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TESTING THE GLOBAL WARMING HYPOTHESIS

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Abstract. The temperature record for the global surface air temperature indicates that six of the warmest years occurred in the period 1980-1988. Here we address the question on the likelihood that such an arrangement is simply a manifestation of the natural variability of the system. Our results indicate that the probability that such an arrangement will arise naturally is between 0.010 and 0.032.

Introduction

Carbon dioxide (CO_2) is a gas which absorbs strongly in the infrared region of the electromagnetic spectrum. The earth is warmed during the day by solar radiation. During the night, and the day, the earth radiates energy back to space. However, the sun's and planet's electromagnetic spectra differ on the wavelength, λ_{max} for which the emitted energy peaks. For the sun $\lambda_{max} \approx 0.5$ µm and for the earth $\lambda_{max} \approx 11$ µm. Thus, CO_2 tends to absorb the terrestrial radiation more than the solar radiation. Because of that some of the heat generated by the planet is trapped by CO_2 in the lower atmosphere. The consequences of increased amount of CO_2 in the atmosphere are thus straightforward in theory: more CO_2 will result in more heat trapping and thus in higher surface air temperatures. This is commonly referred to as the "greenhouse effect" to make the connection to the very well known function of the greenhouses used to grow plants.

The existence of the greenhouse effect is not questioned. It is responsible for the very hot temperatures on Venus (whose atmosphere is mostly carbon dioxide) and the very cold temperatures on Mars (whose atmosphere contains very little carbon dioxide) and it has been demonstrated in various numerical experiments involving atmospheric models. The models, even though they may differ on the exact response to a realistic CO_2 increase, on the exact warming and on the regional pattern of climatic change, are all consistent in producing a warming of the lower atmosphere with increasing levels of CO_2. The modeled differences have to do with structural differences of the models, with the absence of cloud interaction in the models which is believed to contribute a major source of uncertainty and with the not so well understood role of the oceans as a carbon dioxide "sink" [Manabe and Wetherald, 1975, Manabe and Wetherald, 1980, Manabe and Stouffer, 1980, Ramanathan et al., 1979, Washington and Parkinson, 1986, and Smagorinski, 1982].

What is questionable, however, is evidence that a global warming due to the increased concentrations of CO_2 is already underway. In order to address this very important issue we must begin with the fact that the amount of CO_2 is constantly increasing in the last 100 years due to industrialization and burning of fossil fuels. It is estimated that CO_2 levels have increased by about 20% compared to the pre-industrial values. At the same time the average surface air temperature of the planet seems to be on the rise and it has long been speculated and debated that the two trends are related. It is notable, however, that until 1980 no statistical evidence has emerged from the one hundred year long global temperature record to associate the trend with atmospheric CO_2 increase [Jones et al., 1982]. Until last year, when Jones et al. (1988) presented evidence for global warming in the past decade. Based on updated temperature records they reported that in the period 1901-1987 five of the warmest years on record (1980, 1981, 1983, 1986, 1987) have occurred in the last eight years (1980-1987) of that period and speculated that such an arrangement could indicate the consequences of increased concentrations of CO_2 and other greenhouse gases such as water vapor, methane, etc. Lately, Jones (personal communication) reported that 1988 was the warmest year ever. That will make six of the warmest years in the record occuring in the last nine years. In this report we investigate the statistical significance of such an arrangement. We are interested in addressing directly from the observed data the specific question on the likelihood that such an arrangement will occur as a result of the natural variability of the system. This approach is quite different than the approach of Hansen et al. (1987) who addressed the above question using a three-dimensional climate model to simulate the global climate effects of time-dependent variations of atmospheric trace gases and aerosols.

Data Analysis and Results

Global and hemispheric annual mean values for the surface air temperature have been produced and are available from 1851 to 1988, thanks to the efforts of Jones et al. (1986a), Jones et al. (1986b), Jones et al. (1986c), and Jones (1988). In this study only their global annual mean values in the period 1881-1988 (Figure 1) will be considered (data set 1). The reason for not employing the whole available period is that prior to 1881 a much larger variance in the data is apparent. This may be due to the inadequate measuring network prior to this time. Indeed, based on this record it has been demonstrated [Schonwiese, 1987] that

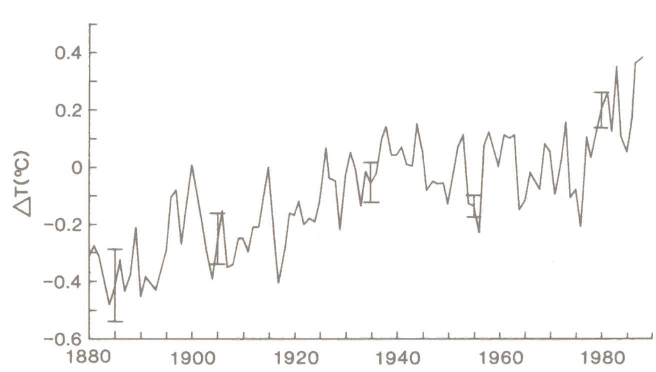

Fig. 1. Yearly global surface air temperature departures for the period 1881-1988 from the reference period 1951-1970 [from Jones et al., 1986a, 1986b,1986c and Jones, 1988]. Selected uncertainty bars indicate 95% confidence limits for global values [from Hansen and Lebedeff, 1987].

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there exists a considerable doubt in the reconstructed temperature series prior to 1881. As a result, data prior to 1881 are not used in studies that assess global temperature trends. Another set of global annual mean values for the period 1880-1987 has been compiled thanks to the efforts of Hansen and Lebedeff (1987) and (1988) (data set 2). Recently, Hansen (personal communication) has informed us that his preliminary calculations estimate that 1988 was either the warmest or the second warmest year ever recorded. That makes five of the warmest years on their record (1980, 1981, 1983, 1987 and 1988) all occurring in the 1980s. The two data sets are in general in very good agreement. It should be stressed that there exist many difficulties in constructing a representative global temperature record. The oceans are not adequately presented, the quality of the measurements and the density of the reporting stations has not remained the same throughout the record period, urbanization effects are not included etc. Nevertheless, a very careful construction with what is available has been performed and at this point addressing the global warming issue has to rely on these data.

We begin with data set 1 and we follow the strategy as outlined next. First we described the 1881-1988 global temperature series by an optimum autoregressive model using the approach described in Katz (1982). This approach is a parametric modeling of a given time series. The time series under consideration is viewed as a realization of a stochastic process which is taken to be stationary and having a Gaussian distribution. This assumption has been widely used with the global temperature data and is approximately supported by the fact that the slope of the spectrum scales over most of the frequency (f) range as f^{-b} where b is very close to two [Lovejoy and Schertzer, 1986]. The optimum autoregressive model for data set 1 was found to be of fourth-order. The model seems to reproduce the qualitative properties of the global temperature record very well. Compare for example Figure 2 (a simulated record of length 108) and Figure 1 (the actual global temperature record). Subsequently, we performed Monte-Carlo simulations using the derived autoregressive model. We simulated many series of one-hundred and eight values corresponding to the 1881-1988 record. Then we searched each simulated record in order to see if the highest or the two highest or the three highest etc. values fall in the interval 100-108 (which will correspond to the period of years 1980-1988). This way from all the simulated records we can find the probability, $P_x^{n,m}$ that in the record of x values the n highest values are found in the last m values.

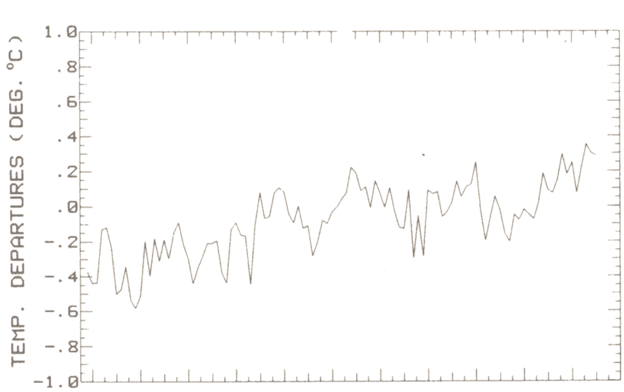

Fig. 2. Simulated global mean temperature record of length 108 years using a fourth-order autoregressive model. This model is an optimum model derived from the observed global mean temperature record shown in Figure 1. Note the similarities between Figures 1 and 2.

TABLE 1. This table shows the probability that in a record x time steps long n highest magnitude events will occurr in the last m events. The entries represent the lower bound of such probability with the higher bound being at most twice the lower bound. These results are based on one-hundred-thousand Monte-Carlo simulations.

n x,m	0	1	2	3	4	5	6	7	8	9
108,9	.616	.158	.091	.058	.037	.021	.012	.005	.002	<.001

The results from 100,000 Monte-Carlo simulations for x=108 and m=9 are shown in Table 1. As can be seen the probability that six of the highest values will be found in the last nine years is 0.012. Note that this (as well as the other values in Table 1) would indicate the minimum chance that such an arrangement will happen. The reason for that is the following. Evidence for global warming are based on a temperature record which shows a marked positive trend. Observing n highest values in the last m values will be more likely when a positive trend is present than when a negative trend is present. The Monte-Carlo simulations will produce with about 50%-50% chance a positive or a negative trend. If we only deal with positive trends this probability may then be as high as 0.024. Thus, we may assume that $0.012 \leq P_{108}^{6,9} < 0.024$. We wish to stress at this point that the above procedure is quite robust. We obtain almost identical values when we repeat the same experiment but with different initial conditions.

Furthermore, we performed similar simulations based on an optimum autoregressive model which described the global temperature record excluding the last nine years. The results remain virtually unchanged. In addition to the above and insofar as the evidence presented for global warming [Jones et al., 1988] which is based on the temperature record in the last 88 years (1901-1988) we repeated everything but for x=88. The results are shown in Table 2. Here, as expected, we estimate higher values of $P_x^{n,m}$ for n not equal to zero. As an example $0.015 \leq P_{88}^{6,9} < 0.03$.

Subsequently, we repeated the analysis but now using the second data set [Hansen and Lebedeff, 1987, 1988]. Due to the great similarity between the two data sets the results turn out to be very close to those reported in Tables 1 and 2.

Finally, we approached the problem from a somewhat different angle. In Figure 1 each year's value is a mean value with some standard error due mainly to the incomplete spatial and temporal coverage provided by the finite number of reporting stations. Thus, we may produce certain confidence limits for these mean values. Such limits have been estimated using a general circulation model in Hansen and Lebedeff (1987). Instead of ordering the warmest years according to their mean value we may adopt the following strategy. We consider all the years prior to 1980 and their representative 95% confidence limits bars (as indicated in Figure 1). Then we take every year in the 1980s and we

TABLE 2. Same as Table 1 but for smaller x values.

n x,m	0	1	2	3	4	5	6	7	8	9
88,9	.557	.170	.104	.069	.046	.029	.015	.007	.002	<.001

place it in the warmest years list only if its value is above the 95% confidence limits of all the years prior to 1980. When we do that, four years (1981, 1983, 1987 and 1988) from data set 1 and five years (1980, 1981, 1983, 1987 and 1988) from data set 2 make it in the warmest years list. If we now repeat the Monte-Carlo simulations but require the above strategy to be followed for each simulation we can estimate the probability, $F_x^{n,m}$ that in a record of x values long n values in the last m values will be above the 95% confidence limits of the first x-m values of the record. According to the results $0.013 \leq F_{108}^{4,9} < 0.026$, $0.016 \leq F_{88}^{4,9} < 0.032$, $0.010 \leq F_{108}^{5,9} < 0.020$, and $0.013 \leq F_{88}^{5,9} < 0.026$.

Conclusions

Our analysis can not directly address the question: is the observed global warming due to the increased concentration of CO_2 and other greenhouse gases? It does, however, indicate that if the warming in the 1980s is a result of the natural variability of the system then it is a rather extreme event. Depending on the underlying assumptions, on data length, and data analysis, the warming of the 1980s is an event which has only 1.0% - 3.2% chance of happening as a result of the natural variability of the system. This result may provide high confidence levels for supporting the global warming hypothesis.

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