Buoyancy driven currents in eddying ocean models

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Lecture 1: Interplay between numerics and parameterizations

Lecture 2: Case study 1: Romanche fracture zone

Lecture 3: Case study 2: Mediterranean water overflow, and a few questions about the North Atlantic subpolar gyre
The Mediterranean overflow in basin scale ocean models

T and S profiles compared with climatology (data):
Three models, none is adequate.
(Treguier et al, 2000-2002).
Spreading of the Med water in the Atlantic

Review from observations.

There are three steps /three regimes:

Initial descent

Mediterranean undercurrent

Mediterranean salt tongue
1) Initial descent


Max salinity below 250m. Nuno Serra, Isabel Ambar et al, 2005
2) The Mediterranean undercurrent

Repeated hydrographic surveys, Serra et al, DSR 2005
The Mediterranean undercurrent

Variability of the Mediterranean undercurrent

Section T6: the thickness of Med water is increased in January 1998 compared to the September 1997 survey: higher T,S in winter (Ambar et al., 1999; Ferreira 2004). Hypothesis: link with the depth of the interface at Gibraltar?
Meandering branches of the flow: role of lateral entrainment?

ROMS code, 1/30°, 21 layers. « Lock exchange » experiment (Uniform initial profiles in the Gulf of Cadiz and the Alboran sea, no wind forcing).
Formation of the Mediterranean salt tongue

Spreading of Med water properties is due to eddies (entirely? to a large extent?)

Rafos floats during the MEDTOP experiment (Ambar et al 2008)

magenta — 300 m; green — 500 m; red — 800 m; blue — 1200 m; cyan — 1500 m
What sets the shape of the salt tongue?

Advection by mean currents

Advection / diffusion by eddies (meddies)

…the stability properties of the Mediterranean undercurrent matter

- stratification, potential vorticity, velocity profile;
- interaction with bathymetry
- Bottom friction
- seasonal cycle
Anticyclones and cyclones

Formation of dipoles (cyclone-anticyclone) has been observed (Ambar et al. 2008).

Cyclones influence the path of meddies.
Anticyclones and cyclones

Carton et al, 2010: observations of the interaction of two meddies (floats, buoys, hydrography, satellite altimetry).

A simple QG model shows that the presence of cyclones explains the complex path of the meddies.
Spreading of the Med water in the Atlantic

Spreading of the salinity by coherent eddies:

Often eddy effects are calculated as perturbations of a time-average \((u', S')\).

Is there a turbulent flux \(u'S'\)?
Spreading of Med water into the Atlantic

A difficult problem for models:

1) Initial descent: numerical entrainment? Unresolved processes such as tidal effects?


+ Vertical structure: double diffusive mixing?
Spreading of Med water in the Atlantic

Model comparison (Treguier et al, 2000-2002).
Initial descent: sensitivity experiments

Grey: 50% Med water, S > 37.15 PSU.

Test model: Bottom boundary layer (left) large bottom friction (right)
Shape of the salinity tongue

Salinity at 1000m: Levitus climatology (all salinity data, 1950-2000)

Salinity at 1000m: Atlas from data of the 1990s: Cambios, Canigo, Arcane…
Le Fur and Gaillard (2002)
Salinity tongue in the ATL6 model

Clipper ATL6 1/6° Model: open boundary in the Gulf of Cadiz (Molines, et al, LEGI, Grenoble)

Climatology
ATL6 model: open boundary at 8°W

Velocity and salinity at 800m
Micom: too many northern meddies

Micom 1/12° model:
salinity on isopycnal 27.38

Black contour: 35.7 PSU
Red: same contour in climatology

Climatology
Eddies in numerical models do not always follow the right path….

Surface EKE from POP 1/10° global model, Maltrud et al 2005.

Eddies have complex stability properties, and their displacement depends on many parameters: stability, size (beta effect), stratification…
More recent North Atlantic models?

Temperature and salinity profiles in the Med Water tongue in two North Atlantic 1/12° models:
- NATL12, NEMO code, z coordinates,
- Hycom (Xu et al, 2010), hybrid coordinate model.
Improving the initial descent in a z-coordinate model (NATL12)

Engineering fix....
Bottom friction and meddy formation

Without enhanced bottom friction

With enhanced bottom friction

Frictional processes (bottom friction) influence the stability of the Mediterranean undercurrent
Salt tongue : 1000m salinity

Climatology

NATL12

HYCOM 1/12
Modelling the Med water in the Atlantic

Models have improved over the last decade but we are not there yet…

- Initial descent: numerical entrainement? Unresolved processes such as tidal effects?


- Salt tongue: eddy advection/diffusion. Number of eddies, preferred sites for generation, cyclone/anticyclone interaction.

- Vertical structure: double diffusive mixing?
Buoyancy driven flows in the North Atlantic subpolar gyre

- Labrador sea
- Irminger sea
- Reykjanes ridge
- Iceland basin
- Hatton Bank
- Rockall trough
Barotropic circulation of the subpolar gyre

A comparison of different numerical models (Treguier et al 2005):

- ATL6 1/6° Atlantic model (CLIPPER project, OPA/NEMO numerical code)
- FLAME 1/12° model (Eden and Böning, 2002): MOM GFDL code;
- MICOM 1/12° model (Chassignet et al, isopycnic model)
- POP 1/10° model (Smith et al 2000; POP – NCAR code)
Deep convection – Labrador sea
Chanut et al, JPO 2007: restratification in the Labrador sea at 1/3° and 1/15°

Use of nesting to study the effect of eddies in a domain, and the feedback on the global ocean.
Impact of resolution from 1/6 to 1/15°

AR7W section across the Labrador sea

NATL3 + AGRIF 1/15°

NATL6
Convection in the Labrador Sea in NATL12

Extent and depth of convection region still too large

Eddy variability is underestimated
Convection in the Labrador Sea in eddying models

Models demonstrate the importance of eddy driven restratification;

Parameterizations of this effect are available;

Many questions remain about other processes that affect the convection:
Large uncertainties on the air-sea fluxes?
Wrong water mass properties/ deep stratification?
Problems with the horizontal circulation (subpolar gyre): advection of high salinity water from the east.

What about overflows from the Nordic seas?
Transport of light and dense water ($\sigma > 27.8$)
Transport of overflows and water mass properties downstream

Can the overflows supply enough dense water with the right properties, so that large scale properties of the deep waters in the modelled subpolar gyre match the observations?
Overflows: downstream properties

Levitus bottom density

ATL6 model (Treguier et al 2005)
Overflows downstream
Bottom density: Levitus vs Hydrobase

In order to validate models we need a better analysis of deep water properties.

Left: initial model bottom density (from Levitus). Contour 27.9.

Hydrobase bottom density (R. Curry). Contour 27.9.
Conclusion (1)

Limited area model, one overflow, adequate resolution: example, Romanche fracture zone.

Basin scale model, rotating case, multiple overflows+ open ocean convection: North Atlantic models at 1/10°-1/12° resolutions.

Numerical models do not represent well the link between the overflows and the global overturning circulation.
Conclusion (2)

From a dense buoyancy driven current down a slope…

To the « conveyor belt » of the global thermohaline circulation…

Eddies do most of the spreading of dense waters.