V. Ramanathan:

Until the mid 1970s, CO\textsubscript{2} was considered to be the sole anthropogenic greenhouse gas responsible for global warming. This picture changed when in 1975 I identified the greenhouse effect of chlorofluorocarbons (CFCs), and found that, on a per molecule basis CFCs were about 10000 times more effective than CO\textsubscript{2}. This surprising finding opened the door to the discovery of the greenhouse effect of numerous other trace gases and the field of trace gases-climate-chemistry interactions. I turned to climate models for predicting the greenhouse warming and played a key role in developing the first community climate model – now the major American climate simulation research model – and used it to show that realistic treatments of the radiative effects of trace gases and cirrus clouds are necessary to accurately model the atmospheric general circulation.

Clouds, the Gordian knot of the climate problem, were my next focus. Towards this goal I helped design the Earth Radiation Budget Experiment (ERBE) along with NASA and university scientists to examine the role of clouds and water vapor greenhouse effect on climate. ERBE was launched on three satellites. Using data collected by ERBE, I demonstrated that clouds had a large net radiative cooling effect on the planet; i.e. the reflection of solar radiation to space by clouds far exceeded their greenhouse effect, thereby providing new and reliable observational constraints on the influence of clouds in climate. The next step of my ERBE research was to show that the atmospheric greenhouse effect can also be estimated quantitatively without resorting to models. ERBE greenhouse effect data were used in conjunction with surface temperature and water vapor data to demonstrate that water vapor exerted a positive feedback effect on surface warming, supporting climate model predictions. In addition, The ERBE of the 1987 El-Nino phenomenon revealed the existence of an unstable water vapor super greenhouse effect over the tropical western Pacific warm pool. This super greenhouse effect has been confirmed by numerous studies. I then postulated the Thermostat hypothesis, which postulates that thick tropical clouds regulate the ocean surface from excessive warming caused by the super greenhouse effect.

To understand the role of clouds in regulating maximum ocean surface temperatures, I conducted the Central Equatorial Pacific Experiment from the island of Fiji. This field experiment pointed to solar absorption in cloudy skies of tropical atmospheres as a potentially important factor missing in the radiation energy budget equations of climate models. This surprising development motivated Ramanathan to focus on absorbing aerosols which led to the Indian Ocean Experiment (INDOEX; http://www-indoex.ucsd.edu) and the study of brown clouds. Black carbon and other carbonaceous aerosols in polluted atmospheres are important constituents of the brownish haze, i.e., “brown clouds”.

During INDOEX (designed by Ramanathan and Crutzen; see http://www-indoex.ucsd.edu/publications/white_paper/) , Ramanathan and colleagues documented the wide spread nature of brown haze over most of the Arabian Sea, Bay of Bengal, and
India, due to long range transport of aerosols from pollution sources. The spatial extent of the brown cloud was shown to be larger than the surface area of continental USA. He, along with students and post doctoral fellows in his laboratory, made direct measurements and discovered the large impact of the haze’s absorbing black carbon in reducing the solar radiation over the Arabian Sea and northern Indian Ocean by as much as 10-15%. The haze also increased the atmospheric solar heating by 50% to 100%. Using data collected during INDOEX, Ramanathan led a global climate model study (with colleagues at the National Center for Atmospheric Research). This study suggested that the absorbing haze can lead to drying in the tropics and disrupt monsoonal rainfall patterns, thus linking human activities in the tropical regions to key aspects of regional climate and fresh water budget a fundamental issue for developing countries.

The INDOEX work culminated in a major UN-initiated, international research program named Atmospheric Brown Clouds (ABC), led by Ramanathan and Crutzen, to study the impact of such brown clouds worldwide, with an immediate focus on Asia. Participating countries include India, China, Japan, Korea, Maldives and many countries in SE Asia and S. Asia. The major thrust of ABC is to understand the impact of air pollution on monsoon, agriculture, and public health.

I am now designing an experiment using miniaturized instruments and unmanned aircraft to understand how the planet regulates its albedo, i.e, percent reflection of solar radiation by the planet. It is strongly influences by both natural (e.g, clouds, ice sheets) and manmade processes (e.g, aerosols, land surface modification). The albedo now is about 30% and just a few percent change in the albedo is sufficient to trigger a major climate change.

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**Principal Research Findings:**

The numbers within parentheses refer to publications cited at the end.

A. *Trace Gases and Global Warming*

1975: Identified the strong greenhouse effect of Chlorofluorocarbons (CFCs); showed that adding one molecule of CFC11 or 12 has a stronger greenhouse effect than adding 10000 molecules of CO$_2$. (1)

1976: Identified the global cooling effect of stratospheric ozone reduction. (2)

1979: Identified that anthropogenic increase in tropospheric ozone can have strong greenhouse effect. (3)

1980. Predicted that the global warming signal should rise above natural fluctuations by 2000. (4)
1985. Showed that non-CO$_2$ trace gases, including, CFCs, Methane and Nitrous oxide, are just as important as CO$_2$ in global warming. (5) The Trace gas work culminated in a WMO sponsored assessment report (chaired by me) on Trace Gases Effect on Climate which established the fundamental importance of non-CO2 trace gases to the Global warming problem. (6)

B. **Clouds, Water vapor, Climate Forcing and Climate Feedback**

1981. provided a conceptual picture and quantitative explanation of how water vapor greenhouse effect amplifies global warming (in climate models). (7)

1983: Developed Radiation and Cloud Models for the now well known NCAR community Climate model, one of the leading American Climate Models. (8)

1989: Elucidated the critical role of clouds in the climate system with global satellite observations from the Earth Radiation Budget Experiment (ERBE). Showed that clouds on the whole reflect more solar radiation energy from the earth-atmosphere system than their contribution to greenhouse warming. (9)

1989. Showed that satellite radiation Infrared radiation budget data from ERBE can be used to directly infer the atmospheric greenhouse effect and study the water vapor feedback effect. (10)

1991. Used ERBE and other data to propose that tropical high-thick clouds act as a thermostat for regulating surface temperatures of the warmest oceans in the planet. (11)

1993: Proposed and Conducted the Central Equatorial Pacific Experiment with aircraft, ships and satellites for testing the Thermostat hypothesis. The data revealed that evaporation was not the limiting factor for the regulation. (12) Another major new finding is that clouds may be absorbing significantly more solar radiation than predicted by theory and models. (13)

C. **Aerosol, the Indian Ocean Experiment(INDOEX) and Atmospheric Brown Clouds(ABC)**

**1995 to 2001: INDOEX**

As co-chief scientist (with P. J. Crutzen) of the Indian Ocean Experiment (INDOEX), discovered (in collaboration with 40 principal investigators) the S. Asian brown cloud and its significant environmental impacts. (14,15) We (16) first demonstrated the widespread nature of this haze due to long range transport. The haze was shown (16,14) to cover most of the Arabian Sea, Bay of Bengal, and the Indian subcontinent. Also provided the first observational demonstration that the highly absorbing S. Asian haze significantly reduces sunlight reaching the Earth's surface over a very broad region. (17)
The INDOEX results linked human activities in this heavily populated area to key aspects of global and local climate. (18)

2001 to 2003: ABC:
Proposed the Atmospheric Brown Clouds concept to study how local pollution around the globe impacts regional and global climate with the initial focus on the Asian Brown Clouds. (19,20)

Cited Publications:


4) Madden, R. A. and V. Ramanathan, 1980: Detecting Climate Change Due to Increasing CO₂ in the


