Preliminary assessment of the potential for particle trajectory modelling to support ocean search and rescue operations

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Abstract. Finding a person (or object) lost at sea is like looking for a needle in a haystack. The ability to provide more precise search area coordinates for rescuers to conduct their searches will help optimise search and rescue operations. A particle trajectory model for at sea search and rescue applications is presented. The model incorporates the effects from wind, surface currents, as well as stochastic diffusivity in order to determine the horizontal trajectory of each virtual particle released. Two scenarios are presented based on real-life search and rescue scenarios which occurred along the coastline of South Africa. These scenarios demonstrate the abilities of the particle trajectory model in search and rescue operations for varying object types and in different regions of the Greater Agulhas System.

1. Introduction

Objects lost at sea are subject to forcing from ocean currents, winds and waves. How much an object is influenced by these processes depends on the object's characteristics. Each year numerous incidents, varying from ships sinking and colliding, recreational and professional marine activities and objects falling overboard, occur in the world's open oceans and in the coastal regions. In South Africa, a significant part of these incidents involves the National Sea Rescue Institute (NSRI) which, in 2017, conducted 1,050 rescue operations (NSRI, 2018). This resulted in the rescuing of 1,224 people and 2,723 hours of operational activity (NSRI, 2018). In order to reduce operation times and costs and to improve the overall quality of operations, several new and innovative techniques have been developed. In search and rescue operations, the focus is on estimating the search area based on a number of factors and computing the evolution of the search area over time (Breivik and Allen, 2008). These factors include physical forces that would act on an object such as winds, currents and waves. The complexity increases when computing the motion of different objects with varying shapes in the ocean (Breivik and Allen, 2008). Initial techniques looked at the current wind direction and magnitude, making a rough estimation on the position of the object based on the object type and position in the water column. The improved ability of numerical models to make estimations about the ocean state has resulted in these models being increasingly used to estimate the pathway of objects in the ocean. Several tools have been created to account for the type of object being tracked in order to better understand their drift (Breivik et al., 2011, Hart-Davis et al., 2018a). The tools presented in (Breivik et al., 2011, Hart-Davis et al., 2018a) independently combine the use of particle tracking and the leeway object divergence methodology presented in Chapter 5 of (Allen and Plourde, 1999). Lagrangian analyses of ocean fluids from virtual particles, advected with the background flow information from ocean models, have been increasingly used to study physical and biogeochemical oceanographic processes (van Sebille et al. 2018). The tool has broad and diverse application to a variety of objects (including persons) lost at sea, with great potential for optimising search and rescue operations in the future. Here we demonstrate the usefulness of using a virtual particle tracking tool forced with ocean and wind forecast data and adjusted for windage using empirical relationships provided by the NSRI to predict the trajectories of objects lost at sea in two separate scenarios.

2. Data and method

Particle Trajectory Model

Particle tracking is the observation of the motion of an individual particle within a fluid. Particle tracking uses a Lagrangian modelling framework that moves with the flow of the ocean and is particle specific instead of being point specific (MacDonald et al. 2006). In the case study presented here, a Lagrangian particle tracker known as Parcels ("Probably A Really Computationally Efficient Lagrangian Simulator") (Lange and van Sebille 2017) was used. Parcels is a virtual particle tracking tool aimed at exploring novel approaches for Lagrangian tracking of virtual ocean particles (Lange and van Sebille 2017). Parcels requires gridded velocity data to compute the Lagrangian trajectories of virtual particles. Here, virtual particles were forced using both ocean surface currents from the operational Mercator global ocean analysis and forecast system and global surface wind forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF). Additionally, the response of the virtual particles to winds, known as windage (u_{wind}), was incorporated based on wind drift tables made available by the NSRI. For the two case studies, the following windage parameters were used: Capsized Catamaran: u_{wind} x 0.04 and Rigid Inflatable Boat: (u_{wind} x 0.03) + 0.08.

Operational ocean current and wind forecasts

The operational Mercator global ocean analysis and forecast system provides 10-day 3D global ocean forecasts on a daily basis. This 3D product includes daily files of temperature, salinity, currents, sea level, mixed layer depth and sea ice parameters. It also includes hourly mean surface fields for sea level height, temperature and currents. The global ocean output files are available at a 1/12º horizontal resolution with regular longitude/latitude equirectangular projection and 50 vertical levels ranging from 0 to 5500 meters. The ocean model is forced using winds from the ECMWF (European Centre for Medium-Range Weather Forecasts) Integrated Forecast System, which are also the winds used to account for the wind drift of the virtual particles. The ocean current data are available from the Copernicus Marine Environment Monitoring Service.

The ECMWF produces operational ensemble-based analyses and predictions that cover time frames ranging from medium-range, to monthly and seasonal, and up to a year ahead. These are available to its Members and the Co-operating States, as well as through licenses via the World Meteorological Organization (WMO) and the academic and commercial sectors. The South African Weather Service routinely receives these forecast data. Here, the 3-hourly 1/10º wind forecasts 10m above the ocean surface are averaged to daily mean winds and interpolated to the 1/12º Mercator ocean forecast grid to obtain consistent spatio-temporal resolution between the ocean and wind forecasts products used to advect Parcels.

Case studies

Capsized Catamaran

On 14 December 2014 Anthony Murray (58), Reginald Robertson (59) and Jaryd Payne (a 20-year-old first-time sailor) set sail from Cape Town to deliver a luxury catamaran (a Moorings A5130, Sunsail RC044-978) to Phuket, Thailand. Tragically, they were last heard from on 18 January 2015 approximately 2190 Nautical Miles north-west of Perth, Australia, and after multiple attempts to establish their whereabouts, the catamaran was reported missing by the Maritime Rescue Coordination Centre (MRCC) in Cape Town on 11 February 2015 and the search and rescue activities were officially closed on 15 May 2015. Approximately 1 year after the search was called off, on the 18th of January 2016 a Brazilian Navy Ship, Amazonas, spotted the upturned hull approximately 113 Nautical Miles off Cape Recife, near Port Elizabeth, South Africa. 5 days later on 22 January 2016, the National Sea Rescue Institute (NSRI) found the capsized catamaran south of Cape Agulhas. Unfortunately, while the tug, the Peridot, was towing the capsized catamaran back to Cape Town, the tow line broke (due to adverse sea conditions) and the catamaran was lost.

However, the approximate locations of the vessel being spotted off Cape Recife (25° 41' 59.46"E and 34° 24' 11.08"S) and being found off Cape Agulhas (20° 07' 32.58"E and 35° 01' 31.94"S) provide a good case study to test the application of virtual particle tracking tools in search and rescue applications.

Rigid Inflatable Boat

At 17h03 on the 4th of June 2019, the NSRI were activated following reports of a vessel that had lost power within False Bay in Cape Town, South Africa.

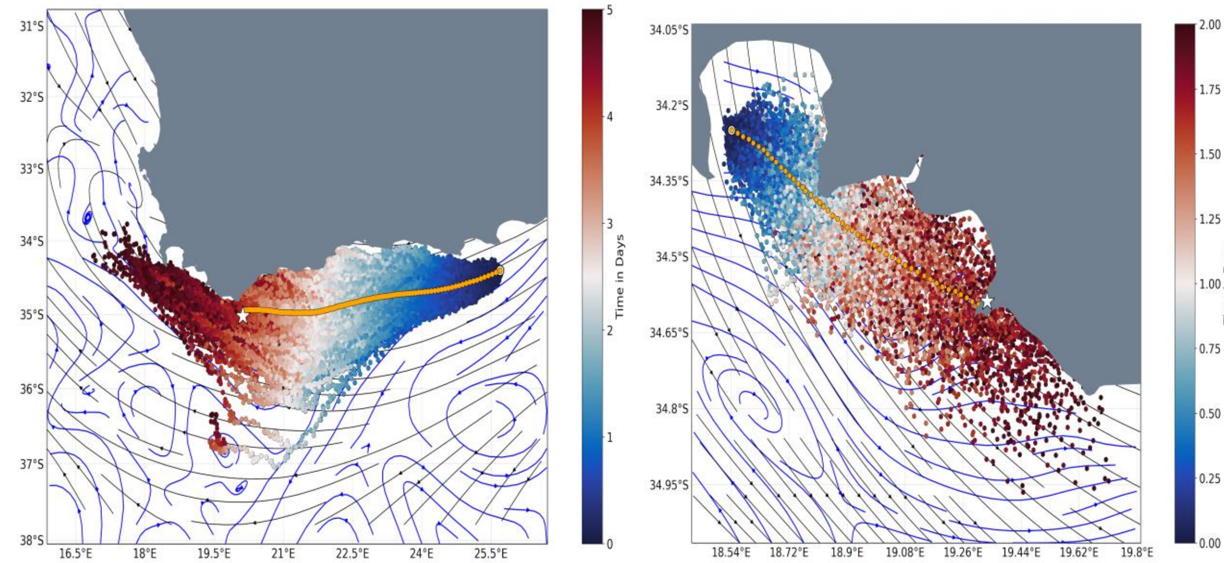

Figure 1: A simulation of 1000 virtual particles deployed at the location where the (left) capsized vessel and (right) rigid inflatable boat were last seen (white circle). The color bar represents the time in days since deployment of the virtual particles. The orange dots represent the mean trajectory of the 1000 particles with the white star indicating the position where the objects were eventually found. The black and blue contours respectively represent the mean winds and surface currents over the period for which the particle trajectory model was run.

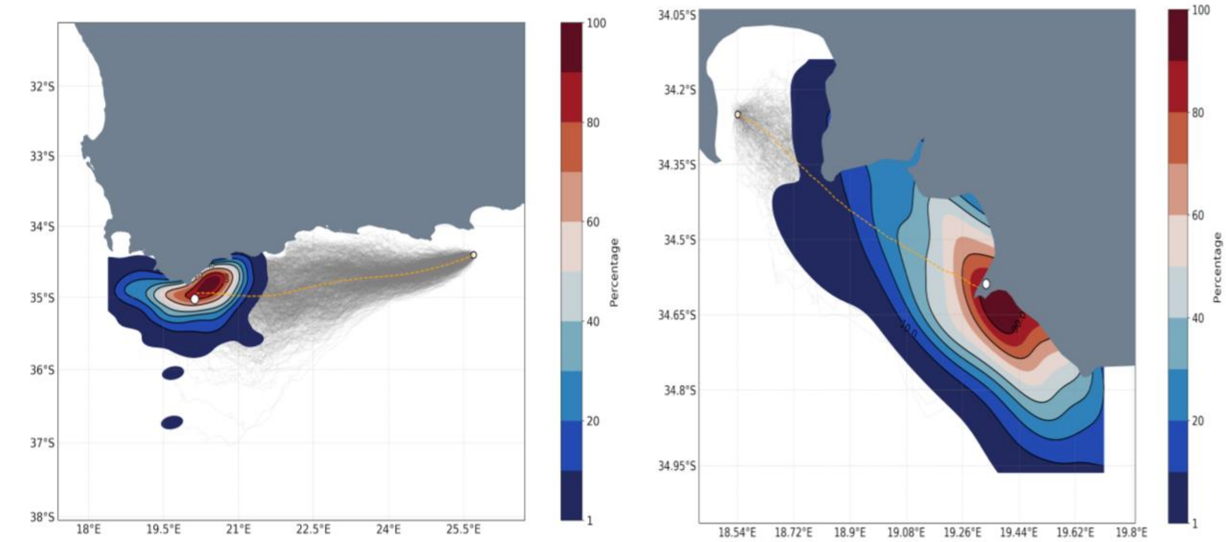

Figure 2: Density plots of the final position of the virtual particles. The grey lines represent all the trajectories of the 1,000 virtual particles, with the orange line representing the mean trajectory.

The vessel was a five-meter rigid inflatable boat that was last seen near Roman Rock, at 34° 10' 48'S and 18° 27' 36"E, with an unknown number of people on board. After an extensive search in strong winds and heavy seas, the vessel was later recovered almost two days later on the south coast near a beach known as Gaansbaai (19° 20' 05.11" E / 34° 35' 19.14"S). The complexity of this scenario due to the vessel containing sailors on board as well as due to the heavy sea conditions provides an extremely challenging scenario to assess the ability of the particle trajectory model in real-life scenarios.

3. Results

The particle trajectory model was used in two different search and rescue scenarios to assess its ability in estimating the trajectory of objects lost at sea. For each scenario, one thousand virtual particles were deployed at the location where the object was last seen (Figure 1). Each virtual particle, incorporated windage to account for the characteristics of the object (capsized vessel and inflatable boat respectively) following the Leeway approach presented in Allen and Plourde (1998). The virtual particles were deployed for the duration that the object was lost at sea and the particles were forced by the Copernicus surface current data and ECMWF 10m wind product. In each scenario, the effects of stochastic motion were applied to the virtual particles to account for the unresolved physical process not present in the forcing data (van Sebille et al 2018). Figure 1 shows the trajectories of all virtual particles deployed for both case studies. The orange dots represent the mean of all trajectories and the stars indicate the position where the two objects were eventually located by the NSRI. Additionally, the mean currents and winds for the duration of the simulation experiments with Parcels are overlaid. It is evident from these figures that wind plays an important role in determining the trajectories of the virtual particles. The parameterised stochastic motion accounting for sub-grid scale effects is responsible for the spread of the trajectories. Calculating the mean of these and taking into consideration the position where the two objects were found, highlights the importance of adding stochastic motion to the virtual particles in terms of determining accurate search area coordinates. Using the data from the 1,000 virtual trajectories, one can calculate the density of the particles for each time step and contour these on a map. Figure 2 shows the density of the virtual particles in percentage of the total particles deployed for both case studies. The areas outlined by, for example the 90% contour, indicate regions where virtual particles accumulate. This information could be used to inform search and rescue operations in terms of optimising their search efforts to those regions.

4. Discussion and Conclusion

It is shown that, by incorporating wind and surface current data into the particle trajectory model, the model predicts the drift of the two different objects to a reasonable degree of accuracy. Incorporating the impacts of stochastic motion into the model facilitates a spread of trajectories (Figure 1 & 2). By then calculating the mean trajectory and density distribution of the virtual particles (Figure 2) highlights the ability of the particle trajectory model to estimate the location where the objects were found with a relatively high degree of confidence. There remains scope for improvement however, in particular the global wind and ocean forecast models used in both scenarios are not optimised for regional or near coastal applications, the latter requires careful downscaling to the requisite fine coastal scales (Kourafalou et al., 2015). Despite this the test cases demonstrate the need to combine both wind and ocean currents correctly when simulating trajectories of different types of objects lost at sea. Moreover, the application demonstrates skill in open ocean as well as near coastal environments under different dynamical ocean conditions, despite limitations in the global reanalysis and forecast products used to force the particle trajectory model. Addressing limitations of the global reanalysis and forecast products, this study highlights the importance of using appropriate parametrization for sub-grid scale processes when using these data to force particle trajectory models applied to search and rescue. Additionally, accurate positions of the objects' initial conditions (in time) is a critical factor. Future work to further improve the accuracy of the application includes adding tidal currents, Stokes drift, as well as incorporating improved drift responses of different objects, taking into consideration both ocean currents and winds. Furthermore, integration with traditional search and rescue workflows will further enhance support for search and rescue operations.

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