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Assessment of ocean forecast models for search area prediction in the eastern Indian Ocean

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ABSTRACT

The following study describes a technique to improve maritime search area prediction by using consensus forecasting to quantify areas of higher probability within a model defined search area. The study included forecasting search areas for 45 five-day drifter tracks, each simulated independently using different ocean models (BLUElink, FOAM, HYCOM and NCOM) throughout 2012 in the eastern Indian Ocean, off the coast of Western Australia.

It was found that zones where all four model search areas overlapped (defined here as a consensus search area) were significantly smaller than those areas generated by any single model forecast. The average consensus search area was quantified to be up to 56.9% smaller at 24 h and 72.5% smaller at 120 h than the average single model search areas at corresponding times. However the average hit rate (the frequency that the drifter was contained within the forecast search area) for the consensus search area was reduced by up to 26.2% at 24 h and 52.8% at 120 h, when compared to average hit rates from single model search areas. This indicated that the four model consensus search area had a higher hit rate per unit of search area than any individual model search area. Hence if search resources were a limiting factor for a particular search effort, then search resources may be most effectively deployed by prioritising the effort initially to the smaller, four model consensus search area.

1. Introduction

Lagrangian stochastic particle trajectory models are widely used by search and rescue (SAR) agencies worldwide to forecast the potential drift and estimate the most likely search area for persons, craft or other objects adrift at sea. Sea surface currents and winds are required by particle trajectory models to represent the metocean conditions that an object adrift at sea may be subject to. Operational forecast, nowcast or hindcast currents (typically obtained from ocean models driven by ocean observing satellite measurements – including sea surface temperature and sea surface elevation) and winds (from atmospheric forecast models and measurements) are routinely used as input into SAR drift models to provide the required and best available environmental forcing (Spaulding et al., 2006; Breivik et al., 2013; Brushett et al., 2011).

There are currently several different ocean and atmospheric models available for the same given locations and timeframes, and hence it may be difficult for the SAR operator to determine which single ocean model (or atmospheric model) may perform best when being used as input into SAR drift models at a given location and timeframe. One forecast model may perform best in a specific location or at a certain time, but not do so well in another location or timeframe and hence it is important to have a number of models available operationally. Studies by King et al. (2010, 2011) investigated the use of multiple metocean datasets for operational drift prediction purposes. Where possible, self-locating datum marker buoys (SLDMBs) are routinely dropped in the vicinity of the LKP (last known position) during SAR incidents to ground truth the surface currents in the area, and hence can be used to continuously validate which ocean model may best replicate the surface currents during the incident (Breivik et al., 2013).

With the availability of several different ocean models, an ensemble forecast may be constructed by re-running the SAR drift model with each of the available individual ocean model forecasts, and combining the resulting forecast search areas from each of these SAR drift model runs into an ensemble or consensus forecast. This ensemble forecast can be used to provide an indication of the likely search

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areas based on each individual ocean model forecast, as well as an indication of areas where consensus between the ocean models may have been achieved (where two or more ocean model search areas are in agreement with each other). The consensus areas may provide a higher confidence in the SAR drift model forecasts due to several independent ocean models predicting a similar outcome, compared to the areas where there was no consensus evident.

To date there has not been any comprehensive research in the application of consensus forecasting to search and rescue modelling. Brushett et al. (2011) undertook preliminary investigations into the use of multiple metocean datasets combined into an ensemble or consensus forecast to predict the trajectory of a drifter deployed during operational oil spill response, focussing on six ocean models and two wind models (thus generating an ensemble of 12 combinations). The concept of consensus forecasting to prioritise search areas has not been extensively investigated, and as such one of the aims of the present study is to assess whether there may be potential benefits to be gained from implementing consensus forecasting to SAR drift forecasting on an operational basis.

The present study investigated the use of a search and rescue particle trajectory model (SARMAP) to predict the 5-day trajectories (and resultant search areas) of 45 Surface Velocity Program (SVP) drifters off the coast of Western Australia during 2012. The SAR drift model used ocean currents and winds provided by ocean models and an atmospheric model, to provide the required environmental forcing. Each of the 5-day drifter trajectories was independently simulated with SARMAP using GFS model winds and each of the four available ocean current models (BLUElink, FOAM, HYCOM and NCOM). The above process was repeated for four independent experiments. The horizontal dispersion coefficient (K) was changed between each experiment, with values of 1000 m^2/s, 100 m^2/s and 10 m^2/s being used for experiments 1–3 respectively, to ascertain the effect the horizontal dispersion coefficient had upon the drifter forecasts. A fourth experiment provided a single deterministic solution, where no horizontal dispersion was included in the model simulations.

There were several key objectives to address in this paper. The first included determining which ocean model was the most reliable (i.e. ability to replicate an object's drift), during the study period and within the study domain, from the four ocean models available. The second objective was to test three different horizontal dispersion parameters used within the SAR drift model and quantify their respective average distance errors (the distance between the modelled drifter and the actual drifter), hit rates (the frequency that the drifter was located within the model search area), and the average size of their search areas. The third objective was to utilise all four ocean models in a single ensemble forecast, to quantify if there was an improvement in defining the forecast search area over using a single ocean model.

2. Data and models

The following sections contain an outline of the study domain (Section 2.1), an overview of the SVP drifters (Section 2.2), the details of the SAR drift model, known as SARMAP (Section 2.3), and a summary of each of the environmental forecast models (forecast currents and winds) that were used as input for SARMAP (Section 2.4).

2.1. Study domain

The spatial domain for the study extended from the Western Australian coastline offshore into the Indian Ocean (refer to Fig. 1). A review of AIS (Automatic Identification System) vessel track data revealed the region of interest contained shipping routes with higher vessel traffic compared to surrounding areas (Australian Maritime Safety Authority, 2013). Search and rescue incident data (National Search and Rescue Council, 2012, 2013) indicated a high density of SAR incidents within this area, possibly due to the higher density of vessel traffic. A review of the status of the SVP drifters in the Global Drifter Program (GDP) from NOAA (National Oceanic and Atmospheric Administration) during 2012 indicated that there were a sufficient number of drifters with drogues attached (45) distributed throughout the domain to conduct the study. Fig. 1 shows the study domain (light grey shaded area), the SVP drifter tracks used for the study (thick black lines represent the 5-day tracks from the 1st to the 5th of each month and dark grey lines represent the 5-day tracks from the 6th to the 10th of each month), and other SVP drifter tracks within the area (thin light grey lines), some with and some without drogues attached. The start dates of the 1st and the 6th of each month were arbitrarily selected to ensure that no selective sampling of drifter tracks took place. Note that not all of the other SVP drifters within the study domain (indicated by thin grey lines) had their drogues still attached; many of the drifters in the region were missing their drogues and hence were deemed not suitable to be used for the present study.

2.2. SVP drifter details

Drifters from the Global Drifter Program (GDP), previously known as the Surface Velocity Program, have been measuring the upper ocean circulation since the first deployments of modern holey sock drogues in 1979 (Lumpkin and Pazos, 2007). SVP drifters (with drogues nominally centred at 15 m) have been used extensively worldwide as a means to measure the physical properties of the surface layer of the ocean, including temperature, current velocity and later barometric pressure at the sea surface.

The quality controlled SVP drifter data for January to September 2012 was collected from the online historical and near real time database (National Oceanic and Atmospheric Administration, 2014) run by NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML), Physical Oceanography Division (PHOD). The drifter data was available as either near real time raw data (which is temporally disparate and not quality controlled) or historical quality controlled kriged data where the drifter positions are temporally and spatially interpolated to regular 6 hour time intervals and associated positions (Lumpkin and Pazos, 2007).

The drogue on/off status for each of the drifters within the chosen spatial domain was examined, and only drifters with drogue still attached were used for this study. This ensured that effects of wind (leeway drift) on the drifter were minimised as it was not a focus of this study, hence ensured that the drifter was moving predominately with the near surface ocean currents, as the study was intended to focus on the ability of the four different ocean current models to replicate the track of the drifters. Previous work by Niiler et al. (1995) indicate that SVP drifters with their drogues attached follow the near surface currents to within $\sim$1 cm/s (0.01 m/s) in up to 10 m/s winds, in the direction of the wind (downwind). This relates to a leeway speed of approximately 0.1% of the wind speed and a divergence angle of 0° (directly downwind). The low leeway speed indicates the SVP drifters move almost entirely with the ocean currents, and are very minimally influenced by the wind. Studies by Poulain et al. (2009) and Pazan and Niiler (2001) indicate that the leeway of SVP drifters which have lost their drogues (known as SVP-L) is approximately an order of magnitude larger than when the drogues are attached. The increase in leeway is due to the SVP-L drifters having minimal area submerged compared to the area exposed to the wind, resulting in a low drag area ratio (the ratio of the drogue area to the tether and float area), hence why they were excluded in this study which was intended to focus on the movement due to ocean currents only.

2.3. SARMAP drift model

The search and rescue modelling software SARMAP (Applied Science Associates, Inc., 2013; Spaulding et al., 2006) was utilised in