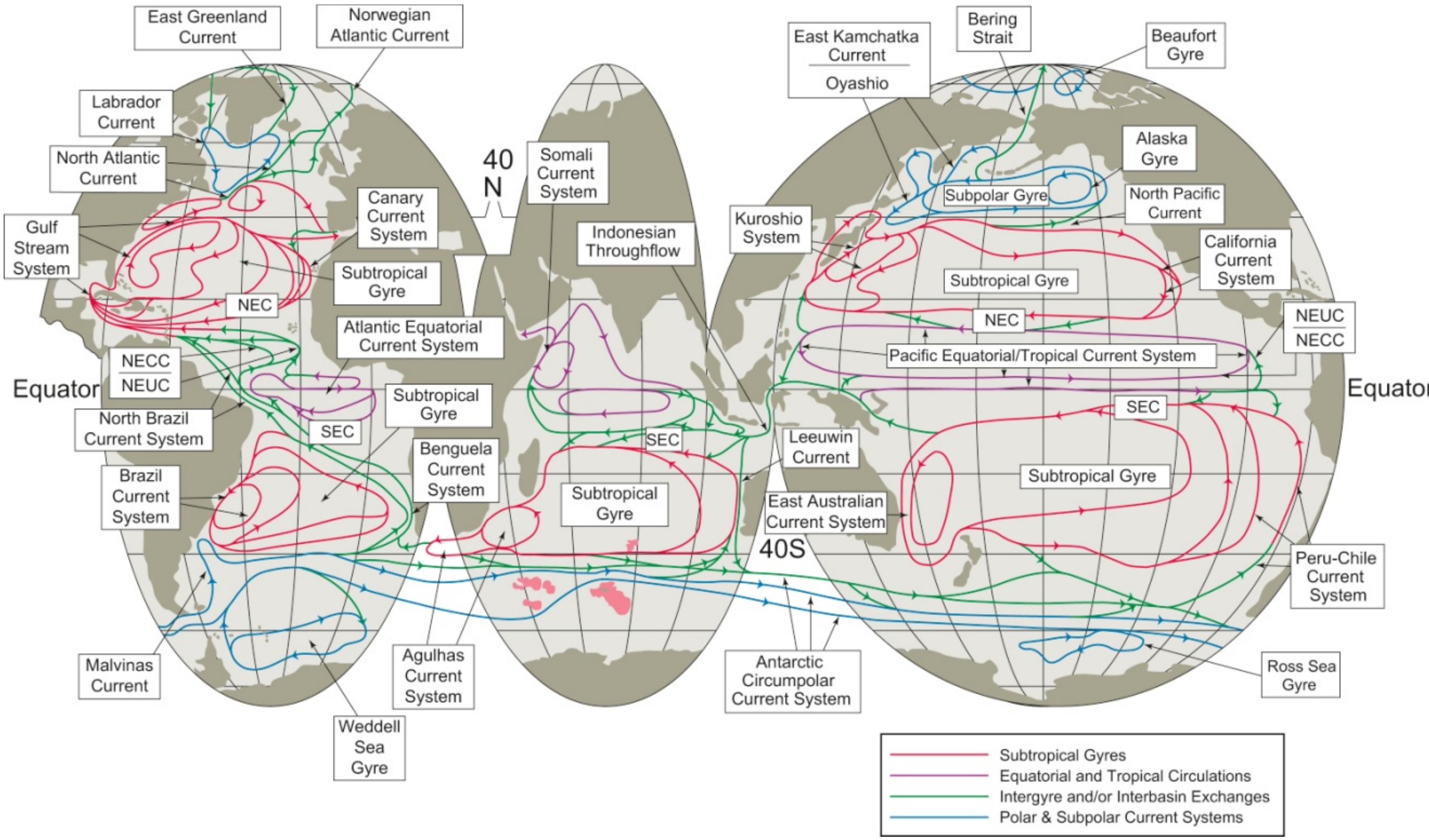
Global Circulation

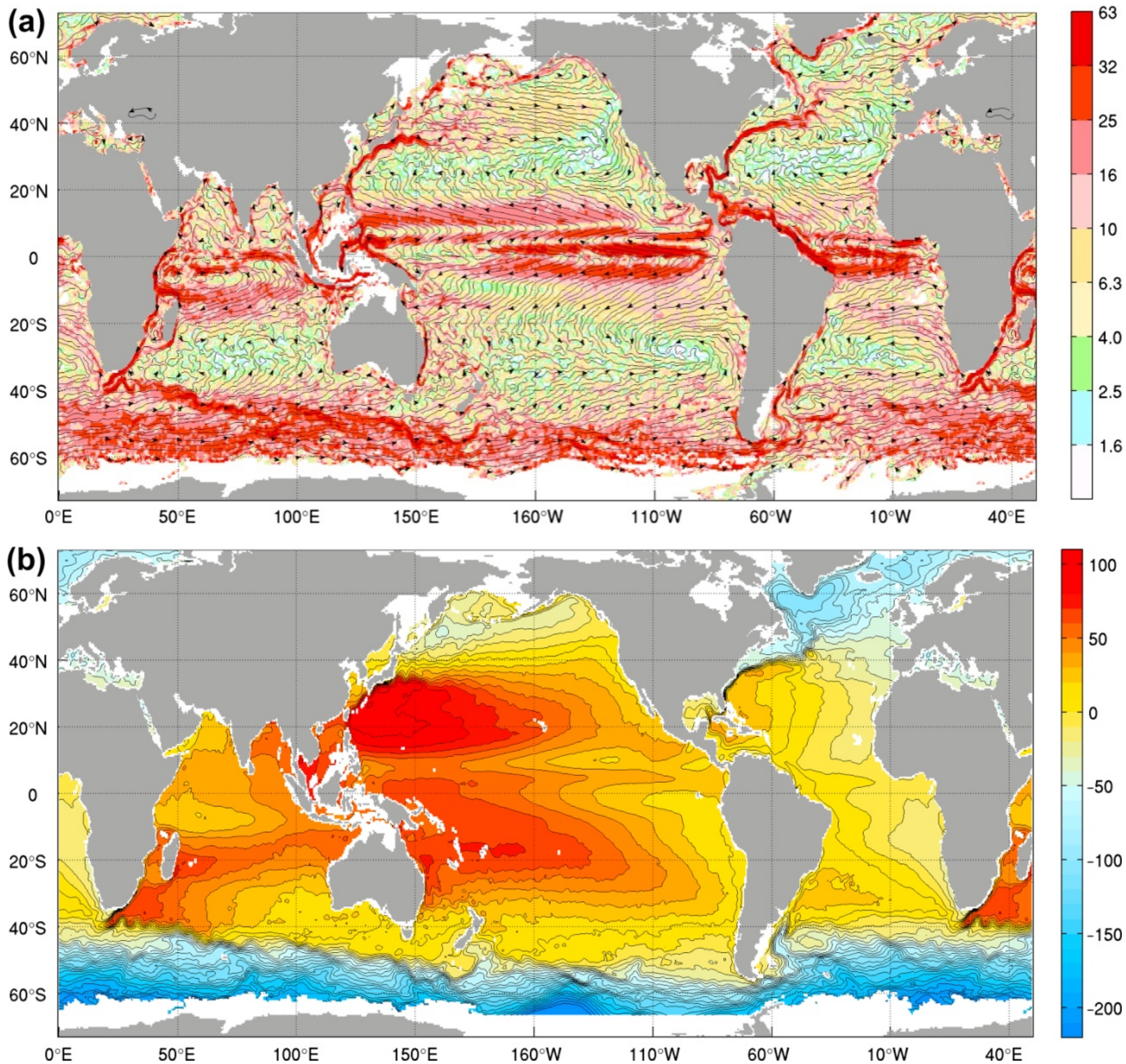
AOS660

Fall 2013



Surface circulation schematic. This figure can also be found in the color insert.
Modified from Schmitz (1996b).

FIGURE 14.1



(a) Surface dynamic topography (dyn cm), with 10 cm contour intervals, and (b) surface velocity streamlines, including both geostrophic and Ekman components; color is the mean speed in cm/sec. This figure can also be found in the color insert. *Source: From Maximenko et al. (2009).*

FIGURE 14.2

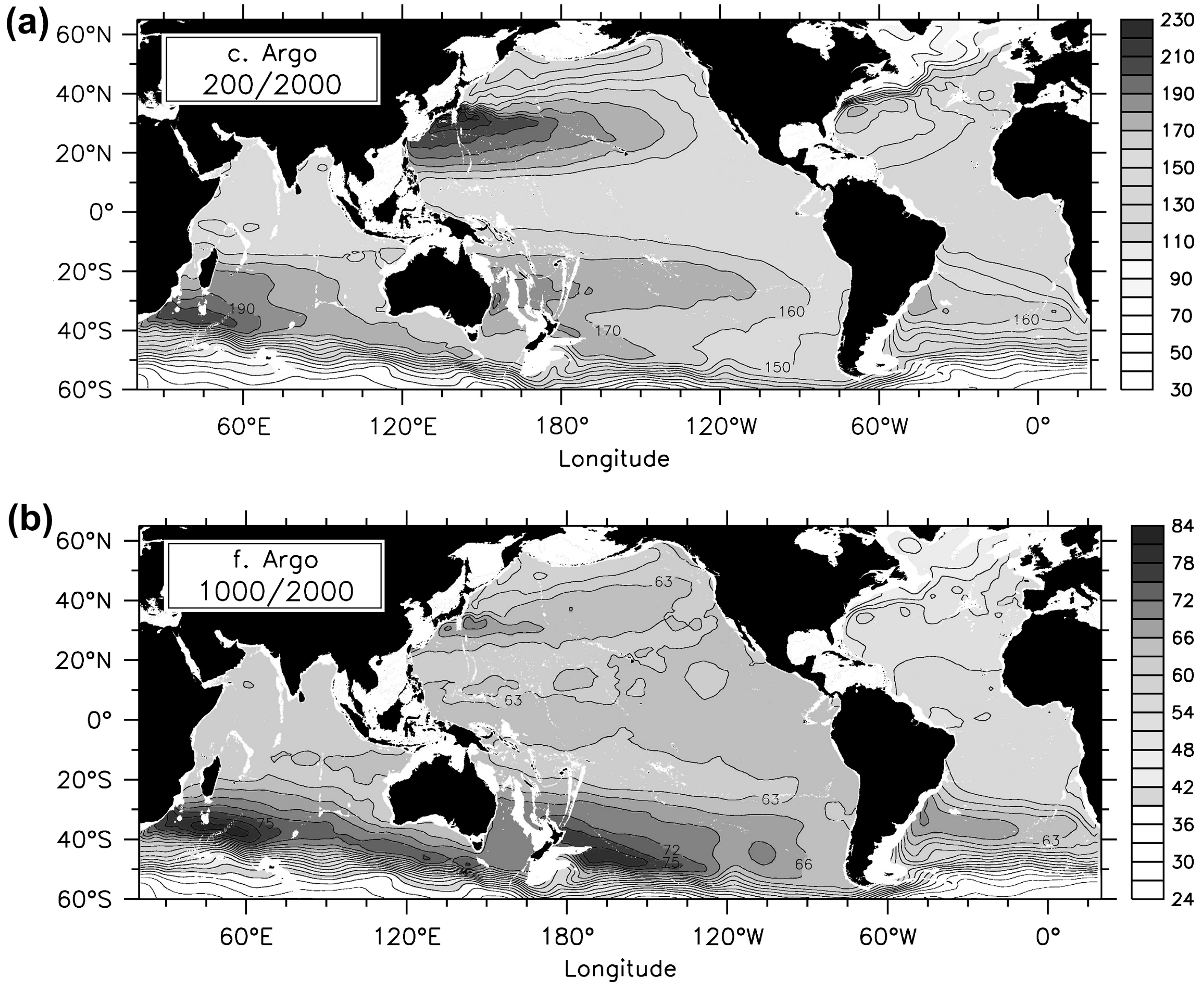


FIGURE 14.3

Steric height (dyn cm) relative to 2000 dbar at (a) 200 dbar and (b) 1000 dbar, using mean temperature and salinity from five years of float profiles (2004-2008). *Source: From Roemmich and Gilson (2009).*

TALLEY

(a)

2500m

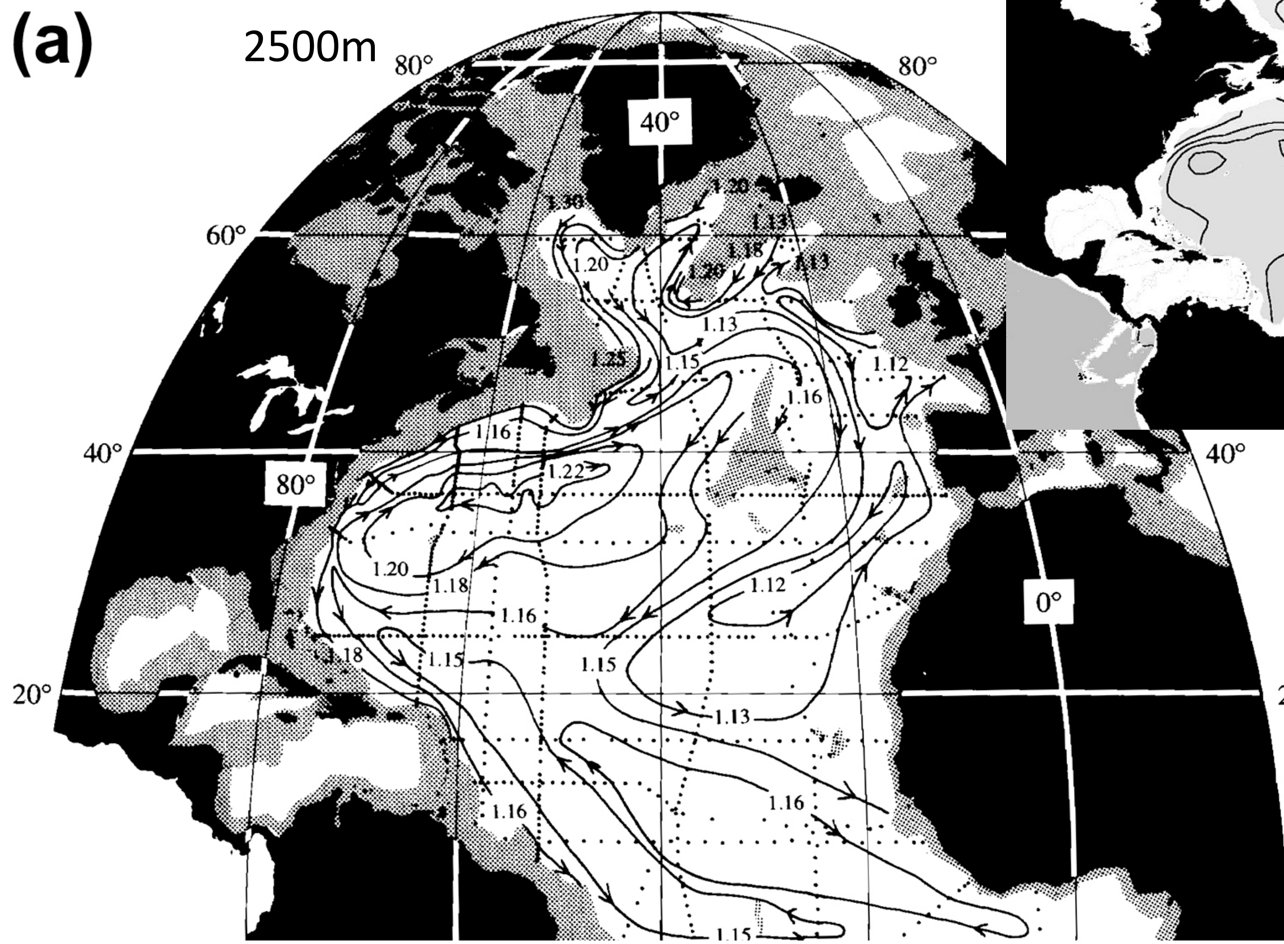


Fig 14.3 1000m relative to 2000m (ARGO)

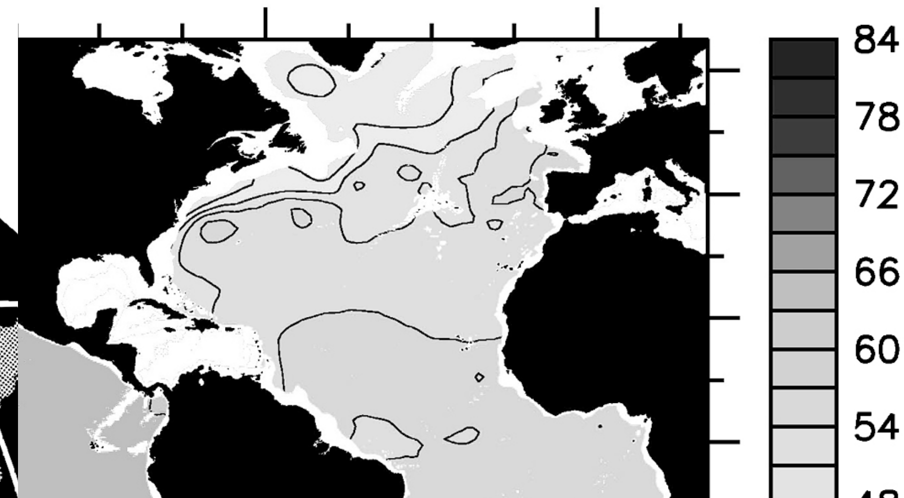
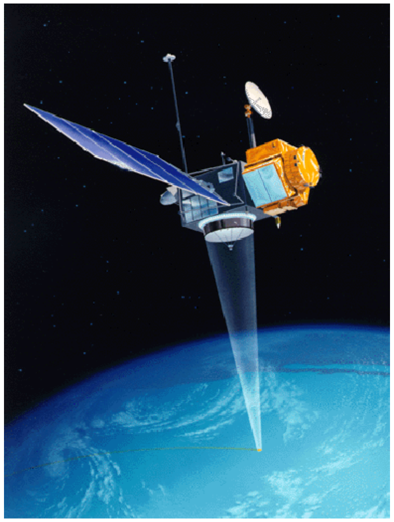


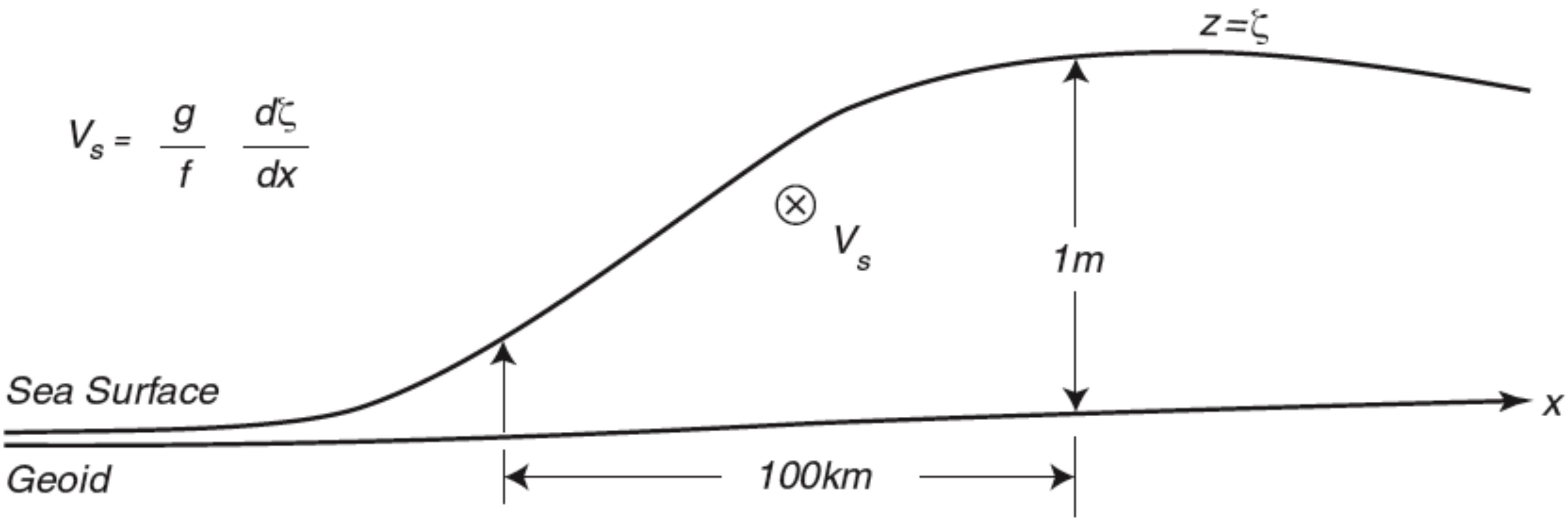
FIGURE 9.14a

Steric height (10 m^2 s^{-2}) at (a) 2500 dbar …., adjusted to estimate the absolute geostrophic circulation. *Source: From Reid (1994).*

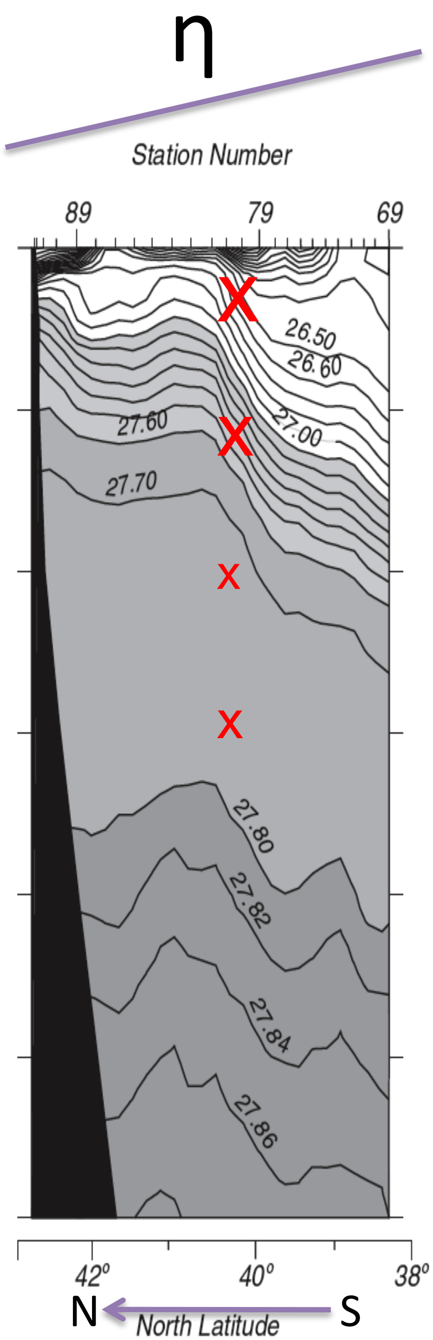
ALLEY



Dynamic Topography to get surface currents



heavy



light

+ −

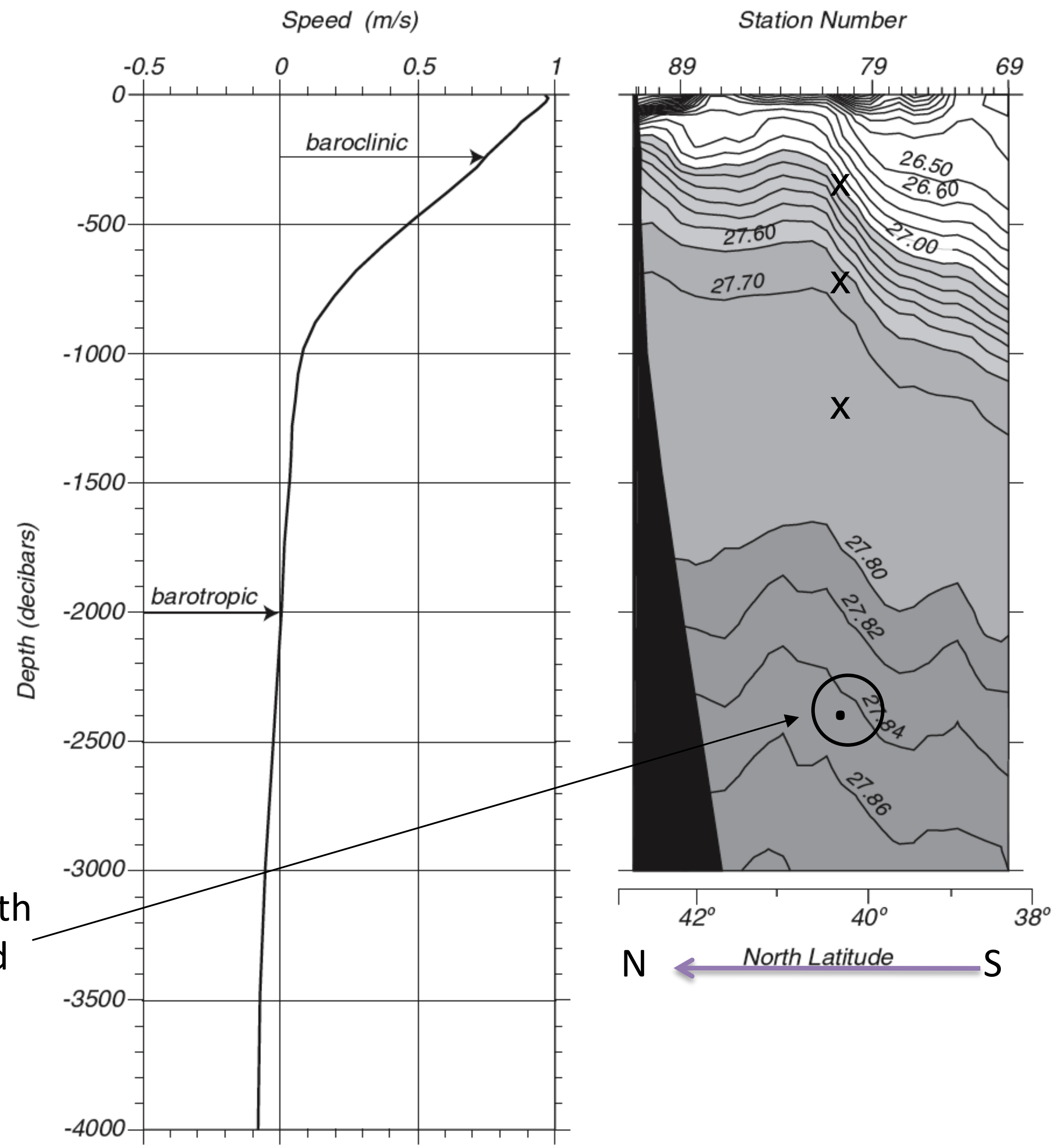
$$u_g = -\frac{g}{f}\frac{\partial \eta}{\partial y} - \frac{g(\eta - z)}{f\rho_0}\frac{\partial \langle \rho \rangle}{\partial y}$$

$$\Delta y > 0$$

$$\Delta \eta < 0$$

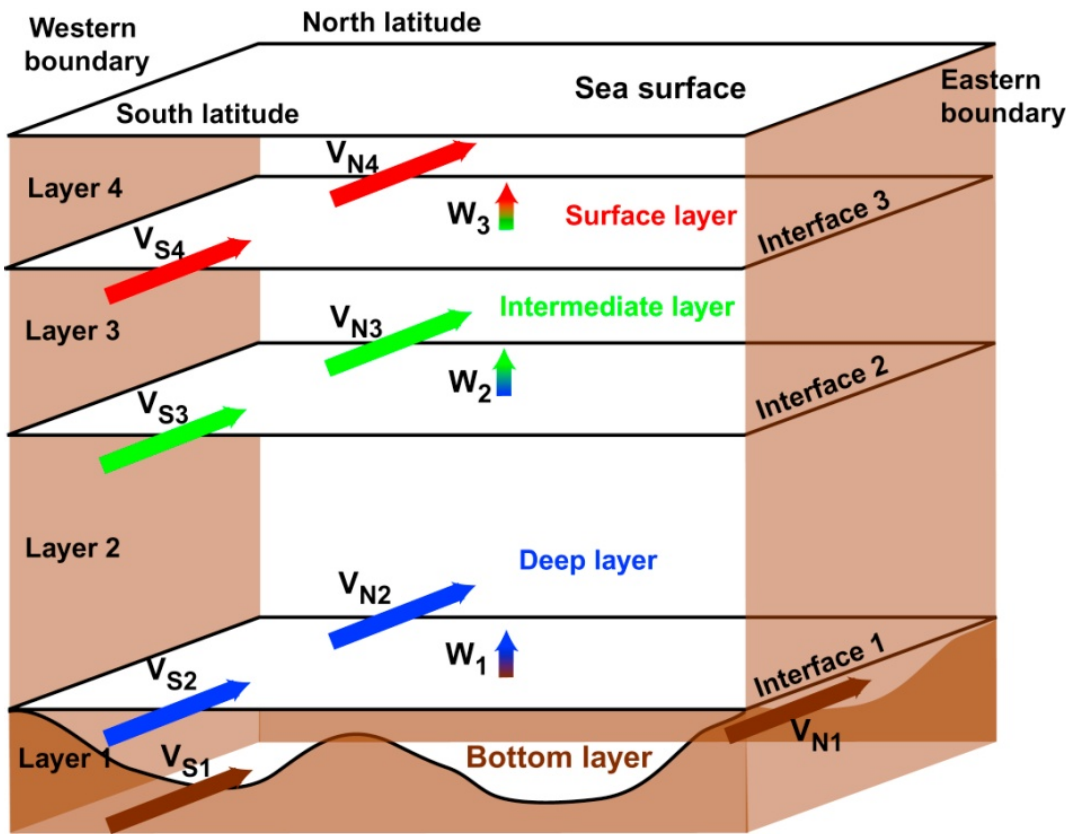
$$\Delta \langle \rho \rangle > 0$$

Gulf Stream Section at 64W



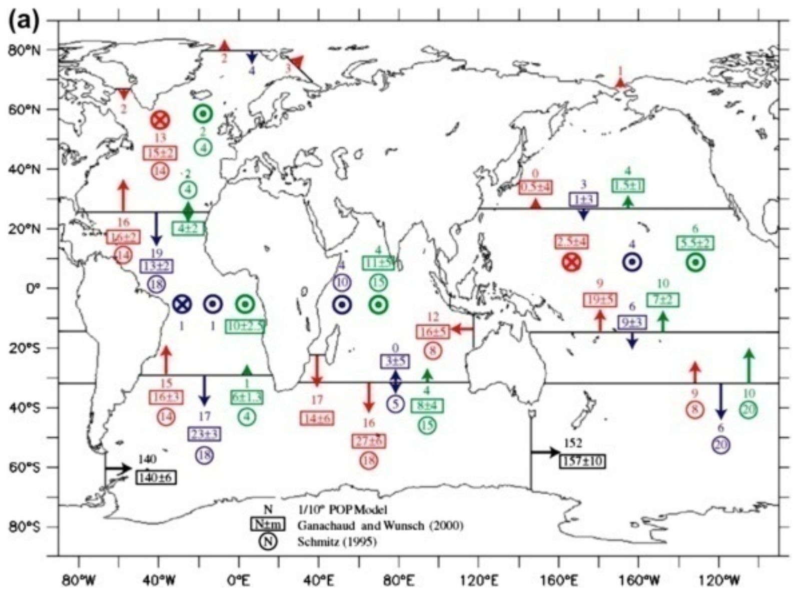
Direction changes at depth because here density and pressure are aligned

HEAT, MASS AND FRESHWATER TRANSPORT



Meridional overturning circulation transport calculation: example for four layers. The mass transports for each layer "i" through the southern and northern boundaries of each layer are V_{Si} and V_{Ni}. The vertical transport across each interface is W_i. Arrow directions are those for positive sign; the actual transports can be of any magnitude and sign. The sum of the four transports (two horizontal and two vertical) into a given closed layer must be 0 Sv. The small amount of transport across the sea surface due to evaporation and precipitation is not depicted.

FIGURE 14.5



Net transports (Sv) in isopycnal layers across closed hydrographic sections (1 Sv = 1 $\times 10^6$ m^3/sec). (a) Three calculations from different sources are superimposed, each using three isopycnal layers (see header). Circles between sections indicate upwelling (arrow head) and downwelling (arrow tail) into and out of the layer defined by the circle color. This figure can also be found in the color insert. *Source: From Maltrud and McClean (2005), combining results from their POP model run, Ganachaud and Wunsch (2000), and Schmitz (1995).* (b) Fourth calculation based on velocities from *Reid (1994, 1997, 2003)*, with ribbons indicating flow direction and overturn locations schematically. *Source: From Talley (2008).*

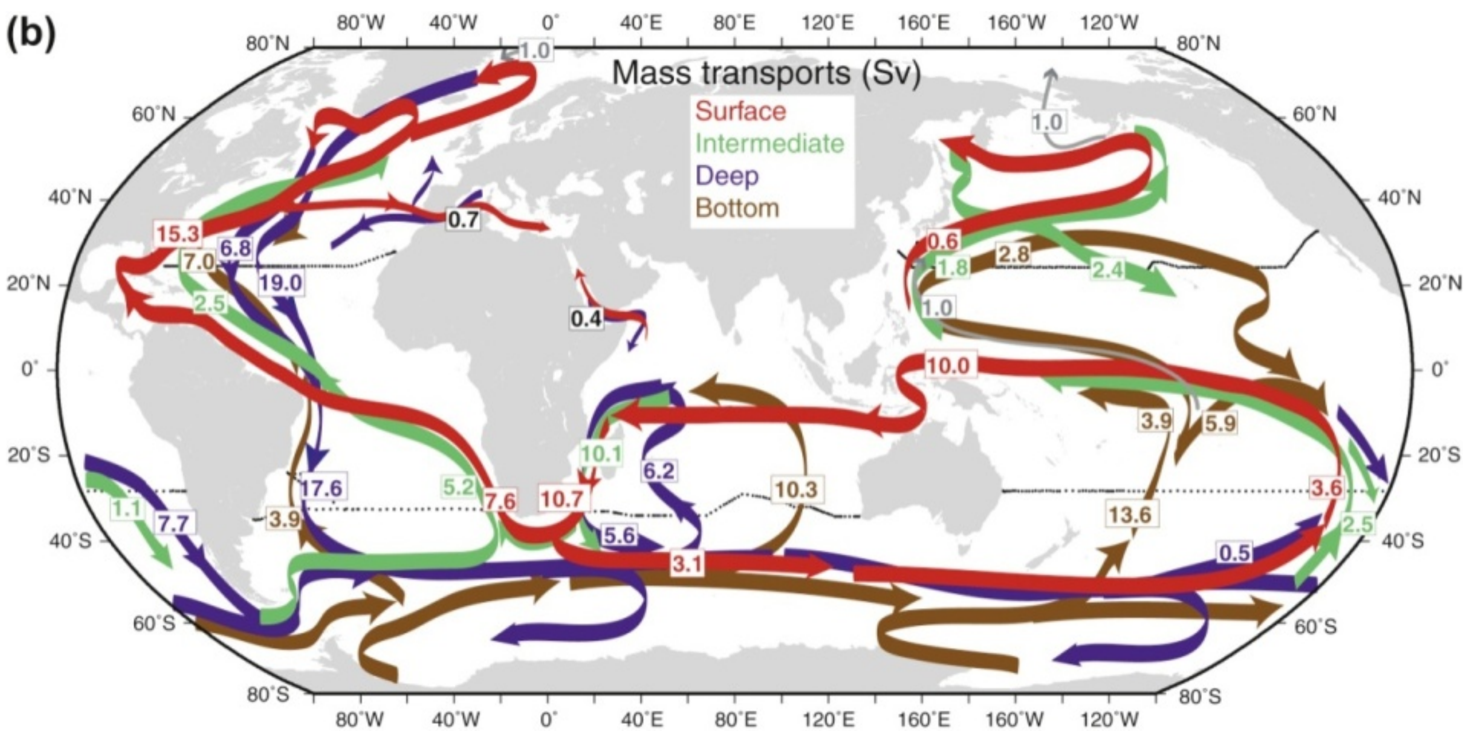
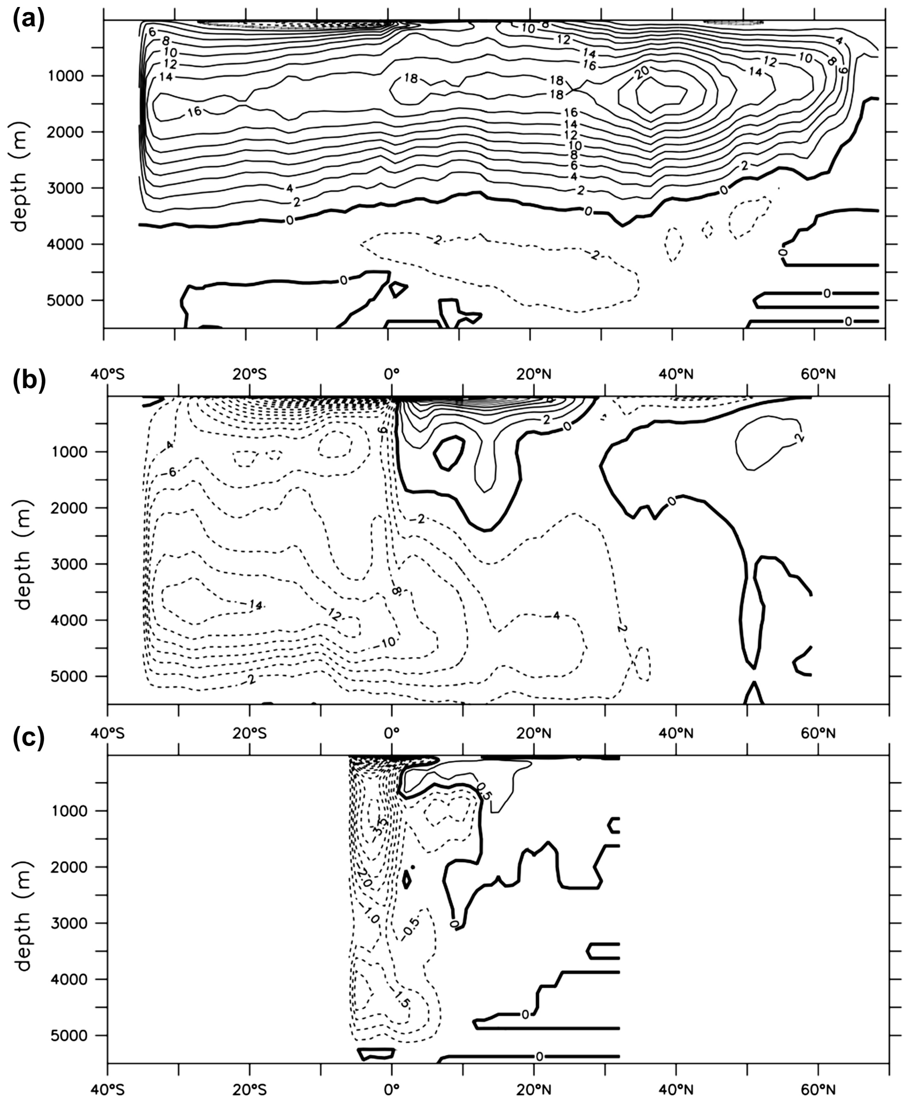
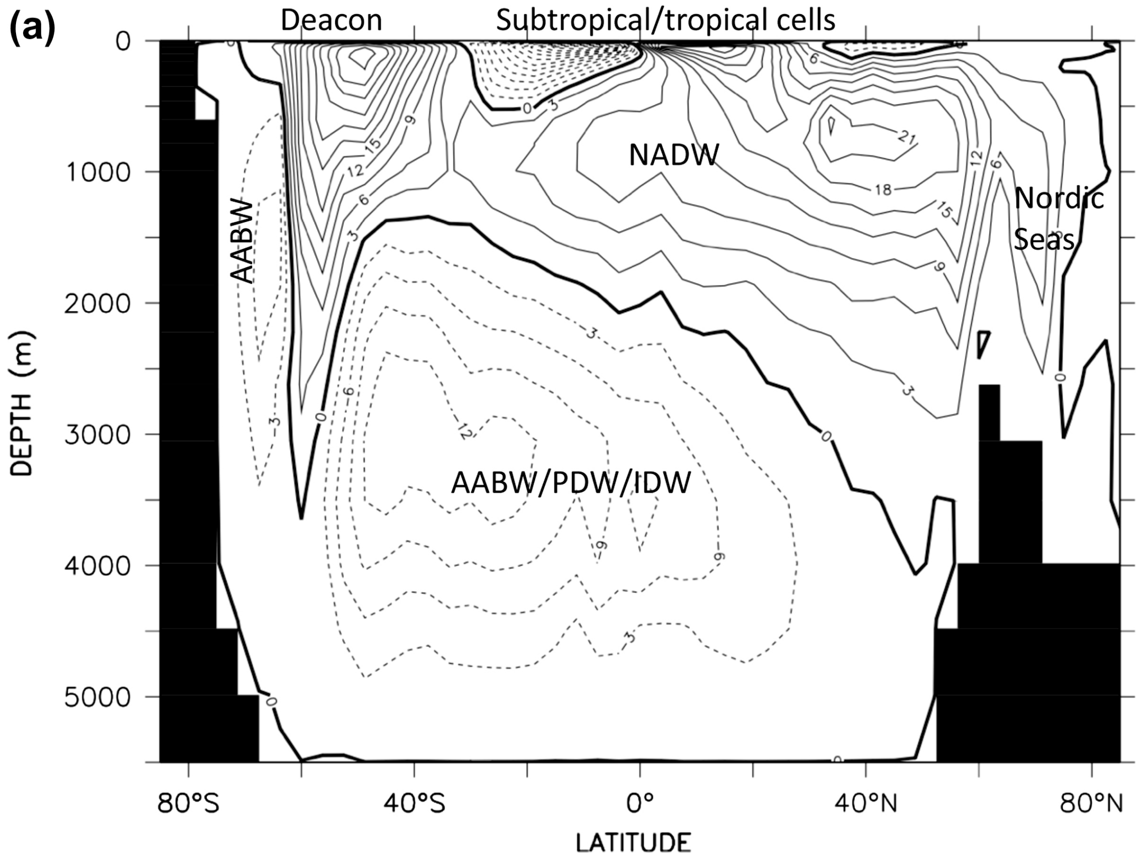


FIGURE 14.6



Meridional overturning streamfunction (Sv) from a high resolution general circulation model for the (a) Atlantic, (b) Pacific plus Indian, and (c) Indian north of the ITF. The Southern Ocean is not included. *Source: From Maltrud and McClean (2005).*

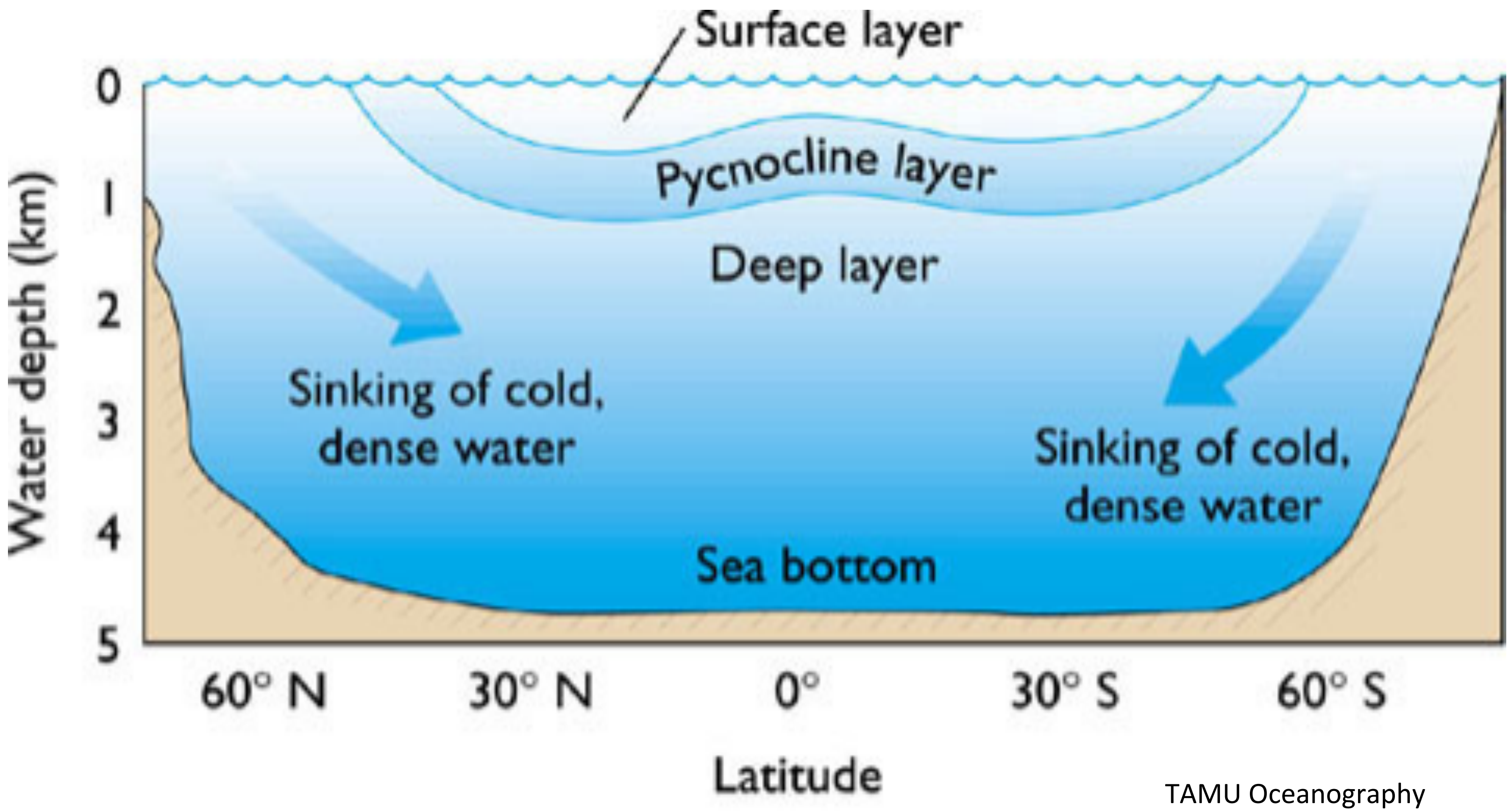
FIGURE 14.8



Global meridional overturning streamfunction (Sv) for (a) a global coupled climate model with high resolution in latitude. *Source: After Kuhlbrodt et al. (2007)*. (b, c) For hydrographic section data at several latitudes, plotted as a function of neutral density and pressure; contour intervals are 2 Sv. The white contours are typical winter mixed layer densities; gray contours indicate bathymetric features (ocean ridge crests). *Source: After Lumpkin and Speer (2007).*

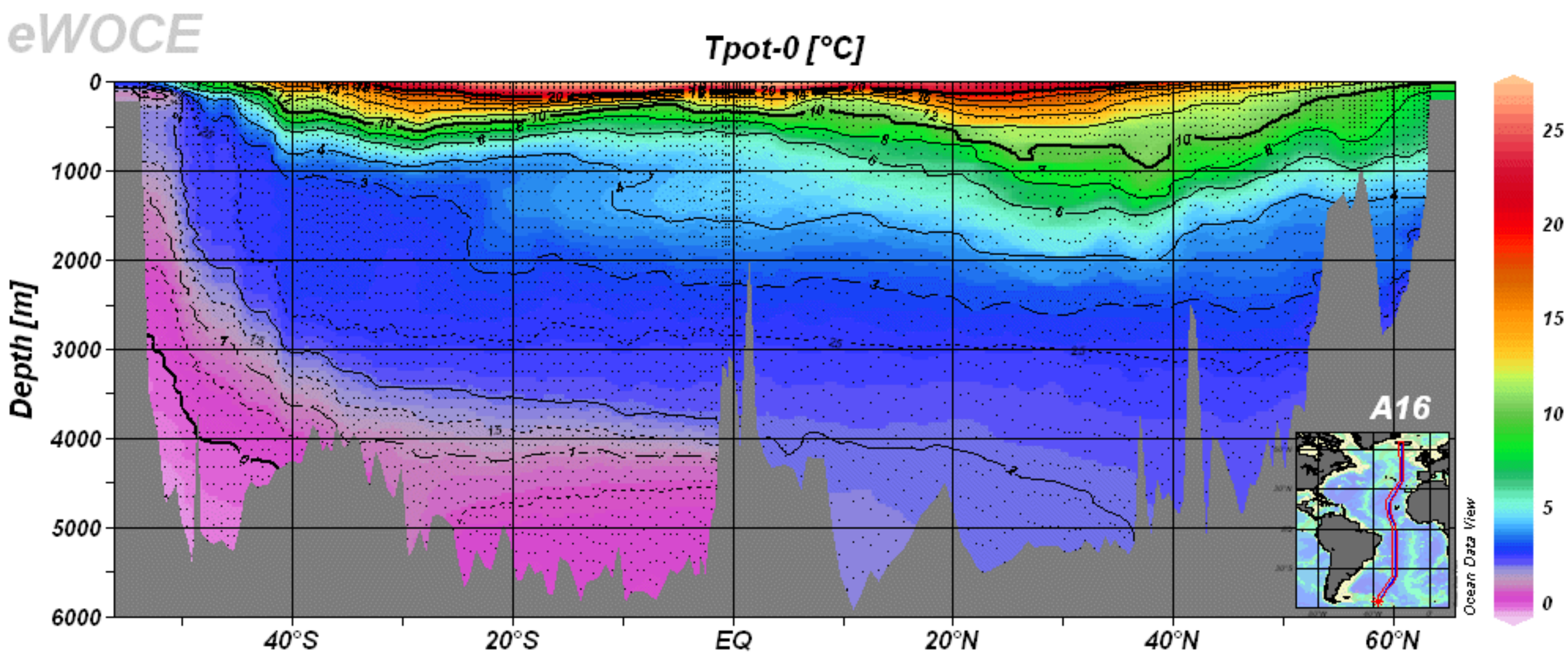
FIGURE 14.9a

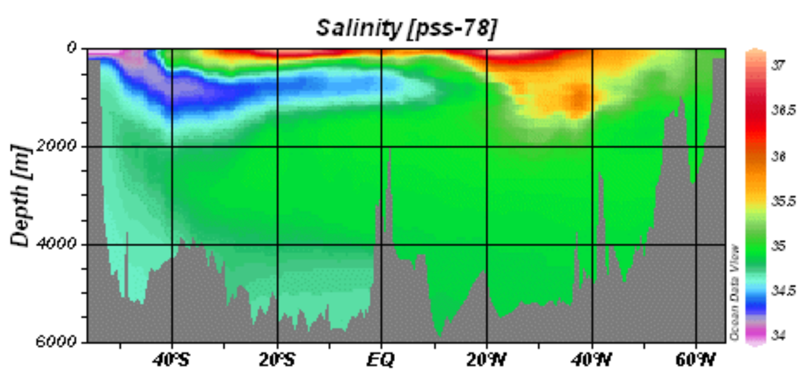
Density Cross-Section

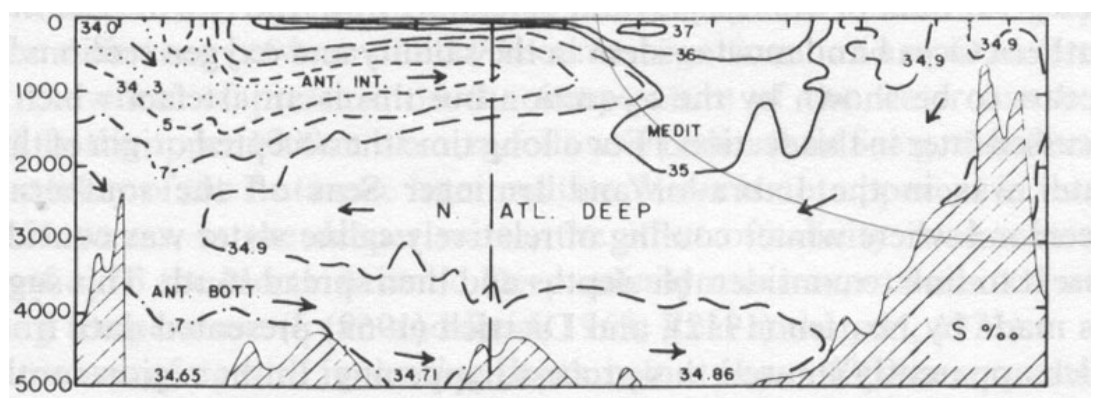


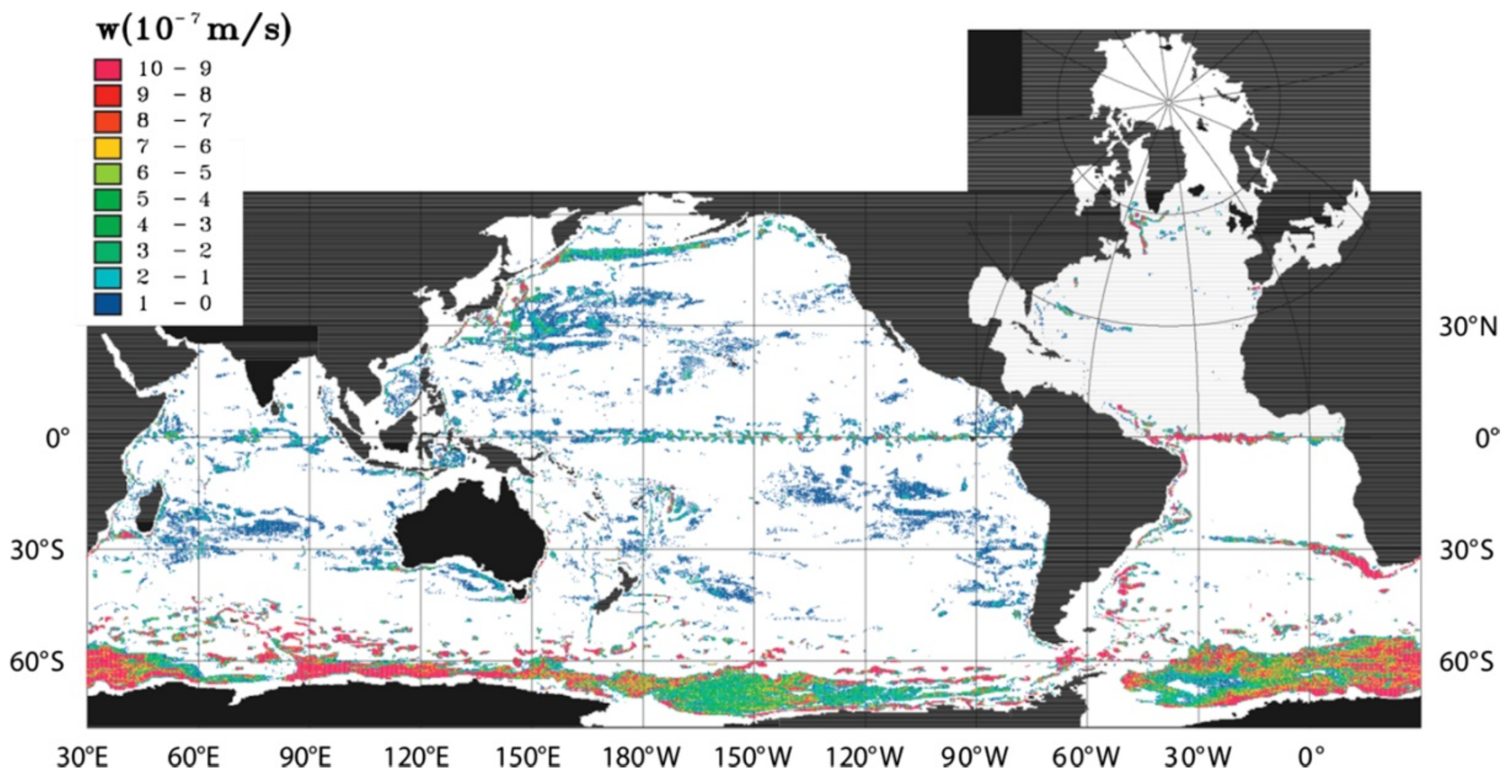
TAMU Oceanography

An oceanographic section





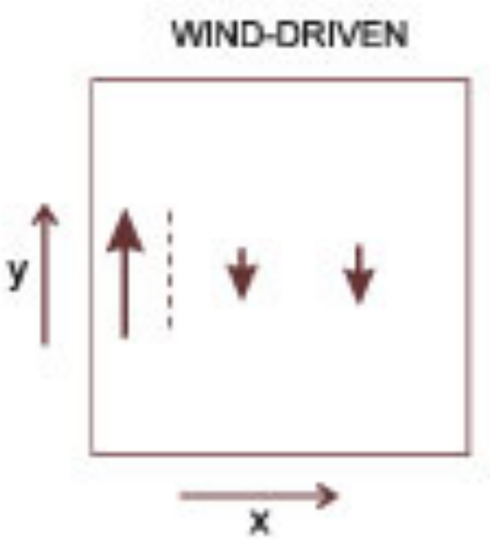




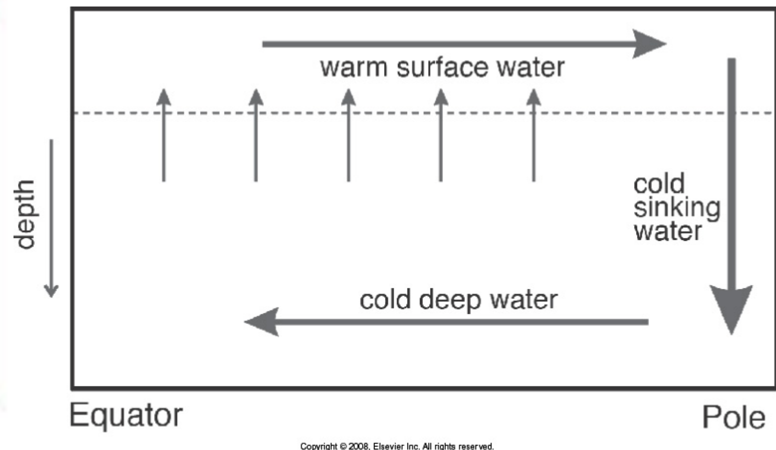
Modeled upwelling across the isopycnal 27.625 kg/m^3, which represents upwelling from the NADW layer. This figure can also be found in the color insert. *Source: From Kuhlbrodt et al. (2007); adapted from Döös and Coward (1997).*

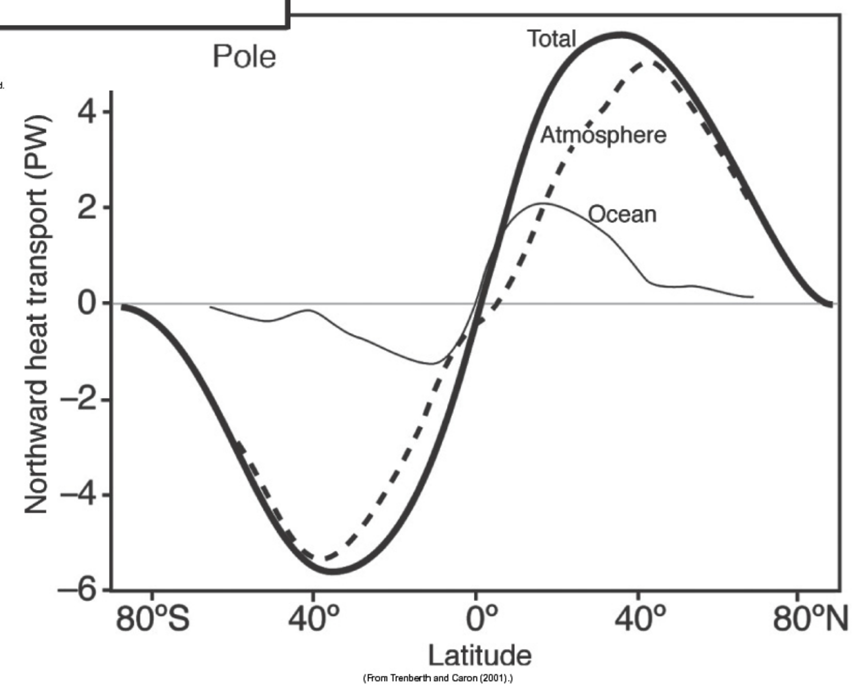
FIGURE 14.7

Heat Transport in Ocean



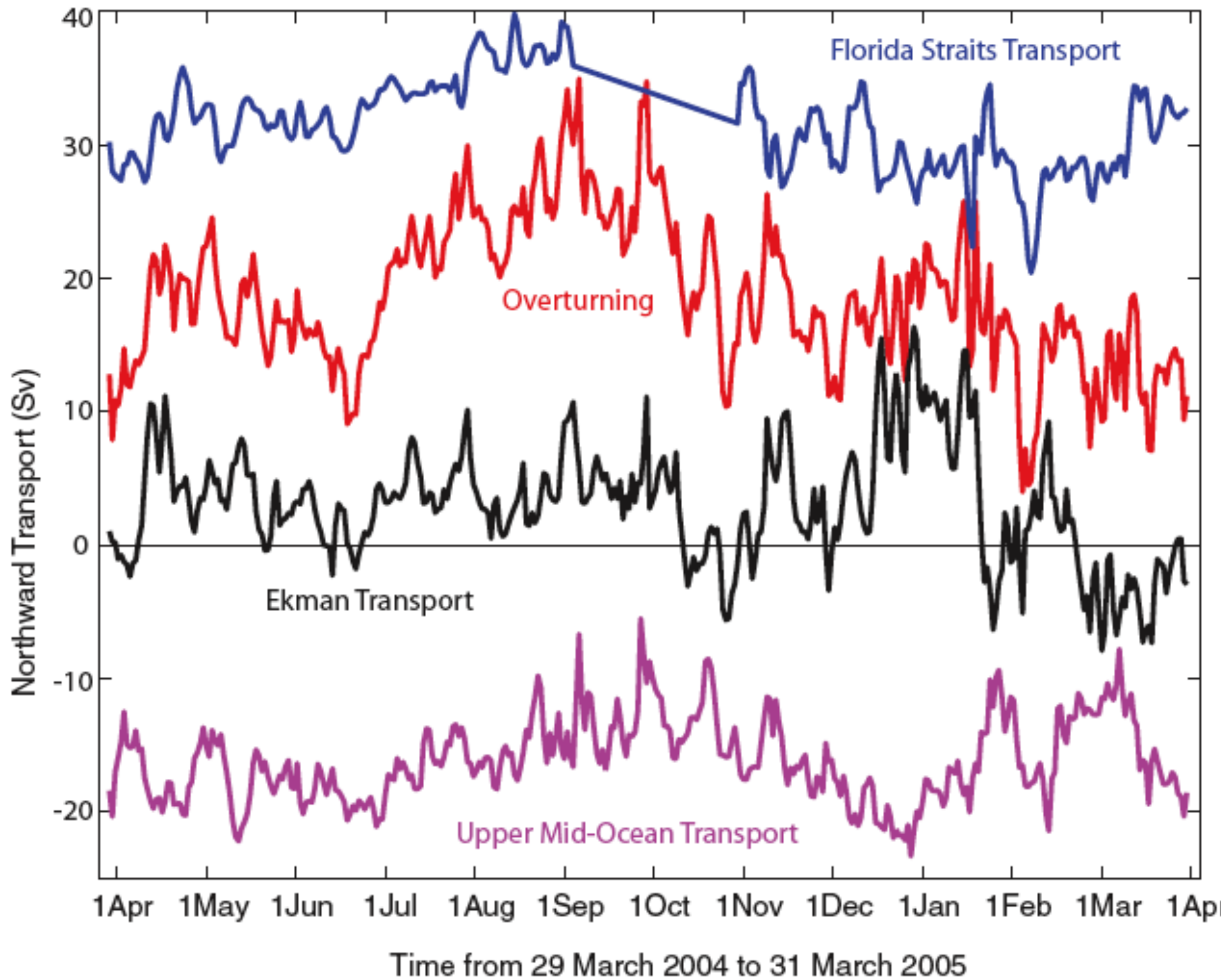
Thermohaline





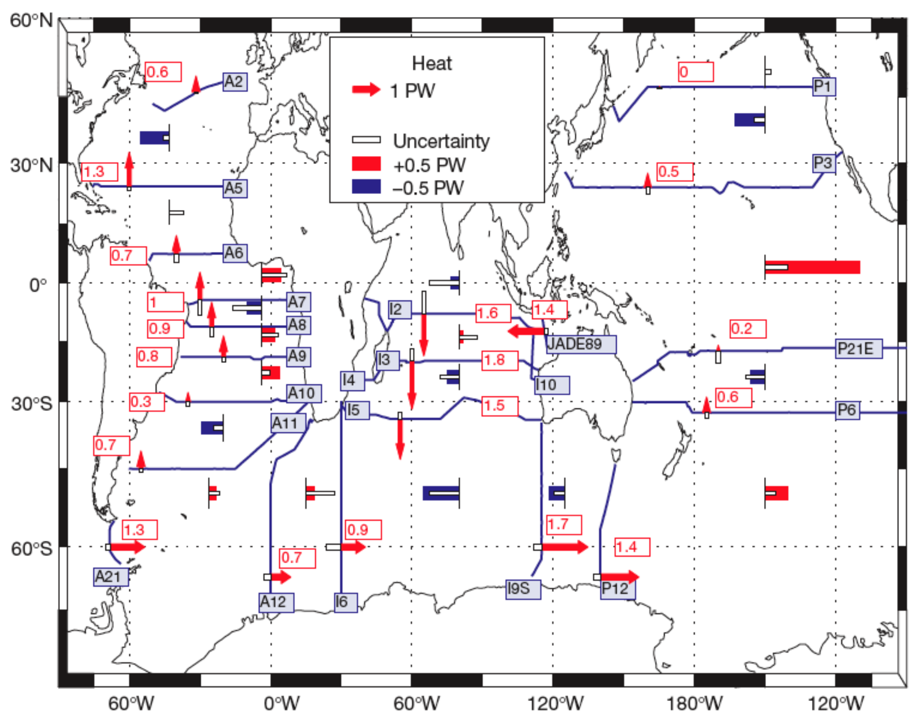
Marshall and Plumb, 2003

Remember – we now know that the intra-annual variability is significant

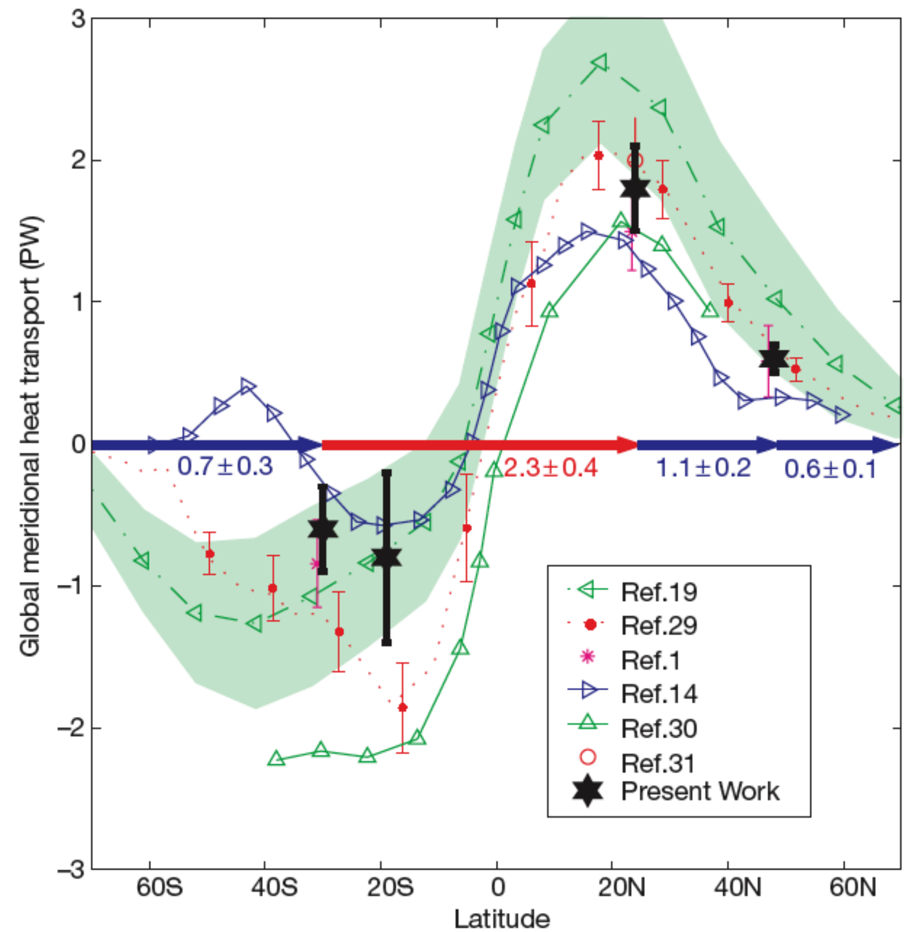


Cunningham et al. 2007

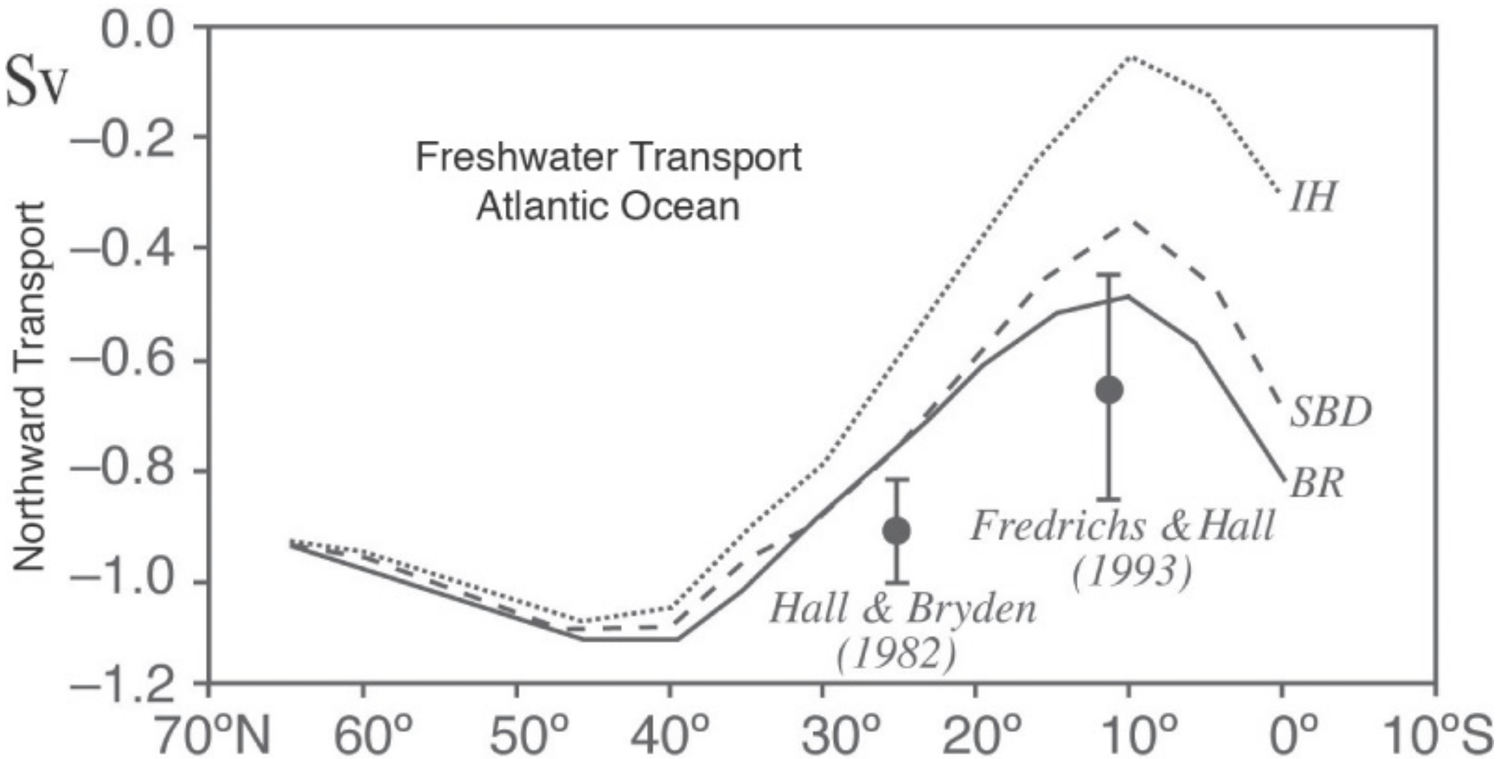
Heat Transport based on same hydrographic inverse model



Ganachaud and Wunsch, 2000



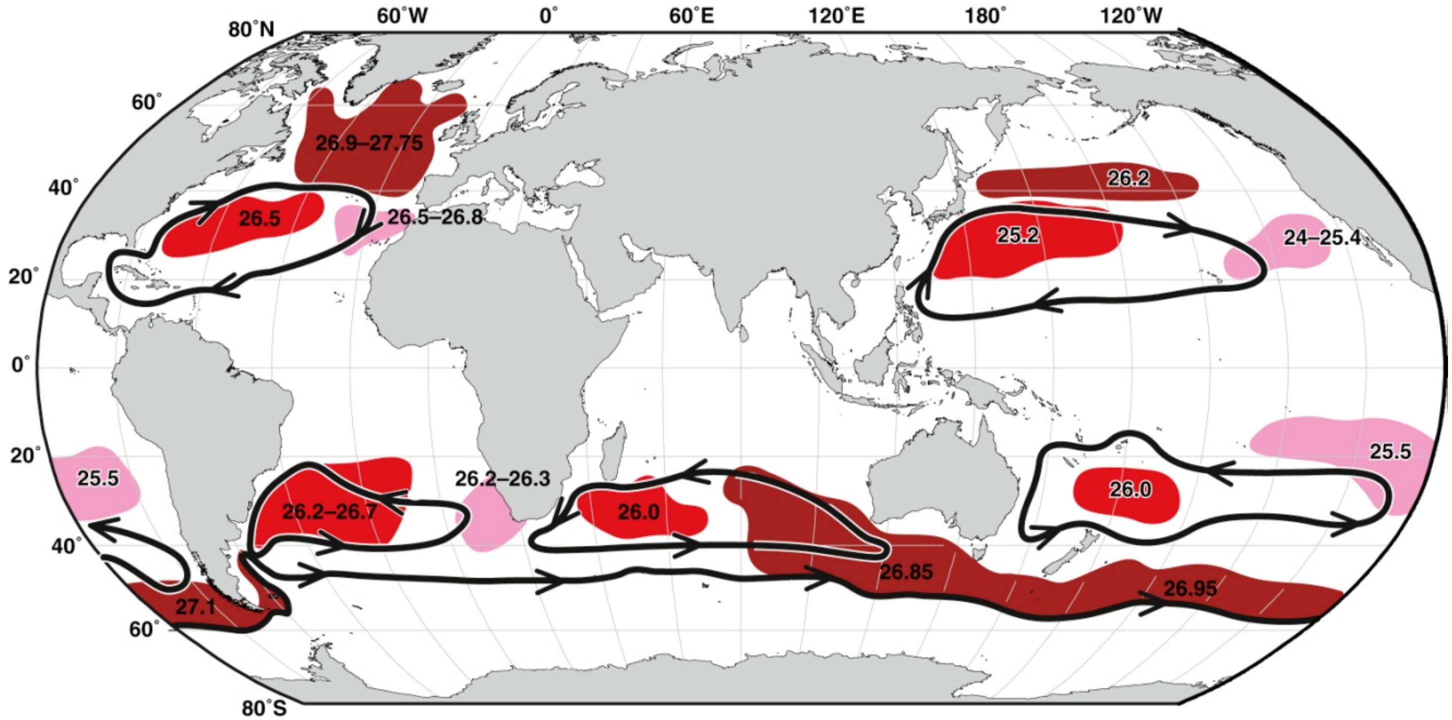
Freshwater Transport by Ocean is Equatorward



(From Schmitt (1994) and Stewart (1995).)

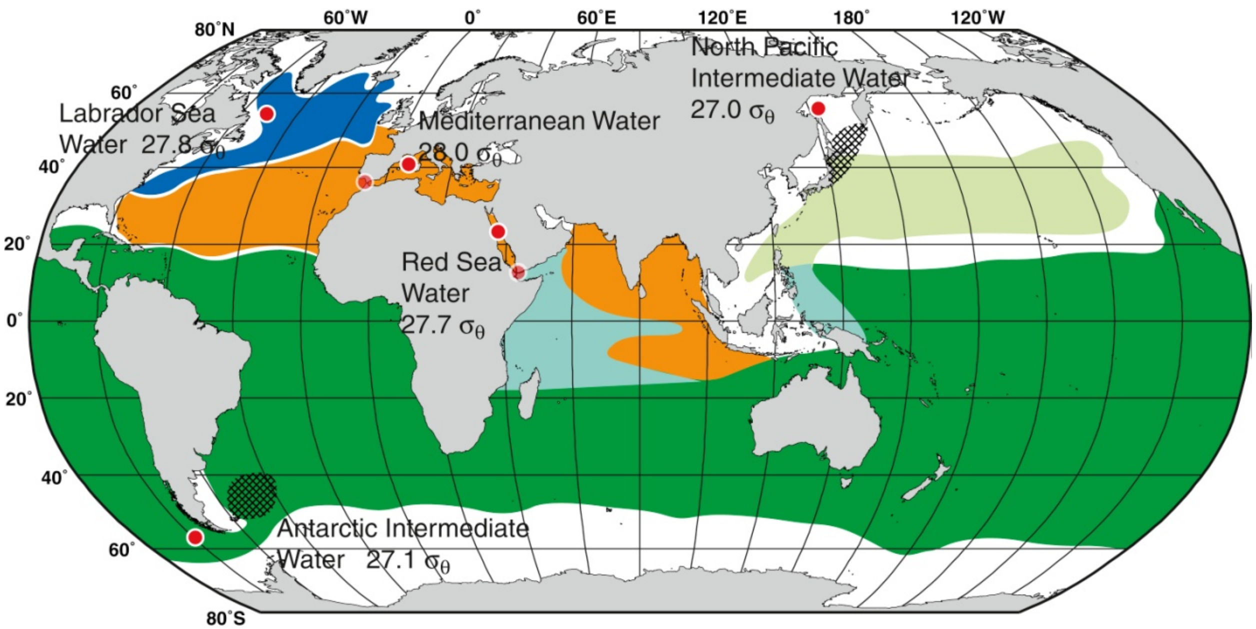
Must be equatorward in steady state to compensate for northward moisture transport by the atmosphere

GLOBAL WATERMASS DISTRIBUTIONS



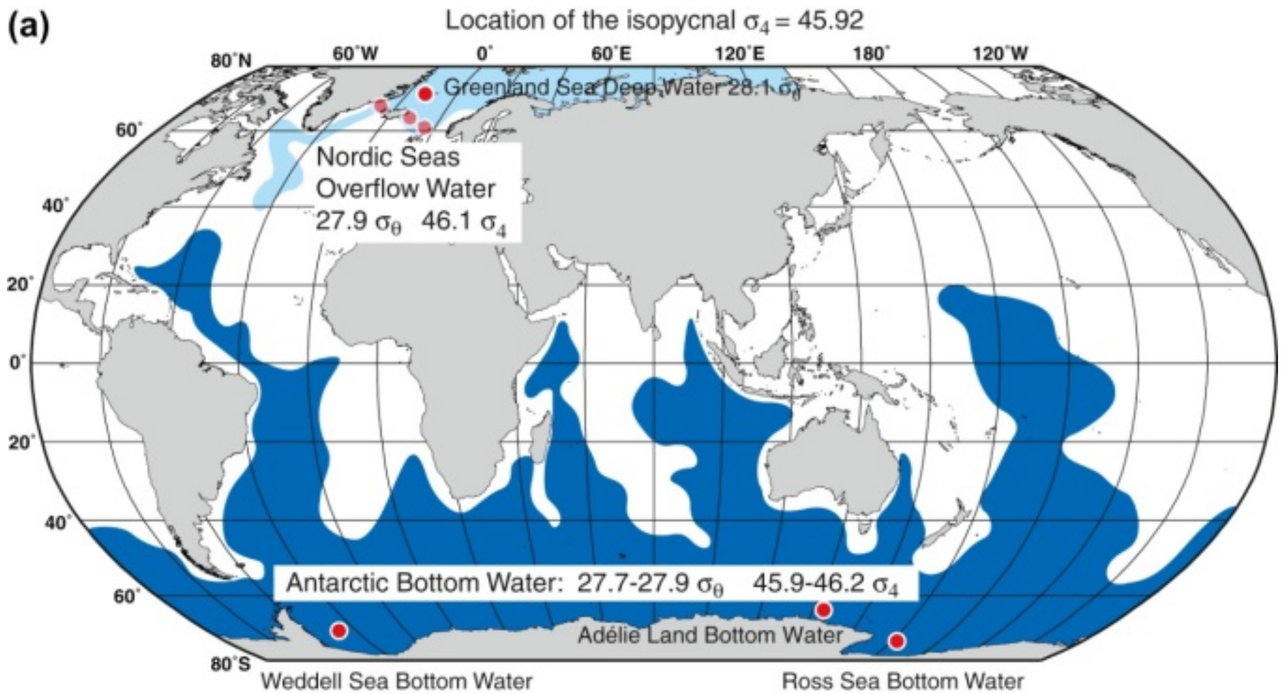
Mode Water distributions, with typical potential densities and schematic subtropical gyre, and ACC circulations. *Source: After Hanawa and Talley (2001).* Medium grays are STMWs in each subtropical gyre. Light grays are eastern STMWs in each subtropical gyre. Dark grays are SPMW (North Atlantic), Central Mode Water (North Pacific), and SAMW (Southern Ocean).

FIGURE 14.12



Low- and high-salinity intermediate waters. AAIW (dark green), NPIW (light green), LSW (dark blue), MW (orange in Atlantic), RSW (orange in Indian). Light blue in Pacific: overlap of AAIW and NPIW. Light blue in Indian: overlap of AAIW and RSW. Cross-hatching: mixing sites that are particularly significant for the water mass. Red dots indicate the primary formation site of each water mass; fainter dots mark the straits connecting the Mediterranean and Red Seas to the open ocean. The approximate potential density of formation is listed. This figure can also be found in the color insert. *Source: After Talley (2008).*

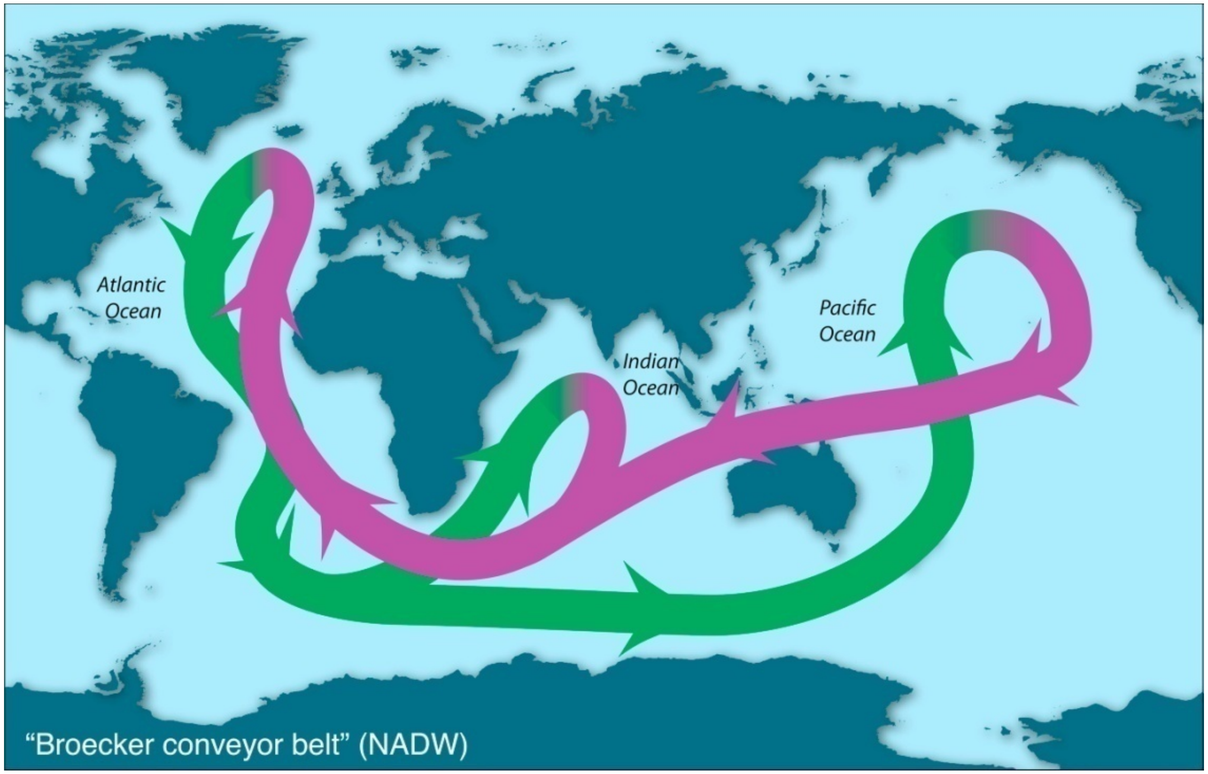
FIGURE 14.13



Deep and bottom waters. (a) Distribution of waters that are denser than s_4 = 45.92 kg/m^3. This is approximately the shallowest isopycnal along which the Nordic Seas dense waters are physically separated from the Antarctic's dense waters. At lower densities, both sources are active, but the waters are intermingled. Large dots indicate the primary formation site of each water mass; fainter dots mark the straits connecting the Nordic Seas to the open ocean. The approximate potential density of formation is listed. *Source: After Talley (1999).* (b) Potential temperature (°C), and (c) salinity at the ocean bottom, for depths greater than 3500 m. *Source: After Mantyla and Reid (1983).*

FIGURE 14.14a

Thermohaline, simplified, 1980's

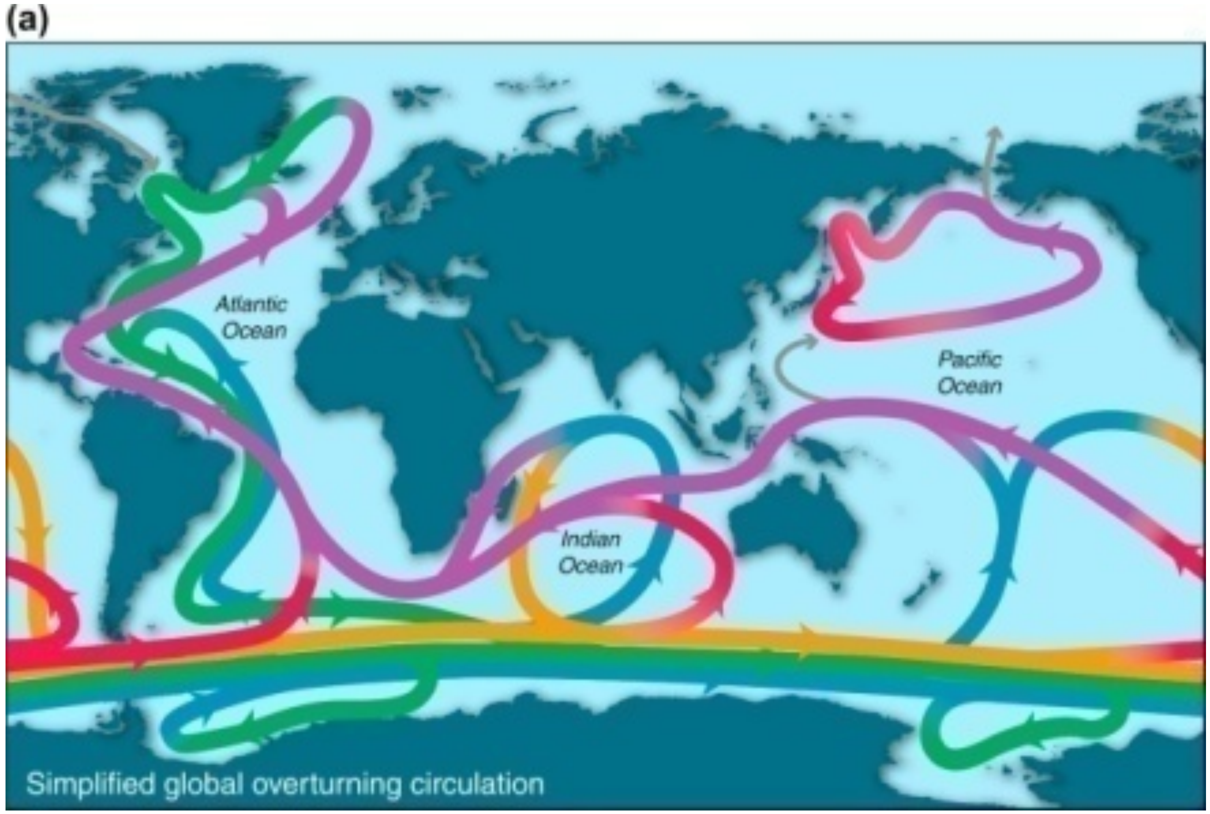


Simplified global NADW cell, which retains sinking only somewhere adjacent to the northern North Atlantic and upwelling only in the Indian and Pacific Oceans. See text for usefulness of, and also issues with, this popularization of the global circulation, which does not include any Southern Ocean processes. *Source: After Broecker (1987).*

TALLEY

FIGURE 14.10

Thermohaline, still simplified, 2000's



Global overturning circulation schematics. (a) The NADW and AABW global cells and the NPIW cell. (b) Overturn from a Southern Ocean perspective. *Source: After Gordon (1991), Schmitz (1996b), and Lumpkin and Speer (2007).* (c) Two-dimensional schematic of the interconnected NADW, ID
W, PDW, and AABW cells. The schematics do not accurately depict locations of sinking or the broad geographic scale of upwelling. Colors: surface water (purple), intermediate and Southern Ocean mode water (red), PDW/IDW/UCDW (orange), NADW (green), AABW (blue). See Figure S14.1 on the textbook Web site for a complete set of diagrams. This figure can also be found in the color insert. *Source: From Talley (2011).*

TALLEY

FIGURE 14.11a

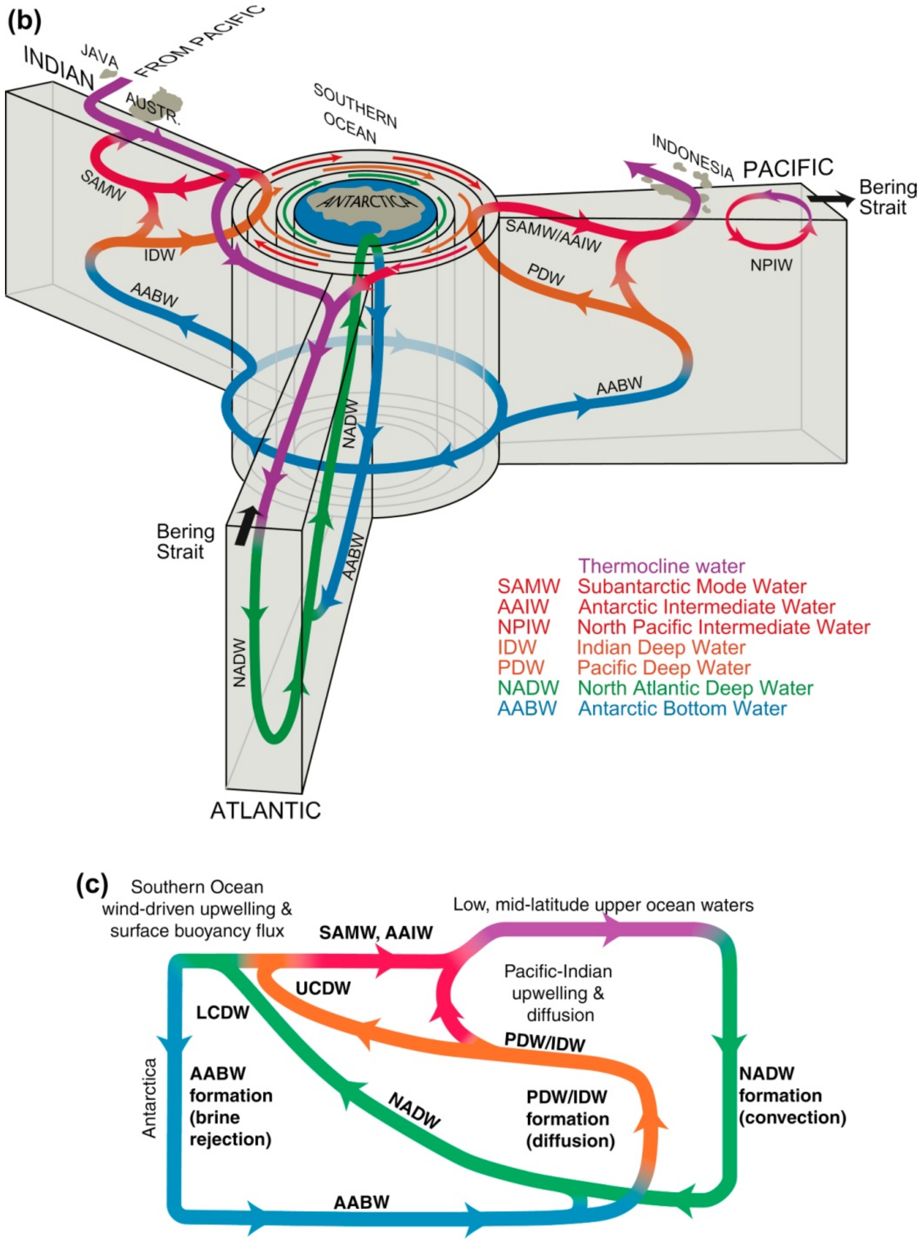
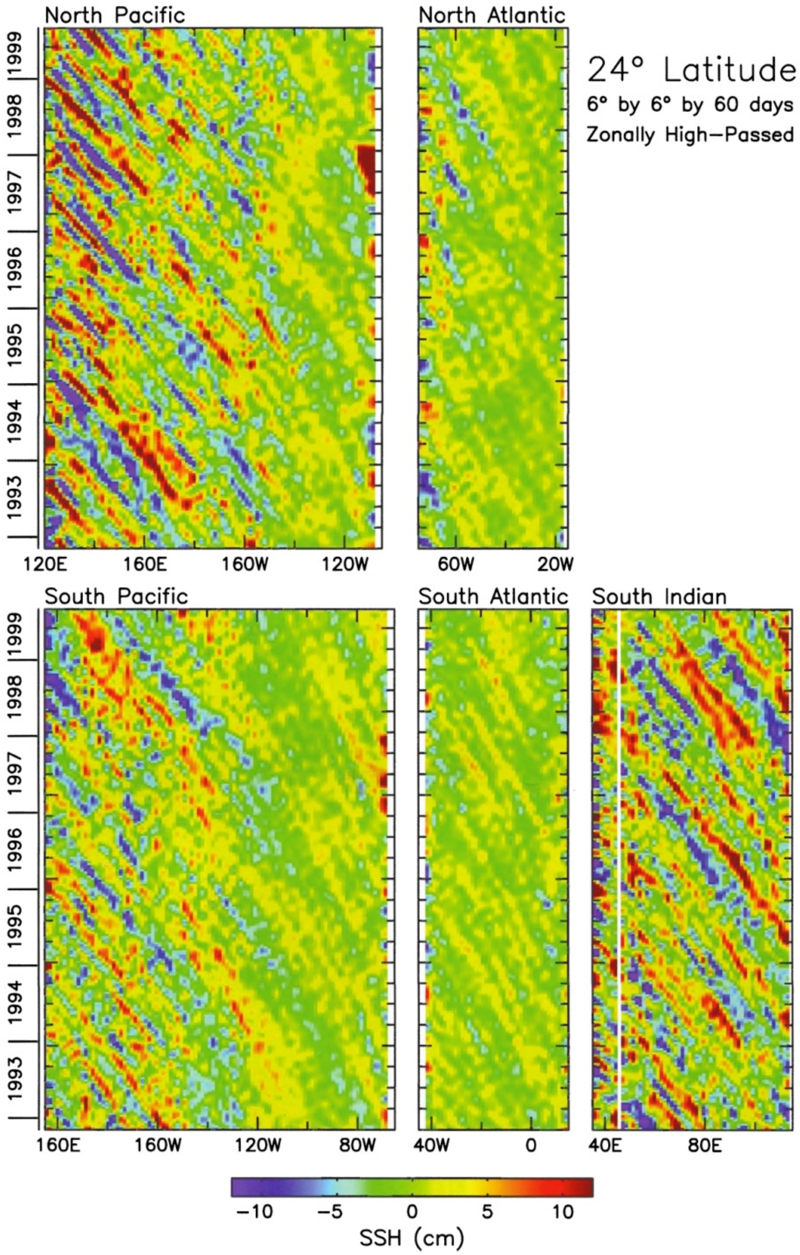


FIGURE 14.11bc

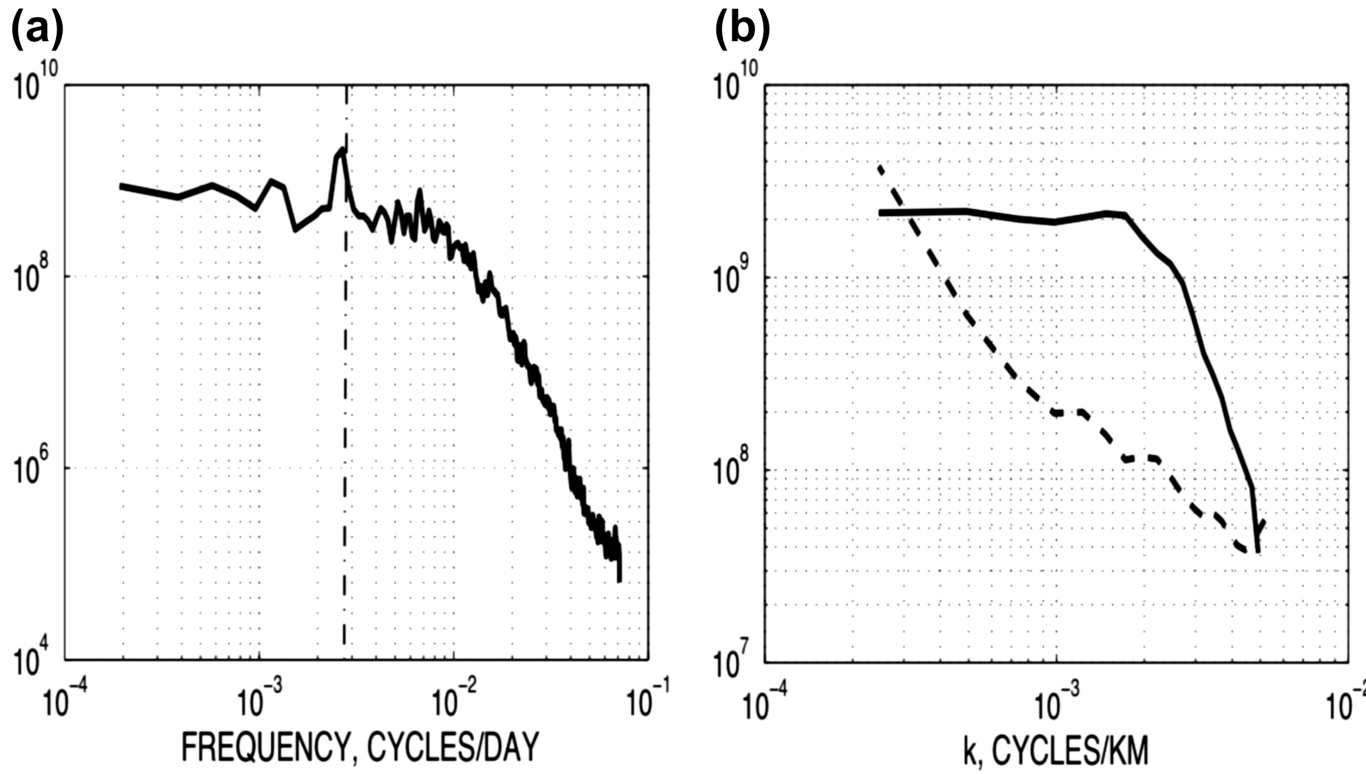
Global overturning circulation schematics. (a) The NADW and AABW global cells and the NPIW cell. (b) Overturn from a Southern Ocean perspective. Source: After Gordon (1991), Schmitz (1996b), and Lumpkin and Speer (2007). (c) Two-dimensional schematic of the interconnected NADW, IDW, PDW, and AABW cells. The schematics do not accurately depict locations of sinking or the broad geographic scale of upwelling. Colors: surface water (purple), intermediate and Southern Ocean mode water (red), PDW/IDW/UCDW (orange), NADW (green), AABW (blue). See Figure S14.1 on the textbook Web site for a complete set of diagrams. This figure can also be found in the color insert. Source: From Talley (2011).

EDDIES



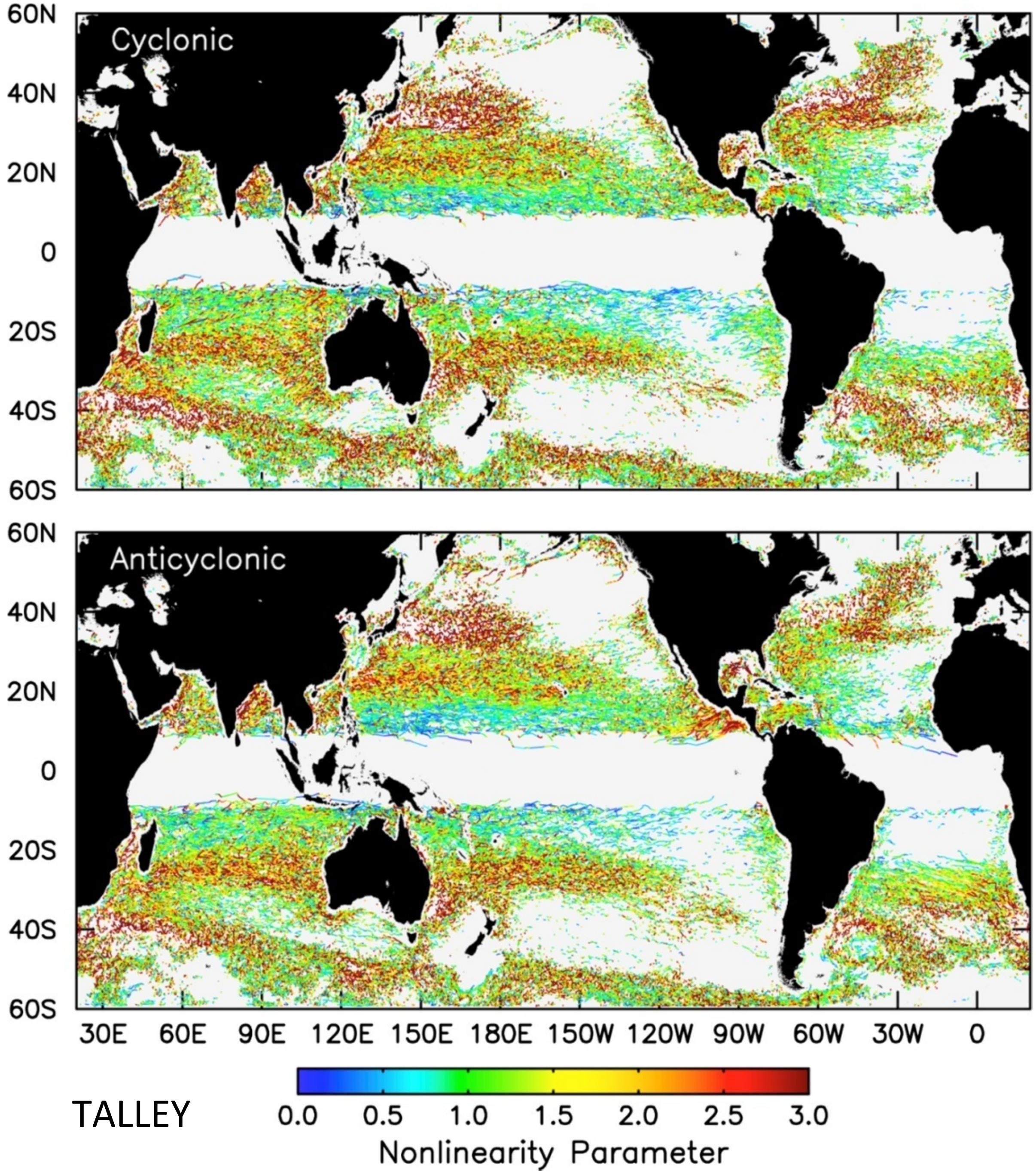
Surface-height anomalies at 24 degrees latitude in each ocean, from a satellite altimeter. This figure can also be found in the color insert. *Source: From Fu and Chelton (2001).*

FIGURE 14.18



(a) Frequency and (b) wavenumber spectra of SSH in the eastern subtropical North Pacific, using 15 years of satellite altimetry observations. The dashed line in (a) is the annual frequency. In the wavenumber panel, solid is westward propagating, and dashed is eastward propagating energy. *Source: From Wunsch (2009).*

FIGURE 14.20



TALLEY

Tracks of coherent cyclonic and anticyclonic eddies with lifetimes of more than 4 weeks, based on altimetric SSH, color coded by a "nonlinearity parameter," which is the ratio of velocity within the eddy compared with the eddy propagation speed. White areas indicate no eddies or trajectories within 10 degrees latitude of the equator. This figure can also be found in the color insert. *Source: From Chelton et al. (2007).*

FIGURE 14.21