METEOROLOGICAL DATA

OF

CUMARU - PE

2009-2012

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1. Introduction

Cumaru is a municipality in the central Agreste of the Brazilian state of Pernambuco, about 90 km west of the South Atlantic coast and near the 8th southern latitude. The village is about 370 meters above sea level, amidst a group of hills on the Borborema Plateau. Here the sun stands in the zenith on the 27th of February and on the 14th of October. The climate is characterized by a period of very irregular rainfalls between April and July and a long dry period between August and March. According to the "Atlas pluviométrico do Brasil" (1948), April, May and June are the wettest months, October, November and December the driest months of the year.

For the indigenous population, the climate is of great importance: rainfall and distribution are crucial factors for both extensive agriculture and pastoralism. Many houses in rural areas also have no water supply; these inhabitants are completely dependent on water from local, rain-fed dams and cisterns.

In long periods of drought there is a lack of water in rural areas for both animals and plants as well as for humans. The irregularity of rain during the rainy season often damages crop growth. Finally, heavy rainfalls in winter cause major damage to the infrastructure of the community, especially on the many unpaved and poorly drained natural roads. Given the irregular nature of rainfall in winter, there is great uncertainty among farmers about when to plant. Several people assured me that farmers had used to plant corn and beans in the dry soil just before March 21 because they knew the rainy season would begin. These people complained that the rainy season is starting much later nowadays.

I got these problems and discussions in conversation with neighbors and friends. In addition, my curiosity was fueled by my own project to build a second cistern next to my house, and I wanted to know how big that would have to be. So I started to measure and write down some meteorological data. Unfortunately, this work was interrupted after a good three and a half years. Nevertheless, it is possible to use the data collected to draw some interesting conclusions about the climate of Cumaru.

I would like to thank the following people for their support: Paulo de Assis Nascimento, Fabio-Junior, José Andrade Lima, Leandro Agostinho Alves Costa, José Maximiano de Souza, Branquinho Maximiano de Souza and Rhuan de Cássio Silva Nascimento.

If you have suggestions, opinions, comments, questions and ideas while reading: do not hesitate to let me know! Send an e-mail to: gotobrasil[at]gmx.ch

This report is available for free download (also in German and Portuguese) on the Internet site

www.cumaru-pe.com.br.

2. Method

Basically, the rainfall, air temperature, relative humidity and barometric pressure were measured at 6 o'clock in the morning. To measure the amount of rain, a cylindrical vessel of 11 cm diameter was mounted on a pole about 150 cm above the ground and covered with a plastic funnel that protected the contents of the bucket from evaporation during the day. The air temperature, barometric pressure and humidity were measured inside my home: A well-ventilated house near the village center of Cumaru, about 390 meters above sea level. The gauge was located on an inner wall of this house, about 170 cm above the ground. From January 1, 2009 to August 31, 2010, an analogue metering station was used; from August 1, 2010, this unit was replaced by a VION branded digital metering station called "Meteoscan" (www.vion-marine.com), which allowed more accurate data collection.

During the measurement period, several incidents happened: When I was traveling, I called a helper to record the data in my place. Some of these data were poorly legible or untrustworthy and were therefore not used for the evaluation. Twice the 12 cm deep water collection container overflowed within the measuring period of 24 hours. When I replaced the analogue metering station with a digital one, I raised the data on both devices for a month. In doing so, I found systematic errors in measuring the barometric pressure of -15.3 hPa and the humidity of + 18.6%. The analogue data used in this report (those before 1st August 2010) have been corrected in this sense to allow a proper comparison of all data among themselves.

In order to be able to improve the previous measurement method and to know the course of the measurement parameters during the day, temperature, barometric pressure and humidity were measured from hour to hour during some days of the years 2011 and 2012.

This report presents only the most representative data in the form of tables and Diagrams. The original data can be seen from the respective annual reports.

Diagrams 8 (page 12) and 12 (page 19) show the morning temperature, relative humidity, rainfall, and barometric pressure. In order to be able to compare the course and interdependence of these parameters from day to day, they are summarized in the same diagrams. The values of y-axis have been deliberately omitted, because here ithey are less important than the interdependence of their changes. The y-axis of each parameter has been adjusted as follows:

Table 1: Conversion of the y-axis in diagrams 8 (page 12) and 12 (page 19):

Value in the Diagram	Morning temperature	Morning barometric pressure	Morning air humidity	Rainfall the day before
5	25º C	961 hPa	90 %	50 mm
4	24º C	959 hPa	80 %	40 mm
3	23º C	957 hPa	70 %	30 mm
2	22º C	955 hPa	60 %	20 mm
1	21º C	953 hPa	50 %	10 mm
0	20º C	951 hPa	40 %	0 mm
Formula	x-20	(x-951):2	(x-40):10	X:10

Criticism of the method: The daily measurement time at 6 o'clock has been chosen as a workable compromise, in principle, but it would have been much better to collect the data at the respective exact time of sunrise, which is slightly different depending on the season. This inaccuracy easily falsifies the results of the daily cycles. The measurement of barometric pressure would have been better done at the time of the lowest daily value, i.e. at about 3 o'clock or 15 o'clock, or at the respective time of the highest value, at about 9 o'clock. In view of the frequent irregularities, it would have been useful to collect the data over a longer period of time than it was done. It would also be useful to additionally measure the degree of cloud cover or the tanning, the wind direction and the wind force during the day. It would be even more informative, however, to enlarge the examination perimeter. I am e.g. convinced that the data collected is strongly related to the amount of rain in the east of Cumaru and to the sea temperature.

3. Results

3.1. Annual average of the measured climatic variables

The data were collected during three years and 8 months. The average early morning air temperature, which also coincides with the lowest daily temperature, was 22.70º C in Cumaru, the annual standard deviation of the temperature varied between 1.3º C and 1.7º C. The mean morning relative humidity was 78.87%, with annual standard deviations from 3.3 - 7.3%. The mean morning barometric pressure was 957.75 hPa, with annual standard deviations of 1.3 - 3.2 hPa. Large, however, were the fluctuations in the annual rainfall. On average, it was 1'013 mm, the difference between the smallest and the largest annual rainfall was 1001 mm.

Table 2: Annual averages and standard deviations of morning temperature, morning barometric pressure, morning relative humidity and rainfall:

2009	365	23.12	1.555	959.60	3.176	76.35	7.30	916.0	0.912
2010	365	23.29	1.709	958.32	2.386	77.67	5.08	858.3	1.552
2011	365	22.34	1.498	956.92	2.072	82.08	3.47	1633.7	1.913
2012	243	22.10	1.291	952.15	1.268	80.35	3.33	534.4	0.787
2012[1]	365[1]	22.03[1]		956.15[1]		79.39[1]		633.8[1]	
Ø 2009-2012[1]	1460[1]	22.70[1]		957.75[1]		78.87[1]		1010.5[1]	

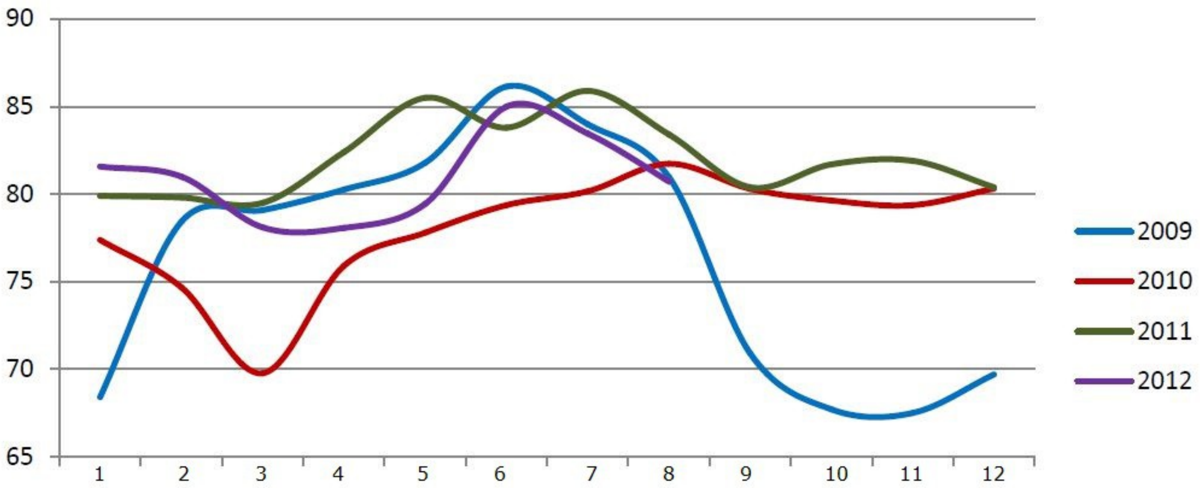
3.2. Monthly mean of early morning humidity

The values can vary widely between one month of a year and the same month of another year. Basically, there is a strong correlation between the relative humidity and the rainfall of the same month. In the years 2009 and 2011 e.g. the graphs of the monthly mean humidity (diagram 1, page 5) are very similar to the graphs of the monthly rainfall (diagram 5, page 9), from which we can conclude that the humidity increases or decreases in parallel with the rainfall. From the monthly mean values, it is not possible to determine whether the increase in humidity is the result or the cause of the rain events.

The greatest increases in humidity were observed at the beginning of the rainy season in 2010 and 2012. In 2010, the dry March was followed by a period of heavy rainfall that increased the humidity. The strongest decrease in humidity took place from August to October 2009.

However, there are developments in the monthly mean values of humidity, which can not be explained by the monthly rainfall. For some months, the humidity differs greatly from the amount of rain. These are the months of January, February, June, July and August 2010. This phenomenon can be explained by the fact that the relative humidity is not only dependent on the amount of rain. High temperatures, for example, reduce the relative humidity, and an excess of rain within a short time no longer increases an already high relative humidity, because a large part of this water does not evaporate, but drains after water saturation of the soil over streams and rivers. A more detailed relationship between humidity and other measurement parameters is explained in chapter 3.9 (page 10).

Diagram 1: Monthly mean values of the early morning relative humidity [in%] :



1) The numbers available between January and August 2012 have been extrapolated for the remainder of the year.

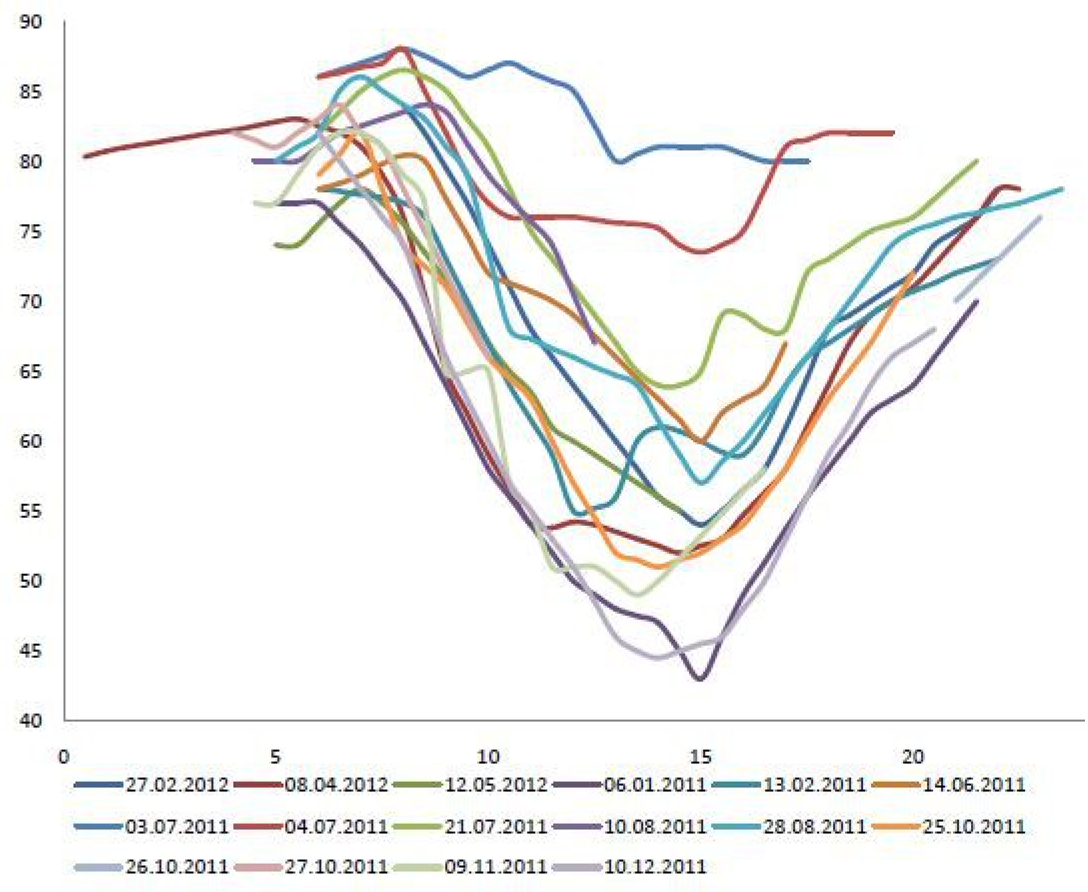
3.3. Daily course of relative humidity

Over the course of the day, the relative humidity changes much more than the annual averages of morning air humidity. Over the course of the year, the humidity fluctuates about 15%, but during a single summer day, humidity may drop by up to 35%! These fluctuations are mainly the result of temperature fluctuations: At constant absolute humidity, the relative humidity decreases with increasing temperature. The graphs of the daily course of the humidity (diagram 2, page 6) and those of the temperature curve (diagram 4, page 8) are practically inverse.

In general, the relative humidity reaches its highest daily value between 5 and 6 o'clock in the morning, i.e. just when the temperature reaches its lowest value. The amount of this value depends mainly on the rainfall of the previous days. In the following hours, the humidity drops to the lowest value of the day, until about 15 clock, shortly after the highest daytime temperature has been reached. From then on, the relative humidity increases again; until about 20 o'clock at the same speed as it had fallen in the morning, then a little slower until it reaches the highest value of the next day before sunrise. In the rainy season, the humidity drops much less during the day than during the dry season. On a rainy day, the morning relative humidity may be the same throughout the whole day.

The highest relative humidity value for the entire study period was 91% on March 3, 2011 at 4:15 pm. During the five previous days it had rained a lot (219 mm), on the test day itself a record amount of 100 mm. On this day, the temperature did not rise higher than to 24 º C. 12 July 2011 was another day with a high humidity: After more than two rainy weeks, the humidity reached the high value of 90% at 6 o'clock in the morning. This high humidity was maintained until 11:40 and fell in the afternoon only to 86%. The lowest humidity was measured at 43% in the summer, on the 6th of January 2011 at 15h, at the time of the highest daytime temperature (30.5º C), after twenty rain-free days.

Diagram 2: Relative humidity over some selected days [%]:

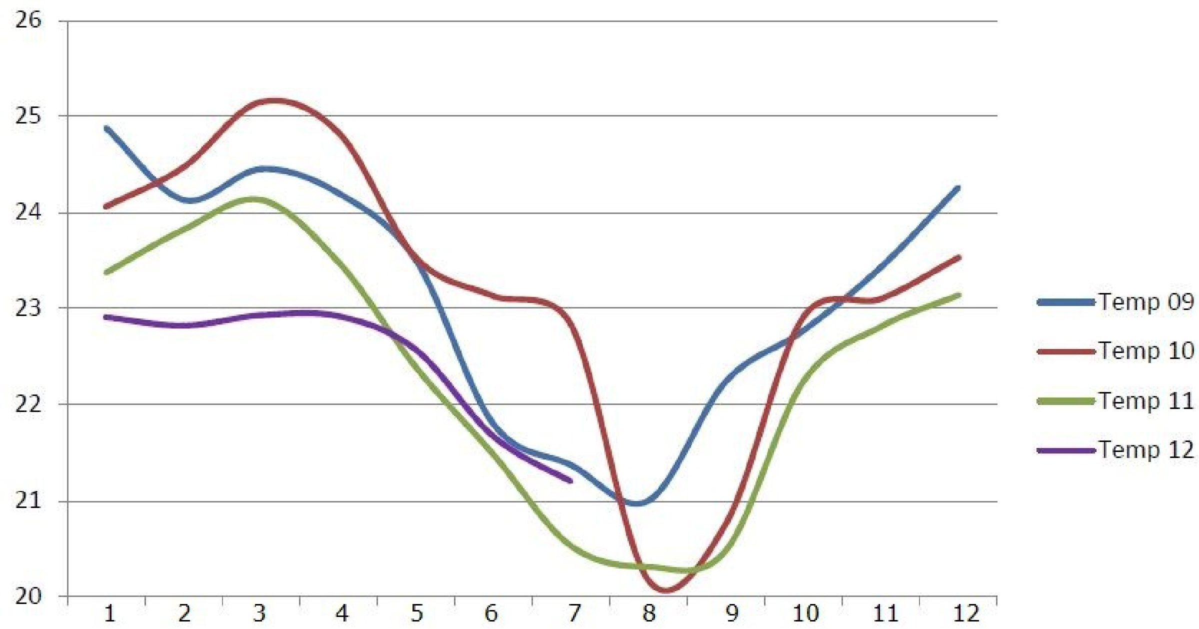


Every now and then the usual course of the day suffers irregularities: Especially during the rainy season, the morning decline in humidity is interrupted by a rise during a few minutes or during one or two hours before sinking again. This happened for example on the 5th and 6th of January 2009, on the 13th of February and on the 3rd, 4th and 21st of July 2011. These deviations can be explained by the arrival of clouds or humid air masses.

3.4. Monthly mean values of the early morning air temperature

Above all, the mean temperatures of the morning temperature reflect the amount of energy that reaches the earth and which can be stored in the soil and vegetation during the night. The energy input depends essentially on the position of the sun and the degree of cloudiness. In order to explain diagram 3 (page 7), we must take into account that the clouds of the rainy season, the moisture of the soil and vegetation are factors that slow down the daily warming. In Cumaru the sun will be in the Zenith on the 27th of February and on the 14th of October, the sun's lowest point will be reached on the 21st of June. Throughout the study period, the lowest monthly mean of the morning temperature was measured in August, two months after the day of least solar irradiation. The highest value in the years 2010-2012 was reached in each case in March, thus one month after the day of the theoretically highest insolation of the year. The temperature difference between rainy season and dry season is approximately 4-5º C. The largest temperature jump between dry season and rainy season was reached in 2010: From March to August, the monthly average of the morning air temperature fell from 25.15º C to 20.17º C, i.e. 5º C in five months.

Diagram 3: Monthly mean values of the early morning air temperature [°C]



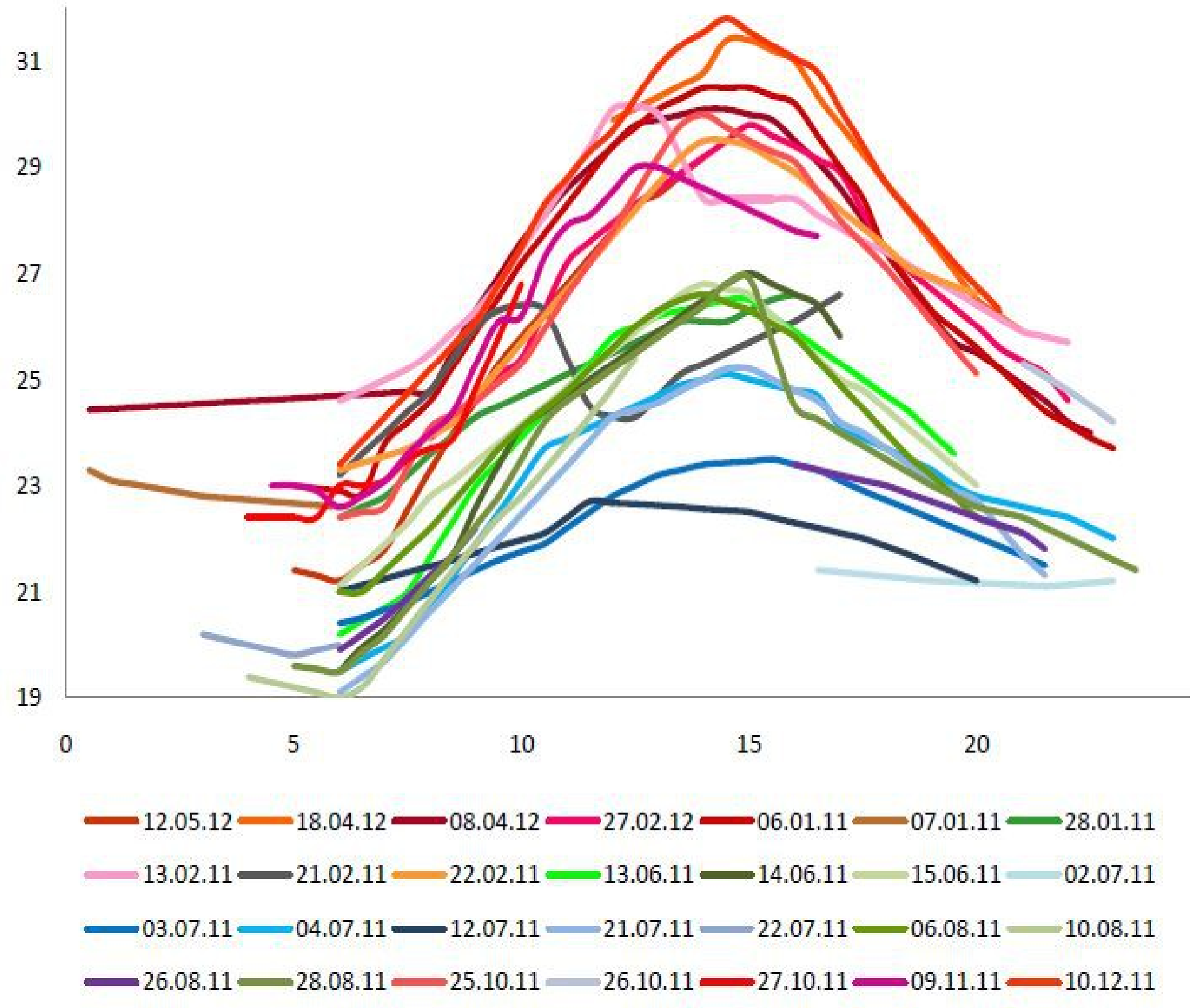
3.5. Daily course of the air temperature

The air temperature has a very characteristic course during the day: Before sunrise, around 6 o'clock, prevails the lowest temperature of the day. In the dry season this is around 23º C, in the rainy season it is about 3º C lower. The lowest recorded temperature was 18.6º C, on the 15th of August 2010 at 6 o'clock in the morning. Since it had not rained during the previous six days, we can assume that the sky was not covered at night, so the low temperature is easy to explain. From sunrise, the temperature rises almost linearly to the highest daytime temperature. This temperature increase is about 9º C in the dry season and about 6º C in the rainy season. During the dry season the highest temperature of the day is reached between 14 and 15 o'clock. The highest temperature measured was 35º C on the 7th of March 2010 at 15:30h. On this day, the temperature had been 25º C before sunrise. It was a rain-free day, but it had rained on the previous two days. During the rainy season, temperatures are generally lower, and the maximum day temperature is reached slightly earlier than during the dry season.

From that moment on, the temperature drops again to the lowest temperature of the following day before sunrise. This temperature decline is much stronger before midnight than after midnight.

Temperatures follow this pattern for most days of the year. However, the course is influenced by rain and clouds. Overcast during the day and rain, the temperature is lowered, cloud cover during the night increases the temperature. On 21st of February 2011, for example, a rainfall in the morning caused a temperature drop of 2º C for two hours, and on the cloudy night of 8th of April 2012, the air temperature decreased instead.

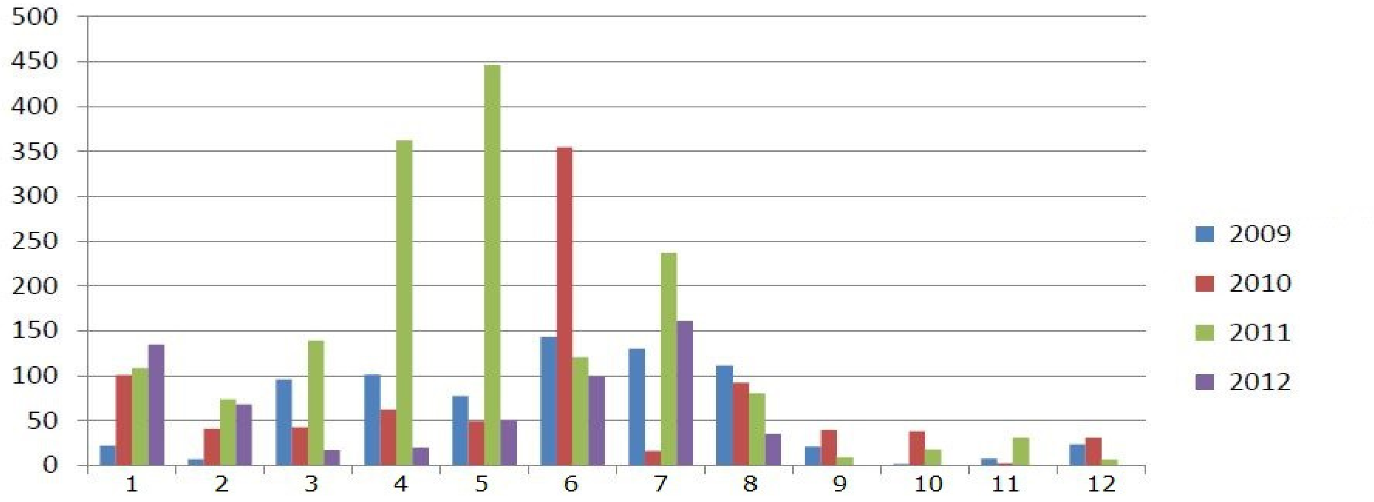
Diagram 4: Air temperature trend on some selected days [°C]



3.6. <u>Monthly rainfall</u>

In Cumaru, the amount of rain varies greatly from one year to the next. In 2009 fell 916 mm, the following year 858 mm, in 2011 it was 1'633.7 mm. The driest months of the year are September, October, November and December, the wettest months are May, June and July. January also has a small rainy season. The monthly rainfall also varies greatly in the same month of different years: In the month of May 2011, for example, fell nine times the amount of rain compared with the same months of 2010 and 2012. In general, a large part of the rainfall falls within a few days: In May 2011, within four days it rained 81% of the total monthly rainfall or 22% of the annual rainfall, and within three days of June 2010 fell 31% of the total annual rainfall. The driest month of the measurement period was October 2009 with a monthly rainfall of only 1.5 mm. Not taking into account daily rainfall of less than 1 mm, the longest rainless period lasted 48 days. It started on 26th of September 2009 and lasted until 12th November 2009.

Diagram 5: Monthly rainfall [mm]



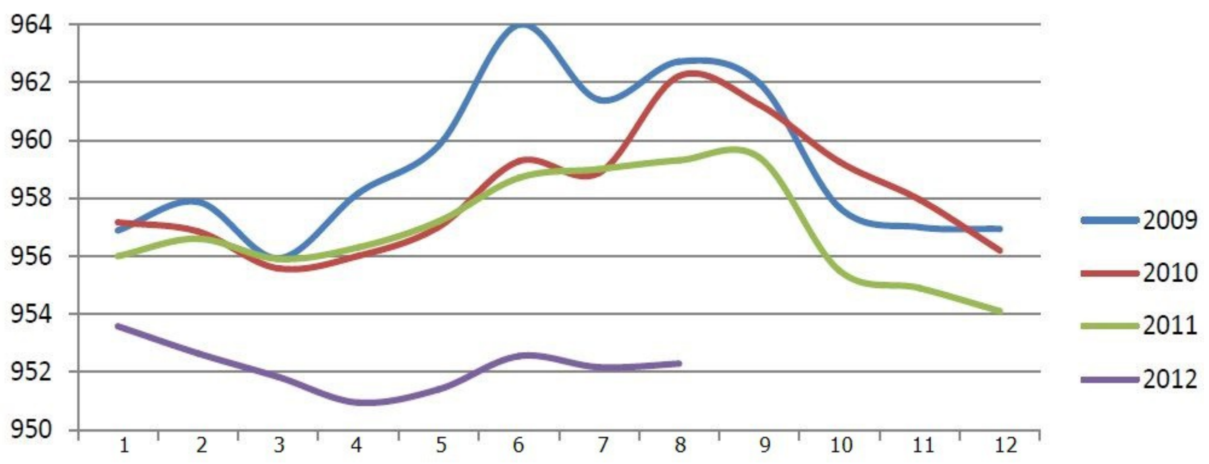
With a highest rainfall season in the months of May - July, the climate of Cumaru can be compared with the climate of the coast region of Pernambuco (group 7b, page 21 of the Atlas pluviométrico do Brasil), which is quite different from the climate of the Sertão, where the highest rainfall occurs between January and April. According to Lyra et al. 2014, there can be made a distinction between a dry, a rainy and a transitional season. The transitional season usually extends with increasing distance of the place from the seashore. In Cumaru, according to the definition of Lyra et al. 2014, the dry season lasts from September to December, the transitional period from January to May and the rainy season from June to August.

3.7. Monthly means of early morning barometric pressure

Basically, the early morning barometric pressure during the rainy season is high, and there is also a relative high in the months of January or February. During the driest months of the year, the barometric pressure is lowest. The highest mean values were measured in the months of June and August.

In the months of July of 2009 and 2010, the barometric pressure fell for no apparent reason. The high barometric pressure in the months of February of the year 2009 and 2011 can not be explained with the collected data. Another unexplained phenomenon is the overall low barometric pressure in the year 2012. There is only a weak correlation between the monthly mean barometric pressure and the monthly mean rainfall values. Therefore we can not conclude with the data collected that a high barometric pressure has a high rainfall result.

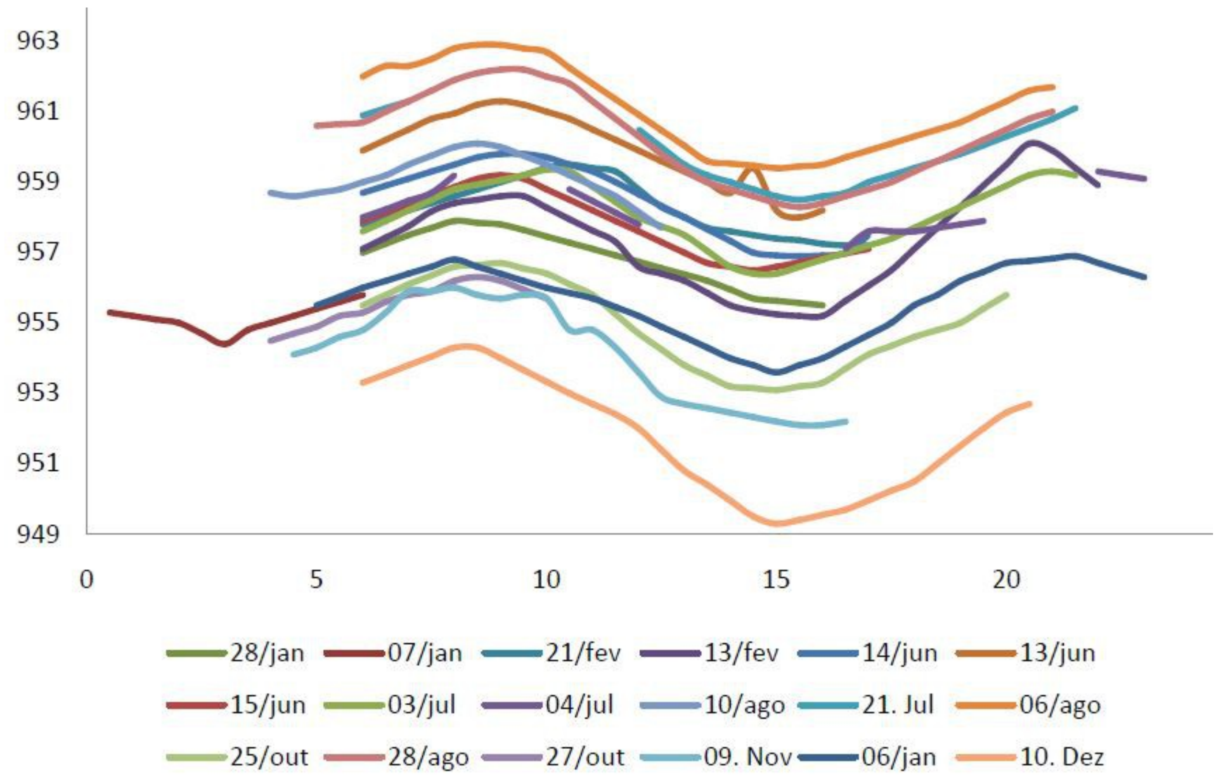
Diagram 6: Monthly mean of early morning barometric pressure [hPa]



3.8. Daily course of the barometric pressure

During the day, the barometric pressure suffers an interesting, very regular course, which seems to be independent of all other parameters. Diagram 7 (page 10) shows two phases of high and low barometric pressure during 24 hours. The first high-pressure phase occurs approximately at 8.30 - 9 o'clock, the second 12 hours later, namely at approximately 21 o'clock. Between these high pressure phases, the barometric pressure regularly drops by about 3-5 hPa. This pressure difference is far greater than described in the literature. According to Dai 1999, the largest daily pressure fluctuations are around 1.3 hPa (page 3'879).

Diagram 7: Course of the barometric pressure during some selected days [hPa]:



The highest barometric pressure, 962.9 hPa, was measured on 6th of August 2011 at 9 o'clock, the lowest value, 949.3 hPa, on 10th of December 2011 at 14:37h.

At this point, another phenomenon related to the barometric pressure shall be mentioned: During my travels I asked one of my friends to record the weather data every morning. Once, one of my helpers decided to take the weather station home. My house stands on a northeast exposed flat slope at 390 m above sea level, my friend's house approximately 400 m beeline in direction northeast of it, on a rather steep south-exposed slope, about 420 m above sea level. Although the two places are located in the same terrain chamber and differ only insignificantly from each other in the sea level, I measured several times a pressure drop from my house to the house of the helper of respectable 3.5 hPa. I suspect that the different exposure and the different wind conditions are cause of the big pressure difference. Of course, in retrospect I corrected these barometric pressure values noted by my friend.

3.9. Relationship between individual rain events, the barometric pressure and the humidity

Diagram 8 (page 12) shows the course of the meteorological parameters within the year. On the basis of this diagram, we can see the beginning and duration of the rainy and dry seasons, as well as the increases and decreases of temperature, humidity and barometric pressure in larger time periods.

The beginning of the rainy seasons seems to coincide with an increase in barometric pressure and a decrease in air temperature. This relationship can already be seen in diagrams 3 (page 7), 5 (page 9) and 6 (page 9), but appears even more clearly in diagram 8. The higher the black line of the barometric pressure climbs and the lower the red line of the temperature falls, more regular is the rainfall. During the periods in which the temperature curve is below the barometric pressure curve, daily rain events are frequent. It can be concluded that the rainy season in Cumaru is not triggered directly by the intra-tropical convergence zone, because the rainfall within the intra-tropical convergence zone would have to be accompanied by a reduction in pressure.

The rainy season lasted from 21th of May to 15th of September 2009, from 4th of June to 27th of September in 2010, from 7th of April to 3rd of September in 2011, and on 24th of May 2012. The temperature drops and pressure increases occurred at the following days:

Table 3: Time of temperature drops and increases in barometric pressure with regard to the beginning of the rainy season:

Year	Time of the fall in temperature with respect to the beginning of the rainy season	Time in the fall with respect to the beginning of the rainy season
2009	- 2days	+ 2 days
2010	+ 5 days	- 1 day
2011	+ 7 days	+ 42 days
2012	- 4 days	+ 29 days

For the following table 4 (page 11), the averages of the early morning temperature and the early morning atmospheric pressure of the 10 or 20 days preceding the beginning of the rainy season were compared with those following the beginning of the rainy season. It results that on average the 10 days following the start of the rain were 0.53 ° C colder than the 10 days preceding the start of the rain. Simultaneously the barometric pressure increased by 1.58 hPa.

Table 4: Difference of the mean values of early morning temperature and early morning barometric pressure of the days preceding and following the beginning of the rainy season :

Year	Difference Temperature +/-10 days	Difference Temperature +/-20 days	Difference Barometric pressure +/-10 days	Difference Barometric pressure +/-20 days
2009	- 0.8º C	- 1.265º C	+ 2.6334 hPa	+ 3.791 hPa
2010	- 0.3º C	- 0.25º C	+ 1.5 hPa	+ 1.95 hPa
2011	- 0.66º C	- 1.165º C	+ 0.79 hPa	+ 0.04 hPa
2012	- 0.36º C	- 0.3787º C	+ 1.42 hPa	+ 1.168 hPa
Ø of the 4 years	- 0.53º C	- 0.765º C	+ 1.586 hPa	+ 1.737 hPa

Furthermore, it can be observed that before summer rainfall events both barometric pressure as well as the relative humidity and the air temperature sink. Table 5 (page 13f) shows all the major summer rains and depressions of 2009-2012, together with the associated relative humidity reductions. The values that support the above thesis are highlighted in yellow, those values that contradict the thesis are highlighted in red.

Table 5 (page 13f) shows that there were 66 situations within 44 months in which there were either actual summer rain events or at least pressure conditions indicating summer rain events. 58 of these situations actually resulted in rainfall events. Only before 6 summer rain events it was not possible to detect any drop in atmospheric pressure. In all other cases the barometric pressure dropped significantly before summer rain events. On average, it began to fall 3.57 days before the beginning of rain and rose again shortly after the start of the rainfall. This meant an average pressure drop of 2,736 hPa within 3.33 days. In the 3 days before the beginning of summer rainfall, the pressure fell on average by 0.725 hPa. Before the rainfall, the relative humidity also decreased with great regularity, namely in 64 of the 66 investigated events. The relative humidity began to fall on average 3.29 days before the respective rain event and reached its low point 1.12 days before the rain event. On average, the relative humidity decreased by 5.042%. The reduction in relative humidity between the 3rd and the 1st day before summer rain events is 1.23% on average. In two-thirds of all situations examined, there was also a drop in temperature just before the rainfall. This started on average 1.7 days before the rain event and lasted until just before the rain event. The temperature drop was 1.257 °C on average.

Diagram 8: Morning temperature (red), barometric pressure (black), humidity (green) and daily rainfall (blue)

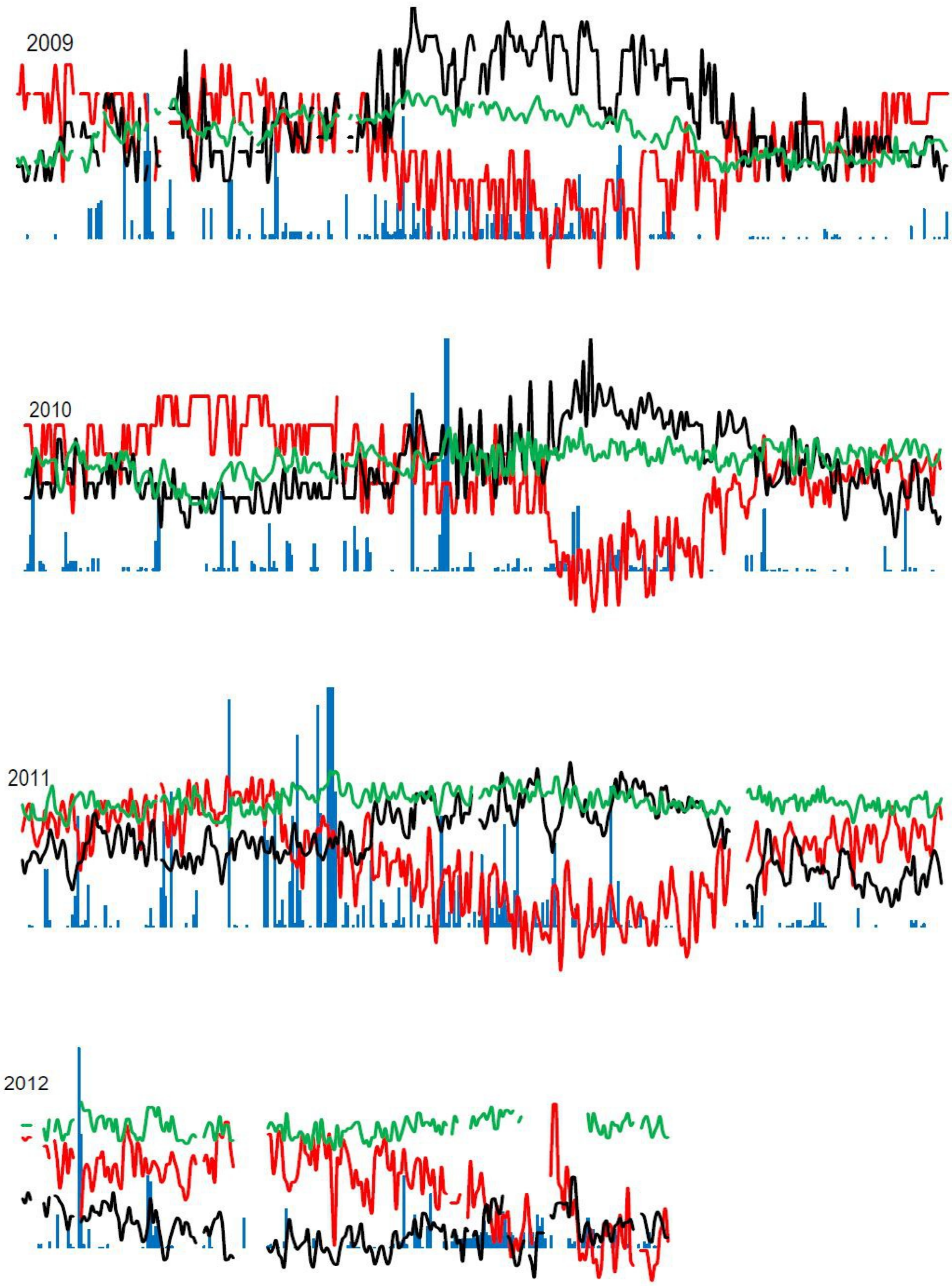


Table 5: Relationship between summer rain events, the previous history of air pressure, temperature and relative humidity:

Number of the event	Date of the rain event	Rainfall [mm]	Date of temperature drop	Extent of temperature drop [°C]	Duration between the beginning of the fall in temperature and the beginning of rain	Duration between the end of temperature fall and the beginning of rain [days]	Period of summer pressure drop	Duration between start of pressure drop and rain start [days]	Duration between end of pressure drop and start of rain [days]	Duration of pressure drop [days]	Extent of pressure drop [hPa]	Pressure drop within 3 days before the beginning of the rain event [hPa]	Period of reduction of relative humidity	Duration between start of reduction of rel. Humidity and rainfall [days]	Duration between end of reduction of rel. humidity and rainfall [days]	Reduction of relative humidity [%]	Reduction between day 3 and 1 before rain starts [%]
1.	29.01.09-3.02.09	55	29.01.09-30.01.09	-1	0	1	27.01.09-02.02.09	-2	4	6	-3	-0	23.01.09-28.01.09	-6	-1	-7	-5
2.	12.02.09	30	11.02.09-13.02.09	-3	-1	1	07.02.09-13.02.09	-5	1	6	-5	-2	04.02.09-11.02.09	-8	-1	-11	-2
3.	20.02.09-23.02.09	112	20.02.09-21.02.09	-1	0	1	18.02.09-21.02.09	-2	1	3	-4	0	17.02.09-18.02.09	-3	-2	-6	-3
4.	01.03.09-03.03.09	32	-	-	-	-	24.02.09-25.02.09	-5	-4	1	-2	?	24.02.09-28.02.09	-5	-1	-6	-3
5.	15.03.09	10	15.03.09-16.03.09	-1	0	1	08.03.09-13.03.09	-7	-2	5	-9	+6	10.03.09-15.03.09	-5	-2	-5	-0.5
6.	18.03.09	10	18.03.09-19.03.09	-1	0	1	15.03.09-18.03.09	-3	0	3	-6	-6	-	-	-	-	+3
7.	25.03.09-26.03.09	40	-	-	-	-	22.03.09-24.03.09	-3	-1	2	-2	-2	19.03.09-24.03.09	-6	-1	-8	-3
8.	07.04.09-08.04.09	11	05.04.09-06.04.09	-0.5	-2	-1	03.04.09-05.04.09	-4	-2	2	-2	-1	03.04.09-05.04.09	-4	-2	-5	-2
9.	12.04.09-13.04.09	66	11.04.09-13.04.09	-2	-1	1	08.04.09-09.04.09	-4	-3	1	-5	+4	09.04.09-10.04.09	-3	-2	-2	+2
10.	18.04.09-22.04.09	10	18.04.09-19.04.09	-1	0	1	16.04.09-19.04.09	-2	1	3	-4	-3	16.04.09-18.04.09	-2	0	-2.5	-1
11.	10.05.09	15	07.05.09-11.04.09	-2	-3	-1	09.05.09-14.05.09	-1	4	5	-4	-0.5	06.05.09-09.05.09	-4	-1	-5	-4
12.	11.09.09-15.09.09	16	08.09.09-09.09.09	-1	-3	-2	07.09.09-08.09.09	-2	-1	1	-2	+1	08.09.09-11.09.09	-3	0	-5	-3
13.	25.09.09	1	23.09.09-24.09.09	-2	-2	-1	20.09.09-25.09.09	-5	0	5	-4	-3	21.09.09-24.09.09	-4	-1	-9	-7
14.	-	0	-	-	-	-	29.09.09-30.09.09	-	-	1	-4	-	27.09.09-28.09.09	-	-	-2	-
15.	-	0	01.10.09-02.10.09	-2	-	-	01.10.09-05.10.09	-	-	4	-5	-	01.10.09-04.10.09	-	-	-5	-
16.	-	0	-	-	-	-	08.10.09-12.10.09	-	-	4	-5	-	08.10.09-09.10.09	-	-	-2	-
17.	13.11.09-14.11.09	5	12.11.09-13.11.09	-1	-1	0	05.11.09-13.11.09	-8	0	8	-6	-3	06.11.09-10.11.09	-7	-3	-3	+2
18.	17.12.09-22.12.09	14	16.12.09-17.12.09	-1	-1	0	16.12.09-17.12.09	-1	0	1	-1	-1	14.12.09-16.12.09	-3	-1	-4	-4
19.	31.12.09-04.01.10	61	-	-	-	-	25.12.09-29.12.09	-6	-2	4	-3	0	28.12.09-31.12.09	-3	0	-4	-3
20.	03.01.10-04.01.10	50	03.01.10-04.01.10	-1	0	1	-	-	-	0	0	0	02.01.10-03.01.10	-1	0	-2	+5
21.	07.01.10-09.01.10	5.1	06.01.10-07.01.10	-1	-1	0	05.01.10-07.01.10	-2	0	2	-3	-1	05.01.10-08.01.10	-2	1	-6	+3
22.	17.01.10-21.01.10	24	16.01.10-18.01.10	-2	-1	1	15.01.10-20.01.10	-2	3	5	-3	-2	13.01.10-15.01.10	-4	-2	-11	-1
23.	23.01.10	0.5	-	-	-	-	21.01.10-25.01.10	-2	2	4	-4	+2	21.01.10-23.01.10	-2	0	-7	0
24.	16.02.10	1	15.02.10-16.02.10	-	-	-	13.02.10-16.02.10	-3	0	3	-3	-3	13.02.10-15.02.10	-3	-1	-10	-10
25.	22.02.10-23.02.10	35	21.02.10-22.02.10	-	-	-	20.02.10-24.02.10	-2	2	4	-4	0	19.02.10-22.02.10	-3	0	-9	-7
26.	-	0	02.03.10-03.03.10	-1	-	-	01.03.10-06.03.10	-	-	5	-4	-	05.03.10-08.03.10	-	-	-7	-
27.	17.03.10-21.03.10	29.1	15.03.10-16.03.10	-2	-2	-1	13.03.10-16.03.10	-4	-1	3	-2	+2	-	-	-	0	-1
28.	08.04.10-11.04.10	20.5	07.04.10-08.04.10	-1	-1	0	-	-	-	0	0	-1	02.04.10-05.04.10	-6	-3	-4	+1

29.	15.04.10-17.04.10	24	13.04.10-14.04.10	-1	-2	-1	-	-	-	0	0	+1	11.04.10-14.04.10	-4	-1	-6	-4
30.	25.04.10-27.04.10	11	-	-	-	-	-	-	-	0	0	0	22.04.10-23.04.10	-3	-2	-5	-5
31.	08.05.10	10	05.05.10-07.05.10	-3	-3	-1	07.05.10-08.05.10	-1	0	1	-3	-1	07.05.10-08.05.10	-1	0	-2	+6
32.	12.05.10-13.05.10	22	-	-	-	-	-	-	-	0	0	0	09.05.10-10.05.10	-3	-2	-1	-1
33.	17.05.10-18.05.10	17	16.05.10-17.05.10	-2	-1	0	14.05.10-17.05.10	-3	0	3	-3	-3	14.05.10-16.05.10	-3	-1	-5	-5
34.	15.10.10-17.10.10	10	12.10.10-15.10.10	-1.2	-3	0	14.10.10-17.10.10	-1	2	3	-2.1	0	10.10.10-12.10.10	-5	-3	-7	+5
35.	21.10.10-22.10.10	27	-	-	-	-	20.10.10-23.10.10	-1	2	3	-3.2	-0.4	18.10.10-21.10.10	-3	0	-5	-3
36.	24.11.10	1	22.11.10-23.11.10	-0.2	-2	-1	20.11.10-23.11.10	-3	-1	3	-4.1	-2.7	20.11.10-22.11.10	-4	-2	-5	-3
37.	09.12.10	8	-	-	-	-	03.12.10-09.12.10	-6	0	6	-3.9	-3	05.12.10-09.12.10	-4	0	-4	-1
38.	-	0	-	-	-		11.12.10-13.12.10	-	-	2	-3	-	11.12.10-13.12.10	-	-	-7	-
39.	10.01.11-12.01.11	40	-	-	-	-	06.01.11-09.01.11	-4	-1	3	-0.3	+0.2	05.01.11-07.01.11	-5	-3	-5	0
40.	21.01.11-27.01.11	67.6	-	-	-	-	17.01.11-21.01.11	-4	0	4	-3.3	-2.8	13.01.11-18.01.11	-8	-3	-13	+5
41.	03.02.11	7	01.02.11-02.02.11	-0.4	-2	-1	30.01.11-05.02.11	-4	2	6	-2.9	-0.3	31.01.11-02.02.11	-3	-1	-4	-4
42.	19.02.11-22.02.11	6.7	-	-	-	-	17.02.11-19.02.11	-2	0	2	-1.6	-1.2	14.02.11-16.02.11	-5	-3	-7	+1
43.	25.02.11-01.03.11	103	-	-	-	-	122.02.11-01.03.11	-3	4	7	-3.3	-2.6	-	-	-	0	0
44.	10.03.11-11.03.11	16	08.03.11-10.03.11	-0.9	-2	0	03.03.11-07.03.11	-7	-3	4	-1.2	-0.3	07.03.11-09.03.11	-3	-1	-5	-5
45.	24.03.11	76	23.03.11-25.03.11	-0.8	-1	1	16.03.11-21.03.11	-8	-3	5	-3.8	+2	23.03.11-24.03.11	-1	0	-4	+2
46.	03.09.11	8	-	-	-	-	-	-	-	0	0	-0.4	30.08.11-01.09.11	-4	-2	-6	-2
47.	-	0	29.09.11-02.10.11	-1.4	-	-	25.09.11-02.10.11	-	-	7	-3	-	27.09.11-29.09.11	-	-	-5	-
48.	19.10.11-21.10.11	12.2	-	-	-	-	16.10.11-18.10.11	-3	-1	2	-2.2	+0.3	16.10.11-17.10.11	-3	-2	-3	-3
49.	28.10.11-31.10.11	1.1	26.10.11-29.10.11	-1.2	-2	1	24.10.11-30.10.11	-4	3	7	-3.6	-0.7	27.10.11-29.10.11	-1	1	-5	+4
50.	04.11.11-05.11.11	4	01.11.11-05.11.11	-1.1	-3	1	03.11.11-08.11.11	-1	4	5	-3.4	+2.5	03.11.11-04.11.11	-1	0	-5	+1
51.	07.11.11-14.11.11	19.1	-	-	-	-	-	-	-	0	0	-1.4	06.11.11-07.11.11	-1	0	-4	+4
52.	28.11.11	6	27.11.11-29.11.11	-1.1	-1	1	24.11.11-30.11.11	-4	2	6	-3	-1.2	23.11.11-26.11.11	-5	-2	-7	-1
53.	05.12.11	0.5	04.12.11-06.12.11	-1.2	-1	1	02.12.11-07.12.11	-3	2	5	-1.9	-0.9	04.12.11-05.12.11	-1	0	-3	+1
54.	19.12.11-21.12.11	5	16.12.11-18.12.11	-1.1	-3	-1	17.12.11-19.12.11	-2	0	2	-0.5	+0.1	17.12.11-18.12.11	-2	-1	-3	-3
55.	18.01.12-23.01.12	112	14.01.12-16.01.12	-1.6	-4	-2	14.01.12-19.01.12	-4	1	5	-2.3	+0.4	15.01.12-17.01.12	-3	-1	-7	0
56.	-	0	-	-	-	-	05.02.12-08.02.12	-	-	3	-3.2	-	06.02.12-07.02.12	-	-	-7	-
57.	17.02.12-21.02.12	66	14.02.12-16.02.12	-1.1	-3	-1	11.02.12-17.02.12	-6	0	6	-2.1	-1.2	11.02.12-14.02.12	-6	-3	-7	0
58.	24.02.12	0.2	20.02.12-23.02.12	-0.7	-4	-1	21.02.12-24.02.12	-3	0	3	-3.3	-3.3	22.02.12-24.02.12	-2	0	-8	-3
59.	09.03.12-12.03.12	6.6	06.02.12-07.02.12	-0.3	-3	-2	03.03.12-07.03.12	-6	-2	4	-1.4	?	06.03.12-07.03.12	-3	-2	-1	?
60.	24.03.12	10	19.03.12-21.03.12	-1.5	-5	-3	16.03.12-23.03.12	-8	-1	7	-3.2	?	19.03.12-20.03.12	-5	-4	-5	?
61.	09.04.12-10.04.12	15	07.04.12-11.04.12	-2	-2	2	06.04.12-09.04.12	-3	0	3	-1.8	-1.8	08.04.12-09.04.12	-1	0	-5	+2
62.	13.04.12	0.1	-	-	-	-	11.04.12-14.04.12	-2	1	3	-2	-0.1	11.04.12-12.04.12	-2	-1	-2	-9
63.	20.04.12	3	16.04.12-19.04.12	-1	-4	-1	18.04.12-20.04.12	-2	0	2	-2.5	-1.8	18.04.12-19.04.12	-2	-1	-5	-2
64.	-	0	23.04.12-25.04.12	-0.8	-	-	25.04.12-28.04.12	-	-	3	-1.1	-	26.04.12-28.04.12	-	-	-4	-
65.	13.05.12	0.1	10.05.12-12.05.12	-1.1	-3	-1	11.05.12-13.05.12	-2	0	2	-1.2	-0.9	10.05.12-11.05.12	-3	-2	-2	+1
66.	19.05.12-20.05.12	1.2	17.05.12-19.05.12	-1.1	-2	0	16.05.12-18.05.12	-3	-1	2	-1.2	-0.6	17.05.12-18.05.12	-2	-1	-4	-1
	Ø	22.775 mm		1.257° C	1.705 Tage	0.136 Tage		-3.57 Tage	0.174 Tage	3.33 Tage	-2.736 hPa	-0.725 hPa		3.29 Tage	1.12 Tage	5.042 %	-1.2307 %

From diagram 12 (page 19), it can be seen that, as a rule, the relative humidity increases with each rain event. In order to understand the exact relationship between rainfall and relative humidity, nearly all rain events of the study period are presented in Table 6 (page 15).

Table 6: History of relative humidity before, during and after isolated rain events:

Nr.	Date of rainfall event	Duration of the rainfall event	Total of rainfall	Average daily rainfall	Summer/Winter	Beginning of the rise of rel. humidity	Duration of increase of rel. humidity	Difference between the duration of the increase in humidity and the duration of the rainfall	Extent of increase in rel. humidity
1	29.01.09-03.02.09	5	55	11	S	-1	7	2	21
2	12.02.09	1	30	30	S	-1	2	1	7
3	20.02.09-23.02.09	4	112	28	S	-2	6	2	11
4	15.03.09	1	10	10	S	0	1	0	3
5	18.03.09	1	10	10	S	0	1	0	2
6	25.03.09	2	40	20	S	-1	3	1	10
7	07.04.09-08.04.09	2	11	5.5	S	-2	4	2	5
8	10.05.09	1	15	15	S	-1	3	2	5
9	21.05.09-22.05.09	2	16	8	W	0	2	0	3
10	18.08.09-19.08.09	2	7	3.5	W	0	4	2	4
11	24.08.09-25.08.09	2	57	28.5	W	0	3	1	7
12	06.09.09-07.09.09	2	2	1	S	0	2	0	3
13	15.10.09-16.10.09	2	0.7	0.35	S	-1	3	1	5
14	13.11.09-14.11.09	2	5	2.5	S	0	2	0	7
15	17.12.09	1	4	4	S	-1	2	1	8
16	22.12.09	1	10	10	S	0	2	1	5
17	21.02.10-23.02.10	3	35.5	11.5	S	1	3	0	13
18	14.03.10	1	2	2	S	0	2	1	8
19	17.03.10-21.03.10	4	29.1	7.3	S	0	7	3	12
20	25.03.10-26.03.10	2	11	5.5	S	0	3	1	6
21	01.04.10-02.04.10	2	5	2.5	S	0	1	-1	7
22	15.04.10-17.04.10	3	24	8	S	0	3	0	6
23	25.04.10-27.04.10	3	11	3.7	S	-1	2	-1	3
24	08.05.10	1	10	10	S	0	1	0	1
25	12.05.10-13.05.10	2	22	11	S	0	2	0	8
26	16.05.10-18.05.10	3	17.1	5.7	S	0	3	0	4
27	04.06.10	1	61	61	W	-1	3	2	9
28	25.06.10-28.06.10	4	8.8	2.2	W	-1	4	0	10
29	07.07.10-08.07.10	2	1.4	0.7	W	0	1	-1	11
30	10.07.10	1	0.1	0.1	W	0	1	0	2
31	12.07.10	1	2	2	W	0	1	0	8
32	14.07.10-16.07.10	3	5.4	2.8	W	0	2	-1	14
33	27.07.10-31.07.10	5	6.5	1.3	W	-1	6	1	5
34	02.08.10-07.08.10	6	35	5.8	W	0	7	1	7
35	09.08.10	1	22	22	W	0	1	0	3
36	21.08.10-26.08.10	6	31.5	5.3	W	0	6	0	5
37	29.08.10-04.09.10	7	9.2	1.3	W	-1	8	1	6
38	06.09.10	1	1	1	W	0	1	0	3
39	09.09.10	1	5	5	W	0	1	0	4
40	11.09.10-14.09.10	4	17.1	4.3	W	0	3	-1	9
41	16.09.10	1	6	6	S	0	1	0	2
42	27.09.10	1	3	3	S	-1	2	1	6
43	01.10.10	1	0.1	0.1	S	0	1	0	5
44	15.10.10	1	5	5	S	-3	4	3	7
45	17.10.10	1	5	5	S	0	1	0	4
46	21.10.10-23.10.10	3	27.1	8.7	S	0	1	-2	7
47	28.10.10	1	0.5	0.5	S	0	1	0	3
48	04.11.10	1	0.5	0.5	S	-1	2	1	12
49	08.11.10	1	0.2	0.2	S	-1	1	0	1
50	10.11.10-11.11.10	2	0.3	0.15	S	-1	2	0	13
51	19.11.10	1	0.1	0.1	S	-1	2	1	7
52	24.11.10	1	1	1	S	0	1	0	6
53	09.12.10-11.12.10	3	8.2	2.7	S	0	2	-1	8
54	16.12.10-17.12.10	2	21.1	10.6	S	-3	5	3	7
55	21.12.10	1	0.5	0.5	S	-3	2	1	5
56	28.12.10	1	0.1	0.1	S	0	3	2	6
57	04.01.11-05.01.11	2	0.6	0.3	S	0	1	-1	5
58	10.01.11-12.01.11	3	40	13.3	S	0	3	0	11

59	19.01.11	1	0.1	0.1	S	0	1	0	5
60	21.01.11-27.01.11	7	67.6	9.7	S	-1	8	1	6
61	03.02.11	1	7	7	S	-1	2	1	4
62	08.02.11	1	2	2	S	-1	1	0	1
63	19.02.11-22.02.11	4	6.7	1.5	S	-1	4	0	6
64	25.02.11-27.02.11	3	58	19.3	S	0	2	-1	2
65	01.03.11	1	45	45	S	0	1	0	5
66	07.03.11	1	1	1	S	-1	1	0	1
67	10.03.11-11.03.11	2	16	8	S	-1	1	-1	9
68	24.03.11	1	76	76	S	0	1	0	10
69	26.03.11-27.03.11	2	0.6	0.3	S	1	1	-1	2
70	31.03.11	1	0.5	0.5	S	-1	1	0	2
71	07.04.11-08.04.11	2	66	33	W	0	1	-2	5
72	11.04.11-15.04.11	5	53.3	10.7	W	0	3	-2	8
73	17.04.11-22.04.11	6	131	21.8	W	0	4	-2	6
74	28.04.11-29.04.11	2	112	56	W	0	1	-1	4
75	01.05.11-05.05.11	5	362	72.4	W	-1	5	0	6
76	08.05.11-10.05.11	3	15.5	5.2	W	0	2	-1	4
77	14.05.11	1	4	4	W	0	1	0	1
78	16.05.11	1	7	7	W	0	1	0	2
79	19.05.11-20.05.11	2	22.5	11.3	W	0	1	-1	6
80	23.05.11-25.05.11	3	18	6	W	-1	2	-1	6
81	28.05.11-01.06.11	5	19.5	3.9	W	-1	4	-1	5
82	04.06.11	1	15	15	W	0	1	0	2
83	07.06.11	1	4	4	W	-1	2	1	3
84	10.06.11-12.06.11	3	4.3	1.4	W	0	2	-1	4
85	15.06.11-19.06.11	5	56.1	11.2	W	0	5	0	10
86	21.06.11-23.06.11	3	30	10	W	0	2	-1	3
87	27.06.11	1	1	1	W	0	1	0	6
88	01.07.11-17.07.11	17	167.7	9.9	W	0	17	0	6
89	22.07.11-01.08.11	11	70.9	6.4	W	-1	12	1	8
90	07.08.11-08.08.11	2	9	4.5	W	-1	2	0	7
91	13.08.11	1	0.5	0.5	W	-1	2	1	6
92	15.08.11-17.08.11	3	1.6	0.5	W	0	2	-1	6
93	19.08.11-23.08.11	5	51.2	10.2	W	0	5	0	7
94	25.08.11-26.08.11	2	15.5	7.8	W	0	1	-1	2
95	29.08.11-30.08.11	2	2.1	1.1	W	-1	2	0	4
96	02.09.11-03.09.11	2	8.2	4.1	W	-1	2	0	2
97	10.09.11	1	0.5	0.5	S	-1	2	1	7
98	13.09.11	1	0.1	0.1	S	0	1	0	3
99	15.09.11	1	0.2	0.2	S	0	1	0	1
100	18.10.11-21.10.11	4	12.3	3.1	S	1	3	-1	1
101	28.09.11	1	1	1	S	1	1	0	4
102	31.10.11-02.11.11	3	1.2	0.4	S	0	3	0	2
103	04.10.11-05.11.11	2	4	2	S	0	2	0	4
104	07.11.11-15.11.11	9	19.9	2.2	S	0	9	0	8
105	22.11.11	1	6	6	S	-2	3	2	9
106	05.12.11	1	0.5	0.5	S	0	1	0	4
107	19.12.11-21.12.11	3	5	1.7	S	-1	4	1	7
108	23.12.11-24.12.11	2	1.1	0.6	S	1	1	-1	2
109	11.01.12	1	2	2	S	0	1	0	7
110	14.01.12	1	11	11	S	0	1	0	4
111	18.01.12-24.01.12	7	113.1	16.2	S	-1	8	1	8
112	30.01.12-31.01.12	2	0.2	0.1	S	-1	3	1	5
113	02.02.12	1	1	1	S	0	1	0	3
114	15.02.12	1	0.1	0.1	S	-1	1	0	1
115	17.02.12-21.02.12	5	66	13.2	S	-1	6	1	11
116	24.02.12	1	0.2	0.2	S	0	1	0	3
117	26.02.12	1	0.5	0.5	S	0	1	0	5
118	11.03.12-12.03.12	2	6.1	3.2	S	-1	2	0	5
119	03.04.12-04.04.12	2	1.5	0.8	S	0	1	-1	2
120	07.04.12	1	0.1	0.1	S	-1	1	0	2
121	09.04.12-10.04.12	2	15	7.5	S	0	1	-1	9
122	13.04.12	1	0.1	0.1	S	-1	3	2	3
123	20.04.12	1	31	31	S	-1	2	1	9
124	03.05.12-08.05.12	6	2.8	0.5	S	-1	4	-2	3
125	13.05.12	1	0.1	0.1	S	0	1	0	5
126	19.05.12-20.05.12	2	1.2	0.6	S	0	2	0	4
127	22.05.12-25.05.12	4	27.1	6.8	W	0	3	-1	8
128	28.05.12-31.05.12	4	19.1	4.8	W	0	4	0	3
129	02.06.12-03.06.12	2	18.1	9.1	W	1	1	-1	2
	Ø	2.49	21.50	8.09		-0.40	+2.64	+0.14	+5.59
	Ø Summrer	2.02	14.16	6.61		-0.48	2.35	0.33	5.65
	Ø Winter	3.33	34.74	10.75		-0.26	3.15	-0.2	5.48

From table 6 (page 15) can be concluded the following: 129 rain events were examined. 83 of them took place during a dry season, 46 during a rainy season. On average, each rainfall lasted 2.49 days, during which it rained an average of 21.5 mm. This makes up for an average daily rainfall of 8 mm. The relative humidity increased on average by 5.59% per rain event. The increase in relative humidity began on average 0.4 days before the start of the rain and lasted on average 2.64 days, which is 0.14 days longer than the rain event. The rainfall events during the summer time were shorter and less than half as productive as those of the rainy season. The daily rainfall was much lower during the dry season than during the rainy season. The increase in relative humidity began much earlier in the dry season than in rainy rainfall, but the end of the increase in relative humidity occurred before the end of the rainfall, during the rainy season. In 38% of all rain events, the humidity began to increase before the start of the rainfall, in 58% of all rain events it happened on the same day the rain started, in 4.7% of the rain events one day after the start of the rain. So we can conclude that the rain can be both cause and consequence of high humidity, or in other words: the variations of the relative humidity in the range of days are partly homemade, i.e. consequences of previous rain events.

Diagram 9: Increase in relative humidity during rain events as a function of rainfall duration [hPa]:

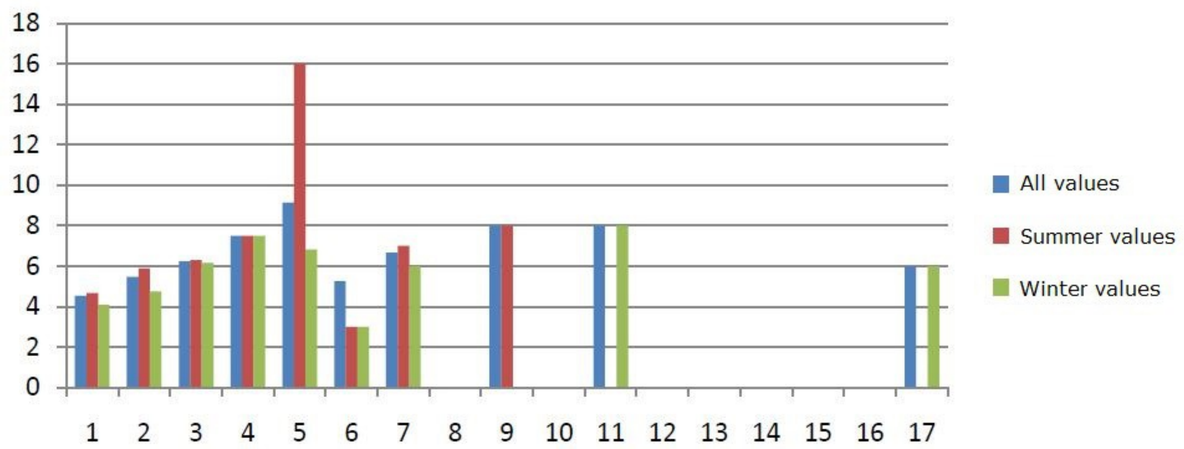


Diagram 10: Increase in relative humidity during rain events as a function of average daily rainfall [hPa]:

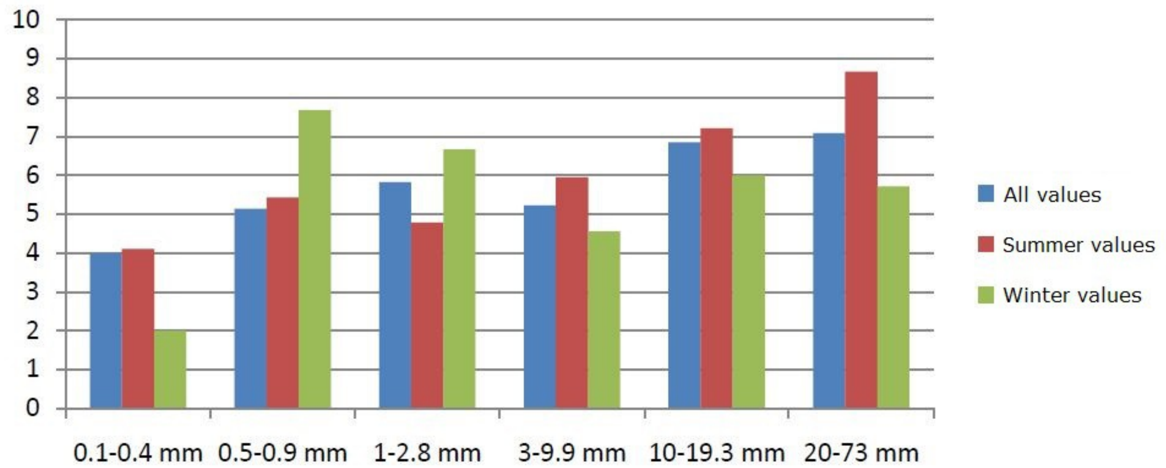
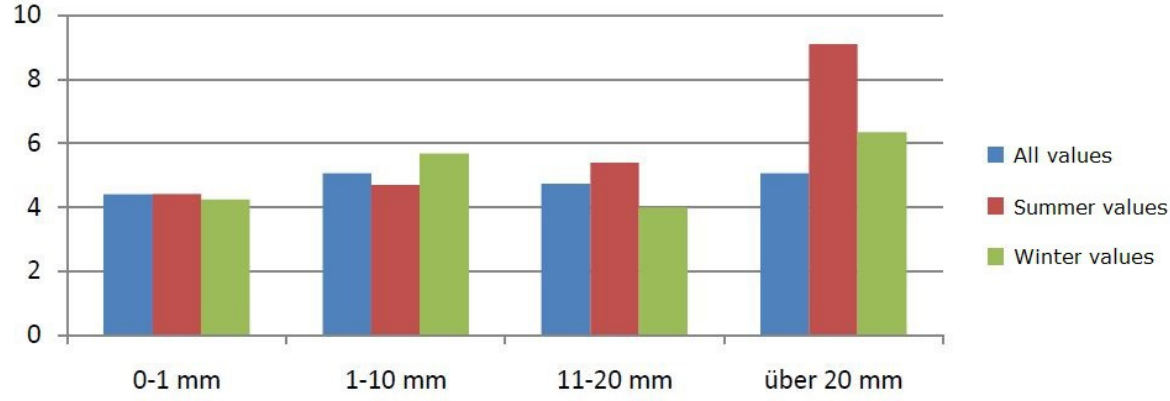


Diagram 11: Increase in relative humidity during rain events as a function of rainfall per event [hPa]:

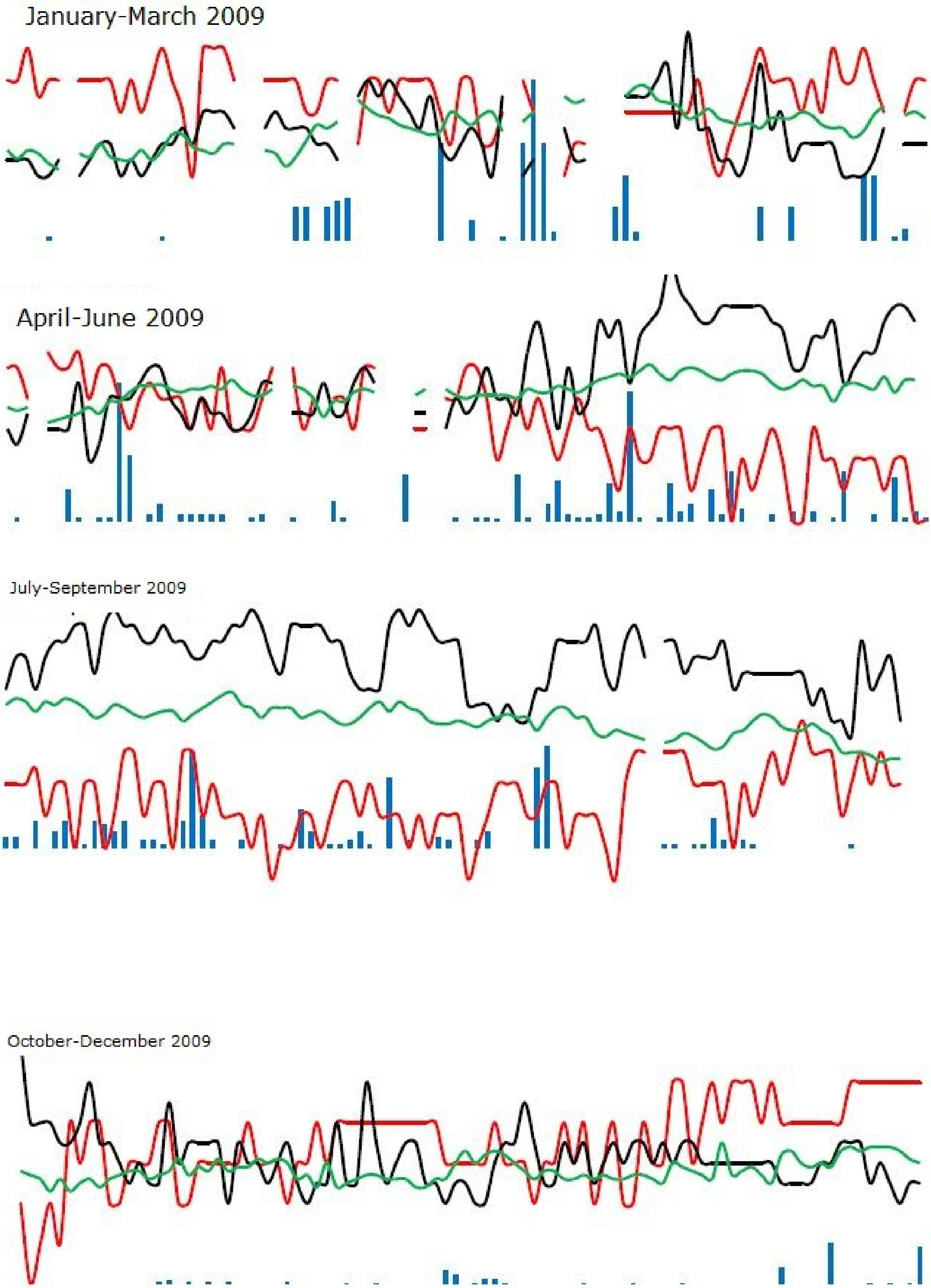


Although the increase in humidity obviously depends on the existence of rainfall events in the previous days, it does not depend much on the amount of rainfall. Even very small amounts of rain can cause a considerable increase in humidity, on the other hand a large amount of rain does not necessarily cause a correspondingly large increase in humidity. The longer the rainfall lasts, the greater is the increase in relative humidity. Increases in humidity accumulate when rainfall events continue for several days. However, this statement is only valid until the 5th rainy day, to which a mean increase in relative humidity of around 9% can be expected. If the rain event lasts longer, the relative humidity doesn't increase any longer (see diagram 9, page 17). Obviously, there is a maximum of relative humidity that will not be exceeded. The increase in relative humidity is almost independent of the average daily rainfall, except for very low values of up to 0.4 mm of rain per day. Even with very high daily rainfall, the relative humidity increases only slightly more than with low daily rainfall above 0.5 mm (see diagram 10, page 17). Also, the absolute amount of rain per rain event has little effect on the increase in relative humidity. Rainfall of 1mm causes a similar increase to record rainfall events. Only heavy precipitation during the dry season causes the relative humidity to rise more strongly.

Two observations suggest that relative humidity is not only a cause but also a consequence of rainfall events: on the one hand, the fact that the increases in relative humidity are due to rain events lasting several days, and, on the other hand, the fact that after completion of the rainfall event Rain event the humidity increases even further.

What happens during dry periods with relative humidity? Diagram 12 (page 19) provides information: After the conclusion of a rain event, it only continues to rise for a short time, after which it begins to decrease if there are no more downpours, until it has reached the usual mean of the season. Shortly before the next rain event, the relative humidity usually drops again. Not infrequently, however, are variations in the relative humidity during the dry season, with or without minor downpours.

Diagram 12: Morning temperature (red), barometric pressure (black), humidity (green) and daily rainfall (blue)



4. Interpretation of the results

There is a great number of literature on climate conditions in northeastern Brazil. They all deal mainly with the question of which meteorological phenomena are responsible for rain events. The following weather phenomena are mentioned:

1. sea breeze
2. cold fronts
3. Cyclonic whirlwind of the upper trophonic (= Upper trophopheric cyclonic vortex)
4. Trade wind
5. Intertropical zone of convergence
6. South Atlantic Subtropical Anticyclone SASA
7. Disturbance of the tropical wave (= easterly wave disturbance = ondas de leste)
8. Steep rain on mountains
9. instability lines (= Linhas de instabilidade)
10. Cloud groups (= Cloud clusters = Complexos convectivos de mesoescala)
11. Madden-Julian oscillation

The local data collected in Cumaru can only partially confirm or refute one or other of these majority regional phenomena. However, the phenomena described in the literature are only partially able to explain the conditions established in Cumaru. Therefore, I first try to establish connections between the prevailing conditions in Cumaru and the explanations for rain events in the literature, after I'll try to make an attempt to interpret the climatic conditions of Cumaru in my own way.

4.1. Remarks on climate phenomena described in the literature:

The ocean breezes and trade winds are certainly the climate phenomena that determine weather in Cumaru. On the one hand, in Cumaru there is always a wind blowing from the east during the day, on the other hand, the distribution of rainy season and dry season in Cumaru is largely consistent with coastal locations, but differs significantly from places further inland. The rare summer rains in Cumaru are often preceded by a reduction in pressure, a drop in temperature and a reduction in humidity, which are indications that they are triggered by cold fronts from the south. According to Dantas Marciano 2012, the disturbances of the tropical wave (Easterly Wave disturbance = ondas de leste) occur in the months of May to August and seem to have an influence on the coastal region between Bahia and Ceará. Accordingly, it can be assumed that Cumaru is also within the sphere of influence of this climate phenomenon. C. Dizerens also confirms in her letter (see chapter 7) that the cold fronts are to be seen in connection with the middle latitudes. The direct influence of the intra-tropical convergence zone can be clearly excluded in Cumaru because the rainy season in Cumaru does not coincide with the southern summer and is accompanied not by a reduction, but by an increase in atmospheric pressure. Given that the center of Cumaru - and thus the measuring station of the data discussed here - lies to the west of a mountain range, precipitation rain can be excluded as the cause of precipitation. On the contrary, it is more likely that the rainfall due to these heights in Cumaru is lower than, for example, in Passira. A possible influence of cyclonic whirlwinds of the upper troposphere, the South Atlantic anticyclone, cloud groups, the Madden-Julian oscillation and the instability lines on the climate of Cumaru can not be assessed on the basis of the local data.

4.2. Attempt of an own interpretation of the meteorological data of Cumaru:

In order to better understand the phenomena described in Chapter 3, we can distinguish between the daily events and the course during the year.

Daily course of the climate parameters

Based on the measured data, the day in Cumaru can be divided into the following five phases from a meteorological point of view. See also illustration 1 (page 22).

a) Air heating during the morning: At sunrise, the lowest temperature of the day prevails. As soon as the sun begins to shine, the soil and atmosphere heat up, and the relative humidity decreases. The heated air expands, becomes lighter and rises. This creates an elevation in the higher layers of the atmosphere. The elevation is in the form of a wave that moves from east to west at the speed of the earth's rotation, because the sunrise occurs all along the longitude. This speed is over 1,500 km per hour in Cumaru. As the warm air rises, it cools down again, which in turn decreases the relative humidity. This can lead to cloud formation, which in turn reduces the warming of the earth's surface and the overlying layers of air. High humidity and soil moisture at the beginning of the day increase the likelihood of cloud formation. Sunlight increases until lunchtime, but the warming of the ground is delayed because it stores the cold of the previous night better than the atmosphere. The warming of the atmosphere by solar radiation increases until about 2:30 pm.

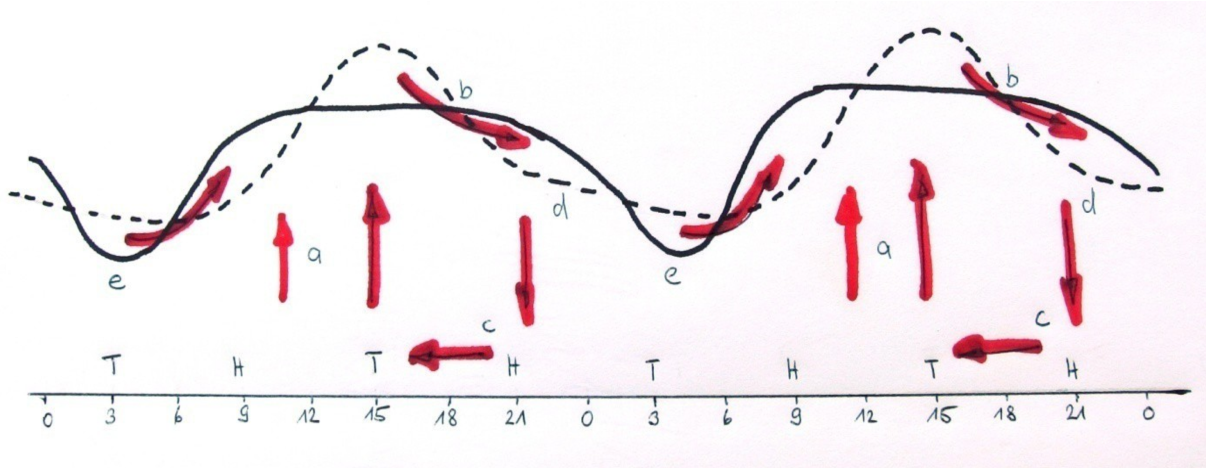
b) Distribution of the air wave to the east: The air wave created by the warming of the atmosphere seeks level compensation by wind flow into the wave trough. This air mass transport occurs mainly to the east because the wave propagates faster to the west than the maximum wind speed. In summer, a deflection of this northeast wind is also conceivable, because the atmosphere above the Atlantic there warms up less quickly than over the land mass, so the air wave above the water is lower.

c) Increase of barometric pressure near the ground and pressure-compensating wind: The transport of the high-altitude air to the east causes a decrease in the ground-barometric pressure under the wave and an increase in the ground-barometric pressure below the wave-valley in the east. Near the ground, a wind is created from east to west, trying to balance the neighboring differences in ground pressure. This wind is felt daily in Cumaru. This phase continues as long as the air is heated by the sun.

d) Cooling of the atmosphere in the afternoon and evening: Around 2:30 pm the warming of the atmosphere decreases. The air masses begin to condense, forming a trough in the upper layers of the air. Until about 21 o'clock, the incoming mountain air from the west succeeds in filling up this wave trough. At this time, there is high barometric pressure on the ground. As the atmosphere cools, the relative humidity increases. The decrease in temperature and the increase in relative humidity is continuous until the next sunrise.

e) Nocturnal changes in barometric pressure: Surprisingly, the barometric pressure drops sharply after 9 pm and reaches a new low at around 3 am. Thereafter, he rises again until about 9 o'clock in the morning. I cannot explain meteorologically this course of the barometric pressure, but at best physically: Very regular wave movements seem to tend to overshoot on their return to the starting position on the target. This tendency is called “Gibbsian phenomenon”. If this phenomenon explains the pressure differences at about 3 o'clock and 9 o'clock in the morning, a high-altitude wind would have to blow in this time interval to the east, which generates the pressure differences. At ground level, in any case, according to my observations, no pronounced or everyday wind is noticeable early in the morning. Perhaps the nocturnal changes in atmospheric pressure also have to do with the land-water distribution in the tropics and subtropics, because according to Dai 1999, a relative high occurs just above the relatively warm Atlantic Ocean at midnight, which moves to the west in the following hours.

Illustration 1:Daily course of the movements of the air masses over Cumaru. 48 hours are shown. T = low pressure; H = high pressure. The letters a-e correspond to the description on page 21, the red arrows air movements



The distribution of land and water influences the wind directions: In southern summer, the atmosphere above the land warms more than over the neighboring sea in the north and east. The daily air wave is thus higher over the continent than over the sea, and the air masses at the border between land and water are diverted from their eastern to the northeast direction.

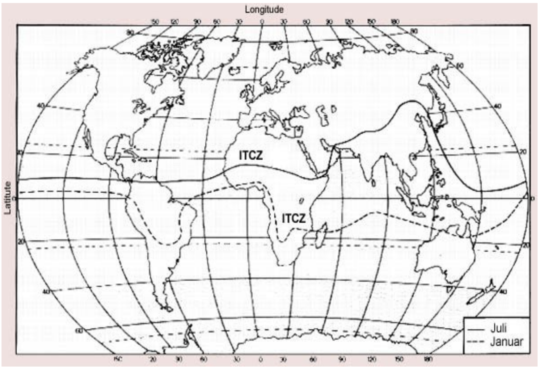
Basically, this process runs daily. In winter, however, the sun is much weaker. The daily course of atmospheric pressure observed in Cumaru corresponds exactly to the description of Riehl 1979 (page 286 f.). Unfortunately, this author doesn't provide any explanation for this phenomenon. The daily history of atmospheric pressure above-described also corresponds largely to the observations of Dai 1999. He noted two high-pressure waves revolving around the earth every day at the speed of Earth's rotation. According to his observations, they should be in Cumaru at about 8 o'clock a.m. and at about 10 o'clock p.m., about an hour later than actually observed. This difference may be related to the fact that Cumaru's local time is not the same as the Brazilian time zone, or the fact that Dai only used data collected every 3 hours. Dai's data show that the high-pressure wave is stronger across the continent and in the southern summer than over the sea and in winter, and it can also be seen that the nocturnal high-pressure wave is weaker than the morning and seems to weaken over the land mass of South America. However, even Dai provides no plausible explanation for the phenomenon.

Yearly history of climate parameters

The above-mentioned daily cycle is overlaid by the effects of the intra-tropical convergence zone. Northeastern Brazil is outside this zone throughout the year, but within the area of influence of the areas adjacent to the convergence zone. We can distinguish between the situation in winter and in summer:

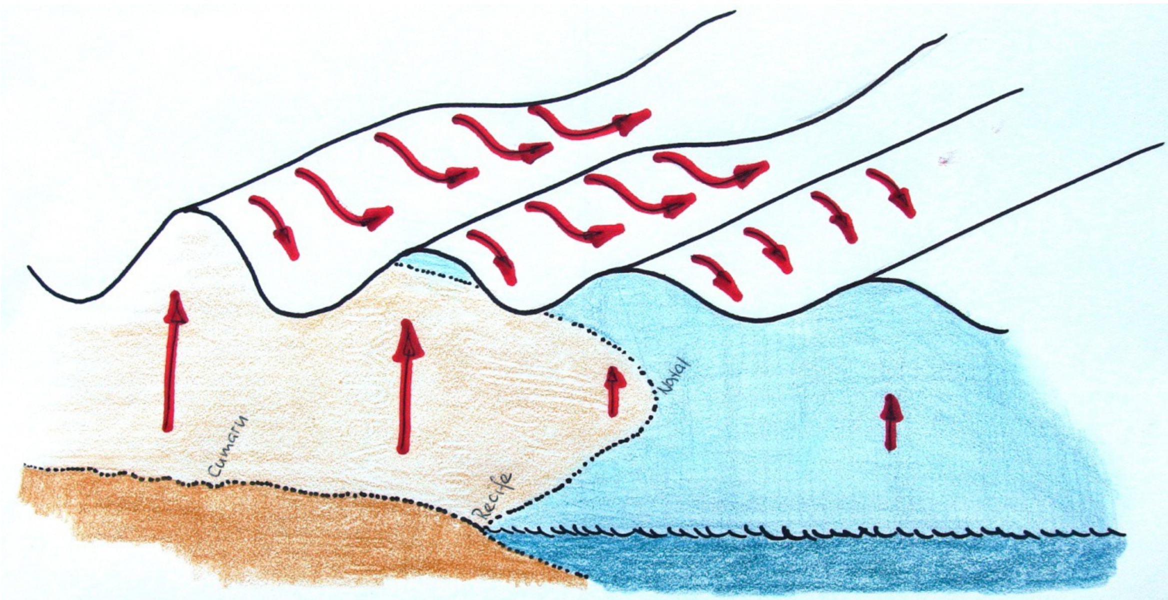
In southern summer, the intra-tropical convergence zone in the north and west normally leads around northeastern Brazil. Its location is mainly determined by the sea temperature. The Northeast itself is under the influence of the falling winds, which come partly from the Amazon basin. Since these winds had previously flowed not over the sea, but over warm land mass, they had less opportunity to saturate with moisture, lost more moisture in the intra-tropical convergence zone and warm up more when falling over the Northeast of Brazil. This results in dry winds in the Northeast during the southern summer. The rare rain events in summer are likely to be mostly due to foothills of cold air fronts, which determine the summer rain regime in Bahia and sometimes push forward to Cumaru.

Illustration 2: Location of the Intertropical Convergence Zone in summer and winter



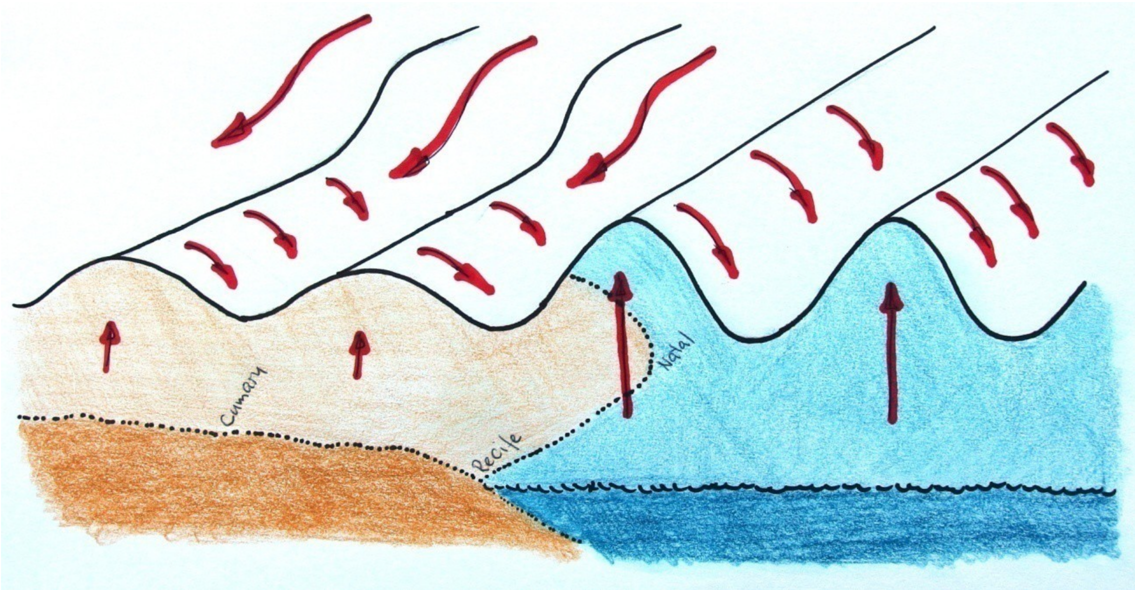
In the southern winter, the intra-tropical convergence zone moves away from the South American continent to the north. The relatively dry winds that come from the Amazon basin in the summer slowly lose their power in Northeastern Brazil and are replaced by wetter winds from the Atlantic. In winter, the intra-tropical convergence zone of Brazil is completely above the relatively warm Atlantic Ocean. The winds are carried farther south in winter than in summer, because the atmosphere over land is less heated during the day and more strongly cooled during the night. This effect creates a depression in the upper layers of the air above the landmass, into which the humid and relatively warm winds of the intra-tropical convergence zone invade, especially at night, mixing with the local atmosphere and causing rainfall. In Cumaru, the wettest months coincide with the period in which the intra-tropical zone of convergence is above the sea and with the period of weakest local sunshine. The rainy season starts earlier in the more distant regions of the Northeast, because the more continental the climate is, the sooner the lack of solar radiation will be felt.

Illustration 3: barometric pressure and movements over northeastern Brazil in summer



The theory above described explains Hastenrath's observation that the abnormal weather events in Guiana are reverse of those in Northeastern Brazil. If the hypothesis is correct, it should rain in winter, especially at night or in the early morning. Unfortunately, the respective beginning of the rain events in Cumaru has not been duly considered. After all, Ramos 1975 mentions that the winter rains occur mainly in the east of Petrolina at night and early in the morning.

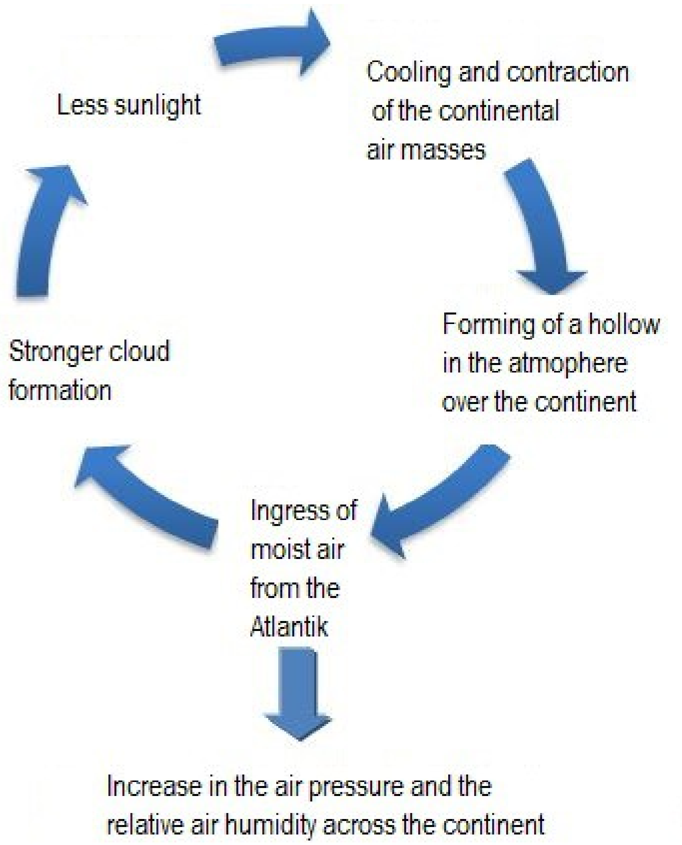
Illustration 4: Air pressure and air movements over northeastern Brazil in winter :



The moist air masses that invade the Northeast of Brazil from the north in winter increase the likelihood of rainfall. The moister the air is, the greater the rain probability. However, the coincidence of two factors is probably necessary to create a rain-promoting situation: on the one hand, the intrusion of moist air masses from the Atlantic through the wind turbine of the intra-tropical convergence zone and through the atmospheric sink over the cold continent, on the other hand, a sufficiently high humidity of the local air masses over the continent. It can be assumed that a considerable part of the local rainfall consists of water that has evaporated in neighboring regions during the previous day.

The processes that change during the rainy season are shown in the following fluxogram:

Diagram 13: Changes in the climatic situation in Cumaru during the winter:



In winter, Cumaru is not only under the influence of the humid air masses from the north, but also below the one of the trade winds that come from the southeast to the northeast of Brazil and determine the climate in the coastal region. With the highest rainfall in the months of May to June Cumaru is in the same family of similar rain regimes according to the "Atlas pluviométrico do Brasil" (1948) as coastal cities such as Maceió-AL or Escada-PE.

Low rainfall is only stored for a short time in the soil. Generally the water evaporates within the first two days after a rain event. I've found that a millimeter of rain penetrates no more than one centimeter into the ground. Probably rain events of less than 15 mm are hardly available for plant roots and evaporate within a day or two. This evaporation is most responsible for the increase in relative humidity in the time after a rainfall event. If the rainfall is very large, some of the water is led away from the area via streams and rivers and is no longer available for evaporation on site. A small part of this water shifts to deeper soil layers or is incorporated into biomass. From there, the return to the atmosphere is slower. In this context, I would like to draw attention to the importance of vegetation and the storage capacity of the soil: A rocky surface without vegetation can hardly retain water, and also becomes very hot during the day and cools down strongly during the night. Deep soils and dense vegetation are able to store a lot of water, slow down the return of the water to the atmosphere, slow down the wind and reduce temperature and humidity fluctuations. The denser the vegetation and the more profound the soil is, the more balanced the climate and the more regular the distribution of rain events.

I suspect a close correlation between the climate-influencing factors of the Amazon basin and the climate of the Northeast. Especially in summer, the intra-tropical convergence zone leads air masses of the Amazon basin directly into the northeast. Therefore, the better the Amazon Basin is able to provide the atmosphere with moisture, the more water is left over for the Northeast. According to Hastenrath (p. 353), the soil moisture, the roughness and the reverberation of the terrain surface are the main influencing factors. These properties, in turn, are significantly influenced by the vegetation: It stores water, increases the evaporation surface, slows down the wind and reduces the reverberation. Water surfaces also have a positive effect on the climate because they evaporate water and balance the temperatures (see Riehl p. 280 ff.)

It is also to be assumed that there is a strong relation between the sea temperature in the north of the Northeast and the amount of rain in the Northeast: the warmer the sea is, the less the intra-tropical convergence zone moves northwards in winter, the more water evaporates in the vicinity of Brazil and the greater are the temperature differences between land and water, the greater the rainfall.

4.3. Weather forecast

The collected meteorological data allow the following conclusions:

1. The start of the rainy season in Cumaru coincides with a drop in early morning temperature of over 0.5º C and a rise in atmospheric pressure of 1.5 hPa over several days.
2. If, in the dry season, the early morning barometric pressure decreases by more than 2.5 hPa within 3 days, the early morning relative humidity falls by more than 5% in the same period, and aditionally on the third day the early morning air temperature drops more than 1º C, these are signs of a summer rain, due to a cold front coming from the south.

4.4. Dimensioning of cisterns

Whoever builds a cistern to store rainwater wants to know the dimensions of the cistern in relation to the roof area, to loose as little building material and water as possible. With the collected data it is possible to calculate the ideal size of cisterns:

A cistern capable of withstanding the heaviest rainfall would have to be about 400 liters per square meter of horizontal capacity of the roof. An example: A house with a roof area of 100 m^2 would need a cistern volume of 40 m^3 (a cube with a side length of 3.50 m). In this way, 400 liters of water could be taken from the cistern daily. Smaller cisterns would overflow during a rainfall event such as that from 28th of April to 5th of May 2011, or from 15th to 18th of June 2010. So if you decide to build a smaller cistern, you don't do it because of the supply of rain, but because of other criteria, such as the water demand, the available space, construction costs, etc.

In order not to waste water unnecessarily, it is important to clean the cistern at the right moment, that is, when it is almost empty, or at the beginning of the rainy season. It is therefore recommended to separate the cistern volume into two individual cisterns connected by a closable tube so that the water can be pumped into the other cistern to clean one cistern. It is also advisable to drain the first (polluted) rainwater after long periods of drought (there are simple, cheap semi-automatic installations) and run all the rainwater into the cistern through a sieve, which fits into the pipe. Exposing a few small fish ("piabas") in each cistern prevents the growth of mosquito larvae. Finally, I recommend floating in each cistern a 2 cm thick Isopor plate on which any fallen land animals will be saved and thus not pollute the water.

5. Used literature

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Hamilton Kevin, Ryan Steven C., Ohfuchi Wataru, **Topographic effects on the solar semidiurnal surface tide simulated in a very fine resolution general circulation model**, in: Journal of geophysical research, Vol. 113, D17114, 2008

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Henner Marco, **Der Jahresverlauf der ITC** (ITCZ): https://www.youtube.com/watch?v=yBScl_UpGvQ

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Mishra S. K., Brahmananda Rao V., Sergio H. Franchito, Instituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil, **Genesis of the Northeast Brazil Upper-Tropospheric Cyclonic Vortex: A Primitive Equation Barotropic Instability Study**. April 2007

Ramos, R. P. L., 1975, **Precipitation characteristics in the northeast Brazil dry region**. J. Geophys. Res., 80, 1665-1678

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Schwerdtfeger Werner, World Survey of climatology Volume 12, **Climates of Central and South America**, Elsevier Scientific Publishing Company, Amsterdam-Oxford-New York 1976

University of Hawaii at Manoa, **Why Atmospheric Pressure Peaks At 10am And 10pm In The Tropics**. ScienceDaily. ScienceDaily, 14 December 2008. <www.sciencedaily.com/releases/2008/12/081203092437.htm>.

6. Useful links

- http://www.apac.pe.gov.br/meteorologia/
- Why high air pressure at 10 o'clock and at 22 o'clock in the tropics: http://www.sciencedaily.com/releases/2008/12/081203092437.htm
- atmospheric tide: http://de.wikipedia.org/wiki/Gezeitenwind
- Square wave: http://de.wikipedia.org/wiki/Rechteckschwingung
- Overshoot: http://de.wikipedia.org/wiki/%C3%9Cberschwingen

7. Correspondence

Inquiry of 30.11.2014 to the climate group of the University of Bern and the Instituto Nacional de Meteorologia INMET:

Dear Ladies and Gentlemen!
For 4 years, I recorded the weather data in Cumaru to understand which key factors shape the local climate. In the evaluation of these data, two questions have arisen that I have not been able to answer. As a former biology student at the University of Bern, I therefore turn to the climatology research group with the question of whether you know someone who will help me or if there is a book in your library that answers my questions. To illustrate my questions, I send you an excerpt of my unfinished report with two diagrams in the appendix (temperature, red, barometric pressure (black), relative humidity (green) and daily amount of rain (blue)). For eventual further information I am of course happy to help.
Here are my questions: Cumaru is a village in the semiarid Northeast of Brazil, in the state of Pernambuco, about 8 degrees south latitude and about 100 km from the South Atlantic. I have found that the barometric pressure rises twice daily and drops twice, almost at identical times of the day: the pressure is low at around 3 o'clock and at 15 o'clock, high at 9 o'clock and at 21 o'clock. Especially in the afternoon a wind blows from the east. Can you explain to me how these pressure conditions come about? My own explanation is the following: After sunrise, the atmosphere warms up and generates a wave until about 14 o'clock in the upper air layers, which is transported to the east due to the earth's movement and generates there an anticyclone (at 21 o'clock). In the lower layers of the air, the wind tries to compensate for these pressure conditions (wind in the afternoon). In the afternoon and evening, the atmosphere cools down again, creating a wave trough, which is filled up by the wave. So far so good. I do not understand the emergence of the bottom low at 3 o'clock in the morning and the bottom high at about 9 o'clock. Can you help me here?
And a second question: Each 2-3 days before the rare rainfalls during the dry period, which lasts from September to March, pressure and humidity drop sharply, but rise again during the rain event (see diagram in the appendix). Why?
Thank you in advance for your help! With kind regards: Bruno Kägi

Answer of the climate group of the University of Bern

Dear Mr. Kägi
Please excuse the late reply. What you have observed is observed throughout all tropics. Here is an explanation: http://www.sciencedaily.com/releases/2008/12/081203092437.htm. I can also recommend the paper by Dai (1999), which shows that North Brazil has particularly high fluctuations in atmospheric pressure. The observations of sinking pressure and decreasing humidity before an event indicate that

the precipitation events are related to cold fronts. In fact, Kousky (1979) has already described that. I think this study might interest you because the same phenomena that you identified are there. I annex the papers by Lyra et al. (2014) and by Liebmann et al. (2011), which deal with precipitation events and extreme events in Northeastern Brazil. It is nice to see that, as expected, the cold fronts have to do with the well-known mid-latitudes. It would be interesting to have wind data. I suspect that the wind comes from another direction in front of such cold fronts, compared to the sea breeze, which is certainly more humid and blows there in "calm" days. Maybe there are also small "mountains" (up to 1'000m) west of Cumaru, which can cause a "foehn" effect. But that's just speculation ... Maybe you get more informations from other stations in the area? e.g.
http://www.wunderground.com/history/airport/SBUF/2014/11/2/MonthlyHistory.html or
http://www.wunderground.com/history/airport/SBPL/2014/11/2/MonthlyHistory. html. The mentioned studies can be found in the appendix.
I hope that this information will help you. With kind regards

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Answer of the INMET:

Dear Bruno,
Air is a fluid, and like the ocean, it suffers the effects of the gravitational pull of the sun and the moon. While in the ocean we have the phenomenon of the tides, in the atmosphere the same phenomenon occurs, and it is called the barometric tide. That is why the daily variation of pressure, very well perceived by you.
As for the 2nd question: It is natural that the pressure of the atmosphere falls before the rains, due to the change of movement of the winds. Pressure is force on area, so a region with high pressure is under the domain of a descending air (exerting force down, therefore on the surface); a region with low pressure, the air is in the ascendancy, hence decreasing the force on the surface and causing low pressure which, in general, is associated with atmospheric instabilities, therefore in conditions to change the weather and cause rains. As for the variation of the humidity, probably the change in the circulation of the winds causes the variation of the relative humidity.
Regards, Communication Advisory
INMET - INSTITUTO NACIONAL DE METEOROLOGIA