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# Mapping landscape features related to soil Carbon using ASTER Thermal Infrared images

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**Abstract**. Climatic change derived from greenhouse gases (GHG) anthropogenic emissions consists in one of the main concerns of public policy makers. In Brazil, agricultural activities and livestock are responsible for 23% of gross GHG emissions, and land use and soil management are the main factors that drive these emissions levels. Soil carbon is mainly stocked as soil organic matter (SOM), and SOM stocks are related to clay content in soil and soil management. In order to improve the monitoring of these factors, we propose the use of ASTER TIR images data to map quartz, phyllosilicated clays, and non-photosynthetically active vegetation (NPAV) in order to assess remote sensing techniques to large-scale mapping of environments with greater or less soil carbon accumulation. We used thermal bands ratios to get quartz, phyllosilicated clays, and NPAV image fractions, that were compared to ASTER VNIR images and to the soil classes map of the study area. Results show that areas with higher values in quartz image fraction are related to bare soils areas in quartz-enriched soils. Higher values in phyllosilicates image fraction are related to bare soils areas with clay soils and higher values in NPAV image fraction are consistent to the vegetation activity throughout the study area, including crop residues areas detected in large-scale farms.

**Keywords**: remote sensing, spectral indices, agriculture, quartz, phyllosilicates, non photosynthetically active vegetation, sensoriamento remoto, índíces espectrais, agricultura, quartzo, filossilicatos, vegetação não fotossinteticamente ativa.

## 1. Introduction

There is a global growing concern about climate change due to greenhouse gases (GHG) emissions from human activities, such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). In Brazil, the GHG direct emissions from agricultural activities and livestock (use of fertilizers, animal waste management, etc.) are the third largest emissions source (23% of the gross emissions) (Observatório do Clima, 2016). The land use and soil management are fundamental activities for the balance of GHG emissions in this sector, since they represent an important carbon poll in the nature. A major part of the carbon on soil is found in the form of Soil Organic Matter (SOM) and the increase of SOM stock is a slow process. SOM stock increase process is dependent on a proper soil management and on soil conservation practices (e.g. no-till agricultural system) (Cerri, et. al. 2007) especially in tropical regions, where decomposition rates are accentuated due to high temperatures and soil moisture (Six et al., 2002). It should be stressed that, despite the higher rate of SOM decomposition, soils in tropical regions stock 32% of organic carbon total content in the world soils (Eswaran et al.,

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1993).

The main determinants factors to the SOM' dynamic are the soil clay content, the climate, and overall, the soil management system, once that soil management system influences the increase or decrease of soil carbon stock as balance between the inputs (photosynthesis or animals), and the outputs (products, respiration, oxidization, fermentation, erosion, etc.) of carbon in the system. The carbon accumulation is measured considering total soil carbon stock, however its storage potential and storage period also depends on carbon pools on the soil (active/ labile vs recalcitrant/ passive) and the recycling time (Six et al., 2002), stabilization (physical or chemical) (Kaiser et al., 2002), and localization (inter/intra-aggregated and free carbon in soil) (Balesdent et al., 1996).

In general, it can be stated that soils with higher clay content are more efficient in SOM's conservation and stabilization (Lepsch et al., 1982) and conservationist agricultural management techiniques which promote higher amount of plant residues cover on the soil surface (Salton, 2005) are favorable condition to provide carbon sequestration on agricultural soils. Thus, the texture and superficial coverage of the soil with plant residues in agricultural soils affected by the relief with more erosion or less erosion can represent discretizing features for remote sensing techniques in order to map landscapes with high or low possibility of carbon accumulation.

The use of remote sensing in carbon researches is strategic taking into account (i) the goals ratified in COP21 and component of the Brazilian Low Carbon Agriculture Plan (ABC Plan) (NAMAs - Nationally Appropriate Mitigation Actions) (Brasil, 2015) (ii) the need to improve carbon estimation models for large areas, (iii) the establishment of alternative/auxiliary methods to traditional methods of carbon soil measurement (lengthy and expensive). In this regard, this work goal is to propose and assess remote sensing techniques for large scale mapping of features related to environments with higher or low accumulation of soil carbon, considering soil texture variations (presence/abundance of sandy soils vs clayey soils) and the identification of non-photosynthetically active vegetation (VNFA – dry matter of crop residues). For this, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data were used in order to propose and apply the spectral thermal infrared (TIR– 10-14 bands – 8.125-10.95µm) indices.

## 2. Study area

The study area is located in southern State of Piauí, in northeastern Brazil, comprising parts of the municipalities of Gilbués, Monte Alegre do Piauí, Barreiras do Piauí, São Gonçalo do Gurgueia, and Corrente. We selected this study area based on its landscape complexity, once that it presents terrain characteristics ranging from plateaus with deep arable soils (in altitudes of 800 m in the south and 550 – 600 m in the north) to dissected relief areas with intense erosion processes linked to Gilbués Desertification Core (550 – 450 m in the center of tne study area).

The complexity of the area can be synthetized by the soil classes it presents. The plateaus are dominated by deep and well weathered Oxisols. The slopes of these plateaus have predominance of Entisols *Lithic...Orthents*. The lower areas have Quartzipsamments, Oxisols, Alfisols, and a small area with Ultisols.

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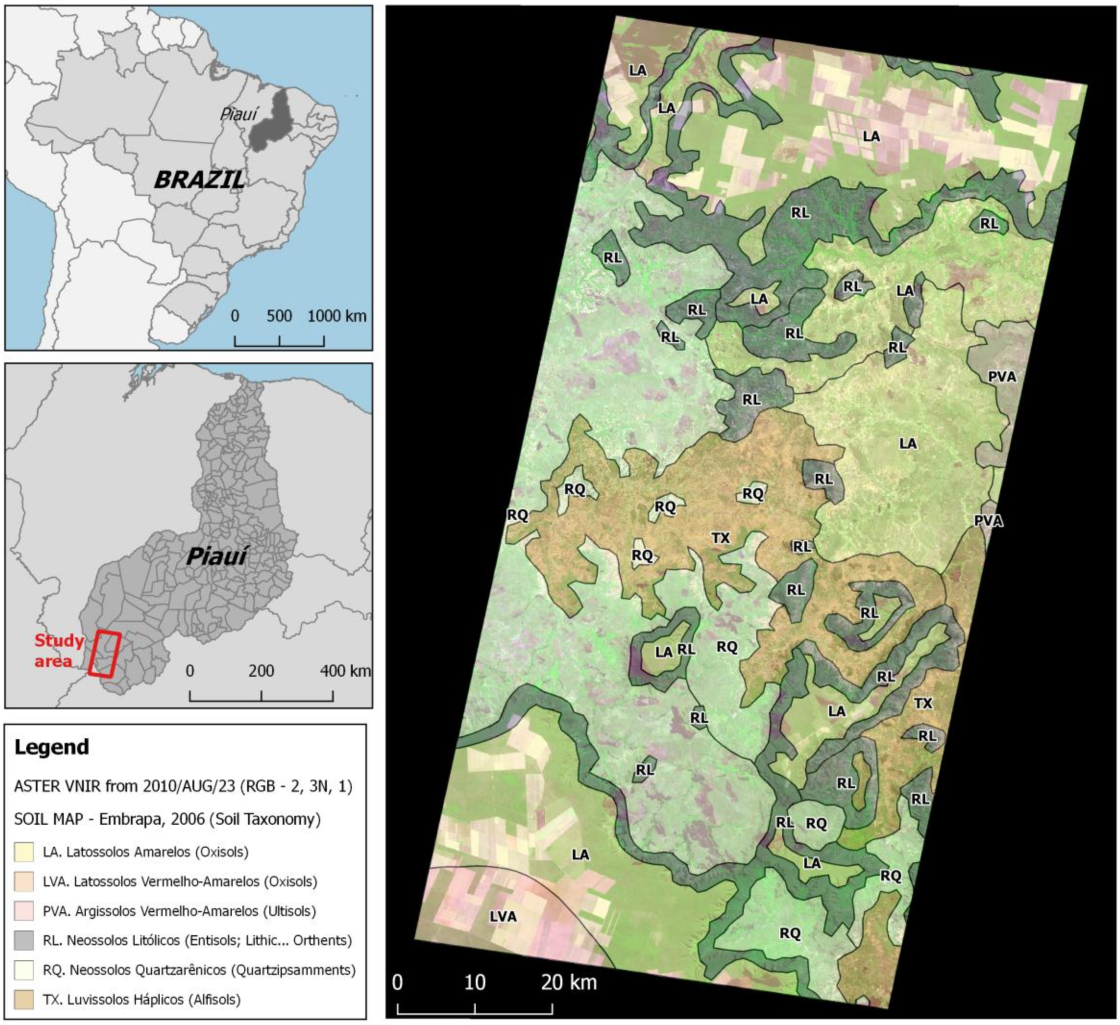


Figure 1. Study area location and distribution of the main soil classes.

The land use and land cover in the plateaus is dominated by large scale high technological crop areas, mainly soybeans. The low lands are more prone to subsistence farming and little scale breeding areas of cattle and goats.

## 3. Material and methods

ASTER sensor thermal infrared data has generated a great number of good results for environmental and natural resource mapping since its operationalization in 1999, mainly related to geological applications (Sobrino et al., 2016; Ninomiya et al., 2005). Despite ASTER TIR data potential for agriculture applications, in Brazil ASTER TIR data still underused, particularly as regard the agricultural mapping. In this work we used the ASTER spectral region (10-14 bands – 8.125-10.95μm) in order to evaluate the sensor capacity to identify features indirectly associated to soil carbon variations, estimating their presence and abundance as follow: (i) soil texture (clayey soils vs sandy soils) and (ii) Non-Photosynthetically Active Vegetation – (NPAV) regarding to crop remains.

### 3.1 ASTER data

ASTER images were acquired during the region’s dry season, on August 23rd, 2010. In order to cover a representative section of the Gilbués Desertification Core, two ASTER L1B images were used, already geometrically and radiometrically calibrated. Even that nowadays most ASTER images levels are available for free download, including emissivity data, the choice of ASTER unprocessed images associated to perform spectral indices is based on its facility to use in massive computational algorithms (e.g. cloud computing) applied to automatic monitoring system. Furthermore, the TIR spectral region, in opposite to Visible and Short Wave Infrared (0,4-2,5 µm), has lower sensitivity to atmospheric and topographic effects on images, providing the possibility to use these bands in spectral math methods without atmospheric correction (Kahle et al., 1993; Ninomiya et al., 2005; Vicente, 2009).

The use of TIR bands to map soil mineral composition associated to clayey/sandy soils and non-photosynthetic active vegetation (NPAV) is based on their diagnostic spectral absorption features in this spectral region. Silicate minerals, the most abundant mineral component of soils, present distinguishing absorption features around 10µm due to Si-O stretching vibrations (*reststrahlen* bands) (Walter et al., 1987; Salisbury et al., 1991). These TIR features allow an accurate identification and relativization of quartz and clay phyllosilicates (e.g. kaolinite, smectite), not possible with VNIR-SWIR data due to the lack of silicate diagnostic features in this region of the spectra (Salisbury et al., 1991; Hook et al., 1999). Identifying NPAV, hence differentiating it from green vegetation and bare soil, is based on the reduction of radiant energy at the soil surface, and its two characteristic absorption features in the thermal region (around 10.7µm and 11.5µm) (French et al., 2000). It is also known that conventional VNIR-SWIR classification methods are unable to distinguish NPAV from bare soil, especially sandy soils (Daughtry et al.,1995 ; French at al., 2000).

## 2.2Spectral Indices

Based on these TIR spectral features, band ratio operations were used in order to discriminate quartz and clay phyllosilicates and, therefore, access the extent of the land degradation in the Gilbués Desertification Core. In addition, an index that separates NPAV from green vegetation and sandy soils is proposed and tested in this paper. The use of NPAV in this paper aims to identify crop residues (e.g. dry matter), thus allowing the identification of crop areas where no-till agricultural system was performed. The different indices used in this paper, along with its details, are shown in Table 1.

Table 1. Spectral indices applied to ASTER TIR bands

| Band ratio objective | ASTER TIR band ratios | Diagnostic features | References |
|---|---|---|---|
| (1) Differentiating quartz from other minerals | AST11/(AST10 + AST12)*AST13/AST12 | High concentration of quartz – 8.300µm and 9.100µm | Rockwell & Hofstra, 2008 |
| (2) Differentiating clay phyllosilicates | AST10/AST11*AST12 | High concentration of phyllosilicates - 8.300µm | Vicente, 2009 |
| (3) Differentiating non-photosynthetically active vegetation (NPAV) | AST11/(AST13 + AST14) | High concentration of non-photosynthetically active vegetation – 10.7 µm and 11.5µm | Proposed in this paper |

The first index (1), proposed by Rockwell & Hofstra (2008), differentiates quartz from other minerals based in the relation between the low emissivity quartz features at ASTER bands 10 and 12, and the high emissivity features at bands 11 and 13. The second index (2), proposed by Vicente et al. (2009), is used to identify clay phyllosilicates based in the spectral relation between the bands 10, characterized by high emissivity values, and bands 11 and 12, which present characteristic absorption features of clay minerals. Both indices provide information about the soil composition and its texture, which are diagnostic properties used to map texture levels of soils (sandy soils vs clayey soil) (Vicente et al., 2005; 2009).

The third index (3) is proposed in this paper, and is based in the emissivity spectra for dry grass, available at ASTER spectral library. The index explores the relation between the high emissivity feature in band 11, and the sum of both diagnostic absorption features at bands 13 and 14, located in the low emissivity region.

The indices were applied to unprocessed ASTER/TIR data, followed by interactive histogram stretching and application of a median 3x3 filter in order to reduce the spectral noise. The final product of the three indexes is shown in Figure 2.

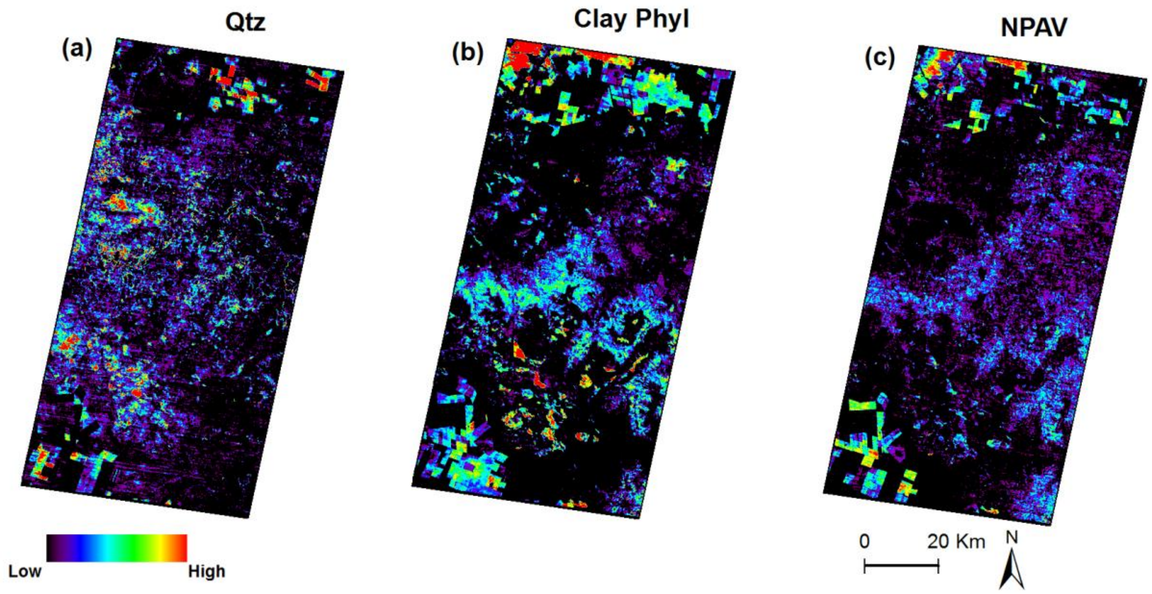


Figure 2. Products of the different indices. (a) Abundance of quartz as result of index (1); (b) Abundance of clay phyllosilicates as result of index (2); (c) Abundance of non-photosynthetically active vegetation as result of index (3).

These products were then combined in a RGB composition, where the quartz index is used as input for the Red band, the NPAV as input for the Green band, and the clay phyllosilicate as input for the Blue band. The product, an RGB triplet image (Figure 3), illustrates de distribution and abundance of all three targets (quartz, clay phyllosilicates and non-photosynthetically active vegetation), and will be discussed in the next section.

## 4. Results and Discussions

The use of the color composite image (Fig. 3) as result of the spectral index allows to map different levels (presence and abundance) of quartz (QTZ – red channel), Phyllosilicates (PHYL – blue channel), and non-photosynthetically active vegetation (NPAV – green channel) associated respectively to sandy soils, clayey soils and dry matter/crop residues. The areas of sandy soils in the soils map (quartzipsamments - RQ) (Fig. 3.c) are associated to quartz high values (red pixels – fig. 3.b) and is less pronounced in crop areas, since these areas are in the plateaus with predominance of clayey soils. In opposition, blue pixels are less intense due to a lower presence of phyllosilicates at the study area. The presence of blue pixels in Fig. 3.b is associated to soils with presence of clay (e.g. oxisols, alfisols – LA, TX) and crop areas (Fig. 1 – ‘b’). It is important to notice that the higher values in both mineralogic indices are related to areas with little or no presence of vegetation, photosynthetically active or non active. Fig. 3.a shows that high values areas in quartz and phyllosilicates index are related to wildfire scars, areas with intense erosion process, and bare soil related to crop activities.

The NPAV (green pixels – Fig. 3.b) is present in the crop areas, pastures and, due to the dry season, shrublands (Fig. 3.a). As expected, photosynthetically active vegetation (PAV) was not mapped by any index (Fig. 3.a), once that it does not have spectral features in ASTER TIR bands (French et al., 2000).

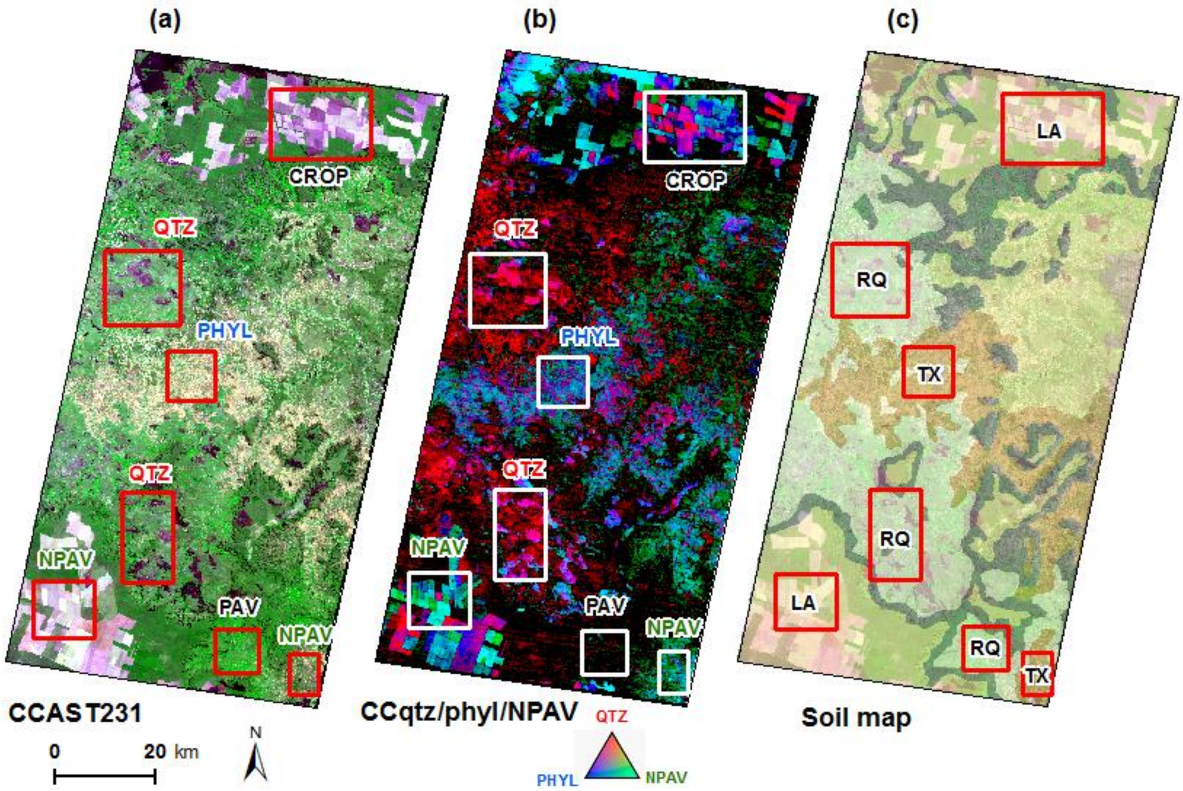


Figure 3. Comparision between (a) ASTER VNIR Bands 2, 3N, and 1 color composite; (b) quartz, phyllosilicates, NPAV RGB color composite; and (c) Soil map of the study area. Highlighted areas show predominance of quartz (QTZ), phyllosilicates (PHYL), non photosynthetically active vegetation (NPAV), photosynthetically active vegetation (PAV), and crop areas (CROP). Soil classes symbology stands for Oxisols (LA), Alfisols (TX), and Quartzipsamments (RQ).

## 5. Conclusions

Quartz index shows higher values in areas with no vegetation cover related sandy soil classes. Phyllosilicates index shows higher values in areas with no vegetation cover in clayey soil classes. Non photosynthetically active vegetation index shows higher values in areas with presence of dry vegetation and crop residues.

The use of ASTER TIR bands associated to spectral indices specially designed for and tested in this work was highly efficient to map features regarding to quartz, phyllosilicates and non photosynthetically active vegetation. These indices can help to provide good estimates concerning to large-scale soil carbon mapping especially when we combine them with temporal analysis in order to verify the interchange between bare soils and vegetation cover along the year.

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## References

Abrams, M.,; Hook, S. J. **Aster User Handbook**: Advanced Spaceborne Thermal Emission and Reflection Radiometer. USA: NASA/Jet Propulsion Laboratory California Institute of Technology, 2, 135p. 2002.

Balesdent, J.; Mariott, A. Measurement of soil organic matter turnover using $^{13}$C natural abundance. In Boutton, T.W.; Yamasaki, S. (Eds). **Mass spectrometry of soils**. Marcel Dekker, New York, 1996, p. 83–111.

Brasil. Ministério das Relações Exteriores. **Pretendida contribuição nacionalmente determinada para consecução do objetivo da Convenção-Quadro das Nações Unidas sobre a mudança do clima (NDC)**. 2015. 6 p. Disponível em http://www.itamaraty.gov.br/pt-BR/ficha-pais/11915-contribuicao-brasil-indc-27-de-setembro

Cerri, C.E.P.; Cerri, C.E.P.; Easter, M.; Paustian, K.; Killian, K.; Coleman, K.; Bernoux, M.; Powlson, D.S.; Batjes, N.H.; Milne, E.; Cerri, C.C. Predicted soil organic carbon stocks and changes in the Brazilian Amazon between 2000 and 2030. **Agriculture, Ecosystems & Environment**, v. 122, p.58-72, 2007.

Eswaran H,; Van Den Berg, E.; Reic, P. Organic carbon in soils of the world. **Soil Science Society of America Journal**, n. 57, n. 1, p. 192-194, 1993.

French, A. N.; Schmugge, T. J.; Kustas, W.P. Discrimination of senescent vegetation using thermal emissivity contrast. **Remote Sensing of Environment**, v. 74, n. 2, 2000, p. 249-254.

Hewson, R. D.; Cudahy, T. J.; Mizuhiko, S.; Ueda, K.; Mauger, A. J. Seamless geological map generation using ASTER in the Broken Hill-Curnamona Province of Australia. **Remote Sensing of Environment**, v. 99, p.159-172, 2005.

Hook, S. J.; Abbott, E. A.,; Grove, C.; Kahle, A. B.; Palluconi, F. D. Use of multispectral thermal infrared data in geological studies. In: Rencz, A. N. (Ed.). **Manual of remote sensing: Remote sensing for the Earth sciences**. New York: John Wiley and Sons, 1999. v.3, 3rd ed., p. 59–110.

Kaiser, K.; Eusterhues, K.; Rumpel, C.; Guggenberger, G. ; Kögelknabner, I. **Stabilization of organic matter by soil minerals**—investigations of density and particle-size fractions from two acid forest soils. Journal of Plant Nutrition and Soil Science, v. 165, p. 451-459, 2002.

Kahle A.B.; Palluconi F. D.; Cristensen P. R. Thermal emission spectroscopy: application to Earth and Mars. In: Pieters, C. M.; Englert, P. A. J. (Eds.). **Remote geochemical analysis: Elemental and mineralogical composition**. Topics in Remote Sensing 4. Cambridge, UK: Cambridge University Press, 1993, p.99–120.

Lepsch, I. F.; Silva, N. M. & Espironelo, A. Relação entre matéria orgânica e textura de solos sob cultivo de algodão e cana-de-açúcar, no estado de São Paulo. **Bragantia**, Campinas, v. 41, p. 231-236, 1982.

Ninomiya, Y.; Fu, B., & Cudahy, T. J. Detecting lithology with Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) multispectral thermal infrared "radiance-at-sensor" data. **Remote Sensing of Environment**, v.99, n. 1-2, p. 127-139, 2005.

Observatório do Clima. **Análise das emissões de GEE no Brasil (1970-2014) e suas implicações para políticas públicas e a contribuição brasileira para o acordo de Paris**. Sistema de Estimativas de Emissões de Gases de Efeito Estufa (SEEG), Relatório Síntese. 2016. 44 p. Disponível em http://seeg.eco.br/wp-content/uploads/2016/09/WIP-16-09-02-RelatoriosSEEG-Sintese.pdf

Ninomiya Y, Fu B; Cudahy T. J. Detecting lithology with Advanced Spaceborne Thermal Emission and Reection

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Radiometer (AS- TER) multispectral thermal infrared "radiance-at-sensor" data. **Remote Sensing of Environment**, v. 99, p. 127–139, 2005.

Ramsey, M. S.; Christensen, P. R.; Lancaster, N.; Howard, D. A. Identification of sand sources and transport pathways at the Kelso Dunes, California, using thermal infrared. Remote Sensing. Geological Society of America Bulletin, v. 111, p. 646–662, 1999.

Salton, J.C. **Matéria orgânica e agregação do solo na rotação lavoura-pastagem em ambiente tropical**. Porto Alegre, Universidade Federal do Rio Grande do Sul, 2005a. 158p. (Doctorate Thesis)

Salisbury, J.W.; Walter, L. S.; Vergo, N.; D'aria, D. M. **Infrared (2.1-25 micrometers) Spectra of Minerals.** USA: Johns Hopkins University Press, 1991, 294 p.

Schmugge,T.; French, A.; Ritchie, J. C.; Rango, A.; Pelgrum, H. Temperature and emissivity separation from multispectral thermal infrared observations. **Remote Sensing of Environment**, v. 79, p.189-198, 2002.

Six, J.; Conant, R. T.; Paul, E. A.; Paustian, K. Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. **Plant Soil**, v. 241, p. 155–176, 2002.

Sobrino, J.A.; Del Frate, F.; Drusch, M.; Jimenez-Muñóz, J.C.; Manunta, P.; Regan, A. Review of Thermal Infrared Applications and Requirements for Future High-Resolution Sensors. **IEEE Transactions on Geoscience and Remote Sensing**, v. 54, n. 5, p. 2963-2972, 2016.

Sparovek, G.; Bernoux, M.; Easterling, W.E.; Melilllo, J.M. & Cerri, C.C. Tropical agriculture and global warming: Impacts and mitigation options. Scientia Agricola, v. 64, p. 83-99, 2007.

Vicente, L.E.; Souza Filho, C.R. Detecção de quartzo e argilominerais para o monitoramento de degradação de terras a partir de dados do infravermelho termal do sensor ASTER. **Revista Brasileira de Geofísica**, v. 28, p. 229-247, 2010.

Walter, L. S.; Salisbury, J. W.; Vergo, N. Spectral Variations in the Thermal Infrared Reststrahlen Band of Silicates. In: Lunar and Planetary Science Conference, 18., 1987. Houston, TX. **Abstracts,** p.1052.