APPLICATION OF HIGH-RESOLUTION THERMAL INFRARED REMOTE SENSING TO ASSESS LAND SURFACE TEMPERATURE AND EMISSIVITY IN DIFFERENT NATURAL ENVIRONMENTS

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ABSTRACT:

Airborne thermal infrared image data at high spatial resolution (2-4 m) acquired with the Airborne Hyperspectral Scanner (AHS) over Barrax (Spain), Görmin (Germany) and Cabauw, Loobos and Speulderbos (The Netherlands) were used to study the thermal signatures of land cover types. The processing of the airborne imagery includes atmospheric correction of the AHS thermal infrared (TIR) bands and the retrieval of different biogeophysical variables such as Land Surface Temperature (LST), Land Surface Emissivity (LSE) and Evapotranspiration (ET). The AHS instruments consists of 80 spectral bands which cover the visible and near infrared (VNIR), short wave infrared (SWIR), mid-infrared (MIR) and thermal infrared (TIR) spectral range. This paper is mainly focused on the 10 AHS TIR bands (71 – 80), located in the region between 8 and 13μm, which are used for LST, LSE and ET. The AHS imagery used in this study was acquired in the framework of three different campaigns performed in different natural environments and supported by the European Space Agency (ESA): SEN2FLEX (June and July 2005), AGRISAR (June and July 2006) and EAGLE (July 2006). LST has been retrieved from AHS TIR data using Two-Channel (TC) and TES algorithms, taking into account different band configurations. LSE has been estimated using a simplified approach with the NDVI and also with the TES algorithm. LST and LSE products have been used to retrieve the daily ET applying the simplified SEBI model. The results have been tested against measurements collected in situ, showing errors lower than 2 K for temperature and errors around 1 mm/day for evapotranspiration.

1. INTRODUCTION

Land surface temperature (LST) and land surface emissivity (LSE) are key parameters which can be retrieved from thermal infrared (TIR) data. Hence, except for solar irradiance components, most of the fluxes at the surface/atmosphere interface can only be parameterized through the use of surface temperature. LST can play either a direct role, such as when estimating long wave fluxes, or indirectly as when estimating latent and sensible heat fluxes (Kerr et al., 2004). LST can be also used as an input data in water and energy balance studies, which is an important issue in environmental studies in order to achieve a better understanding on the exchange of heat and moisture between the land surface and lower atmosphere, also leading to a better understanding on the water and carbon cycles. Moreover, many other applications rely on the knowledge of LST (geology, hydrology, vegetation monitoring,

global circulation models, evapotranspiration, etc.). Knowledge of LSE is required to obtain accurate values of LST. Surface emissivities are also indicative of composition for silicate minerals, thus being important for mineral mapping.

Different approaches have been published in the last years in order to retrieve LST and LSE from satellite data. Among these methods, we highlight the single-channel and two-channel or split-window algorithms for LST retrieval, and methods based on NDVI for LSE retrieval, specially designed to be applied to low spectral resolution data. Nowadays, different high spectral and spatial resolution sensors are available, with several thermal bands, as the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) or the Moderate Resolution Imaging Spectrometer (MODIS) flying in the Terra (or also AQUA for MODIS) satellite, and also different aircraft sensors as the Digital Airborne Imaging Spectrometer (DAIS),

the Airborne Hyperspectral Scanner (AHS) or the future Airborne Reflective/Emissive Spectrometer (ARES). New methods have been developed in order to retrieve LST and LSE from multispectral data, as for example the TES method (Gillespie et al., 1998).

The goal of this paper is to analyze the feasibility of retrieving LST and LSE from AHS thermal infrared data as well as the accuracy obtained depending on the number of thermal bands used. For this purpose, single-channel, split-window and TES algorithms have been applied to AHS data and tested using field measurements collected over different plots. Regarding to the LSE retrieval, methods based on NDVI and also the TES algorithm have been employed. As an example of the application of thermal remote sensing, LST and LSE products were used as input to estimate daily evapotranspiration (ET) using a simplified model. A previous analysis of LST retrieval from AHS data acquired over the agricultural area of Barrax (Spain) in 2004 is presented in (Sobrino et al., 2006a). However, in that paper some calibration problems on the AHS instrument were found, which limited the analysis only to certain thermal bands, and discussion on the emissivity results were not presented. A complete database of AHS imagery acquired in 2005 and 2006 in different natural environments (described in Section 2) with the calibration problems solved will allow us to extract stronger conclusions on the useful of multispectral data in the LST and LSE retrieval topics.

2. DATABASE

2.1 Field Campaigns and Test Sites

The study presented in this paper has been carried out over different natural environments under the umbrella of three funded field campaigns: SEN2FLEX (Spain, 2005), AGRISAR (Germany, 2006) and EAGLE (The Netherlands, 2006). In all these three campaigns several field radiometers were used to measure LST as well as LSE. Field radiometers included single broadband ones (8-13μm) and also two multiband radiometers (model CIMEL), one of them with five TIR narrowbands in coincidence with the ASTER configuration. This instrument was used to retrieve surface emissivities with the TES algorithm applied to ground measurements (Jiménez-Muñoz and Sobrino, 2006). Detailed information of the instrumentation used and the procedure followed to measure LST and LSE can be found for example in Sobrino et al. (2006a, 2006b).

The SENtinel-2 and FLuorescence EXperiment (SEN2FLEX) is a campaign that combines different activities in support of initiatives related both to fluorescence experiments (AIRFLEX) in order to observe of solar induced fluorescence signal over multiple surface targets, and to GMES Sentinel-2 initiative for prototyping spectral bands, spectral widths, and spatial/temporal resolutions to reach mission requirements (http://www.uv.es/~leo/sen2flex/). SEN2FLEX was carried out during June and July, 2005, over the agricultural area of Barrax (39º3' N, 2º6' W, 700m), in Albacete (Spain). This experimental area has a flat terrain and a Mediterranean type climate. The soils of the area are *Inceptisols* in terms of soil Taxonomy. About 65% of cultivated lands at Barrax are dryland (67% winter cereals; 33% fallow) and 35% irrigated land (75% corn; 15% barley/sunflower; 5% alfalfa; 5% onions and vegetables). Three agro-meteorological stations are located in the study area (Moreno et al., 2001).

The lack and urgent need of data for the development and validation of models and inversion algorithms for quantitative crop vegetation and surface parameter estimation under the vegetation layer, has resulted in the AGRISAR campaign. Since the understanding of bio/geo physical parameter retrieval from multi-parameter SAR as well as the direct modelling in the domain of agricultural cultivation for vegetated and non-vegetated crop fields is still unsatisfactorily, and appropriate data for their evaluation is missing, the campaign's main aim is to build up a data base for the investigation and validation of the retrieval of bio-/geo-physical parameters, obtained at different radar frequencies (X-, C- and L-Band) and at thermal as well as hyperspectral optical bands acquired over vegetated and non-vegetated agricultural fields. The Demmin test site (Görmin farm, 53º59.5' N, 13º16.5'E, 15m) is located in Mecklenburg-Vorpommern in North-East Germany, approximately 50km north of Neustrelitz and 150km north of Berlin. It is based on a group of farms, covering approximately 25,000 ha, being the main crops wheat, winter barley, winter rape, maize and sugar beet.

The EAGLE2006 campaign was carried out in order to collect data to make a profound study of bio-geophysical parameter retrieval from multi-parameter optical and SAR data as well as the direct modelling of the underlying physical processes in forests and grassland. The use of different airborne sensors, the acquisition of multi-angle and multi-sensor satellite data, as well as the procurement of a great amount of simoultaneous ground measurements, lead to one of the campaign´s main aim: build up a data base for the investigation and validation of the retrieval of the above mentioned parameters. It took place, from the 8th of June until the 2nd of July 2006, over central parts of the Netherlands, being these ones the grassland site at Cabauw (51°58' N, 4°54' E, 0m) and two forest sites at Loobos (52°10.03' N, 5°44.6' E, 52m) and Speulderbos (52°15.14' N, 05°41.43' E, 52m). Some characteristics are a yearly precipitation around 750 mm and a yearly average temperature about 10° Celsius.

2.2 AHS imagery

The Airborne Hyperspectral Scanner AHS (developed by SensyTech Inc., currently ArgonST, USA) is operated by the Spanish Institute of Aeronautics (INTA). It has 80 spectral bands in four ports (VNIR, SWIR, MWIR and TIR). This study is focused on the exploitation of the 10 AHS TIR bands ranging from 71 to 80.

In SEN2FLEX, AHS flights took place on June 1st, 2nd and 3rd and July 12th, 13th and 14th 2005. In AGRISAR, flights were carried out on June 6th and 10th and July 4th and 5th 2006. During EAGLE, flights took place on June 13th 2006. AHS flights were carried out at two nominal altitudes, 975m (low flight) and 2740 m (high flight) above ground level. Other altitudes were also considered due to operational reasons. The following total amount of AHS imagery is available: 24 images for SEN2FLEX-2005, 48 images for AGRISAR-2006 (6 of them not geo-referenced due to a technical problem) and 13 images for EAGLE-2006. AHS images are provided in level 1b

(at-sensor radiance) with IGM files for geometric correction. In addition, level 2b products of land surface temperatures and at-surface reflectances were provided by INTA for the AGRISAR campaign. These products were obtained using ATCOR -4 software developed by Richter (DLR).

3. LAND SURFACE TEMPERATURE AND EMISSIVITY RETRIEVAL

Three different algorithms/methods have been considered for retrieving the LST from the AHS data:

i)   Single-Channel (SCh) method, which uses only one thermal band and LST is retrieved from inversion of the radiative transfer equation,
ii) two-channel or split-window technique (SW), in which LST is retrieved from a combination of two thermal bands,
iii) Temperature and Emissivity Separation (TES) algorithm, developed by Gillespie et al. (1998).

The application of these algorithms to AHS data acquired in July-2004 is presented in detail in Sobrino et al. (2006a). A complete description of the application of these methods to the AHS imagery acquired during SEN2FLEX can be found in Jiménez-Muñoz et al. (2006). In that paper, the algorithms were validated against 97 values of surface temperature measured in situ over different crops (water, wheat, grass, corn, vineyard, bare soil). The results showed low bias (<0.4 K) and Root Mean Square Errors (RMSE) lower than 1.8 K.

LSE required in split-window algorithms was estimated from the NDVI, as indicated in Jiménez-Muñoz et al. (2006). LSE was also estimated with the TES algorithm.

As an example, Figure 1 shows LST maps obtained with a split-window algorithm applied to AHS bands 75 and 79 and LST maps produced with the TES algorithm for the SEN2FLEX-2005 campaign. Figure 2 shows an example of the LST product provided by INTA for AGRISAR-2006, whereas Figure 3 shows a LST map obtained with the TES algorithm for EAGLE-2006. Land surface emissivity maps obtained with the TES algorithm for different AHS bands over a sand site (EAGLE-2006) are shown in Figure 4.
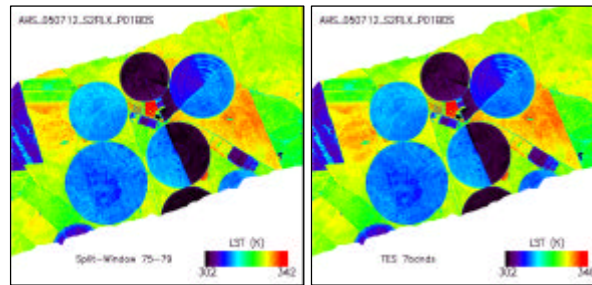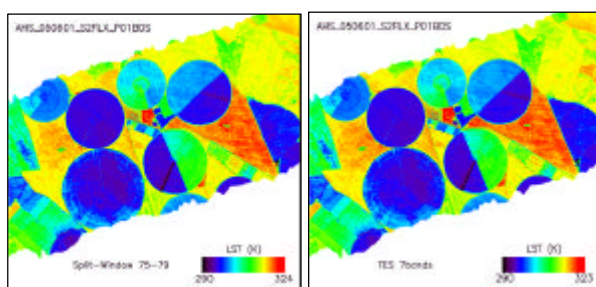

Figure 1. Land Surface Temperature maps obtained from AHS data with split-window and TES algorithms during the SEN2FLEX-2005 campaign.
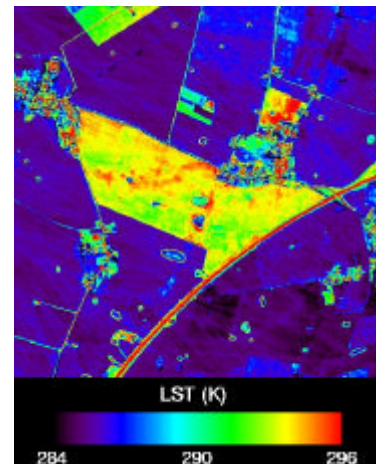

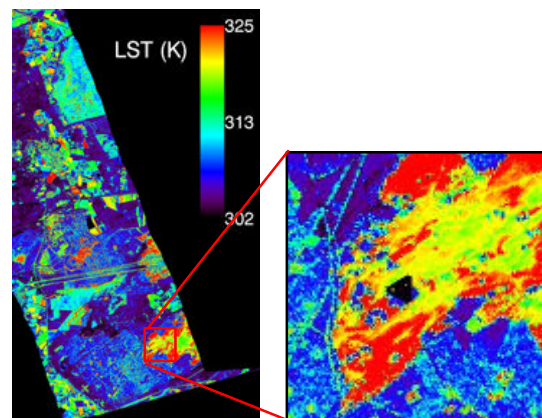Figure 2. Land Surface Temperature product provided by INTA for the AGRISAR-2006 campaign.

Figure 3. Land Surface Temperature map obtained from AHS data acquired during EAGLE-2006 and using the TES algorithm. The resized image corresponds to a sand site.
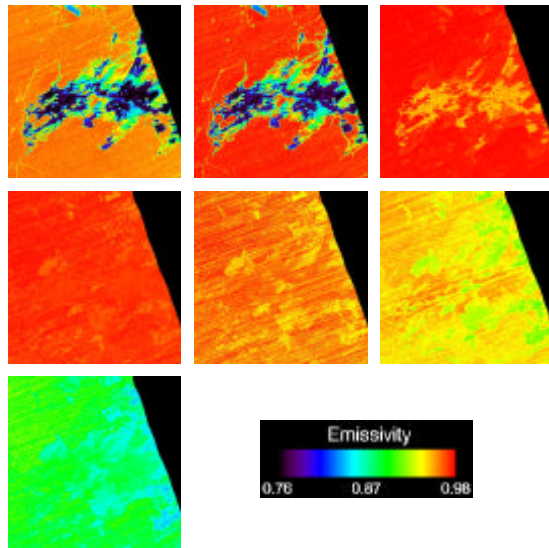
Figure 4. Land Surface Emissivity maps obtained with the TES algorithm for the sand site (see Figure 3). From left to right, images correspond to AHS bands 72, 73, 75, 76, 77, 78 and 79.

4. SIMPLIFIED METHOD FOR EVAPOTRANSPIRATION RETRIEVAL

In this paper, daily ET has been retrieved according to the methodology presented in Sobrino et al. (2005) and Gómez et al. (2005). It is based on the Simplified Surface Energy Balance Index (S-SEBI) model (Roerink et al., 2000), which solves the energy balance equation using the evaporative fraction concept.

Daily ET was retrieved from AHS data acquired during SEN2FLEX-2005 as explained in Jiménez-Muñoz et al. (2006). Values were tested against in situ measurements collected in a lysimeter station of festuca (14 test points), with a bias of 0.2 and RMSE of 1.1 mm/day. Figure 5 shows some examples of daily ET maps obtained from AHS data acquired during the SEN2FLEX-2005 campaign.
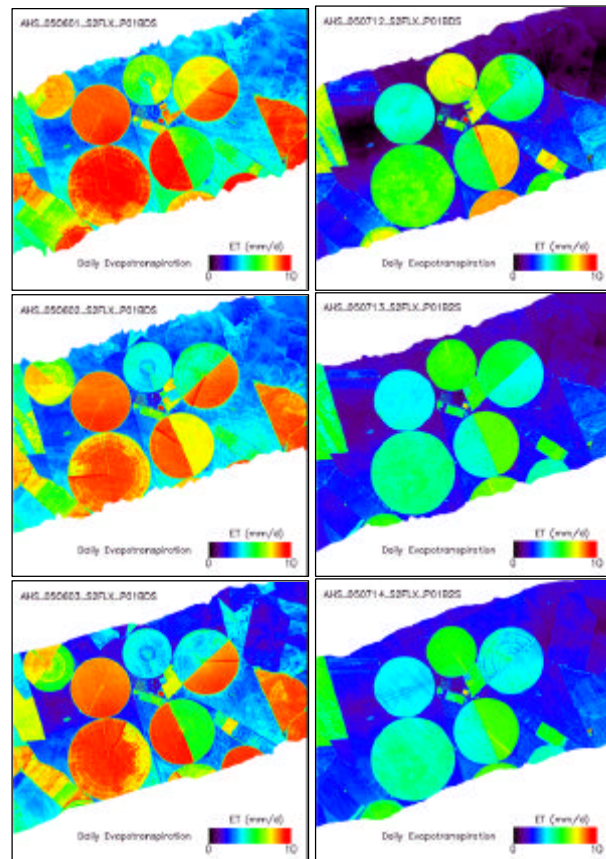

Figure 5. Daily Evapotranspiration maps obtained from AHS data acquired during the SEN2FLEX-2005 campaign.

5. CONCLUSIONS

Land Surface Temperature, Land Surface Emissivity and Daily Evapotranspiration have been retrieved from AHS data acquired in 2005 and 2006 in the framework of three different campaigns (SEN2FLEX, AGRISAR, EAGLE) carried out in different natural environments. Accuracies for LST are bellow 2 K (typically around 1.5 K), whereas errors for evapotranspiration are around 1 mm/day. All these variables, which are of interest in different environmental applications, have been retrieved mainly from thermal infrared data, so we claim the availability of multispectral TIR capabilities in future Earth Observation sensors.

Future wok of the authors includes the processing of the complete AHS imagery, with a total amount of around 80 images, which will allow us to extract conclusions regarding the accuracy of the LST and LSE depending of the methods and number of TIR bands used.

6. ACKNOWLEDGEMENTS

7. REFERENCES

Gillespie, A., Rokugawa, S., Matsunaga, T., Cothern, J. S., Hook, S., and Kahle, A. B., 1998. A temperature and emissivity separation algorithm for advanced spaceborne thermal emission and reflection radiometer (ASTER) images. *IEEE Transactions on Geoscience and Remote Sensing*, 36, pp. 1113-1126.

Gómez, M., Sobrino, J. A., Olioso, A., and Jacob, F., 2005. Retrieval of evapotranspiration over the Alpilles/ReSeDA experimental site using airborne POLDER sensor and Thermal Camera. *Remote Sensing of Environment*, 96(3-4), pp. 399-408.

Jiménez-Muñoz, J. C., and Sobrino, J. A., 2006. Emissivity spectra obtained from field and laboratory measurements using the temperature and emissivity separation algorithm. *Appl. Opt.*, 45(27), pp. 7104-7109.

Jiménez-Muñoz, J. C., Sobrino, J. A., Gómez, M., Barella-Ortiz, A., Fernández, G., Guanter, L., and Moreno, J., 2006. Processing of the AHS VNIR and TIR data for surface temperature/emissivity and evapotranspiration retrieval. In: *Proceeding of SEN2FLEX*, Holland, published on CD-ROM.

Kerr, Y. H., Lagouarde, J. P., Nerry, F., and Ottlé, C., 2004. Land surface temperature retrieval techniques and applications: case of AVHRR. In: *Thermal Remote Sensing in Land Surface Processes*, D. A. Quattrochi y J. C. Luvall (eds), CRC Press, Florida, USA, pp. 33-109.

Moreno, J., Caselles, V., Martínez-Lozano, J. A., Meliá, J., Sobrino, J. A., Calera, A., Montero, F., and Cisneros, J. M., 2001. The Measurments Programme at Barrax. In: *DAISEX Final Results Workshop*, Holland, pp. 43-51.

Roerink, G., Su, Z., and Menenti, M., 2000. S-SEBI: A Simple Remote Sensing Algorithm to Estimate the Surface Energy Balance. *Phys. Chem. Earth (B)*, 25(2), pp. 147-157.

Sobrino, J. A., Gómez, M., Jiménez-Muñoz, J. C., Olioso, A., and Chehbouni, G., 2005. A simple algorithm to estimate evapotranspiration from DAIS data: Application to the DAISEX Campaigns. *Journal of Hydrology*, 315, pp. 117-125.

Sobrino, J. A., Jiménez-Muñoz, J. C., Zarco-Tejada, P. J., Sepulcre-Cantó, G., and de Miguel, E., 2006a. Land surface temperature derived from airborne hyperspectral scanner thermal infrared data. *Remote Sensing of Environment*, 102, pp. 99-115.

Sobrino, J. A., Cuenca, J., Sòria, G., Jiménez-Muñoz, J. C., Gómez, M., Zaragoza, M., Romaguera, M., Julien, Y., Shen, Q., Barella-Ortiz, A., Morales, L., Gillespie, A., Balick, L., Peres, L., Libonati, R., Nerry, F., and Fortier, M., 2006b. Thermal Remote Sensing in the Framework of the Sen2flex Project: Field Measurements, Airborne Data and Applicagtions. In: *Second Advances in Quantitative Remote Sensing*, Valencia (Torrent), Spain, pp. 142-146.