A Study of Mauna Loa Seasonal Variation of CO2 Concentration

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INTRODUCTION

The CO2 atmosphere concentration measured at the Mauna Lao Observatory (MLO), Hawaii have been used by advocates of Anthropological Global Warming (AGW) as a bellwether of climate. In this paper these data, in conjunction with carbon cycle parameter data, show the extent that CO2 atmosphere concentration and its time-line trends are related to CO2 emissions from use of hydrocarbon fuels depends on the green period of biota.

RESULTS AND DISCUSSION

<u>Mauna Loa Observatory Data</u>

The Mauna Loa Observatory (MLO) is located at 19.54^o latitude, -155.58^o longitude and 3400 m above sea level. Carbon dioxide concentrations, in units of 'parts per million'.(ppm) have been measured daily and monthly averages reported, since 1958. Figure 1 is the data from 1965 through 2008; the blue is the monthly data and the red is the smoothed. The per-annum increases are 1.513 ppm and 1.515. ppm, respectively. The start date in this report will become clear later.

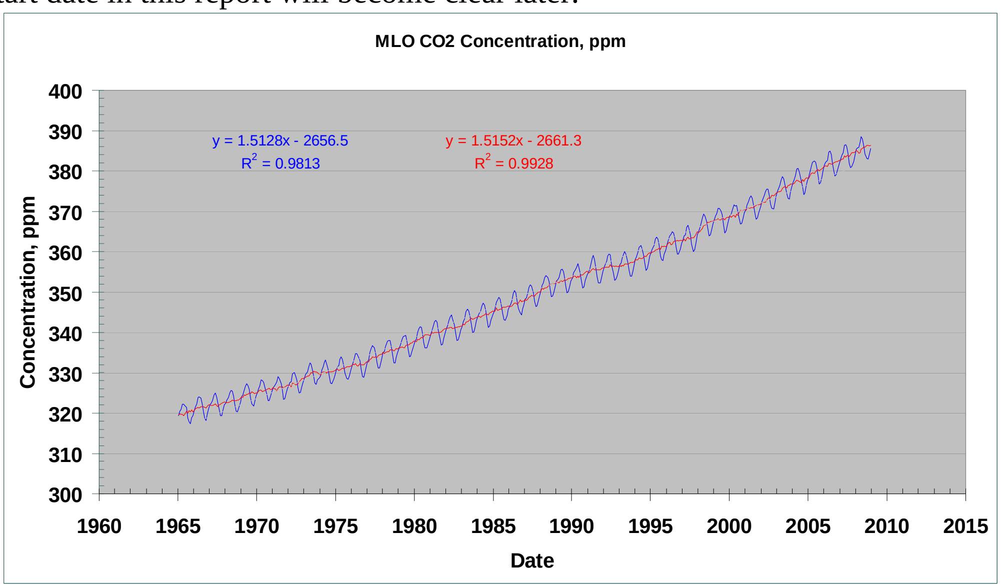


Figure 1 – Mauna Loa Observatory, MLO, HI CO2 concentration

The air at MLO is believed to be relatively free of pollutants, and assumed representative of air in the Northern Hemisphere. In the opinion of some, Ref.1, the general increase in CO2 concentration to be "due to the combustion of fossil fuels and deforestation". NOAA has been more generous and attributed the change to a combination of human activities and natural causes, Ref 2. Ref 1 attributes the "wiggles" in the curve, to a seasonal variation in carbon flow between biota and atmosphere. A "sink period", during Spring and Summer, is attributed to biota photosynthesis exceeding biota respiration. A "source period", during Fall and Winter, is attributed biota respiration exceeding photosynthesis. There seems to be some confusion in these statements in that decay appears to be classified under respiration. No comment is made in either Ref 1 or Ref 2 for the possibility of CO2 emission wiggles being in part due to variation of ocean absorption and emission..

The MLO Wiggles

Figure 2 is a short portion of the data to facilitate describing the parameters in the following discussion. Each year, there is a Spring Maximum and a Fall Minimum.

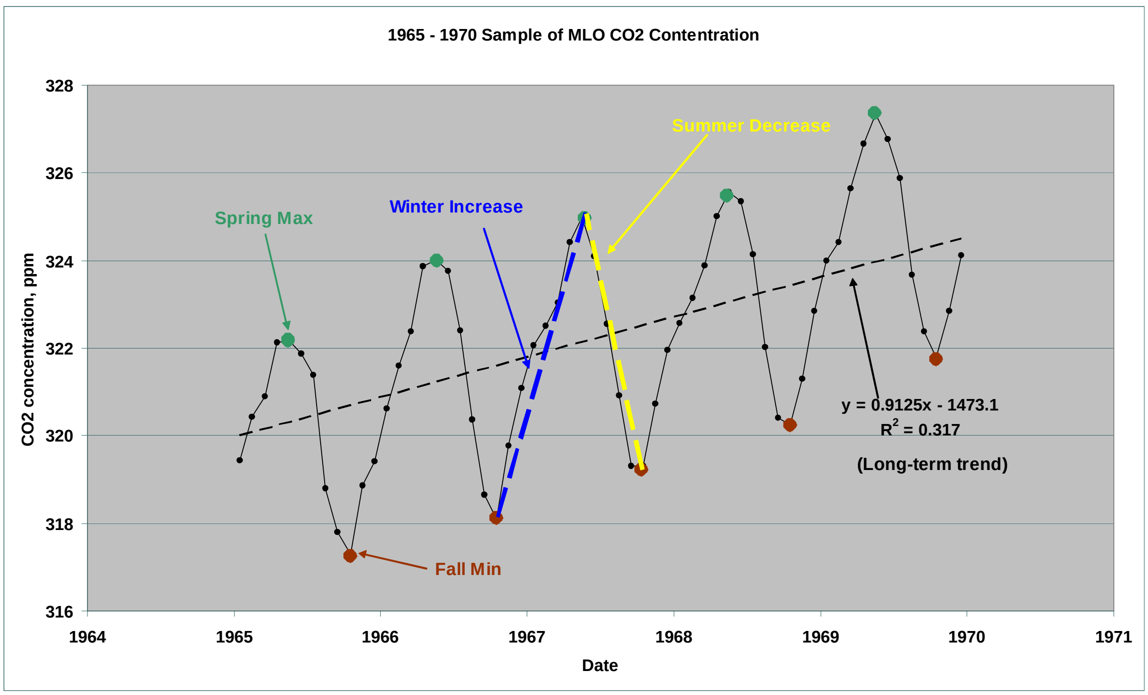


Figure 2 – Sample of the MLO CO2 concentration data

The 'Fall Min' (FM) occurs approximately during October, at the end of the 'growing' season. The 'Spring Max' (SM) occurs approximately in May, at the beginning of the 'growing' period. The 'Winter Increase' (WI) occurs from approximately October of one year to May of the following. 'Summer Decrease' (SD) occurs from approximately May to October. (This is not meant to suggest that biota activity alone is responsible for the CO2 increase or decrease.) The alternate SD and WI is the source of the long-term trend, a net increase; the particular value in this figure, 0.91 ppm/year, included only to identify the parameter.

The magnitudes of the SD and WI, from 1965 to the present, are plotted in Figures 3a and 3b, respectively. The average of the SD is – 5.74 ppm and the average of the WI is +7.16 ppm. The respective annual rates, SDR and WIR, are -15.76 ppm/yr and +11.36 ppm/yr; the SDR being the larger magnitude. Photosynthesis is assumed to dominate respiration during the warm seasons and decay occurs year round. The magnitudes of SDR and WIR are, on the average, increasing each year, SDR's 40 % that of WIR. An increasing WIR magnitude may be explained by increasing Fossil Fuel emission, ocean warming, and/or other contributors, such as burning. But, if any or all of these contributors are increasing they are doing so year-round, thus photosynthesis would also have to be increasing even more in order to offset those contributors and provide a the net growth for during the growing season. Certainly this calls into question the accuracy of statements made that loss of forest in parts of the world is the cause of a net decrease in Biota. Thus, an increase of SDR suggests land biota is either increasing or is using more CO2 per unit of biota. If this is assumption is correct then it is reasonable to assume that decay would increase accordingly, if not for deforestation. However, since the rate of increase of WI's magnitude is about 2.5 that of SD, something additional, such as ocean warming, is taking place.

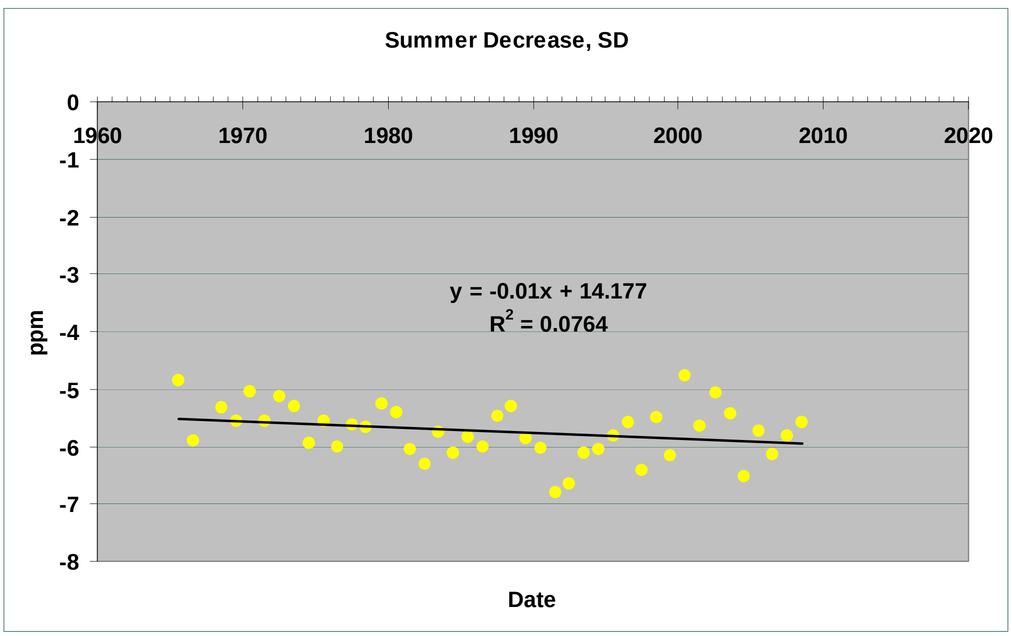


Figure 3a – Summer Decrease

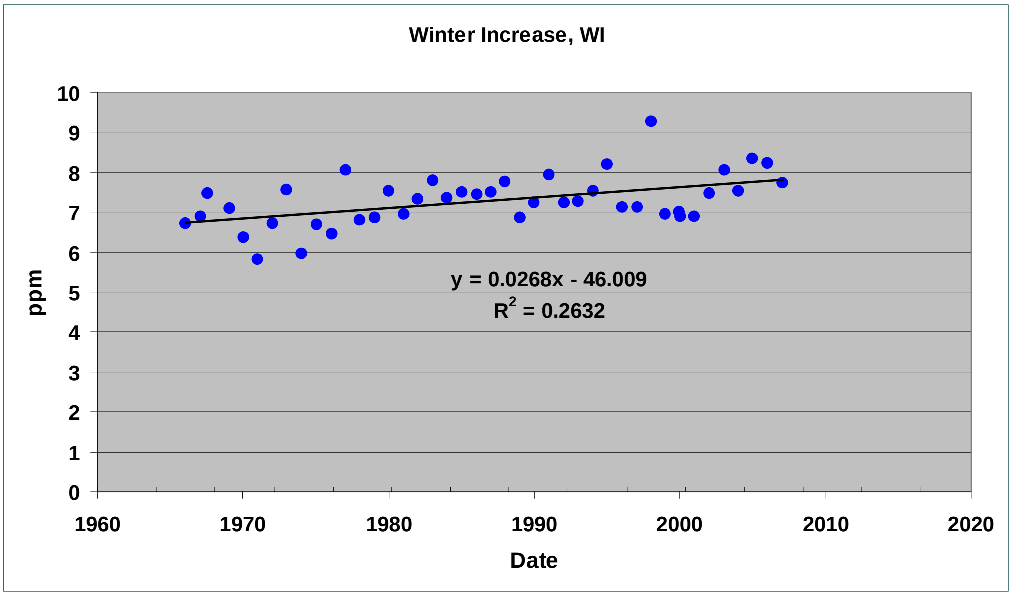


Figure 3b – Winter Increase

The net SD and WI, annual and cumulative, are plotted in Figure 4. As expected, the slope of the cumulative net is the same as in Figure 1. This also implies there is no source or sink in addition to that in the Wiggles. The slope of the annual net is also increasing, albeit small, thus suggesting ocean warming and/or increasing Fossil Fuel emission.

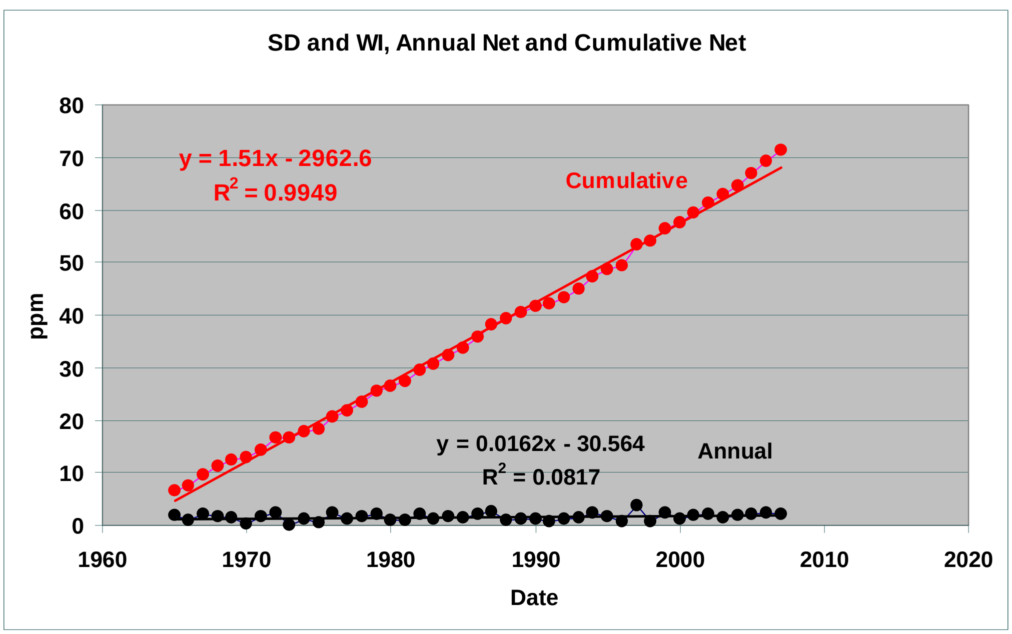


Figure 4 – Net Per-Annum Effect of Winter Increase and Summer Decrease

Simple Carbon Cycle Modeling of MLO CO2 Annual Increase and Wiggles

To some extent, an understanding for what are the parameters contributing to these wiggles can be had using carbon cycle data, such as provided by NASA, NOAA, and others, Ref 3 – 6, summarized in Table I. Refs 3 and 6 do not qualify what of their values are pre-industrial while Ref. 4 and 5 do. Ref. 5 provided no Fossil Fuel rate, so an average of the other three, 6.1 GMT/yr, has been used.

Table I – Annual CO2 increase from carbon cycle data.

	Ref 3		Ref 4		Ref 5		Ref 6	
Atmosphere Level (AL), GMT	750		751		600		750	
	Down	**Up**	**Down**	**Up**	**Down**	**Up**	**Down**	**Up**
Fossil Fuel (FF), GMT/yr		5.5		5.9		6.1		7
Ocean (O), GMT/yr	-92	90	-21.9	20	-96	96.51	-92	90
Biota (B), GMT/yr	-61.3	60	-57	56.1	-63.1	62.5	-62	60
ANC, ppm/yr	1.13		1.59		3.88		1.54	

GMT = Giga Metric Ton
Down => CO2 taken from atmosphere
Up => CO2 inserted into atmosphere

The Annual Net Change (ANC) of atmospheric CO2 for each of these set of data is determined using the simple relationship

ANC = (385/AL) x [(FF(Up) +O(Up) – O(Dn) + B(Up) – B(Dn)], **(E1)**

where '385' is the current MLO CO2 concentration in units of ppm. All of the Fossil Fuel emission is assumed to go directly into the atmosphere; Ref. 7 suggests only 50 % of the Fossil Fuel is emitted into the atmosphere, with the remainder absorbed into the Ocean and Biota. The ANC values for references 4 and 6, 1.59 ppm/yr and 1.54 ppm/yr, 3-percent different, are in good agreement with that from MLO, 1.51 ppm/yr.

If CO2 emission into the atmosphere is due in part to ocean warming, Ref 8, and Biota burning, Ref. 3, and additional Biota-absorption is caused by reforestation, Ref. 3, as shown in Table II, then the Fossil Fuel Fraction, FFF, absorbed into the atmosphere required for agreement with the MLO value of CO2 annual increase is less than half that of the total FF source, as shown in Table III.

Table II – Ocean warming CO2 emission and Biota burning emission and reforestation absorption, GMT/yr.

	Down	Up
Ocean Warming, GMT/yr		2.84
Reforestation, Burning, GMT/yr	-0.5	1.6

Table III – Annual CO2 increase from carbon cycle data, including Ocean warming and Biota burning and reforestation.

	Ref 3		Ref 4		Ref 5		Ref 6	
Atmosphere Level (AL), GMT	750		751		600		750	
	Down	**Up**	**Down**	**Up**	**Down**	**Up**	**Down**	**Up**
Fossil Fuel (FF), GMT/yr		2.3		1.8		0.0		3
Ocean (O), GMT/yr	-92	92.84	-21.9	22.84	-96	99.35	-92	92.84
Biota (B), GMT/yr	-61.8	61.6	-57.5	57.7	-63.6	64.1	-62.5	61.6
ANC, ppm/yr	1.51		1.51		2.47		1.51	
FF Fraction, FFF,of Table I		0.42		0.31		0.00		0.43

GMT = Giga Metric Ton
Down => CO2 taken from atmosphere
Up => CO2 inserted into atmosphere

That such a simple expression, based on carbon cycle parameter values, provides a reasonable agreement with the long-term MLO data begs the question of whether or not a similar one can be constructed to provide an explanation of the Wiggles. Table IV is a capture from an Excel spreadsheet, using expressions E2-a and E2-b, to determine SD and WI for the year 2001 using the NASA carbon cycle data, Ref 3 .

SD=[At(ppm)/At(GMT)]x{GFxB(Dn)+[ABP/12]x[B(Up)+O(Up)+O(Dn)+FFF x FF(Up)]} **(E2-a)**

WI=[At(ppm)/At(GMT)]x{[1-GF]xB(Dn)+[[12-ABP]/12]x[B(Up)+O(Up)+O(Dn)+FFFxFF(Up)]} **(E2-b)**

The annual Ocean CO2 emission is determined for multi-month periods prior to SD and WI, -92.664 GMT and – 96 GMT respectively. The first value, 92.664, is determined by adding the product of OTI (Jan-May) and OEF to the O(Up) value in Table I. The second, 96, by adding the product of OTI(May-Oct) and OEF to the first value. OEF is taken from Ref 8. OTIs are determined from the University of Alabama at Huntsville, UAH lower troposphere temperature anomalies, Ref 9. The B(Dn) is the sum of the value in Table I and the reforestation value, -0.5, Ref 3. The B(Up) is the sum of the value in Table I and the Biota burn value, 1.6, Ref 3.

The Green Fraction, GF, is that portion of the B(Up) and B(Dn) that occurs during the assumed Active Biota Period, ABP, a.k.a. growth season. B(Up) is the net of photosynthesis and respiration. The GF and ABP values were determined from USGS MODUS data, Ref 10, MYD13C2 and MOD13C2. The application MultiSpec, Ref 11, was employed. The GF determinations were tedious in that for each month of the year the images were divided into five latitudinal groups for which the 'green' portions were respectively determined and then corrected for the respective portions of the total surface area.

The portions of the table are color-coded to facilitate explanation. The parameter in all but the light blue and gray portions were determined from the noted references. The FFF was then adjusted until the results of expression E2-a and E2-b, SD and WI, in the gray portion, best agreed with the MLO values, provided in the white portion.

Table IV – 2001 Summer Decrease, SD, and Winter Increase (WI) from carbon cycle data, including Ocean warming and Biota burning and reforestation absorption in the carbon cycle data.

2001 SD and WI			
Ocean Emissions factor, ppm/C, OEF	8		
UAH NH OceanTemperature Increase, OTI		Jan-May	May-Oct
		0.333	0.417
Green Fraction, GF	0.612		
Active Biota Period, ABP (mo)	5		
Fossil Fuel Fraction, FFF	0.2		
	(GMT)	**(ppm)**	
Atmosphere, At	751	370.85	
	(Dn), GMT	**(Up), GMT**	
Fossil Fuel, FF		5.629	
Ocean, O	-92	92.664	96
Biota, B	-61.80	61.6	
Summer Decrease, calculated	-5.63	ppm	
Winter Increase, calculated	7.38	ppm	
SD, MLO	-5.65	ppm	
WI, MLO	6.9	ppm	

(a)

2001 SD and WI			
Ocean Emissions factor, ppm/C, OEF	8		
UAH NH OceanTemperature Increase, OTI		Jan-May	May-Oct
		0.333	0.417
Green Fraction, GF	0.76		
Active Biota Period, ABP (mo)	6.85		
Fossil Fuel Fraction, FFF	0		
	(GMT)	**(ppm)**	
Atmosphere, At	751	370.85	
	(Dn), GMT	**(Up), GMT**	
Fossil Fuel, FF		5.629	
Ocean, O	-92	92.664	96
Biota, B	-61.80	61.6	
Summer Decrease, calculated	-5.64	ppm	
Winter Increase, calculated	6.90	ppm	
SD, MLO	-5.65	ppm	
WI, MLO	6.9	ppm	

(b)

Table IV-a used an ABP of 5 months, based on which the value of the GF is determined from the MODIS data. The 5-month length is an order-of-length of the SD in the Wiggles in the MLO data. The FFF value 0.2 resulted in a calculated SD of -5.63 ppm and a calculated value of WI of 7.38 ppm. The MLO value of SD is -5.65 ppm, thus very good agreement. The MLO value of WI is 6.9 ppm thus the calculated value is about 7 % high. Expressions E2-a and E2-b are simple ones, thus the difference may have been less had a more complex relationship been employed. However, what is significant is that the value of FFF used to obtain values of SD and WI is far less than, 40 % of, the accepted value of 0.5, Ref 7.

Table IV-b used an ABP of 6.85 months, based on that typical of the mid-latitude U.S. (It would be longer for lower latitudes and shorter for higher latitudes. On the other hand, since the higher latitudes occupy less area, the 6.85-month value is likely a reasonable value.) The GF value of 0.76 from the MODIS data followed from this ABP value. In this case, the calculated values of SD and WI are the same as those from the MLO data for FFF=0. This is, no Fossil Fuel CO2 emission was necessary to cause the WI because Ocean and Biota factors wer sufficient in them selves.

These results are not to say that Fossil Fuel Emission, FFE, does not contribute to the long-term increase in atmospheric CO2 level. But they do suggest the assumption that FFE is the only driver of the increase, or that it is even significant, may not be correct. Moreover, the results indicate the extent that CO2 atmosphere concentration and its time-line trends are related to CO2 emissions from use of hydrocarbon fuels depends on the green period of biota. The simple expressions used do not take into account the Biota and Ocean absorption of FFE, so one could argue that assuming that the B(Dn) value is too large. On the other hand, a more aggressive Biota usage of FFE per unit of Biota, a.k.a. CO2 fertilization, has not been taken into account. And, while it has been popular to assume that deforestation has diminished Biota activity, no where can we find a consideration for increased Biota activity due to increased agriculture production, increased greening of suburban lawns, or the effect, until 2004, of a longer warm season due to Global Warming. Ocean warming certainly should cause a larger emission of CO2 into the atmosphere and that is a major contributor in this modeling. But the Ocean aspect is far more complex due to the many Ocean oscillations, such as the PDO, SO, and NAO, pumping, etc. None of this has been explicitly included, yet can provide for Ocean absorption of FFE at the same time that Ocean warming provides the opposite. In regards to the extent of the role of FFE contributing to atmospheric CO2, the assumption that 50 % of the FFE finds its way into the atmosphere, Wigley and Schmel, Ref. 12, note, “The increase since 1957 can be attributed largely to anthropogenic CO2, although considerable uncertainty exists as to the mechanisms involved.” The latter portion of this quote portends of the ambiguity of the first portion. Wigley and Schimel go on to discuss a myriad of complexities associated with Ocean and Biota CO2 sources and sinks, and the discussion only points to a significant degree of lack of understanding that is in current modeling.

Trade Winds and Volcanoes

Surely the effects of volcanic activity local to the MLO have been explored, even though with our meager means we have not found the discussion. Kilauea is said to discharge from 0.008 to 0.03 MMT CO_2/day (3 to 11 MMT CO_2 per year) into the atmosphere, Ref. 13. Though this quantity is small compared to the GMT/yr levels From Fossil fuels, Ocean, and Biota, it is local, see Table V, whereas the latter are world-wide sources. If a radial dispersion occurs then when reaching the MLO the Kilauea CO_2 emission is equivalent to a range of world wide emission from 452 to 1657 GMT CO_2/yr.

Table V – Relative locations of MLO, Kilauea, and Hilo

Site	Latitude	Longitude	Dist from MLO, km	Dist from MLO, mi
Hilo	19.72	-155.07	57.0	35.4
MLO	19.54	-155.58	0.00	0.00
Kilauea	19.425	-155.292	32.8	20.4

Figure 5 shows trade winds relative to and locations of these Hawaiian sites, Ref 14. Clearly MLO is downwind to Kilauea. Even though the products of Kilauea's tend to wrap around Mauna Lao there is photographic evidence to that the products do gather at Mauna Lao, Ref. 14, as shown in Figure 6. To quote Ref 14: "This digital shaded-relief map shows the usual wind conditions on the island of Hawaii. Moderate to strong trade winds carry gases and vog from Kilauea Volcano around the southern tip of the island where the gas tends to accumulate on the leeward or "kona" coast. During these usual conditions, vog often becomes trapped by daytime (onshore) and night-time (offshore) breezes (double-headed arrows). During the day, onshore sea breezes carry vog up the slopes of Hualalai and Mauna Loa volcanoes, and into the topographic saddle between Mauna Loa and Mauna Kea. When the landmass cools in the evening, cooler, denser air and vog flow back down to the coast. However, when the trade winds are light or absent or when winds blow from the south, Kona Winds, much of the vog stays on the eastern side of the island where it sometimes moves into the City of Hilo."

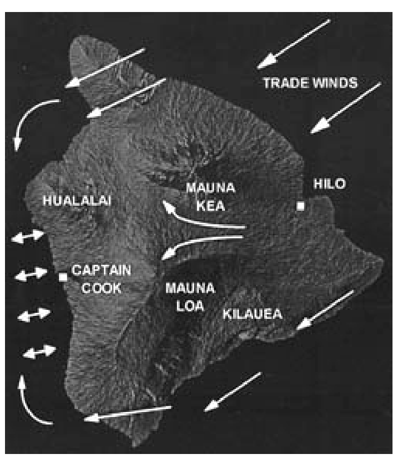
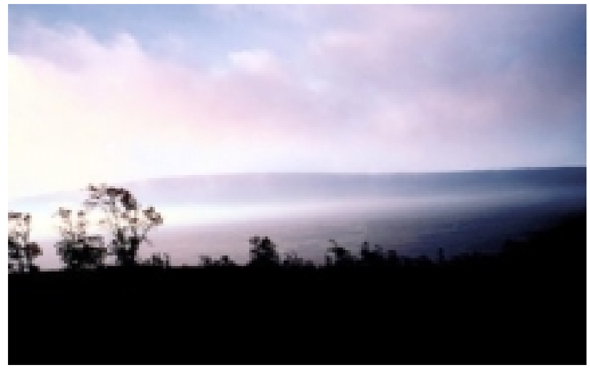


Figure 5 - Map of the Island of Hawaii showing volcanoes & trade winds



a- March 2, 1988, vog-free view of Mauna Loa Volcano, S.R. Brantley

b. December 2, 1994 vog-obscured view of Mauna Loa Volcano, C. C. Helikeron

Figure 6 – View of Mauna Lao Volcano from USGS Hawaiian Volcano Observatory

To further quote Ref 14: "When the usually strong northeast trade winds are interrupted, east Hawaii and the Hawaiian Volcanoes National Park often experiences vog conditions. The Environmental Protection Agency (EPA) primary standard for sulfur dioxide gas says that a person's exposure should not exceed 0.139 parts per million averaged over a 24-hour period, more than once each calendar year. Between 1987 and 1997, the concentration of SO_2 exceeded the standard about 70 times in Hawaii` Volcanoes National Park.

So, it is somewhat surprising CO2 from Kilauea activity does not find its way into the MLO CO2 sensors and appear in the MLO data, at least from time-to-time. So the regularity of the inclined, regular saw-tooth, or wiggle, pattern, and the absence of some amount of short-time-span irregularities, is surprising.

SUMMARY

A simple model of measured values of the Mauna Lao Observatory Summer Decrease and Winter Increase of CO2 concentration suggests these variations can be attributed primarily to Ocean and Biota, with little or no Fossil Fuel Emission. Though the model is simple, and a candidate for improvement, it includes the major sinks and sources due to Ocean, Biota, and Fossil Fuel. The results suggest though earlier reports, termed iconic, concluded at least half of the annual increase of MLO's CO2 concentrations is attributable to Fossil Fuels an objective re-evaluation of sources of atmospheric CO2 concentration is in order. For example, given the proximity of volcanic activity and prevailing winds the regularity of the MLO CO2 data is surprising and engenders questioning of the CO2 sources.

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