CC/NUMBER 38
SEPTEMBER 20, 1993

# This Week's Citation Classic®

**Manabe S & Wetherald R** T. Thermal equilibrium of the atmosphere with a given distribution of relative humidity. *J. Atmos. Sci.* 24:241-59, 1967. [Geophysical Fluid Dynamics Laboratory, Environmental Science Services Administration, Washington, DC]

By use of a radiative, convective equilibrium model of the atmosphere, this study explores the sensitivity of the atmospheric thermal structure to changes in clouds and in greenhouse gases such as $CO_2$ and $O_3$. It is the first to incorporate the vertical, convective mixing of heat into a model developed for the study of climate sensitivity. The study quantitatively elucidates the role of the feedback process involving water vapor in enhancing the sensitivity of climate. [The *SCI*® indicates that this paper has been cited in more than 455 publications.]

## Modeling Study of Greenhouse Warming

Syukuro Manabe
Geophysical Fluid Dynamics Laboratory
National Oceanic and
Atmospheric Administration
Princeton University
Princeton, NJ 08542

In the early fall of 1958, when I completed my PhD thesis at the University of Tokyo, Joseph Smagorinsky of the US Weather Bureau kindly invited me to join his group to develop a general circulation model of the atmosphere. At that time, Joe already had a grand vision of modeling the atmospheric general circulation and climate as a major component of the Earth system, and had begun to construct such a model. Immediately, I was involved in simple parameterizations of land surface processes and cumulus convection, and the construction of a radiative transfer algorithm. This was the beginning of a long-term research project which continues today. It was very timely that Dick Wetherald joined our group from the Westinghouse Electric Corporation as a young, promising meteorologist with an expertise in computer programming. During this early stage of my career, I was very fortunate to be able to collaborate and consult with Fritz Moller and Giichi Yamamoto. Richard Goody was also extremely helpful in sending me the voluminous preprint of his classic textbook on atmospheric radiation.[1] Thanks to the prudent advice of these pioneers, we successfully constructed a one-dimensional model of the atmosphere in radiative, convective equilibrium as an important stepping stone toward developing a three-dimensional model of climate.[2] By using the model, we began to explore the crucial role that greenhouse gases play in maintaining climate and causing it to change.

This study was the first to incorporate in a model the effect of very efficient convective heat flux from the Earth's surface into the atmosphere. By considering the radiative heat budget of the coupled atmosphere-surface system, it avoided the basic flaw in earlier estimates of the greenhouse warming which were based upon the perturbation analysis of the radiative heat budget of the Earth's surface alone (see, for example, G.S. Callendar[3] and F. Moller[4]). As noted in the bibliography on greenhouse warming compiled by M.D. Handel and J.S. Risbey,[5] this wasthefirst modeling study of this topic that held up to modern scrutiny. It has instigated a large number of studies on climate and greenhouse warming. The report of the Intergovernmental Panel on Climate Change[6] discusses the recent developments.

1. **Goody R M.** *Atmospheric radiation. I. Theoretical basis.* Oxford, England: Oxford University Press. 1964. 436 p. (Cited 890 times.).
2. **Manabe S & Wetherald R** T. The effect of doubling the $CO_2$ concentration on the climate of a general circulation model. *J. Atmos. Sci.* 32:3-15. 1975. (Cited 310 times.)
3. **Callendar** G S. The artificial production of carbon dioxide and its influence on climate. ***Quart. J. Roy. Meleorol. Soc.* 64:223-40. 1938.**
4. **Moller F.** On the influence of changes in the CO, concentration in air on the radiation balance of the Earth's surface and climate. *J. Geophys. Res.* 68:3877-86. 1963.
5. **Handel M D & Risbey J** S. An annotated bibliography on the greenhouse effect and climate change. *Climatic Change* 21:97-255. 1992.
6. **Houghton J T, Jenkins G J & Ephraums J J,** eds. *Climate change: the IPCC scientific assessment.* Cambridge. England: Cambridge University Press. 1990. 366 p.

Received May 16. 1993