Revista Brasileira de Cartografia (2012) Nº 64/6: 813-820
Sociedade Brasileira de Cartografia, Geodésia, Fotogrametria e Sensoriamento Remoto
ISSN: 1808-0936

IN-FLIGHT ABSOLUTE CALIBRATION OF CBERS SENSORS

Calibração Absoluta em Vôo dos Sensores do CBERS

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Recebido em 02 de julho, 2012/ Aceito em 29 de julho, 2012
Received on july 20, 2012/ Accepted on july 29, 2012

ABSTRACT

The National Institute for Space Research (INPE) decided to freely distribute the orbital images available on its own catalog since the beginning of the last decade. One of the most important consequences of that decision has been the wide usage of the remote sensing technology among different Brazilian user profile, including students, private companies and scientific academies. Besides that, the China-Brazil Earth Resources Satellite (CBERS) program has opened several applications and research possibilities to the Brazilian community, which have not been restricted to mapping or qualitative information extraction from the images, but including quantitative approaches that need an accurate link between the images digital numbers and the effective in-flight radiance measured by the CBERS sensors. This link is established by the so called "absolute calibration" that can be performed before launch and during the flight by internal system or by procedures conducted on the Earth surface (external to the satellite). This last possibility has been carried out on reference surfaces such as those endorsed by the Committee on Earth Observation Satellites (CEOS) that basically are located in desert regions of the planet. The Brazilian territory does not have desert surfaces or any one CEOS endorsed surface, but in-flight calibration campaigns have been performed using agricultural crops surfaces located in the northeast region of the country whose results have been comparable with those achieved internationally. The objective of this chapter is to describe the main CBERS sensors absolute calibration procedures that have been adopted in Brazil.

Keywords: CBERS; Absolute Calibration; In-flight Absolute Calibration.

RESUMO

O Instituto Nacional de Pesquisas Espaciais (INPE) decidiu pela distribuição livre (sem custos) de imagens orbitais disponíveis em seu catálogo desde o início da última década. Uma das mais importantes conseqüências dessa decisão foi a ampla utilização da tecnologia sensoriamento remoto por parte de diferentes usuários, incluindo estudantes, companhias privadas e a academia em geral. Além disso, o programa China-Brazil Earth Resources Satellite (CBERS) abriu novas possibilidades de aplicação e de pesquisa à comunidade brasileira em geral, o que não tem se restringido a extração de informações qualitativas das imagens como os mapeamentos, como também tem incluído a exploração de abordagens quantitativas que necessitam do conhecimento das relações estabelecidas entre os números digitais e os valores de radiância efetivamente medidos pelos sensores CBERS. Essas relações são estabelecidas pela chamada "calibração absoluta" que pode ser realizada antes do lançamento ou durante o vôo por sistemas internos dos sensores ou por procedimentos realizados na superfície da Terra (externos ao satélite). Esta última possibilidade tem sido conduzida em superfícies de referência tais como aquelas selecionadas pelo Committee on Earth Observation Satellites (CEOS) que

basicamente correspondem a regiões desérticas do planeta. O território brasileiro não possui superfícies desérticas ou qualquer outra selecionada pelo CEOS, porém campanhas de calibração absoluta têm sido realizadas usando superfícies destinadas ao desenvolvimento de culturas agrícolas localizadas no nordeste do país e os resultados têm sido comparados com aqueles alcançados internacionalmente. O objetivo deste capítulo é descrever os principais procedimentos adotados em território nacional na calibração absoluta dos sensores CBERS.

Palavras Chaves: CBERS; Calibração Absoluta; Calibração Absoluta em Vôo.

1. INTRODUCTION: CBERS PROGRAM

Brazil and China are huge countries with complex environments and resources to be monitored. In order to monitor both countries and contribute to monitor other environments around the planet it is necessary a continuous satellite data availability. In order to attend these objectives, the CBERS Program was conceived. CBERS is the acronym for China Brazil Earth Resources Satellite. It is a joint program between Brazil and China which aims at the design, construction, launching and operation of a series of satellites for Earth observation. The program began in 1988 with the objective of launching two satellites; however, later on the program was extended to accommodate additional satellites (Epiphanio, 2009). By now, three satellites were launched: 1999, 2003 and 2007 (CBERS-1, 2 and 2B, respectively). The next generation of satellites is composed by CBERS-3, to be launched in 2012, and CBERS-4 (Epiphanio, 2011).

CBERS satellites are medium to large size satellites (1,500 kg category), operate in near-polar, sun-synchronous, phased orbit at 778 km altitude above Earth surface. The payload of the first two satellites - CBERS-1 and 2 - were composed by three imaging cameras (Table 1). The spatial resolution ranged from 20 m to 260 m, the temporal revisiting time ranged from 5 days to 26 days, and the spectral c range varied from blue to thermal infrared. All cameras are 8 bits. The technologies for two cameras were pushbroom type (WFI – Wide Field Imager and CCD – High Resolution CCD Camera) and the third camera was a mechanical scanner radiometer type (IRMSS – Infrared Multispectral Scanner). For CBERS-2B, the IRMSS was replaced for HRC (High Resolution Camera), a pushbroom, 2.7 m pixel size, panchromatic, 27 km swath camera (Table 1).

CBERS-3 and 4 are a new generation, with new sensors. The satellites are bigger in order to accommodate the four cameras onboard (Table 2). Two of these cameras are under Chinese responsibility and two under Brazilian responsibility. The imaging capability is improved. The spatial resolution ranges from 5 m to 64 m, the revisit time ranges from 3 to 26 days, the spectral coverage ranges from blue to thermal infrared, and the swath ranges from 60 km to 866 km. All satellites provide onboard recording capability. CBERS 3 and 4 are expected to fulfill many of the imaging necessities of agriculture, environment, forest subjects, just to mention a few.

As part of any satellite program is the definition of a data policy. For CBERS, it was decided by a free data distribution to all registered users. As a consequence of this data policy, CBERS data was made available to many new users,

Table 1 – Main characteristics of CBERS-1, 2 and 2B imaging cameras

Table 1. Characteristics of the imaging sensors on board CBERS-1, -2 and 2B.

Cameras	Bands	Wavelength (µm)	GIFOV	Swath (km)	Band Registration (pixel)	Radiom. Sens. Max. Rad.	Radiom. Sens. Min. Rad.	S/N at Max. Rad.	S/N at Min. Rad.	MTF
CCD	B01	0.45 - 0.52	20	113	<0.3	28.7	4.6	48	32	>0.18
	B02	0.52 - 0.59				30.1	3.7	50	31	>0.18
	B03	0.63 - 0.69				25.9	2.4	48	26	>0.18
	B04	0.77 - 0.89				35.6	2.7	52	29	>0.18
	B05	0.51 - 0.73				55.6	9.0	53	37	>0.18
IRMSS	B06	0.50 - 0.90	80	120	<0.3	35.3	<0,4%	300	26	>0.4
	B07	1.55 - 1.75				25.7	<1%	100	9	
	B08	2.08 - 2.35				12.9	<2%	50	5	
	B09	10.4 - 12.5	160		<0.6	8.9	<1.2 K (300 K)	-	-	
WFI	B10	0.63 - 0.69	241	925	<0.47	9.5	0.01	-	-	>0.30
	B11	0.77 - 0.89				15.1	0.02	-	-	>0.30
HR	B12	0.50 - 0.8	2.4	27	-	-	-	≥47	≥26	≥0.15

GIFOV = ground instantaneous field of view (m); Radiom. Sens. at Max. Rad. = radiometric sensitivity at maximum radiance ($W.m^{2-}.sr^{1-}.\mu m^{1-}$); Radiom. Sens. Min. Rad. = radiometric sensitivity at minimum radiance ($W.m^{2-}.sr^{1-}.\mu m^{1-}$); S/N = signal to noise ratio; MTF = modulation transfer function.

Table 2 – Main characteristics of CBERS-3 and 4 imaging cameras

Table 2. Characteristics of the imaging sensors on board CBERS-3 and 4.

Cameras	Bands	Wavelength (µm)	GIFOV	Swath (km)	Band Registration (pixel)	Max. Rad.	Min. Rad.	Radiom. Res.	S/N at Max. Rad.	S/N at Min. Rad.	Max. Refl.	Min. Refl.	MTF
PAN	B01	0.51 - 0.85	5	60	<0.3	227	18	0.84	48	27	0.6	0.05	>0.18
	B02	0.52 - 0.59	10			339	38	0.80	44	25	0.7		>0.20
	B03	0.63 - 0.69	10			328	27	1.00	43	21	0.8	0.10	>0.20
	B04	0.77 - 0.89	10			251	16	0.80	45	21	0.9		>0.18
MUX	B05	0.45 - 0.52	20	120	<0.3	344.4	35.3	0.70	>47	>31	0.6	0.02	>0.23
	B06	0.52 - 0.59				361.8	25.7	0.6	>49	>29	0.7	0.04	>0.23
	B07	0.63 - 0.69				352.3	12.9	0.6	>49	>23	0.8	0.02	>0.30
	B08	0.77 - 0.89				275	8.9	0.5	>49	>24	0.9	0.04	>0.18
IRS	B09	0.50 - 0.90	40	120	<0.3	233	20	<0.4	49.5	28.0	0.90	0.20	>0.30
	B10	1.55 - 1.75	40			44.5	4.2	<1.0	40.0	19.0	0.90	0.20	>0.30
	B11	2.08 - 2.35	40			18.5	1.8	<2.0	34.0	14.0	0.90	0.20	>0.30
	B12	10.4 - 12.5	80			-	-	<1.2 K (300 K)	-	-	-	-	>0.30
WFI	B13	0.45 - 0.52	64	866	<0.3	343.4	35.3	0.6	>48	>32	0.6	0.02	>0.23
	B14	0.52 - 0.59				361.2	25.7	0.5	>48	>31	0.7	0.04	>0.23
	B15	0.63 - 0.69				306.9	12.9	0.5	>47	>25	0.7	0.02	>0.23
	B16	0.77 - 0.89				243.4	8.9	0.4	>47	>26	0.8	0.04	>0.18

GIFOV = ground instantaneous field of view (m); Max. Rad. = maximum radiance ($W.m^{2-}.sr^{1-}.\mu m^{1-}$); Min. Rad. = minimum radiance ($W.m^{2-}.sr^{1-}.\mu m^{1-}$); Radiom. Res. = radiometric resolution (NEDr) or temperature sensitivity (NEDt) (% or K); Max. Reflect. = maximum reflectance (%); MTF = modulation transfer function.

especially to scientific community, public institutions and small business. The system for data processing, archiving, distribution and management was completely developed in Brazil for the Brazilian side of the cooperation. Since the beginning of CBERS-2 and 2B operations, more than one million images were made available to the user´s community. For CBERS 3 and 4, the same data policy is going to be adopted.

In order some satellite data can be used across various applications and inter-compared with other satellite data, its data must be reduced to a common and comparable basis. To accomplish this task, a process of calibration is necessary. The process of calibration aims to reduce the output and registered signal of a sensor into an acknowledgeable, meaningful and repeatable physical value. There are two broad calibration processes: relative and absolute. The objective of the relative calibration is to assure that equal radiance levels at the entrance of the sensor generate same output levels at the final satellite product. Thus, some mechanisms of providing same levels of energy to the detectors must be provided, thus we can detect differences among detectors outputs when subjected to same energy levels. The objective here is to know the behavior of each detector respective to energy inputs. Once this is known, it is possible to derive an algorithm to correct the output signal of each detector and put all of them in a similar basis. At the end, same signal output levels should mean same energy signal input. However, after this process, the user still does not know the real level of the input energy based solely on the signal registered at the final product. There must be derived an algorithm that relates the output signal registered in the final product to the input energy level. This process is the absolute calibration. There are various methodologies to derive the absolute calibration coefficients for some specific sensor or imaging camera (THOME *et al*., 1997, 2004; SLATER *et al*., 1987; TEILLET *et al*., 2011).

In this paper, we describe the procedures adopted to make the absolute calibration for CCD camera (High Resolution Imaging CCD Camera) of CBERS-2. As a result of absolute calibration process, the users can take some CBERS-2 CCD data, identify the satellite data used to generate the calibration coefficients, apply the calibration coefficients derived from the calibration process to his image, and get the absolute radiance values which were responsible to generate the digital values registered for each pixel at the satellite image. Such kind of calibrated data can be compared to data provided by other satellites or by data acquired during different dates. Calibrated procedures broaden the usefulness of satellite data (CHANDER *et al*., 2004; ZHANG *et al*, 2001; PONZONI *et al*., 2006).

2. CBERS-2 IN-FLIGHT ABSOLUTE CALIBRATION

2.1 Looking for a reference surface

The CBERS sensors in-flight absolute calibration needs coincided with the Working Group on Calibration/Validation of the Committee on Earth Observation Satellites (WGCV/CEOS) activities, which includes the identification of ideal reference surfaces all over the world. This identification was not complete and no international surface characterization criteria had been defined. Thus, it was necessary to find some reference surface located in the Brazilian territory that minimally presented the characteristics such as those mentioned by Scott *et al*. (1996) related to the geographical positioning (mainly altitude), spectral homogeneity and isotropy, access etc. Considering the geomorphology of the Brazilian territory, there are no surfaces that have all the desired characteristics, but it was possible to identify some that presented part of them.

Some potential calibration sites were identified in the west part of the State of Bahia (northeast region of Brazil), which have positive characteristics for calibration purposes such as:

1. The region presents lower cloud cover indices during winter time at the satellite over pass;
2. The altitude is around 850m over the sea level;
3. Sandy soil is dominant (relatively high reflectance);
4. During the winter time, large areas are prepared to plant economical crops and they present enough spatial dimensions for CBERS sensors calibration purposes;
5. The agricultural schedule that is followed every year makes possible to find a specific calibration site with the same characteristics at that specific time of the year;
6. The coefficient of variation of measurements, indicator of the spectral/spatial uniformity, is around 6-8%;
7. The region is one of the most arid region of the Brazilian territory;
8. As the reference surfaces are located within farms, there are a lot of roads and the access is very easy.

Fig. 1 shows the localization of the interest region (red circle) in the Brazilian territory including the average cloud cover indices for June 2003.

Fig. 2 shows a color composition of CCD-2 (green), CCD-3 (blue) and CCD-4 (red) spectral bands from 06/25/2004. Yellow rings indicate the crop fields that were selected as reference surfaces (or test sites) to be radiometrically characterized in 2004. The ring-2 indicates the surface that was effectively used in the CBERS-2 CCD absolute calibration campaign.

Actually, it would be interesting to repeat the radiometric measurements at the same reference surface every calibration campaign, thus making

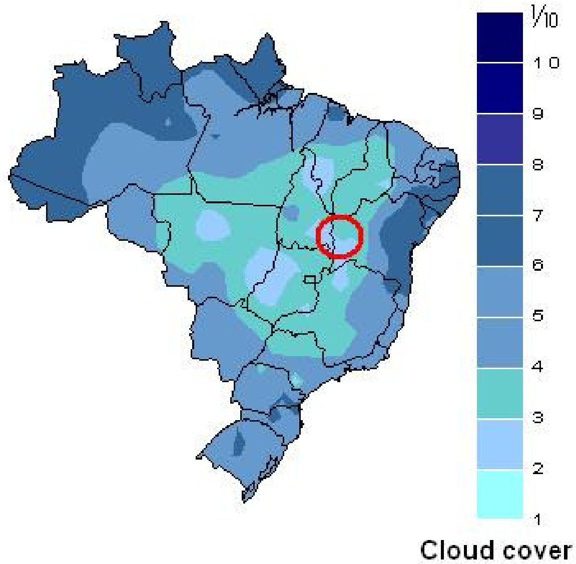

Fig. 1: Interest region in the Brazilian territory showing the low cloud cover.

possible the data comparison. Unfortunately, this has not been possible due to specific farms planting and harvesting schedules that frequently do not coincide with the satellite flight time. So, at each calibration campaign it is necessary to identify a new reference surface previously, contacting the farmer and convincing him to permit the access to the surface.

2.2 Spectral characterization of the reference surface

The surface characterization does not start in the test site surface as well. Actually, it starts in a laboratory, where the radiometers and the reference panels have to be absolutely calibrated. During this phase, the calibration procedures include repetitions in order to calculate the uncertainties associated.

After the in-lab equipment calibration, everything is ready to be transferred to the field. The surface characterization explores two different approaches: the spectral homogeneity and the isotropy. Lamparelli *et al*. (2003) and Ponzoni *et al*. (2004) have characterized spectrally the Salar de Uyuni (Bolivia) surface for the TM/Landsat 5 absolute calibration purposes considering these two approaches. The WGCV/CEOS has also explored the same strategy in the Tuz Golu (Turkey) reference surface characterization, in which the spectral homogeneity evaluation has been based on radiometric measurements from the surface using the ASD FieldSpec PRO spectroradiometer running from 0.350mm to 2.500mm performed in specific

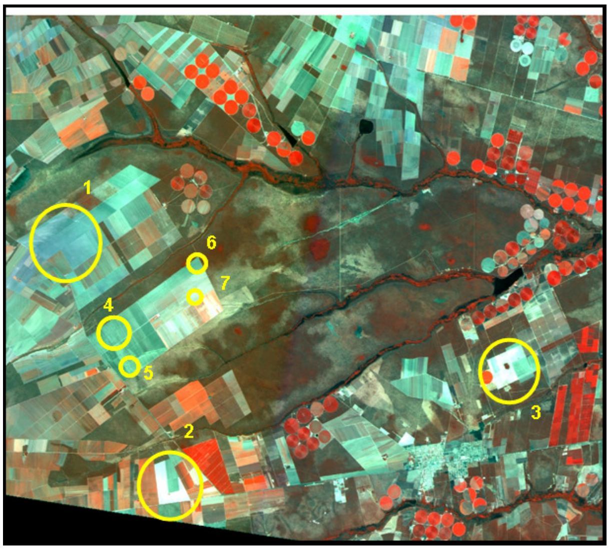

Fig. 2: CCD-2 (green), CCD-3 (blue) and CCD-4 (red) color composition from 06/25/2004.

traits of the entire surface. These traits generally are defined as squares or rectangles of 300m x 100m, 400m x 400m or bigger, depending on the spatial resolution of the sensor to be calibrated. Statistical procedures are also applied in order to estimate the uncertainties associated. The isotropy is also referenced as Bidirectional Reflectance Function (BRF) characterization, which has been carried out by the so called "goniometer", as illustrated in Figure 3 (PEGRUM-BROWNING *et al.*, 2008).

As there are no available goniometers, the alternative was to take radiometric measurements in sample points located in a imaginary line in the surface during a day long in specific time intervals. The idea is to identify any variation in the BRF as the illumination geometry changes.

2.3 Radiometric measurements during the satellite over pass

Taking into account the satellite flight schedule, the radiometric measurements are carried out starting 30 minutes before and ending 30 minutes after the satellite flight time over the surface, following the same strategy adopted during the surface spectral characterization procedures, i.e., taking radiometric measurements from square or rectangular surfaces previously defined on the ground. Small color flags or plastic tarps have been used to show both the limits of the surface to be measured and the sample points localization within this surface. These sample points can or can not be considered as a localization reference within the surface, since the ASD FieldSpec PRO radiometer can also operate in a continuous mode. In this case, the radiometric measurements (radiance mode) are taken continuously as the operator walks and the reference panel is frequently positioned in one of the surface border line by another operator that moves it along this line as the radiometer operator comes back from the opposite side of the surface.

When the sample points are considered, the ASD FieldSpec radiometer can be adjusted running at the reflectance or radiance mode and the radiometric measurements are performed near each sample point, including repetitions. Here, the repetitions are carried out changing the position of the instrument optical cable in order to collect data from a different pixel from the ground, but maintaining the relative sun-operator positioning to avoid significant changes in the shadowing. These repetitions are crucial to the uncertainties estimation. The reference panel can be carried by the operator that follows the radiometer operator in order to put the panel near the sample point. The radiometric measurements from the ground are intercalated with those from the reference panel at each sample point. The number of sample points is dependent on the size of the reference surface, since the entire surface has to be measured in 60 minutes timeframe.

These radiometric data are averaged and statistics from this average are calculated. This average (reflectance or radiance) is the basis of the Top of Atmosphere (TOA) radiance estimation at each sensor spectral band. Here the sensor response curves are taken into account.

Fig. 3: Goniometer used in the surface BRF characterization according to Pegrum-Browning *et al*. (2008).

2.4 Atmospheric characterization and atmospheric correction code application

The objective of the atmospheric characterization is to estimate data of some atmospheric parameters that are used in the TOA radiance estimation from the surface reflectance or radiance data. In Brazil it has been based on the usage of sunphotometers whose data have been used to calculate the aerosols type and content, water vapor and ozone contents and optical depth. The values of these parameters have been considered as input data of atmospheric correction codes such as 5S (Simulation of the Satellite Signal in the Solar Spectrum), 6S (Second Simulation of the Satellite Signal in the Solar Spectrum) or MODTRAN (Moderate Resolution Atmospheric Transmission).

The atmospheric characterization generally starts one or two days before the satellite over pass in order to study the atmospheric conditions and to calibrate the sunphotometers as well. During that one hour radiometric measurements are performed in the reference surface (which includes the satellite flight over the region), the sun photometer collects the direct Sun irradiance in shorter time intervals. This irradiance set of data will effectively be used in the atmospheric correction codes that will calculate the TOA radiance at each sensor spectral band.

2.5 Image processing and absolute calibration calculation

This step includes the definition of which sensor product will be used in the absolute calibration coefficients determination. For "sensor product" one can understand which sensor image will be considered as the basis for the calibration procedure. Here we are talking about the radiometric, geometric or both correction levels that are applied to the images.

It is important to emphasize that before the images are available to the users, they have to be radiometrically and/or geometrically corrected. Here, there are a lot of options and criteria that could be adopted by the sensor administration agency and any decision must to be taken in terms of which product will be used as the base for the absolute calibration.

Frequently, the absolute calibration coefficients are determined using the so called "level 1" image, which is characterized by just the relative radiometric correction, whose objective is to equalize the intensity response of each detector that composes the entire image. Since the individual detector response in each spectral band is corrected according a reference value (mainly the general average response calculated from each individual detector response), the image is considered radiometrically corrected. Nevertheless, as mentioned before, the result of this procedure application is dependent on different criteria and specific options; thus, different acceptable results can be achieved, impacting dramatically the absolute calibration. Once defined the way to be followed in the relative calibration, it is also defined the level 1 image to be generated. This level 1 image is then used in the absolute calibration coefficients determination.

Level 1 images from the reference surface acquired during the field campaign are imported to some image processing software. Using the tarps or any other target as the reference surface localization guide, the reference surface is located visually in the image. Pixels values (digital numbers) from the reference surface in each spectral band image are averaged. Statistics from the average calculation are also determined. The resulting averages (each band) are used in the absolute calibration coefficient determination through the Eq. 1:

$$CC_{\lambda} = \frac{ADN_{\lambda}}{L_{\lambda}} \qquad (1)$$

where: CC_{λ} is the absolute calibration coefficient at λ spectral band; ADN_{λ} is the averaged digital number calculated from the level 1 image at λ spectral band and L_{λ} is the TOA radiance at λ spectral band.

The absolute calibration coefficients are used to convert the digital numbers into physical values such as reflectance or radiance, which are frequently related to biophysical and/or geophysical parameters through the spectral characterization of different targets.

This conversion procedure is also needed when the comparison between data from different orbital sensors has to be performed.

2.6 Results evaluation

The absolute calibration results evaluation has been a multi-approach task since it can be carried out with engineering or user points of view. In the first case uncertainties estimated in the different steps of the entire procedure are taken into account. Thus, steps that present higher uncertainties levels should be reviewed and improved. From the user point of view, the important aspect to be considered is how trustful is the spectral characterization of the targets through the DN conversion into physical values carried out by application of absolute calibration coefficients.

In Brazil, there is not a formal strategy to evaluate the absolute calibration results considering both points of view after launch. The engineering approach has just been recently incorporated in the in-flight absolute calibration routine and it also will include the uncertainties levels as an evaluation criterion. The user approach has diffuse and wide ways to evaluate the results, since there are a lot of possibilities and target natures such as vegetation, water bodies, ocean, soils, agriculture, minerals, etc. Here, quantitative studies which include both empirical and physical approaches have been conducted with different level of success. This sort of evaluation is also called "validation" and it is more dedicated to the image-oriented procedure rather than to a sensor-oriented because users understand the images as an evaluation product starting point. Thus, the agency responsible for the image processing and distribution to the remote sensing community has to pay attention in the users demands, informing them about the absolute calibration coefficients compatible with the correction procedures applied to the available images.

Generally, the user approach evaluation takes into account the correlation levels between radiometric and biophysical or geophysical variables through empirical models. This strategy is fragile since the correlation levels can not be explained by the calibration accuracy. The application of radiative transfer codes (physical approach) seems to be more efficient but these codes have to be adjusted to fully describe the relationship between the image radiometry and the biophysical or geophysical properties of the targets.

3. NEAR FUTURE AND PERSPECTIVES

CBERS-3 and 4 are satellites expected to be in operation for long time after their launching. New ground stations outside China and Brazil are installed or under consideration to be installed. There are perspectives their data become more and more available to a broaden community – national and international. At the same time, new satellites are always being launched and considered to be part of global monitoring programs. The scientific community is demanding data which can be comparable with multiple satellite sources and existent databases. Thus, there is an increasing demand for scientific sounding satellite data, which means calibrated data. CBERS program is struggling to consolidate its continuous calibration program in order their data can be incorporated into global monitoring and modeling programs.

ACKNOWLEDGEMENTS

The authors express their gratitude to farmers that allowed the installation of calibration experiments and to Brazilian Council for Scientific Research (CNPq) for providing scholarships to the authors.

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