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Potential of sequential EnKF for the short-range prediction of a maritime severe weather event

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ABSTRACT

The Western Mediterranean coastlands are persistently affected by severe phenomena related to maritime convective systems. Areas with low density of observations around highly populated regions pose serious forecasting challenges due to the risk of misrepresenting crucial structures. This forecast problem is exemplified by the squall line that affected Mallorca (Spain) on 4th October 2007. Ensemble Kalman Filter (EnKF) assimilation algorithms exploit the statistical information conveyed by ensembles and are specially suited for regions with poor knowledge about climatological error statistics and covariances. We investigate the potential for predictability improvement from the assimilation of standard observations in the squall line event. Ensemble forecasts are assessed in terms of probabilistic products which clearly bring out the differences between assimilation and control experiments. Results show the large improvements rendered by the EnKF system in terms of severe weather threat. The attribution of these improvements is discussed in terms of the environmental ingredients linked to squall line formation. Experiments reveal that forecast improvements are fully attributable to the ability of EnKF to accurately represent the convergent flow over the Alboran Sea responsible for the thunderstorm initiation. Additional sensitivity experiments are performed to confirm the hypothesised primary role of the terrestrial observations in the accurate representation of the low-level convergent flow. These experiments confirm the ability of the sequential assimilation system in conveying crucial observational information from terrestrial to marine areas, and thus bestowing the EnKF a central role in future upgrades of high impact weather prediction systems in the Western Mediterranean region.

1. Introduction

The numerical prediction of high-impact weather over islands and coastal areas remains a global daunting challenge. Observing systems with large in-situ data-void regions, such as maritime areas, critically affect the accuracy of forecasts as important structures are frequently missed in the analyses (Wu et al., 2013). Over the past 40 years, increasingly sophisticated methods have been developed to improve the representation of the atmosphere in numerical weather prediction models from a wealth of observations, both in situ, and most importantly, from remote sensing instruments (Rabier, 2005; Palmer and Hagedorn (2006); Shen et al., 2016). This progress has unquestionably led to significantly reduced errors in the initial fields, and thus to improved numerical predictions, mostly in the medium term (Cacciamani et al., 2000; Courtier et al., 1998; Houtekamer et al., 2005; Bouttier and Kelly, 2001). However, established techniques at synoptic-scale in global forecast systems (Buizza et al., 2005) require reconsideration when transferred to the meso- and convection-allowing scales, due both to the fundamentally different dominant dynamics, and the higher nonlinearity, which produces faster error propagation and growth (Zhang et al., 2003; Hohenegger and Schär, 2007; García-Moya et al., 2011; Vich et al., 2011).

Ensemble Kalman filter (EnKF; Evensen, 1994) has been proposed as the data assimilation technique meant to become a reference for subsynoptic scale prediction systems (Torn, 2010; Stensrud et al., 2013). Data assimilation methods, amongst them EnKF, determine the most likely estimate of the atmospheric state by blending information from an initial guess (background) and a set of observations. Essentially, the EnKF contributes to the data assimilation scene by proposing an ensemble-based method to derive an estimate of the background error covariance matrix used in the Kalman filter (Houtekamer and Mitchell, 2001). In this sense, the EnKF is similar to variational methods, like 3DVAR or 4DVAR (Buehner et al., 2009; Lorenc, 2003), with some important differences found between them. The EnKF is conceptually formulated following a sequential algorithm, as opposed to the iterative variational algorithm used by the 4DVAR. The way the error covariance matrix is evolved or the use of dynamic background-error covariances are also fundamental differences between both approaches. EnKF algorithms have been widely used to initialize limited-area models (Meng and Zhang, 2011, e.g.), and most studies investigate cases initialized and evolved over land. We lay the foundations of this study over the

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hypothesis that cycling ensemble Kalman filters which intensively assimilate observations from coastal regions have a great potential for improving socially relevant phenomena initiated over maritime areas. The ability of cycling data assimilation methods to transport information from relatively well instrumented areas towards maritime regions draws the fundamental motivation for the experiments presented in this paper as not only improves the prediction per-se, but it has the promising potential of making an efficient use of remote sensing observations over the sea.

On 4th October 2007, an intense squall line swept across the Balearic Islands (Fig. 1), producing 3 tornadoes (surveyed by the Spanish Weather Agency, AEMET), severe winds and very high precipitation intensities that produced local floods in Palma. One person was killed by debris, more than 200 people were injured by wind-related incidents and material losses were estimated at several tens of millions of Euros (Ramis et al., 2009). Severe convective storms during autumn are not uncommon in the Western Mediterranean area (Riosalido, 1990; Tudurí and Ramis, 1997) mainly because of two ingredients: convective instability by strong latent heat flux from the relatively warm Mediterranean sea, and the uplift provided by the complex orography of the area when interacting with the impinging low-level flows (Romero et al., 1997; Malguzzi et al., 2006). Historical examples of these severe convective episodes in the Western Mediterranean basin are the tornadoes recorded in Mallorca and Menorca on 26th October 1991 and 8th October 1992 respectively (Gayà and Solio, 1993); the heavy precipitation event with amounts exceeding 800 mm in 24 h on 4th November 1987 in Gandía (Valencia) (Romero et al., 1998); the 6 cm diameter hailfall on 15th August 1954 and on 26th August 1968 in Mallorca (Miró-Granada, 1969), amongst other similar cases (García-Dana et al., 1982; Benet, 1986; Fernández et al., 1995; Ramis and Romero, 1995; Ramis et al., 1994; Homar et al., 2003). The precise short-range prediction of the time, location, and intensity of severe phenomena is still beyond current operational prediction systems. The Spanish Weather Service (AEMET) continuously develops numerical tools, based on data assimilation methods and km scale prediction, for the short-range forecasting of high impact weather events in Spain (Navascués et al., 2013). Ducrocq et al. (2008) describe the key role played by orography in anchoring the highly efficient precipitation systems and so increasing the predictability of the location of these events. On the contrary, Cohuet et al. (2011) performed experiments with the 4th October 2007 squall line over Mallorca and concluded that the numerical prediction of the event is extremely challenging due to the high sensitivity of the mesoscale convective system to the initiation phase, which occurred over the sea. In particular, Cohuet et al. (2011) identified a maritime convergence zone over the Alboran Sea during the first hours of 4th October as a determinant precursing structure for the successful simulation of the severe episode. Their finding exemplifies common scenarios that produce high impact events over the densely populated coastal regions of the Western Mediterranean. Despite Cohuet et al. (2011) managed to produce a reasonably good simulation of this convective event with the Meso-NH model, an operationally oriented application requires taking into account the uncertainties associated with the forecast, and thus the use of an ensemble prediction system with the objective of rendering a reliable and high resolution probabilistic description of the plausible outcomes. Given the large and particular challenges identified to numerically predict this squall line, we hypothesize that the application of a cycling EnKF to produce more accurate analyses has a large potential to translate into a higher confidence in predicting the genesis, development and impacts of the severe convective event, than deterministic forecasts.

The paper is organized as follows: Section 2 presents a brief description of the case based on the available observations; Section 3 describes the model and data assimilation system used in this study, as well as the design of the cycling data assimilation experiment. The effects of assimilating conventional data in the forecast of the squall line are discussed in Section 4. Once the positive impact of the assimilated observations is proved, Section 5 describes the role of terrestrial and oceanic measurements on the simulation of the key aspects that produce the improvement in the EnKF experiments. A factor separation technique is used to isolate the influence of the different types of observations in the assimilation. Section 6 provides the discussions and concluding remarks of this study.

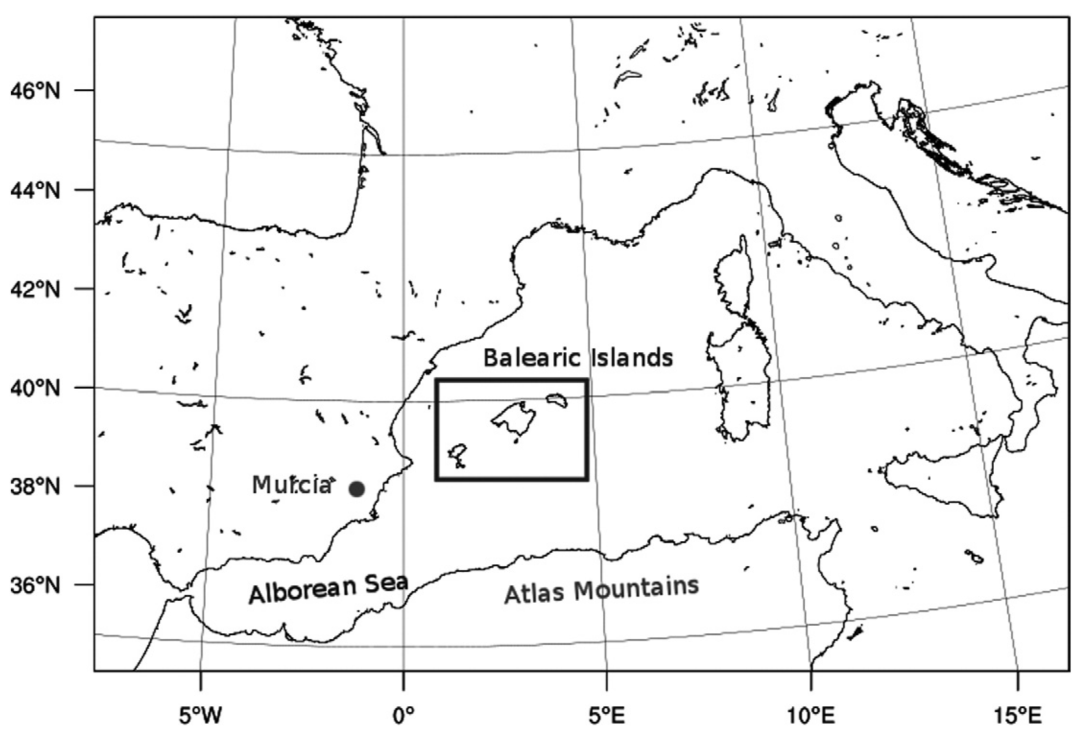

Fig. 1. Numerical domain used in all experiments.