REPORT OF THE NSF SITE VISIT PANEL TO THE GEOPHYSICAL STATISTICS PROGRAM AT THE NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

12−14 MAY 2002

EXECUTIVE SUMMARY

The NSF site visit panel to the Geophysical Statistics Project (GSP) at the National Center for Atmospheric Research (NCAR) strongly endorses the activities of the project. The GSP has developed into a model program for the way that interdisciplinary efforts can impact both the applied and mathematical sciences. The program is well managed and has improved both the atmospheric sciences and statistics through the production of research results and the development of human and intellectual resources. Postdoctoral fellows involved in the GSP contribute to the short−term research production of projects in which they are involved, but former members of GSP have continued their associations, and are now contributing to new problems in statistics as well. Although the GSP constitutes a success story as it now stands, the panel believes that the full potential of the project has yet to be realized. The new directions and broadening scope of activities proposed under the NCAR Strategic Plan could benefit from increased activities by GSP. This will not occur, however, without an increase in resources allocated to the project. A clear determination needs to be made by the administration of NCAR regarding the role of GSP as the center moves toward fulfilling its future mission.

Selected specific recommendations made by the panel are:

- Methods and models developed by members of GSP in cooperation with other scientists at NCAR need to move beyond the 'proof of concept' stage and be incorporated into real atmospheric models at large scales.
- Additional work is needed in the area of model assessment for both probabilistic and deterministic process models, as well as the areas already identified for future efforts by GSP.
- Postdoctoral fellows should be brought into the program on a staggered basis, to the extent possible.
- GSP should expand its efforts in collaboration with university statisticians beyond the opportunities afforded by universities within Colorado.
- If GSP is to play an increased role in the central mission of NCAR, additional permanent research positions would be needed, with at least some of these at a senior level.
- GSP should investigate avenues to creatively foster topical research efforts among both statisticians and geophysical scientists at a national level.

1. CURRENT PROGRAM CONDITION

1.1 Program Overview

The Geophysical Statistics Project (GSP) at the National Center for Atmospheric Research (NCAR) is a research and training program designed to encourage the application and development of statistical methods and analysis to address fundamental problems in the atmospheric and related geosciences. The core of the project revolves around the research conducted by postdoctoral scientists, all of whom are recent recipients of statistics Ph.D.'s from well recognized degree programs in the country, and are jointly mentored by senior investigators in the GSP and atmospheric scientists at NCAR. Other key components of the program consist of supporting short and longer term visitors to NCAR, as well as close collaborations between GSP personnel and NCAR geophysical scientists. Since its inception in 1993, 13 postdoctoral researchers have successfully completed the program. There are currently an additional 5 postdoctoral researchers supported by the GSP. Well over 100 publications in leading statistical and geophysical journals have resulted from the GSP. This panel knows of no other program in the United States that has been so successful at recruiting and training statistics postdoctoral fellows.

Since 1997, strong and energetic leadership for the project has been provided by Doug Nychka, who now has a permanent position funded through core NCAR funds. By funding this position, as well as key support personnel, the NCAR administration has acknowledged the success of the program, as well as the growing importance and tremendous potential that statistical analysis has in geophysical research. The project also benefits from contributions by the other original project Principle Investigators Rick Katz and Joe Tribbia. Tim Hoar provides valuable assistance; the current postdoctoral fellows indicated that it would not have been possible to complete many of their projects in a timely fashion without Tim's guidance and help. The administrative tasks associated with GSP appear to be quite capably handled by Liz Rothney, although the panel was not able to spend much time on this aspect of the program.

The panel concurs that, by almost any measure, the GSP has been a resounding success, and that NSF funds have been used wisely and efficiently. Moreover, the GSP has demonstrated the impact that statistics can have in solving fundamental geophysical problems, and in turn how this can lead to new developments in statistics.

1.2 Impact on Statistics

Statistics is a field in which researchers active in the development of the core body of theory and methods impact the evolution of problem conceptualization, model formulation, estimation, and inferential analysis of problems in the applied sciences. Conversely, consideration of the unique circumstances that occur in nearly all applications often lead to new issues and approaches that foster development of the core of statistical science. Many, if not most, statisticians participate in both activities, characterized in a recent NSF sponsored workshop on the future of statistics as scientific 'outreach' and statistical 'inreach'. The GSP program at NCAR has served as a model

by which the tandem activities of outreach and inreach can impact the development of statistics. We mention here only two examples, to illustrate the overall impact realized by GSP.

One broad area of statistical research that has been impacted by members of GSP is the formulation of spatio−temporal models. The analysis of atmospheric problems virtually demands consideration of both spatial and temporal dimensions, and also requires methods for dealing with large volumes of data that are characterized by the presence of measurement error. Statistically, a common approach to this latter aspect of the problem is to formulate a hierarchical model, sometimes also called 'state−space' models. Research emanating from GSP has advanced our ability to deal with such situations, as is evidenced not only by the resultant publication record, but also by many presentations made by current or former members of GSP at conferences, workshops, and invited paper sessions dealing with these topics. The methodologies considered should influence statistical applications in other fields that face similar problems, such as modeling of environmental pollution fields and models of various measures of financial activity.

An additional area of statistical activity addressed in research conducted by members of GSP is incorporation of physical process model knowledge into overall probabilistic formulations of observable processes. The fundamental approach taken by members of GSP to this problem is to modify the usual strict parameter hierarchy of Bayesian hierarchical models to reflect deterministic process models as well as model parameters. This approach has led to, inter alia, new techniques for formulation of spatial and spatio−temporal covariance matrices.

Relative to the human and intellectual resources that drive progress in statistics (as well as science in general) the impact of the GSP is reflected in the career paths of former postdoctoral associates. Of the 13 former postdoctoral fellows listed in the document prepared by GSP for this site visit, 9 have entered tenure−track positions in departments of statistics or mathematics. The other 4 hold positions in research laboratories or government agencies. All are positioned to continue to influence the directions of both statistical research and application.

1.3 Impact on the Geophysical Sciences

The review panel believes that the GSP has been successful in fostering and encouraging collaboration with geophysical modelers, as evidenced by the noteworthy publications by GSP participants. The idea of bringing statisticians and geophysicists together to collaborate on important problems is good in principle, but often falls short in practice. The success of GSP in this endeavor is impressive with few precedents.

Despite its short life and small size, there is evidence that GSP already has had significant impact in the atmospheric sciences. The hierarchical Bayesian methodology for blending data sets to construct ocean winds addresses an outstanding problem and has resulted in an alternative synthesized data set for understanding global air−sea interactions. NCAR scientists have expressed interest in GSP work involving Markov chains to construct parameterizations of cloud cover based on cloud resolving models. The use of flexible discriminant analysis for forecasting clear−air turbulence, particle filters in ensemble Kalman filtering, and observation driven models to construct stochastic weather generators for crop modeling, all seem promising from a geophysics perspective. Moreover, these topics are not merely academic exercises, but address important problems in the geophysical sciences. The GSP should be complimented on its careful choice of

collaborative topics. Indications are that this astute choice of problems is continuing, with efforts planned in the areas of massive data sets and the design of computer experiments.

In order for GSP to have a real impact in atmospheric sciences, the panel believes that the statistical methods developed by GSP participants must be tested against real atmospheric models. If history is any guide, it is not enough to demonstrate that a new statistical method merely behaves better than other methods in an "offline" mode or in idealized settings. One must also demonstrate that the new method works in interactive modes and realistic settings. The review panel believes that the GSP has had outstanding success in fostering collaboration between statisticians and geophysical modelers. The key to future success will be in identifying further geophysical collaborators who will work with the statisticians in a serious manner.

An area of vital importance to the geophysical sciences is the identification and quantification of model errors based on real observations. This challenging problem probably cannot be solved without developing new and innovative statistical methods. The panel believes that many geophysical scientists at NCAR would be interested in developing new areas for collaborative research with GSP to address this problem.

1.4 Mentoring of Postdoctoral Fellows

When postdoctoral appointees arrive at NCAR, Doug Nychka serves as their primary mentor. The post−docs are exposed to atmospheric scientists through a series of short, focused presentations on various atmospheric problems. During the early stages of their tour at NCAR, the post−docs meet regularly with Dr. Nychka. They are presented with a series of key projects that are complimentary to their doctoral training and are asked to choose projects. Dr. Nychka has done an excellent job of identifying key problems that fit the post−doctoral students Ph.D. training. He serves in the role of research facilitator not only among the post−docs but also among disconnected groups of scientists within NCAR. Once post−docs are committed to a project, the atmospheric scientist with whom they work serves the crucial role of a secondary mentor. A few of the more proactive and experienced post−docs seek opportunities for collaboration outside of Dr. Nychka's mentoring and simply inform him of their activities. In some cases, weekly and regular meetings are held with the post−docs, while in other cases Dr. Nychka is able to transition to a supporting role and a resource for discussions of scientific questions. The entire group meets on a weekly basis.

There is strong camaraderie within the group. They occasionally participate in group activities such as group hikes. This close connection continues after participants leave NCAR. Often post−doctoral participants develop productive research collaborations that continue beyond their NCAR experience. A specific example is the case of Chris Wikle and Andrew Royle. Wikle and Richard Levine have also participated in developing an NSF Focused Research Group proposal in cooperation with Mark Berliner of Ohio State and NCAR scientists. This is an example of the highly successful GSP program that has facilitated important statistical methodological research in areas amenable to atmospheric science and beyond NCAR boundaries.

The current group of post−docs arrived at NCAR within 2 months of each other. The program would benefit from a staged admission of post−docs, admitting two to three post−docs each year. In this way, the second year post−docs can serve as peer mentors to the entering group of scientists.

It is also possible that continuity on projects can be maintained if entering post−docs begin collaborations with current post−docs and the atmospheric scientists with whom they work. In this scenario, however, it is important that entering post−docs are also given an opportunity to develop new projects maintaining individual growth and ownership of a project.

Post−docs are encouraged to polish off and submit their doctoral research for publication. Some program participants are more successful than others at accomplishing this task. Submission of doctoral work for publication should be strongly encouraged by the program. Possibly implementing a six month review with paper submission as a critical component of the review would be worthwhile. The substantial startup time for the collaborative research with atmospheric scientists precludes immediate and consistent publication submission while at NCAR. Students may leave their post−doc with no papers submitted for publication from the collaborative research even though the publication rate of the group is significant. Clearly, this is not advantageous to the post−doctoral student in their job search beyond NCAR. It is also not advantageous to the program. It is important to note that, overall, the publication rate for the group is high and the collaborative submissions often occur after the transition to the next job.

Maintaining a consistent publication rate while learning a new collaborative science is a difficult problem to address, but is an important issue. One possibility would be to extend the length of the post−doctoral program to three years so that participants can reap the benefits of their collaborative efforts. Another solution would be to shorten the startup time. Maybe it is possible to develop intensive focused short courses, for example a two week intensive study of key atmospheric problems on which the group has a history of success. Also with staggered admissions of new post−docs, entering post−docs can join successful collaborative teams and possibly facilitate the publication process. Such a strategy might shorten the startup time for program participants.

The post−docs in the program are encouraged to participate in statistical conferences. Many give a substantial number of talks during their tenure. This is an important growth step for the participants and serves the dual role of bringing increased visibility to the program. To increase the impact on the atmospheric sciences, advanced postdoctoral fellows should be encouraged to participate in key atmospheric conferences as well. Dr. Nychka and the atmospheric science mentors should facilitate this involvement.

The mentoring of post−docs is limited by the availability of senior statistical scientists. The key scientists are Doug Nychka and Rick Katz, both excellent in their own regard. However, the opportunities for a significant and positive impact that statistical science can bring to the NCAR research agenda is far greater than the abilities of two scientists. The addition of permanent statisticians and probabilistic modelers to the GSP team would not only benefit research conducted at NCAR but also the experience of the post−doctoral participants. The limited availability of senior scientists for purposes of mentoring can be somewhat mitigated through extensive collaborations with university researchers. The advisory board also serves an important role in this regard by providing a broad base of expert statistical opinion and feedback to program participants at the annual meeting. Nevertheless, this extended group of researchers cannot replace the need for additional permanent faculty in the GSP group.

The current post−docs are nearing the end of their tenure at NCAR. Each has clearly benefited from their post−doctoral experience as have their predecessors. The collaborative research conducted is of high quality both in the statistical arena and in the atmospheric science arena. The

participants also have a reasonable understanding of the atmospheric problem on which they are working. In short, they are a great asset to the scientific community. The opportunities provided by the GSP NCAR post−doctoral experience cannot be replicated in any statistics group in the nation.

2. PROGRAM POTENTIAL AND FUTURE DIRECTIONS

2.1 The NCAR Strategic Plan

The thrust of the NCAR Strategic Plan is integration of research in basic atmospheric and geophysical sciences with other disciplines, ecosystem effects, and societal impacts. This requires cross−divisional research efforts within the components of NCAR as well as cross−disciplinary research efforts among the geosciences, applied mathematics, and statistics communities as a whole, particularly with regard to modeling approaches and assessment of model output. Such efforts will be needed, for example, to tackle difficult problems such as formulation of self−consistent models that can operate at multiple levels of resolution in time and space. Especially for efforts across existing divisions of NCAR, GSP is well situated to facilitate the transfer of methods and the cross−fertilization of ideas. Members of GSP currently interact with scientists from a number of NCAR divisions in collaborative research efforts, and seem to have earned the respect of scientists in other divisions for these efforts. The presence of Doug Nychka in a Focused Research Group that includes former GSP members was credited at the panel review with enabling the participation of several atmospheric scientists at NCAR in this group as well. The GSP can potentially play a major role as NCAR "redefines itself for the 21st century" (NCAR Vision Statement, January 2002). The NSF review panel does not view this potential as being in conflict with recommendations from the GSP Advisory Panel that GSP develop a clear program direction of its own, rather than "trying to introduce statistics into all branches of atmospheric science" (Report of the GSP Advisory Panel, May 2000). Indeed, it is the success of GSP in cross−disciplinary research, as opposed to statistical service activities, that has positioned it to play a leadership role in developing the type of integrated activities envisaged in the NCAR strategic plan.

Just as NCAR as a whole must develop new approaches to meet the needs of creating a research environment that fosters integrated approaches, so too must GSP explore new avenues for strengthening ties, both within existing NCAR divisions and between GSP and the larger statistics and atmospheric sciences research communities. Some of the potential techniques to address these needs, such as video−conferencing across remote sites, include a level of risk in terms of devoting resources to their development. This is true not only in terms of dollars spent on technology, but also in terms of time and human resources devoted to taking the lead in organization and coordination of research efforts among groups of workers that may be separated by substantial distances and operating under a variety of organizational structures.

Although the potential for leadership by GSP in shaping the future overall direction of NCAR is substantial, such a role will not be realized without a significant increase in core NCAR support. Shifting the Project Leader (Nychka) and half of an Associate Scientist position (Hoar) to base funding indicates that NCAR has recognized the value of GSP to the central mission of the Center, as has the provision of what the panel views as adequate physical space, computing resources, and logistical support. While the GSP can remain healthy and vital without a broadening of its mission

and activities, a decision will need to be made relative to its role in contributing to the larger NCAR vision of a center for integrated research efforts.

2.2 Interaction With Statistical Research Community

The GSP group is successfully developing relationships with several key university faculty. The prototypical example is the previously mentioned Focused Research Group proposal to NSF with Berliner as the PI and GSP and other NCAR faculty as key co−investigators. The outreach to the local Colorado universities is significant as well. The proposal to increase the number of mentors for post−docs coming from local statistical scientists is quite reasonable and certainly will serve to expand the key areas covered for post−doctoral mentoring. While increased participation of the local university community is important, GSP must continue to look outside the boundaries of Colorado universities.

The program is growing in visibility and their success will bread success. Two key planned activities to facilitate university involvement include the thesis in residence program and the summer extensive visiting program. The thesis in residence program will allow a graduate student to visit GSP/NCAR while they are pursuing their doctoral research. The student will maintain close contact with their major advisor and in some cases the student's visit to GSP will be augmented by the advisor visiting as well. This activity will serve many roles but most certainly will provide the student with a greater degree of exposure in key atmospheric areas of research that are in line with their doctoral research. Certainly students participating in the thesis in residence program will be well suited to follow up with a post−doctoral visit to NCAR and may prove highly successful post−doctoral participants.

A second key activity is the group of ten or so senior scientists scheduled to visit GSP during the summer months. This intensive visiting program will serve to identify key collaborations that can continue long after the visiting scientists have returned to their home institutions. The group of visitors can serve as extended mentors to the post−doctoral participants. Furthermore, the GSP group should continue to offer focused conferences on a three year frequency that highlight key research areas.

A small outreach step to universities would be the advertisement of the research conducted by the post−doctoral trainees. The senior mentors can facilitate appropriate university invitations for post−doctoral trainees to give colloquia through their extensive university collaborations and contacts.

One area in which GSP could, and probably should, increase activity is in the development and coordination of nation−wide research projects. Although several colloquia have been held (in 1994, 1998 and 2000), the primary focus of these workshops seems to have been providing graduate students in statistics and related fields with overview material on problems at the interface of statistics and the geophysical sciences. The 2000 conference was jointly sponsored by the National Center for Statistics and the Environment and did focus more on current research projects and results. The panel feels that, while holding such workshops and colloquia are valuable, one role that is available to national centers is to stimulate and coordinate continuing activity in selected areas that emerge from workshop discussions as fruitful research directions. This might take the form of additional, more narrowly focused workshops, longer−term visits by outside scientists to NCAR, or extended visits by NCAR staff to university campuses. This 'shepherding' of research activities is roughly equivalent to management of an NSF Focused Research Group,

although it is not necessary that GSP members be actively involved in the conduct of research projects that would be appropriate. This would be a unique activity among federally funded research institutes and centers, and presents opportunities for considerable creativity in developing approaches to fostering topical research projects.

2.3 The Case for Additional Senior Positions in GSP

The GSP has clearly demonstrated that statistics can play an essential role in attacking core problems in the geophysical sciences. With the ever increasing stream of geophysical data available, the inherent uncertainties in these data and in characterizing the state of the atmosphere and ocean, and the sheer complexity of the systems under study, we anticipate that statistics, as well as other areas of the mathematical and computational sciences, will play an increasingly important role in making progress on the fundamental problems of the geosciences. While NCAR has over 1000 employees, including hundreds of senior scientific personnel, there are currently only two senior scientists with advanced degrees in statistics, Doug Nychka and Rick Katz, both part of the GSP. Through our observations during the site visit, and particularly through interviewing current postdoctoral researchers, it is clear that in his role as principal mentor and focal point for the postdocs, Dr. Nychka is probably stretched close to his limits. By all accounts, he has done a superb job in acting as a broker who matches postdocs with appropriate atmospheric scientists, as well as in guiding them and acting as a statistical sounding board for their research projects. However, it is also clear that adding more permanent personnel in statistics would significantly enhance the program, take a bit of pressure off of Dr. Nychka, and would allow for expansion of the postdoctoral program. In the larger scheme, and perhaps even more importantly, hiring more statisticians at NCAR would most likely broaden and strengthen the impact that statistics can have in the atmospheric and related sciences. Moreover, we expect that other areas of applied mathematics, probability, and computer science, could play a similarly pivotal role as statistics in advancing our understanding of the core issues in the geosciences. We strongly encourage the administration of NCAR to consider hiring more mathematical and computational scientists to augment their programs across the wide range of scientific studies ongoing at NCAR. The panel believes strongly that building on the demonstrated successes of the GSP, and hiring a group of top young mathematical, computational, as well as statistical scientists, say at the Scientist 1 level (in NCAR terms), would bring to bear new points of view and powerful techniques on the very challenging and complex problems addressed by NCAR.