FINAL

Parlee Beach and Shediac Bay
Hydrodynamic Modelling Study
New Brunswick

Submitted to:

Department of Health, New Brunswick
520 King Street, Carleton Place
Fredericton, New Brunswick, E3B 5G8

Submitted by:

Amec Foster Wheeler Environment & Infrastructure
a Division of Amec Foster Wheeler Americas Limited
50 Troop Avenue, Unit 300
Dartmouth, NS B3B 1Z1

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1.0 INTRODUCTION

Amec Foster Wheeler has prepared the following desktop modelling study of hydrodynamics and pollutant transport near Parlee Beach and Shediac Bay, NB, to support the New Brunswick Department of Health in determining how bacteria are transported through the coastal environment, and thus to assist in identification of potential sources.

Previous studies of coastal circulation and transport patterns, by Henderson Environmental Consulting Ltd. And Coastal Ocean Associates Inc. (September, 1999), have characterized potential transport patterns due to astronomical tidal forcing, therefore the applicability of the conclusions has been limited to calm wind and wave conditions. The present study aims to assess the potential pollutant transport patterns for a wider range of atmospheric forcing conditions, through the development and implementation of a coupled hydrodynamic and wave model, forced by wind inputs from a wide range of possible directions.

The available historical and hindcast data from the coastal ocean area near Shediac Bay includes tide gauge stations in Shediac Bay and at Cap de Caissie, as well as regional tidal constituent databases, as well as wind and wave hindcasts. Further available datasets include bathymetric surveys by the Canadian Hydrographic Service, with varying spatial resolution over different areas. Current meter data was not available in the project area.

Figure 1-1 Historical tide gauge stations used for model validation

1.1 Study Objectives

The hydrodynamic and pollutant transport modelling study for Parlee Beach and Shediac Bay was guided by two main objectives:

1. Develop and implement a numerical ocean model that will enhance understanding of the coastal circulation patterns in Shediac Bay and near Parlee Beach due to the combined influence of tides, winds and waves.
2. Model potential pollutant trajectories of particles and dissolved plumes, to contribute to the investigation of potential initial sources.

The study objectives were accomplished by developing a coupled hydrodynamic and wave model of the coastal area around Shediac Bay and Parlee Beach, by using the Delft3D modelling suite.

1.2 Outline

The report is outlined as follows. The following Section 2.0 provides a summary of the wind and wave climatology in the study area, that forms the basis for defining the modelling scenarios. Section 3.0 summarizes the methodology used to develop and validate the hydrodynamic model of the coastal area around Shediac Bay, NB. Furthermore, modelling results are presented in Section 4.0, including an overview of the modelled ocean circulation patterns, as well as drogue and dissolved plume trajectories for a range of environmental forcing conditions. Finally, conclusions are presented in Section 5.0.

2.0 MET-OCEAN FORCING CONDITIONS

The ocean circulation and transport patterns in the study area are determined by the influence and interactions of astronomical tidal forcing (COA, 1999), as well as wind stress on the ocean surface, and finally by wave-generated currents in the shallow surf zone. The following section presents wind and wave climate statistics from the Meteorological Service Canada long-term wind and wave hindcast (MSC50), which are used to define meaningful and distinct forcing scenarios for the coupled hydrodynamic and wave model, with applied tidal and wind forcing. The MSC50 hindcast node M6010119 is located approximately 10 km northeast of Parlee Beach.

The MSC50 hindcast represents a robust and long term source of regional wind and wave statistics, from which the latest available 30-year record (1985-2015) is used to derive monthly statistics and frequencies of occurrence of distinct forcing conditions. The present study aims to characterize the ocean circulation for a wide range of frequently occurring conditions, with a particular focus on the mean conditions during the summer months, when water quality issues may pose a particular concern for seasonal users of Parlee Beach.

2.1 Wind Climate Statistics

The wind climate in the study area is characterized by a distinct seasonal cycle, with mean hourly speeds ranging from 4.5 - 4.8 m/s between May and August, to 7.7 – 8.3 m/s between November and January (Table 2-1). The seasonality of the wind conditions is also reflected in the distribution of wind directions (Table 2-2 and Figure 2-1), with southwesterly winds being the most frequent in the summer months (June – August), and northwesterly winds being the most frequent in the winter and early spring months (December - April).

While southwesterly winds are the most frequent during the summer months, occurring between 21-29 % of the time between June and September, southerly winds (16.5-25.9 % during those months) and westerly winds (13.1-18.4 %) are also very frequent, followed by northwesterly and southeasterly winds. By comparison, winds from the north, northeast and east directions occur relatively less frequently, with each wind direction occurring less than 10% of the time during these months.

In order to represent average seasonal conditions applicable most of the time in the study area, the average annual wind speed value of 6 m/s was selected for use in the model scenarios, in combination with 8 discrete wind directions spanning the entire directional range.

Table 2-1 Monthly wind statistics for MSC50 node M6010119 (1985-2015) near Shediac Bay.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean hourly speed [m/s]	7.9	6.8	6.5	5.9	4.8	4.5	4.5	4.7	5.8	7	7.7	8.3	6.2
Std. Wind Speed [m/s]	3.1	3	2.9	2.7	2.3	2.1	1.9	2.1	2.4	2.7	2.9	3	2.9
Most frequent Direction from	NW	NW	NW	NW	S	SW	SW	SW	SW	W	W	NW	W
Max. hourly speed [m/s]	21.7	20.2	21.7	19.3	16.3	13.1	21.8	19.8	21	22	19.9	21.8	22
Direction of max. hourly speed from	NW	W	NE	W	SE	S	W	S	SE	N	NW	N	N

Table 2-2 Monthly frequency distributions of wind directions from the MSC50 hindcast near Shediac Bay.

Wind Direction From	N	NE	E	SE	S	SW	W	NW
January	9.2	6.1	4.2	5.2	8.1	12.2	27.4	27.5
February	13	7.1	6	5	7.1	12.1	22.7	27
March	15.6	9.9	5	6.3	11	12.6	18.6	20.9
April	15	11.9	9.2	9.7	12.2	11.5	15.1	15.4
May	11.6	12.4	8.8	11.1	18.8	16.3	10.7	10.5
June	7.4	8.8	7.8	11.5	19.8	21.4	13.1	10.3
July	4.6	3.1	4	8.9	25.9	28.7	16.4	8.4
August	6.9	4.6	5.1	7.4	19.5	28.6	16.7	11.1
September	9.6	4.6	4.3	7.2	16.5	22.9	18.4	16.6
October	10.2	7.5	6	7.8	11.9	16.8	21	18.8
November	10.9	6.6	5.2	7.1	11.2	14.5	22.6	22.1
December	10.3	6.9	5.6	5.8	8.2	12.3	23.5	27.5
Year	10.3	7.4	5.9	7.8	14.2	17.5	18.8	18

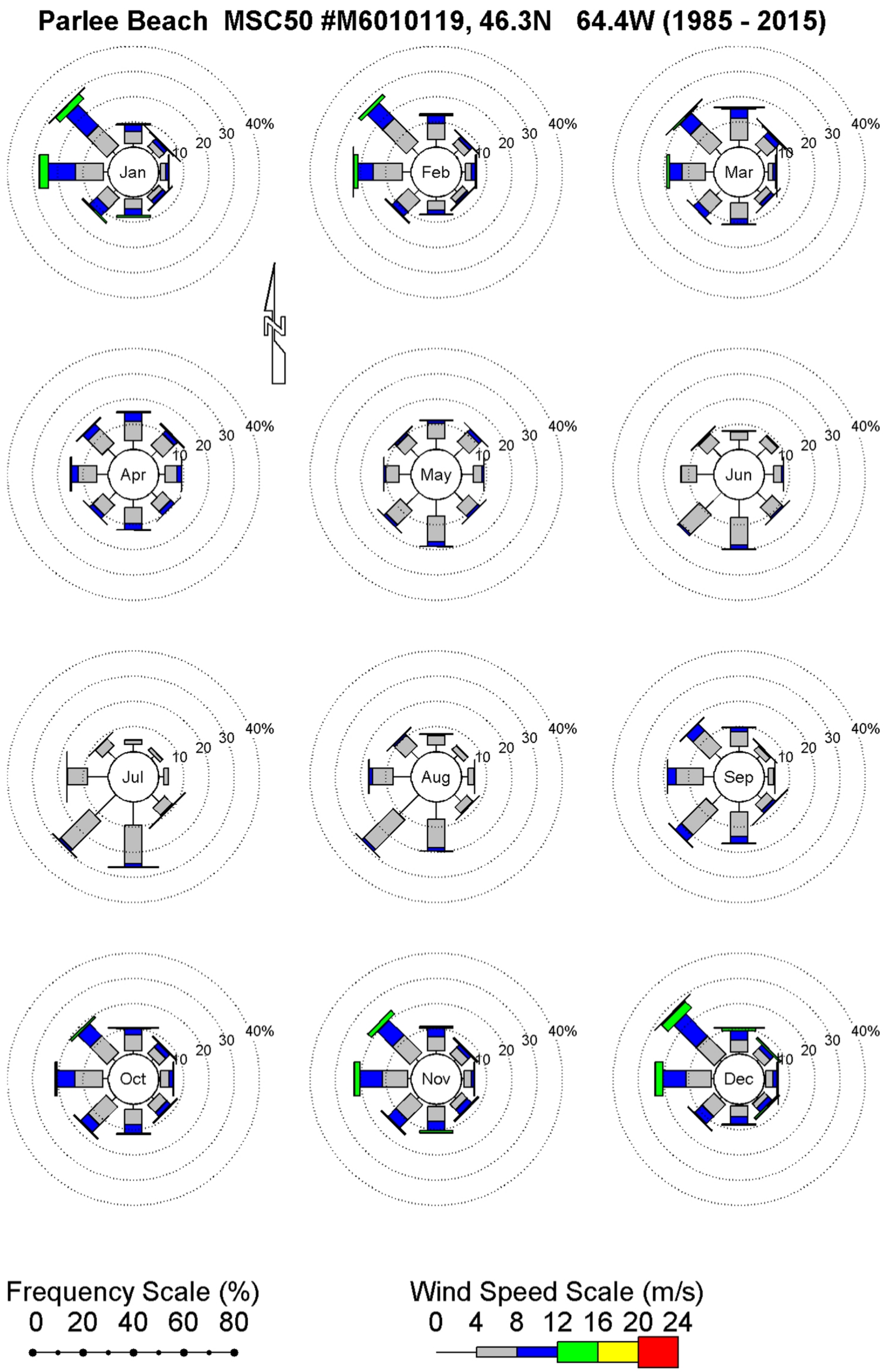

Figure 2-1 Monthly wind direction distributions from the MSC50 hindcast node near Shediac Bay.

2.2 Wave Climate Statistics

The wave climate in the study area is characterized by relatively low mean significant wave heights, ranging from 0.1 m in February to 0.6 m in November, and 0.2 m through June, July and August (Table 2-3). The most severe sea states, occurring relatively infrequently, exhibit significant wave heights of up to 2.6 m, with a characteristic wave period of up to 6.2 s. Therefore the study area is subjected to relatively low energy wave forcing from the offshore in the Northumberland Strait, and the locally wind-generated waves are expected to play a significant role in determining the local wave conditions in Shediac Bay and in the vicinity of Parlee Beach.

The incident wave direction at the hindcast node offshore from Parlee Beach is most frequently from the north during the months of April to September, and from the northwest during October – March, with the exception of July when the most frequent direction is from the south. Other relatively frequent incident wave directions in the summer months are from the southeast and south (Figure 2-2).

In order to represent average seasonal conditions applicable most of the time in the study area, the average significant wave height value of 0.3 m was selected for use in the model scenarios, in combination with characteristic wave periods of 4s, and discrete wave directions that are either aligned with the wind, or otherwise represent the most frequent direction.

Table 2-3 Monthly wave statistics for MSC50 node M6010119 (1985-2015) near Shediac Bay.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean Hsig [m]	0.1	0	0.1	0.2	0.3	0.2	0.2	0.2	0.4	0.5	0.6	0.5	0.3
Std. Hsig [m]	0.2	0.1	0.2	0.3	0.3	0.3	0.2	0.2	0.3	0.4	0.4	0.5	0.4
Most frequent direction from	NW	NW	NW	N	N	N	S	N	N	NW	NW	NW	NW
Mean Tp [s]	0.4	0.1	0.4	1.6	2.3	2.1	2	2.2	2.8	3.4	3.6	2.6	2
Max. Hsig [m]	1.7	1.7	2.5	1.9	1.8	1.5	2	1.7	2.3	2.6	2.3	2.6	2.6
Direction of Max. Hsig from	SE	N	NE	N	E	N	SE	SE	E	N	N	N	N
Tp of max Hsig [s]	5.5	5.3	5.7	5.5	5.5	5.1	5.9	5.3	6.1	6.2	6	6.2	6.2
Max. Tp [s]	6.4	5.4	6.4	7.6	11.8	6.9	6.6	6.7	7.7	6.3	6.1	6.3	11.8

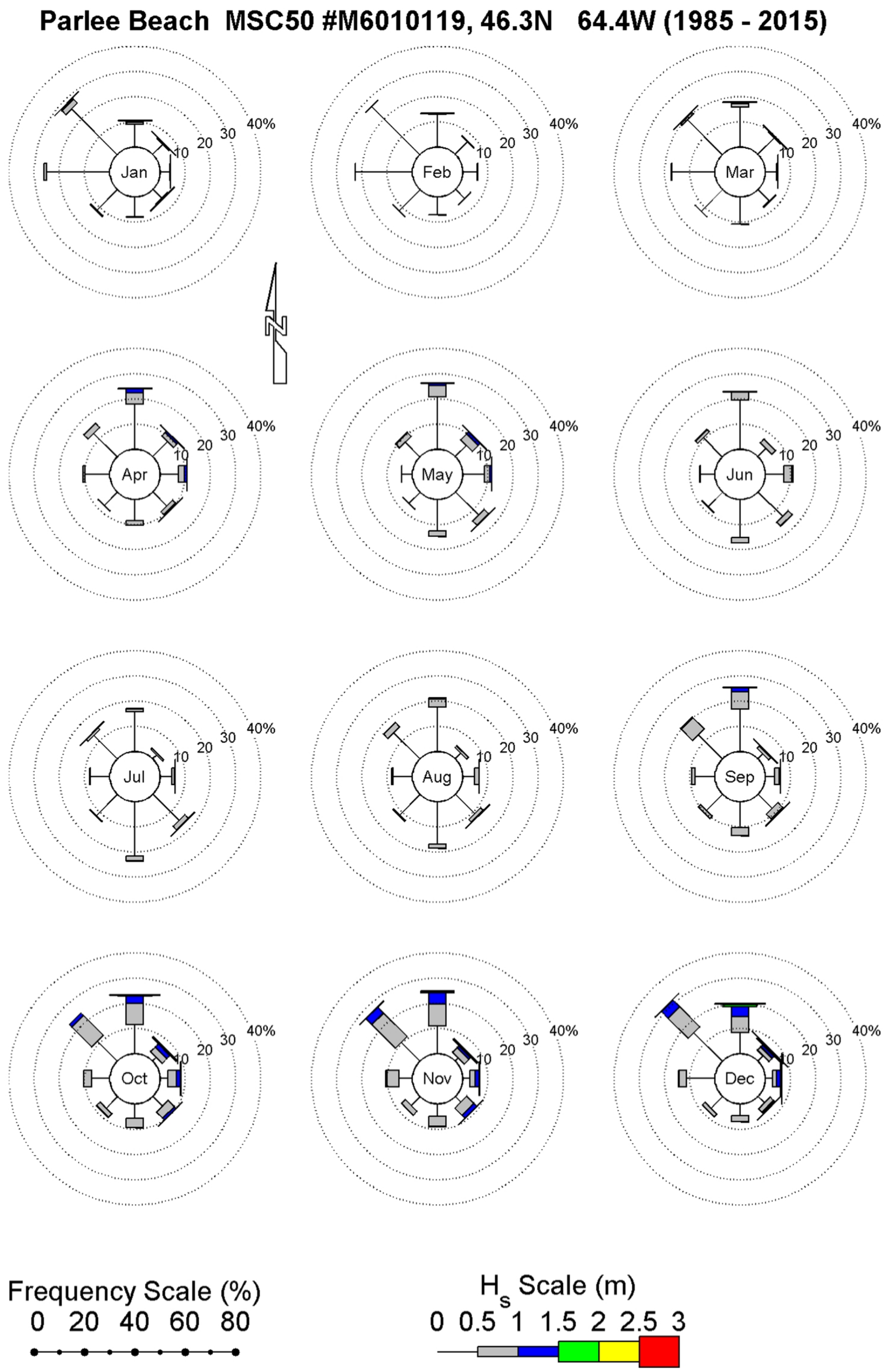

Figure 2-2 Monthly wave direction distributions from the MSC50 hindcast near Shediac Bay.

3.0 MODELLING METHODOLOGY

Amec Foster Wheeler has developed a coupled hydrodynamic and wave model of the coastal ocean encompassing Shediac Bay and the coastal areas to the east and north, including Parlee Beach, using the comprehensive Delft3D modelling suite by Deltares. The Delft3D suite consists of a highly-integrated set of modules to compute water levels and ocean currents by using the shallow water equations, as well as to employ the advection-diffusion equations for computations of dissolved and particulate tracers. The hydrodynamic model is coupled with the third-generation spectral wave model SWAN (Simulating Waves in the Nearshore), which provides the capability to simulate the local wave conditions due to offshore incident waves combined with locally wind-generated waves, as well as provide wave forcing terms to the hydrodynamic model. These features make the Delft3D suite an ideal platform for coastal ocean studies of potential pollutant transport for idealized or historical conditions, that could support the investigation of likely sources of contamination for a given geographic location.

3.1 Delft3D Hydrodynamic and Wave Model Setup

The design of the Delft3D hydrodynamic model grid was guided by considerations of the complex coastline and ocean circulation features inside and adjacent to Shediac Bay, characterized by large areas with depths shallower than 2 m, as well as the propagation patterns of different tidal components within Northumberland Strait. The circulation in this area is driven by the interaction of relatively weak tidal forcing with the wind and wave forcing over the relatively shallow coastal zone. In order to resolve the resulting circulation patterns, the model domain was extended to include the wider coastal zone approximately 15 km east and 10 km north of Shediac Bay. The domain was also extended over approximately 10 km in the offshore direction (Figure 3-1). The computational grid for the wave module is largely overlapping with the hydrodynamic model grid, with additional lateral span in the north and east directions of about 10 km, in order to provide continuous coverage of wave conditions for the hydrodynamic model.

In order to capture the complexity of the coastal ocean features, as well as to optimize computational efficiency, a curvilinear computational grid was developed with a variable horizontal resolution of the order of 100-200 m in the deeper offshore areas, and approximately 40-60 m in Shediac Bay and the vicinity of the Parlee Beach (see Figure 3-2).
The model bathymetry and topography were developed using several sources as follows:

1. Canadian Hydrographic Service: high resolution multibeam datasets, combined with intermediate and lower resolution single-beam datasets. The multibeam bathymetry datasets were considered of the highest quality and were used preferentially in the relatively limited areas of coverage, primarily in the area southeast of Shediac Island.
2. Canadian Hydrographic Service: electronic navigational charts in S57 vector format. These datasets were considered to provide the best representation of the contours delineating the coastline and extent of the shallow tidal flats, where survey data are very sparse. Ad-hoc interpolation was applied in these areas, largely based on the contours in the navigational charts.
3. USGS: Shuttle Radar Topography Mission (SRTM) 30 m DEM, used to cover land areas, and provide a more robust basis for triangular interpolation along the coastline areas.

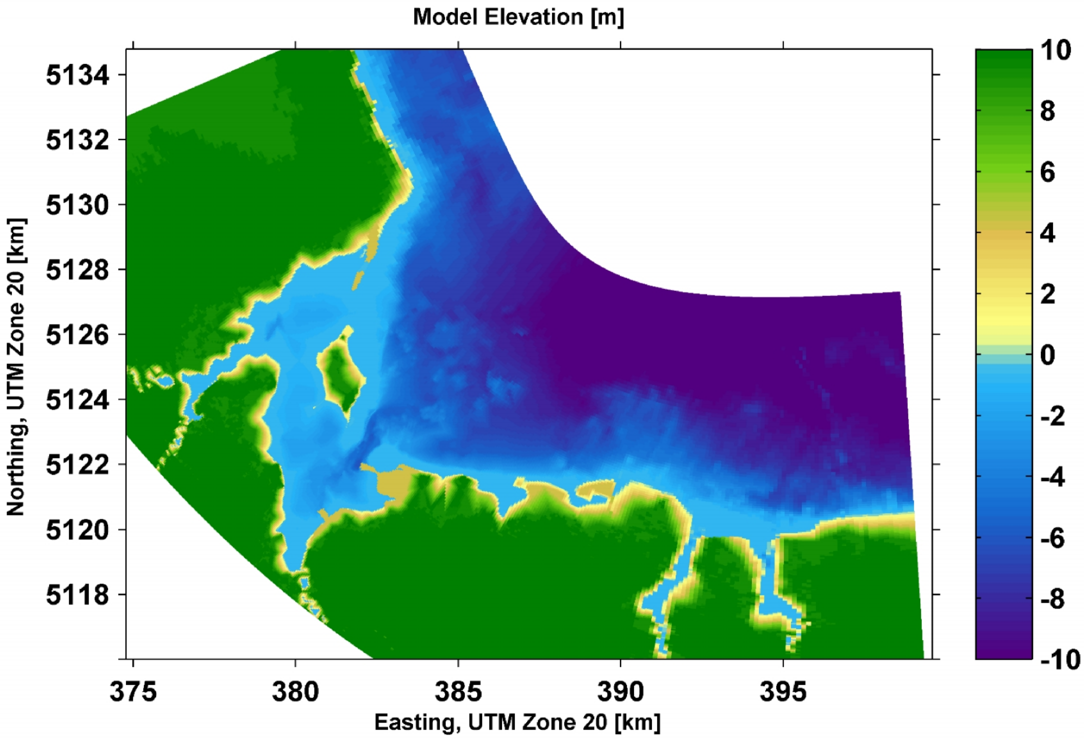

Figure 3-1 Bed elevation in the Delft3D hydrodynamic model

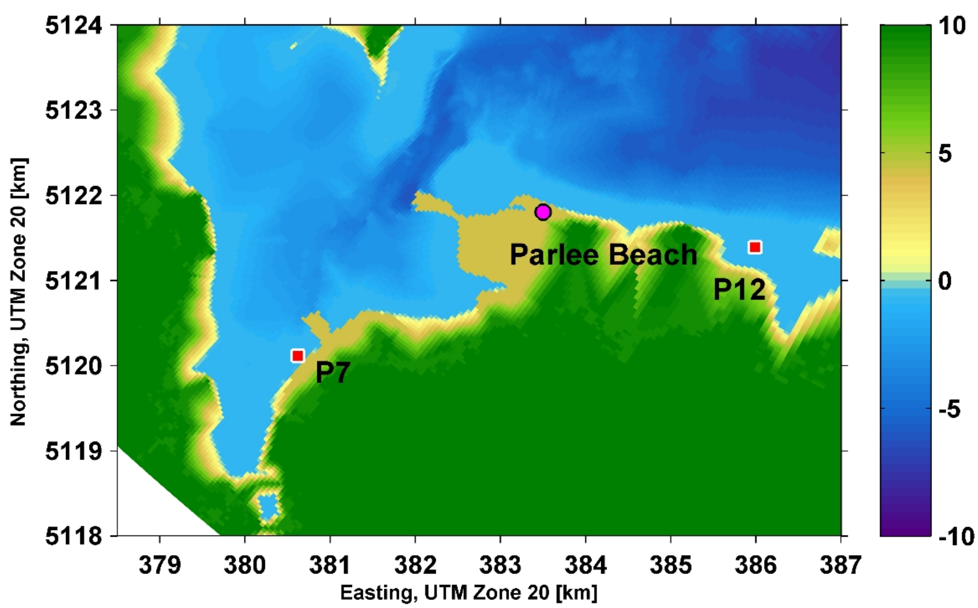

Figure 3-2 Bed elevation in the Delft3D hydrodynamic model in the vicinity of Parlee Beach and the southern part of Shediac Bay. The red square markers indicate the locations of the two hypothetical dissolved pollutant sources.

The hydrodynamic model was forced with tidal boundary conditions at the three open boundaries, with harmonic tidal water level boundary conditions prescribed for the offshore boundary, and harmonic water level gradient (Neumann) boundary conditions prescribed for the two lateral boundaries at the north and east of the model domain. The astronomical tidal constituents for the boundary conditions were derived from the WebTide model (Northwest Atlantic mesh) by Dupont et al. (2002). The relatively minor freshwater discharges based on dry weather flows (COA, 1999) by the Shediac River (0.5 m^3/s) and Scoudouc River (0.4 m^3/s) were also included in the model.

The hydrodynamic model was allowed to run for periods of 1 week in all cases to allow the gradual spinup under tidal and atmospheric forcing, before any drogues or dissolved pollutants were released. The model was set up in depth-averaged mode, assuming a fully vertically mixed layer, using standard seawater properties, and a time step based on the limits for horizontal advection of 0.5 minute.

3.2 Delft3D Tidal Model Validation

The performance of the Delft3D hydrodynamic model was evaluated based on the available historical tide gauge datasets at two stations in the Fisheries and Oceans Canada tides, currents and water levels database:

- Shediac Bay (Station 1805)
- Cap de Caissie (Station 1810)

The comparison of modelled and observed water levels was made based on the constituents derived from a harmonic tidal analysis of the historical data and model output at the given locations. The harmonic tidal analysis was performed by using the UTide Matlab toolbox by Codiga (2011), for the three main dominant constituents accounting for approximately 97 percent of the tidal variability: M2, K1, and O1.

The comparison between observed and modelled harmonic tidal constituents, shown in Table 3-1, indicates that the model resolves the tidal propagation well, with consistently good matches between model and observations both in terms of the tidal amplitudes and phases. While current data were not available for further site-specific validation, these findings indicate that the model captures the dynamics of the system well, and they further provide validation of the computational grid setup, the overall quality of the bathymetry data, as well as the choice and implementation of the boundary conditions.

Table 3-1 Comparison of modelled and observed tidal constituents near Shediac Bay, NB.

Shediac Bay			
Constituent	**M2**	**K1**	**O1**
Amplitude Model [m]	0.175	0.231	0.235
Amplitude Obs [m]	0.186	0.229	0.235
Amplitude Difference [m]	**-0.010**	**0.001**	**0.000**
Phase Model [deg]	37.134	318.725	286.888
Phase Obs [deg]	62.240	337.169	285.475
Phase Difference [deg]	**-25.105**	**-18.444**	**1.413**
Cap de Caissie			
Constituent	**M2**	**K1**	**O1**
Amplitude Model [m]	0.145	0.227	0.231
Amplitude Obs [m]	0.134	0.188	0.227
Amplitude Difference [m]	**0.011**	**0.039**	**0.004**
Phase Model [deg]	28.562	316.674	285.015
Phase Obs [deg]	51.735	314.915	283.188
Phase Difference [deg]	**-23.173**	**1.759**	**1.826**

3.3 Model Scenario Definitions

In order to characterize the widest range of average conditions contributing to the transport in Shediac Bay and the vicinity of Parlee Beach, eight distinct atmospheric forcing scenarios were defined, in combination with the tidal forcing, summarized in Table 3-2. Due to the relatively low mean wave heights incident from the offshore, it is expected that the locally wind-driven generated wave properties will contribute significantly to the surf zone circulation, and therefore the scenarios are defined primarily to span the full range of wind directions at 45 degree intervals.

In all cases, the offshore wave condition was prescribed at the outer model boundaries, but the wave model was allowed to grow wind-generated waves to the fully developed sea state, based on the fetch available for the given wind direction. In most cases the wave direction was prescribed to be roughly aligned with the winds, except when the winds were from the direction of the land (southwesterly and southerly), where offshore waves were prescribed as northerly, representing the most frequent offshore wave direction.

Table 3-2 Summary of modelled scenarios of hypothetical pollutant dispersion near Parlee Beach, NB.

Modelled Scenarios		
Scenario ID	**Wind Condition**	**Offshore Wave Condition**
1. Northwesterly Winds	6 m/s from 315 deg	Hsig = 0.3 m, Tp = 4s, Dir = 315 deg
2. Westerly Winds	6 m/s from 270 deg	Hsig = 0.3 m, Tp = 4s, Dir = 315 deg
3. Southwesterly Winds	6 m/s from 225 deg	Hsig = 0.3 m, Tp = 4s, Dir = 0 deg
4. Southerly Winds	6 m/s from 180 deg	Hsig = 0.3 m, Tp = 4s, Dir = 0 deg
5. Southeasterly Winds	6 m/s from 135 deg	Hsig = 0.3 m, Tp = 4s, Dir = 90 deg
6. Easterly Winds	6 m/s from 90 deg	Hsig = 0.3 m, Tp = 4s, Dir = 90 deg
7. Northeasterly Winds	6 m/s from 45 deg	Hsig = 0.3 m, Tp = 4s, Dir = 45 deg
8. Northerly Winds	6 m/s from 0 deg	Hsig = 0.3 m, Tp = 4s, Dir = 0 deg

Since the present study is considering hypothetical releases of dissolved pollutants and drogues for a wide range of possible conditions, the eight scenarios were modelled with constant wind and wave conditions over periods of a week following the release of the materials, to assess the distinct patterns of advection and dispersion for each condition. However it is noted that for any given historical period, the conditions over periods of several days are likely to vary and produce a combination of the distinct patterns identified in the present study.

Hypothetical pollutants were released at two locations, approximately 3.5 km east of Parlee Beach, as well as approximately 3.5 km southwest of Parlee Beach (within the southernmost area of Shediac Bay). The two pollutants were distinct for each source and tracked separately, with discharges occurring over a 24 hour period, with nominal discharge rates of 0.01 m^3/s, and nominal pollutant concentrations of 1 kg/m^3. The pollutants were conservative, without any decay, and therefore the resulting drop in concentrations over the period of days is due to the physical dispersion and dilution within the model.

In addition to the hypothetical dissolved pollutant sources, three sets of 25 drogues were released at three distinct time periods (hours 0, 6 and 12) during the 8th day of the simulation.

4.0 MODELLING RESULTS

The Delft3D model was run for a period of 2 weeks, with the first week representing the spin-up period for the model, while pollutants and drogues were released on day 8 of the simulations. Model results were saved at hourly intervals for the whole grid, and at 10 minute intervals at the Parlee Beach location. The results summarized in this section include descriptions of the resulting residual circulation, as well as drogue and plume transport patterns and relative nominal concentrations predicted at Parlee Beach for each of the eight modelled scenarios.

Maps of the magnitudes and directions of the residual currents produced by including the wind and wave forcing are presented in Appendix A. Maps of modelled 48-hour composite maximum pollutant concentrations are presented in Appendix B, while the drogue trajectories tracked over 24 hours are presented in Appendix C. The following section summarizes the overall patterns identified in the eight modelled scenarios.

4.1 Modelled Circulation Patterns

The circulation patterns in Shediac Bay were assessed based on 24-hour average residual currents for the eight dispersion scenarios, as well as for a base case tide-only forcing scenario. The currents produced by the tides alone (Figure 4-1) are relatively weak, with local speeds at Parlee Beach on the order of 5 cm/s or less, with a prevailing direction toward the west. Local asymmetries in the tidal flow at different stages of the tide also produce residual weak current flows within Shediac Bay, with flows generally into the bay south of Shediac Island, and out of the bay at north of the island.

The results from the scenarios with wind and wave forcing (Appendix A) indicate that distinct and persistent residual circulation patterns are expected to develop due to the non-tidal forcing, with the direction of the wind playing a dominant role in the local conditions within Shediac Bay and at Parlee Beach. In particular, relatively strong (10-15 cm/s) alongshore residual currents are predicted to develop along the coastline at Parlee Beach (as well as similarly shallow areas further north at Shediac Island and in the north of the domain), that overwhelm the tidal currents during all stages of tidal forcing. The results also indicate that due to the L-shaped geometry of the coastline north and east of Shediac Bay, the circulation patterns can sometimes converge or diverge from the channel to the south of Shediac Bay, leading to varying levels of efficiency of the transport of pollutants from within the south part of Shediac Bay toward the coastal area of Parlee Beach.

The surf-zone alongshore residual currents at Parlee Beach were found to be toward the east when winds were prescribed from the north, northwest, west, and southwest directions. In contrast, the alongshore residual currents were predicted to be oriented toward the west for southerly, southeasterly, easterly, and northeasterly winds. It is notable that the two most frequent wind directions during the summer months, from the southwest and south, are expected to drive local residual currents at Parlee Beach in opposite directions, with relatively weak magnitudes (less than 10 cm/s) than most of the other scenarios (range of 10-15 cm/s). However, given the fact that winds from other relatively frequent directions (e.g. from the west and northwest) produce relatively stronger coastal currents, a future analysis of any historical period would have to take into account the full range of conditions and their variability in the preceding hours and days prior to the time of interest when pollutant measurements are investigated.

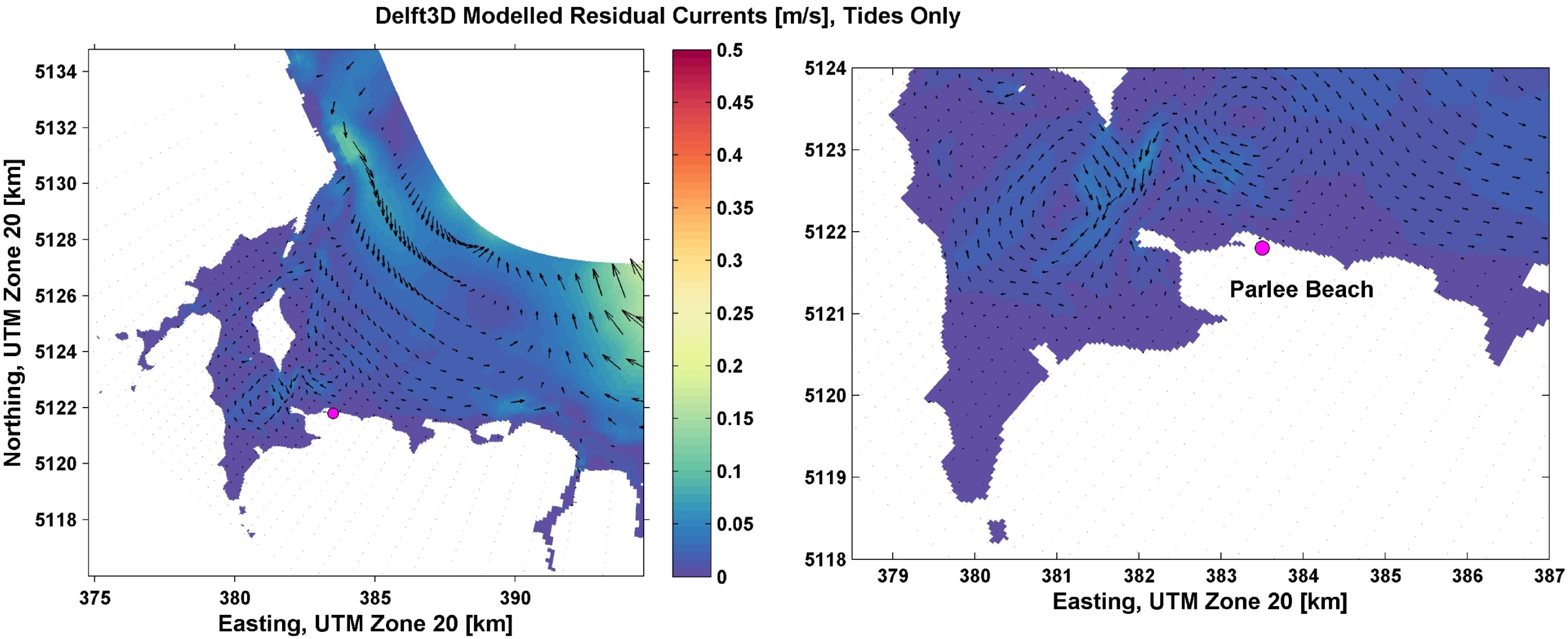

Figure 4-1 Modelled residual currents under tides-only forcing, averaged over a full diurnal cycle.

4.2 Hypothetical Pollutant Transport Patterns near Parlee Beach

The modelled dissolved pollutant (Appendix B) and drogue trajectory patterns (Appendix C) broadly reflect the trends identified in the residual circulation patterns. Considering the potential pollutant sources for observations at Parlee Beach, it is noted that the eight forcing scenarios considered in this study have produced distinct source signatures at the Parlee Beach location, with either the source in Shediac Bay (label P7) or the source east of Parlee Beach (label P12) contributing to the pollutant concentrations at Parlee Beach (see Figure 4-2). As the residual current maps and drogue trajectories indicate, the flow in the area to the west of Parlee Beach and the exchange with Shediac Bay exhibits complex patterns even in the relatively constrained forcing scenarios considered in the present study. Depending on the overall circulation patterns, and relative strength of the alongshore surf-zone currents near Parlee Beach and the flow out of the channel south of Shediac Island, there is a range of possible outcomes and trajectories of any advected materials from within Shediac Bay.

Aside from the complexities of the local coastal circulation, the findings indicate that in the scenarios with consistent wind (and wave) forcing from distinct directions, pollutants from Shediac Bay would be detected at Parlee Beach for northwesterly, westerly, southwesterly and northerly winds, and sources from east of Parlee Beach would dominate in all other cases. The modelling results also indicate that the sources east of Parlee Beach would result in faster pollutant transport from comparable distances, with peak concentrations reaching Parlee Beach within less than 1 day of the beginning of release, compared to 1.5 to 2 days for the source within Shediac Bay. It is also noted that on a relative basis, for comparable intensity of the sources, the modelled pollutant concentrations at Parlee Beach are approximately an order of magnitude higher for sources east of Parlee Beach, due to the relatively direct transport route within the conveyor-belt like surf zone currents along this part of the coastline. In comparison, the circulation patterns in the south of Shediac Bay are relatively more complex, with significantly higher physical dispersion and dilution rates occurring during the transport process.

The model results also indicate that while the alongshore residual transport of any pollutant plumes (in either direction) is modulated by the influence of the tides, and therefore the same pollutant plume can result in multiple peaks (diminishing through time) of concentration at the same location over several days. However the interpretation of the present results should also take into account that no pollutant decay was prescribed within the present model, and in reality the absolute bacterial concentrations expected at any location and time will be strongly affected by the timing of the release, as well as the effective decay rates.

Table 4-1 Summary of modelled transport patterns of hypothetical pollutant dispersion near Parlee Beach, NB.

Modelled Scenarios		
Scenario ID	**Dominant Transport Direction at Parlee Beach (to)**	**Dominant Pollutant Source at Parlee Beach**
1. Northwesterly Winds	East	Shediac Bay South (P7)
2. Westerly Winds	East	Shediac Bay South (P7)
3. Southwesterly Winds	East	Shediac Bay South (P7)
4. Southerly Winds	West	East of Parlee Beach (P12)
5. Southeasterly Winds	West	East of Parlee Beach (P12)
6. Easterly Winds	West	East of Parlee Beach (P12)
7. Northeasterly Winds	West	East of Parlee Beach (P12)
8. Northerly Winds	East	Shediac Bay South (P7)

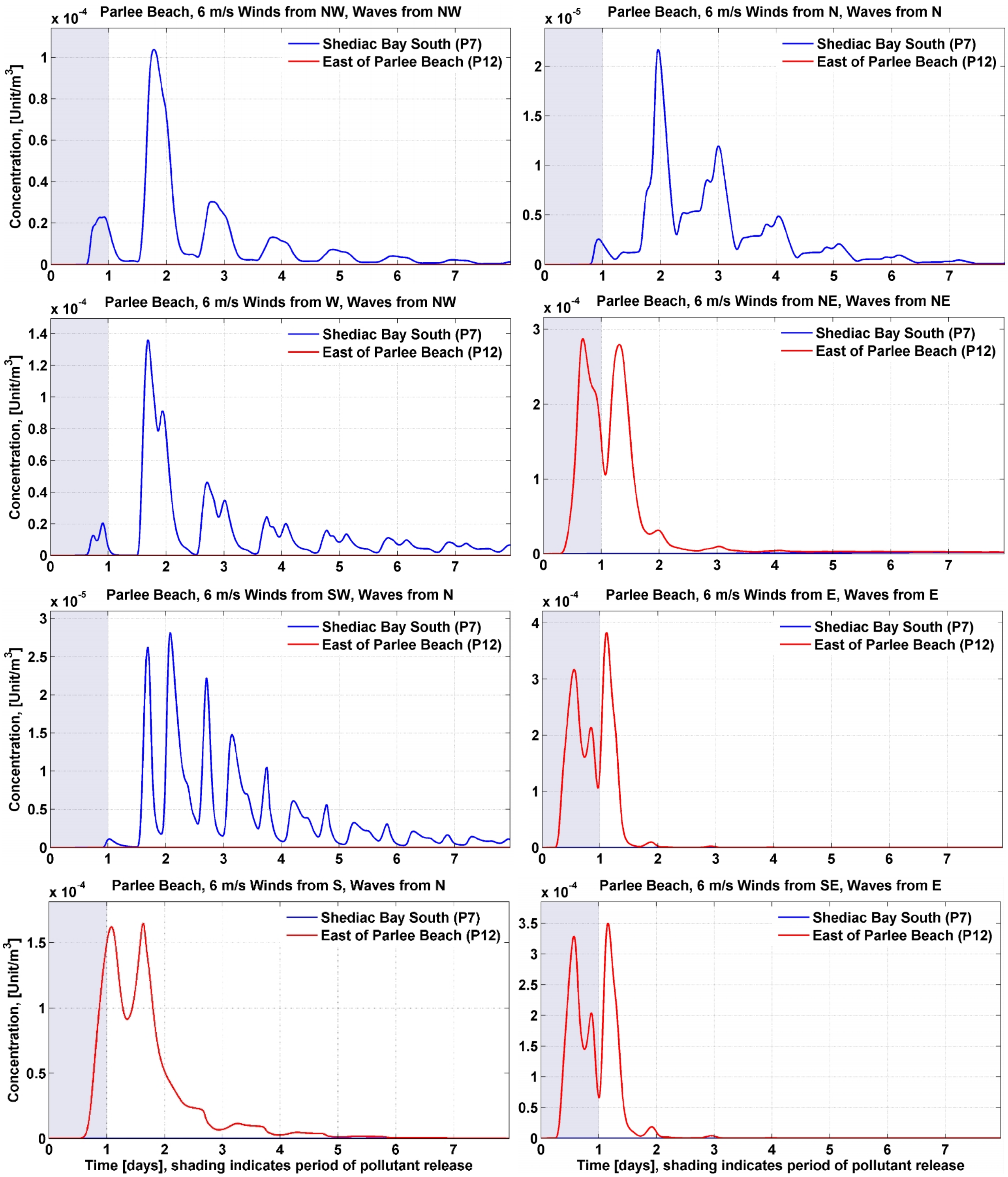

Figure 4-2 Modelled pollutant concentrations (nominal units) at Parlee Beach for the eight modelled wind scenarios.

5.0 CONCLUSIONS

Amec Foster Wheeler has developed a high-resolution coastal hydrodynamic and wave model of the area around Shediac Bay and Parlee Beach, based on the Delft3D modelling suite. The goal of the present modelling study was to develop a model capable of assessing the circulation and transport patterns near the coastline of Parlee Beach, to support the New Brunswick Department of Health in determining how bacteria are transported through the coastal environment, and thus to assist in identification of potential sources.

To this end, the present study assessed the circulation and transport patterns under the combined influence of astronomical tides with average wind forcing conditions from eight distinct directions. The modelled pollutant and drogue transport patterns, in conjunction with the long-term wind and wave climate statistics derived from the Meteorological Service Canada hindcast, can be used to assess the potential sources of bacteria observed at Parlee Beach in a general sense. The present study indicates that the most frequent wind forcing conditions during the summer months, from the southwest and to a significant extent from the west, are expected to produce circulation patterns that could effectively transport pollutants from the south of Shediac Bay toward Parlee Beach within a period of 1.5 to 2 days.

In contrast, relatively frequent southerly winds are expected to produce westward residual currents in the coastal zone near Parlee Beach, however the actual transport conditions at any given time are expected to be influenced by conditions in the preceding hours and days at any given time. The model results indicate that the relatively less frequent conditions that induce westerly transport conditions at Parlee Beach may be relatively more effective in transporting pollutants from any hypothetical sources east of Parlee Beach, with shorter arrival times from the time of release (less than 24 hours), as well as higher relative concentrations (for the equivalent source intensity) compared to sources in Shediac Bay.

6.0 REFERENCES

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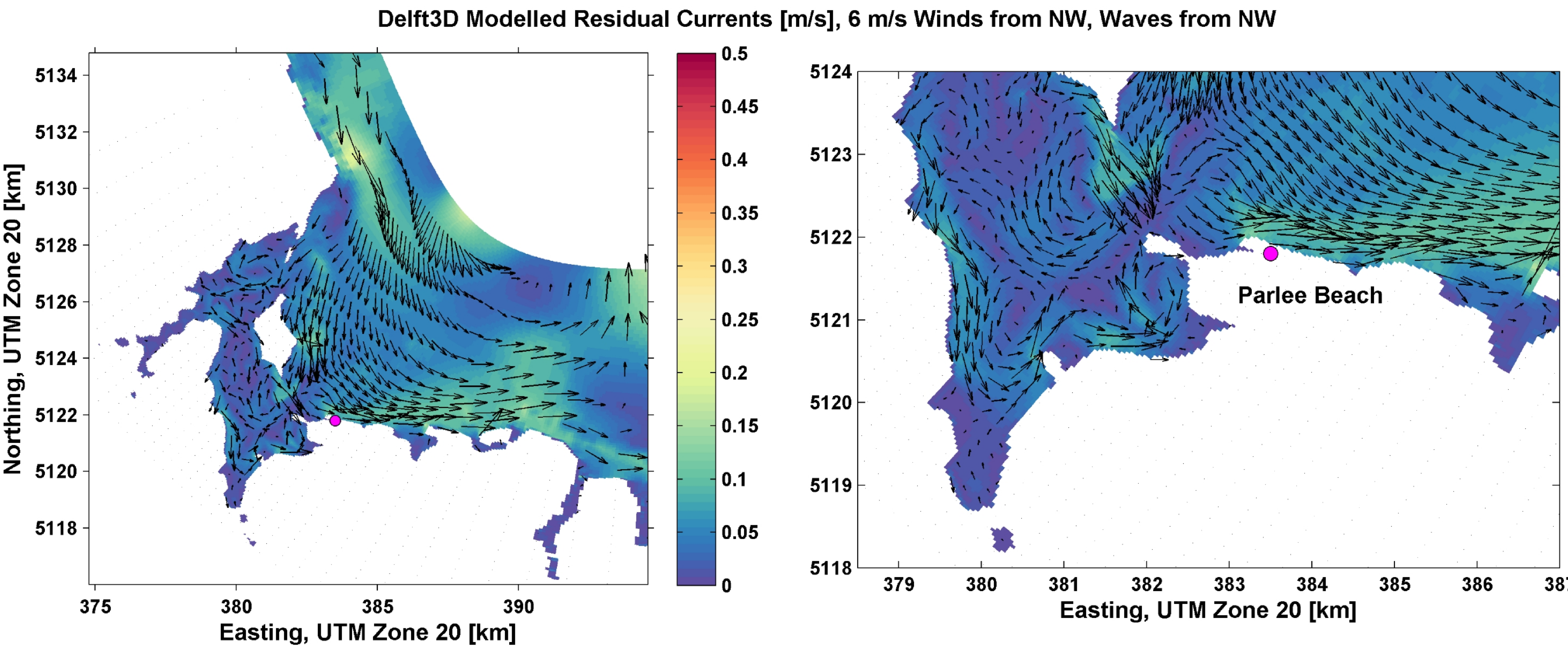
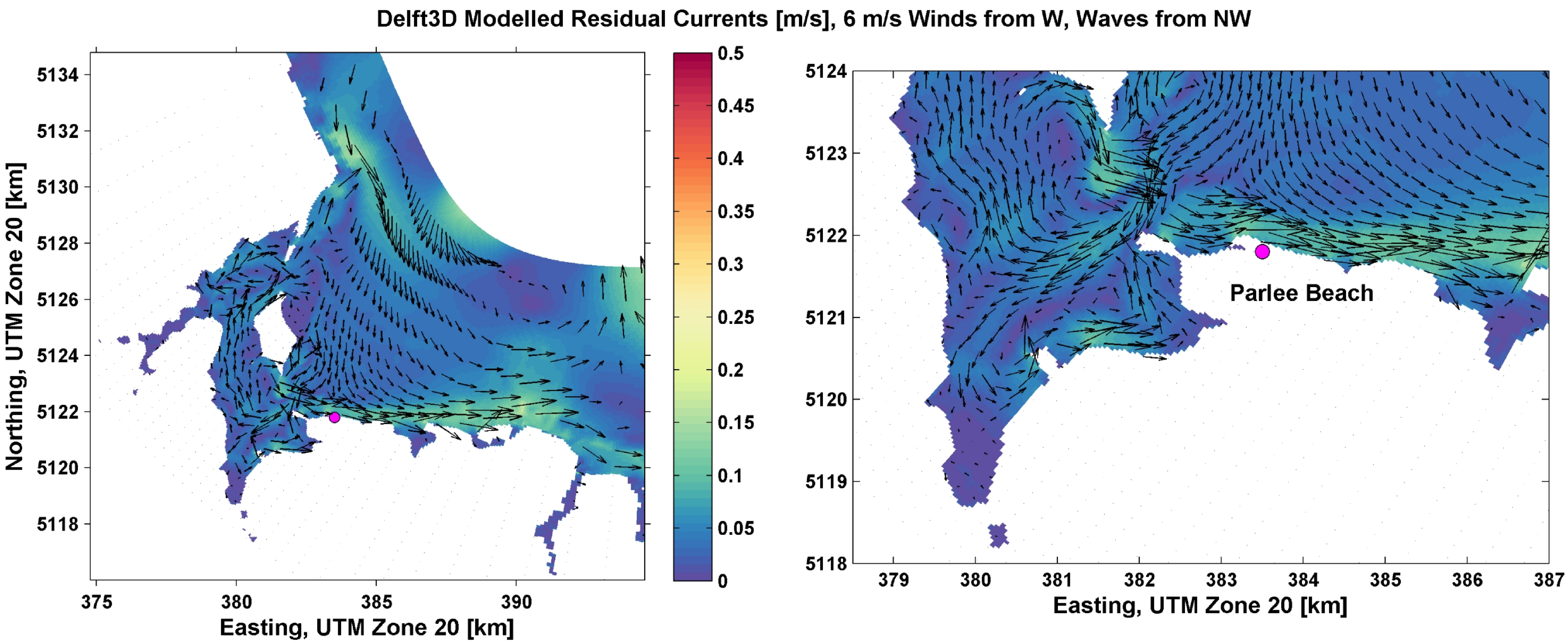
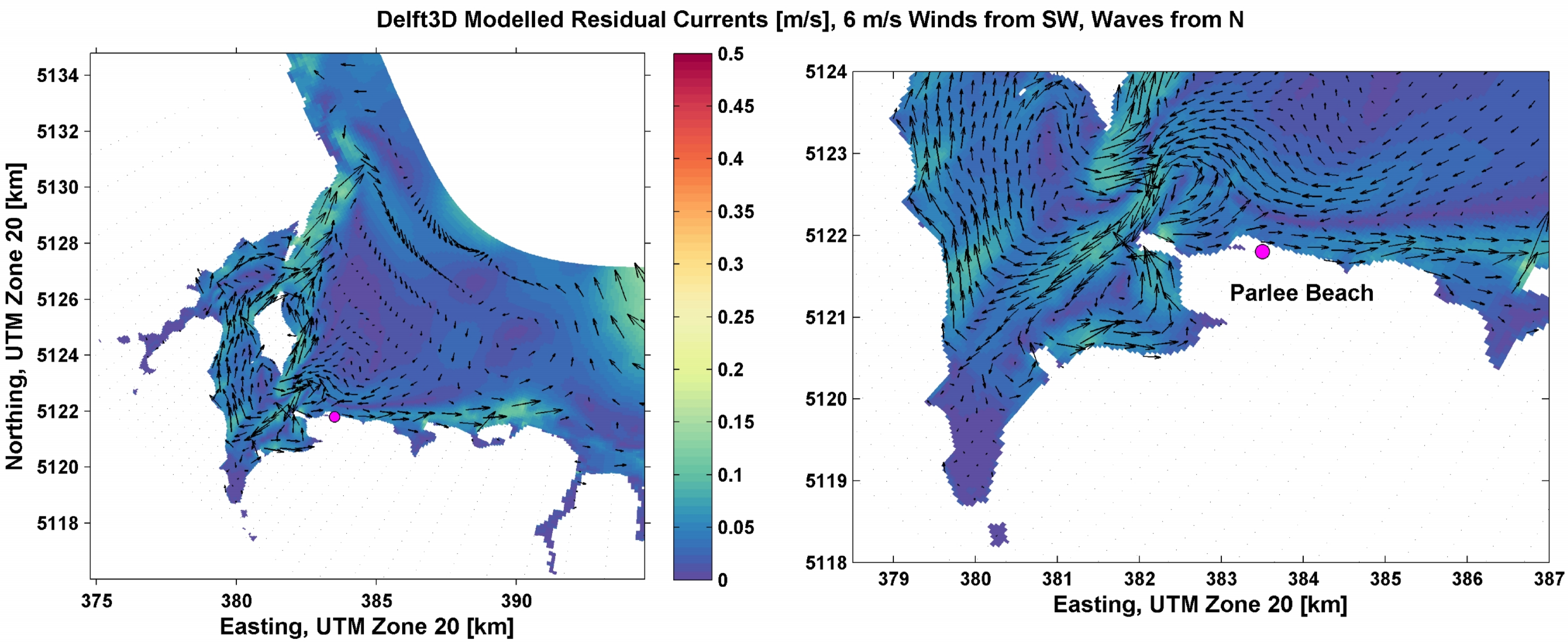
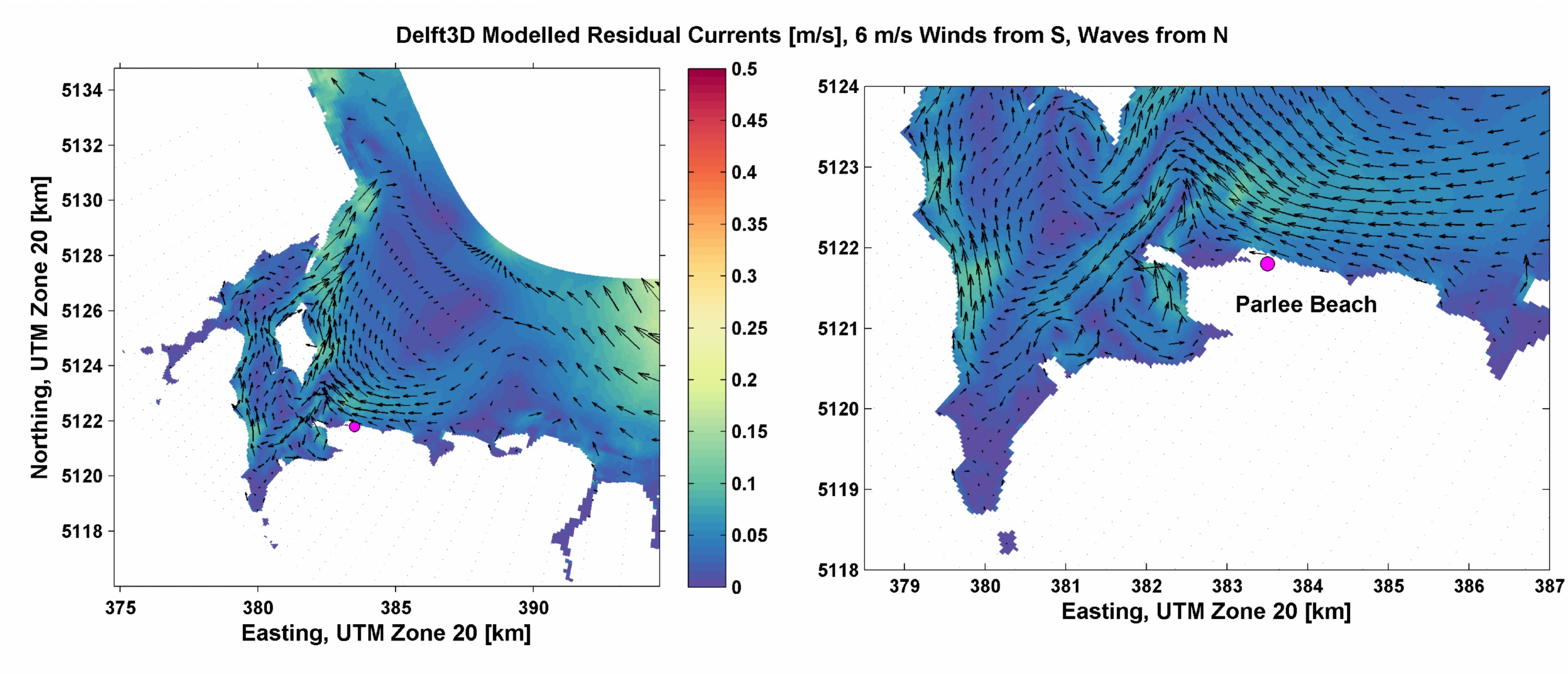
APPENDIX A

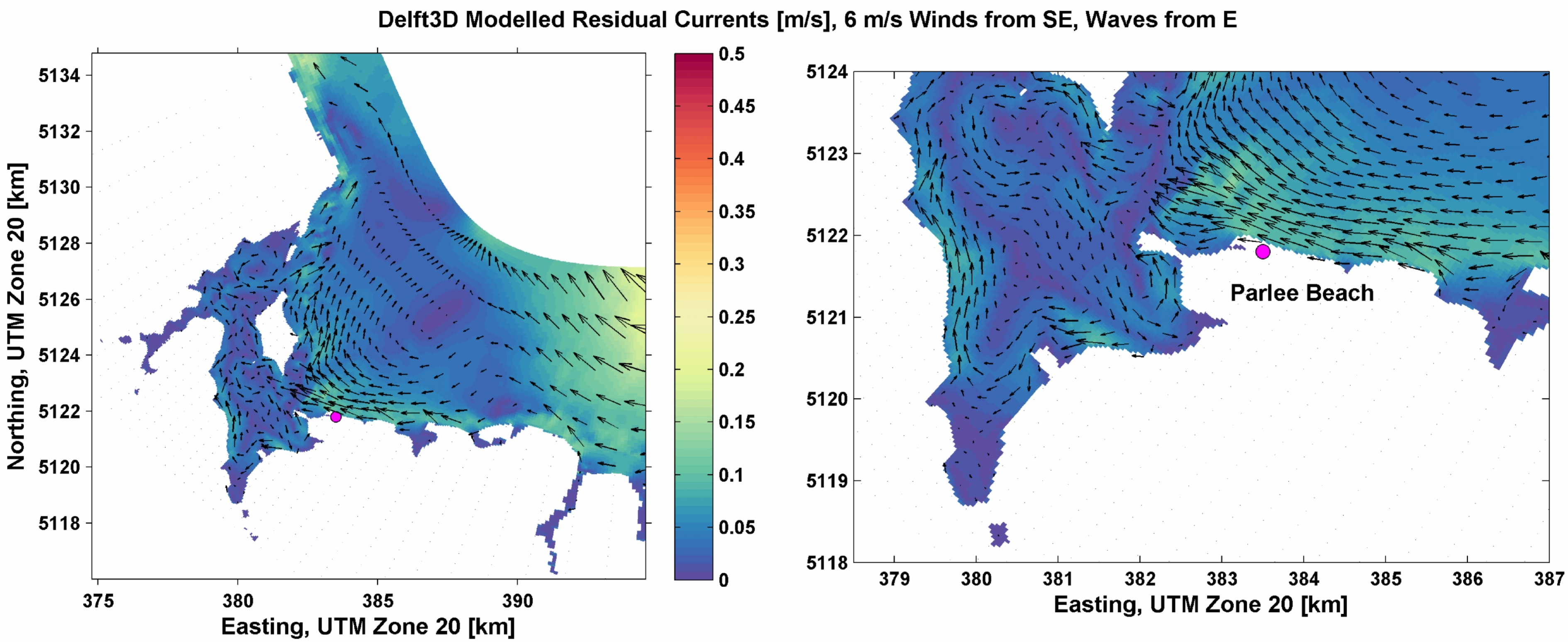
Maps of modelled non-tidal current residual magnitude and directions, for 8 atmospheric forcing scenarios

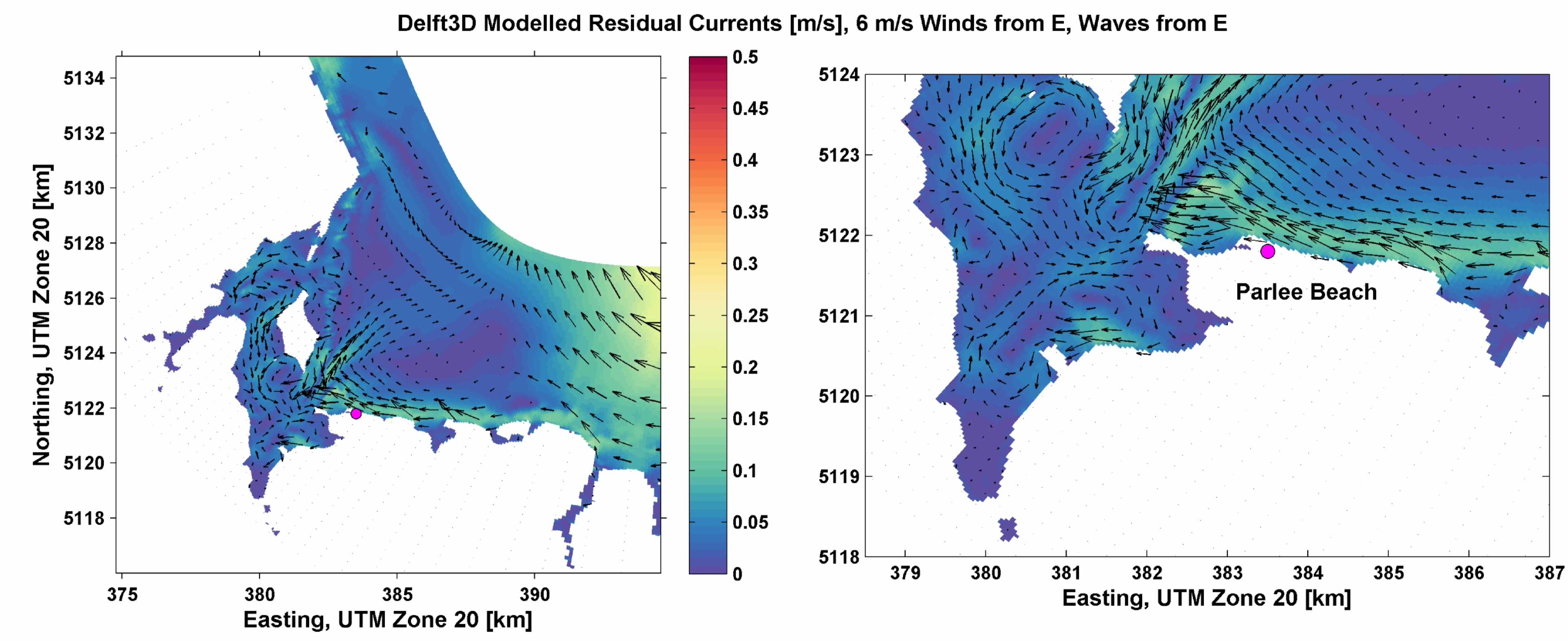

Delft3D Modelled Residual Currents [m/s], 6 m/s Winds from NW, Waves from NW
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
5134
5132
5130
5128
5126
5124
5122
5120
5118
375
380
385
390
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5124
5123
5122
5121
5120
5119
5118
379
380
381
382
383
384
385
386
387
Parlee Beach
Easting, UTM Zone 20 [km]


Delft3D Modelled Residual Currents [m/s], 6 m/s Winds from W, Waves from NW
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
Parlee Beach
Easting, UTM Zone 20 [km]


Delft3D Modelled Residual Currents [m/s], 6 m/s Winds from SW, Waves from N
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
Parlee Beach
Easting, UTM Zone 20 [km]


Delft3D Modelled Residual Currents [m/s], 6 m/s Winds from S, Waves from N
Northing, UTM Zone 20 [km]
5134
5132
5130
5128
5126
5124
5122
5120
5118
375
380
385
390
Easting, UTM Zone 20 [km]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5124
5123
5122
5121
5120
5119
5118
379
380
381
382
383
384
385
386
387
Parlee Beach
Easting, UTM Zone 20 [km]


Delft3D Modelled Residual Currents [m/s], 6 m/s Winds from SE, Waves from E
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Parlee Beach
Easting, UTM Zone 20 [km]


Delft3D Modelled Residual Currents [m/s], 6 m/s Winds from E, Waves from E
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
5134
5132
5130
5128
5126
5124
5122
5120
5118
375
380
385
390
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
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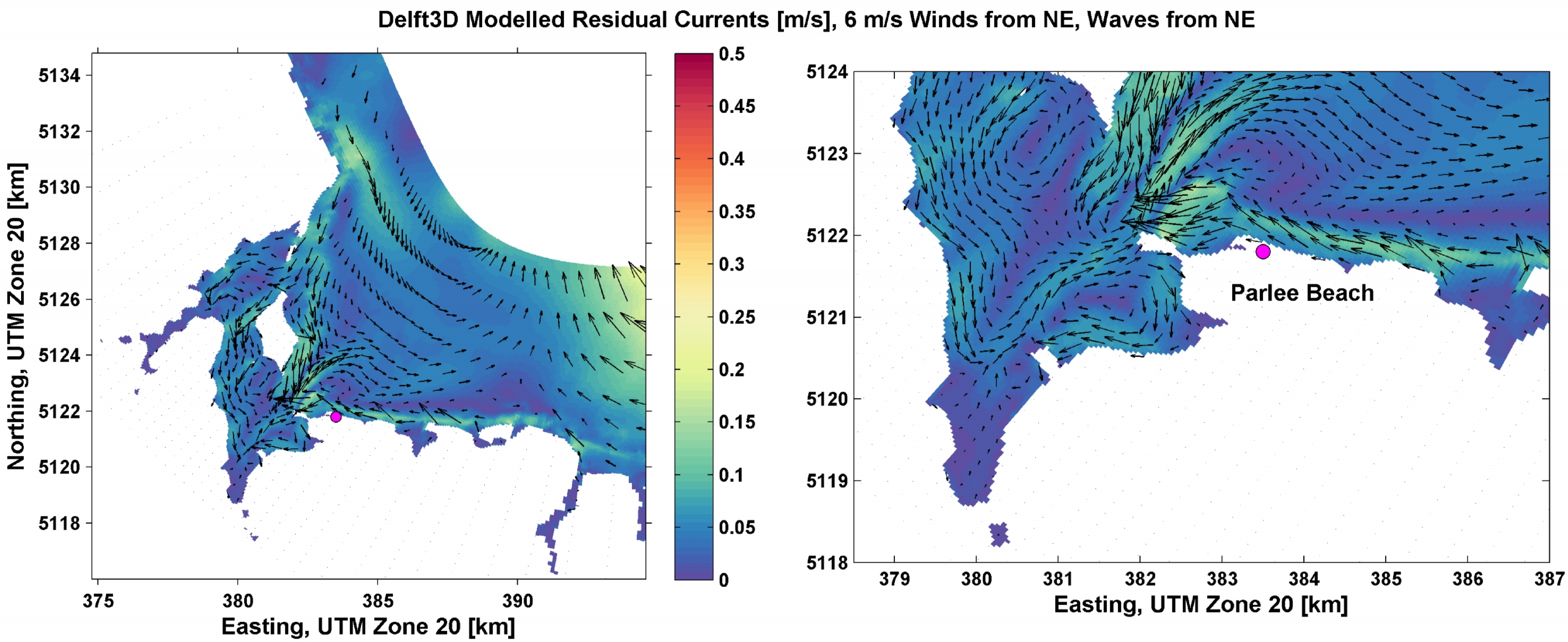
387
Parlee Beach
Easting, UTM Zone 20 [km]


Delft3D Modelled Residual Currents [m/s], 6 m/s Winds from NE, Waves from NE
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
5134
5132
5130
5128
5126
5124
5122
5120
5118
375
380
385
390
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5124
5123
5122
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5120
5119
5118
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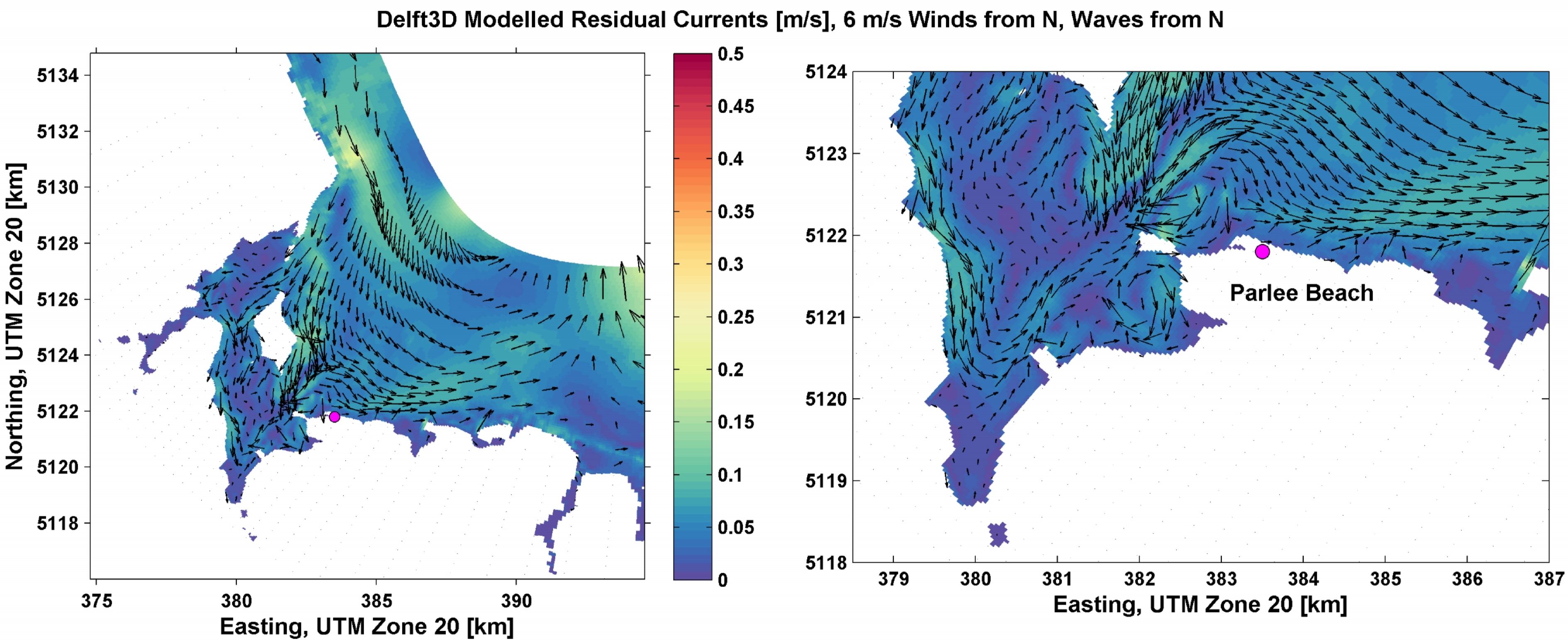
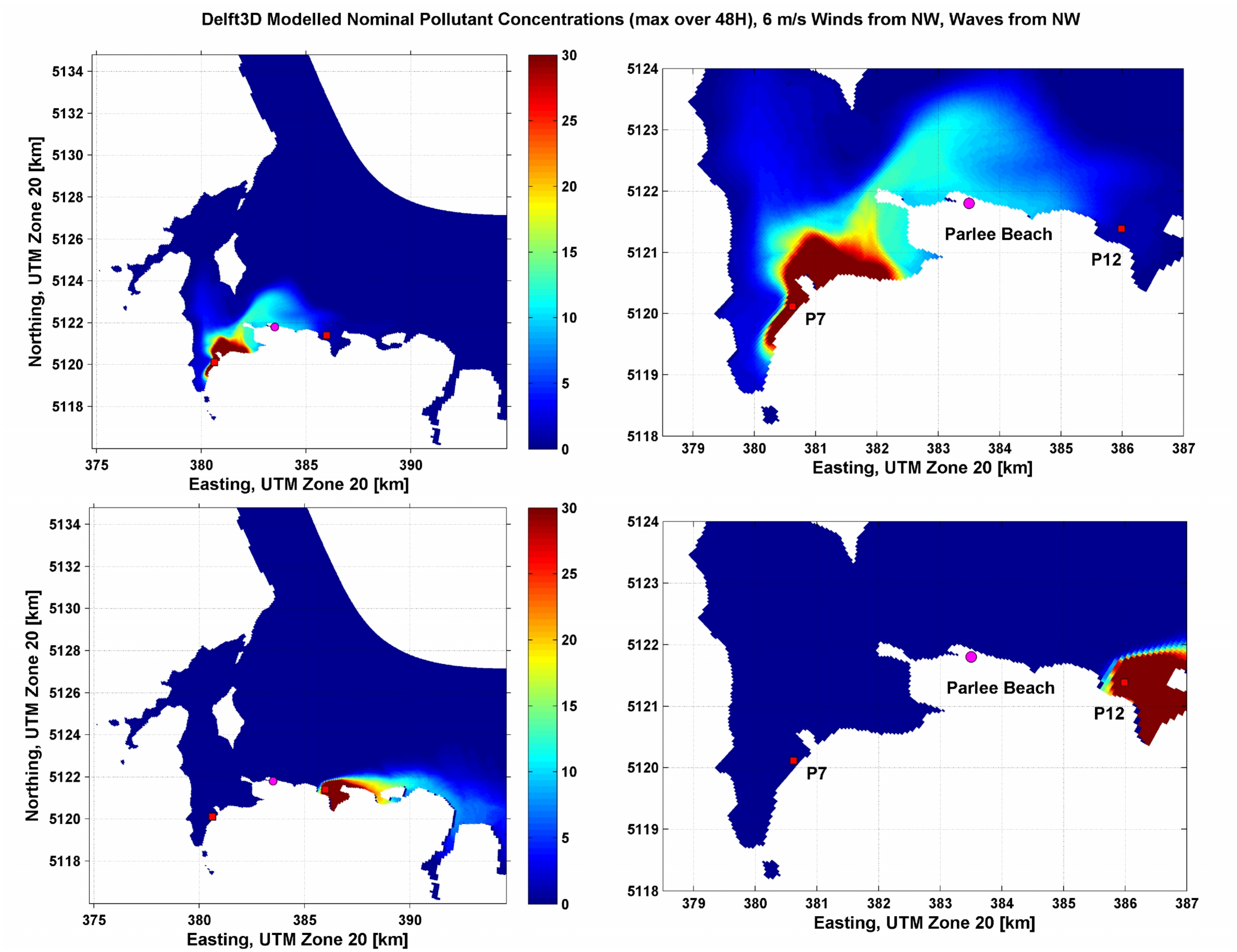
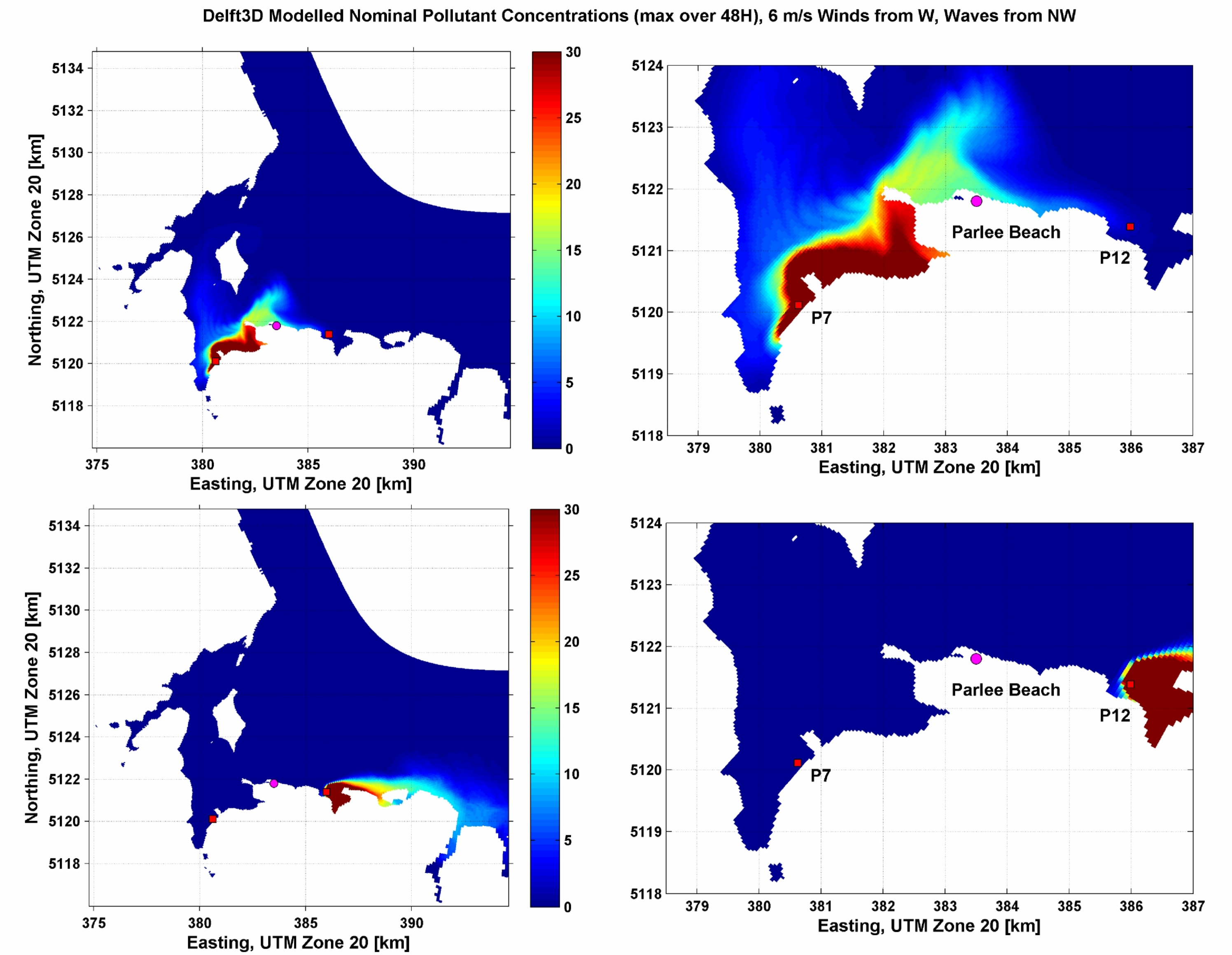
382
383
384
385
386
387
Parlee Beach
Easting, UTM Zone 20 [km]

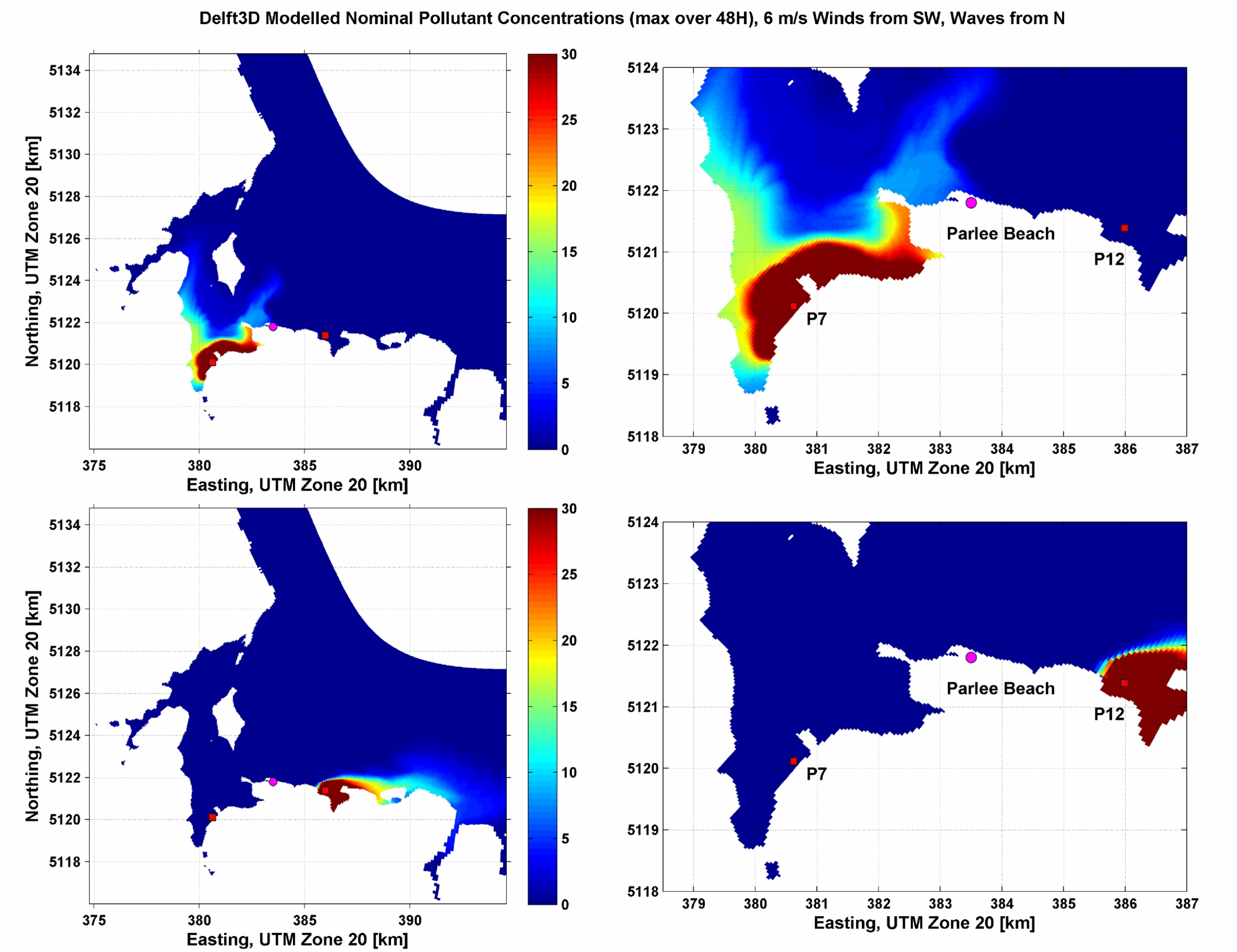

Delft3D Modelled Residual Currents [m/s], 6 m/s Winds from N, Waves from N
Northing, UTM Zone 20 [km]
5134
5132
5130
5128
5126
5124
5122
5120
5118
375
380
385
390
Easting, UTM Zone 20 [km]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5124
5123
5122
5121
5120
5119
5118
379
380
381
382
383
384
385
386
387
Parlee Beach
Easting, UTM Zone 20 [km]

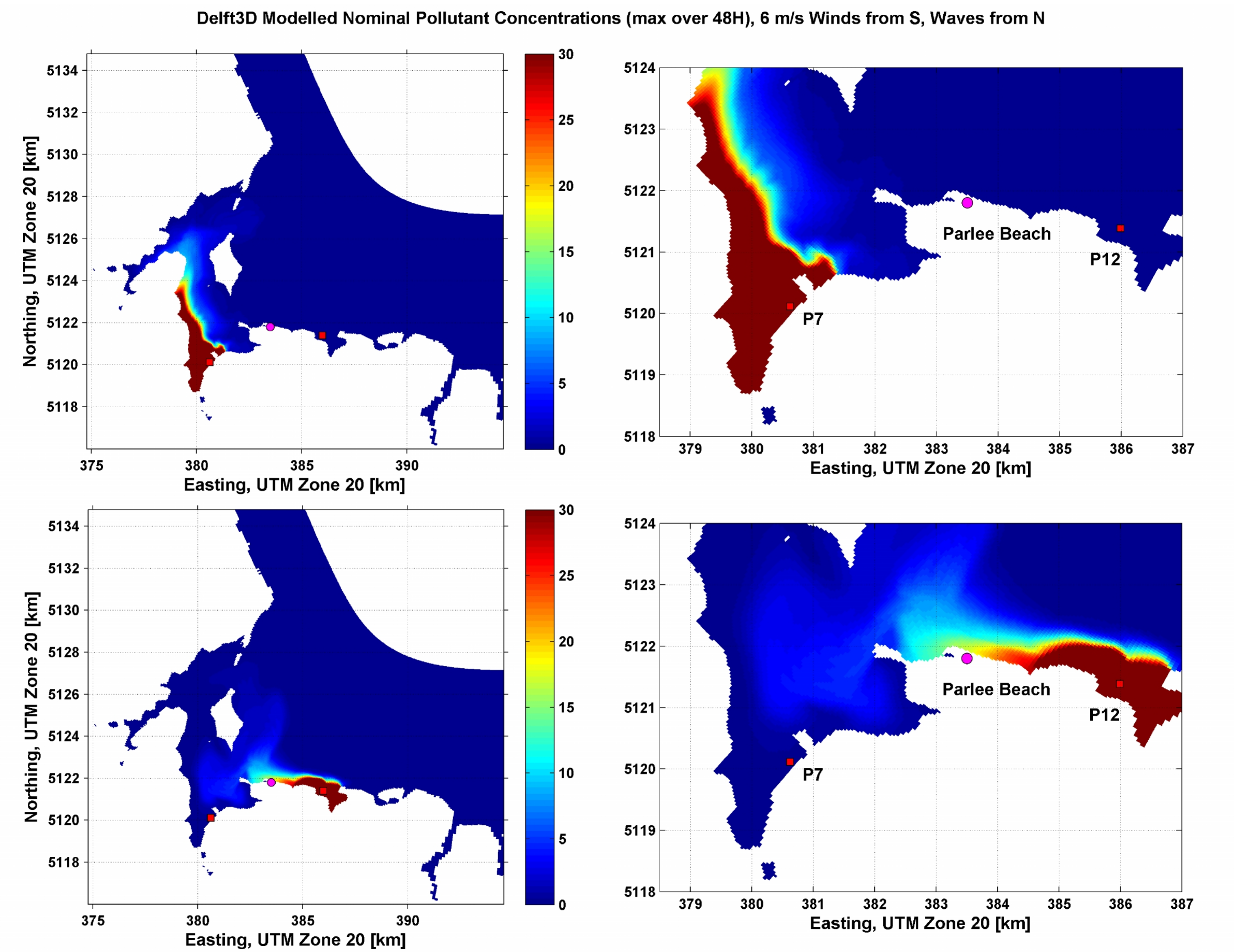
APPENDIX B

Maps of modelled 48h composite maximum pollutant concentrations, for 8 atmospheric forcing scenarios

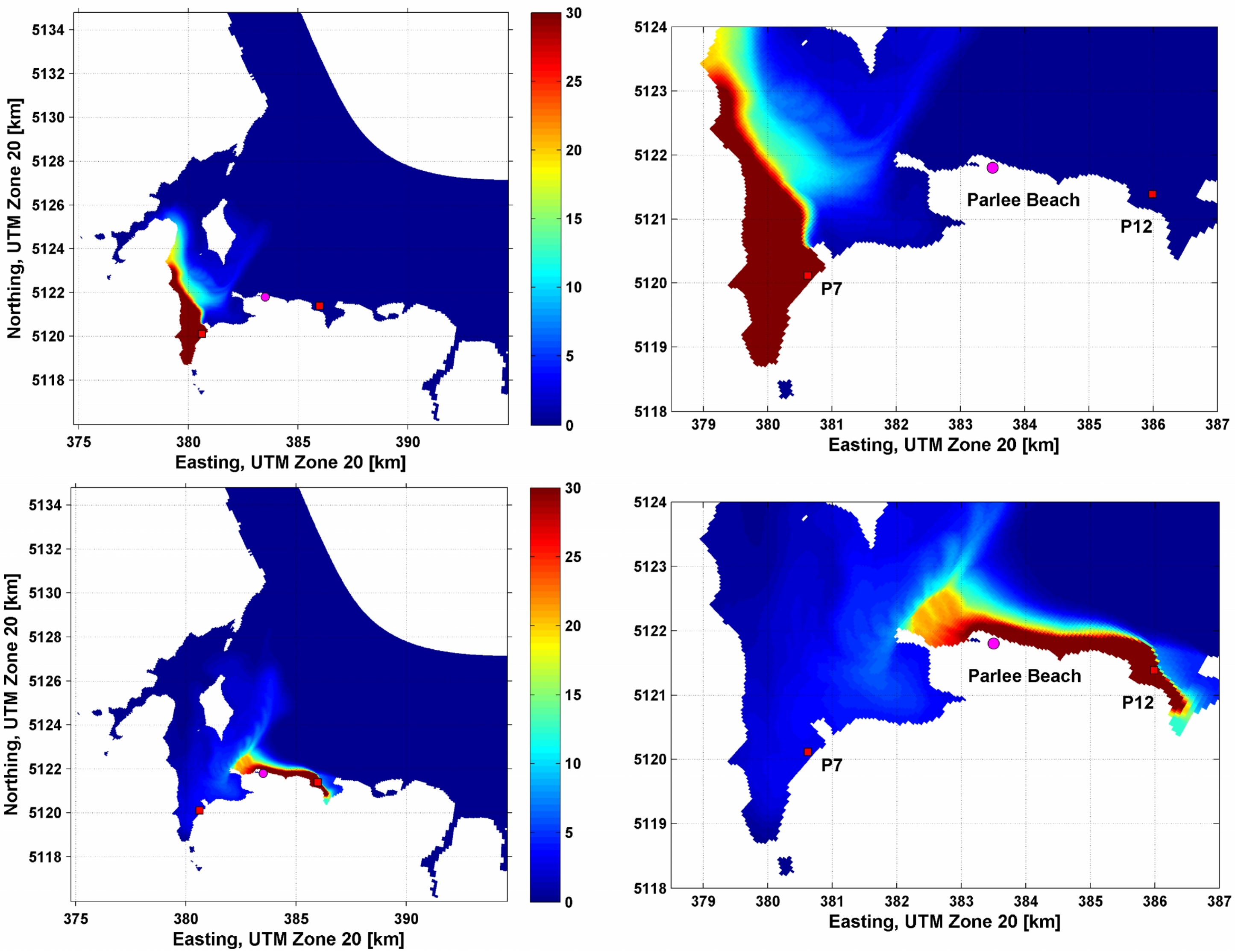

Delft3D Modelled Nominal Pollutant Concentrations (max over 48H), 6 m/s Winds from NW, Waves from NW
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
Parlee Beach
P7
P12

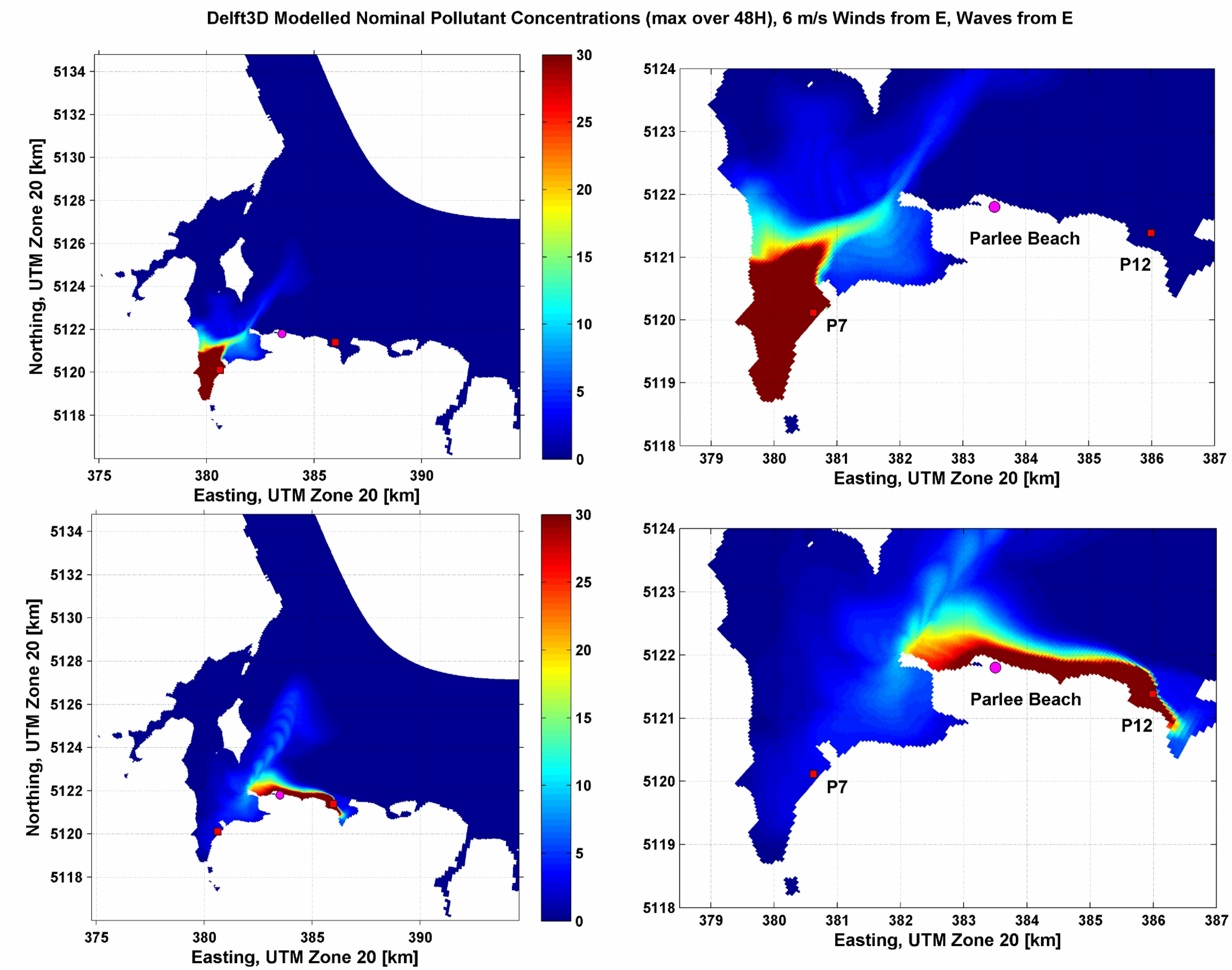

Delft3D Modelled Nominal Pollutant Concentrations (max over 48H), 6 m/s Winds from W, Waves from NW
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
Parlee Beach
P7
P12


Delft3D Modelled Nominal Pollutant Concentrations (max over 48H), 6 m/s Winds from SW, Waves from N
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
Parlee Beach
P7
P12
0
5
10
15
20
25
30

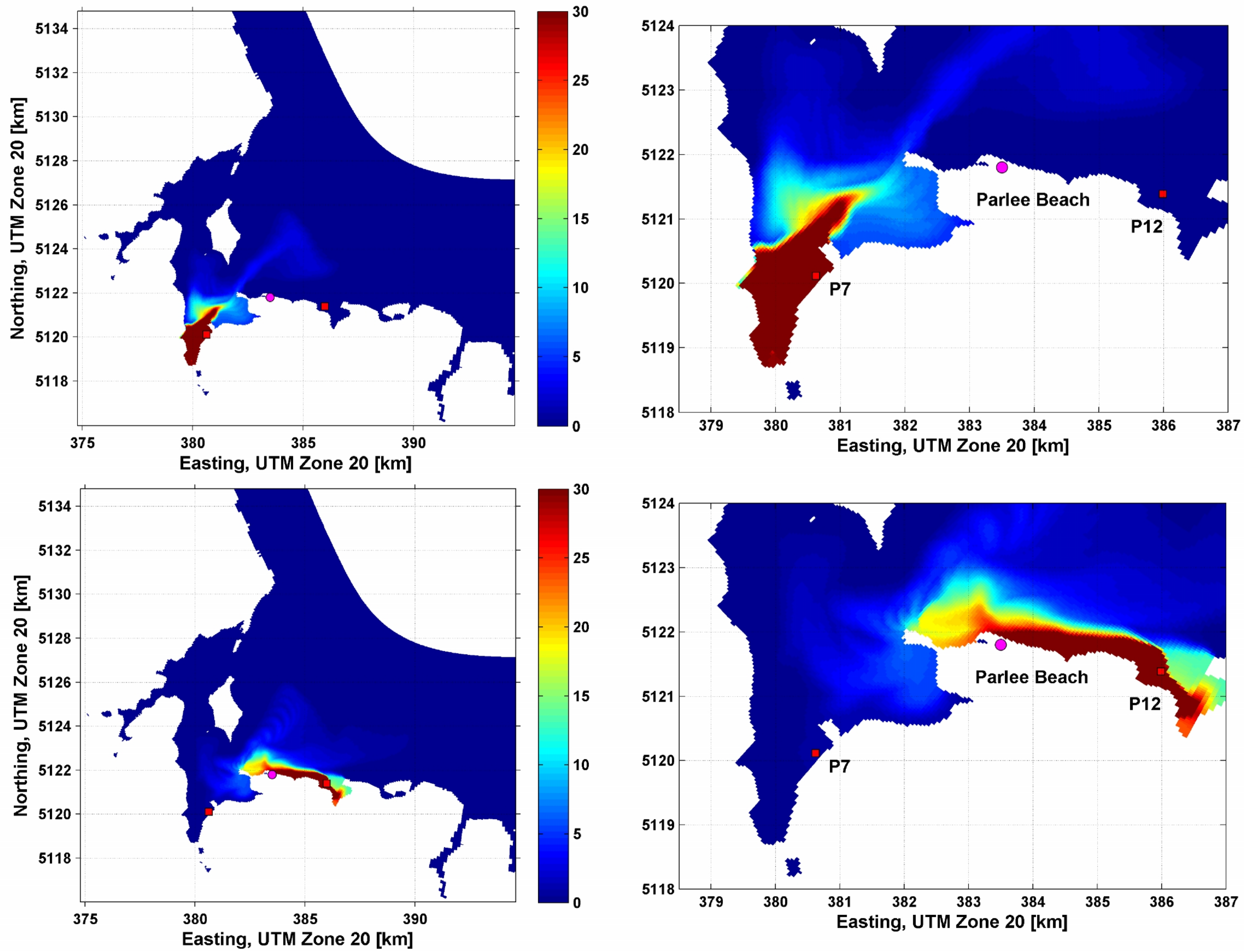

Delft3D Modelled Nominal Pollutant Concentrations (max over 48H), 6 m/s Winds from S, Waves from N
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
Parlee Beach
P7
P12

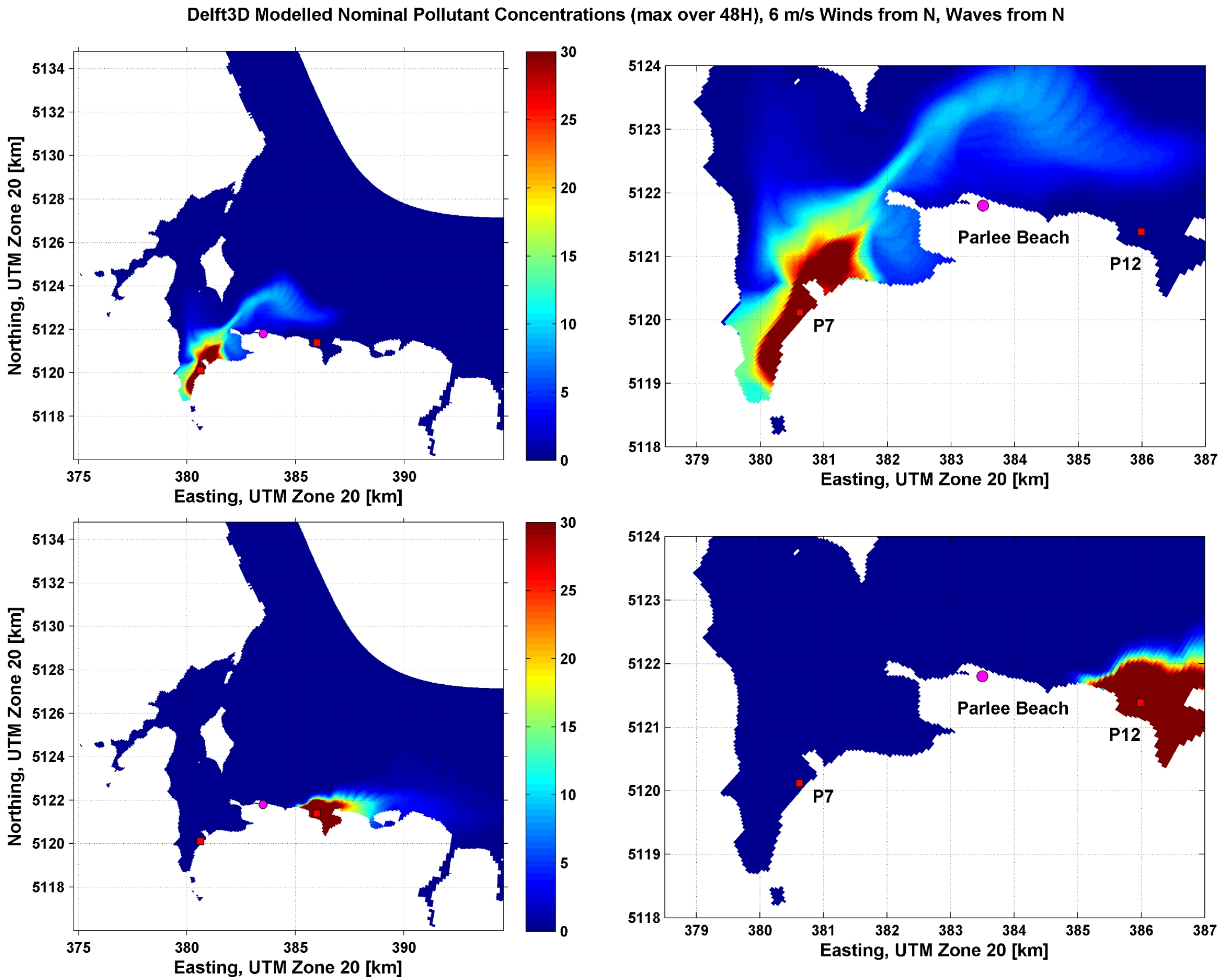
Delft3D Modelled Nominal Pollutant Concentrations (max over 48H), 6 m/s Winds from SE, Waves from E




Delft3D Modelled Nominal Pollutant Concentrations (max over 48H), 6 m/s Winds from E, Waves from E
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
Parlee Beach
P7
P12

Delft3D Modelled Nominal Pollutant Concentrations (max over 48H), 6 m/s Winds from NE, Waves from NE

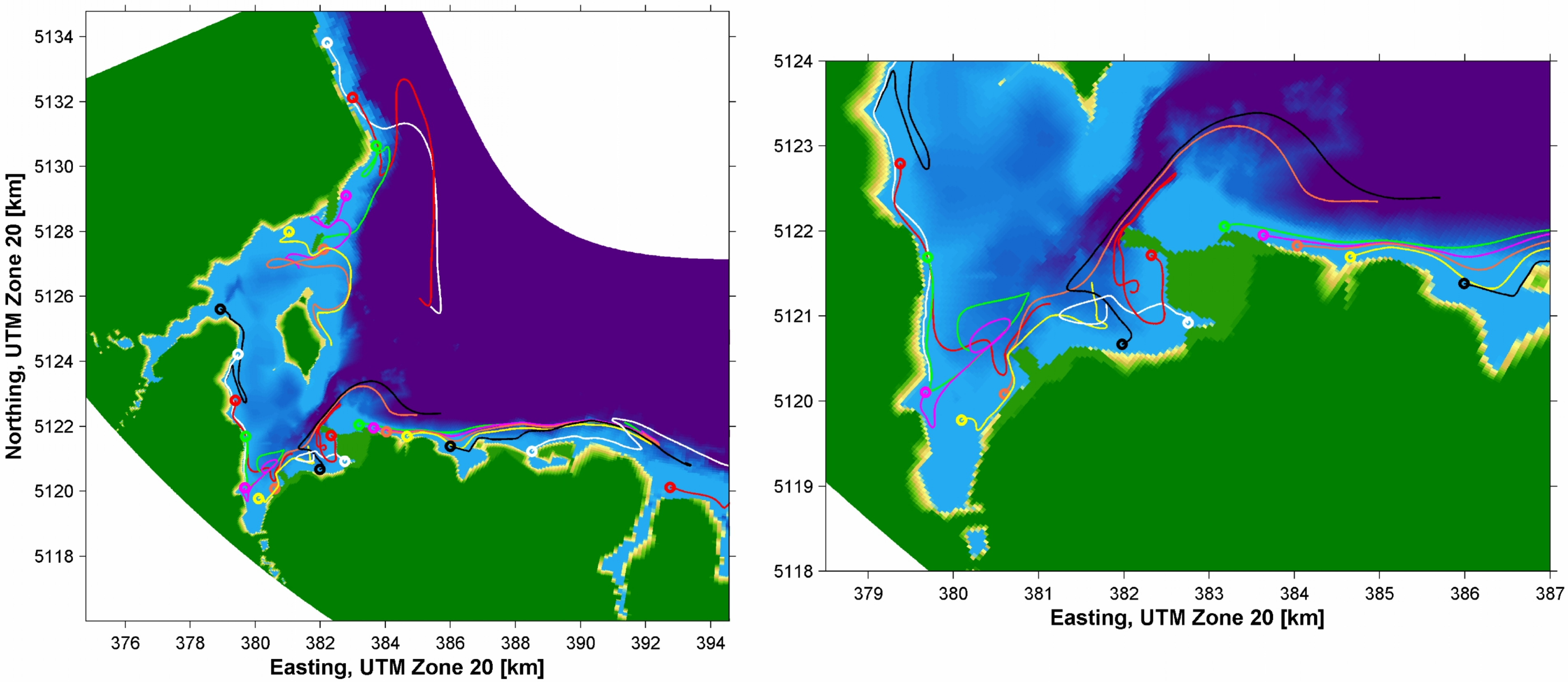



Delft3D Modelled Nominal Pollutant Concentrations (max over 48H), 6 m/s Winds from N, Waves from N
Northing, UTM Zone 20 [km]
Easting, UTM Zone 20 [km]
Parlee Beach
P7
P12

APPENDIX C

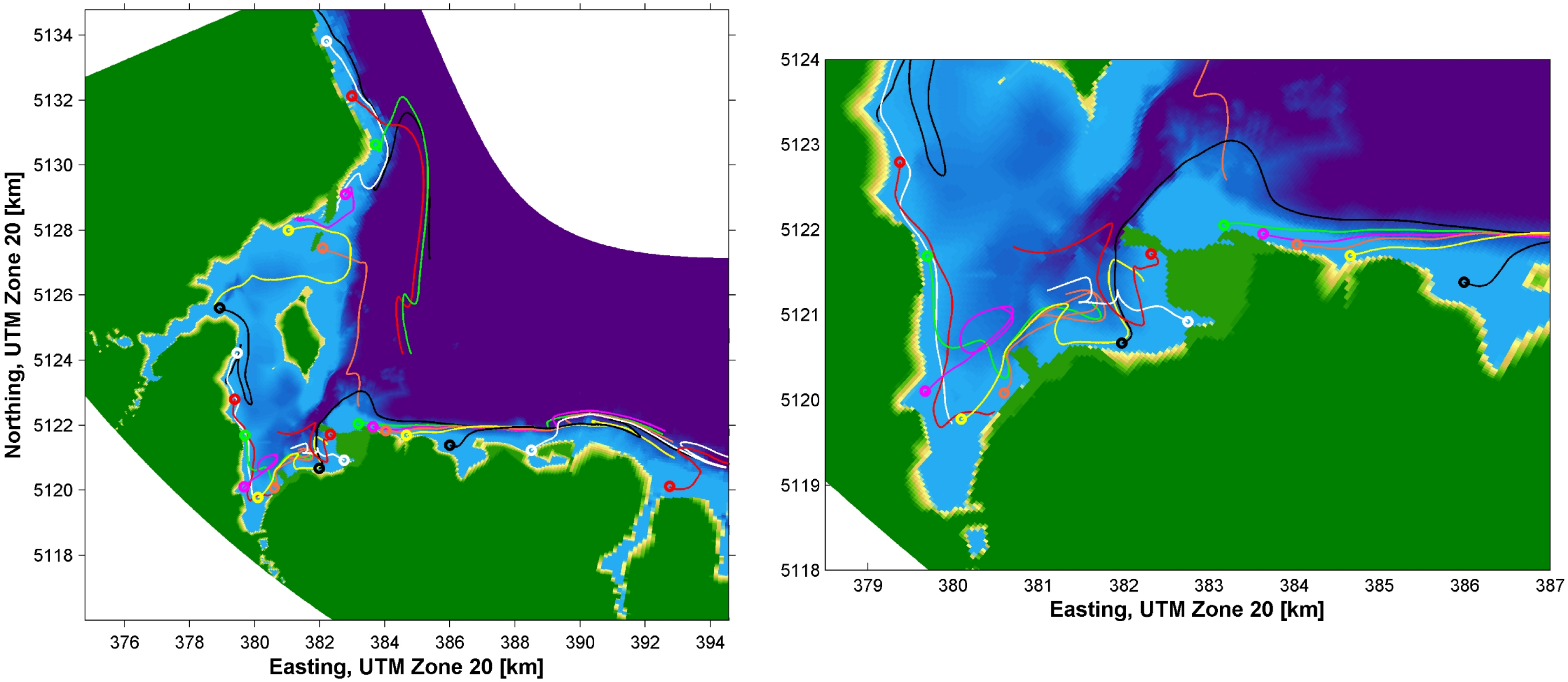
Maps of modelled 24-hour trajectories, for drogues released at 0h 6h and 12h from the beginning of pollutant release, for 8 atmospheric forcing scenarios

Modelled Drogue Release at Time = 0 hr, 6 m/s Winds from NW, Waves from NW



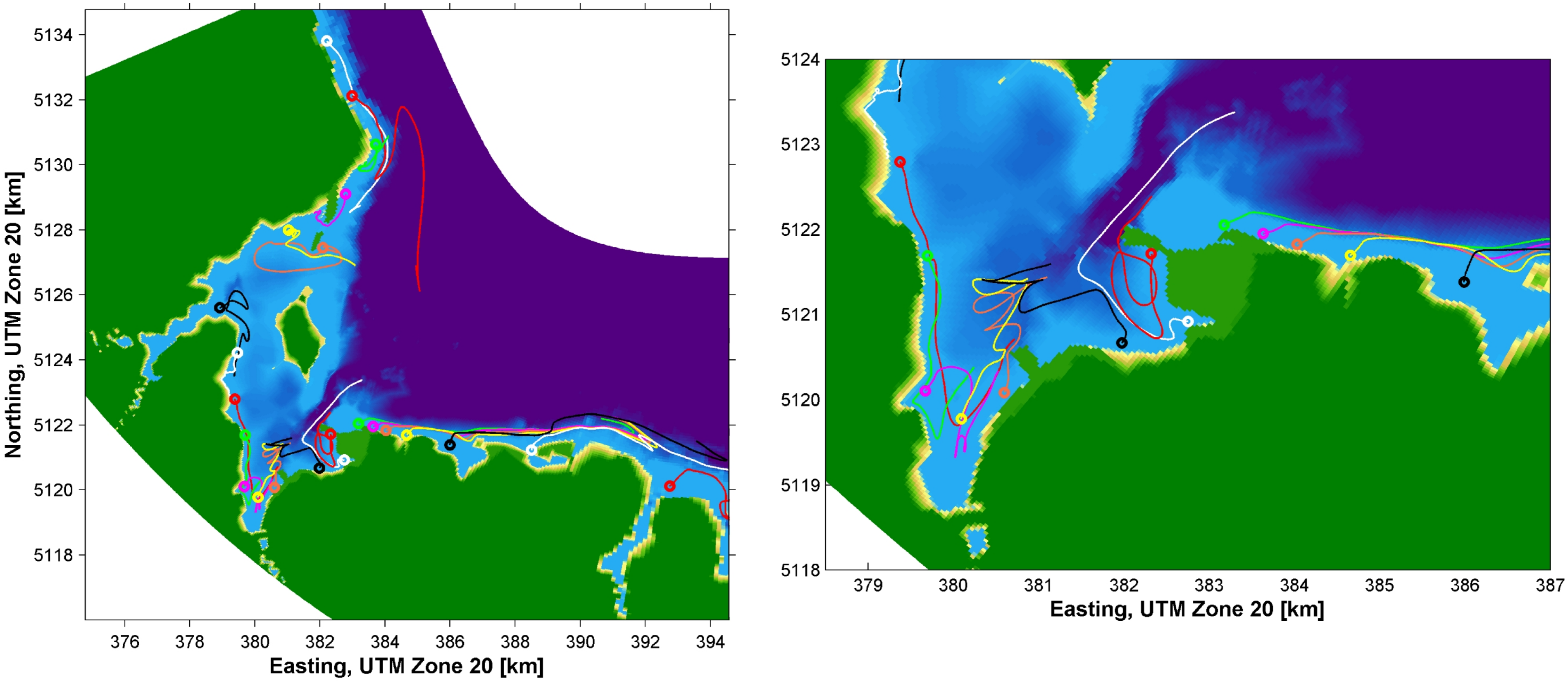
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

Modelled Drogue Release at Time = 6 hr, 6 m/s Winds from NW, Waves from NW



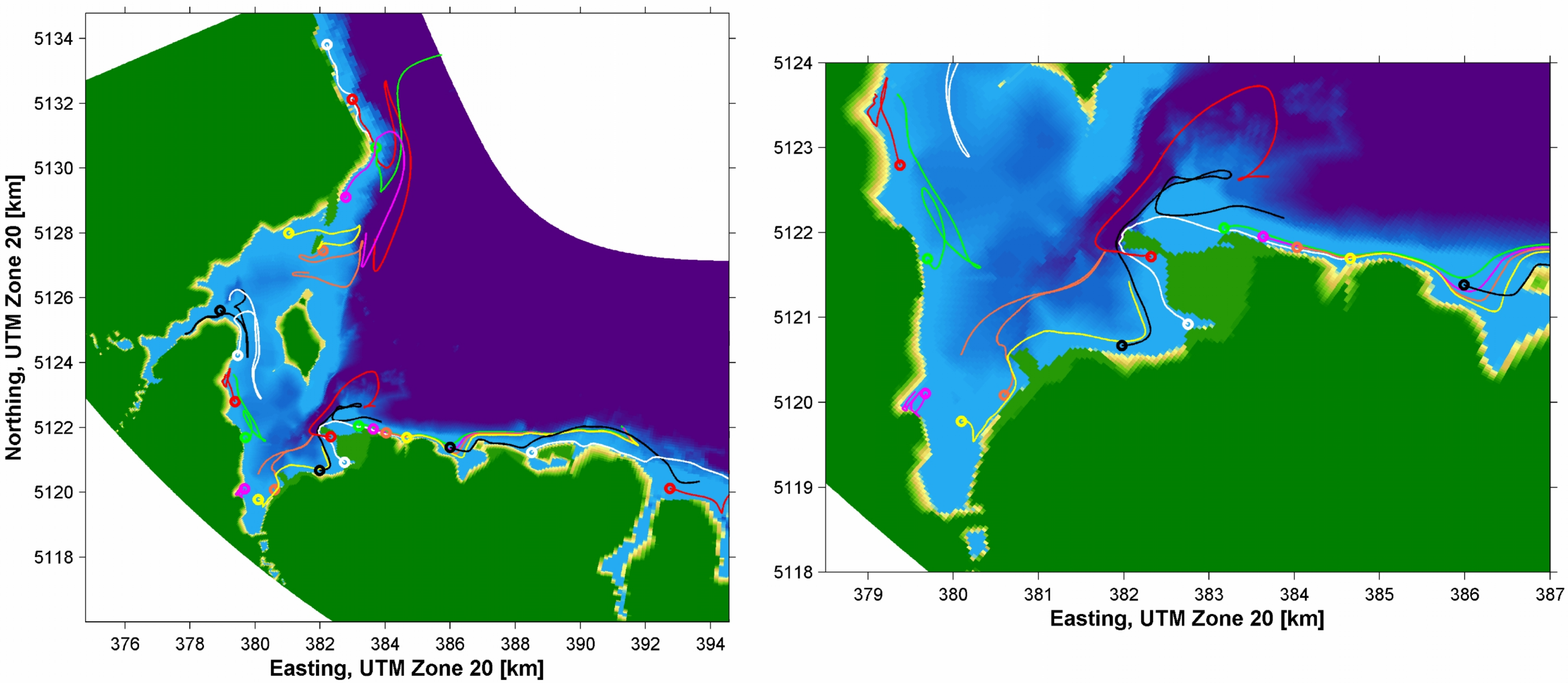
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

Modelled Drogue Release at Time = 12 hr, 6 m/s Winds from NW, Waves from NW

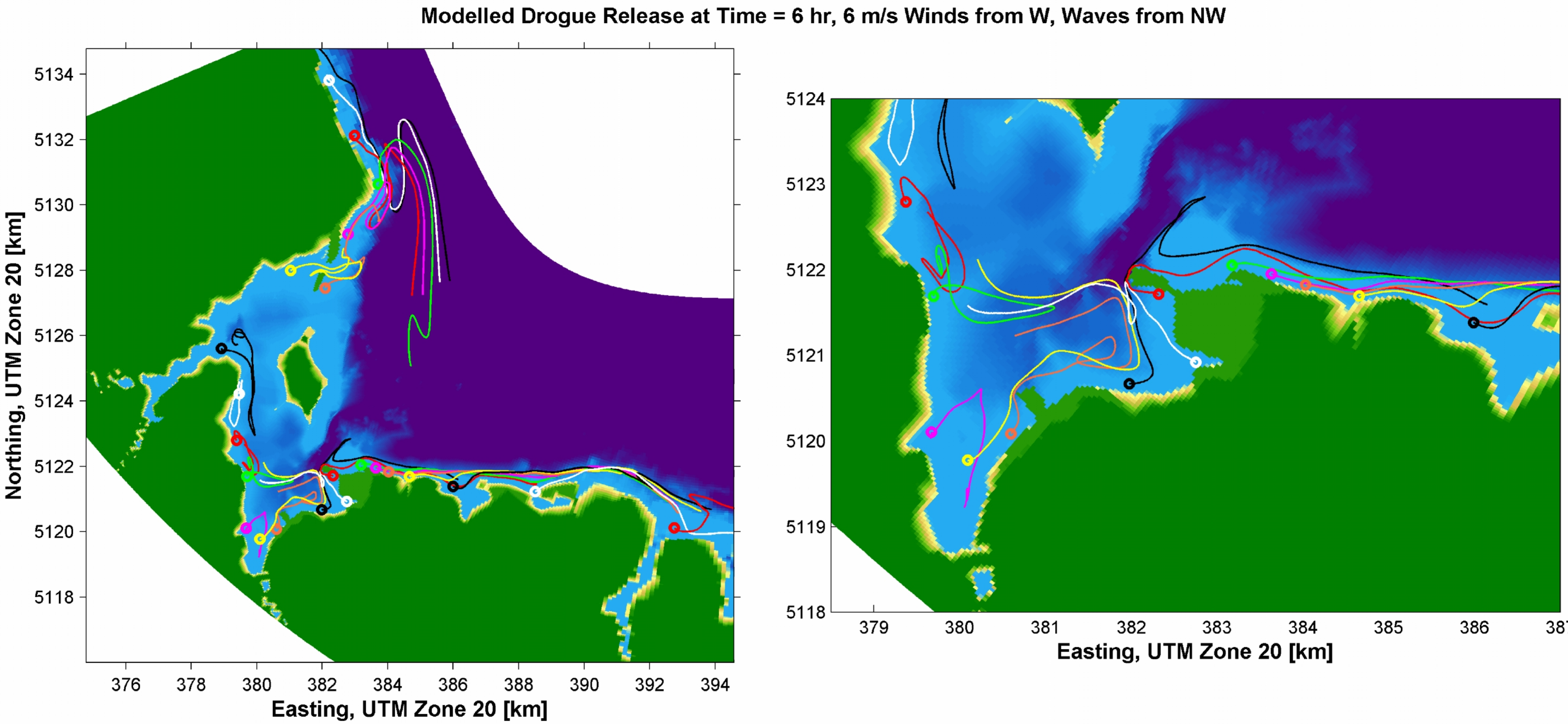


Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

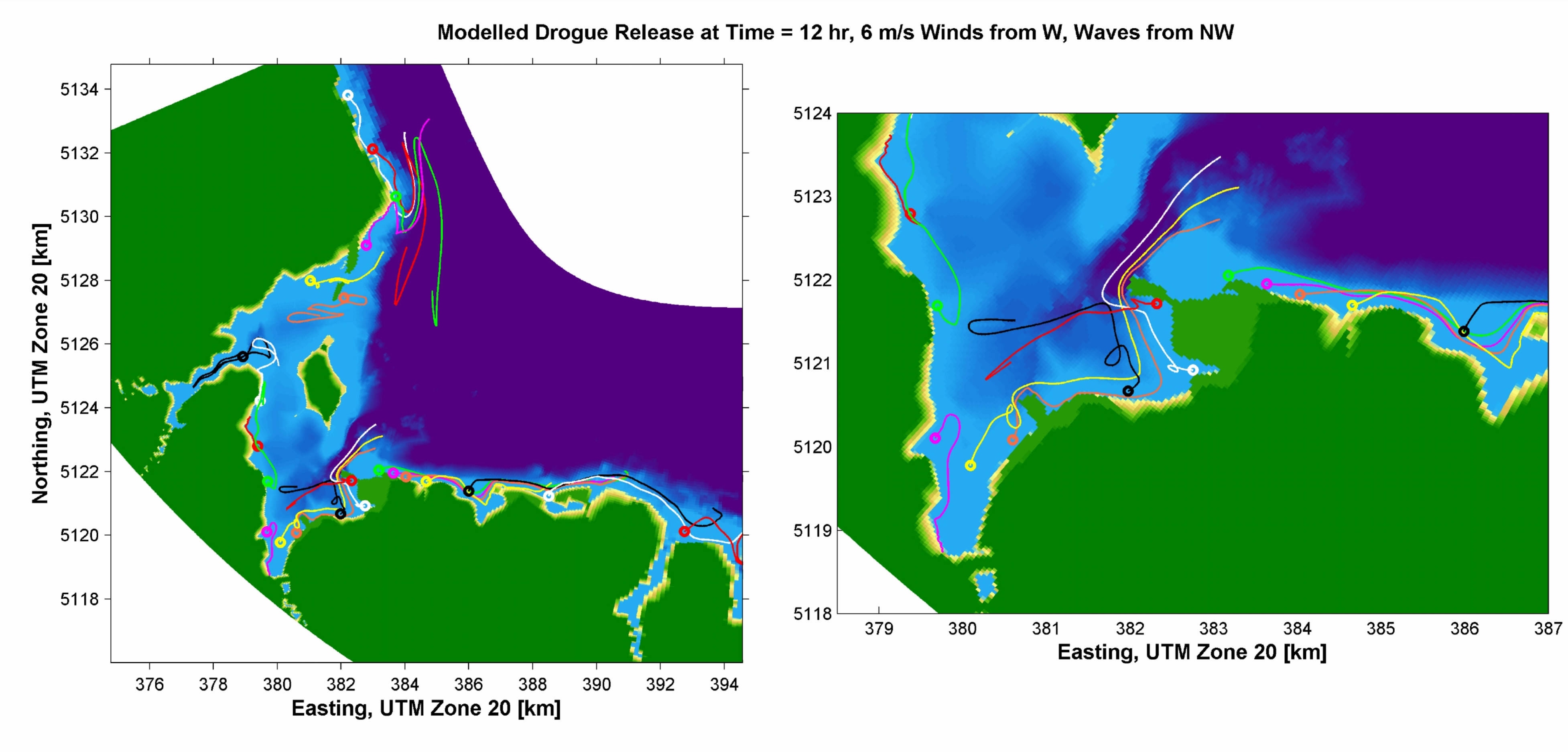
Modelled Drogue Release at Time = 0 hr, 6 m/s Winds from W, Waves from NW



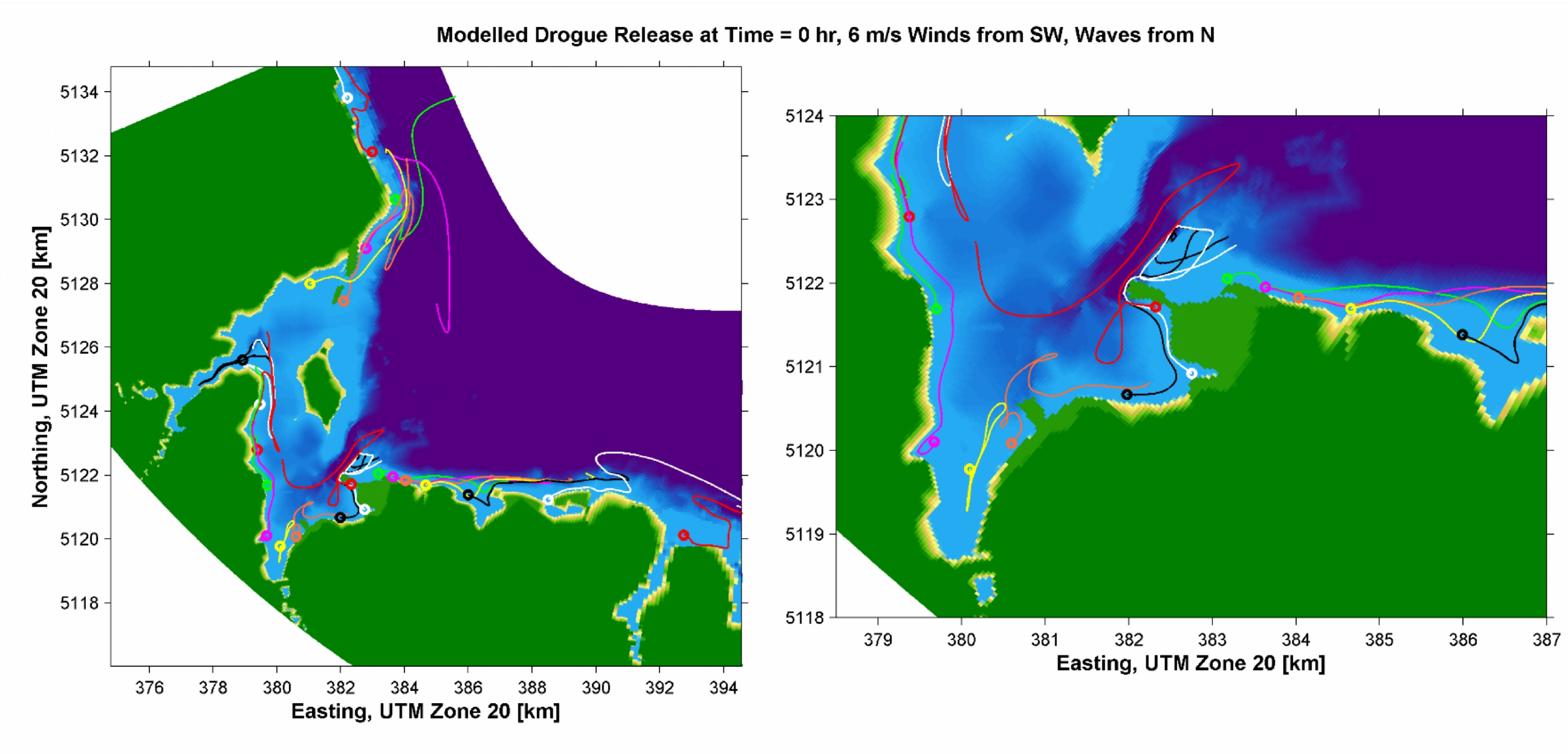
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.



Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

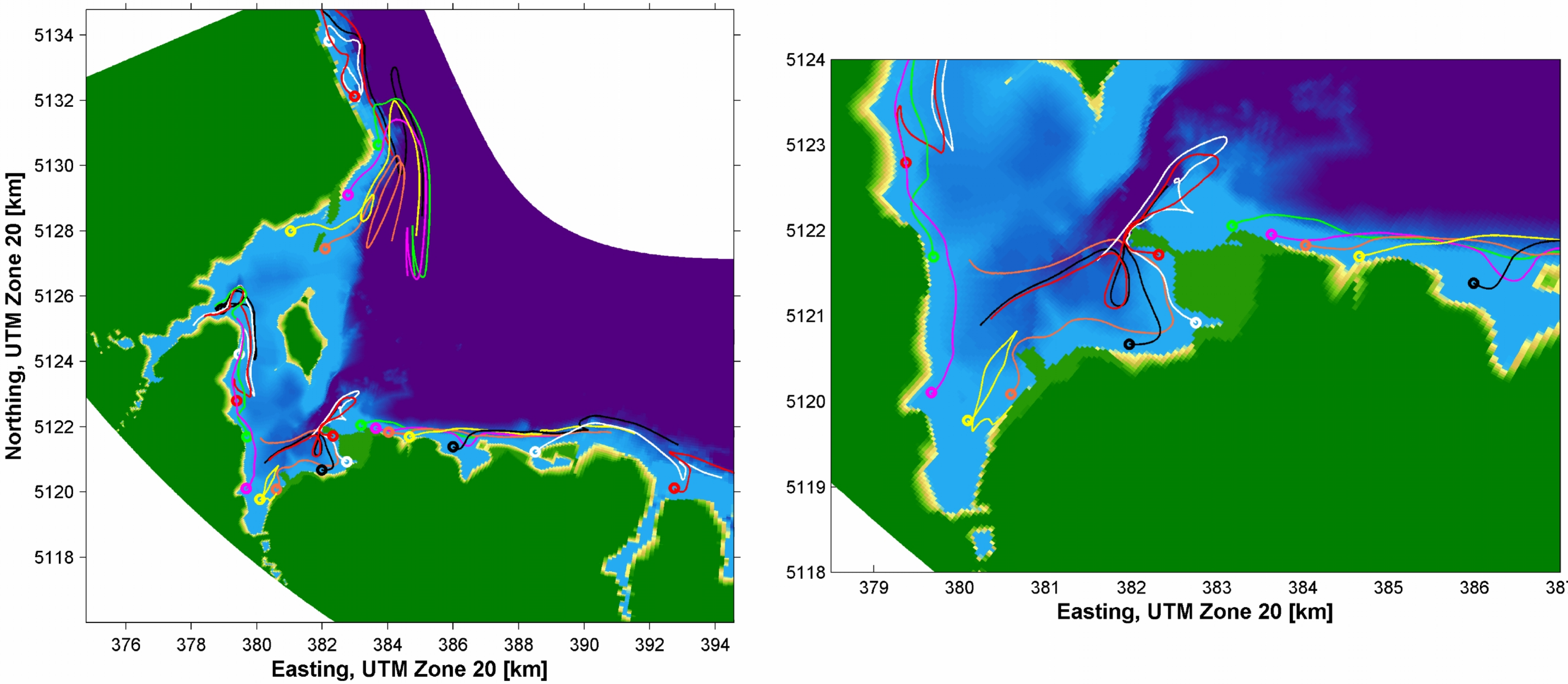


Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.



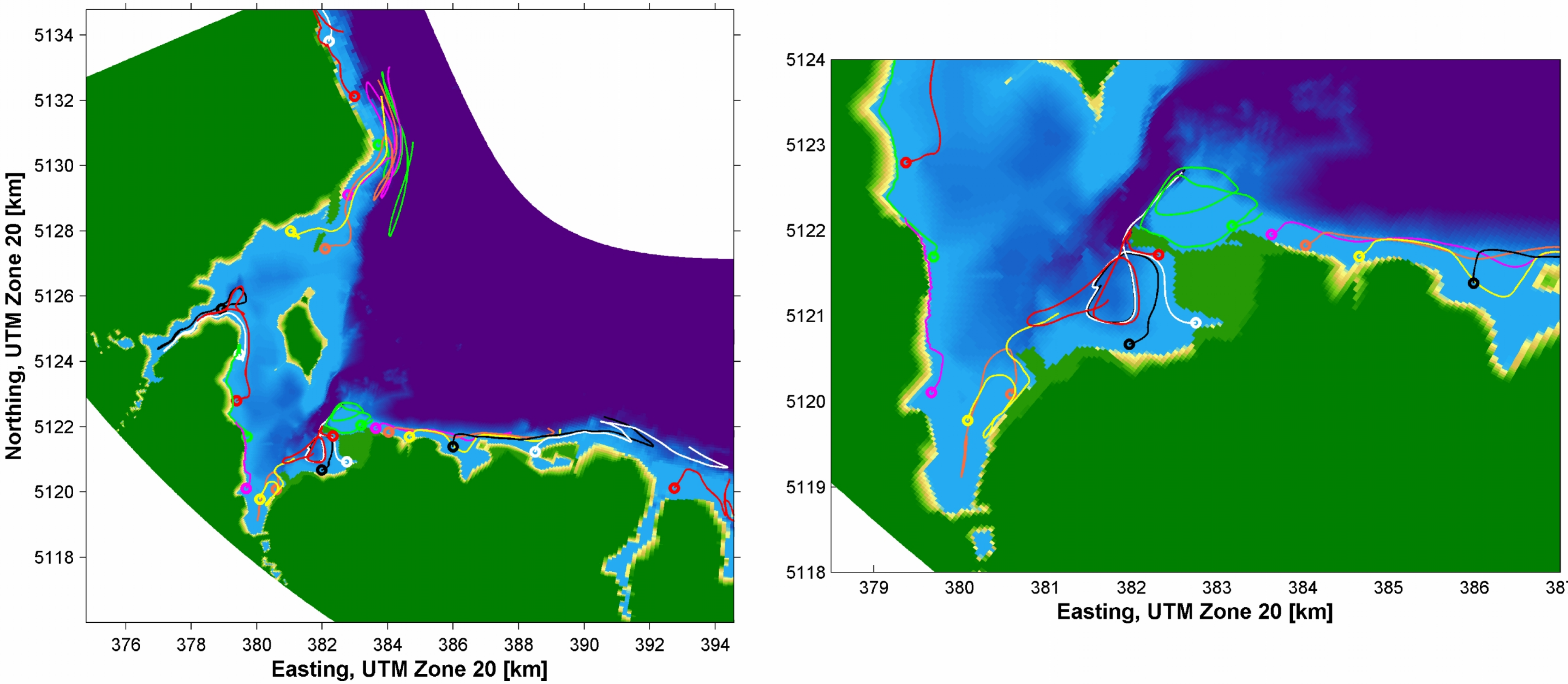
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

Modelled Drogue Release at Time = 6 hr, 6 m/s Winds from SW, Waves from N



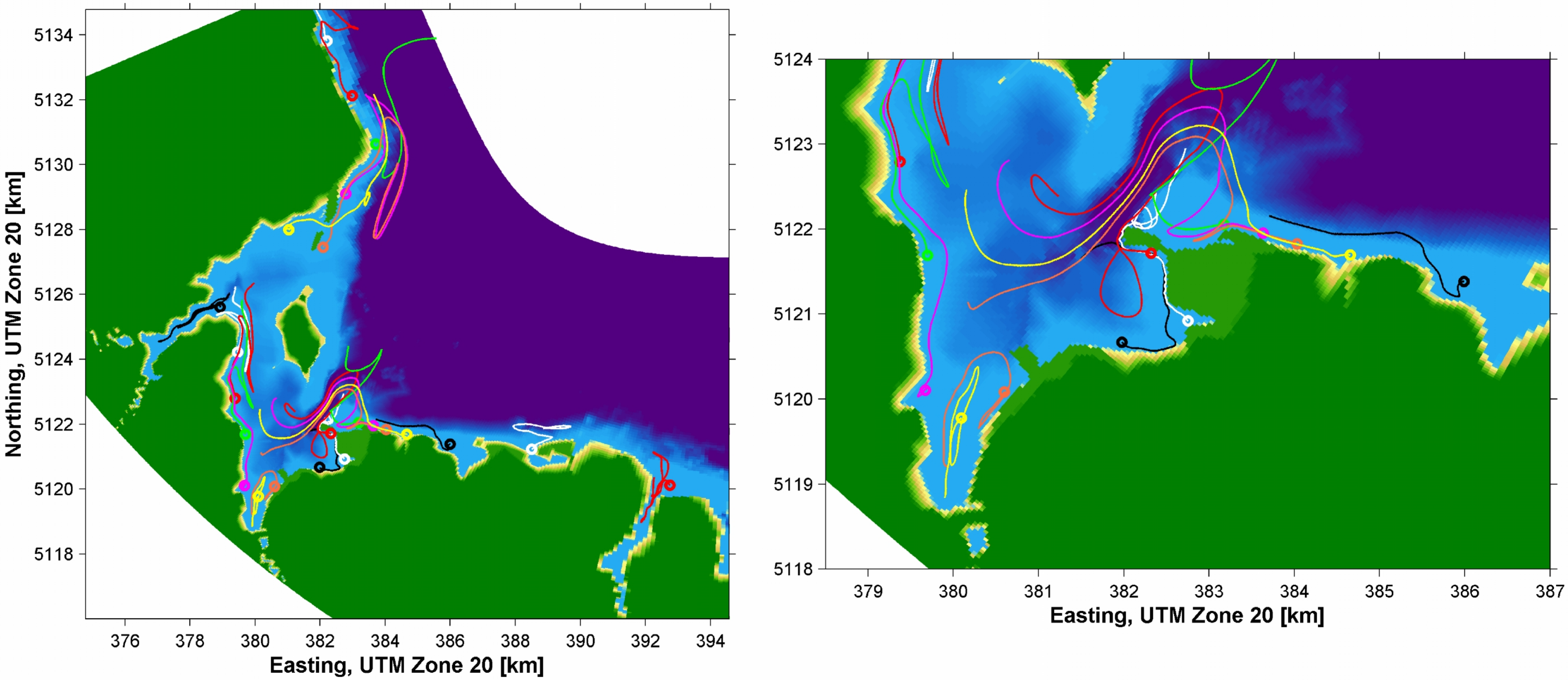
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

Modelled Drogue Release at Time = 12 hr, 6 m/s Winds from SW, Waves from N



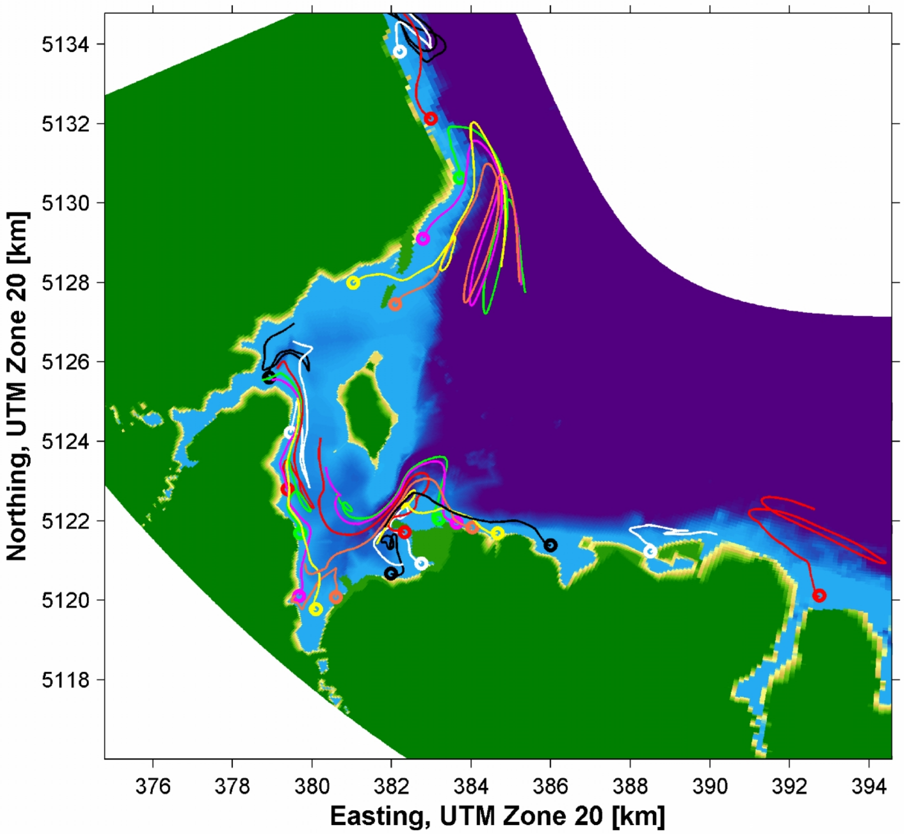
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

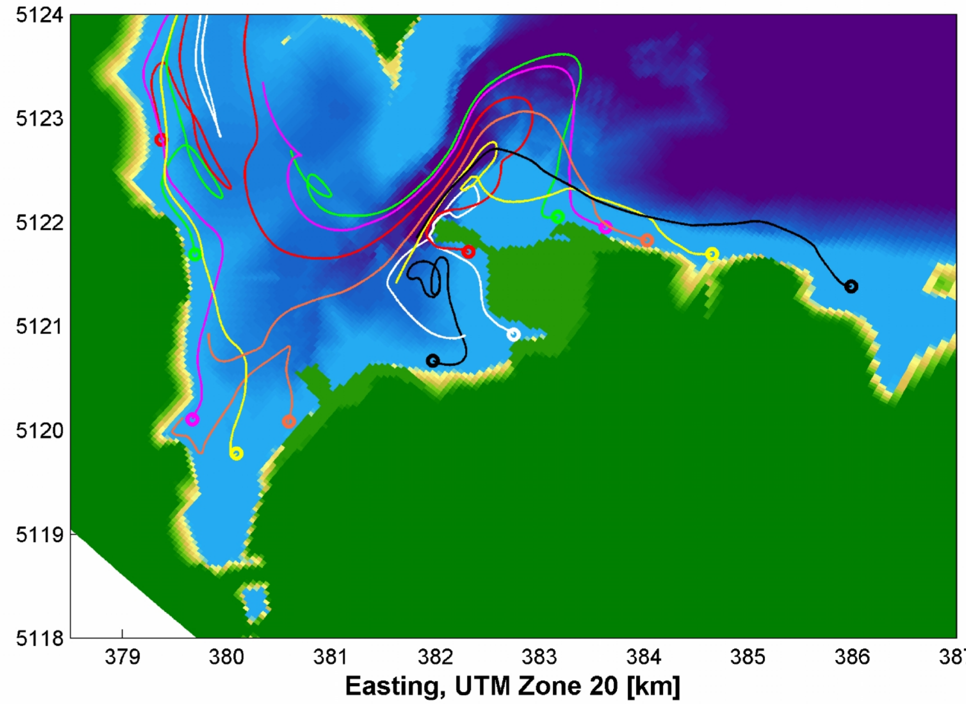
Modelled Drogue Release at Time = 0 hr, 6 m/s Winds from S, Waves from N



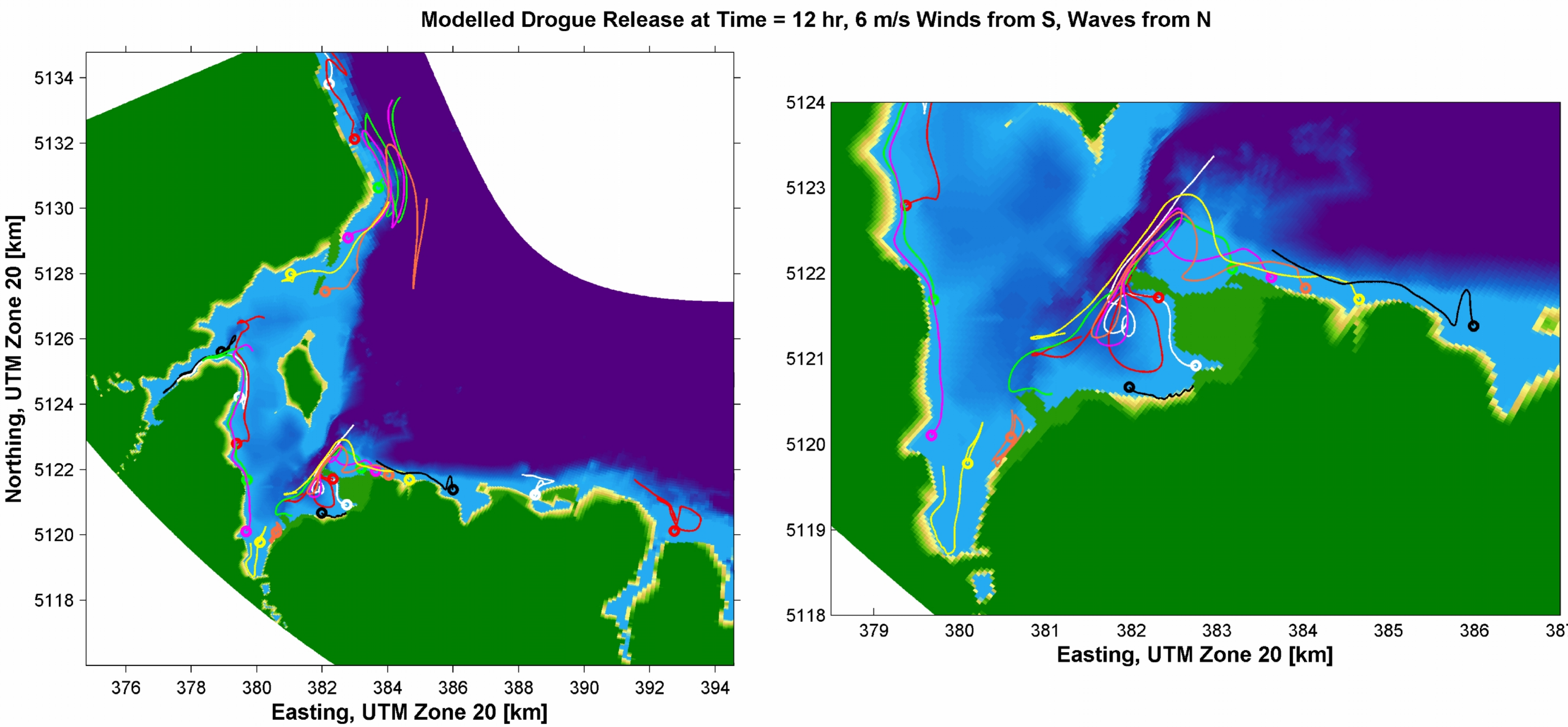
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

Modelled Drogue Release at Time = 6 hr, 6 m/s Winds from S, Waves from N



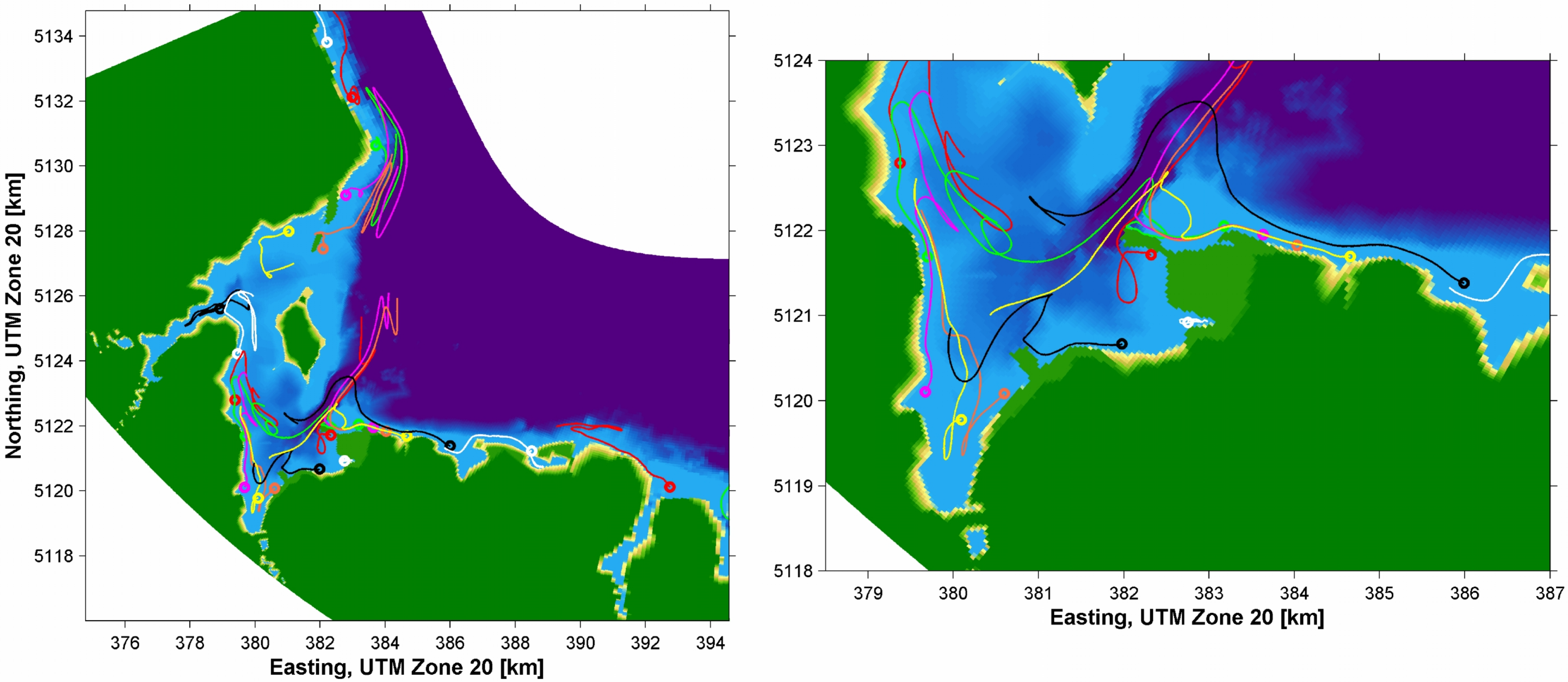


Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

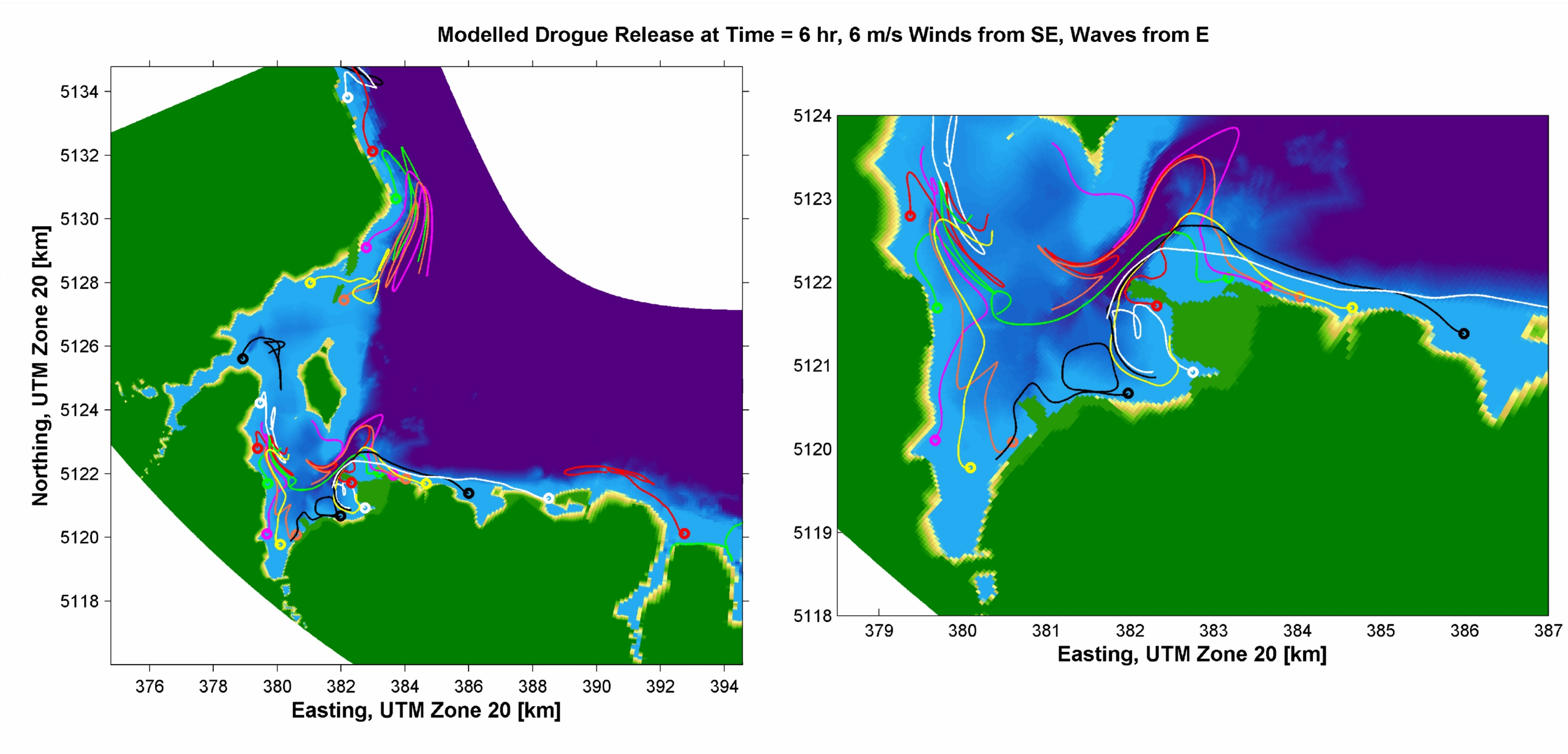


Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

Modelled Drogue Release at Time = 0 hr, 6 m/s Winds from SE, Waves from E

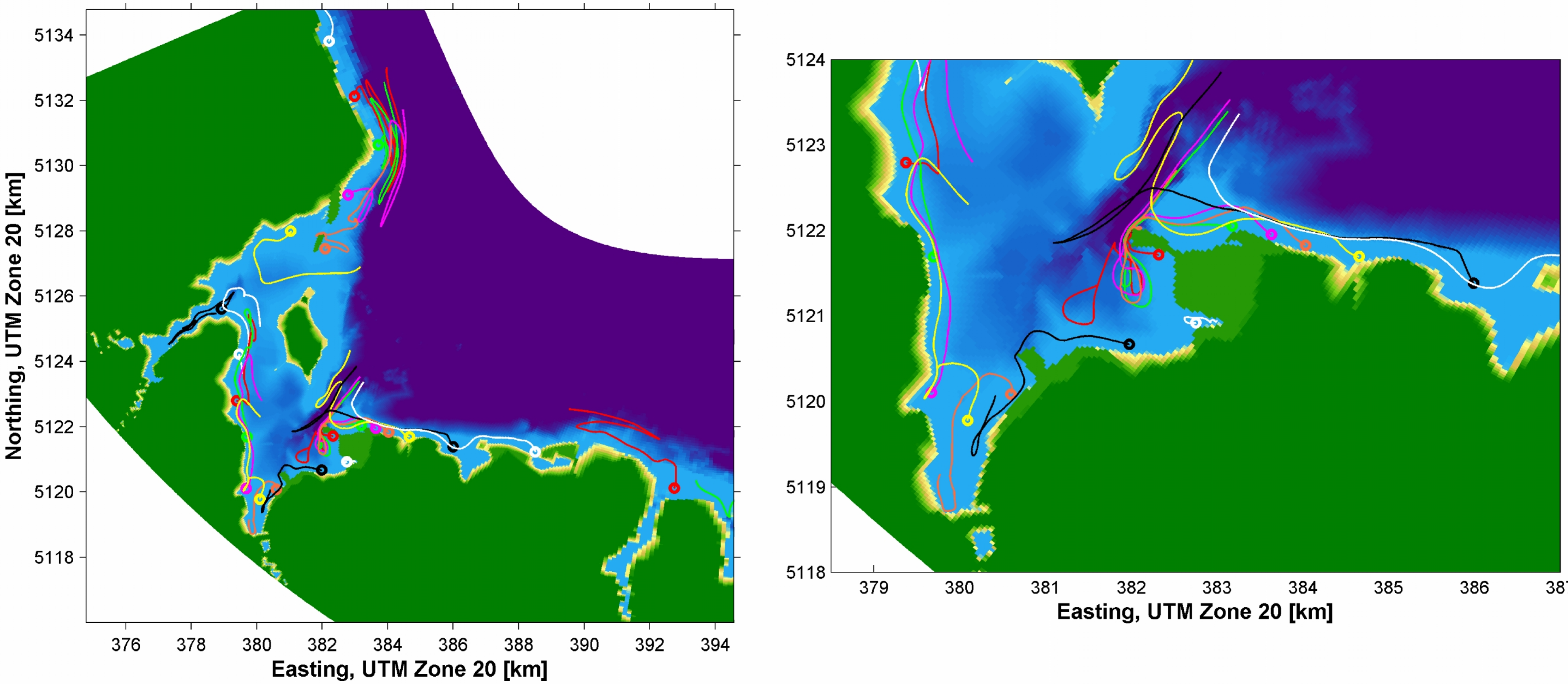


Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.



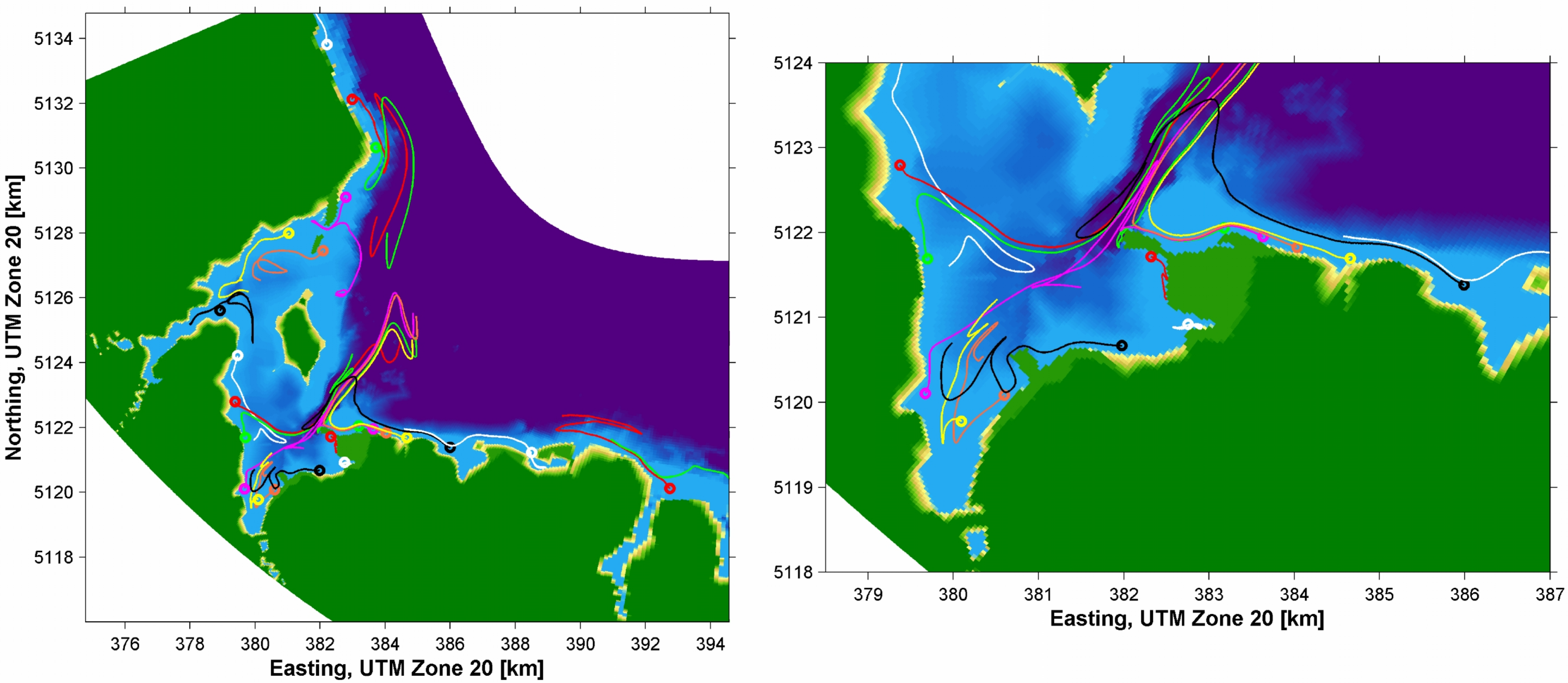
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

Modelled Drogue Release at Time = 12 hr, 6 m/s Winds from SE, Waves from E



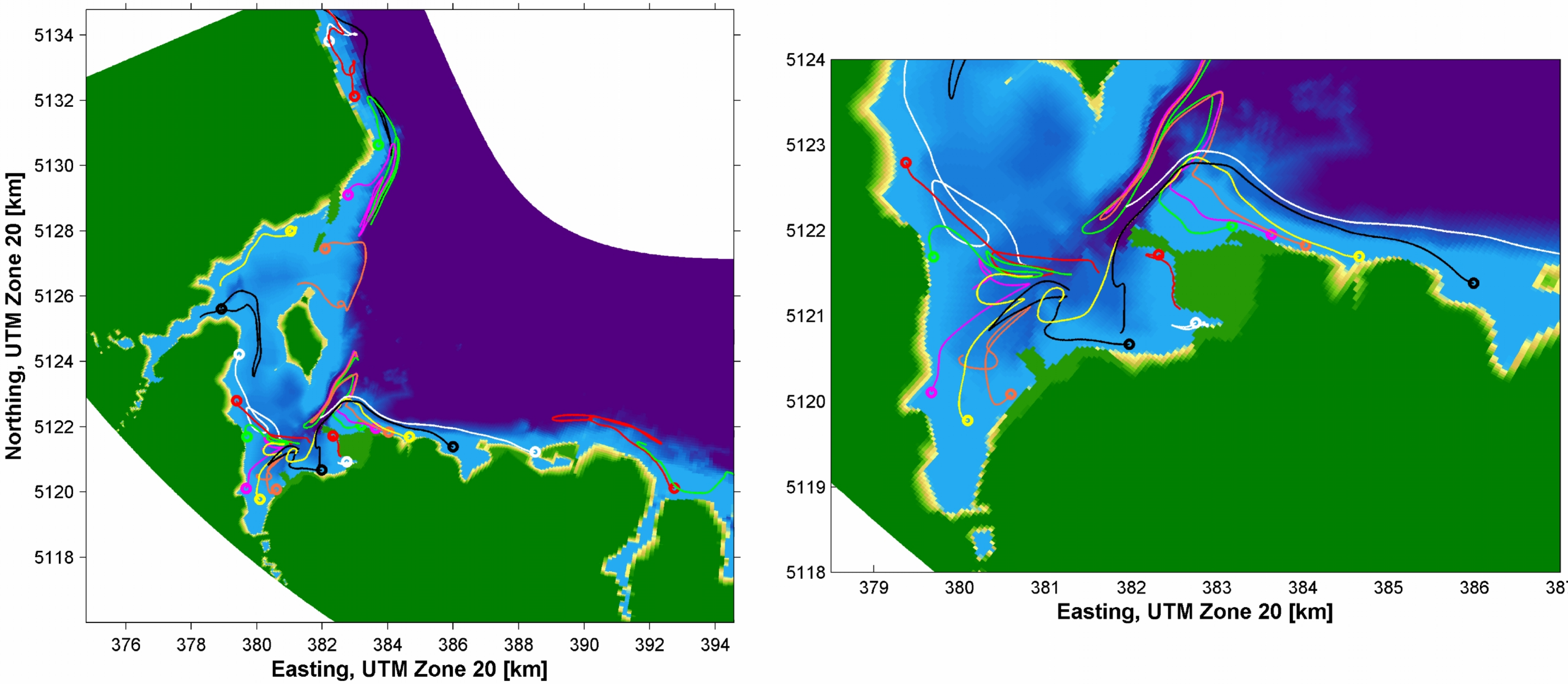
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

Modelled Drogue Release at Time = 0 hr, 6 m/s Winds from E, Waves from E



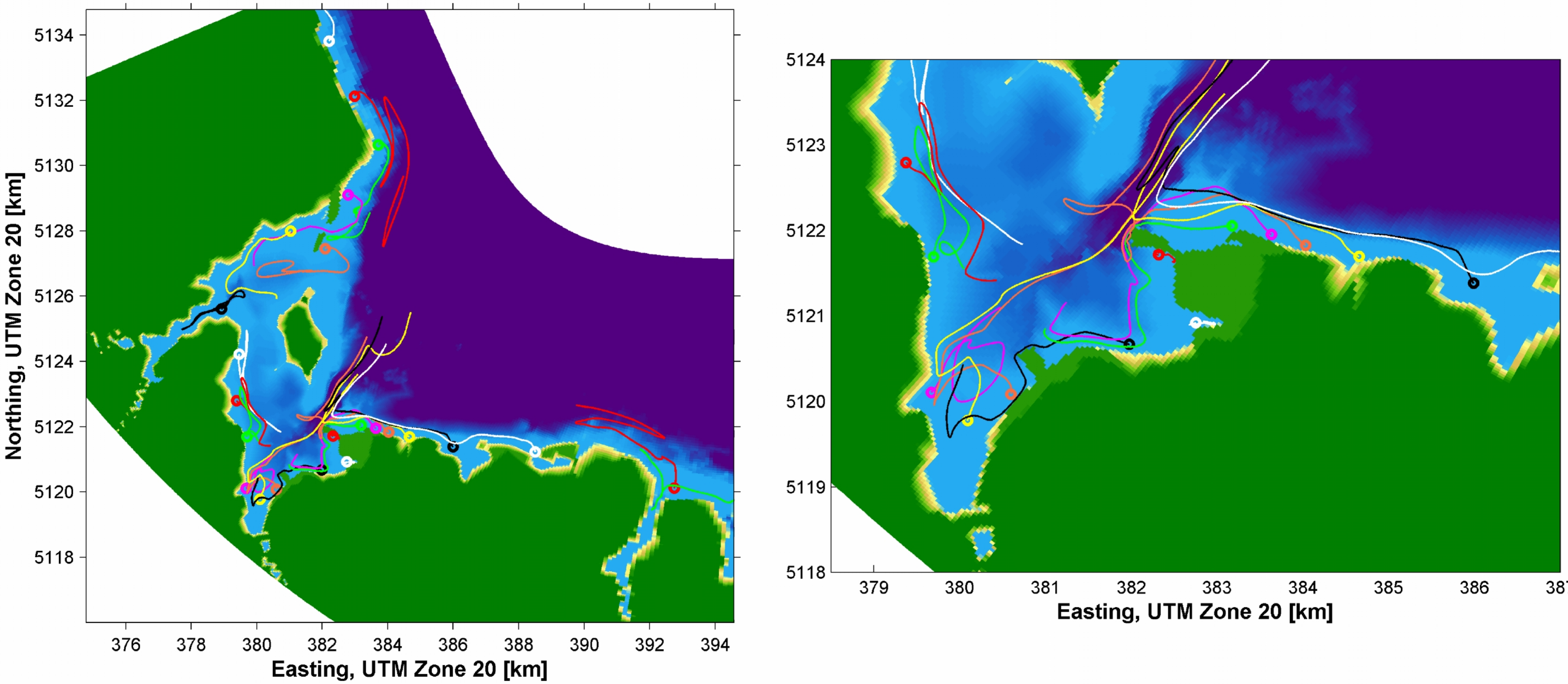
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

Modelled Drogue Release at Time = 6 hr, 6 m/s Winds from E, Waves from E



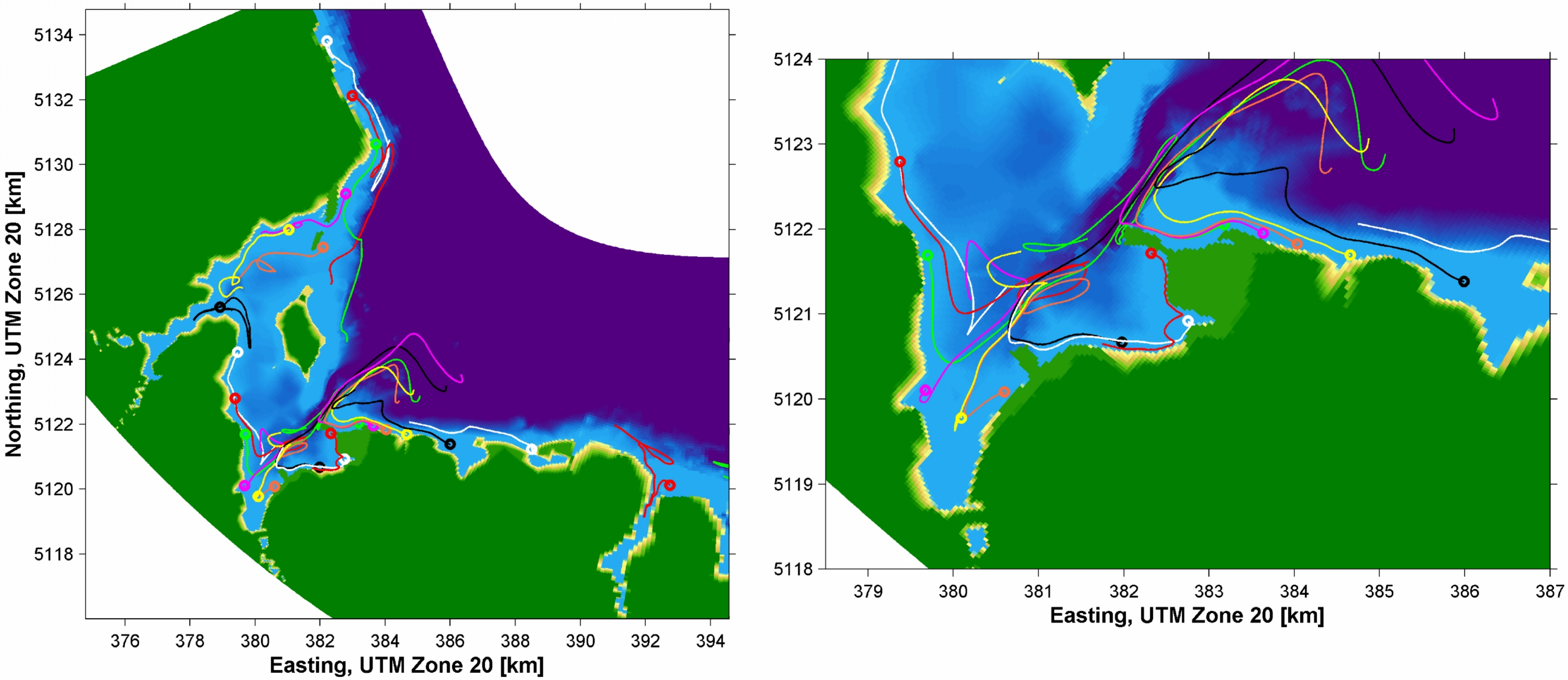
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

Modelled Drogue Release at Time = 12 hr, 6 m/s Winds from E, Waves from E

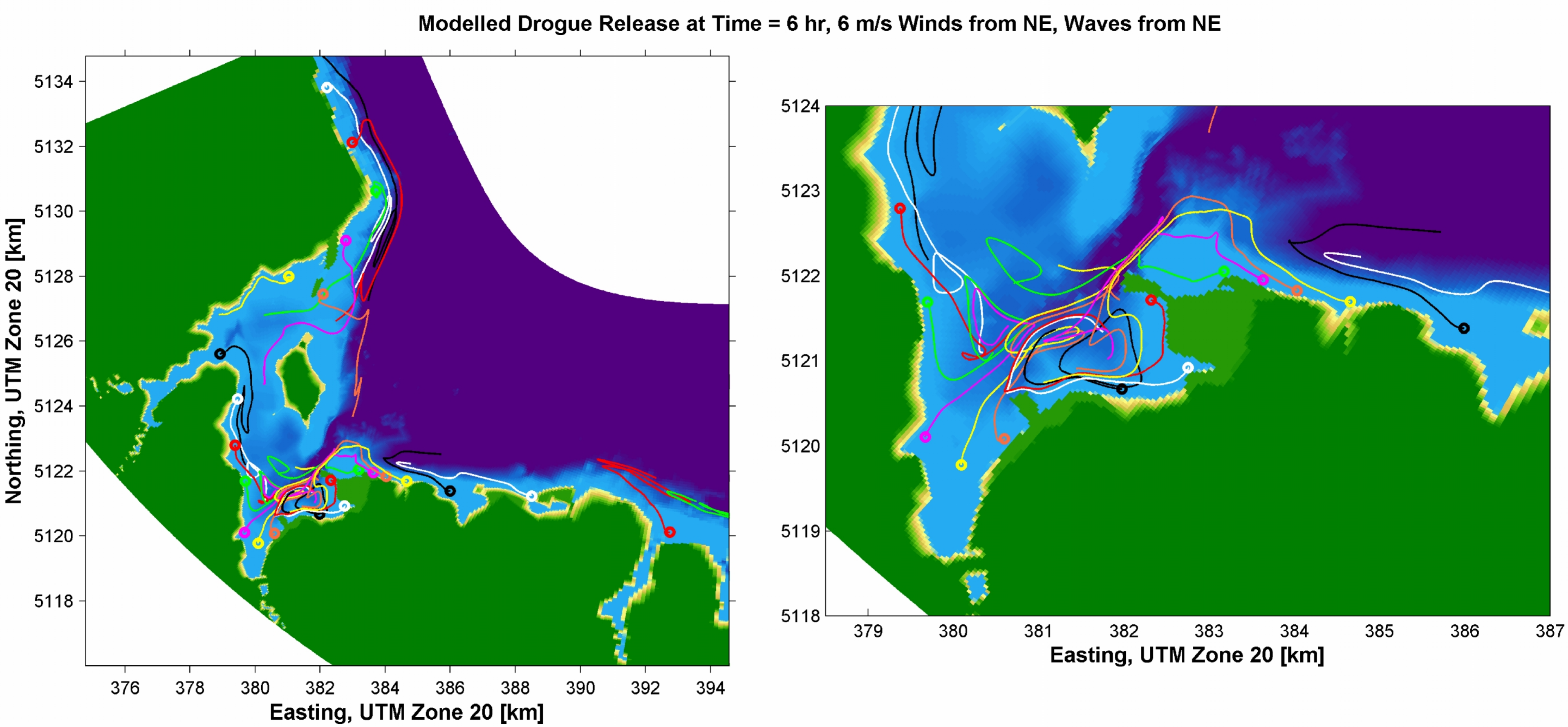


Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

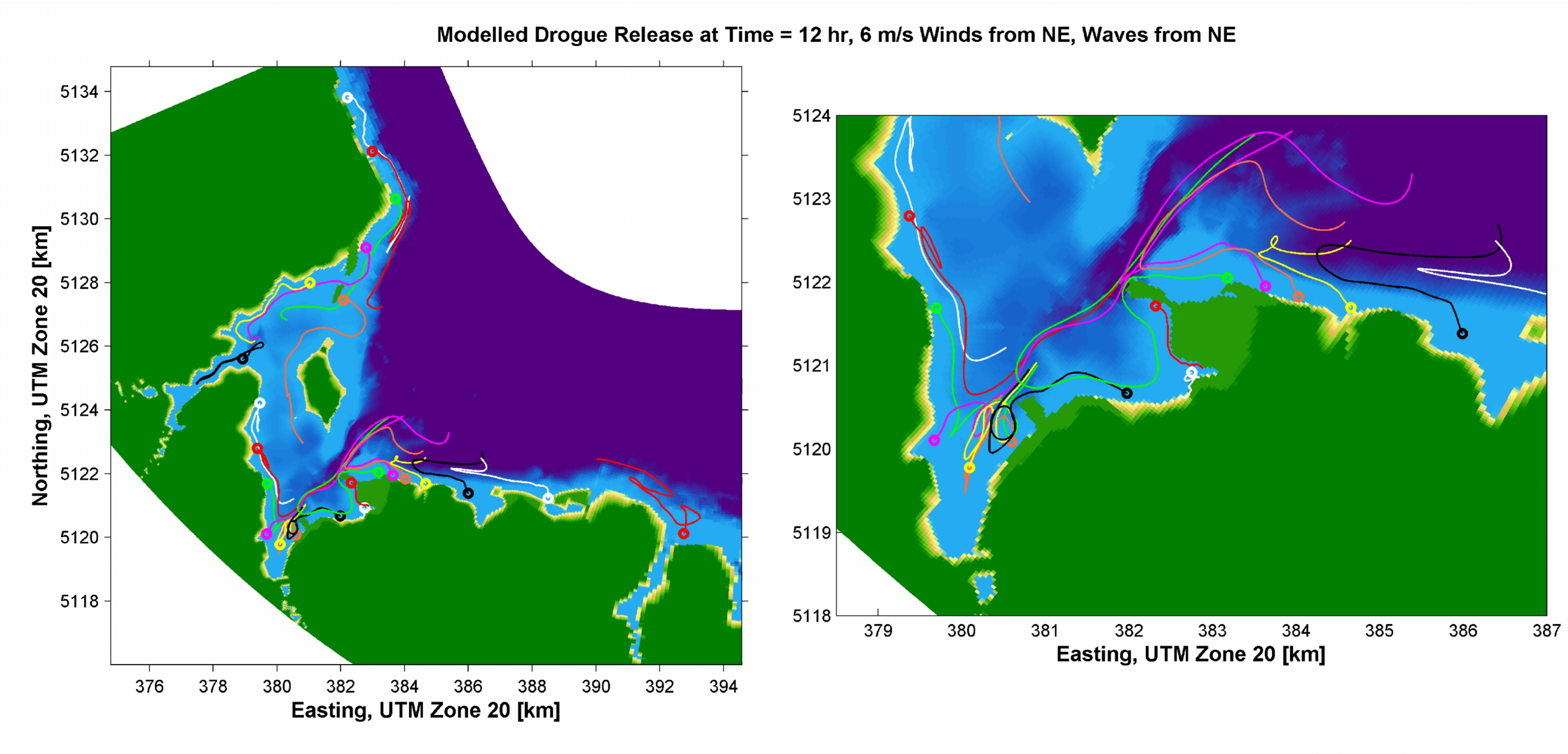
Modelled Drogue Release at Time = 0 hr, 6 m/s Winds from NE, Waves from NE



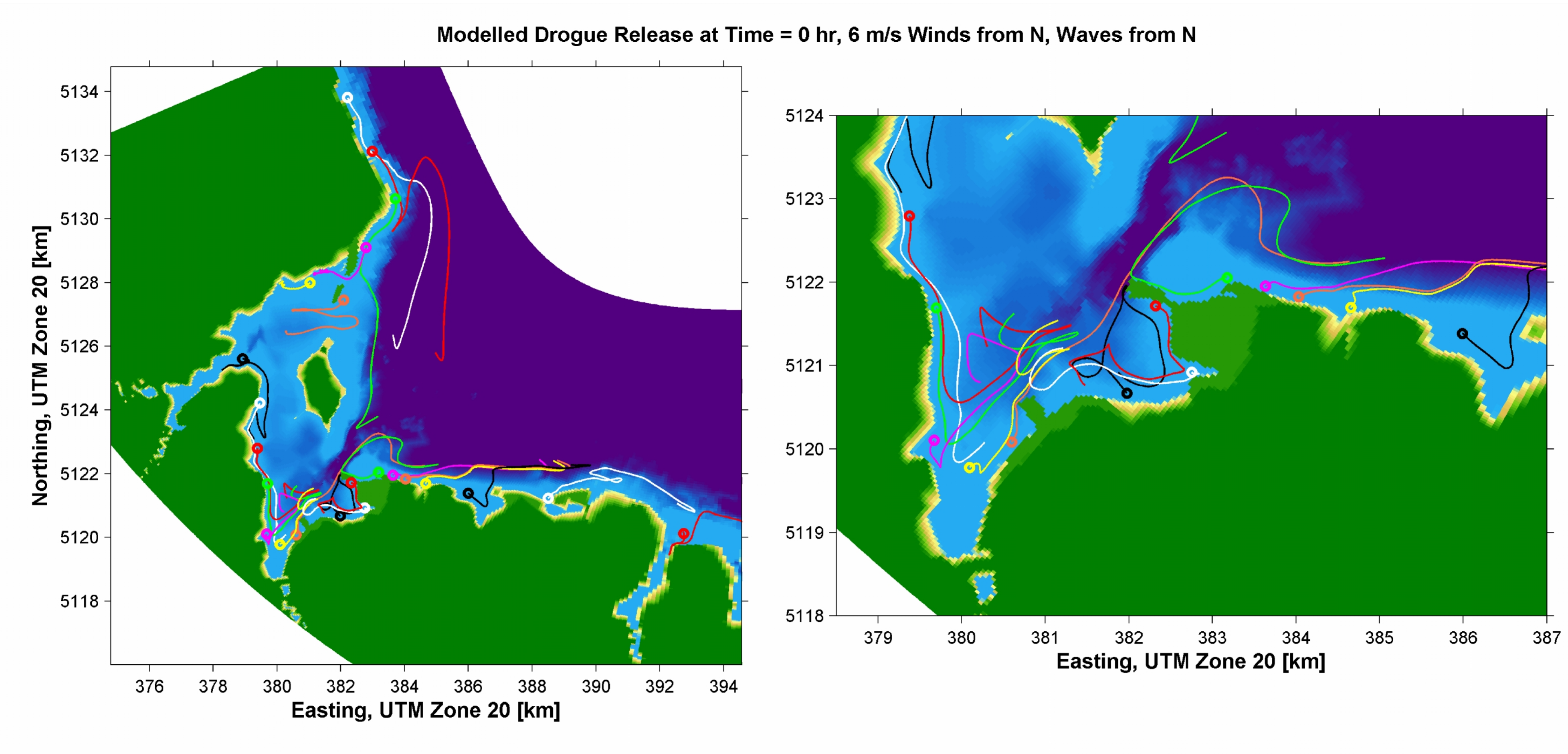
Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.



Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

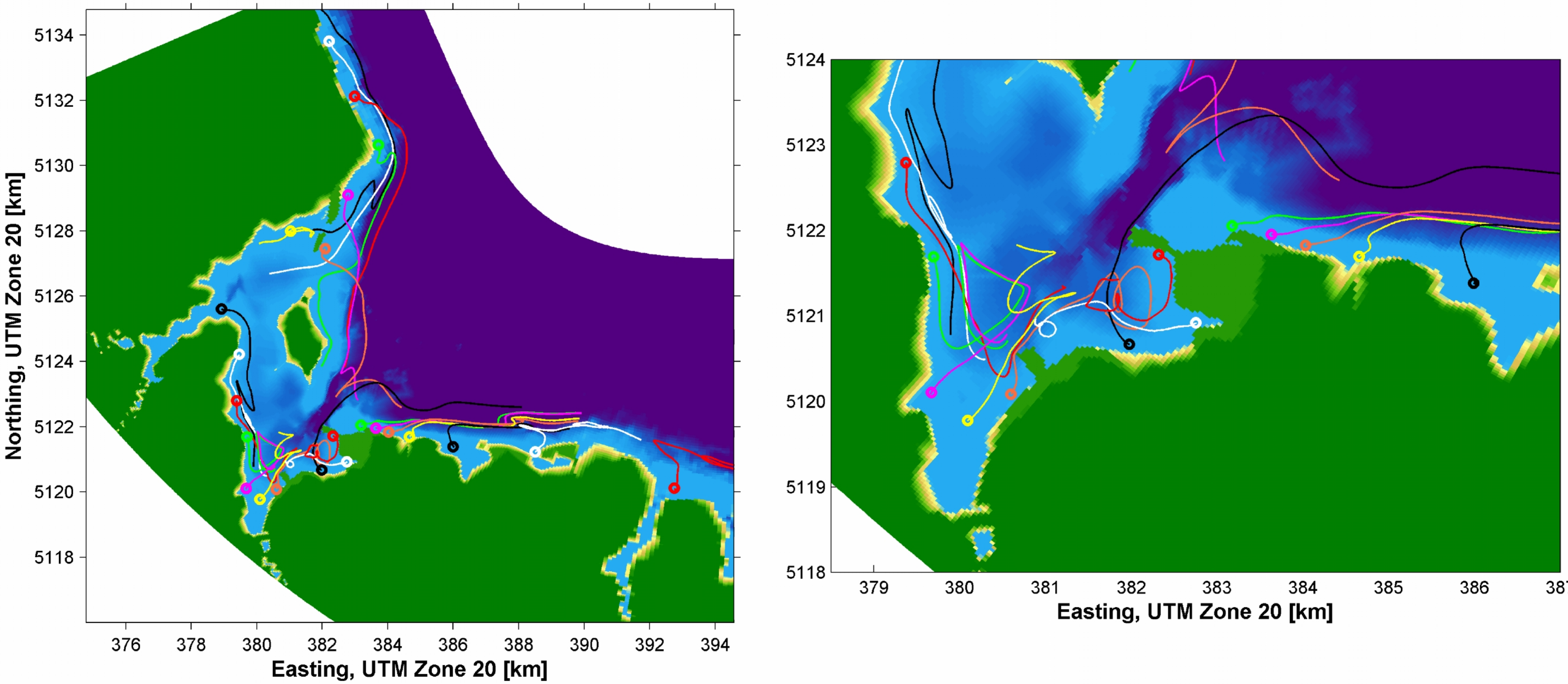


Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

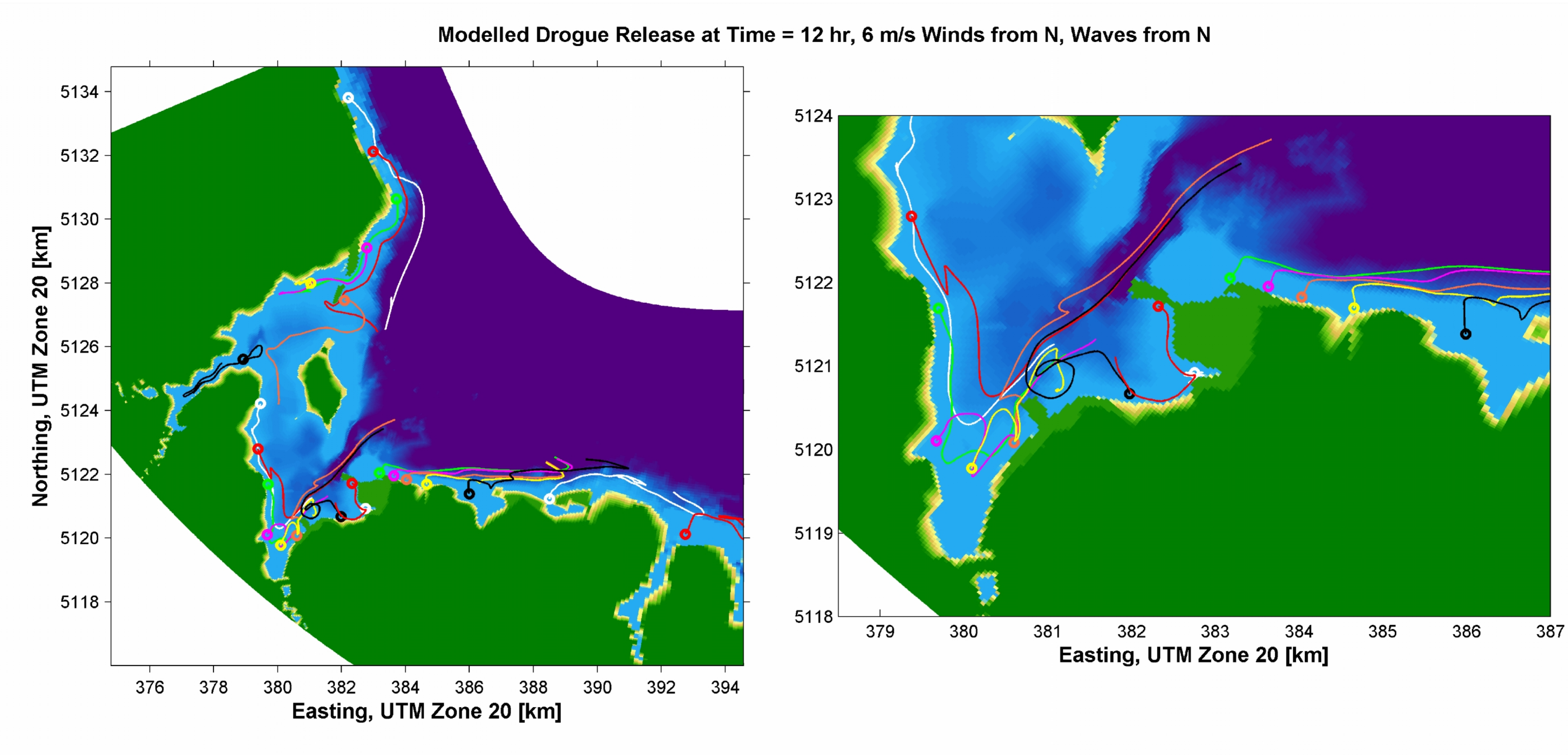


Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.

Modelled Drogue Release at Time = 6 hr, 6 m/s Winds from N, Waves from N



Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.



Note: Drogue trajectories span a 24 hour period. The initial drogue release points are indicated with circle markers.