From Polar Ice Cores to Better Climate Models?

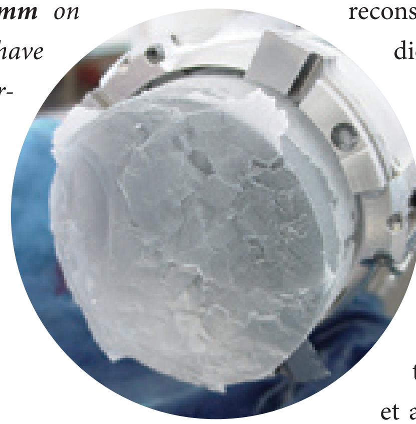
***Thomas Stocker**, Professor of Climate and Environmental Physics and Co-Director of the Physics Institute at the University of Bern in Switzerland, spent his 2006 sabbatical at the IPRC. He worked with IPRC research team leader **Axel Timmermann** and postdoctoral fellow **Oliver Timm** on modeling the abrupt climate changes in the past that have resulted from changes in the Atlantic meridional overturning circulation. Understanding processes that have shaped past climates is central to determining what lies ahead for climate change. We asked Professor Stocker to write for the* IPRC Climate *about this work and how it advances our knowledge of Earth's climate system.*

Climate models require accurate forcing data

Numerical models are used to simulate and understand past climate conditions. The forcing conditions in the distant past, such as the concentration of the greenhouse gases or the extent of ice areas, however, were very different from today and must be quantified before experiments with climate models can be performed.

Knowledge of past greenhouse gas composition in the atmosphere is necessary to drive climate models that are to simulate past conditions. This composition can be obtained from polar ice cores. When snow falls on polar ice sheets, it soon forms a porous material, firn, in which air can circulate. The air in the firn becomes trapped under the slow compaction of snowfall, year after year. These bubbles contain tiny samples of ancient air that can be analyzed, and the physical and chemical composition of the atmosphere can be reconstructed by applying various analytical techniques to the ice core samples. Currently, more than 50 components in the ice and in the enclosed gas of a polar ice core are measured (photo below). Such analyses have enabled us at the University of Bern, in partnership with many European colleagues, to trace back climate change in Antarctica to at least 740,000 years ago (EPICA Community Members, *Nature* 2004) and reconstruct the concentrations of carbon dioxide and methane, the two most important greenhouse gases after water vapor.

Within the resolution of the current measurements, our results show that today's levels of CO_2 in the atmosphere are 27% higher than any time during the last 650,000 years (Siegenthaler et al., *Science* 2005). Today's concentrations of CO_2 (annual average in 2006: 382 ppm, as measured on Mauna Loa, Hawai'i, **www.cmdl.noaa.gov/ccgg/trends**) are clearly outside the range of natural fluctuations over the past several 100,000 years (Figure 1). These data provide an indispensable forcing boundary condition for climate models that are used to simulate ice ages and dynamical processes in the distant past.



Above. Drill head with ice core drilled on November 30, 2002, from a depth of 2,874 m at Dome Concordia Station. The ice is about 491,000 years old. The drilling is part of the European Project for Ice Coring in Antarctica (EPICA). This ice core contains a continuous time series of greenhouse gases over the last 650,000 years. The drill head and cutters were designed and constructed by Henry Rufli (University of Bern, Switzerland; *photo courtesy of L. Augustin, LGGE, Grenoble, France*).

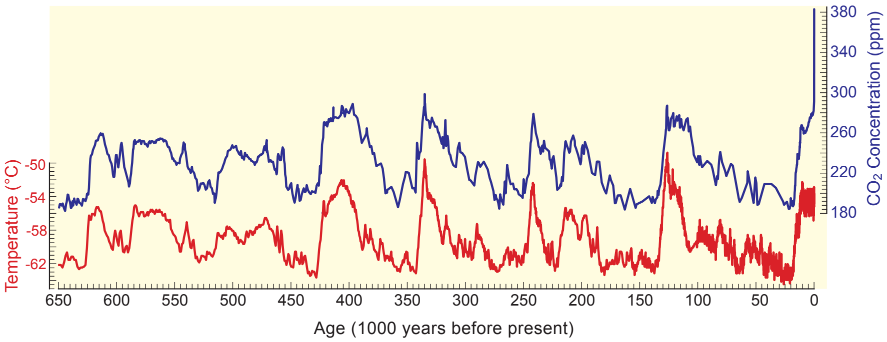


Figure 1. Reconstruction of the atmospheric CO_2 concentration of the last 650,000 years (blue curve) based on data from several Antarctic ice cores, combined with the observed increase measured since 1958 on Mauna Loa (Hawai'i). The estimate of temperature in Antarctica (red curve) is derived from measurements of the stable isotopes of the water molecule.

Signals of abrupt climate change

Ice cores from Greenland and Antarctica have radically changed the way we look at climate as a dynamical system on many time scales. More than 10 years ago, two independent international projects, one in the U.S. (GISP2) and one in Europe (GRIP), confirmed earlier reports that a series of abrupt warmings characterized the last ice age. These abrupt swings of climate in Greenland are now commonly known as *Dansgaard/Oeschger* events, and are thought to cause climate change worldwide. A recent, more detailed ice core from North GRIP (NorthGRIP Members, *Nature* 2004) shows 25 of these events during the last ice age. During Dansgaard/Oeschger events temperature in Greenland rises over a few decades by as much as 16°C and then falls over the following millennia (Huber et al., *Earth Plan. Sci. Lett.* 2006). (These short-term events are different from the gradual deglaciation described in the work by Timmermann and his team on p. 3.)

The synchronization of ice core records from Greenland with those from Antarctica by using global time markers, shows that the strong Dansgaard/Oeschger events in the north have a counterpart in Antarctica (Blunier and Brook, *Science* 2001). When Antarctica is warming, Greenland ice cores register very cold temperatures. However, when an abrupt warming occurs in Greenland, the warming in Antarctica stops, and a cooling trend starts. The pattern is very consistent during the entire ice age and is referred to as the bipolar seesaw (Broecker, *Paleoceanogr.* 1998; Stocker, *Science* 1998). This is illustrated in Figure 2, which shows temperature reconstructions from ice cores from Greenland and Antarctica in a typical time window during the last ice age.

Two questions arise from these ice core records: (i) What is the physics behind this north-south connection, and (ii) can current coupled climate models simulate the time and space signature of such dramatic climate events? This is a hard but crucial test for models that are used to assess the likelihood of low-probability but high-impact climate events in response to global warming.

The combination of numerous paleoclimatic reconstructions, climate model simulations, and theory suggests that the Atlantic meridional overturning circulation is a key component in the physics of these abrupt changes (Clark et al., *Nature* 2002; Alley, *Science* 2003). When freshwater is discharged into the North Atlantic Ocean from unstable ice sheets, the meridional overturning circulation is reduced or even stopped. This leads to a decreased meridonal heat flux in the Atlantic Ocean and an associated hemispheric cooling owing to response of the atmospheric circulation.

In fact, climate models are able to capture many aspects of these abrupt changes, such as the rapidity of the events, the amplitude of the cooling in the Northern Hemisphere (Knutti et al., *Nature* 2004), and various other changes reconstructed by paleoclimate archives (LeGrande et al., *Proc. Natl. Acad. Sci.* 2006). They make specific pre-dictions as to what one may find in the paleoclimatic record of variability in the tropical Pacific (Timmermann

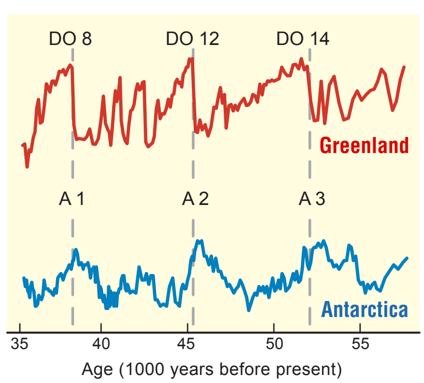


Figure 2. Reconstructions of temperature changes in Greenland (red curve) and Antarctica (blue curve) during a sequence of six Dansgaard/Oeschger events during the last ice age. The curves are put on a common time scale obtained by synchronizing the two ice cores using measured methane variations in both cores. Time is running from right to left (1000 years before present).

et al., *J. Clim.* 2005). While the response of climate models is consistent in the Northern Hemisphere, their signals in the high latitudes of the Southern Hemisphere are ambiguous: one comprehensive model shows cooling, another warming (Stocker, *Science* 2002).

In the current partnership between IPRC (**Axel Timmermann** and **Oliver Timm**) and the University of Bern (**Thomas Stocker** and **Manuel Renold**), established during my sabbatical visit to the IPRC, we set out to better understand this ambiguity. We are analyzing results from a comprehensive coupled climate model that has no flux corrections (NCAR CCSM3-T31). The climate model is perturbed with a strong freshwater flux delivered to the North Atlantic Ocean. Freshwater is injected into the North Atlantic, increasing linearly from 0 Sv (1 Sv = 10^6 m^3/s) to 2 Sv over 100 years, and decreasing to 0 Sv again over the following 100 years. We are considering two cases. In the first case, we applied a globally uniform negative freshwater flux (*i.e.*, saltier water) of the same total magnitude to ensure conservation of mean salinity in the simulation. In the second case, we applied no compensating flux. The model response in the Northern Hemisphere is very similar. The reduction in the meridonal overturning circulation in the Atlantic causes a strong cooling (Figure 3), which is rather uniform but strongest in the northern North Atlantic except for a warm spot in the northwestern part of the subtropical gyre. This is caused by the displacement of this gyre due to changes in the wind stress curl.

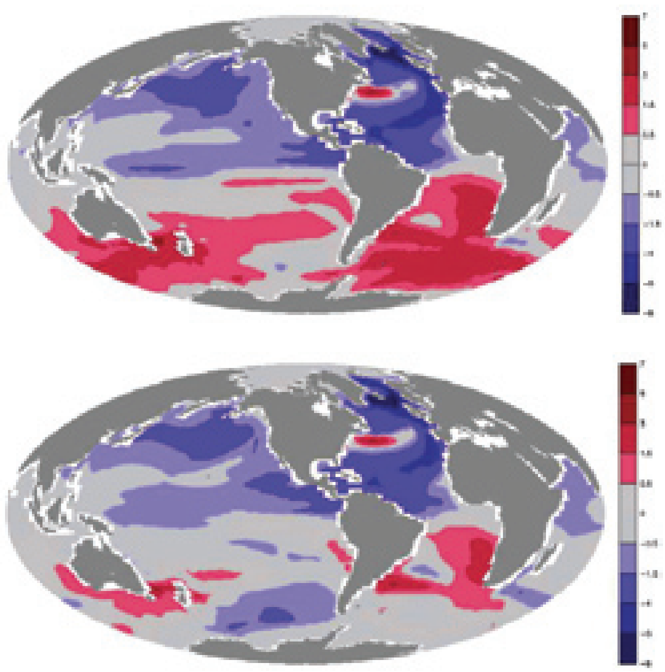


Figure 3. Anomalies of sea surface temperature (°C) in a freshwater experiment using the NCAR CCSM3 model. Freshwater is delivered to the northern North Atlantic increasing to 2 Sv over 100 years and then decreasing again, and globally compensated to ensure salt balance (top panel), or not compensated (bottom panel). Shown are the changes with respect to a control simulation.

The model response in the Southern Hemisphere differs markedly in the two cases. In the experiment with global compensation fluxes, the warming is widespread throughout the entire Southern Hemisphere (top panel); in the uncompensated case, the warming is limited to the South Atlantic and regions south of Australia (bottom panel). Although the compensating freshwater fluxes are comparatively small and uniform, they strongly modify the response beyond the Atlantic Ocean. Particularly in the South Pacific, large spatial differences are found. Thus, while the simulations produce robust results for the Northern Hemisphere (Stouffer, *et al. J. Clim.* 2006), the response of the tropics and the Southern Hemisphere is inconclusive and appears to depend on small changes in how these models are forced. We are now focusing on the dynamical processes responsible for the different response.

Towards models for climate-change impact

Paleoclimate models are indispensable tools to understand the full dynamics of the coupled atmosphere–ocean–land–surface-ice system under altered boundary and forcing conditions. They are also useful for better quantifying changes measured in various paleoclimatic archives such as polar and mid-latitude ice cores, marine sediments, tree rings and speleothems. As models are being improved and their capability is being demonstrated in combination with high-resolution paleoclimate records, future research with these models will be aimed at assessing impacts of climate change on regional scale to continental scale. Of particular interest are extreme weather and climate events and how they might respond to the warming.

As a visitor to the IPRC, I experienced the 46-day rain in February and March 2006, which caused widespread damage in the Hawaiian Islands. What are the odds that such an extreme event occurs again in the next five years, and how will those odds be in the year 2020? Although just one particular example, it stands for the type of questions our science will have to answer in the near future.

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Climate Effects of a Regional Nuclear Conflict

***Alan Robock**, Professor in the Department of Environmental Sciences at Rutgers University, New Jersey, visited the IPRC in August 2006. He gave two seminars, "Climatic Response to High-Latitude Volcanic Eruptions" and "Climatic Effects of Regional Nuclear Conflict." The effects of nuclear explosions described in the second seminar have very grave implications for climate and societies, and we asked Professor Robock to contribute this article based on the seminar.*

The first nuclear war, in which the United States dropped two atomic bombs on Hiroshima and Nagasaki, Japan, in 1945, so shocked the world that in spite of the massive build-up of these weapons since then, they have never been used in war again. In the mid-1980s, research conducted jointly by Western and Soviet scientists discovered that if a third of the then existing nuclear arsenal were exploded, a nuclear winter would result. The climatic consequences and indirect effects of the collapse of society would produce famine for billions of people far from the target zones. This realization helped end the arms race between the United States and the Soviet Union, reducing their arsenals by about two-thirds, but each still retains many thousands of deployed nuclear weapons. In the meantime, the number of nuclear weapon states has grown to nine (Table 1), with 40 more countries possessing enough enriched uranium and/or plutonium to quickly assemble nuclear weapons.

The climate effects of the regional nuclear conflict simulated in this study would last much longer and be much larger than those of the June 15, 1991 Mt. Pinatubo eruption, which followed the smaller June 12 eruption pictured here.

In this context, I have been working with **Brian Toon** and **Charles Bardeen** (University of Colorado), **Richard Turco** (UCLA), **Georgiy Stenchikov** (Rutgers University), and **Luke Oman** (Johns Hopkins University) to examine the effects of a regional nuclear war between new nuclear weap-

Country	No. of Weapons
Russia	10,000
United States	10,000
France	350
China	200
Britain	200
Israel	75–200
India	40–50
Pakistan	<50
North Korea	<15

Table 1. Approximate number of nuclear weapons in the arsenals of different countries. (From Table 2.1 from **International Panel on Fissile Materials**, 2006, with original data from Norris and Kristensen, 2006). The totals for the United States and Russia do not include warheads awaiting dismantlement.

ons states. (Turco, Toon, Stenchikov, and I had been deeply involved in nuclear winter research 20 years ago.)

With support from the National Science Foundation, we studied the following scenario: A nuclear war between two countries in which each country is using 50 Hiroshima-size (15 kilotons) weapons to attack the other's most populated urban areas with populations that could exceed 10 million. These 100 bombs represent less than 0.03% of the explosive power of the current nuclear arsenal worldwide. In our 100-weapon scenario, we estimate that five megatons of smoke would result from urban firestorms rising into the upper troposphere due to pyro-convection. Direct fatalities due to fire and smoke would be comparable to those worldwide in World War II. Furthermore, the megacities exposed to atmospheric fallout of long-lived radionuclides would likely have to be abandoned indefinitely, with severe national and international implications. We also anticipate substantial perturbations of global ozone.

To investigate the climate response to this massive smoke injection, we conducted simulations with a state-of-the-art general circulation model, ModelE from the NASA Goddard Institute for Space Studies, which includes a module to calculate the transport and removal of aerosol particles. Our experience with this model shows it simulates realistically the climate response to large volcanic eruptions.

The atmospheric model is coupled to a full ocean general circulation model that allows the surface-ocean to respond quickly and the deeper ocean on yearly time scales. We ran both models at 4°×5° latitude–longitude resolution, the atmospheric model with 23 vertical layers extending to a height of 80 km, and the ocean model with 13 layers.

We conducted a 30-year control run with no smoke aerosols and three 10-year simulations in which we injected five megatons of black carbon on May 15 into a column of grid boxes at 30°N, 70°E, and placed the black carbon in the model-layers that correspond to the upper troposphere (300–150 mb). Compared to the control run, the three ensemble members differed little in their response to the smoke injection, ensuring us that natural, chaotic weather variability is not responsible for the effects we see.

In the model, the black carbon particles in the aerosol layer are heated by absorption of shortwave radiation. This heating induces vertical motions and the aerosols are lofted close to the top of the stratosphere, much higher than is typical of weakly absorbing volcanic sulfate aerosols. As a result, the carbon aerosols have a very long residence time and continue to affect surface climate for more than a decade. The mass e-folding time for the smoke is six years; for typical volcanic eruptions, one year; and for tropospheric aerosols, one week.

The global-average surface shortwave radiation in response to the aerosols decreases by up to 15 W/m^2 (Figure 1). Five years after the initial smoke injection, the global-average perturbation is still at −7 W/m^2. This exceeds the maximum global-average surface cooling of −4 W/m^2 following the 1991 Mt. Pinatubo volcanic eruption, the largest of the 20th century. The cooling is also greater than the global average increase of 1.5 W/m^2 at the surface or 4 W/m^2 at the tropopause for a doubling of atmospheric CO_2.

The smoke cloud lowers surface temperature significantly (Figure 1). (Stratospheric temperatures are also severely perturbed.) A global average surface cooling of −1.25°C persists for years. After a decade, the cooling is still −0.5°C (Figure 1). The temperature changes are largest over land. A map of the temperature change for the Northern Hemisphere summer one year after the smoke injection is shown in Figure 3. Large areas of North America and Eurasia, including

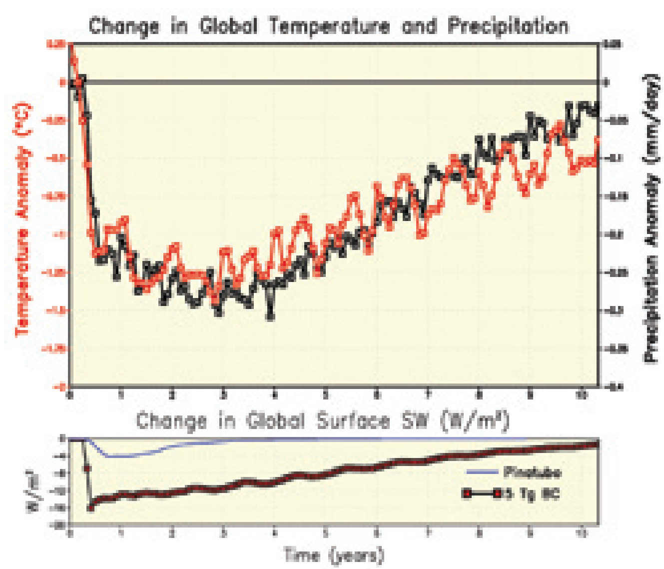

Figure 1. Time variation of global average net surface shortwave radiation, surface air temperature, and precipitation changes for the five megaton standard case. The global average precipitation in the control case is 3.0 mm/day, so the changes in years 2 to 4 represent a 9% global average reduction in precipitation. Precipitation recovers faster than temperature, but both lag the forcing. For comparison, the global average net surface-shortwave forcing from a model simulation of the 1991 Mt. Pinatubo eruption is shown.

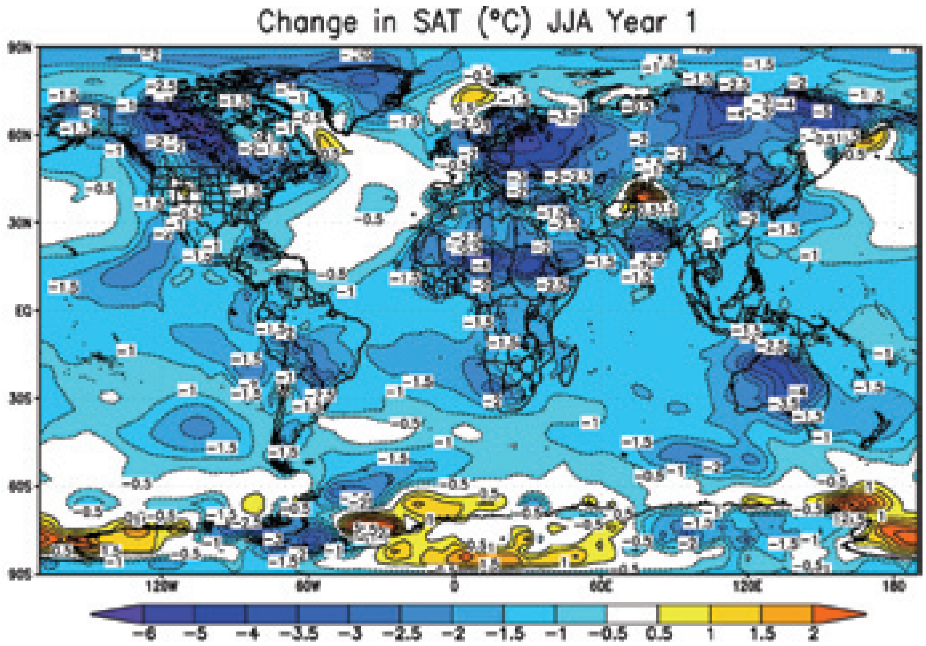

Figure 2. Surface air temperature changes for the five-megaton standard case averaged for June–August of the first year following the smoke injection. Effects are largest over land, but there is substantial cooling over tropical oceans, too. The warming over a small area of Antarctica is part of normal winter interannual variability and is not significant.

most of the grain-growing regions, are several degrees cooler. As in the case with the earlier nuclear winter calculations, large climatic effects are felt in regions far removed from the countries involved in the conflict.

As a result of Earth's surface cooling, evapotranspiration slows and the global hydrological cycle is weakened, with global precipitation reduced by about 10% (Figure 1). Although rainfall decreases mostly in the Intertropical Convergence Zone, as observed after the 1991 Pinatubo eruption, large areas on the continents are also affected, including the Asian summer monsoon.

The temperature, precipitation, and insolation changes would affect agriculture greatly. For example, the growing season in some regions of North America and Europe are shortened by 10 to 20 days. Such a reduction in growing season may completely eliminate crops that have insufficient time to reach maturity. And these reductions continue for several years.

To put the results in a larger historical context, the greatest volcanic eruption of the past 500 years, the 1815 Tambora eruption in Indonesia, resulted in a "Year Without a Summer" in 1816 in the Northern Hemisphere. Killing frosts disrupted agriculture throughout the summer in New England and led to significant emigration. In Europe, the wet cold summer caused a widespread harvest failure, resulting in famines and economic collapse. That climatic disruption only lasted one year. Because the black carbon aerosols in the current nuclear simulation are lofted into the upper stratosphere where their residence time is close to a decade, the climatic effects of the five-megaton case are significantly greater and more persistent than those following the Tambora eruption. Moreover, the cooling in the decade following our five-megaton injection is almost twice as large as the global warming of the past century (about 0.7°C) and would lead to temperatures cooler than the pre-industrial Little Ice Age.

The calculations presented here are the first ever of the effects of black carbon from nuclear conflicts as simulated in a coupled air–sea general circulation model, presumably the most complete and accurate representation of our understanding of the climate system. (Detailed results are found in Toon et al., *Atm. Chem. Phys. Disc.*, 2006, and Robock et al., *Atm. Chem. Phys. Disc.*, 2006.) The results may differ with finer model resolution and models that include smoke other than black carbon rising from burning cities, coagulation of black carbon particles, and photochemical processing in the stratosphere.

In our scenario, the estimated quantities of smoke generated by the detonation of one megaton of nuclear explosives could lead to global climate anomalies exceeding any changes experienced in recorded history. The current global arsenal is about 5,000 megatons!

The results in this paper need to be tested with other climate models, and the detailed consequences on agriculture, water supply, global trade, communications, travel, air pollution, and many more potential human impacts need further study. Each of these potential hazards, however, already now deserves careful analysis by governments, advised by a broad section of the scientific community.

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What's New at the Asia-Pacific Data-Research Center?

The Asia-Pacific Data-Research Center (APDRC) at the IPRC provides the research community and the general public with one-stop shopping for climate data and products. Besides developing server technology and building a climate-relevant database, it has expanded its services to generating data products and assisting other centers with establishing their own data centers. For example, APDRC's procedure for integrating different types of servers is becoming a model for other data centers. Some of the recent outreach activities by the APDRC are described below.

Participation in the Pacific Argo Regional Center

The autonomous Argo floats are a key component of the Ocean Observing System. Almost 3000 floats are now reporting ocean conditions (temperature and salinity) in near-real time. These data are transmitted to two global data assembly centers and nine national centers. The Argo program is setting up procedures to combine, compare, and create products from Argo-float data for specific ocean regions. The APRDC has been active in setting up the Pacific Argo Regional Center (PARC) (see *IPRC Climate*, Vol. 4. No. 2).

This fall has seen several Argo-related meetings. The Fourth PARC meeting was held on October 16 at the Korean Oceanographic Research and Development Institute (KORDI) in Ansan, Republic of Korea. The APDRC, along with JAMSTEC, JMA, KORDI and other oceanographic institutes in the Pacific, used the meeting to determine the needs for Argo data, products, and applications for the Pacific region.

The PARC meeting was followed by the Argo Trajectory Meeting, in Incheon, Korea. Former IPRC postdoctoral fellow **Hiroshi Yoshinari** presented his work on the YoMaHa05 data product (*IPRC Climate*, Vol. 6, No. 1), which he developed with **Nikolai Maximenko** and **Peter Hacker**. The Sixth Argo Data Management meeting, held in Tianjin, China, followed from November 1 to 3. As part of APDRC's continued commitment to the Argo program, **Jim Potemra** represented the APDRC at the three meetings.

SOPAC Partnership

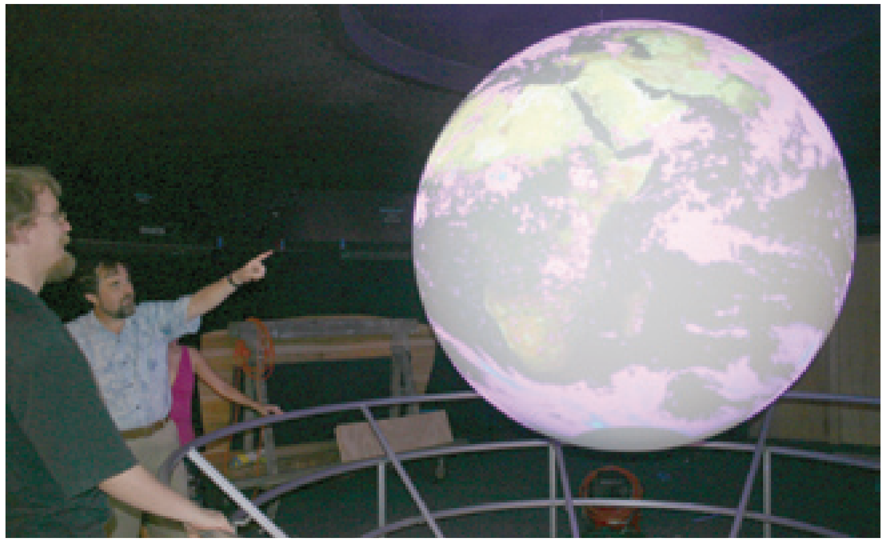
Arriving by propeller plane in Suva, Fuji, where Jim Potemra installed an APDRC server for the Pacific Islands Applied Geoscience Commission (*photo courtesy James T. Potemra*).

As part of its work with NOAA, the APDRC has been providing data to countries in the South Pacific through the Pacific Islands Applied Geoscience Commission (SOPAC). The commission is an inter-governmental, regional organization dedicated to promoting sustainable development in its member countries, which include nearly all the South Pacific Island nations: American Samoa, Australia, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, New Zealand, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu. SOPAC's work is carried out through its Secretariat based in Suva, Fiji.

SOPAC had shown interest in becoming a sister-server with the APDRC, but bandwidth limitations restricted serving many of the larger data sets. The APDRC, therefore, decided to set-up a stand-alone server for SOPAC, essentially a personal computer having all the functions of the APDRC machines but serving only a subset of the available data. To install the server, IPRC Assistant Researcher **Jim Potemra** visited the SOPAC Secretariat in Fiji in September. The APDRC is now working with SOPAC members to determine which data sets and products are most useful to these island nations, and it will then help to keep these data sets up-to-date. This is also an opportunity for the APDRC to obtain feedback about the servers and user interfaces and about the ease of applying the data to practical uses.

SCSIO Partnership

As part of IPRC's new partnership with the South China Sea Institute of Oceanology (SCSIO) in Guangzhuo, China (see p. 26), **Yingshuo Shen** visited the institute in November to help set up data servers on the local SCSIO machines. As an *in situ* data server, Shen installed dapper/dchart (a new server of the Pacific Marine Environmental Laboratory) and trained SCSIO staff on its various functions. This server gives SCSIO a platform by which it can integrate its own datasets into publicly available datasets (such as the World Ocean Database and Argo). Shen also set up an OPeNDAP server for gridded products, which will be used to serve SCSIO model outputs. **Dongxiao Wang**, director of the Laboratory of Tropical Marine Environment Dynamics, a frequent visitor to the IPRC, said of this effort, "Our dream of such a server finally comes true; it will greatly support our ongoing research. One of the goals in the IPRC-SCSIO MOU now has seen great progress."



Axel Timmerman (left) and Kevin Hamilton studying the display of hourly precipitation rates from a high-resolution global model on the Bishop Museum *Science on a Sphere.*

Collaboration with Bishop Museum's *Science on a Sphere*

The Bishop Museum in Honolulu has installed one of a handful of NOAA *Science on a Sphere* exhibits that have been established throughout the United States. When visitors enter the darkened exhibit room, they have the illusion of looking from outer space at beautiful Earth. The illusion is created with a series of projectors displaying global satellite images or computer simulations of earth-system data onto a six-foot diameter sphere (sos.noaa.gov). Animated images of atmospheric and oceanic data can be projected on the sphere to show complex environmental processes. *TIME* magazine selected the *Science on a Sphere* system as one of the best inventions of 2006.

The Bishop Museum exhibit opened on November 17, 2006. IPRC's Assistant Researcher **Jim Potemra** has been working with **Leon Geschwind** at the museum to generate animations from APDRC's large holding of global climate data for the sphere-display. For the exhibit opening, Potemra had made animations of global mean surface temperatures, precipitation, and ice-cover from four different model runs for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Team leaders of IPRC Impacts of Global Environmental Research **Axel Timmermann** and **Kevin Hamilton** are working to produce climate and weather "exhibits" for the sphere.

Participation in the Ocean Observing System

A huge international effort is underway to monitor and understand the global climate system. The ocean component of this effort is the Global Ocean Observing System (GOOS) and the U.S. is contributing to this effort through the Integrated Ocean Observing System (IOOS). Both GOOS and

IOOS have regional associations, with PI-GOOS and PacIOOS representing the Pacific region for the international and the U.S. efforts, respectively.

The APDRC participates in PI-GOOS mainly by supporting SOPAC (see above), with **Jim Potemra** serving on the PI-GOOS Steering Committee. In October, Potemra attended in this capacity the latest PI-GOOS Steering Committee Meeting that took place in Honiara on the Solomon Islands. Regarding participation in PacIOOS, the APDRC contributes to the newly formed NOAA Integrated Data and Environmental Applications (IDEA) Center. The PacIOOS effort consists largely of serving integrated climate data for the Pacific region, and the APDRC is at the forefront of this activity.

APDRC Demonstrates New Uses of Unidata Technology

Unidata at UCAR is a key developer of data-archiving and data-serving technologies. Unidata, for example, developed the widely used netcdf format. The APDRC relies on Unidata's THREDDS server to aggregate data housed at remote locations. In other words, the data physically reside at other sites, for example at the Jet Propulsion Laboratory, but they are aggregated and served by the APDRC through THREDDS. This new technology gives users a more friendly, logical, and complete pathway to such aggregated data than before.

This use of THREDDS servers is still rare, and **Jim Potemra** was invited to attend the recent annual Unidata meeting to demonstrate how the APDRC uses Unidata products. The meeting was held in September and hosted by the IPRC. The Unidata newsletter featured APDRC's novel use of this Unidata product (**www.unidata.ucar.edu/newsletter/2006oct/index.html**).

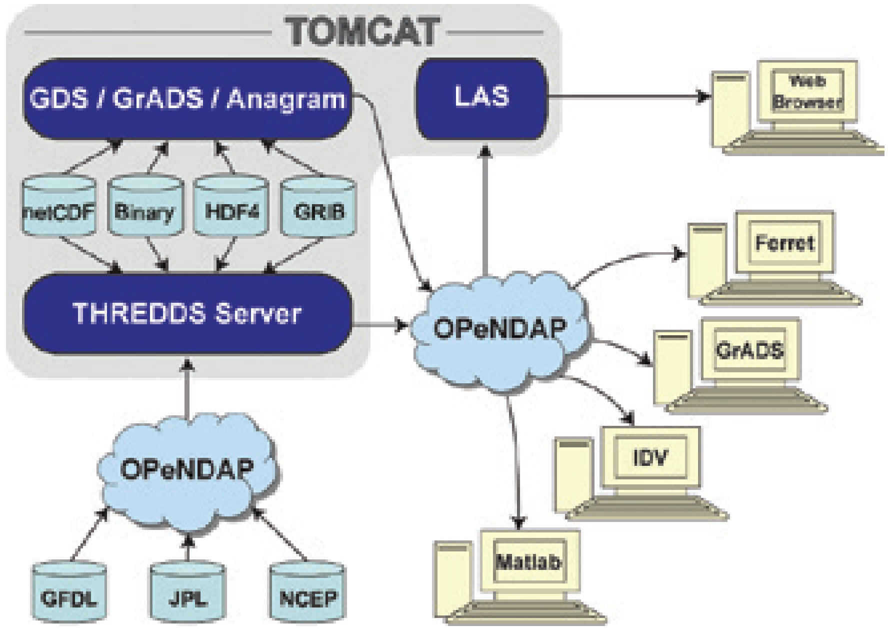


Illustration of THREDDS Server function: for example, NCEP runs a numerical model of the atmosphere every day, and places the output files on its OPeNDAP server. These files typically have the date as part of the file name, and the files might exist in separate directories for different years, or model runs. If a researcher wanted to make a timeseries of the model results, he would typically have to load each file for each day of interest. Using THREDDS, the APDRC can merge these files in a virtual sense, and the user then needs to only processes a single file to get a timeseries. The APDRC can also use THREDDS to present the data in a more meaningful way, for example through our data search tool, or pass it directly to the LAS server for web-based plotting.

A concern for users when data are archived in different locations is access speed because two servers are needed. To give users an indication of the access time, **Sherwin Gao** worked with **Yingshuo Shen** this summer to develop an automated method for determining remote access rates. These rates are now displayed for all data that the APDRC servers access on other (non-APDRC) servers.

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