LIDAR Data on Plankton in a fjord in Washington State

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LONG-TERM GOALS

Our long-term goal is to understand how physical-biological, biological-biological and chemical-biological interactions control the formation, maintenance and dissipation of thin layers of plankton and how the resulting thin layers impact *in situ* and remote sensing technologies of critical interest to the Navy. We are also interested in improving our ability not only to detect, characterize and map the temporal and spatial extent of thin layers, but also to improve our ability to predict their occurrence in a variety of ocean environments.

OBJECTIVES

Our short-term objective was to support the Naval Research Laboratory (NRL) in a continuing series of measurements in East Sound, Orcas Island, Washington. Specifically, the objective was to use the airborne lidar to locate layers in the sound and relay the position and depth of these layers to the NRL surface vessel in real time. The objectives of this program do not include data processing or analysis.

APPROACH

The approach was to fly the NOAA Fish Lidar over the sound each morning and again in the afternoon. The lidar data and aircraft position were monitored via radio modem from the hotel at the head of the sound. The layers in the sound are strong enough to be observed in the real-time display of the raw data. When layers were observed, the information was relayed to the surface vessel using cell phone or marine radio.

WORK COMPLETED

The surveys were completed as planned, except for 18 September, when the morning flight was canceled because of weather.

RESULTS

We saw very little evidence of layered structure in East Sound during the entire period. On 14 September, after three days of flights over East Sound, Alan Weidemann of the Naval Research

Laboratory (NRL) suggested a reconnaissance flight to West Sound. Very strong internal waves were observed in the lidar returns in West Sound, and these were reported to the NRL vessel, which began sampling in West Sound as a result. This is an excellent example of the power of adaptive sampling with aerial surveilance.

Figure 1 is an example of one of the internal waves observed in West Sound. Two distinct layers are being perturbed by the same internal wave field. Because the aircraft made multiple passes over this internal wave field, its propagation speed and evolution can be inferred from the data and compared with theoretical predictions based on coincident density profiles made by NRL.

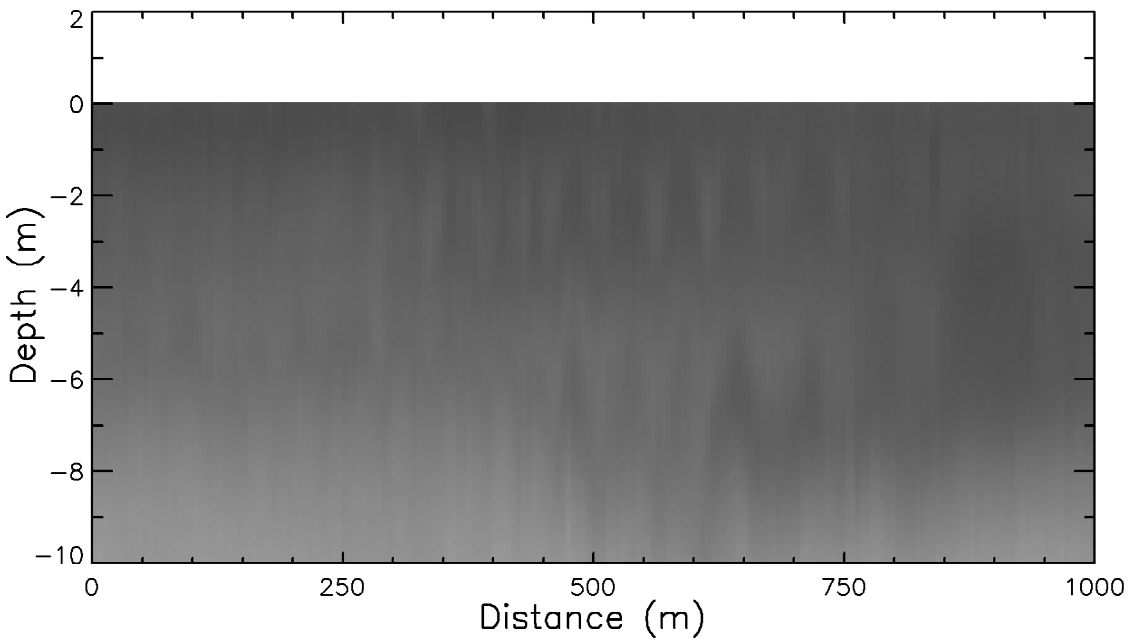

Fig. 1. Lidar return (darker is higher return) as a function of depth and distance along the flight track. Two distinct layers can be seen; both are being perturbed by an internal wave.

IMPACT/APPLICATIONS

Our re-analysis of 80,000 km of data collected by the NOAA airborne fish lidar developed by Dr. Churnside has shown that this system has the capability to rapidly detect and synoptically sample the spatial extent, intensity and prevalence of thin (and not so thin) backscattering layers in a wide variety of coastal and oceanic waters (Churnside and Donaghay, 2009). The specialized optics, extremely high data rates (10^9 samples/sec), 5 to 10 m horizontal resolution and better than 50 cm vertical resolution of the fish lidar provide an unparalleled synoptic picture of optical fine structure of the upper 50 m of the ocean. Our search for thin layers in this data not only greatly increased our understanding of the spatial extent and the types of environments where thin layers can occur, but it has also given us new insights into the role of large scale forcing in controlling their occurrence. For example, not only was it shown that thin layers can be equally prevalent in shallow and deep ocean environments during upwelling relaxation events, but also that thin layers can extend uninterrupted for more than 10 km in regions with strong internal wave activity. However, since *in situ* verification/validation efforts have thus far been driven by the need to rapidly assess fish stocks (NOAA's objective in developing the lidar), we can only speculate about the source of the thin layers that are so evident in the data.

In the analyses of the data completed to date, we have shown unequivocally that the layers observed in the lidar return correspond to biological scattering layers through simultaneous in-water measurements of the optical and biological properties of those layers. These data will allow us to develop algorithms that will greatly increase the amount of information that the Navy will be able to infer from current and future lidar systems. Examples from these data include quantitative measurements of internal waves and turbulence levels. We are particularly excited about the potential breakthroughs that will occur when we can combine (a) recent advances in bio-physical modeling, (b) the capabilities of airborne lidar to spatially map fine-scale structure, and (c) the capabilities of autonomous profilers to quantify temporal and spatial changes in fine-scale physical, chemical, bio-optical and bio-acoustical structure.

RELATED PROJECTS

This work was done in collaboration with a project by Dr. Alan Weidemann from the Naval Research Laboratory.

REFERENCES

Churnside, J. H. and P. L. Donaghay (2009) Thin scattering layers observed by airborne lidar. ICES J. Mar. Sci. **66,** 778-789.