Connecting Flow over Complex Terrain to Hydrodynamic Roughness on a Coral Reef

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Supplemental Material
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Journal of Physical Oceanography

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**Wave analysis methods**

Wave analysis was conducted on instantaneous measured pressure $p$ and velocity data by dividing each 15 minute segment into sections of equal length, each with 75% overlap, applying a Hanning window to the segments and computing spectra $S(f)$ of frequency $f$. The significant wave height $H_s$ was calculated by, $H_s = 4\left[\int S_\eta(f) df\right]^{1/2}$, (rms wave height $H_{rms} = H_s/\sqrt{2}$), integrated from 3 to 25 s for the swell band (ss), where $S_\eta(f)$ is the power spectral density of $\eta$, (Dean and Dalrymple 1991). Mean wave direction $\theta_m$ was computed from the first spectral moment of $\theta(f)$ (Herbers et al. 1999). Radiation stress components were calculated from, $S_{xx} = E\left[n(\cos^2 \theta_m + 1) - \frac{1}{2}\right]$, $S_{yy} = E\left[n(\sin^2 \theta_m + 1) - \frac{1}{2}\right]$, $S_{xy} = S_{yx} = \frac{E}{2}[n \sin 2\theta_m]$, where energy $E = \frac{1}{8} \rho g H_{rms}^2$, and $n = \frac{c_g}{c}$, the ratio of group velocity to wave celerity (e.g., Dean and Dalrymple 1991).

**Pressure filtering methods**

We adopt an approach similar to previous reef studies (Lentz et al. 2016). The measured hourly-averaged pressure $p$ at site $x$ is decomposed into $p(x,t) = p_0(x) + p_{hyd}(x,t) + p_{atm,t}(t)$, where $p_0 = \bar{p}$, the time average over the measurement period. $p_{atm,t}$ is the pressure due to atmospheric and large scale processes, taken as the 25 hour low pass filtered $\bar{p} - p_0$ on the forereef. $p_{hyd}$ is the pressure due to reef-scale hydrodynamic processes and is corrected for drifts (instrument error) and shifts (instrument settling) by comparing the 13.5 hour low pass filtered $\bar{p}_{hyd} - \bar{p}_{hyd}(x_{ref})$ between similar sites, where $\bar{p}_{hyd}(x_{ref})$ is derived from a stable reference site. For sites that showed drift/shift errors, $\bar{p}_{hyd}$ is replaced with $\bar{p}_{hyd}(x_{ref})$ from the stable reference site. The total depth $D(x,t) = h(x) + \bar{\eta}(x,t)$ is relative to MSL, and the mean pressure is set to atmospheric pressure.
free surface $\bar{\eta} = \eta_{hyd}(x, t) + \eta_0(x)$, where $h = p_0/\rho g$, and $\eta_{hyd} = p_{hyd}(x, t)/\rho g$, and $\rho(x, t)$ is the density computed using the measured temperature and an average salinity of 34.98 psu from site D0.

**References:**

Chirayath, V., 2016: Fluid lensing & applications to remote sensing of aquatic environments. 177.


Figure S1. Fluid Lensing Algorithm Results. The general fluid lensing algorithm is used to process high frame rate multispectral imagery to remove refractive distortions from ocean waves and enhance the signal to noise ratio (SNR) of benthic images. (A-D) present imagery from the fluid lensing test pool showing removal of ocean wave related refractive distortion and signal enhancement of a USAF test target at a depth of 4.5m. The flat fluid reference (A) shows target under flat fluid conditions over a one second integration time. The raw distorted frame (B) shows target under typical ocean wave conditions for shallow marine systems. Mean image (C) is the 90 frame average of raw frames over one second of integration time. The 2D fluid lensing result (D) uses these same 90 frames to successfully recover the test target with an effective 0.25cm spatial resolution and uses caustics to enhance SNR.

Airborne fluid lensing is used to survey shallow marine systems with UAVs. Raw airborne imagery from the airborne field campaign in American Samoa is shown in (E), with the 2D fluid lensing result from 90 frames in (F). Cm-scale 3D remote sensing of coral reef in American Samoa with fluid distortion (G), and without fluid distortion as processed using the 3D airborne fluid lensing algorithm (H). Additional details in (Chirayath 2016).
Figure S2. Average horizontal velocity profiles at Pool 400 sites showing logarithmic profile in mid-water column. Height above bottom $\tilde{z}$ normalized by local depth $D$ and horizontal velocity magnitude $|u_E|$ normalized by depth averaged velocity $U$. 