FALL 2021

GFDL BULLETIN

Research Highlights from the Geophysical Fluid Dynamics Laboratory Community

Advancing the Modeling, Understanding, and Prediction of Weather and Climate

*This issue celebrates the pioneering scientific accomplishments of **Dr. Syukuro (Suki) Manabe, a co-recipient of the 2021 Nobel Prize in Physics**. Suki was with NOAA/GFDL and its predecessor agency from 1958 until retirement in 1997. We highlight four of his groundbreaking efforts in climate modeling and science, which opened new frontiers in the physics of climate and have constituted important scientific bases for the modeling and understanding of climate change. These represent a sample of his visionary thinking, meticulousness, and fundamental advances in climate science achieved through mathematical modeling. Suki's results have proven remarkably prescient. His indefatigable spirit of exploration and his insights have inspired countless students, postdocs, and scholars in climate science.* — V. Ramaswamy, Director, NOAA/GFDL

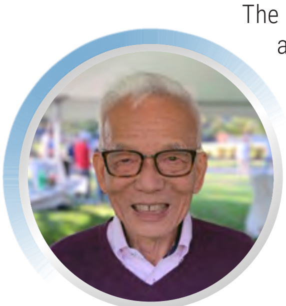
CLIMATE SCIENCE & UNDERSTANDING: MANABE SHARES NOBEL PRIZE IN PHYSICS

Published in 1967, Syukuro Manabe's landmark paper became the foundation for modeling Earth's climate.

In the winter of 1966, the Journal of Atmospheric Sciences received an unassuming and rather straightforward research paper for consideration. Published in 1967, it ultimately became the foundation of Earth climate modeling through physics, and in the process predicted global warming.

Led by scientists Syukuro "Suki" Manabe and Richard T. Wetherald at GFDL, the work remains the most important climate science research ever published, and leading scientists continue to agree.

The paper, "Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity," earned Manabe a shared Nobel Prize for Physics in 2021.



Manabe began his journey after choosing to focus on meteorology throughout the 1950s as a student at the University of Tokyo. He downplayed the choice to forgo his parents' hopes he would pursue medicine. "I had a horrible memory and I was clumsy with my hands," Manabe said. "I thought that my only good trait was to gaze at the sky and get lost in my thoughts."

Profoundly influenced by the work of computer pioneer John von Neumann, who was tackling weather forecasting, Manabe left his home country after earning his Ph.D. in 1959. Moving to Washington, D.C., he entered the 1960s on a new path at the General Circulation Research Section of the U.S. Weather Bureau, now GFDL on the Forrestal Campus of Princeton University.

Isaac Held, a retired senior research scientist of GFDL, was a graduate student under Manabe. He reflects back on how the seminal paper provided the first "robust, physically-based estimate" of how much the Earth will warm given the increase of CO_2 in the atmosphere. "I believe that people realized its significance immediately," he said, "but this significance grew as the level of interest in climate change increased over time."

Manabe's work earned the Nobel Prize, he said, because of its overall effect on other areas of climate research. While the paper outlines climate sensitivity, it is also the foundation for understanding sea level rise, and changes in precipitation patterns, including droughts and floods.

"All increase in severity as the level of the overall warming increases," Held said. "So, knowledge of the overall level of warming is the key piece of information that tells us how severe the climate change problem is." He said scientists continued to reinforce the results found within the Manabe-Wetherald model in the decades that followed, "based on Suki's clear vision as to what the important factors are that control the climate sensitivity, and what factors are secondary, or of little importance." This clarity and focus of vision are threads connecting Manabe's research throughout his career. It all begins with understanding the problem.

In an interview with Adam Smith, chief scientific officer of Nobel Prize Outreach, Manabe discussed how climate science and meteorology started more as art forms until computers and mathematics advanced their understanding into solidly scientific realms.

With droughts and flooding increasing all over the world, Manabe sought to understand why. He tasked himself with continually tweaking the climate model he created, like a chemistry experiment.

GFDL Senior Scientist Tom Delworth worked many years with Manabe, watching him continually "boil down climate science to its very essence. At every seminar I went to at GFDL, Suki was there in the front row, on the right side. He was amazingly engaged with every single speaker who came through," Delworth said. He said hard work and constant curiosity fueled this mission.

THE EFFECTS OF DOUBLING THE CO_2 CONCENTRATION ON THE CLIMATE OF A GENERAL CIRCULATION MODEL

Journal of the Atmospheric Sciences, 1975 *Syukuro Manabe and Richard T. Wetherald*

DOI: 10.1175/1520-0469(1975)032<0003:TEODTC>2.0.CO;2

The landmark Manabe and Wetherald (1967) paper firmly established the scientific basis for estimating the response of global mean climate to increasing carbon dioxide. The next logical step required moving beyond the global mean picture to understand how climate change would impact different regions of the globe. This required the development and use of a global climate model that represented not just the global mean climate, but its variations across the planet.

Kirk Bryan, Suki Manabe, and Joseph Smagorinsky at Geophysical Fluid Dynamics Laboratory in the 1970s

The Manabe and Wetherald (1975) paper was a milestone, providing crucial early scientific findings on multiple aspects of climate change around the planet using their newly developed global climate model. Several foundational aspects of climate system responses to increasing carbon dioxide – that are widely accepted today – were beautifully illustrated in this early work.

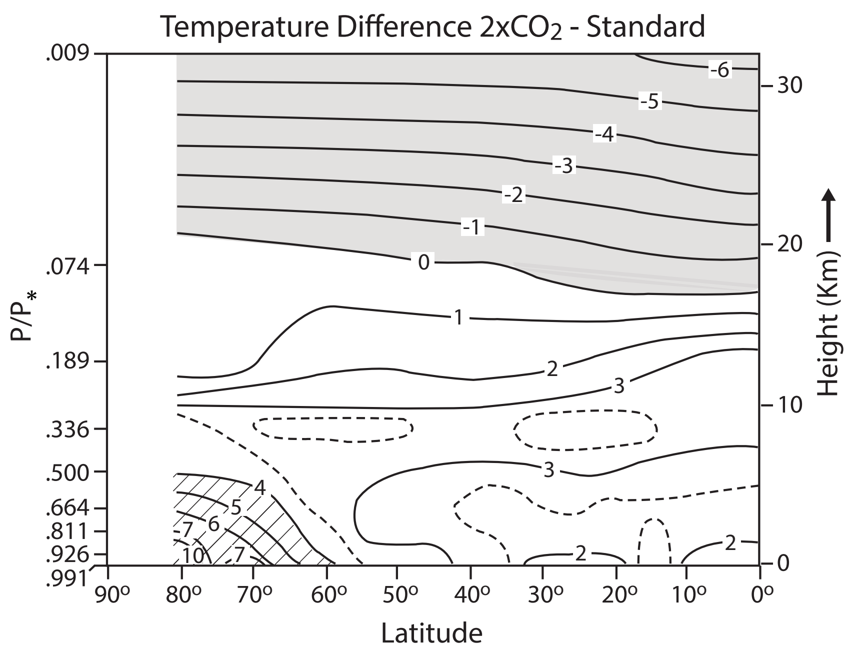
First, total warming was somewhat larger than expected compared to their earlier work, due to feedbacks with snow cover. A warming climate reduces snow cover, making the planet darker and thereby absorbing more solar energy, an early demonstration of albedo feedback – crucial for rapid Arctic warming and sea ice decline. Second, a pronounced cooling of the stratosphere was simulated, and is now observed. Finally, the intensity of the global hydrologic cycle (including rainfall) was increased, an early harbinger of extreme changes that are becoming apparent in our modern record.

Atmospheric Temperature Change in Response to Doubling of CO_2

This figure shows the zonal mean atmospheric temperature change in response to doubling of CO_2. The y-axis can be interpreted as height in the atmosphere (increasing upward), and the x-axis is latitude.

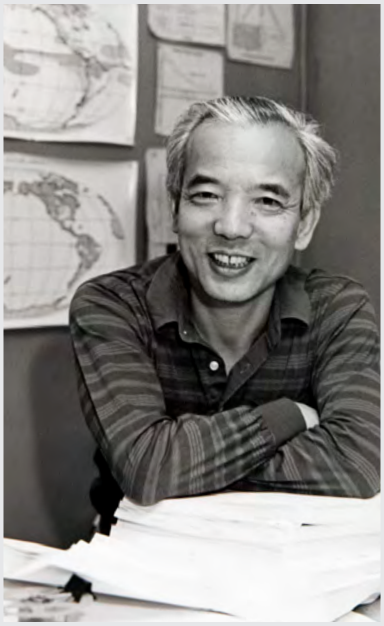
Two features to note:

(a) temperature in the stratosphere (upper atmosphere above about 12-20 km) decreases, and (b) the largest temperature increases occur near the surface over the Arctic. This latter feature is an early demonstration of "Arctic Amplification", where warming over the Arctic is much larger than over the global mean. Arctic Amplification is seen in modern observations and contributes to the observed rapid decline of Arctic sea ice in recent decades.



"Suki's groundbreaking efforts opened new frontiers in the physics of climate, and have constituted important scientific bases for the modeling and understanding of climate change and its sensitivity." — *V. Ramaswamy, Director, NOAA/GFDL*

Syukuro Manabe at GFDL in the 1990s



CAN EXISTING CLIMATE MODELS BE USED TO STUDY ANTHROPOGENIC CHANGES IN TROPICAL CYCLONE CLIMATE?

Geophysical Research Letters, 1990 *Anthony J. Broccoli and Syukuro Manabe*

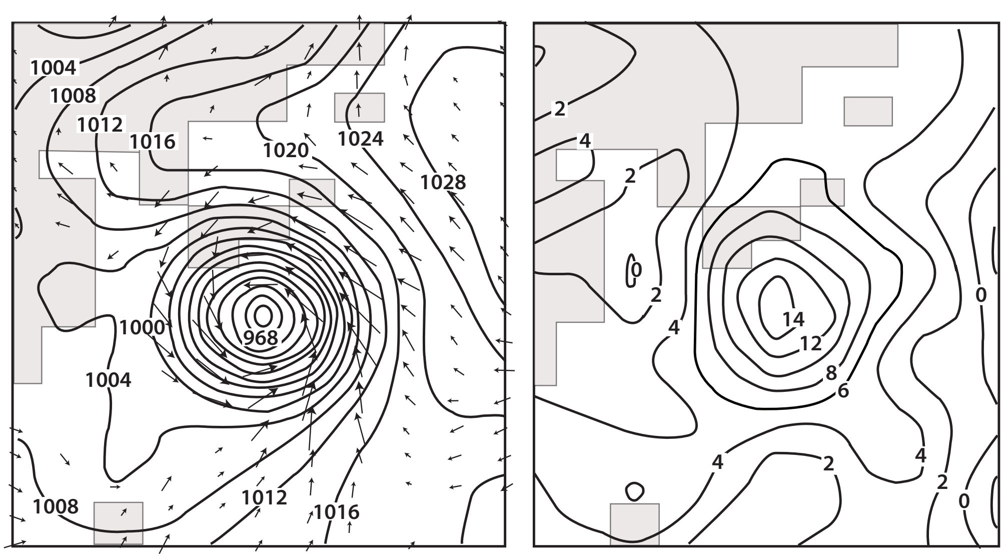
DOI: 10.1029/GL017i011p01917

Following his pioneering modeling studies of the influence of CO_2 doubling on global climate, Manabe turned to the problem of how global warming would influence other aspects of climate and weather, including tropical storms. He and collaborators Holloway and Stone had written a paper in 1970 describing the appearance of tropical storm-like features in a 341-day simulation of a very coarse-resolution global atmospheric model.

In 1990, Broccoli and Manabe published a pioneering study analyzing such tropical storm-like features in a series of 30-year simulations of a coarse-resolution global climate model. Their model simulated large cyclonic storm systems in the tropics which had a distinct warm-core structure (see figure) – a key characteristic of observed tropical storms. Importantly, they found that the frequency of such tropical storm-like features in their most realistic model version decreased slightly in a doubled-CO_2 warming scenario.

Since tropical storms form over relatively warm ocean surfaces, there had been wide speculation that their occurrence would increase in a warming climate. Broccoli and Manabe's 1990 study was the first to show clear evidence from climate model simulations that this overly simplistic view of tropical storms and climate warming was not likely to be correct. Later modeling studies have generally supported their early findings.

Warm Core Structures Seen in Model Simulations of Cyclonic Systems



Maps of (left panel) sea level pressure (mb) and surface wind vectors and (right panel) upper tropospheric temperature anomalies (ºC) for a sample storm from a GFDL climate model simulation. These depict a near-surface circulation and upper tropospheric warm-core structure that is characteristic of observed tropical storms.

See GFDL's full bibliography at: https://www.gfdl.noaa.gov/bibliography
The bibliography contains professional papers by GFDL scientists and collaborators from 1965 to present day.

LOW-FREQUENCY VARIABILITY OF SURFACE AIR TEMPERATURE IN A 1000-YEAR INTEGRATION OF A COUPLED ATMOSPHERE–OCEAN–LAND SURFACE MODEL

Journal of Climate, 1996 *Syukuro Manabe and Ronald J. Stouffer*

DOI: 10.1175/1520-0442(1996)009<0376:LFVOSA>2.0.CO;2

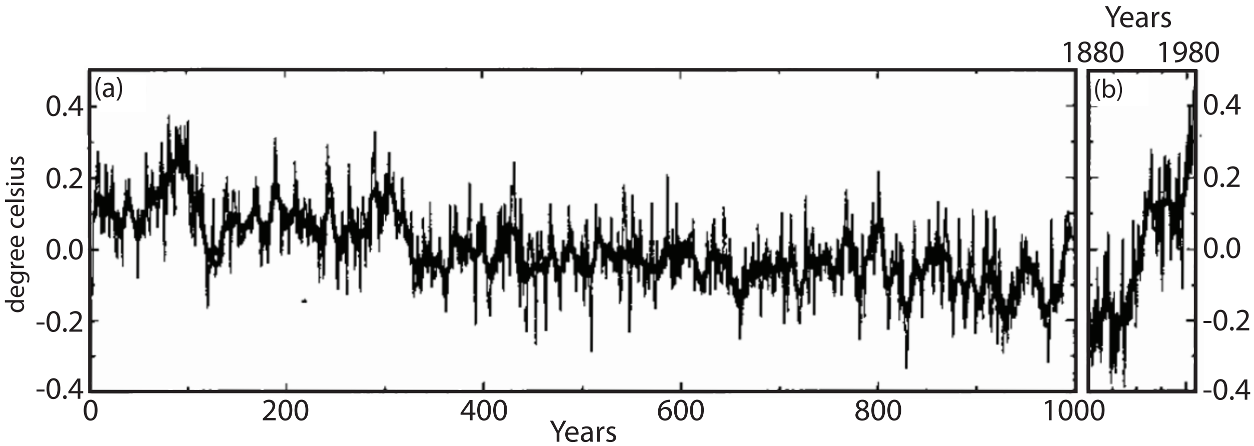
The interactions between various components of the climate system – atmosphere, land, ocean, sea ice, etc. – create natural variability in the climate system. This variability can hinder the attribution of change in climate, especially when the observed record is short. In such cases, it can be difficult to separate natural variability from a response to changes in radiative forcing, such as increases in greenhouse gases.

Manabe was one of the first to study variability in a systematic way. For this study, he used 1,000 model years of simulations from a coupled ocean-atmosphere model with only natural variability. He compared surface air temperature interannual variability from the model to observations.

Manabe found that the model reproduced the observed global mean temperature quite well on time scales of a few years or less, although the simulated variability was too small in the tropical Pacific (ENSO region) and the comparison was limited by the relatively short observational record (~130 years at that time). On longer time scales (centennial), the increase in global temperatures seen in the observational record — not captured in the model with only natural variability — could be attributed to changes in radiative forcing, i.e., greenhouse gases.

This was an early example of a detection and attribution study. The reasonable simulation of surface air temperature variability by the model encouraged the use of model estimates of variability on long time scales, as a surrogate for the observed where records were lacking. Many other climate scientists have since used this method.

Surface Air Temperature: Model Simulation Compared to Observations



Time series of globally averaged, annual mean surface air temperature anomaly from the long-term mean: (a) 1,000-yr time series from the coupled model; (b) 110-yr (1881-1990) time series of observed globally averaged surface air temperature. (10-year running mean curves are added for both).

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Kirk Bryan (left) and Suki Manabe receiving the U.S. Department of Commerce Gold Medal Award in 1970.

GFDL Scientist, Ronald Stouffer (left) pictured here with Suki Manabe in the 1990s.