Nobel Prize for climate science in 2021

The Nobel Prize for Physics in 2021 was shared by three scientists. Two of them, Prof. Syukuro Manabe and Prof. Klaus Hasselmann, were awarded the Prize 'for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming'. The impact of increasing carbon dioxide on global climate was first studied by Joseph Fourier and Svante Arrhenius in the nineteenth century. In 1896, Arrhenius estimated that the global mean temperature can increase by 5–6°C, if carbon dioxide increased by 280 parts per million (ppm). His calculation included the impact of increases in both carbon dioxide and water vapour. The accuracy of his estimate was limited by the lack of precise data on the absorption bands of carbon dioxide and water vapour. The lack of accurate data on infrared absorption by minor gases continued for a long time because the concern about global warming faded after the global mean temperature decreased from 1940 for about 20 years.

Syukuro Manabe was born in Japan in 1931 and migrated to the United States after completing his Doctor of Science degree from the University of Tokyo. He joined the General Circulation Research Laboratory (later called Geophysical Fluid Dynamics Laboratory) in the United States Weather Bureau in 1959. The Director of the Laboratory, Joe Smagorinsky encouraged Manabe to examine the potential of computer models to study the evolution of the Earth's climate. In the 1950s, Von Neumann had initiated the use of computers for weather prediction in the US. Manabe developed the first one-dimensional radiative transfer model to understand the impact of increasing carbon dioxide on the Earth's climate. Many scientists had assumed that global warming may be due to an increase in incoming solar radiation. Manabe showed that an increase in solar radiation will lead to the warming of both the troposphere and stratosphere, while the impact of increase in carbon dioxide will lead to warming of the troposphere and cooling of the stratosphere. This is a unique fingerprint of the impact of increase in greenhouse gases such as carbon dioxide and water vapour. These results were in agreement with observations and hence increased credibility of theories related to global warming. Manabe also showed that global warming leads to increase in water vapour and thereby enhances the effect of the initial increase in carbon dioxide levels. This was achieved through a three-dimensional numerical model of both the atmosphere and the oceans. These models solved the equations governing the conservation of mass, momentum, energy and species. These models had to be integrated for hundreds of years to obtain an equilibrium response to the doubling of carbon dioxide. Manabe used these numerical models to simulate the last ice age that occurred around 20,000 years ago. He was able to demonstrate the impact of ice and snow on the amount of solar radiation reflected by the Earth to space. The models that we use today are more sophisticated because the computing speed available now is a billion times higher than what Manabe had in the 1960s. He established the foundation for the modern climate models that are used today to decide how much the world must decrease carbon dioxide emissions to limit global warming. Manabe has highlighted the need to understand how complex models work. According to him 'The prediction of climate change without accompanying understanding of it is no better than prediction of fortune teller'. This is an important advice in an era where big data, artificial intelligence and machine learning are used for prediction of complex processes.

Klaus Hasselmann was born in Germany 1931, and grew up in the United Kingdom, returning to Germany after the Second World War to train in physics and mathematics. For his Ph.D., he worked on fluid mechanics, studying shock waves and his early work applied methods of theoretical physics to study interactions between waves. He worked on ocean–atmosphere interactions through surface waves, which led him to consider long-term variability in the ocean. Hasselmann shared the Nobel Prize for work done in two areas. First is the study of stochastic climate models, starting with his 1976 paper, which shows how climate can be predicted even though the weather is chaotic. This paper introduces a model for slow climate variability using the distinction between fast weather and slow climate, and models climate as depending on cumulitive effects of weather. Hasselmann treated the weather component as a random influence on climate owing to its rapid variation, giving rise to stochastic differential equations. Such equations originated in modelling diffusion processes such as Brownian motion, and Hasselmann was able to employ the tools that had been developed to study such processes. Most significantly, Hasselmann was able to quantify how an input weather spectrum that is concentrated in high frequencies can give rise to a climate spectrum that is concentrated in low frequencies. The second contribution is optimal fingerprinting. Just as humans have unique fingerprints, carbon dioxide has its unique signature on the observational record, and Hasselmann developed an approach to optimally identify these fingerprints. By the late 1970s, the carbon dioxide effect on climate had become noticeable in observations, and through the 1980s the scientific community had become interested in searching for fingerprints of the carbon dioxide effect on climate. Potential fingerprints were identified through the climate modelling began by Manabe, but there was no objective method to identify a fingerprint. In a series of three papers, Hasselmann developed an objective approach to fingerprinting. An article written by him in 1979 laid the foundation, noting that the signal that can most readily be found might not correspond directly to the external forcing, because it will also depend on where the natural variability has small variance. The optimal fingerprint would be some combination of strong signal and low natural variability. He developed this insight further in a paper in 1993, which presented a procedure for determining the optimal signal-to-noise direction using climate models. Hasselman's work has provided the foundation for subsequent detection and attribution studies, which have demonstrated anthropogenic fingerprints in the observational records with a high degree of confidence.

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