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Notes on Lab Activity #7: Global Patterns of Temperature and Salinity

(Refer to the annual-average heat budget equations for low, middle, and high latitudes, provided in class.)

* Latitudinal Heat Transport by Ocean Currents: Fixed Volume Perspective

There is a large-scale gyre in each of the five major ocean basins, straddling the low and middle latitudes (see ocean surface currents schematic, from Lab #7: Global patterns of Sea Surface Temperature and Salinity). On the western side of each gyre, currents flow poleward and are relatively warm. They carry heat from low latitudes into the middle latitudes.

On the eastern side of each gyre, the currents flow toward the equator but are relatively cooler. These currents transport heat from the middle latitudes into low latitudes, but if we assume that the same amount of water enters and leaves the low latitudes via these currents (a reasonable assumption), then they carry less heat (because the water is cooler). Hence, the gyres produce a net transport of heat from low to middle latitudes.

This is a perspective in which we consider the heat budget for a *fixed volume* of the ocean consisting of a slab or layer with boundaries at 30°N & S and a top boundary at the ocean surface. (The same idea applies to a fixed volume that extends from below the ocean surface to the "top" of the atmosphere, which we considered when analyzing radiative energy fluxes.) From this "fixed volume" perspective, we must consider not only fluxes of energy in and out the top of the volume but also fluxes in and out the sides.

Latitudinal Heat Transport by Ocean Currents: Parcel Perspective

As an alternative perspective, consider a "parcel" of water circulating in a gyre, starting (arbitrarily) in the eastern part of an ocean basin in the low latitudes, where the parcel is still relatively cool. While in the low latitudes, as the parcel moves from the eastern side of an ocean basin to the west side near the equator, the parcel gains more heat than it loses and hence warms up the whole time it spends near the equator.

Observations (see Figure 3 from Lab Activity #7) show that the ocean surface gains heat (net) most rapidly in the eastern part of the gyre along the equator. While there, the parcel gains heat not only by absorbing solar radiation, which is relatively intense at low latitudes, and by absorbing LWIR radiation emitted downward by the atmosphere, which is also relatively intense because the atmosphere is relatively warm and water vapor (a greenhouse gas) is relatively abundant in the tropics, but also by conduction from the atmosphere because the parcel is still relatively cool in the eastern part of the gyre—cooler than the atmosphere. The parcel loses heat by emitting LWIR radiation, but it emits less intensely than it does farther west because the parcel is cooler in the eastern part of the gyre. The parcel also loses heat by evaporation, but evaporation tends to be slower when the water is cooler. Hence, both of these sinks of heat are smaller than they are farther west, which increases the difference between the sum of the sources and the sum of the sinks and causes the water to warm more rapidly.

The bottom line, though, is that while the parcel moves westward in the low latitudes, it gains heat faster than it loses heat, so it warms up the whole time.

As the parcel reaches the western side of the ocean basin and deflects poleward, observations show that it begins to lose more heat than it gains. At the point where the parcel stops gaining heat (net), it will have reached its highest temperature, which explains why the warmest water in ocean basins is on the western side at low latitudes.

Observations (see Figure 3 from Lab Activity #7) show that the ocean surface loses heat most rapidly in the western part of the gyre at midlatitudes, where the water is moving eastward. While there, it gains heat by absorption of solar radiation, but solar radiation is less intense at midlatitudes than at low latitudes. It also gains heat by absorption of LWIR radiation emitted downward by the atmosphere, but that is less intense than at low latitudes because the atmosphere is cooler (and there is less water vapor in the air). Hence, both of these sources of heat are smaller than they are at low latitudes.

In contrast, the water is still relatively warm, so it emits LWIR radiation more intensely than it does in the eastern parts of the gyre; water evaporates from it more quickly; and it is warmer than the atmosphere, so heat conducts from the water into the atmosphere. Hence, the sinks are greater than they are the eastern parts of the gyre, explaining why the water loses heat most rapidly in the western part of the gyre at midlatitudes.

Again, though, the bottom line is that while the parcel moves eastward in the middle latitudes, it loses heat faster than it gains heat, and hence cools off.

Hence, if we track the progress of a parcel of water around a gyre, we find that it gains more heat than it loses while it is in the low latitudes, and loses more heat than it gains while in the midlatitudes. That is, it picks up heat in the low latitudes and dumps it off in the middle latitudes (into the atmosphere by conduction and evaporation and by emission of LWIR radiation, which is mostly absorbed by the atmosphere), then goes back to the low latitudes to pick up another "load" of heat.

Latitudinal Heat Transport by Ocean Currents: The Bottom Line

Note that, as viewed from the "fixed volume" perspective, the sources and sinks of heat for water at the ocean surface are the same as they are for the "parcel" perspective, except that the fixed volume perspective also consider the effects of net transport of heat by moving fluid into and out of the fixed volume. In contrast, when following a parcel of fluid around and keeping track of its heat budget, such an idea would have no meaning.

Viewed either way—from the perspective of net transport of heat between low and middle latitude zones by currents in the western and eastern parts of gyres flowing simultaneously, or from the perspective of individual "parcels" of water first picking up heat in the low latitudes and then transferring it into middle latitudes (where they dump heat into the atmosphere)—the net transport of heat by ocean currents in gyres constitutes a sink of heat for low latitudes and a source of heat for middle latitudes.

Contribution of Latitudinal Ocean Heat Transport to the Annual-Average Heat Budgets for the Low and Middle Latitude Zones

In the annual average at low latitudes, as we discovered in Lab #4: Introduction to the Earth's Energy Budget, the *radiative* source (absorption of solar radiation) exceeds the *radiative* sink (emission of LWIR radiation) for the atmosphere and the earth's surface combined. It turns out that net transport of heat by ocean currents out of the low latitudes largely compensates for this radiative imbalance, producing a roughly balanced annual average heat budget for the low latitudes, and so the annual average temperature changes only a little from one year to the next.

However, the heat that the gyres carry out of the low latitudes, they carry into the midlatitudes. This constitutes an additional source of heat for the midlatitudes, where the *radiative* source and sink approximately balance. Hence, net transport of heat to the midlatitudes by ocean currents appears to unbalance the heat budget for the midlatitudes, even though we know that the annual average temperature of the midlatitudes doesn't typically change that much from year to year (that is, the heat budget for the midlatitudes approximately balances). Now we must be missing something from the heat budget for the midlatitudes!