QUALITY CONTROL IN RECENT AND PENDING COADS RELEASES

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ABSTRACT

In the context of the long-term monitoring of global climate, the Comprehensive Ocean-Atmosphere Data Set (COADS) offers the most complete marine surface data collection (1784-1997) currently available for global climate research. Its long duration and the international nature of its data sources necessitate particularly careful quality control (QC) measures. The final portion of COADS QC — flagging statistical outliers and removing them from the computation of areal averages — is referred to as 'trimming'. Based on a review of the trimming impacts of COADS Release 1 (1854-1979), recent COADS Releases 1a (1980-97), 1b (1950-79) and 1c (1784-1949) were modified to allow for a better representation of large-scale climate anomalies such as major ENSO events. This paper summarizes these changes in COADS QC, and discusses related trimming modifications for near-real-time products and future COADS Releases.

1. INTRODUCTION

Preceding most land-based climate records, marine weather observations have been systematically archived for well over a century. The Comprehensive Ocean-Atmosphere Data Set (COADS) (Woodruff *et al.*, 1987) has made this data openly available for global climate research. The original COADS Release 1 (Slutz *et al.*, 1985) covered the world ocean from 1854-1979 with about 72 million marine reports. The most recent COADS update for 1980-97 (Release 1a; Woodruff *et al.*, 1993) adds almost 67 million unique reports to this data bank. Releases 1b and 1c (re-)processed data for the periods 1950-79 and 1784-1949, respectively, which included new data and other improvements (Woodruff *et al.*, 1998; and Woodruff *et al.*, this publication) compared to Release 1. While marine reports were originally derived from observations on board ships of opportunity, the last two decades have seen a steep increase in other sea-borne platforms, most notably moored and drifting buoys launched in international efforts like FGGE, EPOCS and TOGA (Woodruff *et al.*, this publication).

Although individual marine reports are available, the most commonly used products of COADS are monthly summaries for 2° × 2° and, more recently, 1° × 1° latitude-longitude boxes. These summary statistics include the monthly average and median for eight *observed* variables (including sea surface temperature (SST)) and a number of *derived* variables, such as relative humidity, wind stress and heat flux terms (Woodruff *et al.*, 1998).

Surface marine data deviate from land data in several ways. The number of observations per month is not constant in time and space. Marine observations originate from a variety of vessels plying a given ocean region, often from different countries and with different instrumentation, resulting in non-trivial sampling errors. On the other hand, oceanic surfaces are vastly more homogeneous in their physical properties than land surfaces, so they can be more reliably sampled with only a few measurements. In addition, the large heat capacity of water contributes to the high daily to seasonal persistence of SST.

Given the relative importance of each marine observation, comprehensive quality control (QC) procedures have been applied to COADS. In particular, the process of flagging and removing statistical outliers from the computation of 2° box averages is referred to as ‘trimming’ (Slutz *et al.*, 1985). Such outliers were originally defined as individual observations that reside outside the long-term median plus/minus 3.5 ‘standard deviations’ (σ; defined separately for positive and negative departures; see next section for details) for each 2° box. In the *standard* version of COADS Releases 1a-c, the original (3.5σ) trimming limits were kept, but only ship data were admitted (as far as that can be ascertained). In the *enhanced* version, the trimming limits have been expanded to include all observations up to 4.5σ away from *g*, using most ocean surface-based platforms.

In observational data sets, the separation and trimming of statistical outliers from climate extremes is prone to errors. It can either happen that an extreme, but valid, observation is erroneously excluded (statistical Type I error), or that a 'bogus', erroneous observation (a 'true outlier') is included (statistical Type II error). The original COADS trimming procedure was explicitly designed to minimize Type II errors (Woodruff *et al.*, 1987) since these could distort average fields of affected variables. On the other hand, large climate anomalies entail observational distributions close to COADS trimming limits, meaning that the attempt to remove Type II errors through trimming may have led to Type I errors which artificially reduce climatic variability through the COADS record, as first discussed in Wolter *et al.* (1989) and summarized in Wolter (1997), the main topic of which is how to reconcile the competing objectives of trimming erroneous observations while preserving the authenticity of the climate record.

The current paper reflects the fact that most of the research in COADS QC revolves around SST. Nevertheless, many of our comments address more general trimming issues that apply to other COADS variables as well. A brief review of COADS QC is given in section 2. Evidence of trimming errors in Release 1 is presented in section 3. Alternative trimming procedures have been applied to COADS Releases 1a-c, and are summarized in section 4. Pending COADS QC issues are introduced in section 5.

2. COADS QUALITY CONTROL

COADS is intended as a database both for climate and weather studies. While individual records are available as a COADS product, so that synoptic studies can be performed on the complete, uncensored record, COADS monthly summaries provide the basis for many climate studies. For the latter, it is the main objective of COADS to record the climate history of the surface of the world ocean as faithfully as possible. This includes large-scale, extreme climate anomalies such as the 1982-83 ENSO event that lasted well over a month. In a nutshell, the philosophy of COADS QC is to include all observations that reflect typical conditions in a given 2° box, while trying to exclude brief weather extremes and erroneous observations that would seriously distort the mean of a poorly sampled month.

Monthly summaries in COADS Release 1 blend all surface-based marine observations in a single product, be they ship-, buoy-, or ice-based. However, ship data constitute the vast bulk of Release 1 before the 1970s (Table 3-1c, Slutz *et al.*, 1985). In contrast, Releases 1a-c distinguish between exclusive ship records in the *standard* set (as much as this could be ascertained; Woodruff *et al.*, 1993, 1998) and the blended, or *enhanced* set which continues to include a large variety of in situ observations. Otherwise, COADS monthly summaries do not differentiate among observational techniques or platforms. However, such 'metadata' are retained, when available, in COADS individual reports, e.g. the 'platform type' flag in Releases 1a-c.

In general, COADS data are not adjusted for inhomogeneities or biases, since increases in the number of observations typically outweigh concerns about these errors. However, platform types or data sources that are found to introduce significant biases are excluded from monthly summaries. For instance, wind data from drifting buoys and fishing fleet observations were excluded due to their systematic bias towards low wind speeds (Woodruff *et al.*, 1993). There are remaining differences in wind speed between *standard* and *enhanced* COADS Release 1a data (Figure 3, Woodruff *et al.*, 1993), which for regions with moored buoys appear to indicate a localized low bias in the *enhanced* COADS version. In addition, known errors associated with a variety of data sources are corrected on an ongoing basis, as documented in Woodruff *et al.* (this publication) and on pertinent COADS web pages (http://www.cdc.noaa.gov/coads/e-doc/other/).

Given these general principles, the QC procedures applied to the original COADS Release 1 were as follows:

- All marine reports were subjected to an NCDC procedure that checked for observations outside climatological means plus/minus 5.8 standard deviations, developed for 5° boxes on older NCDC files, as well as checks for consistency and code legality. This QC procedure assigned a flag to each report that was used in the selection among duplicate reports. Owing to overlapping data sources, around one quarter of the original input reports were rejected during duplicate elimination processing (Woodruff *et al.*, 1987).
- Observations exceeding the 5° × 5° QC limits were not transferred into the Compressed Marine Reports (CMR) that formed the input records for Release 1 statistics. For missing 5° × 5° limits, observations were transferred to CMR without this QC. In addition, observations exceeding global physical limits for each variable (e.g. air temperatures outside the range of -88°C and +58°C) were excluded from CMR.
- Trimming - the final QC procedure in COADS - was designed to reject statistical outliers and questionable weather observations from 2° monthly summaries. After some smoothing across time and space, upper (lower) trimming limits for each calendar month were defined as the long-term median g plus (minus) 3.5 upper (lower) standard deviations σ_u (σ_l), which derive from the difference between the 5th (1st) sextile and the median of all observations within the trimming period (1854-1909, 1910-49 or 1950-79). Thus, systematically skewed observational distributions were taken into account in the trimming process. Table 1 documents typical values for σ_u and σ_l in sea level pressure (SLP), SST, and wind speed (W), confirming the well-known positive skewness of wind speed measurements, and the mid-latitude negative skewness of SLP observations. All observations outside the trimming limits were excluded from the computation of trimmed monthly 2° × 2° summaries in COADS. Derived COADS variables were trimmed indirectly by using only trimmed observed variables as input (Slutz *et al.*, 1985, Figure A4-1).

Interim COADS summaries (1980-91) and the *standard* version of Releases 1a (1b) for 1980-97 (1950-79) have been trimmed based on the 1950-79 trimming limits. These limits were expanded to include all observations up to $4.5\sigma_{u/l}$ away from the median for the *enhanced* version of Releases 1a and 1b (Woodruff *et al.*, 1993, 1998). In the *standard* version of COADS Release 1c (Woodruff *et al.*, this publication), the original Release 1 trimming limits for 1854-1909 were used for all ship-based data before 1910, and 1910-49 limits for that same period. Analagous to Release 1a and 1b, the *enhanced* version of Release 1c employs expanded $4.5\sigma_{u/l}$ trimming limits (see also: http://www.cdc.noaa.gov/coads/r1c.html).

3. EVIDENCE OF TRIMMING PROBLEMS IN COADS

If the climate of a given area were stationary, standard COADS trimming limits of +/- 3.5σ around the median would typically remove 1 in 2500 observations (i.e. for normal distributions; Slutz *et al.*, 1985). In reality, two independent factors increase the trimming removal rates by inflating the tails of the observational distributions: first, a variety of error-generating mechanisms introduce mostly *random* outliers, and second, climate variability translates into *systematic* shifts of the observational distribution, since this year's climate is different from that of last year.

Considering the first factor, erroneous outliers may be created by missing or altered digits, wrong conversion into SI units, or simply by replacing the true value with zero. The second factor is related to the ratio of interannual variability

Table 1—Upper and lower standard deviations ($\sigma_{u/l}$) for SLP, SST and wind speed (W) in January and July of 1950-79, zonally averaged for 10° latitude belts of interest (using Release 1b data). Mid-latitude data imply negative skewness for SLP and widespread positive skewness for W. Units are in 0.01mb for SLP, 0.01°C for SST, and 0.01m/s for W. Underlined values indicate a 10 per cent surplus in σ_u vs. σ_l, or σ_l vs. σ_u.

Lat.	SLP (jan)		(jul)		SST (jan)		(jul)		W (jan)		(jul)	
	σ_u	σ_l	σ_u	σ_l	σ_u	σ_l	σ_u	σ_l	σ_u	σ_l	σ_u	σ_l
50-30S	194	$\underline{212}$	267	$\underline{296}$	42	42	34	34	$\underline{128}$	112	$\underline{130}$	114
30-10S	118	124	135	141	45	45	45	44	$\underline{131}$	118	$\underline{149}$	134
10N/S	101	101	91	92	45	43	48	46	121	111	125	114
10-30N	234	251	155	166	85	84	76	74	$\underline{255}$	227	$\underline{208}$	189
30-49N	732	$\underline{834}$	377	$\underline{429}$	127	124	144	146	$\underline{440}$	362	$\underline{290}$	244
50-69N	752	799	430	470	73	71	100	100	$\underline{341}$	284	$\underline{257}$	216

versus sub-monthly variability. If short-term variability within a calendar month is large, trimming limits tend to be wide and accommodate large interannual variability as well. If short-term variability is small, it may result in narrow trimming limits, which can screen out valid observations associated with large interannual climate anomalies (statistical Type I errors; Wolter, 1992). Note that systematic skewness-related departures from the normal distribution are addressed via upper and lower standard deviations (Table 1), and are not considered to be an important trimming problem.

The most prominent examples of Type I trimming errors were found for tropical Pacific SST which, in association with persistent ENSO conditions, can lead to significant distortions of the climate record for those regions (e.g. Wolter, 1997). Here, we reproduce a figure from Wolter *et al.* (1989) for January 1878, at the zenith of the biggest known El Niño of the 19th century (Kiladis and Diaz, 1986). Within the general area chosen here (10°N-10°S, 80°-180°W), two thirds of all observations were rejected, although the most anomalous observation was less than 5°C above its applicable long-term median g (Figure 1(a)). Note how 'normal' the distributions of SST anomalies appear in Figures 1(a) and (c), which include all observations, and how 'truncated' they appear if only observations within the trimming limits are considered (Figures 1(b) and (d)). The highest reported untrimmed SST within the domain in January 1878 is just above 30°C for a 2° box and 31°C for an individual observation, certainly within plausible limits of tropical SST. In sum, excessive trimming reduces the SST anomaly by up to 1°C for the ENSO event of 1878. Similar errors were found for the peak of the 1982-83 El Niño (Wolter, 1997), which, until recently, was considered as the strongest El Niño of the 20th century, justifying a major revision of COADS trimming procedures.

Excessive trimming can also be found for other variables, and outside the tropics, for instance near polar ice-edges where marine observations are rare to begin with. However, tropical Pacific SST trimming losses have received the most attention due to their systematic, direct impact in the assessment of ENSO events and associated global climate anomalies, while other trimming losses appear less systematic and widespread, and with unknown ramifications for global climate.

Wind variables could probably be trimmed better than in the current procedure which analyses zonal and meridional wind components separately, removing all wind information if either component fails the test. This procedure can be argued to censor winds from the four cardinal wind directions more frequently than winds from other points of the compass. Of course, there are

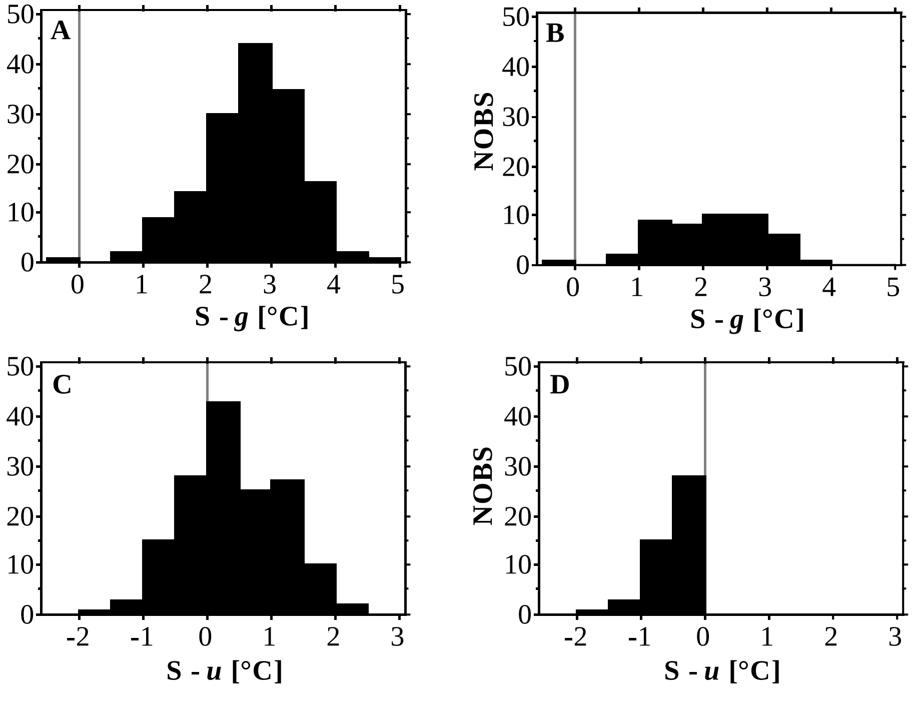

Figure 1—Histograms of general ENSO area [10°N-10°S, 80°-180°W] SST anomalies for January 1878. Frequencies are given for individual SST observations (S) minus the applicable local long-term median (g) for January 1854 - 1909, computed for each 2° box separately: (a) untrimmed, (b) trimmed. Analogous frequencies are shown for S minus the applicable local upper trimming limit (u) for the same period: (c) untrimmed, (d) trimmed. Data are from COADS Release 1. Bins are partitioned into 1/2°C intervals, with observations being greater than the lower boundary, and smaller than or equal to the upper boundary (after Wolter et al., 1989).

many other problems associated with wind estimation and measurements (Woodruff *et al.*, 1998) that will need to be addressed in future COADS updates (see also section 5).

Prior to the creation of COADS Release 1a, tests were run on 1970-89 data to delineate excessive trimming removals for all primary COADS variables. In turn, this information was used to determine the scope of trimming procedure changes appropriate for Release 1a. Differentiated by variable and decade (Table 2), the fraction of global $3.5\sigma_{u/l}$ trimming removals in the number of observations is highest in SST (generally above 2 per cent), followed by air temperature and wind (well above 1 per cent), and lowest for SLP and relative humidity (about 1 per cent). Lower trimming rates for non-temperature variables are probably due to the inherently larger variability and noisiness of these fields, resulting in wider trimming limits.

Trimming removal rates in 1980-92 are more than cut in half by widening the trimming limits from $3.5\sigma_{u/l}$ to $4.5\sigma_{u/l}$ (using the identical set of *enhanced* input data; Table 2). Based on the examination of histograms of individual observations in selected areas, global trimming removal rates of up to 1 per cent appear justifiable, presumably associated with digitization and communication errors. Any remaining trimming losses are inferred to be statistical Type I errors.

4.

ALTERNATIVE TRIMMING IN COADS RELEASES 1A-C

Given the extent of the trimming problems discussed in the previous section, it was decided to modify the COADS trimming procedure for Release 1a, while preserving continuity with Release 1. In statistical terms, the balance of Type I to Type II errors was shifted from mainly minimizing Type II errors to minimizing errors of both types.

After some experimentation with different trimming approaches, we decided to inflate the existing limits from $3.5\sigma_{u/l}$ to $4.5\sigma_{u/l}$. This was the method implemented in the *enhanced* version of COADS Release 1a, because $4.5\sigma_{u/l}$ trimming limits appeared to be far more accommodating to extreme climate states than $3.5\sigma_{u/l}$ limits, while still removing the vast majority of true statistical outliers. This was verified with histograms, and with correlation maps of trimming losses compared to regional anomalies. A more drastic inflation of trimming limits to $5\sigma_{u/l}$ was rejected, because the increased risk of admitting statistical outliers was not outweighed by better accommodation of climate extremes.

Given the interest in a data set for 1980-92 that was compatible with COADS Release 1 (1854-1979), which consists mostly of ship data, a *standard* set of the monthly trimmed 2° box summaries was produced for COADS Release 1a that keeps the original trimming limits established for 1950-79 and admits only ship data (as far as it can be ascertained). In contrast, 1950-79 trimming limits for the *enhanced* set have been expanded to include all observations up to $4.5\sigma_{u/l}$ away from *g*. It includes most ocean surface-based observational platforms. Further processing details are given in Woodruff *et al.* (1993), while Wolter (1997) documents the improved spatial patterns of global trimming losses in SST (and SLP) fields.

Subsequently, *standard* and *enhanced* sets with $3.5\sigma_{u/l}$ and $4.5\sigma_{u/l}$ trimming limits, respectively, were created in the same fashion for 1950-79 data for COADS Release 1b data (Woodruff *et al.*, 1998), even though this period was characterized by less extreme ENSO events and a large majority of conventional ship-board observations (Woodruff *et al.*, this publication). However, consistently trimmed

Table 2—Global trimming removal rates (in percentage of total number of observations for each variable) for air temperature (AT), SLP, relative humidity (RH), SST, and zonal and meridional (U&V) wind. These are listed for COADS Release 1 data from the 1970s (Table 3-3 in Slutz et al., 1985), for interim *data from 1980-91, and for Release 1a data from 1980-92. The* enhanced *$3.5\sigma_{u/l}$ portion of this table is based on an analysis of all individual observations (i.e. an* enhanced *platform mix flagged in the* standard *($3.5\sigma_{u/l}$) manner). For details (see Wolter, 1997).*

	AT	*SLP*	*RH*	*SST*	*U&V*
1970-79, $3.5\sigma_{u/l}$	1.5	0.9	0.4	2.3	1.4
1980-91, *interim* $3.5\sigma_{u/l}$	2.5	1.6	0.6	3.4	1.9
1980-92, *standard* $3.5\sigma_{u/l}$	1.9	1.3	0.4	2.9	2.2
1980-92, *enhanced* $3.5\sigma_{u/l}$	1.9	1.5	0.4	2.6	2.1
1980-92, *enhanced* $4.5\sigma_{u/l}$	0.8	0.6	0.1	1.1	0.8
1980-92, *enhanced* ($3.5\sigma_{u/l}$ -$4.5\sigma_{u/l}$)	1.1	0.9	0.3	1.5	1.3

versions of COADS from 1950 through to 1997 are useful in the assessment of interannual and decadal climate variability (e.g. IPCC, 1996).

Most recently, *standard* and *enhanced* sets were created for COADS Release 1c (1784-1949) in a similar manner (Woodruff *et al.*, this publication), but utilizing original trimming information (g, $\sigma_{u/l}$) from 1854-1909 for the early part of the record (1784-1909), and 1910-49 trimming limits for the latter four decades. These trimming periods were originally designed to accomodate the historic shift from sailing ships and early steamers to 20th century observing platforms (Slutz *et al.*, 1985). There is a remaining concern that even *enhanced* trimming limits at $4.5\sigma_{u/l}$ may still lead to excessive Type I errors under extreme ENSO conditions (Figure 1; also Wolter, 1992). However, the addition of substantial new data (Woodruff *et al.*, this publication) without the resources to recompute trimming limits necessitated this compromise solution.

5.
PENDING COADS QC ISSUES

A variety of near-real-time observational and statistical products are produced by CDC within the COADS framework, using marine data supplied by the National Center for Environmental Prediction (NCEP). The most recent El Niño ‘event of the century’ (1997-98) serves to remind us that extreme climate events and their associated trimming problems are not just a phenomenon of the past (Figure 2). In fact, both in terms of the measured SST anomalies in late 1997, and in terms of $3.5\sigma_{u/l}$ trimming losses, the most recent El Niño event even surpassed 1982-83 (compare current Figures 2(a) and (b) against Figures 2 and 5 in Wolter, 1992, respectively).

Near-real-time monitoring should be undertaken in a consistent manner with recent COADS Releases. In that context, current trimming limits at the ‘inherited’ $3.5\sigma_{u/l}$ level should be replaced with $4.5\sigma_{u/l}$ limits. Given the recent shift towards non-traditional marine observing platforms (Woodruff *et al.*, this

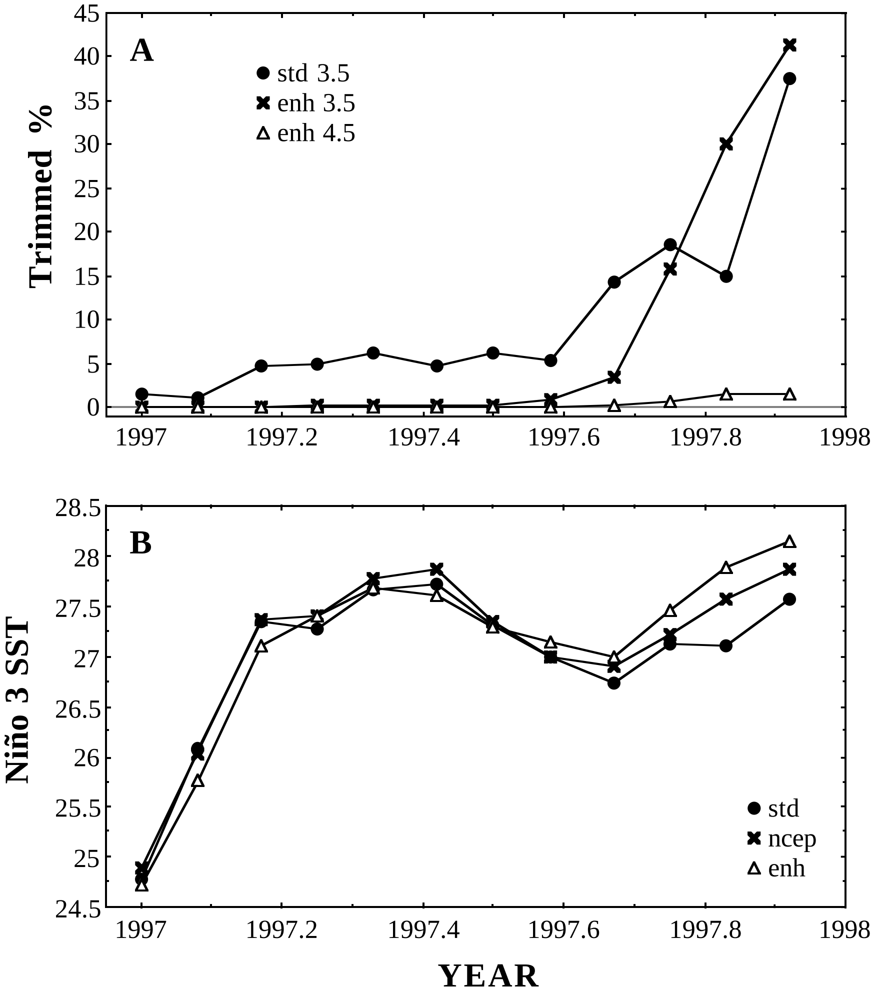

Figure 2—Impact of the 1997 El Niño event on the Niño 3 region [2°N-10°S, 90°-150°W] SST. The first panel (a) shows the monthly trimming losses during 1997 for the standard *and* enhanced *COADS Release 1a data (labelled std 3.5 and enh 4.5), as well as the hypothetical trimming losses for the* enhanced *platform mixture trimmed at* $3.5\sigma_{u/l}$ *(enh3.5). The latter most closely mimics the near-real-time trimming setting whose trimming rates are not available. The second panel (b) shows the resulting monthly SST for the same region and year, in the* standard *and* enhanced *COADS sets, as well as in the near-real-time (NCEP) product.*

publication), a single *enhanced* near-real-time product that encompasses all platforms at the 4.5$\sigma_{u/l}$ trimming level should be sufficient for most purposes.

However, the TOGA-TAO moored buoy array transmits over the GTS during local daytime only, for logistic and cost-saving reasons (cf. http://www.pmel.noaa.gov/toga-tao/gts.html). It contributes a large fraction of real-time SST observations in the tropical Pacific. This raises the possibility of a warm bias due to daytime heating of the sea surface. In the Release 1a (1980-97) update we were able to replace GTS receipts of TOGA-TAO data with delayed-mode data obtained from PMEL. During the latter half of 1997, the potential positive bias due to real-time TOGA-TAO data may have partially cancelled out the negative bias due to the conventional trimming limits (3.5$\sigma_{u/l}$) employed in COADS near-real-time processing (Figure 2(b)). In order to best adjust for the potential daytime bias by the TOGA-TAO array, historic differences should be assessed between daytime only and full 24-hour records for all TOGA-TAO moored buoys.

Trimming should not be considered in isolation. It is an important part of comprehensive QC procedures applied to COADS. Future COADS updates (such as Release 2) may include separate products for different times-of-day and types of observational platforms. These goals need to be balanced against the penalties of reduced sample sizes. Especially in the early instrumental record, observations were so few and far between that any attempt at more sophisticated QC measures is severely handicapped.

Nevertheless, collaborative efforts are under way (Woodruff *et al.*, this publication) to further improve COADS QC. As originally discussed in Wolter (1992), trimming should apply to the scatter of observations about the *individual* monthly median rather than about the *long-term* median g. This type of trimming has been hampered in the past in regions of low observational density, but optimum interpolation techniques can be brought to bear at least on SST fields to capture the large-scale monthly mean (or median) fields correctly, as described in Reynolds and Smith (1994). Similar improvements in the trimming of wind observations are considered to be important as well. The proper balance of Type I and Type II error will remain an active research topic in COADS for many years to come.

ACKNOWLEDGEMENTS

The numerous discussions with Henry Diaz, Roy Jenne, Dick Reynolds and Steve Worley on COADS QC are gratefully acknowledged. We also thank the anonymous reviewers for their insightful comments that hopefully led to an improved manuscript. This research has been supported through EPOCS and the NOAA Climate and Global Change program.

REFERENCES

IPCC (Intergovernmental Panel on Climate Change), 1996: *Climate Change 1995. The Science of Climate Change.* Cambridge University Press, Cambridge, xii + 572 pp.

Kiladis, G.N. and H.F. Diaz, 1986: An analysis of the 1877-78 ENSO episode and comparison with 1982-83. *Mon. Wea. Rev.*, 114, 1035-1047.

Reynolds, R.W. and T.M. Smith, 1994: Improved global sea surface temperature analyses using optimum interpolation. *J. Climate*, 7, 929-948.

Slutz, R.J., S.J. Lubker, J.D. Hiscox, S.D. Woodruff, R.L. Jenne, D.H. Joseph, P.M. Steurer and J.D. Elms, 1985: Comprehensive Ocean-Atmosphere Data Set (COADS). Release 1. NOAA Environmental Research Laboratories, Boulder, CO, 268 pp.

Wolter, K., 1992: Sifting out erroneous observations in COADS—the trimming problem. *Proceedings of the International COADS Workshop* (Boulder, Colorado, 13-15 January 1992). H.F. Diaz, K. Wolter and S.D. Woodruff, Eds., NOAA Environmental Research Laboratories, Boulder, CO, 91-101.

Wolter, K., 1997: Trimming problems and remedies in COADS. *J. Climate*, 10, 1980-1997.

Wolter, K., S.J. Lubker and S.D. Woodruff, 1989: Trimming — a potential error source in COADS. *Tropical Ocean-Atmosphere Newsletter*, 51 (Summer 1989), 4-7.

Woodruff, S.D., S.J. Worley, J.A. Arnott, H.F. Diaz, J.D. Elms, M. Jackson, S.J. Lubker and D.E. Parker, 2001: COADS updates and the blend with the UK Met Office

Marine Data Bank. *WMO Guide to the Applications of Marine Climatology,* WMO/TD-No. 1081, 2003, JCOMM Technical Report No. 13.

Woodruff, S.D., R.J. Slutz, R.L. Jenne and P.M. Steurer, 1987: A comprehensive ocean-atmosphere data set. *Bull. Amer. Meteor. Soc.*, 68, 1239-1250.

Woodruff, S.D., S.J. Lubker, K. Wolter, S.J. Worley and J.D. Elms, 1993: Comprehensive Ocean-Atmosphere Data Set (COADS) Release 1a: 1980-92. *Earth System Monitor*, 4, No. 1, 6 pp. [on-line at: http://www.cdc.noaa.gov/coads/coads1a.html].

Woodruff, S.D., H.F. Diaz, J.D. Elms and S.J. Worley, 1998: COADS Release 2 data and metadata enhancements for improvements of marine surface flux fields. *Phys. Chem. earth*, 23, 517-527.