JP8.1. WEB-BASED GLOBAL QUALITY CONTROL AND MONITORING OF NESDIS AVHRR SST PRODUCTS FOR LONG TERM STABILITY AND CROSS-PLATFORM CONSISTENCY IN NEAR REAL-TIME

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1. INTRODUCTION

Sea surface temperature (SST) products have been operationally generated by NESDIS, since the early 1980s, from the Advanced Very High Resolution Radiometers (AVHRR) onboard NOAA and, recently, MetOp satellites. Ensuring their quality, stability, and cross-platform consistency in near real-time (NRT) is important for many SST applications. SST products are typically validated against collocated *in situ* measurements. Although the number of *in situ* match-ups has increased in recent years, it still requires up to a month to collect enough collocated data points to perform reliable quality control of *in situ* data, and generate trustworthy SST validation statistics. Also, the *in situ* data are sparse and geographically biased, and their quality is often suboptimal and non-uniform as data with different measurement protocols originate from different sensors manufactures, nations, and programs. As a result, the quality of the SST product in remote oceanic areas of the globe may remain uncertain.

To monitor global satellite SST products for quality, stability, and cross-platform consistency in NRT, another approach is complementarily needed that is global in nature. This study explores another approach based on analyses of anomalies in satellite SST (T_S) with respect to global reference SST fields (T_R). Such fields suitable for this type of anomaly analysis could be a blended satellite/*in situ* SST field (*e.g.*, Reynolds *et al.,* 2002; 2007) or an SST climatology field (*e.g.*, Bauer & Robinson, 1985). The underlying assumption is that the probability density function of global anomalies (T_S–T_R) is close to a Gaussian shape (although the distributions of both T_S and T_R are highly asymmetric). Global statistical moments (mean, standard deviation, skewness, and kurtosis) of a Gaussian distribution can thus be used to QC the satellite SSTs and to monitor them for stability and cross-platform consistency. (Note that, the validation against buoys also reports global mean bias and standard deviation, but with respect to *in situ* SST). Robust statistics of global SST anomalies are first used to identify and remove outliers. The moments of the empirical distributions are then trended in time to check the products for long-term stability. Overlaying data from different platforms is subsequently done to check for cross-platform consistency. Additional diagnostics of products for self-consistency are produced by plotting bias *vs.* geophysical variables and by plotting global maps of SST anomalies. The maps and dependencies on the observational and environmental parameters are helpful in identifying persistent anomalous features in the data.

Based on these considerations, the SST Quality Monitor (SQUAM) was designed and implemented, which routinely monitors the AVHRR SST products from NOAA-16, -17, -18, and MetOp-A platforms. The SQUAM is based on a set of statistical self- and cross-consistency checks and conceptually draws on previous case studies (Ignatov *et al.*, 2004; Dash *et al.*, 2007).

This paper employs SQUAM to test SST products generated by the NESDIS Main Unit Task (MUT) heritage system (McClain *et al.*, 1985; Walton, 1988; McClain, 1989). Data from 2004 to the present, from four platforms have been compared against the following SST reference fields: weekly Reynolds-Smith OI.v2 SST (Reynolds *et al.*, 2002), two daily Reynolds OI SSTs (AVHRR-based and AVHRR+AMSR-E based) (Reynolds *et al.*, 2007), RTG low and high resolution (Thiébaux *et al.*, 2003; Gemmill *et al.*, 2007), OSTIA (Stark *et al.*, 2007), ODYSSEA (Autret & Piollé, 2007), and Bauer-Robinson climatology (Bauer & Robinson, 1985). The four satellite products are also evaluated for cross-platform consistency. The new SST product generated by the Advanced Clear-Sky Processor for Oceans (ACSPO) system is also preliminarily evaluated using the same set of reference SSTs, except that ODYSSEA and Bauer-Robinson 1985 SSTs have been excluded and NCEP Global Forecast System (GFS) SST and Pathfinder climatological SSTs (Kilpatrick *et al*., 2001) have been included.

Although the absolute values of the statistical moments of SST anomaly do depend upon a given reference SST, this does not affect their monitoring for cross-platform consistency. Overall, all products show a high degree of stability, except for SST from NOAA-16.

So far, only the products from the MUT heritage system have been extensively analyzed. Comprehensive evaluation of ACSPO (the MUT successor) with more data is currently underway. The SQUAM implementation is based on IDL codes and UNIX scripts and the resulting diagnostics are automatically posted on the web at *www.star.nesdis.noaa.gov/sod/sst/squam*, in near-real time (NRT). This tool can be easily adapted to SST products from other platforms and sensors. Currently, it is being tested on the MSG SEVIRI products (Shabanov *et al.*, 2009). In the future, we also plan to employ it to monitor the SST products produced from NOAA-N'/AVHRR, NPOESS/VIIRS and GOES-R/ABI.

2. SST QUALITY MONITOR (SQUAM) CONCEPT

Within the scope of SQUAM, "SST anomaly", ΔT_S, is defined as the difference between satellite-retrieved SST (T_S) and a global reference SST (T_R), $\Delta T_S = T_S - T_R$. The two datasets were merged using the nearest neighbor approach. All reference SST fields provide near-global and almost gap-free coverage so that there are only a few MUT/ACSPO pixels outside the domains covered by these fields. The satellite SSTs that have no corresponding reference SSTs have been excluded from the analyses. Fig. 1 shows a ΔT_S map for MetOp-A night SSTs with respect to OSTIA daily 0.05°×0.05° SST (Stark *et al.*, 2007).

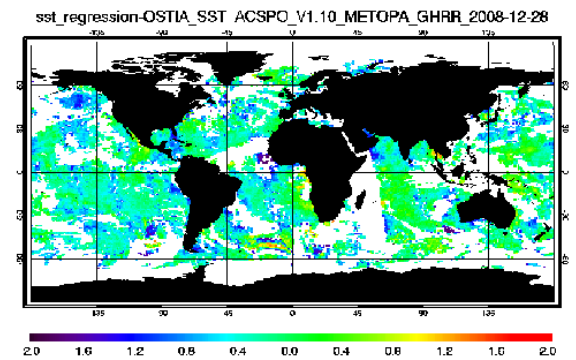
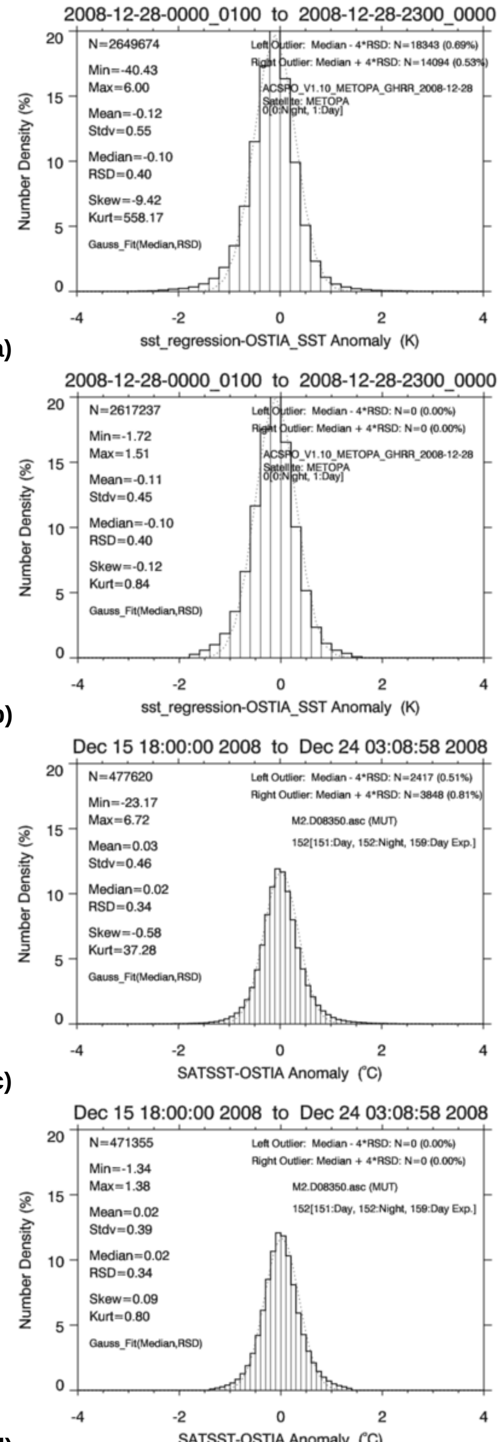


Figure 1: Night MetOp-A SST anomaly (ΔT_S) map on 28 December 2008, from ACSPO, using OSTIA global analysis SST as reference. Data are resampled to 1°×1° spatial resolution for display.

The ΔT_S distributions, similar to shown in Fig. 1 but for different satellites and reference SSTs, are analyzed to measure the proximity to a normal distribution. The first four statistical moments of the distribution are then used for monitoring stability and cross-platform consistency.

The distribution of ΔT_S is expected to be near-Gaussian. Significant deviations from a Gaussian shape are possible in the presence of outliers, which are typically present in the data. Therefore, analyses in SQUAM are performed both before and after removal of outliers. Handling of outliers is based on robust techniques. Full details of outlier handling and in-depth analyses of SQUAM results is reported in Dash *et al*. (2009). The purpose of this document is to introduce the web-concept and present preliminary analyses of SQUAM results.

Example histograms of global night ΔT_S values, for MetOp-A SSTs are shown in Fig. 2. Statistics are annotated on each histogram, *i.e.*, # of Observations (N), minimum, maximum, mean, median, standard deviation (Stdv) and robust Stdv (RSD), skewness, kurtosis, and left and right outliers outside "median ± 4×RSD" range.



(a) (b) (c) (d)

Figure 2: Frequency distributions of global nighttime MetOp-A SST anomalies (against OSTIA SST) for: ACSPO daily SST on 28 December 2008 (a) before outliers' removal, (b) after outlier removal, and MUT SST for 15 December to 24 December, 2008 (c) before outlier removal, and (d) after outlier removal. Statistical parameters, outlier information, and source filenames are also annotated on each histogram.

The statistical moments (before and after outlier removal) and outlier information are subsequently trended as a function of time, separately for day and night, to monitor satellite SST for long-term stability. Also, the time-series of different platforms are overlaid to monitor SST products for cross-platform consistency. These analyses performed with native spatial resolution products are further discussed in Section 5.1. Additional diagnostics also include a gridding of ΔT_S values into a lower resolution and a binning of the mean anomaly as a function of different variables representing retrieval conditions. Examples of these analyses are given in Section 5.2. All the diagnostics are made available in NRT on a dedicated SQUAM website.

3. INPUT DATASET

3.1 *Satellite SST Data*

This study evaluates NESDIS heritage **MUT** SST products from four AVHRR/3 sensors onboard NOAA-16 and -17 (13 July 2004 - present), -18 (16 August 2005 - present), and MetOp-A (24 April 2007 - present) platforms and the newer **ACSPO** products (September 2008 – present) from the same four platforms. A brief description of the MUT products is found in Ignatov *et al.* (2004) and the ACSPO products are currently being documented (*e.g.*, Liang *et al.*, 2009; Petrenko *et al.*, 2009).

3.2 *Reference SST Data*

The reference SST fields used in SQUAM MUT analyses include: weekly Reynolds-Smith OI.v2 SST (Reynolds *et al.*, 2002), two daily Reynolds OI SSTs (AVHRR-based and AVHRR+AMSR-E based) (Reynolds *et al.*, 2007), RTG low and high resolution (Thiébaux *et al.*, 2003; Gemmill *et al.*, 2007), OSTIA (Stark *et al.*, 2007), ODYSSEA (Autret & Piollé, 2007), Bauer-Robinson climatology (Bauer & Robinson, 1985). In the ACSPO analyses, the Bauer-Robinson 1985 climatology was replaced by the Pathfinder climatology (Kilpatrick *et al*., 2001) and ODYSSEA SST by NCEP GFS SST. These data are available free-of-charge *via* various file transfer protocol (*ftp*) sites, and some of them will also be briefly described in Dash *et al.* (2009). Some information is also available at: www.star.nesdis.noaa.gov/sod/sst/squam.

4. SQUAM FLOWCHART

The SQUAM includes two sub-systems that process native (pixel) resolution and gridded data, respectively. The major objective of the pixel-resolution analysis is to identify and remove outliers in the data. Also, stability and cross-platform consistency are checked by plotting anomaly statistics derived from data at native spatial resolution (pixel-level) and an additional diagnostic includes sampling the anomalies to lower resolution and trending against variables representing retrieval conditions (gridded-level).

Fig. 3 shows flow-charts of SQUAM processing for pixel-level data and Fig.4 for gridded-level data. After processing the newly arrived data, statistical parameters stratified by reference state and by day/night flag are appended to the data summary files. Currently, all pixel-level processing is performed both before and after outlier removal, to evaluate the effect of outliers on SST statistics. Gridded-level analyses (maps and dependency plots) are performed after removing outliers. The time-series plots are updated each time new data are processed. Additionally, graphs of global anomaly histograms, maps, and dependencies are animated for visual inspection of data quality. All the diagnostics are made available, in NRT at: http://www.star.nesdis.noaa.gov/sod/sst/squam.

5. SQUAM DIAGNOSTICS

5.1 *Time-series analyses for product stability and cross-platform consistency*

Fig. 5 shows the nighttime time-series of mean SST anomalies against eight reference fields for the MUT heritage processor after removal of outliers. The mean values are slightly larger than the median values (figures not shown) with a difference of a few hundredths of a degree Kelvin. Note that all the reference SSTs are representative of average diurnal bulk SST (except for OSTIA which is a foundation SST). Hence, colder biases are expected for night and warmer biases for day.

The global mean anomalies change smoothly in time, and are close to “zero” for all reference states (except for Bauer-Robinson 1985 climatology, CLISST). Choice of reference state does affect the time series, including trends in SST anomalies and point-to-point noise. However, it is not critical for monitoring cross-platform consistency of the satellite product.

Among the four platforms, SSTs from NOAA -17 and -18 track each other closely, whereas MetOp-A SST is biased systematically high by ~ +0.05 °C. This systematic offset is likely due to incorrect specification of the free-term in the MetOp-A nighttime empirical regression equation. Some unexplained “humps” and “bumps” are occasionally observed in the time-series. *E.g.*, there is a spike in OSTIA SST anomaly in the first quarter of 2007, and a dip in ODYSSEA in the second quarter of 2008. This may indicate some artifacts in these reference SSTs for those specific time periods. NOAA-16 shows anomalous behavior for all four years. NOAA-16 currently flies very close to the terminator, and its AVHRR/3 sensor has experienced problems since September 2003.

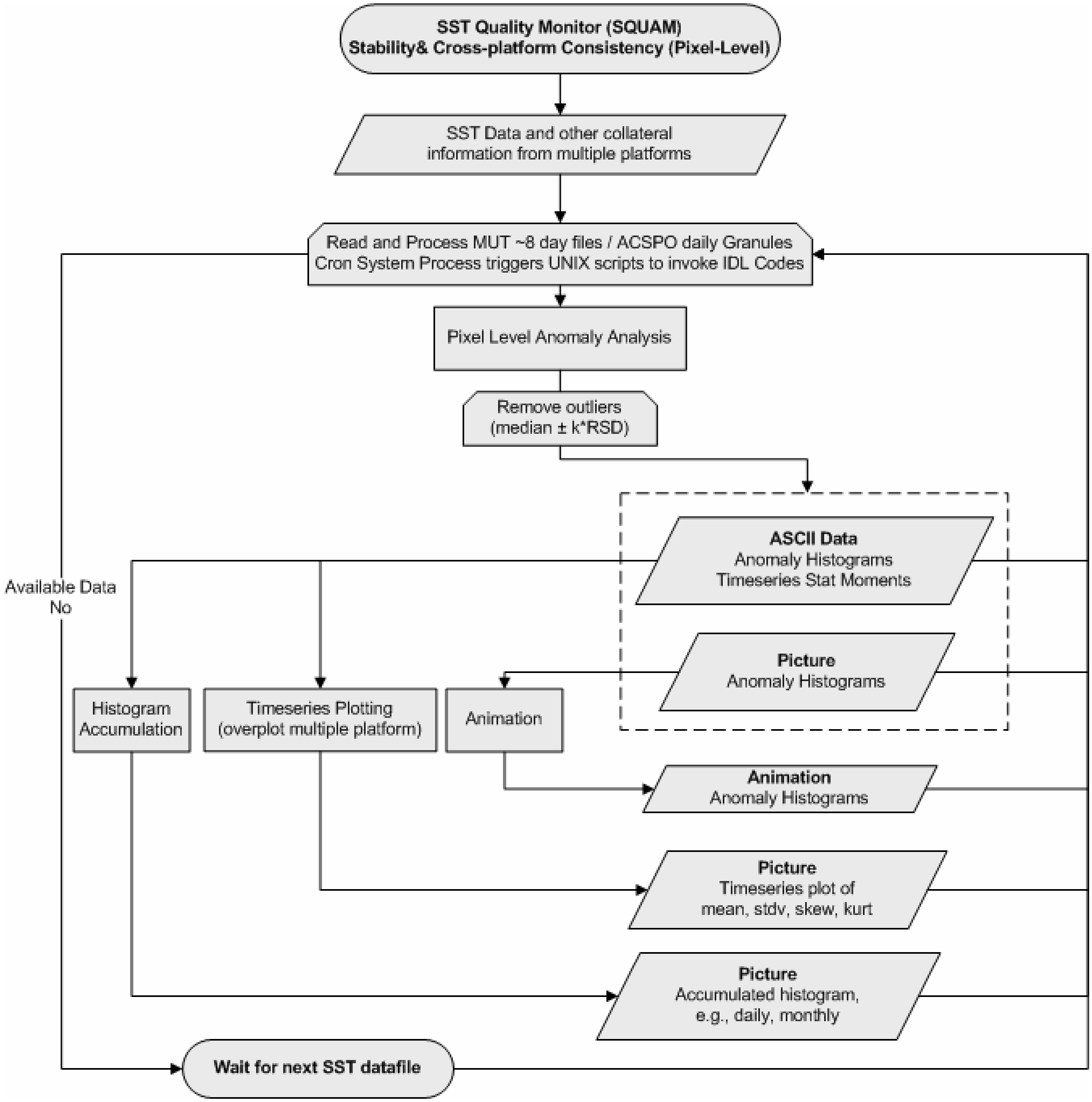


Figure 3: SQUAM Processing Scheme of SST anomaly analyses on native spatial resolution data (pixel-level).

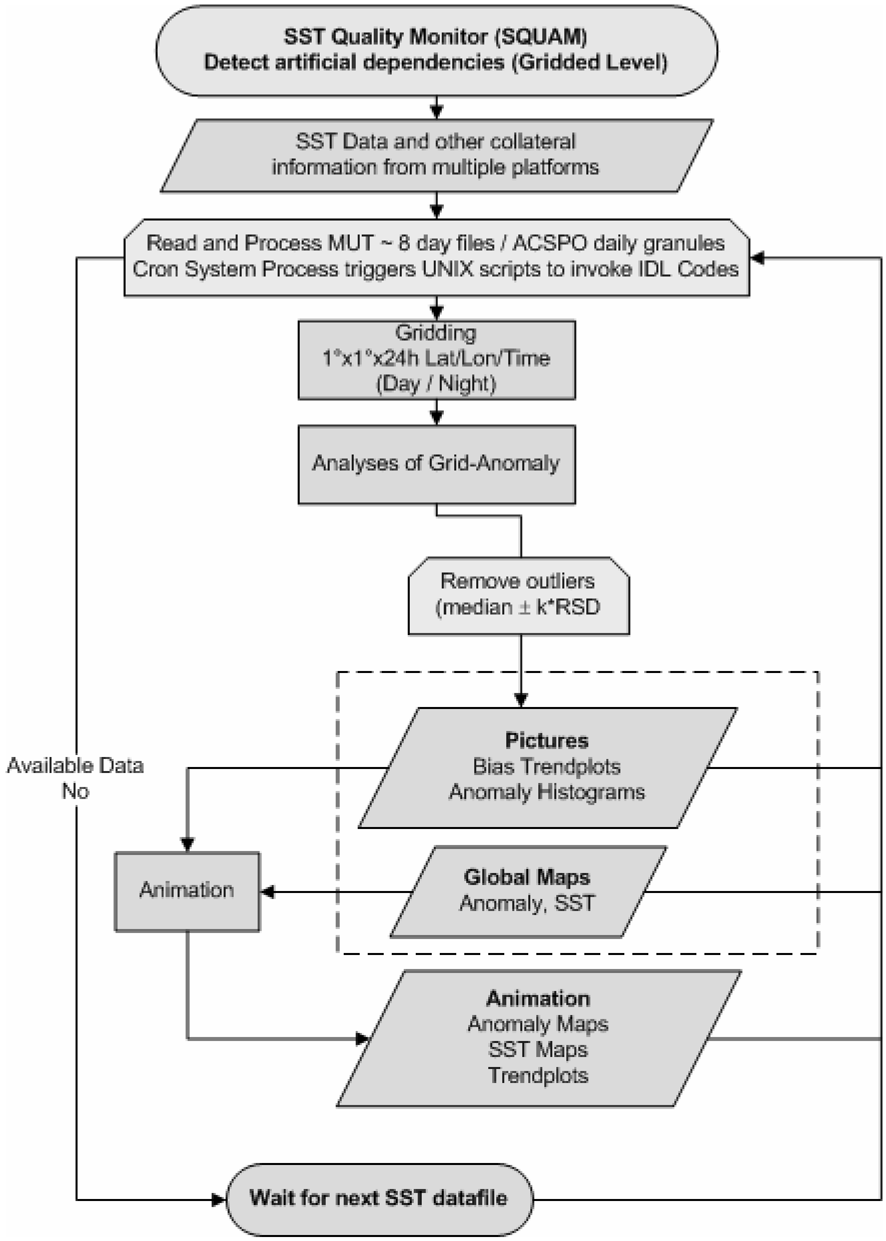


Figure 4: SQUAM Processing Scheme of SST anomaly analyses on resampled data (gridded-level).

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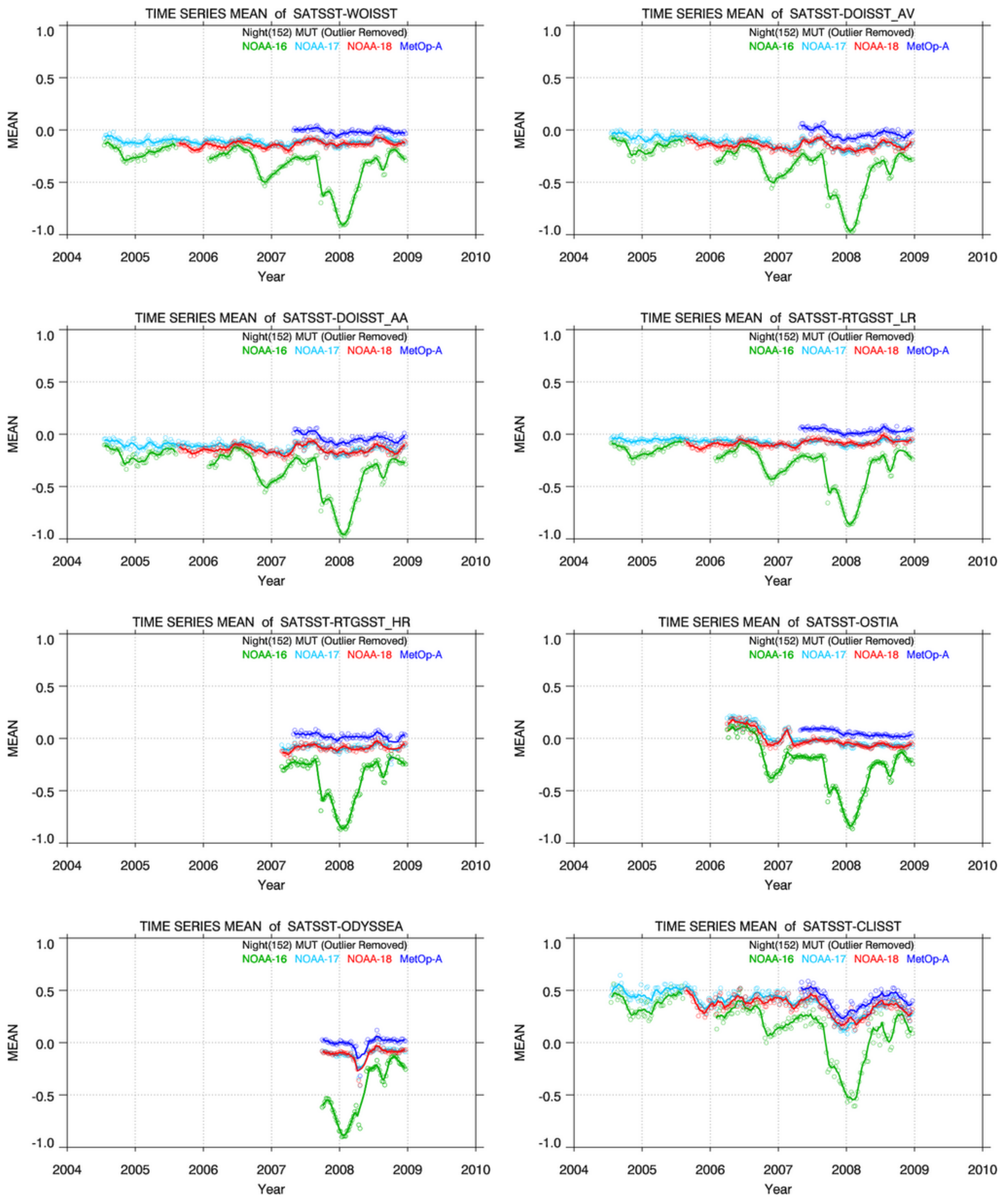

Figure 5: Time-series of nighttime mean MUT SST anomalies from NOAA-16, -17, -18, & MetOp-A against eight global reference SSTs, after outlier removal. Each data point represents 8 days of global data (which corresponds to ~500000 observations). These time series are also available at: *http://www.star.nesdis.noaa.gov/sod/sst/squam/MUT*. [SATSST: satellite SST, WOISST: weekly Reynolds, DOISST_AV: daily AVHRR based Reynolds SST, DOISST_AA: daily AHVRR+AMSR based Reynolds SST, CLISST: Bauer-Robinson 1985 climatology]. The four platforms are shown in different colors.

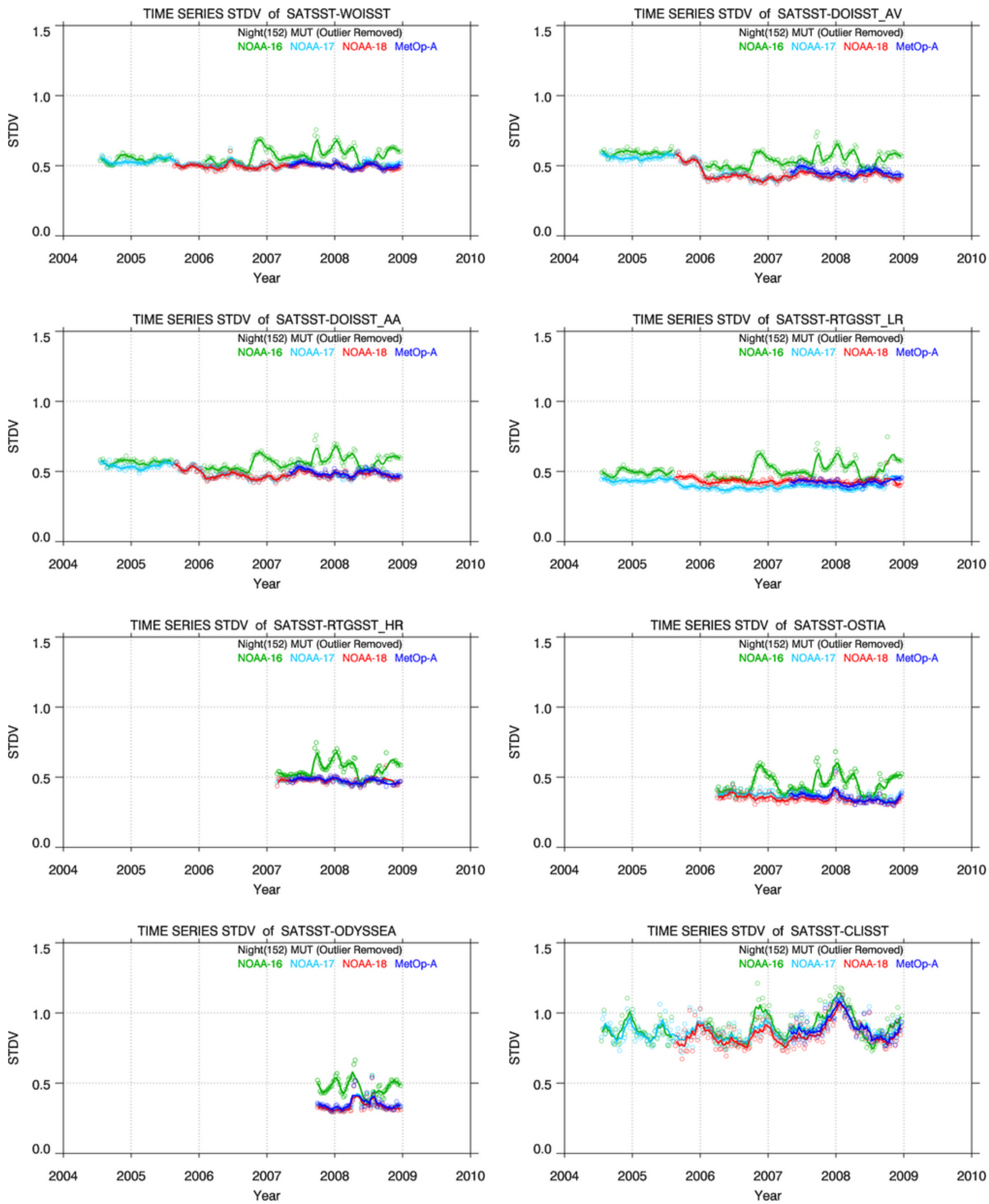

Figure 6: Same as in Fig. 5, but for standard deviation.

Fig. 6 shows the nighttime time series of standard deviation (Stdv) of SST anomalies corresponding to Fig. 5.

The lowest Stdv values are obtained from comparison with OSTIA and ODYSSEA (~0.40°C), followed by the RTG and Reynolds SSTs (~0.50°C). These precisions of satellite SST with respect to global reference fields are close to the precision of satellite SST measured with respect to *in situ* data. The comparison against DOISST_AV and DOISST_AA daily products (Reynolds *et al.*, 2007) from 2006 onward shows a drop of Stdv by ~0.10°C which is likely due to the change in the reference field itself. This discontinuity also coincides with the switch from Pathfinder SST to NAVOCEANO SST (May *et al.*, 1998) as the primary input to the daily OISST products (Reynolds *et al.*, 2007). For daytime, similar but slightly higher Stdv values are obtained (figures not shown).

For comparison with Fig. 6, the Stdv of ACSPO SST anomalies against daily Reynolds (DOISST_AV) are shown in Fig. 7. Consistently with Fig. 6, the outliers have been removed. An in-depth analysis of SQUAM ACSPO results is currently underway pending availability of longer time-series. Fig. 6 suggests that performance of ACSPO is comparable to that of the MUT. Note that, ACSPO generates from ~30 to 50 times more data points than MUT at a higher spatial resolution (currently GAC ~4 km processing is operational and FRAC ~1 km product is being tested).

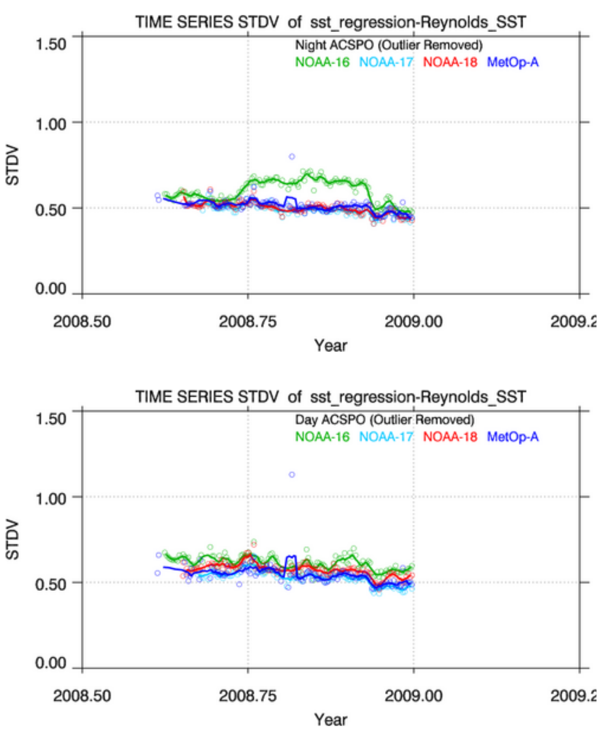

Figure 7: Time-series of ACSPO SST anomalies Stdv with respect to Reynolds daily SST (AVHRR based), for NOAA-16, -17, -18, & MetOp-A, after outlier removal (each point represents daily global data, ~ 3×10^6 data points).

5.2 *Artificial dependency of SST accuracy on observational and geophysical parameters*

For the diagnostics of artificial dependencies in the retrieved SST, the data and collateral information are first sampled (averaged) to chosen Lat/Lon grids, separated for each date, for both day and night, *i.e.*, 1°×1°×24h grid cells. Gridding is based on simple averaging, *i.e.*, sum of a variable within a Lat×Lon×24h cell divided by the number of observations (NOBS) in that cell. The NOBS is also stored for each grid-cell, which may serve as an inverse proxy for ambient cloud amount (*i.e.*, the more the NOBS the clearer is the grid-cell; note that the cloud amount parameter is not available in MUT files, but one can reasonably expect that it is approximately inversely proportional to NOBS). For the newer ACSPO data, column water content is available along with an improved cloud mask (Petrenko *et al.*, 2008). After re-sampling, the bias (anomaly) is plotted against observational and geophysical parameters to check if there is any artificial trend induced by these parameters. Such plots are hereafter referred to as "dependency plots".

Fig. 8 shows an example of such MUT diagnostics for VZA for two periods: end of 2005 and beginning of 2006. The artificial cross-scan SST gradient caused by a misallocation of HIRS footprint VZA to AVHRR footprint was detected using such trend plots analyses and was subsequently rectified (Ignatov *et al.*, 2004). The improved result is shown in red and is symmetric with respect to nadir.

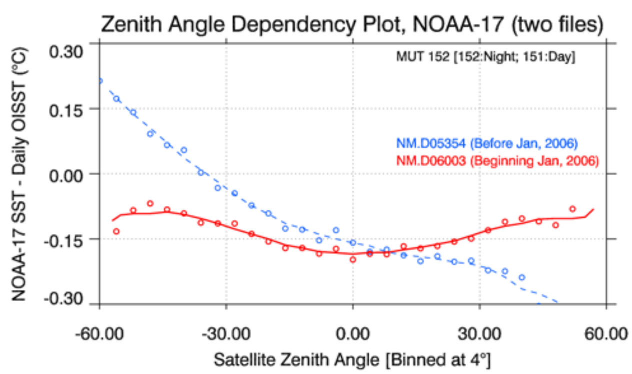

Figure 8: Dependency plots of NOAA-17 MUT night SST anomaly as a function of satellite zenith angle for two different time periods shown in different colors. The anomaly has been calculated with respect to daily OISST (Reynolds *et al.*, 2007). For the time period before January 2006 (dotted blue), note the gradient in the dependency plot skewed to the left, caused by misallocation of zenith angle. This was fixed in the beginning of 2006, resulting in a relatively flatter plot.

6. CONCLUSIONS AND FUTURE OUTLOOK

In this work, multiple years of SST data from NOAA-16, -17, -18, and MetOp-A AVHRRs, generated by the NESDIS heritage Main Unit task (MUT) system, were compared against global reference SST fields, employing the SST Quality Monitor (SQUAM). Also, about three months of SST data from the same four platforms but generated by the newer Advanced Clear-Sky Processor for Oceans (ACSPO) system has been preliminarily analyzed. The SQUAM nicely complements the customary validation approach against *in situ* data. Relying on the comparisons of satellite SST (T_S) against SST analysis fields (T_R), a near real-time (NRT) robust SST quality monitor (SQUAM) was implemented for monitoring of the MUT and ACSPO SST products, based on statistical self- and cross-consistency checks. Global SST anomalies (T_S - T_R) are analyzed at both native spatial resolution and in gridded form. The native spatial resolution analyses are important for handling outliers. Statistical moments of the distribution are trended as a function of time for monitoring stability of the products. Overlaying these plots for different platforms helps in evaluating the cross-platform consistency. The gridded-level analyses help in detecting any artificial dependency of the product on observational and geophysical parameters.

In this work, the SQUAM concept and preliminary analyses haave been reported. In-depth analyses of the MUT time-series data are reported in Dash *et al*. (2009), which also includes analyses of the outliers. The time series trends of other parameters not reported here, stratified by day and night, are available in near real-time at the SQUAM website at: *http://www.star.nesdis.noaa.gov/sod/sst/squam*.

Currently, the SQUAM is fully functional in NRT for MUT and ACSPO, both of which process AVHRR/3 data from NOAA-16, -17, -18, and MetOp-A platforms. Also, this web-based tool is being tested for MSG SEVIRI data, and will be tuned for future platforms and sensors such as NOAA-N' AVHRR, NPOESS VIIRS, and GOES-R ABI.

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