

## Eddies in the Gulf of Alaska

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It was in mid-September 1998 that we met over coffee to discuss Frank's Line-P cruise on the Coast Guard Vessel *J.P. Tully*. While senior scientist on board ship the previous three weeks, Frank had found a huge, warm, fresh water mass more than 200 km wide and 1000 m deep, partway along the Line-P oceanographic stations, about 600 km west of Vancouver Island. (See Figure 1.)

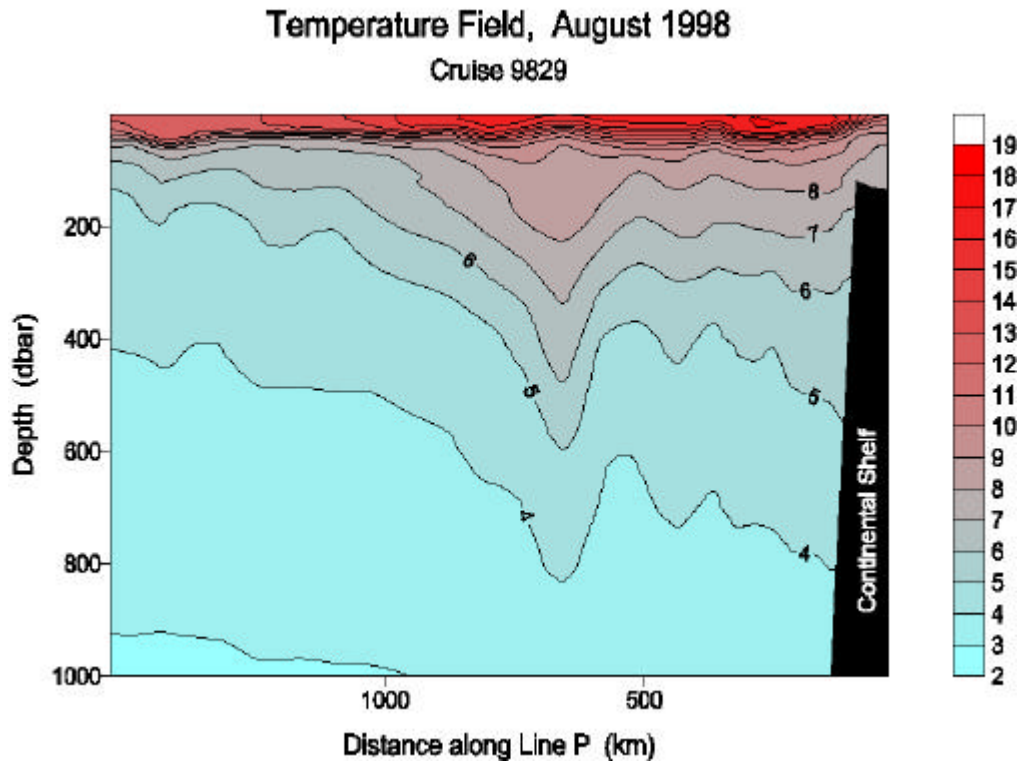


Figure 1: Temperature along Line-P in the Gulf of Alaska as measured in Aug-Sept 1998 from the Canadian Coast Guard Ship *J/P. Tully*.

"Do you see this feature in the TOPEX data?" he asked. TOPEX, or more accurately TOPEX/Poseidon, is a satellite that measures sea surface height. Bill and colleague Josef Cherniawsky of IOS had been processing TOPEX data for several months to look for sea level rise in coastal waters, as part of the El Niño event the previous winter.

Josef Cherniawsky had found a new web site that posted near-real-time TOPEX images. Bill signed on and entered the latitude and longitude range of the Gulf of Alaska, and the cruise date, and there it was: a red bulls-eye of water whose core rose 30 cm above its surrounding ocean, at the same place and diameter as Frank's warm, fresh water mass. (See Figure 2.) He had just found a web site that posted, for free, the most up-to-date, accurate information on these eddies.

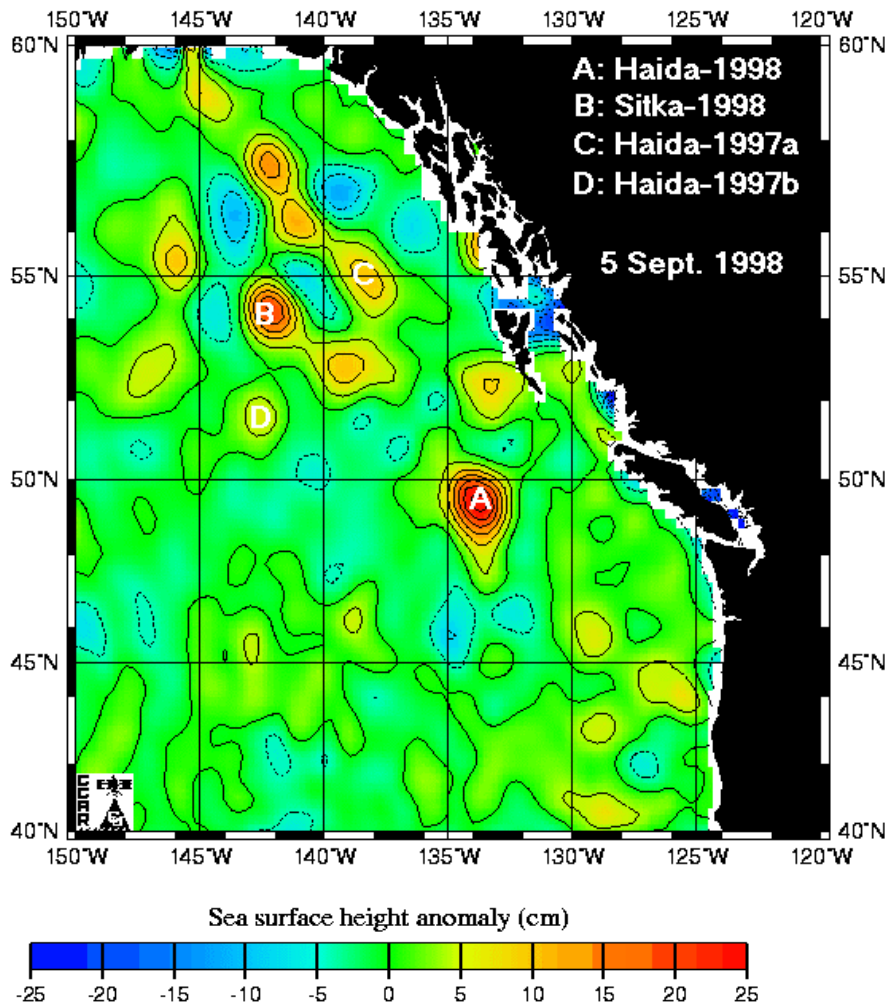


Figure 2  
 Contours of sea surface height from ERS-2 and TOPEX altimeters, as displayed on the web site [www-ccar.colorado.edu/~realtime/global-real-time\\_ssh/](http://www-ccar.colorado.edu/~realtime/global-real-time_ssh/).

Bob Leben of the University of Colorado had posted this web site only three weeks before to enable the public to find their own eddies. He combined TOPEX altimetry data with similar observations by the ERS-2 satellite that had been launched and tracked by the European Space Agency. He then applied spatial filters to enhance the ocean eddies and suppress large-scale seasonal signals. He developed this tool for his own studies in the Gulf of Mexico, but by putting all the data on his web site, he provided digital eyes to the world.

To see for yourself, visit his site at [http://www-ccar.colorado.edu/~realtime/global-real-time\\_ssh/](http://www-ccar.colorado.edu/~realtime/global-real-time_ssh/)

Bill quickly used this web site to plot images of the eddy over the previous seven months, and continues to track this eddy in November 1999. The images showed the eddy to form in winter along the West Coast of the Queen Charlotte Islands. He labelled it Haida-1998, after the First Nations name for the region and its year of formation.

The web site showed Haida-1998 to be one of an annual supply of eddies that transport fresh water and nutrients into mid-gulf from the Alaskan Panhandle and the Canadian West Coast. The unusually high elevation of the eddy core marks it as one of the largest eddies observed in this region. Haida eddies belong to a class of anti-cyclonic, coastal-generated eddies noticed by Tabata (1982) in water property data near Sitka, Alaska at 57 °N. Our observations identify another preferred generation region between 51°N and 54°N, off the West Coast of the Queen Charlotte Islands. Over the years 1994 to 1999 he found that three to five large eddies formed along the Alaskan Panhandle and Canadian West Coast in any one winter.

Frank's salinity and temperature measurements in August 1998 showed it to be to be fresher and warmer than surrounding waters below 100-m depth (Figure 1). Above 100 m, both salinity and temperature were slightly lower. Our dynamic height calculations (0/1000dbar) reveal that sea surface in the core of this eddy was 30 cm higher than outside the eddy, matching the altimetry measurements. Nutrient levels in its thermocline were substantially higher than in surrounding waters. The ocean water type of this eddy matches that found near the Queen Charlotte Islands in winter (53°N 133°W).

In February and June 1999, Bill sent the web-generated images to Frank at sea on the *J.P. Tully*, to direct him to its location for sampling. These measurements in September '98, February '99 and June '99 show the steady erosion of the nutrient excess in the eddy waters, and enhancement of phytoplankton in the September 1998 samples. The eddy provides nitrates to a nitrate-starved region of the Gulf of Alaska first described by Whitney, Wong, and Boyd (1998.)

Melsom et al. (1999) find Sitka and Haida eddies to be frequently set up in their numerical simulations of wind-driven currents along this coast. They believe it is baroclinic instability of the coastal flow that triggers the set up of eddies. A competing mechanism at the southern tip of the Queen Charlotte Islands may be the formation of gyres in the outflow jets past Cape St. James.

Based on calculations of dynamic heights of the 100-m surface relative to the 1000-m surface, using archived water property data, two of the highest-elevation eddies were Haida-1998, and Haida-1983, both generated in severe El Niño winters. This finding supports the study by Melsom et al. (1999) that suggests these eddies are larger in El Niño winters when northward, along-shore currents are stronger.

Thomson and Gower (1998) noticed a line of these eddies in a series of infrared images of sea surface temperature taken by one of the NOAA satellites in March 1995. Five eddies spanned the continental margin between Cape St. James and the extreme northern arc of the gulf. Such images are rare due to the prevailing cloud cover in winter. The skies open a bit in summer, but the ocean surface waters heat nearly uniformly in spring and summer, hiding these eddies from infrared eyes.

Radar sensors on altimeter satellites easily penetrate clouds. Indeed Gower and Tabata (1993) observed several of these eddies in the Geosat altimeter record between 1986 and 1989, and picked out their main features: anti-cyclonic rotation, formation at the continental margin and westward drift. TOPEX/ERS imagery generally confirms this westward drift with a few notable exceptions. Sitka-1998 and Haida-1998 both drifted southwards between April and November 1998, then turned toward the southwest. Several eddies that formed at the most northern extent of the Gulf of Alaska drifted mainly southwards, and often stalled completely.

The web site performance degrades on continental shelves where tides are big. Tides of 8 to 14 metres range sweep through the eddy-spawning regions along the Canadian Northwest Coast and the Alaskan Panhandle. These signals must be removed before the eddies can be resolved accurately. We rely on global tidal models to provide the local tidal features, but these models degrade on continental shelves, especially where tides exceed 5 metres. Josef Cherniawsky et al. (submitted) have analyzed the TOPEX/Poseidon data to calculate tidal constituents along the satellite tracks in the NE Pacific, and have reprocessed T/P data sent by Richard Ray and Brian Beckley of the Goddard Space flight Centre with these constituents. The new analysis shows that the formation of Haida-1998 actually began in early January 1998, or even late 1997. Bill and Josef have turned their attention to the eddies that drift along the Alaskan Stream from the Kenai Peninsula to the Aleutian Islands and beyond. These eddies can reach 70 cm in height, and survive for three years or more (Crawford, Cherniawsky and Foreman, submitted.) The T/P record provides a good view of their entire life history.

Michael Foreman et al. (submitted) have developed a numerical model that simulates the tidal heights of the Gulf of Alaska. The model uses almost 100,000 triangular elements for the region, with smallest elements on the continental margin to resolve the rapidly changing tides in shallow waters. Once completed, the simulated tides will improve the accuracy of altimetry signals from the complete satellite set: Geosat, Geosat Follow-on, TOPEX/Poseidon, ERS-1 and ERS-2, and also the proposed series of Jason satellites that will carry on the observations by TOPEX/Poseidon.

We are presently using the same models to determine the average seasonal height of the sea surface along the Canadian margin of the gulf (Foreman et al, 1998.) Once combined with all satellite altimetry data, we will be able to determine absolute sea surface heights, and use them to compute northward flow of surface currents along our coast.

## **Appendix:**

### **Altimeters on satellites.**

An American-French program launched TOPEX/Poseidon in 1992, and released the first data from it in October that year. It senses sea surface height along a 20-km-wide swath, on an orbital track that repeats about every ten days. Each ten-day sample is denoted a "cycle". "TOPEX" refers to the American dual-frequency radar sensor that is turned on for nine of ten cycles. "Poseidon" is the French radar unit that samples on the tenth cycle. Early studies showed the rms accuracy of TOPEX/Poseidon sea surface height measurements, after all corrections, to be about 5 to 7 cm.

Physical oceanographers usually want to know the sub-surface pressure gradient in the ocean rather than the sea surface height. This gradient is formed by the weight of sea water plus atmosphere above. Therefore, as part of the processing prior to release of data, the inverse barometer correction is applied using the best estimate of sea surface air pressure along the T/P track. Both the European and American global weather models provide air pressure records for this "correction". This calculation assumes the ocean responds to air pressure changes as a perfect inverse barometer. Uncertainties in the air pressure above the T/P tracks and in the oceanic response to changes in air pressure make up some of the larger errors in the T/P calculations of sea level. Obviously, any scientist comparing T/P measurements of sea level and float gauge measurements at shore should remember the former are "pressure compensated", whereas the latter are not.

Most studies of T/P and other satellite data look at anomalies from a long term record. The T/P record now exceeds seven years and embraces the 1997/98 El Niño, so this anomaly record is interesting by itself. To compute absolute sea surface height requires knowledge of the geoid, or of the ocean currents along the T/P tracks. In most regions the geoid is too poorly known to be of use. Several Canadian efforts, ( Keith Thompson and Ross Hendry on the Atlantic coast, and Mike Foreman, Josef Cherniawsky and Bill Crawford on the west coast) are in progress to develop dynamical ocean models to compute seasonal sea surface elevations in Canadian waters of the Pacific and Atlantic. The combination of these models and T/P observations will produce a more accurate geoid over the ocean, and permit calculations of absolute currents in these regions from T/P data.

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