Anais XII Simpósio Brasileiro de Sensoriamento Remoto, Goiânia, Brasil, 16-21 abril 2005, INPE, p. 173-179.

# Vertical variation survey of the nocturnal air temperature using NOAA/AVHRR satellite data

Aníbal Gusso [1]
Denise Cybis Fontana [2]

[1] Centro Estadual de Pesquisas em Sensoriamento Remoto e Meteorologia - CEPSRM
Universidade Federal do Rio Grande do Sul - UFRGS
Caixa Postal 15044, Porto Alegre, Brasil
anibal.gusso@ufrgs.br

[2] Faculdade de Agronomia
Universidade Federal do Rio Grande do Sul - UFRGS
Porto Alegre, Brasil
Denise.fontana@usq.edu.au

**Abstract.** An accurate estimation of land surface temperature (LST) implies understanding of the energy/matter interactions and physical parameters that change in space and time into the biosphere. Additionally, the local physical conditions often makes the relation between air temperature (Tair) and LST a lot obscure. In this paper the authors compare a short-term monitoring of surface temperature and air temperature variations by means of two different night-time satellite overpasses. The main problem is to observe the relationship of LST and Tair by means of the multi-temporal satellite survey and ground based stations records. In order to quantify it, a simple linear regression to makes possible an operational understanding is developed. For the LST estimate it is used a published *split-window* algorithm. The Tair data were obtained from ground based stations under shelter. The LST and emissivity methods use both data collect from Advanced Very High Resolution Radiometer (AVHRR) instruments from National Oceanic and Atmospheric Administration (NOAA) satellites.

**Keywords:** surface temperature, multi-temporal analysis, NOAA/AVHRR, temperatura da superfície, análise multi-temporal, NOAA/AVHRR.

## 1. Introduction

The land surface temperature (LST) is an important factor controlling most physical, chemical and biological processes in the Earth. Knowledge of the LST is necessary for many environmental studies and management activities of the Earth surface resources (Li & Becker 1993).

It is possible to obtain measures of the radiance data from space-borne devices by means records of the emitted energy directly from the earth surface. In order to obtain this parameter from space radiometry in the thermal infrared part of the eletromagnetic spectrum, it is necessary to take into account emissivity and to correct the recorded signal for the perturbations created by the atmosphere along the path between the Earth's surface and the sensor (Becker & Li 1990). McMillin (1975) proposed a method called split-window based on the differential absorption in two adjacent spectral windows in the thermal infrared for correct the atmospheric effects.

The LST results from energy exchange at the surface and satellite-based monitoring can be regarded as an important prerequisite of regional or global observations of surface water, energy and radiation budgets (Andersen 1997). This is because accurate estimation of LST implies understanding of the energy/matter interactions and physical parameters that change in space and time in the biosphere. In the last 10 years, very complex models have been extensively applied to the accurate of LST estimation by means space-borne devices for monitoring some bio-geo-chemical processes over the Earth. However, a detailed knowledge of the processes that leads to errors in the LST estimations are still waiting to be addressed for.

The parameter temperature is classically referred as the kinetic movement of the particles inside the matter. On other hand, LST retrieved from satellite generally is defined as the skin temperature of the ground surface due to the longwave thermal infrared radiation that escapes from the surface. However, the ground surface is far from a skin or homogeneous surface with two dimensions (Vogt 1996 apud Qin & Karnieli 1999). Usually it is compared to various objects on the surface and some of them such as vegetation may be best described in three dimensions, even so, several times they are not conservative on time scales.

The difference between Tair and LST varies particularly with the surface water status, the roughness leght and the wind speed. Such physical conditions often makes the relation between Tair and LST into the biosphere thermodynamics understanding a lot obscure.

In this paper the authors compare a short-term monitoring of LST and Tair variations by means of two different night-time satellite overpasses. The behaviour of the lower layers of the atmosphere somewhat above the surface can be very useful for sensible heat flux and evapotranspiration studies during the growing crop fields.

The data were acquire by visible, near infrared and thermal orbital scanning with "*Advanced Very High Resolution Radiometer*" (AVHRR) instruments of the "*National Oceanic and Atmospheric Administration*" (NOAA) of "*Polar Operational Environmental Satellites*" (POES) system.

Currently, in orbit we have morning and afternoon satellites, which provide global coverage six times daily. Because of the polar orbiting nature of the POES system, these satellites are able to collect global data on a daily basis for a variety of land, ocean, and atmospheric fine structure applications.

## 2. Material and Methods

This study area cover twelve (12) groud-based stations distributed over the Rio Grande do Sul state with 281,731.64 $Km^2$, in the South Brazil and delimitated by following coordinates: Longitudes 49°42'22''W and 57°38'34''W. Latitudes 27°04'49''S and 33°44'42''S. The study area presents particularly features of relief (canyon) and crop fields covering to the north and it is often covered by shrub and grassland vegetation in the other sites.

The satellite data used in this study with the highest elevation angle overpasses in the Winter season of the 2002, were received, analysed and selected from the permanent available files at the Centro Estadual de Pesquisas em Sensoriamento Remoto e Meteorologia (CEPSRM-UFRGS). The CEPSRM is located at coordinates: 51°11'35''W and 30°06'39''S.

It were selected 4 (four) night-time images from NOAA-15 and 16 with two overpasses in the dates July 15 and September 04, on High Resolution Picture Transmission (HRPT) format as shown in Table 1.

Table 1. Selected night-time images for LST data retrieval.

| AVHRR data | Date | Overpassing (GMT) | Overpassing (local time) |
|---|---|---|---|
| 02196a16 | July/15 | 04:59 | 01:59 |
| 02196a15 | July/15 | 10:18 | 07:18 |
| 02247a16 | September/04 | 05:41 | 02:41 |
| 02247a15 | September/04 | 10:31 | 07:31 |

The determination of the LST variation analysis requires the use of data obtained from satellites together measurements taken on ground based stations (*in situ*) measurements.

The Table 2 present the geographical position of the 12 ground based-stations under shelter installed 1.5 meters above the surface in the study area.

Table 2. Geographical position of the stations

| | Ground based stations | Latitude | Longitude | Altitude (m) |
|---|---|---|---|---|
| 1 | Bajé | 31º 20'S | 54º 06'W | 212 |
| 2 | Bom Jesus | 28º 40'S | 50º 26'W | 1046 |
| 3 | Caxias do Sul | 29º 10'S | 51º 12'W | 817 |
| 4 | Encruzilhada do Sul | 30º 32'S | 52º 31'W | 432 |
| 5 | Farroupilha | 29º 14'S | 51º 26'W | 783 |
| 6 | Iraí | 27º 11'S | 53º 14'W | 776 |
| 7 | Porto Alegre | 30º 05'S | 51º 10'W | 3 |
| 8 | Quaraí | 30º 23'S | 56º 26'W | 112 |
| 9 | Santa Rosa | 27º 51'S | 54º 25'W | 277 |
| 10 | Santa Vitória | 33º 31'S | 53º 21'W | 23 |
| 11 | São Luiz Gonzaga | 28º 23'S | 54º 58'W | 231 |
| 12 | Taquarí | 29º 48'S | 51º 49'W | 54 |

The main steps undertaken were: a) clear-sky satellite overpasses selection; b) georreferencing data; c) monthly maximum NDVI data genneration; d) emissivity data retrieval; e) computing of the 9 *pixels* mean LST over the ground-based stations position; f) generate of a *scatterplot* of LST variation against Tair variation data for each day.

The variation temperatures are computed by the later night values subtracted from the early night values. This is because the lower temperature values are supposed to occur in the later night-time.

Formerly, it was applied in the software ERDAS™-Imagine version 8.5 the orbital algorithm for control points calculation based on the efemerids data provided by NOAA for the orbital route. This type of georreferencing with the *Spheroid* and *DATUM WGS84* for high elevation overpasses often present a mean accuracy of 2 *pixels* (2200m) for this region. Latter, it was undertaken a second georreferencing with a number of control points based on the well known location of water bodies in the dimension of few *pixels*. The obtained results in the georreferencing are quite good and necessary in the same way.

The ERDAS-Imagine 8.5 software was used to transform the 10 bits radiometric records, i. e. 1024 digital counter, in temperature data. This module permit to transform digital counters value into radiance and to get brightness temperature data through Planck's equation (Gusso & Fontana 2003). Details of the physical fundamentals of thermal interpreting signals by the brightness temperature from the observed radiance in remote sensing theory, are very well discribed at Sullivan (1999).

### 2.1 Land Surface Temperature

At any time the value taken by the surface temperature, Tskin, results from the balance between the various forms of energy exchanges at the surface: net radiation, convective sensible and latent heat fluxes and soil conduction heat flux.

Because the long wave radiation losses of the surface Tskin (LST) and Tair both decrease during the night and reach their minimum values generally just before sunrise (Lagouarde & Brunet 1993).

Low values of soil thermal conductivity, roughness and wind speed act in the same direction, by limiting the energy exchanges between the surface and the air above. Tskin usually remains slightly lower than Tair. However, in most cases the night-time temperature differences Tair – Tskin does not usually exceed 3 degrees Kelvin (Oliveira 1997). Values greater than 4 or 5 Kelvin are rarely found and correspond to very stable atmospheric situations (Lagouarde & Brunet 1993). The daily amplitude of Tskin is strongly related to the intensity of soil cover and evapotranspiration. Under clear-sky conditions Tskin generally poses the same type of evolution (Lagouarde & Brunet, 1993). All over this behaviour the loss energy evolution of Tskin may be affected by fluctuations due to instantaneous variations of local weather conditons associated for instance with cloud passes or wind speed changes (Lagouarde & Brunet, 1993).

The potential of obtaining information about energy budget, soil moisture and water status of a surface through the relation between remotely sensed surface temperature and vegetation index (NDVI) has been investigated by several authors (Goetz 1997; Sandholt *et al.* 2002; Ouaidrari *et al.,* 2002). In keeping with Kerr *et al.* (1992) for no corrections on the emissivity factor the split window technic will give good results over water, slightly less over fully vegetated areas, and poor results on dry bare soil. The differences between LST and Tair are also highly related to temperature magnitude and predominant soil type (Ouaidrari *et al*., 2002).

For the LST estimation we applied the Sobrino *et al.* (1993) method that use a combination of the channels 4 and 5 of the AVHRR sensor. Gusso (2003) evaluated the LST results for the method proposed by Sobrino *et al.* (1993) over this same region. This algorithm, called *Weak Split-window* (WSW) as shown at equation 1, they consider four atmospheric models: *Tropical* (T), *Midlatitude summer* (MLW), *1976 standard USA* (US) e *Midlatitude winter* (MLW).

$$T_S = T_4 + [0{,}53 + 0{,}62(T_4 - T_5)](T_4 - T_5) + 64(1 - \varepsilon) \qquad (1)$$

where: $T_S$ = land surface temperature;
$T_4$ and $T_5$ = brightness temperature for channels 4 and 5 of AVHRR;
$\varepsilon$ = mean emissivity for channels 4 and 5, $(\varepsilon_4 + \varepsilon_5)/2$.

The Sobrino *et al.* (1993) method (equation 1) use the retrieved emissivity computed by Valor & Caselles (1996) (eq. 2, 3 and 4) algorithm, by means of the NDVI as representative of the emissive characteristics. The emissivity factor was retrieved as follows:

$$\varepsilon = 0{,}985 P_V + 0{,}96(1 - P_V) + 0{,}06 P_V (1 - P_V) \qquad (2)$$

thus:

$$P_V = \frac{\left(1 - i/ig\right)}{\left(1 - i/ig\right) - k\left(1 - i/iv\right)} \qquad (3)$$

and $k$ is:

$$k = \frac{\rho_{2v} - \rho_{1v}}{\rho_{2g} - \rho_{1g}} \quad (4)$$

where: $i$, $ig$, $iv$ = NDVI, NDVI bare soil, NDVI vegetated surface;
$\rho_1$ and $\rho_2$ = channels 1 and 2 reflectances of AVHRR
$v$ and g = indexes for vegetation and bare soil.

The monthly (July and September) mean values of NDVI for bare soil and vegetated areas and the reflectances of channels 1 and 2 of AVHRR, are presented in the Table 3. The NDVI data computed (Rouse *et al*., 1974) were extracted from monthly composites produced using the maximum value composite (MVC) procedure (Holben 1986). The later LST is subtracted from the early LST, so that (early LST – later LST = LST var) and in the same way to the air temperature variation.

Table 3. NDVI and channels 1 and 2 reflectances values applied corresponding for vegetation and bare soil as proposed by Valor & Caselles (1996).

| Sample | $\rho_1$ | $\rho_2$ | NDVI |
|---|---|---|---|
| Bare soil | 0.18 | 0.2 | 0.1 |
| Vegetation | 0.12 | 0.48 | 0.6 |

## 3. Results and Analysis

The Figure 1 shows the *scatterplot* of the variation in the LST and Tair (*in situ*) measurements between two overpasses during night-time. A slightly direct trend is observed.

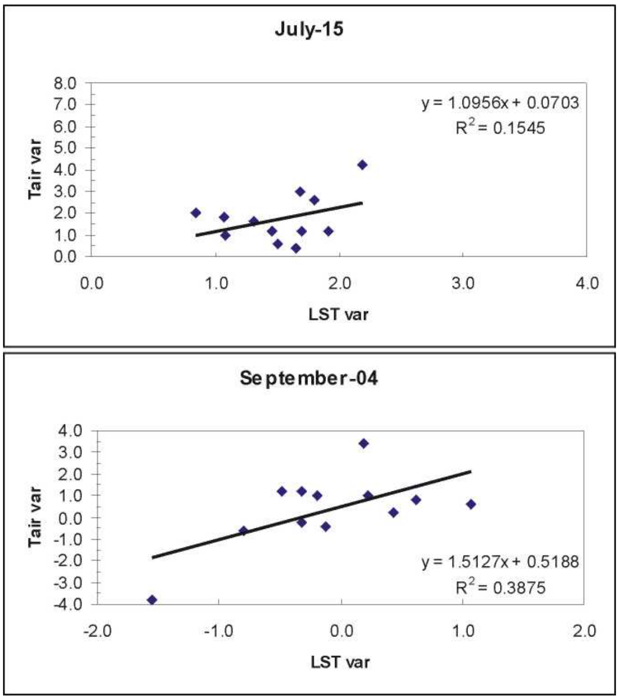


Figure 1. *Scatterplot* of LST and Tair (*in situ*) variation between two overpasses during night-time.

In the both dates, changes in the LST are followed by changes in the Tair. However, it is worthy to note the variations range in September 04 is almost twice in July 15. Also, in September 4, the negative values are indicative of higher temperature in the early morning.

In spite of the strongly relationship established between Tair and LST for each one of the images, individually (as found by Gusso 2003), the linear relationship profiles performed at the Figure 1 are not clearly reliable.

## 4. Conclusions

The general patterns of decreasing night-time temperature conditions for which minimum air and surface temperatures appear correlated can improve the understanding of the mechanisms of their day-time maximum values. On other hand, the quite different situations of the lower layers dynamics of the atmosphere can help to explain the difficulties to improve the LST retrieval for global validation.

In this study, the Tair measurements obtained from meteorological stations under shelter has demonstrated does not seems to be a suitable data for accuratelly calibration of the LST methods. The Tair, by nature, is very less variable than night-time LST and less adapted to witness the surface conditions (Lagouarde & Brunet 1993).

As emphasized by Wan & Dozier (1996), the better LST algorithm must have the following two features: 1) it retrieves LST more accurately; and 2) it is less sensitive to the uncertainties in our knowledge of surface emissivities and atmospheric properties, and to the instrument noise. Cresswell *et al*. (1999) testing Meteosat data, suggest that, with a greater number of observations, and with detailed information about site conditions, soil moisture, vertical atmospheric measurements., a model with finer detail and greater accuracy may be achieved.

This is because the high uncertainty of the atmosphere (as wind speed regime) from one day to another, in the lower layers somewhat above the surface.

## 5. Acknowledgements

The authors would like to thank the National Oceanic and Atmospheric Administration and NOAA Satellite Information System for the NOAA/AVHRR data and informations continually provided. To the 8º DISME/INMET and FEPAGRO (brazilian) institutions for the meteorological data provided.
The authors are also thankful to the researchers Cleusa Bianchi and Luiz Marchiori.

## 6. Selected Bibliography

Andersen, H. S. Land surface estimation based on NOAA-AVHRR data during the HAPEX-Sahel experiment. **Journal of Hydrology,** 189, 788-814, 1997.

Becker, F. and Li, Z-L. Towards a local split window method over land surfaces. **International Journal of Remote Sensing,** 11, (3), 369-393, 1990.

Cresswell, M. P., Morse, A. P. Thompson, M. C. and Connor, S. J. Estimating surface air temperatures from Meteosat land surface temperatures using an empirical solar zenith angle model. **International Journal of Remote Sensing,** 20, (6), 1125-1132, 1999.

Goetz, S. J. Multisensor analysis of NDVI, surface temperature and biophysical variables at a mixed grassland site. **International Journal of Remote Sensing,** 18, (1), 71-94, 1997.

Gusso, A. **Monitoramento de temperaturas noturnas da superfície terrestre no Estado do Rio Grande do Sul com uso do sensor orbital AVHRR/NOAA.** UFRGS 2003, 77p. Porto Alegre: Dissertação de mestrado

(Mestrado em Sensoriamento Remoto) – Centro estadual de Pesquisas em Sensoriamento Remoto e Meteorologia, Universidade Federal do Rio Grande do Sul. Porto Alegre.

Gusso, A. and Fontana, D.C. Ensaio comparativo sobre métodos de monitoramento da temperatura da superfície terrestre no Estado do Rio Grande do Sul com uso dos satélites NOAA. In: *XI Simpósio Brasileiro de Sensoriamento Remoto,* Belo Horizonte, 2003. **Anais...** Belo Horizonte. Sessão Técnica Oral.. p.1185-1192. . Repositório da URLib: <dpi.inpe.br/lise/2003/03.28.12.35>. Disponível em: <http://iris.sid.inpe.br:1908/col/ltid.inpe.br/sbsr/2003/03.28.12.35/doc/sumario_index.pdf>. Acesso em: 19 nov. 2004.

Holben, B. N. Characteristics of maximum-value composite images from temporal AVHRR data. **International Journal of Remote Sensing,** 7, 1417-1434, 1986.

Kerényi, J. and Putsay, M. Investigation of land surface temperature algorithms using NOAA/AVHRR images. **Advances in Space Research,** 26, 1077-1080, 2000.

Kerr, Y. H.; Lagouarde, J. P.; Imbernom, J. Accurate land surface temperature retrieval from AVHRR data with use of an improved split window algorithm. **Remote Sensing of Environment,** 40, 1-20, 1992.

Li, Z.-L., and Becker, F. Feasibility of land surface temperatureand emissivity determination from AVHRR data. **Remote Sensing of Environment,** 43, 67-85, 1993.

Lagouarde, J. P. and Brunet, Y. A simple model for estimating the daily upward longwave surface radiation flux from NOAA-AVHRR data. **International Journal of Remote Sensing,** 14, (5), 907-925, 1993.

McMillin, L. M. Estimation of sea surface temperature from two infrared window measurements with different absorption**. Journal of Geophysical Research,** 80, 5113-5117, 1975.

Oliveira, H. T. **Climatologia das Temperaturas Mínimas e Probabilidade de Ocorrência de Geada no Estado do Rio Grande do Sul.** Porto Alegre: UFRGS, 1997. 81p. Dissertação de mestrado (Mestrado em Fitotecnia) – Programa de Pós-Graduação em Agronomia, Universidade Federal do Rio Grande do Sul. Porto Alegre.

Ouaidrari, H.; Gowart, S. N.; Czajkowski, K. P.; Sobrino, J. A.; Vermote, E. Land surface temperature estimation from AVHRR thermal infrared measurements: An Assessment for the AVHRR Land Pathfinder II Data Set. **Remote Sensing of Environment,** 81, 114-128, 2002.

Qin, Z.and Karnieli, A. Progress in remote sensing of land surface temperature and ground emissivity using NOAA-AVHRR Data. **International Journal of Remote Sensing,** London, v.20, p.2367-2393, 1999.

Rouse, J. W.; Haas, R. H.; Schell, J. A., Deering, D. W. and Harlan, J. C. Monitoring the vernal advancement and retrogradation (greenwave effect of natural vegetation, **NASA/GSFC type III Final Report,** Greenbelt, MD, 1974.

Sandholt, L.; Rasmussen, K.; Andersen, J. A simple interpretation of the surface temperature/vegetation index space for assessment of surface moisture status. **International Journal of Remote Sensing,** 79, 213-224, 2002.

Sobrino, J. A.; Caselles, V.; Coll, C. Theoretical split-window algorithms for determining the actual surface temperature. **Il Nuovo Cimento,** Verona, 16C, 3, 219-236, 1993.

Sullivan, J. T. New radiance-based method for AVHRR thermal channel nonlinearity corrections. **International Journal of Remote Sensing,** 20, 3493-3501, 1999.

Valor, E. and Caselles, V. Mapping land surface emissivity from NDVI: Application to European, African and South Americam Areas. **Remote Sensing of Environment**, 57, 167-184, 1996.

Van de Griend, A. A. and Owe, M. On the relantionship between thermal emissivity and NDVI for natural surfaces. **International Journal of Remote Sensing**, 6,1119-1131, 1993.

Wan L. and Dozier J. A generalized split-window algorithm for retrieving land-surface temperature from space. **IEEE Transactions Geosciences in Remote Sensing**, 34, 892–905, 1996.