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CHARACTERIZATION OF THE ATMOSPHERE TO THE PASSAGE OF SQUALL LINES AT DAKAR FROM 1968 TO 2006

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ABSTRACT

By performing a composite analysis of the vertical profile of humidity, temperature and wind on the basis of radiosounding data and rain gauge Dakar Yoff (Senegal) at 14 ° 44 N and 17 ° 30 W, in the period 1968-2006, we studied exchanges water, heat and momentum within the squall line (SL) and between it and its immediate environment. A similar analysis has been performed with the re-analysis of NCEP / NCAR for the period 1981-1995 for the specific humidity at a grid point near Dakar (15° N and 17 ° 30 W). A statistical study of clouds and rain, combined with the composite analysis of moisture profile showed that the precipitations generated by the squall line (SL) are mainly from the convective part. With less than ten hours before the passage of the squall line, there is an increase in relative humidity in the lower layers of the atmosphere. The passage of this, the humidity is maximum in the layer 700-600 hPa. After its passage, humidity decreases gradually in the lower and middle layers. Analysis of the results obtained on the basic parameters of the data with NCEP / NCAR shows that the vertical distribution of the atmosphere is disturbed at the passage of a SL; the composite analysis yielded 48 temporal classes.

The state of the atmosphere during the 24 hours preceding the passage of SL is characterized by:

- A net warming at 700hPa up to 6 hours before;
- A significant crowding in the layer 850-700 hPa up to 13 hours before;
- A west wind at 925 hPa between 10 and 5 hours before;
- An increase in wind speed at 700hPa up to 15 hours before. During the passage of SL, the characteristics of the atmosphere are:
- A strong cooling in the layer located below 600hPa;
- A noticeable humidification in the layer 850-700hPa;
- A strong east wind at 700 hPa between 4 hours and 9 hours later.

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INTRODUCTION

Squall lines (SL) incorrectly referred to as tornadoes occur in the boreal summer in the Sahel from east to west. They generally weaken gradually, reaching the coast of West Africa (Aspliden, 1976). The disturbances are SL convective rainfall. They are as a juxtaposition of grains formed in cumulonimbus (Cb) along a north-south line.

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A low pressure in front of the SL followed by deep Monsoon, are the conditions governing its organization on a large scale (Desbois, 1988), although local conditions (high air temperature, high relative humidity level soil and a relatively calm wind) that promote the development of convection are needed (Pujol, 2011), are the conditions governing its large-scale organization (Desbois, 1988), even if local conditions that favor the development of convection are required (Pujol, 2011). On satellite imagery, the SL looks like cloud mass whose western edge is sharp and convex, the eastern edge is more diffuse. Its north-south extent is generally between 300

and 800 km, but can reach 1500 km (John Rozbicki and George Young, 2012). Studies of (Bryan, 2012), showed 75% of rainfall in the Sahel area come from SL precipitation. In this climate zone the people draw their from subsistence agro-pastoral activities. This phenomenon of primary importance was the subject of numerous studies, primarily descriptive and dynamic (Lothon, 2011 and Gaye, 2005). Here we describe the vertical water structure of the atmosphere before, during and after the passage of SL. We tried to explain the transfer of water masses in the SL and between it and its immediate environment. By a composite method of analysis, we determine the average vertical profiles of moisture and the temporal structure of rain associated to 334 SL, radio soundings of Dakar from 1968 to 2006 helped highlight the features of the SL water. Then we present the composite analysis, the results for a two-hour class time using radio sounding and a finer scale (amplitude of one hour) analysis using the re-analyses of NCEP from NCAR. This climatological study over several years of meteorological parameters of this climate zone is a boon available to operational forecasters West African meteorology and researchers from the world of atmospheric physics.

MATERIALS AND METHODS

The theoretical support of the study is the composite analysis. This method has been used by (Reed, 1977) and (Burpee, 1976) and by many other authors to study the structure of easterly waves. The spatial division of the phenomenon into categories can adapt a template for each event and average these events and, even though their dimensions are different. If the phenomenon we are trying to describe has a physical reality, the results of all averages taken show the weather have a coherent structure. This method is well suited to the phenomena. We adapted this technique for the characterization of SL from setting water like several other authors (Diop, 1995), to study the energy exchange in the SL from the radiosounding of Dakar, (http://www.crh.noaa.gov/sgf/?n=spotter_squall_lines#Squall%20Line%20), to highlight the characteristics of the SL phenomenon approaching the coast of West Africa from the analysis of the European Centre for Medium-Range Weather Forecasts (ECMWF). (Gaye, 2005), using GATE data on the Atlantic, gave a detailed overview of the structure, dynamics and life cycle of an SL and (Arnault, 2011) from two surveys launched in Korhogo in Ivory Coast has studied the vertical structure of the atmosphere before and after the passage of SL experience Deep Tropical Convection (COPT 81).

Description of the classes in the composite analysis

Using soundings launched between 1968 and 2006 at Dakar we have proceeded to a climatological study of the meteorological parameters (Absolute temperature, Wind speed, Wind direction, Relative Humidity) at the passage of SLs. During this period, we have two radio soundings per day, launched at 1200 TU and 0000TU. After selecting 15 pressure levels (ground, 1000, 950, 900, 850, 800, 750, 700, 650, 600, 500, 400, 300, 200, 100hPa), we performed a composite analysis by regrouping all radio-soundings in different temporal of 2-hours each, for the whole 38 years of data and at all levels. 24 hours for meteorological parameters are divided into 13 categories (class time). Classes (Figure 1) before the passage of the SL are then: 2 hours (2 hours before), -4 hours (4 hours before), 6 hours (6 hours before), -8 hours (8 hours

before), -10 hours (10 hours before), -12 hours (12 hours before). The zero hour class corresponds to the passage of SL, which coincides with radio sounding. Note that in reality, the time of wind shift (which marks the arrival of SLs) is chosen as the origin of the referenced dates (Figure 1). The passages in the wake of SL are then: 2 hours (2 hours after), 4 hours (4 hours after), 6 hours (6 hours after), 8 hours (8 hours after), 10 hours (10 after), 12 hours (12 hours after). For class i hours before the passage ($i = 2, 4, 6, 8, 10, 12$), we put all radiosoundings assigned in the time interval between $i+1$ and $i-1$ hour before the passage of the SL. For class j hours after passage ($j = 2, 4, 6, 8, 9, 10, 12$), we put all radiosoundings assigned in the time interval between $j+1$ and $j-1$ hour after the passage of the SL.

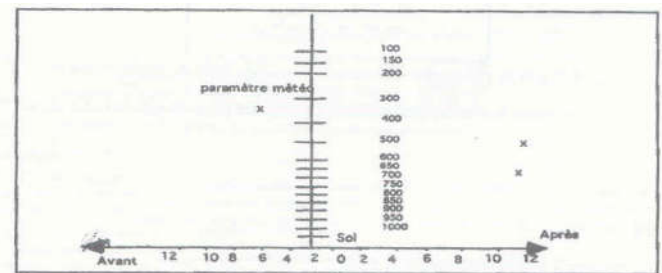


Figure 1. Marking associated with the squall line

Validity of the method: The structure of the parameters obtained by this analysis in Figure 2 are in good agreement with the results of numerical simulation and the radar given by (Lafore, 2010). In comparing these two results we find that we have qualitatively similar profiles Figure 2, 3, 4 and 5.

RESULTS-INTERPRETATION

We identified 334 passages of SL and examined the profiles of the mean parameters of the atmosphere from the radiosounding associated with them. To study the water exchange of the atmosphere under the influence of SL, we used the relative humidity derived from radiosounding, cloud cover and rainfall data obtained from the observation notebook and monthly climatological table of the Directorate of Meteorology of Senegal. These data are combined with SL. We compared the results of the specific humidity soundings from a grid point of NCEP / NCAR near Dakar.

Relative Humidity at the ground

Figure (2c) shows that pre-ground atmospheric SL reveals a humidity with a peak slightly above 86%. It becomes more humid and between 0 hour 4 hours after wind shift associated with the LG, with values of 86-88%. The atmosphere returns to its minimum well after the transition to 10 hours with a relative humidity of about 78%. Ground relative humidity is important after the wind shift, especially in class 2 hours and 4 hours later. The evolution of the moisture is out of phase with that of the temperature state in Figure 2b.

Relative humidity in altitude

Figure 6 shows that at the time of passage of the SL there is a more humid atmosphere in very low levels (1000-800hPa) compared with the summer average. In contrast atmosphere is less between 800 and 750hPa. At other levels, the two profiles are almost the same pace.

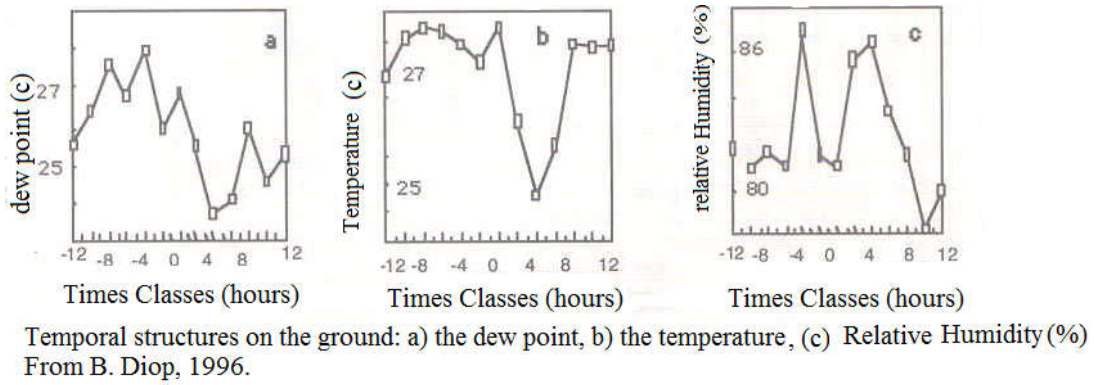


Figure 2. Temporal Patterns: dew point, temperature b), relative humidity, cloud cover d)

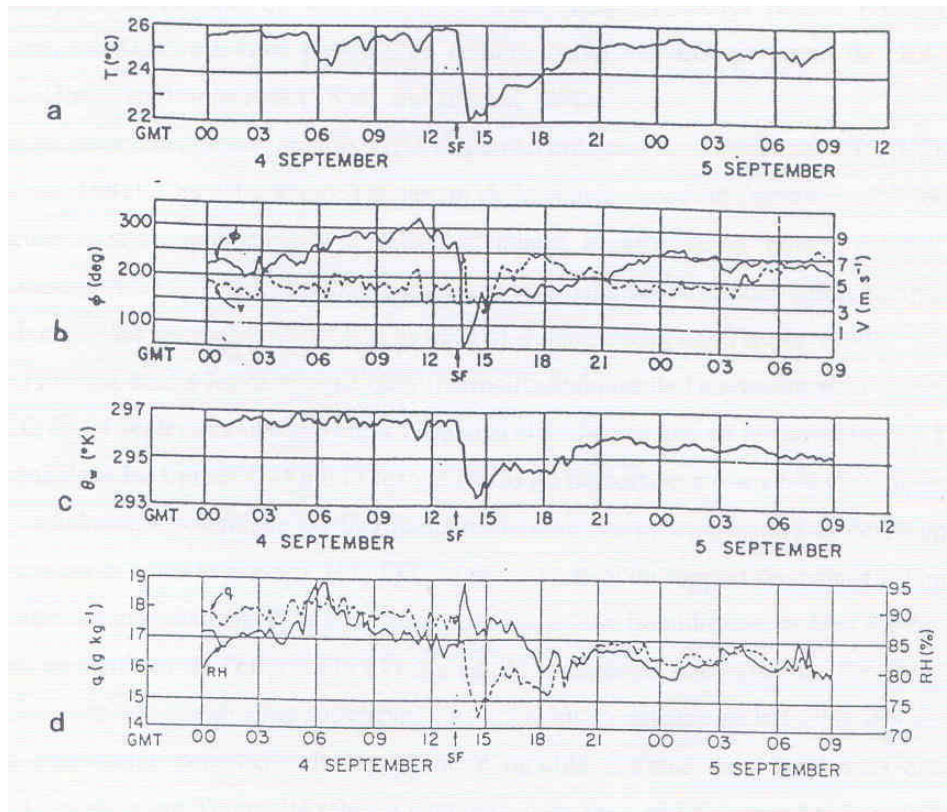


Figure 3. Temporal variations in space: a) temperature ($^{\circ}\text{C}$), b) wind direction (m/s), c) the pseudo adiabatic temperature wet bulb potential (K) and d) specific humidity (g/kg) and relative (%) during the GATE experiment. SF indicates the time of passage of the front of the SL (Gaye, 2005)

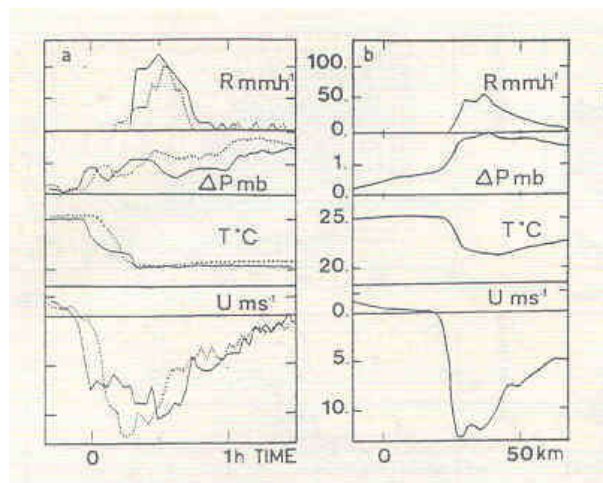


Figure 4. Comparison of surface parameters observed (a) and simulated (b) of a squall line COPT81. Reprinted from (Redelsperger, 1988)

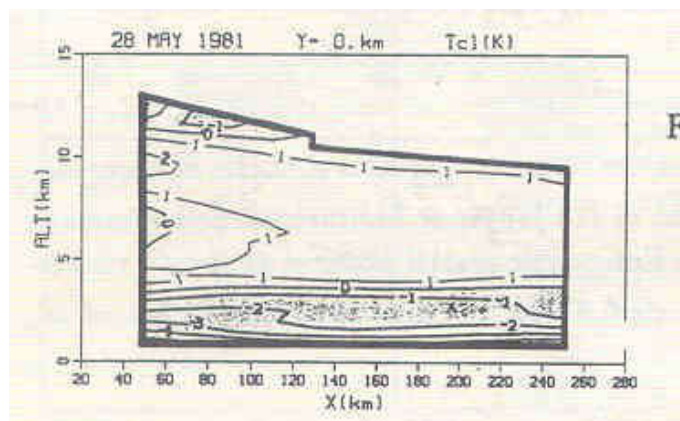


Figure 5. Crossvertical temperature perturbation, inferred from radar observations of a squall line

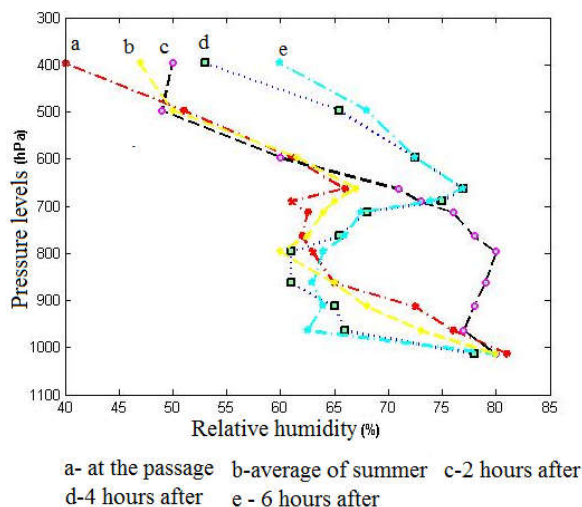


Figure 6. Profile of differences in the relative humidity of the class compared to the average summer

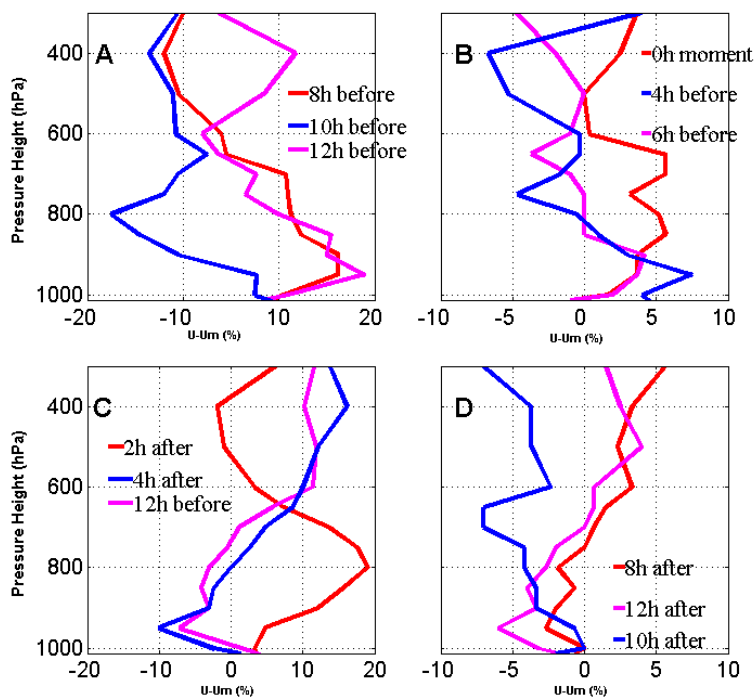


Figure 7. Profiles of relative humidity differences before and after the passage of SL

When the wind shift we find the average summer profile (Figure 6). Layer (1000-700 hPa) of the atmosphere of the class 2 hours after the wind shift is wetter than any other. Between 800 and 700hPa class two hours later, was a reduction in moisture so there was a 700-300hPa

humidification of the class after 4 hours. Between 4 hours and 6 hours after the wind shift, the humidity is higher in the 750-300hPa layer (at least between 4:00 and 2:00 for the same layer). One note that at the very moment of the wind shift the relative humidity of the air has not changed much compared to

the average summer. From the viewpoint of the configuration is found, the one proposed by (Lothon, 2011) and (Gaye, 2005) and we meet in the figures of (Arnault, 2011), given by the radar Dakar-Yoff in Senegal. Long before the SL (12 before) (Figure 7a) there was drying atmosphere compared to the average summer. This phenomenon is very pronounced between 800 and 750hPa. At the approach of SL (Figure 7b), there is a humidification of the atmosphere, which strengthens the layers between 1000 hPa and 800hPa, while in the lower layers drying continues. Up to 2 hours after the wind shift, the layer 1000-800hPa is very moist with a humidifier by about 10% of about half of the absolute value of the drying in the layer 800-750hPa class 4 hours later. Between 8 hours and 12 hours after the wind shift a drying is noted with regard to the summer average in the very low levels (1000-850hPa) and moistening between 750 and 400hPa (Figure 7c). Figure 7d shows that in class 12 hours after the wind shift there is a vertical structure of humidity similar to the pace of the class 12 hours before the passage of SL. The study of the interest to SL humidity and rainfall associated with it, requires a large-scale analysis. The lack of correlation between water vapor generated over oceans and continents available above, lead us to investigate the causes of these variations in the humidity of the atmosphere in the advection (<http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/svr/type/mline/sat.rxml>). The flux of water vapor of interest to rain have been the subject of several studies (Defelice, 1990 and Barthe, 2011 and Druyan Leonard, 2011). The advection of water is essential for SL, which makes us say that most of the transport come from the East and is carried through the AEJ and TEJ.

The rainfall associated with squall lines

Their measurements constitutes a basis for prediction and validation of forecasting model. The high variability of rainfall associated with the rainfall does not prevent us from having information on the distribution according to the different classes of temporal SL. The rainfall data that we analyzed are from the notebooks of observations of the direction of the meteorology of Dakar. They are associated with changes in the SL station Dakar-Yoff (Gooy). Figure 8 shows that most of the precipitation comes from convective SL and is concentrated in the convective part consisting of vigorous deep convective cells. The convective part of the SL takes about 2 hours on average. In this figure 8, we see that the largest cloud cover is late in relation to the convective rain.

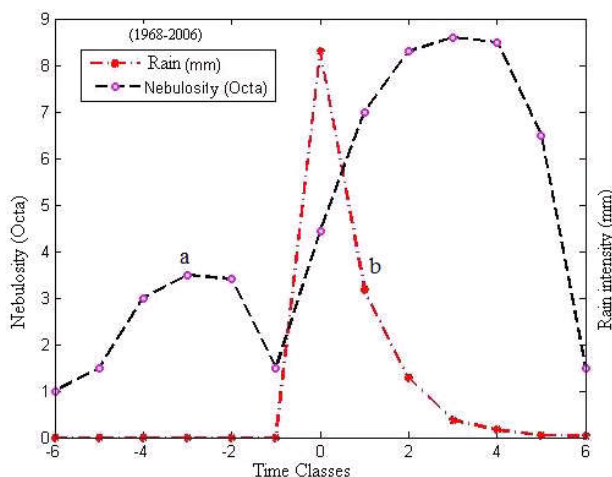


Figure 8. A mean cloud cover before, during and after the passage of the SL. brain associated with the average SL

Aspects dynamic and thermal

To study the dynamic and heat transfer in the atmosphere under the influence of a squall line, we use the wind and temperature.

Wind

To address the dynamic aspect, we use the strength and direction of the wind. The average wind speed in each class is broken down into its zonal and meridian component. The observed zonal wind marked u is given by the expression 3.1:

$$u = \text{ff} \cos((\arctan(1)/180)(270 - 10\text{dd})$$

That of the meridian wind v is given by:

$$v = ((\text{ff})^2 - u^2)^{1/2}$$

Where ff is the wind, dd the direction given by the rose 36.

Expressions 3.3, 3.4, 3.5 show the calculations that have allowed to get the statistical values.

$$\text{Average : } \bar{\text{ff}} = \frac{1}{n} \sum_{i=1}^n \text{ff}_i$$

$$\text{Variance : } \sigma^2_{\text{ff}} = \frac{1}{n} \sum_{i=1}^n (\text{ff}_i - \bar{\text{ff}})^2$$

$$\text{Standard deviation: } \sigma_{\text{ff}} = \sqrt{\frac{1}{n} \sum_{i=1}^n (\text{ff}_i - \bar{\text{ff}})^2}$$

Here n=338.

Squall lines that we studied during the period 1968 - 2006 had the average dynamic characteristics. Recorded in Table 1. In this study period, we determine the average length of the wind shift, the average wind speed on the ground and the mean wind direction in the soil (Table 1). The results show that the disturbances are actually SL. The study of this dynamic aspect continued in altitude

Table 1. Statistics on the ground dynamic parameters as sociated with the passage of LG

Statistic	Duration of the wind shift	speed	Direction
average	12,5 min	13 m / s	10°
variance	5(min) ²	4(m/s) ²	(4°) ²

Figure 9 shows the meridian component of the wind is southwest and whose value is quite high before the passage of the SL, while the zonal component is small and positive. At the time of passage of the SL, there is a wind shift with significant zonal component. Six hours after the wind shift, there is still the zonal component of the East. Figures 10 and 11 show that in about five hours after the wind shift, wind strength decreases with altitude. In addition, there is between 750 and 700hPa, the prevailing winds from east to 13 m / s which would correspond to the presence of the AEJ (African Easterly Jet), between 200 and 100hPa winds up to 20 m / s, especially in the class "2 hours after "correspond to the TEJ (Tropical Easterly Jet). In the lower layers, the prevailing winds of 5m / s oriented southwest indicate the monsoon flow.

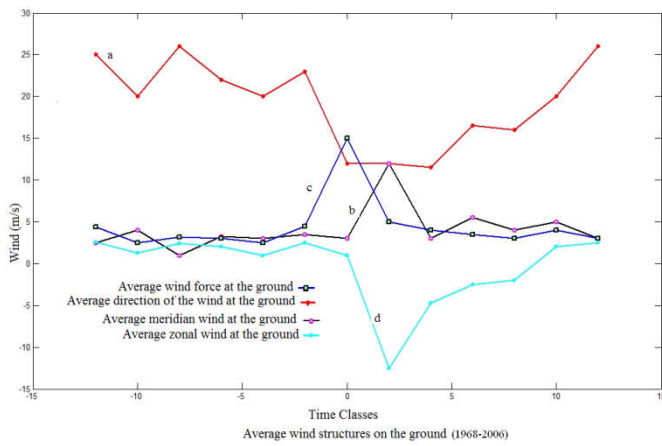


Figure 9. Meantime profiles at the ground: Direction a) meridian wind b) wind speed c) zonal wind d)

As we approach the SL fluctuations become more important between 600 and 200hPa (Figure 11b). We find the normal upright configuration more than 6 hours before and after the wind shift.

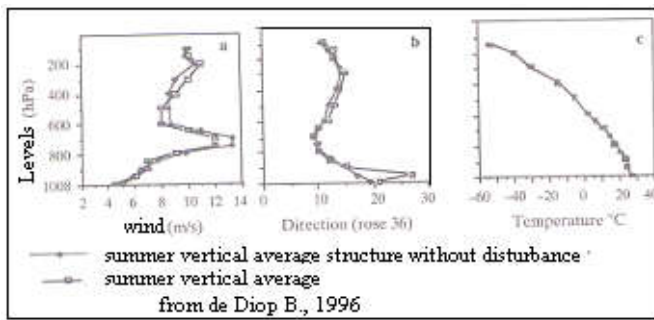


Figure 10. Profiles of wind speed, direction and temperature as a function of altitude

The atmosphere seems more dynamically disturbed less than 6 hours after the LG as shown by the irregularity of the curves in Figure 11c. The difference between the class structures midnight and 2 hours is about 3 m / s. The vertical profile of wind direction (Figure 10c) indicates a east wind between 700 and 650hPa (flows east) and a west wind between 1000 and 800hPa (the monsoon).

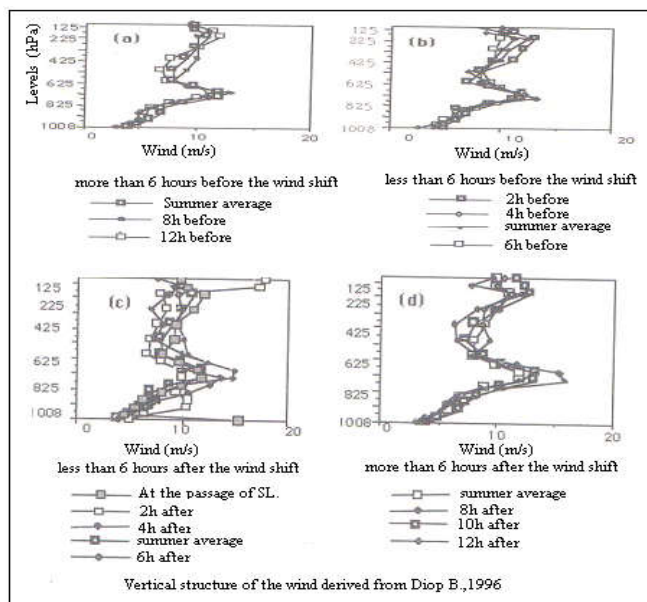


Figure 11. Profiles of the wind passing SL

The meridian component is greater in the lower levels between 850 and 750 and the ground two hours after the wind shift. More than 6 hours after the passage of the SL, the atmosphere seems to return to normal summer. On the other hand, we note a rotation of the wind from west to east with the approach of SL during the transition there is a strong wind between 800 and 750 which coincide with a radiative heating (Heinrich Gustav Magnus-Tetens, 2011). Figure 10 a,b shows the presence of a prevailing wind from the southwest to the ground and in the lower layers. At altitude, between 800 and 600hPa winds are stronger (12m / s on average) above this layer there are more light winds. Figure 11c shows that of the vertical structure of the middle atmosphere in summer is almost identical to the average vertical structure of the atmosphere without the disturbance (the one where we exclude situations involving atmospheres disruption) ; it remains unchanged until the arrival of the squall lines. The remainder of this paper is made from the climatological mean summer (including disturbed situations).

Aspect heat

The temperature is directly given by the radiosounding. The dew point Td is obtained with Heinrich Gustav Magnus-Tetens Formula (Heinrich Gustav Magnus-Tetens, 2011).

Range of validity:

- T measured temperature: 0 ° C < T < 60 ° C
- Relative humidity RH: 0.01 (1%) < RH < 100 (100%)
- Td Dew point: 0 ° C < Td < 50 ° C

$$T_d = \frac{b\alpha(T;RH)}{a - \alpha(T;RH)}$$

With:

$$\alpha(T;RH) = \frac{aT}{b+T} + \ln RH$$

a = 17,27 et b=237,7 [°C]

Temperatures and dew points have identical time profiles on the ground (Figure 12). Figure 12 b shows a rise in temperature 2 hours before reaching a maximum at the transition from the SL and just of the wind shift with a minimum of 2 hours and 6 hours after the wind shift. The cooling ground between times zero and four hours is accompanied by a rise in relative humidity. Before the SL the difference between the temperature and dew point is fairly low, indicating high humidity.

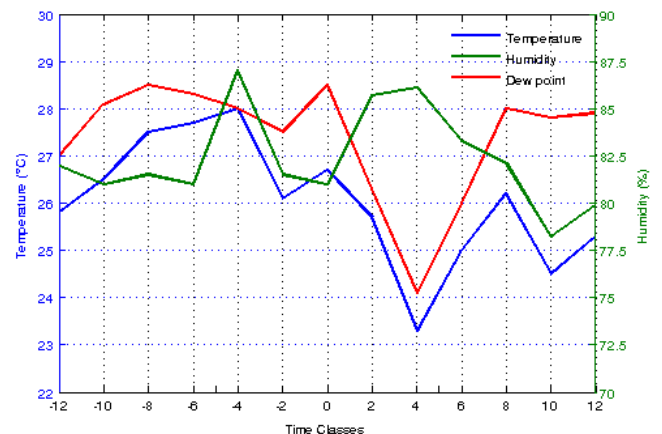


Figure 12. Temporal Patterns ground dew point, temperature and humidity (c)

Figure 13 a, b,c represents the vertical structures of the differences in these parameters compared to the average summer.

Thermal fluctuations are more important for cases of more than six hours before, more than 2 hours between 950 and 600hPa.

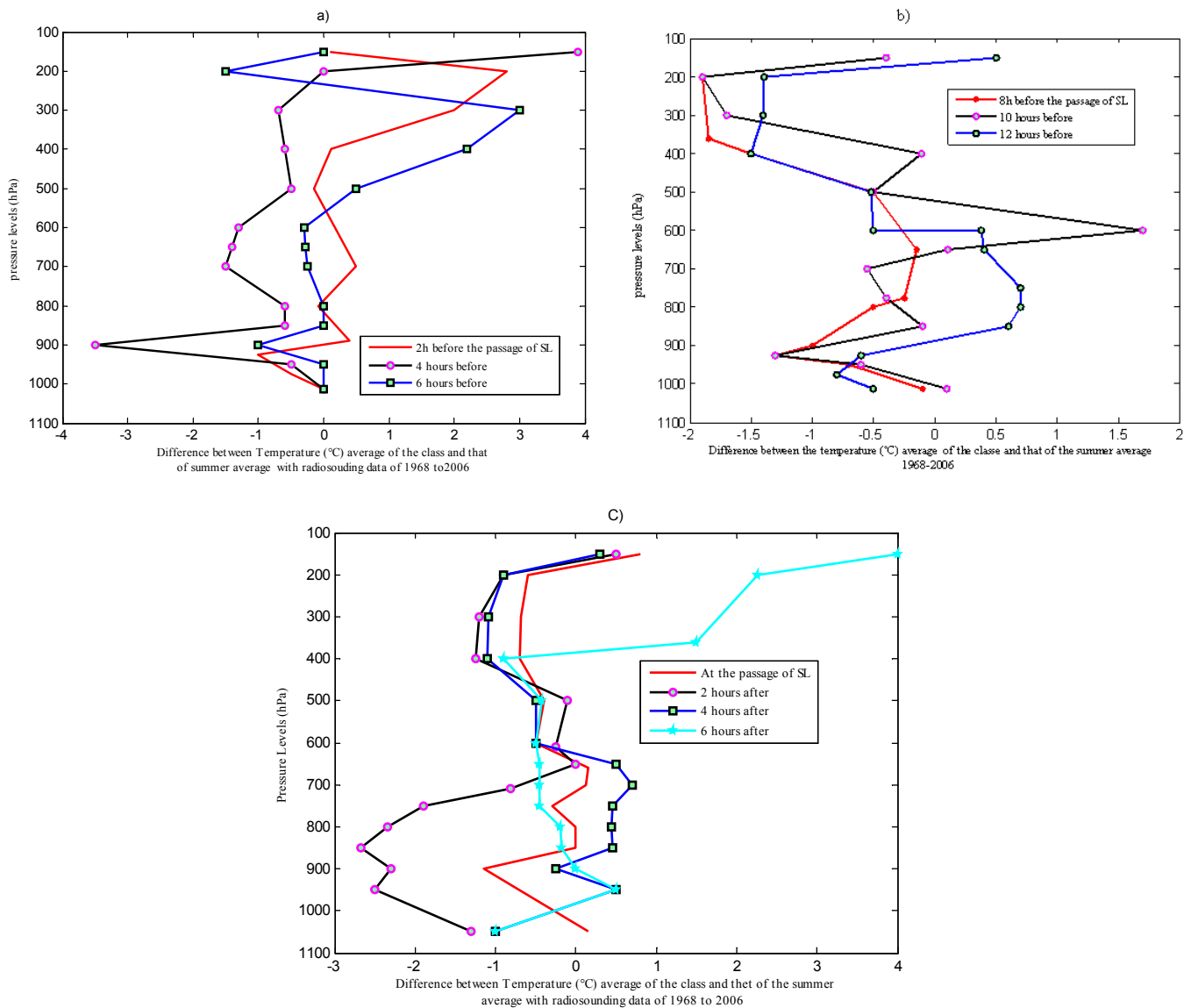


Figure 13. Difference between the average temperature of the class and that of the averagesummerof1968 to 2006 Average profilesa, b) before the passage of LG, average profile, c) after the passage of SL

Between 1000 and 600hPa, we note in the zero hour classes and two hours a cooling that diminishes gradually with distance class zero. In class six hours after there is a structure quite similar to that of zero hour class between 950 and 400hPa. But it is a slice of atmosphere warmer than the summer average and the time of passage of the SL 4 hours, the layer (900-600hPa) is warmer than 6 hours, with a look almost identical to that of the average summer, but deviating by positive values between 950 and 600 hPa. More than 6 hours before the passage of the SL (Figure 13a) there is a cooling relative to the average between 950 and 800hPa, a warming in the layer (800-500hPa) and cooling between 500 and 200hPa. There is also a change from -1 to 1 degree around the average summer. Less than 6 hours before the passage of the SL (Figure 13b) we have a vertical structure of temperature that is nearly the same as the average between the ground and 600hPa. There is an increase of temperature between 500 and 200hPa. A slight warming in the 750 and 500hPa layer is obtained in the class 4 hours before we find the average structure was between 500 and 200 hPa.

The atmosphere within 6 hours before and after the wind shift, presents profiles that deviate from the average structure of the layer was 950-600hPa.

Profile of the atmosphere with NCEP / NCAR

To improve understanding of water exchange, thermal, and dynamic of the raining systems, type SL, we felt it necessary to use a finer time scale (of the order of hours). For this we used the data analysis re NCEP / NCAR over 15 years. We worked with the nearest point of Dakar, whose geographical coordinates are 15 ° east and 17.5 degrees north. The study data covers 51 cases of SL. We present for each level of pressure changes in various parameters according to of the class time. The values shown in Figure a, b, c, d, e are the averages of all situations. Averaged for each parameter we described the temporal variations at different levels between 24 and 24 hours after the passage of SL, we give the results for the grid point closest to Dakar. Pressure levels are 12 in

number (1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150 and 100hPa).

After a composite analysis we obtained the following results

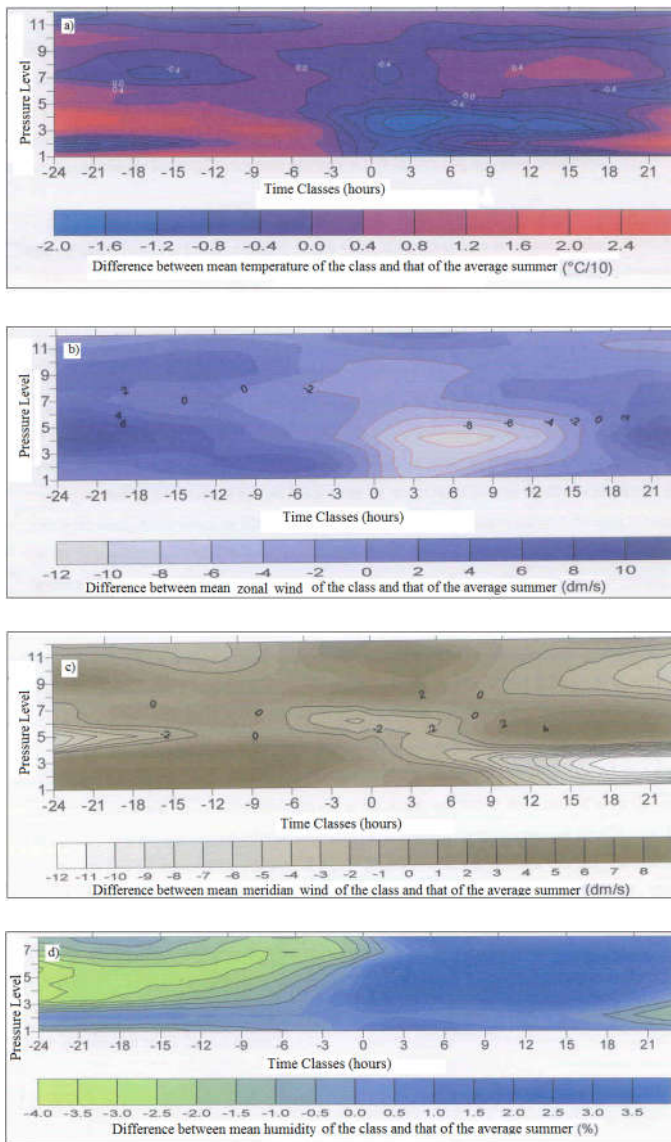


Figure 14. Profiles of the different variations of basic parameters

Results of the analysis data with composite NCEP / NCAR

With the dates of passage of SL Dakar and re-analysis NCEP / NCAR 15-Sahelian summers (1981 to 1995) to the land-sea interface, we applied a composite analysis of the basic meteorological parameters (temperature, humidity and wind). The average vertical profiles of these parameters (Figure 13) have uncovered the classical results obtained by other authors (Karan, 2010 and Lu, 1997) a decrease with altitude and temperature moisture, a west wind in the lower layers and a maximum of east wind in 700hPa representing the AEJ. Analysis of the results obtained on the basic parameters shows that the vertical distribution of the atmosphere is disturbed at the passage of a SL, the composite analysis yielded 48 temporal classes.

The state of the atmosphere in the 24 hours preceding the passage of SL is characterized by:

- A net warming of around 700hPa up to 6 hours before (Figure 14 a);
- A significant crowding in the layer 850-700 hPa up to 13 hours before (Figure 14 d);
- A west wind at 925 hPa between 10 and 5 hours before;
- An increase in wind speed is up to 15 hours before 700hPa (Figure 14 b c). At the passage of SL, the characteristics of the atmosphere are:
- A strong cooling in the layer located below 600hPa;
- A high humidification in the layer 850-700hPa;
- A strong east wind at 700 hPa between 4 hours and 9 hours later.
- 79 % of the rainfall come from the convective part.

DISCUSSION

(Lafore, 2010), studied the evolution between the thermodynamic mean states before and after the passage of SL during COPT81 with vertical profiles of potential temperature variations and water vapor content. He used 13 radiosoundings before the arrival of SLs and 11 radiosoundings after the passage of SL. Our results confirm for the temperature of the lower layers cooling and warming in the layer 450-250hPa. The warming in the layer 850-500hPa found by [13] does not appear in our results that show a cooling of 0.3°C to 850hPa. For specific humidity, found a drying between 0 and 3.5 km (approximately ground-700hPa) with a maximum of one-to-4g.kg 1km (850hPa) and a humidification between 3.5 and 11 km, either above 700hPa, with up to 5km (around 500hPa). We find a large humidification above 900hPa with up to 850hPa, draining the lower layers found by (Lafore, 2010), does not appear in our results. The results of (Lafore, 2010), also give the amplitudes of variation of relative humidity on the ground to the passage of SL 11 These amplitudes are between 13% and 32% (Tourre Yves, 1978) conducted a study of composite SLs based on the ECMWF analysis. It is a full-wave drying front (over 6 hours) followed by wetting and then drying and finally a high humidification throughout the atmosphere. Our results show a drying corresponding to negative variances before the transition and wetting corresponding to positive differences after the passage of SL. (Sow, 2005), applied the method to composite several radiosounding stations in West Africa in an area between 10°E and 27°West and between the equator and 20°N for the SL description of the summer 1974. Among the results of (Gamanche, 1983), who used the temperature and mixing ratio: there is a strong cooling in the layer 700-600hPa with a moistening. Warming in the upper troposphere to the front and back of the SL and warming with a drying in the lower layers in the front of SL. Cooling with a moistening in the 700-500hPa layer is reflected in our results and those of [25] with a large cold and moist layer between 900 and 500hPa.

Conclusion

The climatological study of meteorological parameters highlighted the interactions between the SL and its environment. We studied these interactions from radiosoundings and reanalyses. There was a progressive drying at all levels while the SLs were moving away, in the lower layers and humidification which extends to higher levels. This climatological study we deduce that between the wind shift and 2 hours after we have the convective part. Analysis of rainfall associated with SL confirms the work of [7,6-26]. For these

authors the SL also includes stratiform part also. The state of the atmosphere within 24 hours preceding the passage of SL is characterized by a significant crowding in the layer 850-750hPa up to 13 hours before. After the passage of the SL characteristics of the atmosphere are: a strong cooling in the layer located below 600hPa; A high-humidification in the layer 850-700hPa. This composite analysis involves the interaction between scale and large-scale upper air. Observations indicate that most of the precipitation in these systems comes from tropical convective. from these results We offered to researchers of the physics of the atmosphere in this Climatological meteorological study of parameters a means of validating weather numerical models mesoscale or satellite data retrievals).

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