Role of Coastal Topography in Pre-Tropical Cyclone Disturbance Formation

Dean Pryles, Jenni Evans, Jose D. Fuentes, Holly Hamilton

Abstract:

Mesoscale Convective Systems (MCSs) are the primary source of rainfall in the Sahel region of West Africa. These MCSs may strengthen over the ocean and transition into tropical cyclones. MCSs in this region are associated with the inland intrusion of southwesterly monsoon winds during late summer and early fall. MCS formation is observed in the convergence zone between this moist, monsoonal flow and the easterly winds inland.

We hypothesize that the mountains to the south of Senegal, in Guinea, Sierra Leone, and Liberia have a modulating influence on MCS development in this region. A secondary topographic element of importance is the highlands just northeast of Senegal in Mauritania.

In late August 2006, a MCS developed over West Africa. It transitioned from land to ocean on 31 August, and days later became a tropical cyclone, eventually strengthening into Hurricane Florence. We use a series of idealized sensitivity studies to examine the influence of the topography on the initiation and development of the pre-Florence MCS using the Weather Research and Forecasting (WRF) model.

Introduction:

The Weather Research and Forecasting (WRF) model was used to look at a Mesoscale Convective System (MCS) moving off the coast of Senegal on 31 August 2006. This MCS merged with another tropical wave and formed a tropical cyclone which later became Hurricane Florence. Hurricane Florence was a long-lived tropical cyclone that began as a tropical wave, strengthened to hurricane status, and transitioned to an extratropical system that ran along the coast of Nova Scotia and towards Greenland.

The main focus of this research is to investigate the influence that the topography has on the storms in the monsoon region of West Africa. The Sahel region located just south of the Sahara, ranging from northern Burkina Faso, through southern Mali, to the coast of Senegal, gets the majority of its yearly rainfall in the late summer to early fall. The West African monsoon causes the rain. It blows warm moist air onshore from Guinea to Ivory Coast, which then interacts with the easterlies and allows for MCS development. If the thermodynamic conditions allow it, these MCS's can continue over the Atlantic Ocean and intensity to become tropical cyclones.

Methods:

Version 3.5 of WRF was configured and compiled using the PGI compiler with gcc. Version 3.4 of WPS was configured and compiled using the PGI compiler, with no GRIB2. National Centers for Environmental Prediction (NCEP) Final Analysis (FNL) global data were used as input for the model, which was configured to run and simulate the atmospheric conditions. The FNL has 1° by 1° grid resolution globally. The FNL is used to input terrestrial data, as well as the meteorological data at 27 vertical levels in the atmosphere.

The model was run on two domains. The inner domain is nested in the larger domain. The larger domain (D1) extends from 32° W to 2° E longitude, and 3° S to 25° N latitude. D1 has a grid size of 15 kilometers and has 240 by 200 gridpoints. Its inner domain (D2) has a grid size of 5 kilometers with 226 by 256 gridpoints, and includes the domain from 22° W to 11° W longitude and 6° N to 18° N latitude. Figure a1 shows D1, along with the terrain height as calculated by WRF. Figure 1b is showing D2, with its WRF calculated terrain height, as well.

The model was run from 0000UTC on 27 August 2006 until 0000UTC on 2 September 2006. The run totaled 6 days and each time step was 90 seconds for D1 and 30 seconds for D2. WRF was used to recreate the storm and compare it with the topography zeroed throughout the whole domain. The run with the topography zeroed will be called FLAT and the run with the topography will be called TOPO. The key reason for choosing this starting time was that it would be long enough for the mountains in Sierra Leone, Liberia, and Guinea to affect the run with zeroed topography. The idea is that since the FLAT run will not be getting the orographic ascent, descent, and flow around those mountains, it will have a different result than TOPO.

The FNL data were input at the first time step and the WRF model created hourly outputs for the 144 hours of simulations. Comparisons were made between the FNL data and the WRF model outputs to make sure that it was not deviating too significantly. Changes needed to be made to the parameterizations of the model in namelist.input to best simulate the storm and show all variables needed to fully investigate the storm. The microphysics are set on the WRF

Single-Moment 5-class scheme (Hong, Dudhia and Chen 2004), which allows for ice, snow, and mixed-phase processes and super-cooled water. The radiation parameterizations are set on MM5 shortwave (Grell, Dudhia, Chauffer 1994) and Rapid Radiative Transfer Model longwave scheme (Mlawer et al 1997). The boundary layer physics are set on the Yonsei University Boundary Layer scheme (Hong and Kim 2008). The surface layer physics are set on Monin-Obukhov similarity theory (Monin and Obukhov 1954). The surface land/ocean parameter is set on the Noah Land Surface Model (NCAR). The cumulus parameter is set on the New Kain-Fritsch scheme (Kain and Fritsch 1993) for the larger domain and turned off for the inner domain. Radar reflectivity was turned on for both domains. Once convinced the model was performing properly with these parameterizations on the TOPO run, the model was run again with the topography set to zero everywhere, FLAT.

Results:

The storm of interest is an MCS that passes through Dakar, Senegal at 0600UTC on 31 August. This system has very different structure and strength when looking at the runs with (TOPO) and without (FLAT) topography. In TOPO, it appears to have formed a very distinct squall line separate from another bulk of convection (Figure 2a,2c). In FLAT, the convection centered over Sierra Leone and Guinea is not separated from the MCS (Figure 2b,2d). The FLAT run results in a large area of convection all south of the observed MCS and does not capture the MCS development, beginning from near Kayes, Mali (Figure 2b,2d).

The radar reflectivity in TOPO (Figure 2a,2c) is very similar to operational radar from the day of the storm (Delonge 2010). The timing of the MCS in TOPO is later than observed by the radar: the distinct squall line passes through Dakar at 0600UTC on the WRF run, but at 0800UTC according to the radar. This two hour separation is a good result given that the run began over 100 hours before this time. The radar has the storm coming from about 75°(ENE) and the TOPO run has it moving in from due East (~85-90°).

In the FLAT run, the African Easterly Jet (AEJ) appears to be stronger (max ~35 m/s) and broader than the AEJ in the TOPO run (Figure 3). It is causing more vertical shearing of the wind, killing the convection of the squall line. At the place where convection initiates in the TOPO run, there is a minimum in wind speed at 700 hPa (Figure 3a,3c). This region of low wind speeds is collocated with the MCS at this time then moves with the storm (Figure 3a,3c); this is not seen in the FLAT case (Figure 3b,3d). This location of minimal wind is being advected by high wind speeds right behind it. These results at 700 hPa tell us that the AEJ could be a reason that the FLAT case is not able to develop the squall line. The squall line is not evident at 700 hPa in the FLAT case but is very evident at 700 hPa in the TOPO case.

Examination of the TOPO run at 950 hPa reveals that there are strong 20+ m/s easterlies advecting the storm westward. This strong flow driving the squall line is met with convergent, moist air associated with the Monsoon flow coming from the west. In the FLAT run there is a much different result: the moist air from the Monsoon flow coming from the west is met with a dry flow of air from the northwest and is diverted to the southeast toward the mountainous area that this run is oblivious to. The convergence of these two boundary layer air masses is coincident with a large region of organized convection to the southeast of Dakar (Figure 2b,2d, and Figure 4b).

Conclusion:

The topography of West Africa has a direct effect on MCS development. They not only change the path of the system, but completely change its structure and intensity. The result of the FLAT run does not indicate formation of a squall line. Thus making it very different than the TOPO run and what is observed by radar. Both the TOPO run and the observational radar (Delonge 2010) indicate a substantial squall line of convection traveled through the city of Dakar, Senegal on 31 August 2006. This lack of squall line formation shows that the mountains over Guinea, Sierra Leone, and Liberia play a key part in the initialization of MCSs in West Africa. Without the influence of the mountain range to the south of Senegal, the monsoon flow and easterly flow would not interact in the same way, thus decreasing the likelihood of MCS development in the area.

Acknowledgements:

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Figures:

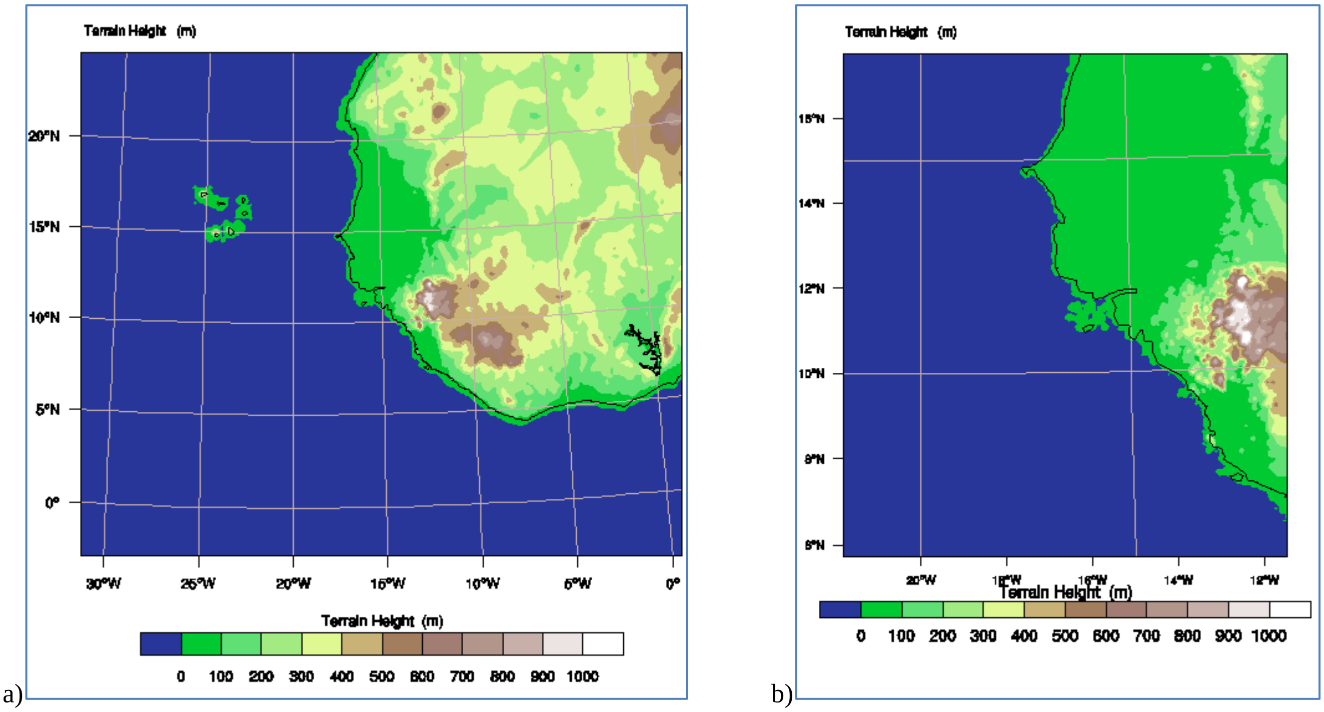

Figure 1: Large (15 km resolution) and nested (5 km resolution) WRF domains uses in this study. The WRF model terrain heights are plotted in meters.

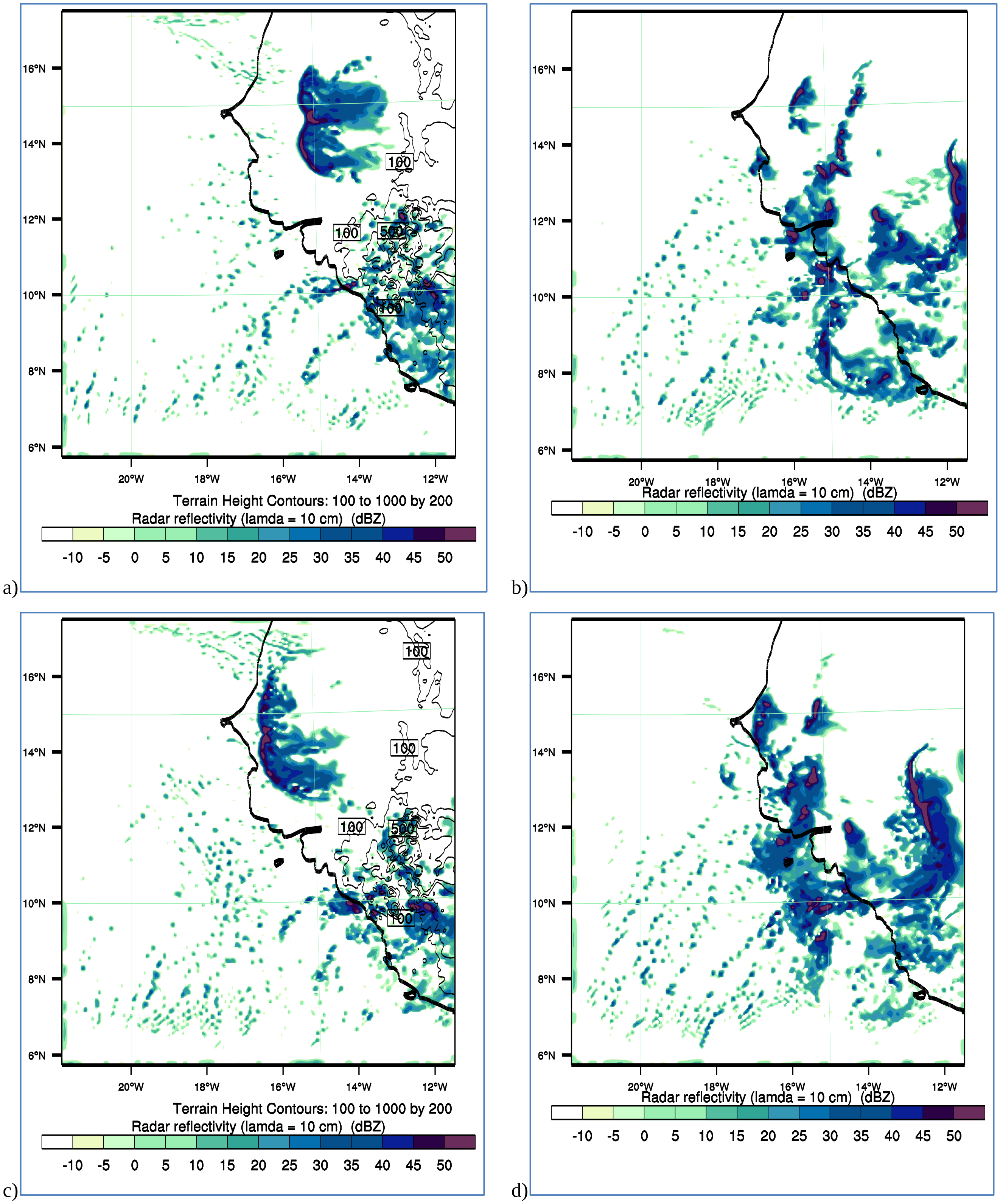

Figure 2: Radar Reflectivity (λ=10cm,dBZ) and topography (m, contours) over the nested WRF domain. The TOPO run in 2a and 2c, and FLAT run in 2b and 2d. Valid on 31/08/2006 at 0200 UTC(2a,b) and 0400 UTC(2c,d).

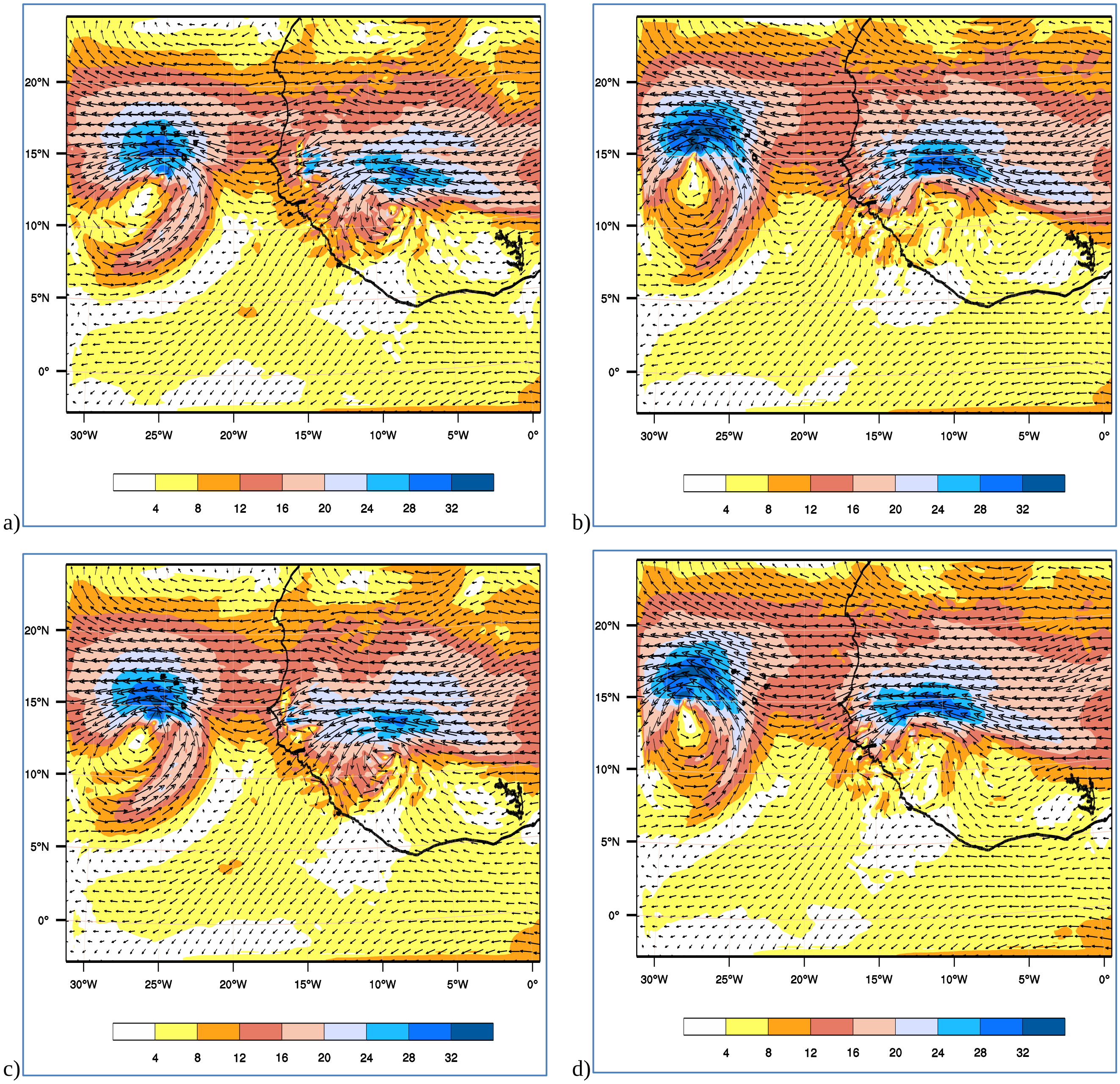

Figure 3: Wind speed (m s-1, contours) and wind vectors at 700 hPa over the large WRF domain. Model was initialized at 27 August at 0000UTC and are plotted on 31 August at 0200 UTC and 0400 UTC. The TOPO run in 3a and 3c and FLAT run in 3b and 3d.

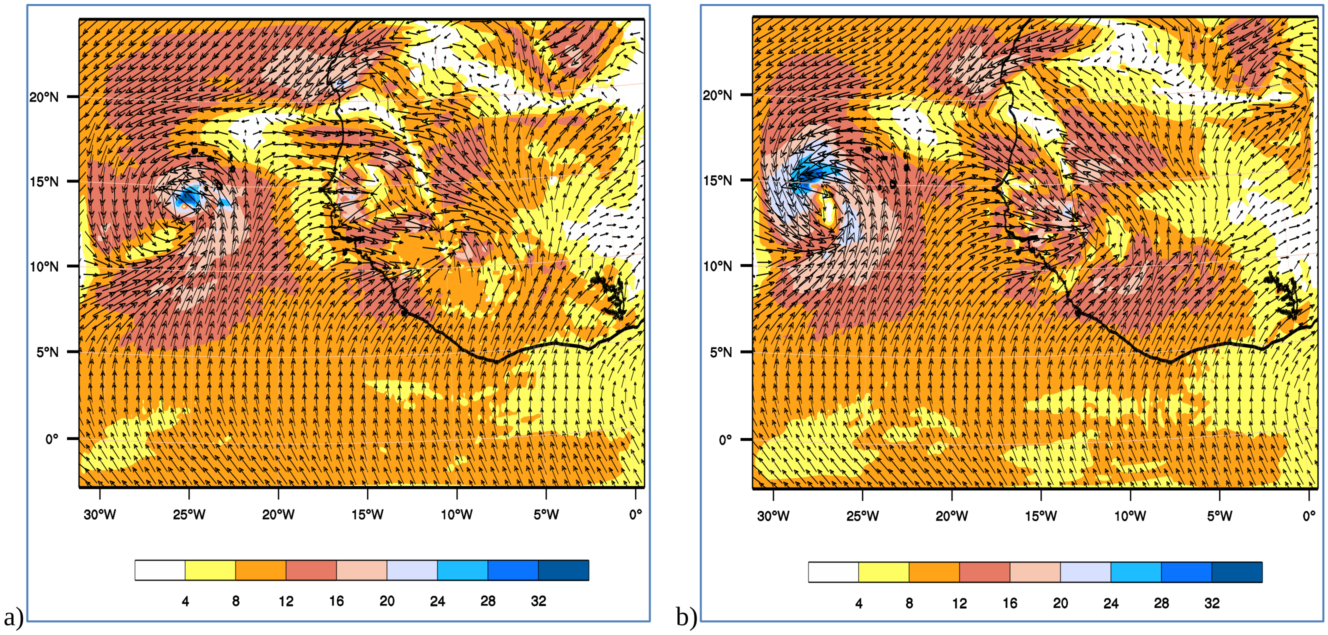

Figure 4: Wind speed (m s-1, contours) and wind vectors at 950 hPa over the large WRF domain over nested WRF domain. Model was initialized at 27 August at 0000UTC and is plotted 31 August at 0400UTC. The TOPO run in 4a and FLAT run in 4b.