THE APPLICATION OF GEOSPATIAL AND REMOTE SENSING TECHNOLOGIES FOR MONITORING THE IMPLEMENTATION AGENDA 2063 AND UN-SDGs.

SANSA SOUTH AFRICAN NATIONAL SPACE AGENCY

NEPAD TRANSFORMING AFRICA

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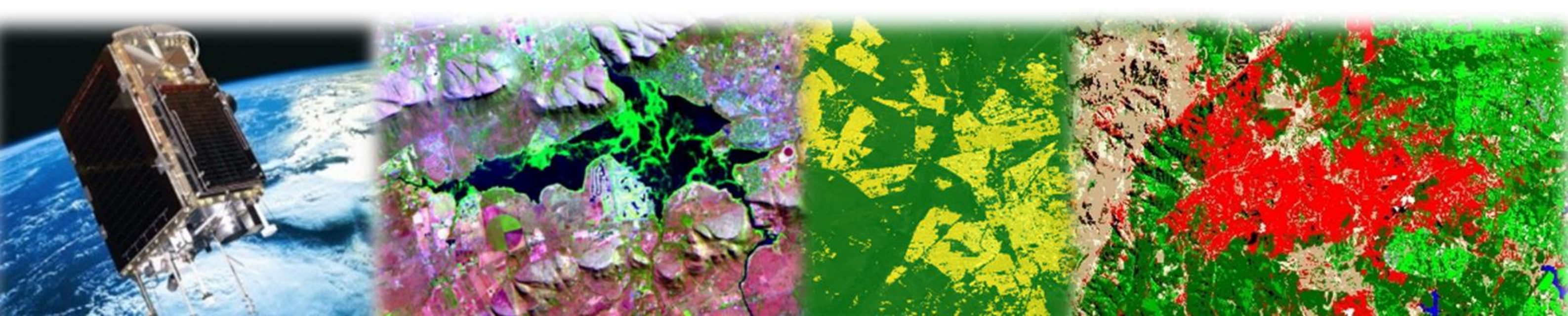

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How to use this handbook

This handbook was developed to address remote sensing skills gaps in Africa. The content was simplified considerably, balancing the theoretical content with the practical component. The handbook comes with complimentary DVD disk containing:

1. Open-source software (QGIS with GRASS, and SNAP with Sentinel 1 & 2 Toolboxes)
2. Earth Observation & Vector Data, and
3. PDF version of this handbook.
4. Other Reading Materials

For best learning experience, this handbook should be used together with a complimentary DVD and all practical exercises should be attempted.

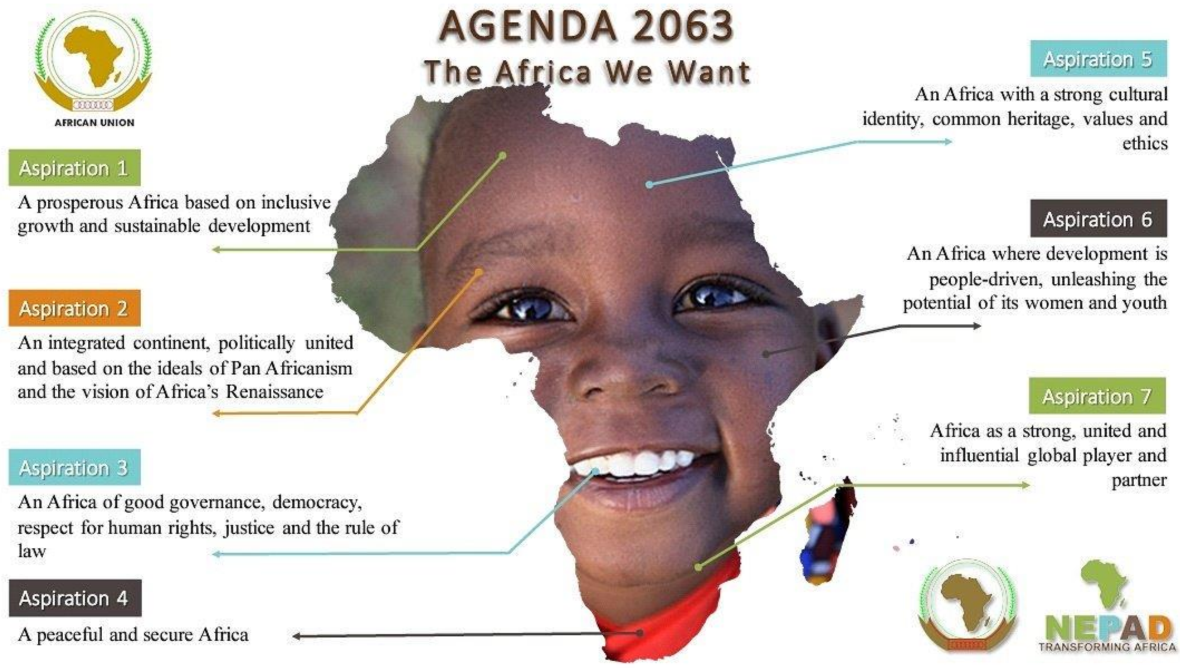
This handbook can be used by, but not limited to; technical staff with working experience of GIS (Geographic Information System) such as GIS technicians, analysts, technologists, specialists, etc., university students, lecturers, and other specialists interested in learning about remote sensing such as ecologists, botanists, forestry, town planners, policy and decision makers, etc.

For assistance, we encourage the use of existing well-established online blogs and forums such as FOSS Africa, GIS Lounge, GIS exchange, STEP Forum, etc. Specific questions related to this handbook can be addressed to mkganyago@sansa.org.za.

BACKGROUND

Context

During its twenty fourth Ordinary Assembly, held in Addis Ababa on the 30 and 31 January 2015, the African Union Assembly of Heads of State and Government adopted Agenda 2063 – "The Africa We Want"[1]. Agenda 2063 is Africa's 50-year strategic blueprint for socio-economic and political transformation to optimize the use of continent's resources for transformed and prosperous livelihoods for all. In June 2015, the AU Assembly adopted the Agenda 2063 First Ten Year Implementation Plan[2] (FTYIP) spanning from 2013 to 2023.



On the other hand, in September 2015, the United Nations General Assembly adopted the 2030 agenda and associated Sustainable Development Goals[3] (SDGs). Consequently, efforts to domesticate the SDGs and FTYIP at regional and national level are ongoing.

The lessons drawn from numerous regional and continental programmes and initiatives, including NEPAD, as well as the Millennium Development Goals (MDGs) underscores that integrated nature of the sustainable development agenda demands integrated approaches, innovative and incentive systems that facilitate cross-sectoral action and accountability across levels of government and non-governmental players and stakeholders, including all Ministries and Government Agencies. This approaches negates the ideals of the traditional 'silo' approaches to development, and promises a more credible integrated planning model for greater transformative impacts. The integrated approaches promotes collaboration across sectors, within continental, regional, national and sub national spheres, involving sectors, academia, development partners, civil societies, women and youth and private sector. This cross-sectoral approach increasingly requires the use of innovative tools to manage multi-sectoral, multi-partner implementation of public policies, flagship investment programs and service delivery.

Furthermore, integrated approach increasingly emphasizes the planning and budgetary processes that shapes development priorities as well as institutional arrangements in collaborative and responsive processes across the development cycle: from planning, implementation, to monitoring, evaluation, learning and new-planning.

[1] https://au.int/en/agenda2063
[2] https://au.int/sites/default/files/documents/33126-doc-11_an_overview_of_agenda.pdf
[3] https://sustainabledevelopment.un.org/?menu=1300

In its assembly on the 28 – 29 January 2018, the African Union (AU) requested NEPAD Agency to strengthen its monitoring and evaluation function in order to effectively deliver tangible and visualized results and guide the implementation of continental development frameworks as stipulated in Agenda 2063 (Assembly/AU/Dec.685)[4]. The Assembly further requested NEPAD Agency to "develop projects and programmes for the operationalisation of the Blueprint (policy framework) through the application of geo-spatial planning and remote sensing technologies." In addition, world leaders have recognised the important role that remote sensing and geo-spatial information could play in making the whole framework of SDGs feasible through the provision of essential evidence, including tracking indicators over time, and supporting the implementation of solutions to reach specific targets.

In this context, the effective use of remotely sensed and geo-spatial information can have transformational impact on many of Africa's most significant challenges, such as agriculture and food security (rainfall variability, agricultural productivity, crop types and distribution, soil and land sustainability, etc.), declining water resources (aquifers, water bodies, water quality, etc.), degradation of marine and coastal zones, health and nutrition (Disease vectors, hunger and malnutrition), degradation forests and other ecosystems, natural disasters, Urban-rural transformations, infrastructure and industrialisation, peace and security, safe and secure transportation, etc. In addition, Remote sensing and geo-spatial technologies provide data and tools that present a credible mechanisms and an invaluable analysis framework for planning, implementation, and monitoring of harmonised Agenda 2063 and SDGs. Because of their data and information capturing, storing, analysis, and presentation capabilities, Remote sensing and geo-spatial technologies are the basis to foster the application of multi-sectoral analyses of increasingly complex and dynamic development process; and their ability to enable more frequent testing of theories of change and facilitating timely course corrections based on evidence provides the credibility. Institutions that are capable of absorbing real-time information and have efficient systems to effectively utilize the information often achieve better results - accruing from timely corrective measures, more informed policy reforms, effective designs of programs and improved service delivery.

[4] https://au.int/sites/default/files/decisions/33908-assembly_decisions_665_-_689_e.pdf

In addition, the spatial and temporal analysis capabilities of remote sensing and geo-spatial technologies can be provided through web to allow for timely data capturing, decision making and statistical deductions.

Purpose

This handbook has been developed to provide a simple introduction to remote sensing and geographic information systems (GIS), as well as to highlight the role of these geospatial technologies in supporting the implementation and monitoring of SDGs and Agenda 2063 aspirations and goals. The general objective is to enhance capacity in national systems for geo-referenced impact monitoring and reporting, benchmarked to regional and continental targets in line with Agenda 2063-SDGs scope, goals and targets. The handbook has been developed in cooperation with NEPAD Agency.

Contents

The handbook is divided into three sections, namely; Introduction to Geographic Information System (GIS), Introduction to Remote Sensing, and Sustainable Development Goals (SDGs), Agenda 2063 and Geospatial tools. The first section provides a brief introduction to GIS, including the evolution of GIS as a term, components of GIS and typical application areas of GIS. The second section, provide an introduction to remote sensing, including history of remote sensing, the process of acquiring images, and images analysis concepts. The third section, provides some case studies that demonstrate the role of remote sensing and geo-spatial technologies in implementation and monitoring of SDGs and Agenda 2063.

INTRODUCTION TO GEOGRAPHIC INFORMATION SYSTEM (GIS)

Geographic Information System (GIS)

The evolution of GIS term

The Geographic Information System (GIS)[5] has been defined differently by different authors and organisations throughout the years. So what exactly is a GIS? Is it computer software? Is it a collection of computer hardware? Is it a service that is distributed and accessed via the Internet? Is it a tool? Is it a system? Is it a science? The answer to all these questions is, "GIS is all of the above—and more." Below is how the definition of GIS has evolved through the years:

Duecker (1979) defines GIS as "a special case of information systems where the database consists of observations on spatially distributed features, activities or events, which are definable in space as points, lines, or areas. A geographic information system manipulates data about these points, lines, and areas to retrieve data for ad hoc queries and analyses"

According to Ron Abler (1988) "GISs are simultaneously the telescope, the microscope, the computer, and the Xerox machine of regional analysis and synthesis of spatial data."

According to Burrough (1986), "Geographic information systems are powerful tools for ingesting, storing, retrieving, transforming, processing, and displaying geographic data."

Cowen D.J. (1988) defines GIS as "a decision support system involving the integration of spatially referenced data in a problem solving environment".

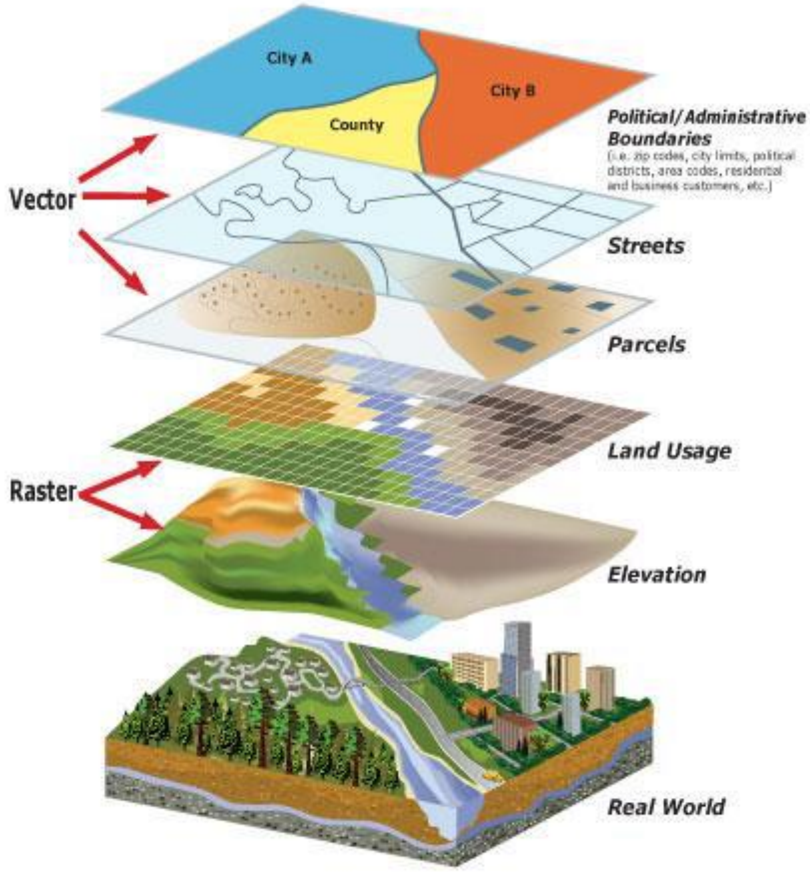
Star and Estes (1990) defines GIS as "An information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially-referenced data, as well as a set of operations for working with the data."

According to NASA GIS is "an integrated system of computer hardware, software, and trained personnel linking topographic, demographic, utility, facility, image and other resource data that is geographically referenced."

Clarke (1995) "automated systems for capture, storage, retrieval, analysis, and display of spatial data."

One can notice the similarities between these definitions. In general, there is no single or universal definition of a GIS; it is defined and used in many different ways. Geographic Information Systems (GIS) represent a combination of hardware, software and data, which allows for the capture, management, analysis, and display of geospatial (geographically referenced) information. According to Cowen (1988) GIS can become an important decision-making tool or a decision support system since it involves the integration of geographically referenced data in a problem-solving situation. GIS also allows overlaying of layers of spatially explicit data that are linked to tabular (attribute) data in relational databases, thus allowing the user to analyse and visualize patterns and trends.

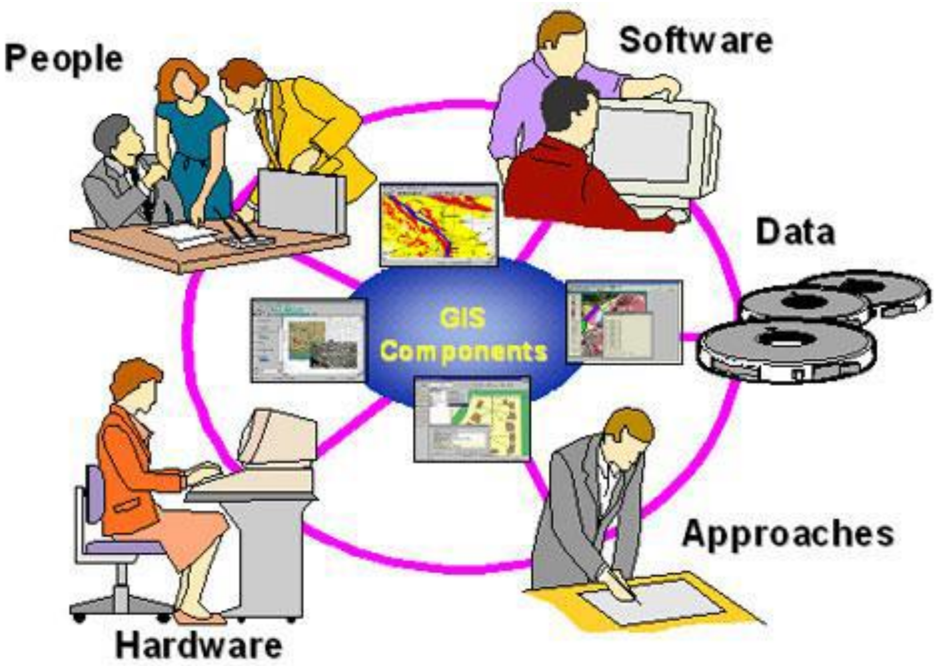
[5] National Research Council. 2002. Down to Earth: Geographical Information for Sustainable Development in Africa. Washington, DC: The National Academies Press. https://doi.org/10.17226/10455.



Components of GIS

From the definitions of GIS above, the components that make up a Geographic Information System can be deduced. These are: hardware (computers, scanners, GPS receivers, etc.), software (a computer program), data (spatial and non-spatial/attribute data) and methods or approaches for displaying and analysing information about the earth in digital computing environment. Spatial data[6] refer to the real-world geographic objects of interest, such as streets, buildings, lakes, and countries, and their respective locations. In addition to location data, each of these objects also possesses certain traits of interest, or attributes, such as a name, number of stories, depth, or population, i.e. non-spatial/attribute information.

[6] https://saylordotorg.github.io/text_essentials-of-geographic-information-systems/



I. DATA & STORAGE

GIS data is perhaps the most important component of a GIS. GIS data can be separated into two categories: geospatial data (spatially referenced data, representing data that is referenced to locations on Earth) and attribute data (any type of additional information linked or which can be linked to spatial data; typically organized in tabular format). Below is an example of spatial data and associated attribute information in a GIS.

OID	FEA_C	Area_PC	FEA_CODE_1
0	165	2.557509	Paved Driveway
1	165	0.177594	Paved Driveway
2	161	404.664113	Paved Road
3	165	25.081809	Paved Driveway
4	169	11.185954	Grass or Planted Med
5	165	85.809233	Paved Driveway
6	163	27.941142	Public Sidewalk
7	165	104.295646	Paved Driveway
8	165	85.484622	Paved Driveway
9	165	80.315827	Paved Driveway
10	163	17.667767	Public Sidewalk
11	165	147.556552	Paved Driveway
12	165	75.181746	Paved Driveway
13	165	199.456888	Paved Driveway

There two fundamental spatial data models[7] that exists, namely; Vector and Raster. Vector data uses coordinates to represent geospatial data. Vector data can be points, lines (or arcs), or polygons. Points are represented as by a pair of coordinates in latitude and longitude or some other reference system. A point feature is a zero-dimensional cartographic object and specifies the geometric location and no other meaningful measurement. The size of the point may vary, but the area of those symbols is disregarded.

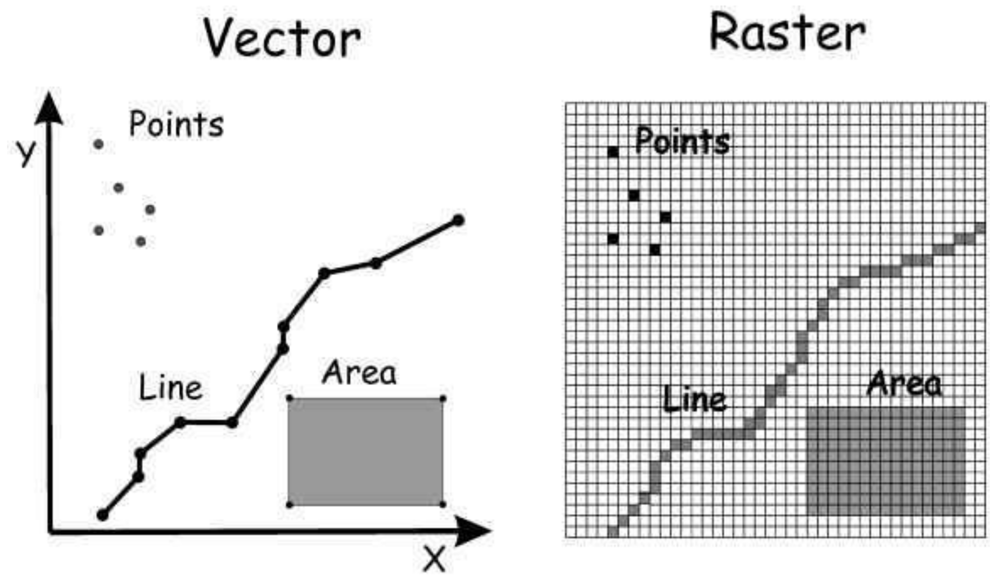
[7] Models are an abstraction of the real world incorporating only properties relevant to the application. They are a set of constructs for describing and representing selected aspects of the real world in a computer.

Points can be used to represent locations of weather stations, bus stops, or individual buildings. On the other hand, lines are an ordered sequence of points connected by straight lines. Line features are one dimensional features, despite occupying two-dimensional space. Lines can be used to represent linear features such as rivers, water utility distribution networks, roads and railway networks, etc. Polygons are areas formed by an ordered rings of points connected by straight lines and are two-dimensional, bounded and continuous. A simple polygon consists of an interior area and an outer ring (boundary). Polygons can be used to represent areas such as watersheds, provinces, countries, water bodies, etc.[8]

The most common vector file format is the shapefile (.shp), developed by ESRI. Shapefiles are simple, non-topological files for storing the geometric location and attribute information of geographic features. The .shp files (feature geometry) must be accompanied by their index format for the feature geometry (.shx), feature attribute information (.dbf) and projection information (.prj).

On the other hand, Raster models are an abstraction of the real world where spatial data is organized into a regular grid structure of rectangular cells. Surfaces are represented as a mesh of discrete units, while the location of the cells is "encoded" within the ordering of the data matrix, as opposed to the explicit location storage of vector data.

The following figure is a schematic representation of vector and raster data models in GIS[9]



Both vector and raster data have their particular features, advantages and disadvantages:

- Vector data is the best option for representing spatial features with limited generalization (e.g. high-resolution depiction of linear features, such as rivers and streams).
- Analysis involving topology typically make use of vector data (e.g. proximity or network analysis).
- Simplified data model makes raster data ideal for quantitative analysis and modelling, especially with large datasets.
- Raster data models are well suited for continuous/discrete surface data, common with remote sensing information.

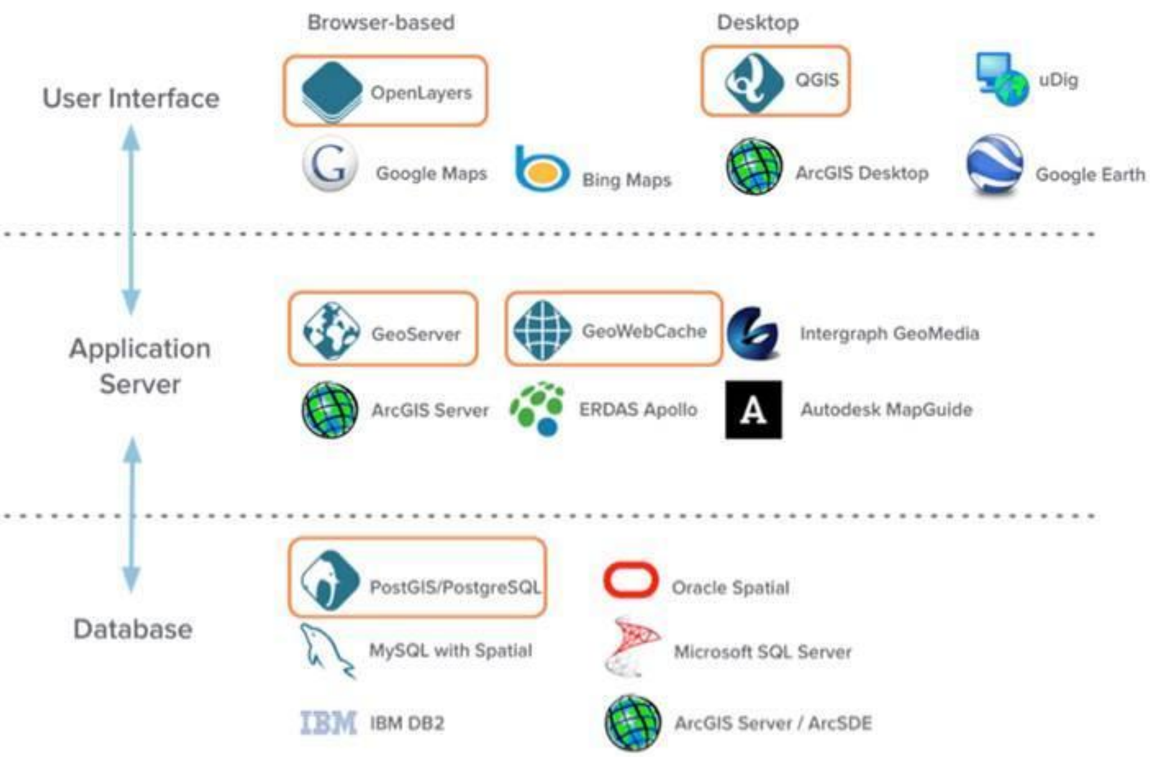
[8] http://www.ucd.ie/sumschol/pdf/dmci_spatial-data-types.pdf
[9] Bolstad, P. 2005. GIS Fundamentals: A first text on Geographic Information Systems, Second Edition. White Bear Lake, MN: Eider Press

- Raster data is characterized by the generalization of spatial data; careful consideration of objectives and cell size selection are required for each analytical framework.

The common raster file format in GIS are GeoTIFF, JPEG2000, JPEG, PNG, and TIFF. Native JPEG, TIFF, and PNG files do not have georeferenced information associated with them and therefore cannot be used in any geospatial mapping efforts. In order to employ these files in a GIS, a world file; a separate, plaintext data file that specifies the locations and transformations that allow the image to be projected into a standard coordinate system, must be created. The world file extension name for a JPEG is JPW; for a TIFF, it is TFW; and for a PNG, PGW.

2. SOFTWARE

Software are a special type of computer programs capable of storing, editing, processing, and presenting geographic data and information as maps. A large variety of GIS software platforms exist, ranging from proprietary to open-source programs, from web-based to desktop applications, each with their respective strengths and weaknesses. Web-based GIS applications attract an increasing number of users for their usability and accessibility. On the other hand, Desktop and (LAN, WAN) server-based applications form an important segment of the GIS market due to their power and versatility, but ever-increasing computational capabilities in the cloud are closing the gap. There are a range of GIS software available including those that are open source (i.e. free of charge) and those that are proprietary (i.e. available at a cost). These can be classified according to three-tier GIS architecture[10] below.



A database is a structured collection of data files. A database management system (DBMS) is a software package that allows for the creation, storage, maintenance, manipulation, and retrieval of large datasets that are distributed over one or more files.

[10] Calamito, A. 2015. Considering a Hybrid Proprietary/Open Source Architecture. Available online at: http://boundlessgeo.com/2015/04/considering-hybrid-proprietaryopen-source-architecture/ (Accessed September 29th, 2015).

Below is a summary of the key capabilities of some of the most common GIS software platforms[11] available today.

ArcGIS (ESRI)	Cartographical output, Functionality, Large user community, Stability, Interoperability, Scalability, Modeling, Web mapping, Maintenance, Data driven pages, High cost
QGIS (Quantum GIS)	Large user base, 64-bit background geoprocessing, plugins, quality cartography, widely believed as best open source option, stunningly beautiful options for labeling objects, free GIS software
GRASS GIS	Steep learning, good for Lidar data, clunky UI, defining projects on start-up, extensive help documentation, batch processing, network analysis, interoperability
MapInfo (Pitney Bowes)	Ease of use, 64-bit processing, better table management, querying, side-by-side mapping, geological mapping, lower cartographical output, poor format support, less expensive, clone tool, MapBasic
Global Mapper (Blue Marble)	Working with elevation, LiDAR data, cost-effective, reads large number of formats, poor symbolization and print layout, geodatabase support
GeoMedia (Intergraph/Hexagon Geospatial)	Data maintenance, multiple layouts, fast querying and analysis, on-the-fly projections, web-based and all-purpose mapping, high government use, surfaces and terrain models
Manifold System (Manifold)	Stable, intuitive GUI, wide range of functions, programmability, natively 64-bit, low price, minimal cartographical tools available
SAGA GIS	Terrain data, physical geography, open source, raster and vector data, command line interpreter, poor cartography, line and point symbology
Smallworld (General Electric)	Network infrastructure, Magik code, spatial tools, specialized software, versioning
ILWIS	Image processing, digitization, visualization of stereo image pairs, WMS, extensive help documentation
IDRISI (Clark Laboratories)	Time series, object-based image processing, land change modelling, neural networks, 2D and 3D visualization, classification, mapping layout support, topology support
AutoCAD Map 3D and Autodesk Geospatial (Autodesk)	CAD/GIS fusion, statistics, topology analysis, thematic mapping, querying, buffer analysis, 3D surfaces, data conversion
GeoDa	Data exploration, statistics, data display, geosimulation
gvSIG	Simple GUI, well-documented, powerful CAD tools, gvSIG mobile application, intuitive GIS processing, stable free GIS software
Bentley Map	CAD/GIS fusion, 2D and 3D viewing, 3D analysis, poor labeling and annotation, lack of KMZ/KML support

3. HARDWARE

Hardware is the computer system on which a GIS operates. Today, GIS software runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations. Global Positioning Systems (GPS), are handheld units which can access positional data from satellites and log the information for subsequent retrieval. The recorded data can then be uploaded to the GIS for visualization and further analysis. GPS is becoming increasingly incorporated into other new technologies such as smartphones. These new technologies maintain comparable accuracy to similarly priced stand-alone GPS units and are largely responsible for a renaissance in facilitating portable, real-time data capture and sharing it to the masses.

4. PEOPLE

GIS technology is of limited value without the people who manage the system and develop plans for applying it to real world problems. GIS users range from technical specialists who design and maintain the system to those who use it to help them perform their everyday work. The identification of GIS specialists versus end users is often critical to the proper implementation of GIS technology[12].

[11] http://gisgeography.com/mapping-out-gis-software-landscape/
[12] http://planet.botany.uwc.ac.za/nisl/gis/gis_primer/page_12.htm

5. APPROACHES

A successful GIS operates according to a well-designed implementation plan and business rules, which are the models and operating practices unique to each organization. As in all organizations dealing with sophisticated technology, new tools can only be used effectively if they are properly integrated into the entire business strategy and operation. To do this properly requires not only the necessary investments in hardware and software, but also in the retraining and/or hiring of personnel to utilize the new technology in the proper organizational context. Failure to implement your GIS without regard for a proper organizational commitment will result in an unsuccessful system!

Some Applications of GIS[13]

Urban Planning	Urban growth and the direction of expansion can be analysed using GIS, and suitable sites for further urban development can be determined. In order to identify the sites suitable for the urban growth, certain factors to be considered include: land should accessible, land should be more or less flat, land should be vacant or having low usage value presently and it should have good supply of water.
Transportation Planning	GIS can be used in managing transportation and logistical problems. If transport department is planning for a new railway or a road route then this can be performed by adding environmental and topographical data into the GIS platform. This will easily output the best route for the transportation based on the criteria like flattest route, least damage to habitats and least disturbance from local people. GIS can also help in monitoring rail systems and road conditions.
Environmental Impact Analysis	EIA is an important policy initiative to conserve natural resources and environment. Many human activities produce potential adverse environmental effects which include the construction and operation of highways, rail roads, pipelines, airports, radioactive waste disposal and more. Environmental impact assessments are usually required to determine the magnitude and characteristics of environmental impact. The EIA can be carried out efficiently by the help of GIS, by integrating various GIS layers, assessment of natural features can be performed.
Agricultural Applications	GIS can be used to create more effective and efficient farming techniques. It can also analyse soil data and to determine: What are the best crops to plant? Where should they be planted? How to maintain soil nutritional levels to support crop growth? GSI is fully integrated and widely accepted for helping government agencies to manage programs that support farmers and protect the environment. This could increase food production in different parts of the world so the world food crisis could be mitigated. In addition, pest control helps in the agricultural production. Increasing in the rate of pest and weeds can lead to decrease in the crop production. Therefore GIS plays an important role to map out infested areas. This leads in the development of weed and pest management plan. GIS is also a valuable tool used to monitor the changes of rangeland resources and for evaluating livestock and wild life impact on environment. Accurate observation and measurements are made to find out the changes in the rangeland

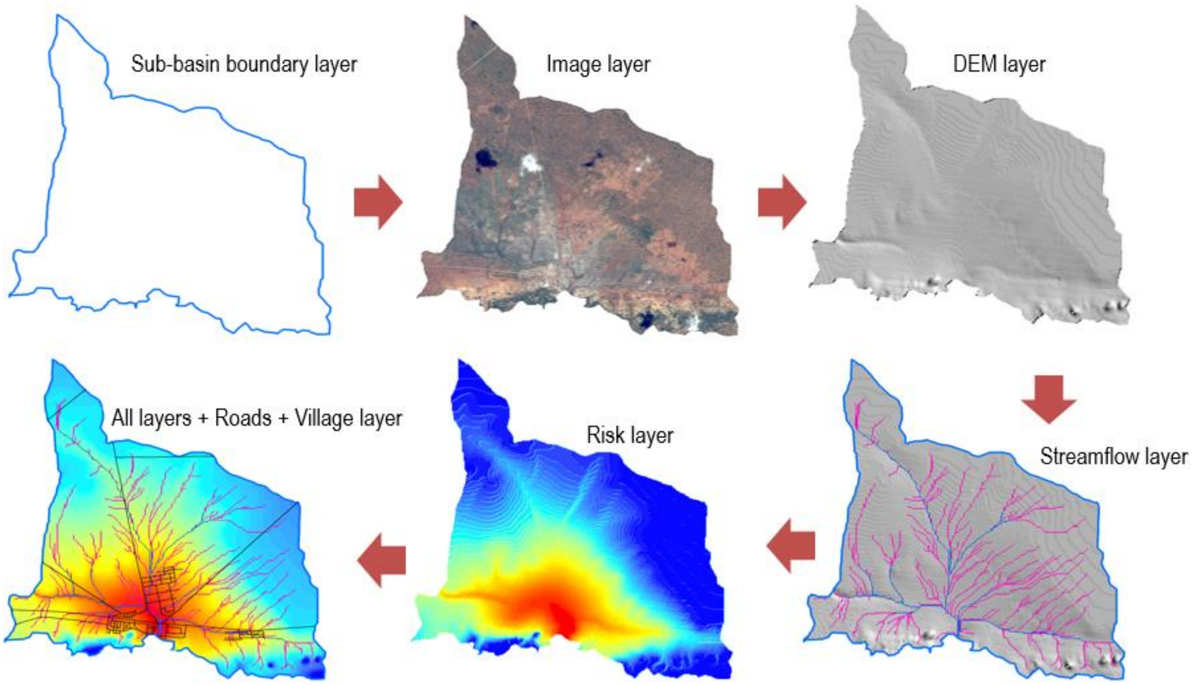
[13] http://grindgis.com/blog/gis-applications-uses

	conditions. GIS is also used to monitor ecological and seasonal rangeland conditions.
Disaster Management and Mitigation	GIS has become an integrated, well developed and successful tool in disaster management and mitigation. It can help with risk management and analysis by displaying areas that are likely to be prone to natural or man-made disasters. When such disasters are identified, preventive measures can be developed. GIS helps to document the need for federal disaster relief funds, when appropriate and can be utilized by insurance agencies to assist in assessing monetary value of property loss. A local government need to map flooding risk areas for evaluate the flood potential level in the surrounding area. The damage can be well estimated and can be shown using maps. Forest and bush/veld fires can cause extensive damage to the communities and environmental resources. GIS can effectively be used for mapping forest and bush fire hazard zones and also for the loss estimations. GIS also help to capture real time monitoring of fire prone areas (see https://southernafrica.afis.co.za/). This is achieved by the help of GNSS and satellite Remote Sensing.
Determine land use/land cover changes	Land cover means the feature that is covering the barren surface. Land use means the area in the surface utilized for a particular use. GIS technology can be used to determine land use/land cover changes in the different areas. It can also detect and estimate the changes in the land use/ land cover patterns over time. It enables to find out sudden changes in land use and land cover either by natural forces or by other activities like deforestation. Nowadays forest area is decreasing every year, due to different human activities. GIS is used to indicate the degree of deforestation and vital causes for the deforestation process. GIS can provide the information about the degraded land which can be managed by governmental agencies or by the communities themselves. GIS plays a vital role to reduce the desertification, the local governments are increasing adopting GIS for reducing desertification. With location based GIS analysis we can find where or which area is suitable for planting new vegetation and which area for the pipeline construction.
Navigation	Web-based navigation maps encourage safe navigation on roads and waterways. Ferry paths and shipping routes are identified for the better routing. GIS supports safe navigation systems and provides accurate topographic and hydrographic data.
Land Information System	GIS based land acquisition management system provides complete information about the land. Land acquisition managements would help in assessment, payments for private land with owner details, tracking of land allotments and possessions identification and timely resolution of land acquisition related issues. Revenue can be increased, operations and maintenance cost can be reduced when GIS is used to help manage space. Real estate and property managers can see and make queries about space including its availability, size and special constraints for the most cost effective use.
Planning and Community Development	GIS helps us to better understand our world so we can solve global challenges. Today, GIS technology is advancing rapidly, providing many new capabilities and innovations in planning. By applying known part of science and GIS to solve unknown parts, would help to enhance

	the quality of life and achieve a better future. Creating and applying GIS tools and knowledge allow the integration of geographic intelligence into how we think and behave.
Fisheries and Ocean Industries	GIS tools add value and the capability to ocean data. GIS is used to determine the spatial data for a fisheries assessment and management systems. It is extensively used in the ocean industry area and can provide accurate information regarding various commercial activities. To enhance minimizing cost for the fishing industry, it can also determine the location of illegal fishing operations.

An example GIS Analysis

Hydrological analysis started by creating a sub-basin of Masisi village, Limpopo Province, South Africa and from that basin we created a stream flow layer adopting the Strahler method. This method was chosen as it was closer to how water accumulates in real life downstream. It shows that the greater the stream order or further down the stream is in the basin, the higher the water will accumulate.



INTRODUCTION TO REMOTE SENSING

HISTORICAL EVOLUTION OF REMOTE SENSING

Defining remote sensing

There is a number of definitions of remote sensing in literature. Let's have a look at some of these definitions below:

"*Remote Sensing is the Science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation*" (Lillesand and Kiefer, 1994).

"*Remote Sensing is the science of acquiring, processing and interpreting images that record the interaction between electromagnetic energy and matter*" (Sabins, 1996).

Campbell & Wynne (2011) defines remote sensing as "*the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth's surface*".

"*Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information.*"

These definitions have some common terms that describes remote sensing worth noting. These include that remote sensing:

- is a science and art or the practice
- acquires information about characteristics of the earth (including earth's water and land)
- measured information is in a form of electromagnetic radiation
- acquires information at a distance and has an overhead perspective

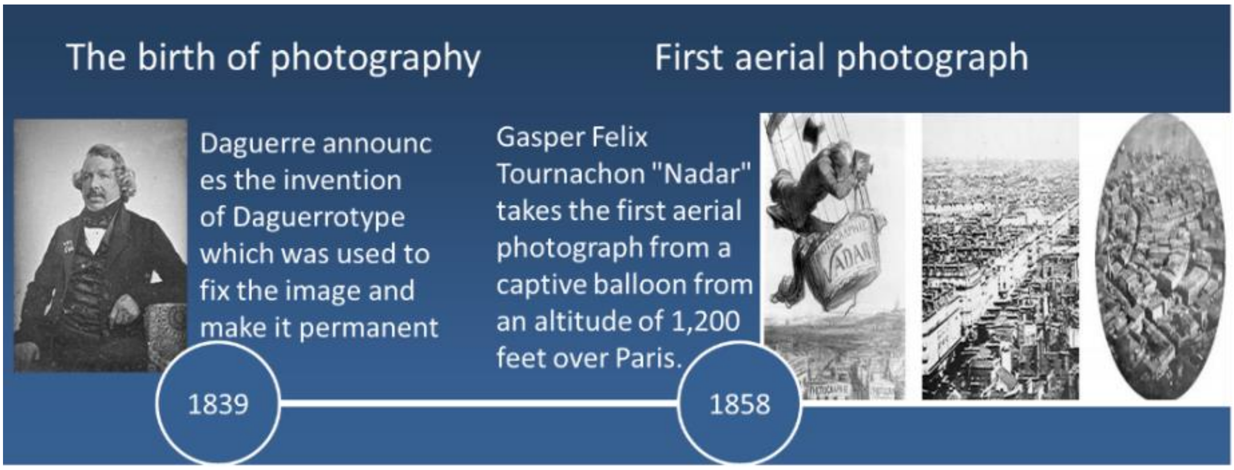
Remote sensing and earth observation are often used interchangeably, however; terms are different. However, earth observation refers to the gathering of information about planet Earth's physical, chemical and biological systems. It involves monitoring and assessing the status of, and changes in, the natural and man-made environments.

Aerial photography to satellite reconnaissance

The practice of remote sensing is rooted in photography. The term "photography" is derived from two Greek words meaning "light" (phos) and "writing" (graphien).

- **1839:** Daguerre announced the invention of Daguerrotype which consisted of a polished silver plate, mercury vapors and sodium thiosulfate ("hypo") that was used to fix the image and make it permanent. This date forms a convenient although arbitrary, milestone for the **birth of photography.**

- **1858:** Gasper Felix Tournachon "Nadar" takes the first aerial photograph from a captive balloon from an altitude of 1,200 feet over Paris.



- **1909**: Wilbur Wright takes an aerial photograph from an airplane of Centocelli, Italy. A motion picture camera is employed. Wright is in Italy trying to sell planes to the Italian government for their campaigns in Northern Africa. The powered aircraft provided the platform for furthering development of aerial photography.

- **1915:** Lt. Col. J.T.C. Brabazon designed and produced the first practical aerial camera in collaboration with Thornton Pickard Ltd.
- **1918** - By this time in the war French aerial units were developing and printing as many as 10,000 photographs each night, during periods of intense activity. During the Meuse-Argonne offensive, 56,000 aerial prints were made and delivered to American Expeditionary Forces in 4 days.

WWI provided a boost in the use of aerial photography, but after the war, enthusiasm waned.

1915 - Lt. Col. J.T.C. Brabazon designed and produced the first practical aerial camera in collaboration with Thornton Pickard Ltd.

1918 - By this time in the war French aerial units were developing and printing as many as 10,000 photographs each night, during periods of intense activity.

World War I
1914 - 1918

- **1919**: Canadian Forestry Mapping Program begins. Hoffman first to sense from an aircraft in thermal I.R. (Infra-Red).
- **1920's**: First books on aerial photo interpretation. In this period, interest in the peaceful uses of aerial photography was increasing (USDA, USAF, TVA).
- **1931**: Development of an I.R. sensitive film (Black & White)
- **1934**: "American Society of Photogrammetry" founded. Photogrammetric Engineering first published. This journal of the American Society of Photogrammetry was later named Photogrammetric Engineering and Remote Sensing. Later renamed, "The American Society of Photogrammetry and Remote Sensing". The innovations led to successful civilian applications in aerial mapping (e.g. Fairchild surveys)

1919 - Canadian Forestry Mapping Program begins and Hoffman first to sense from an aircraft in thermal IR.

1920's - First books on aerial photo interpretation.

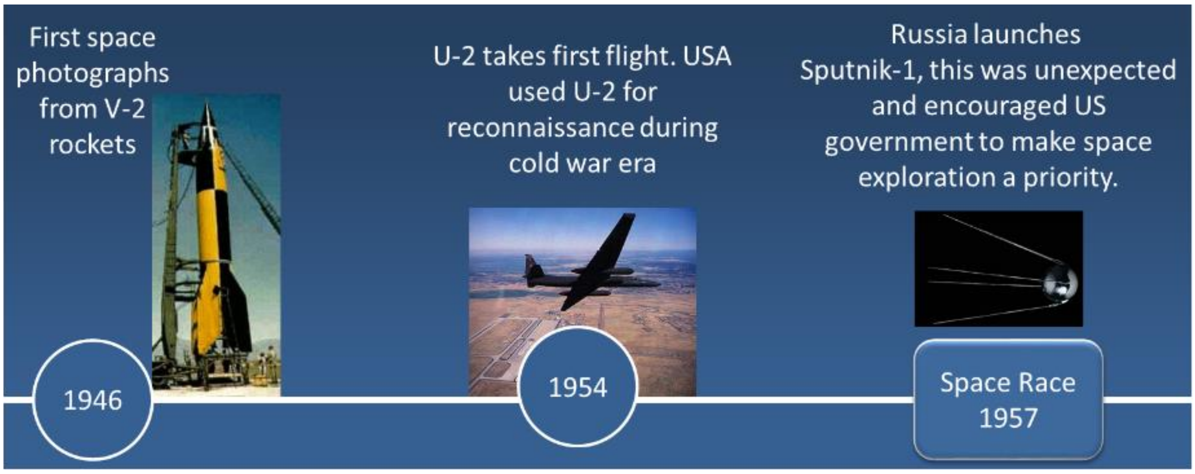
1931 - Development of an IR sensitive film (Black & White)

1934 - American Society of Photogrammetry founded.

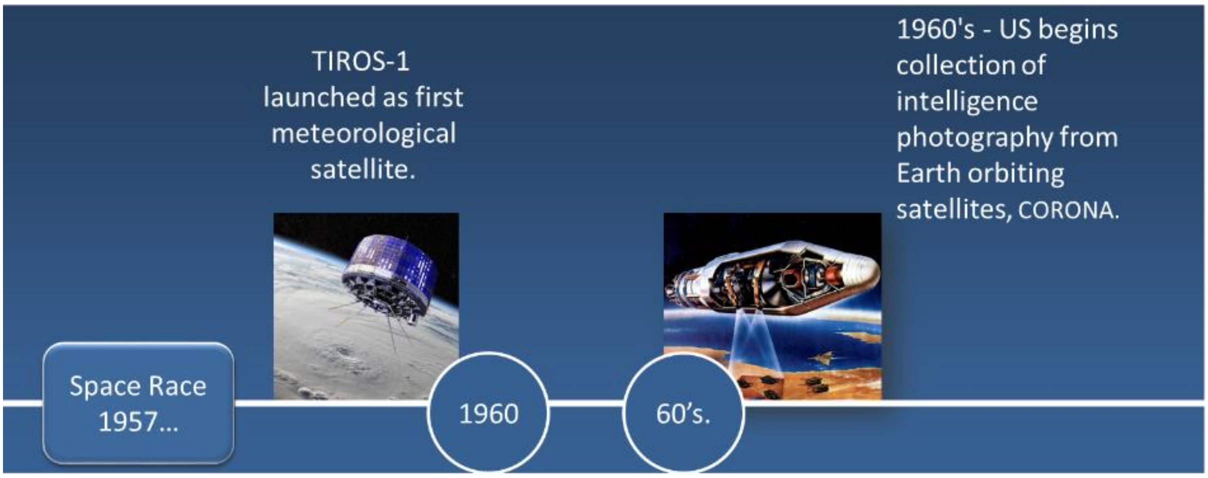
Interwar
Years
1919 - 1939

- **1940**: WW II brought about more sophisticated techniques in air photo interpretation. Germany pioneered many of the applications of photo reconnaissance. The beginning of WW II gives a real boost to photo interpretation; some notable successes from the war are the identification of V-1 rockets, radar, water depth for amphibious landings, vegetation indicators of trafficability. **Traf·fic·abil·i·ty** refers to the quality of a terrain that permits passage (as of vehicles and troops).
- **1942**: Kodak patents first false color I.R. sensitive film.

- **1950's:** Advances in sensor technology move into multi-spectral range, Color-infrared photography (CIR) recognized for non-military applications. A multispectral image is one that captures data at multiple and specific frequencies across the electromagnetic spectrum.

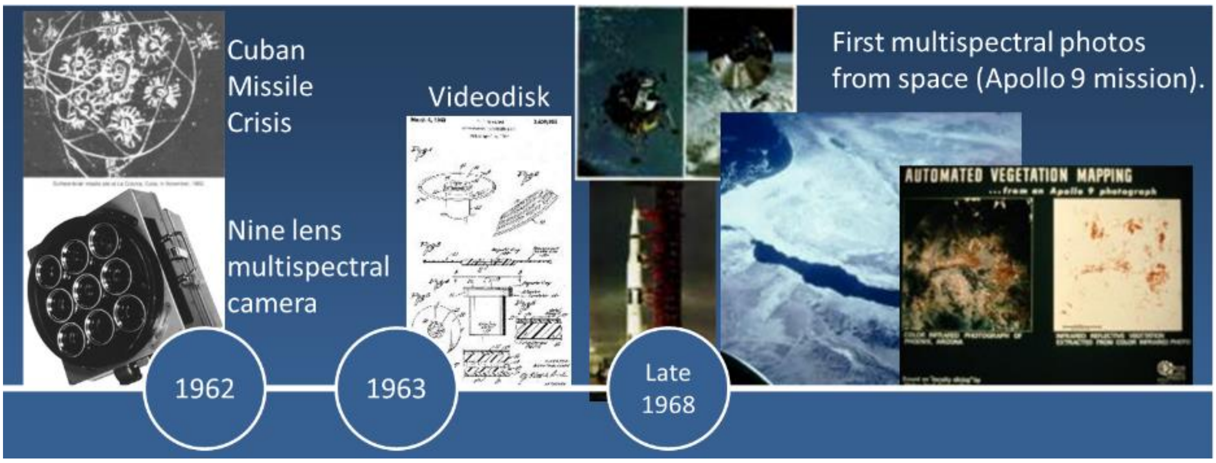


- **1960:** TIROS-I launched as first meteorological satellite.
- **1960's:** CORONA strategic reconnaissance satellite.

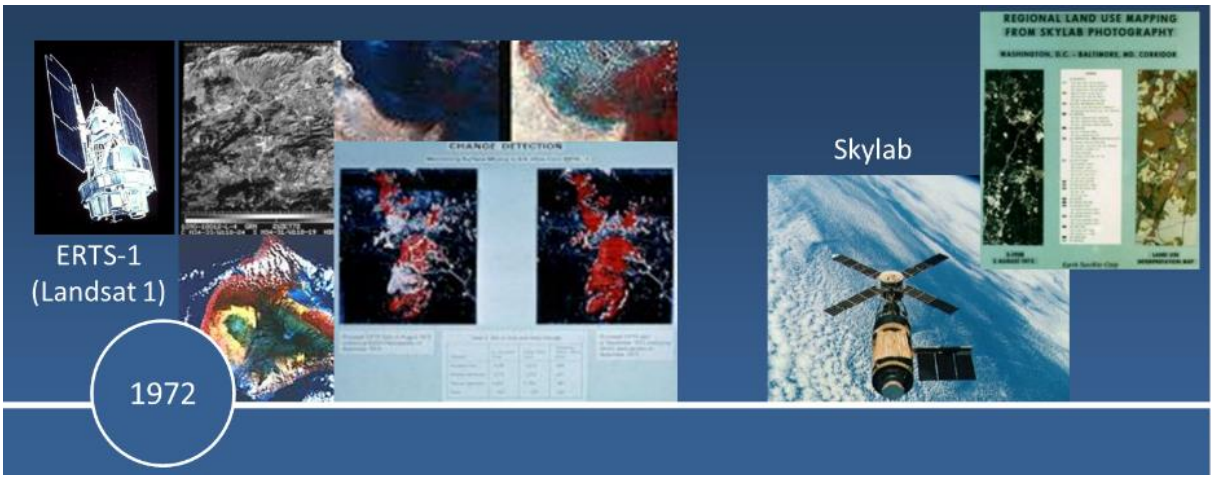


- **1962:** Zaitor and Tsuprun construct prototype nine lens multispectral camera permitting nine different film-filter combinations. USA comes very close to nuclear war when military intelligence photography was brought into the lime light by the Cuban Missile Crisis. In the fall of 1962, there were unconfirmed reports that the Soviets were installing intermediate range nuclear missiles in Cuba. Remotely sensed imagery, mainly from high flying U-2 airplanes provided irrefutable proof that the rumours were true. The resulting confrontation between Soviet Premier Khrushchev and US President John F. Kennedy in October 1962 brought the world to the brink of nuclear war.

- **1963:** D. Gregg, while working at Stanford University, creates a primitive predecessor to digital photography, called the "videodisk", which could capture and store images for a few minutes.
- Late **1960's:** Gemini and Apollo Space photography. The first multispectral photography from space took place during the 1968 Apollo 9 mission. Four Hasselblad cameras were mounted in a frame that the crew could hold. A trigger was rigged to all four cameras so they would all expose at the same time. The multispectral imagers acquired during this mission were digitized and used in the development of Landsat.

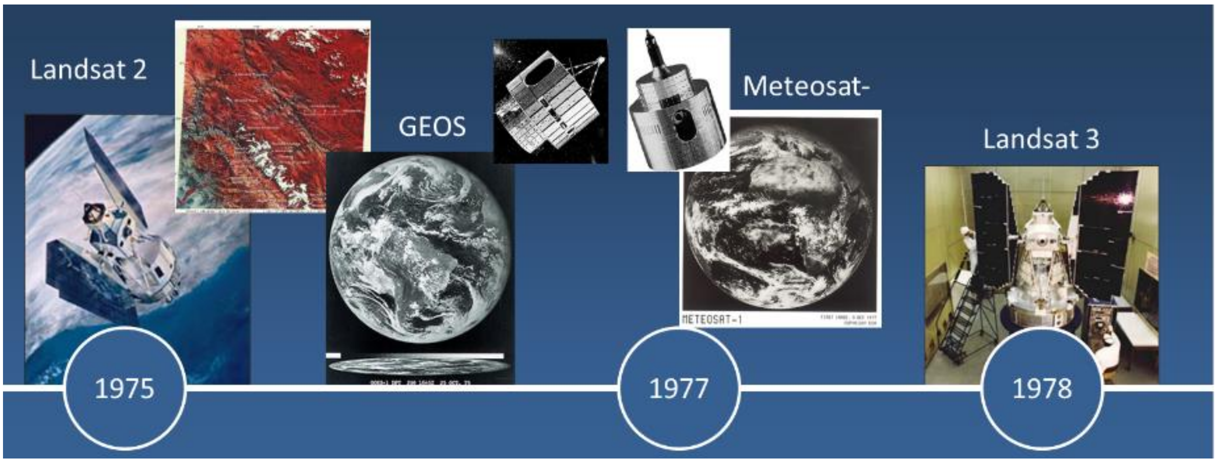


- **1972:** ERTS-1 launched July 23, 1972 is the first earth observation satellite later renamed Landsat 1. Carried the MSS (Multispectral Scanner) which imaged the earth from a 900 km altitude with green, red and two I.R. spectral bands at 80 m spatial resolution. Landsat provided, for the first time, systematic repetitive observation of the Earth's surface. During this period, photography from Skylab, America's first space station, was used together with Landsat 1 to produce first land use maps from space-borne sensors.



- **1975**: Launch of Landsat 2. Created for rapid and broad expansion of uses of digital analysis for remote sensing. Launch of the first of the GEOS satellites. The Geostationary Satellite system (GEOS), operated by the United States National Environmental Satellite, Data, and Information Service (NESDIS), supports weather forecasting, severe storm tracking, and meteorology research.

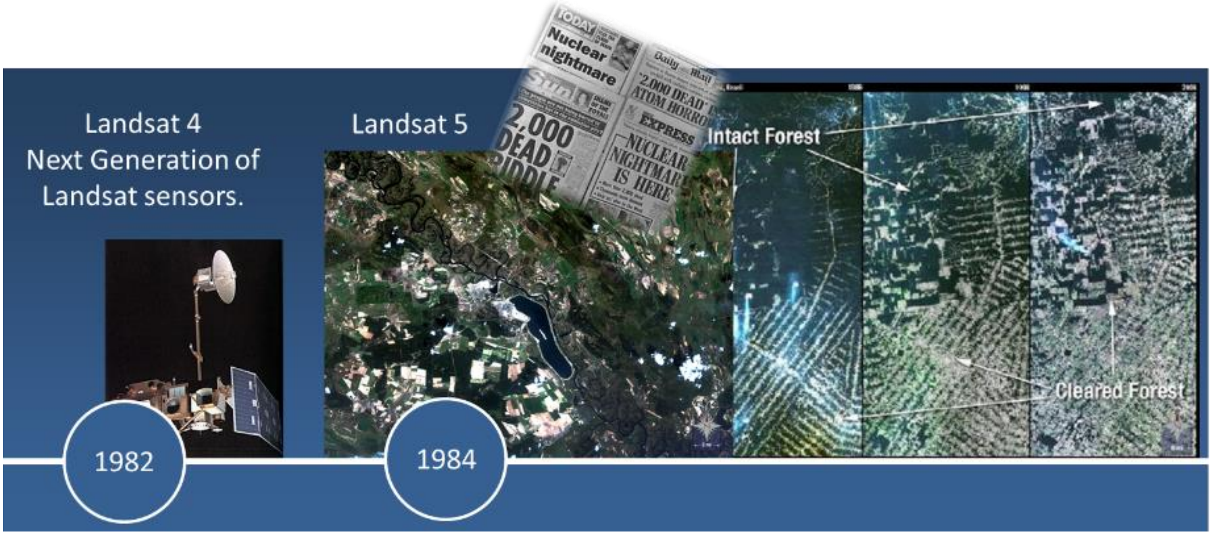
- **1977**: Launch of Meteosat-1, the first in a long series of European weather satellites. The first generation of Meteosat satellites, Meteosat-1 to Meteosat-7, provides continuous and reliable meteorological observations from space to a large user community. In addition to the provision of images of the Earth and its atmosphere every half-hour in three spectral channels (Visible, Infrared) and Water Vapour, via the Meteosat Visible and Infrared Imager (MVIRI) instrument, a range of processed meteorological products is produced.
- **1978:** Launch of Landsat 3. Landsat 3 had essentially the same design as Landsat 2. It carried a Multi-Spectral Scanner (MSS), which had a maximum 75 m resolution. Unlike the previous two Landsat missions, a thermal band was built into Landsat 3's MSS, but this instrument failed shortly after the satellite was deployed. Landsat 3 was placed into a polar orbit at about 920 km's, and took 18 days to cover the entire Earth's surface.



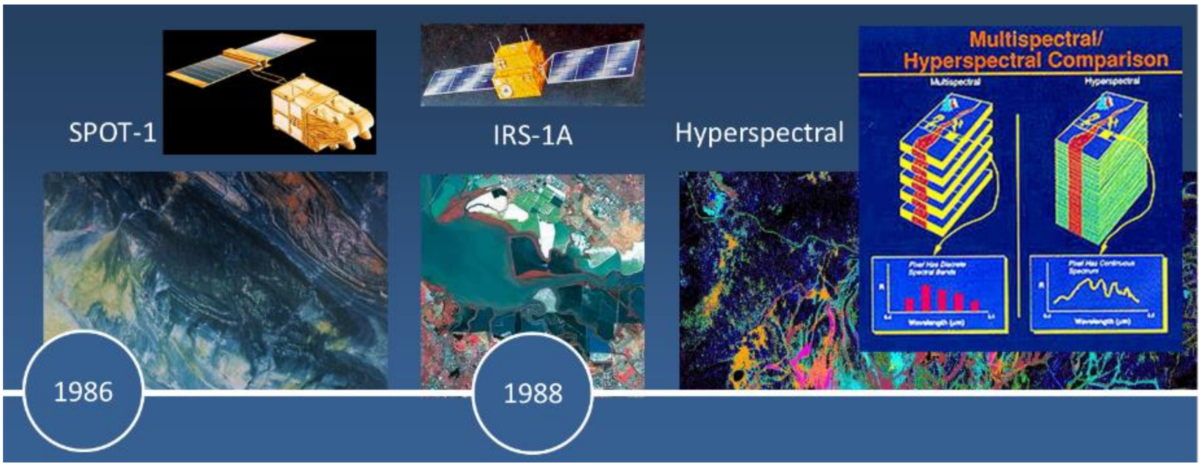
- **1976:** South Africa establish the Satellite Remote Sensing Centre (SRSC) for the reception of geo-information from satellites.
- **1978:** First images were received from Meteosat.

- **1982:** Landsat 4 launched. Landsat 4 carried the experimental thematic mapper (TM) sensor on-board as well as the multi-Spectral scanner (MSS). In 1983, Landsat 4 began experiencing malfunctions, which prompted the early launch of Landsat 5.
- **1983:** South Africa (SRSC) becomes part of the worldwide tracking network of the French National Space Agency (CNES).
- **1984:** Launch of Landsat 5. Landsat 5 recorded many significant events. It was the first satellite to image the nuclear accident at Chernobyl in 1986. Landsat 5 also documented deforestation occurring in tropical regions, and captured the devastating 2004 tsunami in southeast Asia.

Landsat 5 captured data for 29 years, making it the longest operating earth observing satellite in history.

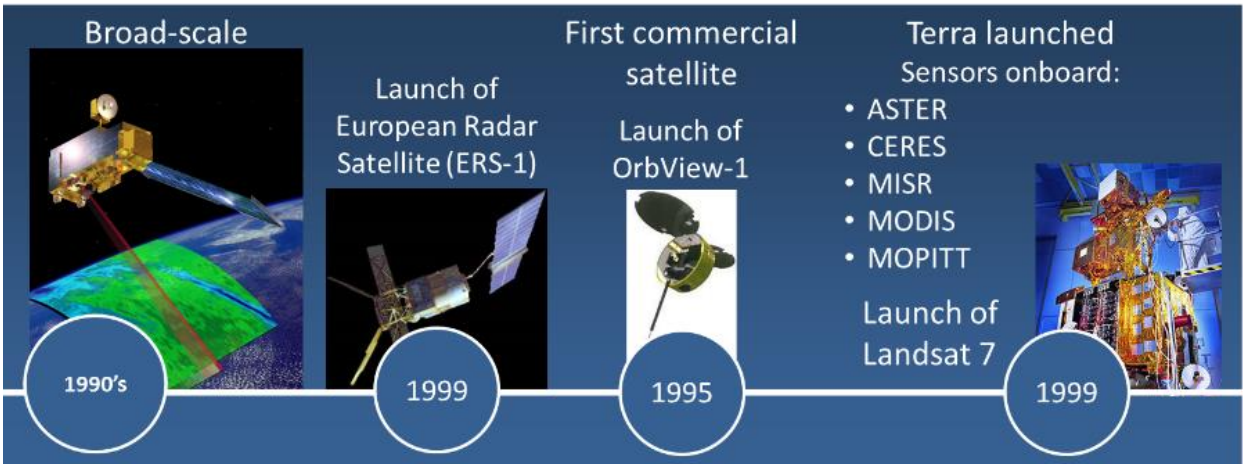


- **1986**: Launch of SPOT-1 (Systeme Probatorie de la Observation de la Terre). Since 1986 the SPOT family of satellites has been orbiting the Earth and has already taken more than 10 million high quality images. SPOT 1 was launched with Ariane 2 on February 22, 1986. Two days later, the 1800 kg SPOT 1 transmitted its first image with a spatial resolution of 10 or 20 m.
- **1988**: Launch of IRS-1A, the first in a long series of Indian Remote Sensing Satellites. IRS-1A was the first remote sensing mission undertaken by the Indian Space Research Organization (ISRO). It was a half-operational, half-experimental mission to develop indigenous expertise in satellite imagery which traditionally belonged in the realm of developed nations. In South Africa SRSC is renamed the Satellite Applications Centre (SAC).
- **1980's**: Development of hyperspectral sensors. NASA's Jet Propulsion Laboratory (JPL) developed instruments that could image the Earth at unprecedented levels of spectral detail. This lead to the development of the hyperspectral remote sensing field. Hyperspectral imaging, like other spectral imaging, collects and processes information from across the electromagnetic spectrum. Engineers build hyperspectral sensors and processing systems for applications in astronomy, agriculture, biomedical imaging, mineralogy, physics, and surveillance. Hyperspectral sensors look at objects using a vast portion of the electromagnetic spectrum.



- **1991**: Launch of European Radar Satellite ERS-1, the first satellite with an altimeter able to map the earth surface to within 5 cm.

- **1995**: Launch of OrbView-1 the world's first commercial imaging satellite. Launch of ERS-2.
- **1999:** NASA launched the Earth Observing System's flagship satellite "Terra," named for Earth, on December 18, 1999. Terra has been collecting data about Earth's changing climate. Terra carries five state-of-the-art sensors that have been studying the interactions among the Earth's atmosphere, lands, oceans, and radiant energy. Each sensor has unique design features that will enable scientists to meet a wide range of science objectives. The five Terra on-board sensors are:
  - ASTER, or Advanced Spaceborne Thermal Emission and Reflection Radiometer.
  - CERES, or Clouds and Earth's Radiant Energy System.
  - MISR, or Multi-angle Imaging Spectroradiometer.
  - MODIS, or Moderate-resolution Imaging Spectroradiometer.
  - MOPITT, or Measurements of Pollution in the Troposphere.
- Landsat 7 launched. Carried the sensor Enhanced Thematic Mapper Plus (ETM+). Offered a 15 m spatial resolution band and 30 m spatial resolution multispectral bands.



- **1999**: The **S**tellenbosch **UN**iversity **Satellite** is the first miniaturized satellite designed and manufactured in South Africa. It was launched aboard a Delta II rocket from the Vandenberg Air Force Base on 23 February 1999. Sunsat was built by post-graduate engineering students at the University of Stellenbosch. Its AMSAT designation was SO-35 (Sunsat Oscar 35).

- **2005:** The first decade of 21st century saw the power of the internet influencing public access to remotely sensed imagery. Google Earth - virtual representation of the Earth's surface as a composite of varied digital images defined a new class of applications of remotely sensed imagery that contrast sharply with those of earlier more restrictive eras.

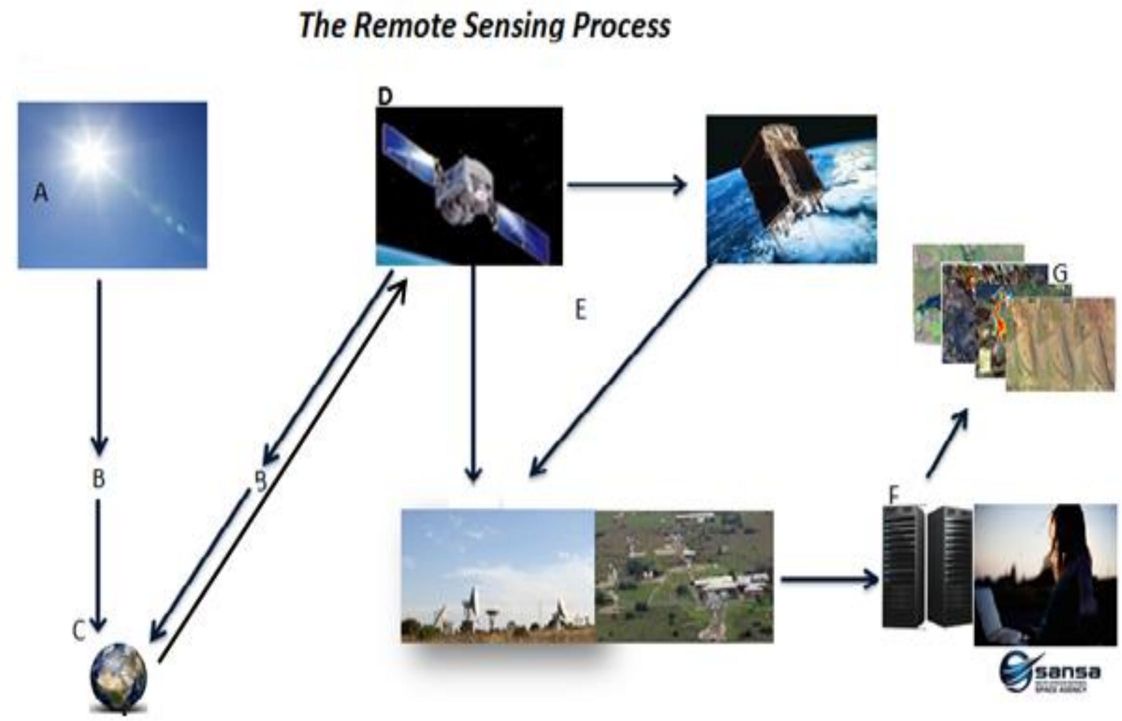
- **2008:** the South African government's Department of Science and Technology (DST) set out to develop a national Space Agency. SAC was identified as one of the key centres to form what is today known as the South African National Space Agency (SANSA). The South African National Space Agency Act, 36 of 2008, mandated the establishment of a National Space Agency to provide for the promotion and use of space and cooperation in space- related activities, foster research in space science, advance scientific engineering through human capital and support the creation of an environment conducive to industrial development in space technologies within the framework of national government policy.
- **2009**: SumbandilaSat (formerly ZASAT-002), is a South African micro earth observation satellite, launched 2009-09-17 on a Soyuz-2 launch vehicle from the Baikonur Cosmodrome. The first part of the name, Sumbandila, is from the Venda language and means "lead the way". The University of Stellenbosch, SunSpace and the CSIR (Council for Scientific and Industrial Research) were key players in constructing SumbandilaSat. The CSIR's Satellite Application Centre (CSIR-SAC) will be responsible for operations, telemetry, tracking, control as well as data capturing. SumbandilaSat is part of a closely integrated South African space programme and will serve as a research tool to investigate the viability of affordable space technology. Furthermore, the data will be used to, amongst others, monitor and manage disasters such as flooding, oil spills and fires within Southern Africa.
- In June 2011 the satellite was damaged during a solar storm. The damage caused the on-board computer and the camera to stop functioning. This has caused it to stop fulfilling its primary objective and has been written off as a loss by SunSpace, its builder.

IMAGE ACQUISITION PROCESS

As seen in section 1.1., remote sensing involves the measurements of electromagnetic radiation in one or more regions of the electromagnetic spectrum. In this section, we will answer the questions:

- What is electromagnetic spectrum and its different regions?
- How are images acquired?
- What are the main types of remote sensing sensors?

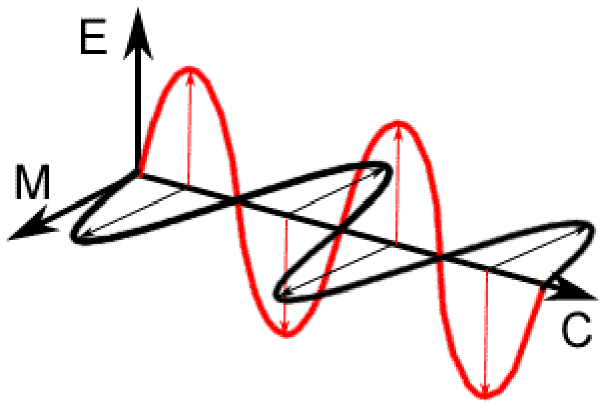
Let's first have a look at the following diagram showing the whole process of image acquisition.



So, what does each mean?

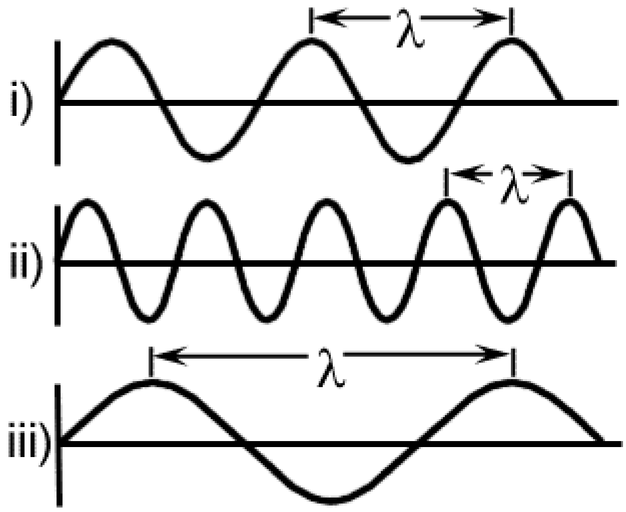
A is the **Energy source**. This is the first requirement for remote sensing and its role is to illuminate or provide electromagnetic energy to the target of interest. The energy source may be the sun for passive sensors (those that require external illumination) or microwave energy for active sensors (those that produce their own energy such as RADAR or LiDAR). These will be discussed in detail later.

Before we continue identifying other processes in the diagram, let's examine the properties of electromagnetic radiation. All electromagnetic radiation has fundamental properties and behaves in predictable ways according to the basics of wave theory. Electromagnetic radiation consists of an electrical field (E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c).



There are two characteristics of electromagnetic radiation that are particularly important for understanding remote sensing. These are the wavelength and frequency.

The wavelength (λ) is the length of one wave cycle, which can be measured as the distance between successive wave crests.[14] Wavelength is measured in metres (m) or some factor of metres such as nanometres (nm, 10-9 metres), micrometres (μm, 10-6 metres) (μm, 10-6 metres) or centimetres (cm, 10-2 metres). Frequency (Hz) refers to the number of cycles of a wave passing a fixed point per unit of time.



Wavelength and frequency are inversely related to each other. In other words, the shorter the wavelength, the higher the frequency. The longer the wavelength, the lower the frequency.

$$c = \lambda \nu$$

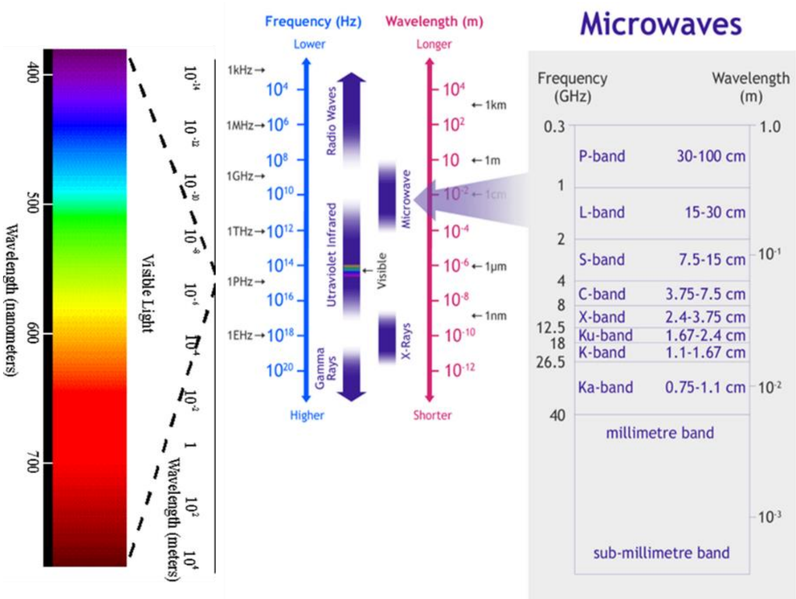
where:

λ = wavelength (m)
ν= frequency (cycles per second, Hz)
c =speed of light $(3 \times 10^8 m/s)$

14 https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/resource/tutor/fundam/pdf/fundamentals_e.pdf

The knowledge of the characteristics of electromagnetic radiation in terms of their wavelength and frequency is crucial to understanding the information to be extracted from remote sensing data. Let us now examine electromagnetic radiation in detail.

The electromagnetic spectrum ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). There are several regions of the electromagnetic spectrum which are useful for remote sensing.



There are several regions of the electromagnetic spectrum which are useful for remote sensing. We will only focus on the common ones such as Visible, Infrared and Microwave portions of the electromagnetic spectrum.

i. Visible region

The light which our eyes can detect is part of the visible spectrum. It is important to recognize how small the visible portion is relative to the rest of the spectrum. There is a lot of radiation around us which is "invisible" to our eyes, but can be detected by other remote sensing instruments and used to our advantage. The visible wavelengths cover a range from approximately 400 to 700 nm. The longest visible wavelength is red and the shortest is violet. It is important to note that this is the only portion of the spectrum we can associate with the concept of colours.

Visible	Infrared	Microwave
Violet: 0.4 - 446 μm	NIR: 0.7 - 2.5 μm	P-band: 30 – 100 cm
Blue: 0.446 – 0.5 μm	SWIR/MIR: 2.5 – 25μm	L-band: 15 – 30 cm
Green: 0.5 – 0.578 μm	Thermal/FIR: 25 - 1000 μm	S-band: 7.5 – 15 cm
Yellow: 0.578 – 0.592 μm		C-band: 3.75 – 7.5 cm
Orange: 0.592 – 0.62 μm		X-band: 2.4 – 3.75 cm
Red: 0.62 – 0.7 μm		Ku-band: 1.67 – 2.4 cm
		K-band: 1.1 – 1.67 cm

ii. Infrared region

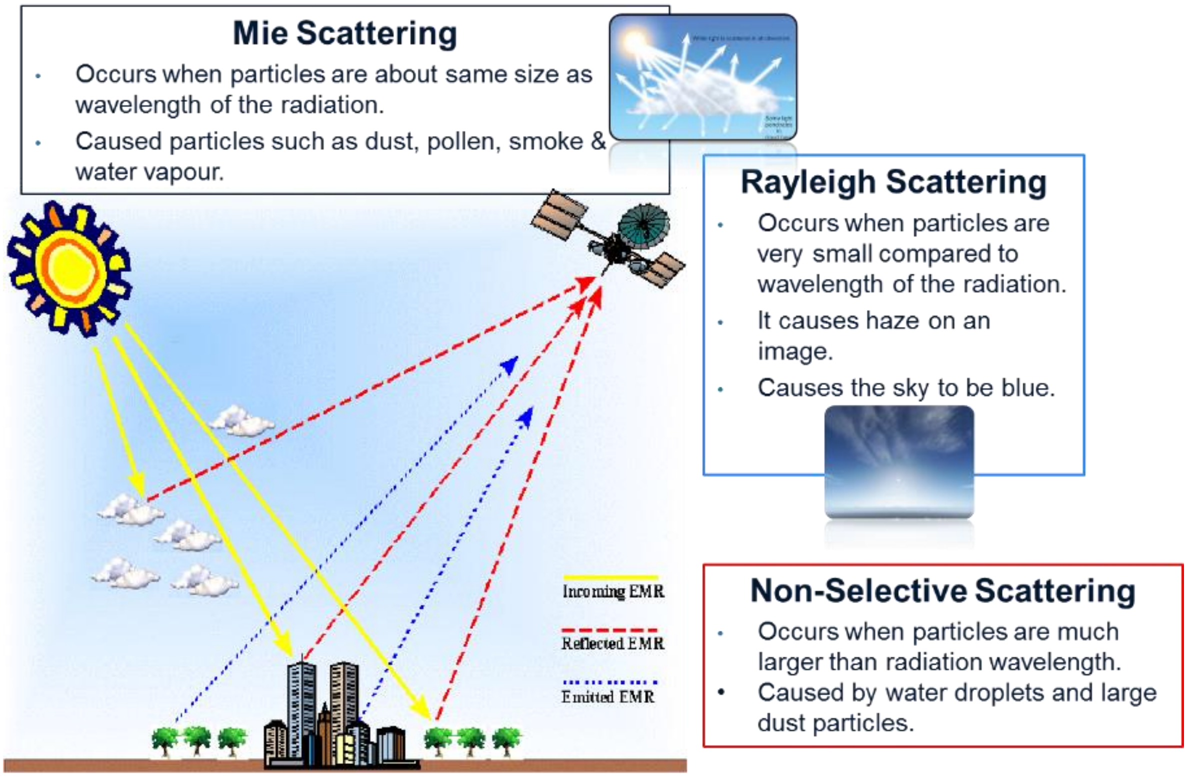
The infrared (IR) region covers the wavelength range from approximately 700 nm to 1000 nm - more than 100 times as wide as the visible portion! The infrared region can be divided into two categories based on their radiation properties - the reflected IR, and the emitted or thermal IR. Radiation in the reflected IR region is used for remote sensing purposes in ways very similar to radiation in the visible portion. The reflected IR covers wavelengths from approximately 0.7 µm to 3.0 µm. The thermal IR region is quite different than the visible and reflected IR portions, as this energy is essentially the radiation that is emitted from the Earth's surface in the form of heat. The thermal IR covers wavelengths from approximately 3.0 µm to 100 µm.

iii. Microwave region

The portion of the spectrum of more recent interest to remote sensing is the microwave region from about 1 mm to 1 m. This covers the longest wavelengths used for remote sensing. The shorter wavelengths have properties similar to the thermal infrared region while the longer wavelengths approach the wavelengths used for radio broadcasts.

B is the **Radiation and the atmosphere**. As the energy travels from its source to the target, it will come in contact with and interact with the atmosphere as it passes through. This interaction may take place a second time as the energy travels from the target to the sensor. The particles and gases in the atmosphere can affect the incoming light and radiation by absorbing and scattering some of the radiation. So what is the difference between **scattering** and **absorption**?

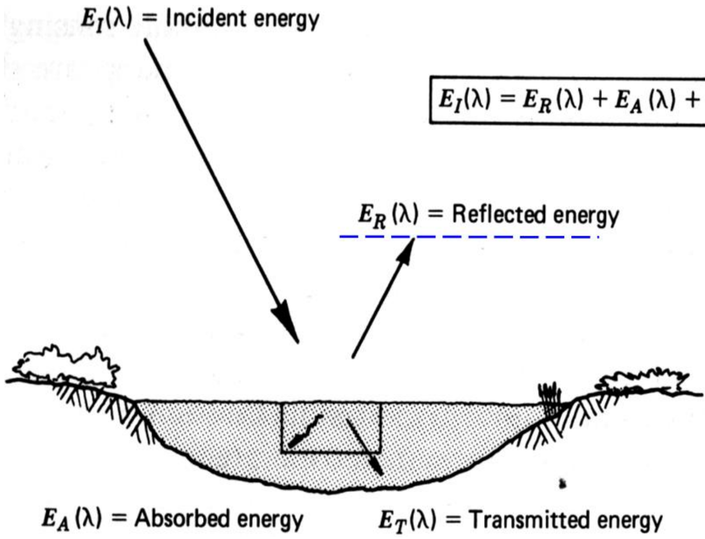
Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path. Let us have a look at the following diagram, summarizing the types of scattering that occurs in the atmosphere.



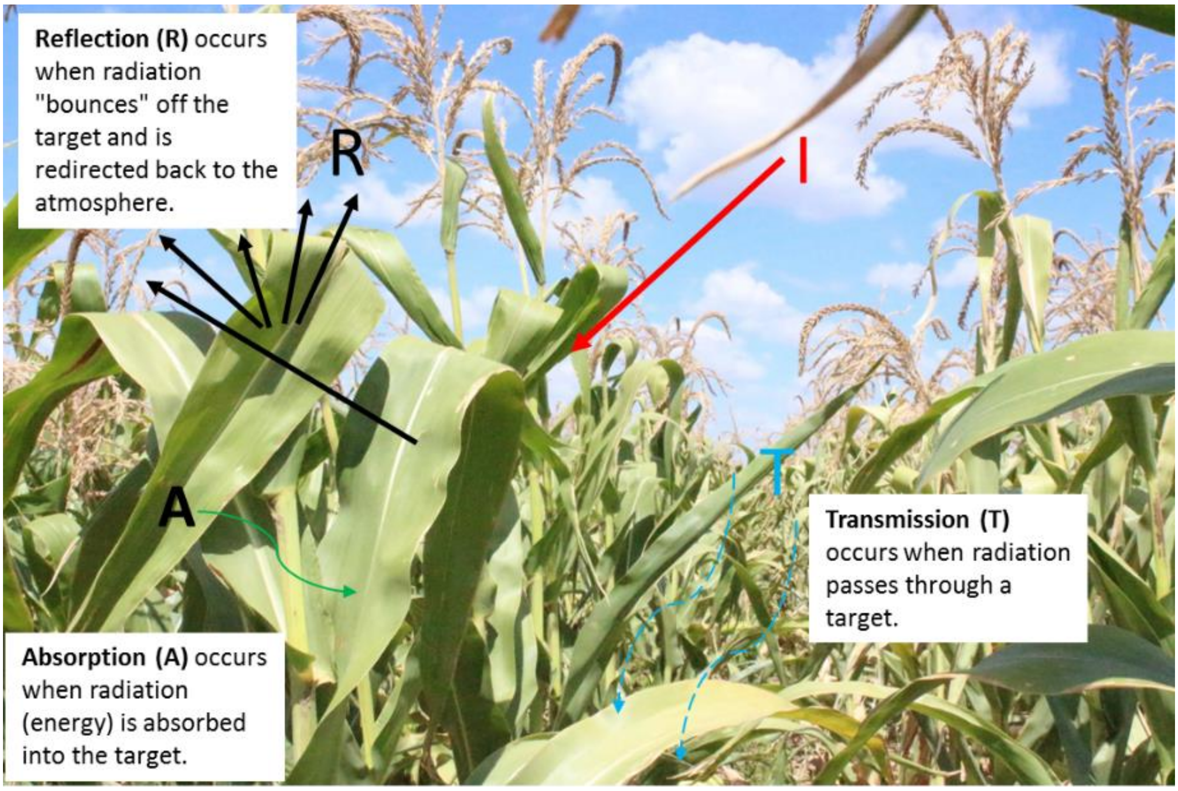
Absorption occurs when molecules in the atmosphere to absorb energy at various wavelengths. Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation.

C is the **Radiation and the surface**. The radiation that has made it through the atmosphere to the surface of the earth, will interact with the target depending on the properties of both the target and the radiation.

There are three forms of interaction that can take place when energy strikes, or is incident (I) upon the surface, namely; 1. absorption (A); 2. transmission (T); and 3. reflection (R). In remote sensing, we are mostly interested in measuring the radiation reflected from targets (also called reflectance).



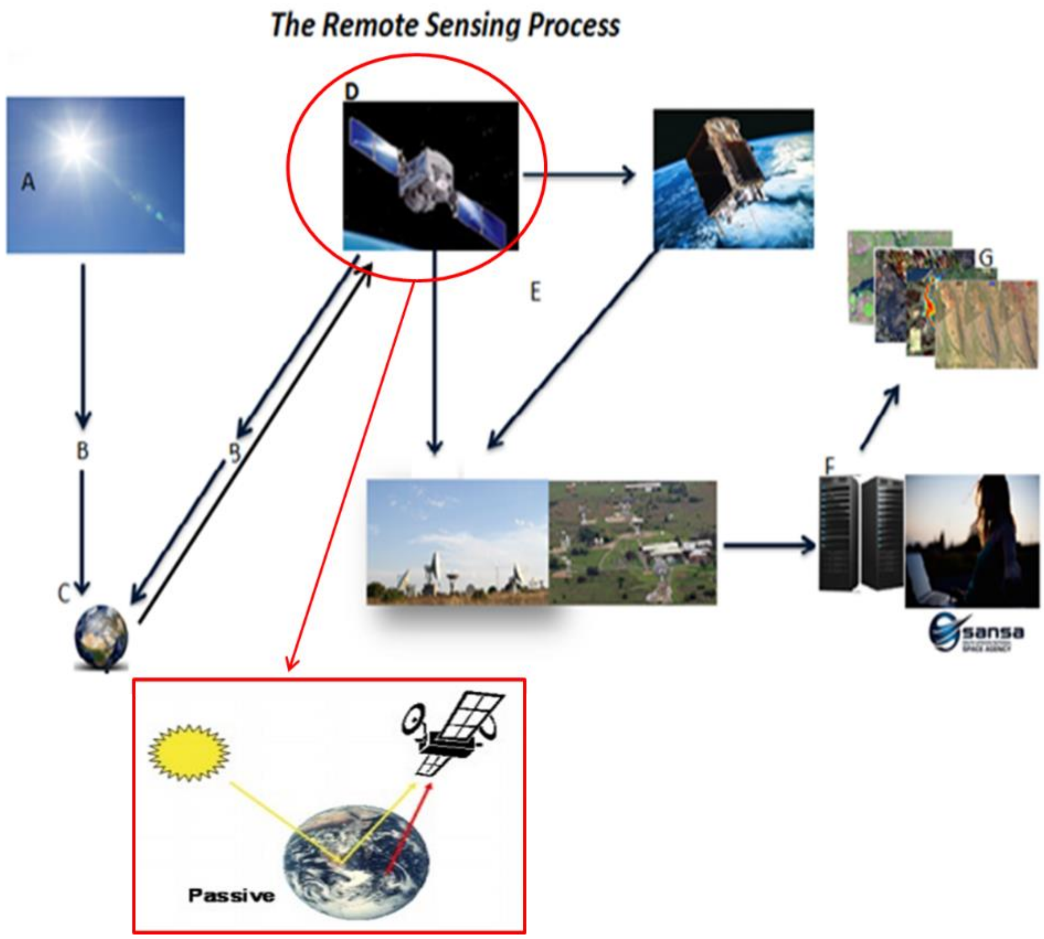
Let us have a look at the example target, i.e. maize leaves and how it interacts with the (I) incident radiation. A chemical compound in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelengths. Leaves appear "greenest" to us in the summer, when chlorophyll content is at its maximum. In autumn, there is less chlorophyll in the leaves, so there is less absorption and proportionately more reflection of the red wavelengths, making the leaves appear red or yellow (yellow is a combination of red and green wavelengths).



The internal structure of healthy leaves act as excellent diffuse reflectors of near-infrared wavelengths. If we were able to see beyond the visible region of the electromagnetic spectrum (in other words, sensitive to near-infrared radiation), then trees would appear extremely bright to us at these wavelengths. In fact, scientists can determine the vigor of vegetation based on measurements in the near-infrared reflectance.

D is the **Recording of energy by the sensor**. The reflected or emitted energy from earth's targets reaches a sensor (that is remote - not in contact with the target) to collect and record the electromagnetic radiation.

The sensors can be divided into two groups, namely; **passive sensors** and **active sensors**.
Passive sensors measure the energy that is naturally available (i.e. sun's energy). These sensors record reflected and emitted energy from the targets. Although, emitted energy can be measured during the night, reflected energy can only be measured during the day and clear whether conditions.

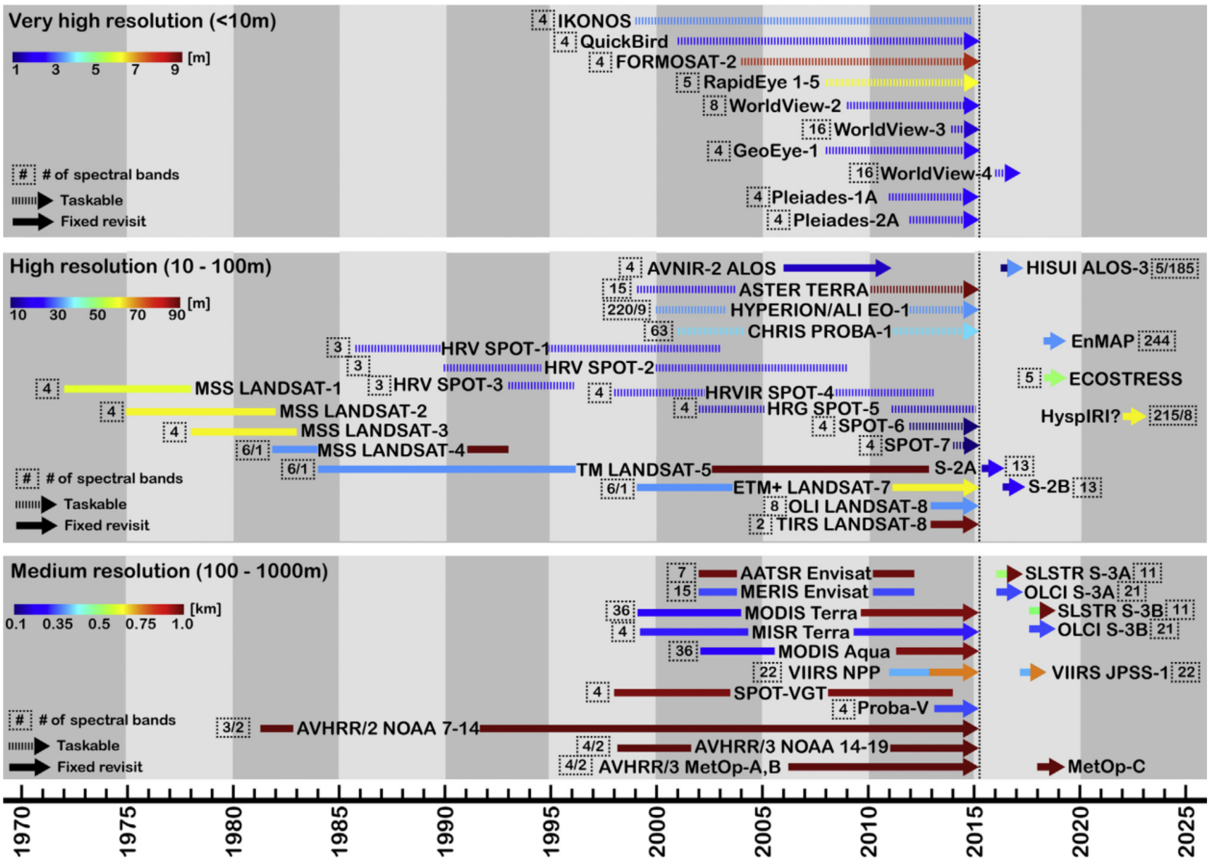


The passive sensors can be categorized further according to the bandwidths they measure, namely:

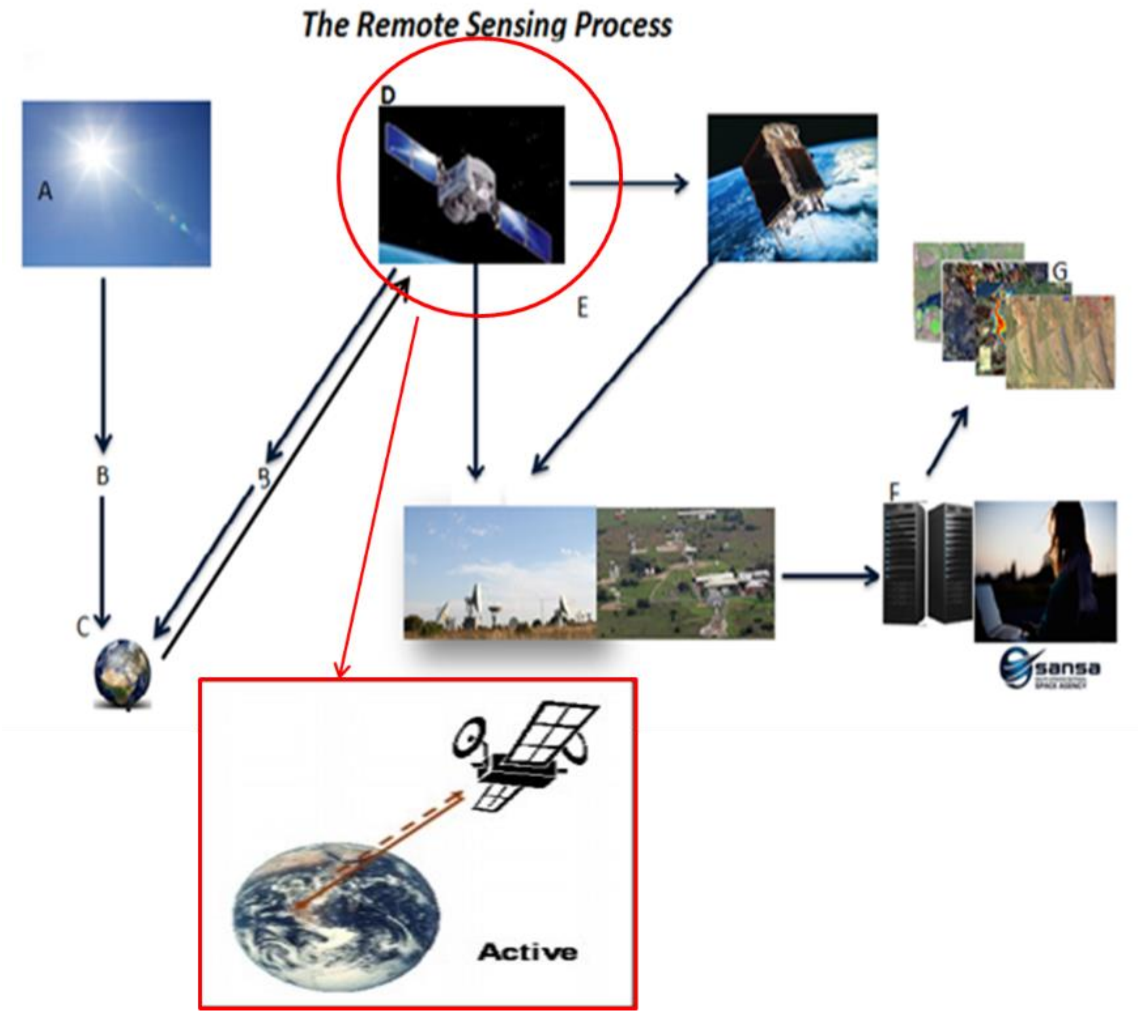
- **Multispectral sensors** – refers to sensors which measures the reflected energy within few broad spectral bands at specific positions across electromagnetic (EM) spectrum. Some examples that you will use are in this handbook are Landsat, SPOT, MODIS, ASTER, Sentinel 2.
- **Hyperspectral sensors** – refers to sensors that measure reflected energy in many (hundreds to thousands), narrow contiguous bands across the EM spectrum. Hyperspectral images can contain as many as 200 (or more) contiguous spectral bands (e.g. AVRIS, Hyperion, HyMap, EnMap, Hydice, etc.).

Below is are the timelines of historical and planned passive satellite sensors relevant at medium to very high spatial resolution[15].

[15] Rasmus Houborg, Joshua B. Fisher, Andrew K. Skidmore (2015) Advances in remote sensing of vegetation function and traits, International Journal of Applied earth Observation and Geoinformation 43, 1- 6



Active sensors, on the other hand, provide their own energy source for illumination which is emitted towards the targets and reflected back to be measured by the sensor. These sensors are not limited by the presence of clouds or absence of light, hence can obtain measurements anytime or season. Examples of active sensors include laser fluorosensor and a synthetic aperture radar (SAR).



These sensors are recently becoming a topic of interest due to high presence and persistence of clouds in the tropical regions of Africa, and due to limitations of passive sensors especially for disaster management (e.g. floods). Let's have a look at the following table indicating some advantages and disadvantages of active sensors (SAR) as compared to passive sensors.

Advantages

- All weather capability (small sensitivity of clouds, light rain)
- Day and night operation (independence of sun illumination)
- No effects of atmospheric constituents (multi-temporal analysis)
- Sensitivity to dielectric properties (such as water content, biomass, etc.)
- Sensitivity to surface roughness (ocean wind speed)
- Accurate measurements of distance (interferometry)
- Sensitivity to man-made objects
- Sensitivity to target structure (use of polarimetry)
- Sub-surface penetration.

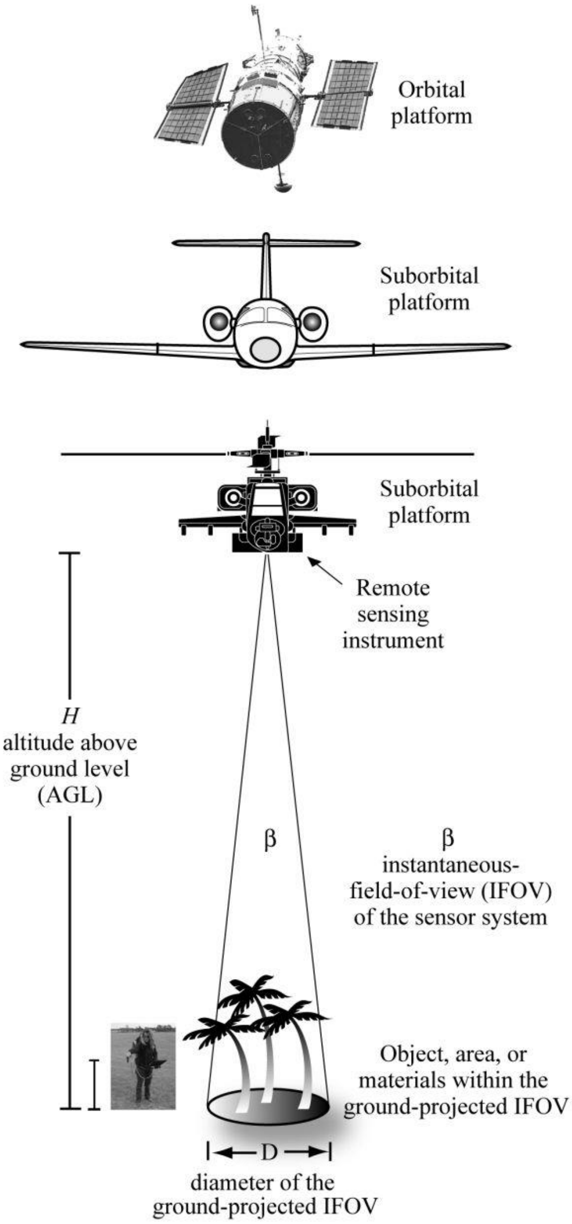
Disadvantages

- Complex interactions (difficulty in understanding, complex processing)
- Speckle effects (difficulty in visual interpretation)
- Topographic effects
- Effect of surface roughness mixed up with soil moisture
- Bio-, geochemical variables NOT measurable.
- Difficulty in understanding and interpretation

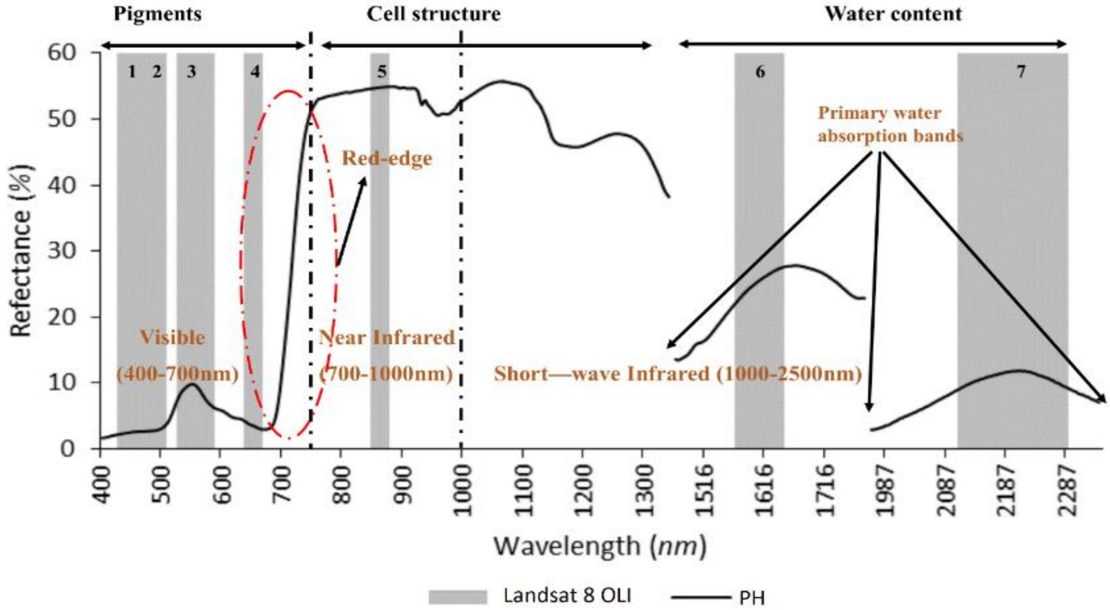
Platforms

The sensors (both Passive and Active) can be hosted at different platforms ranging from the ground-based platforms such as vehicles, handheld spectrometers and cameras to suborbital such as unmanned aerial vehicles and fixed wing aircrafts and space-based platforms such satellites or space craft.

Remote Sensing Measurement



Ground-based platforms are used to carry sensors that record detailed information about the targets on the surface to validate or compare with information collected from an aircraft or satellite sensors. These include LAI (Leaf Area Index) Analyzer and Spectrometers. In the case of handheld field spectrometers, the information collected can be used for detecting subtle differences, including discriminating between plants species, and soil/rock minerals. This is because of their capability to measure spectral reflectance across the EM spectrum usually between 350-2500nm in very high spectral resolution (see the discussion about resolutions in the next chapters). Spectra obtained through spectrometer can be used to assess vegetation health at different spectral regions (visible = health, NIR = cell structure, SWIR = Water content).



LiCOR LAI Analyzer measures reflectance below 490nm where leaf reflectance and transmittance is minimal. It enables the calculation of the area covered by leaves.

Suborbital or aerial platforms such as aircrafts or unmanned aerial vehicle (UAVs) host sensors that capture aerial photographs taken by at horizontal, oblique or vertical angle. These have been in use since 1858 and initially consisted of only black and white film (0.4μm to 0.7μm), now are expanded to include hyperspectral sensors. Most of the platforms contain customized mounts that in addition to the sensor contain GPS, and IMU in order to calculate pitch and yaw of aircraft during acquisition.

Space-based platforms such as space crafts and satellites, are used to keep the sensors (payload) alive, and properly positioned for as long as necessary to complete the mission (i.e. based on user or project needs).

The satellites follow specific orbits[16] such as:

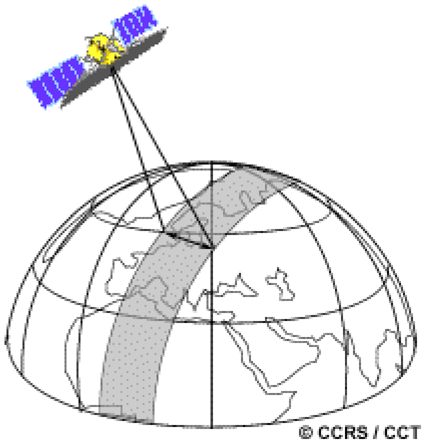
- **Geostationary orbit**, with the following characteristics:
  - Stationary with respect to a location on earth (examples include GEOS, MeteoSat)
  - circular orbit around the equator
  - orbital period is equal to the earth's rotation
  - orbital altitude is about 36 000km above the equator
  - constant contact with ground stations, can cover about 25-30% of earth surface
  - Examples are weather and communications satellites
- **Polar orbit**, with the following characteristics:
  - Sun-synchronous[17] (examples in Landsat, CBERS, Terra/Aqua)
  - Satellite crosses the equator at the same time each day
  - inclination is retrograde (backwards pointing)
  - equatorial crossing time depends on nature of application (low or high sun angle)

---

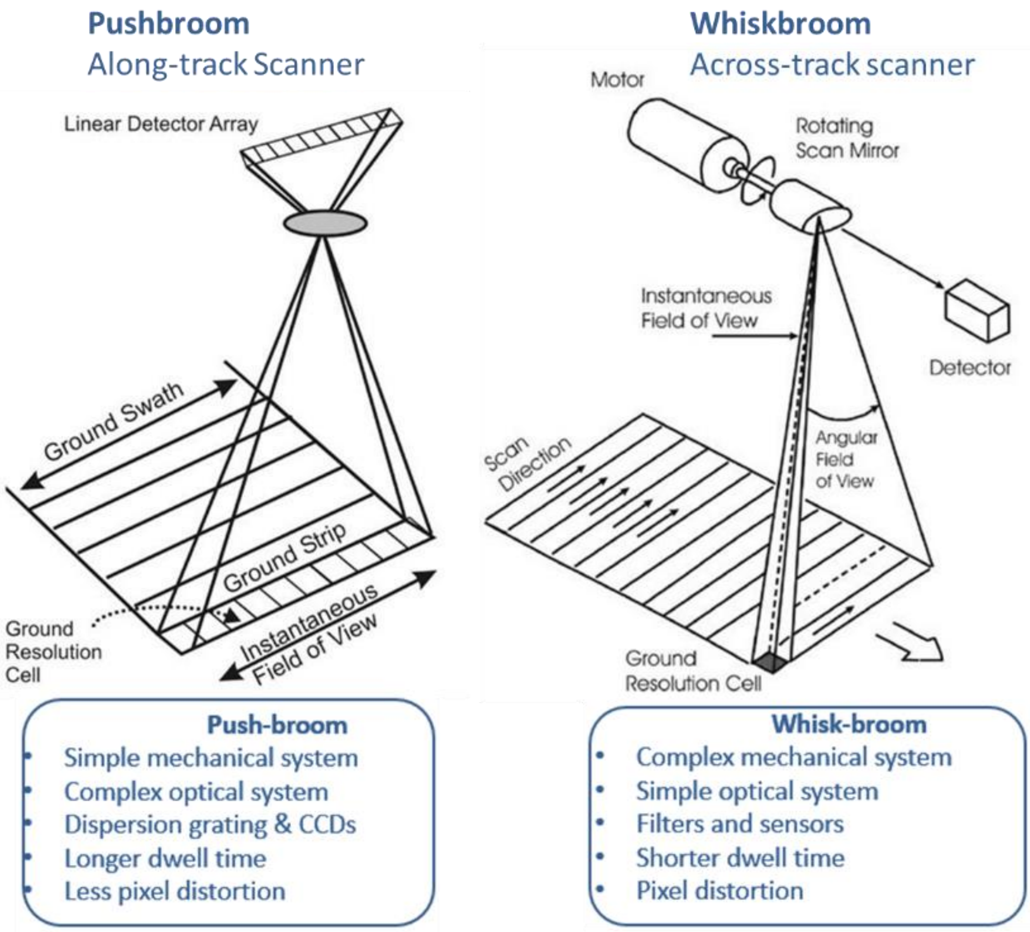
[16] **Orbit** is the path followed by a satellite while it's in space. They vary in terms of their height above the Earth's surface (altitude) and their orientation and rotation relative to the Earth.

[17] They cover each area of the world at a constant local time of day called local sun time. Synchronization with the sun ensures consistent illumination conditions when acquiring images in a specific season over successive years, or over a particular area over a series of days.

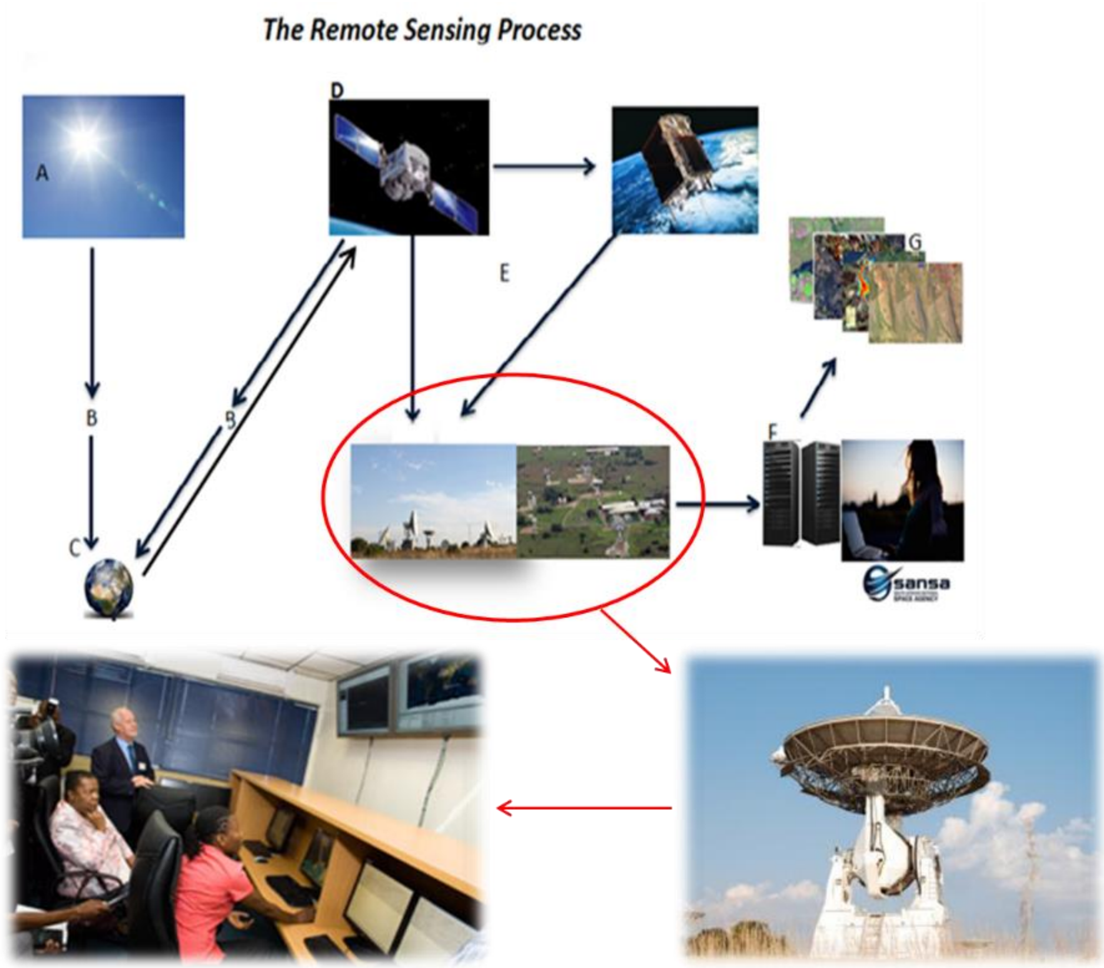
Another important aspect of satellite sensors worth mentioning is that they can only "see" a particular portion of the earth's surface as they revolve around the earth. This area imaged on the surface at each satellite pass is the **swath** of the sensor, often varies between tens to hundreds of kilometers wide.



The sensors also have different scanning mechanisms that are used when imaging over an area.



E is the **Transmission, Reception, and Processing.** The energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (usually in a digital format). Data is wirelessly transmitted from the satellites to a ground station where it will be subject to processing chains which will prepare the satellite imagery for interpretation and further analysis. Ground-based antennae makes it possible to communicate with the satellites.



F is the **Storage & Archiving** of satellite imagery. The satellite imagery often come in huge volumes due to a number and operational nature of satellite sensors. Data should be easily accessible and retrievable for further use and can be disseminated users such as governments, universities and private companies using online catalogues (e.g. SANSA catalogue) and hard-disks. We will explore how to access data from different online catalogues later in this handbook.

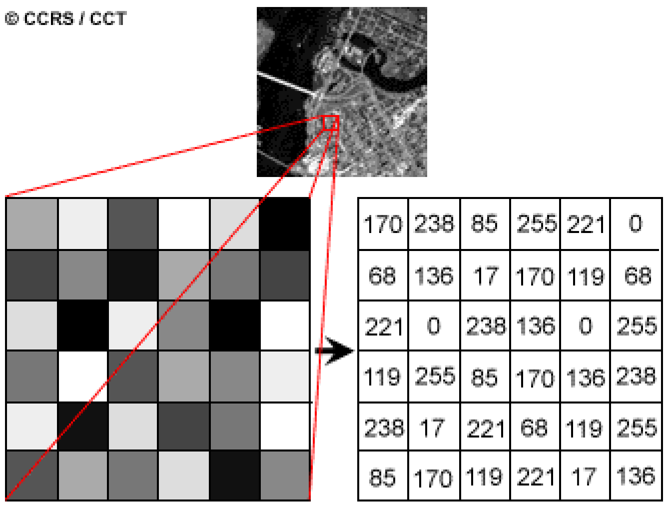
G is the **Applications**. Different applications can be developed based on satellite imagery to address social, economic, and environmental challenges. Some common applications include environmental management, natural resources management, urban planning/rural development, disaster management, policy formulation and implementation, infrastructure planning and monitoring, population growth estimation, land use planning and management, service delivery and monitoring, GIS mapping.

IMAGE ANALYSIS: BASIC CONCEPTS

Understanding image characteristics

In order to extract meaningful quantitative and qualitative information from satellite imagery, one has to first understand the basic image characteristics. Electromagnetic energy may be detected either photographically or electronically. The photographic process uses chemical reactions on the surface of light-sensitive film to detect and record energy variations. It is important to distinguish between the terms images and photographs in remote sensing. An image refers to any pictorial representation, regardless of what wavelengths or remote sensing device has been used to detect and record the electromagnetic energy. A photograph refers specifically to images that have been detected as well as recorded on photographic film. Photographs are normally recorded over the wavelength range from 0.3μm to 0.9μm - the visible and reflected infrared. Based on these definitions, we can say that all photographs are images, but not all images are photographs. Therefore, unless we are talking specifically about an image recorded photographically, we use the term image.

A photograph could also be represented and displayed in a digital format by subdividing the image into small equal-sized and shaped areas, called picture elements or pixels, and representing the brightness of each area with a numeric value or digital number. The photograph can be scanned and subdivided into pixels with each pixel assigned a digital number representing its relative brightness. The computer displays each digital value as different brightness levels. Sensors that record electromagnetic energy, electronically record the energy as an array of numbers in digital format right from the start. These two different ways of representing and displaying remote sensing data, either pictorially or digitally, are interchangeable as they convey the same information (although some detail may be lost when converting back and forth).



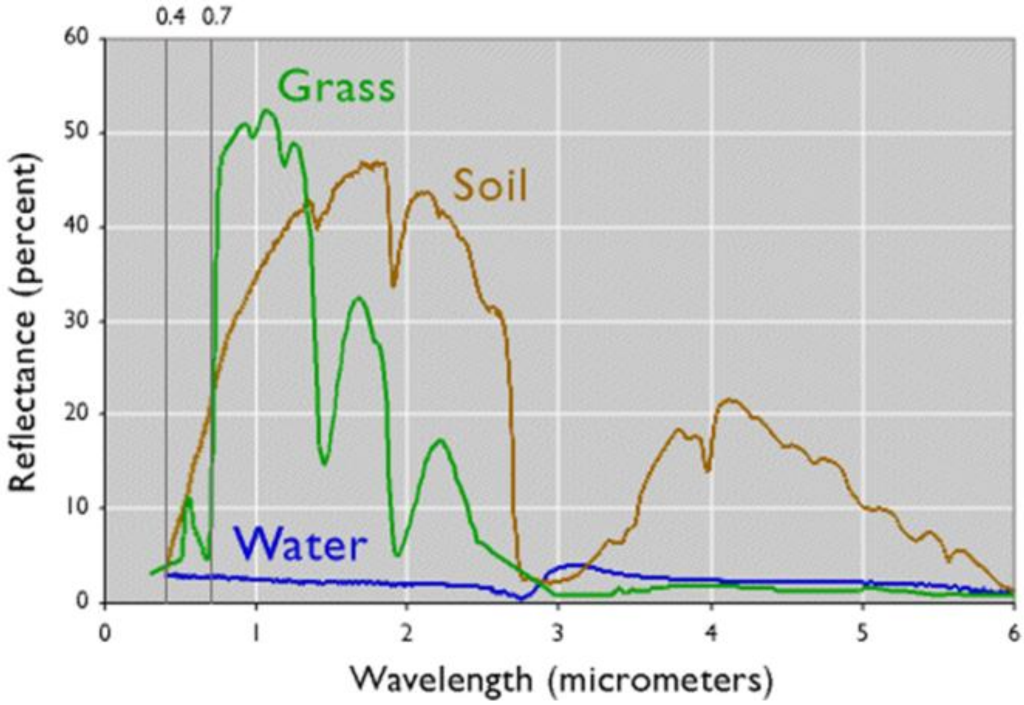
The information from a narrow wavelength range is gathered and stored in a channel, also referred to as a band. We can combine and display channels of information digitally using the three primary colours (blue, green, and red). The data from each channel is represented as one of the primary colours and, depending on the relative brightness (i.e. the digital number value) of each pixel in each channel, the primary colours combine in different proportions to represent different colours.

Image Resolution

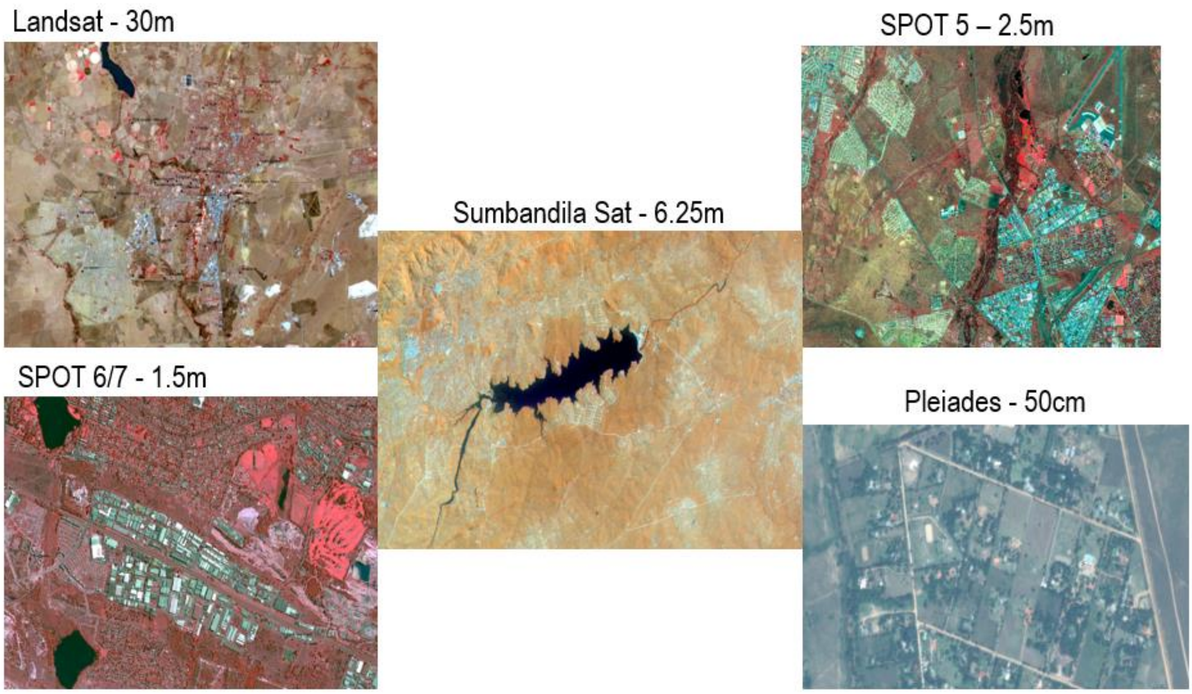
Resolution[18] is a broad term commonly used to describe, the number of pixels you can display on a display device, or the area on the ground that a pixel represents in an image file. Four distinct types of resolution are considered when describing remotely sensed data.

[18] Simonett, David S., et al. 1983. "The Development and Principles of Remote Sensing." Chapter 1 in Manual of Remote Sensing, edited by Robert N. Colwell. Falls Church, Virginia: American Society of Photogrammetry.

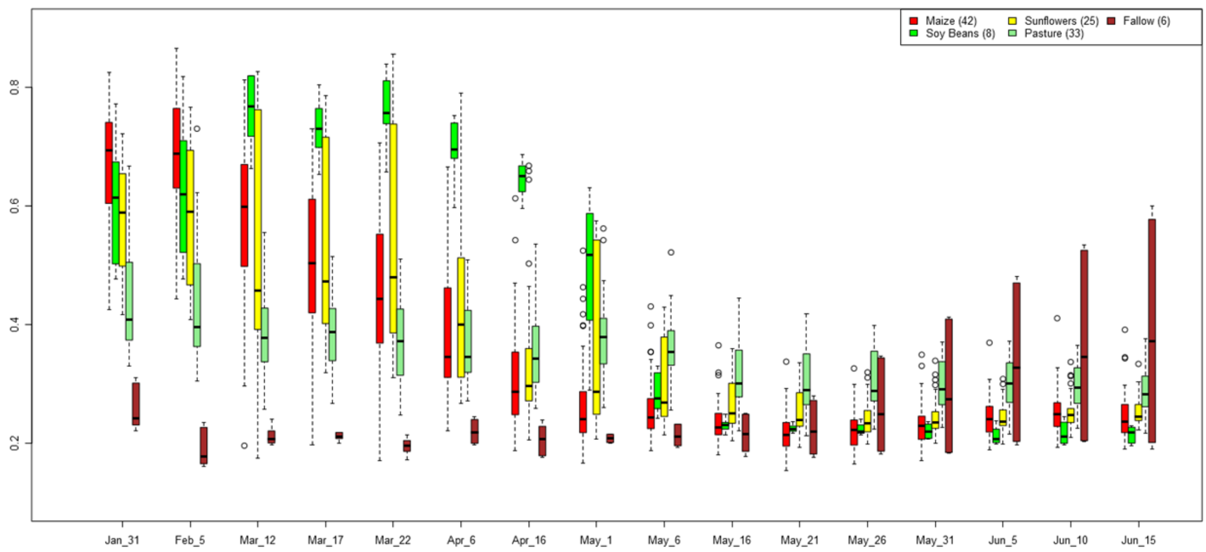
Spectral resolution refers to the specific wavelength intervals that a sensor can record. In other words, it is the specific wavelength intervals in the electromagnetic spectrum that a sensor can record.



Spatial resolution is a measure of the smallest object that can be resolved by the sensor, or the area on the ground represented by each pixel. In other words, it refers to the area on the ground represented by each pixel. The finer the resolution, the lower the number.



Temporal resolution refers to how often a sensor obtains imagery of a particular area. For example, the Landsat satellite can view the same area of the globe once every 16 days. SPOT, on the other hand, can revisit the same area every three days.



Radiometric resolution refers to the number of possible data file values in each band (indicated by the number of bits into which the recorded energy is divided). For instance, in 8-bit data, the data file values range from 0 to 255 for each pixel.

Elements of image interpretation

Human interpretation is the basic form of image analysis based on human knowledge to recognize and extract information about the shapes, location, structure, characteristics, quality, condition, and relationships between and of different objects. However, this is not as straight forward as recognizing objects in our everyday life or pictures from a hand-held camera. This is because we are used to viewing objects in more than two dimensions and our perspective is always from a vantage point from the ground. The view of objects from above provides a very different perspective than what we are familiar with. This unfamiliar perspective, together with a very different scale and a lack of recognizable detail can make even the most familiar object unrecognizable in an image. Finally, we are used to seeing only the visible wavelengths, and the imaging of wavelengths outside of this window is more difficult for us to comprehend. Significant training and experience are needed to produce a skilled image interpreter. Below we have a look at some elements of image interpretation used by human image interpreters (Campbell, 2007).

Image tone

Image tone is the fundamental element for distinguishing between different objects. It can be defined as the relative brightness or darkness or colour of objects or a region within an image. The variations in image tone also allows the elements of shape, texture, and pattern of objects to be distinguished.

Image texture

Image texture refers to the arrangement and frequency of tonal variation in particular areas of an image. In other words, it can be regarded as the apparent roughness o smoothness of a region within an image. For example, rough textures would consist of a mottled tone where the grey levels change abruptly within a small area as a results of heterogeneity of features such as a forest canopy, whereas smooth textures have very little tonal variation as a result of homogeneous features such as fields, asphalt, or grasslands. Texture is one of the most important elements for distinguishing features particularly in radar imagery.

Shadow

The shadow from different objects and features may reveal information about the size and shape of an object which cannot be discerned from an overhead view alone. Shadow is also helpful in interpretation as it may provide an idea of the profile and relative height of a target or targets which may make identification easier. However, shadows can also reduce or eliminate interpretation in their area of influence, since targets within shadows are much less (or not at all) discernible from their surroundings. Shadow is also useful for enhancing or identifying topography and landforms, particularly in radar imagery.

Pattern

Pattern refers to the spatial arrangement of individual objects in distinctive recurring patterns, such as urban streets with regularly spaced houses or fruit trees in an orchard. A regular repetition of similar tones and textures will result in a distinctive and recognizable pattern.

Association

Association refers to the relationship between objects or features that are in proximity to recognizable features. The occurrence of one type of object may infer the presence of another commonly associated object nearby. The identification of features that one would expect to associate with other features may provide information to facilitate identification. For example, commercial buildings may be associated with proximity to major transportation routes, whereas residential areas would be associated with schools, playgrounds, and sports fields.

Object shape

Shape refers to the general form, structure, or outline of objects or features. Typically, manmade features such as buildings and agricultural fields have regular, and straight edge shapes, while natural features such as forest edges often have irregular shapes. Shape element alone provides clear identification and can be a very distinctive clue for interpretation.

Object size

The size of objects in an image is highly dependent on the scale. The relative size of an object related to other familiar objects gives the interpreter a sense of scale, which can aid in the recognition of objects less easily recognized. It is important to assess the size of a target relative to other objects in a scene, as well as the absolute size, to aid in the interpretation of that target. For example, in identifying land-use, an area with large buildings such as factories or warehouses would suggest commercial property, whereas small buildings would indicate residential use. In another example where agricultural system need to be distinguished, circular agricultural fields may suggest irrigated fields, whilst rectangular fields may suggest rain fed agriculture.

Site

Site refers to topographic position. For example, certain crops are commonly grown on hillsides or near large water bodies.

The following are the tasks that you will typical be involved in when interpreting images:

1. **Classification**: assigning objects, features, or areas to thematic classes.
2. **Detection**: determining the presence or absence of a feature.
3. **Recognition**: assigning an object or feature to a general class or category.
4. **Identification**: specifying the identity of an object with enough confidence to assign it to a very specific class.
5. **Enumeration**: listing or counting discrete items visible on an image.
6. **Mensuration**: measurement of objects and features in terms of distance, height, volume, or area.
7. **Delineation**: drawing boundaries around distinct regions of the image characterized by specific tones or textures.

The results of image interpretation are most often delivered as a set of attributed points, lines, and/or polygons in any one of a variety of Computer Aided Design (CAD) or Geographic Information Systems (GIS) data formats. The classification scheme or interpretation criteria must be agreed upon with the end user before the analysis begins.

Image band combinations

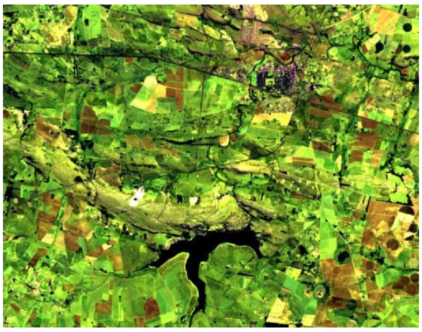
The interpretability of multispectral images can be improved through the spectral enhancement of the image. Such enhancements can either be temporary and reversible, or they can result in the creation of new data layers. Image enhancements that are commonly used to support the analysis of remotely sensed imagery. One way of doing this is by creating image band combinations or colour composites. Band combinations can be thought of as assigning different bands of the image to colours such as Red, Green and Blue for computer displays.

The characteristics of the natural color image closely resembles what you would expect to see looking down from a plane. To create a natural color image, the spectral bands from the image are matched directly to the representative color display channels, or color guns, of the computer. For example, the red spectral band of a Landsat image is matched to the Red color gun of the computer while the Green spectral band is matched to the Green color gun and Blue band is matched to the Blue colour gun. In addition to the natural colour/True-colour-composite, False-color-composite images are commonly used in remote sensing. False-color-composite image is created by assigning spectral bands to color guns in combinations that do not create a natural color image. A common false-color-composite image used to support analysis of vegetation reassigns the near-infrared spectral band to the red color gun, the red spectral band to the green color gun, and the green spectral band to the blue color gun. The reassignment of spectral bands to different color guns can improve the visibility of some image feature. The major advantage of the false-color-composite is the increased ability to detect variations in vegetation due to the fact that vegetation strongly reflects the NIR electromagnetic energy. Let's examine the examples provided below from Landsat 8.

Band	Purpose
Band 1 - Coastal	Coastal and aerosol studies
Band 2 - Blue	Bathymetric mapping, distinguishing soil from vegetation &
Band 3 - Green	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 - Red	Discriminates vegetation slopes
Band 5 –Near Infrared (NIR)	Emphasizes biomass content & shorelines
Band 6 – Short-wave Infrared (SWIR 1)	Discriminates moisture content of soil and vegetation;
Band 7 - Short-wave Infrared (SWIR 2)	Improved moisture content of soil & vegetation & thin cloud penetration
Band 8 – Panchromatic (Pan)	15m resolution, sharper image definition (This band will not be used)
Band 9 - Cirrus	Improved detection of cirrus clouds contamination
Band 10 – Thermal Infrared (TIRS 1)	Thermal mapping and estimated soil moisture
Band 11 - Thermal Infrared (TIRS 2)	Improved thermal mapping and estimated soil moisture

4, 3, 2 - Natural Colour

True color means that objects look as they would to the naked eye—similar to a color photograph.



7, 6, 4 - False Colour (Urban)

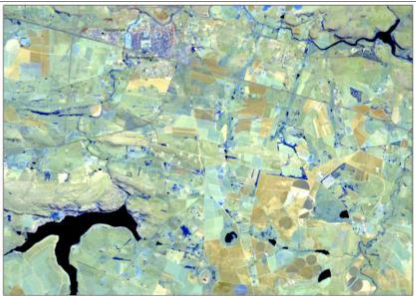
This band combination can penetrate atmospheric particles, smoke and haze. Vegetation appears in shades of dark and light green during the growing season, urban features are white, grey, cyan or purple, sands, soils and minerals appear in a variety of colours, well defined coast lines and highlighted sources of water within the image. Water is black or dark blue depending on the shallowness of the water feature.

5, 4, 3 - Colour Infrared (Vegetattion)

Vegetation appears in shades of red, urban areas are cyan blue, and soils vary from dark to light browns. Coniferous trees appear darker red than hardwoods. This band combination is popular for vegetation studies, monitoring various stages of crop growth. Water will appear dark blue to light blue and cyan depending on the level of depth and salinity Generally, deep red hues indicated healthier vegetation and or broad leaf while lighter reds signify grasslands or sparsely vegetated areas.

6, 5, 2 - False Colour (Agriculture)

Healthy vegetation will be a bright green, grasslands will appear green, pink to white areas representing barren soil or sandy areas, oranges and browns represent sparsely vegetated areas, and dry vegetation will be orange. Agricultural fields have a range of colours from bright green, to pinks. Water will appear dark blue to light blue and cyan depending on the level of depth and salinity. Urban areas appear in varying shades of magenta and the light-green spots inside the city indicate of vegetation. This band combination is useful for agricultural as it indicative of different growth stages of fields.



5, 6, 2 - False Colour (Atmospheric penetration)

This combination involves no visible bands. It provides the best atmospheric penetration. Coast lines and shores are well defined. It may be used to find textural and moisture characteristics of soils. Vegetation appears blue. This band combination can be useful for geological studies.

5, 6, 2 - False Colour (Healthy vegetation)

Healthy vegetation appears in shades of reds, browns, oranges and yellows. Soils may be in greens and browns, bare areas are presented in white, urban features are white, cyan and grey, light greens represent recently clear-cut areas and reddish areas show new vegetation growth, probably sparse grasslands. Clear, deep water will be very dark in this combination, if the water is shallow or contains sediments it would appear as shades of lighter blue

5, 6, 4 - False Colour (Land/Water)

This combination of shortwave-IR (Band 6), near-IR (Band 5) and red (Band 4) offers added definition of land-water boundaries and highlights subtle details not readily apparent in the visible bands alone. Inland lakes and streams can be located with greater precision when more infrared bands are used. With this band combination, vegetation type and condition show as variations of hues (browns, greens and oranges), as well as in tone. This combination demonstrates moisture differences and is useful for analysis of soil and vegetation conditions. Generally, the wetter the soil, the darker it appears, because of the infrared absorption capabilities of water.

7, 5, 3 - False Colour (Natural colour with Atmospheric removal)

The combination provides a "natural-like" interpretation, while also penetrating atmospheric particles and smoke. Healthy vegetation will be a bright green and can saturate in seasons of heavy growth, grasslands will appear green, pink to white areas represent barren soil or sandy areas, oranges and browns represent sparsely vegetated areas, water will appear dark blue to blue based on the level. Dry vegetation will be orange and water will be blue. It is useful for geological, agricultural and wetland studies. If there were any fires in this image they would appear red. This combination is used in the fire management applications for post-fire analysis of burned and non-burned forested areas. Urban

	areas appear in varying shades of magenta and the light-green spots inside the city indicate vegetation
	**7, 5, 4 - False Colour (Shortwave Infrared)** This combination provides the user with information on urban Healthy vegetation is bright green and soils are mauve. This combination is useful for vegetation studies, and can be widely used in the areas of timber management and infested plantations.
	**6, 5, 4 - False Colour (Vegetation analysis)** This combination provides the user with a great amount of information and colour contrast. Healthy vegetation is bright green and soils are mauve. This combination is useful for vegetation studies, and can be widely used in the areas of timber management and infested plantations.

Image Pre-processing

Image pre-processing[19] operations, sometimes referred to as image restoration and rectification, are intended to correct for sensor- and platform-specific radiometric and geometric distortions of data.

Geometric correction

The geometric correction involves correcting for the geometric distortions that result from the instrument flight-line orientation or orbit characteristics. Remotely sensed data provided by the supplier may exhibit undesirable geometric distortions, depending on the supplier's processing level at the time of delivery of the data. Correction for any geometric distortions may be required before proceeding with further analysis. Geometric corrections are also necessary when conducting quantitative image analysis between images of different dates or acquired by different sensors.

The geometric distortions in digital image data consist of:

- Systematic error caused by Earth's eastward spinning motion and curvature (more evident from space than at lower altitudes aerial platform). Well defined orbital geometry correction parameters can be achieved using predefined transformations which model the aspect, skew and rotational distortions of a sensor. These errors are commonly removed at the sensor's processing center. Previously, images from sensors such as Landsat MSS 1 to 3 were not corrected before distribution.

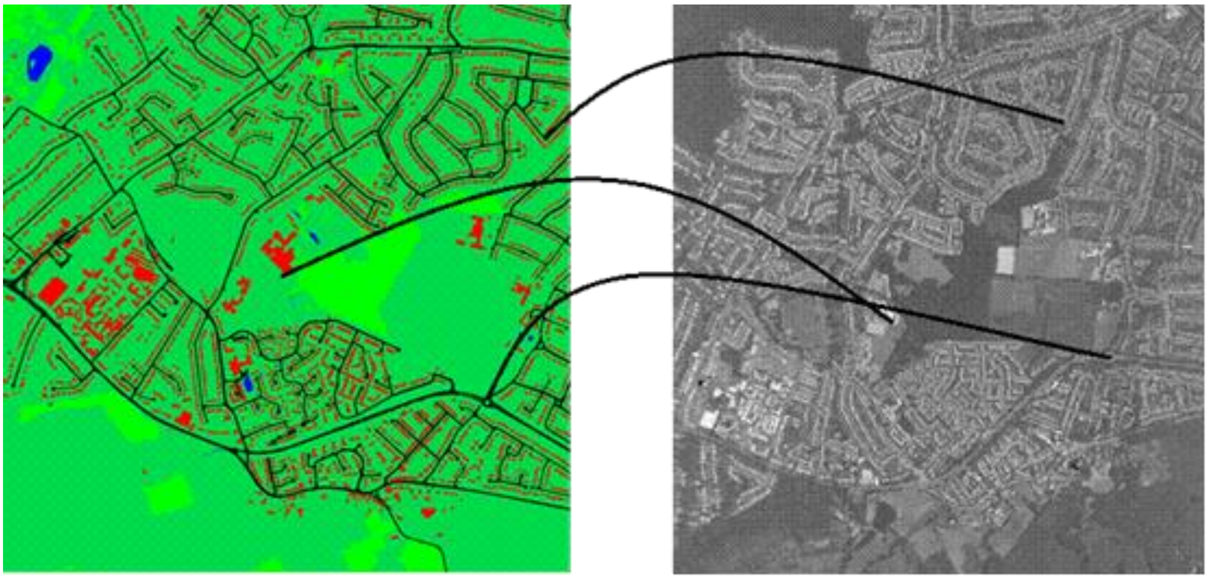
- Random geometric distortions result from relief displacement, variations in the satellite altitude and imaging angle, payload instrument anomalies. Relief displacement is caused by variations in terrain elevation and it is more evident from unrectified aerial imagery.

Random geometric errors can be corrected through **polynomial transformation** or a multistep process known as **rubber sheeting.** Polynomial equations are used to convert source file coordinates to

[19] http://www.nrcan.gc.ca/node/9403

rectified map coordinates. Depending upon the distortion in the imagery, the number of GCPs used, and their locations relative to one another, complex polynomial equations may be required to express the needed transformation. The degree of complexity of the polynomial is expressed as the order of the polynomial. The order is simply the highest exponent used in the polynomial. Usually, 1st-order or 2nd-order transformations are used. On the other hand, rubber sheeting involves stretching and warping an image to geo-register control points shown selected in the image to those selected from other reference map datasets or known ground control point (GCP) locations on the ground.

GCP locations are used to calculate the transformation matrix between the image and the reference map. The transformation to the new coordinate system for each pixel is done to generate a new image, where the actual DN is assigned to each pixel in the new image.



Guidelines for selecting GCPs:

- The GCPs should be distinct features in both the reference map and the image.
- The GCPs should have clear and sharp boundaries and regular geometry (e.g. buildings corners, field corners and road intersections). Features such as water bodies, natural vegetation and other oval or circular features should be avoided when selecting the GCPs.
- The minimum number is the number required to estimate the transformation coefficients. General rule of thumb is that, the more the better.
- Try to avoid excessive clustering and leaving un-sampled areas.
- Always ensure that you have GCPs close to the image boundary.
- Sample more intensively in areas where you think there may be considerable distortion of high spatial frequency (e.g. mountainous landscape).

The geometric accuracy of selected coordinates that are resulting from a transformation are an estimate and therefore need to be assessed. The accuracy is normally expressed for each control point as overall root mean square error (RMSE[20]).

RMS error is calculated with a distance equation:

$$\text{RMS error} = \sqrt{(x_r - x_i)^2 + (y_r - y_i)^2}$$

Where:

x_i and y_i are the input source coordinates

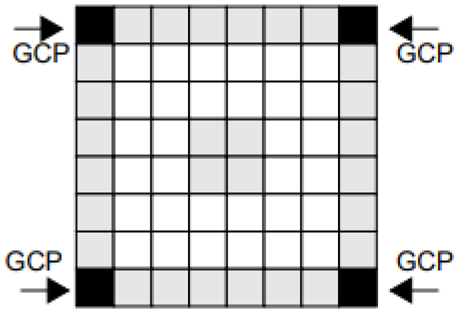
x_r and y_r are the retransformed coordinates

High RMSE values (> 1 pixel) indicate the level of inaccurate transformation. If the chosen GCPs were inadequate, the registration process can be repeated with additional or different GCPs in order to decrease the total error.

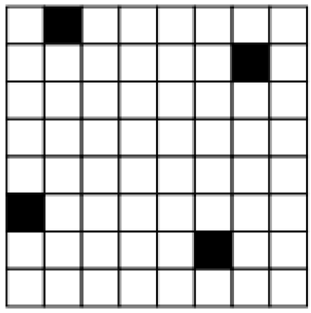
Point	Error X	Error Y	Point Error
1	-1.542023	1.346588	2.047226
2	-0.960491	1.837280	2.073196
RMSE = 1.909580 (pixel)			

Once the least squares coefficients (by least squares regression method) have been derived and the (x, y) calculated for a pixel, a DN must be assigned to it by a reverse least squares estimation. The resulting col/row of an X/Y is likely not to be an integer as the corrected pixel lies across two or more pixels in the raw image (see illustration below).

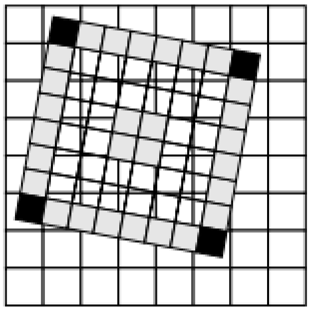
[20] http://web.pdx.edu/~emch/ip1/FieldGuide.pdf



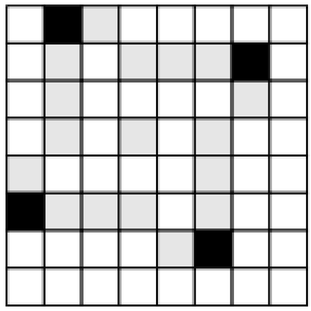
1. The input image with source GCPs.



2. The output grid, with reference GCPs shown.



3. To compare the two grids, the input image is laid over the output grid, so that the GCPs of the two grids fit together.



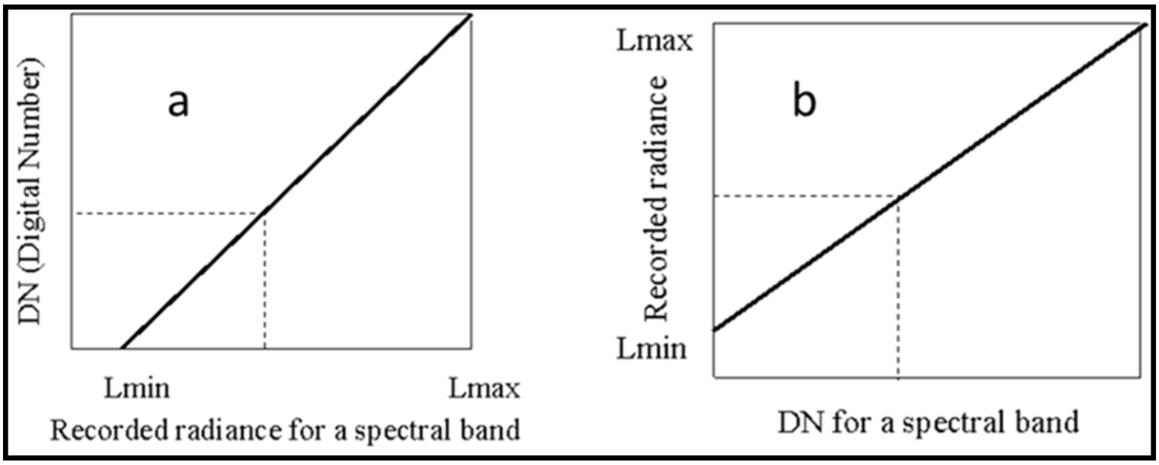
4. Using a resampling method, the pixel values of the input image are assigned to pixels in the output grid.

Since the pixels of the new grid may not align with the pixels of the original grid, the pixels must be resampled. Resampling is the process of extrapolating data values for the pixels on the new grid from the values of the source pixels. Below are brief descriptions of common resampling techniques:

- Nearest neighbor: uses the value of the closest pixel to assign to the output pixel value.
- Bilinear: uses the data file values of four pixels in a 2 × 2 window to calculate an output value with a bilinear function.
- Bi-cubic: uses the data file values of sixteen pixels in a 4 × 4 window to calculate an output value with a cubic function.

Radiometric calibration

During image acquisition process, recorded radiance measurements in each spectral band are converted into quantized, calibrated scaled digital numbers (DN) – stored for each ground sampling area (pixels). DN is linearly transformed representation of at-sensor radiance for a discrete ground sampling location. In the figure below, panel (a) represents the conversion of DN to radiance and panel (b) represents radiance to DN.



The slope and offset of the linear transformation is specific for each spectral band, so that the sensor's initial calibration values can be used to calculate radiance (L) and inversely used to calculate pixel DN.

$$DN = \frac{DN_{max}}{L_{max} - L_{min}}(L - L_{min})$$

So

$$L = \frac{L_{max} - L_{min}}{DN_{max}} \times DN + L_{min}$$

that is

$$L = gain \times DN + offset$$

which can be thought of as

$$L = slope \times DN + intercept$$

mesured in

$$W - m^{-2} - sr^{-1} - \mu m^{-1}$$

The radiometric calibration (slope/gain and offsets/intercept) values are often provided in the metadata with the image data. Below is an example from Landsat 8[21] MTL file, RADIANCE_MULTI_BAND_* represent the slope/gain factor and RADIANCE_ADD_BAND_* represents the offset/intercept factor for each band respectively. Note that each sensor has its own naming convention and values will differ per image scene.

[21] https://landsat.usgs.gov/using-usgs-landsat-8-product

```
GROUP = RADIOMETRIC_RESCALING
  RADIANCE_MULT_BAND_1 = 1.2844E-02
  RADIANCE_MULT_BAND_2 = 1.3153E-02
  RADIANCE_MULT_BAND_3 = 1.2120E-02
  RADIANCE_MULT_BAND_4 = 1.0220E-02
  RADIANCE_MULT_BAND_5 = 6.2543E-03
  RADIANCE_MULT_BAND_6 = 1.5554E-03
  RADIANCE_MULT_BAND_7 = 5.2425E-04
  RADIANCE_MULT_BAND_8 = 1.1567E-02
  RADIANCE_MULT_BAND_9 = 2.4443E-03
  RADIANCE_MULT_BAND_10 = 3.3420E-04
  RADIANCE_MULT_BAND_11 = 3.3420E-04
  RADIANCE_ADD_BAND_1 = -64.22103
  RADIANCE_ADD_BAND_2 = -65.76312
  RADIANCE_ADD_BAND_3 = -60.60015
  RADIANCE_ADD_BAND_4 = -51.10146
  RADIANCE_ADD_BAND_5 = -31.27155
  RADIANCE_ADD_BAND_6 = -7.77695
  RADIANCE_ADD_BAND_7 = -2.62125
  RADIANCE_ADD_BAND_8 = -57.83279
  RADIANCE_ADD_BAND_9 = -12.22163
  RADIANCE_ADD_BAND_10 = 0.10000
  RADIANCE_ADD_BAND_11 = 0.10000
  REFLECTANCE_MULT_BAND_1 = 2.0000E-05
  REFLECTANCE_MULT_BAND_2 = 2.0000E-05
  REFLECTANCE_MULT_BAND_3 = 2.0000E-05
  REFLECTANCE_MULT_BAND_4 = 2.0000E-05
  REFLECTANCE_MULT_BAND_5 = 2.0000E-05
  REFLECTANCE_MULT_BAND_6 = 2.0000E-05
  REFLECTANCE_MULT_BAND_7 = 2.0000E-05
  REFLECTANCE_MULT_BAND_8 = 2.0000E-05
  REFLECTANCE_MULT_BAND_9 = 2.0000E-05
  REFLECTANCE_ADD_BAND_1 = -0.100000
  REFLECTANCE_ADD_BAND_2 = -0.100000
  REFLECTANCE_ADD_BAND_3 = -0.100000
  REFLECTANCE_ADD_BAND_4 = -0.100000
  REFLECTANCE_ADD_BAND_5 = -0.100000
  REFLECTANCE_ADD_BAND_6 = -0.100000
  REFLECTANCE_ADD_BAND_7 = -0.100000
  REFLECTANCE_ADD_BAND_8 = -0.100000
  REFLECTANCE_ADD_BAND_9 = -0.100000
END_GROUP = RADIOMETRIC_RESCALING
GROUP = TIRS_THERMAL_CONSTANTS
  K1_CONSTANT_BAND_10 = 774.8853
  K2_CONSTANT_BAND_10 = 1321.0789
  K1_CONSTANT_BAND_11 = 480.8883
  K2_CONSTANT_BAND_11 = 1201.1442
END_GROUP = TIRS_THERMAL_CONSTANTS
```

Conversion of at-sensor radiance or Top-of-Atmosphere (TOA) Radiance to apparent at-sensor spectral reflectance Top-of-Atmosphere (TOA) reflectance is required before applying atmospheric correction. At sensor-reflectance involves taking into account temporal changes in solar illumination due to Earth-Sun geometry and can be converted using REFLECTANCE_MULTI/ADD_BAND_* values.

Atmospheric correction

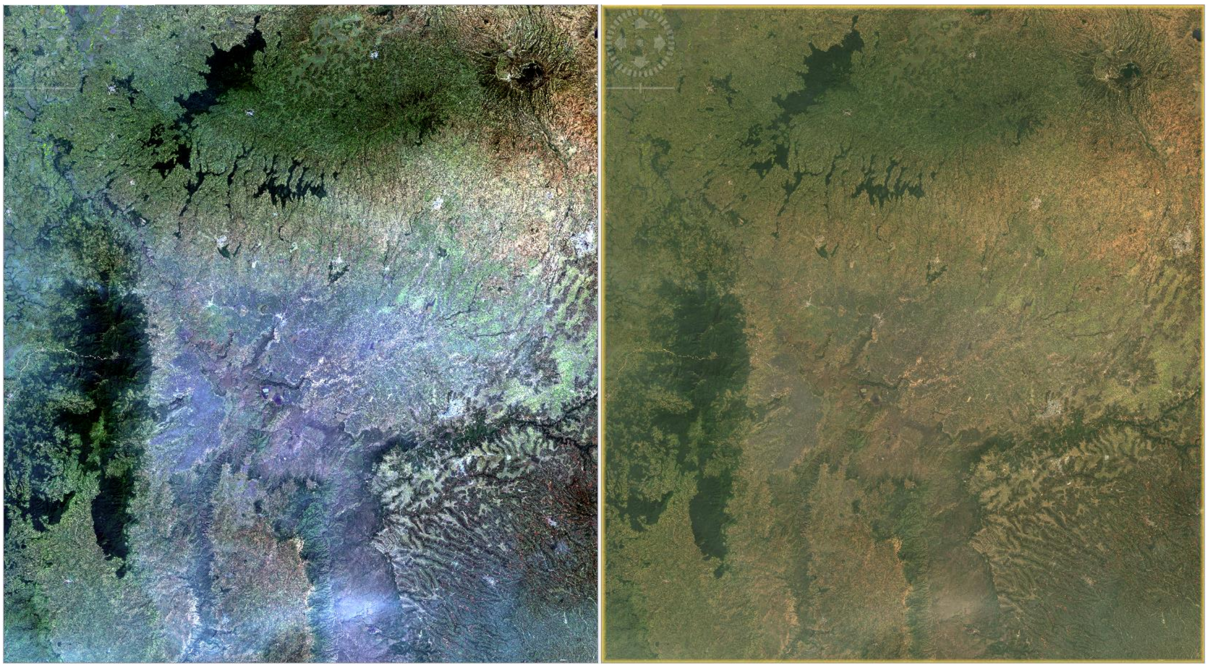
The nature of remote sensing data is that reflected and/or emitted radiance from the earth's surface travels through the atmosphere before it is intercepted by the remote sensing instrument. This process can both attenuate (reduce strength) and add to the at-sensor radiance recorded. Several atmospheric phenomena are known to affect at-sensor reflectance, such as Rayleigh scattering, Ozone, water vapour and aerosols. It is therefore important to separate the atmosphere's contribution to the measurements made by the instrument from the contribution of the underlying surface. This can be achieved by following two approaches:

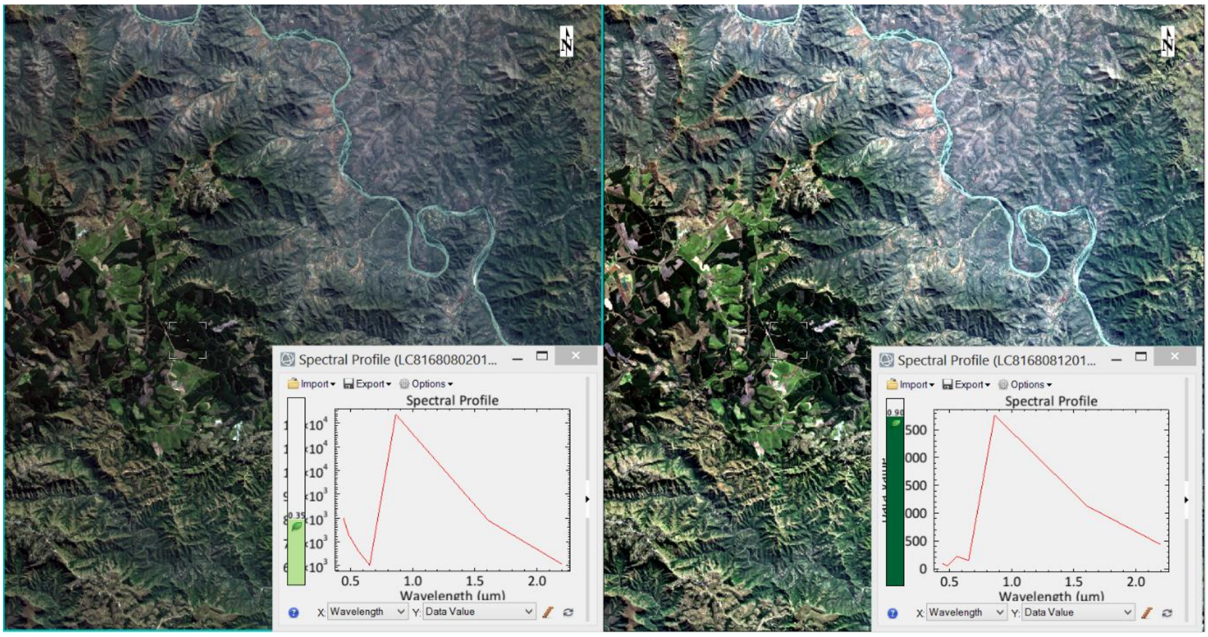
1. Physical-based environmental models – are based on a mathematical understanding of atmospheric radiation transfer theory and atmospheric scattering and require detailed estimates of the state of atmospheric optical thickness and atmospheric aerosols. These models are complex and data intensive, requiring field data, validation and they are computationally intensive.

2. Semi-empirical modelling approaches – use complex models but for a significantly reduced set of input parameters compared to the physical models. The correction can be based on an estimate of atmospheric visibility and standard atmospheric constants for latitude/longitude/date, however the results may not be as accurate as the one that can be obtained for same targets using the physical-based models due to effects of atmospheric visibility.

3. Empirical estimation approaches - uses only the image data to remove atmospheric effects, only corrects for atmospheric path radiance which is at-sensor radiance contributed by atmospheric scattering and only account for Rayleigh atmospheric scattering.

The image panels below show a satellite image (Landsat 8) before atmospheric correction (Left) and after atmospheric correction (Right) using semi-empirical modelling approach.





The image panels below show an atmospherically corrected satellite image in True colour (Bands 4,3,2 of Landsat 8, Left) and the same image in False colour composite (Bands 5,4,3 of Landsat 8, Right).

Image pre-processing top-tips

At the start of a project always:

- Obtain as much information from the supplier on what processing has been done on the image supplied to you. This can be done by reading product specifications manuals or user guidelines or contact their customer services department or helpline.

- Carefully assess the image header and all files supplied with it. Ensure that all files are supplied as per product specification manual or user guidelines.

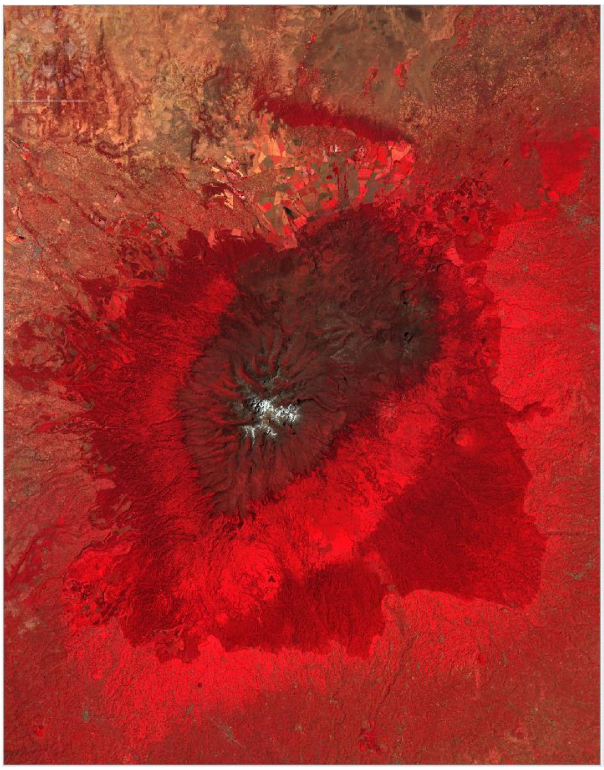
- Visually check the image for visual atmospheric effects, e.g. visible haze can occur in the blue spectral-band.

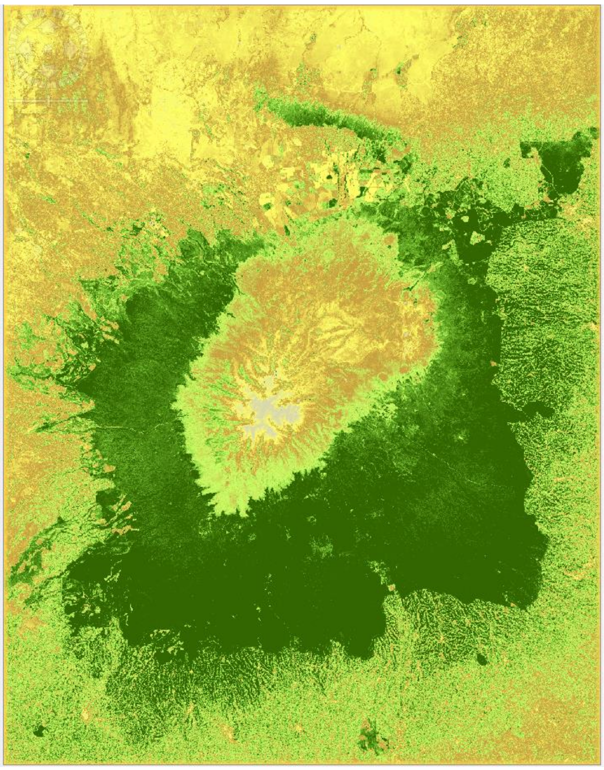
- Evaluate your needs: If you are not performing spectral classification, change detection or band ratios; you may not need to perform atmospheric correction.
- Use bi-cubic resampling technique for non-quantitative analysis only (e.g. visual overlay or analysis).
- Know your algorithms: Be aware of the implications, assumptions and limitations of a particular approach.

Vegetation Indices

Vegetation Indices (VIs) are the statistical or mathematical methods used to exploit relationships between spectral bands to create new products. The Normalized Vegetation Difference Index (NDVI) is an example of such a product that is commonly used to support analysis of vegetation. NDVI is the ratio of the subtraction of the near-infrared and red bands to their sum [(NIR-RED)/(NIR+RED)], and its values range from -1 to 1, where green vegetation typically ranges between 0.2 and 0.9. The example below shows agricultural fileds at Bothaville in the Free State province of South Africa from

Landsat 8 false colour composite (Near IR, Red, Blue) image (left mage). The colour combination [22] used shows healthy vegetation in deep red, water bodies in black and non-cultivated areas in different shades of green. A Normalized Difference Vegetation Index (NDVI) calculated from Landsat 8 image (right image) was calculated by using the near infrared and visible spectral bands using the following formula (Near IR - Red/Near IR + Red). The image shows healthy vegetation in red, water bodies in blue and non-cultivated areas in cyan. You can interact with other examples on http://atlas.sansa.org.za/atlas-agriculture.html.





We have now looked at several methods for enhancing the spectral data from remotely sensed images. In order to maximize the usefulness of such transformations, an analyst must choose the enhancement most appropriate to the task at hand. Spectral enhancements alone are not enough on their own to make interpretation accurate; a good command of the various interpretation elements, combined with strong contextual knowledge of the image under analysis, contributes to successful interpretation.

Image Classification

Image classification uses the quantitative spectral information contained in an image, which is related to the composition or condition of the target surface. Image classification can be performed on multispectral as well as hyperspectral imagery. It requires an understanding of the way materials and objects of interest on the earth's surface absorb, reflect, and emit radiation in the visible, near-infrared, and thermal portions of the electromagnetic spectrum. In order to make use of image analysis results in a GIS environment, source image should be orthorectified so that the final image analysis product, whatever its format, can be overlaid with other imagery, terrain data, and other geographic data layers. Classification results are initially in raster format, but they may be generalized to polygons with further processing. There are

[22] The colour combinations are reassignment of spectral bands to different colour guns of the computer, for display purposes. For example, to create a natural colour image, spectral bands (red, green & blue) are matched directly to the corresponding colour guns (Red, green & blue).

several core principles of image analysis that pertain specifically to the extraction of information and features from remotely sensed data.

- *Spectral differentiation* is based on the principle that objects of different composition or condition appear as different colors in a multispectral or hyperspectral image. For example, a newly planted cornfield has a distinct color when compared to a field of mature plants, and yet another color when the field has been harvested. Corn has a distinct color as compared to wheat; healthy plants are a different color than pest-infested or drought-impacted plants. The use of spectral signature, or color, to distinguish types of ground cover or objects is called spectral differentiation.
- *Radiometric differentiation* is the detection of differences in brightness, which may in certain cases be used to inform the image analyst as to the nature or condition of the remotely sensed object.
- *Spatial differentiation* is related to the concept of spatial resolution. We may be able to analyze the spectral content of a particular pixel or group of pixels in a digital image when those pixels comprise a single homogeneous material or object. It is also important to understand the potential for mixing of the spectral signatures of multiple objects into the recorded spectral values for a single pixel. When designing an image analysis task, it is important to consider the size of the objects to be discovered or studied compared to the ground sample distance of the sensor.

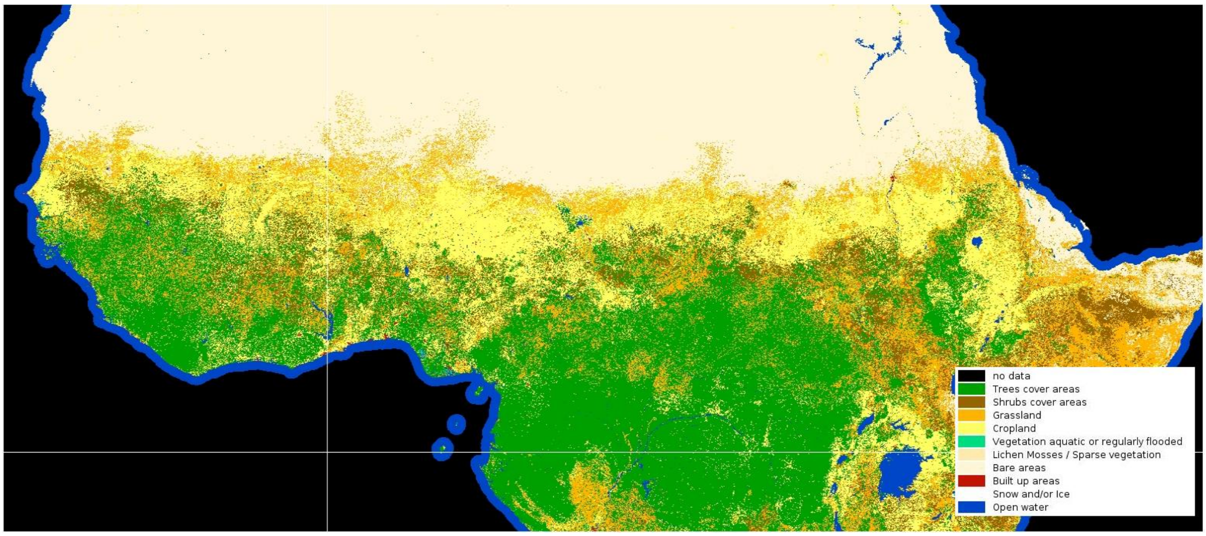
The extraction of information from remotely sensed data is frequently accomplished using statistical pattern recognition; land-use/land-cover classification is one of the most frequently used analysis methods (Jensen, 2005). Land cover refers to the physical material present on the earth's surface; land use refers to the type of development and activities people undertake in a particular location. The designation of "woodland" for a tree-covered area is a land cover classification; the same woodland might be designated as "recreation area" in a land use classification.

While certain aspects of digital image classification are completely automated, a human image analyst must provide significant input. There are two basic approaches to classification, supervised and unsupervised, and the type and amount of human interaction differs depending on the approach chosen.

- *Supervised classification* requires the image analyst to choose an appropriate classification scheme, and then identifies training sites in the imagery that best represent each class. A simple land cover classification scheme might consist of a small number of classes, such as urban, water, wetlands, forest, grass/crops. Individual sites that fall into a single class may have slightly different spectral characteristics; for example, the spectral signature of a water body will depend on the amount of suspended sediment or plant material in the water. Urban land cover signatures will vary based on the type of materials used; asphalt has a very different spectral signature from concrete, wood, or glass. The image analyst must select a sufficient number of training sites in each class to represent the variation present within each class in the image. The classification algorithm then uses spectral characteristics of the training sites to classify the remainder of the image. Training sites developed in one scene may or may not be transferrable to an entire study area. If ground conditions, lighting conditions, or atmospheric effects change from scene to another, then training sites must be developed independently for each scene. Furthermore, training sites may not be transferrable across time; in addition to the conditions noted above that change over time as well as space, real changes in the land cover occurring at a training site location over time will cause incorrect classification results in the second image. Accurate supervised classification results depend entirely on the analyst's ability to collect a sufficient number of training sites and to recognize when training sites can or cannot be transferred from one image to another.

- *Unsupervised classification* requires less input from the analyst before processing. The classification algorithm searches and analyses the image, grouping pixels into clusters which it deemed to be uniquely representative of the image content. After classification, the image analyst must determine if these arbitrary classes have meaning in the context of the end-user application. A significant amount of time may be spent trying to determine the physical meaning of a class identified by the unsupervised algorithm. In addition, experimentation is required to determine the optimal number of unique classes used for initialization of the algorithm. Furthermore, there is no basis to believe that the classes discovered in one image will be the same classes discovered in a second image. Time spent trying to optimize and interpret the unsupervised results may far exceed the time an analyst would have spent selecting training sites for supervised classification. Finally, because it is impossible to ensure consistency in class identification from one image to the next, unsupervised classification is not useful for change detection.

Classification schemes may be comprised of hard, discrete categories; in other words, each pixel is assigned to one, and only one, class. Fuzzy classification schemes allow a proportional assignment of multiple classes to pixels. The entire image scene may be processed pixel-by-pixel, or the image may be decomposed into homogeneous image patches for object-oriented classification. As stated by Jensen (2005), "no pattern classification method is inherently superior to any other." It is up to the analyst, using his/her knowledge of the problem set, the study area, the data sources, and the intended use of the results, to determine the most appropriate, efficient, time and cost-effective approach.



Measuring the accuracy of classification requires either comparison with ground truth or comparison with an independent result. Errors of omission are committed when an object is left out of its true class (a tree stand which is not classified as forest, for example); errors of commission are committed when an object that does not belong in a class is incorrectly included (in the example above, the tree stand is incorrectly classified as a wetland)[23],[24].

[23] http://isepei.org/technologies/gis

[24] https://www.e-education.psu.edu/geog480/node/492

SUSTAINABLE DEVELOPMENT GOALS (SDGs), AGENDA 2063 AND GEOSPATIAL TOOLS

APPLICATIONS OF GEO-SPATIAL TECHNOLOGIES AND REMOTE SENSING FOR MONITORING THE IMPLEMENTATION OF SDGS AND AGENDA 2063

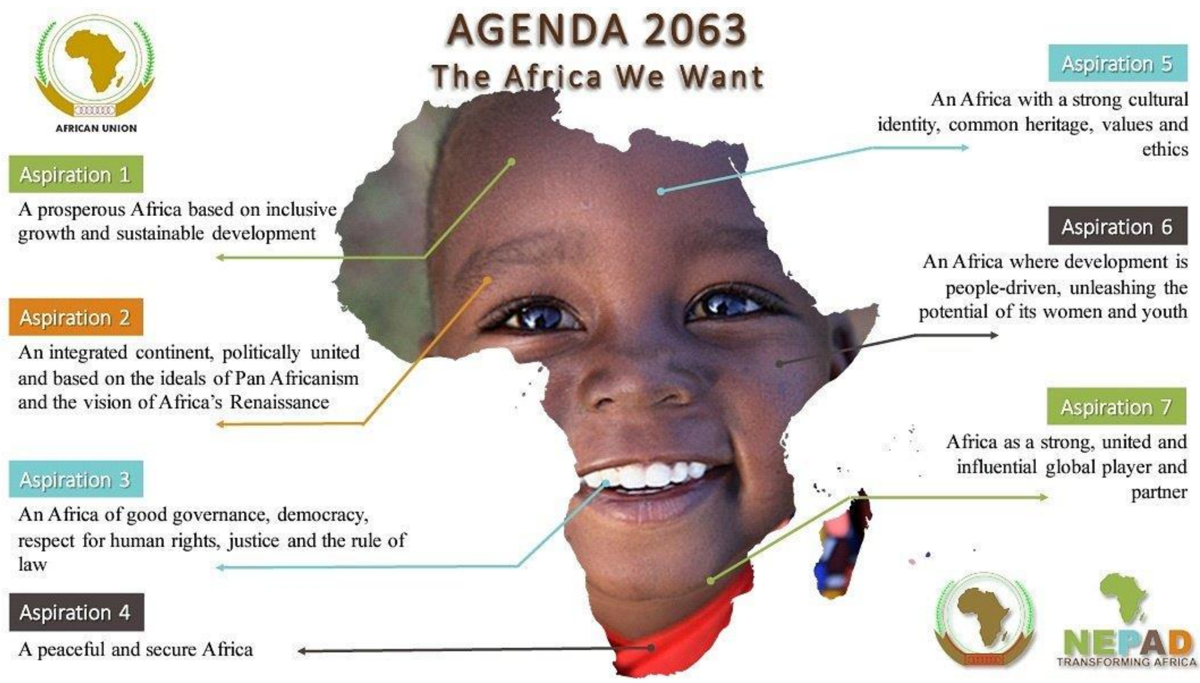
Overview of the SDG[25]s

The Sustainable Development Goals (SDGs) are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. The17 Goals build on the lessons learned and successes of the Millennium Development Goals, while including new areas such as climate change, economic inequality, innovation, sustainable consumption, peace and justice, among other priorities. The goals are interconnected – often the key to success on one will involve tackling issues more commonly associated with another. This sections focuses briefly on how geospatial technologies and remote sensing can assist in monitoring efforts towards the achievement of these goals. The following figure classifies these into three tiers.

25 http://www.undp.org/content/undp/en/home/sustainable-development-goals.html

Overview of the Agenda 2063[26]

It is a strategic framework for the socio-economic transformation of the continent over the next 50 years. It's builds on, and seeks to accelerate the implementation of past and existing continental initiatives for growth and sustainable development. Some of the past and current initiatives it builds on include: the Lagos Plan of Action, The Abuja Treaty, The Minimum Integration Programme, the Programme for Infrastructural Development in Africa (PIDA), the Comprehensive Africa Agricultural Development Programme (CAADP), The New partnership for Africa's Development (NEPAD), Regional Plans and Programmes and National Plans. It is also built on national, regional, continental best practices in its formulation. The following extract shows the aspirations of the Agenda 2063.



Case study: Applications of earth Observation for human settlement monitoring

More than half of the world's human population lives in an urban areas and the dynamic trend of urbanization is growing at an unprecedented speed. In emerging economies, the urban population is expected to double in 30 years (2000-2030), adding 2 billion more people, especially in South Asia and **Africa**. Rapid urbanization brings challenges, such as access to basic services and infrastructures, effective waste management, air pollution control, investment in public transportation and urban traffic control. Sustainable urban development requires an effective monitoring of urban sprawl and in particular of the relationship between land consumption and population growth. Cost effective and accurate regular monitoring of urban expansion for present and historical times is required in order to track urban development over time.[27]

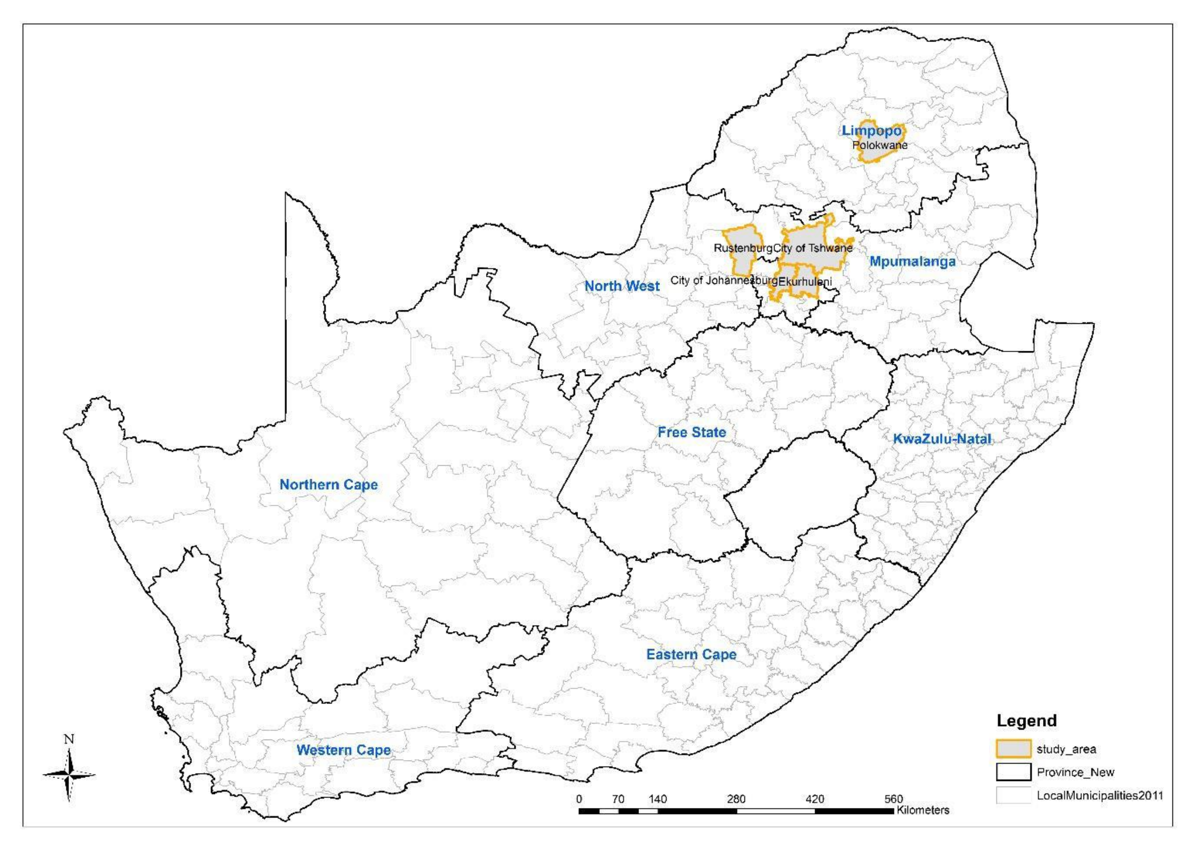
11.3 by 2030, enhance inclusive and sustainable urbanisation and capacity for participatory, Integrated and sustainable human settlement planning and management in all countries.
11.3.1. Ratio of land consumption rate to population growth rate.

This indicator requires defining the two components of population growth and land consumption rate. Computing the population growth rate is more straightforward and more readily available, while land consumption rate is slightly challenging, and requires the use of new techniques. In estimating the land consumption rate, one needs to define what constitutes "consumption" of land, since this may cover aspects of "consumed", "preserved" or available for "development" for cases such as land occupied by wetlands. Secondly, there is not one unequivocal measure of whether land that is being developed is truly "newly-

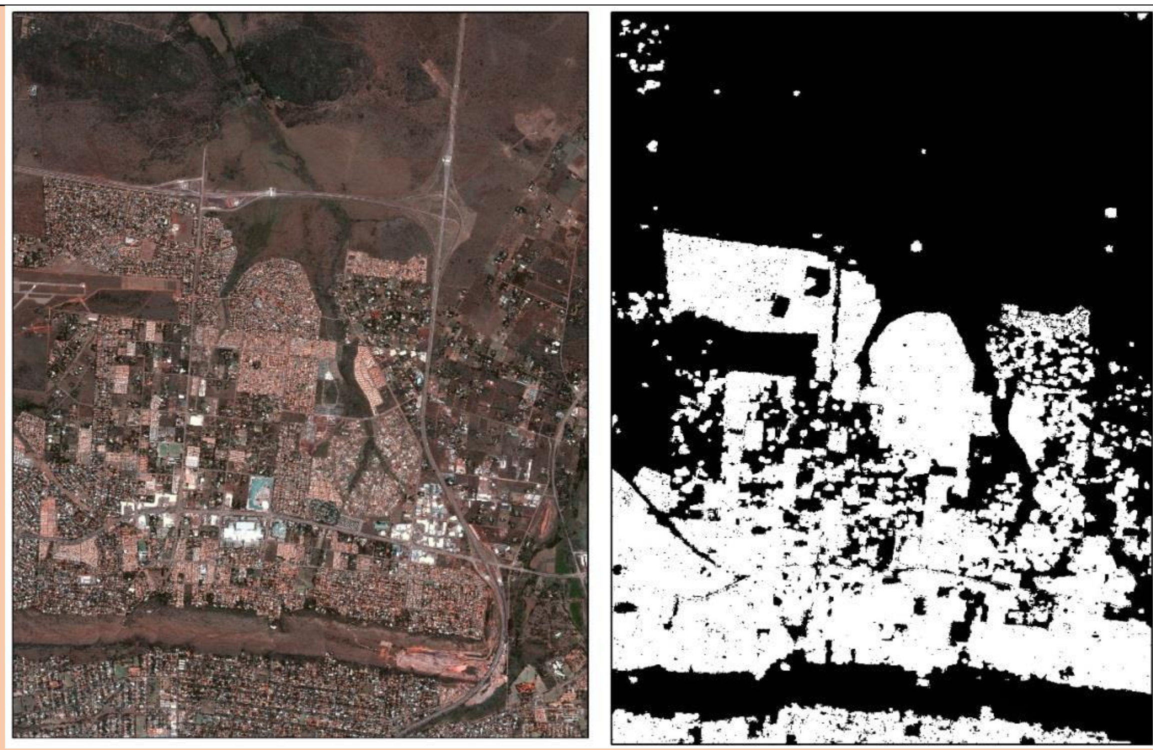
[26] https://au.int/agenda2063/about
[27] http://www.earthobservations.org/documents/publications/201703_geo_eo_for_2030_agenda.pdf

developed" (or vacant) land, or if it is at least partially "redeveloped". As a result, the percentage of current total urban land that was newly developed (consumed) will be used as a measure of the land consumption rate. The fully developed area is also sometimes referred to as built up area, (metadata-11-03-01, UN HABITAT).

Earth Observation (EO) and other geospatial technologies play an important role during the planning of census and for determining the land consumption rate. South African National Space Agency (SANSA) in collaboration with Joint Research Centre (JRC) has been mapping human settlements using high resolution SPOT data spanning from 2006. This case study was done in partnership with STATSA to demonstrate the use of EO and population data for addressing Target 11.3.1. Three metropolitan municipalities in Gauteng province (City of Tshwane, Ekurhuleni, City of Johannesburg), and one in North West (Rustenburg) and one in Limpopo province (Polokwane) were selected for as case studies. The location of these provinces is depicted in the map below.



In the example below, human settlements were derived from SPOT 5 satellite images over some part City of Tshwane, South Africa. The mapped areas (Right) show only two land cover classes, i.e. built-up areas in white and non-built-up areas in black. The areas with high density of building structures appear brighter than other areas in the SPOT image (Left). Smaller road network cannot be seen in such areas, however road network can be seen in areas with lower density building structures.



Human settlement maps of 2001 were extracted from SPOT 4 images, while for 2011 SPOT 5 was used. Based on these, urban expansion was assessed by performing change detection in built-up areas between 2001 and 2011. Population growth was calculated using the respective Census data according to the formula below.

LCRPGR=(((LN(Urb_(t+n)/Urb_t))/y))/((LN(Pop_(t+n)/Pop_t)/y));

Where:

Popt Total population within the city in the past/initial year

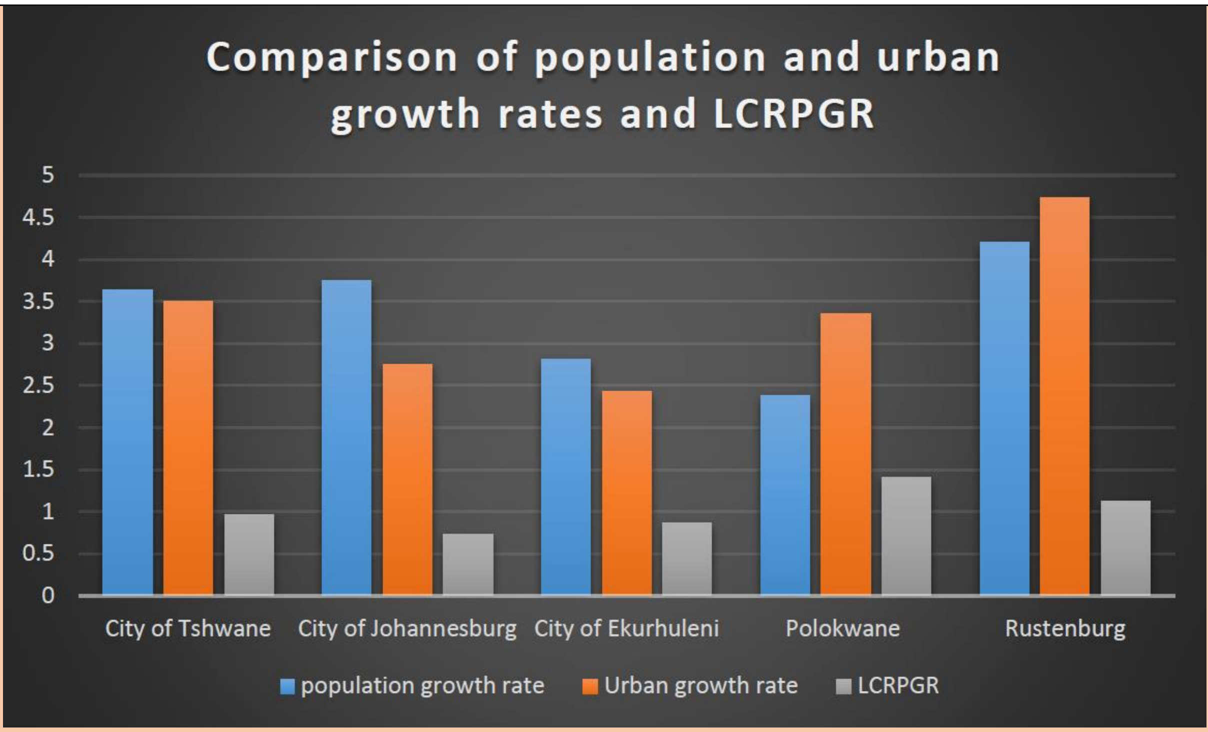
Popt+n Total population within the city in the current/final year

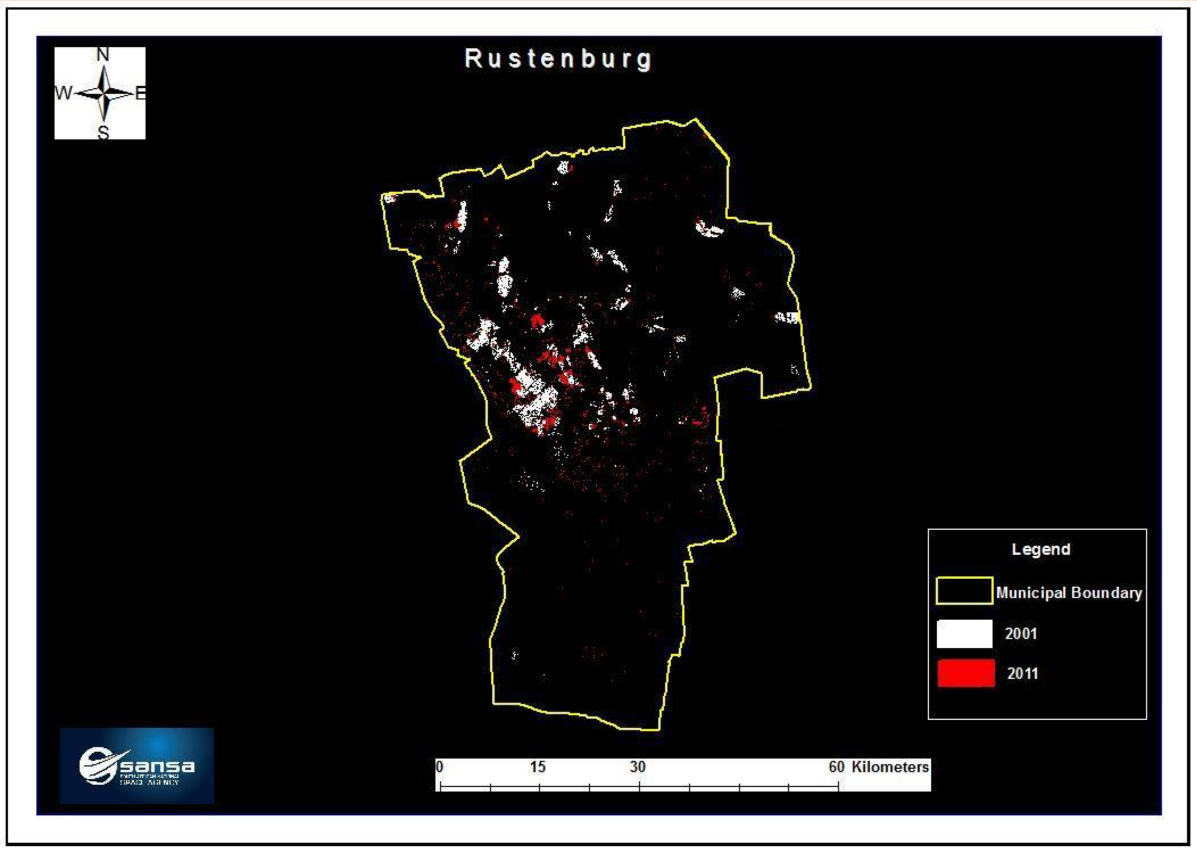
Urb_t Total areal extent of the urban agglomeration in km2 for past/initial year

Urb_(t+n) Total areal extent of the urban agglomeration in km2 for current year

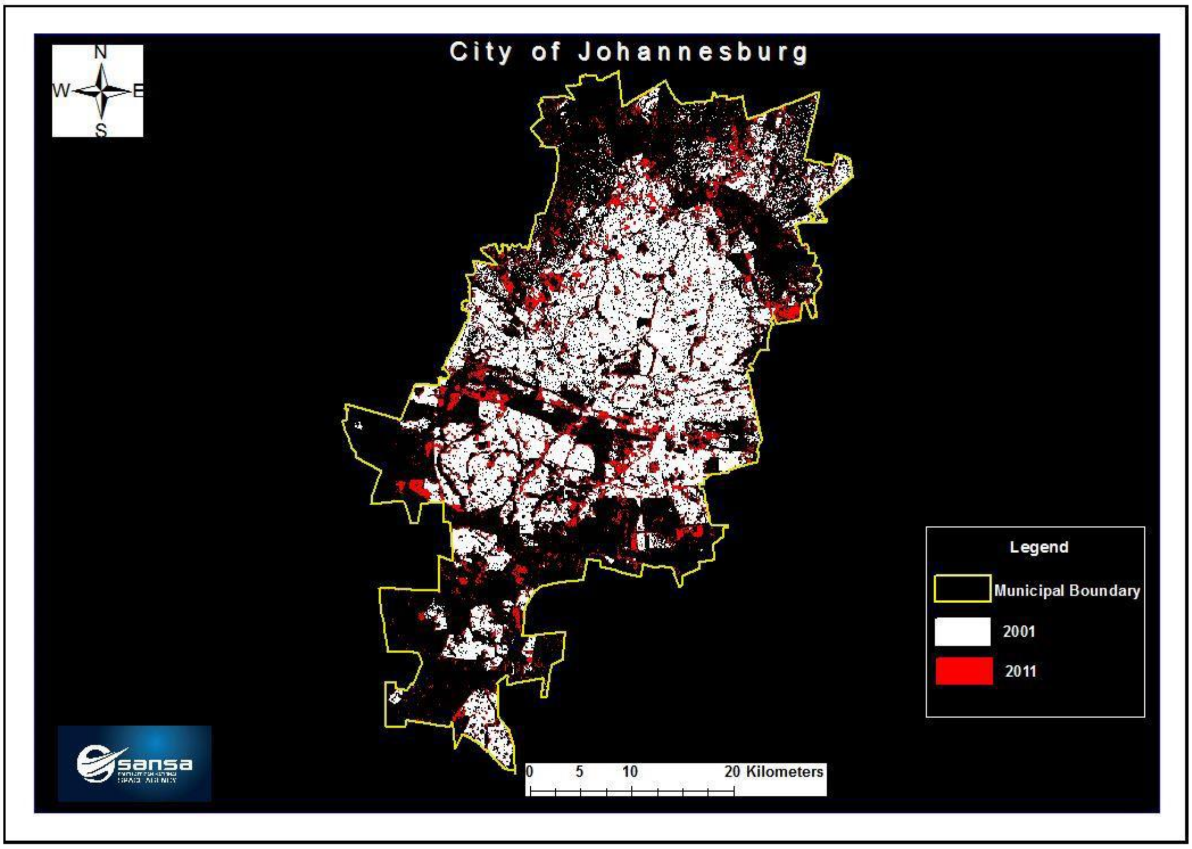
y The number of years between the two measurement periods

The results show the rate of urban growth within the three metropolitan cities in Gauteng was lower than the rate of population growth between 2001 and 2011. However, City of Tshwane had the highest urban expansion compared to the other two metropolitan cities. Polokwane and Rustenburg experienced the highest urban expansion than the metropolitan cities which confirms the projections for higher urbanisation in smaller cities (United Nations, 2014). Refer to the figures below for spatial distribution of urban growth at the areas of interest. In terms of population, Rustenburg and City of Johannesburg experienced the higher growth rate compared to other municipalities, while Polokwane experienced the lowest population growth rate. Rustenburg experienced the highest population and urban growth rates compared to the other cities. In terms of **ratio of rate of land consumption to rate of population growth** (LCRPGR), Polokwane experienced the highest LCRPGR compared to other cities. Lower population growth in Polokwane is influenced by out migration of youth to the metropolitan cities whereas higher urban expansion is attributed to informal settlement upgrade programme where new Low Cost Housing units are built for informal settlement dweller. City of Tshwane experienced the highest LCRPGR compared to other metropolitan cities in Gauteng. The assessment shows that Polokwane and Rustenburg, which are secondary cities have experienced higher LCRPGR that metropolitan cities.

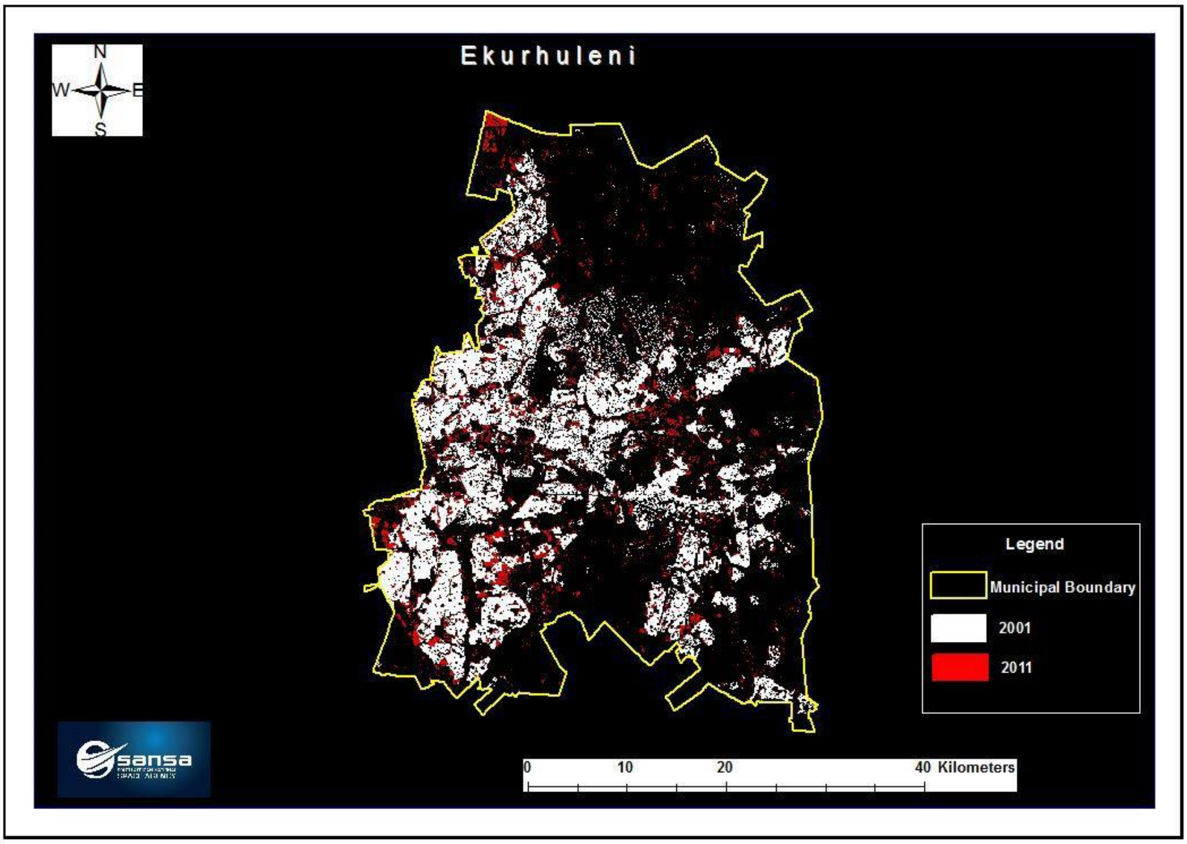




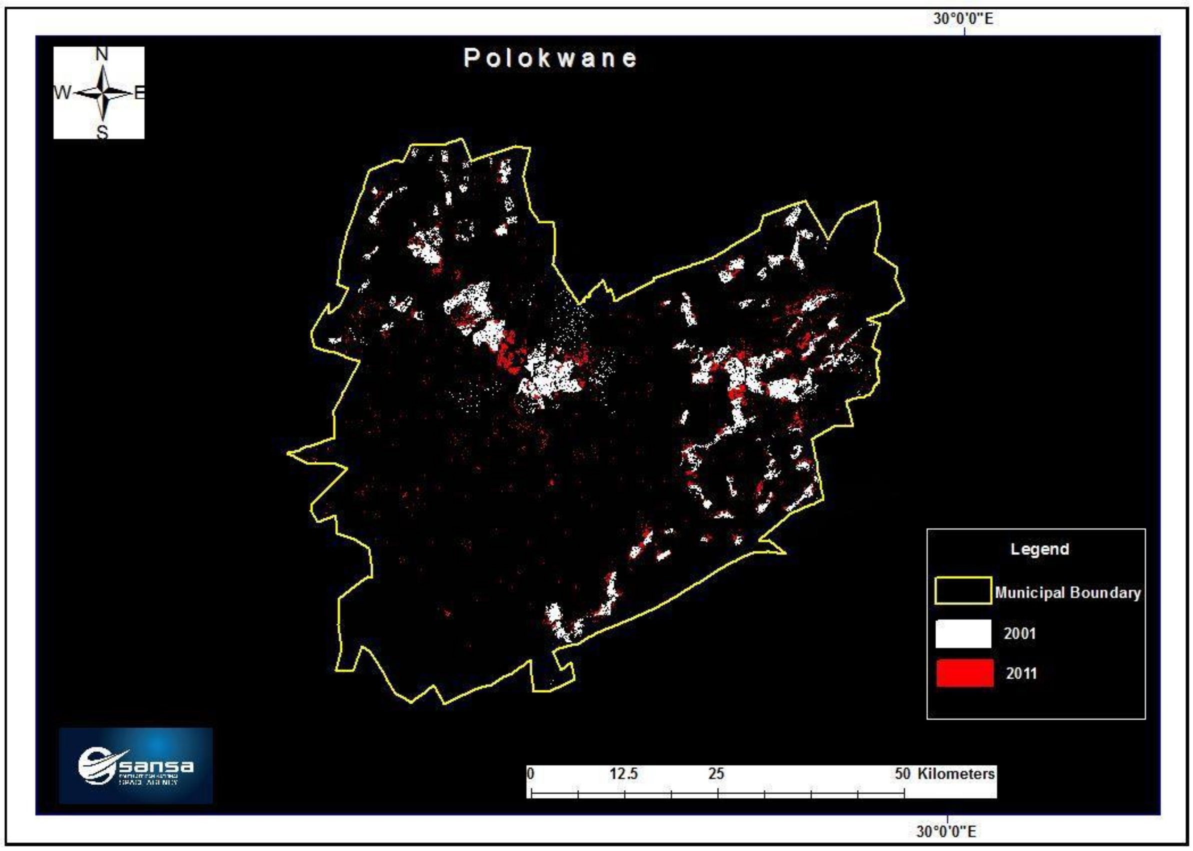
Rustenburg 2001 -2011 urban growth.



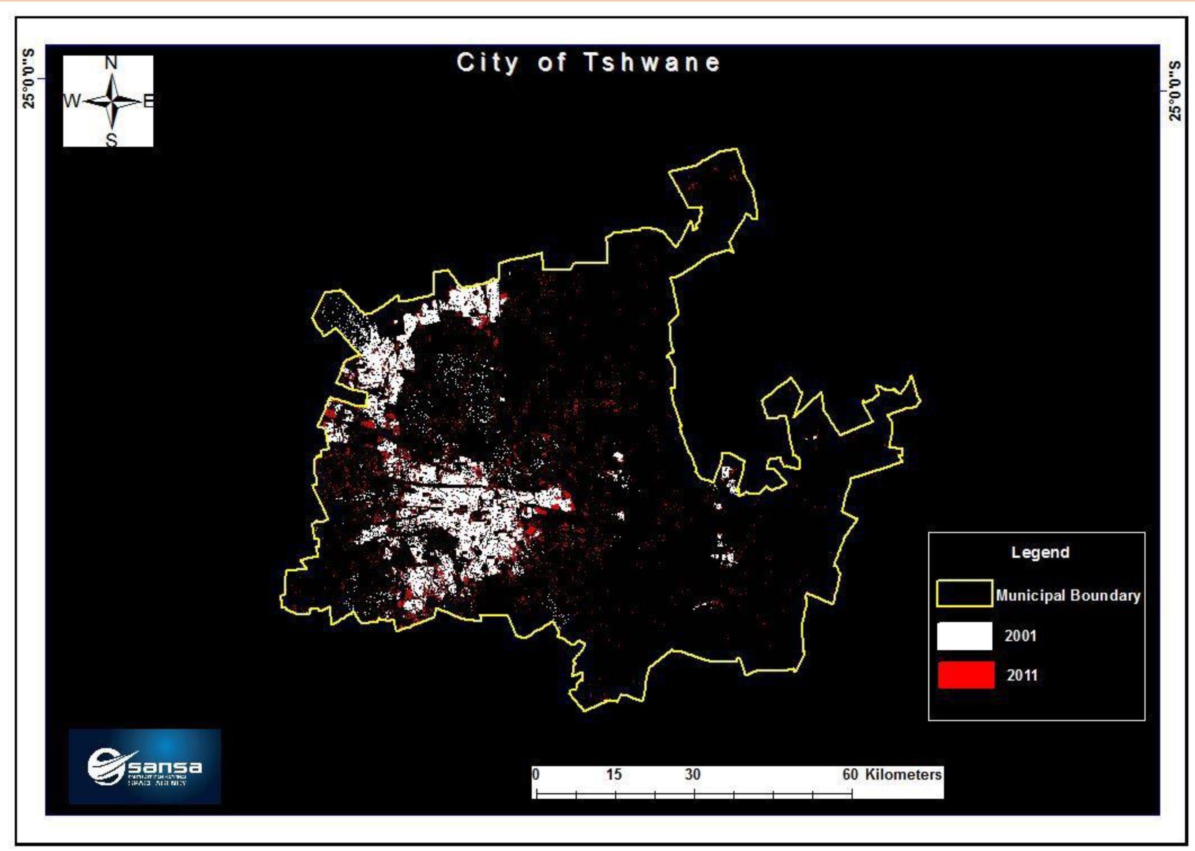
Johannesburg 2001 -2011 urban growth.



Ekurhuleni 2001-2011 urban growth.



Polokwane 2001-2011 urban growth.



Tshwane 2001-2011 urban growth.

This case study demonstrate the use of integrated EO and census data for monitoring the achievement of Target 11.3.1 of SDG Goal 11. It also demonstrate the that a variety of stakeholders can work together in monitoring the achievement of SDGs.

Case study: Applications of earth Observation for Water resources monitoring

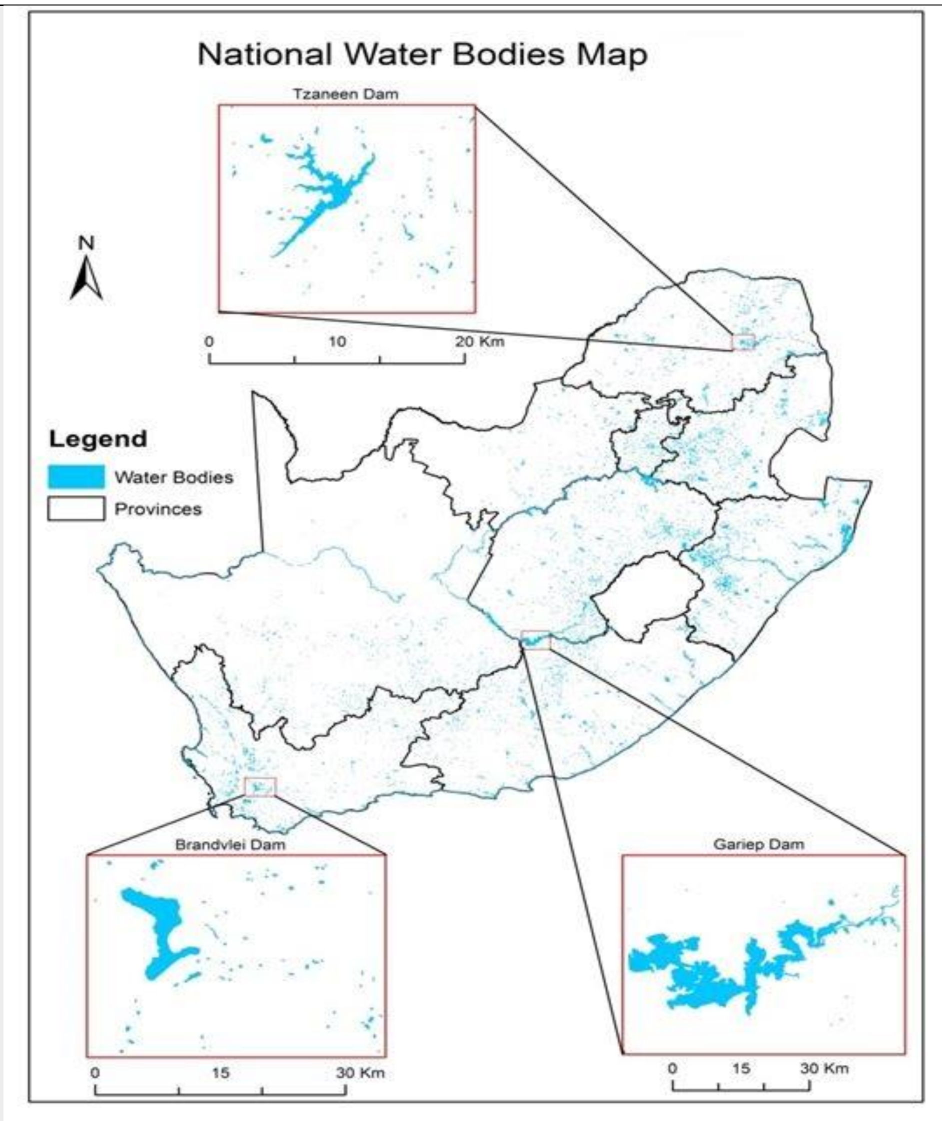
Freshwater is an important natural resource required to sustain life on earth, although its availability is limited in some countries. Unfortunately many countries of the world are experiencing shortages of freshwater and dwindling freshwater ecosystems due to acidification, eutrophication, sedimentation, increased turbidity, heavy metal contamination, population growth, global climate change, groundwater extraction and introduction of non-native plant species. Specifically, Algal blooms, are of increasing concern in inland waters, because some species produce potent toxins that pose a major hazard to human health, livestock, wildlife and the aquatic environment. Traditional field monitoring for algal bloom detection involves identification and cell counting which, whilst reliable, imparts a lag time and is limited in spatial extent[28]. Earth observation data are used to complement traditional methods for water quality monitoring.

South African National Water Act (No. 36 of 1998) has a central purpose of ensuring that water resources are protected, used, developed, conserved, managed and controlled in ways which take into account various socio-economic, environmental, biological and political factors nationally. However, currently not everyone has access to freshwater resources as stipulated in the South African Bill of Rights[29]. This is due to a multiple of factors that have direct or indirect bearing on freshwater sources, water quality as well as climate variations over the years. Thus, it becomes imperative to conserve the existing water resources. For an effective management of water resources to be possible, it is important to take cognisance that water resources are divided into two categories where NWA can be exercised. These categories are (i) water as renewable resource, and (ii) non-renewable resource. The renewable resource include groundwater and surface water, while the non-renewable water resource include deep aquifers which do not have significant replenishment rate on the human time scale. In order to manage limited water resources effectively, South Africa needs policies and investment reforms on multiple fronts, including economic intervention, climate studies, agricultural research, medical research, water resource management, community-based research, infrastructure development amongst others. These dimensions to water related issues are effective when treated as part of an integral approach for managing water resources. The South African National Space Agency (SANSA) relies on earth observation technology (satellite remote sensing) for water resource monitoring and detection. Among others, water bodies (including small water bodies), water quality, irrigation and water-use are continuously observed, assessed and monitored over time using freely available data sources such as Landsat 8 (NASA/USGS) and Sentinel 2 (ESA, Copernicus Programme).

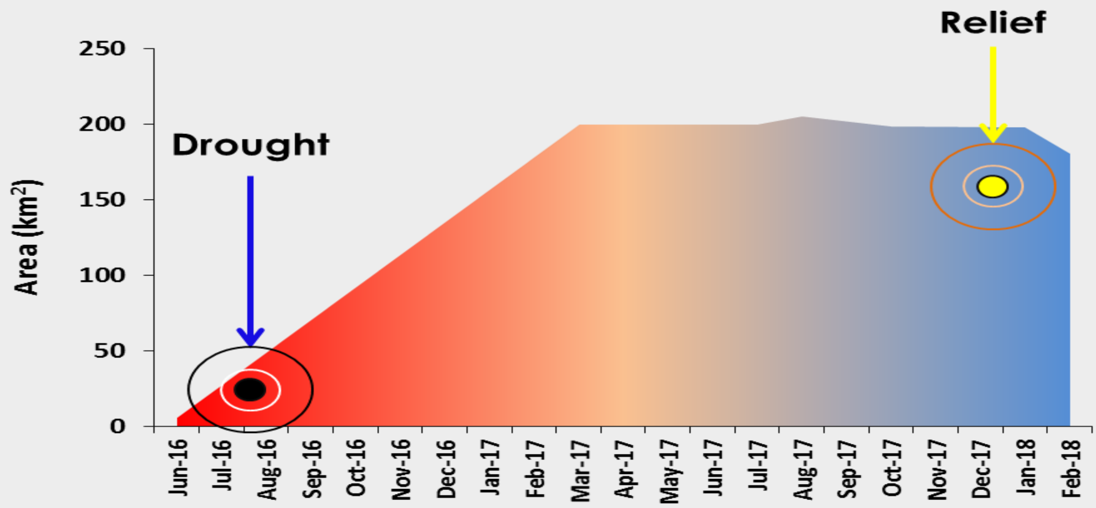
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.
6.3.2. Proportion of bodies of water with good ambient water quality.
6.4.2. Level of water stress, freshwater withdrawal as a proportion of available freshwater resources.

In order to understand the water quantity challenge faced by South Africa as a semi-arid country, it is important to map the surface water bodies at national scale. In order to accomplish this task, the SANSA produces seasonal water body products (see figure below). These products are aimed at outlining the status of water in the country and to support projects aimed at conserving freshwater resources. This product is crucial considering the dwindling water quantities in South Africa which put pressures on the extraction of groundwater and service delivery.

[28] http://www.earthobservations.org/documents/publications/201703_geo_eo_for_2030_agenda.pdf
[29] http://www.justice.gov.za/legislation/constitution/SAConstitution-web-eng-02.pdf

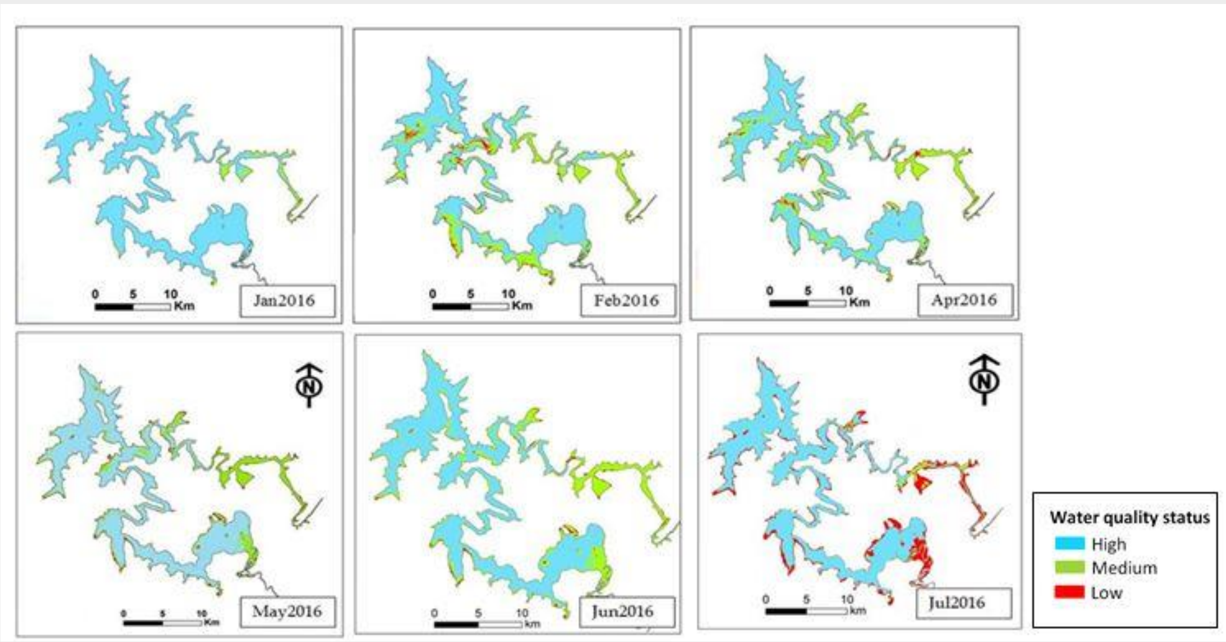


Recent climate change phenomenon has accelerated evapotranspiration, thus further reducing the dwindling water resources. This information provides the baseline of assessing the rate at which important small water bodies such as farmland reservoirs and wetlands recede and how agricultural intervention measures could be put in place to remedy agricultural water security.



	Jun-16	Mar-17	Jun-17	Jul-17	Aug-17	Oct-17	Jan-18	Feb-18
Area (km2)	5.46	199.81	199.67	199.70	205.13	198.11	197.55	180.06

In addition to mapping the extents of water bodies, monitoring the status of water quality is key to ensuring that we have safe, consumable water by various sectors contributing to the national economy. SANSA in collaboration with Rand Water[30] have embarked on assessing the status of water quality in Vaal Dam. The aim was to test the methods that will be applicable to other parts of the country in order by use of remote sensing. All the models used were based on Landsat 8 data, coupled with field observations, to detect varying classes of chlorophyll-a within the dam. The project commenced in January 2016 and ended in June 2016, with a multi-temporal algal information being produced monthly (see the figure below). The Vaal Dam is one of the most important dams in South Africa because it provides the heartland of the country (mainly Gauteng province) with drinking water. In addition, it supports several recreational activities such as fishing and boat cruise, which demand improved aesthetic and water quality. The results of the project are mainly used by the Rand Water and have implications in many other sectors such as agriculture, with inter-connected agro-system that has direct or indirect impacts on the algal concentrations within Vaal Dam and downstream.



30 http://www.randwater.co.za/Pages/Home.aspx

The map above demonstrates water quality by considering only algal blooms within the Vaal Dam where the blue areas of the dam show high water quality and red areas showing low water quality. SANSA continues to map South African open water resources (such as dams, rivers, and lakes) and also assesses the quality of water in some of the economically important water bodies using earth observation satellite images. The water quantity and selected water quality (chlorophyll-a concentrations) products are accessible to the public from SANSA website http://products.sansa.org.za/mapApp/index.html.

Another important areas of water monitoring is irrigation and agricultural water use monitoring. SANSA, in collaboration with the DWS are monitoring irrigation using satellite imagery. The major purpose of satellite applications in agriculture was to determine the extent of irrigation that is taking place across various water catchment management areas (CMAs) of South Africa. Assessing the use of water for agriculture is key to understanding water allocations, authorization and use in various CMAs. In addition, this assists in monitoring whether some farmers at particular properties comply with the water regulations as set forth by the NWA and water abstraction license issued by the DWS. In this instance earth observation is used to determine whether some fields are agricultural fields under irrigation or are rain-fed. The figure below shows the results of the operation aimed at discriminating between irrigated and non-irrigated fields, making it important to set baseline for compliance and monitoring operations by the department concerned.

Case study: Applications of earth Observation for Agricultural resources monitoring & Food security

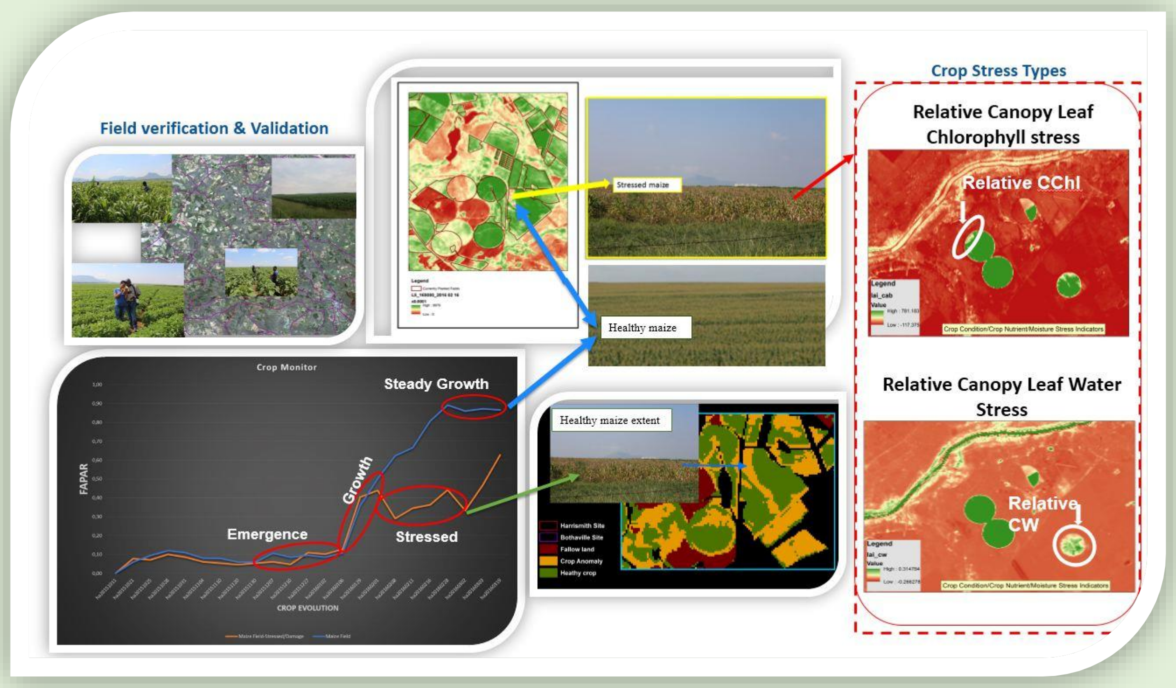
A projected increase in the frequency of disruptions in food production and supply is challenging efforts to achieve global food security. The issue of food insecurity is linked, among others, to agricultural systems response to pressures of climate change, environmental degradation, land use competition, population increase and weakening economies. These factors put many countries at risk of under producing food or constraining their ability to import food supply. At the same time, it is a sovereign requirement for every country to provide access to sufficient food supplies and prevent malnutrition, so contribute towards achieving a set of United Nations (UN) Sustainable Development Goals (SDGs).

Target 2.3. By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment. Target 2.4. by 2030, ensure sustainable food production systems and implement agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

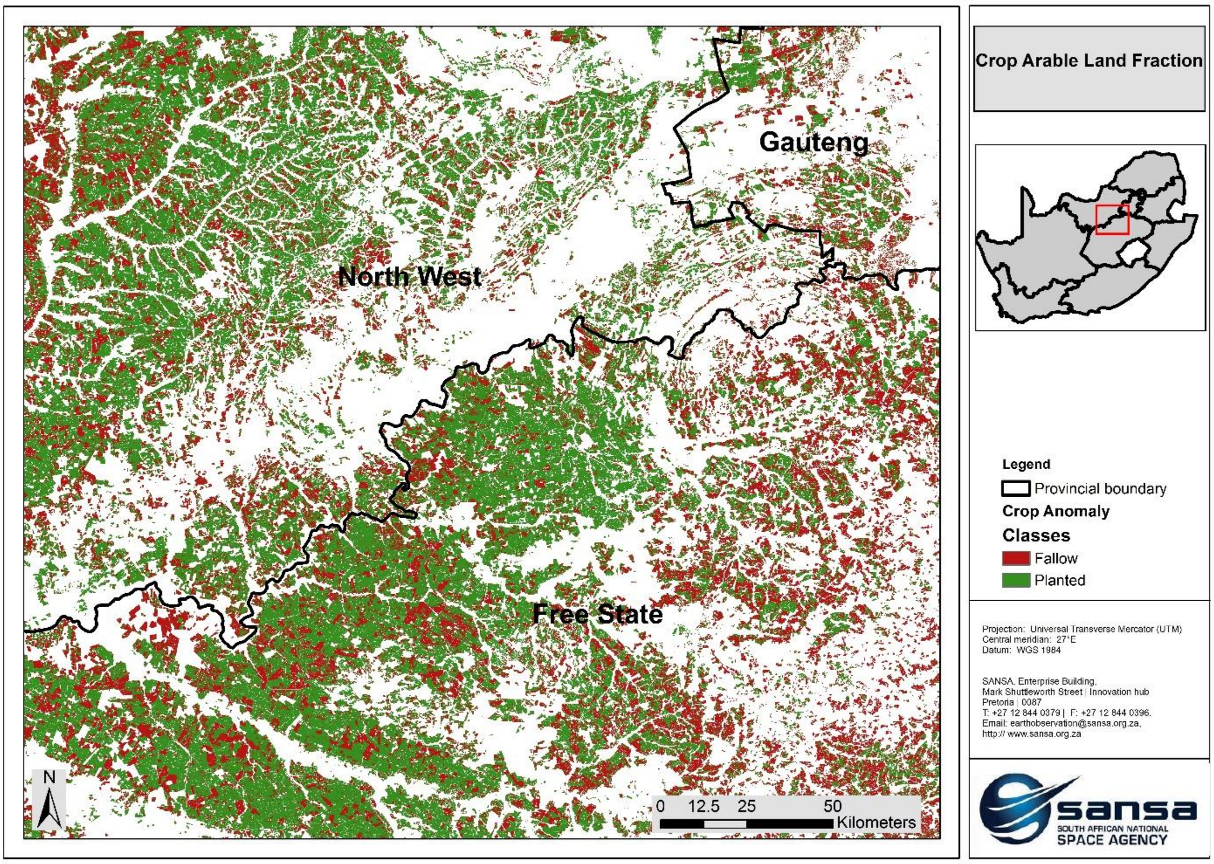
For Africa, the aspirations of the SDGs underline its Agenda 2063 strategic framework for socio-economic transformation of the continent. Some of the key initiatives contributing to the Agenda 2063 with regard to agricultural transformation include the Programme for Infrastructural Development in Africa (PIDA), the Comprehensive Africa Agricultural Development Programme (CAADP), as well as other regional plans and Programmes of the New Partnership for Africa's Development (NEPAD). Earth Observation (EO) and other geospatial technologies such as satellite-based remote sensing and GIS play an increasingly critical role in assessing and monitoring agriculture and food production through the provision of actionable information that supports informed food security management policy and decision making at national, regional or continental levels and can help in the implementation of Agenda 2063, Goal 5 (Modern agriculture for increased production and productivity) and Goal 3 (Healthy and well-nourished citizens).

This case study demonstrate the application of EO and related geospatial technologies to support several government departments and other agencies concerned with food security and agricultural management of the country. The information provided can also be used to monitor the achievement of SDGS and Agenda 2063 goals.

The south African National Space Agency (SANSA) has developed a prototype agricultural monitoring system (i.e. Crop Watch for South Africa), with the aim is of affording end-user departments EO information in support of food security policy and decision making in the country. Crop Watch for South Africa (CW4SA), is demonstrating societal benefits of EO capability for assessment and monitoring of food security and agriculture. A set of crop stresses based on retrieval of biophysical parameters from satellite data are provided. CW4SA combines EO-derived biophysical variables with agro-meteorological information to optimise the monitoring of field crop areas in both irrigated and dryland production systems. Below is an example of nutrient and water stress from EO data.



Earth observations have proven helpful in the estimation of cropped arable land fraction and other agricultural productivity assessments, such as water planning and irrigation management, and crop yield modelling on a range of spatial and temporal scales. The figure below illustrate some data products and information services that the CW4SA system produces.



Overall, SANSA is providing critical Earth observation data and applications dedicated to supporting the African agricultural sector including: Promoting open data, access to data, data fusion and capability for handling big data for agricultural applications, National mosaic of high-resolution satellite imagery, National base maps of vegetation density layers, Vegetation condition and stress monitoring capabilities, Assessment of crop and other vegetation phenometrics, Estimating cropped arable land fraction and production area statistics, Environment risk assessment and monitoring, Water resource assessment and monitoring, Above ground biomass and yield estimation, and Agricultural drought assessment and monitoring,

The capability is ready to be expanded to other African Countries.

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We have included several materials that presents the application of Earth Observations and other Geographic information for supporting 2030 Agenda for Sustainable Development ("EBooks" Folder of the DVD Disk). These include:

Index	Title	Edition
1	Satellite Earth Observations in Support of the Sustainable Development Goals	Special 2018 Edition
2	Earth Observations in Support of the 2030 Agenda for Sustainable Development	March 2017
3	Handbook on remote sensing for agricultural statistics	
4	Satellite Earth Observations in Support of Disaster Risk Reduction	Special 2015 WCDRR Edition