Analyze of climate variability and change impacts on hydro-climate parameters: case study of Côte d'Ivoire

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Abstract- The water resources of Côte d'Ivoire are very much used for water drinking supply of populations, breeding and also for the agriculture. But the abundance of this resource knew disturbances as from the years 1968 to 1970. These upheavals resulted in a fall of precipitations of 12.4% to 31.4% and flows which varied from 31.40% to 55.4%.
The projections carried out on the hydro-climate parameters under scenario A1B with the climate model RegCM3 give an increase in the annual average temperatures of 3°C to 4.2°C and a downward trend of annual precipitations from 4.9% from 2100.

Index Terms: Climate variability and change, impacts, hydro-climate parameters, Côte d'Ivoire

INTRODUCTION

The economy of Côte d'Ivoire is based on agriculture (1st producer of cocoa and 3rd producer of coffee on the world). It is known that rainfall distribution, alternating rainy or dry seasons and their duration, are important factors in agricultural production. Any climate change has important impacts on agricultural production. A reduction in rainfall leads to a reduction of the main export crops production (cocoa, coffee, palm oil, rubber cotton,...) and food crops (rice, yams, cassava, ...). In Côte d'Ivoire, several authors [1, 2] highlighted the impacts of climate variability on water and the environment. Indeed, these studies showed that rainfall dropped by 10 to 37% according to localities and the flows of the large rivers decreased from 30% to 60%. This situation of dryness modified the behavior of the populations. One of the remarkable illustrations of the drought in Côte d'Ivoire since thirty years has been the displacement of the loop of cocoa in the Center-east region (Dimbokro) to South-west (San Pedro).
Moreover, we note that the temperatures increased of 1°C since 1960 [2] and an increase of the seas on the continents.
Therefore, study climate change in Cote d'Ivoire is a major innovation because human must anticipate the climate change to adjust to reduce harmful impacts to life.

1. Presentation of Côte d'Ivoire

Côte d'Ivoire is located in West Africa. It forms a square with sides between 2°30 and 8° 30 west longitudes and between 4°30 and 10°30 north latitudes. The territory has an area of 322462 km ^{2} and is bounded to the north by Mali and Burkina Faso, east by Ghana, west by Liberia and Guinea and the South by the Atlantic Ocean.
There are four climate zones (Fig. 1):
- transitory tropical climate (North) rainfall fluctuate between 1000-1300 mm/year ;
- mitigation transitory equatorial climate (Center) has an annual rainfall between 1300 and 1750 mm ;
- transitory equatorial climate (South) has abundant rainfall ranging between 1500 and 2500 mm /year ;
- mountain climate (West) which has an annual rainfall between 1500 and 2000 mm / year.

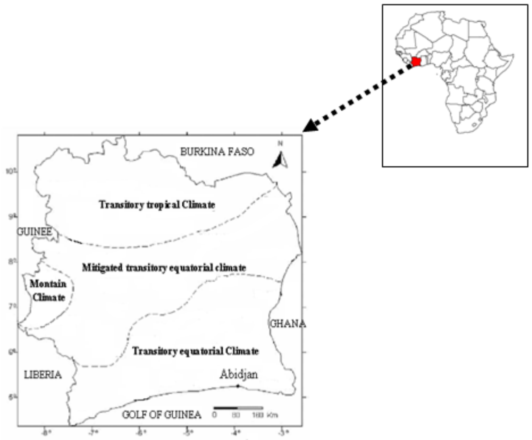

Fig. 1: Overview of Côte d'Ivoire with its climatic zones

2. Data, tools and methods

2.1. Hydrometric and rainfall data

Climate data used to characterize the current climate change come from the National Meteorology of Côte d'Ivoire. These data concern precipitations (Table 1) and temperatures.
Hydrometric data were provided by the Department of Hydrology of Côte d'Ivoire. These data are annual average of overflow for ten gauging stations in three main basin of Côte d'Ivoire (Bandama, Comoé, Sassandra) and the coastal basin of Agnéby (Table 2).

2.2. Description of the climate model RegCM3

The climate model RegCM3 (Regional Climate Model version 3) was used to assess the evolution of future climate. It is a regional climate model developed by International Center for Theoretical Physics [3]. It is capable of multiple fitments and includes three components that are preprocessing, processing and post-processing.

2.3. Inputs of climate model

The model uses the following data:
- Physiographic data such as topographic data (elevation, slope) of the USGS (United State Geological Survey) and the land cover of the GLCC (Global Land Cover Characterization) for the study area;
- Weather data consist of reanalysis data to initialize the calculations. These include meteorological data respectively thermodynamic and dynamic variables (temperature, pressure, humidity and wind field horizontal and vertical) of the continent part and the data of Sea Surface Temperature (SST).

2.4. Stationarity of hydro-climate series: Pettitt test [4]

Pettitt's test is to cut the main series of *N* elements into two sets at each time t between 1 and *N-1*. The main series has a break at a time *(T)* given if the two subsets have different distributions.

2.5. Determination of changes in rainfalls and flows

For parameters already measured (rainfall, flow ...), this method determines the percentage changes in these variables after the rupture with the period before the rupture climate [5]. This method was applied to hydro-climatic stations whose time series has a rupture. Variations in rainfall and flow are obtained through the following formula:

Change (Δ) = (average after rupture - average before rupture) / average before breaking

$$\Delta = \frac{\overline{X}_j}{\overline{X}_i} - 1 \quad (1)$$

$\overline{X}_j$: average of the parameter on the period after the rupture;

$\overline{X}_i$ average of the parameter on the period before the rupture.

If $\Delta \geq 0$ then there is excess rainfall or flow;
If $\Delta < 0$ then we speak of low rainfall or flow.

2.6. Simulation of temperature and precipitation using the model RegCM3

RegCM3 climate model was used to simulate the temperature and precipitation over three periods: a reference period (1991-2000) and two horizons (2031-2040 and 2091-2100). The simulation was carried out under the A1B emission scenario with 60 Km x 60 Km. spatial resolution.

2.7. Determination of the amplitudes or the variations in climate parameters (precipitations and temperatures) simulated by the model RegCM3

The amplitudes and rates of changes in each horizon are determined to find out how often the parameters decreased or increased over the period.
The temperature variations are expressed in °C and those of precipitations in mm of water fell

$$\Delta_i^{hor} = \left(\overline{X}_i^{hor} - \overline{X}_i^{réf}\right) \quad (2)$$

With $\overline{X}_i^{hor}$ = monthly /annual average calculated on the horizon determined

$\overline{X}_i^{réf}$ = monthly/annual average calculated on the reference period,

Δ_i^{hor} = monthly/annual variations average of a given horizon.

The rate of change in climatic parameters estimated are expressed as a percentage and expressed as:

$$\Delta_i^{hor} = 100 \times \frac{\left(\overline{X}_i^{hor} - \overline{X}_i^{réf}\right)}{\overline{X}_i^{réf}} \qquad (3)$$

With $\overline{X}_i^{hor}$ = monthly/annual average calculated on each horizon,

$\overline{X}_i^{réf}$ = monthly/annual average calculated on the reference period,

Δ_i^{hor} = Rate variations of a given horizon.

3. Results and discussion

3.1. Rainfall variability

Climate variability in Cote d'Ivoire is manifested by the fall of precipitations following the appearance of rupture in rainfall series (Table 1). These ruptures were held between 1963 and 1982. The rainfall deficits that have resulted vary of 12% to 31%.

Table 1: Ruptures and rainfall deficits in Cote d'Ivoire

Type of climates	Pluviometric Stations	Periods	Ruptures	Rainfall deficits (%)
transitory tropical climate	Ferkessedougou	1931-2000	1970	-15
	Odienne	1922-2000	1972	-16
	Korhogo	1945-2000	1970	-17
mitigation transitory equatorial climate	Dimbokro	1922-2000	1968	-13
	Gagnoa	1930-2000	1966	-13
transitory equatorial climate	Sassandra	1920-2000	1979	-24
	Adiake	1944-2000	1982	-22
	Abidjan	1936-2000	1982	-23
	Alepe	1956-2000	1963	-31
Climate of mountain	Man	1923-2000	1966	-12

3.2. Hydrological variability

Flows in main rivers of Côte d'Ivoire have been influenced by fluctuations in rainfall. Indeed, as precipitations, the ruptures in the hydrological series were detected between 1968 to 1979 period. Deficits calculated after ruptures in hydrological series on some basin are included between 31% and 55% (Table 2).

Table 2: Ruptures and flow deficits in four watersheds of Cote d'Ivoire

Watershed	Stations	Rivers	Period	Ruptures	Flow deficits (%)
Comoé	Sérêbou	Comoé	1955-2000	1971	**-48%**
	Akakomoekro	Comoé	1955-2000	1971	**-54%**
	Aniassué	Comoé	1955-2000	1971	**-50%**
	M'basso	Comoé	1955-2000	1971	**-44%**
Bandama	Tiassale	Bandama	1955-2000	1970	**-55%**
	Bouafle	Marahoué	1955-2000	1971	**-53%**
	N'zianoua	N'zi	1955-2000	1968	**-51%**
	Fêtêkro	N'zi	1955-2000	1968	**-49%**
Sassandra	Semien	Sassandra	1955-2000	1969	**-31%**
	Gaoulou	Sassandra	1955-2000	1969	**-39%**
Agneby	Agboville	Sassandra	1955-2000	1979	**-51%**

3.3. Temperatures variability

Since the accession of the Côte d'Ivoire to independence, the promotion of agriculture was at the base of the economic revival. Thus, the populations are rushes on the forests for the culture of coffee and cocoa.

This agricultural policy reduced considerably the forests of 16 million hectare to 3 million hectares today.This agricultural policy reduced considerably the forests by 16 million hectare to 3 million hectares today. This situation exploited the reheating of the atmosphere since the forests constitute a significant carbon well.The follow-up of the annual temperatures observed between 1960 and 2000 in various areas of Côte d'Ivoire shows a continuous increase in this one (Fig. 2). It appears clearly that the air becomes increasingly hot in Côte d'Ivoire. Indeed, between 1960 and 2000, the graphs show a rise in the temperatures of approximately 1°C. This situation could be caused at the same time by the reduction in the local vegetable cover and by the world gas emissions for purpose of greenhouse of anthropic origin.

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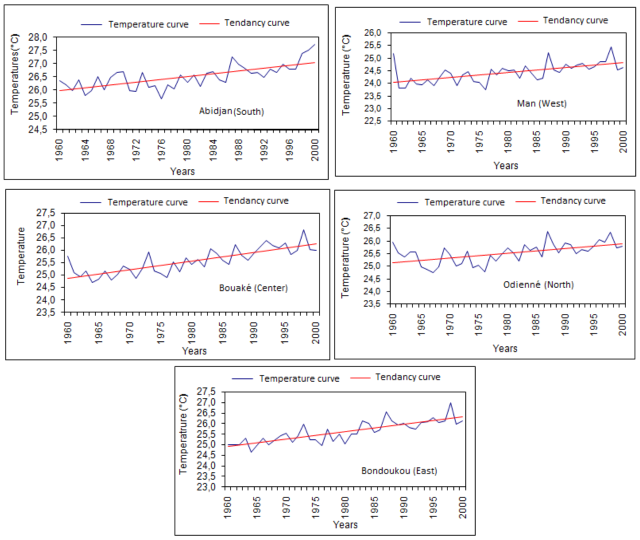

Fig. 2: Change of the observed annual temperatures in different regions of Côte d'Ivoire

3.4. Impacts of the sea level dynamic on the coastal zones

Certain effects of the climate change are already observable and others impacts are awaited if the increase in the gas for purpose of greenhouse concentrations is not controlled. These effects touch all the sectors of the life and the majority of human activities. Among the climate change manifestations, there is the increase of the atmosphere and oceans temperature, the cast iron of the glaciers and the increase in the sea level. In the same way, the countries of the Gulf of Guinea are also under the threat of coastal erosion. In Côte d'Ivoire, coastal erosion already caused many damage **in coastal cities like** Port-Bouët (Abidjan), Bassam, Jacqueville and Grand-Lahou. Indeed, much of dwellings are destroyed by coastal erosion in these cities as attests the fig. 3.

Fig. 3: Destruction of dwellings in the commune of Port Bouet (Abidjan)

3.5. Projected temperatures in Cote d'Ivoire over the 2031-2040 and 2091-2100 horizons

Table 3 shows, by report the reference period 1991 - 2000, the evolution of annual cycle of temperatures in Cote d'Ivoire at 2031-2040 and 2091-2100 horizonsThus, on the 2031- 2040 period, increases in monthly temperatures could rise from 0.41°C in March to 1.19°C in June with an annual average equal to 0.72°C. These increases in temperatures become more significant at 2091- 2100 horizon Indeed, at this horizon, the annual increase temperature reaches 3.57 °C. Therefore, monthly average changes may range from 2.55°C in October to 4.6°C in April and December.

Table 3: Evolution of temperatures in Côte d'Ivoire on 2031-2040 and 2091-2100 horizons

$\Delta T1$: difference of temperatures between the reference period (1991-2000) and 2031-2040 horizon

$\Delta T2$: difference of temperatures between the reference period (1991-2000) and 2091-2100 horizon

	$\overline{1991-2000}$ [°C]	$\overline{2031-2040}$ [°C]	$\Delta T1$ [°C]	$\overline{2091-2100}$ [°C]	$\Delta T2$ [°C]
January	29,60	29,54	0,94	32,31	3,71
February	30,11	30,74	0,64	34,32	4,21
March	31,44	31,86	0,41	35,24	3,80
April	30,13	30,68	0,56	34,69	4,56
May	27,80	28,33	0,50	31,88	4,07
June	25,89	26,84	0,95	29,51	3,63
July	25,03	25,74	0,71	28,13	3,10
August	24,75	25,54	0,79	27,55	2,80
September	25,15	25,83	0,68	28,13	2,98
October	26,27	26,76	0,49	29,18	2,91
November	28,39	29,14	0,75	30,94	2,55
December	28,34	29,54	1,19	32,91	4,56
Annual average	27,66	28,38	0,72	31,23	3,57

Maps of Fig. 4 & 5 were also performed to show the spatial variations of temperatures expected for both horizons. The following observations can be drawn from these maps.

Indeed the regions of South-west and West formed by the towns of San Pedro, Man, and Guiglo and the North-east (Bouna will become the zones with strong rise in temperature with variations ranging between 0,72 °C and 0,8 °C. In North-west (Odienné), North (Korhogo) and finally the south-est regions, increases could fluctuate between 0.58 °C and 0.68 °C.

At the 2091-2100 horizon, temperatures could annually vary of 3 °C to 4.2 °C by report 1991-2000 period. But this variation is a function of thermal gradient occurs in continental and it appears in parallel band with the lowest values are in the South Seas and the highest are in the North.

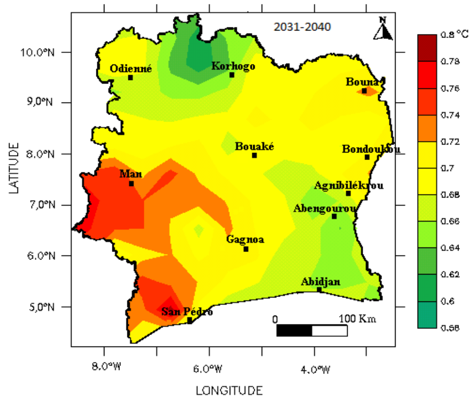

Fig. 4: Map of annual temperature variations in Côte d'Ivoire over 2031-2040 horizon compared to reference period 1991-2000

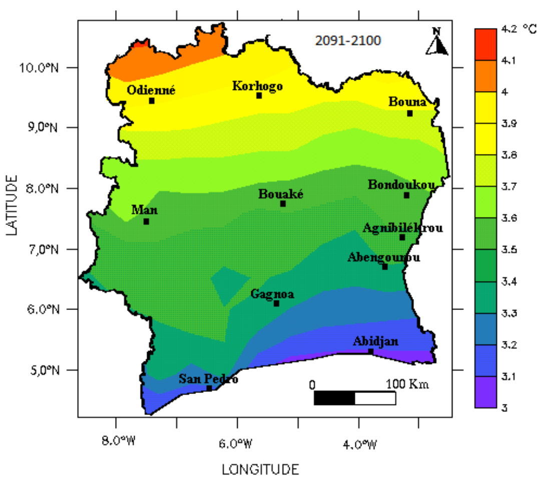

Fig. 5: Map of annual temperature variations in Côte d'Ivoire over 2091-2100 horizons compared to reference period 1991-2000

3.6. Projection of rainfalls in Côte d'Ivoire

Simulations carried out on precipitations using the RegCM model allowed to obtain the results which are consigned in table 6

The rates of variations awaited of annual precipitations shows a decrease of the rain in Côte d'Ivoire of 2.5% and 4.9% respectively on 2031-2040 and 2091-2100 horizons.

However, specificities exist in the annual cycle. Indeed, the months of March and October will become wetter in Côte d'Ivoire on 2031-2040 and 2091-2100 horizons with respective increase rates of 52.74% (98.41 mm) and 7.8% (14 mm) 52.74% (98.41 mm) 7.8% (14 mm). At the 2091-2100 horizon, the increase rates in precipitations of October and March pass to 69.04% (44.5 mm) and 22.2% (40 mm). Regarding the other months, the general tendency of the rains is with the fall on the two horizons especially the months of the rain season from April at September.

Table 6: Evolution of rainfall over 2031-2040 and 2091-2100 horizons in Côte d'Ivoire

	1991 - 2000 [mm]	2031 - 2040 [mm]	$\Delta P1$ [mm]	$\Delta P1$ [%]	2091 - 2100 [mm]	$\Delta P2$ [mm]	$\Delta P2$ [%]
January	6,62	7,8	1,18	**17,82**	3,26	-3,40	**-50,80**
February	30,22	30,19	-0,03	**-0,10**	26,77	-3,50	**-11,43**
March	64,43	98,41	33,98	**52,74**	108,90	44,48	**69,04**
April	195,87	194,42	-1,45	**-0,74**	131,27	-64,60	**-33,00**
May	211,22	205,47	-5,75	**-2,72**	199,80	-11,42	**-5,41**
June	226,63	201,63	-25,00	**-11,03**	205,11	-21,52	**-9,50**
July	247,75	229,74	-18,01	**-7,27**	240,62	-7,13	**-2,90**
August	298,61	258,47	-40,14	**-13,44**	231,63	-66,98	**-22,43**
September	241,48	236,67	-4,81	**-2,00**	229,19	-12,29	**-5,10**
October	179,68	193,68	14,00	**7,80**	219,58	39,90	**22,20**
November	65,52	59,93	-5,59	**-8,50**	82,02	16,50	**25,2**
December	8,62	16,47	7,85	**91,10**	11,82	3,20	**37,12**
Annual average	**1776,7**	**1732,9**	**-43,77**	**-2,50**	**1690,00**	**-86,7**	**-4,90**

The map of fig. 6 & 7 shows the space evolution of the variations of the rainfall on the 2034 - 2040 and 2091 - 2100 horizons. Two situations arise in the observation of this figure: a downward or rise trend according to localities.

Indeed, the horizon 2031-2040, most of the territory of the Côte d'Ivoire could be under an annual pluviometric deficit from approximately 10%.

In the horizon 2091-2100, the deficits could be accentuated compared to the horizon 2031-2040 with fall going up to 40%.

By report the period 2091-2100, what are the mountainous areas of western and Agnibilekrou, Abengourou and that could become wetter with a surplus of 10% to 20%. On the rest of the country, rainfall is decreasing with deficits of up to 10% to 20%.

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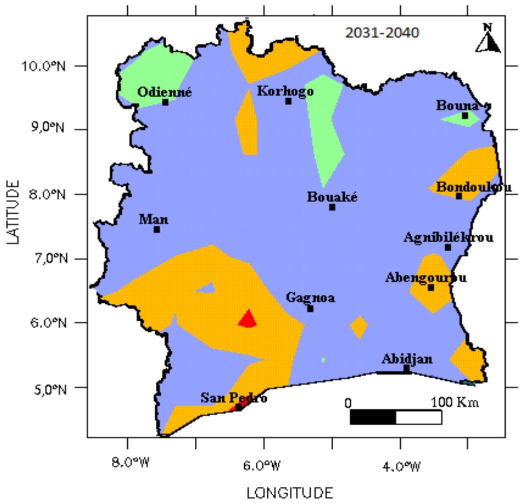

Fig. 6: Map of annual rainfall variations in Côte d'Ivoire over 2031-2040 horizon compared to reference period 1991-2000

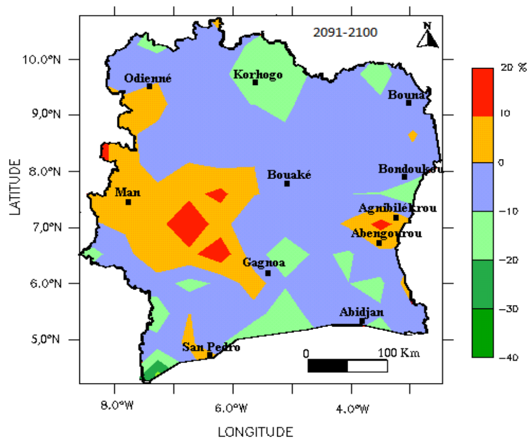

Fig. 7: Map of annual rainfall variations in Côte d'Ivoire over 2031-2040 and 2091-2100 horizons compared to reference period 1991-2000

4. Discussion

The statistical tests applied to annual rains series allowed to observe ruptures between 1963 and 1982.

These results are consistent with studies conducted in West Africa [6, 7, 8]. Variability of rainfall also resulted in significant rainfall deficits ranging between 12% and 31%. The strong reductions of rainfall are located primarily in the forest (south) and the savanna (north).This strong reduction in pluviometry is caused by the massive destruction of the vegetable cover [9, 10, 11].

On basins of Côte d'Ivoire, rainfall variability involved a variability of flows marked by ruptures between 1968 and 1979.

Hydrological deficits after ruptures are important than those of rainfall and vary between 31.4% and 55.4%. Our results agree with those of [7, 11, 10, 12] realized at the time of similar studies. This high incidence of rainfall variability on hydrology variability could be explained by the fact that there is an amplifying effect in flows due to the characteristics of the basin: runoff, infiltration, vegetation type, presence of groundwater.

Climate projections made in Côte d'Ivoire showed some expected impacts of climate change on temperatures and precipitations. The results showed an increase of temperature variations.

According to localities, increases in annual temperatures are included between 0,5°C and 0,8°C at 2031-2040 horizon and between 3°C and 4,2°C at 2091-2100 horizon. The projections made on the temperatures in Côte d'Ivoire are in conformity with those envisaged by the IPCC [13, 14] (2007) which envisage through climate models some increases in temperature of planet between 1.4°C and 5.8°C at 2100 horizon.

Projections of rainfall give a reduction in annual rainfall of 2.50% at the 2031-2040 horizon and 4.9% at the 2091-2100 horizon. At the monthly and space scale, it appears either an increase or decreases in rainfall.

The rainfall increases or decreases discussed in this study are imposed by the thermal variations of the equatorial Atlantic Ocean even if other forcings also seem to exist [15]. According [16, 17] some dominant modes of interannual variability of ocean thermal fields are strongly linked to climate changes in Africa. According to the studies conducted in Cote d'Ivoire [18], an abnormal warming of surface temperatures of the Atlantic Ocean in its southern west part involves decreases in rainfalls and causes a cooling of surface temperatures of the tropical Atlantic in the north of the equator. This phenomenon is also at the origin of the increase in precipitations in certain countries of West Africa as Côte d'Ivoire.

There is also that the space-time variations of the terrestrial environmental context modulate the mosaic of the regional climates, in particular through cycle of water and exchanges with the vegetable cover [19, 20].It is mainly about the continental processes of surface through desertification and degradation of soil properties [21, 22, 23].

Conclusion

This study presents the current and future climate situation of the Côte d'Ivoire. Indeed, at the end of the study, it arises that climate variability generated a decreased of 12 to 31% of the rainfalls and elevation of the temperature since the independence of the Côte d'Ivoire. The rainfall variability caused a decrease in also the mode of the rivers from 31 to 55%.With regard to the horizons, projections showed an increase in temperature of 3 to 4.5 C at the end of this century. The study also showed a continuous increase in the temperatures since independence.

On the level of precipitations, certain the climate change does not have the same influence on the whole of the territory. Certain zones will undergo increases whereas in other, the rains could drop.

Us Côte d'Ivoire has an agricultural vocation, this study makes it possible to draw the attention of the leaders in order to take appropriate measures of adaptation to the climate change. From now on, the use of resources water must be made in a rational way.

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