SOME AVHRR-NOAA PRODUCTS OBTAINED AT FUNCEME INCLUDING NDVI, PWI AND CLOUD TOP TEMPERATURES

Raul Fritz Bechtel Teixeira

Fundação Cearense de Meteorologia e Recursos hìdricos - FUNCEME
Fortaleza, Ceará, Brazil
fritz@funceme.br

Abstract

In this paper it is presented, briefly, some preliminary results on AVHRR-NOAA products such as the Normalized Difference Vegetation Index (NDVI), the Precipitable Water Index (PWI) and the visualization of cloud top temperatures obtained by using the TeraScan System recently installed at the Foundation for Meteorology and Water Resources of the State of Ceará – FUNCEME, Brazil.

AVHRR-NOAA products and images are being used at FUNCEME in research and operational procedures to aid its several activities in meteorology and remote sensing.

The good results already attained with the use of the TeraScan can be considered as a great encouragement to the development and use, in this system, of other similar products from meteorological and environmental satellites.

1 – Introduction

FUNCEME is located in the semi-arid north-northeastern Brazil. This region suffers from recurrent droughts or irregular rains so that the permanent monitoring of the superficial vegetation´s vigor and cover of the State of Ceará by means of the use of the NDVI, is very useful for governmental, economical and social decisions, by the local people, for the agricultural plans, drought´s monitoring, etc.

The NDVI from NOAA satellites can be used to verify the impacts on the vegetation due to the interannual and seasonal climate variability. Specially in the State of Ceará the natural green vegetation is very dependent of the moisture given by the rain. There is a great seasonal variation of the vegetation in this State. Its superficial green cover varies rapidly according to the rains fallen in the region. Therefore, the quite easy attainment of the NDVI by the TeraScan is very important for the crude estimate of the vegetation covering Ceará along the time. It also will be very useful to the validation of the soil´s humidity model used in the institution and this index gives a good idea of this humidity according to the identification of green areas.

On the other hand, the atmospheric precipitable water constitutes an important measure of the water vapor content of the air. It indicates how much water vapor is available to form precipitation. Frequently, a high PWI associated with a high instability of the air can indicate subsequent rains. In this manner, the PWI estimated from the AVHRR-NOAA and by means of the use of the TeraScan is very interesting for the State of Ceará where the rainfall is fundamental for the local society.

Finally, the visualization by means of colored AVHRR (channel 4) images of the cloud top temperatures can help meteorologists to identify and monitor heavy rains (mainly convective ones). Near the earth´s equator it is not rare the deep convection with the formation of very developed cumulus clouds (with very cold tops) accompanied by very intense rains.

2 – The NDVI principle

Green vegetation appears different at visible (AVHRR channel 1) and near infrared (AVHRR channel 2) wave lengths. In the channel 1, vegetated areas are dark, almost black, while they are light in the channel 2. Barren surfaces are about the same in the two channels (*figure 1*).

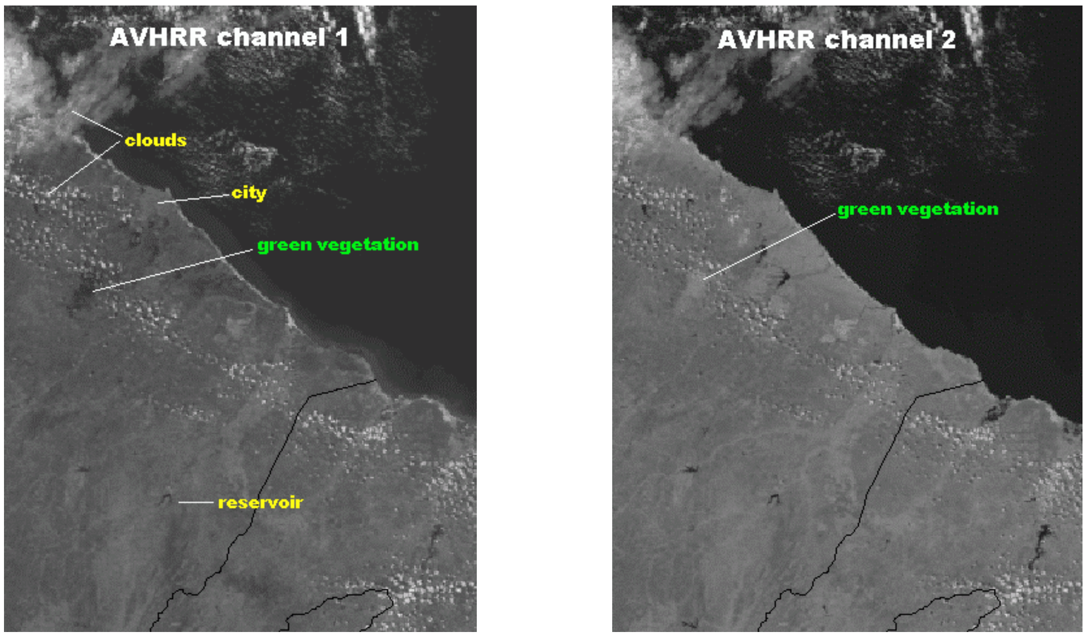


Fig. 1 – TeraScan AVHRR-NOAA channels 1 (on the left) and 2 (on the right) images of part of the State of Ceará, Brazil, during a dry season, showing the different reflectances of the radiation by the green vegetation and other superficial marks. The area referenced as "green vegetation" corresponds to the mountains called "Baturité" covered by tropical forests. Clouds, reservoirs and the city of Fortaleza also appear in the images.

The pigment in plant leaves, chlorophyll, absorbs visible light from the violet to the blue and the yellow-red portion of the spectrum for use in photosynthesis. It presents high reflectance in the visible green but low reflectance in the visible yellow-red (mainly the latter) wave lenghts (0.58 – 0.68 micrometers) of the AVHRR channel 1. However, the reflectance of the green plants is very high at the near infrared band (0.725 – 1.10 micrometers) of the AVHRR channel 2 (*figure 2*) due to special cell structures of the leaves.

NDVI is calculated from the simple difference between the near infrared and visible reflectances (channel two minus channel one). It is yet divided by the sum of the two channel´s reflectances to partially account for differences in illumination conditions and surface slope. Therefore, the NDVI values vary in the range of –1.0 to 1.0 and are unitless.

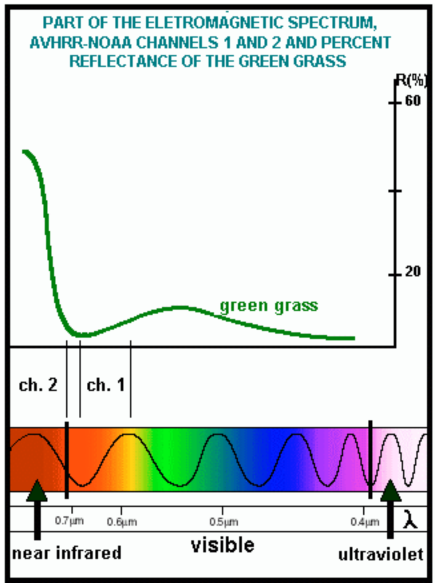


Fig. 2 – Approximate reflectances (R), in percentage, of the green grass according to the AVHRR channels 1 and 2. Note the low reflectance of the grass at the channel 1 and the high reflectance in the channel 2. Diagram adapted and modified from the site of the USGS, EROS Data Center – Science, USA.

NDVI values less than 0 generally indicate water, clouds and aerossols (larger reflectances in the visible as compared to the near infrared). NDVI between 0 and 0.1 indicates "non-vegetated" features such as barren surfaces (rocks and soil with very sparse vegetation) resulting in similar reflectances in both channels). Healthy green vegetation has high channel 2 reflectance and low channel 1 reflectance, and hence, high NDVI values (showing great differences between the channels). Values greater than 0.1 and less than 0.8 generally denote increasing degrees of the "greeness" and intensity of vegetation. NDVI around 0.2 and 0.3 represents moderate vegetation (shrubs, grasslands, etc) and around 0.6 until 0.8 denotes very green areas (forests and rain forests). Low values of NDVI, however, do not necessarily indicate lack of vegetation. For example, that is the case for unhealthy plants or alive plants without leaves.

It is used, in general, composites of some images of NDVI (preferably using the method of the maximum value in the TeraScan composite function) to compensate the presence of clouds. The clouds are the major hindrance to obtain the NDVI. Other important difficulty involves the illumination conditions so that the better moments to infer the NDVI is few hours around the local midday.

NDVI anomalies may also be estimated. For example, a certain period of time can be compared for the same period measured for several years.

3 – The PWI principle

Between the 10 and 13 micrometers of infrared wave lenghts the clouds and the water vapor in the air are the main absorbers of the thermal radiation emitted by the earth´s surface. However, the atmospheric water vapor doesn´t absorb strongly the infrared radiation that reaches the AVHRR channels 4 (10.3 – 11.3 micrometers) and 5 (11.5 – 12.5 micrometers) because they are in atmospheric windows. Due to the fact that the channel 5 deals with wave lengths slightly greater than the channel 4, it is more sensitive to water vapor since the radiation with longer wave length, with smaller energy, passes with more difficulty through the vapor. Moreover, the re-emitted infrared radiation after its absorption by the water vapor occurs in wave lengths greater than before the absorption. Therefore, areas with a high concentration of water vapor show a greater attenuation of the radiation´s intensity in the channel 5 in respect to the channel 4. In this manner, the difference between the brightness temperatures (in Celsius units) of the channel 4 and the channel 5 can indicate the total water vapor amount or the precipitable water of the air because these channels are volume sampled from the top of the atmosphere to the surface. If there is more water vapor (or less intense channel 5 brightness temperature record) the difference between the channels is greater than the case with less vapor. The difference can thus be introduced as the PWI for clear sky conditions (or for areas between clouds).

4 – Cloud top temperatures

The AVHRR channel 4 shows the temperatures of the tops of the clouds. These temperatures can be enhanced, in the TeraScan System, through diverse colors so that extreme cold temperatures can better be recognized. If the clouds are not cirrus, there is a great possibility of intense rain under very cold top temperatures.

5 – Methodology

For the NDVI visualization, it can be used the TeraVision hsl256 color palette but a new palette was developed (using the "palette edit panel" from the TeraVision´s tools) to see the areas of likely vegetation given by the index. In this palette the negative values less than and near –0.4 appear in blue to represent mainly the water. Values between the last beforehand mentioned and close to zero receive white color to denote the clouds. Between zero and 0.1 they receive a "pink" color to represent rocks and barren soils with sparse vegetation. Values from approximately 0.11 to 0.16 are in yellowish tones to denote unhealthy vegetation or vegetation under some water deficit and values from this last to 0.8 are in green colors (from a very light green, almost white, to a very dark one, almost black) to indicate the increasing amounts of vegetation.

To infer The NDVI, it is necessary to use the current radiometric calibration coefficients of the NOAA satellites. If it is not informed, by NOAA, the new post-launch coefficients, it remains valid the pre-launch ones. The TeraScan System adopts the last coefficients and allows its updating. If are used the reflectances from the newest spacecrafts (NOAA-16 and NOAA-17 for the present time, for example), the pre-launch coefficients are probably still valid.

The solar radiation scattering by clouds, dust and aerossols in the atmosphere and the Rayleigh Scattering (which is very intense in the visible blue of the spectrum but still somewhat considerable in the red-yellow of the AVHRR channel 1) act to increase the channel 1 reflectance with respect to the channel 2 reflectance, and hence, reduce the computed vegetation indices. Therefore, it is sometimes necessary to apply an atmospheric correction (related to the diffusion of the radiation) to the NDVI calculations. The simplest way to do this normally complex correction comprises the subtraction from each pixel´s reflectance the lowest reflectance of the image. To avoid the atmospheric correction, however, it is sufficient to estimate the NDVI in areas where the sky transparency is very high and preferably with no clouds.

Another corrections to the NDVI can consider the view´s angle of the sensor and the solar zenithal angle. These corrections, however, are not necessary if are used the areas of the satellite´s passes around the subsatellite point and passes around the noon.

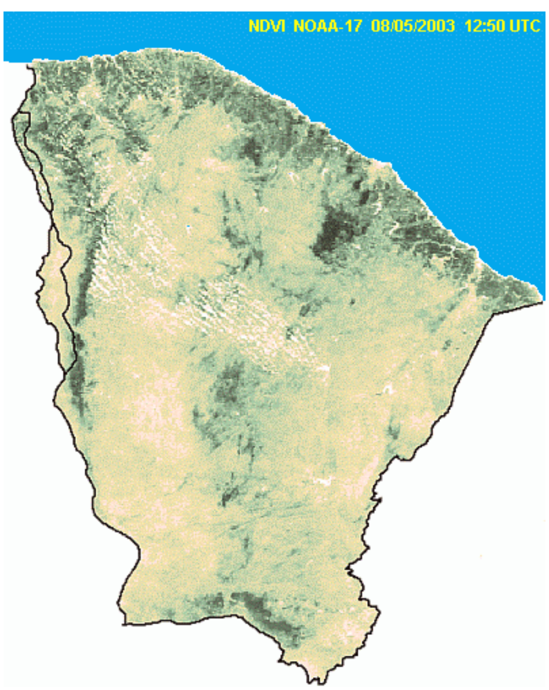
To infer the PWI, it can be used the practical "math" TeraVision tool where the variable 1 is the channel 4 and the variable 2 is the channel 5. Moreover, it was created a new palette to show the PWI image. In this palette the brown, yellow and green colors (between –1.0 and 1.7, approximately) represent low values of water vapor (that is low PWI values) and the colors blue and purple (from 1.7 until 2.8 and upwards) denote high concentration of water vapor (that is high PWI values).

It is noteworthy that cloud masks should be used on the IAP images so that the clouds be not confused with areas of high or low precipitable water according to the cloud type (warm or cold).

New palettes were developed to visualize the temperatures of the tops of the clouds in the AVHRR channel 4. In the first one, it was chosen a gray scale for the high temperatures. From +20 until –80 Celsius, the colors passed from red, orange, yellow, green, blue and purple so that the coldest temperatures received a dark purple for –60 Celsius until a light purple for –80 Celsius. In the second palette, very similar to the first one, the gray scale was until +15 Celsius and from this value until –80 Celsius the colors varied from orange, yellow, green, blue and purple.

6 – Results

TeraScan NDVI images for the State of Ceará can be seen in *figure 3a*. They were obtained from single NOAA-17 overpasses over the region. There is also (in the *figure 3b*), for comparison, a high resolution LandSat image obtained in a more extended period. The vegetation patterns seem about the same in the images 3a and 3b despite the great difference of spatial resolution between them. The epoch of the images corresponds to the "dry" period (outer to the major local rainy season) of the region. The isolated dark green areas in the NDVI images are humid mountains covered by tropical forests. The coast of Ceará also shows more green vegetation due to some breeze rains. Light green areas correspond to less expressive vegetation and the yellowish areas show vegetation with some water deficit. The areas of "pink" appearance represent barren soils with sparse green vegetation and vegetation under water stress where some of these areas are found under processes of degradation (changing into deserts). It is visible, in the images of the *figure 3a*, a dramatical reduction of the green vegetation in the period of one month. In the LandSat image, as more intense is the green, more intense is the vegetation.



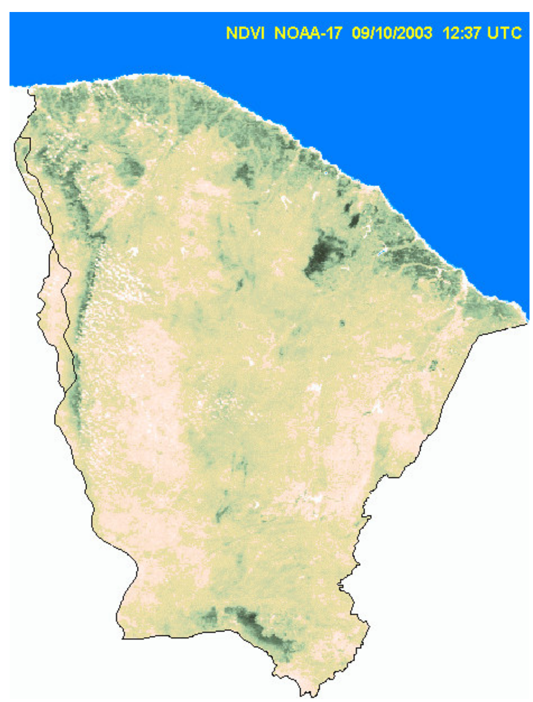


Fig. 3a – TeraScan NDVI images from NOAA-17 passes on August 5, 2003, at 12:50 UTC (on the left) and September 10, 2003, at 12:37 UTC (on the right). The green vegetation has reduced during a period of a month. Some cumulus clouds appear in white at the center and to the left of the images.

Fig. 3b – A LandSat image (for comparison with figure 3a) for july to october of 1999 and 2000 of the State of Ceará (from the Brazilian Agricultural Research Corporation – EMBRAPA).

The *figure 4* shows a TeraScan AVHRR channel 5 image (black and white) of the north-northeastern Brazil where is located the State of Ceará. It also shows a PWI image (colored) from the difference between an AVHRR channel 4 image (not showed here) and the exhibited AVHRR channel 5 image. Note that a cloud mask was not applied to the PWI image.

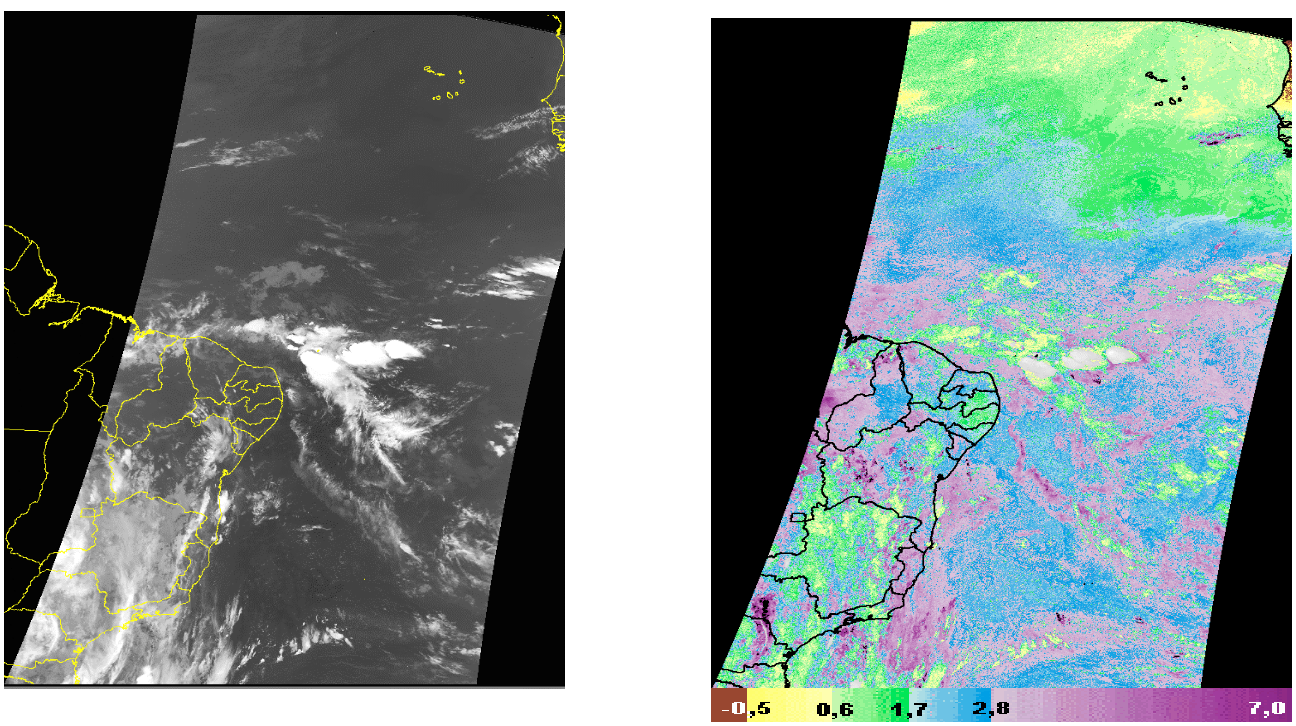


Fig. 4 – A TeraScan AVHRR channel 5 image from a NOAA-16 pass taken on March 11, 2003, at 03:56 UTC (on the left) and a TeraScan PWI image (on the right) generated for the same pass. A cloud mask doesn´t appear in the PWI image. Three groups of very developed and cold clouds appear in gray near to the center of the PWI image.

It is observed, between the clouds of the PWI image, high precipitable water (in blue and violet) around the equator and at the south tropical region. Low precipitable water (in green and yellow) may be seen next to the coast of the northwestern Africa. These patterns correspond to the expected climatology for the period and they agree, for example, with the state of the atmosphere due to the observed sea surface temperatures for the region.

Figure 5 shows AVHRR channel 5 and PWI close ups of the figure 4 centered at the State of Ceará. It also exhibits an AVHRR channel 1 image for the same area but some hours later. It is evident, in the figure, high PWI values (in violet and seen between the clouds) along the coast of Ceará. This very moist condition, among other meteorological factors, may have led to the strong vertical development of some cumulus clouds at the close vicinity of Fortaleza some hours later. These clouds reached the city with the occurrence of rains.

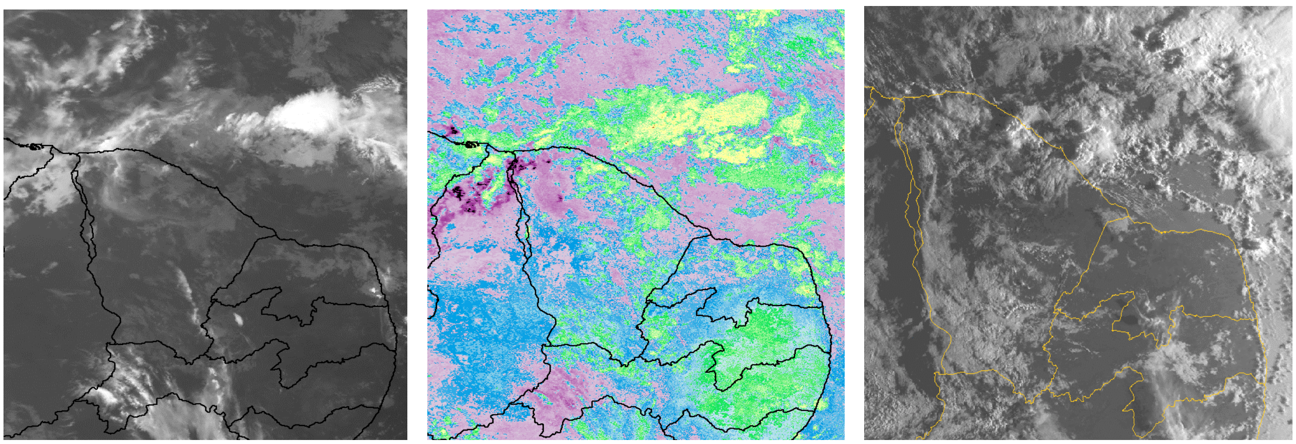


Fig. 5 – A TeraScan AVHRR channel 5 (infrared) image (on the left) and a PWI image (at the center) from the same NOAA´s pass of the figure 4 showing close ups of the State of Ceará. A TeraScan AVHRR channel 1 (visible) image of Ceará (on the right) from a NOAA-15 pass on March 11, 2003, at 09:20 UTC showing well developed cumulus clouds at the vicinity of Fortaleza city at the coast of Ceará.

Other situations such as low values of PWI (represented by green color) leading to predominant clear skies were examined, at FUNCEME, for some dry periods for the State of Ceará.

The *figure 6* shows an example of cloud top temperatures enhanced by some colors. Blue and purple indicates the coldest temperatures. For the given example, there was not cold clouds over the Ceará (next to the center of the image).

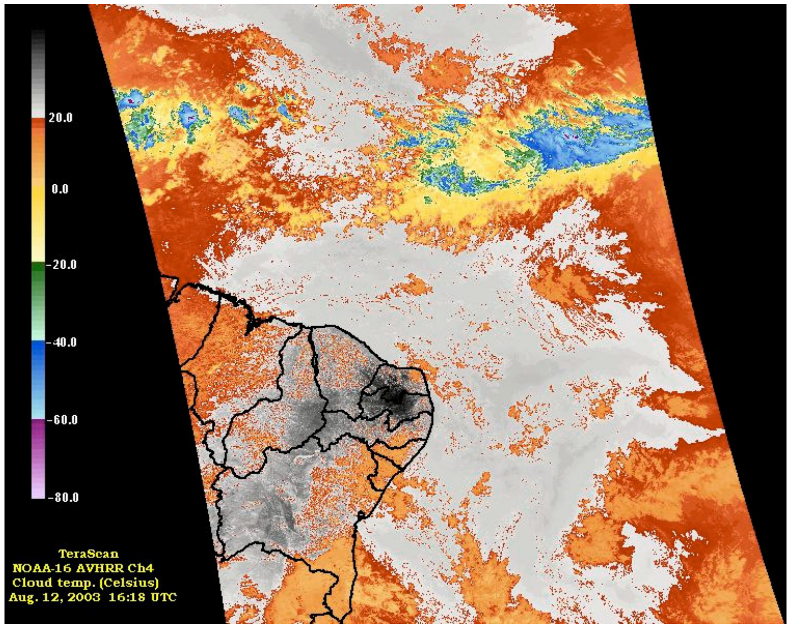


Fig. 6 – A TeraScan AVHRR channel 4 image with the tops of the clouds colored according to its temperatures (in Celsius). NOAA-16´s overpass on August 12, 2003, at 16:18 UTC.

In the *figure 7* it can be seen the Hurricane Isabel over the North Atlantic Ocean and around the meridian 43 west. In the same figure the tops of the clouds appear in varied colors showing its different temperatures. It is clearly evident the very cold tops of the clouds (in purple) around the eye of the hurricane.

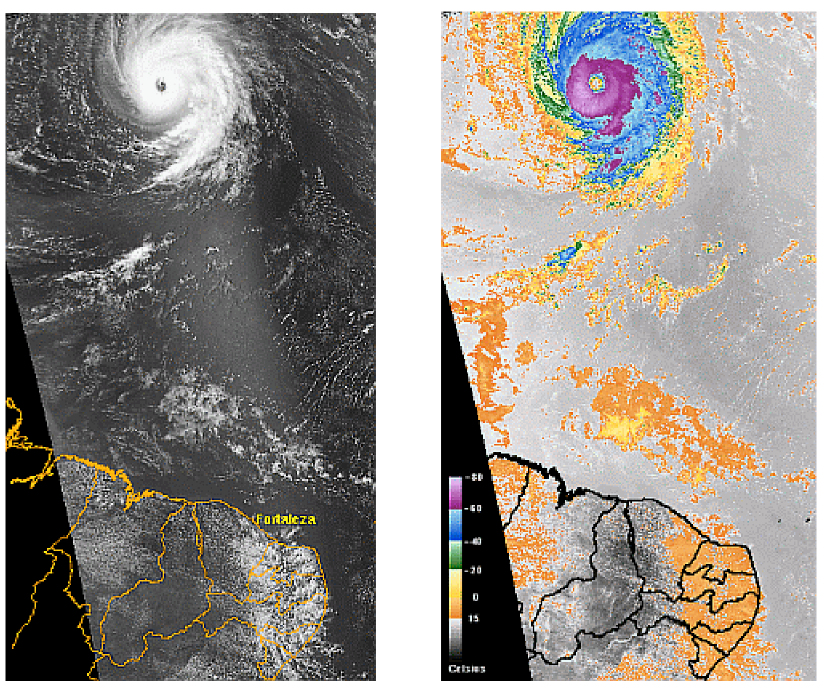


Fig. 7 – AVHRR TeraScan images of the Hurricane Isabel at the tropical North Atlantic Ocean and around the meridian 43 W. Channel 1 (visible) on the left, and channel 4 (on the right) showing the temperatures of the tops of the clouds. Purple varies between –60 and –80 Celsius. Overpass of the NOAA-16 on September 8, 2003, at 16:15 UTC.

6 - Conclusions

The NDVI obtained from the NOAA satellites is very useful for the identification and monitoring of the green vegetation particularly for the State of Ceará which is located in a semi-arid zone.

The PWI from NOAA satellites is useful to guide the elaboration of meteorological analysis and weather forecasts. It is also very important for climatological studies. PWI images can complement moisture information from vertical soundings and water vapor imagery from meteorological satellites.

The easy and rapid identification of the temperatures of the tops of the clouds may help meteorologists to make nowcastings in regards to intense rains and studies about these ones.

Terascan can generate and view good and useful products from NOAA satellites such as the few examples presented here which represent the first steps of FUNCEME into the system. These products may be used in research and/or operational applications by institutions working with remote sensing, meteorology, etc. It is very important, however, the development of the products (computation, creation of color palettes familiar to our sense, etc) according to precise scientific criteria.

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