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# Lagrangian and Eulerian estimates of circulation in the lee of Kapiti Island, New Zealand

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ABSTRACT

Lagrangian drifters, moored acoustic Doppler current meters and hydrographic observations are combined with wind observations to describe the mean and variable nature of flow around Kapiti Island, New Zealand. Thirteen day-long deployments of up to six Lagrangian drifters show the mean flow is to the southwest, with evidence of stronger flows in the channel separating the island from the mainland, and an island wake in the lee of the island. Vortices in this island wake may be tidally driven. Scaling considerations suggest the flow is strong enough that tidal-generated vortices are shed on each tidal cycle. Both the drifters and mooring data suggest that the d'Urville Current around Kapiti Island has a significant wind-driven component. During north-westerlies, the drifters tend to hug the coast, and south-eastwards flows in the Rauoterangi Channel are accelerated. We suggest the observed correlation is the local expression of a South Taranaki basin scale response to the winds.



## 1. Introduction

Kapiti Island in the South Taranaki Bight/Cook Strait region of New Zealand is 9.6 km long by 2.2 km wide and is separated from the North Island by the 5.6 km wide Rauoterangi Channel (Fig. 1). As well as being a popular recreational area, the Rauoterangi Channel contains the Kapiti Marine Reserve, which has been presumed to be a nursery for some species such as blue cod or butterfly fish (Stewart and MacDiarmid, 2003).

The general characteristics of the coastal currents in the South Taranaki Bight were established some time ago from drift card measurements (Brodie, 1960; Heath, 1969) and sporadic radio-tracked Lagrangian drifter measurements (Sanderson, 1979). Subtropical water in the d'Urville Current flows northwards along the west coast of the South Island and then into Cook Strait and retroflects, so that the mean flow around Kapiti Island is to the southwest into Cook Strait. Upwelling of cold water to the sea surface off west coast of the South Island was observed by Garner (1961) and this water appears in the d'Urville Current (Bowman et al., 1983a). Bowman et al. (1983b) observed the upwelling as an elongated cold-core plume extending northwards into the South Taranaki Bight. Cyclonic eddies in this upwelling plume appear to be stable for up to two weeks, allowing increased primary production, followed by increased zoo-plankton abundances and supporting higher trophic levels (primarily squid) (Foster and Battaerd, 1985). The d'Urville Current may be variable in time (Bowman et al., 1983b; Bowman et al., 1983c), and perhaps influenced by coastal trapped waves originating from wind forcing in Cook Strait (Cahill et al., 1991).

The South Taranaki Bight and Cook Strait is a region known to have strong tides (Vennell, 1994). Tidal circulation in the region can be inferred from an existing numerical tidal model (Walters et al., 2001), although validation of this model has been limited (Stanton et al., 2001). There have been few systematic studies of the non-tidal circulation in the region, so that it would be safe to say that the exact nature of the flows in the region, and around the island in particular, is largely unknown.

Studies elsewhere have shown that tidally-rectified eddies entrained in the lee of islands may be effective in entraining plankton and fish larvae (e.g., Furukawa and Wolanski, 1998; Wolanski et al., 1996), and in the summers of 2007 and 2008 a series of experiments was made around Kapiti Island using Lagrangian drifters to investigate possible entrainment of fish larvae in presumed tidally-generated vortices (Shima et al. in prep.). Up to six Lagrangian drifters were released near the island in 13 separate deployments over the two summers with each deployment lasting about one day. About half the drifters had larval traps attached that were designed to collect fish larvae during the hours of darkness. In addition to the drifters, two acoustic Doppler current profilers (ADCP) were moored near the island for a month, vertical profiles of temperature and salinity were made around the island on three separate days, and a limited number of vessel-based ADCP surveys were made.

Lagrangian drifter studies are becoming more common in physical transport studies, and perhaps even more so in biophysical work (e.g., Rasmussen et al., 2009). The data

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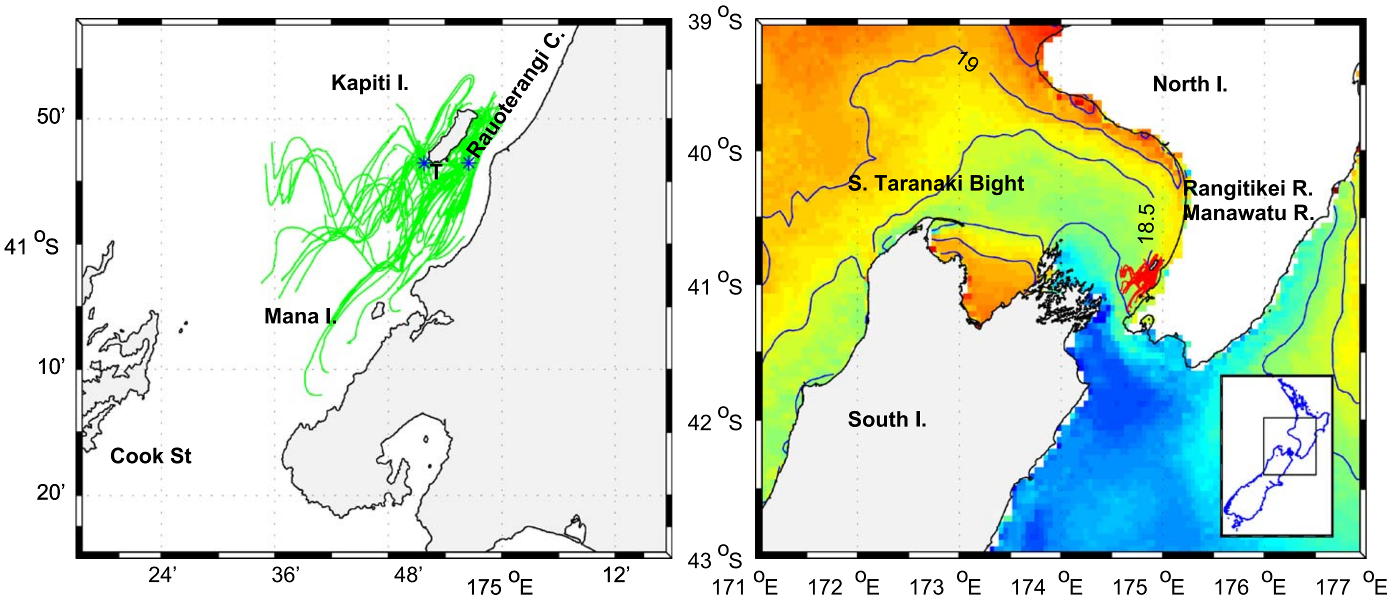


**Fig. 1.** Left-hand panel: Map of study region showing the trajectories of all drifters released during the study (green lines). The locations of the Rauoterangi Channel and Tarapunga Shoal ('T') moorings have been marked with asterisks. Right-hand panel: Mean 2001–2005 February sea surface temperature (SST) from NOAA Pathfinder climatology. Inset shows New Zealand. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

presented here provide a better understanding of the mean and variability in the flow around Kapiti Island. The purpose of this article is to quantify Lagrangian and Eulerian flow statistics in the lee of an island. Questions posed include what are the mean, wind-driven and tidal flows during the experiments. Furthermore, we also document evidence of tidal vortices and make some estimate of the horizontal eddy diffusivity.

## 2. Methods

### 2.1. Drifters

The Lagrangian drifters used in this study consist of a surface float containing two internally-recording GPS receivers and a radio-telemetry link attached to a holey-sock drogue 1 m in diameter, 5 m long, set about 1.5 m below the surface float. The surface floats were ballasted with lead weights so that they had minimal exposure to the wind. Slightly negatively buoyant larval light traps (Shima et al. in prep.) were attached above the drogue to some drifters during each experiment. A guide developed as part of the WOCE programme is to seek a 40:1 ratio of submerged to un-submerged cross-sectional area in order to minimise windage (Niiler et al., 1995). The present design had a slightly under-sized drogue for the surface floats. However, the addition of a light trap increased the area of the drag element.

The drifters were deployed and recovered from an 8-m research vessel equipped to track the drifter telemetry. Because of the small size of the boat, deployments and recoveries were weather-dependent, and experiments were conducted only when the forecast winds were less than 25 knots.

The first deployment of drifters took place near the southern end of Kapiti Island on 16 January 2007 (NZ Summer Time). All but one of the drifters were then redeployed *in situ*, and the drifters were finally retrieved on 18 January 2007 about 30 km offshore. This distance was judged too far offshore for safe boat operations, so in all further experiments, the drifters were recovered about 20 hours after deployment.

Subsequently, drifters were deployed 6 more times in 2007, and 5 times in the summer of 2008. There were a total of 13 deployments, the first two were combined to produce one experiment, whereas the remaining deployments are regarded as separate experiments—thus there were 12 experiments. Initial positions varied based on the requirements of the fish larvae tracking experiments.

**Table 1**
Deployment times, durations, and number of drifters for the 12 drifter experiments.

| Deployment date (NZ Summer Time) | Duration (hours) | Number of drifters |
|---|---|---|
| 16-Jan-2007 19:00 | 37 | 6 |
| 18-Jan-2007 10:20 | 23 | 4 |
| 24-Feb-2007 12:40 | 21 | 6 |
| 25-Feb-2007 12:05 | 20 | 4 |
| 28-Feb-2007 17:21 | 15 | 6 |
| 02-Mar-2007 10:11 | 23 | 6 |
| 03-Mar-2007 10:09 | 22 | 5 |
| 15-Jan-2008 10:08 | 23 | 2 |
| 17-Jan-2008 12:01 | 20 | 4 |
| 09-Feb-2008 14:48 | 21 | 6 |
| 12-Feb-2008 12:52 | 21 | 6 |
| 13-Feb-2008 12:42 | 20 | 6 |

Data from the primary GPS unit were used when available. Occasionally the primary unit failed for various reasons, and data from the backup GPS unit were processed, although these are of lesser quality. The primary GPS data were recorded with a discretization interval of ~8 m, which is larger than the inherent uncertainty in the GPS measurement (~2–3 m), whereas the backup GPS data showed rms error of about 50 m.

Some drifters went aground—these were excluded from this analysis, and in all there were a total of 61 useable drifter trajectories. Table 1 lists the start time, approximate duration and number of useable drifters in each experiment.

### 2.2. Vessel-mounted ADCP

During 2–4 March 2007, vessel-based ADCP flow measurements were made with a RDI 3 kHz Workhorse Sentinel profiler.