Preface to special section on enhanced Subarctic influence in the California Current, 2002

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[1] This special section discusses a rare phenomenon: strong enhancement of Subarctic influence in the California Current system in the summer of 2002. This cold, fresh anomaly in the upper halocline was more extreme than any prior observation, though historical records extend back for several decades. The Subarctic anomaly extended more than 1500 km along the U. S. west coast, from 49°N to 33°N. It brought high-nutrient waters into the coastal upwelling zone off Oregon and northern California, and produced exceptionally high chlorophyll concentrations. Inner shelf oxygen concentrations were very high near the surface and very low near the bottom. The presence of this Subarctic water mass was associated with anomalous southward currents detected by three different methods: by satellite-tracked drifters, a mid-shelf mooring, and by satellite altimetry. Large-scale wind forcing over the northeastern Pacific during the previous winter and spring seems to be responsible for these anomalies. *INDEX TERMS:* 4215 Oceanography: General: Climate and interannual variability (3309); 4516 Oceanography: Physical: Eastern boundary currents; 4223 Oceanography: General: Descriptive and regional oceanography; 4283 Oceanography: General: Water masses; 4279 Oceanography: General: Upwelling and convergences. **Citation:** Huyer, A., Preface to special section on enhanced Subarctic influence in the California Current, 2002, *Geophys. Res. Lett.*, *30*(15), 8019, doi:10.1029/2003GL017724, 2003.

1. Introduction

[2] This collection of papers discusses the occurrence of an unusually strong enhancement of the Subarctic influence that is a fundamental property of the California Current system. The cold, fresh anomaly observed in the upper halocline during July 2002 was more extreme than any prior observation, though historical records extend back for several decades and span both negative and positive phases of the Pacific Decadal Oscillation as well as both La Niña and El Niño episodes. The Subarctic anomaly was associated with exceptionally high chlorophyll concentrations and anomalous southward currents detected by three independent measuring techniques. Large-scale wind forcing over the eastern North Pacific seems to be responsible for these anomalies. This preface provides some relevant background on the California Current, a brief description of the discovery of anomalous conditions, and an overview of the major findings provided in this collection.

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2. Background

[3] Classical studies conducted more than sixty years ago recognized a strong Subarctic influence in the California Current region [*Sverdrup et al.*, 1942; *Tibby*, 1941]. They found that subsurface water properties along the U. S. west coast can be explained largely in terms of mixing of two water masses, Subarctic Water from the north, and Equatorial Water from the south. Subsequent overviews [*Reid et al.*, 1958; *Roden*, 1971; *Hickey*, 1979; *Lynn and Simpson*, 1987] emphasized the importance of Subarctic influence in determining the characteristics of the southward-flowing California Current waters (low temperature, high phosphate, and especially low salinity).

[4] The California Current system is subject to strong seasonal variability [*Lynn and Simpson*, 1987], moderate interannual variability [*Chelton et al.*, 1982], and decadal variability [*Mantua et al.*, 1997; *Chavez et al.*, 2003]. Regular repeated observations of the California Current system began in 1949 with the CalCOFI program [*Lynn and Simpson*, 1987]. Much of the seasonal variability is due to the seasonal reversal in the alongshore winds north of 37°N, which are poleward in winter and equatorward in summer. Coastal upwelling in spring and summer intensifies the equatorward flow of low-salinity Subarctic water; coastal downwelling in winter drives inshore currents northward and reduces the Subarctic influence at a given latitude. Off central and northern California, the core of lowest salinity surface waters lies near the core of the southward current [*Lynn and Simpson*, 1987; *Huyer et al.*, 1991].

[5] Most of the interannual variability is associated with El Niño [*Chelton et al.*, 1982], which can affect this region directly by an oceanic route and indirectly through the atmosphere [*Chavez et al.*, 2002]. The oceanic signal usually arrives first: coastal trapped waves propagate northward along the continental margin from the eastern equatorial Pacific, depressing isopycnals, raising sea level, and intensifying poleward currents along the coast [*Huyer and Smith*, 1985]. The atmospheric response to El Niño includes a southward displacement of the jet stream over the eastern North Pacific and a more intense Aleutian Low, both peaking in winter [*Harrison and Larkin*, 1998]; the enhanced southwest winds cause more intense coastal downwelling which further enhances the northward current along the coast [*Huyer et al.*, 2002]. Strong El Niño episodes (e.g., 1982–3, 1997–8) are associated with strong temperature, sea level, and current anomalies in the California Current region [*Lynn*, 1983; *Huyer et al.*, 2002; *Lynn and Bograd*, 2002]. La Niña episodes in the equatorial Pacific usually do not result in strong anomalies here [*Smith et al.*, 2001].

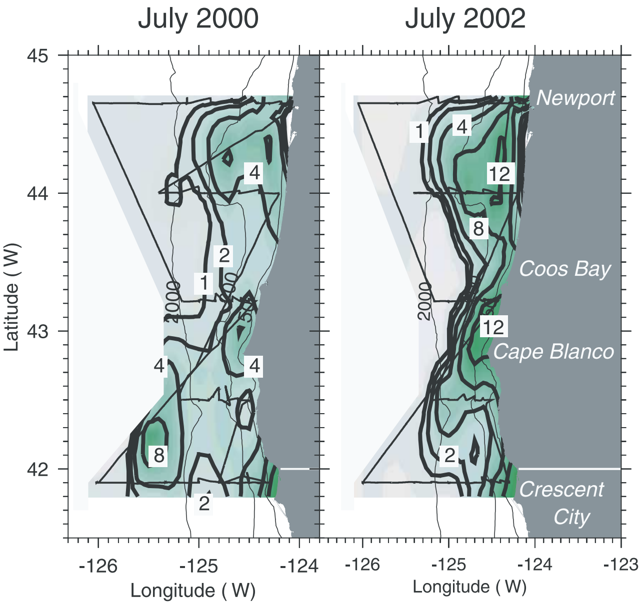

Figure 1. Underway fluorometer-derived chlorophyll ($\mu g\ l^{-1}$) during GLOBEC LTOP surveys off Oregon in July 2000 and July 2002, using water from a 5-m intake on R/V Wecoma. Note that inshore values are offscale (>5.0 V fluorescence, i.e., >13.9 $\mu g\ l^{-1}$ chlorophyll) on all but one section in July 2002; no values were offscale in July 2000.

[6] Decadal variability remains largely unexplained, but it is recognized that the North Pacific was in a cool phase for about 25 years from 1950 to 1975 and in a warm phase for about 20 years from 1978 to 1997 [*Mantua et al.*, 1997; *Chavez et al.*, 2003], with a 'regime shift' occurring about 1976 [*McGowan et al.*, 1998]. The CalCOFI sampling off southern California which began in 1949 spanned both of these periods; many stations off San Diego and Pt. Conception were sampled more than 80 times during the warm phase and more than 100 times during the cool phase [*Bograd and Lynn*, 2003a, 2003b], when we would expect Subarctic influence to be strongest. Line P off Vancouver Island was sampled regularly from 1959 to 1981, and has been sampled intermittently since then [*Whitney and Freeland*, 1999]. The Newport Hydrographic (NH) Line off central Oregon was sampled seasonally from 1961 to 1971 and from mid-1997 through 2002; *Smith et al* [2001] have calculated seasonal averages for the 1961–71 period which falls entirely within the cool phase.

[7] The U. S. GLOBEC North East Pacific (NEP) Program [*Strub, Batchelder and Weingartner*, 2002] to study the effects of changing climate on the marine ecosystem of the northern California Current system was initiated in 1997. The Long-Term Observation Program (LTOP) of the NEP includes a six-year series of seasonal hydrographic cruises, repeated deployments of satellite-tracked drifters, and some mid-shelf moorings. LTOP sampling of the NH-Line off central Oregon began just in time to catch positive temperature and northward current anomalies associated with the 1997–98 El Niño [*Huyer et al.*, 2002; *Kosro*, 2002]. By the end of 1998, the effects of El Niño on the California Current had faded [*Chavez et al.*, 2002], and the ocean off California was unusually cold in the spring of 1999 [*Schwing and Moore*, 2000]. By 2001, the California Current was in its third straight La Niña year [*Durazo et al.*, 2001]. By spring of 2002, a new El Niño was developing in the equatorial Pacific but there were also indications that a regime shift to a new cool decadal phase North Pacific Ocean might have occurred in 1998 or 1999 [*Schwing et al.*, 2002; *Chavez et al.*, 2003].

3. Anomalous Conditions in July 2002

[8] On our GLOBEC LTOP cruise off Oregon during 9–15 July 2002, we noticed unusually high chlorophyll concentrations in coastal waters (Figure 1), and frequent temperature inversions with exceptionally low temperature values at the relative minimum (Figure 2). Simultaneously, independent investigators also observed extreme phenomena over the inner shelf: Dave Fox (pers. comm.) found a

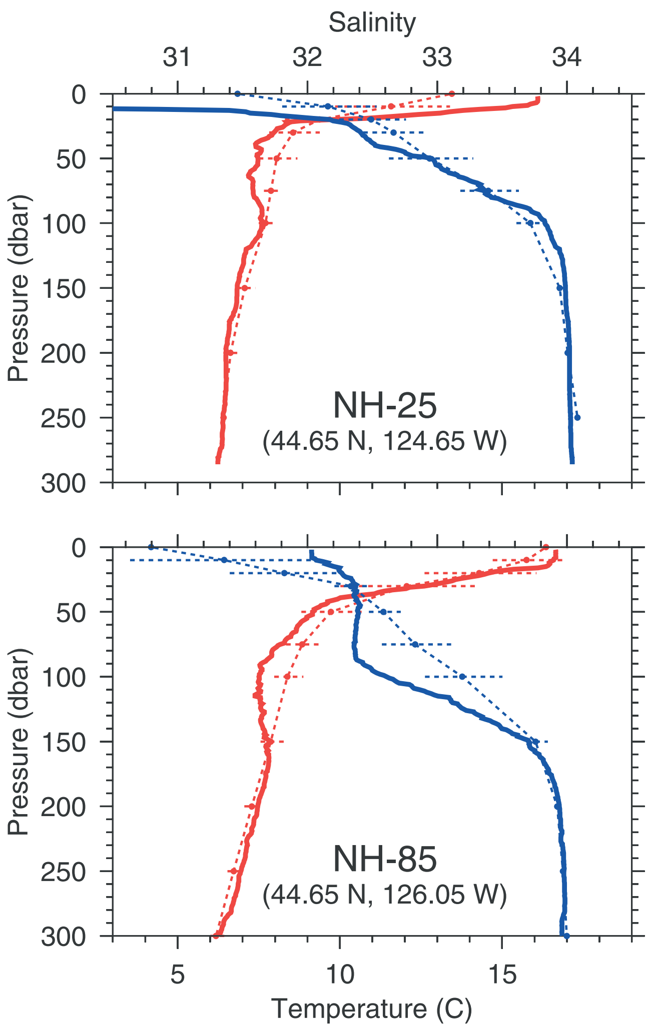

Figure 2. Temperature (red) and salinity (blue) profiles off Newport, Oregon, July 2002 (thick line) compared to the 1961–1971 summer averages (dotted line with bars representing ±1 std. dev.). NH-25 is at the shelf-break, 37 km from shore; NH-85 is the most offshore station, 157 km from shore. See *Freeland et al.* [2003] for corresponding T-S diagrams.

massive die-off of benthic fauna during an Oregon Department of Fish and Wildlife survey of an inshore bank at 44.25°N; Brian Grantham (pers. comm.) and colleagues in PISCO ('Partnership for Interdisciplinary Studies of Coastal Oceans') found an exceptionally strong phytoplankton bloom in the intertidal zone at 44.25°N. Informal discussions quickly led us to recognize hypoxia over the inner shelf, and to appreciate the importance of the combined anomalies. We alerted colleagues at other oceanographic institutions along the west coast of the exceptionally cold halocline off central Oregon, and soon received reports of related phenomena. By mid-September plans were underway for a one-day symposium to be held during the annual meeting of GLOBEC NEP investigators in November 2002. This symposium, entitled "Cold Halocline, Hypoxia and High Productivity in the Northern California Current" was held in Corvallis, Oregon on 19 November 2002; fifteen papers were presented. One of these papers has already been published [*Freeland et al.*, 2003], seven others are included in this special section of GRL, and a few more will likely be submitted to other journals.

4. Overview of Results

[9] *Freeland et al.* [2003] describe the cold, fresh Subarctic anomaly in and above the upper halocline observed in July 2002 on both the NH-line off central Oregon (44.7°N) and Line-P off Vancouver Island (49°–50°N). They consider several probable causes including anomalous advection. *Bograd and Lynn* [2003a, 2003b] show a similar water-mass anomaly off southern California at the same time. Together, these studies suggest that the water-mass anomaly extends at least 1500 km along the U. S. west coast and that its width is at least 150 km. At both ends of the California Current, T-S characteristics at the density of the upper halocline are more extreme (colder and fresher) than any observed in the three preceding La Niña years (1999–2001), and more extreme than any observed in the historical records, even during the cold phase of the Pacific Decadal Oscillation. There are, of course, significant differences between the T-S characteristics at the core of the anomaly at different latitudes: core temperature values are about 6.5°C at 49°N, 7.5°C at 44.7°N and 11°C at 33°N; core salinity values are about 32.5 at both 49°N and 44.7°N, and about 32.8 at 33°N [*Freeland et al.*, 2003; *Bograd and Lynn*, 2003a, 2003b]. The latitudinal temperature gradient (about 2°C per 1000 km) is about the same as normal; the salinity gradient (about 0.15 per 1000 km) is about half of normal.

[10] Two papers in this special section describe some biological consequences. *Wheeler et al.* [2003] show that halocline waters in the coastal upwelling zone had unusually high nutrient concentrations; this is the layer that supplies much of the water upwelled into the photic zone [*Huyer*, 1983]. The chlorophyll fluorescence was much stronger in 2002 than in the preceding La Niña years, both over the shelf off central Oregon [*Wheeler et al.*, 2003] and in large portions of the California Current region [*Thomas et al.*, 2003]. Dissolved oxygen concentrations over the inner shelf off central Oregon waters were very high near the surface (>150% saturation), indicating very high primary productivity there, while bottom waters were nearly depleted (<15% saturation), suggesting local and rapid respiration [*Wheeler et al.*, 2003].

[11] Three separate papers discuss evidence for anomalous advection as the likely cause of the enhanced invasion of Subarctic waters into the California Current Region. *Barth* [2003] presents results from satellite-tracked drifters deployed repeatedly along the LTOP section off central Oregon; the drifters were intended to span the full width of the equatorward coastal jet which forms the core of the California Current at this latitude. *Kosro* [2003] discusses results from a continuous mid-shelf mooring which usually lies inshore of the coastal jet; *Kosro* [2003] was able to determine the onset, duration, mean and peak strength of anomalous shelf currents. Both *Kosro* [2003] and *Barth* [2003] found enhanced southward advection along central Oregon during spring and summer 2002, thus confirming alongshore advection as a principal cause of the cold-halocline anomaly. *Strub and James* [2003] use satellite altimeter data to examine both local and upstream surface currents; their data are relatively coarse in both space (~250 km) and time (~10 days), but provide coverage over a very large area. *Strub and James* [2003] found enhanced southward flow both in the California Current and farther north; they also found enhanced zonal flow toward the Pacific Northwest in the North Pacific Current, first on its northern flank and later on its southern flank.

[12] The paper by *Murphree et al.* [2003] shows that large-scale atmosphere-ocean processes gave rise to these local anomalies in the California Current Region. There was anomalous Ekman transport of Subarctic water into the North Pacific Current during January-February 2002; the eastward transport of the North Pacific Current was enhanced in late winter; and there was anomalously strong upwelling along the west coast of North America in spring and summer. This sequence of large-scale processes led to a stronger California Current, and thus to enhanced Subarctic influence there. Only time and further research can show whether these anomalous conditions in the California Current system will persist or recur, or whether this was a short-lived rare event. Sampling in the California Current by the GLOBEC LTOP, CalCOFI and Line P programs will continue through the summer of 2003.

[13] **Acknowledgments.** I'm grateful to Dave Fox and Brian Grantham for early discussion of anomalous conditions; to Bob Smith, Pat Wheeler, Brian Grantham and Jack Barth for help in organizing the symposium on 'Cold Halocline, Hypoxia and High Productivity in the Northern California Current'; to Ted Strub, Hal Batchelder and Linda Hunn for hosting the symposium as part of the November 2002 GLOBEC NEP investigator meeting. Jane Fleischbein provides invaluable assistance, both at sea and ashore, collecting and analyzing data. Special thanks to Jane for her help with Figure 1 and to Pat Wheeler for converting fluorescence to chlorophyll. The National Science Foundation (Grant OCE-0000733) provides financial support. This is contribution number 396 of the U. S. GLOBEC program, jointly funded by the National Science Foundation and the National Oceanic and Atmospheric Administration.

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