Spatio-temporal variability of clouds and associated shortwave radiative effects in West Africa with a satellite-based and reanalysis data

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Abstract

This study aims to understand and document the occurrence and variability of cloud cover in West Africa (WA) essential for assessing feasibility of planned large-scale solar energy projects. Investigations are carried out with a 10-year hourly record of two cloud cover data products: Clouds and the Earth Radiant Energy System passive satellite observations (CERES SYN1deg) and the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis (ERA5). The seasonal evolution of high-level, mid-level and low-level clouds (HCC, MCC and LCC) as well as the total cloud cover (TCC) over the region is examined. The results show that both products agree on the average seasonal and spatial distribution of cloud cover over the region, although the CERES SYN1deg product presents lower cloud fractions than ERA5. This is partly attributed to the inability of the satellite sensor to detect optically thin clouds in the atmosphere. Southern WA is found to be cloudier than other parts of the region in all seasons. During the monsoon season (June, July, August and September) cloudiness increases over southern WA (mean cloud fraction up to 70% in CERES SYN1deg and 80% in ERA5) but also extends northwards and strengthens over the Sahelian region. The intense cloud coverage over southern WA during the monsoon season leads to a large regional mean reflectance of incoming solar radiation of about 55%. In all seasons, the presence of LCC over large areas of the Sahel/Sahara region is highlighted in the CERES SYN1deg product. This could be due to a potential misinterpretation of Saharan dust as low clouds by the satellite sensor which may have overestimated their occurrences and fractions and may lead to errors in the estimation of cloud radiative effects over the region. Northern WA is associated with higher frequencies of no cloud occurrence events unlike the south where cloudless skies are rare. Furthermore, in southern WA, overcast conditions of LCC which significantly reduce incoming solar radiation are observed for a significant number of times (up to 10% of the time in CERES SYN1deg and 20% in ERA5).

Spatio-Temporal Variability Of Clouds And Associated Shortwave Radiative Effects In West Africa With A Satellite-based And Reanalysis Data

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BACKGROUND

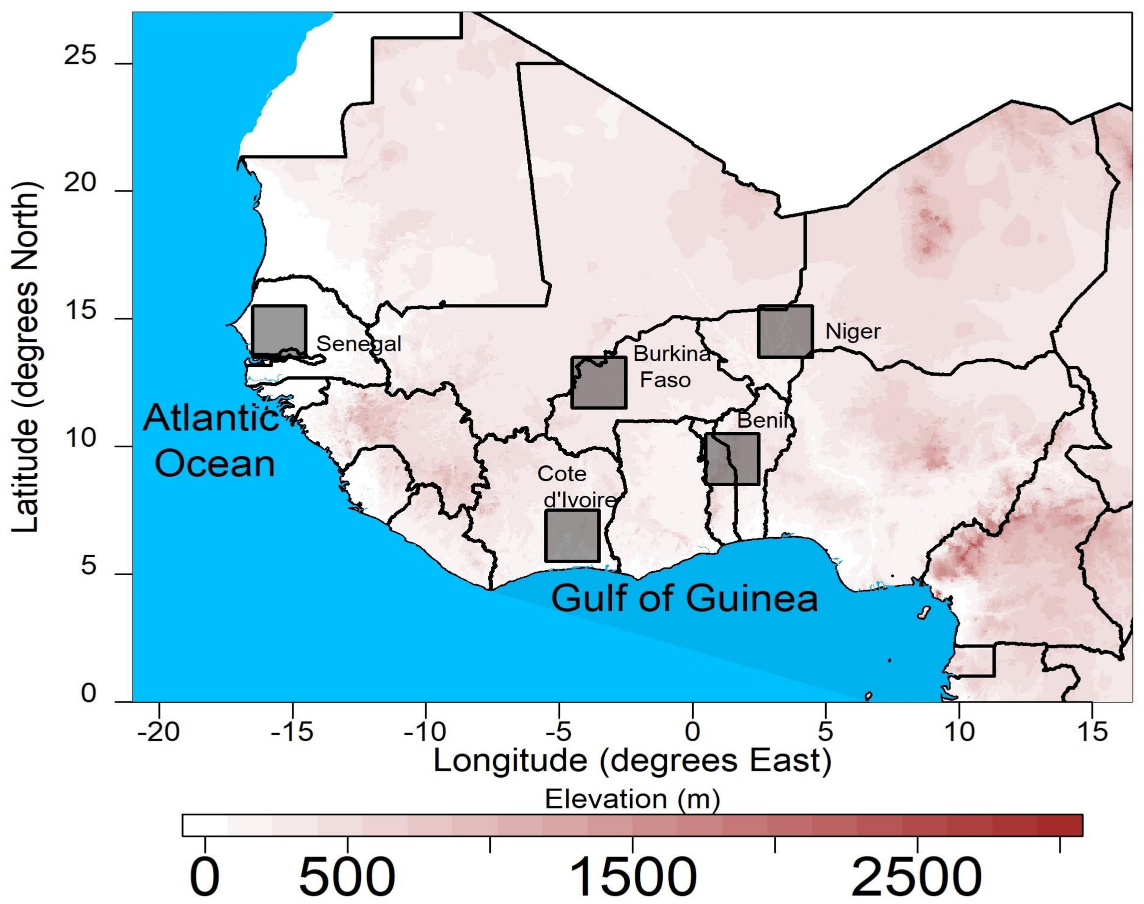
After the Paris Agreement in 2015, many governments and industries have shown great interest in projects dealing with solar photovoltaic (PV) energy and its implementation in West Africa (WA). Nevertheless, many areas in WA present some drawbacks for solar PV energy generation due to intense cloud cover and crustal dust. Cloud cover in particular is highly variable in both space and time, and can significantly decrease the amount of solar radiation received on solar PV panels when in the sun's path. This work presents a climatology of clouds' variability and occurrence frequency in WA essential for assessing feasibility of planned large-scale solar PV energy projects. The annual cycle of lost incoming solar radiation due to clouds is also presented for different areas in WA.

DATA AND METHODOLOGY

- **E**uropean **C**entre for **M**edium-Range **W**eather Forecasts **R**e**A**nalysis 5th generation (ERA5)
- **C**louds and the **E**arth's **R**adiant **E**nergy **S**ystem (CERES) SYN1deg passive satellite observations
- Low-, mid- and high-level clouds as well as total clouds cover and incoming downwelling solar radiation (shortwave) are extracted from ERA5 and CERES over the study region.
- Incoming solar radiation ($SW\downarrow$) lost due to clouds (Cloud Shortwave Radiative Effect ($CRE_{SW\downarrow}$)) is computed and expressed as a percentage of the theoretical value for incoming solar radiation when there are no clouds ($SW\downarrow_{CS}$):

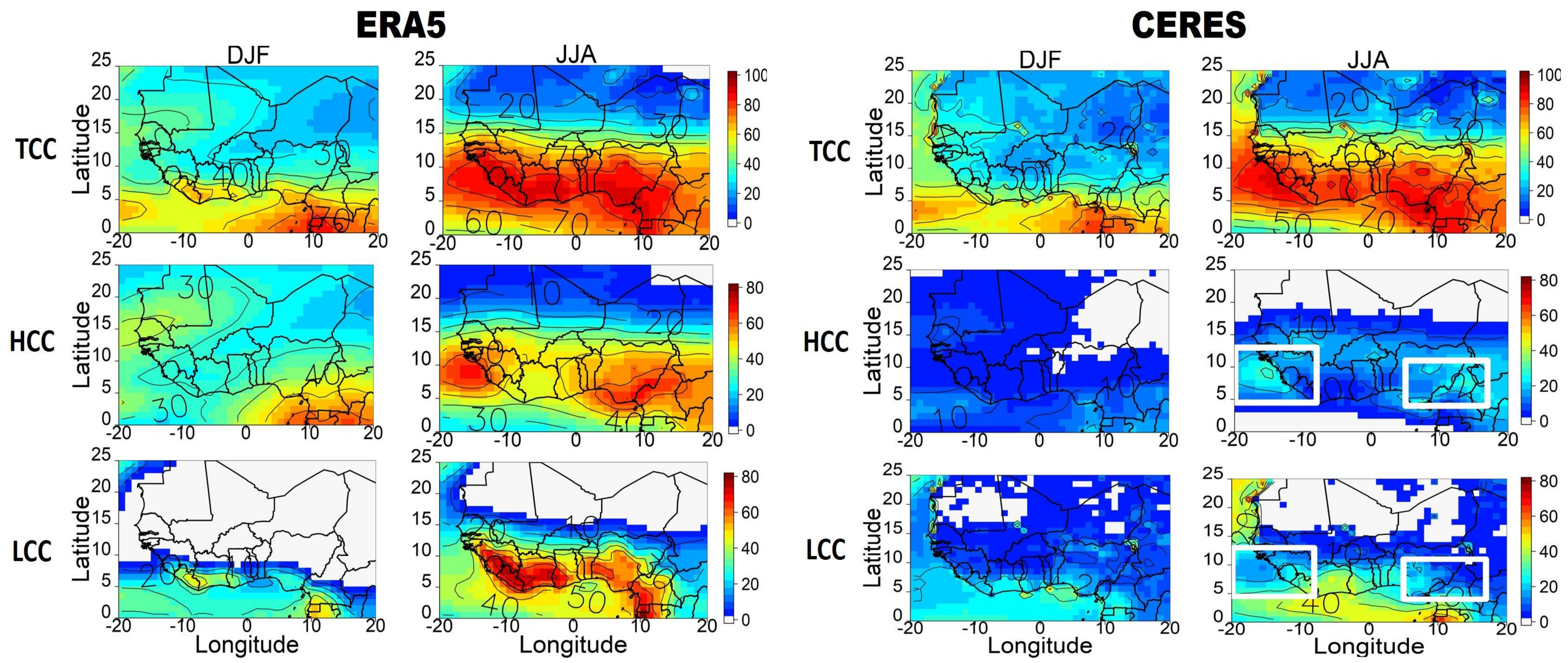
$$CRE_{SW\downarrow} = \frac{1}{n}\sum_{i=1}^{n}\frac{SW\downarrow(t) - SW\downarrow_{CS}(t)}{SW\downarrow_{CS}(t)} \times 100$$

- Daytime hours only (06h to 17h)



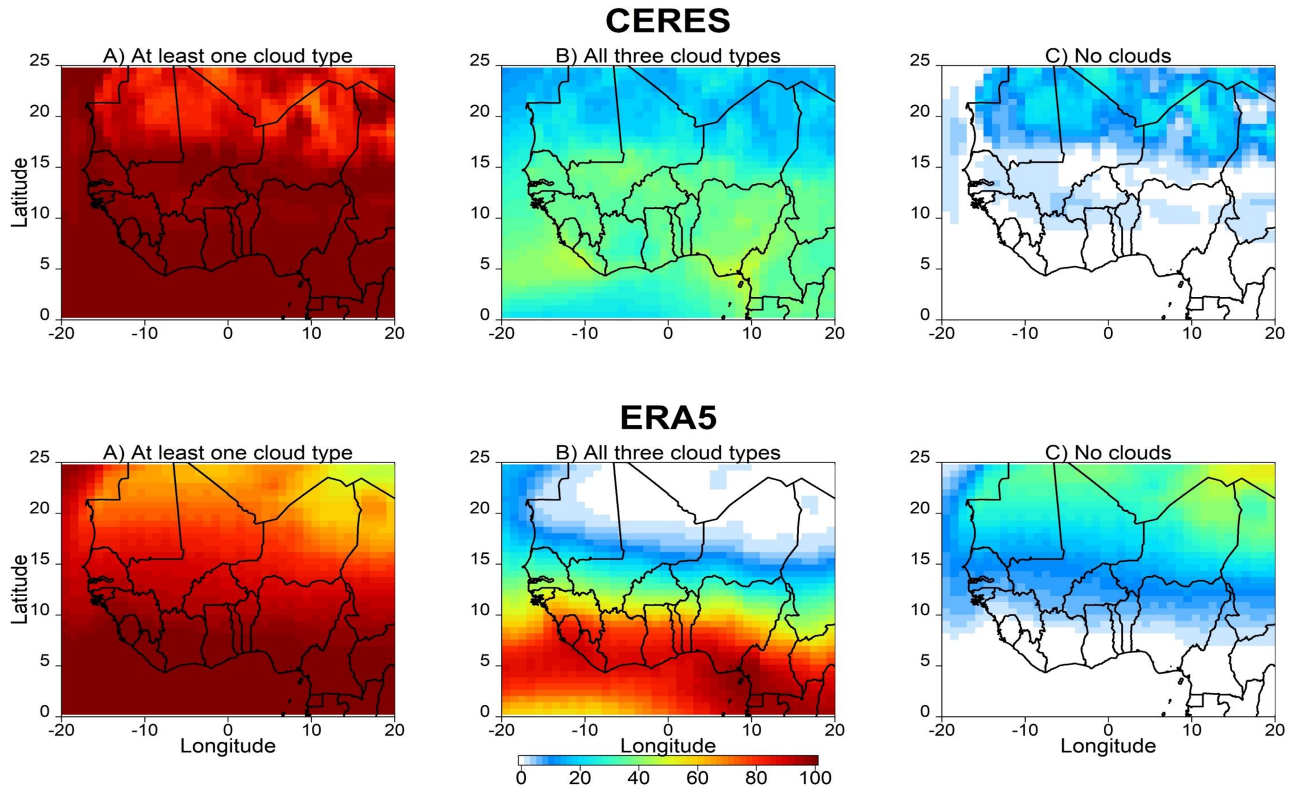
Map of West Africa with locations of 5 grid boxes selected for the estimation of CRE.

SEASONAL MEAN CLOUD COVER FRACTION

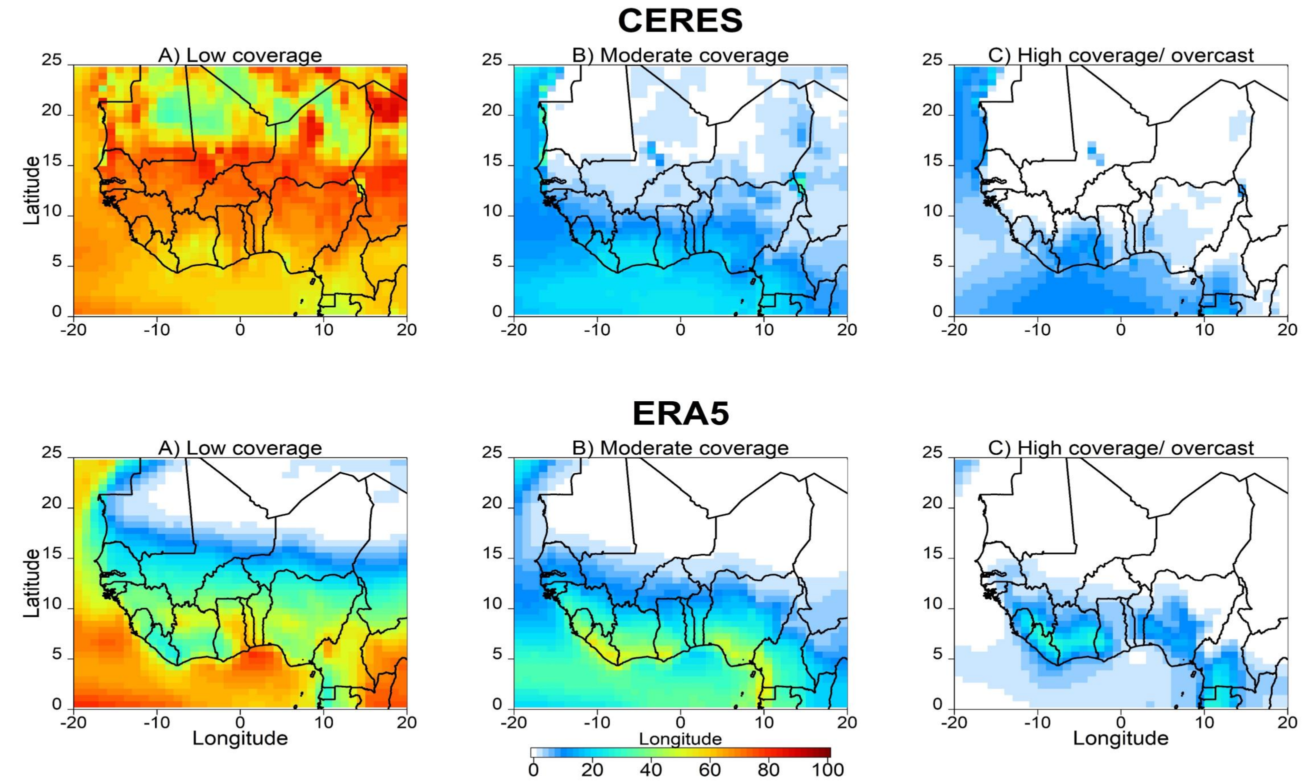


- Clouds strengthen in JJA (monsoon) over southern WA (both ERA5 and CERES).
- Strong N-S LCC gradient in ERA5 (seasonal evolution appears to follow ITCZ evolution) but not in CERES.
- Low values of HCC by CERES linked to the instruments' difficulty to detect optically thin clouds in the atmosphere.
- LCC over Sahara/Sahel region even in DJF in CERES: Possibly due to misinterpretation of Saharan dust as low clouds by the CERES instruments.

CLOUD OCCURRENCE FREQUENCY

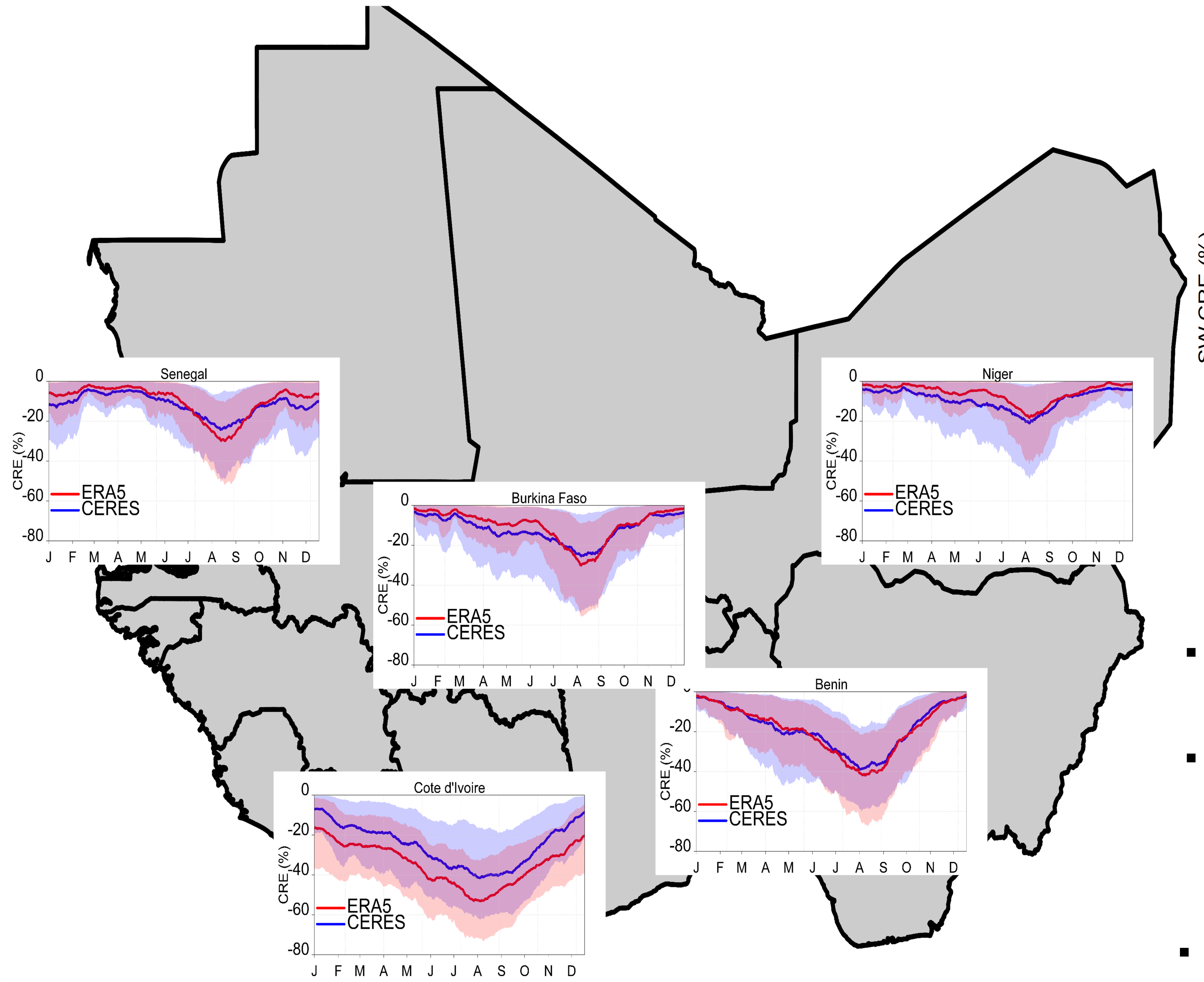


Climatologies of occurrence frequency (percentage of events out of total observations) for (a) at least one cloud type presence, (b) all three cloud types presence and (c) no cloud presence, over WA. Computed with ERA5



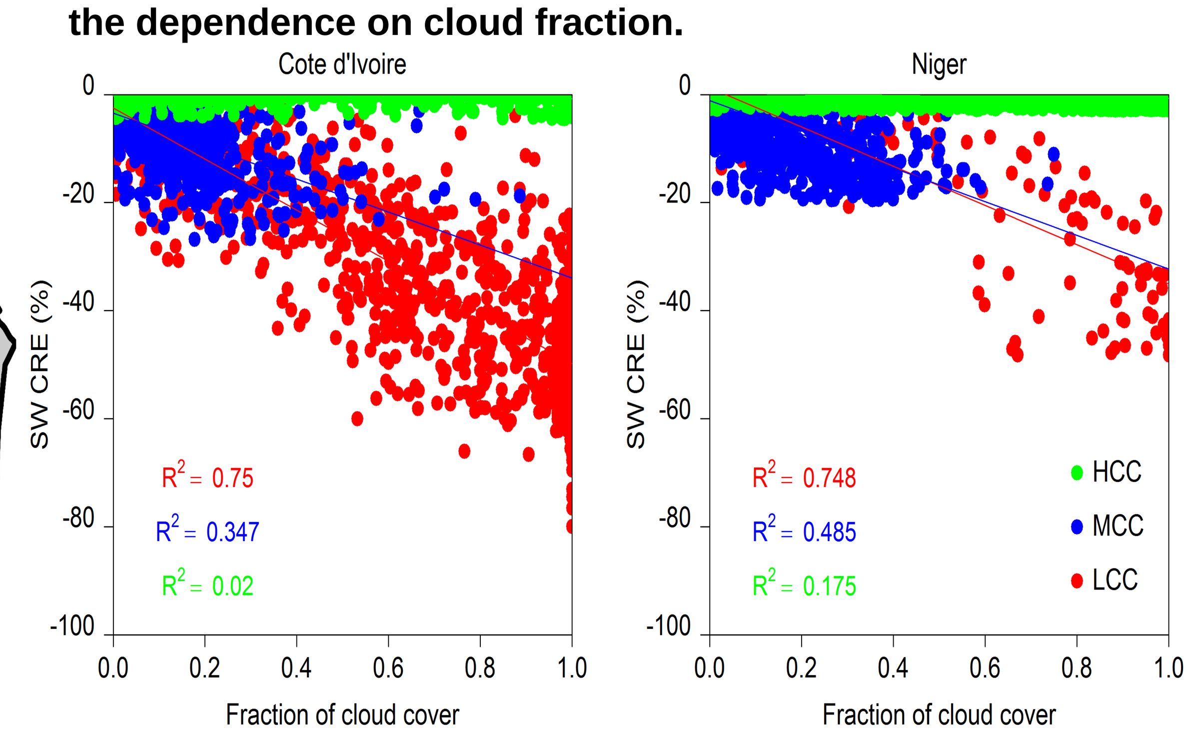
Climatologies of occurrence frequency of LCC with respect to cloud fraction (CF).
[Low coverage = CF < 40%, Moderate coverage = 40% ≤ CF < 80%, High coverage = CF ≥ 80%].

CLOUD SHORTWAVE RADIATIVE EFFECT IN WA



Average annual cycle of percentage of incoming solar radiation lost due to clouds in selected windows (upper and lower bounds of the shaded areas represent the 90th and 10th percentiles of the percentage losses).

Percentage of lost incoming solar radiation by cloud types and the dependence on cloud fraction.



- Low-level clouds lead to the highest losses of incoming solar radiation followed by mid-level clouds.
- Incoming solar radiation loss dependence on cloud fraction is:
  - higher in low-level clouds.
  - non-existent for high-level clouds.
- Largest losses of incoming solar radiation experienced in JJAS (monsoon) season in all windows.
- Losses of incoming solar radiation are higher in southern WA due to intense cloudiness.

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