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OCEAN MODEL

TRACER TRANSPORT DIAGNOSTICS

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VERSION 1

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Introduction

This note documents the calculation of meridional tracer fluxes in the ocean model. Vertically-integrated transports across zonal sections are computed for a set of ocean basins defined by the user. Instantaneous fluxes are calculated in subroutine ROWCALC and processed by STASH. Inclusion of the required code is achieved by *DEF OHMEAD. Heat and salinity transports are computed in units of Petawatts and $10^7 kgs^{-1}$ respectively. The calculations can be extended to further tracers if desired. The code is only guaranteed valid for a no-slip boundary condition.

Calculation of Transport Components

The total transport is calculated, and its gyre, overturning and diffusive components (see Bryan, 1969) are also found. For some tracer T, the total instantaneous advective northward flux F through a zonal section is

$$F = \rho \int_{x_W}^{x_E} \int_{-Z}^{0} f_M vT dz dx,$$

where v is the northward current. If T the tracer is temperature or salinity then ρ is the density of sea-water; otherwise ρ is assigned a value of 1. When ρ represents density it is taken as constant, consistent with the Boussinesq approximation used in the model; the value used must also be consistent with that employed when inserting surface fluxes into the model. $f_M(x,z)$ is 1 at ocean points and zero at non-ocean points (i.e. at land points, or points below the ocean bottom topography when z>0). Z(x) is the depth of the ocean and x_W and x_E are the western and eastern boundaries of the region of interest. v and T may be decomposed into the zonal average ([]) and the deviation (′) from the zonal average, where, for example,

$$[v](z) = (1/W(z)) \int_{x_W}^{x_E} f_M v dx,$$

with

$$W(z) = \int_{x_W}^{x_E} f_M dx.$$

F may then be written as $F = F_M + F_G$, where

$$F_M = \rho \int_{-Z}^{0} W[v][T]dz \qquad ....(1)$$

$$F_G = \rho \int_{-Z}^{0} W[v'T']dz. \qquad ....(2)$$

F_M is identified as the transport due to the mean meridional circulation, whereas F_G arises from correlations between departures from the zonal average, thus being associated with horizontal gyres.

The diffusive transport may also be calculated. This is given by

$$F_D = -\rho \int_{x_W}^{x_E} \int_{-Z}^{0} f_M a_H (\partial T/\partial y)\, dz dx \qquad \text{....(3)}$$

where a_H is the meridional tracer diffusivity. (Note that a_H is not constant if the isopycnal diffusion option is in use.)

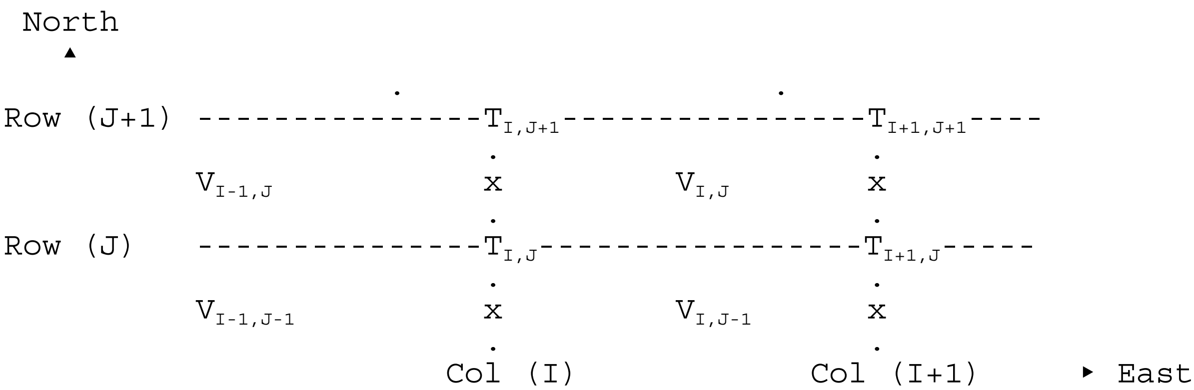
Finally, the total tracer transport F_{TOT} is given by

$$F_{TOT} = F_M + F_G + F_D. \qquad \text{....(4)}$$

When T represents temperature, the corresponding heat flux in Petawatts is obtained by multiplying the transports by $10^{-15}c_p$, where c_p is the specific heat capacity of sea-water. (Note that the code uses potential temperatures in Deg C to calculate the heat transports. In a free-surface version of the model, where the total mass in a given latitude band is not fixed, it might be necessary to convert the temperatures to Kelvins before calculating the heat transports). For salinity the transports are multiplied by 10^{-7} to give the results in $10^7 kgs^{-1}$.

Finite Difference Representation of Equations

This section documents the numerical representation in the code of the integrals identified above. To aid understanding, the diagram below shows a section of the model grid, where x denotes points at which tracer transports are calculated.



<u>Let us define the following variables:</u>

T(I,K) = Tracer value at column I, row J, level K.
TP(I,K) = Tracer value at column I, row J+1, level K.
V(I,K) = Northward current at velocity point immediately north-east of tracer point (I,J).
FM(I,K) = Mask for tracer points; 1 for ocean, 0 for non-ocean.
DXU(I) = Zonal grid spacing across a (u,v) box.

DYU(J) = Meridional grid spacing across a (u,v) box.
DXT(I) = Zonal grid spacing across a T box.
KM = No. of vertical levels.
KZ = Ocean depth at tracer transport calculation points (i.e. the maximum of the depths at the two adjacent velocity points).
AH(I,K) = Meridional diffusivity.
DZ(K) = Thickness of layer K.
TSUM(I,K) = T(I,K) + TP(I,K).
VXSUM(I,K) = V(I,K)DXU(I) + V(I-1,K)DXU(I-1).
ICS = Zonal grid point at start of ocean basin.
ICE = Zonal grid point at end of ocean basin.

$$VBR1(K) = \sum_{I=ICS}^{ICE} VXSUM(I,K), \text{ for points where } K \le KZ.$$

$$SUMDX(K) = \sum_{I=ICS}^{ICE} DXT(I), \text{ for points where } K \le KZ.$$

$$TBR1(K) = (1/SUMDX(K)) \sum_{I=ICS}^{ICE} TSUM(I,K)DXT(I), \text{ for points where } K \le KZ$$

The finite difference form of (1) is then

$$F_M = \rho \sum_{K=1}^{KM} (1/4)VBR1(K)TBR1(K)DZ(K).$$

F_G is calculated from $F_G = F - F_M$, with F represented by

$$F = \rho \sum_{I=ICS}^{ICE} \sum_{K=1}^{KZ} (1/4)VXSUM(I,K)TSUM(I,K)DZ(K).$$

The diffusive transport (equation (3)) is given by

$$F_D = -\rho \sum_{I=ICS}^{ICE} \sum_{K=1}^{KM} AH(I,K)((TP(I,K)-T(I,K))/DYU(J))DXT(I)DZ(K)FM(I,K).$$

Dataset of Basin Indices

The code requires an external dataset, whose contents are read in subroutine SET_CONSTANTS_OCEAN, containing start and stop indices defining the limits of the ocean basins at each model row. Each basin is split into two segments, for computational simplicity when dealing with basins straddling the Greenwich meridian. For a given segment, the start index is the number of the first tracer grid point in the segment, numbering eastwards from Greenwich. The stop index is the last tracer point in the segment. The stop index always has a value greater than that of the start index. For computational reasons the point immediately east of Greenwich cannot be assigned an index of 1, and is instead given a value of (IMT+1), where IMT is the number of points round a latitude circle. Thus a basin which spans an entire latitude circle is described by setting the start index of the first segment to 2 and the stop index to (IMT+1). The second segment is redundant in this case, so its indices are set to zero. However, where the ocean basin spans part of a latitude circle, and also straddles the Greenwich meridian, the second segment is needed. For example if the basin starts at point 20 and ends at point 5, the start and stop indices for segment 1 are 20 and (IMT+1), and those for segment 2 are 2 and 5. If a basin has no grid points at a given row, the relevant indices for both segments should be set to zero.

The format of the dataset is best illustrated by giving the code used to read in the indices:

```
 DO J=JMT,1,-1
 READ(unit,*) JCOUNT,
*((ISHT(J,IB,IS),IEHT(J,IB,IS),IS=1,LDIV),IB=1,LSEGC)
 ENDDO
```

JMT is the number of rows, with J (or JCOUNT) =1 representing the southernmost row. ISHT contains the start indices for each row, for LDIV (=2) segments and LSEGC basins. IEHT contains the end indices. For example, for the global model a four-basin set of indices is available where IB=1 represents the Indian Ocean, IB=2 the Pacific Ocean, IB=3 the Atlantic Ocean and IB=4 the global ocean (i.e. all ocean points incorporated, including inland seas).

Model Output

PP-field output of the meridional tracer fluxes is in the form of zonal mean fields. Each tracer is associated with a unique STASH code as defined by the STASHmaster. The diagnostic type (gyre, overturning, diffusive and total) and the basin number (1,2,3,4,..) are specified by the pseudo-level indicator. The two dimensions are combined so that the diagnostic type is the more rapidly varying index. For example, for a model which has three ocean basins defined by the basin indices dataset, the pseudo levels would be

Diagnostic Type

Basin	1	2	3	4
1	1	2	3	4
2	5	6	7	8
3	9	10	11	12

With this basin configuration, a PP-field with PP-package header variables LBUSER(4)=30212 (STASH code) and LBUSER(5)=7 (pseudo-level code) would correspond to the diffusive component of the salinity flux for basin 2.

Usage, time and domain profiles for the diagnostics are set up through the user interface, the pseudo-levels required being specified within the domain profile. Scaling for heat and salinity fluxes is carried out within the model such that the maximum size of STASH input of these diagnostics will be of order 1. Code for the scaling of additional tracers is not included and users should include their own modifications, if necessary, to ensure that overflow problems do not occur. These diagnostics are rounded to 32 bit precision in the model dump.

Reference

Bryan, K, 1969. Climate and the ocean circulation. III. The ocean model. *Mon. Wea. Rev.*,**97**,806-827.