

# Designing AfriCultuReS services to support food security in Africa

Alexandridis, T.K.<sup>1\*</sup>, Ovakoglou, G.<sup>1</sup>, Cherif, I.<sup>1</sup>, Gómez Giménez, M.<sup>2</sup>, Laneve, G.<sup>3</sup>, Kasampalis, D.<sup>1</sup>, Moshou, D.<sup>1</sup>, Kartsios, S.<sup>4</sup>, Karypidou, M.C.<sup>4</sup>, Katragkou, E.<sup>4</sup>, Herrera García, S.<sup>5</sup>, Kganyago, M.<sup>6</sup>, Mashiyi, N.<sup>6</sup>, Pattnayak, K.<sup>7</sup>, Challinor, A.<sup>7</sup>, Pritchard, R.<sup>8</sup>, Brockington, D.<sup>8</sup>, Kagoyire, C.<sup>9</sup>, and Suarez Beltran, J.<sup>2</sup>

<sup>1</sup> Department of Hydraulics, Soil Science and Agricultural Engineering, School of Agriculture, Aristotle University of Thessaloniki, Thessaloniki, 54124, Greece

<sup>2</sup> GMV Aerospace and Defence S.A.U., Remote Sensing Services and Exploitation Platforms Division. Isaac Newton 11 (PTM), E-28760 Tres Cantos, Spain

<sup>3</sup> Scuola di ingegneria Aerospaziale – Sapienza Università di Roma, Italy

<sup>4</sup> Department of Meteorology and Climatology, School of Geology, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

<sup>5</sup> Meteorology Group, Dpto. de Matemática Aplicada y Ciencias de la Computación, Universidad de Cantabria, Santander, Avda. de los Castros, s/n, 39005, Spain

<sup>6</sup> Earth Observation directorate, South African National Space Agency, The Enterprise Building, Mark Shuttleworth Street, Pretoria, 0001, South Africa

<sup>7</sup> Institute for Climate and Atmospheric Science, School of Earth and Environment, The University of Leeds, LS2 9JT Leeds, UK

<sup>8</sup> Sheffield Institute for International Development, The University of Sheffield, Western Bank, Sheffield S10 2TN, UK

<sup>9</sup> Center for Geographic Information Systems and Remote Sensing, University of Rwanda, Rwanda

\*Contact author: [thalex@agro.auth.gr](mailto:thalex@agro.auth.gr)

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## Abstract

Earth Observation (EO) data are increasingly being used to monitor vegetation and detect plant growth anomalies due to water stress, drought, or pests, as well as to monitor water availability, weather conditions, disaster risks, land-use/land-cover changes and to evaluate soil degradation. Satellite data are provided regularly by worldwide organizations, covering a wide variety of spatial, temporal and spectral characteristics. In addition, climate and crop growth models provide early estimates of the expected weather patterns and yield, which can be improved by fusion with EO data. The project “AfriCultuReS” is capitalizing on the above to contribute towards an integrated agricultural monitoring and early warning system for Africa, supporting decision making in the field of food security. The aim of this paper is to present the design of EO services within the project, and how they will support food security in Africa. The designed services cover the users' requirements related to climate, drought, land, livestock, crops, water, and weather. For each category of services, results from one case study are presented. The services will be distributed to the stakeholders and are expected to provide a continuous monitoring framework for early and accurate assessment of factors affecting food security in Africa.

**Keywords:** earth observation, agricultural monitoring system, early warning system.

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## 1 **1. Introduction**

2 The World Food Summit determines that a population is food secure “when all people, at all times,  
3 have physical, social, and economic access to sufficient, safe and nutritious food that meets their  
4 dietary needs and food preferences for active and healthy life” (FAO, 2009). This concept includes  
5 different dimensions related to food availability (sufficient quantities of food with appropriate  
6 quality), food access (to a nutritious diet), utilization (to reach a state of nutritional well-being  
7 where all physiological needs are met via diet, clean water, sanitation, and health care), and  
8 stability (access to adequate food at all times) (FAO, 2006).

9 In 2017, 31 percent of the total number of food insecure people in the world (821 million people)  
10 were in Africa (CDKN, 2019). In various parts of Africa, climate change has produced lower  
11 animal growth rate and productivity in pastoral systems; impacted on agricultural pests patterns;  
12 increased desertification, which affects 46 out of 57 African nations; and increased the frequency  
13 and intensity of droughts (CDKN, 2019; IPCC, 2019). Droughts and desertification processes  
14 impact adversely on water resources, which play a key role in agricultural management practices  
15 (Falkenmark & Galaz, 2007) via a) withdrawal of water for irrigation; b) land cover change (e.g.  
16 when forests are converted to agricultural land); and c) alterations in water division due to changes  
17 in land use management (Deutsch et al., 2010). In addition, land degradation has decreased  
18 agricultural incomes in different countries, with significant consequences for livelihoods; for  
19 example, in Ghana, loss of agricultural income due to land degradation was anticipated to cause a  
20 5.4 percent increase in national poverty rates between 2006 and 2015 (Diao & Sarpong, 2011). It  
21 has been argued, though, that many statistics for African economy lack reliable data, which is an  
22 important constrain to decision making (Jerven, 2013). Thus, there is an urgent need for accurate  
23 and widely available multi-source information such as land use, farm statistics, crop models, and  
24 climate projections to contribute to well-informed agricultural risk assessments, decision making,

25 and governance at multiple levels.

26 Earth Observation (EO) technology has become a common tool to monitor agricultural production  
27 systems and food insecurity in industrialized and emerging countries (Rembold et al., 2019;  
28 Whitcraft et al., 2019); however, its single use in the context of food security poses challenges  
29 related to estimate crop areas and production forecast (Fritz et al., 2019) . EO data has to be  
30 combined or fused with multiple data sources to accurately predict crop production in complex  
31 food and farming systems. Consequently, agricultural monitoring systems are often based on  
32 rainfall data, sample field measurements, agricultural statistics, agro-meteorological modelling,  
33 and EO-based methods. An example of agricultural monitoring systems that covers Africa is the  
34 CropWatch Cloud (<http://cloud.cropwatch.com.cn/>) that is deployed via Alibaba Cloud and  
35 provides users access to Earth observation information layers for crop monitoring. Another  
36 example is the Agricultural Market Information System (<http://www.amis-outlook.org/>), an inter-  
37 agency platform to enhance food market transparency and encourage international policy  
38 coordination in times of crisis.

39 The EC funded H2020 project "AfriCultuReS: Enhancing Food Security in African Agricultural  
40 Systems with the Support of Remote Sensing" (Grant N° 774652) uses EO-based products,  
41 meteorological and climate data to develop an integrated agricultural monitoring and early  
42 warning system for Africa to support decision making in the field of food security. The target  
43 sectors of the AfriCultuReS project are: the public sector, the agribusiness sector, the financial  
44 sector and the academic sector. We have engaged with potential users from eight African countries  
45 through several workshops and surveys to collect specific requirements and feedback about data  
46 and products useful for monitoring and assessing agricultural production, and to understand  
47 capacity building needs. According to user's feedback, we developed a service portfolio with  
48 seven services (i.e. climate, drought, livestock, land, crop, weather, and water). In this paper, we

49 present how these services have been designed and implemented with several case studies.

## 50 **2. Material and methods**

### 51 **2.1. Study areas**

52 The focus of the AfriCultuReS activities is on the following regions in Africa: Equatorial and  
53 Central Africa, East African Highlands, Gulf of Guinea, Great Horn of Africa, North Africa  
54 Mediterranean, Sahel and Southern Africa. More specifically, eight pilot countries were selected  
55 in the aforementioned regions (Figure 1): Tunisia, Niger, Ghana, Ethiopia, Kenya, Rwanda,  
56 Mozambique, and South Africa. The AfriCultuReS services were developed in these eight African  
57 pilot countries considered to reflect the diversity of climate, eco-systems, and farming conditions  
58 in Africa. Test sites within the pilot countries were selected for testing products at finer spatial  
59 scales. Work in each of the eight countries is carried out in close collaboration with a local African  
60 partner organization, a full list of which can be found on the AfriCultuReS website  
61 ([www.africultures.eu](http://www.africultures.eu)).

62 **[Figure 1 somewhere here]**

63 According to the Koeppen climate classification, which uses the transition zones between two  
64 biomes and climate variables to define boundaries between regions, there are four first-order  
65 climate classifications divisions in Africa: tropical, dry, mesothermal and the East African  
66 highlands. From north to south, the typical climate changes from warm Mediterranean over the  
67 coasts of North Africa to semi-arid and warm desert over the Sahara, switching to tropical savanna  
68 and monsoon climate over the equatorial regions, and then changing again to humid subtropical  
69 and warm/temperate oceanic at the south.

70 The delineation of the major farming systems provides a useful framework within which  
71 appropriate agricultural development strategies and interventions can be determined. The decision  
72 to adopt very broad farming systems inevitably results in a considerable degree of heterogeneity

73 within any single system. However, the alternative of identifying numerous, discrete, micro-level  
74 farming systems in each country - which could result in hundreds or even thousands of systems  
75 worldwide - would complicate the interpretation of appropriate regional and global strategic  
76 responses and detract from the overall impact of the analysis. Only the major farming systems  
77 have, therefore, been identified and then mapped in order to estimate the magnitudes of their  
78 populations and resource bases. Each of these broad systems is characterised by a typical farm  
79 type or household livelihood pattern, although significant sub-types are described where  
80 appropriate.

81 The classification of the farming systems in the Global South has been based on the following  
82 criteria (Dixon, Gibbon, & Gulliver, 2001):

- 83 • Availability of natural resources (water, land, grazing areas and forest), climatic  
84 conditions, landscape, farm size, tenure and organization.
- 85 • Dominant pattern of farm activities and household livelihoods (such as type of crops,  
86 livestock, trees, aquaculture, hunting and gathering, processing and off-farm activities),  
87 main technologies used, which determine the level of intensity of production and  
88 integration of farming activities.

89 Based on these criteria, the following eight broad categories of farming system have been  
90 distinguished:

- 91 • Irrigated farming systems, embracing a broad range of food and cash crop production;
- 92 • Wetland rice-based farming systems, dependent upon monsoon rains supplemented by  
93 irrigation;
- 94 • Rainfed farming systems in humid areas of high resource potential, characterised by a crop  
95 activity (notably root crops, cereals, industrial tree crops - both small scale and plantation  
96 - and commercial horticulture) or mixed crop-livestock systems;

- 97       • Rainfed farming systems in steep and highland areas, which are often mixed crop-livestock
- 98       systems;
- 99       • Rainfed farming systems in dry or cold low potential areas, with mixed crop-livestock and
- 100       pastoral systems merging into sparse and often dispersed systems with very low current
- 101       productivity or potential because of extreme aridity or cold;
- 102       • Dualistic (mixed large commercial and small holder) farming systems, across a variety of
- 103       ecologies and with diverse production patterns;
- 104       • Coastal artisanal fishing, often mixed farming systems; and
- 105       • Urban-based farming systems, typically focused on horticultural and livestock production.

## 106   **2.2. User Requirements and EO data identification**

107   Gaining understanding of user needs necessitated addressing three main issues: the crops most  
108   important to food security in the eight focus countries, the most important agricultural risks in  
109   each country, and the kinds of EO-based products which could best contribute to ameliorating  
110   these risks. Secondary data sources used to understand these issues included the EarthStat  
111   (Monfreda, Ramankutty, & Foley, 2008) and FAOSTAT databases in the case of key crops, and  
112   an in-depth review of academic literature in the case of agricultural risks.

113   Secondary data were complemented by engagements with potential users through surveys, as well  
114   as through rounds of in-country stakeholder workshops organised in collaboration with local  
115   African partner organisations in 2018 and 2019. Representatives were invited to workshops from  
116   the four identified user sectors (public sector, academia, finance and agribusiness), although  
117   representation of different sectors varied between countries. Further rounds of workshops are  
118   planned for 2020 and 2021, during which potential users will be able to interact with the  
119   AfriCultuReS platform and provide further input into design and functionality.

120   These various data sources were combined, analysed and translated into users' requirements

121 following the Group on Earth Observation (GEO) User Requirements Registry (URR) approach  
122 (<http://www.geo-tasks.org/urr-tutorials>) and linking this information to the GEO Societal Benefit  
123 Areas (SBAS) (<https://www.earthobservations.org/sbas.php>). Requirements mainly cover the  
124 SBAS of Food Security and Sustainable Agriculture and Water Resources Management. Finally,  
125 users' requirements have been stored in a database. Similar review processes will follow in order  
126 to adjust and consolidate the database.

127 Questionnaires and surveys were also sent to local partners to identify EO, meteorological, and  
128 in-situ data available for the regions of interest. In order to satisfy the users' needs and to produce  
129 food security related estimates and warnings, a broad range of EO raw and processed data were  
130 investigated. The EO products that were considered are either already available from third parties  
131 or being produced by the project. For the selection of the relevant EO-based geo-data the following  
132 key characteristics were taken into account: the spatial, temporal, and spectral resolutions; the  
133 radiometric resolution; the timeliness of data; the accuracy of data; the swath width; the launch  
134 date, availability of archive data and continuity of data provision; the simplicity and easiness of  
135 access; the interoperability; and the automation.

### 136 **2.3. Development of AfriCultuReS' services**

137 In order to provide the information identified through the analysis of the users' requirements,  
138 several services have been proposed at various temporal and spatial scales. For instance, the early  
139 warning system based on the climate seasonal forecast provides one month in advance information  
140 for the next season in order to identify the intensity and occurrence of drought events and plan  
141 accordingly the planting dates and growing season of crops. In addition, climate change services  
142 provide the needed information for the authorities to define and establish mitigation and  
143 adaptation measures (e.g. identifying new optimal crops) for climate change.

144 As a general rule, after extensively analysing the project's needs in particular in terms of EO



145 products to be developed, several guidelines were followed for the implementation of  
146 AfriCultuRes' services. The same guidelines have been taken into consideration for the selection,  
147 processing, and management of the EO data. These guidelines are:

- 148     ▪ to deliver space-based agricultural production services that will be aligned with the African  
149       Space Policy and Strategy and AfriGEOSS, the African segment of the Group on Earth  
150       Observation (GEO) in the domain of food security and
- 151     ▪ to rely upon the data and services provided by Copernicus and the GEO initiatives, as well  
152       as other third party EO data and value-added services, such as the ESA Food Security  
153       Thematic Exploitation Platform, or the Landsat archive on Amazon Web Services.

154 The AfriCultuReS services rely on the users' exploitation of information products that alone, or  
155 in combination with other information products, satisfy the users' requirements. Figure 2 depicts  
156 the whole value-added cycle from data, through information and knowledge layers up to decision  
157 making or wisdom which will be followed for the design of the AfriCRS' services.

158                                   **[Figure 2 somewhere here]**

159 In addition, in order to address the diversity of users (i.e. decision and policy makers to farmers  
160 and land managers) and needs, the products within AfriCultuReS project were developed  
161 following a multi-scale approach. As a result, three spatial scales were considered as indicated in  
162 Table 1.

163                                   **[Table 1 somewhere here]**

164 The definition of the project's service portfolio in support of enhanced food security decision  
165 making was mostly based on the exploitation of EO data. The analysis of users' needs and the  
166 technological capacity of project partners have gone a step further into the detailed definition of  
167 the services' components, leading to the seven general categories of services described hereafter.

### 168 **2.3.1 Climate services**

169 The Climate services provide information about mid-term climate variability and long-term  
170 climate change scenarios. To this aim, the current state-of-the-art climatic information was  
171 considered. In particular, at seasonal scale, the multi-model seasonal forecast system provided by  
172 the Copernicus Programme (<https://www.copernicus.eu/>) through the Copernicus Climate Data  
173 Store (<https://climate.copernicus.eu/climate-data-store>) was used, while at decadal scale and  
174 climate change projections, the Phase 6 of the Coupled Model Intercomparison Project (CMIP6)  
175 and CORDEX-Africa (Hewitson, Lennard, Nikulin, & Jones, 2012) were considered,  
176 respectively; both of them distributed through the Earth System Grid Federation (Carenton-  
177 Madiec, Denvil, & Greenslade, 2015). All this climatic information was downloaded and post-  
178 processed to make it remotely available through the Santander User Data Gateway (UDG,  
179 <http://www.meteo.unican.es/udg-wiki>, (Cofiño et al., 2018) in order to obtain the final products  
180 defined/requested by the users by applying the tools included in the framework climate4R  
181 (Iturbide et al., 2019).

### 182 **2.3.2 Crop services**

183 Crop services provide manifold information for decision making on crop production. The  
184 AfriCultuReS Crop services include crop and calendar yearly mapping, frequent crop phenology  
185 and condition monitoring, as well as forecasts on expected yield for main crops, based on crop  
186 growth models. These multi-scale crop services, including the crop early warning service, provide  
187 the basis for evidence-based decision making on food security. Current and seasonal maps on crop  
188 land use and main crops grown, allow the precise identification, location and acreage of  
189 production areas. These inputs are a cornerstone of planning and prioritization of zonal  
190 interventions to improve crop cultivation conditions or to cope with food production shortages.  
191 In the case of crop condition assessment, this is done directly through the use of vegetation indices

192 such as NDVI and LAI or using the same period comparing indicator Vegetation Condition Index  
193 (VCI) which compares the current NDVI to the range of values observed in the same period in  
194 previous years. VCI is widely used to monitor vegetation and drought conditions (Quiring and  
195 Ganesh, 2010). VCI was designed to evaluate vegetation health, while separating the weather-  
196 related component of the NDVI from the ecological element. Next, the VCI data is characterized  
197 using the vegetation condition classes previously proposed (0.7-1: normal vegetation condition,  
198 0.5-0.7: moderate vegetation condition, 0.3-0.5: poor vegetation growth, <0.3 extremely poor  
199 growth condition) (Qian et al., 2016). The service at high resolution is based on NDVI and LAI  
200 historical values retrieved from Sentinel-2 images (Figure 3).

201 **[Figure 3 somewhere here]**

### 202 **2.3.3 Drought services**

203 Drought is the major disaster affecting food production, alone drought accounted for the 19% of  
204 the crop and livestock losses by disasters in Africa during the period 2005 to 2014 (FAO, 2017)  
205 .The Drought services provide mid-term drought monitoring, forecasts and warnings. The Drought  
206 service addresses two main types of drought: meteorological and agricultural drought.  
207 Meteorological drought is defined by a precipitation deficiency threshold over a predetermined  
208 period of time. In turn, agricultural drought is defined by the availability of soil water to support  
209 crop and forage growth rather than by the departure of normal precipitation over some specified  
210 period of time. The impact of drought on food production depends on the intensity, duration and  
211 spatial coverage of drought.

212 In case of the Seasonal Drought Forecast service, it is based upon the calculation of the  
213 standardised precipitation evapotranspiration index (SPEI), which is able to provide an estimation  
214 of the onset, duration and intensity of a drought event (Vicente-Serrano, Beguería, & López-  
215 Moreno, 2010). In addition, SPEI allows for a multi-scalar analysis, by calculating its values on

216 different temporal windows. The multi-scalar nature of SPEI enables the identification of the  
217 return time of different drought types (Schwalm et al., 2017).

### 218 **2.3.4 Land services**

219 The Land services provide facts on land cover current situation and land cover changes as well as  
220 abiotic factors that affect, or can affect, food production. Land use competition between  
221 agricultural and/or pastoral land with other uses, mainly urban areas expansion, constitute a key  
222 factor when tackling sustainable land use planning. The increasing demand of space for urban and  
223 other non-food production activities development is increasingly relegating food production to  
224 land areas lesser suitable for human and economic activities. These changes lead to lower  
225 productivity of agricultural land. In addition, other factors, like land degradation, soil erosion or  
226 the occurrence of recurrent natural disasters, while not always coincident with land use-cover  
227 transformations, exacerbate the decrease of land productivity. With three proposed Land services,  
228 AfriCRS will contribute to an improved and informed decision making aiming at mitigating the  
229 adverse effects of the above factors on Land and Food security.

230 In particular, the high resolution burnt areas mapping service uses multi-temporal Sentinel-2  
231 datasets to compute the Normalized Burn Ratio (NBR), which is a spectral index that combines  
232 the near infrared (NIR) and shortwave-infrared (SWIR) bands to distinguish between burned and  
233 unburned areas (Key and Benson, 2006):

$$234 \quad NBR = \frac{R_{NIR} - R_{SWIR}}{R_{NIR} + R_{SWIR}}$$

235 where  $R_{NIR}$  and  $R_{SWIR}$  are the reflectance of the NIR and SWIR spectral bands, corresponding to  
236 band 8 (0.842  $\mu\text{m}$ ) and 12 (2.190  $\mu\text{m}$ ) of the MSI sensor of Sentinel-2.

237 The Differenced Normalized Burn Ratio (dNBR) index was also calculated, defined as:

238

$$dNBR = NBR_{pre} - NBR_{post}$$

239 that is, the difference between the NBR values computed by using a pre-fire and a post-fire image  
240 allows the detection of the burned areas as well as to quantify the severity of the damage by  
241 introducing appropriate thresholds on the possible values of dNBR. The dNBR index provides a  
242 continuous scale of differences that can be related to a magnitude of ecological change, which in  
243 turn offers a conceptual model for the severity of damage caused to vegetation in the burned area:  
244 the greater the change detected due to fire, the greater the severity. A relativized form (RdNBR)  
245 of the dNBR has been introduced (Miller & Thode, 2007) to remove the biasing effect of the pre-  
246 fire condition. The RdNBR is defined as:

247

$$RdNBR = \frac{dNBR}{\sqrt{\text{abs}(NBR_{pre}/1000)}}$$

248 Employing RdNBR allows, in principle, creating categorical classifications using the same  
249 thresholds for fires occurring in similar vegetation types without acquiring additional calibration  
250 field data on each fire. However, an alternative relativized burn severity index, the Relativized  
251 Burn Ratio (RBR) was recently introduced (Parks, Dillon, & Miller, 2014). This index is defined  
252 as:

253

$$RBR = \frac{NBR_{pre} - NBR_{post}}{NBR_{pre} + 1.001}$$

254 The dNBR maximizes reflectance changes in plants and soil due to drastic changes like forest  
255 fires. Like RdNBR, RBR is a relativized version of dNBR, designed to detect changes even where  
256 pre-fire vegetation cover is low. It was demonstrated that both RBR and RdNBR are less  
257 correlated to pre-fire NBR than dNBR, indicating that the relativized metrics are better at detecting  
258 high severity effects across the full range of pre-fire vegetation cover. The RBR is an improvement

259 upon dNBR in terms of correspondence to field measures of burn severity and overall  
260 classification accuracy. Furthermore, the reduced variability in RBR thresholds values among  
261 fires indicates that RBR thresholds are more stable compared to RdNBR thresholds and are thus  
262 more transferable among fires and eco-regions. By using suitable thresholds, the range of values  
263 of RBR can be exploited to provide the burn severity in the form of discrete thematic categories,  
264 distinguishing, generally, between "no burned", "low severity", "moderate severity" and "high  
265 severity".

266 The burnt areas maps give an effective support to estimate damages and plan management. This  
267 service provides key information to many diverse applications such as forestry, agriculture, risk  
268 management and give the possibility to assess the amount of crop, forested and pastoral areas  
269 affected to fire. The high spatial resolution service consists of an automated satellite-based dataset  
270 of RBR maps computed continuously for the area of interest. The data are computed using  
271 Sentinel-2 L2A images downloaded automatically from the Copernicus Hub. The AfriCultuReS  
272 burned area service at medium spatial resolution is taken from the Copernicus Global Land  
273 Services that is based on PROBA V images.

### 274 **2.3.5 Livestock services**

275 The Livestock service provide satellite-based products to support livestock agricultural  
276 management decisions. To this end, the service entails multi-scale historical assessment, seasonal  
277 and on-the-go pasture and rangeland mapping and condition monitoring. This includes the  
278 assessment of the capacity of these environments to ensure sustainable livestock production and  
279 the sustainability of the rangelands. Pastoralism is a vital part of the economies of many African  
280 countries, practiced in about 43% of Africa's land mass (FAO, 2018). Livestock is generally the  
281 rural households' most valuable asset, providing nutritional requirements, transport, and profits  
282 for their livelihoods. However, rangelands and grasslands, as the major source of feed for grazing

283 and browsing livestock, are faced with several challenges, including; bush encroachment, the  
284 proliferation of invasive alien plants, wildfires, droughts and as well as displacement due to  
285 competing land-uses (Sullivan & Rohde, 2002). In order to tackle these phenomena and ensure  
286 their sustainability, farmers, land managers and decision-makers have to be more effective in their  
287 implementation of land use management approaches and plan ahead of time to avoid the pitfall of  
288 a forage shortage and reduce degradation of grasslands (Müller, Quaas, Frank, & Baumgärtner,  
289 2011). Livestock service provides spatially explicit, objective and actionable information such as  
290 recommendations on carrying capacity and stocking rates, status and conditions of rangelands and  
291 grasslands, as well as risks facing productivity, to inform better range management decisions that  
292 will maintain agro-ecological integrity for current and future use.

293 In case of the grazing and rangeland mapping service at high-resolution, it is generated based on  
294 Sentinel-2, and the training data generated from European Space Agency (ESA) Climate Change  
295 Initiative (CCI) prototype high-resolution land cover map of Africa as well as machine learning  
296 approaches such as Random Forest. On the other hand, the coarse resolution product, i.e. Global  
297 Rangeland Mask from the Joint Research Centre (JRC) as well as South African National Land  
298 Cover are used as reference for comparison purposes. The ESA CCI-LC for Africa (released in  
299 September 2017) is a prototype land cover map covering the entire African continent at high  
300 spatial resolution of 20m based on Sentinel-2 images acquired in 2016 (Lesiv et al., 2017). On the  
301 other hand, the South African National Land Cover (2017/18) is provided by the Department of  
302 Rural Development and Land Reform (DRDLR) based on Landsat 8 images with 30m spatial  
303 resolution acquired in 2017 and 2018. JRC-Global Rangeland Mask over Africa is generated from  
304 land cover/land use dataset from Vancutsem, Marinho, Kayitakire, See, and Fritz (2013) at 1 km  
305 spatial resolution, available from <https://mars.jrc.ec.europa.eu/asap/> (Rembold et al., 2019).

### 306 **2.3.6 Water services**

307 The Water services provide geospatial products for water bodies extent mapping and lake water  
308 quality assessment and monitoring. Other products are designed to deliver information on soil  
309 water availability for crop growing, as well as crop water consumption. According to FAO (Turrall,  
310 Burke, & Faurès, 2011), the impacts of climate change on the global hydrological cycle are  
311 expected to modify the patterns of water supply and demand for agriculture, the dominant user of  
312 freshwater. The extent and productivity of both irrigated and rainfed agriculture can be expected  
313 to change. As a result, the livelihoods of rural communities and the food security of a  
314 predominantly urban population are at risk from water-related impacts linked primarily to climate  
315 variability. The rural poor, who are the most vulnerable, are likely to be disproportionately  
316 affected. Adaptation measures that build upon improved land and water management practices are  
317 fundamental in boosting overall resilience to climate change.

### 318 **2.3.7 Weather services**

319 The Weather services provide seven-day to near real-time deterministic weather forecasts at  
320 continental scale (0.25° longitude x 0.25° latitude). In addition, probabilistic weather forecasts will  
321 serve to deliver early warnings on weather extremes at continental scale (0.5° longitude x 0.5°  
322 latitude). In the short term, weather factors may produce food production shortages and what is  
323 more, extreme weather events in a climate changing environment produce extreme shortages.  
324 Projected impacts vary across crops and regions and adaptation scenarios, reaching yield losses  
325 of more than 25%, compared to the late 20th century (Porter et al., 2017). Therefore, weather  
326 forecasts, both short-term and medium range, are required for making decisions., day-to-day farm  
327 management requires weather information for the schedule of farming practices, for example, the  
328 application of fertilizers requires some water in the upper to mid layers of the soil, the spaying  
329 must be done on non-windy days, etc. Weather conditions are also a key driver for the outbreak  
330 of pests and diseases, like fungal diseases, knowing in advance the likelihood of these events can



331 support early decision making towards the mitigation of the adverse effects of weather on food  
332 production.

### 333 **3. Results**

#### 334 **3.1. Identified user requirements and list of EO-data**

335 Gathering user needs has provided service providers with valuable information about data gaps  
336 and farming systems in the project's pilot countries, in order to refine the suite of AfriCultuReS  
337 services. In particular, the user requirements for which EO products are relevant are related to the  
338 provision of information for: the selection of the most appropriate crops for the given growing  
339 conditions; the optimization of fertilization in order to achieve an optimum crop production;  
340 sowing/planting advice for rain-fed agriculture; data and tools for effective irrigation planning  
341 based on crop water requirements (CWR) at irrigation systems; and the facilitation of timely  
342 agricultural management practices. One of the main concerns reflected during some of the national  
343 workshops was related to the water availability and droughts at different time scales, from climate  
344 seasonal forecast to decadal and long-term climate change projections, as it strongly affects the  
345 crop planning and growth, and the livestock management. Moreover, climate and weather  
346 information is also needed as input for the crop models.

347 The list of the users' requirements identified through review of secondary sources and  
348 engagements with potential users in the AfriCultuReS' pilot countries can be summarized by the  
349 following:

- 350 ▪ EO monitoring of crop conditions, crop pests, crop diseases, and crop management.
- 351 ▪ Provide ready to use information for irrigation management.
- 352 ▪ Provide a smart system to predict crop yield for tackling hunger and disasters that affect crops.
- 353 ▪ Integrate information on traditional cultivation techniques for the assessment of the most

- 354 appropriate land for agricultural production.
- 355 ■ Support the development of an index-based insurance.
  - 356 ■ Enhance service provision to farmers by county governments (policy monitoring, seed and  
357 fertilizer subsidy, field extension services, crop insurance, precision farming, early warning  
358 for drought, pests, diseases, disaster management, agricultural downstream logistics, farm-  
359 level calendars).
  - 360 ■ Produce information for main crops yield forecasting.
  - 361 ■ Set-up index-based livestock insurance against extreme events for pastoralist to minimize  
362 their risk.
  - 363 ■ Calibrate and evaluate climate services at local and regional scale, meteorological information  
364 based on the available national and/or international observational networks is needed.
  - 365 ■ Provide information on the likelihood of extreme weather conditions (frost, high temperatures  
366 and heat waves, extreme precipitation events) related with agricultural activities.

367 The user requirements were then connected to actual services, intended to be designed and  
368 developed by the AfriCultuReS project. For the implementation of these services a set of EO  
369 products was identified as most appropriate. The EO products are presented in Table 2 along with  
370 the data source or provider for each considered scale.

371 **[Table 2 somewhere here]**

### 372 **3.2. The AfriCultuReS' service portfolio**

373 Following the guidelines described in section 2 and taking into consideration the identified users'  
374 requirements and the availability of relevant EO products, the AfriCultuReS' service portfolio  
375 was designed. It is presented in Table 3.

376 **[Table 3 somewhere here]**

377 Due to the large number of services developed, one representative service per service category  
378 identified in section 3.2 is provided below. A case study accompanies each service description.

### 379 **3.2.1 Climate services: AFRICRS-S1-P02 – Seasonal Climate Forecast and Early Warnings**

380 Climate services aim to provide seasonal forecast and decadal and long-term climate projections  
381 at continental and, when possible, local or regional scales. At seasonal scale, these services obtain  
382 one month in advance the expected climate evolution for the next months (typically 6-9 months)  
383 as given by the state-of-the-art seasonal forecast systems produced by the Copernicus initiative.  
384 As a result, this service will allow to plan proper adaptation measures according to the expected  
385 seasonal climate conditions.

#### 386 *Case study*

387 As an example, the seasonal forecast of 2-meters mean daily air temperature for autumn 2019 is  
388 shown in Figure 4 at continental scale, including the tercile plot corresponding to Rwanda. In this  
389 figure, the most probable tercile (lower than normal, normal, and higher than normal) for each  
390 grid box is shown in colours (blue, yellow and red, respectively) whilst the transparency of the  
391 bubbles represents the uncertainty of the forecast as given by the hindcast (retrospective forecast).  
392 This is illustrated more in detail in the tercile plot in which the forecast for each year and the  
393 observed tercile are shown, reflecting the capability of the forecast system to predict each class in  
394 the past and, as a result, the uncertainty associated to the new forecast.

395 **[Figure 4 somewhere here]**

### 396 **3.2.2 Crop services: AFRICRS-S2-P02 – Crop condition monitoring (high resolution)**

397 The crop condition assessment service consists in providing information about the status of  
398 vegetation and crops through the VCI.

#### 399 *Case study*

400 As an example, one of the Tunisian test areas has been considered, that is, Jendouba. Figure 5  
401 shows the historical max and min NDVI computed on the area by using S2 images acquired from  
402 January 2018 to 13 July 2019. In addition, Figure 5 shows the VCI map computed by using the  
403 S2 image acquired on the 23 of July 2019. VCI is presented with 4 classes according to Qian et  
404 al, (2016).: (4) normal vegetation condition, (3) moderate vegetation condition, (2) poor  
405 vegetation growth, (1) extremely poor growth condition.

406 From the map of VCI the statistics on the distribution of VCI values for the pixels classified as  
407 crop or grass or shrub were retrieved. They are 81.5% for (1), 4.37% for (2), 3.11% for (3), and  
408 11% for (4).

409 **[Figure 5 somewhere here]**

### 410 **3.2.3 Drought services: AfriCRS-S3-P01 - Seasonal Drought Forecast**

411 The Seasonal Drought Forecast service aims to provide the probability of drought conditions for  
412 the next season one month in advance in order to plan proper adaptation measures according to  
413 the predicted drought conditions, using the time series of the SPEI index.

#### 414 *Case study*

415 As an example, the one month in advance seasonal forecast of the SPEI for the drought affecting  
416 South Africa in 2016 is shown in Figure 6. On the one hand, panel (a) shows that drought  
417 conditions (blue colour) were predicted for all the continent. The dot-size and the transparency  
418 show, respectively, the percentage of members corresponding to the most probable tercile and the  
419 skill of the prediction as given by the evaluation of the hindcast against the observations, in this  
420 case the EWEMBI dataset. Based on this, only the south and mid-centre of the continent show  
421 reliable forecast of those drought conditions. Tercile plot (panel b) shows, for a location or a  
422 (climatologically homogeneous) region, the probability predicted for each tercile in the historical

423 period and the target season, in this case the Spring 2016. The white dots show the observed tercile  
424 reflecting the capability (or not) of the seasonal forecast system to reproduce the observations.  
425 This skill is shown together the forecast in order to reflect its uncertainty according to historical  
426 predictions. As could be expected, for this particular season and region (green box in panel (a)),  
427 all the members predicted normal or dry conditions for the season and the uncertainty of the  
428 prediction is very low, leading to a high confidence in these results, Thus, a source of valuable  
429 information is established to farmers and authorities to plan adaptation measures based on the  
430 given forecast.

431 **[Figure 6 somewhere here]**

432  
433 **3.2.4 Land services: AFRICRS-S4-P03 – Disasters mapping and monitoring (Burnt areas**  
434 **mapping, high resolution)**

435 This service provides key information to many diverse applications such as forestry, agriculture,  
436 risk management and give the possibility to assess the amount of crop, forested and pastoral areas  
437 affected to fire. The service consists of an automated satellite-based map dataset for burnt areas  
438 by continuously updating data available on the area of interest, using Sentinel-2 L2A images.

439 *Case study*

440 As an example, one of the Tunisian test areas has been considered. The burnt area map at high  
441 resolution has been computed using Sentinel-2 images. The image corresponds to the tile T32SMF  
442 (see **[Figure 7 somewhere here]**  
443 ).

444 **[Figure 7 somewhere here]**

445 Figure 7 shows an example of a RBR map, based on Sentinel-2, computed for one of the test area  
446 Jendouba (Tunisia) of the AfriCultuReS project. The map has been computed by using two  
447 Sentinel-2 images acquired on 17<sup>th</sup> and 22<sup>nd</sup> August 2019. Four fire severity levels are

448 distinguished: unburned, low, moderate and high. Monitoring burned areas could help in assessing  
449 the loss of agricultural areas as well, in case of wooded areas, the damage severity and the potential  
450 susceptibility to soil erosion.

### 451 **3.2.5 Livestock services: AFRICRS-S5-P01 - Grazing and Rangeland Mapping (high** 452 **resolution)**

453 Pastoralism is often listed as one of the major livestock production systems in Africa (Dixon et  
454 al., 2001), thus making an obvious contribution to economic development through agriculture and  
455 a supply of affordable food products. Dixon et al. (2001) point out that for the about 55% of the  
456 Africa land surface described as arid and semi-arid lands (ASALs), 47% is arid and is largely  
457 suitable for pastoralism only, while Agyemang (2017) indicates that according to the Africa Union  
458 pastoral areas occupy about 40% of the entire Africa's land mass. Livestock production, both  
459 large and small-scale commercial, depends mainly on rangelands. Subsistence farmers in rural  
460 communities also depend directly on rangelands for their livelihoods.

#### 461 *Case study*

462 As an example, South African rangelands were mapped using Sentinel-2 data at 20m resolution  
463 and Random Forest (RF) classifier. The training data were generated from ESA CCI-LC, i.e.  
464 Africa Prototype Land Cover Map (released 2017). A visual comparison of the preliminary  
465 rangeland map for South Africa (Figure 8d) with a reclassified National Land Cover map (NLC  
466 2017/18) and the JRC-Global Rangeland Mask (Figure 8e) indicates huge differences between the  
467 maps. The observed differences may be due to a number of factors, related to dates of acquisitions  
468 of input data, differences in spatial resolutions and temporal compositing methods used. For  
469 example, the rangeland map in Figure 8a is based on Sentinel-2 data acquired in 2019 March/April  
470 at 20m spatial resolution, while the map in Figure 8b is based on Landsat 8 collected between  
471 2017 and 18 and Figure 8c, i.e. JRC Rangeland mask is based on MODIS data. Another

472 contributing factor of the difference is the accuracy of ESA CCI-LC, i.e. 65% (Lesiv et al., 2017),  
473 while NLC has about 96%. Therefore, future work will involve improvement of the rangeland  
474 map.

475 **[Figure 8 somewhere here]**

476  
477 **3.2.6 Water services: AFRICRS-S6-P03 – Soil Moisture Monitoring (coarse resolution)**

478 Soil Moisture Monitoring service provides decadal information about moisture conditions in  
479 different soil depth for Africa's continental tile. This information is provided through the  
480 Copernicus Global Land Service 10-day Soil Water Index (SWI), with a mean value computed  
481 over a period of 10 days. SWI quantifies the moisture condition at various time intervals from  
482 which the depths in the soil can be retrieved, according to the equation:  $T = L/C$ , where T is a  
483 factor determining how fast the soil moisture content decays with the time, L is the depth of the  
484 reservoir layer referring to the soil profile extending downward from the bottom of the soil surface  
485 layer which is accessible to C-band scatterometers and C is a pseudo diffusivity constant. The soil  
486 moisture is defined as the amount of water ( $m^3/m^3$ ) contained in soil layers identified according  
487 to their depth measured from top surface. Soil moisture is intimately involved in the feedback  
488 between climate and vegetation, since local climate and vegetation both influence soil moisture  
489 through evapotranspiration, while soil moisture and climate determine the type of vegetation in a  
490 region. Changes in soil moisture therefore have a serious impact on agricultural productivity,  
491 forestry and ecosystem health. Thus, SWI is used in soil-vegetation-atmosphere transfer schemes  
492 to improve the accuracy of general circulation models or to improve the understanding of the  
493 feedback between climate and vegetation. Soil moisture is directly derived from SWI (SWI10) by  
494 comparing actual observations with the long-term statistics, based on the 10-year period 2009-  
495 2018. This product is displayed in a regular latitude/longitude grid (plate carrée) with the ellipsoid

496 WGS 1984 (Terrestrial radius=6378km). The resolution of the grid is  $0.1^\circ$  and is provided as  
497 multi-band GeoTIFF.

#### 498 *Case study*

499 The SWI10 product for the country of Tunisia was considered as a case study (see Figure 9).

500 **[Figure 9 somewhere here]**

### 501 **3.2.7 Weather services: AFRICRS-S7-P02 – Weather Extremes Early Warning (coarse** 502 **resolution)**

503 Early warning systems regarding weather extremes are widely used around the globe, providing  
504 valuable information about potential extreme weather conditions and risk information in order to  
505 protect lives, livelihoods and assets. The Weather Extremes Early Warning service (AFRICRS-  
506 S7-P02) aims at informing end users about temperature and precipitation extremes every day for  
507 the upcoming seven days by utilizing the NCEP Global Ensemble Forecasting System (GEFS:  
508 (Hou, Toth, & Zhu, 2004; Toth & Kalnay, 1993, 1997; Wei, Toth, Wobus, & Zhu, 2008; Wei et  
509 al., 2006).

510 The service addresses the probability of extreme temperature in 3hr time and daily intervals and  
511 precipitation extremes at daily basis. Extremes (0.01, 0.05, 0.1, 0.9, 0.95, 0.99 quantiles) are  
512 defined by the ERA5 reanalyses dataset (C3S, Climate Data Store) or any other additional dataset  
513 fit for purpose. The service products come at  $0.5^\circ \times 0.5^\circ$  horizontal resolution at continental  
514 (Africa,  $-20^\circ - 55^\circ\text{E}$ ,  $-40^\circ - 40^\circ\text{N}$ ) scale, in graphics (.png) and NetCDF format.

#### 515 *Case study*

516 As a case study, the extreme precipitation products (0.9, 0.95, 0.99 quantiles) on 25<sup>th</sup> of September  
517 2019 (forecast day 1) and on 29<sup>th</sup> of September 2019 (forecast day 5), of the 24<sup>th</sup> of September  
518 2019 (12UTC) GEFS prognostic cycle are illustrated in **Error! Reference source not found.** and Figure  
519 11. Shaded contours depict the probability of precipitation occurrence (%) above a specific



520 threshold, which has been computed by the climatology (ECMWF/ERA5 dataset). According to  
521 **Error! Reference source not found.**, extreme precipitation was likely to occur in the central parts of  
522 Mozambique (over 90 % probability, in all quantile plots) on 25<sup>th</sup> of September 2019, while the  
523 southern parts of South Africa were prone to extreme precipitation events on 29<sup>th</sup> of September  
524 2019 (see Figure 11).

525 **[Figure 10 somewhere here]**

526 **[Figure 11 somewhere here]**

## 527 **4. Discussion**

### 528 **4.1. Issues of accuracy and operationality**

529 For each AfriCultuReS' service the relevant scale(s) for implementation was defined. While  
530 climate, weather, and drought services run using coarse resolution global Numerical Weather  
531 Prediction (NWP) models, other services such as crop and land services are more meaningful at  
532 high resolution, where a higher level of detail about the crop types and farmlands are used. Other  
533 services such as vegetation condition are run at all scales from high to low resolution in order to  
534 feed other services and provide information for multi-level decision making.

535 Each scale has pros and cons. Low resolution products present little detail but cover a wide area.  
536 High resolution products on the other hand provide a high level of detail but for a limited area.  
537 Heavier processing burden and storage requirements when using high resolution data need to be  
538 taken into account.

539 Regarding the temporal scale the services will be provided, for each service and according to  
540 users' requirements the appropriate time scale is selected. Time scales for weather forecast and  
541 climate change monitoring vary from a few days to the end of the century. A crop growth  
542 monitoring service has dekadal (10-day composites) time steps, while a land cover product is

543 considered stable throughout the year. Besides, each pilot country has its specificities e.g. different  
544 crop calendars and growth seasons which result in specific requirements in temporal analysis.  
545 Monitoring services require frequently available data; this condition was fulfilled by the use of  
546 Copernicus 10-day products and Sentinel-1 and 2 images with 5 to 6 days revisit time.

547 As a result, for the selection of the most useful products for each specific service a consensus was  
548 made between the thematic accuracy of the data and the temporal and spatial resolutions of the  
549 data so that to allow the operational implementation of the service.

550 A rather common constraint of satellite EO data is the cloud cover, where the surface reflectance  
551 of optical wavelengths or emissivity of thermal wavelengths is disrupted by the cloud, and there  
552 is large distortion at the cloud's shadow. Depending on the nature of the service, the workaround  
553 was to use lower resolution (but more frequent) satellite images, for which there is a higher chance  
554 to be acquired on a date without cloud cover, to use composite products (e.g. MODIS 8-day  
555 composite LAI product) which incorporate cloud filling techniques in order to overcome the issue  
556 of gaps from cloud cover and to use microwave images (e.g. SAR) that are not affected by cloud.

557 For all service products accuracy information is reported. For some service products that are  
558 federated and need few additional processing (e.g. Copernicus products), the accuracy given by  
559 the service provider is directly reported. For those requiring some pre-processing, which may not  
560 provide equally accurate results when applied in the various agro-ecological zones in Africa, or  
561 for newly implemented methodologies some extra validation work is being performed, as part of  
562 the project's validation phase. Therefore, the data are tested at different levels according to  
563 available reference data and the level of processing. The reference datasets include non-EO data  
564 collected for the purpose of AfriCultuReS through new campaigns at test sites, historical non-EO  
565 data available to project partners and identified through questionnaires for data availability, EO  
566 products of higher spatial resolution, as well as data coming from other reliable sources.

## 567 **4.2. Case studies assessment and relation to food security**

568 A case study was presented in this paper for each category of services thus providing seven  
569 specific examples of food security-related service outputs in specific areas of the African  
570 continent.

571 The climate services provided the seasonal forecast of precipitation and temperature at continental  
572 and national scale for autumn 2019 reflecting both the forecast and its uncertainty as defined by  
573 the corresponding hindcast. In general, warmer than normal conditions were predicted for this  
574 season. The climate services also provide information about mid-term climate variability and  
575 long-term climate change scenarios enhancing the user's knowledge and understanding about the  
576 impacts of climate on their field, allowing enhanced decision making. One of the most significant  
577 impacts of climate variability and climate change is the potential increase of food insecurity and  
578 malnutrition. All the components of food security are affected by climate related issues: crop  
579 quantity and quality as well as yield are affected by the change and variability of climate patterns  
580 such as rainfall or temperature, threatening food availability; the deterioration of the agro-climatic  
581 conditions could lead to the increase of the price of major crops, affecting the food access to low  
582 income population; climate risks are tightly woven with calorie intake, recurrent extreme events  
583 lead to the modification of the traditional diet affecting the health conditions in societies with low  
584 coping and adaptation capacity; food stability is also threatened by the occurrence of uneven  
585 phenomena affecting food production.

586 The crop condition service provided some statistics on crop condition over a specific area showing  
587 some deviation of the current vegetation condition from the historical minimum and maximum  
588 values thus highlighting the areas where vegetation growth status is poor.

589 In the case of the seasonal forecast and early warnings of drought conditions, the drought event  
590 occurred in spring of 2016 was considered as an example reflecting, one month in advance, the

591 high probability and confidence for drought conditions during this season. This kind of forecast  
592 may let the farmers and authorities to establish adaptation measures according to the climate  
593 conditions predicted. Drought information may lead to adjustments in crop selection, cropping  
594 patterns and water use efficiency measures (de la Poterie et al., 2018).

595 A burnt area was successfully identified using a pre- and post-fire events S2 images and applying  
596 the RBR index in the Jendouba area in June 2019. This can lead to the estimation of the biomass  
597 loss and to support through monitoring recovery and rehabilitation operations.

598 An example of rangeland map of South Africa was presented for the livestock service. The  
599 monitoring of rangeland extent is important to ensure that there is enough forage for the livestock  
600 and to monitor the degree to which overgrazing has already taken place. The service will provide  
601 information not only on the extent of rangelands but also on its condition on which forage  
602 production is also dependent.

603 The SWI10 product is used to monitor soil moisture at coarse resolution over Africa. Through the  
604 Copernicus SWI10 product the resolution at which soil moisture can be determined directly with  
605 Earth observation is considerably improved providing critical information to farmers'  
606 organisations and agencies responsible for water management and irrigation.

607 The Weather Extremes Early Warning precipitation maps provide an insight on the probability of  
608 extreme precipitation occurrence over Africa ( $0.5^\circ \times 0.5^\circ$  horizontal resolution), based on an  
609 ensemble of model runs and according to climatology thresholds. Deterministic precipitation  
610 forecasts (mm, at 3 hourly intervals), are also available at finer scale ( $0.25^\circ \times 0.25^\circ$  longitude-  
611 latitude). The precipitation product is a critical input to various AfriCultuReS services including  
612 drought early warning and crop yield prediction.

613 As shown above, many products and services are interconnected. The early warning for drought  
614 uses input from the weather service and crop condition products. For the livestock service,  
615 information on land cover, pastures conditions, and water availability are required.

## 616 **5. Conclusions**

617 In the present paper the concept behind the description of services of the AfriCultuReS project  
618 was presented with results regarding the users' requirements collected through review of  
619 secondary sources and engagement with potential users. Based on these requirements a list of  
620 services related to the climate, drought, land, livestock, crops, water and weather was established  
621 and relevant EO products were selected for their implementation. Several case studies were  
622 presented from the application of the selected methodology in the project's pilot sites, pilot  
623 countries, or over the whole African continent according to the appropriate spatial scale. Future  
624 communication will be presented regarding the integration of these services into the project's  
625 platform, their validation by the users' and their demonstration over a different area in Africa.

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741 **Tables:**

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744 Table 1: Spatial scales for the AfriCultuReS products.

Spatial scale	Description and relevance
Coarse: 1:1.000.000 - 1:4.000.000	Useful at a continental and regional level especially for applications such as drought monitoring or extreme weather risk assessment. The scale is relevant to address the needs of decision and policy makers from regional institutions in agribusiness, finance, security, etc.
Medium: 1:250.000 - 1:1.000.000	Useful for monitoring vegetation status, flood risk assessment, or water resources assessment at a national to provincial scale. The scale is appropriate to address information needs of national and provincial government ministries.
High: 1:10.000 - 1:250.000	Useful for crop yield prediction, crop health and anomalies detection at a landscape to field level. The scale can address information needs of farmers and land managers.

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Table 2: List of selected EO data and provider per pilot country and scale level

EO products	Coarse	Medium	High
LULC	FAO GLC-SHARE	500m MCD12Q1 v6 Land Cover (LC) v2 (2015)	Tunisia: OSS 30m (2015-2016), Kenya: 15m 2015, Ethiopia: OSS 30m (2014-2015), Ghana: OSS 30m (2014-2015), Niger: OSS 30m (2014-2015)
Rangeland		250m JRC rangeland mask	
NDVI	1km 10day Copernicus v2.2	300m 10day Copernicus v1	Sentinel-2
NDVI anomaly		250m 8day NDVI Anomaly (GMOD09Q1)	
VCI (Vegetation Condition)	1km 10day Copernicus		Sentinel-2



<b>EO products</b>	<b>Coarse</b>	<b>Medium</b>	<b>High</b>
<b>LAI</b>	1km 10day Copernicus v2	300m 10day Copernicus v1  NOAA Climate Data Record (CDR) of AVHRR	Sentinel-2
<b>FAPAR</b>		NOAA Climate Data Record (CDR) of AVHRR	Sentinel-2
<b>Burnt area</b>		300m 10day Copernicus v1 (pre- operational)	Sentinel-2
<b>Water bodies</b>	1km 10day Copernicus v2	300m 10day Copernicus v1	Sentinel-1
<b>Soil moisture</b>	SWI Surface 10km 10day Copernicus		
<b>Soil erosion</b>	25km Global Soil Erosion (2012, 2001) (ESDAC)		
<b>Evapotranspiration</b>	3km daily LSA- SAF DMET 5.6km monthly SSEBop v4 ET anomaly	500m 8day MOD16A2	Ethiopia, Ghana, Kenya, Mozambique, Rwanda, and Tunisia: 100m 10day FAO/WaPOR (2009- 2016)
<b>DEM</b>			30-90m SRTM

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768 Table 3: List of the AfriCultuReS services per scale level.

	<b>Product ID</b>	<b>Product Name</b>	<b>Coarse</b>	<b>Medium</b>	<b>High</b>
Climate	AfriCRS-S1-P01	GAEZ Agro-Climatic Condition	✓		
	AfriCRS-S1-P02	Seasonal Climate Forecast and Early Warnings	✓		
	AfriCRS-S1-P03	Decadal Climate Change Predictions	✓		
	AfriCRS-S1-P04	Long term Climate Change Projections	✓		
Crop	AfriCRS-S2-P01	Crop Type Mapping			✓
	AfriCRS-S2-P02	Crop Condition Monitoring	✓	✓	✓
	AfriCRS-S2-P03	Crop Yield Forecast	✓		✓
	AfriCRS-S2-P04	Crop Calendar			✓
	AfriCRS-S2-P05	Crop Phenology Monitoring			✓
	AfriCRS-S2-P06	Crop Early Warning	✓	✓	✓
Drought	AfriCRS-S3-P01	Seasonal Drought Forecast	✓		
	AfriCRS-S3-P02	Drought Monitoring and Early	✓		

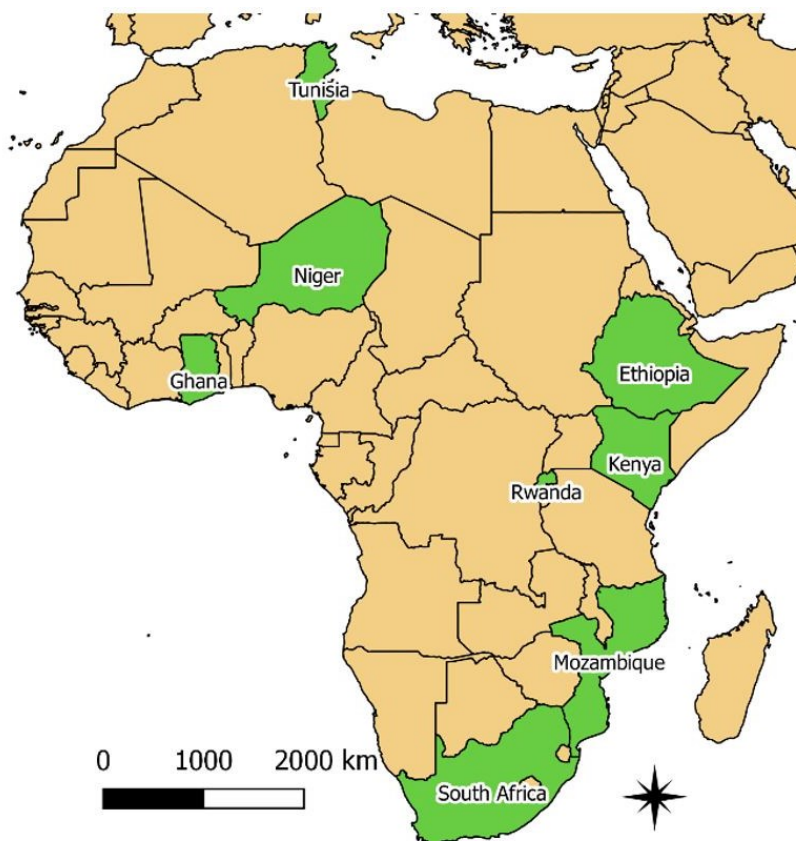
		Warning			
Land	AfriCRS-S4-P01	Land Use & Land Use Change Monitoring	✓	✓	✓
	AfriCRS-S4-P02	Land Degradation	✓		
	AfriCRS-S4-P03	Disasters Mapping and Monitoring (Fire, Flood)		✓	✓
Livestock	AfriCRS-S5-P01	Grazing and Rangeland Mapping	✓	✓	✓
	AfriCRS-S5-P02	Grazing and Rangeland Condition Monitoring	✓	✓	✓
Water	AfriCRS-S6-P01	Water Bodies Mapping	✓	✓	✓
	AfriCRS-S6-P02	Lake Water Quality Monitoring	✓	✓	✓
	AfriCRS-S6-P03	Soil Moisture Monitoring	✓	✓	
	AfriCRS-S6-P04	Water Consumption Monitoring	✓	✓	✓
Weather	AfriCRS-S7-P01	Weather Forecast	✓		
	AfriCRS-S7-P02	Weather Extremes Early Warning	✓		

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771 **Figures and figure legends:**

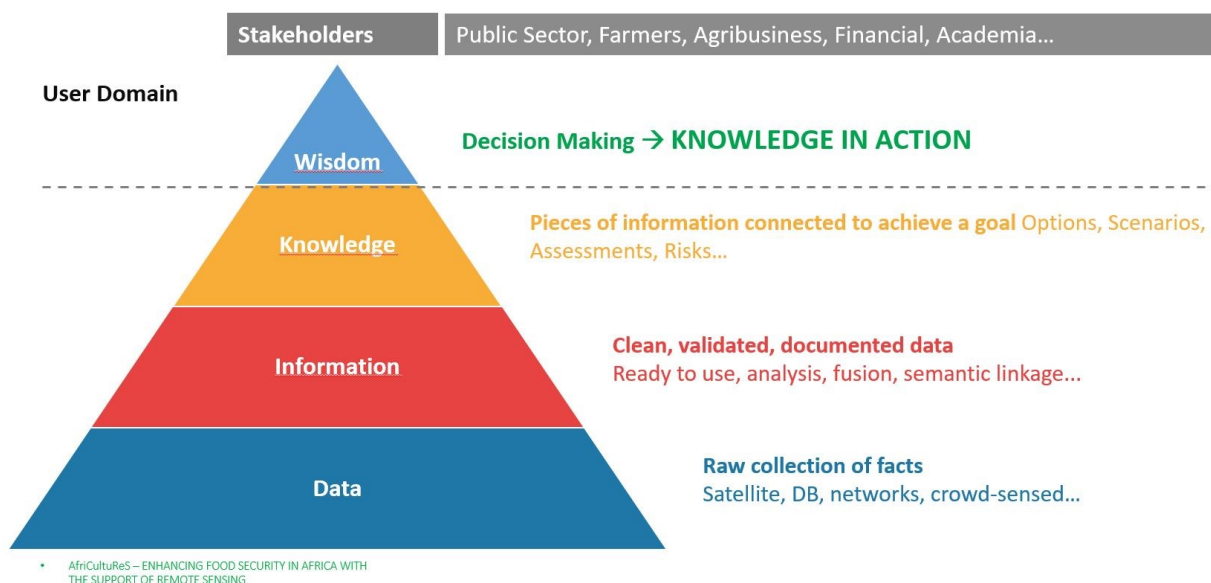
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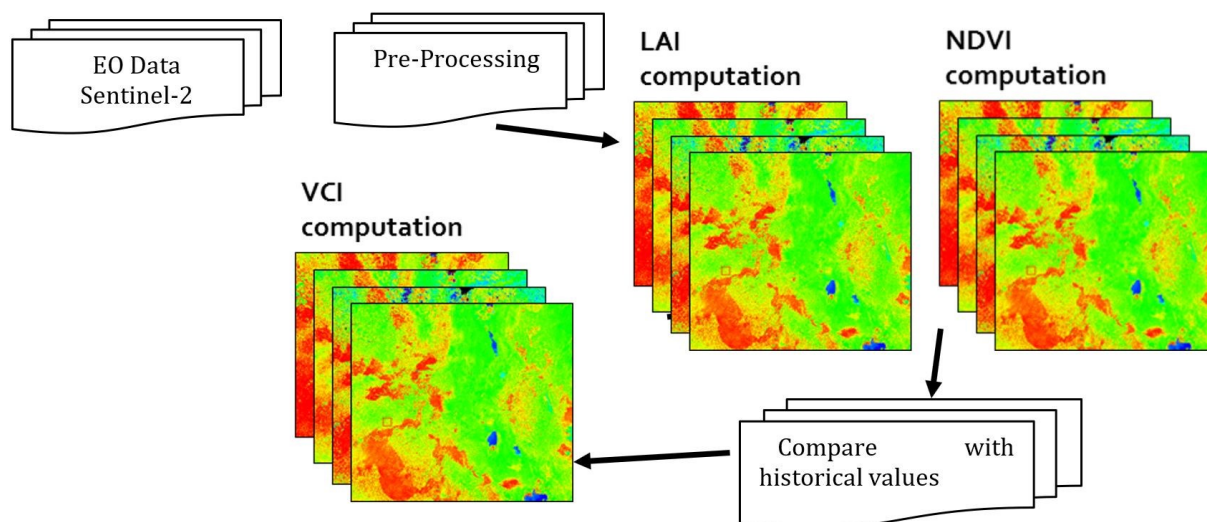
Figure 1: Distribution of the AfriCultuReS' pilot countries.



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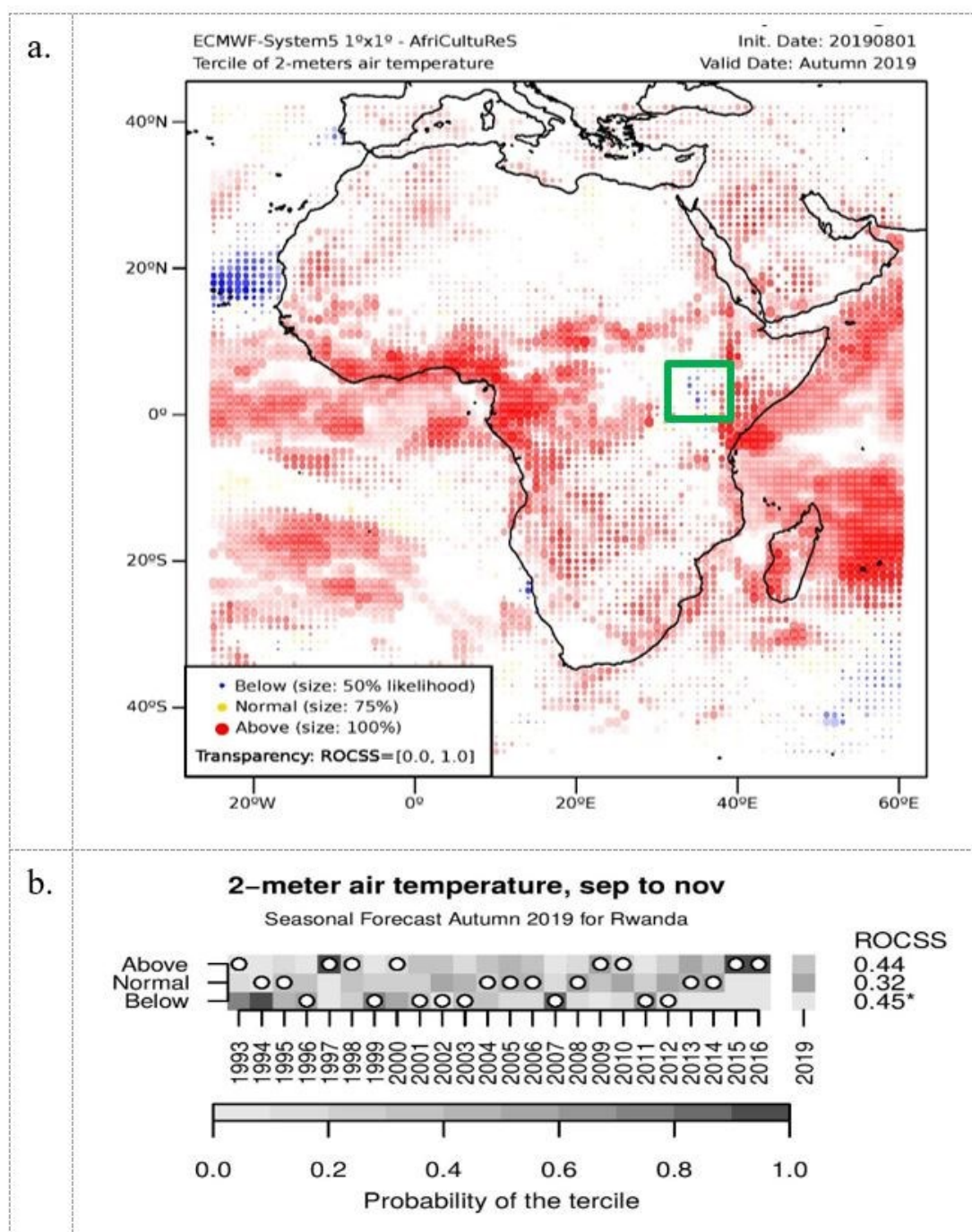
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Figure 2: Mainstreaming data into decision making

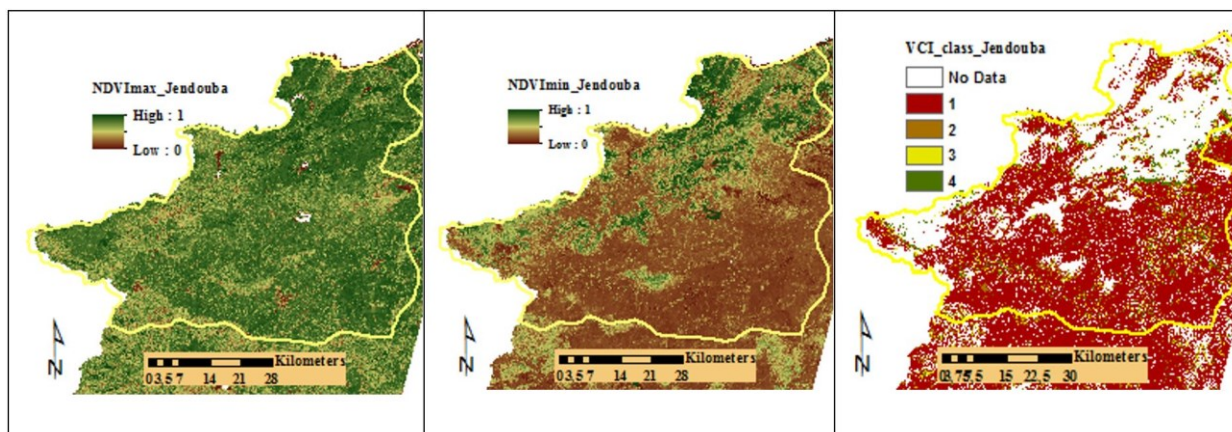


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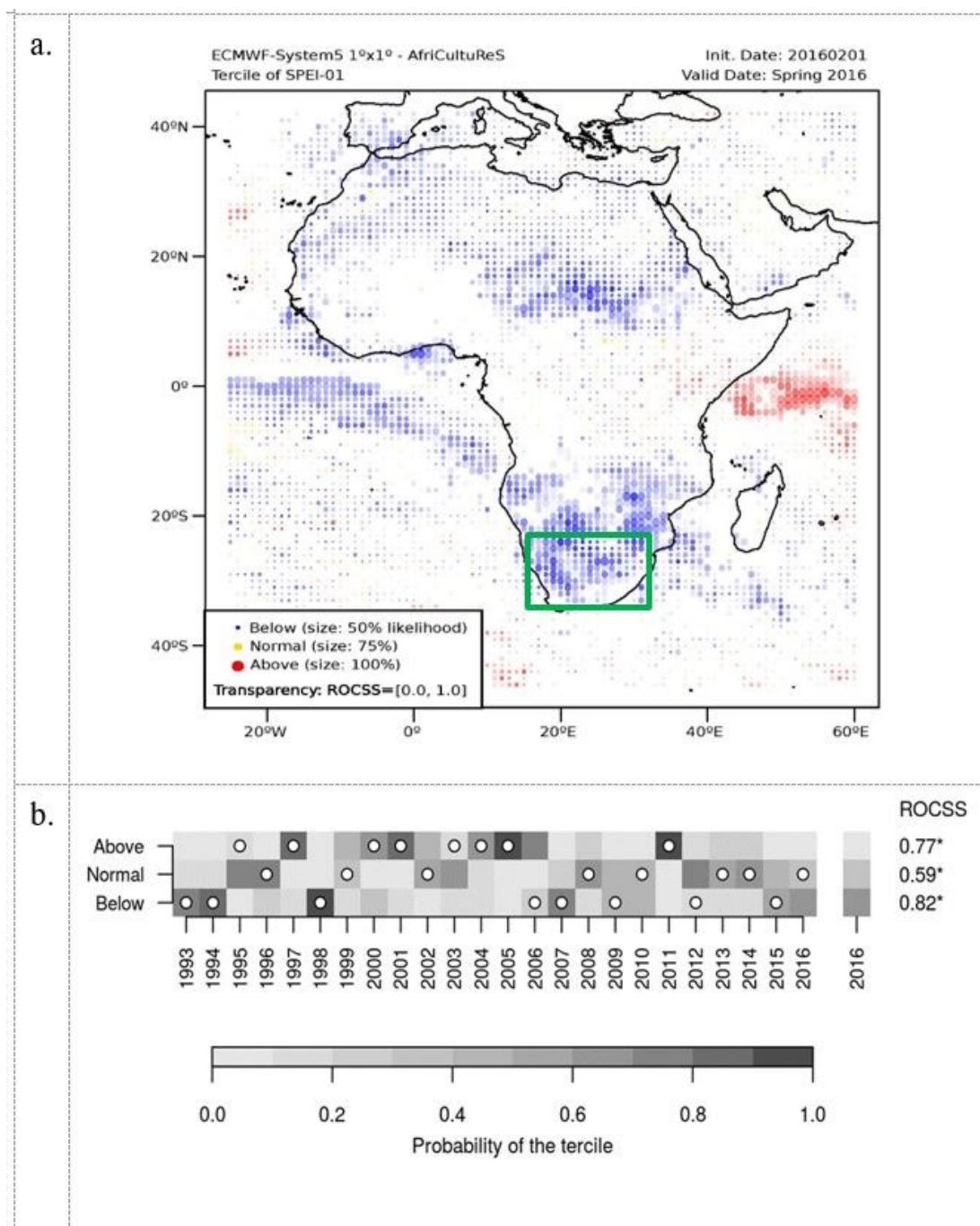
Figure 3: Schematic view of the procedure for computing the AfriCultuReS crop condition monitoring using VCI, NDVI or LAI.



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 781 Figure 4: (a.) Overview of 2-meter air temperature from September-November 2019 (the study  
 782 area of Rwanda is indicated with a green box) and (b.) seasonal forecast for the Rwanda study  
 783 area for autumn 2019.

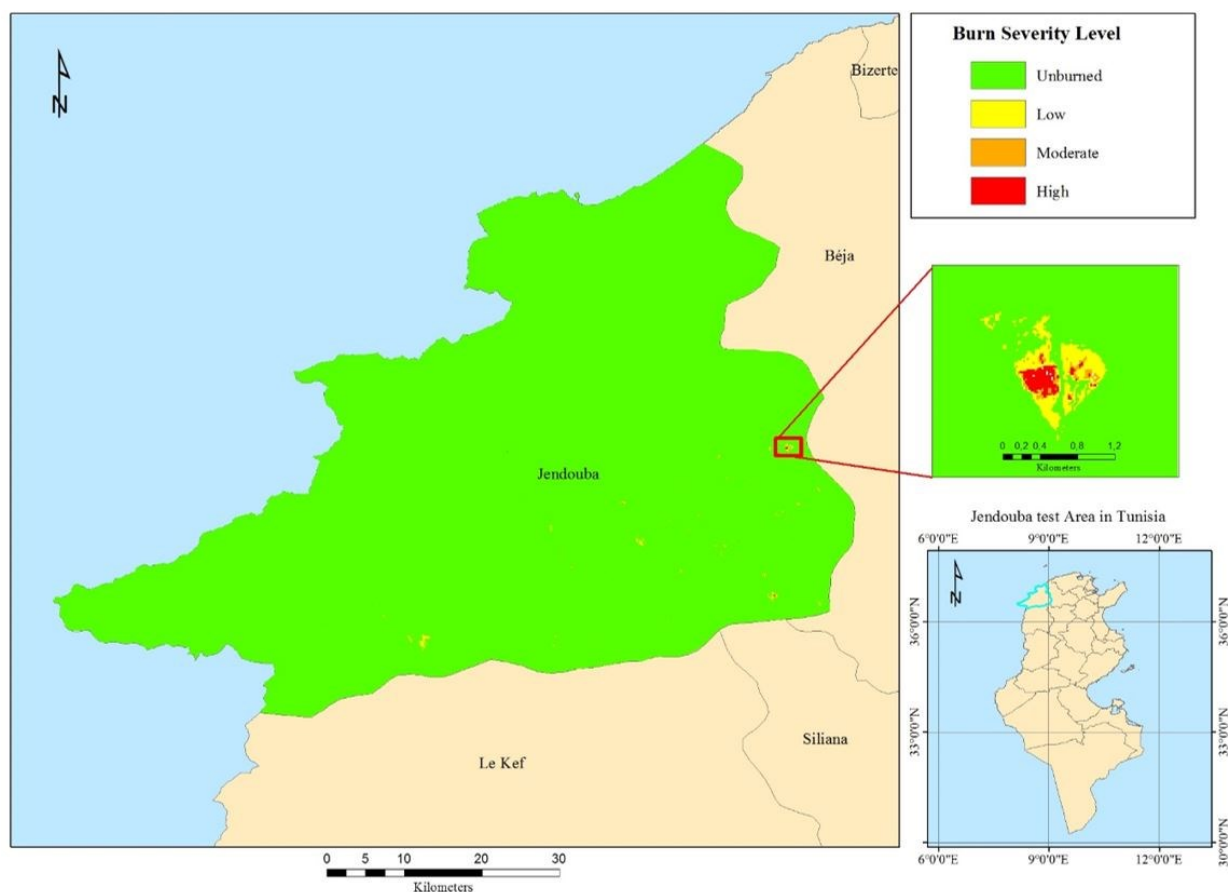


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785 Figure 5: Example of crop condition maps computed for the Jendouba test area in Tunisia. Left:  
786 Historical max of NDVI, Centre: Historical min of NDVI, Right: VCI computed for day 23 July  
787 2019. Note: white area refers to cloudy pixels.

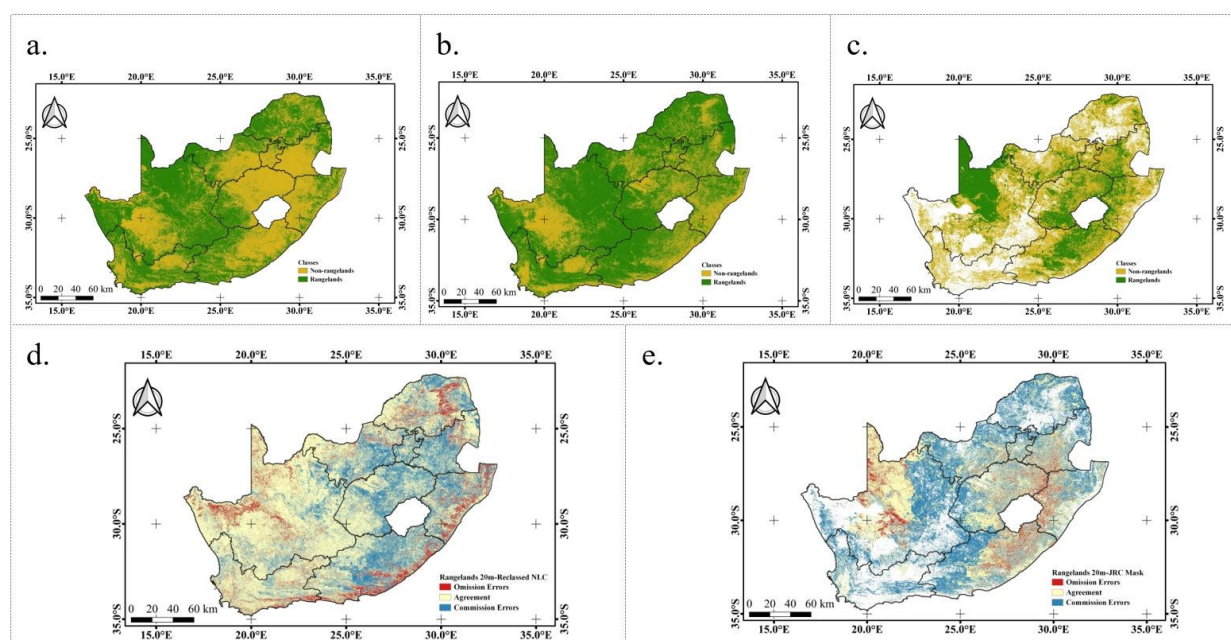


788 Figure 6: (a.) Seasonal Drought forecast for the African continent during spring of 2016 (the  
 789 study area of South-Africa is indicated with a green box) and (b.) Standardized Precipitation-  
 790 Evapotranspiration Index 1 from March-May 2016 in South Africa  
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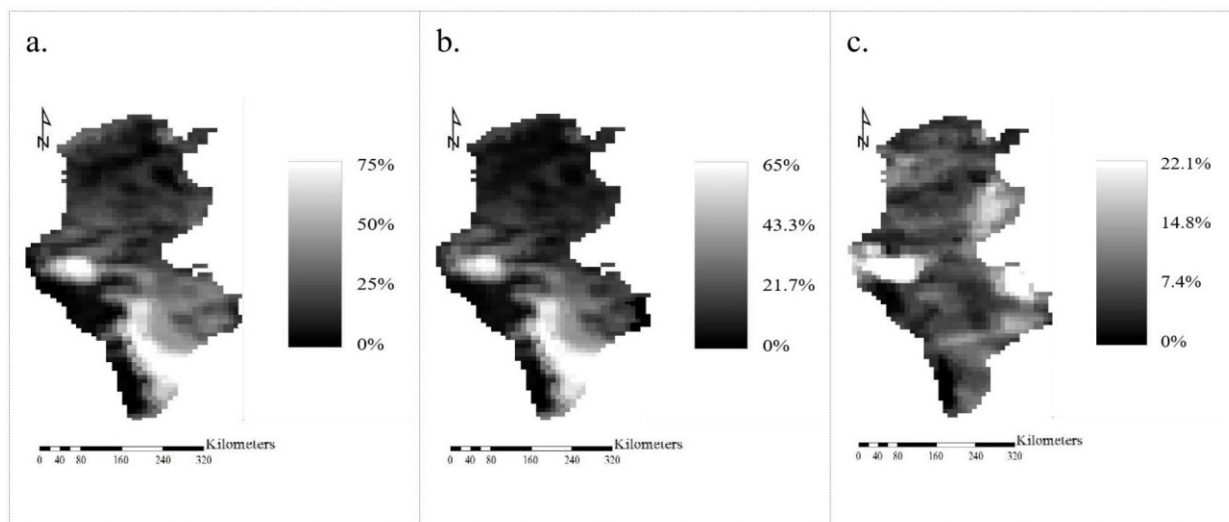




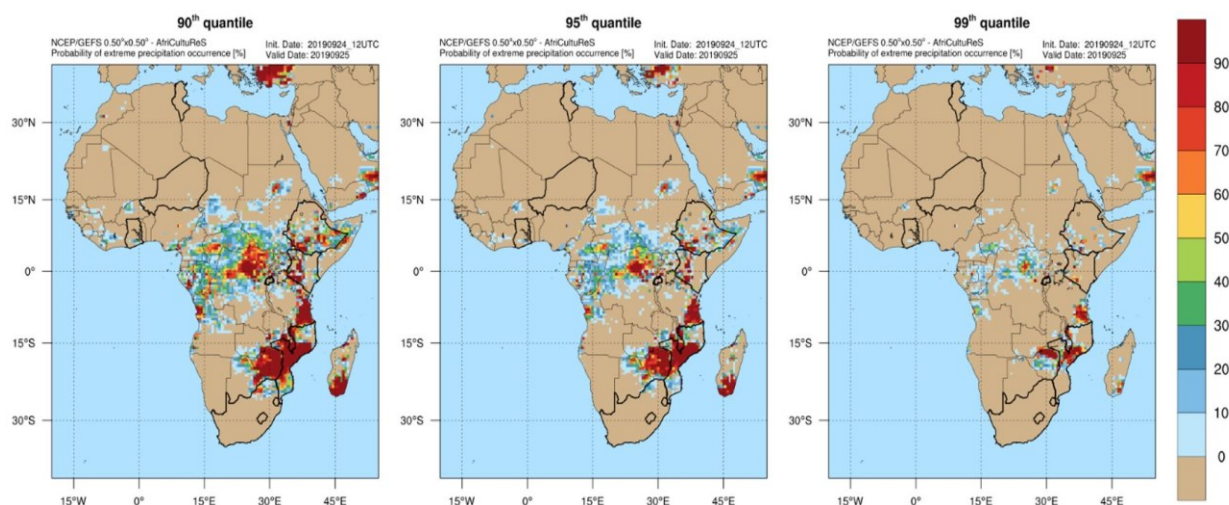
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 793 Figure 7: Example of high-resolution fire disaster mapping computed for the test area of  
 794 Jendouba in Tunisia, between August 17th and August 22nd, 2019 by using the RBR index.



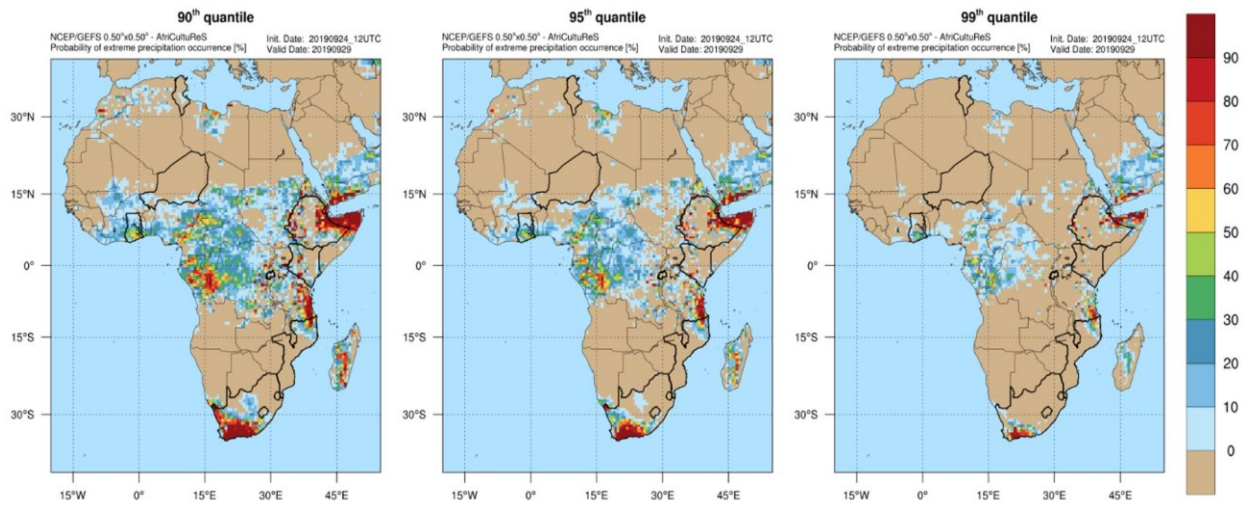
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 796 Figure 8: A comparison between a preliminary rangeland map from Sentinel-2 and ESA CCI LC  
 797 (a), reclassified rangeland map from NLC (b) and JRC Global Rangeland Mask (c). Figures 8d  
 798 and e indicate the differences between preliminary map and NLC, and JRC-Rangeland mask  
 799 respectively.



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 801 Figure 9: Example of soil moisture maps for Tunisia. SWI10 map of 01 July 2019 (a), the  
 802 historical 10-year mean SWI10 value (b), and the historical 10-year standard deviation of  
 803 SWI10 (c). The latter two were computed using Metop-ASCAT time series.



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 805 Figure 10: Probability of extreme precipitation occurrence (%), shaded contours), on 25th of  
 806 September 2019, based on the GEFS/NCEP 12UTC prognostic cycle, on 24th of September  
 807 2019. The AfriCultuReS pilot countries are illustrated with bolder borderlines.



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Figure 11: As in Figure 10, but on 29th of September 2019.