Ocean color variability in the Tasman Sea

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[1] The Tasman Sea contains the largest noncoastal surface chlorophyll-a concentrations within the South Pacific Ocean. Observations of ocean color from SeaWiFS demonstrate that the chlorophyll-a seasonal cycle is characterized by a large austral spring bloom and a much smaller fall bloom separated by periods of lower concentrations, typical of communities within the North Atlantic Ocean. However, the seasonal cycle of the mixed layer depth of the Tasman Sea is much more similar to the North Pacific Ocean, whose persistent winter stratification results in relatively constant chlorophyll-a concentrations. Examination of eddy kinetic energy from satellite altimetry (TOPEX/Poseidon and ERS-2 blended product) reveals that the western Tasman Sea contains a large number of eddies originating within the East Australian Current that coincide spatially with the blooms. Upwelling and downwelling associated with these eddies greatly increase vertical mixing within the upper ocean, offsetting the normally shallow winter mixed layer, which leads to a chlorophyll-a seasonal cycle much like that of the North Atlantic Ocean. INDEX TERMS: 4275 Oceanography: General: Remote sensing and electromagnetic processes (0689); 4279 Oceanography: General: Upwelling and convergences; 4855 Oceanography: Biological and Chemical: Plankton; 4572 Oceanography: Physical: Upper ocean processes

1. Introduction

[2] Recent satellite observations using SeaWiFS (Sea-viewing Wide Field-of-view Sensor) demonstrate that the Tasman Sea, a relatively deep (~5000 meters) partially enclosed sea, contains the largest noncoastal chlorophyll-a concentrations in the South Pacific Ocean (Figure 1). While the seasonal cycles of chlorophyll-a concentrations within the North Atlantic and Pacific Oceans have been relatively well-documented [e.g. Denham and Gargett, 1995; Banse and English, 1999], the lack of in situ observations has severely restricted the examination of the South Pacific Ocean. However, with the advent of an array of satellite-based remote sensing devices, we are now able to investigate the dynamics governing chlorophyll-a, the primary photosynthetic pigment present in all plants, within ocean regions whose properties are not easily measured in situ. Combining ocean color observations obtained from SeaWiFS, sea surface height (SSH) anomalies derived from satellite altimetry, and density from climatological datasets, we examine the seasonal cycle of chlorophyll-a, an indirect measure of phytoplankton abundance, and make inferences into the dynamics governing primary productivity in the Tasman Sea. We show that while the seasonal stratification of the Tasman Sea is similar to the constantly stratified North Pacific Ocean, the presence of large eddies greatly contributes to vertical mixing within the upper ocean. This increased mixing effectively counteracts the winter stratification responsible for the constant chlorophyll-a concentrations apparent in the North Pacific Ocean and results in a seasonal cycle much more similar to the strongly varying North Atlantic Ocean.

2. The Data

[3] In this investigation available in situ measurements are combined with satellite-based remote sensing data. Temperature and salinity are obtained from the Levitus Atlas [Levitus and Boyer, 1994] to create vertical density profiles and estimates of mixed layer depth. SeaWiFS Global Area Coverage (GAC) level 3 binned map data (8-day chlorophyll-a concentration) from the NASA-GSFC Distributed Active Archive Center (DAAC) are used to examine the seasonal cycle of ocean color. This study includes 3 years of data (1998–2000) at 1/2° spatial resolution. The 10-day repeat-cycle data from Topex/Poseidon (T/P) altimetry and European Remote Sensing Satellite altimetry (ERS-1 & 2) blended product (1/4° spatial resolution) during 1998–2000 [Le Traon et al., 1998] are used to analyze dynamics evident in SSH anomalies.

3. Results and Discussion

[4] The Tasman Sea is a nutrient rich sea whose western half is characterized by frequent eddies and a strong seasonal chlorophyll-a cycle. Directly north of the Tasman Sea, a majority of the South Pacific western boundary current, the East Australian Current (EAC), separates from the coast of Australia and proceeds eastward. Eddies formed during the separation of the EAC migrate southward into the Tasman Sea producing a region of intense upwelling and downwelling. Analysis of SeaWiFS derived surface chlorophyll-a concentrations within the western Tasman Sea (Figure 2a) reveals a strong seasonal cycle characterized by an austral spring (September–November) bloom containing concentrations greater than 0.8 mg m⁻³, a modest fall (March–May) bloom, and periods of lower concentrations in the winter and summer. Seasonal cycles of chlorophyll-a have been linked to changes in mixed layer depth (Figure 2b) and consequently used to explain differences in chlorophyll-a concentrations within the North Atlantic Ocean, which is characterized by an extremely deep winter mixed layer, and the North Pacific Ocean, whose winter mixed layer is much shallower [Denham and Gargett, 1995]. Observations of regions of high phytoplankton concentrations within the North Atlantic Ocean have shown that during winter the water column is well mixed and contains high concentrations of nutrients; however, the deep mixed layer (Figure 2b) results in light limited conditions that prevent significant growth of phytoplankton and zooplankton. The arrival of spring brings increased light levels and decreased mixed layer thickness due to weakened wind stirring and increased atmospheric buoyancy flux, which causes a rapid increase in phyto-
plankton that cannot be suppressed by the limited number of the slower growing zooplankton, resulting in a spring phytoplankton bloom. The shallow mixed layer, however, results in the detachment of relatively well mixed water and prevents entrainment of nutrient rich water from lower layers, effectively limiting the available nutrients. The phytoplankton eventually exhaust the limited supply of nutrients and again decline in abundance during the summer due to both lack of nutrients and the grazing of zooplankton. The arrival of fall results in lower surface temperatures and a deeper mixed layer, which allows the upward flux of nutrients into the surface layer and produces a temporary increase in phytoplankton. The North Pacific, however, does not respond in the same fashion. The shallow winter mixed layer of the North Pacific (Figure 2b) results in much less winter mixing than that of the North Atlantic, supporting a stable population of both phytoplankton and zooplankton. Any increase in phytoplankton due to spring time stratification results in a similar increase in grazing by zooplankton, effectively eliminating the spring bloom [Denham and Gargett, 1995; Banse and English, 1999].

Examination of the mixed layer depth in the Tasman Sea reveals that the magnitude of its seasonal cycle is very similar to that of the North Pacific (Figure 2b). However, the chlorophyll-a concentrations within the western Tasman Sea are clearly related to the seasonal cycle of stratification as in the North Atlantic Ocean. The spring phytoplankton bloom evident in the SeaWiFS chlorophyll-a concentrations (Figure 2a) coincides with the rapid shoaling (160 meters in September to 40 meters in November) of the mixed layer. The fall bloom coincides with the gradual deepening (50 meters in April to 100 meters in June) of the mixed layer. Although the winter mixed layer depth of the Tasman Sea is much shallower (180 meters) than regions of the North Atlantic (500 meters) [Denham and Gargett, 1995], the

Figure 1. Annual mean sea surface chlorophyll-a concentrations (mg m⁻³) for the South Pacific Ocean obtained from SeaWiFS during the period 1998–2000. Note the large concentrations in the Tasman Sea (southwest corner of figure). The large signal east of New Zealand at ~42°S is associated with the Chatham Rise, a large shallow underwater plateau extending to 177°W whose steep sides act like continental slopes.

Figure 2. (opposite) (a) Seasonal sea surface chlorophyll-a concentrations [thick lines] ± one standard deviation [thin lines] (mg m⁻³) averaged over the western (37°S–42°S, 150°E–157°E) and eastern (37°S–42°S, 158°E–165°E) Tasman Sea obtained from SeaWiFS during the period 1998–2000. (b) Seasonal cycle of the mixed layer depth (m) for the North Pacific and Atlantic Oceans and the Tasman Sea (37°S–42°S, 150°E–165°E) obtained from Levitus and Boyer [1994]. Note that while the cycles of the North Pacific Ocean and the Tasman Sea are exactly out of phase (since they are located in different hemispheres) their magnitudes are very similar, while the North Atlantic Ocean has a significantly deeper winter mixed layer.
presence of upwelling and downwelling eddies in the western Tasman Sea increases the vertical mixing (Figure 3). While eddies have no effect on the region dominated by the nutrient poor East Australian Current (~33°S), their presence significantly amplifies the seasonal cycle of the nutrient rich Tasman Sea. This effect can be seen by comparing the eddy rich western Tasman Sea with the less energetic eastern Tasman Sea. Chlorophyll-a concentrations within energetic eastern Tasman Sea (Figure 2a), while higher than those of the EAC, are still characterized by much smaller spring and fall peaks than the western Tasman Sea, agreeing with the study by Hadfield and Sharples [1996], who showed in their 1-dimensional model of the eastern Tasman Sea that modest spring phytoplankton blooms coincided with the shoaling of their mixed layer.

An illustration of the effect of eddies on the mixed layer depth demonstrates that downwelling associated with eddies can temporarily double the mixed layer depth (Figure 4), greatly increasing the vertical mixing in the upper ocean and mimicking the light limited conditions of the North Atlantic Ocean. Assuming a two layer ocean, deviations of the pycnocline, $\eta$, can be related to sea level anomalies (SLA) by

$$\frac{\eta}{SLA} \approx -\frac{H_0}{\Delta \rho H_2}$$

where $\Delta \rho$ is the density difference between the two layers (2 kg m$^{-3}$), $\rho_0$ is a scaling density (1027 kg m$^{-3}$), $H$ is the ocean depth (5000 m), and $H_2$ is the depth of the lower layer when the ocean is at rest ($\approx$ 4700 m). Applying these scale estimates results in a value for $\eta$/SLA of $\sim$ −550. Following [Siegel et al., 1999], we assume that isopycnal displacements linearly decrease from a maximum at the pycnocline to zero at the surface and produce an estimate of the eddies’ effect on the mixed layer depth. Examination of this estimated mixed layer at 40°S, 152°E (Figure 4) reveals that the eddies can temporarily increase the depth of the mixed layer during the winter to depths much closer to those of the North Atlantic Ocean, resulting in increased vertical mixing that supports smaller winter populations of phytoplankton and zooplankton. These conditions result in spring and fall blooms of chlorophyll-a evident in SeaWiFS. In addition, upwelling associated with these eddies has been shown to supply more nutrients to the surface layer once the blooms have begun [McGillicuddy et al., 1998], delaying the exhaustion of nutrients and prolonging the duration of the blooms.

4. Conclusions

Examination of climatological observations of the mixed layer depth within the Tasman Sea reveals that its seasonal cycle is similar to that of the North Pacific Ocean, which exhibits relatively constant chlorophyll-a concentrations. While SeaWiFS derived measurements show that the seasonal cycle of chlorophyll-a concentrations within the eastern Tasman Sea is similar to that of the North Pacific Ocean, the seasonal cycle of the western Tasman Sea contains both spring and fall blooms, similar to the North Atlantic Ocean. These blooms coincide with the shoaling (spring) and deepening (fall) of the mixed layer. Although the winter mixed layer depth of the Tasman Sea is significantly shallower than that of the North Atlantic Ocean, the presence of a large number of eddies spawned by the East Australian Current results in a large degree of vertical mixing, which decreases the effective stratification and limits the winter phytoplankton and zooplankton populations. These conditions produce a seasonal cycle of chlorophyll-a concentrations that is remarkably similar to, although somewhat smaller than, the strongly varying North Atlantic Ocean.

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References


Figure 3. Mean eddy kinetic energy (m$^2$ s$^{-2}$) for the period 1998–2000 as determined from T/P-ERS 2 satellite altimetry. Note the region of the plankton bloom (western half of Tasman Sea) is a region of high eddy kinetic energy formed by eddies separating from the East Australian Current.

Figure 4. Sea level anomaly, climatological mixed layer depth (MLD), and estimate of the instantaneous MLD derived from the SLA for (40°S, 152°E) in 1999. Note the large increase in winter mixed layer depth due to the passage of a downwelling eddy.


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