Stochastic Optimization Model Using Remote Sensing Technology for Agricultural Management in Africa

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Abstract

- Information communication technology is the key to agricultural development if less developed countries (LDCs) are to optimize agricultural management (Di Bella, 2004).
- limited accessibility to ICTs, LDCs still lag behind in exploiting technologies for timely decision making in agricultural management (Elisabetta Carfagna, 2005).
- Agricultural management in Africa is hampered by among other parameters the uncertainties that surround the following questions: when is the next rainy season? How long are the next rains expected to take? What is the likely intensity of these rains? Are they sustainable? What if we planted now? Are we likely to gain if we waited for two more months? How do we determine the disease or pest attaching our plants? How about if we used the other chemical/fertilizer?
- We also present a model that attempts to minimize the common phenomenon in LDCs of time wastage between planting of crops, hence optimization of agricultural management in Africa.

Introduction

- Satellite imagery and related information and communication technology are the most important avenues of information and knowledge discovery, an aid to making timely, accurate and informed decisions in agricultural production in the world.
- The Meteosat Second Generation spacecraft was designed to take advantage of new technologies and to improve on the already successful and proven spacecraft design of the original Meteosat satellites. The SEVIRI radiometer on-board the MSG satellite has a total of 12 channels that scan images of the earth every 15 minutes (Project, 2004).

Agricultural Management in Africa

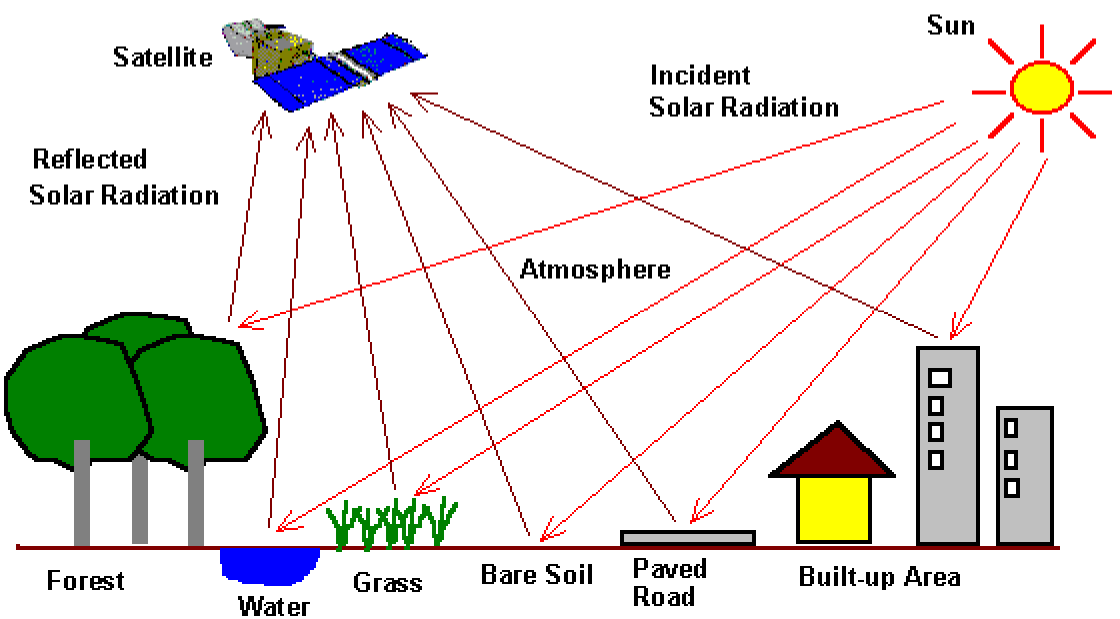
- Agriculture is undoubtedly the most important sector in the economies of most non-oil exporting African countries. It constitutes approximately 30% of Africa's GDP and contributes about 50% of the total export value, with 70% of the continent's population depending on the sector for their livelihood.
- (Mike Hulme, 2000) discussed the five main climate change related drivers: temperature, precipitation, sea level rise, atmospheric carbon dioxide content and incidence of extreme events
- The impact of these adverse climate changes on agriculture is exacerbated in Africa by the lack of adapting strategies, which are increasingly limited due to the lack of institutional, economic and financial capacity to support such actions plus limited ICT usage for the monitoring such as remote sensing technologies.

Climate Change and Agricultural Management in Africa

- Agriculture in low latitude developing countries is expected to be especially vulnerable because climates of many of these countries are already too hot
- Further warming is consequently expected to reduce crop productivity adversely
- reductions of impacts across regions consequently suggest large changes in the agricultural systems of low latitude mostly, developing countries

Using Remote Sensing technology in Agricultural Management in Africa

- remote sensing refers to the activity of using electromagnetic properties to view or interpret phenomena while not physically in contact with it



Eminent Agric mngt problems in Africa solvable by remote sensing techniques

- Reliability of data
- Cost and benefits
- Timeless
- Incomplete sample frame and sample size
- Methods of selection
- Measurement of area
- Non sampling errors
- Gap in geographical coverage
- Non availability of statistics at disaggregated level.

Remote Sensing techniques for Agricultural management

The following factors influence the use of remote sensing in agricultural surveys

- **Characteristics of the agricultural landscape**

  Detection, identification, measurement and monitoring of agricultural phenomena are predicated on the assumption that agricultural landscape features e.g. crops, livestock, crop infestations and soil anomalies have consistently identifiable signatures on the type of remote sensing data.

  Some of the parameters which may cause these identifiable signatures include crop type, state of maturity, crop density, crop geometry, crop moisture, crop temperature, soil moisture, soil temperature.

Remote Sensing techniques for Agricultural management cont'd

- Characteristic of EMR on Agricultural management

  Factors that evidently affect soil reflectance are moisture content, soil texture, surface roughness and presence of organic matter. Determination of spectral signatures implies basic understanding of interaction of electromagnetic radiation with agricultural resources management.

Use of wavelength region Correlation

Area of agricultural phenomena	Possible Remote sensor	Wavelength employed
Plant diseases and insect infestation	MSG, Radar, Photographic cameras	0.4-0.9 mm and 0.6-1.0 mm
Natural vegetation, types of crop and fresh inventories	MSG, Radar, Photographic cameras	0.4-0.9 mm and 0.6-1.0 mm
Soil moisture content (radar)	MSG, Radar, Photographic cameras	0.4-0.8 mm and 0.3-1.0 mm
Study of arable and non-arable land	MSG, Radar, Photographic cameras	0.4-0.9 mm
Assessment of plant growth and rigor for forecasting crop yield	MSG, Radar, Photographic cameras	0.4-0.9 mm
Soil type and characteristics	MSG, Radar, Photographic cameras	0.4-1.0 mm
Flood control and water management	MSG, Radar, Photographic cameras	0.4-1.0 mm and 0.6-1.2mm
Surface water inventories, water quality	MSG, Radar, Photographic cameras	0.4-1.0 mm and 0.6-1.2mm
Soil and rock type and conditions favorable for hidden mineral deposits	MSG, Radar, Photographic cameras	0.4-1.0 mm and 0.7-1.2 mm

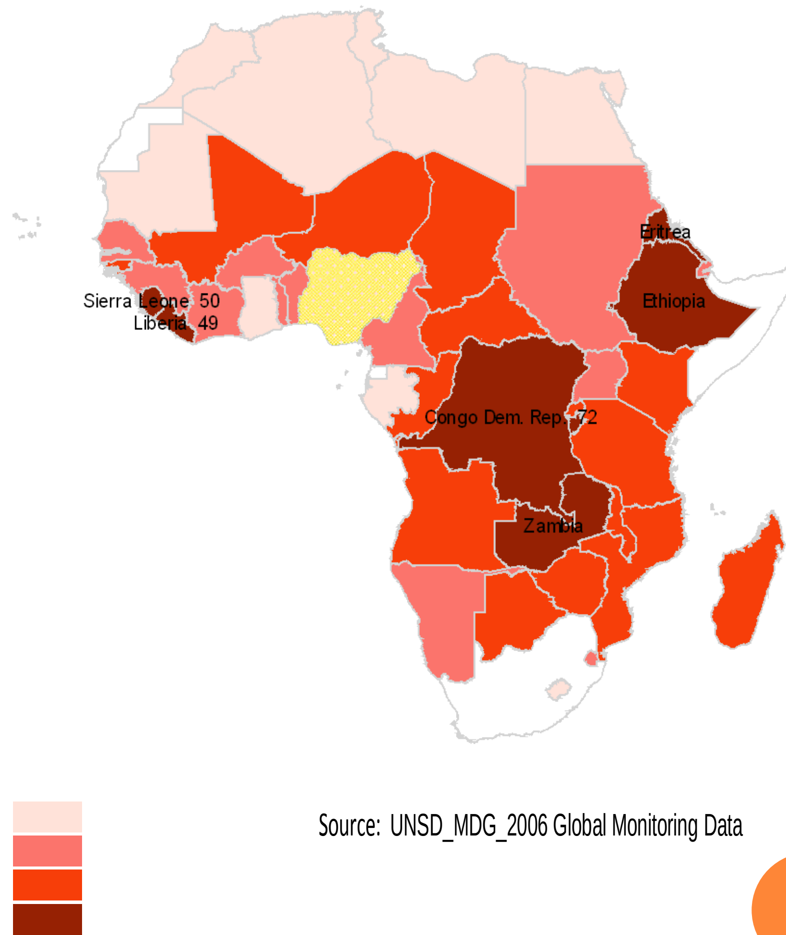
Eumetsat Satellite Applications Facilities

- African National Meteorological Services, in close partnership with others involved with development in Africa, and in addition to the traditional meteorological services, develop applications in the following fields: Water Development and Management, Flood Forecasting and Monitoring, Flood Damage Assessment, Agricultural Management, Landslide Risk Monitoring, Food Security, Post Crisis Food Aid Assessment, Forest Fire Monitoring, Forest Fire Risk Assessment, Land Cover Changes and Pest Monitoring
- Other products delivered by the VGT4AFRICA partners include: NDWI-water index, burnt area, phenology, small water bodies, albedo and fcover

Drought Monitoring using MSG Satellite data

- The EUMETSAT Satellite Application Facility on Land Surface Analysis (LSA SAF) led by the Portuguese National Meteorological Service, has been used to monitor desertification and drought threatened areas, providing an important source of information to combat environmental degradation
- The operational Land SAF products are available free of charge in near real time via EUMETCast – EUMETSAT's Broadcast System for Environmental Data that is accessible to Africa.

Map of Africa showing the Undernourished Population



Source: UNSD_MDG_2006 Global Monitoring Data

Stochastic Optimization Model for Agricultural Production in Africa

- The model developed in this paper seeks to help decision making by obtaining an optimal situation to minimize unnecessary delays in agricultural production using stochastic modeling
- Decisions made in agricultural production depend on a number of parameters including the stochastic weather conditions which also resolve a number of things among which are the planting and harvesting periods, besides whether or not a crop will successfully grow within a predetermined time period

The Model

$$Min\sum_{q\in\Theta}P\{q\}x\left\{\left[\sum_{c\in\Phi}\sum_{t=Plantc}^{T+1}(t-Plantc)x\left(X_{c,t}^{q}-X_{c,t-1}^{q}\right)\right]+\lambda\times\sum_{t=1}^{T}W_t^q\right\}$$

$$X_{c,t}^{q}-X_{c,t-1}^{q}\geq 0 \quad \text{for all} \quad \begin{array}{l} t\in\{Plantc,\ldots,T+1\} \\ c\in\Phi \\ \mathbf{q}\in\Theta \end{array}$$

$$W_{t-1}^{q}-W_t^q+\sum_{c\in\Phi}\left(X_{c,t}^{q}-X_{c,t-1}^{q}\right)\leq M_t^q \quad \text{for all} \quad \begin{array}{l} t\in\{1,\ldots,T+1\} \\ q\in\Theta \end{array}$$

$$W_0^q=W_{T+1}^q=0$$

$$X_{c,T+1}^{q}=1$$

NOTATION AND DEFINITIONS

$\Phi = \{1,2,....,C\}$ be a set of crops

$\Gamma = \{1,2,....,T+1\}$ be a set of finite time periods, seasons

Given crop $c \in \Phi$ then $Plant_c \in \Gamma$ and $Harvest_c \in \Gamma$

Let $\lambda \geq 1$ where λ the unit cost is for dry season and rainy assumed for all crops

Let Θ be a set of capacity scenarios where $q \in \Theta$ and

P{q} be the unconditional probability of occurrence of a scenario $q \in \Theta$

M_t^q be scenario-specific time varying capacity of the farm where $t \in \Gamma$ and $q \in \Theta$ which set upper bounds on the number of crops that can be grown during each time period

M_{T+1}^q is the farm capacity of the last time period

Decision variables

$$X_{c,t}^{q} = \begin{cases} 1\, if \text{ crop c is planned to be ready by end of time period t under scenario q} \\ 0 \text{ otherwise} \end{cases}$$

where

$$q \in \Theta$$
$$c \in \Phi$$
$$t \in \{Plant_c, ..., T+1\}$$

Assumptions

- System – field/farm is empty(no crops) at the beginning of the planning period
- All crops grow and are harvested by the end of period T+1

Some sample data – model validation

c	t	$X^q_{c,t}$	$X^q_{c,t-1}$	$X^q_{c,t} - X^q_{c,t-1}$	W^q_t	$\sum_{t=1}^{T} W_t^q$	P{q}	c-t		λ	$\sum_{t=1}^{T} W_t^q$
Plantc	time period	crop planned to be ready in time t given scenario q	crop planned to be ready in time t-1 given scenario q	difference	No. of crops planned at end of t, scenario q	Total number of crops, time t, under scenario q	Probability of occurrence of scenario q	plantc minus time t	product of first term	unfavourable to favourable	Total number of crops, time t, under scenario q
1	1	1	0	1	500			0	0	1	
	2	1	0	1	500			1	1		
	3	1	0	1	500	1500	0.28	2	2		
2	1	1	0	1	1000			-1	-1		
	2	1	0	1	1000			0	0		
	3	1	0	1	1000	3000	0.56	1	1		
3	1	1	0	1	300			-2	-2		
	2	1	0	1	300			-1	-1		
	3	1	0	1	300	900	0.17	0	0		
					5400		1		0	5400	

Some sample data – model validation

c	t	$X^q_{c,t}$	$X^q_{c,t-1}$	$X^q_{c,t} - X^q_{c,t-1}$	W^q_t	$\sum_{t=1}^{T} w_t^q$	P{q}	c-t		λ	$\sum_{t=1}^{T} w_t^q$
Plantc	time period	crop planned to be ready in time t given scenario q	crop planned to be ready in time t-1 given scenario q	difference	No. of crops planned at end of t, scenario q	Total number of crops, time t, under scenario q	Probability of occurrence of scenario q	plantc minus time t	product of first term	unfavourable to favourable	Total number of crops, time t, under scenario q
1	1	1	0	1	500			0	0	1.5	
	2	1	0	1	500			1	1		
	3	1	0	1	500	1500	0.28	2	2		
2	1	1	0	1	1000			-1	-1		
	2	1	0	1	1000			0	0		
	3	1	0	1	1000	3000	0.56	1	1		
3	1	1	0	1	300			-2	-2		
	2	1	0	1	300			-1	-1		
	3	1	0	1	300	900	0.17	0	0		
					5400		1		0	8100	

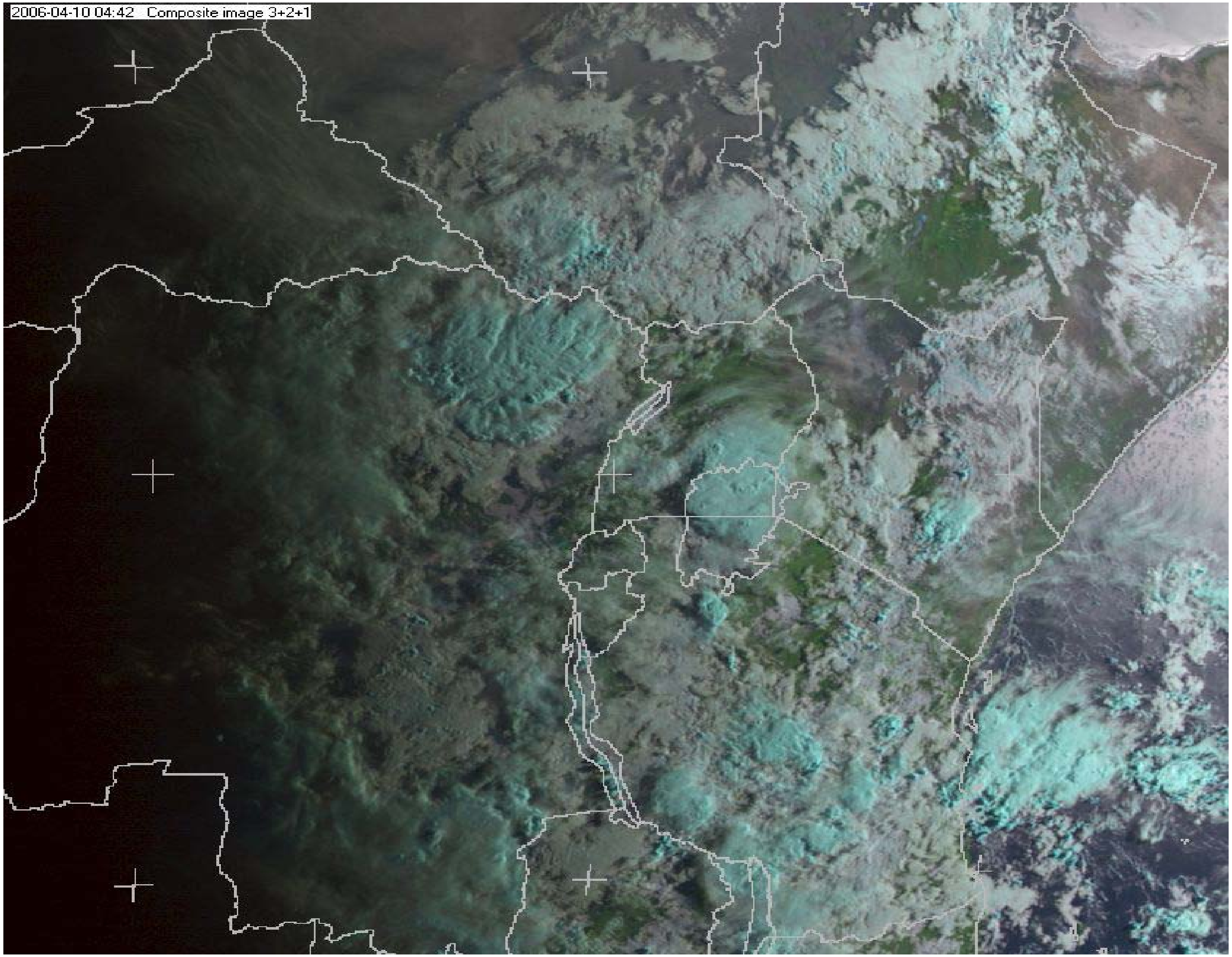
Discussion

- Agricultural delays of crops in Africa is a function of the time period amongst other parameters.
- Some time periods are more favored with the necessary optimal weather and resource facilitation than other time periods resulting into difference in cost of production
- Quite often the weather parameter is stochastic in nature and tends to vary in an unpredictable way such that for the majority of peasants in Africa, a whole season or more may go without any agricultural production.
- These delays are actually a source of food insecurity and hunger in Africa as a whole despite the vast amount of productive land.
- The question of how to minimize agricultural production delays for crops was the major concern in this paper

Conclusion and Recommendations

- In order to maintain a consistent and sustainable agricultural production, one requires perfect knowledge of a number of parameters necessary for agricultural management that may be possible with use of the available remote sensing technologies such Meteosat Second Generation satellite data
- Study recommends use of tools such as the stochastic optimization model developed in this paper
- It was showed that to minimize the cost of production while maintaining agricultural production throughout the year, λ, the cost ratio of production between unfavorable and favorable seasons should be kept as close to one as possible, by having just in time decisions through use of MSG satellite data
- It is recommended that there should be coordination of activities in different ministries of African Governments

Some satellite imagery



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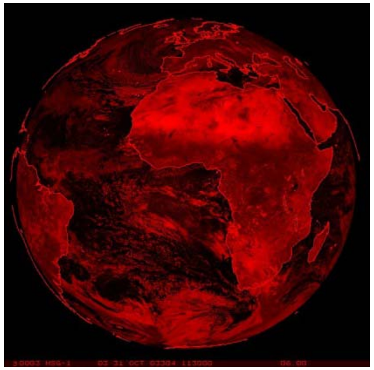

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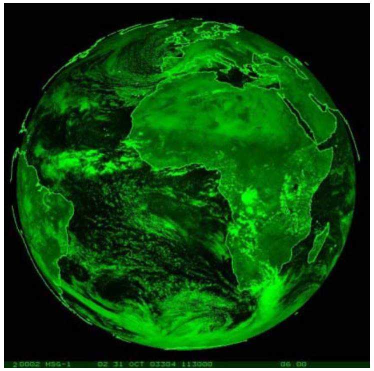

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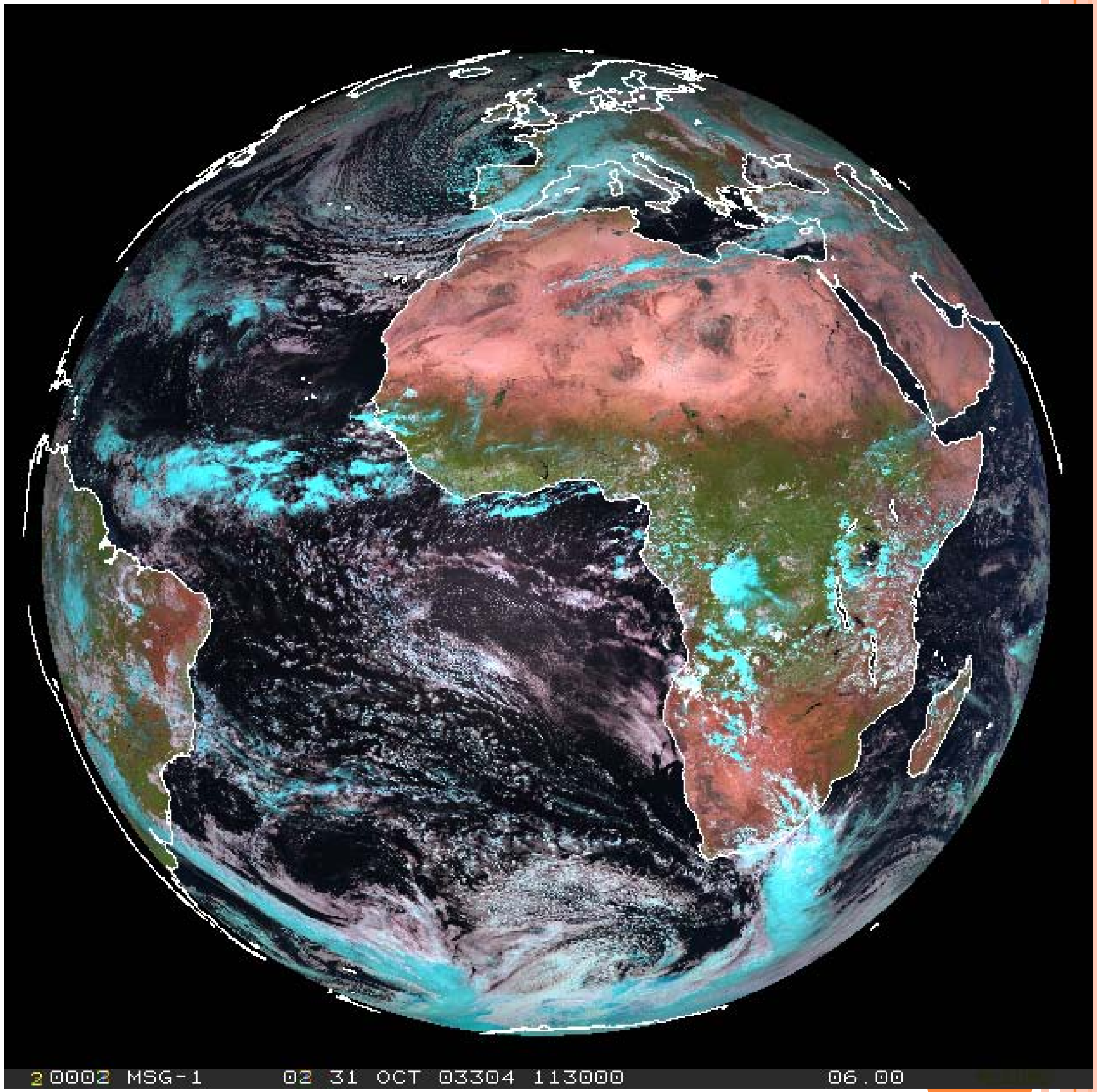

NATURAL COLOURS physical interpretation

Red	Cloud depth as well as snow/ice and droplet differentiation, provided by the visible reflectance at 1.6μm.
Green	Cloud depth and “greenness” of vegetation, provided by visible reflectance at 0.8μm.
Blue	Cloud depth, some haze and non green-sensitive land surface information, provided by reflectance at 0.6μm.

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ACRONYMS

LDC	Least Developed Country
ICT	Information Communication Technology
MSG	Meteosat Second Generation
SEVIRI	Spinning Enhanced Visible and Infrared Imager
NDWI	Normalised Difference Water Index
GERB	Geostationary Earth Radiation Budget
GEOSAR	Geographic Synthetic Aperture Radar
GDP	Gross Domestic Product
MTA	Meteorology Transition Africa
VGT4AFRICA	Vegetation for Africa
EUMETSAT	European Meteorological Satellite
LSA	Land Surface Analysis
SAF	Satellite Application Facility
UN	United Nations
MDG	Millennium Development Goal