DFD15-2015-002917

Abstract for an Invited Paper
for the DFD15 Meeting of
the American Physical Society

New methods for state estimation and adaptive observation of environmental flow systems leveraging coordinated swarms of sensor vehicles

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Accurate long-term forecasts of the path and intensity of hurricanes are imperative to protect property and save lives. Accurate estimations and forecasts of the spread of large-scale contaminant plumes, such as those from Deepwater Horizon, Fukushima, and recent volcanic eruptions in Iceland, are essential for assessing environment impact, coordinating remediation efforts, and in certain cases moving folks out of harms way. The challenges in estimating and forecasting such systems include: (a) environmental flow modeling, (b) high-performance real-time computing, (c) assimilating measured data into numerical simulations, and (d) acquiring in-situ data, beyond what can be measured from satellites, that is maximally relevant for reducing forecast uncertainty. This talk will focus on new techniques for addressing (c) and (d), namely, data assimilation and adaptive observation, in both hurricanes and large-scale environmental plumes. In particular, we will present a new technique for the energy-efficient coordination of swarms of sensor-laden balloons for persistent, in-situ, distributed, real-time measurement of developing hurricanes, leveraging buoyancy control only (coupled with the predictable and strongly stratified flowfield within the hurricane). Animations of these results are available at http://flowcontrol.ucsd.edu/3dhurricane.mp4 and http://flowcontrol.ucsd.edu/katrina.mp4. We also will survey our unique hybridization of the venerable Ensemble Kalman and Variational approaches to large-scale data assimilation in environmental flow systems, and how essentially the dual of this hybrid approach may be used to solve the adaptive observation problem in a uniquely effective and rigorous fashion.