ATMOSPHERIC CORRECTION OF SATELLITE IMAGES IN A TROPICAL REGION

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ABSTRACT

This paper describes our work on atmospheric correction of satellite images, started in 1990, focusing on the computer system called *SCORADIS*. It gives also special attention to the acquisition of the atmospheric parameters used as input data to the System, the importance of the atmospheric correction and the studies in development at UNICAMP. All experimental work is being done under the conditions of tropical atmosphere, soil occupation and data disposable existent in São Paulo state. Our main objective is to contribute to a better use of satellite images in applications related to vegetation monitoring, like the biomass estimating, for example. The most part of the atmospheric studies in remote sensing corresponds to the atmospheric conditions of the north hemisphere that are very different of our conditions.

RESUMÉ

Ce papier decrit le travail sur la correction atmosphèrique des images satellitaires qui est en developpement a l'Université de Campinas depuis 1990. On present le logiciel de correction d'images satellitaires *SCORADIS*, les méthodes d'aquisition des paramètres atmospheriques d'entrée au Système et l'importance de la correction atmosphèrique. Le travail experimental est fait sur les conditions atmosphèriques, d'occupation du sol et de disponibilité de données de l'état de São Paulo. L'objectif principal du travail est d'améliorer la qualité des images satellitaires pour les applications agricoles.

1. INTRODUCTION AND MOTIVATION

The importance of using satellite images without atmospheric effects in agricultural applications, like vegetation monitoring, for example, motivated the beginning of this work. We are in a very important agricultural region of Brazil that has great areas of sugar cane, corn, wheat and soybean. The sugar cane, for example, has a production system well developed and very technical that admits a monitoring by satellites. A part of its production is destined to the production of alcohol that is used like fuel by cars.

We have a tropical atmosphere with some conditions that are very particular and different of the most part of the research work done around the world: the high water vapor content in the most part of the year, the concentration and the type of the aerosols.

The state of São Paulo locates in the southeast region of Brazil, with latitudes varying from 20°S to 25°S and longitudes from 44°W to 53°W. The Capricorn Tropic crosses its territory. Campinas (22°54'S, 47°05'W) is the city where the most part of the experimental work takes place.

The first part of this work (1990-1994) was devoted to treat images with homogeneous or constant atmospheric conditions in the whole image. This is the case, for example, of the most part of Landsat-TM and Spot-HRV images and also of small pieces of Noaa-AVHRR images. Our main interest since the acquisition of a Noaa-AVHRR antenna on December 1994 is in correct images with spatial variability of atmospheric parameters to use them in monitoring applications, like biomass estimating, for example. Our main interesting in this paper are the visible, near and middle infrared images although some results are useful to treat thermal infrared images. This is the case of the estimate of water vapor content explained in the section 3.1.1

The following section (The Scoradis) describes the version 1.0 of the computer system that was produced during the first part of our work (1990-1994) and the improvements that are being done to generate the version 2.0 on June 1996. The section 3 (Input data) describes our efforts to have good input data to run successfully the Scoradis. Section 4 is about the importance of the atmospheric correction in two typical uses of satellite images for agricultural purposes: calculation of vegetation indexes and automatic pattern classification.

2. THE SCORADIS

The *SCORADIS* ("**S**istema de **CO**rreção **RAD**iométrica de **I**magens de **S**atélite" or System of Radiometric Correction of Satellite Images) is a computer system written in FORTRAN-IV, based in the 5S Model (Tanré et allii, 1990), to treat satellite images. It cans correct images from spectral bands situated between 0.4μm and 2.5μm, like the Landsat-TM, Spot-HRV, Noaa-AVHRR1 and Noaa-AVHRR2, for example. The type of our main applications of the satellite images explains our preference for correcting images instead of some pixels only. The possibility to parallel its calculation modules is very interesting in monitoring applications where the decisions have to be taken quickly.

The version 1.0 is disposable to the Sparc/SUN, PC/IBM and Risc/IBM systems and can treat images with homogeneous or constant atmospheric conditions. It means, to the calculating point-of-view, to have a unique set of atmospheric parameters to the entire image.

The *SCORADIS* 1.0 has three principal modules, which are:

(a) Data processing in the 5S Model
This module aims to simplify the data input by keyboard, letting the 5S Model "transparent" to the user. The 5S model has a semi-rigid input format related to the FORTRAN language characteristics. This module can perform atmospheric simulations, which is one of the original applications of the 5S Model. It is not necessary, using this module, to know all the particularities and characteristics of the 5S Model.

(b) Calculation of look-up tables
This module is a separated part of the correction procedure. It allows the execution of remote correction of images using only look-up tables. The correction tables are calculated using the atmospheric parameters of the area and transferred to the user to correct its images.

(c) Image processing
This is the main module of the system that has motivated its development. *The correction of surrounding effects* (1st part) and *the correction of the "pure" atmospheric effects* (2nd part) are the two principal parts of the correction procedure. After the first treatment, the pixels have the influence of the "pure" atmospheric process (scattering and absorption) but no have the influence of their surrounding pixels. The subdivision of the correction procedure allows to evaluate the influence of each module in the final results. It is possible to use only the second module when the resolution of the image pixels is greater than 100x100m, simplifying the correction process. The specific treatment of the surrounding effects is an interesting characteristic of the System because they are always neglected due to the difficulty to describe them adequately. The grey level of the output images can represent radiance or reflectance levels.

The hypothesis of atmospheric homogeneity is very reasonable when working with Landsat-TM and Spot-HRV images. For Noaa-AVHRR images, it is important to be prepared to work with the spatial variability of the atmospheric parameters. The processing of images with spatial variability is an important improvement of the *SCORADIS* that will be present in the version 2.0 on June 1996. It will use a man-machine interface based on X-Windows systems to simplify its use by any kind of user. New versions will substitute the version of the 5S Model used in the *SCORADIS* 1.0.

3. INPUT DATA

The principal input data that are necessaries to run the 5S Model, used by the *SCORADIS*, are *the atmospheric model of gaseous components*, *the type of the aerosols* and *the concentration of the aerosols*. Other data like *the spectral conditions of the satellite bands* and *the calibration coefficients* are inside the system. The *SCORADIS* calculates by itself the geometrical conditions of illumination by the sun and observation by the satellite.

We have adapted a spectroradiometer LI1800/LICOR to measure the direct solar radiation with a black tube that limits its field of view from 180° to 2.4°. The great advantage of this adaptation is the possibility to have spectral direct solar radiation data from 330nm to 1100nm each 1, 2 or 5nm.

3.1. Atmospheric model of gaseous components

The atmospheric model of gaseous components is defined in the 5S model most precisely by radiosonde data or approximately by the water vapor and ozone contents using a standard atmospheric model.

It was possible to launch some radiosondes only in the beginning of the work (June and July 1991) when it was observed a good agreement between the tropical atmospheric model (McClatchey et allii, 1971) and the experimental data.

Considering the difficulty to obtain radiosonde data with a good spatial and temporal resolution, we define the atmospheric model of the gaseous components using the tropical model proposed by McClatchey et allii (1971) with the water vapor and ozone contents determined experimentally. It is justified because, for our purposes, the quantity of water vapor and ozone is more important than their distribution profile through the atmosphere. This approach is becoming more attractive to us due to disposable of precipitable water and ozone contents data from TOVS data in our laboratory since December 1994.

3.1.1. Water vapor. The estimate of atmospheric columnar water vapor is a matter that interests many investigators it has a long time. This is a very important parameter considering the high quantity of water vapor presents in the tropical atmosphere and the important effects of water vapor in the remote sensing images. The more simple way to estimate the water vapor contents in absence of any other method more accurate is using the tropical profile of water vapor corrected by ground measurements of water vapor density. This method was used in the first years of our work.

We are working now in a more accurate approach based on the main ideas of the method of differential solar transmission measurement presented by various authors like Reagan et allii (1987) and Holben & Eck (1990), to our conditions of equipment and data.

We have chosen two extreme wavelengths (870nm and 1026nm) that have not any gaseous influence (that is, total gaseous transmistance equal to one) and another one intermediate (948nm) that has a strong influence of water vapor, using the gaseous transmission calculated by the 5S Model.

The well-known Equation 1 expresses the relation between the gaseous transmitance by the water vapor (tg), the water vapor contents (uw) and the air mass (m):

$$tg = \exp[-k.uw^{b}.m^{c}] \quad \textbf{(1)}$$

with k, b and c constants, where k depends on the measurement equipment, b and c are near 0.5. Applying the natural logarithm two times in the two sides of Equation 1 one can obtain the following fitting equation:

$$\ln(-\ln tg)) = \ln k + b.\ \ln uw + c.\ \ln m \quad \textbf{(2)}$$

The 5S Model calculates the value of tg for given values of uw and m. The triple $[tg;\ uw;\ m]$ is used then to fit the Equation 2 to obtain the values of k, b and c. The following equation was obtained using 216 fitting triples $[tg;\ uw;\ m]$ (18 values for m and 12 (0.5, 1.0, 1.5, ... , 6.0) for uw) with r = 0.999952:

$$tg = \exp[-0.6767\ .\ uw^{0.5093}\ .\ m^{0.5175}] \quad \textbf{(3)}$$

The linear interpolation between the direct solar radiation at 870nm (***Rdir$_{870}$***) and 1026nm (***Rdir$_{1026}$***) gives the direct solar radiation at 948nm (***$\underline{Rdir}_{948}$***) for the theoretical case of an atmosphere without water vapor. The gaseous transmission ***tg*** at 948nm is equal to the ratio between the measured (***Rdir$_{948}$***) and the estimated (***$\underline{Rdir}_{948}$***) values for the direct solar radiation at 948nm:

$$tg = Rdir_{948}\ /\ \underline{Rdir}_{948} \quad \textbf{(4)}$$

Applying this value of tg into Equation 3 (our case) or Equation 1 (general situation), it is possible to obtain the value of the water vapor contents uw for a given air mass m.

The INRA/Avignon develops a similar method to use with the CIMEL sunphotometer.

This method will be useful to intercalibrate the ground level measurements of water vapor content with the TOVS data, which is very interesting to correct images with spatial variability of atmospheric parameters. The estimate of water vapor contents is very useful also to process thermal infrared images.

3.1.2. Ozone. The ozone content is obtained in the table proposed by London et al. (1976) since its values are in a good agreement with our tropical conditions (Lazutim, 1993).

The UNICAMP has a Russian ozonometer that measures the ozone contents three times a day since July 1993. Lazutim et allii (1994) presents some results of these daily measurements. This equipment will be very useful to intercalibrate the TOVS data that can be used to correct images with spatial variability of atmospheric parameters.

3.2. Aerosol concentration

We calculate the aerosol concentration using the Beer-Bouguer Law and the spectral direct solar radiation measured in the ground level by a LI1800/LICOR spectroradiometer adapted by us.

Another possibility is to use the global solar radiation in a method presented by Zullo et allii (1994). It is possible to estimate the aerosol concentration with a good precision knowing the type of the aerosols.

There are some big and clear rivers and a part of the Atlantic Ocean in the state of São Paulo that can also be used to calculate the aerosol concentration from the image. It is very interesting to correct Noaa images, for example.

3.3. Aerosol type

There are three main regions in the state of São Paulo according to the predominant type of aerosol present in each one: the coast (where there are only maritime aerosols), the big cities (where the aerosol is predominantly urban) and the interior (with continental aerosols). The maritime aerosols no penetrate in the interior of the state because the "Serra do Mar" (sea mountain ridge) is a sufficient natural obstacle.

4. APPLICATIONS AND IMPORTANCE

The calculation of the vegetation index NDVI (Rouse et allii, 1971) and the automatic pattern classification are two typical uses of the satellite images for agricultural purposes. These treatments illustrate very well the practical importance of the atmospheric correction.

The results were obtained using a Landsat-TM image with 512 pixels by 512 rows, acquired on August 6th, 1992 at 12:27GMT, orbit-point 219.76, quadrant A, whose center is on $22^{o}49$'S and $47^{o}03$'W. The atmospheric optical thickness was equal to 0.283 for continental aerosols. The water vapor and ozone contents were equal to $3.08 g.cm^{-2}$ and 0.31cm.atm, respectively.

The Table 1 shows the NDVI values of three typical surfaces existing in the test-image (forest, sugar cane and water) calculated from images whose grey levels correspond to radiance and reflectance.

Surface	Radiance		Reflectance	
	Original	Corrected	Original	Corrected
Forest	0.317	0.553	0.434	0.648
Sugar Cane	0.363	0.530	0.476	0.621
Water	-0.306	-0.433	-0.251	-0.475

Table 1. NDVI

The difference between the NDVI calculated from the original image and the corrected image is near 0.2 for forest and sugar cane. This value is very important and significant considering that the agronomic parameters are usually expressed by exponential curves. This can leave to estimating errors greater than 100% for the fresh biomass, for example, if we use the models presented by Tucker (1979).

The importance of the atmospheric correction in the automatic pattern classification is presented here using a self-organized method based on the algorithm proposed by Pao (1989). This method, by its time, is based on the Adaptive Resonance Theory described by Carpenter & Grossberg (1987). The original method proposed by Pao (1989) was implemented with some additional resources and controls to improve its efficiency considering its application to classify satellite images.

Tables 2 and 3 present the relative variance of the classified images (original and corrected) with various values for the confidence radius (R = 0.100, 0.125, 0.150, 0.175, 0.200). This is the principal input parameter of the classification method used.

R	Cl.	Relative Variance				
		TM2	TM3	TM4	TM5	General
0.100	20	70.8	76.5	57.3	91.1	64.7
0.125	10	55.3	56.0	9.0	77.5	48.3
0.150	9	54.8	55.1	9.0	75.7	47.3
0.175	7	50.3	50.6	8.3	69.0	43.0
0.200	6	45.6	47.8	8.1	69.0	42.5

Table 2 - Original image

R	Cl.	Relative Variance				
		TM2	TM3	TM4	TM5	General
0.100	39	79.1	84.6	82.7	89.1	70.2
0.125	21	74.3	78.4	67.2	85.2	64.0
0.150	19	75.1	80.3	67.0	84.3	64.1
0.175	14	70.7	76.1	59.0	77.9	58.6
0.200	11	64.6	64.3	9.8	75.1	44.4

Table 3 - Corrected image

We have always more classes in the corrected image than in the original image. The relative variance is always greater in the second case, mainly for the band TM4 that is very important to the distinction of vegetal surfaces. The visual analysis confirms the better classification of the corrected image mainly for the vegetal surfaces that is our main interest.

5. FINAL DISCUSSIONS

This paper has done a general presentation of our work on atmospheric correction of satellite images in a tropical region. One of the principal characteristics that can be seen in this description is the work on various phases like the collecting of input data, the processing of the image with a software developed by us and the evaluation of the importance of the atmospheric correction in our situation.

The influence of the atmospheric effects in two typical applications of the satellite images as showed in the section 4 illustrates the importance of the work that has increased after the acquisition of a Noaa-AVHRR antenna on December 1994. The necessity to have good input data justifies the work on acquisition of atmospheric parameters. It is very important also to have a software developed according to our conditions of data, applications and processing, mainly considering the low disposability of such kind of systems around the world.

It is important to emphasize that this work is inside a research program of the Campinas State University (UNICAMP) about the application of satellite images in the agriculture. The European Unit, EMBRAPA and CNPQ support this program.

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