THE ROLE OF CARBON DIOXIDE IN CLIMATE FORCING OVER THE PAST 26 YEARS

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ABSTRACT
Air samples are collected through the Climate Monitoring and Diagnostics Laboratory (CMDL) global network, including a cooperative program for the carbon gases which provides samples from about 100 global clean air sites, including measurements at 5 degree latitude intervals from three ship routes. Greenhouse gas concentrations are analyzed in terms of the changes in radiative forcing during the 26-year period encompassing 1979 through 2004. The growing fraction of the total radiative forcing due to carbon dioxide is emphasized and the nature of the interannual variations in the radiative forcing is explored. The interannual change in total radiative forcing is used to define an Annual Greenhouse Gas Index (AGGI).

INTRODUCTION
The perturbation to radiative climate forcing which has the largest magnitude and the least scientific uncertainty is the forcing related to changes in long-lived and well mixed greenhouse gases, in particular carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the halocarbons (mainly CFCs). The weekly station data are used to create a smoothed north-south latitude profile in sine latitude space from which a global average is calculated. The growth rate of CO_2 has averaged about 1.5 ppm per year over the past 26 years. The growth rate of methane has declined substantially since about 1992. The cause of this is likely related to several factors, including changes in emissions related to changes in the former Soviet Union and the short lifetime of methane (8-9 years) resulting in a pseudo-equilibrium between sources and sinks on this time scale [*Dlugokencky et al.*, 1998, 2003]. Nitrous oxide continues to increase with a relatively uniform growth rate while the CFCs have ceased the increase observed before about 1992 and have either leveled off or are in decline [*Montzka et al.*, 1999]. The latter is a response to decreased emissions related to the Montreal Protocol on substances that deplete the ozone layer.

RADIATIVE FORCING CALCULATIONS
To determine the total radiative forcing of the greenhouse gases, we have used IPCC (2001) recommended expressions to convert greenhouse gas changes, relative to 1750, to instantaneous radiative forcing. This is not a measure of the integrated climate forcing which can only be determined through an atmospheric radiative transfer model. In addition, only the direct forcing has been calculated. Model-dependent feedbacks, for example, due to water vapor and ozone depletion, have not been included. Contrary to climate models, these results are thus based mainly on measurements and have relatively high precision. Fig. 1 shows the radiative forcing results for the major gases and a set of 10 minor long-lived halogen gases. As expected, CO_2 dominates the total forcing with methane and the CFCs becoming relatively smaller contributors to the total forcing over time.

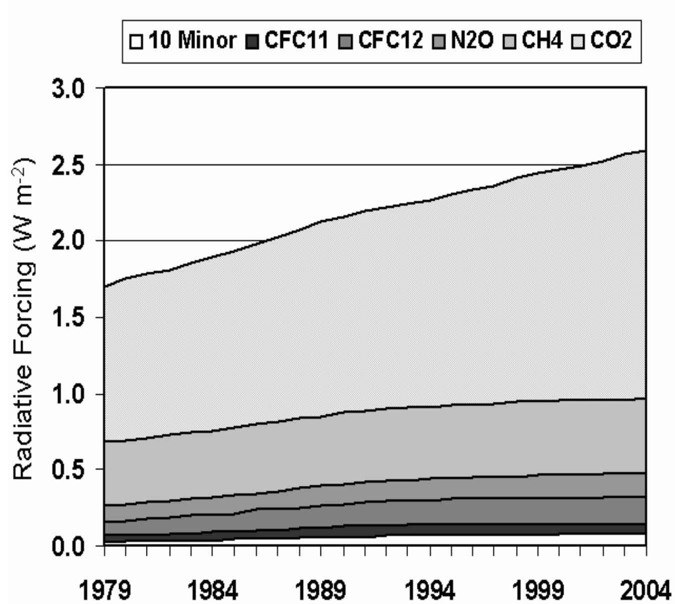

Fig. 1. Cumulative radiative forcing by well-mixed greenhouse gases.

RESULTS

Since 1979, the instantaneous radiative forcing by CO_2 has increased from 59% to 62% of the total forcing by long-lived greenhouse gases. Of the four major groups of long-lived green-house gases that contribute to radiative climate forcing, CO_2 and N_2O are the only ones that continue to increase at a regular rate. The contribution to radiative forcing by methane and CFCs has been nearly constant or declining, respectively, in recent years. An Annual Greenhouse Gas Index (AGGI) has been defined as the ratio of the total forcing to that which was present in 1990. This index is a measure of the interannual changes in conditions that affect carbon dioxide emission and uptake, methane and nitrous oxide sources and sinks, and the decline in the atmospheric abundance of ozone-depleting chemicals related to the Montreal Protocol. Most of this increase is obviously related to CO_2. For the year 2004, the AGGI was 1.20 (an increase in total forcing of 20%).

Figure 2 shows the interannual variation in the CO_2 radiative forcing growth rate. While there does not appear to be a significant global trend, the rate varies by up to a factor of 5 from year-to-year. The very low values in the 1992 period are likely related to the eruption of Mt. Pinatubo in June 1991. Both reduced tropospheric temperatures and increased diffusive radiation are believed to have been involved. Similar effects after the eruption of El Chichón in April 1982 were largely countered by increasing growth rates associated with the ENSO event of 1983. Similarly, the high growth rates of 1998 are believed to be related, at least in part, to the major 1997-98 ENSO event. These events are often followed by droughts and major biomass fires. In addition, 1998 was a record warm year.

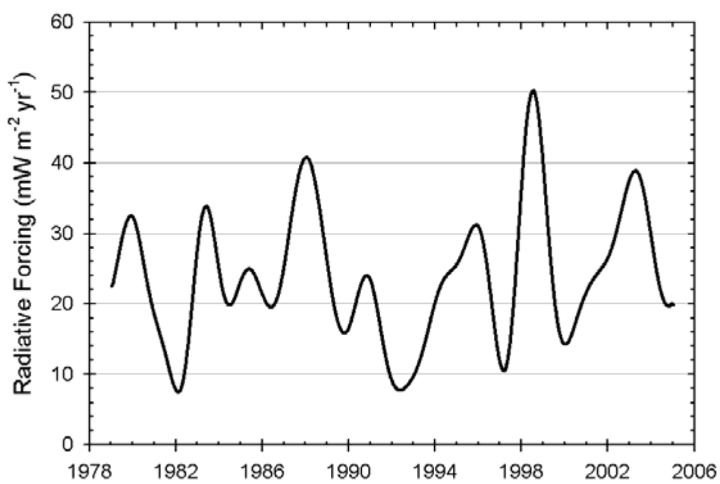

Fig. 2. Global carbon dioxide radiative forcing growth rate from monthly average data.

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