CFC HOWTO

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So you want to simulate CFC-11 and CFC-12 in your ocean model according to standard OCMIP-2 protocols? This document provides step-by-step information to do just that.

Contents

1 Recuperation of OCMIP-2 files by ftp:

To comply with OCMIP-2 guidelines, all modelers must make simulations according to OCMIP-2 standard boundary conditions. To do so, one must first recuperate the following files via this Web page (you can save a file to disk by clicking a link while holding down the Shift key).

- rgasx_ocmip2.f
- gasx_ocmip2.nc.gz
- vgasx_ocmip2.jnl
- read_cfcatm.f
- cfc_interp.f
- cfc1112.atm
- sc_cfc.f
- sol_cfc.f

After transferring the file `gasx_ocmip2.nc.gz` (binary mode), one must then uncompress it:

```
gunzip gasx_ocmip2.nc
```

Other files are text and need no special treatment after transfer. Use of these files is described below.

2 Model runs

2.1 Gas exchange flux

For simulations of CFC-11 and CFC-12, we will directly model the finite air-sea flux **F**. In other words, surface CFC concentrations will NOT be set equal to temperature-derived equilibrium values determined from the solubility. Modelers must use the formulation for the standard OCMIP-2 air-to-sea flux,

(1a) **F = Kw (Csat - Csurf)**

with

(1b) **Csat = alpha * pCFC * P/Po**

where

- **Kw** is the gas transfer (piston) velocity [m/s] ;
- **Csurf** is the modeled surface ocean CFC-11 (or CFC-12) concentration [mol/m^3];
- **alpha** is the CFC solubility for water-vapor saturated air [mol/(m^3 * picoatm)];

- **pCFC** is the partial pressure of CFC-11 (or CFC-12) in dry air at one atmosphere total pressure [in picoatm], which is the same as the dry air mixing ratio of CFC-11 or (CFC-12) multiplied by 10ˆ12 ;
- **P** is the total air pressure at sea level [atm], locally;
- **Po** is 1 atm.

All right hand terms, except P and Po, in equations (1a) and (1b) are different for CFC-11 and CFC-12, as well as other tracers.

2.2 The Piston Velocity Kw

For simulations of CFC-11 and CFC-12, modelers must use the standard OCMIP-2 formulation for the piston velocity **Kw**. The monthly climatology of **Kw**, to be interpolated linearly in time by each modeling group, is computed with the following equation adapted from Wanninkhof (1992, eq. 3):

(2) **Kw = (1 - Fice) [Xconv * a *(u2 + v)] (Sc/660)**-1/2**

where

- **Fice** is the fraction of the sea surface covered with ice, which varies from 0.0 to 1.0, and is given as monthly averages from the Walsh (1978) and Zwally et al. (1983) climatology (OCMIP-2 modelers must resest **Fice** values less than 0.2 to zero, after interpolation to their model grid)
- **u2** is the instantaneous SSMI wind speed, averaged for each month, then squared, and subsequently averaged over th e same month of all years to give the monthly climatology. (see the OCMIP-1 README.satdat for further details);
- **v** is the variance of the instantaneous SSMI wind speed computed over one month temporal resolution And 2.5 degree spatial resolution, and subsequently averaged over the same month of all years to give the monthly climatology. Again, see the OCMIP-1 README.satdat for further details.
- **a** is the coefficient of 0.337, consistent with a piston velocity in cm/hr. We adjusted the coefficient **a** for OCMIP-2, in order to obtain Broecker et al.'s (1986) radiocarbon-calibrated, global CO2 gas exchange of 0.061 mol CO2 /(mˆ2 * yr * uatm), when using the satellite SSMI wind information (**u2 + v**) from Boutin and Etcheto (pers. comm.). Our computed value for **a** is similar to that determined by Wanninkhof (**a** = 0.31), who used a different wind speed data set and assumptions about wind speed variance; we use the observed variance.
- **Xconv** = 1/3.6e+05, is a constant factor to convert the piston velocity from [cm/hr] to [m/s]. This conversion factor is already included in the forcing field **xKw,** provided below.
- **Sc** is the Schmidt number which is to be computed using modeled SST, using the formulation from Zheng et al (1998). The function sc_cfc.f computes the Sc's (unit-less) for both CFC-11 and CFC-12.

Practically speaking, to use equation (2) each group will interpolate the OCMIP-2 standard information to their own model grid. The standard information is provided by IPSL/LSCE as a monthly climatology on the 1 x 1 degree grid of Levitus (1982) in netCDF format (in file gasx_ocmip2.nc). Gridded variables in that file include

- the variable **Fice**,
- the second term, **[Xconv * a * (u2 + v)]**, denoted as **xKw** [m/s]
- the mask **Tmask** (1 if ocean; 0 if land),
- the total atmospheric pressure at sea level **P** [atm]
- the longitude **Lon** at the center of each 1 x 1 degree grid box,
- the latitude **Lat** at the center of each 1 x 1 degree grid box.

For the variables **Fice** and **xKw**, continents on the 1 x 1 degree standard grid have been flooded with adjacent ocean values. Such an approach avoids discontinuities at land-sea boundaries during interpolation. See the Fortran program rgasx_ocmip2.f for an example of how to read the information in cfc1112.atm into your interpolation routines. After compilation, to link and use rgasx_ocmip2.f, one must have already installed netCDF.

`<http://www.unidata.ucar.edu/packages/netcdf/>`

The file `gasx_ocmip2.nc` may also be inspected with software that uses netCDF format, such as ncdump or Ferret. Ferret will be used for some of the analysis during OCMIP-2. We encourage participants to become familiar with Ferret now

`<http://ferret.wrc.noaa.gov/Ferret/>`

After installation, one can visualize maps of the standard information in gasx_ocmip2.nc, by using the Ferret script vgasx_ocmip2.jnl.

After launching Ferret, simply issue the following command (at Ferret's "yes?" prompt)

```
yes? go vgasx_ocmip2.jnl
```

2.3 Oceanic and Atmospheric Components

Apart from Kw, there are two other terms in equation (1a). The ocean component **Csurf** [in mol/m^3] is computed by the model each timestep; the atmospheric component **Csat** is specified *a priori* via the three remaining terms:

1. **alpha**: The CFC solubility **alpha** is to be computed using modeled SST and SSS, both of which vary in time at each grid point. For OCMIP-2 we use the solubility formulation determined by Warner and Weiss (1985, Table 5 for solubility in [mol/(l * atm)]). The function sol_cfc.f determines alpha accordingly, for both CFC-11 and CFC-12, but changes the units to [mol/(m^3 * picoatm)] so that model CFC concentrations can then be carried in SI units [mol/m^3].

2. **pCFC**: Extrapolated records for observed CFC-11 and CFC-12 [in picoatm] constructed at 41S and 45N (Walker et al., pers. comm.). For OCMIP-2, each station will be treated as representative of its own hemisphere, except between 10S and 10N where those station values will be interpolated linearly as a function of latitude. Thus there are 3 zones:

    - 90S-10S, where CFC's are held to same value as at the station at 41S;

- 10S-10N, a buffer zone where values are interpolated linearly; and
- 10N-90N where values are held to the same value as at the measuring station at 45N.

3. **P**: Is the total atmospheric pressure [atm] from the monthly mean climatology of Esbensen and Kushnir (1981). The latter, given originally on a 4 x 5 degree grid (latitude x longitude) in bars, is converted to atm by multiplying by (1/1.101325). Land and sea ice values in the original data set were filled with average values from adjacent ocean points. These monthly mean arrays were then linearly interpolated to the 1 x 1 degree grid of Levitus (see netCDF file gasx_ocmip2.nc).

Technical notes:

1. The Fortran subroutine cfc_interp.f interpolates **pCFC** spatially following the above algorithm. The code allows, in one pass, to spatially interpolate atmospheric pCFC-11 and pCFC-12, at a given timestep, to all grid points as a function of latitude.
2. The ASCII file cfc1112.atm provides mid-year values of atmospheric pCFC-11 and pCFC-12 [in picoatm] at both stations for the period from 1931 to 1997. See the program read_cfcatm.f.
3. Temporal interpolation of atmospheric pCFC-11 and pCFC-12 is to be made linearly for each time step, based on mid-year values (file cfc1112.atm).

3 Duration of simulation

Following the atmospheric record, the standard OCMIP-2 simulation for CFC-11 and CFC-12 will begin at the beginning of 1931 with zero concentrations in the atmosphere and ocean. CFC simulations will stop at the end of 1997.

4 Output type and frequency

1. **Early Output:** prior to 1982 (no oceanic CFC data are available).
   - Frequency: monthly averages every 10 years (1940, 1950, 1960, 1970, 1980)
   - Type:
     - 3-D Fields:
       * CFC-11 and CFC-12 tracer distributions [mol/m^3]
     - 2-D Fields:
       * Monthly mean flux of CFC-11 and CFC-12 [mol/(m^2*s)]
       * Cumulative flux of CFC-11 and CFC-12 [mol/m^2]
       * Model SST (online models every year; offline models year 1940 only) [C]
       * Model SSS (online models every year; offline models year 1940 only) [psu]
2. **Late Output:** from 1982 to 1997

- Frequency: monthly averages every year
- Type: same as above

3. **Transport Output:** in 1990 (just one year)

- Frequency: monthly averages
- Type:
  - The rate of change of each tracer ([mol/mˆ3*s] at tracer grid points) due to advection, diffusion, and convection,

    Split according to *process* **and** *direction*
    * Total rate of change dC/dt
    * Rate of change due to advection (from x, y, and z directions, separately),
    * Rate of change due to diffusion (from x, y, and z directions, separately), and
    * Rate of change due to convection (from z direction), if modeled
  - Tracer fluxes (3-D) [mol/mˆ2*s]

    Split according to *process* **and** *direction*
    * advective fluxes (from x, y, and z, separately) at advection grid points,
    * diffusive fluxes (from x, y, and z, separately) at diffusion grid points, and
    * convective fluxes (z), if modeled, at ”convection” grid points

    Conventions **for the direction of fluxes:**
    * rectangular grid: positive from the west, from the south, and from below
    * curvilinear grid: postive from i, j, k directions
    * *other grids* (e.g., AWI, MPI, and ULG): contact orr@cea.fr

4. **Equilibrium Output:** *All models* provide first output year (1940); *Online models* also provide output for the year 1990

- Frequency: monthly averages
- Type:
  - Active tracers (T and S) in 3-D
  - Advection field (u,v,w) [m/s] as separate scalar values at advection grid points (u,v,w), which usually do not coincide
  - Tracer diffusion coefficient [mˆ2/s] as separate values at diffusion grid points

5 Output Format

Each modeling group must provide their output in the standard OCMIP-2 format. Model output that does not follow these formatting conventions cannot be included for analysis during OCMIP-2. Model groups must use the standard routines that we have developed specifically for writing output in standard form for OCMIP-2.

5.1 Spatial information

Some of the models participating in OCMIP-2 are *Irregular*, which means that one 1-D array in latitude and one 1-D array in longitude are insufficient to describe the position of all grid points. Models with an irregular grid require a 2-D array in latitude and a 2-D array in longitude to describe the horizontal positioning of grid points. During OCMIP-2, regularly spaced models (those for which 1-D arrays in latitude and longitude are sufficient), will still write their output in the same *irregular* format. This will allow consistency between models for analysis, although at the price of somewhat larger output files.

Following the GDT conventions, all OCMIP-2 models will provide latitude and longitude information at the center of each tracer grid box and on all four corners (lower left, lower right, upper left and upper right) that are associated with each tracer grid point. Here is an example of a 2-D array in longitude and its corresponding boundary array (both with indices at their maximum values):

```
lon(imt,jmt)
bounds_lon(imt,jmt,2,2)
```

where

- `bounds_lon(i,j,1,1)` is the longitude of the *lower left* corner of the grid box *i*,*j*, where the meanings of *lower* and *left* are obvious for rectangular grids; for curvilinear grids, those terms correspond to the direction from grid boxes with smaller *j* and smaller *i*, respectively;
- `bounds_lon(i,j,2,1)` is the *lower right* corner;
- `bounds_lon(i,j,1,2)` is the *upper left* corner; and
- `bounds_lon(i,j,2,2)` is the *upper right* corner.

Analogous arrays are needed for latitude.

5.2 Output routines

For 1 and 2 each modeling group must use the three routines listed in the following table. Input to these routines consists of your model's output and characteristics. The first routine `write_nc_MaskAreaBathy.f` must be called only once (for the 1st output year–1940). The second routine `write_nc_CFC_year.f` must be called for every output year (see previous section 4). The third routine `write_nc_SurfTS_year.f` must also be called for every output year for online models, but only once (the first output year) for offline models.

```
--------------------------------------------------------------------------------
Routine                        Input                Units               Comments
--------------------------------------------------------------------------------

write_nc_MaskAreaBathy.f     Tracer Mask          Land=0/Ocean=1         (1)
                             Surface Area         m^2
                             Bathymetry           m
```

```
write_nc_CFC_year.f          Conc. of CFC-11      mol/m^3
                             Conc. of CFC-12      mol/m^3
                             Mean Flux of CFC-11  mol/(m^2*s)
                             Mean Flux of CFC-12  mol/(m^2*s)
                             Cum. Flux of CFC-11  mol/m^2
                             Cum. Flux of CFC-12  mol/m^2

write_nc_SurfTS_year.f       Sea Surf. Temp.      degrees C              (2)
                             Sea Surf. Salinity   psu
--------------------------------------------------------------------------------
(1) Also includes other input arguments, as necessary to define
    position of grid boxes (latitude, longitude, and depth specifications)
(2) For online models,  monthly SST and SSS should be saved each year
    for which other output is written (with write_nc_CFC_year.f);
    for offline models, monthly SST and SSS may be saved for just one year,
    since there is no year-to-year variation.
```

Please send e-mail now (orr@cea.fr) concerning whether you have an offline or online model.

Conventions

1. Longitudes must be expressed in degrees as eastward positive (e.g., 120W is to be expressed as -120; 120E is to be expressed as +120).
2. Latitudes must be expressed in degrees as northward positive. (e.g., 90S is to be expressed as -90; 90N is to be expressed as +90).
3. Depth must be expressed in meters as positive downward (e.g., the depth of 1000 m is to be expressed as 1000).
4. For irregular model grids which must be stored as a 1-D vector instead of a 2-D array (e.g., model AWI), you must set jmt=1, and not imt=1.
5. You must provide model output on a grid without overlapping boxes. For example, if for longitudes of your model
   - i = 1 is the same as i = imt-1 and
   - i = 2 is the same as i = imt,

   then you must only provide model output for values from i=2 to i=imt-1. Future reference to i during OCMIP-2 analysis will thus be shifted by one, relative to that used in your model.

5.3 Downloading the output routines

The output routines for your model class can be found in `<http://www.ipsl.jussieu.fr/OCMIP/phase2/simulations/CFC/distrib/>` or, in the HTML version of this document, by clicking on the three links below, while holding down the Shift key.

- write_nc_MaskAreaBathy.f
- write_nc_CFC_year.f
- write_nc_SurfTS_year.f

Routines for writing out results for 3 and 4 will be made available soon.

You will also need to transfer the subroutine handle_errors.f to properly deal with errors while you are writing your netCDF files.

5.4 Compiling the output routines

Here is a an example of how you would compile one of the output routines:

```
f77 -c -O -L/usr/local/lib -lnetcdf -I/usr/local/include \
    write_nc_MaskAreaBathy.f
```

Because we have made these routines F77 compatible, you may need a function len_trim.f (from F90), which we also provide and which returns the length of a character string (after neglecting trailing blanks).

5.5 Using the output routines

These routines write out your model results following the naming and output conventions (netCDF, COARDS, GDT) chosen for OCMIP-2. The output filename is constructed automatically within each routine from three of the arguments: the tracer name, the year, and the *standard model code* `<http://www.ipsl.jussieu.fr/OCMIP/phase2/#modgroups>` used during OCMIP-2 to identify your group.

For example, after compiling and linking the OCMIP-2 output routines, we add the following code to the IPSL routines to store output in standard OCMIP-2 form

```
        call write_nc_CFC_year("IPSL","NGL46_SI",
     &  imt, jmt, kmt,
     &  1985, 60*60*24*365, 1200,
     &  CFC11, CFC12,
     &  MF_CFC11, MF_CFC12,
     &  CF_CFC11, CF_CFC12)
```

By line, the arguments include

1. the OCMIP-2 *model code* AND your own *model version* indicator (in GDT 1.2 terminology, these 2 variables refer to the *institution* and *production*, respectively);
2. dimensions;

3. the year, the number of seconds per year (in your model), and the number of timesteps per year;
4. the 12 monthly means for the 3-D tracer arrays for CFC-11 and CFC-12;
5. the 12 monthly means for the 2-D air-sea flux for CFC-11 and CFC-12; and
6. the end-of-year 2-D cumulative flux (from t=0) for CFC-11 and CFC-12.

All arguments are input. The only output is the final netCDF file, (`"IPSL_CFC_1985.nc"`), which contains the information for analyzing the IPSL results for 1985. This file along with all others from the 3 routines above should be 6. Filenames should NOT be changed. At IPSL, files will subsequently be (1) tested for consistency, (2) included in the OCMIP-2 data base, and (3) processed for base analysis.

5.6 Need more details?

See `<http://www.ipsl.jussieu.fr/OCMIP/tech>`. for additional information about the format netCDF and other conventions (COARDS, GDT) chosen for storing OCMIP-2 model output.

If you have other questions, please contact Patrick.Brockmann@ipsl.jussieu.fr, or orr@cea.fr

6 Transfer of output

All files written by the OCMIP-2 output routines should be grouped according to type of analysis (1, 2, 3, and 4). To do so, just recuperate the shell script stocmip2.sh, copy it to the directory where you have stored your standard OCMIP-2 output, `cd` to that same directory, and issue the following two commands:

```
./stocmip2.sh
gzip *.tar
```

If gzip is not available on your machine, the alternative is to use `compress`.

Given the requested fields and frequencies specified in section (4) above, model output could be quite large, depending upon model resolution. If output is larger than 200 Mb per simulation, we request that it be written to tape (DDS, DDS2, Exabyte, or DLT) and mailed to

```
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```

If smaller than 200 Mb, an attempt can be made to send this output via ftp (contact orr@cea.fr for details). The first analysis will be undertaken at IPSL (France) and at Penn. State (U.S.A.).

7 Who has submitted what?

For a record of who has submitted what model output, see
`<http://www.ipsl.jussieu.fr/OCMIP/phase2/progress/>`.

8 References

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Zwally, H. J., J. Comiso, C. Parkinson, W. Campbell, F. Carsey, and P. Gloerson, 1983. Antarctic Sea Ice, 1973-1976: Satellite Passive Microwave Observations, NASA, 206 pp.

9 Contacts

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10 Same document, another format?

This document is available in other formats:

- HTML (`<HOWTO-CFC.html>`)
- Postscript (`<HOWTO-CFC.ps>`)
- ASCII (`<HOWTO-CFC.txt>`)
- LaTeX (`<HOWTO-CFC.tex>`)
- DVI (`<HOWTO-CFC.dvi>`)
- RTF - as 2 files

1. *Table of Contents* `<HOWTO-CFC.rtf>`
2. *Body* `<HOWTO-CFC-0.rtf>`