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Received: 3 May 2023 | Revised: 5 July 2023 | Accepted: 25 July 2023

DOI: 10.1002/met.2146

RESEARCH ARTICLE

Meteorological Applications Open Access
Science and Technology for Weather and Climate
RMetS

Rainy season and crop calendars comparison between past (1950–2018) and future (2030–2100) in Madagascar

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Funding information
FORMAS (SE), DLR (DE), BMWFW (AT), IFD (DK), MINECO (ES), ANR (FR), European Union, Grant/Award Number: 690462

Abstract

This paper analyzes rainfall data to characterize the rainy season and define rice and maize crop calendars for current and future conditions in Madagascar. The daily rainfall data are taken from observational climate records and climate model simulations from the CMIP6 under the SSP245 and SSP585 scenarios. Rainy season characteristics are calibrated to fit rice and maize crop growth stages. The comparison between the past (1950–2018) and the future (2030–2100) highlights changes in the onset and cessation dates, which happen later and earlier, respectively. This causes the reduction of the rainy season duration, which affects the rice and maize crop calendars, especially its sowing or seeding periods. The worst (best) case is mainly observed in the southeast (southwest). On the one hand, the southwestern region may need to adapt to grow rice and maize crops with short or medium crop cycles in the future. In the Highland or Central land, the length of the sowing or seeding period increases. On the other hand, the North and East face a significant reduction in the length of the sowing or seeding period. Rice endures more than maize. Growing rice crops twice a year may not be possible in the future. But rather, we observe minor changes in the West. Our analysis suggests the imperative necessity to advise smallholder farmers to rely on short crop cycle varieties of rice and maize crops. Predominantly, the harvesting period is postponed. It is recommended to carefully consider our results for the definition of food policies.

KEYWORDS

climate projection, Madagascar, maize and rice crop calendars, rainy season

1 | INTRODUCTION

The rapid population growth pressures global food security (Gerardeaux et al., 2012), especially in Africa (Sasson, 2012). Rice and maize are among the world's most important crops to support food security. For instance, they are a staple food and main crops in Madagascar.

Rice crops can grow under three environments such as irrigated, rainfed upland, and lowland. Madagascar has the largest rice fields, which represent around 15% of

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all of Africa (Diagne et al., 2013). However, the rice fields, which have been divided for generations, diminish in size in the Highland of Madagascar (Andrianantoandro & Bélières, 2015). Moreover, smallholder farmers had constraints due to pests and weeds for rainfed rice and water management and infrastructure problems for irrigated rice in the eastern part of Madagascar (Dröge et al., 2020). On the other hand, global climate change effects would affect rice crop growth and production (Lanka, 2004; van Oort & Zwart, 2018). Randriamarolaza et al. (2022) found that the amount of precipitation decreased, and drought events appeared frequently during September–October–November. Therefore, some studies have been set up to tackle such issues. For instance, Saito et al. (2018) focused their research on the improvement of crop varieties in the tropics, especially for rainfed upland rice crops. Fujisaka (1990) established for the western part of Madagascar, three and four research priorities on rainfed lowland and upland rice, respectively. In Madagascar, promoting upland rice cultivation is one key major to increasing rice production.

In Africa, Baskin (2022) noticed that climate change might decrease maize production as it affected the growth stages of maize crops. Therefore, Epule et al. (2022) highlighted that increasing maize yields did not depend only on increasing harvest area. They recommended thinking about high-yielding and drought-tolerant varieties as well as climate-smart information to brief farmers about changes in the growing season. For instance, Kostandini et al. (2013) indicated the benefits earned from drought-tolerant maize.

The objective of this work is to understand the effects of the changing climate on rainfed maize and rice crops in Madagascar by studying the characteristics of the rainy season, its onset, duration, and cessation, and formulating crop calendars for the present and future based on observed and projected climate data.

The remainder of the paper is organized as follows: Section 2 describes the data and methodology. Section 3 presents key findings. Finally, Section 4 sets out both the discussion and the conclusion.

2 | DATA AND METHODOLOGY

2.1 | Data

This study uses observational data (OBS) provided by the Directorate General of Meteorology of Madagascar (DGM) and Global climate projection data from the Sixth Phase of the Coupled Model Inter-comparison Project (CMIP6).

OBS consists of 26 quality controlled and homogenized time series of daily atmospheric precipitation sums. The time series were developed by Randriamarolaza et al. (2022). The spatial location of the corresponding weather stations on the territory of Madagascar is shown in Figure 1. Their data period covers 1950–2018.

Global Climate Models (GCMs) projection data are obtained from the CMIP6 under the Shared Socioeconomic Pathways SSP245 and SSP585 scenarios. Their data range from 2030 to 2100. They are publicly available through the Earth System Grid Federation (https://esgf-node.llnl.gov/, last visited on May 2022). Three criteria were set out to select the GCMs, which are:

- Native resolution of GCMs is 100 km
- GCMs products contain daily precipitation
- GCMs are chosen from the five ensemble members, which have different realizations but similar initialization methods, perturbed physics, and forcing as in Randriamarolaza et al. (2023). However, ensemble members should contain at least two GCMs.

The selected GCMs are listed in Table 1. The number of GCMs and ensemble members is the same for both SSP245 and SSP585 scenarios. A Madagascar land mask was used to extract daily precipitation from GCMs. Then, the data of spatial resolution were converted to 1 degree by 1 degree using "remapbil" function in the Climate Data Operators (CDO) package (Schulzweida et al., 2017). Afterward, we created a multimodel ensemble mean for each five ensemble members by employing "ensmean" function in CDO. Then, all multimodel ensemble means were ensembled to build a super-ensemble model. From the super-ensemble model, the data were interpolated to the weather station locations by means of the nearest-neighbor method.

2.2 | Methodology

Our analysis consists of two steps: the determination of the rainfall season characteristics (onset, cessation, length) defined according to the local climate and the needs of each crop and the definition of the crop calendar. The analysis, detailed in the remainder of this section, is performed with self-developed software INCLICS, available at https://github.com/Lucmto/INCLICS.

2.2.1 | Rainy season characteristics

Madagascar is an island in the Indian Ocean. It is boarded by the Indian Ocean at the East and Mozambique channel at the West. The rainy season straddles 2 years. Climatologically, the rainy season lasts from November to April. As the rainy season may start and end either earlier or later,

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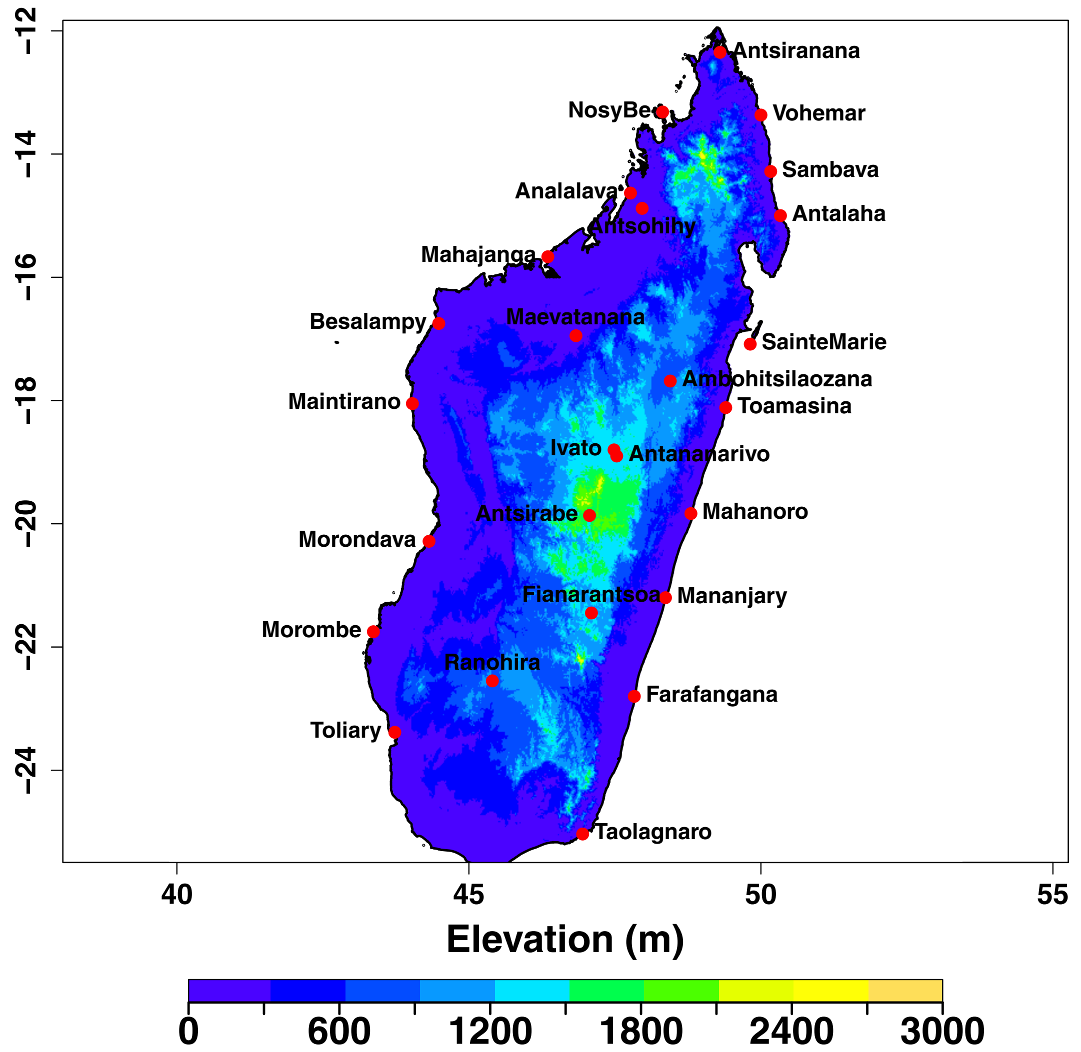

FIGURE 1 Spatial location of the synoptic weather stations on the territory of Madagascar and its topography.

TABLE 1 GCMs list.

	MRI-ESM2-0	CESM2-WACCM	CESM2	BCC-CSM2-MR
r1i1p1f1	x	x		x
r2i1p1f1	x	x		
r3i1p1f1	x	x		
r4i1p1f1	x	x	x	
r5i1p1f1	x	x		

we set the rainy season from August to July. Rice and maize are the main crops in Madagascar. Oldeman (1990) established the agroclimatology zones favorable for growing rice in Madagascar. He calculated the monthly precipitation and potential evapotranspiration ratio to define water availability. He found nine zones to be potentially adequate for rice cultivation. However, a poor irrigated rice system exists in Africa and Madagascar.

Therefore, most farmers especially smallholder farmers grow rice and maize crops following the rainy season. Rainfed lowland and upland rice are the types of rice cultivation in Madagascar.

In this paper, we improve the criteria by using daily precipitation instead of monthly precipitation to define the onset and cessation dates of the rainy season. Liebmann et al. (2012) determined that the onset and cessation dates occurred when daily precipitation are greater and lower than the annual daily average respectively. However, this definition gives only potential dates of the start and end of the rainy season. This may cause a high

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TABLE 2 Literature review of onset and cessation dates definition.

ZAE	Onset definitions	Cessation definitions	Countries	Crops	References
Sahel	First occasion after May 1 that the 10- day total exceeds half the evaporation assuming a daily evaporation of 5 mm. Date after 1 May when rainfall accumulated over three consecutive days was at least 20 mm and when no dry spell within the next 30 days exceeded 7 days.		Mali Southern Sahelian and Sudanian of West Africa	Cereal crops (maize, millet, sorghum)	Akinseye et al., (2016), Sivakumar, (1988)
Savanna	20 mm in 2 days or at least 2 days of rainy days within 7 days and no dry spell within the next 21 days exceeded 7 days. 30 mm within 10 days, after which there is no dry spell longer than seven (7) days within the next 30 days.	10 mm in 10 days after which no rain falls for the next 10 days.	Mali Ghana	Cereal crops (maize, millet, sorghum) Maïze	Akinseye et al., (2016), Kasei & Afuakwa, (1991)
Guinea	20 mm in 2 days or at least 2 days of rainy days within 7 days and no dry spell within the next 21 days exceeded 7 days.			Cereal crops (maize, millet, sorghum)	Akinseye et al., (2016)
	Def1: 25 mm in 5 days and at least 2 days of rainy days (which are 0.1 mm) and no dry spell more than 7 days within 30 days. Def2: 25 mm in 6 days and no dry spell more than 10 days within 40 days.		Mali and Burkina Faso		Dodd & Jolliffe, (2001)
	First occasion after May 1st with more than 20 mm of rain in 2 days and with no dry spell of 10 days or more in the next 30 days.	First day after September 1st when soil with a 60 mm water-holding capacity gets completely depleted, assuming daily evapotranspiration rate of 5 mm and remains depleted for at least 5 consecutive days without recovering to maximum capacity in the next 15 days respectively.	Southwest Burkina Faso and Upper East Ghana.		Boansi et al., (2019)

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rate of false alarms, especially for onset dates. Therefore, we learn from the knowledge of different research studies listed in Table 2. Rice crops are more sensitive to drought than maize crops. Moreover, water stress is more important in rice than in maize crops. We establish two definitions of the onset of the rainy season according to the rice and maize crops respectively. For rice crops, we define the onset dates as the first day after August 1 with more than 20 mm of rain in 2 days and at least 2 days of rainy days within 5 days and no dry spell within the next 21 days exceeding 7 days. This definition ascertains the availability of water for juvenile rice plants, especially for upland rice. For maize crops, we define the onset dates as the first day after August 1 with more than 25 mm of rain in 7 days and no dry spell within the next 21 days exceeding 10 days. Maize crops can grow without excessive rainy days. Notice that a dry day is a day with less than 0.85 mm of rainfall. These definitions avoid false alarms.

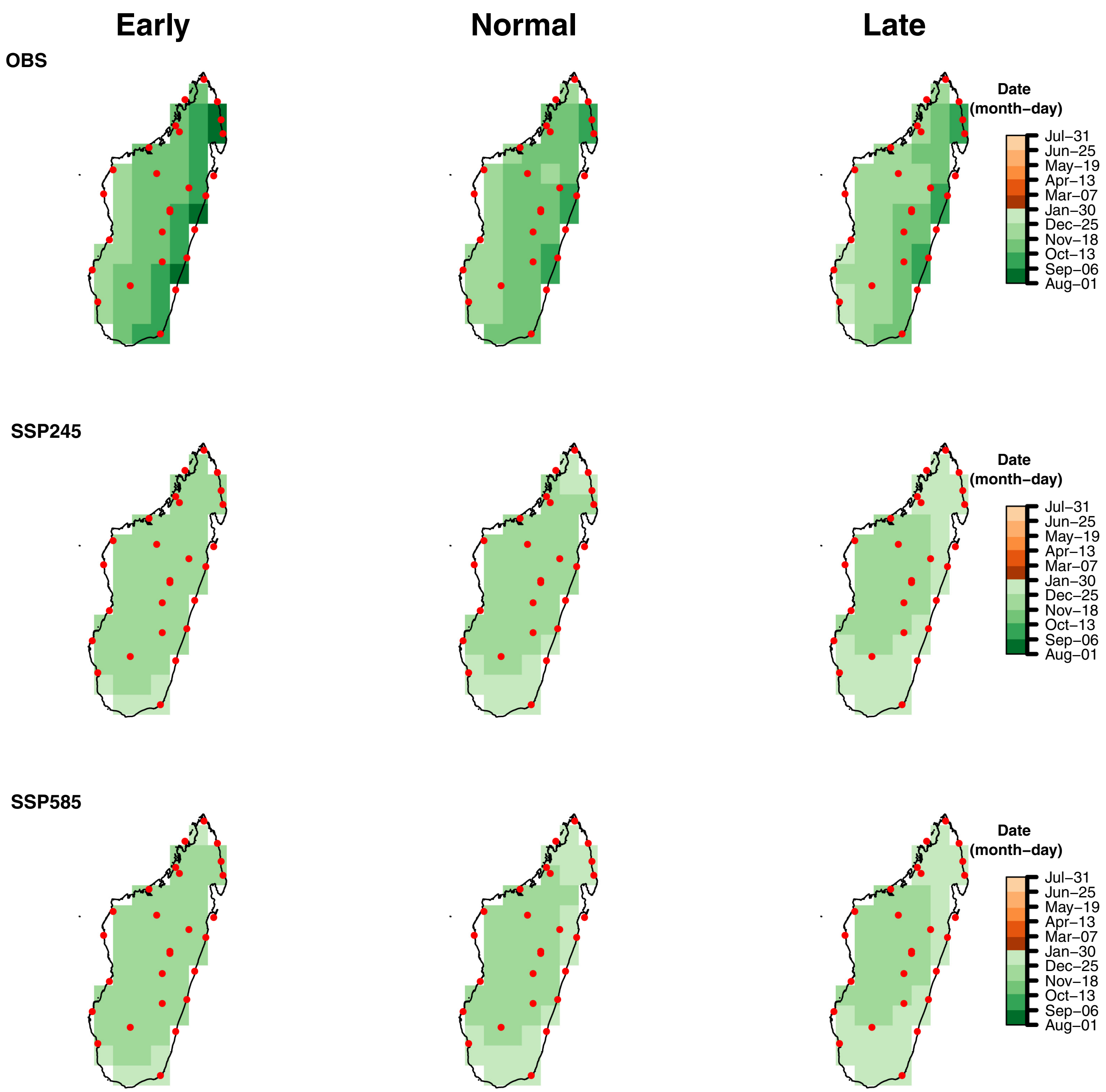

FIGURE 2 (a) Rainy season onset dates for rice crops. Dots represent synoptic weather stations. (b) Rainy season onset dates for maize crops. Dots represent synoptic weather stations.

The similar cessation dates definition adopted by Boansi et al. (2019) depending on the soil's water-holding capacity and daily evapotranspiration (PET) is applied. Soil's water-holding capacity depends on soil texture and other factors such as soil preparation on fertilizers and nutrients. Mostly, soil texture is defined by sand, silt, and clay percentage. Oldeman (1990) described that Ferrallisol is the major soil type in Madagascar. In the middle West of Madagascar, the percentage of sand, silt, and clay are 47%, 21%, and 32%, respectively (Fujisaka, 1990). According to a workshop note prepared by Armstrong et al. (2001), this texture is classified as clay loam. Therefore, its water-holding capacity is 150 mm. Oldeman (1990) found that PET reaches more than 6 mm/day during the summertime, especially in the western part. It decreases to 2 mm/day over the wintertime, especially in the highland or central land of Madagascar. Therefore, we set the PET value to 5 mm/day. By gathering those elements, we define the cessation dates as the first day after March 1 when soil with a 150 mm water-holding capacity gets completely depleted, assuming a daily evapotranspiration rate of 5 mm/day and remains depleted for at least five consecutive days without recovering to maximum

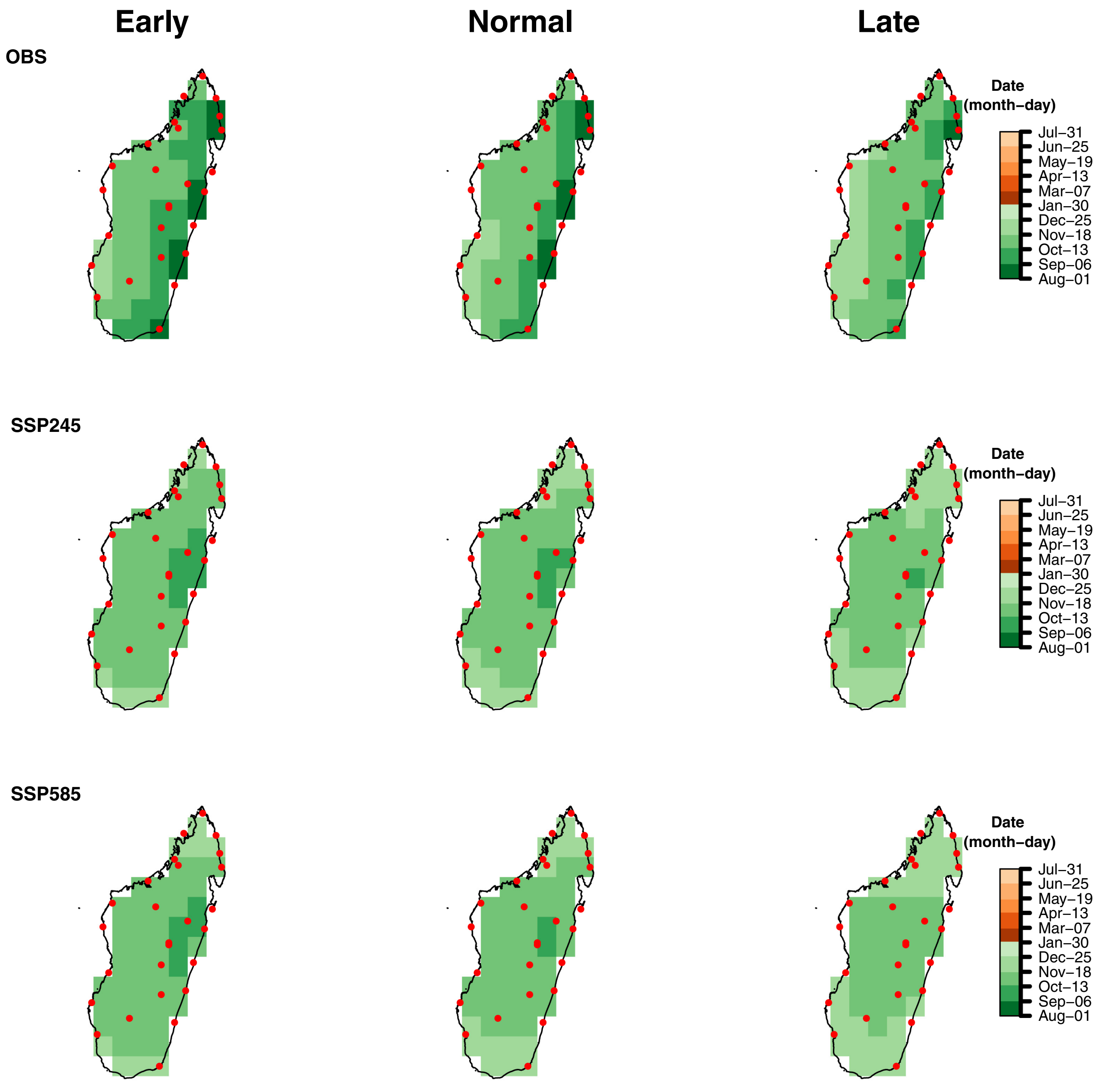

FIGURE 2 (Continued)

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capacity in the next 15 days respectively. This definition is applied to rice and maize crops.

As explained by de Shannon (2021), onset and cessation dates are supposed to be normally distributed. Then they are classified as early, normal, and late when their probabilities are less than 0.33, between 0.33 and 0.67, and greater than 0.67, respectively. The length of the rainy season is the number of days between the onset and cessation dates.

These definitions have been applied to OBS and CMIP6 under SSP245 and SSP585 scenarios.

The onset dates, cessation dates, and the length of rainy season deduced from OBS are spatialized using inverse distance weighted (IDW) interpolation to 1 degree by 1 degree resolution. IDW was predominantly used to interpolate rainfall as Chen and Liu (2012), Muzakky et al. (2022), and de Oliveira Aparecido et al. (2022) used it to estimate spatial rainfall in Tawain, Indonesia, and Brazil, respectively. This step converts the onset dates, cessation dates, and length of rainy season deduced from OBS to have the same resolution as CMIP6 under SSP245 and SSP585 scenarios. This permits to calculate the spatial differences between OBS and CMIP6 under SSP245 and SSP585 scenarios. The results highlight the evolution of onset dates, cessation dates, and length of rainy season in the future.

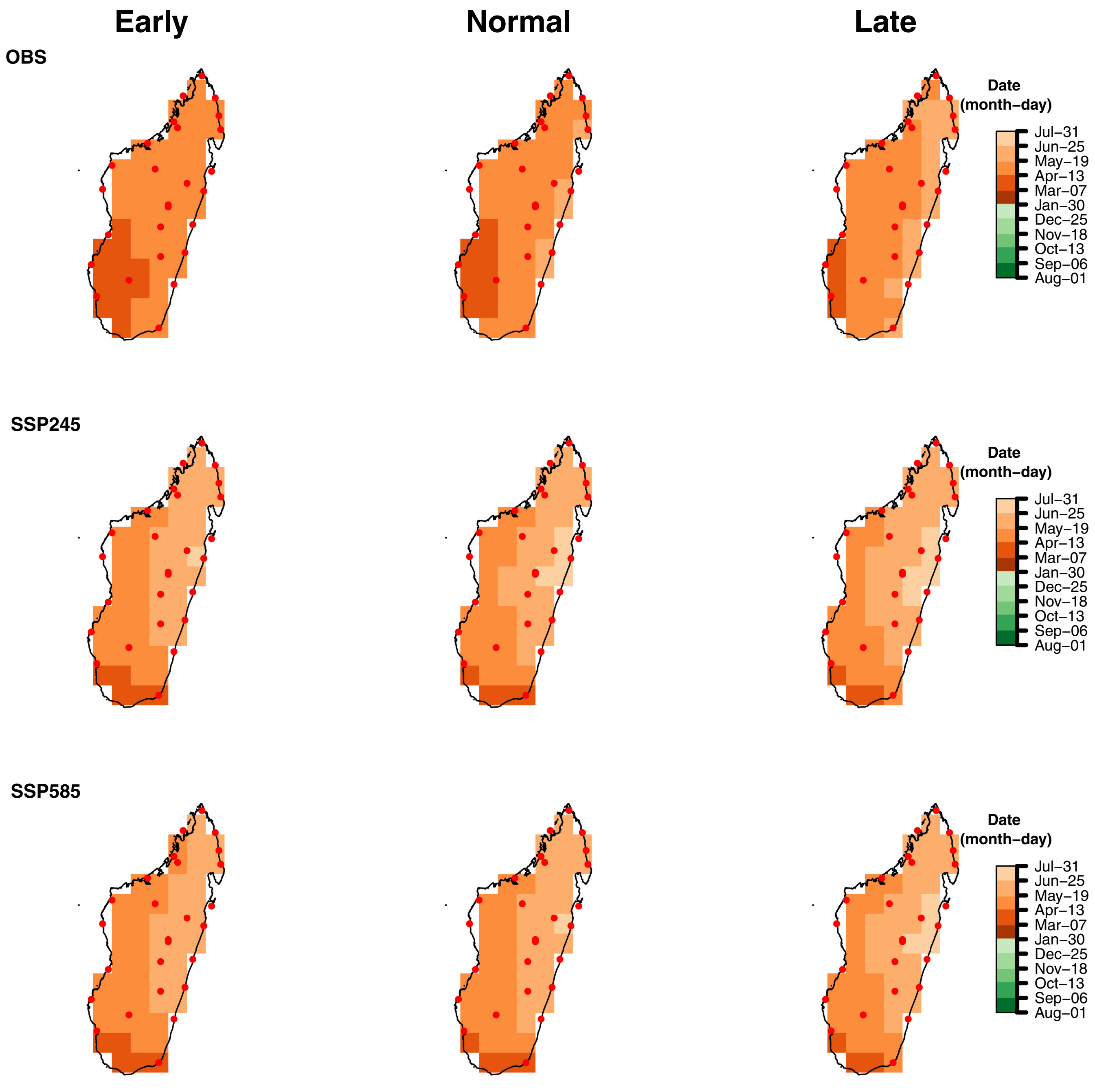

FIGURE 3 Rainy season cessation dates for rice and maize crops. Dots represent synoptic weather stations.

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2.2.2 | Crop calendars

In general, farmers needed decadal information on climate or weather to manage crop growth. The rice and maize crop calendars are established by referring to the latest date for sowing or seeding. The seeding period is the dates range between the earliest and latest of seeding dates. Thus, the harvesting period is defined by the earliest and latest dates to start the harvest. In this paper, we transform the rainy season to fit the rice and maize crops' growing seasons. Crop varieties are different following their length of crop cycle (LCC). In Madagascar, LCC is classified into three categories: short (S), medium (M), and long (L). It is 105, 130, and 145 days (90, 120, and 150 days) for rice (maize) crop varieties respectively. We suppose that the growing season does not end later than late cessation dates. Then, we combine crop cycle lengths and late cessation dates to determine the latest dates for sowing or seeding. Thereafter, crop

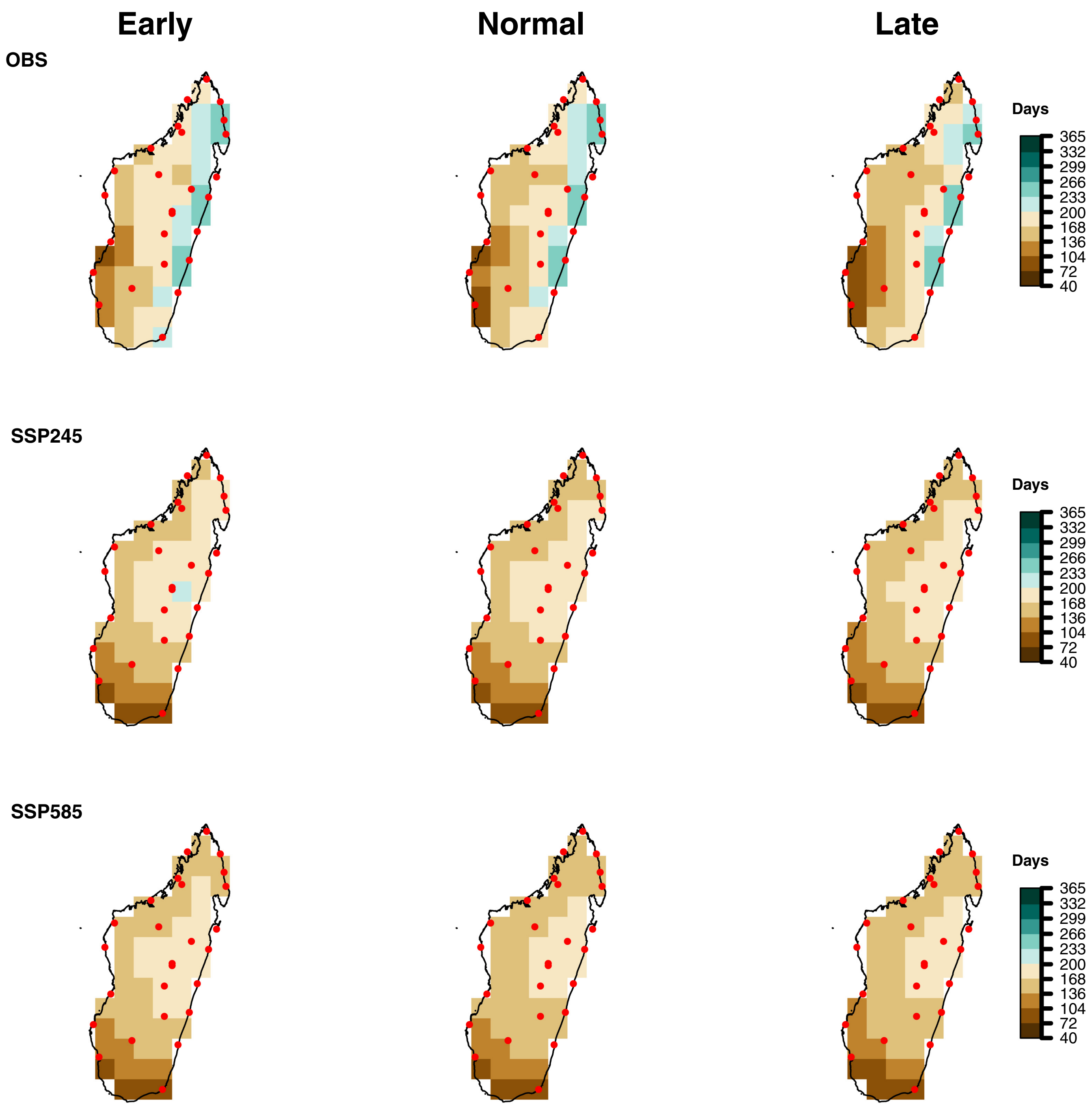

FIGURE 4 (a) Rainy season duration for rice crops. Dots represent synoptic weather stations. (b) Rainy season duration for maize crops. Dots represent synoptic weather stations.

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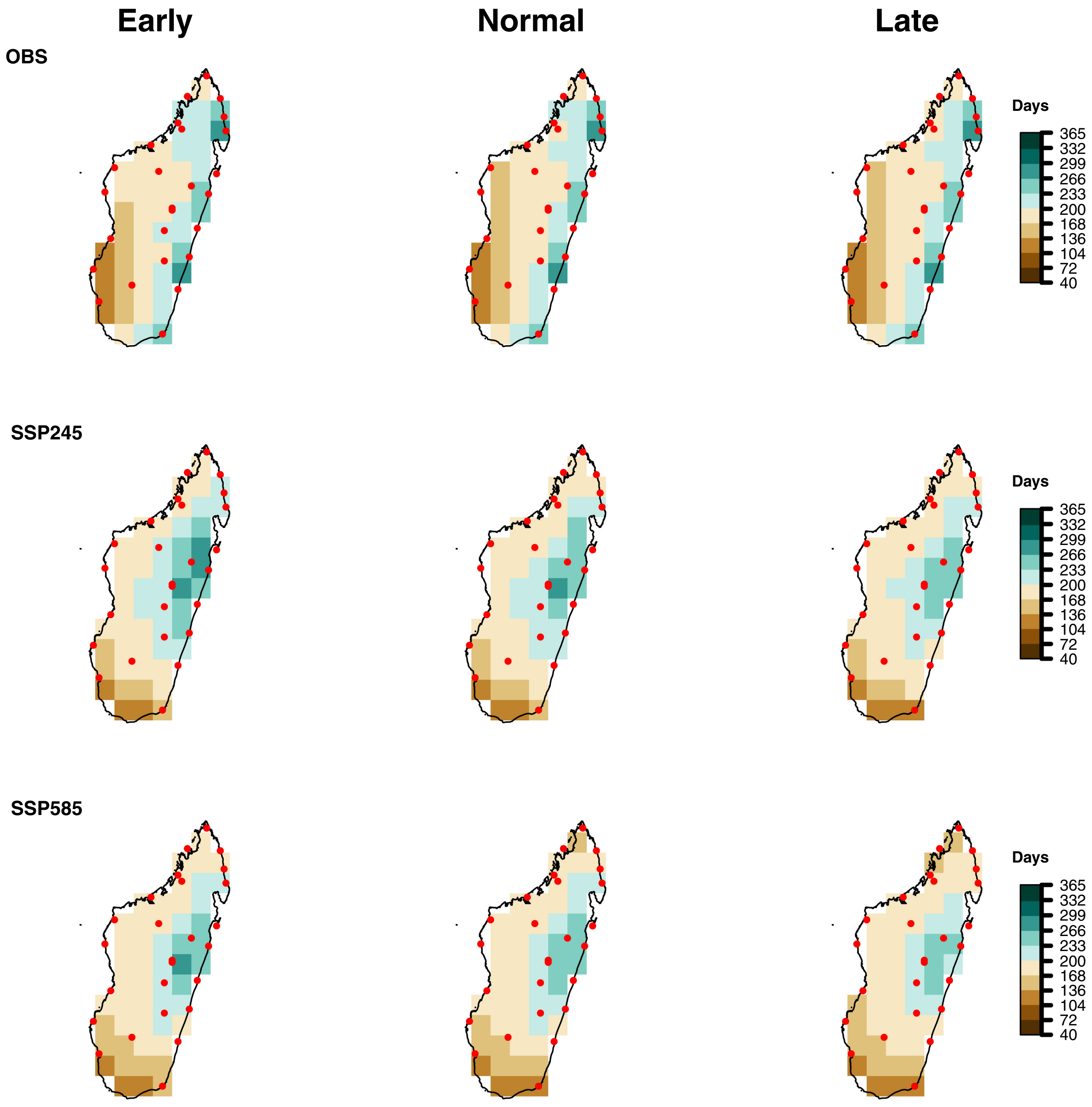

FIGURE 4 (Continued)

calendars are established and contained the sowing or seeding and harvesting periods. The crop calendars are established for each weather station location. They are grouped in five regions such as North (NosyBe, Antsiranana, Vohemar, Antalaha, Sambava), West (Mahajanga, Maintirano, Besalampy, Maevatanana, Analalava, Antsohihy), Highland (Ambohitsilaozana, Antananarivo, Ivato, Antsirabe, Fianarantsoa, Ranohira), East (Sainte Marie, Toamasina, Mahanoro, Mananjary, Farafangana, Taolagnaro), South-west (Toliary, Morombe, Morondava). Then the results obtained from OBS and CMIP6 under SSP245 and SSP585 scenarios are compared, especially the mean length of sowing or seeding period for each region.

3 | RESULTS

3.1 | Rainy season characteristics

Figure 2a, b shows onset dates for rice and maize. In the past, the earliest, and latest onset dates happen in the East (August–September) and the South-west

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(December–January) respectively. Rice onset dates lagged maize 1 month, that is, November–December (October–November) see the majority of normal onset dates for rice (maize). In the future, the onset dates are delayed. They shift from November (October) to January (December) for rice (maize). Moreover, we observe the latest onset dates in the North and the South. Instead of September–October, the onset dates become December–January for rice during the late rainy season in the East.

Figure 3 displays cessation dates for rice and maize. The earliest and latest cessation dates are March–April and June–July, respectively. The earliest cessation dates remain in the South. However, this situation is more tangible in the South-east than South-west in the future. Furthermore, the cessation dates extend to May–June in Highland in the future. Generally, the early (late) onset dates are associated with the late (early) cessation dates.

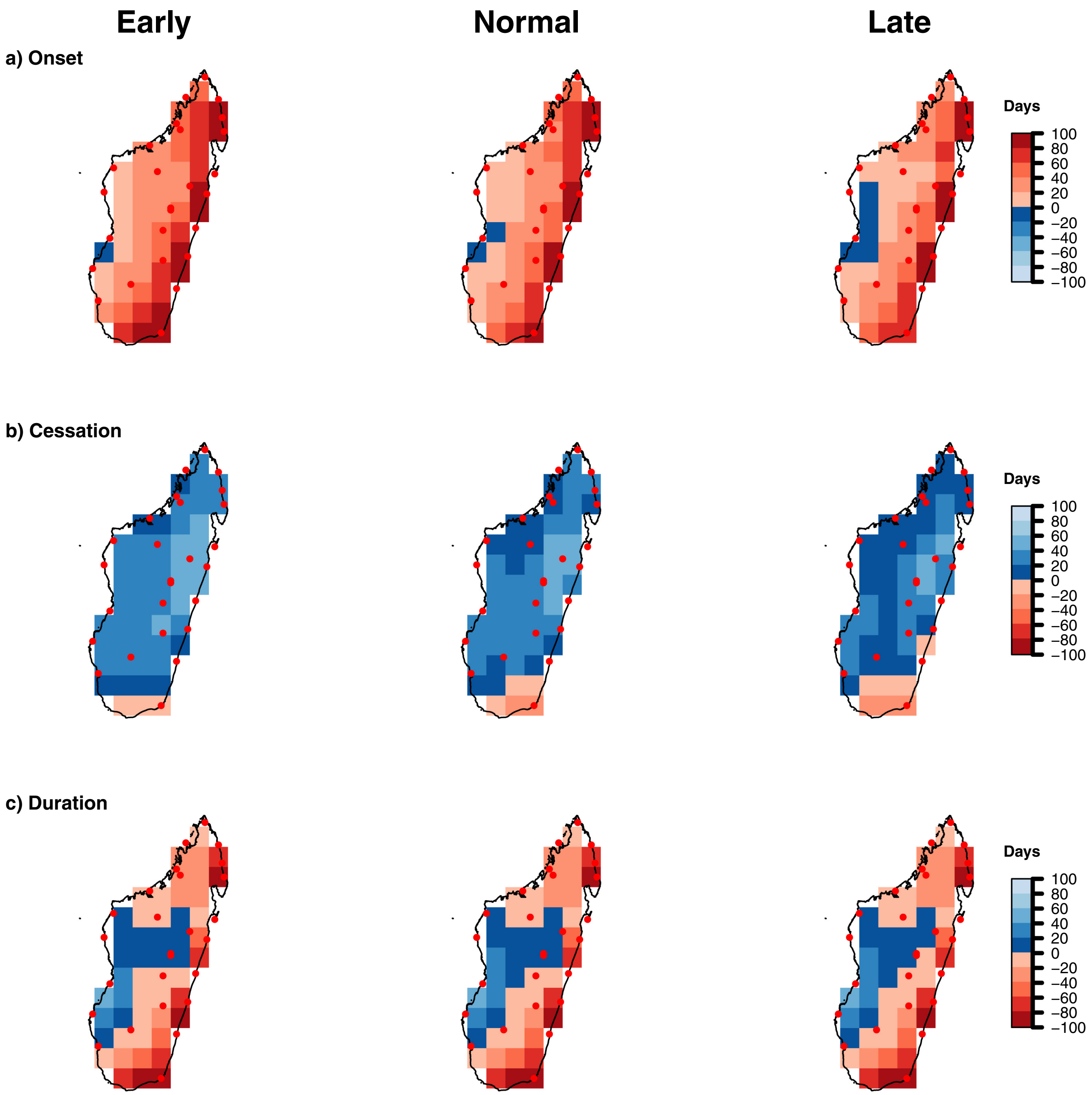

FIGURE 5 (a) Spatial differences between OBS and CMIP6 under SSP245 scenario according to rice growing conditions. Dots represent synoptic weather stations. (b) Spatial differences between OBS and CMIP6 under SSP585 scenario according to rice growing conditions. Dots represent synoptic weather stations.

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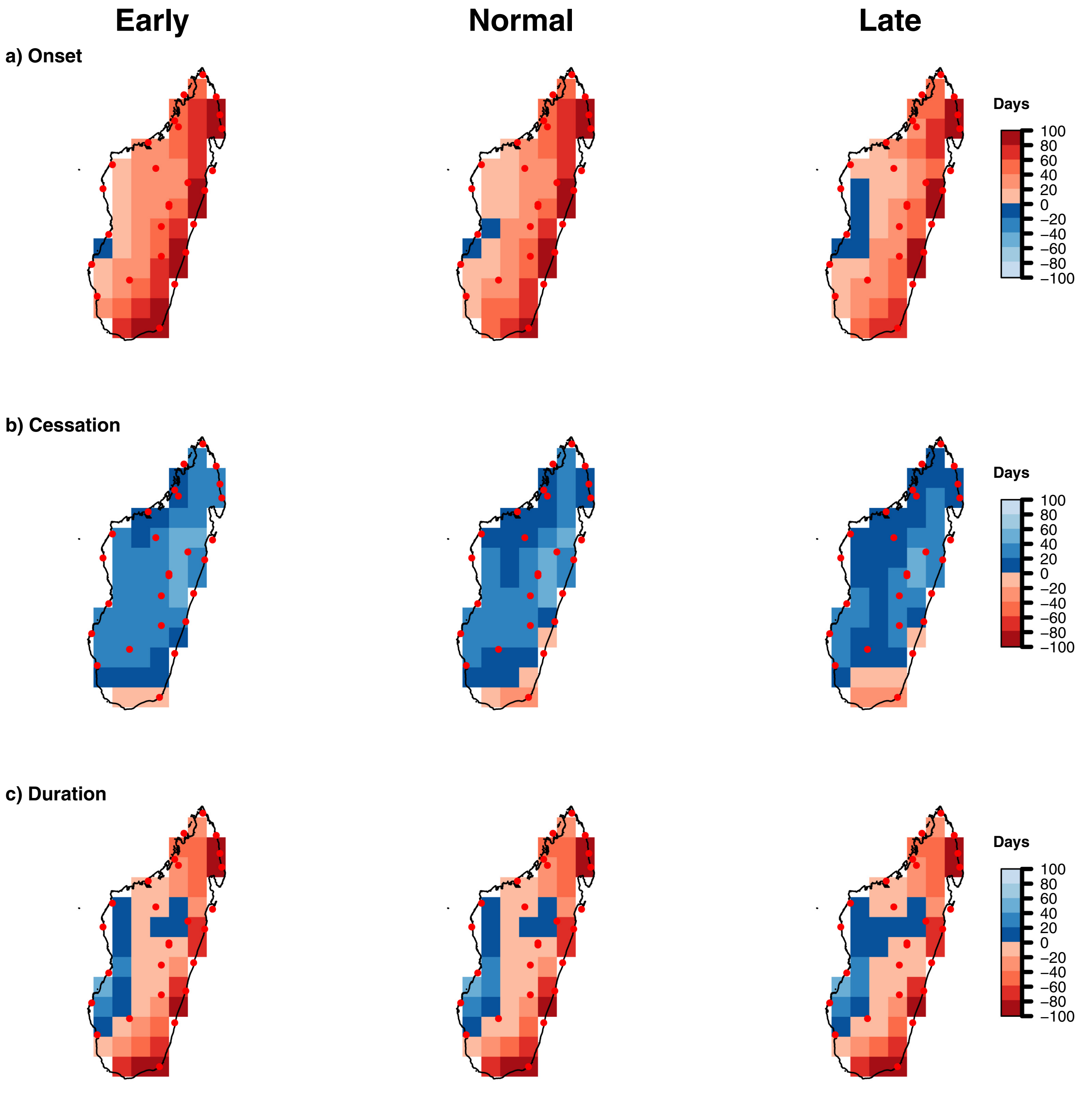

FIGURE 5 (Continued)

These results reflect the variability of the rainy season duration. Figure 4a, b exhibits that the rainy season duration is more than 200 days in the East and the North. Nevertheless, It becomes less than 200 days for rice in the future. Alongside, a significant improvement in rainy season duration, more than 200 days, is seen for maize on Highland. Mostly, the reduction of rainy season duration affects the North, East, and South-east in the future. The reduction is between 20 and 80 days.

This is because the onset and cessation dates are late and early, respectively. For instance, the worst situation is in the South-east. However, some parts of West and Highland or Central land benefit from the lengthening of the rainy season duration. For instance, the best illustration is the case of the South-west (see Figures 5a, b, and 6a, b).

3.2 | Rice and maize crop calendars

The sowing or seeding period starts principally from August to December for rice and maize crops in the observation period. It is shifted from November to January,

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especially for rice crops in the future. This situation postpones the harvesting period. On the one hand, the negative impacts are more important for rice than maize crops, especially in the North and East. For instance, all districts grew predominately rice and maize crops twice a year in the North and East. Nevertheless, any and short rice crops can be grown twice a year respectively for North and East in the future (Figures 7a and 8a). Regarding maize crops, all (i.e., short, medium, and long) and only short varieties may be grown for East and North respectively, but the harvesting period is postponed in January instead of November (Figures 7b and 8b). Moreover, Tables 3 and 4 ascertain the decreases in the length of sowing or seeding period of more than 75 (70) and 100 (35) days for rice (maize) crops in the North and East, respectively. Insignificant changes are seen for the West as the length of sowing

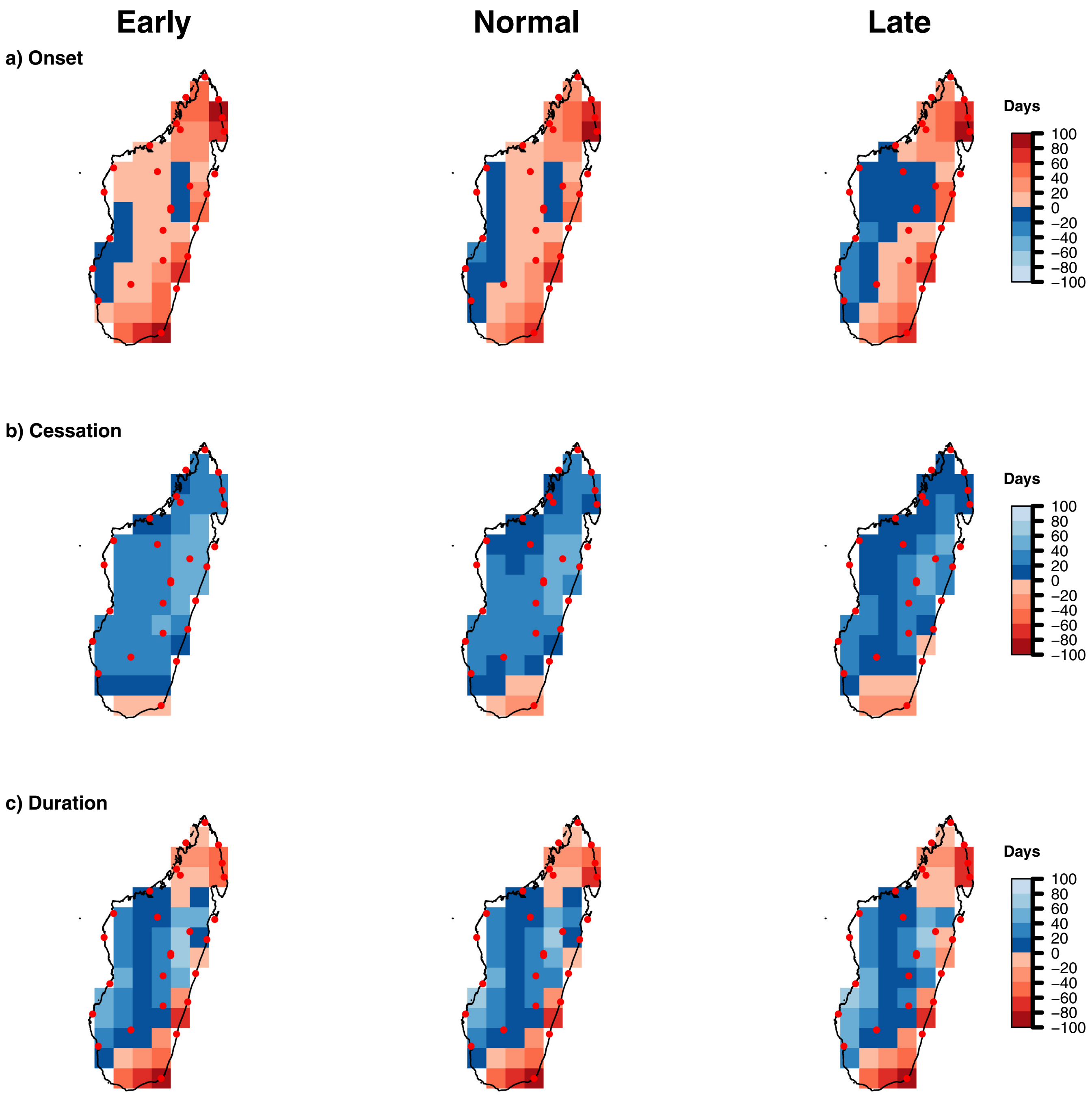

FIGURE 6 (a) Spatial differences between OBS and CMIP6 under SSP245 scenario according to maize growing conditions. Dots represent synoptic weather stations. (b) Spatial differences between OBS and CMIP6 under SSP585 scenario according to maize growing conditions. Dots represent synoptic weather stations.

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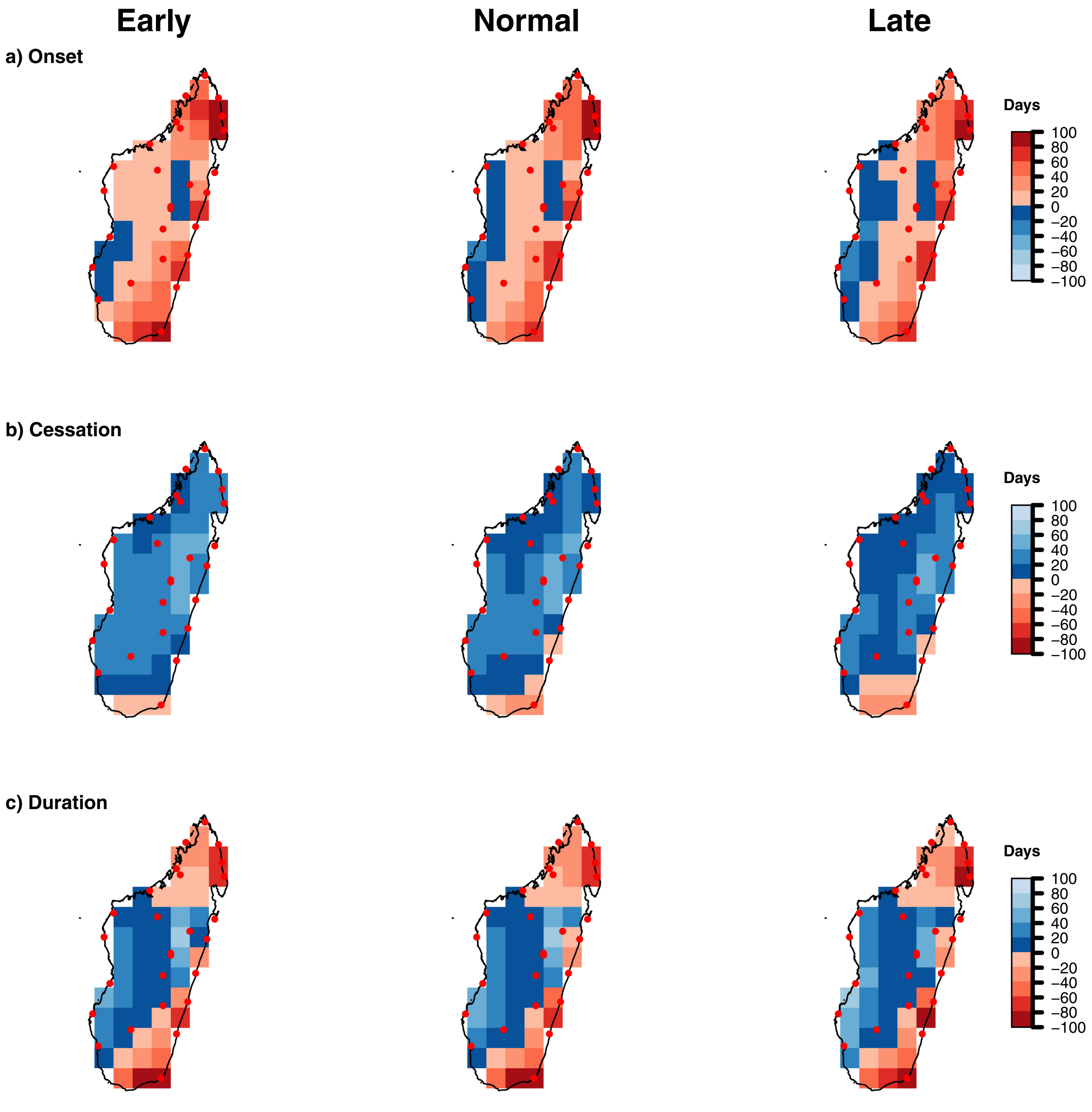

FIGURE 6 (Continued)

or seeding period diminishes around 10 and 2 days for rice and maize crops respectively in the future (Figures 9a, b, Tables 3 and 4). On the other hand, the positive impacts are observed in the Highland and South-west. The length of the sowing or seeding period increases to around 10 and 30 days for rice and maize crops respectively in the future (Tables 3 and 4). The granary rice of Madagascar (i.e., Ambohitsilaozana) may have a chance to improve rice growth conditions (Figure 10a). As the South has a dry climate, rice crops are mostly not suitable. However, a new opportunity may be observed in the future as far as growing rice and maize crops are concerned (Figure 11a, b).

4 | DISCUSSION AND CONCLUSIONS

This paper uses the state-of-the-art science to produce climate and weather information critically important for agriculture sectors. The quality of climate and weather datasets

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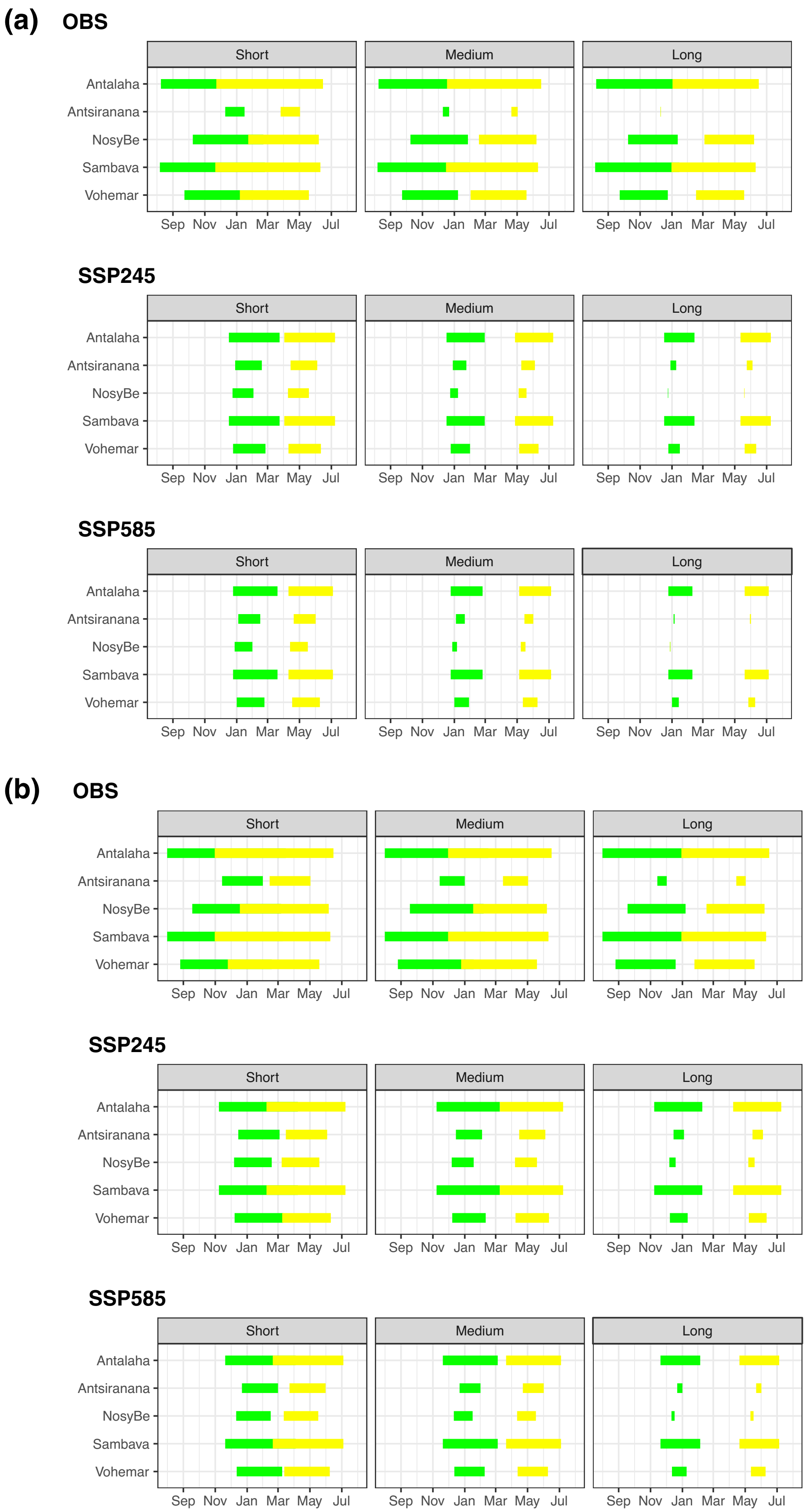

FIGURE 7 (a) Rice crop calendars for North. Green and Yellow colors represent the sowing or seeding and harvesting periods respectively.
(b) Maize crop calendars for North. Green and Yellow colors represent the sowing or seeding and harvesting periods respectively.

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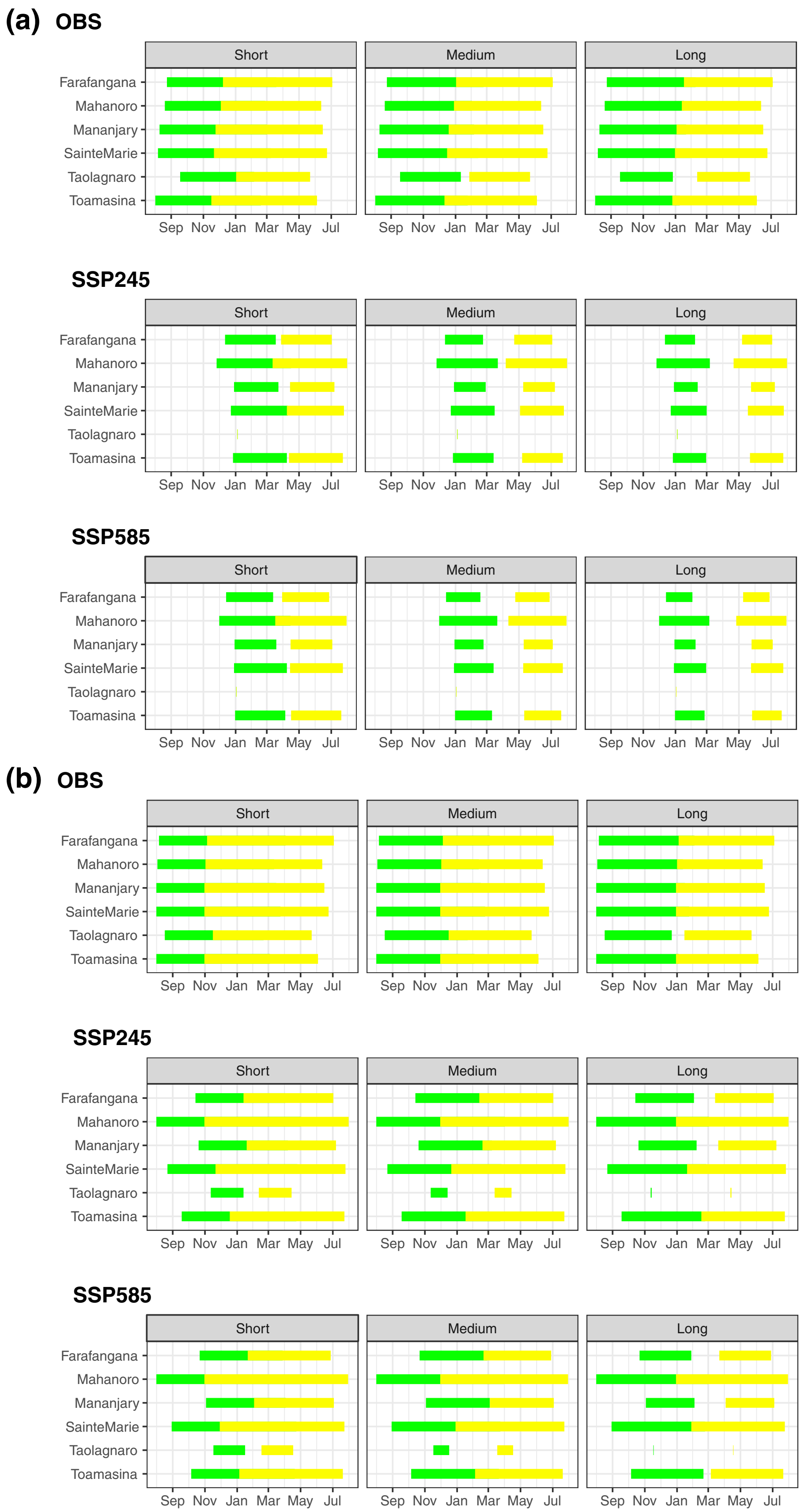

FIGURE 8 (a) Rice crop calendars for East. Green and Yellow colors represent the sowing or seeding and harvesting periods respectively. (b) Maize crop calendars for East. Green and Yellow colors represent the sowing or seeding and harvesting periods respectively.

is assessed. For instance, OBS datasets are quality controlled and homogenized (Randriamarolaza et al., 2022). Climate model simulation datasets are taken from the Sixth Phase of the Coupled Model Inter-comparison Project

TABLE 3 Mean length of sowing or seeding period for rice crops in days.

Regions	North			West			Highland			East			South-west		
LCC	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
OBS	142	117	103	59	34	20	70	45	30	192	168	153	0	0	0
SSP245	69	45	30	49	24	9	83	58	43	88	68	56	19	5	0
SSP585	60	35	21	47	22	7	80	54	40	83	62	50	21	6	1

TABLE 4 Mean length of sowing or seeding period for maize crops in days.

Regions	North			West			Highland			East			South-west		
LCC	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
OBS	174	145	115	91	61	31	100	70	40	221	192	162	9	0	0
SSP245	109	80	50	90	60	30	134	104	75	190	160	130	58	29	9
SSP585	98	69	39	88	58	28	128	99	69	179	149	119	57	29	9

(Eyring et al., 2016) under the Shared Socioeconomic Pathway SSP245 and SSP585 scenarios (O'Neill et al., 2017). Babaousmail et al. (2021) showed that the multi-model ensemble had a performance in simulating the spatial pattern of rainfall over North Africa. Monteverde et al. (2022) ascertained the performance of GCMs, especially with the ensemble model, to produce precipitation in the Amazon River Basin in Brazil. This paper studies daily rainfall to draw rainy season characteristics and crop calendars. Based on these previous studies, we built a super-ensemble model. The CDO software, written by Schulzweida et al. (2017), is used to realize the spatial comparisons between observation and projection datasets. Besides, in-depth research on literature review was helpful to define and set up criteria for rainy season characteristics, which fit rainfed rice and maize crops on water needs. Then crop calendars were deduced by mixing rainy season characteristics and the length of crop cycles. The main results on rainy season characteristics indicate that the past results agree with Oldeman (1990). The early and late onset dates are always started in the East and the South respectively. The opposite is observed for the cessation dates. The length of rainy season is between 70 (in the South) and 300 (in the East) days. Major zones have a length of rainy season between 100 and 200 days. They are mostly found in Central land or Highland. Oldeman (1990) identified that these zones represented 36% and rainy season was from November to April. Precisely, early and late onset dates may occur in October and December, respectively. Moreover, early and late cessation dates may be April and May, respectively.

The consideration of climate projections under SSP245 and SSP585 scenarios allows us to value the opportunities and constraints for growing rice and maize crops in the future. Mostly, the onset and cessation dates became late (December–January) and early (March–April), respectively. This involves the shortening of the rainy season duration as well as the displacement of the sowing or seeding period. Therefore, rice crops were principally more sensitive to the changes than maize crops. Egbebiyi et al. (2019) also noticed that the suitability of maize crop growth conditions was improved than cassava and pineapple crops in West Africa. On the one hand, positive impacts were observed in Highland and South. Crop calendars stated that the South might have a chance to grow short or medium rice and maize crops. These opportunities might be due to the increase in rainfall associated with tropical cyclones under climate change effects (Otto et al., 2022). Moreover, Fitchett and Grab (2014) pointed out that no statistically significant trends were found for the frequency of tropical cyclone landfalls in Madagascar and Mozambique, despite their trajectories seeming to move to the South of Madagascar. Besides, Gerardeaux et al. (2012) showed the positive effects of climate change on rice production in the Highland. We find an extension of the sowing or seeding period, especially for rice granaries in Ambohitsilaozana. Barimalala et al. (2021) highlighted that the 2.0°C global warning level generated an increase in total rainfall during the summertime, especially for West and South-west regions. These findings lined up with our findings, as the rice and maize growing conditions are improving in the West and South-west. For instance, the length of rainy season increases in the future. On the other hand, negative impacts were seen in the North and East of Madagascar. For instance, the South-east was mainly affected. The length of the rainy

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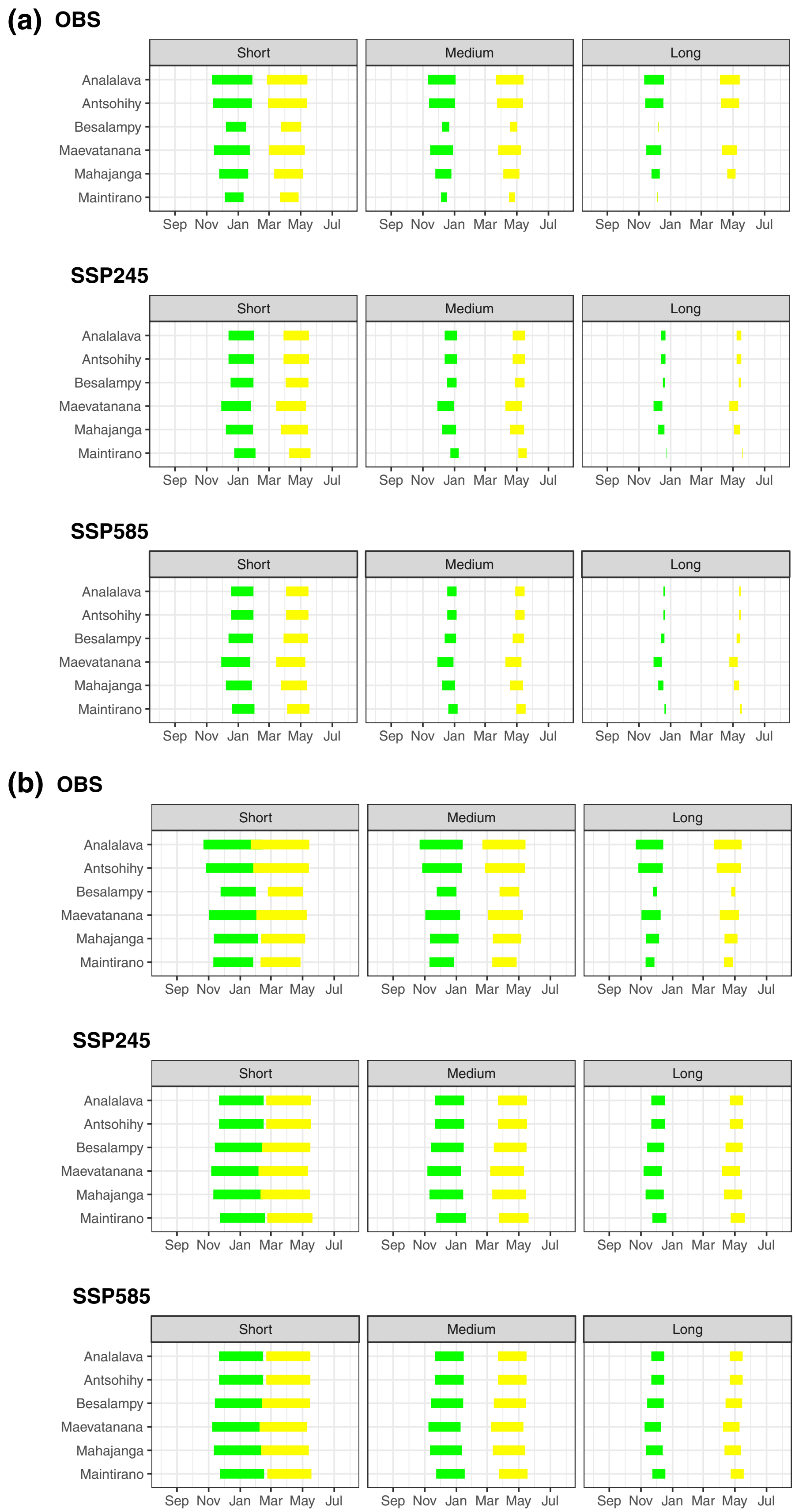

FIGURE 9 (a) Rice crop calendars for West. Green and Yellow colors represent the sowing or seeding and harvesting periods respectively. (b) Maize crop calendars for West. Green and Yellow colors represent the sowing or seeding and harvesting periods respectively.

season was from 70 (100) to 100 (140) days concerning rice (maize) crop needs. A previous paper by Dröge et al. (2020) confirmed that pests and water were the factors limiting rice yields in eastern Madagascar. Furthermore, Barimalala

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FIGURE 10 (a) Rice crop calendars for Highland or Central land. Green and Yellow colors represent the sowing or seeding and harvesting periods respectively. (b) Maize crop calendars for Highland or Central land. Green and Yellow colors represent the sowing or seeding and harvesting periods respectively.

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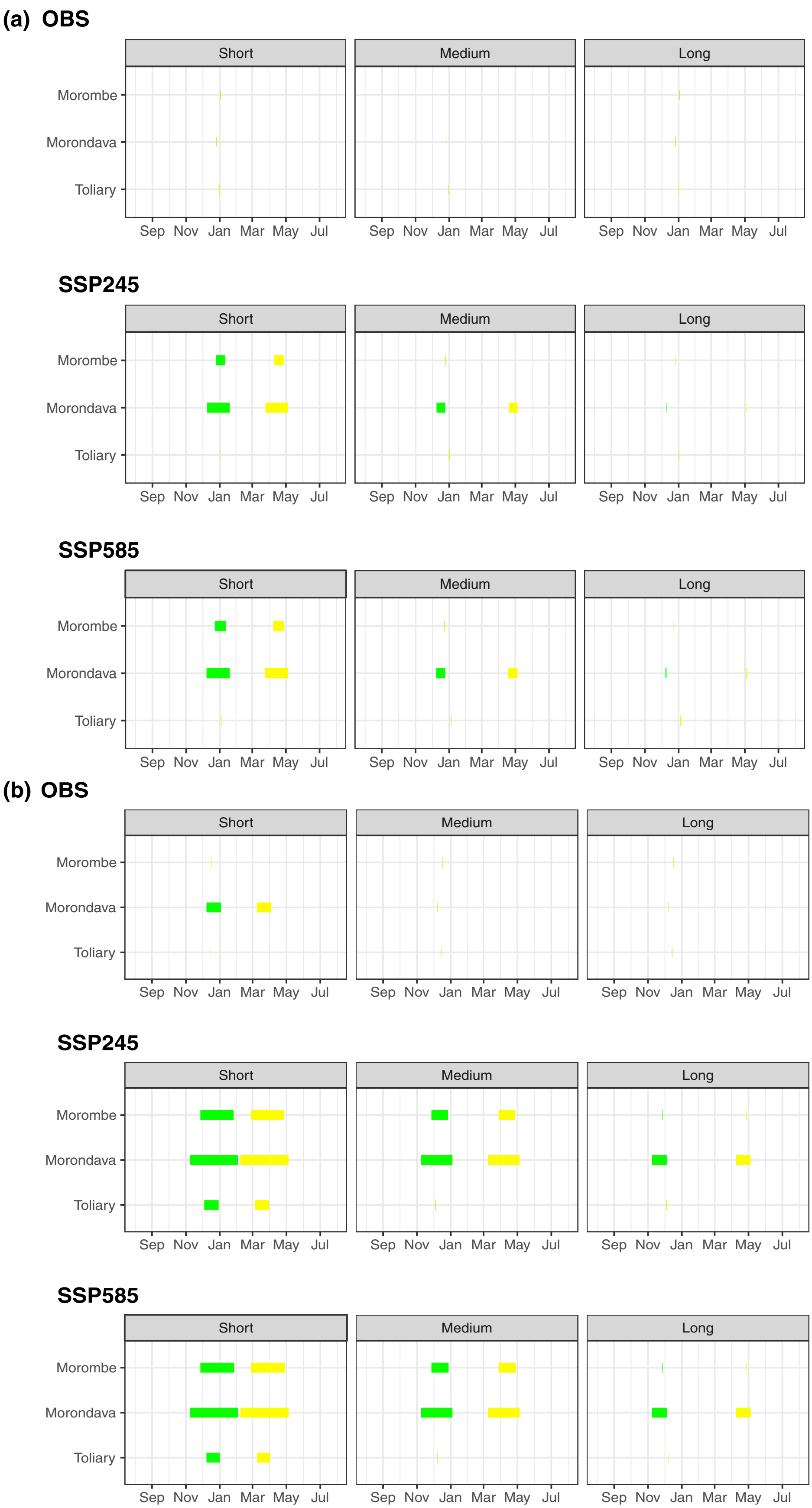

FIGURE 11 (a) Rice crop calendars for South-west. Green and Yellow colors represent the sowing or seeding and harvesting periods respectively. (b) Maize crop calendars for South-west. Green and Yellow colors represent the sowing or seeding and harvesting periods respectively.

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et al. (2021) pointed out that the North and East were subject to a deficit in total rainfall. In the North and East, a significant diminution in the length of the sowing or seeding period was observed. Nevertheless, the interpretation of the results should be taken with caution for food policies.

As climate change adaptation and coping strategies, Madagascar has implemented a system of rice intensification (Thakur & Uphoff, 2017) and conservation agriculture (Bruelle et al., 2015). New seeds, with shortened crop cycles, drought tolerance, and resistance to storm damage, were developed and introduced. For instance, new rice crop varieties were tested such as NERICA stands for New Rice for Africa (Somado et al., 2008). This variety supports the temperate climate in Highland or Central land where the minimum temperature may reach lower than 5°C. Our findings might reinforce and contribute to improving these techniques for increasing rice or maize yield production. Nevertheless, this paper could be upgraded by adding other variables than precipitation, by focusing on crops' phenology for further details on crops calendars. Further research might concern the seasonal forecast of onset and cessation dates as done in East and West Africa (MacLeod, 2018; Rauch et al., 2019).

AUTHOR CONTRIBUTIONS

Luc Yannick Andréas Randriamarolaza: Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); resources (equal); software (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Enric Aguilar:** Conceptualization (equal); funding acquisition (equal); methodology (equal); project administration (equal); resources (equal); software (equal); supervision (equal); validation (equal); writing – review and editing (equal).

ACKNOWLEDGEMENTS

We acknowledge the Directorate General of Meteorology in Madagascar for sharing the climate data. We are also thankful to WMO's CREWS (see https://www.crews-initiative.org/en/projects visited on 22 December 2022), APA, and ENANDES projects (see https://www.adaptation-fund.org/project/chile-colombia-peru-enhancing-adaptive-capacity-andean-communities-climate-services-enandes/visited on 22 December 2022).

FUNDING INFORMATION

This work is done with the financial support of the INDECIS project, which is a part of ERA4CS, an ERA-NET initiated by JPI Climate, and funded by FORMAS (SE), DLR (DE), BMWFW (AT), IFD (DK), MINECO (ES), ANR (FR) with co-funding by the European Union (Grant 690462).

DATA AVAILABILITY STATEMENT

The observational records that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions. However, the climate data simulations from CMIP6 are publicly available at the following URL/DOI: https://esgf-node.llnl.gov/search/cmip6/.

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How to cite this article: Randriamarolaza, L. Y. A., & Aguilar, E. (2023). Rainy season and crop calendars comparison between past (1950–2018) and future (2030–2100) in Madagascar. *Meteorological Applications*, *30*(5), e2146. https://doi.org/10.1002/met.2146

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