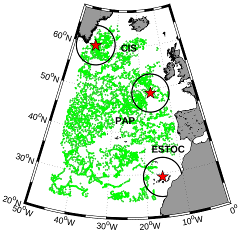
Combining near real-time mooring and float data at mooring sites in the North Atlantic: Mixed layer cycles and heat balances

J. Karstensen, U. Send, C. Begler, T. Müller

Leibniz-Institut für Meereswissenschaften (IFM-GEOMAR) an der Universität Kiel, Kiel, Germany

Location of the three ANIMATE mooring sites (ESTOC, CIS, PAP). Yellow dots locations of profiles taken by the ARGO floats between 2002 and 2004. Circles denote the radius to which we used floats for analysis at the mooring sites.



Introduction

The heat content at a certain location in the upper ocean is an interplay between local air/sea interaction and advection of water with a different temperature. The mixed layer cycle is an important part in the local balance as it controls the exchange between the interior ocean and the surface mixed layer. It controls not only physical (heat) but biogeochemcial cycling (nutrient supply).

Moored physical and biogeochemical instruments allow to resolve processes often with a high temporal resolution but only in one space dimension (vertical). Hence the magnitude of lateral gradients is unknown. Exceptions are place where a number of moorings is installed (e.g. TOGA/TAO array in the equatorial Pacific; Cronin and McPhaden, 1997). Under the umbrella of the international ARGO project, a fleet of floats was/is launched globally into the oceans that are a potential useful complement to mooring data to resolve lateral gradients. As long as 'enough' floats encircle a mooring site they may allow to derive lateral gradients of certain parameters, typically temperature and salinity, and allow for a better understanding of processes at a mooring site.

Here we show an example for a combination of mooring and float data for the Northeast Atlantic to derive details on the mixed layer cycling. Potentially three mooring sites could be used which are part of the Atlantic Network of Interdisciplinary Moorings and Time-series for Europe (ANIMATE), an EU funded project of the FP 5. Each site is equipped with physical (temperatur, salinity, velocity) and biogeochemical (nutrient analyzer, pCO_2, flourescence, sediment traps) sensors, some nearly continously record parameters which send to shore in near real time via satellite link. The data is accessible via the project website (www.socton.soc.ac.uk/animate).

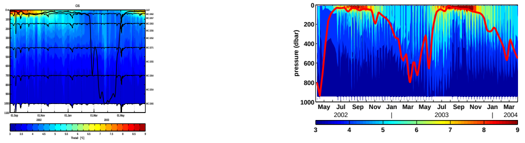
Mixed layer depth cycle from float and mooring data

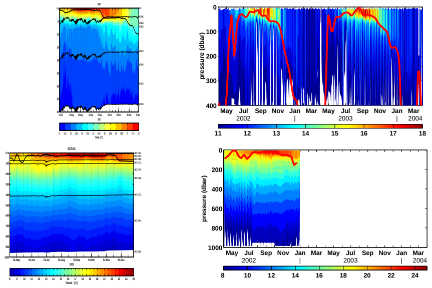
The interface between mixed layer and the interior ocean is the mixed layer base. The exchange rate (S; instantaneous subduction rate) at the mixed layer base (h) can be written as a composition of: the mixed layer base change (1; bouyancy driven), vertical velocity through Ekman pumping, corrected for the meridional flow in the mixed layer (2), and the vertical component from the lateral flow field through the titlted mixed layer base (3):

$$S = -\overset{1}{\partial h/\partial t} - \overset{2}{w_h} - \mathbf{v}_h \overset{3}{\nabla} h$$

The mixed layer base can be derived utilizing a number of criteria (see Kara et al. 2000 for a review). We used the depth associated with an increase of the surface density by $0.125 kgm^{-3}$ utilizing float and mooring data. In the figures below float data in the vicinity (500 km) of the mooring was considered.

ANIMATE mooring sites **ARGO float data**





Temporal development of the temperature derived at the mooring sites (left) and from all ARGO float data in the vicinity of the mooring sites (right). The thick red/black line is the mixed layer depth.

Mixed layer base depth derived from float data at is in good agreement with the mixed layer base depth at the mooring sites. However, individual float show a very different mixed layer depth.

9.

References:

Cronin, M.F. and M.J. McPhaden (1997) The upper ocean heat balance in the western equatorial Pacific warm pool during September-December 1992, J. Geophys. Res. 102:8533-8553

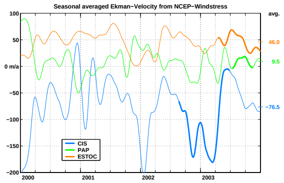
Kara, A. Birol ; Rochford, Peter A. ; Hurlburt, Harley E. (2000) An optimal definition for ocean mixed layer depth, J. Geophys. Res. Vol. 105 , No. C7 , p. 16,803 (2000JC900072).

Acknowledgements:

The NCEP NCAR reanalysis data was provided by the NOAA CIRES Climate Diagnostics Center, Boulder, Colorado, from their Web site www.cdc.noaa.gov

The role of Ekman pumping

One factor driving the local mixed layer cycle is the wind stress curl. In the annual mean, ESTOC is a typical subtropical regime with an year-round downward pumping (order $50my^{-1}$), PAP is a westerly strom track regime and switches between up- and downward suction/pumping (average is pumping order $10my^{-1}$), finally CIS is located in an upwelling regime in the cyclonic Irminger Sea gyre with a strong suction order $80my^{-1}$.

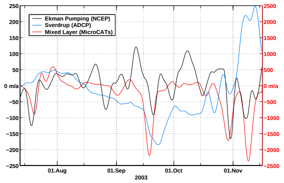


Ekman pumping at the three mooring sites between 2000 and 2004 derived from NCEP/NCAR reanalysis data. The thicker part of the lines are associated with periods mooring data is available.

Contributions to mixed layer base changes

For the PAP site we analyzed the vertical velocities (S) resulting from the mixed layer base deepening ($-\partial h/\partial t$) in relation to the wind stress curl and a wind stress curl corrected for the meridional barotropic forcing of the mixed layer ($-w_h$ labelled: Sverdup). The mixed layer base deepening in winter and in particular in early spring is about 10 time larger then contributions from the wind field. However, it occurs only during a very short period of time.

Contributions to the vertical movement of the mixed layer base. Note the different scale for buoyancy driven vertical (right scale) movement and wind driven vertical movement (left scale).



Conclusion

Combining mooring and float data allow to resolve and consequently 'monitor' local mixed layer cycles. As the mixed layer cycle is the main player for the air-sea exchange, hence the local heat fluxes, it should be reasonably well resolved in numerical models. It could be advisable to test models against data in respect to their reproduction of the mixed layer cycle rather then doing a pattern match utilizing tracers (temperature, salinity).

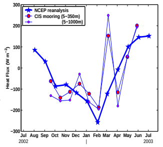
As float data is not always avaliable near the mooring sites (e.g. in our case at ESTOC), certainly a more regular sampling around the moorings is desirable – a solution would be the deployment of autonomous gliders.

EXAMPLE: CIS (Central Irminger Sea mooring)

Heat balance

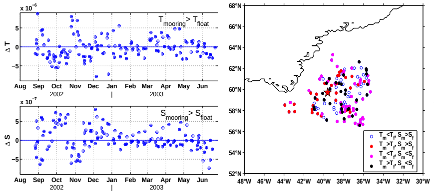
The observed temperature at the mooring site can be transformed into a heat content ($Q=m \cdot c_p \cdot T$). Integrating over (different) depth and considering monhtly averages one can calculate the heat flux required to obtain the observed changes in heat content.

Heat fluxes from the NCEP/NCAR reanalysis for the period 2002/2003 agree reasonably well with the heat fluxes required to explain the observed changes in heat content. This would suggest that the advective contribution on the temporal evolution of the temperature at the CIS site is small. The differences in March 2003 could be related through lateral transports during the active convection phase.



Horizontal gradients from float and mooring data:

As the CIS site had a relative high population of floats we estimated the lateral gardients at the mixed layer base (**3 in equation at left**).



(left) gradient (dT/dr, dS/dr) at the mixed layer base between float and mooring mixed layer base temperature/salinities.

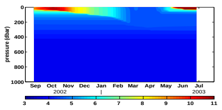
Overall, the gradients are small. It appears, however, that there might be a seasonal change but this might be masked through the merging of temporal and spatial information and has to be analyzed in more detail.

1-d and 3-d modeling of the mooring sites:

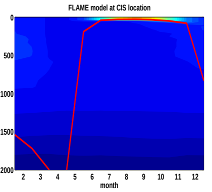
In addition to the observations the output from numerical models was analyzed. Attention was given on how the mixed layer cycle was resolved in comparison to the data. Two model have been used:

- 1-d mixed layer model initialized with observational data at the mooring site form the 15. Sept. 2002 and driven with 3 hourly NCEP/NCAR heat and momentum fluxes
- 3-d North Atlantic model output (FLAME group) were analyzed. The FLAME model is forced with monthly climatological data.

1-d mixed layer model (GOTM)



3-d FLAME model (1997-2000) average



1-d mixed layer model (left) and 3-d North Atlantic model (FLAME) temperature simulations at the CIS site location. The 1-d model does not include salinity simualtions yet and no density derived mixed layer can be calculated. In the FLAME model the thick red line indictes the mixed layer (0.125 kgm^{-3} density increase). Note the different depth scale.

Both models did not resolve the mixed layer cycle at the CIS site in all details. The mixed layer base in the 1-d model was too shallow, suggesting that entrainment of salinity (which was not considered in the model run) during deepening of initially thermal convection may contribute to the deep mixed layer depth observed in the Irminger Sea (CIS location).
The 3-d model, in contrast, showed a too deep mixed layer base.

Contact: Johannes Karstensen @ Leibniz-Institut für Meereswissenschaften (IFM-GEOMAR), Düsternbrooker Weg 20, 24105 Kiel, Germany. email:jkarstensen@ifm-geomar.de, phone: +49 431 600 4156 Fax: +49 431 6004152 www.ifm-geomar.de