P4.22 GEOSTATIONARY SEA SURFACE TEMPERATURE PRODUCTS (CURRENT AND FUTURE)

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1. INTRODUCTION

The National Oceanic and Atmospheric Administration's Office of Satellite Data Processing and Distribution are generating operational sea surface temperature (SST) retrievals from the Geostationary Operational Environmental Satellite (GOES) 9/10 and 12 satellite imagers. They are situated at longitude 154.5^{o} E, 135^{o} W and 75 ^{o} W, respectively, thus allowing the acquisition of high-temporal-resolution SST retrievals from 110^{o} E to 330^{o} E (i.e. 30^{o} W). Combined with data from the European Meteosat Second Generation (MSG) series of satellites, the Japanese Multi-functional Transfer Satellite-1 Replacement (MTSAT-1R) and the Chinese Fengyun-2C (FY2C), we can now determine the diurnal cycle of SST throughout most of the world's oceans. This is an important capability for the generation of a new global high-resolution SST analysis that combines polar and geostationary observations.

A new cloud masking methodology based on a probabilistic (Bayesian) approach has been implemented for improved retrieval accuracy. This new GOES SST Bayesian algorithm provides each SST retrieval with an estimate of the probability of cloud contamination. This indicates the confidence level of the cloud detection for the retrieval, which can be related to retrieval accuracy.

The GOES-SST products generated from these algorithms include hourly regional sectors and 3-hourly hemispheric imagery, 24 hour merged composites and the new combined POES/GOES 10-km resolution SST analysis. Other GOES-SST related activities that are ongoing include the reprocessing of GOES Variable (GVAR) data back to 1994 (i.e. GOES-8) and Risk Reduction studies for the upcoming GOES-R program.

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2. GOES SEA SURFACE TEMPERATURE (SST) ALGORITHMS

The NOAA Office of Satellite Data processing and Distribution is generating sea surface temperature (SST) retrievals on an operational basis from the GOES-9, 10 and 12 satellite imagers. In addition, SST retrievals will be generated operationally from MTSAT-1R (replacing GOES-9 by November 15, 2005) and MSG. FY2C SST data will soon be generated experimentally. The algorithm retrieval schemes are based on Radiative Transfer Modeling (RTM), generating skin temperatures not bulk temperatures. SST retrievals are available at high-temporal resolution from 30 degrees west to 110 degrees east. Combined with data from the Meteosat Second Generation Scanning Enhanced Visible Infrared Imager (MSG–SEVIRI) instrument, there is now the capability to determine the diurnal cycle of SST throughout most of the world's oceans. This is an important step in the production of a global high- resolution SST analysis that combines polar and geostationary observations.

The GOES-12 satellite imager has only two channels (3.9 and 11 μm) available to generate SSTs (Tables 1 and 2). The former channel is difficult to use during the day because of solar contributions to the signal that derive from surface reflection and atmospheric scattering. The current scheme for GOES-12 consists of (1) screening out areas of significant sun glint prior to the application of a daytime retrieval that applies a solar correction to the 3.9 μm channel by assuming a typical aerosol loading and accounting for variability in sun-pixel-satellite geometry; (2) a new cloud masking methodology based on a probabilistic (Bayesian) approach to detection using thermal infrared radiances estimated from the OPTRAN model together with a spatial variance predictor. An impending improvement will be the use of actual aerosol estimates in the 3.9 μm radiance adjustment. The current GOES-

12 SST retrievals are comparable in accuracy to those from GOES-9 and 10.

The GOES-SST products generated from these algorithms include regional hourly and 3-hourly hemispheric imagery, 24 hour merged composites and an experimental combined POES/GOES 10-km resolution SST analysis that is now moving into the pre-operational phase. Future plans include generating a merged GOES data product.

Since the operational implementation of the geostationary sea surface temperature product (December 2000, developed by the University of Wisconsin) (Wu et al., 1999), studies have been conducted to analyze and improve the processing methodology. The Office of Research and Applications (ORA) Oceanic Research and Applications Division (ORAD), in collaboration with the University of Edinburgh, identified some improvements, which were implemented in December 2001 and also developed a GOES-M-Q algorithm for implementation on April 1, 2003 with the launch of GOES-12.

Table 1 - *Imager Channels on the GOES-9/10/11Satellites*

Channels	Wavelength (µm)	Resolution
1 (visible)	0.52-0.72	1 km
2 (infrared)	3.78-4.03	4 km
3 (infrared)	6.47-7.02	4 km
4 (infrared)	10.2-11.2	4 km
5 (infrared)	11.5-12.5	4 km

Table 2- *Imager Channels on the GOES-12/N-Q Satellites*

Channels	Wavelength (µm)	Resolution
1 (visible)	0.52-0.72	1 km
2 (infrared)	3.78-4.03	4 km
3 (infrared)	6.47-7.02	4 km
4 (infrared)	10.2-11.2	4 km
5 (infrared)	13.0-13.7	4 km

The Radiative transfer model methodology to generate the current operational GOES-SST retrievals from the GOES-9/10 algorithm improvements and the GOES-12 algorithm development was performed at the University Of Edinburgh Department Of Meteorology in collaboration with NOAA/NESDIS/ORA/ORAD. University of Edinburgh transferred the algorithm software code to the NESDIS Office of Satellite Data Processing and Distribution and assisted in the operational implementation of the code. Retrieval improvements are ongoing.

2.1 *GOES-Imager SST Retrieval Algorithms*

Radiative-transfer-based SST retrieval algorithms are used to generate the GOES-9/10/12 SST retrievals. The form of the current GOES operational SST equation is:

$$SST = a_0 + a_0^{'}S + \sum_i \left(a_i + a_i^{'}S\right)T_i$$

where i is GOES-Imager channel number (2, 4, 5),
$S = sec$ (satellite zenith angle) – 1 and T_i is channel brightness temperature in kelvin.

Coefficients (for kelvin brightness temperatures)
a_0, a_0‘, a_2, a_2‘, a_4, a_4‘, a_5, a_5‘

GOES-9 (day)

-12.98, -8.50, 0.0, 0.0, 3.55541, 0.31219, -2.51366, -0.27704

GOES-9 (night)

-3.56, -2.94, 0.94366, 0.1372, 0.54463, 0.16887, -0.46992, -0.16512

GOES-10 (day)

-5.99, -12.40, 0.0, 0.0, 2.676, 0.588, -1.652, -0.542

GOES-10 (night)

-0.64, -3.06, 0.940, -0.067, 0.402, 0.482, -0.331, -0.401

GOES-12 (day and night)

-2.10, -1.15, 1.177, 0.073, -0.162, -0.069, 0.0, 0.0

(Coefficients for channel 5 are zero because channel 5 (13.3 µm) is not used.) The validation results are presented in section 3.

As shown in Table 2, channel 5 of the Imager on the GOES-12 platform is centered at 13.3 microns (*i.e.* is primarily sensitive to temperatures in the low-to-mid troposphere, rather than the surface) and is therefore not used in the SST retrieval. While SSTs can still be retrieved at night using the 3.9 and 11 micron channels (2 and 4), daytime retrievals are complicated by the contribution of reflected and scattered solar radiation to the channel 2 brightness temperature. Three extra steps are performed: *i)* the region affected by sun glint is estimated using NCEP model winds, the Cox and Munk (1954) slope distribution and the satellite-solar

geometry; *ii)* the clear-sky scattered solar radiation contribution is estimated for a typical value of aerosol optical depth; *iii)* channel 2 brightness temperatures are adjusted to compensate for the solar contributions estimated in *i)* and *ii)*, with the exception that sun glint corrections >1 deg. K are flagged as insufficiently reliable to be used for SST retrieval. SSTs are retrieved for the remaining clear-sky pixels using the adjusted channel 2 brightness temperatures along with the channel 4 data, using the same retrieval equation form described above.

2.2 *Bayesian Cloud Mask*

Although the current cloud detection scheme is based on a series of threshold tests, we are in the process of transitioning a new probability-based cloud mask into the operational processing. As already described in the introduction to section 2, the new methodology applies Bayes' theorem to estimate the probability of a particular pixel being clear of cloud, given the satellite-observed brightness temperatures, a measure of local texture, and channel brightness temperatures calculated for the given location and view angle using NCEP GFS surface and upper air data and the OPTRAN fast radiative transfer model. The method is described in detail in a paper by Merchant *et al.* (2005).

3. VALIDATION METHODOLOGY

NOAA/NESDIS Office of Research and Applications generates a matchup data base for validation of the GOES-SST retrieval algorithms. This is important for the maintenance and improvement of the GOES-SST products.

The global drifting buoys and the TOGA TAO moored buoy array are matched with GOES-SST retrievals within one hour and 5 km. The buoys used are extracted by the Climate Prediction Center (CPC), one of the National Weather Service's National Centers for Environmental Prediction (NCEP). The buoys are quality controlled using the Reynolds's Optimum Interpolation Sea Surface Temperature (OISST) Analysis and NCEP Atmospheric Analysis Fields before being matched with the GOES-SST retrievals. Matchup files are stored in the NOAA Satellite Active Archive (SAA) for user access.

An automated validation system has been in place since the inception of the operational GOES-SST retrievals. This system computes the GOES-SST accuracy statistics (daily, weekly, and monthly) from the satellite-buoy matches. The program uses the match up file as an input to calculate the number of matches, maximum bias, mean bias, and standard deviation. The statistical results are continually updated with the latest computing system. The Office of Research and Application's Oceanic Research and Applications Division will establish a development research machine that will run the operational algorithms and the developmental algorithms for GOES-SST with operational GOES data. This will allow better control of the software changes and allow access by the research community.

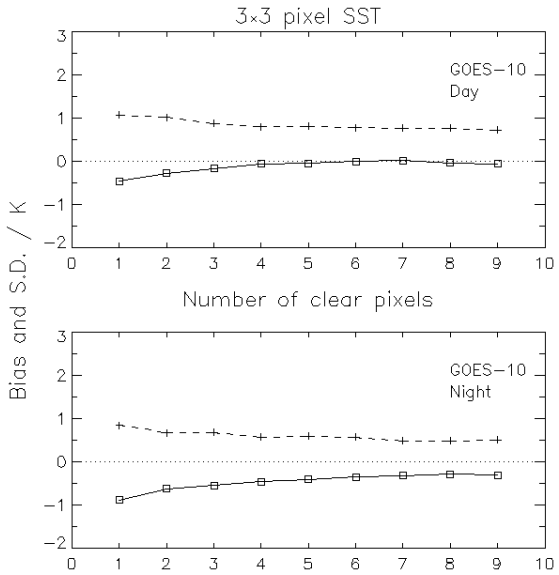

Figure 1. GOES-10 validation results for January – March 2005 showing improvement in bias (solid) and scatter (dashed) with reduction in ambient cloud amount within the 3x3 pixel sample area.

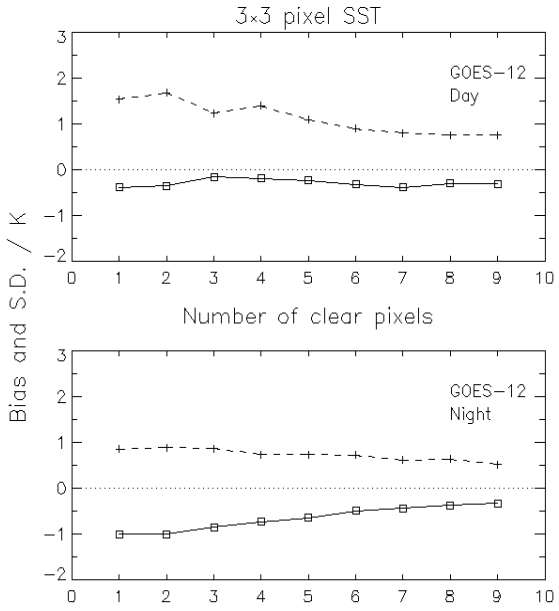

Figure 2. GOES-12 day and night validation results for January-March 2005 (similar to Figure 1).. Note that the nighttime SST retrieval performance is very similar to that of GOES-10. Daytime performance indicates much more scatter in the presence of cloud, but with a less predictable bias behavior, since undetected clouds will artificially raise the radiance in channel 2 due to an increased (but unmodeled) solar contribution.

3.1 *GOES-10/12 Operational SST Validation Results*

Experimental GOES-SST retrievals are validated for a few months to determine whether the bias and the standard deviation are within the range of AVHRR-like operational quality. Once these criteria have been satisfied, then the retrieval algorithms are implemented into operations for product generation. The Office of Satellite Data Processing and Distribution (OSDPD) assumes the responsibility for these products. The suites of products that are operational are described in the following section.

4. GOES SEA SURFACE TEMPERATURE PRODUCTS

The GOES-SST products generated from the operational retrieval algorithms include regional hourly and 3-hourly hemispheric imagery, 24 hour merged composites and a combined POES/GOES 10-km resolution pre-operational SST analysis.

The first type of a product is SST imagery every hour and three hours covering the region between 60□N to 60□S and 30□W to 180□W combined in a single product from GOES-E and GOES-W imagery. SST imagery for GOES-9 (110°E to the dateline) is provided as a separate product. The second type of product includes hourly and three-hourly SST regional imagery.

Imagery includes the NOAA CoastWatch Regions: Northeast, Southeast, Gulf of Mexico, Great Lakes, West Coast, Alaska, and Hawaii. Then there are three 24 hour composite data sets for GOES-10, 12, and a merge 10 and 12. Experimental full disk hourly GOES-9 SST products are generated for the region also, as are 24-hour merged composites and a combined POES/GOES 10-km resolution demonstration SST analysis.

5. FUTURE WORK

Future plans include 1) A GOES-only merged product which will include data from MTSAT-1R, EUMETSAT MSG satellite and FY-2C ; 2) a POES/GOES Blended SST Analysis, to include all the GOES-SST data from all satellites, and a GOES SST reprocessing capability.

These plans include the following tasks: 1) apply the radiative-transfer-based techniques for SST retrieval to new sensors planned for implementation at NESDIS, namely for the SEVIRI sensor on the Meteosat-8 satellite and for MT-SAT; 2) characterize the errors on the GOES-SST data sets and include them in the POES /GOES SST Analysis; and 3) apply the improved GOES-SST algorithms to the recharacterized and recalibrated archive of GOES radiance data (1994-present) being produced by the National Climatic Data Center (NCDC). The result of activity 3) will be a consistent, climate-quality, SST dataset extending back to 1994, which will be made available to the various user communities via the Comprehensive Large Array-data Stewardship System (CLASS) administered by NCDC.

ACKNOWLEDGEMENTS

The authors thank the following individuals for their support of the GOES-SST project: 1) Mark DeMaria for his support through GIMPAP; and 2) Don Gray for his support of the GOES-SST project through PSDI-GOES. Special thanks to Paul Menzel, NESDIS/ORA Chief Scientist, for his encouragement and support of the GOES-SST project. The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official National Oceanic and Atmospheric Administration or U.S. Government position, policy, or decision.

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