# Temporal and Spatial Perspectives on the Fate of Anthropogenic Carbon: A Carbon Cycle Slide Deck for Broad Audiences

## CONTRIBUTORS

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## CITATION

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## ABOUT THE SLIDES

**To get these animations to work in Power Point, simply mouse over the slide and a play bar should appear on the bottom of the slide. Click the triangle-shaped play button to start the animation.**

### Bar Chart and Line Animations (Khatiwala et al., 2009, 2013)

The bar chart and line animations features changes in anthropogenic carbon **SOURCES** (**land biosphere in green**, **fossil fuels in black**) and **SINKS** (**atmosphere in red**, **ocean in blue**) over the industrial era from 1765-2011 (Khatiwala et al., 2009, 2013). Ocean uptake of anthropogenic carbon is calculated using a suite of ocean tracers (chlorofluorocarbons, natural $^{14}C$, temperature, and salinity) from GLODAP and the World Ocean Atlas. Fossil fuel emissions (including a small contribution from cement production) are from Boden et al. (2010). Atmospheric $CO_2$ data are the Carbon Dioxide Information and Analysis Center (CDIAC). The land biosphere component is computed as a residual between the fossil fuel source and the ocean and atmosphere sinks. On the line plot, negative values indicate sinks and positive values indicate sources. Error envelope, indicated by the shaded area on the line plot, includes a 5% uncertainty in fossil fuel emissions. The slide deck includes two versions of the bar chart and line animations: Bar chart version 1 spans 1765-2011 (49 seconds) and version 2 spans 1905-2011 (22 seconds); line plot version 1 animates one reservoir at a time (17 seconds) and version 2 animates all reservoirs at the same time (10 seconds).

**Noteworthy observations**

- Ocean uptake of anthropogenic $CO_2$ has increased sharply since the 1950s, with a small decline in the rate of increase in the last few decades
- Terrestrial biosphere was a source of $CO_2$ until the 1940s, subsequently becomes an annual net sink, thus the cumulative source is diminished
- Integrating over the entire industrial period (and accounting for uncertainties), the terrestrial biosphere has been anywhere from neutral to a net source of $CO_2$,

contributing up to half as much $CO_2$ as has been taken up by the ocean over the same period.

## Map Animations (DeVries, 2014)

**MAP 1:** The first map animation shows the spatial distribution of the oceanic anthropogenic $CO_2$ inventory over the period 1900-2014 based on a combined data and modeling approach that involves assimilation of potential temperature, salinity, radiocarbon ($\Delta^{14}C$), and CFC-11 observations in a global steady state ocean circulation inverse model (OCIM) (DeVries, 2014). The data are first assimilated into the OCIM to obtain optimal estimates of ocean circulation, ventilation, and air-sea gas exchange rates. The optimized circulation and air-sea gas exchange rates from this model are then used to simulate the oceanic uptake of anthropogenic carbon over the industrial era. The units on the map are in C storage per unit area (mol C $m^{-2}$). **INSET:** The accompanying inset on the map shows the total oceanic inventory of anthropogenic carbon through time (Pg), which is comparable to Khatiwala's line plot animation for the ocean (though shown as negative numbers in Khatiwala's plot to reflect that the ocean is a sink). Note that the most current total ocean inventory from DeVries (2014) is slightly higher than that of Khatiwala et al. (2009). Remaining sources of uncertainty include potential variability in the ocean circulation and the biological pump over the industrial era, which is not accounted for in the OCIM.

**MAP 2:** The second map animation shows the cumulative air-sea flux of anthropogenic carbon (mol C $m^{-2}$) over the period 1900-2014, with positive values indicating flux into the ocean. This illustrates where anthropogenic carbon enters the ocean, and how these fluxes have evolved over time. These patterns are distinct and complementary to those shown on the previous inventory slide. The differences between where anthropogenic C enters the ocean (this slide) and where it is ultimately stored (previous slide) are due to ocean currents and water mass movements that redistribute anthropogenic carbon after it is taken up from the atmosphere. **INSET:** Same as in previous slide, indicating that the total air-sea flux of anthropogenic C is equal to the oceanic inventory of anthropogenic C.

**Noteworthy observations**

- Integrated over its total area, the Southern Ocean is the primary conduit for anthropogenic carbon to enter the ocean, taking up ~40% of the contemporary anthropogenic carbon (Map 2, note highest fluxes in the Southern Ocean); however, a large portion of the anthropogenic $CO_2$ taken up in the Southern Ocean is transported northward and ultimately stored elsewhere (Map 1, note highest inventories in the subtropical Atlantic).
- High concentrations (and air-sea fluxes) of anthropogenic carbon are also observed in the North Atlantic, a region of deep convection where light-to-dense water mass transformations lead to transport of anthropogenic carbon to the ocean interior.

## REFERENCES

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