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Surface drift prediction in the Adriatic Sea using hyper-ensemble statistics on atmospheric, ocean and wave models: Uncertainties and probability distribution areas

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Abstract

Despite numerous and regular improvements in underlying models, surface drift prediction in the ocean remains a challenging task because of our yet limited understanding of all processes involved. Hence, deterministic approaches to the problem are often limited by empirical assumptions on underlying physics. Multi-model hyper-ensemble forecasts, which exploit the power of an optimal local combination of available information including ocean, atmospheric and wave models, may show superior forecasting skills when compared to individual models because they allow for local correction and/or bias removal. In this work, we explore in greater detail the potential and limitations of the hyper-ensemble method in the Adriatic Sea, using a comprehensive surface drifter database. The performance of the hyper-ensembles and the individual models are discussed by analyzing associated uncertainties and probability distribution maps. Results suggest that the stochastic method may reduce position errors significantly for 12 to 72 h forecasts and hence compete with pure deterministic approaches.

Keywords: Forecast; Surface drift; Multi-model super-ensembles; Linear regression; Ocean models; Atmospheric models; Wave models

1. Introduction

A plethora of ocean, wave and atmospheric models are currently available on a routine basis at the global, regional and local scale in many coastal areas. Fundamental questions arise concerning which model to select for a given task, what criterion to apply for this selection and what is the resulting confidence level. All such models have varying skills in space, in time, but also in frequency. A master model may introduce direct errors on a slave model in a one-way coupled implementation or even feedback errors on itself in two-way coupled implementations, generating a complex chain of errors known as the “uncertainty cascade”.

Much effort is spent on individual model improvements, limited at a point beyond which processes have to be simulated in a non-deterministic way. An original statistical approach was recently proposed to circumvent this limitation, aimed at combining optimally different models into a super-ensemble for weather and climate

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forecast (Krishnamurti et al., 2000a,b; Kumar et al., 2003; Shin and Krishnamurti, 2003a,b) using least squares optimization, dynamic linear models and probabilistic approaches.

These techniques have been also successfully applied in the ocean for sound velocity profile estimations (Rixen and Ferreira-Coelho, 2005) and for surface drift problems (Rixen and Ferreira-Coelho, in press).

Surface drift prediction can be very challenging in certain areas because of the number, and the complex interplay, of processes involved (*e.g.* Carniel et al., 2002; Rixen and Ferreira-Coelho, in press), including Ekman transport, tides, Stokes drift, ocean currents, inertial oscillation, leeway effects, etc. As a rule of thumb, Ekman drift will set up a surface current of roughly ~ 3% of the wind speed, ~ 15° to the right of the downwind direction in the Northern hemisphere. But these values may vary according to the sea state and the stratification (*e.g.* Gill, 1982). Other processes may have similar contributions to the flow, such as the effect of waves and ocean. Deterministic methods do not yet exist to combine these effects, and it is hence natural to try non-deterministic or statistical approaches to solve surface drift problems.

In the present study, the hyper-ensemble approach developed in Rixen and Ferreira-Coelho (in press) is applied: (1) to forecast at short time scale surface drifts from combined atmospheric ocean, wave models and local drifter observations in the Adriatic during a "Bora" event that occurred in February 2003, a wind responsible for deep water formation in the area in winter (*e.g.* Signell et al., 2005); and (2) to derive uncertainty/probability areas for drifter positions. Data, models and the hyper-ensemble methodology are detailed in Section 2. Results are presented in Section 3 and conclusions are drawn in Section 4.

2. Data and models

2.1. Data — drifters

Lagrangian drifters provide a broad basin-scale coverage of mesoscale surface circulation and surface temperatures to study the movement of water masses (*e.g.* Kovacevic et al., 1999; Poulain et al., 2003). Typical drifters that track the top one-meter of the ocean surface show excellent coupling to the surface layer and exhibit little wave rectification. During field experiments ADRIA02 and ADRIA03 with the R/V ALLIANCE between fall 2002 and spring 2003, some 144 drifters were launched in the Adriatic, building the comprehensive database used in this study (Fig. 1).

2.2. The atmospheric, ocean and wave models

2.2.1. ROMS circulation model

To simulate near-surface ocean circulation, the Regional Ocean Modeling System (ROMS) version 2.1 was used. This model was selected because it has several features of potential benefit for the study of near-surface currents. The *s*-coordinate allows more flexibility than the sigma coordinate in specifying vertical grid spacing, allowing thin layers near the surface to have a more uniform thickness. In addition, version 2.1 contains the Generic Length Scale (GLS) mixing scheme of Umlauf and Burchard (2003), which can be configured with parameters that allow the model to represent the correct dissipation profile under strong wind driving with breaking surface waves. The model was configured in curvilinear coordinates with variable grid resolution ranging from 3 to 4 km in the northern Adriatic to 7–9 km in the southern Adriatic. The model was initialized in mid-September 2002 using *in situ* observations and driven with tides and no-gradient temperature and salinity open boundary conditions at the narrow entrance to the Adriatic Sea. Wind, air temperature, air pressure, cloud fraction, short-wave radiation and relative humidity were used from LAMI (see below) with sea surface temperature from ROMS to compute bulk momentum and heat fluxes using the COARE 2.6 algorithms. The model was run from September 17, 2002 to June 13, 2003, and output saved every 3 h. For further details on the model implementation, see Signell et al. (2005) and references therein.

2.2.2. LAMI model

LAMI (Limited Area Model Italy) is the Italian operational implementation of LOKAL MODELL, the limited area model originally developed by the German Meteorological Service (Deutscher WetterDienst, DWD) for meso/micro scale weather prediction and simulation developed by several European meteorological services belonging to COSMO (COnsortium for Small scale MOdelling). LAMI is managed by SMR-ARPA-EMR, UGM (Ufficio Generale per la Meteorologia, Italian Airforce) and Regione Piemonte. It has been operational since the beginning of 2001 at the CINECA supercomputing Centre in Bologna. It has a 7 km grid spacing and 35 vertical terrain-following levels. It is a fully compressible, non-hydrostatic 3D model in which initial and boundary conditions are obtained from the DWD global circulation model GME (Majewsky, 1998; Majewsky et al., 2002). LAMI gives output every 3 h and produces a 48-hour forecast daily. We therefore used forecast winds at 03, 06, 09, ... 24 h (00+03, 00+06,