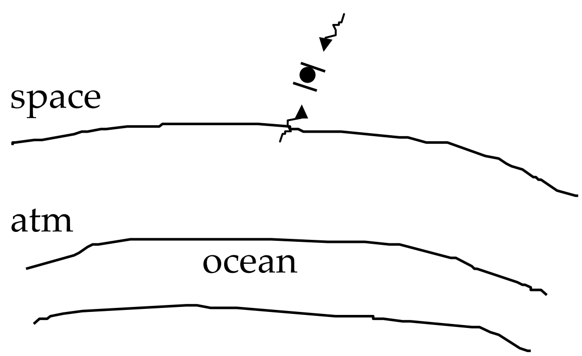
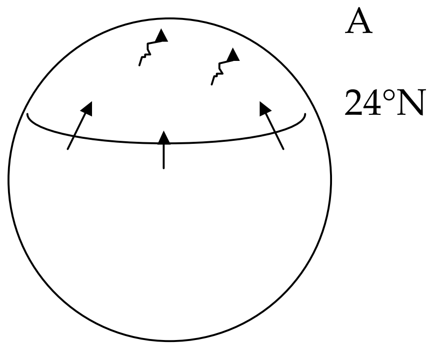
Atmospheric and ocean circulation and meridional transport of heat

(1) What is the meridional heat transport by the atmosphere and the ocean?
(2) How is it measured?
(3) What are the mechanisms?

Satellite measurements. 1985-1989 ERBE: Earth Radiation Budget Experiment. In an annual average, we have

- incoming shortwave and outgoing longwave radiation at top of atmosphere
- total of atmospheric and oceanic contributions





total amount of heat lost to space in area north of 24°N = total amount of heat flux across 24°N in atmosphere and ocean.

$$\iint_A Q_{NET}\, dA = Q_{AT} + Q_{OC} = Q_{TOTAL}$$

We can apply this to every latitude starting at the poles (where Q_{TOTAL}=0) and build up a curve of meridional heat transport as a function of latitude.

Explain units. If you know the air-sea heat flux, you can perform a similar calculation to determine the oceanic heat transport, and this method provided the first estimates before direct measurements of currents and their temperature were available. There have been two decades of disagreement over the roles of the atmosphere and ocean in meridional heat transport, but the estimates from the atmospheric side and the oceanic side are finally starting to converge. The problem arises, in part because the method of calculation amplifies small errors, as you will see in the homework.

Mechanisms:

Atmosphere

Generally divided into three components:

$\langle \bar{v} \rangle \langle \bar{T} \rangle + \langle \overline{v^*} \overline{T^*} \rangle + \langle \overline{v' T'} \rangle$ <> = average around a latitude circle

__ = average with time

( )* = stationary eddy, i.e., $\overline{v^*} = \bar{v} - \langle \bar{v} \rangle$ the permanent ridges and troughs in the atmosphere.

( )′ = transient eddy, i.e. $v' = v - \bar{v}$

In the atmosphere, all three are important

There is an analogous term for latent heat transport

Zonally averaged motions: the net meridional circulation cells. Towards the poles in the Hadley cell near the equator and the Polar cell (direct cells). Tending to warm the equator (!) at midlatitudes in the Ferrell Cell (indirect cell).

Transient eddy heat transport: strongest in midlatitudes, associated with storms “baroclinic disturbances”, strongest in winter

Atmosphere dominates transport poleward of 30°. Maximum is 5 PW at peaking at around 40° latitude caused by midlatitude storms.

Ocean

Ocean contributes a maximum of about 1-2 PW peaking in the center of the subtropical gyre at about 25°N. Slightly weaker heat transport to south in southern subtropics. The Atlantic heat transport is actually working against global heat redistribution.

Mechanisms:

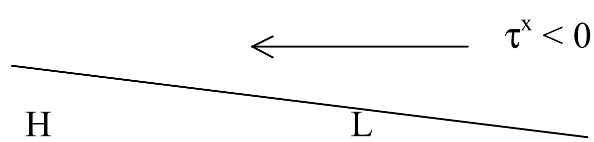
Shallow gyre circulation. A water parcel flows north in the western boundary current loses its heat to the ocean and flows south at a colder temperature, greater density. Thus there is a shallow overturning circulation associated with the wind-driven subtropical gyre.

Tropical cell. Oceanic response to the Walker cell circulation in the atmosphere, although the rising branch of the Walker cell is forced by SST which is a product of the ocean circulation. Circulation in the atmosphere and ocean in the tropics is an inherently coupled phenomenon. But let's start with the trade winds. On the equator, the Coriolis force is identically zero and the force balance near the ocean surface is between wind stress and pressure gradient.

$$\frac{\partial u}{\partial t} = 0 = -\frac{1}{\rho_0}\frac{\partial p}{\partial x} + \tau^x$$

$$\frac{\partial p}{\partial x} \propto \tau^x$$

(blowing to the west), so dp/dx < 0, sea level decreases to the east.



Now, on Monday we talked about what is going on subsurface with a sealevel slope. Where is the water column thicker? So where is it warmer?

In the west. Thermocline slopes up to the east. The western Pacific is filled with a thick layer of warm water…called the Western Pacific Warm Pool. Now the pressure gradient is larger than just the tropics. What is the off-equatorial response to this pressure gradient. A geostrophic flow towards the equator on both sides that reaches down into the thermocline. This converging thermocline water upwells to feed the equatorial divergence in the surface layers caused by the Ekman transport.

This shallow tropical overturning cell is associated with a northward heat transport and is the dominant mechanism to about ± 10°.

<u>Thermohaline circulation</u>. Diagram more confusing
North Atlantic. Upper layer water that does not return in the gyre is

(1) turned into Labrador Sea Water (7 Sv) = 1/3 PW

(2) turned into NADW (9 Sv) = 1/2 PW

(3) small southward heat transport from cold Antarctic bottom water flowing northward and returning south at warmer temperatures as NADW.

South Atlantic transport is also northward because of the northward flowing surface water and colder return flow to the south at depth.

North Pacific. Surface layer water is turned into NPIW, not very deep, about 500 m, just below the thermocline. Most of the Pacific's volume is occupied by the thermohaline cell water masses. AABW flows north and returns south as Pacific Deep Water, but the temperature difference is quite small, so not much contribution to heat transport.

Bottom water is upwelled into deep and intermediate waters in the South Atlantic and South Indian oceans and makes a somewhat higher contribution to southward heat transport there, though we are really not too sure about these processes.

In the far southern ocean, about 1/2 PW of heat is lost to the atmosphere during the formation of new AABW. How is this heat supplied? Current is primarily a zonal flow around the Southern Ocean. Heat flux is accomplished by eddies that grow from the instability of the ACC, much like the midlatitude eddies that grow from instability in the jet streams.