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Temporal variability of marine debris deposition at Tern Island in the Northwestern Hawaiian Islands

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ABSTRACT

A twenty-two year record of marine debris collected on Tern Island is used to characterize the temporal variability of debris deposition at a coral atoll in the Northwestern Hawaiian Islands. Debris deposition tends to be episodic, without a significant relationship to local forcing processes associated with winds, sea level, waves, and proximity to the Subtropical Convergence Zone. The General NOAA Operational Modeling Environment is used to estimate likely debris pathways for Tern Island. The majority of modeled arrivals come from the northeast following prevailing trade winds and surface currents, with trajectories indicating the importance of the convergence zone, or garbage patch, in the North Pacific High region. Although debris deposition does not generally exhibit a significant seasonal cycle, some debris types contain considerable 3 cycle/yr variability that is coherent with wind and surface pressure over a broad region north of Tern.

1. Introduction

The Northwestern Hawaiian Islands (NWHI) are one of the most remote archipelagos in the world, featuring pristine coral reef ecosystems and numerous species unique to the region (Fig. 1). The NWHI have been protected as part of the Papahānaumokuākea Marine National Monument since 2006, yet the region faces ongoing threats associated with the deposition of marine debris along the entire island chain (Selkoe et al., 2008). North Pacific marine debris arrives from a wide range of global sources (Sebille et al., 2012), resulting in numerous detrimental impacts in the NWHI such as entanglement, ingestion, and the bioaccumulation of pollutants (Donohue et al., 2001; Boland and Donohue, 2003; Sheavly and Register, 2007). In this study we consider temporal variations and potential mechanisms responsible for debris deposition at Tern Island, a coral island in French Frigate Shoals of the NWHI (Fig. 2).

Marine debris in the North Pacific tends to congregate in a broad southwest-to-northeast oriented band located north of the NWHI and in garbage patches, as evident in ship-based siting surveys (Mio and Takehama, 1988) and in Lagrangian model simulations (Wakata and Sugimori, 1990; Kubota, 1994; Maximenko et al., 2012; Goldstein et al., 2013; Sebille et al., 2012). Debris congregation is due to convergent wind-driven Ekman transport between the trade and westerly wind bands (Kubota, 1994), in a region known as the Subtropical Convergence Zone (STCZ). The STCZ exhibits seasonal meridional displacements, with a mean winter position between 23 and 28°N and summer position of 34 to 37°N (Roden, 1975) (Fig. 1). The STCZ features the Transition Zone Chlorophyll Front (TZCF), which is indicated by the 0.2 mg m^{-3} surface cholorphyll-a isopleth (Polovina et al., 2001), as well as the 18 °C sea surface temperature (SST) isotherm (Bograd et al., 2004; Howell et al., 2012) that can be used as proxies for the STCZ position. Aerial surveys confirm that high debris concentrations are in the STCZ, just north of the TZCF, during the spring and early summer (Pichel et al., 2007). The nutrient rich STCZ is an important forage habitat for various marine species, such as albacore tuna, loggerhead turtles, and swordfish, hence debris there poses a high risk for species and debris interactions (Polovina et al., 2001; Seki et al., 2002). A similar wind-driven convergence drives marine debris accumulation in the South Pacific Ocean (Martinez et al., 2009).

A region of especially high marine debris density is associated with the North Pacific High (NPH) pressure region located northeast of the NWHI. Regional modeling studies have illustrated how wind-driven surface currents form a dominant debris convergence zone below the NPH (Maximenko et al., 2012; Lebreton et al., 2012; Sebille et al., 2012), referred to as the Eastern Pacific Garbage Patch. This high debris density region has been observed over 34°N to 36°N and 138°W to 142°W (Moore et al., 2001), 35°N, 140°W (Howell et al., 2012), and 20°N to 40°N and 120°W to 155°W (Goldstein et al., 2013). More

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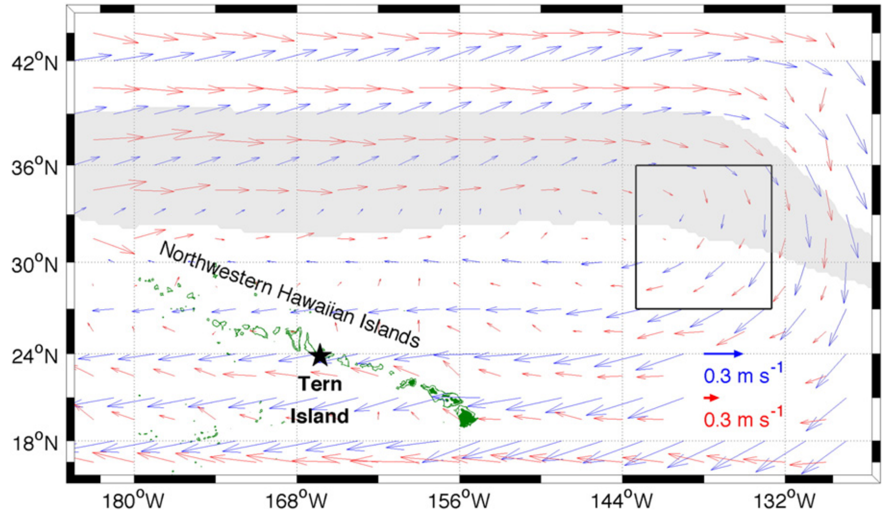

Fig. 1. The Northwestern Hawaiian Islands, including Tern Island, with mean Era-Interim surface wind speed (blue arrows) and SCUD surface currents (red arrows) included (1990–2012). The shaded area shows the seasonal range of the 18 °C isotherm, a proxy for the STCZ. The solid box is the garbage patch described in this study.

recently, Law et al. (2014) examined the spatial distribution of plastic marine debris found from eleven years of plankton net tows in the eastern North Pacific and defined the Eastern Pacific Garbage Patch extending from 25°N to 41°N, 130°W to 180°W. The most densely concentrated debris region from Law et al. (2014) is what this study uses to describe the garbage patch region (27°N to 36°N, 133°W to 143°W, boxed region in Fig. 1. Surveys by Cózar et al. (2014) also show high debris concentrations in this region.

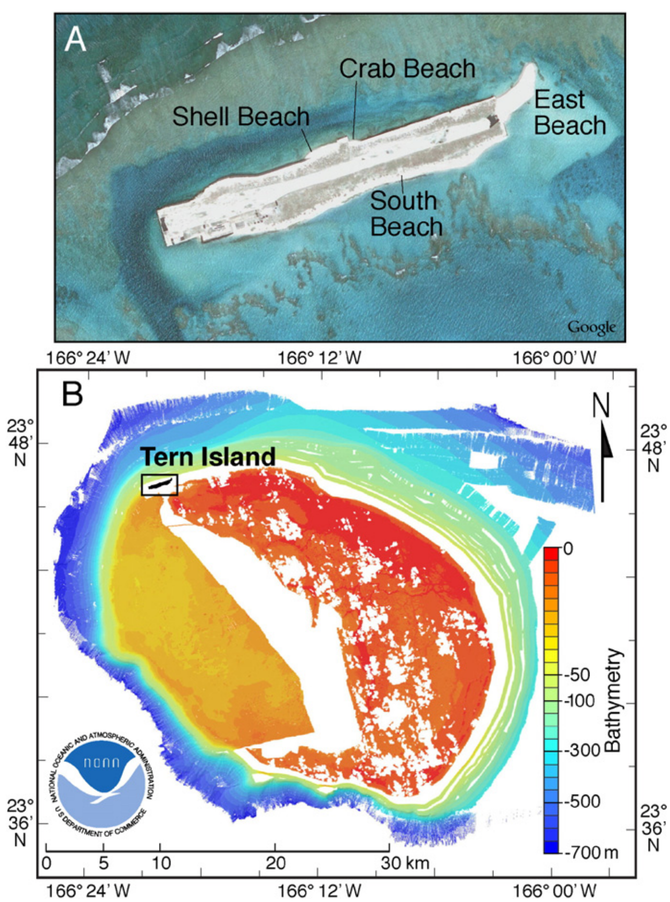

Fig. 2. A: Locations of marine debris collection sites on Tern Island. B: Bathymetry of the French Frigate Shoals with Tern Island at 23°52′ N, 166°17′ W (Coral Reef Ecosystem Division. Zone 3N, ellipsoid: WGS84 20 m grid cell size, data include R/V Kilo Moana, NOAA Ship Hi'lalakai, and R/V Ahi multibeam bathymetry and Ikonos derived depths.) White color indicates no bathymetry data.

The tendency for marine debris to beach on NWHI shorelines has been studied at Tern Island (Morishige et al., 2007) and Sand Island at the Midway Atoll (Ribic et al., 2012). Morishige et al. (2007) examined a 16-year time series of marine debris collected at 2–3 week intervals on Tern Island. They reported considerable year-to-year variations in debris loads and the absence of a seasonal cycle. They found a statistically significant tendency for weaker debris deposition during La Niña conditions compared to neutral and El Niño conditions. This change in debris deposition may be associated with the winter position of the STCZ (Pichel et al., 2007), which is located further south (north) during El Niño (La Niña) years (Polovina et al., 2001; Bograd et al., 2004). The proximity of the STCZ does not appear to be an indicator of debris loads at Tern on seasonal time scales since loads are not observed to be higher during the winter when the STCZ tends to be closest to Tern (Morishige et al., 2007). The influences of large and small-scale circulation patterns on deposition rates at Tern have not been examined. Based on a two-year long record, Ribic et al. (2012) reported that the debris loads at Sand Island were considerably higher than at Tern, which was attributed to Sand Island being closer to the STCZ than Tern (Pichel et al., 2007). A seasonal cycle was evident at Sand Island, with highest debris loads in December–January and lowest in June–August, consistent with the seasonal shift of the STCZ. Ribic (2012) examined debris deposition at the main Hawaiian Islands and did not find a correlation between debris loads and the position of the STCZ.

As noted by Morishige et al. (2007), a variety of physical forcing factors may influence debris rates at Tern, including the position of the STCZ, large-scale circulation patterns, mesoscale eddies (Howell et al., 2012), nearshore surface currents, etc. Prominent regional forcings around the NWHI include the trade winds and northwestern sea swell, which have been found to promote the transportation of marine debris to the archipelago (Howell et al., 2012). Nearshore settings of bathymetry, benthic habitat, sea level, and energy regime have not been well examined with respect to debris deposition rates, but are likely to influence debris transport from the open ocean into the NWHI atolls (Dameron et al., 2007). Drifter experiments performed in Hawai'i demonstrated the importance of the tidal phase for transport of marine debris in nearshore environments (Carson et al., 2013).

Here we extend the study of Morishige et al. (2007) to explore possible factors that influence marine debris deposition on Tern Island to help build upon our understanding of debris deposition in the NWHI. We use an extended version (1990–2012) of the debris deposition