The Global Carbon Cycle

Chris Swanston*

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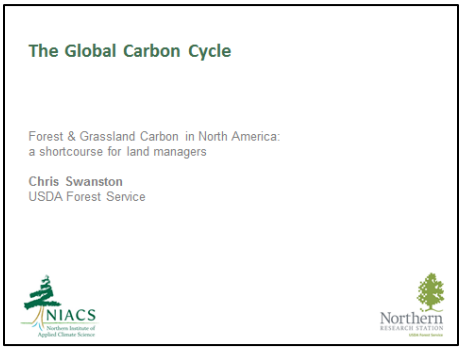
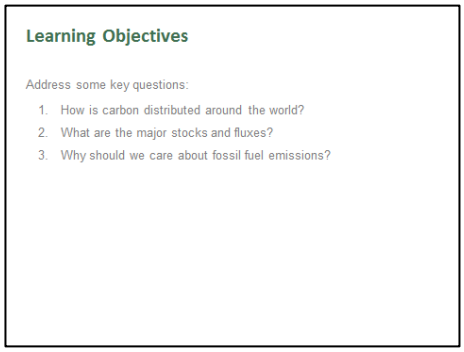
Slide 1. The Global Carbon Cycle



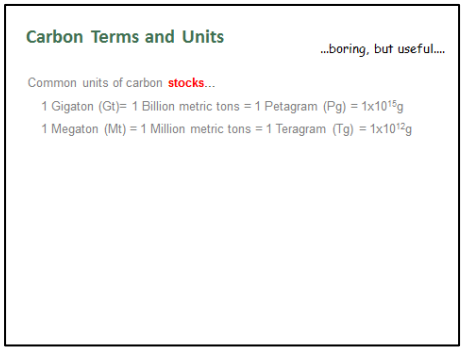
Hi, my name is Chris Swanston. I'm a researcher with the Northern Institute of Applied Climate Science and the U.S. Forest Service, Northern Research Station. Today I'm going to talk about the global carbon cycle.

Slide 2. Learning Objectives



I'm going to address three key questions. One, how is carbon distributed around the world? What are the major stocks and fluxes of carbon? And frankly, why should we care about fossil fuel emissions?

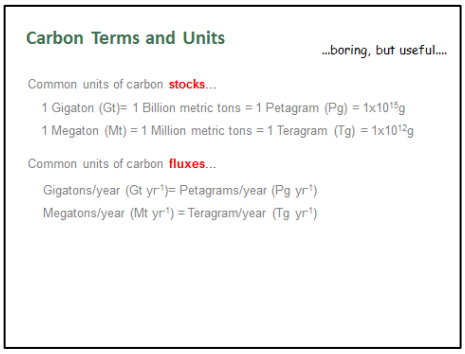
Slide 3. Carbon Terms and Units - Stocks



Before I get to the really interesting stuff, I'm going to cover some common terms that we use when we're talking about carbon. You'll hear these terms throughout my talk, but you'll also hear them in the rest of the talks in this series. The first is one that we use when we're talking about global carbon, and that's a billion metric tons or gigaton or sometimes a petagram of carbon. We use this term when we talk about stocks of carbon. A stock, also called a pool or a reservoir of carbon, is just an amount of carbon. When we're talking about smaller scales such as the United States regions, we often use a term megaton or teragram, that's a million metric tons of carbon.

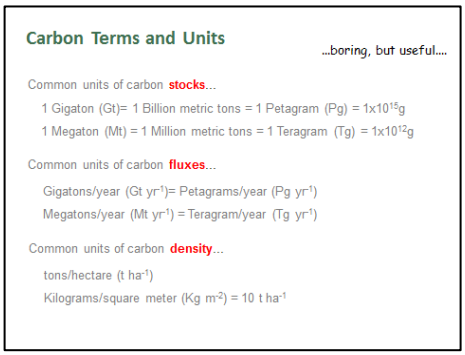
** This document transcribes the presentation given by Dr. Swanston. The presentation is part of General Technical Report NRS-93, "Forest and grassland carbon in North America: A short course for land managers." The full report, comprised of 15 presentations, is in DVD format and can be obtained at http://nrs.fs.fed.us/pubs/order/40110. The presentations and related materials can also be accessed at http://www.fs.fed.us/ccrc/carboncourse/*

Slide 4. Carbon Terms and Units - Fluxes



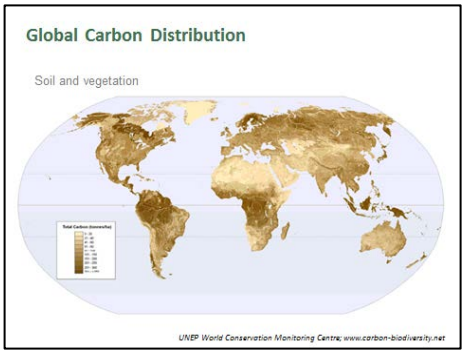
We also use a term fluxes. When we're talking about fluxes, we're talking about an amount of carbon that moves from one stock to another stock in some amount of time. So we'll say gigatons per year or megatons or teragrams per year.

Slide 5. Carbon Terms and Units - Density



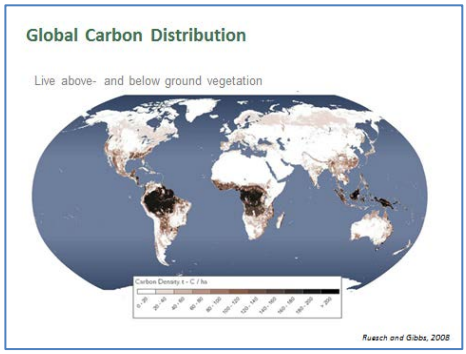
And then we'll use the term density and we'll talk about carbon density, and that's tons per some unit space, so tons per hectare, for example. If you talk about really fine scale sometimes you'll hear about kilograms per square meter. If that confuses you just multiply by ten and then you've got tons per hectare.

Slide 6. Global Carbon Distribution – Soil and Vegetation



Okay, so now to the good stuff. So where is the carbon in soil and vegetation? If you look at this map you see the light colors, and that's less than 20 tons per hectare, this is in carbon density. The darker colors are 800 to 1,000 tons per hectare. So if you look at the equatorial region you see all these dark colors in that warm wet region. And then if you go north to the top of that map, you see more dark brown colors, again lots of carbon there although that's a cold often dry region in the boreal region up in Alaska and northern Canada and in northern Europe. Move slightly south and you're into the temperate regions and you see those colors slightly lighter, somewhat less carbon in the soils and vegetation in those areas. And then again slightly south and into the arid regions in northern Africa and the Middle East, and yet again very little carbon in those arid regions.

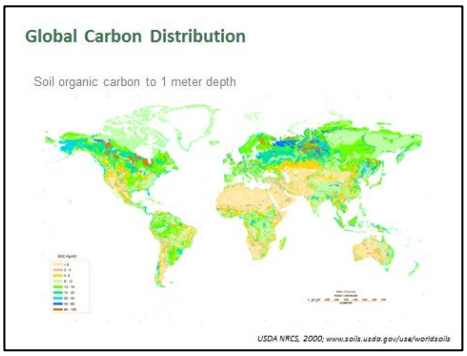
Slide 7. Live Above and Below-Ground Vegetation



So where do we see carbon in the soils versus the vegetation? This is the same idea with this map with live above- and belowground vegetation. The light areas are very little carbon ranging up to more carbon, more than 200 tons per hectare in the very dark colors. And so the first thing that jumps out at you is that equatorial region again. Dark colors there in that warm wet region, lots of carbon in that vegetation. But then, like we did last time, you go back to that boreal region, the cold region up top, and you don't see those dark colors, so not so much carbon in the vegetation in that area. Move slightly south into the temperate zone and what you'll see is a bit more carbon there where you have forests in the live vegetation.

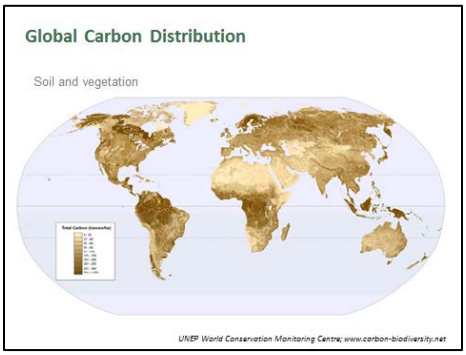
And now if we think about carbons in the soils then, and we go to this next map…

Slide 8. Soil Organic Carbon to 1 Meter Depth



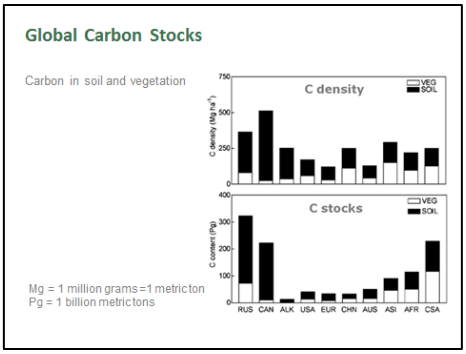
… and I have to apologize for the colors, you'll just have to bear with me. If you look on the lower left you'll see a legend and there are four bars in that legend, sort of green going to blue, going to dark blue to brown, so focus on those colors. Now if you look back in the equatorial region, you don't really see very many of those colors. You see lighter blues or lighter browns. And if you jump up to the boreal, that cold region again, then there you'll see lots of those dark blues, the browns, the darker greens, so more carbon in those soils in that region. And if you come south again into those temperate zones it's a lot more complex, a lot more mixed up in there. The temperate zone tends to be a lot more complex and the way that the major drivers of what holds carbon in place. So if we come back to the original map then, and think about this again in the perspective of those two previous maps…

Slide 9. Soil and Vegetation



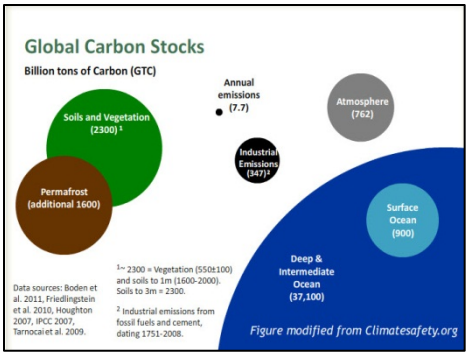
… and you look at that boreal zone, you see the dark there in the carbon, and really now we think of that really being more about vegetation. And then you look in the north in the dry colder zone in the boreal zone, sorry I meant the equatorial zone in the middle with the more carbon being in vegetation, and then you go to the boreal zone up there in the north and you see more carbon there. You think more about carbon in the soils. And then again in that temperate zone, it's much more complex in the way that it's distributed.

Slide 10. Global Carbon Stocks - Soil and Vegetation



We can look at this in a different way, too, with these graphs. So this graph shows carbon density on top in tons per hectare and carbon stocks on the bottom. It says petagrams, but again, petagrams are the same as gigatons, and so in black you have soils, in white you have vegetation. And if you look at those three left-hand bars there you've got Russia, Canada, and Alaska, again that northern boreal zone. Lots and lots of carbon dominated by carbon in the soils, much less carbon in the vegetation in that area. Jump to the far right and those three bars, you've got Asia, Africa, Central and South America and there proportionally you have much more of the carbon in the vegetation. So vegetation plays a much stronger role there in terms of holding the carbon in those biomes. And you look at those central bars of U.S.A. and Europe and China, and again it's a much more complex situation, but you tend to see still lots of carbon in the soils, but a varying amount of carbon in those areas.

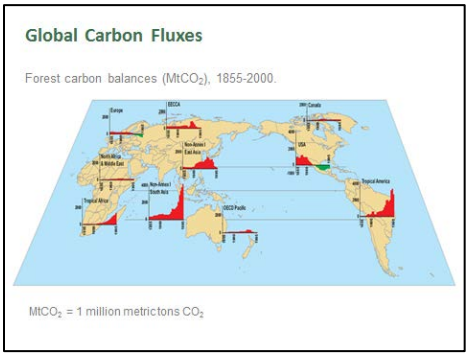
Slide 11. Global Carbon Stocks – Map



So let's think a bit more about the carbon stocks, and when we look at this figure, which I like a lot because it gives you an idea of the relative size of these stocks. You get an idea of where the carbon resides overall, and you look at that big blue circle off on the lower right and that's the ocean. Deep ocean holds a vast amount of carbon in this system, 37,000 gigatons, and a lot of that carbon, a good amount anyway, is also organic. But that actually cycles very slowly. It's trapped down below for long periods of time, actually millennia. And if you look at the surface ocean, still a big pool at 900 gigatons, that is much more interactive with the atmosphere. But still carbon in that pool can cycle at the rate of decades or even centuries. We go over to the left and you look at the soils and vegetation circle, big pool, 2,300 gigatons. And now of course, vegetation has a very dynamic cycling rate in terms of its carbon. In soils, really the bulk of carbon in soils cycles or has a mean residence time on the order of decades, or deeper in the soil, even centuries. When you look at the permafrost soils, those will hold their carbon for thousands of years. Now if you look at the atmosphere, a lot of people are surprised actually that that pool of carbon, 760 gigatons right now, is actually smaller than what we have in soils and in vegetation together, or in the surface ocean.

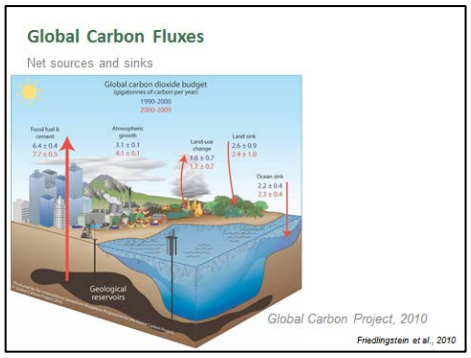
And then really the elephant in the room here is that tiny little dot, annual emissions. And you hear a lot about how important annual emissions are, but you put them on this graph with these giant stocks and it seems kind of small and pathetic, and why should we care so much about annual fossil fuel emissions? Well, I've talked about the residence time of carbon in these other pools, but there is also a residence time of carbon in the atmosphere. And for carbon dioxide, a common estimate of that residence time is upwards of 100 years. So what we're doing with fossil fuel emissions is taking carbon from a reservoir that's outside of these blobs from the fossil fuel reservoir and adding it to the system. So every year we're adding this little bit of carbon to this system where it stays then in the atmosphere potentially for hundreds of years, certainly for decades. And it adds up and accumulates, and as it accumulates, of course, carbon dioxide and other greenhouse gases in the atmosphere contribute strongly to climate change and global warming. So a little bit over a long time matters.

Slide 12. Global Carbon Fluxes – Forest Carbon Balances



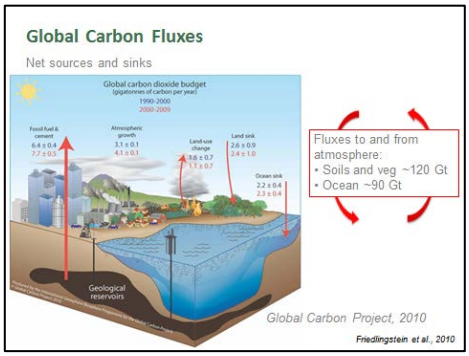
And of course it's not just fossil fuels. It's also land use change that is adding greenhouse gases and carbon dioxide to the atmosphere. And over the last 150 years you can see this trend of adding these gases to the atmosphere around the world. And so right now in many regions there's still a strong contribution of carbon dioxide to the atmosphere from land use change. Mostly from deforestation, and notably in the Unites States and in Europe, there's been for several decades a trend of actually sequestering carbon. And that has a lot to do with previous land use and then changing land use now. And you'll hear more about that in subsequent talks.

Slide 13. Global Carbon Fluxes – Net Sources and Sinks



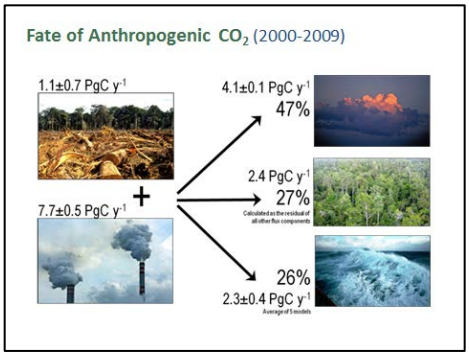
So let's get back to the fluxes. Now in this graph you're going to see two numbers, some that are in green, some that are in red. And the green numbers are flux estimates from the 1990s in gigatons, and the red numbers are flux estimates from the last decade, 2000-2009, also in gigatons. Go to the far left and what you'll see is this big red arrow coming up from geological reservoirs, and in green you'll see 6.4 gigatons of carbon being added to the atmosphere annually. And that's what you'll most commonly see in the literature. The 7.7 gigatons for the last decade is a newer number, you'll be seeing that increasingly. And so what we've seen then is in the last decade an increase in the annual addition of fossil fuel carbon into the atmosphere coming from this geological reservoir, which itself is 4,000 gigatons. So we can continue adding quite a bit of carbon to the atmosphere from that reservoir. Now move to the next arrow to the right and you'll see land use change. That was 1.6 gigatons addition annually into the atmosphere. Now it's been downgraded a bit, which is nice, to 1.1, but still significant.

Slide 14. Fluxes to/from Atmosphere



So again, the elephant in the room. That's 8.8 together gigatons addition to the atmosphere. Is that really such a big deal when you consider the overall fluxes from land and from ocean to the atmosphere and back? You have from the land to the atmosphere about 120 gigatons per year, slightly less. And you have from the atmosphere into the land about slightly more than 120. From the ocean you lose 90 gigatons of carbon to the atmosphere and gain slightly more than that. So those slightlys are actually a really big deal. You have small changes in those big fluxes accounting for major sinks. So in the land that's about 2.4 gigatons in the last decade, and in the ocean that's about 2.3 gigatons per year in the last decade. So again, small changes and big fluxes make a difference. Now they mitigate to some degree what we're putting into the atmosphere from our land use change and our fossil fuel emissions, but not completely, so we're still getting 4 gigatons of atmosphere net put into the atmosphere of carbon dioxide net put into the atmosphere every year, and that adds up.

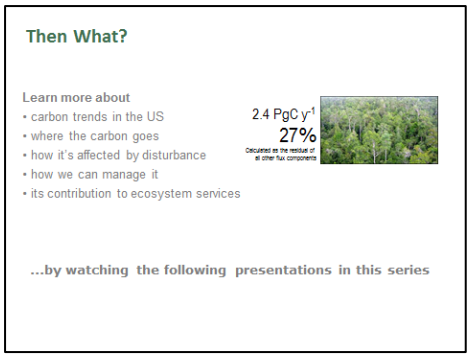
Slide 15. Fate of Anthropogenic Carbon Dioxide



So let's think about that just a bit more. There's the 1.1 land use on top, 7.7 fossil fuel emissions on the bottom. This is in petagrams, but remember petagrams are the same as gigatons. This was a nice slide put out by the Global Carbon Project so I've appropriated it. And so what we see is almost half of those emissions going into the atmosphere. As I said about a total of 4 gigatons per year and accumulate there, again contributing to climate change and global warming. And now if you look at the bottom, you see about 26 percent going into the ocean, and that's a good thing in the sense that it's not going into the atmosphere and contributing to climate change. It's a bad thing in the sense that it strongly contributes to acidification in the ocean, which has a strongly negative effects on ocean life and will continue to have increasing effects on ocean life through time. Now, then you see

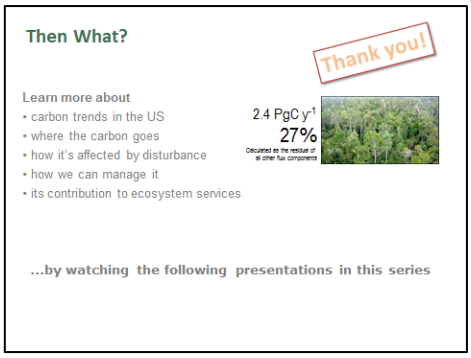
27 percent that actually moves into the terrestrial systems. And so then the question becomes, well, what happens to that 20 percent, that two and a half gigatons?

Slide 16. Then What?



Well, I'm not going to answer that actually because what you're going to see are several more presentations from this same series in which they're going to address the carbon trends in the U.S., where the carbon goes in different kinds of ecosystems, and how it's effected by disturbance, how it's affected by management, and how we can manage it on purpose. And then finally what its contribution to ecosystems services, including markets, may be.

Slide 17. Thank You



So I hope you watch the rest of the talks in the series. I hope you enjoy them and I hope you've enjoyed this one. Thanks very much.