Atlantic Meridional Overturning Circulation and North Atlantic Freshwater Budget in CFSv2

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Acknowledgments: Xingren Wu (EMC/NCEP)
Zeng-Zhen Hu (CPC/NCEP)
OBS at 26.5°N (RAPID-MOCHA Array):
18.5±4.9 Sv (04/2004-10/2007, Johns et al., 2011)
Mean Atlantic Meridional Overturning Streamfunction (Sv)

(a) CFSv2, 30-yr

(b) GODAS, 1979-2004
Mean Atlantic Meridional Overturning Streamfunction (Sv)

(a) CFSv1, 335-YR

(b) GODAS, 1979–2004
Weak AMOC in CFSR initial condition (IC)?

November, YR1

Initial month

November, YR30

Final month
AMOC (Sv), CFS_v2, NEMO, 30–yr

(a) Mean State

(b) 26.5N, 1000m

OBS: 18.5±4.9 Sv (Johns et al., 2011)
Strong initial AMOC in ECMWF IC is also weakened.
Model surface water is too fresh in North Atlantic
Considerable freshening occurs in upper 200 meters.
Where does the excessive freshwater come from?

\[
FW = 1 - \frac{S}{S_{ref}}
\]

\[
FWC = \int_{-h}^{0} \int_{A} FW \, dA \, dz
\]

where \( S_{ref} = 35.0 \, \text{psu} \)

\( h = 335 \, \text{m} \)
Freshwater Budget

\[ FW = 1 - \frac{S}{S_{\text{ref}}} \]

\[
\frac{\partial}{\partial t} \left( \int_{-h}^{0} \frac{\partial}{\partial A} \int_{A}^{B} FW \, dA \, dz \right) = \int_{-h}^{0} \left\{ \int_{y_{S}}^{y_{N}} u_{W} FW \, dy - \int_{y_{S}}^{y_{N}} u_{E} FW \, dy + \int_{x_{W}}^{x_{E}} v_{S} FW \, dx - \int_{x_{W}}^{x_{E}} v_{N} FW \, dx \right\} \, dz \\
+ \oint_{A} w_{-h} FW \, dA + \oint_{A} (P - E) \, dA + R
\]
Freshwater Budget, CFSv2–NEMO

13-mo running mean

\[ \text{Net} = U_W - U_E + V_S - V_N + W_{-h} + P - E \]
Freshwater Transport Terms, CFSv2_NEMO

13-mo running mean

Net Transport

\(-V_N\) (too large?) (too large?)

P - E

\(-U_E\)

\(V_S\) (too small?)

Transport (Sv)

Into Box

Out of Box

Time

Top panel: OBS-based zonally averaged surface freshwater fluxes over the North Atlantic

Lower panel: Freshwater transport integrated from 65°N (bottom panel), with estimates for different latitudes summarized in Wijffels (2001) and Talley (2008).

From Romanova et al. (2010, Tellus, Fig.14)

Compare with CFSv2:

\[ V_N(64°N) \approx 0.2\text{Sv}(\text{over-estimated?}) \]

\[ V_S(40°N) \approx 0.1-0.2\text{Sv}(\text{under-estimated?}) \]
Is the subtropical water transported northward too fresh?

Increased tropical SSS does not affect mid latitudes significantly

- NORUNOFF
- CFSv2_NEMO
Surface Current Climatology

Surface drifter data
Lumpkin and Garraffo (2005)

CFSv2-NEMO
Artificial Sea Ice melting in Arctic Ocean could be a source of freshwater flux into North Atlantic.
Sensitivity Experiment
Albedo (ICE) Run (10-yr)

Sea Ice Albedo 0.8
(Control 0.6)

Temperature range of albedo change with ice melt
1.0°C (Control 10.0°C)

Based on suggestions from Dr. Xingren Wu
(EMC/NCEP)
Sea Ice Concentration, CFS_v2

Sensitivity Experiment
Albedo (ICE) Run
(10-yr)

Sea Ice Albedo 0.8
(Control 0.6)

Temperature range of albedo change with ice melt
1.0°C (Control 10.0°C)

Based on suggestions from
Dr. Xingren Wu
(EMC/NCEP)
Improved Sea Ice increases AMOC (but not enough)
Brackish water “leaked” from Baltic Sea may also cause the North Atlantic freshening.
Sensitivity Experiment
TOPO Run (10-yr):

Sill depth between Baltic Sea and North Atlantic is raised from 100m (Control) to 30m

The freshening in the eastern part of North Atlantic is reduced

Sea Surface Salinity Difference
TOPO-ICE
Summary

Atlantic meridional overturning circulation (AMOC) is weakened in CFSv2

A freshening trend in northern North Atlantic shuts down deep convection in Greenland and Labrador Seas

Extra freshwater storage is associated with weak (excessive) subtropical (arctic) transport and strong regional precipitation

Arctic sea ice thickness can be maintained with increased sea ice albedo

Improved sea ice and marginal sea outflow only have transient influence on AMOC strength in CFSv2
Mean SSS, CFSv2

CFS–NEMO

- CFSv2
- CFSv2_NEMO

$10^4\text{km}^2$

Model years
Where does the excessive freshwater come from?
Mean E–P Climatology (mm/day)

CFSv2 pattern similar to OBS
Equatorial and mid-lat precip excessive?