Aspen Global Change Institute Energy Project

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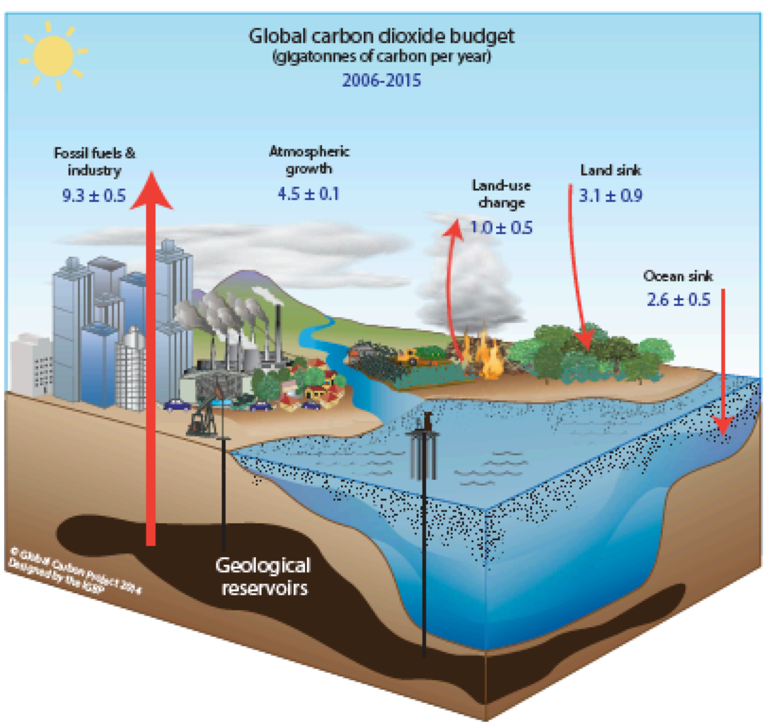
Counting Carbon: Is the CO_2 Uptake by the Land Changing?

The ocean and the land absorb roughly half of the human-caused carbon dioxide emissions that would have otherwise accumulated in the atmosphere, acting as “carbon sinks.” These processes have partially slowed the rate of global warming since pre-industrial times. Two independent studies in 2016 focused on an enhanced terrestrial carbon sink observed in recent decades (Zhu 2016; Keenan 2016). Because the land is both a source and a sink of carbon, better understanding of the driving mechanisms in this two-way process and the resulting net effect for carbon emissions is a critical factor in predicting the trajectory of greenhouse gas forcing and the resulting change in climate.

The concentration of carbon dioxide in the atmosphere continues to increase – now over 400 ppm, some 120 ppm above pre-industrial measures. The Global Carbon Project (GCP), a massive international effort of researchers from numerous institutions, produces periodic updates on the carbon dioxide budget tracking sources and sinks and how they change over time.



The above diagram from the GCP 2016 assessment shows the global average emissions in gigatonnes of carbon (GtC) per year between 2006 and 2015 (Le Quéré 2016). Table 1 below shows averages from the last decade (as in the GCP diagram), compared to the single year results for 2015. It's important to note that the land sink in 2015 was 1.2 GtC less than the previous decade average, which partially explains the 1.8 GtC gain in the growth rate of the atmospheric CO_2 concentration.

Table 1: Mean GtC yr^{-1}		
	2006-2015	2015
Emissions		
Fossil fuels and industry	9.3±0.5	9.9±0.5
Land-use change emissions	1.0±0.5	1.3±0.5
Partitioning		
Growth rate in atm. CO_2 conc.	4.5±0.1	6.3±.0.2
Ocean sink	2.6±0.5	3.0±0.5
Residual land sink	3.1±0.9	1.9±0.9
Excerpt from Table 8 C. Le Quéré et al.: Global Carbon Budget 2016		

The Earth's carbon cycle operates on many time scales, from the few seconds it takes a mammal to exhale to the slow process of tectonic plate subduction carrying carbon into the mantle over tens of thousands of years. On century timescales—most relevant to human interactions with the climate—is the partitioning of annual carbon dioxide emissions into three reservoirs: the atmosphere, the land, and the ocean. Humans add to these reservoirs by combustion of fossil fuels and other industrial processes such as cement manufacture, and by changes in vegetation and land use. In round numbers the annual disturbance is 10 gigatonnes of carbon emitted in the form of carbon dioxide annually with about 1 GtC from land use change.

The ocean takes up about a third of these emissions and the land about a fifth. The fraction of total carbon dioxide emissions remaining in the atmosphere from human sources (not absorbed by the ocean and land sinks) is the airborne fraction (AF). In a sense, the airborne fraction is a marker of the industrial age. A noteworthy aspect of the airborne fraction (see Figure 1) is that while it has fluctuated year to year, on average it remains about 45 percent of anthropogenic emissions over recent decades even though emissions have been increasing for decades. Two key questions arise from this: 1) How is the remaining half of emissions partitioned between the land and ocean sinks? And 2) are the land and ocean sinks able to keep pace, or will they become saturated, eventually becoming sources of carbon rather than sinks?

Zaichun Zhu and colleagues examined how terrestrial vegetation is responding to changing environmental factors such as climate change. They utilized three satellite datasets to derive a global leaf area index (a measure of leaf area to ground area) for the years 1982-2009 combined with a set of vegetation models to determine key attributes of the greening effect. The study concluded that CO_2 fertilization, nitrogen deposition, climate change, and land cover change are driving the increase in global vegetation, which would indicate a greater terrestrial sink for carbon (Zhu 2016).

In the paper by Keenan and colleagues, their focus was on understanding a decrease in the airborne fraction of CO_2 in the atmosphere between 2002 and 2014 compared to an increase in previous decades. This decrease in the AF is surprising, given that emissions steadily increased during this period, as shown in Figure 1b from Keenan (2016).

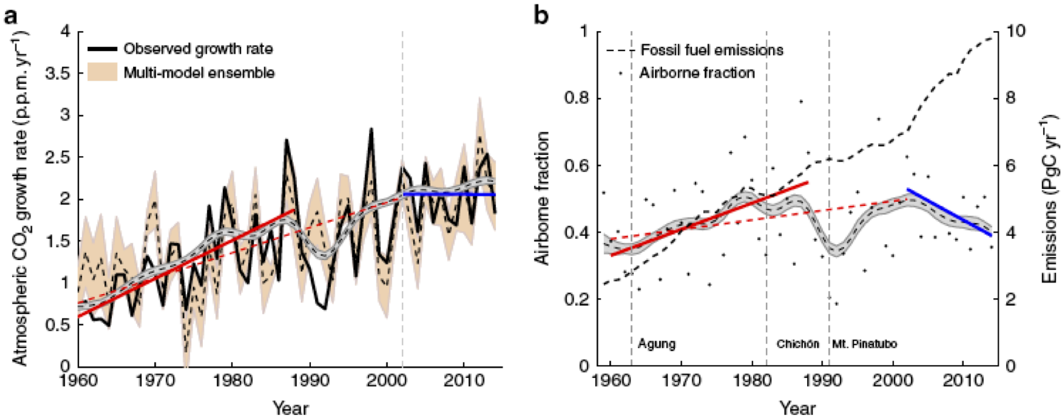


Figure 1. **Fig 1a** shows the growth rate of atmospheric CO_2 ppm per year. **Fig 1b** shows both the airborne fraction and carbon emissions per year. The black line in **Fig 1a** shows the observed growth rate in atmospheric CO_2 in ppm per year from 1959 to 2012. The solid red line shows the trend from 1959 to 1990. The dashed red line, the trend until 2002. The blue line shows that from 2002 to 2014 there was no trend. In **Fig 1b** the dashed black line shows the annual fossil fuel emissions from 1959 to 2014. The solid red line represents the trend in the airborne fraction from 1959 to 1988. Black dots, the annual AF. The dashed red line shows the trend in AF from 1959 to 2002. The blue solid line illustrates the decreasing trend in the AF from 2002-2014. Volcanic eruption dates coincide with a reduction in the AF. Caption abbreviated from Keenan et. al. 2016.

Keenan's analysis used a set of methods including ground and satellite observations, carbon budget estimates and global vegetation models. Their results show an increase in the airborne fraction of 1.8 percent per year from the 1960s to the 1990s, but for the period 2002 to 2014 the airborne fraction decreased by 2.2 percent per year. They attribute this decrease in the AF primarily to a positive change in the land sink—a greening of the Earth's vegetative cover resulting from a variety of factors similar to Zhu's finding. They concluded the fertilization effect as the key factor. Keenan cautions that the recent enhanced terrestrial uptake, while welcome for its dampening effect on the increase of atmospheric CO_2 and slowdown in the pace of global warming, may have already ended with the El Niño of 2015 and 2016.

The result of these recent studies is that there has been an observable greening of the Earth, which has increased the terrestrial sink for carbon. Fire and deforestation drive carbon emissions into the atmosphere from the land, but haven't changed as much over the same period as the enhanced greening of the Earth. The net effect has been a greater land sink. The increase in the terrestrial sink has slowed the accumulation of carbon dioxide in the atmosphere and thereby reduced the warming that would have otherwise been realized in recent years. While the increase in the terrestrial sink is a welcome turn, most research indicates it is temporary. As global warming proceeds, many studies indicate the land sink is expected to diminish (Canadell 2007; Raupach 2014; Arneth 2017) and potentially become a net source of carbon (Weider 2015). The implication of a contraction of carbon sinks is that as we move forward in time, for each quantity of carbon dioxide emitted, a greater percentage will remain in the atmosphere directly affecting climate change. Curbing deforestation activities and stepping up reforestation projects are key forest management practices to bolster the carbon land sink (Arneth 2017).

Arneth, A., et al. (2017). "Historical carbon dioxide emissions caused by land-use changes are possibly larger than assumed." Nature Geosci 10(2): 79-84.

Canadell, J. G., et al. (2007). Saturation of the Terrestrial Carbon Sink. Terrestrial Ecosystems in a Changing World. P. D. Canadell JG, Pitelka L., Springer-Verlag.

Le Quéré, C., et al. (2016). "Global Carbon Budget 2016." Earth Syst. Sci. Data 8(2): 605-649.

Keenan, T. F., et al. (2016). "Recent pause in the growth rate of atmospheric CO2 due to enhanced terrestrial carbon uptake." Nature Communications 7: 13428.

Raupach, M. R., Gloor, M., Sarmiento, J. L., Canadell, J. G., Frölicher, T. L., Gasser, T., Houghton, R. A., Le Quéré, C., and Trudinger, C. M.: The declining uptake rate of atmospheric CO_2 by land and ocean sinks, Biogeosciences, 11, 3453-3475, doi:10.5194/bg-11-3453-2014, 2014.

Wieder, W. R., et al. (2015). "Future productivity and carbon storage limited by terrestrial nutrient availability." Nature Geosci 8(6): 441-444.

Zhu, Z., et al. (2016). "Greening of the Earth and its drivers." Nature Clim. Change 6(8): 791-795.