The Role of the Ocean in the General Circulation

1. Order-one interactions with the atmosphere

2. Sea surface temperatures

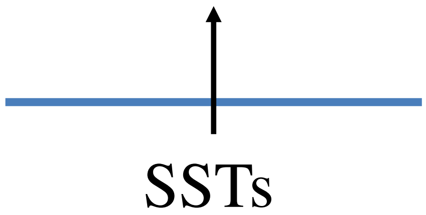
3. Salinity and the thermohaline circulation

4. North Atlantic Bottom Water formation

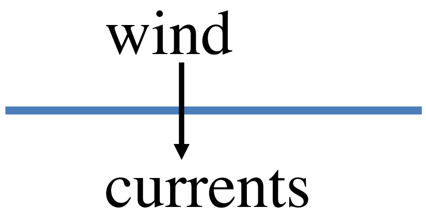
5. An atlas of the ocean

6. Ocean acidification

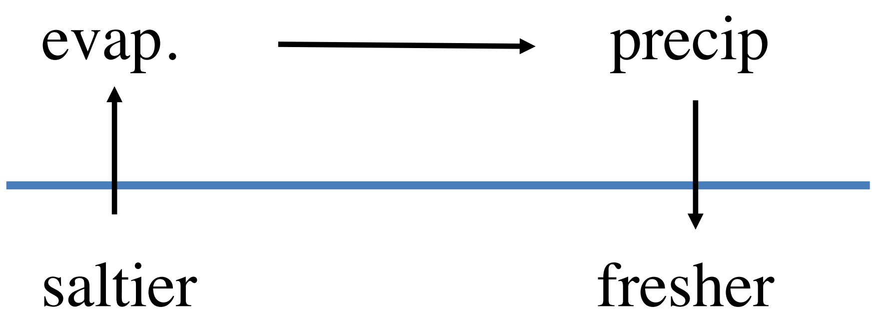
Order-one interactions between the atmosphere and the ocean



Ocean temperature anomalies heat and cool the atmosphere



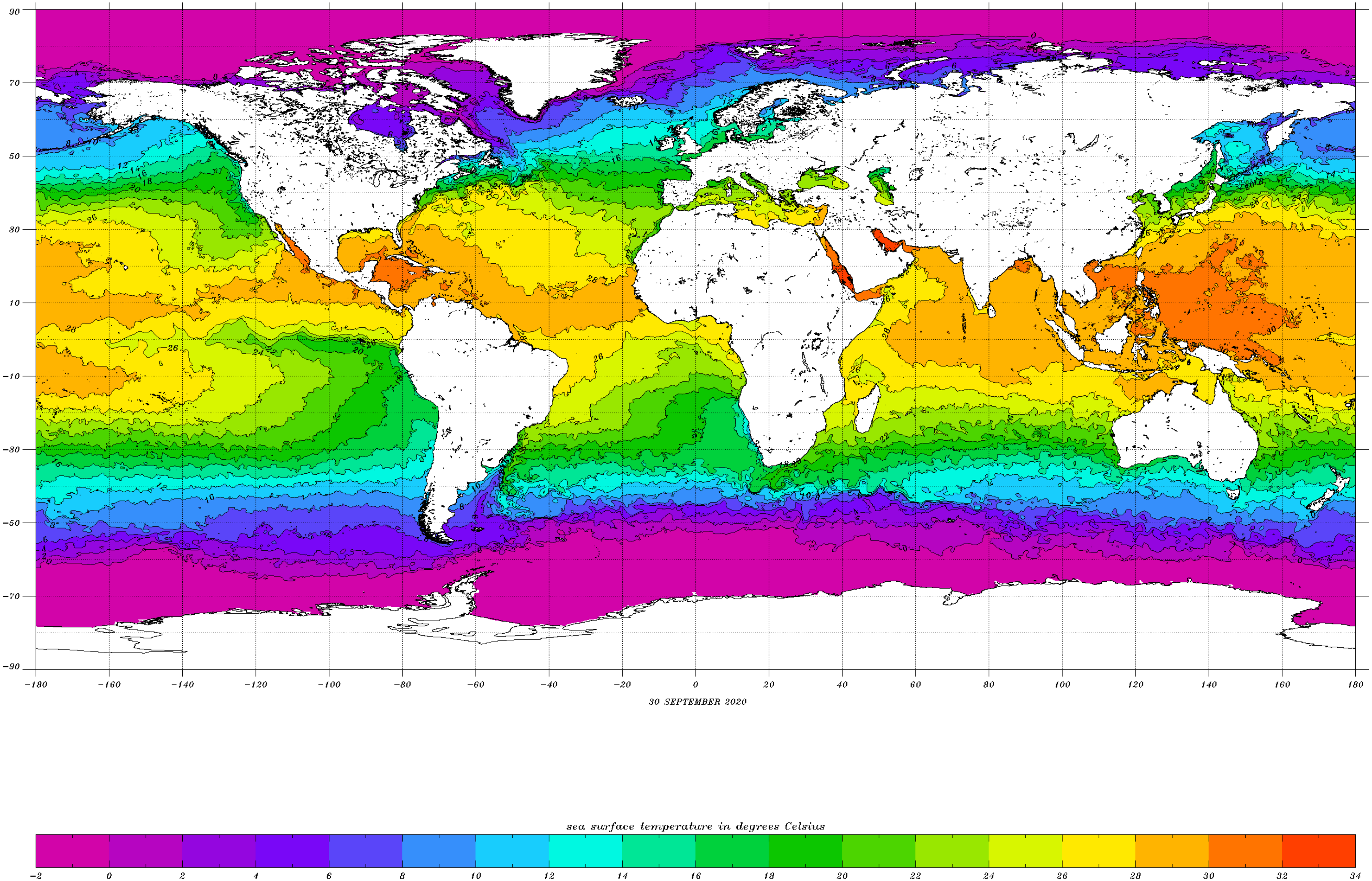
Wind stress causes currents, ocean gyres, upwelling



Latent heat transport linked to ocean salinity

Extra heat and CO_2 stay in ocean for ~1000 yr

NOAA/NESDIS GEO-POLAR BLENDED 5 km SST ANALYSIS
FOR THE FULL GLOBE



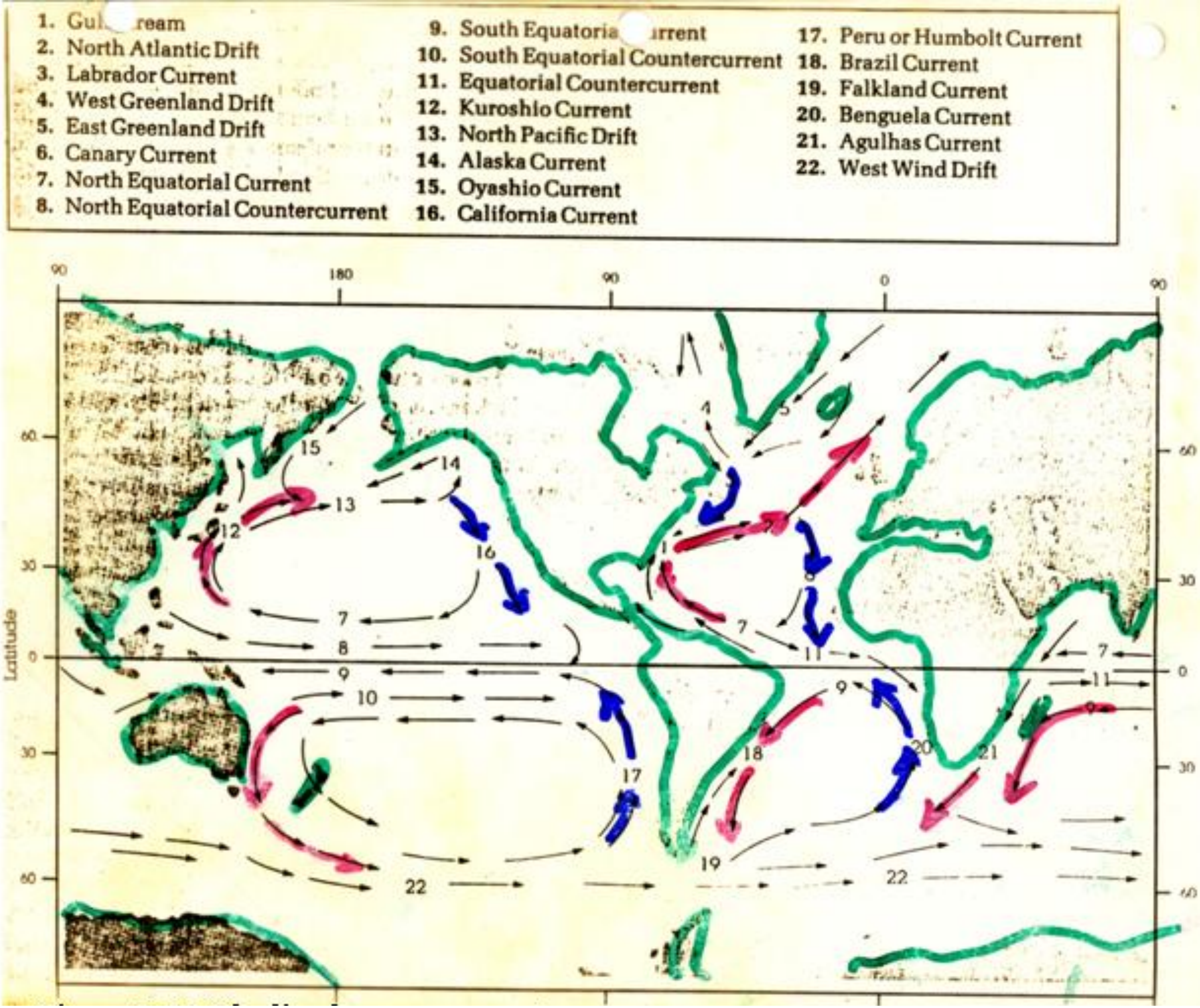
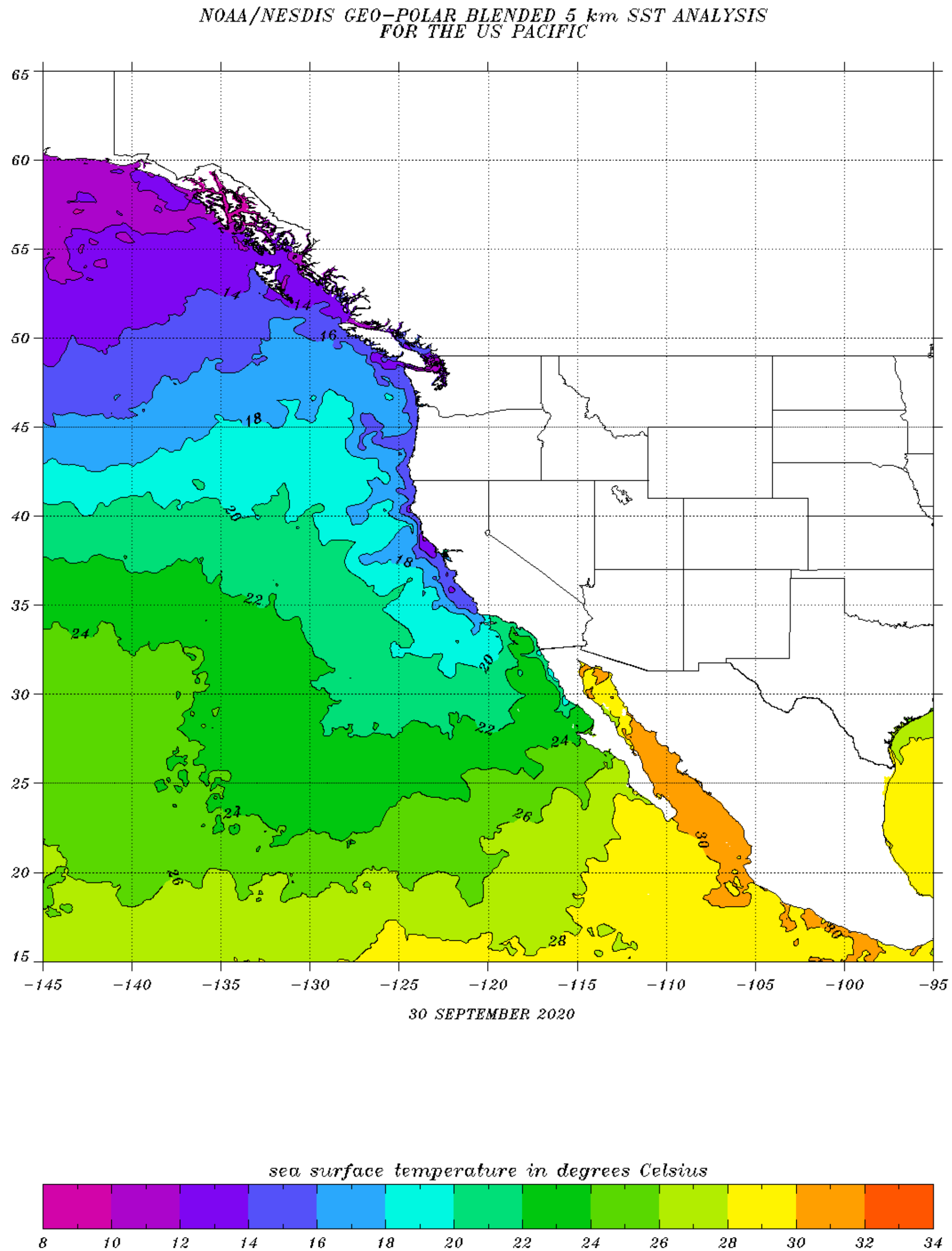
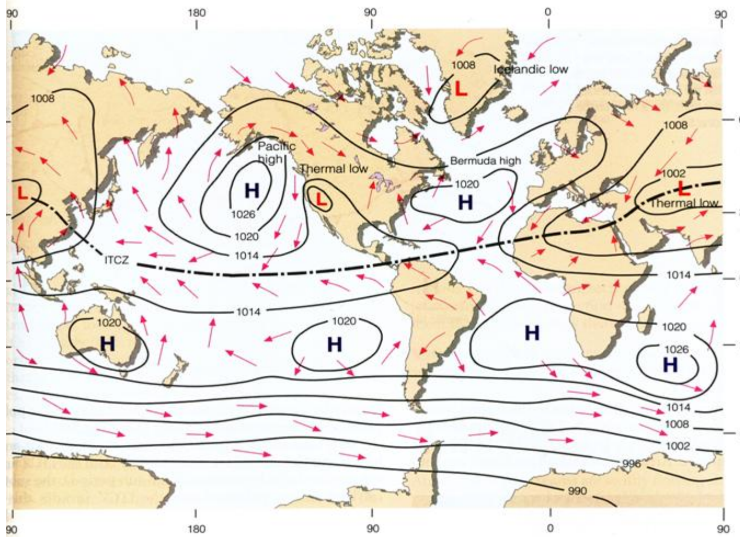


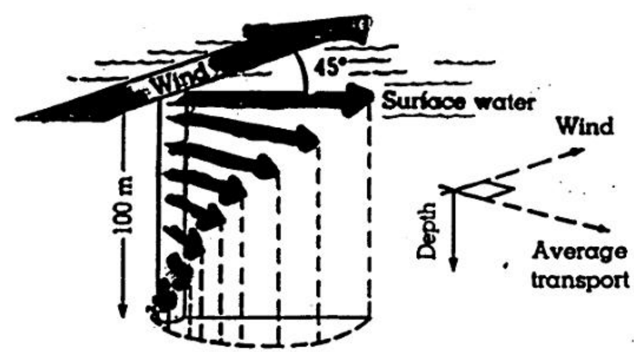
Figure 3.12 Idealized ocean currents [Ahrens].



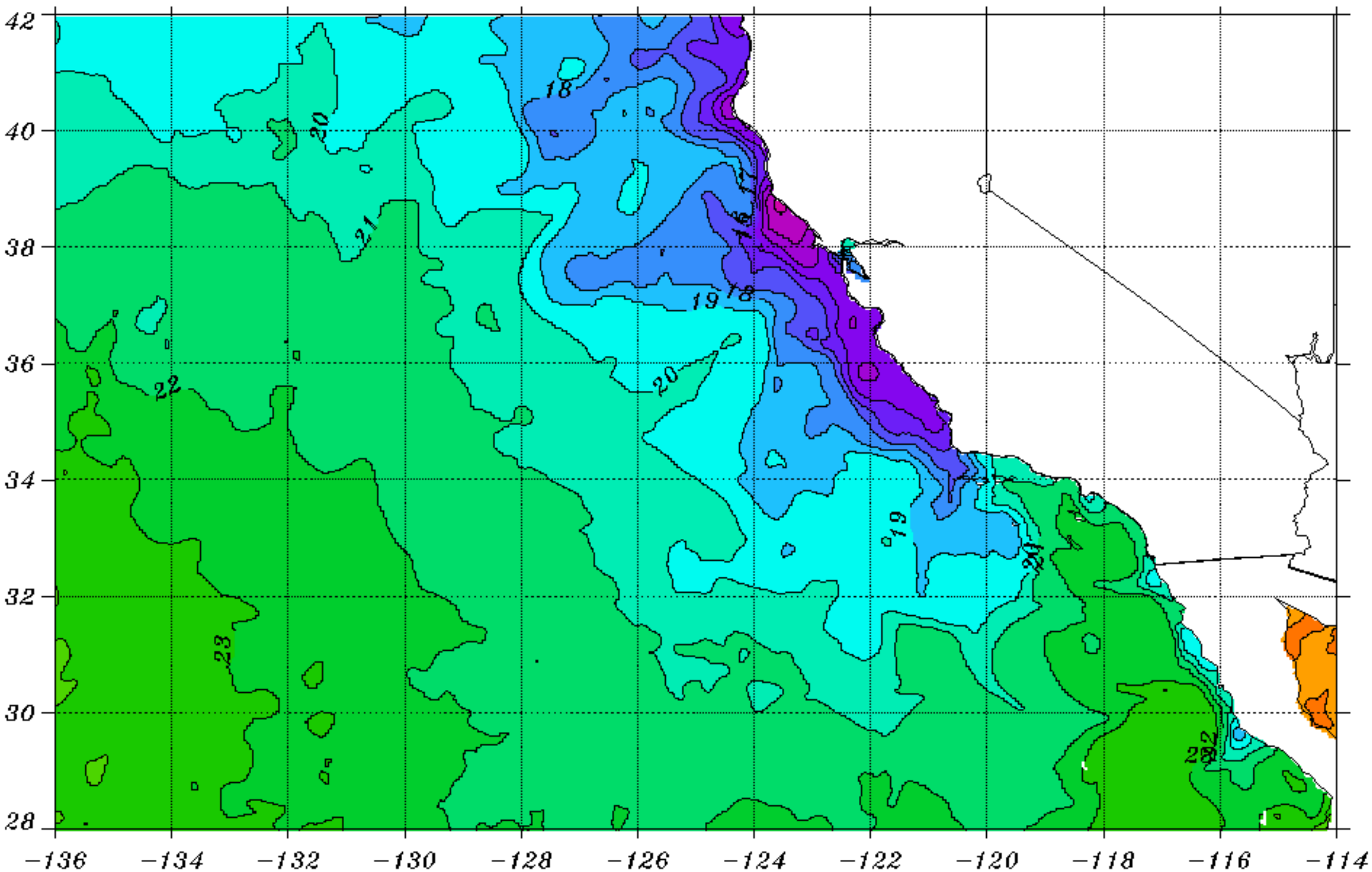
Southward winds along the coast drive offshore flow and upwelling.



July

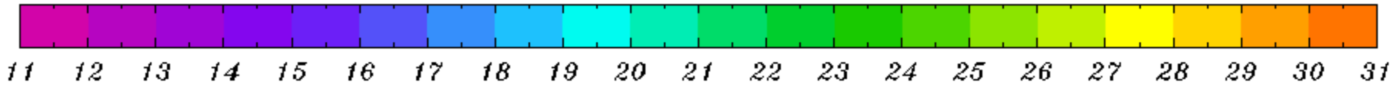


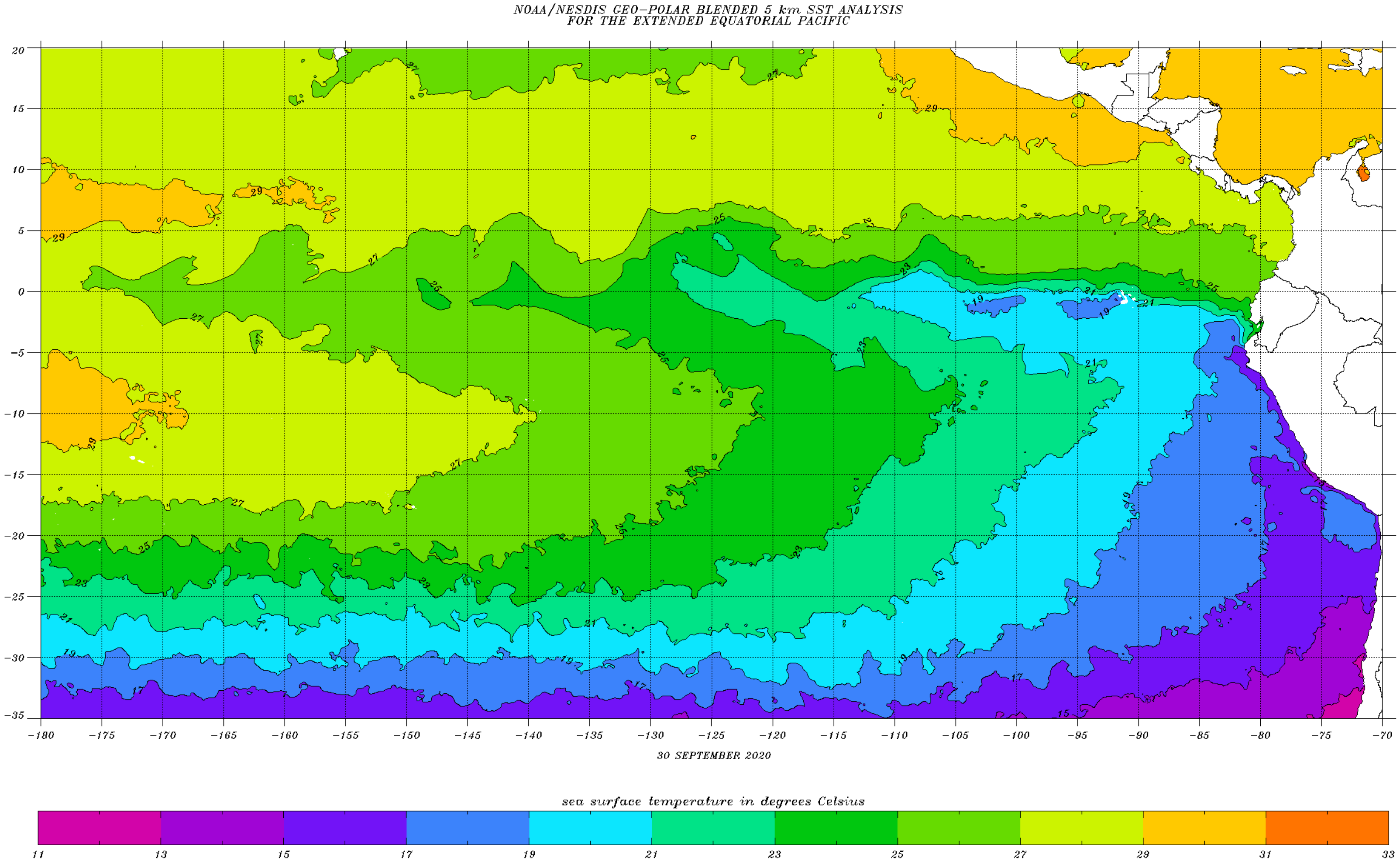
NOAA/NESDIS GEO-POLAR BLENDED 5 km SST ANALYSIS
FOR THE CALIFORNIA COAST



30 SEPTEMBER 2020

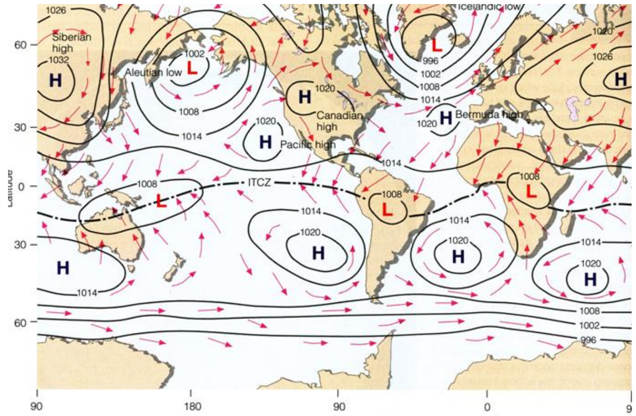
sea surface temperature in degrees Celsius





Northward winds along the coast drive offshore flow and upwelling.

January



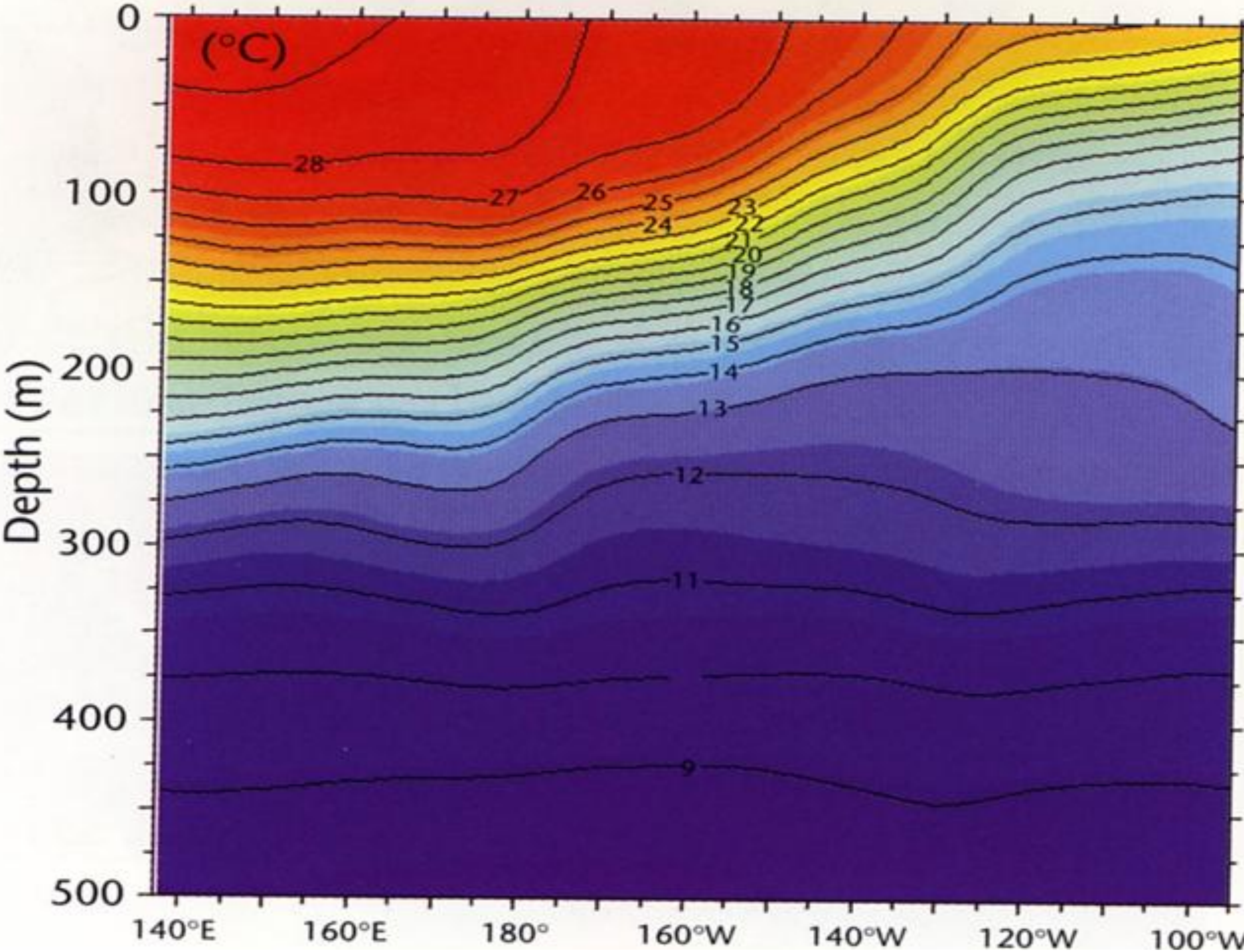
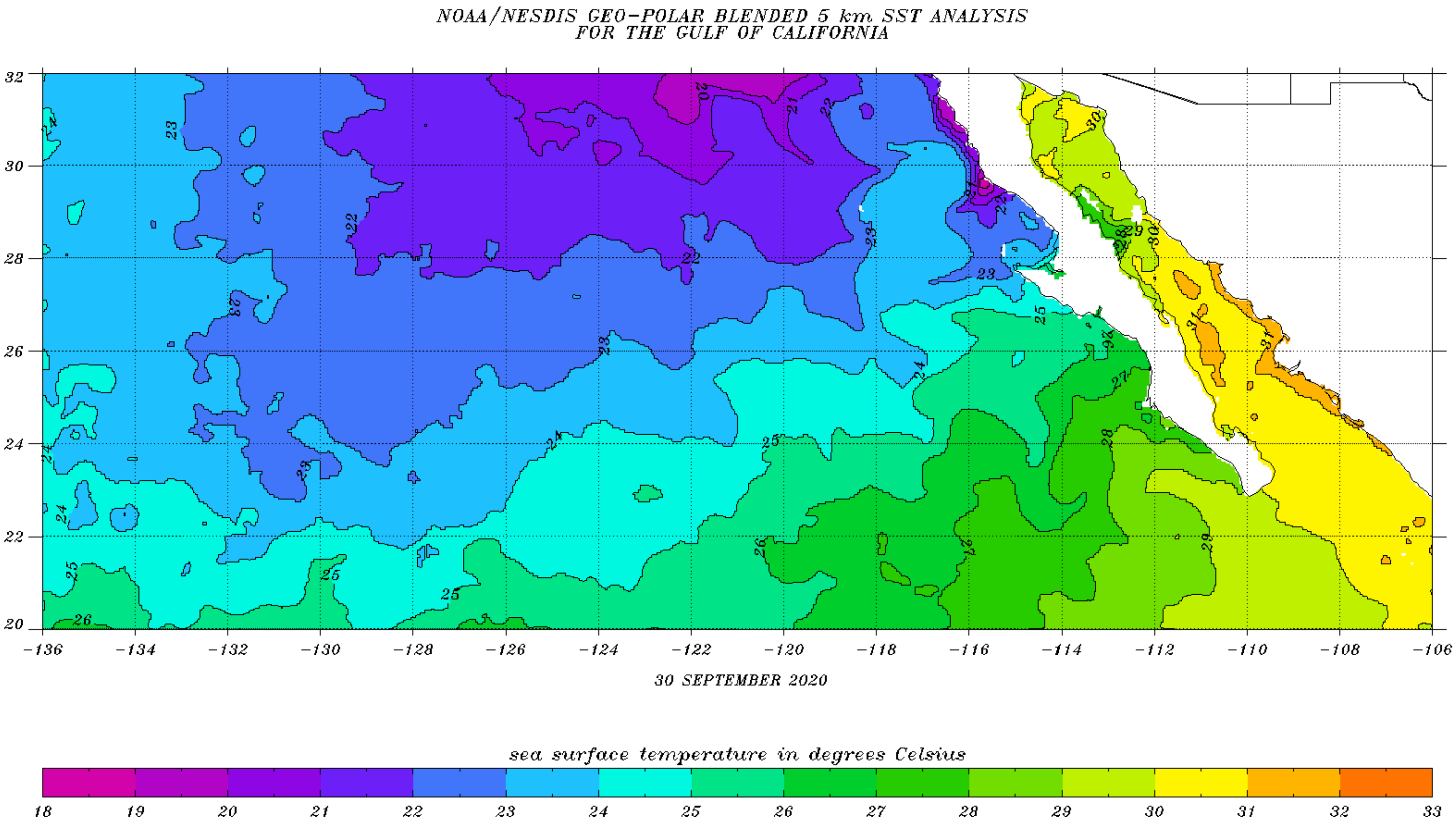
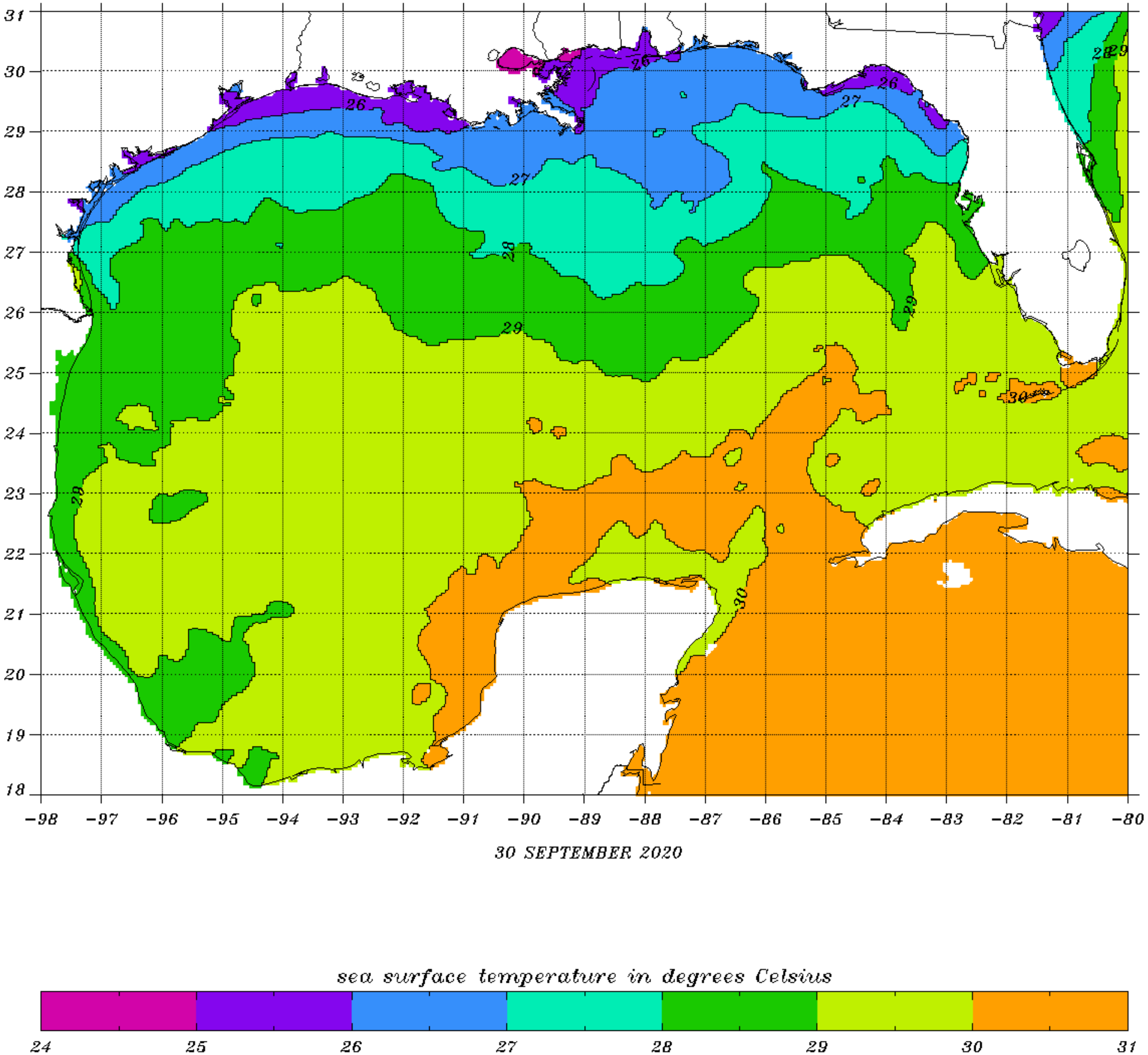


Figure 3.13. Vertical section along the equatorial Pacific showing the sloping thermocline, contour interval 1 K [www.cpc.noaa.gov].

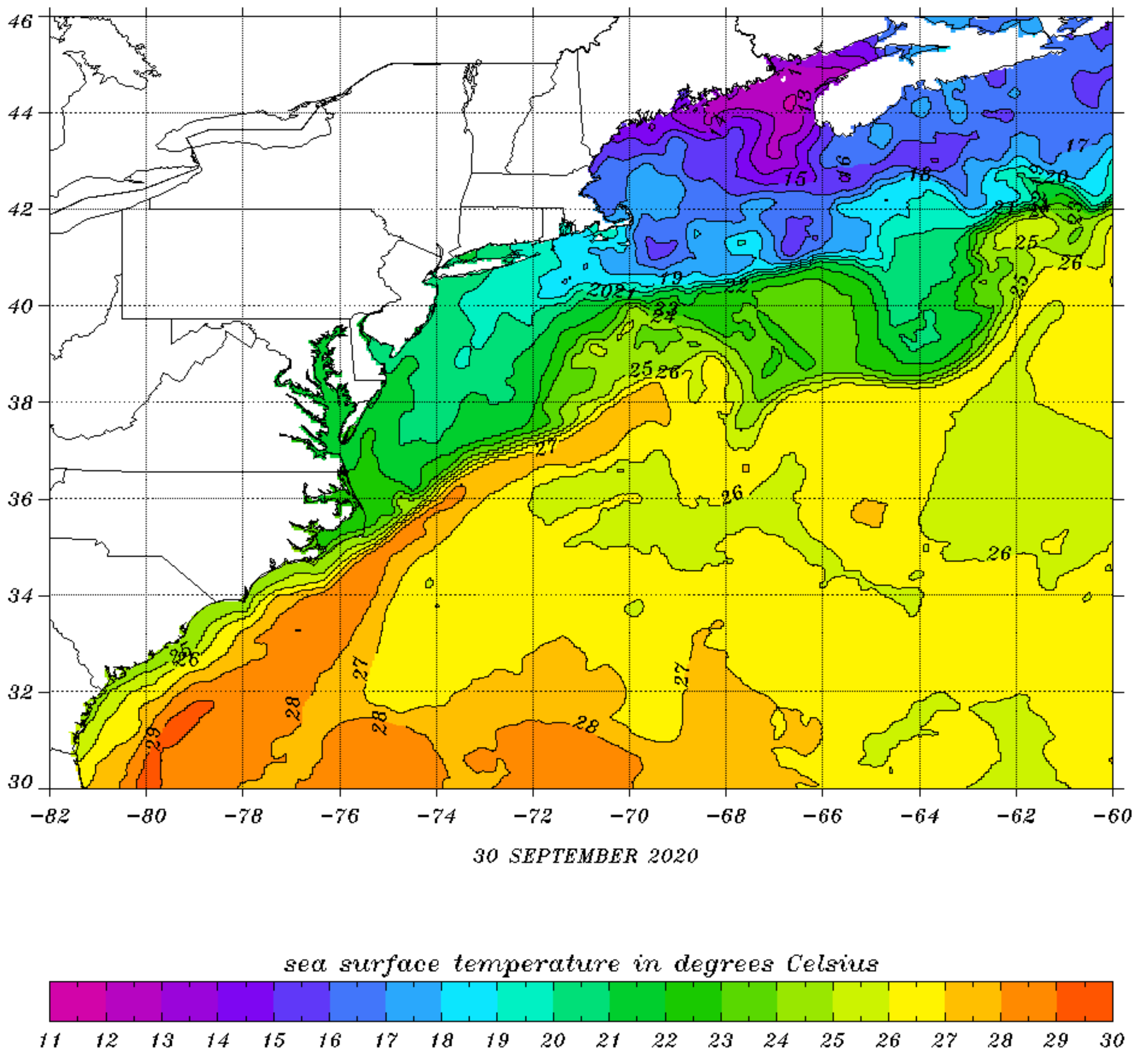
Tropical cyclones and coral are favored above about 28°C



NOAA/NESDIS GEO-POLAR BLENDED 5 km SST ANALYSIS
FOR THE GULF OF MEXICO



NOAA/NESDIS GEO-POLAR BLENDED 5 km SST ANALYSIS
FOR THE NORTH ATLANTIC



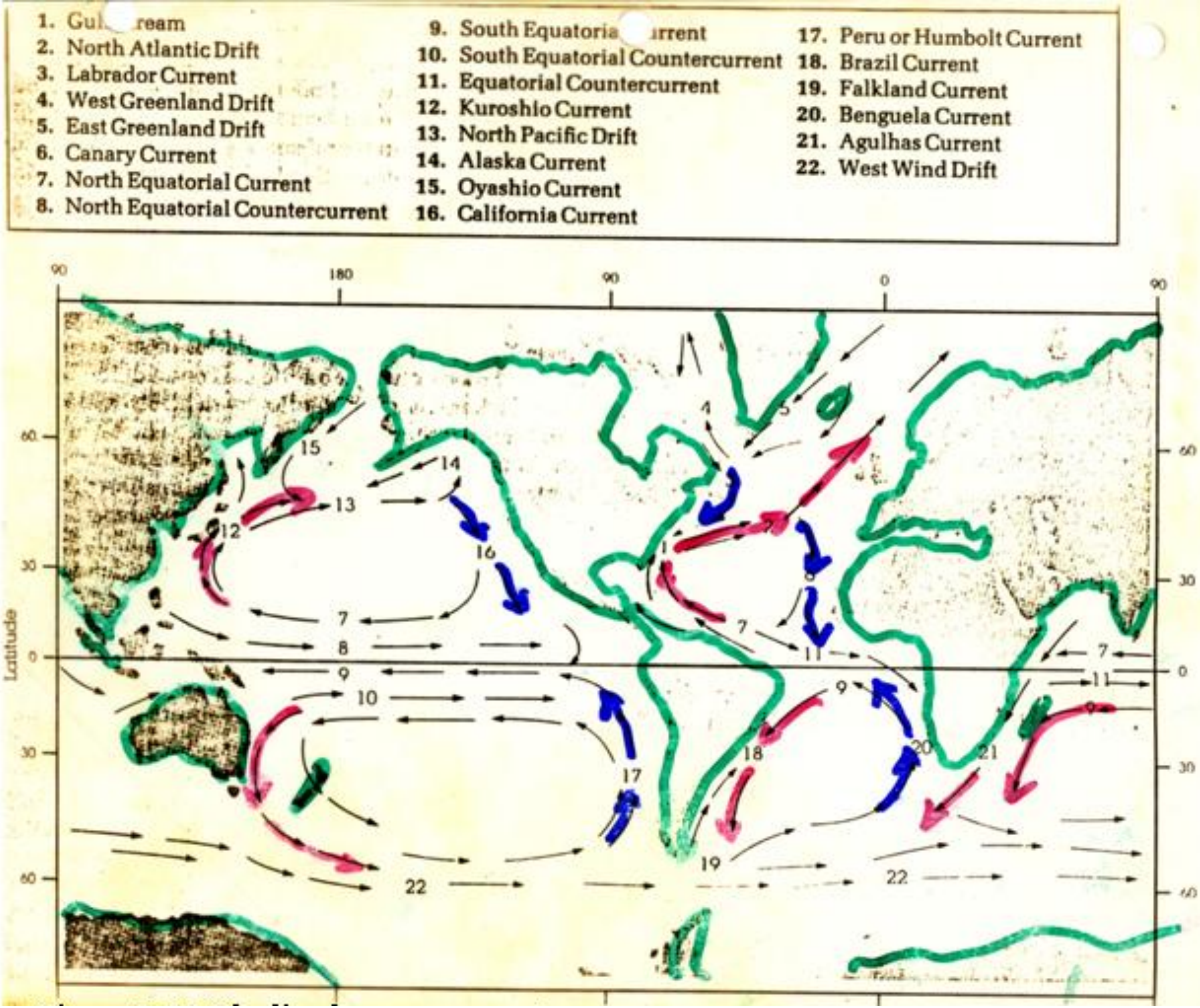


Figure 3.12 Idealized ocean currents [Ahrens].

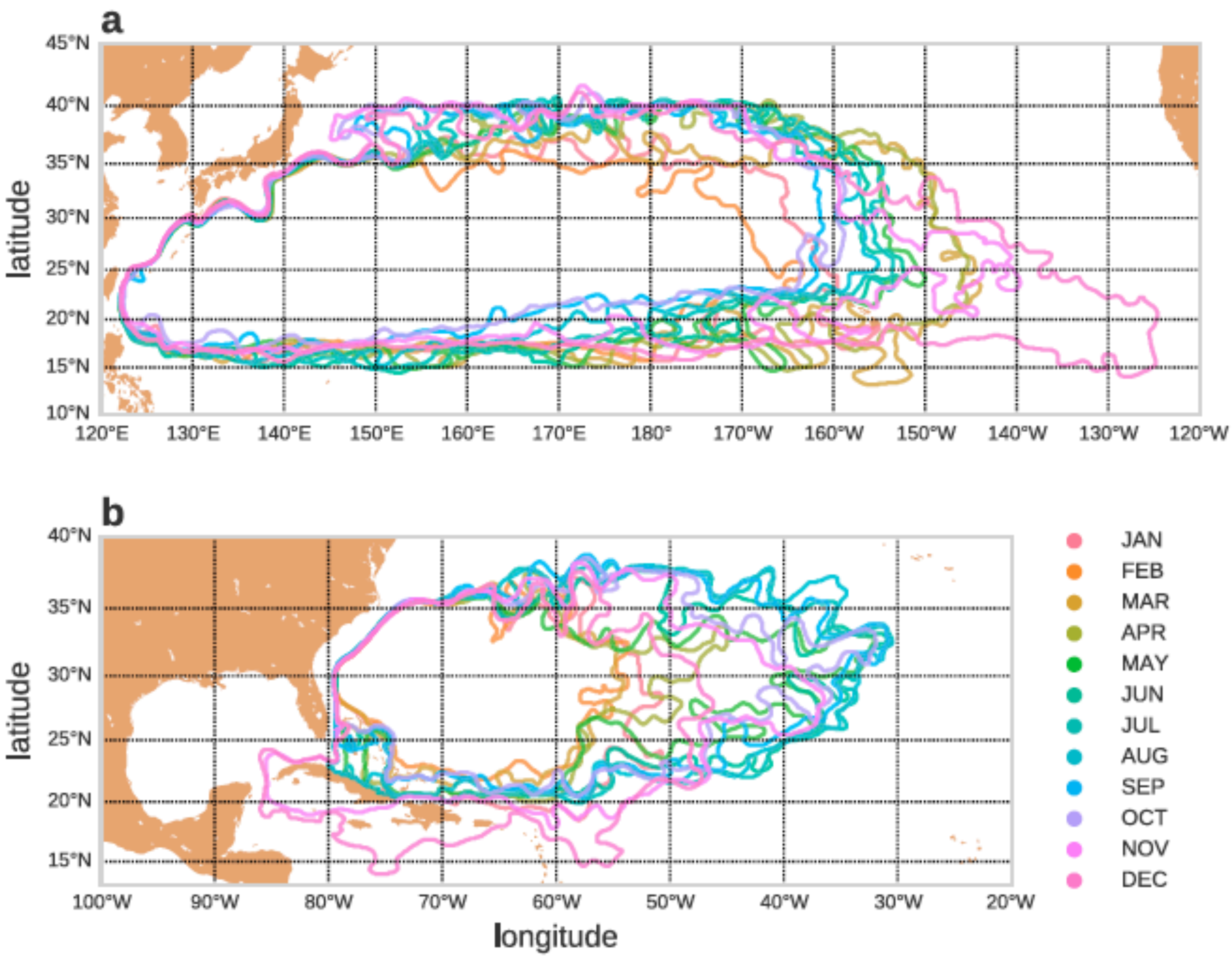
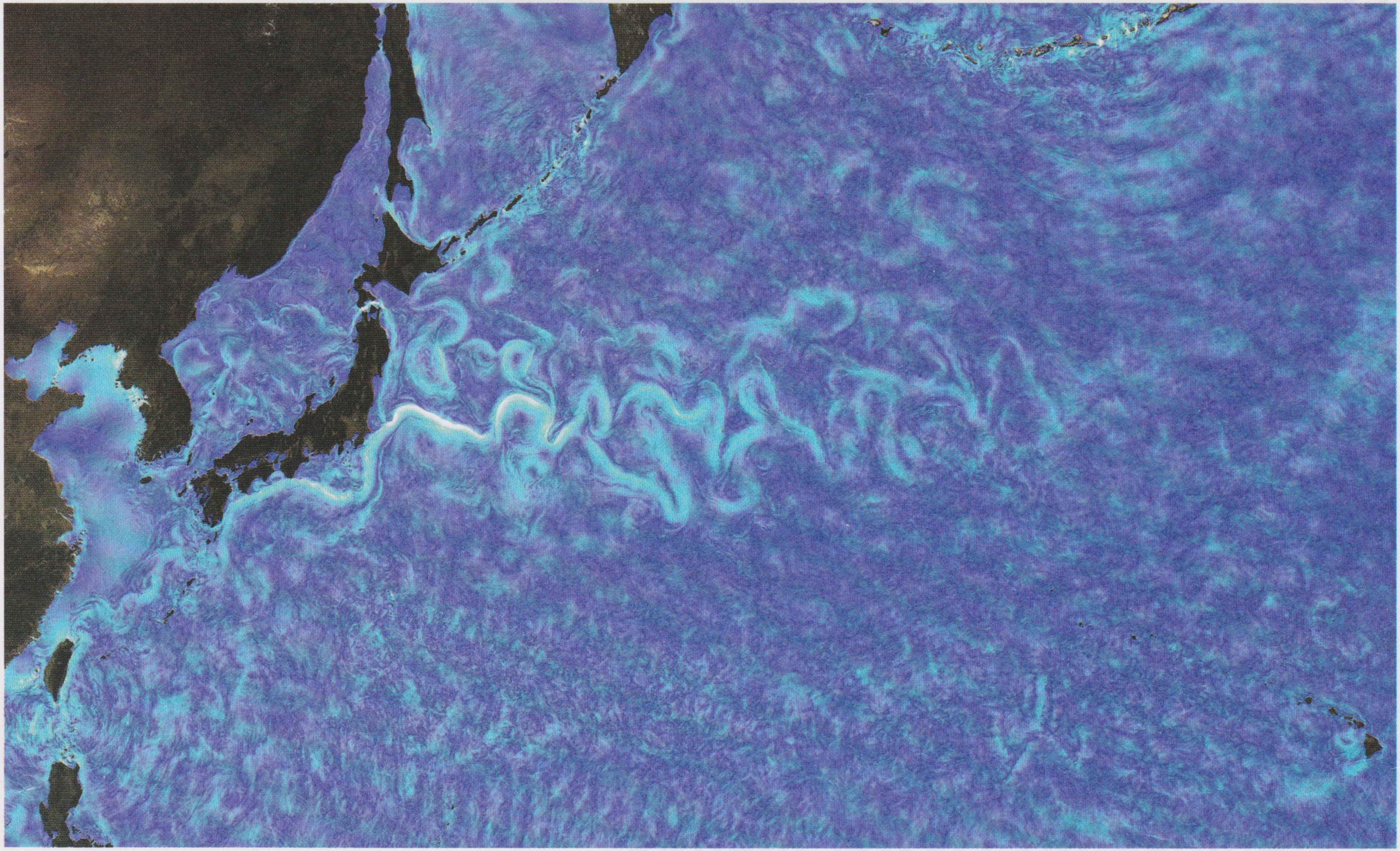


Figure 2. Monthly climatological positions of the subtropical gyres in this study, defined by using monthly mean barotropic mass quasi-stream function integrated over the upper 1,000 m. (a) $\Psi = 20$ Sv was chosen for the North Pacific and (b) $\Psi = 25$ Sv was chosen for the North Atlantic subtropical gyres as the quasi-stream function that encloses the largest areal extent over the whole year.



C. Henze, NASA Advanced Supercomputing Division

Snapshot of surface speed from a high-resolution computer simulation. The Kuroshio Current hugs the eastern coast of Japan before meandering eastward and farther into the Pacific Ocean. A new study of seasonal, fine-scale upper ocean dynamics in this region raises important considerations for the upcoming Surface Water and Ocean Topography (SWOT) mission.

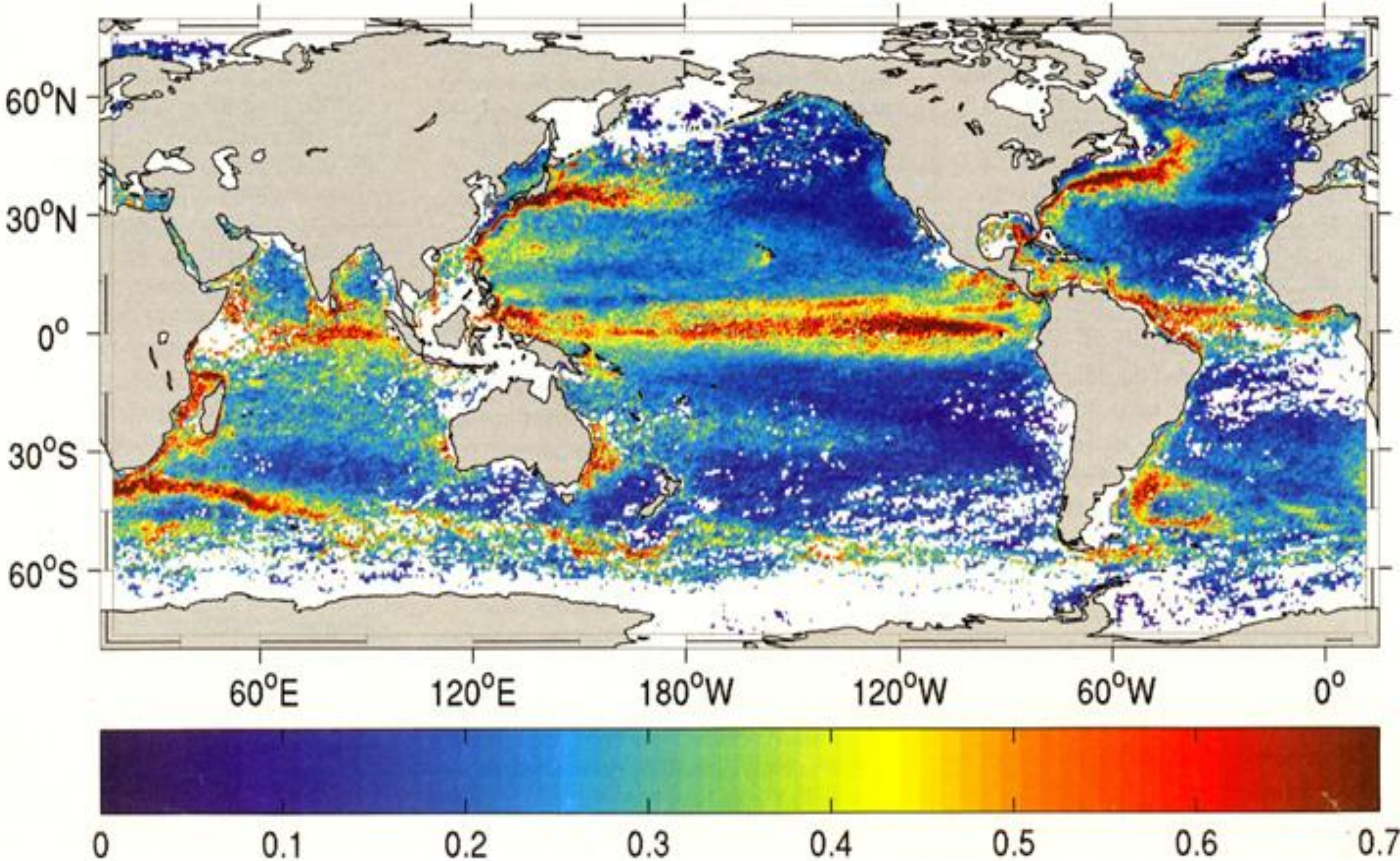


Figure 3.18. Variability of current velocity as detected by global drifters [Pazan 2004].

The Thermohaline Circulation

The density of sea water is controlled by temperature and salinity.
It is more dense when colder and saltier (more likely to sink).
It is less dense when warmer and fresher (more likely to rise).

Sea water is ~ 40 ppt salt
or 40 kg salt/1000 kg water (recipe: 2 t salt per 1 c water)
Variations of only a few ppt salt can make a big difference!

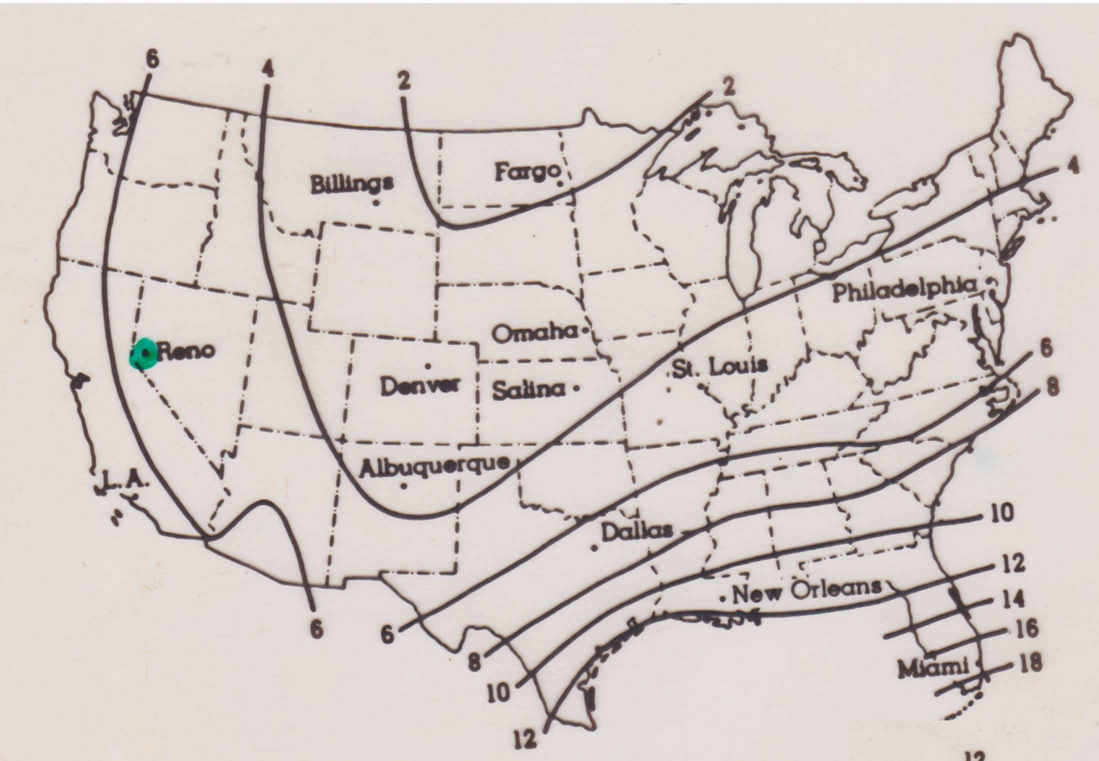
Physical processes that favor formation of deep water (sinking):
1) evaporation (leaves salt behind in the water)
2) cooling (thermal contraction)
3) ice formation (leaves salt behind in the water)

(Heating and precipitation inhibit formation of deep water)

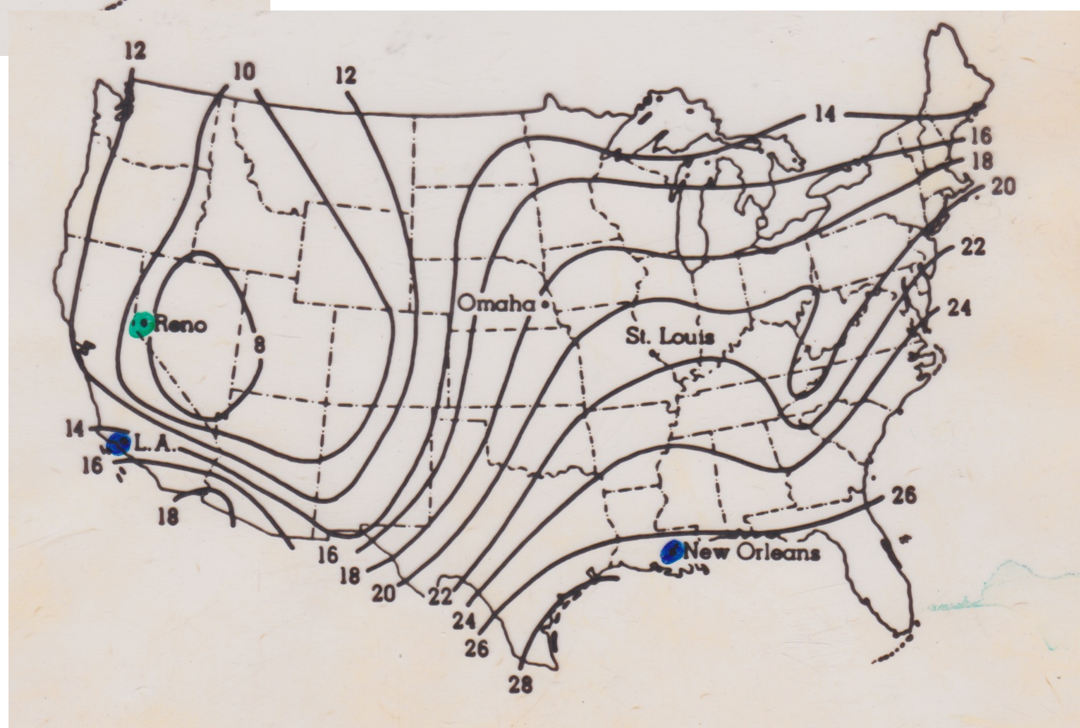
The THC controls storage of heat and CO_2 and the Ice Ages!

Vapor Pressure at Sea Level in mb

January



July



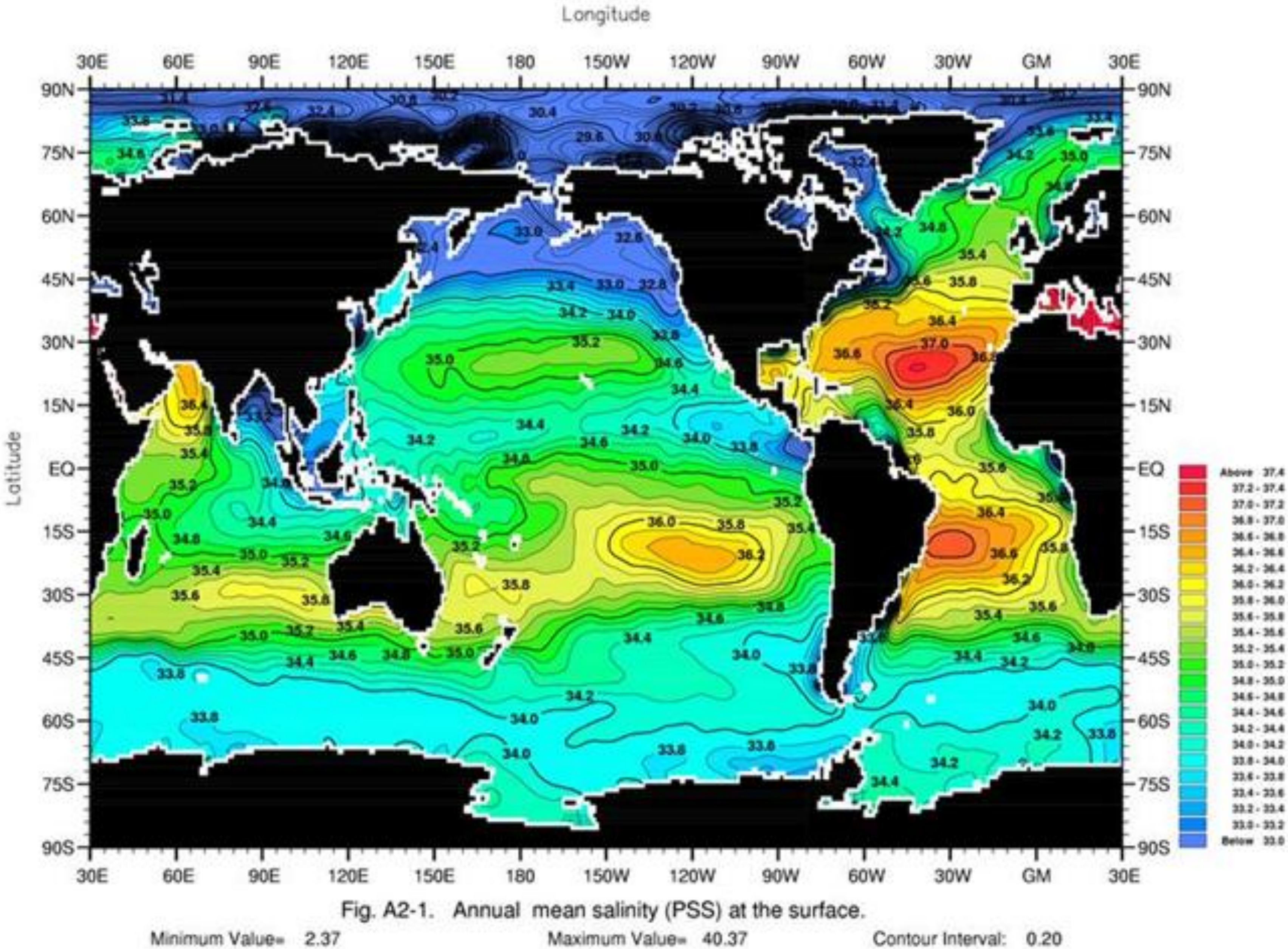


Figure 3.14. Average surface salinity during August, contour interval 0.2 ppt [World Ocean Atlas 2001].

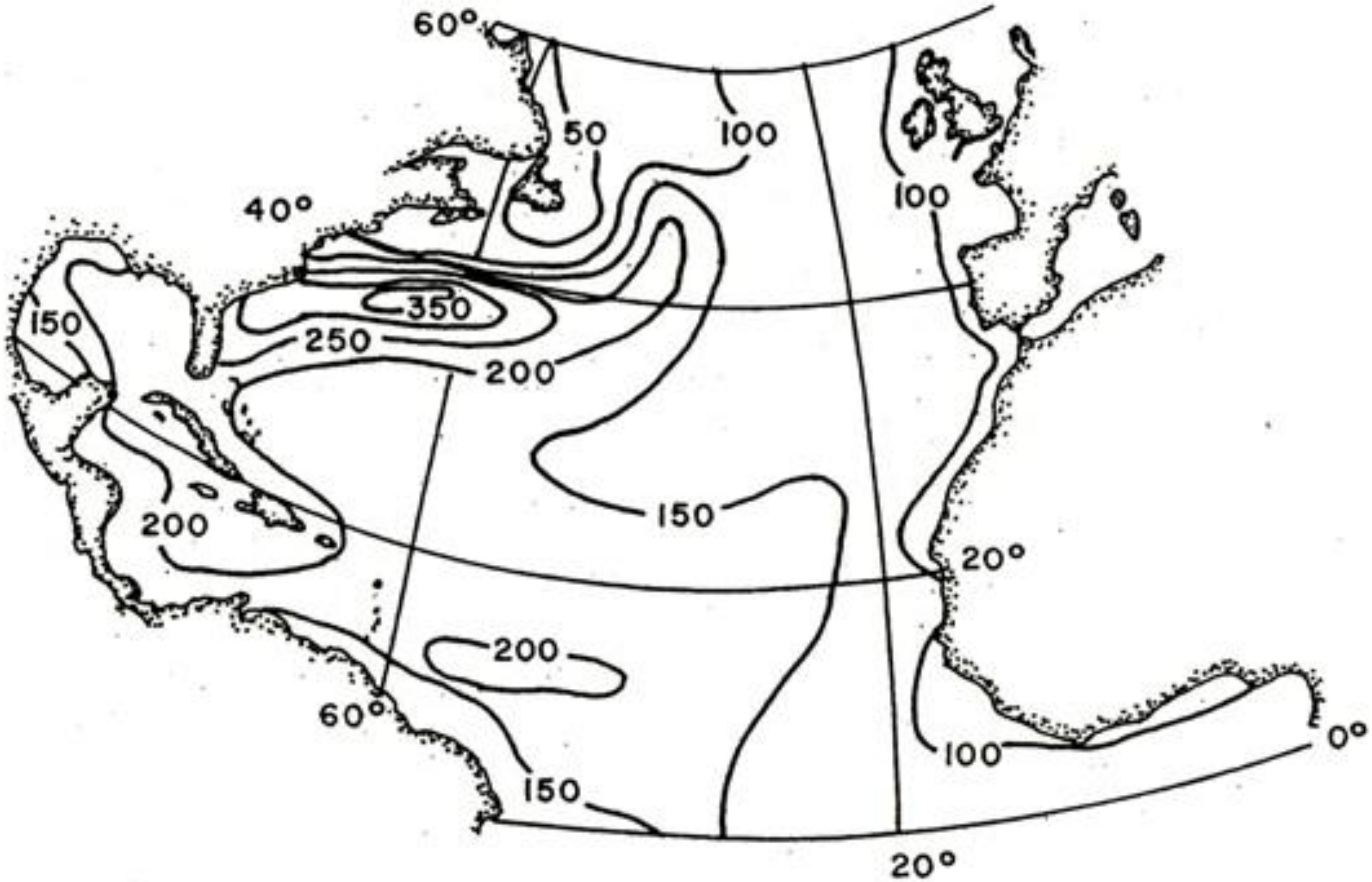


Figure 3.15. An estimate of the evaporation rate for the North Atlantic, contour interval 50 cm/yr [Bunker 1976].

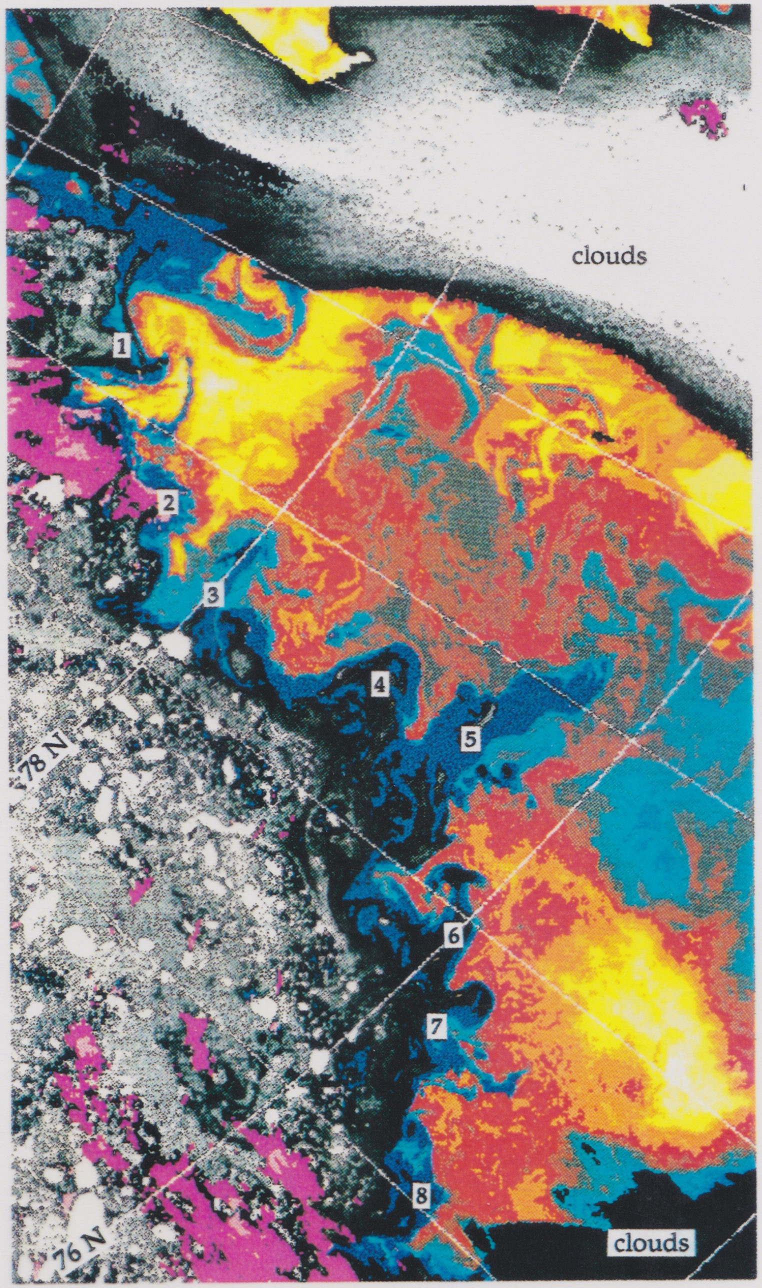


Plate 1. NOAA AVHRR image from July 1 1984 during the MIZEX 84 experiment. The image combined visual (channel 2) data over ice with IR data (channel 4) in open water. The dark blue indicates cold water along the ice edge, while light blue, red and yellow shows warmer water (> 2°C). The numbers indicate ice tongues similar to the SAR observations in MIZEX 87.

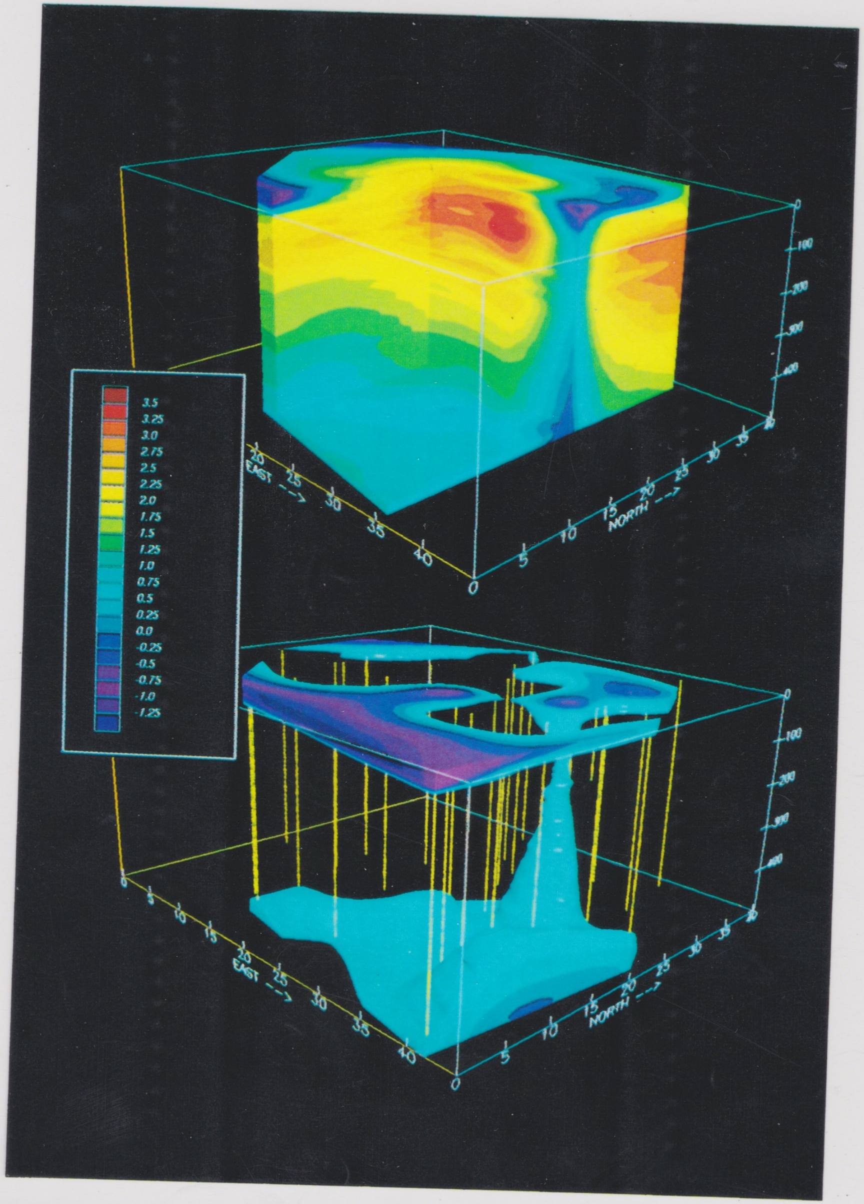


Plate 1. a) Volumetric rendering of the relict-chimney's thermal structure based on data taken during the 'star survey'. The volume is 40 km x 40 km x 500 m. Local coordinate axes have major tick marks every 5 km in the horizontal and 100 m in the vertical. Color key changes are every 0.25 °C. North and east are indicated below the axes. All thermal layers are retained, but model is cut to show the interior structure of the relict-chimney. b) Only temperatures less than 0.75 °C are shown. The relict-chimney's structure is best observed in this manner. Station locations are indicated by vertical lines within the volume.

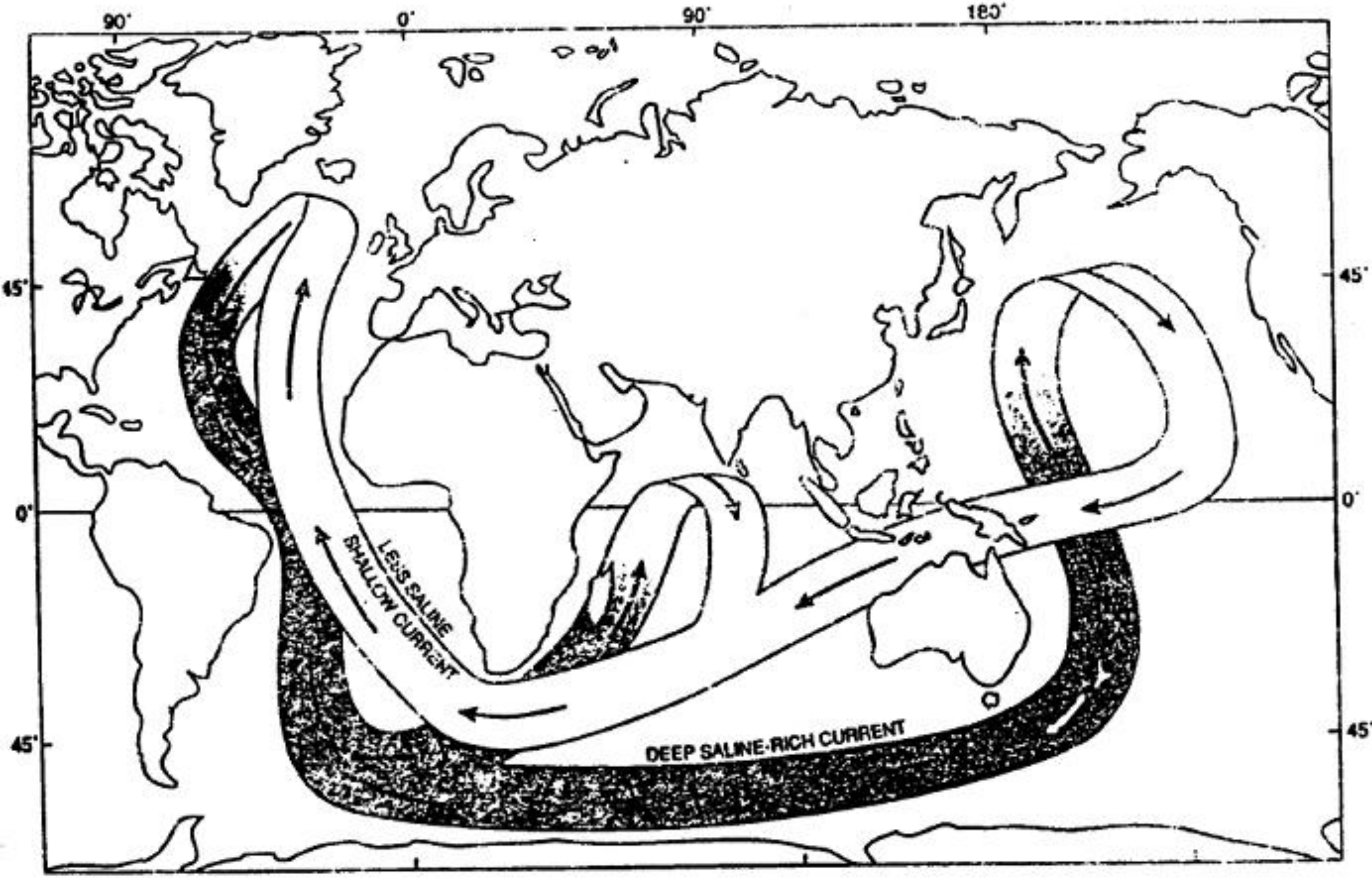


Figure 3.16. Idealized "conveyor belt" view of the thermohaline circulation, with sinking in the North Atlantic, spreading throughout the deep ocean, rising, and return at the surface.

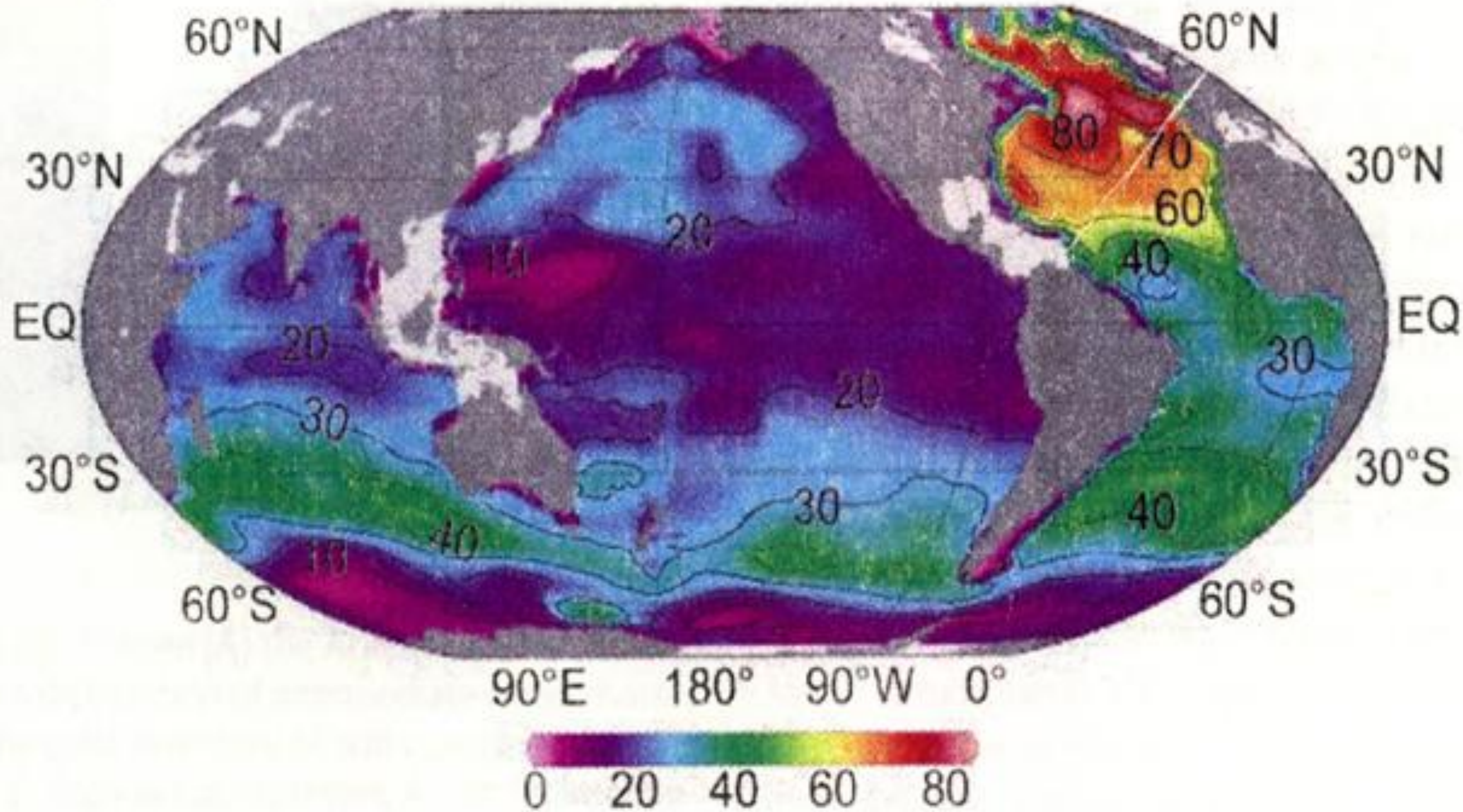
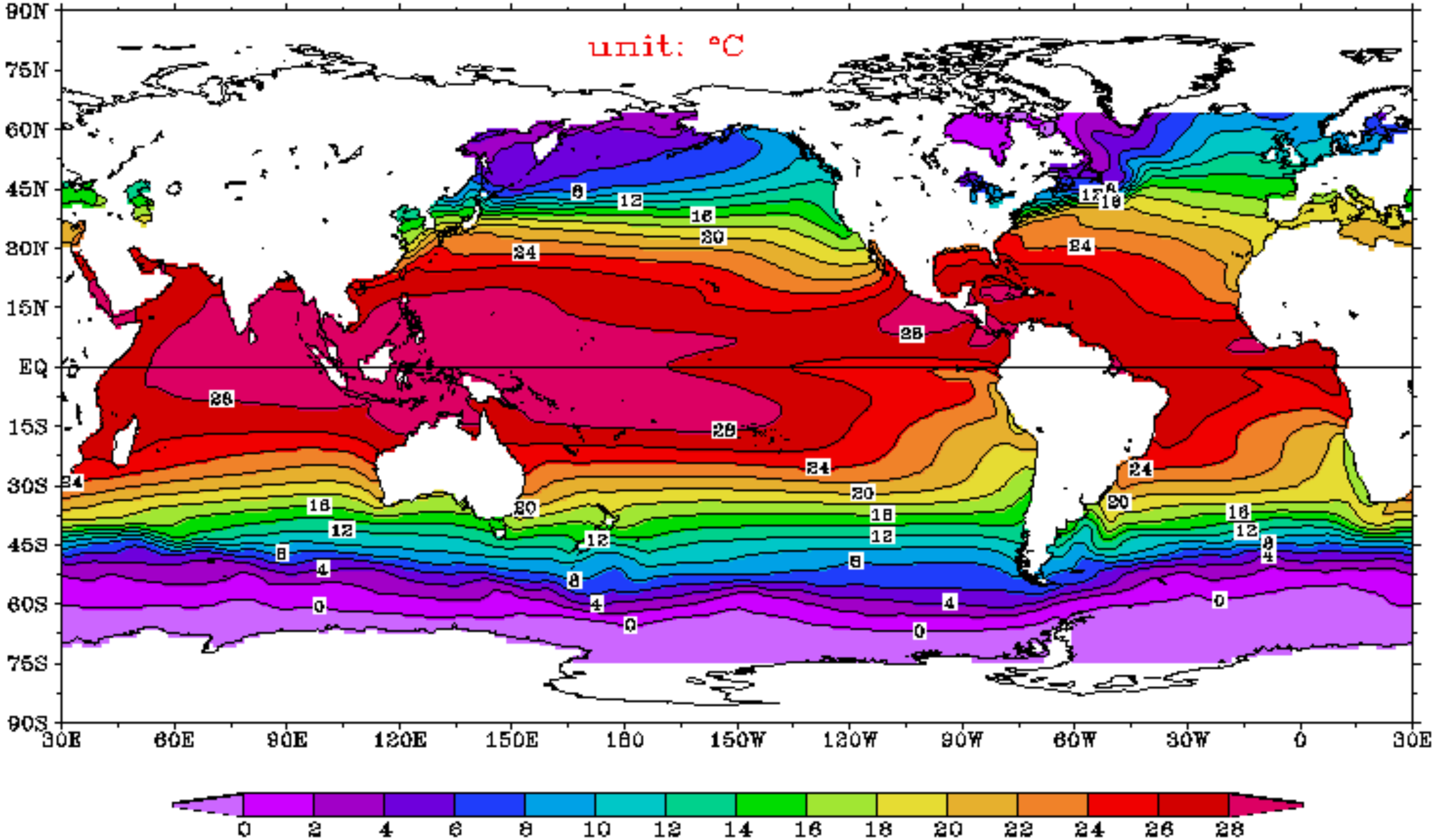


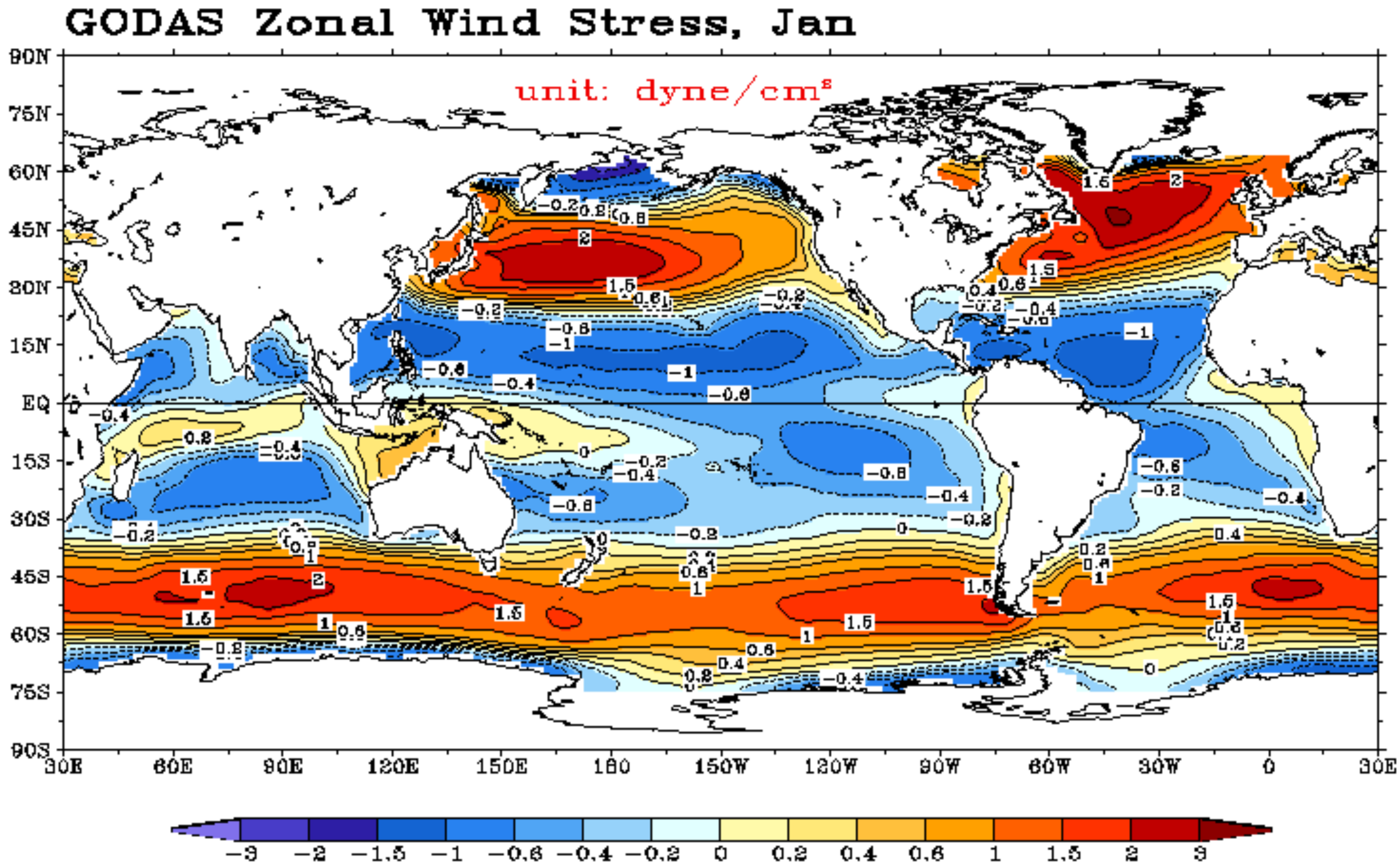
Figure 3.17. Column inventory of anthropogenic CO_2 in the ocean, in mol m^{-2} (color bar). High inventories are associated with deep water formation in the North Atlantic and intermediate water formation near 30-50°S. The total inventory is 106±17 Pg C. [Sabine et al. 2004].

A Global Ocean Atlas

Annual Mean Sea Surface Temperature °C

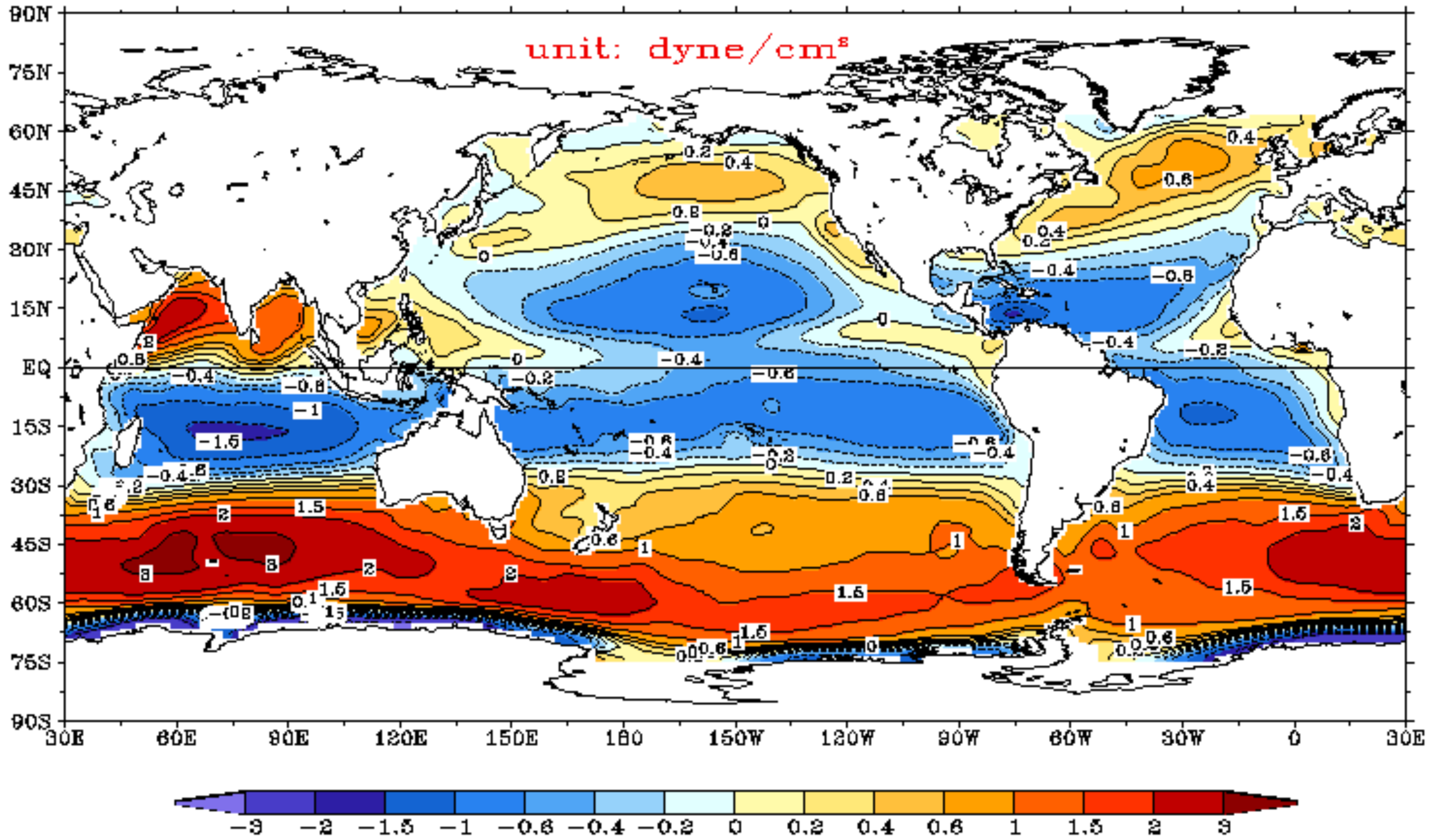


1982-2004

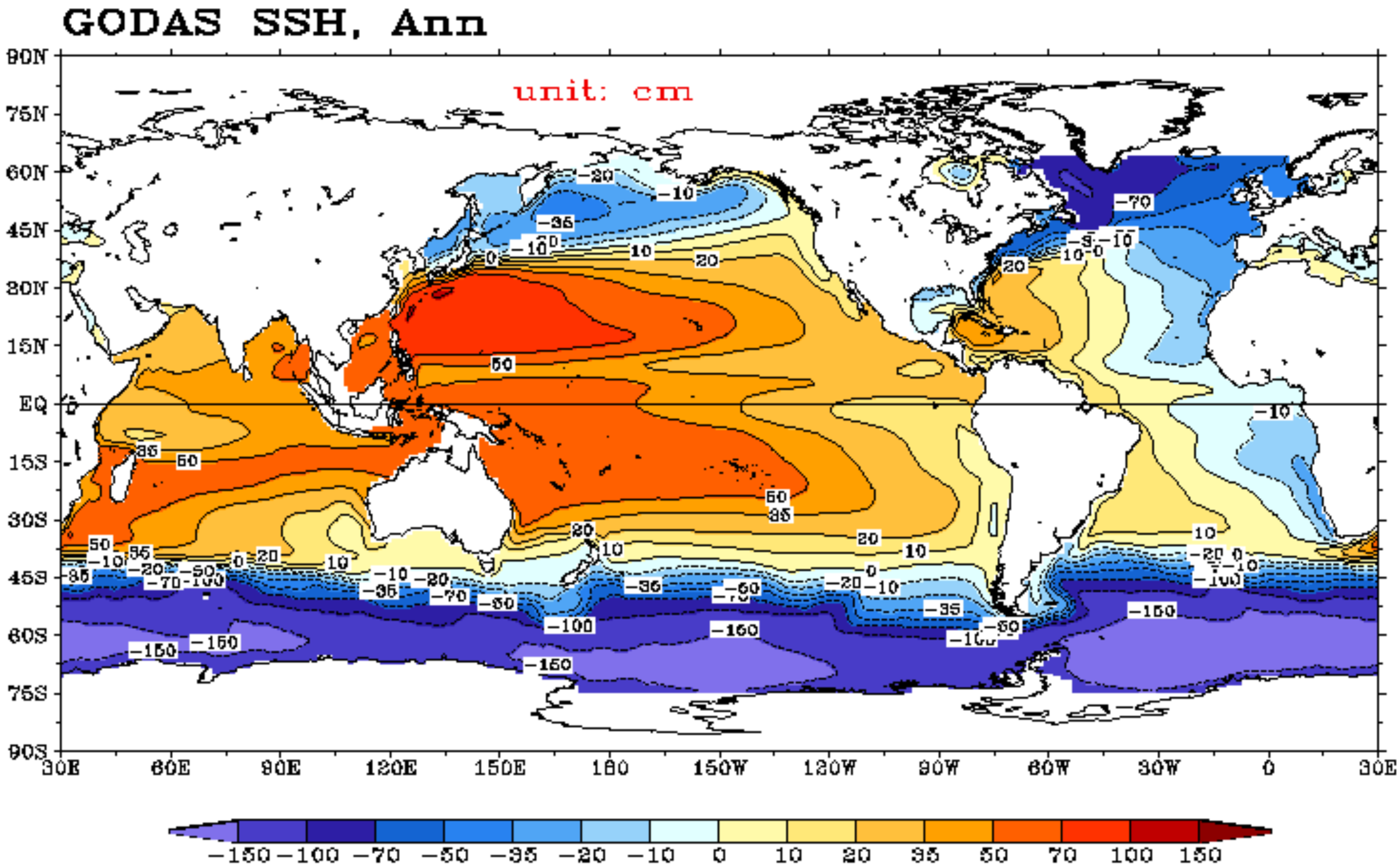


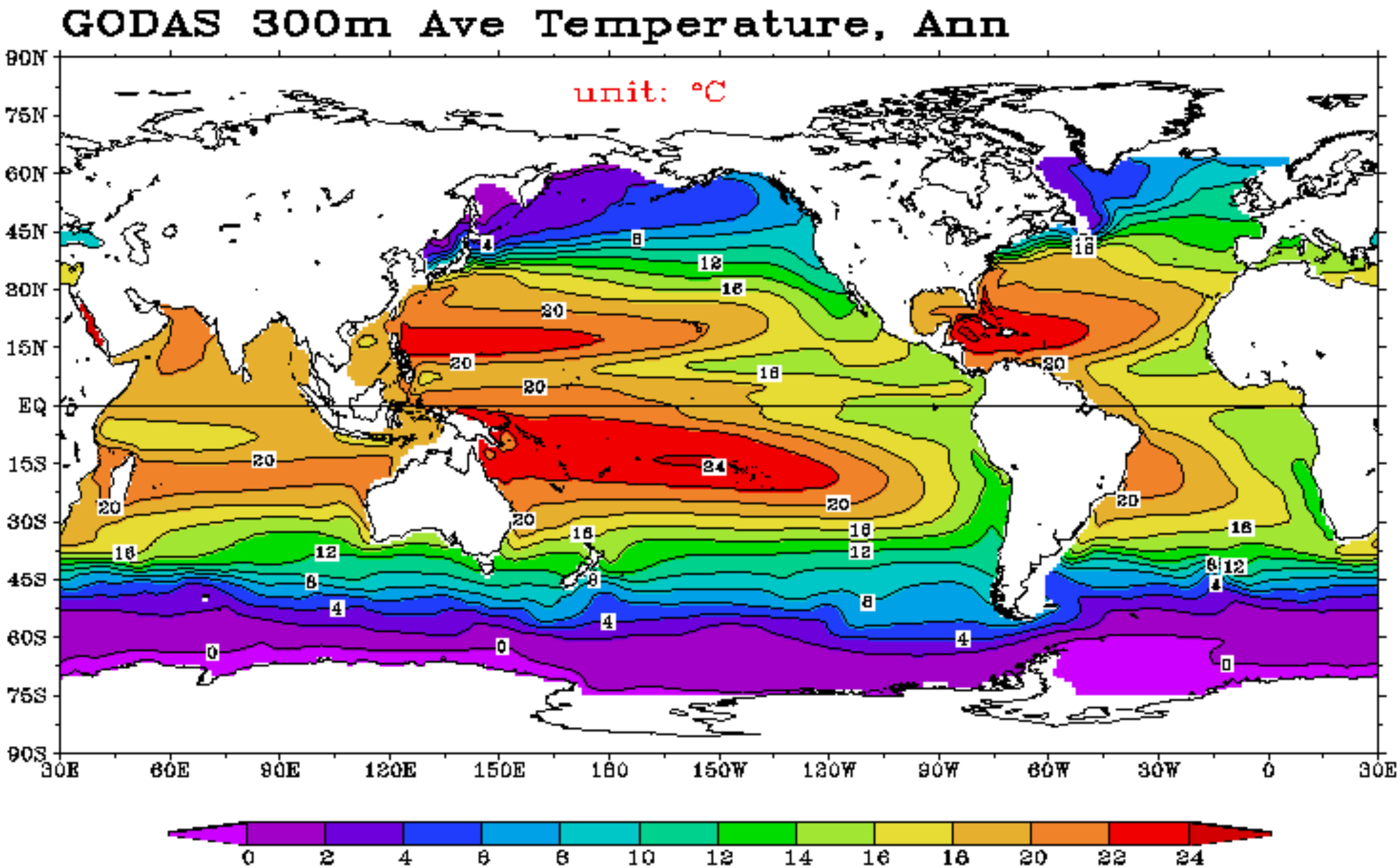
GODAS Zonal Wind Stress, Jan
unit: dyne/cm²
90N
75N
60N
45N
30N
15N
EQ
15S
30S
45S
60S
75S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
30E
-3
-2
-1.5
-1
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
1
1.5
2
3

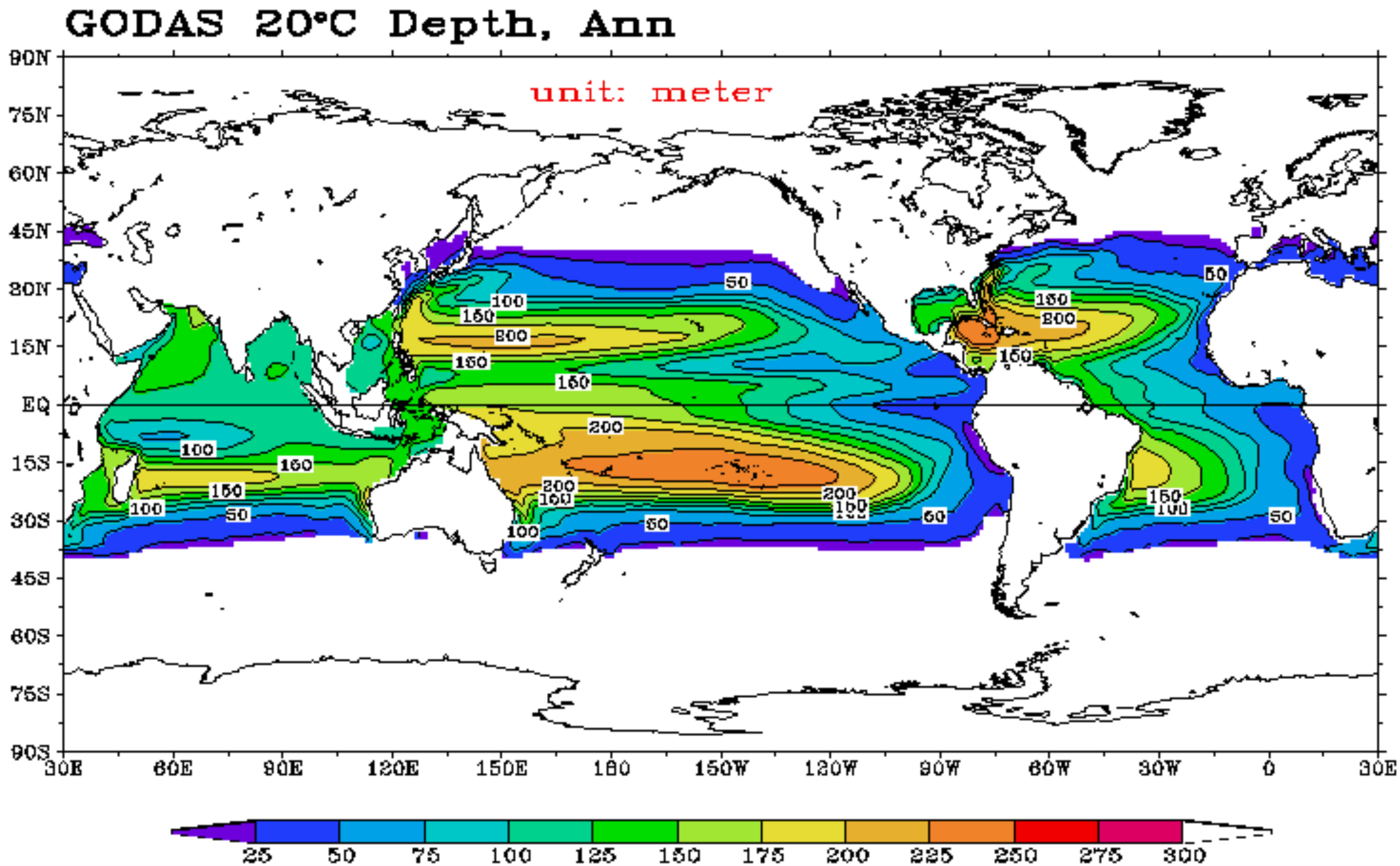
GODAS Zonal Wind Stress, Jul

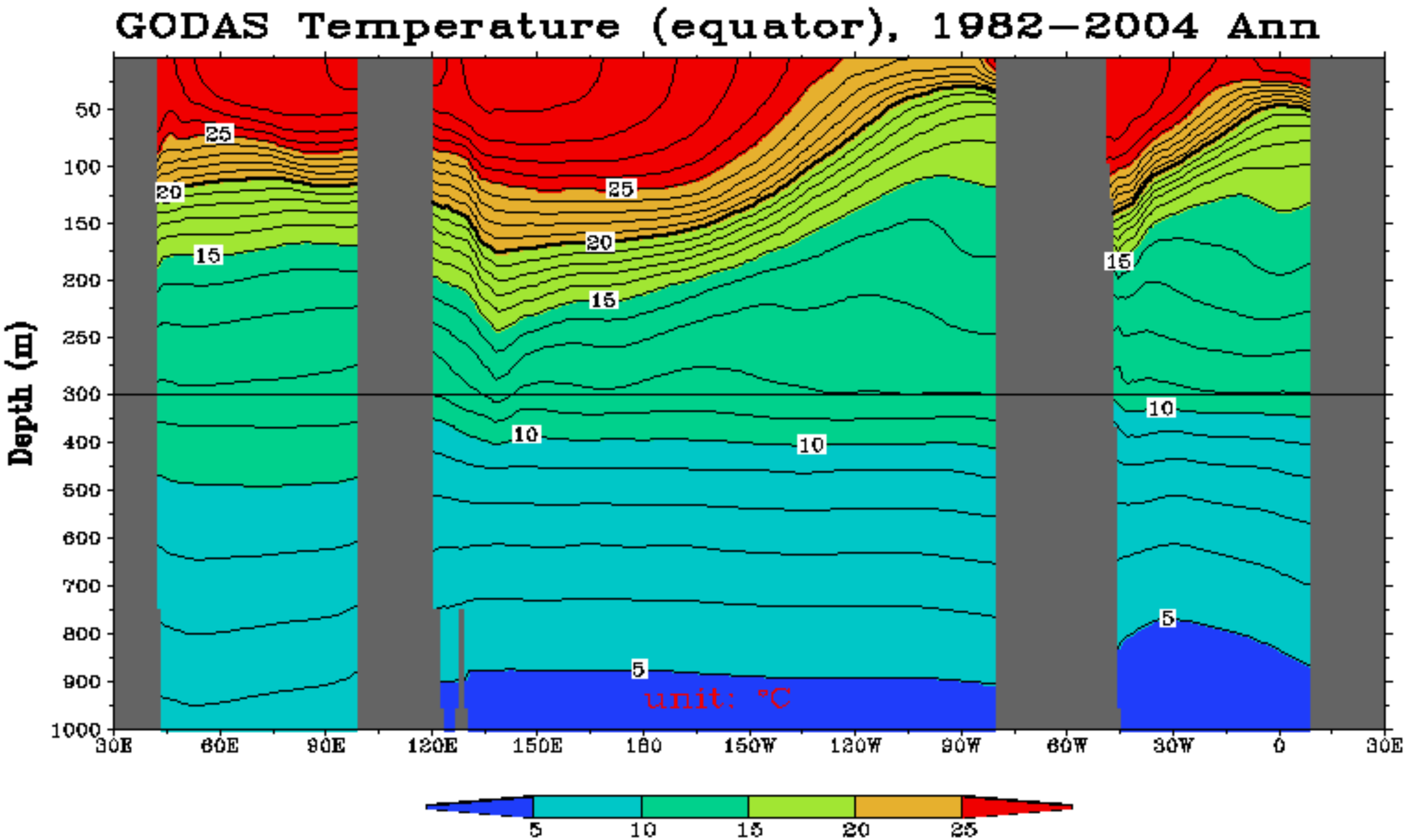


Annual Mean Sea Level (cm)

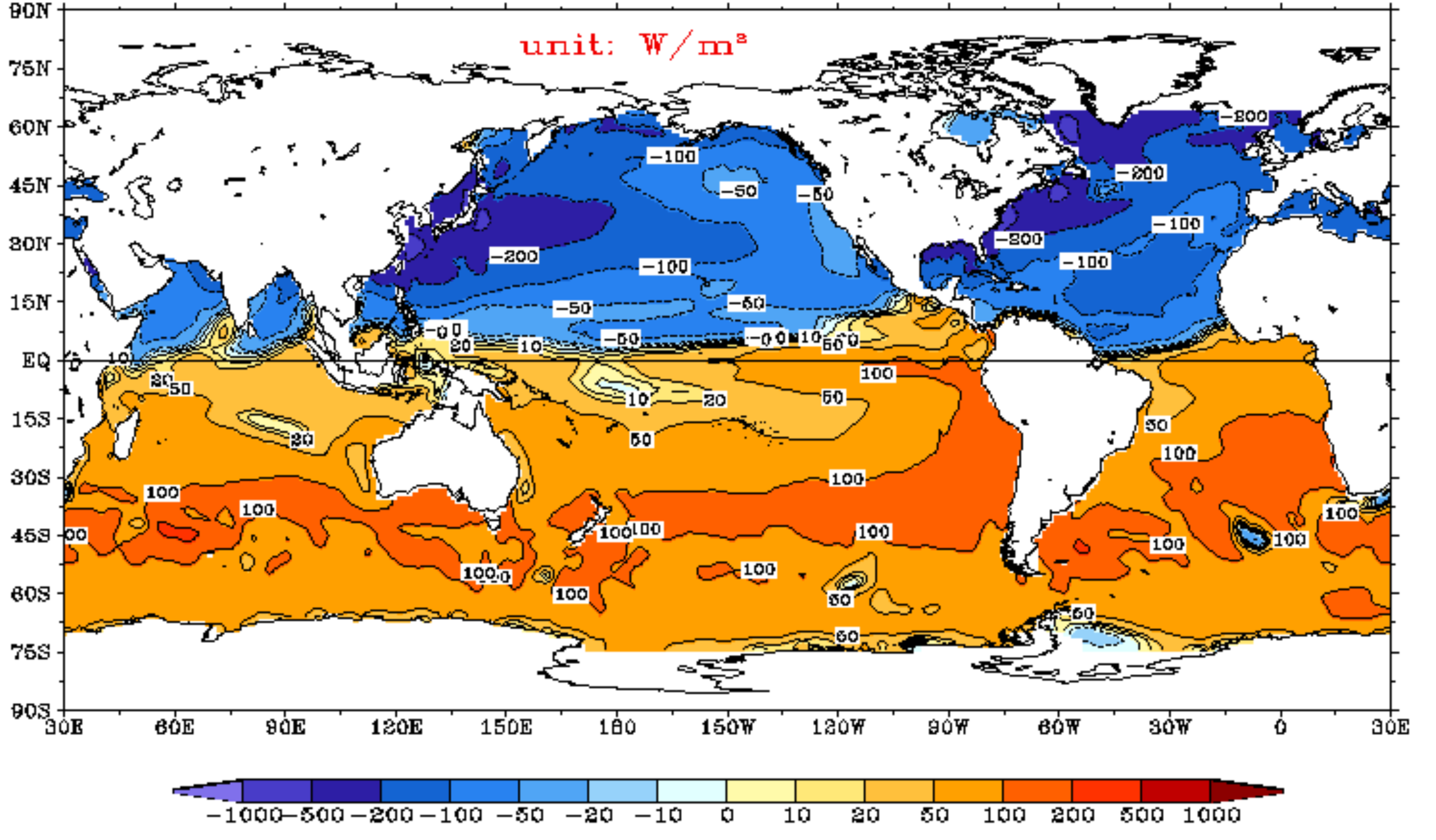



GODAS 300m Ave Temperature, Ann
unit: °C
90N 75N 60N 45N 30N 15N EQ 15S 30S 45S 60S 75S 90S
30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0 30E
0 2 4 6 8 10 12 14 16 18 20 22 24

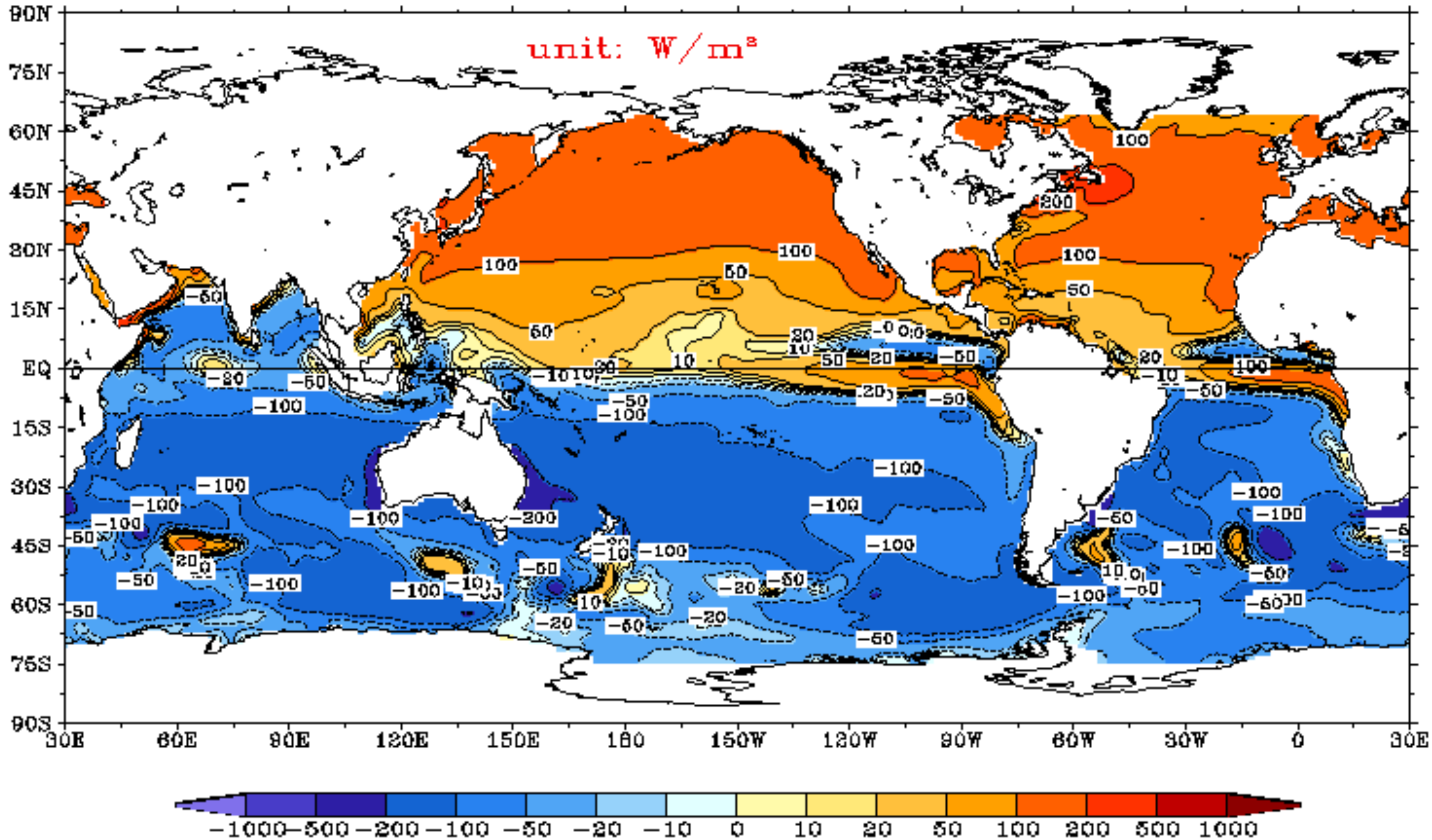

GODAS 20°C Depth, Ann
unit: meter
90N
75N
60N
45N
30N
15N
EQ
15S
30S
45S
60S
75S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
30E
50
100
150
200
25
50
75
100
125
150
175
200
225
250
275
300

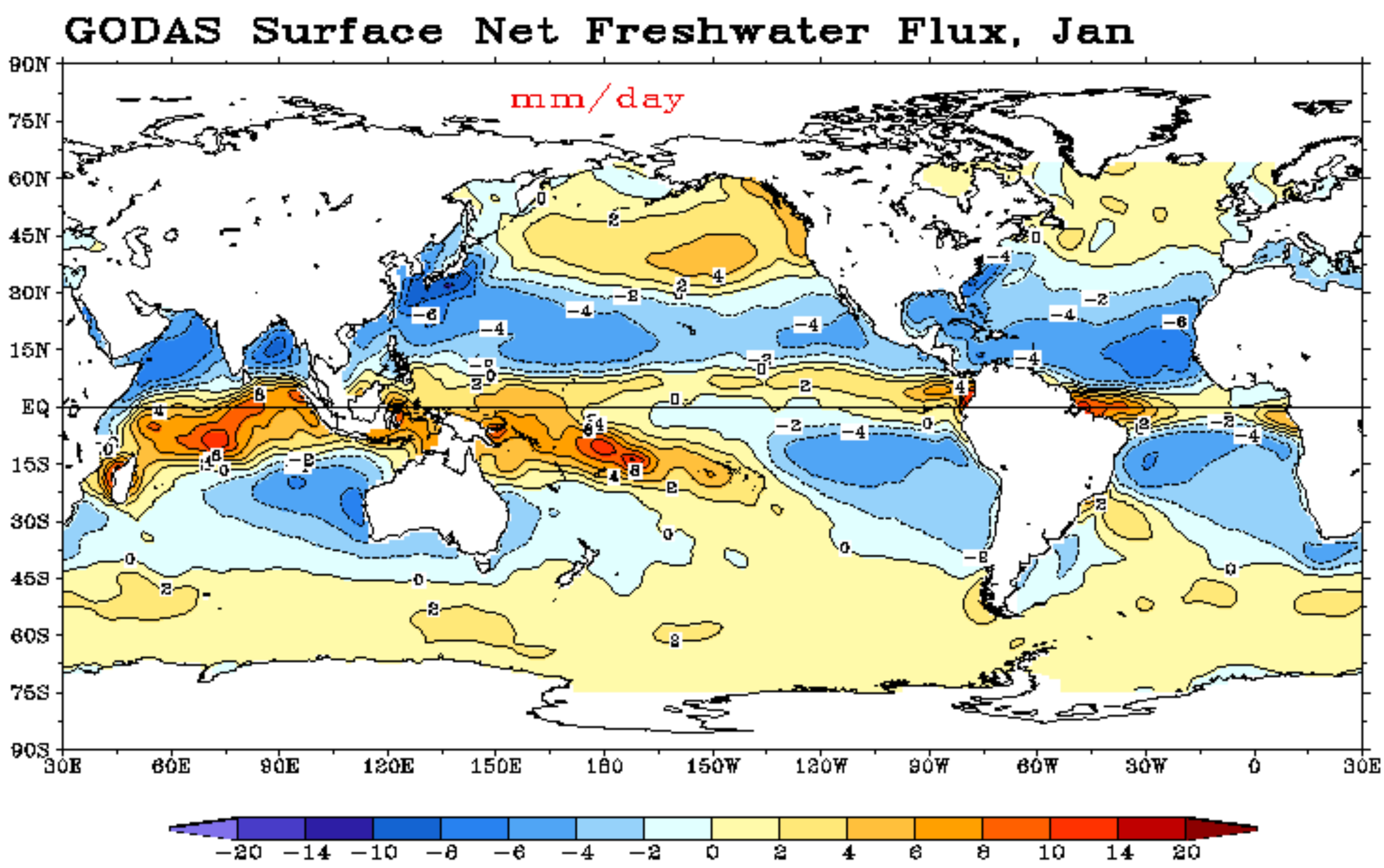

GODAS Temperature (equator), 1982–2004 Ann
Depth (m)
50
100
150
200
250
300
400
500
600
700
800
900
1000
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
30E
25
20
15
10
5
unit: °C
5
10
15
20
25

GODAS Surface Net Heat Flux, Jan

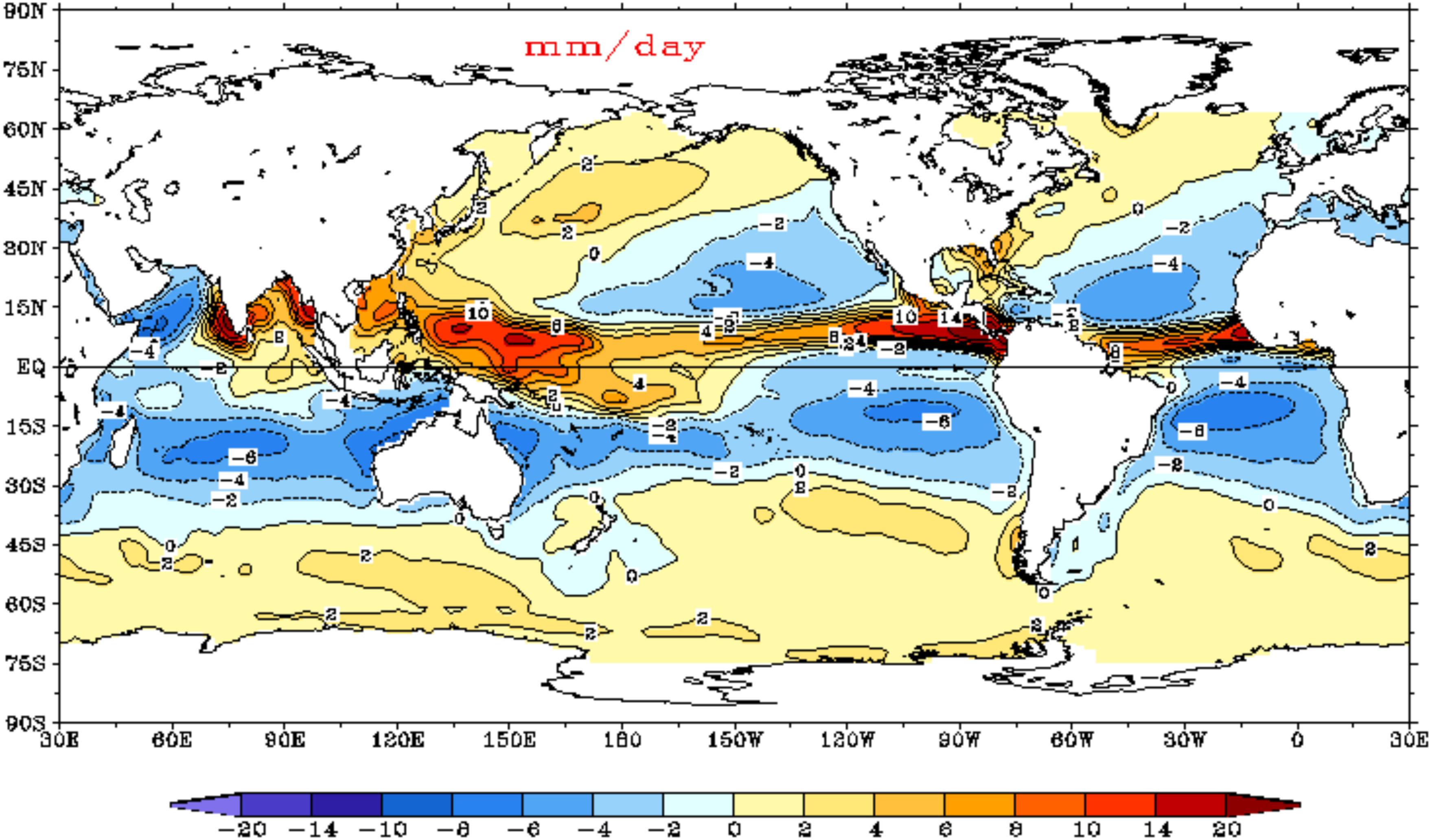


GODAS Surface Net Heat Flux, Jul




GODAS Surface Net Freshwater Flux, Jan
mm/day
90N
75N
60N
45N
30N
15N
EQ
15S
30S
45S
60S
75S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
30E
-20 -14 -10 -8 -6 -4 -2 0 2 4 6 8 10 14 20

GODAS Surface Net Freshwater Flux, Jul



Annual Mean Salinity

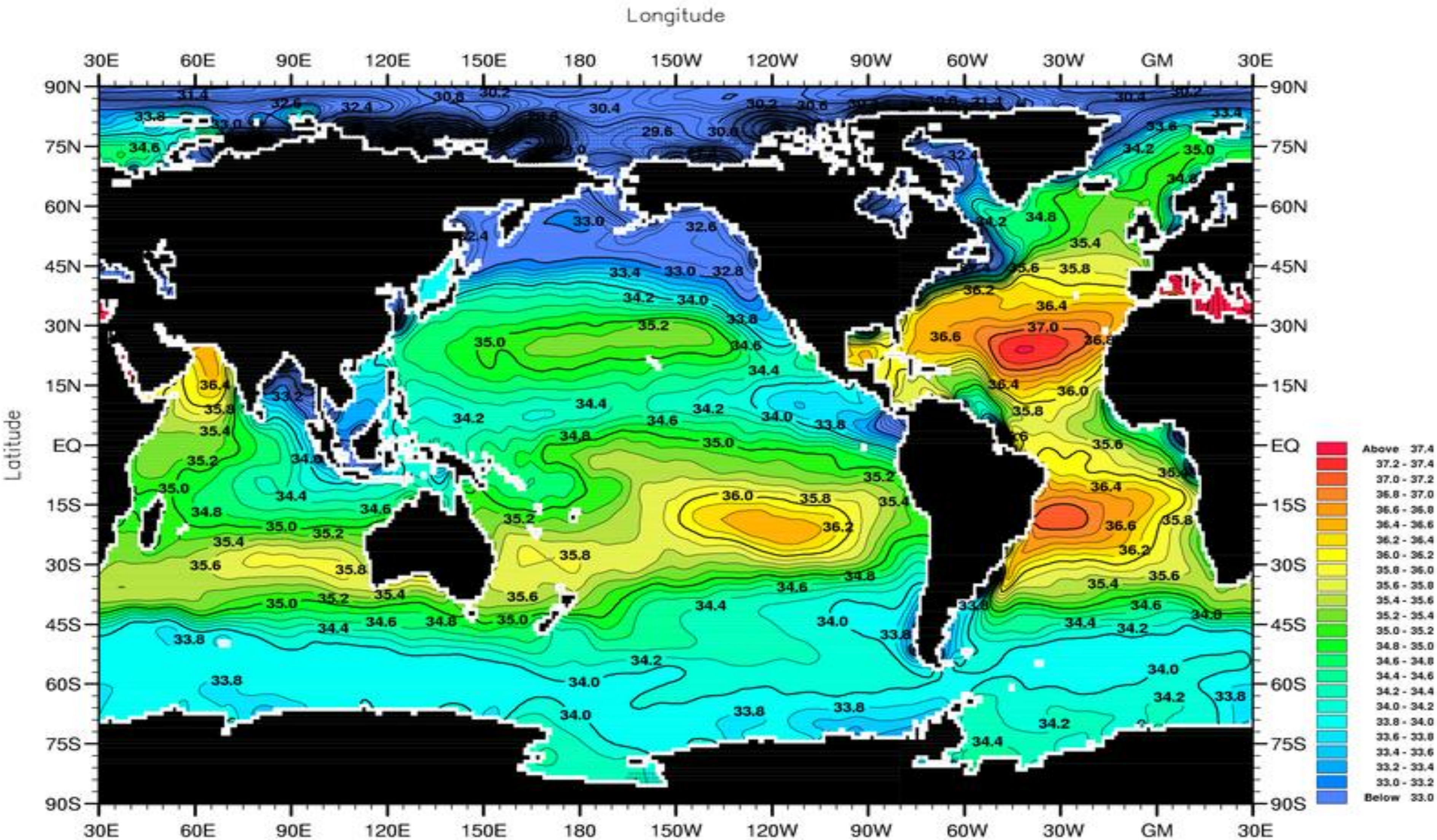
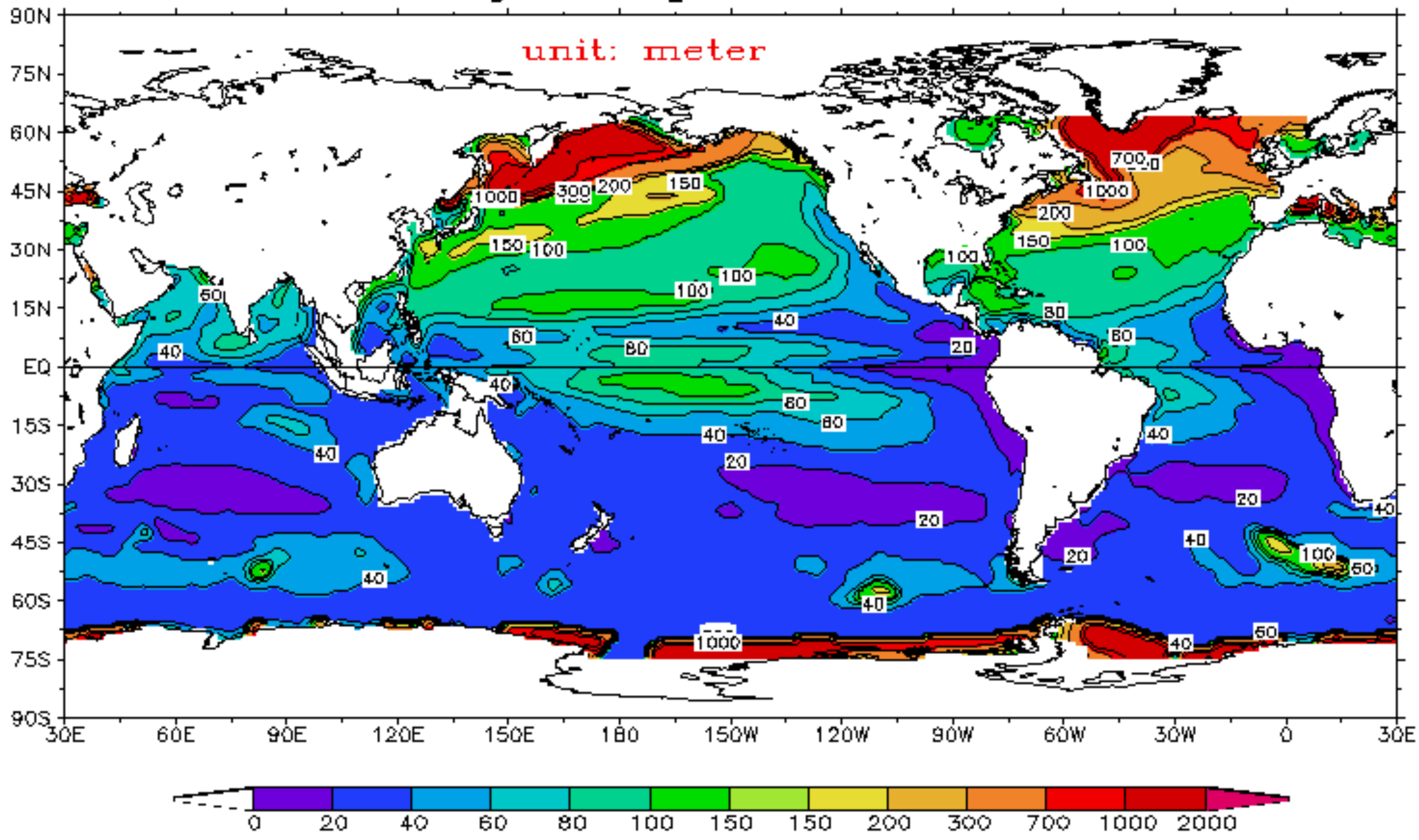


Fig. A2-1. Annual mean salinity (PSS) at the surface.

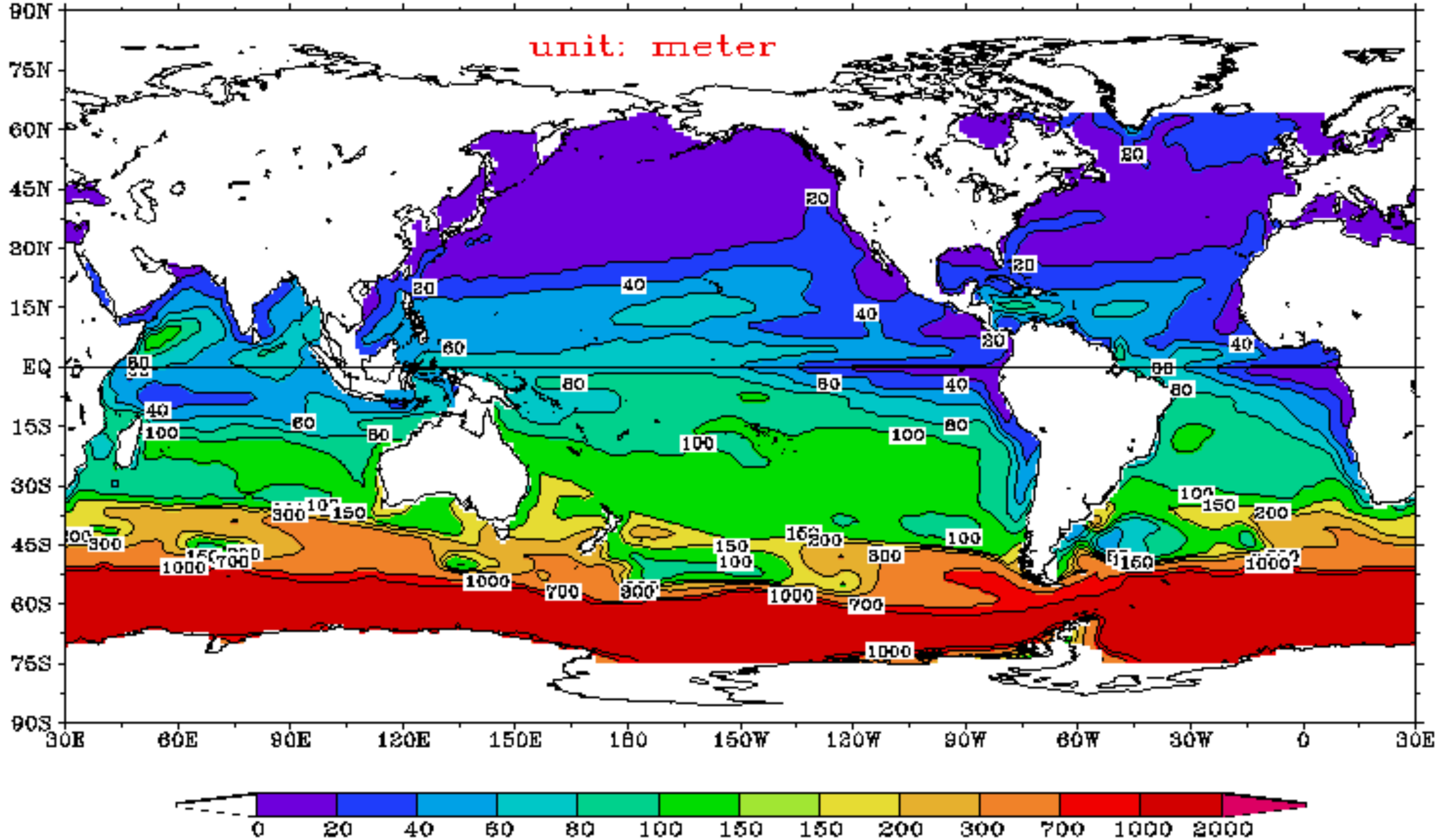
Minimum Value= 2.37 Maximum Value= 40.37 Contour Interval: 0.20

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

GODAS Mixed Layer Depth, Jan



GODAS Mixed Layer Depth, Jul



Annual Mean Oxygen

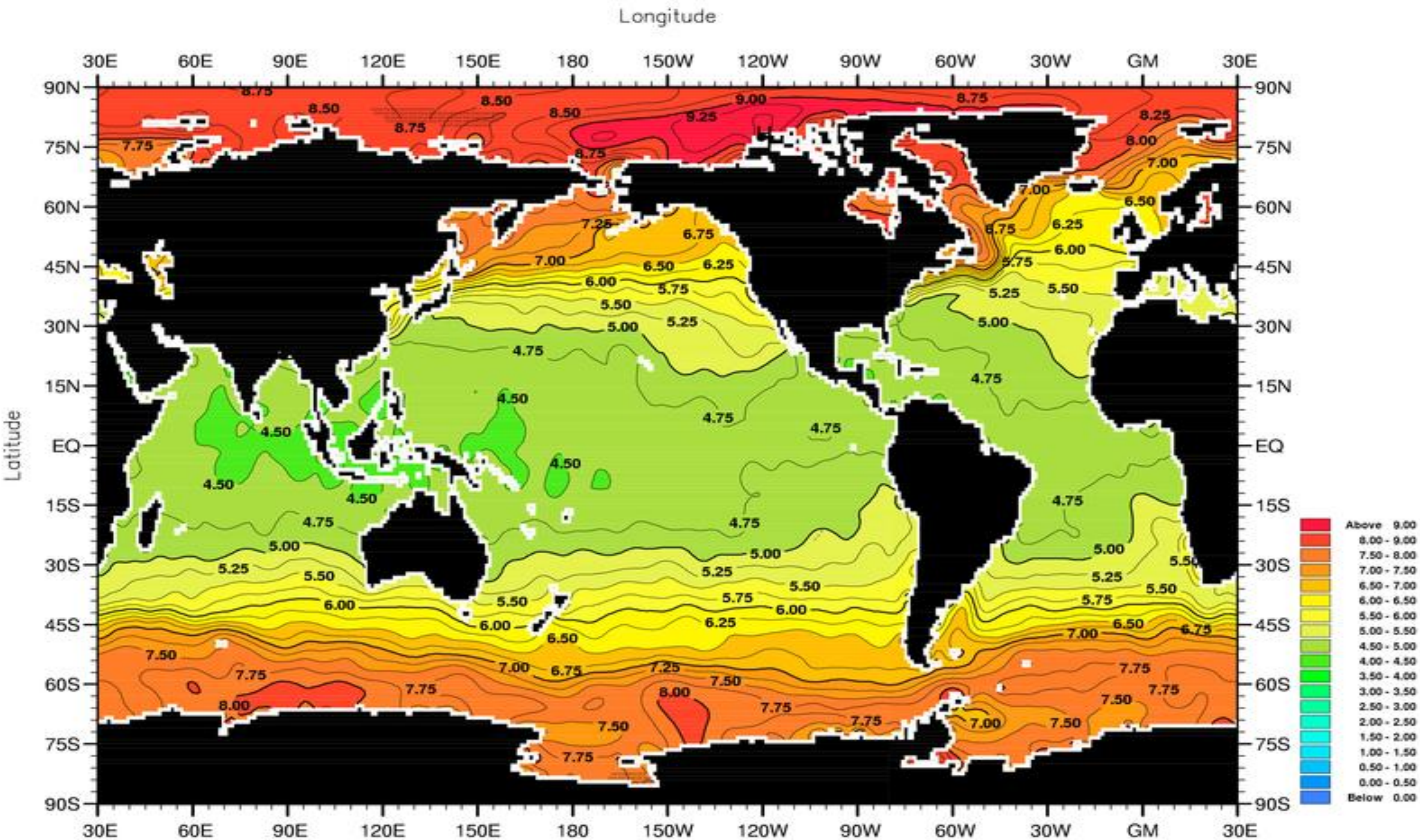


Fig. A2-1. Annual mean oxygen (ml/l) at the surface.

Minimum Value= 4.07 Maximum Value= 9.64 Contour Interval: 0.25

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

Annual Mean Nitrate

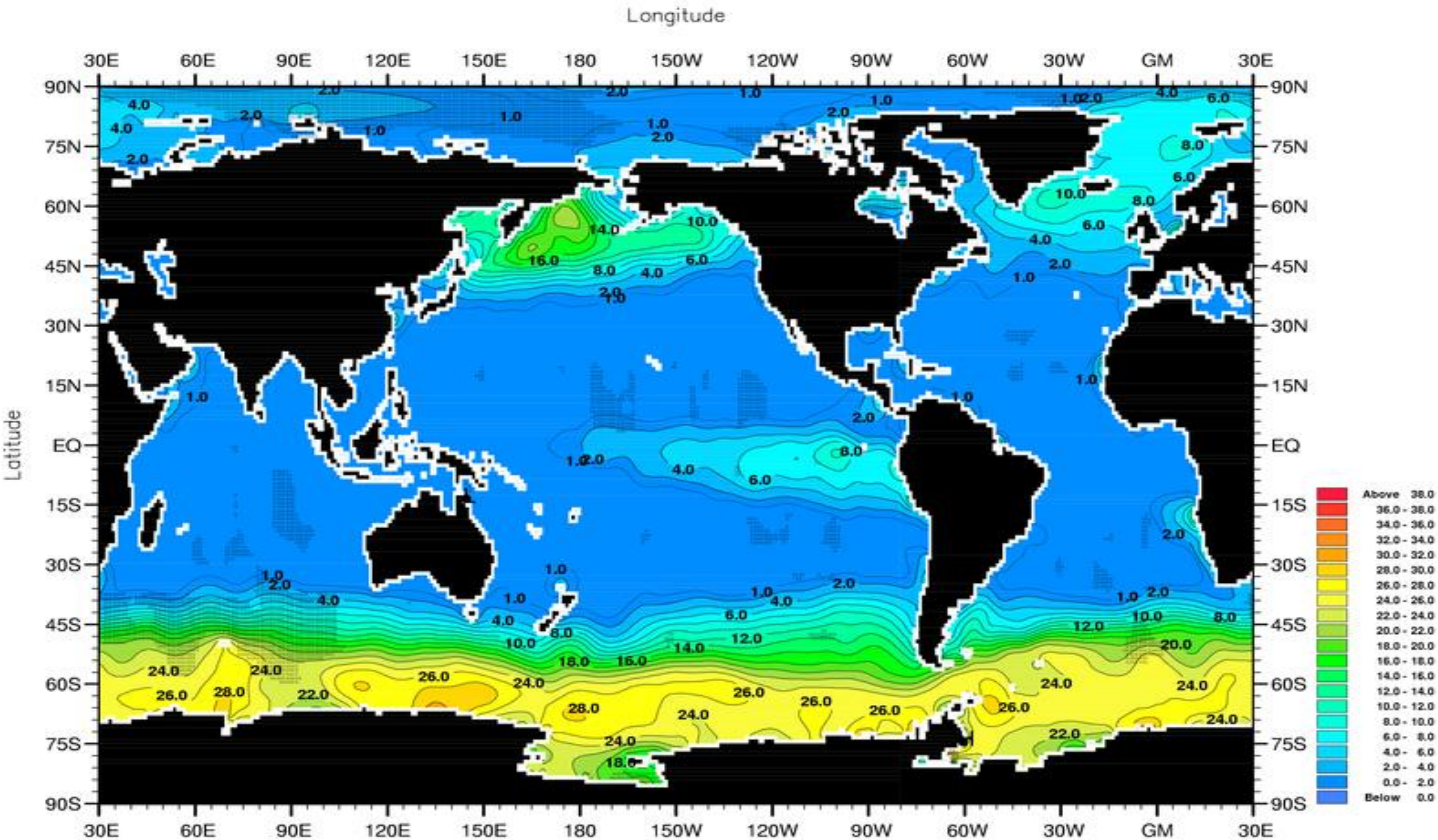


Fig. A2-1. Annual mean nitrate (μM) at the surface.

Minimum Value= 0.00 Maximum Value= 32.72 Contour Interval: 2.00

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

Annual Mean Phosphate

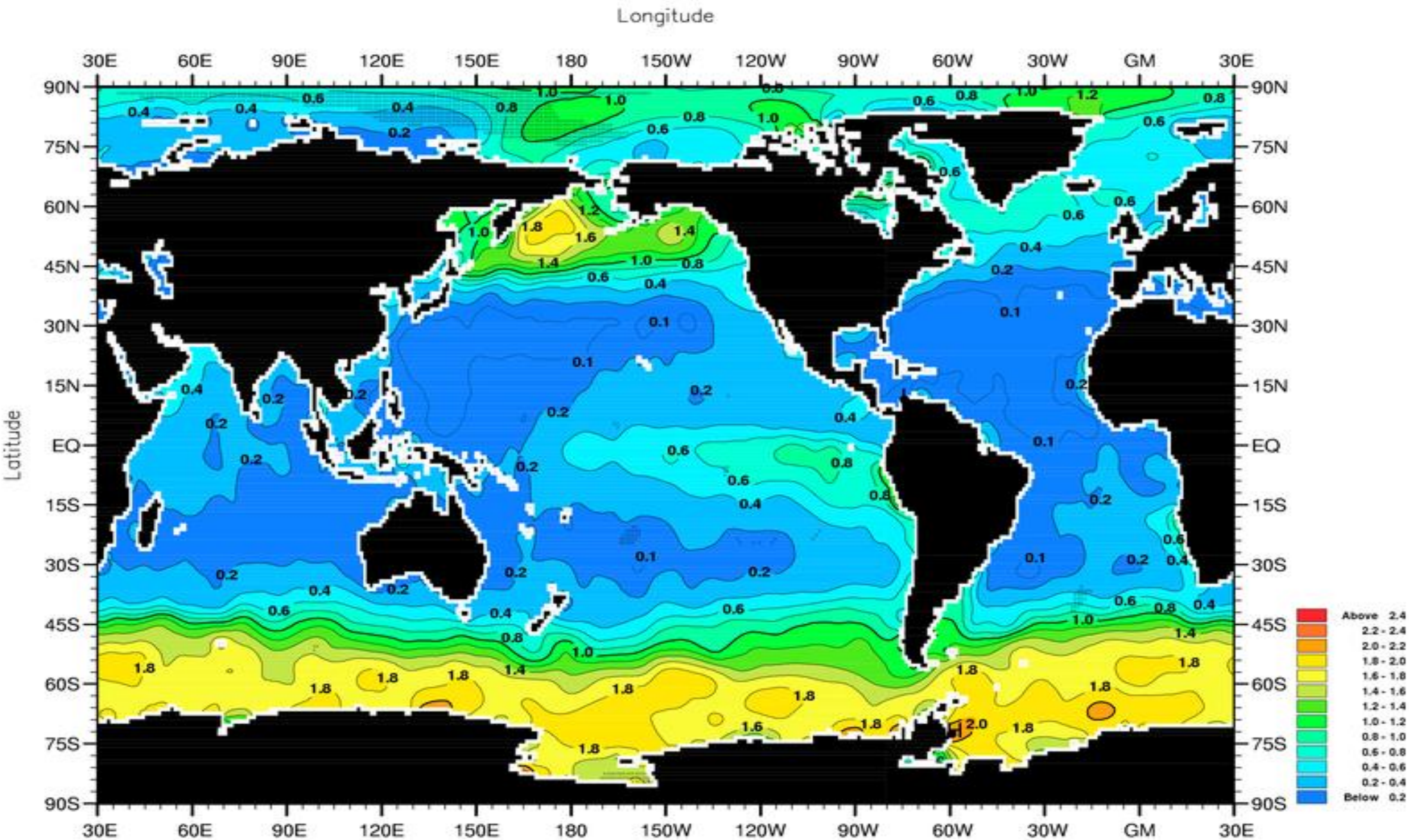


Fig. A2-1. Annual mean phosphate (µM) at the surface.

Minimum Value= 0.01 Maximum Value= 2.43 Contour Interval: 0.20

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

April – June Chlorophyll

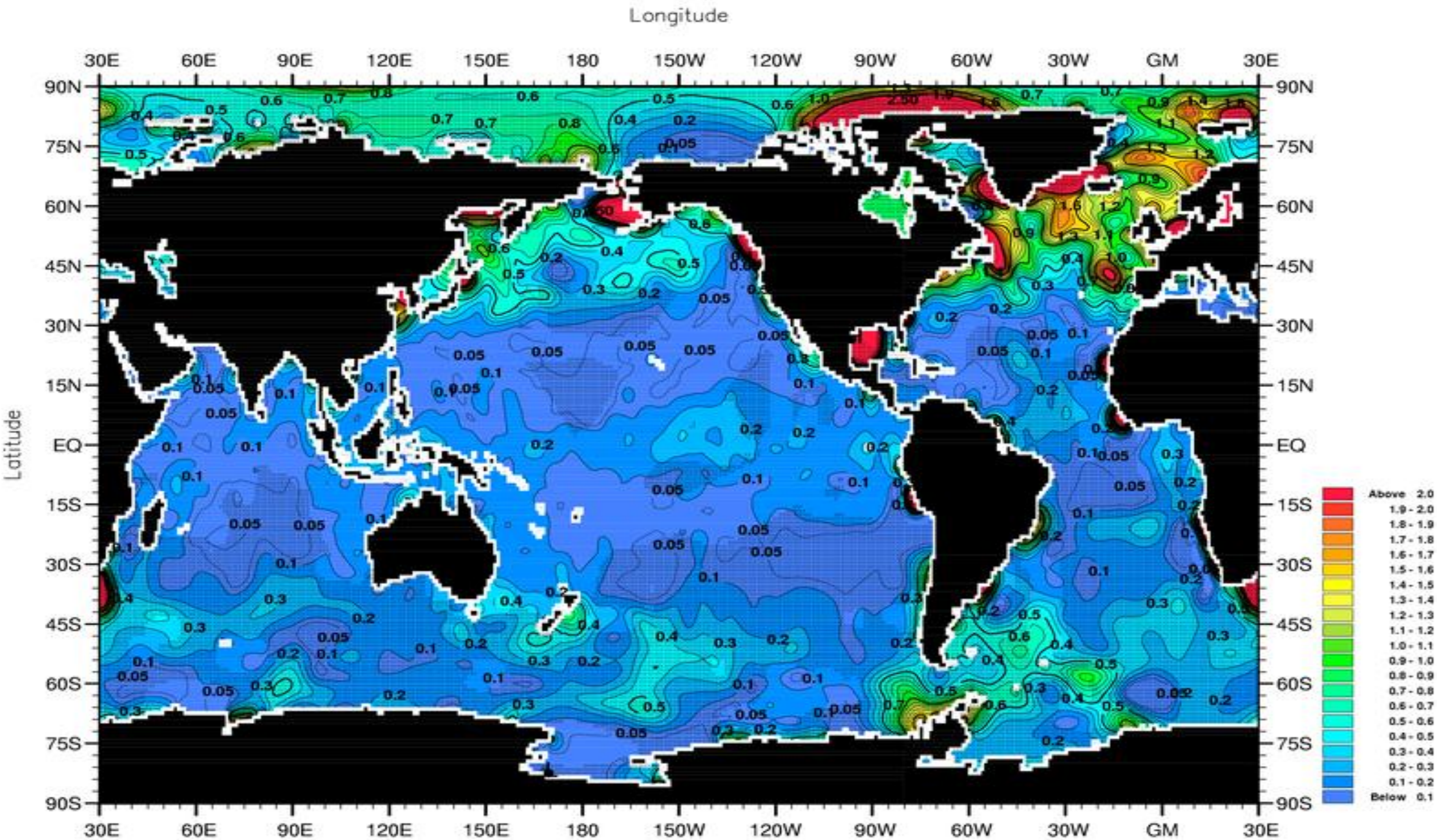


Fig. C2-1. Spring (Apr.-Jun.) mean chlorophyll (µg/l) at the surface.

Minimum Value= 0.00 Maximum Value= 13.42 Contour Interval: 0.10

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

October – December Chlorophyll

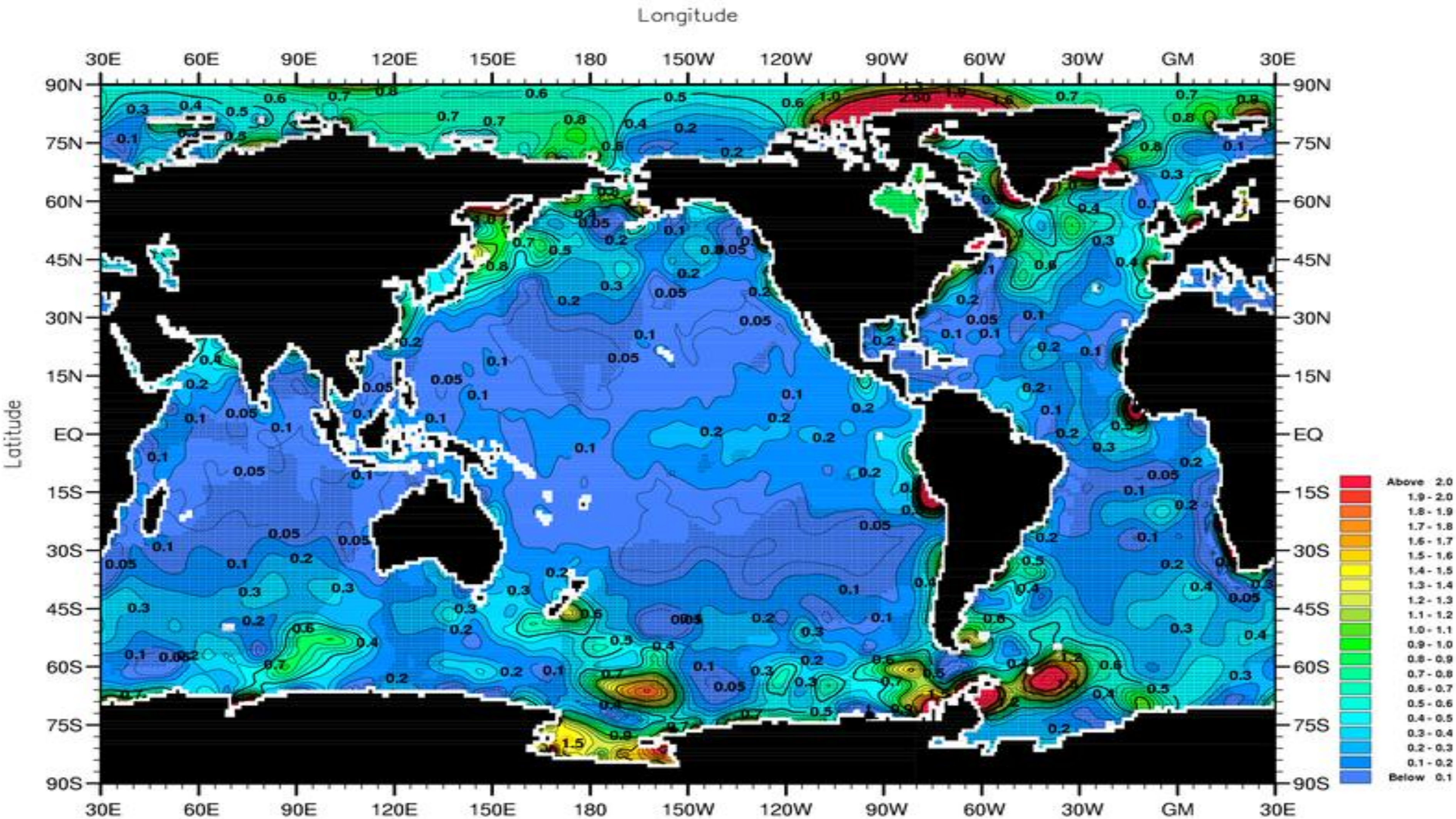
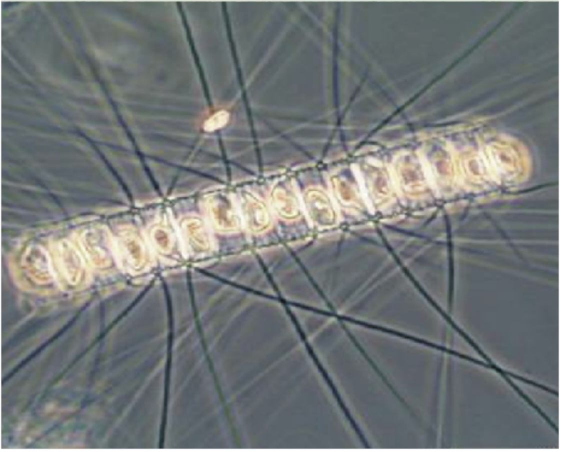


Fig. E2-1. Fall (Oct.-Dec.) mean chlorophyll (µg/l) at the surface.

Minimum Value= 0.00 Maximum Value= 8.68 Contour Interval: 0.10

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC



Annual Mean Silicate

Diatoms

Opal SiO_2

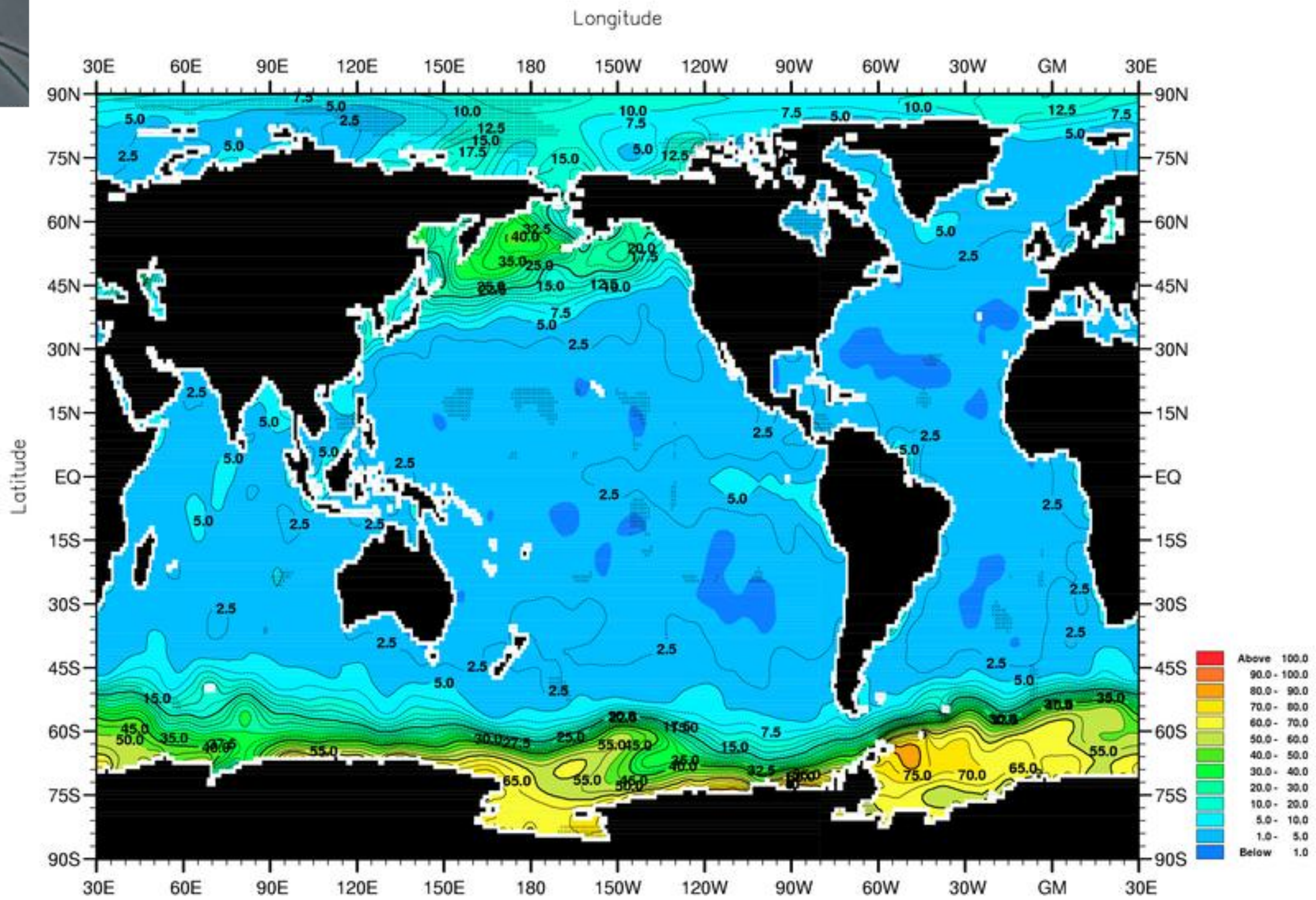
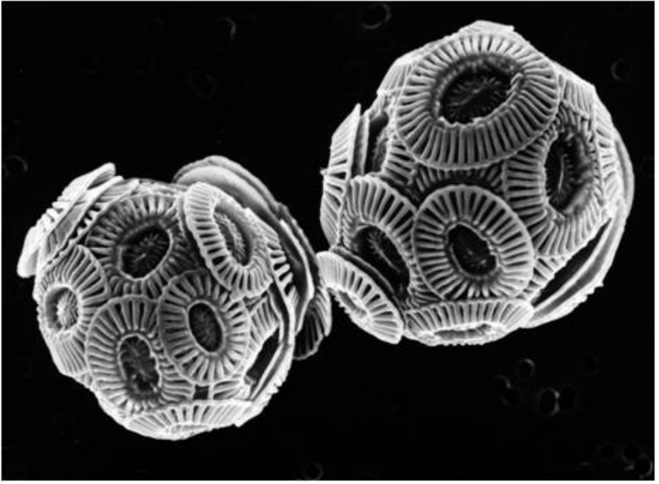


Fig. A2-1. Annual mean silicate (μM) at the surface.

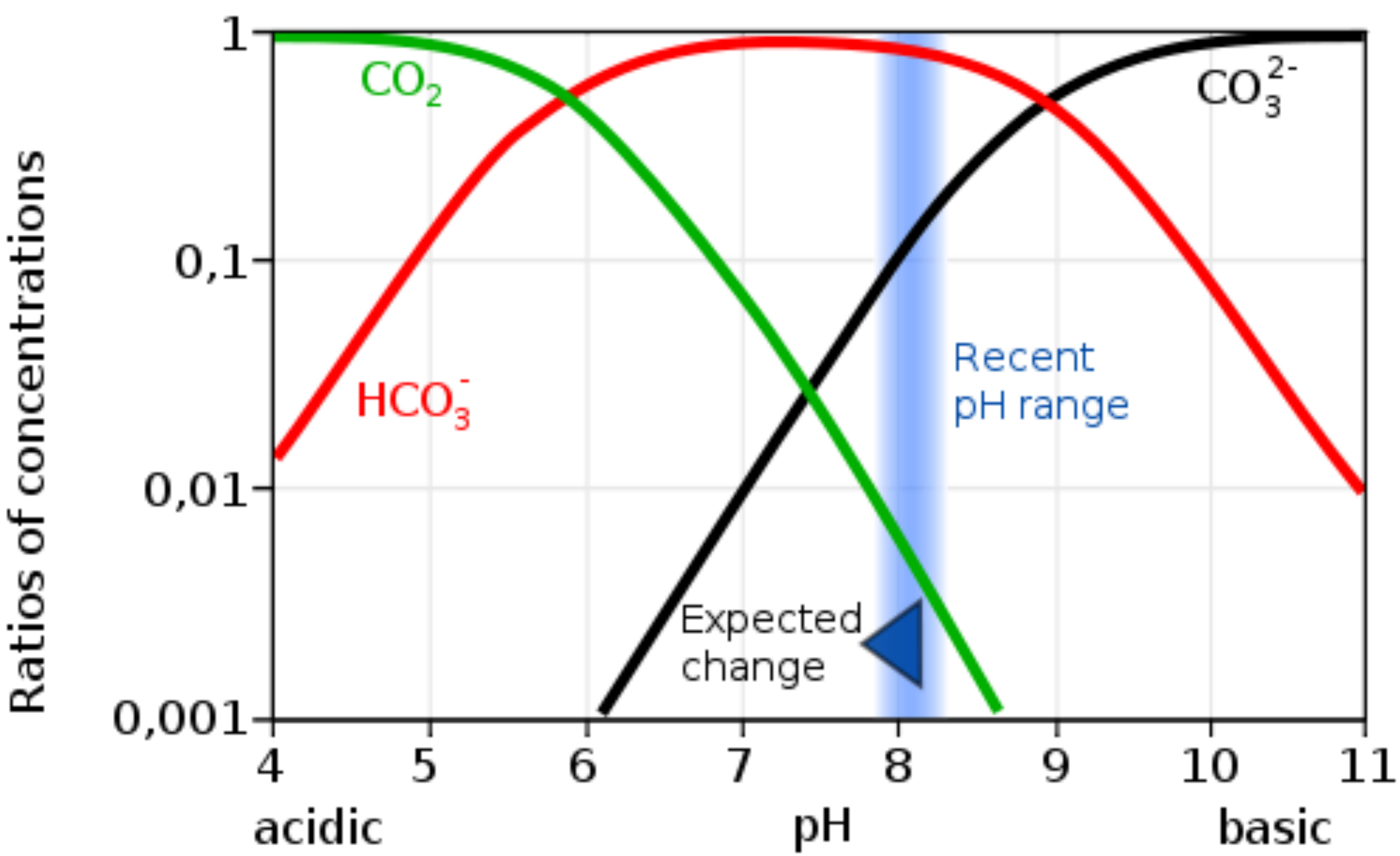
Minimum Value= 0.03 Maximum Value= 89.82 Contour Interval: 5.00

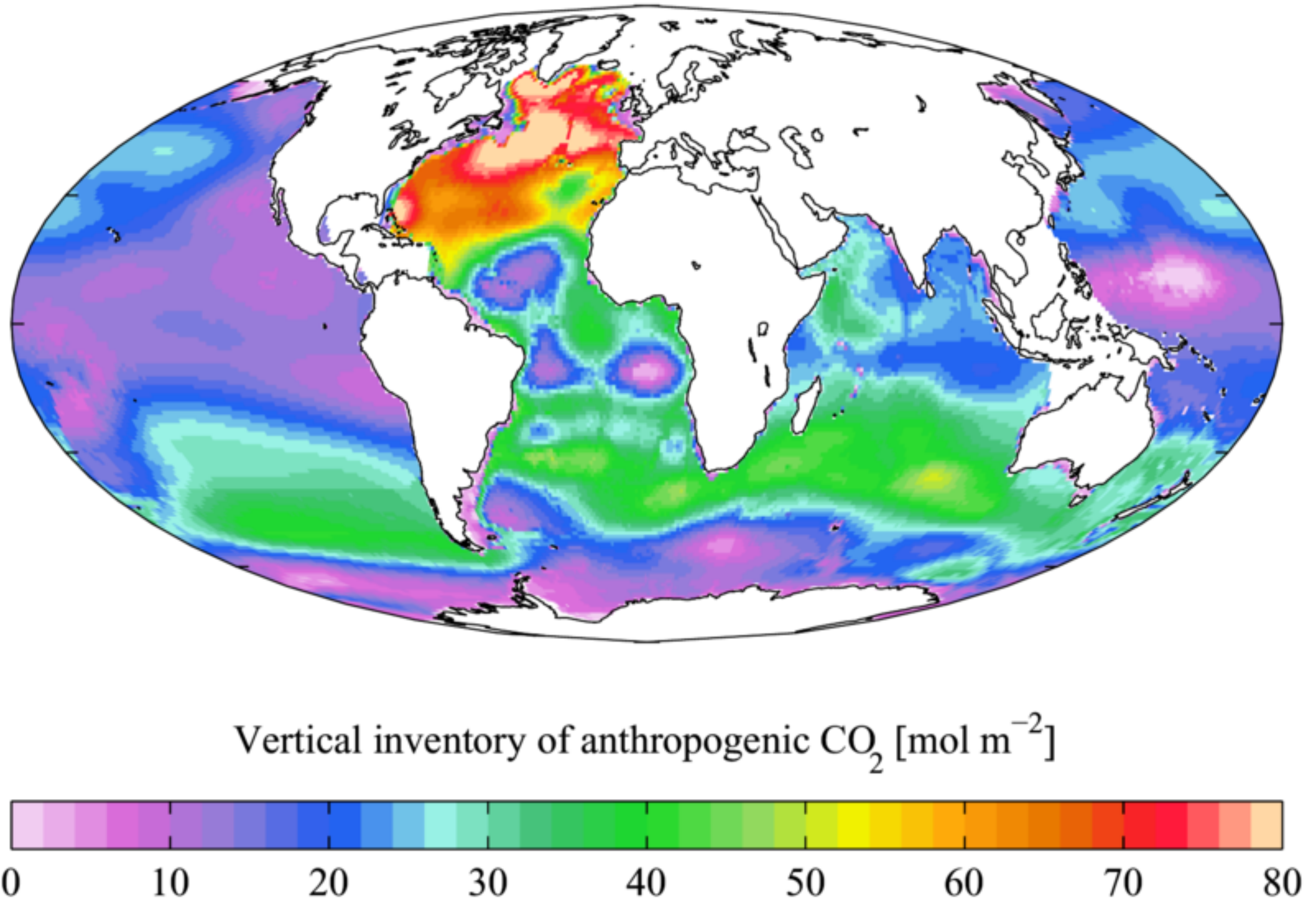
World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

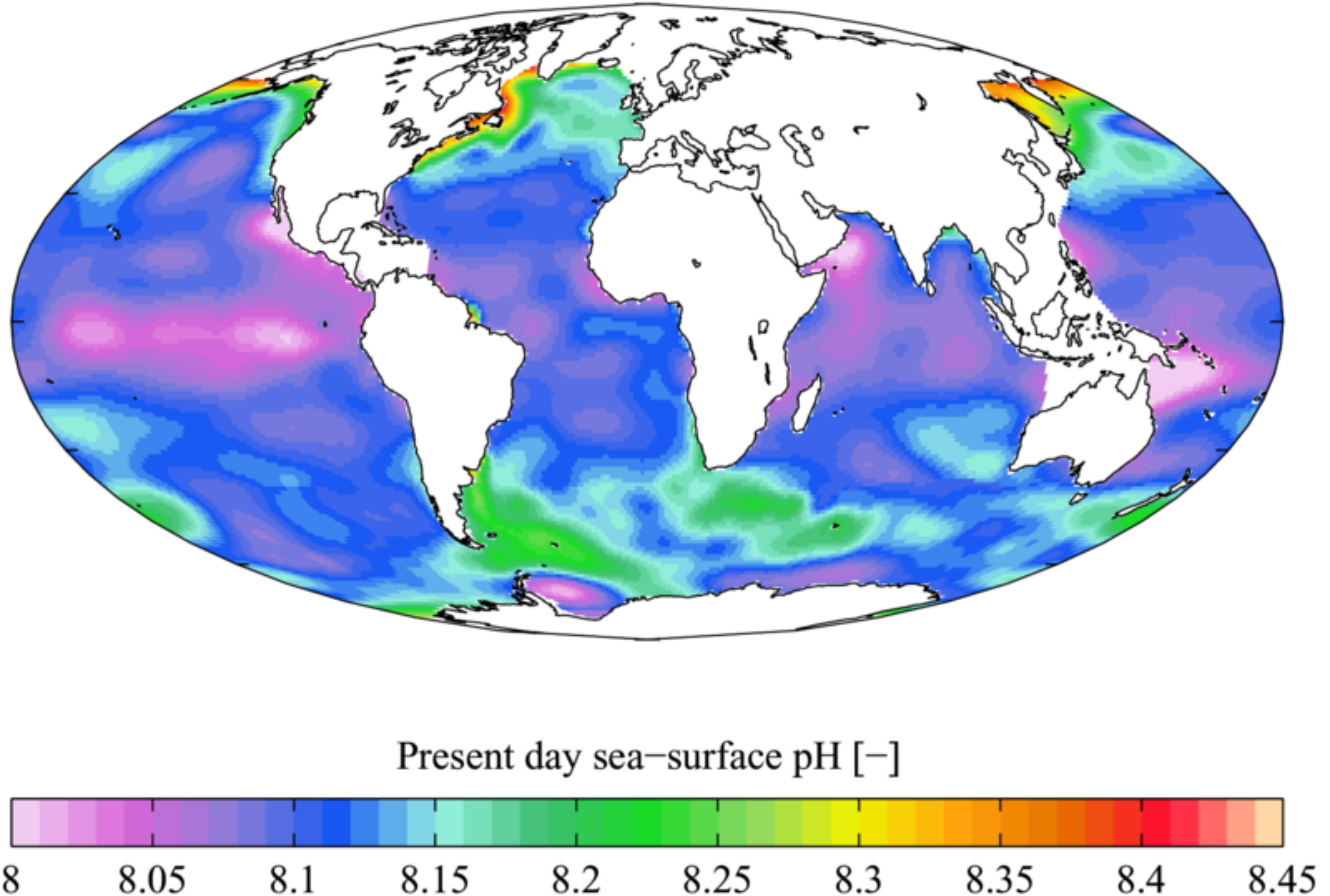


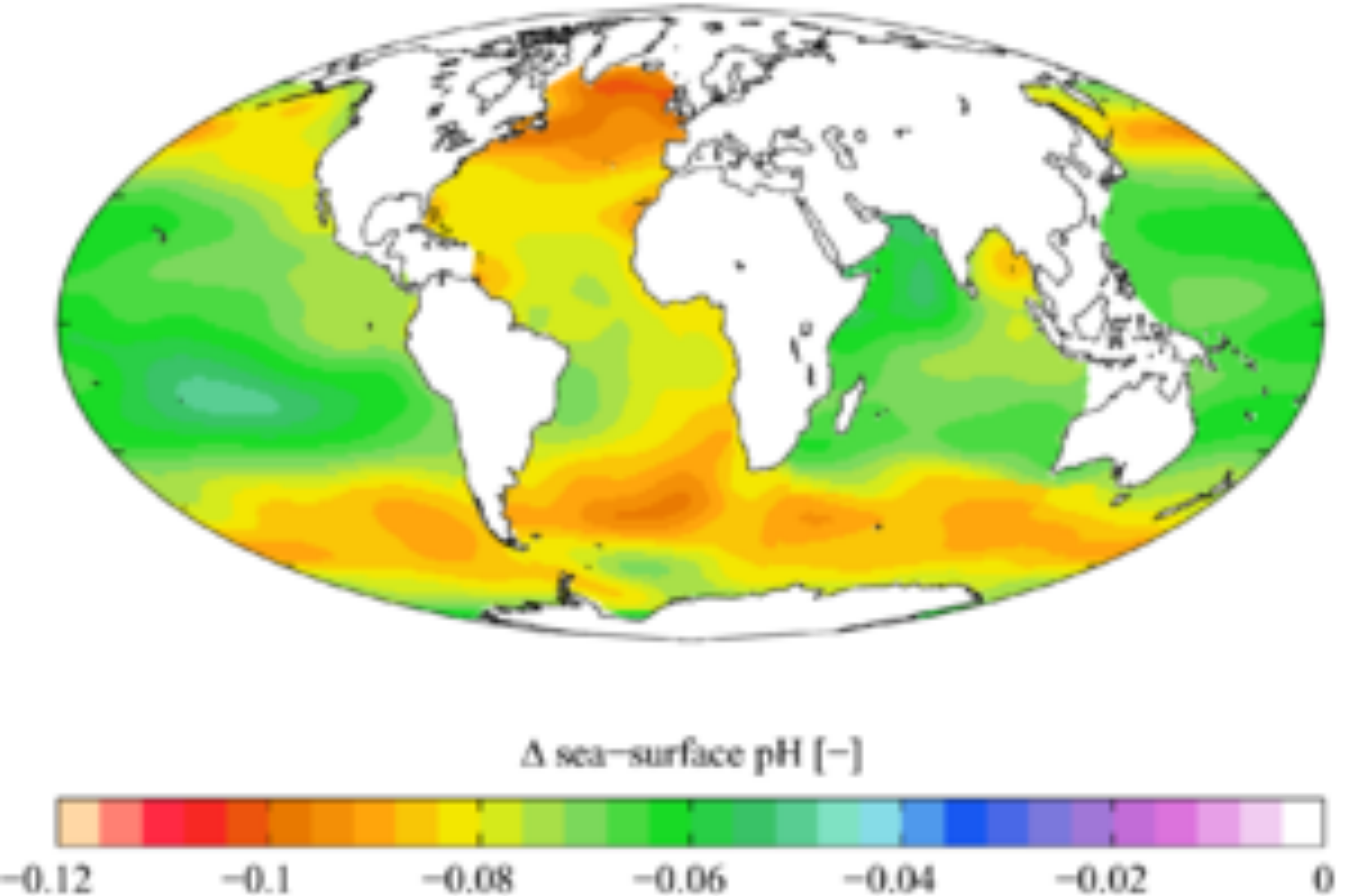
Coccolithophores

Calcium Carbonate
$CaCO_3$




Vertical inventory of anthropogenic CO2 [mol m−2]
0
10
20
30
40
50
60
70
80


Present day sea−surface pH [−]
8
8.05
8.1
8.15
8.2
8.25
8.3
8.35
8.4
8.45


Δ sea−surface pH [−]
−0.12
−0.1
−0.08
−0.06
−0.04
−0.02
0