NUMERICAL SIMULATION USING WRF MODEL OF THE JANUARY 2002 OFF-SEASON EXTREME CLIMATE EVENT OVER WESTERN SAHEL

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Abstract : This study investigates fewer known features, the off-season rains occurring out of the rainy season period over Sahel and more broadly the West Africa Monsoon (WAM). The Weather and Research Forecast model (WRF ARW) 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 designed to end up with a higher horizontal resolution of 10 km (inner domain).
The model forced by reanalysis NNRPs (R1éR2) was able to reasonably well simulate the event and its intensity more than 2 days in advance, demonstrating the usefulness of such tools in a chain of early warning system (EWS) for weather hazards protection. The location of rain band was closer to the observed situation in higher resolution domains as well as the associated cold wave. 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 toward the continent.

Keywords: 4 Off-season; WRF model; monsoon; Inter tropical convergence zone.

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, from May to October north of 10°N and thus, corresponds to major agricultural activities. Over Western Sahel, rainfall occurring from late October to April over 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) among others.
This is a common feature occurring over western Sahel and affects mainly Cape Verde, Senegal and Mauritania between late October and March considered to be the dry season as opposed to the monsoon one. In most cases only light rain lasting hours below an overcast sky dominated by mid-level clouds. When the system is strong enough convective clouds giving moderate to heavy rains are observed.
Other important elements, associated with this weather type, are the cold wave and dust conditions due to the temperature drop, strong and turbulent surface winds. As they occur during a post-harvest period, they can have severe impacts of different forms on a strategic sector like agriculture and livestock.
In this study, we focus on the extreme case which occurred in January 2002 and caused tremendous damages in Senegal and Mauritania.
In section 2, we present the data and methods used. Section 3, typically focusses on mechanism before the validation of simulation results before the conclusion presented in section 4.

1. Data and Methods

1.1. Experiment design and Data

Predictability to support early warning systems of weather extreme events is essential in order to mitigate the spectrum of impacts they can cause. An international effort is done to improve model performance for various types of applications from climate to weather. The Weather Research and Forecast (WRF), a non-hydrostatic model under continuous development with two major cores, the WRF ARW (NCAR) and WRF NNM of NCEP is one of the most intensively used worldwide.
In this study, we use the (WRF ARW) using a multi nest strategy (Skamarock et al. 2008). The choice of domains should be guided by the weather phenomenon to study and then implies local knowledge of the mean climatology of the region. The model is initialized by NCEP reanalysis R1 and R2 (Kalnay et al. 1996) using their native horizontal resolution of 2.5°x2.5°. The major aim consists in assessing the ability of the WRF model to simulate the event days ahead.
The runs are initialised on January 7, 2002 at 00Z and 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. They also found the same skill in ECMWF medium range forecast in a previous study (Knippertz, 2004). This is in line with our objective in the design of an integrated early warning system of weather and climate hazards. Our method will better indicate weakness and strength in simulating the event by each forcing dataset as well as the level of accuracy with time.
We assess the performance of the different runs using observation from the National Meteorology Service of Senegal and Africa Risk Capacity (ARC) daily rainfall data at 0.1° horizontal resolution (Novella N., and W. Thiaw, 2012). The second dataset is the Tropical Rainfall Measurement Mission (TRMM), which is an also an advanced satellite estimation with respectively a spatial and temporal resolution of 0.25° and 3 hours.
Large scale environment using key variables from model outputs are analysed in order to understand the mechanism and the 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. Apart from the predictability interest, a lot of questions were raised about the intensity, the duration and the cold wave, which exacerbated the disaster.

1.2. Mechanism

Off season rains represent a typical climate interaction case between temperate and tropical regions. They are mainly due to air masses "conflict" within an area of confluence. Polar air (AP) intrusion coming through a trough, an 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 can generate rainfall with variable intensity. This structure is well represented by the WRF model outputs as shown in the map of clouds at mid-level represented in octas.

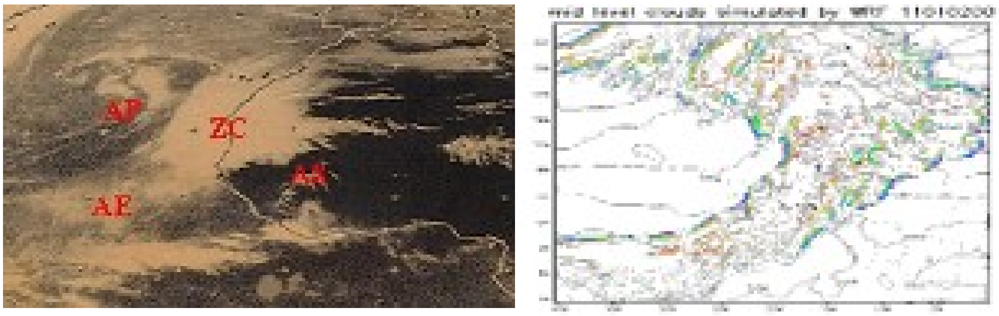

figure 1: Satellite image of an off-season case with continent in black, clouds in white with the different air masses (left) and the representation with the wrf model clouds in octas at mid-level (right) on 11th of January 2002.

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2. Results

2.1 Large scale environment

The vertical structure of the atmosphere is analysed at low, mid and high levels of the troposphere in order to better understand the genesis of this disturbance over Western Africa and moreover to identify indictors that could potentially explain the intensity of this extreme event.

The cold air from mid-Atlantic trough and reaching lower latitudes triggered the formation of a cut-off low off the coat of North-West Mauritania. On January the 7th at 00Z, the vertical structure exhibits at 850 hPa a low off the coast of northern Mauritania with an area of temperature ranging between 6-8°C with a cyclonic circulation of winds around the low and relative humidity above 90%. At 700 hPa, the low remains surrounded by strong winds with a west-southwest component and the speed reaching 35 kts. At 500 and 200 hPa (not shown) the low located south of Canary Islands directs strong westerlies over Western parts of Mauritania and Senegal. On the 8th, the low at 850 hPa extends a southwest trough toward Northern Cape Verde Islands with winds shifting slightly west-southwest up to 500 hPa. At 200hPA the sub-tropical jet with a western component has speeds reaching 90 kts over Senegal (not shown).

On the 9th, the low is deeper at all level with high values of relative humidity at 850 hPa and winds having a southwest component even at 200hPa. The low centered now 23°N26°W deepen again on the 10th of January, and exhibit a large band of relative humidity between 80 and 100% from the Equator to Canary Islands (Figure 2).

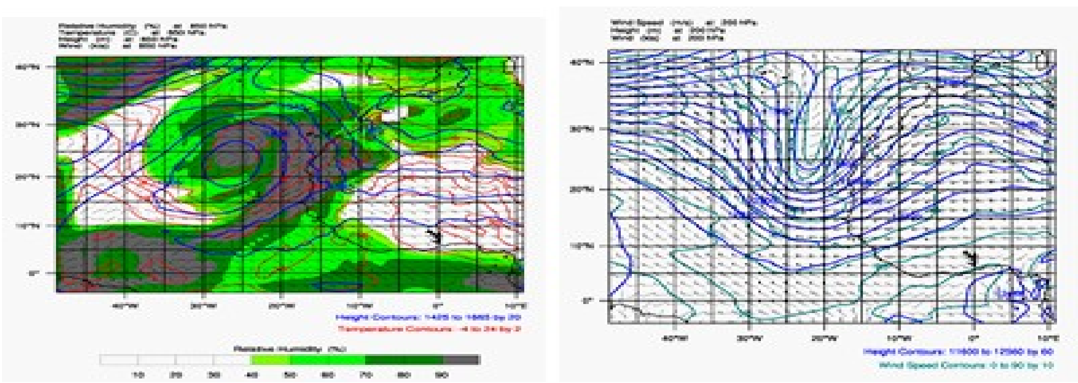

figure 2: Wind barbs from d01 at 850 hPa, January 10 at 06Z, with shaded relative humidity in %, geopotential height blue contours and temperatures red contours in °C (left); Geopotential height and wind (kts) at 200hPa on January 10, 2002 from wrf forced by reanalysis 2(wrf_r2)(right).

On January 07th 2002, when looking at precipitable water (PW), the map exhibits high values between the equator and 10°N corresponding to the position of the ITCZ at this time of the year in agreement with the normal retreat of the monsoon, corresponding to the dry season over Sahel. Another elongated band of high values of PW goes from 22°N50W to 43°N25W. With time, the second band moves southeast weakening while the ITCZ band seems attracted northward with a core reaching southern Senegal on the 8th at 1200Z. From January 9 at 12Z (Figure 3) a broad band of high PW going from the southwest corner of the domain to northern Senegal/southern Mauritania is observed and reached Canarias Islands on the 10th at 12Z (not shown). The location of the core of maximum PW area corresponds to the area where the maximum precipitation has been recorded over land. On the 12th the link between the ITCZ and the lower PW over Senegal is observed. Even the cloud band is still visible the rainfall stopped, showing the importance of the feeding mechanism from the main ITCZ core attraction.

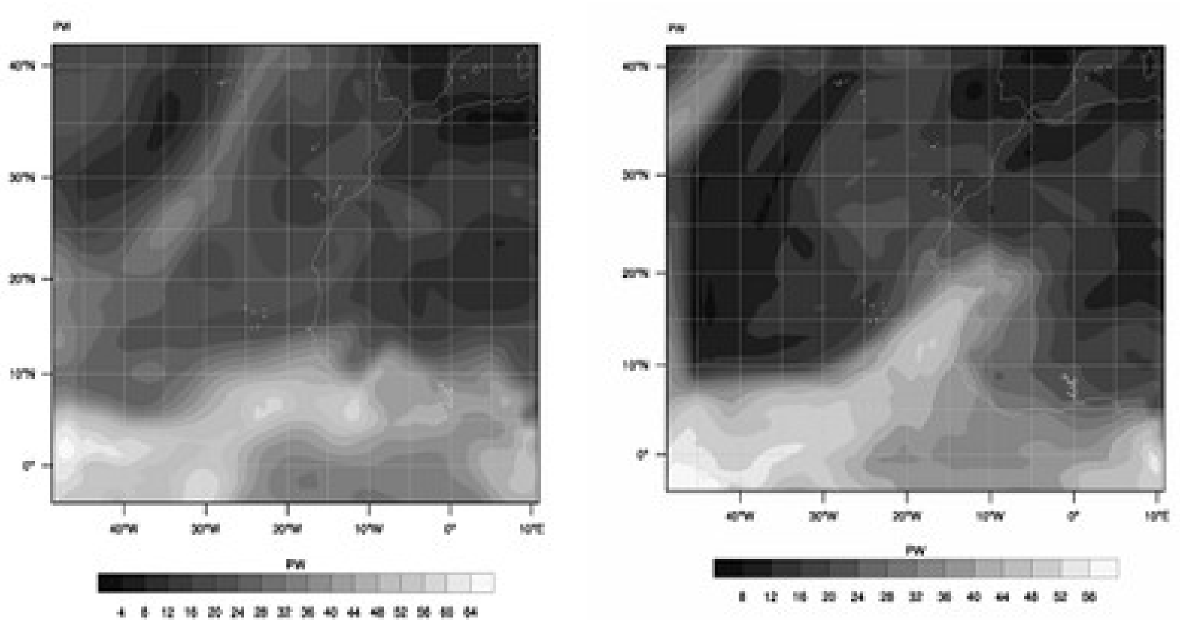

figure 3: Precipitable water (PW) simulated by the model on the 8th (left) and January 10, 2002 (right) showing PW attracted and advected from the Equator towards Senegal and Southern Mauritania. of pushed with a south-west/North-east component.

2.2 Precipitation

A comparison of model output fromwrf_r1 and wrf_r2 highlights the differences on the rainfall band location. Both runs are able to simulate the system and intensity but outputs from R1 (wrf_r1) are mainly located off the coast of Senegal in domains 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.

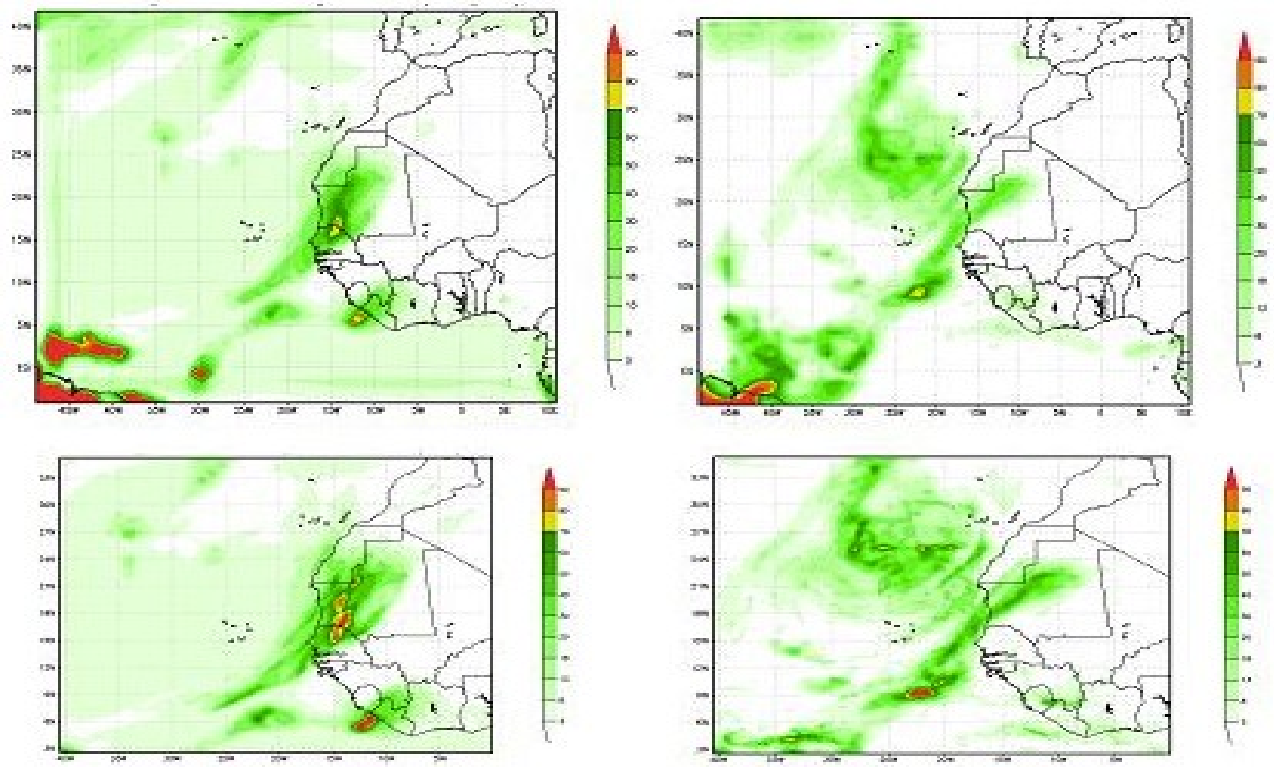

figure 4: Rainfall simulated by wrf_r1 domains 01 and 02 (left panel) and wrf°r2 (right panel) on January 10, 2002.

The Intensity is better simulated in d02 while d03 slightly overestimates it over Mauritania when compared to the satellite estimate datasets ARC2 and TRMM (not shown). A station in northern Senegal Podor recorded more than 100mm in 3 days from the reports from Senegal Met Service (not shown).
In terms of precipitation the system lasted 3 to 4 days withn the maximum amount observed on the 10th. The event was combined with a cold wave due to a big drop in surface temperature, almost constant around 18°C contrasting with business-as-usual temperature in this region with a wide diurnal amplitude with a maximum reaching above 35°C in this period of the year. The hazard caused unprecedent environmental damages on agriculture and livestock with a high death toll. Additional indication from the sounding of Dakar (not) shown clearly indicated the sharp change in the troposphere during the event.

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.

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