Predictability of Dry Season Extreme Events over Western Africa: Assessing WRF simulation of 2002 case over Senegal

A. Sarr

Département Climat et Applications, Agence Nationale de la Météorologie (ANACIM), Dakar, 16688 Dakar-Fann, Senegal
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Presenting author email: layesarr@voila.fr

Abstract: West Africa climate and mainly its northern part known as Sahel has experience the longest and most devastating drought ever recorded in the 70s and 80s. A lot of attention has been given to this climate shift characterized by rainfall deficit during the monsoon season. This trigged many studies focusing at different time scales on climate features modulating rain producing systems but also large scale factors controlling rainfall variability.

This study investigates less known features like off season rains occurring out of the rainy season period over Sahel. The Weather and Research Forecast model (WRF ARW version 3.2) is use to simulate an extreme case which occurred in January 2002 on the western coast around the land/ocean interface and caused huge damages in Senegal and Mauritania. A nesting strategy with three domains is carried out to have a higher resolution of 10km in the inner domain while the mother domain covering a large area is at 90 km.

The model was able to reasonably simulate the event and its intensity 2 to 3 days in advance, demonstrating the usefulness of such tools for early warning system (EWS) which could help mitigate the impacts. The location of rain band was closer to the observed situation in higher resolution domains. The study showed key dynamic and thermodynamic conditions associated with the event. Precipitable water (PW) evolution played a central role on the intensity due to north-east transport from the Inter Tropical Convergence Zone (ITCZ) over the Ocean near the Equator.

1. Introduction

The major climate features, over West Africa Sahel, on which all attention is focused, occur during the monsoon season. Rainfall is mainly recorded during this period and corresponds to rainfed agriculture activities and last from May to October north of 10°N. Over Western Africa Sahel, rainfall occurring from November to April over Western Africa is not well documented. In recent years a few studies have been done on these systems using observational (Gaye et Fongang 1997; De Félice 1999; Thorncroft et Flocas 1997) and modelling studies (Meier and Knippertz 2008).

This is a common feature occurring over western Sahel and affects mainly Cape Verde, Senegal and Mauritania between late October and March considered as dry season as opposed to the monsoon season. They are very well known by local population who name them “heug” or “mago rain” in Senegal. In most cases only light rain lasting hours with cloud structure dominated by mid level clouds altocumulus or altostratus. When the system is strong enough convective clouds giving moderate to heavy rains are observed.

Other important elements, associated with these weather types, are cold waves and dust conditions.

As they occur during a harvest and transaction period, they cause damages of different forms.

In this study, we focus on the extreme case which occurred in January 2002, causing tremendous damages on livestock in Senegal and Mauritania.

In section 2, we present the model configuration and data. Section 3) the typical mechanism and structure of these weather types is highlighted before the validation of simulation results in sections 4 and 5 with an emphasis on large scale dynamic and precipitation . Summary and conclusion are presented in section 6.

2. Modelling strategy and data

Predictability for early warning is essential in order to mitigate the high impacts weather and climate systems.

In the study, a nesting strategy using the Weather Research and Forecasting model (WRF ARW version 3.2 Skamarock et al. 2008), to simulate the case adopted. Two nest domains and a parent domain are configured for simulation at respectively 90, 30 and 10 km horizontal resolutions (figure 2).

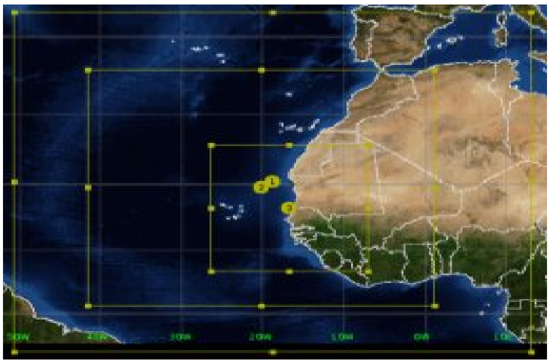
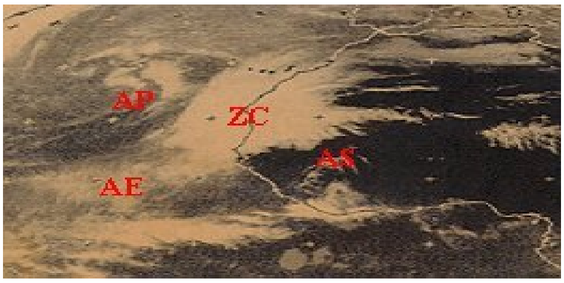


Figure 2: Map showing the 3 domains at respectively 90km for the d01, 30 for d02 and 10km horizontal resolution for d03.

The model is initialized by NCEP reanalysis 1&2 (Kalnay et al. 1996) January 7, 2002 at 00Z and the simulation lasted 8 days in order to assess the predictability of such kind of events.
Meier and Knippertz (2008) used the GME model at 40km horizontal resolution to simulate the event and found skills in predicting the event 7 days ahead even though the precipitation location was not well simulated.
Data used to validate the model outputs are the ARC2 which combine gauge and satellite estimation datasets and TRMM (only estimation) as well as gauge rainfall from stations in Senegal. They are at high resolutions close to those of the nested domains. Large scale environment using key variables from model outputs are analysed in order to understand the mechanism and dynamic which lead to the formation of the system. The most difficult aspect to predict is certainly the heavy precipitation which occurred in 3 consecutive days and caused damages on livestock, crops and people. Beside the predictability, a lot of questions were raised about the intensity, the duration and the cold wave which exacerbated the disaster.

3. Mechanism and schematic

Off season rains represent a typical climate interaction case between temperate and tropical regions. They are mainly due to air masses "conflict" or an area of confluence, above the region depicted earlier. Polar air (AP) coming through a trough, equatorial air (AE) transported by the sub tropical jet and Saharan air (AS) from the continent as shown in figure 1. A large band of clouds is then observed around the ZC area and generate rainfall of different intensity.



Figuue 2: Satellite image of an off season case with continent in black, area of cloud is in white and the different air masses contributing to the system formation AP (polar air) AE (equatorial air), AS (Saharan air) and ZC the confluence zone.

To investigate these kinds of weather events, a large area, covering continent and ocean, has to be considered.
We tried to identify the schematic describe above in model outputs using model clouds at mid level (figure 3). The results are consistent with this behaviour with cloud band with comma shape showing the cloud band structure with a comma structure. This indicates potential ability of WRF model in simulating off season systems.

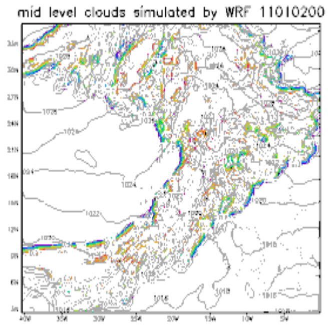


Figure 3: Mid level clouds simulated by WRF model and extracted from domain 1the contour lines represent sea level pressure for 11 January 2012.

4. Large scale environment

The vertical structure of the atmosphere is analysed mainly low, mid and high levels of the troposphere to better understand the formation of these disturbances over Western Africa and mainly in this case what could explain the intensity of the event.
The cold air from mid Atlantic Ocean reaching the lower latitudes through a trough created the formation of a cut off low off the coat of North-West Mauritania. On January the 7th at 00Z, the vertical structure exhibit at 850 hPa a low off the coast of northern Mauritania with an area of temperature ranging from 6-8°C and cyclonic winds around the low geopotential height with relative humidity above 90%. At 700, the low persists surrounded by strong winds with a west-south-west component and speed reaching 35kt. At 500 and 200hPa the low located south of Canary Islands directing strong westerly winds over Western parts of Mauritania and Senegal. On the 8th, the low at 850hPa extends a southwest trough toward Northern Cape Verde Islands with winds shifting slightly west-south-west up to 500 hPa. At 200hPA the sub tropical jet with a western component has speeds reaching 90kts over Senegal.
On the 9th, the low is deeper at all level with high values of relative humidity at 850 hPa and winds having a south-west component even at 200hPa. The low centered now 23°N26°W deepen again on the 10th of January figure 4a, and exhibit a large band of relative humidity between 80 and 100% from the Equator to Canary Islands.

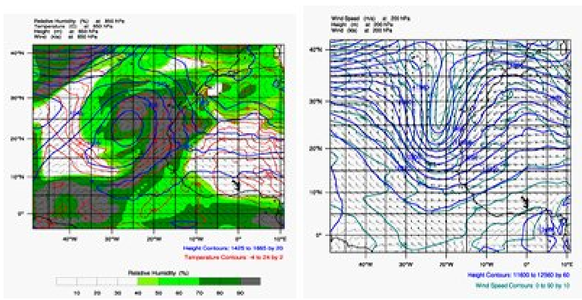


Figure 4: Wind barbs over d01 at 850 hPa, January 10 at 06Z, with shaded relative humidity in %, geopotential height blue contours and temperatures red contours in °C (left); Geopotential height and wind (kts) at 200hPa on January 10, 2002 from wrf forced by reanalysis 2(wrf_r2) (right).

At 700hPa, strong south-westerly winds of 45kts are observed over Cape Verde, Senegal and Mauritania East of the deep low. The same configuration remains at upper levels (500 and 200hPa). On the 11th the trough at 200hPa moved eastward and is located off the coast of Mauritania with north-west winds over Cape Verde turning west to south-west over Senegal. On the 12, wind at 200hPa with the northward shift of the low centered 35°N23°W became westerly with speeds of 40 to 60kts over Senegal.
When considering domain d03 at higher temporal and space resolution, the peak rainfall between 10 and 11 January 2002 fig xx abcd beter depict the structure of parameter discussed above using d01. At 850 hPa a broad band of high relative humidity of more than 90% and south-western wind are observed at all levels up to 200 hPa (figure zzc). At 200hPa a broad sub tropical jet with very strong south-westerly winds in observed.

The hovmöller plot of precipitable wáter (PW) (not show) demonstrates its time evolution from the equatorial región of the ITCZ, southwest of the domain, towards the area of confluence.

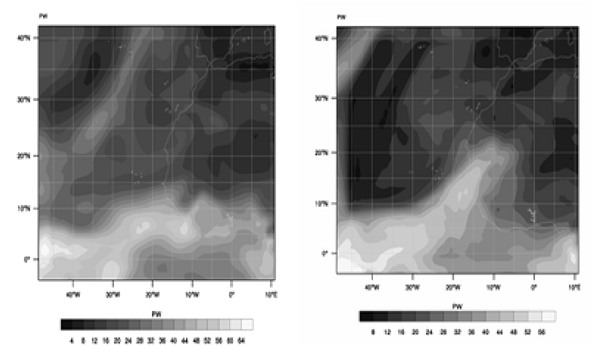


Figure 5: Precipitable water (PW) simulated by the model on the 8th (left) and January 10, 2002 (right) showing PW attracted of pushed with a south-west/North-east component.

On January 07, 2002 (figure 5), precipitable water (PW) chart shows high values between the equator and 10°N corresponding to the position of the ITCZ. At this time of the year with the retreat of the monsoon, it corresponds to the dry season over Sahel while Guinea coast region which has a bimodal regime is experiencing the first part of their bimodal regime. Another elongated band of high values of PW goes from 22°N50W to 43°N25W with a core around 45. With time the second band move southeast weakening while the ITCZ band seems attracted northward with a core reaching southern Senegal on the 8th at 1200Z . From January 9 at 12 a broad band of high PW going from southwest corner of the domain to northern Senegal/south Mauritania is observed and reached canaries islands on the 10 at 1200Z (not shown). The location of the core of maximum PW area corresponds to the area where the maximum precipitation has been recorded. On the 12 the link between the ITCZ and the lower PW over Senegal is observed. Even the cloud band is still present the rainfall stopped, showing the importance of the feeding role of the main ITCZ core.

5. Precipitation

A comparison of model output from R1 and R2 exhibit differences on the rainfall band location. Both runs are able to simulate the system with the intensity but outputs from R1 (wrf_r1) are mainly located off the coast of Senegal in domain 1, 2 and 3 (not shown). For R2 (wrf_r2) in both domains mainly d02 and d03 the inland position is closer to observed situation.

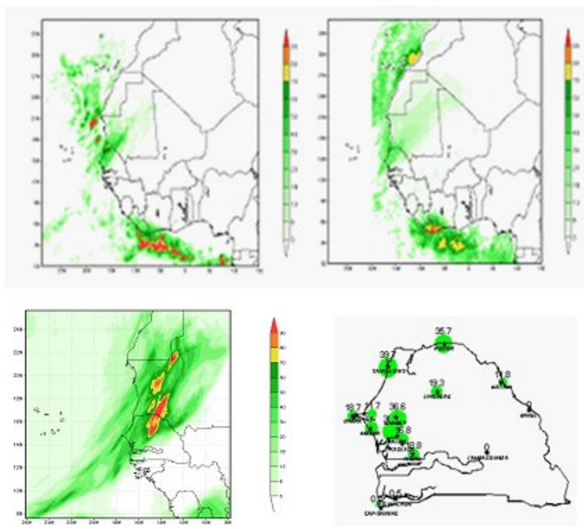


Figure 6: Rainfall from two estimated datasets ARC2 and TRMM (top panel) and WRF model domain 03 (bottom left) and rain gage observation over Senegal on January 10, 2002.

Intensity is better simulated in d02 while d03 slightly overestimates the intensity over Mauritania with reference to ARC2 and TRMM (figure 6). Care should be taken on rainfall amount validation between the different sources of information. The observed values from rain gages are from 06Z to 06Z the previous days, while here from TRMM and ARC the 24 hours is from 00Z to 24Z. We don’t have rain gages information in Mauritania to better assess the model output which seems giving more rain.
In terms of rainfall the system lasted 3 to 4 days but the cold wave a big drop of surface temperature contribute to increasing the negative impacts of the event. The official statistics reported 8 people dead, more than 100,000 bovine, 350,000 ovine, 64,000 caprine, 2,867

flooded new rice plants, 3,488 tonnes of rice production destroyed.

6. Summary and Conclusion

Western Africa Sahel, from Cape Verde to Senegal and Mauritania, experience in January 2002 an off season rain extreme event witch cause huge damages to affected countries. The statistics for Senegal are catastrophic demonstrating vulnerability to such events. To better understand the system and prospect predictability we use a modelling approach with the Weather Research and Forecast model WRF ARW force by NCEP reanalysis R1 and R2. A nesting strategy to have high resolution (10km) surrounding the targeted area, the parent domain covering a large area being at 90 km. We showed differences between wrf_r1 and wrf_r2 in reproducing the system 2 to 3 days in advance. In both domains wrf_r1 simulated the event but rainfall band was located mainly off the coast of Senegal, while for wrf_2 the simulated rainfall is closer to the observed situation over land. The analyse of large scale environment in the troposphere helped understand the role played by the ITCZ through precipitable water (PW) when attracted and/or propagated from southwest to northeast. The study shown that modelling is a forecasting tool which could help for early warning in case of extreme events to mitigate the impacts, mainly on highly vulnerable countries in Sahel region.

Acknowledgement

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