What Causes Anomalies in Subtropical Mode Water Volume?

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CLivar MOde water Dynamics Experiment CLIMODE

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Abstract

Subtropical Mode Water (STMW) in the western North Atlantic Ocean is a deep isothermal layer that is formed by wintertime heat losses to the atmosphere and dissipated by mixing and subduction. Eighteen Degree Water (EDW), as it is commonly known owing to its nearly constant temperature, stores and discharges large quantities of heat over periods of several years, contributing to the memory of the climate system. To supplement detailed analyses from the CLIvar MOde Water Dynamic Experiment (CLIMODE) 2-year field program with an understanding of interannual variability, we have combined altimetric and historical hydrographic data to examine the contribution of several processes to EDW volume anomalies.

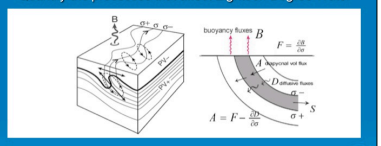
EDW formation estimates derived from OAFlux sea surface temperature and heat flux fields are compared with volume estimates for 1985-2007. A simple box model is then used to hindcast dissipation in 2 regions: a region in which EDW is formed and an adjacent region of subducted EDW. Proxy variables from the altimeter are used to examine the roles of mixing and advection in volume anomalies. Unlike in the North Pacific, much of the interannual formation region variability can be attributed to heat flux forcing anomalies, while advection is critical in the subduction region. As in the North Pacific, mixing plays an important role in dissipation.

1.

CLIMODE

CLIvar MOde water Dynamics Experiment

Quantify the processes that affect Eighteen Degree Water

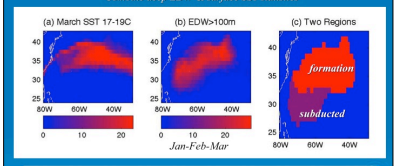


Subtropical Mode Water near the Gulf Stream ("EDW") is formed by heat losses through the surface, is subsequently dissipated by mixing and is subducted southward. Two years of field measurements from CLIMODE are being analyzed to quantify the relative importance of these processes. To estimate the contribution of these processes to the longer term variability of EDW we use proxies from altimeter data in a simple model of EDW volumes.

2.

EDW formation and subducted regions

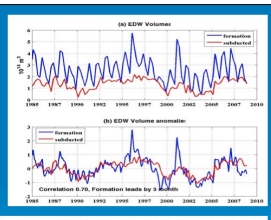
Combine deep EDW & surface SST statistics



Two regions of EDW were defined based on their wintertime statistics: (a) March SST of 17-19C and (b) EDW with thickness greater than 100m. Shown above are the number of years that each criterion was met. Locations that met both criteria for at least 3 of 23 winters were defined as the "formation" region. Locations that met only the thickness criterion were defined as the "subducted" region, because EDW found there was not formed locally. EDW may also be subducted in the "formation" region.

3.

EDW Volume and Anomalies



Data from the World Ocean Database (2005) were used to estimate EDW volume in each of the two regions (a). The seasonal cycle of EDW formation and dissipation is clearly seen in the formation region (blue), while interannual variations dominate in the subducted region (red). Removing the seasonal cycle shows a high level of correlation (0.70) between the volume time series, with the formation region anomalies leading by 3 months, the temporal resolution of the observations.

4.

Simple Model for Volume Anomalies

Model EDW volumes V_f and V_s in each region:

- *Formation: dV_f/dt = formation - outflow - mixing*
- *Subducted: dV_s/dt = inflow - mixing - loss*
- *Formation: ΔF - difference between water entering & leaving 17-19C outcrop*

$$F(T) = \frac{-1}{\rho c_p \Delta T} \int_{\substack{outcrop \\ area\,A(T)}} Q_{net}(x,y,t)\,dA$$

$$\Delta F = F(T + \Delta T/2) - F(T - \Delta T/2)$$

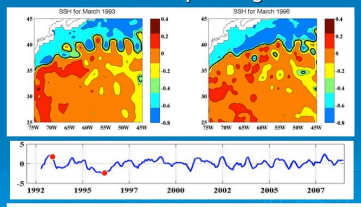
(ΔT = 0.5C), Net surface heat flux Q

(Walin (2003), Maze et al (2009)

- *Use proxies for outflow, mixing and loss terms*

5.

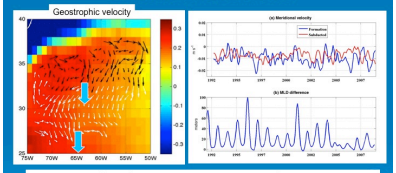
Proxy for EDW Mixing: Gulf Stream path length



Maps of AVISO merged SSH were used to define the length of the Gulf Stream path, as a proxy for mixing in the region. The longer the path, the more eddy activity and therefore more mixing of EDW in the formation region (following Qiu & Chen, 2006).

6.

Proxies for EDW Loss



Previous studies of EDW (Dong et al 2007; Trossman et al, 2009) suggest that advection and mixed layer depth gradients are important factors in volume anomalies and subduction rates, respectively. A proxy for loss by advection was defined as the mean meridional geostrophic velocity in each region (left and top right). The gradient of MLD was parameterized as the MLD difference between the formation and subduction regions (bottom right).

7.

Model with Losses Proportional to Volume

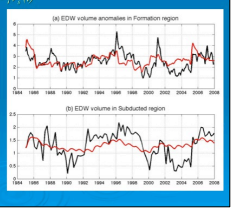
proportional rates of mixing & outflow

Formation: $dV_f/dt = \Delta F - \alpha V_f(t) - \beta V_f(t)$

Subduction: $dV_s/dt = \beta V_f(t) - \gamma V_s(t)$

Black: observed
Red: model

In the formation region observed EDW loss rates are proportional to existing EDW volume. This relationship was used to formulate a simple model for EDW losses by mixing and by advection out of the region ("outflow"). Outflow from the formation region was assumed to be inflow into the subducted region. Using constant coefficients in this model gave a best fit with 35% outflow and 65% mixing in the formation region.



8.

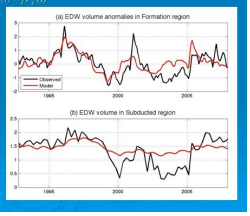
Model with Time-Dependent Mixing

Formation region mixing includes path length

Formation: $dV_f/dt = \Delta F - \alpha(\text{path length})V_f(t) - \beta V_f(t)$

Subduction: $dV_s/dt = \beta V_f(t) - \gamma V_s(t)$

Including the path length proxy in the mixing term greatly improves the fit to the observations. No change was made in the subducted region. Note that the comparisons could only be made for 1993 onward.



9.

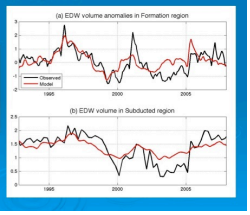
Model with Time-Dependent Losses

Loss from subducted region includes proxy for loss by advection

Formation: $dV_f/dt = \Delta F - \alpha(\text{path length})V_f(t) - \beta V_f(t)$

Subduction: $dV_s/dt = \beta V_f(t) - \gamma v_s(t) V_s(t)$

Including the advection proxy in the loss term greatly improves the fit to the observations in the subducted region. No change was made in the formation region. The importance of advection in this region is consistent with Dong et al 2007.



10.

Model Fit Statistics:

fraction of variance described

Model	V_f %	V_s %	Terms
1	0	0	Annual ΔF
2	28	<0	Actual ΔF
3	17	30	Proportional V
4	43	43	Path length mixing
5	43	58	v_s for V_s loss
6	44	45	v_s for V_f outflow
7	22	<0	ΔMLD^*v_s outflow

11.

Conclusions

EDW volume 2 regions:

Formation (EDW outcrops) & Subducted (no outcrop)

- Formation explains seasonal variations in EDW and some anomalies (unlike Qiu and Chen, 2006)
- About 65%/35% of EDW lost by mixing/advection
- Path length mixing explains formation region losses (as in Qiu and Chen, 2006)
- Advection explains subducted region losses (as in Dong et al 2007)

References

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