ATMOSPHERIC CO_2 GROWTH-RATE ANOMALIES IN 2002-03

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ABSTRACT

We examine the growth-rate of atmospheric CO_2 in 2002 and 2003. Observations show consecutive increases of greater than 2 ppmv per year for the first time on the Mauna Loa record. We use a statistical regression to show that increasing anthropogenic emissions and ENSO activity are unable to account for the CO_2 growth-rates of 1992 and 1993 following the Pinatubo volcanic eruption, or the anomalously high growth-rate of 2003. Increased forest fires in the northern hemisphere, consistent with remote-sensing and carbon monoxide measurements, seem likely to have contributed significantly to the 2003 anomaly. We hypothesise that the hot and dry Eurasian summer of 2003 led to an increase in forest fire emissions from Siberia, and may also have directly suppressed land-carbon uptake. Model results lead us to expect a steady increase in airborne fraction as climate change weakens the natural carbon sink and accelerates CO_2 rise.

Figure 1(a) shows annual growth rates of atmospheric CO_2 at Mauna Loa. 2002 and 2003 are the first consecutive years to exceed a growth-rate of 2 ppmv yr^{-1}, sparking speculation of a possible indication of accelerating climate change through carbon cycle feedbacks [e.g. *Cox et al*., 2000]

In the long-term the CO_2 growth-rate will increase with the upward trend in anthropogenic CO_2 emissions. The assumption that 40% of these emissions remains in the atmosphere (figure 1a) explains the upwards trend of CO_2 rises, but does not explain their inter-annual variability, which is correlated with ENSO. During an El Nino event large areas of tropical land become dryer and warmer, leading to a net emission of CO_2 from the land, enhancing the CO_2 growth-rate [*Keeling et al*., 1995]. The opposite happens during La Nina.

The CO_2 growth-rate anomaly about the long-term trend of emissions shows that 2002 is not an exceptional anomaly, and 2003 is only the 4th largest anomaly on record. However, the three larger anomalies in 1973, 1988 and 1998 are all associated with significant El Nino events (Fig. 1b). The similarity between figures 1(a) and 1(b), shows positive growth-rate anomalies corresponding to El Nino events, and the negative growth-rate anomalies corresponding to La Nina events. By contrast, the 2003 CO_2 growth-rate anomaly follows a weak El Nino, and the Nino3 preceding 2002 is slightly negative.

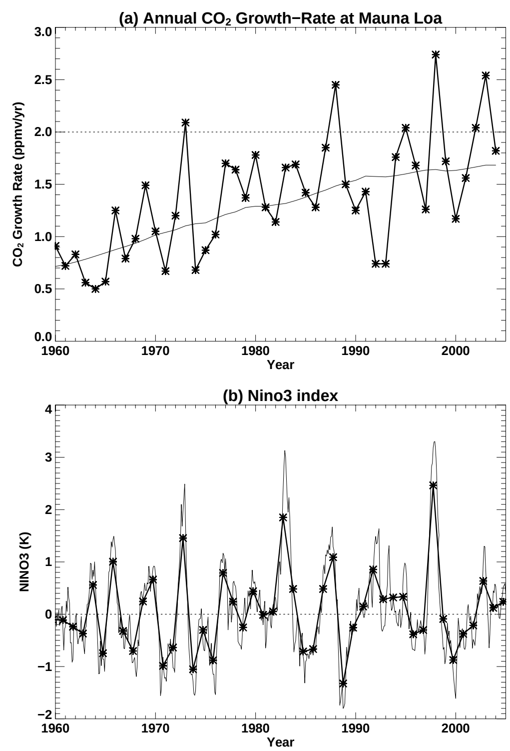

Fig. 1. (a) annual CO_2 growth rate and 40% of anthropogenic emissions; (b) monthly and annual Nino3 index

We regress the ΔCO_2 data simultaneously against anthropogenic emissions, ε, and the Nino3 index, N:

$$\Delta CO_2 = \alpha_1 + \alpha_2 N + \alpha_3 \varepsilon$$

yielding the expected correlation with Nino3 and finding that in the long-term, 40% of emissions remain airborne. Comparing each year's ΔCO_2 with those predicted by emissions and Nino3 reveals several features (Fig. 2). Notable negative anomalies in 1992 and 1993 when the CO_2 growth-rate was unusually low due to the climatic effects of the Mt. Pinatubo eruption in 1991 [*Lucht et al.,* 2002]. 2003 has the largest positive anomaly.

To quantify the statistical significance level of the 2003 anomaly, we extend the previous regression to add in a hypothesised extra process which operates for a single year:

$$\Delta CO_2 = \alpha_1 + \alpha_2 N + \alpha_3 \varepsilon + \alpha_4 \delta(y)$$

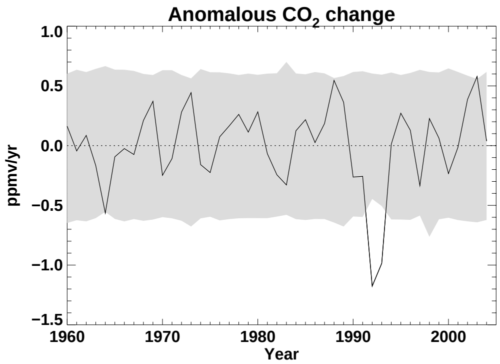

Fig. 2. "anomalous" CO_2 change which cannot be explained by ENSO and emissions. Values outside the shaded area are significant at the 90% level.

We apply the delta function, $\delta(y)$, to each year, y, in turn, and test the significance of the null hypothesis that the ΔCO_2 can be explained in terms of anthropogenic emissions and the Nino3 index. If the null hypothesis is rejected statistically, we can be confident that some other process is required to explain that ΔCO_2. The shaded region in figure 2 shows the range of ΔCO_2 for which the null hypothesis is not rejected at 90% confidence. 2003 is the only year with a high anomaly significant by this measure.

Measurements of carbon monoxide and other trace gases [e.g. CH_4, H_2 and CH_3Cl; *Simmonds et al.,* 2005] indicate large increases in biomass burning in 2002 and 2003 in the Northern Hemisphere (particularly Siberia). They estimate a CO_2 source of about 0.6 GtC (equivalent to 0.3 ppmv rise) from boreal fires.

Results from our coupled climate-carbon cycle model show that positive feedbacks between climate and the carbon cycle will significantly increase the airborne fraction of emissions over the 21^{st} century (fig. 3). Our simulation agrees with the observed airborne fraction from 1960 to 2000, but then simulates an increase until the airborne fraction exceeds unity by 2100.

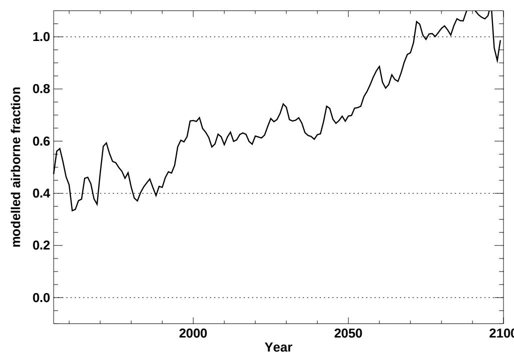

Fig. 3. modelled airborne fraction of emissions. Values exceed unity by 2100.

CONCLUSIONS

2002 and 2003 are the first consecutive years to show rises of greater than 2 ppmv yr^{-1}; rises which cannot be explained by emission changes alone, nor on the basis of strong El Nino signals. There is thus a high probability that some other process contributed to the 2003 ΔCO_2 anomaly.

Increased CO_2 release from Northern Hemisphere fires, possibly driven by anomalous climatic conditions in these years, and suppressed land carbon uptake due to the dry European summer of 2003 [*Ciais et al.*, 2005] are the most likely reasons for the high growth-rates.

As climate warms we expect an increase in the long-term airborne fraction. If the anomalous 2003 CO_2 rise was due to the hot conditions of that year which in turn may be due to man-made global warming [*Stott et al.,* 2004] then might we be seeing the first signs of this positive feedback? Although it is clearly too early to detect a significant trend in the annual airborne fraction from the observed data, we cannot exclude this explanation as a possibility.

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