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Geospace research with optical measurements during the fourth International Polar Year

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Abstract. The fourth International Polar Year (IPY) will be conducted from March 2007 to March 2009. Scientific work during the IPY years will be arranged as more than 400 interacting core projects covering a wide variety of different research disciplines both in natural and social sciences. This paper describes activities of the 63rd IPY project "Heliosphere impact on geospace". We outline the resources available for geospace research with optical methods and discuss some interesting challenges for the optical community to address with their IPY data sets.

1 Introduction

Research of near-Earth space phenomena was one of the focus areas of the third International Polar Year (known also as the International Geophysical Year, IGY, 1957-1958). Technical panels were established to assess topics like aurora and airglow, cosmic rays, geomagnetism, ionospheric physics, and solar activity. IGY research catalyzed the first rocket and satellite launches and the establishment of pioneering scientific measurement stations in the Antarctic. Important discoveries were made in Earth and space science as a consequence of the IGY program.

The IGY legacy of accomplishments sets high expectations also for the fourth International Polar Year (IPY Project Office, 2006a) to be held during the years 2007-2009 as a 50th anniversary celebration of its predecessor. Due to its potentially tremendous impact on humanity and the fact that the polar environment is at risk, the issue of global warming has a central role in the overarching themes of this IPY. As in the previous IPYs, space research also figures prominently. The IPY Science Plan chart (IPY Project Office, 2006b) has eight segments: Earth, Land, People, Ocean, Ice, Atmosphere, Space, and Education and Outreach. The number of core projects conducting this science program is more than 400. The Space segment has nine core projects which are clusters of several sub-projects.

Optical study of auroral processes was an important element of earlier IPYs. In fact, it was during the first IPY (1882-1883) that the first multi-site visual observations of the aurora were carried out. This was built upon in the second IPY (1932-1933) with multi-point optical observations. For another example, the all-sky camera for systematic recordings was developed during the IGY. With this and other history in mind, the 33rd Annual European Meeting on Atmospheric Studies by Optical Methods was arranged roughly half a year before the launch of the fourth IPY programme. Thus this proceedings book and the Annales Geophysicae special issue of the meeting give a nice overview about the scientific interests of optical research groups when heading towards the multidisciplinary IPY-campaigns. This paper widens the picture by describing some networking opportunities, resources and science topics where the contribution of coordinated optical measurements and their careful analysis will be highly appreciated.

2 IHY, ICESTAR and IPY networking

International Heliophysical Year (IHY Secretariat, 2006) will act as a "sister program" of IPY and coordinate during the year 2007 multinational research advancing our understanding of the fundamental heliophysical processes that govern the Sun, Earth and Heliosphere. IHY will serve as a contact point for the extensive suite of spacecraft missions which the different space agencies will maintain during the IPY years. With the support of the United Nations IHY will also establish space science activities in developing countries.

IHY research will be conducted as Coordinated Investigation Programmes (CIPs) which have been organised under

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eight main themes: Solar, Heliosphere or Cosmic Rays, Planetary Magnetospheres, Ionized Atmospheres, Neutral Atmospheres, Climate, Astrobiology or Space Medicine, and Other. By the beginning of December 2006 56 research groups had submitted their proposals for CIPs. IHY Discipline Coordinators will help the research groups to communicate with each other and to make campaign schedules with instrument PIs if necessary. The final goal is to find a set of universal processes which several CIPs assess from their own specific viewpoints and to get these CIPs to discuss with each other.

ICESTAR (Interhemispheric Conjugacy Effects in Solar-Terrestrial and Aeronomy Research) is a Scientific Research Programme of SCAR (Scientific Committee on Antarctic Research). ICESTAR (Weatherwax, 2006) operates during the years 2005-2009. True to its acronym the program coordinates research on geospace-atmosphere coupling under the influence of solar activity, with emphases on the networking of ground-based instrumentation and on the study of interhemispheric relationships. The work of ICESTAR is conducted by four topical action groups: (i) Differences and similarities of the Southern and Northern polar upper atmospheres, (ii) Effects of magnetospheric processes on the polar atmosphere and ionosphere, (iii) Global electric circuit and its coupling with geospace phenomena, and (iv) Creating a data portal that will integrate all the polar data sets and modeling results. The program includes research groups from eight SCAR member countries (USA, Italy, UK, Finland, Norway, Japan, China, Australia).

Under the guidance of the IPY Project Office ICESTAR and IHY together with 27 other initiatives submitted in June 2006 a proposal for a IPY core project on geospace research. This proposal was accepted as the 63rd IPY core project with the title "Heliosphere impact on geospace" (Kauristie and Ketola, 2006). This core project includes a sub-project called "Auroral Optical Network" (Sandahl and Brändström, 2006) whose main goal is to provide the community maintaining optical instrumentation with a forum for planning common measurement and intercalibration activities. The Annual European Meetings on Atmospheric Studies by Optical Methods will serve as the official meeting point for this IPY initiative.

Fig. 1 outlines the first attempt to link the IHY, IPY and ICESTAR research activities which took place in October 2006. The IHY CIP coordinators under the theme of ionized atmospheres inspected the CIP proposals and the IPY Expression of Interest letters and compared their scientific objectives with the ICESTAR science programme. Opportunities for synergy were found at least in nine different research topics (listed in Fig. 1). For each cluster the leaders of the projects were contacted and introduced to each other and some help with communication and data retrieval issues were offered. The immediate response to these coordination efforts was limited (only one announcement of collaboration) but it is hoped the situation will improve by March 2007 when the IHY and IPY activities start in earnest.

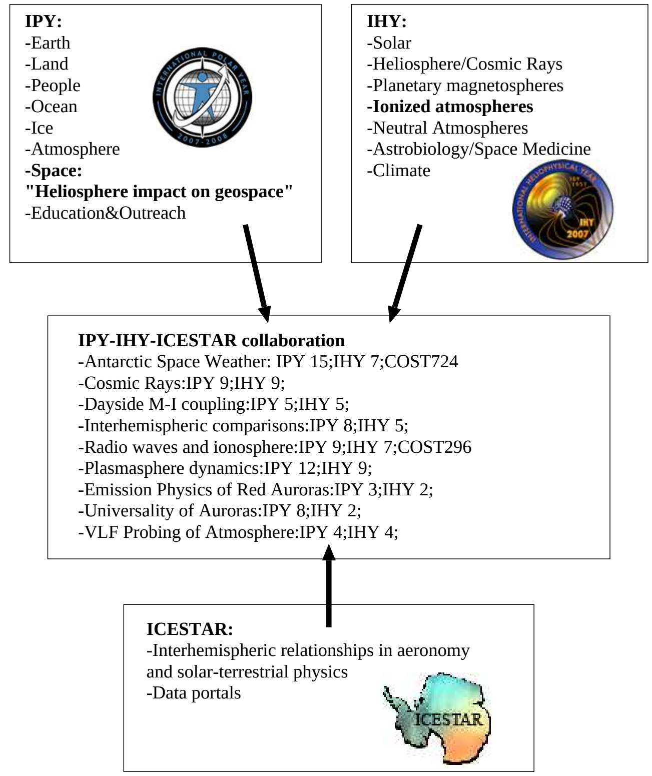

Fig. 1. Networking between IPY, IHY and ICESTAR programs. The figures listed in the box of IPY-IHY-ICESTAR collaboration tell for each cluster the number of sub-projects contacted.

3 Arctic and Antarctic optical networks

The auroral substorm concept introduced by Akasofu (1964) is a widely known scientific breakthough based on IGY measurements. Akasofu made his conclusions on the basis of systematic recordings by an extensive network of all-sky cameras. This work focuses on the morphology and dynamics of auroras and less attention is paid to the absolute auroral intensities. The pioneering modelling work of Rees and Luckey (1974) represents the other viewpoint: Emission intensities of the brightest visual auroral wavelengths (557.7, 428.7 and 630.0 nm) are used to deduce the energetics of the electron precipitation causing the auroras. Both the Akasofu and Rees branches are still today visible in auroral research.

Fig. 2 shows the geographic distribution of optical stations maintained by the groups of the Auroral Optical Network in late 2006. The number of stations is anticipated to increase significantly during the IPY years. Examples of today's IGY type activities are the MIRACLE and Canadian Geospace Monitoring programmes which monitor the auroral activity more or less continuously in the Fennoscandian and North

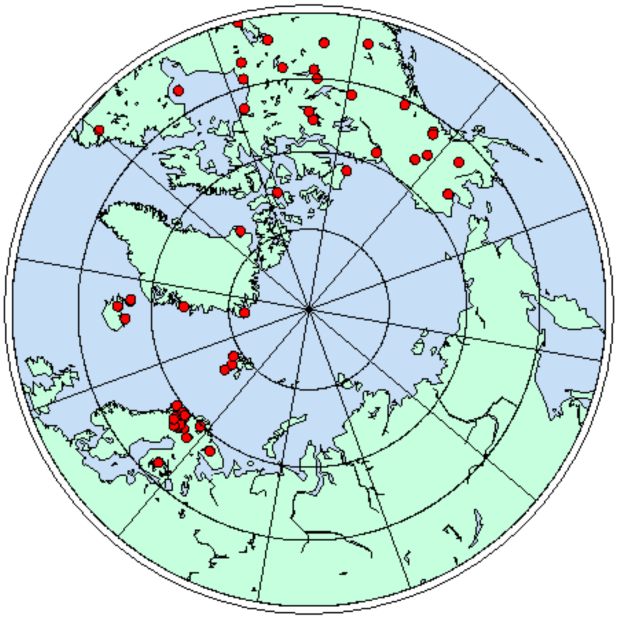

Fig. 2. Optical stations in the Northern polar regions.

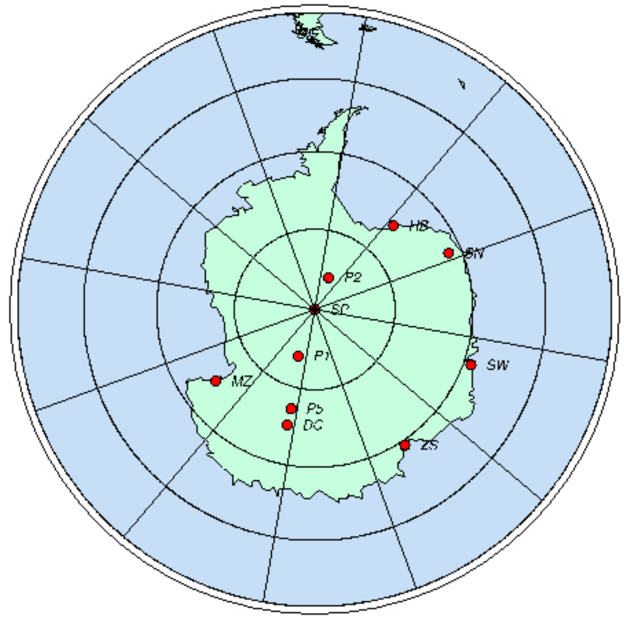

Fig. 3. Antarctic measurement stations which, according to their homepages, have optical instrumentation suitable also for auroral observations. Abbreviations: HB=Halley, SN=Sanae IV, SW=Syowa, ZS=Zhong Shan, MZ=Mario Zuccheli, P1, P2, P5=AGOs, SP=South Pole, DC=Dome C.

American sectors. Data from these networks have been used in numerous auroral morphology studies which typically utilize ground-based data together with magnetospheric observations from different satellite missions. The map also shows two stations (in Canada) of the Japanese OMTI-programme which addresses ionosphere–neutral atmosphere interactions in addition to standard auroral physics.

The incoherent scatter radars and heating facilities of EISCAT (Northern Scandinavia and Svalbard) and HAARP (Alaska) have around them several optical stations which have been used in studies of small scale auroral structures and energetics of auroral precipitation and the consequent effects in the ionospheric plasma. Several interesting new findings about artificial auroras have been made with the data from the Swedish (ALIS-system), UK (Skibotn), US (HAARP), and Finnish (Oulu University) campaign instrumentation. The rocket ranges in Poker Flat (Alaska) and Andoya (Northern Norway) have nearby optical stations for monitoring launching conditions and interpreting the rocket measurements in a wider context.

The US and Italian stations in Greenland and the Japanese stations in Iceland have important locations in the gap between the Fennoscandian and Canadian networks. Similarly, the Russian auroral observatory in Kola Peninsula provides an important eastward extension to the MIRACLE network.

The number of points on our Antarctic map (Fig. 3) is only a fraction of the number of the Northern stations discussed above. This is partly because the Antarctic land mass has less optical instrumentation but also because retrieving information and data of these stations from the Internet is difficult. Getting access to both Arctic and Antarctic stations from a single data server is one of the main goals of the ICESTAR programme. The map of Fig. 3 shows US South Pole and Automatic Geophysical Observatories (AGOs) P1, P2, and P5, the French-Italian base Dome C, and the Italian Mario Zuchelli (Terra Nova Bay) and South-African Sanae IV stations. The Japanese Syowa station is located in the nominal magnetic conjugacy region of the Japanese Iceland stations in the Northern hemisphere. Similarly the Chinese Zhong Shan station is magnetically linked with the Svalbard measurement sites and the AGO P1 and South Pole cameras are coupled with Canadian Archipelago instrumentation.

4 Data sharing and archiving issues

The IPY Data Policy document (IPY Project Office, 2006c) sets high goals for the core projects' data sharing and archiving procedures. IPY data should be carefully collected, freely accessible and adequately preserved. In addition to high quality measurement networks IPY's goal is to leave a legacy of versatile data and data systems to support ongoing polar research and monitoring. The data must be accompanied by a full set of metadata that completely document and describe the observations. For long-term data preservation IPY has established a service which guides the core projects to find appropriate archiving solutions. To recognize the valuable contribution of data providers when publishing final results IPY recommends acknowledgements in the form of formal citations similar to those for articles and books.

The concept of the Virtual Observatory (VO) has been presented in several forums as the most reasonable solution for the IPY data sharing challenge. A VO is a federated and integrated system of mutually linked distributed data archives and analysis software systems. An observatory transfers data from one site to another only upon users' requests and does not perform systematic centralized archiving like the World Data Centers (WDCs) do. VOs and WDCs are not competing systems as WDCs can easily be integrated to the grids of VOs where the centers can extract newly available data to their permanent archives (Baker et al., 2004). Examples of VOs for solar-terrestrial research are VMO (Virtual Global Magnetic observatory, Papitashvili et al. (2006)) and VSO (Virtual Solar Observatory Gurman, J. B. et al. (2006)).

GAIA (GAIA Working Group, 2006) is an international VO program which research groups at the University of Calgary, Lancaster University, and the Finnish Meteorological Institute were developing during 2005-2007. Around the time of the 33rd Optical Meeting GAIA provided tools for browsing summary images and keograms from allsky imagers (ASIs), meridional scanning photometers (MSPs), riometers, and satellite borne global imagers. The browsable data base already included more than 10 million summary images and keograms. These summary images and other metadata provide a quick overview of data availability, quality, and content from a number of international programs, including MIRACLE, NORSTAR, the THEMIS ASI array, IRIS, and OMTI. The final system is planned to include summary data from additional programs including IMAGE FUV, Polar UVI, the Alaska Geophysics Institute MSPs and ASIs, and others. In the short term, the objective for GAIA is that it will grow to provide a readily usable and informative summary of all data obtained by remote sensing of auroral precipitation. GAIA is the VO for the optical and riometry component of ICESTAR, and is designed specifically to adhere to an open data policy consistent with the eGY "Declaration for a Geoscience Information Commons".

At the beginning of the IPY-period GAIA will provide an excellent capability for browsing summary data. In the longer term, GAIA will be expanded to provide additional capabilities that will facilitate research with multi-instrument networks. The GAIA philosophy is to develop a work plan made up of a number of elements that contribute to the larger international program which at the same time are fundable projects under different national programs. The elements in the plan of the final system include development of the following: 1) the data base of metadata and summary images and keograms (construction began in 2006); 2) browsing tools (development began in 2006); 3) tools for integrating data from different instruments together to increase the scientific usefulness of that data (being proposed in 2007); 4) pattern recognition and content based image retrieval tools (being proposed in 2007); 5) a system to provide access to full-resolution data (being developed in 2007). We point out that GAIA will not require that programs contributing summary data to GAIA also allow access to full-resolution data through GAIA. Data providers will be given the choice of having prospective data requests served by GAIA or having the requestor be given a link to the data provider's preferred data access system.

5 Future Challenges

5.1 Estimating precipitation energy

One objective for the IPY activities will be to increase our quantitative knowledge about auroras. The question about the energy fluxes associated with auroral precipitation has been assessed both with space-borne imager data and with simulations (Palmroth et al., 2004). The results, however, have not been conclusive. The total Northern hemisphere precipitation power values achieved from satellite data vary significantly depending on the calibration method used. Preflight calibrations yield roughly 2-3 times larger values than the results based on statistical cross-calibration with DMSP particle data which again are roughly three times higher than the corresponding simulation results. Here, ground-based optical data could provide valuable reference information, although achieving global estimates from distributed cameras each with a meso-scale field-of-view is difficult. As an example Fig. 4 shows the distribution of power values achieved by integrating over an ASC field-of-view (station KIL in the MIRACLE network, MLAT $\sim 66^{\circ}$) during 28 substorm periods. Empirical rules associating the AE-index values of these events with hemispheric precipitation power values suggest that during moderate activity one ASC can catch roughly 10% of the global precipitation power (Kauristie et al., 2006).

5.2 The concept of magnetic conjugacy

Interhemispheric comparison studies often utilize Arctic and Antarctic measurement sites which are magnetically conjugate (i.e. threaded by the same magnetic field lines). The conjugacy is typically determined with statistical models representing the average magnetic field topology in the near-Earth space. A recent study by Sato et al. (2005) has shown that in a real situation the conjugacy point location can vary significantly (tens of km in the latitude and hundreds of km in the longitude). The statistical magnetic field models also underestimate the interhemispheric asymmetries in auroral distributions as driven by large IMF By values (Østgaard et al., 2006). These studies demonstrate that optical observations will have a key role in the research of interhemispheric relationships. No other type of instrumentation can yield such

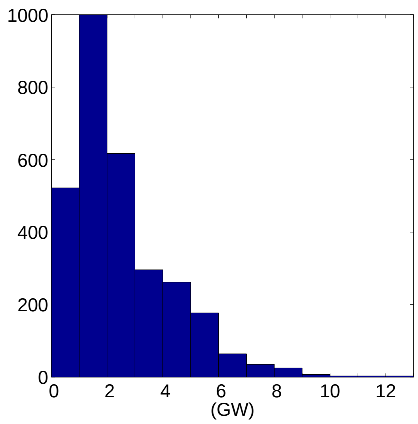

Fig. 4. Distribution of auroral precipitation powers as integrated over the field-of-view of the MIRACLE ASC at Kilpisjärvi. Vertical axis: number of ASC-frames.

easily adoptable information about the varying conjugacy situation. The data sets of global scale spaceborne imagers which have revealed the problems of statistical conjugacy models can be used for quantitative error estimates in different conditions. The continuously accumulating data sets of nominally conjugate all-sky imagers will finally help us to understand what are the smallest spatial scales which still have relevance in interhemispheric comparison studies.

5.3 New avenues

One important task for the coordinators working within the IPY, IHY, and ICESTAR programmes is to shake up the researchers to see their own expertise and data sets in a new light. In addition to the well established and safe standard approaches new research concepts should also be tested. IHY CIP proposals include concrete openings in this direction. The project assessing the universality of auroras is one of the most fascinating examples for the optical community. In this initiative scientists which so far have been analysing only terrestrial auroras will have opportunities to study auroral images from other planets taken by the Hubble Space Telescope.

IPY and ICESTAR activities will put much emphasis on the research of geospace coupling with atmospheric phenomena. Consequently it is important to get solar-terrestrial scientists to exchange ideas with the community conducting aeronomy research. The Optical Meetings have established traditions for such discussions as the informal atmosphere of these gatherings has catalyzed broad-minded research ideas since the 1970's. The fourth IPY programme will provide a unique forum to test these ideas with coordinated measurement campaigns and to discuss the results among a broader community of experts from different science disciplines.

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