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SEASONAL METEOROLOGICAL VARIATIONS IN SOUTHERN MALI, WEST AFRICA PART 1: SURFACE METEOROLOGICAL OBSERVATION FROM 2001 TO 2004

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Abstract Local meteorology observations in southern Mali, West Africa were performed from 2001 to 2004. Daily precipitation data over 4 years reveal common seasonal variations, allowing the seasons to be resolved into pre-rainy, early rainy, break in rain, late rainy and dry seasons. These seasonal cycles are closely connected with seasonal changes in surface meteorological parameters.

Key words: West Africa, Mali, rainy season, seasonal variation, agriculture

1. Introduction

The semiarid regions of West Africa have suffered major drought and famine twice since the 1970s. Famine occurred in the Sahel from 1972 to 1974 and from 1983 to 1985. Several researchers have sought to determine the mechanism of rainfall variability giving rise to famine conditions (Lamb 1983; Folland *et al.* 1986; Hastenrath 1990; Lamb and Peppler 1992; Fontaine and Janicot 1996). Le Barbe *et al.* (2002) recently investigated the rainfall variability in West Africa using high-resolution data, presenting the spatial extent and structure of rainfall on intraseasonal and decadal time scales.

The recent unstable climate conditions attributed to global warming have heightened the importance of meteorological study in semiarid areas. In such meteorological and agricultural studies, both accurate meteorological observations and comprehensive investigations of farming productions are required, necessitating both simulation and fieldwork. However, in comparison

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with developed countries, the meteorological observation networks in the developing countries typical of subarid regions are sparse, and range of observation parameters is limited. The deficiency in meteorological data is exacerbated by the difficulty in performing fieldwork in such countries. It is thus necessary to define the study area and the scope of meteorological investigation, and deploy appropriate field equipment on an individual basis.

In southern Mali, farmers cultivate maize, paddy rice, cotton, sorghum and other cereals. Cotton is a cash crop and very important for the local economy, while other grains and cereals are of primary importance for food. All of these crops are greatly affected by seasonal and interannual variations in rainfall, and it is prudent to investigate the effect of recent climatic variations on the farming crops and drought risk management. The experimental sites were selected and suitable meteorological equipment was deployed for hourly observations from June 2001.

Figure 1 shows the isohyetal map of Mali. The climatic zone of Mali is composed of a northern desert region, the Sahel, Sudan and southern Guinea zones. In southern Mali, crop farming is conducted in regions supporting greater than 500 mm of precipitation per year, and wet-rice cultivation under rainwater is conducted in the 800 mm area. As raw cotton is the main export crop of Mali, annual variations in rainfall have a profound effect on both agriculture and the economy. Two experimental sites in Mali were selected for analysis of meteorological risk, and meteorological observation systems were set up at both sites. However, as the unit deployed in Niessoumana proved to be trouble-prone, the present meteorological analysis is performed using data from the other station installed at Diou in the southernmost part of Mali. Diou is in an area supporting 1400 mm of precipitation per year, which appears to be sufficient for cultivation. However, interannual rainfall variability is relatively large, and drought conditions are not uncommon. Reports on agricultural risk management related to meteorological variations in Niessoumana and Diou have been presented by Caldwell *et al.* (2002, 2005) and Berthe *et al.* (2005).

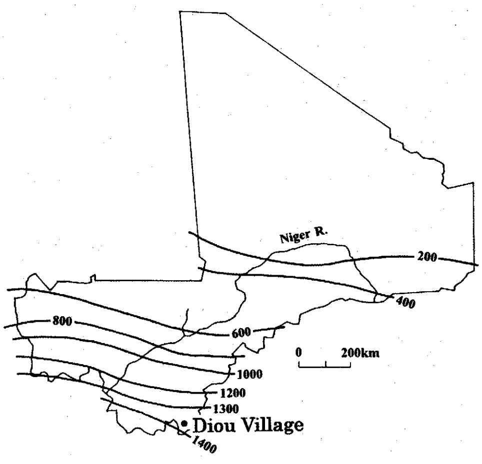

Fig. 1 Isohyetal map of Mali, showing Diou Village at 10.6°N, 6.0°W. Isohyet data are from Traore and Monnier (1980).

2. Data and Methods

Figure 2 shows the Diou station. Meteorological observations of air temperature, air pressure, relative humidity, solar radiation, precipitation, wind direction and wind speed were made at 1 h intervals and stored by a data logger. Air temperature, air pressure, relative humidity, and wind direction are instantaneous values, while wind speeds are 10 min means prior to the hourly data log. The station was powered by a solar-charged battery, and was installed in a wide bare area in the center of the village. Absolute humidity was calculated from air temperature, relative humidity, and air pressure data. Observation began in late May 2001 and was ceased in the middle of 2005. However, due to data gaps as a result of equipment failure (e.g., lightning damage), precipitation data from May 2001 to December 2004 are used to define the rainy season, and other meteorological parameters are taken from contiguous data from 2002 for use in the analysis of seasonal change.

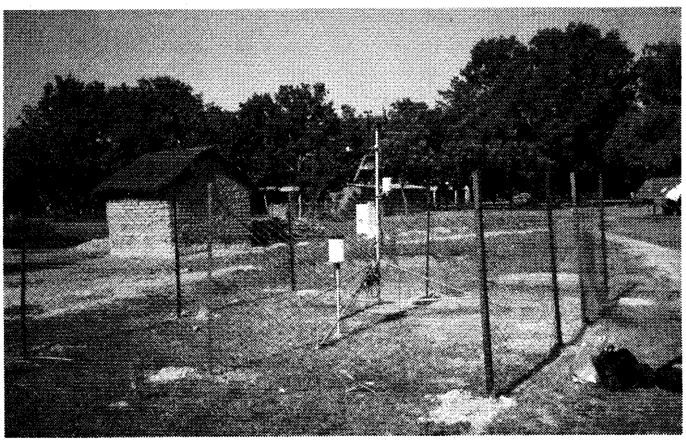

Fig. 2 Meteorological observation site in Diou Village.

3. Results

Daily precipitation in Diou from 2001 to 2004

Time series of daily precipitation from May 22, 2001 to December 2004 are shown in Fig. 3. Annual precipitation was 1027 mm in 2002, 1216 mm in 2003, and 991 mm in 2004. The interannual variation is therefore large, and the annual precipitation was lower than the long-term average of ca. 1400 mm (Fig. 1).

The years 2001 to 2004 display some common and characteristic features in the annual variation in rainfall. Rain first appears in April in most years; on April 6, 2002 (highest single-day precipitation, 73.3 mm), April 13–17, 2003 (10 mm), and April 15, 2004 (55.1 mm). After these rain events, no continuous rains are observed until the middle of May in 2002 and 2003. In 2004, a dry period of longer than 10 days occurred prior to mid-May. After mid-May, the accumulated precipitation increased regularly until early July. As the rainfall in the period from early April to

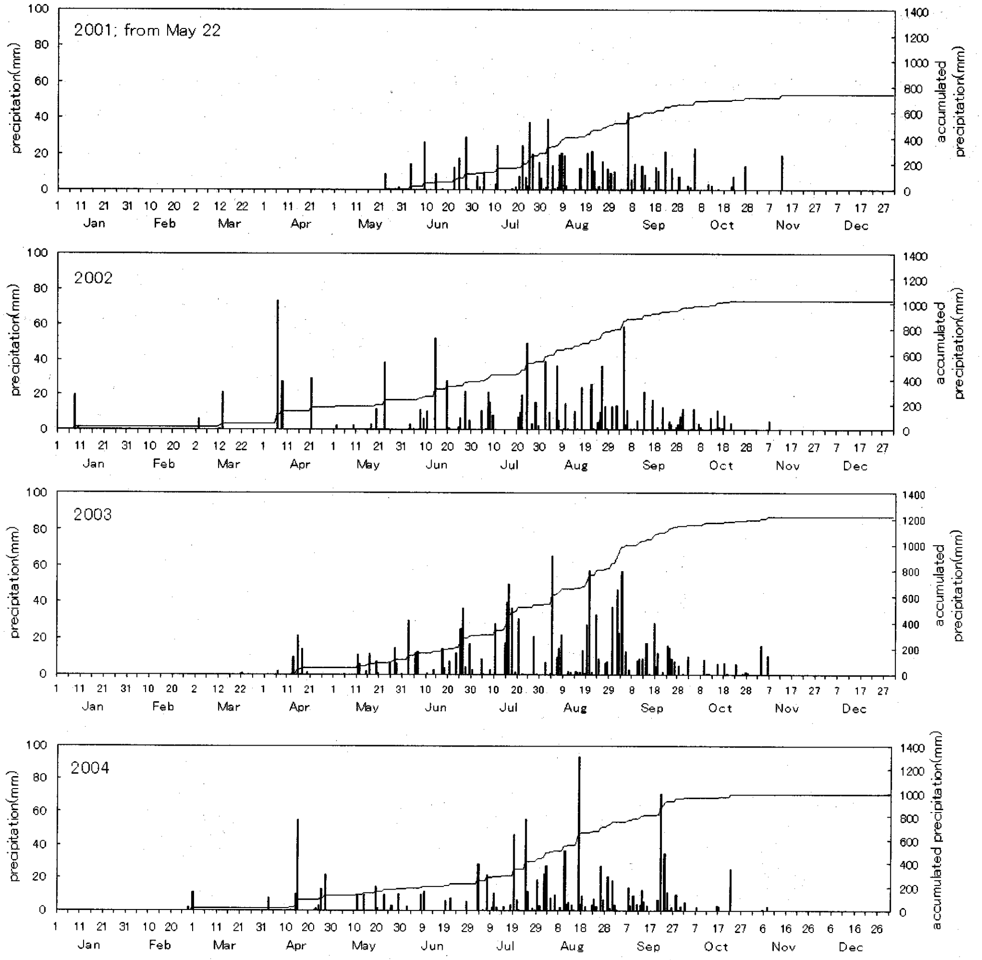

Fig. 3 Temporal variations in daily and accumulated precipitation in Diou, 2001–2004. Data in 2001 are available from May 22.

early May appears to differ from that in the period after early May, the earlier period is defined as the pre-rainy season, and the later period from mid-May to early July is defined as the early rainy season.

Around mid-July, short dry periods of approximately 10 days in length occurred in 2001 and 2002, and precipitation in the same period was very low in 2003 and 2004. Following these drier periods, the accumulated precipitation increased discontinuously. From late July, the frequency of precipitation increases, and the accumulated rainfall rises continuously until late September in all 4 years. The rain interruption in mid-July is defined here as the break in the rainy season, and the subsequent rainy period from late July to late September is defined as the late rainy season. The remaining period from September to April is defined as the dry season.

Seasonal variations in surface meteorological parameters

Temperature

Figure 4 shows the time series of temperature in 2002 at Diou. The daily maximum, mean, and minimum temperatures gradually rise from January to early April, but upon the first rains in April begin to fall discontinuously, followed by a gradually decrease until mid-June. The daily range remains large (ca. 15°C) from January to February, then rapidly decreases until early April, and finally decreases gradually until July. The first rains in April occur simultaneously with the turning point in the seasonal temperature variation.

During the rainy season from mid-May to September, the daily range narrows gradually until mid-June and remains narrow (ca. 9°C) until the mid-July break in the rainy season, after which the daily range further narrows in a discontinuous manner to 7–8°C. The temperature displays a different pattern of variation before and after the break in the rainy season. From September, the mean temperature remains at approximately 25°C until December, while the daily range rises gradually due to the drop in minimum temperature.

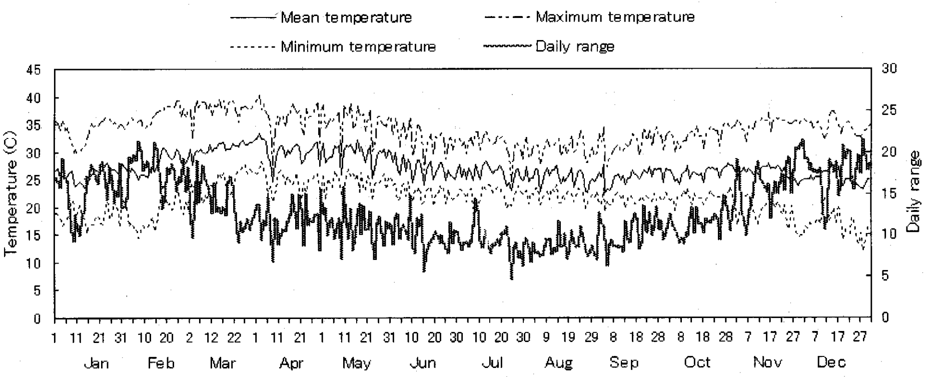

Fig. 4 Temporal variations in daily mean temperature, maximum temperature, and minimum temperature in Diou, 2002. Daily range is the difference between maximum and minimum temperatures.

Humidity

Figure 5 shows the time series of relative humidity (RH) and absolute humidity (mixing ratio; X) in 2002. Both RH and X are generally low until February except for two brief peaks. From March, RH and X begin to fluctuate between in the ranges 20–75% and 4–15 g/kg. At the time of the first rains in April 6, RH and X rise rapidly and then increase gradually until July. It is noteworthy that the absolute humidity in early April is similar to that in the following June, indicating that the water content in the air briefly increases in April to the same levels seen in the rainy season. The relative humidity increases gradually until early July, and then falls briefly in mid-July corresponding to the break in the rainy season. From late July, RH remains at 60–80% until mid-October. From late October, both RH and X decrease gradually until late December. This seasonal change contrasts with the large inter-day fluctuation in spring.

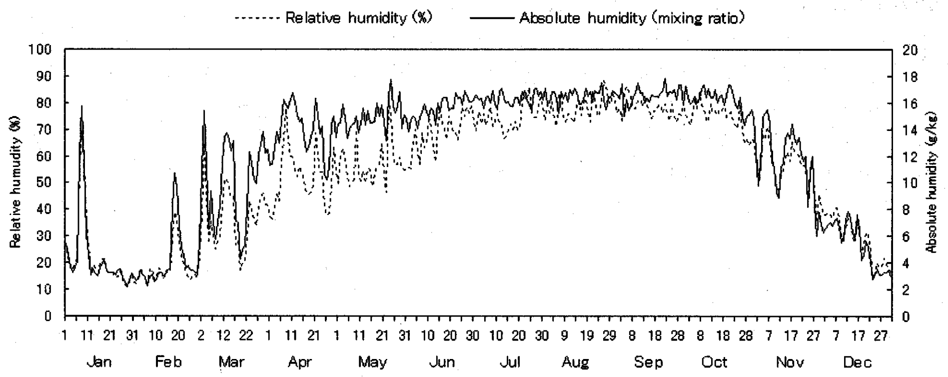

Fig. 5 Temporal variations in daily mean relative humidity and absolute humidity in Diou, 2002.

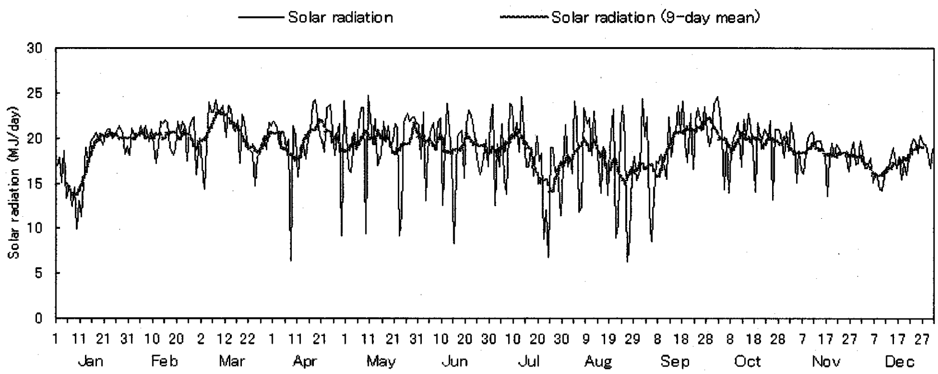

Fig. 6 Temporal variations in daily accumulated solar radiation in Diou, 2002. Thick solid line denotes 9-day running mean.

Solar radiation

The time series of solar radiation is shown in Fig. 6. In mid-January, 2002, solar radiation drops for approximately 1 week, corresponding to the precipitation on January 8 and associated cloudy weather. This precipitation event therefore appears to have been a synoptic-scale disturbance. From mid-January, high solar radiation continues through February and March with small inter-day variations. On April 8, the solar radiation drops to ca. 6 MJ/day simultaneous with a 27 mm precipitation event 2 days after the first rain. On the maximum rainfall day, April 6, solar radiation was 19 MJ/day, suggesting that the rainfall was produced by a cumulonimbus storm resulting from strong convection. From April to early July, solar radiation drops frequently in association with rain and/or cloudy weather, but the 9-day mean remains relatively high (20 MJ/day). From mid-July to early September, solar radiation drops markedly to a 9-day mean of 15 MJ/day. From mid- to late September, solar radiation again rises to 20 MJ/day. These periods of low solar radiation from mid-July to early September are also included in the break and late-rainy periods, indicating that the kind of rain and cloud thickness differ from those in the early rainy season.

Wind

Figure 7 shows time series of hourly wind speed and wind direction. Wind speeds are generally lower than 2 m/s throughout the year, although speeds exceeding 3 m/s occur from May to October. These winds speeds are exceptionally weak in comparison with mid-latitude areas. In contrast, the wind direction displays a distinct seasonal change. From January to mid-February, the wind directions are predominantly in the 0–90°quadrant (N-E). However, around March, the wind direction become unsettled, and from April the prevalent wind direction becomes SW (150–240°). This wind direction change from NE to SW occurs almost simultaneously with the first rains in April. The SW winds blow throughout the rainy season until October, when the wind direction again becomes unsettle in early to mid-November and then changes to NE from late November. These seasonal changes between NE and SW correspond well with the beginning of the pre-rainy season, but not with the beginning and end of the rainy season.

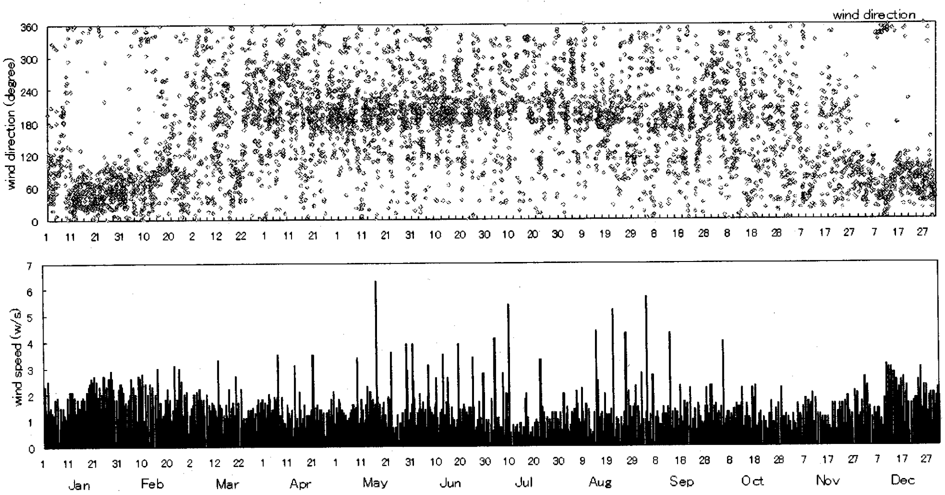

Fig. 7 Temporal variations in hourly wind speed and directions in Diou, 2002.

4. Summary

To better understand the meteorological features in study area, a comparative analysis was performed taking every meteorological parameters into consideration. The seasonal changes in surface meteorological parameters are arranged in Fig. 8.

Based on 4 years of precipitation data, seasons and sub-seasons can be defined as follows. The period from October to March, characterized by little rain, can be defined as the dry season. Early to mid-April marks the first rains, and is followed by a period without continuous rain from late April to early May. This period from early April to early May is defined as the pre-rainy season. From mid-May until early July, rains are frequent, and this period is denoted the early rainy season. Around mid-July, rain stops briefly, defined as the break in the rainy season, followed by frequent rain until late September, constituting the late rainy season.

<table>
<tr><td colspan="2"></td><td colspan="9">Dry Season</td><td colspan="4">Pre Rainy Season</td><td colspan="6">Early Rainy Season</td><td colspan="1">Break</td><td colspan="7">Late Rainy Season</td><td colspan="9">Dry Season</td></tr>
<tr><td rowspan="2"></td><td>month</td><td colspan="3">January</td><td colspan="3">February</td><td colspan="3">March</td><td colspan="3">April</td><td colspan="3">May</td><td colspan="3">June</td><td colspan="3">July</td><td colspan="3">August</td><td colspan="3">September</td><td colspan="3">October</td><td colspan="3">November</td><td colspan="3">December</td></tr>
<tr><td>ten days period</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td></tr>
<tr><td rowspan="6">Surface observation at Diou, Mali</td><td>Precipitation 2001-2004</td><td colspan="9">few rains</td><td colspan="2">first apparent rains</td><td colspan="2">no continuous rains</td><td colspan="6">frequent rains</td><td colspan="1">interruption</td><td colspan="7">frequent rains</td><td colspan="9">few rains</td></tr>
<tr><td>temperatures in 2002</td><td colspan="9">large diurnal range</td><td colspan="11">small diurnal range
temperatures gradually decrease</td><td colspan="7">small interdiurnal variation</td><td colspan="9">diurnal range increases</td></tr>
<tr><td>Relative humidity in 2002</td><td colspan="6">around 20%</td><td colspan="3">large intradiurnal variations</td><td colspan="1">blief increase</td><td colspan="9">gradually increase</td><td colspan="1">drops</td><td colspan="9">keeps around 60-80%</td><td colspan="7">gradually decrease</td></tr>
<tr><td>Mixing ratio in 2002</td><td colspan="6">around 2g/kg</td><td colspan="3">large intradiurnal variations</td><td colspan="1">blief increase</td><td colspan="6">gradually increase</td><td colspan="13">keeps around 16 g/kg</td><td colspan="7">gradually decrease</td></tr>
<tr><td>Solar radiation in 2002</td><td colspan="9">small interdiurnal variation</td><td colspan="10">large intradiurnal variation with about 20MJ mean value</td><td colspan="6">large interdiurnal variation with small solar radiation</td><td colspan="2">over 20MJ again</td><td colspan="9">small interdiurnal variation and gradually decreases</td></tr>
<tr><td>Wind direction in 2002</td><td colspan="5">NE</td><td colspan="4">unsettled</td><td colspan="21">SW</td><td colspan="2">unsettled</td><td colspan="4">NE</td></tr>
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Fig. 8 Seasonal variations in upper and surface meteorological parameters.

The definition of the seasonal transition from the early to late rainy seasons on the basis of precipitation amount and frequency suggest that conditions change from a disturbance lines rain system to a cloudy, prolonged rain system (Barry and Chorley 1987). The break period in mid-July occurs between these two rain stages. Although the mechanism for this break is unclear, the break occurred in all 4 years of the study and thus appears to be an important phenomenon in the general seasonal march and weather cycles.

At the end of the dry season, certain surface meteorological parameters underwent a distinct transition. The daily range of temperature, inter-day variation in humidity and solar radiation, and wind direction all changed markedly at this transition. The period of the dry season and pre-rainy season can therefore be regarded as an important seasonal change. After the pre-rainy season, the early rainy season begins (mid-May) without an accompanying change in meteorological parameters.

Around the break in the rainy season, relative humidity drops bricfly. In thc late rainy season, the temperature displays a small inter-day variation, while solar radiation undergoes large inter-day variations at low values and the relative humidity remains high. Therefore, the break period and subsequent late rainy season are characterized by a distinct seasonal change at the surface. Around the end of the late rainy season (beginning of the dry season), certain meteorological parameters change, including solar radiation and relative humidity.

We will present upper air meteorological data analysis and discuss the relationship among them in Part 2.

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