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Overlooked Scientific Issues in Assessing Hypothesized Greenhouse Gas Warming*

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ABSTRACT

This paper presents several issues related to the greenhouse gas global warming hypothesis which should be satisfactorily addressed before costly control requirements are imposed on society. The questions which need to be answered include the importance of other anthropogenic influences such as landscape changes and enhanced atmospheric aerosol loading. Controls such as conservation and improved energy efficiency, of course, which are benefits to society should be implemented regardless of global climate change.

KEY WORDS

Greenhouse warming issues, Climate change, Global warming issues.

1. INTRODUCTION

During the last several years, there has been considerable concern expressed by the media, members of the scientific community, politicians, and others concerning a global warming resulting from anthropogenic-caused increases in certain trace gases in the atmosphere. These trace gases, which include carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide, reduce the amount of the earth's radiation which is emitted to space. Since 1880, for example, the concentration of carbon dioxide has apparently increased very systematically with only seasonal fluctuations of about 6-7 parts per million from an estimated annual average value of 290 parts per million in 1880 to 350 parts per million at the current time (see Figure 1a for the 1958 - 1984 period), while the surface air temperature record (based almost exclusively on land data) has behaved as shown in Figure 1b. Numerical models of the global atmosphere and ocean circulations (referred to as general circulation models - GCMs) have been used to investigate the impact on climate of an increase in these trace gases. The Environmental Protection Agency (EPA) concluded in 1983 based on these models, for example, that an increase of the average global temperatures of 5°C by the year 2100 with an increase of sea level up to around 2 meters will result because of the global enhancement of these gases. The World Meteorological Organization has concluded that greenhouse gas caused warming could cause a global warming of 1.5°C to 4.5°C by the middle of the next century.

The purpose of this paper is to discuss a number of serious shortcomings in the GCM model simulations which have produced these conclusions regarding climate change. These limitations, which are either inadequately handled or not represented at all in GCMs, are summarized in this paper.

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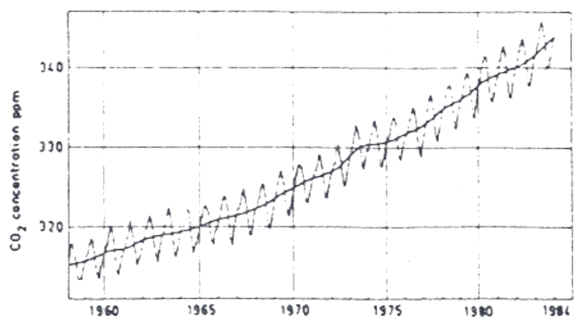

Figure 1: *(a) Concentration of atmospheric CO_2 at Mauna Loa Observatory, Hawaii. Dots indicate monthly averages determined from continuous measurements. Based on data reported by Bacastow and Keeling*[1]*, supplemented by data from recent years supplied by personal communication (from Bolin et al.*[2]*.)*

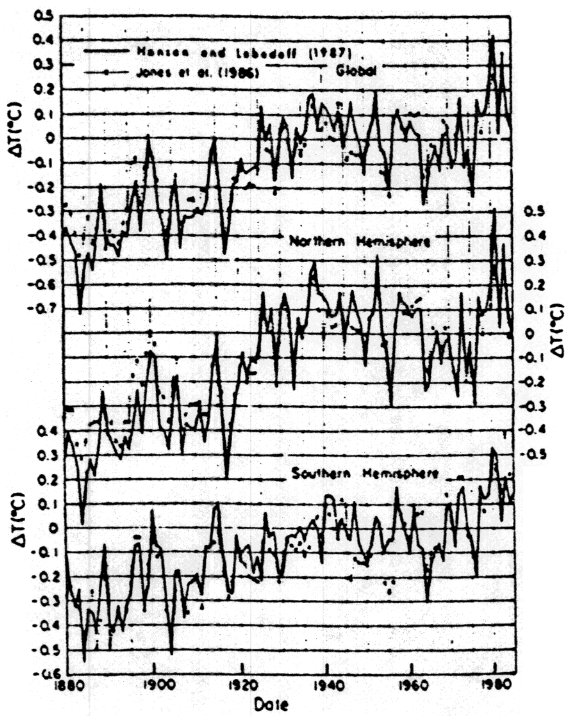

Figure 1: *(b) Comparison of the annual global and hemispheric temperature change for the Hansen and Lebedeff*[3] *data and the Jones et al.*[4,5] *data set (after Hansen and Lebedeff*[3]*; from Karl et al.*[6].

Other scientists have also raised concern that a greenhouse global warming has been overstated because of natural and man-caused compensating effects (e.g. Reifsnyder[7] and Lindzen[8]). P. Michaels, State Climatologist of Virginia, has been particularly outspoken concerning an overstatement of a greenhouse gas caused warming (e.g. Michaels[9]). GCM investigators are also raising cautions regarding the realism of their simulations. Cess *et al.*[10], for example, compared 14 GCMs and found a large sensitivity between models of simulated sea surface temperature due to different treatments of the cloud-climate feedbacks in the models. Gutowski *et al.*[11] have shown that the discrepancies between GCMs in the simulation of downward longwave radiative fluxes are larger than the flux changes associated with doubling carbon dioxide in the modeled atmospheres.

Also, as evident in Figure 1b, and reported by Thomas Karl of the National Climatic Data Center (NOAA Report[12]), most of the global warming that has occurred over the last century occurred *before* the recent rise in greenhouse gas concentrations. Between 1919 and 1986, according to that Report, temperatures rose only 0.15°C yet greenhouse gases increased by 30%. From 1921 to 1979, the global temperatures over land actually cooled.

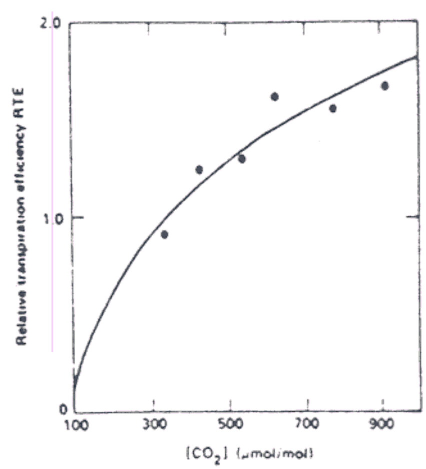

Figure 2: *Soybean transpiration efficiency as a function of CO_2 relative to transpiration efficiency at ambient CO_2. The points were determined from the measurements of Rogers* et al.[14]*. The curve is a log regression fit ($RTE = -3 \cdot 236 + 0 \cdot 7297$ ln CO_2, $r = 0 \cdot 94$; from King et al.*[13]*).*

2. INCREASED CARBON DIOXIDE CONSUMPTION RESULTING FROM INVIGORATED PLANT GROWTH ON LAND AND IN THE OCEAN

If vegetation growth is enhanced because of an enrichment in carbon dioxide, the importance of this greenhouse gas to global warming would be reduced. Figure 2, reproduced from King *et al.*[13], documents that soybean transpiration efficiency, and therefore soybean yield, would increase if CO_2 concentrations are elevated. If the response is characteristic of natural and other agricultural crops, a substantial portion of the anthropogenic carbon dioxide emissions could be absorbed in biomass resulting in a benefit to mankind.

3. INABILITY FOR GCM MODELS TO PROPERLY RESOLVE THE EVOLUTION OF EXTRATROPICAL AND TROPICAL CY CLONES DUE TO THEIR POOR SPATIAL RESOLUTION

The horizontal grid spacing of general circulation models is around 400 km. As shown by Pielke[15], as least four grid increments are required to reasonably represent an atmospheric feature, thus this grid resolution would only permit features 1600 km or larger to be reasonably represented in the models. Since extratropical cyclones often are observed to have horizontal wavelengths as small as 500 km or so, they are poorly represented in these models. Since these features provide the major physical mechanism for the exchange of heat, moisture, and momentum between the subtropics and the polar regions, the inability of GCM representations to adequately represent these exchanges is a serious shortcoming. Tropical cyclones, which also provide an important mechanism for exchanges between the tropics and higher latitude is even more poorly represented since its scales of important physical processes includes the eye wall which can be tens of kilometers in radial size. Pielke[16] discusses this shortcoming further.

4. INABILITY FOR GCM MODELS TO PROPERLY RESOLVE REGIONS OF OCEAN UPWELLING WHOSE COLD WATERS CAN ENHANCE THE OCEANIC UPTAKE OF CARBON DIOXIDE

Upwelling of deep, cold ocean waters occurs at a number of locations around the world including the equatorial Pacific, around Antarctica, and off the west coast of North America, northern South America, northwest Africa, southwest Africa, and elsewhere. Caused by the direction and speed of the wind at the ocean surface, these upwelled regions of cold surface waters usually have an extent in one spatial direction of 50 km or so. Since atmospheric-ocean GCMs have spatial resolutions on the order of 400 km, these important, potential sinks for carbon dioxide are ignored.

5. OCCURRENCE OF GREATER GLOBAL CLOUD COVERAGE AS A RESULT OF COLLOIDALLY MORE STABLE CLOUDS DUE TO ANTHROPOGENIC INPUT OF AEROSOLS

Figure 3, reproduced from Warren *et al.*[17], indicates that cloud coverage over the oceans has increased by about 3% since 1930. While the physical explanation for this increase is unknown, it could be because the anthropogenic input of aerosols (i.e. cloud condensation nuclei) has made the clouds colloidally more stable, so that they persist longer before precipitating.

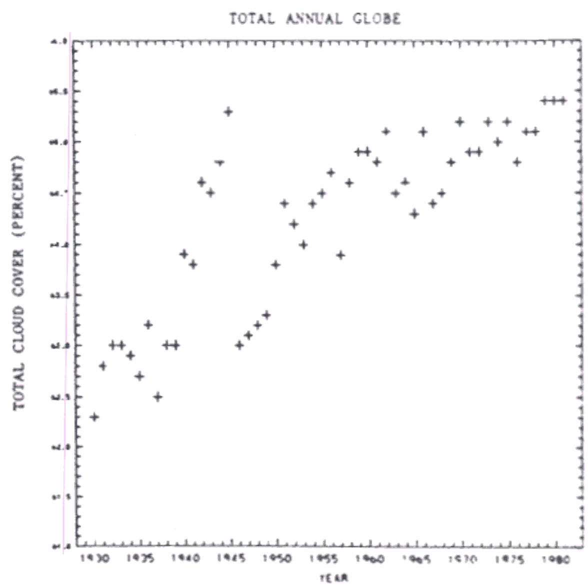

Figure 3: *Total annual global cloud coverage in percent over the oceans (reproduced from microfiche in Warren et al.*[17]*).*

To estimate the potential impact of such a change in cloud coverage on the earth's equilibrium temperature, T_E,

$$\sigma T_E^4 = S(1 - A) \tag{1}$$

where σ is the Stefan-Boltzmann constant, S is the mean solar irradiance at the earth's mean orbital position, and A is the average albedo. Equation (1) is a balance equation between the incoming radiation energy from the sun which is absorbed by the earth (the right side of (1)), and the radiation energy emitted by the earth (the left side (1)). While this heat balance does not provide any information regarding the global surface temperature, it does provide a measure of the sensitivity of the land-ocean-atmosphere system to changes in the amount of solar radiation available to the planet.

By using differential calculus and assuming small changes and inserting observed values for σ and S (Pielke and Avissar[18]), Equation (1) can be rewritten as

$$\Delta T_E = -268\Delta A \qquad (2)$$

where $T_E = 283°K$ was used.

Equation (2) indicates that a change of albedo of +3% over the oceans (which cover about 75% of the earth's surface so that the global average change of albedo would be $\Delta A = 2.25$ if no cloud changes occurred over land) would result in an equilibrium temperature change of over −6°C! Such a sensitivity to albedo suggests that the increase in cloud coverage reported on above could compensate for any greenhouse gas warming, and even result in a global cooling!

6. MODIFICATION OF THE AMOUNT OF SOLAR RADIATION REFLECTED BACK INTO SPACE DUE TO MAN-CAUSED LANDSCAPE CHANGES

Changes in land surface reflection, if over a large enough area, could similarly influence the earth's equilibrium temperature. If Equation (2) is rewritten as to consider only land surfaces (which cover about 25% of the earth's surface), then

$$\Delta T_E = -67\delta A$$

Here δA is the average change of albedo on land.

Therefore a land-average increase of δA of 1% would result in a change in the equilibrium temperature of −0.67°C. A decrease of 1% would correspond to a 0.67°C warming. Similarly, a 25% change in land surface albedo over 1% of the land surface would yield the same result.

As an example of documented land surface changes, a forest in the eastern United States has an albedo as viewed from space on the order of 0.15 to 0.20, while if it were cleared and replaced by agricultural crops, the albedo can be up to 0.30 (Rosenberg[19]).

7. MODIFICATION IN THE AMOUNT OF EVAPORATION AND TRANSPIRATION TO THE ATMOSPHERE AS A RESULT OF MAN-CAUSED LANDSCAPE CHANGES

Landscape changes also alter the partitioning of turbulent heat fluxes into sensible and latent heat components and the movement of water between the earth's surface and the atmosphere. Sensible heat fluxes directly warm the atmosphere, while latent heat is represented by evaporation from surfaces and transpiration from vegetation with any warming not realized until condensation and/or deposition to liquid and/or ice occurs (primarily in clouds). All man-caused landscape changes will have some impact on this heat and water budget.

Irrigated land represents one example of this effect. Figure 4 documents satellite measured surface temperatures over an area in northeast Colorado in which this land practice is applied. Temperatures are over 10°C cooler over the irrigated area at this time of the day, as averaged over two weeks during a particular summertime period. Aircraft measurements made over this area (Segal *et al.*[21]) document that this area is also much more moist than the surrounding dryland area, thus irrigated areas may be associated with changes in cumulus cloud coverage and intensity (Pielke and Zeng[22]).

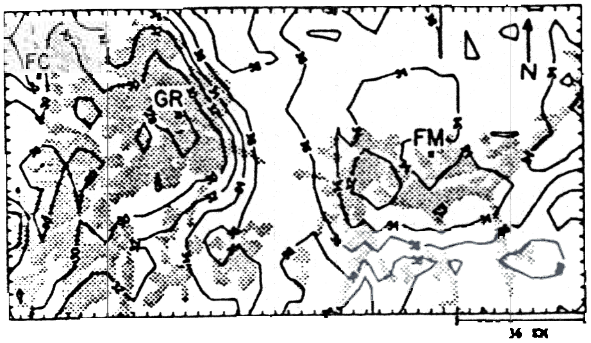

Figure 4: *Composite of GOES derived surface temperature at 1300 LST for the period 1 August 1986 to 15 August 1986 for northeast Colorado (FC - Fort Collins; FM - Fort Morgan; GR - Greeley; from Segal et al.*[20]*).*

8. CLOUDS WHICH CONTAIN SULPHATE PARTICLES, RESULTING FROM FOSSIL FUEL COMBUSTION, HAVE A HIGHER ALBEDO THAN PRISTINE CLOUDS

Satellite observations discussed in the November 1989 issue of *Scientific American*, and as suggested by Twomey *et al.*[23], indicate that sulphate particles in clouds introduced by fossil fuel burning could be enhancing the brightness of these clouds from what they would be naturally (the percent of cloud coverage could also be higher because the additional sulphate aerosols act to make clouds colloidally more stable – see Section 5 above).

Using Equation (2), if the increase in albedo is 10%, and the affected area represents 10% of the earth's surface, a decrease in T_E of 2.7°C would be expected.

9. GREATEST WARMING IS PREDICTED TO BE IN POLAR REGIONS, AND YET WARMING HAS NOT OCCURRED

All GCM simulations indicate that global warming should be more pronounced at polar latitudes. Figure 5, reproduced from Sansom[24], shows that since 1960, at least, temperatures have not been increasing at representative sites on the Antarctic continent despite the continued increase in greenhouse gas concentrations. According to Schlesinger's[25] summary of the results from several GCMs, a doubling of carbon dioxide is simulated to cause a warming of 2°C to 6°C in the surface air temperature in December, January, February, and of even larger increases in June, July, and August. Not even a hint of warming is seen, however, in the Antarctic data.

Similarly, Michaels *et al.*[26] finds a departure of only 0.3°C in 1985 above the 100 year mean over most of North America, despite the model results given in Schlesinger's summary which indicates a substantial warming should be occurring in that geographic location.

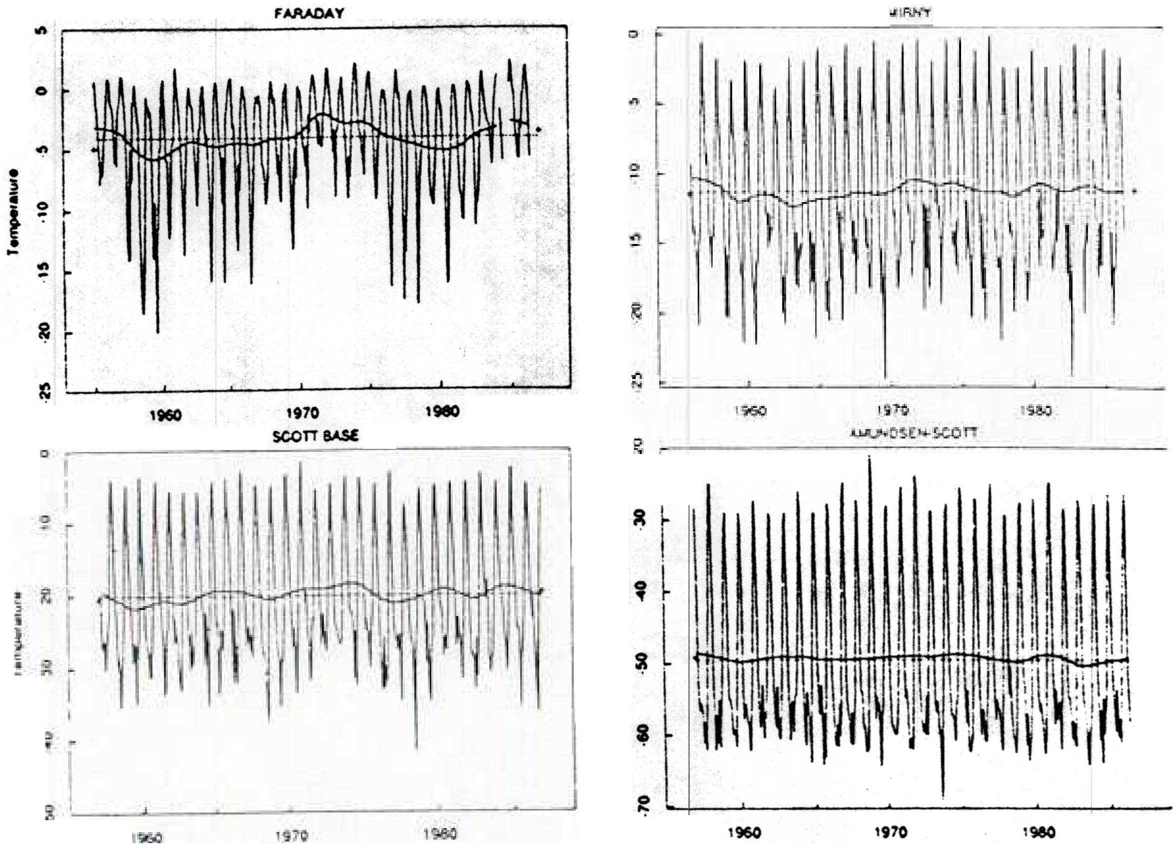

Figure 5: *Time series plots for Faraday, Mirny, Scott Base, and Amundsen-Scott. The large amplitude line shows the actual monthly mean temperatures, the small amplitude line a trend component, and the dotted line a reference line at the 5% trimmed mean level. Also, the end points of a regression line through the raw data are shown by "+" signs (from Samson[24]).*

10. SINCE THE ATMOSPHERE IS A NON-LINEARLY RESPONDING SYSTEM, EVEN WITH ALL RELEVANT PHYSICS FAITHFULLY REPRESENTED, THE GCMS COULD ONLY SIMULATE EXAMPLES OUT OF A SPECTRUM OF POSSIBLE ATMOSPHERIC RESPONSES TO INCREASED GREENHOUSE GASES

The shortcomings described above regarding GCMs, however, does not suggest that we forego using these tools. GCMs represent an important assessment procedure of potential effects on the global climate pattern, but we must maintain the proper perspective regarding their limits.

Climate change *is* a natural aspect of the atmosphere and has been occurring since the beginning of the earth. Moreover, it is likely that the atmosphere responds chaotically to an imposed external (e.g. change in solar constant) or internal (e.g. increased greenhouse gases) change since weather is a highly nonlinear system. If a chaotic response occurs, the future state of the atmosphere to these changes would be unpredictable with a single GCM result presenting just one possibility out of a spectrum of climate responses even if all the physical processes were properly represented. Even the Gaia hypothesis, in which Lovelock[27] proposes that biological responses to changes in the environment damp the resultant net environmental change may not accurately represent the actual response of the earth's atmosphere. Zeng *et al.*[28], for example, use the Watson and Lovelock[29] example of a simplified Gaia response (daisyworld) to show that if the interaction between the biosphere and atmosphere is sufficiently nonlinear, a chaotic response will occur.

11. POLICY RECOMMENDATIONS

Since climate change is a natural feature of the earth, we need to husband our resources even if there were no man-caused changes (e.g. Schneider[30]). With respect to man's potential influence on climate, the "path-of-least-regret" is that we should immediately adopt policies which mitigate man's impact providing there are no deleterious economic, environmental, or political effects of these policies. Even better, of course, is if these policies result in positive benefits to mankind. Conservation of fossil fuel resources, for example, and utilization of renewable energy resources represent examples of beneficial activities which should be promoted by government policy makers regardless of the direction of climate change. Recommendations by Rosenfeld and Hafemeister[31] represent definite steps which could be taken to achieve this goal. Policies which require significant hardship, however, are in this writer's opinion premature.

12. ACKNOWLEDGEMENTS

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13. REFERENCES

Bacastow, R. and C.D. Keeling, 1981: Atmospheric carbon dioxide concentration and the observed airborne fraction. *Carbon Cycle Modelling*, SCOPE 16, B. Bolin, Editor, John Wiley and Sons, Chichester, 103-112.

2. Bolin, B., B.R. Döös, J. Jäger, and R.A. Warrick, Editors, 1986: *The Greenhouse Effect, Climatic Change, and Ecosystems*, SCOPE 29, John Wiley and Sons, Chichester.

3. Hansen, J. and S. Lebedeff, 1987: Global trends of measured surface air temperature. *J. Geophys. Res.*, 92, 13,345-13,372.

4. Jones, P.D., S.C.B. Raper, R.S. Bradley, H.F. Diaz, P.M. Kelly, and T.M.L. Wigley, 1986a: Northern hemisphere surface air temperature variations: 1851-1984. *J. Climate Appl. Meteor.*, 25, 161-179.

5. Jones, P.D., S.C.B. Raper, and T.M.L. Wigley, 1986b: Southern hemisphere surface air temperature variations: 1851-1984. *J. Climate Appl. Meteor.*, 25, 1213-1230.

6. Karl, T.R., J.D. Tarpley, R.G. Quayle, H.F. Diaz, D.A. Robinson, and R.S. Bradley, 1989: The recent climate record: What it can and cannot tell us. *Rev. Geophys.*, 27, 405-430.

7. Reifsnyder, W.E., 1989: A tale of ten fallacies: The skeptical enquirer's view of the carbon dioxide/climate controversy. *Agric. Forest Meteor.*, 47, 349-371.

8. Lindzen, R.S., 1990: Some coolness concerning global warming. *Bull. Amer. Meteor. Soc.*, (in press).

9. Michaels, P., 1990: The greenhouse effect and the global change: Review and reappraisal. *Int. J. Environ. Studies*, (in press).

10. Cess, R.D., G.L. Potter, J.P. Blanchet, G.J. Boer, S.J. Ghan, J.T. Kiehl, H. Le Treut, Z.-X. Li, X.-Z. Liang, J.F.B. Mitchell, J.-J. Morcrette, D.A. Randall, M.R. Riches, E. Roeckner, U. Schlese, A. Slingo, K.E. Taylor, W.M. Washington, R.T. Wetherald, and I. Yagai, 1989: Interpretation of cloud-climate feedback as produced by 14 atmospheric general circulation models. *Science*, **245**, 513-516.

Gutowski, W.J., D.S. Gutzler, and W.C. Wang, 1990: Surface energy balances of three general circulation models: Implications for simulating regional climate change. *J. Climate*, (submitted).

12. NOAA Report, December 11, 1989, U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

13. King, D.A., G.E. Bingham, and J.R. Kercher, 1985: Estimating the direct effect of CO_2 on soybean yield. *J. Environ. Mgt.*, 20, 51-62.

14. Rogers, H.H., R.D. Beck, G.E. Bingham, J.D. Cure, J.M. Davis, W.W. Heck, J.O. Rawlings, A.J. Riordan, N. Sionit, J.M. Smith, and J.F. Thomas, 1981: *Response of Vegetation to Carbon Dioxide.* 005: Field studies of plant responses to elevated carbon dioxide levels. Prepared for DOE and USDA.

15. Pielke, R.A., 1984: *Mesoscale meteorological modeling.* Academic Press, New York, N.Y., 612 pp.

16. Pielke, R.A., 1988: Evaluation of climate change using numerical models. In "Monitoring Climate for the Effects of Increasing Greenhouse Gas Concentrations. Proceedings of a Workshop". R.A. Pielke and T. Kittel, Eds., Cooperative Institute for Research in the Atmosphere (CIRA), Fort Collins, Colorado, August 1987, 161-172.

17. Warren, S.G., C.J. Hahn, J. London, R.M. Chervin, and R.L. Jenne, 1988: Global distribution of total cloud cover and cloud type amounts over the ocean. Prepared for the United States Department of Energy, Washington, D.C. and the National Center for Atmospheric Research, Boulder, Colorado.

18. Pielke, R.A. and R. Avissar, 1990: Influence of landscape structure on local and regional climate. *Landscape Ecology*, (accepted).

19. Rosenberg, N., 1974: *Microclimate: The Biological Environment.* Wiley, New York.

20. Segal, M., R. Avissar, M.C. McCumber, and R.A. Pielke, 1988: Evaluation of vegetation effects on the generation and modification of mesoscale circulations. *J. Atmos. Sci.*, **45**, 2268-2292.

21. Segal, M., W. Schreiber, G. Kallos, R.A. Pielke, J.R. Garratt, J. Weaver, A. Rodi, and J. Wilson, 1989: The impact of crop areas in northeast Colorado on midsummer mesoscale thermal circulations. *Mon. Wea. Rev.*, **117**, 809-825.

22. Pielke, R.A. and X. Zeng, 1989: Influence on severe storm development of irrigated land. *Natl. Wea. Dig.*, **14**, 16-17.

23. Twomey, S., R. Gall, and M. Leuthold, 1987: Pollution and cloud reflectance. In "Interactions Between Energy Transformations and Atmospheric Phenomena. A Survey of Recent Research" M. Beniston and R.A. Pielke, Eds., D. Reidel Publishing Company, Dordrecht, Holland, 335-348.

24. Sansom, J., 1989: Antarctic surface temperature time series. *J. Climate*, **2**, 1164-1172.

25. Schlesinger, M.E., 1988: Model projections of the equilibrium and transient climatic changes induced by increased atmospheric CO_2. In "Monitoring Climate for the Effects of Increasing Greenhouse Gas Concentrations. Proceedings of a Workshop". R.A. Pielke and T. Kittel, Eds., Cooperative Institute for Research in the Atmosphere (CIRA), Fort Collins, Colorado, August 1987, 3-50.

26. Michaels, P.J., D.E. Sappington, B.P. Hayden, and D. Stooksbury, 1988: Nonthermometric measurement of recent temperature variability over the coterminous United States, southern Canada, and Alaska. In "Monitoring Climate for the Effects of Increasing Greenhouse Gas Concentrations. Proceedings of a Workshop". R.A. Pielke and T. Kittel, Eds., Cooperative Institute for Research in the Atmosphere (CIRA), Fort Collins, Colorado, August 1987, 119-134.

27. Lovelock, J.E., 1982: Gaia as seen through the atmosphere. *Biomineralization and biological metal accumulation* (Eds. P. Westbroek and E.W. de Jong). D. Reidel Publishing Co., Dordrecht, The Netherlands, 15-25.

28. Zeng, X., R.A. Pielke, and R. Eykholt, 1990: Chaos in Daisyworld. *Tellus*, (accepted).

29. Watson, A.J. and J.E. Lovelock, 1983: Biological homeostasis of the global environment: the parable of daisyworld. *Tellus*, 35B, 284-289.

30. Schneider, S.H., 1976: The Genesis strategy: Climate and global survival. Stephen H. Schneider with Lynn E. Mesirow. Plenum Press, New York.

31. Rosenfeld, A.H. and D. Hafemeister, 1988: Energy efficient buildings. *Scientific American*, 258, 78-85.

Errata

R.A. Pielke

In Pielke (1991), a factor of 4 was left off of equation (1) when this relation is applied to global average conditions. For local daytime evaluations, it is the correct scaling form provided. S is modified to represent the Solar radiation at that locale and time of year. The more appropriate heat budget equation to use in scaling the importance of albedo change is

$$\sigma T_E^4 = \frac{S}{4}(1 - A)$$

With this correction equation (2) becomes

$$\Delta T_E = -67\Delta A$$

So that a +3% change of albedo over the oceans would yield an equilibrium temperature change of more than -1.5°C. The equation in Section 6 should then read

$$\Delta T_e = -17\delta A$$

so that a land-average increase of δA of 1% would result in a change of equilibrium temperature of -0.17°C. A decrease of 1% would correspond to a 0.17°C warming. Similarly, a 25% change in land surface albedo over 4% of the land surface would yield the same result.

In Section 8, the correction of the original equation (2) to (C2) results in an increase in albedo of 10% over 10% of the Earth's surface would result in a decrease in T_e of 0.67°C.

The conclusion of the Pielke (1991) paper is not affected by these corrections. It is clear from even this simple analysis that even relatively small changes in landscape characteristics (in this case albedo) can have an impact on global climate as significant as the hypothesized enhanced warming caused by anthropogenically input greenhouse gases.

References

Pielke, R.A., 1991: Overlooked scientific issues in assessing hypothesized greenhouse gas warming. *Environ. Software*, **6**, 100-107.