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Synoptic estimates of an eddy field in the North Atlantic Current

Northeast Atlantic
Mesoscale
Assimilation

Atlantique Nord-Est
Mésoéchelle
Assimilation

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ABSTRACT

We show various synoptic estimates of the North Atlantic Current (NAC) eddy field in a domain 450 x 350 km at 52.5°N 25.0°W in the theoretical path of the NAC. Temperature, salinity, and surface streamfunction estimates are derived from the AthenA hydrological data collected in the summer of 1988. These estimates are discussed and compared with two surface streamfunction estimates obtained from Geosat altimetric measurements: one statistical, and the other resulting from quasi-geostrophic assimilation. The estimates show a frontal structure associated with a jet, sharply separating cold and fresh water to the north from warmer and saltier water to the south. Temperature and salinity values on both sides of the front are consistent with climatological values. The assimilation estimates indicate that there may have been an eddy merger event during the experiment. The eddy field is much more energetic than the mean; no clear propagation is evidenced; time scales are longer than twenty days. Local transport by the jet as calculated from model results is of the order of $30 \times 10^6 \text{ m}^3 \text{ s}^{-1}$; the vertical structure is that of the "sheared barotropic mode", where transport has the same sign and direction from top to bottom, but is weaker at the bottom.

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RÉSUMÉ

Estimation synoptique d'un champ de tourbillons dans le Courant Nord-Atlantique

Nous montrons plusieurs analyses synoptiques du champ de tourbillons associé au Courant Nord-Atlantique (CNA) dans un domaine de 450 x 350 km à 52.5°N 25.0°O sur le passage théorique du CNA. La température, la salinité, et la fonction de courant de surface sont analysées à partir des données hydrologiques de la campagne AthenA recueillies pendant l'été 1988. Ces analyses sont discutées et comparées avec deux analyses de la fonction de courant de surface obtenues à partir des mesures altimétriques de Geosat: l'une statistique, et l'autre résultant d'une assimilation quasi-géostrophique. Les analyses montrent une structure frontale associée à un jet et séparant de manière abrupte une eau froide et douce au nord d'une eau plus chaude et plus salée au sud. Les valeurs de température et de salinité des deux côtés du front sont en accord avec les valeurs climatologiques. Les résultats d'assimilation indiquent la possibilité de la fusion d'un tourbillon et d'un méandre pendant l'expérience. Le champ de tourbillons est beaucoup plus énergétique que le champ moyen; il n'y a pas de propagation nette; les échelles temporelles sont supérieures à vingt jours. Le transport local par le jet calculé à partir des résultats du modèle est de l'ordre de $30 \times 10^6 \text{ m}^3 \text{ s}^{-1}$; la structure verticale est celle du «mode barotrope cisaillé», où le transport a le même signe et la même direction sur toute la colonne d'eau, mais où il est plus faible en profondeur.

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INTRODUCTION

Synoptic representations and detailed phenomenological analyses in energetic regions of the eastern basin are very few, in contrast with western regions (*e. g.* Hua *et al.*, 1986). The eastern basin has had a reputation for being rather quiet and devoid of a dominant current system, and consequently of strong energy radiation mechanisms. Nevertheless, mesoscale activity is present in most regions of this basin, and is often linked (with no clear causality) with mean currents. One of these regions is the so-called "instability zone" of the North Atlantic Current (NAC), just downstream of its multiple crossing of the mid-Atlantic ridge.

The existence of the North Atlantic Current (NAC) and its branching out of the Gulf Stream were first postulated some time ago by several authors, including Iselin (1936), Mann (1967) and Dietrich (1969). The picture has only recently been refined by experimental means by Clarke *et al.* (1980), Krauss and Meincke (1982), Krauss (1986), and Sy (1988). The NAC as a "mean" is hard to identify, as it is composed of non-permanent branches past the ridge. Eddies, jets and meanders seem to dominate the mesoscale fields. Particular attention has recently been paid to the communication of the NAC system and of the subpolar gyre with the Mediterranean outflow *via* a northward mid-depth current along European coasts (*e. g.* Schopp, 1987; Dickson *et al.*, 1985). However, we shall not be concerned with Mediterranean water in this study, as the longitude of the estimates (25°W) is probably too far to the west to see any of it (*e. g.* Reid, 1979).

The 1970s and 1980s have seen statistical or systematic studies of the variability at all scales of the Northeast Atlantic, including the mesoscale. Most types of measurements have been used: drifting buoys (Krauss and Böning, 1987); currentmeter moorings (in particular the Neads programme, *e. g.* Gould, 1983; Dickson, 1983; and the Topogulf programme: Colin de Verdière *et al.*, 1989); intensive surveys (Le Groupe Tourbillon, 1983; Mercier and Colin de Verdière, 1985); satellite altimeter data (Le Traon *et al.*, 1990; Le Traon, 1991), to cite a few. From these studies, the characteristics of the variability in the eastern basin began to emerge. It was shown for instance that space scales increase as one moves towards the ridge, that the longest time scales are found on top of the ridge between 30° and 50°N, and that vertical coherence is generally high in the mesoscale band.

A few studies are more directly relevant to the results shown in this study, as they are concerned with the NAC eddy field east of the ridge. Among the oldest, the IGY Polar Front surveys (Dietrich, 1969), and surveys reported by Erofeeva (1972) show the meandering and large variability of the polar front. Howe and Tait (1967) describe an eddy at 53°N 19°W with a Mediterranean water core thought to result from the pinching off of a NAC meander. Pollard (1983) shows estimates of an eddy field at 59°N 11°W with typical scales O (100 km), obtained by an inverse technique. Krauss and Meincke (1982) report on drifting buoys launched over the mid-Atlantic ridge between 46°N and 52°N, and entrained into an eddy field west of the ridge. In addition, a few eddy generation mechanisms have been postulated in the eastern basin. Le Groupe Tourbillon (1983) and Harvey and Glynn (1985) describe a deep winter convection eddy at 47°N 15°W and its temporal evolution. Müller and Frankignoul (1981) discuss on theoretical and statistical grounds the influence of direct wind forcing on eddy generation in the eastern basin. Finally, the Topogulf programme, although not focused on mesoscale dynamics (*e. g.* Sy, 1988; Colin de Verdière *et al.*, 1989), has demonstrated the influence of bottom relief and in particular of the mid-Atlantic ridge on the variable circulation, including the mesoscale band.

In this study we shall present and discuss synoptic estimates of oceanographic variables near the surface obtained with *in situ* data collected during the AthenA experiment (data report: Le Squère, 1992). This experiment was carried out in the summer of 1988 within the path of the NAC, downstream of the point where the NAC crosses the mid-Atlantic ridge (Gibbs fracture zone). It consisted of two hydrographic surveys beneath tracks of the Geosat altimetric satellite (*e. g.* Cheney *et al.*, 1987), drifting buoys, currentmeter moorings and meteorological measurements at the air-sea interface. The purposes of the experiment were: 1) to study the NAC eddy field downstream of the ridge; 2) to evaluate the usefulness of altimetric data in such a context; 3) to collect a local dataset for assimilation studies both in the deep ocean and at the air/sea interface; and 4) to practise real-time design. It is hoped that this paper will contribute to objectives (1) and (2), *i. e.* present a synoptic and detailed local view of the eddy field from various

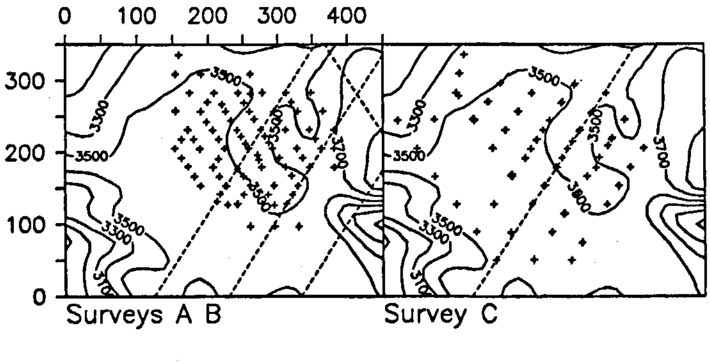


Figure 1

Bottom relief in the estimation domain. Contour interval is 200 m. Station locations (crosses) and available Geosat tracks (dotted lines) for both AthenA legs are overlayed. Units on axes are kilometres. The centre of the domain is 52.5°N 25.0°W. In all estimates presented hereafter, contours are shown both inside and outside the data region. The transition between both regions is probably unphysical but makes it possible to follow climatological contours within the eddy field.

Relief du fond dans le domaine d'analyse. L'intervalle entre deux isolignes est de 200 m. L'emplacement des stations (croix) et les traces Geosat disponibles (tirets) sont indiqués pour les deux legs d'AthenA. Les axes sont gradués en kilomètres. Le centre du domaine est à 52,5°N et 25,0°O. Toutes les figures présentées ci-après montrent des isolignes à la fois à l'intérieur et à l'extérieur de la zone de mesures ; la transition entre les deux régions n'est probablement pas physique, mais elle permet de suivre les isolignes climatologiques à l'intérieur du champ tourbillonnaire.

sources, *e. g.* as in Pollard (1983). Estimation techniques at differing degrees of complexity will be used, but the statistical background is unique (optimality in the least-squares sense, same statistical structure functions).

This paper gives first a brief overview of the estimation domain and of the AthenA hydrographical surveys (next section), then shows temperature and salinity estimates at 310 m (third section) and streamfunction estimates near the surface (fourth section).

ESTIMATION DOMAIN AND ATHENA HYDROGRAPHICAL SURVEYS

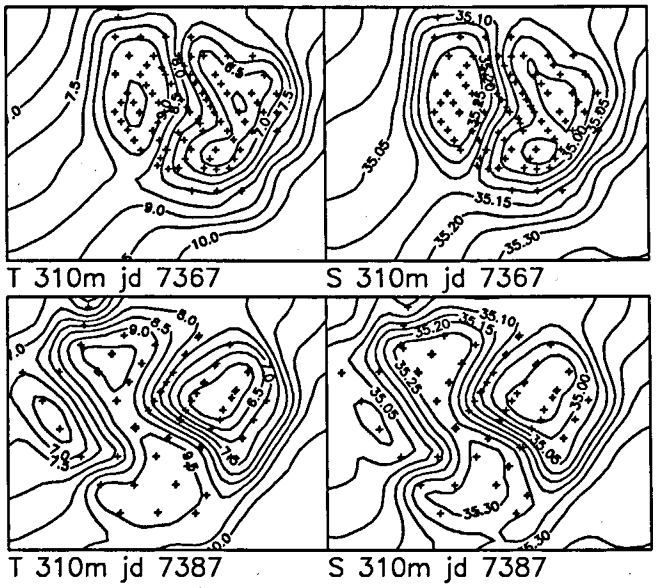
The AthenA-88 experiment was carried out between 18 July and 25 August 1988, within the path of the NAC at 53°N 25°W. Figure 1 shows the local bathymetry, the Hydro measurements during the two legs, about twenty days apart, and available Geosat tracks during the experiment. The Geosat passes are concomitant with the underlying hydro casts. Surveys A and B on one side, and C on the other, can be considered synoptic, since they were both completed in six days at most. Geosat data were processed as in Le Traon *et al.* (1990), using the repeat-track method.

The relief is shown in the estimation domain. The centre of the domain is 52.5°N 25.0°W. Its east-west extent is 450 km, its north-south extent 350 km. Strong relief appears southwest and southeast of the domain (mid-Atlantic ridge and East Thulean rise). The general slope is upward to the north. The relief is otherwise smooth within the survey area. A north-south, 100 m-high ridge stems out from the northern slopes to the south, occupying the eastern part of the survey area. This ridge and its southern terminal bump seem to have played an important role despite their modest amplitude, as illustrated later.

One of the originalities of the cruise was that the processing of hydrological and satellite data was done on board in real-time. Thus array C has been designed in real-time from the results of the first leg. It is looser than array A, which appeared to have been overly sampled.

TEMPERATURE AND SALINITY ESTIMATES

Estimates are obtained as follows: AthenA CTD and XBT data are converted into temperature and salinity profiles; anomalies with respect to the annual Robinson *et al.* (1979) climatology are objectively analyzed; the climatological mean is added back. The objective analysis scheme (De Mey and Ménard, 1989) is locally optimal in the least-squares sense and uses three-dimensional statistical structure functions (two horizontal dimensions, and one temporal). First-guess correlation scales for objective analysis are 80 km and 20 days. The space correlation scale is consistent with Le Traon *et al.* (1990). The time correlation scale was chosen as a compromise between values in Le Traon (1991) and the desire to limit the smoothing out of temporal variations between hydro surveys. Truncated Woods Hole julian dates (jd) are used. The central date for surveys A and B is jd 7367 (25 July); for survey C it is jd 7387 (14 August).



T 310m jd 7367 S 310m jd 7367

T 310m jd 7387 S 310m jd 7387

Figure 2

T and S estimates at 310 m (see text). Surveys A/B stations are overlayed on jd 7367 maps, survey C stations on jd 7387 maps. Contour intervals are 0.5°C and 0.05.

Cartes analysées de T et S à 310 m (*voir* texte). Les cartes du jour 7367 montrent les stations des réseaux A et B, celles du jour 7387 montrent les stations du réseau C. Les intervalles entre isolignes sont de 0,5°C et 0,05 (salinité).

Temperature and salinity estimates at 310 m are shown in Figure 2. Contours are shown both inside and outside the data region in order to allow to follow visually the climatological T and S contours within the eddy field. The transition between both regions, and in particular the closing of the structures at the outer edge of the data region, are probably unphysical. What we see is a meandering front separating eddy-like features. However, cruise measurements alone do not permit a conclusion as to whether these features are or are not closed eddies. The typical spatial scale is 100 km. The typical temporal scale is longer than 20 days, since the temporal correlation between both dates is higher than 0.8 for both variables. Le Traon (1991) has obtained with Geosat in the same area a lower correlation value (0.35) for a 17-day lag; however, his figure cannot be directly compared with ours, since: 1) the Geosat error variance after processing is still high for a 17-day lag; 2) altimetric data contain the sum of all dynamic modes, including the barotropic; 3) altimetric data do not contain the contribution of time scales beyond the length of the repeat-track analysis period. An expected result here is the simple relationship between temperature and salinity at 310m: the cross-correlation is 0.98 on both dates. This is typical of the North Atlantic Central Water (NACW; *e. g.*, Le Groupe Tourbillon, 1983). This simple relationship made it possible to include XBTs in the dynamic calculations. It does not hold any more below 1 500 m.

Two features are present on jd 7367, one warm and salty, one cold and fresh. The cold/fresh feature is actually composed of two kernels, the southern kernel sitting on top of the terminal bump of the 100 m-high ridge in the bottom relief mentioned in the second section. On jd 7387, the cold/fresh feature is more monolithic, as an even warmer and saltier feature appears south of the estimation domain. It is not known whether another front is present south of this new feature.

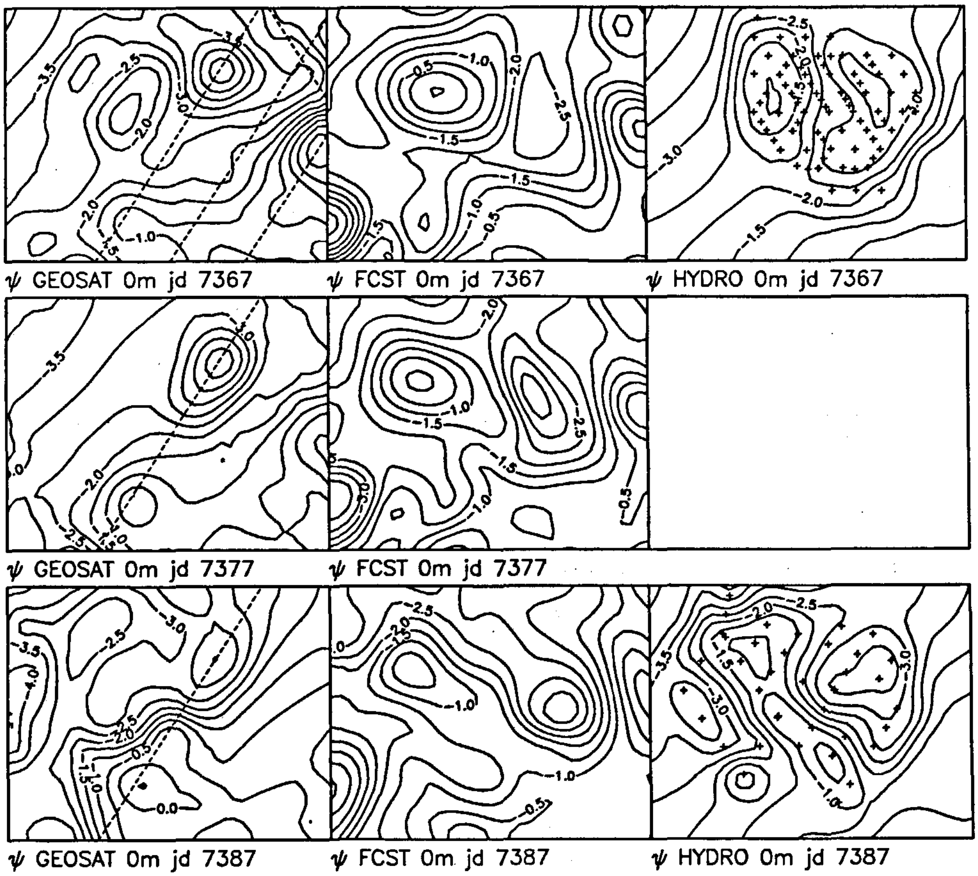
Extreme T-S characteristics on both sides of the meandering front are typical of waters north and south of the North Atlantic Current (Robinson *et al.*, 1979; Levitus, 1982; Maillard, 1986): 6.0°C/34.95 are observed here on the northern flank, against 9.5°C/35.30 on the southern flank at 310 m. The sharp contrast between both sides of the front further increases near the surface. At 310 m depth, T and S gradients are approximatively five times greater than climatological gradients. Extreme values on the southern flank occur within the third feature (appearing jd 7387 south of maps). Anomalies with respect to the local climatology are very coherent in the layer 0-2 000 m where the most significant empirical mode (Lorenz, 1956) takes 93.6 % of the variance for T, and 90.4 % for S. The possible but unlikely presence of Mediterranean water near 800 m (Reid, 1979) was not detected during the experiment.

It is difficult to determine from these estimates how the two warm features are connected to each other, and whether such a connection existed at the time of the first array. The estimates on jd 7387 visually suggest that both features could form a northward meander being slowly pinched off (as for the eddy in Howe and Tait, 1967). Another hypothesis could be the interaction of a front-like meander with an warm eddy shed by the North Atlantic Current upstream of AthenA months before the experiment, partially mixed by submesoscale processes, and entrained with the NAC on its northern flank. Stern and Flierl (1987) have suggested, with Gulf Stream rings in mind, the possibility of such a mechanism where a vortex interacts with a shear flow on the f-plane; they have shown that the vortex eventually captures water and potential vorticity from the meander and creates a "ridge" between them. This mechanism, whose applicability here we shall not discuss, and which will tend to be confirmed by the surface streamfunction estimates, would account for the T-S discrepancies between both warm features.

SURFACE STREAMFUNCTION ESTIMATES

The hydrological streamfunction estimate, termed "Hydro", is first discussed. It is shown in Figure 3. It is obtained as follows: the anomaly geopotential thickness of the layer 0-2 000 m with respect to the annual Robinson *et al.* climatology is objectively analyzed as above; the climatological thickness is added back; the climatological dynamic height at 2 000 m with respect to 3 000 m (the bottom of the Robinson *et al.* dataset) is added; finally, the dynamic height is converted into nondimensional streamfunction. The scaling coefficient for streamfunction is TU^2, where U is a typical velocity scale and T a typical horizontal length. Here, $U = 0.1\ ms^{-1}$, and T = 8 days is the local advective time scale.

As expected, Hydro is very coherent with temperature and salinity estimates. The sampling is looser in the southern


ψ GEOSAT 0m jd 7367 ψ FCST 0m jd 7367 ψ HYDRO 0m jd 7367

ψ GEOSAT 0m jd 7377 ψ FCST 0m jd 7377

ψ GEOSAT 0m jd 7387 ψ FCST 0m jd 7387 ψ HYDRO 0m jd 7387

Figure 3

Surface streamfunction estimates Geosat, FCST, and Hydro (see *text*). *Survey stations are overlayed on Hydro estimates. Satellite passes less than five days away from the estimation date are overlayed on Geosat estimates. No Hydro estimate is available on jd 7377. The FCST estimate is borrowed from Dombrowsky and De Mey (1992).*

Cartes analysées de fonction de courant de surface obtenues par les filières Geosat, FCST et Hydro (*voir* texte). Les stations sont indiquées sur les cartes Hydro. Les passages altimétriques qui se situent à moins de cinq jours de la date d'analyse sont indiquées sur les cartes Geosat. Il n'y a pas de carte Hydro le jour 7377. L'analyse FCST a été réalisée par Dombrowsky et De Mey (1992).

part since few stations to 2 000 m were available there. A meandering jet, best visible on jd 7387 and flowing between cyclonic features to the north and anticyclonic features to the south, is associated with the meandering front described above. Its vertical coherence is even larger than the vertical coherence of hydrological variables in the front: the most significant empirical mode of dynamic height with reference to 2 000 m takes 99.5 % of the variance at 0 m. The largest departures from this mode are found in the south during survey C. The maximum velocity estimate at the surface is 0.2 ms^{-1} on jd 7367 and 0.3 ms^{-1} on jd 7387. For reference, the climatological velocity of the NAC within the domain is approximatively 0.04 ms^{-1}.

Hydro is also very coherent with bottom relief. On jd 7387, when it is best sampled, the jet roughly follows the 3 500 m isobath, with the possible exception of its undersampled southwestern segment. In addition, the cyclonic feature northeast of the jet appears to sit on top of the 100 m-high ridge mentioned earlier.

The altimetric estimate, termed "Geosat", is calculated as follows. The variable heights obtained as the result of the repeat-track method are assumed to measure only the variable part of the oceanic circulation; they are objectively analyzed as above; the climatological topography (from Robinson *et al.*) is added; the result is converted into non-dimensional streamfunction.

Unfortunately, only a very limited set of tracks are available in the area during the experiment, for reasons which have never been totally elucidated. As a consequence, only a very limited amount of information can be drawn directly from the Geosat estimate. Let it be said that portions of the jet can be recognized, *e. g.* on jd 7387 near the centre of the estimation domain, with an amplitude similar to Hydro. The use of temporal structure functions in the analysis seems to have some skill in interpolating in gappy regions of the domain.

In order to match Hydro with a suitably sampled independent estimate, and using the fact that the Geosat coverage had been satisfactory for almost two years before the experiment, we have derived a third estimate, termed "FCST", for "forecast". This estimate is the result of two-year-long assimilation of Geosat altimeter measurements in a three-level limited-area quasi-geostrophic model. The method, the experimental arrangements, and the estimate itself, are shown and discussed in Dombrowsky and De Mey (1992) and De Mey and Dombrowsky (1992). Only a brief overview will be given here. The assimilation domain is 1000km on a side, and contains the estimation domain in its NW corner. Assimilation starts on jd 6807 (12 January 1987). The method pertains to sequential estimation (*e. g.*, Ghil *et al.*, 1983); the model is integrated in time for 20 days, at the end of which model fields are optimally corrected with incoming observations, and another cycle begins. Correction steps are done optimally in the least-squares sense. The statistical structure functions for observational and modelling errors and for the signal are fully consistent with the choices made for the objectively analyzed estimates. As a consequence, the FCST estimate can be directly compared with the others, at least in a statistical sense. Energy and modal partition are satisfyingly stable throughout the assimilation period, which is discontinued on jd 7427 (23 September 1988) as useable Geosat data become the exception. The scheme has been found to be robust when submitted to various parameter changes (Dombrowsky and De Mey, 1992).

The FCST estimate, shown in Figure 3, is 560 days away from model initialization time; therefore, it can be expected that the model's trajectory has become adequate to make the best possible use of the few available data (this was the major reason for performing assimilation). Jds 7367 and 7387 are cycle ends, corresponding to twenty-day forecasts, and jd 7377 is a ten-day forecast.

FCST is rather coherent with Hydro wherever the latter shows an eddy field. The cross-correlation between estimates is 0.7 on both dates. The main innovation is the fact that the meandering jet in Hydro is not continuous any more in FCST. The north-south jet at the centre of the domain on jd 7367 does not recirculate to the northeast; instead, it is part of a large eddy, corresponding to the anticyclonic structure in Hydro. The southwestern segment of the jet is reproduced and appears to form a meander south of the anticyclonic eddy. Its general direction is consistent with the direction of the NAC. The cyclonic feature present in the eastern part of the survey area only appears as a weak hollow between the large eddy and another meander located east of the first one. As days go by, the large anticyclonic eddy merges with the meander and its amplitude diminishes. The hammerhead shape of the "merged" meander in the Hydro estimate is confirmed by FCST, but its location is off by 50 km to the west. However, the location of its attachment to the meander seems to be correct. The strengthening of the cyclonic feature and its transformation into an eddy is also captured by FCST. Assimilation stops soon after jd 7377, so that it is not known whether this cold eddy is eventually shed by the meandering jet. Finally, FCST poorly accounts for the emergence from the south of the warmest/saltiest structure on jd 7387. This may be due to the fact that the most significant empirical mode, used in the assimilation procedure, is not as dominant there as it is in the other areas.

Let us endeavour to be somewhat more quantitative in the comparison of our estimates.The table shows the transport between the warm/salty eddy (which merges with the meander) and the cold/fresh structure east of it, integrated over model layers for Hydro and FCST. Robinson *et al.* climatological transports in the NAC over the width of the estimation domain are shown for reference. When they can be

Table

Transport (10^6 m^3 s^{-1}) on Julian dates 7367/7387 (see *text*).

Transport (10^6 m^3 s^{-1}) les jours juliens 7367 et 7387 (*voir* texte).

Layer	Hydro	FCST	Climatology
0-450 m	7.9/8.8	10.4/11.3	4.1
450-1 900 m	10.0/9.4	13.2/10.2	3.0
1 900-3 500 m		10.1/5.6	1.5
0-3 500 m		33.7/27.	8.6

compared, both estimates agree on the sign and order of magnitude. FCST transports are higher: in the top layer, there is a 2.5 x 10^6 m^3 s^{-1} transport on both dates not accounted for by Hydro, which could be explained by variability below 2 000 m and the missing barotropic mode. The transport has the same sign from top to bottom; it is only weaker at the bottom. This may be another illustration of the "sheared barotropic mode" discussed by Gould (1983) from Neads records. Both estimates also agree on the increase in time of the shear between the top layer and the lower layers, possibly an effect of the merger event. A similar calculation performed with a five-level version of the model leads to similar results, with the difference that the top level is less correlated to the bottom levels and to the relief; this is due to better resolution of the thermocline, and consequently of the higher-order baroclinic modes.

SUMMARY AND CONCLUSION

We have shown various synoptic estimates of the NAC eddy field in a domain 450 x 350 km at 52.5°N 25.0°W in the theoretical path of the NAC. Temperature, salinity, and surface streamfunction estimates were derived from the AthenA hydrological data collected in the summer of 1988. These estimates were discussed and compared with two surface streamfunction estimates obtained from Geosat altimetric measurements: one statistical, and the other resulting from quasi-geostrophic assimilation. The estimates show a frontal structure associated with a jet, sharply separating cold and fresh water to the north from warmer and saltier water to the south. Temperature and salinity values on both sides of the front were consistent with climatological values (Robinson *et al.*, 1979; Levitus, 1982; Maillard, 1986). The assimilation estimates indicate that there may have been an eddy merger event during the experiment. The eddy field was much more energetic than the mean; no clear propagation was evidenced; time scales were longer than twenty days. Local transport by the jet as calculated from model outputs was of the order of 30 x 10^6 m^6 s^{-1}; the vertical structure was that of the "sheared barotropic mode", where transport has the same sign and direction from top to bottom, but is weaker at the bottom.

It is difficult to obtain a strong picture of the mesoscale dynamics and eddy/mean flow interaction in the area (*e. g.* Krauss and Käse, 1984). The separation between mean field and eddy field, and the eddy shedding/merger dynamics are not as clean here as they are in Western boundary currents such as the Gulf Stream or the Kuroshio. Instead, we can form a picture of an "average" current formed by multiple jets meandering between eddies or forming open meanders. Despite the relatively long time scales of the eddy field, jets do not seem to exist as lasting independent dynamic features, and they constantly change position. Dynamics of this kind was observed for instance in the California Current (Mooers and Robinson, 1984) or in the Azores Current (*e. g.* Käse and Siedler, 1982).

The spatial scales appeared to have been strongly constrained by the underlying bottom topography, even of small amplitude and extent. As a consequence, eddy patterns and scales found on the site of AthenA cannot be extrapolated to regions of the NAC upstream or downstream. However, this illustrates the rule that bottom topography at all scales plays one of the major roles in the eastern basin. A merit of satellite altimetry in this respect is that it contains the signature of all dynamic modes at the surface, including the barotropic mode which is not contained in hydrographical profiles. However, bottom-intensified events, if present, will probably only have a weak signature in the altimeter record.

Another issue of this work was the comparison between *in situ* and altimetric estimates. The hydro and altimetric signals clearly differ in content and error characteristics. Altimetric heights obtained by the repeat-track method lack the longer time scales (including of course the climatological time scales); the Geosat heights used here still contain residual errors (orbit, tropospheric path delay, electromagnetic bias, missing tidal components near the shelf). *In situ* data do not contain information about the barotropic mode, and the streamfunction estimates are subject to the validity of the dynamic calculation. Steps have been taken here to compensate for the deficiencies of both datasets: an external climatology has been used, in particular at depth; assimilation has been used to filter out topographic and sampling errors. The estimation techniques used (purely statistical, mixed statistical/dynamic) share common elements; in particular, they are consistent with each other on statistical grounds. Direct comparisons of eddy transport lead to similar figures and temporal tendencies. On the other hand, the juxtaposition of the estimates produced interesting synthetic conclusions about the local dynamic regime. To sum up, the assimilation estimate has proved coarser, but more global than the Hydro estimate, while being remarkably consistent with it. ERS-1 and Topex/Poseidon together, with their lower error budgets, should do considerably better.

Acknowledgements

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