TECHNICAL MEMORANDUM

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Program description of a barotropic model on the sphere

J. Quiby

Research Department

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European Centre for Medium-Range Weather Forecasts
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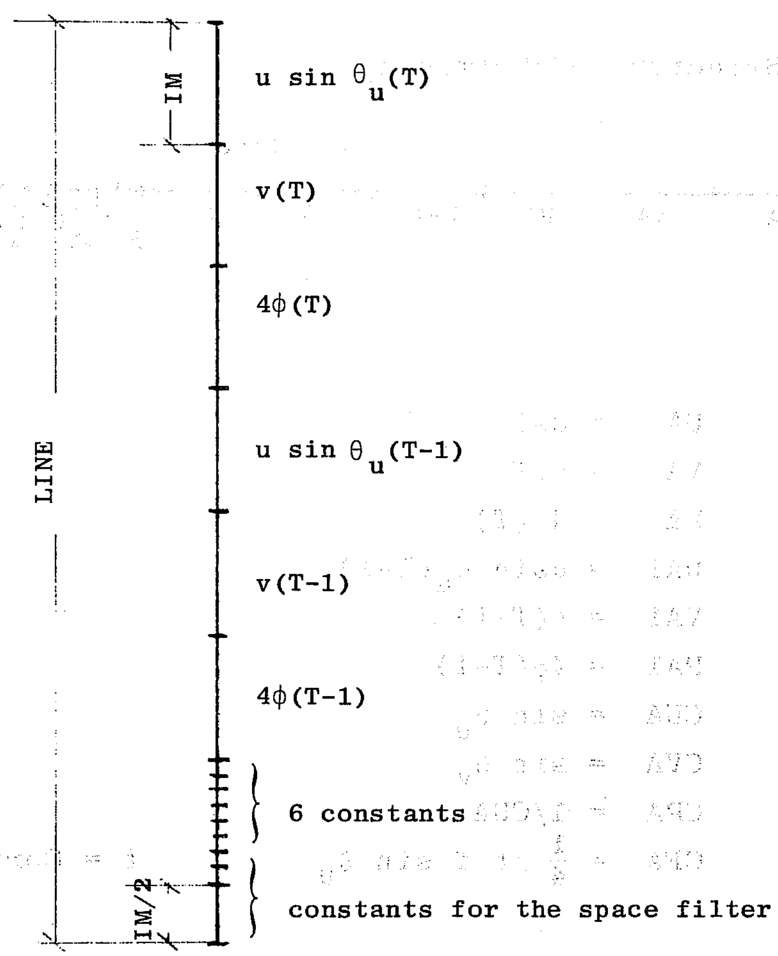
1. GENERAL CONCEPT

This technical memorandum gives a program description for the barotropic model described in Technical Report No. 17. The whole code and all the data are stored in the memory and stay there for the whole duration of the execution. No such facilities as OVERLAY are used and there is no provision in the code for exchange of data between memory and disks as is done with the main model.

2. THE THREE MAIN ARRAYS

The variables at two adjacent timesteps, together with other constants, are kept in a 2D-matrix Q(LINE,JMP1), each column of which corresponding to a row of the finite-difference grid.

Arrangement of the data in the columns of matrix Q:



θ_u = colatitude of the u-line of row J

IM = number of longitudinal points

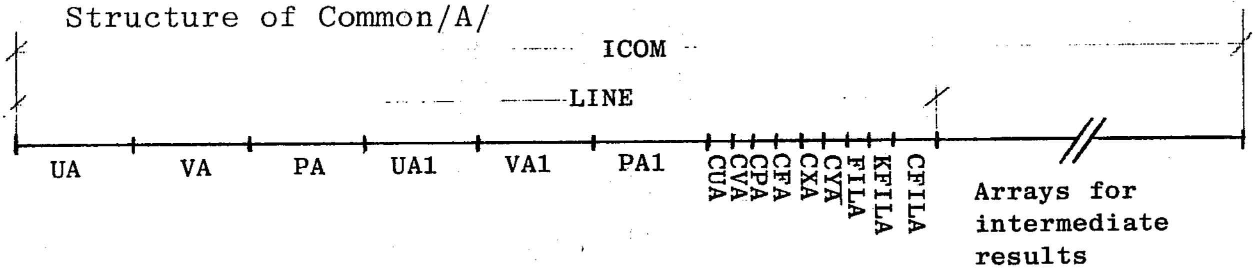
JMP1 = number of rows in the finite-difference grid

LINE = length of the columns in matrix Q.

The updating of the variables of row J at each timestep occurs in two sets of one-dimensional arrays grouped under COMMON/A/ and COMMON/B/. Thus, when the rows are scanned from the North Pole to the South Pole, there are constant transfers of data between matrix Q on one side and COMMON/A/ and COMMON/B/ on the other side in the following schematic way:

Column J in matrix Q is copied into COMMON/A/; the data in COMMON/A/ are transferred into COMMON/B/ where they are updated, then the LINE-first words are transferred back into column J of the matrix Q.

Structure of Common/A/



UA = usin θ_u(T)
VA = v(T)
PA = 4ϕ(T)
UA1 = usin θ_u(T-1)
VA1 = v(T-1)
PA1 = 4ϕ(T-1)
CUA = sin θ_u
CVA = sin θ_v
CPA = 1/CUA
CFA = $\frac{1}{4}\Delta t\ f \sin\theta_u$ f = Coriolis parameter on the v-line

CXA = $\Delta t/2a\ \Delta\lambda\ \sin\theta_u$

CYA = $\Delta t/2a\ \Delta\theta\ \sin\theta_u$

FILA =
KFILA = } values for the space-filter
CFILA =

θ_u = colatitude of the u-line of row J

θ_v = colatitude of the v-line of row J

ICOM = length of COMMON/A/

COMMON/B/ has exactly the same structure as COMMON/A/. It contains the same physical variables and constants as COMMON/A/ but, obviously, not necessarily with the same numerical values. Its array and variable names are: UB, VB, PB, UB1, VB1, PB1, CUB, CVB, CPB, CFB, CXB, CYB, FILB, KFILB and CFILB.

3. CALCULATION CONTROL

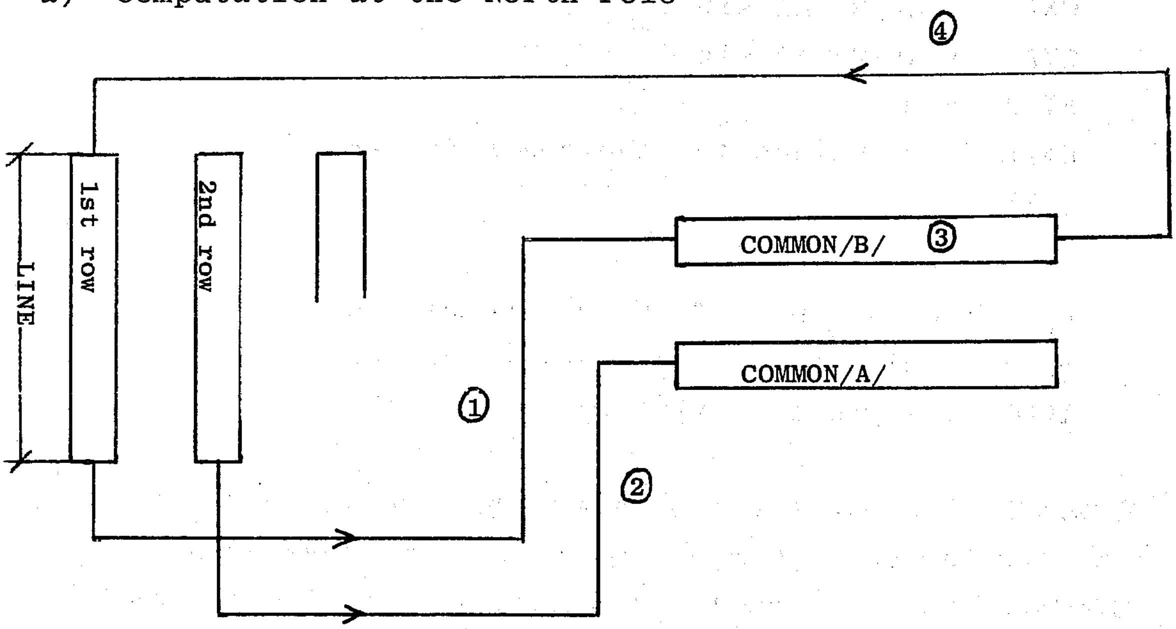
In the main unit of the program, PROGRAM GLOBE, a loop limited by

```
1000   CONTINUE
         .
         .
         .
         .
       IF (NDT·LT·NEND) GOTO 1000
```

where NDT = the current timestep
NEND = the last timestep

controls the arithmetic calculations, one loop operating each timestep a full north-south scan in the following manner:

a) Computation at the North-Pole



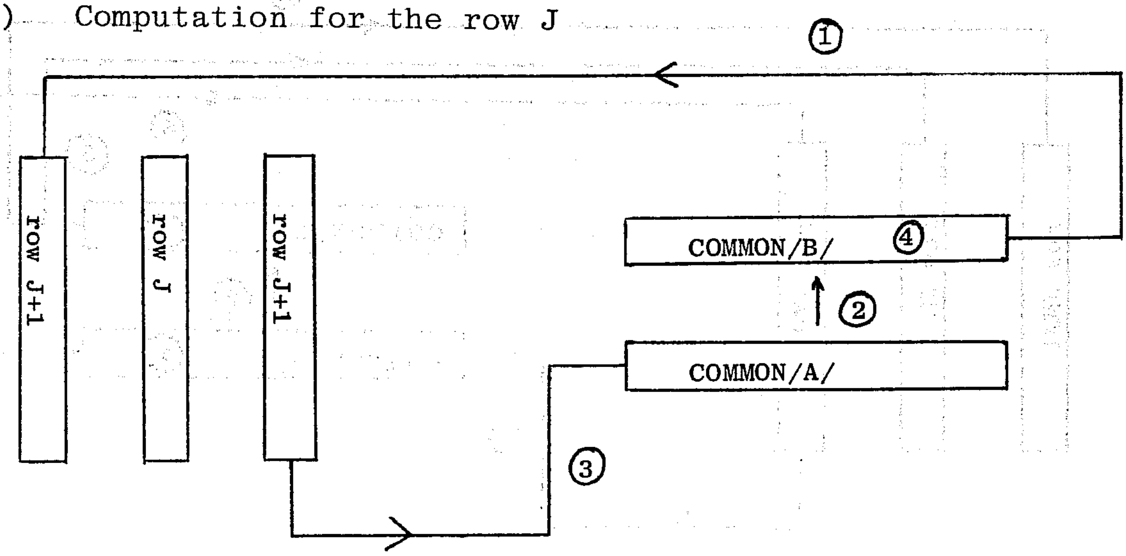
① The first column of the matrix Q, which contains the historical variables and some constants for the North Pole is copied into COMMON/B/.

② The second column of the matrix Q, which contains the historical variables and some constants for the second row of the finite-difference grid, is copied into COMMON/A/.

③ In SUBROUTINE NORTH, the variables UB(T), VB(T), PB(T), UB1(T-1), VB1(T-1), PB1(T-1) in COMMON/B/ are transformed into UB(T+1), VB(T+1), PB(T+1), UB1(T), VB1(T), PB1(T) by a centered time-stepping scheme (leapfrog).

④ The LINE first words of COMMON/B/ are transferred back into the first column of matrix Q. They are the updated North-Pole variables with their constants.

b) Computation for the row J



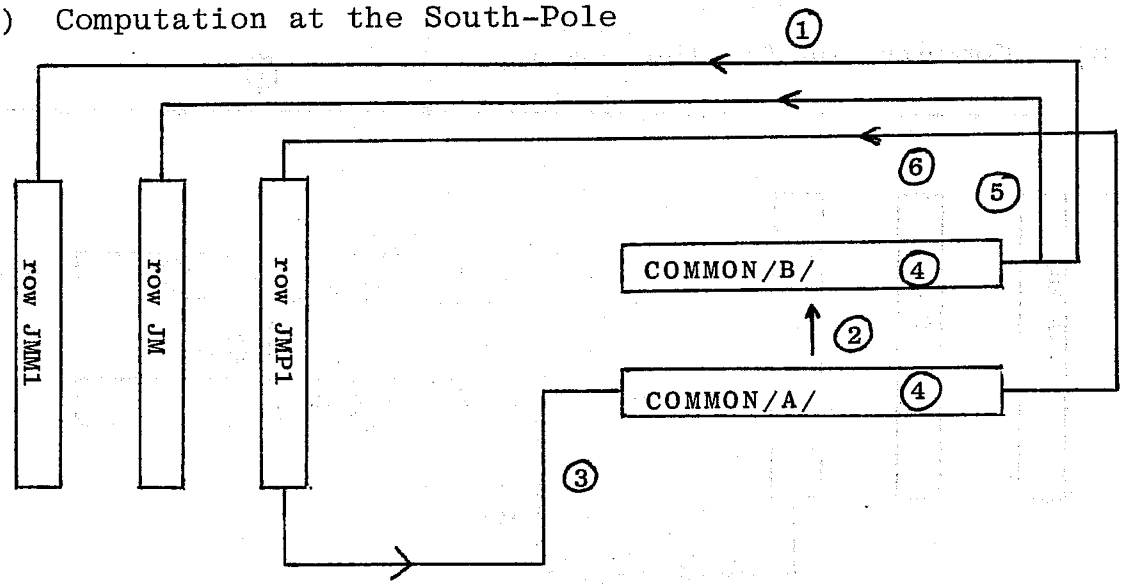
① The updated variables of row J-1 (UB(T+1), VB(T+1), PB(T+1), UB1(T), VB1(T), PB1(T)) with their constants are transferred back into the (J-1)-column of matrix Q.

② The whole content of COMMON/A/ (with the variables of row J before updating) is moved into COMMON/B/.

③ The variables of row J+1 with their constants are copied from the (J+1)-column of the matrix Q into COMMON/A/.

④ The variables of row J in COMMON/B/ are updated by SUBROUTINE NORMAL.

c) Computation at the South-Pole



row JMP1 : the last row (South-Pole)
row JM : the penultimate row
row JMM1 : the antepenultimate row

① The updated variables of row JMM1 are transferred back with their constants into the matrix Q.

② The whole content of COMMON/A/ (the variables of row JM before updating) moves into COMMON/B/.

③ The data of row JMP1 are copied into COMMON/A/.

④ The data of row JM in COMMON/B/ and the data of row JMP1 in COMMON/A/ are updated in SUBROUTINE SOUTH.

⑤ The updated variables of row JM are transferred back into matrix Q.

⑥ The updated variables or row JMP1 are transferred back into the matrix Q.

Throughout the whole program, data transfers in the memory are carried out by the CDC Fortran facility CALL MOVLEV.

4. SUBROUTINE NORMAL

The tasks performed by SUBROUTINE NORMAL can be divided into three parts:

a) The tendencies for u sin θ_u, v and 4ϕ are computed in COMMON/B/ for row J.

b) Auxiliary variables of row J+1 (the row stored in COMMON/A/) are computed and will be needed for the computation of the tendencies of row J+1.

c) Execution of the time-stepping scheme and alteration of the updated variables by the physics and the time-filter.

Sequence of the operations:

u sin θ_u(T+1) is computed, i.e. UB(T) changed to UB(T+1)

UB(T+1) is altered by the linear drag

UB(T+1) is altered by the linear diffusion

UB1(T-1) is changed to UB1(T)

UB1(T) is time-filtered

Then the same procedure is undergone by VB, VB1 and by PB, PB1.

The tendencies for row J are stored in COMMON/D/ where:

DUB = u sin θ_u(T+1) - u sin θ_u(T-1)

DVB = v(T+1) - v(T-1)

DPB = 4ϕ(T+1) - 4ϕ(T-1)

5. OROGRAPHY

With respect to the orography, two versions of the model have been developed.

VERSION I:

In this version, the orography consists of one unique circular mountain $\cos^2$-shaped, which can be placed anywhere on the globe. Its location and dimensions are controlled by the NAMELIST/MNT/ parameters (see Annex III).

VERSION II:

Here, the orography has to be supplied on TAPE1 according to the following specifications:

a. Units: m

b. Unformatted WRITE must be used

c. Each latitude row is stored in one record

d. No other data record should precede the orographical data

e. For the North-Pole row, the height at the North-Pole must be repeated as many times are there are longitudinal points. (Same for the South-Pole row).

If the orography is supplied by the user (VERSION II), the parameters of NAMELIST/MNT/ become irrelevant, with the exception of NDTSTA and NDTSTO which, for both versions, control the pace at which the orography should grow.

If no orography is desired, simply set to the parameter NDTSTA (in NAMELIST/MNT/) a larger value than to the parameter NEND (in NAMELIST/D/. See Annex II).

The orography with full height (or the "grown-up"orography) is stored in COMMON/XO/XORO(IM,JMP1) and the orography used at each timestep - a fraction of the full orography when it is growing - in COMMON/O/ORO(IM,JMP1).

6. INITIALIZATION

The initialization of the constants needed for the integration and the determination of the initial data take place in SUBROUTINE INIT. Two versions of this subroutine have been written:

In the first version, the stream function for a Rossby-Haurwitz wave No. 4 is computed for each row J and stored in the array UA1. In the array UB1 is stored the stream function for the row J-1. In the arrays UA and VA are respectively computed u sin θ_u and v.

In the second version, the meridional wind is set equal to zero and the zonal wind u must be input in ms^{-1} on punched cards according to FORMAT(I2,4X,F5.1), the first two columns containing the row number. For the polar rows (where u is not defined), note the difference. Example:

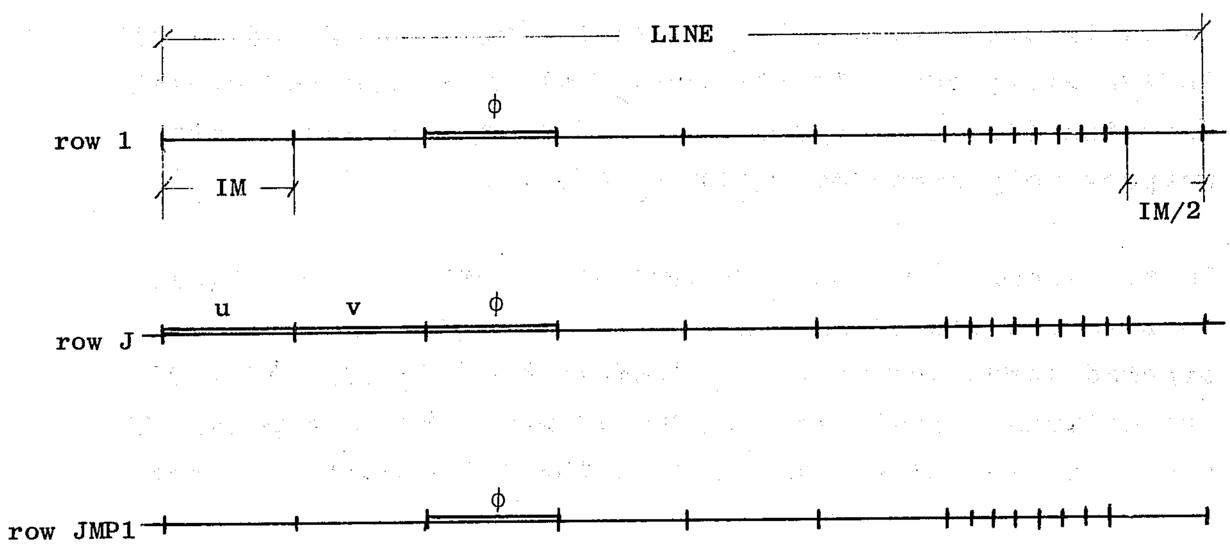
	1	2	3	4	5	6	7	8	9	10	11	12	13
North-Pole row		2					U	N	P				
		2							3	.	3		
	1	2						1	8	.	Ø		
	1	3						1	7	.	4		
	4	8							1	.	3		
South-Pole row	4	9					U	S	P				

No stream function is computed in this case.

For both versions, PØ (see NAMELIST/D/) is set to a constant value for the whole globe, the average geopotential value of the free surface (m^2s^{-2}). SUBROUTINE BALANS will adjust the mass-field (PØ) to the wind field by means of the reverse balance equation.

If desired, an initial data set can be defined on TAPE5Ø. The data must be unformatted and form one record only because the whole TAPE5Ø is read into the matrix Q in one go.

The structure of TAPE5Ø must be:



For each row, u v and ϕ must be given with the exception of the polar rows where only ϕ needs to be specified. Dummy values can be set for all the other variables of TAPE5Ø because they will be initialized by SUBROUTINE INIT. The initial data given to the model through TAPE5Ø can afterwards, if desired, be initialized either by dynamical initialization or by the reverse balance equation depending on how the relevant parameters of NAMELIST/D/ (see Annex II) have been set.

7. OUTPUT OF THE RESULTS

When the integration is completed, control calls SUBROUTINE PLOTQ which outputs the results. They are copied on TAPE2Ø with an unformatted WRITE, each row of data forming one record. There is no common block or other record preceding the data.

The row-records are organised in the following manner:

$H_1, \ldots, H_{IM}, P_1, \ldots, P_{IM}, HH_1, \ldots, HH_{IM}, U_1, \ldots, U_{IM}, V_1, \ldots, V_{IM}$

where:

H is the orography in m

P is the pressure at the ground in Nm^{-2}

HH is the height of the free surface in m

U is the zonal velocity in ms^{-1}

V is the meridional velocity in ms^{-1}

The user can also have the end-results printed. He can choose the rows for which he would like the results printed by means of a card whose format is 1l1 starting in column 1. l must be either T or F. There should be no blank between the letters. There are four possibilities:

TFF Only a selection of rows will be printed; they are automatically selected by SUBROUTINE WRITJ.

FTF The choice of the rows to be printed is left to the user by amending the card DATA ICHROW.

Example:

DATA ICHROW/1,2,3,12,13,15/

The rows 1,2,3,12,13 and 15 will be printed.

FFT All the rows will be printed.

FFF No results will be printed

The results for one row are printed as follows:

$H_1 H_2 \ldots H_{IM}$

$P_1 P_2 \ldots P_{IM}$

$HH_1\ HH_2 \ldots HH_{IM}$

$U_1 U_2 \ldots U_{IM}$

$V_1 V_2 \ldots V_{IM}$

There is no provision in the code for storing or printing results at intermediate timesteps.

Results written on TAPE2Ø can be plotted by one of the two following plotting packages:

1) Henry Larson's package
   For its use, see:

   Documentation of a comprehensive plotting package for ECMWF's grid point model.
   Release 1.3 issued 19 May 1978

2) Jean Quiby's package
   For its use, see Chapter 8: How to run the model.

There is also the possibility to have printed every NSTAT timesteps (NSTAT is a variable of NAMELIST/D/, see Annex II) the global space average of mass, enstrophy, total energy and angular momentum. As the code stands at the moment, these values are only correct in the absence of orography.

If the logical variable PLOTU of NAMELIST/D/ is set equal to .TRUE., the initial meridional zonal flow at the longitude zero will be plotted.

8. HOW TO RUN THE MODEL

Two versions of the model have been catalogued.

VERSION 1: The model initiates a Rossby-Haurwitz wave No.4. The orography consists of a circular isolated mountain.

VERSION 2: The model starts from an unperturbed zonal flow which has to be input by the user. A global orography has to be input as well.

For both versions of the model, the specifications for an integration are given by:

A PARAMETER-card (see below)
NAMELIST/D/ and NAMELIST/MNT/
A "logical" card

a) The PARAMETER card

For a successful run of the model, the source code has first to go through a precompiler developed at the Laboratoire de Météorologie Dynamique (LMD) in Paris. This precompiler is described in Annex I. The resolution of the model is given by the PARAMETER card. On that card, IDM is the number of points per latitude-row and JDM the number of rows. The resolution set by default is N24 : IDM=96, JDM=49.

b) NAMELIST/D/

With the exceptions of the resolution and the orography, all the parameters governing an integration are grouped in this record. A list of these parameters is given in Annex II.

c) NAMELIST/MNT/

This statement groups the parameters defining the circular, $\cos^2$-shaped, isolated mountain which can be placed anywhere on the globe and can grow in time at any desired pace. A list of these parameters is given in Annex III. (See also Chapter 5: Orography).

d) The "logical" card

It specifies the rows for which the end-results should be printed. The use of this card is described in Chapter 7: Output of the Results.

Running the model on the CDC CYBER 175

Below is an example of a typical card deck, with some explanations.

This job will compute the deformation brought to a pure Rossby-Haurwitz wave by an idealized circular mountain (VERSION 1).

job card	
ACCOUNT card	
ROUTE card	long output
ATTACH,OLDPL,BAROTROPROSSBYHAURWITZWAVE4, ID=EWJQ3,MR=1.	The source is an UPDATE-file
UPDATE,F.	
ATTACH,FTNP,LMDFTNPARAMETER, ID=EWJQ3,MR=1	The LMD-precompiler is attached
SWITCH,4.	Necessary
FTNP,I=COMPILE.	Precompiler card
FTN,A,OPT=2,R=3,I=SOURCE.	
REQUEST,TAPE2Ø,*PF.	Where end-results will be written
LGO.	

CATALOG,TAPE2Ø,RESULTS,ID=....	
7/8/9	UPDATE modification
*IDENT N48	
*DELETE N24.1	The resolution of the model is changed from N24 to N48
PARAMETER IDM=192,JDM=97,....	
rest unchanged (see listing)	
7/8/9	
$D	
BAL=.T.,	The balance equation will be used for the initialization
ADJUST=.F.,	
FIL=.T.,	The space-filter will operate from the Equator
COLATØ=1.,	
NEND=2880,	10 days
NSTAT=72,	Model statistics will be printed every 72 steps
DT=600.,	Δt=300 sec (5 min)
PØ=68670.,	Average height of the free surface: 7000 m
CODIFF=3.E5,	
$	
$MNT	
NDTSTA=288,	Mountain starts growing after one day.
NDTSTO=1151,	Growing-time: 3 days
TOPCLA=60.,	Mountain at 30^{O}N and 140W
TOPLON=220.,	
$	
FFT	End-results will be printed for all the rows
6/7/8/9	

If, in NAMELIST/D/, we have PLOTU=.T., the following library cards have to be attached:

ATTACH,GLIB,P3OBJLIB,ID=EWP3,MR=1.

ATTACH,VLIB,VARIANLIB,ID=EWPLOT,MR=1

ATTACH,EWLIB,ECMWF,ID=EWP3,MR=1.

plus the loader-card

LDSET,LIB=GLIB/VLIB/EWLIB.

If the VERSION 2 of the model is used, the card deck has to be modified as follows:

The UPDATE-source to attach is

ATTACH,OLDPL,BAROTROPINPUTZONALFLOWOROGRAPHYONTAPE1,

ID=EWJQ3,MR=1.

and a global orography must be input

ATTACH,TAPE1,OROGRAPHY,ID= ....

The cards for the zonal wind must be placed between the two NAMELIST records (see Chapter 6: Initialization).

<u>Memory and CPU-time requirements on the CYBER175</u>

There are only small differences between the two versions of the model.

Core requirement for N24: 260000_8 words

CPU-time for 10 days with N24 and Δt = 5 min :

42 minutes

Running the plot package for the global barotropic model on the ECMWF computer system

As this is the case with the model, this plot package can only be used with the LMD precompiler. The resolution of the finite difference grid must be given on the PARAMETER card.

job card	
ACCOUNT card	
ATTACH,OLDPL,PLOTPACKAGEFORGLOBALBAROTROPIC, ID=EWJQ3,MR=1.	The source is an UPDATE-file
UPDATE,F.	
ATTACH,FTNP,LMDFTNPARAMETER,ID=EWJQ3, MR=1.	Cards for the LMD-precompiler (ATTACH,FTNP … to FTNP,I=COMPILE.)
SWTICH,4.	
FTNP,I=COMPILE.	
FTN,A,OPT=2,R=3,I=SOURCE.	
ATTACH,TAPE2Ø,RESULTS,ID=....	Results to be plotted
ATTACH,NLIB,NEWCONTLIB,ID=EWPLOT,MR=1.	Libraries and file needed for the generation of the pictures (ATTACH,NLIB … to ATTACH,TAPE9Ø …)
ATTACH,VLIB,VARIANLIB,ID=EWP3,MR=1.	
ATTACH,TAPE9Ø,BACKBASE,ID=EWPLOT,MR=1.	
LDSET,LIB=NLIB/VLIB/EWLIB.	
LGO.	
7/8/9	
*IDENT N48	UPDATE modifications The resolution of the finite-difference grid is set to N48 (*IDENT N48 … to PARAMETER …)
*DELETE PICT.6	
PARAMETER IDM=192,JDM=97,ID1=IDM+1	
7/8/9	
6/7/8/9	

ANNEX I

The Precompiler of the "Laboratoire de Météorologie Dynamique" in Paris

Although of a straightforward use, this precompiler is a very powerful utility which allows the greatest flexibility for the change of resolutions or dimensions in a program.

This precompiler systematically replaces throughout the program integer variables or array subscripts by the integer constants specified on the PARAMETER card. Thus, by amendment of one card only (the PARAMETER card), a whole program can be "redimensionalised".

The PARAMETER-card must be the first card in the main program unit after the PROGRAM card.

Example:
If the precompiler finds the card, starting in column seven

```
      PARAMETER IJK=72, NML=123
```

it will, everywhere in the whole code, replace the variables IJK and NML by the integer constants 72, respectively 123.

This precompiler does not generate a binary object; it only brings modifications in some of the card images of a source coded in FORTRAN.

Neither the input source (input into the precompiler) nor the precompiled source (output from the precompiler) are printed.

The default name for the input source is INPUT. The default name for the precompiled source is SOURCE.

This precompiler can be used with an UPDATE file as input source. It also works with the error-processor MANTRAP.

ANNEX II

NAMELIST/

Parameter	Explanations	Default value
BAL	Logical. If true, the reverse balance equation is used for the initial initialisation	.FALSE.
ADJUST	Logical. If true, the Nitta-Hovermale dynamical initialization scheme is used	.TRUE.
NADJ	Number of cycles for the Nitta-Hovermale dynamical initialization scheme	36
GARP	Logical. If true, the initial data are input from TAPE5Ø	.FALSE.
FIL	Logical. If true, the space filter (Fourier filtering) is used	.FALSE.
COLATØ	Cosine of the latitude where the space filter starts	0.5
NSTART	Step number at start of run	0
NEND	Step number of final timestep	1440
NMAP	(no longer relevant)	30
NSTAT	Multiple of timesteps when statistics is written up	2
DT	Twice the time increment ($2\Delta t$) in seconds	120.0
PØ	Average geopotential value of the free surface (m^2s^{-2})	98100.
OMEGA	Angular velocity of the flow in a solid body rotation (s^{-1})	2.616E-6
EPS	Constant for the linear time-filter	0.001
COFRIC	Coefficient of the linear drag (s^{-1})	0.0
CODIFF	Coefficient of the linear diffusion (m^2s^{-1})	0.0
PLOTU	Logical. If true, the meridional profile of the initial zonal flow at the longitude zero is plotted	.FALSE.

ANNEX III

NAMELIST/MNT/

Parameter	Explanations	Default value
NDTSTA	Step number when orography starts growing	100000
NDTSTO	Step number when orography reaches its full height and stops growing	100000
TOPCLA	Colatitude of the summit of the mountain in degrees	90.
TOPLON	Longitude of the summit of the mountain in degrees (0 to 360)	200.
RADORO	Radius of the base of the mountain in m	4440.E3
TOP	Height of the summit in m	3000.

ANNEX IV

List of the subroutines

Name	Function
GLOBE	Controls the north-south scanning and all the data-transfers it implies. See Chapter 3: Calculation Control
INIT	Initializes the constants needed for the integration. Depending on the version of the model, determines or reads in the initial wind field. Can also read the full initial data from TAPE50. See Chapter 6: Initialization
NORTH	Contains the modified spatial differencing scheme for the North-Pole. Updates the geopotential at the North-Pole.
NORMAL	Contains the spatial differencing scheme. Updates the geopotential and the wind. See Chapter 4: SUBROUTINE NORMAL
SOUTH	Contains the modified spatial differencing scheme for the South Pole. Updates the geopotential and the wind at the row preceding the South-Pole row and the geopotential at the South-Pole.
STAT	Computes the model statistics See Chapter 7: Output of the Results
BALANS	Initializes by means of the reverse balance equation. See Chapter 6: Initialization
FILTRE	Space filter (Fourier filtering)

ANNEX IV (Cont.)

Name	Function
INIFIL	Initializes the constants for the space filter
SLOWFT	Fourier transform and its reverse (no FFT)
INITOR	Initializes the orographical constants See Chapter 5: Orography
OROGR	Controls the growth of the orography See Chapter 5: Orography
MOUNT	Defines the circular mountain See Chapter 5: Orography
DISTCE	Computes the linear drag
DIFFUS	Computes the linear diffusion
PLOTZF	Plots the initial meridional zonal flow at the longitude zero. See Chapter 7: Output of the Results
WRITJ	Selects the rows whose results are printed. See Chapter 7: Output of the Results
PLOTQ	See Chapter 7: Output of the Results