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Observations and parameterizations of surfzone albedo

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HIGHLIGHTS

- Surfzone albedo can reach 0.45 and varies rapidly with breaking-wave foam.
- Image-based parameterization accurately predicts albedo at wave time scales.
- Wave-model based parameterization predicts time-averaged cross-shore albedo.

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ABSTRACT

Incident shortwave solar radiation entering the ocean depends on albedo α and plays an important role in the temperature variability and pathogen mortality of the nearshore region. As foam has an elevated albedo, open-ocean albedo parameterizations include whitecapping effects through a wind-based foam fraction. However, surfzone depth-limited wave breaking does not require wind. Surfzone albedo observations are very rare, the variability of surfzone albedo is not known, and parameterizations are not available. New, year-long upwelling and downwelling shortwave radiation observations were made from the Scripps Institution of Oceanography pier spanning the surfzone and inner-shelf. Surfzone albedo was elevated due to foam with mean observed albedo of $\alpha = 0.15$ and one-minute average albedo as high as $\alpha = 0.45$, far exceeding expected albedo (0.06) from standard parameterizations. Using a pier-mounted GoPro camera, an image-based albedo parameterization is developed that estimates the fractional foam area to derive albedo. This parameterization has high skill ($r^2 = 0.90$) on time scales as short as a wave period (9 s). A second wave-model based parameterization for (hourly) averaged albedo is developed relating the non-dimensional roller energy dissipation to the mean

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foam fraction and thus albedo. The parameterization has good skill ($r^2 = 0.68$) and resolves cross-shore albedo variations. These new parameterizations can be used where imagery is available or wave models are applicable, and can be used to constrain local heat budgets and pathogen mortality.

1. Introduction

The nearshore region ($\leq$ 7 m water depth) is critical both economically and ecologically. The region is a center for tourism, recreation, and commercial use, and is also home to a wide variety of fish, birds, plants and invertebrates. Water temperature is an important ecological aspect, affecting growth rates, recruitment rates, egg-mass production, pathogen ecology and many other factors (e.g., Phillips, 2005; Fischer and Thatje, 2008; Broitman et al., 2005; Goodwin et al., 2012; Halliday, 2012). In this sensitive region, incident shortwave solar radiation entering the ocean (Q_{sw}) plays an important role in both the temperature variability (Sinnett and Feddersen, 2014) and pathogen mortality through UV-B photobiological damage (e.g., Sinton et al., 1994, 2002).

Shortwave solar radiation entering the ocean is defined as

$$Q_{sw} = Q_d - Q_u, \tag{1}$$

where Q_d is the total downwelling (downward) component of solar shortwave radiation, and Q_u is the upwelling (upward) component of shortwave radiation reflected from the ocean surface. The albedo α (surface reflection coefficient) is defined as

$$\alpha = \frac{Q_u}{Q_d}, \tag{2}$$

making

$$Q_{sw} = (1 - \alpha)Q_d. \tag{3}$$

Under direct sun, open ocean albedo α depends on the solar zenith angle θ_s (the angle of sun declination from vertical) and has a daily average of $\alpha \approx 0.06$ (Payne, 1972; Briegleb et al., 1986; Taylor et al., 1996). Under cloudy (diffusely lit) skies, open ocean albedo is near 0.06 and is independent of θ_s (Payne, 1972). However, wind generates ocean whitecaps (foam) (e.g., Monahan, 1971; Monahan and Muircheartaigh, 1980) associated with elevated albedo. Wind also enhances the sea-surface slope variability (e.g., Ross and Dion, 2007), which affects albedo at large solar zenith angles (e.g., Saunders, 1967). Laboratory measurements indicate that pure foam has albedo $\alpha = 0.55$ (Whitlock et al., 1982). For a fractional surface coverage of foam ζ, the combined effects of foam and open water on albedo are often (e.g., Koepke, 1984; Frouin et al., 1996; Jin et al., 2011) represented as

$$\alpha = \zeta\alpha_f + (1 - \zeta)\alpha_\theta, \tag{4}$$

where α_f is the foam albedo, and α_θ is the parameterized solar zenith angle dependent open ocean albedo (e.g., Taylor et al., 1996). The foam fraction ζ from open ocean whitecapping has been parameterized using a surface wind speed $|u_w|$ dependence (e.g., Hansen et al., 1983; Jin et al., 2004, 2011), but has a negligible effect on albedo (less than 0.002) for winds $|u_w| < 12$ m s^{-1} (Payne, 1972; Moore et al., 2000; Frouin et al., 2001).

In the surfzone, foam is generated by depth-limited wave breaking regardless of wind, potentially elevating surfzone α and reducing Q_{sw}. Nearshore temperature evolution (e.g., Sinnett and Feddersen, 2014; Hally-Rosendahl et al., submitted for publication) depends strongly on Q_{sw} in the surfzone and inner-shelf, the region just seaward of the surfzone. Elevated surfzone albedo may also help explain reduced surfzone pathogen mortality relative to the inner-shelf (e.g., Rippy et al., 2013a,b) making the

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