Large-scale variability in the midlatitude subtropical and subpolar North Pacific Ocean: observations and causes

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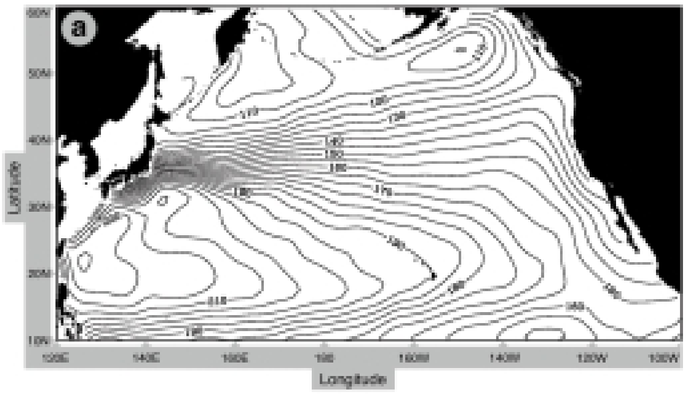
Our knowledge about the variability in the midlatitude North Pacific is relatively fragmented. Although regional long-term measurements exist, investigations that examine the individual current systems as entities and explore their interconnections have been lacking. The launch of the TOPEX/ POSEIDON satellite in 1992 and its successful multi-year measurements of the sea surface height provide a means to study the variability of gyre-scale ocean circulations. Using the T/P and forth-coming Jason-1 data, our first objective to quantify the large-scale changes in the current systems of the midlatitude subtropical and subpolar North Pacific.

The longer time series of the satellite SSH data allows us to, not only document the low-frequency changes in a particular geographical domain, but also to test hypotheses and explore the underlying dynamics of the observed circulation changes. This study attempts to pursue both of these objectives.

Large-scale interior circulations in the North Pacific Ocean north of 32° consist of four major current systems: the Kuroshio Extension, the North Pacific Current (NPC), the Alaska Gyre, and the Western Subarctic Gyre (WSG) (figure 1). Figure 2 shows the time series of the relative intensity of these four current systems deduced from the T/P observations. Both the WSG and the Alaska Gyre in figures 2a and 2b show clear annual variations with a maximum in January-March and a minimum in August-October. Interannually, the WSG was relatively strong in 1993-96, weakened in 1997, and remained in a weakened state after 1998. With the exception of 1993 and 1998, the Alaska Gyre, on the other hand, shows a weak, but generally increasing, trend in its intensity. The intensity of the Alaska Gyre is found to depend not only on the interior SSH anomalies, but also on those along the Alaska/ Canada coast. The interannual changes are most clearly seen in the NPC (figure 2c). The intensifying trend of the NPC appears to be leveling off following 1998.
Much of the interannual signal in the NPC is due to the large-scale SSH dropping on the northern side of the NPC. Notice that the NPC has a much weaker annual variation than the two subpolar gyres.

For the NPC, the Alaska Gyre, and the WSG, we expect their large-scale changes to be externally forced and governed by linear dynamics. Despite this expected linear dynamics, there remain questions and hypotheses that are not yet fully answered. For example, does the SSH variability in a midlatitude subtropical and subpolar ocean simply reflect changes in Ekman flux convergence/divergence? How important are baroclinic adjustment processes for the SSH changes in a subpolar ocean? Given the slow propagation of midlatitude baroclinic Rossby waves, what role does eddy dissipation play in determining the midlatitude SSH signals? In addition to these questions that are general to the SSH changes in any midlatitude ocean, there are also questions that are specific to the midlatitude North Pacific Ocean. For example, are the SSH changes generated in the eastern tropical Pacific important for the variability in the Alaska Gyre? In the Western Subarctic Gyre, are the changes in the western boundary currents, the EKC and the Oyashio, in balance with the time-dependent interior Sverdrup flow? Our goal is to address these questions under a simple and unified dynamic framework. Specifically, we will use a two-layer ocean model that takes into account the first-mode



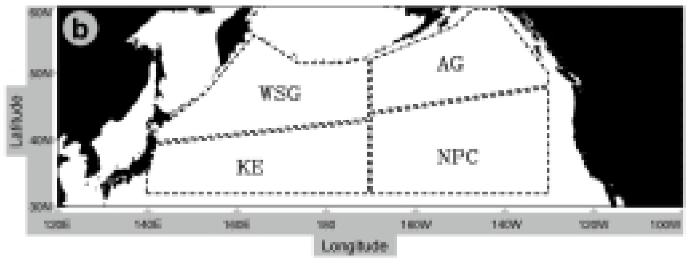


Figure 1: (a) Surface dynamic topography (in cm) relative to 1000 dbar calculated from the 1994 Levitus climatology. (b) Areas defining the four current systems: the Kuroshio Extension (KE), the North Pacific Current (NPC), the Alaska Gyre (AG), and the Western Subarctic Gyre (WSG).

baroclinic Rossby wave dynamics and barotropic Sverdrup dynamics. Though simple in dynamics, we find this model is adequate to reproduce many of the observed large-scale SSH signals.

Interannual variability of the Kuroshio Extension exhibits a quite different characteristic (figure 2d). The Kuroshio Extension weakened gradually from late 1992 to 1995-1996 and reversed the weakening trend after 1997. These interannual changes of the Kuroshio Extension are found to reflect the oscillation between the Kuroshio Extension's elongated mode and its contracted mode. In the elongated mode, the Kuroshio Extension has a larger eastward surface transport, a more northerly axis position, and is associated with a more intense southern recirculation gyre. The reverse is true when the Kuroshio Extension is in the contracted mode. Dynamics controlling the low-frequency Kuroshio Extension variability are likely to be nonlinear. A three-layer primitive equation model will be used to address the following questions:
What determines the interannual path and transport changes in the Kuroshio Extension? Is it the surface wind or the buoyancy fluxes?
What is the relative importance between the local and remote forcing? How important are the instability processes in "regulating" the oscillation between the elongated and contracted modes?

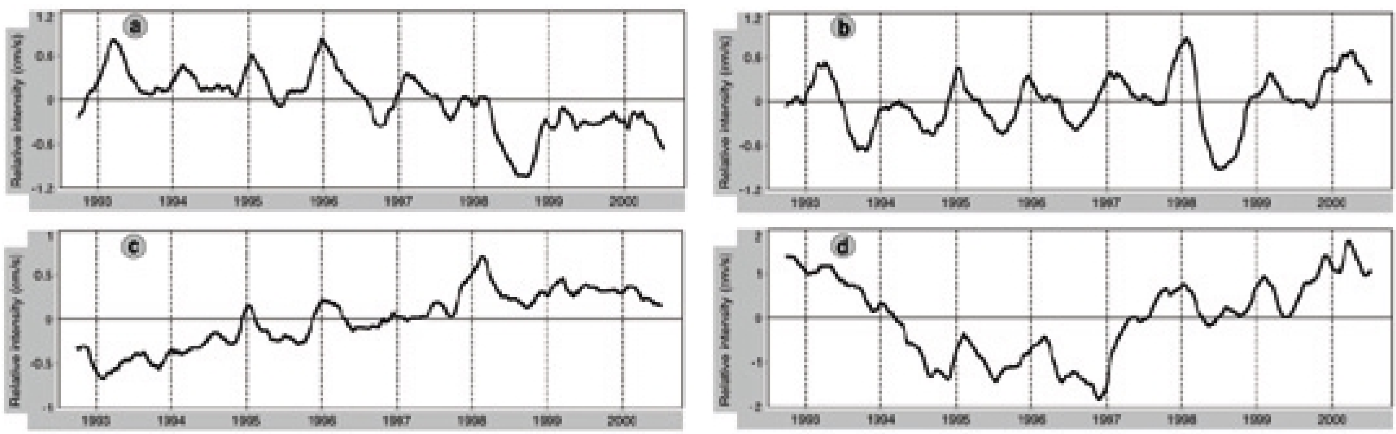


Figure 2: Relative intensity of the four current systems in the midlatitude North Pacific, a) Western Subantarctic Gyre, b) Alaska Gyre, c) North Pacific Current, and d) Kuroshio extension. Here, the intensity is computed by first projecting the residual geostrophic flows (inferred from the T/P data) onto the Levitus climatological surface geostrophic streamlines, and then by averaging the projected residual geostrophic flows in the specified geographic area (see figure 1).

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