The state of the eastern North Pacific through summer 2003

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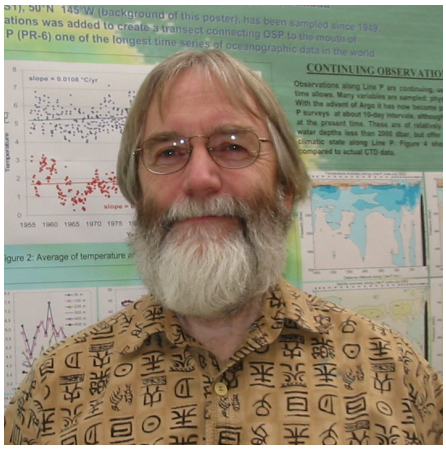

Frank A. Whitney has led the Line P program for the past 12 years, carrying out repeat oceanographic sections for WOCE (1991-97) and hosting the Canadian JGOFS program (1992-97) on these cruises. Through this time, his main research interest has been in understanding processes which control nutrient supply to the upper ocean. He has also surveyed mesoscale eddies several times in an attempt to estimate offshore transport of coastal waters in the Gulf of Alaska. Frank has been working in oceanography on the British Columbia coast since 1969.

The cold layer which has been underlying the surface waters of the Gulf of Alaska in the past couple of years, and caused extreme biological responses in North American coastal waters during the 2002 upwelling (Huyer *et al*., *Geophys. Res. Lett*. 30, 2003), prompted us to assess the uniqueness of this event at Ocean Station Papa (50ºN, 145ºW). Monthly temperature anomalies in the upper several hundred meters show that warm and cool periods can persist for several years (Fig. 1, courtesy of Marie Robert, Institute of Ocean Sciences), especially below the mixed layer (winter Mixed Layer Depth ~100 m). The 1960s were the coolest period in the past ~50 years and the 1990s were warmest.

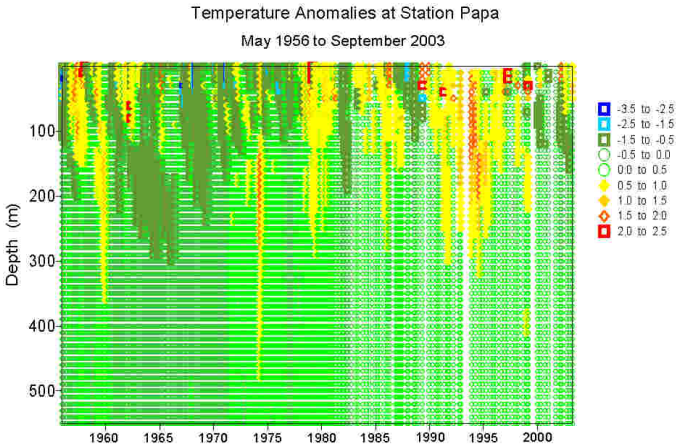

Fig. 1 Temperature anomaly at Ocean Station Papa from 1956 to present. The dark green (strong negative anomaly) to red (strong positive anomaly) shading shows periods of cool and warm waters below the mixed layer.

Huyer and others showed results which defined the coastal upwelling of 2002 along the British Columbia to California coast as the most extreme cool event yet observed. Our results from Stn. Papa are not as dramatic. Cool waters similar to those found in the 1960s, and sporadically in the 1980s, are again observed in the upper 150 m. These waters are slightly less saline than recently seen (Fig. 2, from Marie Robert also), but are well within the range observed at this site. Overall at Stn. Papa, we continue to observe a warming trend in both the surface and subsurface layers, with the rate of warming appearing greater at depth. Salinity shows little change in surface waters and an increasing trend in the 150-250 m layer. An increase in temperature and salinity in subsurface waters suggests that subtropical waters are becoming more dominant. These waters are relatively impoverished in nutrients, thus their presence will reduce nutrient supply to the mixed layer and may decrease the productivity of this area.

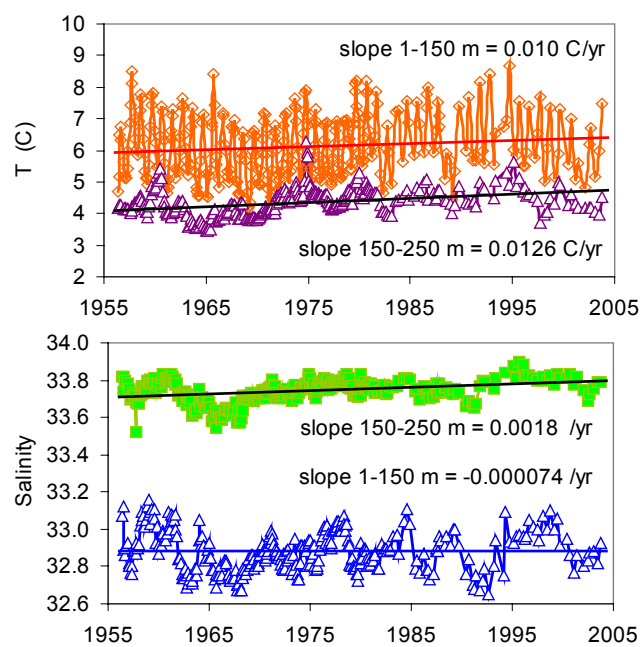

Fig. 2 Average temperature and salinity at Ocean Station Papa in the upper 150 m and 150 to 250 m layers.

The recent development of a cold layer in the Gulf of Alaska, however, did reduce the winter mixed layer depth to ~75 m in 2002. The enhanced stratification of the upper ocean affected nutrient supply and led to extensive silicate limitation of diatom growth in summer 2002 (PICES Press, July 2003). Nutrient supply in February 2003 suggested silicate limitation could be even more severe in the following summer (Fig. 3). Diatoms typically utilize silicate and nitrate at a ratio of 1.2 uM Si:1 uM NO_3. If the supply ratio of nutrients is less than this, then silicate depletion would be expected. However, there is little evidence of silicate limitation in September 2003. Conditions during late summer are quite similar to the long-term average (Whitney and Freeland, *Deep-Sea Res. II* 46, 1999) and show a broadening of the HNLC (high nitrate, low chlorophyll) domain in the Gulf of Alaska.

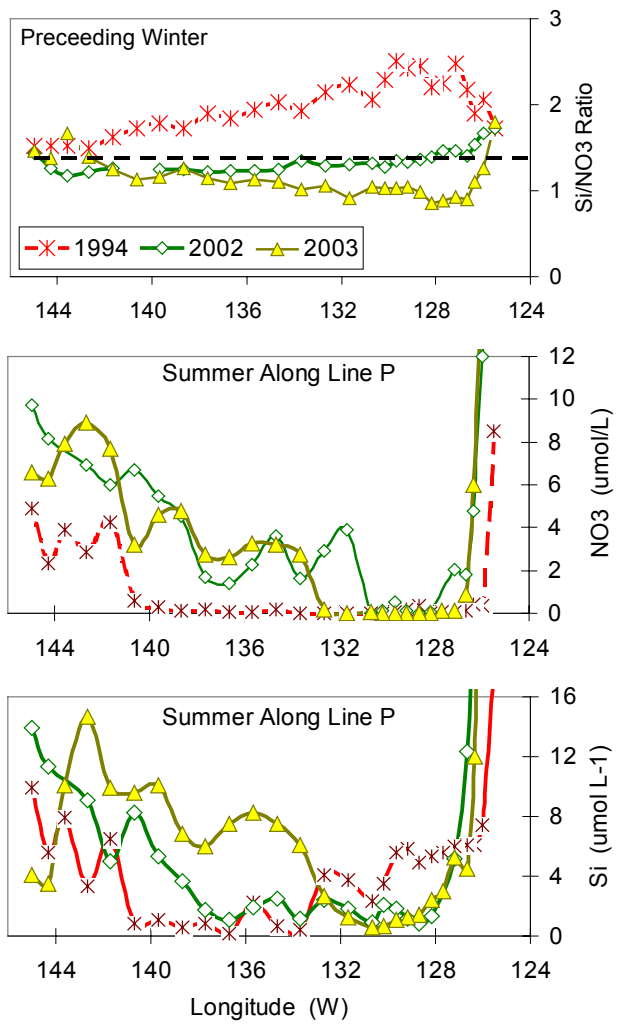

Fig 3 Silicate/nitrate ratios in surface waters along Line P in winters of 1994 (warm, near normal), 2002 and 2003. Dashed line indicates the ratio needed to support diatom growth. Lower panels show nutrient concentrations in summer for the same 3 years.

How to make sense of such seasonal inconsistencies? Howard Freeland (Institute of Ocean Sciences) has been using Argo data (http://argo.jcommops.org/) to compute the location of the axis of the subarctic current from the dynamic height field (details can be found at www.pac.dfo-mpo.gc.ca/sci/osap/projects/argo/Dhgts_e.htm). His analysis shows the subarctic current rapidly shifted 700 km south in spring 2003 at 145ºW, the longitude of Ocean Station Papa (Fig. 4). Because this analysis starts in early 2002 when the axis is to the north, it is not possible to determine from these data which position of this current is "typical". But the sudden southward shift of subarctic waters does explain why silicate depletion was not observed along Line P in summer 2003.

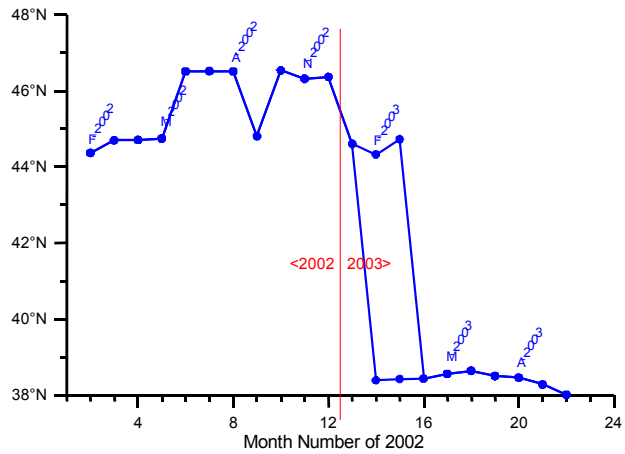

Fig 4 The position of the maximum in dynamic height at 145ºW is plotted over time starting in January 2002. The plot shows a rapid shift south of the center of the subarctic current in the NE Pacific in spring 2003.

These Argo results are showing that we cannot assume a similar water mass is being sampled on successive cruises. Many papers have been written making this assumption, and have attempted to estimate seasonal rates of new production based on nutrient drawdown. These estimates are at the core of our understanding of ocean productivity in the subarctic Pacific and are extremely vulnerable to north-south water mass displacements. Whitney and Freeland (*Deep-Sea Res. II* 46, 1999) estimated N-S gradients of nutrients at ~1 uM nitrate and 2 uM silicate per 100 km. A 700 km southward displacement of the subarctic current, as observed in 2003, potentially introduces a nutrient change larger than the annual estimated drawdown of ~7 uM nitrate and 11 uM silicate at Stn. Papa. Several years (decades?) of Argo data will be needed before we can assess the instability in major ocean currents and the frequency of latitudinal shifts. Until this data is available, at least some of the observations of anomalous nutrient utilization along Line P must be considered the result of rapid N-S advection of waters with either subtropical or subarctic characteristics.