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RESEARCH ARTICLE

DYNAMIC OF HEAT WAVES IN THE SAHEL OF 1982-2014: STUDY THE POTENTIAL ROLE OF PRECIPITATION AND VEGETATION

[1,2,*]Keita, N.S., [1]Pellarin, T., [1]Diedhiou, A. and [1]Rome, S.

[1]Laboratoire des Transferts en hydrologie et en environnement (LTHE)
[2]Physics Department, Faculty of Science and Technology Bamako, USTTB, Mali

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**Corresponding author:*
Keita, N.S.,

ABSTRACT

This report aims to make a state of the art of the evolution of heat waves during the period 1982 to 2014 in the Sahel and to try to establish a link between heat waves and precipitation as well as Normalized Difference Vegetation Index (NDVI). This will allow a better predictability of future changes in heat waves, the only way to minimize the damage because the models predict that warming will continue even beyond the 21st century. Estimation of heat waves was made on the basis of the heat index that combines air temperature and relative humidity to get a value which determines the temperature felt by the skin. The threshold is set at the 90th percentile of the heat index for a period of at least 3 days together with a minimal spatial extension. Heat waves appear seasonally, with a maximum during the month April-May-June (WAN) and they had a high inter-annual variability during the period 1982-2014. The years 1998 and 2010 have been severe heat waves extensions while those of 1982, 1984 and 1985 recorded low. The study on the severity of episodes of summer heat waves carried on the threshold of the intensity of the heat index and duration. It appears that the years 1998, 2001 and 2010 were severe. The correlation between heat waves in spring and summer precipitation in the same year give a correlation coefficient $r = 0.30$. This result was impacted by the effect of El Nino Southern Pacific (Multivariate ENSO Index (MEI)) and lowered $r=0.10$. The MEI is correlated with heat waves of spring and summer precipitation for respective values of correlation coefficient $r = -0.20$ and $r = -0.17$. Then the correlation coefficient of the precipitation of the year (n-1) and the heat waves of the year (n) was $r = 0.29$. This correlation value is found to be very strong by eliminating the abnormally hot years (1998 and 2010), with a coefficient $r = 0.56$.The studies also try to link heat waves and the last year normalized difference vegetation index (NDVI) a correlation coefficient equal to $r = 0.28$ was found and correlation between NDVI and summer precipitation gave $r = 0.67$.

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INTRODUCTION

Africa is one of the most vulnerable continents to climate variability and change, a situation aggravated by the interaction of multiple stresses occurring at various levels of people with low adaptive capacity [IPCC AR4, 2007]. Temperatures in West Africa, especially in the Sahel, have evolved faster than the global trend, with increases ranging from 0.2°C to 0.8°C per decade since the late 1970s in the Sahel-Saharan zone, Sahelian and Sudanian [CEDEAO-CSAO/OCDE/CILSS, 2008]. These temperature increases in the Sahel region can extend over a significant period thereby generating heat waves episodes.

This will result, heavy rainfall flooding in the Sahel such as Ghana (2007), Ouagadougou (2009), Senegal and Niamey (2012). On the only region of Niger, nearly 80 episodes of torrential rains and floods have been recorded between 1970 and 2000 [Tarhule, 2005] changes in recent decades. The years 1950-1960 were particularly rainy in the center of the Sahel (Niger), while the next 20 years (1970-1980) were extremely dry [Lebel et al., 2009]. Since the late 1990s, there has been a succession of dry and wet years with very strong interannual variability, which seems to respond to an intensification of the hydrological cycle in this region [Panthou et al., 2013]. Another consequence is that heat waves are now major risk events due to their impact on health by creating stress in living things.

This stress is all the reactions from the body due to application of adaptation caused by heat waves. Indeed it is the physiological function of thermoregulation which sets the body temperature around 37°C in normal conditions and that can produce a defense reaction when the temperature exceeds this value. The defense capability of this feature varies by gender and age. Heat waves can generate serious health problems such as dehydration, heat stroke, which is very common in children and in the elderly, and can also cause worsening of existing diseases. During the August 2003 heat wave in France, the report of the National Institute of Health and Medical Research (INSERM) showed that women were more affected than men, with respective increases mortality of 70 and 40%. As for people over 75 years exposed for five days in Paris, the excess mortality was 135% for men and 275% for women (National Heat wave Plan 31/05/04 version of the Ministry of Health and French Social Protection). although it is difficult today to give figures on the death rate due to heat waves in the Sahel, but the finding shows greater increase in deaths during the summer (of occurrence of heat waves period).

Data

MERRA: To conduct the study on the estimation of heat waves we used MERRA called a data set. MERRA [Modern-Era Retrospective Analysis for, Research and Application] is a re-analyzed database of NASA, for simulation of earth observation. The reanalyzed data from meteorological satellite data assimilation models meteorologists, and which have been reworked to ensure long term stability and consistency required for climate [Rienecker et al., 2008]. The analysis of the estimated heat waves depends on two climate variables of air temperature and relative humidity. For this purpose for our study area, we extract MERRA the air temperature values and specific humidity at 2m altitude. The MERRA version used is 5.2.0 of GEOS-5 (Goddard Earth Observations Simulation) which each model and analysis have a resolution of ½° x 2/3°. The data of MERRA update regularly and are compiled in three phases of 10 years from 1979: 1979 to 1989, 1989 to 1998 and 1998 to today. It is time data that can be compared to the scale daily, monthly or yearly. The data are NETCDF format and available in the following configuration: Dimensions, Variables, Global awarded.

GPCP: In order to check a possible impact of the precipitation regime on heat waves in the Sahel, we extracted the precipitation data at a data set called GPCP (Global Precipitation Climatology Project). It is a global precipitation database that was established by WCRP (World Climate Research Program) to quantify the distribution of precipitation around the world for several years. One of the main objectives of GPCP is to develop a more complete understanding of the spatial and temporal patterns of global precipitation. This is a set of data from the stations and satellite observations to estimate monthly merged precipitation on a global grid resolution of 2.5°x 2.5° available from 1979 to the present day.

AVHRR-NOAA: To assess the potential impact of vegetation on heat waves, we used the Normalized Vegetation Index (NDVI), produces AVHRR (Advanced Very High Resolution Radiometer) of NOAA (National Oceanic and Atmospheric Administration). AVHRR imager is radiation detection used remote sensing to determine cloud cover, snow and the surface of the earth (bare soil, water, vegetation). The satellite data are available NETCDF format. They are available every 15 days, the dates 10 and 25 of each month with a resolution of 1.09 km.

Multivariate ENSO Index (MEI): The Pacific Southern Oscillation (ENSO) is the ocean-atmosphere fluctuation strongest on Earth in the inter-annual scale and has global impacts although having originated the tropical Pacific [Mazzarella et al., 2012]. It is a complex phenomenon and oceanic air which has deep economic and social consequences [Wang & Fieldler 2006]. MEI is a multivariate measurement of ENSO signal. This is the first major component of the six main observed variables over the tropical Pacific: sea level, pressure, zonal and meridional component of surface winds, ocean temperature, and air temperature and cloud sky. These are available monthly values from January 1950 to date.

METHODOLOGY

90th percentile threshold and duration: There are several methods of detecting heat waves that their relevance depends on the climate of the study area. For this work we adopted the method of estimation based on the threshold percentiles. This choice is justified through the works of [Rome et al, 2014] which aimed to bring some elements terminology thermal events in the Sahel. [Rome et al, 2014] indicate that a heat wave in the Sahel region is set when the air temperature (Tmin and Tmax) at or above the 90th percentile (T90p) for at least three (3) consecutive days. This general definition they gave two variants, the explanation of the first fixed threshold T90p for a period of 3 days and the second threshold for a T85p (85th percentile) for a period of 5 days. The 90th percentile threshold means that 10% are above this threshold and are the heat waves (figure3). Finally, to estimate these heat waves from the value of the heat index in our study area (latitude 10-17N-20E and 13W longitude), we made a program that extracts all relevant pixels by heat waves by imposing the condition, heat index (HI) greater than T90p for a period of at least three (3) consecutive days. The formula of T90p is given by:

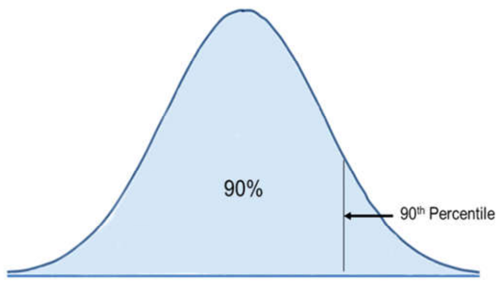

Figure 3. 90th percentile threshold of a Gaussian distribution HI

Criterion of representativity: After stopping the estimation method based on heat waves heat index (HI) of US, choose the 90th percentile threshold for a period of at least three days, we set a heat wave representativeness criterion field of study [10N-17N_13W-20E]. That is to say, in addition to the 90th percentile threshold and duration of at least 3 days, it is considered a heat wave only if it covers at least 20% of the study area. So for the rest we notes HI_P90_3j_20% on [10N-17N_13W-20E]. All pixels that meet the conditions to be above the 90th percentile in terms of HI, for at least three days and whose area exceeds 20% of the area of study.

Exploring the relationship between heat waves and other weather parameters: To try to understand the role of land surfaces in the emergence and dynamics of heat waves in the Sahelian zone, we were forced to make a correlation study between the evolutions of the extension of the heat wave with other meteorological variables. For this article we tested two weather variables which are: precipitation and Normalized Difference Vegetation Index (NDVI).

RESULTS AND DISCUSSION

Dynamics of heat waves 1982-2014: The table1 below shows the monthly evolution of the number of pixels affected by heat waves for the period 1982-2014 in the [10N-20E-17N_13W], that is to say which checks the definition HI_P90_3j_20% on 510N-17N_13W-20E]. It appears that most heat waves occur during the months of April, May and June (AMJ). This period is specific in the Sahel because it determines the end of the dry season and the rainy season begins. And it is also the time of year when temperatures are highest. Figure 4 show the evolution of the extension of heat waves on the basis HI_P90_3j_20% on [10N-20E-17N_13W] similar to Table 2. From top to bottom these graphs indicate the daily, monthly and yearly evolution of heat waves over the period 1982-2014. The number of pixels increases as one moves from the daily scale to the monthly and annual basis since we summon the concerned pixels. It appears that the years 1998 and 2010 were the highest in heat wave, those of 1982, 1984 and 1985 recorded the lowest. The year 1998 appears most affected compared to 2010 in terms of the evolution of the daily extension as it hits 500 pixels against 400 for 2010. But two years (1998 and 2010) are almost the same compared to changes in the monthly and annual extension. The equality of the dynamics of the expansion of heat waves between 1998 and 2010 at the monthly and annual changes is due to the extension in 2010 of heat waves until July (with 206 pixels concerned). Then from years of low heat wave is the year 1985, which is the lowest with less than 1000 pixels affected by heat waves throughout the year 1985. It is surprising that the period 1982-1985 has been the driest period as the Sahel has experienced in the 20th century [Lebel et Barbé, 1997].

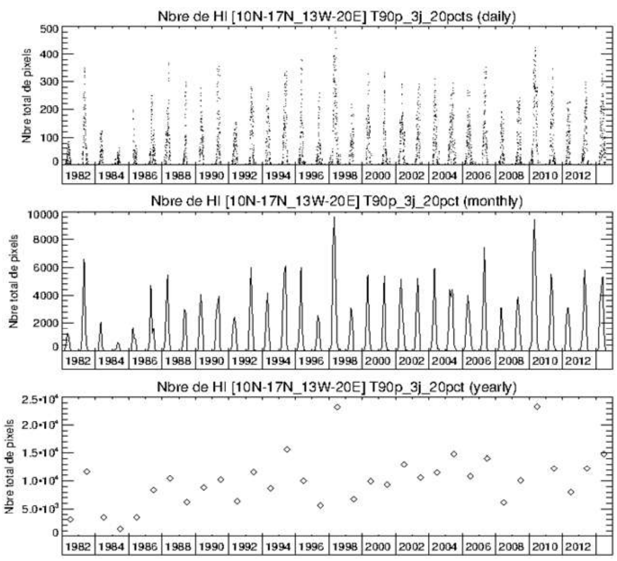

Figure 4. Evolution of the daily, monthly and annual expansion of heat waves in the study area bounded by 10N-17N latitude and 13W-20E longitude based on the heat index above T90p with duration of at least 3 days and a representative rate of 20% of the total number of pixels (HI_P90_3j_20%).

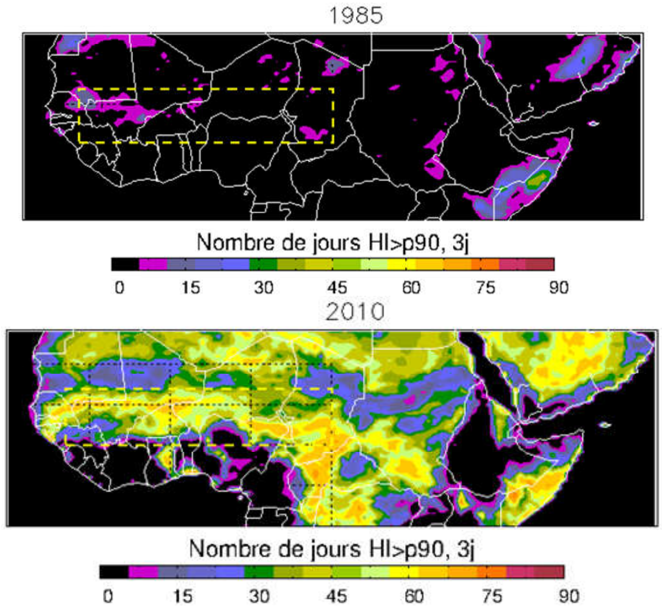

Figure 5. spatial evolution of heat waves 2D in the field [0-24N_10W-60E] for 1985 (lower heat wave year) and 2010 (a year of strong heat wave)

Figure 5 shows an example of the spatial extension of heat waves for the Africa area bounded by the 0-24N latitude and longitude 10W-60E for two contrasting years (1985 and 2010). In 1985, there is a maximum of 15 days of heat waves in northern Senegal, while in 2010 some part of the central Sahel, including northern Burkina Faso, the heat waves were observed for more than 70 days. There is also certain homogeneity of these two contrasting years, 1985 has practically no heat wave across Sahelian Africa while the presence of heat wave is almost universal in 2010. The yellow dotted area materializes the study area. To illustrate what may be the spatial extent of an episode of heat waves, we have chosen a date selected in AMJ interval (eg 26 May). Figure 6 show the extension of heat waves that day for 1985 and 1998. It appears that to date, the Mali-Niger border has recorded a HI of 35°C for 1985, while for 1998, the HI values exceed 43°C in the same area.

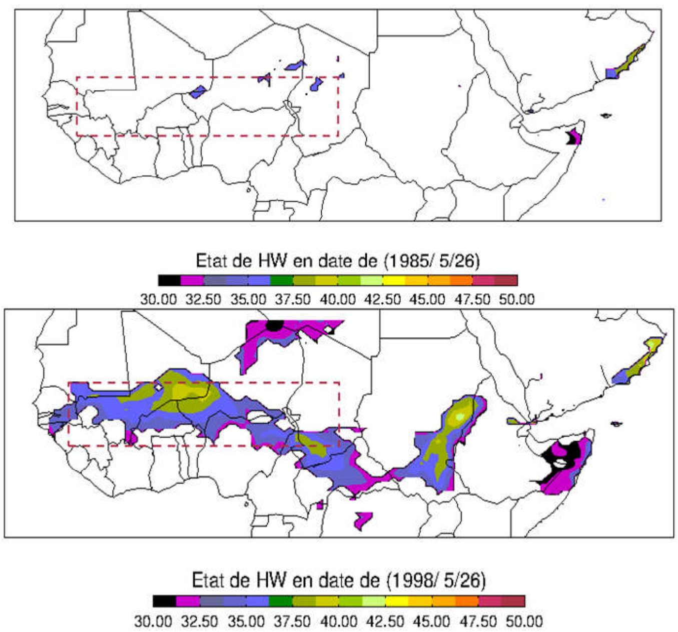

Figure 6. State of the heat waves dated May 26 for 1985 and 1998.

Study the severity of heat waves: The study of the severity of a weather event is based on two aspects. The first aspect is related to the intensity and frequency of the event while the second aspect is based on the event's impacts on the economic and societal. It is now conducting a retrospective study hard on the latter in the Sahel due to the lack of statistics on mortality and economic loss of data due to heat waves. So our severity study deals only with the first aspect. This is to see the intensity and duration of the HI heat waves episodes from 1982 to 2014 in the Sahel. For that two cases were studied: severity due to the HI intensity and severity due to the duration of heat waves episodes.

Severity due to the duration of heat waves episodes: This part consists of fixing the 90th percentile threshold HI while varying the duration. Figure 8 shows the evolution of the spread of heat waves for different criteria over time (5, 15 and 25 days). This indicates a decrease in the number of pixels affected by the waves. The years 1998, 2001 and 2010 appear to be the most severe heat wave in years because the number of pixels involved reached 1000 for a period of not less than 25 days. The extension of the heat waves in 2001 is lower than that of 1998 and 2010, with 6000 pixels affected by the heat wave in 2001 for a period of at least five days against 18000 pixels concerned in 1998 and 2010. Despite this difference in the number of pixels involved, heat waves episodes in 2001 have the same severity due to the duration of at least 25 days than in 1998 and 2010. To this end, we can say that the severity related to the duration of an episode of heat waves does not depend on its expansion in the area.

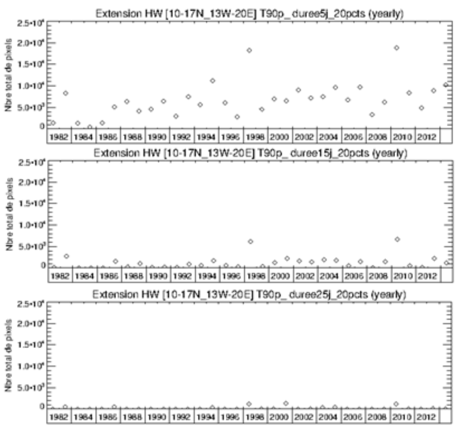

Figure7: Annual evolution of the expansion of heat waves as a function of time: Severity due to a threshold for the duration of HI or greater T90p and a representativeness criterion of 20% of the pixels.

Severity due to HI intensity: The study of this severity was conducted by fixing the duration of heat waves episodes at least three days and varying the intensity of the HI. We sought to characterize heat waves referenced as "Extreme discomfort" and "Danger" HI in the table, that is to say, respectively upper HI at 33 ° C and 40 ° C in place of HI above the 90th percentile. We thus obtain the two graphs of Figure 9 below. HI above 33 ° C, all the years of 1982-2014 experienced heat waves with extreme discomfort with the maximum in 1998 and 2010. With the condition SI greater than 40, only 2010 registered about 1000 pixels concerned for heat waves episodes in the area of danger. The year 2010 appears as a very severe year in terms of heat waves.

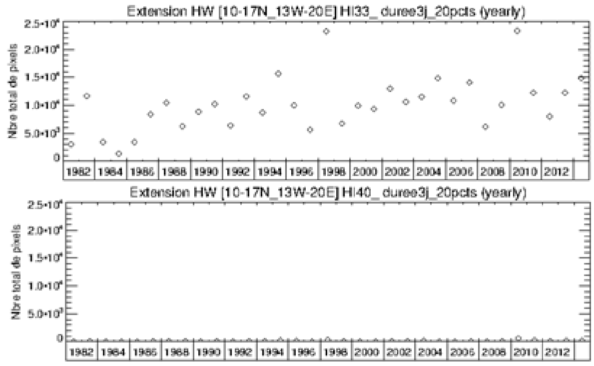

Figure 8. Annual evolution of the extension of heat waves with HI threshold above 33°C (top) and 40°C (bottom) for a period of at least three days with representative criterion pixels 20%.

Correlation study

Correlation between heat waves and precipitation: Figure 11 shows the result as a "point cloud" between the heat waves of the year n (abscissa) and precipitation of the year n-1 (ordinate). The correlation (r) is 0.29 but seems much influenced by two very strong years in terms of heat waves (1998 and 2010). However, it seems there is some organization less extreme years. If one performs the correlation calculation only on the red dots in FIG 11, there is obtained r = 0.56. In addition to its relatively high value suggesting a statistical link, the positive correlation may seem surprising. Intuitively, it is easier to imagine a very rainy season will tend to reduce the heat waves the following spring. This is exactly the opposite occurs. As the season is rainy (year n-1), more heat waves are strong (year n).

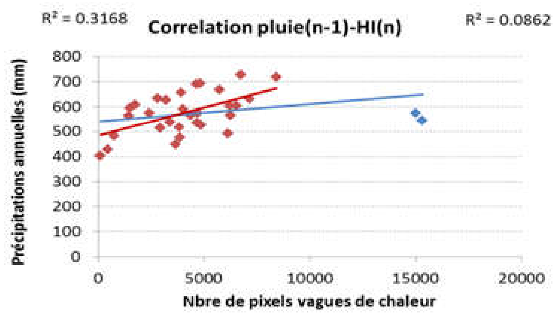

Figure9: Correlation between the annual rainfall of the year (n-1) and the heat waves of the year (n) during the period 1982-2014, field [10-17N_13W-20E]

We then looked to see if there is a correlation between heat waves and precipitation of a year. Indeed, there is a perception in Mali who says that a major heat wave in the spring often announces good rains during the next summer. We found a correlation coefficient r = 0.30, worth quite comparable to the correlation between rainfall in the previous year. However, if we perform the calculation without taking into account the extreme years (1998 and 2010) we obtain r = 0.16. This reflects that it does not seem to be any statistical link between heat waves in spring and the precipitation accumulated following the rainy season. To explain the statistical link of precipitation (n-1) on heat waves (n) is a hypothesis that precipitation can influence the humidity in the following spring and, consequently, increase the risk of wave heat. This hypothesis has been tested and provides the results presented in Table 2.

Table 1. Monthly evolution of the number of pixels affected by heat waves during the period 1982-2014 in the field [10N-17N_13W-20E]

Année	Janv.	Fév.	Mars	Avr.	Mai	Juin	Juil.	Août	Sept.	Oct.	Nov.	Déc.
1982	0	0	0	27	253	387	34	0	0	0	0	0
1983	0	0	0	1841	3707	555	24	0	0	0	0	0
1984	0	0	0	34	430	0	0	0	0	0	0	0
1985	0	0	7	0	21	78	0	0	0	0	0	0
1986	0	0	0	558	178	25	0	0	0	0	0	0
1987	0	0	0	176	2847	267	558	0	0	0	0	0
1988	0	27	139	891	2187	412	0	0	0	0	0	0
1989	0	0	0	58	1607	1541	0	0	0	0	0	0
1990	0	0	0	605	1158	655	0	0	0	0	0	0
1991	0	0	7	1284	1029	1536	0	0	0	0	0	0
1992	0	0	0	542	504	447	16	0	0	0	0	0
1993	0	0	0	961	3080	639	7	22	0	0	0	0
1994	0	0	61	1381	1764	167	0	0	0	0	0	0
1995	0	0	10	1076	3311	4023	0	0	0	0	0	0
1996	0	0	39	680	3421	229	0	0	0	0	0	0
1997	0	0	0	71	863	512	16	0	0	0	0	0
1998	0	14	209	5862	6999	2228	14	0	0	0	0	0
1999	0	0	0	414	1394	995	0	0	0	0	0	0
2000	0	0	0	1232	2954	479	0	0	0	0	0	0
2001	0	0	31	1544	3089	32	0	0	0	0	0	0
2002	0	0	37	1505	3274	1024	374	0	0	0	0	0
2003	0	0	39	1306	3263	260	0	0	0	0	0	0
2004	0	0	35	851	3464	484	1	0	0	0	0	0
2005	0	11	615	2355	2183	1000	75	0	0	0	0	0
2006	0	0	23	1104	1951	715	218	0	0	0	0	0
2007	0	0	249	1783	4400	723	0	0	0	0	0	0
2008	0	0	20	287	1060	390	0	0	0	0	0	0
2009	0	0	0	719	2259	850	94	0	0	0	0	0
2010	0	51	156	4903	6991	2693	206	0	0	0	0	0
2011	0	0	580	2974	2076	86	0	0	0	0	0	0
2012	0	0	0	1021	1208	708	0	0	0	0	0	0
2013	0	24	230	608	3519	2348	0	0	0	0	0	0
2014	0	0	28	1369	2271	2671	194	0	0	0	0	0

Table 2. Correlations between the rainfall of the year n-1 and humidity of the air (1000 hPa) for year n (January-June)

Pluie (n-1) / humidité de l'air	Janv.	Févr.	Mars	Avril	Mai	Juin
r	0.72	0.56	0.39	0.38	0.14	0.18

It is noted that there is a strong correlation for the month of January (r = 0.72), but this correlation decreases rapidly for the following months. The strong correlation in January is probably related to a moisture remains in the lower layers of the atmosphere associated with the rainy season. However, the correlation is relatively low for the month occurring heat waves (AMJ).

Partial correlation between heat waves and precipitation ineffective MEI: We know that there is also a signal of ENSO on rainfall in the Sahel. It might be interesting to check if the relationship between we get a warm spring and an abundant monsoon could then be explained by a common influence of ENSO on these two phenomena. For this article we conducted a partial correlation study between heat wave, precipitation and MEI to remove the impact MEI. After this study we find a new correlation coefficient value of r = 0.10 between precipitation and summer heat waves of spring. This means that the relationship between heat waves and precipitation in the Sahel region is impacted by El Niño oscillation Pacific, as the first value of the correlation was r = 0.30. The values of the correlation coefficient between heat waves-MEI and between precipitation-MEI are respectively: r= -0.20 and r= -0.17. So heat waves and precipitation in the Sahel region is anti-correlated with MEI.

Correlation between heat waves and NDVI: The idea that vegetation can also play a role in the onset of heat waves was tested.

For this, we used vegetation index called Normalized Difference Vegetation Index (NDVI), which is sensitive to the strength and quantity of vegetation while considering the leaf density. Its calculation is based on the reflectance property of vegetation cover in the visible spectrum (RED) and near infrared (NIR). It varies between -1 and 1 [Rousse et al. 1974].

The value NDVI = -1 corresponds to the surfaces or snow, water or clouds; and to a bare floor surface positive and its value is close to 0. For a vegetated area, its value approaches 1. Figure 10 shows the correlation graph obtained from the annual evolution of heat waves and the vegetation index during the previous year for the [10N-20E-17N_13W] during the period 1982-2012. The value of the correlation coefficient of this study is r = 0.28.

Correlation between precipitation and NDVI: The study of the relationship between the extension of spring heat waves and summer precipitation on the one hand and the Normalized Difference Vegetation Index on the other hand showed a positive correlation in both cases in the Sahel. It seems obvious to us that the correlation between precipitation and NDVI is also positive. Figure 11 shows the graph of this correlation study between precipitation and NDVI. The value of the correlation coefficient between the two variables between 1982 and 2012 gave r = 0.67. To this result, we can say that there is a strong relationship between precipitation and NDVI in the Sahel.

So, Nicholson and Tucker (1998); Milich and Weiss 2000a, 2000b had also said that Sahel region, vegetation dynamics is strongly linked to rainfall changes. [Justice et al. 1991] had also analyzed the relationship between NDVI decadal and decadal rainfall estimated from the duration of cold cloud (Meteosat data). They found a strong relationship between the two parameters while stressing that the vegetation response time to precipitation of one to two decades.

CONCLUSION

The study highlighted a variability extension of heat waves during the period 1982-2014 in the Sahel zone bounded by the latitude 10N-17N and longitude 13W-20E. The occurrence of heat waves in this study area is seasonal and almost entirely takes place in April-May-June (AMJ). It is apparent that the years 1998 and 2010 are recorded the biggest waves of extensions while those of 1982, 1984 and 1985 were the lowest. The study of the severity of heat waves has been conducted under the aspect of the evolution of the HI intensity and the duration of an episode of heat waves; this resulted in two types of severity. The severity due to the length of a heat wave episode, the years 1998, 2001 and 2010 were the most severe episodes with duration of at least 25 days registered. The second severity due to the intensity of the heat index has recorded 2010 as the only in severe heat waves (with HI greater than 40°C and for a period of at least 3 days). This indicates that 2010 was the most severe on both the duration and the intensity of the heat index. This result was found in the works of Justine RINGARD in 2013 on retrospective and prospective study of heat waves in West Africa. Justine said that during the heat wave occurred in April 2010 in Niamey, Niamey National Hospital has seen many deaths including children and the elderly. During this period, more than 30 cases of death have been reported by day; the temperature record was broken in several districts of Niamey reaching absolute temperatures under 47°C shelters. Remember that Niamey is at the center of the Sahel and in our study area [10N-17N_13W-20E].

The study of the research links between the annual change in the extension of the spring and the heat waves in summer precipitation of the previous year over the period 1982-2014 revealed that there is a positive correlation r = 0.30. Then we made a study of the partial correlation to extract the impact of El Niño oscillation Pacific (ENSO) characterized by MEI, and that gave a correlation coefficient value r = 0.10. This result shows that the ENSO oscillation influence both the onset of heat waves in spring but summer rainfall in the Sahel. This result is in line with the work of Mozzarella A. et al in 2012, indicating that the South Pacific is traversed by a poorly explained thermal oscillation known as El Nino, which has an important influence on the climate. Heat waves and annual precipitation were anti-correlated with MEI, the respective correlation coefficient values were: r = -0.20 and r = -0.17. The correlation between the precipitation of the year (n-1) and the heat waves of the year (n) were correlated with the same value of the coefficient r = 0.29. When removes two unusually warm years (1998 and 2010), a strong correlation is obtained as the coefficient r = 0.56. We are not able to explain this result by the hypothesis that excessive rain in a given year could create excess air humidity the following spring and thus increase the risk of heat waves. The correlation between precipitation and humidity being strong enough to January but too low to influence the WAN heat waves. The value of the correlation coefficient between the Normalized Difference Vegetation Index (NDVI) for the previous year and the evolution of the spread of heat waves gave r = 0.28 over the period 1982-2012 while between NDVI and precipitation annual, the correlation coefficient is r = 0.67. This allows to infer that vegetation cover is closely related to precipitation in the Sahel [Nicholson and Tucker (1998); Milich and Weiss, 2000a, 2000b]. According to IPCC (2007), in the 21st century global warming in Africa and the Sahel in particular will be more important at the global level. To this end, it will expect even more severe heat waves that can have painful consequences on health if nothing is done to increase the adaptive capacity of the population to global warming. Finally, the policies in the Sahel countries must integrate into their society project methods, coping skills means to climate change in general, and to heat waves and its consequences in particular to minimize the risks.

REFERENCES

Mazzarella, A. Giuliacci and N. Scafetta, 2012: Quantifying the multivariate ENSO Index (MEI) Coupling to CO2 Concentration and to the length of day variations. *Theoretical Applied Climatology*. DOI: 10.1007/S00704-012-0696-9.

Anonymous, Heat-related illnesses, deaths, and rsik factors-Cincinnati and Dayton, Ohio, 1999, and United States, 1979-1997. MMWR Morb Mortal Wkly Rep 2000; 49 (21): 470-473.

Atmosphère, Océan et Climat : Robert DELMAS, Serge CHAUZY, Jean-Marc VERSTRAETE, Hélène FERRE. BELIN pour la science

Besancenot JP. 2002 : Vagues de chaleur et mortalité dans les grandes agglomérations urbaines. Environnement, Risques et Santé. 1(4) : 229-40

Besancenot JP.1997: Les grands paroxysmes climatiques et leurs répercussions sur la santé. Presse thermal et climatique

Canicules et Froids extrêmes : l'événement climatique et ses représentations (II) Histoire, Littérature, peinture : sous la direction de Jacques BERCHTOLD, Emmanuel LEROY LADURIE, Jean-Paul SERMAIN, Anouchka VASAK. Edition Hermann

CEDEAO-CSAO/OCDE/CILSS, 2008

climat.meteo.gc.ca/climate_normals/normals_documentation_f.html?docID=1981.

Evaporation in the grazing lands of the Gourma (northern Sahel) and in the croplands of the Niger-Nigeria border (southern Sahel) », International Journal of Remote Sensing, 21, pp. 261-280.

GIEC, 2013: Résumé à l'intention des décideurs, Changements climatiques 2013: Les éléments scientifiques. Contribution du Groupe de travail I au cinquième Rapport d'évaluation du Groupe d'experts intergouvernemental sur l'évolution du climat [sous la direction de Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex et P.M. Midgley]. Cambridge University Press, Cambridge, Royaume-Uni et New York (État de New York), États-Unis d'Amérique.www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SummaryVolume_FINAL_FRENCH.pdf

Heinrigs P. 2010: Incidences sécuritaires du changement climatique au Sahel: perspectives politiques. http://www.academie-sciences.fr/ activite/rapport/rst29_rec.pdf https://a casis .locean-ipsl.upmc.fr

HUTH, R. and al. 2000: A GCM simulation of Heat Waves, Dry Spells, and their Relationships Circulation. Climatic change 46: 29-60, 2000

GIEC, 2004: Intergovernmental Panel on Climate Change. Fourth Assessment Report Climate Change.

Koppe, C., Kovats, S., Jendritzky, G., Menne, B., Breuer, D.J., Wetterdienst, D., 2004. Heat Waves : risks and responses. *Regional Office for Europe, World Health Organization*.

Lebel et Le Barbé: Rainfall climatology of the HAPEX-Sahel region during the years 1950-1990; Journal of Hydrology 188-189 (1997) 43-73

LYON, B. 2009: South Africa Summer Drought and Heat Waves: Observations and Coupled Model Behavior. DOI: 10.1175/2009JCLI3101.1. American Meteorological Society.

Marcel Leroux, la dynamique du temps et du climat 2ème édition, collection DUNOD, Décembre 2004

Meehl, G. A., and C. Tebaldi, 2004: More Intense, More Frequent, and Longer Lasting Heat Waves in the 21st Century. Science, **305**,994; DOI: 10.1126/science.1098704

Mémoire M2R de Justine RINGARD : Etude rétrospective et prospective des vagues de chaleur en Afrique de l'Ouest.

MILICH L. & WEISS E. (2000a), « GAC NDVI interannual coefficient of variation (CoV) images: ground truth sampling of the Sahel along north-south transects », International Journal of Remote Sensing, 21, pp. 235-260.

MILICH L. & WEISS E. (2000b), « GAC NDVI images: relationship to rainfall and potential

NICHOLSON S.E., TUCKER C.J. & BA M.B. 1998: Desertification, drought and surface vegetation: an example from the West Africa Sahel, Bulletin of American Meteorological Society, 79, pp. 815-829.

Panthou, 2013 : Analyse des extrêmes pluviométriques en Afrique de l'Ouest et de leur évolution au cours des 60 dernières années. Thèse de doctorat, UJF-Grenoble1

Pentad: Xie, P., J.E. Janowiak, P.A. Arkin, R.F. Adler, A. Gruber, R.R. Ferraro, G.J. Huffman, S. Curtis, 2003: GPCP Pentad Precipitation Analyses: An Experimental Dataset Based on Gauge Observations and Satellite Estimates. J. of Climate, 16, 2197-2214

Plan National Canicule version 31/05/2004 du Ministère de la Santé et de la Protection Sociale Française.

Randal D. Koster et al, Science 305, 1138 (2004): Regions of strong coupling between Soil Moisture and Precipitation DOI: 10.1126/1100217

Rienecker, M.M., and Coauthors (2008), the GEOS-5 Data Assimilation System-Documentation of Versions 5.0.1, 5.1.0, and 5.2.0 Technical Report Series on Global Modeling and Data Assimilation 104606, V27

Rienecker, M.M., and Coauthors (2011), Assessment and enhancement of MERRA land surface hydrology estimates, J.Clim., 24,6322-6338, doi: 10.1175/JCLI-D-11-00015.1.

Robinson, 2000. On the definition of the heat waves. J Appl Meteorol 2000; 40: 762-775

ROUSSE J.W., HAAS R.H, SCHELL J.A. and DEERING D.W.1973: Monitoring vegetation systems in the great plains with ERTS, ERTS Symposium, NASA, SP-351, Washington DC, vol.1, pp.309-317.

Rome.S et al. 2014 : Analyse sémantique des vagues de chaleur ; exemple dans le Sahel Ouest et Central : Proposition de définition des vagues de chaleur-Programme ANR-ACASIS

SG: Adler, R.F., G.J. Huffman, A. Chang, R. Ferraro, P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind, P. Arkin, 2003: The Version 2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979-Present). J. Hydrometeor., 4, 1147-1167.

Tarhule, 2005: Climate Information for Development: An Integrated Dissemination Model, *Africa Development*, Vol.XXXII, No. 4, 2007

Wang C, Fiedler PC (2006). ENSO variability and the eastern tropical pacific: A review. *Progress in Oceanography* 69: 239-266.

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