The IMAPP MODIS Sea Surface Temperature Algorithm

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1 INTRODUCTION

This document describes the implementation of the MODIS Sea Surface Temperature (SST) code within the International MODIS AIRS Processing Package (IMAPP). The operational MODIS SST code, developed at the University of Miami, is referred to herein as PGE10. The IMAPP MODIS SST code is referred to simply as IMAPP.

In Section 2 the pertinent expressions for SST are transcribed from the MODIS SST Algorithm Theoretical Basis Document (ATBD) [1]. The method for computing MODIS band brightness temperatures needed for the SST algorithm is given in Section 3. In Section 4 the IMAPP algorithm is detailed together with the specific coefficient values for Terra and Aqua, night-time and day-time, observations.

A comparison is made between PGE10 and IMAPP retrieved SSTs in Section 5 and with an appropriate ECMWF (European Centre for Medium range Weather Forecasts) analysis field. Finally, brief conclusions and recommendations are presented in Section 6.

2 ATBD DESCRIPTION

The ATBD gives the working definition for the multi-channel sea surface temperature estimate (MCSST) as,

$$T_S = a_0 + a_1 T_1 + a_2 T_2 \qquad , \tag{1}$$

where T_1 and T_2 are window channel brightness temperatures and a_n are empirically derived coefficients.

A non-linear form of the SST (NLSST) is given as,

$$T_S = b_0 + b_1 T_1 + b_2 (T_1 - T_2) T_{env} + b_3 (1/\mu - 1) \qquad , \tag{2}$$

where T_{env} is an environment temperature and μ is the cosine of the viewing zenith angle.

PGE10 delivers two SSTs, denoted *sst* and *sst*4. According to the MOD28L2 file specification document, *sst* is the SST from MODIS bands 31 and 32 (i.e. the 11/12 μm split window) and *sst*4 is the SST from MODIS bands 22 and 23 (i.e. the 3.9/4.1 μm split window). In addition to these four bands, MOD28QC stores radiances and brightness temperatures for band 20, which is used to estimate T_{env} in the absence of ancillary data. Table 1 lists some characteristics of these MODIS bands.

According to the document entitled "PGE10ProdRules.txt", PGE10 requires NMC processed ancillary data (winds, surface pressure, relative humidity, column water vapor), EP_TOMS ozone, Reynolds optimally interpolated SST (OISST) data and daily predicted ephemeris data. The IMAPP algorithm uses OISST if available (for T_{env}), but otherwise requires no ancillary data inputs.

MODIS Band	Bandwidth (μm)	Radiance @ 300 K ($\mathrm{Wm^{-2}\mu m^{-1}sr^{-1}}$)	NEΔT (K)
20	3.660 - 3.840	0.45	0.05
22	3.929 - 3.989	0.67	0.07
23	4.020 - 4.080	0.79	0.07
31	10.780 - 11.280	9.55	0.05
32	11.770 - 12.270	8.94	0.05

Table 1: MODIS bands used for SST estimation. MODIS band 20 is used to estimated T_{env} in the absence of Reynolds optimally interpolated SST (OISST) data.

3 BRIGHTNESS TEMPERATURE

IMAPP computes brightness temperature, T_b (in K), for MODIS band b, via,

$$T_b = \frac{B^{-1}\left(\widehat{\lambda}_b, L_b\right) - c_b}{d_b} \quad , \tag{3}$$

where $B^{-1}(\widehat{\lambda}_b, L_b)$ is the inverse Planck function for the calibrated (and de-striped [3]) MODIS band radiance, L_b ($\mathsf{Wm^{-2}}\mu\mathsf{m^{-1}sr^{-1}}$), evaluated at central wavelength, $\widehat{\lambda}$. The quantities c_b and d_b provide small adjustments to account for the finite width of each MODIS band.

4 SEA SURFACE TEMPERATURE

IMAPP uses Eqn. (2) for $sst4$ and a slightly modified form for sst [2]. Specifically,

$$\begin{aligned} sst4 &= k_0 + k_1 T_{22} + k_2(T_{22} - T_{23}) + k_3(1/\mu - 1) \quad , \\ sst &= k_0 + k_1 T_{31} + k_2 \langle T_{31} - T_{32} \rangle \; T_{env} + k_3 \langle T_{31} - T_{32} \rangle \, (1/\mu - 1) \quad , \end{aligned} \tag{4}$$

where the k_i are platform (Terra or Aqua) dependent coefficients (Table 2). Note that in Eqn. (4), the T_i are now band brightness temperatures (in Celsius). In PGE10 $\langle T_{31} - T_{32} \rangle$ is an ensemble average over 3×3 cloud-free pixels. In IMAPP pixels are not checked for cloudiness. Also in IMAPP, the spatial average is limited to within a single scan-line and so may be only 2×3 pixels at the scan-line boundaries. The environment temperature T_{env} is $sst4$ for night-time observations or, for day-time observations, either the weekly OISST or T_{20} if the OISST is unavailable.

The $sst4$ product is only accurate for night-time observations. During the day-time $sst4$ computed brightness temperatures are contaminated by reflected solar radiation. The sst algorithm is applicable day and night through the use of day-time and night-time coefficients. To accommodate observations at the margin of night and day, a weighted sst is calculated from the day-time and night-time values using $\langle T_{31} - T_{32} \rangle$ to weight their relative contributions. That is, if $0.5 < \langle T_{31} - T_{32} \rangle < 0.9$, then a weight w is defined as $w = (0.9 - \langle T_{31} - T_{32} \rangle)/0.4$, and,

$$sst = w \times sst_D + (1 - w) \times sst_N \quad , \tag{5}$$

where sst_D and sst_N are the SSTs computed using the day-time and night-time coefficients, respectively.

Fig. 1 shows an example sst image generated by IMAPP. Because no land or cloud mask is applied prior to processing, IMAPP generates an SST for land and cloud pixels as well as cloud-free ocean pixels.

SATELLITE	D/N	ALG.	COEFFICIENTS			
			k_0	k_1	k_2	k_3
Aqua	Day	*sst*	1.152	0.960	0.151	2.021
	Night	*sst*	2.133	0.926	0.125	1.198
	Night	*sst*4	0.987	1.031	0.349	1.766
Terra	Day	*sst*	1.052	0.984	0.130	1.860
	Night	*sst*	1.886	0.938	0.128	1.094
	Night	*sst*4	-0.065	1.034	0.723	0.972

Table 2: NLSST coefficients for IMAPP *sst* and *sst*4 algorithms.

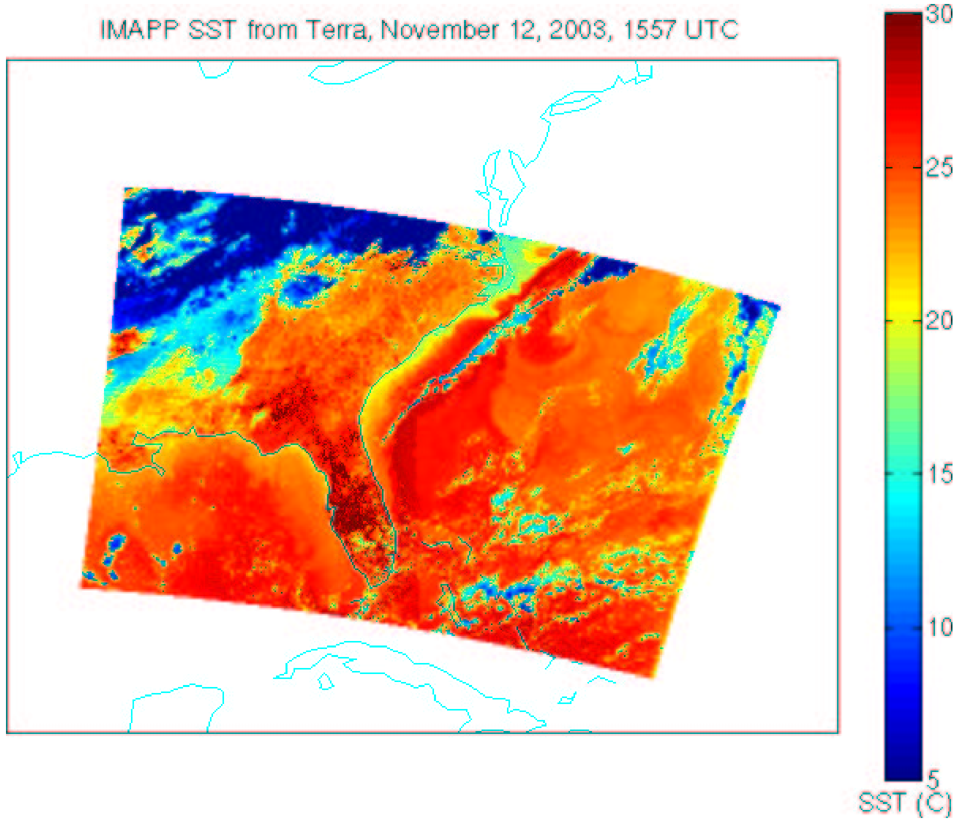

Figure 1: Part of a day-time MODIS Terra overpass down-linked at 15:57 UTC on 12 November, 2003. The image was processed with the IMAPP/*sst* algorithm. As illustrated here, land and cloud pixels are processed along with cloud-free ocean pixels. It is left to the user to mask out these areas if so required.

5 COMPARISON BETWEEN IMAPP AND PGE10

Fig. 2 shows part of a night-time MODIS Terra overpass down-linked at 04:35 UTC on 6 November, 2003. The image was processed with the IMAPP/*sst*4 algorithm (the land area has been masked by a separate process). Histograms show the distribution of the SST differences between IMAPP and PGE10, for both *sst*4 and *sst* algorithms. In the *sst* processing, IMAPP has a $\frac{1}{2}$ deg negative bias compared to PGE10 and a relatively broad distribution. For the *sst*4 processing, the distribution is much narrower and the bias much smaller. Also shown is a comparison of both IMAPP/*sst* and PGE10/*sst* with the ECMWF analysis field for 06:00 UTC. PGE1O shows a small negative bias compared with ECMWF; IMAPP shows a larger negative bias (approx. $\frac{1}{2}$ deg).

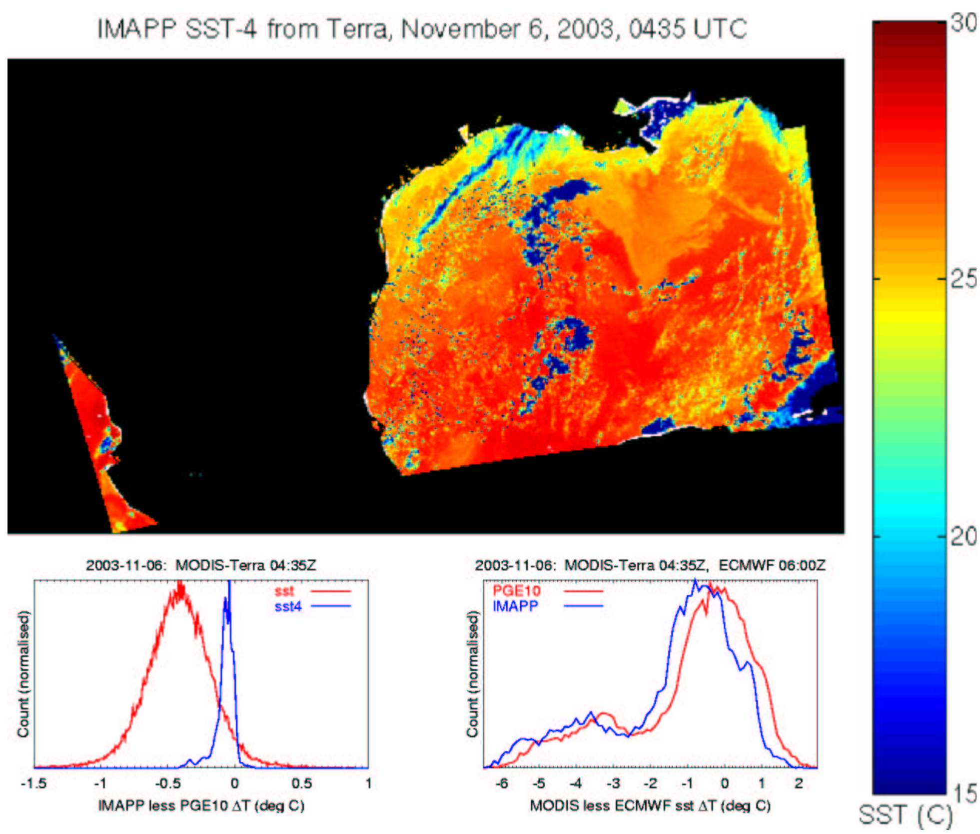

Figure 2: Part of a night-time MODIS Terra overpass down-linked at 04:35 UTC on 6 November, 2003. The image was processed with the IMAPP/*sst*4 algorithm and, for clarity, the land area has been masked by a separate process. The histograms at bottom left show the distribution of the SST differences between IMAPP and PGE10, for both *sst*4 and *sst* algorithms. At bottom right, IMAPP/*sst* and PGE10/*sst* are compared with the ECMWF analysis field at 06:00 UTC.

6 CONCLUSION

The very limited comparison performed in this report indicates that the software is performing sensibly and is now ready for beta testing. The IMAPP algorithm does not promise to deliver the same absolute accuracy as PGE10, but the algorithm is fast and can deliver SST products to direct broadcast users in near real-time with a minimum of ancillary data inputs. It is recommended that IMAPP operate on "de-striped" MODIS radiances to reduce the appearance of artifacts traceable to post-launch changes to the reflectivity of the scan mirrors and to sensitivity changes in individual sensors.

References

[1] Otis B. Brown and Peter J. Minnett, *MODIS Infrared Sea Surface Temperature Algorithm*, Tech. Report ATBD25, University of Miami, Miami, FL 33149-1098, 1999.

[2] Kay Kilpatrick, 2003, Personal communication, 20^{th} October.

[3] M. P. Weinreb, R. Xie, J. H. Lienesch, and D. S. Crosby, *Destriping GOES M image by matching empirical distribution functions*, Remote Sensing of Environment **29** (1989), 185–195.