SIO 210 Advection, transports, budgets
L. Talley, Fall, 2011

Reading: DPO Chapter 5

- Transport, flux
- Radiation, Advection, Diffusion
- Conservation of volume
- Continuity
- Conservation of salt
- Freshwater transport
- Heat budget
- Heat transport

Course url: http://www-pord.ucsd.edu/~ltalley/sio210

Assignments and exams

Upcoming

Assignment 1: due Oct. 10 (Monday)

Mid-term: 10/31

Paper or project due: 11/14 (interim dates: 10/24 for topic)

Paper:

One historical "classic" paper

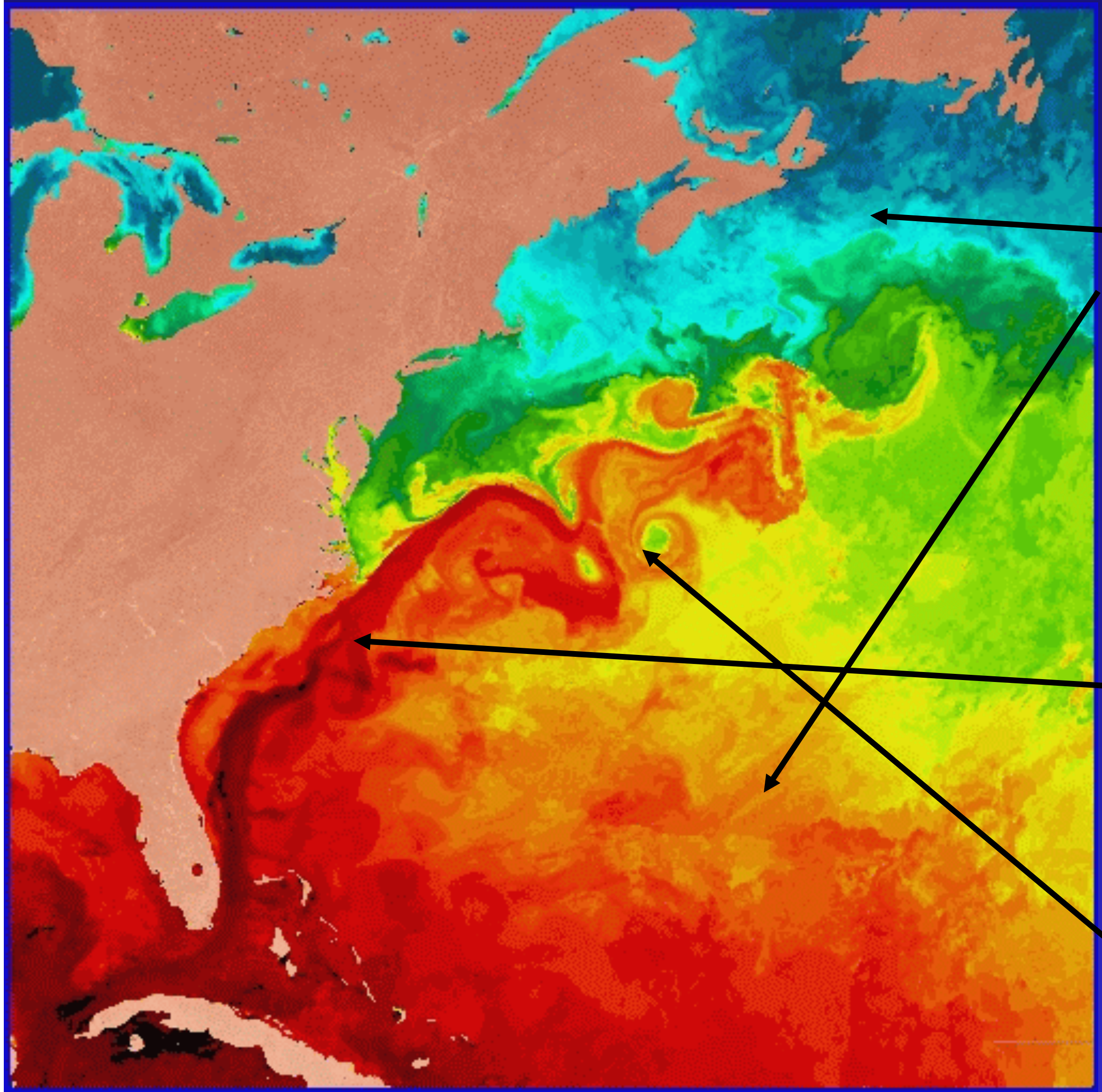
One modern paper.

Review papers with emphasis on concept/breakthrough in "classic" paper and how it was continued in modern paper. What were the simplifications in the original paper? What is still unresolved with the modern paper?

OR DPO JOA project

Work with the JOA examples, define a large-scale phenomenon to look at with profile data within JOA, and write a short description of results

Transport processes: radiation, advection, diffusion



(1) The surface heat balance, including radiation, makes the ocean warmer to the south, colder to the north (Northern Hemisphere).

(2) The Gulf Stream flows northward, advecting warm water.

(3) Eddies diffuse the heat.

Radiation, Advection, Diffusion

- Radiation: electromagnetic waves carry heat energy - sunlight, infrared radiation
- Advection: carry properties in currents
- Diffusion: moves properties through random motions, so somewhat similar to advection

Convergence and divergence of property fluxes can change local property

- Advection: convergence or divergence of the property flux
- Diffusion: convergence or divergence of the diffusive flux (next lecture – effects of mixing)

Flux and transport: definitions

- Flux of a property

Velocity times concentration (times density)

Flux = vρC

units of

(m/sec)(kg/m^3)(moles/kg) = moles/(m^{2}sec)

(same as Transport per unit area)

~~Special cases:~~

~~Volume transport is velocity times area~~

~~Units are~~

~~(m/sec) m^2 = m^3/sec~~

Mass flux is velocity x density

Units are

(m/sec)(kg/m^3) = kg/(sec m^2)

Transport and flux: definitions

- Transport

Velocity times concentration (times density) integrated (summed) over area normal to the velocity

Transport = $\iint v \rho C dA$

units of

(m/sec)(kg/m^3)(moles/kg) m^2 = moles/sec

(same as Flux normal to an area integrated over that area.)

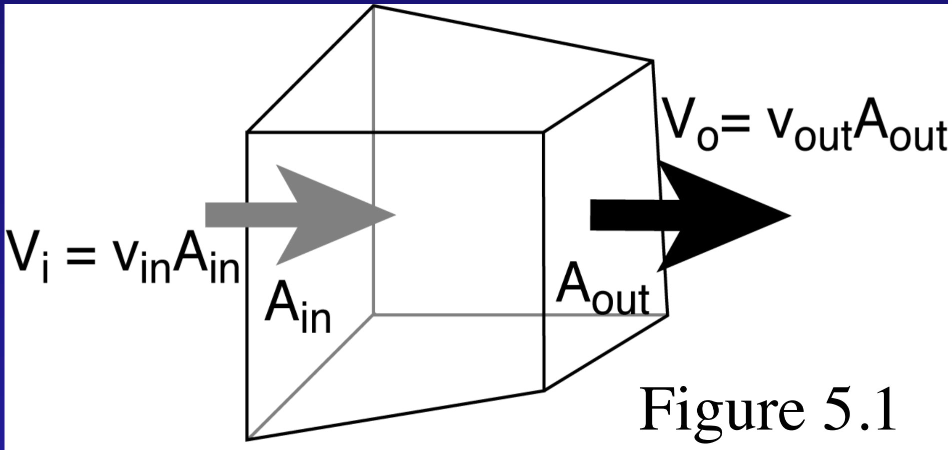


Figure 5.1

Special cases:

Volume transport is velocity times area

Units are (m/sec) m^2 = m^3/sec

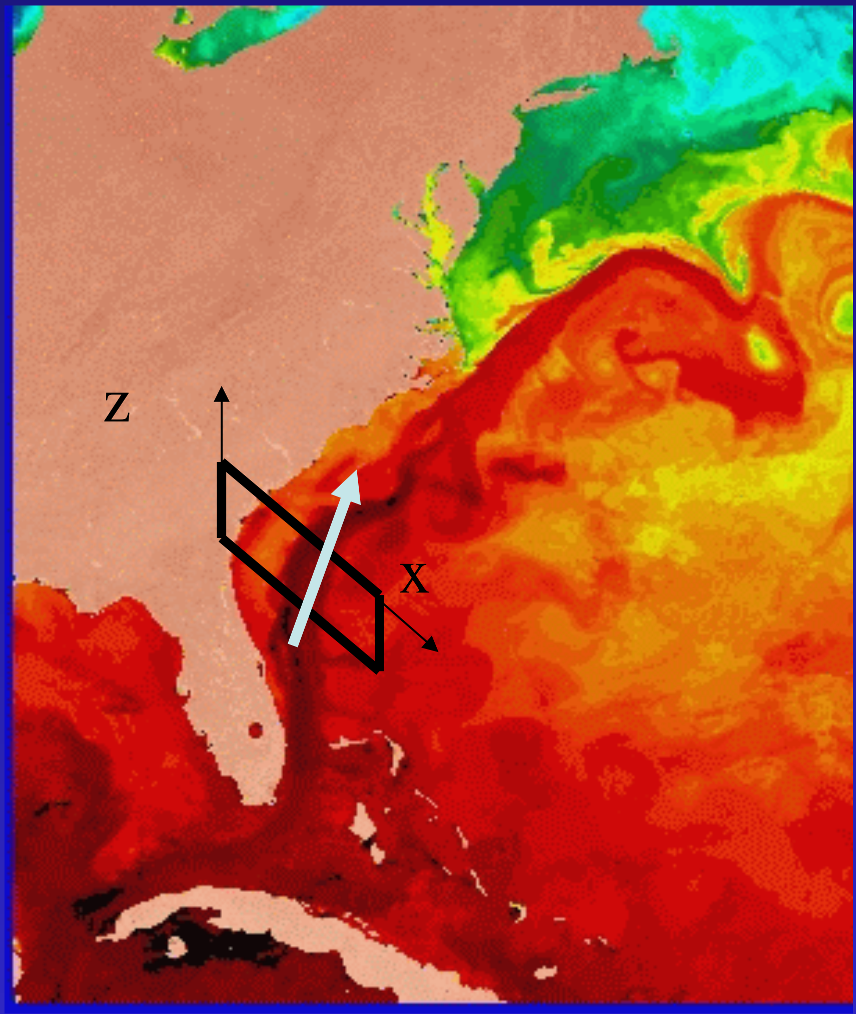
Mass transport is velocity x density x area

Units are

(m/sec)(kg/m^3)m^2 = kg/sec

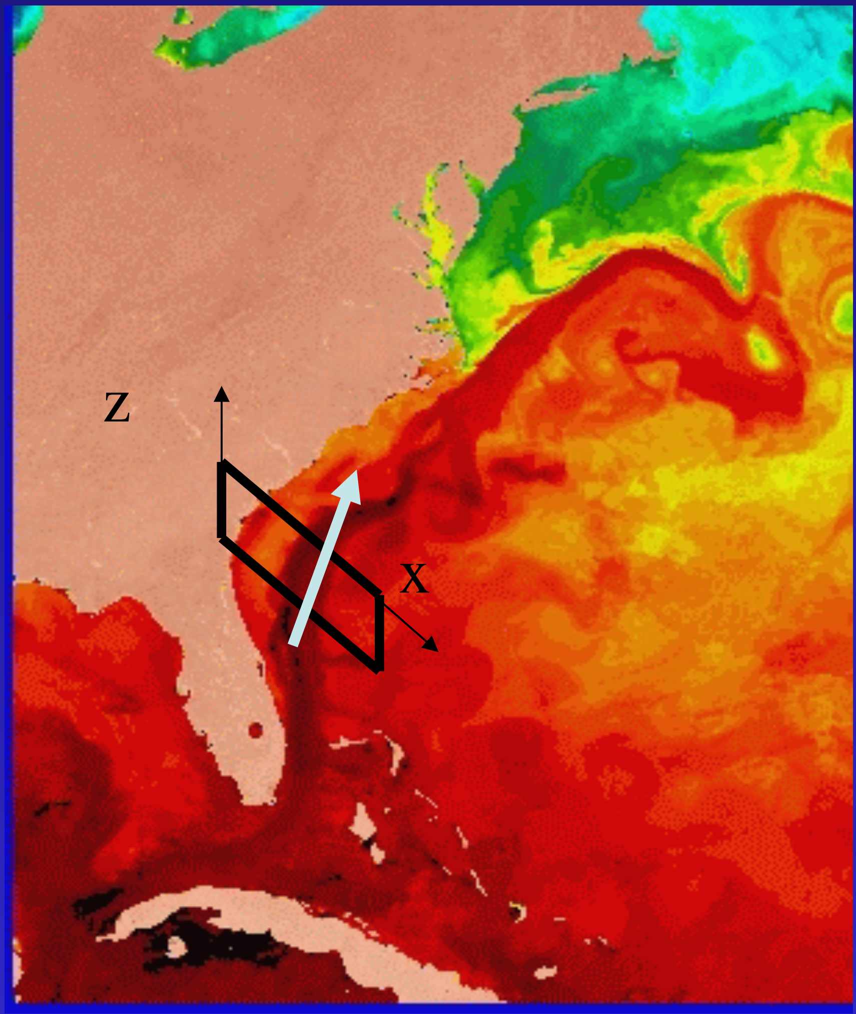
Quantify transport resulting from advection

- Gulf Stream advects volume, mass, warm water northward
- How much water, how much mass is carried by the G.S past a certain point ?
- Draw a vertical plane across the current (x,z are across-stream and vertical)
- Measure current velocity at each point in the plane, normal to the plane
- Compute volume transport (velocity times area) for each small location in the plane and add them up (integrate) for total transport through the cross-section



Quantify volume transport (advection) (example)

- Gulf Stream velocities are about 5 cm/sec at the bottom, up to more than 100 cm/sec at the top of the ocean. Assume an average of 20 cm/sec for this simple calculation.
- Assume a width of the current of 100 km
- Assume a depth of the current of 5 km
- The area of the G.S. is then 500 km^2
- Volume transport is then 20 cm/sec x 500 km^2 = 100 x 10^6 m^3/sec = 100 Sv



Transport definitions

- Transport: add up (integrate) velocity time property over the area they flow through (or any area - look at velocity "normal" to that area)

- Volume transport = integral of velocity v m^3/sec
- Mass transport = integral of density x velocity ρv kg/sec
- Heat transport = integral of heat x velocity $\rho c_p T v$ J/sec=W
- Salt transport = integral of salt x velocity $\rho S v$ kg/sec
- Freshwater transport = integral of Fwater x velocity $\rho(1\text{-}S)v$ kg/sec
- Chemical tracers = integral of tracer concentration (which is in μmol/kg) x velocity $\rho C v$ moles/sec

- Flux is just these quantities per unit area

Transport definitions: more quantitative

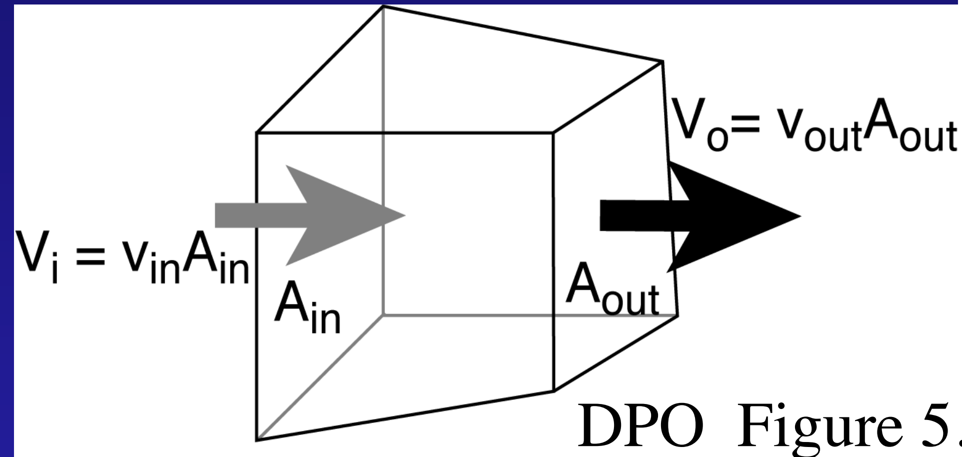
- Volume transport = $V = \sum v_i A_i = \iint v\,dA$ m³/sec
- Mass transport = $M = \sum \rho\, v_i A_i = \iint \rho v\,dA$ kg/sec
- Heat transport = $H = \sum \rho\, c_p T v_i A_i = \iint \rho c_p T v\,dA$ J/sec=W
- Salt transport = $\mathscr{S} = \sum \rho\, S v_i A_i = \iint \rho S v\,dA$ kg/sec
- Freshwater transport = $F = \sum \rho\,(1\text{-}S)\, v_i A_i = \iint \rho (1 - S) v\,dA$ kg/sec
- Chemical tracers = $C = \sum \rho\, C v_i A_i = \iint \rho C v\,dA$ moles/sec

- Flux is just these quantities per unit area
  e.g. volume flux is V/A, mass flux is M/A,
  heat flux is H/A, salt flux is $\mathscr{S}$/A, freshwater flux is F/A, C /A

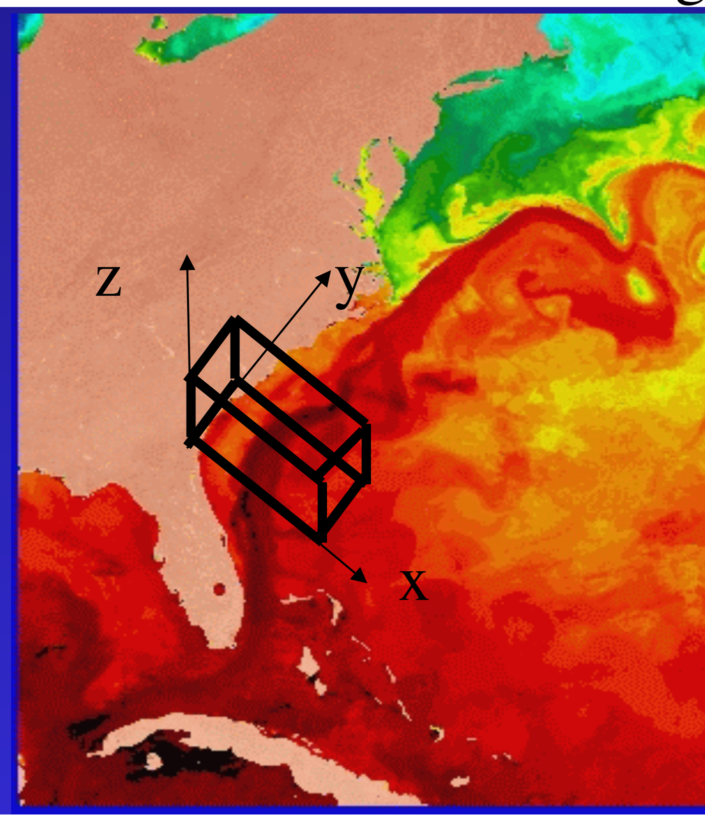
Conservation of volume and Continuity

- Continuity: transport into a box must equal the transport out of the box
- A very very small residual for evaporation and precipitation, which we usually neglect when looking at volume and mass balance.

- (We will actually account for it on the next slide when looking at freshwater balance rather than volume and mass balance)
- Compute transport through each face of the volume. Total must add to 0
- (NO HOLES)



DPO Figure 5.1



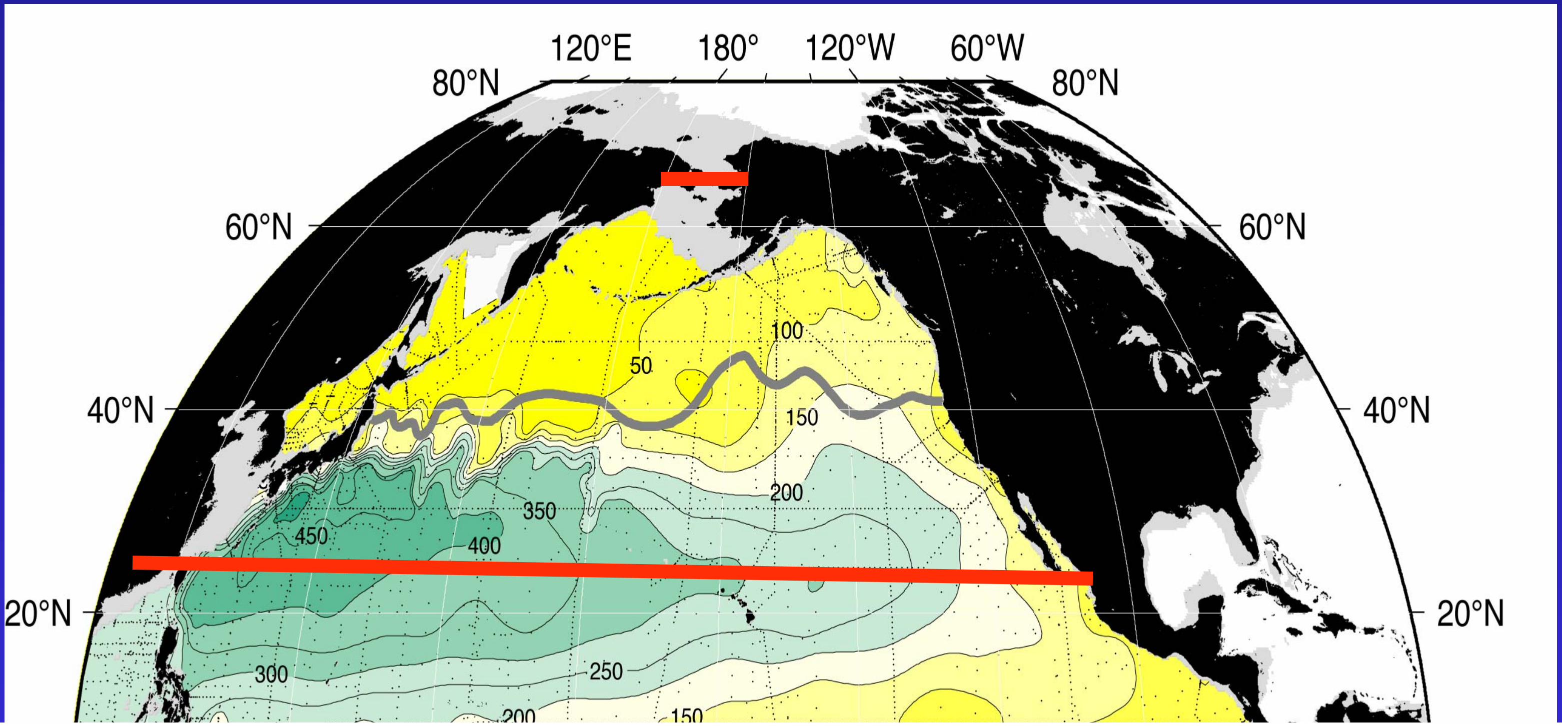
Continuity (conservation of volume): NO HOLES

- Continuity in 1-D, 2-D, 3-D (at board)
- 1D: $0 = \Delta u/\Delta x = \partial u/\partial x$
- 2D: $0 = \Delta u/\Delta x + \Delta v/\Delta y = \partial u/\partial x + \partial v/\partial y$
- 3D: $0 = \Delta u/\Delta x + \Delta v/\Delta y + \Delta w/\Delta z = \partial u/\partial x + \partial v/\partial y + \partial w/\partial z$
- (Net convergence or divergence within the ocean results in mounding or lowering of sea surface, or within isopycnal layers, same thing) NO holes in the ocean

Conservation of volume and Continuity

- Much extreme example, for entire North Pacific
- The total volume (mass) transport in the north/south (meridional) direction across a coast-to-coast vertical cross-section (extending top to bottom)

  MUST EQUAL
- The total volume transport through Bering Strait



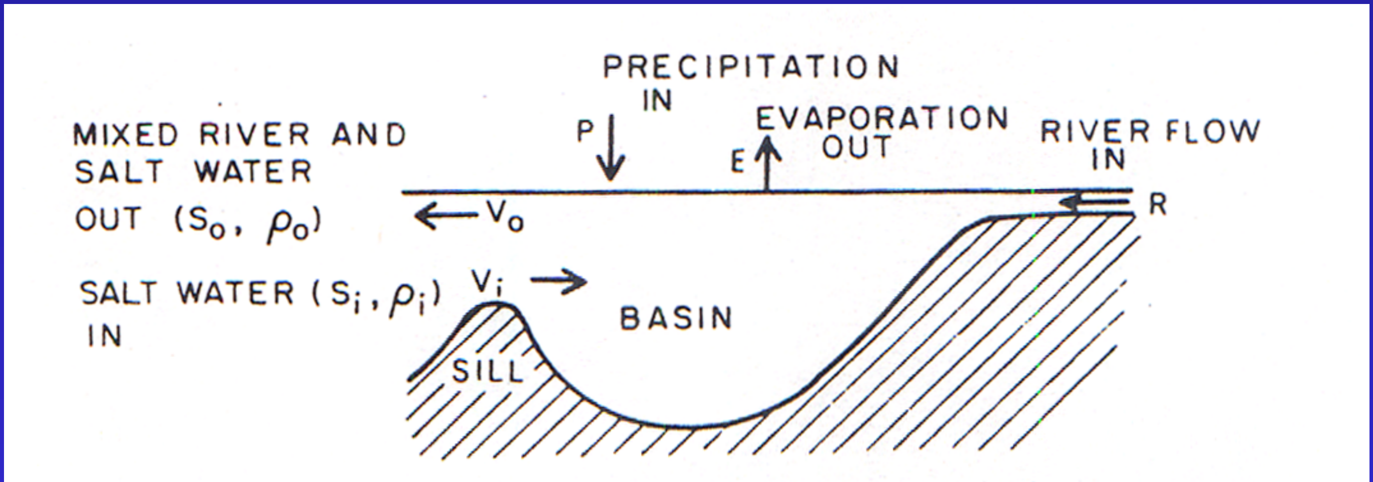
Conservation of volume, salt

(1) Mass conservation:

$$F \equiv \rho_o V_o - \rho_i V_i = (R + AP) - AE$$

(F = "freshwater" = net amount of rain, evaporation, runoff into the area)

(2) Salt conservation: $V_i \rho_i S_i = V_o \rho_o S_o$



DPO Fig. 5.1

Conservation of freshwater

Mass: $F = \rho_o V_o - \rho_i V_i = (R + AP) - AE$

Salt: $\xi = V_o \rho_o S_o - V_i \rho_i S_i = 0$

Salt divided by an arbitrary constant, about equal to mean salinity:

$\xi / S_m = V_o \rho_o S_o / S_m - V_i \rho_i S_i / S_m = 0$

Subtract $F - \xi / S_m = F - 0$

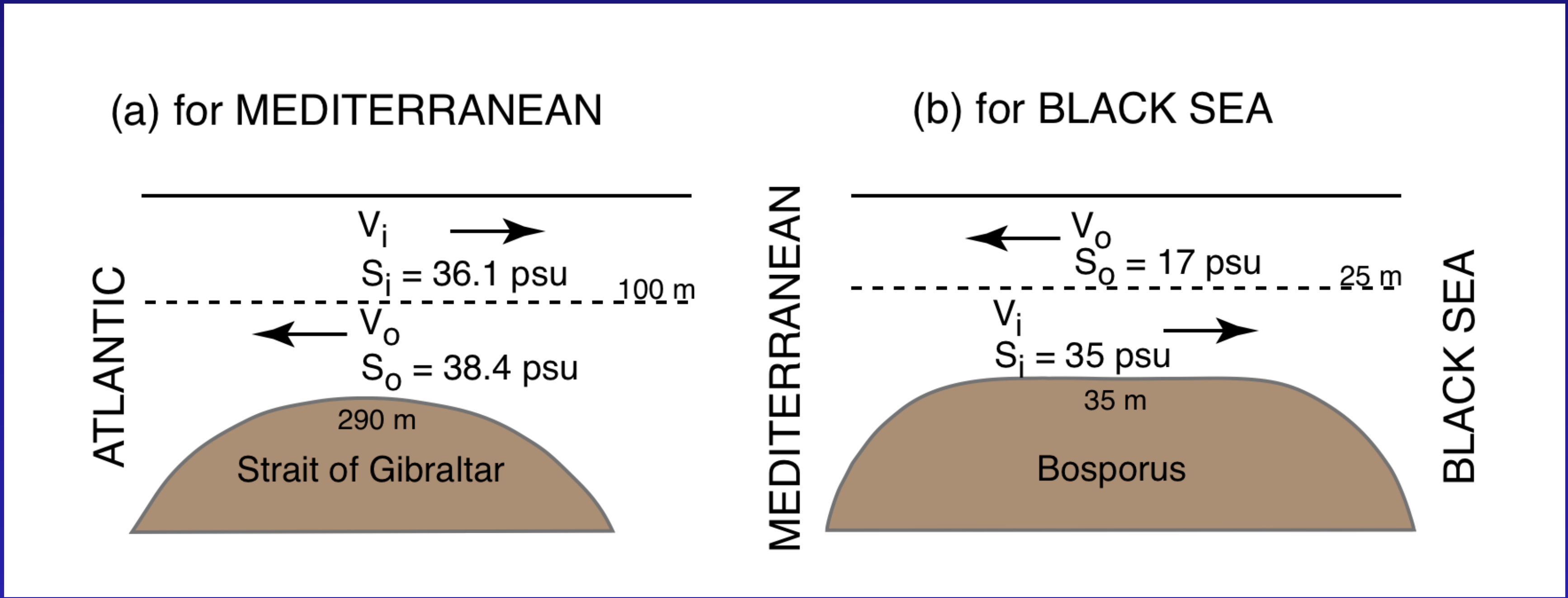
$F - \xi / S_m = \rho_i V_i (1 - S_i / S_m) - \rho_o V_o (1 - S_o / S_m)$

Assume $\rho_i V_i \sim \rho_o V_o = \rho V$ given error in observations, so

$F \sim \rho V (S_o / S_m - S_i / S_m)$

So the freshwater input calculated from the difference in salinity between inflow and outflow equals the net precipitation, evaporation, runoff

Mediterranean and Black Seas

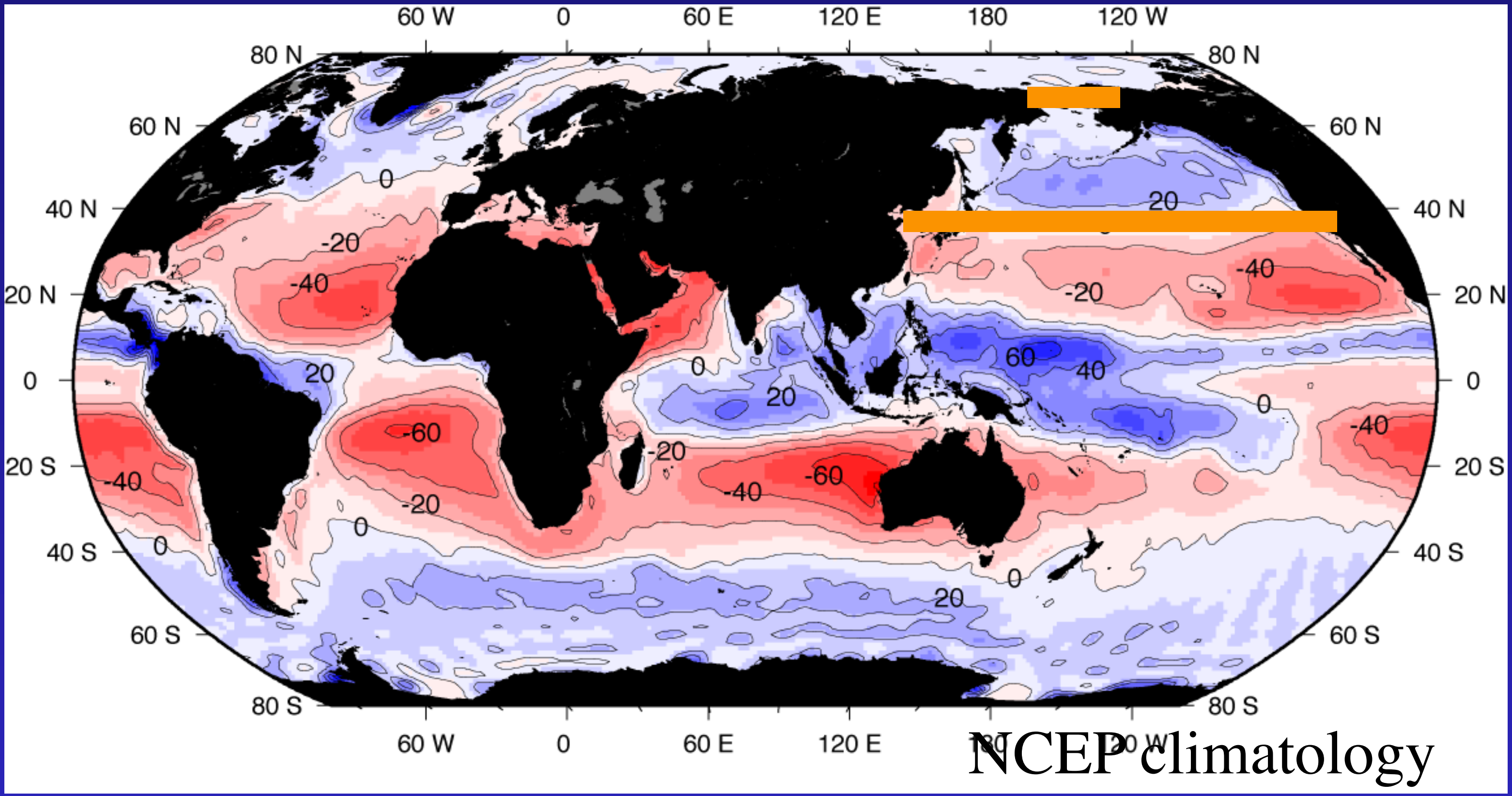


Evaporative basin

Runoff/precipitation

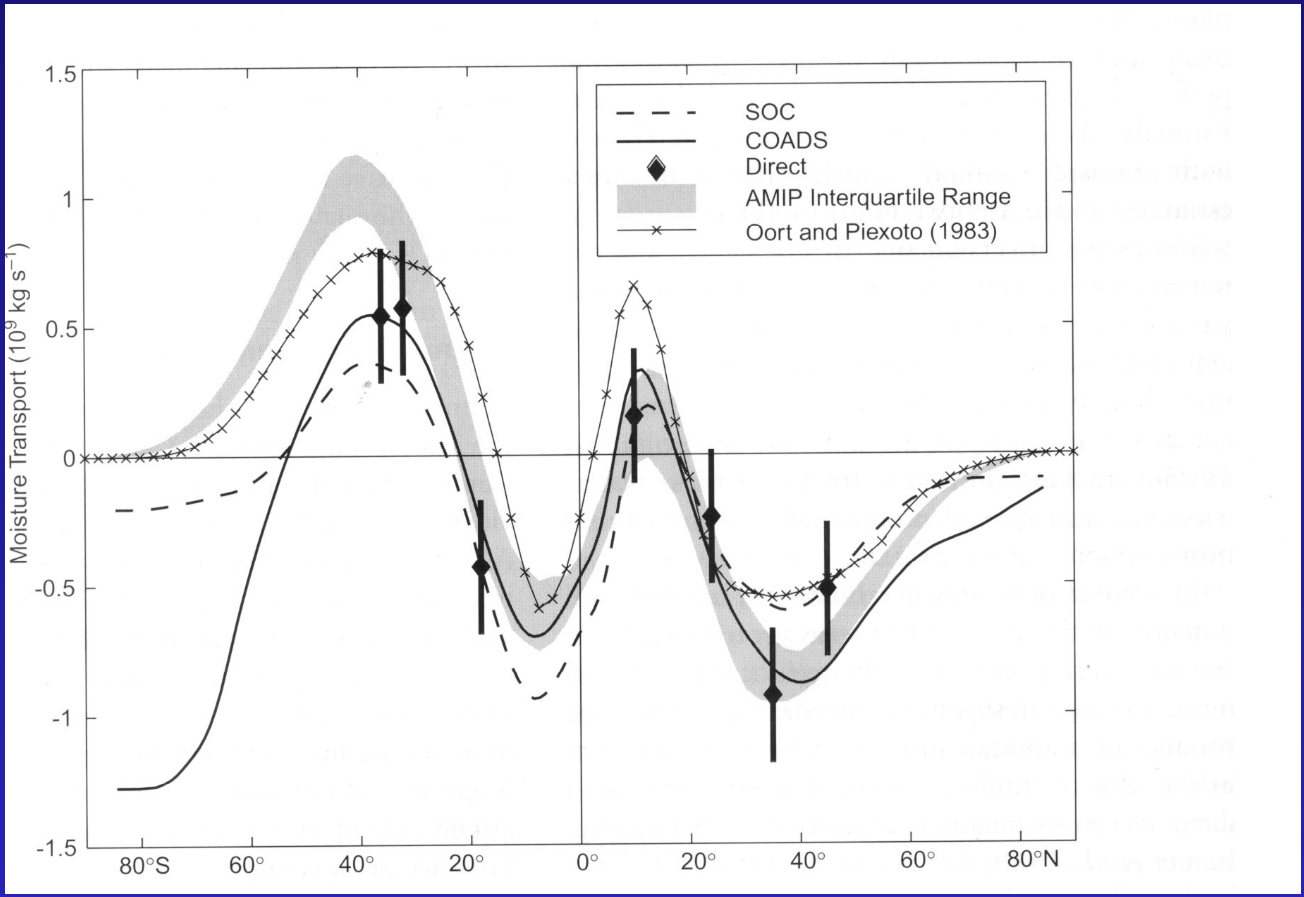
DPO Figure 5.3

Precipitation minus evaporation (cm/yr): what freshwater transports within the ocean are required to maintain a steady state salinity distribution in the ocean given this P-E?



- Consider N. Pacific box, Bering Strait to north, complete east-west crossing between net P and net E areas, for example
- Total freshwater transport by ocean out of this box must equal the P-E
- FW transport across the long section must equal take up all the rest of the net P-E in the area to the north, after Bering Strait is subtracted

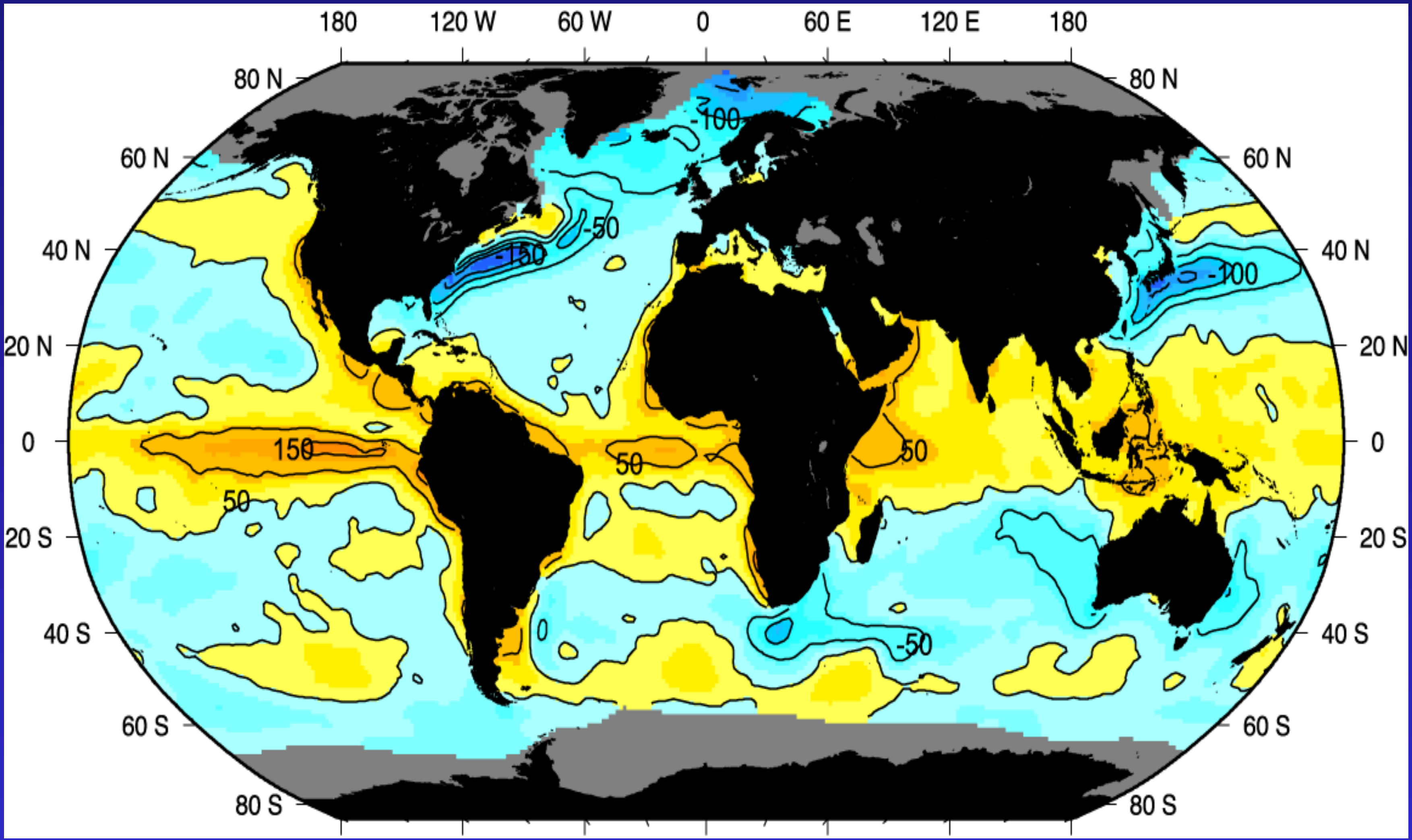
Global ocean freshwater transport



Wijffels (2001)

- Continuous curves show different estimates of ocean FW transport based on observed P-E+R (atmosphere and rivers)
- Diamonds with error bars are estimates of FW transports based on ocean velocities and salinities

Heat and heat transport
Surface heat flux (W/m^2) into ocean

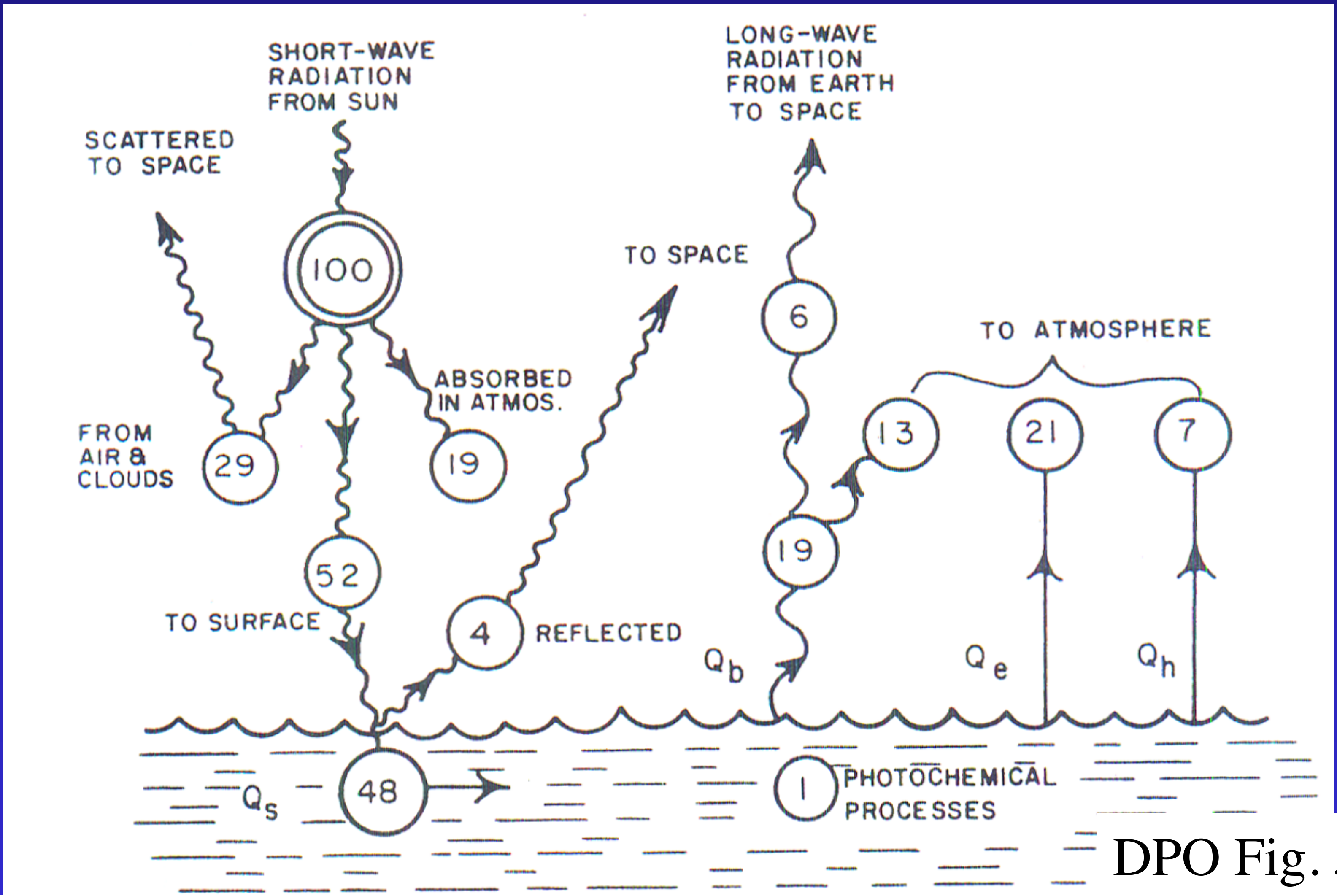


DPO Figure 5.12

Ocean heat balance, including radiation

$$Q_{sfc} = Q_s + Q_b + Q_h + Q_e \qquad \text{(in W/m}^2\text{)}$$

Total surface heat flux = Shortwave + Longwave + Latent + Sensible

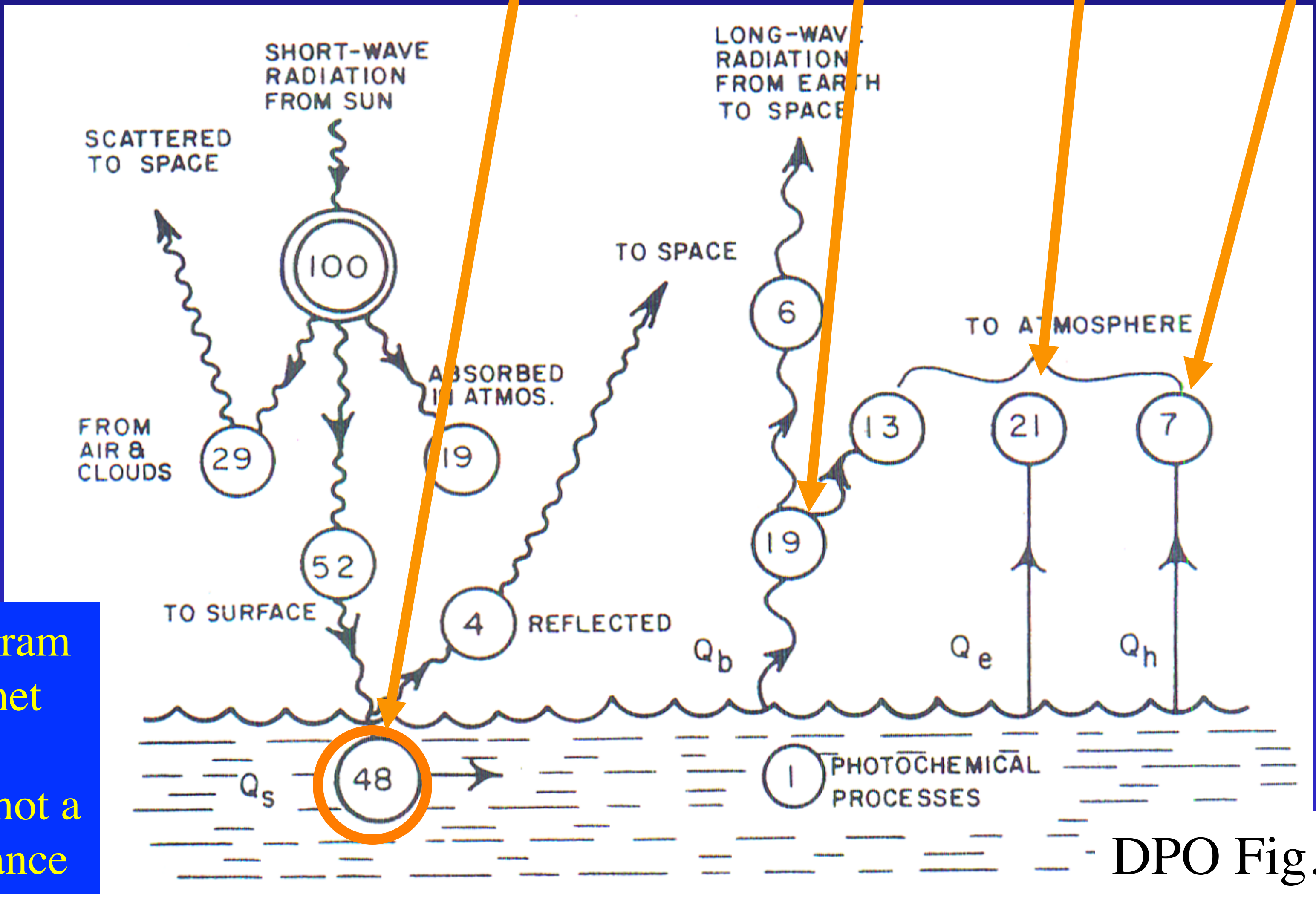


DPO Fig. 5.5

Ocean heat balance, including radiation

$$Q_{sfc} = Q_s + Q_b + Q_e + Q_h$$

Total surface heat flux = Shortwave + Longwave + Latent + Sensible



This diagram shows a net global balance, not a local balance

DPO Fig. 5.5

Ocean heat balance

$$Q_{sfc} = Q_s + Q_b + Q_e + Q_h \text{ in } W/m^2$$

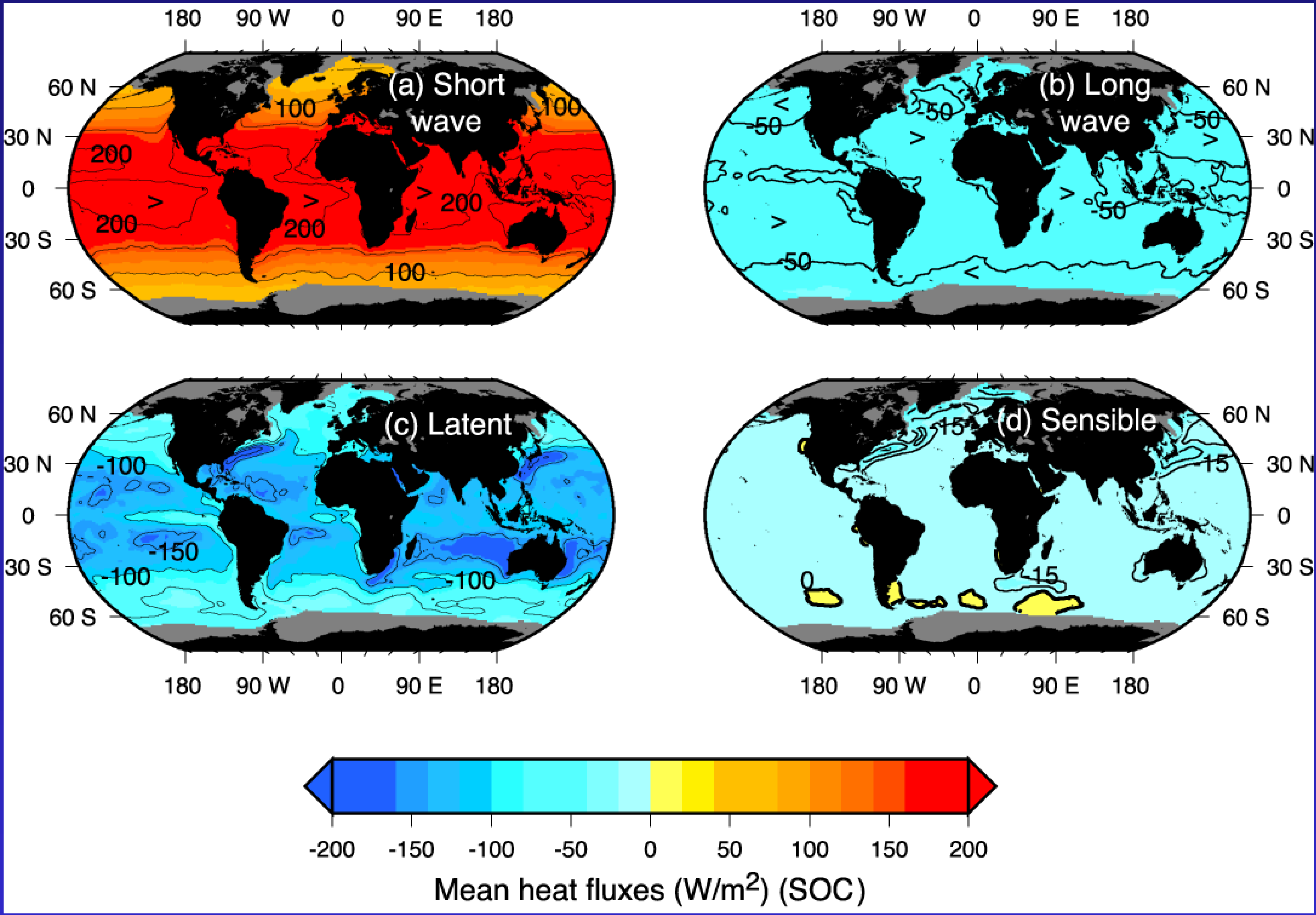
Shortwave Q_s: incoming solar radiation - always warms. Some solar radiation is reflected. The total amount that reaches the ocean surface is $Q_s = (1-\alpha)Q_{incoming}$ where α is the albedo (fraction that is reflected). Albedo is low for water, high for ice and snow.

Longwave Q_b: outgoing ("back") infrared thermal radiation (the ocean acts nearly like a black body) - always cools the ocean

Latent Q_e: heat loss due to evaporation - always cools. It takes energy to evaporate water. This energy comes from the surface water itself. (Same as principle of sprinkling yourself with water on a hot day - evaporation of the water removes heat from your skin)

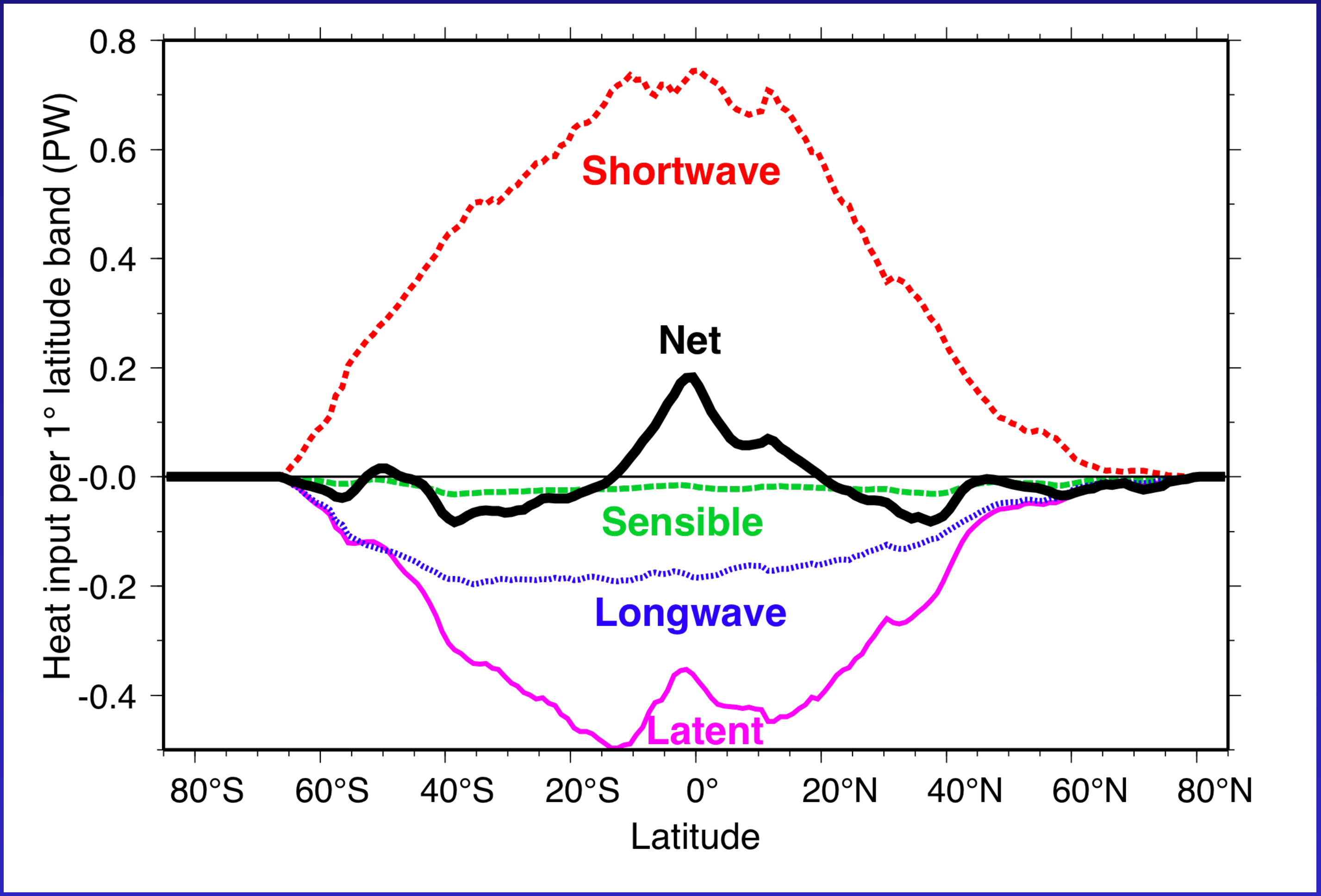
Sensible Q_h : heat exchange due to difference in temperature between air and water. Can heat or cool. Usually small except in major winter storms.

Annual average heat flux components (W/m^2)



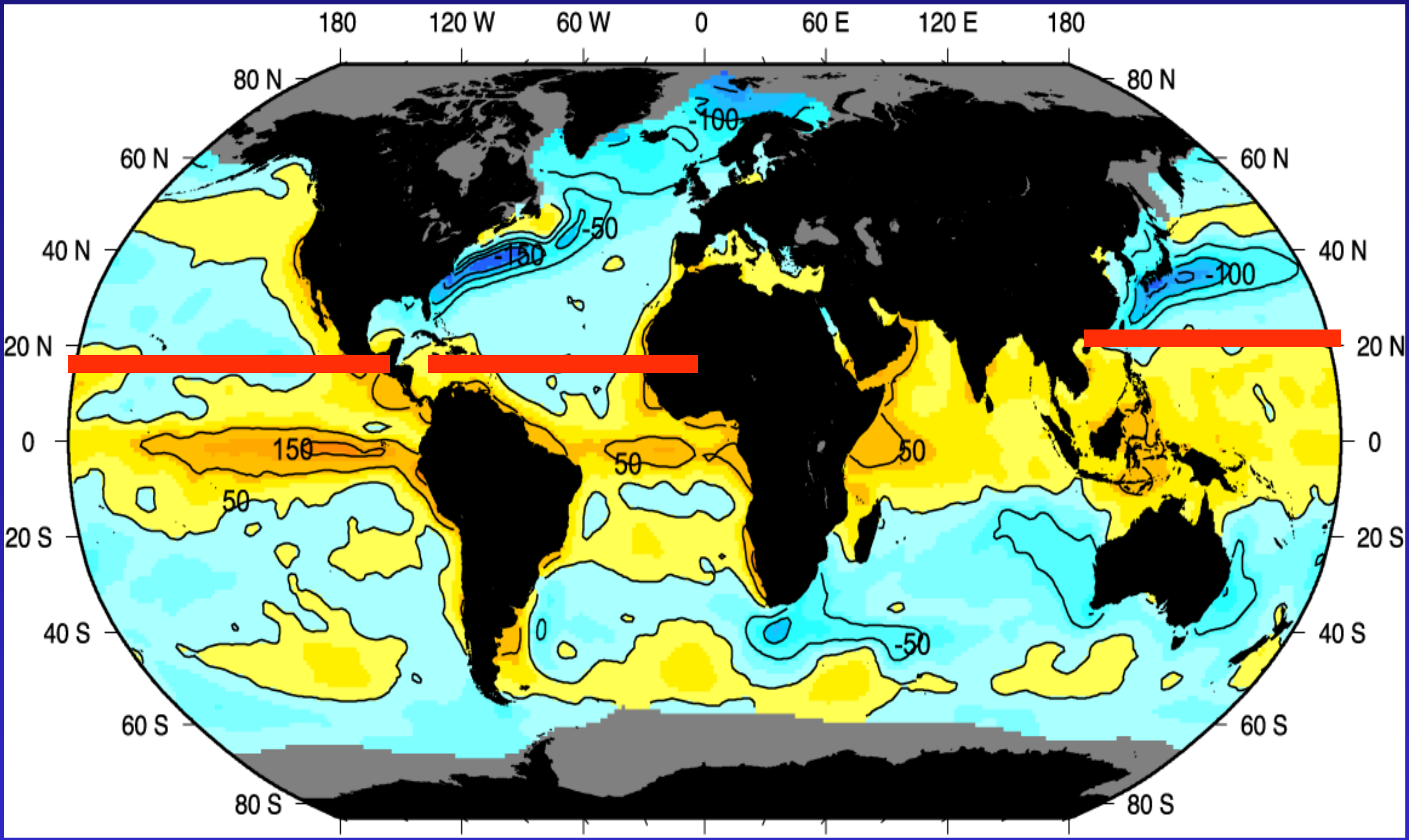
DPO Figure 5.11

Heat flux components summed for latitude bands (W/m²)



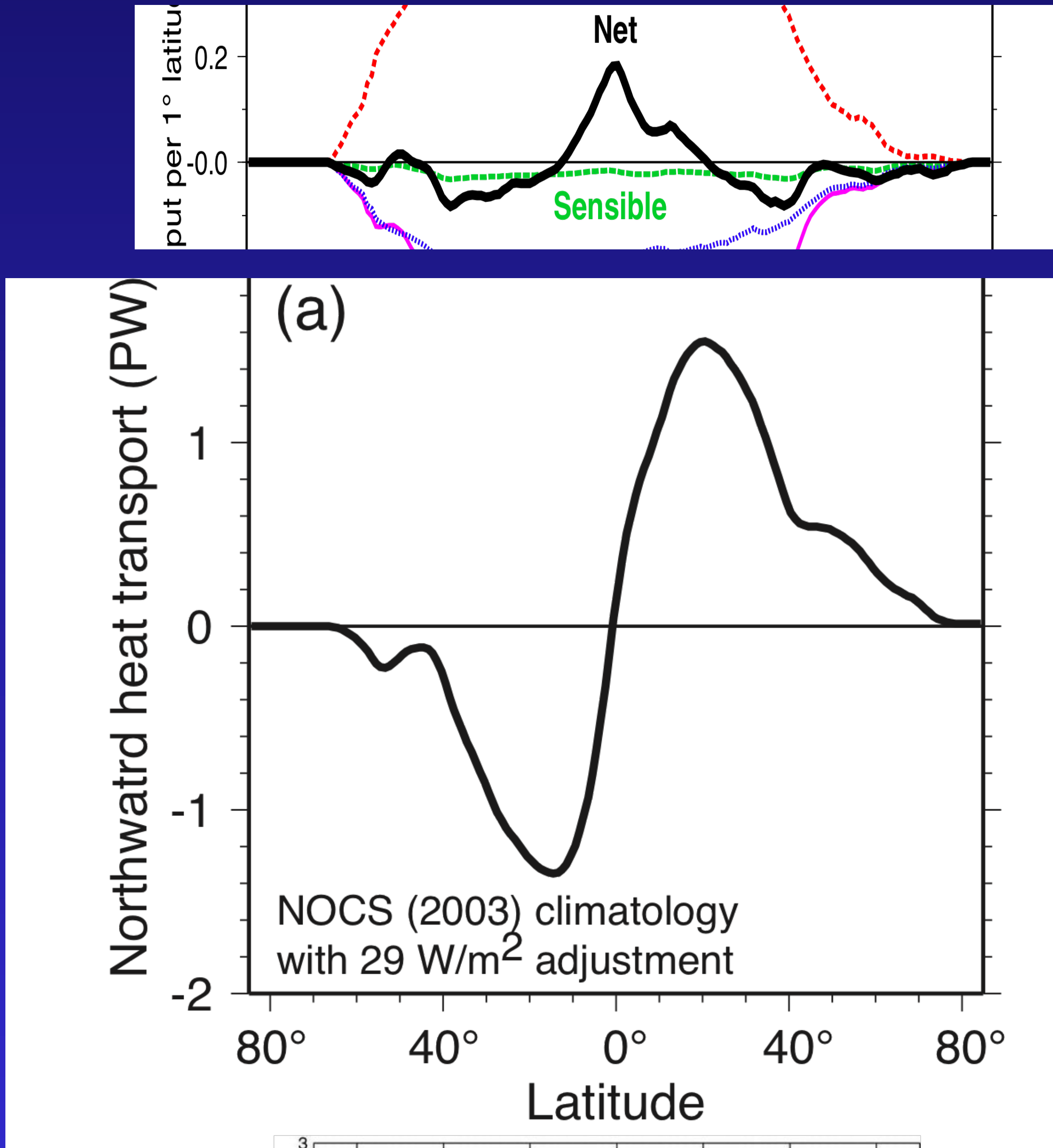
DPO Figure 5.13

Net
Surface heat flux (W/m²) into ocean



DPO Figure 5.12

Heat transport



Heat input per latitude band (PW)

1 PW = 1 "Petawatt" = 10^{15} W

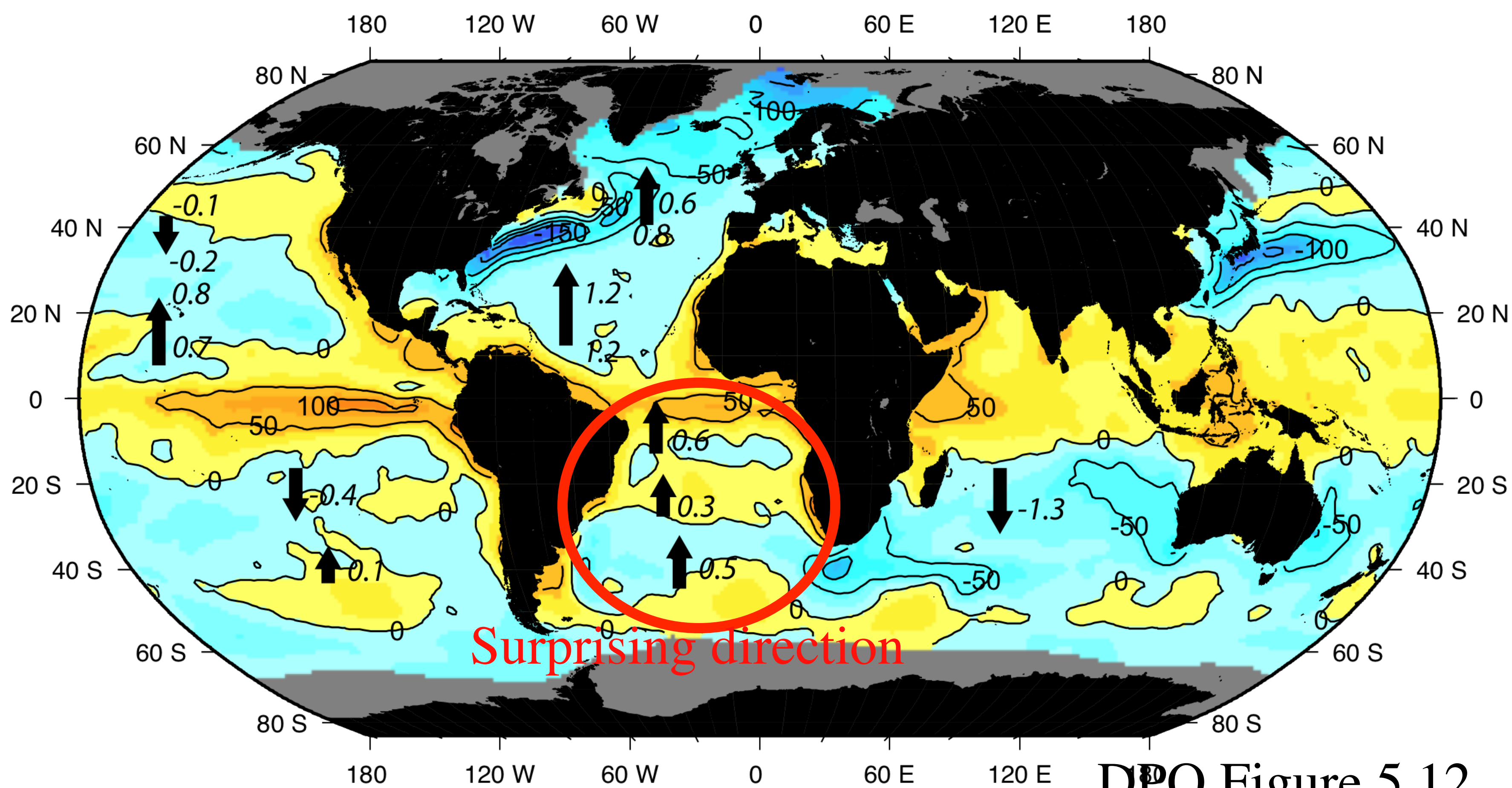
Heat transport (PW)

(meridional integral of the above)

DPO Figure 5.14

Heat transport

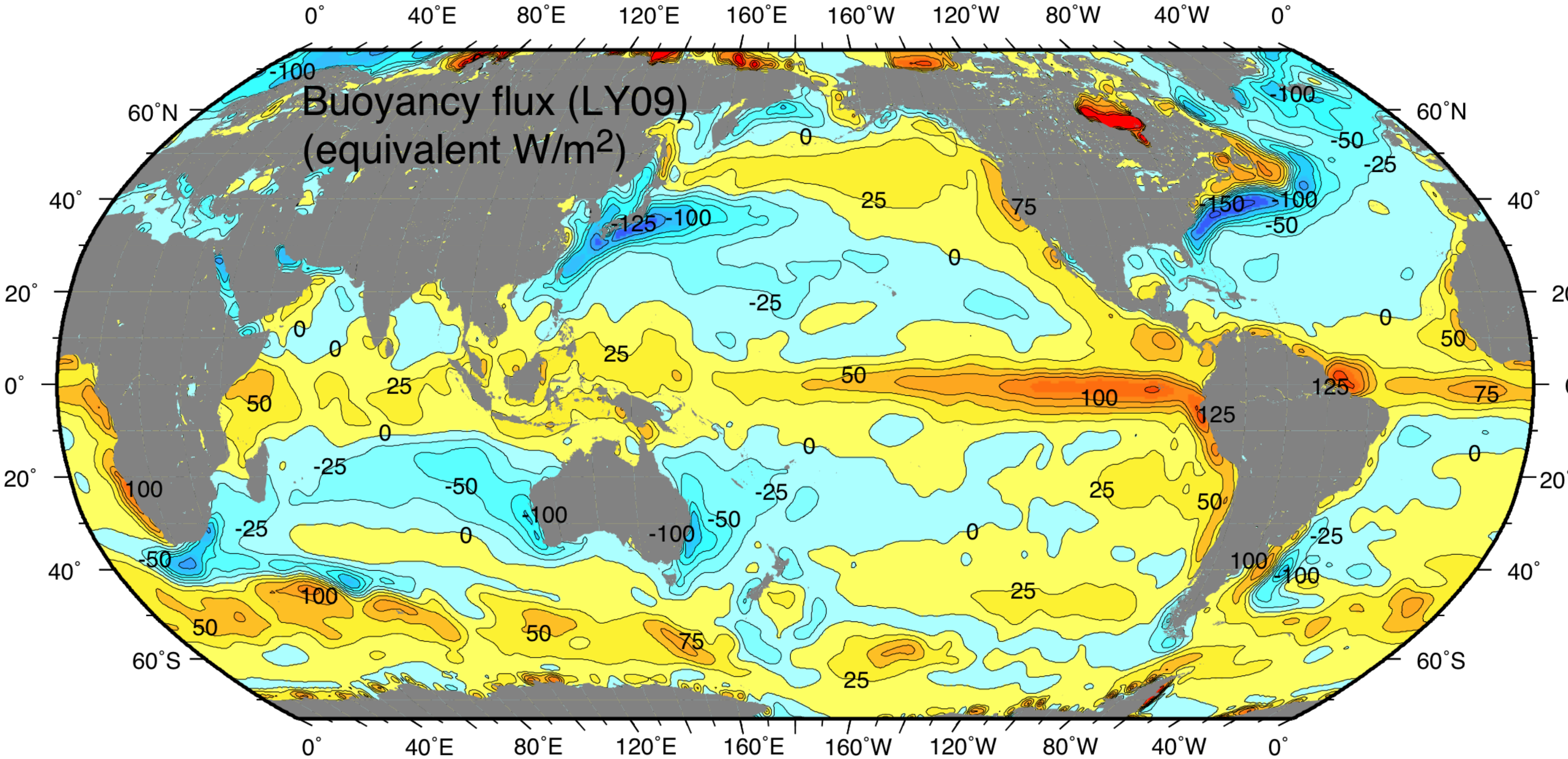
- Meridional heat transport across each latitude in PW
- Calculate either from atmosphere (net heating/cooling) and diagnose for ocean
- OR from velocity and temperature observations in the ocean. Must have net mass balance to compute this.



DPO Figure 5.12

Buoyancy flux

- Density is changed by buoyancy flux, which is the sum of heat and freshwater flux (changing temperature and salinity)
- Map is mostly related to heat flux, little impact from E-P



DPO Figure 5.15

Production rate, turnover time, residence time

- How do we quantify the rate that a basin (small or large) overturns, or has its waters renewed?

- Production rate: how much volume transport comes out of a formation site? (measured in Sverdrups)
- Turnover time: time to replenish a reservoir = (volume of reservoir)/(outflow rate) measured in $m^3/(m^3/sec)$ = sec
- = (concentration x volume)/(outflow rate of tracer), measured in Cx $m^3/(C \times m^3/sec)$ = sec

- Residence time: average time a parcel spends in a reservoir. Average residence time = turnover time if in steady state.

- Example:
- Deep Pacific Ocean: 2 km deep, 6000 km N-S, 8000 km E-W, so volume ~ $100 \times 10^6\ km^3 = 100 \times 10^{15}\ m^3 = 1 \times 10^{17} m^3$
- Outflow rate is about 10 Sv = $10 \times 10^6\ m^3/sec = 10^7\ m^3/sec$
- Turnover time is therefore 1×10^{10} sec ~ 500 years