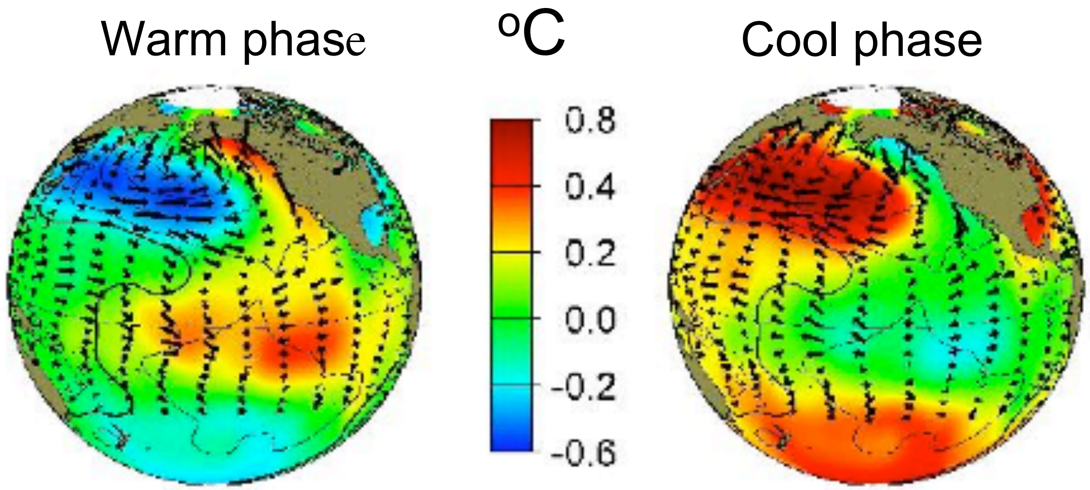
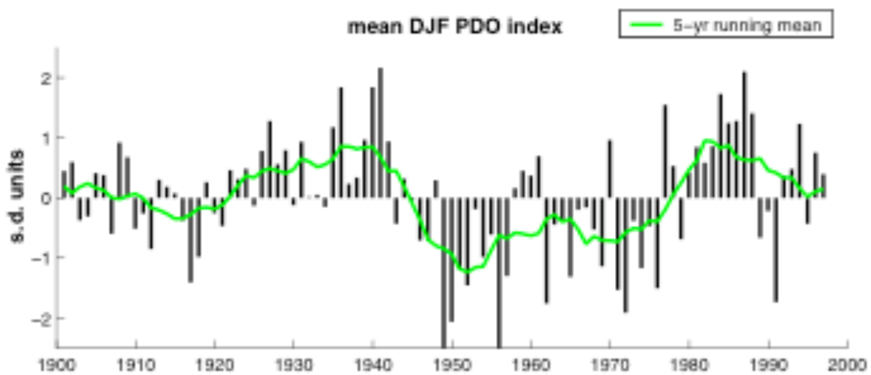
The Pacific Decadal Oscillation





Example of PDO impacts

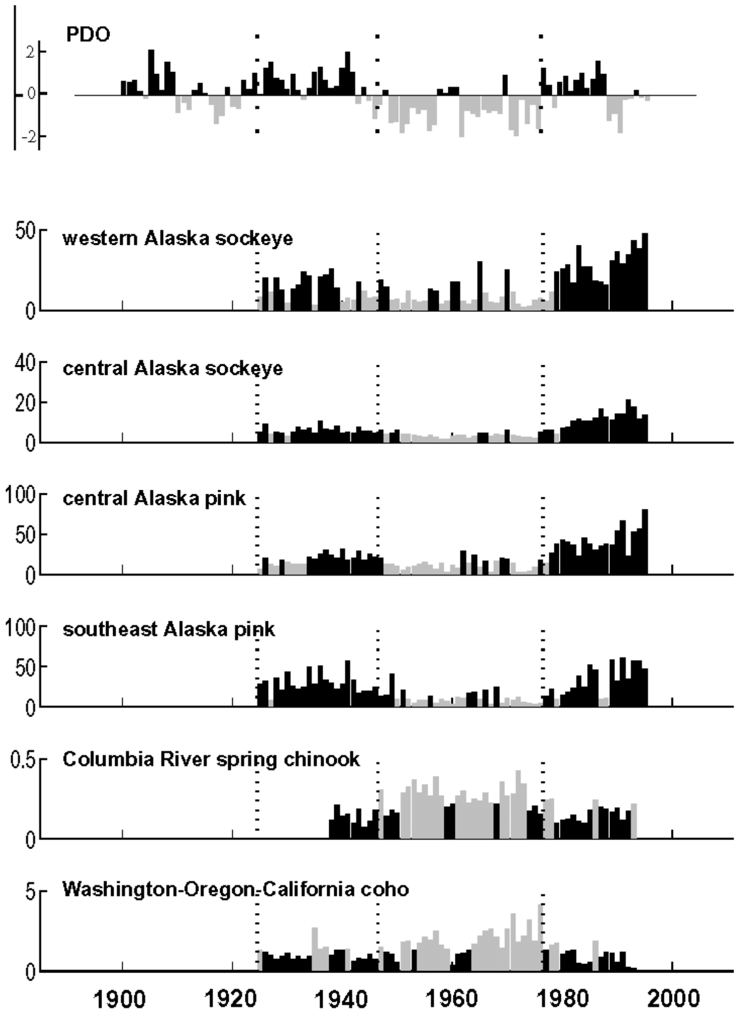
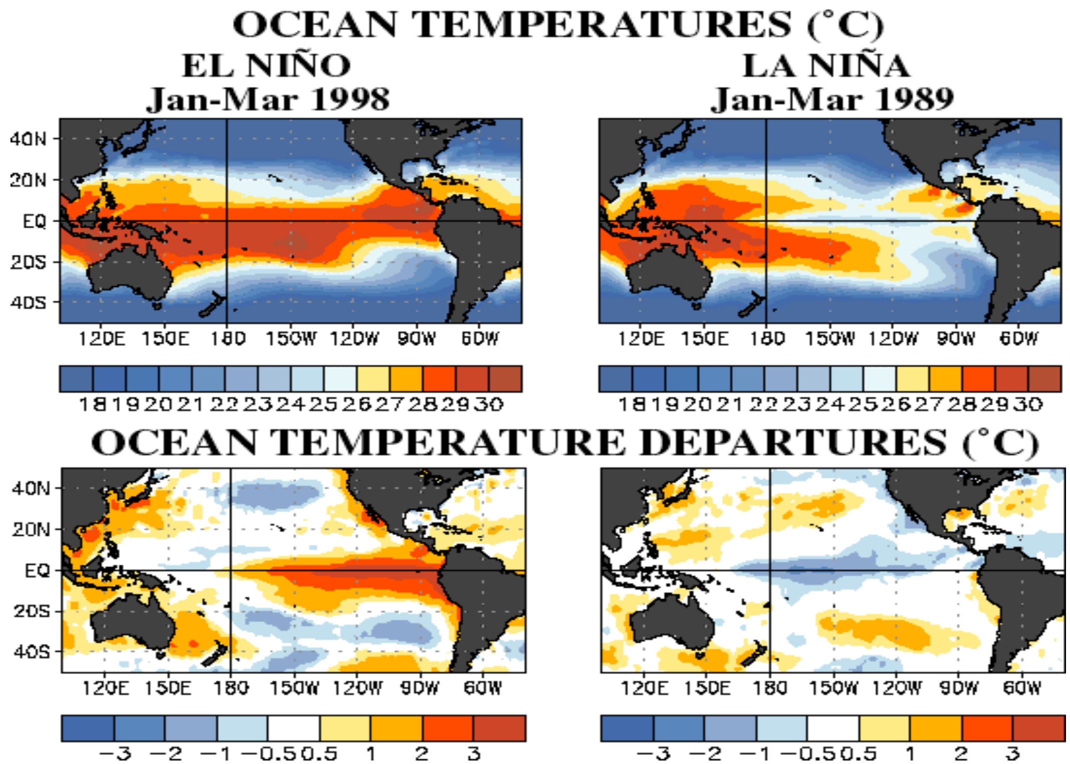


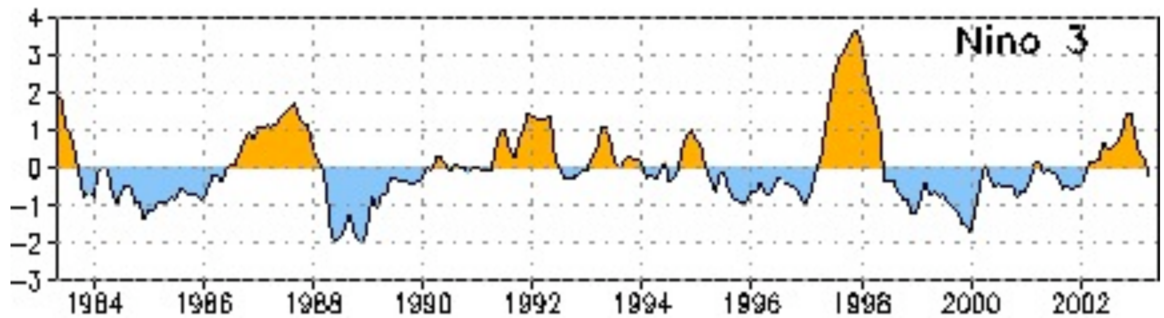
Figure 6: Selected Pacific salmon catch records with PDO signatures. For Alaska catches, black (grey) bars denote values that are greater thant the long-term median. The shading convention is reversed for WOC coho and Columbia River spring chinook. Light, dotted vertical lines are drawn to mark the PDO reversal times at 1925, 1947, and 1977. The PDO index from Figure 1 is repeated in the top panel.

Mantua et al., 1997

El-Nino Southern Oscillation



Nino 3 index of Pacific sea surface temperatures



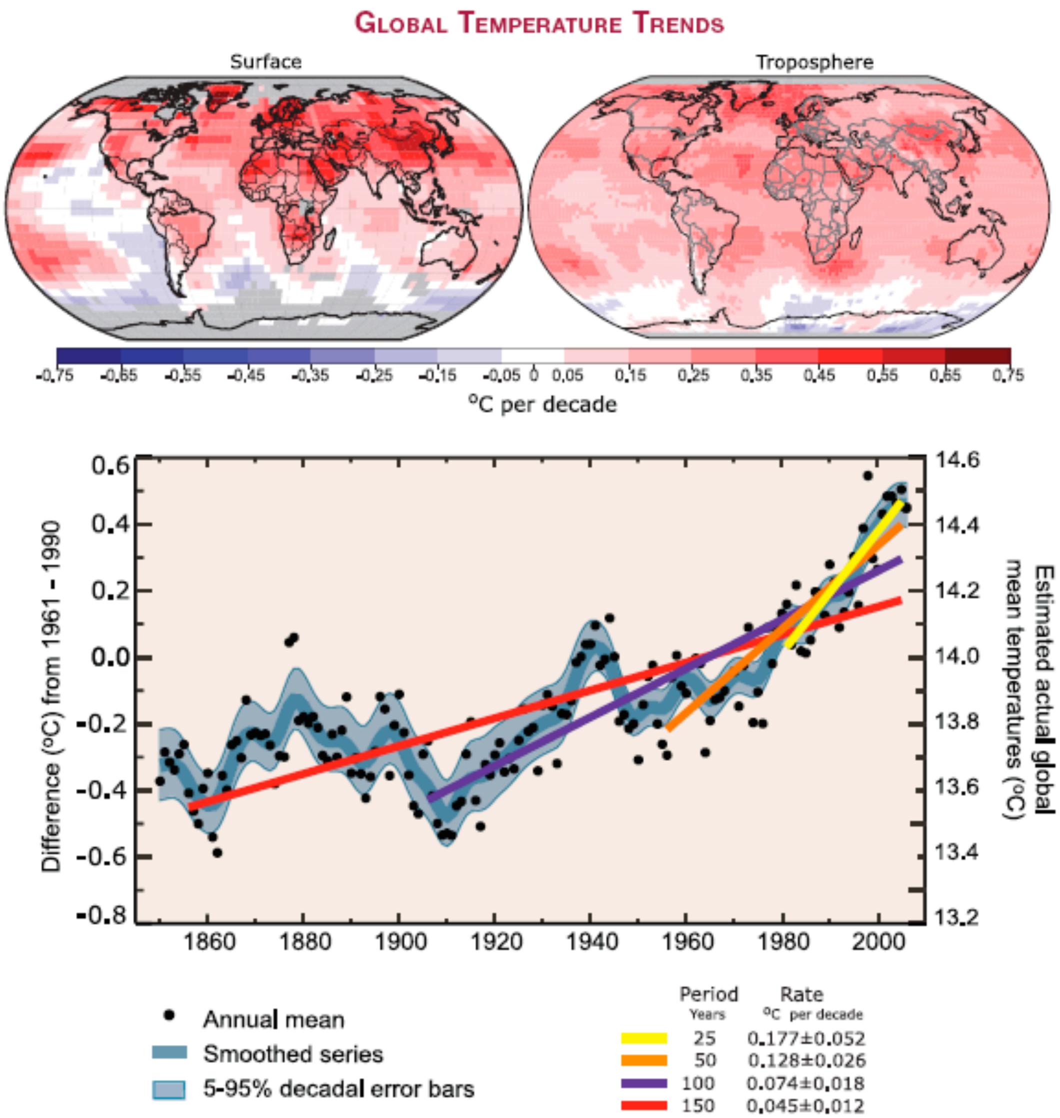
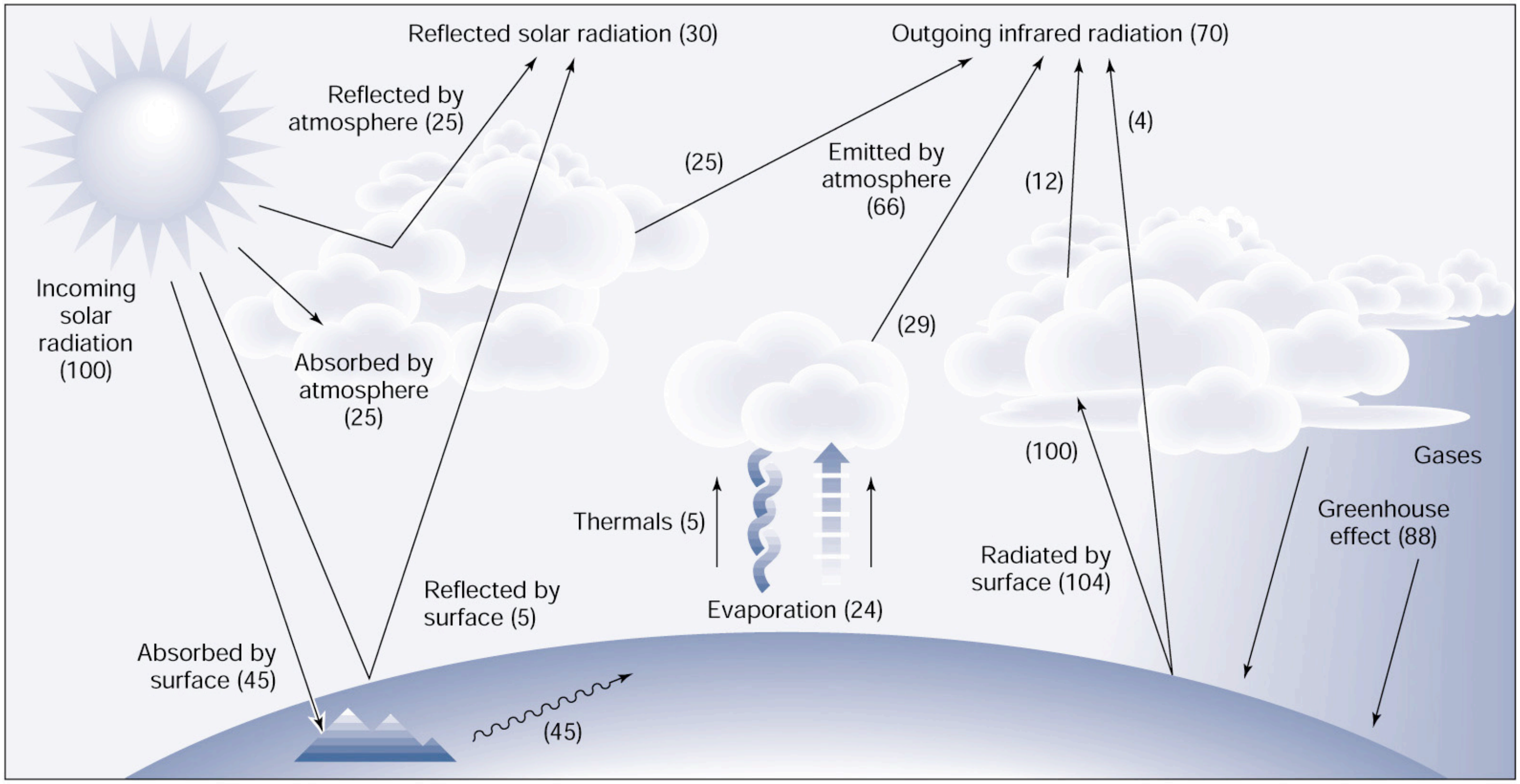


Figure TS.6. *(Top) Patterns of linear global temperature trends over the period 1979 to 2005 estimated at the surface (left), and for the troposphere from satellite records (right). Grey indicates areas with incomplete data. (Bottom) Annual global mean temperatures (black dots) with linear fits to the data. The left hand axis shows temperature anomalies relative to the 1961 to 1990 average and the right hand axis shows estimated actual temperatures, both in °C. Linear trends are shown for the last 25 (yellow), 50 (orange), 100 (purple) and 150 years (red). The smooth blue curve shows decadal variations (see Appendix 3.A), with the decadal 90% error range shown as a pale blue band about that line. The total temperature increase from the period 1850 to 1899 to the period 2001 to 2005 is 0.76°C ± 0.19°C. {FAQ 3.1, Figure 1.}*

Energy pathways in the climate system



ENERGY IN = ENERGY OUT
BUT LOTS OF COMPLICATED THINGS HAPPEN ON THE WAY…

Peixoto and Oort, 1992

Energy balance as a function of latitude

- Albedo
- Absorbed insolation
- Emitted terrestrial
- Net energy

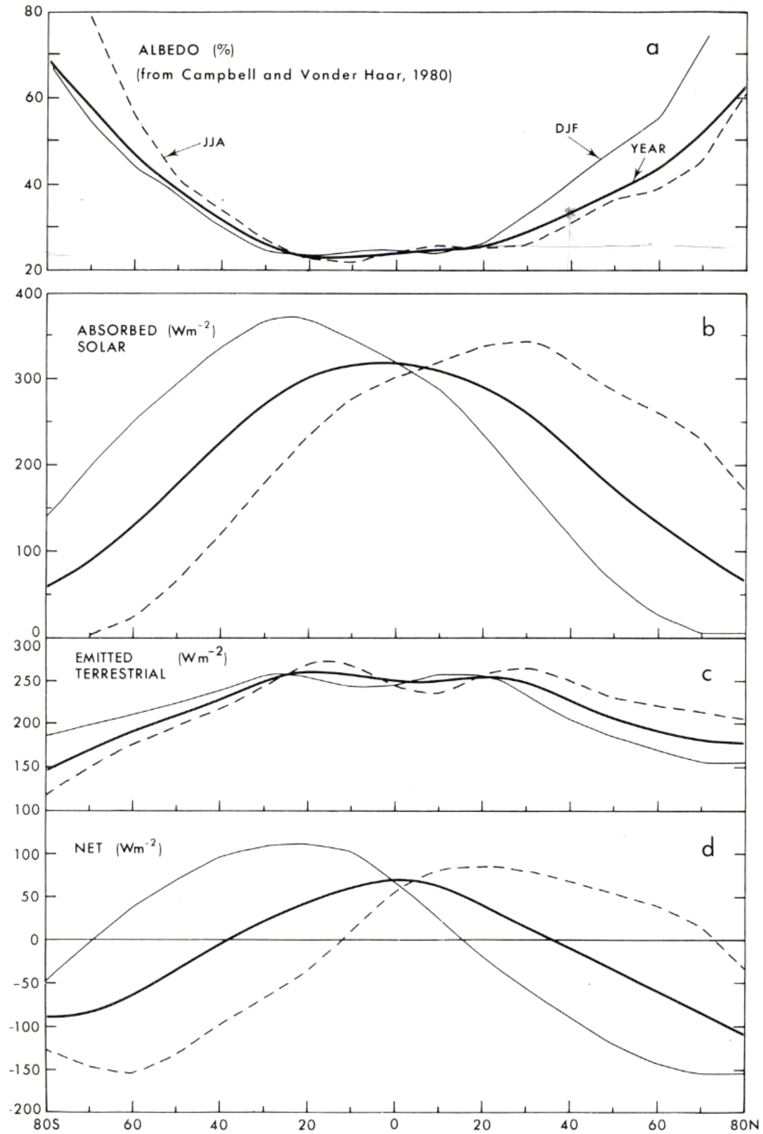
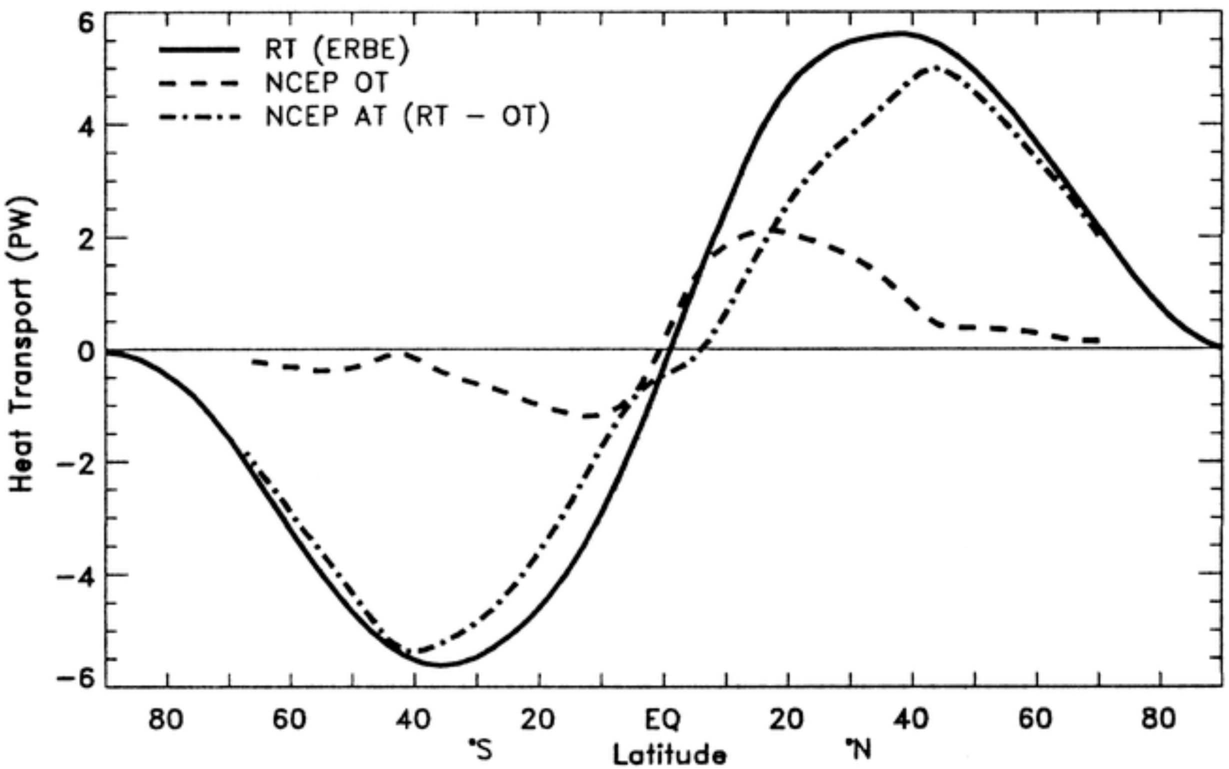


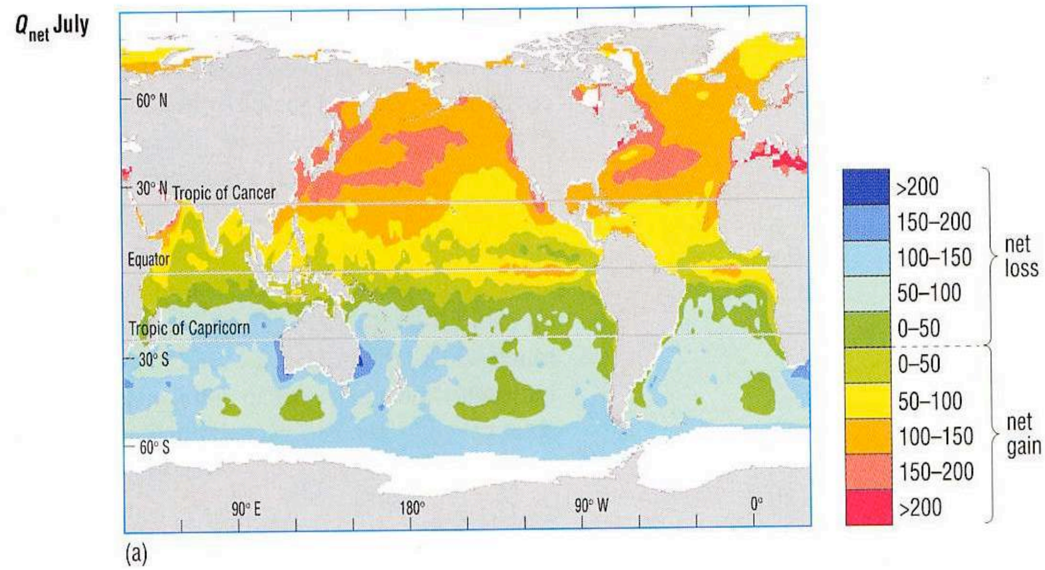
FIGURE 6.14. Meridional profiles of the zonal-mean albedo (a), absorbed solar radiation (b), emitted terrestrial radiation (c), and net radiation (d) at the top of the atmosphere for annual, DJF, and JJA mean conditions (based on data from Campbell and Vonder Haar, 1980). No corrections were made for global radiation balance.

Peixoto and Oort, 1992

Heat Transport by the Atmosphere and ocean



Total Net Surface Heat Flux (W/m^2)



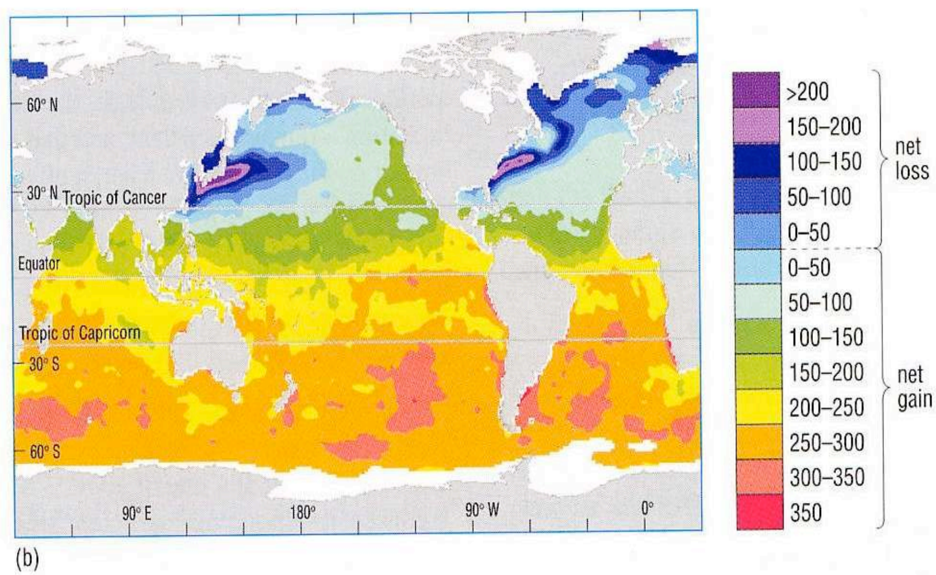
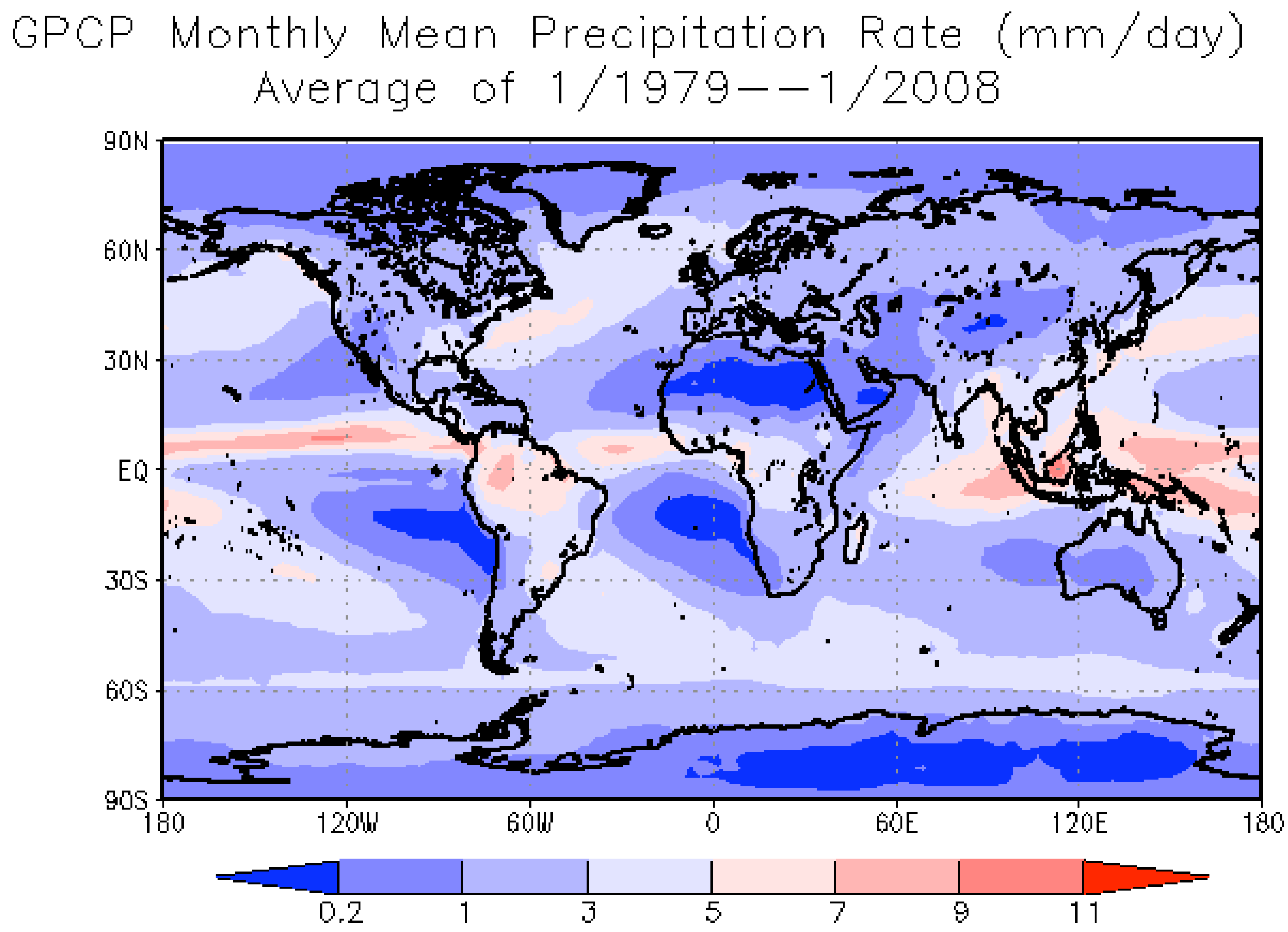
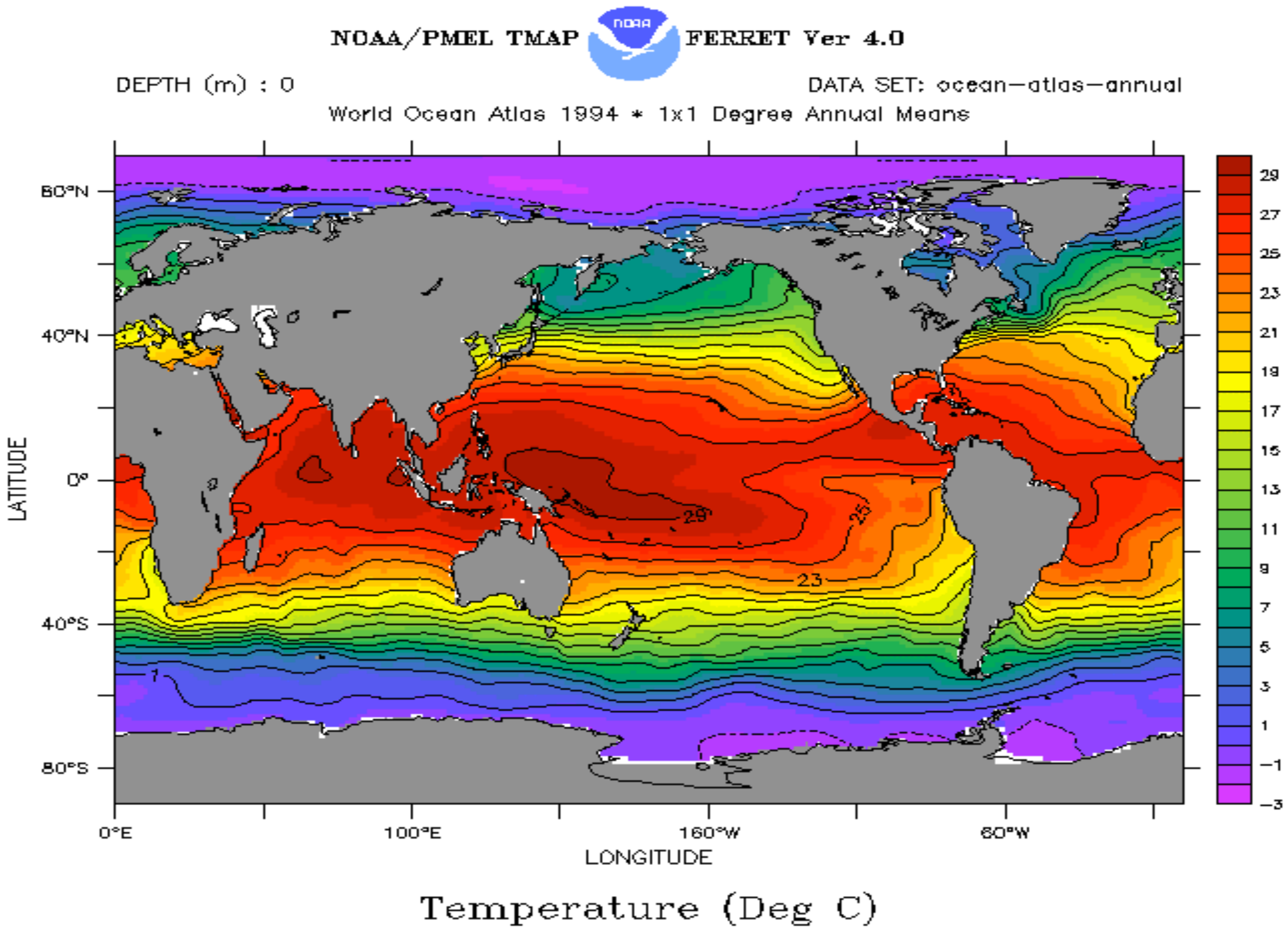


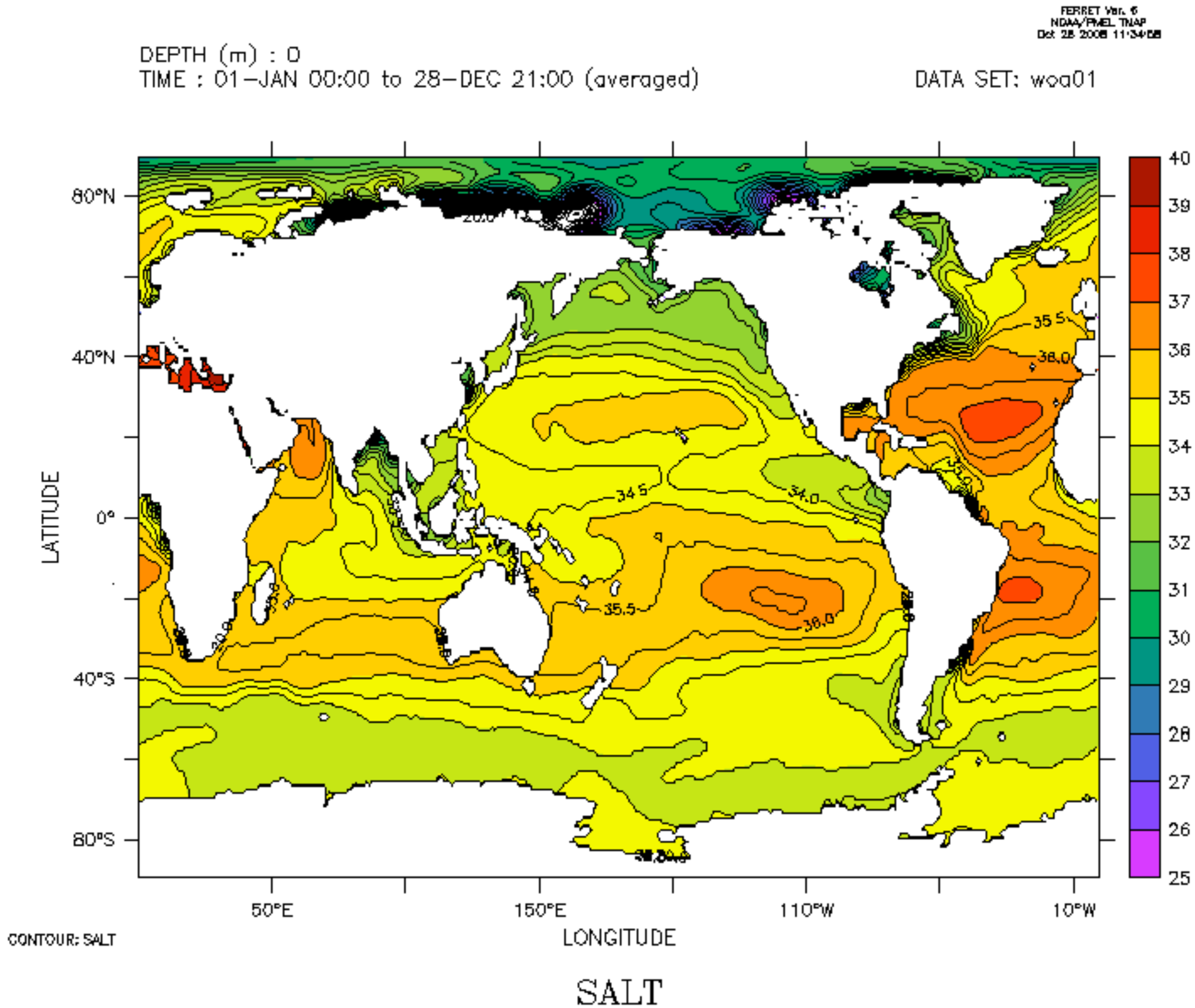
Figure 6.10 The global distribution of Q_{net}, the net heat loss/gain at the sea-surface, for (a) July and (b) January. Red, orange and yellow indicate the areas where there is the greatest net gain of heat by the sea; darker blues and purple indicate the areas where there is the greatest net loss of heat from the sea.


GPCP Monthly Mean Precipitation Rate (mm/day)
Average of 1/1979--1/2008
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
0.2
1
3
5
7
9
11

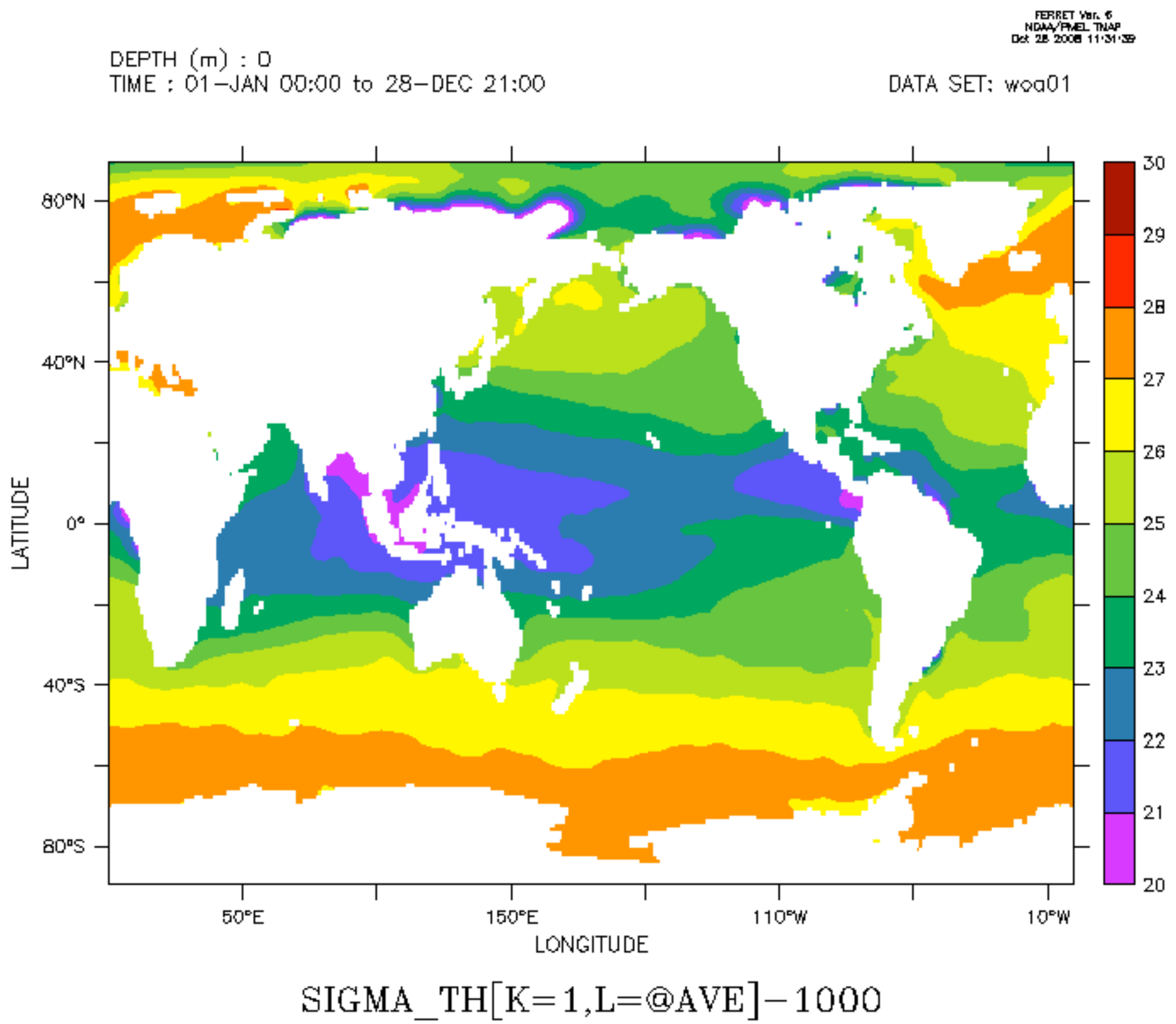
Sea Surface Temperature (SST)



Sea Surface Salinity



Sea Surface Density (σ_{theta})



Equation of State for Seawater

TABLE A.3.2 *Accuracy of measurement of salinity, temperature and pressure and related accuracies of density and specific volume*

Accuracy of measurement	Related accuracies of: Density ($kg\,m^{-3}$)	Related accuracies of: Specific volume ($m^3\,kg^{-1}$)
$\Delta S = \pm 0.003$	$\Delta\rho = \Delta\sigma_t = \pm 0.002$	$\Delta\alpha = \Delta(\Delta_{s,t}) = \mp 0.2 \times 10^{-8}$
$\Delta T = \pm 0.02°C$	$\Delta\rho = \Delta\sigma_t \mp 0.002$ ($T = 2°C$, $S = 35$) to ∓ 0.006 ($T = 25°C$, $S = 35$)	$\Delta\alpha = \Delta(\Delta_{s,t}) = \pm 0.3 \times 10^{-8}$
$\Delta p = \pm 50$ kPa ($\equiv \Delta z = \pm 5$ m for upper 1000 m)	$\Delta\rho = \pm 0.24$*	$\Delta\alpha = \mp 2.2 \times 10^{-8}$

For sea water of: $S = 35.00$, $T = 10.00°C$, $p = 0$ then

$\rho = 1026.95\ kg\,m^{-3}$
$\sigma_t = 26.95\ kg\,m^{-3}$
$\alpha = 0.973\,76 \times 10^{-3}\ m^3\,kg^{-1}$
$\Delta_{s,t} = 109.7 \times 10^{-8}\ m^3\,kg^{-1}$

* The uncertainty due to pressure differences may be greater in deep water because of greater uncertainty in pressure measurement.

A.3.2 International Equation of State of Sea Water, 1980

The new equation of state is presented by Millero and Poisson (1981) and also given in Unesco Technical Paper in Marine Science Number 36 (Unesco, 1981). The density of sea water as a function of practical salinity (S), temperature (T°C) and sea pressure (p bars) is given by

$$\rho(s,t,p) = \rho(s,t,o)/[1 - p/K(s,t,p)]$$

where $K(s,t,p)$ is the secant bulk modulus (see Section A.1.11). The specific volume is given by

$$\alpha(s,t,p) = \alpha(s,t,o)\,[1 - p/K(s,t,p)].$$

The polynomial expressions for $\rho(s,t,o)$ and $K(s,t,p)$ are given below.

For the IES 80, the density of sea water at one standard atmosphere pressure ($p = 0$) is given by:

$$\begin{aligned}
\rho(s,t,o) = & +999.842\,594 && +6.793\,952 \times 10^{-2} \times T \\
& - 9.095\,290 \times 10^{-3} \times T^2 && +1.001\,685 \times 10^{-4} \times T^3 \\
& - 1.120\,083 \times 10^{-6} \times T^4 && +6.536\,332 \times 10^{-9} \times T^5 \\
& + 8.244\,93 \times 10^{-1} \times S && -4.089\,9 \times 10^{-3} \times T \times S \\
& + 7.643\,8 \times 10^{-5} \times T^2 \times S && -8.246\,7 \times 10^{-7} \times T^3 \times S \\
& + 5.387\,5 \times 10^{-9} \times T^4 \times S && -5.724\,66 \times 10^{-3} \times S^{3/2} \\
& + 1.022\,7 \times 10^{-4} \times T \times S^{3/2} && -1.654.6 \times 10^{-6} \times T^2 \times S^{3/2} \\
& + 4.831\,4 \times 10^{-4} \times S^2.
\end{aligned}$$

For the IES 80, the secant bulk modulus is given by:

$$\begin{aligned}
K(s,t,p) = & +19\,652.21 \\
& + 148.420\,6 \times T && -2.327\,105 \times T^2 \\
& + 1.360\,477 \times 10^{-2} \times T^3 && -5.155\,288 \times 10^{-5} \times T^4 \\
& + 3.239\,908 \times p && +1.437\,13 \times 10^{-3} \times T \times p \\
& + 1.160\,92 \times 10^{-4} \times T^2 \times p && -5.779\,05 \times 10^{-7} \times T^3 \times p \\
& + 8.509\,35 \times 10^{-5} \times p^2 && -6.122\,93 \times 10^{-6} \times T \times p^2 \\
& + 5.278\,7 \times 10^{-8} \times T^2 \times p^2 \\
& + 54.674\,6 \times S && -0.603\,459 \times T \times S \\
& + 1.099\,87 \times 10^{-2} \times T^2 \times S && -6.167\,0 \times 10^{-5} \times T^3 \times S \\
& + 7.944 \times 10^{-2} \times S^{3/2} && +1.648\,3 \times 10^{-2} \times T \quad S^{3/2} \\
& - 5.300\,9 \times 10^{-4} \times T^2 \times S^{3/2} && +2.283\,8 \times 10^{-3} \times p \times S \\
& - 1.098\,1 \times 10^{-5} \times T \times p \times S && -1.607\,8 \times 10^{-6} \times T^2 \times p \times S \\
& + 1.910\,75 \times 10^{-4} \times p \times S^{3/2} && -9.934\,8 \times 10^{-7} \times p^2 \times S \\
& + 2.081\,6 \times 10^{-8} \times T \times p^2 \times S && +9.169\,7 \times 10^{-10} \times T^2 \times p^2 \times S
\end{aligned}$$

The above polynomials are taken from Unesco *Technical Papers in Marine Science* No. 36, 1981.

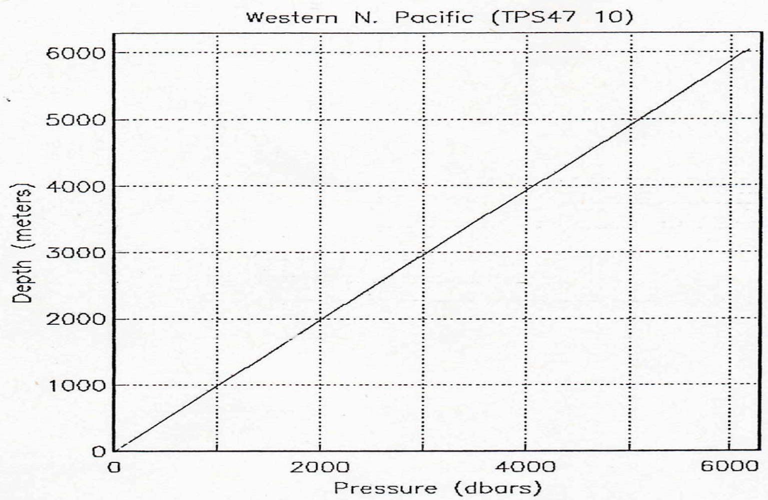
The following values may be used for checking the correct use of the IES 80, ρ being in $kg\,m^{-3}$ and K in bars:

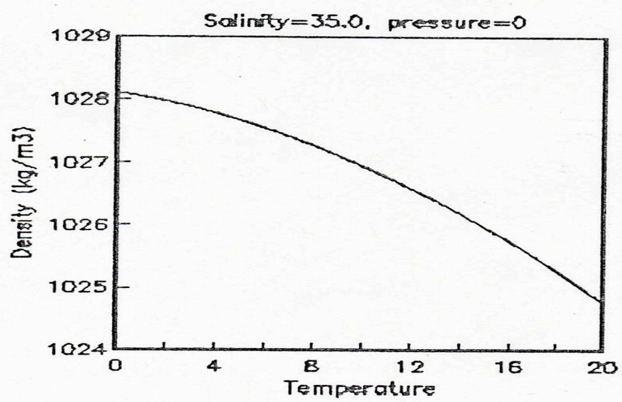
S	T°C	p bars	$\rho(s,t,p)$	$K(s,t,p)$
0	5	0	999.966 75	20 337.803 75
		1000	1044.128 02	23 643.525 99
	25	0	997.047 96	22 100.721 06
		1000	1037.902 04	25 405.097 17
35	5	0	1027.675 47	22 185.933 58
		1000	1069.489 14	25 577.498 19
	25	0	1023.343 06	23 726.349 49
		1000	1062.538 17	27 108.945 04

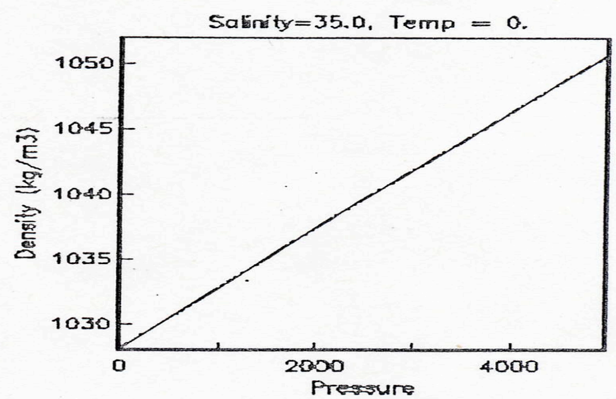
In the above polynomials, the pure-water terms are those not containing salinity (S). Procedures for converting salinities estimated by earlier methods to the Practical Salinity Scale, 1978, for use with the above polynomials are given by Lewis and Perkin (1981).

Tables of sea-water properties derived from the International Equation of State 1980 are promised as future volumes of the International Oceanographic Tables (Unesco, 1981).

Pressure and Temperature Effects on Density





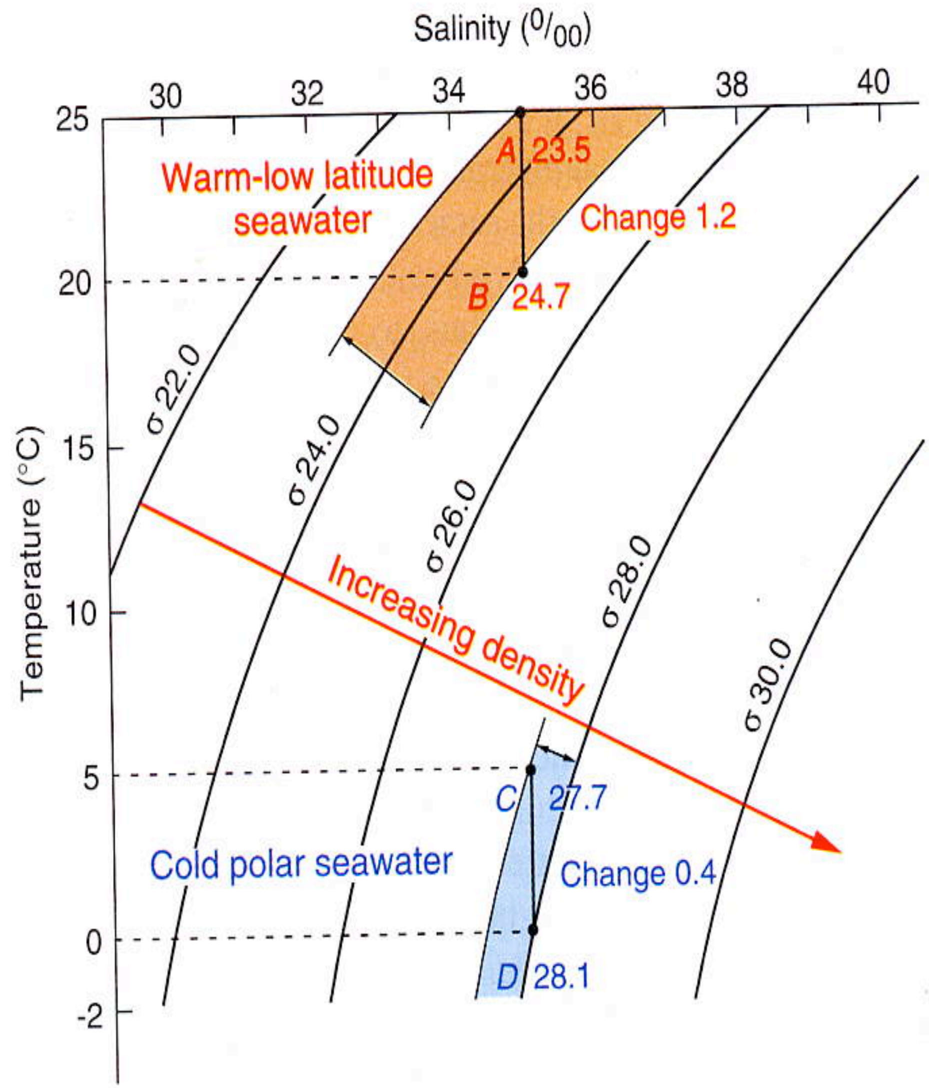


1-3

Density has non-linear dependence on T and S

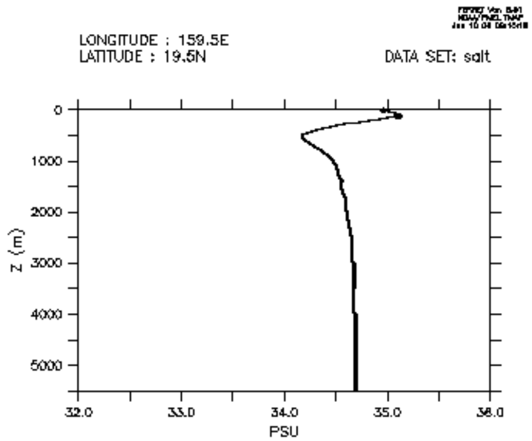
Figure 7-5 **Seawater Density Variations with Temperature and Salinity**

Density, plotted as σ contours, is shown as a function of temperature and salinity. A warm, low latitude water is shown at point A (25°C, 35 ‰), with a σ of 23.5. If this water were cooled to 20°C, point B, the density would increase, resulting in a σ of 24.7. If a cold, high latitude water, point C (5°C, 35 ‰) is cooled to 0°C, point D, σ changes from 27.7 to 28.1. Note that the 5 degree temperature change has a much greater effect on density for warmer waters than it does for colder waters.

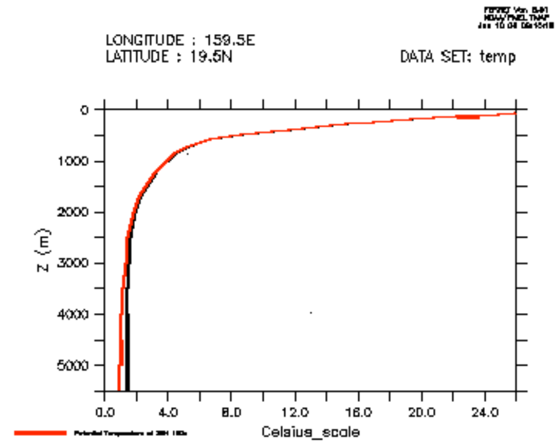


Range in T, S and σ in the ocean

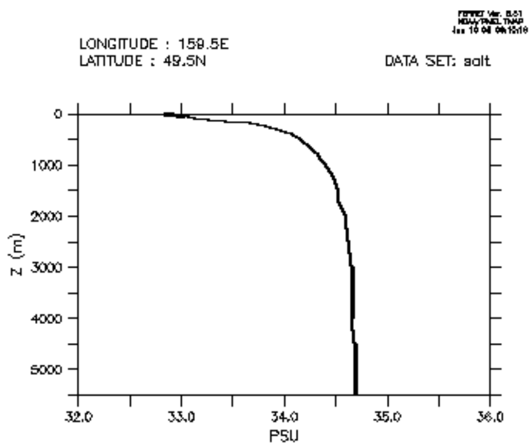
Temperature and salinity at 20N 160E
and 50N 160E in the Pacific.



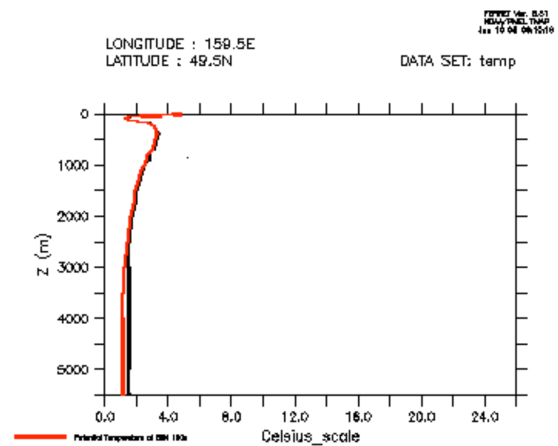
Salinity at 20N 160e



Temperature at 20N 160e

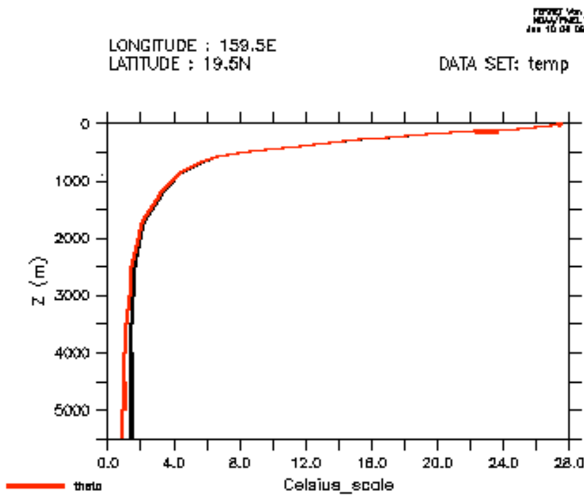


Salinity at 50N 160e

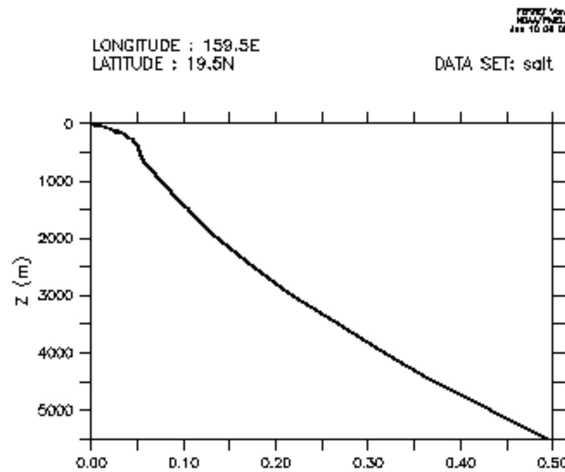


Temperature at 50N 160e

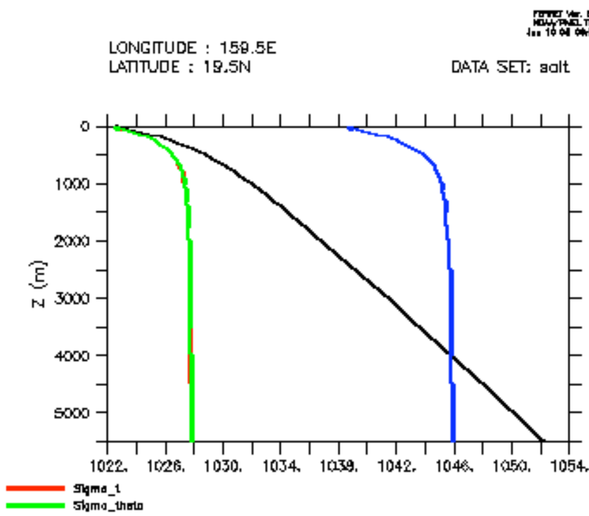
Temperature, potential temperature, sigma at 20N 160E



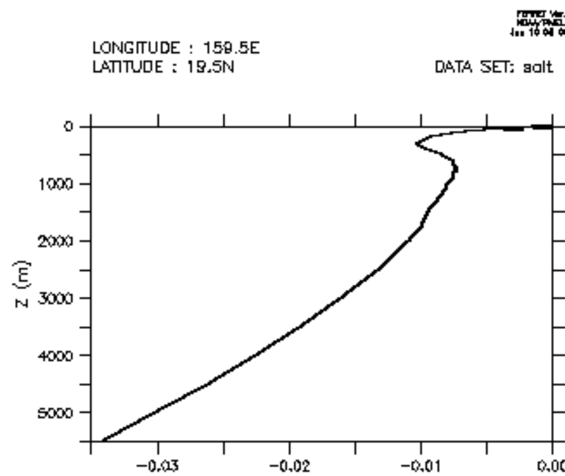
Temperature, Theta



Temperature−Theta

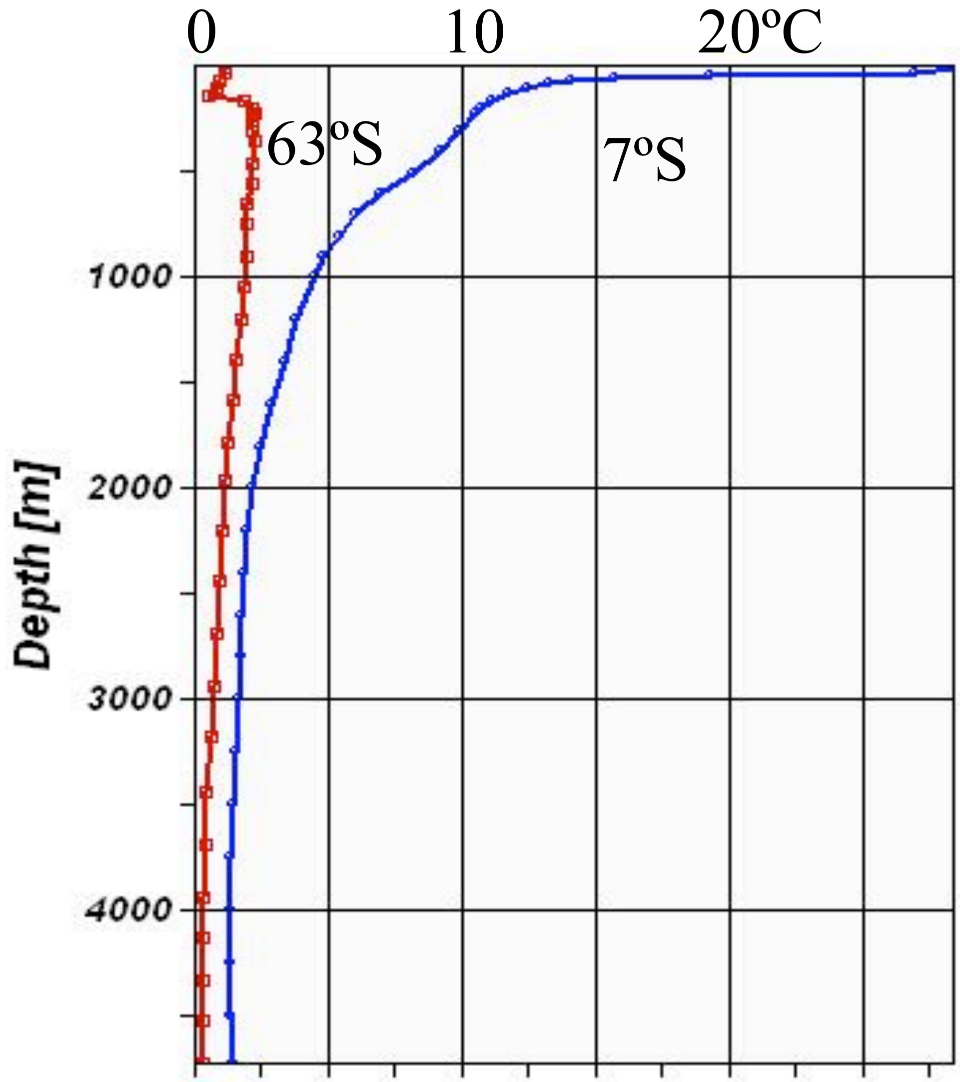


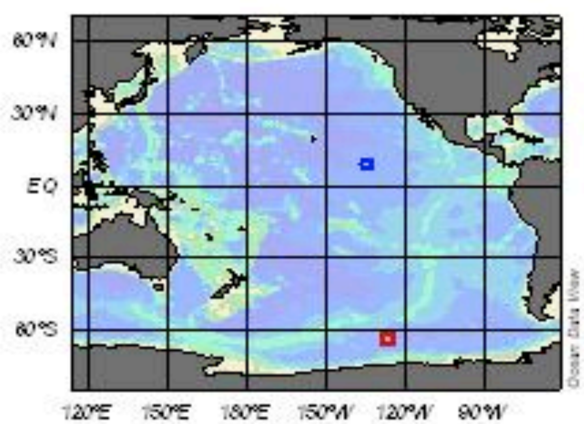
Sigma at 20N 160e



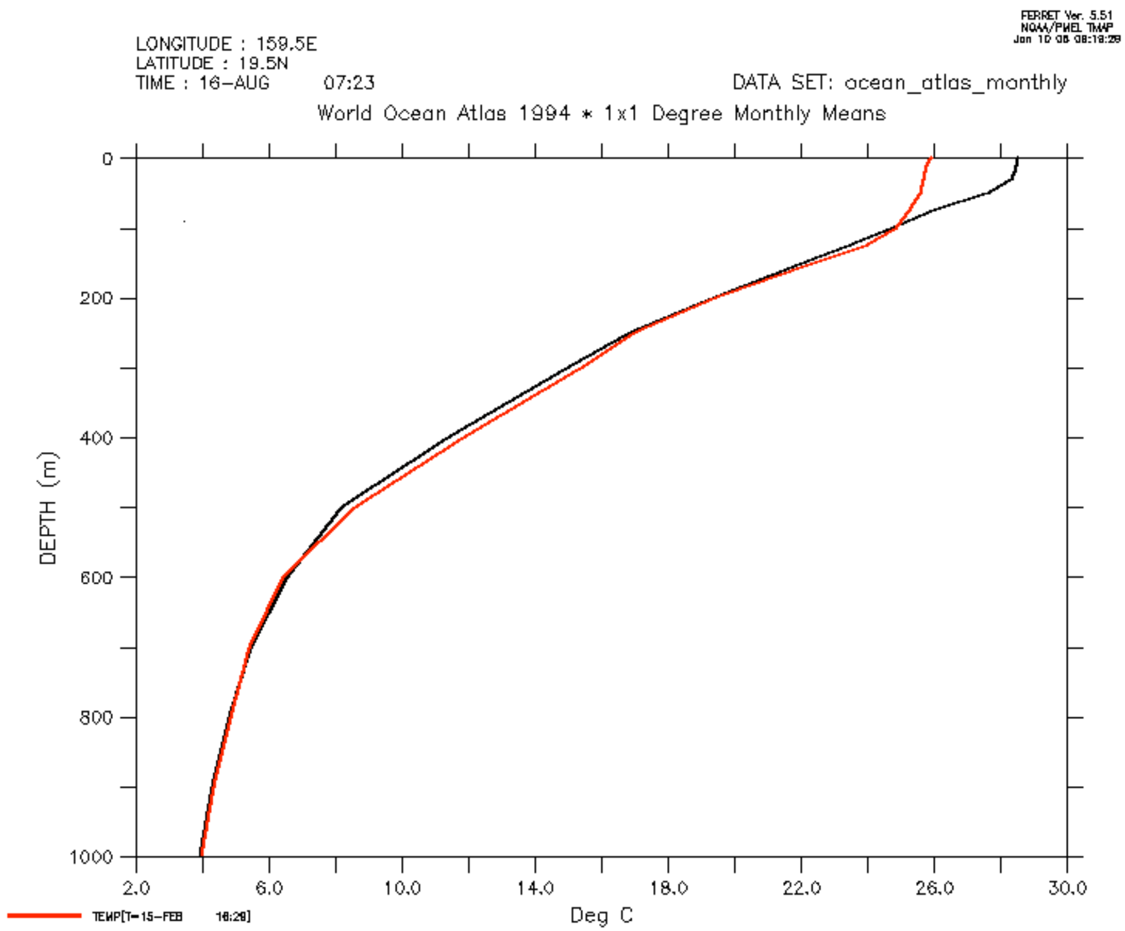
Sigma t − Sigma_theta

Depth Profiles of Temperature



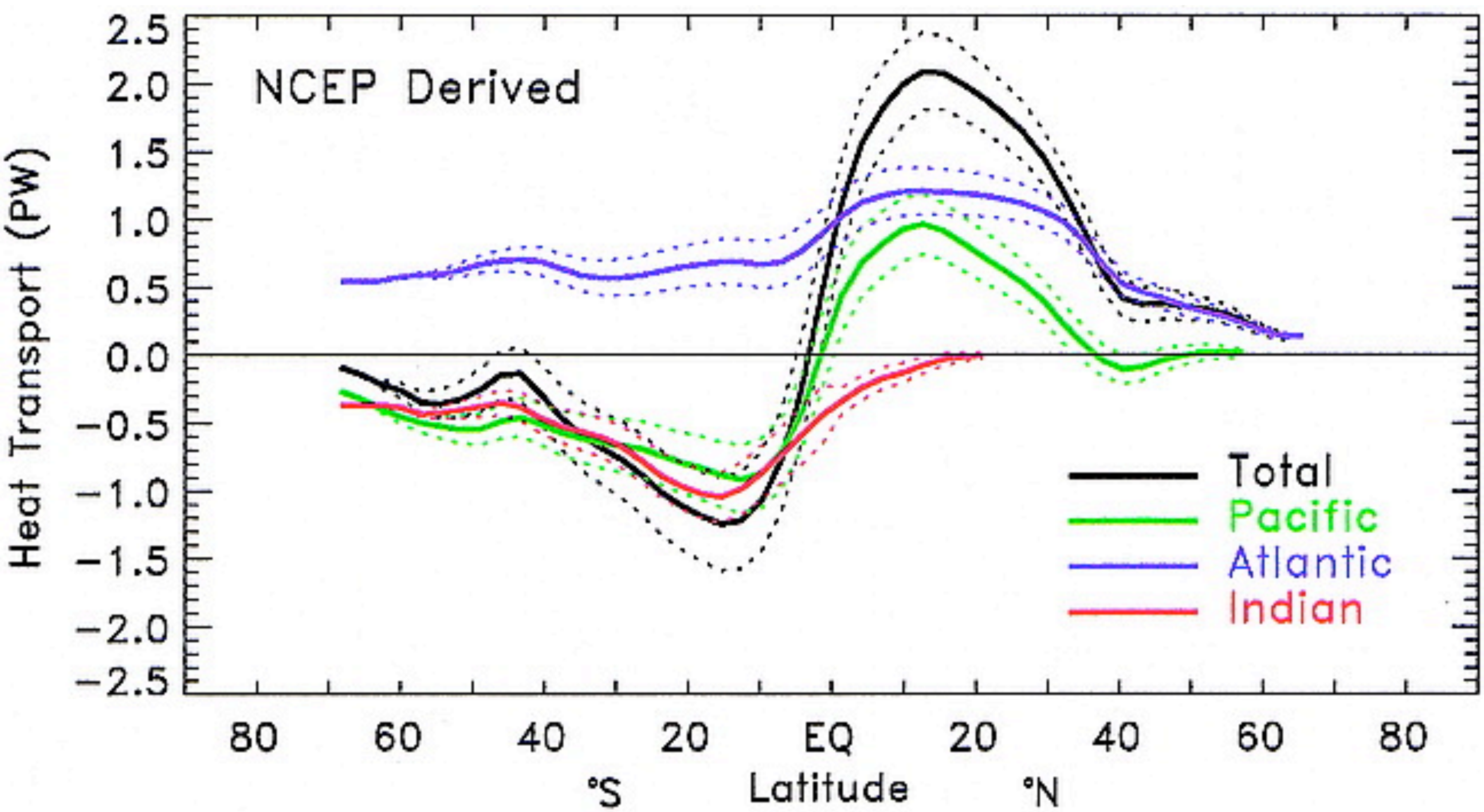


Temperature in summer and winter at 20N 160E

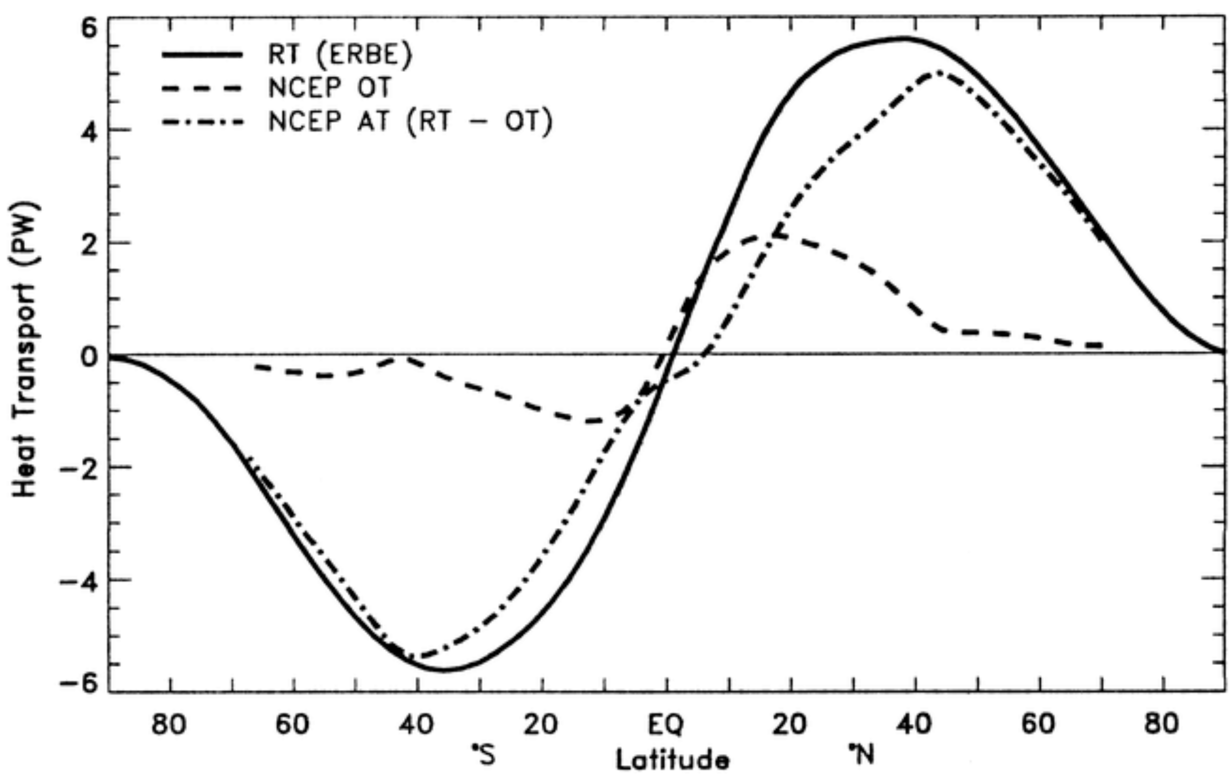


Temperature at 20N 160E

Heat Transport by the oceans



Heat Transport by the Atmosphere and ocean



Annually averaged energy flux

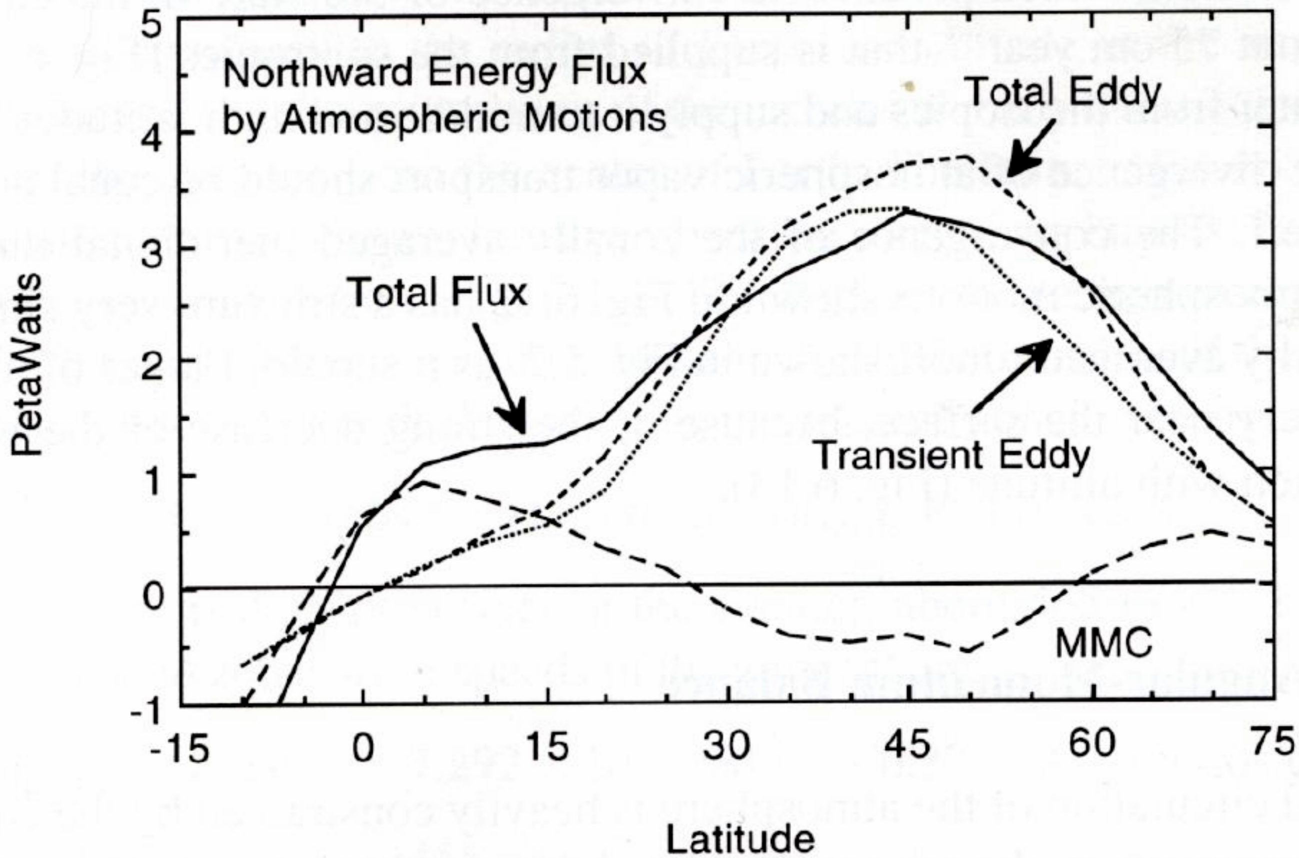


Fig. 6.11 Annual average northward energy flux plotted versus latitude in the Northern Hemisphere. Units are 10^{15} W. Mean meridional circulation (MMC). [Data from Oort (1971). Reprinted with permission from the American Meteorological Society.]

Hartmann