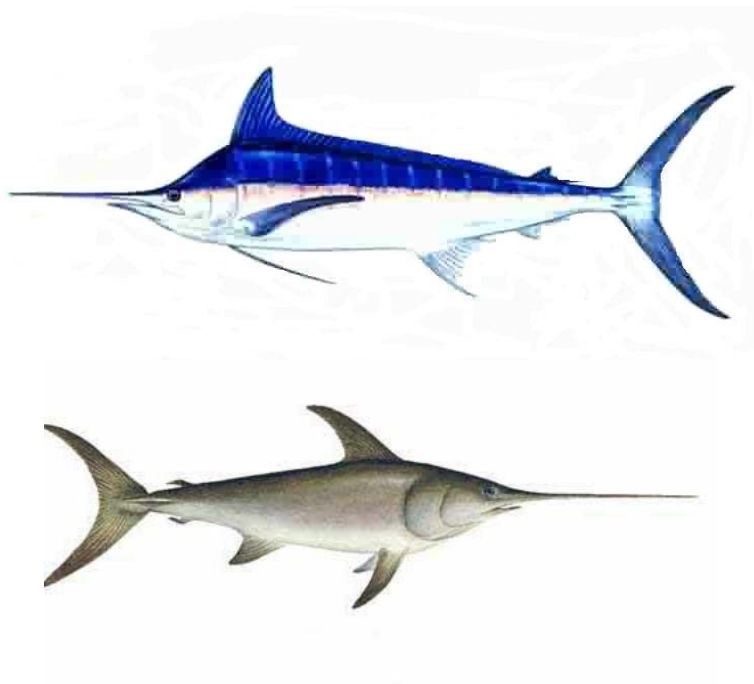




Oceanographic Features in the Vicinity of a North Pacific Swordfish Stock Boundary

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Abstract

Oceanographic features are depicted in the vicinity of a swordfish stock assessment boundary previously identified by analysis of swordfish CPUE. The approximate location of the swordfish stock assessment boundary is characterized by gradients at depth in temperature, salinity, dissolved oxygen, and nitrate. Strong gradients in DO and nitrate were evident in the vicinity of the swordfish stock assessment boundary at a depth of 100 m. Within the eastern tropical Pacific (ETP), there was seasonal variation in temperature, salinity, DO, and nitrate at depths of 50 to 75 m. However, the seasonal variation did not appear to extend across the gradients separating the northwest Pacific and southeast Pacific areas. Gradients in oceanographic features at depth in the vicinity of the swordfish stock boundary may provide an additional line of evidence for the location of a stock boundary for billfishes separating the northwest Pacific and the southeast Pacific areas.

Introduction

This report presents plots of oceanographic features in the vicinity of a swordfish stock boundary identified by analysis of swordfish CPUE separating the northwest Pacific and the southeast Pacific areas (Figures 1 and 2) (Ichinokawa and Brodziak 2008, DiNardo and Wagatsuma 1998 and 1999).

Pelagic ecosystems can be characterized by regional conditions of temperature, salinity, nutrients, and irradiance that influence the distribution of organisms and are driven largely by surface currents (Longhurst 1998, Miller 2004). In the North Pacific, primary production in the central Pacific gyre runs mostly on recycled nutrients, there is a chlorophyll maximum at about 100 m, and nitrogen becomes increasingly depleted towards the surface (Miller 2004). In the Eastern Tropical Pacific (ETP), elevated nutrients, exemplified by nitrate, center on the equator and extend west past the dateline (Miller 2004). In addition, nitrate becomes enriched and oxygen becomes depleted at intermediate depths in the central north Pacific and ETP (Figures 3 and 4).

Methods

For this report, temperature, salinity, dissolved oxygen (DO), and nitrate were plotted as annual means and as winter (January, February, and March) anomalies from annual means. Seasonality was based on the timing of fishing effort in the ETP. The Mexican swordfish longline fleet operated in Mexican waters from September-October to

February, and swordfish catches declined after February and were very scarce in the summer months of July and August (Fleischer et al. 2009). Effort in the Japanese offshore and distant water longline fleet in the ETP occurred in all quarters of the year (Okamoto and Bayliff 2003). Swordfish catch in the Japanese offshore and distant water longline fleet in Sub-Area 2 also occurred in all quarters of the year (Courtney and Piner 2009).

Gradients in oceanographic features vary with depth. For this report, annual mean temperature and DO were plotted at the surface, 100 m, and 250 m. A 100 m depth contour approximates the extent of a hypothesized habitat compression zone for istiophorid billfish in the ETP (Prince and Goodyear 2006) where DO concentration is low (i.e., DO concentration $\leq 3.5 \text{ ml l}^{-1}$ DO). A depth of 250 m approximates the depth of a region of very low concentrations of oxygen ($< 0.5 \text{ ml l}^{-1}$ at depths ca. 200 – 600 m) in the southeastern Pacific which may limit swordfish depth distribution (Abascal et al. 2009). Winter anomalies were plotted at either 50 or 75 m where available.

Results

The approximate location of the swordfish stock boundary is characterized by gradients at depth in temperature (Figure 5) (Locarnini et al 2006), salinity (Figure 6) (Antonov et al 2006), DO (Figure 7) (Garcia et al 2006a), and nitrate (Figure 8) (Garcia et al 2006b). Strong gradients in DO and nitrate were evident in the vicinity of the swordfish stock boundary at a depth of 100 m (Figures 7B and 8B). Within the ETP, there was seasonal variation in temperature (Figure 5) (Locarnini et al 2006); salinity (Figure 6) (Antonov et al 2006), DO (Figure 7) (Garcia et al 2006a); and nitrate (Figure 8) (Garcia et al 2006b) at 50 to 75 m. However, the seasonal variation did not appear to extend across the gradients separating the northwest Pacific and southeast Pacific areas.

Discussion

The swordfish stock boundary identified by analyses of CPUE has some variability (Figure 1) as do the gradients in oceanographic features (Figures 5 – 8). However, the data used to evaluate gradients in swordfish CPUE and oceanographic characteristics are extensive (Locarnini et al. 2006, Antonov et al. 2006, Garcia et al. 2006a 2006b, Ichinokawa and Brodziak 2008). As a result, the coincident occurrence of the swordfish stock boundary and gradients in oceanographic features at depth may provide an additional line of supporting evidence for the location of the stock boundary.

Vertical movements of istiophorid billfish and swordfish may be limited by both temperature and DO (Carey and Robinson 1981, Brill et al. 1993, Prince and Goodyear 2006, Abascal et al. 2009). Striped marlin near Hawaii spent $> 85\%$ of their time in the mixed layer, i.e., above 90 m depth (Brill et al. 1993). Brill et al. (1993) hypothesized that the maximum depth for striped marlin near Hawaii appears to be limited by water temperatures 8 C colder than the mixed layer, rather than the absolute temperature (Brill et al. 1993). In general, striped marlin appear to spend most of their time in the mixed layer above the thermocline but make brief excursions below the thermocline to search

for food. Based on tagging data, Bromhead et al. (2004) estimated that striped marlin spend approximately 75% of their time within 10 m of the surface. In contrast, Pacific Billfishes along the Pacific coast of Central America spent approximately 90% of their time within depths of 0 to 50 m (Prince and Goodyear 2006).

Prince and Goodyear (2006) hypothesized that, in addition to temperature, variations in DO concentrations play an important role in limiting the depth of the acceptable habitat for billfish in the ETP. Along the Pacific coast of Central America, DO levels of 1.5 ml l^{-1} occurred between 50 and 75 m, and this depth range corresponded to the deepest habitat used for both marlins and sailfish (Prince and Goodyear 2006). Prince and Goodyear (2006) also hypothesized that the hypoxic threshold for tropical pelagic istiophorid billfishes is similar to DO levels ($\leq 3.5 \text{ ml l}^{-1}$) which induce symptoms of stress in yellowfin and skipjack tuna. In particular when DO is below physiological requirements to maintain high growth and metabolic rates that are characteristic of tunas and billfishes, the lack of dissolved oxygen may be a more important constraint on habitat utilization than temperature. In the ETP, the pattern of annual average shallowest depths of the 3.5 ml l^{-1} DO isopleths tracked the average depth of the surface mixed layer (Prince and Goodyear 2006).

For swordfish, maximum depth in the eastern Pacific ($< \text{ca. } 200\text{m}$) may also be related to the presence of an oxygen minimum layer (Carey and Robinson 1981, Abascal et al 2009). Shallow behavior by day ($< \text{ca. } 200\text{m}$) was observed in two of 21 electronically tagged swordfish in the southeastern Pacific which swam in areas of low concentrations of oxygen ($< 0.5 \text{ ml l}^{-1}$ at depths $\text{ca. } 200 - 600 \text{ m}$) (Abascal et al 2009). In contrast, one swordfish which swam in areas of low concentrations of oxygen ($< 0.5 \text{ ml l}^{-1}$) and the remainder of the tagged swordfish which did not swim in areas of low oxygen concentration exhibited a typical U shaped pattern foraging in deep water ($\geq \text{ca. } 500 \text{ m}$) in the day and staying in the mixed layer at night (Abascal et al 2009). In the western Pacific where the oxygen minimum layer is deeper and less pronounced (Figure 3), a single electronically tagged swordfish swam in cold water ($3-6 \text{ C}$), deeper than approximately 200 m, during most days of observation and for the majority of the time within a day (Takahashi et al. 2003).

Overall, the observed gradients in temperature and dissolved oxygen in the vicinity of the stock boundary may influence swordfish distribution. The effects of these gradients on striped marlin are unknown but may be similar to swordfish due to similar biological characteristics of high growth and metabolic rates or may be dissimilar due to differences in the preferred depth distributions of striped marlin and swordfish.

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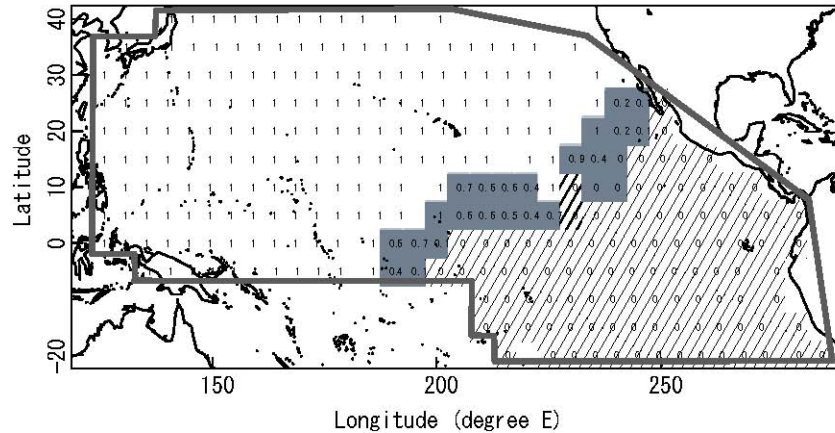
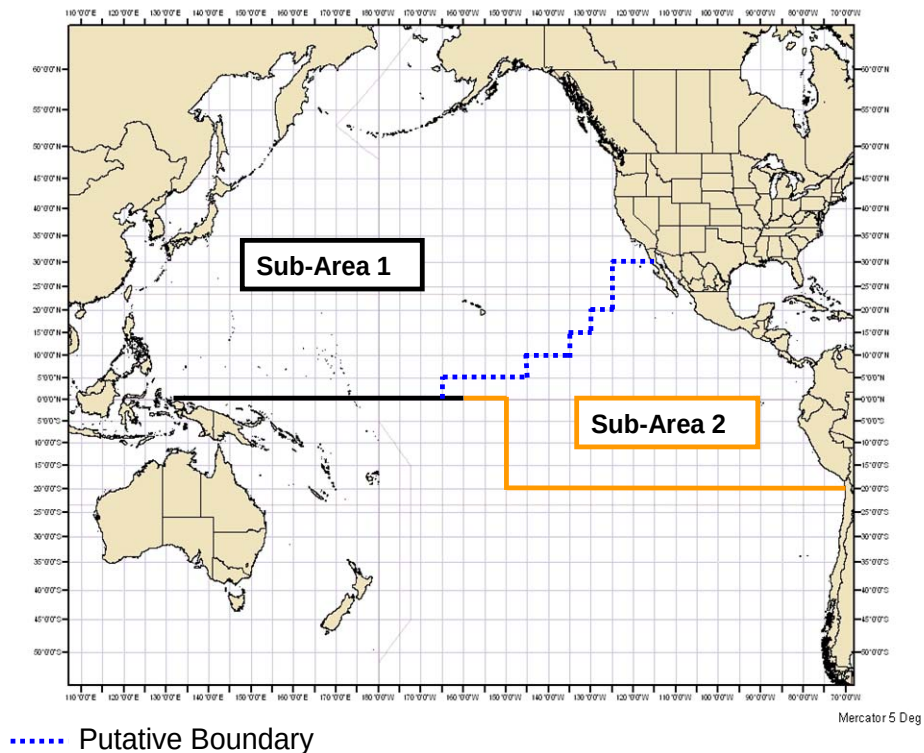


Figure 1. Boundary estimated from bootstrap analysis of general linear models (GLMs) fit to swordfish commercial catch per unit effort (CPUE) data assuming two swordfish stocks in the North Pacific (Adapted from Ichinokawa and Brodziak 2008 Figure 7d). The number at each 5x5 blocks shows the probability that the 5x5 block belongs to the northwest Pacific area: white belongs to the northwest Pacific, hatched belongs to southeast Pacific, and shaded area can be considered as mixed area of the two stocks, where the stock boundary would exist.

Putative Boundary for Stock Scenario - 2



Adapted from Ichinokawa and Brodziak (2008; Figure 7d)

Figure 2. boundary for a North Pacific swordfish stock assessment under a two stock scenario (Adapted from DiNardo and Wagatsuma 2009).

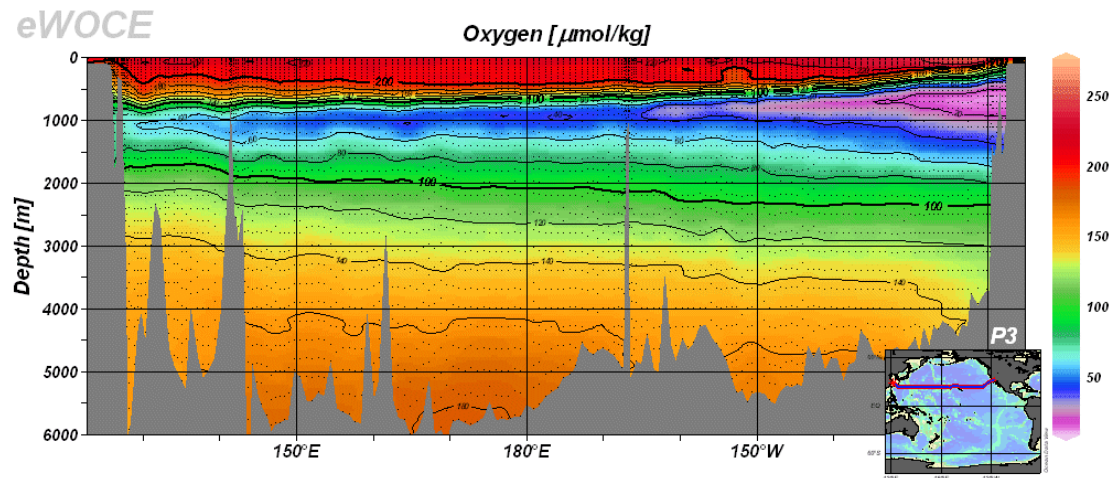
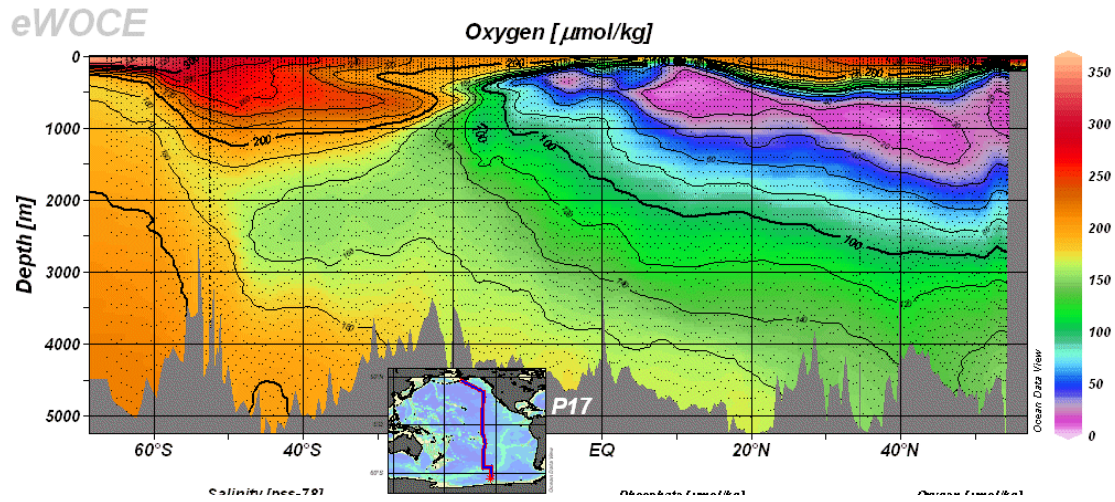


Figure 3. Oxygen tracers from the World Ocean Circulation Experiment (WOCE) Hydrographic Programme (WHP) cruise tracks electronic gallery
<http://www.ewoce.org/gallery/>.

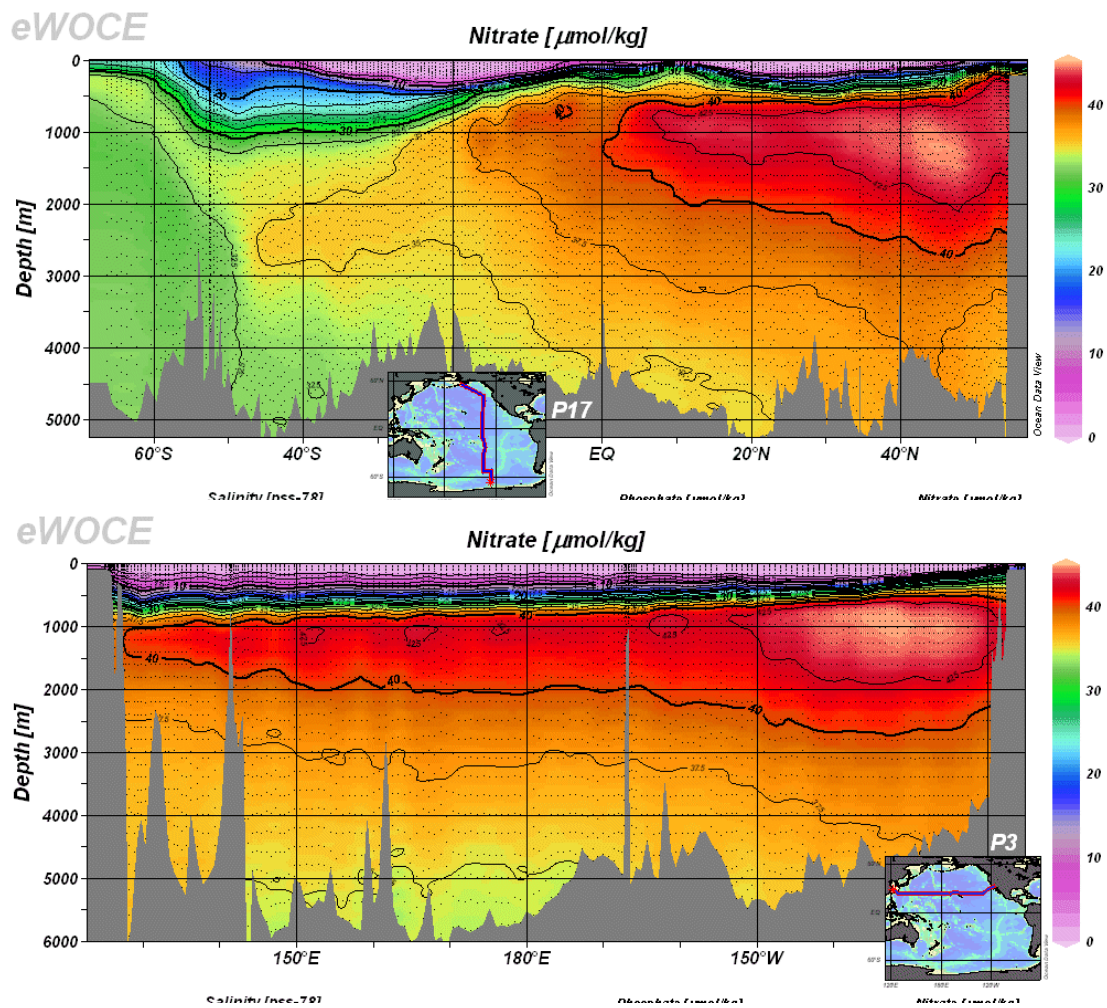


Figure 4. Nitrate tracers from the World Ocean Circulation Experiment (WOCE) Hydrographic Programme (WHP) cruise tracks electronic gallery
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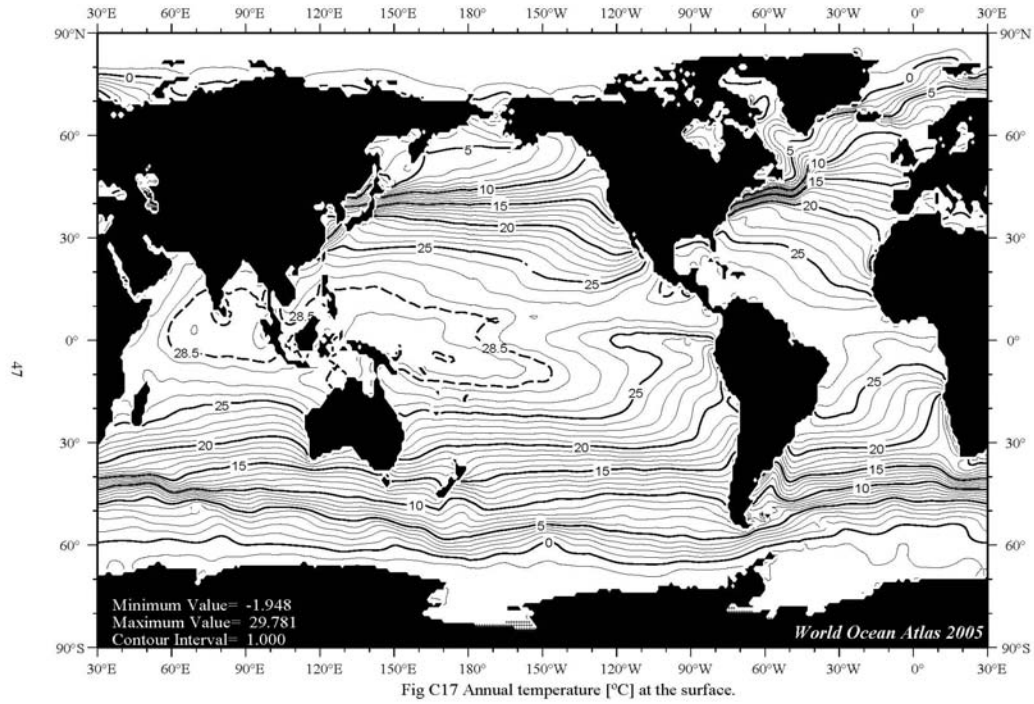


Figure 5A. Annual mean temperature at the surface (Adapted from Locarnini et al. 2006).

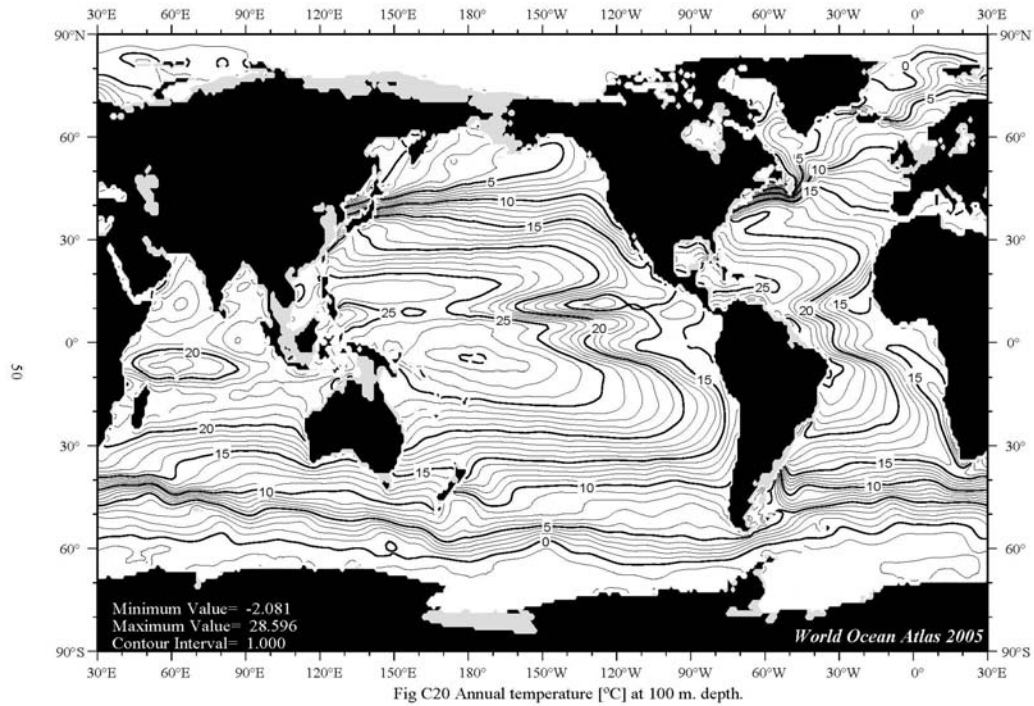


Figure 5B. Annual mean temperature at 100 m depth (Adapted from Locarnini et al. 2006).

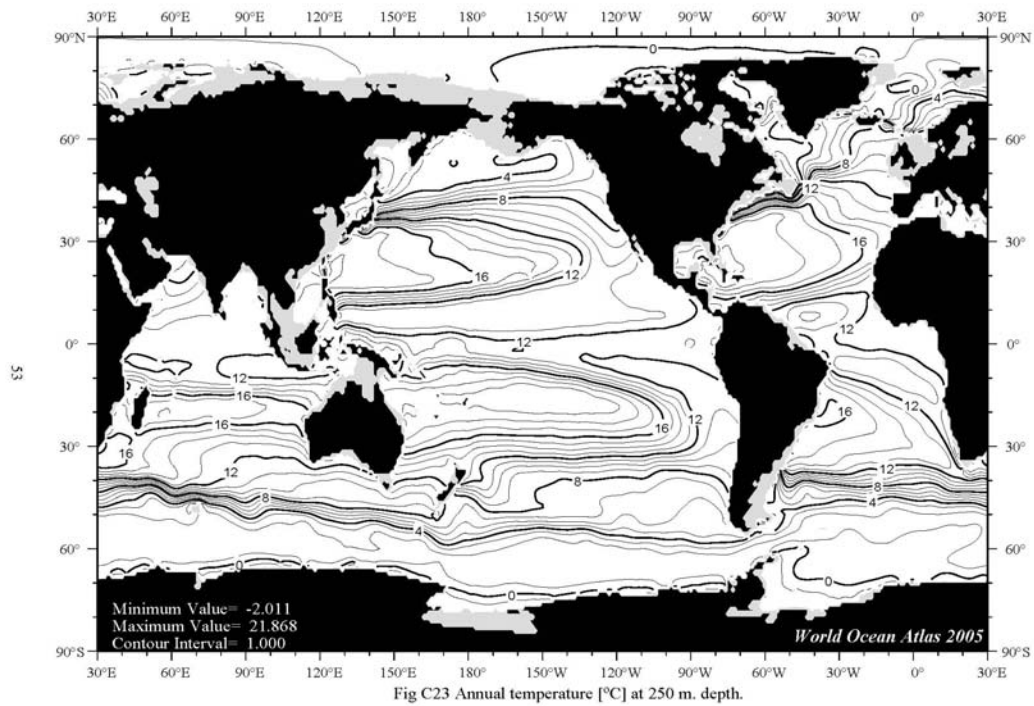


Figure 5C. Annual mean temperature at 250 m depth (Adapted from Locarnini et al. 2006).

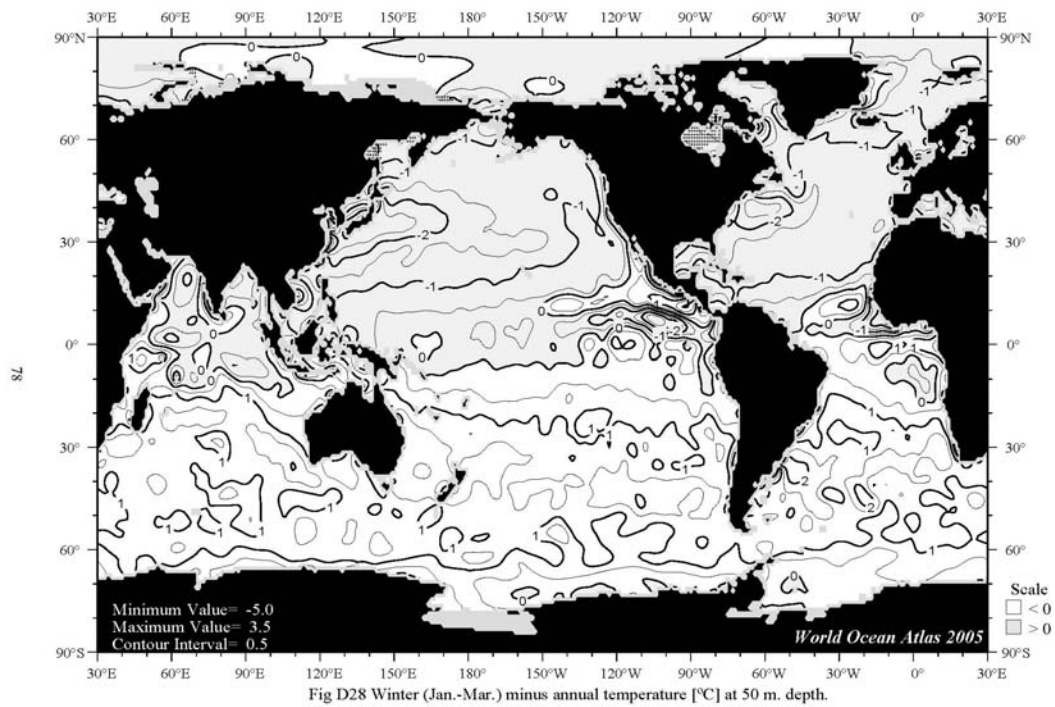


Figure 5D. Winter (January, February, March) mean temperature anomalies (from annual) at 50 m depth (Adapted from Locarnini et al. 2006).

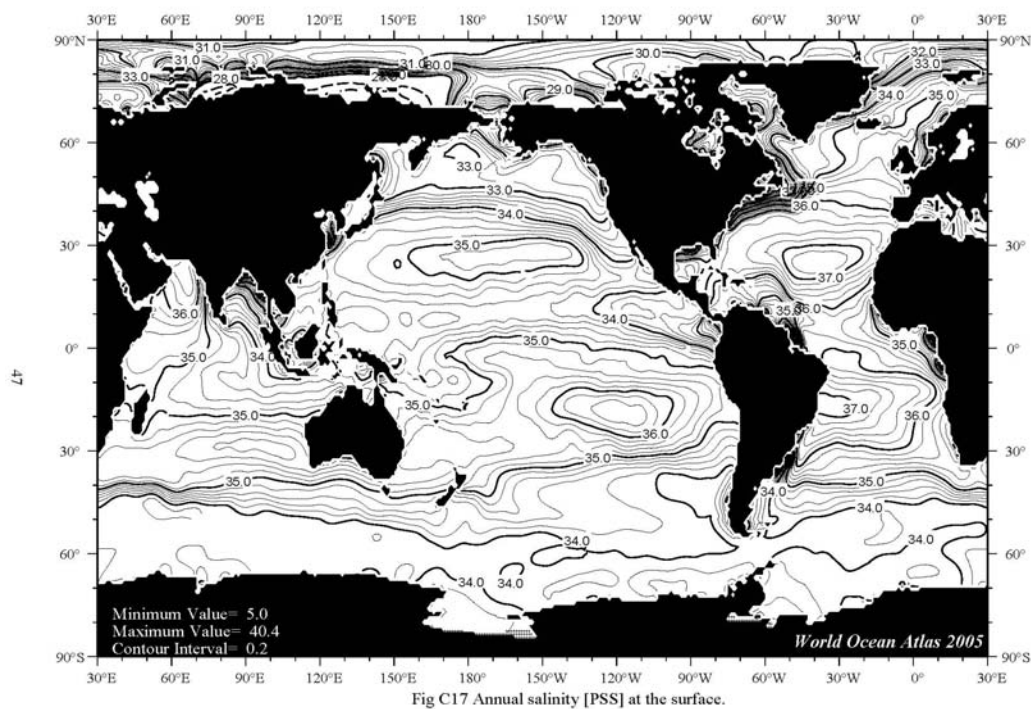


Figure 6A. Annual mean salinity at the surface (Adapted from Antonov et al. 2006a).

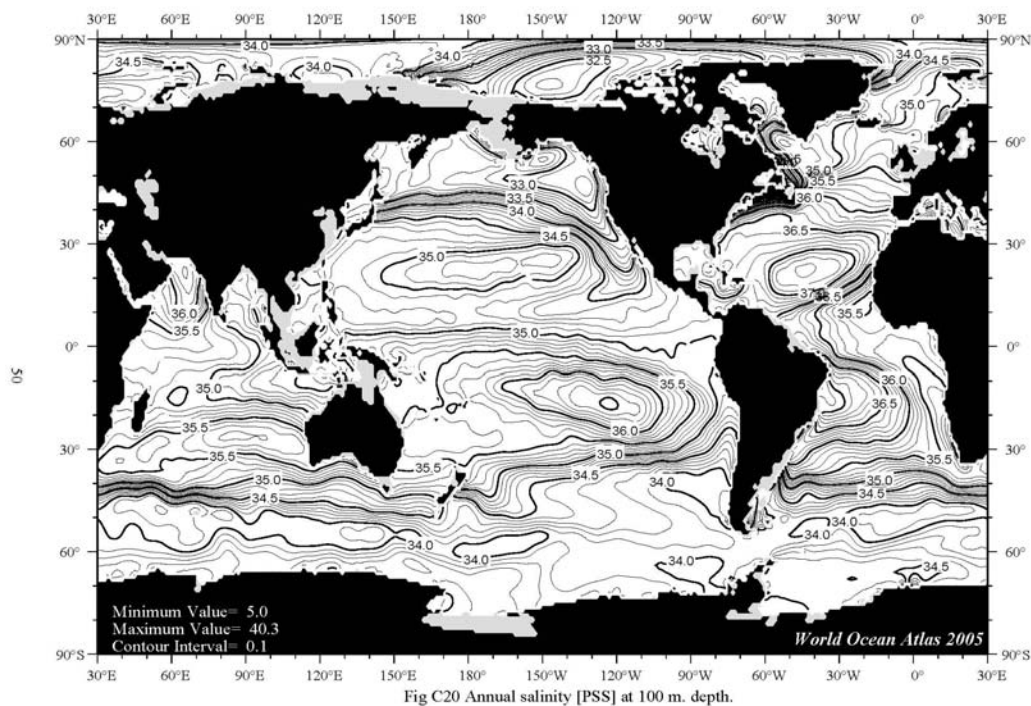


Figure 6B. Annual mean salinity at 100 m depth (Adapted from Antonov et al. 2006a).

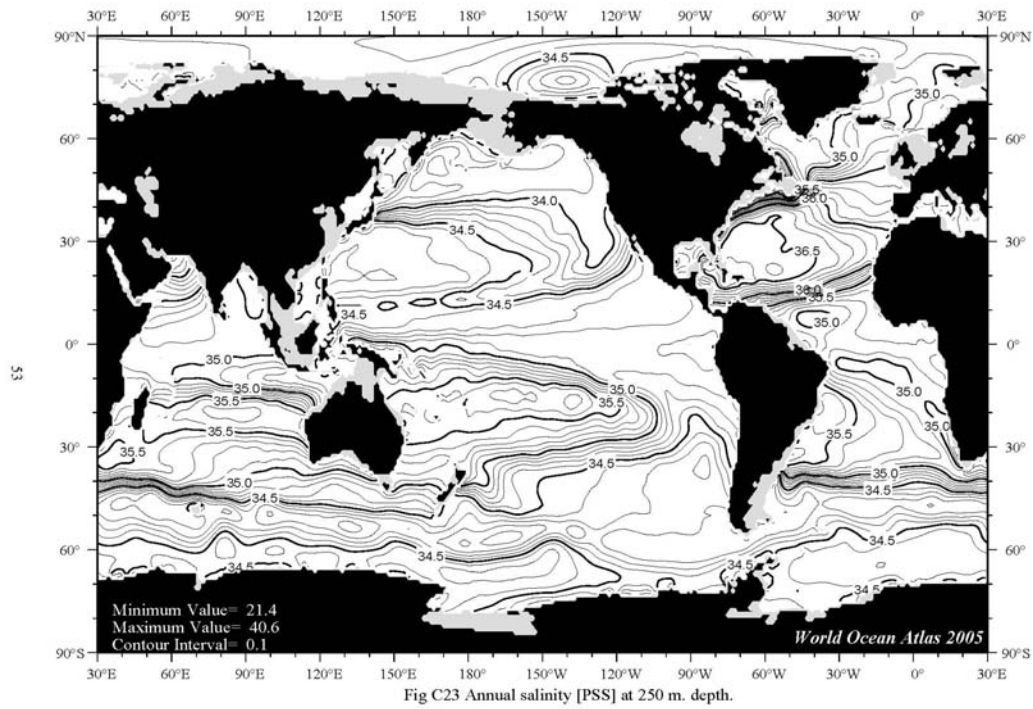


Figure 6C. Annual mean salinity at 250 m depth (Adapted from Antonov et al. 2006a).

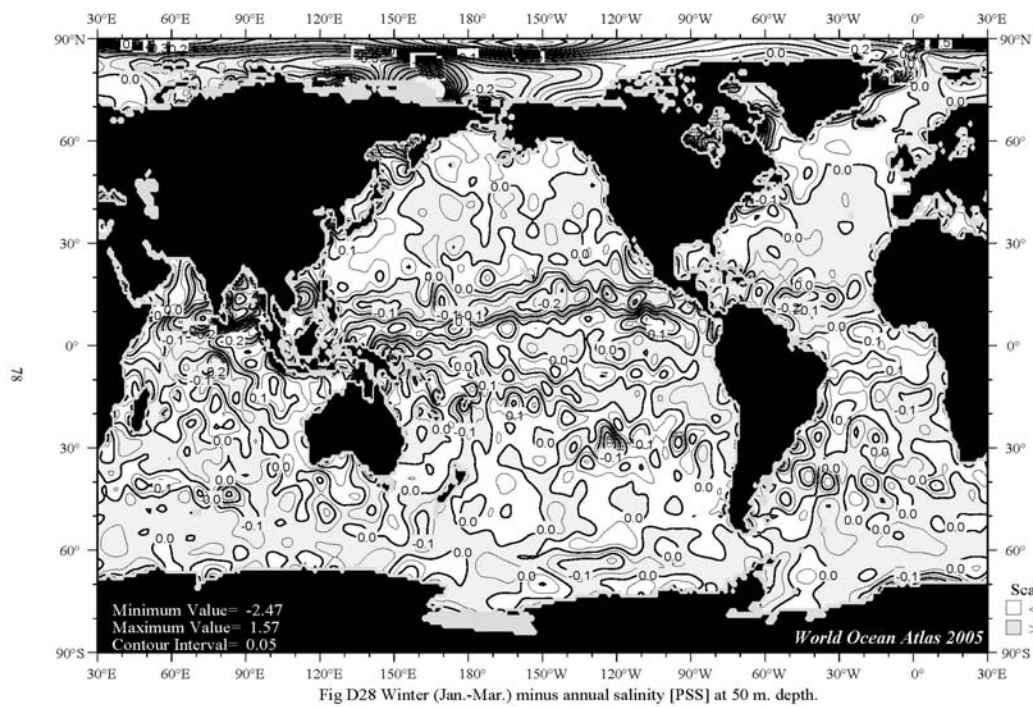


Figure 6D. Winter (January, February, March) mean salinity anomalies (from annual) at 50 m depth (Adapted from Antonov et al. 2006a).

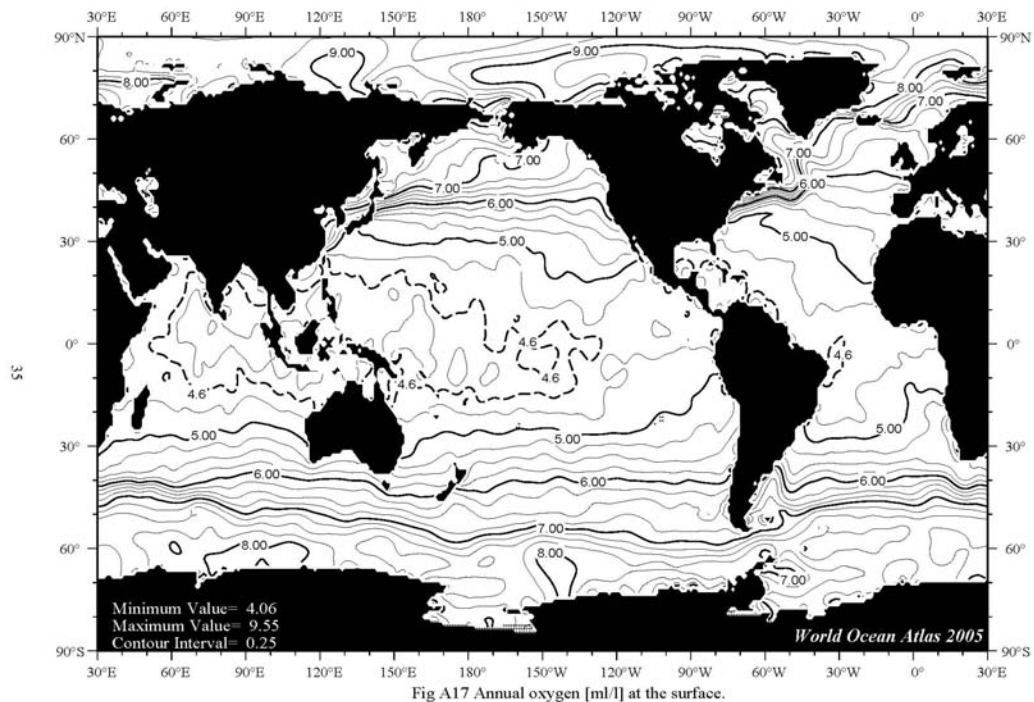


Figure 7A. Annual mean dissolved oxygen at the surface (Adapted from Garcia et al. 2006a).

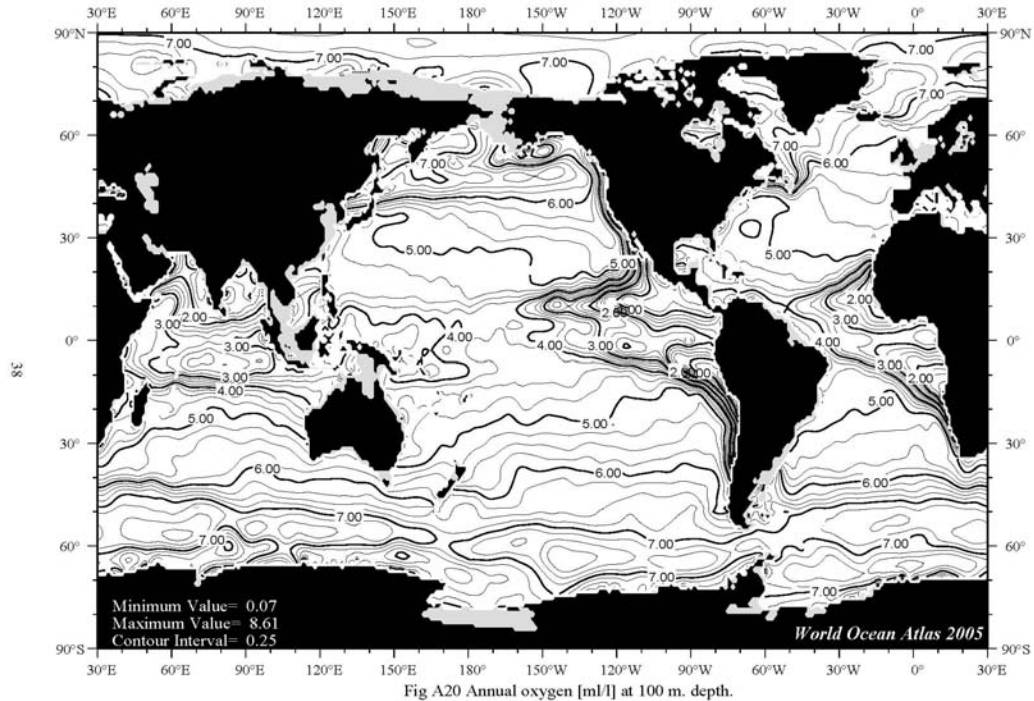


Figure 7B. Annual mean dissolved oxygen at 100 m depth (Adapted from Garcia et al. 2006a).

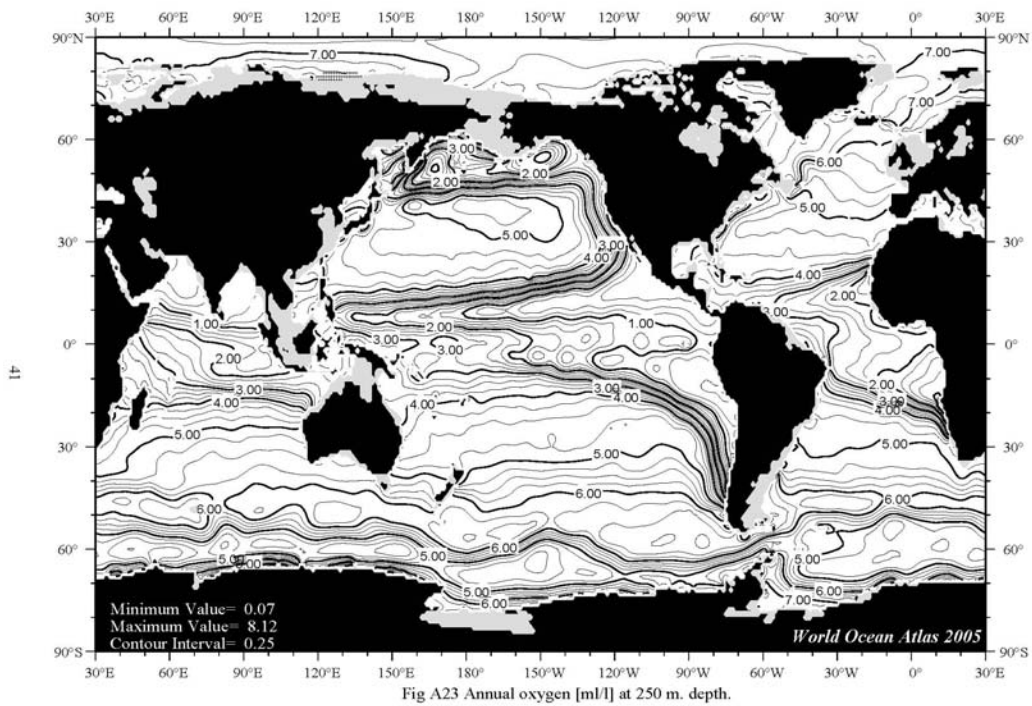


Figure 7C. Annual mean dissolved oxygen at 250 m depth (Adapted from Garcia et al. 2006a).

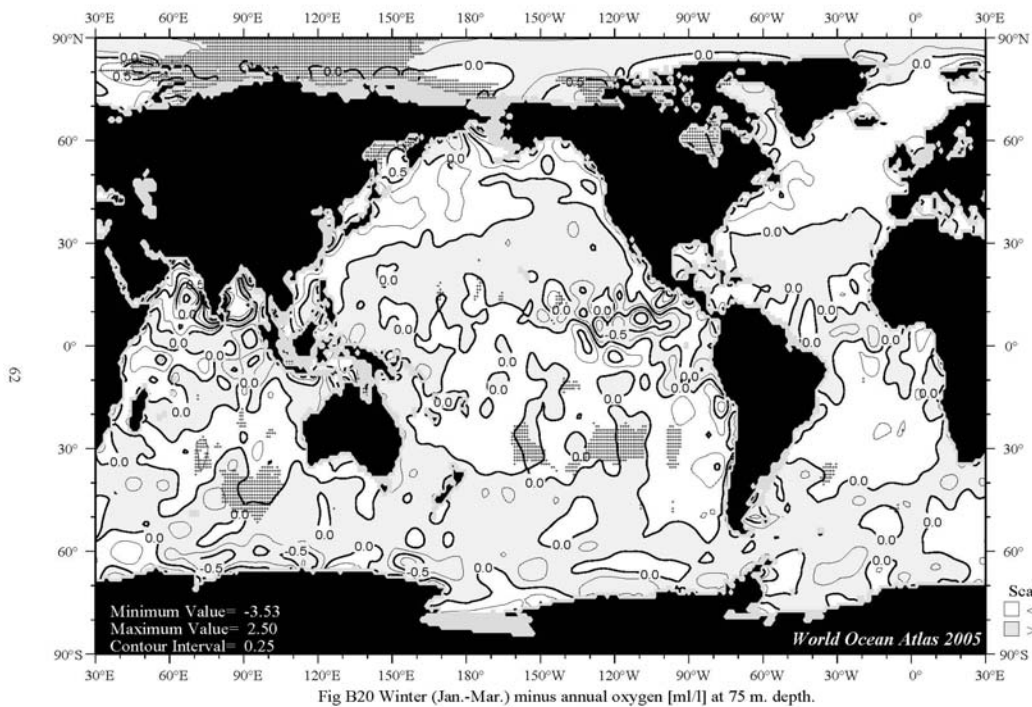


Figure 7D. Winter (January, February, March) mean dissolved oxygen anomalies (from annual) at 75 m depth (Adapted from Garcia et al. 2006a).

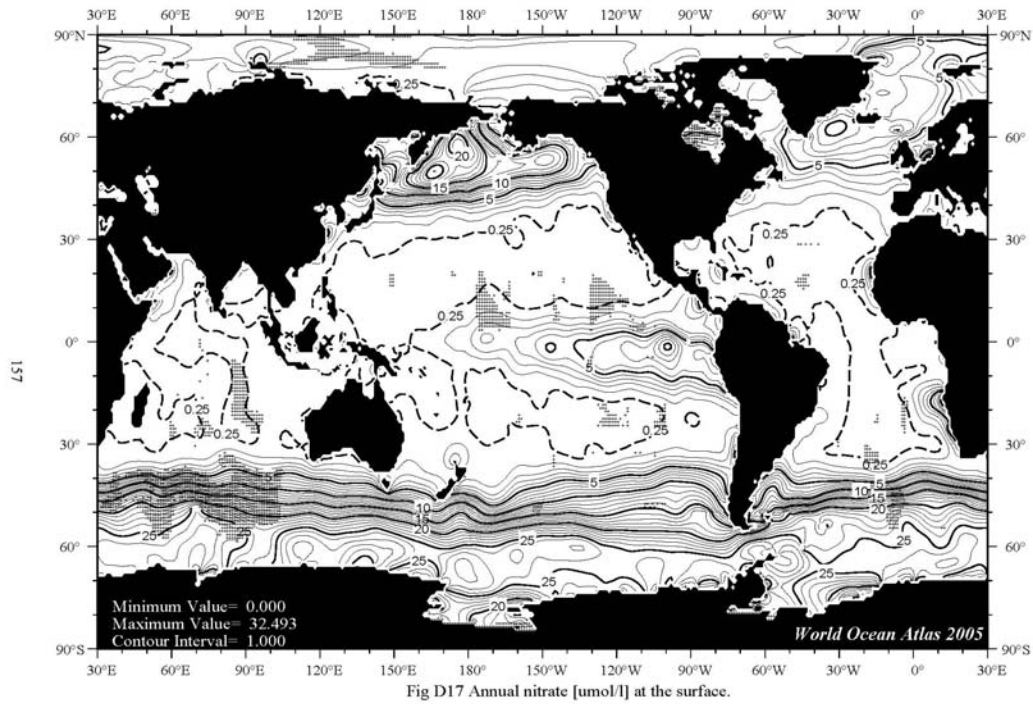


Figure 8A. Annual mean nitrate at the surface (Adapted from Garcia et al. 2006b).

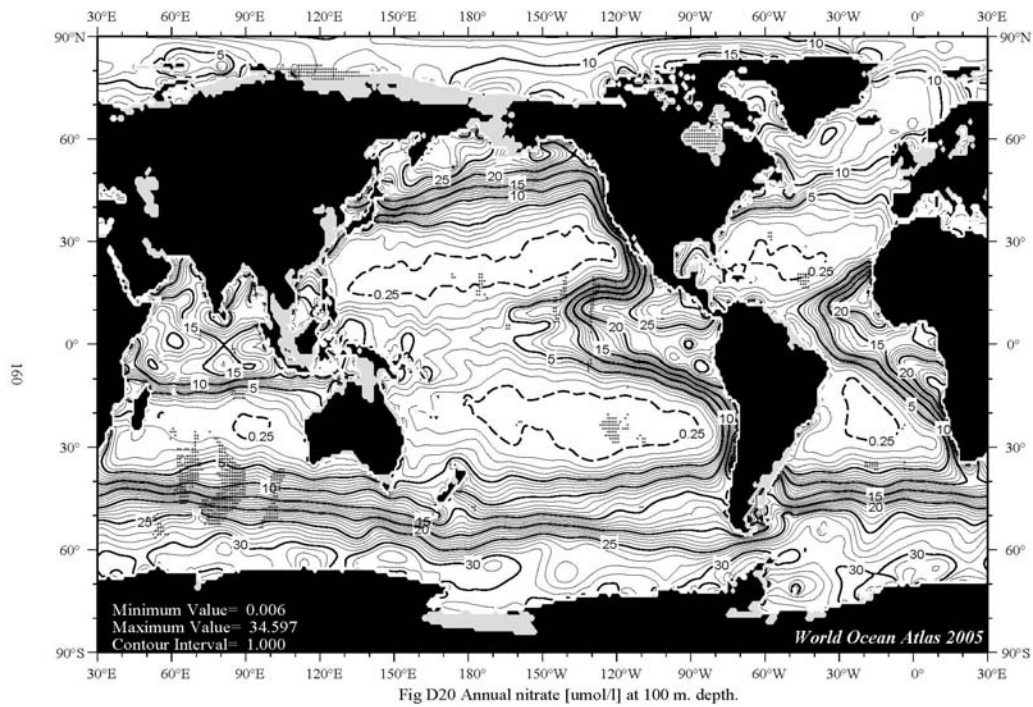


Figure 8B. Annual mean nitrate at 100 m depth (Adapted from Garcia et al. 2006b).

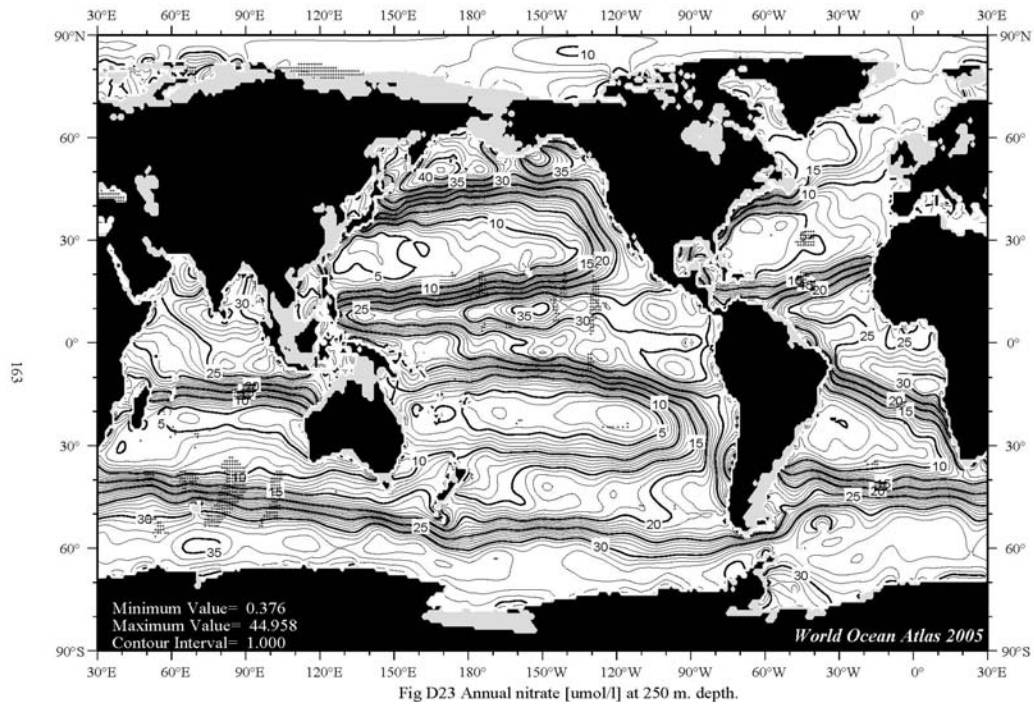


Figure 8C. Annual mean nitrate at 250 m depth (Adapted from Garcia et al. 2006b).

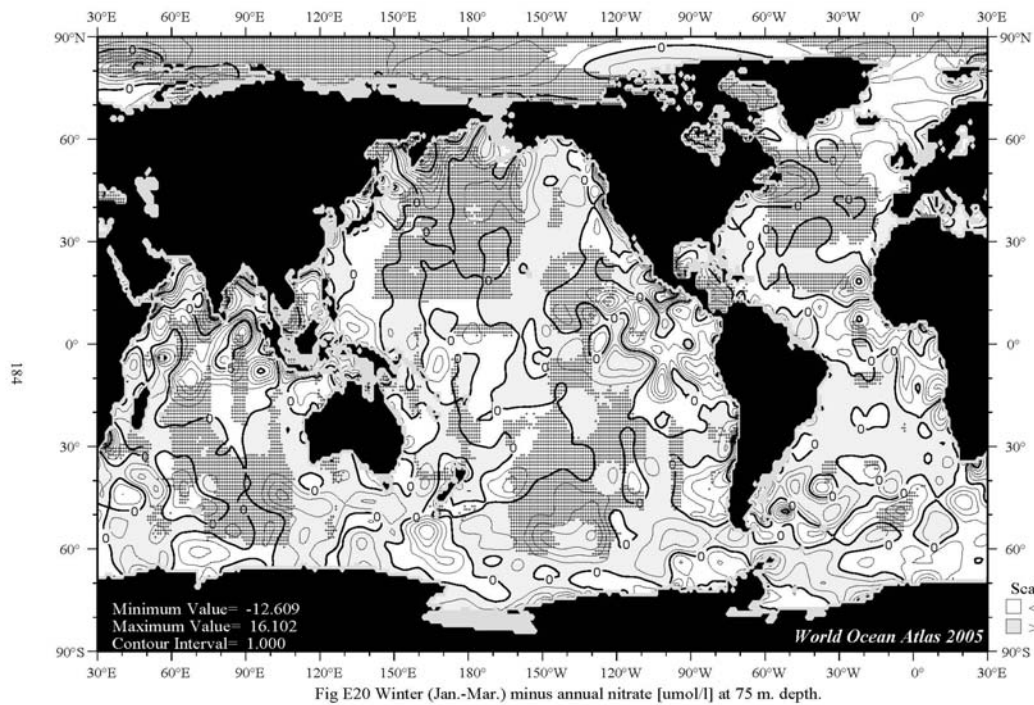


Figure 8D. Winter (January, February, March) mean nitrate anomalies (from annual) at 75 m depth (Adapted from Garcia et al. 2006b).