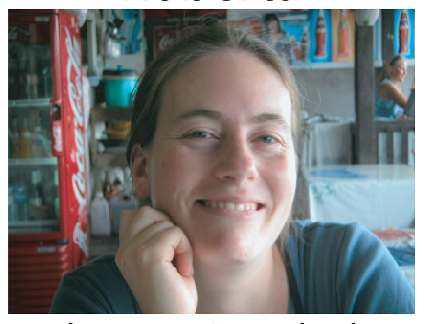
Interannual variability in Atmospheric Potential Oxygen from the Scripps atmospheric oxygen flask sampling network

Roberta



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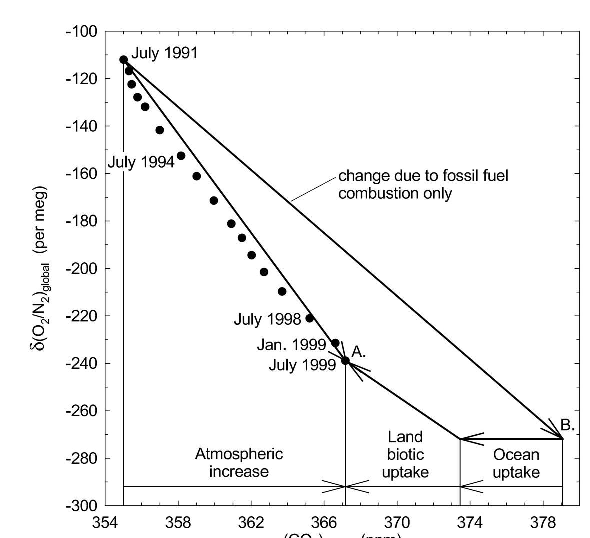
Motivation:

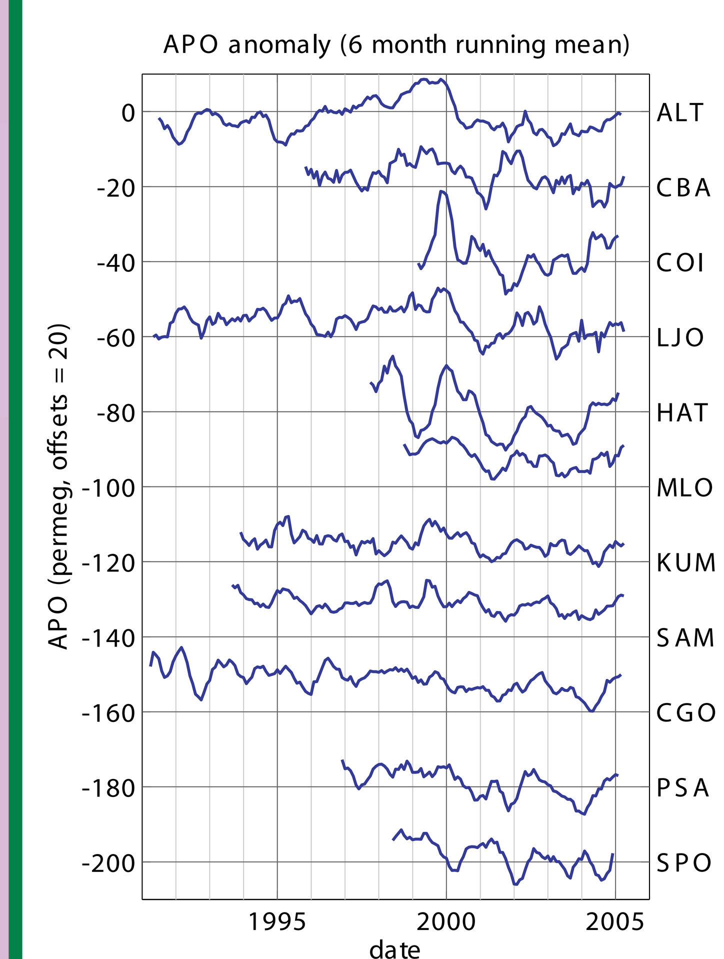
We use discrete measurements of the tracer Atmospheric Potential Oxygen (APO) to investigate interannual variability in large-scale oxygen fluxes between the atmosphere and ocean. Understanding the sources of this variability will lead to improvements in our ability to use measurements of atmospheric CO_2 and O_2 as constraints over ocean uptake of anthropogenic CO_2 (McKinley et al. 2003), the kinetics of gas exchange (Keeling et al. 1998a), and gas cycling in ocean models (Stephens et al. 1998).



Manning (2001) PhD thesis, after Keeling et al. (1996) *Nature* **381**, 218-221.

Above: Global atmospheric O_2 and CO_2 averages from the 1990s, showing vector solution for land and ocean sinks.

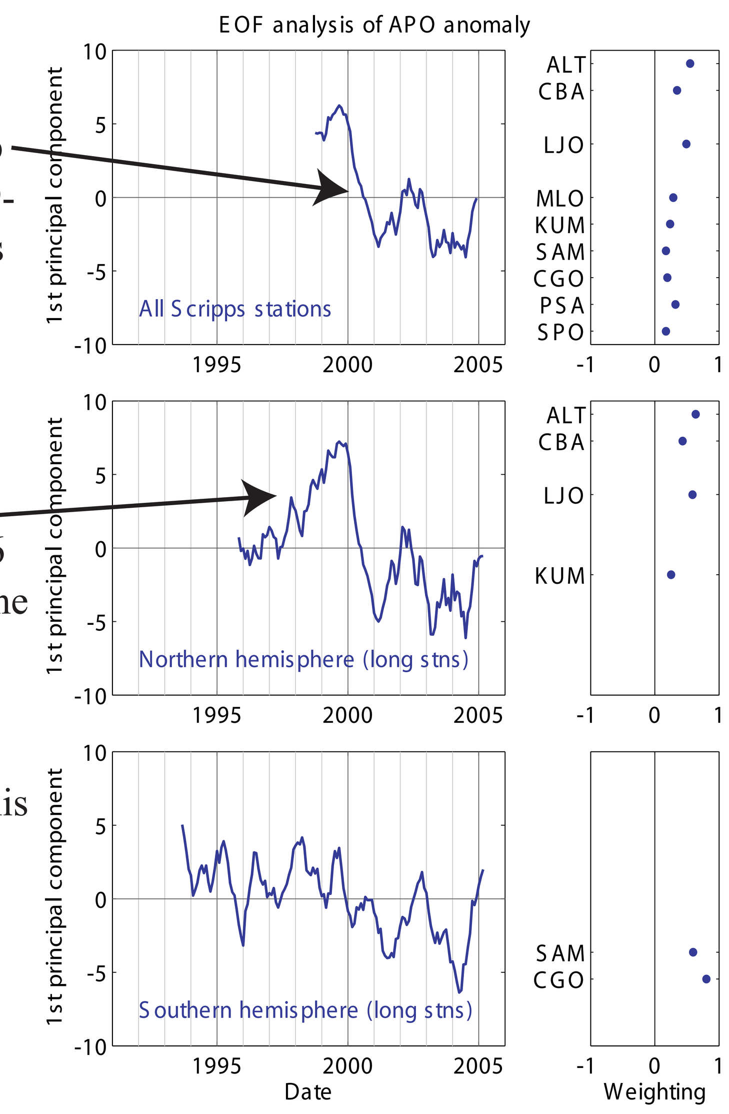
Features in the interannual APO records:



APO anomalies for all stations plotted from north (top) to south (bottom). Seasonal cycles are fit as four harmonic functions to the monthly APO data at each station. To calculate anomalies we subtract off the seasonal cycles and further remove linear trends due to fossil fuel combustion, and CO_2 uptake and O_2 outgassing from the ocean (Manning 2001). A six month running mean was applied to the anomalies shown here.

1. The drawdown: A sharp decrease in APO late 1999-early 2001. This feature is most prominent in the Northern hemisphere stations.

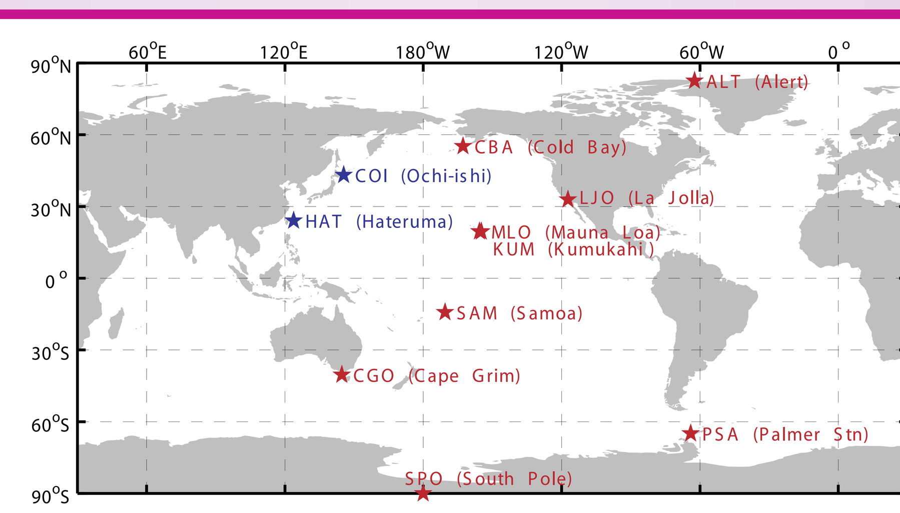
2. The hump: A slower increase in APO from1996 to late 1999 is evident in the Scripps Northern hemisphere stations. The Tohjima data shows more variability at this time. This feature does not appear to be present in the southern hemisphere stations.



We used a principal component analysis (EOF) to pick out the patterns common to several stations. Time-series are shown on the left, weightings for different stations on the right. The length of the EOF time-series is governed by the length of the shortest record.

Sampling stations and methods:

Flasks of air are collected approximately biweekly at nine stations spanning the globe and returned to Scripps for analysis of O_2/N_2 by an interferometric technique and CO_2 using an infrared analyzer (Keeling et al. 1998b). Data from the two stations near Japan (in blue) were generously provided to us by Dr. Tohjima who measures O_2/N_2 by GC/TCD (Tohjima et al. 2003).



Decreasing APO	Increasing APO
More ventilation	Less ventilation
Cooling of sea surface	Heating of sea surface
Less biological production	More biological production
Changing wind patterns alter rates of air-sea gas exchange	

Causes of variability:

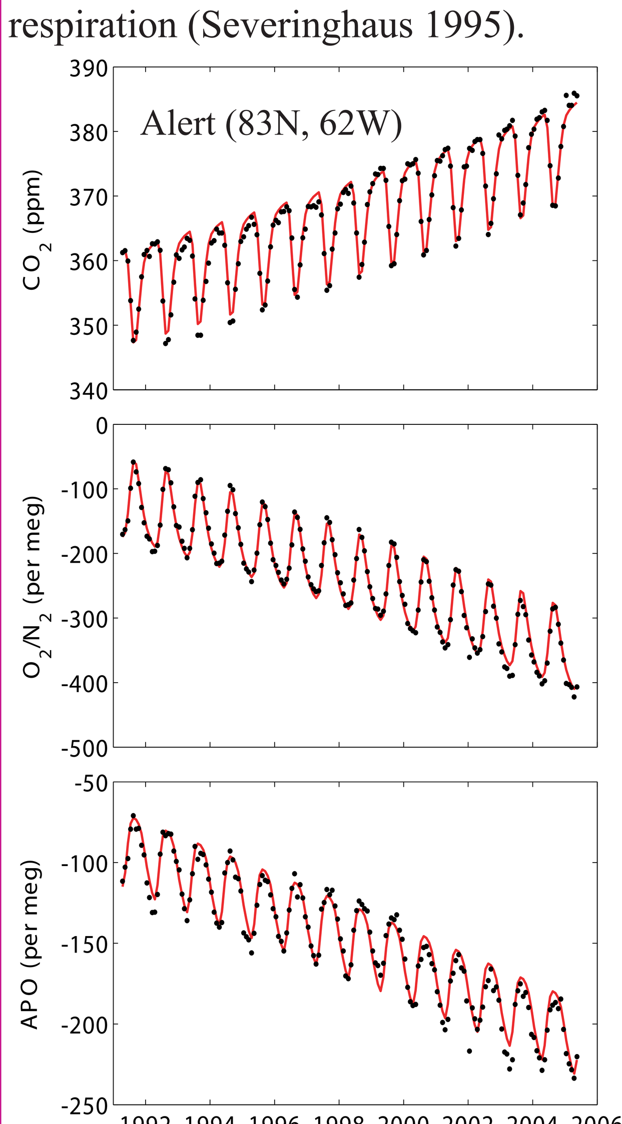
Air-sea fluxes of oxygen can be driven by changes in both physical and biological processes. We have particularly focused on whether the observed large decreases may be driven by ventilation events in areas that do not deeply convect every year.

Atmospheric Potential Oxygen (APO):

Contributions from the terrestrial biosphere can be removed by combining observed O_2 and CO_2 signals to create the tracer Atmospheric Potential Oxygen (APO) (Stephens et al. 1998):

$$APO = \delta(O_2/N_2) + \left(\frac{1.1}{0.2095}\right)(CO_2 - 350)$$

where 1.1 is the ratio of CO_2 to O_2 during photosynthesis or respiration (Severinghaus 1995).

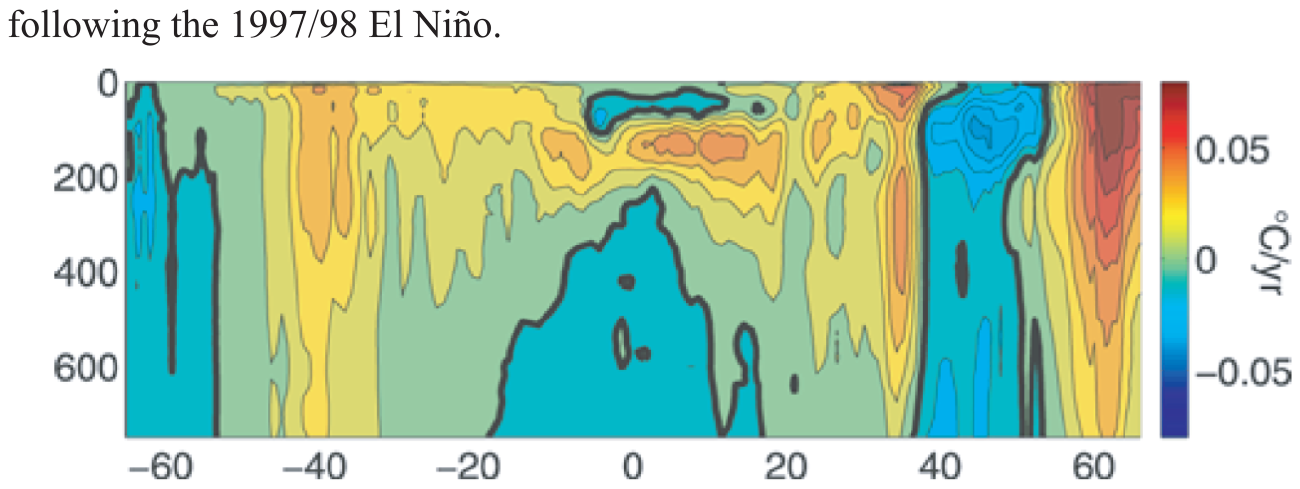


CO_2 (top) and O_2 (middle) from station Alert are almost mirror images. Long-term trends are largely caused by burning of fossil fuels. The seasonal cycle is mostly driven by photosynthesis / respiration of the terrestrial biosphere.

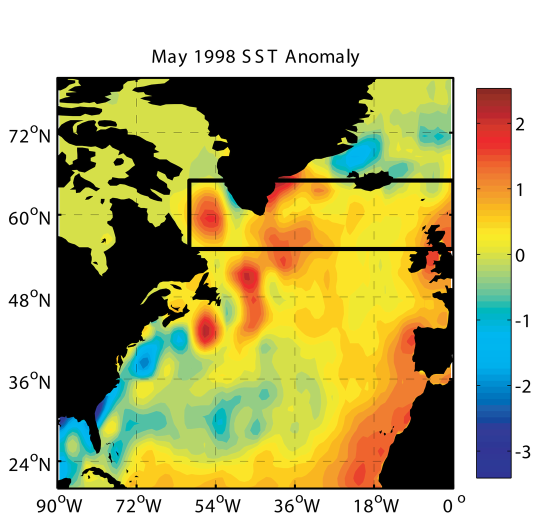
Seasonal cycles in APO (bottom) are driven by air-sea fluxes of O_2. APO also shows a distinct long-term trend driven both by burning of fossil fuels ($CO_2/O_2 = 1.4$) and by ocean uptake of CO_2 (Stephens et al. 1998).

Abrupt warming of the North Atlantic:

Although we have removed a linear APO increase due to O_2 outgassing from anthropogenic warming of the ocean, more rapid or localized warming may cause increases in APO. The far northern Atlantic experienced a rapid warming in the late 1990s, and there are also indications that warmth propagated into the North Pacific following the 1997/98 El Niño.

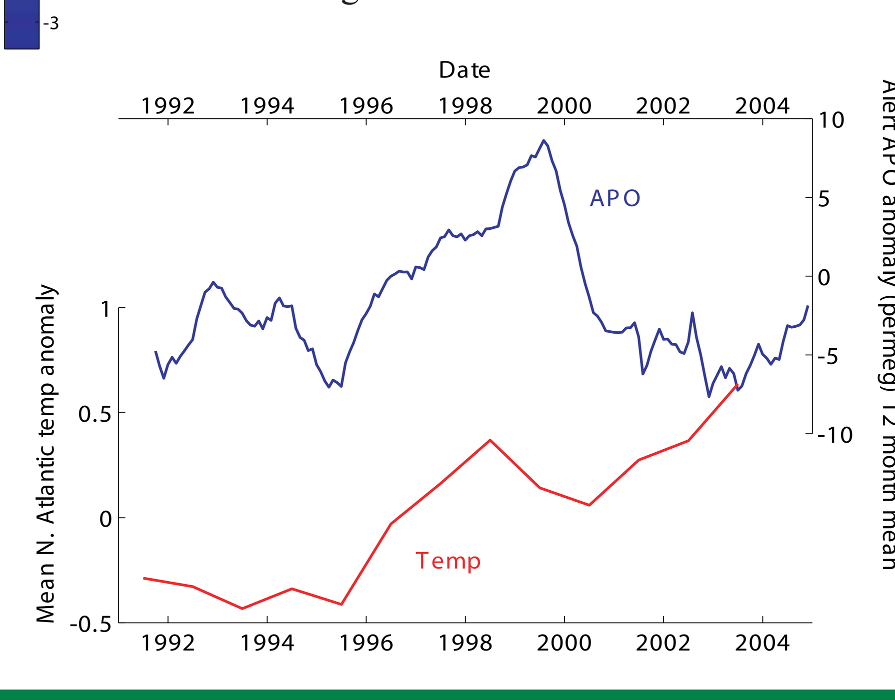


Above: Trend from 1993 to 2003 in zonally averaged temperature vs. depth and latitude. The extreme warming around 60º is concentrated in the North Atlantic (Willis et al. 2004).



Above: Map of SST anomalies in May 1998 in the North Atlantic. The box shows the area where temperatures were averaged for the figure to the right.

The increase in heat content in the North Atlantic was rapid and occurred at about the same time as the increase in APO observed in most of the Northern Hemisphere stations. The increase in APO is greatest at Alert, which is poised to pick up the North Atlantic signal most cleanly. The Pacific stations may be seeing both a combination of the effects of remote Atlantic warming and local warming of the North Pacific.

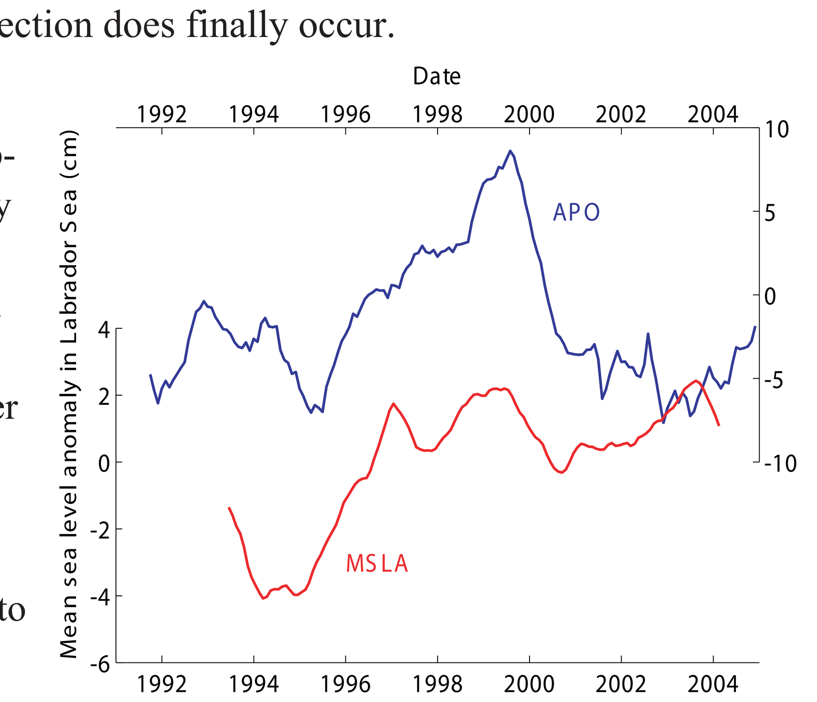


Right: The blue line shows the APO anomaly at Alert (12-month running mean). The red line shows the mean temperature anomaly in the upper 700m of the North Atlantic (weighted toward the surface) taken from temperature fields of Levitus et al. (2005).

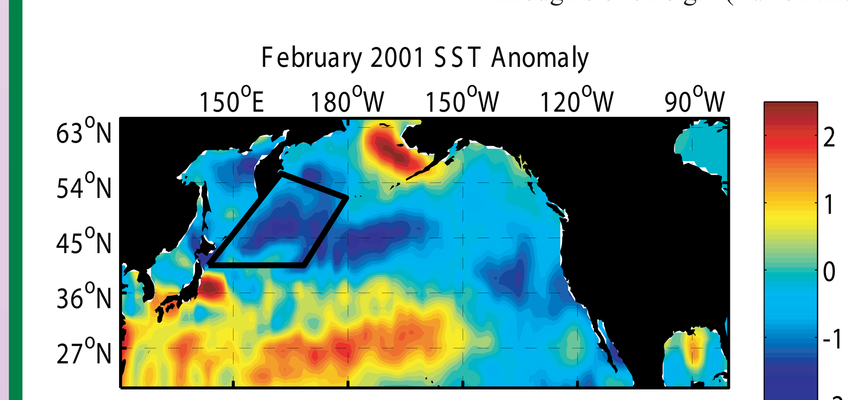
Interannual variability in deep convection:

The greatest potential for large drawdowns in APO may lie with deep and intermediate water formation sites that only occasionally convect deeply. Shallow convection years allow oxygen deficits to build up in the water column, which in turn cause a large flux of oxygen from the atmosphere into the ocean when deep convection does finally occur.

The Labrador Sea experienced a series of deep-convection years in the early 1990s, followed by several years of restratification, and finally another deep-convection year in the winter of 1999/2000 (Lazier et al. 2003). Alert is uniquely placed to capture a North Atlantic signal and appears to start its drawdown about a year earlier than other N. hemisphere sites in 1999/2000.



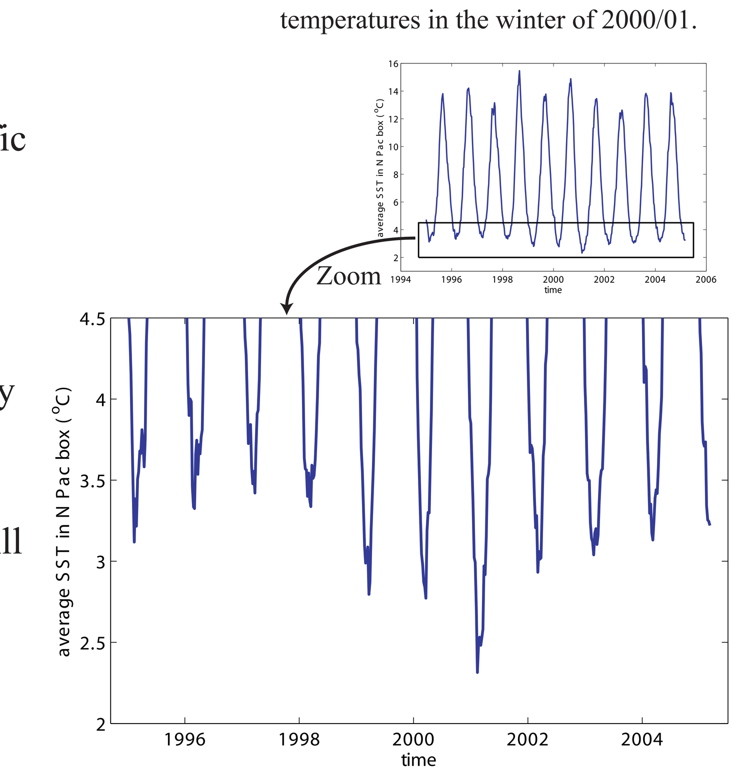
The blue line shows the APO anomaly at Alert (12-month running mean). The red line shows the mean sea level anomaly from satellite altimetry in pixels in and around the Labrador Sea (annual cycle removed and 6-month running mean applied). Sea level is used here as a proxy for heat content through steric height (Turrell and Holiday 2002).



Left: Map of SST anomalies in February 2001 in the North Pacific. The box shows the area where SSTs were averaged for the lower figure.

Below: Average SST in the Western North Pacific derived from the NOAA Optimum Interpolation (OI) Sea Surface Temperature. Note the low temperatures in the winter of 2000/01.

The winter of 2000/01 was particularly cold in the NW Pacific where the densest waters in the Pacific form. SSTs were on average 0.5 ºC colder than recent years and air temperatures over Vladivostok were colder than they had been in over a decade (Talley et al. 2003). This may have ventilated denser waters than usual and resulted in large O_2 fluxes from the atmosphere to the ocean. All the northern hemisphere stations (excluding Alert) see a significant APO drawdown during this time, especially the Japanese stations.



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