What's New in Version 2

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1. Introduction

The purpose of this note is to discuss the upgrade of the version 1 (v.1) daily optimum interpolation (OI) sea surface temperature (SST) analysis (Reynolds et al. 2007) to version 2 (v.2). These changes are relatively small and mostly consist of additional temporal smoothing. In addition, preliminary Pathfinder data (following Kilpatrick et al. 2001) have been processed using NOAA-7. This allows the analysis to be extended backward in time. The daily OI AVHRR-only v2 analysis now begins on September 1, 1981; v1 began on January 4, 1985.

2. Modifications version 2.

Other than the extension of v2 backward in time to September 1981, there are 7 analysis changes in v.2.

a. Temporal smoothing of daily OI data

Day-to-day analysis differences are discussed by Reynolds et al. (2007) on page 5489 and illustrated there in Fig. 13 by 4 partial snap shots of the Gulf Stream from the Advanced Microwave Scanning Radiometer (AMSR) and the Advanced Very High Resolution Radiometer (AVHRR) instruments during 1 day. The day-to-day differences are due to a limited number of observations in regions of high variability. Observations are limited by the spatial width of the satellite swath as well as by cloud cover for AVHRR and by precipitation and the vicinity of land for AMSR.

In v.1 observations used in the daily OI were taken from the day analyzed. To temporally smooth the analysis three days of data were used where the off days (the day before and after the analysis day) have doubled noise to signal ratios (standard deviation) compared to the center day. The doubled noise to signal ratio reduces the impact of the off days. See Reynolds et al. (2007) page 5470 for a discussion of noise-to-signal ratios.

To verify the impact of this smoothing, 43 moored buoys were selected which had daily data for at least 99% of the days for the period 2003-05. These buoys were located off the coasts of North America and Europe and in the tropical Pacific and Atlantic. Auto spectra were computed for the 2003-05 period at each of buoy locations from the daily-averaged buoy data and from 4 daily OI analyses: the OI using either AVHRR-only or AMSR and AVHRR data with 1-day or 3-days of data. The spatial averaged spectra are shown in Fig 1. The low frequencies (< 0.2 cycles per day) are nearly identical. The buoy data and the 3-day OI analyses have similar variances at higher frequencies although the buoy variance is being slightly higher. However, the 1-day OI analyses have considerably larger variance at higher frequencies than the others.

b. Ship SST biases with respect to buoys

As discussed in Reynolds et al. (2007), the random and bias error of ship SST data are larger than the random and bias error of buoy SSTs. Furthermore, as shown in Fig. 2 from Reynolds et al (2002), the coverage of buoys tends to increase with time while the coverage of ship tends to decrease. To determine the variability of a globally averaged bias, monthly averaged ship biases were computed with respect to buoys. However, even with temporal smoothing, differences occurred at irregular intervals and did not seem to be related to seasonal or ENSO events.

Monthly scatter plots of the collocated average global ship and buoy anomaly SSTs are shown in Fig. 2 for two 9-year periods. The least squares linear fit for the two periods is also shown with the slope and intercept given in Table 1. These results strongly suggest that a spatial and temporal constant bias correction is needed. However, finer space and time corrections do not seem to be possible with the limited in situ data available. The fit indicates that the average intercept is -0.13°C. When the average global difference are computed directly, the average buoy minus ship difference is found to -0.14°C. As differences of 0.01°C are not significant, 0.14°C was subtracted from all ship data before they are used in the satellite bias correction and in the OI analysis. No correction was made for the buoy data.

Table 1. The linear least squares fit of the ship and buoy data shown in Figure 2.

Period	Slope	Intercept
1989 - 1997	0.988	-0.136°C
1998 - 2006	0.924	-0.118°C
1989 - 2006	0.965	-0.133°C

c. Zonal satellite bias correction

As discussed on page 5482 from Reynolds et al. (2007), the daytime and nighttime satellite observations are adjusted to the daily average of the in situ (ship and buoy) data. This is done using empirical orthogonal teleconnections (EOT) which are similar to rotated empirical orthogonal functions. The method produces an anomaly SST EOT for in situ data, I(x,y) and an anomaly SST EOT for satellite data S(x,y) where x and y are the longitude and latitude coordinates, respectively. The bias, B, is defined as the difference: B(x,y) = I(x,y) – S(x,y). Only EOT modes which are adequately sampled by both in situ data and by satellite data are used. In regions where there are no EOT modes, the anomalies and hence the biases are zero.

Figure 12 from Reynolds et al. (2002) shows that Pathfinder AVHRR SSTs have cold biases with respect to operational Navy AVHRR. If the bias correction has a residual, long-term differences will indicate it. This is shown in the upper panel of Fig. 3 for July 2006. The tropical differences suggest possible cloud Pathfinder contamination in the Intertropical Convergence Zone. However, there are also high latitude differences where in situ data are sparse. To correct these differences smoothed zonal in situ minus satellite differences, z(y), were computed directly from the data. These differences were subtracted from the satellite data before the EOT procedures and then added back onto the biases. This zonal correction has no net impact on the bias correction unless there are no EOT modes. In that case the B(x,y) = z(y). The lower panel shows the difference between the two daily OI versions with the zonal correction. Here the zonal correction reduces the difference between 60°S and 40°S. It has little impact outside of the region even at high Northern latitudes. Although there are differences at high latitudes which are not corrected by the EOT method, the biases are not zonal between 70°N and 80°N so z(y) is small there.

d. Temporal smoothing of satellite bias corrections

The biases, B(x,y), use 7 days of in situ and satellite. These biases tend to be temporally noisy because the in situ data are sparse. In particular, jumps in the biases can occur as time changes and data either appears or disappears from the 7-day window.

A binomial filter using 3, 5 and 7 days was then used on the mode weights of the original 7-day bias corrections. To examine the impact, spectra were computed over a 6-year period. The spectral results were very similar for both day and night. The globally averaged nighttime bias spectrum is shown in Fig. 4 for each binomial filter along with the original unsmoothed spectrum. All spectra show some ringing which is roughly at frequency multiples of roughly 1/7 cycles per day and due to the use of 7-days of data. All the binomial filters reduce the variance at higher frequencies. It is not clear which version of the binomial filter would be best. However, the 5-day binomial filter seemed to be a reasonable compromise and was selected.

e. Increased number of days of data used in the bias correction

Comments from John Stark, UK Met Office, and preliminary processing of NOAA-7 data indicated that the daily OI Niño-3 time series were noisy with periods of about a week due to the EOT bias correction. The time series was especially noisy in the earlier half of the record before 1990 when buoy data were sparse. Additional filtering of the weights (medians, 9-point box car, etc.) did not give much improvement. Thus, the EOT data period was increased from 7 to 15 days. Figure 5 shows that the Niño-3 anomalies using 7 and 15 days. In particular note the 7-day anomaly sign change centered near 15 January 1982. It is clear that this type of variability is reduced using 15 days.

f. Improved AMSR quality control

Figure 12 from Reynolds et al. (2007) shows that the daily OI interpolates the analysis across the region of missing AMSR data near 130°W and 35°N. This region was missing AMSR data due to precipitation contamination which results in extreme values on the edges of this region. Chelle Gentemann (2007, personal communication) used improved quality control to flag AMSR data with questionable SST obs. The results for 9 February 2003 are shown in Fig. 6. The questionable SSTs (in black) are only a small part of the total observations. The AMSR extra quality control reduces the strong noise shown in Fig. 12 from Reynolds et al. (2007).

g. Modified land/sea tags

There were some errors in the quarter degree land/sea mask. The major change was to eliminate some inland fiords by setting these points to land. These points occurred at the edge of the Arctic in Russia and Greenland, in the Inland Passage areas of Alaska south of Juneau and in the Strait of Magellan. In these regions winter sea-ice was often the only data available to the analysis which often lead to large anomalies in summer. In addition, one badly represented small island in the Red Sea and one spurious island off Antarctica near 75°S and 0.5°W were eliminated and set to ocean.

3. Final comments

The use of 3-days of data in the OI and smoothing of the modes in the bias correction is not possible in near real-time. Thus, two versions will be run: a real-time interim version followed by a final version after a 2 week delay. The interim version uses 1 day of in situ and satellite data in the OI with a satellite bias correction using 7 days (one sided) of data and without smoothing of the EOT modes. The final version uses 3 days (centered) of in situ and satellite data in the OI with a satellite bias correction using 15 days (centered) of data and smoothing of the EOT modes over 5 days (centered). Both versions have a ship bias correction, a preliminary zonal correction of satellite data and improved quality control of the AMSR data. The interim version is replaced by the final version when the final version is computed. The daily OI using AVHRR-only is available from September 1981 to present; the daily OI with AMSR + AVHRR is available from June 2002 to present. Table 2 indicates the differences among Version 1 and the interim and final version 2.

Table 2. Comparison of the different versions

Feature	V.1	Interim V.2	Final V.2
Time delay	1-day	1-day	14-days
Days of data in OI	1-day	1-day	3-days
Ship bias correction	No	Yes	Yes
Preliminary zonal bias	No	Yes	Yes
Smoothing of EOT modes	No	No	5-days
Days of data in EOT bias	7-days	7-days	15-days
AMSR data improved	No	Yes	Yes
Start AVHRR-only OI	Jan. 1985	Replaced	Sep. 1981
Start AMSR+AVHRR OI	Jun. 2002	Replaced	Jun. 2002

References

Kilpatrick, K. A., G. P. Podesta, and R. Evans, 2001: Overview of the NOAA/NASA advanced very high resolution radiometer Pathfinder algorithm for sea surface temperature and associated matchup database. *J. Geophys. Res.*, **106**, 9179-9198.

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. Climate*, **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. Climate*, **20**, 5473-5496.

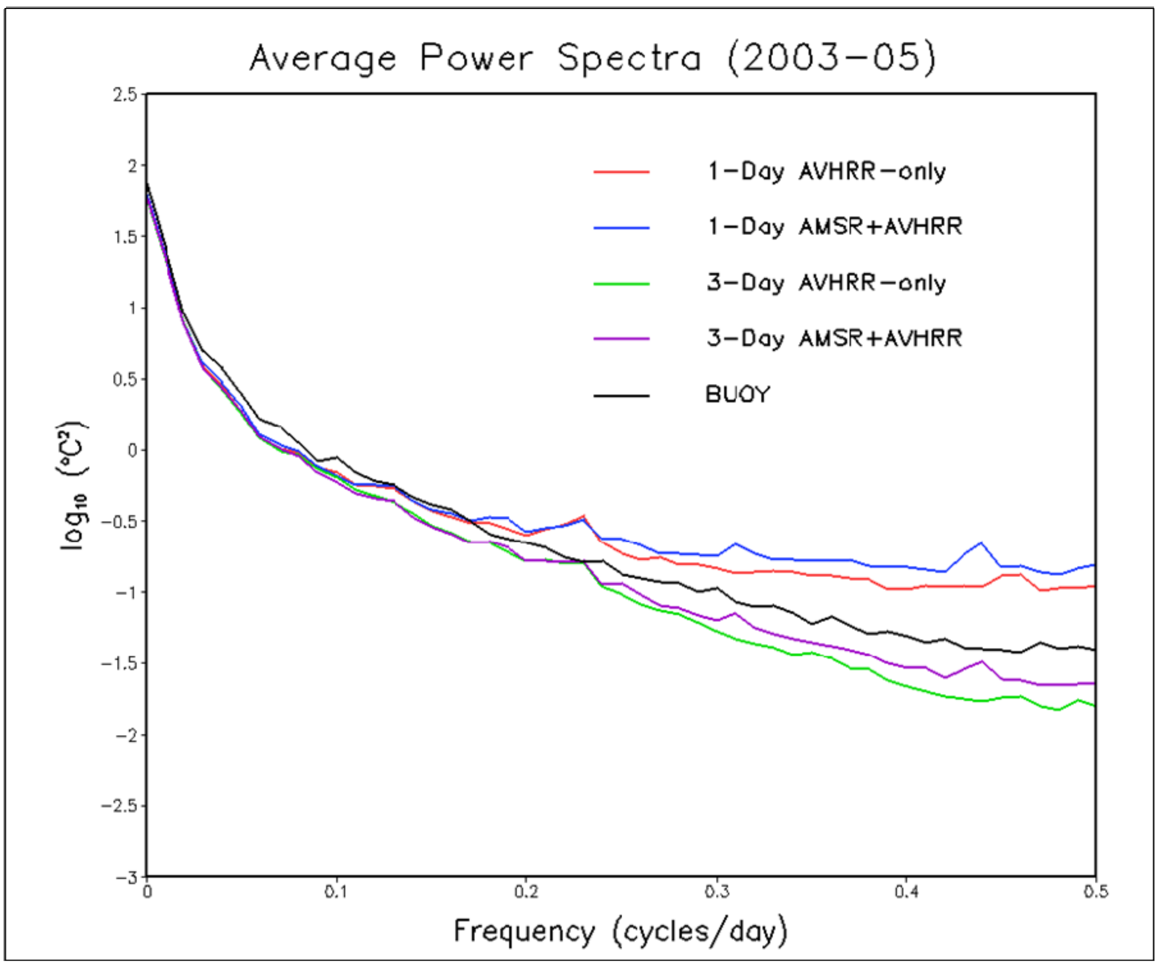

Figure 1. Globally averaged daily spectra for 2003-05 computed at 43 moored buoy locations and averaged. 'AVHRR-only' and 'AMSR+AVHRR' indicate daily OI spectra using either 1-day or 3-days of data. 'Buoy' indicates spectra using daily buoy data.

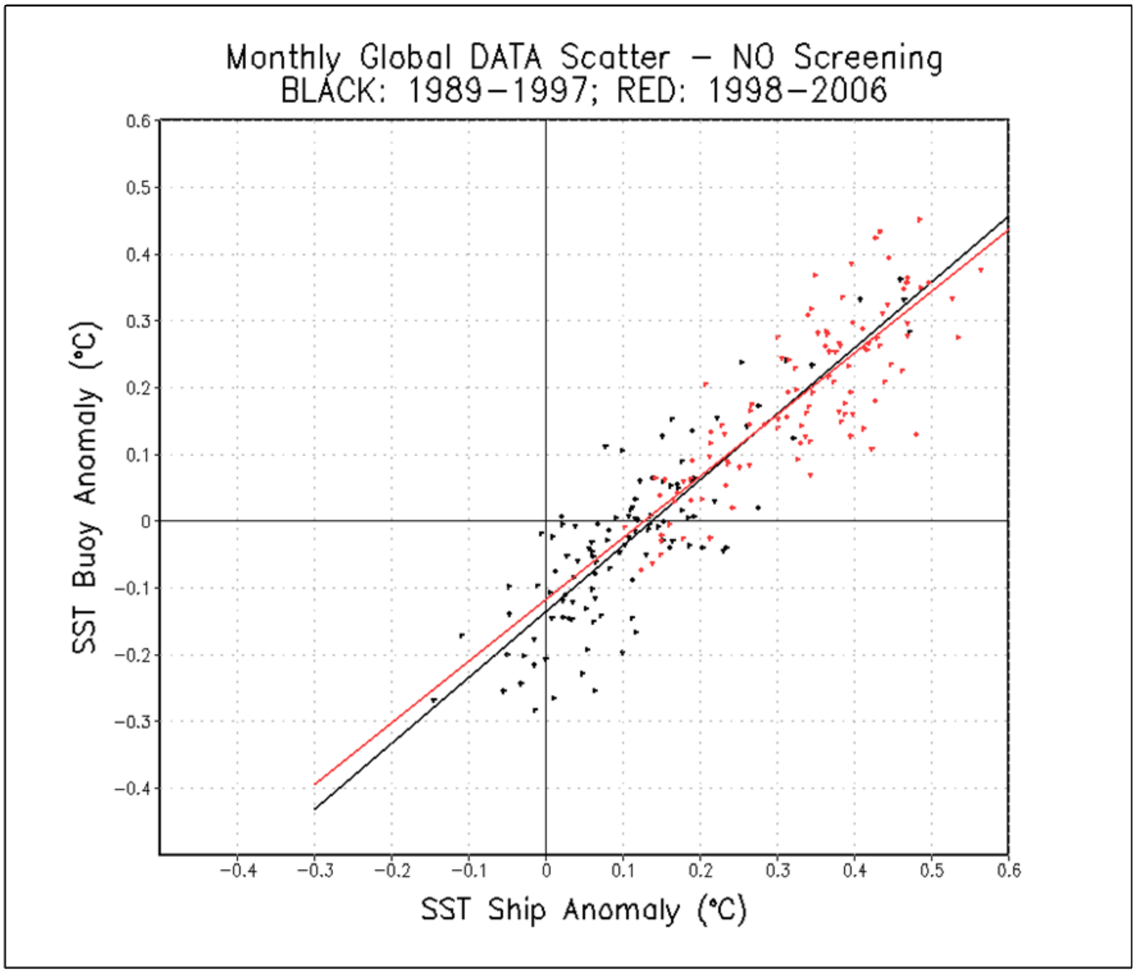

Figure 2. Scatter plot of global collocated average monthly ship vs. buoy anomaly for January 1989 - December 2006. The first 9-years are shown in the black and the second 9-years in red. Least squares linear fits for the two periods are also shown.

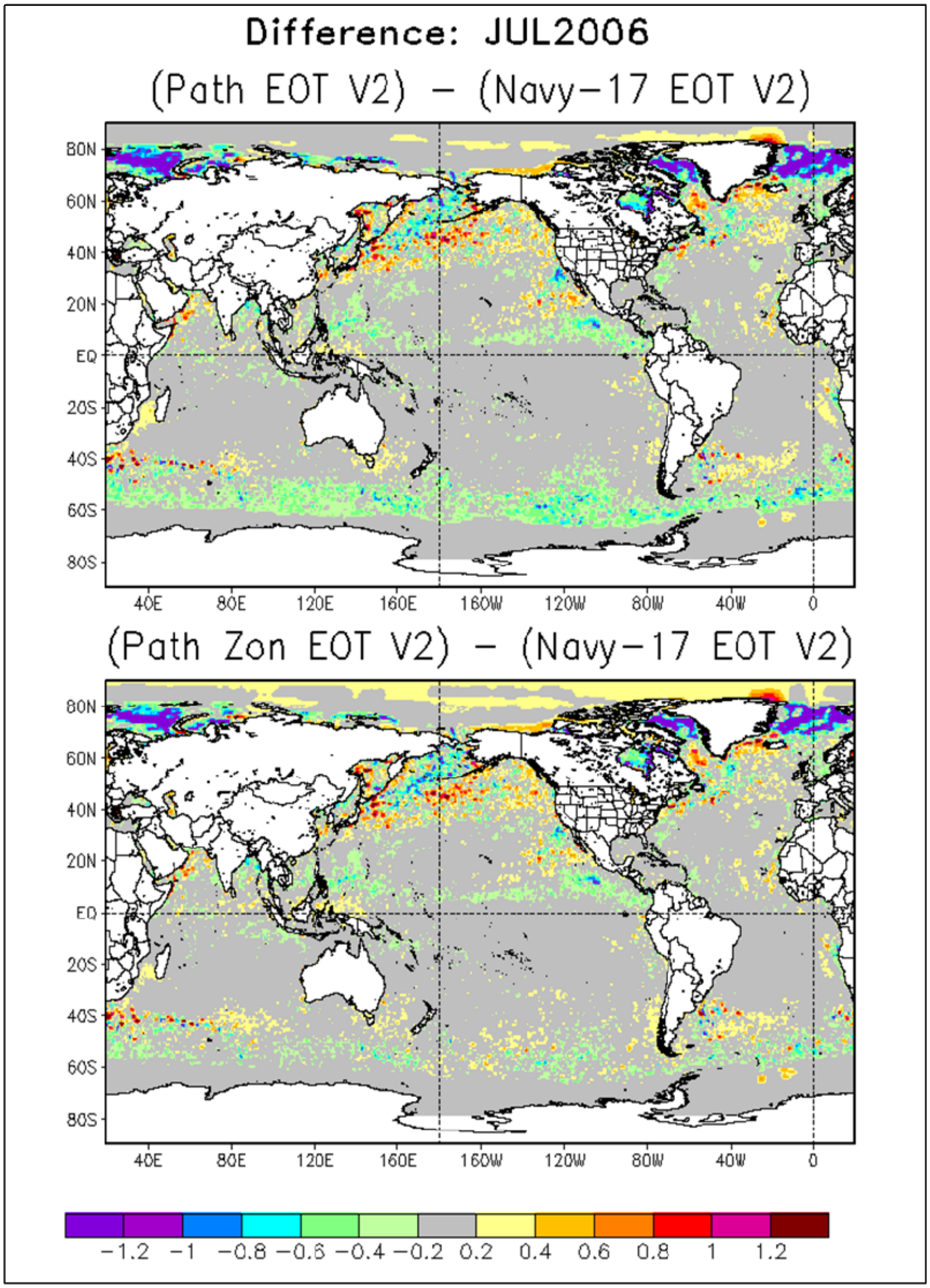

Figure 3. Average July 2006 difference between the daily AVHRR-only OI using Pathfinder NOAA-17 data and Operational Navy NOAA-17 data. All versions use bias corrected satellite data. In the top panel the Pathfinder daily OI uses no preliminary zonal bias correction; in the bottom panel the Pathfinder daily OI uses a preliminary zonal bias correction.

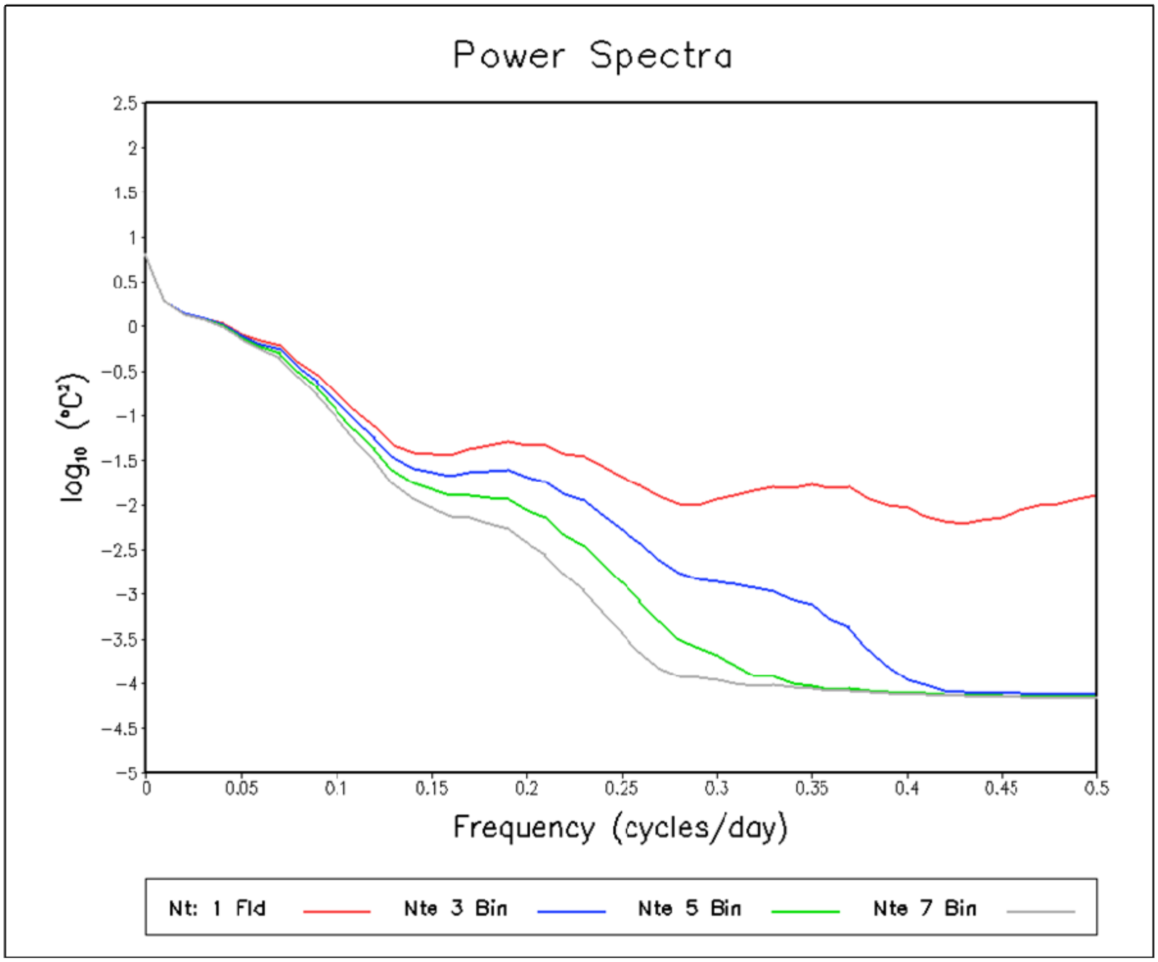

Figure 4. Spatially averaged nighttime AVHRR bias correction spectra for 2000-2005. Binomial 3-point, 5-point and 7-point temporal smoothing are shown; an unsmoothed version is labeled 'Nt 1 Fld'.

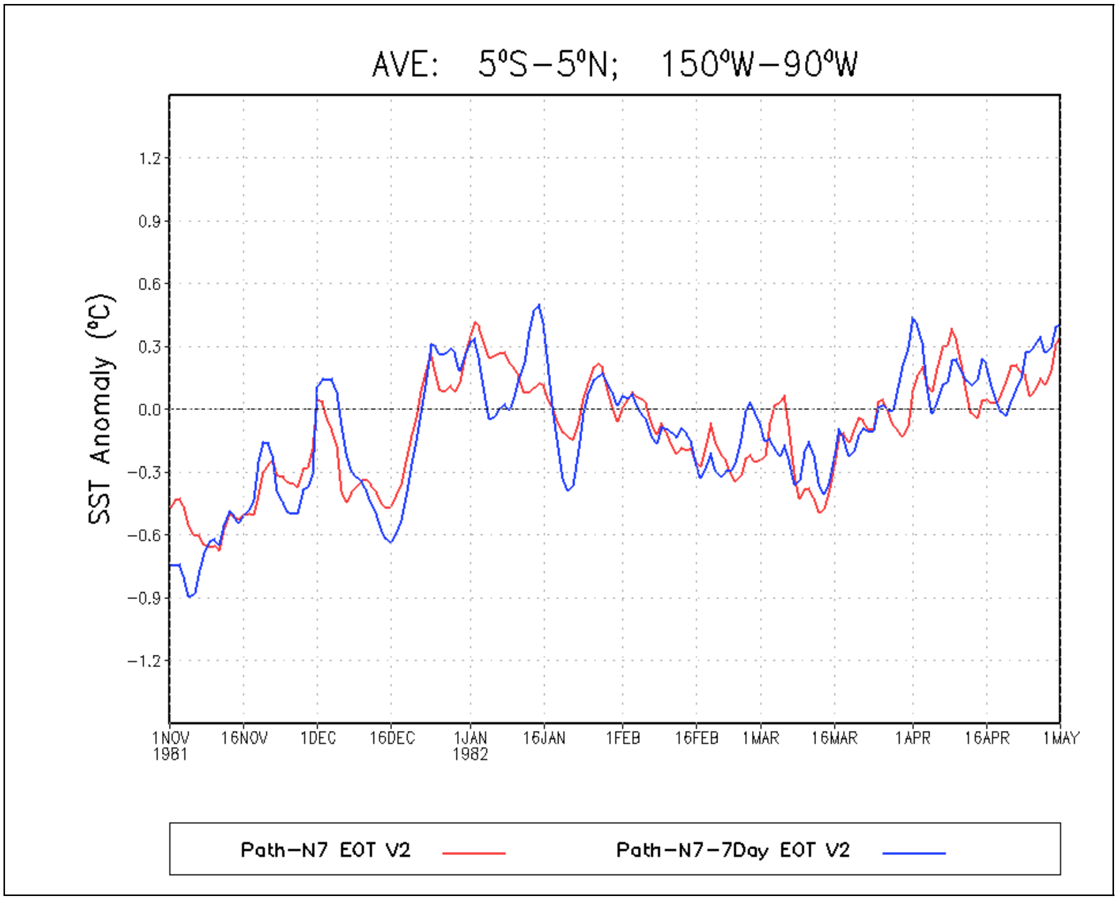

Figure 5. Daily OI Nino-3 anomalies using EOT bias correction with 15 and 7 days of data. 'N-7' indicates that NOAA-7 satellite SST data are used.

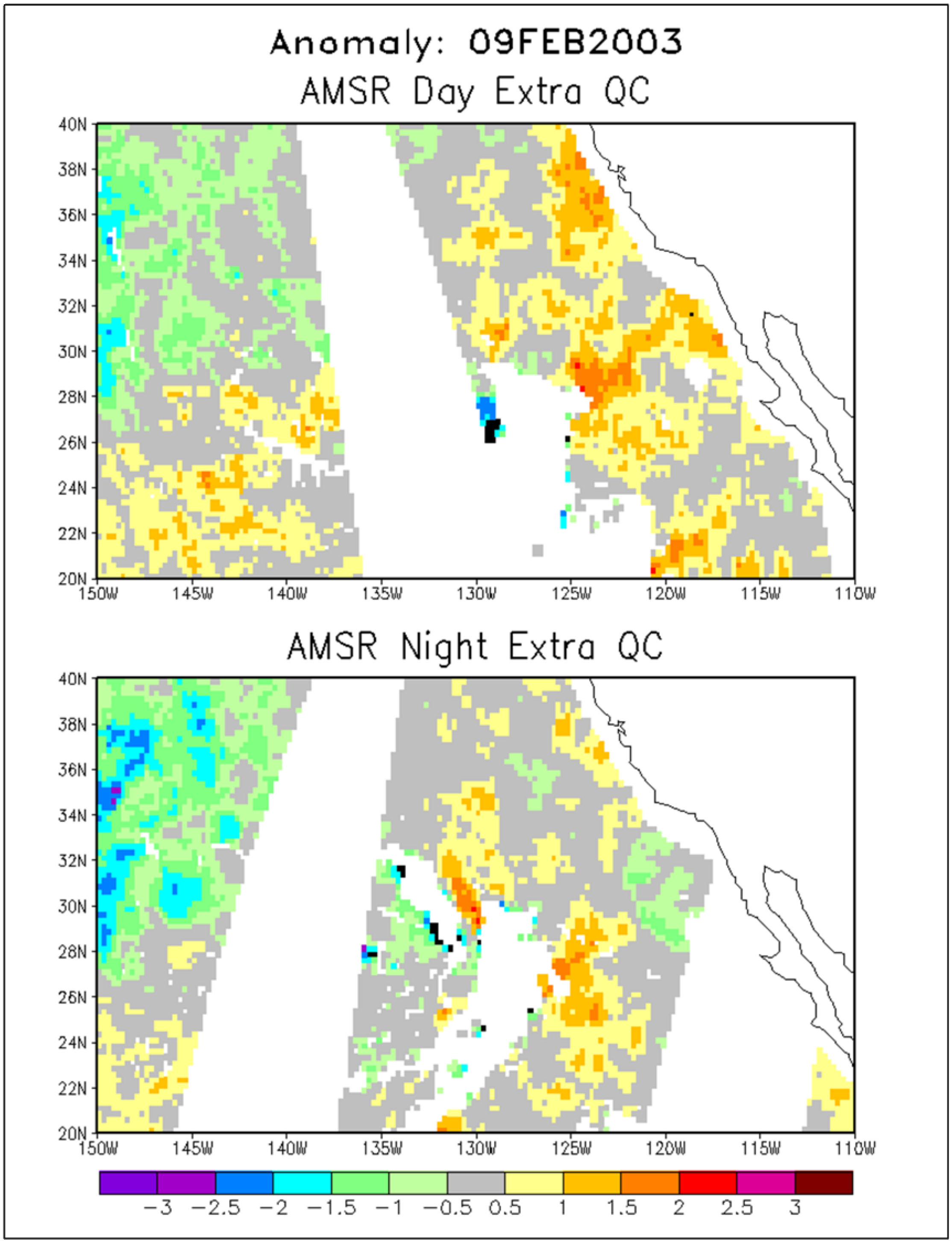

Figure 6. AMSR extra quality controlled SST data anomalies for 9 February 2003. The black regions show where data have been rejected by the extra quality control.