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COMPLEMENTARY STUDY N°2
SEARCH OF THE AF447 WRECKAGE AREA

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Contents

Foreword

Reading of this document will be eased if one has previously read the Scientific committee report which can be downloaded from the BEA (http://www.bea.aero/en/enquetes/flight.af.447/flight.af447.php), and the complementary study (in French) by michel Ollitrault, issued November 17 2010 (Rapport LPO 2010_07, available on request).

Introduction

One year after the crash of the Air France AF447 Airbus (recall it occurs in the early hours of June 1 2009, near 3°N, 30° 30'W) in the Equatorial Atlantic, 8 surface buoys (SLDMB) were launched within the 40 nautical miles ACARS circle centred on the LKP.

These buoys are developed by the US coast guards and follow the motion of the upper meter of the ocean. They are thus well suited to track the motions of floating bodies or debris.

The SLDMB buoys were positioned by the Argos system and by GPS. This will provide the opportunity to compare the localisation accuracy of the Argos Doppler positioning system with the GPS one.

In this report we shall analyse briefly the trajectories of the SLDMB buoys, then we will reconstruct the velocity field from these buoy observations with the same objective analysis used in the scientific committee report. This will allow to validate the method and its basic assumption of horizontal non divergence.

The conclusion of the complementary study mentioned above, was that not enough buoy data was available over the ACARS circle to reconstruct properly the velocity field, even though the method used was correct.

It will be shown that the covering of the ACARS circle with order of 10 buoys, thus with a 50 km spacing, would probably have been adequate to define a reasonable crash zone (within a 30 km circle) with a 5 days back drift.

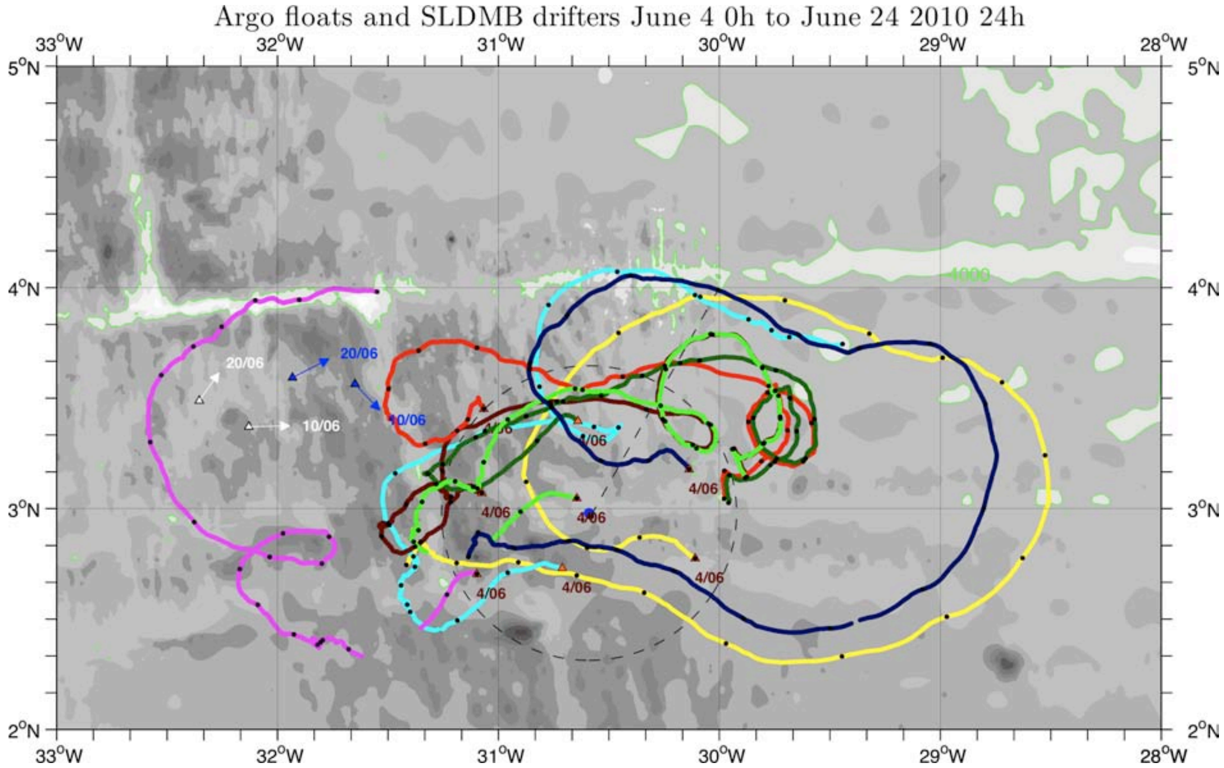


Figure 1 Trajectories from the 8 SLDMB buoys over the period June 4 to 24 2010. These buoys drift at 1 m depth and are designed to be minimally influenced by wind. There is one black dot every day at 0h UTC. Two Argo floats happened to cycle in the region. Their 24h equivalent displacements are also given in the figure. The gap found in the pink and green trajectories around June 6, is due to data lacking in the files communicated (since then the corresponding data has been recovered, but is not added here). Positions given are the GPS ones.

I Analysis of the SLDMB buoy trajectories

Trajectories from the eight SLDMB buoys are given in Figure 1, from the launch date (generally during June 3 2010, but all buoys were transmitting only from June 4) until June 24 2010.

Over the 20-day drift shown in the Figure, the buoy motions reveal a generally clockwise (or anticyclonic) flow. However this is only a large-scale feature and several interesting smaller scale motions are worth mentioning.

A detailed comparison between Argos locations and GPS ones will be done shortly but in Figure 1 and the following Figures only GPS positions will be given (since GPS is at least 10 times more accurate than Argos, i.e. roughly with a 50 m versus 500 m accuracy).

Around June 7 2010 (see Figure 2), the brown and dark green buoys are seen to stall then change direction toward the North East like the other buoys except the pink south west one (which will turn to the North East later). This could be due to a westward propagating perturbation (like tropical instability waves frequently observed in this region).

Figure 2 shows the first 8 days of data (June 4 to June 10 2010). Although not identical, there is a general impression of a strong correlation between the different trajectories. But of course, if we knew only one trajectory, it would be difficult to predict precisely the other ones. This is the under determinacy problem we faced in our scientific study (and which was later explicitly described in the complementary study n°1).

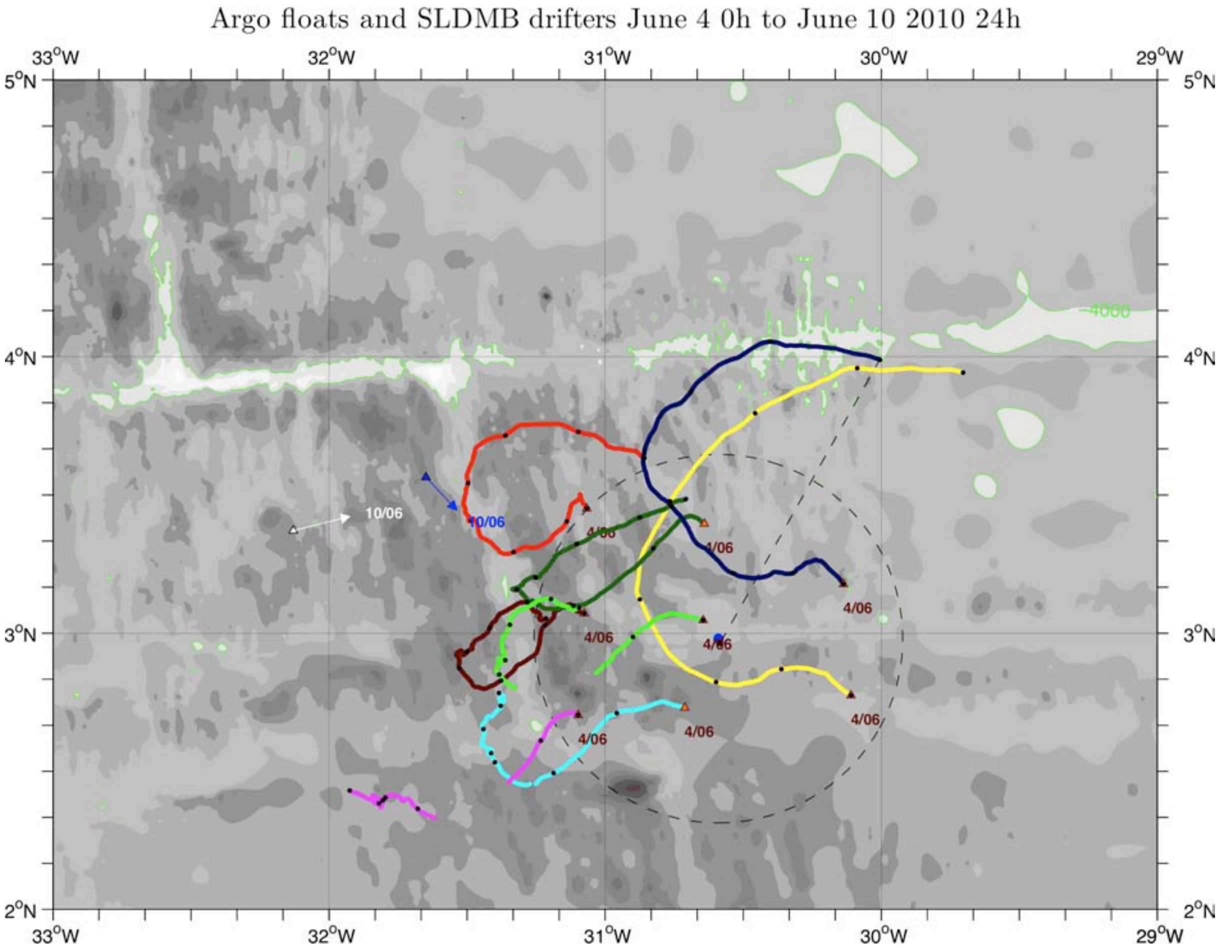


Figure 2 The eight SLDMB buoy trajectories soon after launch, during one week (June 4 to June 10 2010). One black dot every day at 0h UTC. Argo floats 24h equivalent displacements. Gaps in the cyan and pink trajectories are missing locations (not available at the time of this study). But they do not appreciably degrade the flow description, since nearby buoys have very similar trajectories, at these times.

Notice the dark green trajectory, which looks like the reconstructed back drift (the light green trajectory labelled OA in Figure 11 of this report) from the objective analysis of our scientific report. This shows that such a cusped trajectory is possible.

Fundamentally the velocity field is highly variable in time and space and never duplicate itself. This is the manifestation of oceanic turbulence.

The launching of buoys one year after the crash, over the same region, will never tell us what the velocity field was one year before. But it can give us some idea of the statistical behaviour of currents over the region.

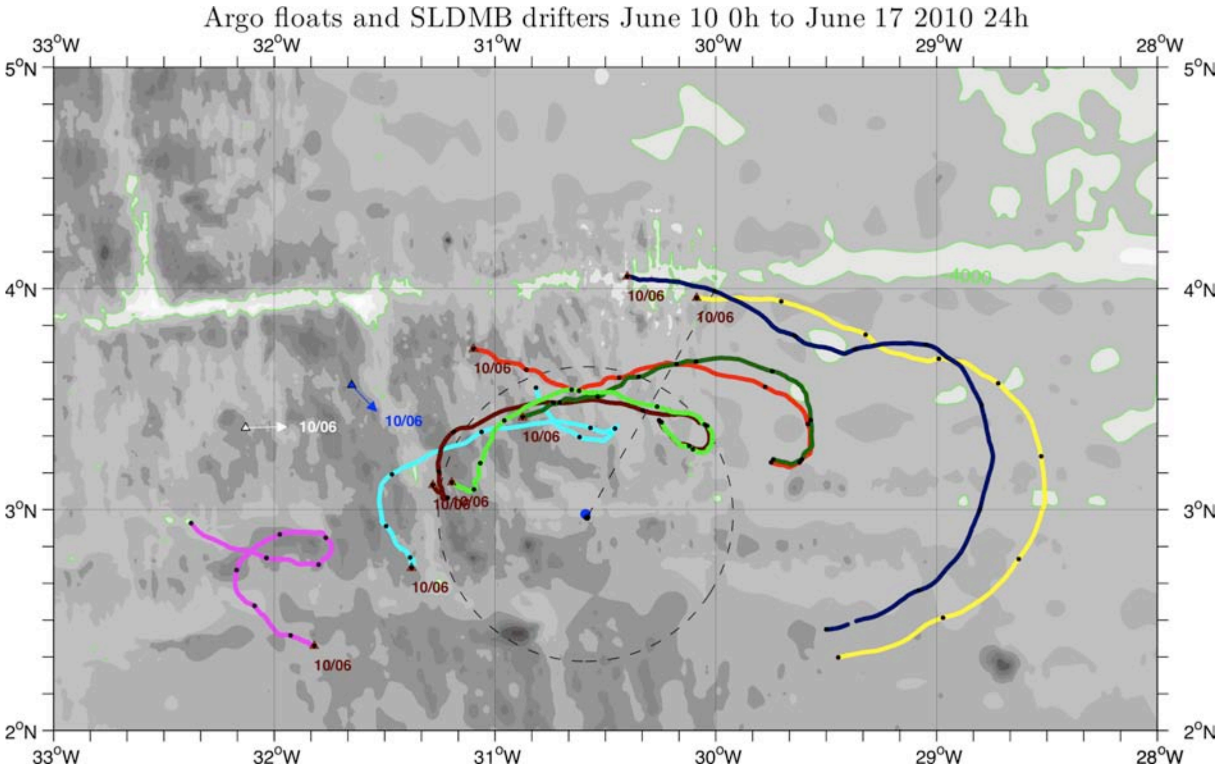


Figure 3 The eight SLDMB buoy trajectories during the 8-day period (June 10 to June 17 2010). One black dot every day at 0h UTC. Argo floats 24h equivalent displacements. The convergence of the red and dark green buoys (within a few km) starting from a 40 km separation is quite impressive, and cast doubt on a back drift calculation, even if we knew perfectly one of the two trajectories.

Figure 3 shows the trajectories over the period June 10 to June 17 2010. The 24h equivalent displacements from two Argo floats that happened to be there are also given and compare favourably with the brown, green and red buoy displacements on the same day (June 10).

This confirms the detailed comparison we did in our scientific report between Argo and SVP drifters. Here the SLDMB are not drogued near 15 m depth but follow rather the 1m depth currents. The comparison is consequently less drastic since Argo floats at the surface also drift near 1 m depth (and have an assumed negligible wind drag).

Now the flow is mainly eastward and a swirling eddy (with solid body rotation) is discerned (in Figure 3) with the six easternmost trajectories (yellow, dark blue, dark green and red, green and brown). A very interesting feature seen in this Figure is the convergence of the two previous pairs (dark green and red; green and brown): over a 5 day time period, the 2 buoys for each pair, initially separated by order of 30 km have converged within a few km of each other. This shows clearly that such convergences can occur, whence a possible induced uncertainty of 30 km on any back drift location, even if we knew a trajectory with a km precision. Are such surface convergences the rule or the exception in this region? Is the SLDMB windage negligible?

Finally, Figure 4 shows the third and last 8-day period (from June 17 to June 24 2010) for the SLDMB buoy trajectories. Now buoys have dispersed: the yellow and dark blue depict a westward flow around 2.5°N, while the others buoys show evidence of a shear between this westward flow to the south and a possible eastward flow around 4°N.

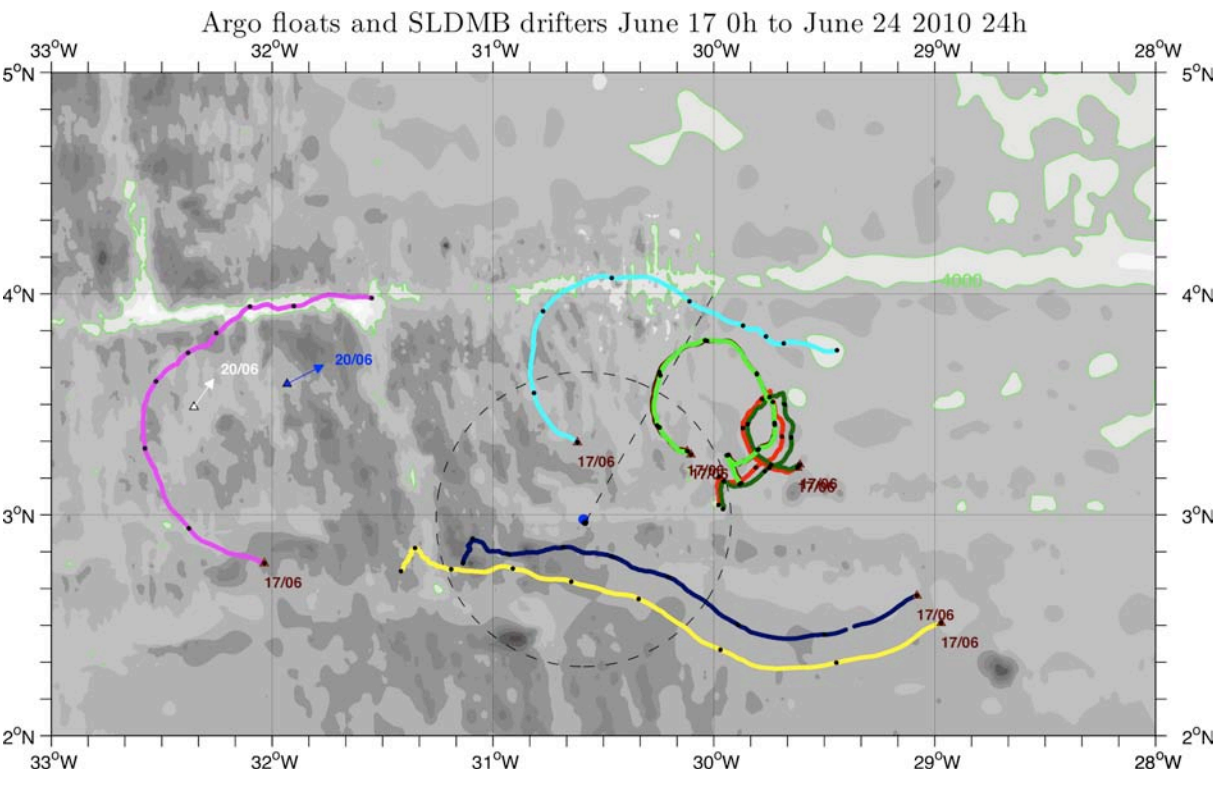


Figure 4 SLDMB buoy trajectories soon over the 8-day period (June 4 to June 10 2010). One black dot every day at 0h UTC. Argo floats 24h equivalent displacements are seen to be in very good agreement with the buoy motions.

There is still the remnant of the clockwise Eastern eddy traced by the two pairs (red and dark green; brown and green) which do not show any sign of separation: the two buoys of each pair stay close within a few km of each other.

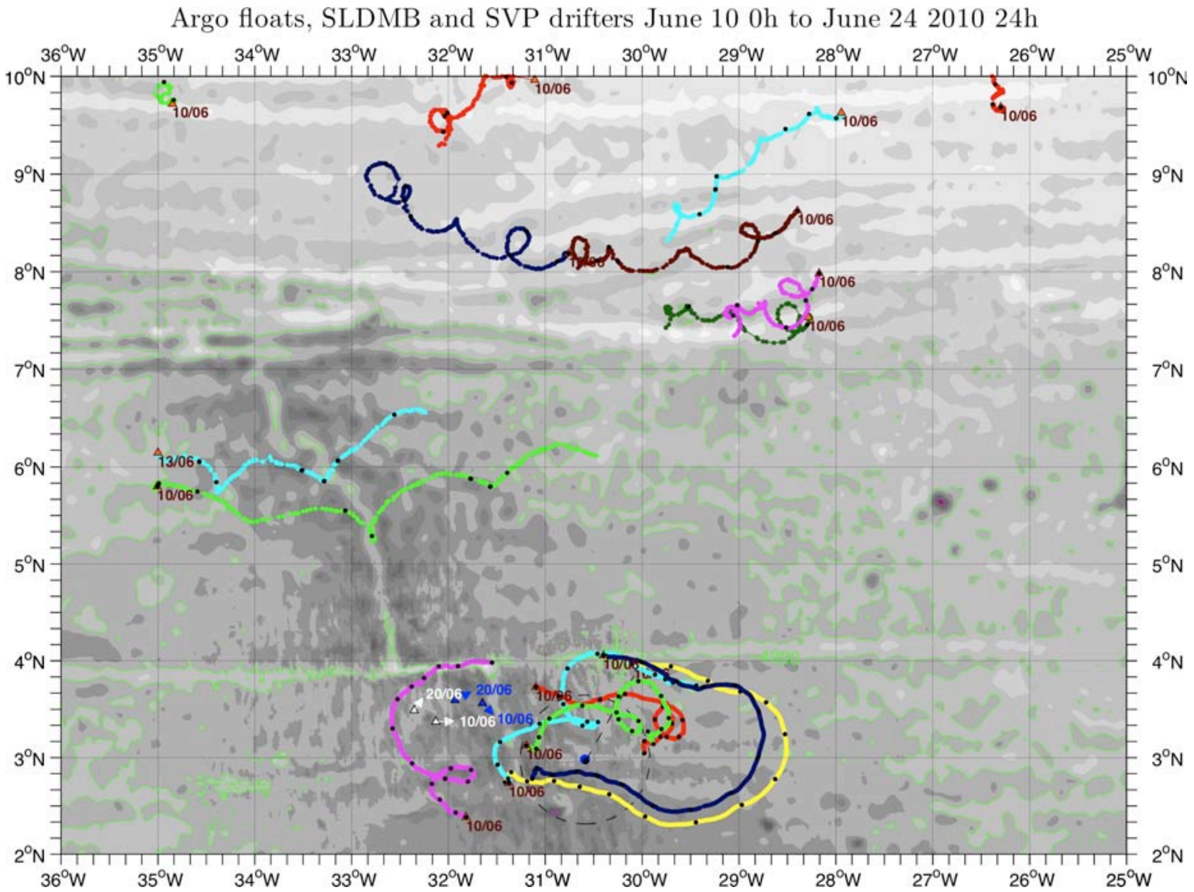


Figure 5 SLDMB and SVP buoy trajectories during the fortnight period 10-24 June 2010 and over a larger area. The alternating zonal current structure characteristic of the equatorial and tropical ocean is becoming apparent. However there is some complex interaction near 3°N, which was also the case one year earlier in June 2009.

A few SVP buoys (drogued near 15 m depth) are found drifting to the north of the SLDMB drifters (see Figure 5). They clearly reveal inertial oscillations superposed on lower frequency motions. These latter larger scale and longer period motions are predominantly zonal, which is a general feature of the equatorial tropical ocean. This means that we cannot expect coherent zonal flows over more than 1° of latitude. This remark concerns transverse correlation (not longitudinal ones).

II Comparison between Argos and GPS positions

From the positions of the buoys, it is easy to obtain velocity estimates. However, due to Argos position uncertainty (of the order of 1 km) it is better to filter the Argos longitude and latitude time series with a Gaussian (σ = 3h) and then estimate the velocities through a cubic spline fit to the filtered positions.

Figure 6 below shows the comparison between the velocities so calculated with the velocities obtained from the (much more accurate) GPS positions (either from a first difference or from a direct cubic spline fit). The agreement is excellent. However the sampling period for Argos is only 6h (versus 30 min). But it would be useless to try a smaller period with the Argos positions, because of their location times which are more or less randomly distributed and their uncertainty (at least 10 times greater than the GPS ones).

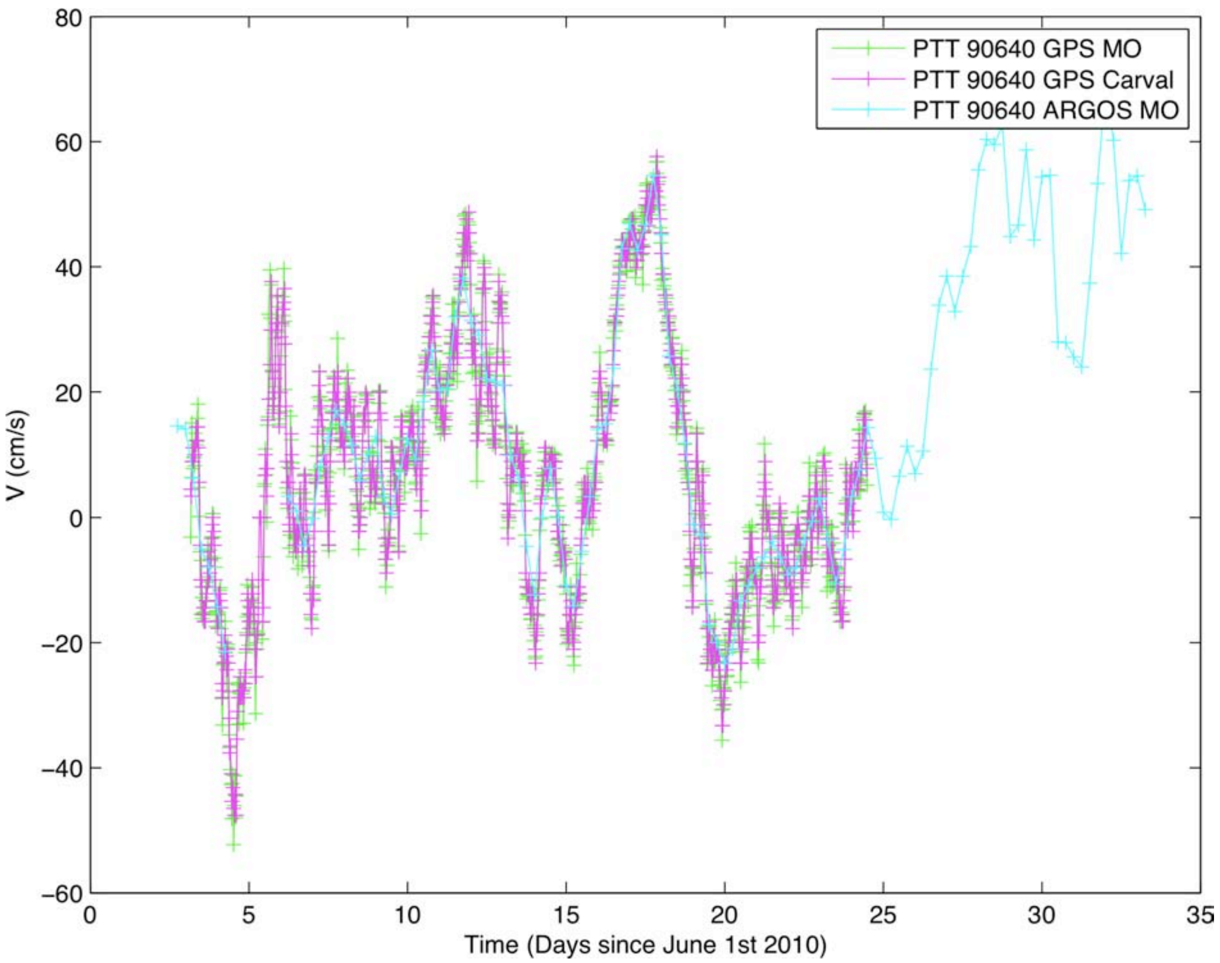


Figure 6 Meridional (or Northward) velocity component estimations for the buoy EXBU0002 (Argos PTT 90640). This is the cyan one in the previous figures. Two different estimates were done on the GPS positions (with sampling period of 30 min). The estimate using the Argos positions is obtained trough a Gaussian filtering followed by a cubic spline fit (sampling period 6h).

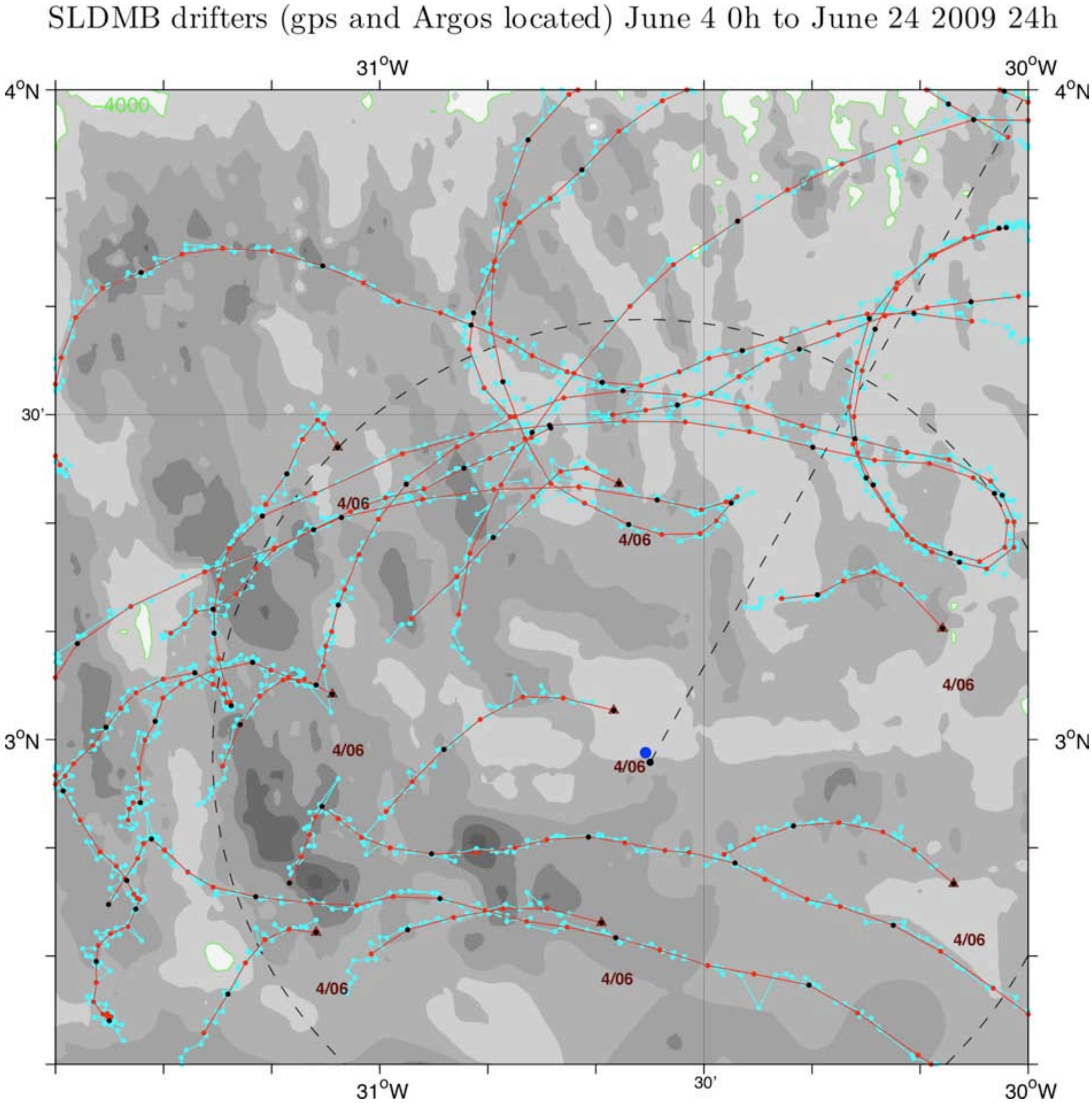


Figure 7 In Cyan, the original Argos locations (with a roughly 1 km accuracy). In red the Gaussian filtered positions (with a 3h standard deviation) given every 6h. One sees the high frequency jitter on the Raw Argos locations is suppressed and the overall general flow well reproduced.

Figure 7 and 8 illustrate the comparison between Argos (raw and filtered) and GPS positions. Although it is certainly better to use the GPS locations, the filtered Argos positions would give almost identical results, as far as only period greater than 12h are considered. Since high frequency displacements are very small, we can confidently use interchangeably the GPS or the Argos filtered displacements. However some caution is required for the velocity estimations since differentiation enhances noise. Figure 6 shows that the different velocity estimates are quite consistent, which gives us faith in the various velocity estimates. Nevertheless, it may happen that a slight error on the velocity at a given time, if this velocity estimate is used in an objective analysis, could have a deviatory effect on the reconstructed trajectory. This will be illustrated in the next paragraph.

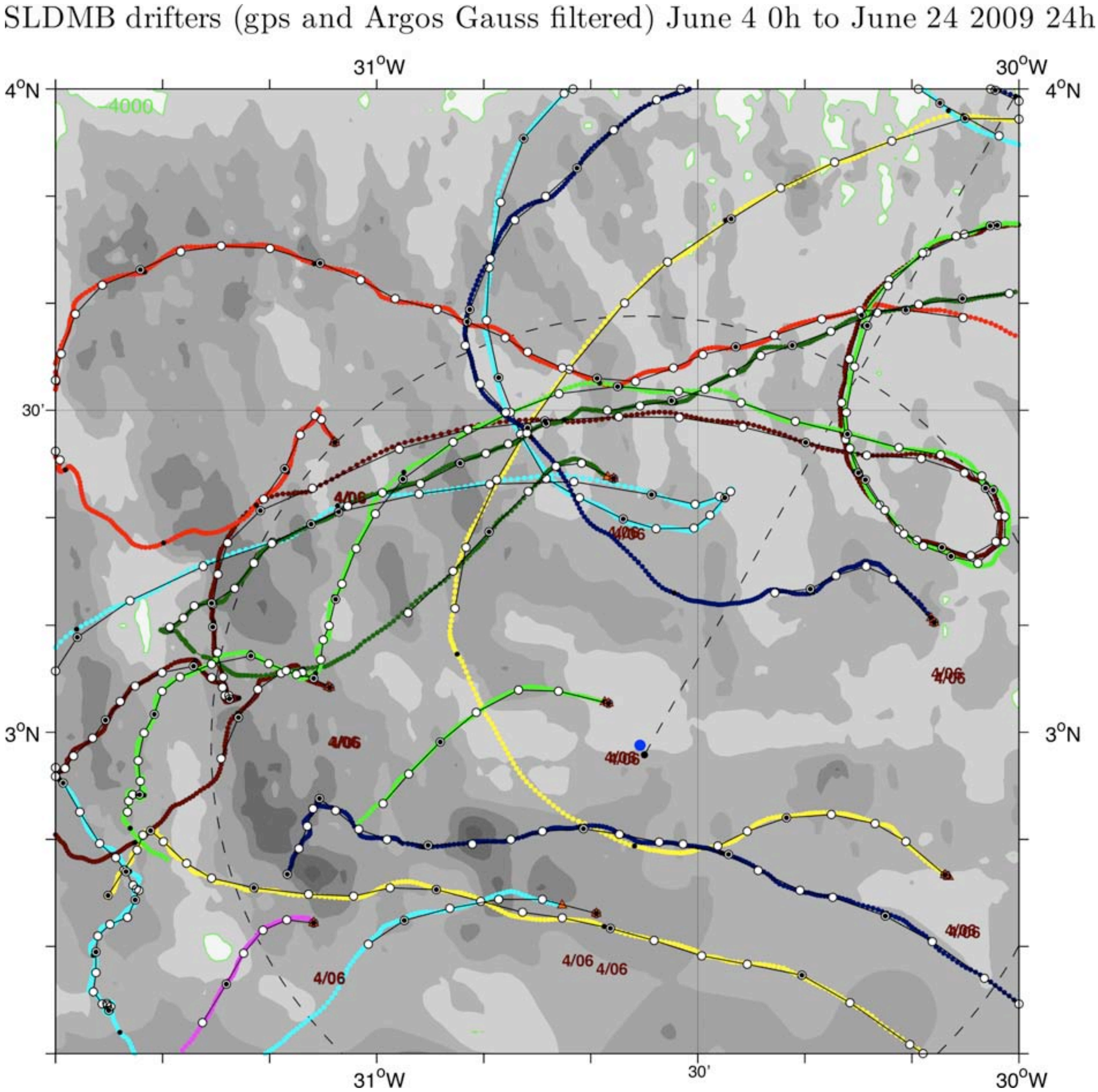


Figure 8 The Gaussian filtered Argos positions (given every 6h) as white open circles are superimposed on the GPS buoy positions (given every 30 min). The agreement is very satisfying although of course the highest frequencies (i.e. periods of 1 h) cannot be reproduced by the Argos filtered positions. Fortunately, but this is a general result in the ocean, high frequency motions are also small scale and do not incur significant displacements.

III Objective analysis reconstruction of the velocity field

It was suggested by Johan Condette (BEA) that the same analysis done in the June 2010 report could be used with the SLDMB buoy data to reconstruct the velocity field from June 4 2010 onward. Thus we could check, if using a more closely located data set (here the buoy velocities) is still compatible with the horizontal non divergence assumption of the objective analysis (for reproducing the buoy trajectories).

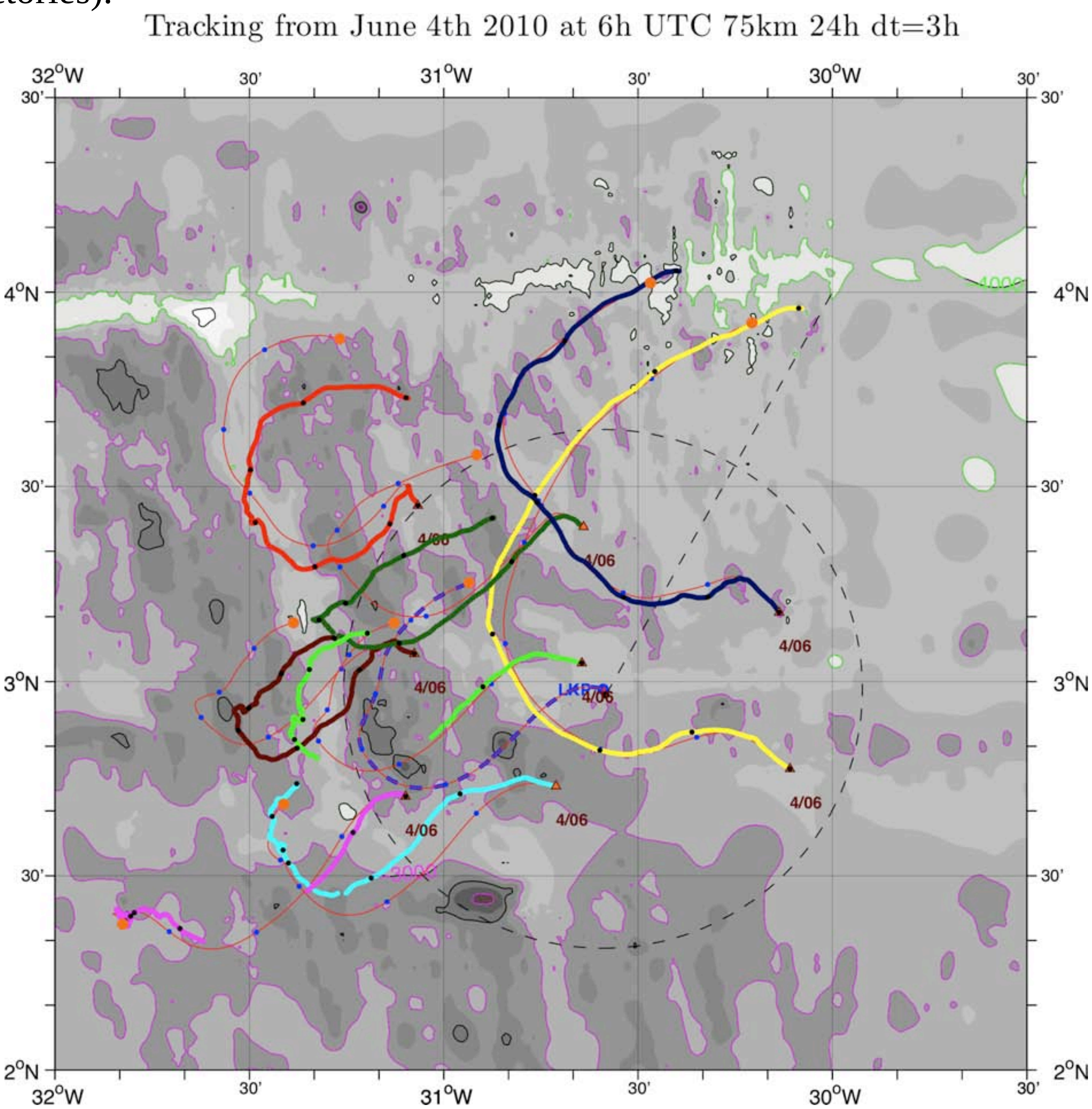


Figure 9 Objective analysis of the SLDMB buoy velocities (sampled every 3 h). The covariance function used is exactly the same as the one given in the drift group report (with r_0=75 km). The buoy trajectories (in colour) span the period June 4 0h to June 10 0h, the reconstructed trajectories (thin red lines) only from June 4 2010 at 6h UTC to June 9 2010 at 18h. The trajectory starting from LKP (dotted blue) is a reconstruction.

Figure 9 shows the reconstruction of the trajectories by the objective analysis of the experimental velocities. It is satisfying for the pink, yellow and blue buoys, but not so for the light green and cyan ones. And even still less satisfying for the brown, dark green and red buoys.

Apparently the small spatial scales are not well reproduced, which could be caused by the covariance functions used. However very similar results are obtained with a parameter r_0 of 35 km (twice smaller than the original one).

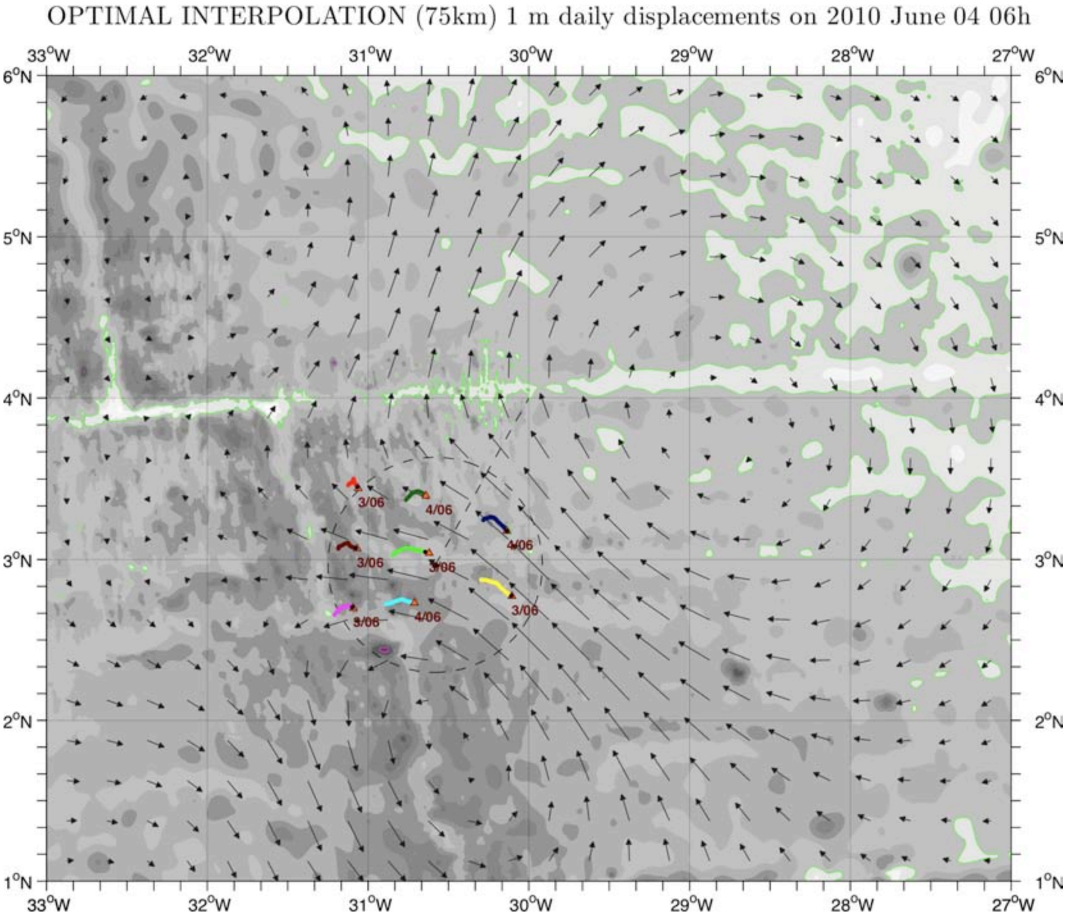
In fact, the (small scale and) high frequency velocity variations are responsible for part of the misfit: an analysis on velocity data sampled every 6h gives reconstructed trajectories diverging still more.

It is nevertheless probable that there is some divergence or convergence in this flow field (as can be seen in Figure 3 for example, one week later) that would prevent a close reconstruction. It is of course difficult to estimate quantitatively such an effect, but a possible upper bound after 5 days may be of the order of 15 km.

But this does not make such an analysis useless: as can be seen on Figure 10a, b and c, the velocity field reconstructed is always quite close to the actual buoy displacements.

The main problem with this kind of analysis is in fact the lack of data at a short distance of the position where one wants to estimate the current. We have shown in the complementary study n°1, that several crash zones were possible because the velocity data was too sparse and too far from the zone of interest to non-equivocally determine the true average trajectory of the plane remains and bodies. We show here that even with enough data it is not possible to get closer than 10 km on average to the true position of a drifting object after 5 days. This is an intrinsic error due to possible divergence and/or convergence (recall the analysis done assumes non divergence of the horizontal velocity field) and to under sampling of higher frequencies.

Had we disposed however of, let us say, one surface buoy every 50 km over the ACARS circle in June 2009, we would have been able to define the crash zone perhaps with a 30 km error but without ambiguity.



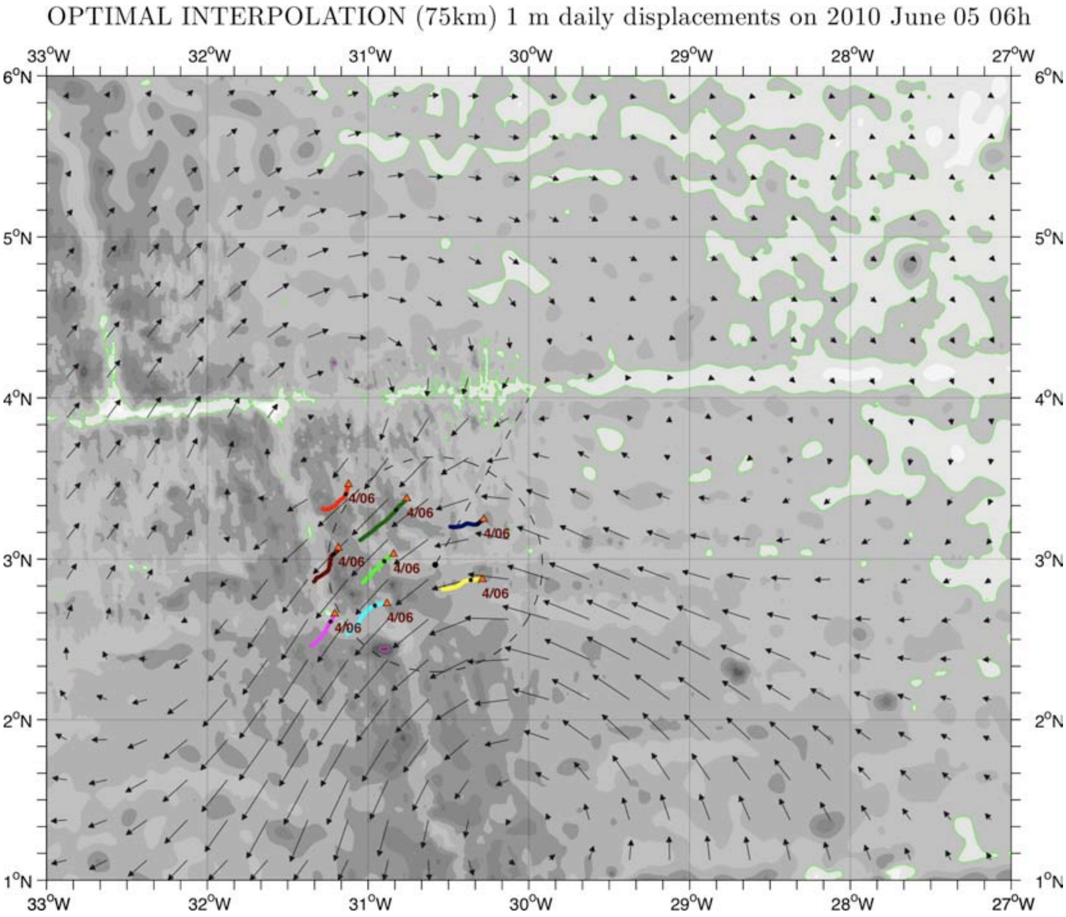


Figure 10a Reconstructed velocity field with actual trajectories superimposed. 24h displacements centred at the date given on top of each figure.

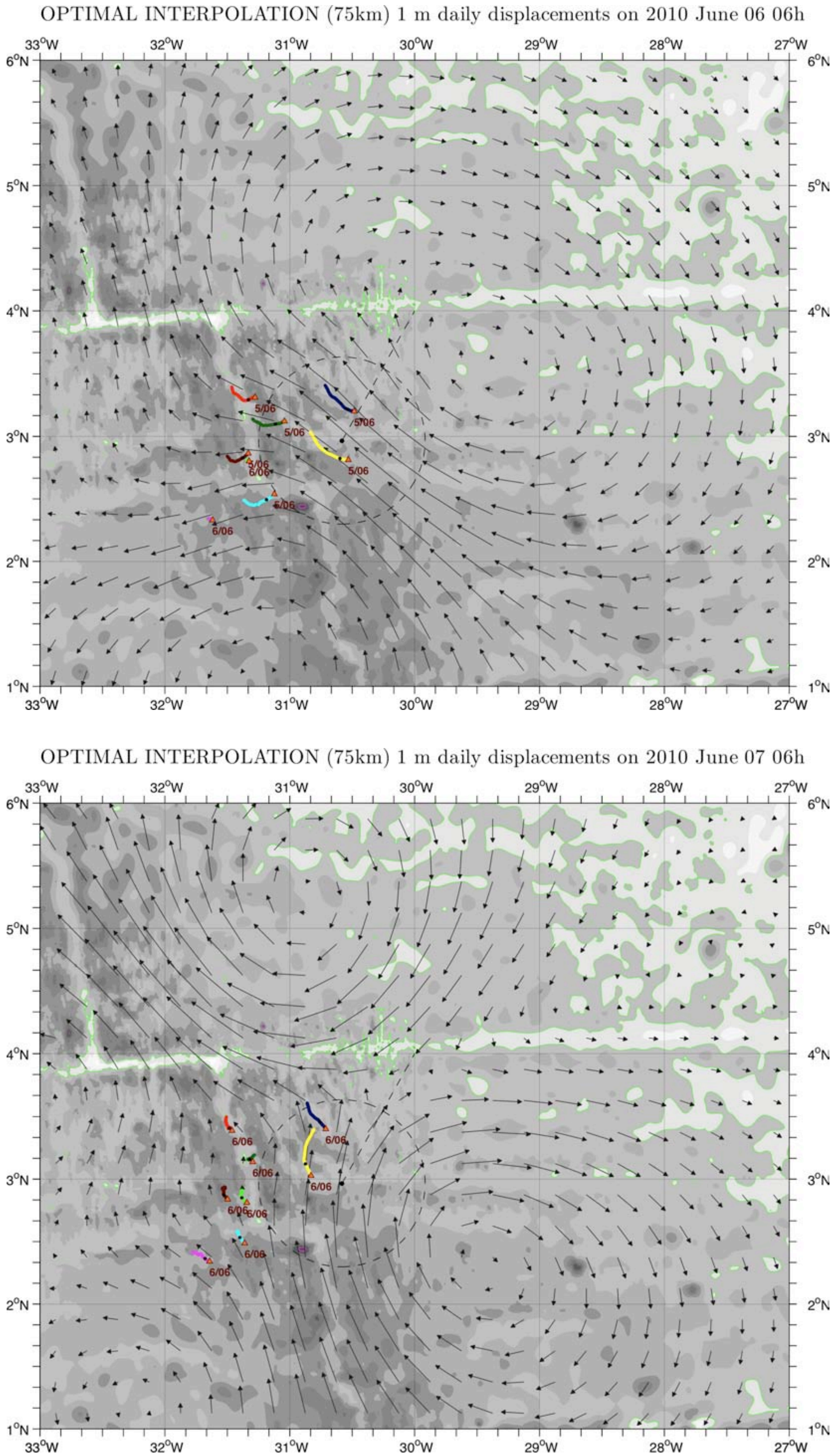
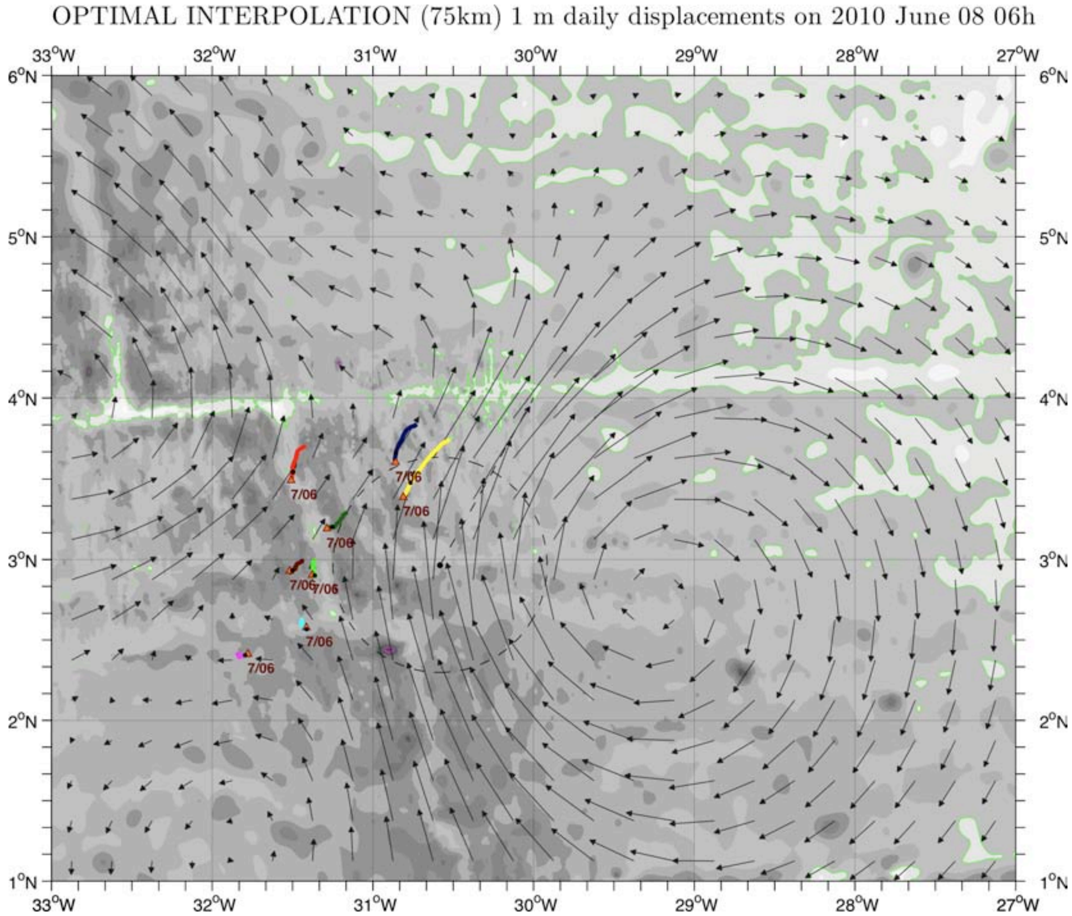


Figure 10b Reconstructed velocity field with actual trajectories superimposed. 24h displacements centred at the date given on top of each figure.



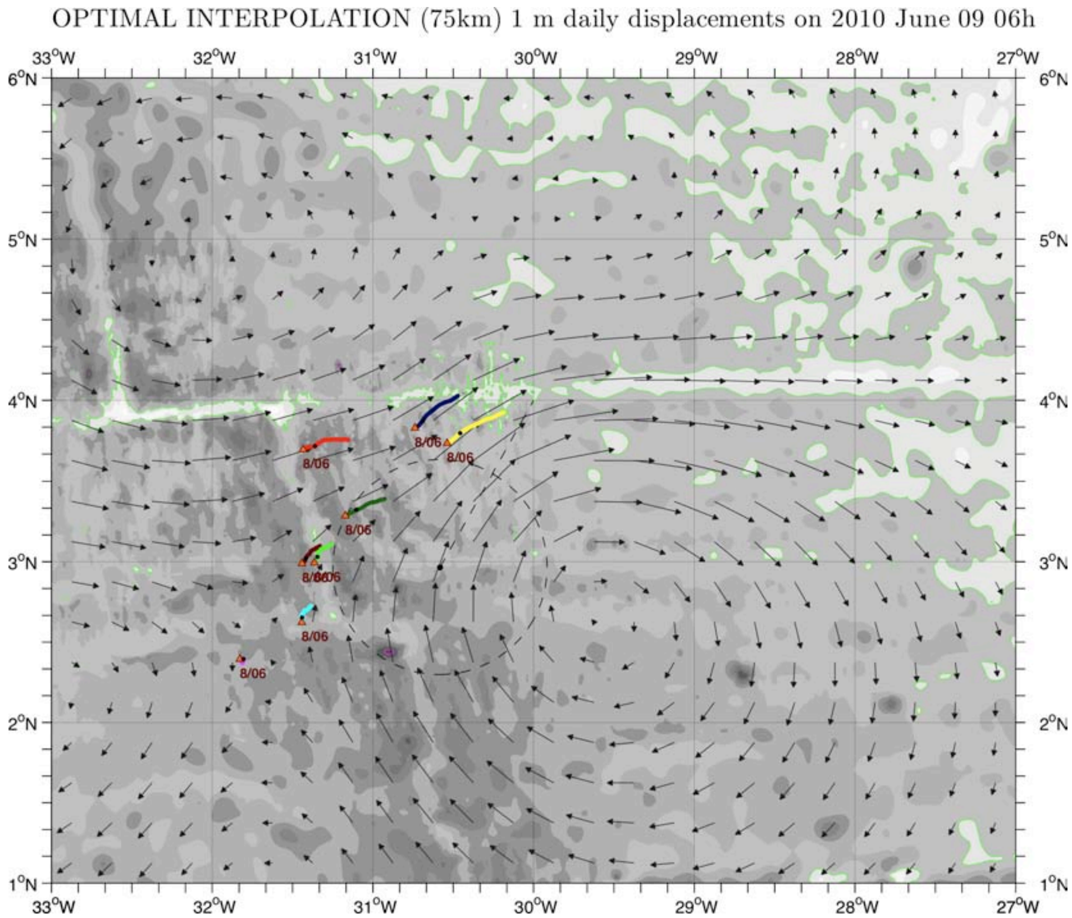


Figure 10c Reconstructed velocity field with actual trajectories superimposed. 24h displacements centred at the date given on top of each figure.

IV Conclusions

This study has shown that possible convergence and divergence in the surface velocity field and the high frequency variations in this velocity field (periods of a few hours and even less), in this region near the Equator, plague the true reconstruction of surface trajectories by the order of 10 km after 5 days, on average.

Nevertheless, the objective analysis (which is based on a non divergence assumption) still give reasonable estimates for the velocity field if the data positions are sufficiently close to the location where one looks for the surface velocity vector, which is the case with the SLDMB buoy data. A 50 km near-neighbour distance seems sufficient to have confident estimates, while a 100 km distance may be too far apart. This latter distance was typical of the data recovered over the first week of 2009.

We have actually shown (see the complementary study n°1) that due to the sparseness of the buoy velocity data, the objective analysis was under constrained and several crash zones are possible (in the drift group study of June 2010 we defined only one possible region, even if it was rather large).

We have not done in the present study the kind of calculation presented in the complementary study n°1, that is the estimation of the sea surface drift due to a known blowing wind. This would certainly be rewarding to do such a study with the SLDMB buoy data.

As a final recommendation, the launching of surface drifters on a regular (one half degree) grid, immediately after the lost of a plane in the sea, would probably permit an adequate monitoring of the surface currents over a week time period (later the drifters may be too dispersed and would not constrain well the current field reconstruction). A convincing example is given by the SLDMB buoys analysed in this report.