract data at any pressure level. Accordingly all the levels of a multi-level field are processed by SITOPR, before ANALYS is called again with a different field as input.  Similarly, if linear interpolation is used in the vertical, ANALYS need only be called once for each multi-level field.

<4.0>  If the field being processed is to be interpolated vertically from sigma to pressure levels, subroutine EVALUE is called to extract the data at pressure level ILEVEL, using as input the array IPC constructed by ANALYS.

<4.1> If mean sea level pressure is the field requested,
      it is calculated by subroutine SEALP.

<4.2> If the field just processed was the first scan of the
      vertical velocity, the second scan is initiated.

<4.3> If the field just processed was the second scan
      of the vertical velocity, the 2 parts are added
      together.

<4.4> If the field just processed was the relative humidity,
      any values calculated to be greater than 100% are
      reduced to 100%.

<4.7> If the field currently being processed is an uninter-
      polated field, of type (c), it is copied straight into
      the output buffer.

<5.1> The next field to be processed is found. The fields
      are processed by SITOPR in the order

      (i)     all levels of first multi-level field (type a)

      (ii)    all levels of next multi-level field

                    . . . . .

      (iii)   all single-level fields (type b)

      (iv)    all uninterpolated fields (type c)

      The fields are stored on the work file in the order
      most convenient for the second part of the post-
      processing package, which is:-

      (i)     all multi-level fields at first level

      (ii)    all multi-level fields at next level

                    . . . . .

(iii)   all single level fields.

(iv)    all uninterpolated fields.

<5.4> When all the fields for the current row have been
      built up in the output buffer, they are written to
      the work file on unit NPOUT.

## 4. Stand-alone version

The stand-alone version of the first part of the post-processing package may take as input an analysis file, or a forecast history file at a single time level, or 2 fore-case history files at adjacent time levels (the second history file is required for certain physics diagnostics fields). Much of the code used by the forecast-called version is also used by the stand-alone version, but the main differences are outlined below.

### 4.1 Subroutine OUTPAC(KIN,KOUT,KCARD,KPRINT)

The stand-alone version is invoked by calling OUTPAC, with the arguments

> KIN = unit number of input analysis or forecast file (if there are 2 forecast files, then time T will be on unit KIN and time T+1 on unit KIN+1)

> KOUT = unit number of output work file

> KCARD = unit number of card input

> KPRINT = unit number of print output

<1.1> Read a data card to determine the number and type of input file(s), where the card has the format (9X,1R1,I10), and

> F in column 10 means an analysis file

> T in column 10 and 1 in column 20 means 1 forecast history file

> T in column 10 and 2 in column 20 means 2 forecast history files

<1.2> For an analysis file, skip the first record, which is a file descriptor record.

<1.3> Read the first data descriptor record. For an
analysis file, call DDANAL to construct the fore-
cast model's common block COMHKP.

<1.4> Call INISDS to construct the forecast model's
common block COMSDS (mainly with dummy variables).

<1.5> Initialise various common variables, including in
particular NLINE1 and NLINE2 which define the dis-
placements of the I/O buffers, so that the addresses
of fields may be built up in the same way in sub-
routine SITOPR for both the forecast-called and
stand-alone versions.

<1.8> Call INISTP (as in Section 3.3) to initialise the
post-processing parameters.

<2.1> Scan from north to south, reading the data. The
input buffers are cycled in the same way as those
for the forecast model, i.e.

NLINE1(1) = start address of row NROW-1, to the
north of the current row

NLINE1(2) = start address of current row, NROW

NLINE1(3) = start address of row NROW+1, to the
south of the current row

NLINE1(4) = start address of row NROW+2, 2 rows
to the south of the current row. The
read for the data of this row is over-
lapped with the processing of the data
for row NROW.

<2.3> Call SITOPR to construct the output work file record
for row NROW.

## 4.2    Subroutine SITOPR

If a forecast file (or 2 forecast files at adjacent time levels) is being processed, then SITOPR is executed as described in Section 3.5.  Analysis fields are given initially on pressure levels, so that fields which are to be fitted by spherical harmonics do not have to be vertically interpolated as well.  For an analysis file, the following separate code is executed:-

<7.1>,<7.2>  Find the displacement of the highest level of the field selected (analysis files are arranged in a different order to forecast files)

<7.3> Except for surface fields, the displacement of the level selected is found.

<7.5> The field is copied to the output buffer, with a spare word before the first word, and a spare word after the last word.  Although the input analysis data is not wrapped, analysis fields on the work file now occupy the space which they would need if they were wrapped.

<7.6> Surface pressure is converted to pascals.  Forecast pressures are held in pascals, while analysis files store pressures in millibars.

<7.6> If the field selected was relative humidity, it is generated by subroutine RELHMA.

## 5.    Reordering fields

The method used to fit spherical harmonics to the velocity
fields is first to fit the divergence and vorticity fields,
using grid point values of both u and v, and then to derive
the u and/or v coefficients from the divergence and vorticity
coefficients.  This means that if any of u, v or vorticity
is selected for post-processing, then both u and v (but
not vorticity) must be written to the work file.  As a
result, there are not necessarily the same number of fields
on the work file as there are on the output post-processing
files which are to be sent to the Cyber.

The fields are classified as 'velocity' fields (u, v or
vorticity) or 'scalar' fields (all other field types).  They
are not necessarily processed in the order given by the user,
but may be reordered to simplify the control of the fitting
of the spherical harmonics.  The work file contains first
the fields on multiple levels, which are to be fitted with
spherical harmonics;  then the fields on single levels
which are to be fitted with spherical harmonics;  then the
uninterpolated fields.  The multi-level fields are stored
by level on the work file, i.e. with first all the fields
at the first level, then all the fields at the second level,
and so on.  The fields at each level are reordered so that
all the scalar fields come at the beginning, followed by
all the velocity fields.  The single-level fields are also
reordered, with first all the scalar fields, then all the
velocity fields.  The uninterpolated fields are not reordered,
but are stored in the order requested by the user.

The routines which fit the spherical harmonics have to
decide how many fields may be fitted at the same time in
the space available.  To do this, the fields are split into
groups, described by the control array NPTAR.  NPTAR(1)
contains the number of groups (if NPTAR(1) = 0, there are
no fields to be fitted by spherical harmonics, just uninter-
polated fields to be processed).  A 'group' consists of

NPLEV levels of data, with each level containing NSCAL scalar fields and NVEL input velocity fields.  To describe the $N^{th}$ group,

NPTAR (3*N-1) = NSCAL, the number of scalar fields
                at each level

NPTAR (3*N)   = NVEL, the number of velocity fields
                on the input work file at each level
                (either NVEL = 0 if there are no
                velocities in the $N^{th}$ group

                or     NVEL = 2 (both u and v are on
                the input work file) )

NPTAR (3*N+1) = NVELO, the number of velocity fields
                to be output to the post-processing
                files at each level
                (where NVELO = 0 means no velocities
                       NVELO = 1,2, or 3 for any or
                all of u, v and vorticity)

The first group contains the multi-level fields.  The next group (or first group, if there are no multi-level fields) contains all the scalar single-level fields, plus the first single-level velocity field (if there are any).  There is a group for each remaining single-level velocity field. If NPLEV is the number of levels of data in each group, then NPLEV=1, unless the group contains the multi-level fields, when  NPLEV = NMLV (where NMLV is the number of levels at which multi-level fields are to be processed).

Section 8 describes in detail how NOLV, the number of levels of data within a group which may be fitted in a single scan, is calculated.  At least one scan is required to fit all the fields within a group, and if NOLV < NPLEV, several scans are required.

Several control arrays are built up in subroutine REORDR to describe the reordered data. MHAIN(200) describes the contents of the work file, in the form most convenient for the spherical harmonic fitting routines. It contains the field codes for all the groups in the order

(i)     codes for scalar fields in first group

(ii)    codes for velocity fields in first group

.  .  .  .

(iii)   codes for scalar fields in $n^{th}$ group

(iv)    codes for velocity fields in $n^{th}$ group

.  .  .  .

If a group contains fields at more than one level, the codes are not repeated in MHAIN.

MHAOUT(200) describes the fields which have been fitted by spherical harmonics, and are to be sent to the Cyber on a post-processing output file. Like MHAIN, it contains the field codes for scalar and velocity fields within each group, without repetition for fields held at more than one level. The only difference between MHAIN and MHAOUT is that the velocities on the input work file may not be the same as those on the output post-processing file.

NCL(2,200) is the control array used on the Cyber to determine the contents of the output post-processing file which contains fields fitted by spherical harmonics.

NCL(1,J)   =   code of $J^{th}$ field

NCL(2,J)   =   level of $J^{th}$ field (in mb * 10)

If fields are repeated at several levels, then they have several entries in NCL.

NCLIN(2,200) is a control array which is not used by the post-processing package, but has been added so that other programs may more easily determine the contents of the work file.

$$\text{NCLIN}(1,J) = \text{code of } J^{th} \text{ field on work file}$$

$$\text{NCLIN}(2,J) = \text{level of } J^{th} \text{ field on work file.}$$

If fields are repeated at several levels, then they have several entries in NCLIN.

The uninterpolated fields are described by the array NGPCL(2,20), where

$$\text{NGPCL}(1,J) = \text{code of } J^{th} \text{ field}$$

$$\text{NGPCL}(2,J) = \text{level of } J^{th} \text{ field}$$

## 6. The post-processing work file

The work file has 6 records containing common blocks,
followed by a data record for each row. The contents of
all the common blocks are described in Section 10. The
common blocks are:-

    (i)    COMHKP,  of length 925 words

    (ii)   COMSDO,  length 34 words

    (iii)  COMGPH,  length 45 words

    (iv)   COMSHH,  length 415 words

    (v)    COMSH1,  length 8715 words

    (vi)   COMHDO,  length 16 words.

There follow NOREC records, each of length (MFDIN+N2D)*NLP2,
where        NOREC (from COMHKP) = number of latitude  rows

           MFDIN (from COMSH1) = number of fields to be
                                    fitted by spherical harmonics

           N2D (from COMGPH)   = number of uninterpolated
                                        fields
           NLP2 (from COMHKP) = size of a wrapped field of
                                    data (number of longitude
                                    points + 2)

If (MFDIN+N2D) ≥ 4, the work file is split into 4 separate
files, which are positioned on disks controlled by 4
different disk controllers, to improve I/O transfer rates.
In this case, the first file contains the 6 common blocks,
followed by NOREC records of length ((MFDIN+N2D)/4)*NLP2,
(i.e. the first (MFDIN*N2D)/4 fields), (NB this is an
'integer divide' by 4). The second and third files contain
NOREC records of length((MFDIN+N2D)/4)*NLP2. The fourth
file contains NOREC records of length

    ((MFDIN+N2D) - 3*((MFDIN+N2D)/4))*NLP2

(i.e. the remaining fields).

If the first file is on unit NPOUT, then the second, third and fourth files will be on units NPOUT+1, NPOUT+2 and NPOUT+3 respectively.

When the data is read back in the second part of the post-processing package, only the fields needed for a particular scan are read, so that all 4 sections of the work file do not necessarily have to be read in every time. This is possible because the data is stored on the work file in the order in which it is used by the second part of the post-processing package, rather than the order in which the work file is built up by the first part.

Each data record contains MFDIN fields which are to be fitted by spherical harmonics (described by the control array NCLIN, see Section 5), followed by N2D uninterpolated fields (described by the control array NGPCL, also defined in Section 5).

The file is read using BUFFER IN.

## 7.    The second part of the post-processing package

The second part of the post-processing package is a
separate job which takes as input the work file generated
by the first part, and the constants files created by
MAKEZZ and MAKELG (see Section 3.3), and produces 3 types
of output file, described in Section 9.

### 7.1    Subroutine HACNTL

The second part of the post-processing package is invoked
by calling HACNTL.

<1.01> Read from a data card with format I10 the unit number,
       NPOUT, of the work file (or the first file, if it
       has been split into 4 parts).  This should be the
       same as was used to create the work file.

<1.01> Read the 6 common blocks from the start of NPOUT.

<1.03> Initialise the creation data and time for the output
       files.  Convert the date in COMHKP for forecast
       files from century days to the form $YY*10^4+MM*10^2+DD$.
       This format is already used by analysis files.

<1.3>  Call SPANAL to decide how many fields may be processed
       in the current scan.  See Section 8 for a detailed
       description of the layout of the fields, and the
       algorithms used to decide how many fields may be
       processed in each scan.

<2.1>  Call DISINI to initialise the arrays NDISGR and
       NDISSH (from COMSH2) containing the displacements
       in blank common of the input grid-point fields and
       spherical harmonic coefficients respectively for the
       current scan.  The displacements are given for
       complex fields, since complex arithmetic is used in
       the calculation of the spherical harmonic coeffic-

ients.  The variable NDIS2D, which defines the real
(i.e. not complex) displacement in blank common
of the start of the buffer for building up uninter-
polated fields for output, is also defined.

<2.2>  A work file record (or 4 records, if the file has
been split into 4 parts ) contains all the fields
for a single row.  The fields which are being proc-
essed in the current scan are wanted at all rows.
Accordingly, for each row from north to south, a
work file record (or records) is read, and the
fields to be processed are copied into the area in
which complete fields are being constructed.  If
the work file has been split into 4 parts, only the
parts containing data for the current scan are read.

<2.4>  The velocity fields are multiplied by cos(latitude),
since it is U = ucos(lat) and V = vcos(lat) which
are used to derive the divergence and vorticity
spherical harmonic coefficients.

<2.7>  If uninterpolated fields are to be processed in this
scan, they are copied from the buffer containing
the work file record for the current row into the
area in which the complete fields are being con-
structed.

<2.8>  If both uninterpolated fields and fields fitted by
spherical harmonics are being processed in the
current scan, subroutine OUT2D is called to output
the complete uninterpolated fields, before the space
they occupy is overwritten by the work space for
the fast Fourier transform.  See Section 9 for a
detailed description of the output file for the
uninterpolated fields.

<3.1> Subroutine FFT99 is called to do a 'half-complex'
fast Fourier transform for each of the complete
input grid point fields of the current scan.
(See equation 5 of Section 2).

<3.11> For forecast data, the Fourier coefficients for the
U-velocities have been generated from data which
is staggered in the east-west direction. The
corresponding 'unstaggered' coefficients are
calculated using

$$U_m^u = e^{-\frac{im\Delta\lambda}{2}} U_m^S$$

where $\Delta\lambda = \dfrac{2\pi}{NLON}$

$U_m^u$ = unstaggered $n^{th}$ coefficient (complex)

$U_m^S$ = staggered $n^{th}$ coefficient (complex)

<3.2> Subroutine SYMASY is called to calculate the
symmetric and antisymmetric parts of the Fourier
fields (see equation 6 of Section 2). The Fourier
coefficients for each field occupy NOREC rows of
length NLP2, but space is available for NOREC+1 rows.
If NPE = NOREC/2+1, then the symmetric parts of
the fields are stored over rows 1 to NPE, and the
antisymmetric parts over rows NOREC+1 to NPE+1.
For forecast model data, v is given on rows staggered
in the north-south direction, so that one row
less of data is available. The symmetric parts
of the V field are stored over rows 1 to NPE-1,
and the antisymmetric parts are stored over rows
NOREC+1 to NPE+2.

<4.1> Subroutine SHCOEF is called to calculate the spherical harmonic coefficients for scalar fields (see equation 18 of Section 2). If velocity fields are to be fitted, SHCOEF calculates the divergence and vorticity coefficients (see equations 23 and 24 of Section 2).

The functions $Z_{mn}(\phi_j^T), Z_{mn}^I(\phi_j^u), Z_{mn}^{II}(\phi_j^u), Z_{mn}^I(\phi_j^v), Z_{mn}^{II}(\phi_j^v)$

where $\phi_j^T$ = latitude of T grid points

$\phi_j^u$ = latitude of u grid points

$\phi_j^v$ = latitude of v grid points

are read from unit NZFILE. For each value of m, n, there is a record containing the 5 functions defined at latitudes from the pole to the equator. The functions are given in the order for the summation

$$\sum_{m=o}^{NTIN} \sum_{n=m}^{NTIN}$$ , where NTIN is the triangular truncation

used to fit the spherical harmonics.

<4.2> If velocity fields are being fitted with spherical harmonics subroutine UVCOEF is called to calculate the u and v coefficients from the divergence and vorticity coefficients. (See equations 29 and 30 of Section 2).

<5.1> Subroutine SHTOLL is called to extract the fields on the output grid, and write them to unit NGPOUT. It is described more fully in Section 7.2

<6> Find out which fields are to be processed in the next scan. Call REPOS to reposition the work file (or 4 work files) at the first data row.

<6.1> If NOLV = 0, i.e. there is insufficient space to
     process all the fields at a single level simultaneously,
     process the next set of scalar or velocity fields at
     the current level.

<6.2> If NOLV > 0 and all the levels in the current group
     have not yet been processed, do the next set of
     NOLV levels.  If NOLV = 0 and all the fields at the
     current level have been processed, do the first set
     of NSC scalar fields at the next level.

<6.3> If all NPLEV levels of the current group of fields
     have been processed, start to do the next group of
     fields.

<7.1> If all the fields to be fitted by spherical harmonics
     have been processed, do the uninterpolated fields,
     in batches of N2D1 fields at a time.  Subroutine
     OUT2D is called to write the uninterpolated fields
     to unit N2DOUT.

7.2    Subroutine SHTOLL

From the spherical harmonics, subroutine SHTOLL extracts
fields on the regular, unstaggered output latitude/longitude
grid.

<2.1> For each latitude row of the output grid, the Legendre
     functions $P_{mn}(\phi)$ are read from unit NNLEG.  There is
     one record for each row, ordered from north to south,
     and the Legendre functions are stored in the order
     corresponding to the summation

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

<2.15> Subroutine POLARV is called to calculate the Fourier
      coefficients of the velocities at the poles, using

equation 33 of Section 2.

<2.2> For all fields except velocities, equation 8 of
Section 2 is used to calculate the Fourier coefficients
at each latitude of the output grid.

<2.3> The Fourier coefficients of the velocity fields are
calculated, using equation 30 of Section 2.

<2.6> Subroutine FFT99 is called to perform an inverse
Fourier transform and extract the entire field on the
output grid.

<2.7> The velocity fields extracted by this process have
been $U = u\cos(\phi)$ or $V = v\cos(\phi)$. u or v can be cal-
culated by dividing the appropriate field by $\cos(\phi)$.

<3.1> Subroutine OUTSHG is called to pack the field on the
output grid, and write it to unit NGPOUT, in the
format described by Section 9.

<3.2> If spherical harmonic coefficients are to be sent to
the Cyber, subroutine OUTSHC is called to write them,
in the format described by Section 9, to unit NSHOUT.

## 8. Space control for the second part of the post-processing package

Knowing NSPACE, the length of blank common available as work space, the number of fields which may be fitted with spherical harmonics in a single scan is calculated in subroutine SPANAL. On the input work file, the data is held in line form, but to fit spherical harmonics to a field, it must be converted to field form (i.e.all the rows must be held in core).

The input latitude/longitude grid has dimensions

NLP2 (number of longitude points + 2)

NOREC (number of latitude rows)

Space for an extra row of data is needed during the calculations, so that the input grid point field needs space NLP2*(NOREC+1).

If spherical harmonics are to be fitted with triangular truncation NTIN, then the spherical harmonic coefficients need space (NTIN+1)*(NTIN+2)

If the output grid has dimensions

NLONO (number of longitude points)

NLATO (number of latitude rows)

then the output grid point field needs space (NLONO+2)*NLATO.

To fit velocity fields with spherical harmonics, both u and v must be held on the input grid, and the spherical harmonics for divergence, D, and vorticity $\zeta$ , must be stored, as well as those for u and v. The divergence and vorticity spherical harmonic coefficients each need space (NTIN+1)*(NTIN+2), while the u and v coefficients each need space (NTIN+1)*(NTIN+4).

If there are NSCAL scalar fields and NVEL velocity fields
at each level, the program calculates NOLV, the number of
levels of data which may be processed in a single scan.
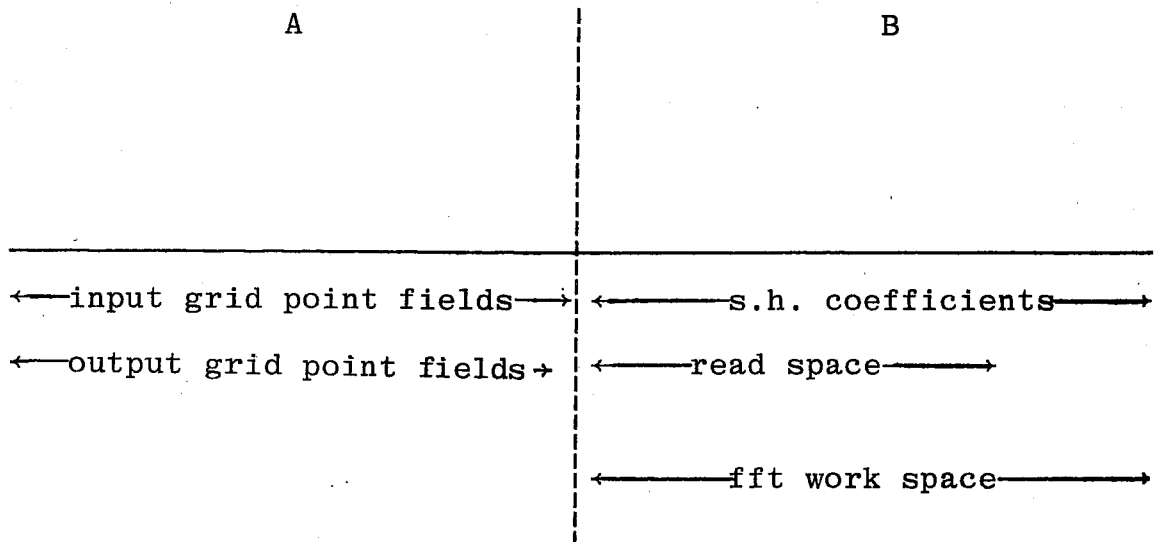


Fig. 8.1

Fig. 8.1 shows how various fields share the work space.
Section A has the length of the maximum of:-

(i)    space needed by NOLV*(NSCAL+NVEL) input grid
       point fields = NOLV*(NSCAL+NVEL)*NLP2*(NOREC+1)

(ii)   space needed by 1 output grid point field + the
       workspace for the fast Fourier transform for the
       output data = 2*NLATO*(NLONO+2)

Section B has the length of the maximum of:-

(i)    space needed by the spherical harmonic coeff-
       icients for NOLV*NSCAL scalar fields and
       NOLV*NVEL velocity fields
       = NOLV*SCAL*(NTIN+1)*(NTIN+2)
         + NOLV*NVEL*((NTIN+1)*(NTIN+2)+(NTIN+1)*
           (NTIN+4) )

(ii)   space to read in 2 lines of data
       = NLP2*(MFDIN+N2D)*2 .

where        MFDIN = number of fields to be fitted with
                     spherical harmonics

             N2D   = number of uninterpolated fields

(iii) work space for fast Fourier transforms for
      input data

      = NLP2*NOREC

Given that A+B ≤ NSPACE, NOLV can be calculated.

If NOLV = 0, then it is not possible to do all of the
fields at a single level in the same scan. If there is
insufficient space to do all the velocities at a single
level in the same scan, the program terminates with an
error message. Otherwise NSC, the number of scalar fields
at a single level which can be done in a single scan,
is calculated. Then for the first level, all the scalar
fields are processed, with NSC (or a remainder < NSC) per
scan, followed by a scan for the velocity fields (if there
are any). This  repeated for the second and subsequent
levels.

If NOLV ≥ NPLEV, the total number of levels to be processed,
there is a test to see if there is sufficient space to
also process all of the uninterpolated fields in the same
scan. If so, they are built up beyond the longest of B(i)
and B(ii). Otherwise the uninterpolated fields are done
after all the fields to be fitted by spherical harmonics
have been processed. Each field needs space of length
NLP2*NOREC, and the space available after 2 lines of data
have been read in is

     NSPACE-(2*NLP2*(MFDIN+N2D))
so the number of uninterpolated fields which can be done in
each scan is

     N2D1 = (NSPACE-2*NLP2*(MFDIN+N2D))/NLP2*NOREC

## 9. Format of the output files

Three different types of output file may be produced by the post-processing package:-

a) fields interpolated using spherical harmonics to a regular unstaggered latitude/longitude grid

b) spherical harmonic coefficients

c) uninterpolated fields on the model grid.

Each file has 3 data description records, followed by a data record for each field. The data description records are converted from Cray to Cyber format, but not packed before being written out. The first 2 data description records are the same for all 3 file types. The first record is the common block COMHKP, described in Section 10.1, which contains information describing the initial model or analysis data - its horizontal grid, vertical structure, date and time, etc. The second data description record is the common block COMSDO, described in Section 10.2. If the post-processing package was called during a forecast model run, then COMSDO contains parameters describing the model options selected for the particular run - such as the time step, the physics version or the tuning parameters. If the stand-alone version of the first part of the package was used, then COMSDO contains default values. The third data description record is different for each of the 3 file types. It contains sufficient information to describe the fields output, their horizontal grids, vertical levels and any parameters used for interpolation.

For file type (a), the third data descriptor record contains words 1→406 and 409→415 of common block COMSHH, described in Section 10.4. For file type (b), the third data descriptor record contains words 1→408 of common

block COMSHH. For file type (c), the third data descriptor
record is common block COMGPH, described in Section 10.3.

Each data record contains a field of data, preceded by a
preliminary array. The entire data record, including the
preliminary array, is packed with 4 15-bit integers per
word. The preliminary array is the common block COMHDO,
see Section 10.7. For grid point data on files of type (a)
and (c), the data is ordered in rows from north to south,
and from west to east within the rows. The rows of data
are unwrapped, i.e. they do not have extra points before
the first longitude point, or after the last point.

For file type (c), and triangular truncation NTOUT, the
coefficients

$$\sum_{m=0}^{NTOUT} \sum_{n=m}^{\alpha} (\psi_{mn}^{real} + \psi_{mn}^{imaginary})$$

(where $\alpha$ = NTOUT for all fields except velocities

  $\alpha$ = NTOUT+1 for velocity fields)

are stored in the order

$$\psi_{00}^{I}, \ \psi_{01}^{R}, \ \psi_{01}^{I}, \ \psi_{02}^{R}, \ \psi_{02}^{I}, \cdots \psi_{0\alpha}^{R}, \psi_{0\alpha}^{I}, \ \psi_{11}^{R}, \ \psi_{11}^{I}, \cdots \psi_{1\alpha}^{R}, \ \psi_{1\alpha}^{I}, \cdots$$

$$\psi_{NTOUT,\alpha}^{R}, \ \psi_{NTOUT,\alpha}^{I}$$

$\psi_{00}^{R}$, which represents the mean value of the field, is stored
in the preliminary array, for reasons concerning the
accuracy of the packing method, described below.

### 9.1 Packing routines

(i)   Subroutine MAXMING searches all the values of a data
      field for the maximum (ZMAX) and minimum (ZMIN) values.

(ii) Subroutine CODEREA is called to store ZMIN as 3 15-bit integers in words 9, 10 and 11 of the preliminary array (see Section 10).

The algorithm used is

$$ZMIN = (K1*2^{15} + K2)*(10**\ AND\ (K3,17777B)\ )$$

where K1, K2 and K3 are words 9, 10 and 11 respectively. The sign of ZMIN is held in bit 15 of K3, and the sign of the exponent is held in bit 14 of K3.

(iii) The scaling factor, ZSCAL, is calculated, where

$$S = (u-ZMIN)*ZSCAL \text{ with } S = \text{scaled integer}$$
$$u = \text{unscaled real data element}$$

If negative numbers could be packed, the method would be

$$IN = INT(\log_2(ZMAX-ZMIN) + \varepsilon) \text{ where } \varepsilon = \text{machine}$$
precision

$$ZSCAL = 2^{(14-IN)}$$

so
$$S = \frac{(u-ZMIN).2^{14}}{2^{IN}}$$

and
$$S < 2^{15} \text{ since } \frac{u-ZMIN}{2^{IN}} < 2$$

To keep IN (the integer stored in word 12 of the preliminary array) positive, the equations are shifted:-

$$IN = INT\ (\log_2(ZMAX-ZMIN) + \varepsilon + 16385)$$

$$ZSCAL = 2^{(16399-IN)}$$

so
$$-2^{14}-1 \leqslant \log_2(ZMAX-ZMIN) < 2^{14}-1$$

(iv) The data field is scaled, using

$$S = (u-ZMIN)*ZSCAL$$

giving scaled integers in the range $0 \leqslant S < 2^{15}$.

(v)   Subroutine IPACK4 is called, to pack the preliminary
      array and the data record, with the lowest 15 bits
      of 4 positive Cray integers packed into the lowest
      60 bits of each Cray word. (It is because the
      preliminary array is packed, with each word to be
      represented by a 15-bit integer that levels are held
      in the non-standard units of pascals/10. 15 bits is
      not usually sufficient to represent low-level
      pressures in pascals).

For packing spherical harmonic coefficients, the real
(m=o, n=o) 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=o, n=o) coefficient, their variation can
be more accurately represented. Subroutine CODEREA (see (ii)
above) is called to store the real (m=o, n=o) coefficient
in words 13, 14 and 15 of the preliminary array.

## 10. Common blocks

### 10.1 COMHKP - input data parameters

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|---|---|---|---|---|---|---|---|
| 1 | I | NSIZDD | length of first data descriptor record, in words | DATCOM or OUTPAC or DDANAL | 925 | – | – |
| 2 | I | NPRELD | length of preliminary array, in words | " | 24 | – | – |
| 3 | I | NSZDD2 | length of next data description record | " | 0 | HACNTL | 35 |
| 4 | I | MAXSIZ | length of maximum data record size | " | input grid dependent | OUT2D,OUTSHC OUTSHG | output grid dependent |
| 5 | I | NFRECD | record number of first data record | " | 2 | HACNTL | 4 |
| 6 | I | NCRDAT | creation date of output files | " | data dependent | HACNTL | actual date |
| 7 | I | NCRTIM | creation time of output files | " | " | HACNTL | actual time |
| 8 | I | NDTYPE | data type | " | 1 | OUT2D,OUTSHC, OUTSHG | 2 for grid point fields 12 for spherical harmonic coefficients |
| 9 | I | NOREC | number of latitude rows of input grid | " | grid dependent | – | – |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|------|------|------|---------|---------------|---------------|-----------------|-----------|
| 10 | I | NTIMST | number of seconds/ common time unit (ctu) | DATCOM or OUTPAC or DDANAL | data dependent | INISTP, DATCOM | INT((TWODT+0.5)/2) |
| 11 | I | NCDATA | date of data on output file | " | " | DATCOM, SITOPR, HACNTL | format YYMMDD |
| 12 | I | NTDATA | time of data on output file ( ctu's from midnight) | " | " | DATCOM, SITOPR | |
| 13 | I | NCBASE | data of initial fore- cast or analysis data | " | " | HACNTL | format YYMMDD |
| 14 | I | NTBASE | time of initial fore- cast or analysis data (ctu's from midnight) | " | " | – | – |
| 15 | R | ANORTH | north-west latitude of input grid (degrees) | " | " | – | – |
| 16 | R | WEST | north-west longitude of input grid | " | " | – | – |
| 17 | R | SOUTH | south-east latitude of input grid | " | " | – | – |
| 18 | R | EAST | south-east longitude of input grid | " | " | – | – |
| 19 | R | GRIDEG | east-west resolution of input grid (degrees) | " | " | – | – |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|------|------|------|---------|---------------|---------------|-----------------|-----------|
| 20 | I | NLP2 | number of longitude points +2 of input data | DATCOM or OUTPAC or DDANAL | data dependent | – | – |
| 21 | I | NVECT | number of fields in input data file | " | | – | – |
| 22 | I | NCHAR | location of character description section (word number) | " | 25 | – | – |
| 23 | I | NUSER | location of user area | " | | – | – |
| 24 | I | NDDNUM | record number | " | 1 | – | – |
| 25–724 | H | CHARS(700) | character description of initial data | " | data dependent | – | – |
| 725 | I | ILEV | number of vertical model levels in following words | " | for a forecast model with NLEV $\sigma$-levels, and NLEV+1 intermediate levels, ILEV=2*NLEV+1. For an analysis file with NLEV pressure levels, ILEV=NLEV | – | – |
| 726 | I | IVTYPE | type of vertical coordinate system of initial data | " | forecast files – IVTYPE=2($\sigma$- levels) analysis files – IVTYPE=1 (pressure levels) | – | – |
| 727 | R | USER(3) | value of top level | " | $\sigma_{\frac{1}{2}}$ (forecast file) or $P_1$ (analysis file) | – | – |
| 728 | R | USER(4) | value of 2nd level | " | $\sigma_1$ or $P_2$ | – | – |
| 729 | R | USER(5) | value of 3rd level | " | $\sigma_{1\frac{1}{2}}$ or $P_3$ | – | – |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|------|------|------|---------|---------------|---------------|-----------------|-----------|
| 726+ ILEV | R | USER (2+ILEV) | value of lowest level | DATCOM or OUTPAC or DDANAL | $\sigma_{NLEV+\frac{1}{2}}$ or $P_{NLEV}$ | - | - |
| 727+ ILEV- NSIZDD | | | spare | | | | |

10.2 COMSDO - Second data descriptor record for output files

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|---|---|---|---|---|---|---|---|
| 1 | I | MSZSDO | length of second data descriptor record, in words | PRESTP | 34 | - | - |
| 2 | I | MPRSDO | length of preliminary array | " | 34 | - | - |
| 3 | I | MNXSDO | length of next data descriptor record | " | 413 | OUT2D or OUTSHG or OUTSHC | 45 or 413 or 418 depending on output file type |
| 4 | L | MLPHYS | switch for physics in model | " | depends on model run (false for stand-alone version) | - | - |
| 5 | L | MLSIMP | switch for semi-implicit scheme | " | " | - | - |
| 6 | L | MLVTMP | switch for virtual temperature | " | " | - | - |
| 7 | L | MLHEM | switch for hemispheric version | " | " | - | - |
| 8 | L | MLPHEC | switch for ECMWF physics | " | " | - | - |
| 9 | L | MLRDEC | switch for ECMWF radiation | " | " | - | - |
| 10 | L | MLKUO | switch for Kuo convection scheme | " | " | - | - |
| 11 | L | MLEVAR | switch for evaporation of rain | " | " | - | - |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|------|------|------|---------|---------------|---------------|-----------------|-----------|
| 12 | L | MLNRAD | switch for radia-tion | PRESTP | depends on model run (false for stand-alone version) | - | - |
| 13 | L | MLCLD | switch for cloud para-meterisation | " | = | - | - |
| 14 | L | MLDIUR | switch for diural variation | " | = | - | - |
| 15 | L | MLSDFM | switch for horiz-ontal diffusion (type 1) | " | = | - | - |
| 16 | L | MLD2D4 | switch for horiz-ontal diffusion (type 2) | " | = | - | - |
| 17 | L | MLHDIF | switch for horiz-ontal diffusion ( type 3) | " | = | - | - |
| 18 | L | MLSPFL | space filter-filter dynamics tendencies only | " | = | - | - |
| 19 | L | MLSPCH | space filter-chop dynamics tendencies only | " | = | - | - |
| 20 | L | MLTFCH | space filter-total field chopping | " | = | - | - |
| 21 | L | MLTFFI | space filter-total field filtering | " | = | - | - |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|---|---|---|---|---|---|---|---|
| 22 | L | MLTTCH | space filter-total tendency chopping | PRESTP | depends on model run (false for stand-alone version) | – | – |
| 23 | L | MLTTFI | space filter-total tendency filtering | " | " | – | – |
| 24 | I | MNRAD | frequency of radiation time steps | " | (0 for stand-alone version) | – | – |
| 25 | R | CTWODT | 2*time step (seconds) | " | " | – | – |
| 26 | R | CEPS | time smoothing constant | " | " | – | – |
| 27 | R | CCTHO | cos(latitude boundary for space filter) | " | " | – | – |
| 28 | R | CCRITT | critical relative humidity for condensation scheme | " | " | – | – |
| 29 | R | CLASYM | mixing length parameter | " | depends on model run (0 for stand alone version) | – | – |
| 30 | R | CTPER | period for soil-heat transfer | " | " | – | – |
| 31 | R | CTDIF | diffusion coefficient for soil processes | " | " | – | – |
| 32 | R | CSSAT | soil-water saturation value | " | " | – | – |
| 33 | R | CZK | horizontal diffusion coefficient | " | " | – | – |
| 34 | I | MRCSDO | record number | " | " | – | – |

## 10.3 COMGPH - 3rd data descriptor record for uninterpolated fields

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|------|------|------|---------|---------------|---------------|-----------------|-----------|
| 1 | I | MSIZR2 | length of data descriptor record | PRESTP | 45 | - | - |
| 2 | I | MSIZP2 | length of preliminary array | " | 45 | - | - |
| 3 | I | MSIZD2 | length of first data record | " | -(NLON*NOREC+MPRELO) | - | - |
| 4 | I | N2D | number of uninterpolated fields | " | 0 | INISTP | user defined |
| 5-44 | I | NGPCL (2,20) | NGPCL(1,J)=code*of $J^{th}$ uninterpolated field<br><br>NGPCL(2,J)=level of $J^{th}$ uninterpolated field ( either pascals/10 or - 100 (surface) or - 200 (mean sea level) ) | " | 0,0 | INISTP | user defined |
| 45 | I | MREC2D | record number | " | 3 | - | - |

* The following field codes are used:-

| | | | |
|---|---|---|---|
| 1 = geopotential | 2 = temperature | 3 = u-velocity | 4 = v-velocity |
| 5 = humidity mixing ratio | 6 = surface pressure | 7 = vertical velocity | (8 - not available) |
| 9 = precipitable water content | 10 = vorticity | 11 = surface temperature | 12 = soil wetness |
| 13 = snow depth | 14 = large scale rain | 15 = convective rain | 16 = snow fall |
| 17 = boundary layer dissipation | 18 = surface sensible heat flux | 19 = surface latent heat flux | 20 = surface stress |
| 21 = surface net radiation | 22 = net radiation at top | 23 = diagnostics - 1 | 24 = diagnostics - 2 |
| 25 = diagnostics - 3 | 26 = diagnostics - 4 | 27 = diagnostics - 5 | 28 = height |
| 29 = relative humidity | | | |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|------|------|------|---------|---------------|---------------|-----------------|-----------|
| 410 | I | NLONO | number of longitude points in output grid | PRESTP | NLON | INISTP | user defined |
| 411 | R | GNLAT | latitude of north-west corner of output grid (degrees) | " | ANORTH | " | " |
| 412 | R | GNLON | longitude of north-west corner of output grid | " | WEST | " | " |
| 413 | R | GSLAT | latitude of south-east corner of output grid | " | SOUTH | " | " |
| 414 | R | GELON | longitude of south-east corner of output grid | " | EAST | " | " |
| 415 | I | MRECSG | record number for grid-point fields output file | " | 3 | - | - |

10.5 COMSH1 - output package parameters

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|---|---|---|---|---|---|---|---|
| 1 | I | NLNSH1 | length of COMSH1 | PRESTP | 8715 | - | - |
| 2 | I | NPOUT | unit number of work file | PRESET, OUTPAC | 60 (forecast-called version)or KOUT (stand alone version) | HACNTL | - |
| 3 | I | NZFILE | unit number of first spherical-harmonic constants file | " | 15 | - | - |
| 4 | I | NNLEG | unit number of file containing Legendre functions at output grid latitudes | " | 16 | - | - |
| 5 | I | NGPOUT | unit number of output file containing grid point fields interpolated using spherical harmoncs | " | 17 | - | - |
| 6 | I | NSHOUT | unit number of output file containing spherical harmonic coefficients | " | 18 | - | - |
| 7 | I | N2DOUT | unit number of output file containing uninterpolated fields | " | 19 | - | - |
| 8 | I | NPSTEP | forecast step at which output package is next to be called | PRESTP | -2 | INISTP, LINEMS | NPWTIM(NPPTR) |
| 9-208 | I | NPWTIM (200) | all forecast steps at which output package is to be called | " | -2 | INISTP | user defined |
| 209 | I | NPPTR | pointer to current element of NPWTIM | " | 0 | INISTP, LINEMS | NPPTR=NPPTR+1 |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|---|---|---|---|---|---|---|---|
| 210 | I | NPLEV | number of vertical levels in current group of fields | PRESTP | 0 | INISTP,SITOPR HACNTL | NMLV or 1 |
| 211 | I | NPE | number of rows between pole and equator on input grid | SYMASY | NOREC/2+1 | - | - |
| 212 | I | NSPACE | length of blank common available for work space | PRESTP | 700 000 | INISTP | user defined |
| 213 | I | NSTADD | start address in blank common of work space | " | 1 | " | " |
| 214 | I | NMFD | number of multi-level fields to be interpolated using spherical harmonics | " | 0 | " | " |
| 215-224 | I | NFDML (10) | codes of multi-level fields | " | 0 | " | " |
| 225 | I | NMLV | number of pressure levels at which multi-level fields are to be output | " | 0 | " | " |
| 226-255 | I | NLVML (30) | levels of multi-level fields (pascals/10) | " | 0 | " | " |
| 2561 | I | NSFD | number of single-level fields to be interpolated using spherical harmonics | " | 0 | " | " |
| 257-286 | I | NFDSL (30) | codes of single-level fields | " | 0 | " | " |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|------|------|------|---------|---------------|---------------|-----------------|-----------|
| 287-316 | I | NLVSL (30) | levels of single-level fields (pascals/10) | PRESTP | 0 | INISTP | user defined |
| 317-516 | I | MHAIN (200) | codes of reordered fields on work file | REORDR | data dependent | – | – |
| 517-716 | I | MHAOUT (200) | codes of fields to be output | " | " | – | – |
| 717 | I | MFDIN | number of input fields to be interpolated using spherical harmonics | " | " | – | – |
| 718-767 | I | NPTAR (50) | control array describing groups of scalar and velocity fields on work file | " | " | – | – |
| 768-777 | I | NFAXI (10) | constants for fft on input grid | HAFFT | grid dependent | – | – |
| 778-787 | I | NFAXO (10) | constants for fft on outptut grid | " | data dependent | – | – |
| 788 | L | NLANAL | true if initial data is an analysis file, false for forecast data | PRESET or OUTPAC | data dependent | – | – |
| 789 | L | NLSTAL | true for stand-alone version, false for forecast-called version | PRESET or OUTPAC | false (PRESET) or true (OUTPAC) | – | – |
| 790 | R | DTHETA | latitudinal grid interval of input grid (radians) | INISTP | $\Pi/(NOREC-1)$ | – | – |
| 791 | R | DLATO | latitudinal grid interval of output grid | " | $\Pi/(NLATO-1)$ | – | – |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | New value |
|---|---|---|---|---|---|---|---|
| 792–4193 | R | DD(3402) | constants used in spherical harmonic interpolation | MAKEDS | $DD_{mn} = -\left(\dfrac{n^2-m^2}{4n^2-1}\right)^{\frac{1}{2}} \cdot \dfrac{1}{n}$ | — | — |
| 4194–7595 | R | SS(3402) | constants used in spherical harmonic interpolation | " | $SS_{mn} = -\dfrac{m}{n(n+1)}$ | — | — |
| 7596–7955 | R | TRIGSI (360) | constants for fft on input grid | HAFFT | grid dependent | — | — |
| 7956–8315 | R | TRIGSO (360) | constants for fft on output grid | " | " | — | — |
| 8316–8715 | I | NCLIN (2,200) | NCLIN(1,J)=code of $J^{th}$ field on work file NCLIN(2,J)=level of $J^{th}$ field on work file | REORDR | data dependent | | |

## 10.6 COMSH2 - output package parameters

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | Initial value |
|------|------|------|---------|---------------|---------------|-----------------|---------------|
| 1 | I | MLEVUP | level number of first level in current scan | HACNTL | 1 | HACNTL | MLEVUP+NOLV or MLEVUP+1 or 1 |
| 2 | I | MNOLV | actual number of levels processed in current scan | HACNTL | data dependent | - | - |
| 3 | I | NOLV | maximum number of levels which could be processed in current scan | SPANAL | space dependent | - | - |
| 4 | I | NF | number of fields at each level which can be processed in current scan | SPANAL | NSCAL+NVEL | HACNTL | data dependent |
| 5 | I | NF1 | first field to be processed at each level in current scan | SPANAL | NFSH | HACNTL | " |
| 6 | I | NSC | maximum number of scalar fields which can be processed in current scan | SPANAL | space dependent | - | - |
| 7 | I | NSCAL | number of scalar fields at each level in current group | REORDR, HACNTL | data dependent | - | - |
| 8 | I | NVEL | number of velocity fields on work file at each level in current group | REORDR, HACNTL | data dependent | - | - |
| 9 | I | NVELO | number of velocity fields to be written to output file at each level of current group | REORDR, HACNTL | data dependent | - | - |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | Initial value |
|---|---|---|---|---|---|---|---|
| 10 | I | NTY | type of scan (1=all fields at each level, 2=scalar fields at current level, 3=velocity fields at current level) | SPANAL | space dependent | HACNTL | data dependent |
| 11 | I | NLENG | (complex) length of a field of data on the input grid | DISINI | $NLP2*(NOREC+1)/2$ | – | – |
| 12 | I | NLENHS | (complex) length of a field of scalar spherical harmonic coefficients | " | $(NTIN+1)*(NTIN+2)/2$ | – | – |
| 13 | I | NLENHV | (complex) length of a field of velocity spherical harmonic coefficients | " | $(NTIN+1)*(NTIN+4)/2$ | – | – |
| 14 | I | NHAST | start address of spherical harmonic coefficient space in (complex) blank common | " | data dependent | – | – |
| 15 | I | NRSP | space required to read a work file record | SPANAL | $NLP2*(MFDIN+N2D)$ | – | – |
| 16–115 | I | NDISGR (100) | (complex) displacement in blank common of each grid point field to be processed in current scan | DISINI | data dependent | – | – |
| 116–215 | I | NDISSH (100) | (complex) displacement in blank common of each field of s.h. coefficients to be processed in current scan | " | " | – | – |
| 216 | I | NPASS | number of group of fields currently being processed | HACNTL | 1 | HACNTL | NPASS=NPASS+1 or NPASS=0 |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | Initial value |
|---|---|---|---|---|---|---|---|
| 217 | I | N2DST | control parameter for handling uninterpolated fields (0=no uninterpolated fields; 1=uninterpolated fields to be done at a later stage, 2=uninterpolated fields currently being processed) | HACNTL | data dependent | HACNTL | data dependent |
| 218 | I | NR2D | no longer used | | | | |
| 219 | I | NDIS2D | start address in blank common of uninterpolated fields | DISINI | data dependent | – | – |
| 220 | I | NFSH | element of MHAIN containing first input field of current group | HACNTL | 1 | HACNTL | NFSH=NFSH+NSCAL+NVEL |
| 221 | I | N2D1 | number of uninterpolated fields being processed in current scan | SPANAL | space dependent | HACNTL | data dependent |
| 222 | I | NFOSH | element of MHAOUT containing first output field of current group | HACNTL | 1 | HACNTL | NFOSH=NFOSH+NSCAL+NVELO |
| 223 | I | NF2D | first uninterpolated field to be processed in current scan | HACNTL | 1 | HACNTL | NF2D=NF2D+N2D1 |

10.7  COMHDO - preliminary array for data records on output files

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | Initial value |
|---|---|---|---|---|---|---|---|
| 1 | I | MSIZDO | total (unpacked) data record length | PRESTP | MPRELO+NLON+NOREC | OUT2D, OUTSHC, OUTSHG or | MPRELO+NLON*NOREC or MPRELO+(NTOUT+2)*(NTOUT+4)-1 or MPRELO+(NTOUT+1)*(NTOUT+4)-1 or MPRELO+NLONO*NOREC |
| 2 | I | MPRELO | length of preliminary array | " | 16 | - | - |
| 3 | I | MNXDO | length of next data record | " | MSIZDO | OUT2D, OUTSHC, OUTSHG | data dependent |
| 4 | I | MX1DO | maximum subscript of first dimension | " | NLON | OUT2D, OUTSHC, OUTSHG | NLON or NTOUT+1 or NTOUT+2 or NLONO |
| 5 | I | MX2DO | maximum subscript of second dimension | " | NOREC | OUT2D, OUTSHC, OUTSHG | NOREC or NTOUT+1 or NLATO |
| 6 | I | MTYDO | data type (1=uninterpolated fields, 2=grid point fields interpolated using spherical harmonics, 3=spherical harmonic coefficients) | " | 2 | OUT2D, OUTSHC, OUTSHG | 1, 3 or 2 |
| 7 | I | MFDO | code of field output in this record | " | 0 | OUT2D, OUTSHC, OUTSHG | field dependent |
| 8 | I | MLEVO | level of field output in this record | " | 0 | OUT2D, OUTSHC, OUTSHG | level dependent |

| Word | Type | Name | Meaning | Where defined | Initial value | Where redefined | Initial value |
|---|---|---|---|---|---|---|---|
| 9 | I | MZM1 | minimum value of field, | PRESTP | 0 | OUT2D, OUTSHC, OUTSHG | data dependent |
| 10 | I | MZM2 | stored by method described | | | | |
| 11 | I | MZM3 | in Section 9.1 | | | | |
| 12 | I | MINO | scaling factor for packing routines | | | | |
| 13 | I | MSHOO1 | real (m=o,n=o) spherical | " | 0 | OUT2D, OUTSHC, OUTSHG | data dependent, or 0 |
| 14 | I | MSHOO2 | harmonic coefficient, | | | | |
| 15 | I | MSH003 | stored by method described in Section 9.1 [undefined for grid point fields] | | | | |
| 16 | I | MRECDO | record number | " | 4 | OUT2D, OUTSHC, OUTSHG | |

## 11. Sample programs

Three sample programs are given. Fig. 11.1 is an example
of the forecast-called version of the first part of the
output package. Fig. 11.2 shows the stand-alone version
of the first part of the package taking as input an analysis
file. Fig. 11.3 is an example of the second part of the
post-processing package.

## References

| | | |
|---|---|---|
| Machenhauer, B. and Daley, R. | 1972 | "A baroclinic primitive equation model with a spectral representation in 3-dimensions" |
| Haseler, J. and Burridge, D. | 1977 | "Documentation for the ECMWF grid point mode" ECMWF Internal Report No.9 |

Input cards for output package

| CARD | NAME | MEANING | DEFAULT | FORMAT |
|---|---|---|---|---|
| 1 | IRQ | If IRQ = T, read remaining cards. If IRQ = F, do not read any more cards and do not call output package | F | 9x, 1R1 |
| 2 | NLATO | Number of latitude rows in output grid | MAXROW | 9x, 1R1, I10 |
| 3 | NLONO | Number of longitude points in output grid | NLON | 9x, 1R1, I10 |
| 4 | GNLAT | Latitude (degrees) of northern boundary of output grid | ANORTH | 9x, 1R1, F20.10 |
| 5 | GWLON | Longitude (degrees) of western boundary of output grid | WEST | 9x, 1R1, F20.10 |
| 6 | GSLAT | Latitude of Southern boundary of output grid | SOUTH | 9x, 1R1, F20.10 |
| 7 | GELON | Longitude of Eastern boundary of output grid | EAST | 9x, 1R1, F20.10 |
| 8 | NTIN | Triangular truncation of grid point to spherical harmonic transformation | 0 | 9x, 1R1, I10 |
| 9 | NTOUT | Truncation of spherical harmonic coefficients to be output | 0 | 9x, 1R1, I10 |
| 10 | NVINT | Vertical interpolation type (1 = Linear, 3 = spline) | 3 | 9x, 1R1, I10 |

Fig. 3.1 (a)

| CARD | NAME | MEANING | DEFAULT | FORMAT |
|---|---|---|---|---|
| 11 | IWRITE | Number of output package write-up times | 0 | 9x, 1R1, I10 |
| 12→ 11+IWRITE | N,NPWTIM(N) | $N^{th}$ write up at step NPWTIM(N) | -2 | 2I10 |
| 13 | NSPACE | Work space available for second part of output package (in words) | 700000 | 9x, 1R1, I10 |
| 14 | NSTADD | Start address in blank common of work space for second part of output package | 1 | 9x, 1R1, I10 |
| 15 | NMFD | Number of fields at multiple levels | 0 | 9x, 1R1, I10 |
| 16 → 15+NMFD | N,NFDML(N) | $N^{th}$ multiple level field has field code NFDML(N) | 0 | 2I10 |
| 17 | NMLV | Number of levels for multiple level fields | 0 | 9x, 1R1, I10 |
| 18 → 17+NMLV | N,NLVML(N) | $N^{th}$ multiple level field is at level NLVML(N) (units = mb x 10) | 0 | 2I10 |
| 19 | NSFD | Number of fields at single levels | 0 | 9x, 1R1, I10 |
| 20 → 19+NSFD | NFDSL(J), NLVSL(J) | $J^{th}$ single level field has field code NFDSL(J) and level code NLVSL(J) | 0,0 | 2I10 |

Fig. 3.1 (b)

| CARD | NAME | MEANING | DEFAULT | FORMAT |
|---|---|---|---|---|
| 21 | N2D | Number of uninterpolated fields on model grid | 0 | 9x, 1R1, I10 |
| 22 → 21+N2D | NGPCL(1,J) NGPCL(2,J) (J=1toN2D) | $J^{th}$ uninterpolated field has code NGPCL (1,J) and level NGPCL (2,J), with the level in pascals/10, or -100 for surface fields or -200 for fields at mean sea-level pressure | 0,0 | 2I10 |
| 23 | NLCALC | If NLCALC = TRUE, calculate spherical harmonic constants files | FALSE | 9x, 1R1, 9x, 1R1 |

Fig. 3.1 (c)

70

```
NAJAN,CM2000,STCRA,T1000.    ** EXTRACT FIELDS ON PRESSURE LEVELS **
CFT.
ASSIGN(DN=FT10,BS=22,OV=DD-10-20)
ASSIGN(DN=FT11,BS=22,OV=DD-10-32)      } forecast work files
ASSIGN(DN=FT12,BS=22,OV=DD-10-40)
ASSIGN(DN=FT13,BS=22,OV=DD-10-52)
ASSIGN(DN=FT15,OV=DD-10-40)
ASSIGN(DN=FT16,OV=DD-10-20)            } post-processing constants files
ACCESS,DN=INITIAL,PDN=X010365,ID=EW0365.} forecast initial data
ASSIGN(DN=INITIAL,A=FT20)
ASSIGN,DN=FT60,OV=DD-10-20.
ASSIGN,DN=FT61,OV=DD-10-35.            } post-processing work files
ASSIGN,DN=FT62,OV=DD-10-41.
ASSIGN,DN=FT63,OV=DD-10-52.
ACCESS,DN=M48,PDN=M48URJMEW,ID=DUMP48.
ACCESS,DN=FT30,PDN=CASDS,ID=DUMP30.    } forecast start data set
ACCESS,DN=X02,PDN=P10X02,ID=DUMP36.
ACCESS(DN=ILTR,PDN=FCRWFILTR,ID=DUMPDUR)
ACCESS,DN=MAG,PDN=MAGLTR,ID=DUMP06.
LDR,ILIB=ILLTR:MAG:BFILIR,DN=BPLD:M48:X02.
REWIND,DN=FT15.
SAVE,DN=FT15,PDN=ZZ,ID=NAJ.
REWIND,DN=FT16.
SAVE,DN=FT16,PDN=NIFG,ID=NAJ.          } post-processing constants files
REWIND,DN=FT60.
SAVE,DN=FT60,PDN=P60,ID=NAJ.
REWIND,DN=FT61.
SAVE,DN=FT61,PDN=P61,ID=NAJ.
REWIND,DN=FT62.                         } post-processing work files
SAVE,DN=FT62,PDN=P62,ID=NAJ.
REWIND,DN=FT63.
SAVE,DN=FT63,PDN=P63,ID=NAJ.

(EOR)  PROGRAM GPMODEL
       COMMON B(250000)
       CALL MASTER
       STOP
       END
(EOR)
```

Fig. 11.1

TEST
POST
PROCESSING
PACKAGF

} label cards for forecast run

0   do not override start data set values for forecast model

| | | |
|---|---|---|
| F | | |
| F | 0 | NLATO |
| F | 0 | NLOGO |
| F | 0.0 | GDLAT |
| F | 0.0 | GDLON |
| F | 0.0 | GSLAT |
| F | 0.0 | GELON |
| T | 40 | NTIM |
| T | 40 | NTOUT |
| T | 3 | NVTRT |
| T | 1 | TWRITE |
| 1 | 2 | NSPACE |
| F | 0 | NSTAOD |
| F | 2 | NSFD |
| 1 | 1 | |
| 2 | 3 | |
| 1 | 2 | NMHLV |
| 1 | 500 | |
| 2 | 10000 | NSFD |
| F | 0 | N2D |
| 1 | 2 | |
| 6 | -100 | |
| 11 | -100 | |
| 1 | T | NLCALC |

Data cards for
post-processing
package

Fig. 11.1   (Continued)

```
NAJAN,CM1500,STCRA,T1000.   ** EXTRACT FIELDS ON PRESSURE LEVELS **
CFT.
ACCESS,DN=FT20,PDN=FEBCLIM,ID=DAZ,ED=1.
ACCESS,DN=N48,PDN=N48OBJNEW,ID=DUMP4U.
ASSIGN,DN=FT60,DV=DD-19-20.
ASSIGN,DN=FT61,DV=DD-19-33.
ASSIGN,DN=FT62,DV=DD-19-41.
ASSIGN,DN=FT63,DV=DD-19-52.
ACCESS(DN=LLIB,PDN=ECMWFLIB,ID=DUMPUU)
ACCESS,DN=NAG,PDN=NAGLIB,ID=DUMPUU.
LDR,LIB=LLIB:NAG:SFILIB,DN=SBLD:N48.
REWIND,DN=FT60.
SAVE,DN=FT60,PDN=P60,ID=NAJ.
REWIND,DN=FT61.
SAVE,DN=FT61,PDN=P61,ID=NAJ.
REWIND,DN=FT62.
SAVE,DN=FT62,PDN=P62,ID=NAJ.
REWIND,DN=FT63.
SAVE,DN=FT63,PDN=P63,ID=NAJ.
```
} post-processing work file

(EDR)

```
      PROGRAM GPMODEL
      COMMON G(220000)
      CALL OUTPAC(20,60,5,0)
      STOP
      END
```

(EDR)

```
F                               ANALYSIS FILE
I
F          0                    NLATO
F          0                    NLONO
F          0.0                  GNLAT
F          0.0                  GNLON
F          0.0                  GSLAT
F          0.0                  GELON
T          40                   NTIN
I          40                   NTOUT
I          5                    NVINT
F          0                    IWRITE
F          0                    GSPACE
F          0                    NSTADD
I          2                    NFFD
1          2
2          5
I          2                    NMLV
1          5000
2          10000
F          0                    NSFD
F          0                    020
T          F                    RECALC
```
} Data cards

Fig. 11.2

```
NAJAN,STCKA,CASJJJ1,IT3U.     ** GENERATE SH COEFFS **
CFT.
ACCESS,DN=FT6U,FDN=PO0,ID=MAJ.  ┐
ACCESS,DN=FT61,FDN=PO1,ID=MAJ.  │  post-processing
ACCESS,DN=FT62,FDN=PO2,ID=MAJ.  │  work files
ACCESS,DN=FT63,FDN=PO3,ID=MAJ.  ┘
ACCESS,DN=FT15,FDN=WZZ,ID=MAJ.  ┐  post-processing
ACCESS,DN=FT1A,FDN=MLEG,ID=MAJ. ┘  constants files
ACCESS,DN=OUT,FDN=MINOUT,ID=DUMP50.
ACCESS,DN=CONV,FDN=MINCONV,ID=DUMP40.
ACCESS,DN=FFT,FDN=CALFFIPACK,ID=DUMP50.
LDR,LIB=FFI,DN=XBLD:OUT:CONV.
REWIND,DN=FT17.
DISPOSE,DN=FT17,SDN=NGPOUL,ID=MAJ,DF=KB,MF=CY,DC=SI.- Fields in  regular
REWIND,DN=FT15.                                         lat/long grid
DISPOSE,DN=FT15,SDN=NSHOUL,ID=MAJ,DF=KB,MF=CY,DC=SI.- Spherical harmonic coefficients
REWIND,DN=FT19.
DISPOSE,DN=FT19,SDN=N2OOUL,ID=MAJ,DF=KB,MF=CY,DC=SI.- uninterpolated fields
  (EOR)
    PROGRAM P
    COMMON X(5),B(7800000)
    CALL MACNTL
    STOP
    END
  (EOR)
60                                        GPOUL - unit number of first
                                                  post-processing work file
```

Fig. 11.3