Response by Dennis Baldocchi and Lianhong Gu

“Here we concur that changes in the Earth’s carbon cycle due to a pulse of aerosols are not simple processes that can be explained by changes in a single variable. We proffer the explanation that regional differences in several climate forcings have conspired to produce a complex answer to this question. We also critique the evidence upon which Dr. Arora bases his conclusion.”

Mutliple ecosystem interactions lead to overall reduced growth in atmospheric CO_2 concentration

The terrestrial biosphere is a complex system, which by definition consists of intertwining parts that are subject to multiple feedbacks. The emergence of new properties, as one transcends scales, is one particular feature of complex systems. The ability to perform an experiment on a large and complex system like the terrestrial biosphere is difficult and rare, but in 1991 a unique pulse experiment was performed on the Earth’s climate system and biosphere-- Mt Pinatubo erupted, injecting huge quantities of dust and sulphate aerosols into the atmosphere. The dust and aerosols from this volcanic eruption veiled the Earth’s surface for several years and has provided us the opportunity to examine how the terrestrial carbon cycle is responding to coincident changes in the Earth’s surface radiation budget.

One of the notable feature of this ‘pulse-experiment’ was a 0.5 ^{o}C global cooling [1]. The second notable feature was a short-term reduction in the secular trend of growing atmospheric CO_2, as measured at the Mauna Loa monitoring station [2]. Because simultaneous reductions in the anthropogenic sources and increases in oceanic sinks were not recorded, it has been deduced that the net terrestrial biosphere sink increased [3]. One school of thought has concluded that the 0.5 ^{o}C global cooling reduced global respiration and leaf area index (e.g. [4]). Another group of investigators [5-7] have proposed that the veil of dust following the Mt Pinatubo eruption may have led to an increase in photosynthesis in some regions of the world. These researchers based this proposition on theoretical and experimental evidence that canopy photosynthesis is more efficient under diffuse light than under clear skies.

Dr. Arora addresses this issue in the Discussion Forum of this newsletter and concludes that the reduction in temperature explains the temporal change in atmospheric CO_2 post Pinatubo; his arguments are derived mostly on the work of Slaybeck et al. [8] and Lucht et al. [4] and their observed and modelled changes in NDVI.

Here we concur that changes in the Earth’s carbon cycle due to a pulse of aerosols are not simple processes that can be explained by changes in a single variable. We proffer the explanation that regional differences in several climate forcings have conspired to produce a complex answer to this question. We also critique the evidence upon which Dr. Arora bases his conclusion.

In order to understand how the terrestrial carbon cycle responds to environmental perturbations, one needs to decompose the net carbon flux into its constituent components and examine the forcing upon each component. By definition, net ecosystem exchange is the difference between gross photosynthesis (GPP) and ecosystem respiration (Reco). GPP is most sensitive to changes in sunlight, temperature, leaf area index and soil moisture. Reco is most sensitive to changes in temperature, soil moisture, size of the soil and plant carbon pools and disturbance. To understand how the terrestrial carbon cycle responded to the Mt. Pinatubo eruption we must assess how the volcanic eruption changed environmental forcings of the carbon cycle (light, temperature, soil moisture) in time and space. We must also assess if the relative sensitivity of GPP and Reco changed.

With regards to the issue of global cooling and reduced respiration we present the data on the global temperature anomaly after the Mt. Pinatubo eruption (Figure 1). Upon inspection, one sees that major cooling was concentrated in the middle of North America and Siberia, little or no cooling occurred over the tropics and warming over west Europe. Since there are regional differences in cooling and warming, so there will be regions with decreased respiration (e.g. the boreal forest region) and regions with increased respiration. While global respiration might have been reduced, since global mean temperature decreased after the Mt. Pinatubo eruption, the question is: could this factor alone explain the observed large drop in the growth rate of atmospheric CO_2? Gu et al. [7] listed several lines of evidence that suggested a no to this question:

"First, long-term records of CO_2 and temperature generally show that there is a time lag between fluctuations in CO_2 and those in temperature [2]. However, the response of atmospheric CO_2 after the eruption appears to be rapid. Second, the magnitude of the global surface cooling (up to 0.5^{o}C in mid-1992) is within the range of annual temperature swings since the 1950s [1]. Previous cooling of this magnitude did not cause a drop in the atmospheric CO_2 growth rate as large as the one observed after the eruption. Third, modelling of the effects of the eruption on atmospheric CO_2 using a coupled general circulation climate-carbon cycle model showed that the cooling stops short of fully accounting for the observed atmospheric CO_2 anomaly [3]."

In using cooling to explain the post-Pinatubo variations of atmospheric CO_2, one must also note that cooling can potentially reduce annual GPP by shortening the length of the growing season and by decreasing leaf area index. Given these considerations, we believe other mechanisms, in conjunction with the cooling scenario, are needed to account for the atmospheric carbon budget. To support this view further, we cite new evidence from a recently published global inversion modelling study of interannual variability of CO_2 exchange, by Rodenbeck et al. [9]. They state:

"…according to our estimates the distribution of anomalous carbon uptake regions across the globe is markedly uneven. The regions that are mainly responsible for enhanced carbon uptake are the Amazon basin and the East of North America. For the rest of the world, flux anomalies are small. Comparison of these flux anomalies with the climate anomalies indicates that increased carbon uptake tends to coincide with increased precipitation, although the comparison is not entirely conclusive."

The regional enhancement of photosynthesis in eastern North America, deduced by the data inversion work of Rodenbeck et al. [9], is consistent with our results deduced from direct carbon flux measurements [7].

With regards to Arora's dismissal of the diffuse radiation effects, we raise several caveats. First, his arguments were based on the interpretation of NDVI data using the Lund-Potsdam-Jena (LPJ) biogeochemical model. The LPJ model has many strengths but it does not consider diffuse light effects on photosynthesis. Secondly, temperature response functions of carbon exchange of ecosystems are not static. Respiration rates of most ecosystems will acclimate and shift with long-term changes in temperature [10]; at present most biogeochemical models do not account for this effect. Thirdly, changes in NDVI are used to infer changes in leaf area index and GPP. NDVI based models only infer GPP, they do not measure it directly like we did with the eddy covariance technique [7]. Finally, there still remains the question of imperfect aerosol corrections to NDVI after the Pinatubo eruption [8].

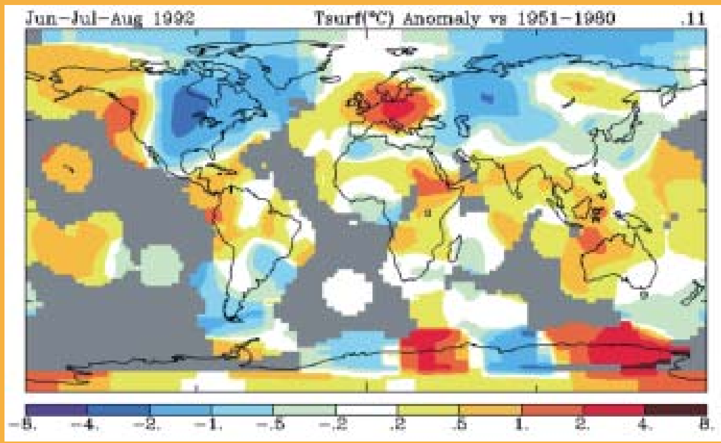

Figure 1. Global temperature anomaly after the Mt Pinatubo eruption. Data are generated from NASA GISS. http://www.giss.nasa.gov/data/update/gistemp/maps/; data source Peterson, T.C., and R.S. Vose 1997. An overview of the Global Historical Climatology Network temperature database. Bull. Amer. Meteorol. Soc. 78: 2837-2849.

In closing we note that a growing number of FLUXNET field sites are installing diffuse radiation sensors at their field sites. We now anticipate the next volcanic eruption and are ready to observe directly how carbon fluxes at points across the globe may respond to such an event.

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