AATSR Validation:

LST Validation Implementation Plan

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Summary

This document provides information about the strategic requirements and the pratical implementation of validating the Land Surface Temperature product from the Advanced Along-Track Scanning Radiometer (AATSR) series of instruments as well as the future Sea and Land Surface Temperature Radiometer (SLSTR) to be launched on the Sentinel-3 platform. The current validation status of the AATSR LST product is provided and the strategy for ongoing and future validation of the LST product by the University of Leicester is provided. Finally, the proprosed implementation of this LST validation strategy is described.

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1. Introduction

Land Surface Temperature (LST) is an important geophysical parameter controlling the effective radiating temperature of the Earth's surface. It plays a singificant role for a wide variety of applications, including climate change, land/atmosphere feedbacks, modelling studies, land cover change, crop management, water management, fire monitoring, and geology.

LST is most often derived using thermal infrared imagery acquired by satellite instruments using the split-window technique. In order to utilize LST to the fullest extent possible it is essential to carry out rigorous validation activities to determine the uncertainty involved with spaceborne observations of LST. The University of Leicester (UL) has been carrying out extensive validation of LST derived from the series of Along-Track Scanning Radiometer (ATSR) instruments. For this purpose UL primarily used highly accurate in situ measurements of LST as a reference against which the satellite retrievals of LST were compared, but also inter-comparisons with other sources of LST data such as alternative satellite instruments. Furthermore, radiance-based validation as well as time series analysis have also been considered.

While the current validation activities deliver important information about the quality and accuracy of the ATSR LST products, additional techniques and data sources could be used to improve upon the validation. After briefly describing the background of LST validation with a specific focus on the Advanced Along-Track Scanning Radiometer (AATSR) LST algorithm and the planned Sea and Land Surface Temperature Radiometer (SLSTR) algorithm, this document describes the strategy for ongoing and future validation of LST. Subsequently it describes which techniques are proposed to be implemented for the continuation and improvement of LST validation activities into the future.

2. Background

2.1. Instruments

2.1.1. The AATSR instrument

The Advanced Along-Track Scanning Radiometer (AATSR) is a space-borne multi-channel imaging radiometer with the main purpose of providing highly accurate global data on sea surface temperature (SST) and land surface temperature (LST). The AATSR instrument was launched in 2002 onboard of the European Space Agency's (ESA) ENVISAT satellite as the third in a series of instruments in order to continue the data record acquired by its predecessors, the ATSR-1 and ATSR-2 instruments onboard the ERS-1 and ERS-2 platforms respectively.

AATSR measures reflected and emitted radiation at wavelengths of 0.55 µm, 0.66 µm, 0.87 µm, 1.6 µm, 3.7 µm, 11 µm and 12 µm at both nadir angles and a forward view (Llewellyn-Jones et al., 2001). The instrument is equipped with a highly precise on-board calibration system designed for stability of the reference target. Only the nadir view is currently utilised for operational LST retrieval.

Previous validation efforts have indicated that AATSR is able to provide sea surface temperature with errors of less than 0.3 K (Corlett et al., 2006) and nighttime LST with errors of less than 1 K (Coll et al., 2005).

2.1.2. The SLSTR instrument

The Sea and Land Surface Temperature Radiometer (SLSTR) is an approved instrument designed for continuing and improving the SST and LST record provided by the three (A)ATSR sensors and to provide an operational spaceborne platform for temperature observations of the Earth surface.

SLSTR is currently planned for launch in 2014 onboard of the first of two approved Sentinel-3 satellites which comprise an element of the Global Monitoring for Environment and Security (GMES) programme, the second SLSTR instrument will be onboard the Sentinel-3B satellite – currently planned for launch 18 months after Sentinel-3A. This programme responds to the requirements for an operational and near-real-time monitoring of the Earth surface over a period of 15 to 20 years. Based on the heritage of the (A)ATSR series of instruments, SLSTR is designed to deliver improved SST and LST measurements by providing additional channels and a significantly wider swath than AATSR.

2.2. The operational AATSR LST product

The AATSR LST algorithm uses top-of-the-atmosphere brightness temperatures from the 11 and 12 µm AATSR channels for generating a global LST product. The algorithm is based on the relationship

$$LST = a_0 + b_0 \cdot T_{11} + c_0 \cdot T_{12}$$

where a_0, b_0 and c_0 are regression coefficients depending on land surface emissivity, atmospheric water vapour, and viewing angle. The algorithm uses auxiliary data in the form of land cover data (biomes) and vegetation fraction. The regression coefficients are available in a look-up table, making the execution of the algorithm computationally very efficient.

More details on the algorithm of the operational AATSR LST product can be found in the original AATSR LST Algorithm Theoretical Basis Document (Prata, 2002). The updated AATSR LST product is described in the Interim Algorithm Theoretical Basis Document Update (Prata and Zeller, 2010). The list of biomes used for the updated AATSR LST product is presented in the Site Requirements Report (Schneider et al., 2012b) to the ESA project "Long Term Land Surface Temperature Validation".

3. Current status of ATSR LST validation

LST from the ATSR series of instruments has been validated using a variety of approaches, primarily using in situ observations, but also utilising radiance-based techniques and inter-sensor comparisons – as described in the Validation Protocol (Schneider et al., 2012a). Previous validation activities have for example included a campaign in Morocco, where an average bias of -1.00 K and -1.74 K was found for daytime and nighttime data, respectively (Noyes et al., 2007; Sòria and Sobrino, 2007). Other notable validation activities include those at Lake Tahoe, USA (Hook et al., 2003) and Valencia, Spain (Coll et al., 2009, 2012). The data showed excellent agreement with the in situ observations at both sites with close to zero average biases and standard deviations ≤ 1 K for night-time data.

Currently, in situ measurements from several dedicated and continuously operating LST validation sites are forming the basis for the continuing validation of LST from the ATSR series of instruments - and primarily AATSR – by UL (Ghent and Corlett, 2012). These include the EUMETSAT sites at Gobabeb (Namibia) and Evora (Portugal), but also several permanent and temporary sites of the ARM Climate Research network (Stokes and Schwartz, 1994).

In addition to in situ validation UL has further tested the theoretical sensitivity of the AATSR LST algorithm to surface temperature, emissivity, water vapour, and atmospheric temperature with the fast radiative transfer model RTTOV (Ghent and Corlett, 2012).

Finally, validation of the AATSR LST algorithm was also carried out using a multi-sensor intercomparison. This inter-comparison was performed against LST data derived from the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) instrument on board the Meteosat Second Generation (MSG) geostationary satellites and the MOderate Resolution Imaging Spectroradiometer (MODIS) instrument on board the sun-synchronous, near-polar orbiting satellite Terra (Ghent and Corlett, 2012).

The most recent validation results confirm previous key findings: The operational AATSR LST algorithm is seasonally biased with the peak error occurring during the warmest months of the year. Secondly, the accuracy of the algorithm is highly dependent on the emissivity but also on water vapour and atmospheric temperature. Finally, the bias and sensitivity of the AATSR LST algorithm varies significantly by land cover type (Ghent and Corlett, 2012).

4. Strategy for ongoing and future validation

One of the most important strategic goals of ongoing and future LST validation is to assess potential validation sites for suitability, both in terms of logistics and usefulness. A suitable site should be able to provide continual measurements so as to produce new insights into the accuracy of LST retrievals, and be able to be classified satisfactorily into measurable endmembers. The LST Validation Protocol (Schneider et al., 2012a) and the LST Site Requirements Report (Schneider et al., 2012b) provide more information about currently used and potential new in situ sites.

The ATSR LST algorithm – and the planned SLSTR LST algorithm – are biome-based with the surface emissivity implicit in the fractional vegetation cover auxiliary dataset and retrieval coefficients. Although in situ sites measuring surface types at the limits of the 11µm and 12µm emissivity range - for example quartz and inland water - would be a requirement for emissivity-explicit algorithms, for (A)ATSR (and SLSTR) in situ measurements covering the range of biomes types is the preferred requirement here.

The ATSR LST products are currently validated by UL using in situ data collected over a wide variety of land cover types. However, 13 of the 27 biomes remain without available in situ measurements (Schneider et al., 2012b). As such, it is an important strategic requirement to increase LST validation activities in biomes that are not currently covered by in situ LST data sets. Priority should be given to establishing permanent in situ stations in biomes currently not validated and which account for the largest areas of the terrestrial surface. For instance, if funds were available to install a single in situ station to measure LST the recommendation from this investigation is that this should be sited in the needleleaved deciduous or evergreen forest primarily represented by boreal forest in the northern latitudes (biome 9); this covers more than 7 % of the total land surface of the Earth. Other key biomes which require a first dedicated LST in situ station are documented in the accompanying Site Requirements Report (Schneider et al., 2012b).

A very important component of the LST validation strategy is the continuing support of existing, long-term validation sites such as the ones at Gobabeb (Namibia), Evora (Portugal), and Lake Tahoe (United States) for example. The data acquired by such sites is essential for characterizing instrument drift, for understanding long-term trends in the accuracy of the LST product and for characterizing the suitability of LST time series to be used for climate applications. However, of the 14 biomes with available in situ validation data only six are categorised as being sufficiently covered. The strategy here is to improve upon the quality and/or contiguousness of the data collection covering the other eight biomes; the rationale behind this categorisation is described in the Validation Protocol (Schneider et al., 2012a).

An increase in well-defined campaigns, such as SEN2FLEX (Sobrino et al., 2008) and SEN3EXP is desirable. Such dedicated experiments can provide valuable information complementing the data from existing long-term in situ sites. Furthermore, they have also incorporated airborne measurements in addition to ground measurements.

Land surface temperature retrieval from satellite requires precise knowledge of the physical characteristics of the surface and of the state of the atmosphere at the time of a satellite overpass. As a part of a future LST validation strategy any dedicated in situ LST site or campaign should therefore include measurements of such variables.

The provision of detailed uncertainty budgets for both in situ and satellite LST is also of strategic importance. Indeed, the characterisation of uncertainty in satellite-retrieved LST is essential for many applications, such as data assimilation and climate forecasting. For instance, assignment of an ill-conceived uncertainty budget will lead to non-optimal performance when data is assimilated into land surface models – such techniques require knowledge of both random error and systematic error. Uncertainties could be classified in the data using confidence flags and/or quantitative values.

A further important strategic recommendation is the establishment of a core validation matchup database. Such a database will merge existing and developing databases - such as the UL matchup database and the SEN4LST database – and support the inclusion of further in situ measurements. The expectation being that a core validation matchup database provides a single source of LST validation data freely accessible for all users. The intention would be for both in situ measurements and satellite-derived LST data to be stored here, together with sufficient auxiliary data such as site calibration information, emissivity values, and atmospheric measurements for example.

The LST validation strategy described here also includes the continuation and improvement of supplementary validation activities as categorised in the Validation Protocol (Schneider et al., 2012a). These provide an invaluable source of additional evaluation information regarding the performance of LST algorithms. This is particularly pertinent for LST retrieved across biomes of the Earth not currently covered, or insufficiently covered, by in situ validation.

As a final point it should be noted that any LST validation strategy should include intensified inter-institutional coordination between those responsible for maintaining in situ sites and collecting data, and those responsible for developing the matchup database, analysing the validation data, and improving the algorithms.

5. Implementation for ongoing and future validation

5.1. Continuation of current validation activities

The continuation of LST validation activities, such as comprehensive comparisons of the AATSR LST product with high quality LST in situ observations from long-term sites - Gobabeb (Namibia) and Evora (Portugal) – for example; and inter-comparisons with LST products derived from other sensors plus sensitivity studies using radiative transfer models are perceived as a necessity for maintaining the quality of the ATSR data archive following future operational re-processing. Such activities are dependent upon continuing European or National funding of LST validation activities.

5.2. Establishment of new validation activities

In general, a validation approach following four complementary categories should be adopted for LST validation:

Category A: *Comparison of satellite LST with in situ measurements*
This is the traditional and most straightforward approach to validating LST. It involves a direct comparison of satellite-derived LST with collocated and simultaneously acquired LST from ground-based radiometers.

Category B: *Radiance-based validation*
This technique uses top-of-atmosphere (TOA) brightness temperatures (BTs) in conjunction with a radiative transfer model to simulate ground LST using data of surface emissivity and atmospheric profiles of air temperature and water vapour content.

Category C: *Inter-comparison with similar LST products*
A wide variety of airborne and spaceborne instruments collect thermal infrared data and many provide operational LST products. An inter-comparison of LST products from different instruments can be very valuable for evaluating LST.

Category D: *Time series analysis*
Analysing time series of satellite data over a temporally stable target site allows for the identification of potential calibration drift or other issues of the instrument that manifest themselves over time. Furthermore, problems associated with cloud contamination for example may be identified from artefacts evident in the time series. Care must be taken in distinguishing between instrument-related issues such as calibration drift and real geophysical changes of the target site or the atmosphere.

The categories and their individual advantages and disadvantages are described in detail in the LST Validation Protocol (Schneider et al., 2012a). The application of some of these categories have a long heritage in groups such as UL, in particular the comparison with in situ data and inter-comparison with LST products derived from other satellite instruments. The continuation of these activities, and the establishment of a legacy in less utilised techniques such as radiance-based validation and time series analysis, is critical both for maintaining the quality of LST products from the (A)ATSR instruments, but also for developing climate quality LST data and for supporting the future operational LST product from SLSTR. The latter category is particularly critical for implementing a more long-term perspective to LST validation in view of climate change applications.

5.2.1. Including currently unused in situ data

A first recommendation is the inclusion of data from additional in situ LST validation sites in the current validation activities for AATSR. As described in detail in the LST Site Requirements Document (Schneider et al., 2012b), there are several in situ LST validation sites that are actively collecting data but have to date not been included in the AATSR validation activities, due to reasons such as previous unavailability of data for example. The inclusion of such data is perceived as a relatively undemanding way of improving the biome coverage of Category A validation.

This additional operational LST in situ data that potentially could be incorporated into the AATSR validation scheme include the Lake Tahoe (United States) site operated by the Jet Propulsion Laboratory, and both the RMZ/Heimat station in Namibia and the Dahra (Senegal) station which are operated by the Karlsruhe Institute of Technology (Olesen and Göttsche, 2009; Göttsche et al., 2011). The Lake Tahoe site has been collecting highly accurate radiometer measurements at two minute intervals since the year 2000 and is as such a critical source of data for LST product quality assessment, particularly for long-term monitoring involving the determination of inter-sensor biases and calibration drift of the sensors (Hook et al., 2003, 2007; Coll et al., 2009). The RMZ/Heimat and the Dahra stations have at this point only relatively short measurement records, but have secured funding for several more years and thus will be of equally valuable sources of validation information as the Gobabeb site.

Furthermore, for validation of past LST data – primarily from the ATSR-2 period - it can be also useful to include in situ LST data from stations that are not operational anymore at this point, such as several sites in Australia which collected data until 2002 (Prata, 2003).

5.2.2. Establishment of new in situ stations

The establishment of new in situ sites should be a priority to support validation of the SLSTR operational LST product. Ideally all biomes currently not covered by in situ data should be prioritised; however, a ranking system of importance to the SLSTR LST algorithm should be adhered to. Given the cost of setting up a new site, and the subsequent running costs, the Site Requirements Report (Schneider et al., 2012b) recommends prioritising biomes based on their respective coverage of the Earth's land surface. This means that biome 9, covering more than 7 % of the terrestrial land surface would be the recommendation for establishing the first of any new stations; feasibles locations would include the Canadian or Scandanavian boreal forest.

5.2.3. Data quality from existing in situ stations

It is recommended that LST validation scientists collaborate with in situ site managers to improve upon the quality and/or contiguousness of the in situ data. This may mean for example provision of uncertainty budgets or instrument calibration details. Such additional information should enable re-classification of participating sites to a higher category according to the Validation Protocol (Schneider et al., 2012a) ensuring a greater number of biomes meet the stringent guidelines set out in the Site Requirements Report (Schneider et al., 2012b) for sufficient validation coverage; thereby improving confidence in the LST validation.

5.2.4. Collection of ancillary data

Validation of LST can be improved by collecting additional ancillary data at the in situ LST observation sites. In addition to the usual radiometric measurements and emissivity estimates, such data can include observations of soil moisture and atmospheric measurements - cloud base height and water vapour – by the installation of additional instrumentation and the periodic launching of radiosondes. This provides more information on environmental conditions during periods of low quality LST retrievals.

5.2.5. Re-calibration of in situ radiometers

Radiometers at the in situ sites need to be re-calibrated at regular intervals to correct for potential instrument drift. Long-term in situ sites equipped with regularly re-calibrated radiometers allow for accurate characterization of the temporal behaviour of LST products and for detecting potential drift of the satellite instrument or inter-sensor biases; this supports the determination of the suitability of the LST product for climate applications.

5.2.6. Consideration of site homogeneity

For homogeneous sites a single radiometer may be sufficient, providing the homogeneity of the landscape extends beyond the limits of a satellite pixel. For heterogeneous sites each endmember needs to be independently measured by a calibrated radiometer at the time of a satellite overpass. In future, it is recommended that more effort should be undertaken to fully utilize the validation data at heterogeneous validation sites, such as Evora (Portugal), since the majority of biomes are heterogeneous in terms of their principle surface endmembers. Several current operational in situ sites do not provide a sufficient breakdown of concurrent endmember radiometric temperatures, relying instead on single radiometers measuring the most abundant endmember. Determing the exact geolocation of a satellite overstrike is also of relevance here so as to accurately upscale the individual endmember measurements. Indeed, validation of heterogeneous sites remains a considerable challenge and should be considered a priority for ongoing and future validation.

5.2.7. Evaluation of impact of topography

In areas of significant topography or in landscapes of heterogeneous structure, shadow effects should be modelled in order to enable a more accurate comparison of in situ LST data with satellite retrieved LST. Tools such as geometric projection models exist to facilitate validation of these surfaces. Few validation activities have so far exploited this knowledge, and this is therefore a strategy where emphasis should be placed.

5.2.8. Validation loop

A “validation loop” will be implemented by the validation scientist, similar to the scheme which is described in the SST validation implementation plan.

5.2.9. Core validation data

A core validation matchup data set is to be established in order to support future coefficient and algorithm development. Once updated, it will be necessary to reprocess all of the validation match-ups collected to date, to make a qualitative assessment of the improvement of the updated AATSR coefficients and algorithm.

5.2.10. Aerosol and cloud contamination

Improved tests for identifying aerosol and cloud contamination are a necessity for improving the quality of the AATSR LST products, and to ensure high quality SLSTR LST data. It is further necessary to better understand how a correction for such issues can be provided for the entire ATSR record. The emergence of optimised aerosol and cloud detection algorithms are dependent on financial support for such studies.

5.2.11. Uncertainty budget

It is important to have an estimate of the expected uncertainties when comparing AATSR measurement data with in situ data. A detailed uncertainty budget should therefore be considered a priority for the AATSR instrument. An uncertainty budget is essential for developing climate quality LST, and should include a categorisation of random and systematic errors. Indeed, the provision of an uncertainty budget is a requirement for the SLSTR instrument.

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