OS31B-03 Small-Scale Processes in the Columbia River Buoyant Plume

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Introduction
Buoyant plumes play an important role in fostering primary production and cross shelf transport of scalars and organisms on eastern boundary current coasts. As part of the RISE (River in Influenced Shelf Ecosystems) Project funded by the National Science Foundation (Coastal Ocean Program) we are analyzing some of the small scale tidal and frontal processes that contribute to this productivity and transport in the Columbia River plume area. Plume frontal properties are being analyzed using synthetic aperture radar (SAR) images of the plume area with support from the National Environmental Satellite Data and Information System (NESDIS).

Specifically SAR images come from the Radarsat1 satellite, which was launched for Environment Canada in 1995. It collects images from 3.5 GHz (5.6 cm) signals and orbits the earth every 28 minutes. Radar's long wavelength compared with other bands of the electromagnetic spectrum typically used for remote sensing allows it to see through clouds and darkness. It also produces relatively fine resolution with approximately 12.5m pixels. The term synthetic aperture arises from its need for a very large antenna, too large to be supported by conventional platform such as an aircraft or satellites. To overcome this problem, return collected over a period of time allows the moving platform to act as a “synthetic” larger antenna.

Strength of radar return depends upon surface roughness. Radar is most sensitive to roughness wavelengths of about 1 m. Two factors of interest control surface roughness. Wave-current interaction steepens waves when waves and currents oppose and reduces wave steepness when waves and currents align. Satellite images are most effective at identifying changes in roughness over relatively short spatial scales. Although tides and winds cause large currents these often have little spatial variation whereas wind waves, internal waves, and fronts cause large spatial variation. Length scale and intensity readily identify these processes. The second cause of altered roughness is sea surface slicks. SAR is remarkable effective at identifying oil slick because oil behaves “like oil on troubled water.” Although SAR images typically clearly show fronts it is uncertain to what extent these signatures arise from currents altering surface waves or collections of surface film.

SAR and ADCP Comparison
To assist interpreting the SAR images we compared them with available hydrodynamic data. The OGI School of Science and Engineering’s CORB project has intermittently maintained a downward looking 300 kHz ADCP in a buoy called OGI01 at the location marked by an x on the figure. The buoy also normally supports near surface temperature and salinity instruments. Comparison of times of available SAR images and OGI01 data identified 15 images with corresponding ADCP data. OGI01’s location was chosen to support model calibration and infrequently interacts with plumes. However, the SAR image collected on 19 May 2002, shown below, shows a front approximately 4200m southwest of the buoy. Next to the SAR image is a plot of the ADCP data measured over a 24 hour period centered at the time of the SAR image. The top two panels show the magnitude and direction of currents from the top 10 1 m bins. The top bin is estimated to be about 2m below the surface. The ADCP measures to 100m, which is most of the water column. The next two panels show current magnitude and direction for the full 100m averaged over 10m bins. The bottom panel shows salinity measured by a sensor attached to the buoy.

The SAR images and ADCP record appear consistent. The salinity record shows a wave like increase in salinity probably associated with internal waves passing the buoy 3 hours before the SAR image. With the passage of this front the current veers from southwest to northwest. The southwest direction of the current agrees with the position of the front as shown on the SAR image. The current measured by the ADCP is approximately 50 cm/sec during the time between the passage of the front and the SAR image. The front moving 4200m in 3 hours corresponds to a velocity of 28 cm/sec, reasonable agreement. The SAR image shows two features generally southwest of the buoy location. The one aligned more east west probably is not the one measured by the ADCP because it appears to travel northward, yet it appears to include two internal wave crests, in agreement with the salinity record. The feature aligned NW does not appear to show internal waves yet it does not have an obvious direction of motion.

SAR images appear to contain a large amount of information describing the coastal ocean. However, much of it is ambiguous given our present understanding of SAR images and the coastal ocean. Long time series from ADCP data collected at fixed locations appear to offer a promising avenue to further explain SAR images. OGI01, consistent with its deployment objectives, was not located at the ideal spot to study plume dynamics. We anticipate that buoys deployed as part of the RISE project (OS31B 04) will be better located for providing data to further our abilities to interpret SAR images.

Wavelets
The directionality apparent in the SAR images suggests use of a wavelet that can extract directionality from the image. We therefore chose a 2D wavelet that assumes the shape of a Morlet wavelet in oscillating direction and 2 scales it in the Gaussian direction. The k governs the number of humps in the wavelet.

The above left figure shows the wavelet used. The above right figure shows a raw SAR image. Directionality is not obvious. The two lower images show the wavelet coefficients produced by a wavelet transform. They indicate that variations in the SAR signal are most effective at identifying changes in roughness over relatively short spatial scales. Although tides and winds cause large currents these often have little spatial variation whereas wind waves, internal waves, and fronts cause large spatial variation. Length scale and intensity readily identify these processes. The second cause of altered roughness is sea surface slicks. SAR is remarkable effective at identifying oil slick because oil behaves “like oil on troubled water.” Although SAR images typically clearly show fronts it is uncertain to what extent these signatures arise from currents altering surface waves or collections of surface film.

Front Velocity
Internal waves apparently trapped behind fronts may offer a method of estimating speed of propagation of fronts. The dispersion relationship relates wave length and period using depth of the plume and density difference between plume water and ocean water. The internal waves shown in the image typically have wave lengths of 200 to 300 meters. Assuming a plume depth of 5 m and plume water with a salinity of 20 ppt gives a front velocity of 1.8 m/s. Reducing the salinity difference to where the plume water contains 25 ppt reduces the front velocity to 1.1 m/s. These velocities assume the waves move at their phase speed and also that there are no currents at the bottom of the plume moving in the opposite direction of the front. This method of estimating front velocity will become more applicable as front characteristics become better known.

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Wavelet Application
The panels at right show wavelet coefficients at 5 scales between 63 and 1005 m for the SAR image in the upper left panel. Note the series of internal waves whose wavelength increases toward the top of the image. The intensity of longer scale wavelets also increases in that direction. The plots have different scales as shown by the colorbar attached to each panel. The bring dots in the upper center are boats, which SAR images readily identify. The images showing the 251 and 502 m scales appear brighter to the right of the front.

Reference