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New high-performance computing plan signals a cultural (r)evolution

by Carol Rasmussen and Bob Henson

NCAR and UCAR have submitted a plan to NSF that will reshape both NCAR's computing and its institutional culture in the coming years. *A Strategic Plan for High Performance Simulation* encompasses not only how NCAR's modeling efforts can meet the coming challenges but how to create what is being called an "end-to-end simulation environment" within NCAR and UCAR.

The plan grew from the work of an NSF-appointed Code Assessment Panel that visited NCAR last summer. The panel, whose members were computer science specialists, was asked by NSF to review NCAR's key models from a software standpoint. Their report, issued in August 1999, stressed the need for change. As early as 1997, NCAR had begun a shift from vector machines toward distributed-memory, shared-multiprocessor (SMP) architectures with the introduction of a 64-processor Hewlett-Packard cluster; a 128-processor SGI Origin 2000 went into use in 1998. A much larger SMP machine, an IBM SP, was installed in August 1999, just after the NSF review was completed. While acknowledging the promise of the new IBM, the review panel asserted that NCAR would need to modify its model development strategies in order to remain a leader in its field.

The IBM SP, acquired last year, is an important part of NCAR's supercomputing strategies. (Photos by Carlye Calvin.)

"There was a genuine interest on the part of the leadership here in responding [to the report] in a positive way," says John Michalakes, a visiting computer scientist from Argonne National Laboratory who's been working at NCAR for over a year. Robert Serafin (then the director of NCAR) asked Steven Hammond, manager of the Computational Science Section of NCAR's Scientific Computing Division (SCD), to chair a committee that would prepare a strategic plan for high-performance simulation. Timothy Killeen joined the process shortly after becoming NCAR's director-designate.

Instead of looking at each point in the modeling process separately, the committee studied the entire computing environment "end to end," says Hammond. "There are some fundamental changes [proposed] in the plan."

What will change

"To some extent, the computational aspects of our models have been an afterthought," says Hammond. "The emphasis has been more on the phenomenological." That may have been natural in the early years of earth system modeling, when there were legions of scientific issues to be worked out before viable codes could be produced. But today's huge, multicomponent models like the

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President's Corner

Results from the UCAR survey of the community

From October 1999 through October 2000, UCAR and NCAR celebrated their 40th anniversary. UCAR management, the Board of Trustees, and the UCAR and NCAR directors used this milestone as an opportunity to reflect upon past achievements and to help set the agenda for the institution well into the 21st century.

To that end, this past May we conducted a survey of our constituent communities, with emphasis on the universities. We developed a Web-based survey with four parts:

- Part I asked about the background of respondents and how they had interacted in general with UCAR in the past.
- Part II asked respondents to indicate all specific UCAR programs or activities with which they had had some significant association over the past ten years.
- Part III included questions about challenges, issues, and future activities; these were based on the UCAR Forum at the October 1999 UCAR Members' Representatives meeting.
- Part IV asked questions about specific divisions or programs within NCAR and the UCAR Office of Programs (UOP) and about UCAR activities such as advocacy on behalf of the community. It was tailored to the specific experiences of the respondent, i.e., questions were included only for programs or activities that the respondent had indicated in Part II.

The response of the community was strong, with 599 people responding—29.2% of the 2,048 people asked. Most of the respondents were from universities, and most indicated atmospheric science/meteorology as their primary discipline. However, a significant number of respondents were from other disciplines such as oceanography, astronomy/solar physics, physics, computer science, and geology/geophysics. Many people provided thoughtful comments; these totaled approximately 3,000, covering 250 pages of single-spaced text!

A summary of the quantitative responses is presented at http://www.ucar.edu/may2000survey/PublicResults.html. To assure confidentiality, the statistical results are reported without the comments. In general, people wrote of their frustrations with graduate student recruitment, the importance of interdisciplinary efforts, and the attendant difficulties in obtaining funding for such efforts. They wrote about the need for student understanding of observations, data sources, and analysis; frustrations with low pay in our field compared to others; and the need for experimental science and basic as well as directed research.

While I realize that every person who looks at these results may arrive at somewhat different conclusions about what they mean, I would like to offer my personal interpretation of some of the results. First, and most important, the high response rate of nearly 30% and the very large number of comments indicate that the community has strong interest in UCAR activities and programs and in the issues raised in the survey. In addition, the results strongly demonstrate the interest of the community in a broad UCAR program of science, facilities, education, and outreach.

Past, present, and future interactions with UCAR

When asked to identify their relationship with UCAR over the past ten years, respondents indicated strong participation in all categories. The largest number of responses were from (1) users of data sets or data streams, (2) visitors to UCAR, (3) collaborators, (4) users of UCAR software, and (5) users of a community model. The strong showing of visitors, collaborators, and users of UCAR software and community models, who responded in greater numbers than users of UCAR's computational and observational facilities (though these were strong as well), confirms the importance of having a broad scientific program at the national center and UOP as well as first-class community facilities. This community interest in a broad UCAR was confirmed in Part III. When asked what additional or increased areas of service UCAR should consider, respondents showed widespread interest in all of the categories presented. Leading areas were (1) data sets and data streams, (2) educational and/or training materials, (3) community workshops on topics of interest, (4) provision of real-time data to universities, and—tied for fifth place—instrumentation and community models.

The community also indicated a strong interest in participating in UCAR activities. The types of participation cited most were (1) collaboration with UCAR scientists, educators, or other staff; (2) use of community models; participation in (3) UCAR governance activities and (4) educational activities; and (5) use of computational facilities.

Setting of research priorities

In Part III, respondents were asked to rate, on a scale of 1 to 5 with 5 being highest, how they thought research priorities *should* be determined and how they thought the priorities actually *were* being determined. In the "should be" category, respondents ranked societal need and the intuition and interests of individual scientists equally high (3.8) and higher than needs and priorities of the funding agencies (2.7). However, the perception of the respondents was that the actual priorities were determined more by the needs and priorities of the agencies (4.1) than by societal needs (2.8) or scientists' interests (3.3).

Interdisciplinary research

Not surprisingly (although the margin might surprise some), most respondents said that the present level and quality of interdisciplinary research should be increased (376 yes vs. 35 no and 114 undecided). However, the community felt by a relatively narrow margin that the academic community, including UCAR, was not organized adequately to support interdisciplinary research. There was a stronger perception that the agencies were not organized well to support interdisciplinary research.

Quality and quantity of graduate students

As indicated by other surveys and fora (see, for example, my "President's Corner" in the Spring 2000 issue of the *UCAR Quarterly*, http://www.ucar.edu/communications/quarterly/spring00/president.html), there is a widespread concern that the atmospheric sciences do not attract and keep the best and brightest students. This issue received more comments than any other in the survey and will be a subject of intense interest and attention by the UCAR community in upcoming years.

Balance of types of research

For over a decade, the atmospheric science community has expressed concern about the balance of research among observational, theoretical, and modeling science. The concern that there is not enough effort in the universities in observational science was brought up again at the UCAR Forum last year. The survey indicates that this concern is fairly widespread, with 282 saying that it is a significant problem, 181 saying that it is a minor problem, and only 28 judging it to be no problem. However, when asked more generally about the distribution of effort in field research, modeling, theory, and laboratory work, 147 agreed that the balance was appropriate, 124 disagreed, and 233 were uncertain.

Colwell, Leinen visit NCAR

NSF director Rita Colwell (left) and assistant director for geoscience Margaret Leinen (right) were on hand for UCAR/NCAR's 40th anniversary celebration in June. The two toured NCAR's Research Aviation Facility, where they met Al Schanot and RAF director Jeffrey Stith (back row) and scientist Theresa Campos (front center). Colwell and Leinen also held a town meeting for staff, and Colwell gave a public presentation on NSF's polar research. (Photo by Carlye Calvin.)

Relationship among the academic, government, and private sectors

The rapid growth of the private sector in meteorology and related fields over the past decade has created new challenges and opportunities. These include issues related to commercialization of government-sponsored intellectual property, data rights, and new opportunities for research support. Approximately 33% of the respondents said that they personally were collaborating with the private sector, indicating that there is a significant intersection of the academic and private sector communities. However, the survey suggests that the quality of these interactions could be improved. While respondents rated the quality of academic-government interactions high (3.7 on a scale of 1 to 5), they rated the quality of interactions between the private sector and the academic and government sectors considerably lower (2.5 and 2.6, respectively).

NCAR/UOP divisions and programs

Finally, the community provided much input into the individual divisions and programs of NCAR and UOP in Part IV of the survey. This input has been given to the senior management of the divisions and programs for their use in assessing the strengths and weaknesses of their programs and for planning for the future.

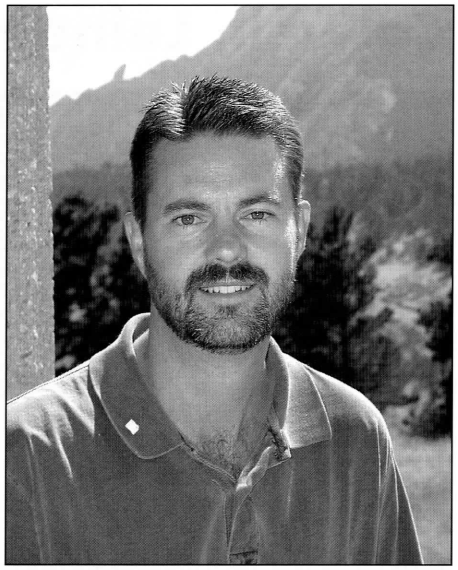
We express our sincere thanks to the people who took the survey. It took longer than we estimated, and we appreciate the time and thought invested by the respondents. The survey results will be useful in the development of a new NCAR strategic plan and a strategic plan for education and outreach as they unfold over this next year.

Rick Anthes

(continued from p. 1)
Community Climate System Model (CCSM) can't be developed or tailored to run optimally by a couple of scientists. The NSF panel proposed—and the NCAR committee agreed—that teams of scientists and software engineers are needed for model creation and development, from beginning to end.

Killeen points out, "During the time that NCAR has existed and models were being developed, computer science has grown out of its infancy to be a mature science. There's great strength now in theory, practice, applications, quality of service, networking, bandwidth utilization, and also on the details of how software gets developed and can be made agile. So you could say that now is the time to do this."

The new emphasis on computation will bring a greater "level of formalism in our modeling activities, consistent with [how we develop] field programs or observational programs," says Hammond. "There haven't typically been design reviews for our software. A lot of things that are part of the systematic process of software development in the commercial sector would be very beneficial to software projects conducted here."


Steven Hammond.

Equal to the scientific challenges ahead is the challenge of creating a social environment where the new interdisciplinary teams can thrive. "But we're good at putting together large teams with a shared vision," says Killeen. "A buy-in from the big community is a social organization feat that Maurice [Blackmon, director of NCAR's Climate and Global Dynamics Division] and his people have already accomplished" in developing the CCSM.

Another question is how to divide labor between the atmospheric scientists and computer scientists. One way is to confine each group's main concern to its own layer in the simulation code. The scientists concerned primarily with algorithms for dynamics and physics are able to work within one layer of the software hierarchy to code these in a standardized, platform-independent form. This leaves parallelism and other computational concerns to an implementation layer tailored to the machine at hand—primarily the domain of the computational specialists. The Weather Research and Forecasting Model (WRF; see p. 6) is being built in this way, with a mediation layer in between.

Frameworks (reusable collections of code) are being explored as a way to streamline the creation of these model implementation layers. NCAR is about to submit a three-year grant proposal to lead the development of an earth system model framework that could be used for multiple models, in collaboration with NASA, Argonne, the National Centers for Environmental Prediction, Los Alamos National Laboratory, the University of Michigan, the Massachusetts Institute of Technology, and NOAA's Geophysical Fluid Dynamics Laboratory.

NCAR staff had an opportunity to discuss these and other issues related to the new plan at a workshop on 31 August. Upcoming workshops are planned to involve university scientists and other community members.

Getting more computer scientists on board

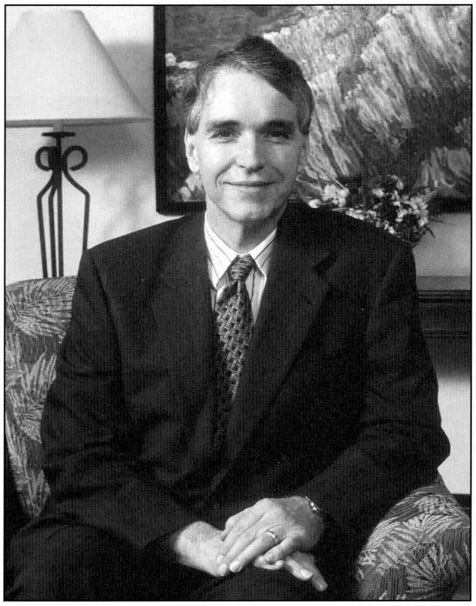
Computer scientists will be more involved at NCAR than ever before. "We're working through a strategy of how to make that happen," says

Next-generation CCSM slated for 2001

Even as NCAR's approach to modeling is being examined, model development continues. The next generation of the Community Climate System Model, developed and supported by NCAR's Climate and Global Dynamics Division, will be designed over the next 18 months, with support from the U.S. Department of Energy (DOE). "We're starting to bring the pieces together," says CGD senior scientist Byron Boville. "We are pushing to have a model at the end of the year which will be running on [NCAR's] IBM," the distributed-memory computer acquired last year. Early next year, CGD hopes to carry out a 1,000-year control run on the CCSM-2. It would be based on preindustrial conditions in order to determine the model's internal variability.

To create the CCSM-2, about 15 people from NCAR and five DOE labs are collaborating on the Avant Garde Project, part of the DOE Accelerated Climate Prediction Initiatives. The project is merging the CCSM with the DOE-supported Parallel Climate Model, originally developed by NCAR's Warren Washington and Gerald Meehl. NCAR has worked with Argonne and Oak Ridge National Laboratories to create software engineering guidelines for the entire model: requirements, documents, unit testers, validation code, and the like.

The newly released *Community Climate System Model Plan 2000–2005* offers details on how these and other advances will be accomplished. It's available on the Web at http://www.cgd.ucar.edu/csm/csmplan2000.



Tim Killeen.

Killeen. His office is hiring a distinguished visiting computer scientist for an initial term of about one year to help with that process.

Killeen believes that the problems we'll be offering to computer scientists are right up their alley. "You have this inhomogeneous set of providers and software; different pieces of the coupled model have very different requirements of memory; [there are issues of] storage, computational efficiency, parallelizability, swapping in and out of memory . . . that's what turns [computer scientists] on. They write papers about how to do that."

Michalakes and NCAR scientist Joseph Klemp work together in exactly the kind of team that's called for in the NCAR plan: the WRF model development group. Michalakes says that for him, "The attraction of the WRF project is that there's a genuine partnership between the scientific members of the team and the software engineering members." Klemp also sees collaboration as its own reward, and he adds that "a sincere interest in the scientific goals of the organization" is likely to attract the right people. Both warn, however, that part of the reason their team works is that "those who wanted to get involved did, and the structure was imposed later," as Michalakes puts it. Efforts that are organized from the top down may meet more pitfalls, they note.

The bottom line

It's estimated that the software engineering changes outlined in the NCAR plan would cost several million dollars a year over five years, and there's no slack in NCAR's budget for it. On the contrary, NCAR modelers are already stretched trying to carry out the community-service aspects of their models without eroding the organization's basic-research agenda, says Klemp. "Somehow we need a mechanism to support these models as facility resources."

Many NCAR and UCAR groups are seeking grants to help in the transition. Proposals are due by December for NSF's Information Technology Research (ITR) program, which is offering grants ranging from single-investigator projects (total budgets below $500,000 each) to large-institution proposals (up to $15 million over five years). The topics include complex geophysical coding, data assimilation, collaboratories, and accessible visualization tools. Killeen has asked SCD to lead the coordination of the development of a large-institution proposal for NCAR. "It'll probably build upon the themes laid out in the high-performance strategic plan as well as other initiatives under way at NCAR," says SCD director Al Kellie. "Some early thoughts are that NCAR could really serve the geosciences community if we could achieve much better efficiencies for our applications on highly parallel, microprocessor-based systems. We need to crack some of the barriers that have been in the way of using these machines." He believes that one of the keys to crafting the proposal will be "to seek strong partnerships with universities and potentially other centers."

Killeen notes that NCAR will also need more flexibility within its core funding. "There definitely has to be a lot of permeability at the boundaries among the divisions, and there already is. We need structures that facilitate cross-divisional and cross-disciplinary interactions," such as those in place in NCAR's Environmental and Societal Impacts Group and Advanced Study Program.

Only the first step

The simulation plan is a crucial piece of the growth he envisions for NCAR, says Killeen, but it's not the whole thing. "It's a first, earnest step toward something that is more comprehensive yet: a plan for a knowledge-system approach. What do I mean by that? It's where scientific simulation is part of [an on-line environment that also encompasses] learning modules, data access, visualization, a general workspace, collaborative tools that support the acquisition and dissemination of knowledge about the earth system. That ties in with the whole information technology revolution, where NCAR just has to be."

Killeen believes that these changes come at an opportune time. "There is a special opportunity now to help define the national agenda in [our] areas [of expertise] and help define the connections between environmental science and information sciences. We have to think hard and get our story straight so we can demonstrate continued leadership."

Killeen has already established the overall theme of the upcoming strategic plan: NCAR as integrator. "Even a national center as well endowed in terms of people and materials as NCAR cannot handle it all, and shouldn't anyway," he says. "Our role is to be a player and often a leader in the development of new science, and I think that [role] requires NCAR to put together consortia and then to learn how to collaborate most efficiently with its partners." ❋

WRF Model ready for beta testing

by Carol Rasmussen

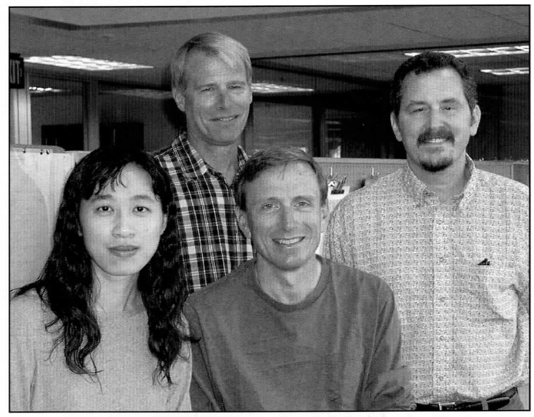
A "bare bones" version of the Weather Research and Forecasting Model, a groundbreaking meso- and finer-scale model for both operational and research meteorologists, will shortly be released to a group of interested users. This group will contribute to the model's further development.

WRF development has been a collaboration among scientists at NCAR's Mesoscale and Microscale Meteorology (MMM) Division, NOAA's National Centers for Environmental Prediction (NCEP) and Forecast Systems Laboratory (FSL), the University of Oklahoma's Center for Analysis and Prediction of Storms, and the Air Force Weather Agency. WRF will offer resolution that's about an order of magnitude better than existing operational mesoscale models. "When we look down the road to greater computer power, we want to have horizontal grids of a couple kilometers so we can resolve small-scale weather features as they're evolving," says Joseph Klemp, who is leading the development effort at MMM.

The bare-bones version has a basic set of physics packages and standard real-data initialization for the users to work with. Getting this version ready for release has been a tradeoff, Klemp says. "We'd like interested users to contribute to the development process, but we don't want to frustrate them. They have to understand it's not the final version." For example, the physics packages that were ported to WRF had to be recoded to interface with WRF's other layers, so "there may be interaction problems."

WRF has a three-layer structure. John Michalakes, a visiting computer scientist from Argonne National Laboratory who is doing WRF development in MMM, explains: A driver layer deals with computer architecture (and also such issues as managing nested grids) so that the user can run the model on distributed-memory, shared-memory, vector, or cluster machines without having to modify it. Theoretically, WRF's driver layer could be used for other models—including general circulation models. However, Michalakes points out that it would have to be modified to deal with, for example, spectral transforms and coupling among component models, since these features don't yet occur in WRF.

Scientists who focus on the algorithms for physics and dynamics can work solely in the other main layer. Joining this "model" layer to the driver layer is a "mediation" layer, which Michalakes describes as "a glue layer that has to know a little bit about both other layers so they can interact."



The WRF team includes (left to right) Shu-Hua Chin, principal implementer of model physics; overall coordinator Joseph Klemp; William Skamarock, head of the working group for dynamic model numerics; and John Michalakes, head of the working group for software architecture, standards, and implementation. Not shown are Jimy Dudhia, head of the working group for workshops, model distribution, and community support; and Dave Gill, implementer for Web pages and real-data testing. (Photo by Carlye Calvin.)

This structure gives WRF a flexibility that will be needed to serve both researchers and forecasters. The idea of a product that could meet the needs of these disparate groups grew from a more modest collaborative effort in MMM. "Within the division, we typically have had half a dozen [separate] models of significant complexity," says Klemp. "We had cloud-scale models for basic research in idealized applications, and the MM5 [Mesoscale Model 5] was good for real data but not for idealized simulations. In research, you often start with a very simple, idealized problem and work your way up to the full-blown problem. We could see the value of doing all that on a single model."

As cloud and mesoscale modelers in MMM began talking about pooling their resources, they recognized that their product might also reduce some of the delays that typically take place between the birth of an innovation in the research community and its adoption by operational meteorologists. "There was rapid recognition among all of the participating organizations that there was value in developing a common modeling system," Klemp says. "With WRF, at least there's a potential for streamlining a lot of technology transfer."

The development effort for WRF is impressive in several respects. For one thing, it has gotten started without a lot of WRF-specific funding. "We've been trying to forge ahead on the resources available," says Klemp. That has certainly had an impact on the pace of work: "A few critical people are moving things forward, so when someone takes a two-week vacation, it throws our schedule back two weeks."

For NCAR, it may be more significant that the development team, which includes software engineers and scientists, works together very well (see p. 4). Klemp says, "Our success is in developing a real team attitude. [The engineers] don't just tell us what to do and leave us to do it or not; there's a lot of going back and forth until we agree on the best way to do it." Michalakes concurs: "There's a joint appreciation, respect, and feeling of ownership by the respective members of the team."

More information on WRF can be found at http://wrf-model.org. ✵

What makes SOARS a standout?

by Zhenya Gallon

Many programs designed to interest students from underrepresented communities in academic and professional science have some of the same features that SOARS does, but none offers its complete blend of personal attention, community building, flexibility, and multiyear support. That's the consensus of educators and administrators whom we asked to comment on UCAR's Significant Opportunities in Atmospheric Research and Science program, now in its fifth year.

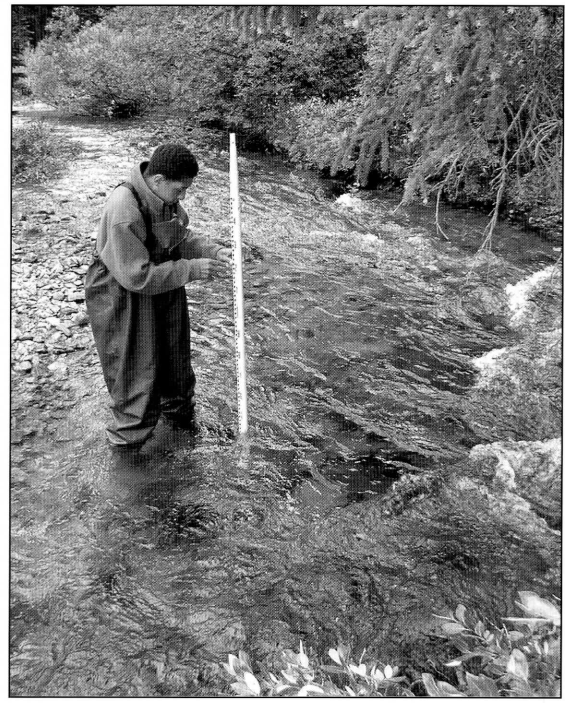
SOARS supports students during the last two years of their undergraduate training and first two years of graduate school. UCAR has built partnerships with NSF, the U.S. Department of Energy (DOE), NASA, NOAA, and the UCAR university community to create a year-round program that includes a ten-week paid internship each summer at NCAR or another national lab. This year 39 students, known as protégés, are enrolled; 23 of them were in Boulder this summer.

The number of mentors per protégé is one of the features that sets SOARS apart. Approximately 70 staff members, mostly at UCAR and NCAR but also at other participating national labs, volunteered as either science research, scientific writing, or community mentors this year. There's a fourth mentor assigned to all incoming SOARS students: a peer who has been in the program for a year or more.

As a program coordinator in NSF's Division of Atmospheric Sciences, Jewel Prendeville is familiar with many internship programs that can only provide one mentor for many students. "In SOARS, the ratios are reversed: one student, many mentors," she notes. That really sets the program apart.

According to John Snow, the intensive mentoring does the students "a lot of good." Snow, the dean of the College of Geosciences at the University of Oklahoma, taught an OU student who participated in SOARS. "I think the experience she had over three summers gave her a lot more professional poise and maturity," he says.

"SOARS is a learning community structured around the mentoring process," explains Tom Windham, the program's full-time director (a position that many other programs do not have). Windham has conceptualized and facilitated the development of a community whose members all learn from each other. A social psychologist by training, Windham has combed relevant research in search of ingredients that have proved significant in helping students from historically underrepresented groups succeed at higher levels. But the concept of a learning community predates that research, and Windham readily cites the now-familiar African proverb that it takes a whole village to raise a child.



Protégé Kevin Green sampled the headwaters of Boulder Creek this summer to study the relationship between streambed mobility and invertebrate abundance in mountain streams. Green says, "Through working with my science research mentors, I gained insight, knowledge, and a broader understanding of science." (Photo by Carlye Calvin.)

A flexible, student-centered approach

Windham "has shown a great deal of flexibility in allowing protégés to follow their own interests at their own schedules," says Prendeville. "He flexes the program to fit the student rather than forcing the student to fit into a narrow mold, and I think that's been very productive."

At Windham's request, NSF and the other sponsoring agencies visit the program annually and receive a considerable amount of feedback from protégés and mentors. That level of interchange between participants and sponsors is rare. Because feedback is so important to the SOARS model, the SOARS staff builds in midcourse appraisals and final evaluations for all participants. Over time, the returning protégés can see their previous year's suggestions integrated into the program. That level of student influence is also rare.

"It's not a one-shot deal"

"Another big strength," says Snow of the program, "is that SOARS is in it for the long run. It's not a one-shot deal." Snow sees multiyear support as essential if the atmospheric scientific community is to be successful in attracting and retaining a diverse professional workforce. Barbara Kraus agrees. She's coordinator for the University of Colorado's Summer Multicultural Access to Research Training program. SMART offers mentoring and community-building activities, but right now students come for one summer. Kraus views the four years of support SOARS offers as a way to keep students "hooked into the pipeline" that leads to a research career. In her experience, the high salaries of summer internships in industry prove tempting to many science and technology majors, who then choose industry over graduate school. By keeping students involved for four years and offering up to 50% support for the first two years of graduate training, SOARS provides "a strong incentive to go on, rather than drop out."

Kraus also praised the personal attention Windham gives to each SOARS protégé. "It takes that kind of one-on-one—of someone watching over you, looking out for you, pushing you along," she says. "It makes a difference." Kraus has observed Windham's ongoing encouragement first hand as two SOARS students have entered Ph.D. programs at CU.

The flattery of imitation

Jeffrey Gaffney, chief scientist for DOE's Global Change Education Program (GCEP), has served not only as a DOE representative but also as a science research mentor for SOARS protégé Cherelle Blazer, who spent the summer of 1999 working with Gaffney at DOE's Argonne National Laboratory in Chicago. Gaffney visited Boulder last year and came away with the impression that "the mentoring program within SOARS was giving the students a feeling of belonging to a greater whole.... It was clear that the program was connecting with undergraduates and encouraging them to enter graduate school in [atmospheric science]." His observations and experiences led Gaffney to adapt the SOARS model in designing GCEP's Summer Undergraduate Research Experience.

The SOARS model is exceptional at this moment. With only six alumni, SOARS is still learning from the experiences of its community of protégés and mentors. There are challenges for those who might want to adopt the SOARS model elsewhere, including issues of size (how large can a learning community get?) and expense (where will the salaries for protégés, which match the pay scale of the hosting lab, come from?). But the interest and support from sister programs and sponsoring agencies suggest that the success of SOARS, and not its uniqueness, is the attribute worth fostering. ❋

Science Bit

Greenland ice cores show natural changes; Himalayan cores show human influence

Almost three years ago, Curt Davis (University of Missouri–Columbia) discovered that some areas of the southern Greenland ice sheet varied dramatically in elevation over a ten-year period. An extensive study by a team of scientists, including Davis, has now found that weather, not long-term climate change, is the cause of these variations. The findings were reported in *Nature* in August.

"When we released our original findings, they were somewhat controversial," said Davis, who has been using satellite data since 1990 to study changes in the ice sheet. "Our data indicated that overall, the ice sheet was maintaining a constant elevation, but we found great variability over short distances, with substantial thickening in some areas and strong thinning in other areas." After his study was released, Davis and a group of researchers led by Joe McConnell (Desert Research Institute) joined together to investigate the cause of the variability in elevation. Other participants in the study were from the University of Washington, Ohio State University, the University of Arizona, and the University of Nebraska. Funding was provided by grants from NASA and NSF.

Using ice cores from 45 to 400 feet (15 to 130 meters) deep that were collected from 12 locations around the southern Greenland ice sheet above 6,000 feet (1,800 meters) in elevation, the researchers measured variations in the concentrations of dust and chemical compounds such as hydrogen peroxide, calcium, and ammonium. The researchers used this analysis to determine the amount of snow that accumulated each year over the time span of the cores. Ice core analysis and modeling revealed that areas where elevation changed dramatically had a corresponding variation in snowfall during the study period. Further analysis indicated these snowfall variations were consistent with natural fluctuations over decades.

A separate study by Lonnie Thompson (Ohio State University) used ice cores drilled through a glacier more than 4 miles (6.4 kilometers) up in the Himalayan Mountains. According to these cores, which give a highly detailed record of the last 1,000 years of climate in the Tibetan Plateau, both the last decade and the last 50 years were the warmest in that entire period.

"This is the highest climate record ever retrieved," Thompson said, "and it clearly shows a serious warming during the late 20th century, one that was caused, at least in part, by human activity."

The cores also revealed periodic failures of the South Asian Monsoon. In 1790, the monsoon cycle changed, and drought took hold on the plateau, a condition that continued for seven years until 1796, when the monsoons returned.

"That event was major," Thompson said. "It killed more than 600,000 people in one region of India alone. And that was at a time when global populations were much less than they are today [an estimated 980 million in 1800]. If a similar event occurred today, the social and economic disruptions would be horrendous." The ice core record showed other serious monsoon failures and ensuing droughts in 1876–77 and around 1640, 1590, 1530, 1330, 1280, and 1230, though none was as devastating as the 1790 event. Thompson's paper on the research, published last month in *Science*, offered no indications of what might have triggered the monsoon failures.

The data, however, do seem to point to the impact human activities have had on the region's climate. Core samples covering the last century reveal a fourfold increase in dust trapped in the ice and a doubling of chloride concentrations, suggesting an increase in both drying and desertification in the region.

The core-drilling expedition was supported by NSF.

University of Missouri, Ohio State University

Basic and applied science at HAO

by Robert Rosner

Editor's note: To celebrate NCAR and UCAR's 40th anniversary, the UCAR Quarterly *is publishing articles by distinguished scientists about their interactions with our people and facilities. Robert Rosner is currently the William E. Wrather Distinguished Service Professor in the astronomy/astrophysics and physics departments of the University of Chicago and its Enrico Fermi Institute. His research has involved analysis and modeling of solar and stellar observations and the study of fluid behavior in the laboratory and in space, especially in the context of stellar convection and stellar magnetic field generation.*

Anyone visiting the High Altitude Observatory will immediately sense that HAO is different: It is much more akin to a university academic department than one would ordinarily expect of a research division at a national laboratory. I would like to discuss the origins of this difference and to comment on the justifications for maintaining it—indeed, for celebrating it.

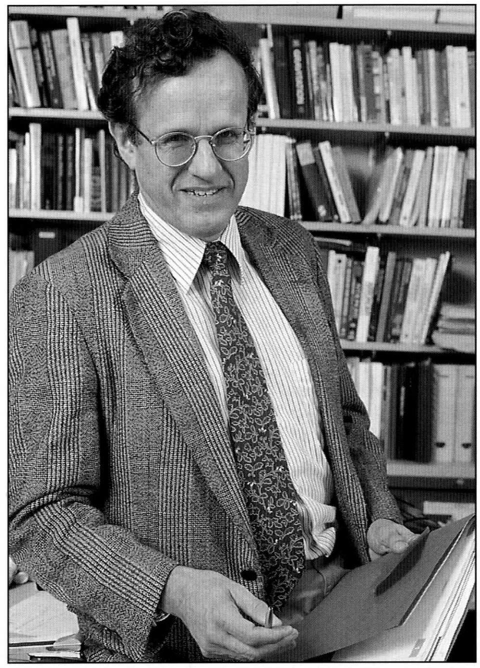
Astrophysics as a discipline separate from astronomy had its origins in the elucidation of visible-light spectra from the Sun and stars. A number of the giants of 19th-century U.S. physics understood the tremendous potential importance of spectroscopy in revealing the fundamental nature of matter. These early studies largely regarded the Sun as a representative astronomical object. Relatively few scientists paid attention to the Sun in itself or as the driver of activity within the solar system. Charles Abbott's work on the terrestrial impacts of the Sun, for example, was isolated from the mainstream of astrophysical—or even solar—research.

With the advent of quantum mechanics in the 1920s, it became possible to establish quantitative connections between observations of solar spectra and physics questions such as the elemental composition of the solar surface. Observations of the Sun, especially of the solar corona, played an important role in the development of atomic physics. Two scientists centrally involved in the founding of HAO were in the thick of this research in the late 1930s: Donald Menzel, a professor of astronomy at Harvard and the director of the Harvard College Observatory, and his student Walter Orr Roberts. Harvard established HAO in Climax, Colorado, to improve observations in this field. The coronal observations from Climax set the theme for much of the science carried out by HAO to this day; the HAO's coronal section is the standard-bearer of this branch of solar research.

Thus, originally, HAO was a remote station for a quintessentially academic research program. Its sole reason for existence was its contributions to the furtherance of basic science objectives. HAO's science program was entirely developed internally, with no need to justify itself to any external agents, and the quality of the science was the sole benchmark by which the observatory was judged. Over the 60 years of HAO's existence, this academic model has continued to influence the way science is carried out there.

The view that the Sun is interesting in its own right, without additional justification, motivated most of the expansion of HAO's research areas since its inclusion in NCAR: the fundamental work on radiative hydrodynamics, the solar wind, the solar dynamo, helioseismology, and (most recently) stellar activity. With this perspective on solar physics, it is not surprising that HAO has played an important role—in some areas at some times, the dominant role—in the field internationally. In certain important subfields of astrophysics, such as theoretical and observational radiation hydrodynamics, it is today the primary institution in the United States.

Walt Roberts was partly motivated to join HAO with NCAR, however, for



Robert Rosner.

a different kind of research: to investigate the terrestrial impacts of the Sun. In this area, I contend that Roberts was extremely insightful but demonstrably scientifically premature. Connections between solar activity and terrestrial phenomena of climatological or meteorological significance have proven to be extremely subtle and difficult to establish. Nevertheless, with modern observational tools and analysis methods, such connections are now being established. With these successes, I predict that solar physics within HAO will experience, to a much greater degree than heretofore, the (hopefully creative) tension that seems to naturally arise between the basic and more applied sciences. The challenge for HAO will be to balance the historical pressure for excellence in basic solar science with the increasing pressures for practical relevance.

The tension between basic, unfettered research and applications-driven research has existed to some extent since HAO joined NCAR, and, of

(Continued on p. 12)

Real-time acquisition and archival of WSR-88D base data

by Kelvin K. Droegemeier

Kelvin Droegemeier is a professor in the School of Meteorology at the University of Oklahoma and director of the university's Center for Analysis and Prediction of Storms. This article is a shortened version of one to appear in the Bulletin of the American Meteorological Society.

With the completed installation of 120 National Weather Service (NWS) WSR-88D (NEXRAD) Doppler radars—and additional NEXRAD radars sponsored by the Department of Defense and Federal Aviation Administration also in place—the United States now has a unique observing system that provides nearly continuous single-Doppler radar coverage across the continental United States. The superb sensitivity and sophisticated processing algorithms of these radars, and advanced user training, have led to a substantial improvement in the identification and short-term warning of hazardous weather.

Although the NEXRAD radars were intended as real-time surveillance systems, scientists soon recognized their value for research, especially that of full-volume, full-precision base data (also known as Level II data; the number differentiates them from the unarchived raw Level I data and the Level III products known as NIDS). As an interim strategy for archiving the Level II data for researchers and other users, the NWS outfitted each radar with an 8-mm tape cartridge recording system.

For many years, the National Climatic Data Center (NCDC) has been making base data available, via these tapes, to the national atmospheric science community. Unfortunately, this process is extremely human-resource intensive (six steps are required to process a single tape), costly (the retrieval of a single data set covering several weeks can cost thousands of dollars), slow (obtaining a single data set can take several weeks), and unreliable (the national data archival rate for NWS radars is only 65%, due in large part to the use of tape recording systems that were not designed for continuous use in the field).

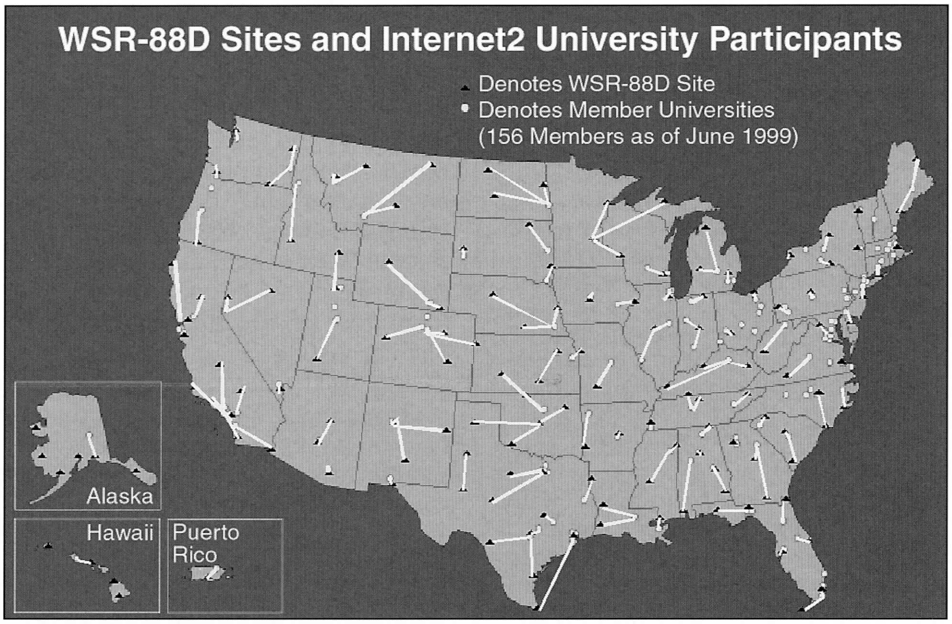


Figure 1. Overlay of NEXRAD radars and Abilene universities. The average distance between a NEXRAD and the nearest Abilene university is only 56 miles (80 kilometers).

To provide real-time base data for evaluation in storm-scale numerical weather prediction, and to begin addressing the problem of archiving base data over the long haul at the NCDC, the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma (OU) joined forces in 1998 with UCAR, the University of Washington, the National Severe Storms Laboratory (NSSL), and the WSR-88D Operational Support Facility to establish the Collaborative Radar Acquisition Field Test (CRAFT). Funded initially by a grant from the Oklahoma State Regents for Higher Education, CRAFT is an experiment in the real-time compression and Internet-based transmission of NEXRAD base data from multiple radars. The initial test bed of six radars has been delivering data continuously for over a year with virtually no outages. These radars are located at Oklahoma City and Tulsa, Oklahoma; Fort Smith, Arkansas; and Fort Worth, Lubbock, and Amarillo, Texas.

CRAFT leverages two important infrastructures to achieve low-cost, reliable transmission of base data in real time. The first is the Unidata Local Data Manager (LDM) software, created by UCAR, which runs on standard PCs or workstations. LDM is used by many universities and by several elements of the NWS to acquire meteorological data. It has the ability not only to transmit data onto the Internet from a given node, but to pass on data from other nodes as well.

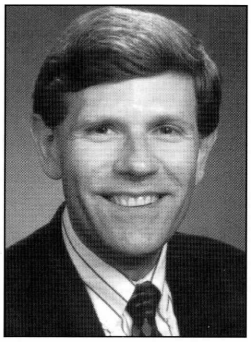
A unique aspect of CRAFT is the addition to LDM of the second of these infrastructures: an off-the-shelf, lossless data compression algorithm, BZIP2. This algorithm compresses the base data in real time down to an average of 1/12th their original size for transmission over low-bandwidth phone lines. In light of the fact that a single 5- or 6-minute volume scan never exceeds about 15 megabytes, the data compression achieved is more than adequate for a 56-kilobit-per-second phone line, even in the most extreme situations (e.g., a hurricane). Indeed, the aggregate compressed base data rate for the entire national WSR-88D network is only 30-40 megabits/sec, so bandwidth is not an issue. Data decompression is performed in real time at the recipient end. In the event of communications failure, the LDM personal computer at the radar site will store and then retransmit up to four days' worth of data. This amount can be increased by increasing the capacity of the local disk.

In June, the NCDC began receiving compressed base data in real time from the 6 CRAFT radars via the commodity Internet. Recently another 6 radars were added, and now all 12 are sending data to the NCDC, where the data are directly and automatically archived on the long-term mass storage system.

Recently, CAPS, NSSL, and the NCDC were awarded a NOAA Environmental Services Data and Information Management grant to expand the successful CRAFT concept for eventual application to the entire NEXRAD network. This new effort, known as CRAFT-2, takes advantage of two major national networking infrastructures, Internet2 and Abilene. Internet2 is a consortium of nearly 200 universities involved in developing new tools and applications for the Next Generation Internet, and Abilene is a high-capacity network backbone that supports these efforts.

An overlay of Internet2 universities and the NEXRAD network reveals that the average distance from any radar to the nearest Internet2 node is 56 miles (80 kilometers; see Figure 1). If a 56-kilobit/sec phone line can be run from each radar to the nearest Internet2 node via collaborative arrangements with regional networks, the CRAFT concept can be immediately reproduced, at relatively low cost, nationwide. Once the base data arrive at an Internet2 site, they can be transferred to the high-speed Abilene backbone where they can be made available to all users. To access data from a particular radar, users will simply enter the appropriate radar LDM/IP address into their local LDM system.

Selected sites on Abilene, such as high-priority NOAA facilities and universities, will serve as transfer points for the entire data stream, while "satellite" nodes not linked directly will obtain base data via the commodity Internet for as many radars as available bandwidth allows. As networking capabilities in the United States continue to expand,



Kelvin Droegemeier.

Science Bit

Link found between El Niño and Bangladeshi cholera outbreaks

About 11 months after the start of an El Niño event in the equatorial Pacific, hospitals thousands of miles away in Bangladesh can expect a surge of cholera cases, according to the first mathematical model to link climatic cycles with subsequent cholera outbreaks. Details of the climate-disease model were reported last month in *Science*.

"We aren't yet seeing a return to the time when cholera was such a scourge of humanity," says Stephen Ellner of Cornell University. "But we are getting an explanation for outbreaks of cholera and diarrheal diseases in South America and the recent, higher-than-historic levels of cholera in South America and Asia." Ellner provided the model for the study. His coauthors are Mercedes Pascual (University of Maryland), Xavier Rodo (University of Barcelona), Rita Colwell (director of NSF and professor at the University of Maryland), and Menno Bouma (University of London).

Cholera is caused by a bacterium that lives among zooplankton in brackish waters and in estuaries and infects humans through contaminated water. Colwell previously had proposed a link between cholera outbreaks and El Niño–Southern Oscillation (ENSO) events involving increased sea-surface temperatures and higher numbers of bacteria-bearing zooplankton.

Data on cholera incidence, which normally can rise and fall twice each year with local influences such as monsoons and seasonal temperature changes, came from a hospital in Bangladesh that had tested all incoming patients for cholera from 1980 to 1998. The Ellner model took into consideration recent frequencies of cholera cases, an ENSO index based on sea-surface temperatures in the Pacific, and seasonal variation in local climates.

Peaks in cholera incidence at the Bangladesh hospital were found to occur every 3.7 years—exactly the same frequency as of ENSO events between 1980 and 1998. A separate analysis of climate variables by coauthors Pascual and Rodo—including humidity in the troposphere, cloud cover, and the amount of absorbed solar radiation—suggested that the 11-month lag breaks down into a 6-month lag between an El Niño and increases in sea-surface temperatures off the coast of Bangladesh plus a 5-month lag between increased sea-surface temperatures and a peak in cholera.

This discovery comes at a time when some ecologists are predicting major increases in disease and death as global climate change provides ideal conditions for disease-causing organisms. Although public-health authorities will now have an 11-month advance warning beginning when an El Niño starts, Ellner says, "this model will be more useful when somebody figures out how to predict El Niño."

The study was supported in part by grants and fellowships from the James S. McDonnell Foundation, the Knut and Alice Wallenberg Foundation, and the Mellon Foundation.

Cornell University, University of Maryland, University of Barcelona, University of London

bandwidth limitations are likely to vanish entirely.

Besides the 6 radars recently added to the original group, CAPS and the NSSL plan to add about 24 more radars to the Internet2/Abilene infrastructure as part of CRAFT-2. The broad geographic distribution will provide an acid test of overall reliability, network efficiency, and real-time ingest at NCDC (and, eventually, NCEP). As part of this effort, NSSL and OU will improve the radar data-compression algorithms to accommodate the larger data sets associated with dual polarization and more dense scanning strategies. We will also work toward implementing the LDM-based data compression and transmission capabilities in the new NEXRAD Open Systems architecture.

Real-time base data will be of rather limited value if not accompanied by suitable analysis tools. Consequently, we are starting to explore the application of data mining techniques to base data, and the creation of synthetic climatologies and other metadata sets by running storm-feature identification algorithms on the data as they arrive from the radar. We may also create one or two sites that would maintain two or three years' worth of base data online for immediate perusal and download. ❋

Science Bit

Carbon dioxide could replace hydrofluorocarbons as refrigerant

Researchers are making progress in perfecting automotive and portable air-conditioning systems that use carbon dioxide as a refrigerant instead of conventional, synthetic chemicals. CO_2 was the refrigerant of choice during the early 20th century. Now it may be on the verge of a comeback, thanks to technological advances that include the manufacture of extremely thin yet strong aluminum tubing.

Although CO_2 is a greenhouse gas, conventional refrigerants called hydrofluorocarbons cause about 1,400 times more global warming than the same quantity of CO_2. Also, the tiny quantities of CO_2 that would be released from air conditioners would be insignificant compared to the huge amounts produced from burning fossil fuels for energy and transportation, says Eckhard Groll (Purdue University). This summer, Groll chaired the Gustav Lorentzen Conference on Natural Working Fluids, at which Purdue engineers discussed their progress on designing and assessing a portable CO_2-based air conditioner.

CO_2 is promising for systems that must be small and lightweight, such as automotive or portable air conditioners. CO_2 systems must be operated at high pressures—up to five times as high as commonly seen in current technology. The high operating pressure required for CO_2 systems enables the refrigerant to flow through small-diameter tubing, which allows engineers to design more compact air conditioners. In the past, however, heavy steel tubing had to be used. Now, extremely thin yet strong aluminum tubing can be manufactured, reducing the weight of the unit.

Environmental regulations now require that refrigerants removed during the maintenance and repair of air conditioners be captured with special equipment, instead of being released into the atmosphere as they have been in the past. The new "recovery" equipment is expensive and will require more training to operate, important considerations for the U.S. Army and Air Force, which together use about 40,000 portable field air conditioners. The units, which could be likened to large residential window-unit air conditioners, are hauled into the field for a variety of purposes, such as cooling troops and electronic equipment.

"For every [conventional] unit [the armed forces] buy, they will need to buy a recovery unit," Groll says. "That's a significant cost because the recovery unit is almost as expensive as the original unit. Another problem is training. It can be done, but it's much more difficult than using carbon dioxide, where you could just open a valve and release it to the atmosphere" since it is a natural, comparatively benign gas.

Groll estimates that CO_2 systems will take another five to ten years to perfect. His work is funded by the U.S. Army, U.S. Air Force, and the American Society of Heating, Refrigerating and Air-Conditioning Engineers, as well as the Air Conditioning and Refrigeration Technology Institute.

Purdue University

(continued from p. 7)

course, it pervades much of what NCAR is about as well. From its inception, however, NCAR has strongly connected with the larger atmospheric sciences community on a wide variety of fronts, including the definition of its science programs. To the extent that HAO succeeds in Walt Roberts's scientific ambitions, it will feel increasing pressure to expand its community-based outlook.

It is my view that applications-oriented science best maintains rigor and discipline when it is closely coupled to a basic science component. But it is also my view that the basic sciences strongly benefit from this kind of coupling as well: The applications provide motivations and directions that the basic sciences at times cannot provide internally. For these reasons, as the connections between solar physics and the atmospheric sciences grow stronger and are placed on increasingly firmer quantitative grounds, I see HAO in a unique position to benefit both itself and the larger scientific community. I therefore salute HAO and its scientists for what they've wrought; and I am excited about their future. ❋

Model sheds new light on solar cycle

by Carol Rasmussen

A new model has pinned down the explanations of some of the solar cycle's curious characteristics: Intense cycles are short and weak cycles long, and strong and weak cycles alternate in a manner that's not random. The model, developed by Paul Charbonneau and Mausumi Dikpati of NCAR's High Altitude Observatory (HAO), is an updated version of a type of solar dynamo model that fell out of favor some 30 years ago. The scientists' results appear in the October *Astrophysical Journal*.

Solar cycles vary from 9 to 14 years in length. Over time, however, they never depart from the 11-year average cycle length for more than a couple of cycles—much less than a random series would. "It's been said that the sun has a clock and the clock is always adjusted," says Dikpati. She and Charbonneau are the first to succeed in simulating this behavior.

The cycles are caused by changes in the sun's magnetic fields, whose behavior is far more complex than that of the earth. A large-scale, toroidal (doughnut-shaped) magnetic field wraps around the sun's rotational axis like a belt, with the inside edge of the doughnut extending into the solar interior. "The toroidal field is easy to observe," says Charbonneau. "You can see it by looking at sunspots." This field reverses polarity about once every 11 years. The sun also has a weaker, poloidal (bar-magnet-shaped) field—the same shape as the earth's magnetic field—which also flips poles every 11 years. This field is usually inferred from structures in the solar corona rather than measured directly, which is hard to do from the earth's viewing angle.

The theory on why these two fields switch back and forth in sync, Charbonneau explains, is that the poloidal field is transformed into a toroidal field, which then turns back into a poloidal one of the opposite polarity, and so on. Modelers have long been able to reproduce the transformation of a poloidal to a toroidal field. "It's not that hard to model the sun's fluid center and shear regions," says Charbonneau. "If you shove a magnetic field in [the model], it behaves like a Slinky"—the north-south field gets stretched further and further until it wraps around the rotational axis.

The hard part has been understanding and modeling the change back from a toroidal field to a poloidal field. Most solar dynamo models rely on small-scale convective turbulence to do the job, but that would require a relatively weak magnetic field in the solar interior, contrary to observational evidence. Also, with these models, a stronger solar cycle takes longer to dissipate and a weaker one is over sooner—the opposite of reality.

Another type of model, the Babcock-Leighton model, uses a different mechanism. Magnetic fields released by decaying sunspots around the equator are carried poleward by north-south (meridional) plasma flows, and thence to the solar interior. Babcock-Leighton models were developed in the 1960s but, with little observational evidence to back them up, fell into neglect.

Helioseismology—the new science that studies the solar interior by way of acoustic oscillations observed on the surface—has changed that. "Now explanations for what is happening in the sun are constrained by reality," says Charbonneau. "It turns out that things we thought happened only on the surface happen well into the sun."

Charbonneau and Dikpati constructed a new Babcock-Leighton model with realistic fluid flows from helioseismology data. The model could reproduce many observed features of the solar cycle, such as the movement of sunspot emergence from higher to lower latitudes and the polarity flips. Furthermore, it could reproduce the observed phase relationship between the poloidal and toroidal magnetic components. "So that was very encouraging," says Charbonneau.

The HAO researchers then turned to the problem of reproducing the variable solar cycle. Although meridional flows carry large amounts of magnetic fields over time, they are quite weak, so they can be easily disrupted by the intense turbulent motions within the sun's convective envelope. To model this disruption, Dikpati and Charbonneau introduced random fluctuations into their meridional flows. These fluctuations caused the modeled solar-cycle lengths to vary from about 9 to 14 years—the same time span that has been observed in the sun over the centuries.

The average rate at which magnetic fields are transported poleward by the plasma flows is about the same in each solar cycle, no matter how large or small the modeled fluctuations are. Thus, when the flows are disrupted more than usual, the cycle lasts longer but is weaker, and conversely less disruption means a shorter, stronger cycle. Although the largest fluctuations suppress or amplify the transport process for a while, it returns to its average rate within a few cycles, just as the sun does.

Charbonneau and Dikpati have presented their results at conferences "and have had a lot of interest," Charbonneau says. "We expect that because of our work, and that of Bernard Durney (University of Arizona) and the team at NRL [the Naval Research Laboratory], more people will be using these models." ✵

Science Bit

Pacific Decadal Oscillation packs a one-two punch

About five years ago, scientists at the University of Washington discovered that every 15 to 20 years the Pacific Ocean undergoes an El Niño–like shift in temperature known as the Pacific Decadal Oscillation. New research shows shows there may be a second, much longer PDO pattern that lasts about 70 years.

Yi Chao (NASA Jet Propulsion Laboratory), Michael Ghil, and James McWilliams (both of the University of California, Los Angeles) have found evidence of the PDO's two-part structure in a study of the past 92-year record of sea-surface temperatures in the North and South Pacific. Their results appeared in August in *Geophysical Research Letters*.

Compared with El Niño, "the PDO is larger, longer, and more difficult to visualize," said Chao. "An explanation might be that it isn't just one thing; it's potentially two big events going on."

In their study, the scientists clearly saw large-scale temperature oscillations of 1–2°C taking place in the Pacific basin approximately every 15 to 20 years. In addition to this regular and relatively short fluctuation in the Pacific basin's temperature, they found evidence of another temperature shift that appears to take place on a scale of about 70 years. At the beginning of this century, sea surface temperatures seem to gently drop to a low in the 1930s, gradually rise again until the 1970s, and then begin a similarly paced decline to the present. "While we were only able to see one cycle in our data, tree-ring records, which go back 200 to 300 years, and fishery data show a similar time-scale shift," Chao explained.

The PDO also reveals striking symmetry between the northern and southern Pacific. In its "cool" phase, the PDO is a giant, horseshoe-shaped arc of warmer-than-normal water off the coast of Japan, enclosing a wedge of cooler-than-normal water near the equator. In the new study, this pattern appears around 1976, 1957, 1941, and 1924.

"What's striking is that the PDO pattern is similar in both the North and South Pacific and covers a huge area from the Aleutian Islands to the South Pacific," said Chao. "No computer models developed so far have been able to reproduce this symmetric pattern across the equator. This symmetry is a key to understanding what creates the PDO."

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