The Spectral Reflectance of Ship Wakes Between 400 and 900 nm

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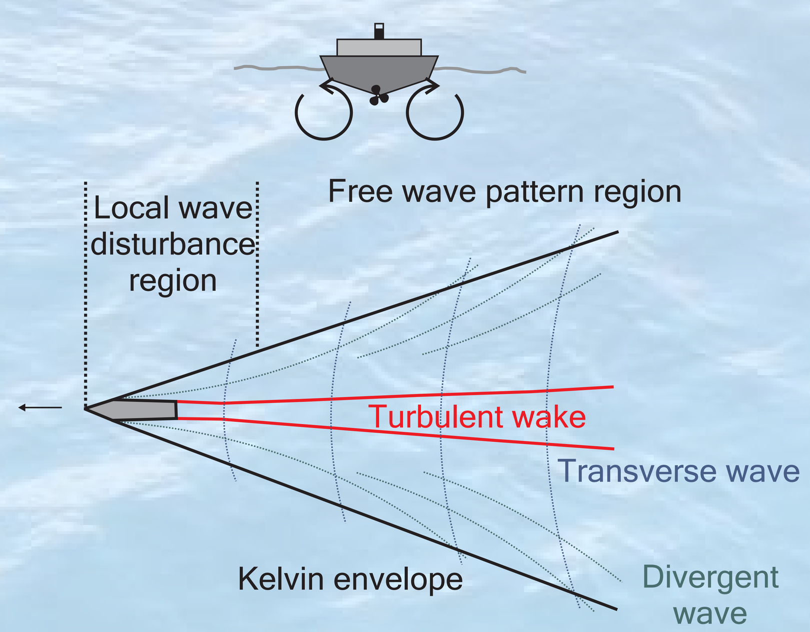
Summary

The objective of this research is to define the spectral reflectance characteristics of ship wakes at high spatial and spectral resolution, for the purposes of identifying maritime traffic using optical remote sensing data. The Hyperspectral Imager of the Coastal Ocean (HICO) was flown over the Hawaiian coast in April 2010. Hyperspectral images of the wake produced by the United States Coast Guard Cutter, "Kittiwake", traveling at speeds of 7, 14, and 21 knots were acquired. Analysis of the spectral reflectance data reveals a) that the spectral reflectance of the wake is distinct from that of background (i.e. deep ocean and sun-glint), and b) that there are systematic differences in the spectral reflectance properties of the wake, both along and across its long axis, as a function of vessel speed. Statistical analysis of the data indicate that the reflectance properties of the wake are significantly different to the ambient background but that the degree of difference decreases exponentially as spatial resolution increases. These results provided insights into how similar instruments operating from low Earth orbit can be expected successfully detect the presence of ships on the basis of the wake they produce.

Background

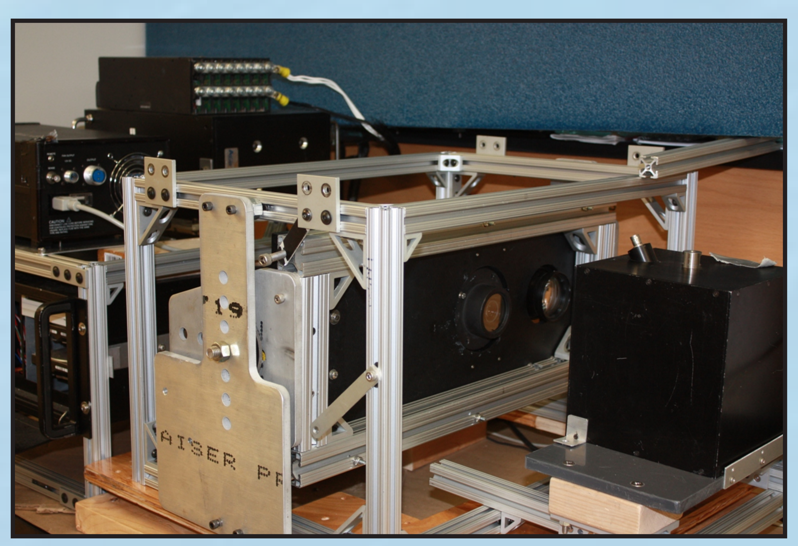
The passage of a ship through water produces a characteristic wake that consists of several components (right). Although each component may manifest itself at one time or another, the turbulent wake is independent of target-sensor-illumination geometry. The turbulent wake is composed of bubbles produced as the ship disturbs the water and air is entrained. With time the bubbles coalesce, rise to the surface, and burst. The reflectance of any foam produced from a liquid is much higher than the reflectance of a coherent volume of the same liquid (e.g. the "head" of a pint of beer). As a result the turbulent wake is highly reflective at visible to very near-infrared wavelengths.

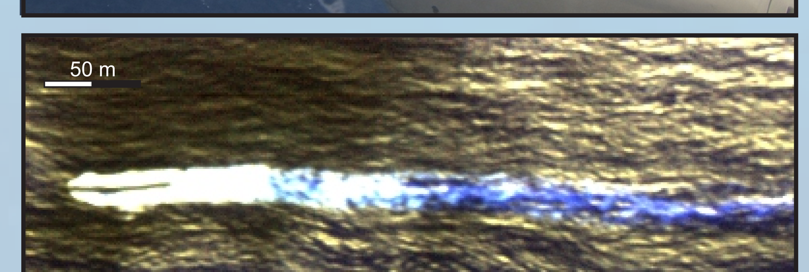


Method

The research presented here focuses on defining the spectral characteristics of this turbulent wake by making high spatial and high spectral resolution images of the wake generated by a vessel of known size traveling at known and variable speeds. The images were acquired using an airborne imaging spectrometer. HICO acquires data in 60 spectral bands between 400 and 900 nm with 12 bit radiometric resolution (i.e. 4095 distinct brightness levels). Spatial resolution varies with flying altitude, the data presented here was acquired from an altitude of ~1500 m (~5000 ft). The HICO instrument is shown to the right. To the lower right is a HICO image of a submarine acquired off the south coast of Oahu, Hawaii, on 2 October 2009.

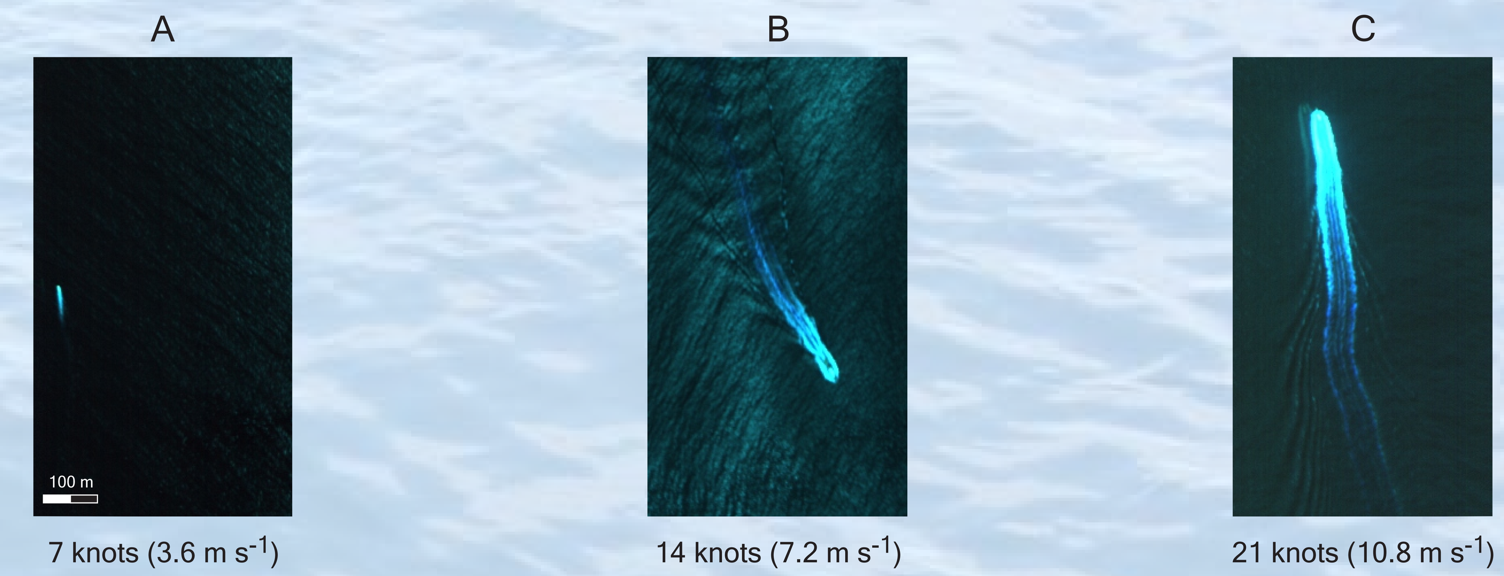
On 8 April 2010, HICO acquired data of the wake produced by the USCG cutter Kittiwake (length = 27 m; draft = 2 m), off the Waianae coast of Oahu, Hawaii. Data were acquired between approximately 13:00 to 14:00 local time. Over a period of 90 minutes the Kittiwake traveled a set course at three speeds: 7, 14, and 21 knots, Each speed was maintained for a 15 minute period allowing HICO to image the wake produced by the vessel under each of these three conditions. The raw HICO data were converted to spectral radiance (W m^{-2} sr^{-1} μm^{-1}) and subsequently to spectral reflectance (unitless).

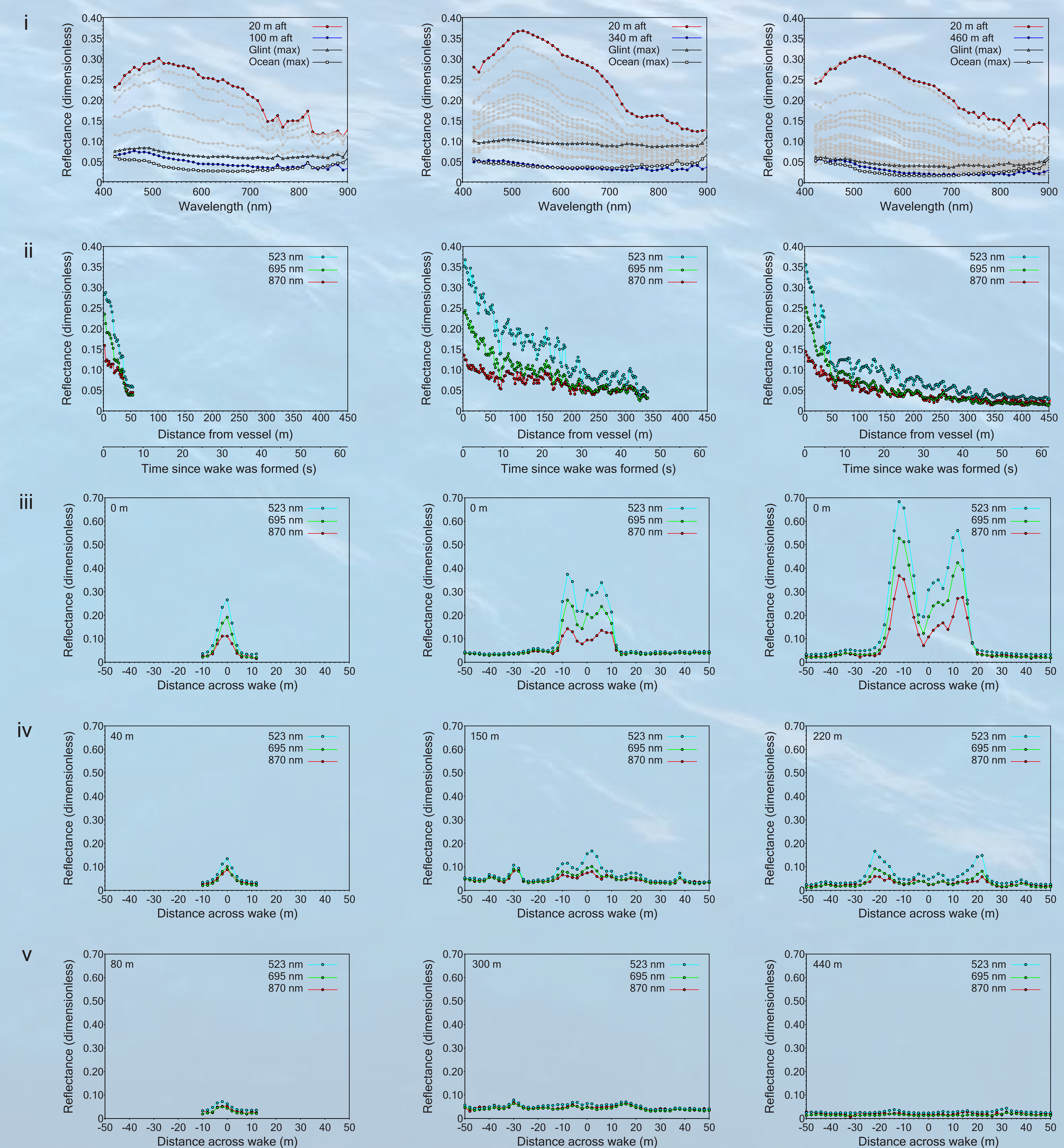




Results

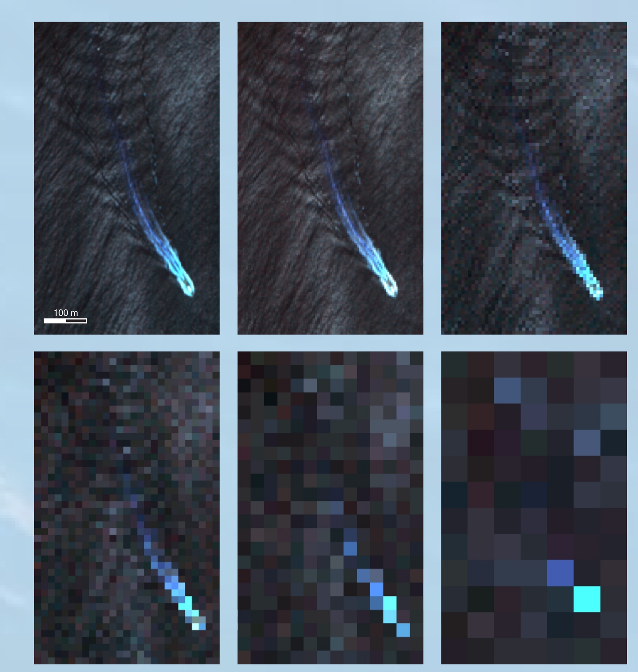
From images acquired at each of the three vessel speeds, the spectral characteristics of the turbulent wakes produced have been extracted (below). In each case it was determined i) how the spectral reflectance signature of the wake varied at approximately 20 m intervals (gray circles) from the stern (red circles) to the end of the wake (blue circles), ii) how the spectral reflectance at three reference wavelengths decayed along the longitudinal axis of the wake and iii-v) how the spectral reflectance at these same three wavelengths varied across the ship wake for the proximal, medial, and distal reaches of the wake. The reference wavelengths were chosen to span the region over which the wake was most (523 nm) and least (870 nm) distinct from the background ocean. As the vessel was traveling at a known speed during the time that each image was acquired, distance can be converted to time, and the results also show how the wake decays with time since the bubbles were formed (ii).

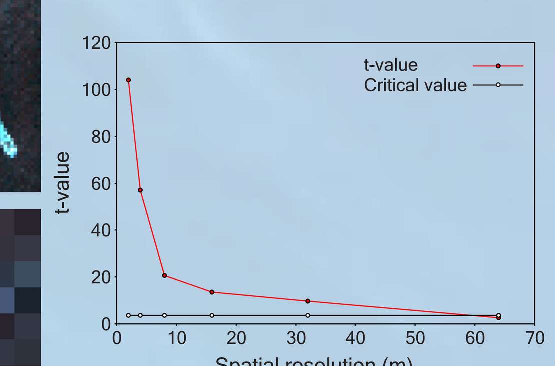




In each case the turbulent wake was most reflective at ~523 nm (from 35 to 70% reflective) decaying to 870 nm, consistent with the propensity of water to strongly scatter blue light while almost totally absorbing light at infrared wavelengths. The wake is distinct from the surrounding ocean which reflects little light (~1-3 %) at all wavelengths in this region (the difference due to the surface vs. volume reflectance effect alluded to in the background section). Sunglint, a source of noise for the purposes of identifying the target wake, while up to 7 % reflective, nevertheless displays a flat spectral reflectance signature between 523 nm and 870 nm, making it easy to discriminate from the wake (i). In each case the reflectance of the wake decreases exponentially with distance from the stern of the vessel (ii). The rate at which the wake reflectance decays depends on the vessel speed, with the wakes produced at higher speeds persisting for longer periods of time at greater distances from the source. Wakes produced at high speeds are also wider than those produced at lower speeds (iii, iv, and v).

The ability to distinguish target (wake) from background (surrounding ocean) depends on the level of spatial detail at which the images are acquired. Simulations of wake reflectance at 4, 8, 16, 32, and 64 m were produced by resampling the raw, full resolution data (below). Using a two-sample t-test it was determined the extent to which the wake is statistically different from the background at 423 nm for each of the simulated data sets. It appears that the wake becomes statistically similar to the background once the spatial resolution of the image data exceeds ~30 m.





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