P5.16 GEOSTATIONARY SEA SURFACE TEMPERATURE PRODUCT VALIDATION AND METHODOLOGY

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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 GOES-9, 10 and 12 satellite imagers. The direct regression based algorithms have been replaced by retrieval schemes based on radiative transfer modeling (RTM). The satellites are situated at longitudes 155 E, 135 W and 75 W respectively, thus allowing the acquisition of high temporal SST retrievals from 30 degrees west to 100 degrees east. Combined with data from the Meteosat Second Generation (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) a new cloud masking methodology based on a probabilistic (Bayesian) approach to detection by comparing thermal infrared and visible data with prior estimates clear-sky values derived from fast radiative transfer calculations using NWP data as input; (2) screening of areas of significant sunglint; and (3) adjustment of the 3.9 µm brightness temperature for solar contamination (from surface and atmospheric scattering) prior to SST retrieval. Early validation results indicate that daytime 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 a combined POES/GOES 10-km resolution demonstration SST analysis. Future plans include the merging of data from the EUMETSAT MSG satellite and an International Geostationary SST Workshop on Global Algorithm Development.

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

Channels	Band (Wavelengths)Φm	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) Φm	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

2. GOES SEA SURFACE TEMPERATURE (SST) ALGORITHMS

The first operational GOES-SST equations for GOES-8/9/10 were generated using a direct regression based technique with buoys (Wu, et al). 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

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

GOES-12 SST algorithms have been operational since June 2003. The absence of the 12 μm channel for GOES-12 SST requires the use of the 3.9 μm channel during the day. This channel is affected by sunglint (specular reflection by the sea) and scattering (by atmospheric constituents) of solar radiation. A methodology has been developed by the University of Edinburgh in conjunction with ORAD to: 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) improving cloud detection by applying a probabilistic Bayesian cloud masking methodology. 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.

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

Some aspects of variability remain unaccounted for: namely, wind speed, aerosol optical depth variability. A physically based operational fast transmittance model, OPTRAN is being applied.

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.

2.3 GOES-9 SST Retrieval Algorithms

Prior to 22 May 2003, the Geostationary Meteorological Satellite (GMS-5) operated by the Japan Meteorological Agency (JMA) provided meteorological data over the Asia-Pacific Region. GMS-5 was the main source of satellite data over the Australian region for the forecast and warning system of the Commonwealth Bureau of Meteorology. However, due to technical problems with the main imaging instrument on GMS-5, the Geostationary Operational Environmental Satellite (GOES)-9 took over as a backup in May 2003.

GMS-5 was due to be replaced by a satellite called MTSAT in November 1999; however the launch vehicle for MTSAT failed and the satellite was lost. Significant efforts to extend the usable life of GMS-5 were implemented by JMA in July 2001, so that it operated for more than 3 years beyond its design life.

Through a joint effort between JMA and USA's National Oceanic & Atmospheric Administration (NOAA) GOES-9 was moved over the Western Pacific to provide images in place of the GMS-5 until its replacement is launched. The replacement is a new Japanese satellite called the Multi-Functional Transport Satellite (MTSAT-1R), which is expected to become operational in late 2004 or 2005. GOES-9 is located at longitude 155 degrees east and is now the primary source of geostationary satellite data for the Asia-Pacific Region including Australia.

GOES-9 sea surface temperatures have been generated since October 2003. The same algorithm used to generate GOES-10 sea surface temperatures is being applied to GOES-9 data. Sea surface temperatures currently being generated by GOES-9 over the Asian Pacific Region and Australia will continue to be generated over the same region when MT-SAT is launched and operational.

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.

ORAD has 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-9 EXPERIMENTAL SEA SURFACE TEMPERATURE VALIDATION RESULTS

Figure 1 shows the GOES-9 Day/Night scatter plots of Satellite – Buoy SST versus Buoy - T11 for January through March 2004. There appears to be a slight trend of overcorrecting at low atmospheric corrections (i.e. low values of Buoy SST - T11) and under correcting at high atmospheric corrections. This implies that some adjustment of the radiative transfer is required. The other thing to note is that the nighttime results are much better than the daytime.

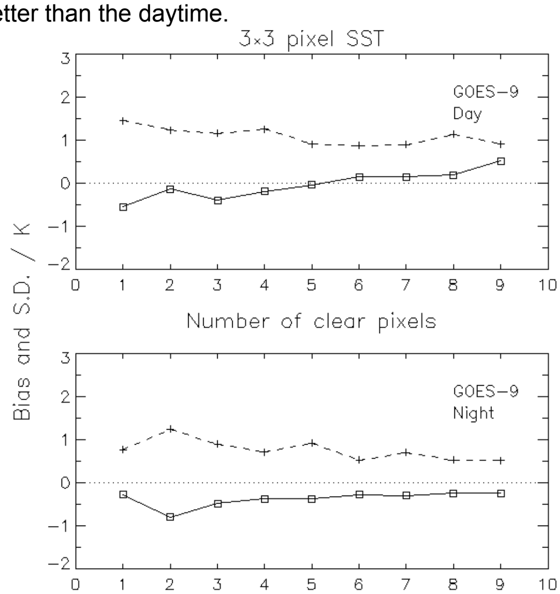

Figure 1. GOES-9 Day/Night scatter plots of Satellite - Buoy SST versus Buoy - T11

Figure 2 shows GOES-9 Day/Night line plots of Bias and S.D. vs. number of clear pixels in the 3x3 validation box. Note that both day and night show improved bias and S.D. with increasing number of clear pixels. The nighttime trends are about 0.3 K cold with a S.D. of about 0.5 K when all 9 pixels are clear.

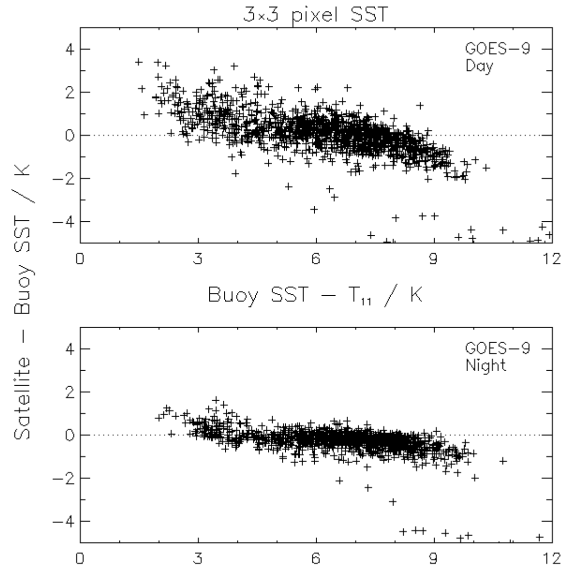

Figure 2. GOES-9 Day/Night line plots of Bias and S.D. vs. number of clear pixels in the 3x3 validation box.

Another thing to remember is that, since these are RTM-based algorithms, we expect them to be biased a little cold at night and a little warm in the daytime. The daytime S.D. is higher for 2 reasons: 1) there are only 2 channels (split-window) to perform the SST retrieval; and 2) the variability of the diurnal thermocline is greater than that of the nighttime skin effect. One final thing to note is that it is possible that the rise in warm bias when all 9 pixels are clear may be due to the fact that such cases are more likely to be in completely cloud-free areas and thus experience greater diurnal warming.

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

Statistics generated from the Matchup data base for GOES-10/12 (January through March 2004) after Quality Control of the Buoys. The standard deviation varies between 0.5 and 0.6 K.

The validation results for GOES-10 and GOES-12 are shown in figures 3 through 6. The results for GOES-10 are better than those for GOES-9 that were shown earlier. There are many more matchups in these datasets, probably because the validation for GOES-9 was a bit intermittent. There is still a trend to cold bias with larger atmospheric correction in GOES-10 for both day and night. Another possible reason why GOES-10 is better (apart from it having been newer and never out of

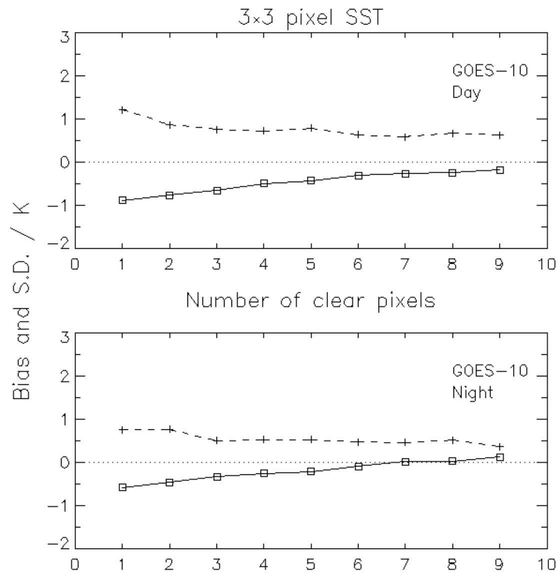

Figure 3. GOES-10 Day/Night scatter plots of Satellite - Buoy SST versus Buoy - T11

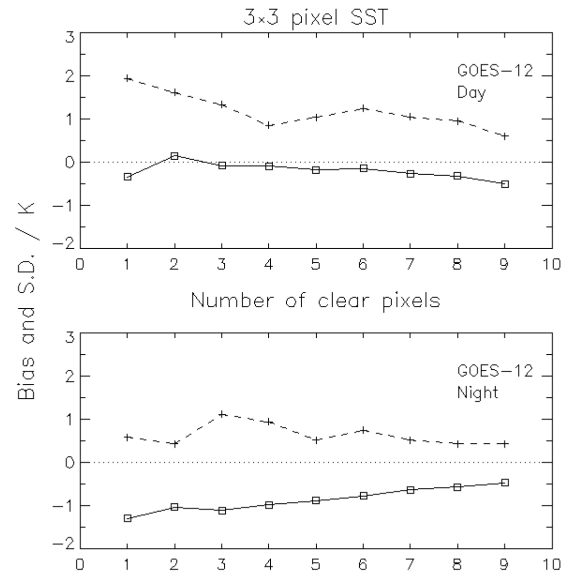

Figure 5. GOES-12 Day/Night scatter plots of Satellite - Buoy SST versus Buoy - T11

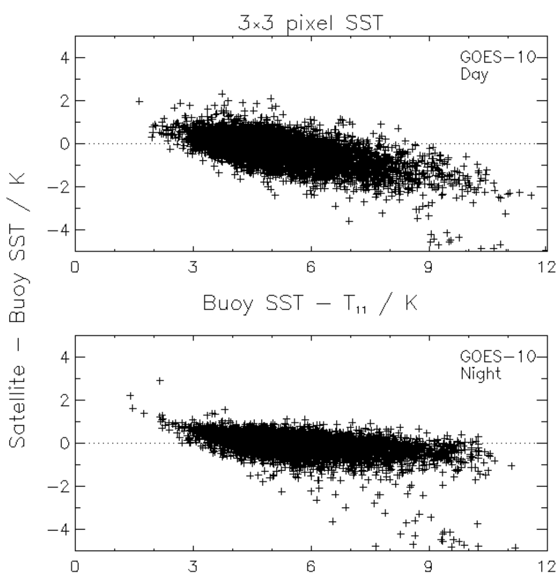

Figure 4. GOES-10 Day/Night line plots of Bias and S.D. vs. number of clear pixels in the 3x3 validation box.

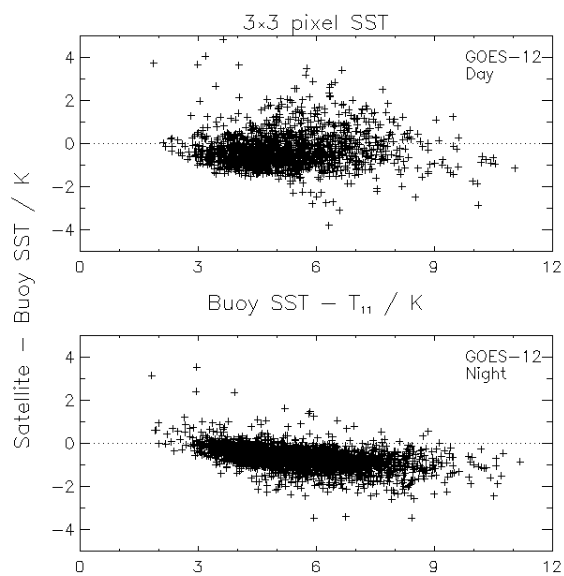

Figure 6. GOES-12 Day/Night line plots of Bias and S.D. vs. number of clear pixels in the 3x3 validation box.

operations) is that it's in the eastern Pacific and there's less water vapor, so the SST retrieval is a bit easier. Also, the diurnal warming tends to be less in the eastern Pacific than in the Warm Pool. Note that every scatter plot apart from GOES-12 daytime has mostly cold outliers - meaning that undetected cloud is the main cause. The reason why the GOES-12 daytime also has warm outliers is because undetected cloud can produce a warm SST with this satellite since we have to use the 3.9 micron data, which will reflect solar radiation from an

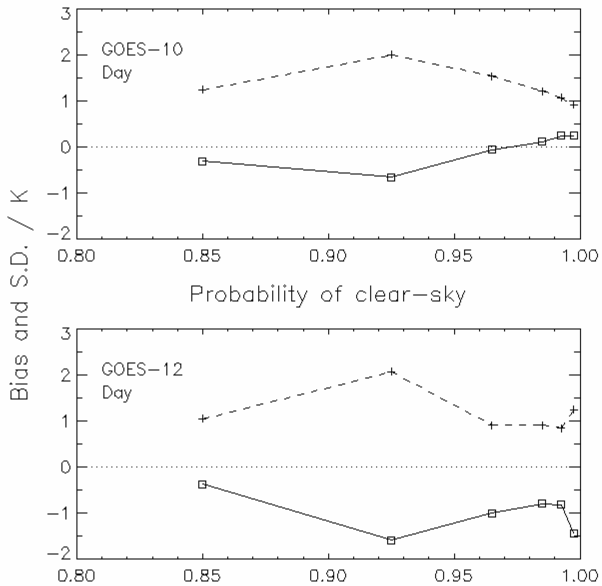

Figure 7. This shows the trend of SST retrieval bias and standard deviation for the new probabilistic cloud screening. Clear-sky and cloudy probabilities are determined by application of Bayes' theorem to joint probability distributions of spectral and textural measures. There is relatively poor sampling below a probability of 0.9 and the very highest probability bin in GOES-12 has been contaminated by erroneous values during the validation process.

undetected cloud. Note also that we applied an empirical correction to the GOES-10 RTM nighttime retrieval last year which is probably no longer needed because the midnight calibration effect correction was introduced in January this year. Both 10 and 12 are tending to ~0.5 K S.D. with all 9 pixels clear at nighttime. There is definitely some RTM adjustment required for GOES-10 daytime (split-window) channels. Still, the daytime S.D. for GOES-10 is about 0.6 K when the 3x3 box is mostly clear.

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. Bayesian Cloud Screening

In December 2003, a Bayesian Cloud Mask was implemented to run in parallel with the operational equations. Limited validation on the Bayesian Cloud Mask has been performed (Figure 7). The Bayesian Cloud Mask is expected to be implemented into operations by September 2004.

The Bayesian cloud detection methodology makes use of physical radiative transfer modeling and empirical priors for cloudy probability distribution functions, together with textural information, in a simultaneous manner to derive an estimate of clear-sky probability on a pixel-by-pixel basis. NCEP upper air fields are used to initialize the fast radiative transfer model (now standardized as Optran) operational SSTs still require a cloud/no-cloud mask and this has been obtained by thresholding the probability at 0.99 in the first instance. Figure 7 shows some initial validation results for GOES10 and GOES-12. Note that, as might be expected, the retrieval errors are a function of clear-sky probability, giving rise to the prospect of individual error estimates of cloud-screening effectiveness for each pixel which can be passed on to the analysis system.

5. GOES SEA SURFACE TEMPERATURE PRODUCTS

The GOES-SST products generated from the operational retrieval algorithms include regional hourly and 3-hourly hemispheric imagery. In addition, twenty-four hour merged composites.

The first is SST imagery every three hours covering the region between (60N to 45S and 30W to 180W). 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. Full disk hourly GOES-9 SST products are also generated for the region centered at 155E and twenty-four hour merged composites.

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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