P2.4 NOAA'S OPERATIONAL GEOSTATIONARY SEA SURFACE TEMPERATURE PRODUCTS

Eileen Maturi*, Andrew Harris, Nicholas Nalli
NOAA/NESDIS/ORA/ORAD, Washington, D.C.

Chris Merchant and Stuart McCallum
University of Edinburgh, Scotland, U.K.

Ralph Meiggs and Robert Potash
NOAA/NESDIS/OSDPD, Washington, D.C.

1. Introduction

The National Oceanic and Atmospheric Administration (NOAA) maintain two operational Geostationary Operational Environmental Satellites (GOES): GOES-10 and GOES-12. GOES-12 is situated at longitude 75W and GOES-10 at longitude 135W. These satellites provide visible and infrared images over the most of the Western Hemisphere (30W-180W, 45S-60N) every 30 minutes.

The NOAA Office of Satellite Data processing and Distribution are generating sea surface temperature (SST) retrievals on an operational basis from the GOES-10 and 12 satellite imagers. In addition, SST retrievals are being generated experimentally from GOES-9, which is currently on station at 154.5E as cover for the failed GMS-5 platform. The original algorithms based on direct regression have been replaced by retrieval schemes based on radiative transfer modeling (RTM). Including the experimental GOES-9 data, SST retrievals are available at high temporal resolution from 30 degrees west to 100 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 presents a particular challenge because it has only two channels (3.9 and 11 μm) available to generate SSTs (Table 1/2). The former 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 sunglint 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 demonstration phase. Future plans include the merging of data from the Eumetsat MSG satellite and an international GOES Workshop on Global Algorithm Development. In addition, the GOES radiance data back to 1994 (launch of GOES-8) will be processed to SST using the latest techniques. This should furnish a unique and powerful dataset for studying both diurnal warming of the ocean surface and the climatology and evolution of mesoscale features such as fronts and eddies.

Table 1 - *Imager Channels on Satellite GOES-8/9/10/11*

Channels	Band (Wavelengths)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 GOES-12-16*

Channels	Band (Wavelengths) 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)	12.9-13.7	4 km

*Corresponding Author: Eileen Maturi, NOAA/NESDIS E/RA3, Camp Springs, MD 20746-4304, USA; e-mail: Eileen.Maturi@noaa.gov

2. GOES SEA SURFACE TEMPERATURE (SST) ALGORITHMS

On December 19, 2000 NESDIS implemented the operational version of the geostationary sea surface temperature (SST) product developed by University of Wisconsin (Wu et al., 1999). Since that time, studies have been conducted to analyze the performance of this first generation operational GOES SST product, with the intent of determining possible improvements to the processing methodology. The Office of Research and Applications (ORA) Ocean 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 in April1, 2003 with the launch of GOES-12.

The first operational GOES-SST equations for GOES-8/9/10 were generated using a direct regression based technique with buoys. Improvements to the algorithm resulted in the implementation of radiative transfer model methodology to generate the current operational GOES-SST retrievals from GOES-9/10/11/12. Using this technique allows accurate retrievals in regions where there are no in situ observations. Residual calibration errors are removed by application of a one-time adjustment to the offset coefficient in the retrieval equation.
The GOES-10 algorithm improvements and the GOES-12 algorithm development were performed at the University of Edinburgh the Department of Meteorology in collaboration with ORAD. University of Edinburgh transferred the algorithm software code to NESDIS Office of Satellite Data Processing and Distribution and assisted in the operational implementation of the code.

2.1 GOES-10 SST Retrieval Algorithms

Direct regression based algorithms were used to generate the original GOES-10 SST retrievals. With the GOES-SST improvement project initiated in July 2000, radiative transfer-based SST retrieval algorithms were used to generate theGOES-10 SST retrievals. The current GOES operational SST equation form 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.

The implementation of this methodology has substantially improved the SST retrievals which will be discussed in the validation section of this paper.

2.2 GOES-12 SST Algorithms

The GOES-8 satellite was replaced by the GOES-12 on April 1, 2003. The principal challenge for GOES-12 SST is the absence of a traditional SST channel at 12 µm. Of the two channels available, at 3.9 and 11 µm, the former is difficult to use during the day because of sunglint (specular reflection by the sea) and scattering (by atmospheric constituents) of solar radiation. The major issues are: i) accounting for solar contributions to the 3.9 µm channel; ii) detecting and masking areas of sun glint; iii) improving cloud detection and devising tests to compensate for non-availability of those based on 12 µm data. These are primarily concerned with ensuring the availability of daytime GOES SST retrievals because the ability of GOES to sample diurnal variability is one of its key strengths.

To continue the accurate retrieval of SST with the replacement of the 12 µm window channel with an atmospheric emission channel at 13.3 µm, a radiative transfer based retrieval algorithm was developed. In 2002, initial GOES-12 SST algorithms were developed and tested on GOES-8 data. The science implemented in the initial GOES-12 SST algorithm consisted of three modifications. As mentioned above, these are: (i) screening out of the area of significant sun glint by a surface-reflection calculation of the likely impact on 3.9 brightness temperature; (ii) a retrieval scheme that uses only 3.9 and 11 µm data and an adjustment for solar contribution to the 3.9 µm signal; (iii) removal of cloud screening tests that depend on 12 µm brightness temperatures, without additional tests using 13.3 µm being added. Since the initial implementation, the University of Edinburgh have continued to improve the daytime retrieval scheme. The objective was to improve the retrieval scheme so that the global mean correction was replaced by a correction that accounts for variability in sun-pixel-satellite geometry. (Some aspects of variability remain unaccounted for: namely, wind speed, aerosol optical depth variability.) This was approached by a physically based modeling exercise using MODTRAN4 chiefly because of its capability to perform the necessary solar scattering calculations. This also ensures that the radiative transfer results are compatible and can be reproduced using standard radiative transfer codes. MODTRAN results are also compatible with those derived from LBLRTM, which is used to generate the absorption coefficients for the operational fast transmittance model, OPTRAN. MODTRAN4 was also modified to incorporate a bi-directional reflectance

Table 3. Retrieval coefficients for GOES-10 and 12

G10 – day	-5.99	-12.40	0.0	0.0	2.676	0.588	1.652	-0.542
G10 – night	-0.64	-3.06	0.940	-0.067	0.402	0.482	-0.331	-0.401
G12 (day & night)	−2.10	1.1474	1.177	−0.162	0.073	−0.069	0.0	0.0

distribution function (BRDF) for the ocean surface as a function of wind speed, based on the well-known Cox-Munk wave facet slope distribution. The upgraded retrieval scheme was available in October 2002. Use of MODTRAN4 also underpinned the development of new cloud screening for GOES10/11/12. A final processing scheme using a new Bayesian cloud screening approach was implemented in parallel with the operational GOES–SST processing in September 2003 and is destined for operational implementation in December 2003, pending successful validation.

The GOES-12 retrieval coefficients are the same for day and night (see table 3), with the terms for channel 5 (13.3 µm) being zero . The daytime channel 2 (3.9 µm) brightness temperatures are adjusted for solar contribution prior to application of this retrieval equation. The validation results are presented in the next section.

3. GOES SEA SURFACE TEMPERATURE VALIDATION

ORA generate 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 National Centers for Environmental Prediction (NCEP). These buoys are quality controlled using the Reynolds OISST Analysis and NCEP Atmospheric Analysis Fields before being match 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 statistics (daily, weekly, and monthly). 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 posted on the NESDIS/ORA/ORAD Web site: http://orbit35i.nesdis.noaa.gov/orad/eil/goes_sst_val.html which is continually updated with the latest statistics. In addition, the current algorithms are posted on this web site, along with the metadata explaining the temperature conversion from counts.

ORAD are in the process of setting up a development research machine that will run both the operational and developmental algorithms for GOES-SST with operational GOES data. This will allow better control of the software changes and allow access to the research community.

3.1 GOES- 10/12 OPERATIONAL SEA SURFACE TEMPERATURE VALIDATION RESULTS

Statistics generated from the Matchup data base for GOES-10/12 (1 April 1- 6 Nov) after Quality Control of the
Buoys. The standard deviation varies between .7 and .9

GOES-12 Type	**#**	***Mean***	***SD***	***RSD***	***50%***	***Min***	***Max***
Day/Night	2448	-0.5	0.77	0.64	-0.47	-5.5	5.9
Day	1165	-0.6	0.81	0.62	-0.53	-3.8	5.9
Night	1283	-0.5	0.74	0.63	-0.40	-5.5	2.3

GOES-10 Type	**#**	**Mean**	***SD***	***RSD***	***50%***	***Min***	***Max***
Day/Night	610	-0.3	0.80	0.73	-0.29	-4.0	1.9
Day	374	-0.5	0.91	0.81	-0.50	-4.0	1.9
Night	236	-0.1	0.51	0.55	-0.08	-1.6	0.9

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 criterions have been satisfied then the retrieval algorithms are implemented into operations for product generation. The Office of Satellite Data Processing and Distribution (OSDPD) assume 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 demonstration SST analysis.

The first is SST imagery every three hours covering the region between (60°N to 45°S and 30°W to 180°W). The second is hourly and three-hourly SST regional imagery including the CoastWatch Regions: Northeast, Southeast, Gulf of Mexico, Great Lakes, West Coast, Alaska, and Hawaii. There are three 24 hour composite data sets for GOES-10, 12, and a merged 10/12. Experimental full disk hourly GOES-9 SST products are also generated for the region centered at 154°E. 24 hour merged composites and a combined POES/GOES 10-km resolution demonstration SST analysis.

5. FUTURE WORK

Future plans include the merging of data from the EUMETSAT MSG satellite and an international GOES Workshop on Global Algorithm Development and a GOES SST reprocessing capability.

The future work involves the following tasks: 1) Apply the radiative-transfer based cloud detection and retrieval techniques to new sensors planned for ingest at NESDIS, namely for the SEVIRI sensor on the MSG satellite and for MT-SAT; 2) Host an international GOES Workshop; and 3) Apply the improved GOES-SST processing to the recharacterized and recalibrated archive of GOES radiance data being produced by NCDC (1994- present). The result will be a consistent climate-quality SST dataset extending back to 1994, which will be made available to the various user communities via the GOES Active Archive being set up by NCDC.

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