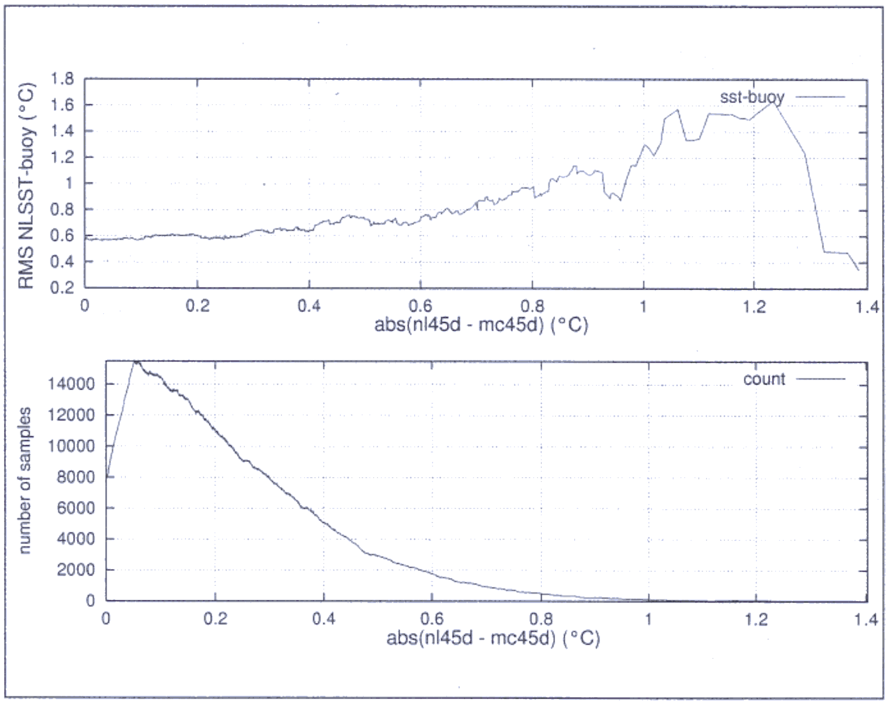
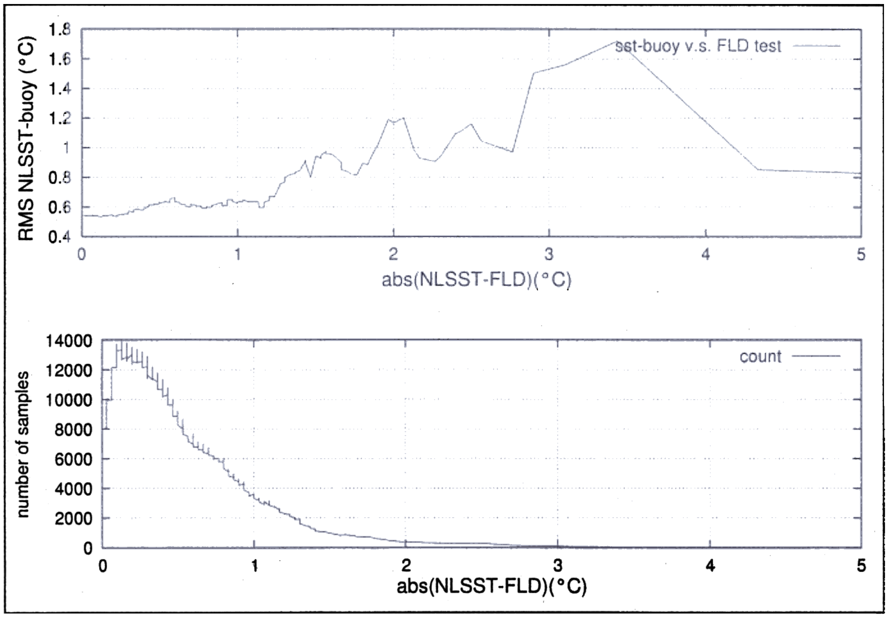
Reliability Estimates for Real-Time Sea Surface Temperature

A Method to Add Real-Time Reliability Estimates to Operationally Produced Satellite-Derived Sea Surface Temperature Retrievals

By Dr. Jean-François Cayula
Principal Scientist
Planning Systems Inc.
Doug May
Data Division Director
Bruce McKenzie
Oceanographer
Dan Olszewski
Oceanographer
and
Keith Willis
Computer Scientist
Naval Oceanographic Office
Stennis Space Center, Mississippi



(Top) Satellite-derived SST minus buoy RMS versus the difference between the SST values obtained from two day-time equations (top). Associated sample quantity histogram (botttom).



(Left) Satellite-derived SST minus buoy RMS versus satellite-derived SST minus SST analyzed field for day-time data (top). Associated sample quantity histogram versus SST analyzed field minus satellite-derived SST (bottom).

The Naval Oceanographic Office (NAVOCEANO) is responsible for analyzing and processing satellite data to produce high-quality multi-channel sea surface temperature (MCSST) data.[1] NAVOCEANO distributes the MCSST data locally for thermal analyses, oceanographic models, and to various external oceanographic and weather centers. Recently, there has been heightened interest in providing quantitative error estimates for satellite SST data.[2] Indeed, such information is crucial to applications such as optimal interpolation analysis or model assimilation. This article describes the scheme developed at NAVOCEANO to add such reliability information, in the form of root-mean-square (RMS) error, to the operational data stream. First, the data are described, this is followed by an explanation of the method used to classify each MCSST sample in categories and how error estimates are assigned to each category. Results of tracking actual, versus estimated, RMS error for over a year of operational processing, as well as the stability of classification parameters, are presented, and possibilities for potential expansion of this work are outlined in the conclusion.

Satellite Data

This study deals with Global Area Coverage Advanced Very-High-Resolution Radiometer (AVHRR) 1b and High-Resolution Infrared Radiation Sounder (HIRS) digital data received by NAVOCEANO from the National Oceanic and Atmospheric Administration, National Environmental Satellite, Data and Information Service (NOAA/NESDIS). The reliability estimation scheme has also been added to local area coverage and geostationary operational environmental satellite (GOES) data processing. A goal of MCSST processing at NAVOCEANO is to generate only high-quality MCSST retrievals and, thus, minimize the inclusion of cloud-contaminated data or otherwise invalid data in the processing stream.[3] First, AVHRR 1b records go through various quality control steps to check parameters such as scan time, calibration coefficients, frame synchronization, localization and data quality errors, and to limit other parameters such as the satellite zenith angle. Cloud detection uses tests on the visible, near infrared and infrared channels, spatial coherence and inter-comparison of different MCSST equations. SST processing is based on 11 by 11 targets of four-kilometer pixels. Only pixels that pass all tests are used to produce SST retrievals from the averaging of two by two pixel unit arrays. Reliability estimates are only computed for those points where SST retrievals are successfully generated. Finally, one should note that although night-time and day-time data are handled in a similar way, the equations and tests are not the same. For example, night-time processing does not use visible channel data. Reliability estimates are separately determined for day-time and night-time data. Also, equations are regularly updated and differ from satellite to satellite. Reliability parameters may be adapted accordingly.

Match-Up Buoys

The initial reliability estimate parameters were determined from three months of buoys matched to SST data for the period of September to December 2001. Continuous monitoring of reliability estimates and updating of the parameters also depend on the last month of buoys matched with SST data. Both drifting and moored buoy data, which are received daily at NAVOCEANO, are used in the match-up database. Although the distance and time-matching parameters are modifiable, buoys are matched to satellite data if they are within a default 25-kilometer distance and four hours of the satellite retrieval.[3]

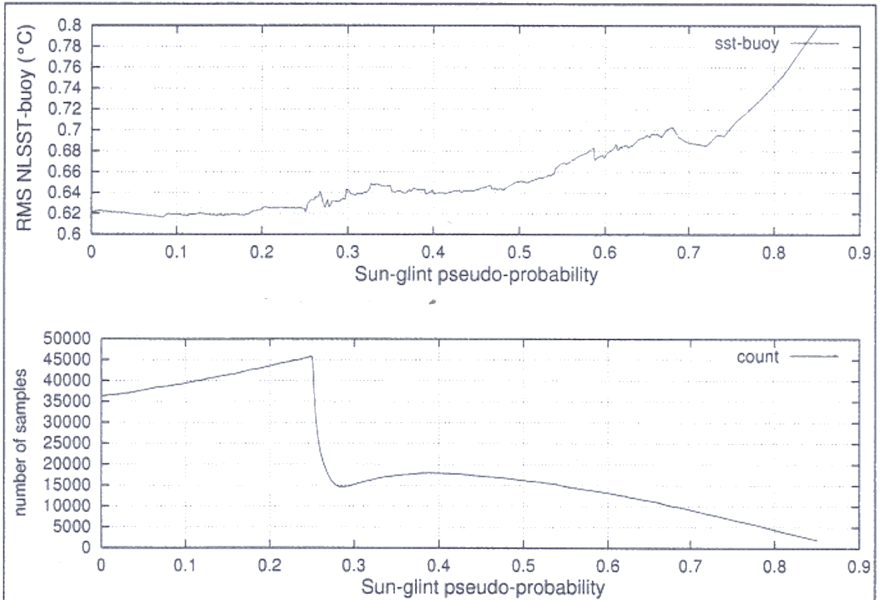
Reliability Estimates

Design. A simple reliability estimate method was chosen for ease of maintenance in an operational environment. As a consequence, it was decided to classify samples in three categories: clear, probably clear and questionable. It was also decided to assign RMS error values to each category, because it encompasses both the standard deviation and the bias in one number.

Determination of Variables to be Used for Classification. The effect of several variables on the temperature difference (RMS error) between satellite and buoy values was investigated on three months worth of satellite data matched to buoys. Several variables were surprisingly found not to significantly affect RMS errors. Among these, the satellite zenith angle, which is already cut off at less than 53°, did not show much effect.

Similarly, uniformity tests on AVHRR channels 2 (day-time), 3 (night-time) or 4 demonstrated relatively little impact, probably because cloud detection already places strong constraints on these variables. For night-time data, a test using HIRS channels 8 and 7 was not conclusive, nor was a ratio of AVHRR channels 1 and 2 for day-time retrievals.

Three derived variables, SST field, equation inter-comparison and sun-glint (this last one being for day-time only) had a definite relationship to the RMS error and were selected to build decision rules for classifying data into the three categories.



Satellite-derived SST minus buoy RMS versus sun-glint pseudo-probability (top). Associated sample quantity histogram (bottom).

The SST field test is based on the absolute difference between the produced SST (opsst), the weighted average of climatology (clim) and the analyzed 100-kilometer SST field (K100).[3] Weights are 1/3 for climatology and 2/3 for the 100-kilometer SST field. The analyzed 100-kilometer field is generated daily from the past

> ***"...it was decided to classify samples in three categories: clear, probably clear and questionable."***

36 hours of SST data and current field values. Each cell in the grid is 1° of latitude by 1° of longitude, hence the 100-kilometer field name. The equation for the field test value follows:

field test=opsst−((clim+(2*K100))/3)

The equation for the inter-comparison test is the absolute difference between two different equations for computing MCSST. For day-time data, the two equations are the non-linear equation[4] that uses channels 4 and 5 (nl45d) and the multi-channel equation[5] that uses channels 4 and 5 (mc45d):

intercomp day=abs(nl45d−mc45d)

For night-time data, the equations are the non-linear equation using channels 3, 4 and 5 (nl345n) and the multi-channel equation, which uses channels 3 and 4 (mc34n):

intercomp night=abs(nl345n−mc34n)

Sun-glint depends on the position of the sun relative to the target and the satellite. It also depends on the roughness of the water surface.[6] Because water surface roughness is not immediately available, the sun-glint pseudo-probability formula is a function of only the solar zenith (solzen) and azimuth (azmuth) angles and the satellite zenith (satzen) angle:

sunglint=exp(−((satzen+solzen)/a)≈
−(azmuth/b)≈)

where a and b are two constants selected such that with angles in degrees, a=50 and b=80.

Classification Rules. The SST field test is the first test to be applied to the data. The following decision rule is implemented:

field test≤tf1 ==> category 1
tf1<field test≤tf2 ==> potential category 2
field test>tf2 ==> potential category 3

where tf1 and tf2 are thresholds. For both day-time and night-time, tf1 is set to 1° C and tf2 to 2° C. These thresholds have remained unchanged since inception. One property of the field test is that it works very well in regions with little variability. However, the test is much less successful in dynamic regions, often failing to classify clear pixels as category 1. Although most pixels are in areas of low variability, dynamic ocean regions with pronounced SST fronts are regions of high interest. To remedy the problem, pixels that fail the category 1 field test are not directly classified in category 2 and 3, but go through additional testing to determine their final category.

For night-time pixels, the additional testing is accomplished with the inter-comparison test. The test relies on the assumption that, under clear conditions, the difference in temperature values between the two equations should be small. In effect, this is an elaborate way to detect the differing responses of channels 3, 4 and 5 in the presence of clouds. The following decision rule was devised:

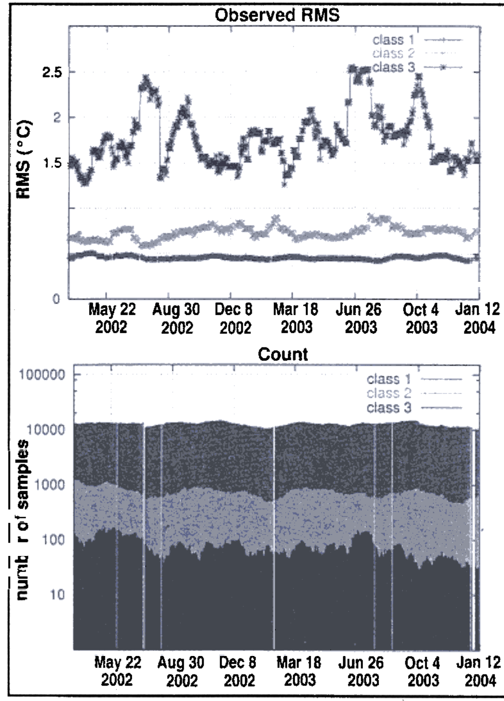
intercomp night<tn ==> category 1
Else category n

where n is either category 2 or 3, depending on the field test results, and tn is a threshold that was determined from the data. The current value for tn, 0.3° C, has remained unchanged since

inception. Day-time pixels in potential category 2 and 3 go through the same testing as night-time pixels, but sun-glint is added as a supplementary test. The decision rule becomes:
intercomp day<td and sunglint<ts ==> category 1
Else category n
where n is again category 2 or 3, depending on the field test results, while td and ts were determined from examining three months of data. The value of td is currently set to 0.3° C, while ts is set to 0.1° C.

Determination of RMS Errors, Monitoring and Updating. The initial values for the RMS errors associated with each category and type of data were derived from the initial three months of matched-up buoy data and the previously selected decision rule thresholds. For day-time, the RMS errors assigned to the categories 1, 2 and 3 were 0.45° C, 0.65° C and 1.5° C, respectively. Values for night-time data were 0.4° C, 0.85° C and 1.5° C. Initially, about 90 percent of the day-time samples were classified as clear, while less than 10 percent were classified as probably clear and the remaining were classified as questionable. About 98 percent and two percent of night-time samples were similarly classified as clear and probably clear, respectively, and the remaining were classified as questionable.

The actual RMS errors for each category and type of data, as well as the number of samples falling in each category, have been monitored daily using the last 30 days of buoys matched to SST data. Results for the combined day-time and night-time data indicate that the repartition of samples among the three categories has remained stable. Likewise, the RMS errors by category have stayed within expected bounds. For category 1, with about 10,000 buoy measurements matched to SST, variability on the order of one hundredth of a degree can be expected. For category 2, with less than 1,000 buoy measurements matched to SST, variability on the order of a tenth of a degree is expected. For category 3, considering the small number of matched samples, the RMS error for 30 days of data can vary by as much 1° C. For this reason,



Observed RMS error: buoy minus MCSST, for each category as a function of time for day-time data (top). Number of matches in each category used to compute RMS errors (bottom).

> *"Results for the combined day-time and night-time data indicate that the repartition of samples among the three categories has remained stable."*

the assigned RMS error for category 3 is not updated and has been kept at 1.5° C, which on average appears acceptable. On the other hand, the assigned RMS errors for categories 1 and 2 have been periodically updated to reflect observed trends.

Conclusions

In this paper, we have presented a method to add quantitative estimates of reliability to every MCSST sample operationally generated at NAVOCEANO. Since the reliability estimate capability was added to the processing stream, thresholds for the various decision rules have not needed updating, while the assigned RMS error values (reliability estimates) have only required minor adjustments. Thus, the current scheme appears to be robust and low-maintenance, both attributes being major requirements in an operational environment. Future work may include expanding the assignment of reliability estimates to samples that are currently discarded. This would allow end-users to select the data according to their actual needs.

Recently, we have examined model winds and aerosol forecast data to contribute to the reliability scheme. It may also be possible to improve the quality of the reliability estimates by thoroughly investigating the correlation between several satellite-derived measurements and temporal and spatial information.

References

For a full list of reference, please contact author Dr. Jean-François Cayula at j.cayula@ieee.org. /st/

Dr. Jean-François Cayula started to work with satellite-derived oceanographic data at the University of Rhode Island, where he received both his M.S. and Ph.D. in electrical engineering. Since 1994, he has been with Planning Systems Inc. supporting several projects for the Naval Research Laboratory and the Naval Oceanographic Office.

Doug May is the Data Division director of the Oceanography Department at the Naval Oceanographic Office. He has over 20 years' experience in the receipt, processing and dissemination of near-real-time oceanographic data from satellites and automated in-situ *sensors.*

Bruce McKenzie is an oceanographer with the Naval Oceanographic Office and has worked on operational SST production since 1991. He received his B.S. degree in oceanography from the University of Washington.

Dan Olszewski has been an oceanographer with the Naval Oceanographic Office working with the collection and processing of remotely sensed data since 1986. He has specializesin the production of satellite-derived multi-channel sea surface temperature retrievals.

Keith Willis is a computer scientist with the Naval Oceanographic Office. He has provided software support for Navy satellite processing for more than 10 years.