Cloud-based agricultural solution: A case study of near real-time regional agricultural crop growth information in South Africa.

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ABSTRACT:

Recent advances in cloud-based technology has led to the rapid increase of geospatial web-based applications. The combination of GIS and cloud-based solutions is revolutionizing product development in the geospatial industry and is facilitating accessibility to a wider range of users, planners and decision makers. Accessible through an internet browser, web applications are an effective and convenient method to disseminate information in multiple formats, and they provide an interface offering interactive access to geospatial data, real-time integration and data processing, and application specific analysis tools. An example of such a web application is GeoTerraImage's monthly crop monitoring tool called GeoFarmer. This tool uses climatic data and satellite imagery processed through a complex rule-based algorithms to determine monthly climatic averages and anomalies, and most importantly the field specific crop status (i.e. is the field fallow, or is the crop emerging, or if the field has been harvested). Monthly field verification has formed a part of calibrating the growth classification outputs to further improve the accuracy of its monthly agricultural reporting. The goal of this application is to provide timely data to decision makers to assist them in field-level and regional crop growth monitoring, crop production and management, financial risk assessment and insurance, and food security applications. This web application has the unique advantage of being highly transportable to other regions, since it has been designed so it can easily be adapted to other seasonal growth response patterns, and up-scaled to regional or national coverages for operational use.

1. MANUSCRIPT

The remote sensing industry has rapidly evolved over the last few years, lending exciting opportunities to a variety of applications including; environmental issues, global conflict, land sustainability, and food security. The technological advances in Earth Observation (EO) can be attributed to the increased computing power, distributed and efficient cloud processing, and the vast array of public and commercial datasets. Another big catalyst of change in the geospatial industry is the Open Source Geospatial Foundation (OSGeo) whose mission is to support and promote the collaborative development of open geospatial technologies, processes and datasets. Being cognitive of the change in industry and adapting to it, is key to an organisation's commercial relevance and sustained longevity. Statistics show that over 2 billion people (globally) use remotely sensed or geospatial datasets, which affects 10% of the global GDP (DigitalGlobe – WP-REMOTE 11/14). Many commercial entities express concern over the global entities (and their seemingly endless resources) having their hand in the EO game, however this may be unwarranted because the inherent optimistic outlook is that they are catalysts for more opportunities in the industry. This paper briefly explores the trends in earth observation, and describes how a commercial focussed company, GeoTerraImage (GTI) in South Africa, is adopting technological advances to create a near-real time crop monitoring tool called GeoFarmer.

In the EO industry, frequently mentioned buzzwords such as 'digital disruption', 'technological advances', 'cloud processing', 'web applications', 'big data', and 'real-time' are indicative of EO's exciting revolution. The revolution is the convergence of driving factors ("drivers"), and enabling technology ("enablers") that make it possible to provide solutions to general end users and decision makers. There is an evident shift from conventional data access and processing workflows, to smarter and more efficient data processing approaches. Due to the 'heavy-lifting' in the EO industry being done by the data and imagery service providers, the value of information products no longer only lies in the acquisition of imagery and delivery of datasets, but in how the imagery is analysed and processed into an easily understood information product. Consequently, the real value (for companies and organisations interacting with the product end-users) has shifted down the value chain, where the end-users no longer expects a geospatial dataset but rather a dynamic near-real time information product (Figure 1).

It is unrealistic to pin-point a single driver of change in the EO industry. Change in EO can attributed to the convergence of multiple drivers (increased internet bandwidth, optic fibre infrastructure in 3rd world countries, adoption of modern technology, data to analytics, CubeSats) that happen outside the sector (https://www.geospatialworld.net/article/earth-observation-trends-during-2014-that-you-need-to-know/). However, a main driver of change in large number of sectors (not only the EO sector) is primarily driven by the ever-increasing population numbers globally, which has compounding social and economic impacts. The consequences of an increasing population include unemployment, poor living standards, shrinking habitable land base, and most importantly is the pressure on global food security. In 2009, the concern over food supply and demand resulted in United Nation's call for increased international cooperation to "improve the quality of national agricultural statistics and early warning and forecasting systems for food insecurity and vulnerability" (http://spacenews.com/food-security-through-earth-observation/). Stakeholder's and decision makers are also realising the unparalleled potential in EO in its ability to monitor and observe the world and support human society. The EO industry provides the sustained global, regional and local data to develop solutions to local, regional and global problems. Addressing problems at a global scale when resources are evidently limited, has created a space for innovative approaches to improve efficiency in the entire EO value chain.

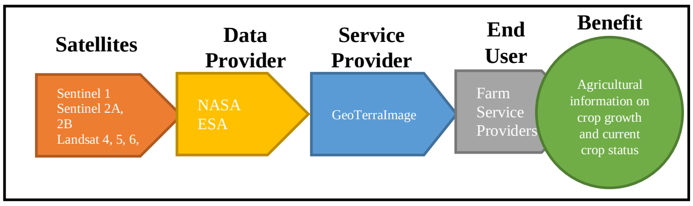


Figure 1: Example of EO value chain in Agriculture (Food Security)

With the realisation that EO data provides a reliable and scientific wealth of information, it is avidly used in the definition of global goals and frameworks, and adopted as the global standard to inform policy makers and to reliably report and monitor. The advances in modern technology no longer require the end-user to have advanced analytical skills and specialised software to interpret data products, but instead they receive "ready-to-use" information packages, from which they simply extract the answer. The answers are no longer supplied to the end-user via hard-drives or USBs, but rather as URLs on the web, or applications on your cell phone or tablet. Evidence of this is the abundant innovation challenges being hosted globally, where the industry challenges the public to create new mobile/desktop apps that use earth observation data (E.g. "ESA's fourth Space App Camp", "ESRI's EO app contest – GEO Appathon", "Hexagon Geospatial's IGNITE Smart M.App Challenge"). This advancement in information dissemination has raised the expectations from the end-user, and similarly pressured the service providers to creating/innovating new products and solutions that are near real-time. The value in information products is shifting from the traditional 'pretty picture/map', to dynamic reports and advanced analytics of information delivered near real-time.

It is difficult to pinpoint whether global issues, socio-economic pressure, or technological breakthroughs (or the combination of all three) are the evitable drivers of changes and innovation in the EO industry, but change can only happen if drivers are coupled with enablers: The noteworthy enablers to mention are:

- *Free Satellite Imagery:* The launch of satellites which provide free image datasets to the public. Landsat 8 was launched in February 2013 becoming the 8th satellite in the Landsat orbit. The European Space Agency joined the EO game with the launch of Sentinel 2 A Satellites in June 2015, and the launch of Sentinel 2 B in March 2017. The combination of Landsat and Sentinel imagery allows for a higher temporal resolution, which means that most areas around the globe area revisited and recorded up to 8 times in a single month. Sentinel imagery has a spatial resolution of 10 meters (Red, Green, Blue, Near InfraRed), and 20 meters, while Landsat has a spatial resolution of 30m, which is of superb quality for monitoring changes is the landscape.
- *Internet/Networks/Connectivity:* The ability to download large file sizes no longer takes weeks or is coupled with connection interruptions (especially in 3rd world countries). There has been a general global improvement in internet connection, and the release of fibre optic cables has been a noteworthy enabler to transfer large data across the internet, improving stability and speed. The problem of connectivity in rural areas is apparent, but the challenge is being taken head on by internet giants such as Google, Facebook, and SpaceX to introduce satellite broadband, where internet is no longer provided by cable but through satellites.
- *Cloud-based enablers:* Over the last few years the 'cloud' has been a hot topic advancing the capabilities in the remote sensing space. In this paper *cloud* is referred to the remote computing infrastructure that allows the remote access, processing and delivery of data products. Organisations no longer require expensive internal infrastructure to process data and generate information products, but can rather rely on *cloud* accessible infrastructure to do so. It is important to mention that in order to use these cloud-based enablers will require certain experience in computer science and programming. The likes of Google Cloud (GE) and Amazon Web Services (AWS) are seen as the forerunners in the cloud game, offering hosting, processing and storage facilities to create the space to form data processing pipelines to collect, process and deliver data information products. Being able to process data using GE or AWS computing power and infrastructure certainly makes the unimaginable possible by technically offering limitless data crunching resources. Both GE and AWS host petabytes of public datasets which include the full inventories of Sentinel and Landsat datasets, and therefore making it possible to integrate spatial data into these data processing pipelines. GE has taken this a step further by combining satellite imagery with planetary scale analysis capabilities into what they call "Google Earth Engine" (GEE). GEE has the ability to take vast amounts of data and process it real-time to detect changes, map trends, and quantify differences in an area of study. GEE has also tried to bridge the gap between novice programmers and cloud technology through this Engine, and has thorough tutorials as to how to analyse imagery using Python or JavaScript on their platform. The current GEE platform primarily caters for the scientists, academics and non-profit organisations.
- *Data Provider Platforms*: There is a noticeable trend that commercial data and service providers are focusing efforts on bridging the gaps between the ever-increasing catalogue of available satellite imagery and the ability to process petabytes of data. Data providers are creating incredible data dissemination platforms to reach even more clientele, where data is no longer an FTP (File Transfer Protocol) connection between provider and client, but a sleek web portal to view, filter, analyse large amounts of data over multiple areas of interest, in record time. An example of this is Planet Labs "The Planet Platform", which passes imagery through a fully automated processing pipeline, makes it available to you online, and provides you with APIs (Application Program Interface) and browser-based tools to quickly find and extract the information you need. Another incredible example is the GBDX platform developed by Digital Globe; it enables users to build, access and run advanced workflows and tools that extract actionable information on a worldwide scale from their robust cloud-based satellite image library.
- *Software Provider Platforms*: As data providers shift their focus to the end-users, the proprietary software developers are being pressured to move their analytical power to the cloud and connect with the other data providers, and with that are producing exciting platforms to connect to remote data sources, process using cloud infrastructure, and then serve the final information through powerful easy to access web applications. ESRI's comprehensive list of products has definitely risen to the challenge by offering a ArcGIS Online solution where the comprehensive platform to manage, process, analyse, and share imagery to extract valuable information. Hexagon Geospatial Smart M.App is

another simple to use platform developed to eliminate the complexity of building web applications and provides an all-in-one solution to combine content, business workflows, and geoprocessing into a single application to produce powerful visualizations.

- *Open Source Geospatial Foundation (OSGeo)*: OSGeo's open philosophy and participatory community driven development has had a big impact on the Geospatial landscape. With over 30 projects (which include software, plugins, libraries, scripts, an ddocumentation) freely available to the broader EO community, the OSGeo enables users to create geospatial information from free content providers at a very low cost. The community and contributors enable users to work together to solve geospatial problems, and these open communities are often even more active than some commercial service providers, and more than willing to assist with solving technical problems.

Although this brief outline of drivers and enablers only begins to scratch the surface of the factors influencing the change in the EO industry, it is enough to justify that these aspects provide the juncture to further innovation and possibility. To elaborate further it is important to place this into the context of a real-world solution, where GeoTerraImage uses these drivers and enablers to provide solutions to the food security industry in southern Africa.

GeoTerraImage (GTI) is a commercially focussed company in South Africa that uses the drivers and enablers mentioned in this paper to provide solutions to end-users. GTI serves many market sectors both in South Africa and increasingly so in Africa, and uses EO data to extract information for client applications. The primary focus is to link locational intelligence with business intelligence in order for their clients to better make informed decisions. GTI has embraced the changes and revolution of the EO industry, and capitalised on the opportunities represented by the new technology into its workflow to remain relevant and profitable.

Although drivers and enablers provide the nexus to develop information products, it is important to realise that key in making relevant business solutions is further introducing skills, capacity and experience into the equation. GTI has approximately 20 years' experience in the EO industry, but more importantly the agricultural (or food security) industry. In collaboration with the Agricultural Research Council (Institute for Soil Climate & Water) and Spatial Intelligence (SiQ), GTI has formed the National Crop Statistics Consortium (NCSC) and have, over the past 8 years supported the Department of Agriculture in terms of annual crop estimates.. The factors that make it possible for GTI to deliver on these products, is a long history of important local knowledge in understanding the local farm management practices, as well as long standing partnerships with key industry stakeholders and decision makers to provide relevant solutions. The use of remote sensing in agriculture is well documented, from applications that include drone operations which generate valuable precise crop and farm level information, to applications using coarse resolution satellite imagery to examine the global elements contributing to food insecurity (Wójtowicz, *et. al.* 2016; Atzberger, 2013). Over the last 2 years GTI has placed focus on using key drivers and enablers to redefine their strategic approach from project specific revenue models to product type solutions. One such product type solution is the "GeoFarmer Crop Monitoring" web based application.

The GeoFarmer solution was developed to support the agricultural industry through the provision of relevant, up-to-date and accurate information, to decision makers in an easy to use cloud based environment. The product aims to cover three aspects of the agricultural industry; this is understanding regional climatic conditions, the provision of detailed crop growth information and change over time, and providing the status of current crop growth (Figure 2). By understanding the regions climate allows one to quantify factors influencing the agricultural production, and this includes comparing prevailing climatic conditions to either long-term or the previous year's climatic information. The regions climate is quantified in terms of rainfall, vegetation condition or a drought index. With this cloud based tool, the user is able to create their own crop growth map to identify infield variation showing field specific plant vigour. The application also allows the user to determine the change in crop growth between two calendar dates based on the available imagery, and efficiently download the processed information. To further understand local agricultural practices in a specific region, users are also able to visualize and quantify (through a downloadable report) the amount of fallow fields, emerging crops, maturing crops, crop senescence, and harvested fields over the previous 12 months. The end product is an easily accessible report that not only summarizes the local regions crop growth stage but also the agro-climate during which these stages occur. The product distinguished itself from the market, by being able to provide timely data to decision makers assists them in field-level and regional crop growth monitoring, crop production and management, financial risk assessment and insurance, and food security applications.

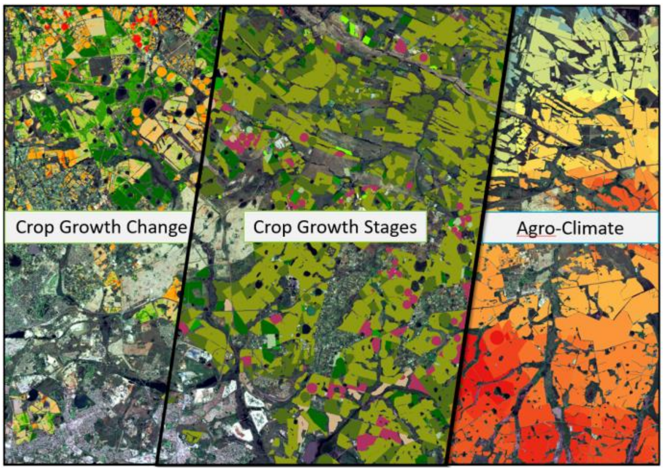


Figure 2: Illustration of information provided in the GeoFarmer web-based application.

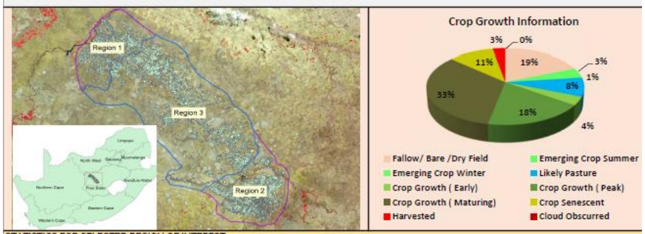
The market appeal of the GeoFarmer product is not in GTI's ability to process volumes of satellite imagery through rule-based algorithms, but rather the simplicity of how the information can be accessed through a web application, and summarized into a single report. Although the end result of the GeoFarmer solution is a simple report, it is important to note the several enablers that make this product possible. The initial GeoFarmer idea was incubated as part of a Hexagon GeoSpatial (HG) Smart M.App Ignite challenge where the general public community was given the opportunity to present their idea (across numerous industry sectors, of which food security was one), and then 20 chosen finalists would have the opportunity to develop their idea on the Smart M.App platform. The Smart M.App is the ultra-modern platform to design, build and deploy dynamic geospatial applications, and GTI with its GeoFarmer idea was one fortunate finalist with that opportunity. With the programming assistance of GEO Data Design (a HG partner) and the HG Development Community, GTI had the opportunity to develop a web application using the new innovative Smart M.App platform.

Key to monitoring monthly crop growth is access to data sources that have quality, consistent and global coverage, and that can be accessed easily and efficiently integrated into inhouse workflows. Landsat 8 and Sentinel 2 are publicly accessible satellite imagery that can be accessed through GE or AWS, and GTI developed a data pre-processing pipeline that checks, downloads, pre-processes (atmospheric corrections and layer stacking), and mosaics the imagery into 'ready-to-use' datasets. The python scripted data pre-processing pipelines are programmed using open-source raster processing libraries, which are free and well-documented products, which have enabled GTI to access and process imagery into ready to use products. Having knowledge and experience in the HG ERDAS Desktop Software and its unique Spatial Modelling environment allowed GTI to use the 'ready-to-use' imagery and create complex rule-base algorithms to model the crop growth stages and its progression over a yearlong crop growing cycle. Using field verification data of current crop growth and growth stages the algorithms were calibrated to verify the growth classification outputs and further improve the accuracy of its monthly agricultural reporting. The HG Smart M.App environment compliments the HG ERDAS Spatial Modeler well by offering a web based environment with options to import rule-based spatial models as a "recipe" to use in a web based application. The GeoCLIM software developed through USGS FEWS NET program is free to download and designed for the climatological analysis of historical rainfall and temperature data. This software tool enabled GTI to link agro-climatic information into their GeoFarmer product, and provided important regional climatic insights into the current crop growth observations. Further open source python programming allowed GTI to collect, summarise and manipulate the agricultural information into agricultural data tables, and then JavaScript/HTML programming was used to automatically generate reports based on the clienteles areas of interest, be it strategic, marketing or general planning (Figure 3).

Important in any agricultural information system is knowing where agriculture is found and what is the total arable area. In South Africa, GTI digitises field boundaries for all commercial agriculture across the country, and is kept up-to-date every year. This provides the ideal base for agricultural monitoring and crop type classifications, providing accurate agricultural crop area estimates for further market analysts. In southern Africa, other national field boundary inventories are often out-dated or incomplete, which proves a challenge in providing agricultural monitoring solutions to decision makers. GTI addressed this challenge in Zambia by using crowd sourced reference data to collect close to half a million training points identifying cultivation. The public satellite datasets and cultivation training sites were once again integrated into a local (in-house) data processing pipeline using non-proprietary machine learning techniques and python libraries to further identify commercial and small scale agriculture across Zambia (90% mapping accuracy). The GeoFarmer approach could be adopted to any landscape where field boundaries and satellite imagery is available, and therefore Zambia is the next on GTI's radar in terms of providing agricultural information.

CLIENT:	Demo Report		
AREA NAME:	Bloemfontein - North West Demo		
AREA ID:	ALL REGION SUMMARY		
PROVINCE:	FreeState		
MONTH QUERIED:	Mar-17		
REPORT GENERATED BY:	Jens Hiestermann		
REPORT ID:	Report_Demo_00001	DATE REPORT WAS GENERATED:	31/03/2017

GEOTERRA IMAGE



STATISTICS FOR SELECTED REGION OF INTEREST

FIELD TYPE (#2)	AREA OF AGRICULTURAL AREA (ha)	PERCENTAGE
Pivots	33481.24	13.28
Irrigated Non-Pivots	1629.36	0.65
Rainfed Fields	190594.12	75.63
Small Holdings	3923.41	1.56
Orchards	199.42	0.08
Tunnel-Crops	16.67	0.01
Other	22163.80	8.79

AGRO-CLIMATE STATUS

CLIMATE INDEX CATEGORY	CATEGORY
DROUGHT INDEX - CURRENT	ABOVE AVERAGE RAINFALL
MONTHLY RAINFALL VS PREVIOUS YEAR MONTH AVERAGE (Millimeters)	> 400mm
MONTHLY RAINFALL VS LONG TERM MONTH AVERAGE (Millimeters)	26mm
VEGETATION CONDITION INDEX	ABOVE NORMAL

CROP GROWTH INFORMATION STATUS	AREA OF AGRICULTURAL AREA (ha)	PERCENTAGE
FALLOW/BARE/DRY FIELD	42450.92	18.81
EMERGING CROP SUMMER	7146.68	3.17
EMERGING CROP WINTER	2279.42	1.01
LIKELY PASTURE	18215.30	8.07
CROP GROWTH (EARLY)	8195.42	3.63
CROP GROWTH (PEAK)	41652.04	18.45
CROP GROWTH (MATURING)	75442.35	33.43
CROP SENESCENT	23778.88	10.54
HARVESTED	6543.71	2.90
CLOUD OBSCURRED	0.00	0.00

Figure 3: A sample report representing the end-user product provided in the GeoFarmer web-based application.

The value of the GeoFarmer product lies in the simplicity of a report that can be understood by a wider audience of non-geospatial agriculturally focused end-users. GTI's focus of uniquely tying together enablers discussed in the paper, as well as integrating key knowledge and experience, make GeoFarmer an operational, near real-time, and automated solution. The example of the GeoFarmer reporting functionality demonstrates how the EO revolution enables satellite imagery to be analysed to provide insightful business intelligence.

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