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The main runs and datasets of the Fine Resolution Antarctic Model Project (FRAM) Part I: The coarse resolution runs

B de Cuevas

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Natural Environment Research Council

INSTITUTE OF OCEANOGRAPHIC SCIENCES
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ABSTRACT

A coarse (1° x 1°) resolution numerical model of the Southern Ocean was used as a testbed for developments during the early part of the FRAM project. This document describes the coarse resolution model. Details are given of the runs made using the model and the storage of the associated datasets.

KEYWORDS

NUMERICAL MODELLING
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1. INTRODUCTION

The Fine Resolution Antarctic Model Project (FRAM) is an NERC Community Research Project designed to set up, run and analyse the results of a fine resolution primitive equation model of the Southern Ocean. It forms part of the UK contribution to the World Ocean Circulation Experiment (WOCE).

The project started in 1987 at the Robert Hooke Institute (RHI), Oxford, with Dr Peter Killworth as project co-ordinator and a core team of project manager, Dr Max Rowe, and two programmers, Mr Richard Offiler and Mr Andrew Anson. In October 1988 the project was transferred to the Institute of Oceanographic Sciences Deacon Laboratory (IOSDL), and Dr David Webb appointed as project co-ordinator. Dr David Beccles was appointed project manager, with Dr Ola Odele as principal programmer and Mr Tim Hateley as graphics programmer. In December 1989 Mrs Beverly de Cuevas took over as project manager and Dr Andrew Coward was appointed principal programmer. The core team was expanded with the addition of two researchers, Mr Simon Thompson, appointed in January 1990, and Dr Kristofer Döös, appointed in December 1990. The operational phase of the project ended in April 1992, but analysis is expected to continue for at least two years.

Some of the detailed information referring to the early development of the project is missing or ambiguous, but that which has been provided should be adequate for most purposes.

The numerical model used is that described by Cox (1984). The model variables of potential temperature[1] (T), salinity (S), two components of horizontal velocity (u,v), vertical velocity (w) and the stream function (ψ), are defined using an Arakawa B grid (Arakawa & Lamb 1977). Temperature, salinity and stream function are defined at the centre of the boxes and the horizontal vector velocity defined at the mid-point of the vertical edges. Vertical velocity is defined at the mid-points of the horizontal edges. The horizontal and vertical grids are illustrated in Table 1.

The original code (Cox 1984) was developed to run on the Cyber computer, and modifications were made to improve efficiency on the CRAY X-MP at the Atlas Centre of the Rutherford Appleton Laboratory (RAL).

---

[1] In the remainder of this document, unless otherwise stated, temperature refers to potential temperature at a pressure of one atmosphere.

TABLE 1

(a) Horizontal grid spacing

```
               |                         |                         |
----U(I-1,J+1)--------U(I,J+1)----------U(I+1,J+1)----
               |                         |                         |
               |                         |                         |
               |       T(I,J+1)         |      T(I+1,J+1)        |
               |                         |                         |
               |                         |                         |
----U(I-1,J)----------U(I,J)-------------U(I+1,J)-----
               |                         |                         |
               |                         |                         |
               |        T(I,J)           |      T(I+1,J)          |
               |                         |                         |
               |                         |                         |
----U(I-1,J-1)--------U(I,J-1)----------U(I+1,J-1)----
               |                         |                         |
```

(b) Vertical grid spacing

```
        |                               |
----|----------W(K)----------|----
        |                               |
        |                               |
        |            T(K)               |
        |                               |
        |                               |
----|---------W(K+1)---------|----
        |                               |
        |                               |
        |           T(K+1)              |
        |                               |
        |                               |
----|---------W(K+2)---------|----
        |                               |
```

A coarse resolution version of the model was used as a test bed for developments. Runs of this model were undertaken at the RHI prior to October 1988 and further developments were made at IOSDL.

2. DESCRIPTION OF THE COARSE RESOLUTION MODEL

2.1 Model grid

The model was designed to cover the entire Southern Ocean south of 24°S at a horizontal resolution of 1° x 1° with 32 levels in the vertical.
The grid is defined in the model by:

IMT	=	362	(total number of T grid boxes zonally)
JMT	=	58	(total number of T grid boxes meridionally)
KM	=	32	(total number of vertical levels)
DXT	=	1.	(zonal grid spacing across T boxes)
DYT	=	1.	(meridional grid spacing across T boxes)

The southern boundary, defined in the model by SWLDEG = -81.0, refers to the latitude of the first interior (ie. J = 1) row of velocity points. The latitude of the first interior row of temperature points is 81.5°S. The northern boundary, 24°S, refers to the latitude of the last interior (ie J = JMT) row of velocity points. The latitude of the last interior row of temperature points is 24.5°S.

Cyclic conditions were applied in the east-west direction. Temperature points for I = 2 and I = 362 correspond to 0° longitude.
The model variables defining depth are:

DZ	=	grid box thickness across u,v,T boxes
ZDZ	=	depth of bottom of boxes
ZDZZ	=	depth of centre of u,v,T boxes (except for the bottom box).

The vertical spacing (in metres) is given in the following table:

TABLE 2

Level	DZ	ZDZ	ZDZZ
1	20.7	20.7	10.35
2	23.3	44.0	32.35
3	26.5	70.5	57.25
4	31.0	101.5	86.00
5	37.3	138.8	120.15
6	46.7	185.5	162.15
7	61.6	247.1	216.30
8	85.9	333.0	290.05
9	121.0	454.0	393.50
10	156.0	610.0	532.00
11	180.0	790.0	700.00
12	195.0	985.0	887.50
13	205.0	1190.0	1087.50
14	211.0	1401.0	1295.50
15	215.0	1616.0	1508.50
16	219.0	1835.0	1725.50
17	221.0	2056.0	1945.50
18	223.0	2279.0	2167.50
19	225.0	2504.0	2391.50
20	226.0	2730.0	2617.50
21	227.0	2957.0	2843.50
22	228.0	3185.0	3071.00
23	229.0	3414.0	3299.50
24	230.0	3644.0	3529.00
25	230.0	3874.0	3759.00
26	231.0	4105.0	3989.50
27	231.0	4336.0	4220.50
28	232.0	4568.0	4452.00
29	232.0	4800.0	4684.00
30	233.0	5033.0	4916.50
31	233.0	5266.0	5149.50
32	233.0	5499.0	5382.50
33			5499.00

The rationale for the choice of level depths was that the function used to generate them should be smooth (ie. its derivatives should be continuous) and the maxima in the rate of change of level depth should occur away from areas of likely strong temperature, salinity or velocity gradients. The function used to generate the levels is

$$DZ(K) = 1.32 * ATAN\ ((K-9)/2) + 121$$

where K is the level number. For the ATAN function, the level number is assumed to be in units of degree.

This produced 32 levels with a cumulative depth of 5500m; a series of similarly spaced levels in the upper ocean and similarly spaced (but thicker) layers in the deep ocean. The maximum error in the depth at which derivatives are calculated through differencing between level centres, was 7.25% of the level thickness, and occurred at a depth of 450m. (M. Rowe, personal communication.)

2.2 Topography

The topography used was based on the DBDB5 depth dataset (US Naval Oceanographic Office). A 1° median filter was applied to the dataset and the result smoothed to give depths not less than the cumulative level depth at each point. This resulted in too much land and too many islands. Some of the islands were manually sunk and Bass Strait and some Antarctic lakes were filled in. These were features which could not be resolved on both the T,S,ψ grid and the u,v grid (M Rowe, personal communication). The topography was further smoothed so that no point was surrounded by a drop greater than half its height. This was to avoid instability problems which developed in the initial spin-up (Killworth 1987).

2.3 Open boundary

The code developed for the open northern boundary is due to Stevens (1991). In effect the barotropic flow is a flat bottom Sverdrup balance and for the baroclinic flow, temperature and salinity are relaxed to Levitus annual mean values where there is inflow.

2.4 Equation of state

The Eckart (1958) equation of state was used for all runs with the coarse resolution model (Webb 1992).

2.5 Bottom friction

Linear bottom friction was applied, of form:

F = -CD * **U** (coefficient CD = 0.1 in cgs units)

2.6 Initial conditions

Instability problems developed in early test runs when the model was initialized with observational temperature and salinity from the Levitus (1982) annual mean dataset. To overcome this, a 'robust diagnostic' method was used. The model was initialized from rest with specified values of temperature (-2.0°C) and salinity (36.69 parts per thousand), and relaxed to the Levitus data on a timescale of 180 days below level 5 and 60 days in the surface levels. The aim was to force the surface levels to realistic values as quickly as possible in order to spin up the model, while using a longer timescale at depth, where errors in the Levitus temperature and salinity data were thought to produce instabilities.

2.7 Input data

The input data file, Fortran unit 5, contains several NAMELIST datafiles defining the model. Variable NMIX determines the frequency of a forward timestep, while the remainder of the variables in CONTRL determine the frequency of output (NNERGY determines the frequency of output of the energetics data). The horizontal and vertical mixing coefficients are given by the variables in EDDY, where AH, AM are the horizontal viscosity coefficients for tracers and momentum and FKPHF, FKPMF are the vertical diffusion coefficients for tracers and momentum respectively. The timestep is given by variable DTTS. In all the runs made with the coarse resolution model, the timestep was one hour.

The stream function is calculated using the method of successive over-relaxation. The variable SORF gives the coefficient of over-relaxation used in the calculation, while CRITF is the convergence criterion and MXSCAN is the maximum number of scans allowed in the relaxation. The full file contains:

```
&CONTRL     NFIRST = 0, NLAST = 1000000, NNERGY = 72, NMIX = 10, NWRITE = 999,
            NDW=5, NTSI=1, NA=0, NB=0, NC=0 &END
&EDDY       AMF = 1.E8, AHF = 5.E7, FKPMF = 10., FKPHF = 0.5 &END
&TSTEPS     DTTSF = 3600, DTUVF = 3600, DTSFF = 3600  &END
&PARMS      ACORF = 0., MXSCAN = 999, SORF = 1.876, CRITF = 1.E8 &END
```

```
&HEAD       NDFIR = 0, NDLAS = 10000000, NDINC = 180 &END
&IBOX       ISIS = 2, 168, 302,  IEIS = 361, 181, 304, JSIS = 2, 35, 29,  JEIS =  19, 47, 31
            &END
```

The choice of timestep, diffusion coefficients and viscosity coefficients were made after reference to Killworth, Smith & Gill (1984). This paper is reproduced in Appendix I.

3 RUNS OF THE COARSE RESOLUTION MODEL AT THE ROBERT HOOK INSTITUTE

3.1 Tracers

Where Levitus temperature and salinity values are used, these were read in and the salinity converted to model units for each latitude row from J = 4, 56 as follows:

```
         DO 20 K = 1, 32
         READ ( ) (T(I,K,1), I=2,361)
         READ ( ) (T(I,K,2), I=2,361)
         DO 20 M = 1, 2
         T(1,K,M) = T(361,K,M)
         T(362,K,M) = T(2,K,M)
         IF (M .EQ. 2) THEN
         DO 10 I = 1, IMT
         T(I,K,M) = T(I,K,M)/1000.-0.035
10       CONTINUE
         ENDIF
20       CONTINUE
```

where T(I,K,1) is temperature, T(I,K,2) is salinity, I is the longitude index and K the depth index. Land values of both variables are stored in the data files as 99.99. In subroutine TRACER of the model code, land values of temperature are set to -20°C when land values of salinity are set to 0.01 model units (45 ppt) to stop convection.

3.2 Winds

The Hellerman & Rosenstein (1983) wind stress dataset was used for surface forcing. These data are available as monthly and annual means on a 2° x 2° global grid (latitude 89°S - 89°N, longitude 1° E - 359° E). Annual mean data were extracted for the latitude range

79°S - 25° S (to correspond to the coarse resolution model gridpoints I = 3, 5,... 361; J = 3, 5, ... 57) and stored in files WINDX, WINDY (2° x 2° grid) on the CRAY.

Interpolation to the 1° x 1° grid was made during the model run using the following scheme:

```
        DO 20 J = 3, 57, 2
        READ ( ) (ARRAY(I,J),I=3,361,2)
        DO 10 I = 2, 360, 2
        ARRAY (I,J) = ARRAY (I+1,J)
10      CONTINUE
        ARRAY (  1,J) = ARRAY(361,J)
        ARRAY (362,J) = ARRAY(  2,J)
        DO 20 I = 1,362
        ARRAY(I,J+1) = ARRAY(I,J)
20      CONTINUE
```

Values for rows J = 1, 2 were initialized to zero. In later runs, when the open boundary code was included, values corresponding to latitude 23°S (ie. J = 59) were obtained by extrapolation from those for latitudes 25°S and 27°S and the above code modified to loop over J = 3, 59.

3.3 Model output and restart data

For most of the coarse resolution model runs there are 14 output files, 13 'cutout' files produced by subroutine ASCOUT, and 1 energetics file produced by subroutine MATRIX. Restart data, consisting of the five files needed to run the model, are also saved at the end of each run. Tables with the Fortran unit numbers assigned for input and output are given in Appendix II.

The 'cutout' files contain horizontal slices of the model fields at selected depths or vertical slices of the model fields at selected latitudes or longitudes, preceded by a 10 record header produced by subroutine HEADER. Before subroutine ASCOUT is called, salinity values are converted to parts per thousand with a value of 10 over land, and temperature values over land are set to -20. In some runs the velocity and stream function fields are multiplied by a land mask array to give a much higher value over land. Subroutine ASCOUT then converts the data into compressed character format with 2 characters representing each value and two spaces for land.

Frequency of model output is controlled by HEAD data in the input data file:

NDFIR	=	timestep at which last 'cutout' was printed (in previous run).
NDINC	=	increment - timesteps between writing out.
NDLAS	=	last timestep to be printed in this run.

Latitude slices are written for indices J = 20, 30, 40 and 50 corresponding to latitudes 60, 50, 40 and 30 degrees S. Longitude slices are written for longitude indices I, stored in array LONG in subroutine STEP. These correspond to longitudes 0, 45, 90, 135, 180, 225, 270 and 315 degrees E. Depth slices are written for the depth indices K = 1, 6, 12, 18 and 28, stored in array LEVEL in subroutine STEP.

The naming convention for all files is XXYYYZZZ where:

XX = two letter run identifier.

YYY	=	RESTART	-	model restart data
		ENE	-	energetics output file
		STR	-	stream function
		SDE	-	salinity at constant depth (longitude vs latitude slices)
		TDE	-	temperature at " " " " "
		UDE	-	u velocity at " " " " "
		VDE	-	v velocity at " " " " "
		SLA	-	salinity at constant latitude (longitude vs depth slices)
		TLA	-	temperature at " " " " "
		ULA	-	u velocity at " " " " "
		VLA	-	v velocity at " " " " "
		SLO	-	salinity at constant longitude (latitude vs depth slices)
		TLO	-	temperature at " " " " "
		ULO	-	u velocity at " " " " "
		VLO	-	v velocity at " " " " "

ZZZ = run number - usually the last day of the run.

3.4 Model runs

The early runs and associated datasets are:

DIAG(DI) - 'robust diagnostic' run relaxing to Levitus, with annual mean winds. Restart data stored at days 360, 720, 1080 and output data at days 180, 720, 1080.

SURF(SF) - one year run with surface temperature and salinity set to Levitus, commencing after three years of DIAG. Restart and output data at day 1440.

ODIAG(OD) - 'robust diagnostic' run as DIAG, but including open boundary. Restart data at days 360, 540, 1080. Output data at days 360, 540, 720, 1080.

OSURF(OS) - one year run with surface temperature and salinity set to Levitus, open boundary and annual mean winds. It follows three years of ODIAG.. Restart and output data at day 1440.

FDIAG(FD) - 'robust diagnostic' run as ODIAG. Restart and output data at days 360, 720, 1080.

FSURF(FS) - one year run with surface temperature and salinity set to Levitus. It follows three years of FDIAG. Restart and output data at day 1440.

S4 - spindown run initialized with Levitus temperature and salinity, with bottom drag coefficient, CD, increased from 0.1 to 0.4. Restart and output data at day 1080.

4 RUNS OF THE COARSE RESOLUTION MODEL AT IOSDL

In October 1988, when the core team transferred to IOSDL, the restart dataset ODRESTART1080, the result of three years of a 'robust diagnostic' run with open boundary and annual mean winds, was used as the basis for further development. Several modifications were made to the code and the model run on for a year.

4.1 Southern boundary

The southern boundary, defined in the model by SWLDEG, was moved from 81°S to 79°S, as the first two latitude rows were found to contain only land. SWLDEG refers to the latitude of the first (J = 1) row of velocity points and the latitude of the first row of temperature points is now at 79.5° S. The northern boundary, defining the latitude of the last (J = JMT) row of velocity points, remained unchanged at 24° S. The total number of latitude rows, JMT, was reduced from 58 to 56.

A new topography file, SMDEPS2, was created to fit the model domain. Other input files, containing the Levitus temperature and salinity data and the Hellerman & Rosenstein annual mean wind stress, were not re-created. Changes were made in the model code to skip over the surplus data.

4.2 Calendar years

Conversion was made from 360-day years to calendar years with every fourth year a leap year. The model was assumed to start on 1st January 1901.

4.3 Winds

Seasonal wind forcing was introduced. The Hellerman monthly winds are stored in files in the same format as the annual mean winds (2° x 2° global grid; latitude 89°S to 89°N, longitude 1° E - 359° E). Information supplied with the data implied that the longitude range was 2° E - 360° E and the interpolation below was made under this assumption.

Data was extracted for the latitude range 79°S to 23°S (ie. I = 4,.6,.. 360; J = 1, 3,... 59) and stored on the CRAY in file HELLERMANWINDS2. Interpolation to a 1° x 1° grid is made in the model run as follows:

```
DO 10 J = 1, 59, 2
         READ ( ) (ARRAY(I,J), I = 2,360,2)
         DO 10 I = 3, 361, 2
         ARRAY(I,J) = 0.5 * (ARRAY(I-1,J) + ARRAY(I+1,J)
10       CONTINUE
20       CONTINUE
         DO 20 J = 2, 58, 2
         DO 20 I = 2, 361
         ARRAY(I,J) = 0.5 * (ARRAY(I,J-1) + ARRAY(I,J+1))
```

```
20        CONTINUE
          DO 30 J = 1, 59
          ARRAY(362,J) = ARRAY(2,J)
          ARRAY(1,J) = ARRAY(361,J)
30        CONTINUE
```

In subroutine STEP, winds for the next month are read in when the middle of the month is reached, and the wind stress for each timestep is calculated by interpolating between values for consecutive months. The change from annual to seasonal winds was made by interpolating between the annual mean and the January mean for the period between the end of year 3 and mid-January of year 4.

4.4 Open boundary code

The tracer arrays TN on the northern boundary were removed from the KONTRL file. These can be computed at the beginning of each run from the arrays of observed tracers read in for the surface forcing calculation.

A correction was made to the open boundary code to ensure that salinity values over land are set to the masked values required by the ASCOUT code.

4.5 Initial conditions

The code for the initialization of temperature and salinity was re-instated in the model. Although only used when starting a run from scratch (i.e. NFIRST = 0), it was included for clarity.

4.6 Input data

Changes were made to the input data file, Fortran unit 5, to reduce the frequency of a forward timestep, set by NMIX, to once a day (24 timesteps), and the calculation of the energetics output to once every 360 timesteps.

4.7 Output data

The two letter run identifier was changed to three letters:

First	=	C	for the coarse resolution model
Second	=	A-Z	for the version of the model
Third	=	A-Z	for the particular run of the version.

Subroutine SLICE, which previously called subroutine ASCOUT, was removed and ASCOUT called directly from STEP.

Headers

New headers were devised and subroutine HEADER modified. The records, with the format used to write them, are as follows:

Record 1
a) The variable name - temperature, salinity, u velocity, v velocity, stream function.
b) In the case of one of the first four variables,the type of slice is also given - ie. control variable - latitude, longitude or depth.
c) The format code, at present always 'CC' indicating two character compressed ASCII format.
Format (10X,A15,T41,10X,A8) for the stream function or (10X,A12,2X,A9,T41,10X,A8) for the other variables.

Record 2
The contents of the comment field, NRUN. This is usually the same as the three letter run identifier.
Format (10X,A55).

Record 3
Indices 1, 2, 3 for header variables in record 4.
Format ('INDEX ',9X,':',3(' ',I1,' :')).

Record 4
The indexing variable names 'QUANTITY' for the file. There are three, of which the first two are combinations of LATITUDE, LONGITUDE, DEPTH and the third is always TIMESTEP.
Format (16X,A9,1X,A9,1X,A9).

Record 5
The starting values 'FROM' of the variables in record 4. These are 78°S for LATITUDE, 0°E for LONGITUDE, level 1 for DEPTH and NDFIR for TIMESTEP.
Format (16X,A9,1X,A9,1X,A9).

Record 6 The increments 'INCR' of the variables, +1 for LONGITUDE and DEPTH, -1 for LATITUDE and NDINC for TIMESTEP.
Format (16X,A9,1X,A9,1X,A9).

Record 7 The last values 'TO' of the variables, 25°S for LATITUDE, 359°E for LONGITUDE, 32 for DEPTH and NDLAS for TIMESTEP.
Format (16X,A9,1X,A9,1X,A9).

Record 8 The number of distinct variables 'NOPS' in record 4; 54 for LATITUDE, 360 for LONGITUDE, 32 for DEPTH and (NDLAS-NDFIR)/NDINC for TIMESTEP.
Format (16X,I9,1X,I9,1X,I9).

Record 9 The values 'VALS' of the control variable for the slice. For the stream function this record is blank.
Format (16I5).

Record 10 The time in seconds TTSEC1 of the first 'cutout' and the duration in seconds of the timestep DTTS used in the run.
Format (12X,F12.0,6X,F5.0).

For 'cutout' files at days 1095, 1186, 1368 and 1461 of run CAA, the first timestep in the header, NDFIR, is the timestep at which the last 'cutout' was computed on the previous run. After run CAA-1461, it contains NDFIR1, the timestep of the first 'cutout' of the current file.

Subroutine ASCOUT

A new version of subroutine ASCOUT was developed to allow for four different masks (..), (.,), (,.), (,,). The mask value (..) is currently used for land and (.,) for submerged land. Previously ( ) had been used for land. The array VMASK(4) is set in a data statement in the main program as follows: DATA VMASK /1.E10, 2.E10, 3.E10, 4.E10/. These values are used to signal the four different masks to ASCOUT. When encountered in a dataset, ASCOUT represents them by the corresponding mask character pair in the ASCOUT file.

Subroutine MATRIX is now only called to print the ENERGETICS file. The code calling MATRIX for the other variables was removed as these are now printed using subroutine ASCOUT.

In order to be able to compare with later runs, new 'cutout' files were created for the OD - 3 dataset to correspond to CAARESTART1080 - ie. with JMT = 56 and the new masking values.

4.8 Updates

Updates were rearranged with consistent numbering so that inserts for a particular modification (eg: open boundary, winds, relaxation...) appear together in the update file.

Surface forcing	Modification	'01'
Wind stress		'02'
Speed up of relaxation		'03'
Code for ASCOUT files		'90'
Open boundary code		'80'

4.9 Model runs

A restart dataset for day 1080, CAARESTART1080, was created from ODRESTART1080 incorporating the changes referred to above, as follows:

a) The TN array was removed from the KONTRL file. The area and volume of the ocean remain the same because the rows removed contained only land.

b) Arrays for J = 2, 3 were removed from the first 6 fields in the KFLDS file. The J values for the island box indices stored in field 7 were reduced by 2, except for the first island which starts at J = 2.

c) Arrays for J = 2, 3 were removed from the LABS files. The arrays for J = 1, corresponding to the boundary, are set to zero and used in the program for initializing some arrays.

The runs undertaken using the new restart dataset, CAARESTART1080, are:

CAA - one year run with seasonal winds and open boundary conditions, surface temperature and salinity set to Levitus. Restart and 'cutout' data were stored at days 1080, 1095, 1186, 1277, 1368 and 1461. At the end of this run an error was found in the code to write out the results of the open boundary calculation.

CAB - 15 day run with corrected open boundary code starting from CAARESTART1080. Same conditions as CAA.

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APPENDIX I :

SPEEDING UP OCEAN CIRCULATION MODELS

P.D. KILLWORTH, J.M. SMITH & A.E. GILL; Ocean Modelling 65, April 1984.

The use of oceanic general circulation models to investigate climate questions leads to problems about the large amount of computer time required to run models to equilibrium. Accordingly, devices have been found for artificially speeding up the process by multiplying some of the time derivative terms in the equation by *ad hoc* factors on the grounds that this does not affect the equilibrium solution in any way (Bryan & Lewis 1979). But then it may be important to include seasonal changes in the model, and these may have a profound effect on the way in which bottom water is formed. In these circumstances, is it legitimate to introduce the *ad hoc* factors?

This question leads on to the idea that for slow enough changes, multiplying some time-derivative terms in the equations may speed up the integrations *without* seriously distorting the physics. So we look into this question here. We base our approach on the idea that for motions large compared with the Rossby radius, the momentum equations are well represented by an exact geostrophic balance, except perhaps in boundary layers, so that time changes occur entirely through the time-derivative terms in the heat and salt equations. The combination of these balances leads to the so-called "thermocline equations" and these are the equations which are the basis for the Hamburg climate model's ability to use large time steps. Here we raise the question about the possibility of achieving a similar efficiency by multiplying the time-derivative terms in the momentum equations by artificial factors. If that does not prevent the momentum balance from being primarily geostrophic, the thermocline equations are still being satisfied and hence the physics of the slow adjustment processes is not being distorted.

So consider the effect of using the Bryan & Lewis (1979) technique of multiplying the $\partial/\partial t$ terms in the momentum equations by an artificial factor α. Bryan & Lewis (1979), for instance, used a value of 20 to achieve a twenty-fold increase in time step. In the GFDL model as described by Semtner (1974), this change is very easily implemented. The artificial factor will clearly distort some shorter time-scale transient effects like inertial oscillations, coastal waves and equatorial waves, but suppose these have come into some sort of equilibrium with friction? Longer time scale adjustments may involve planetary waves. How are these affected by the introduction of the α-factor? This effect may be demonstrated by considering the linear system for a single vertical mode, namely

$$\alpha u_t - f v + p_x = 0 \tag{1}$$

$$\alpha v_t + f u + p_y = 0 \tag{2}$$

$$p_t + c^2(u_x + v_y) = 0 \tag{3}$$

for velocity (u,v) relative to axes (x,y) east and north, with pressure, p, internal wave speed c, and Coriolis term f. Dissipative and boundary effects will be considered later. The dispersion relation for planetary waves varying as $exp\ i(kx+ly-\omega t)$ is then

$$\omega = -\frac{\beta k}{\alpha(k^2+l^2)+a^{-2}} \tag{4}$$

where $\beta = \mathrm{d}f/\mathrm{d}y$ and $a = cf^{-1}$ is the deformation radius. The result of increasing α above unity in (4) is to leave the long wave speed $-\beta a^2$ unchanged, but to slow down the shorter waves, of wave numbers greater than or equal to $\alpha^{-1/2}a^{-1}$. Since we expect the short waves, which are not resolved in coarse-grid models anyway, to be selectively damped by various boundary and scale-dependent frictional processes, it seems that α may be taken quite large without much disturbing the physics. For instance, if α is 20, the long-wave approximation which is essential for thermocline equation physics to hold applies for inverse wavenumbers in excess of 135 km instead of 30 km. This is obviously not a serious deficiency for a model with a resolution of 300 km!

Suppose, on the basis of the above arguments or otherwise, that it is legitimate to introduce an artificial α-factor, what limitations are imposed on it on stability grounds, and how much speeding up can be achieved in practice? We investigate these questions below.

First, as a baseline criterion, the limit on the size Δt of the timestep in thermocline equation integrations is the advective CFL condition coming from the heat and salt equations, namely

$$\Delta t < \left| v \right| \Delta^{-1} \tag{5}$$

where Δ is the grid-size and v is the maximum advection velocity, which in practice may have a value of about 1 ms^{-1}. Also, if K_H is the diffusivity of heat and salt, the condition

$$\Delta t < \Delta^2 / 8 K_H \tag{6}$$

must be satisfied, but this is usually satisfied if (5) is.

A similar limitation on the timestep is the one corresponding to (6) for the horizontal eddy viscosity A_m. When the α factor is included, this condition takes the less restrictive form

$$\Delta t < \alpha \Delta^2 / 8A_m \qquad (7)$$

In coarse resolution models, at least, A_m is much larger than K_H because it is chosen to make the Munk western boundary layer stable. Numerically, one finds that

$$\Delta < (A_m / \beta)^{\frac{1}{3}} \qquad (8)$$

gives "correct" behaviour near the western boundary while the cruder condition

$$\Delta < 2(A_m / \beta)^{\frac{1}{3}} \qquad (9)$$

gives a steady solution which is just beginning to exhibit oscillating behaviour. By eliminating A_m between (7) and (8), or (9), we find the condition on Δt is

$$\Delta t < \alpha / 8\beta\Delta \qquad \text{(resolved layer)} \qquad (10)$$

or

$$\Delta t < \alpha / \beta\Delta \qquad \text{(marginal)} \qquad (11)$$

Clearly the bigger we can make α, the larger the timestep that can be taken. So we now look at other stability criteria associated with internal Poincaré waves to see what restrictions they place on possible values of α.

We consider for definiteness a C-grid as used by Semtner (1974), in which u and v are stored at the same point, shifted $(\frac{1}{2}\Delta x, \frac{1}{2}\Delta y)$ from p. Centred time differences are used for all time derivatives, and we include the possibilities of both explicit and semi-implicit treatments of both inertial terms and pressure gradients. (In other words, fv evaluated explicitly is the current value; semi-implicitly, fv is the average of old and new values.) Semtner's model allows all these options. One could also include the possibility of semi-implicit divergence terms, although the problem would then require iterative solution of a (three-dimensional) Poisson equation. We take f to be constant for the moment, i.e. so that the Poincaré wave dispersion relation is $\omega^2 = f^2 + (k^2 + l^2)c^2$.

Equations (1) to (3) become, in finite difference form,

$$\alpha \delta_t \overline{u}^t - f v = -\delta_x \overline{p}^y \qquad (12)$$

$$\alpha \delta_t \overline{v}^t + f u = -\delta_y \overline{p}^x \qquad (13)$$

$$\delta_t \overline{p}^t + c^2(\delta_x \overline{u}^y + \delta_y \overline{v}^x) = 0 \tag{14}$$

together with possible semi-implicit evaluations on Coriolis and pressure gradient terms. If solutions are sought proportional to $exp\ i\,(kx + ly)$, and time dependence λ^n at time n, where $|\lambda| \leq 1$ indicates stability, then (12) to (14) become

$$A\alpha u + if\,Bv + \frac{2}{\Delta x}\,\sin k' \cos l'\,C_p = 0 \tag{15}$$

$$-if\,Bu + A\alpha v + \frac{2}{\Delta y}\cos k' \sin l'\,C_p = 0 \tag{16}$$

$$\frac{2}{\Delta x}\,\sin k' \cos l' u + \frac{2}{\Delta y}\,\cos k' \sin l' v + \frac{Ap}{c^2} = 0 \tag{17}$$

where

$$k' = \frac{1}{2}\,k\Delta x, \quad l' = \frac{1}{2}\,l\Delta y \tag{18}$$

and

$$iA = \frac{\lambda - 1/\,\lambda}{2\Delta t}$$

$$B = \begin{cases} 1 & \text{explicit Coriolis} \\ \frac{1}{2}(\lambda + \frac{1}{\lambda}) & \text{semi-implicit Coriolis} \end{cases} \tag{19}$$

$$C = \begin{cases} 1 & \text{explicit pressure} \\ \frac{1}{2}(\lambda + \frac{1}{\lambda}) & \text{semi-implicit pressure} \end{cases}$$

Evaluation of the determinant implies

$$A^2\alpha^2 - f^2B^2 - 4\alpha c^2 C \left\{ \frac{K(1-L)}{\Delta x^2} + \frac{L(1-K)}{\Delta y^2} \right\} = 0 \tag{20}$$

where

$$K = \sin^2 k', \quad L = \sin^2 l' \tag{21}$$

The expression in curly brackets can thus take any value of the form $\gamma \Delta^{-2}$, where $0 \le \gamma \le 1$, and $\Delta = \min(\Delta x, \Delta y)$. It will become apparent that the most stringent conditions involve $\gamma = 1$, which will be assumed henceforth.

It is easy to see that if we set $\lambda = e^{i\theta}$, stability requires θ real. Thus (20) becomes

$$\alpha^2 (1-\mu^2) - f^2 \Delta t^2 B^2 - \frac{4\alpha c^2 \Delta t^2 C}{\Delta^2} = 0 \tag{22}$$

where

$$\mu = \cos\theta \tag{23}$$

and

$$(B, C) = 1\,(\text{explicit})\ or\ \mu\,(\text{semi-implicit}) \tag{24}$$

Case 1: Pressure and Coriolis both semi-implicit $B = C = \mu$

Eqn (22) becomes

$$(\alpha^2 + f^2 \Delta t^2)\,\mu^2 + \frac{4\alpha c^2 \Delta t^2}{\Delta^2}\,\mu - \alpha^2 = 0 \tag{25}$$

whose roots lie in the range [-1,1] iff

$$\left\{\frac{4\alpha^2 c^4 \Delta t^4}{\Delta^4} + \alpha^2 (f^2 \Delta t^2 + \alpha^2)\right\}^{\frac{1}{2}} \le f^2 \Delta t^2 + \alpha^2 - \frac{2\alpha c^2 \Delta t^2}{\Delta^2} \tag{26}$$

which after a little algebra reduces to the single condition for stability

$$\alpha < \left\{\frac{D}{2a}\right\}^2 \tag{27}$$

where $a = c/f$ is again the deformation radius.

Case 2: Pressure semi-implicit, Coriolis explicit $B = 1$, $C = \mu$

Eqn (22) is now

whose roots lie in the range [-1,1] iff

$$f\Delta t < \alpha < \left\{ \frac{\Delta}{2a} \right\}^2 . \qquad (29)$$

Case 3: Pressure explicit, Coriolis semi-implicit $B = \mu$, $C = 1$

Eqn (22) now gives

$$\mu^2 = \frac{\alpha^2 - \dfrac{4\alpha c^2 \Delta t^2}{\Delta^2}}{\alpha^2 + f^2 \Delta t^2} \qquad (30)$$

whose roots are stable iff

$$\alpha > \frac{4c^2 \Delta t^2}{\Delta^2} \qquad (31)$$

Case 4: Pressure and Coriolis both explicit $B = C = 1$

The condition becomes

$$0 < \mu^2 = \frac{1}{\alpha^2}\left(\alpha^2 - f^2 \Delta t^2 - \frac{4\alpha c^2 \Delta t^2}{\Delta^2} \right) < 1 \qquad (32)$$

so that stable roots exist iff

$$\alpha \geq \frac{2c^2 \Delta t^2}{\Delta^2} + \left\{ \frac{4c^4 \Delta t^4}{\Delta^2} + f^2 \Delta t^2 \right\}^{\frac{1}{2}} \qquad (33)$$

These results may be summarised as follows. First, unless there is a specific reason to simulate inertial oscillations with high accuracy, there is no reason to use an explicit Coriolis term, since (29), (33) are respectively more restrictive than (27), (31). Second, there is a choice to be made regarding the nature of the pressure gradient terms. If these are explicit, the CFL criterion $\alpha^{1/2} > 2c\Delta t/\Delta$ must at least be satisfied, whereas if these are implicit, there is a limit on grid-spacing $\Delta > 2a\alpha^{1/2}$, so that one cannot have a very fine spacing. However, the choice of scheme is also coloured by which planetary waves will be affected by the choice of α. Equation (4) shows that these have a length scale of order $\alpha^{1/2}a$, so we would prefer that the grid spacing is somewhat larger than this cutoff; there is little point in resolving waves which are distorted. Thus (27) seems a sensible restriction even for explicit pressure gradients. The problem of how (27) leads into equatorial beta-plane dynamics is somewhat difficult, but it seems reasonable to use for a either the value relevant to the nearest point to the equator (for mid-latitude models) or the equatorial deformation radius $(c/2\beta)^{1/2}$ for simulations including the equator. One would presumably want to maintain $\alpha = 1$ in the u equation but make $\alpha > 1$ in the v equation to avoid modifying the long Kelvin waves.

This completes the list of restrictions, save for those relating to the stability of planetary waves. Under normal circumstances these are far less restrictive than those listed earlier, and will be ignored.

We may combine these restrictions in various ways. Table 1 seems to be a useful way of looking at the restrictions. We consider three resolutions: fine (30 km), medium (100 km) and coarse (300 km) on a beta-plane with $f \sim 10^{-4}\ s^{-1}$, $\beta \sim 2 \times 10^{-11}\ m^{-1}s^{-1}$, $C \sim 3\ ms^{-1}$, giving $a \sim 30$ km.

The degree of resolution is crucial in determining both numerical scheme and the value of α, i.e. the degree to which the method may be accelerated, although the advective CFL criterion is important in all cases. For fine resolution, restriction (27) limits consideration to explicit pressure gradient terms only, with no acceleration ($\alpha = 1$). The gravity wave CFL criterion (31) then forces Δt to be less than 5000 seconds.

For medium resolution, however, a degree of acceleration is possible. The best choice seems to be semi-implicit pressure gradients, which permit $1.6 < \alpha < 2.8$, with timesteps as large as 10^5 s (the advective CFL limit). The length scales of the distorted planetary waves are 38 to 50 km, comfortably not resolved by the grid spacing.

For coarse resolution, it is possible to accelerate the process greatly, with $14 < \alpha < 25$ for semi-implicit pressure terms, and timestep of 3×10^5 s, again the advective CFL limit. In this case, the timestep is much larger (i.e. 14 times as large) than would be possible with $\alpha = 1$, and as a result it should be possible to perform distinctly longer integrations.

References

BRYAN, K and L J LEWIS 1979. J.Geophys.Res. 84 (c),2503-2517.

SEMTNER, A J 1974. An oceanic general circulation model with bottom topography. Tech Rept No 9, Dept of Meteorology, Univ of California, Los Angeles.

		Fine (30 km)	*Medium (100 km)*	*Coarse (300 km)*
CFL on ρ equation $\Delta t < v^{-1}\Delta y,\ v \sim 1\ ms^{-1}$		$\Delta t < 3 \times 10^4$ s	$\Delta t < 10^5$ s	$\Delta t < 3 \times 10^5$ s
Diffusion ρ equation $\Delta t < \Delta^2 / 8K_H$	$K_H =$ 10^6 10^7 10^8	$\Delta t <$ 1.1×10^6 1.1×10^5 s 1.1×10^4	$\Delta t <$ 1.3×10^7 1.3×10^6 s 1.3×10^5	$\Delta t <$ 1.1×10^8 1.1×10^7 s 1.1×10^6
Resolved viscosity/Munk	$\alpha > 8\ \beta\Delta.\Delta t$	$\alpha > 4.8 \times 10^{-6}\ \Delta t$	$\alpha > 1.6 \times 10^{-5}\ \Delta t$	$\alpha > 4.8 \times 10^{-5}\ \Delta t$
or				
Marginal viscosity/Munk	$\alpha > \beta\Delta.\Delta t$	$\alpha > 6 \times 10^{-7}\ \Delta t$	$\alpha > 2 \times 10^{-6}\ \Delta t$	$\alpha > 6 \times 10^{-6}\ \Delta t$
CFL on gravity wave (for explicit pressure terms) $\alpha > 4c^2\Delta t^2 / \Delta^2$		$\alpha > 4 \times 10^{-8}\ \Delta t^2$	$\alpha > 3.6 \times 10^{-9}\ \Delta t^2$	$\alpha > 4.8 \times 10^{-10}\ \Delta t^2$
Resolution of cutoff planetary wave by Δx *or* restriction for implicit pressure terms when $\alpha > 1$ $\alpha \lesssim (\Delta / 2a)^2$		$\alpha < 0.25$	$\alpha < 2.8$	$\alpha < 25$
Result (explicit pressure)		$\Delta t \lesssim 5 \times 10^3$ s $\alpha = 1$	$\Delta t < 2.8 \times 10^4$ s $\alpha < 2.8$	$\Delta t < 2.3 \times 10^5$ s $\alpha < 25$
Length scale of altered planetary wave	$\alpha^{1/2}\ a$ for max Δt	—	< 50 km	< 150 km
Result (implicit pressure) Resolved Munk		not usable	$\Delta t < 10^5$ s $2.8 > \alpha \gtrsim 1.6$	$\Delta t < 3 \times 10^5$ s $25 > \alpha \gtrsim 14$
Length scale of altered planetary wave	$\alpha^{1/2}\ a$ for max Δt	—	38 to 50 km	110 to 150 km

Table 1 : Restrictions on α, Δt. Firm line marks restrictions dominant for explicit pressure, dashed line for semi-implicit pressure.

APPENDIX II :

FILES FOR RUNNING THE COARSE RESOLUTION MODEL

The coarse resolution model was run on the CRAY X-MP at the Atlas Centre of the Rutherford Appleton Laboratory. Communication to the CRAY was through the IBM front-end service. The model restart, topography and forcing field datasets were stored on the CRAY, but the model decks and post-processing programs were developed and stored on the IBM front-end. Model output was disposed to the front-end for transfer to other sites. The files are now archived at IOSDL under ID BAC.

1. Files used at the Robert Hooke Institute

1.1 On the IBM front-end

Decks

SPINDOWN DECK	Basic run from initial density field (Levitus temperature and salinity).
SPINWIND DECK	SPINDOWN DECK with annual mean winds.
OBCWIND DECK	SPINWIND DECK with open boundary.
ODIAG DECK	Three year 'robust diagnostic' run with open boundary and annual mean winds, using SMDEPS, SMTEMP and SMSALT. Followed by:
OSURF DECK	ODIAG DECK with surface temperature and salinity set to Levitus.
FDIAG DECK	Same as ODIAG DECK.
ICE DECK	ODIAG DECK with snow and ice additions.
SNOICE DECK	Same as ICE DECK.
MODEL DECK	Cox's MODEL 1 DECK, runs in core contained mode.
ML DECK	A deck of updates written by Mark Lewis. These merge together DO LOOPS to improve vectorization.

Fortran programs

UPDOC FORTRAN	Code to insert updates into main COX code.
SMOOTH FORTRAN	Reads in modified 1° median topography, smooths to ensure there is no point surrounded by a drop greater than half its height. New topography SMDEPS.
MAP FORTRAN	Produces a 'readable' map of the model topography.
CRSALT FORTRAN	Used to create salinity dataset. Reads in LEVSALT, shifts the grid by 1/2°

	and creates new values where necessary for topography SMDEPS.
CRTEMP FORTRAN	As above, for temperature, reading in LEVTEMP.
COX4 FORTRAN	Actual COX code with multitasking implemented.

Job control files

These programs will run the corresponding model decks on the CRAY, assigning the input files needed. They are written for the COS operating system and would need modification to run under UNICOS.

MODEL JOB	Runs MODEL DECK.
ODIAG1 JOB OSURF1 JOB FDIAG JOB	Run corresponding DECKS for 1 year saving restart data.
SPINMIC JOB	Runs COX4 FORTRAN with multitasking code for improved efficiency.
SNOW3 JOB	Runs ICE DECK for 6 days. Prints 'cutouts' once a day.
AUDIT JOB	Produces a list of files stored on the CRAY.
SPIN EXEC	Uses SPIN DATA, SPIN XEDIT and ADDON XEDIT. When run it prints a file changing the various names in the file (starting at exactly the same place), will create new JOB and DATA files with a given name.

In addition there should be DIAG DECK, a three year 'robust diagnostic' run with annual mean winds, and associated DIAG JOB. It seems likely that these were modified to become ODIAG DECK, ODIAG JOB.

1.2 On the CRAY

Fortran programs

COX	Model base code.
UPDOC	Copy of UPDOC FORTRAN to add updates to base code.
SEMP	Semtner's model code and information.

Topography

DEPS SMDEPS	1° median DBDB5 topography + a few points changed manually. Smoothed version of DEPS (smoothed so that no point is surrounded by a drop greater than half its height).

Fields

LEVTEMP LEVSALT	Original Levitus temperature and salinity datasets.

COXSLT COXTP	Temperature and salinity datasets for topography DEPS (runs initializing from Levitus)
BUFFTP BUFFSL	Temperature and salinity datasets used by DIAG DECK, ODIAG DECK and FDIAG DECK (buffered in).
SMSALT SMTEMP	Temperature and salinity datasets for topography SMDEPS (general coarse resolution model).
WINDX WINDY	Annual mean Hellerman wind stress.

NB: Names for data files used on the CRAY under the COS operating system have a maximum of 7 letters, but permanent data names can have up to 15 letters.

1.3 Input and output files assigned in the model runs

Input files

Fortran Unit No. :	*File name :*
5	DATA (standard input file)
7	SMDEPS
8	BUFFTP
9	BUFFSL
11	KONTRL
12	KFLDS
13	LABS1
14	LABS2
15	LABS3
63	WINDX
64	WINDY
65	SMTEMP
66	SMSALT

Output files

Fortran Unit No. :	*File name*
6	(standard output file)
18	£STATS(I/O statistics)
30	TEMPS
31	SALINS
34	WVE
35	UVE
36	VVE
37	TLA
38	SLA
39	STR
50	TLO
51	SLO
54	TDE
55	SDE
56	ULA
57	VLA
58	ULO
59	VLO
60	UDE
61	VDE
62	ENE

2. FILES USED AT IOSDL

2.1 On the IBM front-end

Decks

CAA DECK	ODIAG DECK with changes made as decribed in main text.
CAB DECK	As CAA DECK with correction to open boundary code.

Job control files

CAA JOB	Runs CAA DECK disposing 'cutout' files and storing restart data at the end of each run.
CAB JOB	Runs CAB DECK for fifteen days disposing 'cutout' files and saving restart data at the end of the run.

2.2 Files on the Cray

Fortran programs

COX	Model base code.
COXBASECODE	Model base code used.
UPDOC	Copy of UPDOC FORTRAN to add updates to base code.
UPDOCBIN	UPDOC in binary code
SEMP	Semtner's model code and information.

Topography

DEPS	Basically 1 degree median Levitus topography + a few points changed manually.
SMDEPS	Smoothed version of DEPS.
SMDEPS2	SMDEPS with first two latitude records removed.

Fields

COXTP COXSLT	Temperature and salinity datasets for topography DEPS (not used).
LEVTEMP LEVSALT	Original Levitus temperature and salinity datasets.

SMTEMP SMSALT	Temperature and salinity datasets for topography SMDEPS (general coarse resolution model).
WINDX WINDY	Annual mean Hellerman wind stress.
HELLERMANWINDS2	Monthly wind stress (Jan. x, y stress - Dec. x,y stress) for latitudes 79° - 23° S.

2.3 Input and output files assigned in the model runs

Input files

Fortran Unit No.:	*File name :*
5	DATA (standard input file)
7	SMDEPS2
8	SMTEMP
9	SMSALT
10	DECK (deck with updates)
11	KONTRL
12	KFLDS
13	LABS1
14	LABS2
15	LABS3
20	COX (COXBASECODE)
63	WINDX
64	WINDY
65	HWINDS2 (HELLERMANWINDS2)

Output files

Fortran Unit No. :	*File name :*
6	(standard output file
18	£STATS (I/O statistics)
30	TEMPS
31	SALINS
34	WVE
35	UVE
36	VVE
37	TLA
38	SLA
39	STR
50	TLO
51	SLO
54	TDE
55	SDE
56	ULA
57	VLA
58	ULO
59	VLO
60	UDE
61	VDE
62	ENE

APPENDIX III :

STORAGE OF THE MODEL DATASETS

The output from the model runs and the data needed to restart the model are stored at regular intervals on 3480 cartridge tapes maintained at the Atlas Centre. Back-up copies of the forcing field and topography data are also kept on tape.

1. Runs of the coarse resolution model at the Robert Hooke Institute

1.1 Tape programs

TAPE EXEC — Writes the restart data to tape.

ACCTAPE JOB
TAPEACC JOB
RESTAPE JOB — Used by TAPE EXEC
RESTAPE2 JOB
RESDIAG JOB

1.2 Tape details

Topography and forcing fields

Tape number 801763/4 (IBM standard label)

File name	File sequence	File name	File sequence
COX	1	SEMP	8
COXSLT	2	SMDEPS	9
COXTP	3	SMFSAL	10
DEPS	4	SMFTEM	11
FLDEPS	5	UPDOC	12
LEVSALT	6	COXOCEAN	13
LEVTEMP	7		

Model restart data

Tape numbers 800674/5 (unlabelled)

Dataset name	*File sequence*	*Dataset name*	*File sequence*
DIRESTART1080	1	ODRESTART1080	6
DIRESTART360	2	OSRESTART1440	7
DIRESTART720	3	S4RESTART1080	8
ODRESTART360	4	SFRESTART1440	9
ODRESTART540	5		

Tape numbers 800676/8 (unlabelled)

Dataset name	*File sequence*	*Dataset name*	*File sequence*
FSRESTART1440	1	FDRESTART720	3
FDRESTART360	2	FDRESTART1080	4

Model output

Tape numbers 800892/3 (IBM standard label)

Slice	*Data*	*Fseq*	*Data*	*Fseq*	*Data*	*Fseq*	*Data*	*Fseq*	*Data*	*Fseq*
ENE	DI180	1	DI720	15	DI1080	29	SF1440	43	OD360	57
STR		2		16		30		44		58
SDE		3		17		31		45		59
TDE		4		18		32		46		60
UDE		5		19		33		47		61
VDE		6t		20		34		48		62
SLA		7		21		35		49		63
TLA		8		22		36		50		64
ULA		9		23		37		51		65
VLA		10		24		38		52		66
SLO		11		25		39		53		67
TLO		12		26		40		54		68
ULO		13		27		41		55		69
VLO		14		8		42		56		70
ENE	OD540	71	OD720	85	OD1080	99	OS1440	113	FD360	127
STR		72		86		100		114		128
SDE		73		87		101		115		129
TDE		74		88		102		116		130
UDE		75		89		103		117		131
VDE		76		90		104		118		132
SLA		77		91		105		119		133
TLA		78		92		106		120		134
ULA		79		93		107		121		135
VLA		80		94		108		122		136
SLO		81		95		109		123		137
TLO		82		96		110		124		138
ULO		83		97		111		125		139
VLO		84		98		112		126		140
ENE	FD720	141	FD10800	155	FS1440	169	S41080	183		
STR		142		156		170		184		
SDE		143		157		171		185		
TDE		144		158		172		186		
UDE		145		159		173		187		
VDE		146		160		174		188		
SLA		147		161		175		189		
TLA		148		162		176		190		
ULA		149		163		177		191		
VLA		150		164		178		192		
SLO		151		165		179		193		
TLO		152		166		180		194		
ULO		153		167		181		195		
VLO		154		168		182		196		

2. Runs of the coarse resolution model at IOSDL

2.1 Tape programs

TAPEWR FORTRAN	writes the restart data in compressed form, consisting of the contents of the KONTRL file, most of the KFLDS file, the LABS file for the current timestep (containing temperature, salinity, u and v velocity, the masking array for temperature and salinity and the x- direction wind stress) and the masking array for velocity and y- wind stress from the LABS file for the previous timestep. This comprises all the data needed to restart the model on a forward timestep.
TAPERD FORTRAN	reads the file created by TAPEWR FORTRAN and creates the five restart files needed by the model code
TAPEWR JOB	calls TAPEWR FORTRAN and writes the restart data file to tape
TAPERD JOB	reads the tape,calls TAPERD FORTRAN and writes the five restart files to disk.

These job control files are written for the COS operating system used by the CRAY at the time and need to be converted for use under the current UNICOS operating system.

2.2 Tape details

Topography and forcing fields

Tape numbers 800906/7 (IBM standard label)

File name	File sequence	File name	File sequence
SMDEPS2	7	WINDX	11
SMTEMP	8	WINDY	12
SMSALT	9	BUFFTP	13
HELLERMANWINDS2	10	COXBASECODE	14

Model restart data

Tape number 800671 (unlabelled)

Dataset name	File sequence	Dataset name	File seq.
CAARESTART1095	1	CAARESTART1368	4
CAARESTART1186	2	CAARESTART1461	5
CAARESTART1277	3	CAARESTART1080	6

Tape number 800673 (IBM standard label)

Dataset name	File sequence	Dataset name	File seq.
CAARESTART1080	1	CAARESTART1277	4
CAARESTART1095	2	CAARESTART1368	5
CAARESTART1186	3	CAARESTART1461	6

Tape number 800894 (IBM standard label)

Dataset name	File sequence
CABRESTART1095	1

Model output

Tape numbers 800890/1 (IBM standard label)

Data	Day	Fseq	Day	Fseq	Day	Fseq	Day	Fseq	Day	Fseq	Day	Fseq
CAAENE			1095	14	1186	28	1277	42	1368	56	1461	70
STR	1080	1		15		29		43		57		71
SDE		2		16		30		44		58		72
TDE		3		17		31		45		59		73
UDE		4		18		32		46		60		74
VDE		5		19		33		47		61		75
SLA		6		20		34		48		62		76
TLA		7		21		35		49		63		77
ULA		8		22		36		50		64		78
VLA		9		23		37		51		65		79
SLO		10		24		38		52		66		80
TLO		11		25		39		53		67		81
ULO		12		26		40		54		68		82
VLO		13		27		41		55		69		83

NB: Files CAA-1186 have 'cutouts' at days 1125, 1155 and 1185, files CAA-1277 at days 1215, 1245 and 1275, files CAA-1368 at days 1305,1335 and 1365 and files CAA-1461 at days 1395, 1425 and 1455.