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Looking Back at Research Projecting Global Warming and Climate Variance in Japan

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- **Global warming, its science and public awareness (up to the 1970s)**
- **Public awareness of global environmental issues and the development of climate change research (1980s onward)**
- **What will happen to convectional rains, a typical Japanese climate? (from recent research)**

Introduction

I began research in meteorology as a postgraduate student after graduating from the university in 1957. I would like to talk about my own experience, looking back over the period since then. How did research develop on global warming as a scientific problem, that is to say the issue of a rising global temperature caused by increased CO_2 levels resulting from human activity? Then, as climate change came to be seen by the public as a troubling phenomenon that could actually occur, I will look at what we as climate researchers have been doing about it as a societal challenge.

● Global warming, its science and public awareness (to the 1970s)

An episode from 1954/55

I started to research weather and climate as a Master's student in 1957, but first let me share a brief episode from before that (Slide 4). In 1954 we had a very cool summer. This chart shows the average temperatures for the three summer months in Japan - June, July and August – from when records began around 1900 to this summer. Of these, 1954 is recorded as an unusually cold summer. Climate scientists seriously considered the first H-bomb test carried out at Bikini Atoll that spring as the cause. The thinking was that the cool temperatures were caused by particles being swept high in the atmosphere and blocking out the sun's rays. Now a theory is established that after a major volcanic eruption, aerosols from the eruption rise into the stratosphere and cause global cooling – it is even used to validate models. Back in 1954, the correlation of volcanic eruptions and global cooling was being debated and even found its way into school textbooks. Amid the debate, a senior geophysics student made a display on the subject for the University of Tokyo May Festival in 1955. That year, summer was very hot. Thanks to a dry rainy season the heat came early and the average temperatures were also pretty high. The next thing was someone made a comment in the newspaper about it, and in my dim recollection, they wrote that the climate was warming due to an increase in CO_2 and that as a result, Japan would lose its rainy season. I knew that an increase in CO_2 would lead to warming, but I had never thought it would lead to actual problems in real life and in truth I did not really think about the comment, but for some reason I remember it clearly.

From numerical weather forecasting research to the era of putting it into practice, and the International Geophysical Year (IGY)

Entering graduate school, I began meteorological research under Professor Shigekata Shono. At that time, the University of Tokyo's meteorological research laboratory focused mostly on dynamic meteorology, looking at the movement of air and fluid dynamics as applied to the Earth's atmosphere. This was toward the end of the golden age of the basic and preparatory research focusing on numerical weather forecasting (Slide 5). "Numerical weather forecasting" is the way weather is forecast by the Japan Meteorological Agency (JMA) today. Based on daily weather observation data, changes in air pressure, temperature and wind are fed into a computer which uses mathematical modeling based on physical principles to come up with a forecast of future weather. A coordinate system divides the planet into a grid of 100km square. The minute-by-minute changes in weather conditions at each point – in air pressure, temperature or other aspects – are tracked by the computer. Due to the need for an enormous number of calculations in a short time, a large computer is required. John Von Neumann, who had built a computer at the Institute for Advanced Study in Princeton and proposed weather forecasting as an application for it, published a thesis of how to operationalize this idea together with a meteorologist in 1950 (Slide 6). In Japan, despite the absence of any computer, researchers read the US thesis and continued their work while urging the leaders of the JMA to introduce such a computer. Their campaign was successful and in 1957 an advanced device, the IBM704 – the supercomputer of its age – was delivered, and it went into service in 1959. Collaborating with researchers from JMA and the Meteorological Research Institute at the University of Tokyo meteorological research laboratory, a preparatory team was established and research got underway on the future direction for numerical weather forecasting. I spent 18 months as a postgrad student in the same laboratory as the first Blue Planet Prize laureate, Dr. Syukuro Manabe. This was the starting point of global warming prediction research, as a progression from "calculating tomorrow's weather according to mathematical equations based on physical principles" to "calculating the climate according to a mathematical model of physical principles" and finally to "calculating the climate under conditions of higher CO_2 concentration." The reason that Dr. Manabe became a consistent world leader in the field was because he began research in this direction very early, around ten years after the establishment of numerical weather forecasting.

Coming back to my earlier comments, 1957-58 was the International Geophysical Year (IGY), a very important time for geophysics (Slide 7). In Japan, a research expedition to Antarctica was dispatched for the first time in order to make comprehensive observations under the leadership of our professor, Dr. Takeshi Nagata, a practice that continues today. Looking globally, all theories aside, Sputnik, the world's first satellite, was launched by the Soviet Union, ushering in the space age.

Then came an epoch-making event in terms of global warming. Dr. Roger Revelle, working together with his student Dr. Charles Keeling (Blue Planet Prize laureate) at the Scripps Institution of Oceanography, began continuous recordings of atmospheric CO_2 concentrations on Mauna Loa, Hawaii. The curved line that shows increasing carbon dioxide density ever since is sometimes called the "Keeling curve" and has become a totem of global warming..

Basis of the science of warming was formed in the 1960s

In terms of the science of global warming in the 1960s (Slide 8), Dr. Keeling continued his monitoring in Hawaii, and it was clearly shown that with the annual cycle change due to plant photosynthesis, carbon levels were gradually increasing overall. Meanwhile, Bert Bolin (Blue Planet Prize laureate), who was later behind the establishment of the IPCC, observed carbon dioxide concentrations across the globe, showing changes over space and time in terms of latitude and altitude. This was the basis for confirming that the Northern Hemisphere was the source of most CO_2 from human activity, and later the platform for breakthroughs in understanding its circulation in the atmosphere and the absorption by oceans and forests. It also established the basis for the advance of carbon cycle modelling.

Next, while climate change as a result of increasing CO_2 has been debated since the 19th century, the cumulative research of Dr. Manabe created the framework for the scientific knowledge that we have today. First of all, it explained with remarkable clarity the temperature structure through the radiative-convective equilibrium, and then, within this theoretical framework, derived the temperature level with higher CO_2 levels in the atmosphere. Renowned scientists have argued that increased CO_2 leads to higher surface temperatures since the 19th century, but the correct theoretical framework of Dr. Manabe was the basis of the first decisive calculation using valid experimental data.

Dr. Manabe further expanded the principles of numerical weather forecasting and pioneered in the field of calculating global climate based on the laws of physics. In this respect, his research was at the global cutting edge, and in 1975 he published the research on global climate calculations under higher CO_2 levels based on simplified terrain mapping. The elaborate calculations we perform today are in essence the same but in greater detail – for example, our terrain map is closer to real life, and more atmospheric and oceanic processes are integrated into the model. Allow me to present the research of Dr. Manabe on basic warming theory in simple terms.

(Slide 9) This chart shows the distribution of temperature according to the altitude. Why does it look like this? Answering this question is a classic problem for meteorologists. The “greenhouse effect” concept emerged out through explaining why the average surface temperature is 15°C. In order to correctly quantify the greenhouse effect, Dr. Manabe made meticulous numerical calculations of the infrared spectrum of greenhouse gases such as H2O and CO_2 using the computer. As previous greenhouse effect argument used a simplified equation, it was meaningless to compare theory and the actual results. In Manabe’s theory, convection effects that were caused by further atmospheric instability were well correlated empirically. The results obtained are shown in (Slide 10). The temperature distribution results by theoretical calculations and by observation of average atmospheric temperature are shown, and they are undistinguishable. Thus, it became the first decisive theory for the basic meteorological issue. Due to the fact that it models average atmospheric temperature distribution based on the laws of physics, the same theory can be used to calculate what the distribution would be if the atmosphere were free of CO_2 or ozone, for example. (Slide 11) shows the roles played by H2O, CO_2 and ozone. Comparing a scenario where both H2O and CO_2 are present with a scenario with H2O alone shows us the role of CO_2. Eliminating all CO_2 would result in temperatures 10°C lower than today.

Ththesis paper was presented in 1964. With this theoretical framework, it should be easy to calculate temperatures for scenarios where the CO_2 levels differ from the present. But we must note that when temperatures rise, it increases the amount of water vapour in the atmosphere, the greenhouse effect of which further boosts temperatures. The study considering the idea was published in 1967. (Slide 12) shows the result. As seen in the table, a doubling of the CO_2 level raises temperatures on the surface by 2.4°C. This result assumes no change in relative humidity. If there were no change to the absolute value of the water vapour volume, the temperature rise is no more than 1.4°C. But the water vapour adds momentum to the warming, accelerating it 1.8-fold. As such, results will differ depending on how you treat effects accompanying a rise in temperature. While Dr. Manabe's theory deals with the planetary atmosphere averages, current models include many more of these feedback mechanisms. Current models include a lot more additional effects -- dealing with more feedback mechanisms resulting in having widely varying results. At any rate, the theory devised by Dr. Manabe in 1967 was the starting point for where we are today, and its validity remains unchallenged.

1960s and 1970s – concern about global cooling and unusual weather. Next objective is climate change prediction

Where did the research go next? When Dr. Manabe's theory emerged, it was seen as an issue from an intellectual perspective in terms of addressing the basic questions of meteorology but mostly was not considered in relation to the actual climate at the time (Slide 14) (Slide 15). In fact the climate then seemed to be going the opposite direction. It became known that the 1960s and 70s were a cool period for the planet and as researchers sought to find reasons for this, it attracted the interest of the public.

The period was marked by global cooling, and at the same time unusual weather became a big issue in society (Slide 16). I believe that the climate became an issue not because the actual conditions were unusual but because the post-war economic growth in Japan and Europe by the 1970s had expanded the footprint of industry and the economy as well as human mobility, making us more vulnerable to changes in climate and weather. A lot of research was done on phenomena related to unusual weather such as El Nino, teleconnection and atmospheric blocking. These remain keywords in explaining unusual weather today. In this social context, research on weather and climate moved in pursuit of the causes of unusual weather.

And so a new chapter in research on weather and climate began (Slide 17). I have spoken about the birth of electronic computers and the rise of numerical weather forecasting in the 1960s. It was around the same time that weather observations by satellite became possible. The Global Atmospheric Research Program (GARP) was an exercise in international cooperation carried out from 1967-79 in order to enact the weather forecast of the future, the vision of building a future prediction system where satellites would track weather worldwide, feeding those results into computers with atmospheric models for simulation. Japan took responsibility for one of the five geostationary satellites globally to observe the Earth and launched Himawari in 1977. This is how the weather forecasts we see today came to be.

The tremendous success of GARP resulted in a new weather forecasting system, but at that time, climate change had arisen as the next important societal issue, a problem that was causing unusual weather. Therefore, the next objective became the forecasting over a longer period, that is, changes in annual weather so as to predict whether this summer would be cool or hot, for example. The World Climate Research Program was initiated in

1979 to follow on from GARP. Annual weather such as cool summers and warm winters is influenced by not only the state of the atmosphere but also by ocean surface temperatures and the extent of continental snow cover (Slide 18). Then in order to project climate change, the idea of numerical forecasting was extended to the state of the ocean and the continent, and ocean currents and their changes and ocean surface temperatures were calculated according to equations based on physics, thereby calculating continental snow cover and changes in the moisture content of soil. As the atmosphere, oceans and the continents make changes as a single system mutually affecting each other, considering them together as a “climate system” and to project its future by calculating its changes based on physical law as in the case with numerical weather forecasting were pursued, which became climate change projection.

The budding of global environmental issues in the 1970s

As research on unusual weather and climate change research intensified, “global environmental issues” took root as a public concern (Slide 19). The United Nations Conference on the Human Environment was held in 1972. An issue that gained clarity very early in the 1970s as a worldwide environmental problem was the issues regarding the stratospheric ozone layer. It was pointed out that nitrogen oxide emitted from the supersonic jet aircrafts, which were under development and would fly through the stratosphere, would catalyze the decomposition of the ozoner. An ambitious project was established and I made a keynote speech at the first major conference as someone who was researching the stratosphere at the time. While supersonic travel (SST) in the end failed to eventuate for economic reasons, but after Professor Sherwood Roland’s work demonstrating that chlorofluorocarbons broke down into chlorine that then decomposed ozone, further research was carried out led by NASA resulting in a major change in the field of atmospheric chemistry related to the stratosphere.

While Dr. Manabe’s research into global warming continued, and just as research by another NASA researcher, Dr. James Hansen (Blue Planet Prize laureate) was published, a National Academy of Sciences report was released, compiled by leading global meteorological researcher, Professor Jule Charney of MIT and others. You might call it the first warning sounded by the scientific community to the general public. It included an estimate that a doubling of CO_2 would lead to a 3°C rise in mean temperature, with a margin of 1.5°C either way. This margin of error has not changed in 30 years. Looking at global warming science in Japan, Dr. Giichi Yamamoto of Tohoku University began research on emissions of CO_2 very early with an interest in the problem of global warming. One of his students, Dr. Masayuki Tanaka, began the first monitoring of CO_2 levels for Japan in Sendai in 1979 and expanded the outdoor monitoring to points across the country.

What was happening in Japan during the era of breakthrough and change in meteorology of the 1960s and 70s?

I have talked about the global research into weather and climate during the 1960s and 70s. I would now like to touch on what it was like in Japan at that time. It was the starting point of my later efforts to establish a climate modelling center (Slide 21).

The advent of electronic computers and satellites in the 1960s was a revolution for meteorology and weather forecasting and in the United States. The National Science Foundation (NSF), created to scale up basic research in the field, funded the establishment of the National Center for Atmospheric Research (NCAR). Europe lagged the US somewhat, but in response to growing concerns about unusual weather and future warming in the 1970s, European nations established research organizations specializing in modelling.

In Japan in the 1960s, inspired by the US movements, in 1963 young researchers held discussions on future plans and began a campaign to establish an "institute of atmospheric physics" as a venue for large-scale and comprehensive research like NCAR. A scientific association advised government on the issue in 1965, and a detailed plan was devised before a budget request was made by Kyoto University in 1972. However, the government faced fiscal issues and the proposal was rejected in 1979 (Slide 22). I was involved in this process. In my field of dynamic meteorology, much of the research had been theoretical to that point. My own dissertation had been a theoretical proof of the basic nature of atmosphere and oceans in the equatorial zone. However, research through numerical analysis alone clearly had its limitations. On the other hand, the mechanism behind even a complicated phenomenon can be discovered numerically through use of a computer. In fact, I solved the research problem of the sudden stratospheric warming phenomenon while I was in the United States with the help of a computer.

There was another reason behind my wish to establish a setting for model research in Japan (Slide 23). This is an article that appeared in an American Meteorological Society journal analysing the activities of a Japanese researcher who travelled to the US after World War II. When I was starting my Master's there were many talented researchers hoping to work on numerical modelling. But at that time in Japan, there was no way to compete with the research or computing facilities of the US. Dr. Manabe and many others my senior went to the US and advanced their world-leading research modelling weather and climate (Slide 24). As you can see in this genealogical chart, most of my seniors went to the US, making me the oldest of the generation that remained in Japan to conduct research. That is why I felt I had a role to play in enabling model research as outlined in our atmospheric physics research planning and creating a venue for it.

● The 1980s: Growing public awareness of global environmental issues and the advance of climate change research

Global environmental issues which the scientific field had warned of in the 1970s suddenly exploded on the international political scene in the mid-1980s (Slide 26). The large-scale research led by NASA on the depletion of the ozone layer by CFCs was accepted as a fact and in 1985 the Vienna Convention for the Protection of the Ozone Layer was agreed upon. On this basis, the Montreal Protocol restricting the use of CFCs was established in 1987 (cutting designated CFC production by 50%). In early 1988, my friend Marvin Geller, the head of the Goddard Institute for Space Studies, led a group of American ozone layer scientists on a trip to Japan to urge a response from the Japanese government. Separate meetings were held with the Environment Agency and the Ministry of International Trade and Industry. As an extreme irony, in 1985, the year of the Vienna Convention, a hole in the ozone layer was discovered over the South Pole with a dramatically reduced amount of stratospheric ozone. The science around the ozone had not predicted such a discovery and it came as a major shock. US scientist Susan Solomon, Blue Planet Prize laureate in 2004, discovered in 1987 that ozone was being depleted in large quantities by a distinctive reaction occurring on the surface of the Polar Stratospheric Cloud (PSC) in the stratosphere above Antarctica that reactivated hitherto harmless chlorine compounds from CFCs. The Montreal Protocol, which had been devised before this fact became apparent, was therefore rendered inadequate. Thus, the London Amendment in 1990 controlled two further types of chemical substance in addition to CFCs. As a result of this being implemented, the total volume of chlorine particles in the atmosphere from CFCs and other sources stabilized and then started to fall, and we are on the way to the resolution of the ozone depletion issue (Slide 27: Sudden stratospheric warming).

Alongside the ozone layer issue, “global warming” became a global political issue on the basis of scientific findings that were widely reported even though the climatic effects were not yet being felt. In 1985, SCOPE held a conference in Villach, Austria, bringing together research on the subject. This was effectively the model for the later-formed Intergovernmental Panel on Climate Change (IPCC). The global warming issue had a breakthrough in 1988. North America was hit by drought and extreme heat and NASA’s Dr. James Hansen testified to Congress that anthropogenic CO_2 emissions were largely to blame. Overnight, global warming became a matter of public debate. Later in the same year, the Toronto Summit held by the UN established the IPCC as a clearing house for the science of global warming. The following year, climate change was the major focus of discussions at the Arch Summit in France. In 1990 the Second World Climate Conference ratified the first report of the IPCC, the first official recognition by the United Nations of the possibility that increased greenhouse gases would change the climate. On this basis, the Climate Change Convention was agreed upon at the 1992 Earth Summit held in Rio de Janeiro. Thus, in the mere five years since 1987, a global environmental issue discussed among scientists had catapulted to the top of the international political agenda (Slide 28). A reason for this sudden turnaround, according to science historian Dr. Shohei Yonemoto, was the rise of Gorbachev as leader of the Soviet Union, leading to resolution of the conflict between the superpowers and elimination of the threat of nuclear war. In his analysis, global environmental issues were intentionally placed on the world leaders’ agenda in order to make them talk to each other.

Government officials in Japan grasped the importance of these global environmental issues that had suddenly risen to international prominence and first of all moved to create a solid platform for basic scientific research (Slide 29). The Ministry of Education, which administers scientific research, and the Science and Technology Agency announced a series of new research organizations and large-scale research projects. The most important ones are shown here. As I mentioned earlier, I wanted to start modelling research in Japan and in order to do so, a specialist research organization was required (Slide 30). Therefore, when I was made professor of meteorology at the University of Tokyo in 1984, I believed that modelling research would be needed and in order to prepare for it, Dr. Akimasa Sumi joined me as an assistant professor. While I had no real experience of modelling, he had been involved in numerical weather forecasting model development at the JMA. While mentoring Masters’ students, he gradually furthered the model research and preparations. As part of the new initiatives by the Ministry of Education and the Science and Technology Agency in addressing global environmental challenges, they responded positively to the efforts of Dr. Sumi and myself. The result was that we participated in the launch of three new research organizations from 1991.

The Center for Climate System Research, the University of Tokyo (Slide 31, 32, 33, 34)

In consultation with relevant researchers nationwide, appropriate personnel were assembled to join the organization, which would be small yet independent from the University departments and representing a collective-use facility for Japanese researchers (Slide 35). With regard to our fundamental aim of model development, we were able to secure the services of Dr. Masahide Kimoto who had been involved in the El Nino forecasting model at JMA. We perfected a model that combined both the atmospheric and oceanic elements required for global warming prediction and these independent results were published for the Third IPCC Assessment Report in 2001. Another successful result from an atmospheric model, which was the world's first replication of the mysterious phenomenon of the quasi-biennial oscillation (QBO) in the stratospheric zonal wind, by Dr. Masaaki Takahashi, had been achieved.

The Center for Climate System Research did not simply carry out modelling. Another important theme was analysis of data from satellite observations of actual weather and climate. A result achieved in this area by Dr. Teruyuki Nakajima and his team was the successful analysis of the distribution and characteristics of aerosols using clever techniques. Moreover, the Center was always intended to function as a venue in Japan for joint international research and in this respect also, all staff have carried out activities suited to a climate research center, including the work by Dr. Tsuyoshi Nitta for the Japan end of the joint US-Japan Tropical Rainfall Measuring Mission (TRMM), PI (Slide 36). For my part, as research for the Master's thesis of my student, Mr. Kiyohito Tanabe, we looked at the stabilization of carbon dioxide levels by creating a simplified model of oceanic circulation and applying it to the carbon cycle. The motivation for this came from noticing the remarkably different parameters used for studying the carbon cycle and temperature rise for the simplified model of oceanic circulation in the first report of the IPCC which should have been the same. My interest in this issue continued thereafter (Slide 37). In the autumn of 1994, when I left the Center, it had grown to a teaching staff of 20 and around 10 Masters' students. I am thankful to Itochu Corporation for donating a research department, boosting our research by adding to our full-time positions and playing an important role in the growth of our young scientists.

Graduate School of Environmental Science, Faculty of Environmental Earth Science, Hokkaido University

Being made head of the newly created Course in Atmosphere-Ocean and Climate Dynamics at the Faculty of Environmental Earth Science in 1994, I transferred to Hokkaido University in October (Slide 38). The course was established in the midst of the expansion of the environmental earth sciences, but this was not just a renaming. Researchers in related fields from the Institute of Low Temperature Science and the Faculty of Fisheries became the core and ten new positions were created for the frontline researchers from universities around Japan and worldwide to join the faculty. There was a tremendous sense of excitement that we were at the vanguard. Postgrad students from all sorts of backgrounds signed up from around Japan and we worked together to establish a new postgraduate faculty.

Best of all was always being able to debate with young lecturers in the same faculty and have lunch together (Slide 39). Because of this I took confidence in my knowledge of oceanic cycles and deepened my thinking about simplified oceanic models. I called myself a "lunchtime oceanographer" (Slide 40). Simplified ocean cycle model was the subject taken up by another of my Masters' students, Ms. Yoshie Maeda. First there was the HILDA model which split the polar zones from the ocean cycle. This was revised slightly as the Bern model which has become one of the standards of the IPCC report. However, this model assumes an average upwelling speed of 0.6m per year, which is far less than the generally accepted speed of 4m per year. This is a rather tangled debate but I will make it brief – the outlines are seen in (Slides 41, 42).

Frontier Research System for Global Change

The Frontier Research System for Global Change was a major research project that was started in 1997 by the former Science and Technology Agency to address climate change and other global environmental issues (Slide 43). The National Space Development Agency of Japan (NASDA) under the umbrella of the Science and Technology Agency carried out earth observations using their satellites and the Japan Marine Science and Technology Center (JAMSTEC) began expanding its oceanic observation network in order to track El Nino. There were deliberations and a report compiled as to how the data from these observations could be of use to society. The subtitle of the report was “Toward Realizing the Prediction of Global Change,” which was the goal of the newly created research system. As for earth sciences, how they can be of use to the society is by establishing prediction. We considered what would be necessary and possible to predict within the “global change,” and we set six objectives. In order to achieve these objectives the Frontier Research System for Global Change was established in October 1997 as a joint project of NASDA and JAMSTEC to run over 20 years (two terms with 10 years per term) (Slide 44, 45). As I was in charge of compiling the report, I was made head of the Frontier Research System for Global Change.

The strategy for “realizing prediction” at Global Frontier aimed to create models that could simulate real-world phenomenon. This included models of global warming that were already being constructed by other research institutions. To start anew we had to develop unique models, otherwise there would be no point. Therefore, after discussions with Dr. Sumi at the University of Tokyo Center for Climate System Research (CCSR), I decided on the direction as shown in (Slide 46).

(1) As an issue of vital public importance, Global Frontier should engage in global warming prediction. However, it would be a waste of time and resources to go ahead independently of the University of Tokyo, Meteorological Research Institute and others with experience in the field. We joined the existing grouping of the University of Tokyo CCSR and National Institute for Environmental Studies (NIES), forming a team powerful enough to compete internationally.

(2) At Global Frontier, we planned to develop a model incorporating elements usually not included in climate models, such as atmospheric composition and ecosystems. Such a model incorporating comprehensive global (environmental) systems would also be able to take into account changes in the carbon cycle caused by future climate change.

(3) The Earth Simulator (ES) plan was proceeding and its large capacity was expected to offer great benefits. We were at the global cutting edge: atmospheric and ocean models with higher resolution meant an ability to look at more phenomena, and in the case of the atmosphere a model was developed to show tropical convection on a direct grid.

The essentials of the models in (2) and (3) are seen in (Slides 47, 48).

These unique models are highly regarded today, even though Global Frontier was eliminated in the reorganization of JAMSTEC, the parent organization (Slide 49). Here is a group photo together with the young researchers working there now.

The Earth Simulator and the climate change prediction projects using it Supercomputers, weather and climate research, and prediction (Slide 51)

Of all the scientific fields, researches on weather and climate models are known to require computers the most. The Geophysical Fluid Dynamics Laboratory (GFDL) of the US National Oceanic and Atmospheric Administration where Dr. Manabe worked has always been equipped with the most powerful computers of the time and used by a small number of researchers, the laboratory has always been a world leader.

Japan continued to suffer from underpowered computing by world standards until the 1970s. The JMA installed the biggest computer in Japan, but its main role was weather forecasting and it was barely used for research purposes. Some big universities also had top-level computers for Japan but they were located in university computer centers and used by thousands of people. There were very few chances to access a computer as an individual.

Japan-built computers only caught up with the global standard in the late 1970s and early 1980s. We were finally able to catch up with the world when the Meteorological Research Institute moved to Tsukuba in 1984 and specialist research computers were installed. Independent predictions from the Institute thus somehow made it into the first IPCC report.

In 1990 global warming was a major international political issue. As the power of Japanese computers grew, and trade friction with the US increased, NIES and the National Research Institute for Earth Science and Disaster Prevention procured large supercomputers for the time. The Meteorological Research Institute, using the computer installed at NIES, came up with the same type of calculations performed by other groups in the second report of the IPCC. For the third IPCC report in 2001, the Meteorological Research Institute and the NIES-the University of Tokyo CCSR team made predictions based on their respective models which at that time I feel were a little behind the global mainstream.

This was the context for establishment of a plan to develop the world's top supercomputer, dubbed the Earth Simulator, that would be dedicated to global warming prediction and other environmental research.

(Slide 52)The growth in capacity of the world's most powerful supercomputers over time

(Slide 53)Overview of the Earth Simulator

(Slide 54, 55) The Earth Simulator and Earth Simulator 2

Global warming prediction projects using the Earth Simulator

(Slide 56) The Ministry of Education, Culture, Sports, Science and Technology (MEXT)aimed at putting the Earth Simulator to work on global warming prediction in order to contribute to the IPCC report. It carried out two initiatives, the "Project for Sustainable Coexistence of Humanity, Nature and the Earth", 2002-2007 and the subsequent "Innovative Program of Climate Change Projection for 21st Century", 2007-2011. Happily, through these projects, Japan's climate change research emerged at the global cutting edge. But it was a grueling experience.

(Slide 57) The Japanese climate model researchers involved in the “Project for Sustainable Coexistence of Humanity, Nature and the Earth” faced tremendous problems deriving results in a short period from the ES, which had hugely boosted computing capacity overnight. They were required to complete their calculations by the end of August 2004 in time for the fourth report of the IPCC (Slide 58). In order to make effective use of the Earth Simulator, the joint project would propose experiments on global warming between related Japanese researchers. The result was the emergence of an “All-Japan team” (Slide 59). Researchers from the University of Tokyo CCSR, NIES and the Global Frontier came together as a team and engaged in very close collaboration on the global warming experiments with combined atmospheric-oceanic models that are at the heart of the IPCC report. I have nothing but admiration for the guidance and leadership at the laboratory level by Dr. Sumi from the University of Tokyo and Dr. Kimoto.

The ES is 1,000 times more powerful than existing computers, so models created for it are too big to be tested in advance. Various revisions and adjustments can only be done using the ES. One example was when we realized that an urgent reformation of the basic model structure was required. There were all sorts of challenges like this, but even though it was the first time we had conducted experiments using parallel computing, by some miracle we were able to complete our computations and produce our findings amazingly in a short two years, just in time for the fourth report of the IPCC. Looking back, Dr. Sumi said that we had “the gods on our side” and I would certainly agree. I might add that the tripling of the actual speed of ES since its inception was a tremendous mercy.

Here are a couple of findings from the Coexistence Project. The currents in the seas around Japan and distribution of sea temperatures, as shown in (Slide 60), were included in the fourth report of the IPCC as a highest-resolution model. It shows the Kuroshio Current winding past Japan and veering away to the east off the coast of Choshi. The meandering path of the Kuroshio could not be seen with the existing 100km grid, but was made visible for the first time by our high-resolution 20km grid. A high resolution 100km atmospheric grid that had not previously been available also enabled us to make the rainy season front visible, among other phenomena (Slide 61). With this, we were able to investigate whether rain was falling more heavily as a result of warming as had been suggested, and a model was presented of recent actual trends. While heavy rains will increase, at the same time the number of rainless days will also increase. The Meteorological Research Institute group looked into the future of typhoons on a warming planet, using the atmospheric 20km grid model and applying it to a separate ocean surface temperature global warming model (Slide 62). As a result, they found that the number of tropical depressions will decrease, but looking at their strength (Slide 63), they found that in a warmer world, the biggest typhoons would be much more powerful than the biggest typhoons today. This is a spectacular finding from the global 20km grid model, and it was included in the IPCC report. The model has become well-known among climate leaders through displays and presentations held during Conference of the Parties (COP) and there have been a lot of requests for further information from national institutions, particularly in the countries of the “South.”

Thus, the Earth Simulator and the Coexistence Project shot Japanese climate change prediction research to the global cutting edge, gaining particular acclaim among experts worldwide for predictions of typhoons and heavy rainstorms using high-resolution models. Of course even more advanced findings are required for inclusion in the next IPCC report. Aiming to contribute to the fifth report of the IPCC scheduled for 2013, MEXT carried out the

Innovative Program of Climate Change Projection for 21st Century (Innovative Program) during FY2007-11. In the Coexistence Project, researchers worked tremendously hard to develop new prediction models in the short time period. Another precious result of the Coexistence Project was the knowledge and know-how built up by young researchers over five years and the emergence of an "All-Japan" team.

In formulating the Innovative Program, we decided to develop three types of prediction experiments and models in order to harness our experience with the Coexistence Project and in view of the needs of society and moving the science forward. This is shown in (Slide 64). Something altogether new among these is No. 2, a "forecast" of the climate in 30 years' time. Global warming predictions up to now have shown the dangers in 100 years' time if greenhouse gas emissions continue at the current rate. For No.3, they make projections of the climate in 100 years according to each of the emissions scenarios under various conditions. By contrast, if the projection is just 30 years in the future, it is hard to envisage any major change in current emissions, so we can more or less say that the future is set in stone, obviating the need to come up with various alternative scenarios. In other words, this is a "super long-range forecast," which must therefore take into account natural climate changes such as El Nino. Just like a weather forecast, the "initial conditions" pertaining to the current conditions are key. On a timescale this long, it is likely that the distribution of water temperatures up to hundreds of meters beneath the ocean is vital. This is a pioneering initiative and a tremendous scientific challenge which emerged from the proposal for the Innovative Program. While the world was moving in the same direction, Japan has become the leader in this type of experiment. (Slide 65) In addition to the three major types of prediction experiments under the Innovative Program, cutting-edge models were developed for the future, even if they cannot be used in forecasting immediately. The Program included research tasks leading to measures on disaster prevention, such as using forecast data to investigate how weather disasters might look like in the future. The research findings were so numerous that I will just present them in outline form, but I will then speak about the future of the summer convection rains that I am personally fascinated by and believe will be very important for society in the future. The Innovative Program involved research by an even bigger group of researchers, including impact evaluations. In (Slide 66) you can see a group photo taken in February last year of the final results report meeting.

● What will become of the summer convectional rains characteristic of Japan's climate?

This summer saw record temperatures across Japan, giving us a true taste of the extent of global warming. Another clear signal of continued warming is the frequency of localized downpours. "Unprecedented" violent downpours have led to flooding. This is the terminology used by the JMA to put the public on special alert, but I believe that global warming will cause a type of convectional rain not seen before in Japanese weather. Important issues such as these kinds of violent summer downpours and change in the convectional rains were a strong focus of the Coexistence Project and the Innovative Program. I will give you just a taste of the findings.

(Slide 68) is a weather satellite image from June 2009. There is nothing special about it, but it is an example of the contrast between tropical clouds and mid- to high latitude clouds. Over in the Southern Hemisphere, where it is winter, large cloud bands from temperate zone depressions can be seen. Up in the tropics are convection cloud clumps scattered across the oceans and continents. These clumps of convection clouds are known as "cloud clusters" and have a unique structure. A schematic diagram of the clouds is shown in (Slide 69). They cannot be formed by a single cumulonimbus cloud or thunderhead: a cloud cluster is a collection of many clouds up to 100km in size that lasts much longer than a single cloud. It moves and changes according to its own mechanisms. That is why we need a very fine grid able to show convection clouds. As shown in (Slide 70), using the global 20km grid model, we developed a model in the region of Japan for computing on a 5km grid. We went even further for western and southern Japan, areas especially prone to violent downpours, and integrated a 2km grid model. The convection rains were simulated as closely as possible and any changes were investigated. Our findings are in (Slide 71). The precipitation at each point of the grid is statistically classified by intensity and frequency of rainfall. The stronger the rainfall, the less often it occurs but on the curve obtained from the 20km grid, heavy rain occurs much less frequently than is actually observed on the ground and the curve tails off sharply. With the 5km grid on the other hand, we found hardly any difference between the computed results and curve of actual observations. We discovered that while the 20km grid did not pick up all the heavy downpours, the 5km grid did. When we look at rain in a warmer climate on a 5km grid, it is clear that heavy downpours are increasing.

Let us take another close look (Slide 72). When the per day rain frequency distribution is compared between those with the blue line for the current climate and those with the red line under a warmer climate, it can be seen that gentle rain frequency reduces once per day rainfall gets over 100mm. On the contrary, the heavy rain increases with warming, with an increase of 20-50% in events with daily rainfall of 250-300mm per day, a level that causes flooding. Forecast data of this type is being used as reference for future flood prevention planning.

As we have seen in the satellite image, most rain in the tropics is convectional and therefore cloud clusters need to be shown in a direct model. As seen in Slide 69, cloud clusters build a unique structure and emerge, develop and move according to unique mechanisms so a direct model that incorporates them should be an accurate simulation (Slide 73). In order to squeeze the most out of the Earth Simulator's capacity, a goal was set to model the global atmosphere at a grid size of under 5km – a size that could illustrate tropical cloud clusters. A young team led by Dr. Masaki Sato started from scratch on developing such a model and in 2005, they achieved their first findings. They have retained their perch as world leaders on this since.

As a special characteristic of the tropical zone, the Madden–Julian oscillation (MJO) is a convection system on a 10,000km scale. As briefly outlined in (Slide 74), at the surface there are depressions, one in the Northern Hemisphere and one in the Southern Hemisphere, and in between along the Equator the wind blows from west to east. In this westerly wind area spreads the convection clouds and the system as a whole is moving slowly east.

As if it were a weather forecast, we attempted to make a monthly forecast starting from when an MJO cloud cluster appeared over the Indian Ocean. During that time we also computed a forecast on a 3.5km grid for one week from Christmas 2006 to New Year's Day 2007. Let us compare the result with the actual satellite images (Video 75). The slow movement of the large cloud cluster from the Indian Ocean over Indonesia was simulated very well. In line with the MJO, tropical depressions emerged frequently. In this case, three depressions emerged. Two were recreated perfectly by Nonhydrostatic ICosahedral Atmospheric Model (NICAM), especially the tropical depressions that formed north of Australia two weeks after the start of the forecast were stunningly close in time and location. These events can be seen in (Slide 76, 77).

(Slide 78) With NICAM producing such good results, based on discussions at the 2008 World Modelling Summit for Climate Prediction led by Dr. Shukla, the Indian scientist who has researched monsoons and tropical weather as founder of the US Center for Ocean-Land-Atmosphere Studies (COLA), a project was carried out to confirm the effectiveness of higher resolution on model performances. It involved a 10km grid model from the European Centre for Medium-Range Weather Forecasts and NICAM, and both were run over a long period on a specialized computer, which were funded by the American NSF.. Let me show you the beautiful video of the results it produced (Video 79).

(Slide 80) Japan is located at a lower latitude than Europe. The Gibraltar Straits south of Spain are at 36°N, which is the same as Tsukuba. The main cities of Europe such as London, Paris and Berlin are all near 50°N, which would be the equivalent of Sakhalin in the region of Japan. Traditionally, meteorology has developed in Europe and as such, little emphasis was placed on tropical convection. By comparison, we have a lot of weather in Japan such as the rainy season front rains which force us to consider convection. And with global warming in mind, tropical weather will need to be given much more priority in the future. The science of directly computing convectional rains and typhoons with high-resolution modelling is highly challenging, but it is clearly vital to society. It is therefore a fact that this type of research will contribute widely to forecasting the future climate of countries of the "South", especially countries of Monsoon Asia.

Conclusion

In September this year, the IPCC compiled the basics of natural science in its fifth report. In some ways the report reflects an advance beyond the fourth report of 2007, but many questions of research on warming and climate change prediction remain unanswered. We relish tackling these difficult issues and we consider it our mission to collaborate with our colleagues around the world to resolve them. Experts and general public alike might find it frustrating, but such is the fate of research. I beg your forbearance and hope that you will lend us your strong support.

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