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Monitoring of IR Clear-sky Radiances over Oceans for SST (MICROS): Near-Real Time, Web-Based Tool for Monitoring CRTM – AVHRR Biases for Improved Cloud Mask and SST Retrievals

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ABSTRACT

Monitoring of IR Clear-sky Radiances over Oceans for SST (MICROS, www.star.nesdis.noaa.gov/sod/sst/micros/) is a web-based tool used to monitor the Model minus Observation (M-O) biases in clear-sky brightness temperatures (BT) over oceans, produced by the newly developed Advanced Clear-Sky Processor for Oceans (ACSPO). ACSPO version 1.0 became operational in May 2008 with AVHRR Global Area Coverage data from NOAA-18 and MetOp-A. Currently, it generates clear-sky radiances (CSR), sea surface temperature (SST), and aerosol products from four platforms including NOAA-16 and -17, which are also processed for cross-platform checks. The central part of ACSPO is the fast Community Radiative Transfer Model (CRTM), which is used in conjunction with Reynolds SST and Global Forecast System (GFS) upper-air data to simulate clear-sky BTs in AVHRR Ch3B (3.7 μm), 4 (11 μm), and 5 (12 μm).

CRTM clear-sky BTs are reported on ACSPO product granules alongside with AVHRR measured clear-sky BTs. Currently, MICROS performs three functions in near-real time: it runs ACSPO processing for four platforms, performs statistical analyses of the M-O biases, and publishes summary results on the web. This paper documents the MICROS system and discusses effects of three ACSPO versions on the stability of the global M-O bias. The upgrades did not significantly affect mean M-O biases, but their standard deviations (STD) have significantly improved. Double-differencing technique is employed to check clear-sky radiances over ocean for cross-platform consistency. All analyses show that NOAA-16 radiances are highly unstable in all three bands. This satellite currently flies close to the terminator. Also, its AVHRR sensor has been unstable since September 2003. Radiances from the three other platforms are generally stable and cross-platform consistent to within 0.01-0.04 K, except for NOAA-18 Ch4 which shows a ~-0.11 K bias relative to NOAA-17 and ~-0.07 K bias relative to MetOp-A. Work is underway to extend MICROS functionality to include monitoring of clear-sky BTs from MSG/SEVIRI. NPOESS/VIIRS and GOES-R/ABI data will also be added to MICROS once these sensors are in orbit. For accurate physical (CRTM-based) SST retrievals, biases in AVHRR BTs should be fully understood and minimized. Improvements to daytime CRTM modeling are also underway.

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1. INTRODUCTION

Advanced Clear-Sky Processor for Oceans (ACSPO) has been developed in NESDIS. Its version 1.0 became operational in May 2008 with AVHRR Global Area Coverage (GAC) data from NOAA-18 and MetOp-A. Data from NOAA-16 and -17 are also processed to better understand and to more fully explore the ACSPO potential. The major ACSPO products are clear-sky radiances (CSR) over ocean in all AVHRR bands, sea surface temperatures (SST), and aerosols. Also, clear-sky brightness temperatures (BT) in AVHRR Ch3B, 4, and 5 are simulated using the fast Community Radiative Transfer Model (CRTM; Kleespies et al., 2004; Han et al., 2006) and reported in ACSPO product granules, side-by-side with AVHRR measured clear-sky BTs. Implementation of CRTM in ACSPO in conjunction with Reynolds SST and Global Forecast System (GFS) upper air fields and validation against nighttime AVHRR radiances has been documented in Liang et al. (2009). CRTM BTs are used in ACSPO to explore physical SST retrievals and to improve cloud detection. Long-term monitoring of the Model (CRTM) minus Observation (AVHRR), or M-O, biases for stability and cross-platform consistency is critically important for these applications.

Monitoring of IR Clear-sky Radiances over Oceans for SST (MICROS, http://www.star.nesdis.noaa.gov/sod/sst/micros/) was established in July 2008 to evaluate the M-O and SST (retrieved minus Reynolds, $\Delta T_S = T_S - T_R$) biases in the ACSPO product. Since then, MICROS has been used to validate and improve the CRTM (Liu et al, 2009). This paper additionally demonstrates the utility of MICROS to monitor satellite radiances over clear-sky global ocean for stability and cross-platform consistency.

MICROS can work with ACSPO granules generated offline, or it can run ACSPO and analyze its products. The current version of MICROS performs three functions: it runs ACSPO for NOAA-16, -17, -18, and MetOp-A; it performs statistical analyses of its results; and it displays their summary on the web. This processing is done fully autonomously in the Center for Satellite Applications and Research (STAR), independently of the operational ACSPO processing performed by the Office of Satellite Data Processing and Distribution (OSDPD), also a part of NESDIS. MICROS version 1.0 was implemented in July 2008, initially based on ACSPO version 1.0. In September 2008, ACSPO in MICROS was upgraded to v.1.02 and in November 2008, to v.1.10. In December 2008, MICROS was updated to version 2.0, in which the web interface was restructured and more analyses added. Currently, MICROS runs in near-real time (NRT), once a day, after one full day of AVHRR Level 1B data become available. MICROS results are displayed on the web page lagging AVHRR L1b data acquisition by ~24 hours.

This paper describes results of monitoring the M-O and SST biases in different versions of ACSPO using MICROS. Section 2 describes MICROS. Section 3 describes the three ACSPO versions covered by MICROS from July to December 2008. Section 4 evaluates stability of the global M-O and SST biases. Cross-platform consistency and double differences are discussed in Section 5. Section 6 summarizes the paper and outlines future work.

2. MICROS

Currently, MICROS runs daily and performs three functions: it runs ACSPO, performs statistical analyses of ACSPO data granules in 1-hr increment, and displays summary results on the MICROS web page.

ACSPO processing starts at ~2 am EST after all corresponding L1B data for a full previous day have been accumulated. Processing runs on a local Center for Satellite Applications and Research (STAR) Linux box with 4 2.33 GHz CPUs and 4 GB memory. GAC L1b data from NOAA-16, -17, -18, and MetOp-A are processed and 1-hr ACSPO granules generated. These granules contain AVHRR and CRTM BTs, retrieved and Reynolds SST, and cloud mask in each GAC pixel, among other variables. ACSPO processing time is ~3 minutes per orbit and there are from 14 to 15 L1b GAC orbits per platform, per day. Thus, the total ACSPO processing time for four platforms is close to 3 hours (= 3 min × 14 orbits × 4 platforms).

Once ACSPO granules have been generated, they are statistically processed and results are displayed on the web. Dependencies on main factors affecting the M-O and SST biases, such as column water vapor content, view zenith angle, wind speed, Reynolds SST, air sea temperature difference, and latitude, are produced. The global M-O statistics include histograms of M-O biases and ΔT_S, from which mean and STD are calculated. (Robust statistics including median and robust standard deviation are being tested currently and will replace the conventional statistics in the near future; see Section 5). Time series of the global bias statistics are also plotted in order to monitor them for long-term stability and cross-platform consistency. SST analyses and global maps of geophysical and environmental parameters are also calculated and displayed on the MICROS page, to complement BT analyses. Currently, statistical analyses are performed in the full retrieval domain, with no exemption or additional quality control other than the ACSPO cloud mask, and displayed in the MICROS page. In particular, data in the full swath ±68° are analyzed. The Interactive Data Language (IDL) code takes half an hour to perform statistical analyses for one full day of data from four satellites.

All analyses are performed separately for day and night. At this time, nighttime analyses are much more accurate and appropriate for validation of CRTM and satellite radiances. The daytime data are also reported in MICROS, for completeness and to provide benchmarks for evaluating future CRTM improvements. However, treatment of solar reflection in CRTM v.1.1 currently employed in ACSPO remains suboptimal. In particular, the relative azimuth angle dependence is still not included in the calculations (Liu, 2008, personal communication). Work is underway with the CRTM Team to improve and validate the CRTM daytime calculations. Only nighttime results are discussed in this paper.

The AVHRR BTs and SSTs for NOAA-16, -17, -18, and MetOp-A have been routinely monitored in MICROS version 1.0 in NRT since 1 July 2008. In December 2008, MICROS was upgraded to version 2.0.

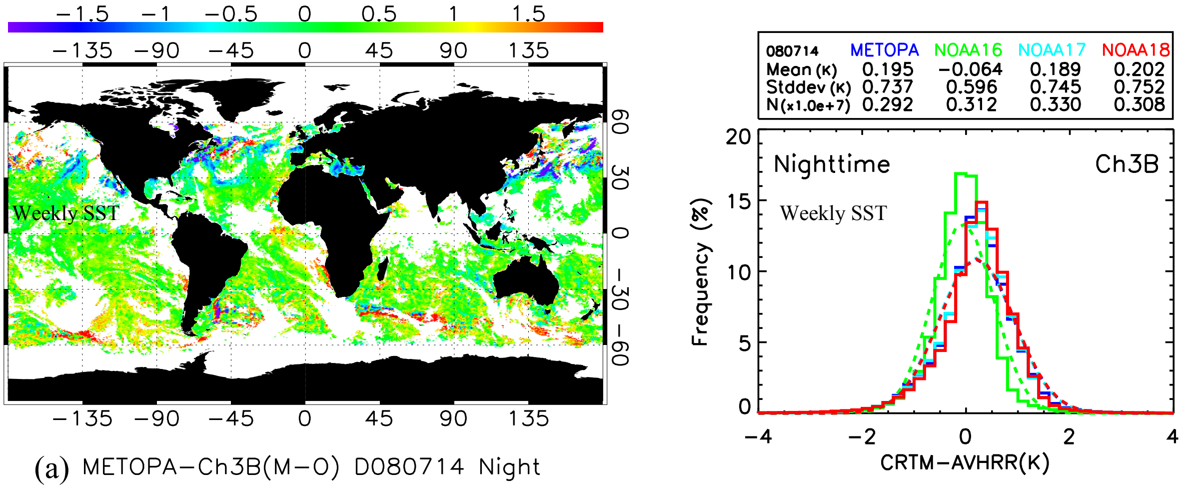
3. **ACSPO VERSIONS TESTED IN MICROS**

Since MICROS was introduced in July 2008, it proved instrumental to quickly evaluate and test all new ACSPO developments. This study documents results of testing three major ACSPO versions: v.1.0 (employed in MICROS from 1 July – 3 September, 2008), v.1.02 (4 September – 11 November, 2008), and v.1.10 (13 November 2008 –present). Note that only v.1.0 and v.1.10 have been officially employed in the NESDIS OSDPD operations, whereas v.1.02 remained internal to the ACSPO Development Team. Nevertheless, it provided a critical update to ACSPO and, therefore, was separately tested in MICROS and documented here. This section provides a brief overview of ACSPO versions. This information is essential to interpret the results observed in the MICROS web page. Also, these ACSPO version upgrades provide a natural way to estimate the stability and improvements in the ACSPO M-O and SST biases.

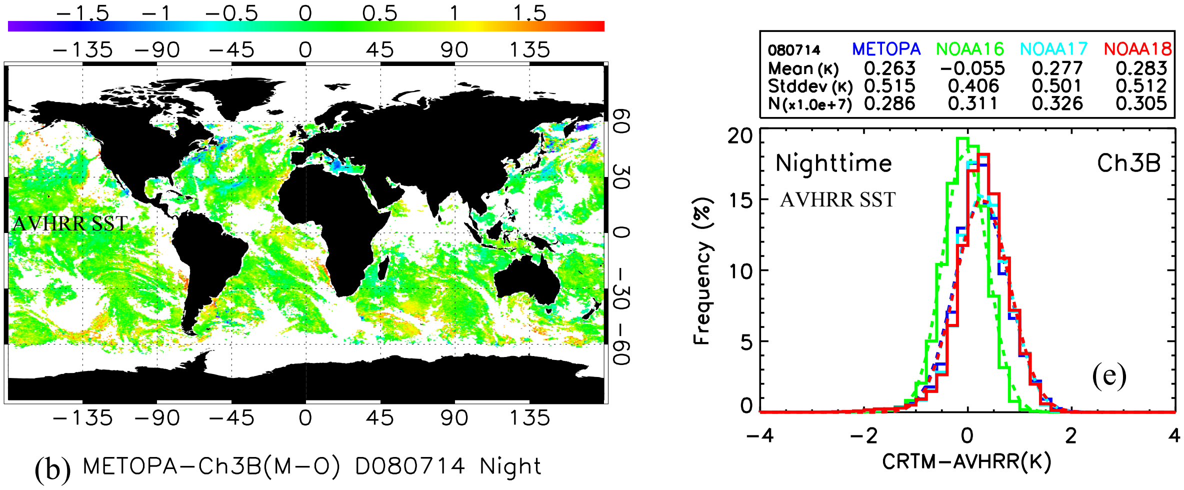
Major features of ACSPO v.1.0 have been described in Liang et al. (2009). To summarize, it used an alfa-version of CRTM (termed "r577") in conjunction with NCEP/GFS upper air data and Reynolds weekly 1º SST (OISST.v2, Reynolds et al., 2002). Also, it employed an initial version of ACSPO cloud mask documented in Petrenko et al (2008).

In ACSPO v1.02 implemented in MICROS on 4 September 2008, a number of critical changes have been made. First, weekly 1° Reynolds OISST.v2 was replaced with a daily 0.25° product (Reynolds et al, 2007). Two daily Reynolds products are available. One is based on blending NAVOCEANO SEATEMP AVHRR SST product (May et al., 1998) with *in situ* SST; hereafter, it is termed "Reynolds daily (AVHRR)." The other product additionally uses retrievals from the Advanced Microwave Scanning Radiometer flown onboard Aqua satellite since 2002. It is termed "Reynolds daily (AVHRR+AMSR)". The AMSR has an all-weather advantage as clouds are essentially transparent to microwave radiation. However, the coarser AMSR footprint may affect SST accuracy in the coastal areas. Users of ACSPO 1.02 have a choice of using weekly, daily (AVHRR), or daily (AVHRR+AMSR) Reynolds SSTs.

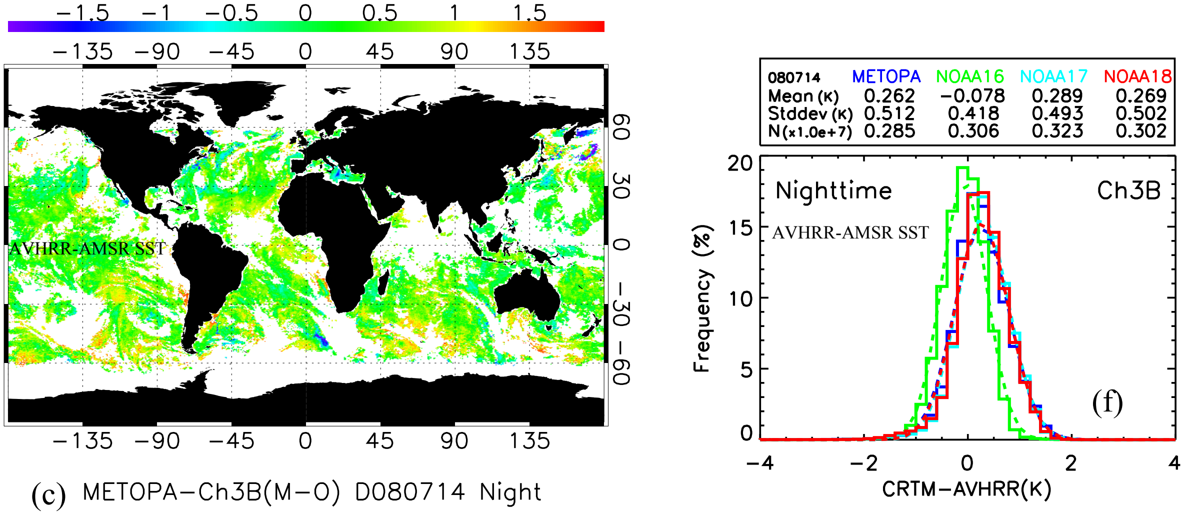
To quantify the improvement, a sensitivity study was performed. Figure 1 shows examples of global distributions and histograms of the M-O bias in nighttime MetOp-A Ch3B data on 14 July 2008 when different SST inputs are used. Using daily Reynolds SSTs significantly reduces global STD M-O bias relative to the case when weekly SST is used, but it increases mean bias by ~+0.08 K. As discussed in Liang et al. (2009), increased bias may not necessarily be "bad news" here as it leaves a wider margin for the future incorporation of aerosols in the CRTM, using skin SST instead of current bulk, and adjusting "daily mean" Reynolds SST for a diurnal cycle. Note that the improvements are largest in the higher latitudes of both the Southern and Northern hemispheres, and over some coastal areas and inland waters. Recall that the ACSPO cloud mask uses CRTM BTs, which in turn use Reynolds SST as input. The fact that the clear-sky ocean domain does not change significantly when weekly SST is replaced with daily product suggests that the ACSPO cloud detection algorithm is largely insensitive to the



(a) METOPA−Ch3B(M−O) D080714 Night



(b) METOPA−Ch3B(M−O) D080714 Night



(c) METOPA−Ch3B(M−O) D080714 Night

Figure 1. Global distributions and histograms of the M-O biases for one day of nighttime data (14 July 2008) for MetOp-A Ch3B. Three SST products are used as CRTM input: (a), (d): weekly 1° SST version 2; (b), (e): daily 0.25° (AVHRR) SST; (c), (f): daily 0.25° (AVHRR-AMSR) SST.

SST input to CRTM. The global mean biases are within ~0.015 K depending upon what daily SST product is used (AVHRR or AVHRR+AMSR), but the STD in the case of AVHRR+AMSR SST is somewhat smaller compared to AVHRR SST input (equivalent to ~0.1 K RMS reduction; e.g., for NOAA-17, $(0.501K)^2$-$(0.493K)^2$=$(0.09K)^2$). This may be due to the fact that the coarser resolution AMSR SST smoothes out higher noise present in the finer resolution AVHRR SST (Reynolds et al, 2007). AVHRR-based Reynolds daily SST was selected for the use in ACSPO, as it is less dependent on the external data (AMSR) and is thus more robust. Also, it offers a better potential for future climate reprocessing AVHRR data using ACSPO when uniform time series of historical Reynolds SSTs will be needed.

Another critical modification in ACSPO v1.02 is replacing CRTM r577 with the official CRTM version 1.1. Also, the default CRTM emissivity model based on Wu-Smith (1997) wind-speed-dependent emissivity is now used instead of Fresnel’s model employed in Liang et al. (2009). Note that in CRTM, both emissivity models are used in conjunction with downwelling radiance coming from a fixed direction of 53º. This incorrect formulation is currently being revised jointly with

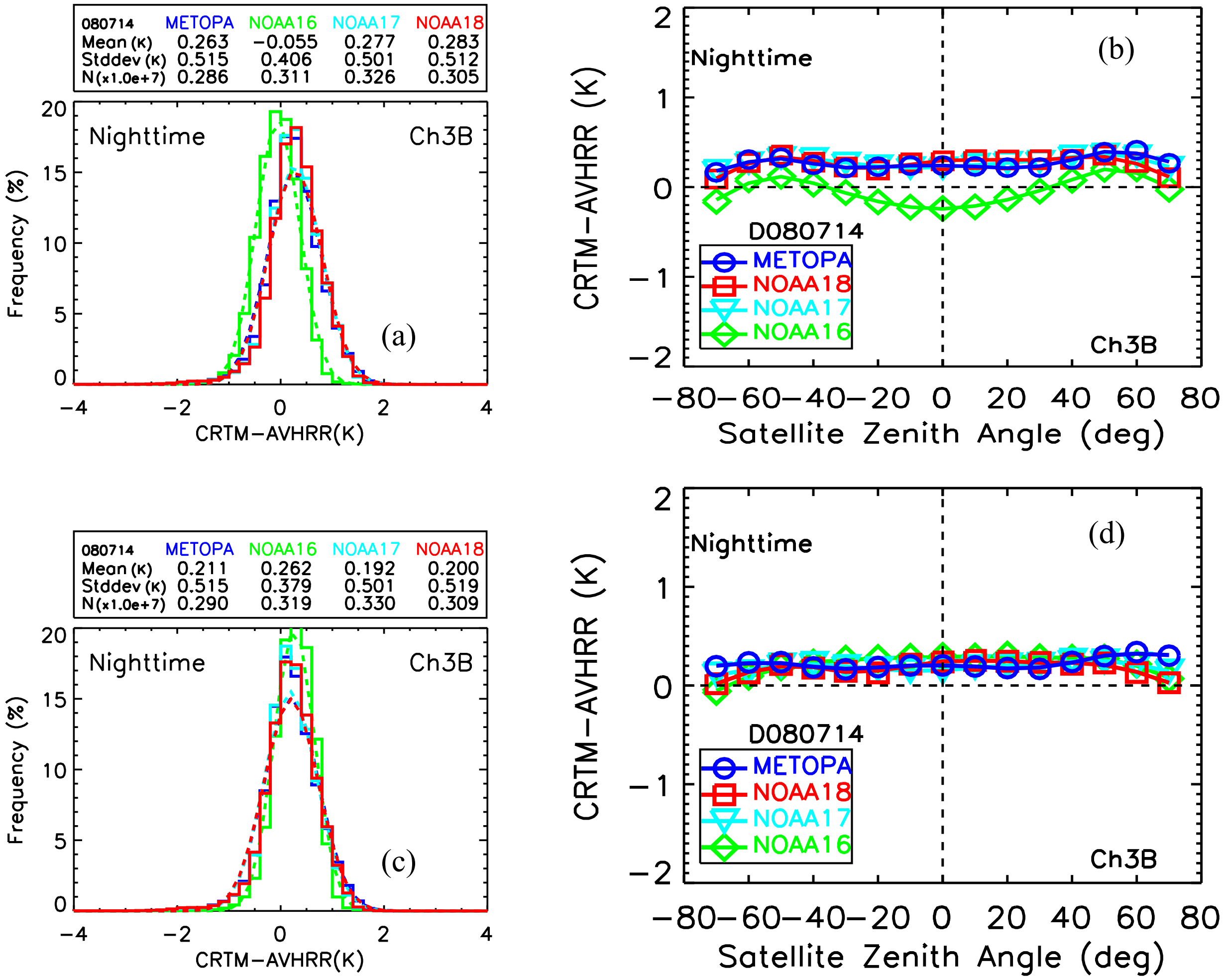


Figure 2. Global statistics and sensor view zenith angle dependences of the M-O bias for Ch3B on the four platforms integrated with the daily AVHRR SST as CRTM input. The data set is the same as in Figure 1. (a) and (b) use CRTM r577, Fresnel’s emissivity model, and the “ordinary” coefficients; (c) and (d) use CRTM v.1.1, built-in CRTM Wu-Smith (1997) emissivity model, and Planck-Weighted coefficients.

the CRTM Team (Liang et al., 2009). However, using the Wu-Smith emissivity model is more self-consistent as it is the default in CRTM. Also, it was found to provide a slightly better M-O bias and to improved satellite zenith angle dependencies, cf. Figs.2b and 2d. Further, more accurate transmittance coefficient data for the wide band are used (referred to as “Planck-Weighted,” or PW coefficients, by Chen, 2007) instead of the “ordinary” coefficient released in CRTM r577. Note that the difference between the BTs simulated using PW and ordinary coefficients is only noticeable in Ch3B (Chen, 2007). As of the time of this writing, PW coefficients have been only available from the CRTM Team for NOAA-17 and -18 and not available for NOAA-16 and MetOp-A, for which “ordinary” coefficients have been used.

Figure 2 checks sensitivity of the global statistics and view zenith angle dependencies of the M-O bias in Ch3B to the new CRTM formulation. Daily Reynolds (AVHRR) SST was used as input in both cases, and only CRTM formulation has changed. The data set is the same as in Figure 1. The top two panels are results of using CRTM r577 with Fresnel’s emissivity model and ordinary coefficient data (formulation adopted in ACSPO v.1.0), whereas the two bottom panels have been produced with CRTM v1.1, the built-in Wu-Smith emissivity model, and Planck-Weighted coefficients (formulation adopted in ACSPO v.1.02). The new CRTM formulation slightly increases clear-sky coverage. It does not change the STD of the M-O biases for NOAA-17 and MetOp-A, but it slightly increases STD for NOAA-18 and significantly improves it for NOAA-16. Moreover, the mean biases for NOAA-17, -18, and MetOp-A are now reduced by ~0.08 K. Additional analyses (not shown here) suggest that this change is due to two factors: using PW rather than ordinary coefficients (Chen, 2007), and using a different water refractive index adopted in the CRTM emissivity model. Note that the ~-0.08 K decrease offsets the previous ~+0.08 K gain from using daily Reynolds SST, making the net balance of both changes in global mean M-O bias close to zero (but leaving the global STD significantly improved).

Figure 2 (top) shows that in ACSPO v.1.0, NOAA-16 Ch3B was biased low with respect to the other three platforms by ~-0.3 K (cf. Liang et al., 2009). This bias is not observed if the new CRTM formulation is used. By working with the CRTM Team, we found that the reason is the treatment of atmospheric layers above the top GFS layer of 10 mbar, which was suboptimal in CRTM r577 and has led to a stronger than expected effect of out-of-band contribution in NOAA-16 Ch3B special response function on CRTM forward calculations (Liu et al., 2009). This problem was fixed in CRTM v.1.1.

ACSPO version 1.10 further improved cloud detection by using flexible BT and SST bias filters for different bands and sensors, which are further stratified by day and night (Petrenko et al., 2009). Also, the threshold at which the day/night flag switches over was changed from the solar zenith angle of 85º (in ACSPO v.1.0 and 1.02) to 90º (in v.1.10). The new v.1.10 has further improved the global M-O biases and their dependencies relative to v.1.02.

4. STABILITY OF NIGHTTIME M-O AND SST BIASES

Time series of the global mean M-O biases in AVHRR Ch3B, 4, and 5 from 1 July to 20 December 2008 and their corresponding STDs are shown in Figs. 3 and 4, respectively. Global mean and STD for regression SST minus Reynolds SST, $\Delta T_S=T_S-T_R$, and sample size statistics are shown in Fig. 5. Note that blended Reynolds SST products are produced by bias-correcting satellite data to match, on average, the *in situ* SSTs. It is therefore expected that Reynolds SST is centered at *in situ* data and, hence, global mean “ACSPO minus Reynolds” bias is close to the “ACSPO minus *in situ*” bias.

For all platforms except NOAA-16, the global mean M-O biases in Ch3B are ~+0.2 K, while in Ch4 and Ch5 they are ~+0.5 K. The warm M-O biases are likely due to a combined effect of aerosols (which are not accounted for in the current CRTM version), using bulk SST instead of skin, and using “daily-mean” Reynolds SST to represent the nighttime SST, which is cooler due to the effect of the diurnal cycle (Liang et al., 2009). All these effects, if included, would lower the M-O biases.

ACSPO SST is biased cold during nighttime by several tenths of a degree Kelvin. In the initial ACSPO versions, the SST formulation was intentionally preserved from the heritage Main Unit Task (MUT) NESDIS SST system (Ignatov et al., 2004), for quick cross-evaluation of the two SST products. During nighttime, the following triple-window Multi-Channel SST (MCSST) equation is employed

$$T_s = a_0 + a_1 T_{3b} + a_2 T_4 + a_3 T_5 + [a_4 (T_{3b} - T_5) + a_5](\sec\theta - 1) \tag{1}$$

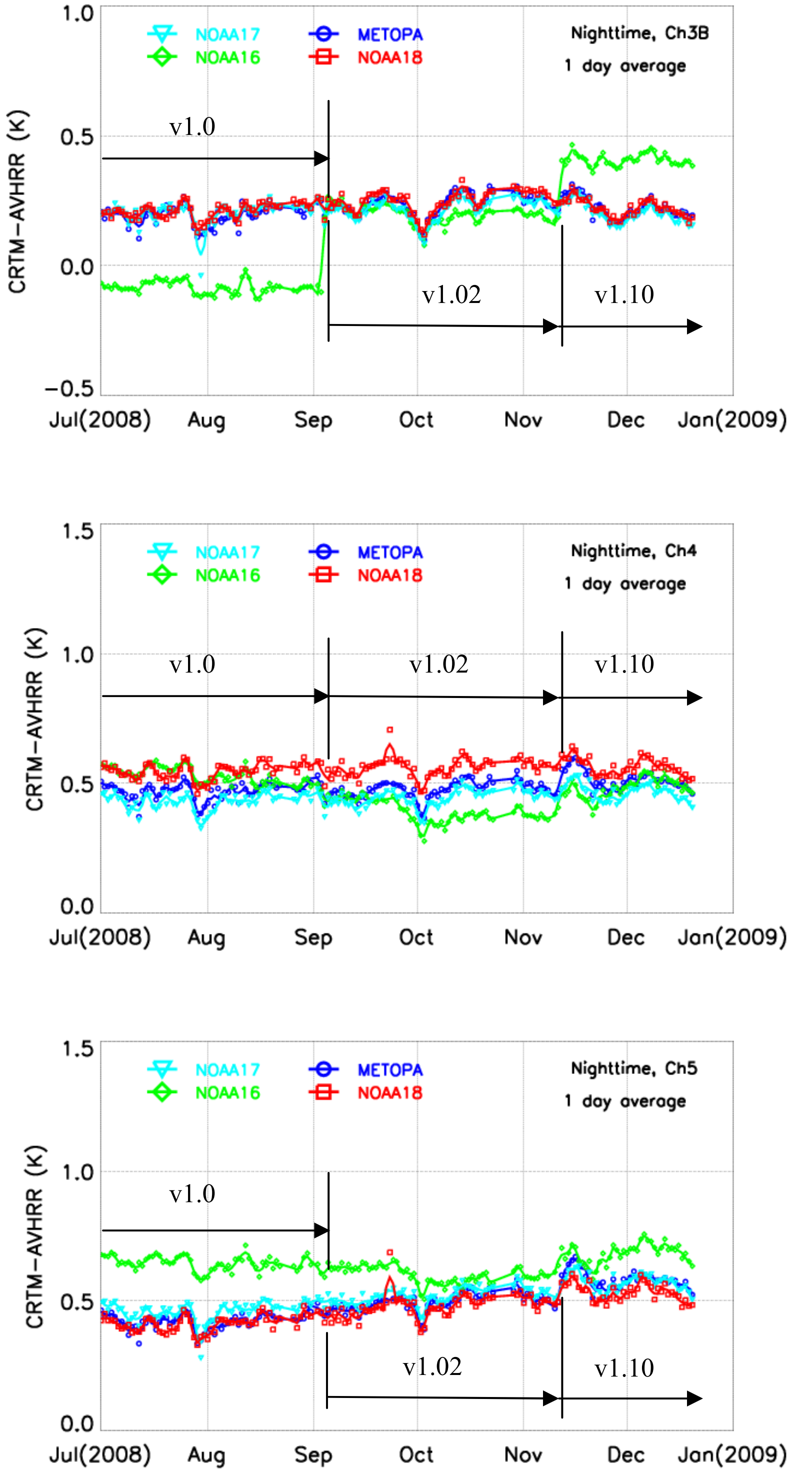


Figure 3. Time series of the global M-O biases in Ch3b, 4, and 5 for NOAA-16, -17, -18, and MetOp-A from 1 July to 20 December, 2008. Each point in the graph is the average over a 24-hour period.

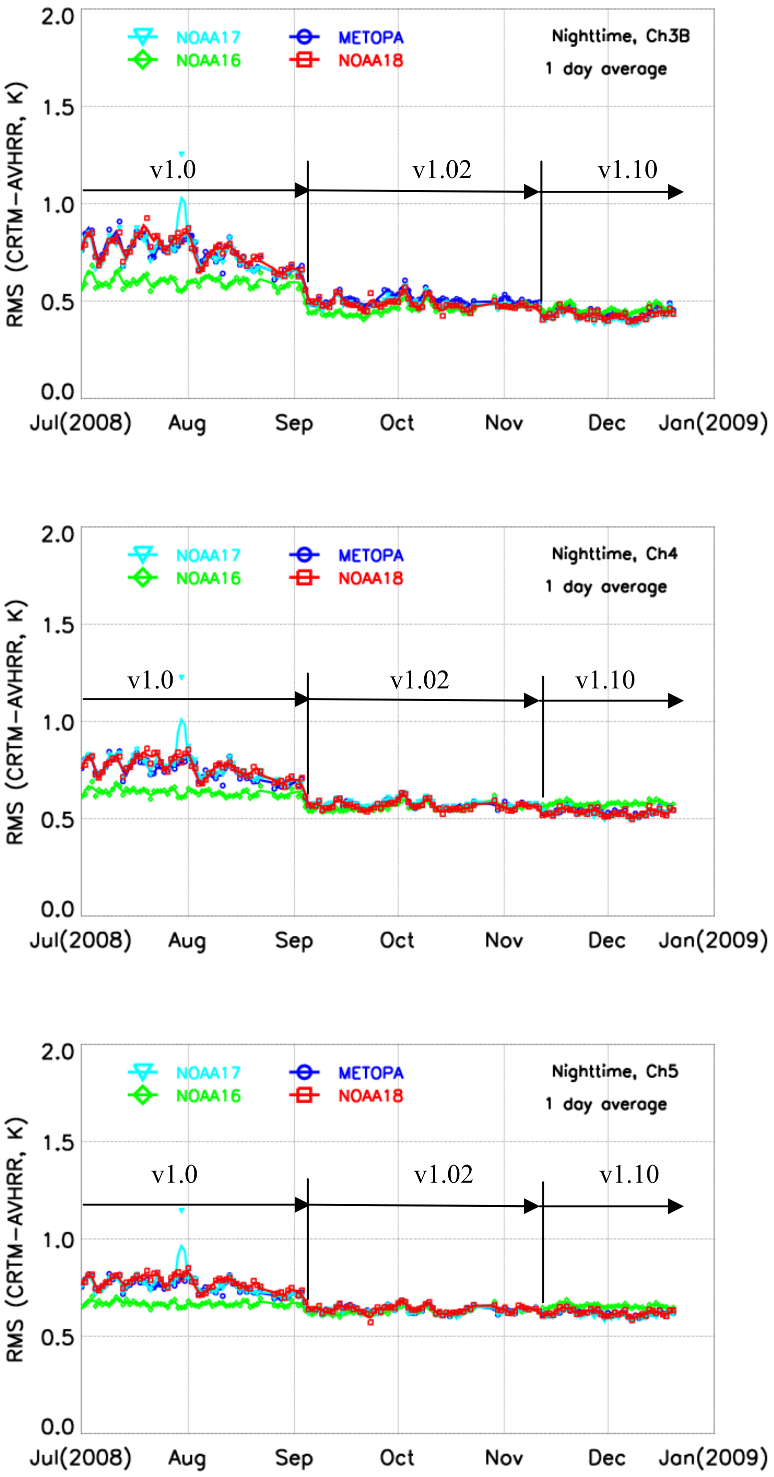


Figure 4. Same as in Figure 3 but for the global STD.

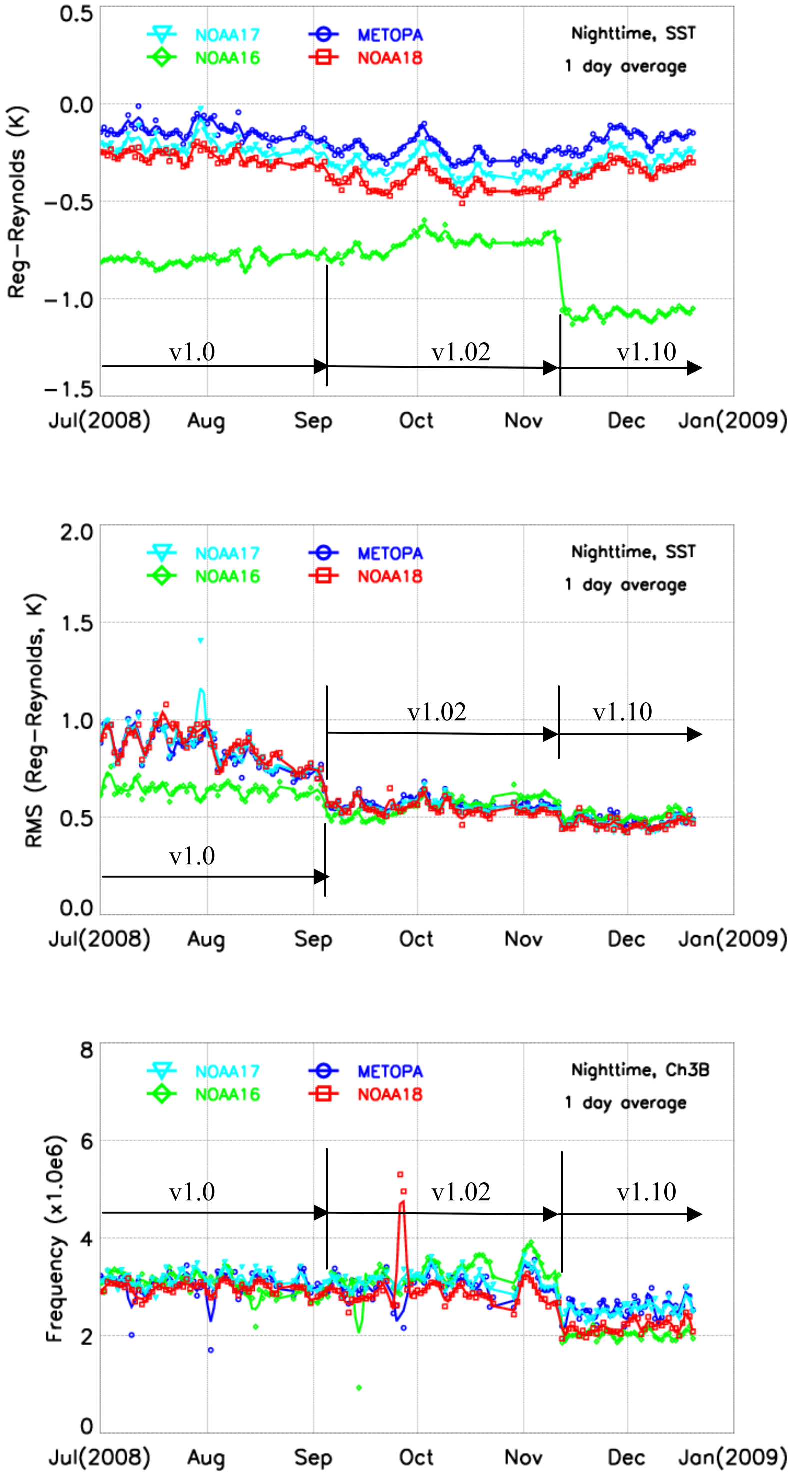


Figure 5. Same as in Figure 3 but for SST biases, STD, and sample size.

SST coefficients in ACSPO have been adopted from MUT without change. During nighttime, MUT selects the warmest AVHRR pixel within a collocated High-Resolution Infra-Red Radiation Sounder (HIRS) footprint, which may result in a warm bias in the MUT SST, and thus appear as a cold bias in ACSPO SST derived using the "biased" MUT coefficients. Optimization of ACSPO regression SST is currently underway and improved formulations will be implemented in the upcoming versions of ACSPO.

There were no significant changes in the mean M-O bias in any band of any platform, when the ACSPO version switched from v.1.0 to v.1.02 on 4 September. This apparent lack of sensitivity is in fact due to a complex compensation between the two mechanisms, which offset each other. For instance, using daily SST instead of weekly increases the M-O bias in Ch3B by ~+0.08 K, while using the new CRTM version decreases it by ~-0.08 K (cf. Figs. 1-2 and discussion in Section 3). Also, the M-O biases did not change noticeably when ACSPO v.1.10 was introduced, despite a significant adjustment in the ACSPO cloud mask (Petrenko et al., 2009).

Unlike global mean biases, the STDs of both M-O and ΔT_S have significantly reduced when ACSPO was upgraded from v.1.0 to v.1.02. This is mainly due to using Reynolds 0.25° daily SST with higher spatial and temporary resolution instead of the 1° weekly SST. In ACSPO v.1.02, the global STDs were close to 0.5 K in Ch3B, 0.55 K in Ch4, and 0.65 K in Ch5, and they have incrementally improved in v.1.10.

Note that before September 4, the global mean M-O and ΔT_S biases and STDs show a prominent weekly cycle, which is largest in the SST, followed by the most transparent Ch3B and then by Ch4 and Ch5. This is an artifact of using weekly Reynolds SST in ACSPO v.1.0, which was resolved when daily SST was employed in ACSPO v.1.02.

Global mean M-O and ΔT_S biases in Figs. 3 and 5 experience long-term excursions with an amplitude of ~±0.1 K. The M-O oscillations are coherent in all AVHRR bands for all platforms, and they are in anti-phase with the SST oscillations. Their amplitude is again largest in the SST, followed by the most transparent Ch3B and then by Ch4 and Ch5. Note, for instance, a strong "hump" in the M-O biases of ~-0.2 K in Ch3B and ~-0.1 K in Ch4 and Ch5 in early October 2008, and then another one in mid-October (about half as deep). There are two corresponding "bumps" in the SST biases in Fig. 5. These observations suggest that these non-uniformities are likely caused by the instabilities in Reynolds SST used in ACSPO. More analyses are needed to understand and reduce such "noise" in the M-O time series.

Figure 5 (bottom) also shows time series of the daily number of clear-sky observations. Note that dropped points are due to the incomplete L1B data on certain days. In ACSPO v.1.10, the number of clear-sky observations has reduced by about 20% at night compared to the two prior versions. This change is in part attributed to the day/night flag change in version 1.10 from 85° to 90°, and it is partially compensated by the increase in daytime sample size.

NOAA-16 biases are unstable, in all bands. NOAA-16 currently flies close to the terminator, and the black body of its AVHRR experiences significant impingement of solar radiation. This affects calibration in all AVHRR bands, but mostly in Ch3B. Recall also that the AVHRR sensor on NOAA-16 has experienced continuous problems since September 2003 and has not been used in the NOAA operations since NOAA-18 was launched in May 2005. We have opted to include data of NOAA-16 in the MICROS analyses to better understand the performance of the ACSPO system in atypical situations. Work is underway to resolve the observed NOAA-16 anomalies.

The root cause of the change in NOAA-16 Ch3B bias in ACSPO v.1.02, when new CRTM v.1.1 was introduced, has been already discussed in Section 3 and documented in details in Liu et al. (2009). After being in-family for about a month, Ch3B has again developed a low bias of ~-0.1 K relative to the major cluster before jumping up by 0.3 K when the new ACSPO v.1.10 was implemented on 12 November 2008. The latter increase in the M-O bias is likely due to a combined effect of the cloud mask and day/night flag change in ACSPO v.1.10 (Petrenko et al., 2009).

To further understand the -0.1 K bias in Fig. 3, Fig. 6 replots Fig. 3 using median (rather than conventional mean) statistics. The consistency of NOAA-16 with other platforms during the ACSPO v.1.02 period is now substantially improved. It is likely that NOAA-16 M-O biases are highly non-Gaussian in this period of time. Analyses of this anomaly continue. Also, day-to-day noise has significantly reduced in all time series, not only NOAA-16. We thus conclude that using robust statistics improves the monitoring potential, and work is underway to implement them in MICROS.

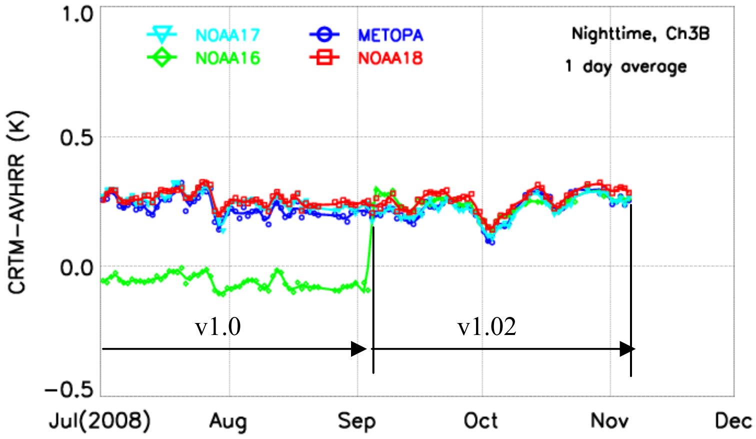


Figure 6. Time series of global median in Ch3B for NOAA-16, -17, -18, and MetOp-A from 1 July to 5 November, 2008.

5. CROSS-PLATFORM AND DAY-NIGHT CONSISTENCY USING DOUBLE-DIFFERENCING TECHNIQUE

Monitoring M-O biases for cross-platform consistency is important to independently verify calibration and spectral response functions of different sensors and evaluate their stability in time. The M-O bias takes into account both sensor calibration and spectral response function. Although M-O biases may not be zero and are band-specific as discussed above, they should be very close for the two platforms, especially if the satellites overpass at the same local time. NOAA-17 and MetOp-A are currently flying very close in time to each other and cross the equator at 21:50 local time, whereas NOAA-16 crosses the equator at ~5:00 a.m. and NOAA-18 at ~1:40 a.m. During the nighttime, the diurnal cycle in SST is small and therefore data from all platforms should be close.

Although cross-platform consistency can be evaluated directly from Fig. 3, the excessive noise in the data prevents accurate quantitative analyses. In MICROS version 2, a double-differencing (DD) technique was adopted to rectify the cross-platform signal from noise. The satellite-to-satellite DD is defined as follows:

$$SAT - REF = SAT[-(M-O)] - REF[-(M-O)] \quad (2)$$

Here, REF denotes reference satellite; SAT-REF denotes the satellite measurement biases with respect to reference. NOAA-17 was selected as a reference satellite because its overpass time is close to MetOp-A, and the DD signal should not be affected by the diurnal cycle, at least for this pair of sensors.

The DD technique has been successfully used, for instance, to establish calibration link between AIRS and IASI sensors using GOES as a radiation transfer standard (e.g., Wang and Wu, 2008). In our case, the CRTM is used as a transfer standard. The DD technique minimizes the effects on the M-O biases that arise from such factors as errors in the reference SST, missing aerosol, possible systemic biases in CRTM forward model, and ACSPO processing algorithm updates. The DD is thus expected to be more effective to cross-calibrate different sensors.

Figure 7 shows DD time series for NOAA-16, NOAA-18, and MetOp-A in all three bands smoothed by a three-day moving averaging filter. A large fraction of the “noise” in the M-O biases comes from the same source (such as Reynolds SST, ACSPO version, and missing aerosol) and is, therefore, correlated between different platforms. It cancels out when DD is calculated. MetOp-A is consistent with NOAA-17 to within ~-0.01 K in Ch3B, ~-0.04 K in Ch4, and ~+0.02 K in Ch5. NOAA-18 is consistent with NOAA-17 to within ~-0.02 K in Ch3B, ~-0.11 K in Ch4, and ~+0.04 K in Ch5. Recall that NOAA-18 may be biased slightly low with respect to NOAA-17, due to the diurnal cooling from ~10:50 p.m. to 1:40 a.m. If it exists, this diurnal signal should be largest in Ch3B and smaller in Ch4 and Ch5. Clearly, different bands of

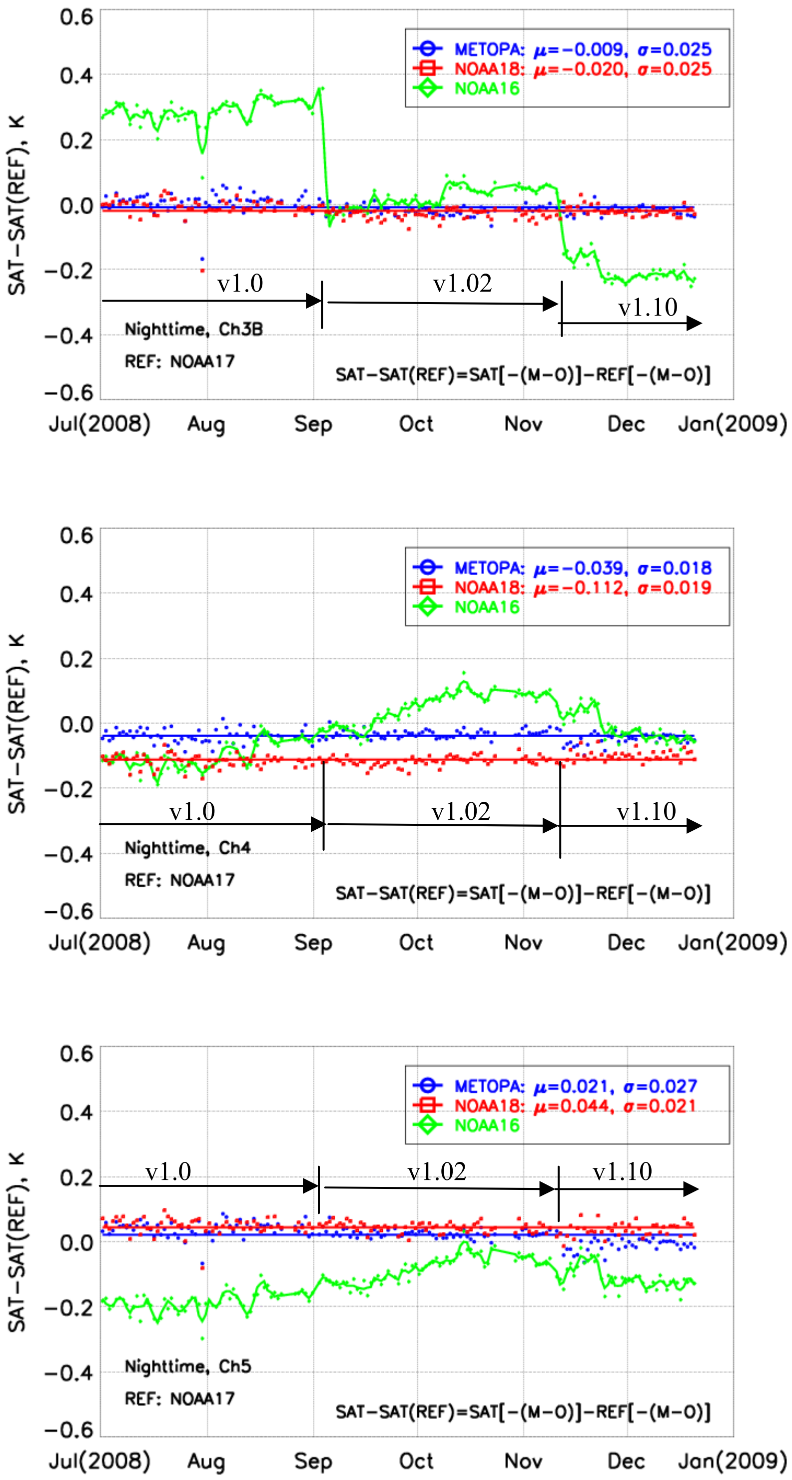


Figure 7. Same as in Figure 3 but for the satellite/satellite double differences.

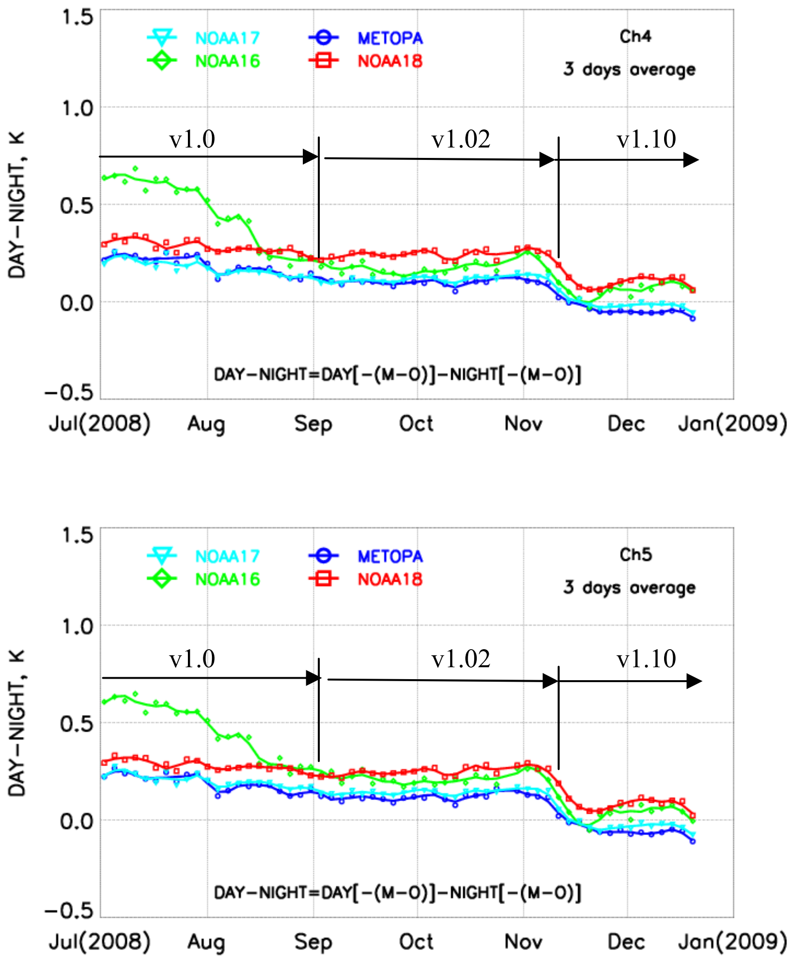


Figure 8. Same as in Figure 7 but for the day/night double differences smoothed out by three-day moving averaging filter.

NOAA-18 do not follow this expected pattern, suggesting that cross-sensor calibration or spectral response functions induced errors that contribute to the DD signal. The DD also further emphasizes and better quantifies the instability of NOAA-16.

The DD technique can be also used to check for day/night consistency in the M-O bias:

$$DAY - NIGHT = DAY[-(M-O)] - NIGHT[-(M-O)] \tag{3}$$

Figure 8 shows the day/night DD in Ch4 and Ch5 for all four platforms. Before mid-November, the day/night DDs have been fairly stable as a function of time for all platforms except NOAA-16. However, the day/night bias suggests that the measured AVHRR BTs are always warmer at night, which is counterintuitive. With introducing ACSPO v.1.10, the day-night biases become more realistic. BTs are now warmer by several hundredths of a degree Kelvin during the daytime for the two afternoon platforms, NOAA-16 (equator crossing time ~5:00 a.m./p.m.) and NOAA-18 (~1:40 a.m./p.m.). On the other hand, daytime BTs are slightly cooler than nighttime for the morning platforms NOAA-17 and MetOp-A (9:50 a.m./p.m.). Recall that daytime M-O biases are currently unusable in Ch3B, and may not be fully reliable in Ch4 and 5 as discussed in Section 1.

6. CONCLUSION AND FUTURE WORK

The MICROS web-based tool was established to monitor global M-O biases in clear-sky brightness temperatures and SSTs over oceans. MICROS is an end-to-end system that processes satellite Level 1B data by ACSPO, performs statistical analyses of BTs and SSTs, and publishes their summaries on the web. Currently, AVHRR BTs in Ch3B, 4, and 5 for NOAA-16, -17, -18, and MetOp-A are monitored in MICROS. MICROS reports global M-O and SST statistics, including histograms, time series, dependencies on main factors, global distributions of these factors, satellite/satellite, and day/night double-differences. All analyses are performed separately for day and night, but only nighttime data were discussed in this paper.

From July to December 2008, the nighttime global M-O biases have been fairly stable in all three AVHRR bands on NOAA-17, -18, and MetOp-A, even at the time of ACSPO version upgrades. Short-term variability in the M-O biases likely arises from instabilities in the Reynolds SST input. Cross-platform consistency between NOAA-17, -18, and MetOp-A radiances was evaluated using a double-differencing technique. Generally, the BTs are consistent to within several hundredths of a degree Kelvin, except for NOAA-18 Ch4, which is biased cold by ~-0.1 K relative to NOAA-17 and MetOp-A. NOAA-16 is out of family and unstable. Analyses are underway to understand its anomalous behavior. The double-differencing technique is also employed in MICROS to continuously evaluate day/night biases. Analyses show that robust statistics are more effective to evaluate the stability and cross-platform consistency than the conventional statistics, and they will be employed in the future versions of MICROS.

Work is also underway to extend MICROS functionality to include monitoring of BTs from MSG/SEVIRI. Data from NPOESS/VIIRS and GOES-R ABI will be also added to MICROS once they become available. Before physical SST retrievals in ACSPO are explored, daytime ACSPO analyses should be improved. In a longer perspective, we also plan to test GOCART aerosols in conjunction with CRTM for improved SST. The effect of all new improvements and developments will be evaluated using the MICROS system.

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REFERENCES

Chen, Y., 2007. On the use of Planck-weighted transmittances in CRTM. CRTM document with CRTM version 1.1 release.

Han, Y., P. van Delst, Q. Liu, F. Weng, B. Yan, R. Treadon, and J. Derber. 2006. JCSDA Community Radiative Transfer Model (CRTM) – Version 1. NOAA Technical Report NESDIS 122, 33pp.

Kleespies, T.J., P. van Delst, L. M. McMillin and J. Derber. 2004. Atmospheric transmittance of an absorbing gas. 6. An OPTRAN Status Report and Introduction to the NESDIS/NCEP Community Radiative Transfer Model. *Appl. Opt.*, 43, 3103–3109.

Ignatov, A., J. Sapper, I. Laszlo, et al., Global operational sea surface temperature and aerosol products from AVHRR: current status, diagnostics, and potential enhancements. *13th AMS Conf. Satellite Oceanography and Meteorology*, Norfolk, VA, 20–24 September 2004.

Liang, X., A. Ignatov, and Y. Kihai. 2009 (submitted). Implementation of the Community Radiative Transfer Model (CRTM) in Advanced Clear-Sky Processor for Oceans (ACSPO) and validation against nighttime AVHRR radiances. *J. Geophys. Res.*.

Liu, Q. 2008. Personal communication.

Liu, Q, X. Liang, Y. Han, P. van Delst, Y. Chen, A. Ignatov, and F. Weng. 2009 (submitted). Effect of out-of-band response in NOAA-16 AVHRR Channel 3B on top-of-atmosphere radiances calculated with the Community Radiative Transfer Model. Submitted to *JTecho*.

May, D. A., M.M. Parmeter, D.S. Olszewski, and B. D. McKenzie (1998). Operational processing of satellite sea surface temperature retrievals at the Naval Oceanographic Office. *Bulletin of the American Meteorological Society*, 79, 397–407.

Petrenko, B., A. Heidinger, A. Ignatov, and Y. Kihai. 2008. Clear-sky mask for the AVHRR Clear-Sky Processor for Oceans. Ocean Sciences Meeting, 2–7 March 2008, Orlando, FL. (http://www.star.nesdis.noaa.gov/smcd/emb/aerosol/ignatov/conf/2008-AGU-OSM-PetrenkoEtAl_ACSPO_CSM_Poster.pdf)

Petrenko, B., A. Ignatov, Y. Kihai, X. Liang, N. Shabanov, and A. Heidinger. 2009 (submitted). Cloud mask and Quality control for SST within the Advanced Clear Sky Processor for Oceans (ACSPO), 38th AMS Annual meeting, Phoenix, AZ.

Reynolds, R. W., N. A. Rayner, T. M. Smith, D. C. Stokes, and W. Wang (2002). An improved *in situ* and satellite SST analysis for climate. *J. Clim.*, 15, 1609–1625.

Reynolds, R. W., T. M. Smith, C. Liu, D. B. Chelton, K. S. Casey, and M. G. Schlax. 2007. Daily high-resolution blended analyses for sea surface temperature. *J. Clim.*, **20**, 5473–5496.

Wang, L. and X. Wu. 2008. GSICS tools used to compare IASI and AIRS. *GSICS Quarterly*, 2, 4, 4-4. (http://www.star.nesdis.noaa.gov/smcd/spb/calibration/icvs/GSICS/documents/newsletter/GSICS_Quarterly_Vol2No4_2008.pdf)

Wu, X. and W. L. Smith. 1997. Emissivity of rough sea surface for 8–13 um: modeling and verification. *Appl. Opt.*, 36, 2609–2618.