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A Validation Framework for ENVISAT AATSR Sea Surface Skin Temperature Observations.

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ABSTRACT: A poor AATSR sea surface skin temperature (SSST) validation strategy will compromise the quality of the AATSR mission because of an inability to quantify appropriate SSST product confidence limits. This presentation reviews some of the options that are available for the on-going validation of AATSR SSST measurements. Particular emphasis is placed on the use of new autonomous ship of opportunity radiometer systems together with high wind speed ship and buoy subsurface "bulk" sea surface temperature observations. The need for a co-ordinated, cost effective strategy implemented through the generation of a dynamic distributed database of validation data is highlighted and discussed.

Introduction

The ENVISAT advanced along track scanning radiometer (AATSR) is a low noise, self calibrating infrared radiometer designed to provide measurements of the sea surface skin temperature (SSST). Atmospheric attenuation of the measured water leaving radiance signal is accounted for using a algorithm derived from atmospheric radiative transfer model calculations so that AATSR SSST products do not consider the relationship between the SSST (representative of the temperature of the surface 10μm of the ocean) and the subsurface bulk SST (BSST). There is a characteristic difference between the SSST and the subsurface BSST traditionally measured at a depth of ~1m from ships and buoys (e.g., Robinson et al. 1984). The mean magnitude of the SSST minus BSST difference, defined as ΔT=SSST-BSST, is about -0.3 K although ΔT has considerable (>1K) variability (e.g., Schluessel et al, 1990). The magnitude and variability of ΔT is controlled by both the heat flux passing through the air-sea interface and the turbulent/momentum characteristics of the near interface regions (e.g., Saunders, 1967). At low wind speeds during the day oceanic thermal stratification confuses the interpretation of ΔT whereas at night, radiative cooling of the surface water causes extreme cool skin temperatures (e.g., Donlon et al., 1999).

Accurate and dependable post launch sensor calibration is achieved by regular views of two precision black body cavities which, together with the reliable and well-characterised along track scanning measurement concept, underpin the integrity of AATSR SSST. Thus, the quality and credibility of ENVISAT AATSR SSST data products depends on comprehensively accounting for the uncertainties associated with the along track scanning technique, the accuracy of the radiative transfer model used to derive appropriate SSST algorithms and, the changes within the AATSR instrument throughout its lifetime. Confidence limits associated with the derived SSST data products are specified as 0.3 K for a 0.5° latitude by 0.5° longitude area having 20% cloud free conditions and in special circumstances to an accuracy of 0.1 K (Parkes, 1996). These specifications can only be verified using independent in situ validation data obtained contemporaneously with the satellite overpass. This paper reviews some of the options available for AATSR SSST validation and suggests a framework for the implementation of key elements required for the long term, cost effective validation and development of AATSR SSST data products.

Requirements for AATSR validation

The most appropriate AATSR SSST validation measurements are of contemporaneous in situ SSST determined at the exact time of satellite overpass using an instrument having similar spectral characteristics to the AATSR instrument. Complex, precision in situ radiometers and spectroradiometers deployed from research vessels have been used to obtain contemporaneous SSST validation measurements for both the ERS-ATSR-1 and -2 instruments. However, due to the limited geographic and temporal coverage of many dedicated validation campaigns, the cost and difficulty of deploying such instrumentation, this approach has only provided limited validation results. By maintaining this strategy, it is clear that the potential AATSR validation data set will also be extremely limited both in spatial distribution and quantity. Consequently a new validation strategy and data framework is required and with this objective in mind, the following aims can be identified:

- To refine and introduce standards for the protocols, methods (e.g., temporal and spatial time-scales, geographical coverage) and quality control procedures (e.g., tractability of in situ instrumentation calibrations) used for the long term validation of satellite SSST measurements. In particular, focus should be towards understanding the limitations of existing ocean-atmosphere measurement capacity complemented by the development and deployment of dedicated cost effective, operational, autonomous instrumentation (including infrared radiometers) in partnership with commercial shipping companies occupying regular ocean passages.
- To establish a long term comprehensive (inter)national validation dynamic distributed database (DDD). The focus is to provide an extensible, long term, quality control resource as a standard reference for current and future re-analysis procedures and for the development of new synergistic data products. The content of the DDD should not be restricted in any way but instead, should provide as much information as possible for contemporaneous satellite and in situ observations. Of primary importance is the need for database structures to have easy and reliable user access with rapid and penetrating data query options linked to "on-the-fly" data processing capabilities.
- To foster international collaboration and data exchange specifically for the development and exploitation of satellite and in situ data synergy. In this way, the maximum potential of global in situ data sets may be realised and provide the on-going instrument validation and inter-comparisons necessary for the generation of new innovative data products.

These aims constitute the foundations of a wider scope multi-sensor satellite validation strategy called the comprehensive global satellite validation strategy (CGVALS), although the scope this paper is specifically limited to satellite sea surface temperature.

The deployment and measurement methodology used by in situ instruments should adhere to internationally agreed guidelines and procedures. The scientific merit and therefore usefulness of in situ data is critically dependent on the specific instrumentation and the deployment method. For example, many different in situ infrared radiometers, spectroradiometers and thermal imaging cameras are currently used to collect precision in situ SSST data sets for SSST validation purposes although there is limited formal agreement regarding the measurement of in situ SSST. For each particular data record, attention must be given to the traceable end-to-end calibration of all in situ instrumentation together with the details of both the calibration strategy employed and the deployment characteristics that should follow agreed procedures.

Implementation of AATSR SSST validation under CGVALS

The essential SSST validation measurement is contemporaneous satellite and in situ SSST over a wide geographical area encompassing a range of ocean-atmosphere conditions. The validation of AATSR SSST products can be undertaken using either *direct* in situ observations (e.g., in situ SSST obtained using a radiometer of similar spectral characteristics) or *indirect* in situ observations (e.g., in situ BSST). These should be complemented by a limited number of conventional atmosphere and ocean parameters providing a context for the SSST validation data (e.g., wind speed, depth of BSST measurements). Finally, contemporaneous atmospheric profiles of temperature pressure, humidity and atmospheric aerosol loading are required to validate the atmospheric transmission model used to generate the AATSR SSST retrieval coefficients. In practice, these will almost exclusively be derived from radiosonde releases during dedicated research campaigns and operational satellite soundings and are not discussed further.

Indirect validation of AATSR SSST

The small number of in situ SSST validation data has perpetuated the use of in situ BSST observations derived from widely available and globally distributed ship and buoy measurements as a primary satellite SSST validation data source. However, the quality of these measurements in this context is complicated by calibration uncertainties associated with the in situ sensors and their installation, ΔT and, thermal stratification of the sea surface. Recently, Donlon et al. (1999) use extensive in situ observations obtained during independent experiments in the Atlantic Ocean to demonstrate the relationship between the wind speed and ΔT. In all cases, at wind speeds $>8ms^{-1}$, the variability of ΔT is diminished and the mean value of approximates a constant cool bias of about -0.14 K ±0.1 K. They conclude that, at high wind speeds, well calibrated subsurface BSST measurements obtained from ships and buoys, when corrected for a small cool bias, may be considered to represent the SSST. A particular benefit of using existing BSST observational infrastructure in this way is that areas of high wind speed are conveniently located in regions such as the Southern Ocean where in situ SSST validation data are extremely scarce.

Contemporaneous BSST and wind speed observations from the Tropical Ocean Global Atmosphere (TOGA) TAU buoy array together with ATSR-1 10 arc minute SSST have been used to assess the viability of high wind speed/BSST data as a satellite SSST validation source. ΔT was computed from ATSR SSST data obtained during the first four years of the ATSR-1 mission and contemporaneous TAU BSST after the satellite data were stringently filtered to exclude cloud contaminated data and areas of highly dynamic SSST. This procedure resulted in approximately 7000 observations (combined day and night time) which have been plotted as a function of TAU wind speed (adjusted to 10m height) in Figure 1. Although limited to a range of wind speed below 12 ms^{-1}, the night-time only results are in excellent agreement with field observations discussed above and highlight the accuracy of the ATSR-1 SSST products following the recent re-processing of the ATSR-1 mission. Results for daytime situations highlight the dominance of thermal stratification. Note that only a small number of observations contribute to the "noisy" observations above 10ms^{-1} highlighting one of the major limitations of this technique: high wind speed regions have a seasonal and regional bias limiting application to specific seasons and regions. Consequently, for the majority of cases, a direct in situ infra red measurement of SSST remain the most important validation measurement for AATSR SSST products.

Direct validation of AATSR SSST

For direct validation of AATSR SSST products, radiometers of similar spectral wavebands are required to contemporaneously determine in situ SSST. The widespread deployment of in situ research instrumentation such as the scanning infrared sea surface temperature radiometer (SISTeR) or the Marine Atmospheric Emitted Radiance Interferometer (M-AERI) from dedicated research vessels and ships of opportunity will provide a limited source of high precision in situ SSST measurements. Both dedicated and opportunistic research cruises have in the past produced a wealth of in situ SSST data but the number of successful satellite SSST validation instances has been disappointingly small. This is due to the availability and difficulty of developing, maintaining and deploying such instrumentation on suitable research ships which, themselves need to be positioned in clear sky conditions within the satellite swath. This identifies a need to shift from a small number of highly sophisticated and dedicated scientific measurement campaigns to the use of accurate, less sophisticated (and therefore lower cost) autonomous telemetering instrumentation that can be widely deployed from opportunistic platforms and ships.

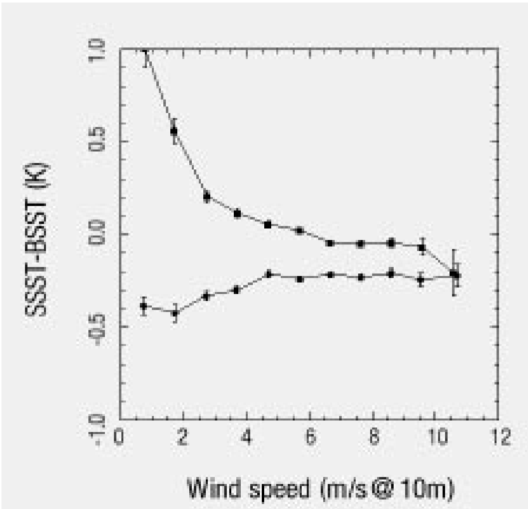

Figure 1. ATSR-1 10 arc minute SSST-TOGA TAU BSST plotted as a function of TAU wind speed corrected to 10m height. The top line considers only daytime observations and the bottom line only night time observations. Error bars show ±1 standard deviation.

The deployment of an operational autonomous infrared radiometer measuring SSST from merchant vessels operating along regular meridional ocean-basin passages is therefore highlighted as a critical component of a successful SSST validation strategy for the ENVISAT AATSR.

Long term autonomous direct SSST validation

There has been a positive development of low-cost infrared radiometer systems suitable for extended autonomous operation has focussed on the use of solid state radiometers (e.g., Donlon et al., 1998). In response to many of these developments, the US Naval research Laboratory (NRL) has commissioned an Anglo-US collaborative project to develop a precision autonomous SSST radiometer for use in the GOES Air-Sea interaction project

(GOES-GASIP). The Infrared SSST Autonomous Radiometer (ISAR) is a narrow band (9.6-11.5μm) single channel, continuously calibrated (using two blackbody cavities) in situ radiometer capable of providing SSST measurements from near contemporaneous sea and sky radiance measurements to an accuracy of ±0.1 K rmse. The ISAR system has been developed for autonomous deployment periods of several months using state of the art technology to protect itself during inclement weather conditions. In addition to SSST measurements, the ISAR system is able to accommodate additional ocean-atmosphere instruments via a dedicated expansion port. Thus ISAR is extremely well suited to the task of ENVISAT AATSR SSST validation and can provide SSST together with supporting observations at 2 minute intervals via satellite communications. The proposed ISAR autonomous SSST validation package consists of the following instrumentation:

1. **ISAR-4 autonomous SSST** radiometer system providing SSST measurements derived from continuously calibrated near contemporaneous sea and sky radiance measurements.
2. **Hull mounted BSST** sensors. We propose to use a similar system to Emery et al (1999) who demonstrate considerable success during a ship of opportunity pilot project. This system uses calibrated low cost adhesive platinum resistance thermometers (PRT) devices attached to the inside of the ships hull. Resistance signals are converted to current signals via small solid state units enabling long cable runs to be taken through the ship to the data logging system. Several devices will be installed to the hull plates inside the vessel in the following configuration: just below the high water line, just above the low water line and a 'deep' sensor. In this way, waterline changes due to the loading characteristics of a particular voyage potentially resulting is a PRT sensor location above the actual waterline will be avoided.
3. **Air temperature** sensor. We propose to use a solid state aspirated psychrometer to determine wet and dry bulb air temperature. This will be located on the ships bridge area requiring that a water bottle is replenished periodically.
4. **Wind speed and direction** sensors. We plan to locate these in clean airflow on the ship fore-mast. Additional modelling of the ships airflow disturbance may be necessary (Yelland et al., 1998).
5. **LW and SW radiation** sensors. These will be located on the ships foremast.
6. **Shadow band radiometer** system for the determination of marine aerosols via optical depth measurements.

In order to ensure that geographically widespread and temporally dense data are collected using the ISAR package, deployments should focus on commercial ships operating repeat long-haul trans-oceanic passages. Discussions in progress focus on partnerships with two international shipping companies operating vessels ranging from small coastal based feeder vessels to the world's largest and technologically most advanced trans continental container vessels. Figure 2 describes the major ocean passages that are potentially available from initial discussions superimposed onto a SSST image obtained from the ERS ATSR-2. A variety of transects that will collectively provide a range of ocean-atmosphere conditions suitable for the long term validation of satellite SSST are clearly evident. In particular, the Atlantic Ocean is well served with passages to both S. America and S. Africa.

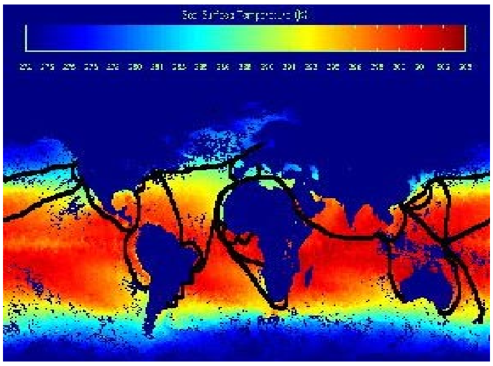

Figure 2. Regular long haul routes used by a commercial shipping company superimposed over an ATSR-2 ASST map for February 1999 (Image data © ESA/CCLRC/NERC processed by RAL).

Establishment of a distributed dynamic database (DDD)

At the core of the CGVALS framework and the proposed AATSR validation strategy proposed here is the generation of a contemporaneous, complementary data set of in situ and satellite observations. These are necessary to provide a quantitative description of the ocean-atmosphere state required to identify the processes that limit the accuracy of AATSR SSST data products. In order to achieve success, a diverse validation data set needs to be generated for a representative suite of ocean-atmosphere conditions obtained over a geographically widespread area from a variety set of satellite and in situ sensor systems. A comprehensive database of all contemporaneous satellite and in situ data facilitates the investigation of fundamental issues such as the physical processes characterising the satellite measured radiance, time-space inconsistencies within the database, the long term performance of the satellite instrument and, the stability of the satellite derived data products. However, the power of the database can only be realised through easy data access and the analysis of synergy benefits inherent within the collective database records. Consequently, powerful query and analysis tools are required to manipulate the project database in a dynamic sense. For example, the database should store the lowest common data streams (e.g., top of the atmosphere brightness temperatures) that can be (re) processed using documented algorithms held in a separate data area "on the fly". The results of this data query would then be merged with contemporaneous observations and output dispatched to a client specified report file for further analysis.

It is proposed that the database structure be *virtual* or *distributed* in the sense that only *access* to certain data are required. Universal data access (UDA) interfaces adhering to internet standards are considered a key aspect of the CGVALS DDD definition. Typically, such interfaces are implemented using "Middleware" virtual database (VDB) engines that provide transparent access to data held in specific formats within distributed databases. An operational implementation would use logical references (via Metedata tags) to specific data access drivers (DAD) that have powerful data translation and data processing capabilities. DAD will access data stored in disparate data structures and formats (often defined and required by the data provider) through a client application program interface (API) in a manner identical to the access of local data files on the client system. DAD can easily incorporate data processing capabilities such as the application of specific calibration algorithms or client specified query restraints. There are significant benefits to this approach:

- Clients are not prevented from accessing data because of storage format incompatibilities.
- Data may be stored and updated by data owners using non-standard data formats at a local sites rather than at a centralised facility where only DAD are required.
- Through the innovative use of DAD and VDB engines providing data processing capability, the database records are continuously updated 'on the fly' independently of the lower level archived data.
- The client is assured of being provided with the most current data version.

Additionally, the development of a DDD inherently stimulates and acts as a co-ordination focus for validation data and activities, forces a consideration of quality control issues (specifically in situ instrument deployment, data processing, and tracability) ensuring that validation data are reliable and representative, maintains and develops calibration standards and international collaborations would be extended and developed. The combination of the virtual database engines, internet based network communications and DAD concept clearly have the capability to provide a powerful tool for the retrieval, sampling, and display of large distributed datasets. This framework is ideally suited to the long term validation management and development of ENVISAT AATSR data products.

Conclusions

This paper highlights the need to develop and maintain a highly structured approach to the validation of the ENVISAT AATSR sea surface skin temperature data products. This is required for the immediate validation of these products but also, for the future re-analysis and synergistic development of AATSR data products. The use of subsurface bulk sea surface temperature as a SSST validation data source is considered acceptable if wind speed conditions are in excess of $8ms^{-1}$ and a small SSST bias correction is applied to the data. However, these data are restricted in their spatial and temporal distribution. The development of cost effective autonomous in situ measurement packages operating from ships of opportunity is considered critical to the comprehensive on-going validation of the AATSR instrument. Observations from such systems will provide long term accurate baseline validation data complemented by precision measurements obtained from research instrumentation deployed during dedicated campaigns. The need for tracability of calibration and formal protocols for the deployment of all in situ instrumentation is highlighted. It is proposed that a core element of the AATSR validation strategy should include the generation and maintenance of a dynamic distributed database of all contemporaneous satellite and in situ observations. This will provide a resource and functionality well suited to the long term validation management and product development of ENVISAT AATSR data. Such a framework can only be achieved through international collaboration with other research groups and national agencies.

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