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Bringing Space Down to Earth

by the World Economic Forum's Global Agenda Council on Space Security

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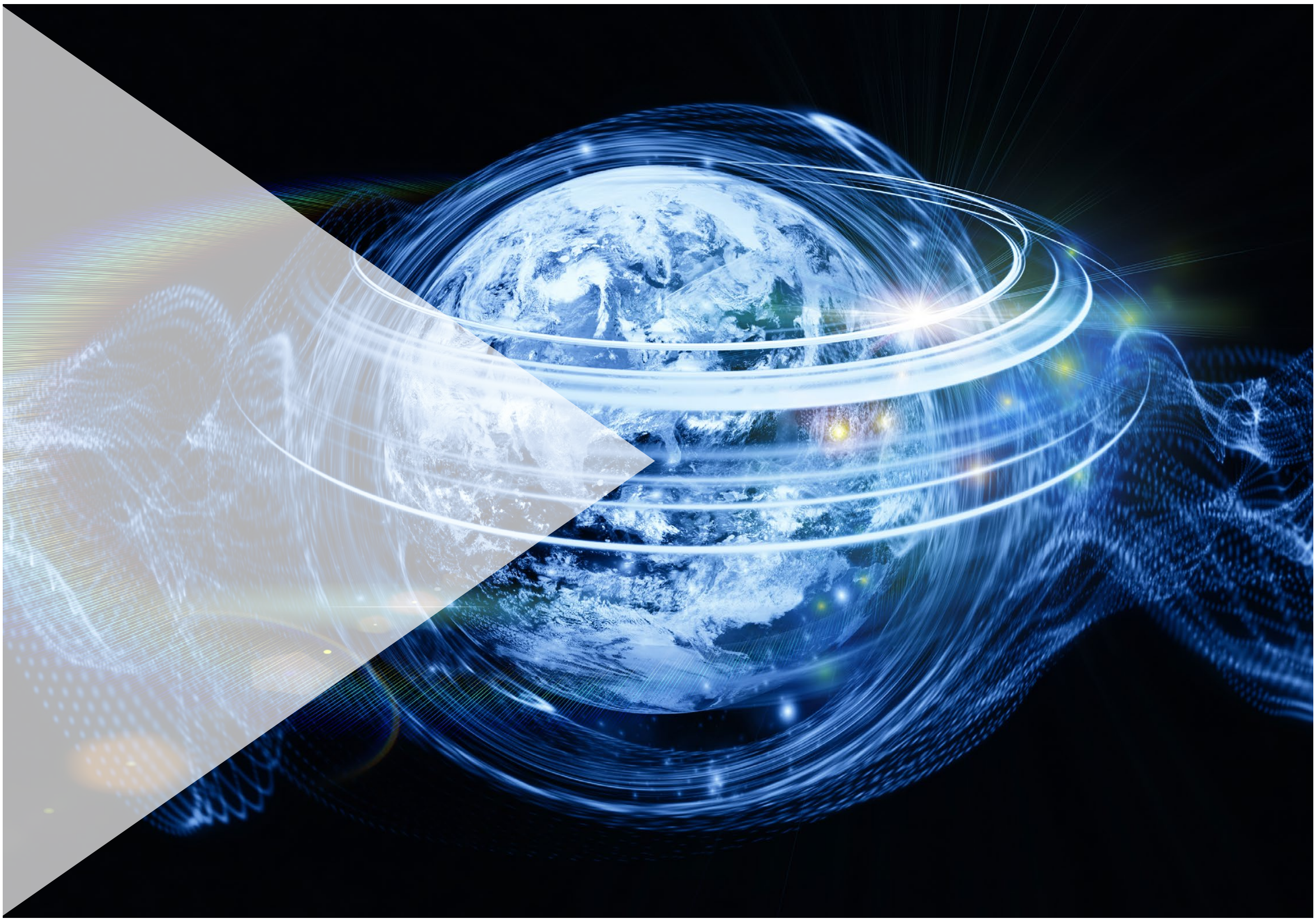

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Foreword

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Over the past five decades, space has been regarded as either the dream and future of humankind or a field of the Cold War space race. Neither view is relevant today. Although the competitive nature of technological achievement and the wish to explore space will never end, the most important role space serves today is as critical infrastructure for the world. This report, *Bringing Space Down to Earth*, demonstrates how important space is in our daily lives, particularly in times of crisis. It also shows why space – and society's ability to use it – must be protected from natural and man-made hazards.

Space is no longer a "big boys club". Today, about 60 countries own and operate at least one satellite, and almost everyone benefits from the services these satellites provide. Space has become an indispensable infrastructure on which everyone relies.

Space capabilities provide information vital for the environment, education, food security, public health, water resource management, human rights, disaster relief and nuclear security. Space-derived services not only improve the efficiency and effectiveness of many terrestrial activities but also provide much of the information and understanding needed to prevent and mitigate a variety of risks.

There are risks in space as well. As the importance of space increases, so too does the need to protect its assets and environment. These various hazards include space debris, radio frequency interference and space weather that can damage or destroy satellites or make operating in space more costly. Asteroids and massive solar storms could pose significant threats to life on Earth. The meteor that exploded over the Russian town of Chelyabinsk in 2013 is just one example.

This report, a collective effort of the members of the Global Agenda Council on Space Security, highlights the key role that space plays in making the world safer, more secure and more prosperous. I recommend it to all those who are interested in improving the efficiency of their activities and security of their daily lives. It reminds us that space is not about space per se, but about humanity and the societies on our planet. It is time to *bring space down to Earth*.

Introduction: Space matters

Snapshot

With $314 billion in commercial revenue and government spending in 2013, and an average annual growth rate between 5% and nearly 8%, the space sector is one of the fastest growing in the world.[1]

Space assets serve as an economic multiplier and enabler for many other sectors, including air, ground and sea transportation, banking, telecommunications and internet services, healthcare, agriculture and energy.

Services provided by satellite are essential for much of modern critical infrastructure and scientific activities, such as water management systems (dams), electronic power grids, weather prediction and disaster monitoring/ management, and climate change studies. Space-based systems are crucial for risk prediction and mitigation all around the globe.

Developing countries are increasingly seeking space assets in their quest for sustainable economic and social development. In particular, space activities contribute to science, technology, engineering and mathematics (STEM) education and thus to the development of a highly skilled workforce.

Space programmes have provided technological spin-offs that have benefited civil society and the non-space commercial sector in many ways.

On Earth, space matters.

The space economy

The space sector is one of the fastest growing in the world, with average annual growth rates between 5% and nearly 8%. This growing sector supports an ever-increasing range of downstream products and services across multiple users and markets. It's not just wealthy nations that are reaping the benefits: as global competitiveness expands and new satellite technologies become cheaper, developing countries are investing in space with the goal of expanding their economies.

In 2012, US government space spending on NASA, the National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense was $48 billion. Other governments spent $31 billion on their civil and military space organizations, with European nations spending $5.1 billion on the European Space Agency (ESA), Russia spending $4.6 billion, Japan $4.4 billion, and China $3.1 billion.[2] While commercial launch vehicle companies like SpaceX and Orbital Sciences are beginning to enter the sector, the primary actors in space are, and shall for some time remain, governments.

But unlike in the past, space is not limited to the world's superpowers. Today, about 60 countries have one or more of their own satellites, up from only 26 countries in 2001. More governments are now viewing space as a worthwhile investment that can ensure their national social, economic and technological development and security.

Small companies and even individuals have also become important parts of the global space economy. The development of space tourism has injected new money and fresh public attention into the space industry. Indeed, a single private company, Virgin Galactic, has already collected paid deposits from more than 650 aspiring astronauts. This dramatically eclipses the total number of humans who have been to space (fewer than 550) and represents more than $100 million in new revenue. The lower price points and more frequent flight opportunities offered by commercially-operated parabolic aircraft, reusable suborbital launch vehicles and orbital platforms such as CubeSats have encouraged new entrants to become involved in space for the first time. As a result, entities ranging from start-ups backed by venture capital to successful R&D firms from adjacent industries are becoming customers of aerospace transportation and manufacturing companies.

Secondary economic and development benefits

Space has a positive economic impact on many markets, adding value through applications ranging from telecommunications to earth observation. Both governments and private corporations benefit, as do users in the biggest cities in the United States right through to those in rural India.

A country's first investments in space are often part of a larger national plan to improve information and communications technology (ICT), infrastructure, agriculture and education – all essential factors in a resilient economy that can drive sustainable development.

These investments are driven by a long-term strategy of progressive capability development, often not realized until a space programme reaches its second or third generation. Technology transfer also plays an essential role, as it allows countries to develop their industry and technology base by gaining experience in satellite design, manufacturing and integration from experienced prime contractors.

In addition, as space programmes require a skilled technical workforce, space agencies and governments therefore invest in education and outreach programmes in primary schools all the way through to universities, and often provide scholarships and internships to students to encourage them to enter the STEM fields. STEM education provides the advanced skills required for a competitive workforce that can generate economic growth.

Worldwide, the space sector directly employs an estimated 120,000 workers in OECD countries[3] and 250,000 in Russia.[4] It indirectly creates many more jobs, thanks to successful technology spin-offs.

Earth observation satellites

Critical to these capabilities are Earth observation (EO) satellites. Data from EO satellites contributes to many activities, including improving agriculture and water management, tracking refugee populations, predicting weather, monitoring disasters, carrying out relief operations and national defence. The value chain for EO satellites is less developed than that for communications satellites, but still generates significant commercial revenues. EO satellite revenues for sales and value-added services from commercial operators totalled $2.3 billion in 2012, and the sensing market is expected to grow to $6 billion by 2020, as nations use satellites for economic development. Between 2001 and 2010, 140 EO satellites from 26 countries were deployed on orbit; between 2011 and 2020 this number is expected to increase to 298 satellites operated by 43 different countries.[5] An increasing number of these EO satellites are being built and operated by private industry.

Global navigation and positioning satellites

Space-based technologies have also revolutionized transportation and navigation capabilities, resulting in more efficient routes, improved safety records and lower operating costs. The key enabling technology is the Global Navigation Satellite System (GNSS), with the most prominent being the US Global Positioning System (GPS), together with the Russian GLONASS, Europe's Galileo, China's Beidou, Japan's QZSS and India's IRNSS. These satellites have provided a flexible, accurate and low-cost method to track position, plan routes and more precisely time delivery/arrival schedules in ground, maritime and air transportation.

Ground transportation systems (trucking and rail) have long used GPS-based navigation and timing services for fleet management and planning schedules, and the personal use of GPS by motorists for navigation has skyrocketed in recent years. The maritime industry – which also relies heavily on communications satellites, since landlines don't exist at sea – has also adopted the technology. For railways, GNSS is frequently used in safety-critical devices supporting signalling (high- and low-density lines) and other applications supporting things such as asset management and passenger information. The aviation industry is the latest transportation sector to adopt the technology, prompted by safety concerns. Airlines are embracing satellite navigation services, which promise to cut costs and increase efficiency by improving flight path planning and traffic flow, enhancing the ability to land in bad weather and high terrain, and reducing emissions.

GNSS satellites have also contributed to the development of efficient and cheaper water management systems, for example by providing precise timing for the working of damns and the routing and time management of electric power grids. As a result, such infrastructure has become more affordable for developing countries.

The installed base of GNSS devices currently stands at just over 1 billion. This is expected to rise to 7 billion by 2022 – one for almost every person on the planet. Growth rates are most remarkable outside of Europe and North America. The global market for GNSS devices is expected to grow from slightly less than €50 billion in 2012 to €100 billion in 2019. The wider market enabled by GNSS services was worth €150 billion in 2012 and is expected to grow to €250 billion by 2022.[6]

Communications satellites

Communications satellites make up the bulk of satellites in orbit, providing television broadcasting, internet services and telephony. They have underpinned the information revolution, enabling long-distance communications in areas where terrain, distance or poor infrastructure make it too difficult to lay cables. The many benefits range from improved banking services to distance education and telemedicine in remote areas. Communications satellites are also bridging the digital divide between developed and developing nations by bringing internet services to remote areas.

Satellite communications, the most commercially mature space industry, generate over $100 billion in revenues worldwide, driven primarily by broadcasting services.[7]

Due to the globalization of the customer base, deregulation, technological advances and economic growth, the satellite television industry has grown significantly over the past two decades. Today, more than 25,000 digital satellite TV channels are available, compared to fewer than 800 analogue channels in 1991,[8] and demand continues to grow.

By taking advantage of the assets of existing players in space-based telecommunications, new entrants are paying less, and countries are benefitting from having their own satellite to provide domestic telecom services. Countries such as United Arab Emirates, Chile, Laos and Nigeria have applied to the International Telecommunication Union (ITU) to operate geosynchronous communications satellites over their countries, and have started placing contracts for manufacturing and launch services. Many of these countries have also started deregulating their telecommunications sector, boosting business and consumer demand.

Technology transfer and commercial spin-offs

Thousands of technologies used in the space sector - from rocket materials to astronaut life-support systems - have been successfully used for terrestrial applications. In fact, many modern industrial innovations have come from the aerospace industry. For example, the need to miniaturize electronics in the 1960s for NASA's Apollo programme laid the foundations of the microelectronics revolution, and, consequently, the development of modern computers.

Space agencies have created technology transfer programmes to facilitate this process and commercialize such applications through licensing and industry partnerships.

Space spin-offs are not limited to high technology. They extend to applications in medicine, energy, food, textiles, agriculture and many more sectors. It is difficult to measure the economic returns generated by spin-offs, because of how broadly they extend, the problem of defining what constitutes a spin-off (NASA, for example, requires commercialization to be as a direct result of its involvement, which excludes thousands of applications), and the fact that the impact of an application may not be evident until long after it is retired. Table 1[9,10,11] shows just a few examples of spin-offs and their space origins.

Table 1: From space to Earth - Examples of spin-offs

Product	Space origin
Tumour tomography	NASA scanner for testing
Battery-powered surgical instruments	Apollo programme
Non-reflective coating on PC screens	Gemini spacecraft window coating
Emergency blankets (survival/anti-shock)	Satellite thermal insulation
Mammogram screening, plant photon-counting technology	Space telescope instruments
Skin cancer detection	ROSAT X-ray detection
Dental orthodontic spring	Space shape memory alloys
Early detection of cancerous cells	Microwave spectroscopy
Carbon composite car brakes	Solid rocket engine nozzles
Car assembly robots	Space robotics
Flameproof textiles, railway scheduling, fuel tank insulation	Various Ariane rocket components, including software
Lightweight car frames, computer game controllers, fuel cell vehicles, coatings for clearer plastics, heart-assist pump, non-skid road paint	Various space shuttle components
Fresh-water systems	International Space Station technology
Corrosion-free coating for statues	Launch pad protective coating
Flexible ski boots, light allergy protection, firefighter suits, golf shoes with inner liner	Various space suit designs
Healthy snacks	Space food

Space matters down here on Earth

Every dollar spent on space is spent right down here on Earth. The design, research, development and manufacture of space assets creates hundreds and thousands of jobs, pumping billions of dollars into the world economy. However, the space sector's impact is far more pervasive than can be detected from its economic footprint. Although it represents only 1% of global economic activity, the space sector's value in terms of its multiplier effect and its stimulus to economic growth is much larger.[12]

Space assets support critical infrastructures around the world, and have lowered costs and increased efficiencies, benefiting millions of consumers. Satellites help save lives through weather and disaster prediction and disaster relief. Investment in space programmes has resulted in new technologies in areas such as healthcare that have improved the quality of life for people everywhere.

Space assets are also playing an increasingly important role in sustainable development and in bridging the digital divide, thus helping to make the world a better place for all.

Space matters, and we must ensure that the space environment remains safe, sustainable and secure so that the next generation can continue to reap its benefits.

Communications satellites and the future telecoms ecosystem

Snapshot

The problem
ICT is indispensable for economic, social and cultural development; free and open communication has come to be expected anytime, anywhere and on any device. However, there is a global digital divide, and in many countries telephone penetration (teledensity) is very low. Even in countries with higher rates of penetration and high-speed broadband networks, users often experience delays as a result of internet traffic congestion. This situation will only get worse as the appetite for content – particularly bandwidth-hungry videos – grows.

The space-based solution
Although we might not be able to see them down here on earth, satellites are all around us. This makes them the ideal solution to the problem outlined above. Satellites can be used alongside WiFi and other terrestrial solutions to deliver high-quality, media-rich content to users no matter where they live, and so ease internet congestion too. Their ubiquitous nature also means they can help bridge the digital divide by connecting people everywhere to broadband internet, ensuring nobody is left behind as we move into the digital era.

Sample applications
Case study 1: Connectivity on all devices
Case study 2: Broadband coverage with O3b's "fiber in the sky"
Case study 3: Scheme to enable satellite TV reception in remote India
Case study 4: 4K TV
Case study 5: Bringing rural communities online in Italy

Introduction

We have become used to being able to use our mobile phones, tablets and other data-hungry devices at all times wherever we are. This trend seems set to continue. In fact, Cisco predicts[13] that 90% of total IP traffic by 2015 will be a form of IP video (internet video, IP video on demand, video files exchanged through file sharing, video-streamed gaming and video conferencing).

All of this technology will depend on the use of frequency spectrum. So too will the robust global telecoms system that we need to support other essential communications services, such as navigation, air traffic control, disaster relief and search and rescue. Governments everywhere are working hard to ensure the frequency spectrum needed to meet this demand is in place.

The technology and its application

Satellites offer tremendous reach and therefore widen access to broadband services. They are also the best way of broadcasting content in a country, between regions and across the globe in the most advanced and high-quality digital format, at a cost that is independent of the number of users.

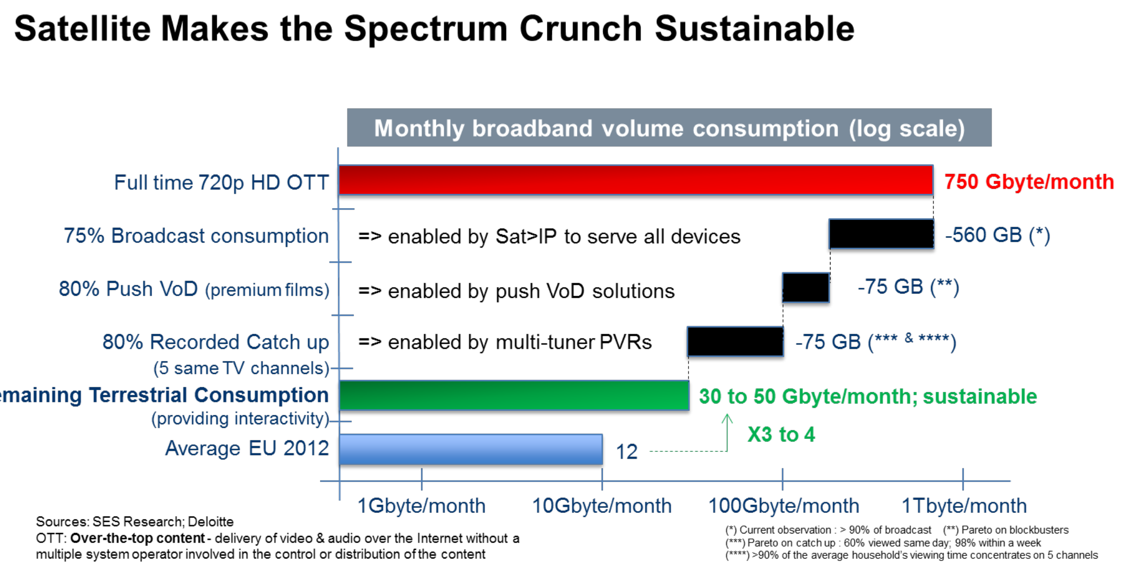
As these video services expand and become more accessible, demand will continue to grow. This raises the question of maximum capacity and congestion: land-based networks cannot support this level of traffic without large delays and costs, which consumers will not accept. By bringing content closer to the users and network edges, using profiling algorithms and local storage, satellites can deliver high-quality content, enable video on demand-type applications and help reduce congestion. Using satellite in this way would reduce the capacity requirement for transmitting through the internet backbone, improve quality and reduce investments required.

The role of satellite in delivering next-generation services

(with reference to average consumption in the European Union in 2013)

Figure 1 shows an estimation of the volume of data that would have to be delivered to each household if consumers watched Ultra HD on web-based over-the-top (OTT) television channels. The volume – over 700 gigabits (Gb) per month – is two orders of magnitude larger than today's European average of 12 Gb per month. Satellite provides a practical solution to deliver Ultra HD to end users by pushing content whenever possible via satellite and then offloading the web-based distribution.

Figure 1: Data needed to watch Ultra HD on web-based OTT television channels



This graph shows an estimation of the volume of data which would have too be delivered in each household, should end-users watch Ultra-HD on web-based Over-The-Top TV (OTT) channels. Such a volume, of above 700 Gb per month, is two orders of magnitude larger than the today's European average of 12 Gb per month. Satellite provides a practical solution to deliver Ultra-HD to the end-user by pushing content whenever possible via & then offloading the web-based distribution.

Case studies

Case study 1: Connectivity on all devices

Satellite operators have developed two technologies, "smart LNB"[14] and Sat>IP[15] that converts satellite TV (DVB-S) signals into Internet Protocol (IP) streams, which can then be distributed to multiple devices around the home. These technologies provide for a direct-to-home antenna that would allow broadcasters to operate their own system of linear television and connected TV services directly by satellite.[16]

These new technologies create new options for distributing high-quality, low-cost satellite TV to multiple TVs, computers and tablets over IP. The satellite reception and the IP bridging functions are located in the antenna, allowing content to be distributed to homes using a single Ethernet cable. The IP-LNB and Sat>IP can also be powered using the same cable, which reduces costs and power consumption.[17]

Case study 2: Broadband coverage with O3b's "fiber in the sky"

It is estimated that almost half of the world's population live in areas not covered by existing broadband networks.[18] In order to connect these people, most of whom live in the developing markets of Latin America, Africa and Asia, a consortium known as the "other 3 billion", or O3b, made up of SES (a satellite operator), financiers and other shareholders, including Google, has come up with an innovative solution. O3b will have a fleet of rotary satellites around the equator that will offer high bandwidth of 700 megabits per second (Mbps) to 1.2 gigabits per second (Gbps), which will potentially improve as the technology develops. With satellites that are closer to Earth than traditional geostationary satellites, the time it takes for data to travel from the user's location to the satellite and then back again to the base receiver equipment and user's computer will be reduced. As a result, satellites will be able to provide backhaul for applications such as 3G and LTE.[19]

Case study 3: Scheme to enable satellite TV reception in remote India

Despite being the country with the most demand for satellite TV channels in the world and the first to bring commercial Ultra High Definition (4KTV) channels to its citizens in 2014, numerous states in India still had no TV. In 2013, the Indian government provided almost 30,000 satellite-enabled set-top boxes to homes in remote areas of the country.[20] Prior to this service, people living in parts of Assam, Chhattisgarh, Jammu and Kashmir, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, Arunachal Pradesh and Uttarakhand had not been able to receive TV signals from the public broadcaster.

Case study 4: 4K TV

After the success of high-definition (HD) TV, the first ultra high-definition channels (UHD or 4K TV) were launched in 2013. Frequently described as "game-changing" technology, UHD will allow viewers to benefit from improved image quality, with four times the image resolution of HD.[21] According to research carried out by IHS, by 2025 nearly one-quarter of all households will have at least one UHD-enabled TV.[22]

As more and more operators and broadcasters look to make their content available in UHD, satellite operators are helping them test their footage and distribute their content.[23] Satellites are the most suitable way of delivering such high-resolution content to large audiences. Over the next couple of years satellite operators will be pivotal in bringing 4K and 8K content to homes and cinemas everywhere. To support the inevitable growth in this sector, satellites will need to be able to continue to access key satellite spectrum.

Case study 5: Bringing rural communities online in Italy

According to Eutelsat, 2.37 million people in 3,600 towns and villages in Italy do not have access to a high-quality internet connection.[24] In order to bridge this digital divide, Poste Italiane is turning to satellite broadband.

With the help of a small dish and a satellite modem connected to a computer, users anywhere in Italy can now connect to the internet and benefit from download speeds of up to 20 Mbps and upload speeds of 6 Mbps.

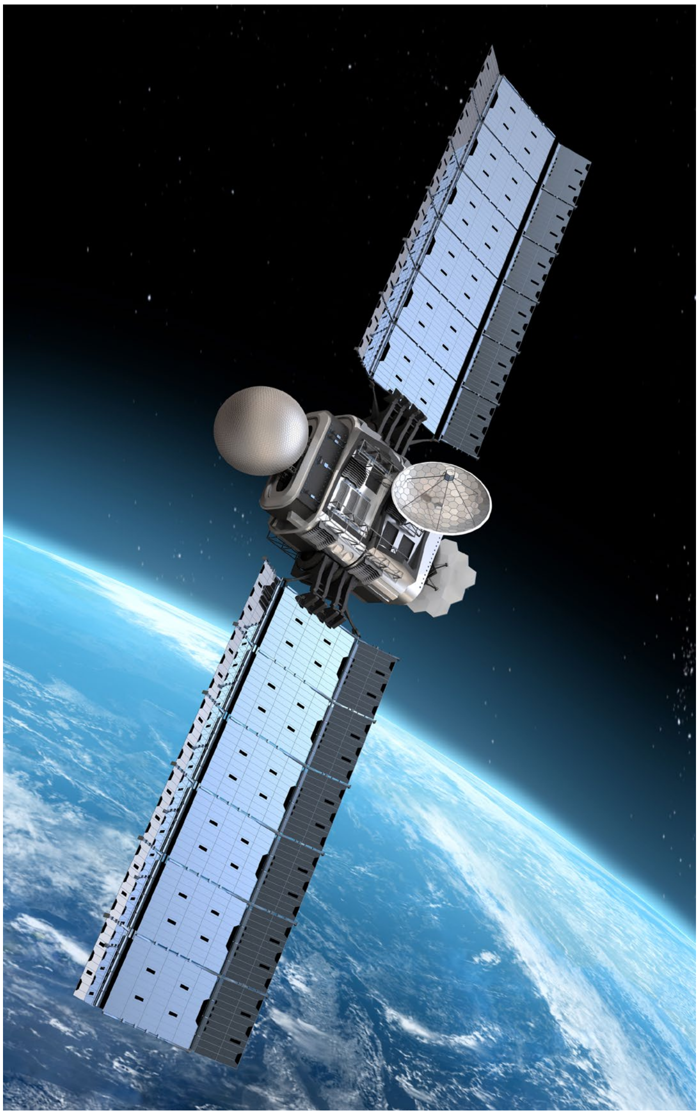
Unintended consequences of regulation: spectrum sharing and loss of service

Satellites are long-term infrastructures, built to operate in particular frequency bands for their entire lifetime of 15-20 years. They depend on allocations and principles adopted by the ITU and once launched, cannot be modified to accommodate new policy decisions. In 2008 the European Union took such a policy decision to open part of the C band - a key radio frequency band used by satellite-to-terrestrial wireless services - to accommodate the future growth of mobile communications.[25] With the principle of technology neutrality[26] in mind, the intention was that the band should be shared by both technologies on a "co-primary" basis (each having the same right to use the band). In reality such sharing is not technically possible given the comparative strength of the terrestrial signal and the interference it causes to the satellite signal that is comparatively weak, after travelling 36,000 km from space to Earth.

As a result of this policy, and in spite of the European Union's decision that the two technologies should share the band, some EU member states stopped giving C band licenses to satellite operators, concluding that sharing between the two services does not work. The decision to allow sharing of satellite spectrum therefore inadvertently jeopardized the future growth of satellite communications in a satellite spectrum band that has important and unique characteristics.[27] This band is used in different parts of the world to provide essential services including cellular backhaul, broadcasting, navigation, air traffic control, disaster relief, humanitarian aid, and search and rescue services.

Conclusion

As the public's appetite for high-speed, high-quality and low-cost data access surges, we will need to turn to a variety of technologies to meet these demands. The case studies above illustrate the multifaceted role of satellite in meeting these needs, from connecting isolated communities to broadband, to delivering high-quality TV in the latest digital formats.



Improving access to education with space technology

Snapshot

The problem
Many people living in remote, rural and sparsely populated areas, often in developing countries, face a "digital divide" that accentuates the inequalities between those who do and don't have access to educational resources.

The space-based solution
Cost-effective satellite-enabled distance-learning programmes that function independently of ground-based infrastructure ensure connectivity across physical boundaries. They increase access to education everywhere in the world and so help bridge the gap between the haves and the have-nots.

Sample applications
Case study 1: EDUSAT - Education in India
Case study 2: The African Virtual University
Case study 3: Satellite operators step up for South Africa
Case study 4: Brazil
Case study 5: Worldreader.org - Creating a literate world
Case study 6: China - Using TV for education

Introduction

In the past, space-based technologies were mainly considered ancillary tools for rich countries. Today they are finding real purpose in the developing world, with some of their most promising applications rooted in education.

In remote, rural and poor communities with limited infrastructure, providing affordable access to education is a great challenge. With space-based satellite technology, it is possible to bring broadband internet access to these communities, reaching students and teachers who would otherwise be left behind in the quest for a basic education.

The technology and its applications

One of the most promising and well-established educational applications of satellite-based technology is distance learning. Thanks to distance learning technology, high-quality educational institutes can share their resources with underserved counterparts, and "train the trainer" programmes can be set up remotely to ensure that teachers everywhere have access to the curricula, tools and highly skilled assistance they need.

The many satellite applications that are helping improve the quality of and access to education are outlined in Table 2.

Table 2: Satellite applications in education[28]

Educational activity	Broadcast	Interactive television	Data broadcast	Internet access	One- and two-way interactivity	VSAT network
Accessing digital library resources				X	X	X
Receiving material	X		X	X	X	X
Communicating with teachers		X		X	X	X
Communicating with peer learners		X		X	X	X
Sending assignments				X	X	X
Group work		X		X	X	X
Exams				X	X	X

One example of this technology in action comes from the Democratic Republic of Congo, where radio stations in rural areas broadcast educational programmes to farmers in their local language. Qualified trainers prepare content, which is multi-cast to rural radio stations via satellite links. The radio stations then broadcast the programme locally and farmers receive it on traditional FM radios. Rural radio stations also produce some local content themselves and share it with other neighbouring radio stations through a cloud system enabled by satellite communications.

Another example is in Australia, where satellites are being used to increase broadband access and bring learning and other opportunities to Australians who live outside urban centres. [29] Thanks to this technology doctors from universities have been able to give virtual lessons in medical pathology, and firefighters and rescue workers have provided remote training to over 6,000 firefighters across New South Wales. Regional fire crews can now receive real-time feedback via livestreaming video camera technology, saving the time and money spent on face-to-face training.

The technological capabilities and the potential uses for satellite broadband technology in the field of e-learning are growing at an exponential rate and development costs are declining. Though certainly not free, the cost of setting up and maintaining e-learning programmes can often be lower than with traditional educational infrastructure, particularly in remote areas and in communities with large numbers of students.

Case studies

Case study 1: EDUSAT - Education in India

India began experimenting with tele-education in 1975, with the assistance of a number of United Nations agencies. In 1983, India commissioned its home-grown satellite constellation, the India National Satellite Systems series (INSAT), which among other things broadcasts tele-education and tele-health programmes. The successful use of INSAT, as well as the PALAPA satellite in Indonesia and AUSSAT in Australia, have encouraged other countries like Brazil, China and Mexico to also develop their own satellite-based educational systems.[30]

In 2004, India launched the first-ever satellite dedicated to education, EDUSAT. The satellite provides one-way TV broadcasts, interactive TV, video conferencing, computer conferencing and web-based instruction for elementary, secondary, university and specialized educational centres. The satellite and long-distance education services are a joint venture of the Indian Ministry of Human Resource Development and the Indian Space Research Organization, and are implemented through the Indira Gandhi National Open University, the All India Council for Technical Education, the Indian Agricultural Research Institute, the National Council for Educational Research and Training, and the University Grants Commission. Nearly 4,000 interactive classrooms have two-way audio/visual and around another 31,000 receive one-way broadcasts.[31]

Case study 2: The African Virtual University

The African Virtual University (AVU) is a satellite-based distance education and e-learning programme with the goal of enabling sub-Saharan African countries to access international educational resources, increasing the number of university students, and supporting sector-specific training of professionals. An initiative of the World Bank in 1995, the AVU currently has 15 member states and a network of more than 50 partner institutions in 27 African countries.[32]

One example of the programme in action is from Somalia, where the AVU installed VSAT systems in several universities, allowing them to access the internet via satellite links.

Case study 3: Satellite operators step up for South Africa

There have been several cases of satellite operators partnering with organizations to increase access to education.

For example, Intelsat, a satellite operator, partnered with the Mindset Network, a South African non-profit dedicated to providing quality educational resources to underserved communities. Through the partnership, Intelsat provides free satellite bandwidth for Mindset's video content for teachers, students, healthcare workers and patients, out-of-school youth and the general public. Content includes information about HIV/AIDS and tuberculosis, as well as science, maths, IT and English.[33]

Another example is the Sway4Edu project of the European Space Agency and SES, a satellite operator. The project provides educational services for teachers and trainers in South Africa through e-learning courses with qualified tutors. It is set up to provide three main services: radio programmes to teach farmers in rural areas about sustainable agricultural development; e-training for electoral management bodies of the Economic Community of Central African States to support their electoral cycles; and a programme called Space4Education, which develops e-learning services for rural schools in South Africa.

The final example is the partnership between Inmarsat, a satellite operator, and Pearson, an education publishing service. In 2013, the two companies launched an e-learning pilot project. Inmarsat's global 3G satellite network was used to extend the availability of Pearson's e-learning platform to areas with little or no internet connection. Teachers could use the e-learning platform to access digital content such as lesson plans and educational material. Students could use the platform to download supplementary material, upload assignments and take online tests.

Case study 4: Brazil

In Brazil, distance education at university level began in 2003. By 2010, 950,000 students in the country were enrolled in a distance learning programme via satellite and internet, and it is estimated that by 2018, this number will reach 3.1 million.[34] The Brazilian Association for Distance Education is just one of many distance learning providers in the country. It works to promote scientific interchange in distance education and e-learning. It also provides information for Brazilians seeking distance education courses, provides professional training opportunities and holds events for professional educators using distance teaching methods.[35]

Case study 5: Worldreader.org - Creating a literate world

Worldreader's mission is to eradicate illiteracy among the world's poorest people. It does so by providing access to books through feature phones and by bringing e-readers to primary and secondary schools. As an internet connection is needed to download content, Worldreader has been partnering with a satellite service provider so as to expand its reach and bring this invaluable literacy tool to Africa and other developing nations.

Case study 6: China - Using TV for education

In China, satellite-assisted educational TV channels have been around since the launch of CETV-1 in 1986. This was followed by CETV-2 in 1988 and SEDTV in 1995. However, the use of satellite technology for education really progressed in 2000 with the introduction of CEBSat, a multimedia platform for selecting courses, recognizing credits and sharing teaching resources among universities.

By 2007, this satellite system covered 98 universities in the country. More than 10,000 satellite students have benefitted from the Western China Project and 530,000 schools were covered in the Rural Area Project.

Conclusion

Nearly 122 countries have agreed to the United Nations Millennium Development Goal of achieving universal primary education by 2015. In spite of this, improving the quality and reach of education continues to be a global challenge.

As the above case studies show, satellite technology can play a large role in tackling this challenge. Satellite-based distance learning can help students in remote areas access education and training at all levels, can provide training for teachers, and can make a variety of high-quality educational resources available to all.

Space technology and healthcare

Snapshot

The problem
In order to provide high-quality healthcare to as many people as possible around the world, we need innovative healthcare technology and delivery methods.

The space-based solution
Telemedicine enabled by space satellites and geographical information systems (GIS), scientific research and space spin-offs are providing new ways to improve human health.

Sample applications
Case study 1: MMC's Global Telemedicine and Teaching Network
Case study 2: WHO's GIS-enabled HealthMapper
Case study 3: NASA's Space Station ultrasound spin-off for use in developing countries

Introduction

Space technologies and research have had a big impact in the area of human health. Space assets - particularly communication satellites and GIS - allow healthcare to be delivered remotely, particularly in low-resource environments. In addition, decades of research into how the human body reacts in the extreme space environment and the need for innovative medical treatment for astronauts have resulted in health technology breakthroughs that benefit us all.

The technology and its applications

Telemedicine

Telemedicine is the use of two-way telecommunications technology, multimedia and computer networks to deliver or enhance healthcare. It allows for the transferring of expertise rather than people: medical staff can perform tele-consultations and tele-diagnostics, and can provide remote training, sharing their medical expertise with isolated and often understaffed areas.

With the developments in telemedicine, hand-held ultrasound smartphone applications could be used to provide real-time imaging from battlefields to trauma surgeons halfway around the world; patients in remote villages can be tested for HIV and their results can be synchronized with central healthcare records;[36] and seriously ill patients can avoid having to travel long distances to the hospital and can instead be monitored from their home, providing their doctor with virtual access to their health records and vital signs.

As other technologies evolve, electronics undergo further miniaturization, mobile devices become more powerful and costs decrease due to scale, telemedicine will become increasingly sophisticated.

GIS and public health

EO satellites, GNSS and communication satellites can provide early warning of the outbreak of diseases. By tracking the environmental parameters that can lead to the spread of diseases (e.g. temperature, dust, rainfall), public health professionals can monitor disease paths and anticipate their movements before they hit.[37]

When space products are integrated with metadata such as hospital admission records and police reports, the resultant GIS maps and interactive multi-variable displays can help healthcare professionals and policy-makers better understand the distribution of health and disease, allowing them to make better decisions.

Medical research

The microgravity environment of space makes it an excellent biological laboratory. Cells and microbes behave differently in space. Monitoring reactions and processes in the absence of the gravity variable - which can mask subtle observations - can lead to a better understanding of infectious diseases and the human immunoresponse to them.

Scientists have been studying the effects of microgravity on astronauts in orbit for some time. For example, research into the loss of bone and muscle mass while in space has yielded invaluable data that can help the diagnosis and treatment of patients suffering from muscle wasting diseases and bone density conditions such as osteoporosis - specifically, the link between mechanical loading and tissue remodelling or deterioration.[38] The International Space Station is where the best scientists on - and off - Earth are performing these experiments.

Health technology spin-offs

Many of the technologies and materials developed for space applications often find uses in the field of health, even if not originally intended for medical purposes. Some examples include:

- Hubble CCDs for biopsies: Charge-coupled devices (CCDs) are used on the Hubble Space Telescope to convert a distant star's light directly into digital images. Many of NASA's enhancements to CCDs have been applied to digital mammography biopsy techniques. As a result, CCDs can be used to image breast tissue more clearly and efficiently.[39]
- Rocket engine technology and cardiology: The MicroMed DeBakey VAD is a life-saving heart pump for patients awaiting heart transplants. Designed by combining supercomputer simulation of fluid flow through rocket engines and cutting-edge medical industry collaboration, the device pumps blood through the body to keep critically ill patients alive until a donor heart becomes available.[40]
- Other health-technology space spin-offs include programmable pacemakers, micro-transmitters to monitor the foetus inside the womb, laser angioplasty, fibre-optic catheters and light-emitting diodes (LEDs) for use in brain cancer surgery.

Case studies

Case study 1: MMC's Global Telemedicine and Teaching Network[41]

The Medical Mission for Children (MMC) developed the Global Telemedicine and Teaching Network (GTTN), a real-time videoconference and satellite broadcast communications platform. It has two key functions: the real-time diagnosis and treatment of critically ill children in remote areas and the education of the global healthcare community. Incorporating a sophisticated telecommunications infrastructure, this ever-expanding network integrates audio and video technology to produce high-quality, high-definition content for medical education. Each GTNN endpoint is provided with all the video, remote diagnostic and communications connectivity technology they need, including internet, satellite communications, a broadcast signal and 3G and 4G cellular networks.

Remote diagnostic instruments such as telephonic stethoscopes allow a paediatric cardiac specialist to accurately assess a child's heart from thousands of miles away. The MMC has also created the Telemedicine Outreach Program - a network of 27 tier-one mentoring hospitals in the United States and Europe linking to hospitals and institutions in more than 100 countries.[42] MMC has developed a knowledge transfer bridge connecting hundreds of the best medical specialists to healthcare professionals from underserved communities across the globe, allowing these doctors to access the resources they need to best serve their patients. In 2006, GTTN partnered with the World Bank's Global Distance Learning Network, expanding its reach even further.[43]

Case study 2: WHO's GIS-enabled HealthMapper

Developed by the World Health Organization and UNICEF in 1993, the HealthMapper is a surveillance and mapping application designed for public health professionals that "aims to address critical surveillance information needs across infectious disease programmes at national and global levels."[44] The GIS-enabled system facilitates the collection and updating of data on epidemiology and interventions, providing immediate visualization of data in the form of interactive charts, maps and tables.

The HealthMapper is available to public health workers at low or no cost and operates at both local and global levels. It has a simple and user-friendly interface and includes a standardized database containing indicators essential to public health such as basic population data, healthcare facilities, accessibility by road and environmental factors (e.g. water sources, elevation, etc.). The system is currently being used to support a range of infectious diseases in over 60 countries.

Case study 3: NASA's Space Station ultrasound spin-off for use in developing countries[45]

Astronauts on the International Space Station have limited medical diagnostic equipment, as there is not enough space for big scanners and X-ray machines. NASA therefore set out to develop a portable ultrasound diagnostic that could be operated remotely in space by astronauts.

Prior to these experiments, ultrasound was not common in diagnostics. However, because it utilizes the reflection of sound waves rather than electrons, ultrasound is cheaper, smaller and more lightweight than X-ray, and does not expose the patient to unnecessary radiation.

After receiving just four hours of training – compared to the hundreds of hours ultrasounds physicians would typically receive – astronauts on the International Space Station carried out the experiments. Satellite downlinks transmitted the diagnostic-quality images to experts on the ground, who were able to guide astronauts to specific imaging targets. The team showed that remote-guided ultrasound could be an effective method of diagnosis, thereby advancing telemedicine.

The technology has been applied to two commercial products: DistanceDoc[46] and MedRecorder, external video frame grabbers that allow a remote ultrasound operator to transmit images securely over the internet in real time and at near-original resolution. Both products are being used in developing countries to monitor maternal health, traumatic injuries and infectious diseases. In April 2013, this successful technology spin-off was inducted into the 2013 Space Technology Hall of Fame, which recognizes world-class technologies repurposed into products that improve the quality of life on Earth.

Conclusion

Space satellites, research and technology are not only advancing human knowledge and capabilities in space, but are also providing health benefits here on Earth. These advances, which have been both intentional and accidental, have enriched mankind's understanding of the human body and created new opportunities to provide quality healthcare to patients across the globe.

Precision agriculture and food security

Snapshot

The problem
Food security concerns - such as global population growth, limited production resources and global climate dynamics - mean we have to continually find ways to feed a growing and developing world.

The space-based solution
By providing navigation, communication and data acquisition (Earth observation, EO) capabilities, space-based technologies enable the adoption of new, innovative, and more efficient farming practices on a global level.

Sample applications
Case study 1: Navigation
Case study 2: Communication
Case study 3: Earth Observation

Introduction

Whenever we talk about some of the world's most pressing concerns, such as energy, the environment or the economy, the issue of food security is never far behind.

Food security is when people can access, at all times, enough safe, nutritious and culturally acceptable food to allow them to live healthy and active lives.[47] According to a report from the Food and Agriculture Organization (FAO) of the United Nations, there were almost 870 million undernourished people in 2012, mainly in Africa and Asia.[48] This figure suggests we are far from having achieved universal food security.

The issue of food shortages is a complex one, with the most common factors being projected global population growth, limited production resources and global climate dynamics. However, the bottom line is that we need to start producing more while simultaneously reducing our impact on the environment and ecosystems.

Space-based technologies are helping to do just that and have led to the emergence of what has been called "precision agriculture" or "smart farming". These technologies have allowed producers to find new and efficient ways of dealing with the economic, environmental and societal challenges of food production.[49] They have helped increase crop yield, reduce environmental waste of commonly overused chemicals, and have led to an emergence of new high-tech professions in traditionally conservative rural communities worldwide.

The technology and its applications

Precision agriculture is based on whole farm management, with the goal of optimizing returns on inputs while preserving resources. By providing navigation, communication and data acquisition (Earth observation, EO) capabilities, the space-based segment of smart farming technologies is one of the most important set of tools in the adoption of new and innovative practices.

Satellite-based navigation

The most widely adopted application of precision agriculture technology has been GNSS-based automatic guidance of agricultural tractors and self-propelled machinery.[50] This is due to its relatively straightforward implementation by end-users, and its proven benefits such as better ergonomics, reduced use of agricultural inputs and the improved logistics of crop farming operations.

Communication

Users of GNSS equipment in agriculture rely on both signals from satellites and the real-time differential correction signals that may be sent either via satellite or ground stations. Various forms of telecommunication have been used to transfer operational and agronomic data between individual farm machines and centralized management or technical support providers. For instance, large producers can now track and manage fleets of farm equipment and employees in real time. They can also remotely upload field-specific tasks to employees and download reports directly from the field, saving time and human resources. In addition, telemetry has enabled precision livestock management and specialty crop production systems.

Data acquisition and Earth Observation

EO satellite services, whether they provide radar, optical or thermal imagery, cover relatively large sections of land in a consistent and repeatable manner and can provide useful information on not only the visible spectrum but also portions of the spectrum outside of what humans can see. Data from many satellite platforms are collected and archived for several decades; this allows for the observation of year-to-year changes in land use and vegetation coverage over time, revealing important data on land productivity.

Satellite-based information products have also been used to observe the differentiation of crop growing conditions (which affect water, carbon and nitrogen cycles) and monitor diseases in crops and other external factors.

While applications such as crop inventory and watershed-level planning require large coverage areas with low resolution, operations on the individual field level need small coverage areas with high spatial resolution. Using the data, producers can evaluate conditions such as water storage and soil productivity, and pursue site-specific management of their key inputs. For example, irrigation water can be distributed according to the current soil water status or the soil-based water storage capacity. Mineral fertilization can be differentiated in accordance with biomass removal derived from historic productivity data, or potential soil productivity derived predominantly from bare soil imagery.

Food production faces significant constraints as a result of global water scarcity, particularly in arid and semi-arid areas. Satellite images are excellent tools for freshwater exploration and management.

For example, Jordan, a semi-arid country, urgently needs to manage and utilise its water resources if it is to meet its immediate and projected demand for water. 43% of the water supply there comes from groundwater sources. As a result, finding new sources of groundwater and managing its use is fundamental to Jordan's long-term water strategy.[51]

Case studies

Case study 1: Navigation

Wherever agricultural production is mechanized, it is difficult to guarantee that every field operation covers the entire field with no overlaps. In response to this, GNSS-based navigation has become one of the best-selling smart farming tools. Depending on the area and shape of the field and the size of equipment, producers can save up to a quarter of their input by avoiding overlaps. While operators of tractors and farm machinery in large-scale production use complete auto-guidance systems, small-scale agricultural operations can use visual navigators, such as light bars.

Case study 2: Communication

When several hundred machines and several thousand employees are engaged in a single agricultural production system, it is essential to have real-time data transmitted by satellites to provide the location and status of everyone involved. Doing so allows more efficient management of resources in view of changing weather and other stochastic challenges. Even individual farmers can benefit from the fact that the technical condition of their vehicles is watched by a dealer, performance of their crops is monitored by a crop adviser, and professional advice can be obtained from the most qualified service providers thousands of kilometres away.

Case study 3: Earth Observation

Satellite-based imagery has become a valuable tool for the rapid recognition of landscape heterogeneity and development of site-specific management schemes. Although well-established in North and South America, Europe, Australia and South Africa, service providers have started to expand their operations to other parts of the world. Satellite images are useful in finding new sources of groundwater and in facilitating irrigation practices.

Current constraints, future improvements

Despite all that this technology has to offer, there are some limitations and concerns. One area of concern relates to the accuracy and reliability of positioning. However, new receivers that can process both GPS and GLONASS signals could provide a solution, and new satellite navigation systems, such as the European Union's Galileo and China's Beidou, will further increase positioning reliability.

Other developments, such as large-area augmentation and measurement improvements that decrease guidance error to less than 2 centimetres,[52] are also improving positioning accuracy. These developments are providing opportunities for innovations such as robotic agriculture, allowing parts of a machine to be operated by remote control. This means that producers can conserve resources by switching off particular tools when they are not needed, such as between field passes and when crossing non-productive parts of the field.

Another area of concern relates to the large masses of data needed for the computation-intense processing involved in these technologies. In the future, this will no longer be an issue thanks to cloud computing and advanced data handling methods such as hierarchical clustering of multispectral imagery data to delineate crop productivity zones.

One final issue is the fact that raw satellite data is a limited indicator that must be calibrated to local conditions. To resolve this problem, researchers have been focusing on data fusion - combining the satellite data with other technologies and techniques such as proximal soil and crop sensing, temporary monitoring, and traditional sampling and laboratory analysis.[53] The development of satellite image-based zones of differentiated field management is an example of the data fusion process. These zones subdivide an agricultural field into areas with different productivity histories. Proximal soil sensing data, such as maps of apparent soil electrical conductivity or field topography, are used to confirm or modify delineated zones according to the probable natural cause of crop production variability. This process is then completed by obtaining soil samples to represent different zones and to utilize prior agro-economic knowledge to define the best site-specific practices to be implemented.

Conclusion

Space-based technologies such as navigation, communication and data collection are playing a crucial role in revolutionizing modern agricultural production, making it more cost-effective and resource-efficient than ever before.

Space technology and other advanced communications technologies are also helping to generate the information needed to better identify those most at risk of food insecurity, to more efficiently address their demands, and to improve the monitoring and evaluation of any intervention.

Although the technology still has some constraints, more and more people in the agribusiness are relying on satellite-based products, and the technology offers many promising opportunities.

Using space technology to protect human rights

Snapshot

The problem
Human rights abuses are often difficult to track, dangerous to investigate, and when reported, full of conflicting and unverifiable data. These constraints make it challenging to decide if, how and when the international community should intervene and prosecute those who violate human rights.

The space-based solution
Human rights and humanitarian organizations can combine "eyes in the sky" – Earth observation (EO) tools, such as high-resolution satellite imagery – with GIS and eyewitness reports from the ground to raise public awareness, support international monitoring, and assist key actors in deterring and responding to human rights violations.

Sample applications
Case study 1: The Second Chechen War
Case study 2: North Korea
Case study 3: Sudan
Case study 4: Zimbabwe
Case study 5: Nigeria
Case study 6: Communication

Introduction

In the past, human rights violators largely went unpunished, mainly because of how easy it is to refute victim testimony, the inability of the international community to adequately monitor abuses, and the resulting failure to intervene.

In 1999, commercially available, high-resolution satellite imagery was used for the first time to uncover mass graves in Kosovo.[54] Since then, there has been a growing understanding of the role this "eyes in the sky" technology can play in detecting human rights violations, particularly in areas where it is difficult or dangerous to collect intelligence on the ground. Today, geospatial imagery is being used more and more by NGOs to assess threats to human security.

Support for such use of the technology goes back as far as the 1986 United Nations Principles Relating to Remote Sensing of the Earth from Space, which encouraged the use of EO satellites.[55] When combined with telecommunications capabilities that enable gathering and sharing of real-time crowd-sourced intelligence, space-based technologies are revolutionizing the field of human rights advocacy and protection. The use of satellite Earth observation data to generate evidence in the adjudication of human rights violations has become a key part of the international judicial system.[56]

The technology and its applications

A range of space-based technologies allow for the observation, tracking and analysis of human rights violations. These include EO satellites, GIS, GPS, and satellite communications.

For example, high-resolution EO satellites can track spatial and temporal shifts in climate, vegetation and rainfall in a given region. GIS allows for the integration of hardware, software and data for analysing and visualizing geographically referenced information in order to reveal patterns and trends by mapping the temporal shifts in map features. This can be used to track key changes such as the physical destruction of villages over time, the movement of vulnerable populations, or the growing appearance of military infrastructure and weapons.

Satellite communications, especially via VSAT, allow users to bypass traditional means of communication and the arbitrary restrictions imposed by oppressive authorities. For this reason, satellite communication tools are becoming more widely used by citizens, particularly in authoritarian countries.

Table 3 outlines some key areas in which space technologies can aid in the monitoring, protection and exercise of human rights.

Table 3: Space technologies and human rights

Monitoring and evidence collection	Satellite imagery can provide policy-makers and tribunals with independent, objective and verifiable evidence of human rights violations. The data can be used both as a secondary source (i.e. substantiation/challenging of eye-witness testimony), as well as a primary source when on-the-ground intelligence is not available or is too dangerous to obtain. These technologies are critical for rapid responses to developing crises, long-term monitoring of adherence to post-conflict agreements, and in prosecuting violators of human rights.
Enforcement strategy	The near-real-time capacity of satellite sensors to provide detailed imagery allows policy-makers to make timely decisions concerning international intervention. It also helps enforcement teams save time and resources by helping them identify and evaluate intervention sites prior to mission deployment.
Refugee tracking	The movement of internally displaced people and refugees is often a primary indicator of systematic violence. The use of satellite imagery to document widespread and systemic destruction of civilian infrastructure and to track the movements and numbers of dislocated populations provides human rights groups a tool for keeping a public eye on these populations. This aids efforts to protect their safety.
Environmental justice	High-resolution imagery allows detection of the environmental changes due to conflict and industrialization. These effects include heat dispersion due to industrial gas flaring, water movement, vegetation growth, livestock migration, toxic contamination, drought and famine.
Public awareness and communication	Telecommunications satellites serve as tools to inform communities and individuals of their rights, provide the infrastructure for reporting violations, and allow people to exercise freedom of expression. This is true even in low-resource areas and in places under regimes that censor information.

Case studies

Case study 1: The Second Chechen War

The release of commercial satellite imagery of the city of Grozny in March 2000 was the first use of open source satellite imagery to observe human rights violations.[57] The images, taken a month after the Russian army occupied the city during the Second Chechen War, show the near total destruction of several thousand buildings. The evidence of war crimes was detailed, graphic and irrefutable. Investigators could collect independent and objective data remotely from an active conflict zone without relying exclusively on potentially biased intelligence from parties to the conflict.

Case study 2: North Korea

In January 2013, the UN High Commissioner for Human Rights, Navi Pillay, said that North Korea had “one of the worst – but least understood and reported – human rights situations in the world”.[58] In response to these concerns, human rights organizations have used satellite imagery to observe political prison camps in North Korea,[59] where up to 200,000 people are believed to be held.[60] The camps’ inhabitants include political prisoners and children, and prisoners are believed to be victims of starvation, torture and other heinous humanitarian abuses.

Case study 3: Sudan

Over the past three years, the Satellite Sentinel Project (SSP) – a partnership between DigitalGlobe and the Enough Project – has fused satellite imagery and analysis with eyewitness reports, photos and videos from the ground, and open-source data to document evidence of mass killings in Sudan. The aim was to use this evidence to support a referral of war crimes and crimes against humanity being committed by the Sudanese government to the International Criminal Court (ICC). In September 2011, SSP issued a human security alert based on satellite imagery of Sudanese troops and heavy artillery massing in Sudan’s Blue Nile state. This early warning allowed civilians to flee hours before indiscriminate bombardment began. In December 2011, the ICC launched an investigation into war crimes committed by the government of Sudan, based largely on reports created from these analyses.[61] SSP has also documented what appear to be eight mass graves and

46 incidents of the deliberate burning of villages in remote areas of South Kordofan, Sudan.[62]

Amnesty International's Eyes on Darfur project makes use of satellite imagery to monitor attacks, track the movement of rebel groups, and raise awareness of conflict trends in Darfur and the rest of Sudan. The team was able to detect clear evidence of deliberate village burnings in Darfur, including when, how and where the destruction took place.[63] Given that access to Darfur is restricted, this data has become an essential resource for humanitarian advocacy and relief organizations.

Yale University also used satellite data to track the change to land cover from 1998 to 2007 in the regions of Darfur most impacted by the genocide.[64] The results indicate a return of natural vegetation (grass and shrubs), not as a result of increased rainfall, but rather abrupt change in land use directly tied to the loss of livestock and farming capability driven by human displacement.

Case study 4: Zimbabwe

In 2005, the government of Zimbabwe was denying the human rights abuses taking place under its Operation Murambatsvina - a programme of mass forced relocation of the urban poor to rural areas through the demolition of homes and businesses. Amnesty International and Zimbabwe Lawyers for Human Rights produced evidence of the abuse in the form of satellite images showing the destruction and forced relocation over time of the Porta Farm Settlement, which had once housed nearly 10,000 people outside Harare.[65] Such evidence of forced relocation can be used to help communities resist relocation or demand compensation for the taking of their land.

Case study 5: Nigeria

Despite the vast natural resources in the Niger Delta, residents continue to suffer from the consequences of oil spills, gas flaring and waste dumping, which are endemic in the region. Amnesty International's Eyes on Nigeria Project,[66] which uses EO technologies to monitor human rights violations in the country, responded to reports of multiple oil spills near the Niger Delta town of Bodo by obtaining imagery of the area that spanned from 2006 to 2011. Analysis of the terrain's near-IR reflectivity revealed that the area - nearly 3 square kilometres - had suffered almost complete vegetation death.[67] The result of environmental disasters such as this is widespread poverty, high unemployment, illness and lack of access to adequate clean water and healthcare. Space-based EO allows projects such as Eyes on Nigeria to identify the locations of environmental injustice, and hold accountable those firms that profit from irresponsible resource extraction.

Case study 6: Communication

As was well documented during the Arab Spring, access to internet and mobile phone technologies enabled by space-based communications satellites allows people everywhere to express their thoughts and to share information on injustices and human rights violations. During the Arab Spring, activists were able to avoid government censorship and use social networks to inform their compatriots about protest locations, provide advice on areas to avoid, and share with the rest of the world what was happening in their towns and cities.

Another example of space-based technology being used in support of human rights is a satellite TV channel launched by Iraq in 2012. The purpose of the channel was outlined in a statement from the Iraqi Human Rights Ministry: "Through this television station, we shall try to define these rights and increase national public awareness about relevant international agreements and conventions [as well as about] what the Iraqi constitution ensures in its chapter on rights and freedoms."[68]

Limitations and constraints

While EO has revolutionized the humanitarian and human rights fields, it is not without limitations. For example, most imaging satellites cannot see at night or peer through dense cloud cover, unless they are equipped with additional sensors that detect changes through the use of infrared, lasers or radar. Even then, laser and radar data is not widely available or easily interpreted. Generally, this limits sensing capability to particular geographical areas and to times of the year when the weather allows for adequate visibility. Satellites also lack the resolution to adequately detect smaller, poorly armed militia groups (who might use rocket-propelled grenades as opposed to tanks), particularly in asymmetric conflicts.

There are also cases where satellite imagery has been used to provide inconclusive, ambiguous and even erroneous results that have misled investigators. One such example is the now discredited interpretation of evidence of weapons of mass destruction presented by US Secretary of State Powell at the UN Security Council in the lead up to the Iraq War.[69]

And while open source tools such as Google Earth are heralded for their accessibility, certain states – especially those whose governments perpetrate human rights abuses - block access. Even when access can be gained, interpretation of the data requires the help of experts, which may be difficult and expensive to come by.

The result of these limitations is a distorted perception of the capabilities of the technologies and sometimes unrealistic expectations in the international humanitarian community. There is a need for more systematic documentation and dissemination of best practices, lessons learned and open debate about the pros and cons of the technology, and the easy and timely availability of accurate data from neutral sources.

Conclusion

From verification of militia violence to the facilitation of open communication infrastructures, space-based technologies such as EO satellites, GIS, GPS and telecommunications are becoming more and more critical to the detection, monitoring and enforcement of human rights everywhere. In conflict zones, these "eyes in the sky" can be used both to support/challenge ambiguous reports from the field and as an independent objective tool when it is too dangerous or politically contentious to collect on-the-ground intelligence. And while the technologies do have their limitations, the ability to remotely observe the effects of conflict and oppressive governments has revolutionized the field of humanitarian law, and empowered human rights organizations to protect vulnerable populations in ways never before possible.

Climate change and space

Snapshot

The problem
Climate change - which affects freshwater resources, global food production, sea levels and human security - is one of the biggest concerns facing humanity.

The space-based solution
Satellites provide researchers and policy-makers with vital information about the Earth's climate system, enabling the monitoring, prediction, modelling and implementation of mitigation and adaptation measures.

Sample applications
Case study 1: ESA Climate Change Initiative
Case study 2: Copernicus Climate Change Service
Case study 3: Monte Rosa Glacier, Italy

Introduction

Climate change is one of the greatest collective challenges we are facing. Its importance has been recognized in several reports from the Intergovernmental Panel on Climate Change (IPCC),[70] the United Nations Framework Convention on Climate Change (UNFCCC),[71] and the overwhelming economic consequences were laid out in the Stern review.[72]

Climate change is affecting our capacity to produce food and manage freshwater, and is dangerously increasing sea levels. There will almost certainly also be consequences for people's security: diminishing resources has the potential to increase local and regional instability, resulting in tensions and conflicts. These disrupted ecosystems and food resources may induce mass migrations, creating major challenges for both displaced persons and the areas to which they move.

The dominant processes related to climate change occur throughout the entire Earth system and have very varied results – from short-term relatively local extreme weather events (e.g. hurricanes, floods, etc.) to long-term large magnitude developments (e.g. deforestation, desertification, etc.). This problem is global, and therefore the solution must be as well. While climate change has been high on national and regional agendas worldwide, by using satellites positioned in space, we are now able to observe and address the problem on its proper global scale.

The technology and its applications

Space-based technology provides important information that helps to understand and manage climate change.[73] Satellites, with their ability to provide global coverage and continuous measurements, give researchers vital data on the planet's climate system, which contributes to climate change monitoring, prediction and the development and improvement of climate models.[74] Satellites also help put in place and monitor mitigation and adaptation measures, such as environmental conventions and international agreements.

The primary areas of satellite-based Earth observation include:

- Meteorology
- Oceanography
- Land cover
- Soil moisture
- Ice caps and glaciers
- Atmosphere: ozone, clouds, aerosols, greenhouse gases, etc.

By combining in situ and aerial data with space-based optical systems, radar, lidar and altimeters, the full range of observation and measurement services can be realized. These efforts are supported by the development of:

- Operational systems such as meteorology and oceanography
- R&D systems such as the European Space Agency's (ESA) Earth Explorers
- Earth observation applications and services for climate such as the European Global Monitoring for Environment and Security (GMES)

Case studies

Case study 1: ESA Climate Change Initiative[75]

In response to the need for climate-quality satellite data, ESA set up the Climate Change Initiative (CCI). The programme, which will run from 2009 to 2106, aims to realize the full potential of the long-term global Earth observation archives that ESA, together with its member states, has established over the past 40 years. This will be an important contribution to the essential climate variables (ECV) database, which is required by the UNFCCC.[76] (See below for more information on ECVs.)

So far the programme has generated datasets from multi-sensor satellite missions for a range of ECVs.[77] The CCI is also using Europe's Earth observation space assets to exploit international ECV records, such as greenhouse-gas concentrations, sea-ice extent and thickness, and sea-surface temperature and salinity.[78]

Case study 2: Copernicus Climate Change Service[79]

The Copernicus Climate Change Service (previously known as GMES), is an EU-developed service designed to respond to environmental and societal challenges associated with human-induced climate change. It benefits from a sustained network of in situ and satellite-based observations, re-analysis of the Earth climate and modelling scenarios, and is based on a variety of climate projections.

By providing access to information for monitoring and predicting climate change, Copernicus will support adaptation and mitigation. Several climate indicators will be made available (such as temperature increase, sea level rise, ice sheet melting and warming up of the ocean) as well as critical climate indices (such as temperature records, precipitation, drought events) for both the identified climate drivers and the expected climate impacts.

The primary users of Copernicus are expected to be policy-makers and public authorities. They can use the service to develop climate policy and legislation, and help with decision-making in the event of emergencies such as climate-related natural disasters.

Case study 3: Monte Rosa Glacier, Italy

Because of climate change, glaciers are starting to melt, threatening to flood communities nearby. In Macugnaga, Italy, one glacier created an ephemeral lake, which threatened to overflow and affect residents of a neighbouring town. By installing a satellite link on nearby Monte Rosa, experts were able to constantly monitor the melting glacier using video surveillance and other communications technology.

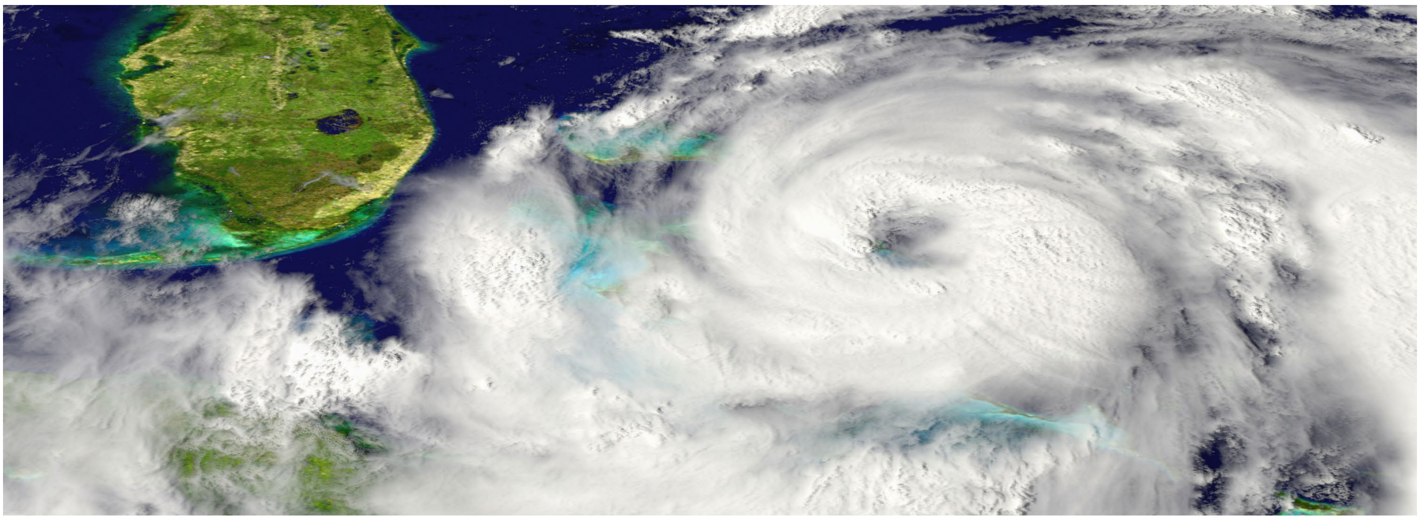
Limitations and constraints

While space assets are invaluable resources for climate observation and management, they do have their limitations. First, satellite data is often limited by a lack of homogeneity and continuity, and by insufficient understanding of the products and their uncertainties. In addition, the data is not always adequately preserved over long periods of time, making it difficult to put together a reliable long-term record.[80]

To help overcome these concerns, over the past decade the Global Climate Observing System (GCOS), in support of the UNFCCC, has put together a set of requirements for satellite data to meet the needs of the climate change community. These are broken down into key parameters of the Earth's system - atmospheric, oceanic and terrestrial - and are known as essential climate variables, or ECVs.[81] The specifications for each ECV data product provide information on the global climate system and facilitate long-term climate monitoring.[82]

Conclusion

Climate change is a global challenge, and tackling it requires global solutions. Space satellites are able to view the entire planet and take continuous measurements, providing unparalleled opportunities for scientists to observe, predict and model the climate. They also allow policy-makers to monitor the implementation of international climate agreements. When combined with in situ field data, historical analyses and international cooperation, space-based technologies are proving to be a critical resource in the fight against climate change.



Space assets for Arctic governance

Snapshot

The problem
In the Arctic, climate change, rapid development and globalization call for new approaches to conservation, resource management and governance.

The space-based solution
Remote-sensing and communication satellites can be used to help develop Arctic infrastructure, to sustainably manage the Arctic environment, to aid scientific research and improve our knowledge, and to ease geopolitical tensions.

Sample applications
Case study 1: Satellites for measuring sea ice minima
Case study 2: Satellite outage reveals critical role in supporting remote communities

Introduction

The Arctic is home to nearly 4 million people and has a $230 billion a year economy, all under the jurisdiction of a multi-state consortium known as the Arctic Council.[83] Containing what is believed to be 30% of the world's untapped gas and 13% of untapped oil, analysts predict development investments in the Arctic may reach $100 billion within a decade.[84]

Over time, development and globalization have led to rapidly shifting conditions, both on land and at sea. Activities such as oil and gas development, shipping and commercial fishing are set to increase, and the impact this will have on the environment, indigenous populations and businesses is of concern. When this is combined with the warming of the climate and the resulting geographical changes, it becomes clear that the dynamics of this vastly understudied region must be better understood so that appropriate action can be taken. Dealing with these challenges requires scientific and technological approaches to conservation, resource management and governance. Space-based assets are key to addressing all these challenges.

The technology and its applications

Arctic infrastructure

As the Arctic warms, one result is a reduction of permafrost, making travel over land difficult and increasing the cost of maintaining ground roads. EO and weather satellites can help map and predict changing conditions, while satellite communications support remote operations and monitoring, potentially reducing the need for travel.

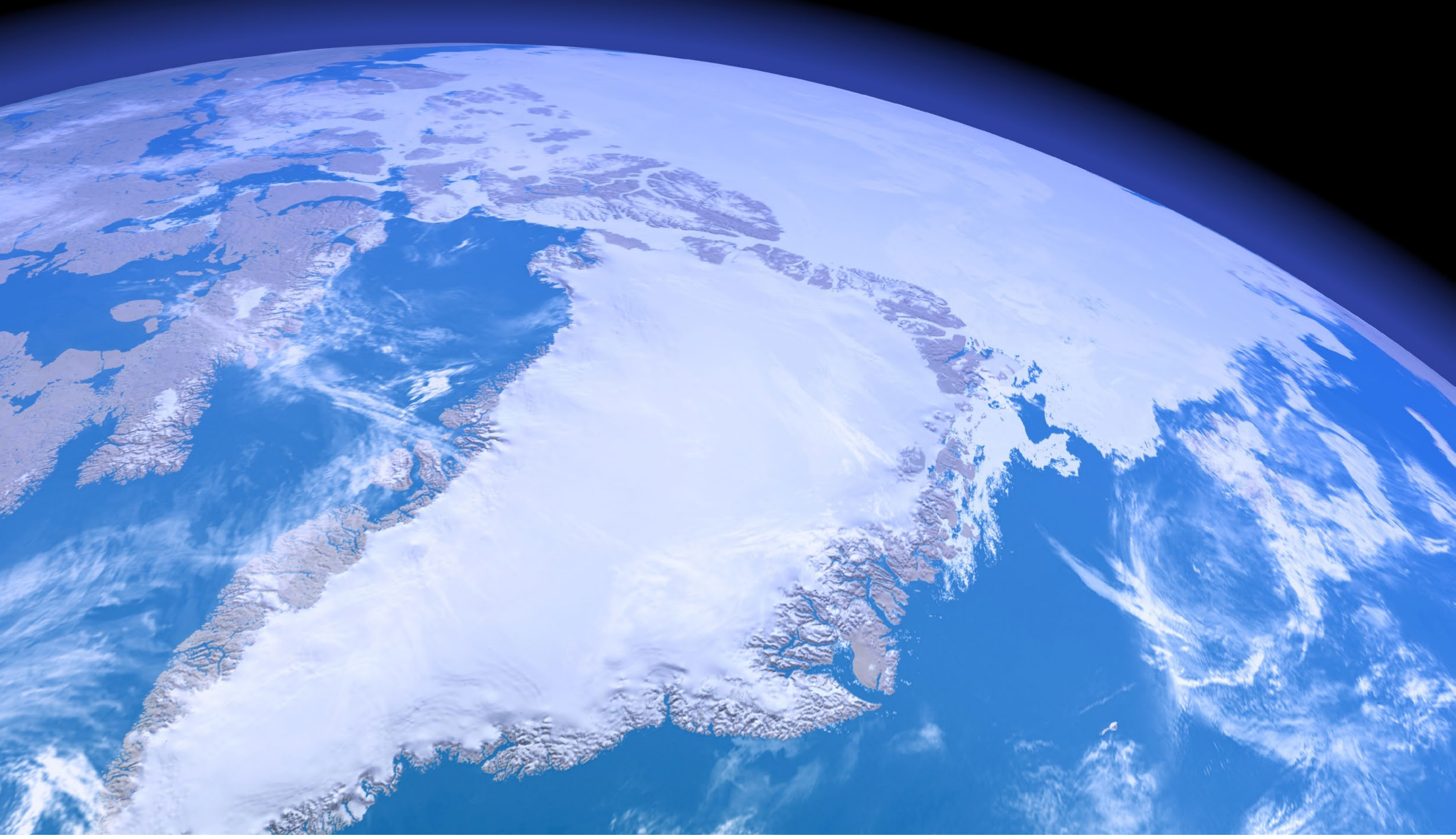
Space technologies can also provide critical communication links for maritime traffic, Arctic outposts and indigenous populations. Satellite communications and surveillance help ships, platforms, outposts and remote communities maintain communications, stay up-to-date on danger (e.g. weather), and deal with disasters by aiding search and rescue efforts.[85]

Satellites also provide the most effective means for monitoring sea ice, which is in a constant state of flux (retreating in summers and returning in winters).[86] Monitoring sea ice enables safer passage of ships across new, more efficient northern routes.[87] Taking an Arctic route between Asia and Europe is estimated to save about $800,000 per trip, reducing both transit time and per-trip emissions.[88]

Sustainable management of the Arctic environment

Outside of a few small areas, the vast majority of Arctic landscapes, oceans, ecosystems and climate have received little study.[89] Space assets can play a significant role in better understanding the Arctic environment and the impact of human interaction with the Arctic ecosystem to ensure that its development benefits the world while remaining fair and just to local indigenous communities.

Space-based EO can map and monitor short- and long-term changes in the Arctic environment, both natural and man-made. For example, EO can be used in the detection of accidents (e.g. oil spills) and support recovery efforts. It can also be used to monitor migratory animal populations through satellite tracking collars, which can provide important clues to changing environmental conditions.



Monitoring sea ice helps track the effects of climate change, as sea ice influences the heat transfer and gas exchanges between the atmosphere and the ocean. Satellite EO allows for temporal and spatial detection of changes in ice thickness, drifts, concentration and type.[90]

Geopolitical decision-making

As with most areas of the world, the Arctic is governed under existing national structures and international frameworks.[91] Just like those other areas, space-based capabilities can help provide information and knowledge to resolve governance disagreements and support collaborative decision-making and the creation of norms. For example, by allowing for more detailed surveying of the Arctic and mapping of boundaries, EO satellites can help resolve disputes regarding territorial and underwater claims that could otherwise spark tensions. Satellites can also monitor shipping traffic and development to forestall security concerns and aid in the development of norms that can improve safety and efficiency.

Case studies

Case study 1: Satellites for measuring sea ice minima[92,93,94]

The NASA-supported National Snow and Ice Data Center (NSIDC) is one of the most important research organizations in the world for tracking sea ice activity. Ice minimum records began in October 1978; over the decades they have been populated with data from multiple satellite missions, including the passive microwave data from NASA's Nimbus 7 satellite (1978-1987), ESA's CryoSat-2 (2010-present) and the Japan Aerospace Exploration Agency's GCOM-W1 satellite (2012-present).[95]

Case study 2: Satellite outage reveals critical role in supporting remote communities

In October 2011, the Anik F2 satellite, which provides coverage over northern Canada, malfunctioned and cut off communications to more than 30 communities in the Northwest Territories and Nunavut.[96] While the satellite operator was eventually able to restore services, the region lost long-distance calling, cell phones, broadband internet, television and ATM services for a whole day.[97] Although many other Anik F2 customers in Canada and the United States were affected by the outage, they were able to use other services such as landlines and mobile cell towers. For the isolated communities in northern Canada, this was not an option. These regions depend on satellite communications, as ground-based infrastructures are either financially or structurally infeasible due to harsh conditions, sparse populations and extreme routing distances.

Conclusion

Arctic economic development, resource exploitation and climate change require that the dynamics of this region be better understood, especially as outside interest in the region continues to grow. Space assets are helping researchers characterize the geography of this delicate ecosystem by tracking sea ice changes and assessing the impact of human development on wildlife, people and the environment. Satellites are also finding commercial value by helping to discover new trade routes, providing communication services to remote areas across long distances, and making sea and land navigation safer.

Sustainable management of forests, fisheries and water

Snapshot

The problem
Many of Earth's most critical natural resources - particularly forests, fisheries and water - suffer from misappropriation, mismanagement and unsustainable use. As a result, their long-term sustainability is at risk.

The space-based solution
Space-based technologies allow for improved observation, tracking and management of resource abundance, depletion and interventions.

Sample applications
Case study 1: Using degraded land for sustainable palm oil in Indonesia
Case study 2: Fisheries
Case study 3: Water resource management and prospecting in Morocco

Introduction

Many of Earth's most critical natural resources - particularly forests, fisheries and water - are being depleted. Information on the health of these resources, their value to communities and the negative impacts of their degradation or loss is essential if we want them to still be around for future generations. However, collecting and disseminating such data can be challenging.

One example of this depletion of natural resources is the current trend of clear-cutting primary forests in tropical regions to make room for agriculture. Primary forests are an irreplaceable source of biodiversity and are important carbon sinks. Every two seconds, an area of forest the size of a football pitch is lost due to logging or destructive practices.[98] In fact, 72% of Indonesia's natural forest landscapes and 15% of the Amazon's have already been lost forever.[99]

Illegal fishing and overfishing is a significant threat to ocean health. Illegal fishing provides between 12-29% of the wild-caught seafood in global markets.[100] In 2006, 27% of global fisheries were fully exploited, 25% over-exploited and 16% collapsed or closed.[101] Aside from the degradation of fish stocks, illegal fishing and overfishing can also damage the local economy in emerging and developing countries and force some people to pursue alternative sources of income such as piracy.

The sustainability of freshwater resources is also in danger. According to the United Nations,[102] out of a total volume of about 1.4 billion cubic kilometres of water on Earth, the volume of freshwater is around 35 million cubic kilometres, or about 2.5% of the total volume. Table 4 details the sources of freshwater on earth and their respective relative abundances.

Table 4: Locations and amounts of Earth's freshwater resources[103]

Location/form	Volume of all freshwater	Percent of all freshwater
Ice and permanent snow cover in the Antarctic and mountainous regions	24.5 million km^3	70%
Underground groundwater[104]	9.45 million km^3	27% (which is 97% of all freshwater available for human use)
Freshwater (lakes and rivers)	105,000 km^3	0.3%
Earth's atmosphere	13,000 km^3	.0317%

Total usable freshwater supply for ecosystems and humans:
about 200,000 km^3 of water - less than 1% of all freshwater resources.

Population growth, especially in environmentally sensitive areas along coasts, has put significant stress on the world's freshwater supply. In addition, the supply of water is disproportionately distributed across the world: Many people face critical shortages of water, and by 2030, approximately 47% of the world will be in that position.[105]

Being able to observe and track forests, fisheries and water resources makes them easier to manage and protect. Given the large areas of the planet that are affected, and the need to observe them constantly, space-based technologies can play a crucial role.

The technology and its applications

Agriculture is the leading cause of some 75% of global deforestation.[106] However, agricultural development does not require the destruction of primary forests. Instead, degraded land - land that has seen a decline in quality due to human activities or environmental changes - is a promising alternative. Up to 70% of the world's land is classified as degraded.[107] Focusing development efforts on degraded land instead of forests is a key part of sustainable development. Satellite imagery can provide the crucial link to help identify, visualize and discriminate between primary forest and degraded land.

Space-based capabilities can also provide data to help countries understand who is using fisheries and enforce sustainable management practices. According to a study conducted by the World Bank and the FAO, $50 billion in lost benefits could be saved each year if marine fishing were better organized and managed.[108] In order to manage such losses, several countries are using a combination of space-based capabilities to monitor their fisheries and enforce their management. Satellite communications can provide the capability to communicate with fishing vessels and the locations of larger ships can be monitored using the Automatic Identification System (AIS). Verification of ship activity and detection of unauthorized or illegal fishing can be carried out using radar imaging satellites.

With water management, traditional means of data collection such as fieldwork can be costly, difficult and resource intensive, especially in remote areas. Many organizations have supplemented their ground-based monitoring with the use of EO technologies. These technologies can be a cost-effective way of either replacing or complementing field data collection. Earth observation can also provide coverage over large and remote areas with systematic and repetitive data capturing, and can be integrated with in-situ real-time collected data to produce up-to-date predictive and analytical models.[109]

US Landsat satellites and French SPOT satellites have often been used for water-related applications. In addition, the introduction of synthetic-aperture radar-based satellites - especially those with high resolution and dual polarization - has revolutionized water mapping and management, marine surveillance and ice monitoring. Accurate digital elevation models are being developed to assist in determining water flows and flooding potential, and NASA's Gravity Recovery and Climate Experiment collects data that is used to determine surface mass and total water storage - which over land includes the sum of groundwater, soil moisture, surface water, snow and ice. Other successful applications of EO sensing technologies for water management include land cover and land usage mapping, wetland mapping, snow extent mapping and water quality monitoring.

Case studies

Case study 1: Using degraded land for sustainable palm oil in Indonesia

Indonesia is the world's leading producer of palm oil, with plantations covering more than 6 million hectares. Palm oil makes up 11% of the nation's annual export income.[110] However, a significant amount of prime forest was cut down to create the plantations, representing almost a quarter of global deforestation between 2009 and 2011.[111] Indonesia has taken significant steps to address this issue. In 2011 the government introduced a moratorium on the clearing of new forest, and recently announced an effort to use degraded land for palm oil production.[112] A combination of satellite data, aerial imagery and on-the-ground field visits was used to identify more than 14 million hectares of degraded land, enough to potentially support expansion of the palm oil industry over the next 20 years.[113]

Case study 2: Fisheries

New Zealand has put in place a vessel monitoring system (VMS) to monitor and enforce management of fisheries. First introduced in 1994, the system is now used to monitor more than 1,000 fishing vessels every two hours.[114] The VMS uses GPS to pinpoint a vessel's location, which is then reported over satellite communication links. The same communication links also allow fishing vessels to report catch efforts. All of this information is used by the country's federal agencies to determine whether a vessel is fishing in closure zones.[115]

Case study 3: Water resource management and prospecting in Morocco

The Moroccan government has invested in a system that uses satellite EO to help local and regional agencies better manage water resources. The Integrated Decision Support System (IDSS), designed specifically for the Souss-Massa Hydraulic Basin Agency (AHBSM), provides an updated spatial database as well as the know-how and appropriate tools to better support the management and arbitration of precarious water resources.[116] Using Earth observation products, the IDSS provided AHBSM with a spatial geo-database with an updated and high-resolution digital elevation model, a land cover map and a selection of modelling tools. These tools allowed the regional agencies to help local communities make better decisions on water management.

Conclusion

Space-based capabilities can play a critical role in the sustainable management of natural resources, including forests, fisheries and water resources. Space-based EO can improve land use and preserve forests by providing information to build the business case for investing in natural capital. It can also identify degraded land that can be used for development. Satellite navigation and communications also help countries understand who is using fisheries and more efficiently enforce sustainable management practices. And due to various advantages related to area coverage, timeliness and measurement frequency, space-based technologies can be used in the efficient management of water resources, both independently and when combined with field data.

How space technologies can help in disaster management

Snapshot

The problem
Governments everywhere are responding to an ever-increasing number of humanitarian crises, often as a result of natural disasters but also in conflict-stricken areas. All such crises have a devastating impact, and when they strike, their large-scale and complex nature stretches human resources and ground-based infrastructure.

The space-based solution
Satellite services and applications provide support both before and after disasters, and play an important role in ensuring a coherent response at times of emergency.

Sample applications
Case study 1: Philippines – Bringing the country back online after a monster typhoon
Case study 2: Syria – Humanitarian aid at times of conflict
Case study 3: Canada – Mapping Manitoba wetlands with space images
Case study 4: Mexico – Landslides cause havoc after storm

Introduction

There has been an increase in both the frequency and intensity of disasters all over the world: in 1975 there were 78 recorded disasters, in 2012 there were 385.[117] In times of disaster, real-time situational awareness is an important part of any rescue or recovery mission. Local infrastructure on the ground - homes, hospitals, schools, communications and power links - are often damaged or non-existent. Accurate maps and reliable communication links provided via satellite to command centres become the backbone of efficient disaster response operations.

Many natural disasters, such as earthquakes, floods or tornados, are difficult to predict and generally inevitable. It is therefore important to have a better understanding of how such events unfold and how their effects might be mitigated. In 2006, the United Nations set out to do this by establishing the Platform for Space-Based Information for Disaster Management and Emergency Response (UN-SPIDER), which aims to provide universal access to all types of space-based information and services relevant to disaster management. As the world's exposure to natural disasters increases, this type of space-based technology will have an even more important role to play.

The technology and its applications

With their extremely high accuracy, near-real time data acquisition, global coverage, resiliency and portability, space assets have long provided unparalleled support to response teams and victims during disasters. They play a role in all phases of disaster management, both before and after the event, including early warning (with predictive models), preparedness, monitoring, response, recovery, and mitigation activities. More detail is provided in Table 4.

Table 4: Space system support during disasters

Prevention/preparedness	Response/post-recovery
– Vulnerability analysis	– Disaster monitoring
– Preparedness	– Immediate response
– Forecast modelling	– Rescue and relief
– Warning systems	– Recovery and reconstruction
– Monitoring space threats	– Communications

Space systems such as EO, and GNSS such as GPS combine to form the critical GIS necessary for timely and efficient data collection both before and after disasters. When complemented by satellite communications, these services often provide life-saving support.

- Earth observation can identify the scale and location of physical impacts such as damage to infrastructure (e.g. roads for relief, medical supply transport and other logistical infrastructure) and landscapes (e.g. post-tsunami shorelines). This information is vital immediately after disasters to prioritize what infrastructure needs to be restored, as well as during reconstruction efforts when an understanding of the new landscapes is essential for coordinating the movement of people, materials and resources.

- Satellite communications become critical when ground-based communication infrastructure (e.g. radio towers and landline telephones) are overloaded or destroyed, usually as a result of large-scale natural disasters such as earthquakes, tsunamis, hurricanes or tornados. When this happens, space-based infrastructure is the only way to keep services running. This allows aid workers to coordinate their efforts and provides victims with the means to communicate with their loved ones. Satellite communications also allow authorities to stay in touch with people and provide televised and mobile messages about impending danger, evacuation procedures, location of shelters and medical facilities, and other critical post-disaster information. They also allow people on the ground to communicate with the rest of the world through television broadcasts or social networks.

- Satellite navigation and positioning provides the location information required for relief operations and precise application of EO data. It also provides details on the precise location of the victims who needs help. The accumulated big data on the movement of people can also be used to design future evacuation routes.

One of the fastest growing related capabilities is mobile GIS. Disaster management professionals can crowdsource real-time information from ordinary citizens dispersed across the disaster area. For example, stranded flood victims may have difficulty identifying their location if prominent local landmarks are underwater. The combination of GPS on their mobile phones and real-time maps of the new landscape collected from Earth observation satellites would allow rescue workers to precisely locate the victims and extract them from danger.

But space assets don't come cheap. Underdeveloped countries that lack resilient infrastructure are disproportionately more affected by disasters and do not always have access to useable data. Also, despite the numerous lessons learned from past disasters, early warning systems are not always in place and satellite equipment is often not accessible. This, along with the fact that the effects of natural disasters often cross state boundaries, is why regional and inter-regional coordination of communication, navigation and EO capabilities is critical in disaster mitigation and management.

One example of such coordination is in Central America and the Caribbean, where the SERVIR team (NASA and USAID) at the Water Center for the Humid Tropics of Latin America and the Caribbean has developed a geospatial portal that provides improved access to regional data and metadata. To date it has responded to over 20 natural disasters and 10 environmental threats across the region. During the 2009 earthquake in Honduras, SERVIR was put to great use: agencies and organizations from different countries worked together with these tools to pinpoint the precise locations where support was needed. As a result of this successful inter-regional cooperation, an African node is being established in Nairobi, Kenya.[118]

Case studies

Case study 1: Philippines – Bringing the country back online after a monster typhoon (extract from an article in The Atlantic)[119]

"For what must have felt like several agonizingly long hours on Friday, as Typhoon Haiyan tore through the Philippines, President Benigno Aquino couldn't get in touch with the two men he had tasked with preparing the country for the super storm. Finally, as evening fell, the defence secretary and interior secretary got their hands on a satellite phone and updated the president from their perch in the stricken city of Tacloban, where telecommunications services had been obliterated. 'We can't even broadcast to tell the people to proceed to the [village] hall for the distribution of relief goods,' Interior Secretary Manuel 'Mar' Roxas II later told a radio station. Instead, Roxas relied on 'scouts' who hopped on bicycles and conveyed messages to isolated communities.

In a country where there are more cell phone subscriptions than people, local telecommunications providers say they've only managed to partially restore service in the most devastated areas. Enter the folks at Télécoms Sans Frontières (TSF, or Telecoms Without Borders) who, along with volunteer online mapmakers, are part of the next generation of humanitarian workers. TSF teams fly into emergencies armed with lightweight satellite communications equipment that can fit in carry-on luggage. That includes the BGAN, which is about the size of a laptop. You can plug a phone into it and get voice service, or connect it to a Wi-Fi router and set up broadband internet access for a small office. The toolset also includes a smaller IsatPhone Pro, which can act as a phone or as a kind of Wi-Fi hotspot when plugged into a computer.

When telecommunications networks on the ground are down, TSF teams use these devices to achieve basic connectivity … though that usually means they have to station the equipment outside, in the line of sight of satellites. TSF teams tend to establish emergency communications centres for first responders in strategic locations, like hospitals or the airport in Tacloban. TSF also operates what it calls a 'humanitarian calling' program, with teams fanning out to areas where displaced people are concentrated and offering them three-minute phone calls to family members or friends."

Case study 2: Syria - Humanitarian aid at times of conflict

The Syrian population is facing a catastrophic humanitarian crisis. After two and a half years of violent conflict, the situation is so bad that many are deprived of even primary healthcare. To provide support to the medical sector in the country, 12 hospitals have been connected to the internet, thanks to high-speed satellite connections.

In addition to this support given to the medical sector, two ICT centres have been set up to allow young Syrian refugees to continue with their education. These centres use computers, tablets and dynamic ICT tools to provide an education to children whose school lives have been cut off by war.

Satellite connections also support a bi-directional high-speed internet service used by the Syrian Red Crescent, which provides medical and administrative support to the Al Salama refugee camp. Without this internet connection, the task of managing the refugee camp and the many daily arrivals would be all the more difficult.[120]

Case study 3: Canada – Mapping Manitoba wetlands with space images

The province of Manitoba in Canada often suffers from floods that are not only dangerous but also make it difficult to plant crops. Satellite-derived flood maps produced in near-real time have already been invaluable in allowing the Canadian authorities to assess the extent of the damage and engage in relief efforts. The latest radar satellites are able to produce these maps even when there are clouds, which was previously not possible.

Based on prior experience, the University of Winnipeg in Canada will use satellite images to map the extent of the coastal wetlands of Hudson Bay. This will help determine if the coastline is changing. Thanks to a grant from the Canadian Space Agency, the university will have access to 20 RADARSAT-2 satellite images. Information obtained from the images will be used in two long-term research projects that can help meet the province's surface water management goal to map and monitor wetlands.

This technology will allow experts to map temporary wetlands in southern Manitoba, as the images will show where the soils continue to have high moisture after the spring flooding has receded, making it too wet to plant crops.

Case study 4: Mexico – Landslides cause havoc after storm

In September 2013 Mexico was hit by a devastating storm, inundating vast areas, destroying infrastructure like roads and bridges, and triggering landslides that affected over 100,000 people and killed more than 100. Because the storm affected phone lines, the Mexican Red Cross used satellite telephones to organize their work and help carry out their relief operations. Victims of the storm, many in isolated areas, were also able to use satellite phones to contact their loved ones.

Conclusion

For responding to disasters, preparation is key. Space systems such as EO satellites, satellite communication and GNSS are accurate, can access data in near-real time, have global coverage and operate in almost all weather. This makes them unrivalled in their ability to support relief operations. Incorporating this technology even earlier on in the planning stage can help reduce the impact disasters have on vulnerable communities.

Many satellite operators cooperate with national governments, NGOs and other agencies to make these potentially life-saving services available in emergencies. Governments all around the world would benefit from knowing about these solutions and making sure they have access to them when they need them.

Nuclear security and satellites

Snapshot

The problem
As the world's nuclear capabilities grow, it becomes increasingly important for the international community to be able to monitor the development, movement and weaponization of nuclear material.

The space-based solution
EO and communications satellites provide a non-intrusive means to monitor nuclear activities on the ground.

Sample application
Canada's Bruce nuclear power plant and a possible fissile materials cut-off agreement.

Introduction

For decades now, the international community has recognized the threat presented by the possibility that some states will convert peaceful nuclear capabilities to non-peaceful ones. In 1953, US President Eisenhower told the United Nations that his country would "devote its entire heart and mind to finding the way by which the miraculous inventiveness of man shall not be dedicated to his death but consecrated to his life".[121]

At the past three Nuclear Security Summits, it was agreed that the physical security of nuclear materials, weapons and facilities, such as reactors and fissile material production facilities, should be a priority area for the international community. All three summits focused on how to put in place measures to protect nuclear material and prevent terrorists, criminals and other unauthorized persons from acquiring it.

Space-based assets are an important tool in achieving this, and they are already central to the International Atomic Energy Agency's (IAEA) work of monitoring nuclear activity. Observation satellites can identify, locate and describe nuclear facilities, and communications satellites can almost instantaneously transmit relevant data acquired by ground- and space-based sensors.

The technology and its applications

A number of multilateral agreements have been put in place to deal with this issue, many of which rely on space-based technologies.[122] For example:

– The Additional Protocol to the Treaty on the Non-Proliferation of Nuclear Weapons: This requires member states to disclose to the IAEA facilities producing nuclear materials such as plutonium-239 and uranium-235. Observation satellites can identify these facilities and determine their operational characteristics, which could help establish whether fissile material is being produced.[123]

– The Comprehensive Test Ban Treaty: Although it is not yet in force, it has already been ratified by over 160 states. Satellite imaging can be used to ensure the terms of the treaty are being adhered to.[124,125]

– Physical Protection of Nuclear Material and Nuclear Facilities under the International Atomic Energy Agency (INFCERS/225/Rev 5).[126]

Observation and communication satellites can contribute hugely to nuclear security. For example, evidence indicates that sensitive nuclear sites - even those that are illegal or constructed in secret - tend to be protected by extensive security, including fences, anti-aircraft weaponry, towers and bunkers. All of this is visible in imagery acquired from satellite-based sensors.

Another major part of nuclear security has been arms control agreements, such as the 1972 Anti-Ballistic Missile Treaty,[127] the Non-Nuclear Proliferation Treaty and a possible Fissile Materials Cut-off Treaty (FMCT). The FMCT, while still only a proposal, was recommended by the United Nations in 1993 as a "non-discriminatory, multilateral and internationally and effectively verifiable treaty banning the production of fissile materials for nuclear weapons or other nuclear explosive devices."[128] Monitoring compliance with such agreements is essential for national and international security, and observations from space can play a crucial and non-intrusive role. Although only observation satellites have been mentioned so far, electronic reconnaissance satellites can also play an important role.

Case study

Canada's Bruce nuclear power plant and a possible fissile materials cut-off agreement[129]

To illustrate the potential usefulness of satellite-based imagery in the monitoring of the adherence to bans on the production of fissile materials for nuclear weapons or other nuclear explosive devices, we can study the example of Canada's Bruce nuclear power plant.

A satellite image of high spatial resolution in November 1999 enabled the identification and description of the Bruce nuclear power plant – a powerful tool for monitoring IAEA's safeguards.

Further satellite images were able to detect thermal plumes from the nuclear power plant and heavy water plants. The presence of warm water plumes is significant because water from lakes, rivers or the sea is often used to cool the core of a nuclear reactor, and the excess warm water is discharged back into the source. This was detected by the infrared thermal band of the satellite sensor.

In a different image acquired in March 1997, warm water plumes were clearly visible. These were caused by the force of the discharged water into the lake. The discharged water into the water reservoir caused the surface disturbances, which were be detected by a radar sensor.

To determine that the disturbance on the water surface was caused by the discharged water from the reactor, the images were corrected to match geometrically and then combined. The plume in both the images coincided, indicating radar images could in fact be used to detect the operating status of a reactor. A radar sensor is a very powerful tool as it has day and night and all-weather monitoring capability.

Conclusion

The international community has committed itself to ensuring the world's growing nuclear capabilities are used for peaceful purposes. To do so, it needs to be able to monitor the development, movement and weaponization of nuclear material. Space-based technologies, particularly EO satellites, have a crucial role to play in achieving this.

Preparing for catastrophic risks from space

Snapshot

The problem
Catastrophic risks from space are low likelihood but high-impact events. For example, extreme space weather could damage satellites, disrupt pipelines and telecommunication networks, and cause electric grids to collapse. Large objects impacting Earth could cause even more damage.

The space-based solution
Space systems can improve knowledge about space weather, provide early warning and assist with preparation against catastrophic risks. They could even potentially be developed to defend against large objects that threaten Earth.

Sample applications
Case study 1: Space weather - The 1859 Carrington event and 1989 solar flare
Case study 2: Objects hitting Earth - The 1908 Tunguska and 2013 Chelyabinsk events

Introduction

Two types of catastrophic risk from space warrant particular attention: extreme space weather and the possibility of large objects hitting Earth. Although the chances of either of these events happening are low, they would have devastating effects. Understanding these threats and taking appropriate steps to prevent, mitigate or respond to them is therefore an essential part of responsible policy-making.

Extreme space weather

Space weather refers to variations in the space environment that can affect the operation of space and terrestrial systems. In space, high-energy particles and radiation from coronal mass ejections (CMEs) and other solar phenomena can cause both rapid and long-term damage to satellites that can disrupt or disable their operation.

Although we have a better understanding of space weather and its effect on satellites than we did even 10 years ago, and have therefore been able to build satellites that can withstand most space weather conditions, extreme space weather still poses a potential threat to vital operations on earth and possibly even to satellites.

We have become increasingly dependent on the services and information provided by satellites – be it GPS navigation data, global telecommunications or weather forecasts. If satellite operations were severely disrupted or even permanently disabled as a result of extreme space weather, the consequences would be felt everywhere.

Some experts believe that these consequences could be even more serious than previously thought. According to some scientists, potentially catastrophic geomagnetic storms could be triggered when particles and radiation from CMEs and other solar phenomena impact the Earth's magnetosphere. The effects of this radiation are most acute at higher altitudes and can generate large geomagnetically induced currents (GICs) - powerful electrical surges – in power grids. GICs of the magnitude caused by this type of event could not only cause large power grids to collapse, but could also result in widespread permanent damage by disrupting or destroying large numbers of transformers within the grids.

Many transformers are custom designed and can take up to a year to build. They are also expensive, with some costing more than $1 million. This, along with the fact that grid operators do not normally stockpile spare transformers, means that millions of customers could be left without power for weeks or even months in the event of an extreme geomagnetic storm.

In June 2013 analysts from Lloyd's of London and Atmospheric and Environmental Research in the United States estimated that an extreme geomagnetic storm could create $2.6 trillion of damage.[130] As a point of comparison, Superstorm Sandy, one of the most expensive terrestrial weather events, caused only $65 billion of damage.[131]

To avoid such devastation, the international community needs to increase knowledge about geomagnetic events, improve early warning and strengthen power grids. The 2011 JASON Summer Study[132] commissioned by the US Department of Homeland Security contains the most comprehensive and balanced findings and recommendations on how the international community can do this. The following are some of its findings:

- Technical means to mitigate GIC risks exist and can be rapidly implemented.
- Because technical mitigations have not been implemented for the US electric grid, severe damage from extreme space weather is possible, but more study is needed to guide the United States' CIG mitigation policy.
- Observations vital for space weather warnings are currently provided by a limited and fragile satellite network made up of SOHO, ACE and STEREO satellites. These were originally launched for research purposes. They are the only ones that would provide a warning if a CME were about to hit Earth and provide three-dimensional observations of the CME structure needed to model how this energy would interact with the magnetosphere.
- Warning times of imminent CME impact could be extended from 30-60 minutes to 5-10 hours by placing new warning satellites closer to the sun. This additional warning time could allow more fundamental mitigation measures and help overcome the inertia of power grids. Predicting CMEs is an important but distant goal that will remain a research effort for the foreseeable future.

The following are some of the recommendations:

- The protection of vital grid components should be a higher priority than avoiding temporary blackouts. Transformer safety should be ensured through mandated operational procedures and technical design standards, including capacitors and autotransformers.
- It is important to develop robust operational satellites for monitoring space weather; these must be optimally positioned. As part of this effort, full funding for the ACE replacement at L1 should be provided. The idea of a small constellation of low-cost satellites operating much closer to the Sun to increase warning times and provide more reliable 3D CME observations should also be explored. Finally, replacements for STEREO should be developed, to be inserted at L4 and L5, or other suitable orbits.

Large objects impacting Earth

The biggest risk from space is the potential for large objects to strike Earth at high velocity. Near-Earth objects (NEOs) – objects in our solar system with orbits that pass close to Earth – pose the biggest threat. These could be near-Earth asteroids, near-Earth comets or meteoroids.

There are millions of asteroids throughout the solar system, but 1,360 of them are currently classified as potentially hazardous objects (PHOs), meaning they have the potential to hit Earth. An asteroid measuring 7 metres across carries about as much energy as the Hiroshima atomic bomb. Comets are similar to asteroids, except they are more visible. There are almost 5,000 known comets, 93 of which are classed as near-Earth comets. They vary greatly in size, composition and orbital period. Meteoroids are rocky or metallic objects that travel through space. They are significantly smaller than asteroids. About 15,000 tons of meteoroids, micrometeoroids and space dust enter Earth's atmosphere each year.

Fortunately, it is rare for large objects to hit Earth. Most of these objects explode in the upper atmosphere and cause limited damage on Earth. Scientists believe the largest NEO impact happened around 65 million years ago, when an object at least 6 miles in diameter formed the Chicxulub crater, which is more than 100 miles wide and located underneath the Yucatan Peninsula in Mexico. Many scientists think this event caused the extinction of most dinosaur species. They also believe that there will almost certainly be another large impact in the future, unless we find a way to prevent it.

This, along with declassified data from the US military's Defense Support Program and research into the collision of comet Shoemaker-Levy 9 with Jupiter in 1994, has galvanized efforts to detect and catalogue all PHOs. As a result, policy-makers are also considering even more options to prevent an asteroid from hitting Earth.

In 1998, the US Congress instructed NASA to detect 90% of NEOs with a diameter of 1 kilometre or greater by 2008; NASA is now working on detecting 90% of all NEOs with a diameter of 140 metres or greater by 2020. There are currently eight international teams of astronomers worldwide that are using sophisticated telescope monitoring and computer modelling techniques to detect and inventory NEOs. These efforts are loosely affiliated under the Spaceguard Survey. NASA also maintains a continuously updated Sentry Risk Table of the most significant NEO threats over the next 100 years. In general, as more observation data is collected, uncertainty is reduced, and fewer and fewer large objects are considered to have any serious potential to impact Earth. The once significant but now greatly reduced concern over the close approaches of asteroid Apophis on 13 April 2029 and 13 April 2036 is the most prominent example of these trends in NEO cataloguing efforts. It should be noted, however, that several recent and significant events, including the Chelyabinsk meteor, were not detected in advance.

After the UNISPACE III Conference in 1999, the United Nations Committee on the Peaceful Uses of Outer Space began discussions on international cooperation and coordination to respond to a potential NEO impact. These discussions have focused on three main areas: detection and warning of potential impacts, coordination of plans to prevent some types of asteroids from hitting Earth, and mitigating the effects of actual impacts through disaster response and management. As a result, efforts are now underway to better coordinate the detection, tracking and warning of PHOs between government space agencies and even amateur astronomers. Several space agencies are also exploring efforts to develop the technology to deflect asteroids and prevent some kinds of impacts.

Case studies

Case study 1: Space weather – The 1859 Carrington event and 1989 solar flare

The Carrington event – the largest known geomagnetic storm – took place in September 1859. The effects of this storm were serious and widespread, and included telegraph system failure all over Europe and North America (some telegraphs gave operators electric shocks, some pylons threw sparks, and others continued transmitting despite being disconnected from their power supplies) and significant disruptions of compasses and other sensitive instruments. At the time, modern sensors and electronic infrastructure were still relatively basic compared to today, so the damage was not as bad as it might have been. As a result, understanding of the event and its impact is also limited, leading to divergent viewpoints about how severe and long-lasting a similar event would be today.

A far better understood event began on 6 March 1989 with a class X15 solar flare (about half as powerful as the strongest ever recorded). This was followed three days later by a coronal mass ejection. This extreme solar activity caused a geomagnetic storm on 13 March that led to an overloaded transformer and general blackout in the Canadian Hydro-Quebec power grid. The blackout lasted more than nine hours and affected 6 million customers. Since then, the Canadian government has spent $1.2 billion hardening the Hydro-Quebec grid through improvements including better operating procedures, more resilient transformers and large capacitors capable of mitigating GIC surges. Finland is also susceptible to GIC problems, but it has largely avoided them through a proactive approach, including specialized transformer design.

Case study 2: Objects hitting Earth - The 1908 Tunguska and 2013 Chelyabinsk events

On 13 February 2013 an object estimated to have weighed between 13,000-14,000 tons and travelling at over 41,000 miles per hour exploded about 76,000 feet above Chelyabinsk in Russia. It was the second-largest known meteor in recorded history with total kinetic energy of 500 KT. Light from the fireball was brighter than the sun and eyewitnesses felt its intense heat. It is the only known meteor event to cause widespread urban damage and mass casualties – shock waves from the explosion damaged 7,200 buildings in six cities and 1,500 people had to seek medical treatment.

It is estimated that objects with 10 megatons of energy enter Earth's atmosphere only once every 2,000-3,000 years. This was the size of the object that hit Siberia in 1908, the largest impact in recorded history. The Tunguska explosion knocked down some 80 million trees over an area of 830 square miles and the shock wave from the explosion would have measured 5.0 on the Richter scale, more than enough energy to destroy any major urban area. Objects with a diameter of 1 kilometre hit Earth an average of twice every million years, while impacts by objects measuring 5 kilometres in diameter are thought to occur once every 20 million years.

Conclusion

Threats from space can be of enormous significance. To date there has been little concerted preparatory action to prevent, prepare or respond to these risks. This challenge should be addressed through a multi-level, multistakeholder international approach.

In both the United States and the United Kingdom, there has been an increased focus on the risk posed by geomagnetic storms, as demonstrated by warnings from science advisors in these countries, more research into the issue, such as the Electromagnetic Pulse Commission and the JASON Study, and the formation of the EMP Caucus in the US Congress. This is encouraging but there is a great deal more to be done to implement safeguards against the effects of extreme geomagnetic storms.

Many deflection options for NEOs have been suggested and should be explored in more inclusive, transparent and intentional ways. NEOs are an avoidable disaster but avoiding them will require unprecedented levels of sustained global attention and resources. Improved space sensors must be developed to provide more accurate data about objects that could potentially hit Earth. New space technologies for deflecting NEOs, perhaps millions of miles away from Earth, must also be developed.

More research, global collaboration and data sharing will contribute to a safer space environment and will increase our ability to respond to shocks from space.

The challenge of the long-term sustainability of space activities

Snapshot

The problem
An increasing number of state and non-state actors are operating in space. As they do, the challenges also increase, including radio frequency interference, collisions due to orbital space debris and the higher number of satellites in space, and the potential for geopolitical instability and conflict in space. All of this poses serious threats to the long-term sustainability of Earth orbits.

The solution
No one solution can deal with all these challenges. Instead, several need to be adopted. These include improving space situational awareness, developing norms of responsible behaviour, reducing the creation of new orbital debris and removing some of the existing debris, and increasing transparency and measures to build confidence.

Case studies
Case study 1: Mitigation of risks in space: the Space Data Association
Case study 2: Interference with satellite signals and resulting loss of service
Case study 3: China's deliberate destruction of a defunct weather satellite
Case study 4: The destruction of USA 193 using a missile defence interceptor

Introduction

There are more than 1,100 satellites orbiting Earth, providing tangible social, scientific, strategic, humanitarian and economic benefits to us all. Yet the ability to provide these important benefits from outer space is under threat. The more we use space, the more challenges we create to its sustainability.

To ensure that we are able to continue to reap all the benefits space provides, these challenges must be addressed by the international community.

The challenges to space sustainability

Increasing number of objects in space

There are a large number of objects in the space around Earth. These include active satellites operated by public and private companies, and space debris, which is inactive or dead satellites, spent rockets stages and other related pieces. This debris poses a potential collision risk to active satellites.[133] Most of these objects are found in low Earth orbit, which is also where Earth observation services are located.

Experts are currently tracking more than 23,000 pieces of space debris larger than 10 centimetres in orbit around Earth. It is estimated that there are up to 500,000 smaller pieces, measuring between 1 and 10 centimetres, nearly all of which are untracked.[134,135]

Because objects in orbit travel at speeds sometimes in excess of 7 kilometres per second, a collision between even the smallest piece of space debris and an operational satellite could result in serious damage or even in its complete destruction. As more debris is added to orbit, there is an increased chance of collisions between pieces of debris that will in turn create large amounts of new debris. Experts are predicting that this will cause a significant increase in the amount of space debris over the next several decades, even if no new spacecraft are launched.[136,137,138] The additional debris will make it more expensive and dangerous to operate in some of the most valuable regions of Earth orbit. In cases of unique satellites, a single collision could result in the loss of vital services such as communications, environmental monitoring, surveillance and reconnaissance, rapid mapping and crisis management.

To prevent this, the first line of action should be debris mitigation – reducing the amount of debris created as a result of space activities. In 2007, the United Nations endorsed a set of non-binding voluntary guidelines for best practices in debris mitigation. Ensuring these guidelines are followed in all space activities could help reduce the creation of new debris.

As a second step, measures must be put in place to limit the risk of collisions in space. The best way of achieving this is by improving the space situational awareness of all space actors – public and private – and developing best practices for detecting and sending out warnings of potential collisions between active satellites and other objects.

Finally, most scientists agree that there will be a need to remove some of the existing space debris. To do so, safe and cost-effective technical measures must be developed and the associated legal and policy challenges must be tackled.[139]

Radio frequency interference

Satellites use radio waves to receive commands from ground controllers (uplink) and in return relay information back to Earth (downlink). Intentional or unintentional radio frequency interference (RFI) can interrupt satellite functions such as television broadcasts, scientific data transmissions and other vital control and communication functions between satellites and their operators.

Unintentional RFI can be the product of equipment failure or human error. It can also be caused by man-made sources such as satellites transmitting too close to one another on the same frequency or terrestrial communications operating on the same or similar frequency to space systems.

Intentional RFI, also known as "jamming", is a deliberate attempt to temporarily disrupt the normal RF communications of a satellite. This might be to block certain radio and television broadcasts or to reduce the ability to use space capabilities.[140]

While international and national mechanisms currently exist to regulate RF communications, they focus mostly on spectrum and frequency allocation rather than on preventing interference. They also lack strong enforcement mechanisms. As orbits become more and more crowded, the shortcomings of these regulatory mechanisms will present a significant challenge to the long-term sustainable use of space. Addressing these shortcomings and improving the coordination and cooperation between countries and satellite operators are important areas for improvement.

International stability and outer space

Specially designed spacecraft and space technology such as GPS and surveillance satellites can support terrestrial military and intelligence operations, and play an increasingly important role in national and international security capabilities.

As a result, there is a chance that incidents in space could create tensions and even lead to conflict. The situation is complicated all the more by the fact that it is often difficult to establish the exact cause of a satellite malfunction – it could be caused by space weather, a collision with space debris, an unintentional interference or deliberate aggression.

Some states are already developing anti-satellite (ASAT) capabilities, including ground and space-based weapons, which can be used to disrupt, degrade or destroy space systems. Without a clear understanding of their intentions, such actions could destabilize international security. By testing or using debris-generating weapons, these states also risk contaminating the orbital environment for centuries to come, significantly affecting all space actors and severely undermining the long-term sustainability of space.

An important step forward in addressing these challenges is the development of norms of behaviour that outline responsible and irresponsible activities in space. Improving the space situational awareness of all actors is also essential as it will make it easier to identify irresponsible behaviour. More transparency in all issues related to space can help build confidence, increase stability and security and reduce the chances that a mishap or misperception could lead to conflict.

Case studies

Case study 1: Mitigating risks in space - The Space Data Association

The Space Data Association (SDA)[141] brings together public and private entities that work together to share reliable data related to the safety and integrity of the space environment and radio frequency spectrum. The association is made up of members from the public sector, such as NASA and NOAA, and private organizations, including satellite operators. Members share data on the locations of their own spacecraft with the Space Data Center. The data is used along with information from the US Joint Space Operation Center's debris catalogue to predict potential collisions and allow satellite operators to perform avoidance manoeuvres if necessary.

This data-sharing model provides a voluntary yet legally binding 'transparency and confidence building measure' that can be built on to bring together authoritative data on objects and activities in space. This would allow experts to analyse and predict potential collisions and warn satellite operators, increase the efficiency of space operations, and improve the transparency of sensitive or risky activities. The result would be a safer and more secure space environment for all.

Case study 2: Interference with satellite signals and resulting loss of service

In May 2006, Bolivia's telecommunications regulator carried out a test to see if radio frequency interference would take place if satellite spectrum was shared with the mobile terrestrial community. The test confirmed interference: satellite signals carrying television channels in Bolivia were severely interrupted. To provide satellite services without interruption, the regulator issued an administrative resolution mandating wireless access system deployments in different frequency bands.

Case study 3: China's deliberate destruction of a defunct weather satellite

On 11 January 2007, China deliberately destroyed its inoperable Fengyun-1C weather satellite using an interceptor launched from a ballistic missile. The destruction created more than 3,000 pieces of debris larger than 10 cm as well as thousands of pieces too small to be tracked. This debris was created in one of the most critical and congested regions of Earth orbit; it will pose a serious collision threat to satellites for decades to come.

Case study 4: The destruction of USA 193 using a missile defence interceptor

In February 2008, the United States used a modified missile defence interceptor launched from an Aegis warship to destroy USA 193, a failed national security satellite. The satellite was meant to de-orbit and re-enter the Earth's atmosphere a few months later, carrying with it sizeable amounts of highly toxic hydrazine fuel. Even though the US maintained the satellite was shot down in the interest of public safety and disclosed their plans in accordance with international agreements, the act was still viewed by many as the dual-use application of hit-to-kill missile defence technology. It has also set a precedent for other countries wishing to test such technology.

Conclusion

An increase in RFI, more and more space objects and debris, and the use of space technology for military purposes all make it more challenging to provide secure, safe and peaceful access to Earth's orbits.

If we are to continue to reap the benefits offered by space, these challenges must be addressed. We can do so by focusing on debris mitigation, improving space situational awareness and collision warning, exchanging space data, and eventually removing some of the existing debris. Mechanisms must also be put in place to deal with deliberate interference and to increase transparency and confidence in all matters relating to space. Finally, existing rules governing behaviour in space need to be strengthened and reliably enforced.

Conclusion

Space is no more than 80 miles away from every person on Earth. As political scientist Daniel Deudney once observed, although that's closer than most people are to their own national capitals, space seems to have become less of a priority since the progress made at the height of the Cold War.[142]

Yet space technology greatly improves many aspects of our lives and we are starting to rely on it more and more each day. Approximately 1,000 active satellites currently provide a whole host of services that improve our world in many ways – from the navigational tools in our cars to the daily weather forecast.

Space technology also helps address some of the major challenges the world is facing, including human rights abuses, depleting natural resources and other environmental issues, universalizing access to healthcare and education, and catastrophic risks.

Despite these and many other benefits, the space industry is under threat. Spectrum congestion and interference can interrupt or block space services, space debris can damage satellites, and the increase in the number and type of actors operating in the space environment could destabilize it.

But by far the biggest threat to the many benefits offered by space is for us to underestimate just how important it is. Without space technology, many services and applications that we now rely on would not exist. To ensure people realize the true value of space, the space industry must forge strategic partnerships with governments, businesses and civil society.

By working with all stakeholders we can raise awareness of the importance of space and develop collaborative solutions to ensure we all continue to reap its benefits on a sustainable basis.

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