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Designing AfriCultuReS services to support food security in Africa

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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.

1. Introduction

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

In 2017, 31 percent of the total number of food insecure people in the world (821 million people) were in Africa (CDKN, 2019). In various parts of Africa, climate change has produced lower animal growth rate and productivity in pastoral systems; impacted on agricultural pests patterns; increased desertification, which affects 46 out of 57 African nations; and increased the frequency and intensity of droughts (CDKN, 2019; IPCC, 2019). Droughts and desertification processes impact adversely on water resources, which play a key role in agricultural management practices (Falkenmark & Galaz, 2007) via a) withdrawal of water for irrigation; b) land cover change (e.g. when forests are converted to agricultural land); and c) alterations in water division due to changes in land use management (Deutsch et al., 2010). In addition, land degradation has decreased agricultural incomes in different countries, with significant consequences for livelihoods; for example, in Ghana, loss of agricultural income due to land degradation was anticipated to cause a 5.4 percent increase in national poverty rates between 2006 and 2015 (Diao & Sarpong, 2011). It has been argued, though, that many statistics for African economy lack reliable data, which is an important constrain to decision making (Jerven, 2013). Thus, there is an urgent need for accurate and widely available multi-source information such as land use, farm statistics, crop models, and 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 Nº 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.

2. Material and methods

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).

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

5

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.

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.

2.3.1 Climate services

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

2.3.2 Crop services

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

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).

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):

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

235   where R_{NIR} and R_{SWIR} are the reflectance of the NIR and SWIR spectral bands, corresponding to

236   band 8 (0.842 μm) and 12 (2.190 μm) 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 $$RdRBR = \frac{dNBR}{\sqrt{abs(NBR_{pre}/1000)}}$$

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

13

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 assert, 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 compassion 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 onSentinel-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 (Turral,

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 (0.25º longitude x 0.25º latitude). In addition, probabilistic weather forecasts will

321 serve to deliver early warnings on weather extremes at continental scale (0.5º longitude x 0.5º

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.

3. Results

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]**

18

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.

[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*

19

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 17th and 22nd 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.

3.2.5 Livestock services: AFRICRS-S5-P01 - Grazing and Rangeland Mapping (high 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

23

496   WGS 1984 (Terrestrial radius=6378km). The resolution of the grid is 0.1° 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 0.5º x 0.5º horizontal resolution at continental

514   (Africa, -20o – 55oE, -40o – 40oN) 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 25th of September

517   2019 (forecast day 1) and on 29th of September 2019 (forecast day 5), of the 24th 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 25th of September 2019, while the

523 southern parts of South Africa were prone to extreme precipitation events on 29th 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.

4.2. Case studies assessment and relation to food security

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

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

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

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

27

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° x 0.5° 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° x 0.25° 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.

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.

6. Acknowledgements

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Tables:

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.

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

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EO products	Coarse	Medium	High
LAI	1km 10day Copernicus v2	300m 10day Copernicus v1 NOAA Climate Data Record (CDR) of AVHRR	Sentinel-2
FAPAR		NOAA Climate Data Record (CDR) of AVHRR	Sentinel-2
Burnt area		300m 10day Copernicus v1 (pre-operational)	Sentinel-2
Water bodies	1km 10day Copernicus v2	300m 10day Copernicus v1	Sentinel-1
Soil moisture	SWI Surface 10km 10day Copernicus		
Soil erosion	25km Global Soil Erosion (2012, 2001) (ESDAC)		
Evapotranspiration	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)
DEM			30-90m SRTM

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

	Product ID	Product Name	Coarse	Medium	High
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:

772
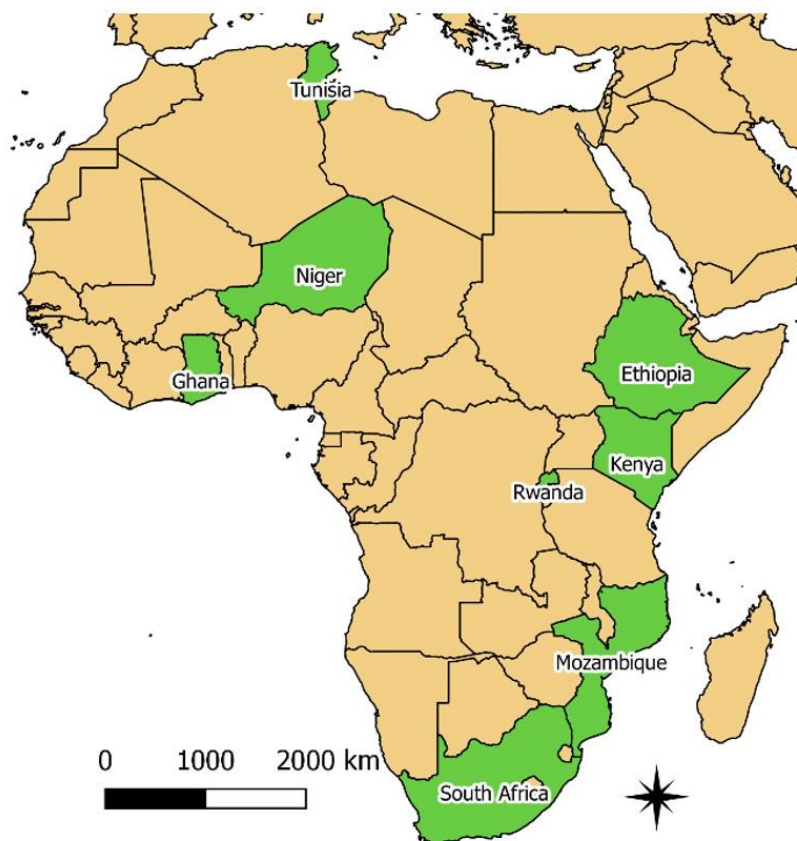
773
774 Figure 1: Distribution of the AfriCultuReS' pilot countries.
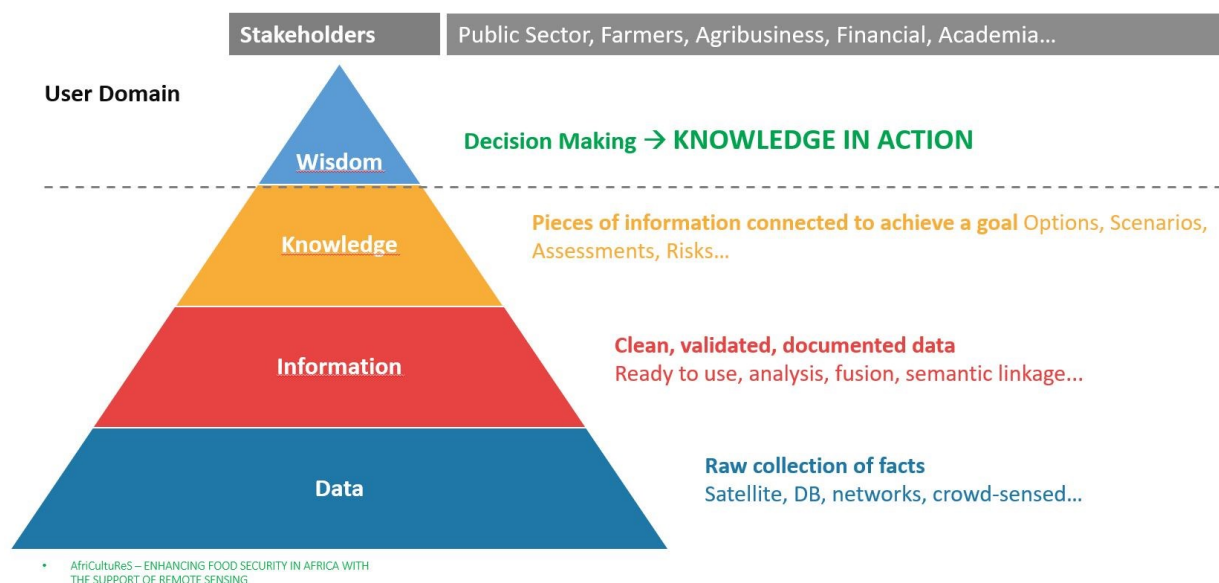
775
776 Figure 2: Mainstreaming data into decision making
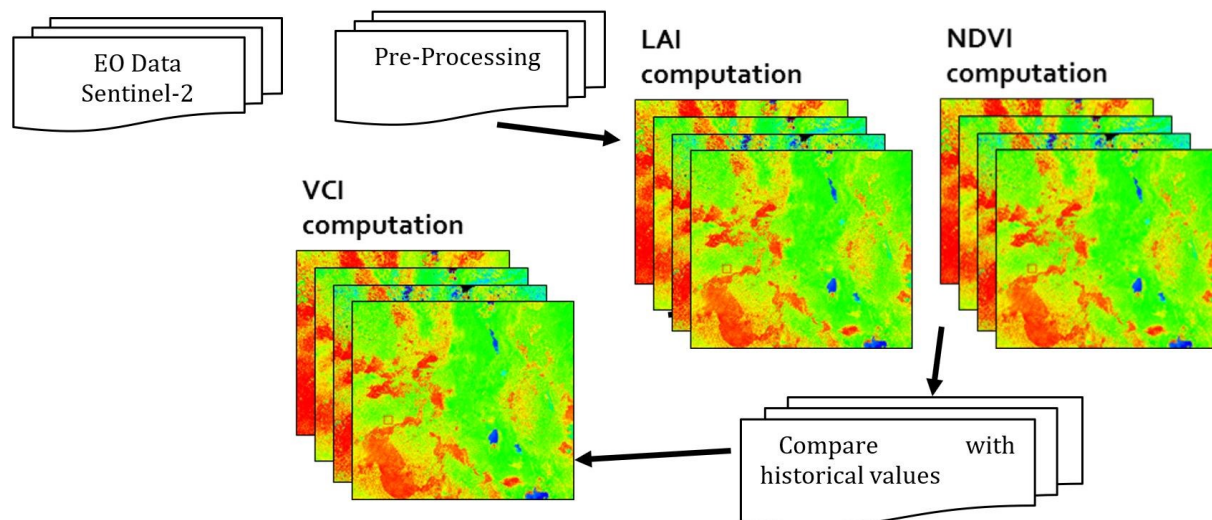
777
778   Figure 3: Schematic view of the procedure for computing the AfriCultuReS crop condition
779   monitoring using VCI, NDVI or LAI.
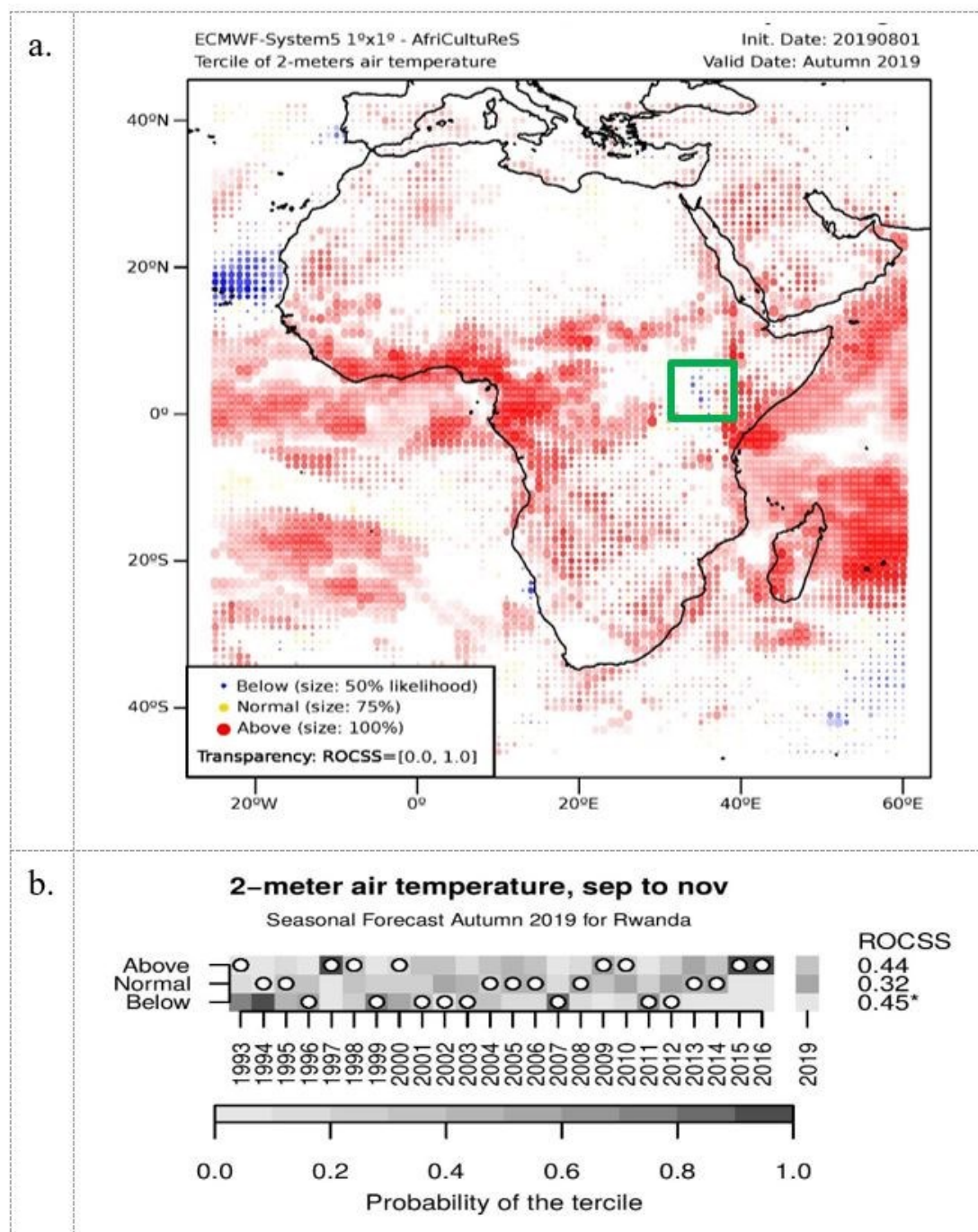
Figure 4: (a.) Overview of 2-meter air temperature from September-November 2019 (the study area of Rwanda is indicated with a green box) and (b.) seasonal forecast for the Rwanda study area for autumn 2019.
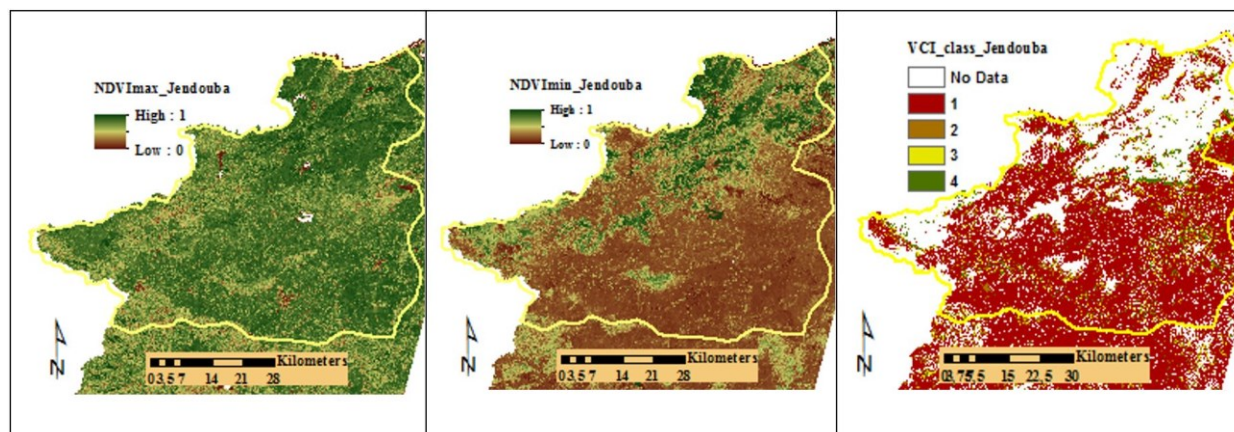
784
785 Figure 5: Example of crop condition maps computed for the Jendouba test area in Tunisia. Left:
786 Historical max of NDVI, Centre: Historical min of NDVI, Right: VCI computed for day 23 July
787 2019. Note: white area refers to cloudy pixels.
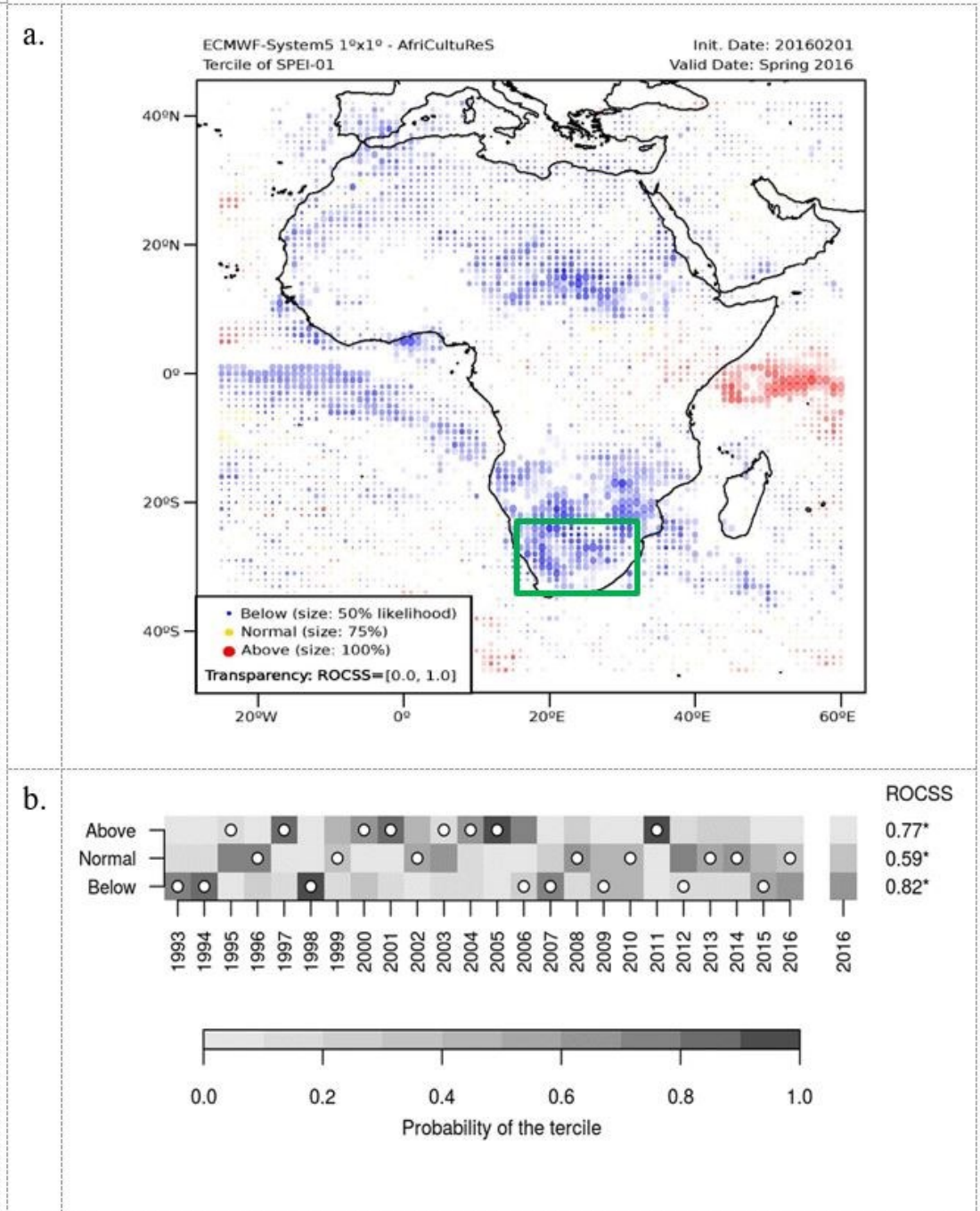
Figure 6: (a.) Seasonal Drought forecast for the African continent during spring of 2016 (the
study area of South-Africa is indicated with a green box) and (b.) Standardized Precipitation-
Evapotranspiration Index 1 from March-May 2016 in South Africa
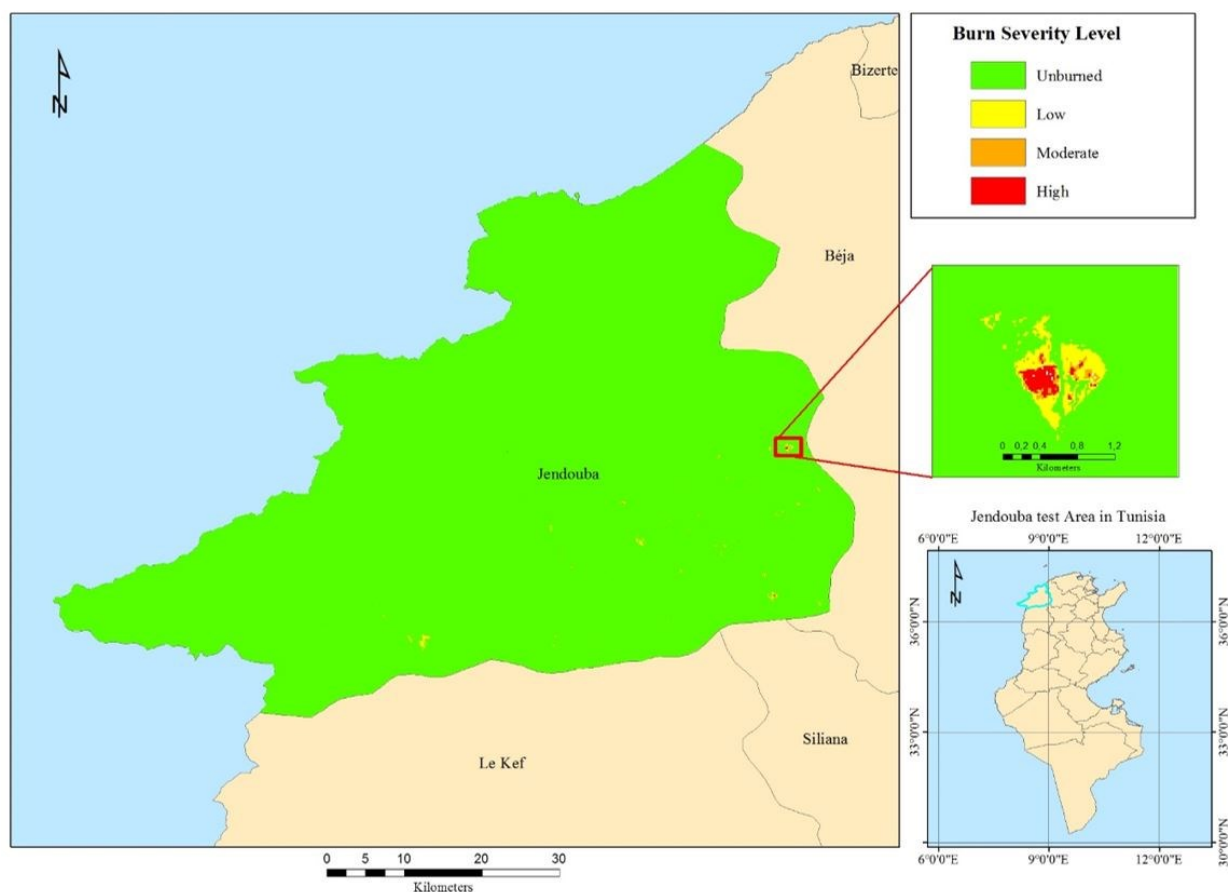
Figure 7: Example of high-resolution fire disaster mapping computed for the test area of
Jendouba in Tunisia, between August 17th and August 22nd, 2019 by using the RBR index.
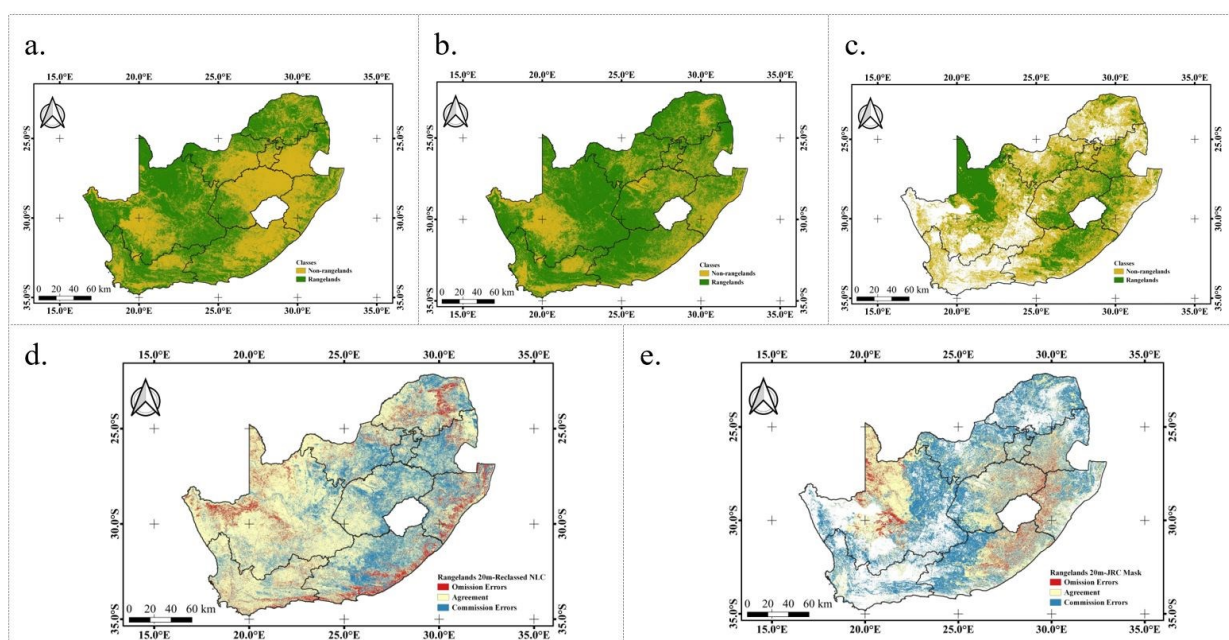
Figure 8: A comparison between a preliminary rangeland map from Sentinel-2 and ESA CCI LC
(a), reclassified rangeland map from NLC (b) and JRC Global Rangeland Mask (c). Figures 8d
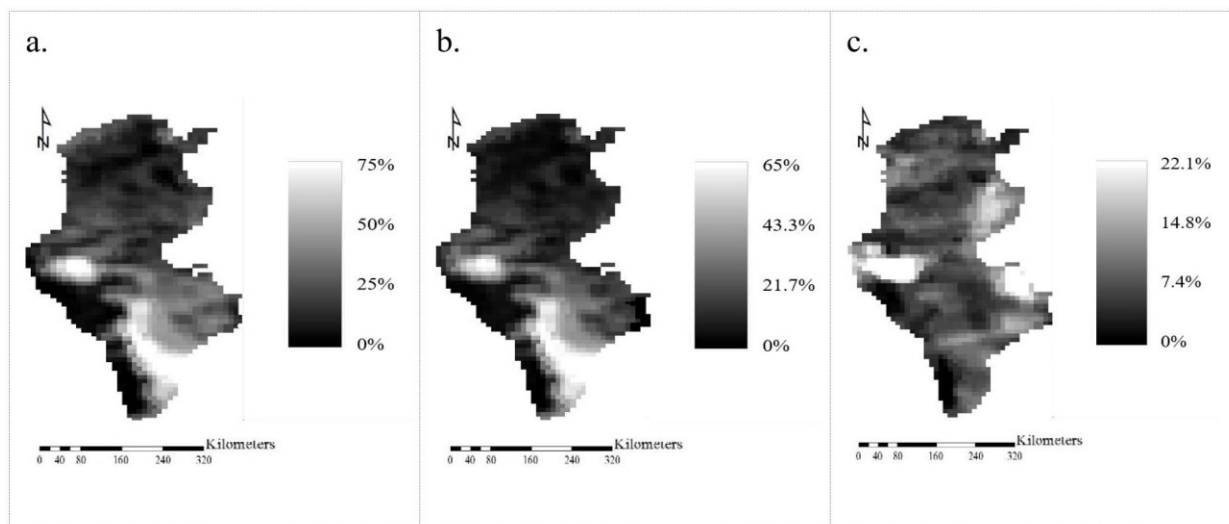and e indicate the differences between preliminary map and NLC, and JRC-Rangeland mask
respectively.

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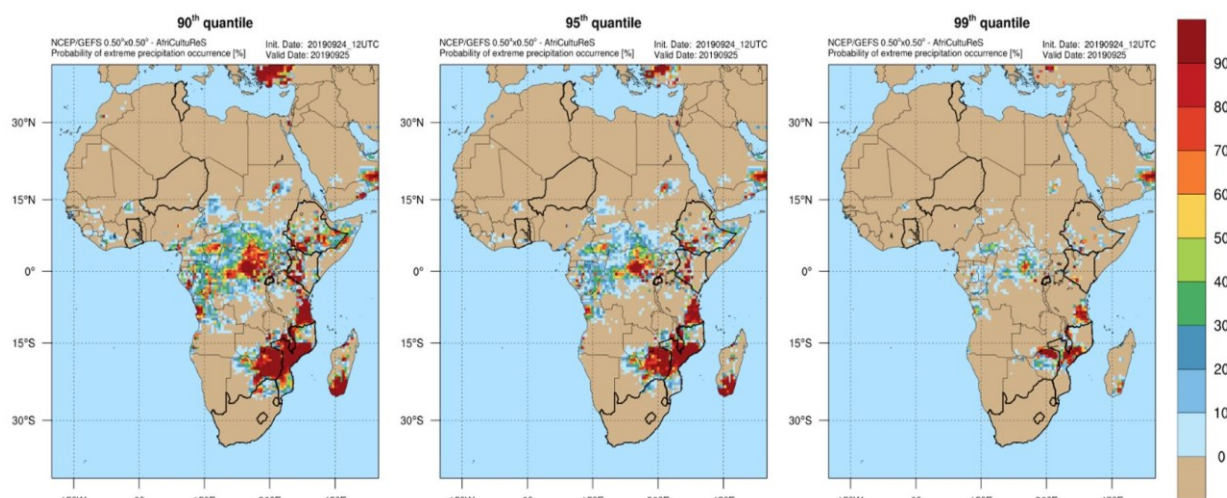

Figure 10: Probability of extreme precipitation occurrence (%, shaded contours), on 25th of September 2019, based on the GEFS/NCEP 12UTC prognostic cycle, on 24th of September 2019. The AfriCultuReS pilot countries are illustrated with bolder borderlines.
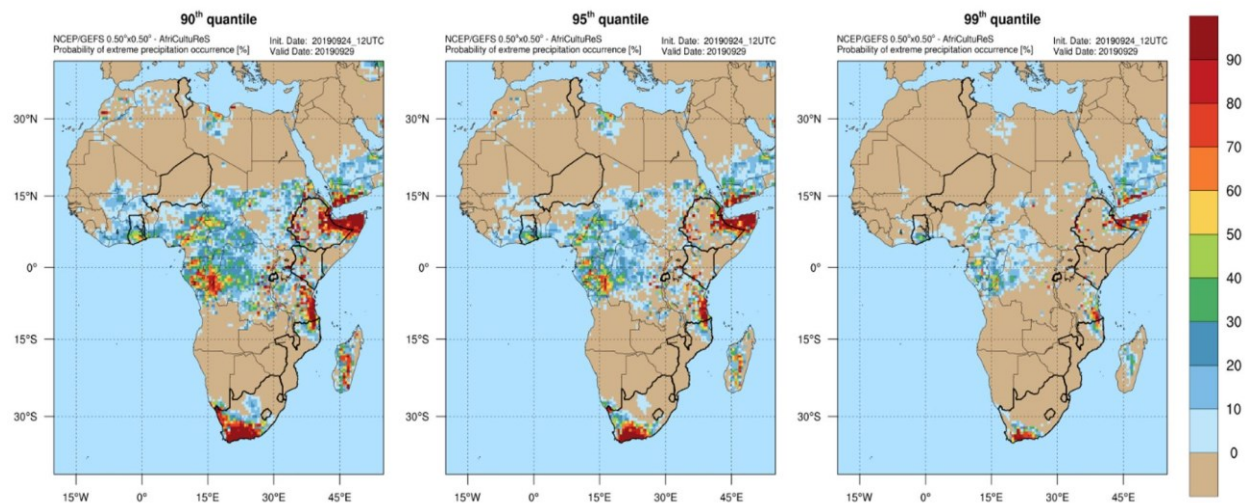
Figure 11: As in Figure 10, but on 29th of September 2019.