Introduction par Francoise Combes

Veerabhadran Ramanathan completed all his undergraduate studies in India in Bangalore, at Annamalai University and at the Indian Institute of Science. After University, he worked a few years in a refrigeration company, and this will have some impact, as we will see, on the future. He had to check whether the compressor components in the sealed refrigeration units were fitted correctly, so that the refrigerant, the CFC or chlorofluorocarbon, did not leak from the sealed units. He worked also in research at the Indian Institute of Science on an interferometer to measure fluid temperature variations, but had not enough means to progress. When he was 26 years old, he travelled to the United States to complete a thesis at the State University of New York, Stony Brook, under the supervision of Robert Cess. His intention was to continue in engineering, on interferometers. However his thesis evolved into a work on the atmosphere of the planet Venus, and its greenhouse effect. This was a turning point in his career, previously focused on engineering. After his PhD, he worked for NASA, and studied the impact of stratospheric ozone depletion by CFC on the Earth's climate. **His attention was focused again on CFC, and he then obtained his first significant results, in 1975, discovering the contribution of CFC gases to the greenhouse effect, i.e. 10 000 times higher than CO_2**, a contribution that was largely ignored at that time. These results, along with a major article in early1980s, fostered awareness of the very important climatic role that gases other than CO_2 could play. NASA and the United Nations invited an international group of scientists in 1983 to review the science behind non-CO_2 greenhouse gases, Professor Ramanathan was asked to chair the committee. Under his leadership, the group released a report which concluded that as of the 1980s, greenhouse gases other than carbon dioxide were contributing **nearly as much as carbon dioxide was to global warming**. Later, after 2014, the group contributed to the establishment of the Climate and Clean Air Coalition, an international group headquartered in Paris and whose work is aligned with the objectives of the United Nations Environment Programme (UNEP).

In the 1980s, Professor Ramanathan and other scientists had predicted the global warming effect, but it was lower than predicted. They suspected that the warming has been partially offset by a cooling effect caused by certain particles in the air, that is air pollution also from fossil fuels. In 1995, with Dr. Paul Crutzen (Nobel Prize laureate in Chemistry) and Dr. Mitra from India, Professor Ramanathan devised a large-scale international experiment, **the Indian Ocean Experiment (INDOEX)**, to observe the cooling effect. With more than 200 scientists from six countries, this major experiment took place in 1998-1999 and involved the satellite data collection and observations by six aircrafts and two ships.

The experiment observed a three-kilometer-thick cloud of air pollution, the so-called atmospheric brown clouds (ABCs), covering much of the Arabian Sea, the Bay of Bengal, and the Indian subcontinent, and found that it was blocking 10 to 15 percent of sunlight. The air pollution blocking the sunlight was largely made of tiny particles called aerosols. More exactly, they established that there are some aerosols reflecting back the sun radiation, with a cooling effect, and some, **like black carbon particles, like soot**, which absorb sunlight and warm the planet. Even the first cooling aerosols are very toxic for humans and have to be eliminated. Trace greenhouse gases are fortunately more short-lived than CO_2 (100-1000yrs), only 10yrs, or 10days like black carbon. Professor Ramanathan worked hard to create the Climate and Clean Air Coalition (CCAC) to eliminate all the short-lived climate pollutants, with great success at several COP meetings.

This work reflects one of Veerabhadran Ramanathan's characteristics: contributions initially focused on atmospheric physics, which have gradually expanded to cover a very broad spectrum, ranging from radiative measurements to climate models and environmental issues, including fieldwork, many of which have been conducted in the maritime domain. These studies benefited from the massive influx of space data, particularly those provided by NASA's ERBE (Earth Radiative Budget Experiment, 1984-2005) missions, for which he was the principal investigator. However, they all shared the ability to analyze these results to offer in-depth and innovative insights that had a significant impact, particularly on the sign of the cloud radiative forcing (article in Science, 1989, that Sandrine Bony will discuss later). It is impossible to cite them all, and only a few examples are included here.

Subsequently, the work of Professor Ramanathan has often focused on slightly different issues. In 1993, he was responsible for a large-scale project, **the Central Equatorial Pacific Experiment (CEPEX).** Its major objective was to determine the climate regulation processes in the intertropical zone. Ocean temperatures in these regions remain lower than those expected at these latitudes. This is particularly true in the vast maritime domain extending between 30°S and 30°N, where these temperatures remain confined within a very narrow range, most often between 25°C and below 30°C. This situation has long been well-known, but understanding the feedback loops that cause it is essential to anticipate possible climate changes in a warming context. The studies, and especially the measurements conducted within the CEPEX framework, highlighted the role of water vapor and clouds. They served as a precursor to the Indian Ocean Experiment (INDOEX) campaign, co-directed from 1996 to 2002 by Ramanathan and Nobel Laureate Paul Crutzen—an international campaign in which French teams from the Laboratoire de Météorologie Dynamique participated by contributing to the satellite component.

In all the studies resulting from these projects, a significant place was devoted **to aerosols and measuring the cooling they cause, both on the ground and at the top of the atmosphere**. They showed that aerosols produce brighter clouds that are less efficient at releasing precipitation. These in turn lead to large reductions in the amount of solar irradiance reaching Earth's surface, a corresponding increase in solar heating of the atmosphere, suppression of rainfall, and less efficient removal of pollutants. This connects directly to availability and quality of fresh water, a major environmental issue of the 21st century.

Ramanathan and his teams demonstrated the existence of a large black cloud **(the Big Brown Cloud or BBC)** covering a significant portion of Asia. This cloud, primarily of anthropogenic origin, is toxic and plays a major role in health in an overpopulated continent. Professor Ramanathan led the analysis of this cloud for 10 years, from 2002 to 2012.

To these few examples, we must add all the studies concerning the evolution of the climate system and its monitoring, most often using satellite methods, as well as the leadership work that has mad**e Ramanathan a prominent figure in the scientific landscape**. The scope and impact of this work should not obscure another dimension of Ramanathan's personality, one that goes beyond science and is certainly inspired by the strong ties he has maintained with his home country. The **Surya Project,** for example, which he has been involved in since 2007, aims to reduce aerosol pollution in India by changing cooking habits. It is a remarkable example of the continuity between scientific diagnosis, such as that of the BBC black cloud, and the implementation of immediate solutions.

Added to this is a keen interest and a much broader involvement in everything related to our environment and the societal consequences of climate change and, more generally, those of human activities on our environment, through the promotion of the concept of "planetary boundaries," to whose definition he contributed. The impact of climate change on the poorest three billion people is a message he continually documents through science and conveys through his publications to international bodies.

In 2004, Professor Ramanathan became a **member of the Pontifical Academy of Sciences** in Rome after being nominated by Dr. Paul Crutzen, who had participated in the Indian Ocean Experiment. In this Academy of Sciences, he was one of the main scientific inspirations for the Encyclical Laudato Si' (2015), a text recognizing the value of the scientific message, the reality of climate change, and calling for global action. He participated in a wide range of conferences as a member of the Academy. In the Vatican, there is another academy called the Academy of Social Sciences. Professor Ramanathan suggested that each of the academies organize a conference on the theme of sustainability, on Sustainable Nature, Sustainable Humanity.

His commitment to science-based climate change education has led since 2016 to the creation of the **“Bending the Curve”** movement, which inspires and develops this education for all students on the 12 University of California campuses, and is gradually expanding to many universities across the country and to state curricula (Alliance for Climate Education).

To summarize his career, Professor Ramanathan conducted his entire scientific career in the United States: he worked from 1976 at the National Center for Atmospheric Research (NCAR, Boulder), then as a professor at the University of Chicago, and finally since 1990 at the Scripps Institution of Oceanography, University of California, San Diego, where he is both "Distinguished Professor of Climate and Atmospheric Sciences" and holder of the Victor Alderson Chair for Applied Ocean Sciences. He is a member of the National Academy of Sciences since 2002, the Royal Swedish Academy since 2008. He received the Carl-Gustav Rossby Medal in 2002, the BBVA Frontiers of Knowledge Award in 2015, the Tang Prize for Sustainable Development in 2018, and the Blue Planet Prize in 2021.

In conclusion: since the 1970s, Professor Ramanathan has played an outstanding leadership role on issues related to the greenhouse effect, climate dynamics, air pollution, and the role of clouds and aerosols, resulting in the high visibility of his published work. His profoundly humanist inspiration has had a major impact in India, his native country, in the United States, and in international forums. **The Academy is very happy to give him the highest and more prestigious award, the Grand Medal, for his exceptional career and well-deserved recognition**.