Sensing Progress

Space Solutions for Food & Water Security

White Paper

Southern Hemisphere Space Studies Program

2016

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Authors' Preface

We hope this White Paper encourages commitment among individuals, professionals, and governments to further the case for space development within the Global South. This White Paper identifies the challenges to food and water security within the Global South, analyzes current strategies that deal with these issues, and provides recommendations to reduce our vulnerabilities to this emerging paradigm. The Southern Hemisphere Space Studies Program 2016 (SHSSP16) consists of 31 participants from eleven countries joining together for an interdisciplinary, intercultural, and international experience. Team members bring their own knowledge, ideas, and experiences to a project we believe helps to address the increasing difficulties in providing food and water security in the Global South. The project capitalizes on the use of space-based applications and decision-making processes specific to the States in the Global South. This report would never have been a success without the dedication and passion of our Program Director, John Connolly, and Co-Director Michael Davis, our White Paper Chair, Ray Williamson, and Co-Chair, Noel Siemon, faculty and staff Carol Carnett, Josh Richards, Sarah Fitzjohn, Rob Hunt, Mark Mackay, and Shripathi Hadigal. We would also like to thank the University of South Australia for providing host facilities and expertise for this program. Gratitude is also extended to all visiting guest lecturers and alumni.

"Really, the only thing that makes sense is to strive for greater collective enlightenment."

\- *Elon Musk*

Faculty Preface

This report, the effort of 31 participants in the Southern Hemisphere Space Studies Program held jointly by the International Space University and the University of South Australia, explores the challenge of improving water and food security in the Global South, defined for this program as the countries touching or below the Tropic of Cancer. Within a five week program, the participants researched the challenges and interrelated issues facing the agricultural and water resource management communities into providing access to nutritious food for all people. They also examined the role space technology, in combination with terrestrial technologies, could play in dealing with some of the issues.

We trust that this report will stimulate debate on the importance and contribution space technology can make to helping decision makers at the international, national and local levels to confront the challenges affecting global water and food security. The faculty recommends this report to anyone interested in understanding how to improve food and water security within the Global South.

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Introduction

Adequate food and fresh water are essential for life and access to sufficient quantities of both is essential for human health. However, not everyone in the world has access to these resources. Such deficiencies can result from a variety of underlying causes, including ineffective policies and programs, inadequate infrastructure, and political or economic reasons. According to the UN Food and Agricultural Organization (FAO, 2014), between 2012 and 2014 some 805 million people remained chronically undernourished, many because they lacked the resources to purchase sufficient food. Regardless of the underlying reason, the need for action to address these issues is clear.

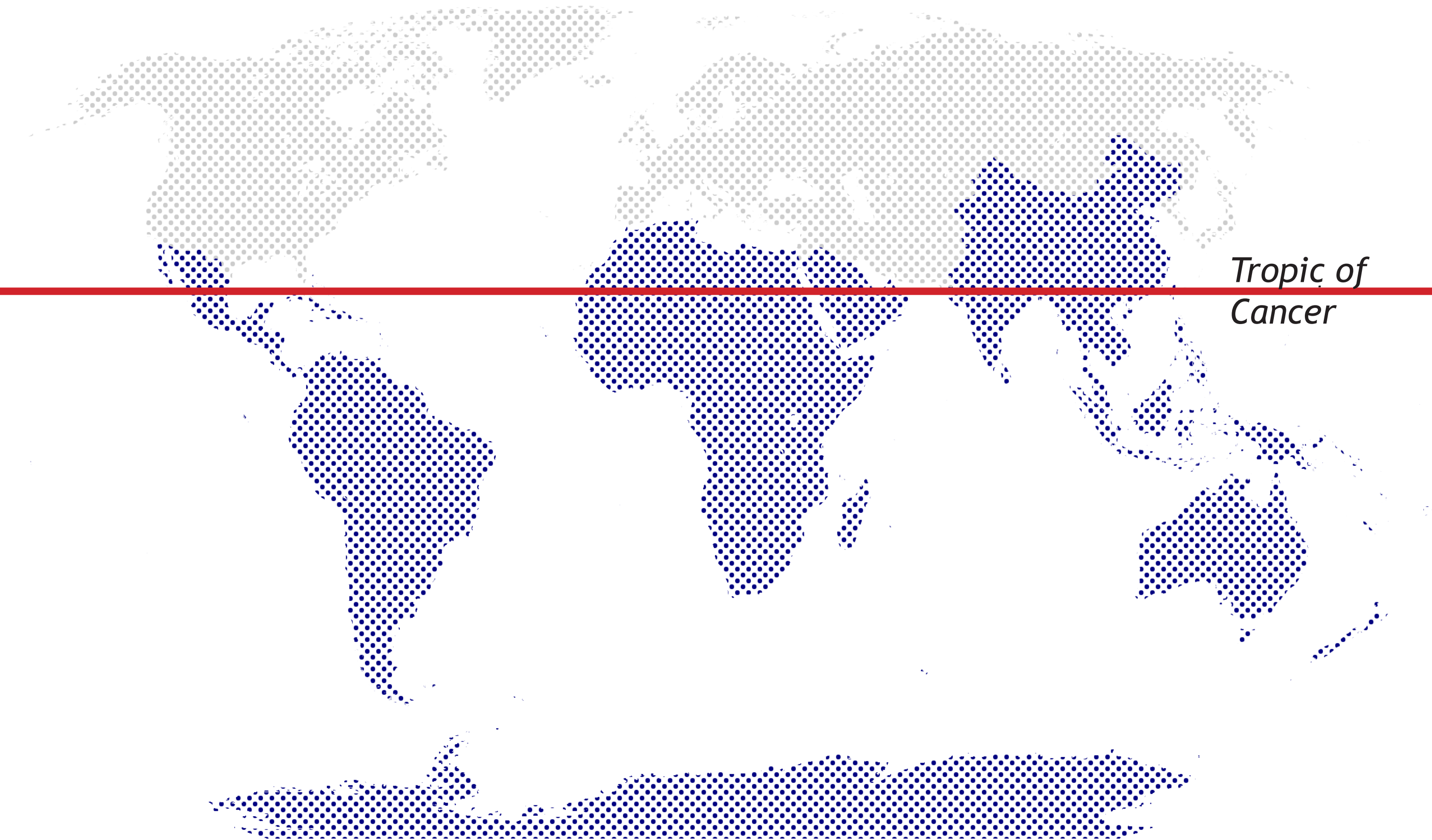
The world community needs to grow sufficient quantities of nutritious food and distribute it effectively. Yet, to increase efficient global food production, improved and more effective management of the world's agricultural resources is required. We also need to find ways to maintain sufficient fresh water for human consumption and for growing crops. Space technologies can help address these needs.

In this paper, the term 'Global South' collectively refers to the countries that lie on or below the Tropic of Cancer. This represents the four main regions of the Southern Hemisphere: Africa, Asia, Oceania and Central and South America, and includes approximately two-thirds of the nations of the world.

These regions lack commonality in the degree of economic development, climatic and environmental conditions, politics, language, and culture; nevertheless population growth, climate change and extreme weather events constitute three key common threats to food and water security.

The respective nations of each region require individualized resource management plans to meet the challenges associated with ensuring food and water security. Ideally, such strategies will include innovative and technological solutions.

This White Paper acknowledges the importance of informing decision-makers about the role that space-based information can play in the development and implementation of policies designed to enhance local and regional food and water security in the face of the key threats we have identified. In particular, we explore the use of some key space-based applications in combination with terrestrial resources.



Definitions of Food and Water Security

"Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (WHO, 2016). Unfortunately, one in eight people globally fail to meet this benchmark, being undernourished and lacking adequate food security (FAO, 2012). 'Water security' is the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being and socio-economic development (UN-Water, 2013).

Looking Down

The 'eyes in the sky' capture imagery of our planet from above. In many parts of the globe, people suffer from malnourishment and thirst on a regular basis. The prevalence of this combined food and water insecurity is particularly acute in the Global South. For example, Sub-Saharan Africa experiences prolonged periods of drought that reduce the availability of arable lands and crop yields (Shiferaw et al., 2014). In contrast, South-East Asia faces monsoonal rain patterns that result in flooding, potentially impacting on food production. To many in the Western world, the concept of being without adequate access to nutritious food and safe water may be difficult to grasp. Historically, the combination of abundant natural resources with centuries of economic, social, and industrial development has largely ensured that food supply has met demand. However, challenges arising from population growth, changing climate, and extreme weather events must now be faced by developed countries as well.

Mission Statement

"To propose internationally cooperative methods to countries of the Global South for developing and strengthening food and water security strategies using a combination of space-based and terrestrial resources."

Looking Up

Throughout history, humanity has looked to the heavens for inspiration and guidance. In the modern era, we look for knowledge from the many man-made 'eyes in the sky' orbiting high above the Earth. For example, Earth observation satellites have been recognized as 'crucial for humanity' by the Group on Earth Observations (GEO Ministerial Declaration, 2015). It is possible to develop geographically specific affordable and effective strategies to address food and water security challenges in the Global South. This can be done by combining data and applications derived from the many different sensors on orbiting satellites with ground-based technology.

Challenges to Food and Water Security

Urbanization and Population Growth

The proportion of the global population located in cities currently stands at 54% and is expected to rise to 66% by 2050 (United Nations, 2014). As the urban population swells, the geographical area covered by cities expands, resulting in increased demand on existing water sources, which interrupts the natural water cycle and decreases water security in urban areas (WWAP, 2015).

Growth and industrialization generate significant quantities of pollutants, such as black carbon, nitrogen oxides, ozone and sulphur dioxide. These substances have been demonstrated to have a wide

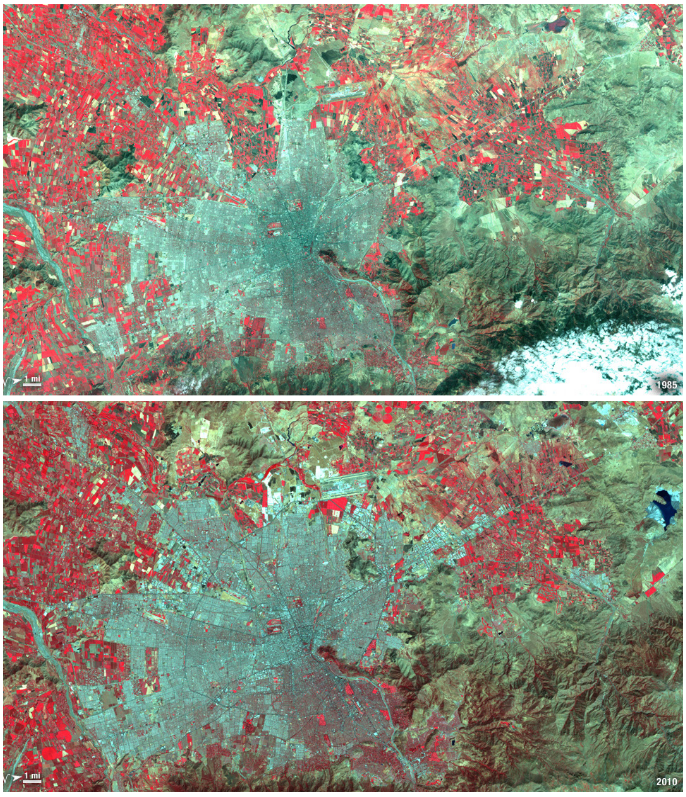


Figure 1: Taken on January 9, 1985, and January 30, 2010, this pair of images from the Landsat 5 satellite illustrates the population growth of Santiago, Chile. The images were made with infrared and visible light so that plant-covered land is red. Bare or sparsely vegetated land is tan, and the city is dark silver. Credit NASA

range of harmful effects on crops, including starving plants of sunlight and exposing them to excessive toxicity. Studies have shown that crops exposed to air pollution in this way have much lower yield (Mina et al., 2013; Burney and Ramanathan, 2014).

Increasing urbanization decreases the availability of fertile arable land. (Matuschke, 2009). This is particularly apparent in the areas surrounding the Nile delta, where urban encroachment threatens to consume the total available arable land within

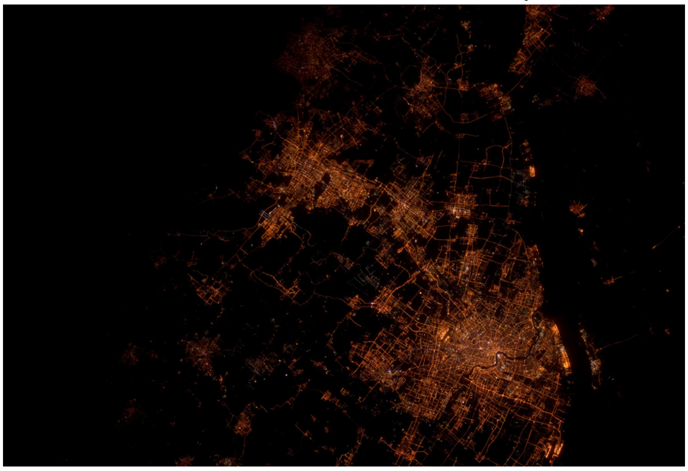


Figure 2: A nighttime view of Shanghai is featured in this image photographed by an Expedition 30 crew member on the International Space Station. The city of Shanghai's population increased by 28% from 2000 (16.4 million) to 2010 (23 million). Credit NASA.

200 years (Al Tarawneh, 2014). Urban encroachment endangers other agricultural areas across the Global South including in China, Indonesia, and Chile (Matuschke, 2009). Urbanization further affects agriculture by reducing the availability and quality of water for agricultural and domestic applications.

Space-based solutions can provide feedback to inform urban planning and management activities. Remote sensing systems can monitor the effects that present levels of urbanization have on water quality and availability. For example, remote sensing techniques have been proposed for detecting suspended particulate matter in bodies of water, a prominent source of pollution (Usali and Ismail, 2010). By combining remote sensing systems with terrestrial sensor networks, it may be possible to detect air and water pollution events in near-real time and act quickly to mitigate the incident as it happens.

Earth observation systems also play a role in validating hydrological models that are used as part of urban planning. By reducing the number of impermeable surfaces it is possible to minimize the effects of urbanization on the water cycle (Kite and Pietroniro, 1996).

Climate Change

The last 150 years have seen a steady increase in the average global temperature, of just under two degrees Celsius (IPCC, 2014). Scientists believe that this temperature increase has resulted in widespread environmental consequences including droughts, storms, floods, and rising sea levels. All of these effects, collectively known as climate change, present challenges especially to agriculture and its associated water requirements. Climate change has been defined in the Framework Convention on Climate Change (UNFCCC) as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods" (United Nations, 1992).

As weather becomes increasingly unpredictable as a result of climate change, farmers are less likely to plan with certainty for the future. Crop failures become increasingly common occurrences and overall food yields also diminish. As a result, farmers in affected areas are adjusting their traditional agricultural practices in order to adapt to unseasonably hotter temperatures throughout the year.

Figure 3: "There is no way out, no loopholes. The Great Barrier Reef will be over within 20 years or so. Once carbon dioxide had hit the levels predicted for between 2030 and 2060, all coral reefs were doomed to extinction, They would be the world's first global ecosystem to collapse. I have the backing of every coral reef scientist, every research organization. I've spoken to them all. This is critical. This is reality." Charlie Veron, former chief scientist of the Australian Institute of Marine Science. Satellite image of the Great Barrier Reef. Credit NASA

Space-based technologies, such as Earth observation satellites, enable the effective remote monitoring of these environmental changes. The data obtained is then transmitted to improve farming practices and inform policymakers. The CGIAR (Consultative Group for International Agricultural Research) Research Program on Climate Change, Agriculture and Food Security recommends that agricultural producers would be ideally served by "a combination of historic and monitored information, and a seamless suite of prediction that ranges from sub-daily to at least seasonal forecasts" (Tall, et al., 2014).

In an effort to achieve such observation data capture and dissemination, the Group on Earth Observations (GEO) is coordinating efforts to build a Global Earth Observation System of Systems (GEOSS). As a

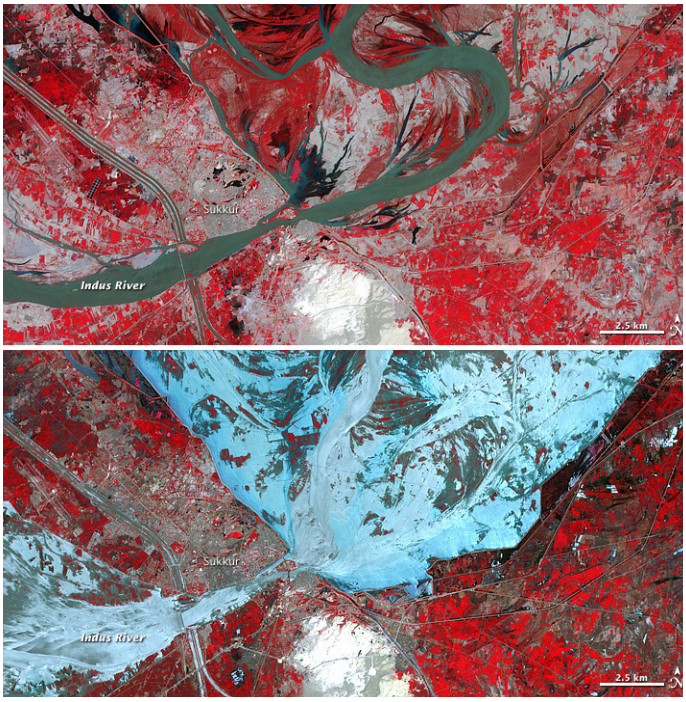


Figure 4: The Indus River at Sukkur was at exceptionally high levels on August 18, 2010, when the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on NASA's Terra satellite captured the top false-color image. The lower image shows the Sukkur region on August 13, 2001. Credit NASA

partnership of 80 governments and 52 international organizations, GEOSS links Earth observation, information, and processing systems to improve monitoring of the state of our planet.

In September 2015, GEO helped launch the Global Partnership for Sustainable Development Data (GPSDD) to support the United Nations Sustainable Development Goals. Climate action is among these goals, with GEO being "one of a number of anchor partners and champions supporting and shaping the GPSDD's vision for a better world through data sharing (Onsenga, 2015).

Figure 5: This astronaut photograph illustrates slash-and-burn forest clearing along the Rio Xingu (Xingu River) in the state of Matto Grasso, Brazil. This photo was taken aboard the International Space Station on the 17th of September, 2011. Credit NASA.

Flooding & Drought: Weather Events

Flooding is one of the most catastrophic of natural disasters. Flooding has taken its toll on agriculture and food supplies and resulted in water contamination and destruction of infrastructure, thus exacerbating malnutrition in the Global South (UNISDR, 2015). Topsoil can be washed away during flooding, causing severe damage to arable land.

Additionally, agricultural infrastructure, such as irrigation systems, can be damaged or destroyed by floods, which can increase pressure on food sources, especially in rural areas. Overall, there is a notable increase in severity of flood disasters, affecting broader geographical areas. Many countries of the Global South are especially vulnerable to flooding (UNISDR, 2015). This topic is addressed in more specific detail later in this document.

More than one billion people were affected by drought between 1995 and 2015; that is more than a quarter of all people affected by all types of weather-related disasters worldwide (UNISDR, 2015). Droughts crucially impact agricultural production and water supply. Decreasing crop yields have direct impacts on food prices, affecting global markets and consumer demand. Reductions in river flows in drought affected regions may have consequences for water supplies and limit the potential for hydroelectric generation. Poor quality water can have significant negative health outcomes for affected populations.

Current space-oriented solutions rely heavily on remote sensing satellites that are used to monitor water levels, inundation, soil moisture, and crop health. Hydrological models interfaced with Geographic Information Systems (GIS) data sets allow managers to monitor water levels for potential flooding and create 3D maps of the terrain to evaluate potential drainage issues. The amount of moisture contained in soil can be detected by satellites and used to ascertain drainage efficiency in flooding situations, and to help predict crop yields in drought conditions (Doorenbos et al., 1979). An organization that facilitates space-based multi-spectral remote sensing technology is the GEOGLAM Global Agricultural Monitoring portal, which is used to provide a near-global measurement area for prediction of crop yield. This is especially valuable in areas where ground-based measurements are difficult or costly to implement, and allows for further determination of at-risk areas.

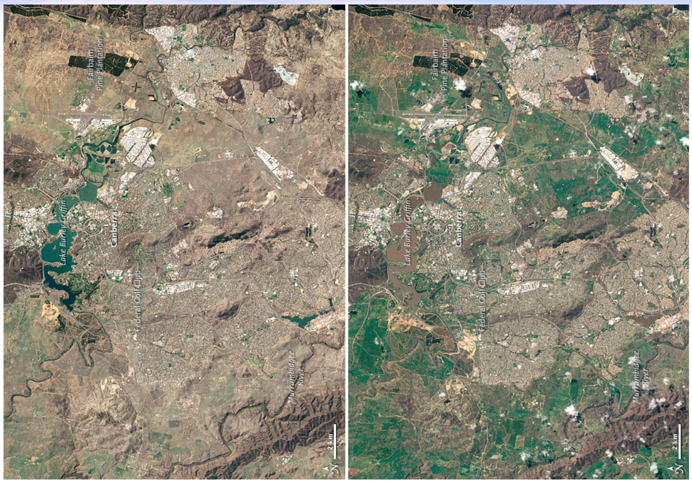


Figure 7: In September 2008, Australia's capital city of Canberra was parched. The Thematic Mapper on the Landsat 5 satellite acquired the left image on September 24, 2008, and the right image on October 19, 2010. These natural-color images show the stark difference that rainfall makes. Credit NASA.

It is necessary to have information and management systems in place to manage the data and deliver the appropriate responses. For example, Remote sensing-based Information and Insurance for Crops in Emerging Economies (RIICE) is an active program in Southeast Asia that collates data on rice crops to provide assessments of crop yield and to quantify losses of crops from natural disasters (ASEAN SAS, 2014).

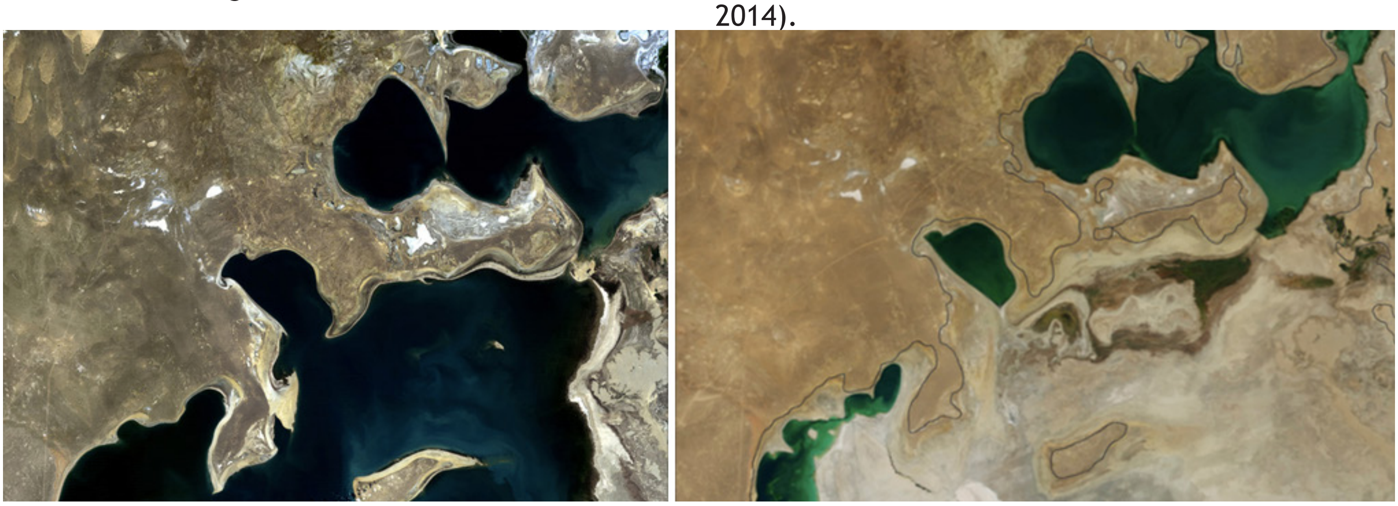


Figure 6: This series of images from the Landsat satellites documents the changes to the northern half of the Aral Sea from 1989 (left) to 2014 (right). The Aral Sea was once the fourth largest lake in the world. However irrigation north of the Aral Sea, which is used to transform the desert into farms for cotton and other crops, has devastated the lake and surrounding area.

Summary of Recommendations

As a result of the detailed consideration of these challenges to food and water security, the authors have developed several recommendations around practical space-based strategies to address the food and water security challenges faced by the Global South. These recommendations are presented in summary form below, and discussed in greater detail in the latter part of the White Paper.

Recommendation 1: International Data Sharing

We recommend the open and timely sharing of Earth observation data, experience and other information resources among nations and peoples. This tangible exchange will foster broader bilateral and multilateral cooperation, enhancing food and water security.

International collaboration should focus on the actual exchange of space-derived data and sharing of analysis systems and techniques. Adequately feeding and hydrating all the people of our planet requires sharing our collective capabilities and tools. This requires the sharing of data, experience, and other information resources. Much of this relevant information is obtained from space-based assets such as Earth observation satellites. Improved information-sharing at the international level enables governments and institutions to directly advise farmers on the ground.

Recommendation 2: Capacity building

Governments in the Global South should invest in capacity building by funding Earth observation and remote sensing education and outreach programs. These programs should be supported by well developed communications infrastructure and access to relevant hardware and software platforms. These programs should be accompanied by setting measurable goals to assess performance.

Earth observation data is freely available via the internet. Nevertheless, some of the people who would benefit the most from this data are unable to access and interpret it to obtain meaningful information.

We recommend that governments in the Global South expand current agricultural education programs to include training on the use and benefits of remote sensing systems and how to convert raw data into useful information. In countries where no agricultural education programs exist, we call for governments to initiate such programs. Education by itself is not enough. Governments must create communications infrastructure to ensure individuals have access to Earth observation data.

Recommendation 3: Expansion

Expand current Earth observation programs by establishing multisectoral policies and programs focused on strengthening food and water security within States where such schemes are already prevalent, and to States where such schemes would greatly improve the quality of life. In particular, successful programs such as Remote Sensing-based Information and Insurance for Crops in Emerging Economies (RIICE) and Famine Early Warning System (FEWS) should be expanded to cover a greater number of countries.

Food and water insecurity are multifaceted issues that are interlinked to a great extent and caused by a variety of factors. We propose that by establishing multisectoral policies and programs, current Earth observation schemes can be expanded to address the issues of food and water security in a holistic manner.

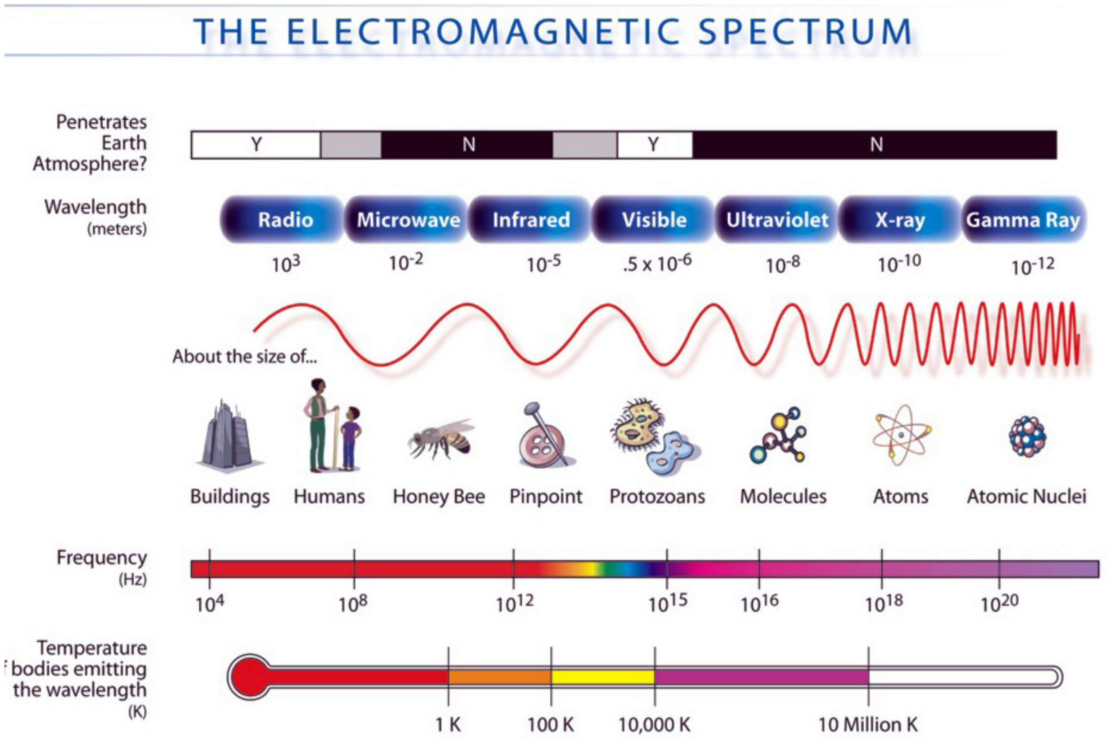
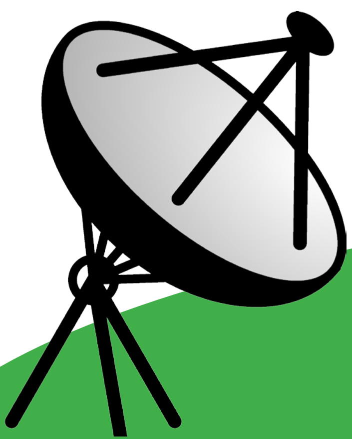


Figure 8: The Electromagnetic Spectrum (NASA, 2016)

The process of remote sensing involves the recording of energy from a target area, then transmitting this energy as data to a ground station where this information is interpreted and applied to the relevant field of study (Kumar, 2005). Remote Sensing includes the analysis of electromagnetic radiation that is emitted from light sources (such as the Sun) and is reflected or absorbed by objects across a wide range of frequencies. The electromagnetic spectrum consists of the visible light spectrum together with a wider range of “invisible light,” which includes infrared and ultraviolet light, as well as radio waves, microwaves, x-rays, and gamma rays.

Remote

Remote sensing uses imagery from cameras to collect useful information about the Earth. These images are obtained via satellites, unmanned aerial vehicles (UAVs), ground based systems, and piloted aircraft.



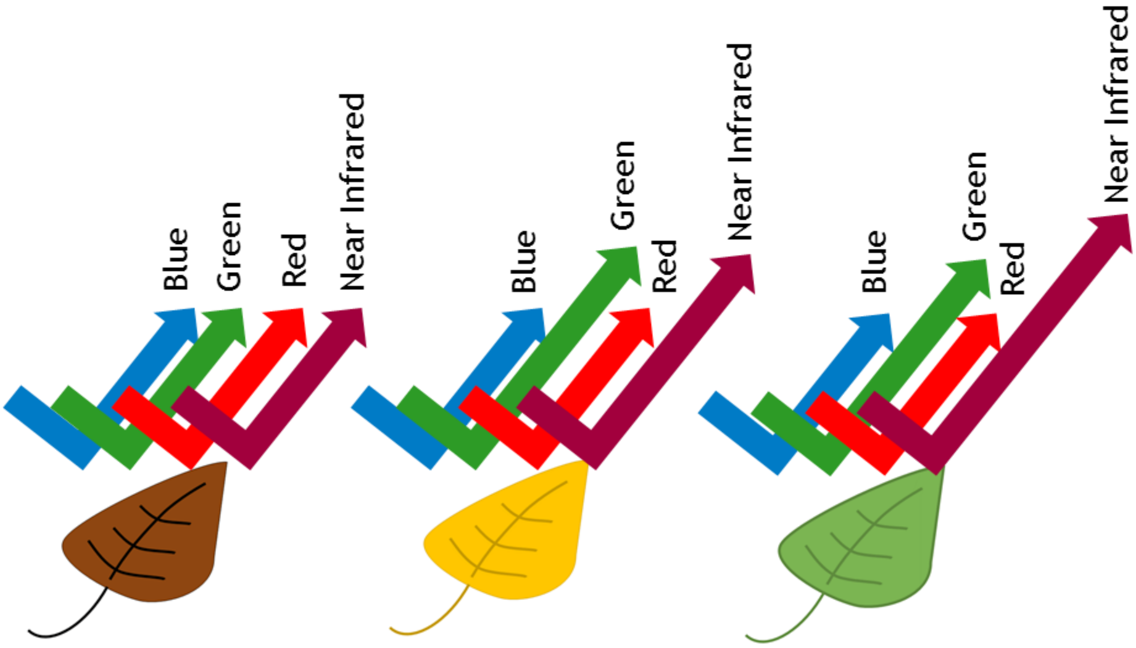


Figure 9: Comparison of leaf health using NDVI

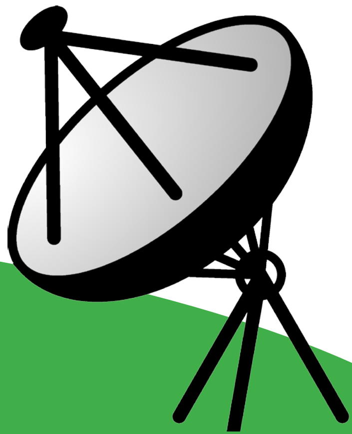
It is possible to detect radiation outside the visible light spectrum using remote sensing technology. Observing this radiation can provide more data than what can typically be captured by a visible light image alone. If data is collected at various electromagnetic radiation frequencies and combined, a multi-spectral image can be formed.

Through the combination of images captured at different frequencies, valuable information about objects in the image can be determined. For example, plant leaves absorb visible light, but scatter near-infrared light. Collecting data at visible and near-infrared frequencies therefore allows vegetation to be analyzed using a multi-spectral imaging process known as the Normalized Difference Vegetation Index (NDVI).

A traditional means of undertaking remote sensing surveys has been fixed-wing aircraft. However, over the past few decades a variety of other modalities have become available. Some examples are provided above.

Sensing

The various methods used to process these images enables them to have relevant applications in agriculture, and by extension, to address issues of food and water security (Kumar, 2005).



Satellites

Satellites are in use for almost all facets of everyday life. There are generally three different orbits used for remote sensing: geostationary, equatorial and sun-synchronous.

Each type of orbit has different advantages and disadvantages. For instance, sun-synchronous orbits are useful for taking infrared and visible spectrum images due to the presence of constant sunlight (Barrett and Curtis, 1999).

There are also advantages and disadvantages to the use of satellites. The disadvantages include high infrastructure costs and imaging not being obtained in 'real time' requiring processing before use. However the advantages of satellites involve the ability to process and archive large amounts of data while simultaneously providing coverage over large geographic areas.

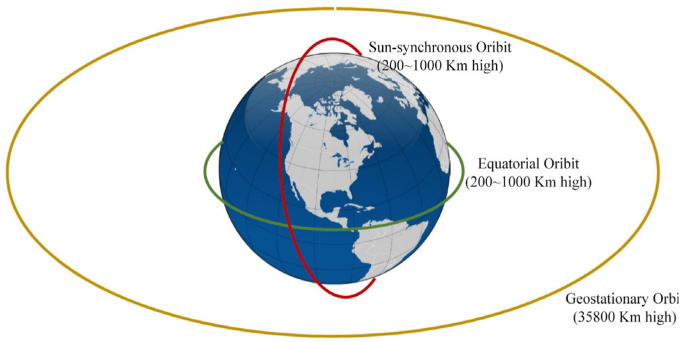


Figure 10: Common types of satellite orbits (Zou, 2016).

UAVs

Imaging from multispectral cameras on UAVs provides information to check crop health, productivity yields, and water volume in catchment areas, as well as ascertaining water contamination, including sewage spills (Laneen, 2007). UAV technology can also be used for tracking cattle and other livestock to support the management of this resource (Gebbers and Adamchuk, 2010).

In-situ monitoring allows for local maps to be created and compared for future modeling, rather than relying on centralized data. It also allows for closing gaps between satellite images and traditional surveying. The in-situ nature of the data collection reduces the time delay between image collection, processing, and delivery, making this method comparably more efficient than that of satellite technologies (New America, 2015). As the images are taken with cameras closer to the ground, higher resolution can be obtained through the use of cheaper cameras compared to the cameras used on low Earth orbit (LEO) satellites (New America, 2015).

An aspect of water security has been demonstrated in Ethiopia by identifying breeding grounds for malaria through mapping water sources that are likely to harbor malaria-carrying mosquitoes (New America, 2015). This information then supports decision-makers in developing strategies to minimize the impact of malaria on the water supply to ensure security to all dependent on the water source.

Figure 11: Using UAVs to create an orthomosaic image for agriculture use (Greenwood, 2015).

The agriculture industry is well placed to use UAV technology for crop and soil monitoring and animal tracking. The New America report on Drones and Aerial Observation indicates that in the past, commercial applications of UAVs have cost between $2,500 to $3,000 USD per hour to operate. However, in recent years, fixed wing and multi-rotor UAVs have been built for use for a significantly reduced cost (New America, 2015), with simple control systems to allow for easier access by developing countries. As the technology develops further, it is likely that the cost would be reduced to allow a higher UAV usage rate by farmers and agronomists.

A key advantage of UAVs is access to real-time data. Given that the infrastructure cost for UAVs is considerably less than that for satellites, it may be feasible to use them as a short to medium term technology-enhancement strategy in addressing food and water security challenges.

Remote Sensing Applications

As technology improves, innovative long-term solutions to enhance water and food security are being developed. Applications, such as real-time flood warning (Al-Sabhan, 2003), systems to track global changes in Earth's climate, and the monitoring of snow and ice coverage (Yang, 2013), could be incorporated into the dataset to support decision-making.

Precision agriculture uses the global navigation satellite system (GNSS) and satellite imaging to identify trends with real-time signals (Maohua, 2001). Precision farming is a comprehensive farm management approach to increase profitability, sustainability, product quality, effective and efficient pest management, energy efficiency, water and soil conservation, and surface and groundwater protection (Grisso et al., 2009). Techniques of precision farming include autonomous systems such as guidance of agricultural tractors and self-propelled machinery.

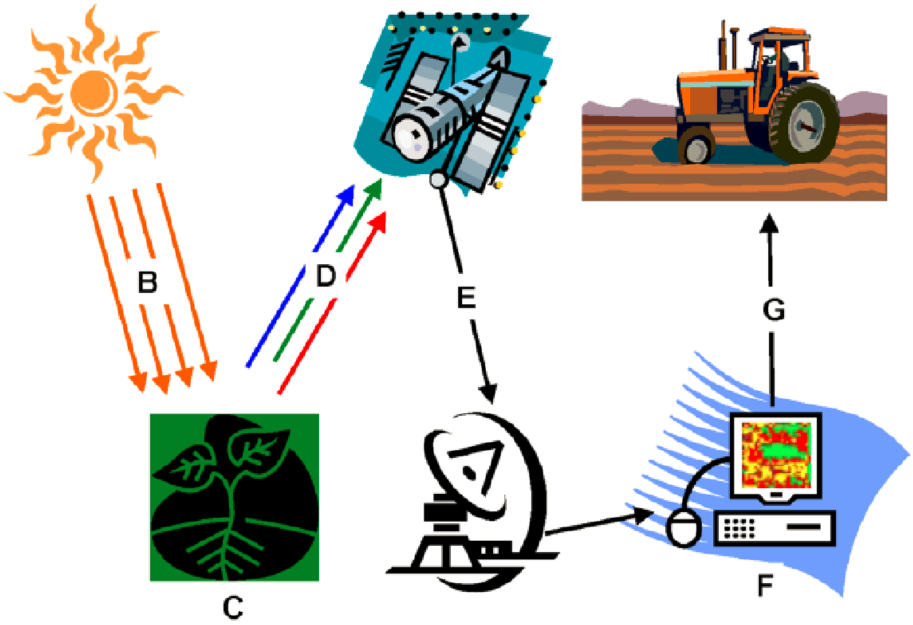


Figure 13: Schematic representation of the componenets of the precision agriculture cycle (image source: Monsanto) (Chatsko,2014)

GNSS (such as the Global Positioning System (GPS)) sensors can be used to record the position of soil samples and create location maps for soil nutrient levels. Airborne cameras with information from GPS sensors allow the substantial differences between soil and plant surface on a sub-field scale to be detected (Noack and Muhr, 2008). Despite its effectiveness and efficiency, the wider use of precision farming techniques is limited by the high initial investment in associated infrastructure, as well as the complex image processing, which increases the cost to the end user. This would require countries in the Global South to adopt long-term investment strategies for such technologies.

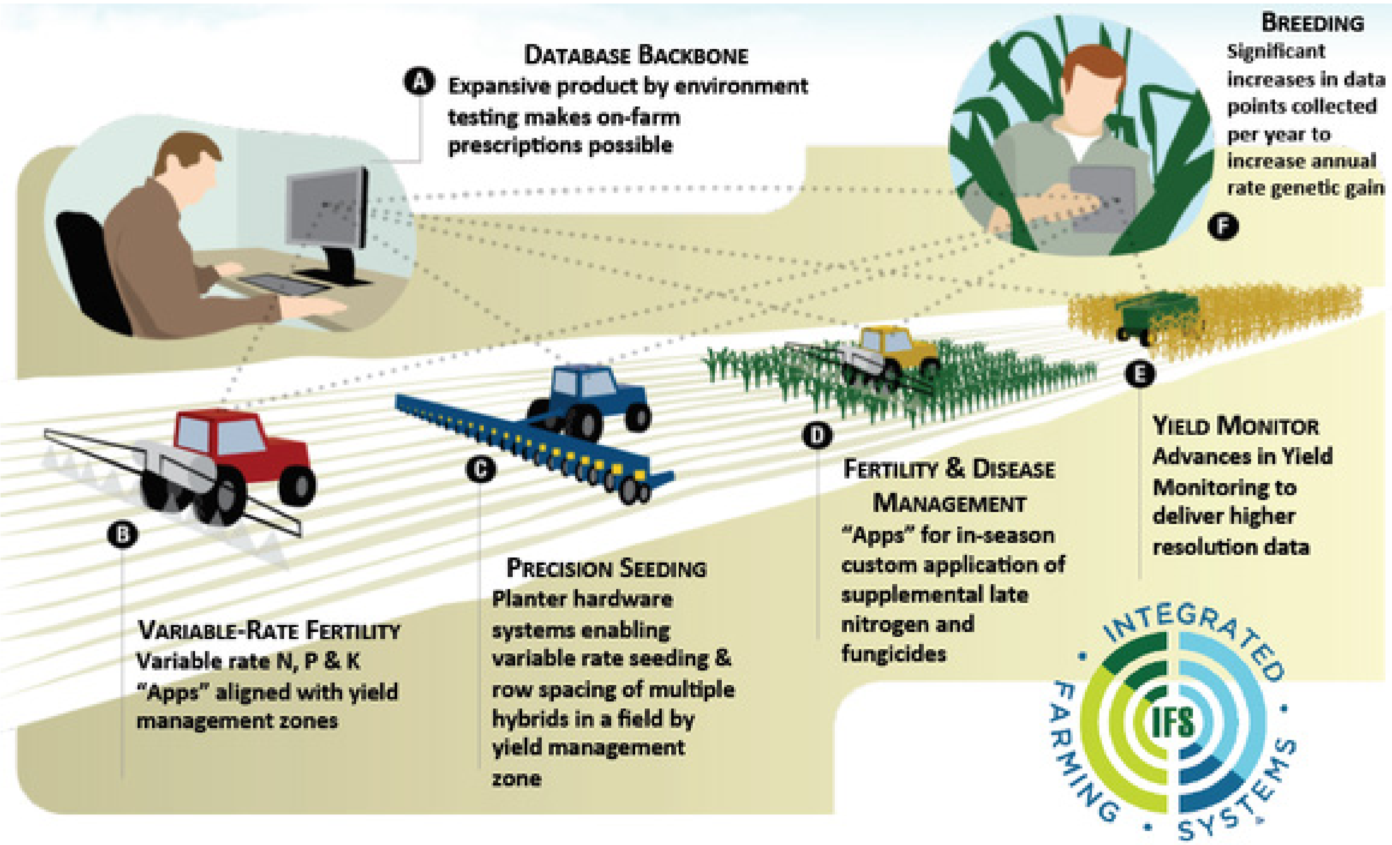


Figure 12: Illustration of the satellite remote sensing process as applied to agricultural monitoring (Nowatzki et al., 2011).

Remote Sensing in Action: Some Agricultural Case Studies

The following case studies demonstrate how remote sensing data assists different elements of agricultural production across a variety of locations.

Case Study: Oceania/Australia

Water security is not just about having potable water for drinking; it is also about how it affects the agricultural industry. Some of these effects include less grazing vegetation for livestock and insufficient water for crops (which are used to feed both people and stock). Tight watering constraints affect productivity and leaves crops more susceptible to disease. The catalytic effect of a lack of usable water is that food security then becomes more of a problem not only in terms of agriculture, but also livestock management. As Australia becomes an increasingly dry environment, there is a need to understand the current and evolving land conditions to ensure that livestock is moved to grazing areas with adequate vegetation.

One group that is assisting farmers with better land management is NRM Spatial Hub. The group provides an online property planning and information system (OPPIS) that uses geospatial technologies and satellite remote sensing to provide online systems, tools, data, and skills needed to access information and knowledge for improving productivity, land conditions, and conservation outcomes at the local property, regional, and national levels (NRM Spatial Hub, 2016).

With the use of satellite data, NRM is able to provide seven key products to farmers that are user-friendly and helpful to users in real time.

These products include:

1. Seasonal Fractional Cover - A representative estimate for each season for areas that are dry, bare or vegetative;
2. Persistent Green - An estimate of vertically-projected green-vegetation fraction where vegetation is deemed persistent over time;
3. Seasonal Fractional Ground Cover - A representative estimate for each season of the proportion of green, dry, and bare ground cover consistent measure of ground cover dynamics to support decisions on long-term safe carrying capacity and monitoring of land condition.
4. Single Date Fractional Cover - Displays estimated fractional cover every 16 days. This is used to track seasonal progression and assist with understanding the impact of management decisions within paddock variability of available pasture biomass or utilization;
5. Seasonal Deciles (total cover and green cover) - compares the level of cover for a specific area. This is used to highlight the impacts of fire, management and/or drought;
6. Ground Cover Analysis - Tools for analyzing/reporting on changes in ground cover; and
7. Green Cover Percentile Analysis - Analyzes the level of green ground cover for any specific period and highlights areas being over or under utilized by stock, or identifies issues such as weeds.

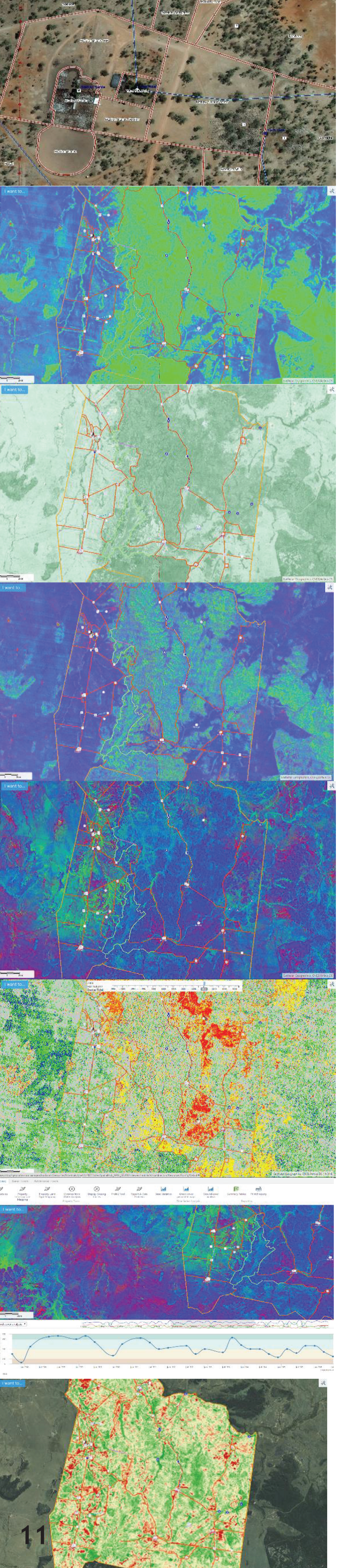


Figure 14: NRM Spatial Hub Time Series Satellite Data Products (NRM Spatial Hub, 2016).

Case Study: Nigeria/Africa

In Nigeria, population growth rate, limited food production facilities, and climate change all impact food security. The agricultural sector represents roughly 18% of Nigeria's nominal GDP; crop production represents 74% of the agricultural sector (Kale, 2015). Nigeria is receptive to adapting space technology and existing infrastructure from its telecommunications industry to tackle challenges in farming (NiMET, 2013). For instance, NigeriaSat-1, the country's first orbiter, provides data and imagery for monitoring conditions for use in the agricultural sector (Sheets, 2013).

This satellite was used to create the first detailed map of the country, allowing the government and other invested parties to locate major agricultural regions and to determine which areas of the nation may need farming support (Sheets, 2013). The four non-commercial National Space Research and Development Agency (NASRDA) satellites are also used to enhance real-time weather forecasting and trends in data, which helps farmers across Nigeria. This data, produced in partnership with Nigerian institutions and universities, has helped increase crop production throughout the country (Sheets, 2013).

NigeriaSat-1 has also been used to help monitor the country's ecological health, with a focus on the degradation of the oil-rich Niger Delta region, which has suffered repeated spills that have discharged more raw petroleum than the BP disaster in the Gulf of Mexico. Millions of barrels of oil go unaccounted for in Nigeria each year. Oil spills have damaged water ecosystems, causing difficulties for local fishermen. Satellite images can help to locate problem areas (Sheets, 2013).

Space agencies such as the South African National Space Agency (SANSA) and NARSDA in Nigeria allow countries in Africa to be more receptive to adaptive technologies which can benefit the agricultural sector and aid in food security.

Figure 15: Food insecurity in Africa (Drake, 2013).

Case Study - Pakistan

As its space agency, the Pakistan Space and Upper Atmosphere Research Commission (SUPARCO) gathers crop statistics on a country-wide basis, developing crop area estimation procedures and crop yield models, issuing monthly agricultural bulletins on its website since 2011. These are based on the application of satellite remote sensing, Geographic Information Systems (GIS), agronomy, agro-meteorology, statistics and other allied disciplines. This system not only provides temporal and synoptic views of the crop areas, but also provides quick and precise crop statistics (SUPARCO, 2016).

The information provided in these monthly bulletins includes a suite of information highly useful to agricultural procedures. This includes a crop situation summary, Normalized Difference Vegetation Index (NVDI), vegetation difference, agro-meteorological conditions, daily hydrological status, irrigation water supply data and other relevant information (Pak-SCMS, 2016).

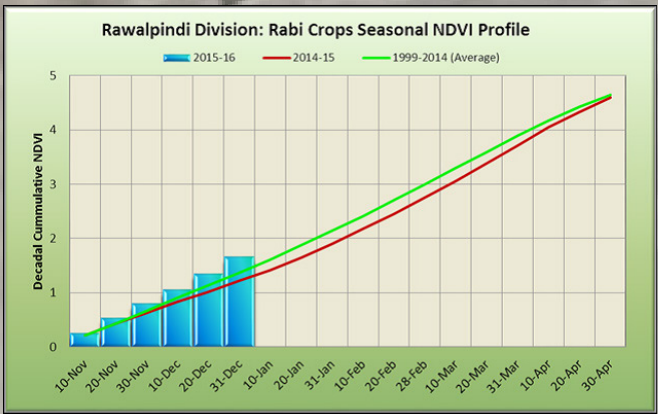


Figure 16: Pakistan Rawalpindi Division: Rabi Crops Seasonal NDVI Profile (Pak-SCMS, 2016)

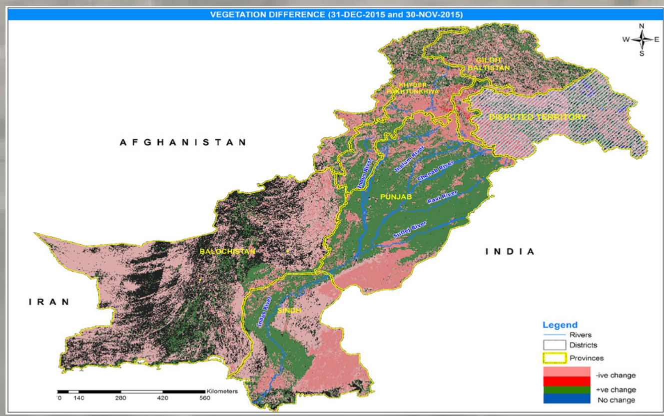


Figure 17: Pakistan Vegetation Difference (30 November to 31 December 2015) (Pak-SCSM, 2016)

Case Study - China

China's food security has been greatly improved in recent years. Nevertheless, it faces problems such as achieving a healthy balance of nutritional components and poor environmental sustainability (Zhang et al., 2015). The Chinese Government is reforming its food safety laws and strengthening surveillance and monitoring systems (Lam et al., 2013).

In China, the projected peak population of 1.45 billion will be reached by 2030, and approximately 60% of the country will be urbanized by 2020. This process brings about dietary changes, including increased meat consumption, which necessitates increased use of water for livestock and creates another challenge for food and water security (Jiang, 2015).

One of the major space-oriented strategies employed in China to address food and water supply issues is the CropWatch monitoring system. Using a combination of Chinese satellites and selected field data, CropWatch uses high and low resolution remote sensing data to calculate and disseminate various crop-monitoring indicators. It provides remote sensing monitoring and data processing for 31 countries which, taken together, account for more than 80% of both the production and export of such crop staples as maize, rice, soybean and wheat (Wu et al., 2014). The CropWatch system implements crop growth and condition monitoring every 10 days, provides drought monitoring every 10 days, and issues a monthly agro-meteorological condition analysis for China. Crop area estimation and yield prediction for the key crops of maize, rice, soybeans, and wheat is conducted monthly, with CropWatch collating this data to produce its Crop Proportion Monitoring and Cropping Index Monitoring each year (Wu and Li, 2015).

Figure 18: Wheat terraces in Guangxi, China. Credit Garcia.

Lessons from the Case Studies

The four case studies demonstrate how remotely-sensed data can contribute to understanding the linkages of food production and water access. Understanding the value of this connection can inform decision-makers of the importance of cross-sector policies and programs in addressing food and water security challenges.

Relationship between Food, Water and Energy

Agricultural productivity is influenced by three interlinked systems. The dynamics of the water-food-energy relationship are governed by the needs of growing populations, increasing urbanization, expanding energy requirements, investment in technology, economic development, and climate change. As a result, we must also consider the consequences of increasing the use of either food, water, or energy. For example, if we choose to increase the supply of sugarcane to produce ethanol, there will be less available land to grow food. Likewise, the adoption of highly efficient irrigation systems could reduce the potential to use a river as part of a hydroelectric scheme. The relationship between the three systems is such that when any individual system is substantially increased, there can be a corresponding trade-off affecting the other two systems.

Agriculture and food production from irrigation consumes approximately 70% of freshwater withdrawals annually (FAO, 2007). Rapid growth in water demand for industry and domestic use removes water for food production. Cereal grain prices are closely tied to the level of available food. This level is determined by the ability to have access to sufficient water to grow the crops. The demand for water for one type of crop could affect the availability of water for another crop adjoining the same water source. Any increase in price reduces access to nutritious food for individuals in poor economic situations, and has the largest impact in low-income developing countries.

Agriculture can also affect regional water quality. Chemicals are normally used in an attempt to improve productivity, but the resulting runoff contains excess chemicals that can influence the quality of water. Pesticides and manure from farm animals can contaminate nearby streams and rivers, creating a hazard to human health. These effects are exacerbated by flooding, which drastically increases the rate and volume at which chemicals and other effluents enter the water cycle.

The authors acknowledge the importance of considering the interconnected influences and cross-sectoral impacts of the water, food, and energy nexus in discussing challenges associated with food, water, and energy security. In this White Paper, we have limited consideration of these influences to urbanization and population growth, climate change, flood, and drought.

Urbanization and Population Growth

Urbanization is defined as population growth that takes place in areas with high population density, such as cities (CIGI, 2015). Though it plays a positive role in overall poverty reduction (Ravallion et al., 2007), urbanization and population growth will strain finite food and water resources in the coming decades. In addition, the proportion of global population located in urban areas has increased from 30% in 1950 to 54% in 2014, and is expected to grow to 66% by 2050 (United Nations, 2014). With such a significant proportion of the global population expected to be urbanized, the distinct impacts of urbanization on food and water security must be considered.

Impacts on Water Security

Urbanization negatively impacts water security in three primary ways: pressure on existing ground and surface water sources, interrupting the natural water cycle, and increasing water pollution (WWAP, 2015). These effects combine to lower the availability of fresh water, and have a detrimental impact on water security in urban areas.

Urbanization, industrialization, and an increase in living standards combine to place significant strain on urban water sources. By 2050, manufacturing, electricity generation, and domestic use will increase global water demand by 55% (OECD, 2012). Easily accessible ground and surface water sources have been largely exhausted in urban areas, meaning that future demand will need to be met using increasingly complex and expensive technology (WWAP, 2015).

In a natural water cycle, rainfall infiltrates ground soils and recharges underground aquifers. This groundwater flows into creeks and rivers as seepage. Excess surface rainfall (runoff) also flows into catchment areas and eventually into surface rivers and streams.

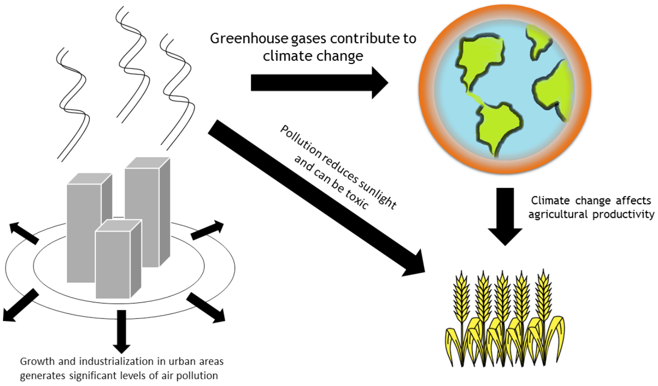


Figure 19: The effect of urbanization on crop growth

In an urban water cycle, there is a higher proportion of impervious surfaces (such as concrete and asphalt), which prevents rainwater infiltration. As a result, there is a higher proportion of urban runoff, which usually flows through stormwater systems and back into the natural water system. Given that stormwater is the primary means of water flow into rivers and streams, these water bodies are more susceptible to drought and flooding (BluePlanet, 2016).

Urban sprawl, the process of "dispersed and inefficient urban growth" (Hasse and Lathrop, 2003) poses a risk to the water cycle by increasing the amount of impervious surfaces in urban areas (Al Tarawneh, 2014). This not only wastes fresh water through urban runoff, but also increases the severity of drought and flooding in the urban environment.

Urbanization can also increase pollution of urban water sources. Urban areas are the single largest sources of water pollution in the world. Increased domestic and industrial use of water and subsequent production of wastewater will put strain on wastewater infrastructure in coming decades. It has been estimated that in developing countries 90% of all wastewater re-enters the natural water system without treatment. This, in turn, creates significant environmental and health hazards associated with polluted water (UN Water, 2014).

Impacts on Food Security

Urbanization has significant impacts on food security. Higher air pollution levels associated with industrialization and urbanization can damage crops, and changing land use patterns can reduce arable land availability. These effects combine to lower the availability of fresh water for agricultural production, and also detrimentally impact water security in urban areas. The sheer number of humans that must be fed due to the continuing explosion of human population levels also places increased strain on an already challenged global food production and distribution system.

Impact of Pollution

Growth and industrialization in urban areas generates significant levels of air pollution. Air pollution in the form of greenhouse gases contributes to climate change, which can impact agricultural productivity. Pollutants such as black carbon, nitrogen oxides, ozone, and sulphur dioxide can have wide ranging negative effects on plant life, including starvation of solar radiation and toxic exposure, leading to reduced growth or premature death. This is not simply a localized issue – it is apparent that air pollution can be transported over intercontinental distances (Mina, Singh and Chakrabarti, 2013; Burney and Ramanathan, 2014).

The impact of pollution on crop yields should not be understated. Simulations (in the form of temperature and precipitation changes) were conducted to determine the combined effects of air pollution and climate change on agricultural productivity in India (Burney and Ramanathan, 2014). The outcomes of this study indicated that in 2010 national wheat production was 36% lower and rice production was 20% lower, in comparison to a situation with no climate change or air pollution effects.

Impact of Land Use Patterns

Urban sprawl can also have a detrimental effect on availability of land for agricultural use in areas surrounding urban regions (peri-urban areas). Peri-urban agriculture plays a significant role in supplying fresh food to urban consumers. As urban sprawl increases, the availability of fertile, productive agricultural land in the vicinity of urban areas is compromised by new urban land usage (Matuschke, 2009). Once land is urbanized, it becomes nearly impossible to reclaim it for agricultural or natural uses.

Historically, cities have flourished in areas of prime agricultural land. A typical example is the Nile delta in Egypt, which has been continuously cultivated for 7,000 years, and represents more than half of Egypt's total arable land (Shalaby, 2012). If growth and urban sprawl continue at current rates, it is estimated that all agricultural land in the Nile delta will be urbanized within 200 years (Al Tarawneh, 2014). This issue is not limited to the Nile delta. Similar urban encroachment has been documented in nations across the global south, including China, Indonesia, and Chile (Matuschke, 2009).

Space-based Solutions

Space-based technologies, in particular remote sensing and Earth observation systems, have the potential to feed timely and accurate data into urban planning and management systems to increase their effectiveness. This information could play a key role in mitigating the negative impacts of urbanization on food and water security.

Remote sensing and Earth observation systems can be used to analyze water quality and pollution. Remote sensing techniques have been proposed for detecting suspended particulate matter, phytoplankton, turbidity, and dissolved organic matter in water bodies. Suspended particulate matter, which consists of organic and inorganic particles, is the most significant source of pollution in surface water bodies, and can be detected in the visible and near infrared ranges of the electromagnetic spectrum. In the infrared range, phytoplankton can be detected in water bodies through chlorophyll absorption and serve as an indication of algal growth. Turbidity refers to the amount of light scattering a water body performs, and can be used to measure sediment concentrations. Finally, dissolved organic matter, which refers to particles too small to be collected by conventional filters, can be detected through the absorption of visible light (Usali and Ismail, 2010). With sufficient temporal resolution, a remote sensing system working in concert with terrestrial sensor networks could be used to detect water pollution and other water quality issues in real time. Such information could be used to mitigate the effects of water pollution incidents as they happen, helping to improve overall water security.

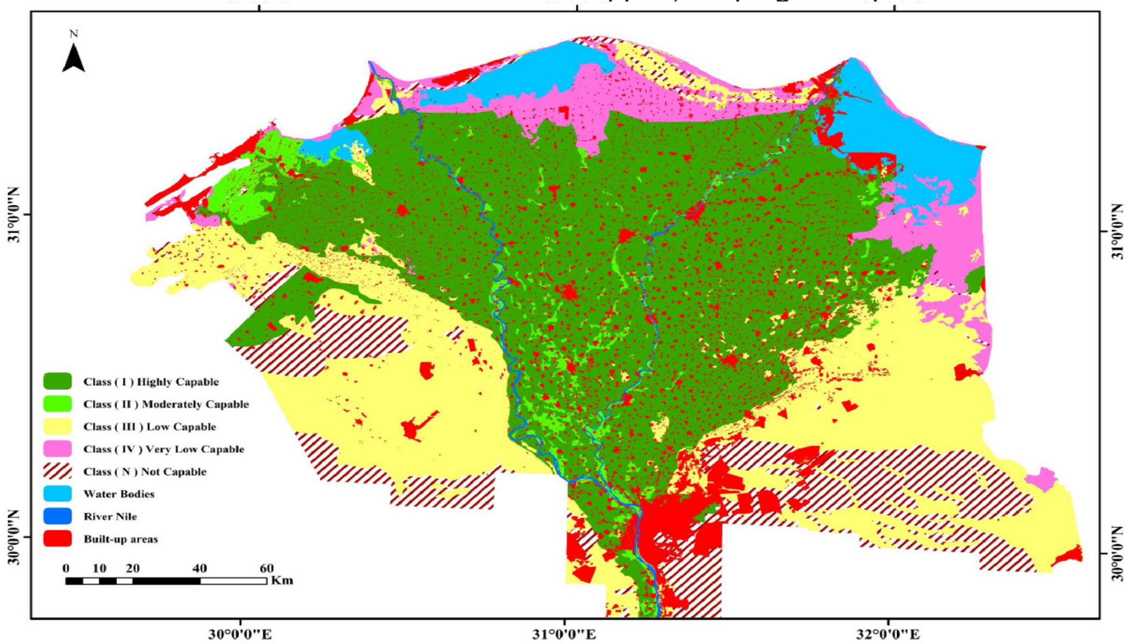


Figure 20: Soil capability and urban land used in the Nile Delta in 2006 (Shalaby, 2010).

Remote sensing and Earth observation systems play an important role in the development and validation of complex mathematical models of the water cycle. Accurate hydrological models require meteorological, soil, vegetation, land cover, and terrain data (Kite and Pietroniro, 1996). These can be used in urban planning to minimize water cycle interruptions by focusing development in areas of low impact, or effectively reducing impervious surfaces in urban areas to maximize rainfall infiltration.

Air pollution can also be detected using remote sensing and Earth observation systems. Developments in remote sensing technology have improved the capability for space-based assets to monitor air quality. It is possible to detect many common air pollutants, including those previously mentioned, which have a destructive impact on plant health (Borowiak and Dentener, 2006). As in the case of water pollution, it may be possible to detect air pollution and other air quality issues in real-time to allow them to be managed effectively. There are unresolved issues with space-based systems having insufficient spectral and temporal resolutions to effectively monitor air quality in an operational context (Borowiak and Dentener, 2006). Future developments such as nanosatellite constellations and improved imaging technology may help to overcome these issues.

Land use can also be accurately measured using remote sensing and Earth observation systems. These systems can detect different uses of land in urban, agricultural, and natural settings. For example, as previously described, remote sensing is used extensively in monitoring urbanization in the Nile delta (Shalaby 2010). This remote sensing data can be combined with other GIS data to create detailed maps of land use in urban and agricultural regions. Figure 20 uses a combination of soil capability data and Landsat thermal imaging to compare agricultural and urban areas in the Nile Delta.

Figure 21 shows the impact of urbanization over a 20-year period in the Pearl River Delta in China. Maps such as these could be an invaluable resource in sustainability-focused urban planning, and could be used to target urban development in areas that will minimize impacts on agricultural productivity.

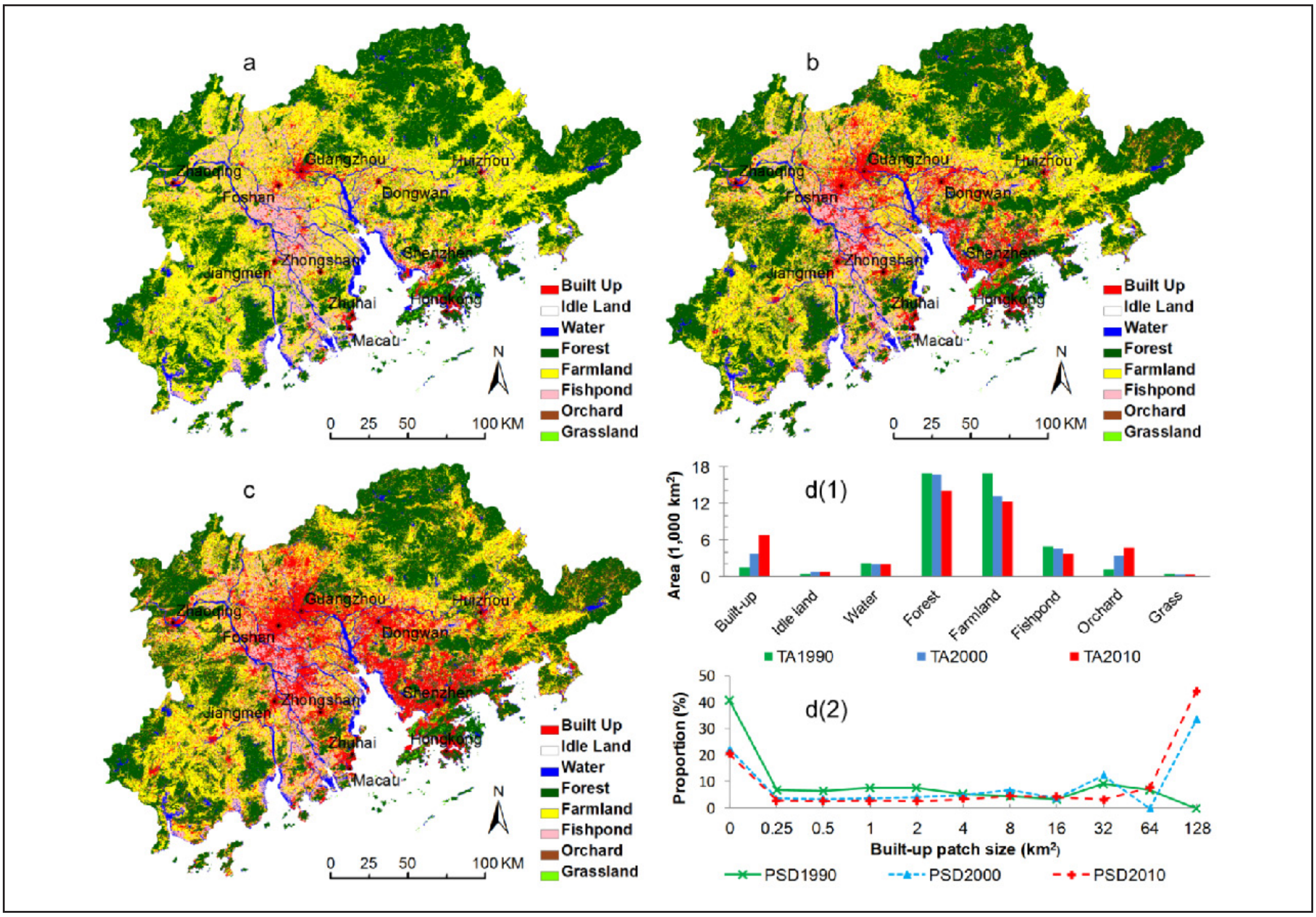


Figure 21: Growth in built-up areas in China's Pearl River Delta in (a) 1990, (b) 2000, and (c) 2010 (Du,Shi and Van Rompaey,2014).

Case Study - Brazil

The increasing urbanization of global populations represents a major international challenge to food security (Stones, 2011). Population growth, economic globalization, improving living standards and urbanization are causing important changes in the global food system and modifications in dietary habits, resulting in a shift from unprocessed to processed and convenience foods. Contemporary food choices put significant pressure on natural resources, including ecosystem impacts from land clearing for agriculture.

In recent decades Brazil has undergone a significant demographic transition as a result of rapid population growth and urbanization, expanding its population from nearly 71 million people in 1970 to almost 200 million today (fourth-highest globally) (World Population Review, 2015).

Brazil's water supply is threatened by both climate change and urbanization. The most recent assessment of the Intergovernmental Panel on Climate Change (IPCC) projects substantial warming with temperature extremes in South America by the end of the 21st century. The IPCC further forecasts the length, frequency and/or intensity of heat waves will most likely experience a "large increase" over most of South America, caused principally by decreased rainfall and/or increased evapotranspiration in Amazonia and Northeast Brazil (Barrett, 2014).

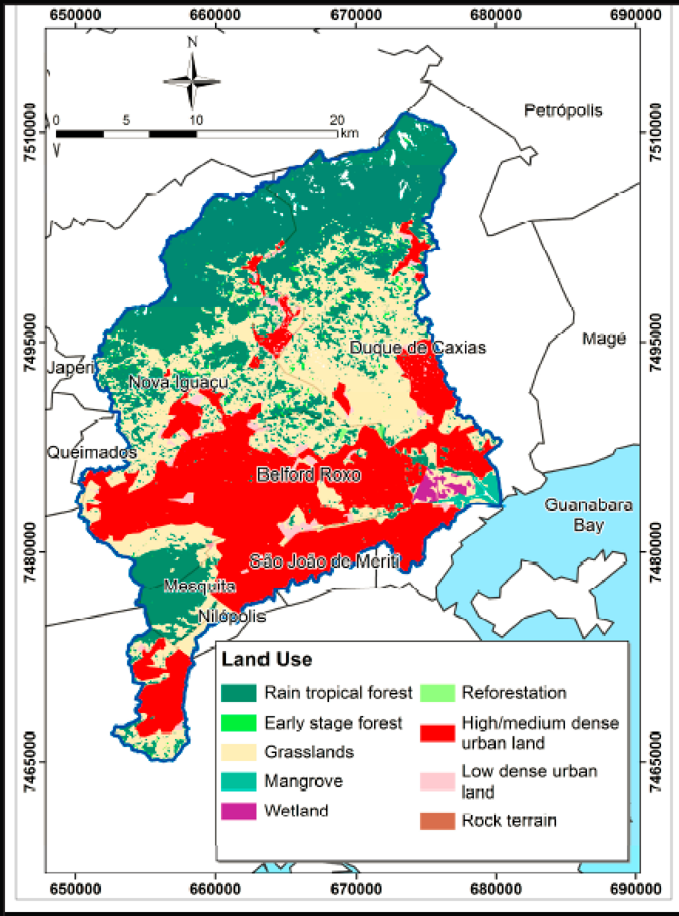


Figure 22: Land use map for the Iguaçu-Sarapuí River Basin, a low-land area of Rio de Janeiro State, Brazil. (Miguez, et.al.2015).

The IPCC also identifies urbanization as having affected the local climate around São Paulo, and that the increasing heat island effect (built-up areas being hotter than nearby rural areas), may be responsible for a 2°C local warming over the last 50 years. By 2100, climate projections show an expected warming of between 2-3°C for São Paulo alone. This regional warming trend will likely be compounded by a magnified heat island effect with the increasing populations of Brazilian megacities. For instance, São Paulo's urban area is projected to increase 38% by 2030. As a result, the potential water security and food security problems become increasingly acute (Barrett, 2014).

Brazil has 12% of world's available freshwater and among the highest renewable freshwater supply per capita in the world. Despite this, water scarcity is an issue, intensified by a culture of water wastefulness (Victor, 2014).

According to the Brazilian Atlas of Natural Disasters, there were about 17,000 drought events recorded in 2944 municipalities in the country between 1991 and 2010, making drought the top disaster in Brazil, followed by various types of flooding. Droughts affected a larger population in Northeast Brazil, causing population displacement and economic losses. Southern Brazil was affected only by sporadic dry seasons, leading to crop loss and economic impacts, with a small number of affected persons having to leave their homes (Sena, 2014).

Credit: NASA

Climate Change

Introduction

The last 150 years has seen a steady increase in the average global temperature. Up to now, this rise has been less than two degrees celsius (IPCC, 2014); however, this seemingly small upturn in temperature may have disastrous environmental consequences. Droughts, storms, floods, and rising sea levels all present challenges, especially to agriculture. Entire crops may fail from poor soil conditions or increased flooding. The nature of these weather events varies from location to location, which means that no one solution can be applied uniformly to all countries.

Space-based technologies such as Earth observing satellites allow us to monitor these environmental changes remotely and to transmit the data to improve everyday farming practices and to inform policymakers in addressing the problem of climate change. These technologies can play a major role in the monitoring and prediction of climate change trends and can make major contributions to enhance food and water security in the Global South.

Definitions of Climate Change

The Framework Convention on Climate Change (UNFCCC) defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods” (Article 1). This definition adopted by the UN makes a distinction between climate change attributable to human activities that alter the atmospheric composition and those attributable to natural causes.

Types of Climate Change

Patterns of climate change can be examined in both global and localized geographic contexts. The Intergovernmental Panel on Climate Change (IPCC) Synthesis Report 2014, details the following types of climate change and subsequent impacts presently occurring on a global level.

Changing precipitation or melting snow and ice are negatively affecting water resources in many regions. The geographic ranges, migration patterns, and abundance of several marine species (including some consumed by humans) have shifted in response to climate change. This planetary rise in temperature also has damaging effects on global crop yields, which do not come close to being offset by the new arable land emerging in some limited areas (eg. Greenland) as a result of global warming (IPCC, 2014).

Current Space Technologies Addressing This Issue

The most well-known space technology that provides data for monitoring and predicting climate change is Earth observation satellites. The Group on Earth Observations is coordinating efforts to build a Global Earth Observation System of Systems (‘GEOSS’). Established in February 2005, GEOSS is a voluntary partnership of 80 governments and 52 international organizations that links Earth observation, information, and processing systems to improve the monitoring of the state of the Earth.

In September 2015, GEO helped to launch the Global Partnership for Sustainable Development Data (GPSDD) to support the Sustainable Development Goals adopted by the United Nations. Among these goals is climate action, with GEO being “one of a number of anchor partners and champions supporting and shaping the GPSDD’s vision for a better world through data sharing” (Onsenga, 2015).

The Global Climate Observing System (GCOS) is one of the participating organizations in GEO. Its mission is “to ensure the availability and quality of the atmospheric, oceanic, terrestrial and related Earth observations needed for monitoring, understanding, predicting and protecting the global climate system and providing communities and nations with assistance to live successfully with natural climate variability and human-induced climate change. GCOS has strong links with the United Nations Framework Convention on Climate Change (UNFCCC) and works to help the Parties to the Convention improve their climate observing networks” (GCOS, 2015).

The GCOS Cooperation Mechanism (GCM) was established to identify and make the most effective use of available resources for improving climate observing systems in developing countries, particularly to enable them to collect, exchange, and utilize data on a continuing basis in pursuance of the UNFCCC (GCOS, 2016).

How Climate Change Affects Food and Water Security in the Global South

Negative Effects

As weather becomes increasingly unpredictable, farmers are less able to plan for the future. Crop failures become more frequent, and in cases where crops don't fail the overall yield is likely to diminish. Studies by IFPRI (International Food Policy Research Institute) have produced evidence that crop yields in sub-Saharan Africa may decrease by between 5% and 20% if temperatures continue to climb (IFPRI, 2009). This danger is further compounded by the rapid population growth that is expected in Africa in the coming decades. Crop yields are not the only quantity affected by changing climate. Farmers may have to adjust their traditional agricultural practices to adapt to unseasonably high temperatures throughout the year. The CGIAR Research Program on Climate Change, Agriculture and Food Security states that farmers would ideally be served by "a combination of historic and monitored information, and a seamless suite of prediction that ranges from sub-daily to at least seasonal forecasts" (Tall,et al., 2014).

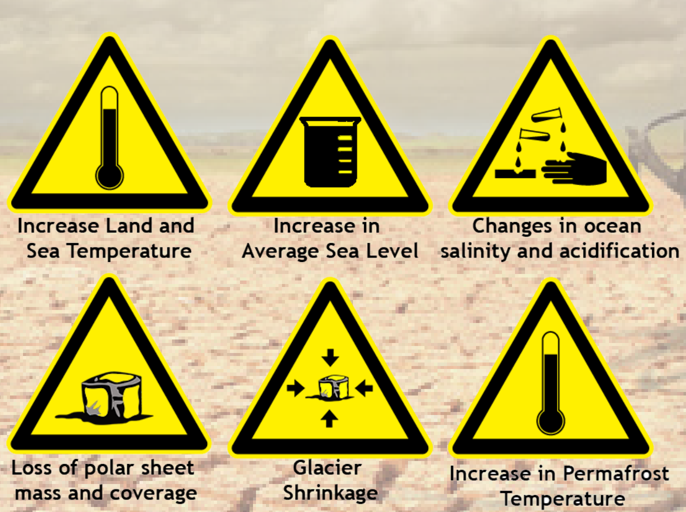


Figure 23: Types of Climate Change. Image credit: Jessica Orr (IPCC, 2014)

Positive Effects

Climate change is usually perceived in a negative light, however there are some aspects of climate change that could have positive impacts on plant growth and food production. Climate change is associated with an increase in greenhouse gasses, especially atmospheric CO_2. An increase in atmospheric CO_2 is known to increase plant biomass (Polley et al., 1993) and water use efficiency (Keenan et al., 2013). This means that the same amount of crop is able to be grown for a smaller amount of water. Climate change is also associated with changes in rainfall and temperature patterns. Over 30% of the variation in the 6 most abundant food crop yields can be explained by variations in rainfall and temperature alone (Lobell and Field 2007). In most studies, climate change has been associated with an increase in local temperature and decrease in local rainfall, resulting in a negative effect on crop yield and thus food security. However, in some areas climate change may cause an increase in rainfall (Trenberth, 2011), which could lead to an increase in crop yield for these areas. For example, in China there is strong regional variability in the effects of climate change, with Noethwest regions predicted to suffer less drought while Southeast regions are predicted to suffer more drought (Piao et al, 2010). This regional variation causes difficulty in modelling the true effects of climate change on a local scale. It has been suggested that by improving the spatial resolution of the modelling data, and by including a wide variety of measurements such as atmospheric aerosols, rainfall, soil moisture, and temperature, a more localized model of climate change and its effects on agriculture can be formed (Piao et al 2010). These improved models can be used to predict when and where crops should placed to maximise their yield in response to a changing climate.

GEO's vision for combining space-based Earth observations with international cooperation and collaboration

"GEO is a strong advocate for sustained and coordinated climate observing systems. It is supporting an ambitious and multidisciplinary effort to strengthen the ability of governments to minimize and adapt to the societal and environmental impacts of climate variability and change. As it matures, GEOSS will represent a quantum leap in the speed, resolution, accuracy and sophistication of weather and climate modeling and forecasting. No single country or group of countries has the resources to achieve these advances on its own, but international collaboration promises to advance climate research and monitoring by ensuring that national investments are coordinated and mutually supportive. To strengthen the link between the providers and users of climate data and predictions, GEOSS disseminates user-friendly information and decision-support tools. Meanwhile, GEO plans to build capacity for using climate and Earth observation data and products more effectively and to integrate climate risk management into national policies for sustainable development." (GEO, 2016).

Flood & Drought: Extreme Weather Events

Food and water security are difficult to maintain in the face of severe weather events such as floods, droughts, and other natural disasters. This section describes how flood and drought affect the Global South's food and water security, as well as how tools offered by space technologies are being used to confront these issues.

Flood

A flood is generally defined as an overflow of water onto normally dry land. A flash flood can be caused by heavy or excessive rainfall or a dam failing, and is usually characterized by raging torrents that rip through river beds, urban streets, or mountain canyons, sweeping everything before them (Geoscience Australia, 2011). Flooding alone accounted for 47% of all weather-related disasters (1995-2015), affecting 2.3 billion people (UNISDR, 2015).

There is an alarming trend of flood disasters affecting increasingly wide areas and at the same time becoming more severe. Flooding has taken its toll on agriculture, water contamination, and destruction of infrastructure, thereby exacerbating malnutrition problems in the Global South (UNISDR, 2015). Topsoil can also be washed away during flooding, causing damage to arable land. Additionally, infrastructure such as irrigation systems, can be damaged or destroyed by floods, which can increase pressure on food sources, especially in rural areas. Floods can also cause population displacements, placing additional pressure on food and energy supply and distribution.

Many countries of the Global South are especially vulnerable to flooding. Figure 24 shows the top 15 countries with the greatest number of people exposed to river flooding risk. The majority of these countries are from the Global South, highlighting the importance of flood mitigation in this region (WRI, 2015).

Drought

Drought results from lower than expected precipitation and high demand on available water supplies. Droughts have a crucial impact on agricultural production and water supply, as decreasing crop yields have direct impacts on food prices, affecting global markets and consumer demand. Reductions in river flows may have consequences for water supply and limit the potential for hydroelectric generation. Poor quality water also has significant negative health outcomes.

Drought intensity and frequency modeling demonstrates an uneven global distribution. The

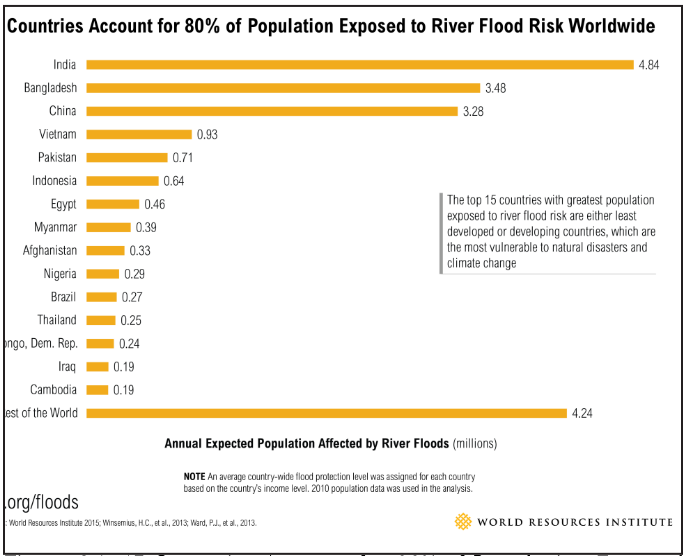


Figure 24: 15 Countries Account for 80% of Population Exposed to River Flood Risk Worldwide (WRI, 2015).

main regions of impact are temperate zones, with winter and spring dominated rainfall patterns and areas dependent on snow melt for replenishing local water sources. These regions need to develop robust adaption and mitigation strategies to reduce future vulnerability. The Mediterranean, Western USA, Southern Africa, and Northeastern Brazil are all expected to see intensification of drought. Russia, Mongolia, China, and Southeast Asia will also see drought intensification from higher temperatures in the drier summer months.

A range of solutions have been either implemented or are being considered for areas vulnerable to drought. These include increased rainwater harvesting, adjustment of silvicultural techniques, channel and pipe leakage reduction, modifying planting dates, and choosing crop varieties that are more drought resistant. Approximately 80% of the world's agricultural land is rain-dependent, so developing mitigation strategies to build ecological resilience into drought-prone and semi-arid agricultural land is critical for food security.

Current Space Approaches

Space-oriented solutions rely heavily on remote sensing satellites, which are used to monitor water levels, inundation, soil moisture, and crop health.

Hydrological Modeling

To monitor water levels for potential flooding, hydrological models of an area are interfaced with

GIS data sets. These models produce 3D maps to convey topographical drainage patterns and to help identify where potential drainage issues may arise. One study used such modeling in conjunction with rainfall data to provide real-time understanding of water distribution (Al-Sabhan et al., 2003).

Soil Moisture

Soil moisture can be detected by satellites and used to determine drainage in flood situations, and increase accuracy of crop yield predictions (Doorenbos et al., 1979). Such remote sensing techniques provide measurements for the top few centimeters of soil, where levels vary rapidly in response to rainfall and evaporation. In Brazil, satellite moisture measurements allowed a 4.3% accuracy improvement compared to ground-based measurements (Chakrabarti et al., 2014).

Multispectral Imaging

Another space technology that can help predict crop yield is multi-spectral imaging. In Eastern India, rice crop areas were mapped using data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites (Gumma et al., 2015). In addition, drought-affected rice areas were identified through analyzing Normalized Differential Vegetation Index (NDVI) data. Space-based remote sensing of yield predictors can reduce the time spent by ground teams in acquiring data and allow determination of risk areas. If these satellites are placed into appropriate orbits, they could provide a near-global field of view, which is especially valuable in areas where ground-based measurements are difficult or costly to obtain.

Communication of Current Solutions to the Public

By combining Earth observation data with human markers of food security (such as household surveys of food stocks) it is possible to validate the space-based dataset and assess when drought conditions begin to negatively affect regional food security (Enekel et al. 2015). An example of this is SATIDA Collect (Satellite Technologies for Improved Drought Risk Assessment), a mobile device application which collects information on the nutrition and health of communities in the Central African Republic. Information sharing such as this have the potential to prevent false alarms and accelerate responses to food insecurity, such as famine, malnutrition and starvation, in real-time.

It is also necessary to have systems in place to manage the data and deliver the appropriate responses. Remote Sensing-based Information and Insurance for Crops in Emerging Economies (RIICE) is a collaborative program that collates remote sensing data on rice crops to provide assessments of yield and quantifiable losses from natural disasters (ASEAN SAS, 2014). This information is shared with insurance companies so that fairer insurance coverage can be provided to farmers. The RIICE project is active in the southeast Asian countries of Bangladesh, India, Thailand, Vietnam, Cambodia, Indonesia, and the Philippines until April 2018.

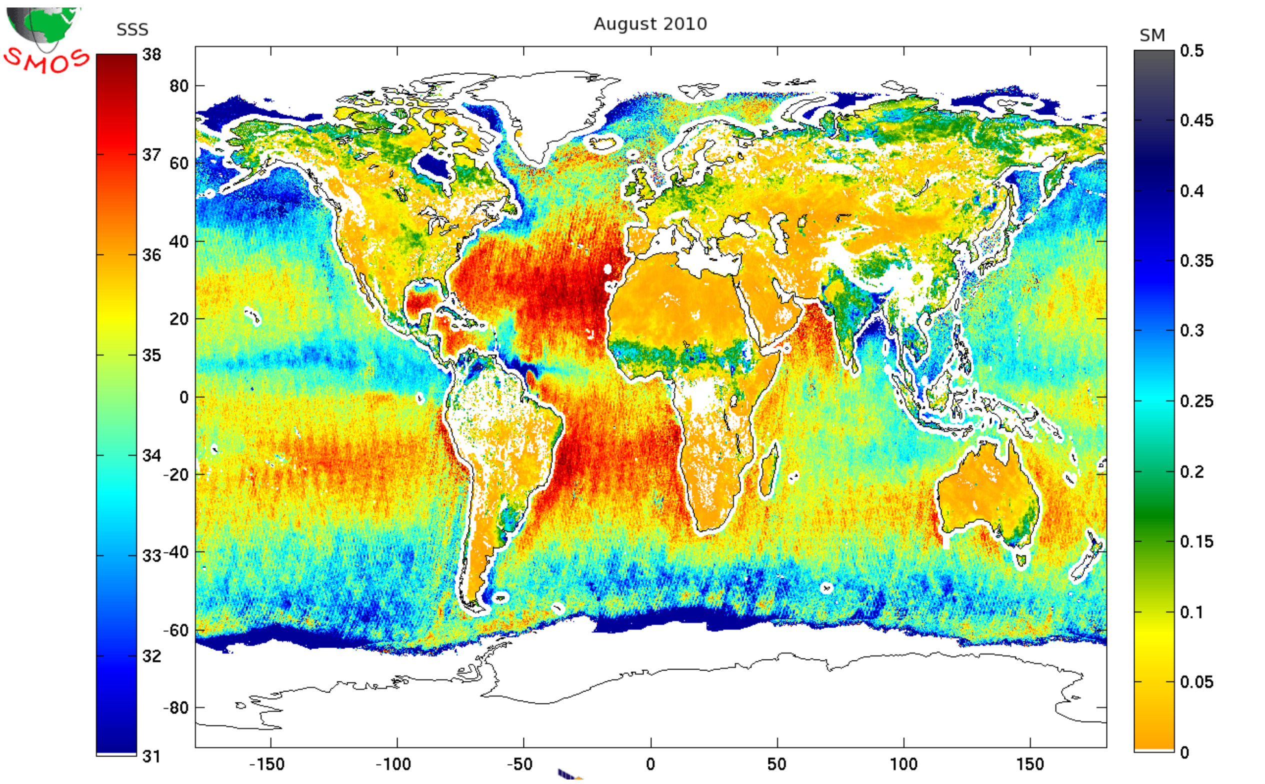


Figure 25: Global sea surface salinity and soil moisture from SMOS (Cabot and Reul, 2010).

Case Study - Space Technology and Floods in Bangladesh

Bangladesh is prone to flooding, due to combined factors such as coastal location, river management, deforestation, population growth, tectonic activities, and climate change (Akhand, 2014). Each year in Bangladesh about 26,000 km2 (around 18% of the country) is flooded, killing over 5,000 people and destroying more than seven million homes (Harris, 2014). In addition to traditional approaches, Bangladesh has beneficially been utilising space technologies to help manage natural disasters, especially flooding.

Bangladesh established its space agency, SPARRSO (Space Research and Remote Sensing Organization) in 1980, and will be one of the first Asian countries to operate its own communications satellite (purchased abroad). To date, Bangladesh has coordinated several space-based programs, including CEAMS (Crop Estimation Analysis and Monitoring System), IRMS (Integrated River Monitoring System), NFMS (National Flood Monitoring Systems), NDMS (National Drought Monitoring System), CRAIST(Cell for Climate Change Research and Impact Study), NWLMS (National Water-logging Monitoring System), SDMS (Seasonal Disaster Monitoring System), SCMS (Satellite-based Coastal Monitoring System), and SaFIS (Satellite-based Forest Information Service) (SPARRSO, 2012).

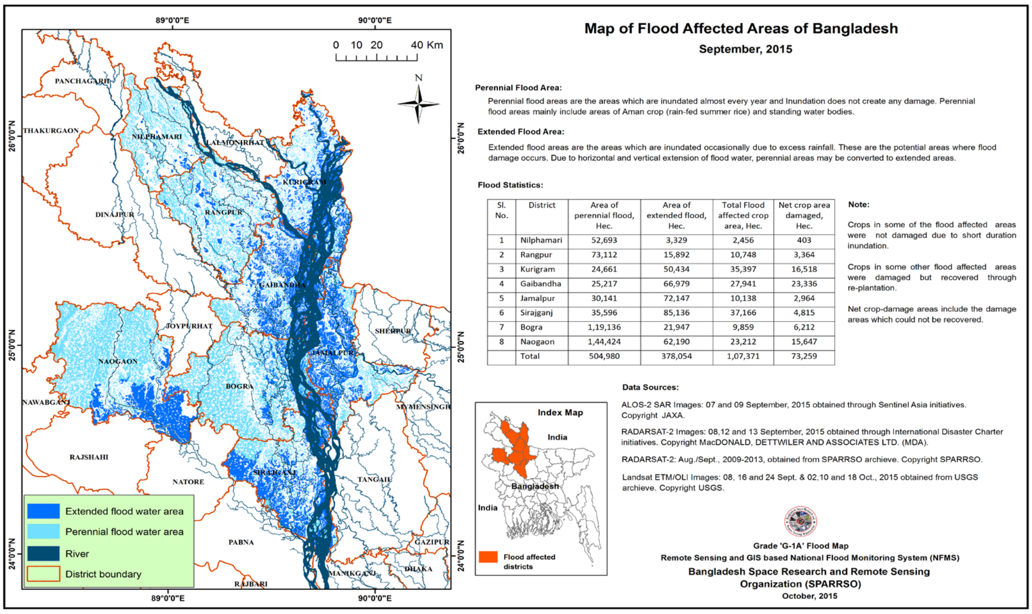


Figure 27: Map of Flood Affected Areas of Bangladesh, September 2015 (SPARRSO, 2015).

Since the major flood of 1988, Bangladesh has given emphasis to space-based data. SPARRSO uses international collaborations to collect and analyze satellite images, weather data, and reports on temperature, air mass, clouds , and rainfall. It detects and forecasts water flows on cycles of 24-48-72 hours and issues early warnings and weather forecasts. Using satellite data, SPARSSO provide flood alerts, monitors flow movements, and contributes to real time forecasting. The Meteorological Department issues weather bulletins and early warnings based on satellite data (Akhand, 2014).

The adoption of these practices in recent years has shown that the use of space-based data reduces the risks arising from flooding, with significant reductions in deaths, economic loss and homelessness. (Akhand, 2014). Bangladesh is actively promoting its space efforts, seeking out more regional and international cooperation, and is planning to launch its first satellite, Bangabandhu-1, in 2017 (BTRC,2011; Islam, 2015).

Case Study - Flood and Drought in Southeast Asia

Food security and poverty are fundamentally linked. Over 730 million people in Southeast Asia live in absolute poverty and over 530 million are undernourished . Over 60% of the world's hungry reside in the region (Asian Development Bank, 2013).

The Remote sensing-based Information and Insurance for Crops in Emerging economies (RIICE) program is helping increase food security for rice farmers in Southeast Asia (ASEAN Sustainable Agrifood Systems, 2014). This program provides imagery from remote sensing satellites to governments as part of a public-private partnership to monitor the size and growth of rice crops, which are a major food source accounting for 31% of Southeast Asian caloric intake (Xiao et al., 2006). This imagery provides assessments of crop yield and quantifiable losses of crop due to natural disasters such as drought and flood.

Following a major flood in Cambodia in 2013, remote sensing data was used to provide estimates of the amount of damaged rice crop to help manage the disaster, ensure better future planning and best inform the delivery of compensation (Dao and Liou, 2015). RIICE was able to provide flood map information after severe events in Thailand and the Philippines with a turnaround time of just a few days. In addition, RIICE has implemented training programs for over 300 employees of agricultural management agencies in SE Asia to help expedite the use of this information in planning and policy decisions (ASEAN Sustainable Agrifood Systems, 2014).

RIICE uses data acquired using Synthetic Aperture Radar (SAR), which can be used to peer through cloud cover, being a prevalent weather pattern during 70% of the rice production season (Nelson, et al., 2014). Developing nations can face challenges when accessing remote sensing data due to infrastructure and technical skills issues. RIICE enhances data accessibility by using low-cost cloud computing and automatic processing of its dataset. During a successful pilot program between 2012 and 2014, RIICE provided high accuracy (higher than 85% correlation) maps of 13 sites across SE Asia (Nelson, et al., 2014). RIICE has partnered with Allianz Re and GIZ to facilitate the development of agricultural insurance products using RIICE map data (GIZ, 2012). This program will continue to expand until at least 2018, with a focus on developing the capability for partner governments to integrate the available data into policy solutions (ASEAN Sustainable Agrifood Systems, 2014).

Figure 26: Taking field measurements in Vietnam to validate RIICE data (correspondence with ground-based measurements of over 85%) (ASEAN Sustainable Agrifood Systems, 2014).

Sensing Progress Team Project

Satellite imagery of the Earth's surface is freely available to anyone with an internet connection. However, there are regions of the world that remain internet blackspots, and many people within these areas - such as agricultural and livestock farmers - could benefit directly from receiving information derived from satellite imagery. Further, even if Internet services are available, many countries and regions do not have the technical expertize needed to pursue remote sensing solutions to agricultural or water management problems.

One possible solution for these populations is to perform localized, small scale remote sensing. There are many ways to do this, but any solution is subject to several constraints. First, any solution must be inexpensive - cost must not be a barrier. Second, the solution must be simple to implement - any technology must be easy to install, intuitive to use, and user-friendly. Third, the solution must be sustainable - governments must provide support if needed and the program must be able to continue on its own after direct government support has been reduced or removed.

One of the possible ways to introduce emerging space countries to remote sensing technology is to provide training using a stratospheric balloon. While drones are easier to control and recover, they can be prohibitively expensive and harder to repair if damaged. A balloon is a cheaper, more robust option that is easier to understand and implement. Building the balloon payload can introduce trainees to technology similar in many respects to small satellite payloads.

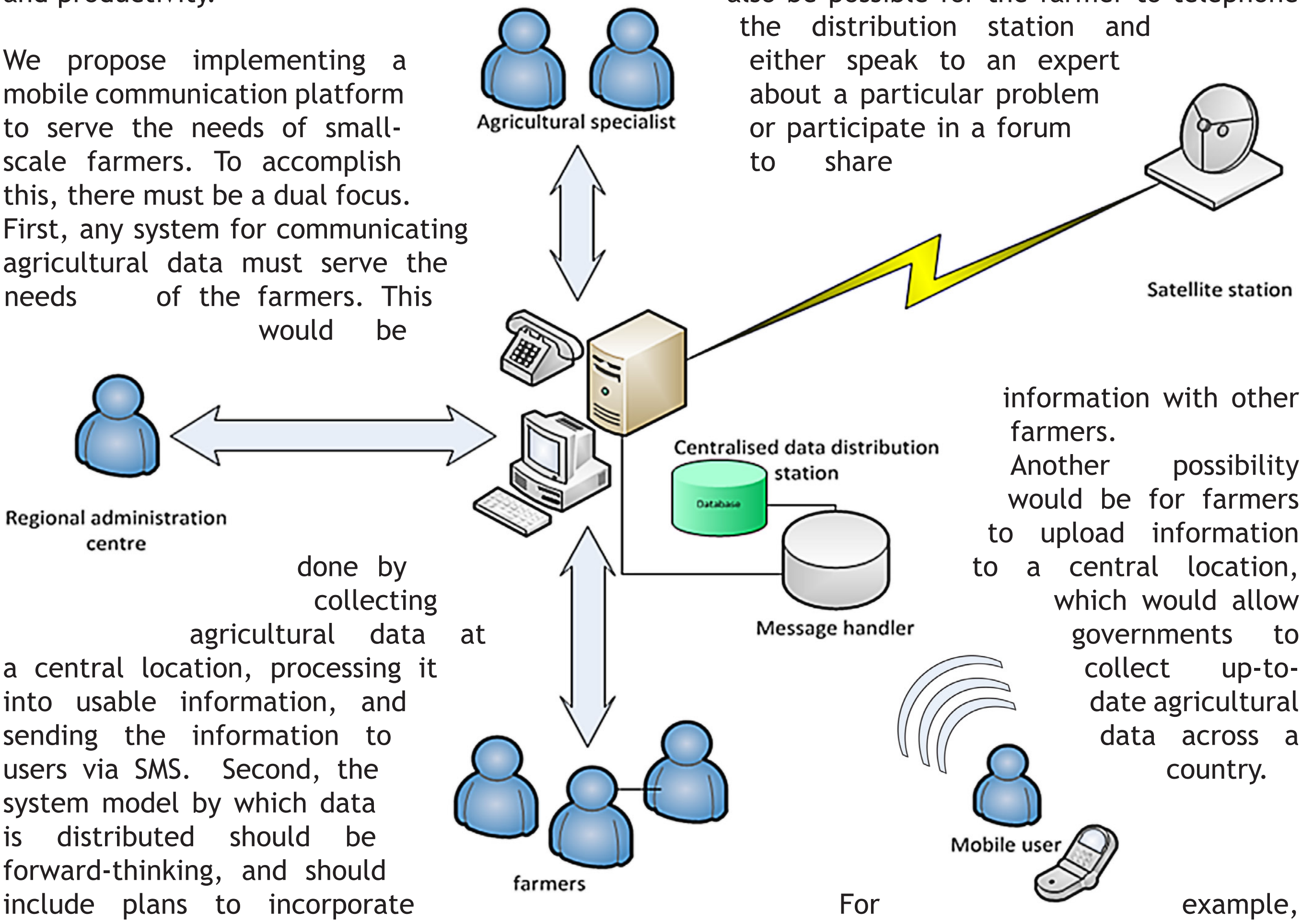
To demonstrate the use of a stratospheric balloon to remotely image vegetation, participants of ISU SHSSP-16 built a relatively simple "cubesat" payload carrying three cameras designed to capture visible and near-infrared images. Overall, the payload took less than a week to assemble with a team of six individuals. It was launched from Mount Barker High School in South Australia on a Helium filled stratospheric balloon by the Amateur Radio Experimenters Group (AREG). Launchbox, an Adelaide based company that designs and supplies small educational payloads, provided the power supply and camera modules as well as technical advice on the overall design and construction of the payload.

The area around the Mount Barker township was successfully recorded, with the payload cameras capturing images in the visible and near-infrared range. The project was completed for less than AUD$2500, and demonstrated that high quality and relevant remote sensing can be achieved for a comparably low price. The details of this project can be found in the Appendix to the White Paper.

Information Distribution Gap

Despite advances in communication techniques and the widespread deployment of communications infrastructure, the economies that would benefit most from agricultural information are the ones least able to access it. If we accept that many agricultural problems could be solved by communicating relevant information directly to the farmer, we could potentially increase small landholder income and productivity.

We propose implementing a mobile communication platform to serve the needs of small-scale farmers. To accomplish this, there must be a dual focus. First, any system for communicating agricultural data must serve the needs of the farmers. This would be done by collecting agricultural data at a central location, processing it into usable information, and sending the information to users via SMS. Second, the system model by which data is distributed should be forward-thinking, and should include plans to incorporate wider internet access and availability of higher-quality mobile communication devices (such as smartphones, laptops and tablets) across the next five to ten years.



Agricultural data would be collected at a central station, analyzed by agronomists, and converted into information that farmers could understand and act on to safeguard the health of their crops. Data would be sent to the farmers via SMS. For example, farmers may be informed that soil moisture levels in their region are above average for a particular time of year, which would encourage them to plant more crops to either store or sell at market to increase their earnings. This communications platform should also allow for a farmer to contact the information distribution center and request specific pieces of information. For example, a group of farmers might receive a daily SMS message informing them of the probability of drought so that they can adjust their irrigation strategies and protect their crops. However, on market days, the farmers might send a request for information to ascertain the price of wheat in the region, so that they can get a fair price at market. It may also be possible for the farmer to telephone the distribution station and either speak to an expert about a particular problem or participate in a forum to share information with other farmers. Another possibility would be for farmers to upload information to a central location, which would allow governments to collect up-to-date agricultural data across a country. For example, if each farmer uploads the amount of surplus corn they have individually produced, the government would be able to correctly prepare in the event of a potential food shortage or similar crisis.

Finally, this type of communications platform has excellent potential as a disaster early warning system. SMS messages containing the nature and location of the disaster can be sent to a broad segment of the population, and potentially help coordinate first responders in the aftermath of an emergency.

ORBITAL SEED VAULT

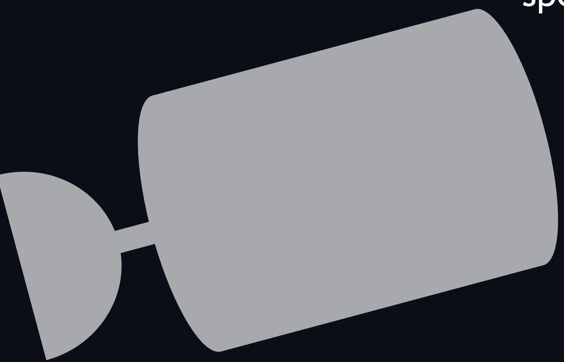
Food security encompasses the management, expansion, and preservation of adequate access to food across the short, medium, and long term. One widespread means of protecting and preserving humanity's access to food over the long-term is through the operation of seed banks. A seed bank (also known as a seed vault) is a form of biorepository, designed to preserve plant seeds as genetic material. These storage facilities hold seeds for long-duration periods in conditions designed to ensure their preservation, with the particular seeds stored in many instances largely comprised of food crops.

The long-term preservation of such seeds helps to guarantee ongoing access to food by safeguarding the seed collections necessary for the continuation of food crops in the event of catastrophic events. Ensuring continued access to the genetic plant material needed to grow crops in the wake of a regional or global disaster is also an important mechanism to help secure the continuation of our species. In particular, seed banks can play a crucial role in protecting staple food crops, since just fifteen plants from the approximately 50,000 edible plant species worldwide provide ninety percent of our total food energy intake (excluding meat). Furthermore, of these food staples, two-thirds consist solely of rice, corn, and wheat (National Geographic, 2016). Protecting these staple crops from cataclysms that may one day occur, including extinction events (five of which have occurred during Earth's 4.5 billion year history), is an issue worthy of attention.

Of the world's approximately 1700 seed banks, the Svalbard Global Seed Vault is the facility specifically designed to provide the highest level of protection for our planet's staple food crops. Located in the Norwegian archipelago of Svalbard, high above the Arctic Circle, this underground seed vault maintains a 4000 plant species inventory, and currently holds some 860,000 seeds in trust for virtually every country.

While the Svalbard seed vault provides the best protection here on Earth for our most important agricultural specimens, it is in fact not the most secure location available to humanity. Given the susceptibility of our planet to catastrophic events such as asteroid impacts, nuclear war, and global pandemics, the setting that provides the highest level of protection is actually outer space. While a seed vault located on another celestial body such as the Moon or Mars would provide the strongest guarantor of the continuance of this crucial agricultural biodiversity, the location currently most suited and achievable for an outer space seed vault would be in orbit high above the Earth. Such an 'Orbital Seed Vault' could store a small collection of seeds from the world's key food staples within a specially designed satellite. Safely preserving these seeds in orbit would require countering the effects of space radiation, in the form of both high energy Galactic Cosmic Rays and lower energy Solar Energetic Particles, to ensure the genetic integrity of the seed samples. A potential countermeasure that may become available is the EU-funded Space Radiation Superconducting Shield project, which is developing a shielding system using superconducting magnets to deflect space radiation (Venupogal, 2015). Just as this technology could potentially be used to shield astronauts on long-duration missions, it likewise could provide necessary shielding to protect seed samples contained within an Orbital Seed Vault.

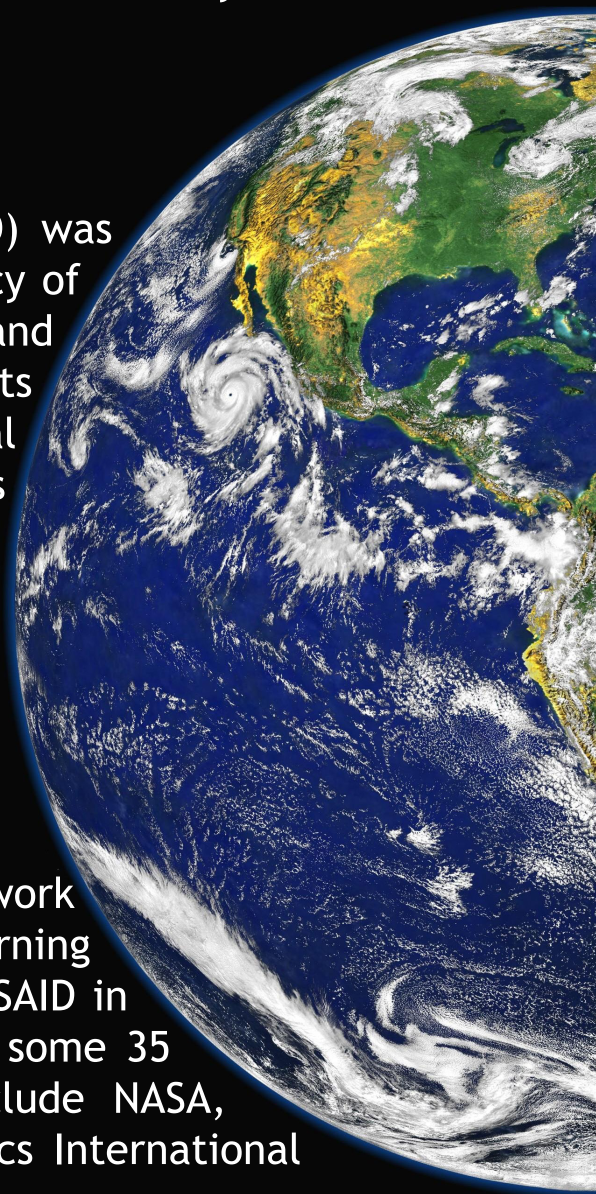
Undertaken as an internationally cooperative project, a single - or even multiple - orbital vaults could greatly assist in the survival of the human species in the face of an extinction event. Providing an important point of difference from the seed vault confined to Svalbard, an Orbital Seed Vault could deorbit and land at a location on Earth where sufficient survivors from a planetary disaster were located. These seed samples safely unaffected by any calamity in space, could then be used to begin the process of replenishing staple food crops, ensuring the preservation of the priceless genetic sequences of this plant material. A satellite could also potentially carry within its refrigerated payload other genetic material such as the DNA of the human race and other animal species.



As a proof of concept, participants in the 2016 SHSSP included in their stratospheric balloon payload a collection of seeds to mimic the parachute landing phase of such an orbital seed satellite. This experiment was a complete success, with all seeds carried (corn, tomato, carrot and pumpkin) landing intact and fully retrieved. Obviously the participants could not recreate effects of microgravity in outer space or the atmospheric re-entry process with this particular experiment. In the past however, seeds have successfully been launched as the major component of a satellite payload, orbited, and then later deorbited. For example, in 2006 a seed satellite developed by the China Academy of Space Technology successfully carried a 215kg payload of seeds (including grains, cottons and vegetables) into orbit where it circled the Earth for 15 days (Global Security, 2016; China Daily, 2006). Some 14.5 million tomato seeds also formed part of the Long Duration Exposure Facility experiment conducted by NASA in Low Earth Orbit (LEO) from 1985 to 1990, with few mutations observed when the seeds were planted after they were returned to Earth on the Space Shuttle Columbia (Success With Seeds, 2008). Seeds stored in proper refrigeration can last far longer, as wheat, corn, and rice seeds all able to be preserved in such conditions for over 1000 years (Pritchard and Dickie, 2003).

FOOD SECURITY

The following desciptions identify and explains international organizations that already support the agricultural sector globally via the provision of information, including remote sensing data. These organizations are detailed here as they stand as some of the best examples of existing institutions where through increased coordination efforts yet at minimal



WMO

The World Meteorological Organisation (WMO) was established in 1950 and is a specialized agency of the United Nations which deals with the state and behavior of the atmosphere and how it interacts with the ocean. The WMO started the Agricultural Meteorology Program to 'assist WMO members in provision of meteorological services to help develop viable agricultural systems'.

FEWS NET

The Famine Early Warning Systems Network (FEWS NET) is a leading provider of early warning and analysis on food insecurity. Created by USAID in 1985, it provides evidence-based analysis on some 35 countries. Implementing team members include NASA, NOAA, USDA, and USGS, along with Chemonics International Inc. and Kimetrica (FEWS NET, 2015).

FEWS NET reporting focuses on acute food insecurity, such as sudden and/or short-term household food deficits caused by shocks, rather than chronic food insecurity. The strength and reliability of FEWS NET forecasting lies in its integrated consideration of the diversity of factors that lead to food insecurity risk. Along with agricultural production, climate and weather, FEWS NET places analytical importance on markets and trade, livelihoods and sociopolitical issues such as conflict and humanitarian response (FEWS NET, 2015).

ORGANIZATIONS

cost, international cooperation can be increased through strengthened and new institutional links and engagement with national governments. Such cooperation in support of food and water security will be of particular benefit to the Global South where agriculture plays an important role in not only feeding populations, but also as major components of national economies.

GEOGLAM

An initiative launched by G20 Agriculture ministers in 2011. The initiative aims to 'strengthen global agricultural monitoring by improving the use of remote sensing tools'.

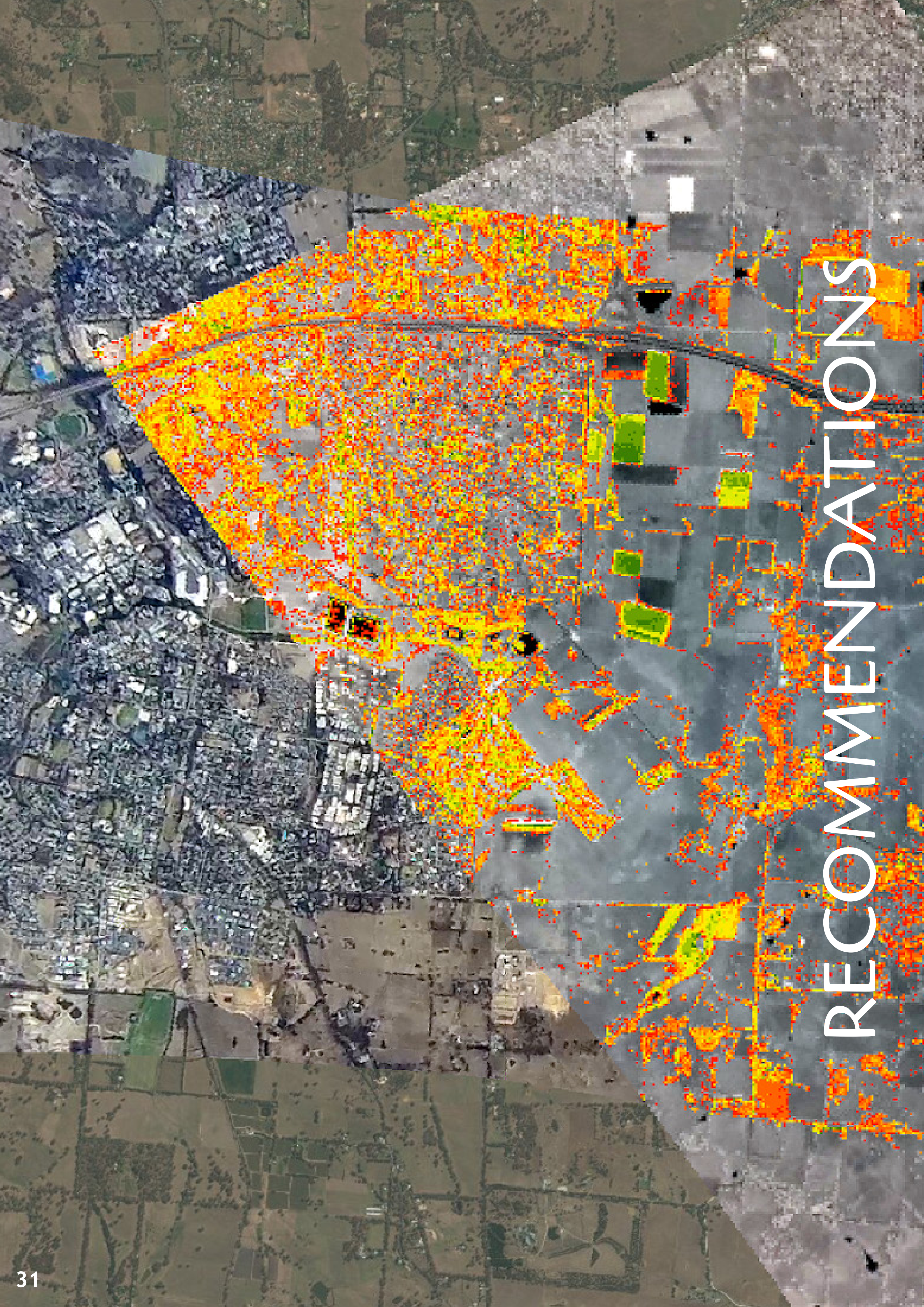
GEOGLAM will help reinforce the international community's capacity to produce and disseminate agricultural forecasts from national to global scales. It will utilise existing monitoring programs and aims to strengthen them through networking, operationally focused research and data sharing (GEO, 2015).

TIGER

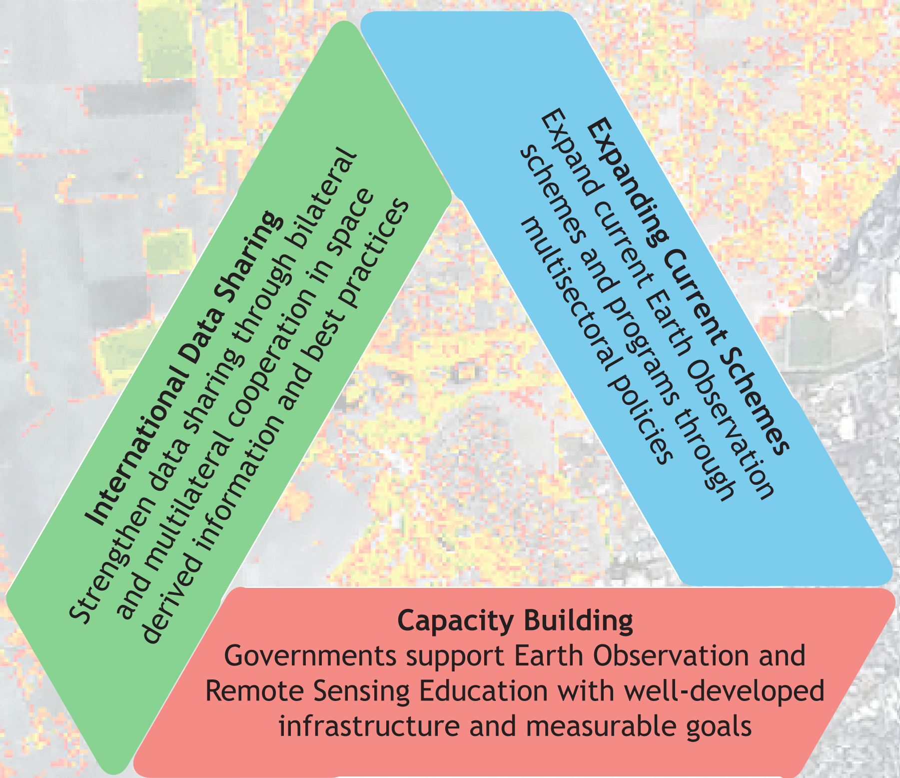
The TIGER Initiative was launched in 2002 after the Johannesburg World Summit for Sustainable Development (WSSD). It promotes the use of Earth observation technology to improve integrated water resource management in Africa.

By exploiting Earth observation technology, TIGER aims to fill existing information gaps to achieve sustainable and efficient water management from national regional scales. TIGER is also designed to build capacity in African countries through research and information networking to instil a resource management culture (ESA TIGER, 2016).

RECOMMENDATIONS



Decision-making with the right information can provide an effective and comprehensive strategy in enabling increased food and water security. Our three core recommendations, combined with the conceptual work arising from our successful stratospheric balloon project, provide an ideal starting point for a wider conversation on adequately feeding the burgeoning population of the Global South in the 21st Century. As identified, the environmental issues of climate change and flood and drought, coupled with population growth and urbanization, will increasingly challenge us in the decades ahead.



Sensing Progress proposes potential solutions that seek to assist decision-makers of the Global South and the international community. The aim is to strengthen the state of food and water security by promoting international cooperation in the sharing of data and encouraging further investment in opportunities involving space technology and associated applications. It is our hope that this report provides global decision-makers with a better understanding of the benefits of remote sensing in building and implementing reliable strategies for food and water security.

International Data Sharing

We recommend the open and timely sharing of Earth observation data, experience and other information resources among nations and peoples. This tangible exchange will foster broader bilateral and multilateral cooperation enhancing food and water security.

International collaboration should focus on the actual exchange of space-derived data and sharing of analysis systems and techniques. Adequately feeding and hydrating all the people of our planet requires sharing our collective capabilities and tools. This requires the sharing of data, experience and other information resources. Much of this relevant information is obtained from space-based assets such as Earth observation satellites. Improved information-sharing at the international level enables governments and institutions to directly advise farmers on the ground.

In addition to the sharing of raw data, as currently demonstrated by the freely available Earth imagery provided the US Geological Survey's Landsat program, cooperation should also encompass increased sharing of data processing and imagery analysis. The technical expertise required for such processing and analysis varies between institutions and governments, with a capability gap in this area existing. We propose increased cooperation in the form of a coordinated global program of exchange among international institutions and governments of personnel involved in the processing and analysis of non-military observation and remote sensing data. Such a program would enable sharing of current effective strategies and practices to help foster the people-to-people links necessary to facilitate wider cooperative mechanisms.

Further opportunities for increased international cooperation and engagement in the realm of space-based agricultural, hydrological, and weather data exist across the full range of space operations. Cooperation can be as simple as the distribution at low or no cost of the specialist software needed to properly process and assess remote sensing data. Engagement of the private sector, comprising both traditional space industries and NewSpace actors, should also be fostered.

Capacity Building

Governments in the Global South should invest in capacity building by funding Earth observation and remote sensing education and outreach programs. These programs should be supported by well developed communications infrastructure and access to relevant hardware and software platforms. These programs should be accompanied by setting measurable goals to assess performance.

Earth observation data is freely available via the internet, yet some of the people who would benefit the most from this data are unable to access and interpret it to get meaningful information. We recommend that governments in the Global South expand current agricultural education programs to include training on the use and benefits of remote sensing systems and how to convert raw data into useful information. In countries where no agricultural education programs exist, we call for governments to initiate such programs.

Education by itself is not enough. Governments must create communications infrastructure to ensure individuals have access to Earth observation data. Furthermore, governments must also supply computers and image processing software so that the Earth observation data can be converted to relevant agricultural information. Inexpensive computers and open source image processing software can be purchased at relatively small cost to fulfil this need. These computers would need to be housed at central locations within a community - for instance a town hall or community center - to allow all users an equal degree of access.

Expanding Current Schemes

Expand current Earth observation programs by establishing multisectoral policies and programs focused on strengthening food and water security within States where such schemes are already prevalent, and to States where such schemes would greatly improve the quality of life. In particular, successful programs such as RIICE and FEWS should be expanded to cover a greater number of countries.

Food and water insecurity are multi-faceted issues that are interlinked to a great extent and caused by a variety of factors. We propose that by establishing multi-sectoral policies and programs, current Earth observation schemes can be expanded to address the issues of food and water security in a holistic manner.

Programs such as RIICE and FEWS NET effectively use Earth observation data to communicate with farmers to improve yields and individual security, as well as with governments to provided accurate assessments of the financial value of particular crops.

RIICE has been implemented successfully in eight countries in Southeast Asia. We recommend that RIICE should be extended further to maximize benefits to farmers within this region. Similarly, international collaborations such as FEWS NET could also extend their reach to areas within and outside current regions of operations. We propose that FEWS NET, which currently provides analysis for 35 countries, broadens its coverage to South and Central America in addition to expanding its presence to include more African states.

For regions in the Global South where no such programs exist, we recommend that governments begin to construct frameworks to facilitate the adoption of programs such as RIICE and FEWS NET.

It is crucial that some program performance measures be considered.This provides feedback showing that agricultural practices are being improved and whether or not the program is having the desired impact on the region. Possible performance indicators include mean income values and crop yields.

To strengthen areas of food and water safety management in the Global South, we developed a concept for a small center for food and water safety. The center will gather and share already available remote sensing data, and provide early warning information to prepare for flood and drought seasons. It will also provide on-site and distance education and training on growing crop techniques. The center aims to research and develop inexpensive and user-friendly space-based applications and solutions to aid farmers and water resource managers, and would work to influence policy-makers on the management and preservation of food and water security. As envisioned, the center would link with well-established research and educational programs such as the UN-affiliated Regional Centre for Space Science and Technology Education for Latin America and the Caribbean (CRECTEALC) or their counterparts in Africa and Asia. It could also establish cooperative programs with operational centers such as RIICE and FEWS NET. The modest funding needed to establish this small center could be supplied by governmental or non-governmental research organizations from countries of the Global South.

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4G - Fourth Generation Wireless
AARSE - African Association of Remote Sensing of the Environment
AGMP - Agricultural Meteorology Program (WMO)
AMCOW - African Ministerial Council on Water
APRSAF - Asia-Pacific Regional Space Agency Forum
AREG - Amateur Radio Experimenters Group
ASEAN - Association of Southeast Asian Nations
ASEAN SAS - ASEAN Sustainable Agrifood Systems
AUD - Australian dollars
CAgM - WMO Commission for Agricultural Meteorology
CCAFS - CGIAR Research Program on Climate Change, Agriculture and Food Security
CEAMS - Crop Estimation Analysis & Monitoring System
CEOS - Committee on Earth Observation Satellites
CGIAR - Consultative Group for International Agricultural Research
CIGI - Centre for International Governance Innovation
CO_2 - Carbon dioxide
GPSDD - Global Partnership for Sustainable Development Data
CRAIST - Cell for Climate Change Research & Impact Study
CRECTEALC - Regional Centre for Space Science and Technology Education for Latin America and the Caribbean
CSA - Canadian Space Agency
DCS - Distributed Control Systems
DMC - Disaster Monitoring Constellation
DMSP - Defense Meteorological Satellite Program
DNA - Deoxyribonucleic acid
DRM - Disaster Risk Management
€ - Euro currency
EM - Electromagnetic
EO - Earth Observation
ESA - European Space Agency
EU - European Union
FAO - Food and Agriculture Organization of the United Nations
FEWS NET - Famine Early Warning Systems Network
GCOS - Global Climate Observing System
GDP - Gross Domestic Product
GEO - Geostationary Earth Orbit
GEO - Group on Earth Observations
GEOGLAM - Group on Earth Observations Global Agricultural Monitoring Initiative
GEOSS - Global Earth Observation System of Systems
GIS - Geographic Information System
GIZ - Gesellschaft für Internationale Zusammenarbeit (Germany)
GNSS - Global Navigation Satellite System
GPS - Global Positioning System
GPSDD - Global Partnership for Sustainable Development Data
ICT - Information Communication Technology
IFPRI - International Food Policy Research Institute
IPCC - Intergovernmental Panel on Climate Change
IR - Infrared
IRMS - Integrated River Monitoring System
ISU - International Space University
ITU - International Telecommunications Union
JAXA - Japan Aerospace Exploration Agency
LEO - Low Earth Orbit
LIDAR - Light Detecting and Ranging
MDG - Millennium Development Goals
MEO - Medium Earth Orbit
MODIS - Moderate Resolution Imaging Spectroradiometer
NASA - National Aeronautics and Space Administration
NASRDA - National Space Research and Development Agency (Nigeria)
NDMS - National Drought Monitoring System
NDVI - Normalized Difference Vegetation Index
NFMS - National Flood Monitoring Systems
NGDC - National Geophysical Data Center
NGO - Non-governmental Organization
NiMET - Nigerian Meteorological Agency
NOAA - National Oceanic and Atmospheric Administration
NREL - National Renewable Energy Laboratory
NRM - Natural Resource Management
NVDI - Normalized Difference Vegetation Index
NWLMS - National Water-logging Monitoring System
OECD - Organisation for Economic Co-operation and Development
OPPIS - Online property planning and information system
Pak-SCMS - Pakistan: Satellite Based Crop Monitoring System
PNT - Position, Navigation and Timing
PPP - Public Private Partnership
R&D - Research and Development
RADAR - Radio Detection and Ranging
RIICE- Remote sensing-based Information and Insurance for Crops in Emerging economies
ROI - Return on Investment
SaFIS (Satellite-based Forest Information Service)
SANSA - South African National Space Agency
SATCOM - Satellite Communications
SATIDA - Satellite Technologies for Improved Drought Risk Assessment
SCADA - Supervisory Control and Data Acquisition
SCMS - Satellite-based Coastal Monitoring System
SDMS - Seasonal Disaster Monitoring System
SE - Southeast
SHSSP16 - Southern Hemisphere Space Studies Program 2016
SKA - Square Kilometre Array
SMOS - Soil Moisture and Ocean Salinity satellite
SMS - Short Message Service
SPARRSO - Space Research and Remote Sensing Organization (Bangladesh)
SSA - Space Situational Awareness
SSP - Space Studies Program
STEM - Science, Technology, Engineering and Mathematics
SUPARCO - Pakistan Space and Upper Atmosphere Research Commission
TCP - Transmission Control Protocol
TDRSS - Tracking and Data Relay Satellite System
TOSS - Tele-reach Operation System of Systems
TTC - Telemetry Tracking and Control
UAV- Unmanned Aerial Vehicle
UN - United Nations
UNCOPUOS - United Nations Committee on the Peaceful Uses of Outer Space
UNEP - United Nations Environment Program
UNESCAP - United Nations Economic and Social Commission for Asia and the Pacific
UNESCO - United Nations Educational, Scientific and Cultural Organisation
UNFCCC - United Nations Framework Convention on Climate Change
UniSA - University of South Australia
UNISDR - United Nations International Strategy for Disaster Reduction
UNOOSA - United Nations Office for Outer Space Affairs
UN-SPIDER - United Nations Platform for Space-based Information for Disaster Management and Emergency Response
UN-Water - United Nations Inter-agency Coordination Mechanism for all Freshwater related Issues, including Sanitation
US - United States
USA - United States of America
USAID - United States Agency for International Development
USD - American dollars
USDA - United States Department of Agriculture
USGS - United States Geological Survey
US NSTC SDR - United States National Science and Technology Council Sub-Committee on Disaster Reduction
VSAT - Very Small Aperture Terminal
WHO - World Health Organization
WMO - World Meteorological Organization
WRI - World Resources Institute
WSSD - World Summit on Sustainable Development
WWAP - United Nations World Water Assessment Programme

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Stratospheric Balloon Project

As noted earlier in this report, the SHSSP-16 team constructed and launched a payload for the stratospheric balloon to remotely image vegetation over the Mount Barker township in South Australia. This appendix describes the details of this experiment.

The balloon carried a payload with a mass of approximately one kilogram. The payload contained a set of three cameras, two of which were controlled by a Raspberry Pi micro-computer. The Raspberry Pi and two of the cameras were powered by a set of six AA batteries providing 9V, which was regulated down to 5V. The payload structure was made from polystyrene and was shaped around the payload components to ensure they remained stable throughout the flight and protected on landing. The structure was designed to minimize the rotation of the camera payload, in order to achieve the most stable possible images.

The Amateur Radio Experimenters Group (AREG) - Adelaide provided the balloon and managed the launch. Details of the launch and the balloon flight are available on the AREG website http://www.areg.org.au/?cat=46.

Camera Setup

The balloon payload contained three cameras; two pointed vertically downwards to capture imagery of the ground and one mounted horizontally. The two vertical cameras included one high-definition video in the visible spectrum and the other was a NoIR (No-Infrared) camera. This was modified to include a low pass filter that permitted only infrared light to pass, allowing it to take pictures only in the infrared range. The third camera was controlled by the microcomputer to capture images of the horizon during the ascent and descent.

Remote Sensing in Agriculture

Remote sensing uses the amount of reflected radiation from different bodies to obtain information. Objects with diverse surfaces and compositions will reflect or absorb the sun's radiation differently. The reflected frequencies for each body will depend of the particular material and its physical and chemical state, as well as surface roughness and geometric properties. Using this information, objects can be analyzed by their spectral reflectance patterns to identify different features.

Farmers have several methods of assessing the health of a crop. They may choose to inspect their crops from the ground, but this method is time-consuming and labor intensive. Aerial inspection requires less manual labor but does not allow the farmer to see the individual leaves and determine the health of the plants. Aerial observations must make use of some aggregate property of the whole crop. Crop health can be determined by collecting images using near infrared and visible light subjecting them to an algorithm that allows analysts to detect the extent of photosynthetic activity. This method results in a so-called Normalized Difference Vegetation Index (NDVI) of the plants. Healthy green plants have a high NDVI due to reflecting less near infrared radiation than unhealthy red-brown plants. To calculate the NDVI the images must be post processed (see below).

Image Processing Methodology

The balloon reached a maximum altitude of 36.4km, allowing the cameras to take approximately 4000 pictures of the region before returning safely to Earth. A large percentage of these images have sufficiently high resolution to be used for analysis.

Georeferencing of the images:

The images were georeferenced with Geographic Information Systems (GIS) software on a global map. The rate of coverage of vegetation was obtained in specifically targeted areas and this information is presented in a color scale over the map.

The georeferencing process involves assigning global coordinates to the images, with each one of the points of the image are detailed specific points related to global coordinates. Images, as they are not totally flat, are twisted until they perfectly fit with the earth's geography. This process is performed for all images in the visual and infrared spectrum.

Estimating the Normalized Difference Vegetation Index (NDVI):

After aligning the images with current global maps, frequencies reflected by each pixel of the image were analyzed.

The balloon payload took pictures in the visible and the near infra-red spectrums. With the information about the red band from the visible image and the near-infrared image, it is possible to calculate the NDVI. This vegetation index is an indicator that describes ‘the greenness’ or photosynthetic activity of plants (the relative density and health of vegetation). By examining the vegetation spectrum, it is possible to observe the interactions of wavelengths with the cells (red and blue visible bands absorbed, green is reflected). Leaves also have certain pigments that reflect wavelengths of near-infrared light, which is invisible to human eyes (SEOS, 2016).

The intensities of reflected light of the registered visible and near-infrared images can be transformed into the NDVI vegetation index by dividing the difference in the near-infrared (NIR) and red colour bands by the sum of the NIR and red colour bands for each pixel in the image as follows:

$$NDVI = \frac{NIR - R}{NIR + R}$$

where NIR is the maximum value of reflectance in the Near Infrared part of spectrum and R is the low value of reflectance in red absorption

NDVI values range from +1.0 to -1.0. Values greater than zero indicate good health of the vegetation and greenness, or an indication that water is present in the leaves. Negative values correspond to drier conditions in leaves, impervious surfaces and water. When analyzed through time, NDVI can reveal where vegetation is thriving and where it is under stress, and also changes in vegetation caused by human activities such as deforestation, natural disturbances such as wildfires, or changes in plants' phenological stages (USGS, 2015)

Different colors can be used to visualize the information. For the current project, the vegetation that has a high amount of water is represented by green, and vegetation with low amount of water is red. It is important to understand and consider that different vegetation types can have different values in the NDVI scale. Other areas that have no useful information for crops coverage were removed, to identify easily where the vegetation is located around the target (Mount Barker Council) area.

Results and Analysis

Images from low, middle and high altitudes were taken by the onboard cameras of the payload. The first analysis is from a middle altitude image. On each image analyzed, the visible image used (1), the infrared image (2) and the satellite image used as a base (3) are indicated.

In Figure 30, the NDVI Analysis covers part of the Town of Mount Barker (localized on the western side), Mount Barker on the eastern side of the city and the area between the city and the Mount Barker Spring Area in the south center.

It can be seen from the NDVI values legend that all readings are positive and greater than zero, meaning we can easily correlate with the water content that they assume. Lower NDVI values, which in the chromatic scale range from red to dark orange, represent vegetation with low irrigation despite appearing as very dark green in the visible image. It is interesting to note that these low NDVI values are located in areas more distant from the town and from the agriculture fields. Cultivated areas show higher NDVI values, greater than 0.4 corresponding to the green colors.

In fact, thanks to irrigation, these areas are lush and extremely green. The intermediate values represented in yellow, which are located in areas more and more distant from irrigation centers and in the city, are probably in small parks or inside private gardens.

The images taken at low and high altitudes can be analysed in the same way. In the image taken at a higher altitude (Figure 28) it is evident that the values of NDVI are very high as the vegetation is close to the river and has easy access to water. Low altitude images have better resolution but less amount of land area covered.

In the high altitude image (Figure 28), the greener areas surrounding the Murray River are due to the proximity of the plants to water. This high altitude analysis covers a wider area and the clouds introduce an error in the NDVI (water absorbs all the infrared band).

Conclusion

The stratospheric balloon experiment demonstrates that it is possible to obtain useful information and high altitude photographs for analysis and health status of vegetation with a limited amount of economic resources and a short period of time to develop remote sensing technology using an open source device. It should be noted that low-altitude images provide more resolution of the geography but a smaller area to analyse. If a larger area of coverage is required, the images must be taken at high altitudes. The atmosphere and clouds can introduce errors in the analysis of the image. This type of analysis can be extended for use in planning and monitoring agriculture health and coverage. The results from the stratospheric balloon images are similar to the use of satellite images. The advantage with using a stratospheric balloon is that you can have faster information about the health status of a specific area. The limitations to this is that users do not have control over the path of the balloon. In cases where a specific point needs to be analyzed, other technologies such as drones can be used to acquire images of a specific place.

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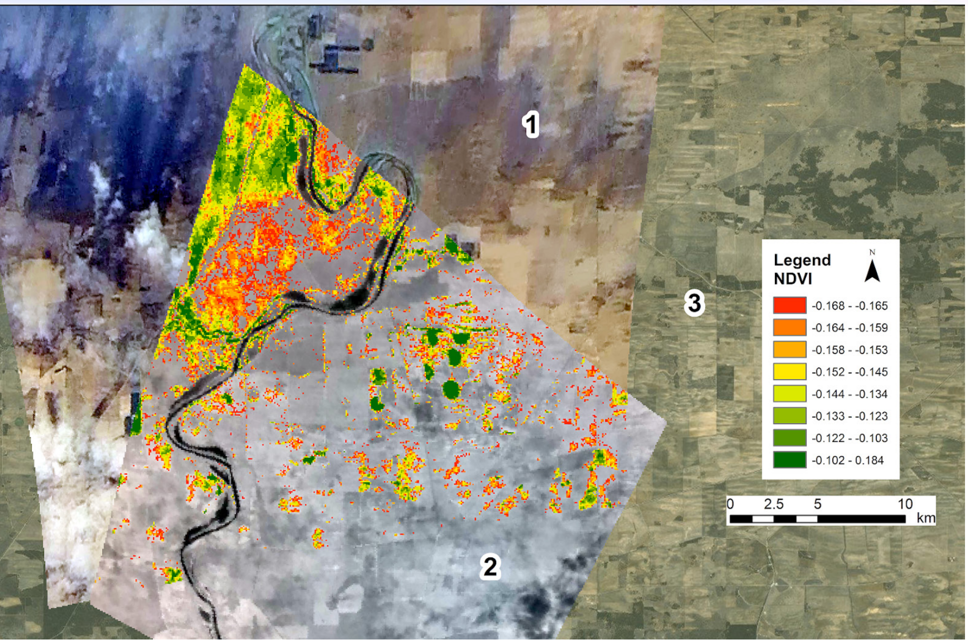

Figure 28: NDVI image at high altitude

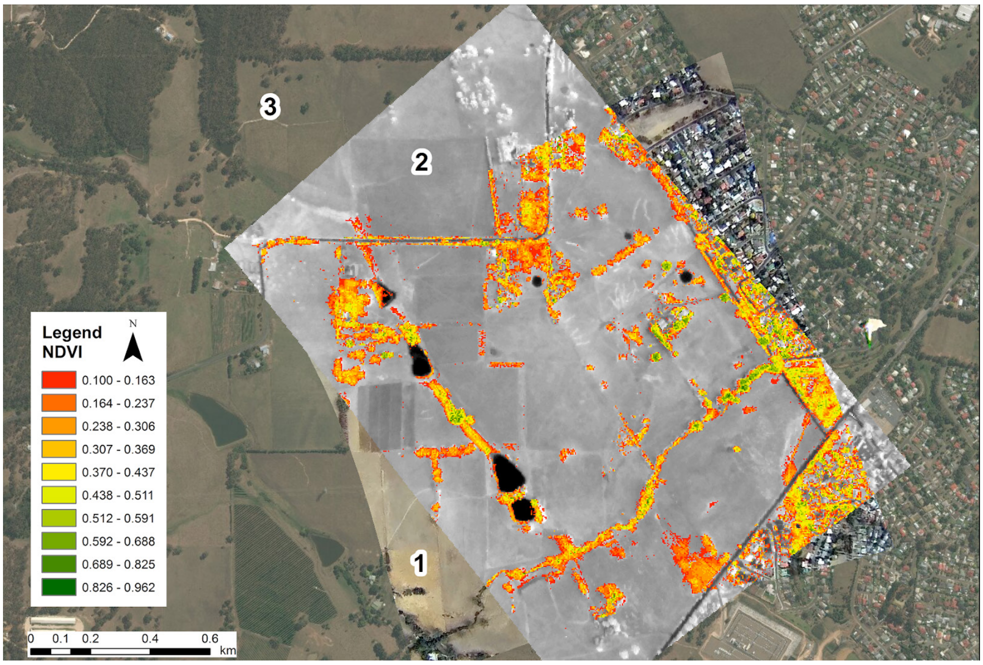

Figure 29: NDVI image at low altitude

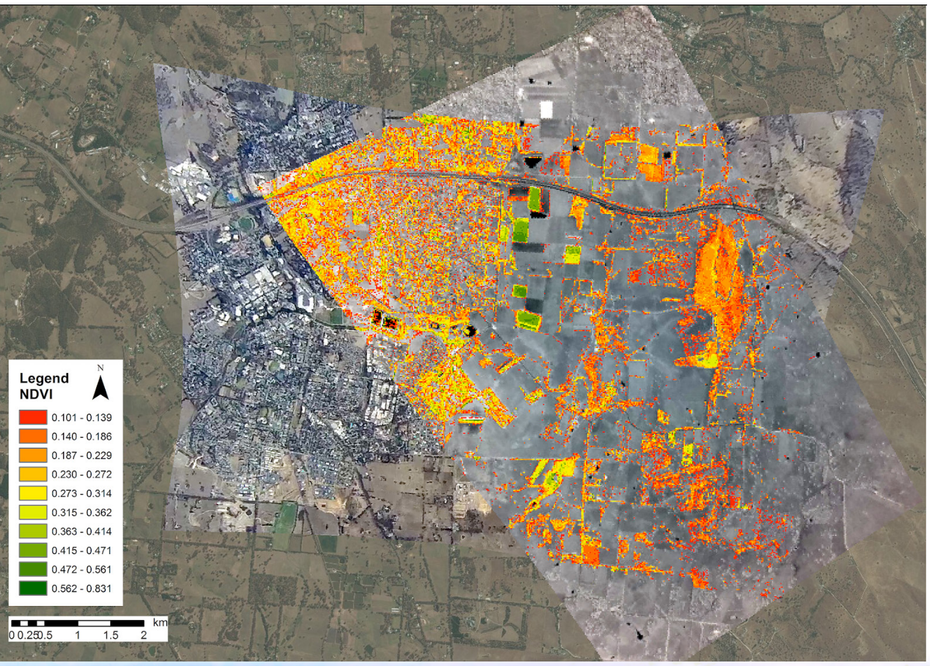

Figure 30: NDVI image at mid altitude

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