Final Progress Report
"Satellite Ocean Front Mapping in Support of Salmonid Resource Management"
For the period: June 1, 2002 – May 31, 2004
PIs: David A. Jay and Todd Sanders

The five primary components of the Satellite Ocean Front Mapping research project are: (a) AVHRR front-detection, (b) SAR front-detection development, (c) in situ data analysis, (d) field support, and (e) correlative analyses. Below, we first list the primary accomplishments in each category, along with the significance and impact of each endeavor. Then, we discuss the progress that was made in terms of ties and collaborations with other researchers or government programs. We conclude by discussing the future directions this research should take.

(a) Map fronts and compute front indices using AVHRR temperature images.
We computed a monthly front frequency index (F1), along with season-average front gradient and front direction maps from 1985-1996 for the Oregon-Washington study area, 43-48.5N, 123-128W. These were compiled from a unique digital archive of frontal fields computed from Pathfinder twice-daily 9-km resolution global AVHRR SST fields. The seasonal variability of F1, shown in Figure 1a, is dominated by a shelf-break front that forms due to late-summer upwelling (Figure 1b). We also explored the applicability of frontal mapping using 1-km AVHRR SST data, concluding that the 1-km resolution is required for mapping fronts near coastlines, and the AVHRR Sea-Surface-Turbidity product might be used separately to identify fronts that do not have a strong cross-front temperature gradient.

Winter 2002-3 AVHRR observations were described in a poster presentation, which was a collaborative effort with in situ data provided by scientists from Oregon State University and the NSF-CoOP Coastal Ocean Advances in Shelf Transport (COAST) project (Belkin et al., 2003). Offshore from the Columbia River entrance, one eddy repeatedly moved on and offshore, and entrained river plume waters into its core. These energetic processes are deemed important for cross-shelf transport of nutrients, phyto- and zooplankton and fish larvae that likely occurred in both directions. The timing of upriver migrations of various salmon stocks was very unusual in winter 2003, possibly due to the anomalous warm (>12°C) water mass at the river mouth, which was rapidly entraining and heating (i.e. concealing) the cool river plume.

(b) Develop Synthetic Aperture Radar front-mapping capability and applications.
We collected all SAR images framing the mouth of the Columbia River and the near-shelf region from 1999 to 2004, and now collect all available images soon after their collection dates. Three different radar backscatter signatures are associated with the edge of the river plume. Two have been documented in the literature (with in situ data and SAR, for other locations) to identify plume fronts, and one, internal waves. The internal waves often radiate in bands just offshore of the plume front, primarily on the western frontal edge. We tested a method for using SAR imagery to estimate convergence rates (and thus, downwelling velocities) experienced by organisms at plume fronts. This will allow us to use SAR imagery to estimate these additional characteristics of plume fronts
when no *in situ* data is available. Internal wave trains were studied in greater detail using *in situ* and SAR data (Chisholm et al., 2003). As a result of our efforts, the ongoing NSF NSF-CoOP project, “River Influences on Shelf Ecosystems” is specifically analyzing mixing processes at these internal waves trains.

**c) Document vertical characteristics of satellite-observed fronts using *in situ* data.**

Shipboard observations from May 2001 show very strong convergence, vertical velocities, mixing and bottom boundary layer impacts associated with the leading edge plume front. Downwelling velocities are 5-35 cm s\(^{-1}\), extending down to the bed below the frontline, reaching our deepest measurements of 70 m. We estimated mean mixing parameters in the plume and mixing layers (down to \(\sim\)20 m depth) from 5 to 8 hours past high-water using instability length-scales in \(\sim\)200 CTD density profiles (a “Thorpe scale” analysis). The mean dissipation, eddy diffusivity, and Thorpe overturn scale are 2 x 10\(^{-4}\) W kg\(^{-1}\), 6 x 10\(^{-2}\) m\(^2\) s\(^{-1}\) and 0.79 m respectively, and decrease with distance behind the front. These mixing parameter estimates will help modelers improve their Columbia plume model simulations. Moreover, the strong mixing also presents the possibility that juvenile salmon might avoid the river plume fronts during ebb tide, to avoid disorientation due to turbulence. This research was summarized in two conference presentations (Orton et al., 2002; Orton and Jay, 2004) and in a paper that will be submitted shortly to Geophysical Research Letters (Orton and Jay, in preparation), and is available online at [http://www.ldeo.columbia.edu/~orton/](http://www.ldeo.columbia.edu/~orton/).

**d) Support 2002-3 shipboard Ocean Survival of Salmonids fisheries research.**

Project partners Pablo Clemente-Colon and Todd Sanders provided access for NMFS personnel to SAR imagery, and advised on plume orientations under differing wind conditions. Also, field operations were often coordinated with a SAR fly-over; the simultaneous SAR imagery will provide for fisheries researchers their first synoptic view of the frontal and internal wave field.

**e) Cross-correlate time-series of frontal indices with salmon ocean survival indices.**

We correlated our 12-year time-series of the monthly frontal frequency index F1 against the Oregon Production Index that measures ocean survival rates of Oregon hatchery coho salmon. We found a moderate positive correlation between OPI and F1 (\(r^2 = 0.21\)), when F1 was averaged from April to August, which is a reasonable averaging time considering that juvenile salmon typically arrive at sea in late springtime. The initial weeks-to-months of ocean life are critical for determining recruitment success in salmonids, and prior studies have shown that salmon with the highest growth rates are the most likely to survive. Removing one outlier lead to dramatic improvement in the regression (\(r^2 = 0.56\)). For comparison, the correlation of the Bakun upwelling index, which has been shown to have a positive correlation to the OPI, has an \(r^2\) value of 0.39.

**Future directions**

Project partner Igor Belkin is partnering with Dr. David Ullman at University of Rhode Island to produce global 1-km AVHRR front maps. The 1-km AVHRR front maps will identify fronts as close as 3 km from shore. Once we calculate the frontal index using 1-km AVHRR front maps, we will repeat the correlative analyses of the present study,
because we expect that this will produce higher salmon-front correlations; Ocean Survival of Salmonids results indicate that 50% of juvenile Coho reside from ~3-16 km from shore.

References:
Figure 1: (a) Frontal index F1, quantifying the spatially-integrated frontal frequency over the study region. The x-axis is the month number, y-axis is the year, and z-axis is F1. (b) Frontal frequency (%) map for September, showing the average frequency, 1985-1996.

Figure 2: Correlation of the April-August mean frontal frequency index (F1) versus the OPI salmon ocean survival index from 1986-1994 shows a reasonable correspondence ($r^2 = 0.21$; if one outlier is removed, $r^2 = 0.56$).