Wave- and Current- Induced Bed Stress on the Waipaoa Shelf, New Zealand: Variations in Time and Space

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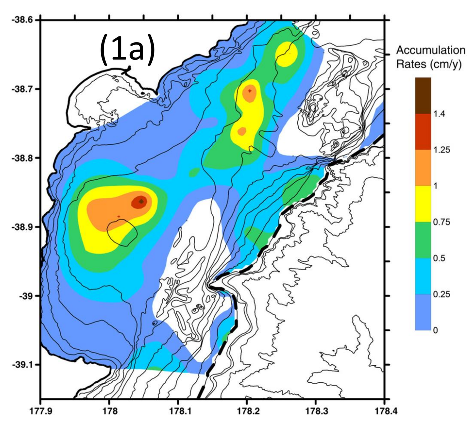
I. Background: Formation, Reworking and Preservation of Flood Deposits on the Waipaoa shelf

Motivation: Deposition of riverine sediments, and the characteristics and physical reworking of flood deposits are controlled by near-bed sediment fluxes, which are determined by bed shear stresses and sediment properties (Wheatcroft et al., 2007; Geyer et al., 2004). This study therefore analyzed bed shear stresses during January – February, 2010 as part of the NSF MARGINS Source-to-Sink Waipaoa Shelf Project, which is studying the formation, reworking, and preservation of flood deposits on the Waipaoa shelf. The occurrence of the Anniversary Day Flood, an eight-year flood event on January 31, 2010, and ongoing field efforts in January 2010 – February 2011 make this time period particularly interesting.

Waipaoa Sedimentary System: Located on an active tectonic margin with steep slopes and a high sediment yield, the Waipaoa River delivers 15 million tons of sediment per year into Poverty Bay, primarily during floods (Hicks et al., 2000). During these floods, and swell-wave events, sediment is transported to the adjacent Waipaoa shelf (Bever, 2010). Long-term accumulation on the shelf is observed in two depocenters to either side of Poverty Bay that run parallel to shore landward of the Lachlan (southern) and Ariel (northern) anticlines, and are separated by Poverty Gap (Orpin et al., 2006; Gerber et al., 2010; Miller and Kuehl, 2010; Figure 1).



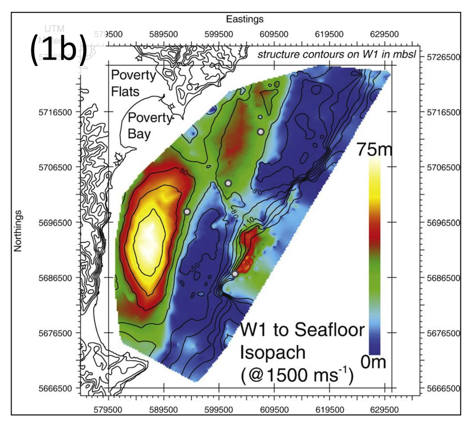
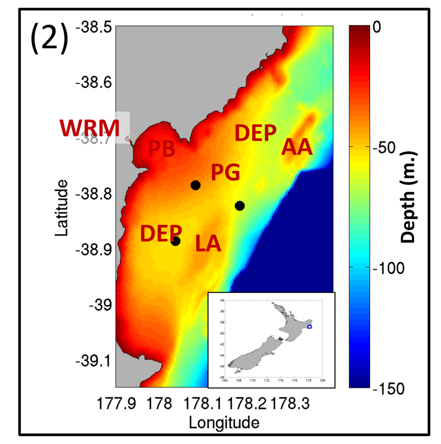


Figure 1 (left): Waipaoa shelf depocenters are indicated by (a) ^{210}Pb accumulation rates from Miller and Kuehl, 2010 and (b) isopach map showing accumulation since the last sea level low stand from Gerber et al., 2010.

Figure 2 (right): Study site map (bathymetry cut off at 150 m.). 'DEP', 'LA', 'AA', 'PG', 'PB', and 'WRM' indicate the two shelf depocenters, Lachlan and Ariel anticlines, Poverty Gap, Poverty Bay, and the Waipaoa River mouth. Black dots indicate tripod locations for Waipaoa Shelf Project.



II. Objective

- What are the relative strengths of wave- and current- induced bed shear stress on the Waipaoa shelf?
- When and where is bed shear stress likely sufficiently high to suspend sediment?

III. Method: Modeling Hydrodynamics on the Waipaoa Shelf: January – February 2010

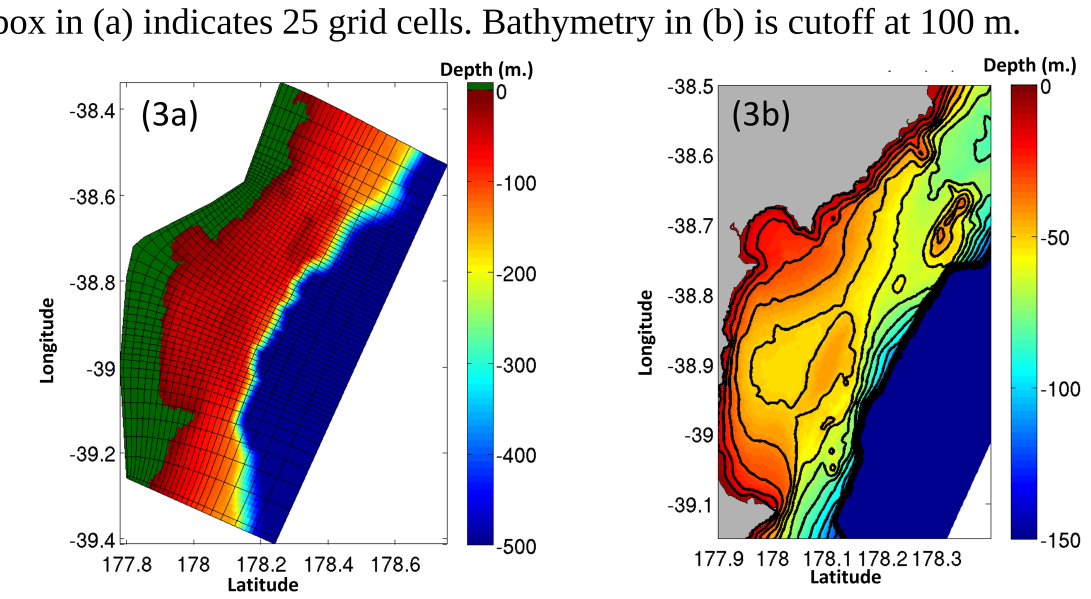
A three-dimensional numerical circulation model, the Regional Ocean Modeling System (ROMS; Haidvogel et al., 2000) and the Simulation WAves Nearshore model (SWAN; Booij et al., 1999) were two-way coupled and implemented on the Waipaoa Shelf for January 1, 2010 – February 11, 2010 (Figures 3, 4; Table 1). Wave-induced, current-induced, and total bed stress were computed according to Styles and Glenn, 2000.

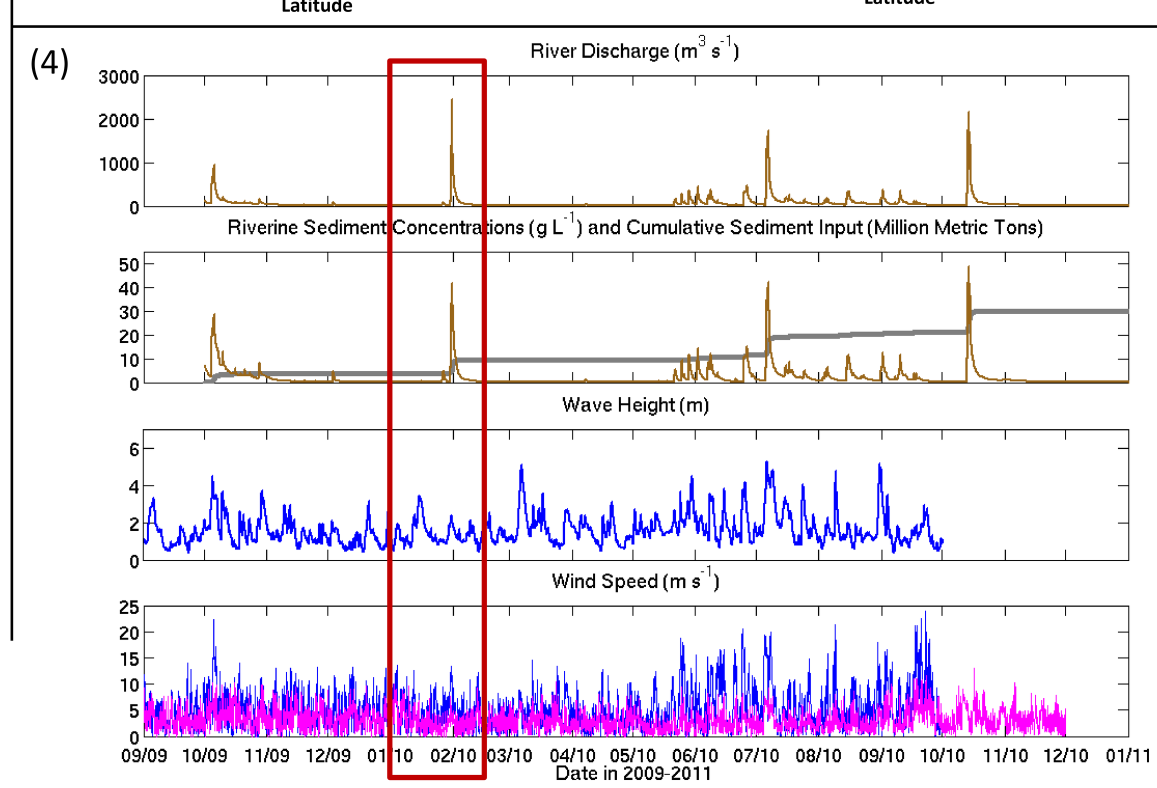
Type of Data	Data Source
Bathymetry • Model grid construction	• Gerber et al., 2010, • McNinch et al., 2008, • S. Stephens (National Institute of Water and Atmosphere; NIWA)
Temperature & Salinity • Initialization , and forcing at the model boundaries	• CTD casts from the 2010 -2011 research cruises
Waves • Forcing at model boundaries	• NIWA's New Zealand Wave (NZWAVE) model • NOAA's global Wave Watch 3 model (WW3; Tolman et al., 2001)
Winds •Forcing at ocean surface	• NIWA's New Zealand Limited Area Model (NZLAM, an implementation of the UK Met Office's Unified Model; Davies et al., 2005) • NOAA's global Wave Watch 3 model (WW3; Tolman et al., 2001) • Gisborne airport observations (obtained from NIWA)
Tidal components • Forcing of sea surface height and 2D momentum	• NIWA's tide model (NZTIDE; Walters et al., 2001)
River Discharge • Forcing at the river mouth.	• G. Hall and D. Peacock (Gisborne District; GDC)

Table 1: Data used to initialize and force the model.

Figure 4 (right): Waipaoa discharge, winds, and waves used to force the model. Data from GDC (brown), WW3 (blue), and Gisborne Airport (pink) indicate both low-energy periods and the Anniversary Day flood were included in the study period.

Figure 3: Model grid bathymetry. The model has ~450m horizontal resolution and 20 sigma layers with 0.24 – 4.6 m vertical resolution at 50 m. depth. Each box in (a) indicates 25 grid cells. Bathymetry in (b) is cutoff at 100 m.





IV. Results: Dominance by Wave-Induced Bed Shear Stress

Bed shear stresses averaged 0.08 Pa 0.21 Pa, and wave-induced bed stresses averaged forty five times higher than current-induced bed shear stresses (Figure 5a,b,c). Variability in bed shear stress corresponded primarily with wave orbital velocities, so bed shear stresses were higher and more variable in shallow depths (Figure 5, 6). Relatively low waves during the Anniversary Day Flood caused bed shear stresses during this time to be lower than average (Figure 5c,d). The coastline sheltered some areas (most notably northern Poverty Bay, but also near Mahia Peninsula) from high wave energy and bed shear stresses. Sheltering behind anticlines was negligible, but lower wavelengths over the anticlines themselves contributed to the relatively high bed shear stress over the anticlines (Figure 5,6,7,8,9,10).

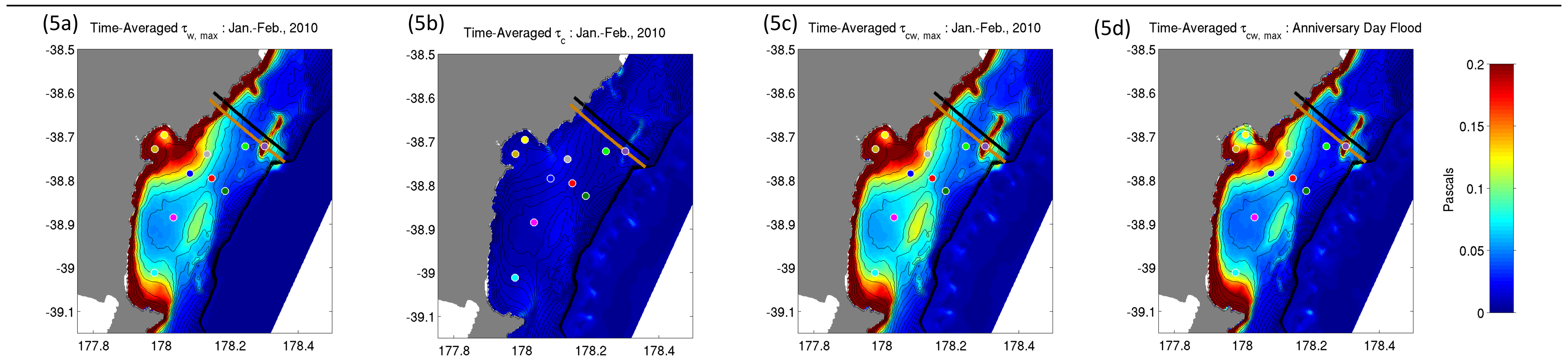


Figure 5: Time-averaged (a) wave, (b) current and © total (combined wave-current) bed shear stress over the study period and (d) over the Anniversary Day Flood (peak flood 48 hrs). Bed stresses above 0.2 Pa are plotted as 0.2 Pa. Colored dots and transects indicate locations analyzed in Figures 6,8 and 9. Bathymetry contours are 5 m. intervals until 150 m

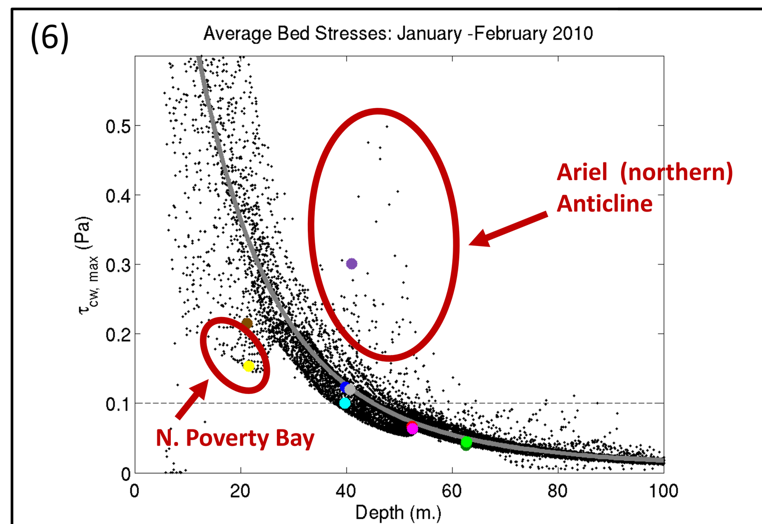


Figure 6: Time-averaged total bed shear stress for each model grid point compared to water depth. Colored dots correspond to locations in Figure 5. The grey line of best fit ($R^2 = 0.83$) is:

$\tau_{cw,\,max} = 42.3e4\,[(3.00e\text{-}6\,(x+69.3))^{-5.43}] + 6.68e\text{-}3$

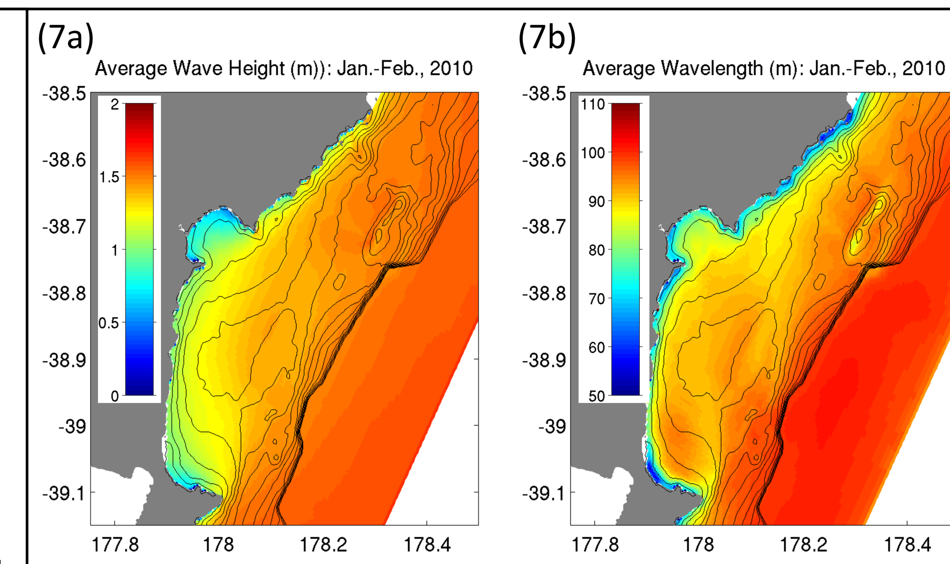


Figure 7 : Wave height (a) and wavelength (b) averaged over the study period showed relatively low values over the Arial (northern) anticline.

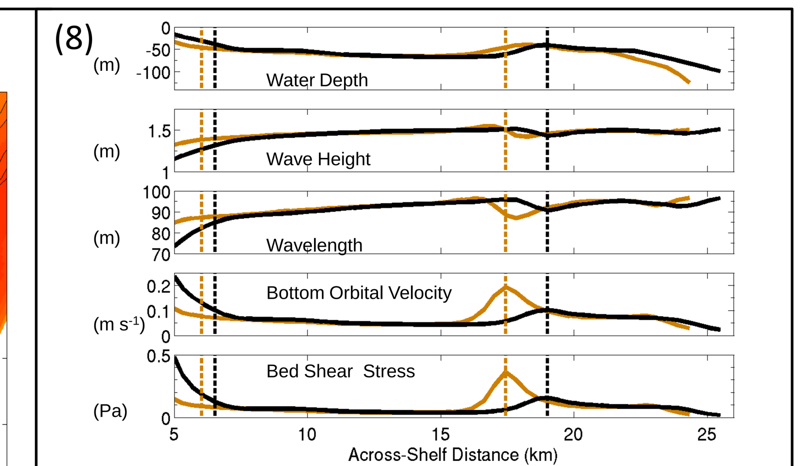


Figure 8: Across-shelf transects (shown in Figure 5) of water depth, wave height, wavelength, bottom orbital velocity and total bed shear stress averaged over study period. Dashed lines at 40 (brown) and 46 (black) m. depth illustrate the relative overexposure of the Ariel anticline (~18 km offshore) compared to other locations at the same depth (~6 km offshore).

V. Discussion: Implications for Flood Deposit Formation and Reworking

Waves and currents were sufficiently energetic ($\tau_{cw,\,max} > 0.1$ Pa) to suspend fine sediments on all parts of the Waipaoa shelf (water depth shallower than 150m.) (Figures 9, 10). The fact that waves dominated shear stresses despite the relatively low wave energy during the study (Figure 4) indicates that waves likely play a substantial role in sediment resuspension on the Waipaoa shelf. Even average bed shear stresses were sufficiently high to suspend sediment at locations shallower than ~40 m. depth (Figures 5c,6). Model results compared favorably to long-term depositional patterns, with relatively low shear stresses over shelf depocenters and relatively high shear stresses in Poverty Gap (Figures 1, 10).

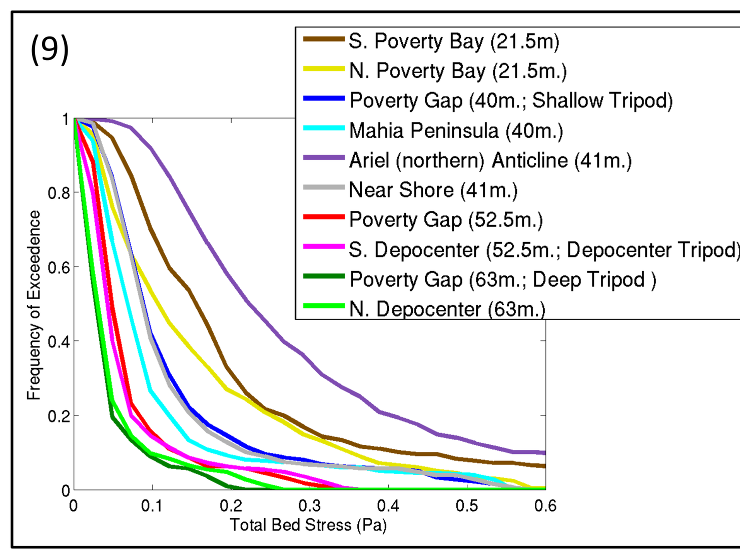
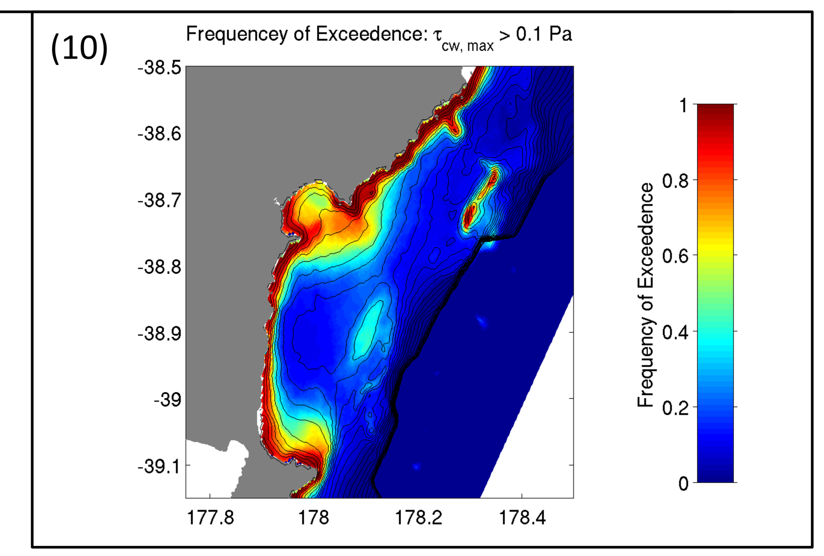


Figure 9 (left): Frequency with which total bed shear stress exceeded a given shear stress for six shelf locations. Locations were chosen to coincide with tripod locations from the ongoing field effort. Shear stresses at similar depths are compared to test for sheltering by anticlines, Mahia Peninsula, and Poverty Bay, and for exposure over the Ariel anticline. Locations shown in Figure 5.

Figure 10 (right): Frequency with which total bed shear stress exceeded 0.1 Pa, an approximate threshold for fine-grained sediment transport.



VI. Ongoing Work

- Account for sediment transport and deposition in the model, and improvement of current boundary conditions
- Collaboration with field efforts, e.g. comparison to field results, incorporation of sediment erodibility data in the model.
- Model 2010 field season (January 2010 – February 2011), including high-wave and flood events and low-energy interludes.

Summary

✓ Waves and currents were modeled on the Waipaoa Shelf for a 40 day period.
✓ Waves dominated total bed shear stress. Low wave energy during the Anniversary Day Flood caused relatively low bed shear stress. Shoaling over the anticlines, as indicated in SWAN wave model estimates, lead to local maximums in bed shear stress.
✓ Frequency with which shear stress exceed fine-grained sediment suspension criteria ($\tau_b > 0.1$ Pa) decreased with water depth. Bottom shear stress patterns seem related to long-term accumulation rates.

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