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SUSTAINABILITY, SATELLITES, AND GROUNDBASED OBSERVATORIES

Vatsala Khetawat, International Space University, vatsala_vk@yahoo.co.uk
&
Ray A. Williamson, Secure World Foundation, rwilliamson@swfound.org

ABSTRACT

As more and more space applications that improve human life on Earth are developed, it has become increasingly clear that sustainability on Earth and sustainability in near-Earth outer space are inextricably intertwined. This was one of the major conclusions of the recent White Paper prepared by the students of the 2013 International Space University-University of Australia Southern Hemisphere Summer Space Program (ISU-UniSA SH-SSP 2013), entitled 'Common Horizons' (http://commonhorizons.wordpress.com).

This White Paper was focused on considering these topics from the perspective of the 'Global South', those countries that lie in whole or part south of the Tropic of Cancer. How can these countries, each of which has different needs and resources, make effective use of developing space capabilities to further their own sustainable future? The team focused on understanding the "big picture" related to industry, education and the critical space infrastructure that underpins so much of our global society.

During the White Paper research and deliberations, several proposals were made for recommendations that the team did not have sufficient time to work through in the short time they had. Two especially promising ones involve space weather and space debris, both threats to the long term sustainability of outer space. This paper takes up these proposals for the Global South, examining the value of filling in the gaps in the networks of magnetic observatories for space weather and optical debris observatories in the Global South by installing both additional magnetic observatories and small debris monitoring telescopes. The paper also explores how these observatories could spur space activity and assist in the development of science, math, and engineering education in the Global South.

I. INTRODUCTION

Common Horizons[i] was produced by a group of 34 participants from 11 different countries, who took part in an intensive five week professional development program focused on gaining a broad understanding of the global space effort. The White Paper discussed issues and recommendations for a sustainable space future for the Global South.

Common Horizons aims to create awareness of the importance of space sustainability by highlighting humanity's ever-increasing dependence on space activities, risks to these activities, and the results that the loss of them would have on Earth. The countries of the Global South and their institutions must recognize the dependence of their activities on access to space technologies and how the space environment, in which these technologies operate, is under threat. During the deliberations leading up to completion of the White Paper report, several proposals were made for recommendations that the team did not have sufficient time to work through—one involving space weather and the other space debris. Both can seriously threaten operations in the space environment. Thus, this paper proposes the advisability of installing additional geomagnetic field and space debris observatories throughout the Southern Hemisphere. Such observatories would contribute to an enhanced understanding of the evolution of the global geomagnetic field and detailed debris pattern in Earth orbit. They would also assist countries of the Global South to advance their technological development by providing the underpinnings of a nascent space capability.

II. THE GLOBAL SOUTH

ISU defines the Global South as those countries along or below the Tropic of Cancer (fig. 1). Although that definition does not satisfy every scholar, it captures much of the region seen as "the location where new visions of the future are emerging."[ii]

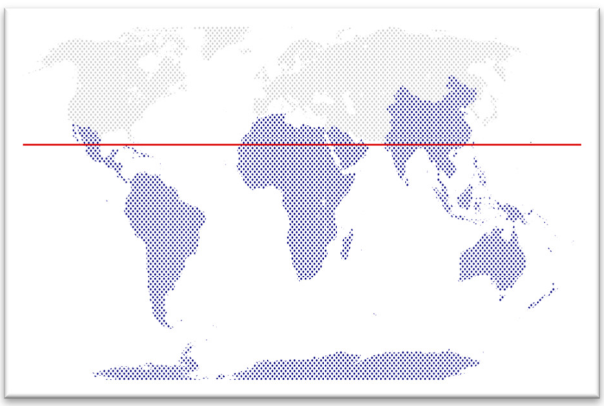

Fig. 1. The Global South

The Global South is composed of more than 150 countries of widely diverse economies, wealth, and technological capabilities. Of these, China and India have well developed, broadly based space activities, including advanced launchers; others have more modest capabilities, or future aspirations to launch their own space effort in the near future. Some countries of the Global South have very little modern technological infrastructure, weak or even warring political institutions, and few aspirations to develop space activities.

Not every country of the Global South aspires to take part in space activities, but all or nearly all already benefit in some way from space activities, whether for agriculture, weather forecasting, or delivery of educational and health services to rural communities.[iii] For certain aspects of space activities, several countries of the Global South have a unique geographical advantage that they can exploit to their benefit. Those countries that aspire to develop capacity in space applications may wish to start the process by developing a modest capacity to contribute to assisting the improvement of space situational awareness.

III. IMPROVING SPACE SITUATIONAL AWARENESS

The ISU report underscores the tight relationship that has developed between assuring sustainability on Earth and the sustainability of the space environment that supports so many beneficial space activities. Further, the report emphasizes that space situational awareness forms a critical element of space sustainability.

What can the countries of the Global South do to contribute to improvements in space sustainability? One of the key elements of maintaining a sustainable space environment is an accurate, instantaneous picture of the fundamental components of the space environment and their dynamical interactions—especially orbital debris and space weather—in other words effective space situational awareness. Currently, our operational picture of the space environment is limited by rather sparse coverage of Earth's magnetic field in the Southern Hemisphere. It is also limited by the relative lack of space debris observatories in the region. Both are important elements for achieving enhanced space situational awareness.

Magnetic field observations

Under normal conditions, Earth's magnetic field operates as a kind of Earth shield, protecting the planet from the solar wind, the constant flux of energetic particles expelled by the sun. However, following a particularly strong solar flare or a coronal mass ejection of energetic particles, if the geometrical conditions between the sun and Earth are such as to direct these energetic particles toward Earth, they can distort Earth's magnetic field, affecting many technological systems that modern society depends upon daily; In the most drastic cases, such solar disturbances cause damaging space weather effects affecting spacecraft and terrestrial communications, electric power, and other human activities in space, the ionosphere, and on Earth.

The magnetic field at any particular place on Earth, which varies over time in intensity and direction, can be measured by magnetic observatories specifically designed to measure disturbances in the field direction and intensity. These changes signal the development of a space weather event. Magnetic observational data, when combined with observations from the network of magnetic observatories situated around the world, contribute to a better understanding of the course of a damaging space weather event.

A glance at the map of the distribution of magnetic observatories around the world shows a relative lack of observatories in the Southern Hemisphere [Fig. 2]. As a result, models of Earth's magnetic field are weaker in the Southern Hemisphere and the ability of space weather experts to predict the intensity and evolution of space weather events also weaker. Placing additional magnetic observatories in the Global South would improve space situational awareness.

Fig. 2. The Distribution of Magnetic Observatories around the world.

Magnetic observatories have much broader application to science and to modern society than their contributions to predicting and monitoring the damaging effects of space weather. Magnetic observations contribute to our general understanding of Earth's geology and climate.

<u>Orbital Debris Observations</u>

Highly used Earth orbits such as geosynchronous orbit (GSO) and the sun-synchronous polar orbits are becoming increasingly congested and even dangerous to spacecraft. Achieving effective space situational awareness first and foremost requires continuous observations of both operational spacecraft and debris, ideally from both Northern and Southern Hemispheres, in order to provide full time coverage of the celestial sphere. Preventing future collisions will require a high level of space situational awareness and the ability to perform rapid conjunction analysis on potentially threatened spacecraft.

The United States military currently operates the most capable orbital debris tracking capability in the world, currently tracking some 1,000 operational spacecraft in orbit and about 21,000 bits of debris greater than about 10 cm in size with both radar and optical telescopes. Yet the U.S. lacks observatories in the Southern Hemisphere and other countries are only beginning to develop the capacity to track orbital debris. Observations from the Southern Hemisphere are important to fill in potential gaps in observations. Unfortunately, the United States does not share its highest quality orbital object data with other countries though it has taken on the task of warning spacecraft operators in danger of being impacted by debris and suggesting how they might avoid danger.

The countries of the Global South can help spread debris observing capabilities to the Southern Hemisphere and reduce the near monopoly that the United States holds over high quality debris tracking by investing in small orbital debris observatories. Orbital debris observatories would not only contribute important SSA information but also help those countries that invest in them to develop their capabilities in astronomy. For example, such observatories can also be used for educational purposes and to search for and track asteroids. Discovering asteroids would add to the asteroid catalogue and enhance the world's ability to protect against potentially destructive asteroids.[iv]

IV. SPACE WEATHER AND MAGNETIC OBSERVATORIES

An important aspect of the space environment derives from the Earth-Sun link. The Sun's hot corona streams out radiation and energetic particles such as electrons and protons, emissions collectively known as the solar wind. This solar wind spreads in all directions at an average speed of 400 km/s. Active regions of the sun such as sunspots generate solar flares and coronal mass ejections. Unlike the solar wind, these specific events release concentrated high energy electromagnetic radiation in a single direction. On occasion, CMEs are directed towards Earth. These cause intense geomagnetic solar storms on Earth. The strongest storm observed is the so-called Carrington event of 1859 that was apparently caused by an Earth-directed CME, and which caused telegraphs around the world to malfunction and produced aurora seen from the equator.[v]

The number of sunspots is an indicator of solar activity and has been observed to follow an eleven-year cycle, indicating varying intensity of solar emissions. The sun is currently heading towards a solar maximum, with higher numbers of intense solar weather events. Historically, an average of two to three CME's per day is observed near solar maximum and about one CME a week at solar minimum.

Impact of space weather on terrestrial technology

Solar flares and CME's increase the speed of solar winds which cause enormous fluctuations of the magnetic field in Earth's magnetosphere. These induce electric fields and currents in the upper atmosphere over Earth's surface, creating a geomagnetic storm, the most intense type of space weather event that causes damage to both space and terrestrial technologies.

Geomagnetic storms create geomagnetically induced currents (GICS), which flow in all available conductors including oil and gas pipelines, high-voltage transmission lines, railways, and undersea communication cables. A severe geomagnetic storm can damage all these conductors leaving blackouts causing multiple power grid failures at once which are difficult to replace. It can knock out nuclear power plant's ability to transmit power which in turn destroys their backup power system and can lead to hundreds of meltdowns. Two such major solar storms have already been experienced in 1921 and 1989 which caused catastrophic damages.[vi] Both of these events affected North American power grids. China is also vulnerable to this potential threat.

The next peak cycle is expected later this year. The Sun enters solar maximum, the phase of most intense solar activity in the coming year. Thus, now is a good time to consider the effects of the solar cycle and strengthen our ability to predict the damaging effects of space weather.

Damages to spacecraft

Spacecraft are designed to sustain a certain level of solar wind activities with normal operations. However, high intensity solar events disrupt spacecraft operations by causing failures to the electric system on board such as communications and navigation. In severe cases satellites can be rendered non-operational.

On October 28th 2003, the earth was struck by one of the most intense solar flares in current record. The SOHO spacecraft observed an X ray flare ejected with an intensity four orders of magnitude higher than the average background intensity. Two days prior on 26th October, active sunspot regions had grown to a diameter 10 times that of the earth, observed by the SOHO spacecraft.[vii] During this storm, the CME arrived earlier than expected, giving just 18hrs for satellite operators to act.

As a result there were several spacecraft failures. This storm enhanced atmospheric ionization from the D region (80 – 100 km altitude) all the way to the F region (the F peak is at 300 km altitude). This caused major impacts to satellites and also disrupted RF radio communications. Sensors aboard the ACE satellite at L1 that measure energetic particle fluxes were severely affected by the storm and did not return to normal functioning until several weeks later[viii]. Several other satellites in LEO also experienced failures.

The Case for Magnetic Observatories

Magnetic Observatories have the broad scientific and practical objective to develop an understanding of the sources and processes, internal and external to the Earth's surface, which generate the magnetic fields that combine to produce the overall field observable at any point in space and time. The data acquired are used to create global field models and for local applications. Fluctuations in the magnetic declination (angle between compass north and true north) on Earth's magnetic field at any time indicate changes in solar wind flux or local electromagnetic processes.

Ideally, magnetic observatories should be distributed in an evenly spaced network around the planet. Nevertheless, as noted earlier in this paper, there is a relative lack of these observatories in the Global South, most notably in Africa and South America. Magnetic observatories established in these regions could assist in the development of more complete models of Earth's global magnetic field and therefore improve scientific understanding of Earth's changing magnetic field structure. More important for space situational awareness, they would also contribute to advance warning of space weather events and help create awareness among local people about the impact of space weather on the environment

These observatories can be established at a minimal cost at University level. Initial magnetic observatory capacity can be developed for a few tens of thousands of dollars and additional modest operational costs. Countries in the Global South should be encouraged to link up with existing observatories and research centers of the North as well as with the observatories already existing in the Global South. Many existing research centers establish space models with the help of these data. A partnership with the INTERMAGNET network of Magnetic Observatories (IMO) is also recommended. They form the International Real-Time Magnetic Observatory Network. It is the global network of observatories, monitoring the Earth's magnetic field. This program exists to establish a global network of cooperating digital magnetic observatories. The INTERMAGNET program has helped to accelerate the modernization of observatories and coordinate activities across the international network. Members of the INTERMAGNET network can provide new observatories with technical assistance and practical information on operating an observatory and producing good quality data.

V. DEBRIS OBSERVATIONS

Building a debris observatory is an excellent way to forward a country's science and technology ambitions. The equipment requirements for observing objects in geosynchronous orbit and sharing the observed data internationally are relatively modest and can be readily achieved by most countries. Perhaps more important, such facilities can provide the starting point for more ambitious scientific facilities as the country builds its scientific and technical capacity.

One excellent option is for countries of the Global South to join the International Scientific Optical Network (ISON). With more than 33 observatories around the world and some 51 active telescopes, ISON is one of largest space object observation systems in the world [Fig. 3]. It focuses primarily on observing space debris and active spacecraft at geosynchronous orbits. Some elements of the network also make observations of asteroids and comets. ISON began in 2004. It is coordinated by the Keldysh Institute of Applied Mathematics (KIAM) of the Russian Academy of Sciences.[ix] Each of the ISON observatories contributes its observations to an expanding database of debris and active spacecraft orbital parameters in the geosynchronous region.

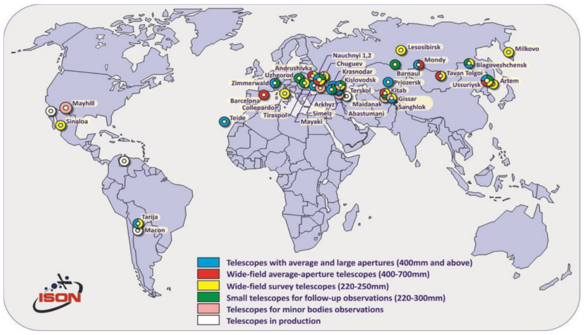

Fig. 3. The ISON network, courtesy, ISON.

The advantage for countries with relatively little scientific capacity in becoming part of the ISON is that there is a ready-built international infrastructure in place and technical assistance available for integrating a country's telescope(s) and observational data into the ISON system. Typically, ISON will provide the telescope and software for an observatory and the country provides the observing facility (telescope pad, observatory building, and computing facilities and Internet connectivity). Daily interaction with other ISON observatories and periodic ISON conferences enable participating observatories to gain useful practical information and assistance and valuable scientific knowledge. Alternatively, countries can acquire their own telescopes and still take advantage of the benefits of joining a functioning network.

Optical observations have some drawbacks. They require good optical conditions and the absence of clouds to be effective. Building and maintaining a reasonably complete database therefore requires several telescopes situated in different locations.[x] Here again, ISON provides the needed additional telescopic capacity through its existing network.

V. THE ROLE OF COOPERATIVE PROGRAMS

International cooperative programs have always had a strong role in improving the scientific and technological capacities of emerging space States. Through close cooperation with U.S. and European companies and government institutions, South Korea, for example, has achieved a significant level of space capacity, developing Earth observation and space communication systems and even its own launch system. In another example, by cooperating with China on the China-Brazil Earth Resources System (CBERS), Brazil has moved its Earth observation program along significantly.[xi]

To advance their capacity in science and technology, countries of the Global South can seek out cooperative programs with technologically more advanced countries, as there are numerous opportunities available. All the major space powers operate cooperative programs that can benefit less capable States. In the long run, however, South-South cooperation will likely be more effective for the countries of the Global South, especially in developing space capabilities. Countries such as Brazil, India and South Africa have quite advanced technological capability and could be excellent partners for those with less advanced capabilities.

VI. CONCLUSIONS

As noted by Fisher, et al., states of the Global South "have unique geographical advantages that can contribute to space sustainability, particularly in terms of Space Situational Awareness."[xii] We are suggesting that those countries take advantage of their geographical advantage to advance their own technological and scientific development while also contributing to space situational awareness and therefore to enhancing space sustainability. Not only will these countries assist their own development but also help make outer space a safer place for operating spacecraft.

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