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Hydrographic and mixed layer depth variability on the shelf in the northern Gulf of Alaska, 1974–1998 ☆

Nandita Sarkar*, T.C. Royer, C.E. Grosch

Center for Coastal Physical Oceanography, Crittenton Hall, Old Dominion University, Norfolk, VA 23529, USA

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Abstract

A time series of hydrographic measurements, temperature and salinity versus depth, on the shelf in the northern Gulf of Alaska (GAK 1) is used to determine the seasonal and interannual variability of the hydrography and mixed layer depth from 1974 through mid-1998. This is one of the first opportunities to incorporate salinity into the mixed layer depth (MLD) determination in this region where the density is highly dependent on salinity. The MLD changes seasonally from about 40 m in summer to more than 160 m in winter. This has potential implications for vertical fluxes of nutrients via winter MLD, leading to their annual replenishment. Spectral analysis of MLDs show that the time series have similar periodicities to the hydrography (decadal and El Niño-Southern Oscillation (ENSO)). The MLD trend during 1974–1998 has a slight increase in the deepest winter MLD that is, however, not statistically significant at the 90% level. This is in contrast to previous studies which found a significant shoaling of the winter MLD in the offshelf region of the Gulf of Alaska at Ocean Station P (OSP) [Freeland, H., Denman, K., Wong, C.S., Whitney, F., Jacques, R., 1997. Evidence of change in the winter mixed layer in the northeast Pacific Ocean. Deep Sea Research 44, 2117–2129]. This difference in the response of the marine system is consistent with an increase in the circulation of the Alaskan Gyre with enhanced upwelling in the central gulf (OSP) and enhanced downwelling along the coast (GAK 1).

Keywords: Mixed layer depth; Seasonal and long term variability; Gulf of Alaska; Coastal oceanography; Freshwater; El Niño-Southern Oscillation; Pacific Decadal Oscillation

1. Introduction

The coastal Northeast Pacific Ocean is a region of high biological productivity despite being forced by a downwelling wind system. The mechanisms are uncertain by which nutrients reach the euphotic zone on the northern shelf of the Gulf of Alaska (GoA). Several pathways have been hypothesized for the transport of nutrients across this shelf: (1) central GoA wind divergence and upwelling of nutrient-rich deep water followed by near surface, cross-shelf transport by winds; (2) cross-shelf transport of nutrient-rich offshore water by mesoscale eddies; and (3) cross-shelf transport of nutrient-rich water near the shelf bottom, especially within

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*Corresponding author. Tel.: +1 757 683 3234; fax: +1 757 683 5550.
E-mail address: sarkar@ccpo.odu.edu (N. Sarkar).

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canyons during periods of relaxed downwelling and subsequent vertical mixing into the euphotic zone.

If indeed the third pathway is important, then the seasonal changes in the surface mixed layer depth (MLD) could be an important "secondary" process by which the deep waters with high nutrient concentrations are injected into the euphotic zone. We hypothesize that to mix the deep nutrient-rich water into the upper layers of the ocean, the MLDs over the shelf must be sufficiently deep at certain times of the year. Thus the deepest annual MLD could be very important to the vertical nutrient flux and hence the biological productivity.

The depth of the mixed layer can affect biological productivity in competing ways. In a nutrient limited situation, when deepening mixed layers mix organisms into more productive deeper waters, productivity increases. However, in a light limited situation, if the organisms are mixed below ambient light conditions, biological productivity may decrease.

Gulf of Alaska (Seward Line) Station 1 (GAK 1) is the most inshore of a series of hydrographic stations extending southward across the shelf from Seward, Alaska (Fig. 1). Situated at 59°50.7′N, 149°28.0′W, it is located at the mouth of Resurrection Bay in a water depth of 263 m. The station is downstream of a region where numerous glaciers discharge cold freshwater at the surface. It has the most extensive temporal record of the Seward Line with 205 profiles beginning in 1974. We have used data from 1974 to 1998.

The surface mixed layer is the layer of almost uniform density resulting from the competition between stratifying and destratifying processes. Stratifying processes include surface heating and freshwater influx, while destratifying forces include wind forcing, surface cooling, evaporation and turbulent mixing. During winter in the Gulf of Alaska, stratification due to freshwater is minimum while cooling, evaporation and wind stress are maximum, causing the deepest MLDs of the seasonal cycle. As a result of the difficulties involved with the measurement of salinity and hence the paucity of those data, MLDs are often calculated based on temperature only, as in Polovina et al. (1995). However, since seawater density is a function of both temperature and salinity, density based on both of these should be used to calculate MLDs. This is especially true for low temperature regions with ample freshwater influx such as at GAK 1. The bottom depth is also important as it determines the maximum possible depth of the mixed layer. On shallow continental shelves, such as that on the east coast of USA, with depths of the order of tens of meters, seasonal mixed layers can extend to the bottom or a significant portion of the water column can be well mixed. For example, in a modeling study by Wijesekera et al. (2003) off the coast of New Jersey, model runs showed a mixed layer of about 40 m in a water depth of 52 m. On the west coast of USA, where the continental shelf is deeper (with depths of the order of hundreds of meters), more energy is required to mix the water column down to the bottom.

The primary goals of this study are (1) to describe the interannual cycles and long term trends in the hydrography at GAK 1 from 1974 to 1998; (2) to describe the seasonal cycle of MLD and the long term trends of deepest winter MLD at GAK 1; (3) to compare the long term trend in deepest winter MLDs with the trend elsewhere; (4) to put the MLDs (and the hydrography) in context of trends and seasonal cycles of various environmental patterns and forcing functions by describing the annual cycles and long term trends of these forcing functions and environmental patterns in the area over this time period; (5) to establish baseline conditions before the start of the US GLOBEC (GLOBal ocean ECosystems dynamics) initiative in the area. The correlation methods in the following sections cannot show a cause and effect relationship, but are used to examine if the different time series covary.

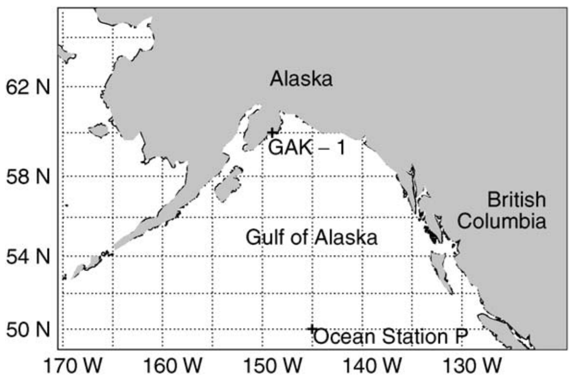

Fig. 1. Location of GAK 1 and Ocean Station P.

2. Northern Gulf of Alaska coastal conditions

The continental shelf bordering the northern Gulf of Alaska stretches in an arc from east to west. It is