Assessment of the Argo sampling in the Mediterranean and Black Seas (part I)

by

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Approved for release by: ……

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Director, Department of Oceanography

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1. Introduction

Since 2000, numerous Argo floats have been deployed in the Mediterranean and Black Seas under various programs and by different institutions/countries. Different cycling and sampling characteristics have been chosen to monitor these marginal seas, including cycles of 5 to 10 days, parking depths between 350 and 650 m for the Mediterranean and between 200 and 1550 m for the Black Sea, and maximum profiling depths between 700 and 2000 m. These parameters are different from the standards defined by the global Argo program. It is therefore important to assess the adequacy of these parameters for monitoring the thermohaline variability of the Mediterranean and Black Seas using the existing float data. This report contains the first assessment results obtained using most of the existing Argo data in the Mediterranean (section 2) and Black Sea (section 3). Conclusions are included in section 4. More results and recommendations for the continuation of the Argo program in the Mediterranean and Black Seas will be published in a separate report (part II).

2. Argo data in the Mediterranean Sea

In total, 85 Argo floats have been operated in the Mediterranean Sea between 2000 and 2008, out of which 27 correspond to the MFSTEP project (Poulain et al. 2007). The maximum density of floats was obtained in April 2006 with 32 floats running simultaneously. Figure 1 depicts the temporal evolution of the float population in the Mediterranean, whereas details on the number of floats and profiles are listed in Table 1.

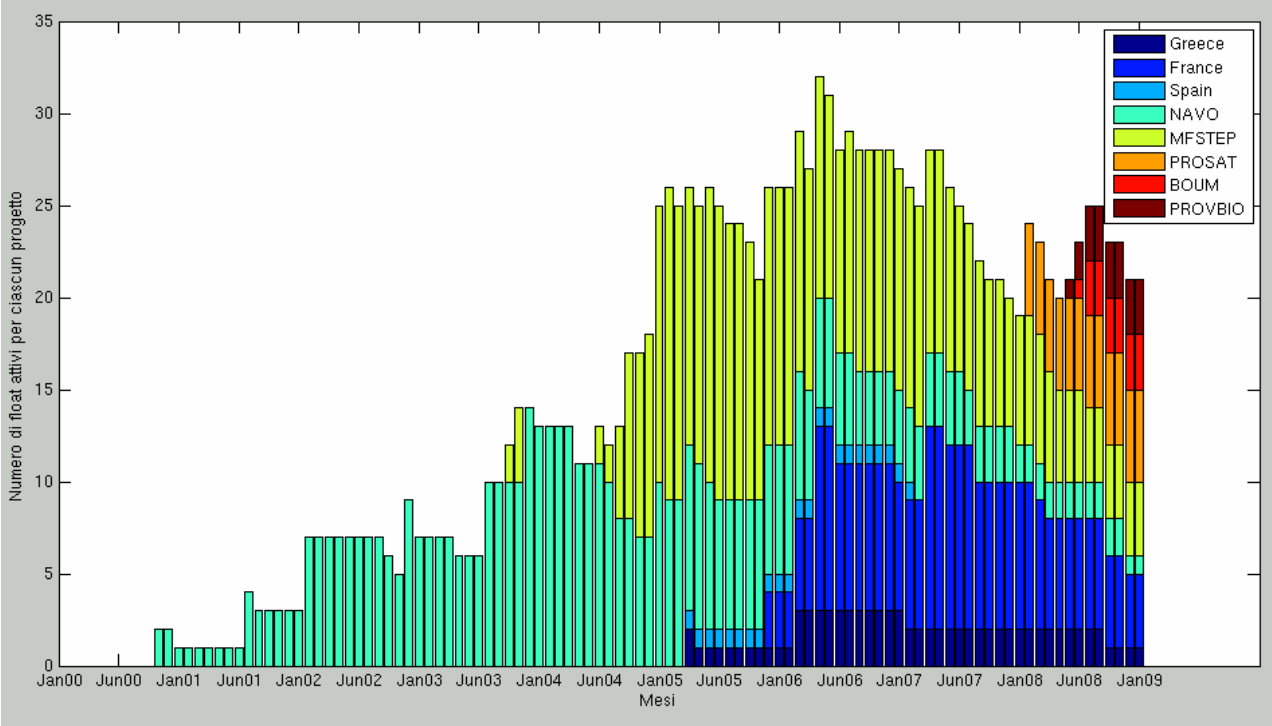

Figure 1. Number of Argo floats per month in the Mediterranean between 2000 and 2008.

Program/Agency/Country	Number of floats	Number of cycles or profiles
MFSTEP + SPAIN	28	3158+137
NAVOCEANO	28	3497
FRANCE (EGYPT,PROSAT,PROVBIO,BOUM)	25	1554
GREECE	4	415
TOTAL	85	8718

Table 1. Number of floats and cycles/profiles for the Argo program in the Mediterranean between 2000 and 2008.

A subset of the Mediterranean Argo database, consisting of 33 floats with the same cycling and sampling parameters (cycles of 5 days, parking depth of 350 m, maximum profiling depth of 700 m, and 2000 m every 10 cycles), was selected to estimate the statistics presented in this report. They correspond to 27 floats of MFSTEP, one float from Spain and 5 floats from France (EGYPT). Figure 2 shows the trajectories of the 33 floats used.

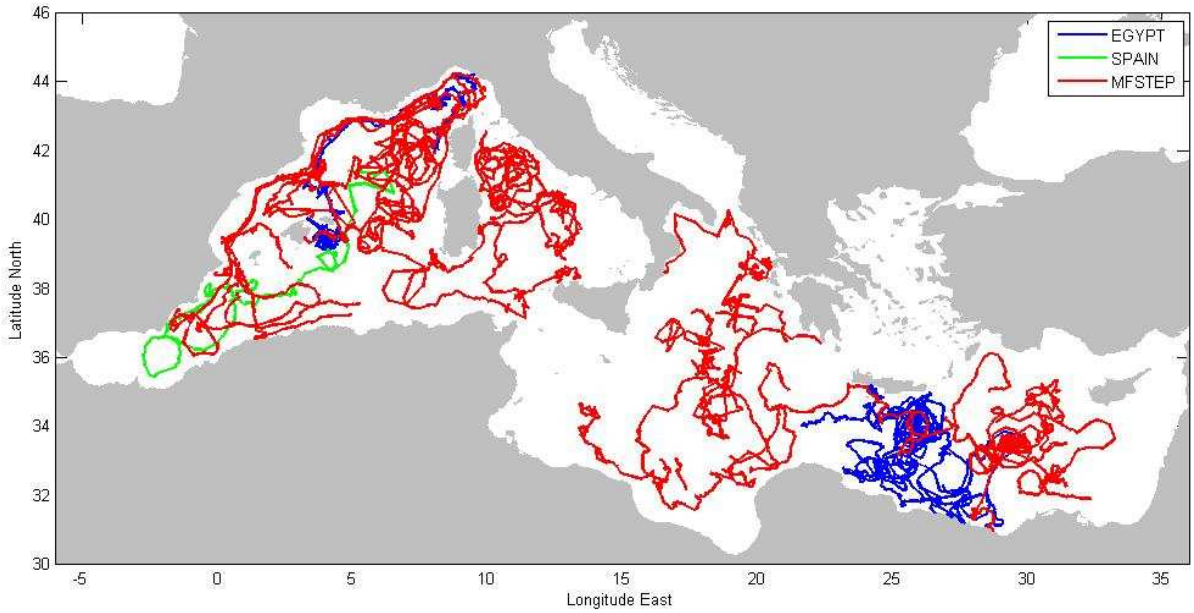

Figure 2. Trajectories of the 33 floats operated in the Mediterranean between 2000 and 2008.

The temporal distribution of the quantity of floats operating per month is depicted in Figure 3. The maximum float density was obtained in April 2006 with more than 20 floats operating simultaneously.

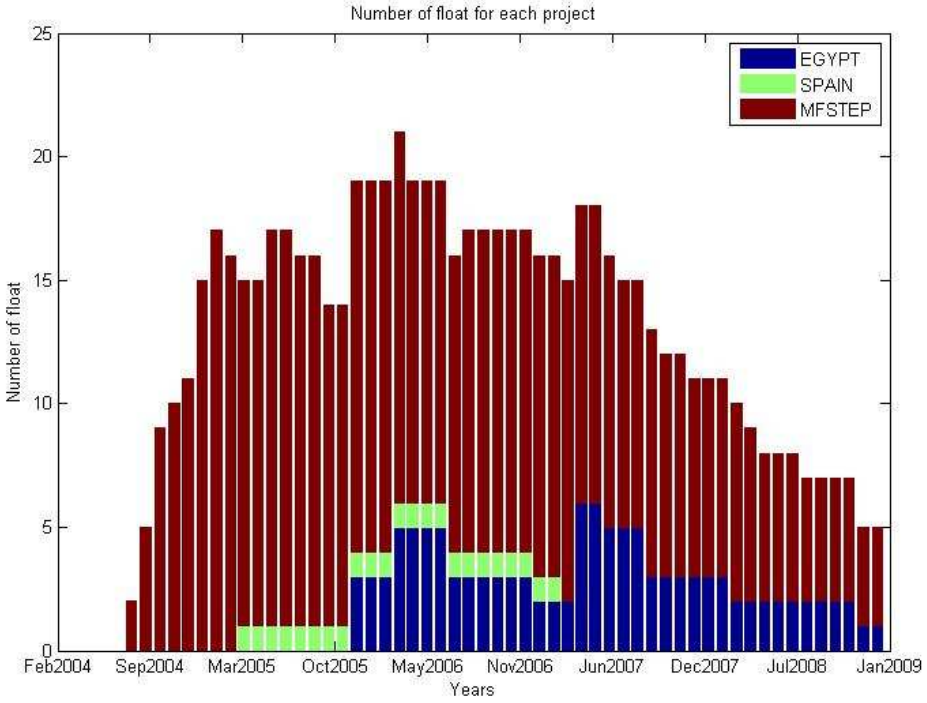

Figure 3. Histogram with the number of floats operating simultaneously in the Mediterranean per month.

Statistics about the operational lifetimes of the floats are illustrated in Figure 4. The mean life of the floats is 653 days. The percentage of active floats versus time after deployment in days or in cycles show that after 1, 2 and 3 years, the number of floats decreased to 22, 14 and 7, respectively. The half mean life, the time after deployment corresponding to 50% decrease in float population, is 563 days. The percentage of active floats is also depicted as a function of the theoretical and actual vertical distances covered during ascent. The half mean distance is 81 and 65 km, for the theoretical and actual values, respectively.

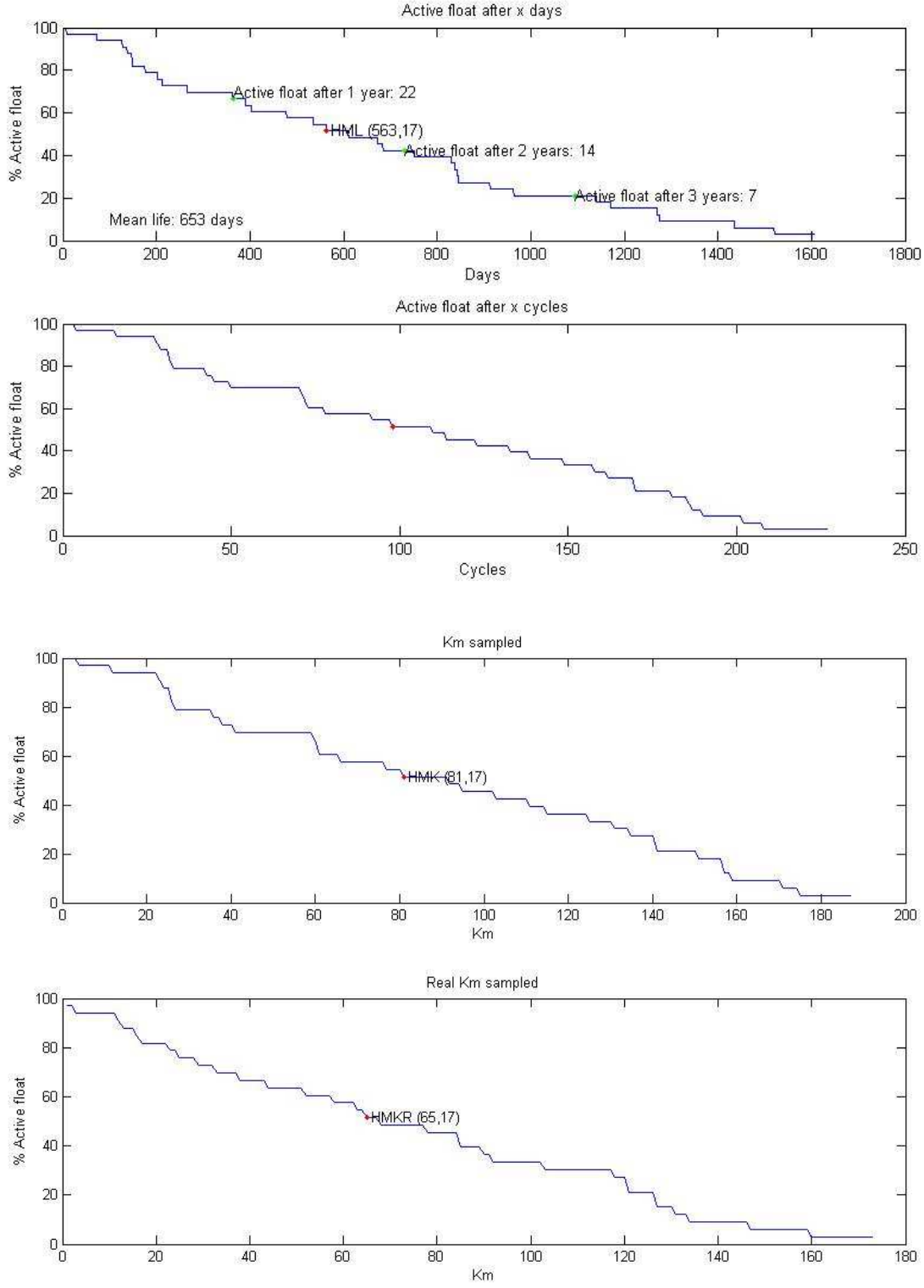

Figure 4. Percentage of active floats as a function of time, number of cycles, theoretical and actual vertical distance performed after deployment.

2.1 Vertical sampling

The effectiveness of the vertical sampling can be assessed by examining the bathymetry at the locations of the profiles performed by the 33 floats. Given hypothetical maximal profiling depths of 700, 1000, 1500 and 2000 m, we can estimate the percentage of the water column sampled by the floats, the percentage of missing data because the float did not go deep enough, and the percentage of data not sampled because the bathymetry was shallower than the maximal profiling depth. The results are listed in Table 2 and illustrated in Figure 5.

Max Depth (m)	%Missing data	Sampled	Not sampled
700	68% (4964672m)	32% (2343998m)	2% (155701m)
1000	56% (4074538m)	44% (3434132m)	5% (336867m)
1500	38% (2748859m)	62% (4559811m)	11% (796688m)
2000	22% (161136m)	78% (5697309m)	20% (1444690m)

Table 2. Statistics (in percentage or in vertical distance) on the effectiveness of the vertical sampling (see text for details).

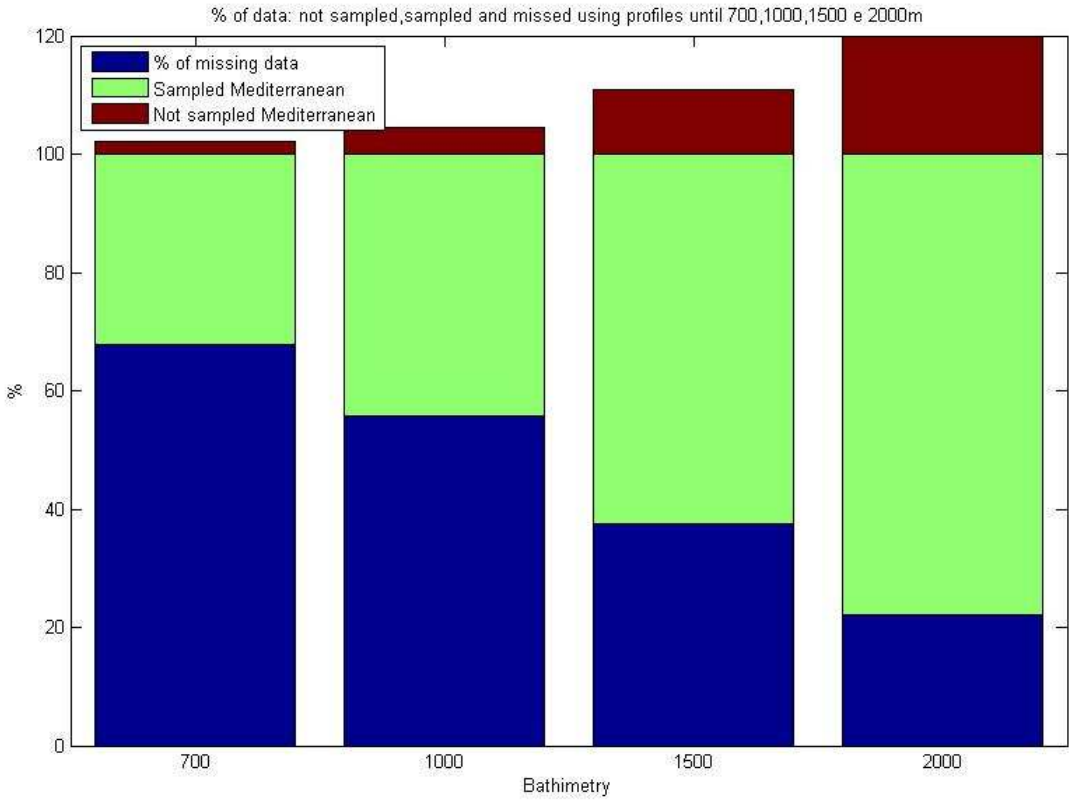

Figure 5. Percentage of the vertical sampling in the Mediterranean, using hypothetical floats profiling down to 700, 1000, 1500 and 2000 m. Green: Percentage actually sampled by the floats. Blue: Percentage of data not sampled below the maximum profiling depth. Brown: Percentage of data cut due to shallow bathymetry.

For instance, profiling down to 2000 m at each cycle would result in sampling 78% of the Mediterranean water column, with the drawback that 20% of the profiling would be cut due to shallow bathymetry. The other extreme case is when the floats only profile the top 700 m of water, resulting in 32% of the water column covered, but with less bottom touching (about 2% of the theoretical profile is not sampled).

2.2 Horizontal sampling

We now concentrate on the horizontal coverage of the floats in the Mediterranean, considering regular grids of 2°x 2° bins and 3°x 3° bins.

2.2.1 Bins of 2°x 2° in the entire Mediterranean

Figure 6 displays the Mediterranean Sea overlaid by a grid of 99 uniform bins of size of 2°x 2°. Using this grid, only a maximum of 25% of the sea was covered in March 2006 (Figure 7). During that month, 25 cells were sampled by the floats. Over-sampling can be defined as the ratio of the number of floats active in a given month divided by the number of cells with at least one float. It exceeded 2 floats/cell in several months (Figure 8), but it is always larger than 1. This means that with a grid of 2°x 2°, the Mediterranean was poorly covered but the cells occupied by the floats were well sampled, even over-sampled.

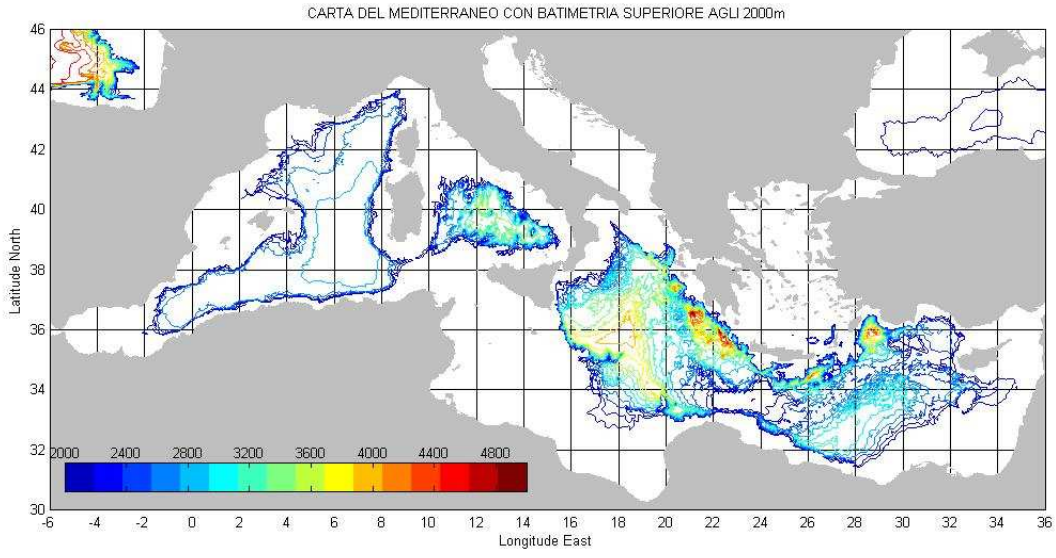

Figure 6. The Mediterranean Sea with bins of 2°x 2°. Isobaths deeper than 2000m are also shown.

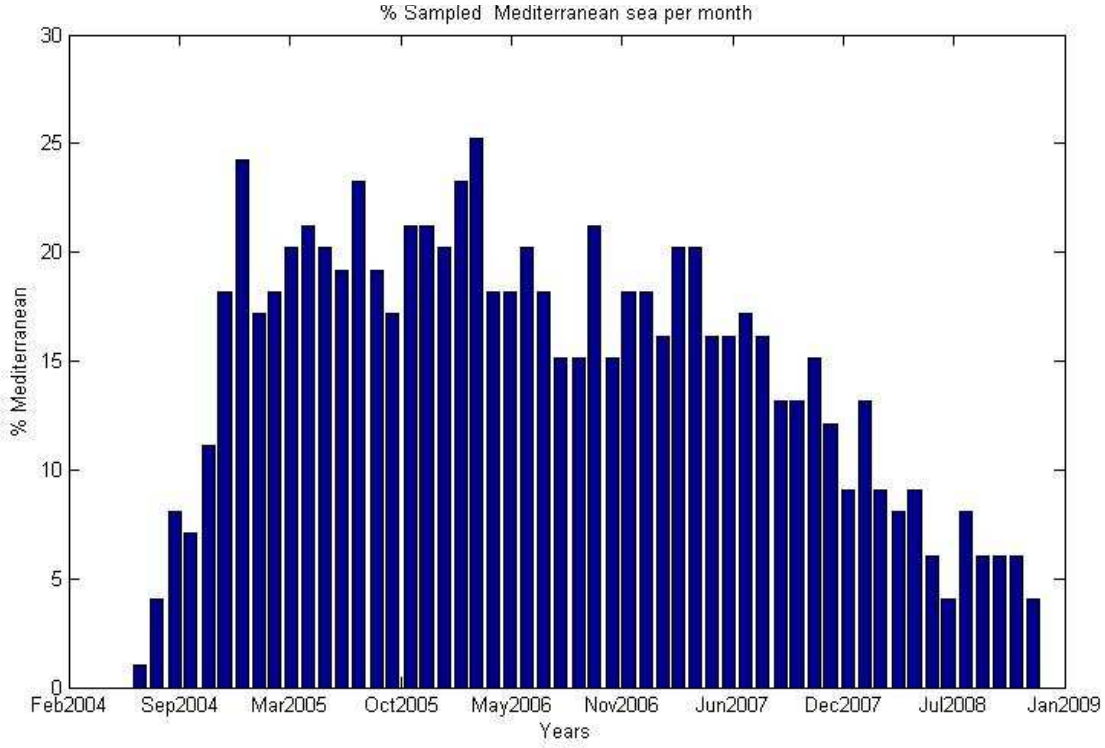

Figure 7. Percentage of 2x2 degrees cells with at least one float per month, for the entire Mediterranean Sea.

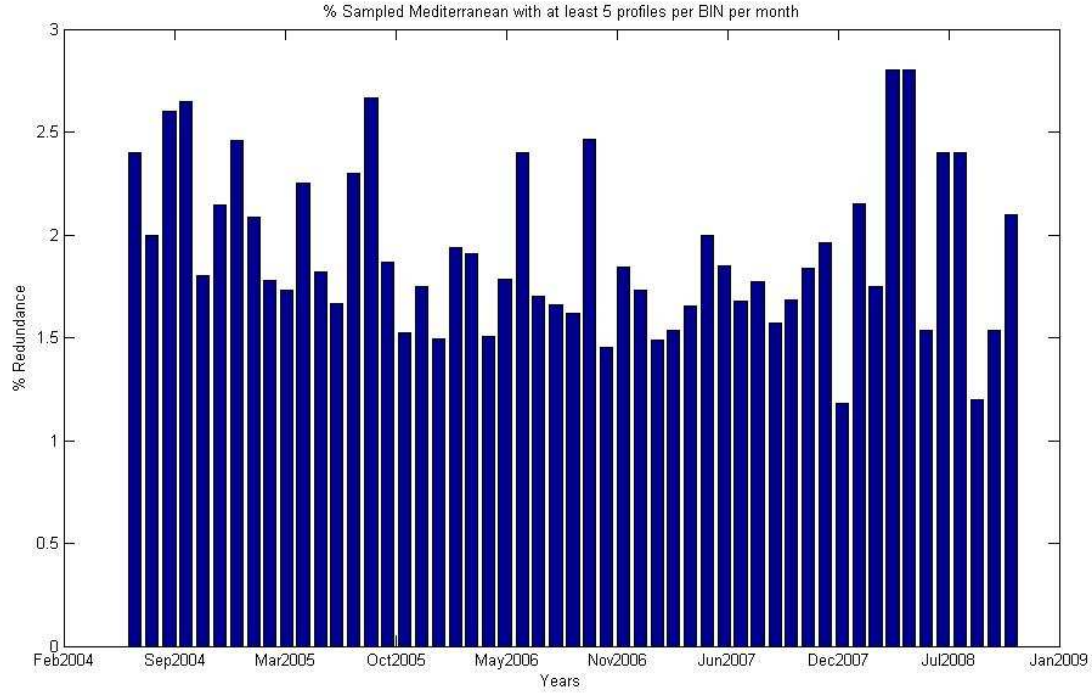

Figure 8. Over-sampling for the entire Mediterranean Sea with cells of 2x2 degrees as a function of time (in months).

2.2.2 Bins of 2°x 2° in the deep Mediterranean

For the deep Mediterranean (> 1900 m, 64 cells, see Figure 9), a maximum of about 45% of the deep Mediterranean was covered in March 2006. The temporal evolution of the deep Mediterranean coverage is depicted in Figure 10.

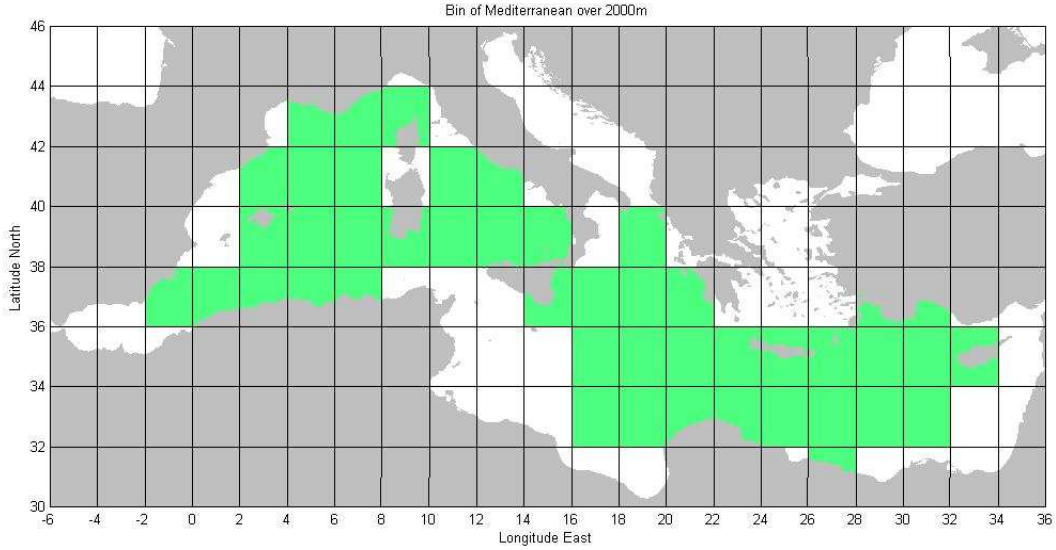

Figure 9. Grid with cells of 2x2 degrees covering the Mediterranean Sea. In total, 45 cells (in green) cover the deep (> 1900 m) basins.

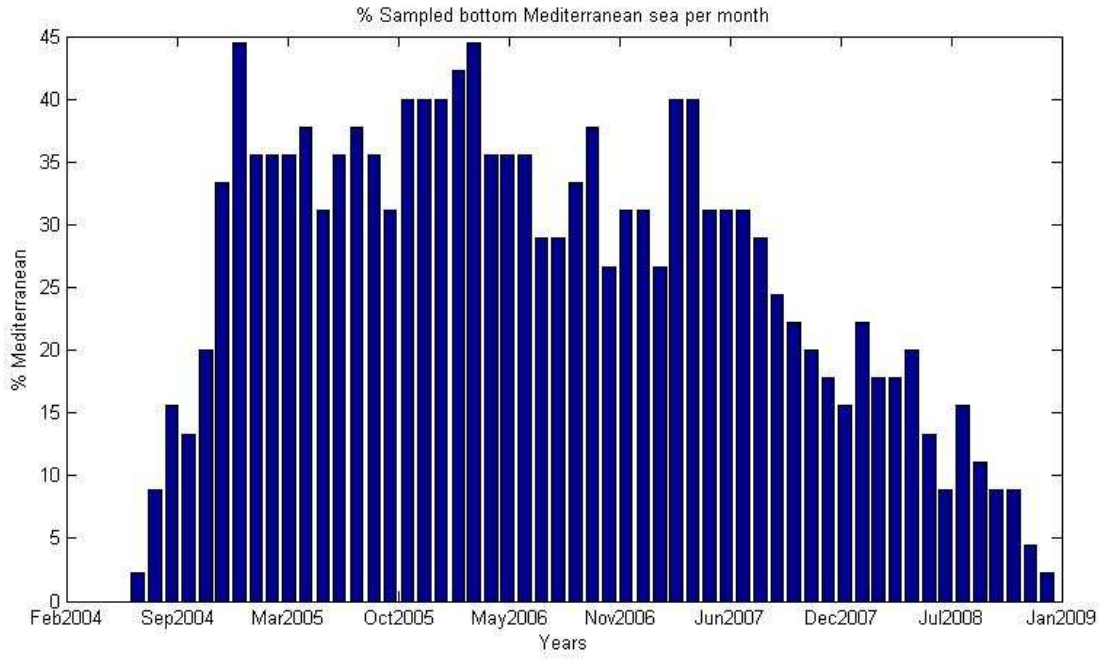

Figure 10. Number of 2x2 degrees cells with at least one float per month, for the deep Mediterranean Sea.

2.2.3 Bins of 3°x 3° in the entire Mediterranean

Using cells of 3°x3° over the entire Mediterranean (46 cells, see Figure 11), only a maximum 38% of the area was covered using 33 floats (see the temporal evolution of percentage of sampled cells in Figure 12).

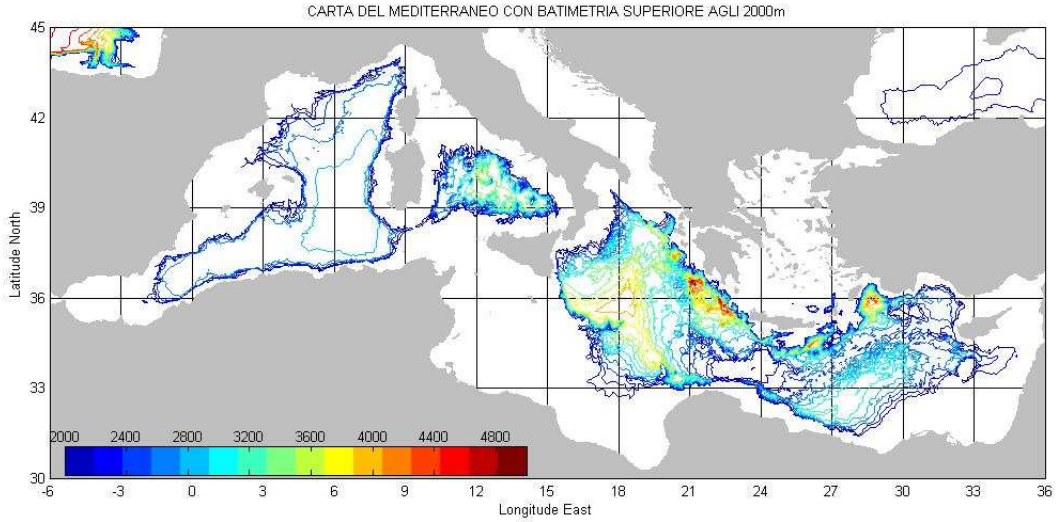

Figure 11. The Mediterranean Sea with bins of 3°x 3°. Isobaths deeper than 2000m are also shown.

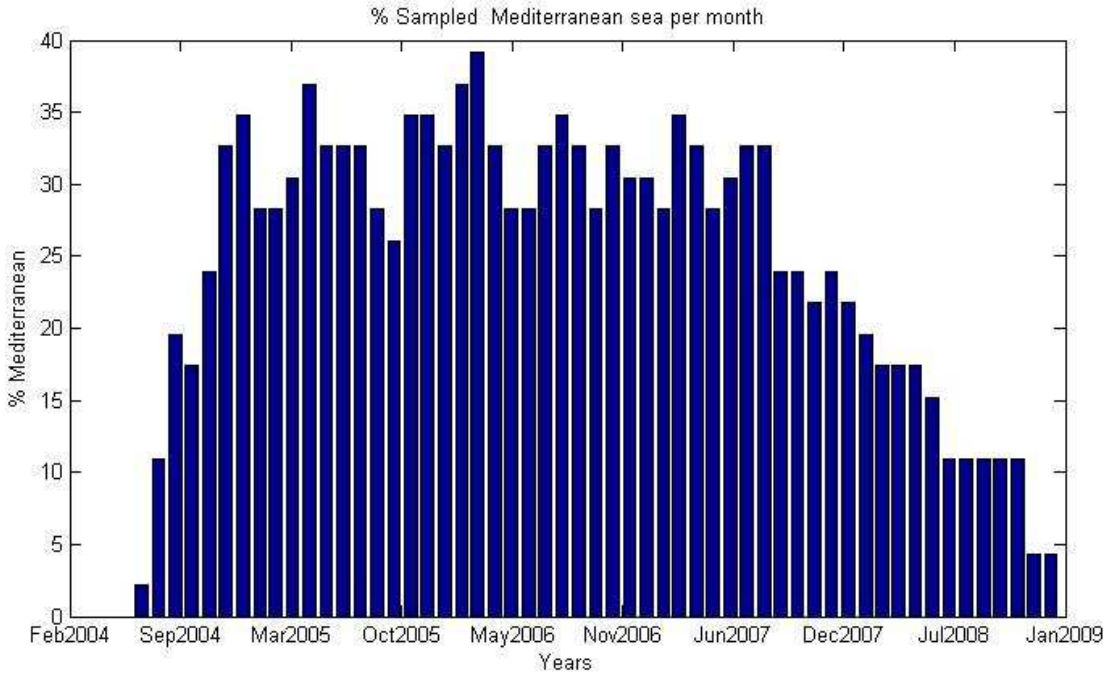

Figure 12. Percentager of 3x3 degrees cells with at least one float per month, for the entire Mediterranean Sea.

Over-sampling in a cell can reach 4 floats per cell for August 2004 in the NW Mediterranean (Figure 13). Otherwise, it is bounded by 1 and 2, indicating a slight over-sampling of the Mediterranean Sea with bins of 3°x3°.

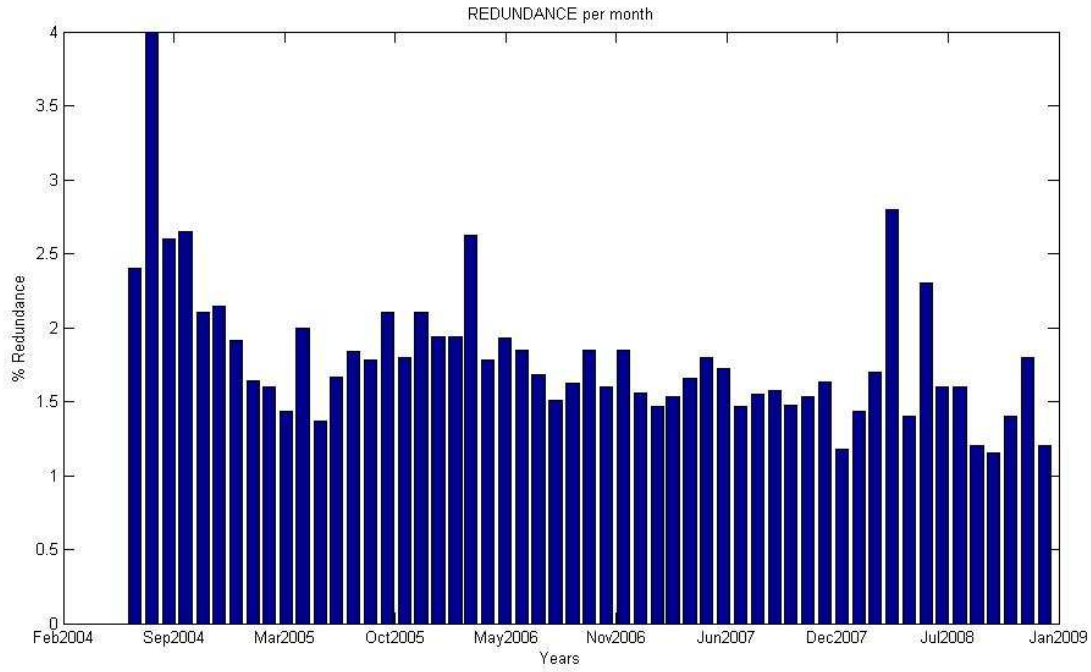

Figure 13. Over-sampling for the entire Mediterranean Sea with cells of 3x3 degrees as a function of time (in months).

2.2.4 Bins of 3°x 3° in the deep Mediterranean

Using a grid with 3°x3° cells over the deep Mediterranean (> 1900 m, 23 cells, see Figure 14), the spatial coverage can reach values above 60% for a few months (Figure 15).

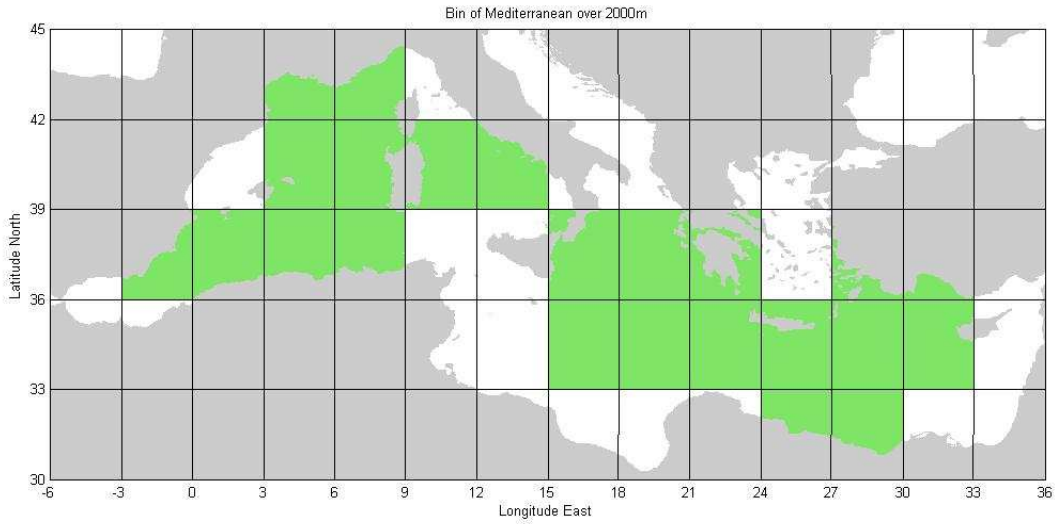

Figure 14. Grid with cells of 3x3 degrees covering the Mediterranean Sea. In total, 45 cells (in green) cover the deep (> 1900 m) basins.

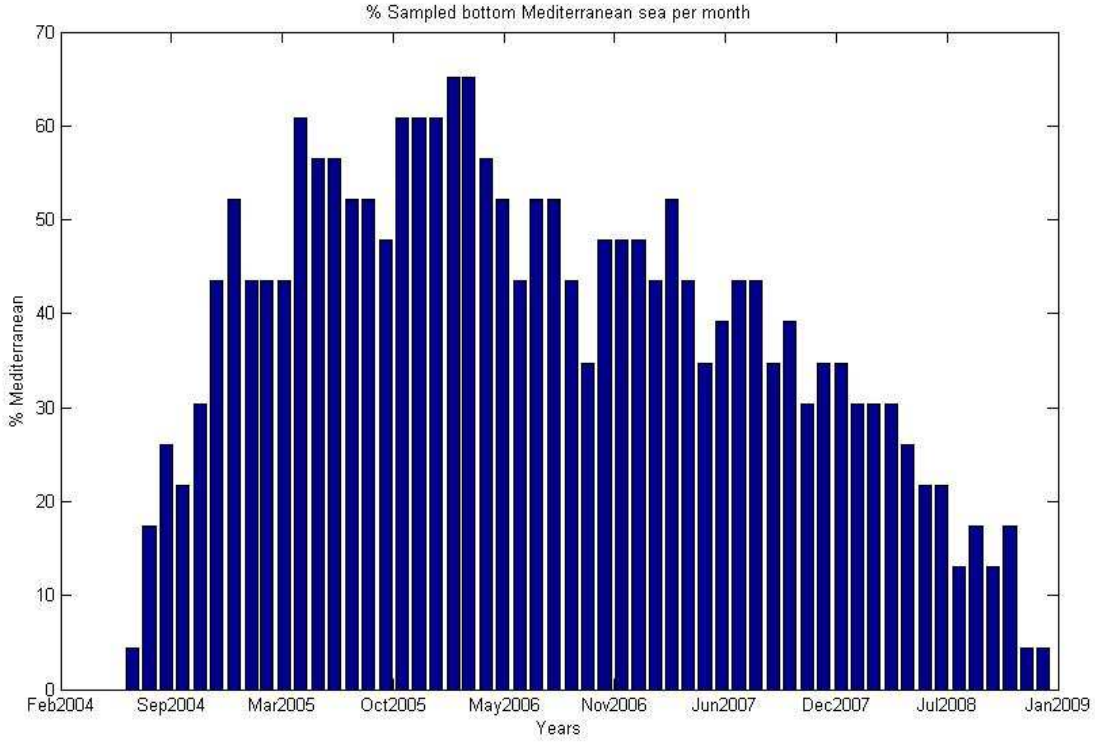

Figure 15. Number of 3x3 degrees cells with at least one float per month, for the deep Mediterranean Sea.

3. Argo data in the Black Sea

A total of 7 Argo floats have been operated in the Mediterranean Sea between 2002 and 2008 and have provided more than 900 CTD profiles. They have been deployed as part of a joint project between the University of Washington (USA), The Middle East Technical University (Turkey) and the Marine Hydrophysical Institute (Ukraine) (Korotaev et al. 2006). These floats had a cycle length of 7 days and a parking depth between 200 and 1550 m. The maximum density of floats was obtained in 2008 with 4 floats running simultaneously (Figure 16). The trajectories of these floats (Figure 17) delineate nicely the mean basin-wide cyclonic circulation in the Black Sea, including the Rim Current and eddies.

Statistics about the operational lifetimes of the floats are illustrated in Figure 18. The mean life of the floats is 1006 days. The percentage of active floats versus time after deployment in days or in cycles show that after 1, 2 and 3 years, the number of floats was 7, 6 and 2, respectively. The half mean life, the time after deployment corresponding to 50% decrease in float population, is 987 days. The percentage of active floats is also depicted as a function of the theoretical and actual vertical distances covered during ascent. The half mean distance is 86 and 64 km, for the theoretical and actual values, respectively.

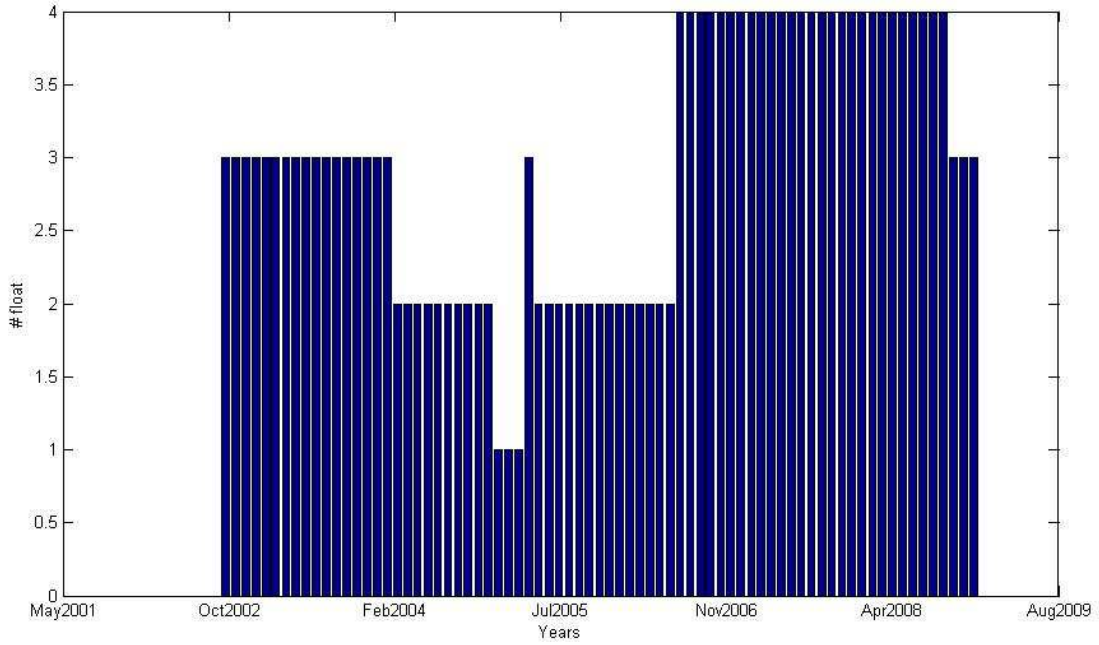

Figure 16. Temporal evolution of the float population in the Black Sea

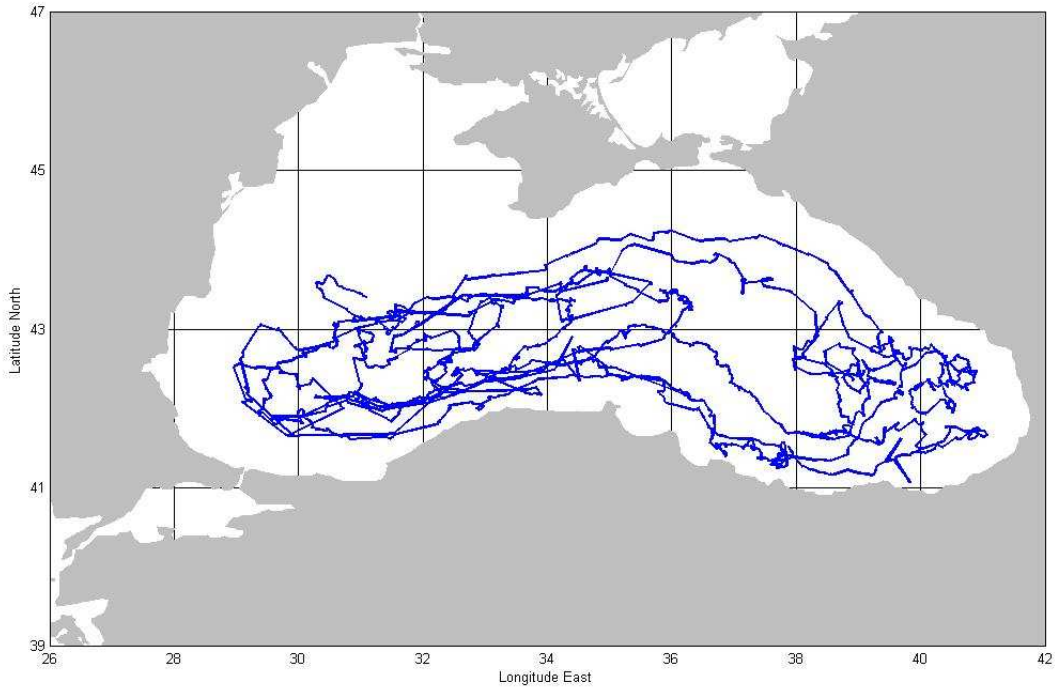

Figure 17. Trajectories of the 7 floats operated in the Black Sea between 2002 and 2008.

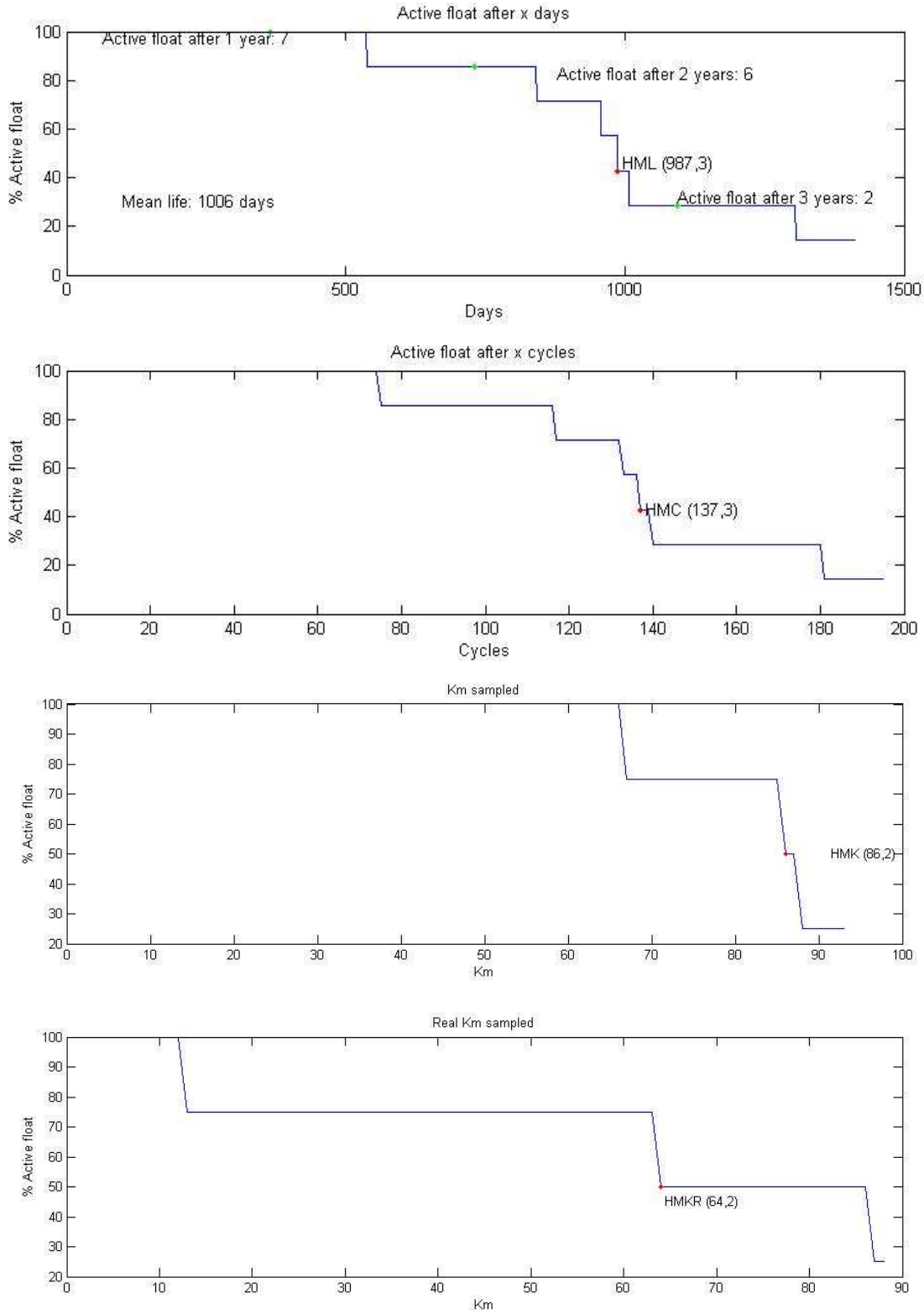

Figure 18. Percentage of active floats as a function of time, number of cycles, theoretical and actual vertical distance performed after deployment.

3.1 Vertical sampling

The effectiveness of the vertical sampling in the Black Sea locations of the profiles performed by the 7 floats. Given hypothetical maximal profiling depths of 700, 1000, 1500 and 2000 m, we can estimate the percentage of the water column sampled by the floats, the percentage of missing data because the float did not go deep enough, and the percentage of data not sampled because the bathymetry was shallower than the maximal profiling depth. The results are listed in Table 3 and illustrated in Figure 19.

Max Depth (m)	%Missing data	Sampled	Not sampled
700	64% (271622m)	36% (151018m)	1% (2981m)
1000	49% (207991m)	51% (214650m)	1% (5349m)
1500	25% (104568m)	75% (318072m)	3% (11927m)
2000	4% (14925m)	96% (407715m)	8% (32284m)

Table 3. Statistics (in percentage or in vertical distance) on the effectiveness of the vertical sampling in the Black Sea (see text for details).

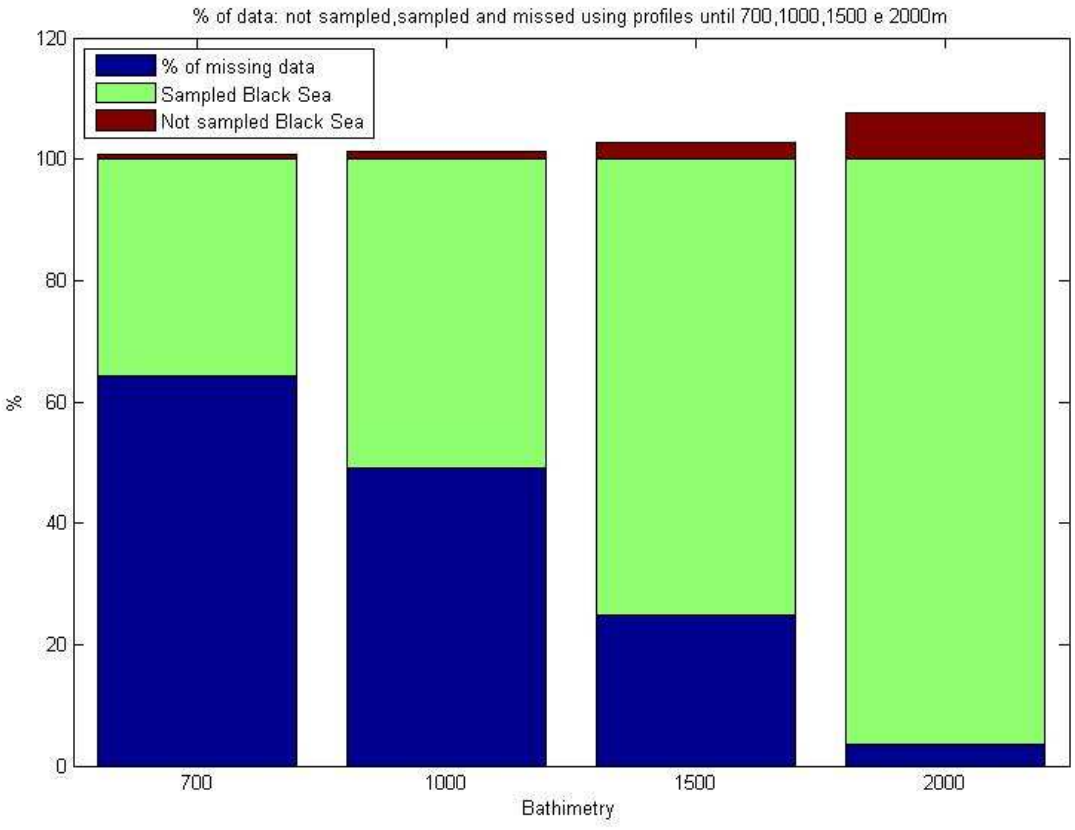

Figure 19. Percentage of the vertical sampling in the Black Sea, using hypothetical floats profiling down to 700, 1000, 1500 and 2000 m. Green: Percentage actually sampled by the floats. Blue: Percentage of data not sampled below the maximum profiling depth. Brown: Percentage of data cut due to shallow bathymetry.

For example, profiling down to 2000 m at each cycle would result in sampling 96% of the Black Sea water column, with the drawback that 8% of the profiling would be cut due to shallow bathymetry. The other extreme case is when the floats only profile the top 700 m of water, resulting in 36% of the water column covered, but with less bottom touching (about 1% of the theoretical profile is not sampled).

3.2 Horizontal sampling (bins of 2°x 2° in the entire Black Sea)

Figure 20 displays the Black Sea overlaid by a grid of 16 uniform cells of size of 2°x 2°. Using this grid, a maximum of 50% of the sea was covered in April 2008 (Figure 21). Oversampling (not shown) reached 3 floats/cell in fall 2002 when the first floats were deployed, but in general it stayed slightly over 1. This means that with a grid of 2°x 2°, the Black Sea was partially covered but the cells occupied by the floats were well sampled, even over-sampled.

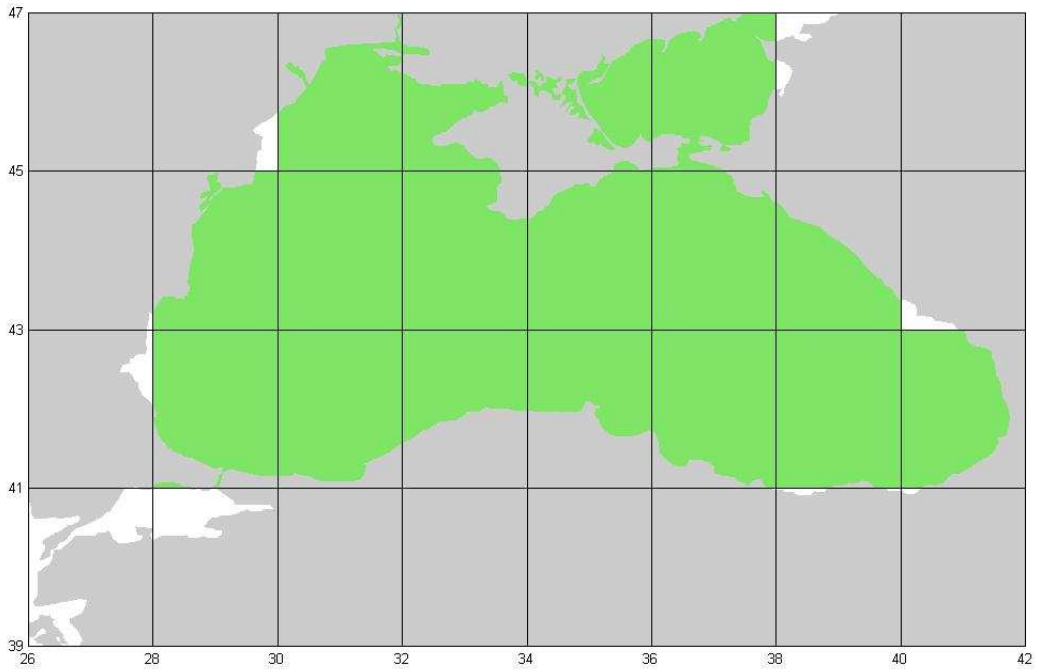

Figure 20. The Black Sea with bins of 2°x 2°.

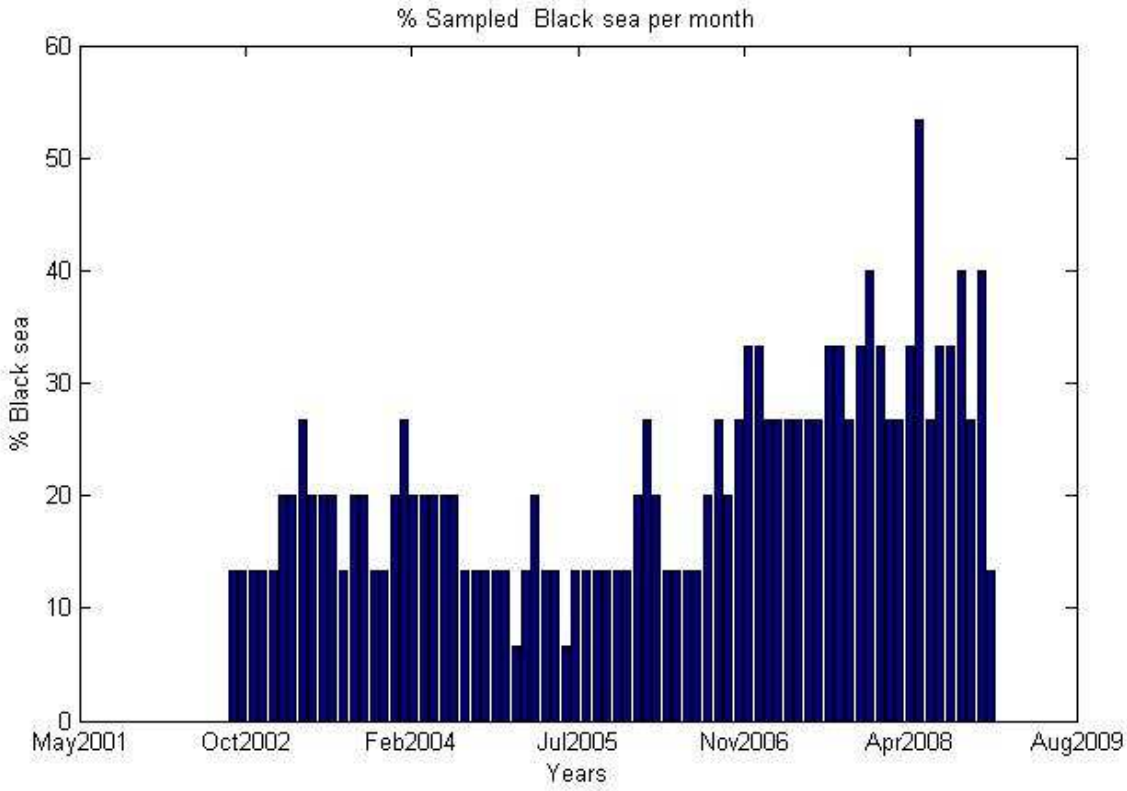

Figure 21. Percentage of 2x2 degrees cells with at least one float per month, for the entire Black Sea.

4. Conclusions

In total, 85 Argo floats have been operated in the Mediterranean between 2000 and 2008, providing more than 8700 CTD profiles. Using a subset of these data (33 MFSTEP floats with parking depth at 350 m and 5 day cycle length), we have shown that:

- The maximum float density was obtained in April 2006 with 20 floats operating simultaneously.
- The mean life and half mean life of the floats are 653 and 563 days, respectively.
- If all the profiles of these floats were programmed to sample as deep as 2000 m, only 22% of the Mediterranean water column is not sampled.
- Using bins of 2°x2°, only 25% of the entire Mediterranean was covered in March 2006. For the deep sea (> 1900 m) this percentage increases to 45%. In general the bins sampled by the floats are oversampled (more than one float per bin).
- Using bins of 3°x3°, only 25% of the entire Mediterranean was covered in March 2006. For the deep sea (> 1900 m) this percentage increases to 45%. In general the bins sampled by the floats are oversampled (more than one float per bin).

In the Black Sea, 7 floats have been used between 2002 and 2008, providing more than 900 CTD profiles. Using these data, we have found that:

- The maximum float density was obtained in 2008 with 4 floats operating simultaneously.
- The mean life and half mean life of the floats are 1006 and 987 days, respectively.
- If all the profiles of these floats were programmed to sample as deep as 2000 m, only 4% of the Black Sea water column is not sampled.
- Using bins of 2°x2°, a maximum of 50% of the entire Black Sea was covered in April 2008. In general the bins sampled by the floats are oversampled (more than one float per bin).

5. References

Korotaev, G., T. Oguz, S. Riser Intermediate and deep currents of the Black Sea obtained from autonomous profiling floats. Deep-Sea Research II 53 (2006) 1901–1910.

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