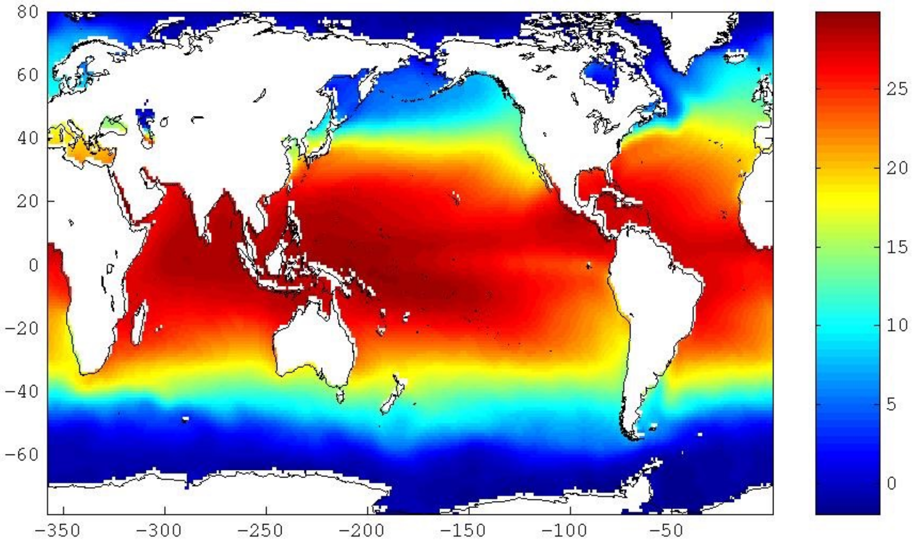
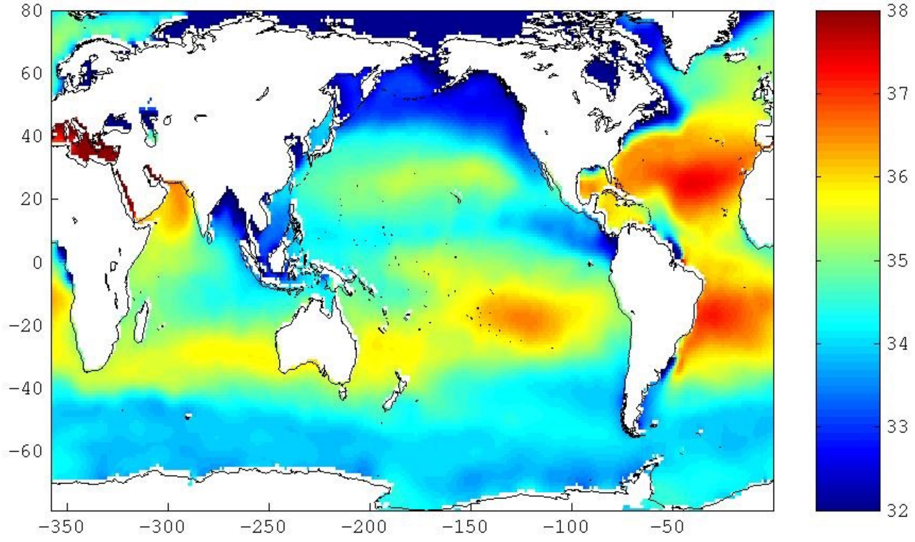
Global Scale Patterns in Air-Sea Interaction

- Freshwater
- Heat
- Momentum – wind (next week)



Temperature



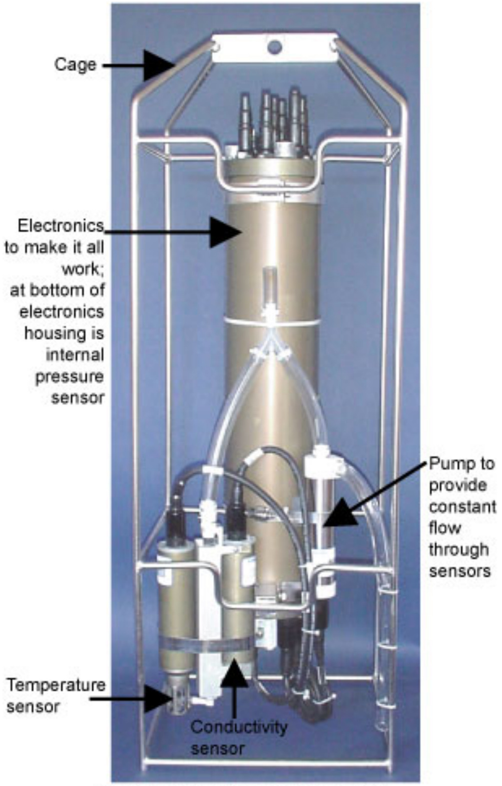
Salinity

Sea surface temperature and salinity are controlled by air-sea interaction

Salinity

- Seawater is typically about 3.5% salt by mass
- This can be expressed as:
- 35 ppt
- 35 ‰
- 35 g/kg
- 35 psu (“practical salinity units” based on conductivity)

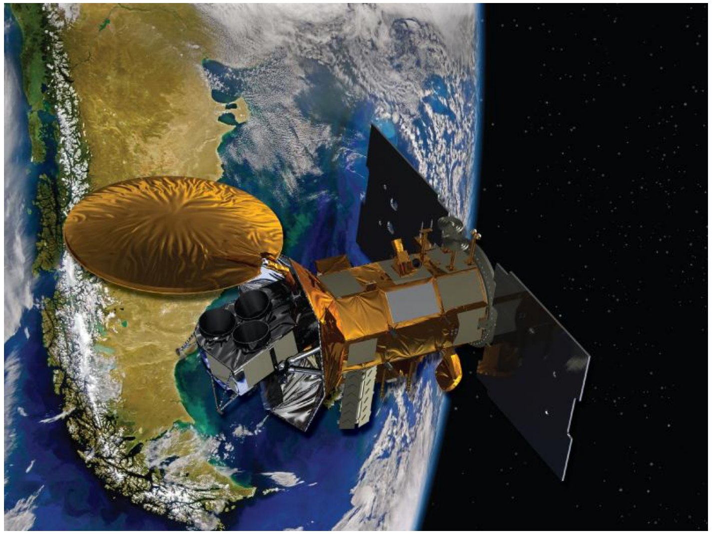
Measuring salinity with conductivity



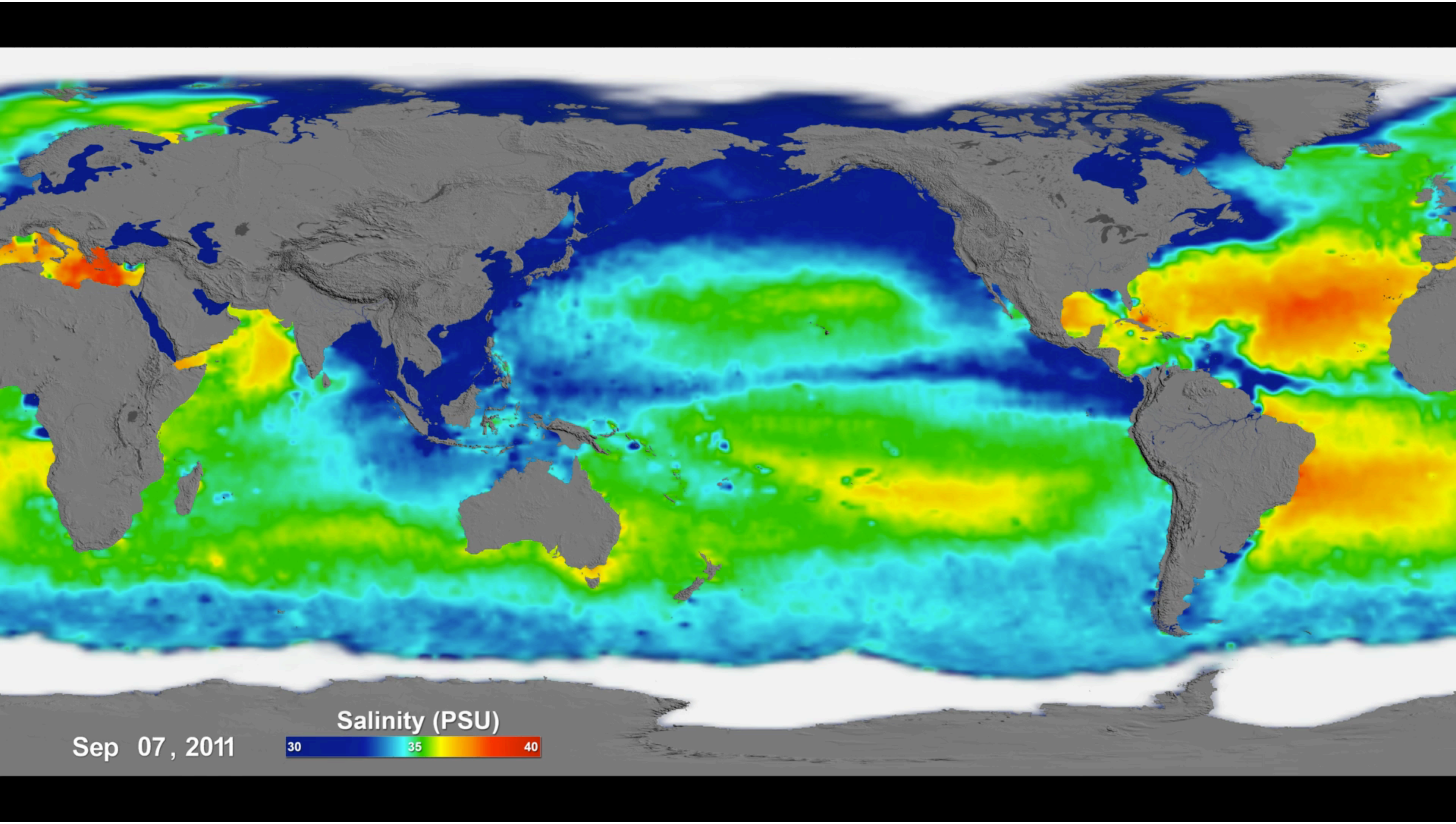
CTD system for profiling from a ship:
SBE 9*plus* CTD has modular Temperature & Conductivity sensors that can be easily exchanged in the field if they are damaged. 9*plus* can also accommodate redundant Temperature & Conductivity sensors for high-level scientific work, where you want a back-up to primary sensors. 9*plus* can provide power to & integrate data from up to 8 auxiliary sensors.

CTD

Autosal

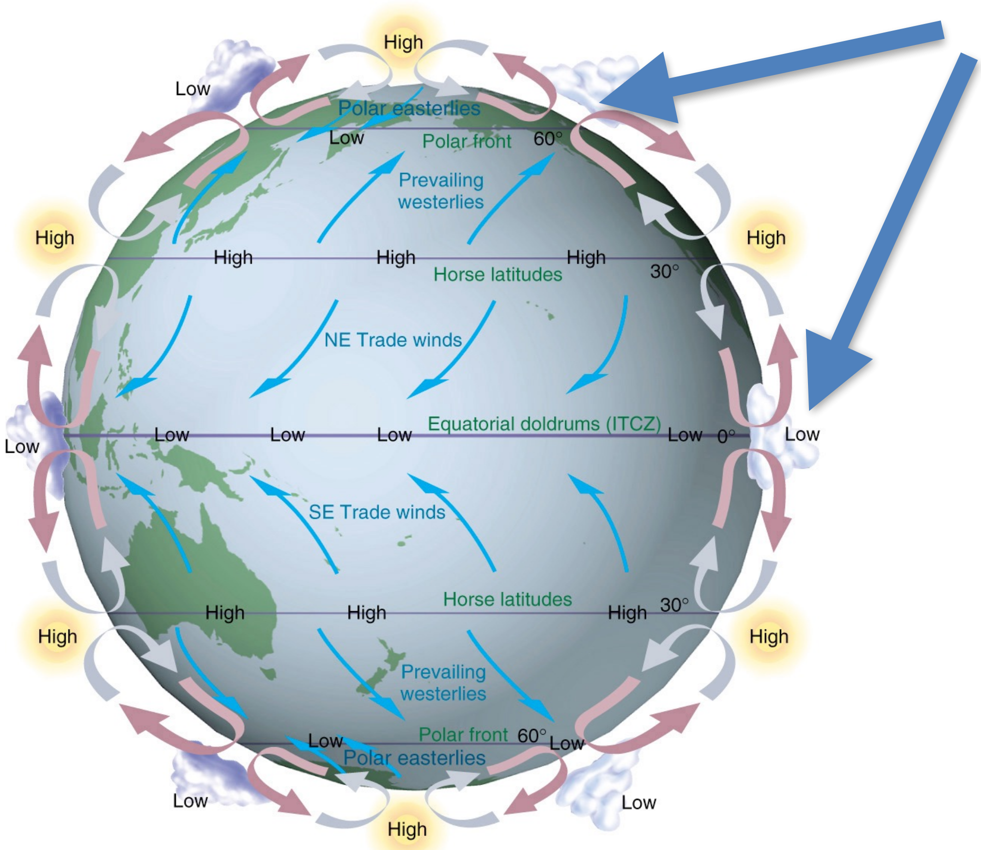


Aquarius



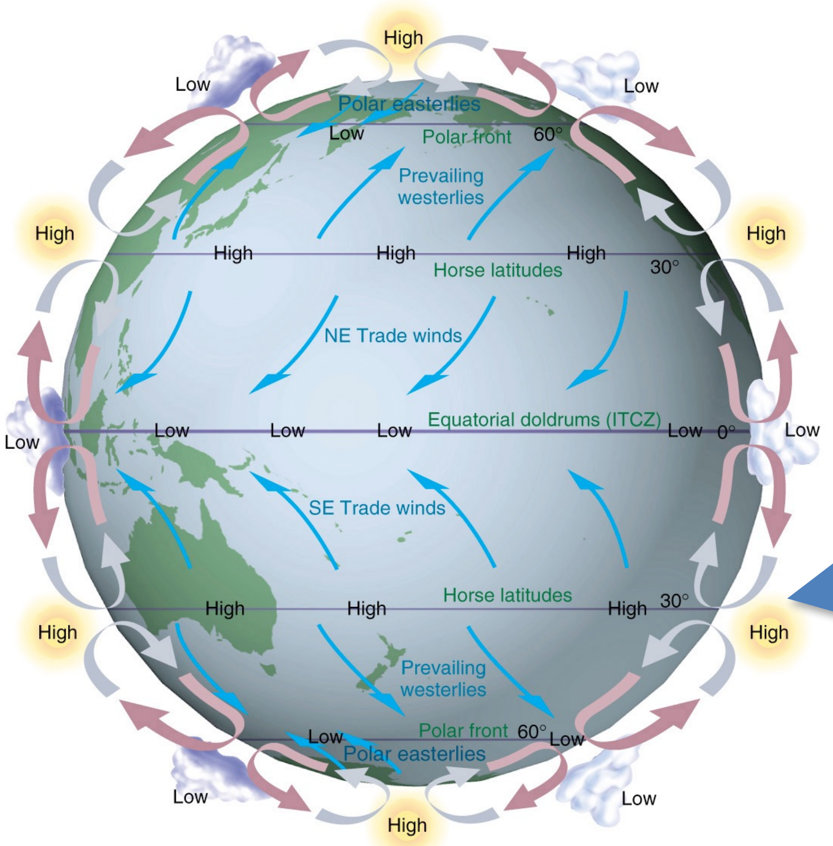
From Aquarius satellite http://aquarius.umaine.edu/cgi/gallery.htm
http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4353&button=recent

Rising motion gives rise to precipitation, sinking motion to evaporation

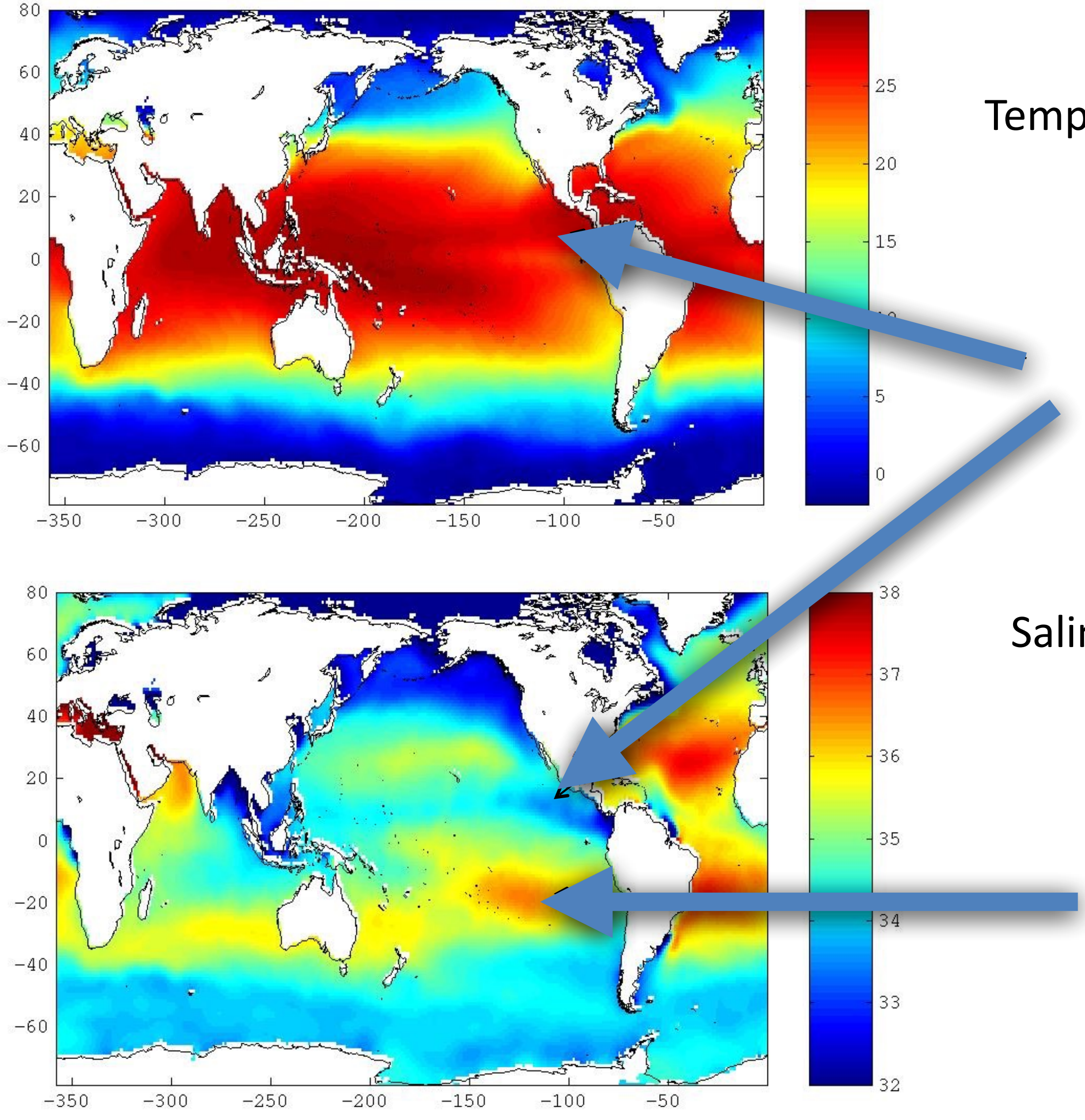


- Rising air at tropics, polar front
- Warm air can hold more moisture than cold air
- Air cools as it rises
- As air cools, water will condense and form raindrops which will fall to earth

Rising motion gives rise to precipitation, sinking motion to evaporation



- Sinking air at subtropics
- Starts out cold (little moisture)
- Warms as it sinks
- Water evaporates from sea surface until air is saturated



Temperature

Salinity

ITCZ
Warm SST, low SSS
Excess precipitation

Subtropics
Warm SST, high SSS
Excess evaporation

Sea surface temperature and salinity are controlled by air-sea interaction

Water balance at the air sea interface

E = evaporation of water from the surface

P = precipitation of water onto the surface

$\mathbf{F_r}$ = addition of water from river runoff

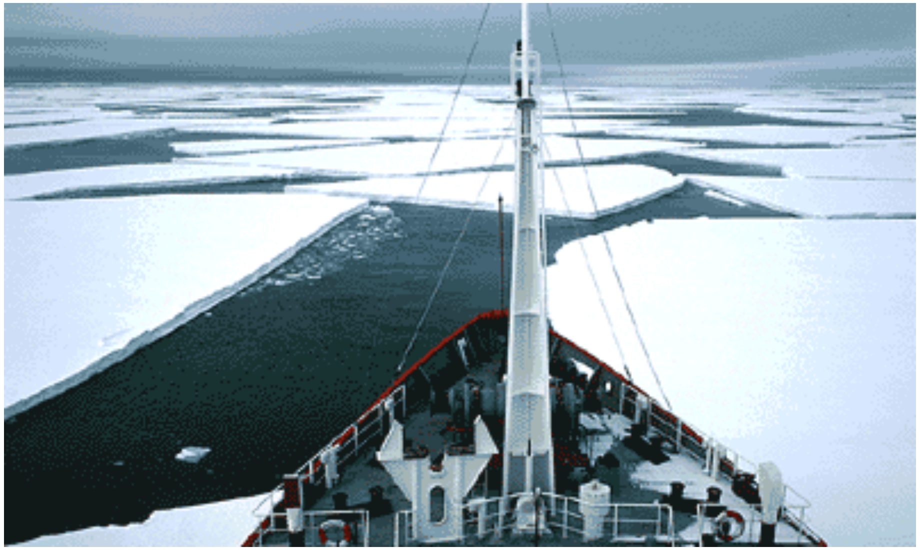
$\mathbf{F_i}$ = addition of water from melting of icebergs

$\mathbf{F_{si}}$ = addition of water from melting of sea ice (negative for sea ice formation)

$\mathbf{F_{mix}}$ = mixing or transport of saltier or fresher water laterally or from below the surface

Fluxes normally expressed in units of m yr^{-1}

equivalent to m^3/(m^2 yr)



- Sea ice- forms from seawater, floats on water

- Land ice - glaciers form from falling snow

Global ocean average water balance at steady state

$$(P + F_r + F_i + F_{si}) - E = 0$$

Annual average values integrated over entire ocean:

$E = 361 \times 10^{12}\ m^3/yr$

$P = 324 \times 10^{12}\ m^3/yr$

$F_r = 35 \times 10^{12}\ m^3/yr$

$F_i = 2 \times 10^{12}\ m^3/yr$

$F_{si} = 0\ (30 \times 10^{12}\ m^3/yr - 30 \times 10^{12}\ m^3/yr)$

$F_{mix} = 0$

Salinity: determined by local water balance

$\mathbf{(P + F_r + F_i + F_{si}) - E = 0}$

Can express freshwater fluxes in terms of equivalent salt fluxes of the opposite sign

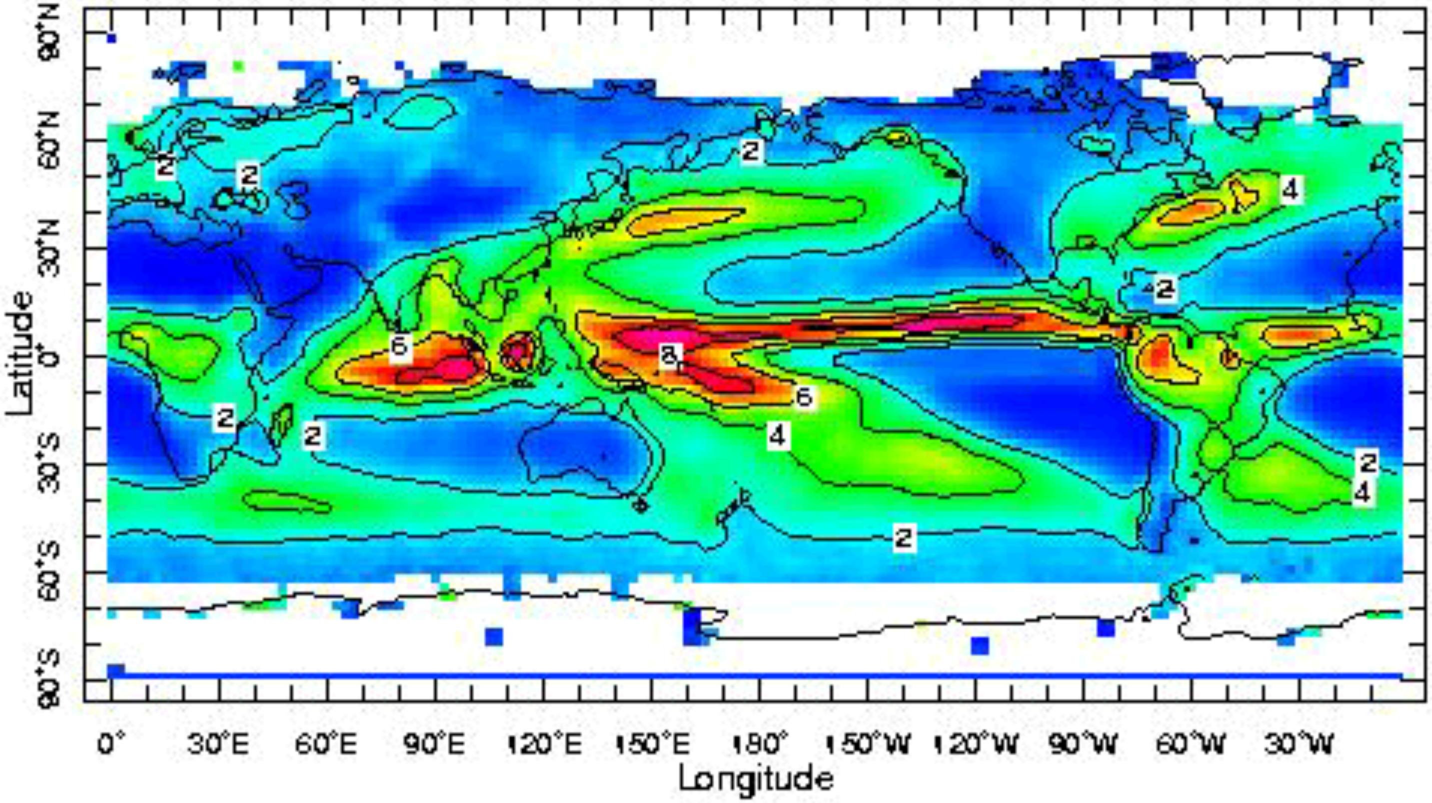
$(Q_P+Q_r+Q_i+ Q_{si}+Q_{mix}) - Q_E = h\rho dS/dt$

Where S = salinity (g kg^{-1})
h = depth of surface ocean layer
ρ = density of seawater
Q = equivalent salt flux (g m^{-2} yr^{-1})

Q_{mix} will depend on salinity gradients and the rate of exchange and transport of water into/out of the area under consideration

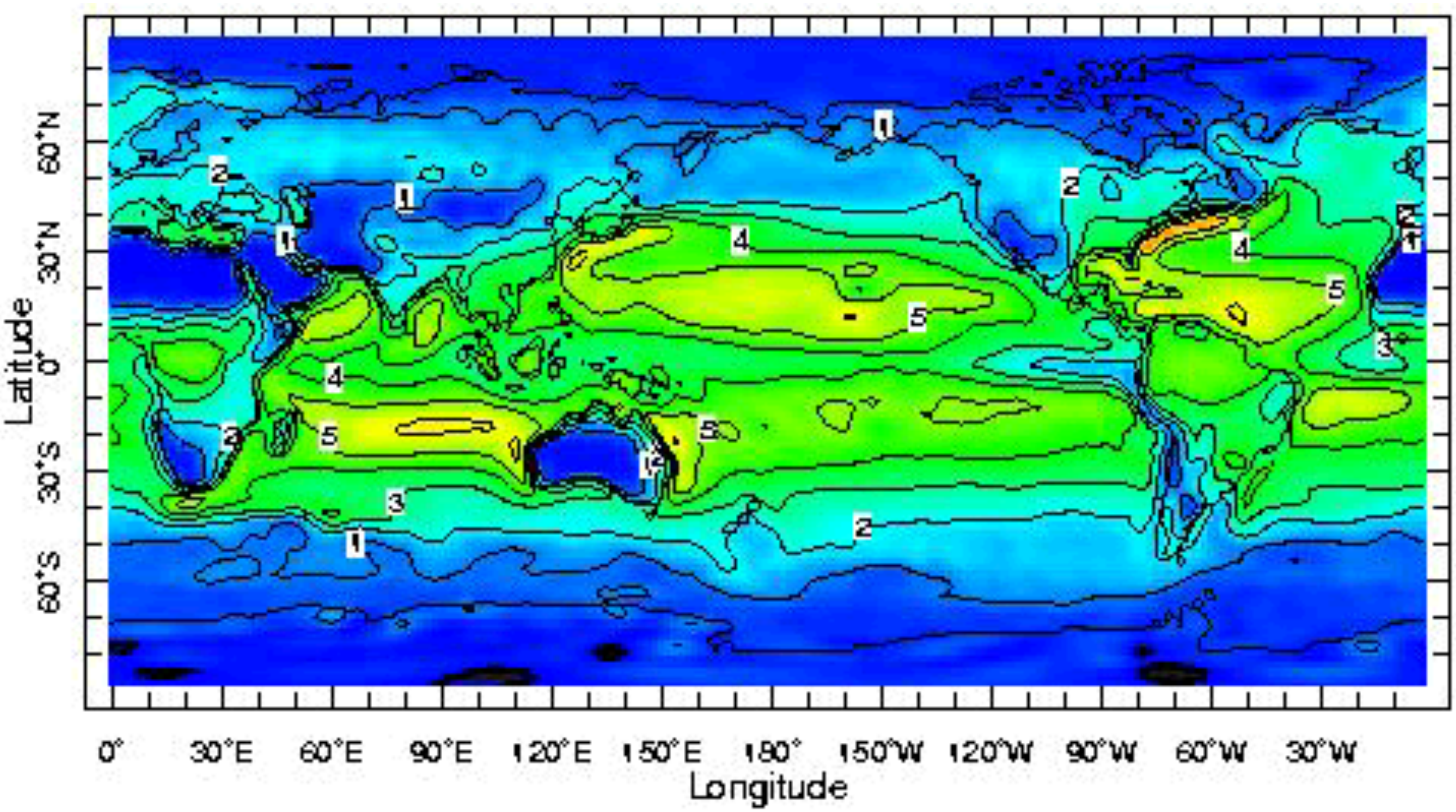
P = precipitation of water onto the surface

Annual Mean Precipitation Rate (kg/m^2/day)

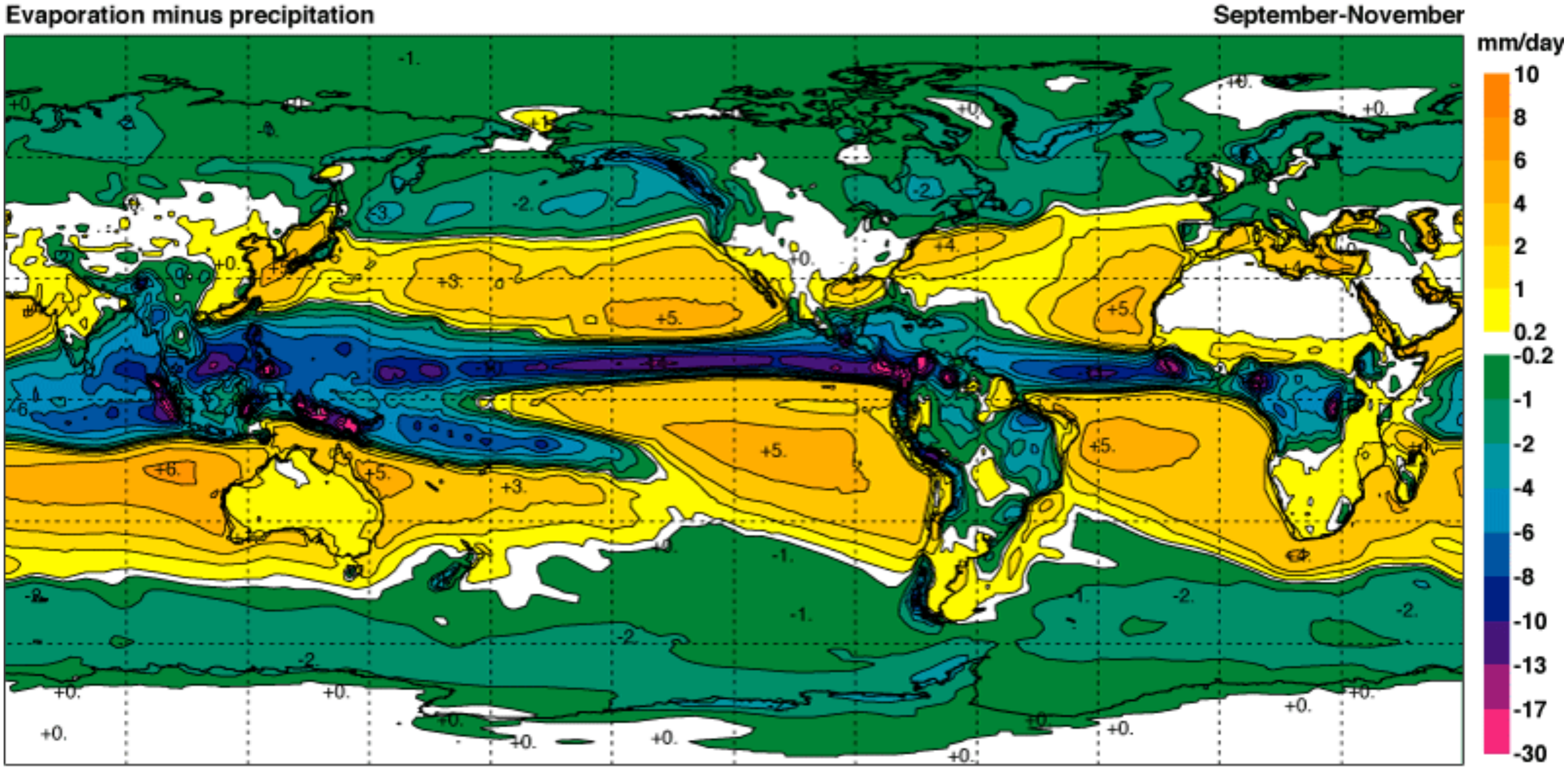


E = evaporation of water from the surface

Annual Mean Evaporation Rate (kg/m^2/day)



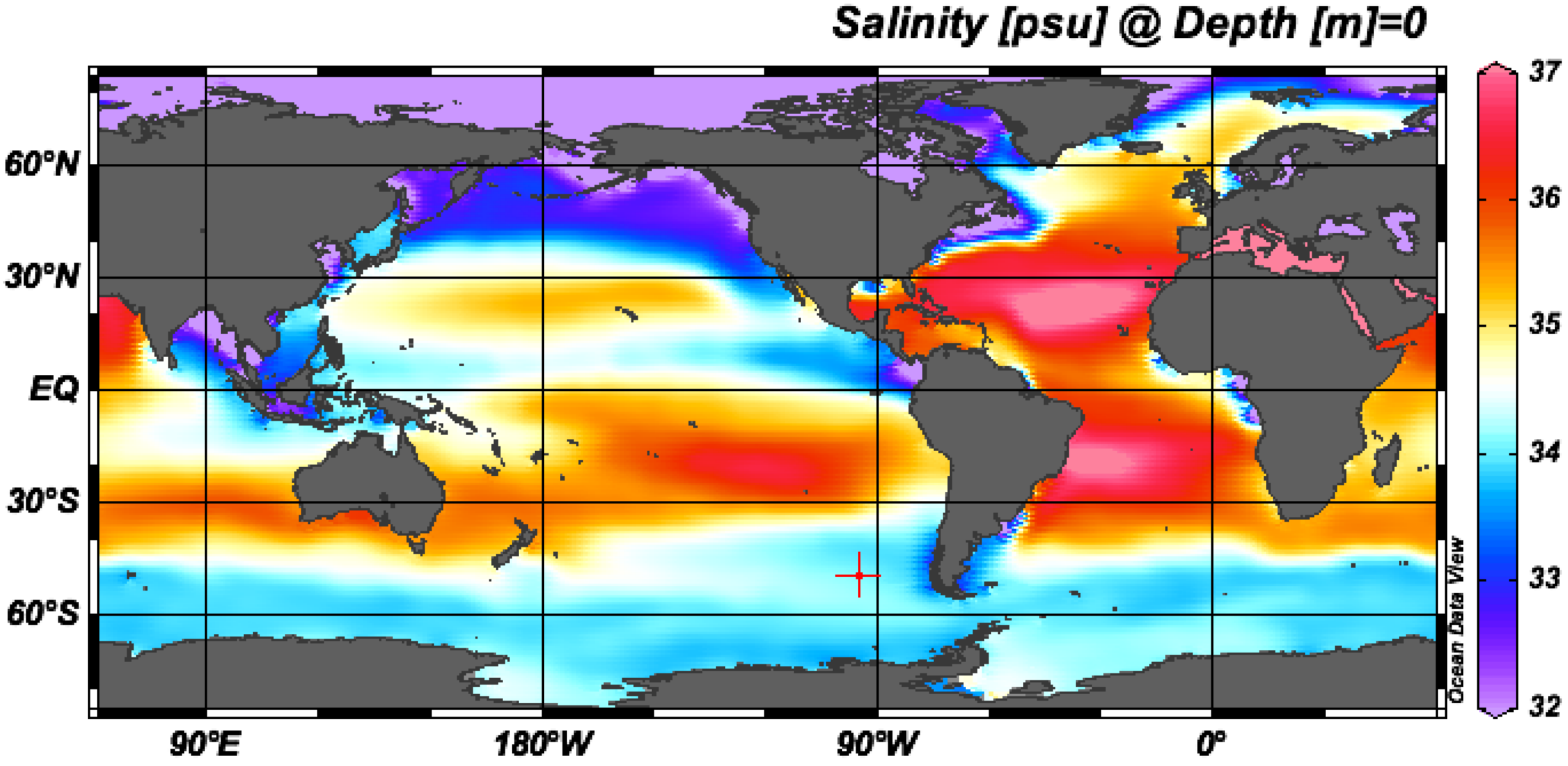
$$E - (P + F_r + F_i + F_{si}) = 0$$



Evaporation minus precipitation

September-November

Global surface salinity



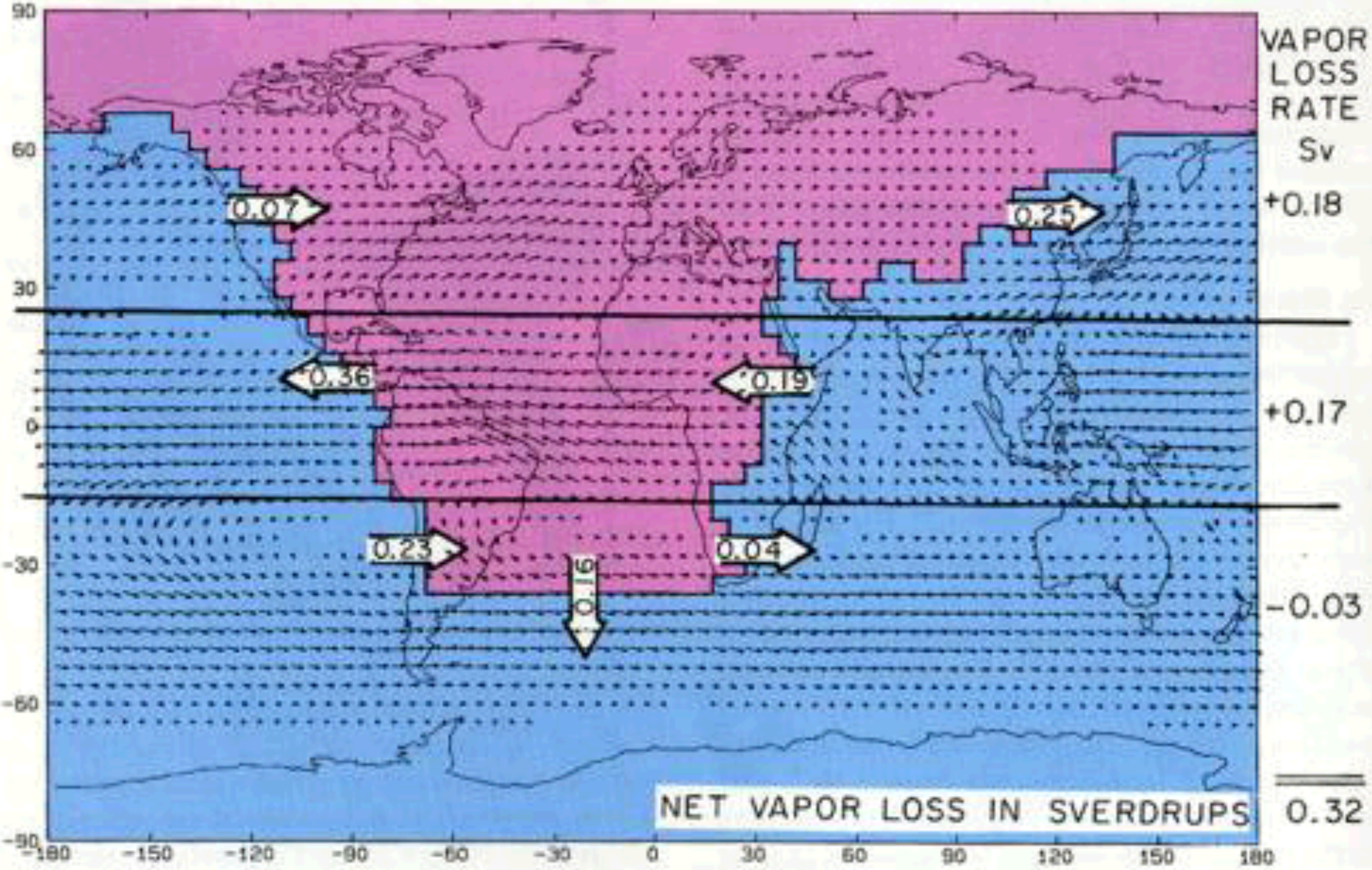
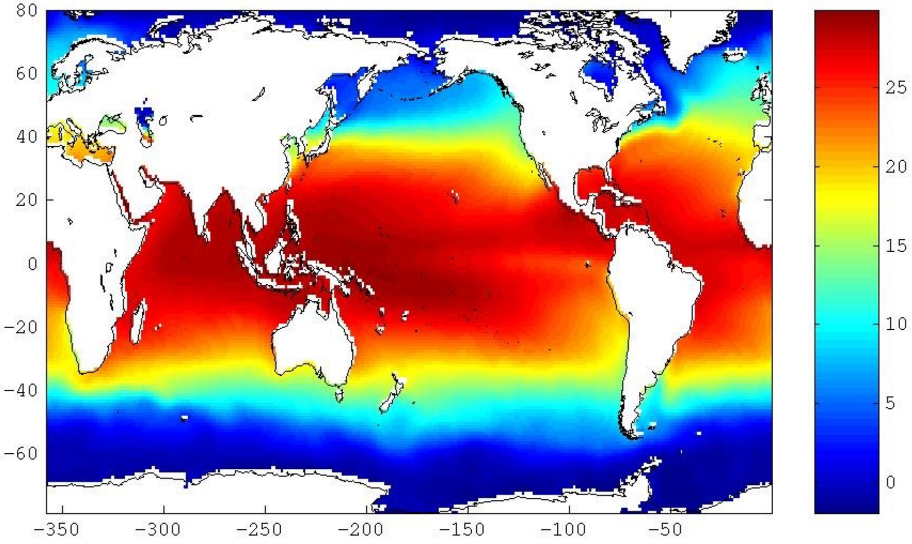
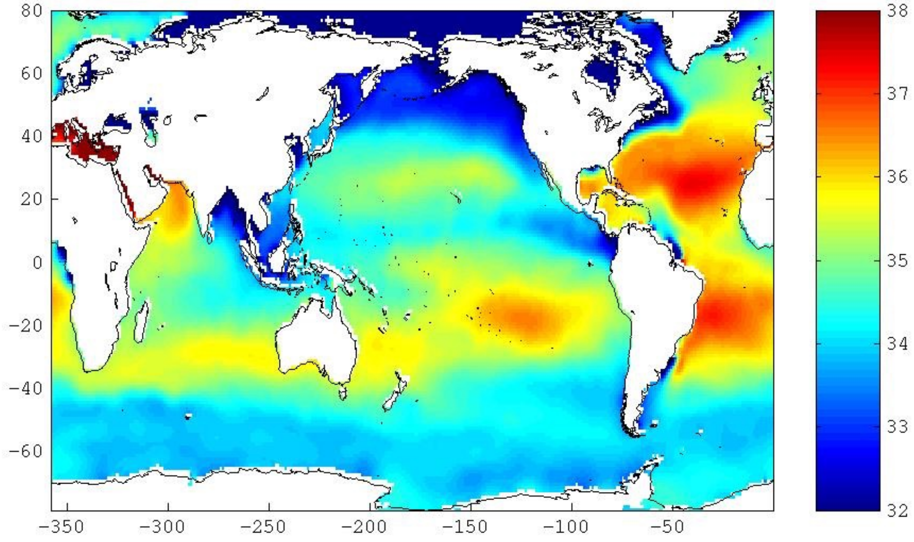


Fig. 6: Map showing vertically integrated and annually averaged water-vapor flux vectors compiled by Oort (1983). Also shown is the boundary of the Atlantic's drainage basin and net fluxes across segments of this boundary. The tropical easterlies carry out more water vapor from the Atlantic basin across Central America than they bring in via Africa. The northern westerlies allow more water escape across Asia than enters across the American cordilera. For the entire basin the rate of water vapor loss is 0.32 Sv.



Temperature



Salinity

Sea surface temperature and salinity are controlled by air-sea interaction

$$HeatEnergy = mass \times (T \times c_p) = \rho \times volume \times (T \times c_p)$$

$$c_p = 4000\, Jkg^{-1} K^{-1}$$

$$LatentHeat = mass_{evaporated} \times L_f = \rho \times volume \times (L_f)$$

$$Power(W) = Heat / time$$

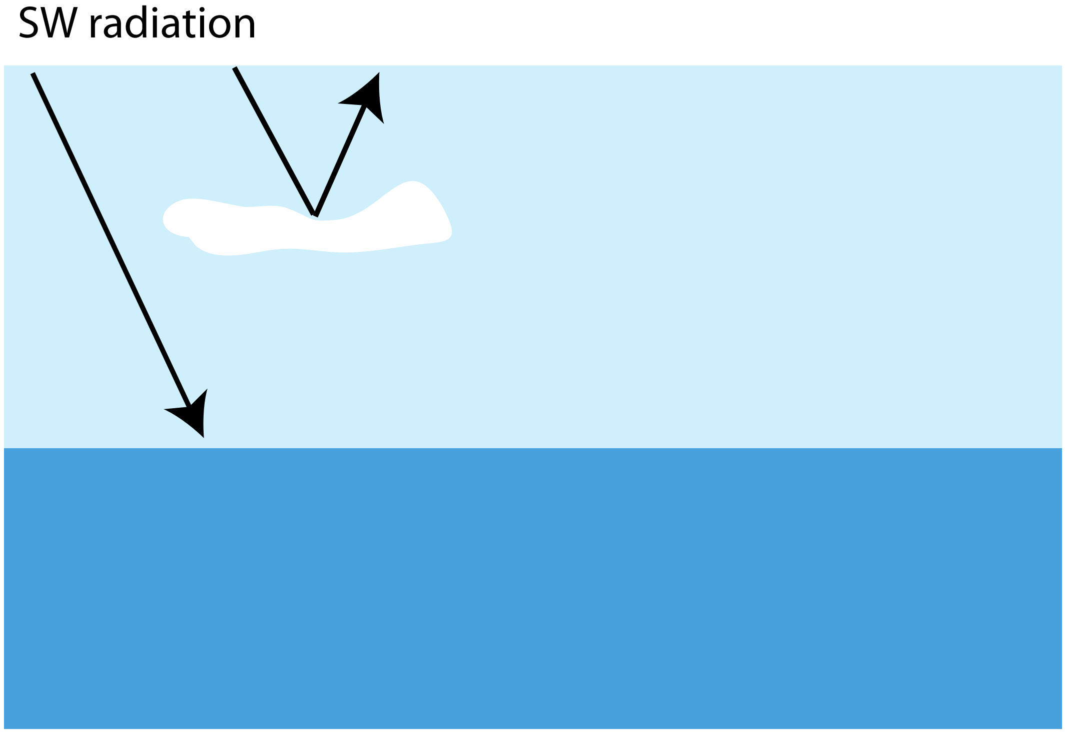
$$HeatFlux(Wm^{-2}) = Power / area$$

4 components of air-sea heat flux

- **Incoming shortwave radiation (SW)**
  - Latitude, cloud cover
- **Outgoing longwave radiation (LW)**
  - Temperature, water vapor, cloud cover
- **Sensible heat flux (SH)**
  - Boundary layer turbulence
- **Latent heat flux (LH)**
  - Evaporation

Factors controlling SW radiation

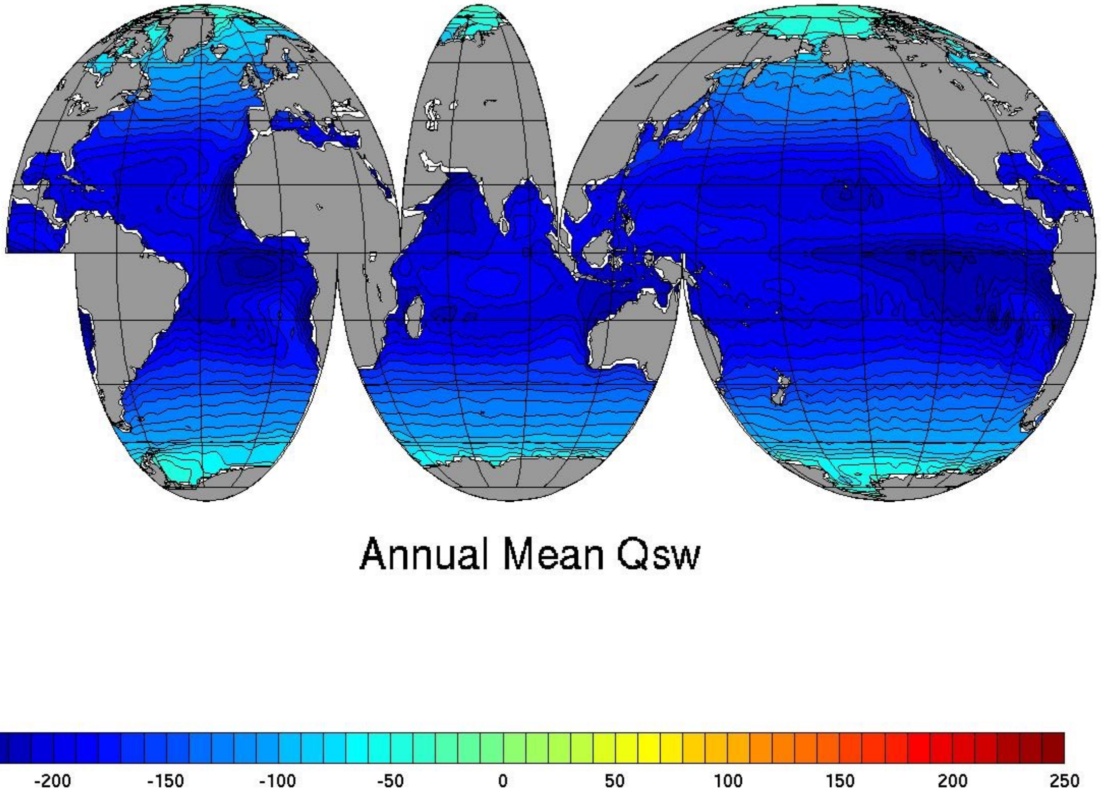
- Latitude
- Cloudines (albedo)



Shortwave radiation

Climatology = average over long time period (1968-1996)

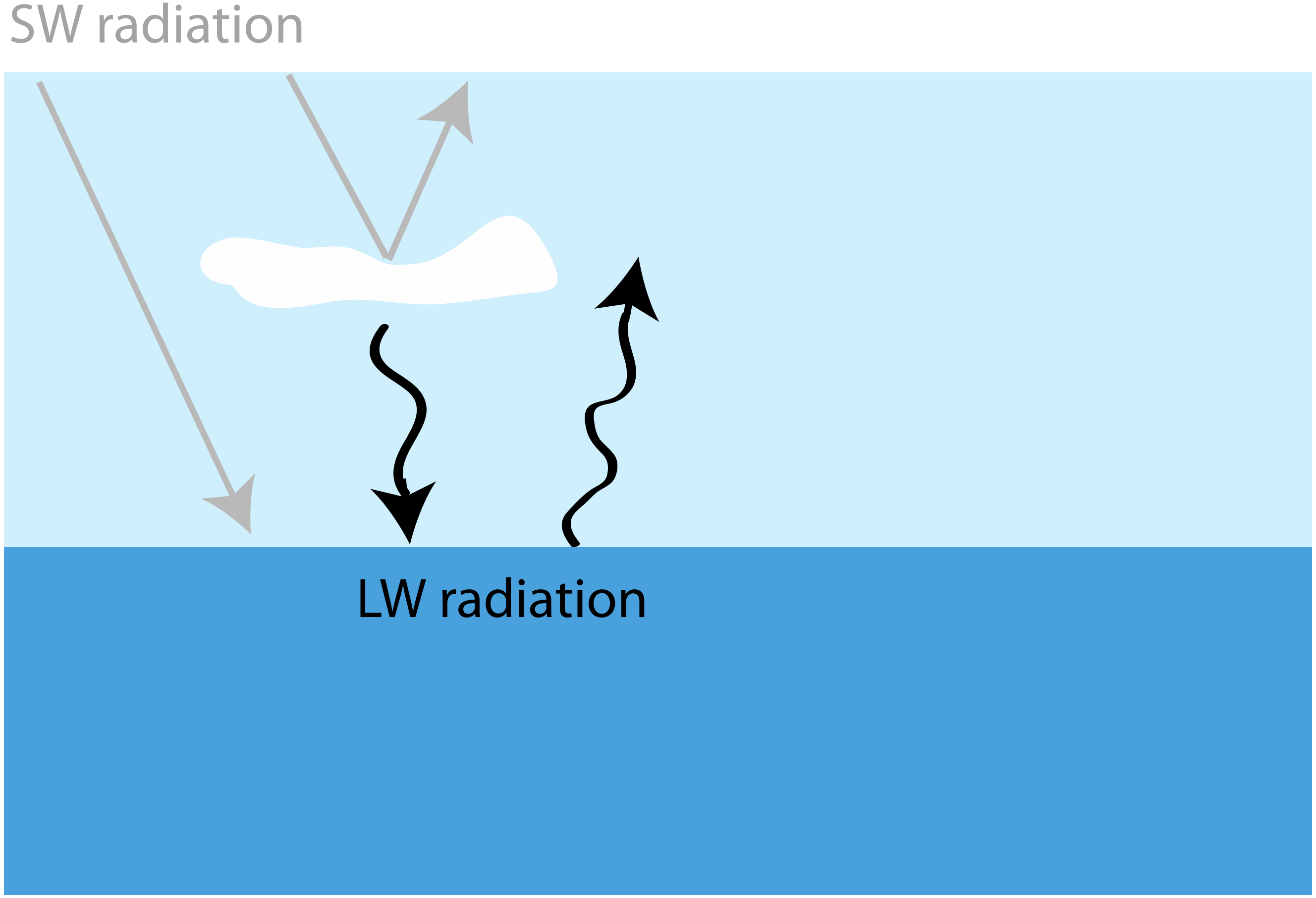
negative = into the ocean



Annual Mean Qsw

Longwave radiation

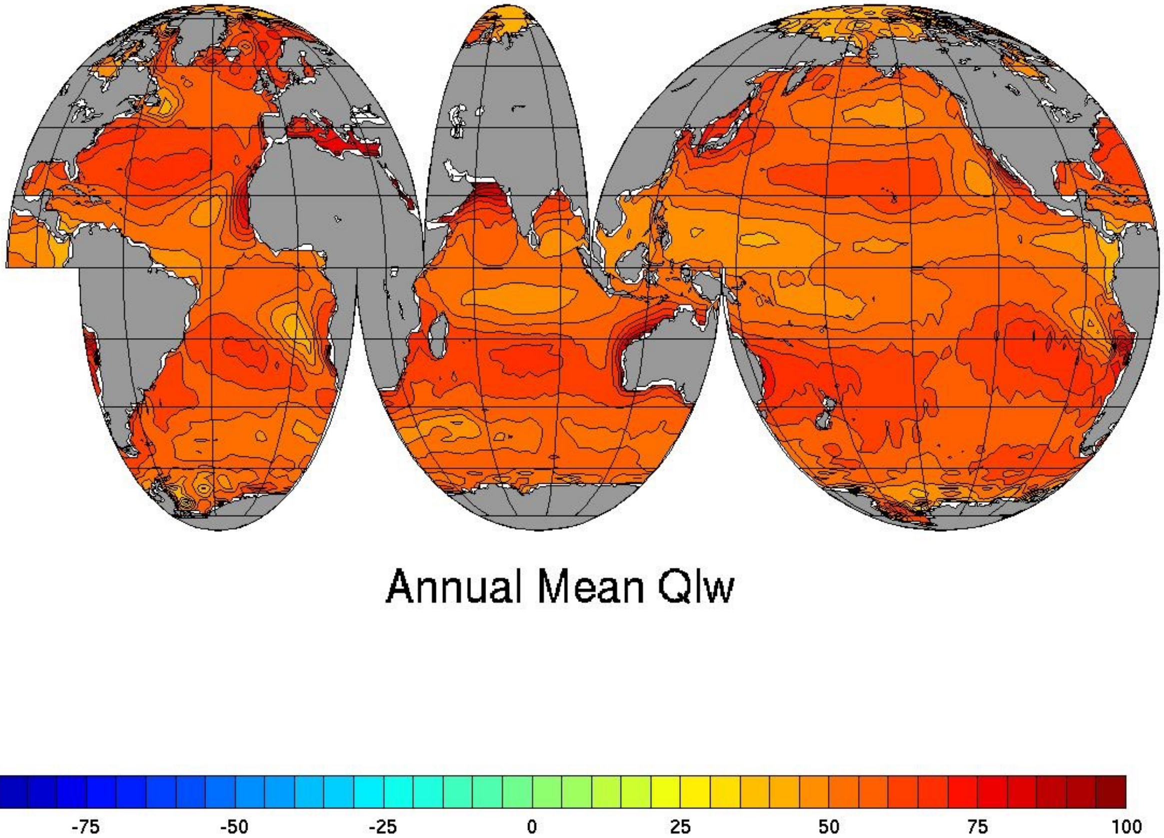
- SST (outgoing) , cloud and water vapor (incoming)
- $Q_{LW} = \sigma T^4$ (T in °K, σ=Stefan-Boltzmann constant)



Longwave radiation

Climatology = average over long time period (1968-1996)

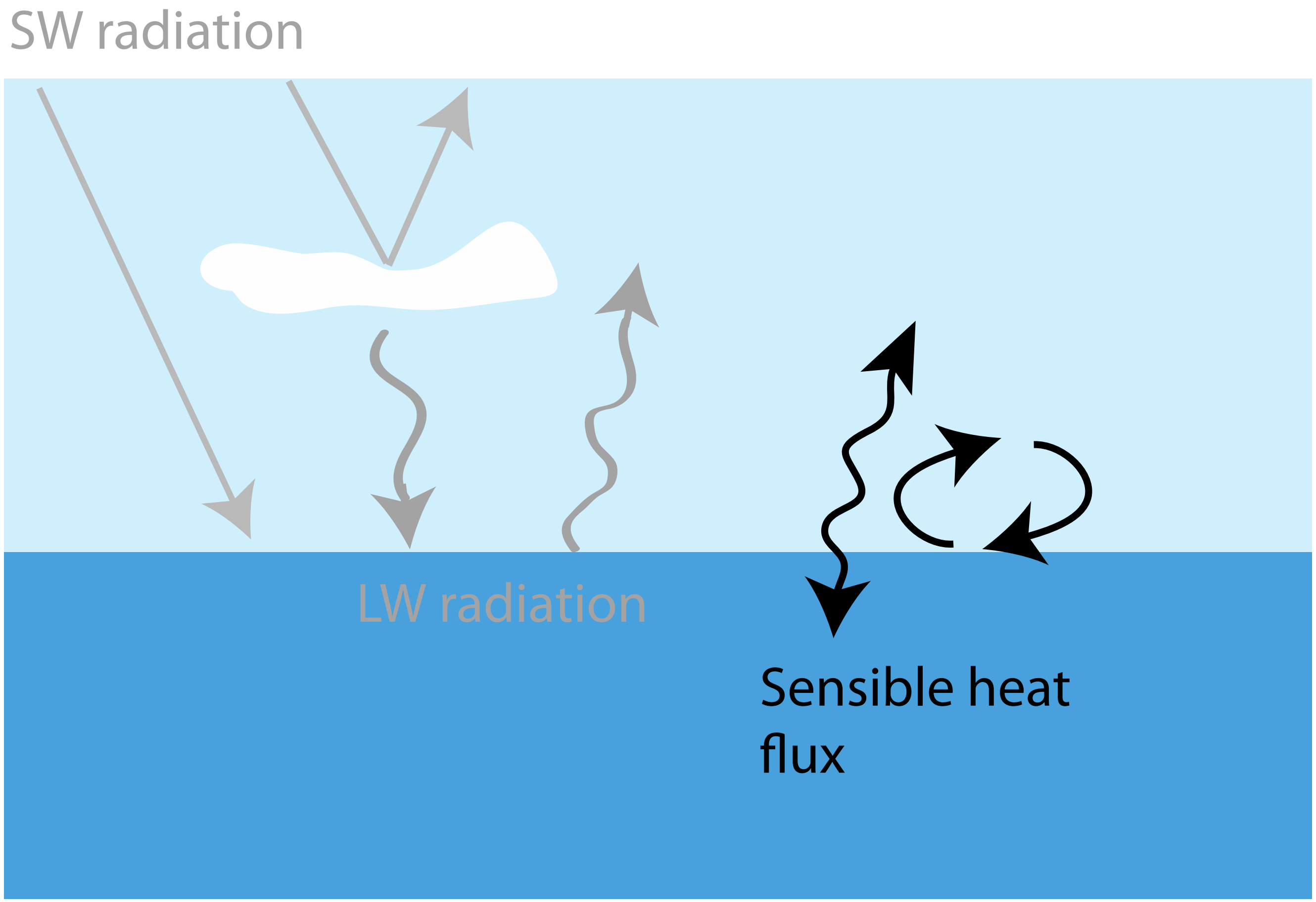
positive = from ocean into the atmosphere



Annual Mean Qlw

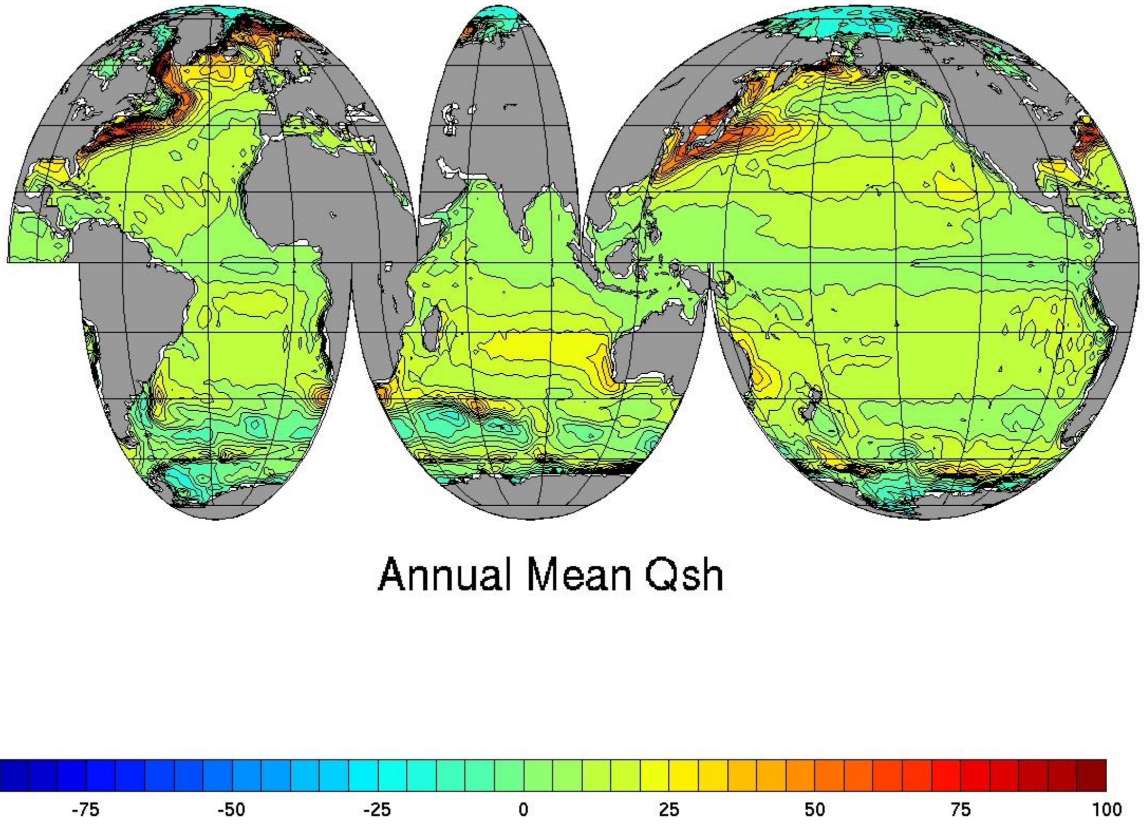
Sensible heat flux

- Driven by surface wind speed (amount of turbulence) and air-sea temperature difference



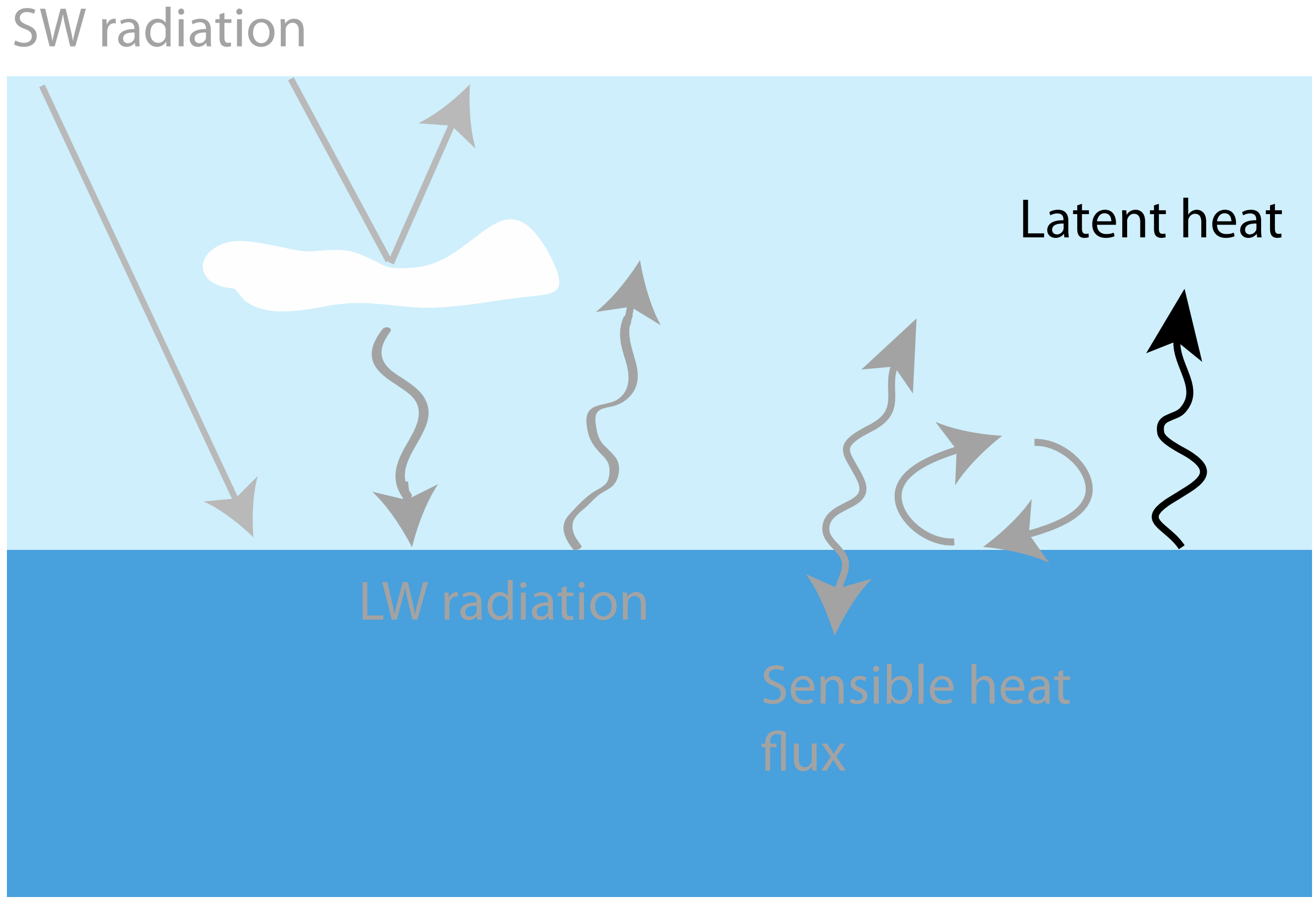
Sensible heat flux

- Climatology (1968-1996)
  - Positive = from ocean to atmosphere)
  - Negative = from atmosphere to ocean
  - Turbulent heat exchange between ocean and atmosphere



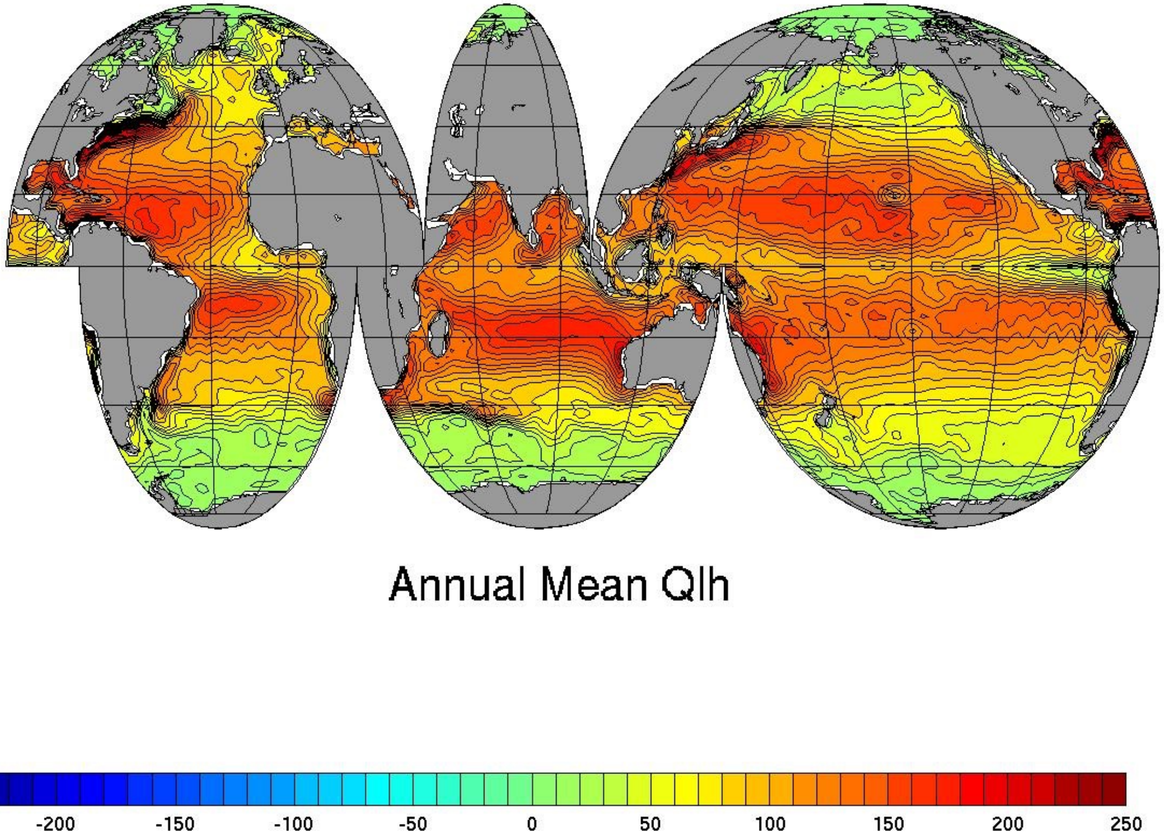
Latent heat flux

- Rate of evaporation
  - Wind speed and relative humidity



Latent heat flux

- Climatology (1968-1996)
    - positive from ocean into the atmosphere
    - Proportional to the rate of evaporation



Annual Mean Qlh

Global ocean average heat balance at steady state

$(Q_{sw} + Q_{lw} + Q_{lh} + Q_{sh}) = 0$

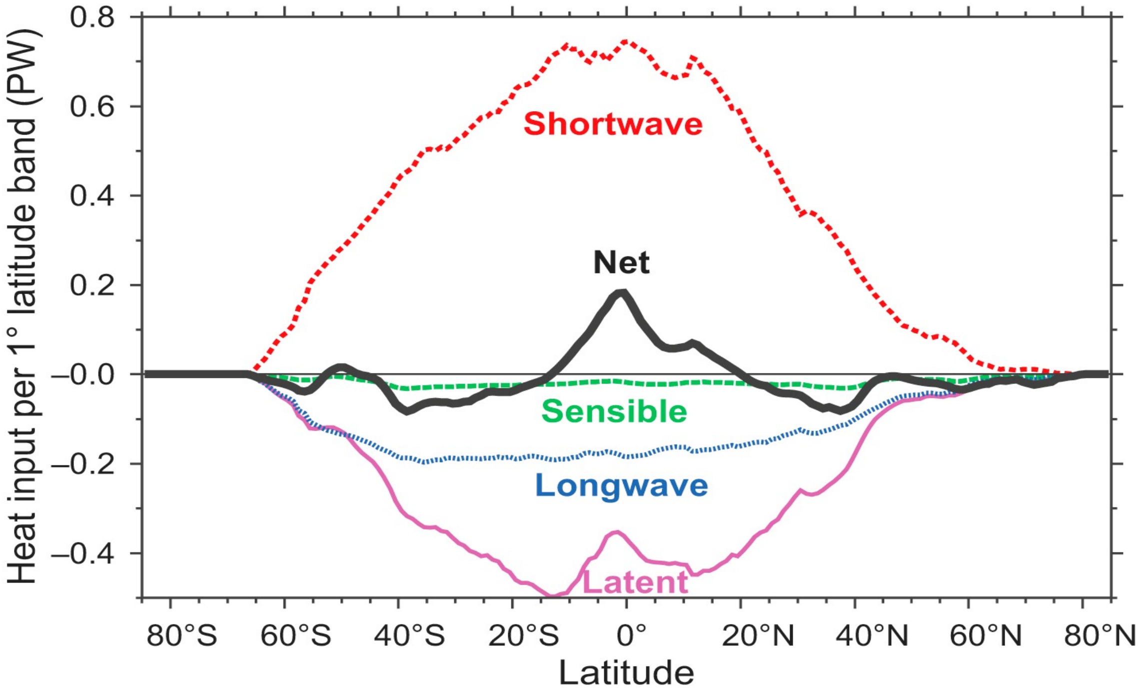
$Q_{sw} = 168\ \mathrm{W/m^2}$

$Q_{lw} = -66\ \mathrm{W/m^2}$

$Q_{sh} = -24\ \mathrm{W/m^2}$

$Q_{lh} = -78\ \mathrm{W/m^2}$

Sea Surface

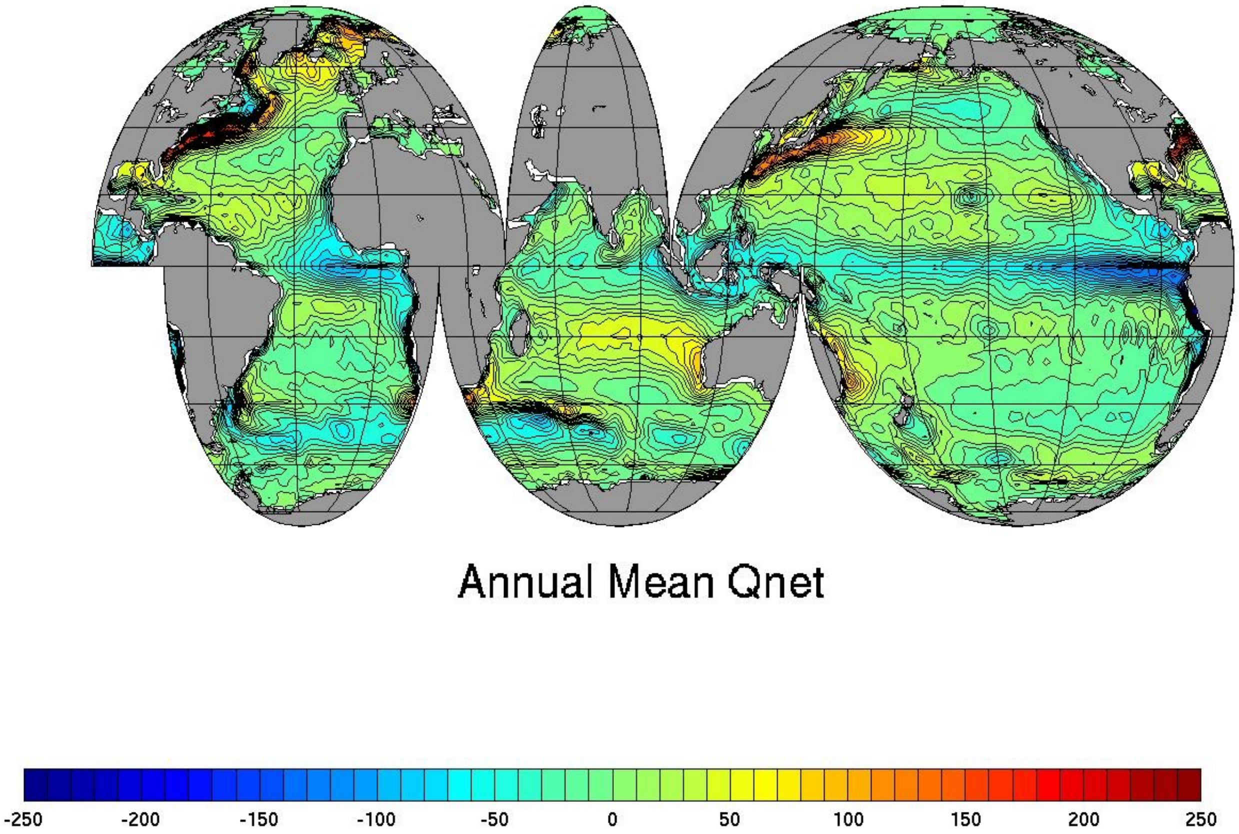


Heat input through the sea surface (where 1 PW = 10^{15} W) (world ocean) for 1º latitude bands for all components of heat flux. *Data are from the NOCS climatology (Grist and Josey, 2003)*.

TALLEY

Net heat flux

- Climatology (1968-1996)
    - Upward positive (positive into the atmosphere)



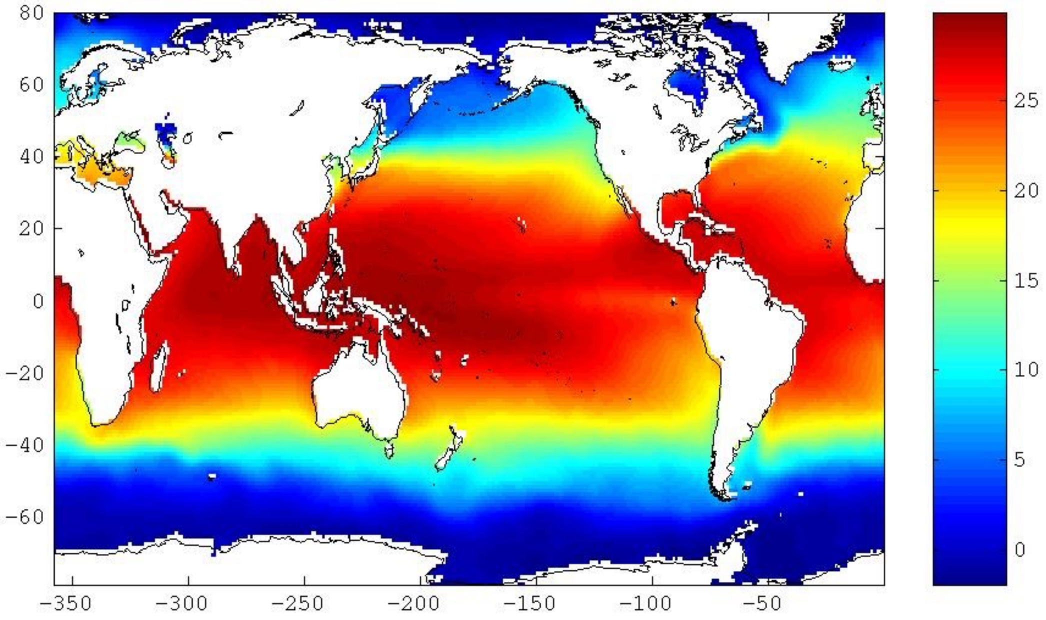
Annual Mean Qnet

Heat balance at the air-sea interface

At a given spot:

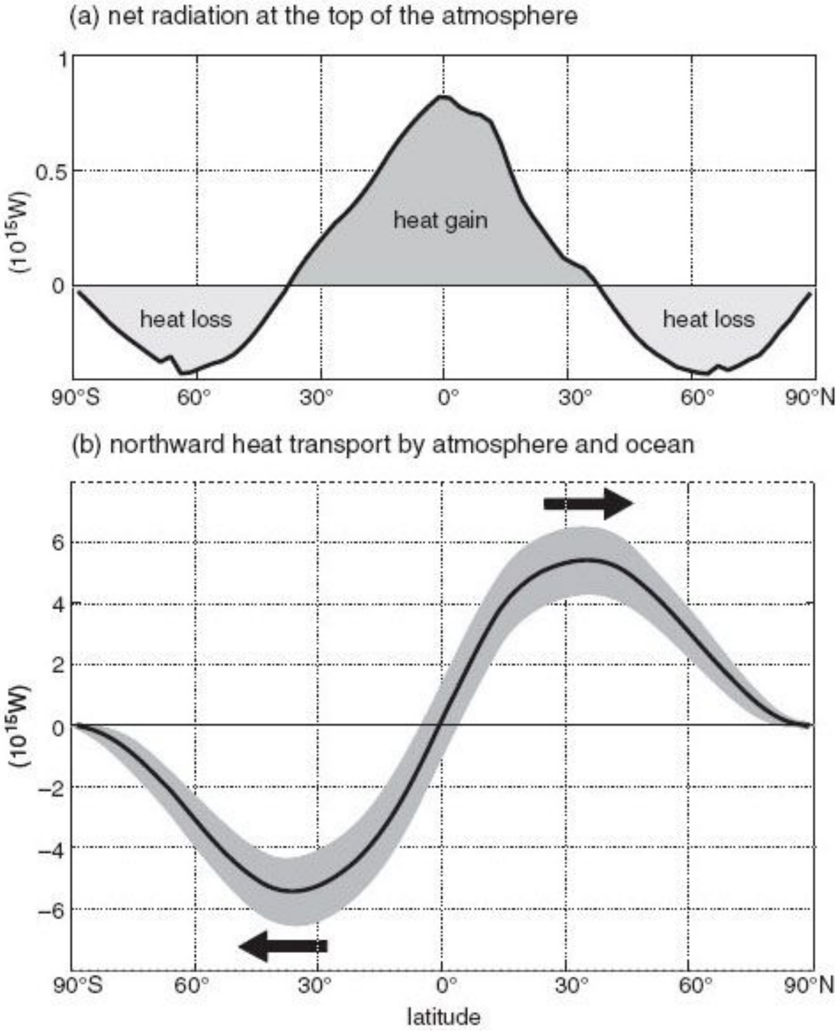
$\rho \mathbf{C_p\ x\ h\ x\ dT/dt = (}\boldsymbol{Q_{sw} + Q_{lw} + Q_{lh} + Q_{sh}}\mathbf{)} + \boldsymbol{Q_{transport} + Q_{mixing}}$

$Q_{transport}$ = Heat brought in from adjacent parts of the ocean (vertical and horizontal motion)



Mer’s activity

Top of the Atmosphere



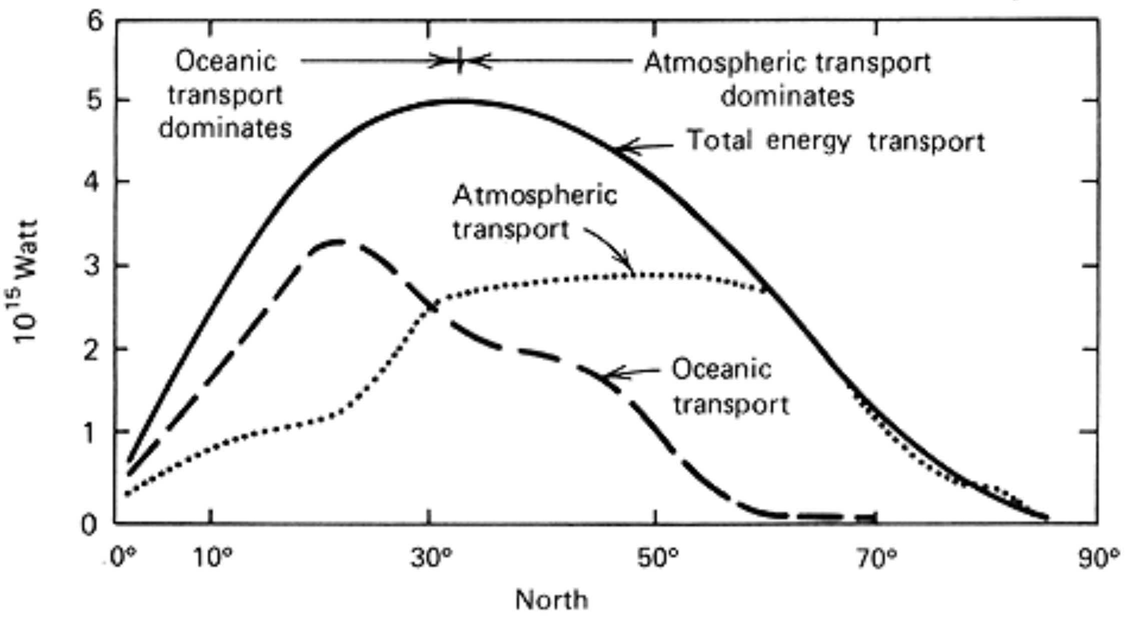
Units for energy

One Peta Watt = 10^{15} W = 1PW

For comparison: one nuclear power reactor generates about a giga watt = 10^{9}W = 1GW

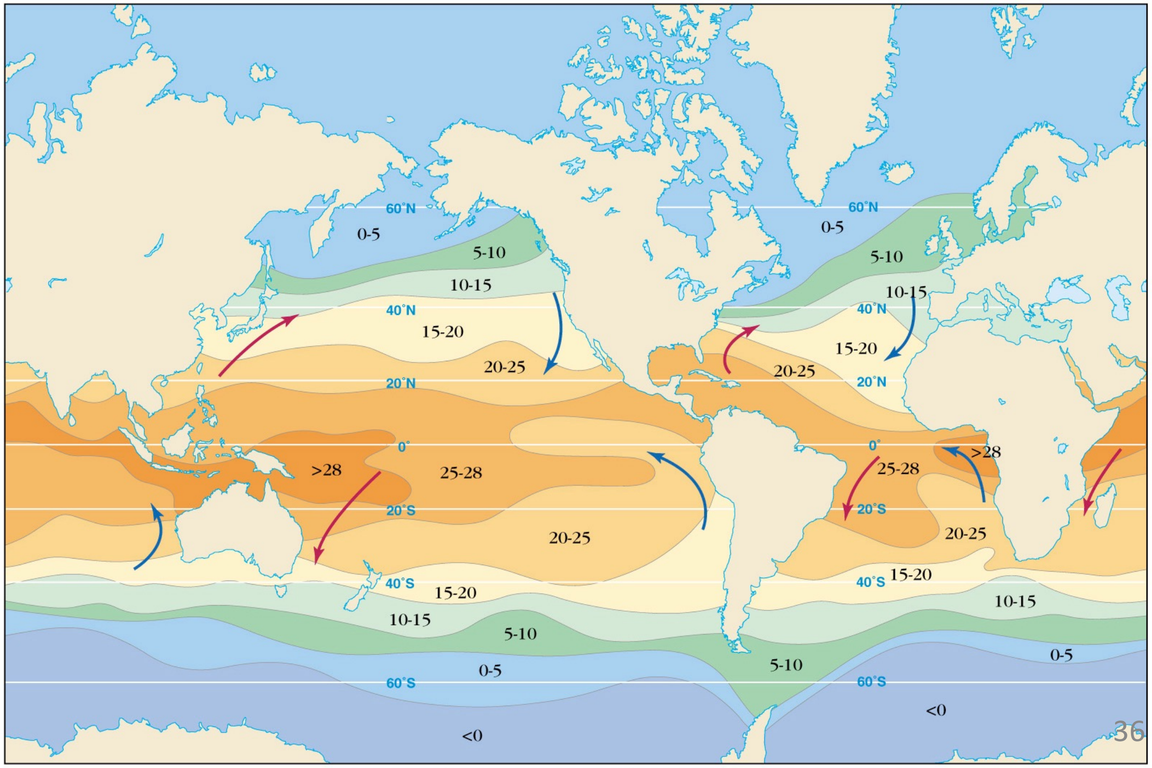
Figure 1.3

Heat Transport by Ocean and Atmosphere



Ocean heat transport

- Ocean gains heat from the atmosphere in tropics
- Ocean circulation transports heat poleward, and release back to the atmosphere at high latitudes
- This is about half of the total poleward heat transport (atmosphere carries other half)



Copyright © 2004 Pearson Prentice Hall, Inc.