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ABSTRACT

In this work we explore the synergistic use of future MSI instrument on board Sentinel-2 platform and OLCI/SLSTR instruments on board Sentinel-3 platform in order to improve LST products currently derived from the single AATSR instrument on board the ENVISAT satellite. For this purpose, the high spatial resolution data from Setinel2/MSI will be used for a good characterization of the land surface sub-pixel heterogeneity, in particular for a precise parameterization of surface emissivity using a land cover map and spectral mixture techniques. On the other hand, the high spectral resolution of OLCI instrument, suitable for a better characterization of the atmosphere, along with the dual-view available in the SLTSR instrument, will allow a better atmospheric correction through improved aerosol/water vapor content retrievals and the implementation of novel cloud screening procedures. Effective emissivity and atmospheric corrections will allow accurate LST retrievals using the SLSTR thermal bands by developing a synergistic split-window/dual-angle algorithm. ENVISAT MERIS and AATSR instruments and different high spatial resolution data (Landsat/TM, Proba/CHRIS, Terra/ASTER) will be used as benchmark for the future OLCI, SLSTR and MSI instruments. Results will be validated using ground data collected in the framework of different field campaigns organized by ESA.

1. INTRODUCTION

Land Surface Temperature (LST) is one of the key parameters in the physics of land-surface processes on regional and global scales, combining the results of all the surface-atmosphere interactions and energy fluxes between the surface and the atmosphere. Because of the strong heterogeneity in land surface characteristics such as vegetation, topography and soil physical properties, LST changes rapidly in space as well as in time. An adequate characterization of LST distribution and its temporal evolution, therefore, requires measurements with detailed spatial and temporal frequencies. With the advent of the ESA's Sentinel 2 and 3 series of satellites a unique opportunity exists to go beyond the current sates of the art of single instrument algorithms. This is the main purpose of the ESA's project *Synergistic Use of The Sentinel Missions For Estimating And Monitoring Land Surface Temperature* (SEN4LST). In the framework of the SEN4LST project, existing atmospheric correction and LST/emissivity retrieval algorithms have been reviewed and adapted to MSI/OLCI/SLSTR characteristics. Synthetic images were constructed to test the proposed algorithms, and real MERIS/AATSR data were also used to analyse the performance of the algorithms. All these correction methodologies will be implemented in the BEAM processor.

2. ATMOSPHERIC CORRECTION AND CLOUD SCREENING

The proposed aerosol correction for Sentinel2/3 is based on the synergy method developed for MERIS and AATSR [1]-[2], and which has been applied to SLSTR and OLCI on Sentinel-3 [3]. The algorithm is a development of the system developed for the ESA Grid Processing on Demand (GPOD) for global aerosol and surface reflectance processing from ATSR, and spectral methods developed within GlobAlbedo. The aim is to fully utilize synergy between SLSTR and OLCI to simultaneously retrieve aerosol parameters, based on a single inversion where information from a combined SLSTR/OLCI image is used as input as if from a single sensor. The output is aerosol optical depth at a reference waveband, an estimate of aerosol model and Angstrom coefficient, and atmospherically corrected surface reflectances for all bands used. A version of algorithm has

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been coded within the ESA BEAM toolbox by Swansea University, applicable to MERIS/AATSR image sets.

A previous synergy cloud mask was developed for MERIS/AATSR instruments, which generates a cloud probability from an ensemble of multilayer perceptron artificial neural networks. In SEN4LST, focus in on the thermal version of the Bayesian cloud detection, which exploits the 11 and 12 μm channels during the daytime.

3. EMISSIVITY CORRECTION

Taking into account the characteristics of instruments on board Sentinel2 and 3 platforms, candidate methods for emissivity retrieval were reduced to approaches based on vegetation indices or Spectral Mixture Analysis (SMA), and classification-based methods. One of the candidate methods is the NDVI Thresholds Method (NDVI-THM) [4]-[5], based on the following equations:

$$\varepsilon_\lambda = \begin{cases} a_\lambda + b_\lambda \rho_{red} & NDVI < NDVI_s \\ \varepsilon_{v\lambda} FVC + \varepsilon_{s\lambda}(1 - FVC) + C_\lambda & NDVI_s \le NDVI \le NDVI_v \\ \varepsilon_{v\lambda} + C_\lambda = 0.99 & NDVI > NDVI_v \end{cases} \quad (1)$$

where C is the cavity term, and subindices "s" and "v" refer respectively to soil and vegetation values.

Approaches based on SMA techniques require a previous selection of the endmembers. Then, emissivity values are assigned to each endmember. A previous application of this technique to Proba/CHRIS data was explored in [6]. Emissivity retrieval from images acquired with large swaths or images acquired at different view angles requires also the correction of angular effects. A definitive solution on this issue is not currently available, since characterization of roughness and structure of component elements inside the pixel is a difficult task, especially if this information needs to be extracted from the remotely sensed data itself. However, it is possible to address the problem using BRDF models adapted to the thermal region [7]. Other methods could be also used, as for example geometrical models [8] or parameterizations based on the gap function [9]. A comparison of results obtained with the different methods was previously addressed in [10].

4. LST ALGORITHMS

LST retrieval from the future S3/SLSTR instrument can be addressed using three different methods: i) single-channel (1 TIR band), split-window (2 TIR bands) and dual-angle (1 TIR band at two different view angles). Analysis if focused on Split-Window (SW) and Dual-Angle (DA) algorithms. The following mathematical structure for both SW and DA algorithms is proposed [11]:

$$T_s = T_n + c_1(T_i - T_j) + c_2\,(T_i - T_j)^2 + c_0 + (c_3 + c_4W)(1 - \varepsilon_n) + (c_5 + c_6W)\Delta\varepsilon \quad (2)$$

where T is the at-sensor brightness temperature at bands "i" and "j", W is the total atmospheric water vapor, and ε and Δε are respectively the mean emissivity and emissivity difference at the two bands. When DA algorithms are used, subindices "i" and "j" refer to the nadir and oblique views, respectively. The coefficients of the algorithm (c_0 to c_6) are obtained from simulation procedures, and the values are sensor dependent. The coefficients of the algorithms were adapted to S3/SLSTR TIR bands using an atmospheric profile database and MODTRAN radiative transfer code. A sensitivity analysis was also performed to obtain the error on LST due to different uncertainties. Table 1 shows the results obtained for the DA and SW algorithms, with total errors on LST of 0.8 K and 1.5 K, respectively.

Table 1. Coefficients for the DA and SW algorithms adapted to S3/SLSTR TIR bands (Equation 2). Results obtained in the sensitivity analysis are also included (values of σ in K).

Algorithm	Coefficients		Sensitivity analysis	
Dual-Angle (11μm)	c_0	-0.441		
	c_1	1.790	r	0.991
	c_2	0.221	σ_{simul}	0.58
	c_3	64.26	σ_{noise}	0.23
	c_4	-7.60	σ_{emis}	0.53
	c_5	-30.18	σ_W	0.11
	c_6	3.14	σ_{total}	0.82
Split-Window (11-12μm)	c_0	-0.268		
	c_1	1.084	r	0.976
	c_2	0.277	σ_{simul}	0.93
	c_3	45.11	σ_{noise}	0.21
	c_4	-0.73	σ_{emis}	1.19
	c_5	-125.00	σ_W	0.08
	c_6	16.70	σ_{total}	1.53

One of the objectives of the SEN4LST project is to propose a combined approach for LST retrieval using both SW and DA techniques. Therefore, the following approach was proposed:

$$
\begin{aligned}
T_s = T_{11n} + c_1\left(T_{11n} - T_{12n}\right) + c_2\left(T_{11n} - T_{12n}\right)^2 + c_0 + \\
+ c_3\left(T_{11n} - T_{11o}\right) + c_4\left(T_{11n} - T_{11o}\right)^2 + \\
+ \left(c_5 + c_6 w\right)\left(1 - \varepsilon\right) + \left(c_7 + c_8 w\right)\Delta\varepsilon
\end{aligned}
\quad (3)
$$

where “n” is nadir view and “o” is oblique view. Table 2 shows the results obtained in the sensitivity analysis of this algoritm, with a total error of 0.7 K.

Table 2. Coefficients for the combined DA+SW algorithm (Equation 3). Results obtained in the sensitivity analysis are also included (values of σ in K).

Algorithm	Coefficients		Sensitiviy analysis	
DA+SW	c_0	-0.510	r	0.992
	c_1	-0.053	σ_{simul}	0.52
	c_2	-0.180	σ_{noise}	0.20
	c_3	2.13	σ_{emis}	0.46
	c_4	0.377	σ_W	0.13
	c_5	71.4	σ_{total}	0.73
	c_6	-10.04		
	c_7	-5.9		
	c_8	1.01		

4. CAMPAIGN DATASET AND SIMULATIONS

One of the objectives of the SEN4LST project is to compile a test dataset of coincident MERIS/AATSR imagery and in-situ data, and also to include in the dataset S2/MSI and S3/OLCI-SLSTR simulated data. This dataset will be used to test the new algorithms developed in the framework of the project.

The campaign data set collected during the project has been limited to three ESA campaigns whose main objectives were related to satellite validation and to algorithm development for future satellite missions such as Sentinels: SEN2FLEX 2005 (Barrax, Spain), CEFLES2 2007 (Les Landes, France), and SEN3EXP (Barrax, Spain; San Rossore, Italy).

Simulated data was constructed using in-situ data and airborne imagery acquired in the different field campaigns. At-sensor values were reproduced using input LST and emissivities, and then applying MODTRAN code to different atmospheric conditions. Figure 1 shows an example of simulated OLCI and SLSTR data.

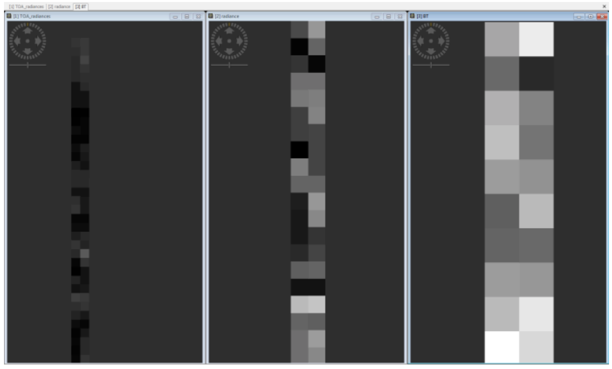

Figure 1. Example of simulated images for OLCI band 1 (300m), SLSTR band 1 (500m), and SLSTR band 7 (1 km).

5. CONCLUSIONS

The SEN4LST project explores the synergistic use of Sentinel missions (2 and 3) for improving LST retrievals. Different atmospheric correction and LST/emissivity retrieval methodologies have been reviewed and adapted to MSI, OLCI and SLSTR characteristics. Currently, the new algorithms are being validated using the simulated datasets and also pairs of MERIS/AATSR images. BEAM implementation has also started. Results extracted from the validation process will allow a final selection of best candidate methodologies to generate LST products from the future Sentinels missions.

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