The secrets of the Keeling Curve

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The Keeling Curve is the standard expression used to describe the rise of atmospheric CO2 concentrations since the 1950’s. This behaviour can be seen by comparing the measured values to a straight line fit. This is shown in Figure 1 with a least squares fit to the South Pole measurements.

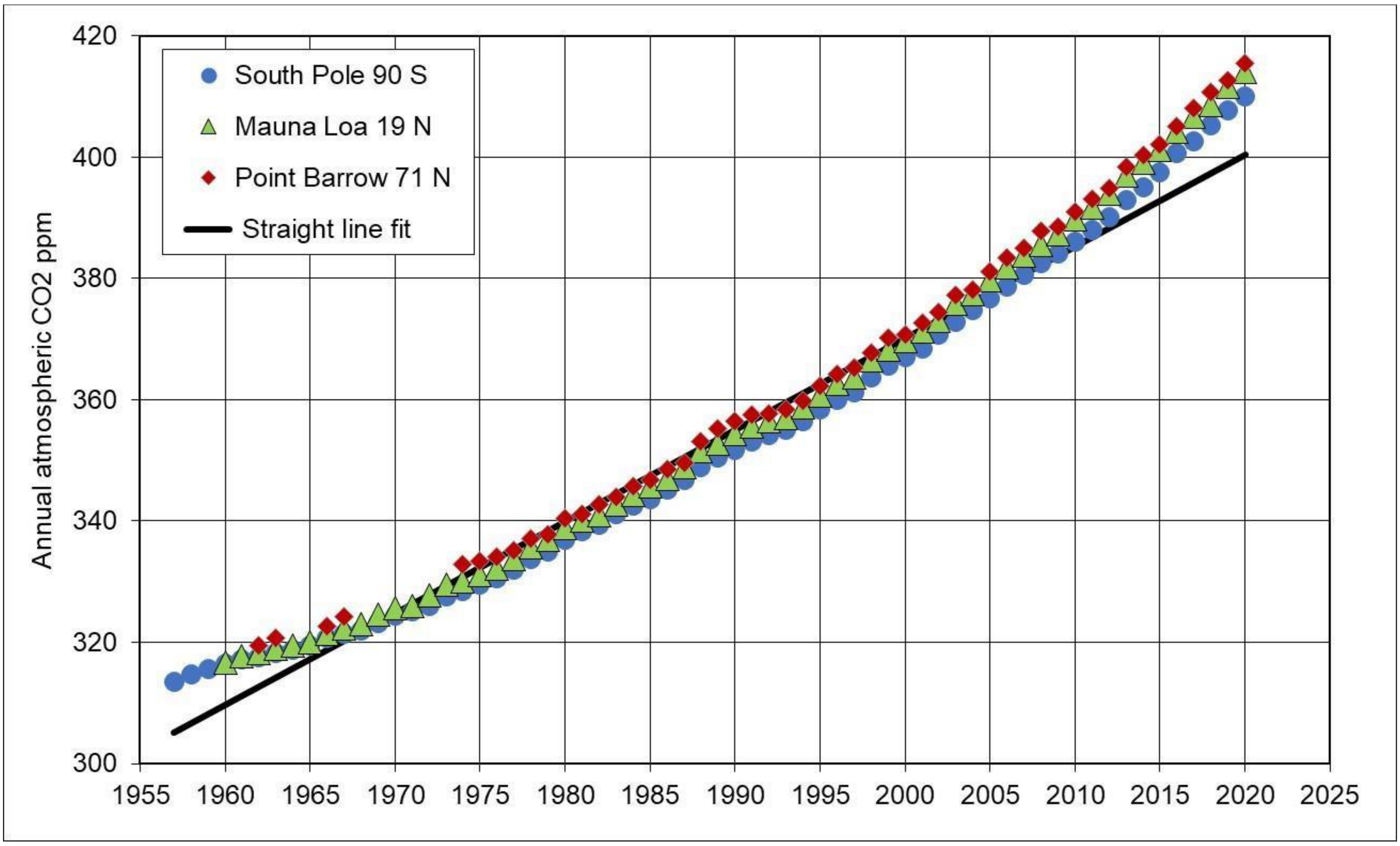

Figure 1: *Measured annual atmospheric CO2 concentrations. The straight line is a fit to the CO2 concentrations at the South Pole.*

The behaviour of the Keeling Curve can be probed further by magnifying the departures from the straight line fit. A simple approach is to look at the residual differences of the measurements from the fitted values. The result of such an action is shown in Figure 2 for the South Pole, Mauna Loa and Point Barrow. The residual values for Mauna Loa and Point Barrow are the residuals from the fit to the South Pole measurements.

The behaviour of the residuals shows a series of straight-line elements and the presence of a “bubble” in 1989 that is just visible in Figure 1. For comparison the phase changes in the Atlantic Multidecadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO) are indicated in Figure 2. The AMO indicates variations in the North Atlantic Ocean sea surface temperature while the PDO indicates sea surface temperature variations in the North Pacific Ocean. There is a coincidence of breaks in the CO2 residuals and the AMO and PDO phase changes. For the AMO these occur in 1965,1995 and 2012 while the PDO has phase changes at 1977 and 2001 (Ref 1).

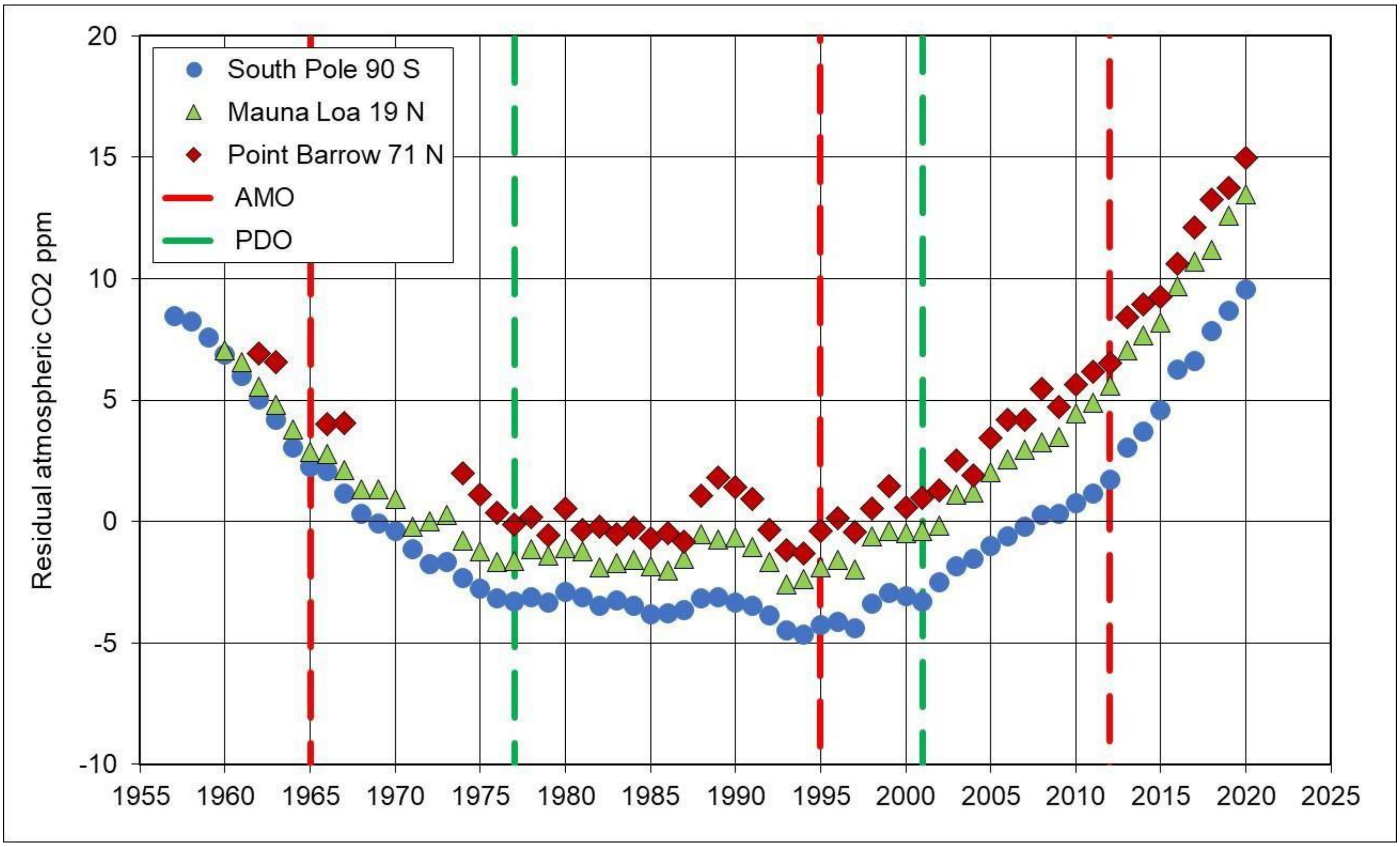

Figure 2: *Residual annual values from a straight line fit to the South Pole measurements. The dashed lines mark the phase changes for the AMO and the PDO. Note also the presence a "bubble" in 1989.*

The most remarkable feature of the Keeling Curves is the presence of a "bubble" in 1989 that has a maximum value at Point Barrow, 71 N. There is a strong El Nino in 1987 but this would not peak in the northern latitudes.

This "bubble" is coincident with a 1989 "regime shift".

In 2000, Hare and Mantua published a detailed study (Ref 2) of 100 time series for biological and physical measurements that showed "regime shifts" in 1977 and 1989 in the North Pacific Ocean and the Bering Sea.

For the 1989 "regime shift" Hare and Mantua found clear evidence in the biological record of significant falls ranging from fish catches to zooplankton biomass. There was no evidence coming from the physical measurements time series.

Phytoplankton are at the base of the ocean food chain so the CO_2 anomaly may be the fall off in phytoplankton biomass. Wind changes will drive ocean current changes with consequent changes in the level of nutrients in the ocean and these may limit the growth of phytoplankton. This is found in El Nino years on the west coast of South America (Ref 3).

The fall in phytoplankton productivity reduced the removal of CO_2 from the atmosphere causing the CO_2 "bubble".

The NOAA satellite derived map of phytoplankton distribution in the oceans, Figure 3, shows substantial massing in the North Pacific Ocean and the Bering Sea.

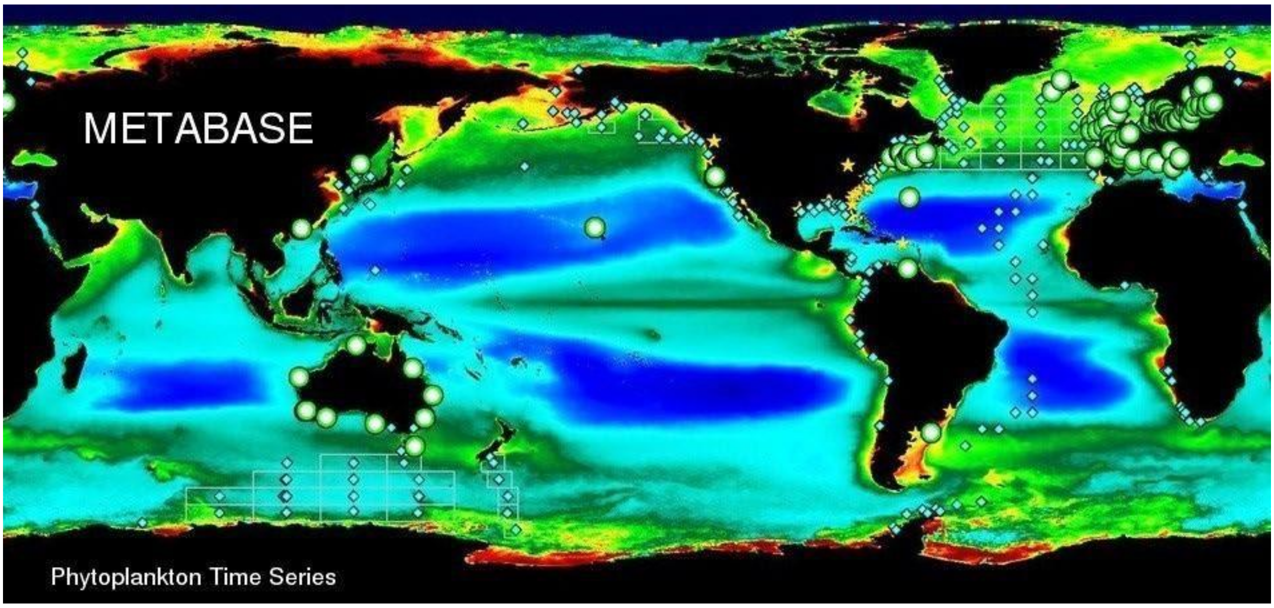

Figure 3: *NOAA satellite derived map of phytoplankton distribution.*

Phytoplankton are also present in the North Atlantic Ocean and across the equatorial Pacific Ocean.

The carbon cycle describes the sources and sinks for atmospheric CO2. This is illustrated in Figure 4 as used in IPCC reports (Source NASA). Phytoplankton are part of the marine biota in the ocean surface layer where they act as a variable sink. However, that is the extent of the interaction with no modification of the composition of CO2 unlike the interaction of land vegetation.

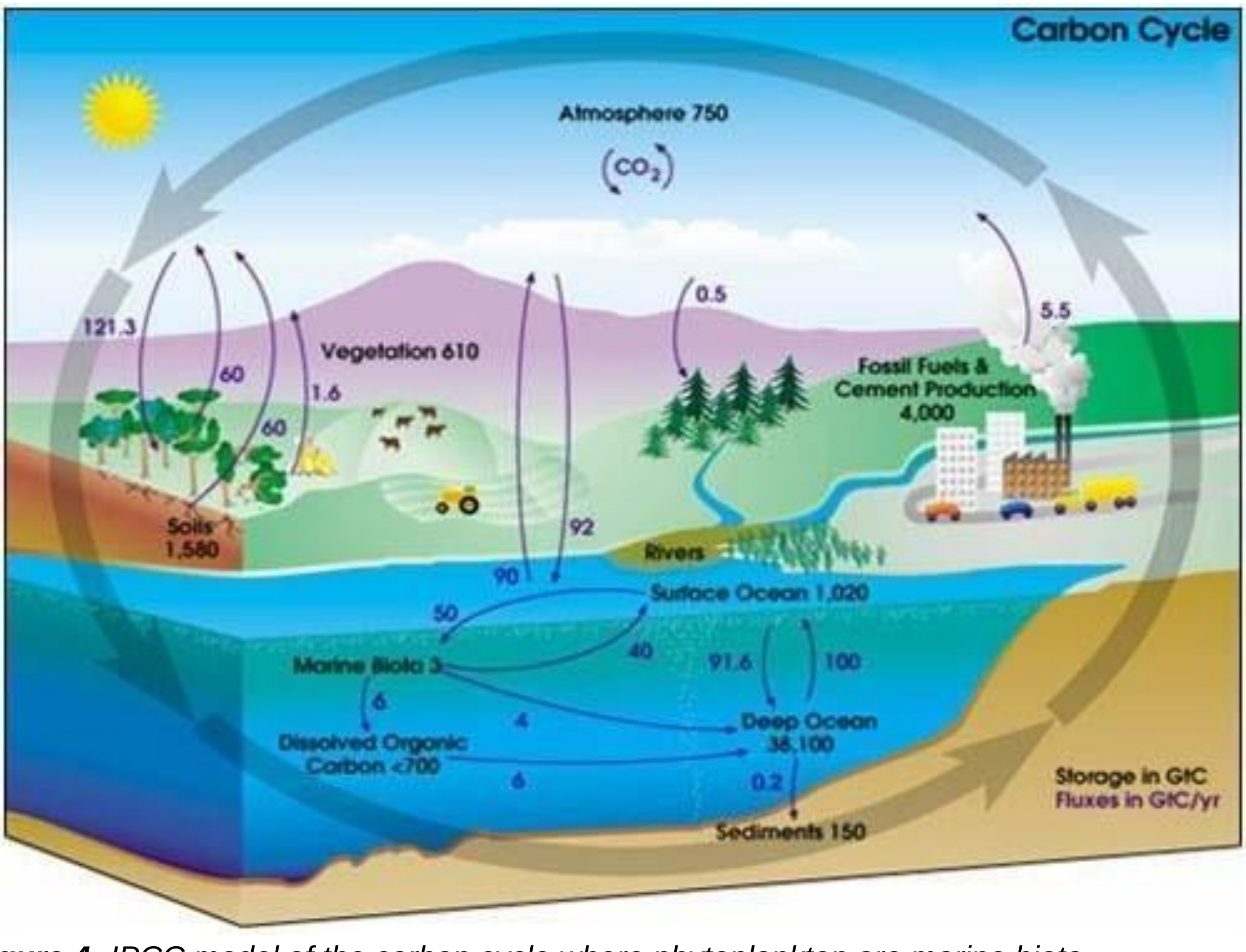

Figure 4: *IPCC model of the carbon cycle where phytoplankton are marine biota.*

But, in 1989 there is interference with the composition of atmospheric CO_2.

The composition of CO_2 is 99% carbon-12 with 6 protons and 6 neutrons in the atomic nucleus and 1% carbon-13 with 6 protons and 7 neutrons in the atomic nucleus. These are the stable isotopes of carbon. The isotopes have exactly the same chemical reactions but the chemical reaction rate is greater for the lighter isotope, carbon-12. $\delta^{13}C$ is a measure of the ratio of carbon-13 to carbon12 compared to a standard carbon value.

The interaction of vegetation, particularly northern forests, with the atmosphere is shown in Figures 5 and 6 for Point Barrow 71 N. Seasonal variations of CO_2 concentrations (Figure 5) show a reduction in atmospheric CO_2 in the summer and coincident with a change in the composition of atmospheric CO_2 shown by changes in $\delta^{13}C$ (Figure 6). This is the carbon cycle for land and atmosphere. However, there are changes in the CO_2 composition in 1988-89 at the time of the 1989 regime shift. This is not included in the carbon cycle model.

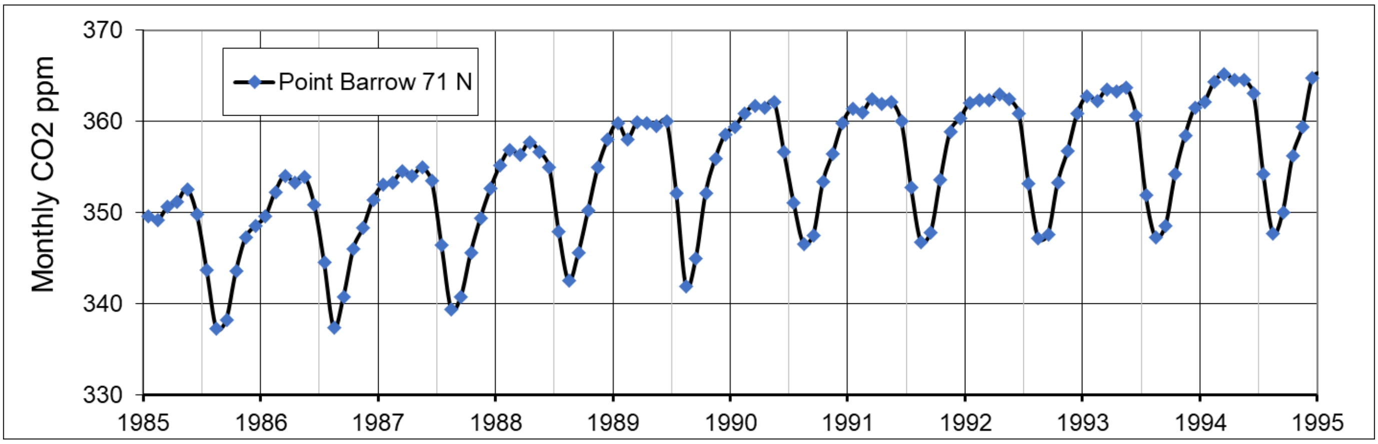

Figure 5: *Monthly measurements of atmospheric CO_2 at Point Barrow 71 N from 1985 to 1995*

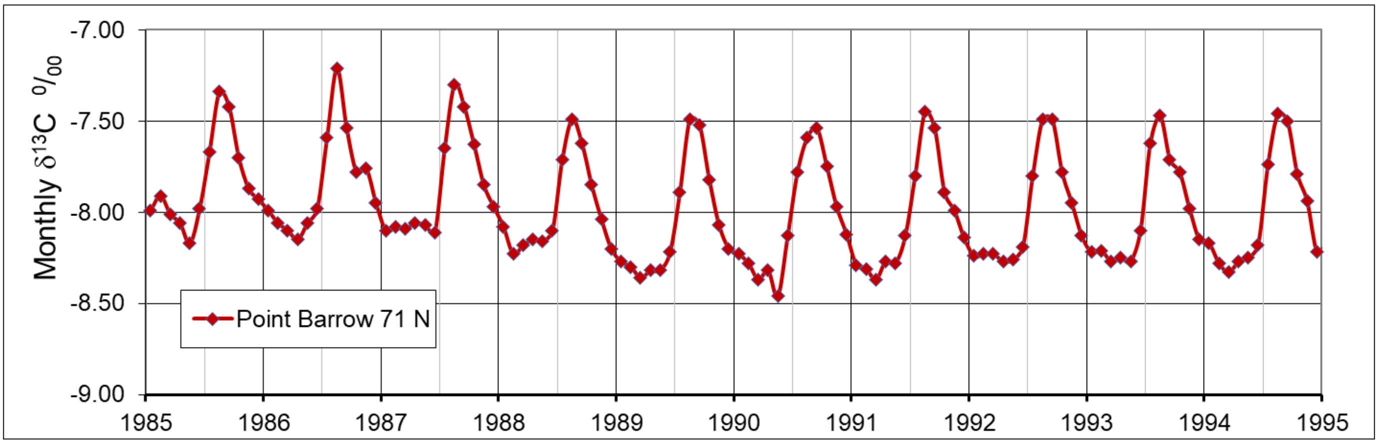

Figure 6: *Monthly measurements of $\delta^{13}C$ at Point Barrow 71 N from 1985 to 1995.*

The annual variation in CO_2 composition represented by $\delta^{13}C$ are shown in Figure 7 for the South Pole, 90 S, Mauna Loa, 19 N, and Point Barrow, 71 N. The 1989 regime shift impact is clearly visible.

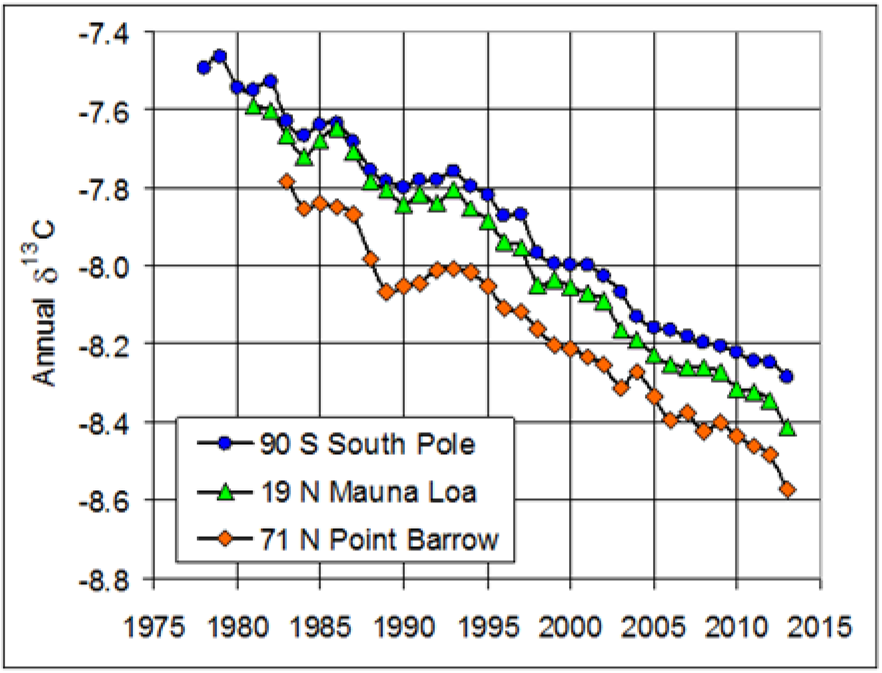

Figure 7: *Annual values of $\delta^{13}C$, a measure of the isotopic composition of atmospheric CO2 for the South Pole Mauna Loa and Point Barrow.*

The 1989 regime shift shows a direct link of a variable sink for atmospheric CO2 that includes changes in the isotopic composition of atmospheric CO2.

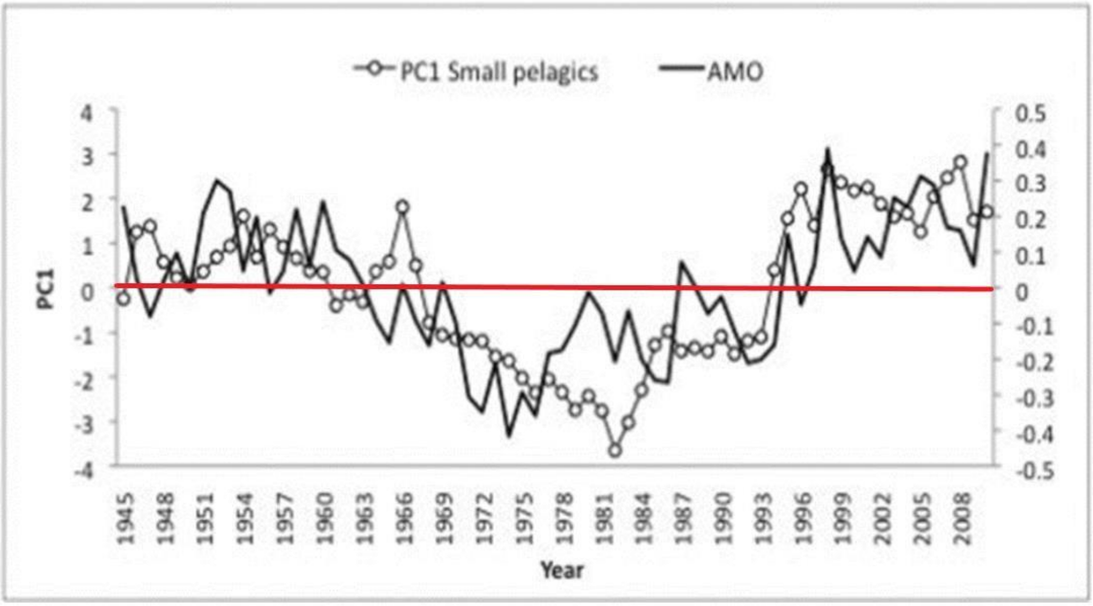

Figure 8: *First principal component (PC1) based on the main long-term data sets of small pelagics available in the Eastern Atlantic and Mediterranean between 1945 and 2010. The Atlantic Multidecadal Oscillation (AMO) is superimposed*. *(Reference 4, Figure 7)*

The coincidence of AMO phase changes with breaks in atmospheric CO2 may be a direct connection with variations of phytoplankton productivity.

First, if phytoplankton are at the base of the ocean food chain, then variations of fish catches reflect variations in phytoplankton biomass. There is evidence for this from a 2014 paper (4) linking pelagic fish, such as sardines, anchovies and herrings catch variations to the AMO variations (Figure 8).

During a cool phase such as from 1965 to 1995 fish productivity is low and reflects a fall in phytoplankton productivity. This implies less CO2 removed from the atmosphere during a cool phase. On the other hand, a warm phase such as 1995 to 2012 implies more phytoplankton productivity so more CO2 removed from the atmosphere.

Second, a direct measure of phytoplankton activity is now possible. This is through the remote sensing of the chlorophyll alpha colour associated with phytoplankton primary productivity.

In papers (5) and (6) phytoplankton primary production was derived from chlorophyll alpha remote sensing measurements from 1998 to 2018. There were AMO phase changes in 1995 and 2012 with the period 1995 to 2012 as a warm phase.

The results of the analysis (Figure 9) show the primary productivity rises from 1998 and falls in 2012. Thus, phytoplankton would be drawing more CO2 from the atmosphere in this warm phase than during a cool phase. The pelagic fish measurements from 1945 to 2010 (Figure 8) show rising catches from 1995 to 2010. This illustrates the food chain from phytoplankton at the base to small pelagic fish well above the phytoplankton in the food chain.

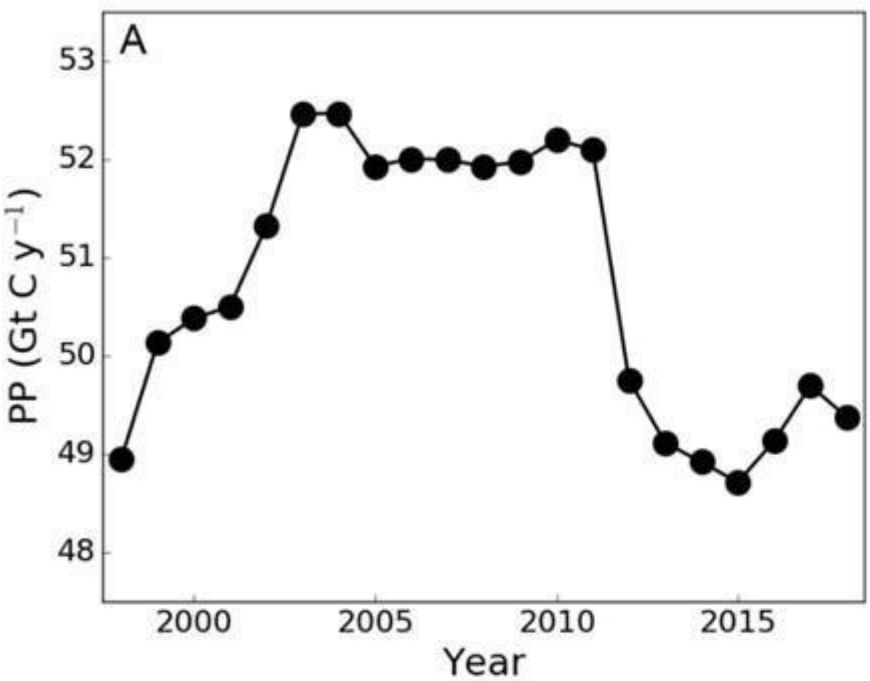

Figure 9. *Trends in phytoplankton primary production (PP) with annual global primary production for each year in the period between 1998 and 2018, (Reference 6, Figure 4)*

The break in atmospheric CO2 seen at 2012 with more atmospheric CO2 is a change from a warm to a cool phase of the AMO.

Conclusions:

1) the connection of the 1989 regime shift found in the ocean to the CO_2 "bubble" in the atmosphere is the result of reduced phytoplankton productivity removing less CO_2 from the atmosphere and changing the isotopic composition of atmospheric CO_2.

2) the connection of AMO phase changes with breaks in atmospheric CO_2 are also the result of variations in phytoplankton productivity due to nutrient variations with the AMO in the north Atlantic Ocean.

These conclusions do not support present accepted IPCC understanding of the carbon cycle where ocean sinks can vary the amount of CO_2 removed from the atmosphere but not vary the isotopic composition of the atmospheric CO_2.

The oceans cover 70% of the earth's surface and for CO_2 the interaction of the oceans with the atmosphere must be fully represented.

References

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6 Correction: Kulk et al. Primary Production, an Index of Climate Change in the Ocean: Satellite-Based Estimates over Two Decades. Remote Sens. 2020, 12, 826. Remote Sens. 2021, 13(17), 3462;