Impact of extreme rainfall variability and changes on Ground Traffic in Cameroon

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Abstract

Extreme rainfall events are a serious threat to the well-being of Cameroon's society. The reliability of studies on extreme events such as floods depends on the quality of the data and their distribution in time and space. Although these topics are still incomplete in many countries. This present work focuses on the action of extreme rainfall variability and changes on ground traffic in Cameroon using the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) estimation data in the simulation of precipitation at the intra-seasonal scale. For this, the performance verification of the CFSv2 model was first made on the basis of two mathematical techniques such as the Generalized Relative Operating Characteristics (GROC) score and the Ranked Probability Skill Score (RPSS). Then, based on this calculation of the different performance scores, the analysis and interpretations of the model outputs, the study is carried out on the extreme events (floods) of the first three (03) weeks of August 2021 to understand the impact of extreme rainfall over road transport in Cameroon. The results suggest that the CFSv2 model is the best performance for rainfall simulation at this intra-seasonal scale with CHIRPS satellite estimation data for the first three weeks of August 2021 in Cameroon and is adequate to improve the prevention of accidents and road transport infrastructure caused by extreme events (flooding) to heavy rainfall in Cameroon.

I- Introduction

Road transport is an important link in the Cameroonian economy and essential support for the country's growth strategy (Transtat, 2000; DSCE, 2009). Although it globally represents less than 10% of the tertiary sector of the Cameroonian economy, it contributes around 4% in current prices to the Gross Domestic Product (NGUESAN KOUASSI et al., 2015; Annuaire Statistique du Cameroun, 2015). Thanks to its flexibility and accessibility, road transport is the main mode of transport for goods and people. As a result, it makes a substantial contribution to the fight against poverty. It provides nearly 90% of domestic passenger transport demand and nearly 75% of freight transport demand.

For all these reasons, in a context where the world is experiencing disasters due to changing weather and climate conditions, the issues related to controlling the components of transport have become crucial. It is, therefore, necessary to study the implications of changes extreme rainfall over road transport in Cameroon in order to improve the safety, reliability, and efficiency of road transport and to optimize the operation of Cameroonian transport services.

To achieve this objective, the verification of the performance of the CFSv2 model from CHIRPS satellite estimation data in the simulation of precipitation at the intra-seasonal scale while calculating the probabilistic scores was made, the output of the most efficient model to anticipate floods and droughts in Cameroon has been highlighted and the impacts of extreme rainfall on road transport in Cameroon have been deduced.

The interest of this study is to make available to the scientific and Cameroonian community that extreme rainfall affects the functioning of existing transport infrastructures as well as the design of new infrastructures. The rehabilitations of catch-up and the new conceptions will be expensive to carry out, so that it is essential to have good climatological data to make the right decisions. With regard to the damage caused by heavy and/or light rainfall recorded in Cameroon, the public authorities and the Cameroonian population are called upon to take seriously the information from the forecasts of numerical models in order to limit the damage caused by these heavy events rainfall leading to floods or low rainfall leading to droughts. However, adequate observational rainfall data are sometimes lacking in Africa (e.g., Nicholson et al., 2003).

The rest of the work is structured as follows: The study area and data are presented in the second section, the model and the methods are offered in the third section, the results and discussions are given in section four and the conclusions are presented in section five.

Ii- Study Area And Data

II.1- STUDY AREA

Our study area is Cameroon, a country in Central Africa, which is located slightly north of the equator between 1–13°N and 7–18°E. It is separated into two large climatic domains which are balanced according to the oscillations of the Intertropical Convergence Zone (ITCZ) (Molua, E. 2006; Vondou et al. 2018; Mboka et al. 2020; Daïka et al. 2022a): the equatorial and subequatorial domain, to the south, and the tropical domains to the north (Fig. 1). In addition to these two major climatic zones, the country has a maritime and mountainous influence due to its exposure to Atlantic monsoon flows and the country's rugged terrain. For example, the coastal plain around Douala has a so-called “hyperhumid” climate with a total absence of a dry season; at the foot of Mount Cameroon, rainfall is at record levels: more than 7,500 mm per year in Limbe. The equatorial climate of the western highlands is one of high rainfall variations and low temperatures. The southern Cameroon trays and the southern coastal plain experience the so-called Guinean-type climate that characterizes the Congo Basin forest. Around the Adamawa massive, the tropical climate is humid at altitude, around the Benoue basin, the tropical climate is said to be Sudanese and in the Far North, the tropical climate is said to be Sudano-Sahelian (Daïka and al., 2022b).

II.2- Study data

In this study, the data used are the CHIRPS satellite precipitation estimate data obtained using the PyCPT data analysis tool on the IRI website. They are a set of quasi-global rainfall data over 35 years old (Katsanos et al., 2016; Paredes-Trejo et al., 2017; Vondou et al., 2021). Extending from 50° S to 50° N (and all longitudes) and going from 1981 to almost today, it integrates our internal climatology, CHPclim, satellite images at 0.05° resolution, and station data in situ to create gridded precipitation time series for trend analysis and seasonal drought monitoring (Dinku et al., 2018, Lei Bai et al., 2018). They are available from 6 hours to 3-month aggregates. Almost all data has a spatial resolution of 0.05° × 0.05°

degree. Some of Africa's daily data are scaled down to 0.25° × 0.25° spatial resolution to support land surface and spatial domain modeling activities (1500×1600 pixels, 20°W to 55°E, 40°N to 40°S). CHIRPS data is provided in NetCDF, GeoTiff and Esri BIL formats. Units are mm per time period, e.g. mm per day, mm per pentad, mm per month. Supporting data is created each month to supplement the CHIRPS data, including the density of stations used, course of multi-time step images of Africa, lists of locations, names of all stations, and the number of stations used per month for each country. Rainfall forecast data from the CFSv2 model is available on PyCPT for the PyCPT intra-seasonal forecast. These data used in the case of this study were initialized in August 2021 in order to obtain intra-seasonal forecasts for the three (03) weeks.

Iii- Model And Method

III.1-**Description of Climate Forecast System, version 2 (CFS v2)**

The Climate Forecast System (CFS), version 2, is a fully coupled ocean-land-atmosphere dynamical seasonal prediction system (Xing et al. 2011; SITI et al. 2019). It became operational at NCEP in 2010 and provides important advances in operational seasonal prediction on a number of fronts.

The atmospheric component of CFSv2 is a 2007 version of the NCEP Global Forecast System (GFS) (Saha et al., 2010; Kingtse et al., 2012; Sanjiv et al., 2014; SHUHUA et al., 2015), with a spectral truncation of 126 waves (T126) in the horizontal and 64 levels in the vertical. The oceanic component is the Geophysical Fluid Dynamics Laboratory (GFDL) Modular Ocean Model version 4 (MOM4) (Griffies et al. 2004). The CFSv2 system increases the length of skillful MJO forecasts from 6 to 17 days compared to its predecessor, CFSv1 (Saha et al. 2014).

Given the pace of model and data assimilation development, such a reanalysis will be needed roughly every 5–10 year. Initial conditions come from NCEP CFS Reanalysis (Saha et al. 2010).

III.2- **METHODS**

The verification of the performance of the CFSv2 model was done on the basis of two mathematical techniques: GROC score and RPSS.

The GROC score determines how well probabilistic forecasts discriminate, even if the forecasts have biases or calibration issues (Mason, 2018). However, it is generalized to encompass all forecast categories collectively, rather than being specific to a single category. The GROC score is bounded by [0, 1] with higher values indicating greater discrimination allowing intuitive comparison of predictions and providing a measure of a forecast's information and does not require a forecast to have sufficient resolution to be considered skillful.

The RPSS is well suited for verifying probabilistic forecasts and is defined as a skill score based on a comparison of squared probability errors for a real set of forecasts. It is given by the relationship (LENSSEN et al., 2020):

$$RPSS = 1 - \frac{RPS_{fo}}{RPS_{cl}}$$

Where RPS_{fo} and RPS_{cl} are the ranked probability score for the forecasts and for the climatology forecasts respectively.

The RPSS is a combined measure of the resolution and reliability of a forecast relative to that of the reference climatological forecast. RPSS values greater than zero indicate that the forecast outperforms the climatological forecast. When RPS_{fo} and RPS_{cl} are equal, RPSS is zero, and when RPS_{fo} is zero, RPSS reaches its maximum possible value of 1.

The method used in this study is a statistical and probabilistic method. The data processing software is PyCPT by running the script to open the software in the terminal from the folder where the software installation took place and entering the script 'jupyter notebook'.

Iv- Results And Discussions

IV.1- **Performance verification of the CFSv2 model in the simulation of precipitation at the intra-seasonal scale**

It was done on the basis of two mathematical techniques: GROC score and RPSS.

IV.1.1- **Performance assessment of the CFSv2 model by GROC score**

Figure 2 represents the representative grid points of the GROC score for the forecast precipitation and the observed climatology of the CFSv2 model for the three (03) weeks of August 2021. According to Fig. 2, the CFSv2 model records a precipitation rate of around 20 to 40% in the great South (East, Center, South, Littoral, West, North-West, South-West) and a relatively 55% in the great North (Adamawa, North, and Far North) in the first week. It records a rainfall rate of around 20 to 40% in the great south and vice versa in the north-west and great north in the 2nd and 3rd week.

IV.1.2- **Performance assessment of the CFSv2 model by RPSS**

Figure 3 represents the representative grid points of the RPSS score measuring the accuracy of the probability forecasts compared to the CHIRPS observation of the CFSv2 model for the first three (03) weeks of August 2021. According to Fig. 3, for the first week, the CFSv2 model tends to underestimate the observation in the Center to the South and Far North zone and to overestimate in the North and North-West zone. For the second week, it tends to underestimate the observation in the northern area and the great south and to overestimate an area of Adamawa. For the third week, CFSv2 tends to underestimate the observation in the Far North and Adamawa zone up to the Center zone while in the West and South zone tends to overstate the observation.

The different results obtained make it possible to make the choice of the most skillful model from the performances assessment of the CFSv2 model in the simulation of the precipitations using the scores of the RPSS and the GROC. The CFSv2 model presents relatively good scores because the values of this model tend to be closer to the climatology in certain areas. So the CFSv2 model performs better.

IV.2- **Amount assessment of extreme rainfall by the CFSv2 model**

The amount assessment of extreme rainfall distributed on a scale of 1 to 100 provided by the CFSv2 model was made on the basis of percentiles. To enable the determination of extreme rainfall events in Cameroon, the 90th and 99th percentile will be chosen in this study.

Figure 4 illustrates the probability of excess of 90th and 99th percentile respectively of CFSv2 for the first three (03) weeks of August 2021. Figure 4a shows that the Center area has a high value of excess precipitation (80–100 percentiles) for the first week and from 0 to 20 percentiles (the low excess values) for the other two weeks. The other areas display a low excess precipitation value (on average 45 percentiles) for the first week and 0 to 20 percentiles for the other two weeks. Figure 4b shows, for the first three (03) weeks of August 2021, a low excess of precipitation from 0 to 20 percentiles in all areas of the country.

In view of these 90th percentile values during the three weeks, the CFSv2 model is better suited to detect areas of excess rainfall in areas of Cameroon.

IV.3- Excess Probability and Precipitation Density Function

The excess exceedance probabilities and the precipitation density function are shown in Figs. 5 and 6. The forecast and climatology curves are shown in red and blue, respectively.

Figure 5 illustrates the Excess Probability and Precipitation Density Function for the 90th percentile of the first three (03) weeks of the CFSv2 model. Figure 5a shows the Excess Probability and Precipitation Density Function for the 90th percentile of the first week of the CFSv2 model. Forecasting and climatology are confused. It will be 0.6% less than the normal amount of precipitation. The forecast and climatology probability density function is shifted before normal; the forecast is high compared to the climatology.

Figure 5b illustrates the Excess Probability and Precipitation Density Function for the 90th percentile of the second week of the CFSv2 model. Forecasting and climatology are almost confused. It will be 0.6% less than the normal amount of precipitation. The forecast and climatology probability density function is shifted before normal; the forecast is high compared to the climatology. An excess of precipitation on average of 9.99% of having an excess of precipitation exceedance is observed.

Figure 5c represents the probability of excess and the precipitation density function for the 90th percentile and the third week of the CFSv2 model. It shows that forecasting and climatology are confused. It will be 0.4% less than the normal amount of precipitation. The forecast probability density function and the climatology are lagged before normal; the forecast is high compared to the climatology. Below-average precipitation of 9.8% to have an excess precipitation overshoot is observed.

Figure 6 represents the excess probability and precipitation density function for the 99th percentile of the first three (03) weeks of August 2021 from the CFSv2 model. According to Fig. 6a, the forecast and climatology are confounded and will be 0.0% less than the normal precipitation amount. The forecast probability density function and the climatology are lagged before normal; the forecast is high compared to the climatology. Figure 6b shows the Excess Probability and Precipitation Density Function for the 99th percentile and the second week of the CFSv2 model. According to Fig. 6b, the forecast and the climatology are confounded and will be 0.0% less than the normal precipitation amount. The forecast probability density function and the climatology are lagged before normal and the forecast is high relative to the climatology. Figure 6c represents the Excess Probability and Precipitation Density Function for the 99th percentile and the third week of the CFSv2 model. For the CFSv2 model, the forecast and the climatology are confounded and will be 0.0% less than the normal precipitation amount. The forecast probability density function and the climatology are lagged before normal; the forecast is high compared to the climatology.

The results obtained with the 90th percentile show that the areas likely to receive an excess amount of precipitation can lead to flooding in this country using the CFS v2 model.

IV.4- **Impact of extreme rainfall variability on road transport in Cameroon**

The results of the re-analyses of the outputs of the CFS v2 model are presented on the rainfall vigilance maps of Cameroon. In view of these results, the country was flooded from the point of view of hydro-meteorological phenomena. These hazardous hydro-meteorological phenomena (extreme rainfall) have a strong impact on Cameroon compared to other phenomena or systems that may occur on an aerological or local scale. Figure 7 displays the Cameroon Floods Vigilance Map. It shows the probability of occurrence and the area of occurrence of floods in this country. These floods are explained by the fact that rainwater cannot infiltrate and accumulates on the surface of the ground because of the infrastructures and the nature of the soil resulting in its compaction and its waterproofing (Hardoy et al. 2001; Nchito 2007; Douglas et al. 2008; Engel et al. 2017).

Most vehicle and motorcycle accidents and delays that are caused by weather are due to rainfall. The latter can submerge roads and flood underground passages. Floods cause scouring and gullying of roads. They damage or undermine the foundations of the railway tracks and cause overflows on the rails and mudslides which damage the tracks (Rosseti, 2002 and Marjorie et al., 2009).

In addition, episodes of heavy rainfall disrupt the entire road transport system, including the transport of goods, people, and properties.

As intense precipitation events lead to loss of traction and control, delays, reduced speeds, stress on vehicle parts and tires, wet pavement, splashed roads, detours, hard braking, and uneven road washouts.

As of August 1, 2021, for example, the Far North region of Cameroon recorded major floods causing various damages. Since that day, the populations of the departments of Mayo-Sava, Logone and Chari, and Mayo-Tsanaga have suffered the inconveniences linked to the phenomenon aroused. In addition, one can cite the collapse of the Palar Bridge on the night of Sunday 30 to Monday 31 August 2020 in Maroua causing economic losses in cross-border exchanges between Cameroon and Chad (OMM No 1275, 2021). These disasters are frequently observed in certain areas of the country such as Douala and Garoua.

Conversely, rainfall deficits lower water levels, which can have a negative impact on the use of inland waterways. Drought brings the risk of dust and smoke reducing visibility. It influences the marketing and production of cereals in the great north of Cameroon.

Conclusion

In this study, the impacts of extreme rainfall events on road transport operations and road transport infrastructure in Cameroon using CHIRPS estimation data in intra-seasonal scale rainfall simulation were plotted. At the end of this study, the scores of the CFSv2 model give precise details of the areas likely to have above-normal rainfall responsible for extreme precipitation events (flooding or drought) in Cameroon. So, it is clear that the CFSv2 model can better simulate weather conditions (extreme precipitation) related to road transport systems at this intra-seasonal scale. Operational information related to weather conditions should be taken into account in the future to be able to mitigate delays and accidents and improve the safety, reliability, and efficiency of transport in Cameroon.

Declarations

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Conflict of Interest

No Conflicting interests exist in this paper.

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Author's Contribution

Daïka Augustin: Investigation, Conceptualization, Visualization, and Writing - original draft and Formal analysis; **Igri Moudi Pascal**: Investigation, Data curation, Methodology, Visualization and Software; **Messanga Etoundi Honoré** and **Mbane Biouele Cesar**: Validation, Writing, Supervision, review and editing.

Availability of data and material:

We have the materials, all the raw and processed data and result products. We can provide the processed data and
 documents if it is required.

Code availability:

The tools used in this work included the CHIRPS estimation data in the simulation of precipitation at the intra-seasonal scale and the CFSv2 model for the analysis and interpretations of the model outputs.

Ethics approval:

Not applicable to this paper because there was no potential conflict of interest.

Consent to participate:

Not applicable to this paper

Consent for publication:

The submission of this paper has been approved by all relevant authors and is the independent work of the authors. The latters have seen and agreed to the submitted version of the paper. It has not been submitted and not published or accepted for publication and is not under consideration for publication in another journal or book.

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Figures

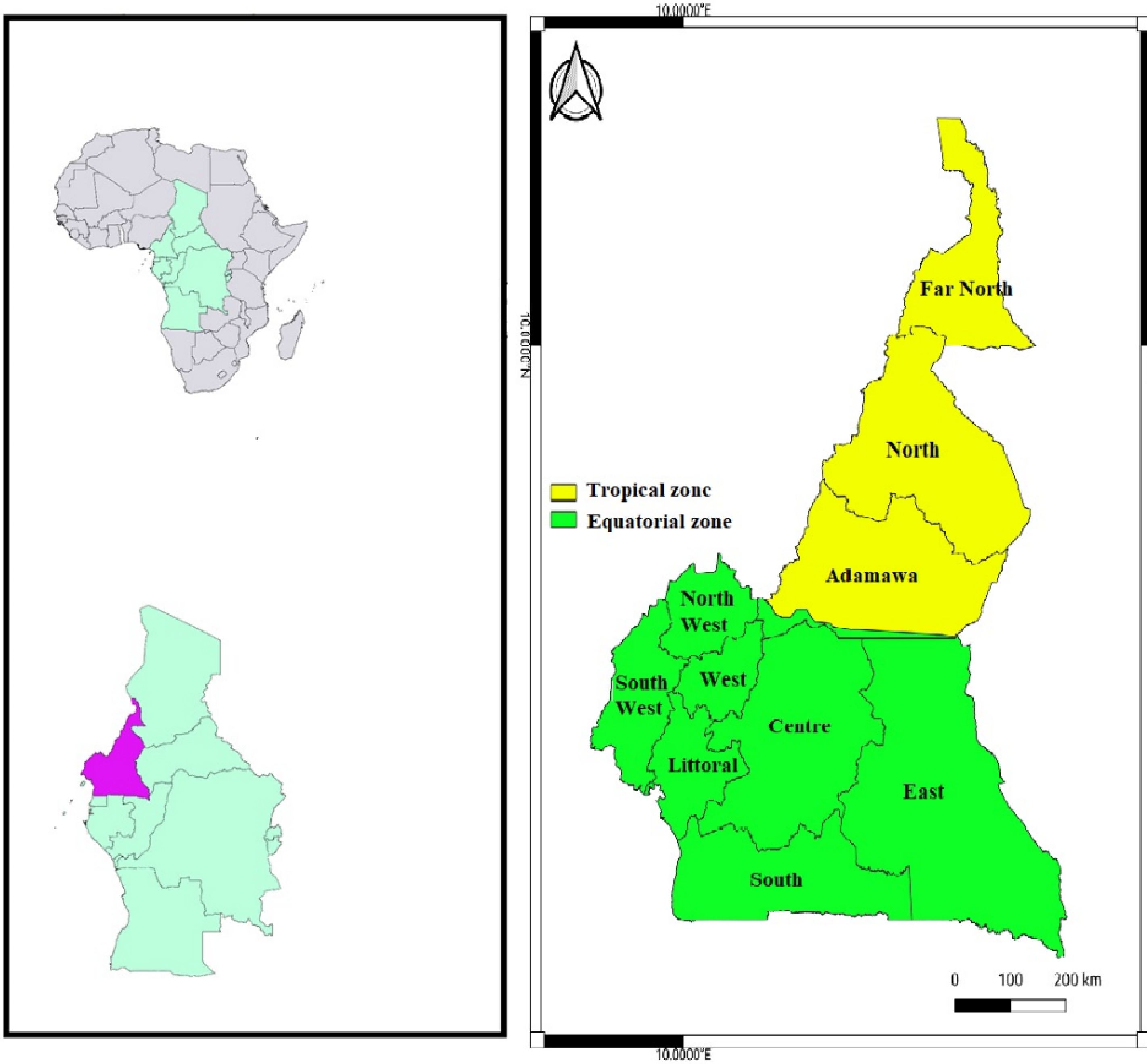


Figure 1

Study area

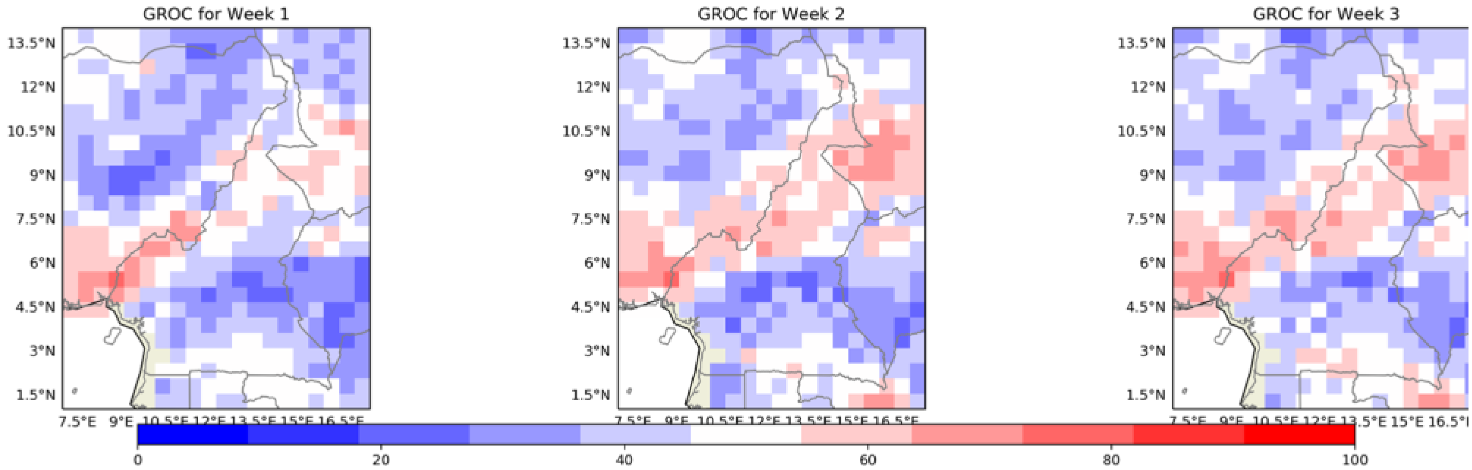


Figure 2

Performance assessment of the CFSv2 model by GROC score of forecast precipitation and observed climatology for the first three (03) weeks of August 2021.

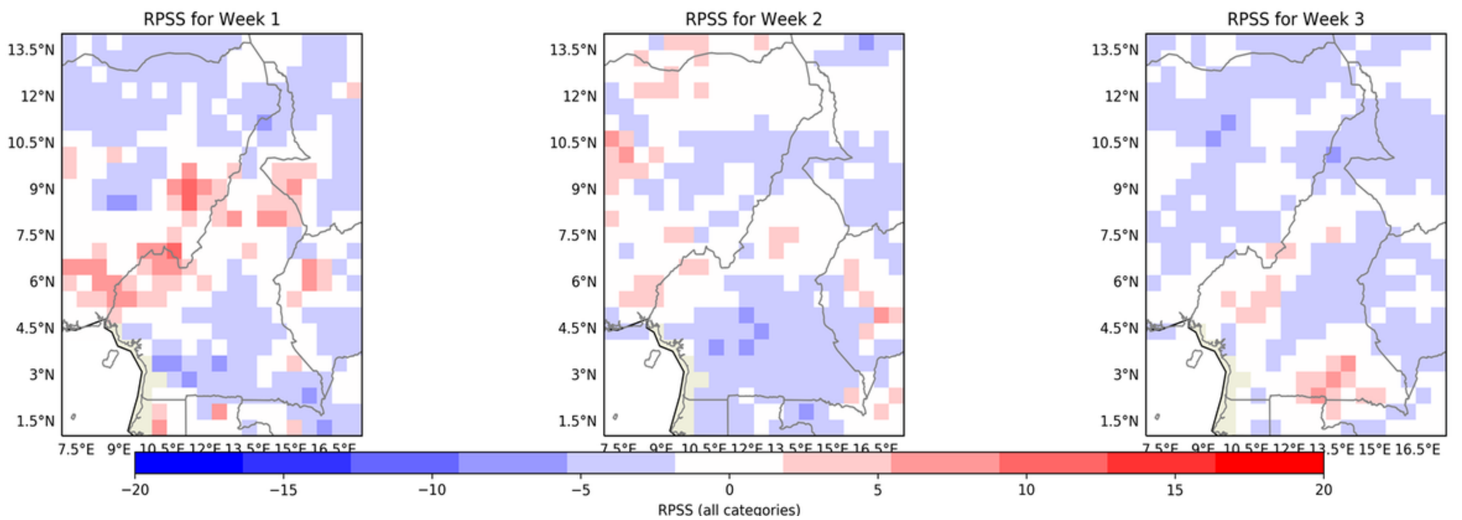


Figure 3

Performance assessment of the CFSv2 model by RPSS of forecast precipitation and observed climatology for the first three (03) weeks of August 2021.

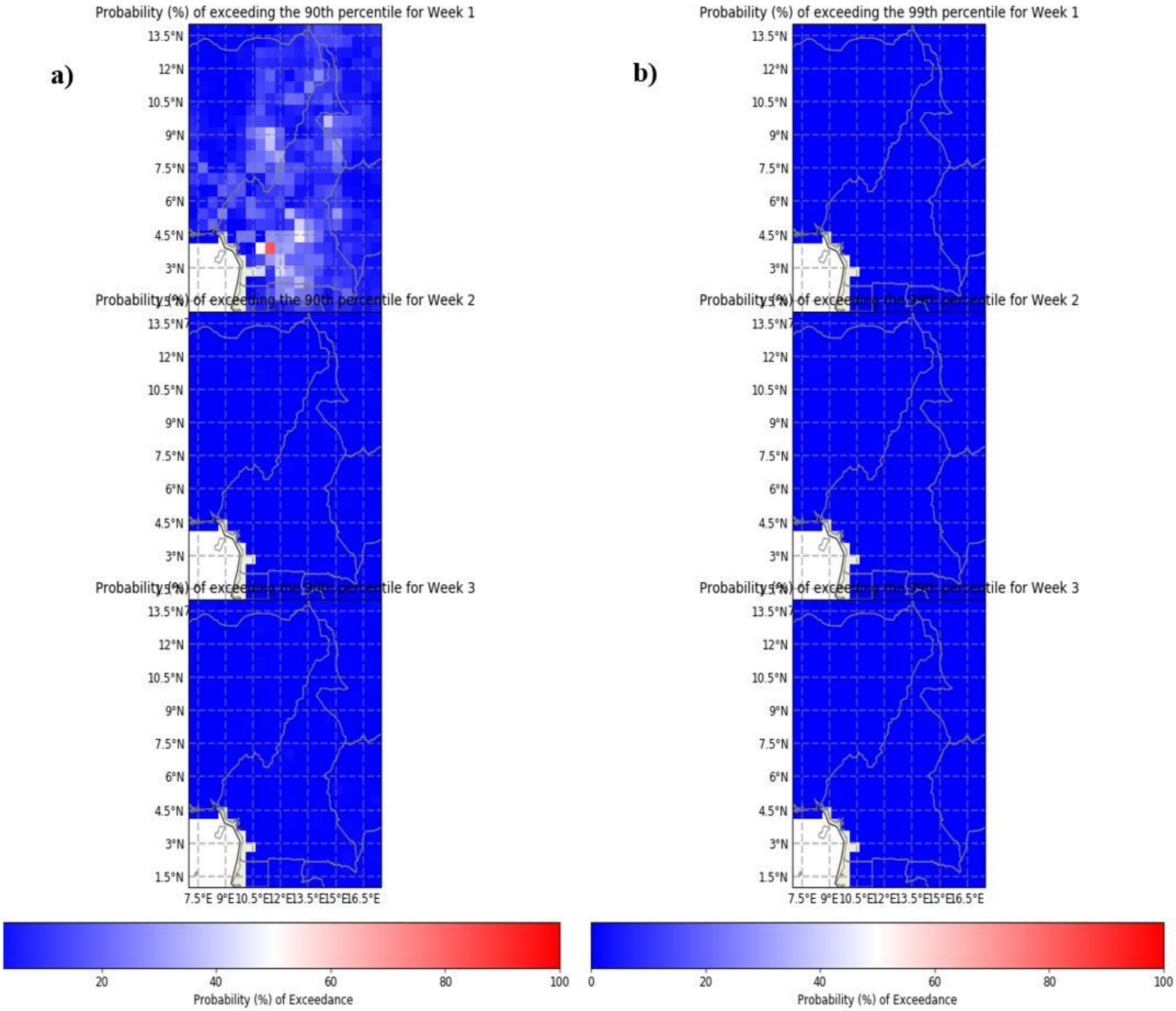
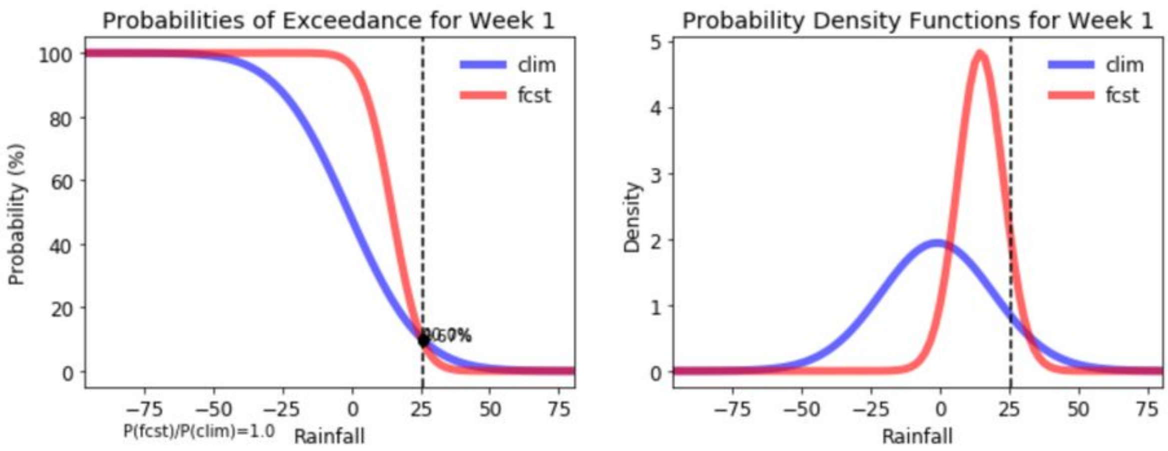
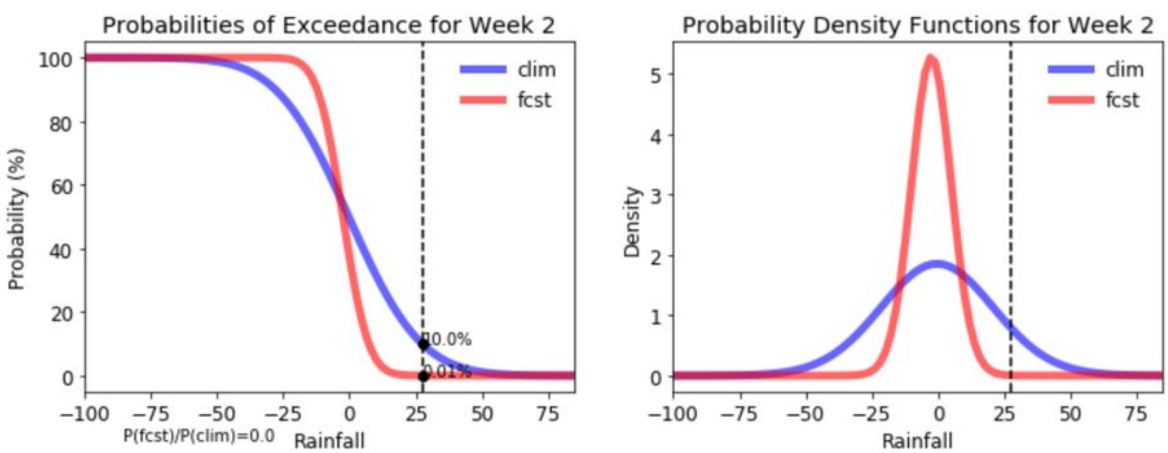


Figure 4

Probability of exceeding 90th and 99th percentile of CFSv2: a) 90th percentile and b) 99th percentile



b)



c)

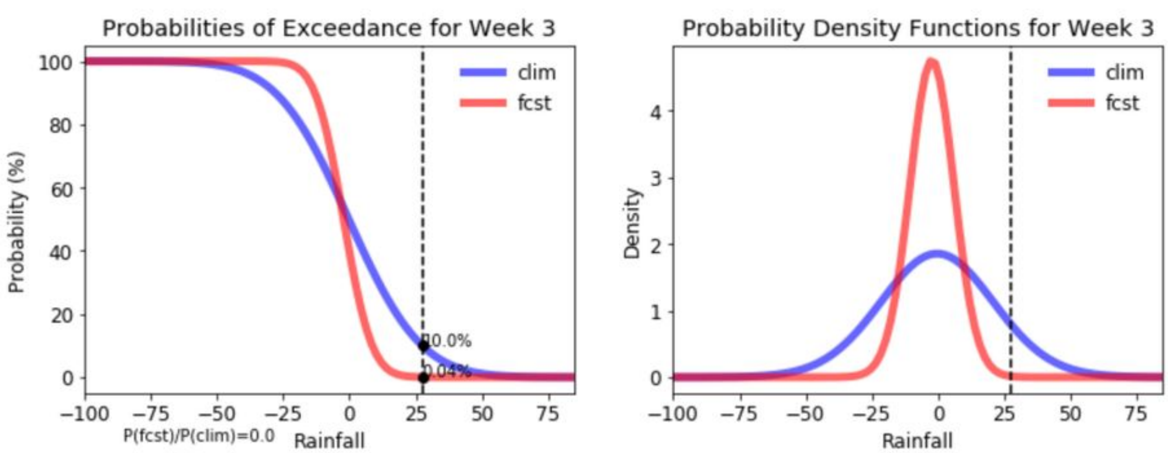
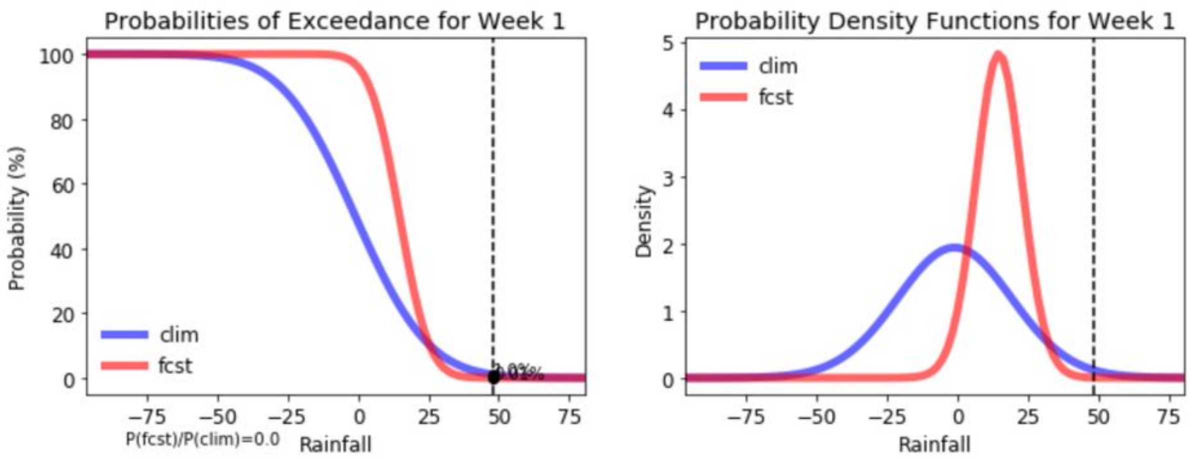
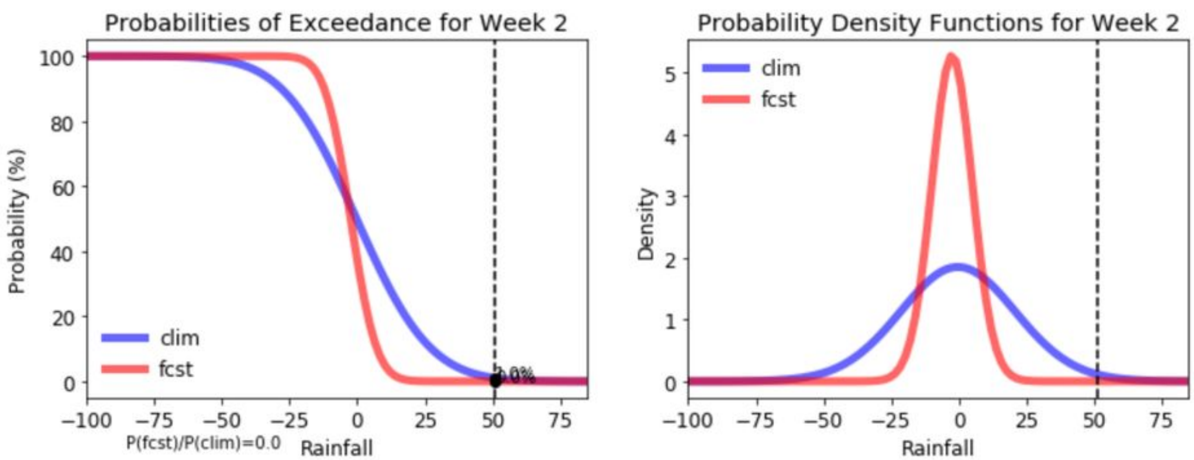


Figure 5

Excess probability and Precipitation density function for the 90th percentile of the first three (03) weeks of August 2021 of CFSv2: a) the first week, b) the second week and c) the third week.



b)



c)

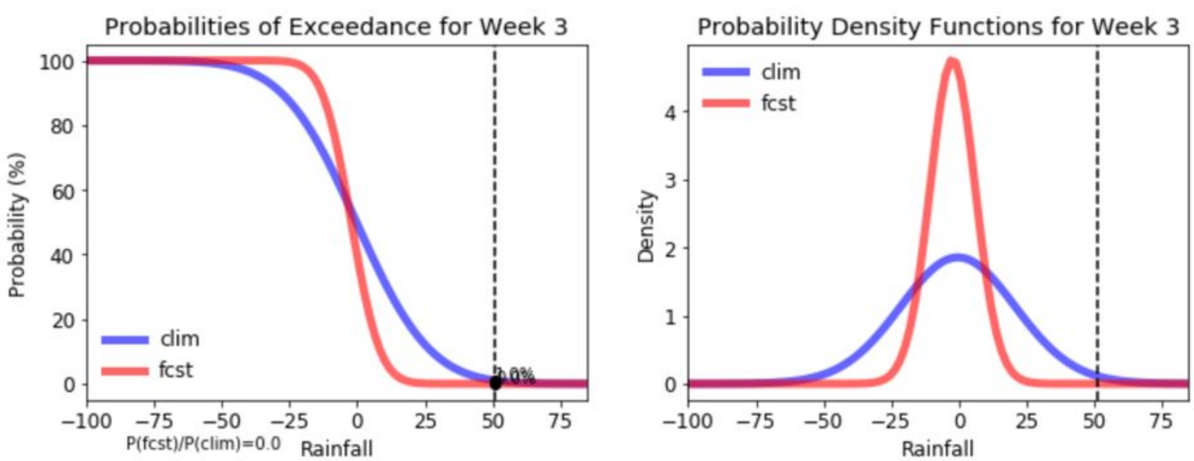


Figure 6

Excess probability and Precipitation density function for the 99th percentile of the first three (03) weeks of August 2021 from the CFSv2 model

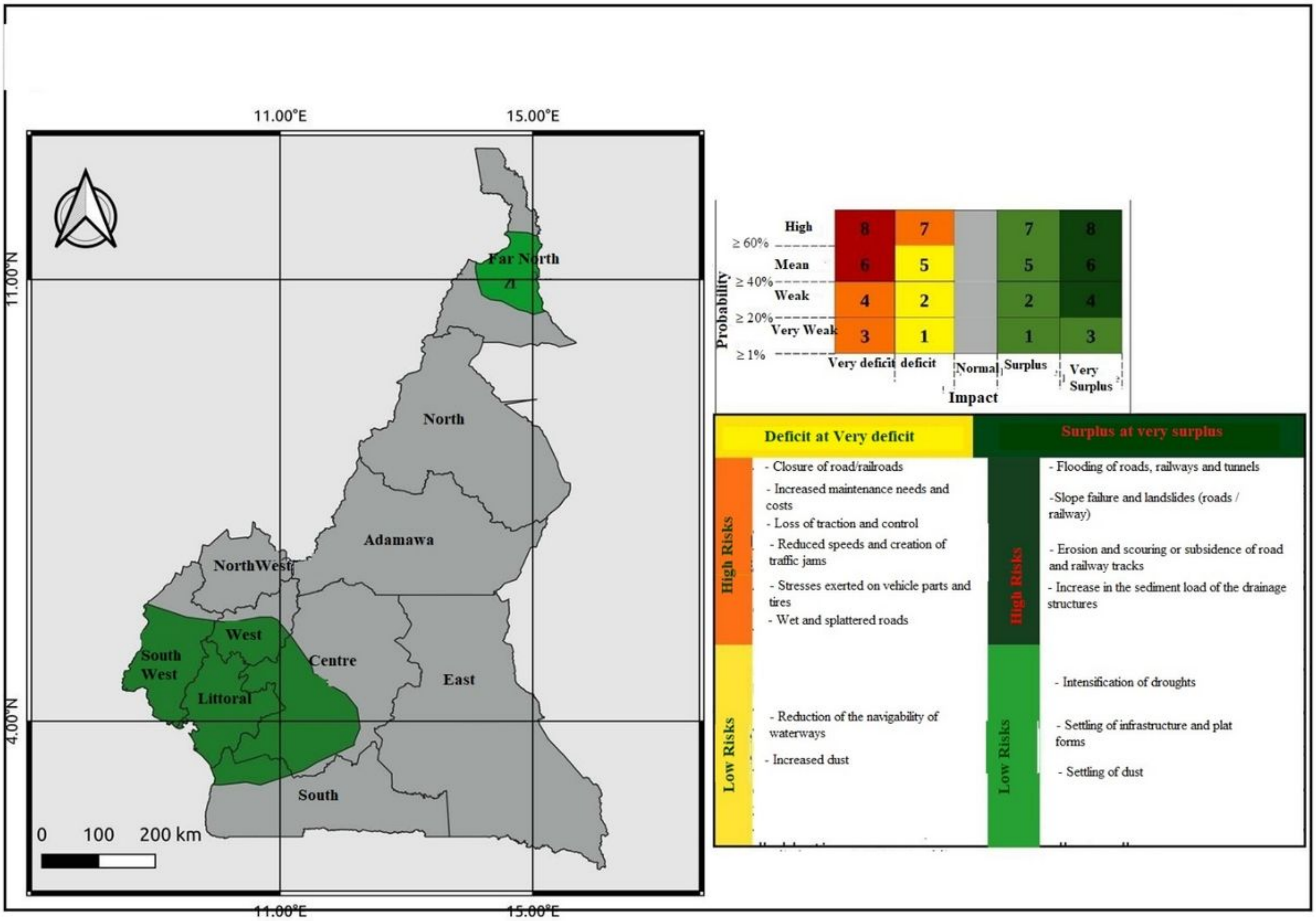


Figure 7

Cameroon Floods Vigilance Map