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# Long-term Variations in Albedo, Solar Flux, and Climatic Parameters in Burkina Faso (1984-2022)

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

In this work, we examined the effects of albedo and solar flux on climate parameters in Burkina Faso (1984-2022). We found that albedo amplitudes in Dori region are higher than those in Ouagadougou, and those in Ouagadougou are higher than those in Bobo Dioulasso. We also observed a continuous decrease in albedo, leading to an increase in temperature, humidity, and

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precipitation. These climatic conditions may increase the risks of prolonged droughts and floods. This drop in albedo is linked to solar activity, growing urbanization, deforestation and global climate change. Low solar activity and solar high speed flows caused by corotative interactions regions lead to heavy precipitation. The use of reflective construction materials, i.e. high albedo, in urban infrastructure and stopping the transformation of forests into cultivable land can contribute to mitigating the diminution in albedo and consequently global warming.

*Keywords: Albedo; solar flux; temperature; precipitation; solar activity; climate; Burkina Faso.*

## 1. INTRODUCTION

The Sun is the main source of energy, through its electromagnetic radiation which heats the earth's atmosphere and determines meteorological processes. Albedo is the ability of surfaces to reflect sunlight (heat from the sun). Measured on a scale of 0 to 1; an albedo value of 0 indicates that all light is absorbed by the surface (dark surfaces) and is not reflected and a value of 1 indicates that all light is reflected by the surface (Clear surfaces) and there is no absorption. Although only one of many factors contributing to climate change, surface albedo is an important parameter in the energy balance of the land cover and is considered an essential climate variable. Variations in surface albedo can be used as a diagnostic tool for local climate change according to authors such as [1,2]. Climate change is defined as general changes in climate over time. This includes global warming, more frequent and intense extreme weather events (like hurricanes and monsoons), and bizarre weather conditions. A change in albedo or a change in global temperatures can create a feedback loop between the two. The Earth's albedo has been declining for decades, contributing to global warming. Local/regional climate change caused by deforestation and land use changes is synergistic with global warming, causing a more dynamic climate change process [3]. The temporal and spatial variation of albedo has been closely related to global climate change as well as regional weather and environment [4,5]. [6] Found a strong inverse exponential relationship with a correlation (r = 0.95) between satellite-observed albedo and precipitation. Similar relationships have been discovered in West Africa between albedo and precipitation by several researchers [7, 8, 9]. [10] Showed the existence of a negative correlation between albedo and land surface temperature, with $R^2$ = −0.6109. [11] Showed that albedo influences surface temperature. [12] Showed that higher rainfall is associated with lower albedos. [13] Showed that flooding caused by heavy precipitation in Canada tends to follow the arrival of high-speed solar wind streams from coronal holes. [14] Revealed that an active Sun is associated with clear skies, while a quiet Sun is associated with cloudy skies, leading to more precipitation and cooling of the Earth's atmosphere. [15,16,17] Have also shown that cosmic rays, which are high-energy particles originating from outside our solar system, can influence the formation of clouds, which generally have a high albedo. The objective of this work is to analyze the long-term variations of albedo, solar flux and climatic parameters in Burkina Faso (1984-2022). For our study, we chose three areas of Burkina Faso with different vegetation covers (Fig. 1). The Sahelian zone in the north with precipitation less than 600 millimeters per year (mm/year), the Sudano-Sahelian region on a savannah plateau with precipitation of 600 to 900 millimeters per year (mm/year) and slightly cooler temperatures, and the wetter southern Sudanian zone with average precipitation between 900 and 1,200 mm/year.

## 2. METHODOLOGY

In this work, we used annual averages of albedo, precipitation, temperature and specific humidity, available at [18]. The solar wind speed available on the site [19] was used to calculate the solar wind energy flux (kg.s$^{-3}$) using the formula:

$$E_{SW} = \frac{1}{2}\rho_{SW}V_{SW}{}^{3}$$

$\rho_{SW}$ =1408 kg/m$^3$ and represents the density of the solar wind. We have also used the sunspot number available on the site [20]. Hourly cosmic ray data were obtained from the Thule Neutron Monitoring Station (76.5°N, 68.5°W, 26.0 m) with a geomagnetic cut-off rigidity of 1.0 GV. Then we calculated the annual averages of cosmic rays to see their influence on albedo and climatic parameters.


**Fig. 1. Climatic zones of Burkina Faso**

These data were used to analyze the impact of albedo and solar flux on climate parameters in three cities in Burkina Faso, namely Bobo-Dioulasso (latitude=11.149; longitude=-4.242), Ouagadougou (latitude=12.365; longitude=-1.507) and Dori (latitude=14.007; longitude=-0.073). These three cities are located in different climatic zones (Fig. 1) of Burkina Faso.

## 3. RESULTS AND DISCUSSION

From Figs. 2 to 7, the relationship between albedo, solar flux and climatic parameters in Burkina Faso is investigated for the period 1984-2022.

Fig. 2, presents the precipitation and albedo profiles in three cities Bobo Dioulasso, Ouagadougou and Dori during the period 1984 to 2022. In Fig. 2.a, we observe a decrease in surface albedo from 1984 to 1990. During this period, we recorded a drop in precipitation. From 1990 to 1999 we observe a constant evolution of the albedo then a slight increase in the albedo. During this period, we observe a fluctuation in precipitation, but we can notice an increase in maximum amplitudes. During the period 2000 to 2001, a strong decrease in albedo is observed. The albedo drops from 0.2 to 0.16. Then we observe a strong fluctuation and continuous decrease in albedo until 2022. During this period we also record a strong fluctuation in precipitation; but we can also notice a continuous increase in the maximum amplitudes of precipitation. The highest rainfall is recorded in 1998 (1223.44 mm), 2010 (1244.53 mm) 2019 (1455.47 mm) and 2021 (1288 mm).

In Fig. 2.b, we observe a decrease in albedo from 1984 to 1989 and a stable evolution of maxima amplitude of the precipitation. A fluctuation in albedo is observed from 1989 to 2000 with an increase in maximum precipitation amplitudes. From 2000 to 2001 a sudden decrease in albedo is observed and a drop in precipitation is also observed. From 2001 until 2022, a linear and constant evolution of the albedo is observed, except 2012 and 2021 which records a slight fluctuation. The year 2021 records the lowest albedo during our study period. During the period 2001 to 2022, a strong fluctuation in precipitation is observed; but overall we remark an increase in the maximum amplitudes of precipitations. The lowest precipitation was observed in 1987 (305.86 mm) and 1990 (295.31 mm).

In Fig. 2.c, we observe a constant evolution of the albedo from 1984 to 1987 before gradually decreasing from 1987 to 1989. During this period we observe a decrease in the maximum amplitudes of precipitations. From 1989 to 2000 we observe a strong fluctuation in albedo. During this period an increase in maximum precipitation is observed. From 2000 to 2001, the albedo drops sharply, leading to a sudden decrease in precipitation until 2002. Then from 2001 to 2022, a linear and constant evolution of the albedo is observed with slight variations in 2016 and 2022. During this period there is a strong fluctuation in precipitation with an increase in maximum amplitudes. The lowest precipitation is recorded in 1983 (442.97 mm), 1990 (500.98 mm) and 2002 (469.34 mm) and the highest precipitation is recorded in 2012 (970. 31 mm), in 2015 (986.13 mm), 2020 (970.31 mm) and 2022 (1096.92 mm).

Fig. 3, presents the temperature and albedo profiles of Bobo Dioulasso, Ouagadougou and Dori during the period 1984 to 2022. In Fig. 3.a, we observe a decrease in albedo from 1984 to 1990; from 1991 to 2000 a linear and constant evolution of the albedo is observed. During these periods we observe a decrease in the earth's temperature from 1984 to 1985 then increases slightly from 1985 to 1987 before fluctuating slightly around 27°C to 28°C from 1987 to 2000.Then the albedo drops sharply from 2000 to 2001. During this period the temperature increased sharply and recorded the highest temperature in 2002 (29.06 °C) during our study period. Then a slight fluctuation in albedo followed by a weak fluctuation in temperature around 27°C to 28°C. The lowest temperature was recorded in 1986 (26.63°C).

In Fig. 3.b, we observe a continuous decrease in the albedo from 1984 to 1989. During this period, we observe an increase in temperature with a peak in 1987 (30.01 °C) before decreasing until 'in 1989. From 1989 to 2000 we observe a weak fluctuation in the albedo and during this period, the largest peak in temperature is observed in 1990 (30.3 °C) before gradually decreasing until 1999. From 2000 the albedo drops sharply until 2001, then a linear and constant evolution is observed until 2022, with slight fluctuations in 2012 and 2021. During this period heat waves are observed, with the largest heat peak recorded in 2004 (30.42 °C).

In Fig. 3.c, we observe a linear and constant evolution of the albedo from 1984 to 1987. During this period a decrease in temperature is observed from 1984 to 1986. A decrease in the albedo is observed from 1987 to 1989 and an albedo fluctuation around 0.23 to 0.26 from 1990 to 2000. During these periods, a weak temperature fluctuation around 27 °C and 28 °C is observed. A sudden decrease in albedo was recorded from 2000 to 2001 and led to a sharp increase in temperature. The highest temperature was recorded in 2002 (29.37°C) during our period covered by our study.

Fig. 4, presents the temporal evolution curves of the annual averages of precipitation and specific humidity in the cities of Bobo Dioulasso, Ouagadougou and Dori during the period 1984 to 2022. The specific humidity (absolute) is the actual amount of moisture in the form of water vapor in the air. Specific humidity is measured in grams of water vapor per kilogram of air (g/kg). The two parameters studied present a good correlation. The correlation is 0.72 for the city of Bobo Dioulasso, 0.76 for the city of Ouagadougou and 0.69 for the city of Dori. The highest precipitation coincides with the highest specific humidity. Also the lowest precipitation coincides with the lowest specific humidity. We also observe an increase in the maximum amplitudes of precipitation and specific humidity from 2001 to 2022. In Fig. 4.a, the lowest specific humidity and the lowest precipitation is recorded in 2002 (11.11 g/kg; 775.52mm). The highest specific humidity and precipitation are recorded in 2010 (13.37 g/kg; 1244.53 mm) and in 2019 (13.12 g/kg; 1455.47 mm). In Fig. 4.b, the lowest specific humidity is recorded in 1984 (8.42 g/kg), in 1987 (8.36 g/kg), in 2000 (8.54 g/kg) and in 2001 (8.48 g/kg) and the lowest precipitation is observed in 1987 (305.86 mm) and 1990 (295.31 mm). The highest specific humidity was observed in 2010 (10.31 g/kg), in 2012 (10.5 g/kg) and the highest precipitation was recorded in 1999 (611.72 mm), in 2012 (580 .08 mm) in 2015 (564.26 mm) and 2020 (622.27 mm). In Fig. 4.c, the lowest specific humidity and precipitation are observed in 1983 (9.64 g/kg; 442.97 mm) and in 2002 (9.64 g/kg; 469.34 mm). High specific humidity and precipitation are observed in 2010

(12.15 g/kg; 885.94 mm) in 2012 (12.08 g/kg; 970.31 mm) in 2022 (11.84 g/kg; 1096. 92mm). These observations show that high specific humidity leads to heavy precipitation.

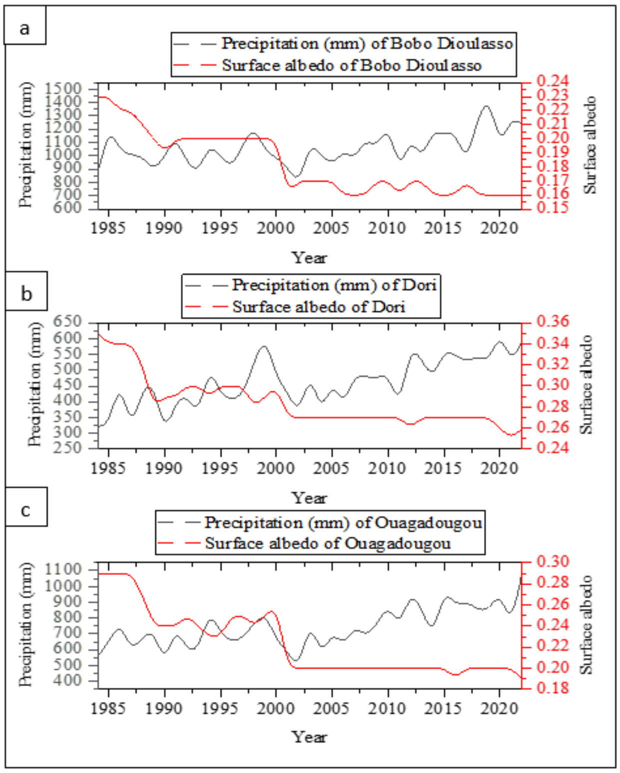


**Fig. 2. Precipitation and albedo profile during the period 1984-2022**

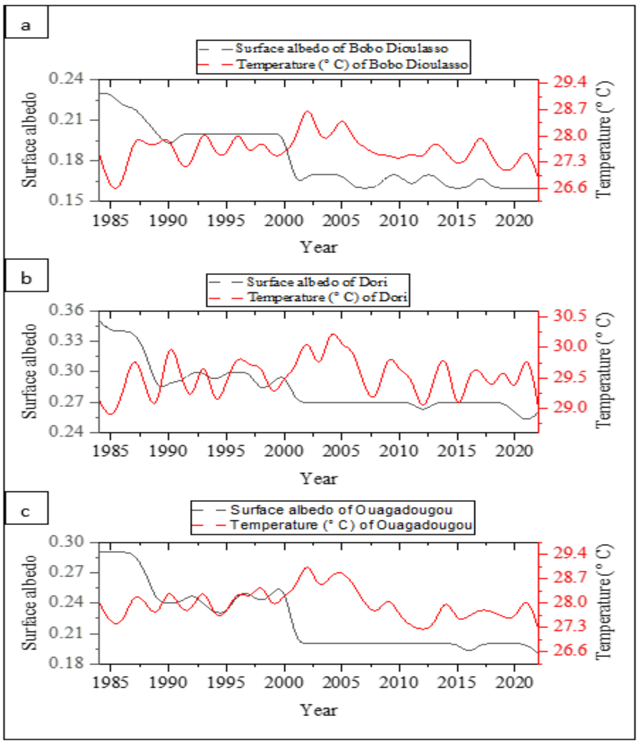


**Fig. 3. Surface temperature and albedo profile during the period 1984-2022**

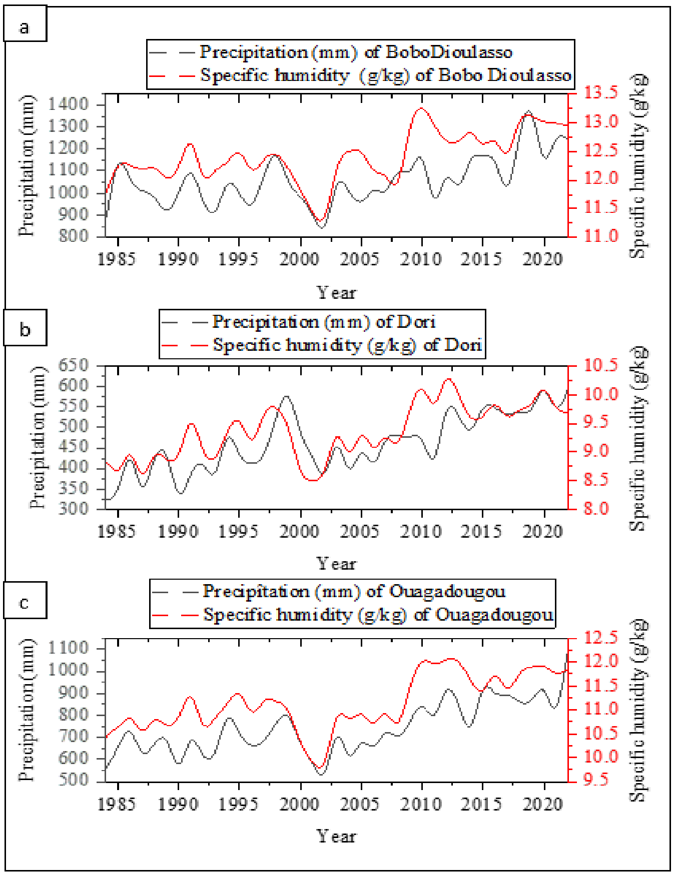


**Fig. 4. Profile of precipitation and specific humidity during the period 1984-2022**

Through the analysis of Figs. 2, 3 and 4 we can see that the quantity of precipitation varies greatly depending on the specific humidity, which varies with the temperature. Indeed, as the temperature increases, the air is able to retain more and more humidity. We are more likely to receive rain when humidity is higher because water vapor expands more quickly. This is based on the Clausius-Clapeyron (CC) relationship which states that as temperature increases, the atmosphere has the capacity to retain more moisture, at a rate of 6% to 7% $°C^{-1}$ [21]. Thus, extreme precipitation scales with surface water or the water column [22,23], so we can expect extreme precipitation to increase with temperature increase. We also observed that a continued decrease in albedo leads to heat waves. Indeed, the reduction in albedo leads to an increase in the absorption of solar radiation by the ground and therefore the transfer of sensible and latent heat to the atmosphere. This produces higher global warming. These observations are in agreement with the work of [10] which showed the existence of a negative correlation between albedo and land surface temperature, with $R^2 = -0.6109$. Also, [11] showed that albedo influences surface temperature. The decrease in albedo contributes to the increase in convective clouds, and therefore precipitation. This global warming and increased precipitation causes the evaporation of a greater quantity of water, therefore high specific humidity, which can lead to more intense droughts and a higher risk of flooding. Overall, weird weather conditions. These observations show that a change in albedo influences climatic parameters (temperature, specific humidity and precipitation). These observations are in agreement with the work of [12] who found higher rainfall at lowers albedos. We also note that the amplitude of precipitation and specific humidity is important in Bobo Dioulasso compared to Ouagadougou and similarly the amplitude of precipitation and specific humidity is important in Ouagadougou compared to Dori. The amplitude of temperature and albedo are significant in the town of Dori compared to Ouagadougou and Ouagadougou compared to Bobo-Dioulasso. This is explained by the fact that the soils of Dori and Ouagadougou are sandy and dry (light surfaces), unlike the soil of Bobo Dioulasso which is a crop soil (dark surface). However, a continuous decrease in albedo is observed in all three cities. This is explained on the one hand by the difference in plant cover and the quantity of water in the soil in these different zones. On the other hand, Burkina Faso knows an increase in population in recent decades as well as rapid urbanization and industrialization concentrated in large cities. This caused a great revolution in land use. This revolution is accompanied by a significant thermal change, creating a thermal imbalance between urban and rural areas. Indeed according to the work of [24] who, through an empirical approach to the climatic effects of urbanization, found a decrease in albedo due to urbanization. This series of extreme heat waves increases cooling energy consumption in buildings, deteriorates air quality and affects people's health [25], leading to an increase in health and mortality [26,27,28,29]. Possible symptoms caused by heat stress include swelling, rashes, and heat stroke related to neurological disorders when body temperature reaches 40.6°C [30]. Thus, strategies must be implemented to reduce the conditions of global warming in Burkina Faso. Several studies have shown a direct link between high urban temperatures and the lack of vegetation, highlighting the potential of vegetation to reduce extreme temperatures, especially during the hot season, through two effects: evapotranspiration and shading [31,32]. Deforestation can decrease evapotranspiration and increase surface temperatures by 3° to 5°C [33]. [34] Through deforestation simulation studies have shown either a decrease in precipitation due to the weakening of precipitation recycling, or an increase in precipitation due to the intensification of convection over areas heterogeneity of the earth's surface. For [24], urbanization can potentially have a global warming effect by reducing the Earth's albedo. Tropical forests are increasingly recognized as major resources for mitigating climate change [35]. The work of [2] showed that reducing deforestation of all forest types, converting annual or grassland agriculture to perennial agriculture, and properly selecting greenhouse covers for new protected agricultural systems could help mitigate climate change regional. According to the work of [10,24], green roofs have a higher albedo than many conventional black/brown roofs. The albedo of urban land is 0.01–0.02 lower than that of adjacent cultivated land [36]. This low albedo observed in urban areas is due to the predominance of dark materials such as asphalt and concrete, which absorb a lot of heat. This contributes to a significant rise in temperatures more in cities than in rural areas.The albedo of urban land can be regulated and improved by using more reflective materials and also by reducing deforestation.

Fig. 5 presents the profile of the solar wind energy flux and precipitation of Bobo-Dioulasso, Ouagadougou and Dori during the period 1984 to 2022. In Fig. 5.a, 5.b and 5.c, the two parameters studied present a weak correlation. However, we can observe some peaks in the solar wind energy flux to coincide with heavy annual precipitation. This can be clearly observed in 1994 and 2003 which correspond to periods of the descending phases of solar cycles 22 and 23. Heavy precipitation is also observed when weak solar wind energy flux are recorded. These periods coincide with the solar minimum of solar cycles, which are dominated by slow solar winds [37,38]. Exceptionally, we generally observe a drop in the amplitude of the solar wind energy flux after the long solar minimum which preceded solar cycle 23 (2008-2022). During this period, there is an increase in precipitation. These observations are in agreement with the work of [14] who found that precipitation is important at solar minimum where quiet activity is dominant. According to the work of [39,40], solar cycle 24 at has knows a lower solar activity compared to solar cycle 23. Also, according to the work of [13], which, analyzing the storm of December 5 and 6, 2010 in New Brunswick found heavy precipitation and a storm surge that caused flooding. This coincided with the arrival of a high-speed HSS/CIR flow with dense high-density plasma at its leading edge on 6 December. According to the work of [41,42], CIRs play a dominant role as a source of geomagnetic disturbances during the solar minimum. Indeed, as the Sun rotates, high-speed fluxes (HSS) emitted from coronal holes can interact with ambient slow solar wind fluxes, compressing the plasma at the boundary, increasing the density in the region of slow solar wind. If the configuration of the solar corona is stable, the pattern of interaction regions repeats with each rotation of the Sun, and they are called corotating interaction regions [43,44]. In the fast solar wind, the kinetic energy of the plasma is converted into thermal energy, resulting in heating of the plasma and a decrease in density [44]. During this interaction of fast solar winds and slow solar winds the plasma becomes very dense and very hot and contributes to heating the convective clouds, increasing precipitation. We can therefore say that solar activity is one of the many factors that affect climatic conditions, in particular precipitation.

Fig. 6, presents the temporal evolution profiles of the sunspot number and the surface albedo of Bobo Dioulasso, Ouagadougou and Dori during the period 1984 to 2022. The two parameters studied present a weak correlation. However, we can notice that the abrupt decreases in albedo are observed at the maximum phase of each solar cycle. We also observe a constant evolution of the albedo after the solar minimum of solar cycle 23, with slight fluctuations in 2011 and 2017 in Bobo-Dioulasso, in 2016 in Ouagadougou and in 2012 and 2021 in Dori. According to [45], the Sun is, on average, more irradiating at maximum activity than at a minimum of its cycle activity approximately 11 years. Also according to [46], the variation in magnetic activity during the course of the 11-year cycle influences not only the sunspot number and the magnetic flux but also the radiation emitted by the Sun and which we receive on Earth called total or "constant" solar irradiance. [47] Showed that the total irradiance varies in phase with the solar cycle by about 0.1%: the higher the sunspot number, the higher the flux we receive from the Sun, due to of the massive presence of faculae which are brighter zones. Furthermore, during the solar maximum, coronal mass ejections are the most important events and dissipate a large amount of energy in the interplanetary medium [14]. Thus, we can say that the Earth receives a large amount of energy during the solar maximum compared to other phases of the solar cycle. This can lead to a reduction in surface albedo. This is clearly observed in 1989 and 1990 at solar cycle 22 and in 2001 at solar cycle 23, where an sudden decrease in albedo was recorded.

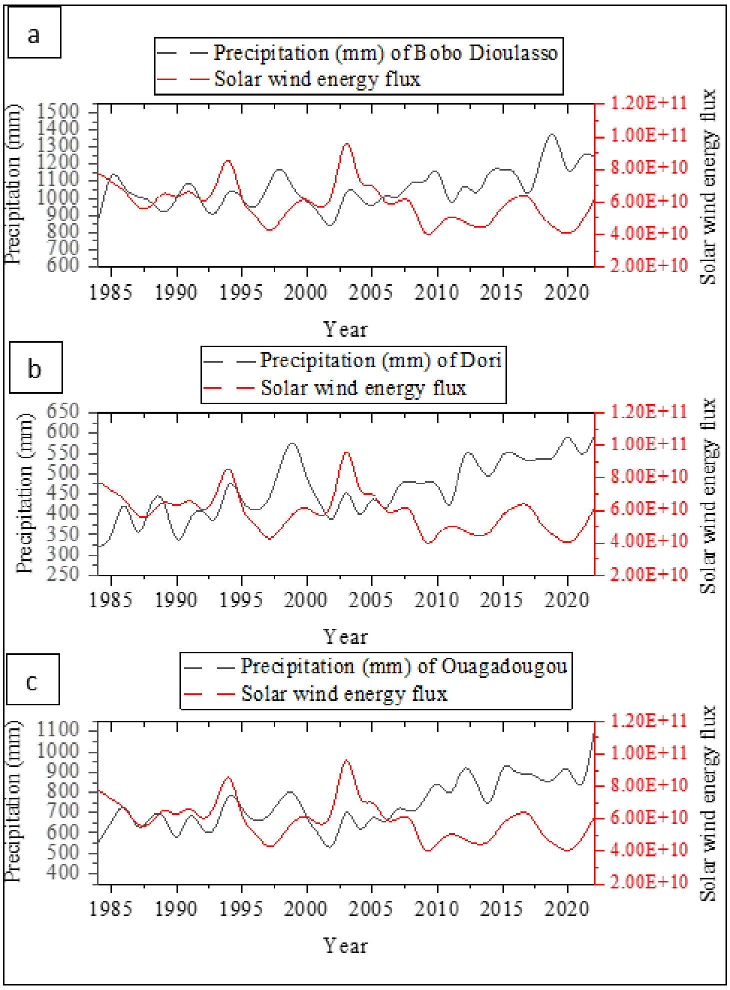


**Fig. 5. Profile of precipitation and the solar wind energy flux during the period 1984 to 2022**

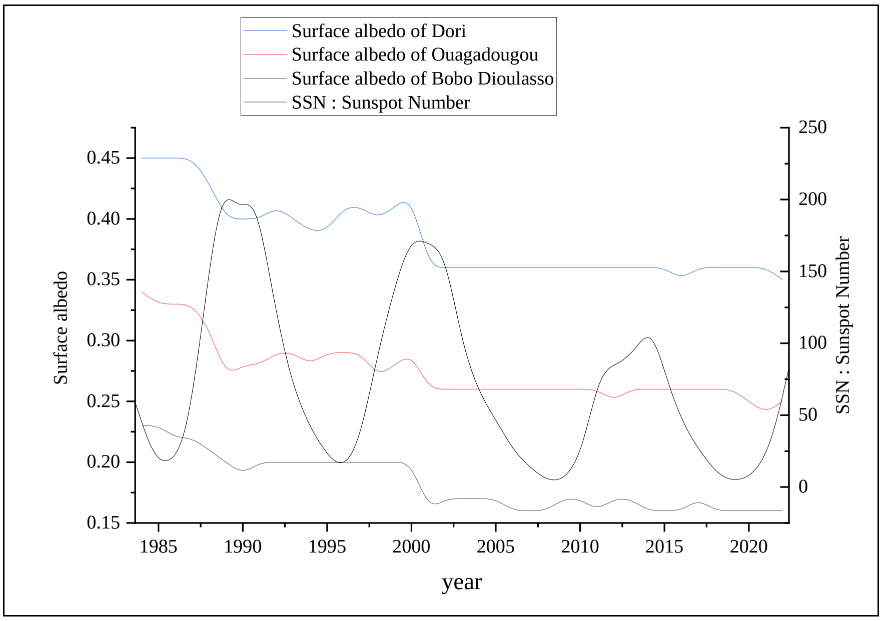


**Fig. 6. Profiles of the sunspot number and the surface albedo during the period 1984-2022**

Fig. 7, presents the cosmic ray and albedo profiles of Bobo-Dioulasso, Ouagadougou and Dori during the period 1984 to 2022. The two profiles show a weak correlation, but however the lowest cosmic ray values are accompanied by a sudden decrease in albedo. We can also note that the amplitudes of cosmic rays are significant over the last decade (2005-2022), with an almost linear evolution of the albedo. This is explained by the low solar activity observed during this period. According to the work of [39,40], the solar activity of solar cycle 24 has been weak compared to solar cycle 23, and is also manifested in the solar magnetic field. Furthermore, according to the same authors, the calm Sun causes significant cloud cover while the active Sun induces less cloud cover. [48] Claims that the magnetic field of the solar wind influences the cosmic rays responsible for the formation of clouds.

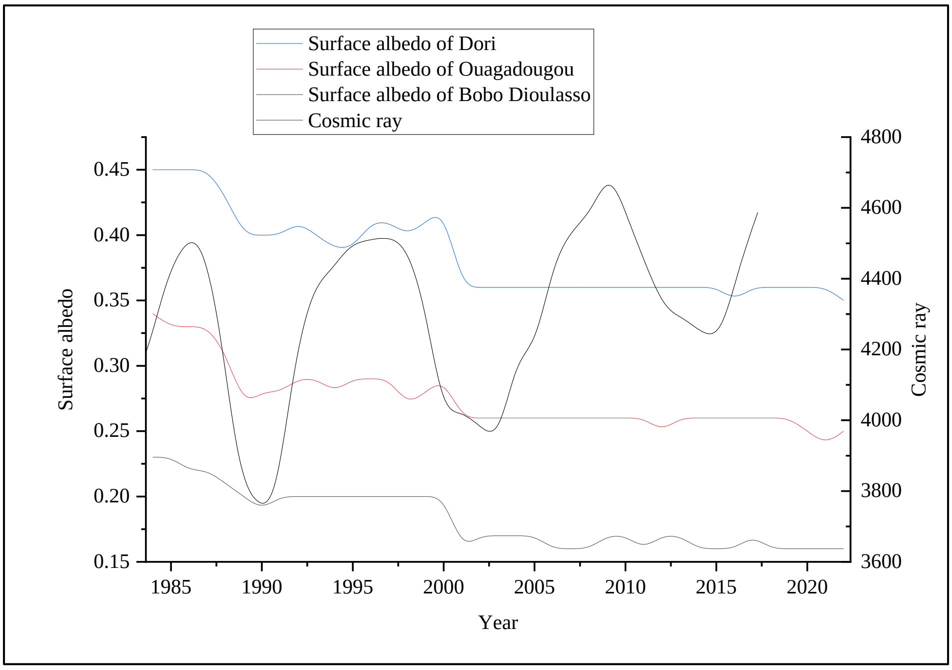


**Fig. 7. Cosmic ray and surface albedo profiles during the period 1984-2022**

Thus, the solar minimum going hand in hand with an increase in cosmic radiation received by the Earth, condensation would be made more efficient and the increase in cloud cover would be favored. Thus we can say that intense solar activity releases a large quantity of energy onto Earth and a low rate of cosmic rays. Which leads to a drop in albedo, low cloud cover, and fluctuating temperatures. Low solar activity leads to a high rate of cosmic rays in the interplanetary medium and this leads to significant cloud cover. Low solar activity results in a high rate of cosmic rays (Fig. 7) and a lower amount of solar flux (Fig. 6) in the interplanetary medium and this results in significant cloud cover. Thus part of the solar energy would be absorbed by this cloud cover, and would have less impact on the surface albedo.

## 4. CONCLUSION

In this study, we examined solar flux and climatic parameters in three cities in Burkina Faso, located in three different climatic zones. The albedo amplitudes of Dori are higher than those of Ouagadougou and those of Ouagadougou higher than those of Bobo Dioulasso. This study reveals a continued decrease in albedo in Burkina Faso leading to significant global warming. This global warming causes an increase in temperature, specific humidity and precipitation, increasing the risks of severe droughts and floods. This decline in albedo can be explained by increasing urbanization, deforestation, manifestations of solar activity and global climate change. Heavy precipitation is observed during periods of low solar activity and also during high-speed flow events caused by regions of co-rotating interactions. The continued decrease in albedo can be mitigated by favoring more reflective construction materials, i.e. high albedo, and stopping the transformation of forests into cultivatable land. A small-scale study and extension to other regions could help to better understand the impact of solar activity on albedo and its influence on climate parameters.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.


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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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