IAC-12-B1.5.8x13132

DESERT MOVEMENT PREDICTOR AND FARMABOOTHS: TWO EARTH OBSERVATION-BASED APPLICATIONS FOR PAN-AFRICAN DEVELOPMENT

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Self-sustaining communities throughout Africa rely on local agriculture rather than external sources. Meanwhile, desertification is a widespread problem caused by a combination of human and natural factors. While desertification has consequences that directly affect agriculture, health, urban planning, and water scarcity, it is known that increasing populations, food demands, and short-term economic interests lead to the overexploitation of resources and unsustainable agricultural practices which drive soil degradation and the destruction of ecosystems. In both of these areas, developing and developed African states can greatly benefit from space-based earth observation applications. Can these earth observation applications assist countries with little or no space infrastructure? As an outcome of the Space and Africa Team Project at International Space University's 2012 Masters Program in Strasbourg, France, this paper will present two innovative applications based on earth observation, and geared towards implementation throughout Africa. The Identifying and Developing Effective Applications of Space for Africa (IDEAS for Africa) team investigated two possible earth observation applications, and using three different African countries as examples, determined how these can be used to promote development across the continent. South Africa, Morocco, and Liberia were selected not only based on their respective levels of space development, but also because they differ geographically, socially, economically, and politically. Consequently, a broad comparative analysis can be performed. Due to the dissimilarity of these three states, analogies can be drawn to other African states at comparable levels of development. The paper will shows how space and the innovations of the space industry can benefit Africa by aiding development across the continent and improving the lives and opportunities of those who live there.

I. INTERNATIONAL SPACE UNIVERSITY

The International Space University (ISU) is the world's foremost educational institution devoted to fostering the development of tomorrow's global space industry workforce. It was founded in 1983 by Bob Richards, Peter Diamandis, and Todd Hawley, and has a principal campus in Strasbourg, France. ISU conducts both a one year Masters Program in Strasbourg and an intensive Space Studies Program held in different locations around the globe. This year's Masters Program included over 40 students from around the world. As part of their curriculum, they were divided into two separate year-long team projects. The authors of the present paper are members of the Space and Africa project, which imagined the myriad ways that the global space industry and the technological innovations it has developed over the past half century can improve the lives of the more than 1 billion peoples of Africa and aid Africa's development in the coming century*.

II. INTRODUCTION

II.I IDEAS for Africa

It is commonly stated that space can provide many benefits to the countries with the means to invest in space. But how is space relevant for Africa? How can space be used to save and improve lives, protect the environment, and mitigate severe weather conditions?

The present paper will examine two proposals laid out from the IDEAS for Africa team. The first is a system to provide up-to-date information to local farming communities to improve agricultural output - called FarmaBooth. The second is an application to predict, model, and provide recommendations for managing desertification - called the Desert Movement Prediction Center.

Furthermore, three African countries were selected to illustrate how the proposals put forward can be applicable across the continent. The IDEAS for Africa team believes that South Africa, Morocco, and Liberia emerge as very good representatives of common African realities. With their geographical locations (northern, southern, and central Africa), their climate and environment (desert, semi-arid, and tropical rainforest), their governance (republics and a constitutional monarchy), and in their levels of development and challenges, the three "target countries" reflect the diversity across Africa and meet our requirements for the study.

II.II Motivation – African Context

Agriculture is the most important sector in the African economy, and employs approximately 60 percent of the labor force, compared to a World average of 3 percent.[1] However, agricultural development suffers from unpredictable environmental conditions and faces a rapidly increasing population. Despite recent improvements, African food security remains a major issue, as shown in Fig. 1. Food security is one of the major issues hampering African development, and stable crop growth in most of the continent suffers persistent threats. These concerns are further exacerbated by natural disasters and ecosystem disruptions. Meanwhile, many African countries depend on agriculture for their economic well-being. While several of them are in the tropical zones, with good annual rainfall and abundant arable land with rich soil, the poor management and inefficient agricultural methods have squandered the continent's plentiful natural resources. It is clear that technological solutions for improving agriculture in Africa are urgently needed.

Sustained agricultural development depends on the continent's environmental health. The diverse and complex nature of Africa's territory poses great challenges. Desertification and droughts are two of the major environmental challenges Africa faces. Every year, the continent loses four million hectares of forests due to desertification.[2] Desertification is a process by which fertile land becomes desert. Population growth, increased food consumption, and short-term economic interests all contribute to desertification. Other contributing factors include over-grazing, excessive firewood gathering, wasteland cultivation, inefficient use of water resources, excessive agricultural harvesting, and lack of environmental protections related to factories, mines, and transportation infrastructure. Human activities are not the only source of desertification, as natural climate effects from wind, water, salination, and freeze-thawing erosion also contribute.[6] The main cause of desertification is deforestation, with trees being cut to meet energy needs and expand agricultural land.[3] An overview of the climatic conditions on the continent is presented in Fig. 2.

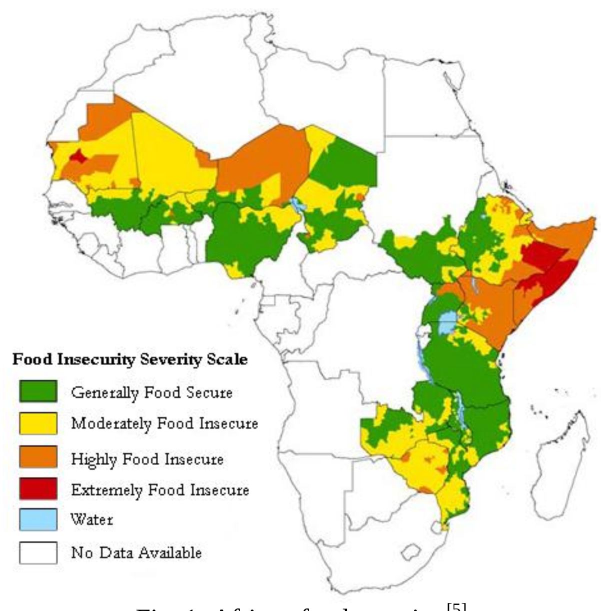

Fig. 1: African food security.[5]

As it can be seen, agriculture and desertification are well connected and influence each other. Bad agricultural and environmental practices will lead to the increase of desertification, which in turn restricts socio-economic development and contributes to poverty in affected regions. Desertification influences everything a local population needs - access to water, crops and livestock maintenance, and even the wood needed for fuel and construction. Desertification leads to weakened opportunities for climate regulation, soil conservation, and recreation. Desertification not only affects the dried

* See also *http://www.africa.isunet.edu* for final report.

region itself, but also makes an environmental impact thousands of kilometers away, as dust clouds formed from vegetation loss cause health problems in densely populated areas. Desertification also leads to human migration to cities, leading to an exacerbated urban sprawl and related sociopolitical problems.[7] There are ways to prevent, reduce, and even reverse desertification, as shown in Table 1.

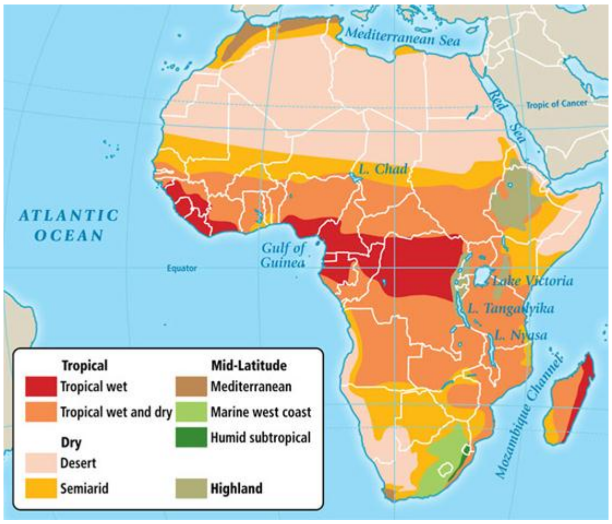

Fig. 2: African climate overview showing the diversity of climatic conditions.[5]

Rehabilitation measures are often difficult and expensive, while prevention measures are cheaper but require management and policy approaches that promote the sustainable use of arid regions. If no countermeasures are taken, the desertification of drylands will threaten future improvements in human well-being.[7]

III SPACE-BASED FINDINGS

It is well known the use of Remote Sensing for agricultural purposes. Most of the Earth Observation satellites are designed to sense the near infra-red band, in which the spectral signature of vegetables reaches their highest amplitude. Precision agriculture, the combination of satellite imagery and GPS technology to assist farmers in increasing the efficiency of their crops and obtaining the most turnout of their lands, is also a wide spread practice in some regions of Europe and North America. However, the use of space-based technology for monitoring deserts and other meteorological phenomena connected to their evolution is not so deeply rooted.

In the last 35 years several studies have attempted to understand wind dynamics (which pertain to the activity of winds to reshape Earth's surface) in the Sahara desert. Since the early 1970s, Landsat satellite images have facilitated the observation of inaccessible landforms in arid regions. These images have been used to recognize sand accumulations, identify different types of dunes, and observe sand dune movement. The near-infrared (NIR) band best discriminates sand dunes from other surface landforms. These Landsat studies however were focused on specific locations in the desert and were always complemented by ground-truthing.[8] Landsat images have also been used to analyze large sand dunes. By using images taken in 1973, 1991, and 2000, Chinese scientists measured the rates of dune migration in the Gobi desert, and the evolution of dune areas and volumes.[9]

In 2006, the Fight Against Desertification in West Africa project showed how InSAR (Interferometric Synthetic Aperture Radar) can be used for studying aeolian transport processes and the detection of active sand dunes. This study was performed in three areas of Western Sahara (Gouré in Niger, Draa Valley in Morocco, and in Mauritania) by analyzing high resolution interferometric products, like DEM, coherence images (which measure local phase correlations between two SAR images, providing a SAR noise measurement), and intensity images (showing intensity of backscatter of a SAR image), complemented by field observations. Tandem pairs of images of one day interval from satellites ERS-1 and ERS-2 were employed. The results illustrate the potential of InSAR as a useful source of information for the detection of light sand dune movements in semi-arid zones.[10]

Fig. 3: Desertified region in Sahel.[8]

In 2011, a two frequency InSAR system for mapping the subsurface topography in deserts and arid regions was demonstrated.[11] Ka-band InSAR systems can be used for mapping the top interface topography and Very High Frequency (VHF)-InSAR can be used for subsurface topography mapping. This is used to map sand layer thickness, which has multiple applications in environmental and archaeological studies, oil field and ground water explorations, and mine field detection.

Prevention, Reduction, and Reversal Strategies	Description
Land restoration	Through reforestation, soil erosion control, water harvesting
Halting cultivation	Done in areas with severe soil erosion and water loss
Mitigating damage	Mitigating wind and sand storm damage through advanced warning systems
Crop conversion	Converting cropland to forest through water saving irrigation projects
Stabilizing sand	Process by which sand is stabilized from moving via various biological, chemical, and engineering techniques
Shelterbelts	Plantations made up of multiple rows of trees planted to provide shelter from wind
Fallow band system	A land management practice for controlling desertification and improving crop production. Fallow bands are placed at right angles to erosive winds in a cultivated field during rainy seasons and catch windblown nutrients. During the following rainy season vegetation on the previous year's fallow bands are cleared and crops are cultivated on them.

Table 1: Methods for preventing, reducing, and reversing desertification

Extensive research has been done in monitoring dust storms with remote sensing imagery. This research has largely focused on identifying individual pixels that were part of a dust cloud. In 2008, Chinese researchers at the Shan Dong University of Science and Technology were able to determine the areal extent of a dust storm, measure its intensity (*e.g.,* amount of dust in the air), and track its movement. They used transient data from the MOderate-Resolution Imaging Spectroradiometer (MODIS) sensor on the Aqua and Terra satellites, and applied multi-channel threshold methods. This measurement technique involves taking the difference between intensities at various wavelengths, and comparing these values to a known threshold that is the value for a specific substance, like sand.[12]

In late 2013, the European Space Agency expects to launch ADM-Aeolus, the first satellite to study the Earth's wind patterns from space. It will measure wind profiles globally, using its Atmospheric LAser Doppler Instrument (ALADIN) payload. This instrument will be the first spaceborne Doppler Wind LiDAR, and will create a vertical wind profile showing the relative strength and direction of winds at different altitudes.

As can be seen, space-based technology is an available an appropriate way of monitoring and fighting against desertification. Already used in the past and in other regions of the world, space-based assets can improve the efficiency and sustainability of agricultural projects throughout Africa.

IV. FARMABOOTHS

The IDEAS for Africa team showcased the concept of satellite-based village resource information centers, called "FarmaBooths". The intent of this application is to provide rural farmers with up-to-date information from satellites about their agricultural lands.

IV.I Background

This proposal is inspired by the Indian Space Research Organization's (ISRO) Village Resource Center (VRC), which used Indian remote sensing satellites to bring data (including data on land, water resources, interactions between crop growth variation and climatic behavior) to rural farmers.[13]

ISRO piloted this project successfully across a wide area of rural India. The end-user applications included tele-education, e-health, land and resource management, interactive advisory services for the farmers, and weather services.

IV.II Technical Overview

FarmaBooths are small information centers in locations for local farmers from four or five villages to easily access information. The main objective of these centers is to provide personalized information on critical agricultural characteristics, including variations in soil type, soil nutrient variations, crop health, and crop growth data. The centers will display processed satellite images for a particular location to aid farmers in agricultural planning. The FarmaBooth system has four major components: the space-segment providing remote sensing and communication capabilities, the data interpretation centers, a centralized FarmaBooth facility, and the individual FarmaBooths themselves as data accessing facilities. In terms of the space segment, there is already an adequate space-based infrastructure to provide both the remote sensing needs and related communication requirements. The data interpretation centers convert raw satellite data into easily accessible information for farmers. The centralized facility can be located in a major city center for training sessions and teleconferences, and the individual FarmaBooths are in rural locations, near to farmers. Fig. 4 shows the flow of information in the system.

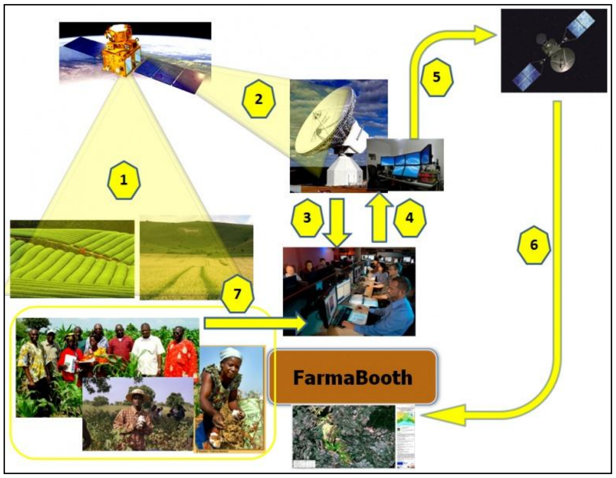

Fig. 4: Information flow across the FarmaBooth system

The flow of information is as follows:

1. *An Earth observation satellite acquires the image*
2. *Images sent to ground stations*
3. *Data sent to processing and interpretation centers*
4. *Interpreted data returned to ground stations*
5. *Interpreted data uplinked to a communication satellite*
6. *Recommendations and map data sent to the FarmaBooths*
7. *Occasional feedback from farmers to interpretation centers*

The FarmaBooth concept is based on utilizing the Pan-African e-Network to fill to connectivity gap between the centralized facilities and the rural farmers. The Pan-African e-Network is an international partnership between the Indian government and the African Union, which connects satellites to both urban and rural locations to establish tele-education and telemedicine in a stepwise manner. The intent is to eventually implement e-commerce, e-governance, resource mapping, and meteorological services.[13] Currently, there are 47 African Union countries which are members of the Pan-Africa e-Network project, of which the target country of Liberia is a part of. Members of the Pan-Africa e-Network have existing facilities that are connected to the internet via satellite (including universities, hospital, and community centers) and these locations can be used as centralized FarmaBooth facilities. The FarmaBooth's satellite system enables remote sensing of crops using three wavebands: microwave, visible, and thermal, which is interpreted to provide information about the size and yields of crops, crop damage, water sources, water use, moisture levels, and an estimation of surface temperatures.[14] Based on plant crop cycles, remote sensing of crops is done in two phases: the vegetative period (in which the plant grows in size before flowering), and the reproductive stage (in which flower groups and grains start developing). Using tropical rice as an example, these periods last between three to four months.[14] Since remote sensing techniques for these insights are well understood, satellite observation can discern the specific spectral reflectance patterns for rice crops because of its water absorption characteristics in the middle infrared (IR) range.[14] To provide these services, the spatial resolution of the imaged area will be approximately ten meters. It is also expected that each FarmaBooth will cover an area of 400 km2, meaning that the region of interest will be 20km by 20km. The reason for selecting an area that size is so that the FarmaBooth will be easily reachable by the local population. The satellites to provide this imagery already exist and are shown in Table 2.

Instrument (Satellite)	Waveband	Application
AVHRR (NOAA)	VIS NIR SWIR MWIR	Soil moisture and vegetation indices
HRG (SPOT 5)	VIS NIR SWIR	Agricultural land management
LISS (IRS)	VIS NIR	Improved crop discrimination and crop yield information
MODIS (Aqua & Terra)	VIS - TIR	Chlorophyll fluorescence
TM (Landsat)	VIS - SWIR	Vegetation state and change

Table 2: Space infrastructure for FarmaBooths

IV.III Technological Availability

One of the most appealing features of the FarmaBooths project is that the technology to implement these services already exists in the form of Indian VRCs. The estimated time for the FarmaBooth project will be the time from the project onset until the information is able to be used by farmers. This will require the setup of the individual FarmaBooth centers, integration into the Pan-Africa e-Network, the setup of the interpretation centers, the image acquisition, and the information transfer. Because the usefulness of this project requires historical data to be gathered, the limiting factor will be the amount of time required to create a database of information accessible by farmers. It is likely that data acquisition will require a full growing season, and interpretation before farmers can begin using the information. All other setups can be done in parallel to the data acquisition. It is therefore estimated that a full year is required from the project onset until the farmers can begin using and benefiting from the information provided by the FarmaBooth project.

IV.IV Financing

FarmaBooth costs include start-up costs and running costs. Start-up costs include providing internet connectivity for the individual FarmaBooths, and power requirements for the centralized facilities. The running costs of the FarmaBooth project include human resources costs for managing the FarmaBooth centers, renting space for the centralized facilities, associated costs with using the Indian VRCs for data interpretation, and any application imagery costs. Table 3 and Table 4 detail setting up and running costs for one FarmaBooth. Non-specialist personnel costs were estimated based on typical wages in the target country of Liberia. It should be noted that the imagery cost estimate used SPOT images, which are the only imagery that requires a fee and hence this is an overestimate.

Personnel Title	Percentage Employed	Total Cost (USD)
Remote Sensing expert	7%	5,500.00
Agricultural expert	7%	5,500.00
Maintenance personnel	100%	30.00
Training personnel	14%	225.00
Total		*11,250.00*

Table 3: FarmaBooth human resources

Item	Start-up Cost (USD)	Annual Cost (USD)
Centralized FarmaBooth Centers		
Human Resources	-	11,000.00
Building Rental Fees	-	600.00
FarmaBooths		
Satellite Connectivity	1,000.00	-
Construction	2,400.00	-
Power Requirements	5,500.00	-
Interpretation Centers		
VRC Services	-	20,000.00
Imagery		
SPOT Imagery	-	15,300.00
Total	-	*47,000.00*

Table 4: FarmaBooth project costs

IV.V Financing Sources

Since FarmaBooths are designed to benefit villages and farmers, who often have limited financial resources, the establishment of the FarmaBooth project will require a great deal of external support. This support will likely come from four major sources: government, international organizations, NGOs, and private enterprises. The Food and agriculture organization (FAO), is once such organization. It is a UN agency promoting efforts to end world hunger and aids developing and transitioning countries modernize and improve their agricultural practices. They would likely support the FarmaBooth project. The United States Agency for International Development (USAID) is a similar organization and provides humanitarian and economic assistance worldwide. One sector of USAID provides agricultural assistance.[15] The European Commission's Humanitarian Aid and Civil Protection program is another international organization that can potentially support FarmaBooths, and has specific policies and programs for food assistance.[16]

Lastly, private enterprise may invest in FarmaBooths. The FarmaBooth brand would be a powerful advertising tool to showcase the quality of crops grown. Food distributors would likely want to show that their crops were grown with the best practices in mind.

V. THE DESERT MOVEMENT PREDICTOR

Our IDEAS for Africa's second proposal is the application of a Desert Movement Prediction Center to provide prediction, modeling, and recommendation services to countries affected by desertification. The following sections discuss the benefits, a technical overview of monitoring growing and/or moving deserts, and an examination of how much such a center would cost along with possible funding sources.

V.I Why Use Space-Based Technology?

Predicting desert movements requires a large amount of data, including historical data on the desert and other desertification indicators (including changes in flora, fauna, and humidity), using both ground-based and space-based instruments.

Space-based technologies have a wide number of benefits over other technologies, including:

- Ability to rapidly and remotely measure large areas
- Abundance of data obtained via multiple remote sensing instruments, including optical and infrared data from passive sensors or SAR and InSAR data from active radar
- Ease of distribution of data
- Ability to predict and provide services with respect to disaster management
- Raising awareness of space-based technologies

V.II Technical Overview

There are currently a large number of satellites in orbit available to provide the required imagery and data products for combating desertification.

To assess sand dune displacement and predict future sand dune movements, both wind patterns and medium-resolution optical images are necessary. Furthermore, to see how sand dunes move over time, a large historical database would be advantageous to enhance the predictability of sand dune movements. To understand the entire process, the main parameters to combine include levels of aerosol, humidity, precipitation, topography, vegetation, and wind. The following instruments can provide these parameters:

- *Aerosols:* CALIOP, MERIS, MODIS, and SeaWiFS
- *Humidity:* MIRAS
- *Precipitation:* TRMM
- *Topography:* SAR
- *Vegetation:* MERIS, MODIS, Thematic Mapper (TM)
- *Wind:* ALADIN, SEVIRI

In addition, several weather stations can provide the much-needed ground-truthing for calibrating satellite data. Table 5 lists various capabilities of these instruments.

Measured Entity	Satellite-Instrument	Spatial Resolution	Scene Size	Revisit Time	Date Available
Aerosols	MODIS - Aqua	1,000m	1,200 x 1,200km	1-2 days	Jul. 2002 - present
	MODIS - Terra	1,000m	1,200 x 1,200km	1-2 days	Mar. 2000 - present
	SeaWiFS - SeaStar	1,100m	2,800km (swath)	1 day	Sept.1997 - Dec.2010
Humidity	MIRAS - SMOS	35km	1,050km (swath)	1-3 days	Feb. 2010 - present
Land Cover	MODIS - Aqua & Terra	500m	1,200 x 1,200km	1-2 days	Mar. 2000 - present
Precipitation	TMI - TRMM	5-40km	750km (swath)	0.5 days	Jan. 1998 - present
	PR - TRMM	4.3-5km	220-250km (swath)	0.5 days	Jan. 1998 - present
Vegetation	TM - Landsat	15-120m	170 x 185km	16-18 days	Fall 1972 - present
	MODIS - Aqua	250m	1,200 x 1,200km	1-2 days	Jul. 2002 - present
	MODIS - Terra	250m	1,200 x 1,200km	1-2 days	Mar. 2000 - present
Wind Measured	SEVIRI - MeteoSat	80km	Visible Earth disc	Continuous	Early 1978 - present
	ALADIN - ADM-Aeolus	N/A	N/A	7 days	Late 2013

Table 5: Remote sensing instruments and satellites for use with Desert Movement Prediction Center

Since imagery is presented in different and varying resolutions, sizes, and physically mapped areas, a number of pre- and post-processing steps are required to ensure data consistency. The envisioned steps are shown in Table 6.

Step	Stage	Name
1	Pre-start	Data acquisition
2	Pre-processing	Geo-referencing
3		Geometrical correction
4	Post-processing	Registration
5		Projection
6		Visualization

Table 6: Imagery processing steps

V. III Technological Availability

Looking to real-world institutions, it was determined that China has successfully combated desertification for over 60 years (*via* tree planting, decreased grazing activity, and moving farmlands to forest and grasslands) further promoting the idea that desertification mitigation is possible.[17]

The activities of a Desert Movement Prediction Center would include:

- Data acquisition from satellite operators
- Remote sensing data-processing and analysis
- Research on the physics of dune movement
- Desert movement prediction and recommendations

As discussed in the Technical Overview section, data acquisition sources are abundant and include free commercially available sources. For data processing and analysis, software (*e.g.,* Oracle) would be used for storing and managing raw and processed data. Radiometric and geometric image processing would be performed by software such as ERDAS. Other processing tasks, such as desert movement prediction models, would need to be internally developed.

Desert sand movement occurs in two ways – the movement of the sand dunes across the desert, and the movement of the desert's edge. Typically desert edge movement is more easily monitored than sand dune movement. Desert edge movement can be easily monitored using optical or multispectral remote sensing devices, as well as radar. However, sand dunes are composed mainly of sand, which is difficult to monitor using the same techniques. The IDEAS team has classified sand dune movement in three ways:

- Violent desert movement - Includes sand storms and has sand movements greater than 1 km/h
- Moderate desert movement - Movement of sand mountains on the order of 1m/day
- Passive desert movement - Slow sand drift less than 1m/day

Desert sand movement and prediction can be done in two ways: directly by monitoring and predicting according to historical trends; and indirectly by observing and studying related factors (such as wind, humidity, vegetation, aerosols, and precipitation of the region) and using these factors to predict future movement.[18] Monitoring this phenomenon entails using suitable sensors for each kind of movement, as detailed in Table 7.

Movement Types	Direct Monitoring Methods
Desert edge movement	Optical imaging, SAR, InSAR, multi-spectral imaging
Mild/Moderate desert movement	Optical imaging, SAR, InSAR, radar altimeter
Violent desert movement	Optical Imaging equipped to a GEO satellite

Table 7: Sand movement monitoring techniques

In terms of available remote sensing technologies, optical imaging sensors, while used extensively, have poor resolution for this application. This is because the drift of the desert's edge, which will be the location tracked, moves only a few meters per year, and with optical resolutions greater than 1m, this measurement technique will not be applicable. Likewise multi-spectral imaging makes desert movement prediction difficult, as this technique performs poorly when the targeted area is homogenous.[19] It was determined that InSAR, with its high spatial resolution and ability for 3-dimensional mapping, is the most suitable method for directly measuring mild desert movements.[20]

For data processing and analyzing, Geographic Information Systems (GIS) and desert movement prediction technology has existed for many years and there are many mature methods and algorithms for both enhancing different kinds of images and interpreting images and data. Data analysis methods, such as decision tree analysis, are also applicable.[21] Weather forecasting techniques are also applicable but predicting desert movement trends via direct monitor will prove difficult. In addition, violent movement prediction using the available data sources will remain a difficulty. These two constraints could be overcome with a geostationary satellite with SAR capabilities, but this solution remains a technical challenge due to the size of the antenna and the power required.

V.VI Time to Deployment

The IDEAS team has estimated that establishing a DMPC will be broken down into four development phases, as shown in Table 8.

Phase	Purpose	Length
A	Clarifying and defining the DMPC concept and objectives	9 months
B	Designing the DMPC organization and structure, and securing financing	1 year
C	Acquiring personnel, hardware, software, and other necessary resources	9 months
D	Operations	as long as needed

Table 8: Development phases of the DMPC

V.V Financing. Costs

Estimating the cost of developing the DMPC entails analyzing the cost of imagery, staff, hardware, and software. Satellite imagery, except for InSAR images, incurs no expense. InSAR image costs can be obtained from SAR images costs by doubling it (two passes) and adding a 25% more in terms of processing. The cost of SAR images for areas larger than 100,000 km2 range from USD 0.25 to USD 0.45 per square kilometer.[22] Using a mean value of USD 0.35 per square kilometer, the cost of InSAR images amounts to USD 0.87. Since the target monitoring area of the three African deserts is estimated 3,300,000 km2 (target area is exterior 200km, or the crown, which is a reasonable portion of land to analyze desert movement with high resolution) as shown in Table 9, an estimation of the costs of the DMPC was performed and the results are shown in Table 10. From this, it is shown that, assuming four pictures per year, a total imagery cost of approximately USD 11.5 million, and hence a 5-year total project cost of almost USD 57.5 million.

Desert	Surface ('000 km²)	Perimeter ('000 km)	Crown ('000 km²)	Total ('000 km²)
Sahara	9,000	13	2,600	
Kalahari	900	3	560	3,300
Namib	90	N/A	80	

Table 9: Size of target area

In a personal conversation on 29th February 2012, according to Dr. Singhroy a staff of twenty is assumed for this project. To obtain an overestimation of the human resources cost, and because data regarding African worker compensation is difficult to obtain, US hourly worker compensation rates were used (at USD 30.18 in 2010) and the annual yearly expense for workers was therefore estimated to be USD 1.3 million.[23] Hardware for the DMPC will include five computer servers (estimated at USD 13,000 per unit) and twenty workstations (USD 2,500 per unit). Total hardware costs are USD 100,000 for the whole project. Software licenses for the center are estimated at USD 25,000. Cost estimation is summarized in Table 10, with costs less than USD 13 million per year.

Concept	Annual Cost (USD million)	Project Cost (USD million)
Satellite Imagery	4.9	25
Human Resources	1.3	6.5
Hardware	0.02	0.1
Software	0.01	0.03
Total	*6.2*	*31*

Table 10: Desert Movement Predictor cost estimation

V. VIII Financing and Funding Sources

African countries affected by desertification will likely be most interested in this project and hence will be the immediate source of funding. Additional sources outside of Africa include bilateral development assistance, which are typically given as grants.[24] The Global Environment Facility (GEF) focuses on land degradation and therefore is a potential source of funding. The GEF is an independent financial organization that provides grants to developing countries, countries with economies in transition, supports projects related to environmental challenges, and promotes sustainable livelihoods. The GEF serves as financial mechanism of the United Nations Convention to Combat Climate Change (UNCCD) and its partnership agencies including the World Bank, the African Development Bank, and the IFAD. All these may be interested investors and funders.[25]

Another major source of funding is the AU's NEPAD. NEPAD aims to mobilize sufficient resources for the implementation of priority programs and projects that address Africa's sustainable development. It looks to achieve this by establishing a platform for global partnerships and collaboration with advanced industrialized countries of the G8 and the Organization for Economic Cooperation and Development. In addition it seeks to establish partnerships with regional organizations like *Comité permanent Inter Etats de Lutte contre la Sécheresse dans le Sahel* (Inter State permanent Committee for the Fight against Drought in Sahel) and with multilateral development institutions such as the *Union Économique et Monétaire Ouest-Africaine* (West African Economic and Monetary Union).[26]

VI. IMPLEMENTATION IN AFRICA OF THE FARMABOOTHS AND THE DESERT MOVEMENT PREDICTOR

VI.I The Three Target Countries of IDEAS for Africa

Different countries and regions have different needs and capabilities. In order to manage this, three target countries were selected to act as representations of the whole continent. The three target countries - South Africa, Morocco, and Liberia - met our requirements for their dissimilar characteristics. With their diversity in geographical location (northern, southern, and central Africa), climate and environment (desert, semi-arid, and tropical rainforest), governance (republics and a constitutional monarchy), and in their levels of development and challenges, they represent a broad representative range of Africa. As a result, the IDEAS for Africa team believes that South Africa, Morocco, and Liberia emerge as very good representatives of common African realities, and excellent discussion points for the implementation of projects such as FarmaBooths and the Desert Movement Predictor.

VI. II Implementation in target countries

FarmaBooths

These village resource centers are especially relevant to Liberia, where rice and cassava are the main staple crops and rubber, palm oil, and cocoa are the dominant export crops. Liberia's agricultural sector constitutes almost 80 percent of real GDP, and almost 70 percent of the Liberian population is involved in agriculture.[27] Nevertheless, in many Liberian counties, there is only enough self-produced food to feed half of the population. External support for agriculture is extremely small, indicating need for FarmaBooths.[27] Figure 5-5 shows the percentage of Liberians involved in food production, the percentage of Liberians self-reliant on their own food production, and the percentage of external aid into Liberia's agricultural sector.

Increasing crop yields through technology can raise farmer incomes, promote food stability, and facilitate the efficient use of resources like water and arable land. As a country rebounding from a generation of bloodshed and disorder, Liberia requires a means of encouraging development and stability, and aiding the largest sector of its economy can drive this stability and development.

Implementing the FarmaBooth project in Liberia is possible as, it is a member of the Pan-African e-Network - which has centers at the University of Liberia, the John F. Kennedy Memorial Hospital, and at the Liberia Telecommunications Corporation, all in Monrovia. Each could serve as a centralized FarmaBooth facility.[28]

For Morocco and South Africa, FarmaBooths are also possible. However, since neither of these countries is part of the Pan-Africa e-Network, implementation there would likely involve additional start-up costs. Consequently, application for these countries was not considered feasible at this time.

Desert Movement Predictor

Almost fully covered by tropical rainforest, the effects of drought and desertification in Liberia are minimal. Less than seven percent of Liberia's territory is in a moderate risk of desertification. The causes of land degradation in Liberia are not related to desert advancement, but to agriculture and logging.[29] Consequently, a DMPC is not directly applicable to Liberia.

Located adjoining the Atlantic Ocean, the Mediterranean Sea, and the Sahara Desert, Morocco has an arid climate and high vulnerability to soil erosion which is caused by both salination and deforestation. The country has desertification concerns in more than 90 percent of its territory. Many Moroccan farmlands are non-irrigated, promoting the conditions for desertification.[30] Cognizant of the inverse relationship between desertification and development, in 2001 Morocco drafted an National Action Plan (NAP) for combating desertification, the *Programme d'Action National de Lutte Contre la Désertification* (PAN-LCD), which was included in the national strategy for reducing poverty and creating sustainable development.

New governmental departments were created in 2003 and 2004, including the Commission for Water, Forests and Desertification. The PAN-LCD also promotes partnerships with other countries and institutions, including the UN, the EU, Germany, and the Observatory of Sahel and Sahara.[31] Within this context, the DMPC meets all the interests of Morocco, and would be a powerful tool for its scientists and environmentalists to forecast the evolution of agricultural lands, to design and apply desertification countermeasures, and to alert populations about dust clouds. These functions will lead to reducing migration to urban areas (*via* preservation of rural and agricultural areas), consolidate Morocco's sustainable agriculture, and an improvement in urban health.

With the vast Kalahari Desert in the north, and the Namib Desert in the west, South Africa's territory is 10 percent desert, as shown in Figure 5-16. More than 90 percent of South Africa is classified as either arid, semi-arid, or sub-humid.[32] Furthermore, 25 percent of the magisterial districts in South Africa have lands in a severe state of degradation.[32] Consequently, desertification and land degradation is a huge problem in South Africa. The edges of the southern Kalahari Desert are the zones of highest deterioration in the country. The introduction of artificial waterpoints and veterinary fences has led to the rapid desertification of large drylands and adjacent areas. The other causes for land degradation include over-grazing, over-cropping, and incorrect irrigation practices.

The South African government is committed to the fight against desertification and land degradation, having ratified the UNCCD in 1997. As a result of this convention, the Department of Environmental Affairs and Tourism (DEAT) prepared an NAP outlining the national policy on desertification.[33] Consequently, the IDEAS for Africa team believes the DMPC will be of interest in South Africa as well, helping to understand the evolution of both Namib and Kalahari Deserts, and assisting the national government to implement efficient environmental policies. The DMPC fits perfectly within this regulatory framework, meeting all the requirements and needs specified by the government for sustainable environmental development.

Fig. 5: Agricultural fields in Morocco

VI. III Application To Other Countries

FarmaBooths

Agriculture is the backbone of many African countries. The continent has an enormous variety of growing conditions. The fertile soils of Sub-Saharan Africa provide many opportunities, while the deserts in the north and south of the continent present many challenges. The application of FarmaBooths throughout the continent is a real possibility to enable farmers to use their available resources to their maximum efficiency.

FarmaBooth information centers can be tuned depending on geographic location, variety of crops, and environmental characteristics of the surrounding area. For example, information provided to croplands in more arid regions would provide advanced details about water reservoirs, whereas crowded agricultural zones would have access to mapping information to ensure farmers were respective property rights. One of the major benefits of the FarmaBooths is the ability to connect it to the information provided by the Desert Movement Prediction Center. The information from that application could be sent to FarmaBooths enabling individuals in rural areas access to this information.

Desert Movement Predictor

Two thirds of the African continent is desert or drylands.[24] In the North, the Sahara Desert covers large areas of eleven countries: Algeria, Chad, Egypt, Libya, Mali, Mauritania, Morocco, Niger, Western Sahara, Sudan, and Tunisia. In the South, the Kalahari Desert spreads over Botswana, Namibia, and South Africa, and the Namib Desert runs along the coasts of Angola, Namibia, and South Africa. Consequently, seventeen countries in Africa (one third of the total) are affected by the environmental and economic challenge that desertification entails.

The Desert Movement Prediction Center is conceived as a cooperative project that involves all the affected countries. Dividing the project into territories, or isolating a country from the project minimizes its scope and efficiency (*e.g.*, imagery costs per km^2 decrease with a larger covered area). All African countries are party to the UNCCD and have developed their NAPs with the review of local authorities, community leaders, and NGOs.[24]

In addition to the NAPs, African countries have created regional and sub-regional plans to facilitate cooperation and to better align their programs to the UNCCD 10 Year Strategy, gaining effectiveness in addressing desertification, land degradation and drought.[24] The DMPC arises as a perfect project which fits into these regional and sub-regional cooperative plans because it fulfills with Strategic Objective 3, which is to generate global benefits through effective implementation of the UNCCD, and Strategic Objective 4, which is to mobilize resources to support implementation of the Convention through building effective partnerships between national and international actors.[34]

VII. SUMMARY AND CONCLUSION

According to 2011 Mombassa Declaration on Space and Africa's Development, Africa is committed to harnessing space science and technology to drive resource management for sustainable development. Following this line, the IDEAS for Africa team has proposed two Earth Observation based applications that clearly aids the furtherance of these goals.

First, the FarmaBooths system will provide time-accurate information to rural farmers on how to effectively use resources to maximize crop production, allowing more stable, predicable, and productive harvests. The technology and infrastructures are available, and the project can be implemented in a reasonable time with reasonable costs. An analysis of the strengths, weaknesses, opportunities and threats to implementing the FarmaBooths project was performed, and is summarized in Table 11.

Strengths
Most data is freely available
Revisit time (2 days for MODIS and 16 days for

	Landsat) makes regular monitoring possible
	High spatial resolution (30m and 250m) enables high detail monitoring
Weaknesses	
	End-users need training in information interpretation
Opportunities	
	New methods for preventing property conflicts, optimizing land usage, and increasing crop yield
	Utilization of the Pan African e-Network
Threats	
	Free access to information may create local conflicts
	Lack of training resources for interpretation personnel in Liberia

Table 11: SWOT analysis for FarmaBooths

Secondly, The IDEAS for Africa team has also recommended the establishment of a DMPC in Africa to aid in the measurement and prediction of desert movement. The DMPC will also provide information that can be used to mitigate or reverse the effects of desert movement. The DMPC is to address the focus areas of agriculture and the environment, and is applicable for the target countries of Morocco and South Africa as these countries have challenges with encroaching deserts. Table 12 shows the SWOT analysis that was performed on the concept of a Desert Movement Prediction Center:

Strengths	
	Most data freely available
	Provides information in regards to health issues, urban planning, and water management
	Shared costs among affected countries
	Aligned with UN strategy for combating desertification, which assures funding sources
	It is a source of highly qualified job positions for local professionals
Weaknesses	
	Difficulty in integrating data from various types of imagery (ex. Aerosols, humidity, topography, vegetation, and winds)
	Ground-truthing necessary to calibrate and validate data
	Wind data services lag in spatial resolution
	Wind information from MeteoSat is estimated by monitoring cloud movements, so surface winds may not match
	Expensive SAR data
Opportunities	
	Foster research and development in the regions of interest
	Set the basis for technology transfer from more developed countries to Africa
Threats	
	Affected countries may prefer individual studies rather than a continental one
	Requires cooperation of diverse groups of African peoples

Table 12: SWOT analysis for the DMPC.

VIII. ACKNOWLEDGEMENTS

The IDEAS for Africa Team would like to thank the entire faculty, staff, and fellow students of the International Space University. Specifically we wish to thank the rest of the IDEAS for Africa Team and our Team Project advisors Prof. Angie Bukley, Prof. John Farrow, Prof. Hugh Hill and Aliakbar Ebrahimi. This paper would have been impossible without your incredible efforts. We wish to thank our external advisors Donald James from New Ventures and Communications at NASA Ames and Dr. Vern Singhroy from the Canada Centre for Remote Sensing for their incredible help. Lastly we wish to extend our most sincere thanks to the NASA Earth Science Division's Applied Science Program for their generous support of this project, and for helping to make space a reality for future African students.

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