Spatial and Temporal Variability in Subtropical to Subpolar Gyre Exchange in the North Atlantic

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1. Introduction:

Historically, buoyancy forcing has been thought to dominate the extent to which subtropical waters are advected to high latitude regions: when cold high latitude waters sink, warm subtropical waters are drawn northward to close the large scale overturning. However, recent evidence has suggested that variability in wind forcing may play a role in either enhancing or suppressing the amount of subtropical water reaching high latitude convection sites. A recent analysis of Lagrangian surface drifter trajectories demonstrated that the amount of subtropical drifters reaching high latitudes increased between 1990 and 2007 (Hakkinen and Rhines, 2009). However, the amount of drifters reaching high latitudes remained well short of the 20-25% suggested by meridional transport calculations.

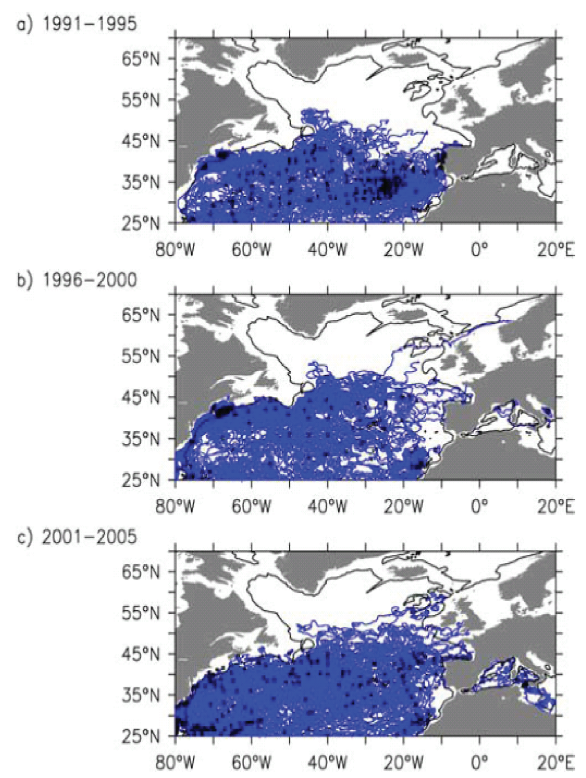


Figure 1: Changes in pathways of drifters launched south of 45°N between 1991 and 2005. (Hakkinen and Rhines, 2009).

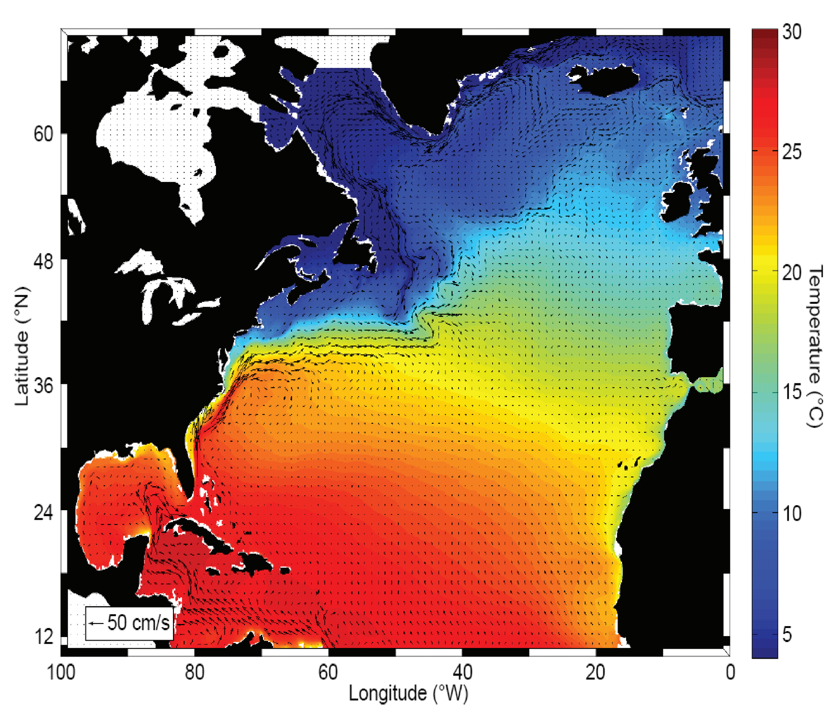
2. Central Questions:

1. Can an eddy resolving ocean general circulation model provide a reasonable reproduction of the surface drifter subtropical to subpolar exchange in the North Atlantic?

2. Can Ekman velocities, sampling bias and short drifter lifetime explain the patterns of exchange observed by Hakkinen and Rhines (2009) and other studies of surface drifter pathways?

3. At what depths are thermocline waters exchanged between the subtropical and subpolar gyres within an ocean general circulation model? Has the amount of exchange changed since 1990?

3. The FLAME Model:



Family of Linked Atlantic Model Experiments
- 45 layer z-coordinate model
- 1/12° horizontal resolution
- Forced at the surface with monthly averaged NCEP/NCAR anomalies superimposed upon ECMWF monthly climatologies.
-Available data: Jan, 1990 - Dec 2004.

Figure 2: Mean temperatures between 1990-2005 at 15 meters depth in the FLAME model shown with the mean 15 meter velocity field averaged onto a 1°x1° grid.

Comparison of EKE fields in FLAME and the Observational Record:
Eddy kinetic energy fields at 15 meters in the model compare well with North Atlantic EKE fields calculated from Lagrangian surface drifters and satellite measurements.

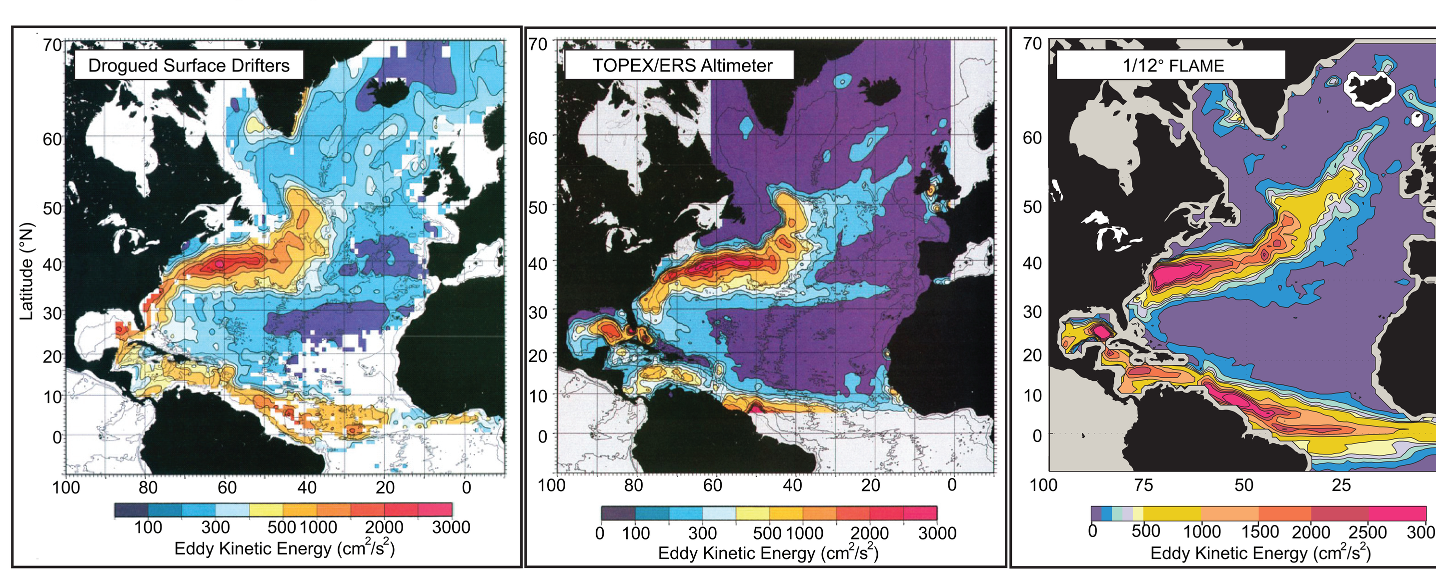


Figure 3: Comparison of EKE field in FLAME with EKE fields from surface drifters and satellite measurements during the 1990s. Drifter and satellite fields are reproduced from Fratantoni (2001).

4. Ekman vs. Sub-Ekman Layer Exchange:

Previous work has suggested that Ekman drift suppresses the amount of floats reaching the subpolar gyre by ~ 6% (Brambilla and Talley, 2006). Here, synthetic drifters in the FLAME model are used to compare the amount of exchange occurring within (15m) and below (100m) the Ekman layer.

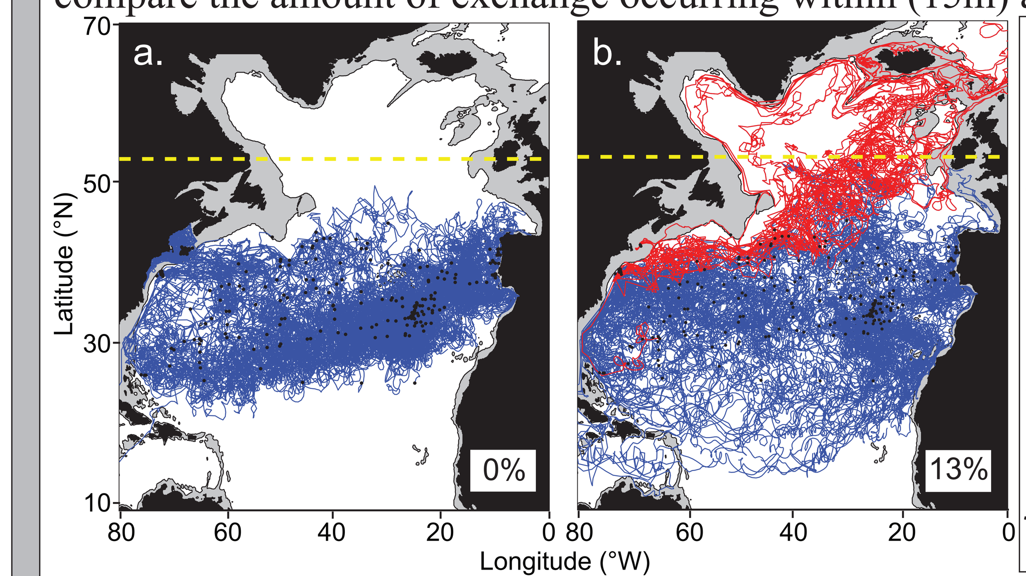


Figure 4: Percentage of drifters launched in FLAME at (a) 15 m and (b) 100 m reaching 53° N. Launch locations were taken from the launch locations of drifters in the observational record. Drifters shown were launched between 1990-1994 and advected through the velocity fields from that period. Red trajectories crossed the 53°N divide within 4 years while blue trajectories remained to the south. Black dots indicate launch locations.

5. The Role of Drifter Lifetime:

The mean lifetime of a drifter in the observational record is 271 days. Increasing the lifetime of drifters in FLAME dramatically increases the number of drifters reaching high latitudes.

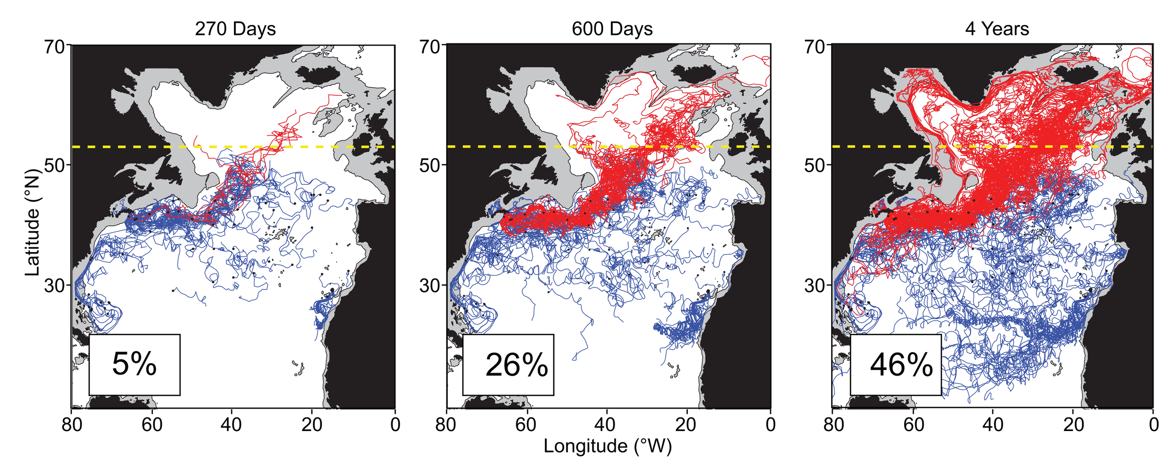
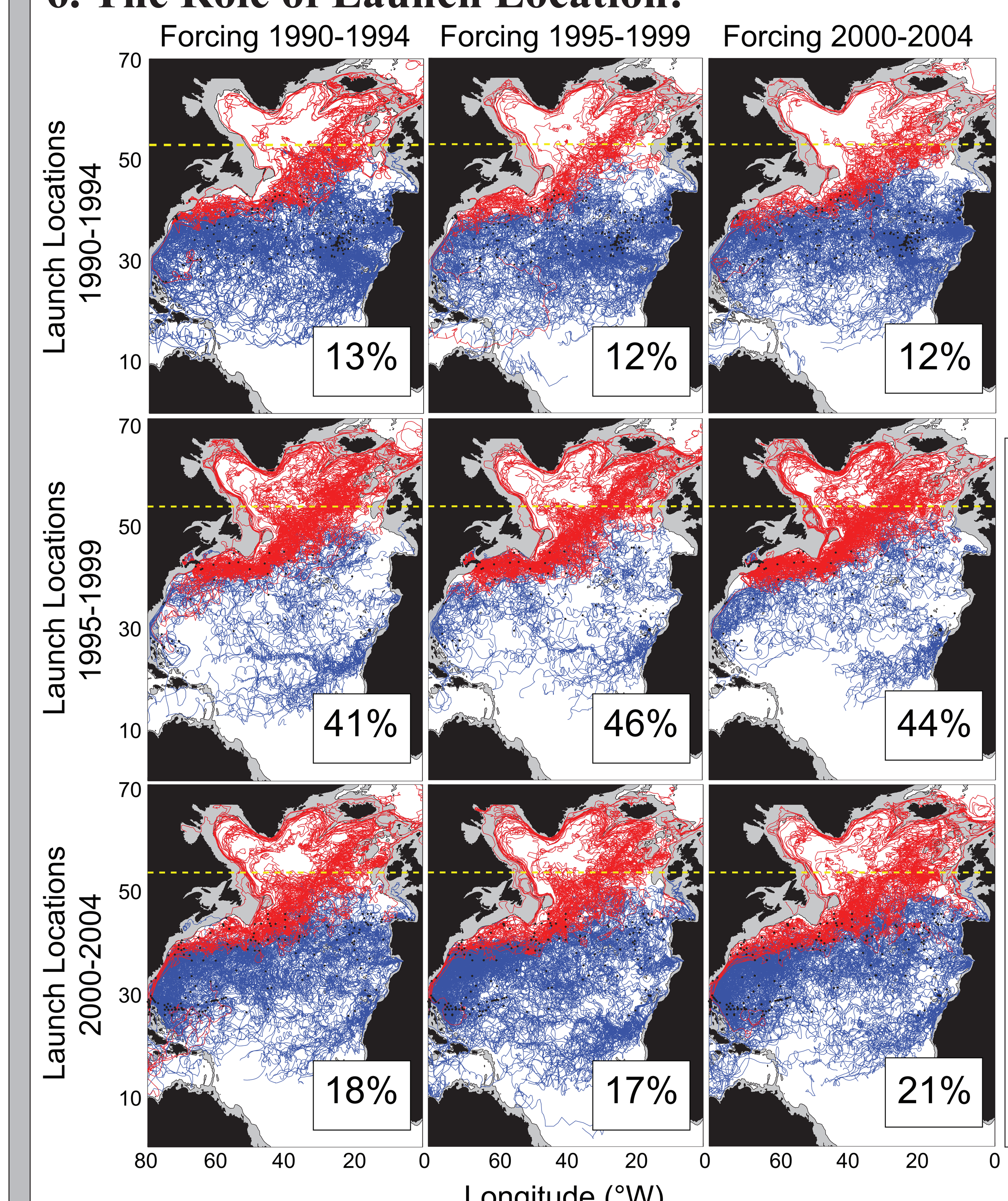


Figure 5: Changes in the percentage of drifters launched in the model at 100 meters reaching 53°N when allowed to run for 270 days, 600 days and 4 years. Red trajectories are those that crossed the 53°N boundary within the specified amount of time. Black dots indicate launch locations, which are the same for each of the three launches.

6. The Role of Launch Location:

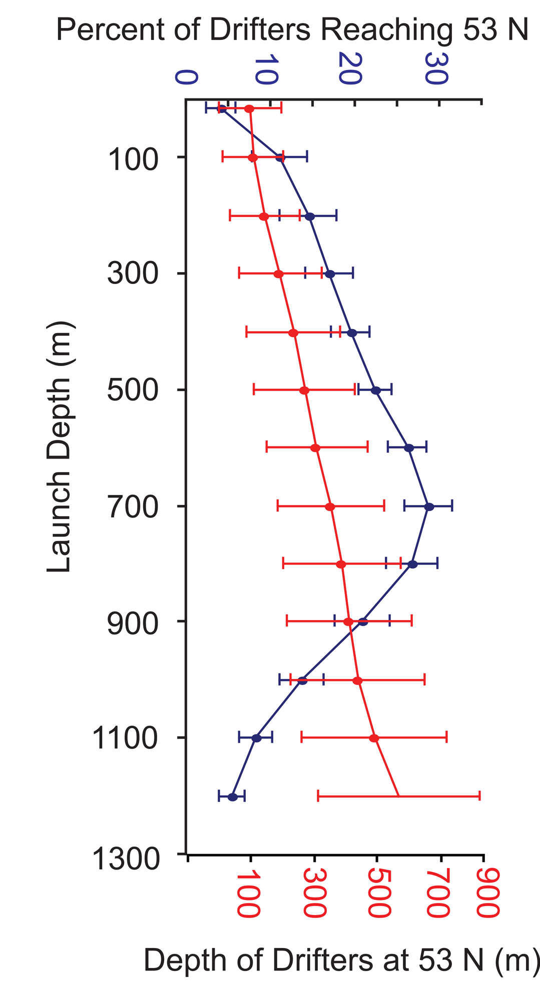


One of the potential limitations of using drifters from the observational record is the possible bias that could result from variability in launch location. Results from 100 meter launches in FLAME suggest that the drifter trajectories are extremely sensitive to launch location.

Figure 6: Drifters were launched in FLAME at the launch locations of drifters from the observational record between 1991-1995 (Location 1), 1996-2000 (Location 2) and 2001-2005 (Location 3). Each set of drifters was advected for 4 years through the velocity fields from each of the three periods. (columns). White box indicates the percent of drifters reaching 53°N within 4 years. Black dots indicate launch locations.

7. Changes in Exchange with Depth:

The surprisingly low amount of inter-gyre exchange recorded by surface drifters has raised the question: if exchange is not happening at the surface, where is it taking place? Here, we investigate changes in the amount of exchange with depth while removing a possible bias due to short drifter lifetime and launch location variability. Synthetic drifters were launched in the region of the Gulf Stream at 1/2° intervals. Launches were repeated every two months, and drifter trajectories calculated for 4 years. While drifters in the observational record are restricted to flow at 15 meters, the synthetic drifters were advected through the full three dimensional flow field. Only drifters launched south of the Gulf Stream front were considered.



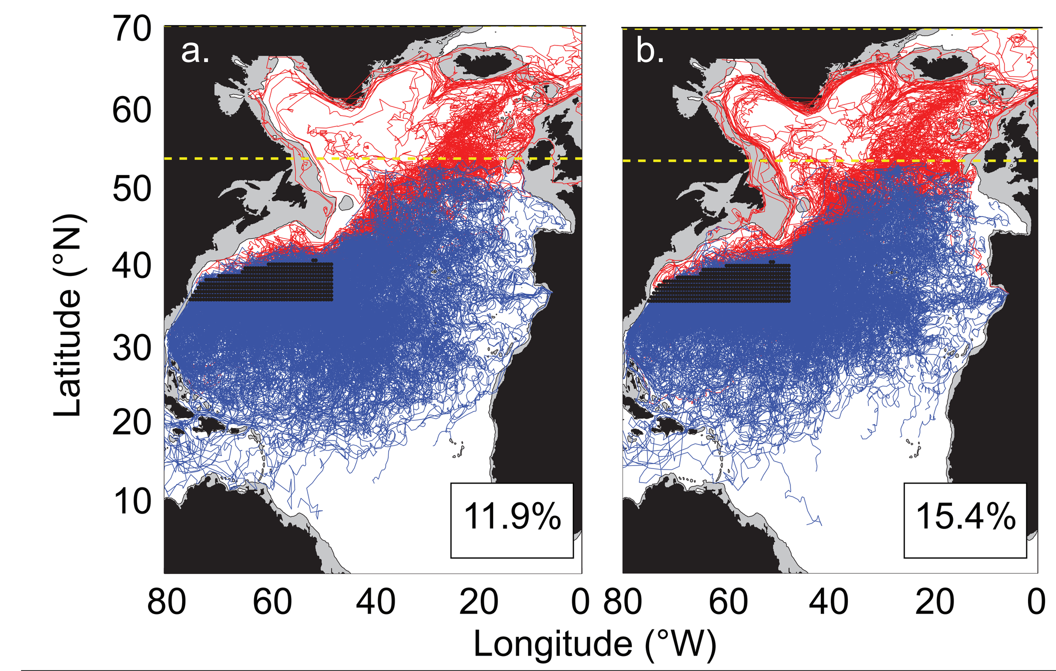


Figure 8: Synethetic drifters launched at 100 meters in FLAME in (a) 1990 and (b) 2000. Percent of drifters reaching 53°N in 4 years is indicated in the white box. Black dots indicate launch positions within the Gulf Stream region grid.

Figure 7 (above): (blue) Percent of synthetic drifters reaching 53°N from various launch depths. (red) Average depth of drifters when they reach 53°N.

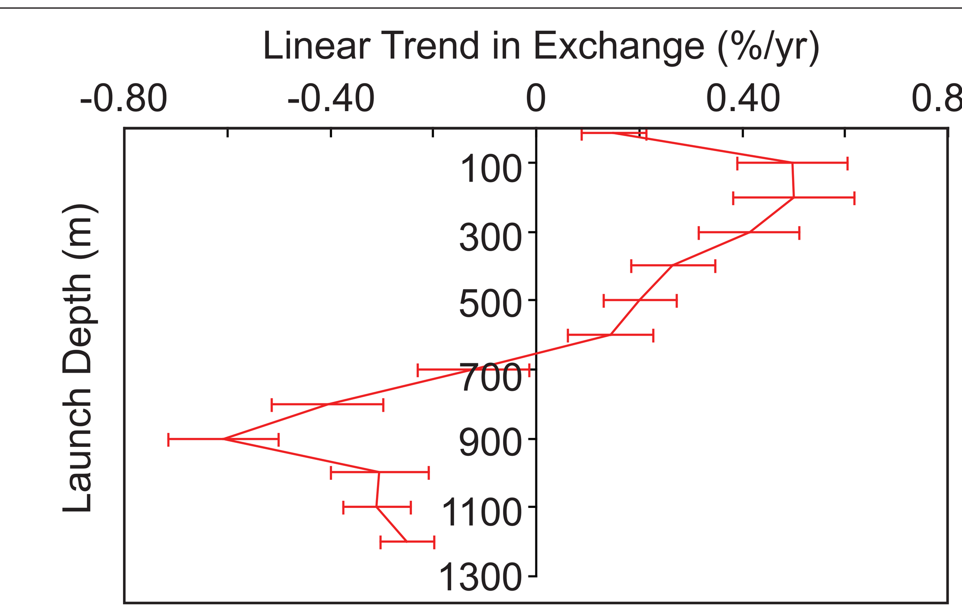


Figure 9 (right): Change in the amount of drifters launched at various depths reaching 53°N between 1990 and 2005.

8. Conclusions:

1. The FLAME model appears adequate for studying drifter pathways from the subtropical to subpolar gyre.

2. Ekman drift appears to limit the amount of exchange at the surface (15 m). Below the Ekman layer, bias in launch location and short drifter lifetime could explain variability in subtropical to subpolar exchange.

3. Results from synthetic drifter launches indicate that the amount of exchange is maximized at a launch depth of ~700 meters. Floats launched at 700 meters have a mean depth of ~350 meters when they reach 53°N.

9. Future Work:

Future work will examine trends in inter-gyre transport as well as investigate the mechanism responsible for the magnitude and variability in those trends.

10. Acknowledgements:

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