MITx Video | 12.340xCarbCyc01v02

In this next section we'll look at earth's carbon cycle. A good place to start out is by reviewing the amount of carbon available in different reservoirs on earth. Here the amount of carbon in each of these reservoirs is expressed as petagrams, which are the same as gigatons, or 10 to the 15th grams. The most important point here is that the carbon in the atmosphere, which is primarily CO_2, is a very small proportion of all the carbon on earth. The importance of this observation is that very small changes in the carbon content of these other reservoirs can lead to very large proportional changes in the amount of carbon in the atmosphere.

Shown here are the atmosphere, the amount of carbon in the ocean, which dwarfs that in the atmosphere, the amount of carbon in vegetation and soils on land, fossil fuels, organic matter in rocks, and inorganic carbon in rocks, which primarily exists as calcium carbonate, the primary constituent of limestone. Also note that this is the carbon budget for the pre-industrial era. Now there is a good deal more carbon in the atmosphere.

Here we see these same reservoirs but with fluxes between the reservoirs depicted. So again we have the atmosphere, the ocean, which is now split into the surface ocean and the intermediate and deep ocean, fossil fuels, and vegetation, and soils. Not shown are the crustal reservoirs. The black arrows show fluxes between the reservoirs. These are estimated for the natural state of the system, before anthropogenic modification. The numbers are in units of petagrams of carbon per year. In red are anthropogenic modifications of those fluxes.

So for example, there is no natural flux of fossil fuels into the atmosphere, but there is an anthropogenic flux that reduces the size of this reservoir, and adds carbon from fossil fuels into the atmosphere. This rate was current for 2002, but is now substantially higher. The reason for partitioning the ocean into the surface ocean, and the intermediate and deep ocean has to do with the different time scales of responses of these different reservoirs. The surface ocean equilibrates with the atmosphere on time scales of years, whereas the intermediate and deep ocean equilibrate only over centuries and millennia.

Again, we see that the atmosphere is much smaller than these other reservoirs. We also see that the fluxes in and out of the atmosphere are very large with respect to its overall size. Again, the atmosphere's reservoir size is very sensitive to small perturbations in these fluxes.

For over 50 years we've been monitoring the amount of carbon dioxide in the atmosphere. The longest lived of these records is from Mauna Loa Observatory in Hawaii. Here we see a steady rise in the carbon dioxide content of the atmosphere. Superimposed on this steady rise we see seasonal variations. Carbon dioxide rises during northern hemisphere fall and winter, and it falls during the spring and summer. These seasonal variations reflect the balance of photosynthesis and respiration on the northern hemisphere continents. As plants grow during the spring and summer photosynthesis is greater than respiration, and so CO_2 is removed from the atmosphere. In fall and winter that CO_2 is returned to the atmosphere as respiration outpaces photosynthesis.

We know fairly well how much carbon dioxide has been emitted to the world's atmosphere due to human activities. Here are estimates going back to the 1870s. We see that early on in the record anthropogenic emissions are dominated by land use change. This is primarily deforestation. But later on fossil fuel consumption becomes the dominant source of emissions. Overall emissions rise from about one petagram of carbon per year to about 10 currently.

Taking these reconstructed emissions and comparing them against how much carbon dioxide has actually built up in the atmosphere, we see that less than 50% of what has been emitted is accounted for by what we measure in the atmosphere today. So where did the rest of the CO_2 go? Shown here are the results from the most recent effort to budget this carbon. This is the average of the last decade. On the left is the last decade's average anthropogenic emissions. These are dominantly related to fossil fuel burning and other industrial emissions, but they also derive from land use change. On the right are the places that that carbon has ended up. About half of it has ended up in the atmosphere, and the remainder has ended up relatively equally split between the ocean and the terrestrial biosphere.

Note that we can directly measure what's ended up in the atmosphere. We can estimate fairly well how much has ended up in the ocean, but we can only calculate how much has ended up in the terrestrial biosphere by difference. That is, as the residual of inputs minus outputs. One thing that becomes clear from this slide is that our CO_2 problem would be a good deal worse if all of the CO_2 that we emitted actually ended up in the atmosphere. Because of this important role of the oceans and the terrestrial biosphere in taking up carbon from the atmosphere, it's important to understand what determines this uptake, and how it's likely to change in the future. As we'll see in the long run, most of anthropogenic carbon dioxide ends up in the oceans. And so we're going to focus particular attention on what regulates oceanic uptake of CO_2.