Scientific Committee on Antarctic Research

Science and Implementation Plan for a SCAR Research Programme

ICESTAR: **I**nterhemispheric **C**onjugacy **E**ffects in **S**olar-**T**errestrial and **A**eronomy **R**esearch

Submitted by the Standing Scientific Group on Physical Sciences

Expected Programme duration: 2005 - 2009

Expected SCAR funding: US $75,000

Programme Summary

A major challenge facing environmental science and policy is understanding the interactions between, and collective behavior of, the many component parts of the Earth system, including the interaction between the natural environment and human society. This requires both the specification and prediction of the state of the system, involving the assimilation and integration of data from disparate sources (disparate instruments, sampling various locations, operated by different people and organizations). Near-Earth space (geospace) is an integral part of the Earth system, providing the material link between the Sun and Earth, primarily through the polar regions, and posing a potential hazard to space-borne and ground based technology on which Society is increasingly dependent. Understanding of the complex geospace environment has matured to the level of being able to describe many of its component parts and a major goal now is to seek a unified framework that can specify and predict its global state and, therefore, “space weather”. To enable this, this programme will establish a forum and working groups to provide a portal on the World Wide Web to all Antarctic geospace data and metadata, and tools for extracting and reducing these data into value-added products, similar to those available or being developed in other areas of SCAR science.

Antarctica offers a privileged position to remotely sense the vast region of geospace (extending over millions kilometers from the planet) because the Earth’s magnetic field focuses the effects of geospace into the polar regions and Antarctica has a land mass on which to base instruments at high latitudes, yet Antarctica has been under-exploited relative to the Arctic. **Recently there has been substantial investment by a number of countries in sophisticated instrumentation providing a grid of instruments over much of the Southern Polar Region. Further instruments are to be installed in the near future that will provide coverage equal to and in some cases better than that in the Northern Polar Region. There is now the capability to investigate conjugate relationships at an unprecedented level of detail.** ICESTAR is designed to exploit this and one of the main results of the programme will be the enhanced visibility, accessibility, and usability of the Antarctic geospace data to enable whole-system geospace research, including interhemispheric and ground-space studies, and new cross-disciplinary research such as teleconnections between the upper and lower levels of the atmosphere.

ICESTAR will have four working groups that will specifically focus on:

1. Quantifying and understanding the similarities and differences between the Northern and Southern polar upper atmospheres, under the varying influence of the solar electromagnetic radiation and of the solar wind.
2. Quantifying the effects on the polar ionosphere and atmosphere of the magnetospheric electromagnetic fields and plasma populations, from the radiation belts to the tail plasma.
3. Quantifying the atmospheric consequences of the global electric circuit and further understanding the electric circuit in the middle atmosphere as guided by the electric fields generated at the solar wind–magnetosphere interface.
4. Creating a data portal that will integrate all of the polar data sets and modeling results. This data portal will enable the research to be conducted by the other working groups.

We request funding to have yearly workshops which will focus on the implementation of the data portal and updating the community on research which has been conducted under this programme.

ICESTAR Programme Goals

ICESTAR is a new SCAR initiative striving for international coordination of interhemispheric research in the areas of solar-terrestrial physics and polar aeronomy, promoting exchange of research ideas, and sharing experimental data from various arrays of geophysical instrumentation deployed over the polar regions and in near-Earth space. The ICESTAR programme will specifically address several challenges articulated in the ***Decadal Research Strategy in Solar and Space Physics*** [*Lanzerotti et al.*, 2003].

Since the International Geophysical Year (IGY, 1957-1958), almost fifty years of observations in space and over high latitudes of the Arctic and Antarctic have provided a good picture of the solar wind's dominating role in driving magnetospheric dynamics and the overall electrodynamic coupling of the magnetosphere to the ionosphere. Nonetheless, important gaps remain in our understanding of the solar wind-magnetosphere-ionosphere interaction. We do not know enough about the changes and dynamics of the Earth's magnetosphere under extreme solar wind conditions, i.e., during strong geomagnetic storms. Much remains to be learned about how the solar forcing can affect the neutral atmosphere, especially at high latitudes where the solar wind-driven processes are most influential. Possible influences of the changing Sun (i.e., its irradiance and magnetic moment) and geospace environment on polar climate and weather are also poorly understood.

However, recently there has been substantial investment by a number of countries in sophisticated instrumentation providing a grid of instruments over much of the Southern Polar Region. Further instruments are to be installed in the near future that will provide coverage equal to and in some cases better than that in the Northern Polar Region. There is now the capability to investigate conjugate relationships at an unprecedented level of detail.

The Initial Outline Science Plan for the International Polar Year 2007–2008, issued by the ICSU's IPY Planning Group in April 2004 (http://www.ipy.org), proposes five main science themes to address. Although the IPY main focus will be to determine the present environmental status of the polar regions and their connections to the potential global climate changes, the fifth theme calls "To use the unique vantage point of the polar regions to develop and enhance observatories studying the Earth's inner core, the Earth's magnetic field, geospace, the Sun and beyond". Thus, this theme is a major thrust of the proposed ICESTAR Scientific Research Programme.

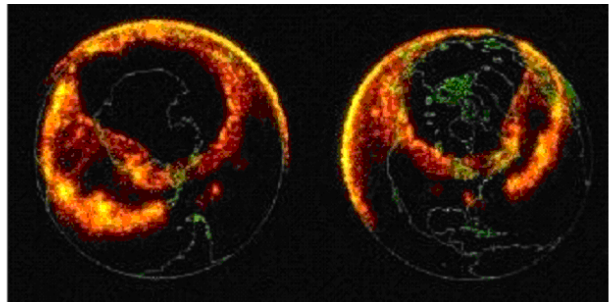

Figure 1: Satellite images of the Southern and Northern auroral ovals during a magnetic storm.

The ICESTAR Programme scientific goals are:

- To identify and quantify various mechanisms that control interhemispheric regional differences and commonalities in the electrodynamics and plasmadynamics of the Earth's magnetosphere-ionosphere coupling system, and in aeronomy of the upper atmosphere over the Arctic and Antarctic.
- To develop a "virtual" data portal that will link together a large number of globally distributed geophysical databases, including both data serving applications and visualization tools; this will enable a systems view of the polar upper atmosphere and geospace.

The polar ionosphere is often compared to a television screen displaying intimate processes of the solar wind - magnetosphere interaction (Figure 1). We need deep understanding of various mechanisms responsible for energy transfer from the solar wind into geospace environment; this is impossible without simultaneous consideration of various geophysical phenomena occurring over both the Northern and Southern polar regions. The long acting solar forcing and short-term solar variability (activity) could also be significant in its influence on the polar terrestrial climate and weather.

Thus, our focus and approach to interhemispheric research are important because: (a) Earth's dipole tilts and, therefore, causes seasonal variations and north-south asymmetries that are not yet accurately understood to be included into various geospace models. Initial conjugate observations of auroras indicate that these models are inaccurate, so we do not yet understand well enough topology of the Earth's magnetospheric field; (b) We need to understand the total energy input into the upper atmosphere from the solar wind–magnetosphere coupling. Most of the geospace models are developed only from northern hemisphere observations, assuming symmetrical response of both the northern and southern polar regions to magnetopsheric disturbances; (c) Polar climate effects could be different because of different circulation patterns in the two hemispheres.

Scientific Background

The near-Earth space environment commences at the top of the troposphere and continues out to the interface between the Earth's atmosphere and the Sun's atmosphere. In this region of space, temperatures range from 150 K up to over 1,000,000 K, flow speeds range from a few m/s to hundreds of km/s, and densities range from 10^{23} particles to 10^{-6} particles per cubic meter. In addition, above 600 km altitude, the ionospheric plasma becomes the dominant component of the atmosphere. This plasma is strongly tied to the magnetic field. Therefore, the proposed research programme will focus on some aspects of the atmospheric, ionospheric, and magnetospheric dynamics, specifically selected because of the possibility to maximize the Antarctic resources in their interhemispheric context.

Magnetospheric Dynamics

At the altitudes higher than approximately 100 km, the region of space that contains charged particles (i.e., the ionosphere) becomes quite important. The ionospheric plasma is intimately linked to the Earth's magnetic field, so one must also consider this. The Earth's magnetic field would extend to infinity if no other planet or star existed, but that is not the case - it encounters the Sun's atmosphere. The Sun's atmosphere is extremely hot and therefore expands radially outward at supersonic speeds. In addition, the atmosphere becomes charged, so it is intrinsically tied to solar magnetic field lines. When the solar wind (i.e., the Sun's atmosphere near the Earth) encounters the Earth's magnetic field, it is diverted around the boundary, like a stream flowing around a rock. The cavity that is carved out is called the magnetosphere, and is dominated by the Earth's magnetic field as illustrated in Figure 2.

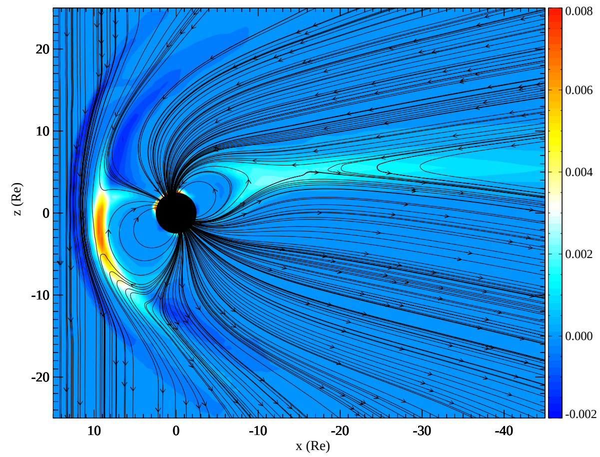

Figure 2: Traces of the magnetic field in the noon-midnight plane, over the magnetopause currents plotted in units of $\mu A/m^2$. The Sun is off to the left, so the solar wind is streaming in from the left. Where the magnetic field lines start to bend in a semi-circle on the left is the bow shock. This figure illustrates a Northern summer solstice condition in at 16:45 UT, in which the Northern hemisphere magnetic pole is pointed towards the Sun.

We want to know the similarities and differences between the Northern and Southern polar upper atmospheres simply to fully understand how the entire planet responds to the varying influence of the solar electromagnetic radiation and of the solar wind. Most of the known geospace phenomena (including magnetic storms and substorms) develop in concert over both the Arctic and Antarctic (Figure 1). High latitude geomagnetic field lines carry a load of field-aligned currents and electromagnetic waves from the magnetopause down to the ionosphere and atmosphere. During equinox, that load is about symmetric over both polar regions, but it becomes quite asymmetric when either of the poles is tilted toward the Sun. In the latter case, the solar UV radiation becomes a controlling factor for the ambient ionospheric conductivity at high latitudes and this causes a great deal of asymmetry in the interhemispheric distribution of various ionospheric electrodynamic parameters, aurora *borealis* and *australis*, and even in influencing polar weather through the heating of the upper atmosphere by the aurora and friction between the ions and neutrals. The difference in the internal geomagnetic field strength over the Northern and Southern polar regions may cause fundamental differences in the energy deposition and create longitudinal asymmetry, for example, because of the South Atlantic magnetic anomaly.

The dynamic state of the inner magnetosphere is highly dependent on geomagnetic conditions. Magnetic storms are the most geodynamic phenomena occurring from the interaction of the solar wind with our magnetosphere. During the main phase of a magnetic storm the plasmasphere gets significantly depleted [*Degenhardt et al.*, 1977]. Then during and long after the recovery phase of the storm the plasmasphere slowly fills up again with new material, the main source region being upflowing ions from the ionosphere. However, it is still not clear how the energy from the solar wind during storm conditions penetrates deep to the inner plasmasphere and couples to the low-altitude atmosphere.

Furthermore, continuous observations of the depletion and refilling of the plasmasphere are necessary inputs to models that track the development of the ring current during storms. Such questions can be investigated by remotely monitoring the density of the inner magnetosphere through the observation of field-line resonant pulsations at geomagnetic latitudes ranging from 20° to 60°. Due to the fact that sufficient *in situ* measurements are not available from the inner magnetosphere, it has become essential to develop good techniques of remotely and accurately monitoring it from the ground.

Very low frequency (VLF) whistler waves and ultra low frequency (ULF) waves have been used to remotely monitor the inner magnetosphere. The whistler dispersed frequency signature observed on the ground can be used to determine whistler wave's path and the equatorial density of the magnetic fluxtube (e.g., *Helliwell* [1965]). This method is accurate but not continuous because whistlers are not always present. They are excited by lightning in the lower atmosphere and they depend on the existence of an appropriate conducting material at those altitudes to keep the whistler field-aligned.

More recently techniques for determining the local field-line resonances have been used to successfully monitor the inner magnetosphere density variations. Once the local resonant frequency is known, the plasma mass density can be inferred if appropriate models of the magnetic field and the plasma density are assumed. According to *Schulz* [1996], the mass density at the equator can be inferred assuming that the observed pulsations represent oscillations of the field line at the fundamental, second, and third harmonic frequencies, and that the density falls off as $1/r^4$ with radial distance.

The Antarctica Peninsula has the great advantage of covering low and mid magnetic latitudes, i.e., inner magnetosphere and plasmasphere, at a magnetic longitude that is reasonably well covered at all latitudes. The recent installation of SAMBA magnetometers on the Peninsula offers the opportunity of remotely monitoring the mass density of the inner magnetosphere. Most importantly, the SAMBA magnetometers are conjugate to the MEASURE chain magnetometers in North America, so determinations of the inner magnetospheric mass density can be done conjugately. Initial results indicate that such conjugate calculations will help restrain the models for inner magnetospheric density calculations.

Finally, the existence of the VLF antennas at Palmer and Vernadsky with SAMBA magnetometers being installed there offers a unique opportunity for the remote study of the inner magnetosphere. VLF whistler waves can determine the number density of the fluxtube, while ULF waves observed from magnetometers can determine the mass density of the same fluxtube so that estimates of the composition changes in the inner magnetosphere can be made.

Ionospheric Dynamics

Here we address the effects of the magnetospheric electromagnetic fields and plasma populations on the polar ionosphere and atmosphere. Sometimes the Sun bursts forth a significant amount of coronal plasma and then a huge magnetic cloud

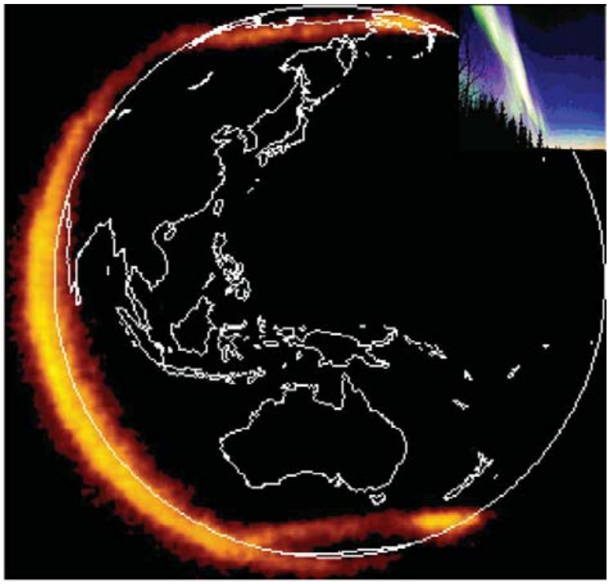

Figure 3: A global auroral substorm as observed by NASA's POLAR spacecraft and from the ground.

(many times larger than the Earth's magnetosphere) begins to propagate through interplanetary space. If this cloud hits the magnetosphere, it causes strong space storms. At times, the power transferred from the solar wind increases nearly two orders of magnitude, disturbing the entire magnetosphere, and disrupting satellite operations and communications. Due to that interaction, magnetospheric plasma particles energize and precipitate into the polar ionosphere causing magnificent aurora that illuminates the northern and southern polar skies (Figure 3). This precipitation, and the associated currents, can cause significant heating of the polar upper atmosphere.

The heating of both polar atmospheres from the above could be quite asymmetric. This is because of the seasonal dependencies on the solar heating and the inherent asymmetry of the Earth's magnetic field. The geomagnetic asymmetry further introduces asymmetry in the distribution of aeronomical characteristics of the polar thermosphere and atmosphere. For example, asymmetry in the energy deposition from the magnetosphere into both polar ionospheres may cause different planetary gravity wave activity that may affect the strength of terrestrial weather fronts in both polar regions.

Atmospheric Dynamics

In this section, we address atmospheric consequences of the global electric circuit and further understanding of the middle atmosphere as guided by the electric fields generated at the solar wind–magnetosphere interface.

The lower atmosphere is mainly driven by solar radiation inputs. The radiation is absorbed by water vapor in the troposphere and ozone in the stratosphere giving rise to a periodic heating of the atmosphere. This heating generates waves, called atmospheric tides, that propagate vertically transporting heat and momentum from the troposphere and stratosphere into the mesosphere and thermosphere. These waves are ubiquitous and globally coherent.

To quantify the effect of waves, such as atmospheric tides and gravity waves, on the geospace environment, distributed measurements of the neutral atmosphere fields of wind and temperature are required. Over the past decade a network of radar and optical systems have been deployed across Antarctica with the capability of measuring such parameters. This has been an international effort with instrumentation installed at Halley, Rothera, Syowa, Davis, Scott Base, McMurdo, and South Pole. To facilitate international cooperation and enhance scientific collaboration, the group of scientists responsible for this instrumentation have developed a memorandum of understanding. Similar efforts are taking place in the Arctic with a significant increase in the number of radar and optical systems over the past ten years. An Arctic chain of instrumentation now exists that includes Alaska, Canada, Greenland, and Russia, with collaborators from Japan, Germany, Australia, and the United Kingdom in addition to scientists from the host countries.

Because the polar regions are free as possible from thunderstorms, they are the best place anywhere in the world to investigate the "fair weather" art of the global atmospheric electric circuit. Regarding the DC circuit, the polar regions are excellent for studying three directly related quantities – vertical atmospheric electric current densities, variations of the ionospheric potential difference across the polar cap associated with the solar wind interaction with the magnetosphere, and variations of atmospheric conductivity associated with geomag-

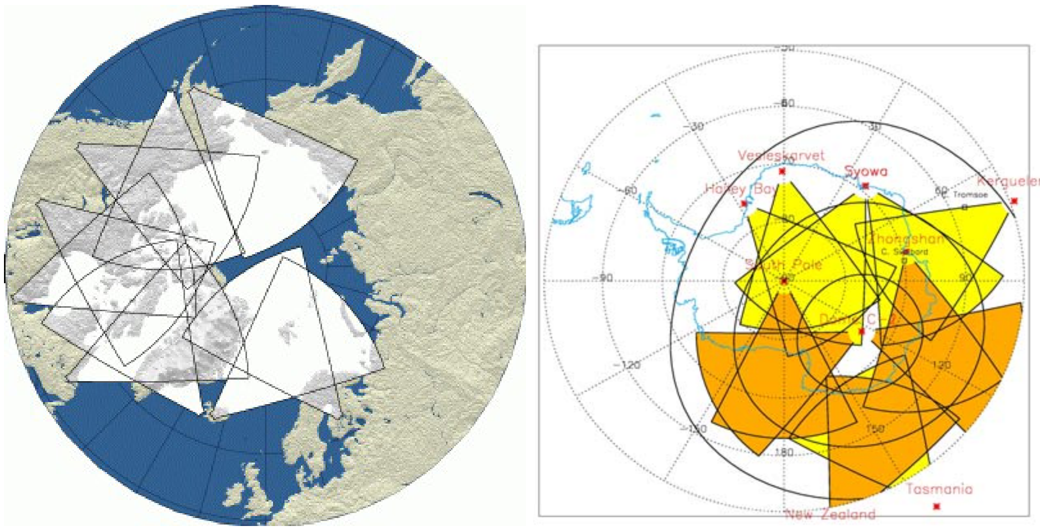

Figure 4: Maps of the Super Dual Auroral Radar Network (SuperDARN) arrays over the Northern (left) and Southern (right) polar regions. The Antarctic map shows fields-of-view for existing and planned radars, which will provide complete coverage of the southern polar region above 60° geomagnetic latitude.

netic activity and/or Forbush decreases of the fluxes of incoming cosmic rays. Studies of Schumann resonances of the Earth-ionosphere waveguide excited by lightnings around the World are invaluable for the AC global circuit.

Data Availability

An excellent example of the interhemispheric coordination is the Super Dual Auroral Radar Network (SuperDARN), which currently offers almost complete coverage of the northern polar region by the high frequency radars“fields-of-view”. By tracking the ionospheric irregularities, the SuperDARN radars actually monitor the global ionopheric convection (electric field) pattern (Figure 4). Unfortunately, the northern SuperDARN is incomplete missing a pair of radars in the Russian Arctic. At the same time, SuperDARN operates four radars in the Antarctic, and in 2-3 years, the Antarctic Plateau will be completely covered by the radars proposed for the construction at the southern tip of New Zealand, Chinese Antarctic station Zhongshan, and at the U.S. and European Antarctic bases South Pole and Concordia. This will make the radar coverage superior in the southern polar region. The SuperDARN data are easily available via the Web site http://superdarn.jhuapl.edu.

Recent development in populating the Antarctic Plateau with many autonomous stations places the Antarctic solar-terrestrial and aeronomy research into a lead position for the implementing the ICESTAR Programme. As shown in Figure 5, the center of Antarctic Plateau is now well covered with a network of autonomous low-powered magnetometers and a number of automatic geophysical observatories. The U.S. Amundsen-Scott South Pole Station is a critical component of this entire network: it is a very well equipped geophysical observatory located at the boundary between the southern auroral oval and polar cap. At the same time, this is a base from where many autonomous sites are easily accessible via air transport.

Another critical component of the Antarctic geospace array is the French-Italian base Concordia, located in vicinity of the southern geomagnetic pole. The station will be opened for year-around observations in 2005, and there are ambitious plans under development to turn this site into a well-equipped geophysical observatory as well.

The Russian Antarctic base Vostok may also play a significant role in the overall operation of the Eastern Antarctic array of autonomous stations, as well as other coastal bases oper-

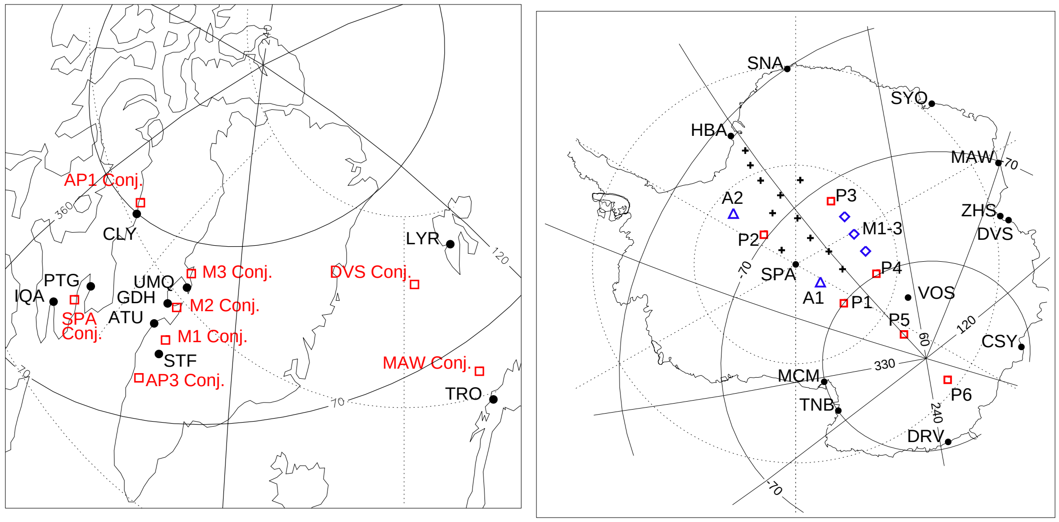

Figure 5: Arctic and Antarctic maps with geographic (geomagnetic) coordinates given by the dotted (solid) lines. Manned stations are shown by a three-letter international station name code. U.S. AGO/PENGUIn sites are shown by P#. Recently deployed British low-power magnetometers are shown by crosses. Proposed U.S. autonomous ow-power magnetometer (M1, M2, M3) sites are shown as blue diamonds and two proposed multi-instrument ARRO sites are marked as A1 and A2. Conjugate locations of selected Antarctic sites are also depicted over the Arctic map.

ated by SCAR member countries. Thus, three inland manned stations, more than a dozen of autonomous sites and another two dozens (including stations at the Antarctic Peninsula) of coastal bases make the "backbone" and "flesh" of the Antarctic Geospace Array, comparable (by its potential and resolution) to various geophysical networks deployed over Alaska, Greenland, Canada, and Scandinavia (Figure 5), such as MIRACLE (http://www.geo.fmi.fi/miracle/), CANOPUS (http://www.sp-agency.ca/www/), and CGSM (http://www.phys.ucalgary.ca/norstar/cgsm.html). INTERMAGNET (http://www.intermagnet.org) and WDC System (http://www.wdc.rl.ac.uk/wdcmain/) offer additional invaluable resources.

At last, studying the magnetosphere-ionosphere coupling, we need to collaborate with various satellite projects, for example, using the ISTP (http://www-istp.gsfc.nasa.gov/istp/), CDAWeb (http://cdaweb.gsfc.nasa.gov), and OMNIWeb (http://cdaweb.gsfc.nasa.gov) resources for comparisons of the ground-based and satellite observations.

One of the fundamental limitations to geospace research at present is the need to identify and visit many of distributed Web sites to get the datasets required to address the increasingly interdisciplinary scientific problems. As a result, a fundamental tenet of this proposal is to establish a single "point-of-contact": a data portal providing a distributed access to all high-latitude geospace data. This would be a very significant contribution to research, that could be badged as a SCAR contribution. It is timely because the emergent GRID technology has now reached a level of maturity where this is possible, and it would be open to all nations because the Internet is now essentially available to all scientists.

Baker et al. [2004] have embarked on a concept of the *electronic Geophysical Year* (eGY, http://www.egy.org), which calls for deployment of *virtual observatories* in cyberspace as a natural extension of the worldwide network of physical observatories. ICESTAR will work together with the SCAR/COMNAP Joint Committee on Antarctic Data Management (JCADM; http://www.jcadm.scar.org) implementing the proposed approach.

Programme Rationale

The ICESTAR Programme will create an integrated, quantitative description of the upper atmosphere over Antarctica, and its coupling to the global atmosphere and the geospace environment. The reasons to embark on the endeavor now are:

The Emergence of New Datasets. The volume of experimental data have been increasing significantly in recent years. In addition, many new datasets are expected to come on-line in the near future. At this time, there are new magnetometer chains, new polar orbiting satellites which allow the simultaneous view of the Southern and Northern polar regions, new ionospheric (SuperDARN, AMISR, and EISCAT) radars, new mesospheric/thermospheric wind measurements (meteor radars, FPIs), new digisonde and TEC data. It is the right time to begin to create tools to examine the entire system as a whole utilizing all of the existing geospace data and preparing for the creation of many new datasets.

Emergence of Grid technology. The "Grid" is just starting to be defined, and has yet to find a real niche. The seamless sharing of data is one possibility, and is one of the main goals of the ICESTAR programme. The creation of visualization tools that can utilize globally distributed data sets will push the limits of the current technologies and will spark the creation of new Grid functions. In addition, enabling the convergence of data and models is another strong goal of the Grid technology, which is synergistic with the Programme goals.

Enable Easy Access to Distributed Data. Many research groups are creating data assimilation tools which require the use of as many data sources as possible. The creation of the ICESTAR data portal and use of the Antarctic Data Master Directory will enable these developments to grow significantly.

Uniqueness of Antarctica. The Antarctic continent offers a unique vantage point for examining the near-Earth space environment, spanning from the top of the troposphere, through the stratosphere, mesosphere, thermosphere and ionosphere, and into the magnetosphere. Here we underscore some of the similarities and differences between the Arctic and Antarctic: (a) very different underlying neutral atmosphere, e.g., planetary waves and gravity waves morphology is very different, and more intense jet stream exists in the Antarctic; (b) much larger displacement of the magnetic dip pole in the South than in the North (24° as opposed to 11°), which means it is much easier to separate effects that are controlled by solar radiation, i.e., ionospheric conductivity, from those caused by interactions of the solar wind; and (c) the geomagnetic field is weakest in the South Atlantic sector, thus the flux of energetic particles is higher than anywhere else allowing to studying the atmospheric consequences of energetic particle precipitation. In addition, the Antarctic Peninsula allows to sample geomagnetically both the high and middle latitudes.

Focused Science. The ICESTAR programme is intended to both enable and to conduct focused scientific research on the upper atmosphere above the Antarctic and how that region of space ties in with the global system. No other programme exists which is focused specifically on the quantitative understanding of the upper atmosphere above the Antarctic continent.

Tying Together the International Community. Studies of the polar upper atmosphere fundamentally require international collaboration. First consider the deployment of instruments across Antarctica. These instruments are either located at manned bases or are remotely deployed and serviced from such bases. From a logistical and financial standpoint it is unfeasible to deploy a network of instrumentation in Antarctica without international collaboration. The problem is even more complex in the Arctic as individual countries there have control over portions of the region. With instruments being deployed and operated by different countries, international collaboration is essential so that data can be exchanged and integrated. Upper atmosphere scientists working with such data typically interact in a collaborative manner in an effort to solve open overarching science questions.

Summary of Science Objectives

The following key questions of the solar-terrestrial physics and polar aeronomy provide a very sound scientific background for the ICESTAR Scientific Research Programme:

- How Earth's magnetosphere differ qualitatively and quantitatively under extreme, moderate, and quiet solar wind conditions?
- What is common and what is different in the solar-terrestrial and aeronomical phenomena observed over both the Arctic and Antarctic.
- Does the auroral activity during substorms arise from instabilities in the ionosphere or does this aurora simply mirror plasma motions in the outer magnetosphere? How much do the dark and sunlit ionospheres control the polar substorm dynamics?
- To what extent are the ionized and neutral high-latitude upper atmospheric regions affected by mechanical and electrodynamic inputs from the lower atmosphere?
- How does the global electric circuit effect the ionosphere state? How this circuit is closed between the low and high latitudes?

Thus, it is important and timely to act now to study the polar regions in their interhemispheric context from observations in space and over the Arctic and Antarctic.

International Scope

As a well-developed international scientific association, SCAR can naturally lead scientific programmes on interhemispheric research in various disciplines. Unlike the southern polar region where the Antarctic Treaty system governs international science activities, the Arctic constitutes a multinational environment where effective coordination of scientific activities and observational programmes is a challenging task. At the same time, it is obvious that the joint, interhemispheric observational potential is very powerful allowing scientists to study largely (simultaneously and globally) various interhemispheric effects in high-latitude magnetospheric and ionospheric processes and their consequences on upper atmospheric and aeronomical phenomena.

Although a significant body of international research exists in the described fields of solar-terrestrial physics and polar aeronomy, ICESTAR will require extended international activities in collecting and coordinating corresponding datasets, models, and research efforts. The interest to ICESTAR has already been shown by a number of SCAR member countries such as Australia, Finland, France, Japan, Italy, P.R. China, Russia, Ukraine, United Kingdom, and the United States of America; other countries are welcome to join. Some of the SCAR member countries are active in the Arctic as well, and with their Arctic neighbors (e.g., Canada, Denmark, Norway, Sweden, Iceland) may participate in the ICESTAR programme studying interhemispheric aspects of the global magnetosphere-ionosphere coupling. Coordination and collaboration with international scientific organizations such as SCOSTEP (Scientific Committee on Solar-Terrestrial Physics) will also be fostered. Their program on Climate and Weather of the Sun-Earth System is of particular interest, and linkages between the upper and lower atmospheres can further be explored via ICESTSAR and the AGCS programmes.

Methodology and Implementation

To accomplish the program's ambitious research goals, we will:

- Create the ICESTAR data portal to facilitate the sharing and interpretation of global geospace datasets. This data portal will be linked to the Antarctic databases, which already ties together many data sets. The data portal will encourage the collaboration of researchers by sharing data and the interpretation of the results.
- Although many data sets are global in nature, they are run by many different institutions and countries. This creates a road-block in the creation of a systems view of the geospace region. The creation of the data portal will break these barriers by allowing transparent and seamless integration of globally distributed similar datasets into a systems view. This will be true of magnetometer networks, image networks, and global radar networks.

- The ICESTAR programme will identify gaps in observation networks and instrumentation and will encourage individuals or groups of researchers to propose to the relevant funding agencies in an effort to acquire more funds to deploy key instrumentation thus allowing a complete understanding of the polar upper atmospheric system.

- The ICESTAR programme will coordinate joint studies on the scientific topics discussed in the preceding sections. In addition, it will hold annual workshops that will bring the community together to discuss these topics, focusing the community towards the programme goals.

- The ICESTAR will have three scientific working groups focused on the following areas:

  1. Quantifying the dynamics of the inner magnetospheric particles and fields and the consequences of those dynamics on the polar atmosphere.
  2. Quantifying the atmospheric consequences of the global electric circuit and further understanding the electric circuit in the middle atmosphere.
  3. Quantifying the general state of the Southern polar region upper atmosphere, ionosphere, and magnetosphere, and its similarities and differences with the Northern polar region. Because this focus area is so large, the working group will be lead by two co-chairs.

- The ICESTAR programme will have a Working Group dedicated to the creation and implementation of the data portal. This working group will have a chair and representatives from each of the other working groups to make sure that the portal is enabling research in each of the focus areas.

Program Management

The implementation of a programme of the proposed scale will require careful management and coordination internationally, as well as nationally. The overall management of the programme will be responsibility of the ICESTAR Steering Committee (8-10 members) led by two Co-Chairs and guided by the SSG/PS leadership *ex officio*. The SC will meet every year to determine the programme progress and outline the venues for international collaboration. ICESTAR will hold dedicated scientific workshops either separately or in conjunction with the biennial SCAR Science Meetings.

The above-listed objectives will be the focus of four **T**hematic **A**ction **G**roups (**TAG**s) established to coordinate activities:

TAG-A: Quantification of the coupling between the polar ionosphere and neutral atmosphere from the "bottom-to-top" and the global electric circuit.

TAG-B: Quantification of the inner magnetospheric dynamics using remote sensing techniques.

TAG-C: Quantification of the state of the upper atmosphere, ionosphere, and magnetosphere over the Antarctic continent and how it differs from the Northern hemisphere during a wide range of geophysical conditions.

TAG-D: Creation and management of the data portal to enable the ICESTAR programme and SCAR's SSG/PS.

Each TAG will establish and maintain liaison with the National Antarctic Programs through SCAR and its relevant scientific groups and committees: ADD (Antarctic Digital Database), MAGMAP (Magnetic Anomaly Map), and READER (Reference Antarctic Data for Environmental Research). The programme goals and objectives will be detailed together with the SSG/PS Expert Group on Solar-Terrestrial Processes and Space weather (STEPS) and the relevant Action Groups APTIC (Antarctic Peninsula Troposphere-Ionosphere Coupling) and MADREP (Middle Atmospheric Dynamics and Relativistic Electron Precipitation).

Similar collaboration will be established with relevant projects of the International Arctic Science Committee (IASC; http://www.iasc.no).

The ICESTAR activities will also be coordinated with the Working Group on Polar Research of the International Association of Geomagnetism and Aeronomy (IAGA) and with the new international programme sponsored by SCOSTEP: Climate and Weather in the Sun-Earth System (CAWSES).

Finally, the proposed period for ICESTAR (2005–2009) overlaps the planned research activities in the framework of fourth International Polar Year (IPY, 2007-2008), which could make the programme one of the IPY's cornerstones.

Deliverables

The ICESTAR programme will deliver a wide variety of products ranging from a better scientific understanding of the polar atmosphere to a data portal that will enable scientists to create a systems-view of the polar region. Specifically, the ICESTAR programme will focus on delivering:

I. A data portal linking together a large number of polar sites with diverse datasets. This data portal will have visualization and data translation modules that will allow users to examine the data and download it in formats that they can easily understand. The following data types will be provided to the portal by the associated groups: magnetometers, HF and MST radars, lidars, passive optical instrumentation, digisondes, riometers, VLF/ULF receivers, TEC measurements, and atmospheric electric field observations.

II. Quantification of the role of seasonal differences in polar ionospheric conductance and the effects on magnetospheric, ionospheric, and thermospheric dynamics.

III. Constraints on models based on conjugate remote sensing of inner magnetospheric dynamics.

IV. Characterization of the spatial and temporal properties of mesoscale convection in the ionosphere.

V. Characterization of the basic state of the polar middle atmosphere.

VI. Quantification of the AC and DC global atmospheric circuit and its effects on the ionospheric state.

Milestones

In order to achieve these ambitious goal, specific tasks have been identified:

1. Creation of the data portal (**2005–2007**):

a. Identify all available geospace data sets to address the programme's scientific objectives and define architecture of the portal.
b. Evaluate existing software that would be used for a portal.
c. Identify nodes and implement data portal.
d. Modify data portal according to community feedback received through workshop forum.

2. Identify and implement the necessary tools to analyze the data collected in the portal.

3. Identify the lack of instrumentation necessary to address scientific objectives and make recommendations to the community to fill the gaps.

4. Utilize the data portal tools to conduct scientific research and complete the list of deliverables.

5. Hold scientific workshops to verify that all participants are working towards to deliverables, access the state of the programme, and determine what needs to be modified to reach the goals of the programme.

6. Apply numerical models based on understanding gained by the previous milestones to provide an integrated, quantitative description of the upper atmosphere, ionosphere, and magnetosphere over Antarctica.

The ICESTAR programme will deliver a variety of products ranging from scientific papers in peer-reviewed journals, presentations at international conferences, reports to SCAR, and most important – better understanding of interrelations between two polar regions through global empirical models of magnetosphere-ionosphere coupling.

One key product will be a data portal - a Web-based system of interfaces allowing scientists and the public to access various geospace datasets collected under the ICESTAR programme. This system will also provide access to a number of global models characterizing polar electrodynamics and plasmadynamics.

The proposed period for the ICESTAR programme is initially set for five years with possible extension for another five years. The proposed start date is January 1, 2005, pending approval by the XXVIII SCAR Delegates:

2005–2006: Start of ICESTAR Programme – Collect information and coordinate observations at the existing instrumental arrays in the Arctic and Antarctic aiming specifically at interhemispheric studies, including global development of the magnetic storms and substorms over the polar regions. Promote the deployment of new instruments where current gaps exist.

2007–2008: Main Phase (coincides with IPY) – Develop time-dependent geospace models controlled by external (i.e., solar wind) drivers; couple these models with the potential input from atmospheric processes including the global electric circuit and thunderstorms.

2009–future: Closure or Renewal Phase – Consider termination or extension of the ICESTAR programme based on its progress and accomplishments.

Success Factors

The ICESTAR Programme success can be measured against above-mentioned deliverables and periodic scientific reports at the ICESTAR Workshops and SCAR Science Meetings. The ICESTAR Steering Committee will also monitor the number of scientific papers published in refereed journals and elsewhere.

Surely, a key success measure will be the usage of the ICESTAR data portal - if this is extensively used by all upper atmospheric scientists then it would be a great success.

References

Baker, D. N., C. Barton, A. S. Rodger, B. Fraser, B. Thompson, and V. Papitashvili, Moving beyond the IGY: The Electronic Geophysical Year (eGY) concept, *EOS, Trans., American Geophysical Union, 85*, No. 11, pp. 105-109, 16 March 2004.

Degenhardt, W., G. K. Hartmann, and R. Leitinger, Effects of a magnetic storm on the plasmaspheric electron content, *J. Atmos. Terr. Phys., 39*, 1435-1440, 1977.

Helliwell, R., *Whistlers and Related Phenomena*, Stanford University Press, Stanford, Calif., 1965.

Lanzerotti, L. J., et al., *The Sun to the Earth and Beyond: A Decadal Research Strategy in Solar and Space Physics*, NRC Report, The National Academies Press, Washington, D.C., 2003.

Schulz, M., Eigenfrequencies of geomagnetic field lines and implications for plasma-density modeling, *J. Geophys. Res., 101*, 17385-17397, 1996.

Wright, J. M., et al., *National Space Weather Program: The Strategic Plan*, FCM-P30,1995, Off. Fed. Coord. Meteorol. Serv. Supp. Res., Washington, D.C., 1995.

Supporting information

ICESTAR Steering Committee

The proposed ICESTAR Steering Committee consists of two Co-Chairs, five leaders of the Thematic Action Groups, 2-3 prominent Antarctic lead investigators, and an *ex officio* member of the SSG/PS leadership. The SC members will be rotated every other year.

- **Chairman, Allan Weatherwax (U.S.A.)** received a PhD in physics from Dartmouth in 1995 and subsequently joined the University of Maryland as a postdoc. He studied auroral radio emissions, radiowave propagation, and wave-particle interactions. In 1998, he was promoted a Research Scientist at Maryland and was part of the U.S. AGO/PENGUIn program. He is currently an Associate Professor of Physics at Siena College, NY. Dr. Weatherwax is an expert in the analog/digital equipment design and has extensive Arctic and Antarctic field experiences. Since 1999, he chairs the IAGA WG on Polar Research.
- **Co-Chairwoman, Kirsti Kauristie (Finland)** received a PhD in 1997. She studied the morphology and dynamics of auroras and auroral electrojets, working at the Finnish Meteorological Institute since 1988. During 1999-2003, she served as the PI of the international MIRACLE network of ground-based auroral instruments operating in the Fennoscandian sector; now she is a member of the MIRACLE Scientific Coordination Team. Within the ESA's Space Weather Pilot Project (2003-2005), she worked on the development of a real time auroral monitoring system. In basic research her interests are focused on the studies of mesoscale ionospheric electrodynamics.
- **TAG A Leader, Martin Fullekrug (U.K.)** received a PhD from Goettingen University in 1994 and then spent three years in STARLab at Stanford University. In 1997, he became a Research Fellow in Frankfurt University, where he studied electrodynamics of lightning, sprites, and ionospheric phenomena in the context of the global atmospheric electric circuit, receiving the Habilitation in 2001. Max-Planck Society awarded him a fellowship to join Tel Aviv University; ever since, he lectured in the Tel Aviv and Frankfurt Universities. In 2004, he joined the faculty of University of Bath.

- **TAG B Leader, Eftyhia Zesta (U.S.A.)** received a PhD from Boston University in 1997. She built and integrated experimental systems for the Magnetometer Array for Cusp and Cleft Studies (MACCS) deployed in the Canadian Arctic. Studying transient ionospheric currents in polar latitudes, she won three AGU awards for best student presentations and a NRC postdoc position at the NOAA Space Environment Center. In 1998, she moved to UCLA, where she works ever since as an Associate Researcher. She is a PI of the SAMBA magnetometer chain deployed along Chile and in Antarctic Peninsula.
- **TAG C Co-Leader, Nikolai Østgaard (Norway)** received a PhD from University of Bergen in 1999. As a postdoc at University of Oslo and NASA/GSFC, he lead the *in situ* calibration of the PIXIE instrument at POLAR spacecraft and studied precipitating electron energy distributions deducted from X-ray imaging. In 2001, he joined University of California-Berkeley as an Assistant Research Physicist and worked on the geocoronal imaging and FUV data form IMAGE spacecraft to study conjugate auroral phenomena. Since 2004, he is an Associate Professor at University of Bergen.
- **TAG C Co-Leader, Scott Palo (U.S.A.)** received a Ph.D. from Univ. of Colorado in 1994. His thesis focused on radar observations and modeling of global scale atmospheric perturbations. As a postdoc at NCAR, he worked on satellite data analysis and understanding the neutral atmosphere using a global circulation model. In 1997, he returned to Univ. of Colorado as a Research Associate; promoted to an Assistant Professor in 2001. He is an expert in the middle atmosphere, designing and deploying meteor radar systems in the Arctic and Antarctic.
- **TAG D Leader, Aaron Ridley (U.S.A.)** received a PhD from University of Michigan in 1997. During graduate school, he won a fellowship through NCAR/HAO, where he used an ionospheric data assimilation technique and manipulated large, globally distributed datasets. As a postdoc at Southwest Research Institute, he created a real-time ionospheric specification technique and conducted research on the thermosphere and ionosphere. In 2000, Dr. Ridley returned to the University of Michigan, where he works with a global model of the magnetosphere and has created a global model of the coupled thermosphere and ionosphere.
- **Lead Member, Dr. Brian Fraser (Australia)** is a Professor of Physics at the University of Newcastle. His outstanding scientific career extends for more than 35 years and he is a renowned expert in the fields of geomagnetic pulsations and magnetospheric physics, mainly studying ULF waves and their generation mechanisms in the Earth's magnetosphere and beyond. He was first who suggested to use triangulation and polarization techniques on an array of ground-based magnetometers, discovered oxygen in the EMIC wave spectra and thus confirmed the presence of cold oxygen ions at geosynchronous orbit, and many more. Dr. Fraser's participation in the ICESTAR programme will help in identifying and studying bi-polar effects of the magnetosphere-ionosphere coupling.
- **Lead Member, Dr. Natsuo Sato (Japan)** is a Professor and Head of the Computing and Communications Center at the National Institute of Polar Research. In his 30+ years of the successful scientific career, he contributed significantly into the studies of conjugate auroral phenomena being a lead scientist of the Syowa-Iceland conjugate geomagnetic and auroral observation program. Dr. Sato is a Principal Investigator of the SuperDARN radars deployed at Syowa Station in Antarctica and an active membr of SCAR. He also leads the Japan-China collaboration for the Syowa and Zhongshan Antarctic stations. Dr. Sato's contribution to the ICESTAR programme will cover many aspects of the magnetospheric and auroral physics.
- **Lead Member, Professor Ruiyuan Liu (P. R. China)** is a Council Member of the Chinese Society on Space Research, and a Fellow of the Chinese Institution of Electronics. Graduating from the University of Science and Technology of China in 1963, he worked as a visiting scientist at the Rutherford Appleton Laboratory in the U.K. Returning to China, Dr. Liu served as a Deputy Director and a Professor of the China Research Institute of Radiowave Propagation, then as a Professor of the Polar Research Institute of China. He is an active member of SCAR and works in the fields of ionosphere, radiowave propagation, and upper atmospheric physics. His participation in the ICESTAR programme will enrich its international aspect bringing the wide experimental expertise and field operations.

• **SSG/PS Deputy Chair, *ex officio*, Maurizio Candidi (Italy)** has a spectacular 30+ years of scientific research in Italy and in the U.S. In 1990s, he served as a Director of the Instituto Fisica dello Spazio Interplanetario in Rome; currently he is an expert of the CNR and PNRA organizing the Italian research program in the fields of space physics and astronomy at the new European station Concordia in the Antarctic. Dr. Candidi has a long history serving SCAR as a Chair of the Working Group on Solar-Terrestrial and Astrophysical Research, and since 1992 – as a Deputy Chair of the SCAR's Standing Scientific Group on Physical Sciences.

Logistic Requirements

The ICESTAR will mainly be utilizing national resources in establishing, maintaining, and expanding geospace observations in the Arctic and Antarctic. SCAR is requested to provide a support for the initial development and maintenance of the data portal. In addition, the ICESTAR Programme requests supporting five scientific workshops focused on the activities of the Thematic Action Groups and the final phase of the overall programme.

The first workshop will be held with a small group of community members to help better clarify the programme goals, timeline, and methodology. In addition, the first workshop will solidify the implementation plan for the data portal. The following workshops will be open to the entire community. The third and fourth workshops will give the community an update on the goals of the programme and will have sessions devoted to examining the implementation of the programme and determining whether any modifications need to be made.

The final workshop will provide the community with the results of the programme activities and will have sessions aimed at determining whether he programme should continue, should be modified significantly, or should end.

Indicative budget for 2005–2009

The ICESTAR will create an integrated, quantitative description of the upper atmosphere over Antarctica, and its coupling to the global atmosphere and geospace environment. In order to accomplish this goal, we will hold workshops focused on the data portal and the discussion of scientific goals.

In 2003-2004, the ICESTAR Planning Group used the support provided through SSG/PS to hold a programme-planning workshop in Villefranche (Nice, France) in April 22-23, 2004 ($10,000). Because the creation of the data portal will require dedicated man-power, there is a budget of $30,000 (over the life of the programme) for the creation and upgrades to the data portal. In addition, there will be yearly workshops over the life of the programme focusing on the scientific goals of the TAGs.

Therefore, the ICESTAR Programme requests the following support for two SCAR budget cycles:

Budget cycle 2004–2006: $30,000

Spring 2005 ($10,000) - Data portal specification meeting, focusing on:

- Identification and metadata description of all available Antarctic data on the Internet for ICESTAR.
- Identification of available value-added products on- and off-line and prioritization of the data and products based on their science merit.

Years 2005–2006 ($10,000) - Development and implementation of the ICESTAR metadata catalogue and “Virtual Data Portal”.

Summer 2006 ($10,000) - ICESTAR Data Portal meeting, XXIX SCAR:

- Strategy for linking existing on-line sites together and providing on-line services for all known geospace data and products.

Budget cycle 2006–2009: $45,000

Spring 2007 ($15,000) - ICESTAR Science Community Workshop (coincides with IPY):

- Workshop centered on using ICESTAR metadata and the data portal to tackle selected problems/event studies in TAG A-C science.

Summer 2008 ($15,000) - ICESTAR Special Session, XXX SCAR:

- Presentation of full ICESTAR data portal capabilities and science outputs from the community workshop.

Summer 2009 ($15,000) - ICESTAR “Forward Look” Workshop:

- Review ICESTAR achievements – the future.