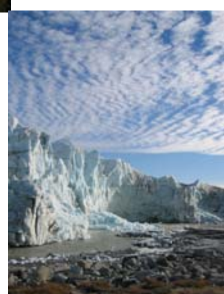
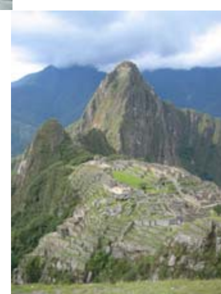
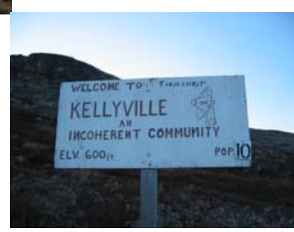
Upper Atmosphere Facilities Review Report





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List of Acronyms

ACF	Autocorrelation Function
AMIE	Assimilative Mapping of Ionospheric Electrodynamics
AMISR	Advanced Modular Incoherent Scatter Radar
AO	Arecibo Observatory
APL	Applied Physics Laboratory
ARCLITE	Sondrestrom Arctic Na/Rayleigh lidar system
ARCUS	Arctic Research Consortium of the United States
ASG	Atmospheric Sciences Group
B	symbol for magnetic flux density, in reference to the Earth's magnetic field
BMEWS	Ballistic Missile Early Warning System
BU	Boston University
CCD	Charged-Coupled Device
CD	Compact disk
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CI	Ciencia Internacional, “Science International’
CIDR	Classless Inter-Domain Routing
CME	Coronal Mass Ejection
CNOFS	Communication/Navigation Outage Forecasting System
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
CSSC	CEDAR Science Steering Committee
D	the lowest ionized layer of the atmosphere
DMI	Danish Meteorological Institute
DMSP	Defense Meteorological Satellite Program
E	the highly day/night variable molecular ionospheric plasma between 90 and 180 km altitude.
EAS	Earth and Atmospheric Science
ECE	Electrical and Computer Engineering
EISCAT	European Incoherent Scatter
ENA	Energetic Neutral Atom
EPO	Education and public outreach
EPSCoR	Experimental Program to Stimulate Competitive Research
ESF	Equatorial Spread F
F	the long lived, atomic ionized plasma in the ionosphere, 180 –1500 km altitude
FPI	Fabry-Perot interferometer
FPS	Fabry-Perot spectrometer
FTE	Full-Time Equivalent
GEM	Geospace Environment Modeling
GPS	Global Positioning System
GUI	Graphical User Interface
GUVI	Global Ultraviolet Imager (on TIMED)
HF	High Frequency

HRDI	High Resolution Doppler Interferometer
IGP	Instituto Geophysico del Peru, Peruvian Institute of Geophysics
IMAGE	Imager for Magnetopause-to-Aurora Global Exploration
IMAX	Large format movie projection
IMF	Interplanetary Magnetic Field
ISIS	Intercepted Signals for Ionospheric Science
ISR	Incoherent Scatter Radar
ISTP	International Solar Terrestrial Physics Program
JHU	Johns Hopkins University
JRO	Jicamarca Radio Observatory
JULIA	Jicamarca Unattended Long-term Investigations of the Ionosphere and Atmosphere
K-12	referring to school grades from kindergarten through high school
KRM	Kamide, Richmond, Matsushita
LOFAR	Low Frequency Array
LTCS	Lower Thermospheric Coupling Study
MADRIGAL	refers to a “database of ground-based measurements and models of the Earth's upper atmosphere and ionosphere
MEDAC	Meteor Echo Detection and Collection
MF	Medium Frequency
MHD	Magnetohydrodynamic
MHO	Millstone Hill Observatory
MHR	Millstone Hill Radar
Mhz	Megahertz
MI	Magnetosphere - Ionosphere
MI	Magnetosphere-Ionosphere
MIDAS	Millstone Incoherent Scatter Data Acquisition System
MISA	Millstone Steerable Antenna
MISETA	Multi-Instrumented Studies of Equatorial Ionosphere Aeronomy
MIT	Massachusetts Institute of Technology
MLT	Mesosphere, Lower-Thermosphere
MPAe	Max Planck Institute for Aeronomy
MRI	Major Research Instrumentation
MST	Mesosphere – Stratosphere - Troposphere
MW	Megawatt
NAIC	National Astronomy and Ionosphere Center
NASA	National Aeronautic and Space Administration
NATO	North Atlantic Treaty Organization
NBS	National Bureau of Standards (now NIST)
NDSC	Network for Detection of Stratospheric Change
NIST	National Institute of Standards and Technology
NLC	Noctilucent Clouds
NSF	National Science Foundation
NSWP	National Space Weather Program
OMS	Orbital Maneuvering Subsystem
PC	Printed Circuit; Personal Computer
PI	Principal Investigator
RET	Research Experience for Teachers

REU	Research Experience for Undergraduates
ROJ	Spanish form of JRO, Radio Observatorio de Jicamarca
SAPS	Sub-Auroral Polarization Stream
SAS	Space & Atmospheric Sciences
SOFDI	Second Generation Optimal Fabry-Perot Doppler Imager
SOUSY	Sounding System
SRF	Sondrestrom Research Facility
SRI	Stanford Research Institute
ST	Stratosphere-Troposphere
SuperDARN	Super Dual Auroral Radar Network
THEMIS	Time History of Events and their Macroscopic Interactions during Substorms
TIMED	Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics
UAF	Upper Atmospheric Facilities
UARS	upper atmosphere research satellite
UDEP (Peru)	Universidad de Piura (University of Piura, Peru)
UHF	Ultra High Frequency
UK	United Kingdom
UOPA	User-Owned, Public-Access
UPR	University of Puerto Rico
USA	United States of America
USGCRP	US Global Change Research Program
UV	Ultra violet
WAAS	Wide Area Augmentation System
WINDII	Wind Imaging Interferometer
WWW	World Wide Web
ZIP	Zenith Ionospheric Profiler

Executive Summary

The external review of the five NSF Upper Atmosphere Facilities (UAF), including the incoherent scatter radars (ISRs) located at Sondrestrom (Greenland), Millstone Hill (Massachusetts), Arecibo (Puerto Rico), Jicamarca (Peru), and the John Hopkins University support for the U.S. contribution to the SuperDARN radar network, indicates a strong and vibrant program of scientific research, experimental design, and technology development. Drawing upon the diversity of institutions and the unique capabilities, each facility has developed some form of educational or public outreach. A key finding of this panel is that the strengths of each of the facilities could be leveraged further with the broader scientific community through the development of an integrated plan that coordinates activities amongst the facilities and with the scientific community. Our recommendations under such an integrated approach include suggestions for enhancing the engagement of the science community, increasing the user base with additional data products, providing more student opportunities, coordinating technology development, providing new models for oversight, and enhancing the fiscal base. To this end we strongly encourage that future proposers to the NSF Upper Atmosphere Programs explicitly list potential interactions with UAF facilities. Additional site-specific recommendations are also provided in the individual site reviews found in the second part of this report.

Each of the five facilities that were reviewed satisfies to various degrees the criteria for a facility established by the NSF as well as community expectations articulated by the previous panel review and reinforced by this panel. In reviewing the performances of the facilities, the panel was challenged by the tremendous differences amongst the sites. Yet in synthesis of the individual site reviews, the panel identified a number of common issues and opportunities. These findings and recommendations are divided into three categories: those pertaining to the space physics and aeronomy communities; those to the facilities collectively; and those to the NSF.

The paucity of collective chain science, the movement towards AMISR technologies, and upcoming major science initiatives and celebrations provide the opportunity for the community to participate in a major UAF integrated planning exercise. Such planning is expected to provide the motivation for UAF observing strategies, articulate the scientific return from developing and utilizing new technologies, and provide the rationale and excitement leading to a request for enhanced funding. A well articulated UAF science strategy will also help to define the roles and the balance of research types at each of the facilities.

Most of the facilities are engaged in technology development, often duplicating efforts. Examples include basic incoherent scatter radar analysis software, digital receiver design, application of information technology advances, and optical instrumentation development. Achieving the engineering goals of all of the facilities requires more cooperative technology development. Regular workshops, working groups, and better communications are all mechanisms for better integrating technology development and planning. Such mechanisms can also serve as opportunities to engage the user communities not only in engineering developments but also in the development of community data products and optimum/effective allocation of the radar observation hours.

Student opportunities and activities are highly variable from facility to facility; yet at all sites, these opportunities could be enhanced. Student engagement is hindered in part by a lack of access to students in the parent institutions of the facilities and often by the geographic separation between those institutions and the facility sites. Mechanisms to increase student opportunities include graduate student workshops at the facilities, targeting CEDAR/GEM graduate students from a broad university base for projects working with the facilities, and developing an affiliate program or university consortium to engage broader university collaboration with the facilities.

Opportunities are also needed for proactively developing the next generation of facility leadership. While the leadership transition has been successful at three of the sites, it has occurred in a rather ad-hoc fashion. Providing opportunities for leadership courses, greater project management responsibilities, and community planning are ways to approach leadership transition in more deliberate ways.

Budget stresses currently exist and will be exacerbated in the future by major facility developments such as AMISR and the heater facility. The NSF and community are encouraged to strategically think of a 10-20 year plan for the next generation facility, including consideration of consolidation of UAF functions; remote functioning/access of the sites; and investment strategies for engineering, observing, and science initiatives. Strategic thinking leading to enhancement of the UAF resource base is also needed.

The NSF is to be applauded for their work with the facilities in developing an excellent program. The future requires a more integrated facilities approach, one that will need greater NSF coordination and oversight. Mechanisms for stimulating the integrated approach include the implementation of a UAF executive committee focusing on immediate issues; the formation of an AMISR implementation committee that would provide short-term thinking on issues urgent for AMISR follow-through; and the formation of an overarching consortium to organize and integrate facility activities and planning.

Part I: Process and Overall Recommendations

Introduction

The NSF Upper Atmosphere Facilities (UAF) Program was established in 1982 with the purpose of supporting "both individually and as a unit, the operation and scientific research associated with the longitudinal chain of incoherent scatter radars and for ensuring that the radars are maintained as state-of-the-art research tools available to all interested and qualified students". The 2003 Upper Atmosphere Facilities Advisory Panel was established to provide an integrated assessment of the five upper atmosphere facilities that are the core of the NSF UAF Program. Since 1982 many of these facilities have augmented their radio instrumentation with optical instruments and extended their observations into the middle and lower atmosphere.

The advisory panel visited all five sites between September and November in 2003. Prior to the site visits, the panel had several e-mail exchanges and a teleconference call. Review material was solicited from each of the facility PI's including:

1. Description of facility, how it operates, how the user community is engaged.
2. Summary of the 3-4 most important science highlights from the last 3-5 years including discussion of impact or payoff (scientific and societal) (no more than 1-2 pages each)
3. Summary of educational/outreach activities/accomplishments/highlights
4. Summary of infrastructure improvements over the last 3-5 years
5. Summary of plan for the next 3-5 years (infrastructure and science)
6. Summary of management, maintenance, and budget challenges along with proposed solutions
7. Response to the recommendations given by the previous site review
8. Appendices
    a. Annual reports
    b. Strategic plan and/or proposal for the next 5 years (including budget)
    c. Publication list for last 3-5 years
    d. List of users and projects supported during last 5 years
    e. Other performance metrics as determined by PI (conference presentations, hardware/software development and use; communication systems; user support, etc)

A review agenda was jointly developed for each site to ensure consistency amongst the site reviews. NSF provided the review criteria (see Appendix A), which include evaluations of the scientific research enabled by the facility, user support, educational activities, facility maintenance, and management and budget.

This report was generated in two steps. First, after visiting each site a draft report was developed. Next, these site review reports were used to produce an additional draft on integrated findings and recommendations. The initial formulation of the integrated draft was developed at a final panel meeting in January 2004 in Boulder, Colorado.

The first part of this report provides background information and the integrated review of the facilities. Findings and recommendations from this integrated appraisal are categorized according to those pertaining to all of the facilities, to the NSF, and to the aeronomy and space-physics research community. The second part of this report contains the individual site review reports including specific findings and recommendations for each facility.

Background

NSF funds the facilities in aggregate at a level of approximately $9M/year. All but SuperDARN is managed by 5-year cooperative agreements between NSF and the host U.S. research institution. Cooperative agreements, as contrasted with grants, require interaction between NSF and the facility PI's in the operation and oversight of the facilities. The cooperative agreements include statements of work and budgets for the core facility operations. These funds, which also include contributions from the CEDAR program funding, leave very little discretionary funds in the UAF program budget for additional facility needs. When additional funds are available, they are usually used for various repairs and upgrades.

The primary users of the facilities are the space physics and aeronomy research communities. The research conducted using facility observations has contributed to the understanding of the ionosphere, thermosphere dynamics, magnetosphere phenomena, the processes that couple these regions, and space-weather events. In addition, the facilities are used for fundamental research in radio science with a particular emphasis on radio wave scattering theory in the atmosphere. Each of the facilities also has an engineering research component that provides for increased capabilities in radar probing of the upper atmosphere. With the advent of new optical instrumentation at many of the sites, collaborative observations have provided new insights into ion-neutral interactions and dynamical and chemical coupling processes.

NSF expectation for a UAF: The Upper Atmosphere Facility Program of NSF requires a "facility" to meet several criteria. These criteria help to distinguish between instrumentation that is developed and deployed under other grants and those supported as a facility. Under these NSF criteria, facilities have:

- A suite of multi-use instrumentation with user demand for the observations.
- A complexity in scale of operations and services that requires a need for stability in management, oversight, and a long-term commitment to funding.
- An integrating function that incorporates a community service function (database development; data products; WebPages) or user support (specific experiments, hands-on guidance).
- A community need for continual state-of-the art observations thus requiring focused expertise in engineering research and development.
- A requirement for collaborative interactions with NSF in the oversight of the facility which implies that funding is obtained as a cooperative agreement rather than a grant.

Each of the five facilities in some measure satisfies these criteria. While each facility has unique characteristics, the four incoherent scatter radar facilities have more in common with each other than with the SuperDARN radars. As is discussed in the individual site reviews, the complexity of the operations of the ISRs requires a different level of engineering and user support than the SuperDARN radars. However, the complexity of the integration of the SuperDARN radars into an extensive international network with integrated user data products requires a different type of partnership and community support than what is in place at the ISR sites. In reviewing the performance of the facilities, the review panel was challenged by the tremendous differences among the sites.

Community expectations for a UAF: The 1996 review panel emphasized the expectations and desirable characteristics of an upper atmosphere facility. This review panel found that background useful in preparation for our own site visits. In concert with the previously developed materials the panel articulated eight primary functions for a facility: A successful upper atmospheric facility:

- Provides accurate, reliable, and validated measurements of key geophysical parameters using the clustered facility instrumentation whose data are easily and readily available to the user communities.
- Performs and enables outstanding scientific research using the facility instrumentation and observation databases.
- Operates and maintains the facility and continuously improves the hardware and software systems to fully exploit the capabilities of the instruments.
- Mentors early-career scientists and provides opportunities to develop leadership skills ensuring the next generation of facility leaders.
- Provides educational opportunities for undergraduate and graduate students.
- Acts as a resource for the space science community on matters that require expert judgments on the use and reliability of radar and radio techniques.
- Engages a broad variety of audiences through outreach activities.
- Exercises good management and budget practices that provide for the successful operation of the facility functions listed above.

Integrated Findings and Recommendations

The upper atmosphere facilities have contributed major science results in the last seven years, demonstrating the overall success of the UAF program. New methodologies, tools, experimental configurations, and datasets have all contributed to the continued vitality of the radars, leading to new science. In addition, each of the facilities, in their own unique way, have contributed significantly to education and outreach efforts, expanding the horizons of the public and developing opportunities for undergraduate and graduate education.

The facilities have explored science at various boundaries. Examples include:

- Providing the experimental background for the development of space-weather models and products that are now becoming operational.

- Coordinating analyses of various data sets for breaking new ground in the understanding of global magnetospheric dynamics.
- Revolutionizing the theory of the physics of meteor ablation and providing new ideas on meteor astronomy.
- Examining long-term relationships to provide information on the vertical coupling with the troposphere and ultimately to the understanding of the climate of the upper atmosphere.

Over these last seven years, there has been a major transition to the next generation of facility PI's and site directors. This change in leadership is providing the momentum for change within the facilities, for the need of new collaborations amongst the facilities, and for greater synergy between the facilities and the broader space science, radio science, space weather and climate communities. While the panel found excellence in science, we noted that chain and clustered instrument science is lagging, community involvement could be greater, and integrated science planning is needed. While we were struck by the uniqueness of each facility, we also noted a commonality of certain issues and challenges, which are summarized below. These findings and recommendations are divided into three categories: those pertaining to the research community-at-large, to the facilities overall, and to the NSF.

Community Findings and Recommendations

Integrated science planning for the UAF: In its review of the science results, the panel noted a paucity of collective chain science among the incoherent scatter radar sites – one of the original founding goals for the UAF. This issue was recognized by all of the PI's even though there are some individual integrated science efforts that are worth noting. (See individual site reviews). A common feeling is that the chain science is thwarted by either a lack of enthusiasm for this type of research or by the absence of community/facility partnerships. The panel believes it is time to re-evaluate the historical rationale for the chain of radars in the context of better-integrated science planning within the UAF.

We note that the time is right for a UAF integrated plan that takes advantage of the attention to AMISR, space weather, and climate science within NSF. Some examples to think about include a major science initiative on storms from the poles to the equator; how the UAF can contribute to the International Heliophysical Year (2007) and the International Polar Year (2007) initiatives; or the establishment of other international year types of recognition to stimulate global scientific thinking.

<u>Recommendation 1:</u> The ionospheric, thermospheric, space weather and climate communities along with the facilities scientific staff and the NSF should undertake an integrated science planning exercise for the UAF. This integrated planning should recognize global and national scientific needs and trends, provide the motivation for UAF observing strategies, articulate the scientific return from utilizing new information technology advances, and provide the rationale and excitement leading to a request for enhanced funding. Specific attention should be paid to the emergence of the AMISR,

coordinated science, and experimental campaign science. The planning exercise should revisit the concept of chain science as a charge for the UAF.

Balance of type of research: The balance of the type of research performed at each site is not planned. The panel noted emphases on research in space physics and aeronomy; radio science; and new experimental developments. For example Jicamarca is a proving ground for radio science techniques emphasizing the interactions of the atmosphere with electromagnetic waves, while Sondrestrom emphasizes cluster research in space physics. As a national observatory, Arecibo science is driven by formal proposal pressure from the community.

Recommendation 2: There should be a conscious decision regarding the balance of types of research conducted at and amongst the facilities. Facility research should develop a balance in response to community science goals and objectives. The panel recognizes that different facilities will have different user communities, but the panel also recommends finding ways to bring those communities together and to enhance them. While recognizing that unanticipated new science will also emerge, a well articulated UAF science strategy and a clear set of goals will help to define the roles and the balance of research types at each of the sites.

Facilities Findings and Recommendations

Technology development: The panel acknowledges the extremely talented engineering research staff in the facilities and encourages leveraging that talent and expertise even more. We also note that there is a duplication of technology development across the facilities – partly driven by perceived uniqueness of each of the facilities, but also due to a lack of technology planning and communication amongst the facilities. Duplication of efforts exists in basic ISR analysis software (conversion of raw data into geophysical parameters). The panel feels that the front ends of the software could be made more standard. This would also require standardization and convergence of computer hardware. In addition, progress towards digital receivers is being pursued at all sites but with relatively low-level of communications among the interested groups. Large investments in development time for digital receivers should be balanced against costs for commercial digital receivers that are now available. All of the facilities struggle with transmitter replacements and investments. Additionally, the panel noted that better synergy amongst the facilities could lead to better coordination and planning of optical instrumentation development, for example the development of fast cameras.

Further UAF technology developments can also be enhanced by capitalizing on the network and computation savvy within the larger community. There should be a conscious investment in information technology. However, due to the limited UAF funding, the panel suggests that the facilities need to achieve some of their goals through cooperative technology development.

Recommendation 3: Integrated technology development and planning is needed. We suggest that regular meetings across the facilities be held with the possible formation of working groups including users and other members of the external community. Areas for working groups include development in software, antennas, receivers, community software/products; and operational software. Communications between workshops can proceed at other meetings and through the internet. This interaction could also promote chain science.

Student opportunities: Although each site interacts in various ways with students, student participation is variable across the facilities and the PI's uniformly recognize this problem. Graduate student opportunities and mechanisms for engaging them in facility research are underdeveloped. The panel believes that this engagement is hindered in part by a lack of access to students in the parent organizations with which the facilities are affiliated and/or the geographical separation between the facility and host university. Regular graduate student workshops at the facilities, such as those at Sondrestrom, provide one means for attracting students from non-affiliated institutions.

<u>Recommendation 4:</u> Examine various methods for attracting graduate students from non-affiliated universities. Possible alternatives include the expansion of the Research Experience for Undergraduates (REU) concept to graduate students; targeting CEDAR/GEM graduate students from a broad university base for projects working with the facilities; developing a university consortium or affiliates program that would specifically engage broad university collaboration with the facilities and include graduate student workshops, an annual facilities meeting, and curriculum development.

Community data products: The CEDAR and MADRIGAL database archive is important and valuable. However, from a wide community perspective, the ISR data is difficult to analyze and interpret. SuperDARN has taken the next step towards the development of community data products, which provide integrated quick looks at the data; are easily accessed and readily available to a broad range of users. Millstone Hill and Jicamarca have also begun to develop this type of product. The panel endorses this concept, which recognizes the spectrum of data products needed in order to stimulate more coordination and more data users.

<u>Recommendation 5</u>: The facilities should develop higher -level data products for broader community use. These products should be co-developed with the potential user community with the goal of having integrated data for chain science, provide coordinated visualization of the data, and be easily accessible.

Observation hours: In examination of the observation hours, the panel noted that the World Days consume a significant percentage of observing hours. However, the science return in recent years on the world day data has been ancillary, in part because these observing periods are not connected to an integrated UAF science plan. The panel questions whether there is a better way to use this observing time. There is a strong community desire for longer-term observations in order to have a climate-like look at the upper atmosphere. The desired goal for most of the facilities is to have nearly continuous observation in some power-saving mode. (Arecibo Observatory could not run continuously due to the competition for time with astronomy). There has been some movement toward more continuous operations in a limited/low powered observing mode and we applaud this development.

Recommendation 6: Re-examine the world day observation strategy in terms of an integrated facility science plan. Evolve the facility observation strategies and build those strategies constructively into the science plan.

Observing time allocation: Currently the allocation of observing time at most facilities is informal (Arecibo is the exception) and appears to meet all current community demands. However, knowledge about how to obtain time at the facilities is not readily available and more users could be involved and accommodated.

Recommendation 7: In order to engage more users, the facility personnel should have proactive conference interaction with potential users. In addition, the sites should clearly outline on their websites a process for obtaining observing time at the facilities.

NSF Findings and Recommendations

Budgets: Not surprisingly, the facilities are operating on tight budgets. This stress is due to the ambitious ideas from innovative scientists and engineers, which enhances the science that can be done. As a community we are ready to take a step up to a new facility concept – AMISR. In spite of the success of the facilities, the full potential of scientific return, educational training, and leadership is limited by current fiscal and oversight structure. Strategic thinking for enhancing the UAF resources is needed.

Recommendation 8: With community help, develop a more proactive funding plan strategy using an integrated science plan, integrated UAF technology and IT plans, and education development to drive new funding opportunities at the NSF. AMISR provides the momentum to do this within the NSF.

Evolution of facilities: AMISR is coming online, producing additional stress on maintenance and upgrade plans for the remaining facilities. The current facilities are aging due to the financial problem noted above. Some of the issues that need crucial long-term thinking include: AMISR technology as replacement technology for the existing facilities; other sites for AMISR-like technologies; consolidated UAF functions; remote functioning/access; investment strategies; Square Kilometer Array (SKA) and LOFAR development in the astronomy community and its impacts on upper atmosphere observing capabilities; the retention of important ongoing measurements in a more limited fashion given that change is inevitable.

Recommendation 9: Develop a facility-wide plan for evolution looking at a phased approach to the facilities, their maintenance, upgrades, and evolution to a complete new technology. We encourage NSF to think of a 10-20 year plan for the next generation facility possibly seeking out an entirely new structure for upper atmosphere facilities.

Leadership: Leadership transition at the facilities is fortuitous rather than proactively planned. It has been fortunate that the next generation of PI's and facility directors has emerged for three of the sites, but there are no obvious leadership transition plans for Millstone Hill and SuperDARN. There is a strong need to foster leadership development emphasizing team building and global, strategic thinking.

Recommendation 10: Create opportunities for proactive leadership development with a concerted effort to teach people how to be leaders. Given the importance of the facilities, more thought must be given to this. Opportunities for leadership courses, increasing project responsibilities, and community planning are worthy of consideration. Plans for leadership transitioning should be articulated in facility proposals.

Oversight and coordination: Many of the recommendations and suggestions posed in this report will require better mechanisms for integration amongst and between the facilities and the broader scientific community. The panel spent considerable time and effort thinking of various mechanisms that NSF might consider for stimulating the integrated approach that we advocate.

Recommendation 11: The panel recommends that NSF UAF develop mechanisms for better integration. Some specific suggestions for consideration are:

- The implementation of a UAF Executive Committee that would work with UAF to ensure a continued healthy program and responsiveness to the panel recommendations. This group could focus on immediate issues such as enhancing graduate student participation, the coordinated technology development plan, and the development of an integrated UAF science plan. The group could help to facilitate the facilities.
- The formation of an AMISR implementation committee that would provide short-term thinking on issues such as operational strategies and deployment; test-bed experiments; and short-term plans for calibration science capabilities of the instrument.
- The formation of an overarching consortium to organize and integrate the facilities. SuperDARN is a model of how the sum of its individual radars is greater than the parts. The capacity of the ISR facilities is currently only equal to the sum of its parts. The former set of radars operates as a network; the latter does not. The consortium would provide that network element and could also be responsible for the recommended integrated technology and science planning.
- Encourage greater community involvement with the facilities through the proposal process by augmenting the NSF proposal guidelines of Intellectual Merit and Broader Impact to specifically point to facility involvement.

Part II: Individual Site Reviews

<u>Sondrestrom Research Facility</u>

1. Introduction

1a. Description of Site

The Sondrestrom Research Facility (SRF) is located approximately 10 km west of the town of Kangerlussuaq, which is about 100 km inland from the West Coast of Greenland. The site lies just north of the Arctic Circle (67°N, 309°E), at an invariant magnetic latitude of 74°. This region has a relatively stable climate (by Greenland standards), offering frequent periods of clear skies, especially during the winter months.

Kangerlussuaq is administered by the Sisimiut District of Greenland Home Rule, a semi-autonomous territory of Denmark. The UAF facility at Sondrestrom has a well-established Memorandum of Understanding with the Danish Meteorological Institute (DMI), which is periodically reviewed by the Danish Polar Center to justify continued joint research and operations in Greenland. In exchange for occasional use of the Sondrestrom facility and its data, the DMI also provide an on-site engineer to assist with the day-to-day operations at no cost to the UAF. The Greenland Home Rule provides local jurisdiction on permitting general access and use of the site and the surrounding area for research activities.

Sondrestrom is primarily accessible year-round through the excellent airport at Kangerlussuaq, with frequent commercial flights via Copenhagen. Additional air support is possible, mainly during the summer months, through the New York Air National Guard 109th Air Wing based at Stratton Air Base, Schenectady, NY, which often provides service for the NSF missions to Greenland. In addition, a nearby shipping port provides the means to deliver heavy materials during the summer months, including essential diesel fuel for the on-site generation of electric power.

The SRF lies in an isolated valley, at an altitude of ~220 m above sea level, and is managed and operated remotely by a small group of scientists and engineers from the Geoscience and Engineering Center at SRI International, Menlo Park, California. Dr. Jeff Thayer is the Principle Investigator for the UAF Sondrestrom Research Program. The working facilities are basic but very well organized and provide a "homey" and efficient atmosphere for the four system operators that live year-round on-site to maintain and operate a diverse array of scientific instrumentation. Five housing units for the site staff and their families are located within 200 m of the main building.

The SRF comprises three facility instruments, a well-maintained 1290 MHz, fully steerable, 32 m diameter, incoherent scatter radar (ISR) system (operational at Sondrestrom since 1982), a recently developed Na/Rayleigh lidar system and a simple intensified all-sky camera system. In addition, the site hosts 21 other "stand-alone" optical and radar instruments operated by guest PI's from various national and international institutions. The passive and active radio instruments stand away from the ISR, at distances from 200m to 600m, taking advantage of topography to reduce mutual interference. The ISR was originally located at Chatanika, Alaska but was moved to

Sondrestrom, Greenland in 1982 to perform detailed studies of the polar cusp region and to further facilitate the UAF ISR "longitudinal chain" science program.

1b. Summary of Site Strategic Goals

The overarching goals of the Sondrestrom Research Facility over the next 5 years focus on three key aspects of a well -founded, ongoing research program:

- To further contribute to the understanding of the high-latitude upper atmosphere and space environment through research, experimentation and education.
- To support and enhance the capabilities of the Sondrestrom facility and to expand the influence of the facility nationally and internationally.
- To technically advance the radar and optical facility instruments for the betterment of scientific research.

The SRF has grown considerably in its capacity for novel, high-latitude radar and optical research over the past 20 years, and the plans for the next 5 years focus on several outstanding problems in the field of polar magnetospheric, ionospheric, thermospheric and mesospheric physics. The research goals are broad and ambitious and include: (a) the investigation of the response and variability of the high-latitude ionosphere from seconds to solar cycles; (b) the exploration of processes within the mesosphere/ lower thermosphere/ ionosphere region; and (c) the exploration of the role of the high-latitude ionosphere in the coupled magnetosphere-ionosphere system. To achieve these science goals the facility plans call for:

- An increase in the ISR operating hours to accommodate the evolving needs of the user community.
- Development of ready access to facility data products from "real-time" usage as well as access to data products obtained over the past 20 years.
- Assimilation of SRF data into physics-based models.
- Active participation in a proposed high-latitude ISR consortium to optimize facility operations and promote national and international scientific exchange.

While the main recommendations are given later (see Section 7), we note here that the panel fully supports these proposed activities to the extent achievable within available funding (noting that the highly variable cost of fuel is a major factor in determining the number of operating hours for the radar).

2. Scientific Research Enabled by the Facility

2a. Science Evaluation

The Sondrestrom facility supports a broad range of cross-disciplinary scientific investigations performed by members of the SRI scientific staff as well as other scientists from the US and the international community. These include upper atmosphere and space research, middle atmosphere research, solid earth and cryosphere research, and information technology research. SRI staff scientists continue to play significant leadership roles in solving fundamental problems in the areas of space and atmospheric research. Some highlights of the scientific accomplishments made by SRI staff members include:

- Investigations of magnetosphere-ionosphere (MI) coupling using ISR and space-borne imagery to establish a quantitative relationship between auroral variability and conductance. Other MI coupling studies have succeeded in resolving the height distribution of current and Joule heating rates in the high-latitude E-region.
- Continued investigations of E and F region electrodynamics including the impact of different temporal and spatial scales, and quantifying the importance of neutral winds on ionospheric energetics.
- Polar lidar measurements of noctilucent clouds (NLC) and their statistics to provide further insight on the ice particle size distributions associated with NLC formation and the effects of gravity waves on the cloud brightness (backscatter ratio) and their lifetimes.
- New understanding concerning the formation of thin ion and neutral layers. This research utilized common volume measurements of sporadic sodium layers (by lidar) and sporadic E layers (by ISR) to test theories of sporadic Na formation and to show that Na density is reduced by auroral ionization.

As noted earlier, in addition to the three facility instruments SRF also accommodates 21 guest PI instruments. These complementary optical and radio measurements represent a diverse and important additional capacity of the SRF for performing unique research in the high arctic.

Uniqueness of Research Performed at Sondrestrom: The incoherent scatter radar at Sondrestrom has enjoyed a distinguished position for the past two decades providing important data and scientific insight into polar-latitude magnetospheric-ionospheric coupling processes under different solar forcing conditions. In recent years the European EISCAT Association has expanded its capability and now operates an ISR at Longyearbyen Svalbard, Norway, at a similar geophysical location (magnetospheric cusp) to the Sondrestrom facility. However, the SRF and EISCAT radars remain unique in their different longitudinal and sun illumination conditions, different operating frequencies, and different complementary optical and radio instrumentation available for coordinated research.

To date, the EISCAT radar has tended to focus on studies of large-scale polar convection and magnetospheric dynamics and on local plasma physics processes. In contrast, most of the research undertaken at the SRF continues to be directed towards improved understanding of the coupled magnetosphere-ionosphere system as well as large-scale, high-latitude dynamics of the cusp region. This includes investigations of the dynamics of the high-latitude neutral atmosphere (altitudes up to ~100 km) using the ARCLITE Na/Rayleigh lidar system. This said, these two distinct facilities provide new opportunities for complimentary high-latitude investigations (as well as encourage a very healthy element of competition), and good communications and interactions exist between the scientists and technicians at both sites. For example, SRI recently hosted the

2003 EISCAT ISR workshop at their facility in Menlo Park, CA and John Kelly serves on the EISCAT council. Furthermore, future plans call for the development of an international high-latitude ISR consortium to optimize facility operations and promote scientific exchange.

Quality of the Scientific Research: The SRI Sondrestrom science team is relatively small but its members are clearly very active in a broad range of space and atmospheric research areas, organizing workshops and special conference sessions, and presenting many invited papers at national and international conferences. One measure of the scientific output and quality of their research is the number of papers published in journals of high merit. SRI scientific staff in collaboration with guest investigators published 32 articles on Sondrestrom related research (from 1988 to date), of which 22 papers were in top tier journals. The panel agrees that the research conducted at the SRF by the SRI staff and by the guest PI's continues to be of high scientific merit and cutting edge in many areas of geophysics. Of particular note is the recent pioneering work by the PI on combining state-of-the-art optical and ISR measurements with theory and modeling to investigate a broad range of phenomena encompassing high-latitude magnetosphere, ionosphere and neutral atmospheric dynamics.

Role of Facility in Supporting National, International, and Satellite Programs: The SRF has been used for research directly relevant to a number of national and international agencies including NSF, NASA, NOAA, DOD, and the DMI, as well as national research programs such as the NSWP and the CEDAR/GEM components of the USGCRP. As mentioned above, SRI scientists associated with the SRF are prominent contributors at national and international scientific meetings where they regularly convene special conference sessions. They also participate on review and steering committees. In particular, they contribute significantly to the GEM and CEDAR workshops and the NSWP where they have provided leadership roles in many areas. SRI researchers have also obtained additional funding to support several radar and/or lidar investigations that are coordinated with the US and international satellite projects. These include ISTP, FAST, TIMED, POLAR, DMSP, IMAGE, and the European satellites Oersted, CHAMP and CLUSTER. Currently, SRF data are being used to help plan for the GEC mission. As part of their research activities SRI scientists have also hosted the Layered Phenomenon of the Mesopause Region Workshop, Asilomar, CA (October 2001) and most recently they held an EISCAT workshop at their facility in Menlo Park, CA (August 2003). In addition, SRI hosted Dr. Tony van Eyken, then director of the EISCAT Svalbard Radar, for collaborative work at Menlo Park for 12 months during 2002-2003.

2b. Research Capacity and Balance

The capacity of the SRF for operating the ISR is limited by three main factors: (a) the cost of diesel fuel for the on-site generation of electric power, (b) available man-hours from the 4-person site crew, and (c) the lifetime of the klystron transmitter. On a time-limited basis SRI can send additional personnel up to the site to assist in specific campaigns, if needed. Operation of the radar during recent years has nominally been at 1600 hours/year, up from roughly 1200 hours/year a decade ago. The new 5-year facility operations proposal budgets for 1800 hours/year to accommodate an anticipated increase in community demand.

The radar can be operated “stand-alone” in several different modes that enable a broad range of investigations to be performed from basic plasma physics to in-depth studies of global magnetospheric-ionospheric electrodynamic coupling. There appears to be a good balance in the utilization of the radar in the support of these investigations, as well as strong involvement by students, young scientists and senior scientist/guest investigators. There also appears to be a good balance between the ISR operations and joint measurements with the other co-located ground-based instruments and with satellite over-flights.

The ARCLITE lidar comprises two laser systems, a Nd:YAG Rayleigh system (operational since 1992) and a Continuum dye resonant scattering system for metal layer studies (operational since 1997). Together, these two systems provide a powerful capability for day and nighttime sounding of the neutral middle atmosphere dynamics, up to ~100 km altitude. The lidar operations are limited by weather, crew availability and costs of materials and supplies. The site crew rotate their weekly responsibilities to obtain, on average, one night of lidar data per week (clear skies permitting). These measurements are usually performed in conjunction with other SRF measurements. During the summer months the lidar systems have been operated more frequently to investigate noctilucent cloud formation (particle size and growth) and associated gravity wave dynamics. Other operational modes for the lidar system, based upon targets of opportunity, are also possible and include coordinated measurements with satellites and specific campaign schedules. The ARCLITE lidar system is an important complementary research instrument to the ISR with a broad range of applications that have yet to be fully exploited.

The all-sky camera system is devoted primarily to auroral science and utilizes an image intensifier coupled to a CCD video camera. Multi-wavelength image measurements can provide much-needed context information important for interpreting the ISR and lidar measurements, particularly during magnetic disturbances when auroral precipitation often dominates the night sky emissions at Sondrestrom. The imager was donated to SRI by Lockheed some time ago and it has been operational at SRF since 1983. Recently the imager was upgraded to include a new Gen III imager intensifier providing significantly improved sensitivity and an enhanced near infrared spectral performance. In operation it requires only limited attention from the site crew and although its current stand-alone scientific capacity is somewhat limited, the image data are helpful for the interpretation of many of the radar measurements.

The SRF is unique amongst the UAF ISRs, both in its remoteness and in the large number of guest PI instruments (radio and optical) that it supports as part of its ongoing research activities. These instruments include, a digital ionosonde, an imaging riometer (both for auroral studies), a meteor radar, a Fabry-Perot and a Michelson interferometer system (for mesospheric and thermospheric wind/ temperature studies), a meridian imaging spectrometer and a photometer system (for auroral/airglow studies), and a narrow-field multispectral auroral imager and an all-sky airglow imager. Other instruments include an ozone spectrometer, a micro-pulsation magnetometer, GPS receivers, and an MF/HF imaging receiver.

In total, over a dozen different institutions are currently involved with ground-based measurements at SRF, with supplementary institutional instrumentation provided for specific campaigns. However, relatively little (or dated) knowledge concerning the status, operational support, productivity, and scientific “impact” of these additional measurement programs is available. The panel believes that up to date information concerning the Guest PI measurement programs is essential and should be made regularly available to assist the SRF PI in assessing the overall scientific productivity of the facility, to help plan for future measurements, and also to help assign priorities to various instrument/measurement operations should there be future competition for on-site resources.

2c. Future Science Plans

In addition to supporting a wide range of science investigations undertaken by various guest investigator instrumentation located at the facility, SRI scientists have selected three key areas of investigation (as noted in section 1b), in which they intend to play a leading role in future high-latitude research. The first effort is novel and focuses on the response and variability of the high-latitude ionosphere over a very broad range of temporal scales (seconds to solar cycles). This study will take advantage of the large database that has been accumulated at Sondrestrom over more than 20-years of operations of the facility. The second proposed area plans to explore the role of the high-latitude ionosphere in the coupled magnetosphere-ionosphere system. This is a fundamental topic that has received considerable attention in both the GEM and CEDAR community and the SRF has already made significant contributions in this area. The third proposed research area involves mesosphere and lower thermosphere/ionosphere processes. This study will build on the recent work on NLC and sporadic E layers where the SRI staff has already published several new findings. It is also planned to initiate a post-doctoral program at the SRF to help advance the ongoing research efforts and to help train the next generation of scientists in the use of the facility and its related instrumentation for a broad range of high-latitude research. In summary, there appears to be a good alignment between the anticipated facility improvements and instrument developments that are planned for the near future and the main science efforts proposed over the next 5 years.

3. Educational Activities

SRI is not an educational institution and has no direct access to research students. The SRF is also located at an isolated part of Greenland with limited access to the outside world. This said, the panel was unanimous in its appreciation of the extensive graduate student interaction that has been developed at Sondrestrom with the SRF scientists, engineers and the site instrumentation. SRI scientists work directly with students whose advisors have explicit projects (either campaign or long-term) running at Sondrestrom. In the past 5 years this has resulted in 20 completed PhD’s, with an additional 12 students currently in the midst of their graduate studies. Of special note, SRF has created a “Graduate Student Research Experience Program” which provides travel and living expenses to support graduate students to visit and work at the SRF for a period of a few months. In addition, there has been further, flexible on-site hosting of graduate, undergraduate, and high school students, as the opportunity arises.

Sondrestrom continues to be a good neighbor with the local community of Kangerlussuaq. The site staff frequently provides impromptu tours for visitors to the facility. While acknowledging that the timing of these visits can occasionally be awkward, the site staff was clearly enthusiastic and strongly supported this ongoing activity. This is because the site staff is well integrated into the local community. Over the years several children belonging to the site staff have attended local schools and currently the spouse of one of the staff assists in teaching English to children in Kangerlussuaq. The panel recognizes the importance of developing this interaction, which is clearly beneficial to the local community, and continues to foster good relations thereby paving the way for future research activities at the facility. The site staff is to be commended for their ongoing interest and dedication to this important activity.

As part of its ongoing education program the SRF enthusiastically seeks to continue its collaborative research program involving graduate and undergraduate students. The main goal is to develop the students' abilities to perform high quality research as well as to nurture their understanding of the scientific role and capabilities of a major radar facility and its associated optical instrumentation. To date, the SRI scientists have achieved this goal primarily by "one-on-one" interactions with the students and their advisors. This plan has worked particularly well, fostering strong national and international relationships that principally affect college students. However, over the next 5-years SRF has perceived an opportunity to invest in more systematic K-12 efforts, to increase scientific literacy in general, and to reduce barriers between research scientists and K-12 students.

This goal will be achieved by SRI staff development of "new tools" and resources for aiding teachers in the classroom to address issues such as data literacy. The new effort would be coordinated by an advisory panel that would draw upon a recently developed "education expertise program" at SRI. Initially this effort would be supported by funds requested as part of the 5-year SRF facility continuation proposal, but the panel was informed that SRI also plans to pursue other funding agencies and opportunities to provide additional support for this program.

While the main panel recommendations are given later, we note here that the planned expansion of the existing, and clearly successful, Education and Public Outreach program at SRF was deemed very desirable. However, the panel also cautions that the new effort should proceed with deliberation so as not to unduly outweigh the balance with ongoing science and engineering and the subsequent demands on the scientific and technical staff.

4. User Support and Facility Infrastructure

4a. User Support

SRI has a long and successful history of providing user support to visiting radar users and to individual PIs who operate their own instruments at the SRF. In total 24 radio and optical instruments are currently located at the Sondrestrom site, although not all are presently functional. Many of the Guest PI instruments are semi-autonomous and require little attention. However, to help the Guest PIs obtain best quality data the SRF provides a dedicated staff member to oversee and maintain each of the instruments (with relevant cross-training for the site crew). Of those instruments that are currently operated at SRF there is a significant subset of guest PI instruments whose present utility and research productivity is not clear. Sondrestrom staff report 28 institutional (e.g. universities) or consortium (e.g. World Day) users of the primary facility data. High community demand, and a favorable USD-DKK exchange rate have enabled a significant increase in the ISR operations (currently ~1600 hours per year), significantly above the target of 1200 hours per year, for each of the past five years.

During the past year, 18 scientists have visited the Sondrestrom facility. The number of scientists visiting the site has diminished somewhat in recent years, most of which is attributed to improvements in internet access (enabling regular data retrieval), and the development of automated, long-term operations for many of the guest PI instruments. Investigators directly associated with SRF have published 32 refereed articles using data obtained at the SRF in the past 5 years. There are currently no up-to-date records available on related scientific publications by Guest PI's or on the status of their research programs.

Community access to the SRF for experimental use of the site instrumentation or for installing a guest PI instrument is generally accomplished informally through telephone or e-mail contact with the Sondrestrom PI, Dr. J. Thayer. After approval of the request the appropriate SRI staff follows through with the requestor to accomplish the new task. SRF staff seems eager to work with guest radar users to develop observing modes that will suit the objectives of the guest's project. In a similar manner the operation (and basic maintenance) of the guest PI instruments is performed by the on site staff and requests for changes in instrument operations etc., are made via e-mail or telephone contact either via SRI staff scientists or directly by the Guest PI. Access to existing facility data is also via contact with the appropriate SRI scientist or guest instrument investigator. Although somewhat uncoordinated, all of these activities appear to work well.

4b. Facility Infrastructure

Highlights: Recent developments in the SRF facility infrastructure have focused primarily on the radar transmitter and receiver system and on improving the operational performance of the lidar systems. The current Sondrestrom radar transmitter uses a Communications and Power Industries (CPI) model VKL-7796SRI, S/N 203 klystron. After several repairs early on in its operation, the CPI klystron has been operating without problems since early 2000. A spare Litton klystron transmitter serves as the backup for the CPI tube, but can be considered as only a temporary tube as it has exceeded its expected lifetime. With an annual radar usage of about 1600 hours the issue of replacing the klystron with an alternative transmitter is paramount. SRI is moving forward with plans to use a Thomson TH2104X tube which together with pulsed cathode and necessary magnet(s) is expected to cost about $215K (subsequent tubes would cost about $160K each). As part of this infrastructure development, a new modulator capable of driving the existing CPI klystron, the backup Litton tube and the new Thomson tube, was transported to Greenland on the same C-130 flight used by this review panel. A new solid-state intermediate power amplifier was also installed in 1999.

The ISR receivers and the data-taking system have been constantly upgraded throughout the 20 plus years of operations at Sondrestrom. Numerous data acquisition modes have been developed that make use of the steadily increasing processing power (which in turn provide for enhancements in the geophysical measurements). SRI is currently developing and testing a new IF-sampling digital receiver card for the Sondrestrom radar. These powerful new cards are expected to be significantly cheaper than commercially available cards and they will be utilized in the new Advanced Modular ISR program (AMISR) that is also under development at SRI. This major development in the digital processing capability of the radar signal (together with the incumbent software) is expected to be of considerable interest to the entire ISR community as it may create the possibility for future standardization – a pressing issue for all of the upper atmospheric radar facilities.

> ***Plans:*** Sondrestrom is a well-founded observatory with clearly defined research goals over the next 5-years. Nevertheless, there are plans for new infrastructure and/or improvements in existing capabilities that would greatly enhance the scientific potential of the facility. Major improvements focus on (a) the evolution toward digital receivers for the ISR with incumbent user-friendly software at all levels; (b) lidar upgrades to provide new science flexibility; and (c) the acquisition of a second imaging system to significantly enhance the existing optical aurora measurement capabilities (e.g. for simultaneous multi-spectral imaging or for fast auroral observations).

A clear advantage of standardization in technology provided by the new digital receiver cards that are currently under development (as part of the AMISR program) was described above. However, the major underlying scientific/engineering driver is the improvement in receiver digital processing capability which is expected to result in much more efficient utilization of the sampled signal bandwidth with consequent gains in the extraction of the measured geophysical parameters.

The deployment in 1997 of a resonant lidar system alongside the Rayleigh lidar system significantly enhanced the capability of the SRF for investigating a broad range of neutral (and coupled ionospheric) high-latitude phenomena. Significant new research capabilities will emerge as planned system improvements are implemented. These include improving the daytime capabilities of both systems, adding a depolarization and an infrared detection capability to the Rayleigh system for more detailed NLC studies, and bettering the existing software capabilities for the data acquisition systems.

All-sky auroral imagery provides important context diagnostics important for interpreting the ISR and lidar measurements. The existing all-sky camera was recently upgraded with a Gen III detector providing a significant improvement in the system sensitivity and an enhanced near infrared spectral capability. Planned improvements to the data-taking/control software will automatically adjust data acquisition-modes to prevailing auroral conditions. This said, SRF made a strong case for the acquisition and implementation of a second digital imaging system that would provide a much needed capability for simultaneous multi-spectral measurements of auroral dynamics recently shown to be more complex and varied then currently accepted. This system would require new software development to allow automatic/remote-controlled observations of weak and strong auroral emissions viewed multi-spectrally.

While supporting the scientific rationale for the new imager, the panel believes that the plan to purchase of a second imaging system of similar type and capability to the existing system is not necessarily the best way forward. This plan should be re-evaluated to include other options, such as fast auroral imagery, that could significantly enhance the overall capabilities of the optical facility instrumentation for future research.

Infrastructure Maintenance Issues: The primary infrastructure maintenance issue that SRF faces over the next several years concerns the replacement of current transmitter klystron. However, a clear strategy was developed and guiding plans for its replacement are proceeding. An additional pressing issue concerns limitations in the available network bandwidth to the outside world and the potential impact caused by adding more data capability to existing instruments or the inclusion of additional guest PI instruments that would further load the network.

The Sondrestrom transmitter has basically one functioning tube and a questionable spare tube that is at the limit of its refurbishment. Based on an anticipated 20000-hour lifetime the remaining "good" klystron has an estimated 10,000 hours of operations available, however, this estimate is rather uncertain. An end-of-life, but working spare klystron is also available. However, with a current annual radar usage of about 1600 hours, it is clear that the issue of transmitter klystron alternatives must be faced soon. As already mentioned, planning is proceeding with the transition to a commercially available Thomson TH2104X tube. The new modulator, capable of driving the current CPI klystron, the spare Litton klystron, and the new Thomson klystron, was recently delivered to Sondrestrom and a new solid-state intermediate power amplifier was installed in 1999. This fundamental infrastructure issue is also being faced by the Arecibo and Millstone Hill ISR facilities and staff from all three of these radars is actively discussing the klystron/transmitter issues.

The remote location of the SRF and the large number of facility and guest PI instruments (24 instruments including the ISR), necessitates a large-bandwidth network and associated infrastructure for real-time communications with SRI and for successful remote community involvement in Sondrestrom research. In addition, the rapid rise in telescience has resulted in fewer visitors while the number of on-site visitor instruments (currently 18 individual PI's) has risen and bandwidth requests may be expected to increase significantly as new instrument capabilities are implemented. This issue has the potential to become dominant and quite costly in the near future. At this time a solution to this growing problem is not apparent but it will certainly require more and more attention. This issue is also common, but to a lesser extent, to operations at the Arecibo and the Jicamarca facilities and the panel strongly encourages joint discussions on this pressing topic.

Each of the UAF radar facilities maintains appropriate analysis software that brings the essentially raw (direct from the data-taking system) data to various forms of interest to the wider community. The SRF staff have consistently maintained and developed the ISR operation and data analysis software providing a standard set of key ionospheric parameters that are made available to the community via the CEDAR and MADRIGAL databases. The SRI staff has done a masterful job in converting all of the radar data products (from the inception of the radar measurements in the early 1980's to the present day measurements), into a modern format with high functionality. At every step in the conversion they have succeeded convincingly in validating their results. This new development is critical for the proposed investigation of the response and variability of the high-latitude ionosphere on a broad range of time scales, and opens the door to other long-term studies of great importance to the scientific community. However, inter-comparison of standard data analysis products between the radars is an important topic and has resulted in some reinterpretation of certain ISR spectral results over the past years. The panel therefore promotes the development of an "open software" initiative, which already exists at some level, and could result in more efficiency in generating and maintaining well documented and validated code for the ISR and other applications. For example, the lidar and imager facility data are also readily available for collaborative research but are not processed to a set format.

5. Broader Impacts

Sondrestrom is a remote but year-round accessible arctic outpost with a diverse capability for research including upper atmosphere and space research, middle atmosphere research, solid earth and cryosphere research and information technology research. The SRF contributes meaningfully to the benefit of our society by supporting cross discipline investigations by a number of national and international agencies, including NSF, NASA, NOAA, DOD and the European DMI. The SRF also participates actively in the US National Space Weather Program (NSWP) and the US Global Change Research Program. Examples of the broader impact of the space research conducted at the SRF include:

- Testing the "geoeffectiveness" of solar storms and providing space weather "alerts" to aid global-scale coordinated measurements and to provide key information for community modeling.
- Development of event-driven radar operations protocol for CME events as part of the NSWP.
- Coordinated research with a broad range of US and European satellites including essential calibration and validation measurements.

The SRF is also designated as a primary field site within the Network for Detection of Stratospheric Change (NDSC). Lidar measurements together with instruments from the DMI monitor ozone and stratospheric PSC as well as mesospheric NLC occurrence and properties that provide important information for the Global Change Research Program. Furthermore, GPS monitoring at SRF is used to study the Greenland ice cap mass balance and for gravity measurements.

The SRF is currently being used as a test bed for information technology research because of its low/unreliable internet connections. This is an example of turning a clear limitation into an advantage for learning how to deal with (and make major improvements) in data retrieval and instrument control/polling at remote field sites with broad reaching benefits for a range of disciplines.

In other outreach efforts, the SRF has recently taken an active role in the Arctic Research Consortium of the United States (ARCUS) program, with its scientists providing popular magazine articles on several topics; Scientific American Magazine (Spring 2001) and Aviation Week and Space Technology (Nov 1999). The Sondrestrom facility also hosted filming of the Solar Max IMAX movie in 2000. Currently, the SRF is looking for opportunities to participate in a space science museum in Greenland, to further the edification of the local inhabitants as well as the growing number of tourists.

6. Management and Budget

The scientific expertise for the Sondrestrom facility resides with the PI and colleagues, all of whom are based at SRI in Menlo Park. The site manager oversees the operations, maintenance, and engineering development with a very capable team of 3-4 technical staff. The site manager is supported in this effort by a project manager located in Menlo Park who handles the facility and logistical issues as well as data management. The interaction between the scientific and technical support personnel is accomplished through weekly (and sometimes daily) phone calls as well as several site visits during the year by the key scientific staff. The total amount of time spent on site by the scientific staff is approximately 3-4 months/year.

This communication and management arrangement appears to work well for the Sondrestrom remote site operations. The on-site crew feels comfortable in contacting the scientific staff whenever operational issues or problems arise, many of which are solved via telephone discussions. The site crew is cross-trained on the primary instrument operations in order to fill-in on duties as the need arises (most guest PI instruments run semi-automatically). The regular site visits provide extended periods for the engineering staff to work together with the scientists, particularly on the development of new ideas and projects. The camaraderie and mutual respect of the crew and the scientists are apparent. On this note the panel strongly encourages the professional development of the site crew including fostering their interest in becoming active members of IEEE and SPIE which in turn would help provide for their continuing education. If appropriate, with facility time schedules, support to attend professional engineering society meetings and/or selected short courses would further enhance their professional development. Currently there is one open position on the site team. The panel believes that it is important to fill this position as soon as possible in order to continue to provide good operations and engineering support.

The NSF budget for Sondrestrom has averaged $2.1M over the last five years. The current year funding is $2.3M, which is approximately 20% larger than the other three ISR facilities (Millstone Hill, Arecibo, and Jicamarca). Approximately half of the budget is spent in operating the facility and half in enabling the science. Due to the remote location of the site, associated costs for its operation and maintenance are expected to be somewhat higher. Flexibility in the budget is therefore desirable, particular as considerable instability in operational costs may be incurred due to the recent decline in the U.S./Kroner exchange rate and the current increases in fuel costs.

The SRF strategic goals in science, infrastructure development, educational activities, and user support over the next 5-years require an enhanced budget of approximately 10%

(plus additional proposal-based support needed for the guest PI's to continue their collaborative research at SRF). The proposed instrumentation infrastructure development has been clearly demonstrated as necessary for the science goals the facility has set for itself. Given that the UAF budget is not expected to increase dramatically, the panel suggests that additional prioritization of the science goals would help in determining priorities for the infrastructure development. On this note we encourage the PI to seek community input to help further prioritize the science objectives, keeping in mind the desire to move forward and to provide state-of-the-art facility and guest PI instrumentation. The panel also recommends that the PI and the program manager seek co-funding by other NSF programs for certain aspects of the budget, particularly those related to new, innovative educational approaches.

The PI has thought through some early strategies for implementing a budget cut if required, with a first approach to reducing the radar operation time (which has increased by 40% over the last decade). The panel supports this early approach but cautions about cuts that would lose site and/or scientific personnel experience in key areas. Because of the flexibility in using SRI human resource support for many projects, this approach should be a viable one.

7. Summary of Findings and Recommendations

<u>Finding:</u> The SRF scientific goals over the next 5-years are broad ranging, ambitious and fully utilize the capabilities of this well-founded arctic facility. The panel has high confidence that considerable progress will be made towards achieving these goals.

- *The panel fully supports the proposed research activities to the extent achievable within available funding (noting that radar operational hours are dictated by the highly variable cost of fuel). The panel is concerned that with the anticipated addition of the new AMISR facility at two additional arctic sites that the scientific goals of the SRF may need to be adjusted in due course.*

<u>Finding:</u> A clear plan has been developed for the replacement of the existing and rapidly aging klystron transmitter with a commercially available tube manufactured by Thomson. To this end a new modulator and a solid-state power amplifier have already been purchased and deployed to SRF.

- *The panel fully endorses the proposed infrastructure plan and recommends that it continue to be pursued as a priority. The panel also suggests that funding for the replacement transmitter tube be identified as early as possible.*

<u>Finding:</u> The proposed addition of a second imaging system will provide a much needed multi-spectral/fast imaging capability for new auroral research.

- *The panel endorses the scientific rationale for the development of this enhanced imaging capability but believes that further examination of commercially available instrumentation should be made to maximize the utility of this new instrument. The panel also notes that other UAF facilities operate similar-type* *imaging systems and encourages the formation of an imager working group to address common problems in data acquisition and reduction.*

Finding: The research activities at the SRF have been strong and productive and there is every expectation that they will continue as such into the future. This said it is not clear whether the facility science is being driven too strongly by SRI researchers.

- *The panel fully endorses the key involvement of SRI scientists in the Sondrestrom research program but also suggests that a better balance between internal and external investigators be pursued for utilizing the facility instruments. The panel also suggests that access to these facilities be further advertised within the scientific community and that the user application and selection procedure be made more accountable.*

Finding: In addition to the three facility instruments the SRF also hosts 21 guest PI instruments of various ages and complexities to operate. The status and productivity of many of theses instruments is unclear and the panel believes that, if unchecked, their continued operation and maintenance will pose a growing and unacceptable burden on the site crew operations.

- *While recognizing the high importance of a healthy guest investigator instrument program for broadening and strengthening the capability of the facility the panel strongly recommends that a full assessment of the existing guest instruments be made including their operational status, current funding, research activities and scientific findings. The panel also recommends that NSF provide the facility PI with the authority to request annual reports from guest PI's detailing scientific contributions of their instruments in both cluster and stand alone operations.*

Finding: SRI staff is currently developing and testing at Sondrestrom a new digital receiver card as part of the AMISR development program. This is a major funded development in radar signal processing capability and is expected to be of considerable interest to the entire ISR community.

- *The panel strongly suggests that cross-facility discussions be held on a regular basis to take advantage of the considerable expertise that also exists at the other ISR facilities and to limit redundant research and development in this important area. This would better harvest the potential of this new infrastructure development for all of the UAF facilities.*

Finding: A looming problem regarding network infrastructure and communications was identified that could become acute at SRF as the rise in telescience for remote instrument control and increased demand for data transmission continues.

- *This problem is also expected to impact other ISR facilities and the panel recommends that further community wide attention (incorporating the current IT research results) be given to this problem while it is still at a manageable stage.*

Finding: The data analysis software is unique for each of the UAF facilities. Although well developed and usually well documented, this has resulted in some measurement reinterpretation over the years and can seriously affect users of multi-radar facility data that choose to reduce the data themselves.

- *The panel fully supports the continued development of an "open software" initiative with a primary goal of improving the efficiency in generating and maintaining well documented and validated common code for all of the ISR facility instruments.*

Finding: The education and public outreach program at SRF has been very successful but somewhat limited in its scope, mainly focusing on the GSRE program. The interaction with the local community continues to be excellent. The panel feels that there is an additional opportunity for increased exposure to undergraduates, through REU activities at other universities.

- *The panel recommends that SRF continue its superb graduate student "one-on-one" interactions and looks for opportunities to gradually increase its activities for undergraduates. The planned expansion of the existing EPO program to embrace K-12 science education was also deemed very desirable. However, the panel cautions that this new effort should proceed with great deliberation so as not to unduly outweigh the balance with ongoing research and the subsequent demands on the scientific and technical staff. The panel further cautions that this latter activity while truly worthy, will require greatly enhanced resources to do justice to this goal.*

Finding: The site crew is content with their working environment and the existing work loads. However, the panel feels that they should be given the opportunity to further develop their engineering and scientific skills as part of their career development.

- *The panel recommends that when appropriate individual SRF staff should be given the opportunity to participate in selected short courses or professional engineering society meetings to further their education and to foster continued good working relations. The panel also recommends that the existing vacancy in the site crew should be filled as soon as possible.*

Millstone Hill Observatory

1. Introduction

1a. Description of Site

The Millstone Hill Observatory (MHO) is located 35 miles northwest of metropolitan Boston at the Massachusetts Institute of Technology (MIT) Haystack Observatory in Westford. The setting is rural on a 1500-acre site that MHO shares with an MIT Lincoln Laboratory field station. It is accessible by automobile with drives of less than an hour from Logan international airport (Boston) and the regional airport in Manchester, NH.

The MHO includes a 440 MHz radar system with two 2.5 MW UHF transmitters, a fully steerable 46-m antenna known as the MISA, and a fixed 68-m zenith pointing dish. The MISA is on a local peak, which offers an unobstructed line of sight to the horizon at nearly all azimuths. The MHO also includes an optical aeronomy facility, and dedicated computer, engineering, and analysis facilities. MIT owns the MHO, including the radars, the optical instruments, the staff offices, and the analysis facilities. The radar control room along with the transmitters and receivers are housed in a secure MIT Lincoln Laboratory building. This is a legacy of the historic connection between MHO and the MIT Lincoln Laboratory.

There are 18 full-time equivalent employees (FTE) comprising research, technical, and support staff in the MIT Haystack Observatory Atmospheric Sciences Group (ASG) who operate the MHO. Dr. John Foster manages the ASG and the MHO operations. The ASG workspace is excellent, including office space in a dedicated wing, an on-site library, several conference rooms, and both wired and wireless computer network access. There are no residential facilities for visiting scientists at the site, but there is a good hotel within a 15-minute drive. The recent growth and development in the Westford area has elevated property values to the extent that few ASG staff lives in the immediate vicinity.

The MHO provides infrastructure support for non-MIT instrumentation as a community service. Some instruments are calibrated with correlative MHO measurements. Others provide complementary measurements and facilitate collaborative studies. For example, Dr. Bodo Reinisch (University of Massachusetts at Lowell) operates an on-site digisonde, which is frequently used to calibrate the MHO radar measurements.

The incoherent scatter radar (ISR) at MHO was built in the 1960s. The NSF has supported the MHO zenith antenna operations since 1974, and the combined MISA and zenith radar system operations since 1978. The MHO staff members lead research studies in the NSF CEDAR program and contribute to NSF GEM research. They also pursue collaborative studies in Space Weather and related research with complementary support from the Air Force and NASA.

The MHO is located at 42.6°N geographic and 55.0°N magnetic invariant latitude. The MHO is ideally suited for middle latitude ionosphere, thermosphere, magnetosphere, and space weather research studies. The horizontal extent of the MISA measurements is unique to the NSF ISR chain. The MISA provides measurements of both auroral and sub-auroral ionospheric processes and insight into magnetosphere ionosphere coupling processes at the plasmapause and the boundary between the inner magnetosphere and the plasmasphere.

1b. Summary of Site Strategic Goals

The overarching 5-year goals of the Millstone Hill Observatory research program focus on four key areas:

- To lead or participate in broad scientific initiatives that investigate magnetospheric, magnetospheric-ionospheric coupling, and thermospheric-ionospheric processes that affect the middle-latitude upper atmosphere and space environment with an emphasis on disturbance effects,
- To modernize, maintain, and operate the ISR facility, and to develop and deploy a prototype distributed clustered-instrument array for continuous ionospheric monitoring at sub-auroral latitudes
- To advance data analysis and distribution techniques and to provide easy access to MHO measurements including derived parameters for both observatory and community-wide use, and
- To foster excitement for scientific research and appreciation for the excellence of the MHO program through the conduct of education and public outreach activities.

The panel is confident that MHO will realize progress in all of these areas given the broad objectives of the proposed research plan and the scientific and high technical expertise of the staff. The panel notes one caveat: at least two major MHO infrastructure initiatives, the MISA repair and the Intercepted Signals for Ionospheric Science (ISIS) funded instrument development, can only be achieved through the realization of significant additional funding which is as yet unsecured.

The 5-year science objectives outlined in the MHO recent proposal include investigations of (a) the prompt effects of solar wind variations on the middle latitude ionosphere, (b) middle latitude ionosphere-magnetosphere coupling processes, (c) the MHO data archive for empirical model development, (d) lower thermospheric storm effects, and (e) fine-scale electrodynamics based on coherent scatter measurements.

The complementary technical activities will facilitate the MHO science objectives. When these achievements are readily transferable, they will also contribute to infrastructure development and science objectives at the other ISR facilities. The 5-year efforts include

- The repair of the MISA, including foundation, structural work, and recoating.
- Continuing development of a workstation based Millstone incoherent scatter data acquisition system (MIDAS-W) for radar control, data acquisition, and signal processing, using off-the-shelf computing elements and standard languages, which became operational for data acquisition in November 2001. These developments are available to the broader radar community through the Open

Radar Initiative, and will form the basis of the MHO contribution to the development of a data acquisition system for the AMISR facility in partnership with SRI International.

- A prioritized 2-phase approach to transmitter upgrade involving 1) the integration of computer monitoring and control, and 2) the replacement of UHF transmitters with new technology.
- Continuing development of the unique capabilities of the MADRIGAL database including support for real-time data and application programming interfaces, and community access to these developments through the Open MADRIGAL Initiative.
- The operation of ancillary instrumentation including, a GPS receiver station as part of the NSF Suominet project (deployed in May 2001), and an on-site fully operational Fabry-Perot interferometer which will be phased out in years 3-5 of the current cooperative agreement.

2. Scientific Research Enabled by the Facility

2a. Science Evaluation

The recent MHO ASG scientific achievements were centered on investigations of the coupled magnetosphere-ionosphere-thermosphere system. Examples include:

- The Sub-Auroral Polarization Stream (SAPS), a region of enhanced westward convection that occurs equatorward of the auroral two-cell convection, was identified and investigated in several papers and presentations. This broad region of persistent enhanced convection that spans the night side from dusk to early morning sector is now understood to be associated with the enhanced convection electric field observed in the inner magnetosphere and the inward movement of the plasmapause boundary. Storm time ($Kp > 4$) enhanced electron density is observed in the ionosphere associated with detached plasma regions that have been stripped off of the plasmasphere during these periods of enhanced magnetospheric convection.
- Prompt effects of the coupled solar wind–magnetosphere–ionosphere system were demonstrated in the midlatitude ionosphere. Solar wind dynamic pressure variations can affect the ionospheric electron density near the F-peak altitude by about 30% within 30 – 70 minutes. IMF variations also can affect the density near the F-peak altitude suggesting that the convection electric field penetrates to the midlatitude ionosphere causing the **ExB** drift to move the F-layer to different altitudes. Since the solar wind and IMF are often variable, this can be a common and important source of midlatitude ionospheric plasma density variability.
- Long duration (30 days of continuous operation) of the vertical incoherent scatter radar has produced new characterization of the ionospheric variability from day to day in Ne, Te, and Ti. During the run, SAPS, storm effects, and oscillations in Ne were observed.
- Coordinated analysis of various data sets, including tail magnetic field, geosynchronous field and energetic particles, IMF and solar wind inputs, IMAGE

ENA and ground magnetic data have been interpreted to show that periodic substorm intervals have a characteristic period of about 2.5 hours. This work appears to be breaking new ground in the understanding of global magnetospheric dynamics.

- Storm time event studies have characterized both the variations in the L=3 ionosphere as well as the lower thermospheric response to intense geomagnetic activity. Statistical investigations using the MADRIGAL database have characterized the ionosphere and have been used to produce empirical models of the F and E region ionosphere (based on 30 years of observations).
- The global-scale dynamical response of the lower thermosphere to the April 2002 solar storms indicates the downward penetration of storm effects to 100 km. This is a notable example of MHO ASG leadership and the power of collaborative studies that capitalize on simultaneous measurements made at the NSF UAF chain of facilities and related observatories around the world.
- The comparison of seasonally averaged UARS/WINDII and MHO lower thermospheric winds revealed similar magnitudes, annual variations, and tidal perturbations in contrast to the unresolved systematic offset between the magnitudes of winds measured by the HRDI and WINDII instruments on the UARS and ground-based MF and meteor winds.

Uniqueness of Research Done Using the Site: The MHO ISR provides unique access to time and space resolved parameters of the upper middle latitude ionosphere. Because the MISA may steer to very low elevation angles, Millstone Hill is capable of observing the greatest horizontal extent of all incoherent scatter radars. Millstone Hill's location permits access to the extremely complex upper mid-latitude ionosphere structure, such as the trough and the more recently identified Sub Auroral Polarization Streams (SAPS), as well as the equatorward expression of expanded auroral activity during magnetic storms.

Millstone's geomagnetic location has enabled some very clever observations of E-region irregularities (through a side lobe of the MISA) while simultaneously observing the F region on the same field-line but at a different range. Other attempts at this type of experiment have required multiple radar systems and associated logistical complications.

The ISR is the strongly dominant instrument at the MHO site.

Over the past several years the MHO staff has also developed and operated a powerful Rayleigh lidar system located at the nearby Fire Pond facility. This system was initially developed under a separate NSF Major Research Instrumentation (MRI) grant. However, programmatic issues and rising staffing costs have limited its operation and scientific productivity. Following consultations with NSF Facilities Program Office, the lidar system was closed down in 2002. A similar situation has recently arisen with the current passive optical measurements. Due to the rising costs associated with regular servicing and operation of the FPS instrumentation in combination with difficulties in recruiting a replacement optical engineer/scientist in anticipation of the retirement of its current staff member, the MHO plans to phase out its optical facility program by 2007. However, the MHO plans to continue to maintain the optical site into the future for possible use by visiting PI instrumentation.

Quality of the Scientific Research: There have been a number of recent accomplishments of very high merit published by the scientific staff of the Millstone facility. Of particular note, years of effort have recently culminated in the global understanding of the MI coupling between the inner magnetosphere and ionosphere during SAPS events, plasmasphere erosion/detached plasma regions, enhanced magnetospheric convection and enhanced stormtime electron densities in the midlatitude ionosphere. These results have been the focus of several invited presentations at scientific conferences and publications in top tier journals. These achievements constitute groundbreaking insight into the global understanding of periodic substorms, sawtooth events, and inner magnetospheric dynamics.

Role of Facility in Supporting National, International and Satellite Programs: Millstone Hill researchers are very active in the field of coordinated measurements with several NASA and DOD satellite programs and they have obtained significant additional external support for this research. These studies include coordinated measurements of basic ionospheric parameters with DMSP overpasses for a variety of investigations including studies of SAPS and storm time effects. Novel observations of recombination holes and plasma kinetic effects have also been made in coordination with Space Shuttle OMS burns. (Millstone Hill Observatory is ideally located for these measurements for launches to the International Space Station.) These studies naturally require a high degree of instrument readiness and are a testament to the prompt response capability provided by MHO personnel. Current, coordinated studies with the NASA TIMED satellite are an integral part of the joint NSF-NASA ground-based component to the TIMED research program, and new measurements are being planned as part of the extended TIMED mission. Finally, ongoing studies of Magnetosphere-Ionosphere (M-I) coupling at MHO are playing a key role in defining coordinated satellite-ground measurement requirements for the new NASA Living with a Star Program.

There are very strong collaborative relationships between MHO and EISCAT. Scientific collaborations are common as is the development of data acquisition, management and analysis software. In large part this appears to result of the common deep scientific and technical interests that have developed between the two institutions.

The MHO scientific staff members are frequent and active participants in national and international scientific meetings. They are active in the coordination of international workshops, data acquisition campaigns, and the organization of World Day data collection activities. They regularly participate in the GEM and CEDAR workshops, and assume leadership roles in these programs. They also participate in space weather activities, research, and meetings. The development of products from the MHO facility that could be utilized for space weather purposes is an area that is receiving considerable attention.

2b. Research Capacity and Balance

The MHO centerpiece is a pair of 2.5 MW 440 MHz transmitters, which may be coupled to either the MISA or the zenith-pointing antenna. Given the hilltop location, the MISA system provides great flexibility in antenna pointing directions and latitude coverage. Staffing and funding constraints limit the ISR operation to about 1000 hours/year.

The on-site digisonde is in continuous operation, and is presently used to assist in the calibration of the absolute power of the ISR. A variety of other major radars are operated at the Observatory. However, these are either dedicated to radio astronomy studies or MIT Lincoln Laboratory projects, and they are beyond the purview of this report.

Complementary to the ongoing ISR and other radio measurements, MHO has an established facility supporting the operation of several optical instruments at a site near the main radar facility and located to minimize stray light contamination. The facility optical instrumentation currently comprises two capable, but aging Fabry-Perot Spectrometers (FPS) designed to study F-region winds using the 630 nm thermospheric nightglow emission. One system employs a cooled photometer and sequentially samples the sky at four orthogonal azimuths (plus zenith) to determine the meridional and zonal wind components (with typical resolution of ~1 hr), while the second, more modern system employs a more sophisticated all-sky imaging method to map wind directions simultaneously at 24 azimuths and with a significantly higher temporal resolution. Both instruments have been operated carefully and routinely over the past several years, resulting in a valuable data set on mid-latitude thermospheric neutral winds. However, they both require daily on-site maintenance (LN_2 servicing etc.) and expert adjustment and calibration to sustain their accurate functionality.

In addition to these facility measurements several other guest PIs have operated their optical instruments at this site. A second trailer belonging to Boston University is also located next to the MHO optics facility and currently houses a multi-wavelength all-sky CCD imager for mesospheric gravity wave and thermospheric airglow studies. Independent comments provided by BU indicate their strong interest to continue to operate at this site into the foreseeable future.

2c. Future Science Plans

The panel was disappointed by the absence of clearly defined science plans in the MHO presentations and review materials. Therein, the MHO science plans are discussed very qualitatively; general research areas are mentioned – e.g., mid-latitude magnetosphere-ionosphere coupling – and the desire to continue to investigate the areas where recent accomplishments (as discussed above) were reported. Despite some urging by the panel the specific problems that remain to be answered and what will be required to determine the answers were not clearly articulated or identified. This led the panel to wonder, for example, whether it may be possible to solve all remaining problems with the 30 years of accumulated data in the Millstone database. In this context, the MHO has not made a strong case for continued future measurement operations nor for the refurbishment of the antenna dish. It would have been more compelling, to state the specific scientific questions that must be addressed and then determine what is required to make progress. In particular, the critical usage of the Millstone centerpiece instruments was not argued very strongly. Rather, it seems that they are assumed to be of critical importance. Since the steerable radar dish is in need of major renovation, now is the time to carefully consider the future mission of this radar and to investigate other strategies for continuation of key MI coupling studies.

In contrast, plans were outlined to respond to the stated demand from the modeling community for newly performed long duration measurements. This appears to be an important need though documentation of the need was not provided. Disappointingly, the MHO presented no discussion to estimate the number of long duration experiments that might be required to provide the answers that would satisfy the needs of the modeling community.

The development of new instrumentation that can be deployed in arrays to determine TEC is another very promising area of future science effort. Again, the problem that drives this development was not well articulated. There presently exist many measurement sites whose data are utilized for TEC measurement and the results presented above appear to have fairly good spatial resolution which begs the question, what more is needed? In sum, the scientific questions that need to be answered and the requirements necessary to obtain these answers are not expressed in a straightforward way in the material that the panel reviewed.

3. Educational Activities

The Review Panel was very favorably impressed by the MHO accomplishments in education and public outreach. These include the opportunities availed by the NSF REU (140 students total, about 4 per year) and RET (2 new and 2 continuing teachers per year) programs, as well as the personalized interaction with the local community. In addition, Millstone has helped develop the Small Radio Telescope, which has been distributed to 80 sites and the subject of a Sky & Telescope article. Of particular note, the Observatory has done a superb job in following their students afterward their REU participation, with a goal of tracking their scientific involvement 5-6 years out. Remarkably, they have succeeded in following practically all students in REU for the past five years.

The Observatory Staff have an envious record of generating good will in the REU program, as evidenced by exit polls and letters from participants. This effort has clearly persuaded a significant fraction of the students to pursue studies in science, and in space physics.

The Observatory staff seems equally driven by a sense of responsibility to NSF's larger outreach goals and genuine personal interest in promoting science awareness in schools and the local community. Although there is tremendous demand for participation in the MIT Haystack Observatory REU program (100 students applying for 8 positions), they limit participants to 8/year in order to maintain large contact time for each student.

The RET program is somewhat newer, but may eventually provide a larger, albeit indirect impact.

4. User Support and Facility Infrastructure

4a. User Support

Millstone's principle user base resides in use of the MADRIGAL database and not in investigator visits to Millstone to conduct observations. Users in all categories numbered about 60 between January 2002 and October 2003. There were ~15 site visitors in 2001 with the majority giving talks, etc, but not participating in observations. This level of activity has resulted in about 90 papers in the refereed scientific literature during the last 5 years.

The MHO hosts several external instruments, including a digisonde, an all-sky imager, a magnetometer, and a Suominet GPS receiver. When the MHO FPI and all-sky Doppler interferometer are phased-out in 2007 (section 2.5), the facility instruments will consist of the CIDR tomography array and the two incoherent scatter radars. The ISRs are the centerpiece MHO UAF instruments and operated for over 1000 hours in FY 2003, including the justly renowned “30-day” run. FY 2002 usage was 348 hours due to a major system failure (discussed later).

Each of the UAF radar facilities maintains appropriate analysis software that brings the essentially raw (direct from the data-taking system) data to various forms of interest to the wider community. At Millstone this process proceeds via the MADRIGAL processing/database software system that includes all MHO ISR data and appropriate geophysical models to assist in data interpretation. The community has granted significant (and growing) acceptance to MADRIGAL with nearly 10 installations worldwide, to date. The MADRIGAL system additionally provides an interface to an observation in progress. We note that the Millstone staff members have at every step attempted to validate all approaches and have convincingly succeeded. A more modern manifestation of MADRIGAL, OpenMADRIGAL, maintains all objectives of the original but is completely web-accessible with high quality documentation and a CVS (Concurrent Versions System) such that all developers can contribute/distribute changes to the code. In a similar manner the MHO staff is developing the OpenRADAR and OpenISR initiatives that encompass the software radar concept. In all these initiatives the contributions are pioneering if not totally unique. The staff should be congratulated on the success of these initiatives and of OpenMADRIGAL in particular.

The MHO ASG has recently developed several empirical models based on ISR measurement archives. These models include the Virtual Millstone Hill and Saint Santin Radars, electric field models, a lower thermospheric wind model, and two regional ionospheric models; one along an American latitude chain and the other along a European longitude chain. These models are user-friendly and include web interfaces. The panel lauds these efforts and the plans to continue their maintenance and development.

4b. Facility Infrastructure

Highlights: The MHO receivers and data-taking system are upgraded on an on-going basis. MHO staff members were early developers of IF-sampling digital receivers as part of the software radar initiative. This initiative was propelled by the October 2001 failure of the MIDAS-1 receiver/controller system that was then replaced with the MIDAS-W Software Radar System, which is truly pioneering in scope and vision. This system continues to evolve at all levels and forms a likely model for the modernization of the radar systems at the other UAF sites. Much of the utility of this approach, the OpenRadar/ISR initiative, is that it lends flexibility and scope to the radar at all levels. In particular, it enables multi-use data strategies where the sampled bandwidth is more efficiently utilized resulting in the extraction of more geophysical parameters.

Additionally, the Millstone staff is developing the technical infrastructure – open software, hardware, protocols, etc. – necessary for distributed instrumentation arrays and fusion of data to create virtual instruments. The panel notes that many of the infrastructure issues/interests prominent at Millstone are common to one or more of the other UAF facilities.

Plans: The Intercepted Signals for Ionospheric Science (ISIS) project has received DoD DURIP support and proposes a prototype array of instruments using off-the-shelf hardware. The prototype ISIS array will provide measurements of mid and sub-auroral latitude phenomena within the field of view of the MHO ISRs facility. These complementary data would enhance the scientific capability of the current MHO facility.

In another pioneering effort, members of the MHO staff suggest that a "low-cost" form of ISR, the Zenith Ionospheric Profiler (ZIP), be considered for wide distribution. The ZIP would yield continuous, moderate resolution electron concentration profiles of the E/F regions. This provocative idea has been introduced at CEDAR meetings and elsewhere.

The science and facility infrastructure emphasis at Millstone for the next five years focuses on ISR issues such as structural maintenance/repairs of the MISA antenna, upgrading the transmitter, evolving to new hardware/software control of the radar, and integrating the data flowing from the radar with MADRIGAL. Major issues, expanded on below, include pressing problems with the structural integrity of the MISA antenna, strategies for replacing current transmitter klystrons, strategic planning for a new transmitter technology, implementation of transmitter protection-control hardware-software that enables unattended transmitter operation, and the evolution toward software-radar (i.e., digital controllers/receivers with appropriate software at all levels).

The optical instruments operated by Millstone staff, an FPI and an all-sky Doppler interferometer, are to be phased-out by 2007. However, the MHO plans to maintain the infrastructure necessary to support instruments fielded by external PIs as the need arises.

The MHO ASG is investigating the synergy between their plans and the design and development work of another MIT Haystack Observatory group, involving the low frequency array (LOFAR). LOFAR is the proposed next-generation large radio telescope array. (In January 2004 the Mileura Station in Western Australia was named as the optimum site for a prototype for the LOFAR system). The expertise of the MHO staff in the area of antenna element design represents one plausible ASG engineering contribution to this new project.

5. Broader Impacts

The basic space weather research on middle latitude ionospheric density gradients responded to the needs of the GPS navigation community to incorporate information on the severity of local gradients into the WAAS (wide area augmentation system) program being developed for commercial aircraft flight control. The NSF was commended by

WAAS applications designers "in terms of the economic benefits of NSF's funding of basic research."

The MHO effort to develop a user-oriented distributed database (MADRIGAL) for ISR, optical, and related data sets for use in the observatory as well as the community-at-large directly contributes to science and education-support infrastructure. Community radio science infrastructure development is also supported through the on-going MHO OpenRadar and OpenMADRIGAL initiatives to coordinate and broadly disseminate instrument and technique-development information and software to the general community.

The ASG is actively engaged in a variety of educational and public outreach activities. These include 140 student participants (females > 50%) in an NSF REU atmospheric physics Haystack Observatory program as well as the newer year-round Research Experience for Teachers (RET) program aimed at developing self-contained classroom units on space weather and the ionosphere. Several staff members actively participate in local community outreach, from the development of museum exhibits to mentoring local high school students. The MHO has also co-developed the Small Radio Telescope, which has been distributed to 80 sites around the nation.

6. Management and Budget

The Atmospheric Sciences Group is part of the MIT Haystack Observatory, which is located in Westford, MA, approximately 35 miles from the MIT academic campus. It is co-located with some MIT Lincoln Laboratory activities on real estate that is owned by MIT. The ASG group (18 people) is led by the Millstone Hill radar PI who reports to the Director of the Haystack Observatory who in turn reports to the MIT Vice President for Research. Most of the Atmospheric Sciences Group personnel are governed by human resources regulations and rules used on the MIT academic campus while the technicians are guided by human resource procedures of a union that operates within MIT. MIT institutional barriers from this arrangement include: the MIT restrictions on PI status which has resulted in only 1-2 senior people (other than the Millstone Hill UAF PI and former PI) allowed to serve as PI on other proposals/grants; working in a research environment with technician union personnel that can occasionally result in conflicts on responsibilities; lack of coupling (physically and intellectually) to the academic departments on campus resulting in lack of access to MIT students and visibility within the academic units; and strict security regulations in the radar building which disallows all citizens from non-NATO countries from entering the building.

The institutional barriers present a number of challenges for the PI and Director of Haystack in establishing a management structure for the group, for mentoring young scientists in career development, and for establishing leadership transition potential. To their credit, they have worked hard within this system and have established a group of scientists, engineers, and support personnel that are very pleased with the work environment, have good accessibility to the PI, and are enthusiastic about the science and engineering development that they do. However, the panel is concerned that a number of researchers cannot receive credit as PI status when their work is submitted as a proposal and is subsequently awarded. This avenue is one of the main areas where early career scientists begin to receive recognition of their contributions to the intellectual advances in upper atmosphere science and engineering.

Finally, it was noted by the panel that the connection with MIT students is rare and limited mostly by differences in intellectual emphasis within the MIT atmospheric science and engineering departments and Millstone Hill research. It is therefore important for MHO to work more aggressively with other universities to encourage students to participate in Millstone Hill research as well as their engineering design. New summer programs that target graduate students to learn and work at Millstone Hill for a period of time are one suggestion, in addition to the university visits already being done, to enhance further the graduate student participation.

7. Summary of Findings and Recommendations

Finding: The ASG has clearly articulated a broad and ambitious set of strategic engineering goals for the MHO site. The panel anticipates that associated plans to repair and further develop infrastructure could be thwarted by limited UAF resources.

- *The panel urgently recommends cross-facility strategic planning and an associated prioritization of UAF activities, including infrastructure improvements in order to optimize all UAF community resources.*

Finding: The MHO plans to phase out its optical facility program by 2007 due to the combination of rising costs in the servicing and operation of the FPS instrumentation, and difficulties in recruiting suitable expertise for continuing optical engineering and science activities after an anticipated ASG retirement.

- *The panel recommends that MHO leadership consult with the CEDAR Science Steering Committee (CSSC) to establish the broader impacts of the decision to eliminate the MHO optical facility program with particular attention to the impacts on CEDAR research objectives, including Space Weather applications. The panel further requests that the MHO leadership partner with the CSSC to develop a plan to minimize negative impact, including the plausibility of relocating and operating the existing FPS instrumentation at some other suitable observatory.*

Finding: The entire suite of UAFs could benefit from the innovative achievements of the MHO staff in the OpenMADRIGAL, OpenRADAR, and OpenISR initiatives. Another provocative and pioneering MHO effort is the anticipated development of a low-cost ISR, the Zenith Ionospheric Profiler (ZIP) for wide distribution.

- *The panel strongly encourages the MHO staff to continue their pioneering radio science efforts. The panel also recommends an annual UAF forum to better leverage related efforts at all UAF sites. We further recommend that ZIP receive serious attention in this proposed forum.*

Finding: The expertise of the MHO staff in the area of antenna element design represents one plausible way that the ASG could collaborate with their MIT Haystack Observatory colleagues in the LOFAR project.

- *The panel encourages this type of activity provided that it does not interfere with the primary ASG responsibilities to develop and maintain the MHO instrumentation.*

Finding: The MHO staff presented the panel with a vague set of plans for future scientific research, which they described in the context of their recent accomplishments.

- *The panel lauds the scientific achievements of the MHO staff, but cannot endorse plans that rely solely on this record, however robust. The panel encourages the MHO to increase the prospect for future support with overt specification of the unresolved research questions to be addressed, clear articulation of planned methodologies, and vigorous discussion of the potential impacts of the anticipated results.*

Finding: The MHO has a well-established and excellent education and public outreach program.

- *The panel strongly encourages the ASG to maintain their future education and public outreach activities at approximately the present level of effort.*

Finding: The ASG is a strong, talented, and committed team. Yet, MHO management is significantly challenged by problematic institutional barriers: most ASG staff cannot submit research proposals to funding agencies; ASG technicians belong to a union, leading to occasional conflicts regarding responsibility and authority; and, strict security regulations in the radar building disallow ASG members from non-NATO countries access to operations.

- *The panel recommends that the MHO leadership aggressively solicit new ideas from their staff, and more frequently request exemptions to the MIT ruling on PI status. The panel strongly believes that researchers should have "hands-on" experience with the radar, and recommends that security clearance exemptions be granted to those who work at the radar full-time.*

JHU Applied Physics Lab SuperDARN Radar Network

1. Introduction

1a. Description of Site

SuperDARN is an international research endeavor, spearheaded by scientists at Applied Physics laboratories (APL) and driven by the common interests of scientists in many countries. SuperDARN comprises a network of fifteen HF (8-20 MHz) coherent scatter radars that are used to measure globally the movement of electron density irregularities in the F-layer of the high latitude ionosphere. Nine of the radars are located in the Northern hemisphere at high-Arctic latitudes while the other six radars are located in the southern hemisphere where their viewing area encompasses much of Antarctica. Three of the northern radars are operated under U.S. support: the Goose Bay and Kapuskasing radars are located in Canada and are operated by JHU-APL (Ray Greenwald, PI.), while the third radar is sited at Kodiak, Alaska and is run by the University of Alaska, (Bill Bristow, PI). The other radars are operated by the SuperDARN international partners using their own national support. This review concerns the two radars that are operated by APL as part of the northern hemisphere SuperDARN network and their associated science, facility operations and infrastructure support at JHU/APL.

SuperDARN derives much of its success from being a collection of nearly identical hardware running common software. The basic HF radar design used by SuperDARN was originated by Dr. Ray Greenwald at JHU/APL. The proliferation of SuperDARN sites has developed at a "grass roots" level. The instruments are affordable to university and institute research groups and the combined SuperDARN data provides a global result that is significantly greater than the sum of the individual parts. SuperDARN is now an international scientific collaboration formalized by an agreement signed by the PIs of the individual radars. This agreement defines the organizational structure within SuperDARN, the categories of radar operations, the responsibilities of PIs for assuring the operation of their radar as elements of a global network, rules for distribution of data and data access rights for individuals from member and non-member countries. Overall responsibility for decisions and policies on the operations of the radars and distribution of data resides in the executive committee. This committee consists of the PIs and representatives from participating countries who do not have PI responsibilities but have contributed significantly to the development of one or more SuperDARN radars. The current chair of the executive committee is Dr. Ray Greenwald.

Under the executive committee are several working groups that are responsible for day-to-day operations of the radars. The most important of these is the Scheduling Working Group because it has responsibility for coordinating the operational modes of the radars. A Satellite Coordination Working Group aids the Scheduling Working Group by identifying interesting satellite conjunctions during the month being scheduled. They also recommend satellite coordination opportunities to the Executive Committee. The Data Distribution Working Group recommends new procedures and media for distribution of SuperDARN data to the SuperDARN community. The Software Working Group is responsible for identifying standards in software development and data product distribution. It makes its recommendations to the Executive Committee as well as the general SuperDARN membership. Other working groups have been created as additional support functions were required and then dissolved when those functions were no longer required.

As there are no formal international agreements between SuperDARN member governments, there is no oversight or advisory group to the Executive Committee. Rather, the PIs respond to the recommendations and requirements of their respective funding agencies and resolve issues within the Executive Committee.

Aside from e-mail contact throughout the year, there is a single annual SuperDARN meeting that is hosted by one of the SuperDARN participating countries and normally held in the month of May. The meeting affords the opportunity for the Executive Committee and the Working Groups to discuss issues and for the general membership to provide feedback on the decisions being made. The meeting also facilitates extensive discussions on space science topics and radar techniques. In addition to general scientific contributions, tutorials are given on SuperDARN analysis procedures and general topics related to Sun-Earth Connections Research.

1b. Description of SuperDARN technique

The radars consist of two linear electronically phased arrays of log-periodic antennas. The primary array consists of 16 antennas, each of which is associated with a 500 – 700 W pulsed transmitter. The primary array has a linear extent of about 750 m and is used both for transmission and reception. A secondary array consists of 4 antennas spaced 100 m in front of or behind the primary array and is used for reception only. The secondary array allows the vertical angle of arrival of the returning signal to be determined. Each radar system can be steered into 16 discrete viewing directions within a 52° azimuth sector. The beam width for each viewing direction ranges from 6° at 8 MHz to 2.5° at 20 MHz.

Electronic phasing of the radars offers many scan possibilities. In practice, the radars dwell in each viewing direction for periods ranging from 1 – 7 seconds. Various scanning sequences of varying complexity are utilized to optimize spatial or temporal resolution. The simplest sequence is a sequential 16 position scan that is used for SuperDARN Common Programs.

HF radar signals are refracted and, under the proper conditions, reflected by the ionosphere. Backscatter from the nearest ranges (180 – 300 km) is from meteor trails at altitudes near 95 km. Backscatter from intermediate ranges (300 – 700 km) is primarily from E-region plasma irregularities. At greater distances the returns are primarily from F-region plasma irregularities with 10 – 20 meter wavelengths or from distant ground reflection. Interferometry is used to determine the elevation angles of the return signals and to separate the signals into their various range and height regimes. Sorting the wide variety of spatial and spectral information contained in the return signals requires the use of special multi-pulse transmission sequences that provide the ability to resolve the Doppler information and also to ensure that the ranges of the reflections are unambiguously determined. Multipulse sequences are analyzed to produce autocorrelation functions (ACFs) of the backscattered signals from each range. The

ACFs are further processed to yield a set of fitted parameters, including Doppler velocity, power and spectral width, and elevation angles of the return signals, and the estimated errors of these parameters. Assuming the motion of the F-region electron density irregularities in the high latitude ionosphere to be identical to that of the ambient plasma motion, the SuperDARN radars are thus able to obtain the global high latitude ionospheric convection, and hence, the driving electric field on a continuous basis at fairly high cadence. ACFs and the derived parameter files are saved at each radar site and written to a CD weekly. A reduced set of fitted parameter data from the northern hemisphere radars is transmitted via the Internet to JHU/APL within a few minutes of the measurement and these data are combined to prepare near-real-time maps of the global ionospheric electric potential pattern. The real time and archived potential patterns are available over the SuperDARN web site http://superdarn.jhuapl.edu/.

1c. Summary of site strategic goals

The strategic goals of the JHU/APL SuperDARN group are to:

- provide increasingly better global specification of the ionospheric electric potential pattern.
- increase the staffing level in order to ease the current burden of radar maintenance, data management, and community support for users of SuperDARN data.
- develop new technological ideas to improve the existing radar capabilities or reduce the costs of installation. For example, there is a plan to develop a less expensive antenna system for the radars.
- install several (about 6 or 7) new radars in the northern hemisphere at mid-latitudes with northward fields-of-view in order to measure the ionospheric convection in the extended storm time auroral oval.

2. Scientific Research Enabled by the Facility

2a. Science Evaluation

Most SuperDARN scientific accomplishments inherently capitalize on the collection of measurements made by the international complement of radars, and often involve significant research collaborations with the staffs at multiple radar facilities. Herein, we focus on the research accomplishments involving significant JHU/APL SuperDARN staff effort.

The most significant contribution of the SuperDARN facility is high latitude plasma convection and electric field imaging based upon line-of-site **E**x**B** drift measurements. APL provides the community-at-large with web access to the northern convection plots in near real time (~10-minute lag) with 2-minute cadence. The northern hemisphere drift data form the basis of the SuperDARN statistical convection models for all orientations of the interplanetary magnetic field. Recent SuperDARN scientific achievements in convection studies include: (1) the first observations of a pair of counter-rotating polar-cap cells under northward IMF conditions with evidence of residual viscous cells near the dawn and dusk meridians, (2) measurement of the saturation of the cross-cap potential drop when the interplanetary electric field at the magnetopause is greater than 20 kV/Re, (3) verification of the nearly simultaneous onset around the auroral oval of the convection response to changes in the IMF, (4) observation of transient surges in flow velocity and direction on both meso- and global-scales that produce neutral atmospheric gravity waves and changes in thermospheric circulation.

Correlative studies of ionospheric features measured by SuperDARN and satellite-borne particle measurements proved that the radar network is able to detect a series of magnetospheric boundaries, including the open/closed field line boundary on the dayside, a coarse determination of the auroral oval position, and the promise that future radars, located at middle latitudes, can determine the nightside open/closed field line boundary.

Uniqueness of Research Done Using the Site: SuperDARN has achieved a unique capability for providing continuous global-scale maps of plasma convection (from which one can derive the electric potential pattern) within the ionosphere. By projecting the SuperDARN ionospheric convection maps into the magnetosphere it is also possible to study the global structure and dynamics of magnetospheric convection. The dual hemispheric capability of SuperDARN, covering vast regions of the northern and southern high-latitude and polar regions, further enhances a variety of satellite studies as well as novel conjugate measurements (unfortunately near real-time data analyses are not yet possible for the Southern Hemisphere measurements). Canadian plans to extend SuperDARN to view the polar cap with a pair of new radars are proceeding. A proposal to extend the USA component to include mid-latitude measurements to better assess the global effects of magnetospheric storms would also provide a novel means for studying thermospheric gravity wave propagation if, in fact it can be shown that the radars can receive useful signals during storm conditions. Often the existing radars do not receive backscatter during active conditions because the signal is absorbed in the D-Region. It will be important to show some proof of concept during storm times to pursue the mid-latitude deployment of radars to measure the storm time plasma drifts in the expanded storm time auroral oval.

As it evolves, SuperDARN will continue to provide essential information for international Sun-Earth Connection Science as well as for the National Space Weather Program, and the in-depth expertise of this multi-national partnership will ensure a bright future for cutting-edge science. At present, the only other method used to measure the global polar electric potential pattern is the inversion of magnetometer data using the KRM method or enhanced to ingest plasma drift data in the Assimilative Mapping of Ionospheric Electrodynamic (AMIE) technique. Each method has strengths and weaknesses.

Quality of the Scientific Research: The SuperDARN group has achieved numerous accomplishments of high scientific merit. These have been published in top tier journals, the subject of invited presentations at scientific meetings, and have focused discussions at the CEDAR and GEM meetings. The APL group, specifically, has been a leader in several areas of cutting edge research. For example, they showed that they could identify the ionospheric signature of the polar cleft in the spectral width measurements from the radar and from this obtained several important new results regarding the dynamics of the polar cusp. They have also produced important analysis of the ionospheric response to changes in the solar wind, helping to resolve recent controversies. The scientific staff is held in high esteem within the science community.

There is a concern that the interpretation of the SuperDARN data contains a large assumption. Specifically, The HF radars measure a return from irregularities in the plasma density with the assumption that these do not propagate independent of the plasma convection. The fact that they are perturbations in density and therefore must follow some dispersion relation implies some actual propagation of waves through the plasma. The radar is sensitive to the phase velocity of the scatterers and it is tacitly assumed that the phase velocity is very small compared to the convection velocity. Usually this is taken with faith, but remains a significant potential weakness in the scientific interpretation of these data. Further work to quantify the errors on these measurements is deemed important by the panel. The point of this comment is not to cast doubt on the nature of the SuperDARN measurements, but rather to express the reasonable attitude that there are good reasons to refine our understanding of the actual source and the behavior of the irregularities upon which SuperDARN relies; i.e. on spatial scales much finer than those which are routinely interrogated by the instrument.

The quality of the electric potential patterns derived from SuperDARN data varies according to the amount and quality of the radar return signals. As already noted, to obtain backscatter signals requires the presence of F-region plasma irregularities with 10 – 20 meter wavelengths. During active conditions, D-region absorption can also cause a lack of radar backscatter signal. Thus, a good global distribution of backscatter signal that can be used to derive the potential pattern is rare during storms. Usually, a statistical pattern is utilized as an initial specification and modification of the pattern is made in regions where good velocity measurements are obtained. Thus, it is always important to examine the distribution of backscatter to determine where the potential patterns are likely the most accurate for the specific time investigated or whether they represent a statistical approximation to the potential. Nevertheless, even with these problems, the SuperDARN potential patterns represent one of the best methods to specify the global potential pattern with a reasonably rapid cadence. The electric fields derived from F-region plasma drift SuperDARN measurements are more direct than the electric potential obtained by the other available method that uses an inversion of global magnetometer measurements.

On this note the KRM method or Assimilative Mapping of Ionospheric Electrodynamics (AMIE) technique obtains the polar ionospheric potential pattern based upon a global distribution magnetic perturbation measurements and a specification of the ionospheric conductivity. The specification of conductivity is, perhaps, the greatest uncertainty in this method; however, the removal of the quiet field also provides a potential source of error. Also, the distribution of magnetic measurement is not uniform nor is it sufficiently dense. In general, comparisons of KRM and SuperDARN real time patterns show qualitative agreement.

This said, the AMIE technique permits the utilization of all ionospheric measurements including radar, magnetometer, and satellite drift meter to be combined to obtain the best possible specification of the potential pattern. In principal, this could be accomplished in near real time by combining a variety of magnetometer measurements available in real time with the SuperDARN line of sight measurements. This would result in a specification of the potential pattern that is generally better than the real time magnetometer-based AMIE potentials and better than the existing SuperDARN potentials.

Role of Facility in Supporting National, International, and Satellite Programs: SuperDARN is an international scientific collaboration that has demonstrated a very effective operation. The collaboration involves 10 different countries. Currently there are 15 radars in 6 countries plus Antarctica, with PIs from Australia, Canada, France, Japan, South Africa, the UK and the USA. Representatives of SuperDARN as well as the members of the APL team have been very active in the international scientific community through participation in international meetings, active collaborations that have resulted in publications in top tier journals, and in providing data to the international community. They actively welcome collaboration and attempt to stimulate it through their participation in many international meetings and workshops and through invitations to their annual SuperDARN workshops.

Over the past decade SuperDARN researchers have collaborated with many satellite missions as well as rocket campaigns and ground-based ionospheric heater experiments. The high-latitude, globally distributed nature of the SuperDARN radar network provides an exceptional capability for creative, coordinated research. For example, SuperDARN measurements of the electric fields combined with satellite UV and visible auroral emission measurements from the NASA Polar and the TIMED spacecrafts have been used to produce some of the first direct global-scale maps of Joule and particle heating and associated energy flow from the Earth's magnetosphere down into the upper atmosphere. Other ongoing correlative satellite research includes the structure and dynamics of space plasmas with the European Cluster satellite mission (with emphasis on reconnection science), and studies of the large-scale magnetospheric plasma distribution using the NASA Image satellite. SuperDARN's multi-national make up has also facilitated several other collaborative studies within the International Solar Terrestrial Physics (ISTP) programs of many countries. Plans for future satellite research include coordinated measurements with the upcoming NASA THEMIS mission (which will use multiple spacecraft and ground-based measurements to study global response to magnetospheric substorms), as well as further auroral studies as part of the extended TIMED mission. Numerous papers have resulted from these collaborative investigations and SuperDARN continues to provide key contextual information to aid the interpretation of spacecraft observations. The SuperDARN science group has been active participants in the GEM and CEDAR workshops as well as other national and international scientific meetings and symposia.

2b. Research Capacity and Balance

The available manpower provides the major constraint on the capacity of the JHU/APL SuperDARN group to: (1) operate and maintain two radars in Canada, (2) maintain and distribute the SuperDARN data base containing data from all SuperDARN radars, (3) maintain the SuperDARN WEB site and (4) undertake scientific studies. APL is the gatekeeper for SuperDARN software including the radar operating system and data analysis software. There are some 450 registered users of SuperDARN software and APL is responsible for technical support of the software. While most hardware at the sites is the same, there are some variations that require slightly different software at different sites to be matched to the hardware. Responsibility for software support, maintenance, and development rests largely with Rob Barnes.

The balance of effort to be evaluated is that spent between supporting community usage of SuperDARN data, operation and maintenance of two radars, and scientific analysis of the data by the JHU/APL scientific staff. At present the effort of post-doctoral members of the group is divided between analysis and operation and maintenance of the radars, with the larger effort devoted to scientific data analysis. This is probably a good balance for the post doctoral members of the group. User support is largely through the web interface; however, special requests are requiring a larger effort by Dr. Mike Ruohoniemi. This is a serious area of strain and one where an additional staff member may be required. The alternative, if increased staff is not possible, will be to limit the community support that can be provided. In this case, extra support may only be provided where scientific collaborations are initiated that have the scientific interest and participation of the JHU/APL scientific staff.

2c. Future Science Plans

The JHU/APL SuperDARN group outlines a clear and detailed plan for continuing research into the dynamics and variability of high-latitude convection and the storm-time expansion of the convection patterns to lower latitudes. They also plan investigations into new areas including plasma structuring, Joule heating, and planetary waves. Specific areas of research include:

- Estimates of parallel electric field effects based upon particle measurements from low-altitude spacecraft (and/or an appropriate precipitation model) and inductive electric field effects based upon time-dependent magnetic fields (e.g., an MHD model) to account for those components of magnetospheric convection that cannot be directly mapped from SuperDARN ionospheric convection patterns into the magnetosphere.
- Investigations into the evolution of high latitude convection after the initial response to IMF transitions.
- Studies of electric field variability on a range of temporal and spatial scales, and its effects on Joule heating estimates.
- Collaborative efforts to resolve anomalies in SuperDARN and DMSP drift data, to optimize the velocity assimilation procedure to accommodate both the ground-based (with possibilities for including ISR drifts) and satellite-borne measurements, and to generate the most definitive maps of the large-scale convection yet realized.
- Common-volume and contextual observations in support of the new AMISR facility development.
- The development of an auroral zone neutral wind and planetary wave climatology based upon the SuperDARN database of meteor scatter spanning a solar cycle for use in correlative studies of TIMED satellite observations.

The plans extend the existing research efforts in natural way and there are some new areas of research that will be developed. All of the areas described are important problems and advancement in these areas will make significant contributions to the field overall. The panel supports the future science plans and believes that advancement in these areas will be possible and will keep the APL SuperDARN group at the forefront of research activity. Plans to investigate mid-latitude plasma irregularities and to identify and track plasma patches and blobs in the radar backscatter respectively require further investigation and would involve the acquisition of a new radar facility. The panel withholds judgment on the proposed expansion of SuperDARN to mid latitudes pending more proof-of-concept documentation regarding the ability to obtain the required backscatter signal during disturbed times and demonstration of the prototype analysis tools.

3. Educational Activities

The APL SuperDARN group has very little direct EPO activity. However, they do take advantage of a more general effort sponsored by JHU/APL. This effort is largely related to the NASA Sun – Earth Connections Program and the Living with a Star Program.

On the other hand, SuperDARN is very productive in terms of supporting the education and training of young scientists and engineers, albeit in limited numbers. Because of access restrictions at the nature Applied Physics Laboratory, it is difficult for the SuperDARN group at JHU/APL to directly mentor students. Nevertheless, the group does support extensive student training through its involvement with research partners at other universities.

The JHU/APL SuperDARN group has been directly responsible for training several recent Ph.D.s as postdoctoral fellows, helping them to become established with their own research programs and funding. An excellent example is Dr. B. Bristow who now operates the third US SuperDARN radar at Kodiak, Alaska. The past five years have seen substantial increases in the overall numbers of students and young scientists involved in SuperDARN research and their gradual development into independent researchers and university faculty.

The education programmatic goals are to continue with the active post doctoral scholar program at JHU/APL to enrich the research environment and to help provide the future SuperDARN scientists and leaders. No specific plans were outlined and the panel was left to e presume that the future activities will be to continue the educational activities much as they have been done in the past, with a focus on postdoctoral scholars at APL and general interactions with students and post docs at other SuperDARN university sites.

4. User Support and Facility Infrastructure

4a. User Support

An area of major strength in the APL SuperDARN effort is that of community and user support. The JHU/APL SuperDARN Web Site is very impressive and provides automatic access to archival radar data and automatic access to electric potential (convection) maps that can be used to make a quick evaluation of current activity, identify promising events for analysis and, with caution, initiate analysis. Summary convection plots for 1997 – 2003 at 10-minute cadence are posted on the Web Site. There are currently 484 registered users who have access to the Convection Map Archive. The web site has between 1 and 2 million "hits" per month serving, on average, about 2000 unique IP addresses per month. Around 5000 or 6000 plots per month are served on average, however, as many as 40,000 plots per month have been served during periods of intense community investigation of specific space weather events.

Occasionally, Dr. Mike Ruohoniemi performs customized analysis for user requests, however, this is not routinely provided. Requests for higher-level validation/analysis/ interpretation are increasing and this is a serious area of strain. The current facilities grant provides only 3 mm/year of funding for community support.

It is possible to request the operation of the radars in special modes and to process data for specific purposes. However, such requests are rare.

Rob Barnes, with 80% support, provides the SuperDARN software development and maintenance. He has developed robust low and high level (GUI interface) software. It is well documented and version controlled.

Improved digital receiver hardware and other technology developments have "broken" some long-standard data structures. Migrating to more capacious structures will require careful planning, especially if backwards compatibility is to be maintained.

The SuperDARN software suite is approximately as old as the MHR Madrigal software, and much older than the fledgling "open radar" project. The panel deemed that it would be beneficial if there were ways to foster a development link between SuperDARN's software and other radars. While this may not be practical for the low level software, the case for the high level user interface (in java) is extremely strong. The ease-of-use of geophysical data products no doubt, partly explains the broad appeal of the SuperDARN WWW site.

The SuperDARN radars use a special real-time operating system QNX at the field sites. There is significant upgrade necessary from v4 to v6 of QNX. Although QNX is proprietary, it is well known to be robust and fairly straightforward to use.

The SuperDARN user software that was examined by the committee was excellent. More SuperDARN products and services are planned for the Web Site, including (1) meteor winds, (2) auroral boundaries, (3) merged SuperDARN/ISR convection mapping.

The international SuperDARN team is well organized and coordinated.
SuperDARN continues to sponsor a very successful annual conference for the community of users, attracting now approximately one hundred interested users and other participants.

4b. Facility Infrastructure

Highlights: The SuperDARN radar networks continue to grow. The Tiger radar in Tasmania was initiated in 1999 by La Trobe University and the Kerguelen Island (Indian Ocean) radar was initiated in 2000 by the Centre National de la Recherche Scientifique. In the northern hemisphere the Prince George radar was initiated in 2000 by the University of Saskatchewan, the Kodiak radar was initiated in 2000 by the University of Alaska and the King Salmon radar in Alaska was initiated in 2001 by the Communication Research Laboratory, Japan.

A commercially available PC-based digital receiver that requires only software development has yielded excellent results at the University of Alaska Kodiak radar. A second similar digital receiver from the same manufacturer is currently undergoing software development at JHU/APL and is scheduled for installation on the Goose Bay radar very soon.

Plans: Near term infrastructure needs include the development of new multipulse sequence modes for operation. The new sequences under development will permit the identification of higher unaliased Doppler velocities and reduce the estimation errors.

There will also be a continuation of digital receiver upgrades at the Goose Bay radar and the Kapuskasing radar. In addition, the computer system that controls the radars will be upgraded from QNX4 to QNX6 because the vendor will cease support of the older system.

There are also plans to develop a new antenna system for the radars. The goal in the new antenna system is to make a significant reduction in cost thus providing benefit to the development of new radar sites and the replacement of antenna systems that may become damaged.

A more long-term plan is to develop a chain of sub-auroral HF radars motivated by the goal to measure the electric potential pattern during storm times when the oval expands beyond the existing stations. As mentioned earlier it is not clear that this is an achievable goal, because one problem that often exists for the HF radar technique is that the signal is absorbed in the D region during active conditions.

***Infrastructure Maintenance Issues*:** Annual visits to the two APL SuperDARN sites will generally continue to be required to provide maintenance while the continued practice of contracting with a local person to provide a variety of day-to-day or month-to-month support tasks appears to work effectively.

The SuperDARN network requires a high degree of cooperation among all sites to achieve the global measurement. This has been achieved and would appear to be in very good shape. Internet connections in the northern hemisphere enable near real time determination of the northern high latitude potential pattern. Southern hemisphere data is periodically returned by CDROM. Where practical, real time acquisition of southern hemisphere data should be pursued.

SuperDARN maintains an aggressive interest in archiving its data. They have recently simplified some of the handling of the data, but it would appear that a technical solution (larger storage medium) would be useful in this regard. As the SuperDARN instruments and data acquisition modes grow, the distribution medium of CDROM and DVD will become underpowered. A new physical storage medium that is at least ten times the capacity of a DVD will eventually be e required; and a hundred times would be much better.

Manpower is a serious constraint in the APL SuperDARN group. SuperDARN lives within tight resource constraints, provided in part by the UAF support and by other grants. However, there is a strong desire to hire an engineer/scientist to help assist with the maintenance of the two existing radar systems operated by the APL group, and to work with the data management. Without this addition, it may be necessary to scale back their "personalized data analysis" for future users because of the very large impact on their time.

Despite its fiscal constraints, the APL component of the SuperDARN network has a specific desire to grow the radar system into mid latitudes, with six new receivers at three sites in the United States. These receivers would extend the view of the system during times of disturbed ionosphere, when interesting convection and irregularities are entirely south of the current SuperDARN field of view.

5. Broader Impacts

The SuperDARN global measurement of the polar electric potential pattern and strength serves a broad spectrum of the scientific community interested in space plasma, magnetospheric, and space weather research as well as providing operational space weather information. This is a fundamental parameter that characterizes the magnetosphere disturbance level and the energy coupling between the solar wind and magnetosphere.

Some software and hardware development may be relevant to the other UAF radar facilities, though there has been little attempt to coordinate these activities with the other ISR facilities.

The primary outcome and payoff of the educational program has been the transition of several young scientists to mature and active leaders in our community. Dr. William Bristow has become a faculty member at the University of Alaska and leads an active research program that operates one of the SuperDARN radars. Dr. Kile Baker is now the director of the Magnetospheric Physics Program at the National Science Foundation. Dr. Simon Shepherd is a Research Assistant Professor at Dartmouth College and runs a research program in magnetospheric electrodynamics that utilizes SuperDARN data very extensively.

As noted above, the APL component of SuperDARN does not explicitly undertake any outreach effort.

6. Management and Budget

The SuperDARN network is an international effort and is managed through agreements between research groups in different nations. Operationally and scientifically the network has been a success. Similar radar design and hardware provide for ease of maintenance; annual meetings provide for detailed discussions of operational and software issues as well as science; and oversight has been achieved through the diligence of the U.S. PI and his counterparts in other countries. The SuperDARN group located at APL has provided nearly continuous data for the upper atmosphere community as well as an excellent community interface for access to the data, user support, and co-development of data products with users. The panel believes that SuperDARN is desirable as a facility and recommends that it be brought up to a more complete facility status with a basic coordinated structure for the three U.S. radars in the network, a joint science budget, and more operational support.

The U.S. component of the SuperDARN network consists of three radars, two operated through a grant to APL from the NSF UAF and one operated by University of Alaska, Fairbanks through a grant funded from the NSF Office of Polar Programs. The panel believes that the current arrangement is cumbersome and potentially could lead to conflicts regarding what constitutes a facility and the responsibilities associated with being a facility. Imposing facility requirements on two of the radars and not the third leads to fragmentation in goals. The panel recommends that the existing three U.S. supported radars be supported as a consortium through a cooperative agreement. A consortium structure would clearly illustrate integrated goals for science, hardware and software development, and community support as well as providing a complete picture on operational costs.

APL currently receives a small portion of the overall NSF Upper Atmospheric Facilities budget. While NSF funding for APL has a small science component, APL is using these funds more and more to provide support to community users of the radar data. Currently, most science is accomplished through other awards and collaborative projects. More NSF science support is desirable in order to encourage early career scientists in learning and using the radar and its data. In addition, new technology development is needed as noted earlier. The integration of science, technology development, and community support are important principles for a radar facility that will remain responsive to cutting-edge science. The panel noted that there is a single-point failure in human resources in the key areas of software development, web development, and community support. Additional operational support would provide relief for this person for additional development of community resources.

Mid-latitude expansion plans for the SuperDARN network were discussed with the panel and those plans deserve separate consideration for funding by NSF. However, a clear demonstration that the radars will obtain the measurements needed during storm conditions is required, since a major problem in using this technique is the D region absorption of the radar signal during active times.

Finally, it was noted that the SuperDARN operation exists within a management structure with associated support and overhead that is designed for large government contracts. Smaller projects such as SuperDARN can suffer significantly in this management environment from a lack of flexibility that is often needed to be resourceful, efficient, and effective. It also seriously inhibits the educational outreach effort as discussed above, and this is generally an important component of a UAF facility. While the arrangement has worked thus far, further security requirements and workplace restrictions may begin to hamper the ability to recruit and retain good scientists.

7. Summary of Findings and Recommendations

Finding: The JHU/APL SuperDARN group is significantly unlike any of the existing upper atmospheric facilities. They rarely support users who utilize the radars for their personal experiments. Rather, they provide a data product that has great utility and high demand. The data products rely upon the good will of the international partners and NSF has no financial responsibility to, or control of, this group. At present, the JHU/APL group receives support from NSF and NASA sources. The current NSF facility support is used for radar operation and maintenance at two sites, postdocs and young scientists (few months per year), the support of data management efforts and for the support of the WEB based user interface.

- *The panel recommends that the NSF facility support for APL should be in the form of a cooperative agreement in order to provide NSF with* more *substantial oversight control. There should be well defined limits to what activities are supported.*
- *The panel believes that high priority for support should continue to be the data management functions that integrate all the SuperDARN data and the WEB tools that support the broad user community's access to these products along with the support for the operation and maintenance of the existing radars. Support for scientific research by the APL staff is also of high priority. Increased staff support is likely required to achieve these goals and the panel supports increased funding for this purpose in line with Recommendation 1 in Part I of this report.*
- *The panel believes that additional support for engineering development would be desirable. At present, Dr. Greenwald is the only person in the group who is able to innovate hardware development. It is important that someone be mentored and prepared to take forward the hardware development of SuperDARN when Greenwald retires in the future. However, the panel does not believe that the existing base research programs within the Upper Atmospheric Research Section should be taxed further to augment facility support for JHU/APL to enable engineering or expansion activities. NSF management must work hard to increase the funding base for the facilities and to enable the engineering support required by APL. Additional radar deployment or the operation of other radars should not be supported by the UAF Program without an infusion of new funding to support such activities.*

- *The panel recommends that APL should endeavor to provide more of the functions that are typical of UAF facilities, including the possibility of supporting additional synergistic autonomous instruments (e.g. optical/radio) at the existing APL radar sites, and additional efforts should be made to engage undergraduate and graduate students in ongoing research activities.*

Finding: The SuperDARN electric potential maps provide a fundamental parameter that characterizes the global coupling between the solar wind and magnetosphere. These maps are now being used extensively by the research community. However, backscatter measurements may not exist at times with the result that the maps obtained are dominated by the statistical pattern that is used to begin the analysis. The APL group plans to optimize the velocity assimilation procedure using more real-time ground-based data, including ISR data, to produce more accurate and definitive electric potential distributions.

- *The panel strongly endorses the plan to extend the potential analysis to utilize other real-time data and specifically recommends that ground magnetometer data be incorporated into the routine potential analysis procedure.*

Finding: The underlying theory for the HF backscatter utilized by SuperDARN from electron density irregularities is still not fully elucidated. Further work to quantify the errors in these measurements is needed.

- *The panel recommends that effort be directed to improve the understanding of the source and behavior of the irregularities upon which the HF backscatter relies (whose spatial scales much finer than those that are routinely interrogated by the radar).*

Finding: The APL SuperDARN Web Site is impressive and provides automatic access to archival radar data and automatic access to electric potential maps that can be used to obtain a quick evaluation of current activity, identify promising events for further analysis. The high level user interface is extremely strong and easy to use.

- *The panel recommends that the UAF program foster a development link between SuperDARN software and the other facilities to take full advantage of this web-based access methodology to data products.*

Finding: The U.S. component of the SuperDARN network consists of three radars, two operated through a grant to APL from the NSF UAF and one operated by the University of Alaska, Fairbanks through a grant funded from the NSF OPP. This arrangement is awkward, and may lead to future conflicts regarding what constitutes a facility and the responsibilities associated with being a facility. In particular, imposing facility requirements on two of the radars and not the third radar leads to fragmentation in goals.

- *The panel strongly recommends that the existing three U.S. sponsored radars be supported as a consortium or collaborative project. A combined structure would clearly illustrate integrated goals for science, hardware and software development, community support as well as providing a complete picture on* *operational costs. It should also provide some stability for the continued operation of all three radars.*

Finding: The current director of the SuperDARN group at APL is Dr. Ray Greenwald. He is also the chair of the SuperDARN executive committee and his vision is responsible for much of the SuperDARN success. Since APL plays a central role in the radar software management, the merging of the SuperDARN data, the data archiving and dissemination of data, an important issue for the international SuperDARN consortium will be to find a suitable successor. While this is not seen as an eminent issue now, the time to begin to consider this issue is at hand.

- *The panel recommends that the international SuperDARN network should discuss the evolution of the leadership within the consortium. Similarly, the time is at hand for the APL group to begin to consider the future leadership of the group and its future role in the SuperDARN consortium. This might be an issue to be raised at the next SuperDARN annual meeting so as to prepare the way for a smooth transition.*

Finding: The SuperDARN operation at APL exists within a management structure with associated support, security, and overhead that is designed for large government contracts. Smaller civilian science projects such a SuperDARN may suffer in this environment. The current workplace restrictions and security requirements clearly hamper the educational outreach effort, and they may hinder the ability to recruit and retain future scientists.

- *The panel acknowledges this situation and encourages the APL SuperDARN group to negotiate with APL management to retain a free and unrestricted environment for their operations.*

Finding: The SuperDARN consortium of radar sites offers the UAF program an example that demonstrates shared effort for hardware and software development that is used across all sites. It shows the benefit of creating data products that utilize the combined measurements and the synergy and enthusiasm that is inspired by the annual team meetings.

- *The panel recommends that some similar practices could significantly benefit the group of UAF facilities in the development of common hardware (digital receivers for example), software, and global science topics. The panel recommends that the facilities consider annual coordination meetings and consider the formation of hardware and software coordination groups with representatives from each site that have regular scheduled virtual meetings.*

Arecibo Observatory Space & Atmospheric Sciences (SAS) Activities

1. Introduction

1a. Basic site description

The National Astronomy and Ionosphere Center (NAIC) radio/radar telescope located in Arecibo, Puerto Rico – Arecibo Observatory (AO; 18.3˚ N, 66.75˚ W, 46.5˚ geomagnetic dip-angle, and L=1.43 at 300 km) – is the instrument that provides more collecting area (more "light gathering power") for centimeter-wave radio science than any other competitive telescope in the world. Operated as a national research facility by Cornell University for the National Science Foundation (NSF), the Arecibo telescope in fact provides nearly three times the collecting area of all the other NSF-sponsored radio telescopes combined. The sheer physical size of the Arecibo telescope makes it a uniquely powerful research instrument. Unique also to the Arecibo Observatory is the program of research supported by the telescope and the diversity of interests of the scientific user community it serves. It is the requirements of this interdisciplinary scientific community – the space and atmospheric sciences, radar astronomy, and radio astronomy – seeking to exploit the wide-ranging research capabilities of the Arecibo telescope that provides the operational challenges for NAIC. In turn, these challenges motivate a structure for the observatory that is based on a partnership of efforts between NAIC, Cornell University, NSF, and the user community.

The impetus for design and construction of the Arecibo Observatory originated with researchers at Cornell University. Established in 1963 as the Arecibo Ionospheric Observatory and used for upper atmosphere research, it was soon (1971) expanded with Cornell guidance to become NAIC, a major research facility also for radio astronomy, and for radar studies of the solar system. Two major upgrades have maintained Arecibo and NAIC at the forefront of centimeter wave radio science. The upgrade in 1974 replaced the surface with a more accurate one, leading the way to use the antenna at wavelengths of 13 cm for planetary radar studies and at 21 cm for galaxy and cosmology studies. The recently installed Gregorian feed system again has greatly increased sensitivity, significantly expanded its frequency coverage and agility, and enabled the dual-beam incoherent scatter radar capability, providing entirely new research opportunities as yet largely untapped. Accompanying the telescope upgrades were major advances in receiver technology, signal processing techniques, and observing modes. The consequence of these upgrades is that the Arecibo Observatory now provides to the scientific community a broad spectrum of unique research capabilities for radio astronomy, radar astronomy and aeronomy that all benefit through the resultant cross-fertilization.

Operation of the Arecibo Observatory to satisfy the requirements of this interdisciplinary user community is the primary responsibility of the scientists, engineers and staff of the NAIC. Management of the NAIC is provided by Cornell University, under a Cooperative Agreement with the National Science Foundation that is administered by the NSF Division of Astronomical Sciences (AST). The Space and Atmospheric Sciences (SAS) program at NAIC is managed by the Upper Atmospheric Facilities (UAF) program of the Upper Atmosphere Research section of the NSF Division of Atmospheric Sciences.

Funding for the SAS program at the NAIC is via a Secondary Statement of Work amended to the NSF/Cornell University Cooperative Agreement for Management and Operations of the NAIC.

1b. Summary of Site Strategic Goals

The SAS group has a multitude of responsibilities to the NSF CEDAR and Space Weather programs. Beginning in 2001 a new strategy was implemented with the goal of increasing SAS productivity and visibility and with improving the level of satisfaction with users (these include visitor observers/users and CEDAR/other community initiatives). This strategy includes focusing SAS efforts into fewer high-impact areas (in addition to exploiting the UAF radar chain). These primary focus areas are:

Studies of the mesosphere and lower thermosphere (MLT). This work exploits the combination of the lidar, imager, and other optical capabilities together with the most sensitive ISR for studies of this region. This area is not only compelling to a large fraction of the CEDAR community but also important for supporting the NASA TIMED mission. (Examples include the LTCS group and many of the proposals funded under the CEDAR-TIMED competition).

Studies of F region energetics and dynamics and ionosphere-thermosphere coupling. These are relevant to a large number of CEDAR and Space Weather initiatives, for example storm studies, the CIC campaigns, etc. SAS plans to particularly emphasize this area to the community that is perhaps not aware of recent advances and topics that new observations have engendered. SAS expects to make a significant impact in this area and thus help reinvigorate it.

Studies of the topside ionosphere. Arecibo is the most sensitive ISR and provides the best data in the topside lower plasmasphere. SAS has also made significant recent breakthroughs in developing the ISR theory/techniques that are now routinely providing a wealth of data in this region and expects to continue being the leader in this area for the foreseeable future.

2. Scientific Research Enabled by the Facility

2a. Science Evaluation

The research effort of the Arecibo Space and Atmospheric Science (SAS) group impacts a wide range of scientific topics and variety of observational studies is supported. The group also undertakes theoretical work to improve understanding of and ability to utilize the incoherent scatter technique.

Recently reported theoretical efforts improve on our basic understanding of the incoherent scatter spectrum via careful inclusion of the effect of Coulomb collisions and result in improvements in the ability to compute Te/Ti from the ISR spectrum. In addition, SAS/NAIC has contributed to the development of new measurement techniques at Jicamarca in early collaborative work by finding and analyzing the effect of Coulomb collisions on the IS spectrum, thus allowing more accurate measurements of temperature and composition. The collisional effect extends into the topside where perhaps the strongest "chain" activity between AO and JRO exists. Perhaps the most exciting development over the next decade will be the combined use of the Arecibo and Jicamarca radars, realizing the full potential of the low-latitude part of the longitudinal chain.

New results have come from the investigation of the radar-scattering signature from the free electrons in the plasma generated by entry of dust-sized meteoroids into the atmosphere (head-echoes). Deceleration of the meteors is determined from the instantaneous radial Doppler-speed determined from the head-echoes. The mass-flux of micrometeors into the upper atmosphere has been determined based on the observed number of meteor events per day measured in the 300-m diameter Arecibo beam. Extrapolation of the measurements to give an annual whole-Earth flux per decade of particle mass compares reasonably well with results obtained from the analysis of small particle impact craters on the orbital Long Duration Exposure Facility reported by other investigators.

A new dual-beam incoherent scatter capability has been developed recently. Two beams are offset in elevation by up to 20 degrees from the magnetic meridian thus providing a means to estimate two components of the ion velocity (the velocity along B and the northward velocity perpendicular to B) without beam swinging. The technique also provides a method to estimate gradients in ionospheric parameters along B. Using this technique, the first simultaneous measurements of density and temperature gradients were obtained at Arecibo. This technique and improvements to the technique will likely enable new scientific investigations.

The Arecibo incoherent scatter radar has the ability to perform high-resolution investigations of the topside ionosphere. Radar observations have been used to develop an extensive dataset of topside parameters, including He^+, H^+, and O^+ ion fractions, H^+, and O^+ temperatures, and H^+ and O^+ ion velocities. This dataset dates back to the 1980s and covers over one solar cycle.

In addition to the incoherent scatter radar, the observatory maintains a very strong optical facility including various lidars and cameras. Observational studies have utilized incoherent scatter radar and optical lidar observations both separately and in coordinated operations to investigate a variety of topics including the relationship between Ca/Ca^+ layers and ionospheric "sporadic E' layers. In another example, Na lidar and the ISR have been used to explore atomic sodium layer enhancements (ALEs) observed above 100 km that were accompanied by ion layers. All these results aid in the study of metals chemistry and are being coordinated with observations of the meteoroid mass flux to the region.

Potassium resonance lidar investigations have been used to measure mesospheric temperatures. Such measurements are very important in determining the seasonal variations of the dynamics in the equatorial MLT region and how those measurements validate global and tidal models.

The Boltzmann lidar system has been used to investigate upper mesospheric temperatures. Results from these measurements show that the MSIS-90 model tends to underestimate the thermal depth of the mesopause at Arecibo. In addition, geomagnetic storm conditions appear to produce strong oscillations in the temperature profiles as well as strong temperature gradients.

Uniqueness of Research Done Using the Site: All of the observations outlined above are unique at some level. For example, the sensitivity of the dual-ISR system is at least a factor of 5 above the next best system. This sensitivity is engendered by the 305 m diameter dish and the 430 MHz system frequency and has found uses ranging from micrometeor observations to daytime winds measured in the lower D-region to high time/range resolution measurements of multiple ion concentrations in the topside. Additionally, the suite of active and passive optical instruments enables unique observations particularly when used in conjunction with dual-beam ISR observations of the MLT region.

In the topside ionosphere, Arecibo and Jicamarca are the only radars capable of measuring the ion line high into the lower plasmasphere, and only Arecibo can make use of measurements of the mega-Hertz wide electron component of the ISR spectrum. In the E region where Arecibo's spectral measurements are inherently self-cluttered, the high sensitivity maximizes the amount of information available through the use of high-resolution radar techniques. Arecibo leads in the measurements of the head echoes from the micrometeors that contribute metals in this region. Arecibo is the only ISR facility capable of measuring electron concentration and line-of-sight drifts throughout the D region to complement its excellent velocity measurements for tidal analysis. With the Gregorian upgrade the radar has acquired the capability to look in two directions at once, the so-called dual-beam measurements

Quality of Scientific Research: There have been over 20 SAS-related PhD theses in the last 10 years and 57 known publications by staff and external users in the period 1998-2003. Quality may also be measured in terms of the over subscription of telescope time requested through a proposal process, and the growing external user numbers. Additional details can be found in sections 2b and 4a of this site report.

Role of Facility in Supporting National, International, and Satellite Programs:
Arecibo SAS related programs are driven by proposal pressure that is derived from community interest as reflected in external PIs submitting observing proposals and/or by the staff submitting proposals in response to community interest. This responsiveness to the community is reflected in the stated larger goals of the SAS group that include:

- Providing broadly accessible, state-of-the-art science and engineering infrastructure for individual researchers and students.
- World "day" participation as a method of promoting "chain" activities and accumulating a relatively general-purpose database for the entire community.
- Having a staff that takes a prominent role in the initiatives of our community including CEDAR, the multi-agency National Space Weather Program and NASA's "Living with a Star", TIMED, IMAGE and other missions.
- Advancing the educational and diversity objectives in NSF's strategic plan.

Additionally a major component of the AO SAS response to external initiatives is found in community outreach activities that bring researchers and their students to AO. These initiatives have included the Radar Meteor Workshop (10-12 March 2003), the 6-7 March 2000 Topside Workshop, and other programs discussed under Educational Activities.

2b. Research Capacity and Balance

SAS related observing programs currently utilize 20-21% of available telescope time—a nominal limit of 15% is based upon the (historical) relative astronomy/aeronomy funding levels. SAS is oversubscribed both in terms of actual telescope time and in terms of requested time per proposed observing programs. In principle, SAS could be required adhere to the 15% usage guideline; however, this balance is also driven by strong SAS proposal pressure. The panel thankfully acknowledges the support of the astronomy component in recognizing and providing the observing time requested by the upper atmosphere community. We also note the synergy and balance between the radar and optics programs both of which are strong programs. AO also hosts (and supports at low levels) several optical instruments for other institutions thus furthering cluster science.

2c. Future Science Plans

The NAIC vision for SAS effort over the next ten years will primarily revolve around realizing the potential of three continuing projects and the addition of a fourth new project. These are:

- Utilize the low latitude part of the chain of radars to understand the physics of the ionosphere and lower plasmasphere through collaborative studies with the Jicamarca observatory using new capabilities at both sites.
- Coordinated study of the mesosphere and lower thermosphere (MLT) regions using SAS's suite of radar and optical instruments, both in cooperative campaigns and also in individual studies. The new lidar systems provide a novel capability for investigating the structure of the mesopause region in detail, including studying the coupling mechanisms between neutral and ionized sporadic layers (which are a common phenomenon at low-latitudes).
- Coordinated radar-optical studies of F-region energetics and dynamics including ionosphere-thermosphere coupling and investigations of the topside ionosphere.
- Undertake one major new project; the construction of a new High Frequency (HF) "heating" facility as requested by the scientific community and use it for experiments in aeronomy and space plasma physics. The airglow optical instrumentation would provide an important complementary capability to the planned ionospheric measurements enabling more comprehensive experiments to be performed.

The proposed new on-dish HF ionospheric heater facility will offer renewed opportunity to undertake studies of basic plasma processes in a more controlled (experimental) environment and could produce a new physical understanding of plasma and aeronomic processes. The strength of the proposed ionospheric modification effort -- that would run in campaign mode -- derives from large Effective Radiated Power (ERP) and the instrumentation cluster that would provide a thorough probing of the heated volume. As the heater would roughly double the SAS user-base, there will be additional tension for observing time with competition between heating campaigns and the current geophysical observations.

Arecibo is exceptionally well instrumented for these studies although optics upgrades may be needed to meet the new science goals, especially those associated with the heater. These plans build significantly on earlier research and the resultant database as well as community science interest.

3. Educational Activities

Arecibo has an active and substantial education and public outreach effort; the Observatory plans to continue much as it has, in welcoming numerous public visitors, maintaining a Research Experience for Undergraduates (REU) site, and interacting with the University of Puerto Rico through the EPSCoR and Geodiversity programs.

The AO SAS group sponsors/hosts a strong seminar, workshop, and science/engineering interaction. As part of this environment it is possible for an undergraduate to eat with and talk/listen to a Nobel laureate. AO has produced at least 68 PhDs in SAS since 1967.

Arecibo has a multifaceted public outreach program. It is striking that Arecibo receives 120,000 visitors each year at its Angel Ramos Visitor Center, which provides unusually high public visibility at an incoherent scatter radar facility. In addition, Arecibo has an active REU site program which hosts 12 students each year, of whom two or three are affiliated with the SAS group.

Arecibo has attempted some outreach to the Puerto Rican community through interaction with the university system, chiefly with the engineering school at Mayaguez, through an EPSCOR award, and through its Geodiversity program. These programs engage students in a wide variety of projects - the Geodiversity program is about 50% wetlands/karst science and 50% upper atmosphere projects with approximately 14 students in each area. Such programs appeal directly to the personal experience of most puertoriquenos, providing a valuable entry to a larger science experience. (AO staff have indicated some difficulty in working with UPR, manifest in occasional budget issues (e.g. EPSCOR) and in relatively low interest from the campus at Mayaguez.)

Arecibo addresses NSF educational goals by participating in an REU site program (75% astronomy and 25% upper atmosphere) as well as the Geodiversity project. These projects do not provide heavy exposure of students to upper atmospheric physics, but they do attract students, some of whom continue on to upper atmospheric research (an excellent example being Mike Nicolls). There is clear interest in engaging Puerto Rican students. The Director clearly appreciates the importance of developing new human capital for the Observatory's benefit. Two principle outcomes are obtained. Most dramatic is the fact that 120,000 people pass through the observatory each year, typically 5 classrooms each day. The exposure of this facility is tremendous. Second, after 40 years of operation, Arecibo continues to attract excellent new and mid-career scientists. All groups benefit from the intersection among the atmospheric/ionospheric science, radar/radio astronomy, and engineering staff and visitors.

4. Facility Infrastructure and User Support

4a. User Support

The last three years, on a 1 October through 30 September basis, saw 1123, 1085, and 1285 hours, respectively, of SAS-related telescope usage by approximately 12 external users and staff per year under 13-14 separate observing programs per year. Over this 3 year period the external users represented about 15 non-NAIC institutions including Cornell and UPR faculty and students. The largest observing program, averaging about 420 hours per year, is the "world day" observations. SAS-related observing programs averaged about 870 hours/year in the 1998-1999 and 1999-2000 periods because of the Gregorian upgrade project. Based on budget divisions, the average SAS-related telescope usage should comprise 15-18% of available time, this has climbed to 20-22% but pressures due to the new Arecibo L-band Feed Array (ALFA: a seven feed system that will allow large-scale radio astronomy surveys of the sky) system will likely force this percentage down again.

Observations at Arecibo require submission of an observing proposal that is peer reviewed by at least two anonymous experts in the area. These proposals typically include at least one SAS staff member as co-investigator as the proposals often evolve via discussions with the staff. If a staff member is not a co-investigator, a successful observing proposal is assigned a staff scientist to assist. Proposals are solicited on a trimester basis with observations initially scheduled during the four-month period that begins four months after the proposal deadline. This proposal procedure is a formalized process that is unique to Arecibo and may be considered burdensome to the community. However, proposal pressure would seem to indicate that the process is clearly articulated and works well.

4b. Facility Infrastructure

Highlights: Recently completed developments include upgrading the 430 MHz radar to permit simultaneous (at divided power -- usually 50/50) dual-beam capability, utilizing both the original carriage-house linefeed and a new focal-plane horn assembly in the Gregorian dome. Additionally, the transmitter is undergoing systematic upgrading/refurbishing that will make it much more reliable and extend its bandwidth to 2 MHz from the current ~1 MHz. Most importantly, a supply of used Litton 5773 klystrons recovered from the Clear Alaska BMEWS is available and not only will extend the life of the transmitter to about 10 years but also are sufficient to allow consideration of doubling the transmitter power to 5 MW at somewhat less than the current 6% duty cycle. The power-doubling project would significantly extend the range of ISR light ion (H^+, He^+, O^+) studies into the plasmasphere.

A new transmitter engineer has been hired bringing transmitter staff to two plus Jon Hagen who oversees transmitter projects. It is essential that planning for a new transmitter proceed in concert with Millstone and possibly Sondrestrom. An additional project is automating the change-over from single- to dual-beam operation (~$100K) that would save hours of manual labor during which the telescope is not usable.

Arecibo is, along with all the other UAF sites, actively pursuing the use of wide-band IF-sampling digital receivers that are based at this time on the EchoTek PCI cards. As these developments parallel those underway at the other sites, it is critical that software/hardware developments be shared on a timely basis among the sites and the UAF user community.

In order to encourage more users, basic data analysis software and associated documentation should be developed and made available to users possibly via CVS (Concurrent Version System) that additionally encourages feedback and questions. All this could be managed in the manner of, or as part of, the Millstone-based Open Radar Initiative.

The AO SAS group sponsors UOPA (User-Owned, Public Access) instruments for which appropriate space and a nominal level of support is provided. SAS views this approach as a mechanism to bring more instruments to the AO cluster without much extra burden on the staff.

Plans: The largest project at ~$3.8M capital and ~$240K incremental annual operating costs is the proposed new dish-mounted HF-heater facility. The proposal for this project was submitted to NSF April 2003. At 8.175 MHz, the heater facility would permit 140 MW CW Effective Radiated Power (ERP) and 450 MW ERP under pulsed mode. These values far exceed the 80 MW ERP for the Islote Heating Facility just before it succumbed to a hurricane. The heater would also run at 5.1 MHz at a lower ERP and a separate proposal would seek a 3.1 MHz heater feed. The facility would operate in a campaign mode with two campaigns of about 100 hours telescope time each per year.

The heater facility combined with the dual-beam ISR and passive optical instrumentation would provide the opportunity for aeronomy studies using accelerated electrons to produce airglow and would enable thermal balance studies of the ionosphere plasma via study of how heating extends from the heated volume into the surrounding ambient ionosphere (especially along the B-field flux tube) that is monitored with the radar. The heater facility would also find use in middle atmosphere studies (as a combined modifier/radar). Additionally the heater would allow studies of resonant Langmuir/ion waves in the interaction region, of the electron acceleration process, and studies of the formation mechanism(s) for (B) field-aligned irregularities on meter through sub-kilometer scales as well as enabling HF radar studies of the MST region.

The proposed HF heater facility would roughly double the SAS user community at Arecibo. This facility is strongly supported by the ionospheric modification community and, aside from AMISR, is the single largest community effort involving UAF radars. However, as a result of this potential user demand, additional stress will be placed on the limited observing hours of the ISR.

A new radar project (2005-2007 study phase) would bring the now dated 46.8 MHz radar with co-axial feed to the 430 MHz linefeed to near MST radar status. The current feed is actually four linear-polarization Yagi antennas arranged in a box surrounding the linefeed. The new system would render each of these feeds, enhanced for higher power, a separate transceive element of a 4-element phased array radar. Each element would be fed by a 25-50 kW transmitter. A second co-axial feed similar to the one just described could provide a 160 MHz radar of similar power levels. These radars combined with the 430 MHz radar with interferometric receive system would be used to determine the meteor flux over a very wide mass range into the upper atmosphere. It would at the same time determine the radiants and thus orbits of many of these micrometeoroids. Preparation for these systems would begin with a proposal to fund a study of the proposed systems.

Additional major projects include significant upgrades to the optical facilities starting with an (~50%) expansion of the airglow building (~$25K) to be completed in 2004. This expansion is meant to better serve visitor instruments. Spectrometer and Fabry-Perot CCD upgrading begins in 2004 and is to be completed in 2006 at a total cost of ~$60K. The CCDs bring more sensitivity and flexibility plus possible enhanced data rates to a variety of observations.

Transmitter related projects include an automated 430 MHz switch-over capability at the Gregorian. This project (~$100K) would enhance flexibility of observing modes and, most importantly as manual switch-over requires several hours, allow high-efficiency usage of telescope time. A new solid-state IPA (Intermediate Power Amplifier) has just been installed (March 2004) simplifying the 430 MHz radar system while enabling wider bandwidth (~2 MHz) transmissions at high power. The replacement of the 430 MHz transmitter is not an immediate priority due to the current availability of spare klystrons. However, the plans for a replacement transmitter must be in place within 5 years so that major technical issues are identified early and that funding planning can proceed. This need is shared by the other UAF radars.

Currently there are two buildings dedicated for optical measurements. The original building (which is now full—see above), houses the passive optical remote sensing instrumentation and is located on a hill above the ISR antenna affording good viewing down to about 10° elevation (limited by local trees). The AO passive-optical instrumentation includes two Fabry-Perot interferometers (FPIs—configurable to support either E- or F-region studies), two Ebert-Faste spectrometers, devoted mainly to mesospheric OH and O_2 airglow intensity and temperature studies, and a suite of airglow photometers. Additional guest investigator instruments include a near infra-red Fabry-Perot Interferometer from Scientific Solutions Inc. (used for Helium studies in conjunction with the ISR and other FPI instrumentation), and two all-sky CCD imagers, one from Boston University used mainly to study MLT gravity waves in the ~80-100 km region and the other, a public access instrument from Penn State University, devoted to F-region 557.7/630 nm measurements. The facility instrumentation is very mature and although well maintained, it requires considerable on site support for set up, operation and calibration. In comparison, the Guest PI instruments are more modern and their operation more automated.

The lidar building was constructed in 1997 and is located about 50m further up the hill from the original building. This facility contains three state-of-the-art lidar systems: a potassium lidar, used for mesospheric temperature profiling, as well as metal layer studies combined together with a Ca and a Ca^+ lidar system. The development of a comprehensive lidar capability at Arecibo is relatively new and the current programs are designed to complement the ongoing ISR studies of the E and F region. There is reasonable room for expansion in this new facility, possibly for housing a future guest lidar as the opportunity arises, and plans to extend the building as the need arises.

Both optical buildings are certainly well used. Vehicle access is restricted (to limit stray light) but scattered light from nearby communities and lights on the antenna support towers do interfere with the passive all-sky imaging studies. Furthermore, the high humidity of the Puerto Rican climate creates significant operational difficulties for all of the optical instrumentation and the Arecibo staff are to be commended for their development of this complementary optical research program which, with the addition of the lidar instrumentation, has started to yield important new results in coordination with the ISR, as well as novel stand alone science.

The all-sky imagers operate automatically (during moon down periods) while the lidars and the other passive instruments are operated manually (typically for 10-14 nights per month) in conjunction with the ISR program and World Day runs. During World Days (typically 20-25 days per year usually near new moon) one of the FPI's is reconfigured to support either E or F-region studies. This requires significant time and effort to change out the etalons and re-stabilize the instrument (~2 days), and also creates a potential for instrument damage. Consequently, the panel is most supportive of the plan to upgrade the existing facility instruments to use modern sensors and associated electronics and, if possible, to deploy an additional FPI to permit continuous E- and F-region wind measurements. The panel also commends Arecibo for its implementation of a guest investigator program that provides on-site help and maintenance for the instrumentation on the condition that the data are made freely available to the community (e.g. via the CEDAR Data Base).

Future plans call for further developments of the lidar systems to enable wind measurements in the MLT region and to expand the sounding capabilities to include daytime measurements to determine density and temperature over an extended altitude range ~10-110 km using a combination of lidar techniques. Future plans also include (per above) upgrading the two interferometers and the spectrometer with new CCD detectors to enhance their sensitivities, and the development of a near-infrared (NIR) capability to observe a new set of atmospheric emissions. A NIR imaging system could also be used to investigate gravity wave dynamics, artificial airglow emissions (induced by the proposed HF heater facility), and to study transient optical emissions (termed sprites and jets) that have recently been detected in association with thunderstorms in the vicinity of Arecibo. On this note the panel recommends that the Arecibo staff discuss their imaging needs with colleagues at SRI who are also interested in a new (possibly NIR) imager for auroral research.

In summary, the combination of ISR and optical observations at Arecibo creates a unique capability for detailed studies of the low-latitude neutral and ionized atmosphere. The proposed upgrades to the current suite of optical instruments together with the anticipated development of new instrumentation (and guest investigator facilities) will provide a comprehensive capability for future multi-diagnostic “clustered” measurements together with the ISR and the proposed heater facility.

5. Broader Impacts

The Arecibo 430 MHz radar has (by far) the largest PA/T ratio (Power × Aperture / System temperature) in the world. The capabilities of this instrument are being continually refined and are considered a scientific (and engineering) resource to the CEDAR and related space science communities. This radar can observe all aspects of the complicated incoherent scatter spectrum. Its (magnetic) mid-latitude location allows the study of the quiet ionosphere as well as surprising storm-related effects. In the F region, where all IS radars observe the relatively narrow ion line, Arecibo splits its power into seven frequencies; this results in unrivaled time and range resolution temperature, composition and density measurements.

The existing optical instrument complement at Arecibo, which coupled with the ISR, is capable of producing high impact science focused on low-latitude phenomena. For example, major initiatives of the CEDAR and TIMED programs are to understand the dynamics, thermal balance, and chemistry in the region between 60 and 150 km, where superior sensitivity of the Arecibo ISR and comprehensive optics provide substantially complete time and altitude coverage. These systems will also be used to study sprites (upward lightning discharges) as well as the meteors that enter the Earth's atmosphere and are the source of the metals detected by lidar and radar between 80 and 100km.

The recent Solar and Space Physics Survey Committee (SSPSC) report pointed out that space physics monitors the broad impacts on society caused by “space weather” and global change. Arecibo’s contribution to these programs is through the chain of radars, soon to be completed with the SSPSC recommended Advanced Modular ISR (AMISR) and through the topside measurements and storm studies. SAS’s topside program also complements the most prominent current global change study in the CEDAR community: the long-term exospheric hydrogen number density variation.

The extensive set of educational activities has had a large impact on reaching the public and K-12 students through the visitor center and through K-12 teacher workshops and research experiences. The hand-on exhibits provide interactive query based informal education that illustrates concepts in upper atmosphere physics and astronomy. These activities complement a visitor program that recently has been enhanced through the hosting of several science workshops by the SAS group. These workshops have been well attended and provide a venue for attracting potential users to the observatory.

6. Management and Budget

The Arecibo Observatory is operated by Cornell University through the National Astronomy and Ionosphere Center (NAIC), which reports to the Vice Provost for Research. The observatory is funded by NSF through the Astronomy division as well as the Atmospheric Sciences division. Approximately 15-20% ($1.8M) of the budget supports the research activities in space and atmosphere sciences (SAS) at Arecibo. The complex management structure requires constant communication amongst the principal leaders at Cornell, NSF, and Arecibo Observatory. Review teams in the form of a Visitors Committee, a Users Committee, and a NAIC Oversight Committee provide regular input to Cornell and Arecibo Observatory leadership.

Within the last year there have been major changes in the Directorship of NAIC (Robert Brown) and the Directorship of the Arecibo Observatory (Sixto Gonzalez). The Director of Arecibo Observatory has been serving as the Assistant Director for the Space and Atmospheric Sciences (SAS) program for the last 3 years and will continue in that capacity at 25% FTE in addition to his duties as the AO Director. This dual set of responsibilities has been carefully negotiated and has resulted in major rethinking of the management structure of Arecibo Observatory. The new structure calls for separate functions for finance, science and technical management, and education/outreach that report to the AO director. Implementing this new structure is currently underway -- a new business manager has been hired and the leader for the education/outreach effort has been identified and is working on an expanded outreach program.

The panel closely questioned Brown and Gonzalez and feels satisfied that they have thoughtfully assembled the mechanisms that will allow Gonzalez to continue to provide leadership for the SAS group while functioning well as the AO Director. The arrangement will also require that the SAS leaders in optics (Craig Tepley) and radar (Mike Sulzer) take on more responsibilities. The arrangement will be reviewed in 6 months with success being determined by a successful competition for the renewal of the NAIC/AO cooperative agreement and people in place to manage the functions of the Arecibo Observatory. Success within the SAS program will be judged by the continued forward science planning and science accomplishments enabled by the powerful array of instruments at Arecibo.

Under Gonzalez's leadership of SAS there has been a major turn-around in science and infrastructure planning. Thought has been given to the science drivers for infrastructure upgrades and enhancements, including the submission of the Heating Facility proposal. The articulation of annual work plans, through a separate statement of work that is submitted to the UAF program, helps focus the work on a regular basis. The evolution of the work plan over the last 3 years is evident. The panel urges the SAS group to complete that evolution of the annual statement of work with clearly articulated science questions and projects under each of its major science theme areas. We also urge SAS to take a leadership role in developing workshops for scientific planning for the community as well as educational workshops/internships for graduate students across the country.

The engagement of faculty and students at Cornell (and other universities) in SAS science and engineering development is an area that requires more attention. It is not clear that Cornell will continue to invest in faculty in this area. Without a critical mass of faculty involvement, it will be difficult to attract graduate students from Cornell. Indeed recent SAS related theses completed using Arecibo instrumentation have primarily come from students at Pennsylvania State University and Boston University suggesting that a broader university faculty and student effort amongst the space weather and climate community might be a better alternative to attracting students to work with Arecibo Observatory. Alternatively, a vigorous programmatic approach to using SAS expertise to teach short courses and give seminars at Cornell and other universities to attract graduate students might be a solution to more thorough engagement of Cornell into SAS research. Perhaps select SAS Arecibo staff could co-direct thesis work.

Recruitment and retention of early career scientific staff was also identified as a major issue. Recruiting post-doctoral scientists and research associates has been accomplished through proactive informal networking at professional meetings and the current group of early-mid career scientists is excellent. However, recruitment and retention of staff can still be difficult (as at other sites) due to the island culture and living logistics. In many ways, the Arecibo Observatory needs to take on the identity of a "family" role to ease the transition of many different cultures into a Hispanic culture.

Housing for short term visitors (6 months or so) may provide greater access to scientists desiring to spend a sabbatical or visiting appointment at the observatory with the potential result of developing long-term collaborations. Housing for 2-3 year appointments is also highly desirable and would eliminate the stress of immediately emerging into the island culture. While we recognize that ultimately permanent staff needs to immerse themselves in the island community, we encourage NAIC and AO to further develop ideas for building or purchasing housing for use by staff until that determination is made – within a reasonable timeframe (2-3 years).

The SAS staff organizes social activities (movie night, beach, etc.) that are greatly appreciated. Getting about the island and planning excursions is often difficult due to language barriers, driving stress, and logistical bureaucracies. Additional ideas for organized activities that were suggested to the panel include plays, concerts, and festivals in San Juan as well as recreational activities. The staff suggested a fitness center on the observatory grounds, racquetball courts, or a good paved jogging track around the antenna.

The panel strongly endorses the need for additional, new office space. The SAS program has clearly outgrown its space that also detracts from bringing on new staff and for retaining existing staff. Creating a good work environment is important for scientific productivity. We understand that plans have been developed for a new building and that partial to full funding has been identified/secured and urge that this be one of the top priorities for NAIC and Arecibo Observatory leadership.

Finally, the panel suggests that scientific staff be encouraged to write more proposals. The reasons for this are two-fold: (1) for mentoring early career scientists that may go on to other positions and (2) for expanding the scientific opportunities at Arecibo Observatory. While we agree that certain key core staff is needed full-time to concentrate on implementing the AO vision, other scientific staff and the scientific program at AO would benefit from part-time support from the cooperative agreement and part-time support from their own proposals. Even key core staff should be encouraged to write proposals for new ideas that are outside the normal statement of work of the core UAF funding in order to support students, workshops, and post-doctoral appointments. We believe this approach would enhance the vitality of the scientific and engineering program at SAS and be in full accordance with legal requirements and observatory policies. This approach becomes more palatable to the wider community if staff writing these proposals have joint appointments at Cornell or other universities.

In the environment of diverse technical needs found at AO, it is important that technical staff is available for SAS initiatives. To this end we encourage NSF to provide additional funding for a SAS-based digital engineer. With this engineering position AO could—as the AO receiver needs are the most demanding—lead in digital receiver development. Identification of funding for this position becomes even more critical if the new heater facility is funded.

7. Summary of Findings and Recommendations

Finding: Enhanced network communications bandwidth is critical on a number of fronts. These include enabling new users via remote observations, solving the data-storage dilemma by allowing terabytes of data to be readily uploaded via the net, and enhanced communications via "iSight-like" (picture & sound) technology not only among the UAF sites but also with the user community. This approach also further enables remote observing and UOPA (User-Owned, Public Access) instrumentation.

- *The panel recommends that the UAF sites with NSF develop a plan to make large bandwidth internet capabilities common to all sites. AO can form the test case for this effort, since astronomy also needs this capability.*

Finding: Quality office space (as well as housing) is required both to retain current staff and to recruit new staff. Additionally, "quality of life" issues particularly regarding families will often be an issue in recruiting new staff for Arecibo.

- *The long anticipated new office building should be constructed as soon as possible with every attempt to make modern, spacious, and well equipped offices available to all the scientific staff and particularly new recruits. Also the possibility of nearby, quality short-term housing should be explored with Cornell as a method of attracting short-term (~6 months) visitors to AO. All this would greatly aid in the recruitment and retention of early career scientific staff—a major issue.*

Finding: The SAS optical facilities have matured greatly in the last few years with new lidar instrumentation, a new lidar building, and now a new building for passive optical instrumentation. However, much of the classic instrumentation such as the interferometers and spectrometer (plus data-taking systems) is in need of modernization to provide greater science yield with substantially greater automation. Additionally, support for user instruments -- particularly UOPA instruments -- needs to be promoted as another method of assuring the highest quality passive optical instrumentation with the minimum of staff time.

- *Funding should be identified as soon as possible to automate the passive optical instrumentation and produce an enhanced data product. Imaging needs should be discussed with colleagues at SRI who are also interested in a new imager for auroral research. Also external users should be encouraged to provide and maintain/operate UOPA instruments identified as critical to SAS goals.*

Finding: The replacement 430 MHz transmitter is not an immediate priority due to the current availability of spare klystrons. However, it is clear that plans for a replacement transmitter must be in place within 5 years so that major technical issues are identified early and that funding planning can proceed.

- *In concert with the Millstone staff and NSF, planning for new 430 MHz transmitters should proceed with due haste. Need for replacement transmitters may well provoke exciting engineering innovations particularly in the area of solid-state technology and/or in areas represented by commercial digital TV transmitter development.*

Finding: The proposed new heater facility is a major new effort that has been proposed and is currently under review. The panel notes that the proposed heater, combined with the full complement of AO instrumentation, especially the extremely sensitive ISR, promises a new era of experimental work in aeronomy and plasma physics. The heater will also produce significant impact in terms of the cost of construction, cost of operation and will reduce the hours available to the user community for geophysical observations.

- *The panel recommends that the construction cost and operational cost of the heater be considered carefully and that new funds be obtained to support these costs. The panel would not like to see the base programs of the Upper Atmosphere Section taxed additionally to support the heater experiments. In addition, the impact on the geophysical user community must be assessed and a plan to accommodate this community must be developed and approved by the community.*

Finding: New leadership has recently been established that has put Gonzalez in a larger leadership position as AO Director while still maintaining a leadership role within SAS. The mechanisms for these dual responsibilities have been worked out but will require periodic review to ensure that all parties are satisfied with the working relationships.

- *The panel recommends regular review of the leadership and management structure and responsibilities to ensure continued success of the SAS program.*

The Jicamarca Radar Observatory

1. Introduction

1a. Description of Site

The Jicamarca Radio Observatory (JRO) features a 50 MHz incoherent scatter radar located near Lima, Peru. The site lies 12 degrees south of the geographic equator, but is almost directly beneath the magnetic equator. Close proximity to Lima, with its airport, seaport, and significant urban support infrastructure addresses the logistics needs of a major science facility.

The distinctive main antenna is a polarimetric phased array consisting of 9,216 crossed dipole pairs in a square aperture whose side has length 300 m. The main antenna is protected from occasional flash floods (which can move large boulders), or *huaycos*, by a dam or dike.

The Jicamarca site is unsuitable for optical instrumentation. Lima and its environs are nearly always subject to an extremely strong troposphere inversion layer that renders the lower atmosphere very murky. However, several other sites managed by the Peruvian Institute of Geophysics (IGP) are suitable for optical instruments, and are frequently used by NSF sponsored scientists.

Scientists visiting the Observatory will find accommodations for one or two at the JRO site, or otherwise at a hotel nearby ("El Pueblo"). Visitors will find their ground transit simplified tremendously by the assistance of the JRO staff. The staff is accustomed to meeting visitors when they arrive at Lima's airport and will shuttle the scientists between the Observatory and the hotel.

The Observatory was constructed by the US National Bureau of Standards (now NIST) and began operations in 1961. Subsequently, the Observatory was supported by the US NSF. Several years later the ownership of the site was transferred to Peru, with NSF's significant support role being established through a cooperative agreement. Currently JRO is operated under the auspices of the IGP whose Executive President is Dr. Ron Woodman. The NSF PI for many years has been Professor Don Farley of Cornell University. In the near future, Professor Dave Hysell will assume the PI role. Similarly Dr. Jorge Chau has recently replaced Dr. Ronald Woodman as the site director at JRO. A Peruvian non-profit corporation, Ciencia International (CI), provides an additional administrative function at JRO by supplying the site staff.

1b. Summary of Site Strategic Goals

In their mission statement, the JRO scientists have identified the goal of "improving our understanding of the low-latitude atmosphere and ionosphere and to the systems which they are coupled" as well as continued development of advanced radar science techniques.

The JRO scientists have organized their ionospheric research goals into topics that may be investigated through incoherent and coherent scatter techniques. The principal incoherent scatter topics are these:

- Topside: light ion distribution, latitude variability, storm time response
- F region: thermal balance, Coulomb collisions and ISR theory, precursor state which results in subsequent ESF generation, interhemispheric transport.
- E region: density, temperature, and composition profiles of the equatorial region, interaction with the F region dynamo.
- D region: composition changes resulting from meteor ablation and mesospheric mixing.

When large amplitude irregularities are present, different phenomena will be investigated:

- F region: improve identification of large and small-scale processes in plasma plumes, precursor phenomena for plasma plumes.
- E region: turbulent equilibrium state of electrojet irregularities, effect of electrojet irregularities on E region conductivity, comparative studies with high latitude electrojet irregularities.

These science investigations will be supported by new radio science techniques that can be described generally as improvements in spatial-temporal resolution, through new radar waveform coding, data analysis, and antenna configuration. In some cases these techniques address range-Doppler ambiguity constraints that are intrinsic to radar experiments.

The JRO scientists seek three major hardware upgrades that address these science goals.

- Electronic antenna phase switch. Reconfiguration of the main antenna now requires several hours of manual staff effort.
- Completion of the fourth main transmitter. This will bring the system up to its original total power, and provide additional robustness in the event of transmitter failures.
- Support for SOUSY operation. The SOUSY 53 MHz radar has been installed at JRO, and (currently) looks 15 degrees south of the zenith. This system will permit estimation of north-south drifts for which the main array is unsuitable. With electronic phase control development further experiments will be possible.

The committee supports the science goals described by JRO scientists. Nevertheless it is unlikely that NSF will be able to support prompt pursuit of all these goals. Thus, priorities will have to be established to work within the available funds.

2. Scientific research enabled by the facility

2a. Science Evaluation

In the past five years JRO scientists and their colleagues have demonstrated several distinctive results.

Resolution of the Te/Ti mystery: For decades, standard analysis of F region incoherent scatter correlation functions extracted from beam directions near perpendicular to B have yielded electron temperatures which are lower than the ion temperatures. After extensive experimental analysis (to rule out flaws in the interpretation of the experiment), and analytic checks of the underlying theory, a correction to the electron collision model appears to account for the discrepancy. This problem attracted significant attention from the community, in particular Arecibo Observatory scientists, who developed a simulation to derive corrections. Subsequently Woodman has developed an analytic Fokker-Planck model that agrees closely (but not exactly) with the Sulzer and Gonzalez results at AO. The resolution of this problem is not merely intellectually satisfying; it now permits confident parameter estimation at the "3 degree" position of the main antenna. This eliminates a significant past barrier to rapid archival of reliable plasma parameters for others' use in the CEDAR and MADRIGAL databases.

High range resolution modes and interferometric imaging: By upgrading the data acquisition systems and transmitter controller, JRO scientists now routinely produce 150 m range resolution in the coherent scatter mode (i.e., in measurements of strong scatter from unstable plasma waves). Furthermore, by clever configuration of the main array and auxiliary receiving antennas, JRO scientists have employed interferometric imaging to reveal a tantalizing glimpse of the evolution of meter scale irregularities in the plane perpendicular to B. The "movies" which result from temporal assembly of these images immediately reveal the drift of decameter and hectometer structures. These movies provide data that can be very easily compared to computational plasma simulations.

Improved Topside Measurements: In recent years the quality of topside data has been improved through progress on several fronts. First, the third transmitter has come on line, boosting the total available transmitter power. Second, new hybrid radar waveforms have been developed to augment the performance of the traditional Faraday Double Pulse mode. Alternating codes, which have been tremendously useful at higher latitudes, have now been implemented at JRO in its nearly perpendicular scattering geometry.

Enhanced modes for study of irregularities: E and F region irregularities are challenging targets despite their large radar cross-sections (compared to Thomson scatter). The extended range and large Doppler content create a fundamental challenge to range and Doppler resolution. For subtle reasons, conventional ISR correlative modes (multipulse, alternating codes) fail. Furthermore, the high radar cross-sections of the irregularities effectively jam the ability of simple radars to extract background parameters from Thomson scatter. JRO scientists have developed a variety of responses, from aperiodic pulse modes, to bistatic Faraday rotation measurements to dramatically improve the quality of the coherent scatter data and to obtain background E region density data.

Meteor studies: Meteor science has enjoyed a renaissance of interest in the aeronomy community in the past five years. With high power-aperture and low frequency, JRO is capable of detecting both “head” and “trail” echoes, and its interferometric capacity permits excellent radiant estimation.

These results highlighted here are the result of highly productive science careers of Farley, Woodman, and Swartz, as well as their protégés Kudeki, Hysell, and Chau.

Uniqueness of Research Done Using the Site. Jicamarca is intrinsically unique in its geomagnetic equatorial location and its very large and flexible antenna system. There are no other US-supported incoherent scatter radars that lie beneath the equatorial electrojet, and none at other longitudes with the sensitivity of JRO. F-region drift measurements yield electric field measurements of remarkable precision. The relatively long wavelength and large power-aperture product make JRO the only radar that can detect scatter at all altitudes from the troposphere to the thermosphere.

There are currently no other aeronomic ISR systems with JRO’s interferometric imaging capacity. Although the main antenna has a limited field of view, it can be readily reconfigured to enable a tremendous variety of interferometric and polarimetric experiments.

The Te/Ti problem perplexed the ionospheric physics community for decades. The geometry and operating frequency of JRO caused the discovery of this “problem.” On the other hand this “problem” would probably have gone unnoticed at all other radars. Thus JRO has provided the opportunity to further refine the extremely successful kinetic theory underlying incoherent scatter analysis.

Quality of Scientific Research: In the past 5 years approximately 75 articles on science at JRO have been published (or accepted for publication) in high quality, peer reviewed international journals (e.g. JGR, JASTP, Ann. Geo., GRL, and Radio Science). Of these, approximately half have first authors among the JRO scientists (or their graduate students). The number of articles published in the past five years is greater than in the preceding five years. Also the variety of authors has increased (i.e. more non JRO scientists). In summary the quality of research is high, and the volume is robust.

Role of Facility in Supporting National, International, and Satellite Programs: JRO is the world’s largest equatorial radar and is ideally situated for coordinated measurements with a number of existing and planned satellite investigations. To date, there have been few such studies, primarily because the duration of the common volume measurements is often limited to only a few minutes, and because it can take several hours to configure the main radar for a particular observing configuration. However, the development of the JULIA system, which utilizes the main radar antenna to provide continuous day and night coverage of several key E and F region parameters, together with the impressive array of complementary instrumentation at JRO (including magnetometers, wind profilers, GPS scintillation, and most recently the SOUSY radar), clearly warrants better usage of the facility for existing and new satellite investigations.

On this note new calibration/validation measurements for the DMSP satellite are expected to start shortly and plans for detailed coordinated studies with the low inclination CNOFS satellite are in progress. The panel recognizes these important developments and at the same time strongly encourages the initiation of coordinated studies with the NASA TIMED (GUVI) instrument and the upcoming COSMIC satellite both of which are ideally suited for coordinated investigations of F-region storm onset and dynamics. Plans for testing substantial parts of the new AMISR radar at JRO together with the development of a "year round" optical capability using new instruments at remote sites will further enhance the importance of the JRO facility for future coordinated rocket and satellite borne measurements of equatorial dynamics

As Peru hosts JRO, it provides an excellent focus for South American aeronomy, with significant collaboration with Brazilian radio scientists. JRO scientists actively coordinate World Day observations with the other NSF incoherent scatter radars and EISCAT. There has been significant interaction with the MU and Chung-Li radars in recent years. JRO is a centerpiece of the Peruvian Institute of Geophysics (IGP). Dr. Woodman has been involved in Peruvian studies of the Antarctic as well as the high impact "El Niño" phenomenon.

Two recent conferences held in Peru have each attracted approximately one hundred diversely international participants (JRO 40th Anniversary, May 2002; and MST-10 (in Piura), May 2003). JRO scientists have provided tutorial lectures in several recent international radar schools.

JRO scientists are active participants in NSF sponsored programs such as CEDAR, and aspects of their effort have been supported by related agencies, such as NASA and the Air Force. One of their future science plans (ESF forecasting) is clearly an important Space Weather topic.

2b. Research Capacity and Balance:

As mentioned above, JRO has provided significant "radio" science as well as radio "science," although the latter aspect has not always been obvious to the wider community. The panel encourages JRO scientists to be perpetually sensitive to the perception that JRO is a closed shop of engineers rather than scientists.

Those who use JRO data seek a very wide array of parameters; classic ISR parameters are requested by a plurality, but nevertheless a minority of investigators. The large catalog of possible radio experiments seems to be generally desired by the broader upper atmosphere community.

The high power ISR is operated for about 1000 hours each year, with about half the time devoted to World Day parameters. This left what initially seemed to be a small number of hours for other ISR experiments. However, the JRO scientists suggest that they are meeting the present community demand, and that it was possible to generate World Day parameters with a variety of different modes, permitting "dual use" of the ISR during World Day runs. While many would favor additional ISR operation, there are significant costs in site staff, electric utility, and transmitter tube lifetime. (The cost of electricity is computed in a non-obvious manner; a large fraction of the cost is based on the peak consumption of the previous 6 months.)

In addition to the 1000 hours of ISR operations, the main antenna is kept active with the medium power JULIA transmitter. JULIA is capable of all coherent radar studies, and provides electric field measurements through observation of the 150 km echo (of unknown origin, but which appears to be a reliable tracer of E x B dynamics).

The location of the observatory was not chosen for quantitative optical studies, and the prevailing meteorological conditions yield poor atmospheric “seeing conditions.” This is primarily due to the presence of a persistent inversion layer that traps large quantities of aerosols below 1000 m. Nonetheless, coordinated radar and optical studies of equatorial F-region dynamics have been performed successfully using a number of visiting PI instruments located at higher altitude in Peru within a few hundred km of JRO, such as Huancayo and Arequipa (altitude ~2000 m), often for extended periods of time. In particular, the MISETA Program supported the operation of a Fabry-Perot Interferometer (FPI) (Clemson University) and a 630 nm all-sky imager (Boston University) for coordinated investigations with JRO until 2001. The IGP continues to maintain these high altitude sites with good infrastructure (electricity, internet, and security) and logistical support for the optical measurements.

To date, coordinated optical observations have been restricted primarily to the Southern Hemisphere winter months (May to November) due to the existence of an extended rainy season during the summer months throughout the Peruvian highlands. In recognition of this problem new optical sites are currently under evaluation. These include a desert region in the Paracas-Nazca area located 200 km to the south of JRO. This site has already been used for radar experiments and has high prospects for extending the capability for optical observations throughout the summer months. On this note, the IGP plans to build a small astronomical observatory in the same area that could provide the essential logistical support and security necessary for long-term coordinated research. A second possible “desert site” for summertime measurements has recently been successfully field tested by Cornell University using an all-sky CCD imager. A MEDAC radar (University of Colorado) is already operational at this site, which is located on the northern coast of Peru in Piura. Piura offers considerable potential for studying equatorial mesospheric gravity waves as well as thermosphere depletion studies, albeit at a large range ~1000 km from the JRO.

As part of these new plans a major upgrade in the capability of some of the optical instrumentation is in progress with the installation of a new high-resolution FPI and an all-sky CCD imager (SOFDI) at Huancayo, expected during December 2004. The multi-etalon FPI instrument is currently under development at Clemson University and its impressive day and nighttime capability is expected to provide an exciting new potential for detailed measurements of winds and temperatures in the mesosphere, thermosphere and topside regions. It is clear that the development of “year-round” observing facilities housing improved optical instrumentation will enhance significantly the capability of the JRO instrument cluster for novel and highly complementary radar, optical and satellite measurements of a large range of important equatorial atmospheric phenomena.

Finally, we note that all optical experimentation is supported by funds external to the NSF grant to JRO.

2c. Future Science Plans

JRO scientists list five principal areas for scientific pursuit in the next five years:

- Composition of the topside ionosphere, light ions, chemistry, and transport
- Thermal balance in the F region
- Equatorial Electrodynamics, dynamo theory, thermosphere wind shears
- Equatorial Spread F forecasting for GPS and other radio scintillation
- D region studies; historically lacking but within reach of new hardware and techniques

These goals are appropriate for an equatorial ISR. Most of these represent continuation of historical inquiries; however the value of these inquiries will grow as the length of the climatological record expands. Furthermore, the continuous improvement of radio techniques provides new opportunities for investigations that require finer spatial and temporal resolution.

3. Educational Activities

In education and outreach, JRO has an excellent record of providing data used as the core of PhD dissertations (approaching 50), of whom 12 have been Peruvian. There are an additional seven PhD students active at Cornell, Colorado, and Illinois. The past five years show active participation by postdoctoral fellows. JRO scientists have developed educational material for 12 undergraduate and graduate courses at Cornell; the panel is aware of additional JRO-motivated material in college courses at other universities (e.g. University of Washington). Finally, JRO scientists have developed a trainee program to introduce Peruvian students to scientific careers.

For the long-term health of Jicamarca, it is important that some Peruvians from the Observatory received advanced training overseas. If they can be convinced to return to Peru and Jicamarca with attractive job opportunities, they will provide the future high-level leadership of JRO. The present Director, Dr. Jorge Chau, is a clear success story for this policy.

JRO scientists have expressed their desire to create attractive career paths for young scientists, by emphasizing undergraduate and graduate education. The PI and his colleagues expect that many students who participate in JRO-inspired programs will not choose careers in aeronomy; however they do expect that the students will prosper from their exposure to the high tech, state-of-the-art work at Jicamarca.

The proposed plan is to continue in essentially the same fashion as has been pursued in recent years. However, the JRO leaders propose to add a “visiting scientist” program, recognizing that graduate students at Cornell have a natural advantage in access to JRO. The JRO science team will solicit proposals through conventional channels. Finalists will be selected by the science team. Travel expenses and a per diem will be supplied for periods of two to three months.

We encourage the JRO leaders to follow through with their education and outreach plan, and take every opportunity to increase the awareness of the larger science and public communities in their efforts.

4. User Support and Facility Infrastructure

4a. User Support

The flexibility of the JRO infrastructure especially as applied to radio science aspects of the upper atmosphere and ionosphere has stemmed from a steady stream of visitors. Visitors include 26 “frequent” users from outside JRO out of a total of 65 users over the 1999-2003 period. The success of JRO’s interaction with the research community is the 40-year total of nearly 50 Ph.D.s from Cornell and other universities including 12 PhDs awarded to Peruvian nationals.

As of August 2003, the Jicamarca radar was operated on average the following hours per year: (1) 700 hours for standard ISR measurements, (2) 4995 hours for JULIA observations, and (3) 340 hours for other experiments requiring the use of the high-power transmitters. The majority of the ISR hours were dedicated to Coordinated World days. JULIA observations include all the radar studies using low-power transmitters. Other experiments using high-power transmitters include *E* and *F* region imaging and aspect sensitivity observations, dual-beam Faraday-mode ISR, detection/characterization of meteor echoes, high-resolution measurements of mesospheric echoes, solar radar experiments, miscellaneous tests of new ISR techniques, etc.

Scheduling observations at JRO is handled informally. Rather than submitting an observing proposal, anyone wishing to observe at JRO needs to contact David Hysell at Cornell and/or Jorge Chau at JRO and discuss arrangements. Depending on the observing requirements and funding agency, expenses directly related to observing may be incurred. Specifically, the staff normally works four 10-hour days per week (Monday-Thursday), and so observations that run at night or during Friday-Sunday will require that the observer pay overtime charges ($30-50 per hour) to the staff members involved. Observing time for research sponsored by NSF comes at no additional cost other than for possible overtime charges. However, for those with other funding, there is a charge of approximately $8000 per day of observing for individual experiments. For longer, on-going programs not supported by the NSF, special arrangements for Observatory support need to be made.

The JRO Science Team has described a variety of improvements, such as upgrading the WWW pages (with Peruvian students in the trainee program) and developing real time data displays for most experiments.

In a number of important cases, processing of ISR and JULIA data has been automated, resulting in rapid injection of JRO data into the CEDAR and MADRIGAL databases.

As mentioned elsewhere, the JRO science team has been very active in coordinating World Day observations.

4b. Facility Infrastructure

Highlights: The antenna infrastructure at JRO has evolved in service of envisioned science outcomes. In particular the basic array structure of the original antenna has been progressively subdivided into interferometric receive arrays that allow imaging of spread-F plumes, etc. Additional "outrigger" arrays including the "Hysell module" have provided many more east-west baselines for the imaging tasks perpendicular to B. One yagi array is located about 300 km to the south to support bistatic measurements of E region electron concentration (via Faraday rotation) when irregularities are present. Such measurements are not possible with the JRO main antenna due to the presence of clutter from strong electrojet irregularities.

The former Max Planck Institute for Aeronomy SOUSY radar has been relocated to JRO and is being completely refurbished and documented. The transmitter bandwidth permits 50 m range resolution while phase control (when implemented) allows 15 steerability of the beam. Co-location at JRO will permit much new science including measurements of the north-south F-region winds via ISR (previously not available), a variety of interferometric studies including meteors, E-region irregularities including the 150-km echo, bistatic radar observations of vertical plasma drifts (via field aligned irregularity scatter) near 3200 km altitude and close to F-region field lines at Arecibo, true MST observations, and wide-angle imaging of turbulent MST structures. Initial tests of the SOUSY system have been performed, but routine operation is not yet available.

JULIA (Jicamarca Unattended Long-term Investigations of the Atmosphere) allows low-power, long-term (unattended) observations aimed at equatorial spread-F studies. Under the JULIA-mode, the main antenna is excited at low power levels that allow the radar to be run almost continuously at low cost and with little maintenance to study ESF via coherent scatter. More than 600 days of coherent scatter data have been collected with JULIA since late 1996, data which can be plotted interactively and retrieved on-line. These data represent all seasons, span nearly a solar cycle, and are useful for climatological as well as episodic studies of spread F.

The UMass Lowell, digisonde has been upgraded to permit near-real-time data availability. The digisonde presents a technical challenge to the JRO staff, as it cannot be externally synchronized to the ISR. Instead, the ISR is (inconveniently) synchronized to the digisonde.

In addition to the above radar infrastructure, JRO maintains or assists in maintaining other instruments including a digisonde, a GPS network, scintillation receivers, magnetometer chain, and various optical instruments located at Arequipa and Huancayo. Additional radar systems (ST/meteor radar, JRO coherent scatter radar imager) are located at Piura.

Plans: Top priority for new infrastructure is electronic steering of the main array via 128 phase switches plus control. This upgrade to the main array is estimated to cost $120 K spread over 3 years (there are various levels/rate at which this task could be done depending on funding). This capability has been desired for well over a decade, and is regarded as necessary to flexibly and efficiently use observing time and to respond to evolving geophysical events such as ESF and to respond to rare geophysical events such as the recent geomagnetic storm. Currently the main array phasing must be adjusted by manual exchange of transmission line sections at 128 points in the main array, a process which takes several hours, as well as the associated staff cost.

The JRO scientists desire additional receiving antenna modules with short baselines in order to nearly double the field-of-view for imaging studies and thus possibly for the first time observe the initial bottom-side growth stages of the instability structure manifested as topside equatorial spread-F. These modules will consist of four small antennas in the eastern corner of the current system and represent two new sub-arrays separated by a distance 1/4 the east-west distance between the existing array modules. Using the new antennas together with six existing modules enables interferometric observations to be made with up to 28 distinct baselines. The longest of the baselines will be about 100 .

Although the SOUSY radar is in place and has been tested, additional support is needed to bring it online. A dedicated electric generator is in place and can be fueled whenever needed. However, electronic phasing must be added to steer the beam. When the first step is taken, north-south F region drifts can be computed (for the first time); with steering, an additional five experiments have been described by the JRO scientists.

A variety of supporting infrastructure have been added or upgraded. The electric power transmission system has been upgraded; a library has been added. Although there is a 2.5 MBps internet connection to Lima, it appears that the network speed to the US remains fairly limited. However, network speed will almost certainly improve.

A modest increase of the capacity of the visitor’s quarters would address a basic limitation of the present facility, which is that two visitors may stay at the site; however they must share a single room. This creates potential problems when the visitors may require separate quarters for a variety of reasons (such as propriety).

The committee briefly examined a facility for production of multilayer printed circuit boards. Several of the committee members were initially concerned about investing in this facility. In the United States, commercial PC board production services are efficient and inexpensive for prototyping as well as production. Also, PC board production requires use of potent chemicals whose proper use and disposal requires significant attention and infrastructure. However, the facility serves as a valuable teaching tool and is the only such facility in Peru. It is a benefit to Peru that continues to build local involvement with the facility by assisting other groups in PC board production. Furthermore, commercial PC board turn around time is fairly long in Peru (using North American production firms). Nevertheless, it is likely that commercial turn around will improve, adding perhaps a week at most to current one-week turn around in North America. While the facility is not funded by the NSF, the NSF should also be diligent in ensuring that the infrastructure is well maintained and that appropriate and safe chemical handling operations are followed. (No other facility depends upon in-house production of PC boards).

Beyond the general desirability of increased transmitter power, the current final transmitter tubes are nearing the end of their expected operating lifetime. Thus, construction of a fourth transmitter could also be viewed as a prudent step in preventative maintenance even if all four transmitters were rarely, if ever used simultaneously. As is the case with the other major radar facilities, the main transmitter tubes are expensive – the 1.5-MW main transmitter final tube is $80K while the 100 kW driver tube is $15K. The SOUSY 300 kW final tube is $40K.

Aside from the major infrastructure concerns described above, additional issues are ongoing. These include repair/replacement of standard electronic test equipment and of computers. Additionally there is issue of corrosion in the myriad antenna connections of the cabling system and in the dipole element interconnections. Also of concern is replacement of the aging fleet of vehicles. The road to JRO is passable but rough and dusty, and is clearly hard on the vehicles. We urge the Observatory to continue to replace their vehicles at the rate of at least one every other year.

The JRO Science Team did not address programs for promoting robust software engineering practice. However, they did mention the creation of a group dedicated to software support has been created at the Observatory. We note that there are opportunities to collaborate with quality software development at Millstone Hill and at SuperDARN.

When presented with the challenge of an NSF allocation that might be significantly less than the request, the JRO science team offered modified schedules for acquisition of the fourth transmitter, and upgraded drivers, with a contingency plan to address an early failure of one of the final amplifiers.

5. Broader impacts

With its unique location and novel instrument configuration, JRO is capable of many unique scientific investigations. The past five years have been especially productive.

On occasion, activities at JRO have been criticized as being more “radio” than “science,” as if there was a neat separation of these concepts. However, active development of new techniques is a sign of vigor at a premier radio science facility. Furthermore, these new radar techniques have always been directed towards investigation of upper atmospheric physics phenomena. The JRO high-resolution techniques have revealed structure on very fine scales and while high-resolution methods are technically interesting, these techniques are also a reasonable response to plasma simulations developed about a decade ago. Several of the new and proposed methods offer increased efficiency of use of the instrument. JRO-developed radar techniques inspire development at a number of other radars, and JRO has been first to implement techniques developed elsewhere (e.g. the aperiodic mode used for ESF).

This conjunction of “radio” and “science” effort at JRO has provided a greater integrated research program than what is generally perceived. There is no mistaking the strong “technique” component of activity at JRO, but this activity has maintained scientific leadership on the back of 42-year-old hardware. JRO’s scientists have the nearest operational experience with a phased array system. This experience will likely prove valuable as AMISR matures; a limited evaluation of AMISR at JRO is planned for 2004.

In education, JRO has had excellent impact at the postgraduate level, with many PhD dissertations emphasizing JRO data sets. Recent years reveal active participation by postdoctoral fellows from many institutions. Engineering topics, ionospheric physics, and plasma physics motivated by JRO have been added to a dozen undergraduate and graduate courses at Cornell. There has been active NSF REU activity at Cornell, too.

There is an active Peruvian trainee program, and excellent ties to two Peruvian universities (Universidad de Piura (UDEP) and Catholic University). JRO scientists have been very active in providing leadership and tutorials at three recent international radar schools.

There has been some general public outreach involving site visits (university students or Peruvian Navy personnel), but relatively little on site or off site outreach at the K-12 level. There are some natural obstacles to broader public outreach:

- A somewhat rugged final road approach and a guarded gate impede spontaneous visits by the public.
- There is really only one full time site scientist, Dr. Chau, whose administrative and scientific tasks claim much of his time.
- There are fundamental geographic barriers impeding visits by the K-12 audience in the US.

The growth of the internet partially addresses these issues by providing a WWW outlet for the curious. Present network speed to JRO leaves something to be desired; one presumes that this will improve.

Nearly 50 PhD dissertations have been produced in JRO's forty-year history; there are at least seven current graduate students using JRO data today, suggesting that 50 will be easily surpassed in short order. JRO users have developed undergraduate and graduate curriculum at several universities. Former JRO students have gone on to productive careers in industry, in academia, and now as directors of two major incoherent radar facilities (JRO and AO).

Geographic and other barriers impede large outreach activities. However, the Peruvian Trainee program is worth special mention, for bringing scientific career opportunities to Peruvian students.

6. Management and Budget

One enormous challenge to JRO has been achieving leadership transition to follow Farley and Woodman. In the space of a very few years, this enormous challenge has been very satisfyingly addressed through the identification of Hysell (at Cornell) and Chau (at JRO) as the new leadership. It is no exaggeration to suggest that many in the community have breathed a sigh of relief to have not one but two so obviously well qualified individuals take up the reins of their distinguished predecessors.

Ron Woodman remains explicitly involved with Jicamarca through his leadership role at the Peruvian Institute of Geophysics (IGP). The IGP is the management structure that implements the Cooperative Agreement with the NSF (the only facility not owned by the USA), and it is critical to have competent and knowledgeable representation there. Furthermore, Woodman has been extremely effective in working with the Peruvian government to assist JRO. Of recent note, Woodman's efforts led to the protection of the lower Jicamarca valley as a reserve, which will prohibit commercial and other development that would interfere with the Observatory's operations.

Another complication of the JRO management structure is the role played by Ciencia Internacional (CI). CI provides a means to attract and retain highly qualified staff at JRO through a salary structure that would not otherwise be possible. Although there are no immediate concerns, it is particularly important for NSF's officers and the occasional review panels to have a strong understanding of this arrangement; it is by no means as transparent as that to be found at other facilities. This arrangement requires attention; it does not require alarm.

Cornell's operations are made a bit more complicated by administration that spans two schools (Electrical and Computer Engineering (ECE) and Earth and Atmospheric Sciences (EAS)). The ECE Department has apparently decided not to recruit new faculty in the radar area to replace Prof. Farley. However they have been helpful in recruiting and arranging for the EAS appointment of Prof. Hysell. The administration at Cornell in collaboration with NSF may wish to explore the potential synergy that may be obtained through NAIC, which administers Arecibo. NAIC commands a significantly larger budget than JRO, and as such that leverage could potentially be useful for JRO in its interactions with Cornell and other agencies.

The panel noted that the Jicamarca facility has a staff of nearly 70, which is far larger than the staff at any other upper atmosphere facility. This number reflects staff associated with IGP as well as those funded by NSF (38). Additional staff is supported by various short-term projects and grants. Some of the staff support is for functions not found at other sites; for example, there is a kitchen staff at JRO, and staff for external grounds keeping. We have mentioned above a concern about the optimality of providing in-house PC board fabrication, which requires additional staff effort, but not supported by NSF. Of course, some of these functions are obscured by overhead charges for other sites. Nevertheless, the perceived size of the dedicated staff is large and can create problems for the Observatory when compared with other sites. When asked about this, JRO has responded that staff is needed whenever the ISR is operating – however this is true for all ISRs, all of which provide more ISR hours than JRO. Regarding their plans for the future, additional staff will be requested to operate the SOUSY radar.

It is possible that there is some confusion about the exact roles of the staff, and of those who are student trainees from UDEP or Catholic University. We realize that it may be very tempting to extend opportunities to Peruvian nationals. However, one can estimate that some of the test equipment desired by JRO could be paid for by controlling staff costs. In any event, it would be useful to perform a detailed accounting of the staff and their roles at JRO in order to determine if the balance of investment between human resources and capital equipment is optimal.

JRO's overall budget has historically been significantly smaller than at the other sites. It would be a mistake to compare the allocations directly in dollar terms without considering the context of the sites. Salaries are frequently one of the dominant aspects of budgets, and salary realities vary widely across the instruments. We note also that there is no optical complement at JRO, for the simple reason that local atmospheric conditions do not permit it. On the other hand, there is significant equatorial optics activity at other sites such as Arequipa and Huayncayo. As these are separately funded, they could be considered a kind of extension of JRO as a facility. JRO scientists have successfully attracted additional funding beyond the Cooperative Agreement, from NSF and NASA and other agencies. We do not wish to assert that JRO is either relatively underfunded, or appropriately funded. This issue should be considered in the context of the entire mission of the facilities, taken together.

7. Summary of Findings and Recommendations

JRO's scientists should be proud of their accomplishments. In recent years the science output has grown in quantity and quality, enabled by clever advances in radio technique also developed at JRO. JRO provides a truly unique laboratory for radar remote sensing technique; it is the only facility that permits and encourages substantial reconfiguration of nearly the entire RF system. The critical issue of leadership transition has been successfully achieved. Programs have been developed to introduce more US and Peruvian scientists and students to the Observatory and its capabilities. JRO has been very active on the world stage by sponsoring well attended workshops and in coordinating world-wide operation of incoherent scatter radars. The site has been appropriately maintained, with capacity added through the JULIA low power transmitter, a third main transmitter, and a rich array of subsidiary antennas useful for interferometer experiments. The JRO team has identified several means to expand the compatibilities of the system. There is potential for added capability through the acquisition and installation of the SOUSY 53 MHz system.

<u>Finding:</u> JRO offers a unique and potent platform for development of radio science techniques. JRO's scientists have proactively encouraged and supported many truly novel experiments.

- *The panel recommends maintenance of this radio science creativity for the benefit of the entire community.*

<u>Finding:</u> Manual reconfiguration of the main antenna clearly limits the capacity of the observatory. The costs in observation time and staff effort are significant.

- *The addition of electronic beam steering capacity for the main array should be a high priority for JRO.*

<u>Finding:</u> The final amplifiers and drivers of the main array transmitter are very near the end of their design life. A fourth main array transmitter can be constructed; a fourth new

transmitter would have more value as a spare/replacement than as an opportunity to increase the total power to 6 MW.

- *Immediate attention should be devoted to replacing the final amplifiers with new tubes. It may be appropriate to buy a new tube for the fourth transmitter, but it is less desirable to operate with all four transmitters than it is to preserve the operational capacity of two to three transmitters.*

Finding: SOUSY will provide opportunities for interesting new science but with a significant cost in new manpower and electricity requirement. Electronic beam steering will be needed for optimal use. Because SOUSY is fairly self-contained, it may be that a different agency may wish to offer support for it.

- *The panel recommends that supporting SOUSY should be a lesser priority within the limited funds that will be available to JRO through NSF.*

Finding: JRO's operations depend critically upon transporting staff, equipment, and visiting scientists in the vicinity of Lima. There is no public transportation available to the Observatory and many employees do not own cars. The current fleet of vehicles is wearing down, with failures likely to impede operations. While maintenance and replacement plans are in place, funding is often lacking.

- *An orderly program of maintenance and replacement of site vehicles is warranted and should be funded.*

Finding: Education and Outreach Programs offer a necessary service to the public as well as a tremendous opportunity to enhance the visibility and tangible awareness of JRO within the aeronomy community.

- *Education and Outreach Programs should proceed at no less then their current levels, or be expanded. Programs to proactively attract scientists and graduate student visitors to JRO are strongly encouraged.*

Finding: ISRs of the twenty-first century will depend critically upon robust software.

- *The panel recommends that JRO energetically continue to promote modern software design practices.*

Finding: Most ISR systems have unique complements of RF hardware. However, the growing use of digital systems and digital receivers provides an opportunity to leverage the experience gained at all ISRs. Commercial offerings may provide hardware that is not optimized for ISR work but which nevertheless exceeds present capabilities, while being relatively inexpensive, documented, and can be offered with warrantees.

- *JRO should proactively share design experience within the ISR and larger radar community. Efforts should be made to avoid the "not invented here" syndrome, without stifling creative thought.*

Appendix: Facility Review Criteria

The NSF strategic plan states that facilities should provide the physical and institutional capabilities necessary

- for scientists and engineers to carry out research which enables the United States to uphold world leadership across a broad spectrum of scientific and engineering fields;
- to promote the discovery and dissemination of new knowledge in service to society, as exemplified by fields such as material science, computer science, and engineering;
- for graduate and undergraduate science, mathematics, and engineering students to acquire skills to perform world class research.

Specific review criteria to be used in the evaluation of the upper atmospheric facilities include:

- Scientific research enabled by the facility: Has the facility contributed to the advancement of science? Has scientific research based on the data been performed by an appropriate blend of both facility staff and members of the larger scientific community? How unique is the data provided by the facility? Is the science performed at the facility of world-class quality and appropriately wide-ranging? Is the research performed consistent with the goals of the NSF UARS program? Are publications based on the data from the facility sufficiently numerous, considering the support provided by the NSF?
- User support: Is the facility responsive to requests from outside users? What outreach efforts are performed to encourage new researchers to use the facility or the data? Has the facility provided innovation, vision, and leadership to the scientific community in its area(s) of specialty? Has the facility established linkages to community-wide experimental programs and campaigns? Has the facility improved its procedures over time to keep in step with changing user demands? Has the facility staff made access for outside users a simple matter, or is the process sufficiently complex that it discourages outside participation?
- Educational activities: Does the facility contribute to the education of graduate students in aeronomy and atmospheric sciences? What steps are taken to educate students and other members of the scientific community on the use of the facility and the data? Are there regular efforts to inform interested scientists of the status of the facility and improvements in capabilities? Are efforts made to reach out to the general public and surrounding local communities, in order to build awareness of the broader impacts of science on society?
- Facility maintenance: Are facility operations reliable? Are there critical components that have jeopardized, or will soon jeopardize, the ability of the facility to function properly? Have all efforts been made, within budgetary constraints, to maintain the facility in optimum condition? Are facility repairs and upgrades completed in a timely fashion?

- Management: Has the facility been managed in an organized and efficient manner? Are there any weaknesses in the management structure that might threaten the ability of the facility to continue serving the scientific community? Is there good communication between the facility management and the staff? *[Note that the NSF Division of Astronomical Sciences has oversight of the Arecibo Observatory and conducts its own review of overall Arecibo management. The UAF panel will consider only that part of Arecibo management pertaining to atmospheric sciences and aeronomy.]*
- Budget: Is there a proper balance between the various budget elements, such as labor, materials, travel, etc.? Are the efforts of the facility staff to bring in additional financial support appropriate and effective? Are there currently unfunded high priority items that must now be funded? If so, what other expenditures might be eliminated to fund them?