Analysis of Meteorological Measurements Made Over the Rainy Season 2007/2008 in Sinazongwe District, Zambia.

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Abstract

Local meteorological observations were made in the Sinazongwe District, Zambia, from September 2007. This study investigates the rainy season of 2007/2008, which was defined as occurring between early December and mid March. Daily precipitation data at three sites reveal distinct seasonal variations. The amount of precipitation amount was large at site B (mid elevation, 1586 mm) and site A (low elevation, 1600 mm), and lower at site C (high elevation, 1426 mm). There were precipitation peaks in the evenings at sites B and A, but this diurnal variation was indistinct at site C. Therefore, the differences in the amount of precipitation between site C and sites B and A may be produced by the evening rain.

The understanding of the local village people was that the amount of precipitation in the highlands is higher than in the lowlands. However, the observational data showed the opposite distribution. This difference between perception and observation may be due to higher land temperature and solar radiation in the lowlands than the highlands, causing faster evaporation of soil moisture in the lowlands.

Each site had large variations amongst the observation points. Differences between maximum and minimum precipitation were 176 mm at site C, 190 mm at site B and 140 mm at site A. The precipitation distribution at each site showed systematic patterns. At site C, points of low precipitation tended to concentrate towards the center of the village. At site B, the amount of precipitation was related to altitude. At site A, points of high precipitation tended to lie in the southwest. Seasonal cycles in precipitation were found to be closely connected with seasonal changes in surface meteorological parameters. Some parameters, including temperature, wind and solar radiation, showed differences between the three sites. The observations will continue in order to develop a better understanding of the climate of the research area.

1. Introduction

According to Lekprichakul (2006), there have been six droughts in Zambia over the past 18 years (1991/1992, 1994/1995, 1997/1998, 2000/2001 and 2004/2005), and agricultural products such as maize have suffered dry weather damage. On a broader scale, the semiarid regions of West Africa have also 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 (Folland *et al.*, 1986; Fontaine and Janicot, 1996; Hastenrath, 1990; Lamb, 1983; Lamb and Peppler, 1992). Le

Barbe *et al.* (2002) recently investigated 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 changing climate conditions attributed to global warming have heightened the importance of meteorological study in semiarid areas. In meteorological and agricultural studies, both accurate meteorological observations and comprehensive investigation of farming production are required, necessitating both simulation and fieldwork. However, in comparison with developed countries, the meteorological observation networks in developing countries typical of semi-arid regions are sparse and the range of observation parameters is limited. The deficiency in meteorological data is exacerbated by the difficulty in performing fieldwork in such countries.

This study aims to understand the meteorology in the Sinazongwe District, Zambia. A field program was undertaken and meteorological parameters were observed from September 2007. This study analyzes this meteorological data for the rainy season of 2007/2008.

Fig. 1: Photograph of the meteorological observation station at site C (Siachaya Village).

2. Meteorological Observation Methods

Two meteorological observation robots were installed at Siachaya Village (site C) and Sianemba Village (site A). Observations began in mid September, 2007. Figure 1 shows a photograph of the station at site C. Meteorological observations of air temperature, air pressure, relative humidity, solar radiation, precipitation, wind direction and wind speed were made at 30 minutes intervals and stored by a data logger. Wind direction was recorded as instantaneous values, whilst the other meteorological elements were recorded as 30 min means for the 30 minutes prior to data logging. The station was powered by a solar-charged battery and installed in a wide bare area in the center of the village. Problems at site C meant that the relative humidity data was observed only at site A over the study period. Equivalent potential temperature and absolute humidity were calculated from air temperature, relative humidity and air pressure.

A total of 38 rain gauges were installed at sites C, B and A, 16 at each site. Figure 2 shows a photograph of a rain gauge, which was fixed in the ground with metal pole and cement. Precipitation data were recorded at 30 minutes intervals and automatically stored in the data logger. This study uses hourly and daily means calculated from 30 minutes interval data.

3. Temporal Variation and Distribution of Precipitation

1) Temporal Variation in Precipitation

Figure 3 shows the daily mean and accumulated precipitation at site C from October 10, 2007, to April 30, 2008. Four observation points failed and were excluded from the statistical analysis. The total amount of precipitation in the rainy season of 2007/2008 was 1426 mm. First rain was observed on November 6, and then continuous rain occurred from December 4 onwards. At the end of December, high precipitation was observed and accumulated precipitation abruptly increased. From early January, the rain was continuous but the amount of daily precipitation tended to decrease. Precipitation was interrupted in the later half of February and then started again in early March. The rainy season ended on March 17.

Figure 4 shows daily mean and accumulated precipitation at site B. Three observation points were excluded from the analysis. The total amount of precipitation was 1586 mm, 160 mm more than site C. First rain was observed on November 6, and then continuous rain occurred from December 5. The time series of daily precipitation show similar variations to site C. The date of first continuous rain and the end of the rainy season on March 18 were both one day later than site C.

Figure 5 shows the daily mean and accumulated precipitations at site A. Five points were excluded from the analysis. The total amount of precipitation was 1600 mm, 174 mm more than site C. First rain was observed on November 6, and then continuous rain occurred from December 6. The time series of daily precipitation show similar variations to sites C and B, but the date of first continuous rain was two days later and the end of the rainy season one day later than site C.

Therefore, the precipitation at the three sites showed closely corresponding temporal variation and the rainy season in 2007/2008 can be defined as between December 4-6 and March 17-18. The total amount of precipitation at site C was 10 % less than at sites B and A.

Fig. 2: Photograph of a rain gauge used in this study. The data logger is installed inside the gauge.

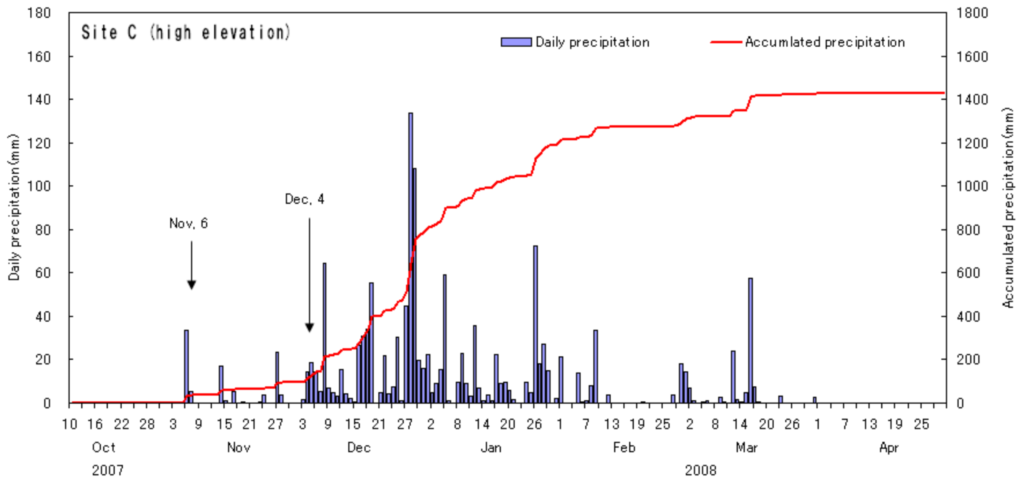

Fig. 3: Daily mean and accumulated precipitation at site C from October 10 2007 to April 30 2008. Precipitation was averaged over 12 data points.

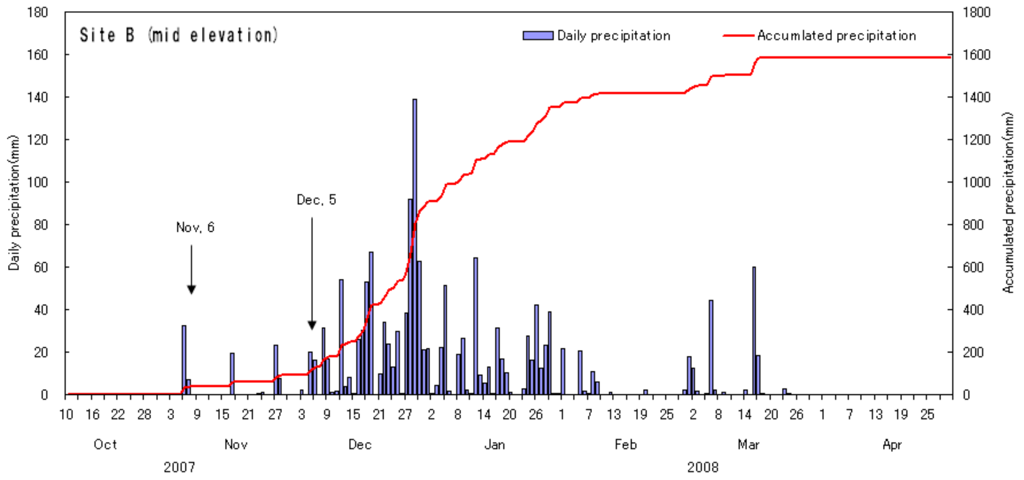

Fig. 4: Same as in Fig.3 except for site B. Precipitation was averaged over 13 data points.

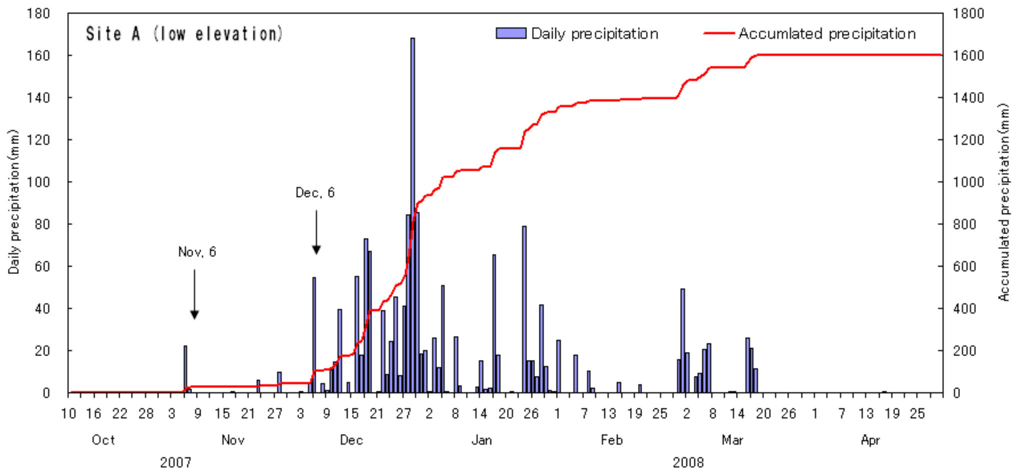

Fig. 5: Same as in Fig.3 except for site A. Precipitation was averaged over 11 data points.

2) Precipitation Distributions

Figures 6, 7 and 8 show the precipitation distributions at sites C, B and A, respectively. At site C, points of low precipitation (less than 1300 mm) tended to concentrate at the center of the village and points of high precipitation (more than 1300 mm) surrounded these. At Site B, points of high precipitation were located to the west, which is mountainous and high altitude, implying that precipitation distribution at this site may be related to altitude and the topography. At Site A, points of higher precipitation were located to the southwest. Site A is flat land along the river, so this distribution was not related to the topography. Other factors such as the route of cumulonimbus and showers may be responsible for this distribution at site A.

Figure 9 shows average, minimum and maximum precipitation and standard deviations at each site from October 10 2007 to April 30 2008. Since the number of precipitation points differs at each site, the standard deviations should be used as a rough estimate. Each site had large spatial variation between the observation points. The differences between maximum and minimum precipitation were 176 mm at site C, 190 mm at site B and 140 mm at site A. The standard deviations were small at site A and large at sites B and C, which may be due to the complicated topography at these sites.

Figures 10 and 11 show the relation between precipitation and altitude at the sites B and C. At site B, precipitation and altitude showed a clear correlation: higher elevation sites tended to have higher precipitation, and the correlation coefficient is 0.54. However, at site C, there was no correlation between elevation and precipitation. This is an important difference as the topography of both sites is mountainous, suggesting that another factor may be affecting the precipitation distribution at these two sites.

3) Hourly Variations of Precipitation

Figure 12 shows the hourly accumulated precipitation from October 10, 2007 to April 30, 2008 at each site. Distinct diurnal variations were present at site A with low precipitation between 03:00 and 05:00 and high precipitation between 16:00 and 18:00. These evening rain are most likely produced by convective rain. Site B showed similar diurnal variations in hourly precipitation to site A, but with high precipitation between 17:00 and 18:00, one hour shorter than site A.

On the other hand, diurnal variations were indistinct at site C and there was no precipitation peak in the evening. This may mean that the convective rain that produces high precipitation at sites B and A does not extend to the highlands. This leads to two hypotheses; 1) The lower total amount of precipitation at site C than at sites B and A may be due to the lack of high precipitation in the evening at site C, 2) The high evening rain may be the cause of the relation of precipitation distribution with topography at site B and lack of high evening rain may make such a relation ambiguous at site C

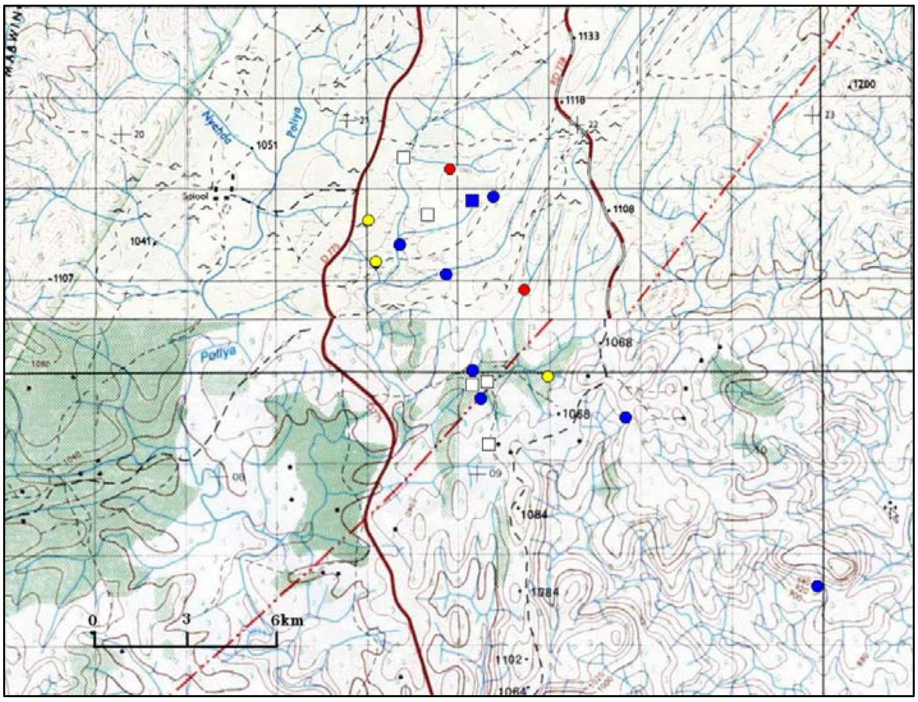

Fig. 6: Precipitation distribution at site C. Precipitation was summed for September 15 2007 to April 30 2008. Red marks indicate precipitation over 1500 mm, yellow marks over 1400 mm, blue marks over 1300mm and white marks indicate lack of data.

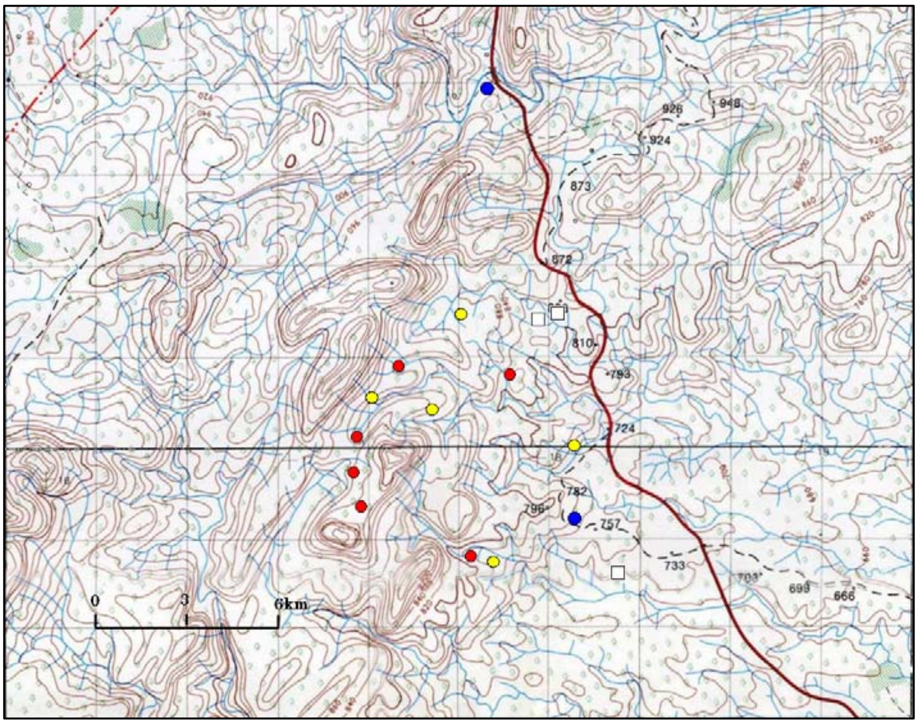

Fig. 7: Same as in Fig.6 except for site B. Red marks: precipitation over 1600 mm, yellow marks: over 1500 mm, blue marks: over 1400 mm.

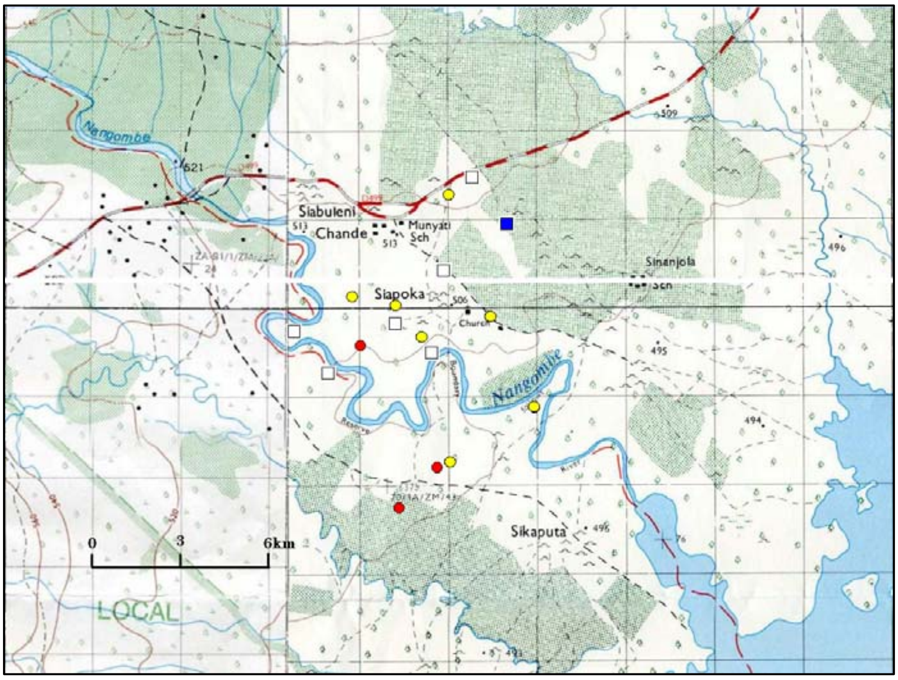

Fig.8 Same as in Fig.7 except for site A.

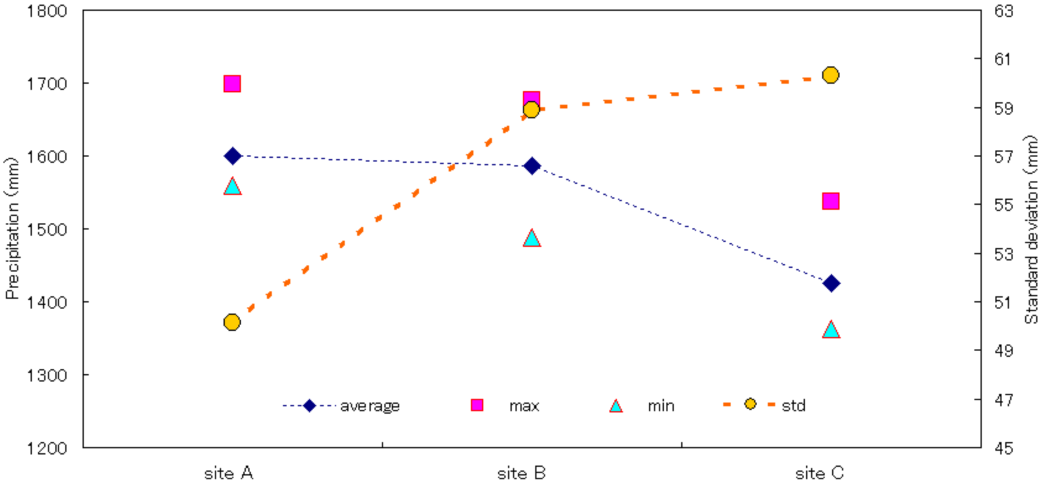

Fig. 9: Maximum, average and minimum precipitation and standard deviations at each site. Period was from October 10 2007 to

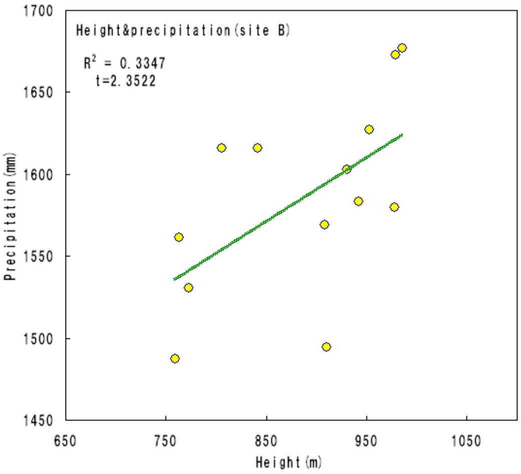

Fig. 10: Relation between precipitation and altitude at site B. The correlation coefficient is 0.54 and significance level is less than 0.05 %.

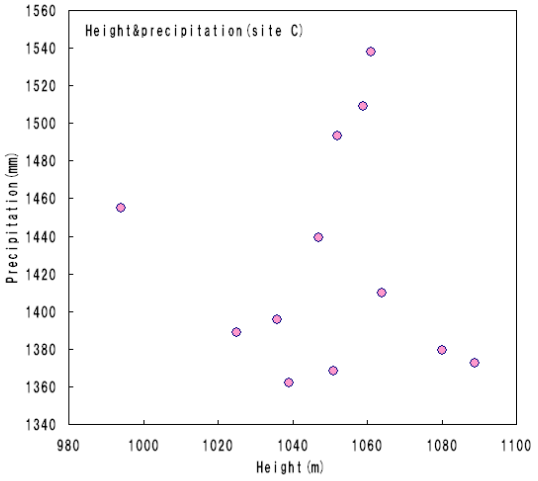

Fig. 11: Same as in Fig.10 except for site C. There is no significant correlation.

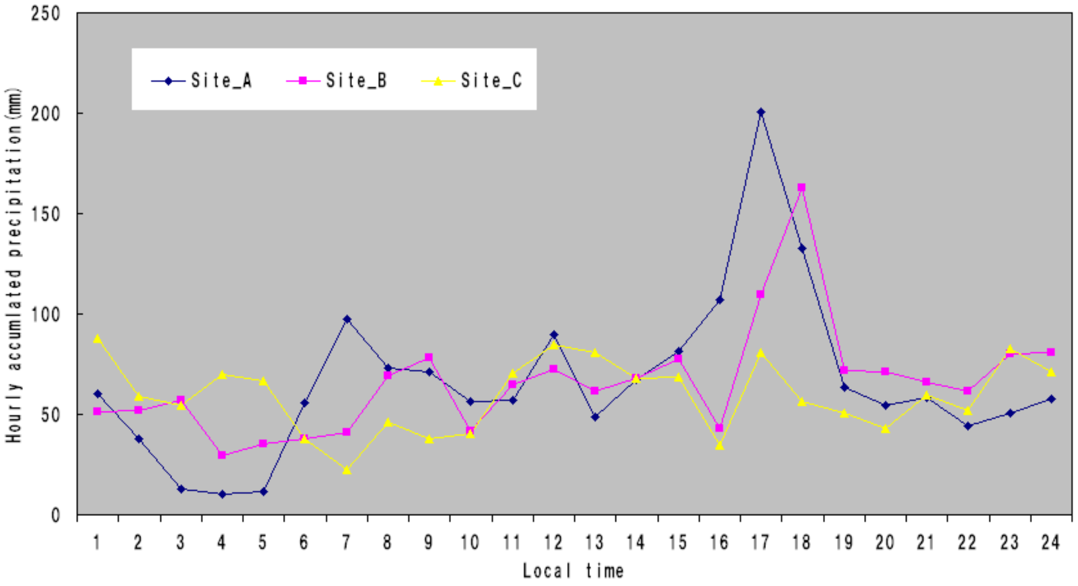

Fig. 12: Hourly accumulated precipitation from October 10 2007 to April 30 2008 at each site.

4. Meteorological Observation Station Data

In this section, daily and hourly variations of the meteorological parameters other than precipitation at sites C and A are discussed.

1) Temperature

Figures 13 and 14 show temporal variations in temperature at sites C and A from September 15, 2007, to April 30, 2008. At site C, the daily mean temperature was around 25 °C and the daily range was around 12 °C before the rainy season (Fig. 13). From the beginning of rainy season, both temperatures and the daily range decreased simultaneously until late January. Through February, both temperatures and the daily range rose again, but to less than before the rainy season. In March, temperatures decreased to around 20 °C on average with a maximum of 25 °C and a minimum of 15 °C.

At site A, the temporal variations in temperature were similar but with values about 5 °C larger than at site C (Fig.14). The maximum temperature occasionally reached around 40 °C before the rainy season.

Figure 15 shows the lapse rate of daily mean temperatures between sites C and A. Temperature lapse rate was calculated by using height difference between the sites (1090 m at Site C minus 515 m at Site A = 575 m). In October and April, the lapse rate was around 0.5 °C. This is almost the same as the moist adiabatic lapse rate at 0.5 °C, implying that stratification may be stable before and after the rainy season. During the rainy season, the lapse rate was around 0.8 °C and sometimes reached around 1.0 °C. Since the dry adiabatic lapse rate is about 1.0 °C, stratification was sometimes absolutely unstable and may produce unstable conditions through the rainy season.

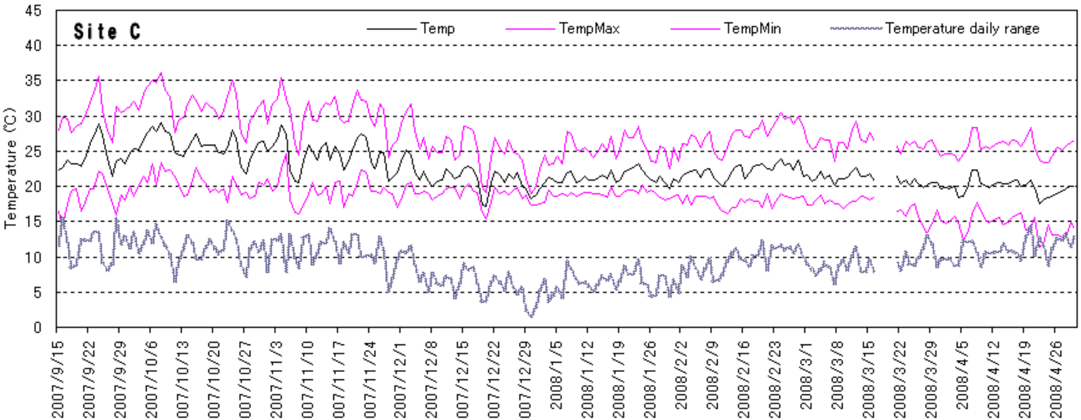

Fig. 13: Time series of maximum, average and minimum temperatures and the daily range at site C from September 15 2007 to April 30 2008.

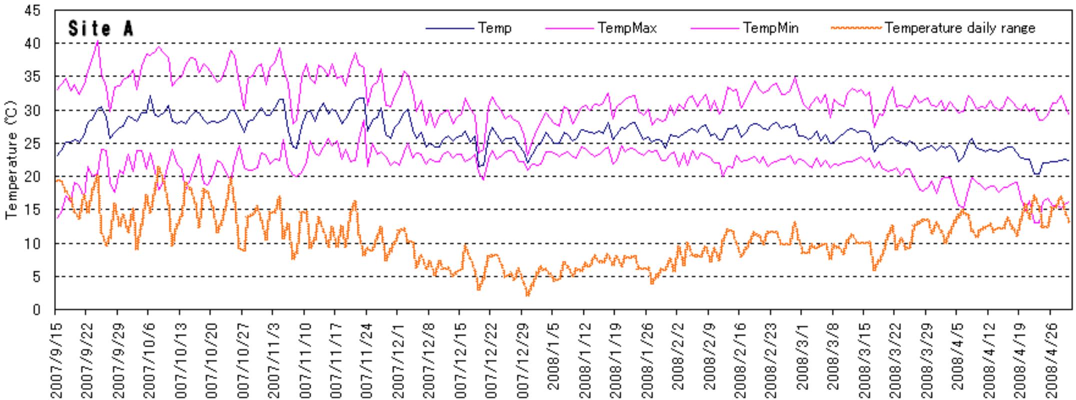

Fig.14 Same as in Fig.13 except for site A.

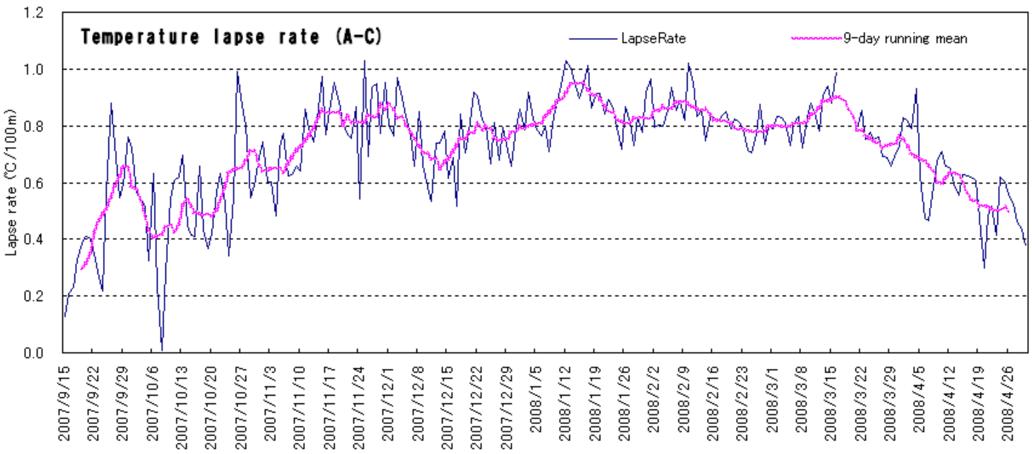

Fig. 15: Temperature lapse rate (℃/100 m) between sites A and C.

2) Wind

Figures 16 and 17 show hourly wind speed and direction at site C from September 15, 2007, to April 30, 2008. The wind speed was generally weak during the rainy season and relatively strong before the rainy season (Fig. 16). The average wind speed during the observation period was 1.5 ms^{-1}. Maximum wind speed was less than 5 ms^{-1} and not strong compared to mid-latitude areas. Wind direction was concentrated around 60 degrees (ENE) and 120 degrees (ESE) (Fig. 17). Figure 18 shows hourly mean wind speed and direction at site C. Distinct diurnal variations in wind speed were present. These were weak (1.0 ms^{-1}) from evening to morning (19:00 to 07:00) and strong (over 2.0 ms^{-1}) from 09:00 to 16:00. There were no distinct diurnal variations in wind direction.

Figures 19 and 20 show hourly wind speed and direction at site A. The wind speed had similar temporal variations to site C, but the average wind speed was lower at 1.3 ms^{-1} (Fig. 19). Wind direction concentrated around 120 degree (ESE) and 240 degree (WSW) (Fig. 20). The wind direction from the WSE is along a mountain ridge and the ESE wind direction is from Kariba Lake. Figure 21 shows hourly mean wind speed and direction at site A. Both wind speed and direction had clear diurnal variations: from 20:00 to 07:00, the wind speed was low and the wind direction was 120 degree (ESE) and from 09:00 to 18:00, the wind speed was over 1.5 ms^{-1} and the wind direction was around 240 degree (WSW). This means that at night, weak wind blows from Kariba Lake, and in the daytime, relatively stronger wind blows along the mountain ridge.

3) Solar Radiation

Figures 22 and 23 show daily solar radiation at sites C and A. At site C, daily solar radiation was around 25 MJ before the rainy season and then decreased to around 10 to 20 MJ until late January. In February, it rose to around 20 to 25 MJ and then decreased again in March. These changes were nearly simultaneous with the precipitation variations (see Fig. 3). After the rainy season, solar radiation gradually decreased, caused by seasonal change of solar altitude. At site A, the seasonal change in solar radiation was nearly the same as at site C, but the values in rainy season were higher than at site C (Fig. 23).

Figure 24 shows the time series of solar radiation at sites A and C and the difference between them. Both before and after the rainy season, solar radiation was generally higher at site C than at site A, but during the rainy season, values at site A were distinctly higher than at site C. In mid January, the difference reached over 10 MJ. These differences in solar radiation in the rainy season are likely produced by the distribution and height of clouds: during the rainy season, high altitude areas may be frequently covered by orographic clouds that block solar radiation.

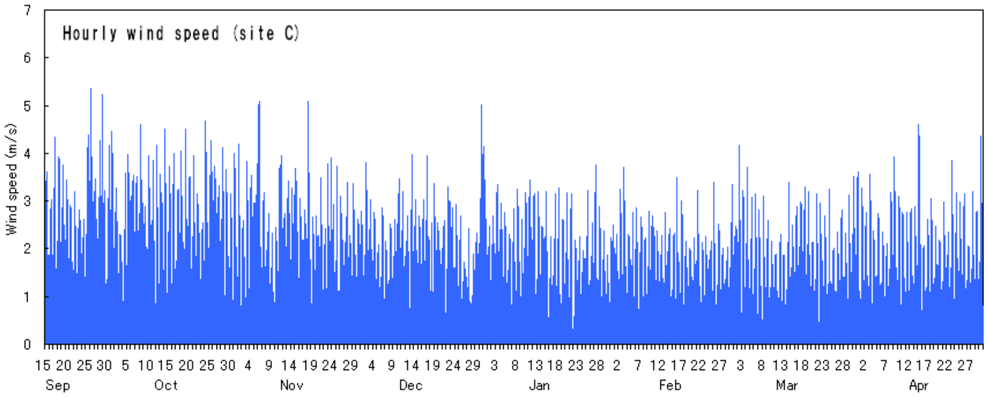

Fig. 16: Hourly wind speed (ms^{-1}) at site C from September 15 2007 to April 30 2008.

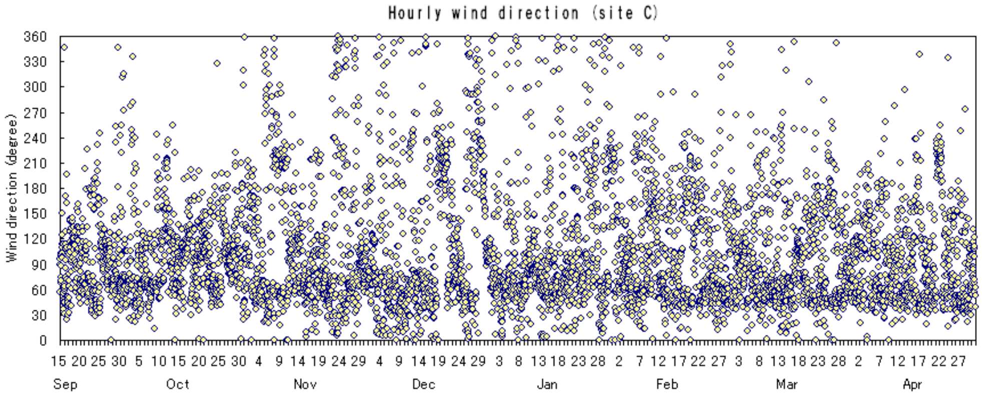

Fig. 17: Hourly wind direction (degree) at site C from September 15 2007 to April 30 2008.

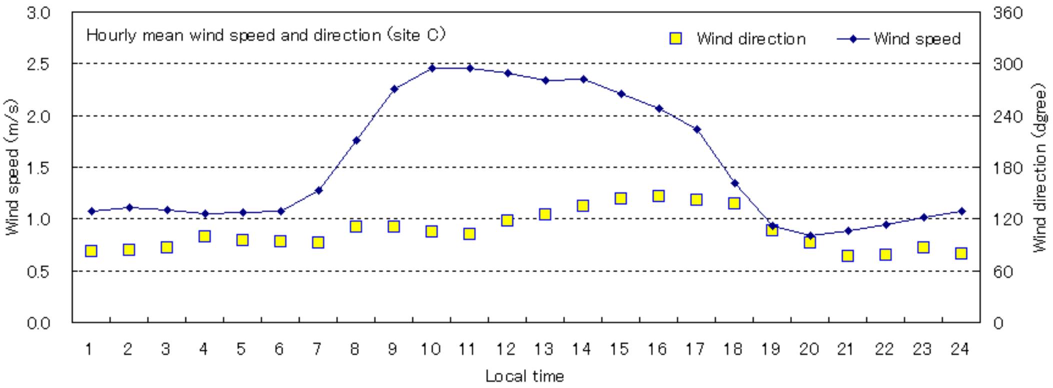

Fig. 18: Hourly mean wind speed and direction at site C. Values were averaged for each hour from September 15 2007 to April 30 2008.

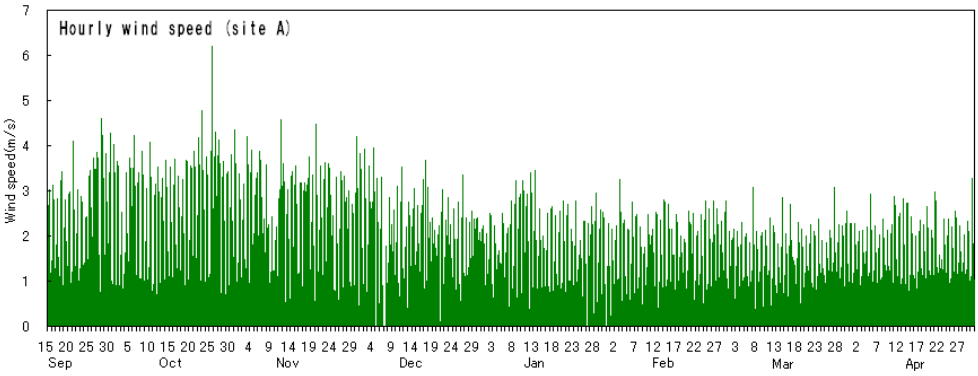

Fig.19 Same as in Fig.16 except for site A.

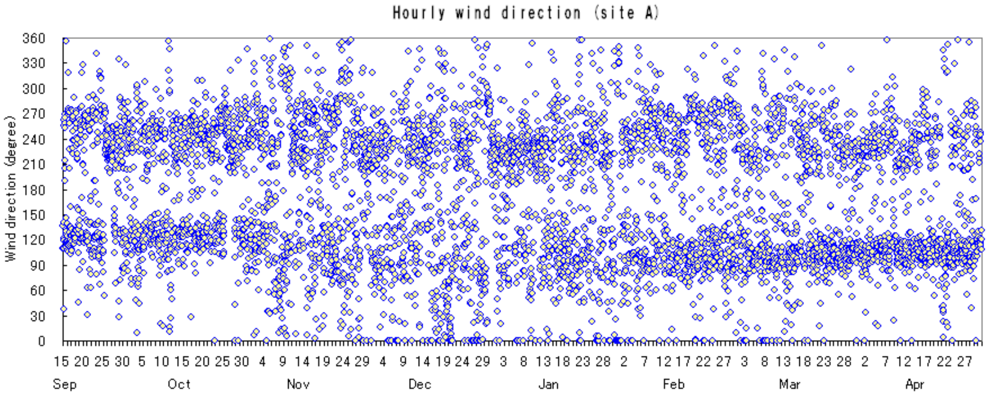

Fig.20 Same as in Fig.17 except for site A.

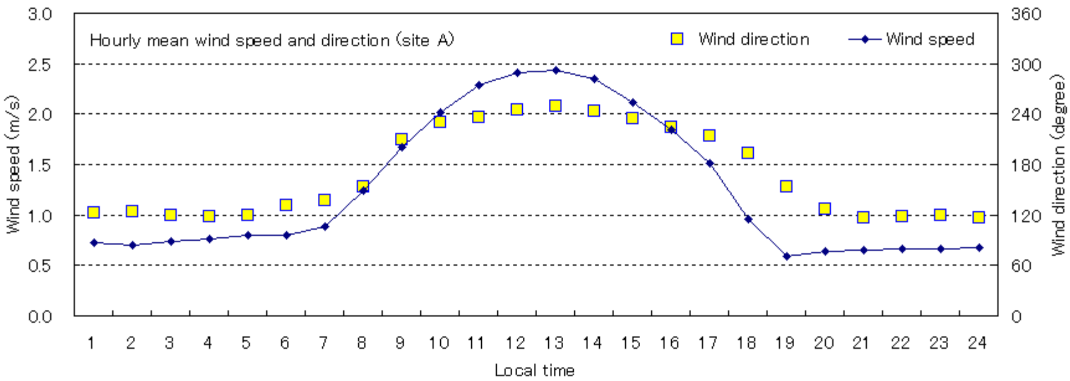

Fig.21 Same as in Fig.18 except for site A.

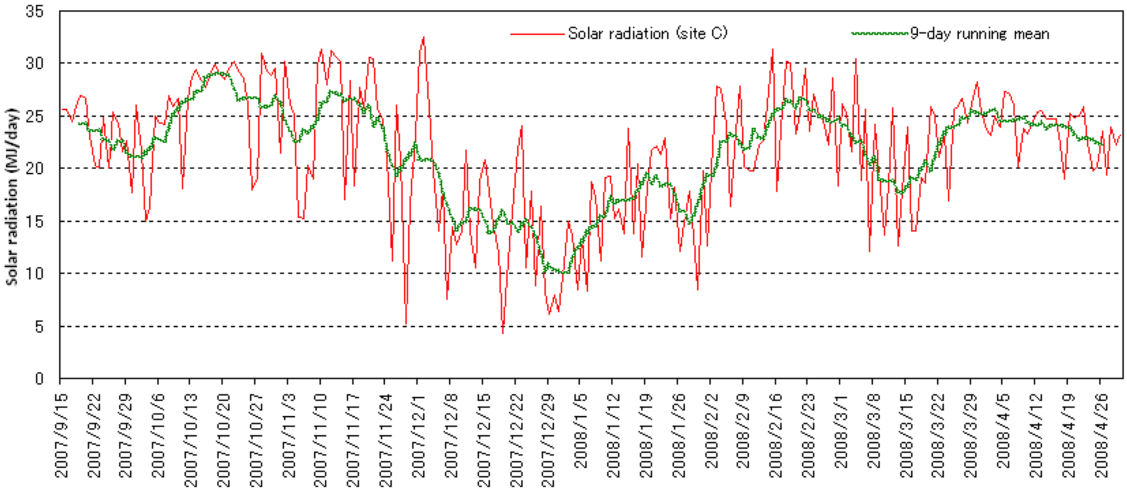

Fig. 22: Time series of daily solar radiation (MJ) at sites C. The nine day running mean is also shown.

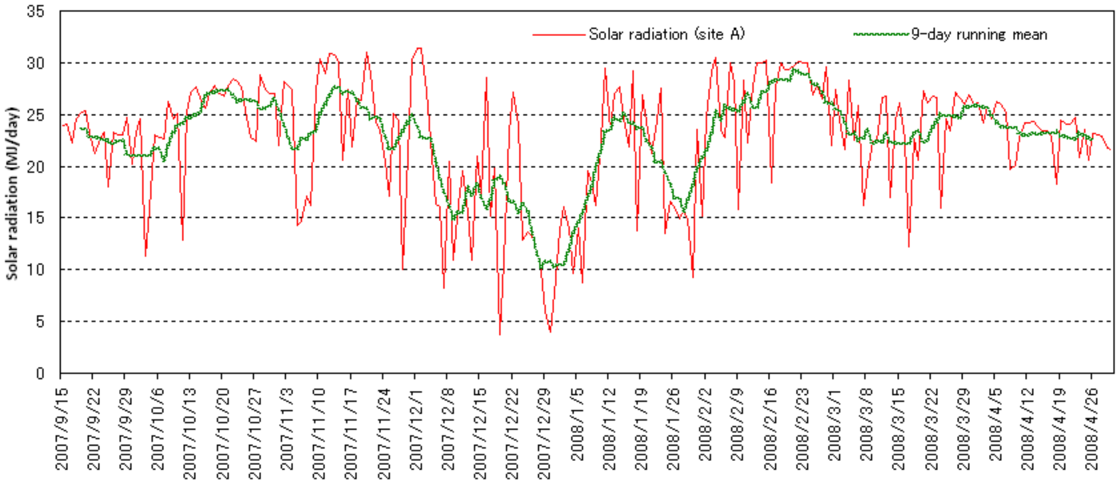

Fig.23 Same as in Fig.22 except for site A.

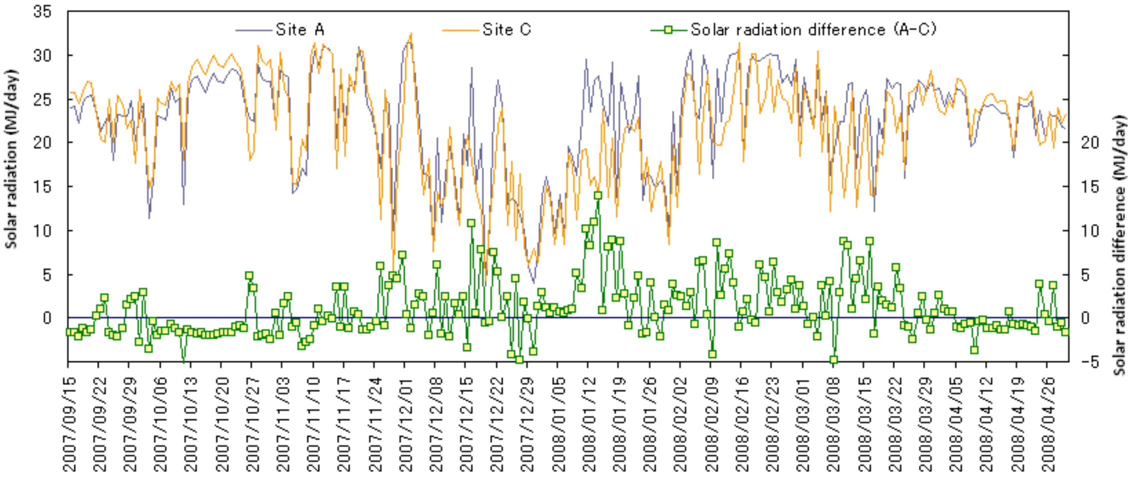

Fig. 24: Time series of solar radiation at sites A and C and the difference between sites.

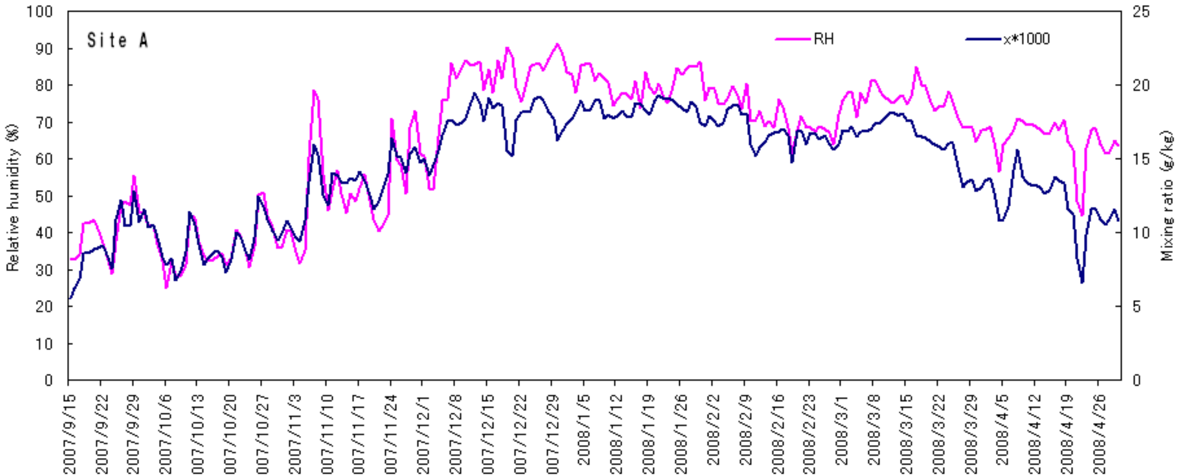

Fig. 25: Time series of relative humidity (%) and mixing ratio (g kg^{-1}) at site A.

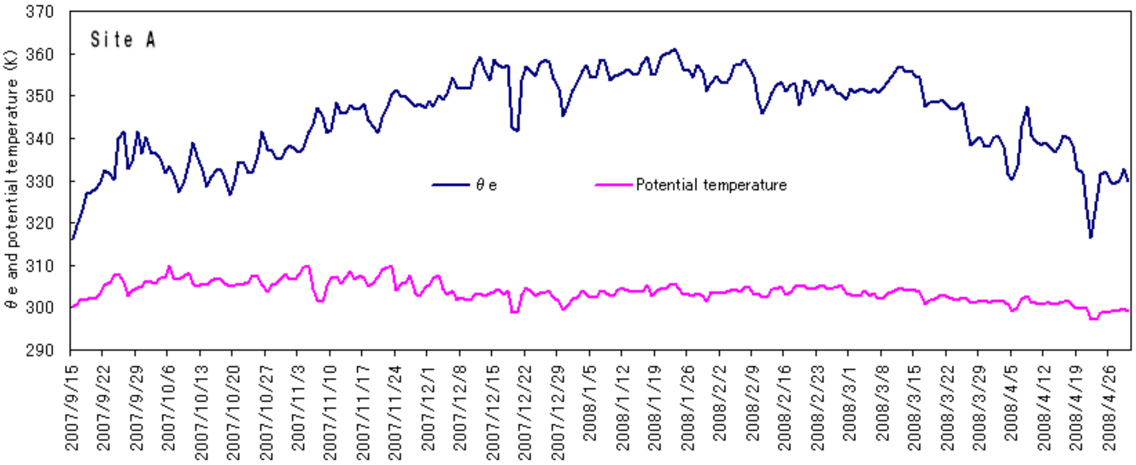

Fig. 26: Time series of equivalent potential temperature and potential temperature (K) at site A.

4) Humidity

Figure 25 shows the time series of relative humidity and mixing ratio at site A. Before the rainy season, relative humidity was about 30 to 40 %. It then rose abruptly with first rain on 6 November. The next abrupt rise was on December 5 with the start of continuous rain. During the rainy season, relative humidity was around 70 to 80 %. It decreased after the rainy season, but it did not return to the level observed before the rainy season. This was due to the temperature decrease after the rainy season.

Seasonal variation of the mixing ratio was similar to the relative humidity, however the values before and after the rainy season ware nearly the same. During the rainy season, the mixing ratio was stable around 16 to 19 g kg^{-1}. Since the seasonal change of mixing ratio was symmetrical from September to April, the amount of water in the air was the same before and after the rainy season.

5) Potential and Equivalent Potential Temperature

Figure 26 shows the temporal variation of potential and equivalent potential temperature at site A. Equivalent potential temperature showed a distinct seasonal change and potential temperature did not. Equivalent potential temperature can be used to define the air mass characteristics and vertical stability. In the continuing fieldwork, the rainy season relative humidity at site C will be observed and the equivalent potential temperature and mixing ratio at the two sites can be compared.

5. Discussion and Conclusion

Local meteorological observations were made at three research sites in the Sinazongwe District, Zambia from September 2007 onward. The rainy season of 2007/2008 was defined as occurring from early December to mid March. The amount of precipitation was lower at the high elevation site (site C) than the mid elevation (site B) and low elevation (site A) sites. There were precipitation peaks in the evening at sites B and A, but diurnal variation was indistinct at site C. The difference in the amount of precipitation between site C and sites B and A may be produced by this evening rain.

Each site had large spatial variations in precipitation between the observation points. The differences between maximum and minimum precipitation were 176 mm at site C, 190 mm at site B and 140 mm at site A. Also, precipitation distribution showed systematic patterns at each site. At site C, points with low precipitation tended to concentrate in the center of the village. At site B, precipitation was linearly related with altitude, and at site A, points with high precipitation tended to lie in the southwest.

The temporal variation in temperature showed a distinct seasonal change and temperatures were about 5 °C higher at site A than at site C. The lapse rate between the two sites was large during the rainy season, indicating that that the stratification around the research sites tended to be unstable at this time.

Wind speeds at the two sites were not strong compared to mid latitudes. There were distinct diurnal variations with wind speeds faster in the daytime and slower at nighttime. Wind direction at site A also had distinct diurnal variations, with the wind coming from the ESE (along a mountain ridge) in the daytime, and from the ESE (from Kariba Lake) at nighttime. At site C, diurnal variation in wind direction was not clear.

Solar radiation at sites C and A decreased during the rainy season and was higher at site A than at site C. Relative humidity and the mixing ratio showed distinct seasonal change simultaneous with precipitation, but relative humidity was not the same before and after the rainy season. The mixing ratio indicated that the amount of water in the air was the same before and after the rainy season. Equivalent potential temperature showed distinct seasonal variations at site A. Over the next rainy season, relative humidity data at site C will be measured, allowing analysis of differences in the air masses between the two sites.

The village people had the impression that the precipitation was higher at the highland site than at the lowland site (Kanno, 2008). However, the observational data showed the opposite tendency. Their false impression may be because at the lowland site, temperature and solar radiation were larger than the highland site, leading to greater evaporation of soil moisture.

The period of rainy season, the amount of precipitation and its distribution have been defined based on only one year of observations. The meteorological observations should be continued to better the understanding of the local meteorology.

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