Chapter 8 CONCLUSIONS

Between the idea

and the reality

Between the motion

and the act

Falls the shadow

Between the conception

and the creation

Between the emotion

and the response

Falls the shadow

Between the desire

and the spasm

Between the potency

and the existence

Between the essence

and the descent

Falls the shadow

This is the way the world ends

Not with a bang but a whimper.

T. S. Elliot

(fragment from* The Hollow Men*)

This research thesis was carried out with the main aim of testing, on a shelf/slope domain, the capabilities of two spatial data analysis methodologies. The first, based on the combination of empirical orthogonal functions (EOFs) and a 2D successive corrections algorithm (SC), provides a 3D analysis that takes into account both the horizontal correlation (through the SC scheme) and the vertical correlation (through the EOFs) between observations. The second, more standard, technique consisted of obtaining the 3D grid values as the superposition of 2D analysis obtained using the SC scheme.

The potential of the EOF-based method to extrapolate profiles downwards has also been tested, with the ultimate aim of estimating dynamic height (and therefore the geostrophic circulation) in shallow areas of the domain. Finally, another goal was to test the potential of using vertical modes derived from historic data (in opposition to single oceanographic cruise data) to reproduce the data from oceanographic campaigns.

For these purposes, we used CTD data from four oceanographic campaigns carried out in the Ebro Delta region and which were expected to be representative of different conditions: FANS I for autumn conditions, FANS II for winter, FANS III for rather well established summer conditions and MEGO 94, a previous winter campaign, for atypical winter conditions (open ocean dynamics that differ significantly from the shelf dynamics). The latter campaign has been useful to outline some of the limitations of the methods.

The most relevant features regarding the EOF-based analysis of observed variables (q, S, s_q) have been sorted out according to the different methodological options and targets:

- Option of using EOFs derived from single cruise data to approach only deep (complete) casts:

- Considering the deep casts only, the total variance explained by the leading EOFs was rather similar for both, the non-standardized and the standardized approaches, although the first approach always provided slightly higher values.

- In general terms, the non-standardized analysis provided a faster convergence to actual data at upper layers, while the standardized one converges faster at deeper ones (an obvious consequence of the different weight given to upper and lower level variances by the two approaches). The selection of one or another method should therefore depend on the objectives of each particular case study.
- For the FANS cruises, the fraction of density level variance not explained by the leading EOFs reached maximum values for the non-standardized density analysis, but always at depths greater than 200 m. For the MEGO 94 cruise, the largest fractions of unexplained density variance were obtained at upper (but not surface) layers, namely between 40 and 80 m.
- The EOF-based analysis always converges towards actual profiles as the number of modes included in the analysis increases, and this is true at all depths. As a consequence, the fraction of non-explained level variance relative to total level variances (hereafter referred to simply as “error”) is never higher than 100%.

All the above points derive naturally from the EOFs basic formulation, when applied to the same data from which they were derived. The only exception is the similarity in the total variance explained values considering six leading modes. The larger variability contained in the upper layers that is explained by the non-standardized analysis is compensated by the largest depth range that is resolved by the standardized analysis, thus rendering similar overall accumulated explained variances.

- Option of using EOFs derived from single cruise data to approach all casts:

The ability of the method to reproduce shallower shelf conditions depends on different aspects, such as the distinctive shape of the different modes (weather or not they represent the shelf conditions), and also on the assumption that the sequential fitting captures the data variability in the first modes. An additional factor which explains the peculiar behaviour of the error profiles might be the fact that, for shallow casts, the orthogonality condition of the modes is not necessarily fulfilled. The complete set of vector modes may not necessarily reproduce the shallow casts profiles, and the variability at a given depth might not be independently explained by different modes, for they are not necessarily uncorrelated.

The extent to which open-sea dynamics can be representative of shelf dynamics (a key hypothesis underlying the use of the EOF-based method) can be checked comparing the mean and standard deviation profiles obtained from a set of open-ocean stations with those obtained from shelf stations (or with those obtained considering all available data at a given depth).

- When also shallow profiles are intended to be approached by EOFs, the fraction of non-explained level variance can occasionally increase when additional modes are considered. As expected, such occasional, local increases are always compensated at the end, when adding further modes. In any case, errors can occasionally be higher than 100%.
- As when considering only deep casts, the largest fractions of level density variance not explained by the leading EOFs are obtained at deep layers with the non-standardized analysis. Also as before, MEGO 94 has larger errors at intermediate depths, but now with larger values. The latter is a consequence of the fact that open ocean conditions encountered during MEGO 94 do not reflect the shelf conditions, as revealed by the basic statistics profiles. Some of the larger errors also coincide with very low variance values in the data.

- Option of using EOFs derived from historical data (to approach either only deep casts or all casts):

The influence of the vector modes shape, their non-orthogonality when fitting shallow profiles and the sequential fitting assumptions are also relevant when dealing with historic eigenvectors. The shape of the historic data eigenvectors is fundamental, for they basically reflect open-ocean conditions from a wider geographic domain within the Balearic Basin. The historic statistics are also different from the cruises ones, particularly during winter. The historic density average profiles also reveal heavier waters at equivalent depths. All these factors account for the following points:

- For this option, error values are usually higher than those obtained with the single cruise eigenvectors (with a few exceptions).
- The density profiles, specially when they are estimated via standardized analysis, render very high error values at upper layers when only the first leading modes are considered. These values decrease as the number of modes increases. MEGO 94 is the only campaign for which errors do not decrease below 60% even with 24 modes (at 50-60 m).
- With the non-standardized analysis, the largest errors are always lower than those obtained from the standardized analysis, and appear normally at deep layers (they also tend to decrease as more modes are considered). The only exception is FANS I, for which the largest errors are obtained at intermediate levels, and 24 modes are not enough to lower them below 30%.
- When the 3D grid is to be obtained, the interpolation of the estimated profiles has revealed to be more appropriate than interpolating the amplitudes associated with the corresponding vector modes. In particular, on-grid standardized density distributions resulting from the amplitude interpolation is highly unreal, particularly as depth increases and regardless of the number of modes considered. The reason is that amplitude values corresponding to shallow stations may differ from the ones at deeper areas in one or two orders of magnitude. These can translate into unrealistic values at lower levels which, despite being in principle located below the bathymetry, have also a negative impact onto nearby locations above the bathymetry.
- The fact that MEGO 94 shows atypical winter conditions (in addition to not being representative of the shelf dynamics) justifies the poor results obtained for this campaign. The same holds for

FANS I, which cannot be considered to be represented either by summer conditions nor by winter conditions.

- Dynamic thickness and geostrophic circulation:

As mentioned earlier, the success of the EOFs for the estimation of dynamic height on the shelf depends on the shape of the corresponding vector modes. A key question is to what extent the statistics of the open ocean might reflect the conditions on the shelf. If the distributions are very different, the approach to the profiles might generate highly unrealistic values below the bottom depth, as was shown in the density distribution profiles from MEGO 94. Another relevant aspect is weather the vector modes have significant fluctuations at depth, for that would also generate thickness fluctuations which would in turn reflect in the dynamic thickness profiles. While additional modes do tend to approach the shallow data thickness profiles, this does not mean that the extrapolated values below the bottom depth are “reasonable”.

- The application of Csanady`s integration path to the Ebro Delta shelf/slope bathymetry renders spurious velocity components with high along-transect speeds in the upper shelf. A test with an analytic thickness distribution has revealed that the contours tend to bend along the transect direction as soon as the bathymetry becomes shallower than 500 m. With actual data, this behaviour is somehow hidden by the actual distribution at deep layers, but the effect must be quite the same.
- For the geostrophic currents estimated with the EOFs methodology, six leading modes seem to give nearly as good results as the method can provide. Considering further modes does not necessarily improve the recovery of open-ocean structures, and neither increases the capability of recovering the shelf dynamics from statistics inferred from the open-ocean dynamics (in some cases it can even worsen the results).
- Regarding the data to be used as input for the spatial interpolation process, the differences between taking all the profiles of the domain (through the amplitude interpolation option) and taking

only those located where the bottom depth is deeper than 100 m (profile interpolation), are significant. The second method has been shown to provide more realistic geostrophic currents on the outer shelf/slope domains.

- Despite the above considerations, the EOF-based method is still a better option than Csanady's method to obtain dynamic height distributions over the shelf.
- As for observed variables (or better, a clear consequence of the latter), the use of campaign eigenvectors usually renders better results than historical ones. The only exception (the amplitude interpolation option applied to MEGO 94) is by no means significant.

From all the above points, it seems reasonable to state that the EOF-based methodology has a considerable potential when applied to a shelf/slope domain in which the number of deep casts is as low as for the presented case studies. The best option to be used (non-standardized vs. standardized analysis) definitely depends on the goals of the particular research. If the upper layer needs to be resolved then the non-standardized analysis is a must, while if an overall three dimensional field is required, then the standardized one might be a better option.

When historical eigenvectors are used to approach the data, a larger number of modes might be required, though the data profiles are finally well approached. The results with FANS I, on the other hand, point out the possible need to consider more than just two seasons. The advantage of breaking the historical data set into four seasons might be a better set of vector modes for the transition periods of spring and autumn; the obvious disadvantage would be that less profiles would be available to derive the seasonal EOFs.

Another important result refers to the best performance of interpolating the profiles in front of the option of interpolating the amplitudes. This was at least the case of the density profiles obtained with the standardized analysis with the historic eigenvectors. The results justify the higher number of operations of this option (one interpolation per level in front of one interpolation per leading mode).

A last remark should be made on Csanady's method, which in combination with the sharp bathymetry of the Ebro Delta shelf/slope, renders spurious along-transect geostrophic velocities. This clearly limits its applications to sharp shelf edges. Conversely, despite the results produced by the EOFs method are far from being good, they can provide some insight on the shelf circulation, even if only from a qualitative point of view.

Another fundamental aspect to be considered regarding the Ebro Delta shelf/slope domain and the above results is the effect of the topography. Csanady's method (Csanady, 1979)) has been successfully used to estimate the dynamic height distribution in many shallow shelf domains, without reports of the along-transect velocity components. Through the analytic distributions it became clear that the abrupt shelf/slope, in which the depth transition from 500 m or more to 100 m takes place in few kilometres, seems to account for this effect. The reason might be the fact that the assumed dynamic height contribution below the bottom becomes more important than the actual on-shelf values.

On the other hand, vertical density distributions (Haney and Hale, 1995) and geostrophic currents (Pedder and Gomis, 1998) have both been successfully determined through EOFs analyses in other geographic domains, where a certain number of casts did not reach an assumed reference depth. In those cases there was a significantly larger percentage of deep casts, and none of the domains consisted of a shallow shelf with an abrupt slope, where the local forcing mechanisms can have very important effects on the dynamics, such as the Ebro outflow. Just to exemplify, we believe that the good results obtained with FANS III in all cases are due to a well established thermocline, which gives stability to the water column, to the low river outflow and to little mesoscale activity.

In our opinion there are at least two aspects that deserve further research. They should be tested in the same geographic domain of the Ebro Delta shelf/slope, and results could be compared with those presented in this research thesis:

One is the possibility of using historic data eigenvectors from four seasons. As mentioned before, this might improve the results for campaigns carried out under transition conditions between the summer and winter seasons.

The second is the need to test these methodologies in combination with a multivariate analysis scheme with high quality ADCP current data. This would allow quantitative results on the shelf geostrophic circulation, which in turn would allow an estimate of the ageostrophic contribution to the shelf/slope dynamics.

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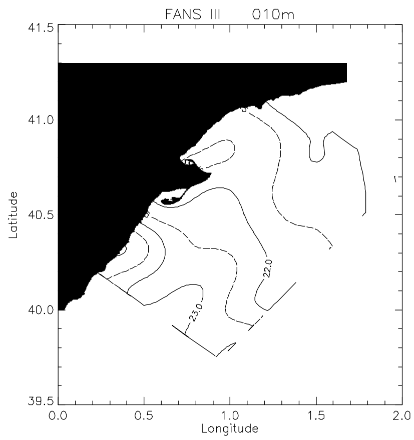
APPENDIX 1

Reference figures for FANS III. Potential temperature (a-b), salinity (c-d) and density (e-f).



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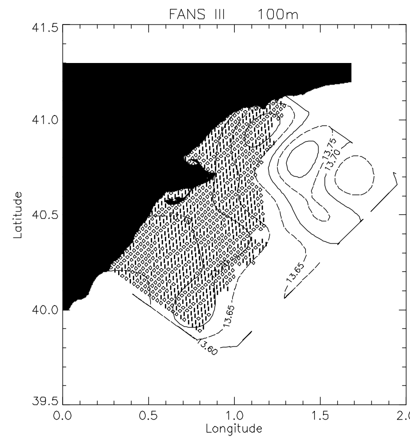

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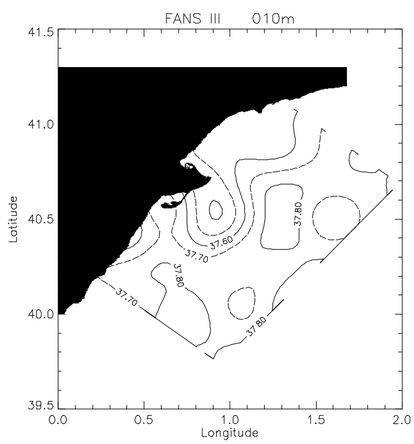

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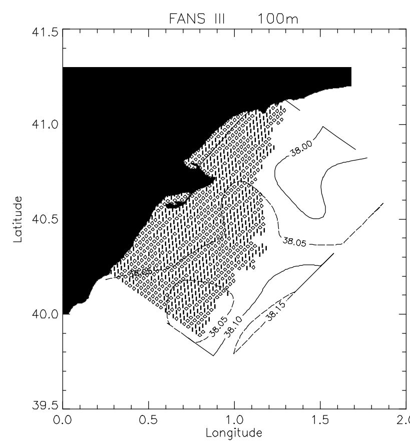

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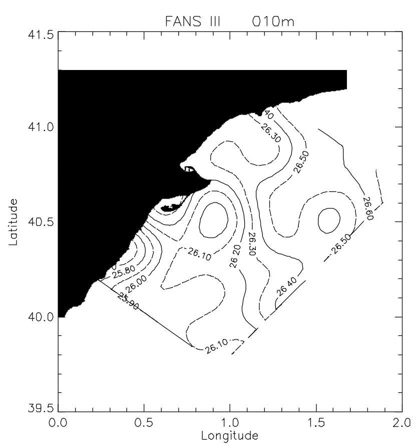

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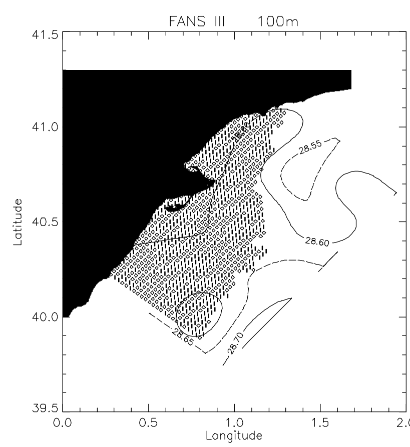

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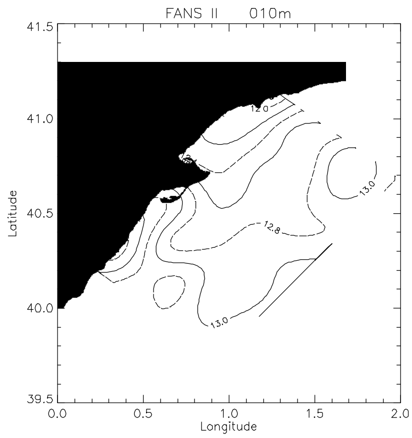

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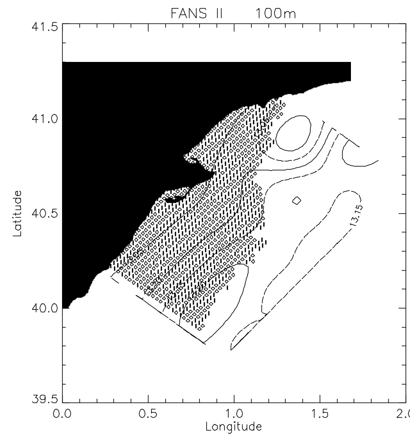

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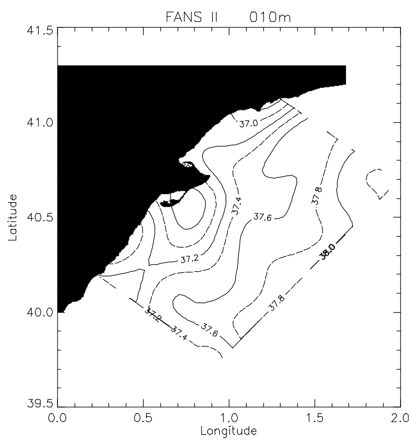

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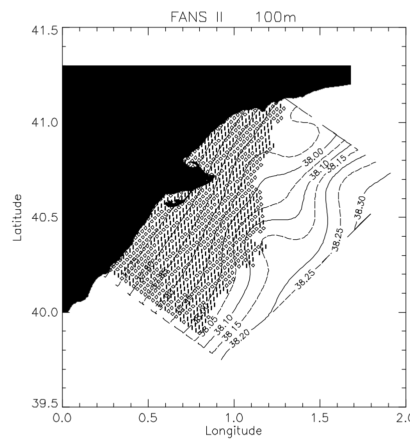

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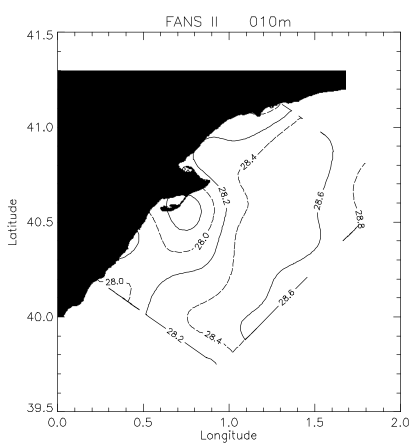

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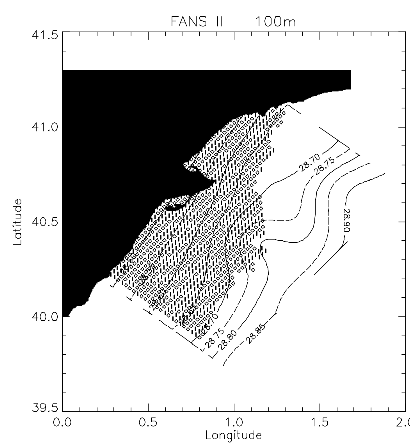

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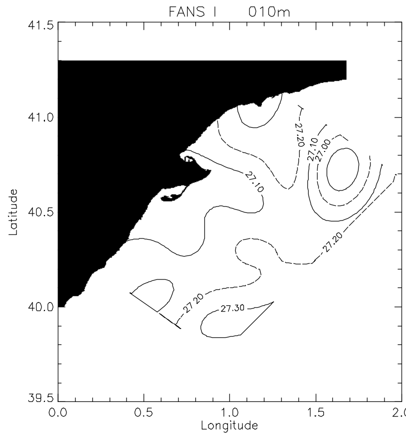
Reference figures for FANS I. Density (a-b).



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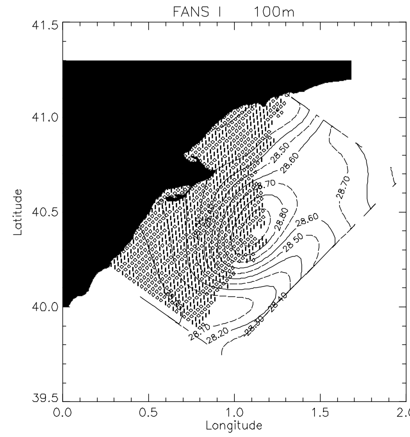

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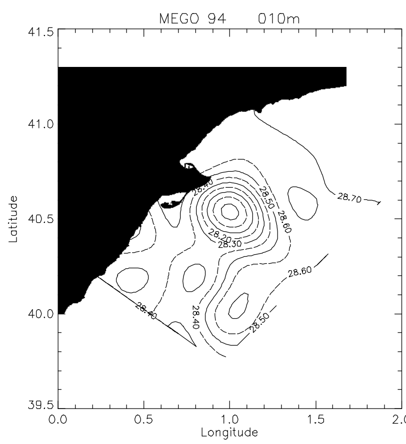

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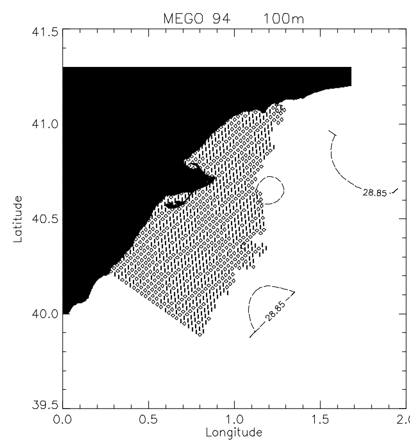

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