Chlorofluorocarbon (CFC)

purely anthropogenic origin, little influenced by biological processes, very stable in the ocean.

ideal tracer for evaluating the model simulated ocean circulation and ability of models to simulate the uptake and redistribution of anthropogenic CO$_2$ in the oceans.

Issues

How is CFC transported to the equatorial oceans from subtropics?
What are the roles of seasonal and high frequency motions?

Contents

• Comparison of CFC between the data and models (eddy-permitting, resolving)
• Meridional volume and tracer transport by mean, seasonal component and eddy
# The Models

<table>
<thead>
<tr>
<th></th>
<th>1/4degree Model</th>
<th>OFES Spinup Run</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Model:</strong></td>
<td>MOM2</td>
<td>MOM3</td>
</tr>
<tr>
<td><strong>Area</strong></td>
<td>75S - 75N</td>
<td>75S - 75N</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>0.25 degree</td>
<td>0.1 degree</td>
</tr>
<tr>
<td><strong>Levels</strong></td>
<td>55 (10m – 400m thickness)</td>
<td>54 (5m – 330m thickness)</td>
</tr>
<tr>
<td><strong>Horiztonal mixing</strong></td>
<td>Biharmonic</td>
<td>Biharmonic</td>
</tr>
<tr>
<td><strong>Wind Forcing</strong></td>
<td>Hellerman and Rosenstein (1983)</td>
<td>NCEP/NCAR climatology</td>
</tr>
<tr>
<td><strong>Surface heat and S flux</strong></td>
<td>Restoring of model SST and SSS to Levitus (1982)</td>
<td>NCEP/NCAR climatology with weak restoring to SSS data</td>
</tr>
<tr>
<td><strong>Polar B’dries</strong></td>
<td>T, S restoring to Levitus (1982) in the Northern bdry in N.Atl.</td>
<td>T, S restoring to WOA98 in zonal band near 75N, 75S</td>
</tr>
<tr>
<td><strong>Spinup before CFC exp.</strong></td>
<td>30 years</td>
<td>50 years</td>
</tr>
<tr>
<td><strong>CFC</strong></td>
<td></td>
<td>OCMIP-2 protocol</td>
</tr>
</tbody>
</table>
Air-Sea exchange of CFC-11:

OCMIP-2 CFCs experiment

Air-Sea Flux

\[
\text{Flux} = k \left( a \times p\text{CFC} \times \frac{P}{P_0} - C_s \right)
\]

- \( k \) : air-sea gas exchange coefficient \( (Wanninkhof, 1992) \)
- \( a \) : solubility \( (Warner and Weiss, 1985) \)
- \( p\text{CFC} \) : CFC atmospheric partial pressure \( (Walker et al., 2000) \)
- \( P \) : atmospheric pressure \( (Esbensen and Kushnir, 1981) \)
- \( P_0 \) : 1 atm
- \( C_s \) : modeled surface ocean CFCs

Piston Velocity (K): Wanninkhof (1992)

- Sea Ice: Walsh (1978) and Zwally et al. (1983) climatology
- SSMI wind

Time duration: 1950-1997
The model simulates the observed characteristic distributions of CFC such as:

- High CFC waters transported from high latitude to subtropics in the thermocline,
- Subsurface maximum in subtropics,
- Shallow penetration around ITCZ latitude and deeper penetration on the equator.

WOCE P13 (165E, Sep 1992) in the North Pacific Data

1/4° model: weak stratification in 24\(\sigma_\theta\)-25\(\sigma_\theta\) (too large volume of STMW)
OFES: improved pycnocline structure
\[\rightarrow\] density of subsurface maximum of CFC: more similar to the observed density

Problems in both experiments: Low CFC in intermediate depths.
Density of subsurface CFC maximum:
OBS and OFES: $25.2\sigma_\theta - 25.4\sigma_\theta$,
$1/4^\circ$ model: $24.5\sigma_\theta - 25\sigma_\theta$

High CFC south of the Kuroshio (30N-35N) in OFES comparable with observation.

Low CFC in the intermediate layers $\sigma_\theta > 26.6\sigma_\theta$ in $1/4^\circ$ models.
OFES improvements & deficiency

- Higher CFC inventory in SAMW compared with 1/4° model
- Horizontal gradient of isopycnals around $27.0\sigma_\theta$
- Too weak stratification in $26.8\sigma_\theta$–$27.0\sigma_\theta$

Both models overestimate CFC concentration in the tropical regions
Both models exhibit the equatorward decrease of density of subsurface CFC maximum, although the modeled density is slightly lower.

The models overestimate the CFC maximum between 5S and 15S.
CFC-11 and Depth of 25.0σ₀ Isopycnal surface

Subsurface CFC maximum in the western North Pacific

Northern (Southern) Hemisphere: March (September) 1990 monthly mean
Low CFC and too deep isopycnal in the western North Pacific in the 1/4d model.
Overturning Streamfunction
– Decomposition into mean and transients –

\[
\psi = \int_{x_w}^{x_e} \int_{\rho}^{\rho_s} \bar{h} v \cdot d\rho' dx + \int_{x_w}^{x_e} \int_{\rho}^{\rho_s} \bar{h}' v' \cdot d\rho' dx
\]

Mean

\( \bar{h}, \bar{v} \) : Temporal mean of meridional velocity and layer thickness from time mean

\( h', v' \) : Anomaly from time mean

# The anomaly can be decomposed into seasonal variation (annual cycle) and high frequency motion (eddy).
Overturning Streamfunction in Density coordinate (OFES) Indo-Pacific Ocean

Strong mean Tropical Cell and compensation by transient motions. There is the contribution by seasonal variation as well as eddy.
Comparison of Indo-Pacific MOC between OFES and 1/4° model
Meridional CFC-11 Flux in the Indo-Pacific Ocean (1/4° model)

black : total, red : mean, green : seasonal, blue : eddy

**Surface Layer:**
- Poleward mean flux

**Thermocline:**
- Equatorward mean flux

**Wind-driven Layer:**
- Significant effects of transients
Indo-Pacific Meridional CFC-11 Flux (1/10° OFES)

black : total,  red : mean,  green : seasonal,  blue : eddy

The results are similar to that in eddy-permitting model.

More significant contribution by seasonal variation is recognized in subtropical area.
Monthly Mean Zonally integrated CFC-11 (color) and MOC (line) in the Pacific
Summary

Improvements by using Higher resolution Model

- Too large volume of STMW in the North Pacific
- Too steep density gradient of isopycnal around $27.0\sigma_\theta$ with SAMW

*Higher APE released with Higher resolution OGCM.*

Meridional Overturning Circulation and CFC flux

- Both eddy-permitting and eddy-resolving model exhibit the strong Equatorial Cell and the compensation by transient motions.
- The eddy-resolving model experiment shows significant contribution by *seasonal variation* to meridional volume and CFC flux.