IV-1: Global Monitoring on Environmental Change

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1. Research objectives

Rainfall is an important factor to dominate environment in Zambia located in the semi-arid tropics. In this sub-theme we investigate climatorogical/meteorological changes, in and around Zambia from a view of two spatial scales, that is, a continental/country scale and a provincial/district scale.

2. Outline of this research

In order to achieve the objective, we focus on two approaches:

1) Analysis of archived global meteorological data to identify typical meteorological characteristics of Zambia and to investigate temporal and spatial rainfall variations in a continental/country scale.

2) Compiling and analysis of ground-based rainfall data to get better understanding of rainfall changes in a provincial/district scale and to identify “meteorological” drought period and region.

3. Results in the pre-research year

Based on our feasibility study in the last fiscal year, we considered appropriate and available global meteorological data for the analysis in terms of 1) a continental/country scale and 2) a provincial/district scale as mentioned above.

3-1. Continental/country-scale analysis

Rainfall and its seasonality is an important factor for climate of Africa. Since there is no large-scale mountain chain, topographic precipitation is not so effective. In a global view variations of rainfall over equatorial Africa are strongly influenced by the Inter-Tropical Convergence Zone (ITCZ) and Zaire Air Boundary (ZAB) (Scholes and Parsons, 1997). In addition to these two streams winds from the Indian Ocean flow is another important factor in the southern part of Africa including Zambia. These global-scale circulations determine African climate such as clear dry-rainy season.

Hence rainfall is influenced by large scale airstreams as mentioned above, analytical research using global meteolorogical data have been made. For example study on relationship between African rainfall and global atmospheric and oceanic variability such as ENSO, the Southern Oscillation Index (SOI), and sea surface temperature (e.g. Shinoda and Kawamura, 1994; Kadomura, 2005; Reason et al., 2005) and on high-resolution GCM over Africa (e.g. Hudson and Jones, 2002;).

Therefore global meteorological data sets are useful resources to investigate meteorological variations in a continental/country scale. At present major institutes which provide global gridded meteorological data sets are the US National Centers for Environmental Prediction (**NCEP**), The European Centre for Medium-Range Weather Forecasts (**ECMWF**), and the Japan Meteorological Agency (**JMA**). They have performed their own operational analysis data (products of their operational weather forecast system using data assimilation) and reanalysis project (which produced by consistent system over some decades producing global objective analysis dataset for over some decades in a consistent way using a weather prediction data assimilation system) such as NCEP reanalysis, NCEP reanalysis 2, ERA-15, ERA-40, and JRA-25. Spatial resolutions of these products are mostly 1.125 x 1.125 or 2.5 x 2.5 degree latitude-longitude grids. Time resolutions are twice or four times a day. Some data sets are charged and some freely and some are not.

Figure 1 shows monthly rainfall over the African continent in January and July 1992 and January1993 obtained from ERA-40 reanalysis (Uppla et al.; http://data.ecmwf.int/) at 2.5x2.5 grids. In January ITCZ located at the equator and brings rainfall over the Congo basin, Lower Guinea. Zambia is also in the middle of rainy season. On the other hand strong rain band spread over the Indian Ocean caused by southeast trade wind from the southern Indian Ocean and and northeast seasonal wind from the northern Indian Ocean, and Zambia is also affected by these circulations. ITCZ moves northward in April and the southern half of Africa go into the dray season. Zambia is also dry as shown in Fig. 1. It is well known that the 1991/92 cropping season in Zambia was hit by severe drought and the 1992/93 cropping season was not. Comparing rainfall in January 1992 with that in 1993 in Fig. 1, spatial change in rainfall is clearly seen in Zambia.

Addition to archived meteorological data sets, products from satellite remote sensing might be also useful. Global Precipitation Climatology Project (**GPCP**, http://www.gewex.org/gpcp.html) formed by the World Climate Research Programme (WCRP) provides monthly mean climatological precipitation data by a 2.5x2.5 degree latitude/longitude grid, averaged over the period from 1979 to 2000. CPC (Climate Prediction Center) Merged Analysis of Precipitation (**CMAP**; http://www.cpc.ncep.noaa.gov/products/global_precip/html/wpage.cmap.html ; Xie and Arkin, 1997) produces global precipitation on a 2.5 x 2.5 grid and extend back to 1979. In a process to make both GPCP and CMAP datasets observations from rain gauges are merged with precipitation estimates from several satellite-based algorithms. **TRMM** (The Tropical Rainfall Measuring Mission and also a name of the satellite; JAXA, http://www.eorc.jaxa.jp/TRMM/index_e.htm ; NASA, http://trmm.gsfc.nasa.gov/) is specially designed to monitor tropical rainfall and was launched in 1997. Based on TRMM data combined with other information observed by rain gauge data and other satellite sensors, various level product have been delivered. Spatial resolutions are 5 to 0.25 degree grid according to the level. Figure 2 is a monthly rainfall in January 2005 obtained from TRMM 3B43 v.6 on 0.25 grid. During a preliminary field research in the last fiscal year we got an information that the 2004/05 cropping season in Zambia was severe drought which is comparable to that in 1991/92. Roughly to say rainfall patterns in Jan. 2005 seems to be similar that in Jan. 1992 (drought period) in Fig.1 rather to Jan. 1993 (normal year). It might be possible to identify characteristic precipitation and other meteorological patterns in drought year in a continental/country scale using these data sets.

Some international programmes have been carried out to investigate African climate and compile various kind of environmental information. Here we outline two programmes; VACS and AMMA.

- **VACS**: Variability of the African Climate System
  - ✓ http://www.clivar.org/organization/vacs/info.php

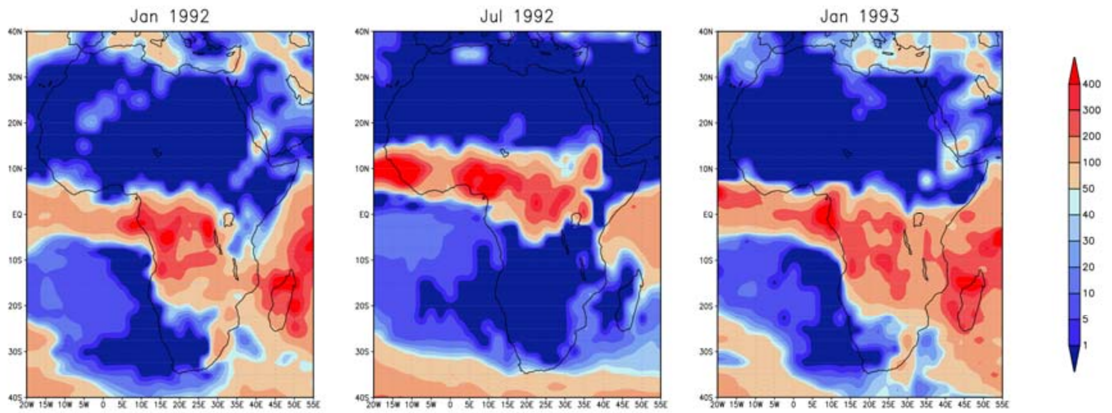

Figure 1 Reanalyzed monthly rainfall (ERA-40) [mm/month] over Africa in January 1992 (left), July 1991 (middle), and January 1993 (right).

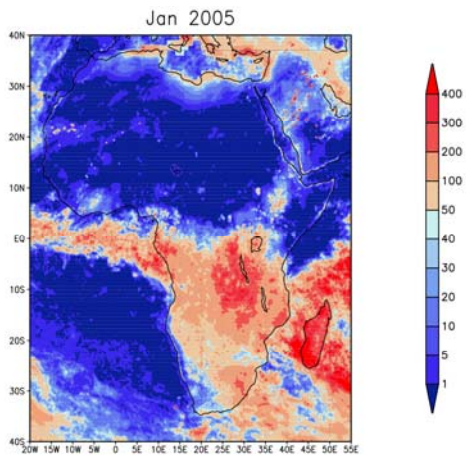

Figure 2 Satellite (TRMM) based monthly rainfall in [mm/month] January 2005.

- ✓ World Climate Research Programme (WCRP, http://wcrp.wmo.int/) carries CLIVAR (Climate Variability and Predictability) programme since 1995 to seek to develop predictions of climate variations on seasonal to centennial time scales, and refine the estimates of anthropogenic climate change. CLIVAR/VACS is one of regional panels which focuses on African climate.
- **AMMA**: African Monsoon Multidisciplinary Analysis
  - ✓ http://amma.mediasfrance.org/
  - ✓ AMMA is a French initiative to accomplish multidisciplinary research on the West African Monsoon (WAM) to improve prediction of WAM and estimate its impacts on West African nations. The main components are: atmospheric dynamics, continental water cycle, atmospheric chemistry, oceanic and continental surface conditions.

3-2. Provincial/district-scale analysis

Agriculture in Zambia heavily depends on rainfall amount in rainy season. To monitor rainfall change in a provincial/distinct scale, ground-based observations are essential. For this purpose, we obtained some of rainfall data observed using rain gauges by Meteorological Department of Zambia, Ministry of Communications and Transport. The department operate 36 meteorological monitoring sites for meteorological elements such as temperature, precipitation, evaporation, air pressure, sunshine, and cloud cover. Some sites have been operated since 1950's. Apart from decrepit measurement devices and question about data consistency, the raing gauge data is variable in consideration that compiled meteorological data are not so may in Zambia.

At present we have

- monthly rainfall at 36 sites from start year to 1991
- monthly rainfall at 23 sites from 1990 to 2001
- annual rainfall at 9 sites from 1993 to 2004.

Figure 3 shows annual rainfall at four sites in Central, Southern, and Eastern province i.e. target regions of our project. In this figure "annual" rainfall is defined as the sum of monthly rainfall from July in the year to June in the next year, according to rainy period in Zambia. Source of monthly rainfall data is observations by Meteorological Department of Zambia. Annual rainfall which has any missing value in monthly rainfall for the period was not plotted.

As seen in fig. 3 annual rainfall at each sites are highly variable and show drastic annual changes. Averaged annual rainfall are 994mm at Chipata, 972mm at Petauke, 827mm at Lusaka, and 806mm at Choma, similar to a definition in "Agro-Ecological Zones in Zambia"; are located in Region I (less than 800mm) and IIa (800-1000mm). It seems that annual rainfall is decreasing after 1980, which should be confirmed by analyses of global meteorological data described in the previous sub-section.

Precedence research in Zambian rainfall (*e.g.* Iwasaki and Shinoda, 1989; Sakaida, 1995) identified that recent drought years were 1972/73, 1983/84, 1990/91, 1991/92. Though interviewees of the preliminary field research in the last FY mentioned that 2004/5 was big drought after 1991/92 drought, the 1994 rainfall show very low values at each site as seen in fig. 3.

Figure 4 is spatial distributions of inter-/extra-polated averaged annual rainfall based on observed sites during 1990's Right-side plate shows average of rainfall in 91 and 94 in which low rainfall were observed, while left-side plate is average of the other 1990 values (i. e. except 1991 and 1994 values). In normal years the rainfall is high in northwest area and decreases towards southeast. On the other hand, in 1991 and 1994 distribution show north-south gradient. Such a rainfall pettern in drought years may help what causes of drought. Some research investigated that drought in southern Africa including Zambia is wheather ENSO-depended or ENSO-independed (influence of variability in the neighbouring

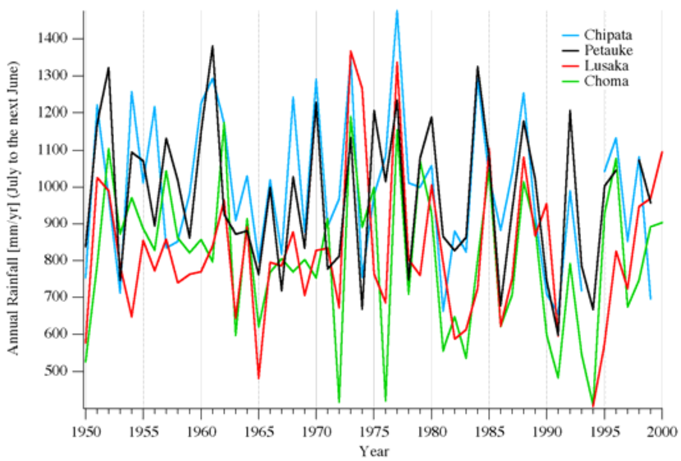

Figure 3 Annual rainfall at four sites in Zambia.

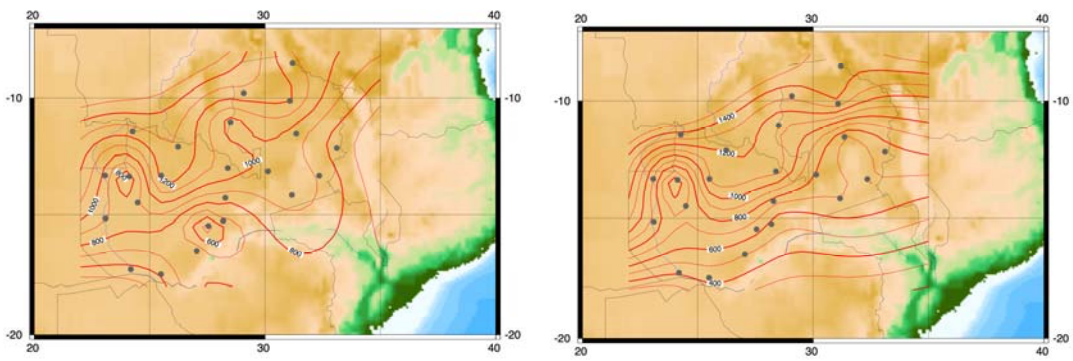

Figure 4 Spatial distributions of averaged annual rainfallin in 1990's normal year (left) and in 1991 and 1994 (right) . Gray dots show location of monitoring sites.

Indian and Atlantic Oceans or in the subtropical and midlatitude Atlantic, or in local land surface processes etc.) (Mason, 2001; Mulenga et al., 2003; Reason et al., 2004; Reason et al., 2006). Further analysis will be required for whole rain gauge data with use of global meteorological data.

4. Summary and future works

Preliminary survey on global meteorological data sets and satellite remote sensing products show that :

- The data capture qualitative characteristics of African climate
- They can be useful resources to investigate continental/country-scale meteorological variations in terms that these data sets cover the globe and keep scientific continuity though their special resolutions are not so fine.
- As for charged data sets we have some kind of global 2.5 grid meteorological data sets and 1.125 grids data in some limited region. To renewal of data sets up to the present and/or to get 1.125 grid data over Africa may be useful. Necessity of these data will be considered while analyzing exist data set in and after the next fiscal year.

Preliminaly provincial/district-scale analysis indicate that:

- To clarify drought area, period and types in a provincial/district scale, it is important to compile more rain gauge data in Zambia.
- The 1994/95 rainy season shows low rainfall while interviewees did not mention it during the preliminary field research in 2005.
- During 1990's the rainfall distribution in low-rainfall years (1991 and 1994) differ from that in normal-rainfall (1990's except 1991 and 1994).
- Statistical analysis will be made on compiled rainfall data to achieve this object.
- Continental/country-scale analysis may help for getting better understanding on provincial/district-scale rainfall changes.

Obtained outcome will be shared with other themes and sub-themes to evaluate resilience of social-ecological systems.

5. Research plan in the FY 2007 (FR1)

To get precise information about "meteorological" drought in Zambia we are planning to:

- Collect ground-based rainfall and related meteorological data in Zambia
- Analyze global meteorological data and ground-based data in focus on Zambia and identify drought area and period.
- Investigate a possibility of integration rainfall data with land cover data surveyed by the theme IV-2 as a first step to synthesize ecological data and social data.

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References

Hudson, D. A., and Jones, R. G., Simulations of present-day and future climate over southern Africa using HadAM3H, Hadley Centre technical note 38, pp. 36, 2002.

Iwasaki, K, and Shinoda, M., Climatic environments of Zambia, Kadomura, H. ed.: *Savannization processes in tropical Africa I*, 43-55.

Kadomura, H., Climate anomalies and extreme events in Africa In 2003, including heavy rains and floods that occurred during northern hemisphere summer, African Study Monographs, Suppl.30, 165-181, 2005.

Mason, S. J., El Niño, climate change, and Southern African climate, Environmetrics, Volume 12, Issue 4 , Pages 327 – 345, 2001.

Mulenga, H.M., M. Rouault and C.J.C. Reason, 2003: Dry summers over NE South Africa and associated circulation anomalies, Climate Research, 25, 29-41.

Reason, C. J. C., Hachigonta, S., and Phaladi, R. F., Interannual variability in rainy season characteristics over the Limpopo region of southern Africa, International Journal of Climatology, vol. 25, Issue 14, pp.1835-1853, 2005.

Reason, C. J. C., Landman, W. A., Tadross, M., Tennant, W. & Kgatuke, M. –J. 2004: Seasonal to decadal predictability and prediction of southern African climate. *CLIVAR Exchanges*, 9, 21-23.

Reason, C.J.C., Landman, W.A., and Tennant, W.J. 2006: Seasonal to decadal prediction of southern African climate and its links with variability of the Atlantic. *Bulletin of the American Meteorological Society,* DOI:10.1175/BAMS-87-7-941, 941-955.

Sakaida, K, Rainfall Changes and their Effects on Maize Production in Zambia, *The Science Reports of the Tohoku University, 7th Series (Geography), Vol. 43, No. 1*, 1993.

Scholes, R.J., and Parsons, D.A.B. (Eds.), IGBP Report 42 - The Kalahari Transect: Research on Global Change and Sustainable Development in Southern Africa -, pp. 62, 1997.

Shinoda, M., and Kawamura, R., Tropical rainbelt, circulation, and sea surface temperatures associated with the Sahelian rainfall trend. J.Meteor.Soc.Japan, 72, 613-624.

Uppala, S.M., Kållberg, P.W., Simmons, A.J., Andrae, U., da Costa Bechtold, V., Fiorino, M., Gibson, J.K., Haseler, J., Hernandez, A., Kelly, G.A., Li, X., Onogi, K., Saarinen, S., Sokka, N., Allan, R.P., Andersson, E., Arpe, K., Balmaseda, M.A., Beljaars, A.C.M., van de Berg, L., Bidlot, J., Bormann, N., Caires, S., Chevallier, F., Dethof, A., Dragosavac, M., Fisher, M., Fuentes, M., Hagemann, S., Hólm, E., Hoskins, B.J., Isaksen, L., Janssen, P.A.E.M., Jenne, R., McNally, A.P., Mahfouf, J.-F., Morcrette, J.-J., Rayner, N.A., Saunders, R.W., Simon, P., Sterl, A., Trenberth, K.E., Untch, A., Vasiljevic, D., Viterbo, P., and Woollen, J. 2005: The ERA-40 re-analysis. Quart. J. R. Meteorol. Soc., 131, 2961-3012.doi:10.1256/qj.04.176

Xie, P., and P.A. Arkin, 1997: Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. Bull. Amer. Meteor. Soc., 78, 2539 – 2558