INFRARED REMOTE SENSING OF RIVER FLOW

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1. INTRODUCTION

In general, a thermal boundary layer of O(1 mm) thickness exists at a natural air-water interface such that the surface, or skin, temperature is less than the bulk temperature below the thermal boundary layer by 0.1 to 0.5 °C. When this cool skin is momentarily disrupted by natural or artificial means, the skin temperature within the resulting turbulent wake is approximately equal to the warmer bulk temperature. As the wake subsides, the skin layer recovers, and the skin temperature returns to its original, cooler value. Since the optical depth of infrared (IR) radiation for water is about 10 µm, the thermal radiation detected by an IR sensor aimed at the water corresponds very nearly to the skin temperature.

The cool skin phenomenon combined with the very small IR optical depth makes it possible to detect the disruption or modulation of the thermal boundary layer by a variety of natural processes. Infrared imagery has provided new insights into processes that include wave breaking at scales ranging from whitecaps [1] to microbreakers [2], Langmuir circulation [3], and internal waves [4, 5]. These findings have significantly increased our understanding of the spatial and temporal variability of naturally occurring thermal phenomena at the ocean surface.

A relatively new and very promising area for IR remote sensing is quantifying river and estuarine flows, which is the emphasis a project called COHSTREX (Coherent Structures in Rivers and Estuaries Experiment). The overall goal of COHSTREX is to determine the extent to which the remotely-sensed signatures of coherent structures (eg., boils, wakes, fronts) can be used to infer flow parameters such as surface velocity and bottom information. In general, coherent structures are generated by the interaction of the flow with bathymetry and coastline variations. We have discovered that these coherent structures produce surface signatures that can be detected and quantified using IR techniques [6]. An important and far-reaching result of COHSTREX is that IR measurements of rivers contain much more exploitable information than previously realized. One reason is that the magnitude of the bulk-skin temperature difference tends to be large at the relatively low wind speeds often found on rivers. Another reason is that there are multiple sources of surface temperature variations in rivers, such as flow convergence, differential solar heating, and stratification.

2. SURFACE TURBULENCE CHARACTERISITICS

Estuarine and river turbulence can be enhanced by flow over bathymetric features and obstructions, rough bottoms, or strongly sheared flow, while density stratification due to salt wedge intrusion can suppress it. Our recent set of experiments in the tidally-influenced Snohomish River (Everett, WA) have documented a range of rapidly evolving structures in infrared image sequences made evident by disruption of the cool skin layer by turbulent straining and upwelling. The novel aspect of this data is its ability to directly reveal spatial scales of turbulence in a snapshot without having to rely on advection of the turbulent field past a sensor.

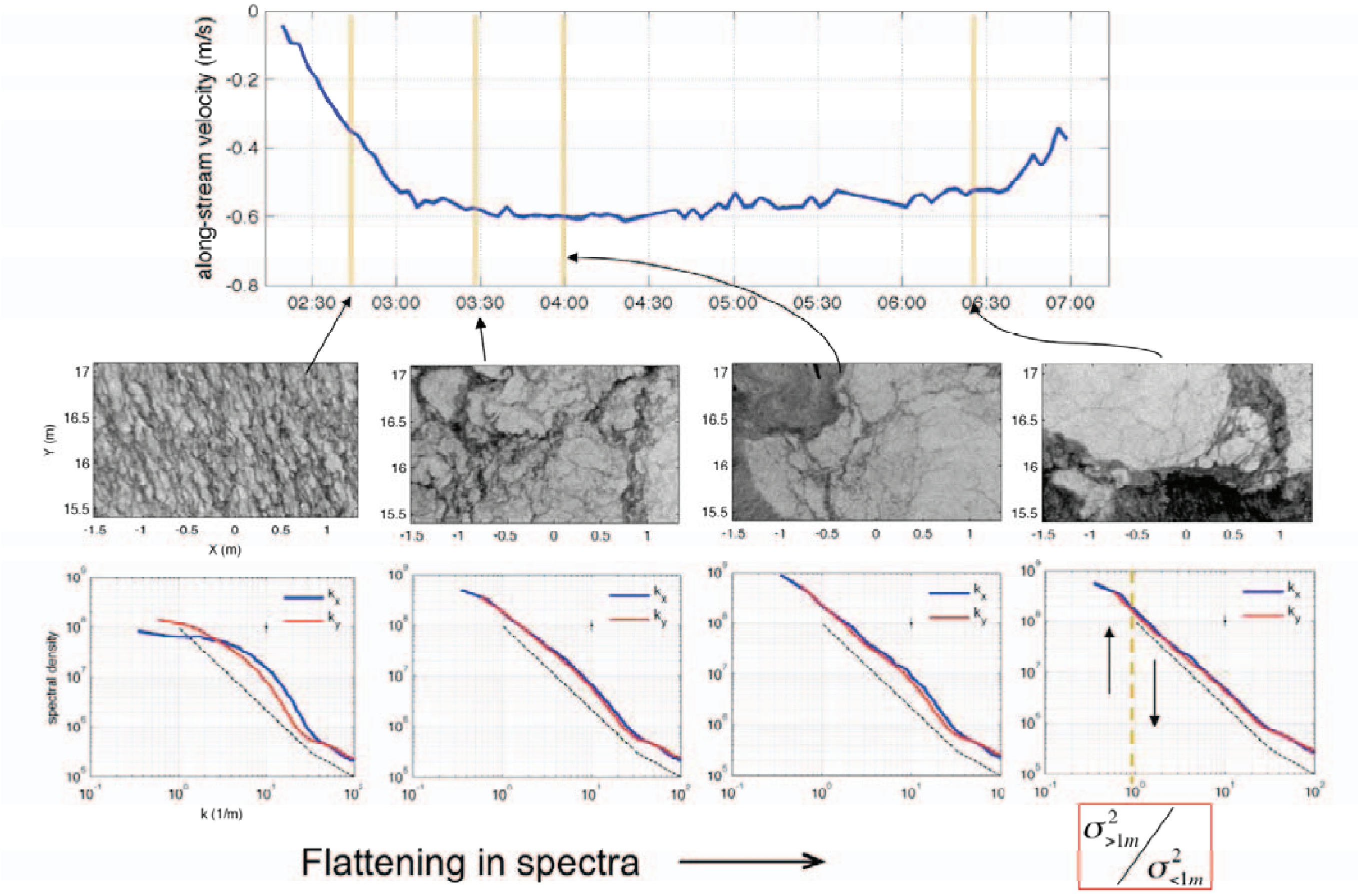

Figure 1. (top panel) Alongstream flow of the Snohomish River during an ebbing tide in 2008. (middle panels) Examples of surface temperature patterns during development of river flow changing from small wind driven structures to flow derived turbulent boils, and (bottom panels) associated wavenumber spectra of the thermal images. The dashed lines indicate the expected $k^{-5/3}$ turbulence cascade transitioning to the k^{-1} thermal dissipation, at high wavenumbers.

In our analysis of data taken in 2008, we have quantified the spatial structure of the surface temperature patterns over the course of a flooding tide through two-dimensional Fourier analysis. As shown in the example in Figure 1, the river flow increases from zero velocity to a stable flow of ~0.6 m/s while the surface temperature structure patterns quickly develop from short length-scale, wind-driven patterns at low flow speeds patterns consistent with the theorized $k^{-5/3}$ Kolmogorov cascade present in fully turbulent flow (lower panels). Comparisons of this data with in situ estimates of turbulence spectra are underway, and we seek to use the thermal turbulence spectra to provide a direct estimate of turbulent energy and dissipation of the flow. In the interim, our analysis is continued by constructing a simple metric to capture the development or surface turbulence as ratio of larger-scale (> 1m) energy to the smaller-scale (< 1m) energy. This metric, plotted in Figure 2, tracks the increasing surface turbulent signature strength as river flow increases, indicated by the relative increase in longer length-scales in the surface signatures. We will report on analysis of a more extensive data set taken in 2009, which included measurements over a range of variable bottom conditions and stratification.

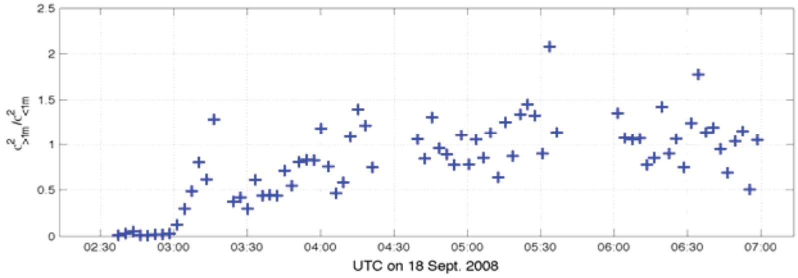

Figure 2. Time series of the ratio of log to short wavelength energy in themal imagery, (see Figure 1). The increase in the metric coincides with the increase in larger-scale surface turbulence (boils) in the river.

3. REFERENCES

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