

**Seasonal Prediction and Climate-Related Information in the Brazilian  
Northeast: Water Resource Impacts in the State of Ceará**



*Satellite image at 1:25,000 (IBGE) from [http://www.cdbrasil.cnpm.embrapa.br/ce/htm0/ce13\\_27.htm](http://www.cdbrasil.cnpm.embrapa.br/ce/htm0/ce13_27.htm)*

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## *Introduction*

The State of Ceará is located in the Northeast of Brazil and is considered one of the most densely populated semi-arid regions in the world. With an estimated population of 7.1 million people, of which 39% percent reside in the capital city of Fortaleza<sup>1</sup>, there are many sectors competing for limited water resources, including municipal (human consumption), industry, agriculture, fishermen, and ranching. There has been a large push from the state government behind the recent growth in industry and tourism, which has centered predominantly on the Fortaleza Metropolitan Region. Of the 48% total rural population, 79% are employed in the agricultural sector<sup>2</sup>, however, many of these farmers do not currently have access to formal water resource infrastructure and are rain fed agriculturalists. The climatic variability of the region and subsequent history of multi-year droughts has made water resources, their allocation and management a forefront issue in social, political and economic issues of the region and the State. This issue is key to social and political systems within the state and nationally, in that the population of Ceará are considered among the poorest in all of South America.

With pressures from the federal government and international funding agencies such as the World Bank, there has been a trend in the past 30 years towards the decentralization of water resource management throughout Brazil. Within the state, this has meant a dramatic increase, and focus on, hydrological infrastructure development, including reservoir and canal systems. In addition to this, there are many statewide and regional approaches to water management and allocation, including the creation of Water Allocation Committees on the river-basin level, which are responsible for bi-annually determining the release of waters from regional reservoirs for the rural population and associated sectors.<sup>3</sup>

### *Sectoral Water Uses in Ceará*

Although the State of Ceará is a semi-arid region, known for long-periods of drought, the actual water reservoir totals throughout the region, under the majority of climatic conditions, are at sufficient levels for current levels of water needs.<sup>4</sup> The agricultural sector of the State of Ceará represents only 7% of the total GDP, approximately 2.69 million people, or 26% of the State's population, are employed in agricultural activities<sup>5</sup>. Therefore, the crop productivity and water needs are imperative to the livelihoods of many, particularly in the face of climate variability. However, there are major inefficiencies within the infrastructure of water allocation, as well as high levels of misallocation and inequitable allocation among competing sectoral water uses. As is seen in Table 1, there are many driving forces behind the sectoral allocation of water including population, relative income and tourism rates.

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<sup>1</sup> Governo do Estado do Ceará, 2000b

<sup>2</sup> Data as of 1999

<sup>3</sup> The Committees meet in January and July, in the beginning and end of the rainy season, respectively.

<sup>4</sup> From December 2, 2004, interview with Renzo Taddei, PhD Candidate, Applied Anthropology, Teacher's College, Columbia University, and field researcher in Ceará.

<sup>5</sup> Estimates calculated using census data from Governo do Estado do Ceará, 2000b.

**Table 1. Main Driving Forces of Sectoral Water Uses in Ceará (1996 to 1998)<sup>6</sup>**

Irrigated area (ha)	43,024
Cows / pigs / sheep (10 <sup>6</sup> )	2.4 / 1.1 / 1.6
Population (10 <sup>6</sup> )	6.7
Industrial gross domestic product (10 <sup>6</sup> 1995-US\$/yr)	2,843
Touristic overnight stays (10 <sup>6</sup> /yr)	36.3

As can be seen in Table 1, there are many demand-side pressures on the water resources available and the methods of allocation in the State of Ceará. This paper will survey some of the data available concerning the weather phenomena, variability, methodologies and applications used in the state to monitor and predict the availability of water throughout the State. Because precipitation is the sole provider of water resources in the majority of the state (with no perennial rivers or groundwater resources), the climatic variability is key to the population.

In the following section, Weather and Climate in the State of Ceará, I will take a closer look at the regional weather and climate phenomena that are monitored and used in forecasting. Following, the section Monitoring Climate Variability and Change discusses examples of tools used and application of climate data in the region. Lastly, Water and Poverty: Climate impacts in the Semi-arid Northeast talks to the integration of climate data into political and social systems and discusses some of the impacts of drought on the region’s population.

**Weather and Climate in the State of Ceará**

*Variability*

Throughout recorded history of Brazil, the Northeast has been plagued with intense droughts and climatic variability. The Great Drought of 1877-79, alone, accounted for over 400,000 deaths in the State of Ceará and spurred mass out-migration. It was at this time during the Colonial Era that the issues surrounding drought first became a part of the Brazilian National Agenda, with mitigation responsibilities allocated predominantly to the States. Since then, much attention and money has been paid towards helping to reduce the region’s population from vulnerability to climate variability, particularly drought (Lemos: 486).

As can be seen in Figures 1-4 below, the amount of precipitation throughout the State is far from uniform spatially or annually; There is a great amount of variability in the amounts of rainfall in a region both due to its topography and proximity to the coast, as well as other factors. The figures below map the

Classification	rain/year
Arid	< 20
Semi-arid	20 < IA < 50
Sub-humid dry	50 < IA < 65
Sub-humid humid	65 < IA < 100
Humid	> 100

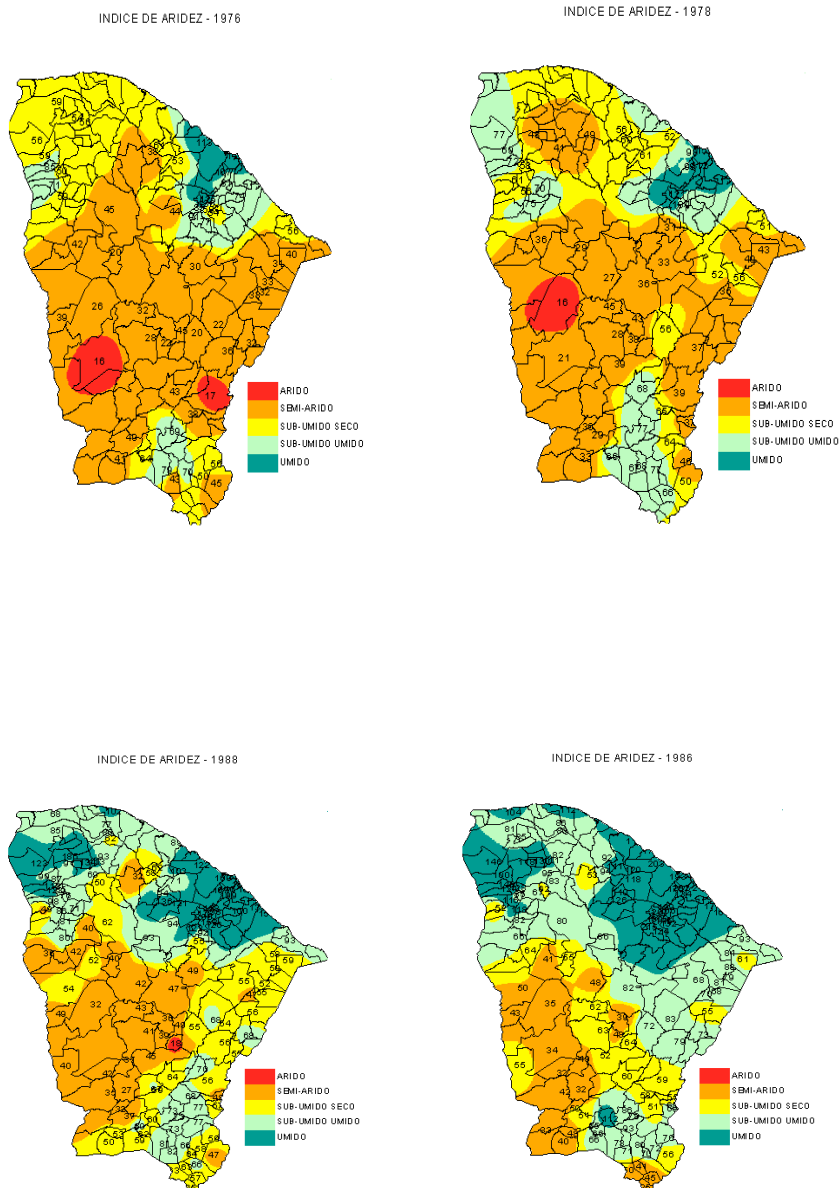
*(From FUNCEME website)*

“Aridity Index” for the State, as calculated by ONU and measured using numerous pluviometric posts throughout the State. As can be seen in Figures 1-4, those regions nearest to the coast tend to be more humid, as opposed to the very dry “hinterlands” of the Sertão, or inland regions of the State. As can be seen in Figure 5 below, the trend for the majority of

<sup>6</sup> P. Doll et al, Table 2: pg. 315

the State for the past 25 years is as a semi-arid region. The spatial and annual variability in precipitation is key to the vulnerability of the populations in the region. Furthermore, it is fundamental to the need for policy development and mitigation strategies for the region. However, it is exactly this issue of variability that also adds to the complexity of the needs for the region, with some areas feeling greater water pressures than others over time and depending on the trends of the year, in particular. Further complicating matters, those inland regions that are consistently semi-arid are home to the majority of the State's poorest populations, who are predominantly rain-fed, landless agriculturalists.

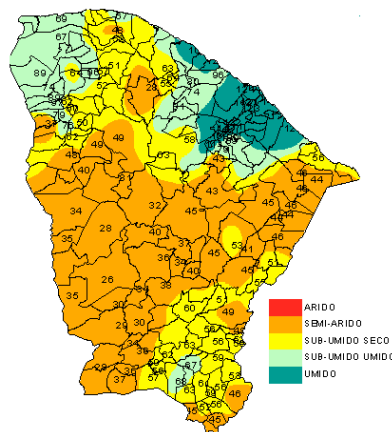
**Figures 1-4: Maps of Aridity Index for 1976, 1978, 1988, 1989 for the State of Ceará**  
*(Upper left, right, lower left, right, respectively)*



from <http://www.funceme.br/DEMET/Index.htm>

**Figure 5. Average “Aridity Index” for the State of Ceará (1975-2000)**

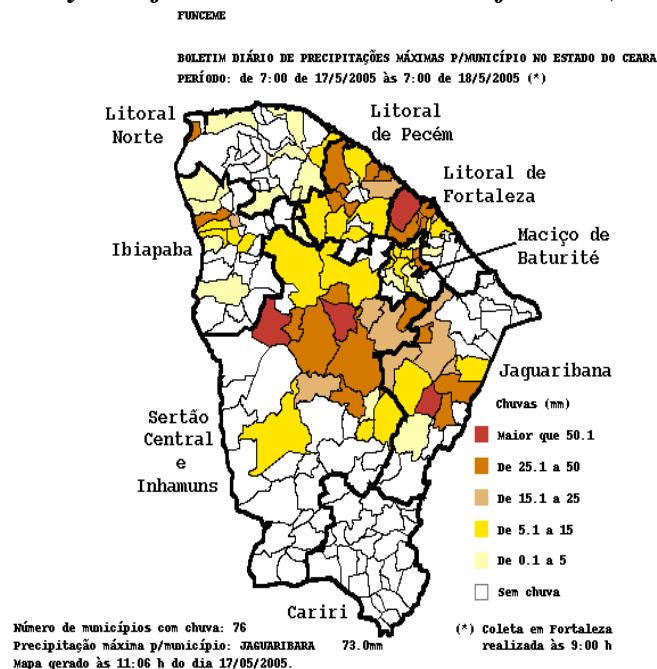
INDICE DE ARIDEZ MEDIO (1975-2002)



from <http://www.funceme.br/DEMET/Index.htm>

In addition to spatial variability in the distribution of precipitation throughout the State, there are differences in daily regional patterns as can be seen in Figure 6 below. In the case below, there are many pocketed regions throughout the State that receive differing amounts of precipitation, which are not necessarily in accordance with the annual trends for said regions in Figure 5.

**Figure 6. Daily Rainfall Patterns in the State of Ceará (17/5/05-18/5/05)**



Análise da Precipitação Ocorrida no Período de 07:00h do dia 17/05/2005 até às 07:00h do dia 18/05/2005 e Sistemas Atmosféricos Atuantes no Estado do Ceará Boletim atualizado diariamente em torno das 11 horas

From <http://www.funceme.br/DEMET/Index.htm>

Needless to say, water is a highly politicized topic throughout the Northeast of Brazil. The regional and annual variability and tendency towards drought create heightened tensions throughout and greatly increase the need for comprehensive water management

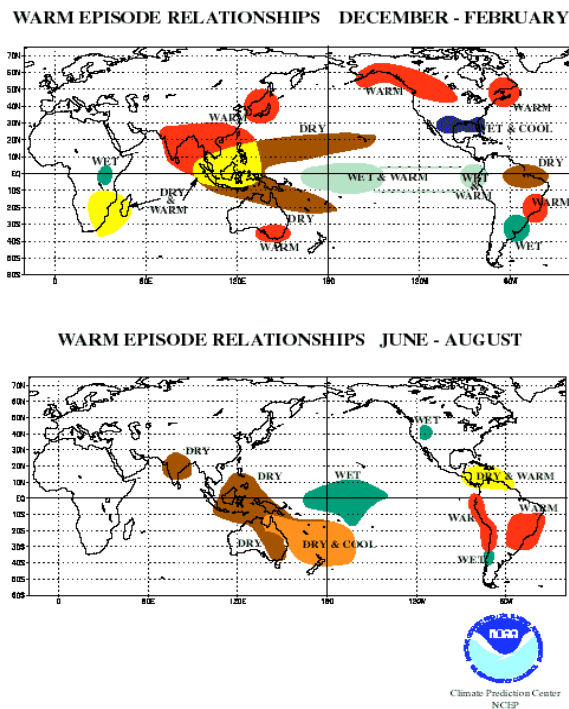
strategies there. In the following section, I will continue to discuss the variability in precipitation of the region, however, I will present in greater detail some of the climatic driving forces behind the patterns prevalent in the Brazilian Northeast.

*Rain in the Northeast of Brazil*

There are many contributing factors to the climate of the Northeast of Brazil. Unlike some regions, the area is known for its' strong correlations with ENSO patterns in the tropical Pacific, as well as the movements associated with the Intertropical Convergence Zone. Due to the region's proximity to the equator, temperatures vary little from month to month. Rainfall, however, is unevenly spread throughout the year and the rainy season for the region is January through May. As was heretofore mentioned, historically, the Northeast of Brazil has been plagued with extreme droughts and consistently semi-arid conditions.

The Northeast of Brazil is composed of nine states, covering about a fifth of the land area of Brazil and including about one third of its population<sup>i</sup>. There are evidences suggesting that Atlantic ITCZ April-May variability is linked to that for the eastern Pacific through the Walker circulation as it responds to changes in equatorial Pacific convection<sup>ii</sup>. Accordingly, major emphasis is given to north versus south Atlantic SST anomalies, surface and upper atmosphere winds when determining prediction methodology.

Based on the established knowledge of teleconnections, we know that in El Nino years the Ceará region tends to be dry (see Figure 7 and Table 3) and when it is La Nina the State of Ceará tends to be relatively wet. As was previously mentioned, crop production and value data spans from 1996 to 2001. Out of this range we chose one year each to represent dry, normal, and wet conditions in Ceará based on the NINO 3.4 SST anomalies that should correlate with those conditions.



The Northeast of Brazil is greatly impacted by SST anomalies in both the Pacific and Atlantic Oceans. Due to the positioning of the region in the Atlantic, the impact of a shifting ITCZ due to changes in SST patterns in the Southern Atlantic greatly impact the regions annual precipitation levels and forecasts using this as a predictor are greatly correlated with precipitation trends.

**Table 3. Nino 3.4 and Likely Conditions in the State of Ceará**

Year	NINO 3.4 conditions	Ceará conditions
1996	Normal	Normal
1997	El nino	Dry
1998	La nina	Wet
1999	La nina	Wet
2000	La nina/normal	Normal
2001	Normal	Normal

**Figure 7. Warm Episode Relationships DJF and JJA**

Below I have outlined in further detail descriptions of and correlations between local weather/climatic forcings and precipitation in the Northeast. Those contributing patterns include: Intertropical Convergence Zone movements, Cold Fronts in November and January, Upper-altitude cyclones, “Instability Lines”, “Mesoescala Convection”, Eastern Waves, and a 30-60 Day Oscillation Pattern. Furthermore, there are strong connections between ENSO patterns, which will be discussed separately in the La Niña and El Niño sections following<sup>7</sup>:

**Intertropical Convergence Zone (ITCZ):** The ITCZ is an important meteorological indicator of the abundance or deficiency of rain in the Northeast of Brazil. Normally, the ITCZ migrates seasonally from approximately 12°N in August or September, to approximately 4°S in March or April. The Southern movement of the Zone is often correlated with the intensity of the rainy season in the region.

**Cold Fronts:** Another important mechanism in the rain patterns of the Northeast are the cold fronts in the tropical latitudes during the months of November and January. These cold fronts bring in cold air which, when mixed with the tropical temperatures, often result in increased cloud patterns and subsequent precipitation.

**Upper-altitude cyclones:** These cyclones contribute to precipitation patterns in the region and form in the Atlantic Ocean between the months of October and March and usually move from the East to West, with increasing frequency during the months of January and February.

**“Instability Lines”:** These “lines”, as they’re referred to in Portuguese, form predominantly in the summer months of the Southern Hemisphere (December to March) and influence the rain patterns in the ‘littoral north’ of the Northeast when situated south of the Equator and tend to appear more in the later hours of the night.

**“Mesoescala Convection”:** This phenomenon<sup>8</sup> influences the formation of very strong, short storms throughout the region. Usually, these storms are isolated events and vary throughout the region.

**Easterlies:** The State of Ceará receives rain in the months of June, July and August when influenced by strong Easterly Wind patterns. According to FUNCEME, this system brings rain to the “Zona da Mata” of the Northeast. When the ocean-atmosphere conditions are such to encourage strong Easterlies, there are often associated increased rain patterns in the State of Ceará, particularly in the Northern center of the State.

**30-60 Day Oscillation:** The 30-60 day atmospheric shifts from West to East (over land regions) influence the level of rain in the Region of the Northeast, depending on the timing and phases of the oscillations.

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<sup>7</sup> Information on regional climatic information is from the FUNCEME website (<http://www.funceme.br/DEMET/Index.htm>).

<sup>8</sup> of which I could not find the actual translation into English

## *La Nina*

Many of the above phenomena are associated with larger patterns of ocean or atmospheric systems, such as those associated with ENSO. La Niña and El Niño greatly impact precipitation patterns in the Northeast of Brazil. As was heretofore mentioned, the presence of La Niña patterns in the Tropical Pacific are often correlated with increased averaged precipitation patterns in the Region. Particularly, more abundance of precipitation is in the Southern-central regions of the Northeast such as Maranhão and Piauí in November and January. La Niña also favors increased precipitation patterns in the semi-arid regions of the Northeast (the Sertão, etc). The La Niña years of the 21<sup>st</sup> Century include: **1904/05, 1908/09, 1910/11, 1916/17, 1924/25, 1928/29, 1938/39, 1950/51, 1955/56, 1964/65, 1970/71, 1973/74, 1975/76, 1984/85, 1988/89 e 1995/96**. All of these years varied in the intensity of the phenomenon, as is true for El Niño years as we will see in the next section.

## *El Niño*

Intense droughts in the Northeast of Brazil are associated with the presence of strong El Niño conditions in the Tropical Pacific. Accordingly, according to FUNCEME, the meteorological and water agency for the State of Ceará, those years where the El Niño phenomenon is officially recorded represent approximately 70% of all of the drought years recorded in the Region. In following sections, I will go into further detail on the presence of drought in the region, which years and the associated impacts on local populations.

As is seen in the quote below, it is important to place the climate information and forcings described in this section within the social context of the region. Scientific information is used by and incorporated into many differing social systems, including local politics, economics and social structures. However, there are various methods for the integration of science into everyday life, as well as many issues surrounding the compatibility of the two, interpretation, and overall use of scientific data, particularly that which surrounds issues of climate variability and forecasting in a highly water-stressed region:

*The second model is a knowledge driven model where science – independent of a specific problem – has discovered new knowledge that displays a potential application. As Weiss puts it, this model assumes that the ‘sheer existence of knowledge presses it toward development and use’ (1978, p. 30). Thus, the solution, rather than the policy problem, provides the main recruitment avenue (Kingdon, 1985; Stone, 1988). This latter model best describes the Ceará case where the availability of ENSO climate information triggered the reorganization of the policymaking apparatus so that forecasts could become part of the drought relief and agricultural policymaking system (Lemos: 481).*

As Lemos describes above, there are many steps between the integration of scientific data and policy. Furthermore, there are many, often unintended consequences, stemming from research and the dissemination of climate-related data:

*Once in the hands of policymakers, the science product loses – in a very critical sense – its desired objectivity and becomes woven into a complex mesh of social, economic, and cultural realities that influence how information is in fact used. It is this interaction of policymaker, end-user, and scientist that is addressed here (Lemos: 480).*

In the following section, I will take a step back and look at the methodologies behind scientific data collection of climate-related information. Following, the final sections will discuss the impacts and integration of these data collection methodologies with social systems, such as is discussed above. Examples from the region will be used to show some of the current strategies being implemented in the Region, many with the aim of reducing the vulnerability of local populations to drought.

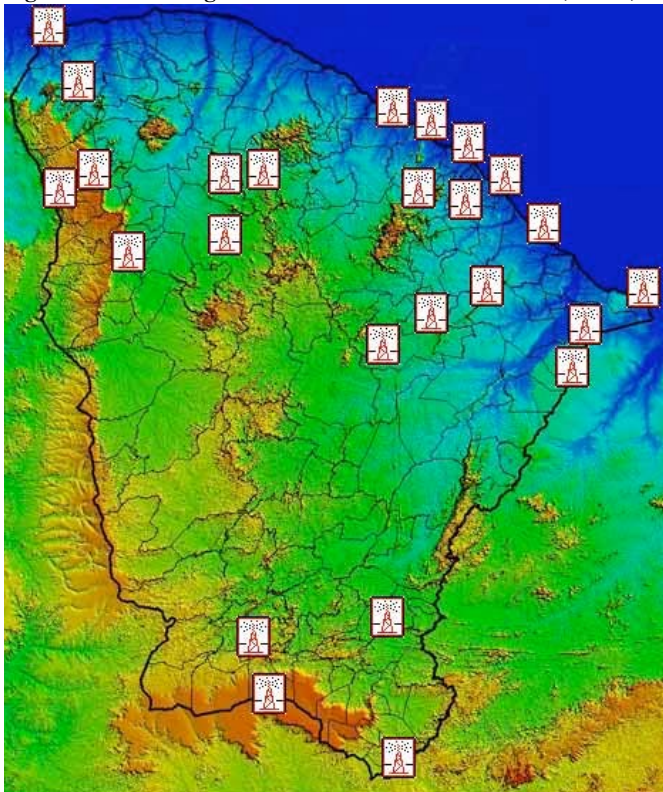
## Monitoring Climate Variability and Change

According to EMBRAPA, the national agronomy research organization of Brazil, there are currently 10 satellites in orbit that are sponsored by the Brazilian government. However, there are many other satellites that provide data to the many departments and organizations using such data. Those satellites that are principally used for the purpose of agriculture and issues concerning the natural environment are as follows:

ADEOS II, EROS, JERS-1, RESURS-01, ALMAZ-1, ERS, LANDSAT, SACI, ALOS, GALILEO, METEOSAT, SCD, AQUA, GOES, NOAA, SIR-C, CBERS, GPS, ORBVIEW, SPOT, DMSP, IKONOS II, QUICKBIRD, SSR, ENVISAT, IRS, RADARSAT, TERRA<sup>9</sup>

The satellites above, however, are used or have been used intermittently, depending on their orbit and amount of time in existence. In the State of Ceará, specifically, the meteorological and water agency, FUNCEME began using a series of 4 NOAA satellites in 2002 (NOAA-12, NOAA-14, NOAA-15, and NOAA-16), as well as the SeaStar satellite from NASA.

Figure 8. Meteorological Stations in the State of Ceará (PCDs)<sup>10</sup>



According to the FUNCEME website, the NOAA satellites in use are polar orbits and are at a height of approximately 860km. In addition to this, there is a “sub-satellite” AVHRR, which has the capabilities of capturing images at the 1km x 1km resolution. The NASA satellite SeaStar orbits the Earth at approximately 707 km in altitude, and maintains a SeaWiFs sensor that has a spatial resolution of approximately 1.13km x 1.13km, providing a lot of oceanographic data for the region.

As can be seen in Figure 8, there are also many meteorological

<sup>10</sup> from <http://www.funceme.br/DEPAM/index.htm>

stations throughout the State of Ceará. However, it is also apparent that there are no stations in the entire central regions of the State, which are also some of the most arid regions, as was seen in previous sections.

#### *Uses of Monitored and Forecast Information*

Although meteorological stations may have differing resources available to them depending on their location within the State, those products of the satellites that are predominantly used by the stations and by FUNCEME are as follows:

- **Sea Surface Temperatures (SST)** and associated anomalies are used to help determining the variability in rains over the region;
- **NDVI (Normalized Differential Vegetation Indices)** allow researchers to view the vegetation coverage of the State and the changes due to rainfall or lack of rainfall;
- **Vertical profiles of the atmosphere** are reviewed to help with forecasting for the region.

As can be seen in Figures 9 and 10, there are many different applications of climatic data useful to the Region. According to EMBRAPA, the Brazilian National Institute for Agricultural Research, there are numerous applications of remote sensing data in the fields of agriculture and the environment, including:

- *Mapping of the current use of lands;*
- *Supporting agricultural plans for development at the municipal level;*
- *Agro ecological, ecological, and, subsequently, economic zoning;*
- *Characterization of agriculture patterns throughout the Region;*
- *Evaluation of environmental impact (agricultural and urban areas);*
- *Monitoring of agricultural sustainability;*
- *Structuring systems of information for environmental and urban management;*
- *Mapping and characterization of fauna habitats;*
- *Mapping and characterization of regional vegetation;*
- *Modeling of ambient processes;*
- *Detention and monitoring of forest fires and deforestation patterns; as well as*
- *Support the management of hydrological basins and micro basins<sup>11</sup>.*

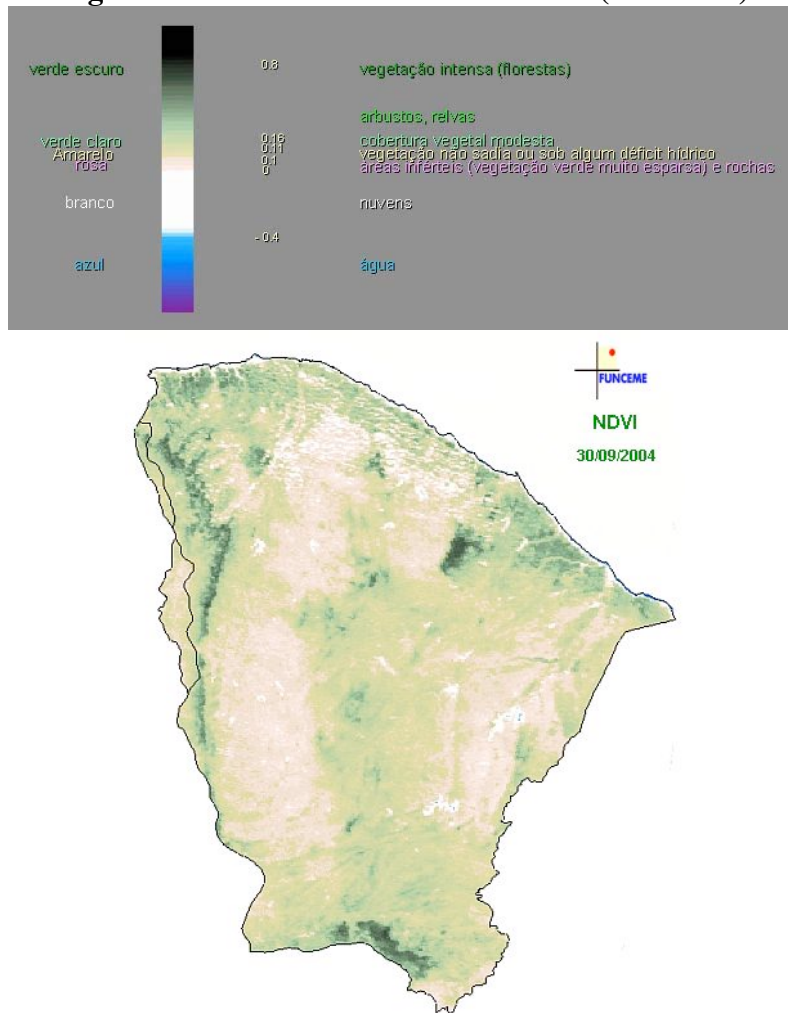
**Figure 9. Soils: Water Capacity**



<http://www.funceme.br/DERAM/index.htm>

<sup>11</sup> <http://www.sat.cnpem.embrapa.br>

**Figure 10. NDVI for the State of Ceará (30/9/2004)**



<http://www.funceme.br/DEPAM/index.htm>

In addition to these tools, the State of Ceará is working in collaboration with the International Research Institute for Climate Prediction (IRI) concerning forecasting and the integration of climate forecasts into the region. One other project of note is the Pilot Research Moored Array in the Tropical Atlantic (PIRATA), which is an oceanographic program led by a collaboration of scientists from Brazil, France and the United States, those who are involved in the Climate Variability and Predictability Program (CLIVAR). The objective of the PIRATA Program is to study ocean-atmosphere interactions in the Tropical Atlantic and its' impacts on regional climate variability.<sup>12</sup>

This section has reviewed some of the data collection and analysis methods used by the State of Ceará to help monitor climatic variability in the region. In the following section, I will outline some of the impacts that have been seen in the region due to this variability, with particular focus on drought.

<sup>12</sup> Information from the FUNCEME website.

## Water and Poverty: Climate impacts in the Semi-arid Northeast

The intense drought resulting from El Niño conditions in 1982-1983 alone, is said to have left more than 30 thousand homeless, 2,000 dead from famine or thirst, and have cost the region over US\$8 billion. Needless to say, the droughts that have plagued the region for hundreds of years have tremendous impacts on local populations, economies, migration patterns, as well as the politics of the region. Furthermore, the frequency of droughts in the region appears to be increasing, which may be attributed to changes in the global climate. This trend can be seen in Table 4 below, which shows a dramatic trend in the increase of droughts per century throughout the past four hundred years.

According to an OPOVO article, the Journal of Ceará, from July 8<sup>th</sup>, 2004, ten percent of the State of Ceará is at risk for desertification; According to satellite data from FUNCEME, more than 15 million km<sup>2</sup> of the State of Ceará is in the process of desertifying. As is true with the regional variability in precipitation, the regions at risk for the most intense desertification are scattered throughout the State, with the region of the Médio Jaguaribe being on of the highest risk areas (a region which totals approximately 10.2% of the area of the State). Accordingly, the entire Northeast of Brazil is a main target for the United Nations Convention to Combat Desertification, of which Brazil is a signatory country.

**Table 4. Four Hundred Years of Drought in the Northeast of Brazil**

<i>Drought years</i>	<i>Drought length</i>	<i>Per century</i>	<i>Drought years</i>	<i>Drought length</i>	<i>Per century</i>
1559	1 year	4 droughts	1833	1 year	
1564	1 year		1844-6	3 years	
1587	1 year		1860	1 year	
1592	1 year		1869	1 year	
1603	1 year	6 droughts	1877-9	3 years	
1609	1 year		1888-9	2 years	
1614	1 year		1898	1 year	
1645	1 year		1900	1 year	15 droughts
1652	1 year		1903-4	2 years	
1692	1 year		1915	1 year	
1710-11	2 years	7 droughts	1919	1 year	
1722	1 year		1931-2	2 years	
1723-28	6 years		1942	1 year	
1744-46	3 years		1951-3	3 years	
1766	1 year		1958	1 year	
1777-8	2 years		1966	1 year	
1790-3	4 years		1970	1 year	
1803-4	2 years	12 droughts	1976	1 year	
1808-10	3 years		1979-83	5 years	
1814	1 year		1987	1 year	
1817	1 year		1990-3	4 years	
1824-5	2 years		1997-9	3 years	

### **TOTALS**

78 years, 44 droughts, 27 droughts lasted one year, 7 droughts lasted two years, 6 droughts lasted three years, 2 droughts lasted four years, 1 drought lasted five years, 1 drought lasted six years<sup>13</sup>

## Conclusions

<sup>13</sup> From <http://iri.columbia.edu/america/project/Ceara/CearaGeographyText.html>

Water not only a limiting resource in the semi-arid state of Ceara, Brazil, it is also a means of power and economic gain. The State of Ceará remains the only state in Brazil without perennial rivers. Further complicating matters, much of the limited groundwater resources in the State either suffer from saltwater intrusion or pollution issues.

In the past, the focus of the State and Federal governments has been to increase the holding capacity of water for the Region. Accordingly, more than 2,500 km of distribution pipes have been built in the past ten years, in addition to many major infrastructure projects such as reservoirs<sup>14</sup>. Currently, many resources are being targeted towards the development of knowledge concerning regional climatic variability and methods for prediction and, eventual, mitigation of droughts in the region. In addition to this, the Federal government has pushed towards the decentralization of and increased stakeholder participation in water resources management and, in 1997, the State of Ceará implemented its first participatory water allocation committee.

As has been seen in this paper, climate and precipitation, in particular, are fundamental to everyday life in the Brazilian Northeast. Although there are many resources in use, there still remain gaps between the integration of climatic data with local policies and customs. Increased understanding of local institutions, resources, and the interlinkages between climate science and local wellbeing are key to mitigation strategies in the Region. However, it is also important that scientists and politicians alike, do not 'place all their eggs in one basket', looking for a quick fix to decades of drought and suffering in the Region. The best solutions will work with technologies such as forecasting and satellite data along side of local knowledge systems and interdisciplinary institutions of varying scales.

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<sup>14</sup> From <http://iri.columbia.edu/america/project/Ceara/CearaWaterText.html>

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