1. Introduction

An essential activity in oceanography consists of estimating and studying the evolution, in space and time, of the physical, biological and geochemical properties of the sea (e.g., Defant, 1961). As in classical mechanics, one is then interested in the ocean fields, i.e., the functions of space and time characterizing the considered ocean state. In this paper, some simple steps are taken towards the extension of this fundamental view to the estimation and study of the evolution, in space and time, of the statistical properties of real ocean fields. For multivariate, multiscale and nonhomogeneous issues, the task is challenging. As a first endeavor, the investigation is restricted to the four-dimensional physical fields, a classic interest, and to the four-dimensional covariances of these fields. The methodology employed for this investigation combines real data and dynamics based on the Error Subspace Statistical Estimation (ESSE) approach (Lermusiaux, 1997). It was exercised in real-time during the operation Rapid Response 96 (RR96), considering mesoscale variability in the Strait of Sicily during August and September 1996. The real-time statistical estimation consisted of a series of prediction and filtering problems (Jazwinski, 1970) and the word estimation in this paper is used in this sense.

The North Atlantic Treaty Organization (NATO) operation RR96 was designed to demonstrate a rapid environmental assessment (REA) in a naval context (Pouliquen, 1997; Sellschopp and Robinson, 1997). Ocean surveys were carried out with several ships continuously sampling the region and aircrafts rapidly deploying temperature vs. depth probes (AXBTs). The main Harvard participation in RR96 consisted of the real-time nowcasting and forecasting of the physical fields, using the Harvard Ocean Prediction System (HOPS, e.g., Robinson, 1996). Several two-way nested sub-domains were employed for higher resolution estimation in coastal areas of specific interest. The products included primitive equation forecasts and data assimilation using Optimal Interpolation (OI), with real-time atmospheric forcing and acoustic computations. An overview of the experiment and a discussion of the Atlantic Ionian Stream (AIS) variability in the Strait is given in (Robinson et al., 1998b).

The intensive data of RR96 and the calibrated primitive equation model of HOPS provided an ideal test situation for ESSE. The physical fields, their variabilities, uncertainties and corresponding dominant covariances, were in fact predicted in real-time. Comparisons with the OI scheme were carried out, and, for the first time, several operational and scientific ESSE products were made available to NATO (W.G. Leslie, personal communication). Fig. 1 is one of these products, especially important for its use in real-time adaptive sampling. Panel (a) is the surface temperature on Sept. 18 after ESSE assimilation of hydrographic data sampled on that day. Panel (b) is the expected mesoscale error field of the assimilated data. Panel (c) is the error standard deviation of the map of Panel (a): it is obtained from the diagonal of the a posteriori error covariance matrix. After the assimilation, the largest surface temperature uncertainties (Panel c) are found in two regions: one (35–37°N, 12–14°E) is mainly associated with the so-called Maltese Channel Crest feature (Section 1.1) and the other (37–38°N, 15–17°E) with meanders of the AIS off the eastern coast of Sicily. For optimal sampling, these locations of high variability appear in most need of future temperature probe gathering.