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LARGE-SCALE SATELLITE-OBSERVED SSTs DURING THE 1980s AS COMPARED WITH CONVENTIONAL SSTs

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1. INTRODUCTION

Data from NOAA's polar orbiting satellites have been used to attempt global mapping of sea surface temperature for the past 17 years (Yates et al. 1986). These remotely sensed retrievals became considerably more accurate following the launch of the AVHRR (Advanced Very High Resolution Radiometer) in late-1978. Multi-channel SSTs (MCSST) have been computed operationally from AVHRR data since late-1981.

Various authors (Bernstein 1982, Strong and McClain 1984, McClain et al. 1985, McClain 1989) have presented statistics indicating RMS differences ranging from ±0.4 to 0.6°C between co-located in-situ buoy SST and satellite MCSST observations. Most importantly the biases of these monthly match-ups when compared with the drifters continue to show small and random biases (e.g., ±0.3°C maximum), with small nighttime monthly mean biases frequently compensating in sign for small daytime biases.

The purpose of this paper is to compare annual MCSST with in-situ (ship and buoy) short-term oceanic surface temperature tendencies for the eight year period from 1982 to 1989. Having combined both daytime and nighttime satellite observations into composite annual means we would expect that little effect will remain of an occasional bias problem noted during late-1988 and early-1989 between daytime and nighttime satellite retrievals over the western tropical Pacific Ocean (Reynolds et al. 1989). Making use of the copious, although admittedly brief, MCSST database with its 3-5 million monthly MCSST observations between 60N and 60S, some notable tendencies are observed in both MCSST and in-situ SST records during the decade of the 1980s.

With the wide ranging diversity of atmospheric conditions through which MCSSTs are corroborated using drifting buoys, there is no reason to suspect accuracies should be any less in those ocean areas where drifting buoy match-ups happen not to be available. The primary exception to accurate MCSST determinations since 1982 was associated with a contamination from stratospheric aerosols from the April 1982 eruptions of El Chichón. This negative offset incorporated within the MCSST measurements was chiefly a Northern Hemisphere event that lasted through October 1983. Although most of the effect was to severely limit the MCSST retrieval density over large areas between 10N and 30N during the six months following the eruption, negative biases appear in the data set until late 1983 (Strong 1984). For this reason earlier presentations of monthly hemispheric short-term (1982-89) trends have been improved by substituting ship and buoy SST monthly mean calculations for questionable MCSSTs during the 1982 and 1983 period until they can be corrected (Robock 1989, Strong, 1989a).

2. DATA AND METHODS

In order to remove monthly or seasonal variabilities, anomalies derived from the Robinson-Bauer climatology are considered in the following annual mean presentations of global and hemispheric data. The data also have been separated latitudinally and by ocean basin to further examine compatibility and time series tendencies. The grid used for all these data is the 2.5 degree latitude/longitude interval previously used by Strong (1989b), and no analyzed conventional data have been used in these calculations. Although this presents little difficulty with the MCSST computations, since virtually all grid-quadrangles have well over 100 observations for each monthly computation, this is not the case with many of the grid values for in-situ data. Frequently, especially south of 10N, grid point values are computed from less than ten monthly in-situ SST observations during a given month.

3. RESULTS

Eight-year tendencies are presented for global, Northern Hemisphere, Southern Hemisphere SSTs in Figures 1, 2, and 3, respectively.

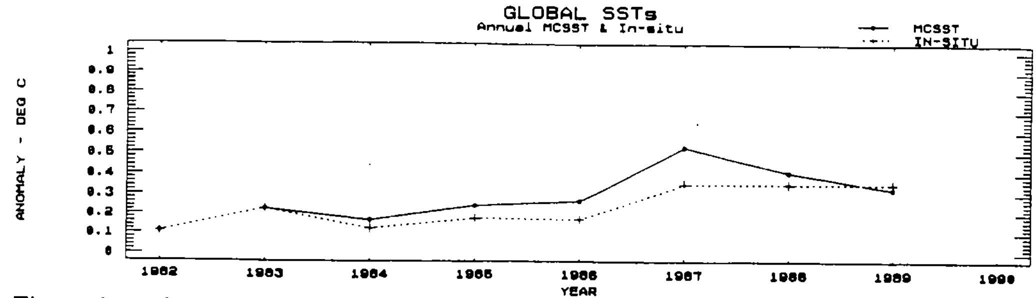

Figure 1 *Annual global MCSST and in-situ SST departures from climatology (°C) for the period 1982 to 1989.*

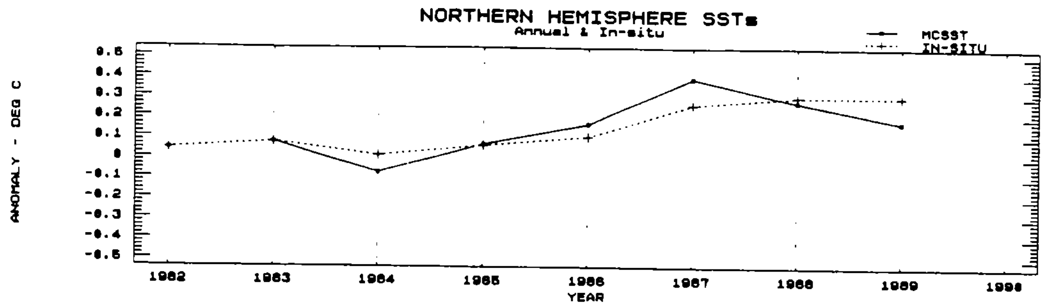

Figure 2 *Same as Fig. 1 except for Northern Hemisphere only.*

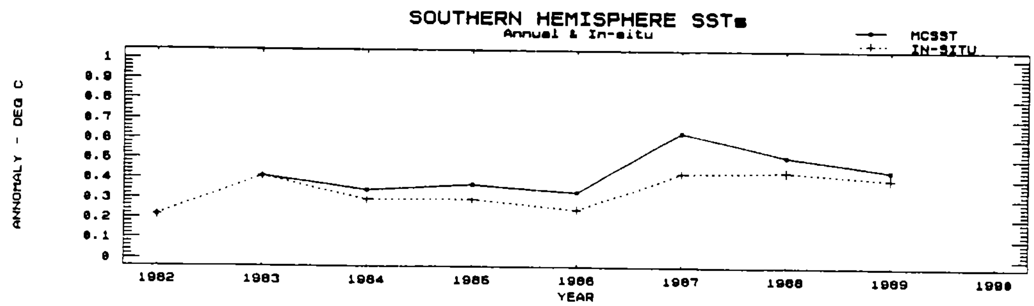

Figure 3 *Same as Fig. 1 except for Southern Hemisphere only.*

In general, more variability is seen in the MCSST than in the in-situ SST year-to-year anomalies. MCSST data show warmer conditions during the 1987 El Niño and, in the Northern Hemisphere, lower SSTs following the 1982/3 and 1987 El Niño than shown by the in-situ data. Nevertheless, using annual data, the upward linear regressions in both data sets in Table 1 do not show any statistically significant differences, i.e. their standard errors all overlap. Interestingly, although concern has been expressed that MCSST values have been erroneously too high at times, the Northern Hemisphere results (Fig. 2) are now revealing in-situ data that exceed the MCSST levels using these processing procedures. Furthermore, the upward trend in the in-situ data over the Northern Hemisphere show the most significant upward trend during this eight-year period (Table 1). Significant also, in this record is the somewhat faster increase in SST over the Northern Hemisphere compared to the Southern Hemisphere, particularly shown by the in-situ data.

AREA	SLOPE - DEG/YEAR		STANDARD ERROR	
	MCSST	IN-SITU	MCSST	IN-SITU
Global	0.042	0.036	0.014	0.009
Northern Hem	0.040	0.044	0.018	0.009
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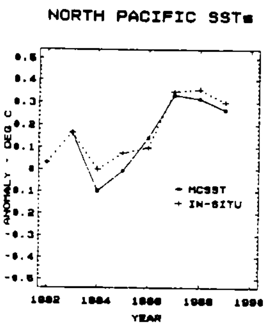
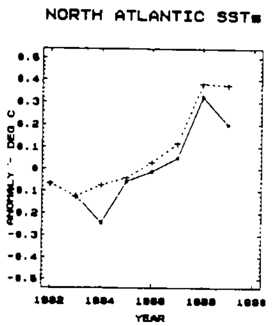
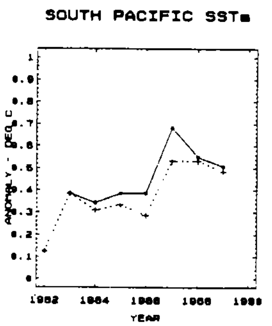
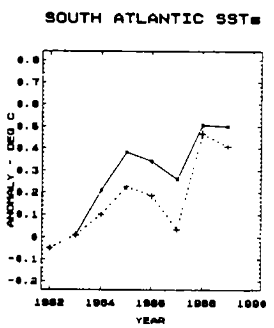
Table 1. *Regional and Zonal variations in SST for both satellite and in-situ data. Standard errors for the slope calculations are included.*

Further observations can be made about the following basins: North and South Pacific Ocean, Figures 4/5; North and South Atlantic Ocean, Figures 6/7; and Indian Ocean, Figure 8. There is good overall correspondence between the two data sets in virtually all areas. Note how well the large excursions seen in the Indian Ocean anomalies are supported by both satellite and conventional SSTs. Both excursions are undoubtedly a function of the El Niños of the 1980s and provide further evidence of air-sea teleconnections between the Indian and Pacific Oceans that has been discussed by Cadet (1985).









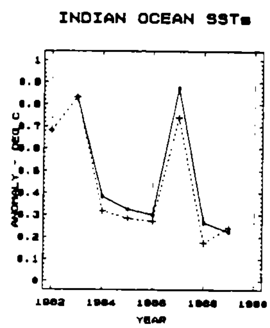


Figure 4 *Same as Fig. 1 except for North Pacific basin only.*

Figure 5 *Same as Fig. 1 except for South Pacific basin only.*

Figure 6 *Same as Fig. 1 except for North Atlantic basin only.*

Figure 7 *Same as Fig. 1 except for South Atlantic basin only.*

Figure 8 *Same as Fig. 1 except for Indian Ocean basin only.*

Remembering that most of the drifting buoys used to establish the MCSST algorithms resided in the Southern Hemisphere, we note that the best correspondence between the two data sets is found in the Northern Hemisphere, where data density for the ship and buoy data set is highest. It is our contention that much of the discrepancy between conventional and MCSST annual values in the Southern Hemisphere is due to reduced data coverage from in-situ sources. From these presentations, it can be seen that over the Northern Hemisphere the greatest SST increases during this period are occurring in the North Atlantic -- with the in-situ annual means increasing slightly faster, although not significantly so, than the satellite means. Again, as with the earlier hemispheric and global cases, Table 1 shows that all tendencies have "standard error bars" that overlap, suggesting there is no significant disagreement between these two data sets. Other than this larger Atlantic Ocean change, perhaps the most noteworthy observation is the observed decrease recently seen in the Indian Ocean trend, apparently associated through teleconnections with the decrease in equatorial Pacific SST following the 1987 El Niño. Temperatures over the Indian Ocean during 1988 and 1989 have been averaging annually below anything observed during the rest of this past decade. When reviewing this basin's annual time series over the period it is apparent that the extreme scatter from the two high-anomaly spikes, coinciding with the 1983 and 1987 El Niños, is responsible for the greater standard errors derived over this region.

From the eight-year trends summarized in Table 1, the most significant rises over this relatively short period are on both sides of the equator in the Atlantic Ocean. Here upward tendencies are seen that are nearly double the rate seen on the global ocean scale. It is apparent that the Indian Ocean, whose surface area represents 21% of the global oceans, has been cooling, helping to offset some of the overall effect of a more rapidly warming Western Hemisphere (and Northern) during the 1982-89 period. Although much of the area of the Indian Ocean lies in the Southern Hemisphere (approximately 90%), both the trend and year-to-year variations in anomaly bear no resemblance to those being seen in the other two oceans of the Southern Hemisphere.

Displaying SST tendencies zonally provides another way to monitor our ocean's variabilities and trends. This is useful because for the most part our planet's climate regimes are best categorized zonally. Zonal slices from the data sets used here have been selectively analyzed for every ten degrees of latitude from the 2.5 degree latitude/-

longitude oceanic grid. Figure 9 presents time-series tendencies for these twelve zones from 60N to 50S for the satellite and conventional SST data sets. Trends and standard errors of these tendencies are summarized in Table 1. From these zonal analyses the similarities in short-term tendencies at approximately the same latitudes in each hemisphere can be compared. Although the only error bars that do not overlap occur at 30S, that higher trends are seen at *both* 30N and 30S may give more credence to the trends seen in these areas than otherwise.

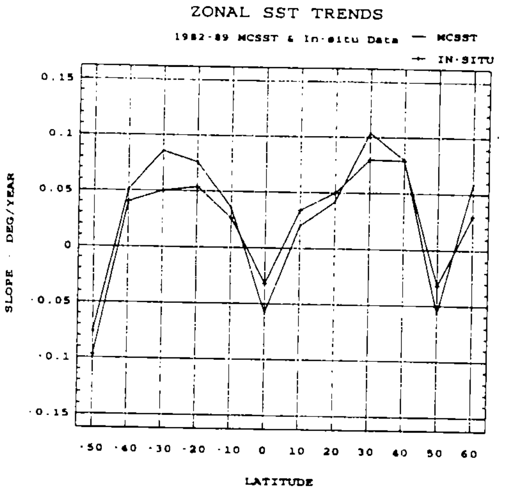


Figure 9 *Zonal tendencies from satellite and conventional data sources between 1982 and 1989 as a function on latitude. See Table 1 for standard errors accompanying each location and data type. (All overlap except 30S location.)*

With the recent discussions of tropical surface warming (Nitta and Yamada 1989) it should be noted that Figure 9 indicates both in-situ and satellite data sets show similar but slightly *cooling* equatorial surface tendencies, which are in opposition to the warming found at subtropical latitudes. At higher latitudes in both hemispheres, these overall SST increases can be seen to fall off, the trends becoming negative at 50N and 50S. Again, what appears most significant from these data sets is the symmetry in tendency apparent over both hemispheres. Poor in-situ SST coverage over the Southern Hemisphere around 30S may help to explain the largest discrepancies between the MCSST and in-situ trends. (Development of the operational MCSST algorithms have extensively employed drifting buoys from this ocean region - giving further weight to their credibility in these latitudes.)

One final latitudinal comparison has been recently made using all the individual monthly mean MCSST and in-situ SST data. This examination was similar to the technique used to examine the El Chichón eruption cloud distribution and evolution that considered the difference between the MCSST and in-situ SST data over the 1982-89 time frame. Figure 10 shows that over high latitudes of the Northern Hemisphere (50N - 60N) a very decided seasonal difference persists that could indicate an in-situ measurement contamination. During the colder winter and early spring months in-situ monthly means cycle to values typically 1°C higher than MCSST. This effect can be seen to latitudes as low as 40N. During the summer months, a reverse offset can be seen in this same data comparison between 25 and 45N. In the southern hemisphere, these features are less conspicuous, probably due to the poorer in-situ coverage.

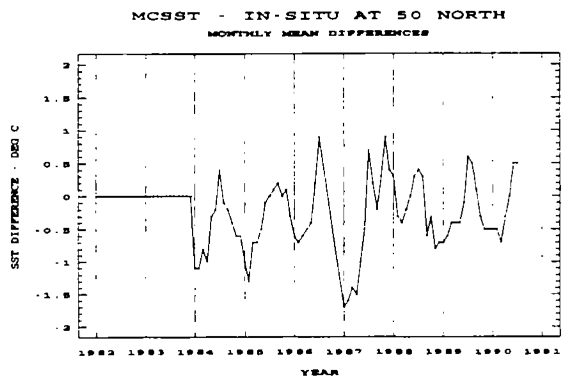


Figure 10 *Differences between MCSST and in-situ SST at 50N latitude for the complete monthly data set.*

4. DISCUSSION

If a case can be made for any increase in SSTs during the 1980s from these analyses, it would be for the subtropical ocean regions -- 20-40° N and S and the Atlantic Ocean. Regions along the Equator, at least globally, appear to show small cooling tendencies as does the entire Indian Ocean. Zonally, the higher latitudes around 50N and S exhibit negative trends during the decade. It should be noted that the low to mid-latitude regions showing greatest increases are dominated by large anti-cyclones in the atmosphere, and they overlie large oceanic anticyclonic gyres in the respective ocean basins. Higher SSTs over these latitudes may indicate a slight migration of th features during the recent 8-year period being considered here and/or changing cloud coverage amounts. The tendencies, furthermore, would indicate a broadening of the warmer tropical waters and a poleward displacement and slight increase of the north-south SST temperature gradient. Provided these trends continue in a similar fashion over the next decade, there are implications for some significant redistributions of heat over the planet's oceans.

As climatologists continue to watch both oceans and atmosphere for signals of changing temperatures from predicted "greenhouse" related adjustments in our coupled air-sea environment, the questions are where should we watch and what should we expect to observe? Recently some sophisticated models have begun to point to certain zones and regions where responses might be most notable. NOAA's GFDL (Geophysical Fluid Dynamics Laboratory) results (Manabe and Stouffer 1988, Stouffer et al. 1989) from their coupled ocean-atmosphere model reveal that little change in SST is expected due to global warming in the region of the Antarctic Convergence -- even some decrease in SST could occur. Their model predicts considerably larger increases should be seen over the Northern Hemisphere where a higher land/sea ratio exists than over the Southern. The results presented here appear to be consistent with these preliminary GFDL findings.

Results from the NASA/GISS (Goddard Institute for Space Science) three-dimensional model (Hansen et al. 1988) target the "low-latitude" oceans for significant warming from augmented greenhouse conditions. The region of 30S exhibits notable warming over the oceans by the 1990's in their "Scenario B". The Northern Hemisphere warming zonal band appears around 40N in the GISS results. Our zonally stratified calculations for tendencies during the 1980s are qualitatively consistent with the findings from the GISS model. Quantitatively, their model shows these ocean areas could expect somewhat more than 0.5°C increases over the decade. Our tendencies over this area are not significantly different.

Possibly the biggest surprise in our findings is the strong apparent correlation between the Indian Ocean SST tendencies and El Niño events in the tropical eastern Pacific. The two warm events from the 1982/3 and 1987 El Niños are mirrored strongly in the average Indian Ocean basin anomalies. Walker (1923) and Berlage (1957) argue that a strong coupling exists between the atmospheres over the South Pacific and the Indian Ocean. Pressures of the lower atmosphere over these two regions correlate strongly, but negatively, in a "seesaw" (Rasmusson and Wallace 1983) effect that points to a strong inter-relationship between these two large ocean areas.

Incorporation of additional MCSST data during the 1990s should help reduce the dependency of trends in these time series resulting from the periodic and far reaching effects of El Niño events. It has been suggested that considering only grid locations with coincident satellite and in-situ values would help remove much of the remaining discrepancies between the two global data sets. If that turns out to be the situation, an excellent case can be made for continuing and maintaining this MCSST time-series to adequately monitor our entire planet's SST, particularly in the Southern Hemisphere.

The differences noted above between the differences of the monthly means of MCSST and in-situ SST during certain seasons may indicate some residual intake or ship effect. Contamination from the heated vessel during winter and air-conditioning in summer would account for the observed seasonal offsets in the in-situ data set. Since these opposing effects are not being observed at the same latitude they do not cancel out when the annual means are considered.

5. ACKNOWLEDGMENTS

The authors are indebted to the continued support, encouragement, and suggestions provided by E.P. McClain, R. Legeckis, and G. Ohring. Helpful suggestions from R. Reynolds and C. Folland provided further direction to the analysis and presentations of these comparison.

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GLOBAL, REGIONAL, AND ZONAL SEA SURFACE TEMPERATURE SIGNALS FROM SATELLITE AND IN-SITU OBSERVATIONS DURING THE 1980s

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ABSTRACT

A time-series of AVHRR derived multi-channel sea surface temperatures (MCSST) has been compared with ship and buoy SST data during the 1982-89 period. Monthly mean results have been converted to annual means to reduce serial dependencies between months. Data separated both into regional and latitudinal time-series show favorable agreement between the satellite and conventional SSTs. Comparisons with the NOAA/GFDL coupled atmospheric/ocean model results (EOS, 70,43 p.1002) indicate that certain changes in some ocean areas may be beginning recently that have been identified as changes to be expected in global warming scenarios. For example, during the past decade the southern hemisphere "ocean" has been warming at a slower rate (0.03C/yr) than is seen over the northern hemisphere "ocean" (0.04C/yr). Our time-series show that during this (albeit short) 8-year record several regions are not showing warming, rather a cooling: the Indian Ocean (-0.05C/yr), the high latitude southern ocean (-0.08C/yr); and the equatorial oceanic belt (-0.06C/yr).

1. INTRODUCTION

Data from NOAA's polar orbiting satellites have been used to attempt global mapping of sea surface temperature for the past 17 years[1]. These remotely sensed retrievals became considerably more accurate following the launch of the AVHRR (Advanced Very High Resolution Radiometer) in late-1978. Multi-channel SSTs (MCSST) have been computed operationally from AVHRR data since late-1981.

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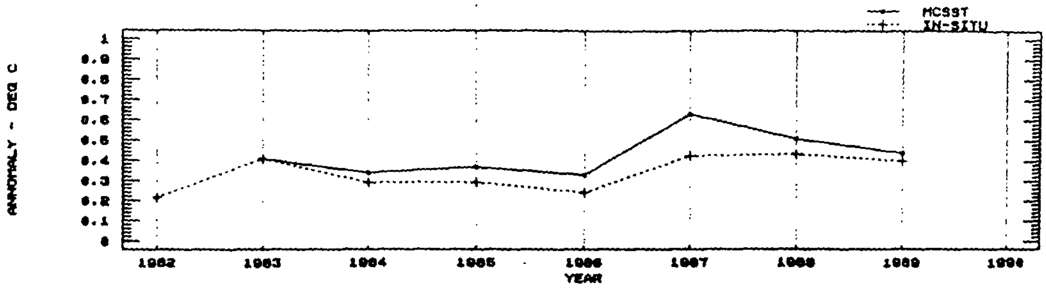
The purpose of this paper is to compare annual MCSST with in-situ (ship and buoy) short-term oceanic surface temperature tendencies for the eight year period from 1982 to 1989. Having combined both daytime and nighttime satellite observations into composite annual means we would expect that little effect will remain of an occasional bias problem noted during late-1988 and early-1989 between daytime and nighttime satellite retrievals over the western tropical Pacific Ocean[6]. Making use of the copious, although admittedly brief, MCSST database with its 3-5 million monthly MCSST observations between 60N and 60S, some notable tendencies are observed in both MCSST and in-situ SST records during the decade of the 1980s.

2. DATA AND METHODS

In order to remove monthly or seasonal variabilities, these data are presented not only as global and hemispheric annual mean anomalies using the Robinson-Bauer climatology, but they also have been separated latitudinally and by ocean basin. The grid used for all these data is the 2.5 degree latitude/longitude interval previously used by Strong[7], and no analyzed data have been used in these calculations. Although this presents little difficulty with the MCSST computations, since virtually all grid-quadrangles have well over 100 observations for each monthly computation, this is not the case with many of the grid values for in-situ data. Frequently, especially south of 10N, grid point values are computed from less than ten monthly in-situ SST observations during a given month.



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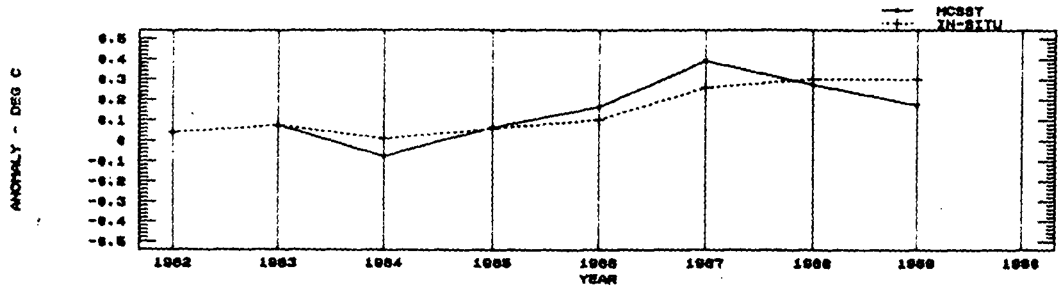

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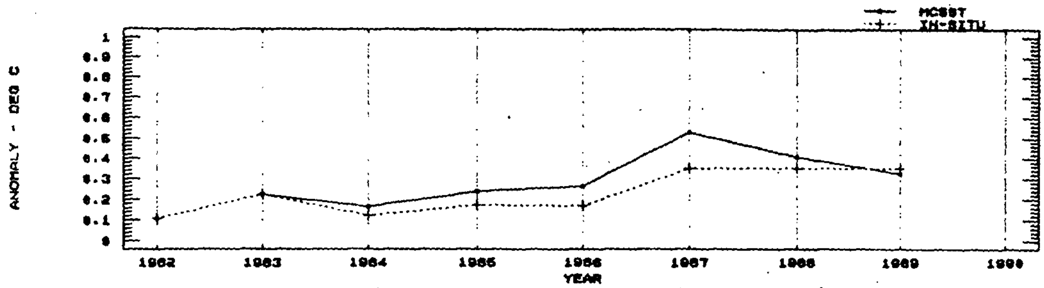

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responsible for the greater standard errors derived over this region.

From the eight-year trends summarized in Table 1, the most significant rises over this relatively short period are on both sides of the equator in the Atlantic Ocean. Here upward tendencies are seen that are nearly double the rate seen on the global ocean scale. It is apparent that the Indian Ocean, whose surface area represents 21% of the global oceans, has been cooling, helping to offset some of the overall effect of a more rapidly warming Western Hemisphere (and Northern) during the 1982-89 period. Although much of the area of the Indian Ocean lies in the Southern Hemisphere (approximately 90%), both the trend and year-to-year variations in anomaly bear no resemblance to those being seen in the other two oceans of the Southern Hemisphere.

Displaying SST tendencies zonally provides another way to monitor our ocean's variabilities and trends. This is useful because for the most part the planet's climate regimes are best categorized zonally. Zonal slices from the data sets used here have been selectively analyzed for every ten degrees of latitude from the 2.5 degree latitude/longitude oceanic grid. Figure 9 presents these twelve zones from 60N to 50S for the satellite and conventional SST data sets. Trends and standard errors of these tendencies are summarized in Table 1. Although more annual variability is often obvious when the data are broken out zonally, with expected lower overall significance, certain features that collectively could become significant may be worth noting. Figure 10 illustrates the similarities in short-term tendencies at approximately the same latitudes in each hemisphere. Although the only error bars that do not overlap occur at 30S, that higher trends are seen at both 30N and 30S may

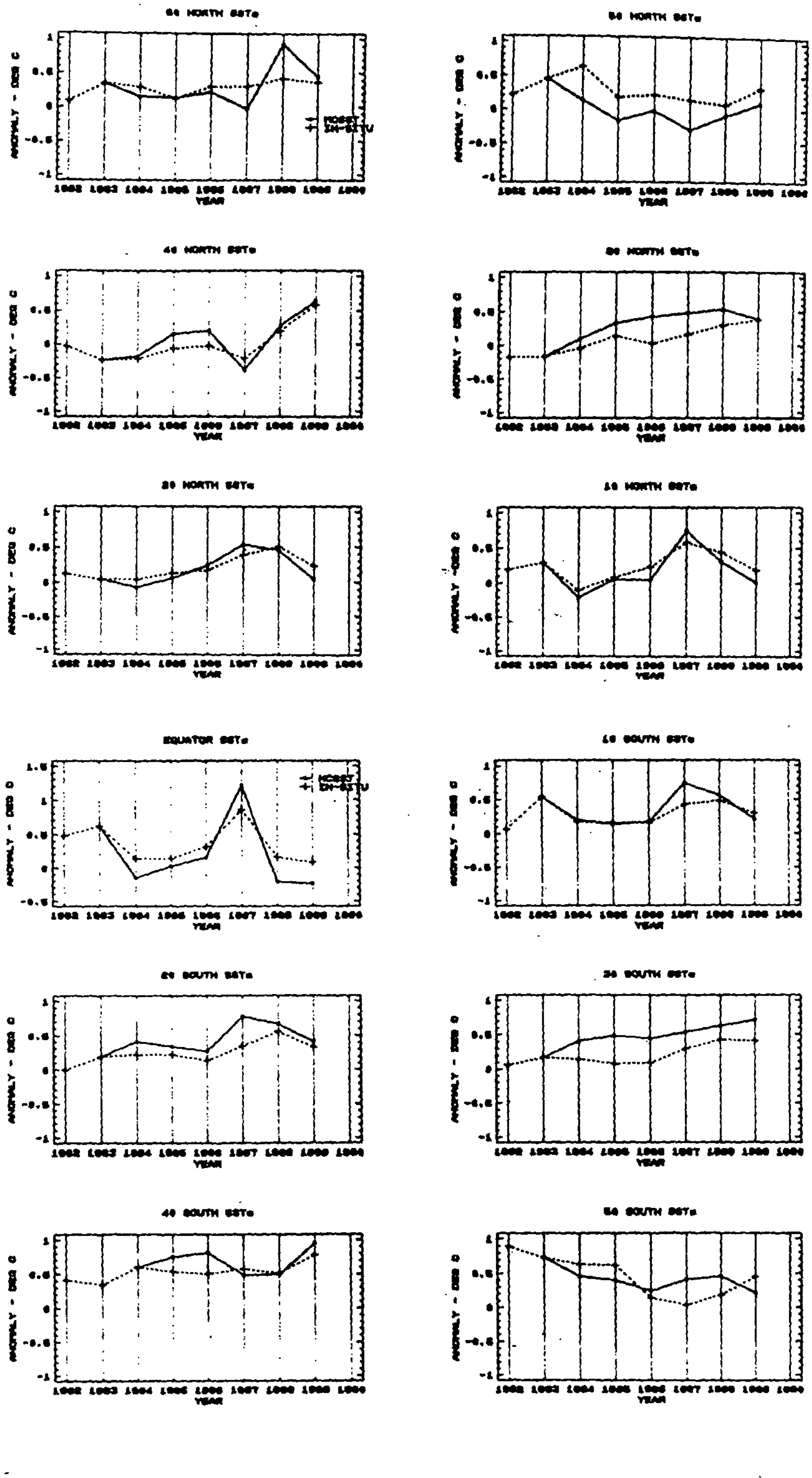

Figure 9 Annual zonal MCSST and in-situ SST departures from climatology (°C) between 60N and 50S from 1982 to 1989.

3. RESULTS

Eight-year tendencies are presented for global, Northern Hemisphere, Southern Hemisphere SSTs in Figures 1, 2, and 3, respectively. In general, more variability is seen in the MCSST than in the in-situ SST year-to-year anomalies. MCSST data show warmer conditions during the 1987 El Niño and, in the Northern Hemisphere, lower SSTs following the 1982/3 and 1987 El Niño than shown by the in-situ data. Nevertheless, using annual data, the upward trends in both data sets in Table 1 do not show any statistically significant differences, i.e. their standard errors all overlap. Interestingly, although concern has been expressed that MCSST values have been erroneously too high at times, the Northern Hemisphere results (Fig. 2) are now revealing in-situ data that exceed the MCSST levels using these processing procedures. Furthermore, the upward trend in the in-situ data over the Northern Hemisphere show the most significant upward trend during this eight-year period (Table 1). Significant also, in this record is the somewhat faster increase in SST over the Northern Hemisphere compared to the Southern Hemisphere, particularly shown by the in-situ data.

Further observations can be made about the following basins: North and South Pacific Ocean, Figures 4/5; North and South Atlantic Ocean, Figures 6/7; and Indian Ocean, Figure 8. There is good overall correspondence between the two data sets in virtually all areas. Note how well the large excursions seen in the Indian Ocean anomalies are supported by both satellite and conventional SSTs. Both excursions are undoubtedly a function of the El Niños of the 1980s and provide further evidence of air-sea teleconnections between the Indian and Pacific Oceans.

Remembering that most of the drifting buoys used to establish the MCSST algorithms resided in the Southern Hemisphere, we note that the best correspondence between the two data sets is found in the Northern Hemisphere, where data density for the ship and buoy data set is highest. Possibly the greater discrepancies between conventional and MCSST annual values in the Southern Hemisphere is due to reduced data coverage from in-situ sources. From these present-ations, it can be seen that greatest SST increases during this period over the Northern Hemisphere are occurring in the North Atlantic -- with the in-situ annual means increasing slightly faster, although not significantly so, than the satellite means. Again, as with the earlier hemispheric and global cases, Table 1 shows that all tendencies have "standard error bars" that overlap, suggesting there is no significant disagreement between these two data sets. Other than this larger Atlantic Ocean change, perhaps the most noteworthy observation is the observed decrease recently seen in the Indian Ocean trend, clearly associated with the decrease in SST following the 1987 El Niño. Temperatures over the Indian Ocean during 1988 and 1989 have been averaging annually below anything observed during the rest of this past decade. When reviewing this basin's annual time series over the period it is apparent that the extreme scatter from the two high-anomaly spikes, coinciding

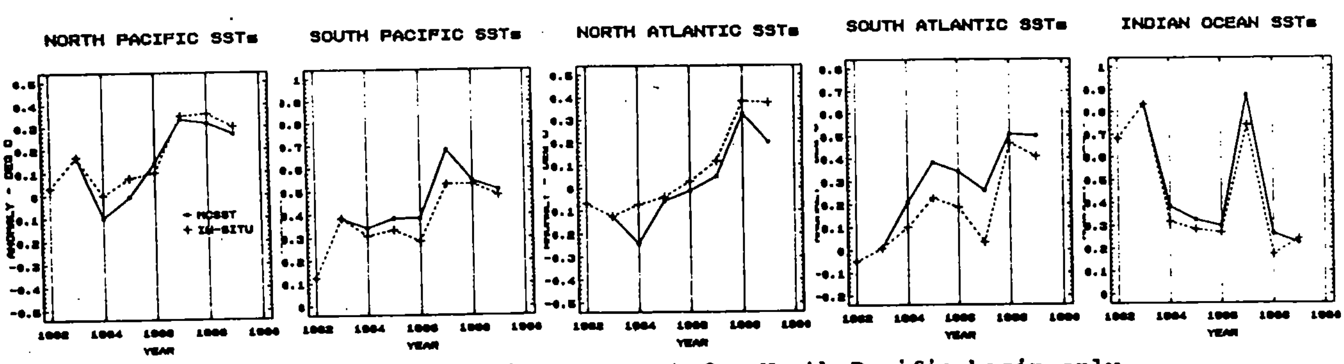

Figure 4 Same as Fig. 1 except for North Pacific basin only.

Figure 5 Same as Fig. 1 except for South Pacific basin only.

Figure 6 Same as Fig. 1 except for North Atlantic basin only.

Figure 7 Same as Fig. 1 except for South Atlantic basin only.

Figure 8 Same as Fig. 1 except for Indian Ocean basin only.

give more credence to the trends seen in these areas than otherwise. It should be noted that these are regions that are dominated by large anti-cyclones in the atmosphere, and they overlie large oceanic anticyclonic gyres in the respective ocean basins.

With the recent discussions of tropical surface warming[8] Figures 9 and 10 indicate both in-situ and satellite data sets show similar but slightly <u>cooling</u> equatorial surface tendencies, which are in opposition to the warming found at subtropical latitudes. At higher latitudes in both hemispheres, these overall SST increases can be seen to fall off, the trends becoming negative at 50N and 50S. Again, what appears most significant from these data sets is the symmetry in tendency apparent over both hemispheres. Poor in-situ SST coverage over the Southern Hemisphere around 30S may help to explain the largest discrepancies between the MCSST and in-situ trends. Development of the operational MCSST algorithms have extensively employed drifting buoys from this ocean region.

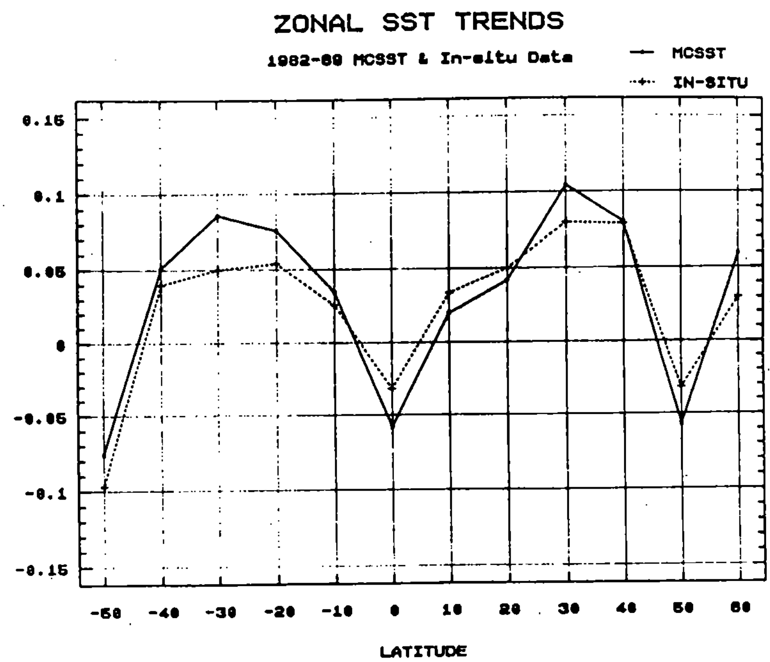

Figure 10 Zonal tendencies from satellite and conventional data sources between 1982 and 1989 as a function on latitude. See Table 1 for standard errors accompanying each location and data type. (All overlap except 30S location.)

4. DISCUSSION

If a case can be made for any increase in SSTs during the 1980s from these analyses, it would be for the subtropical ocean regions -- 20-40° N and S and the Atlantic Ocean. Regions along the Equator, at least globally, appear to show small cooling tendencies as does the entire Indian Ocean. Zonally, the higher latitudes around 50N and S exhibit negative trends during the decade. Provided these trends continue in a similar fashion over the next decade, there are implications for some significant redistributions of heat over the planet's oceans.

As climatologists continue to watch both oceans and atmosphere for signals of changing temperatures from predicted "greenhouse" related adjustments in our coupled air-sea environment, the questions are where should we watch and what should we expect to observe? Recently some sophisticated models have begun to point to certain zones and regions where responses might be most notable. NOAA's GFDL(Geophysical Fluid Dynamics Laboratory) results[9,10] from their coupled ocean-atmosphere model reveal that little change in SST is expected due to global warming in the region of the Antarctic Convergence -- even some decrease in SST could occur. Their model predicts considerably larger increases should be seen over the Northern Hemisphere where a higher land/sea ratio exists than over the Southern. The results presented here appear to be consistent with these preliminary GFDL findings.

Results from the NASA/GISS (Goddard Institute for Space Science) three-dimensional model[11] target the "low-latitude" oceans for significant warming from augmented greenhouse conditions. The region of 30S exhibits notable warming over the oceans by the 1990's in their "Scenario B". The Northern Hemisphere warming zonal band appears around 40N in the GISS results. Our zonally stratified calculations for tendencies during the 1980s are qualitatively consistent with the findings from the GISS model. Quantitatively, their model shows these ocean areas could expect somewhat more than 0.5°C increases over the decade. Our tendencies over this area are not significantly different.

Possibly the biggest surprise in our findings is the strong apparent correlation between the Indian Ocean SST tendencies and El Niño events in the tropical eastern Pacific. The two warm events from the 1982/3 and 1987 El Niños are mirrored strongly in the average Indian Ocean basin anomalies. Walker[12] and Berlage[13] argue that a strong coupling exists between the atmospheres over the South Pacific and the Indian Ocean. Pressures of the lower atmosphere over these two regions correlate strongly, but negatively, in a "seesaw"[14] effect that points to a strong inter-relationship between these two large ocean areas.

Incorporation of additional MCSST data during the 1990s should help reduce the dependency of trends in these time series resulting from the periodic and far reaching effects of El Niño events. It has been suggested that considering only grid locations with coincident satellite and in-situ values would help remove much of the remaining discrepancies between the two global data sets. If that turns out to be the situation, an excellent case can be made for continuing and maintaining this MCSST time-series to adequately monitor our entire planet's SST, particularly in the Southern Hemisphere.

5. ACKNOWLEDGMENTS

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5·8·91

Alan Strong - [illegible] of
where he is [illegible].
Indian Ocean
[illegible] whole hemisphere

greater
since '82 -- [illegible]
w/ Goreau & [illegible]
have put their data
sets together + correlation!

Mark Eakin → NOAA →
Coral bleaching expert &
climate Δ.

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last summer such a dramatic

equator - v. narrow band that is cooling

that is cooling → makes

sense can get upwelling @ equator (currents)

30°C ⇒ 86°F "thermostat" -

still cld kill crops

* he completely agrees w/ Hayes & Grosen

- Spencer & Christy

- [illegible]

during period of overlap

S & C above several yrs. before

'82

'78 ⇒ had some volcanoe ⇒ had nothing overall

cooling in 1st part

last part ⇒ upward trend

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Stop Conveyor

equator & Indian Ocean experiencing
were the same thing - cooling

but this yr. seeing warming of
Indian Ocean → cld be
conveyor belt - involved —
stop conveyor — stop
upwelling of cold H_2O.

ALBERT GORE, JR.
TENNESSEE

393 RUSSELL SENATE OFFICE BUILDING
PHONE: 202-224-4944

United States Senate
WASHINGTON, DC 20510-4202

May 20, 1991

Honorable Joseph Biden
United States Senate
Washington, D.C. 20510

Dear Joe:

I've asked my staff to research your question on ocean temperatures. You had asked whether the oceans were cooling. The answer is that they are not; both the Northern and the Southern Hemisphere oceans are warming.

There is, however, room for confusion here: while the oceans overall are warming, the Indian Ocean and a very narrow band around the equator do show downward trends in temperature during the 1980's. (Note that this trend may be changing. The Indian ocean has reached record warm temperatures recently, and many scientists suspect that the elevated temperatures touched off the severe storm systems Bangladesh has suffered.) Moreover, while the Southern Ocean is warming, the rate of temperature increase has not been as rapid as in the Northern Hemisphere.

These results are derived from satellite data. Importantly, they have very recently been checked against -- and found to be strongly correlated with -- buoy sea surface temperature data. In addition, the results are in agreement with the predictions made by climate modelers of the likely effects of greenhouse warming.

If you would like further information on these trends, Alan Strong (301-267-3561) is NOAA's expert. I enclose his two most recent papers for your information.

Best Regards,

Biden's
OCEAN temp.
Question

APR 20 1989

pt. 1 p. 1, 28

Ocean Data Shows Global Warming May Have Begun

By THOMAS H. MAUGH II, *Times Science Writer*

New measurements reveal that the oceans are warming and rising about twice as rapidly as scientists had thought, strongly suggesting that global warming caused by the burning of fossil fuels has already begun, researchers said Wednesday.

Satellite data indicates that the temperature of the Earth's oceans has been rising at a yearly rate of nearly 0.2 degrees Fahrenheit through most of the 1980s, according to a report scheduled for publication today in the journal Nature.

"We may be just beginning to witness the onset of warming" produced by the accumulation of carbon dioxide in the atmosphere, said oceanographer Alan E. Strong of the National Oceanographic and Atmospheric Administration in Suitland, Md.

Coincidentally, Richard Peltier of the University of Toronto reported Wednesday at an American Geophysical Union meeting in Snowbird, Utah, that the level of the oceans is rising about 1/12 of an inch per year—an outcome of warming caused by the greenhouse effect.

Combined with recently reported data that five of the hottest years in recorded history have occurred during the 1980s—perhaps as a result of the greenhouse effect—the new reports offer evidence that the Earth may already have entered a period of unprecedented heat. The reports seem to add new urgency to predictions that greenhouse warming will lead to widespread coastal flooding and even to the obliteration of some

Please see DATA, Page 28

DATA: Oceans Warming, Rising

Continued from Page 1

island nations, such as the Maldives.

"This is very important work," said glaciologist Richard Williams of the U.S. Geological Survey. "It has taken a long time to get people's attention, but it is happening now. I think you are going to see a lot more things beginning to surface as the recognition comes that we've got severe problems."

Monitoring ocean temperatures has been particularly difficult in the past because little data has been available to cover the vastness of the oceans. Such measurements typically are provided by instruments on floating buoys and by ships traversing cargo routes, leaving large areas of the ocean unmonitored.

In contrast, satellite measurements, which are rapidly becoming the foremost way to monitor global change, cover virtually all areas of the globe and provide as many as 3 million observations per month. The satellite measurements are compared closely to measurements from buoys and ships to ensure accuracy of the data, Strong said.

Variations in Temperature

The satellite data covers the period from 1982 to the present. Although there are large yearly variations in temperature, Strong said, an upward trend of about 0.18 degrees per year is clear, about twice the rate of increase that had been obtained with conventional measurements. The current average temperature is now about 66 degrees.

Strong attributed the apparent discrepancy in measurements to an above-average temperature increase in equatorial regions, where few conventional measurements are recorded. "The global-warming people are saying that ought to be a region where we might start seeing evidence of global warming," he said. "There is no way to say how much of that temperature increase is attributable to global warming, but [at least] part of that increase is due to it."

Measurements of changes in the ocean level are also quite difficult, Peltier noted, because land levels, which serve as a reference point, are themselves changing, a process known as "isostatic adjustment." The East Coast of the United States, for example, is slowly sinking, while Scandinavia and the Hudson Bay region are rising above the ocean.

Measurements of changes in the ocean surface level are normally made by averaging tidal levels around the world as measured by tide gauges. But the changes in the land itself produce widely varying measurements of sea level changes around the globe. Peltier attempted to circumvent this problem by subtracting the effects of isostatic adjustment from the measured tide levels at each location.

Twice the Rate

He told the geophysical meeting Wednesday that his measurements yield an average increase in ocean level of about 1/12 of an inch each year during the 1980s, about twice the rate scientists had previously estimated. He noted, however, that the measurements must be interpreted cautiously because there are very few tidal measurements in the Southern Hemisphere.

Most oceanographers agree that the level of the oceans has risen by as much as two inches over the last century. Various projections of the increase that will result from greenhouse warming range from 10 feet to 25 feet by the end of the next century.

Some of that increase, perhaps as much as a third, is due to expansion of the oceans as they have warmed. Beyond that expansion, however, "the only obvious explanation" is melting of glaciers, particularly in Antarctica, Williams said. This seems to fit with a greenhouse scenario, in which melting glaciers would be one consequence of warmer temperatures.

About 91% of the world's ice is in Antarctica, Williams said, and satellite imagery clearly shows that the ice pack is shrinking. That shrinkage is also evidenced by the increased "calving" of large icebergs, such as the "monster iceberg," 60% of the size of Connecticut, that broke off from the Filchner glacier in 1986.

Floating Ice

So far, he added, most of the Antarctic ice that has disappeared has been floating ice, whose melting will have no effect on ocean levels since the ice was already in the water. But as the fronts of the glaciers retreat, he said, more ice resting on land will melt, and that will lead to a much greater increase in ocean levels.

Such increases, experts predict, would cause large-scale flooding along the Eastern Seaboard of the United States, as well as in other low-lying areas such as Galveston, Tex. Other areas that may be flooded include Lake Maracaibo in Venezuela, Port-au-Prince, Haiti, and Puerto Cortes, Honduras. In addition, areas such as Bangladesh, Pakistan and India that already suffer severe flooding during monsoon seasons will experience even greater devastation, according to the United Nations Environment Programme.

The new studies reflect an increased awareness of the ocean's role in climate and an intensified effort to study it. Said Strong: "We have never looked at the oceans this well."

hepatitis C cases in the early, acute stages because the antibody takes months to develop, notes molecular virologist Daniel W. Bradley of the Centers for Disease Control's Hepatitis Branch in Atlanta. Bradley says he and his co-workers are working to develop other assays for the acute disease as well as a vaccine.

To make the test, the Chiron researchers stitched together three hepatitis C viral clones and inserted them into yeast, which then began making a viral protein from the foreign genetic material. Antibodies to the virus bind to the protein and become visible after a color-producing reaction with another antibody, enabling scientists to use the manufactured viral protein to test blood samples for the hepatitis C vir[illegible] team rep[illegible]

[illegible] in all seven control samples, demonstrating that it detects antibody in infectious samples, Houghton says. And when mixed with blood from 10 prospectively studied transfusion recipients diagnosed with non-A, non-B hepatitis, the test showed that all developed antibodies within a year after infection; for nine, the test picked out a positive blood donor. No such antibodies were detected in blood from 43 people infected with other known hepatitis viruses, he says.

Further use of the test should shed light on whether other agents can cause non-A, non-B hepatitis, Houghton says. Other studies already indicate that a significant portion of the cases may be caused by mutant forms of the hepatitis B virus (SN: 1/28/89, p.52).

The test is now in clinical trials, which should be completed by June, and Chiron plans to apply to the Food and Drug Administration to market the test by the end of the summer, says company spokesman Larry Kurtz. — *I. Wickelgren*

Recent ocean warming: Are satellites right?

Satellites have detected a significant warming in Earth's oceans between 1982 and mid-1988 that conventional methods have underestimated, reports Alan E. Strong from the National Environmental Satellite Data Information Service in Suitland, Md. But another researcher who works with the same measurements sees the purported warming as a largely artificial one created by biases in the satellite information and by the brevity of the record.

According to Strong, who presents his analysis in the April 20 NATURE, "The global ocean is undergoing a gradual but significant warming of [approximately] 0.1°C per year, whereas the trend obtained for the same period from conventional data sources (ships and buoys) is about half that magnitude."

Satellite measurements for ocean temperature go back no farther than 1982. While this relatively short observation period makes it premature to use satellite data to detect long-term trends, such as a greenhouse warming, "we may just be beginning to witness the onset of this warming through satellite surveillance of ocean-surface temperature," says Strong.

Yet Richard W. Reynolds of the Climate Analysis Center in Camp Springs, Md., says he is "flabbergasted" by the reported warming in the satellite data. "I think this whole thing is an error."

The controversy revolves around data taken by thermal sensors aboard several satellites run by the National Oceanic and Atmospheric Administration. These instruments measure infrared radiation emitted by the ocean, which can give an indication of sea-surface temperature once researchers perform difficult corrections for water vapor and clouds in the atmosphere.

By checking the satellite observations against measurements taken by drifting buoys, Strong says he has corrected for the important biases in the satellite data. (Bias is a consistent tendency to overestimate or underestimate.)

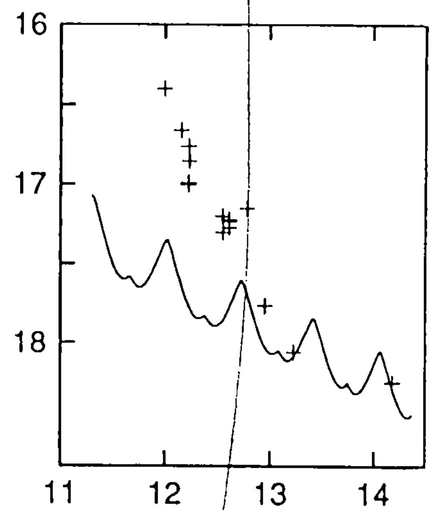
But Reynolds says significant biases remain in the satellite data. The 1982 eruption of the Mexican volcano El Chichón skewed the record by flooding the stratosphere with dust particles that absorbed infrared radiation. For the first two years of the observation period, these particles made the oceans seem cooler than they were. Other biases can affect certain regions of the globe. Right now, satellite instruments consistently indicate the Western Pacific is 0.5°C colder during day than during night, which poses a clear problem, Reynolds says.

In his paper, Strong reports that eliminating the El Chichón years of 1982 and 1983 only slightly reduces the observed warming. But Reynolds contends that these biases introduce a substantial artificial warming into the record. In his own analysis of global ocean temperatures, Reynolds mathematically blends satellite measurements with those taken by both ships and buoys, a technique he says removes the satellite biases. The blended record shows almost no temperature rise between 1982 and 1988.

Reynolds notes that ending the record in mid-1988 exaggerated the satellite errors because the record includes the hot El Niño of 1987 but misses much of the cool La Niña of 1988. Because of such natural fluctuations, he and other researchers caution against using a six-year-long record to talk about temperature trends. — *R. Monastersky*

Chiron's brightening hints it's a comet

When astronomer Charles Kowal in 1977 discovered the object now called Chiron between the orbits of Saturn and Uranus, it was known enigmatically as "Object Kowal." Astronomers could not tell whether it was an asteroid or a comet, since it orbited farther from the sun than most known asteroids but for years failed to show a comet's fuzzy "coma." Now Chiron may have revealed its true identity.



Solid line shows how a typical asteroid brightens as it nears the sun, compared with additional brightening of "Comet" Chiron. Horizontal axis represents distance from sun in astronomical units; vertical axis shows visual magnitude.

Astronomers had speculated that the object might never warm enough to release the frozen surface material that would give it a coma. But as early as November 1987, as it approached the sun, Chiron seemed to brighten more rapidly than would be expected of a bare, rocky object. Now Karen J. Meech of the University of Hawaii Institute for Astronomy in Honolulu and Michael J.S. Belton of Kitt Peak National Observatory in Tucson, Ariz., report a coma around Chiron in images made with the Kitt Peak 4-meter telescope when the object was about 11.8 astronomical units from the sun (1 astronomical unit equals about 92.9 million miles). Chiron is expected to get no closer than about 8.5 astronomical units, but the brightening is apparently due to "sunlight reflected from an extended dust atmosphere," they say, "indicating that it is a very large comet."

The researchers note that Chiron appears about 112 miles in diameter, 10 to 20 times the size of Comet Halley. Ices such as carbon dioxide, which evaporate at much lower temperatures, may have been freed in what could be Chiron's first trip this close to the sun. — *J. Eberhart*

The latter molecule has a star shape comprising four aliphatic arms surrounding a central silicon atom. Both compounds are chemically inert.

The liquid drop profiles are shown in Figs 1 and 2. Note the extreme distorsion of the horizontal to vertical scales (a factor of 10^7). The volumes of the drops were found to be conserved (within errors) over the timescale of the experiment (one week), by numerically integrating the profile in cylindrical geometry. This shows that under constant flow of nitrogen there is no evaporation of the liquids.

The first series of profiles (Fig. 1*a–c*) shows the time evolution of a drop of PDMS. The profiles are extremely flat (with slopes of the order of a few mm per 10^3 m). A 'foot', corresponding to the precursor film, is clearly seen extending out of the central cap, (Fig. 1*a*), with a thickness of 6 Å. This structure may be interpreted as a monolayer of molecules extending for macroscopic distances out from the central macroscopic droplet; the thickness of the 'foot' is comparable to the lateral thickness of the molecule (7 Å) as measured with an atomic force machine (AFM)[13]. As the profile evolves in time (Fig. 1*a–c*), further structure is visible, with the suggestion of a second layer becoming apparent.

The second series of profiles, for the time evolution of a drop of tetrakis(2-ethylhexoxy)-silane, is more striking. Initially (Fig. 2*a*) a molecular foot (of thickness 10 Å) extends out from the central reservoir. As the drop spreads and flattens, a second molecular 'step' (again of thickness 10 Å) appears (Fig. 2*b*), along with some indication of further layers. In Fig. 2*c–f* the drop flattens down to a 'molecular carpet', and in the transient stages more steps of equal thickness become clearly visible: the first layer continues to extend, at the expense of the upper layers which progressively shrink and disappear. In these transient spreading stages, the fluid is strongly structured, with up to four distinct molecular layers forming near the solid wall. One could consider this layering as a form of smectic-like order induced in the liquid by the presence of an impenetrable wall. We note that the roughness of the substrate must be small for such molecular layering to be possible.

There could be a connection between our observations and adsorption studies of rare gases on graphite, where stepwise adsorption has been observed (ref. 14 and references therein). But it should be emphasized that the layering previously observed in these adsorption experiments corresponds only to equilibrium situations. In our case, the situation is a dynamical one: the layering could occur because of a stacking of the molecules near a wall (smectic density wave[15]) or because of anomalies in the shear viscocity as a function of thickness of the fluid (see, for example, the modified AFM shear-viscosity measurements in ref. 16, which show step-like behaviour).

The dynamic structural effect reported here calls for theoretical efforts aimed at a better understanding of such a striking physical phenomenon. □

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Greater global warming revealed by satellite-derived sea-surface-temperature trends

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INVESTIGATING the response of global climate to changes in external forcing is essential to our understanding of climate change. Here I present an analysis of satellite-derived sea surface temperatures for the period 1982–88. It can be seen from this analysis that the global ocean is undergoing a gradual but significant warming of ~0.1 °C per year, whereas the trend obtained for the same period from conventional data sources (ships and buoys) is about half that magnitude[1]. Satellite global coverage, however, is far greater and, although we have no long time series of satellite data (as opposed to conventional data), it is possible to observe short-term trends, as shown here, that may not be discerned using the coarser-resolution conventional data.

Monthly mean daytime and night-time multichannel sea-surface-temperature (MCSST) data from NOAA satellites have been consolidated into $2\frac{1}{2}°$ latitude-longitude quadrangles between 60° N and 60° S. Typically, more than two million MCSST determinations are accumulated each month over this area. During the 1982–1988 MCSST record, approximately 98% of this oceanic grid contains MCSST average-temperature determinations over the period.

Using data from the operational Advanced Very-High-Resolution Radiometer (AVHRR), NOAA has developed the capability to measure remotely the surface temperature of the global ocean employing algorithms that effectively correct for attenuation by the intervening atmosphere, which before 1982 had hampered accurate remote measurement of sea surface temperature[2]. Furthermore, these algorithms are initially tuned using measurements of sea surface temperature (SST) from drifting buoys whenever a new satellite is launched, thus assuring continuity of the program between successive sensors[3]. The AVHRR MCSST time series has been carefully monitored on a monthly basis, with SST measurements from drifting buoys being noted so as to guard against instrumental offsets or trends. No significant adjustments have been made to the operational algorithms between different launches of the satellite.

Monthly statistics derived from close individual match-ups between MCSSTs and the *in situ* drifting-buoy data which NOAA receives via the Global Telecommunications System (GTS) have monthly global average biases (both daytime and night-time) within ±0.3 °C (ref. 3). Most (90%) of these biases fall within ±0.1 °C, and match-up scatter (standard deviation of the differences) averages about 0.6 °C (the range is 0.4–0.9 °C). The buoy-satellite match-up statistics typically represent 300–800 sample pairs per month, both daytime and night-time.

Most significantly in relation to this study, no trends have been observed in these monthly biases and no corrections are made to the operational algorithms on the strength of these biases. Furthermore, no significant biases are observed between daytime and night-time comparisons with drifting buoys, ruling out significant daytime solar heating or 'surface-skin' effects on the monthly means. Because of the paucity of drifting buoys in the Northern Hemisphere that are linked to the GTS, match-ups have been largely restricted to the Southern Hemisphere. A regional survey of bias variability, performed in 1985, revealed no statistically significant variation as a function of atmospheric moisture or location over all major oceanic regions[4].

A monthly mean consolidation and presentation of MCSST

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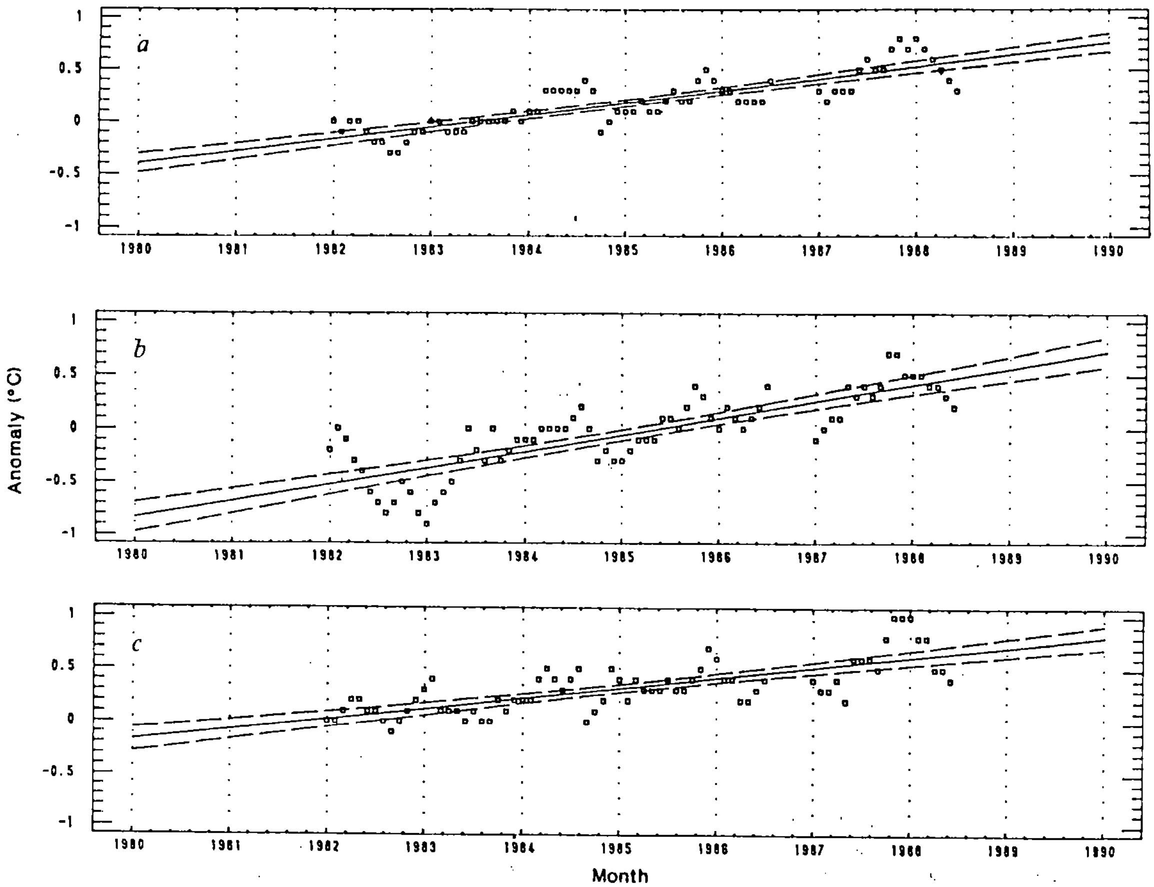


FIG. 1 Satellite-derive multichannel sea-surface-temperature (MCSST) monthly mean departures from climatology (°C) for the period 1982 to June 1988. *a*, Global: slope $b=0.12$ °C yr^{-1}, variance $r^2=0.73$; *b*, Northern Hemisphere (NH): $b=0.16$ °C yr^{-1}, $r^2=0.66$; *c*, Southern Hemisphere (SH): $b=0.1$ °C yr^{-1}, $r^2=0.57$. Regression lines include their confidence limits at 95% level (dashed lines). (With the El Chichon years of 1982 and 1983 excluded (see text) the slope and variance values shift slightly: global—$b=0.11$ °C yr^{-1}, $r^2=0.46$; NH—$b=0.13$ °C yr^{-1}, $r^2=0.53$; SH—$b=0.1$ °C yr^{-1}, $r^2=0.33$.)

TABLE 1 Monthly variations in mean SST

Month	Slope (all months) Global	Slope (all months) Northern Hemisphere	Slope (all months) Southern Hemisphere	Slope (1982 and 1983 excluded) Global	Slope (1982 and 1983 excluded) Northern Hemisphere	Slope (1982 and 1983 excluded) Southern Hemisphere
January	0.11	0.14	0.13	0.11	0.09	0.14
February	0.11	0.11	0.08	0.11	0.07	0.11
March	0.09	0.11	0.09	0.08	0.07	0.08
April	0.08	0.12	0.04	0.06	0.01	0.01
May	0.08	0.13	0.03	0.04	0.11	0.01
June	0.08	0.11	0.08	0.03	0.06	0.05
July	0.15	0.21	0.10	0.10	0.12	0.06
August	0.14	0.20	0.12	0.05	0.05	0.05
September	0.14	0.19	0.12	0.11	0.11	0.14
October	0.18	0.26	0.16	0.20	0.28	0.17
November	0.18	0.26	0.19	0.20	0.24	0.23
December	0.16	0.23	0.17	0.18	0.18	0.19

Month	Variance (all months) Global	Variance (all months) Northern Hemisphere	Variance (all months) Southern Hemisphere	Variance (1982 and 1983 excluded) Global	Variance (1982 and 1983 excluded) Northern Hemisphere	Variance (1982 and 1983 excluded) Southern Hemisphere
January	0.77	0.50	0.76	0.74	0.46	0.80
February	0.79	0.45	0.55	0.77	0.38	0.77
March	0.72	0.58	0.66	0.69	0.69	0.59
April	0.70	0.78	0.35	0.41	0.68	0.01
May	0.73	0.89	0.25	0.31	0.70	0.01
June	0.67	0.68	0.69	0.15	0.69	0.37
July	0.93	0.88	0.85	0.83	0.80	0.60
August	0.75	0.73	0.73	0.25	0.25	0.25
September	0.85	0.78	0.93	0.79	0.94	0.91
October	0.89	0.90	0.89	0.85	0.88	0.86
November	0.89	0.96	0.91	0.85	0.93	0.98
December	0.97	0.85	0.96	0.98	0.78	0.97

measurements has been available for global evaluation since 1982[5]. This study presents an analysis of MCSSTs for a 6½-year time series beginning in 1982 and extending to mid-1988. On a 2½° latitude-longitude grid, the Earth's oceans occupy ~5,000 of these grid boxes. An average of ~500 monthly MCSST observations accumulate at each grid location. An exception to the otherwise nearly perfect coverage in this ±60° zonal band occurred during 1982 and into the first half of 1983, when monthly mean accumulations became briefly less dense, particularly in the Northern Hemisphere tropics. This was a result of contaminating aerosol from El Chichòn precluding MCSST retrievals through the thickest portions of the extensive volcanic cloud[6].

To provide for further evaluation of the MCSST data, 2½° latitude zonal means are calculated; these are then used to compute MCSST means for the Northern and Southern Hemispheres. Before values for each hemisphere are composited, zonal means are appropriately weighted to allow for the varying number of oceanic grid points in each zonal band. A similar treatment is applied to the global ensemble of MCSST data to produce an integrated monthly mean value for the entire ocean data set. An alternative evaluation, which weights grid points by area, produces similar results.

One small segment of the time series is not available at present. This 5-month lapse occurred in 1986 between August and December because of problems with the computer system. These data cannot be used until arrangements for reprocessing can be made.

Global, hemispheric and selected ocean basins were examined for significant MCSST trends during the 1982-1988 period using simple regression techniques. Departures from Robinson-Bauer climatology[7,8] (that is, anomalies) are used in all cases to normalize results. Global MCSST tendencies, with statistics, are shown in Fig. 1 with 95% confidence limits for the slope. Standard errors of all slopes depicted in Fig. 1 never exceeded ±0.01 °C yr^{-1}. In addition, a separate analysis was performed in which all 1982 and 1983 data were excluded from the 6½-year time series to reduce potential effects of stratospheric aerosol contamination from El Chichon. These small differences are noted in the legend for Fig. 1.

Another analysis was performed to investigate trends of the monthly data sets by calendar month. This allows us to focus on any exceptional tendencies during certain months or seasons. The data from Fig. 1 are redistributed for this purpose and are shown in Fig. 2 and tabulated in Table 1.

Figure 3 presents trends of the world's oceans subdivided into five major regions: North and South Atlantic; North and South Pacific; and Indian. Standard errors of the slopes in Fig. 3 ranged from ±0.01 to 0.02 °C yr^{-1}.

Comparisons with past time series are difficult as no truly complete data sets were derived from solely conventional data, for which considerable smoothing is required to produce acceptable global analyses. An analysis of historical SST data by Oort *et al.*[9] also revealed an increased rate of temperature increase in the Northern relative to the Southern Hemisphere, but with a magnitude only half that of the total increase found here for the 1980s. Furthermore, the gradual increase presented in the Oort *et al.* survey occurred over a fifty-year period (1910-1960).

A recent study[1] incorporating data from a Comprehensive Ocean-Atmosphere Data Set (COADS) has also shown increasing surface temperatures (land and sea) during this same time interval, but the observed trend is only about half that found here. Even though some ocean surface temperatures were included, no satellite-derived sea surface temperatures were used in the COADS data sets[10]. Trends in the COADS data may be suppressed because ship and buoy observations typically miss over 25% of the monthly 2½° grid points south of 12.5 °N, where many monthly means must be calculated from fewer than five

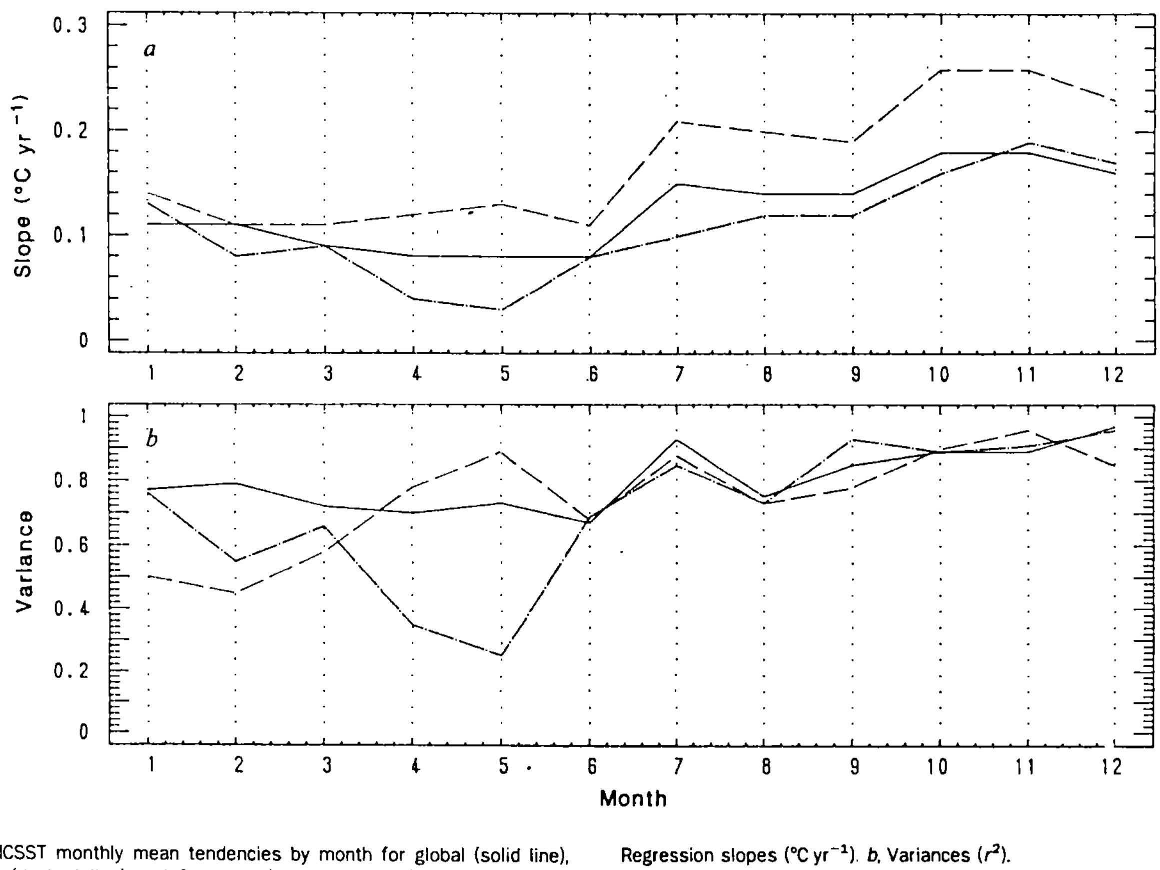
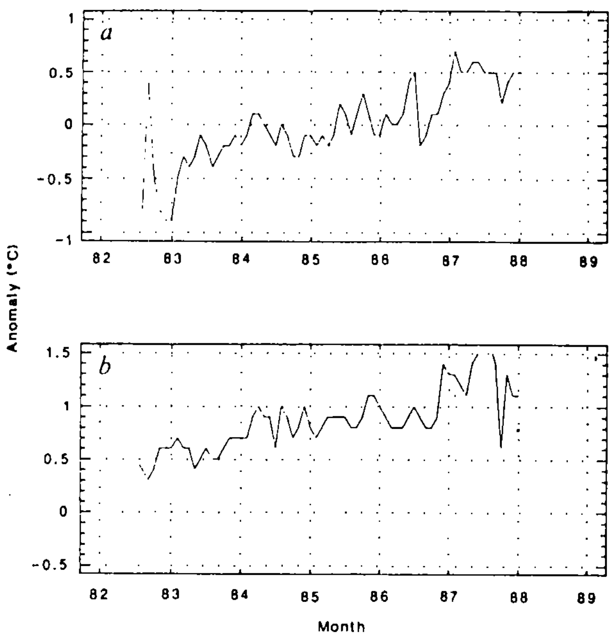


FIG. 2 MCSST monthly mean tendencies by month for global (solid line), Northern (dashed line) and Southern (dot-dashed line) Hemispheres. *a*, Regression slopes (°C yr^{-1}). *b*, Variances (r^2).



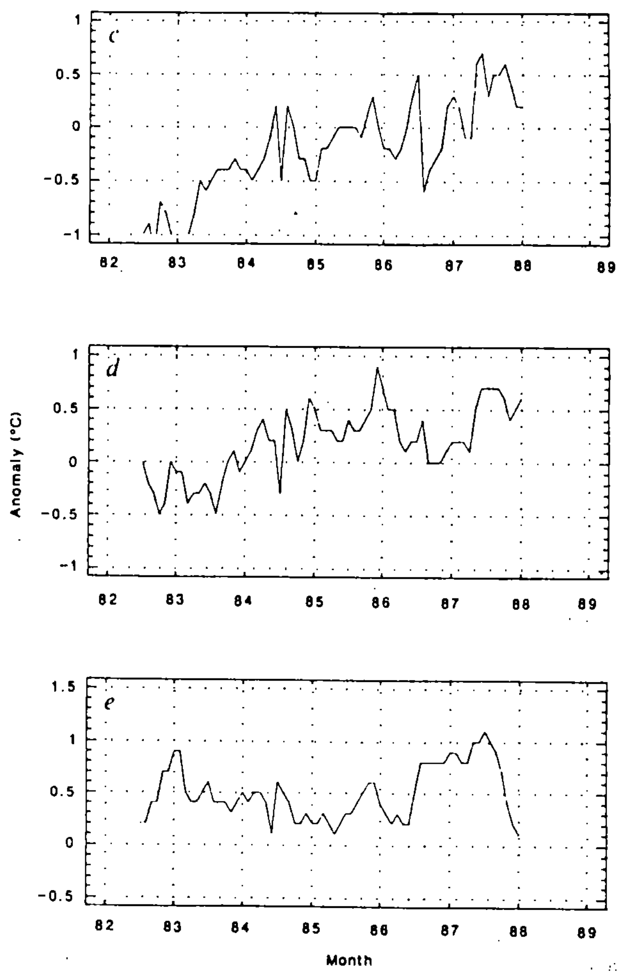


FIG. 3 MCSST monthly mean tendencies over the same interval seen in Fig. 1. *a*, Northern Pacific (slope $b=0.17\ ^{\circ}\mathrm{C\,yr^{-1}}$, $r^2=0.65$); *b*, South Pacific ($b=0.13\ ^{\circ}\mathrm{C\,yr^{-1}}$, $r^2=0.64$); *c*, North Atlantic ($b=0.21\ ^{\circ}\mathrm{C\,yr^{-1}}$, $r^2=0.64$); *d*, South Atlantic ($b=0.13\ ^{\circ}\mathrm{C\,yr^{-1}}$, $r^2=0.46$); *e*, Indian Oceans ($b=0.05\ ^{\circ}\mathrm{C\,yr^{-1}}$, $r^2=0.12$).

observations. COADS data coverage typically exceeds 90% only at grid points between 20° and 40° N. Furthermore it is possible that the land temperature, whose contribution to the total area is nearly twice as great in the Northern than in the Southern Hemisphere, may be warming at a different (slower?) rate than the ocean.

Further inspection of specific regions reveals increasing MCSST tendencies that are similar in the Atlantic and Pacific basins but are insignificant over the Indian Ocean. Closer examination of zonal tendencies, or even pinpointing the 'centres of action' for the months or zonal bands exhibiting marked warming, would seem to be warranted.

When examined on a separate monthly basis, the months of October to December are characterized by considerably more significant MCSST increases than March to June in both hemispheres (Fig. 2). Although this is undoubtedly partly a result of the 1987 El Niño, October and November rates exceed $0.2\ ^{\circ}\mathrm{C\,yr^{-1}}$ in the Northern Hemisphere, with explained variances consistently exceeding 0.90.

With the collection of ship data from thousands of reports having been necessary each month over the last dozen decades[9], the incorporation of satellite-derived, buoy-maintained SSTs would seem to have certain advantages. Using the generally high-quality drifting-buoy data alone to corroborate observed trends in the global MCSST data set would not appear practical because of their paucity and spatial variability from year to year. Nevertheless, these drifters are an invaluable part of the satellite MCSST program. Unfortunately, no other adequate independent system exists for rigorous validation. Long time-series data from moored buoys could be helpful for further comparisons at key sites. But where should these sites be located? Studies are underway to better identify regions showing the greatest trends in MCSST, with the hope that larger sets of quality-controlled conventional data can be secured in these more limited areas.

Global changes of the sort described here have been predicted to increase dramatically over the next few decades as a result of the greenhouse effect. We may be just beginning to witness the onset of this warming through satellite surveillance of ocean surface temperature. Using satellite MCSST time-series data, we are now in a better position to monitor both long- and short-term oceanic changes that, before this decade, were largely unnoticed. □

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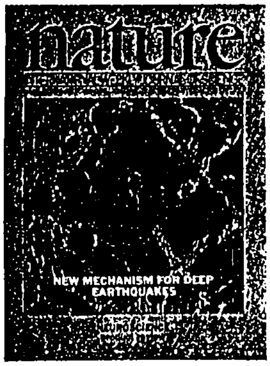

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◄ A cross-polarization micrograph of a crystal of olivine (blue) partially transformed to the spinel phase under stress. The small linear features (white bordered by yellow) are 'anti-cracks' normal to the greatest compressive stress, and may hold the key to the mechanism of deep earthquakes. Pages 733 and 687.

THIS WEEK

San Francisco

The long-feared earthquake on the San Andreas Fault struck in the evening rush-hour last Tuesday. See News pages.

Immune reactions

Following the recent discovery that the cyclosporin-binding protein cyclophilin is identical to a previously described peptidyl-prolyl *cis–trans* isomerase, a cellular binding protein for the new immunosuppressant FK506 is found to be distinct from cyclophilin but to have the same enzymatic activity. As well as having clinical importance in preventing allograft rejection, these drugs are revealing details of the lymphocyte activation process, pages 755, 758 and 692.

Progress report

The first practical applications of ceramic high-temperature superconductors are likely to be SQUIDS — superconducting quantum interference devices. If these new SQUIDS are to be competitive with conventional magnetometers, low intrinsic magnetic flux noise will be necessary. A thin film of $YBa_2Cu_3O_{7-\delta}$ has now been shown to exhibit such low noise (page 723). On page 725, detailed measurements of the current–voltage characteristics of bulk $YBa_2Cu_3O_7$ show that the critical properties of high-T_c superconductors cannot be fully explained by low-T_c theories.

Hot and cold water

How quickly is the global ocean warming? Conventional measurements from ships and buoys point to an increase in temperature of 0.05 °C per year, but satellite data have been interpreted as evidence for an increase of 0.1 °C per year. Reynolds *et al.* attempt to reconcile satellite and terrestrial data. Page 728.

On a microplate

Moai (stone statues) on Easter Island. The statues are carved from volcanic tuff, one of the eruption products of the proposed Easter hotspot. Another manifestation of the hotspot may be the formation of a tectonic 'microplate'. This microplate has now been comprehensively imaged by British and American sidescan sonars, as described in the Article on page 701.

Memory's made of this

Arachidonic acid facilitates a slow-onset, persistent increase in synaptic efficacy in the hippocampal dentate gyrus on weakly activating the perforant path. This is consistent with a 'retrograde messenger' role for arachidonic acid in the later phases of long-term potentiation, a widely studied model of the synaptic basis of information storage in the mammalian brain. Page 739.

Tandem turn off

The crystal factor of the *met* repressor DNA binding protein from *E. coli* reveals a conspicuous absence of the helix-turn-helix binding motif found in the structures of other bacterial DNA binding proteins. The protein recognizes specific sequences of DNA, turning off genes encoding for enzymes involved in methionine synthesis, by binding to them in tandem arrays. Pages 705 and 711.

Guide to Authors

Opposite page 766.

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Satellite data contamination

SIR—Strong[1] claims to have observed a global warming of 0.1 °C yr^{-1} for the period 1982–88 using satellite-derived sea surface temperatures (SSTs). His results show a much larger warming trend than other analyses of the same data[2]. Strong's analysis is in error because, during the initial two years of his analysis period, he excluded SST data when the satellite data were contaminated by the signal from the dust cloud from the El Chichón volcanic eruptions of 29 March and 3–4 April 1982. Because the dust from the El Chichón volcanic cloud absorbed some of the infrared radiation emitted by the surface and re-emitted some infrared radiation at a lower temperature, satellite measurements of the thermal emission of the sea surface gave readings in these areas that were too low.

The excluded data in this region were not randomly distributed with respect to the mean SST, but covered the region of high SST anomalies resulting from the great El Niño of 1982–83. It was precisely where record-breaking SSTs were being observed at the surface that Strong eliminated data. In fact, recognition of the intensity of the 1982–83 El Niño was delayed at the time by dependence on satellite data that did not show the warm SSTs.

Strong[3,4] used the difference between the satellite-derived SST and *in situ* data from ships and buoys as a measure of the thickness and location of the El Chichón dust cloud. It can be seen from his analyses that the *in situ* SST measurements in the region of the El Chichón dust were more than 0.4 °C higher than the satellite-retrieved values between the Equator and 30° N from April 1982 to August 1983, and were more than 1.0 °C warmer for most of this region for most of this time.

The result of excluding the contaminated satellite-derived data was to miss the warm temperatures of the ocean during the first two years of his analysis. Thus the trend in his analysis is much too large, because it starts from temperatures that are too cold for 1982–83. Omitting the data from these two years did not correct this mistake, because the temperatures for these two years were higher than the average for the next two years, not equal.

Had Strong substituted *in situ* data for the missing data in 1982–83 to get a 'blended' analysis, as is done routinely at the Climate Analysis Center[5], he would have calculated the correct trend. Indeed, he had these data available because he used them in his previous work[3,4].

Analyses of the long-term temperature record of the globe show an irregular warming during the past century (as shown in ref. 2 for example), but this warming cannot be unambiguously ascribed only to the effects of anthropogenic greenhouse gases. To separate out the competing effects of volcanic eruptions (which cause cooling for several years, and probably longer), tropospheric aerosols, and random, chaotic variations of the climate system, the actual record of climate change must be known as accurately as possible. This requires a combination of data sources, including satellite data. But when satellite data are not available, such as in 1982–83, the best available data must be used to give correct global temperatures.

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STRONG REPLIES—As mentioned by Robock, the effects of aerosol from El Chichón during the 1982–83 period have been well documented[3,6], showing extensive involvement for about 18 months over large portions of primarily the Northern Hemisphere. I also discussed the effects from El Chichón. Robock is concerned that missing grid-point data (not eliminated by me, but by the Multi Channel Sea Surface Temperature (MCSST) cloud detection procedures) in the areas where aerosol contamination was extensive could distort the data, particularly if those areas were undergoing dramatic warming from the 1982–1983 El Niño. Although many grid boxes in the 10°–30° N latitudinal band over the Pacific were void of data, most of these were during the period April–September 1982 before the development of El Niño during September 1982 along the Equator. By the time the volcanic debris migrated southward during December 1982 over the region being affected by the developing El Niño, some data were available for grid-box MCSST monthly means, although derived from fewer MCSST retrievals, despite volcanic aerosols. The missing MCSST data from the volcanic cloud, therefore, did not substantially affect the region where El Niño was developing.

The major concern is a period of negative offsets in derived MCSSTs from December 1982 to mid-1983 over the eastern and central equatorial Pacific. As Robock points out, an alternative analysis could have been performed to eliminate any possibility of contaminated MCSST data during the 1982–83 period by using a hybrid data set substituting entirely *in situ* sea surface temperatures (SSTs) everywhere for the El Chichón years.

Following Robock's suggestion, I have used monthly ship and buoy *in situ* SSTs over a grid identical to the one I used earlier[1]. These conventional data (not analyses) were then substituted for the initial 1982–1983 portion of the MCSST record. The revised short-term trends are somewhat less, but are still upward. For the 6.5-year record (January 1982 – June 1988) the rates of change are: Global = 0.08 °C yr^{-1}; Northern Hemisphere (NH) = 0.07 °C yr^{-1}; Southern Hemisphere (SH) = 0.07 °C. This compares with my previously reported global, NH and SH MCSST rates of change of: 0.12, 0.16 and 0.10 °C yr^{-1}, respectively. Using entirely conventional data these global, NH and SH rates are: 0.04, 0.04 and 0.03 °C yr^{-1}. For hybrid data spanning an updated period from 1982 to March 1989 the global, NH and SH slopes are: 0.05, 0.04, and 0.05 °C yr^{-1}, respectively; conventional global, NH and SH SST rates: 0.03, 0.04, and 0.02 °C yr^{-1}, respectively. As well as accounting better for some of the contaminated MCSST data in 1982–1983, these updated values reflect the cooling that took place over much of the Earth's oceans during 1988. So far during 1989 the tendency has been again towards higher values.

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High table tales

SIR—Robert May (*Nature* **341**, 386–387; 1989) has Haldane's famous beetle story elicited by a question from Jowett. Haldane was born (in Oxford) on 5 November 1892. Jowett died on 1 October 1893, having left Oxford in September of that year. So while they could have met, they certainly did not have a conversation either at high table at Balliol, or anywhere else.

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MAY REPLIES—Mundane constraints of time and space do not apply to stories about Oxford.

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a heavier isotope[8,9]. This isotope effect leads to the difference in the extent of ionization of the species depending on the isotope mass, which in turn leads to a difference in the chromatographic retention of the isotopic compounds at a pH near the pK_a where both two terms of the righthand side of equations 1 and 2 make significant contributions.

Figure 2*a* shows the separation of a standard mixture (1:1) of DMA-^{14}N and DMA-^{15}N at pH 3.8. We found the nitrogen isotope effects on the dissociation of protonated amines, $^{14}K_a/^{15}K_a$, to be 1.019 for aniline[10] and 1.014 for DMA, in agreement with the reported values[11,12]. A maximum chromatographic separation factor, $^{14}k'/^{15}k'$, of 1.011 was observed at pH 3.5-4.0 for the isotopic DMA.

To enrich ^{15}N from the natural abundance of 0.37%, we collected ~5% of the total peak, including the fraction corresponding to DMA-^{15}N, as shown in Fig. 2*b*. The rechromatography of the collected fraction in Fig. 2*c* shows that the isotopic purity of ^{15}N, by the comparison with the standard chromatograms, is ~6%, which agrees well with the results of gas chromatography/mass spectrometry determination. We can obtain an isotopic purity as high as 90% by collecting an appropriate fraction of the chromatographic separation shown in Fig. 2*c*.

The separation of ^{16}O and ^{18}O requires a similar column efficiency as that required for the separation of ^{14}N and ^{15}N. We have found the oxygen isotope effects on the dissociation $^{16}K_a/^{18}K_a$ to be 1.020 for benzoic acid (BA)-$^{16}O_2$ and BA-$^{18}O_2$ (ref. 13), and 1.017 for PNP-^{16}OH and PNP-^{18}OH. This results in an isotope separation factor $^{18}k'/^{16}k'$ of 1.010 for PNP. About 800,000 theoretical plates are required to achieve complete resolution of PNP-^{16}OH, PNP-^{17}OH and PNP-^{18}OH, which can be provided by a column system of 15-20 m. We show the separation of the three oxygen isotopes by recycle chromatography[13,14] of PNP in Fig. 3. The results show that ^{17}O, which is currently available at less than 60% isotopic purity in the form of H_2O, can be enriched to a very high isotopic purity (90% and above) by simple fractionation of the chromatographic effluent. The enrichment of ^{18}O will be considerably easier than that of ^{17}O because of its greater natural abundance.

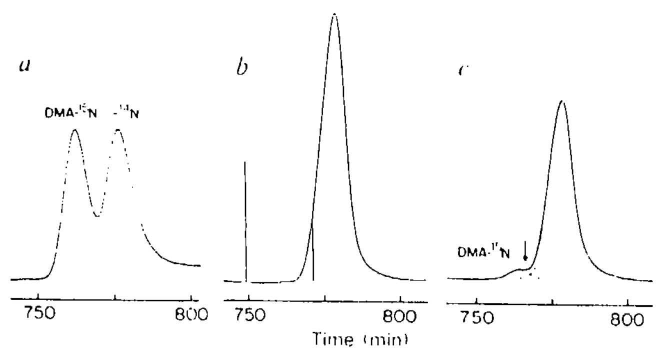

FIG 2 Separation of DMA-^{14}N and DMA-^{15}N *a*, 1:1 mixture of DMA-^{14}N and DMA-^{15}N. *b*, Fractionation of DMA-^{15}N from ordinary DMA. Every 40 min we injected 0.1 mg of ordinary DMA dissolved in 10 µl of the mobile phase (The sample size and separation time depend on the column size and flow rate.) We collected the fraction between the two spikes, containing ~5 µg of DMA, each time. We removed buffering species by chromatography of the combined collected fractions on a C_{18} column using 60% methanol. Following the evaporation of methanol, we extracted the enriched material with ether. The gas chromatography/mass spectrometry analysis of the extracted DMA gave relative intensity, 100.00:80.75:11.11 for m/z values 120, 121 and 122 (M−1, M$^+$, M+1), respectively, compared with 100.00:72.31:5.77 for ordinary DMA, indicating ~6.5% isotopic purity of ^{15}N. *c*, Rechromatography of the separation products from *b*. Dashed lines indicate the simulated traces for DMA-^{15}N and DMA-^{14}N at a 6:94 ratio. We expect a 90% isotopic purity for DMA-^{15}N, when the fraction is collected before the time marked by the arrow[15]. Column: Capcellpak C_{18}-SG, 5-µm particles (Shiseido), 4.6-mm ID, 350 cm (10×15 cm + 8×25 cm). Mobile phase: 0.5M acetate buffer-acetonitrile (90%-10% (v/v)) with 0.01% triethylamine at pH 3.8. Flow rate: 0.37 ml min^{-1}. Temperature: 50 °C.

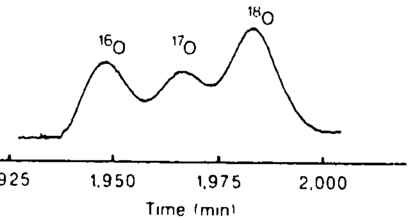

FIG. 3 Separation of PNP-^{16}OH, PNP-^{17}OH and PNP-^{18}O. The solutes were recycled 12 times through a pair of 45-cm column systems by using an automated column-switching valve[13,14]. Increases in the peak width and separation factor were observed because of the effect of the pressure gradient in the column[16]. We expect about 90% isotopic purity for PNP-^{17}OH, if the fraction between the two minima were to be collected[15]. Column: Cosmosil-5C_{18}, 4.6-mm ID, 90 cm (6×15 cm). Mobile phase: 0.02M-phosphate buffer-methanol (95%-5% (v/v)) with 0.001M sodium octanoate at pH 7.6. Flow rate: 0.4 ml min^{-1}. Temperature: 40 °C. A mixture of ~0.5 µg each of PNP-^{16}OH, PNP-^{17}OH and PNP-^{18}OH was injected.

In spite of the small isotope separation factors, the use of high-performance columns and optimized mobile phases has enabled us to achieve a fast separation of oxygen and nitrogen isotopes by reversed-phase liquid chromatography. By carrying out reversed-phase liquid chromatography at a pH value 0.5-1.0 pH units higher than the pK_a for weak acids or 0.5-1.0 pH units lower than the pK_a for weak bases, one can obtain enrichment of the ^{15}N, ^{17}O or ^{18}O atoms involved in the dissociation equilibria. Current polymer-based packing materials allow operation of the chromatographic process in the range pH 2-12. □

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Biases in satellite-derived sea-surface-temperature data

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STRONG[1] indicates from satellite data that global sea surface temperature increased by 0.1 °C per year over the 6.5-year period between January 1982 and June 1988. Here we show that no significant trend can be seen in three analyses of global sea surface temperatures that are based on *in situ* data in this limited period, nor in an independent analysis of sea-surface-temperature (SST) and land-air-temperature data. Satellite data are blended and adjusted in one of the above SST analyses. An unadjusted satellite

SST analysis similar to that used by Strong shows the same, but probably spurious, trend.

Three of the SST analyses we use here were produced at the Climate Analysis Center (CAC) of the US National Meteorological Center, and comprise an *in situ*, a satellite and a blended analysis. The *in situ* SST analysis uses radio-transmitted data from ships and buoys. The satellite analysis uses the multichannel SST (MCSST) data reported by Strong, but with small differences in analytical procedure. The blended SST analysis combines satellite and *in situ* SST observations by using the *in situ* analysis to define 'ground truth' temperatures in regions of sufficient *in situ* data and the analysed satellite data to define the shape of the SST field where there are few or no *in situ* data[2]. Where enough *in situ* observations are available, they provide all the information about SST; elsewhere the adjusted satellite field provides increasing information about SST patterns as *in situ* data become sparser.

We also use a quality-controlled *in situ* SST analysis (produced by the UK Meteorological Office (UKMO)[3,4], as well as a data set of air temperatures measured at night (UKMO). Both data sets use temperatures measured by ships and buoys. We excluded daytime air-temperature measurements because of the risk that variable biases could be introduced by overheating of the ship's thermometer housing by day[5]. In the regional time series, the grid-box data are weighted by the cosine of the latitude.

Figures 1*a* and 1*b* show monthly anomalies for the CAC SST analyses for January 1982-March 1989, averaged over two regions: Equator to 60° N (the same as Strong's Northern Hemisphere area), and 40° S to the Equator. The anomalies were calculated relative to a 1950-79 climatology. The southern limit of 40° S was selected for the second region because of the scarcity of *in situ* observations south of 40° S. The Northern Hemisphere satellite time series (light line) in Fig. 1*a* is similar to that shown by Strong (his Fig. 1*b*); the two series have the same linear trend of 0.16 °C yr^{-1} between January 1982 and June 1988. The two satellite time series are not quite identical because CAC and Strong used different climatologies and averaged the MCSST data on different grids (2° and 2.5°, respectively). In addition, Strong averaged only grid values with data (that is, he did not interpolate data for grids where the satellite data were unavailable because of cloud cover) and did not use cosine weighting to reduce the weight of boxes at higher latitudes. He effectively assumed that all latitude zones over the ocean had the same longitudinal extent because he averaged zonal means of SST with equal weight for each zone (Strong, personal communication). The CAC technique interpolated data for missing grid points over the ocean and used all oceanic grid points (within the given latitudinal bounds) with cosine weighting. Although these analysis differences cause small monthly changes, major features, such as the above trends, were unaffected. (We note that the confidence limits quoted by Strong for his linear trends are too narrow as he did not account for the persistence of SST anomalies for periods longer than a month.)

Figure 1*a* also shows the CAC blended (thick line) and CAC *in situ* SST analyses (dots) for 0° to 60° N; the two data sets are nearly identical (correlation $r = 0.97$ for January 1982-March 1989). There is no significant trend in either set for January 1982-June 1988 or January 1982-March 1989. This agreement between *in situ* and blended SST anomalies demonstrates that the blending technique successfully adjusts the satellite data relative to the *in situ* analysis. The warmth of 1982-83 is mostly due to the 1982-83 El Niño. The uncorrected satellite data, however, indicate very low SSTs during this period (see ref. 6, comment on the same paper).

Figure 1*b*, for the Equator to 40 °S, covers a smaller area than Strong's Fig. 1*c* (Equator to 60° S) but the trend of 0.12 °C yr^{-1} in the CAC satellite data for January 1982-June 1988 is similar to Strong's value of 0.10 °C yr^{-1} over his larger area. *In situ* data

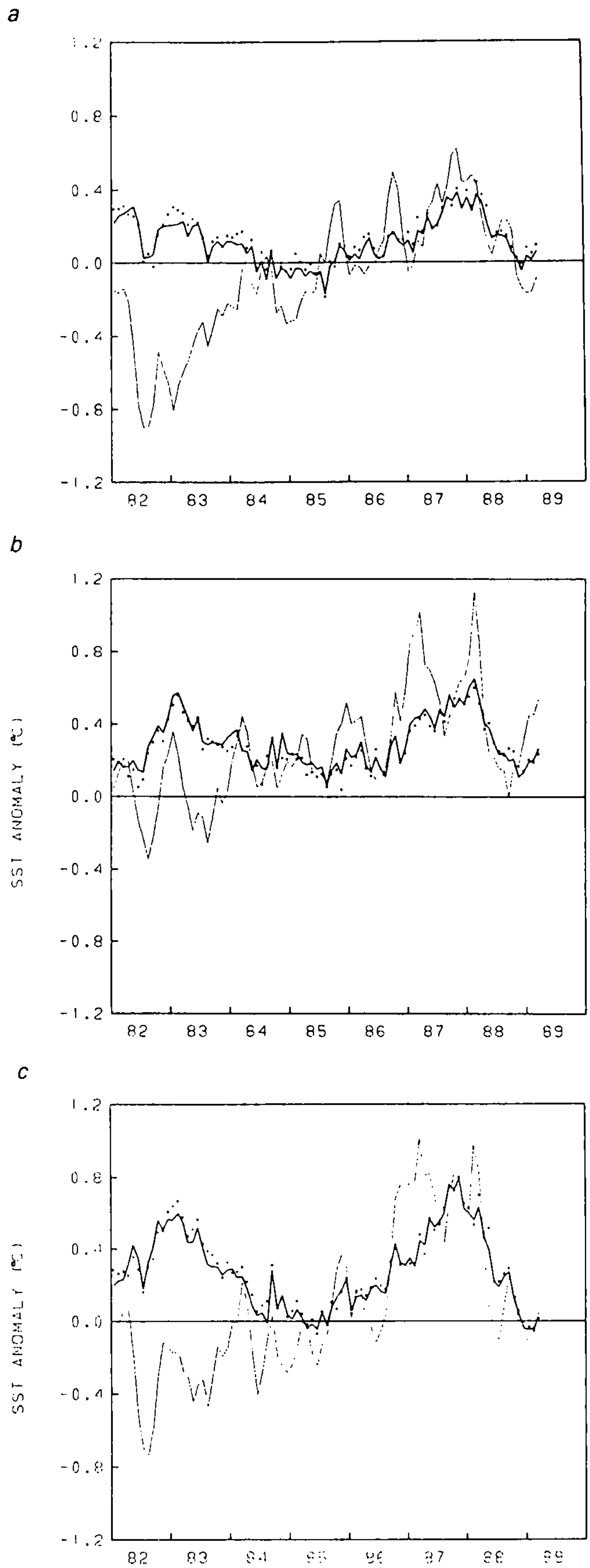

FIG. 1 *a*, Time series of CAC SST anomalies for the Northern Hemisphere between 0° and 60° N, January 1982-March 1989. Satellite anomalies are indicated by a light line; blended anomalies are indicated by a heavy line; *in situ* anomalies are dotted. *b*, As in *a*, except the region is 40° S to 0°. *c*, As in *a*, but for the region 20° S to 20° N.

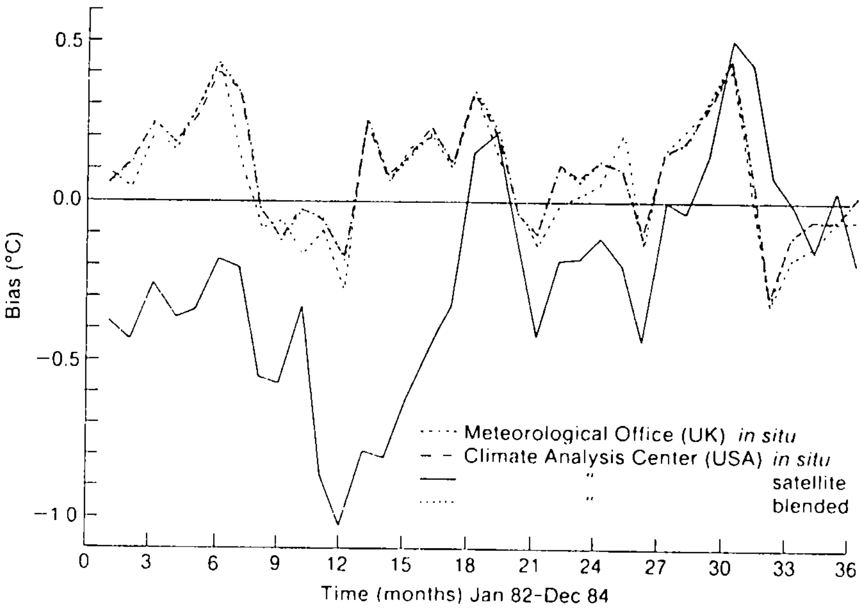

FIG. 2 Mean differences between UKMO *in situ*, CAC satellite, CAC *in situ* and blended analyses and quality-controlled expendable bathythermograph data for the region 0° to 60° N for January 1982-December 1984.

again show no significant trend. Agreement between the CAC blended and *in situ* analyses is again very good ($r = 0.96$ for January 1982-March 1989).

Strong states that the warming trend in the satellite data is about twice that of a warming trend shown by *in situ* data sources. The Oort *et al.*[7] data that he discusses in this connection extend only to 1985; for the period of overlap with Strong's record, Oort *et al.* use the CAC blended analysis (Figs. 1*a* and 1*b*), which, of course, includes adjusted satellite data. No significant global or hemispheric warming trend exists in the limited period of overlap with Strong's data (1982-1985). A linear trend fitted to the Oort *et al.* Northern Hemisphere data over this four-year period shows slight cooling.

To help clarify the relative accuracies of satellite and *in situ* SST data, we have compared them with expendable bathythermograph (XBT) data for January 1982-December 1984. Although the SSTs from XBTs are sparser than the conventional surface marine *in situ* observations used above (the ratio of number of XBTs to conventional SSTs is roughly 5%), they are useful because XBTs are not included in any of the analyses used here and are widely distributed spatially. Figure 2 shows time series of CAC satellite, CAC *in situ*, CAC blended and UKMO *in situ* SST analyses for the Northern Hemisphere subtracted from quality-controlled near-surface SST data derived from XBTs. We call these differences 'biases'. Mean biases were 0.04 °C, 0.04 °C and 0.01 °C for CAC *in situ*, CAC blended and UKMO analyses respectively, and were not statistically significant. The mean bias for the satellite analysis was −0.30 °C and was highly significant, showing that the satellite-derived temperatures were almost certainly too low overall. Furthermore, the satellite bias varied from near −0.8 °C between mid-1982 and early 1983 to small values towards the end of 1984. Thus the satellite biases varied in such a way as to give rise to a pronounced spurious warming trend in 1982-84. In contrast, the XBT data support the lack of trend in the other SST analyses.

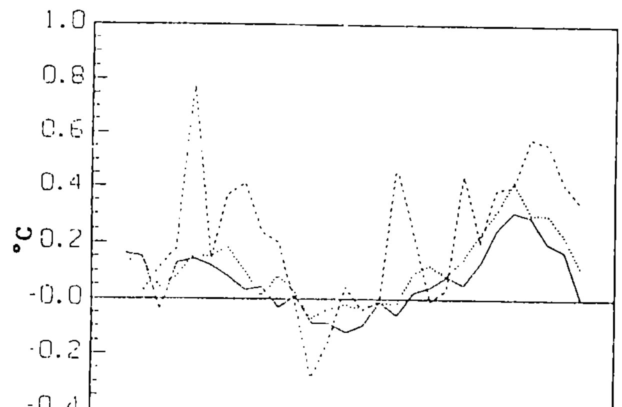

FIG. 3 Seasonal anomalies for the Northern Hemisphere referred to a 1951-80 climatology for January-March 1982 to October-December 1988. Solid line, UKMO sea surface temperature; dotted line, UKMO night marine air temperature; dashed line, land air temperature[8,9].

During the period of interest, two El Niño/Southern Oscillation events (1982-83 and 1986-87) caused strong warming of the tropical oceans, primarily in the central and east Pacific. Figure 1*c* shows time series of the monthly CAC satellite, *in situ* and blended analyses between 20° S and 20° N. These tropical warmings are shown in the *in situ* and blended analyses. As discussed by Robock[6], El Chichón aerosols resulted in a negative bias in satellite SST retrievals from April 1982 to the end of 1983. Thus, the satellite analysis in Fig. 3 does not show the large-scale warming associated with the 1982-83 El Niño event. Despite this, closer analysis shows that the satellite retrievals did detect a locally strong but distorted El Niño warming. The warming observed in the satellite data (south of 5° N in the tropical east and central Pacific) was offset, however, not only by unrealistic negative biases north of this latitude in the Pacific but also by widespread biases in the other tropical oceans.

Further support for the view that the warming trend in the satellite data is mostly false comes from Fig. 3. It shows, for January 1982-December 1988 and the Northern Hemisphere, seasonally averaged (1) UKMO SST anomalies, (2) UKMO night marine-air-temperature (NMAT) anomalies and (3) air-temperature anomalies on land[8,9]. These data are all referred to a 1951-80 average. The correlation between seasonal SST and NMAT data sets over this period is very high ($r = 0.92$); that between the land air and ocean is less, as the land data show more interseasonal variability ($r = 0.54$ with SST and $r = 0.62$ with NMAT). Nevertheless, neither the land nor the marine data show any significant trend over the period 1982-88. Indeed, two El Niño/Southern Oscillation events dominated the record so completely that calculation of a trend over this period is almost meaningless.

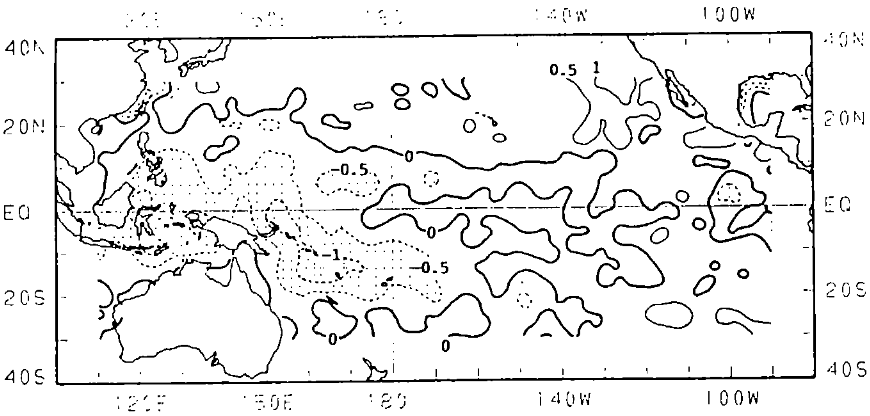

FIG. 4 Mean difference between daytime and night-time satellite SST values over the tropical Pacific for February 1989. The contour interval is 0.5 °C; solid contours indicate positive differences and dashed lines negative differences. The heavy solid line is the zero-difference contour. Dotted regions indicate differences between −0.5° C and −1 °C. Stippled regions indicate differences more negative than −1 °C.

We are much less certain about the adequacy of *in situ* data for the Southern Hemisphere because of its poor coverage. Southern Hemisphere satellite data may not always be completely adequate, however, even after all possible influence from El Chichón ceased. In Fig. 4 we show satellite day-minus-night differences for February 1989, a more recent period than that covered by Strong. In the western tropical Pacific, there is a large region where daytime satellite SSTs are more than 0.5 °C colder than corresponding night-time values. This pattern had persisted since the new NOAA-11 satellite became operational in November 1988, but tropical daytime SSTs could not be colder than night-time SSTs for such a long period. Comparisons of satellite retrievals with drifting-buoy SST measurements in this region since November 1988 confirm that daytime satellite temperatures are lower than the buoy temperatures. Such problems must be corrected before satellite data can be used on their own to estimate climate trends.

Accurate global SST data from satellites are urgently needed, especially in the Southern Hemisphere, to help provide trustworthy analyses of the expected future global surface warming. For the recent past, the best outcome would be that satellite SST data available since the 1970s could be corrected (retrospectively) for their biases, blended with (corrected) *in situ* SST data and combined with surface-land and sea-ice analyses. □

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Beryllium in marine pore waters: geochemical and geochronological implications

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DIAGENETIC remobilization and hydrothermal inputs have been invoked as possible explanations for the discrepancy between the theoretical and measured temporal decrease of the non-detrital ^{10}Be/^{9}Be ratio observed in sediments[1]. Remobilization is also consistent with water-column profiles of beryllium, which indicate a significant benthic flux from sediments[2]. To evaluate the impact of diagenetic recycling on the beryllium isotopic composition of marine waters and the effects of this process on the beryllium geochronometer, we have analysed the ^{9}Be content of interstitial waters from different environments. Here we report the first pore-water profiles for ^{9}Be in oxic and suboxic pore waters as well as some preliminary results from hydrothermal sediments collected in the Guaymas Basin. Our results suggest that the use of the beryllium isotopes as a geochronometer is not affected either by sedimentary diagenesis at oxic and suboxic sites or by input of hydrothermally derived ^{9}Be more than a few kilometres from vent sites.

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Oxic pore waters were collected at MANOP site S in the central equatorial Pacific; suboxic pore-water samples were collected at the Patton Escarpment (Southern California Borderland)[3]. Subcores taken with plastic core liners from box cores were sectioned and centrifuged at *in situ* temperatures and, at the suboxic site, under nitrogen. Pore water thus obtained was immediately filtered and acidified.

Interstitial waters from Guaymas Basin were obtained during dives of the submersible *Alvin* in January 1982. Core 1172 is from the Southern Vent Field immediately adjacent to an active 20-m-high hydrothermal mound, and core 1174 was taken in the vicinity of East Hill near hydrothermal deposits[4]. They were obtained with plastic *Alvin* core tubes. The sediment was extruded, sectioned and squeezed in an acid-cleaned plastic pore-water press. The fluids were immediately filtered and sealed in glass ampoules.

Beryllium analyses were made by gas chromatography with electron-capture detection of its 1,1,1-trifluoro-2,4-pentanedione derivative. The details of the method have been presented in ref. 5. Aliquots ranging from 10 to 30 ml were required for these analyses.

Beryllium concentration-depth profiles for the oxic and suboxic sites are presented in Fig. 1 along with interstitial Mn and Si data. The beryllium concentrations near the interface are a factor of 2.5 (MANOP site S) and 3.3 (Patton Escarpment) higher than the average North Pacific bottom water (29.4 ± 1.7 pM, refs 2 and 7). This, coupled with the observed increase in concentration with depth, implies a flux of beryllium out of the sediments.

We estimated steady-state fluxes to bottom waters for each location assuming molecular Fick's-law diffusion and a linear concentration gradient across the interface. We estimated an effective bulk sediment diffusion coefficient of 1.7×10^{-6} cm^2 s^{-1}

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GLOBAL, REGIONAL, AND ZONAL SEA SURFACE TEMPERATURE SIGNALS FROM SATELLITE AND IN-SITU OBSERVATIONS DURING THE 1980s

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ABSTRACT

A time-series of AVHRR derived multi-channel sea surface temperatures (MCSST) has been compared with ship and buoy SST data during the 1982-89 period. Monthly mean results have been converted to annual means to reduce serial dependencies between months. Data separated both into regional and latitudinal time-series show favorable agreement between the satellite and conventional SSTs. Comparisons with the NOAA/GFDL coupled atmospheric/ocean model results (EOS, 70,43 p.1002) indicate that certain changes in some ocean areas may be beginning recently that have been identified as changes to be expected in global warming scenarios. For example, during the past decade the southern hemisphere "ocean" has been warming at a slower rate (0.03C/yr) than is seen over the northern hemisphere "ocean" (0.04C/yr). Our time-series show that during this (albeit short) 8-year record several regions are not showing warming, rather a cooling: the Indian Ocean (-0.05C/yr), the high latitude southern ocean (-0.08C/yr); and the equatorial oceanic belt (-0.06C/yr).

1. INTRODUCTION

Data from NOAA's polar orbiting satellites have been used to attempt global mapping of sea surface temperature for the past 17 years[1]. These remotely sensed retrievals became considerably more accurate following the launch of the AVHRR (Advanced Very High Resolution Radiometer) in late-1978. Multi-channel SSTs (MCSST) have been computed operationally from AVHRR data since late-1981.

Various authors[2,3,4,5] have presented statistics indicating RMS differences ranging from ±0.4 to 0.6°C between co-located in-situ buoy SST and satellite MCSST observations. Most importantly the biases of these monthly match-ups when compared with the drifters continue to show small and random biases (e.g., ±0.3°C maximum), with small nighttime monthly mean biases frequently compensating in sign for small daytime biases.

The purpose of this paper is to compare annual MCSST with in-situ (ship and buoy) short-term oceanic surface temperature tendencies for the eight year period from 1982 to 1989. Having combined both daytime and nighttime satellite observations into composite annual means we would expect that little effect will remain of an occasional bias problem noted during late-1988 and early-1989 between daytime and nighttime satellite retrievals over the western tropical Pacific Ocean[6]. Making use of the copious, although admittedly brief, MCSST database with its 3-5 million monthly MCSST observations between 60N and 60S, some notable tendencies are observed in both MCSST and in-situ SST records during the decade of the 1980s.

2. DATA AND METHODS

In order to remove monthly or seasonal variabilities, these data are presented not only as global and hemispheric annual mean anomalies using the Robinson-Bauer climatology, but they also have been separated latitudinally and by ocean basin. The grid used for all these data is the 2.5 degree latitude/longitude interval previously used by Strong[7], and no analyzed data have been used in these calculations. Although this presents little difficulty with the MCSST computations, since virtually all grid-quadrangles have well over 100 observations for each monthly computation, this is not the case with many of the grid values for in-situ data. Frequently, especially south of 10N, grid point values are computed from less than ten monthly in-situ SST observations during a given month.

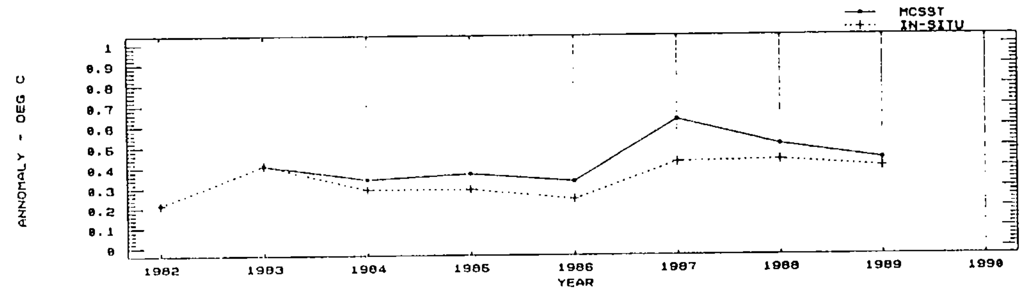


Figure 1 Annual global MCSST and in-situ SST departures from climatology (°C) for the period 1982 to 1989.

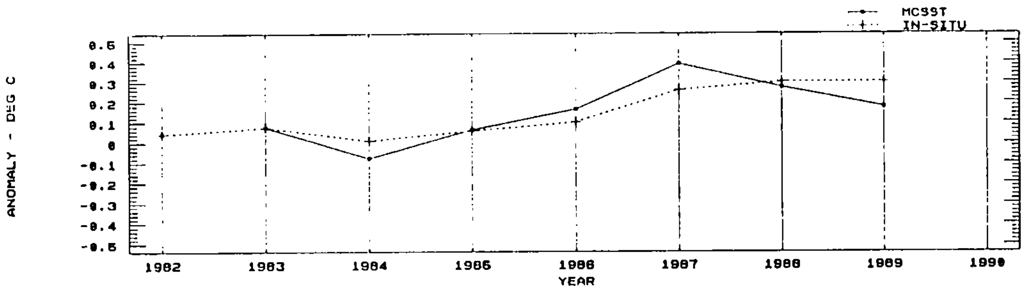


Figure 2 Same as Fig. 1 except for Northern Hemisphere only.

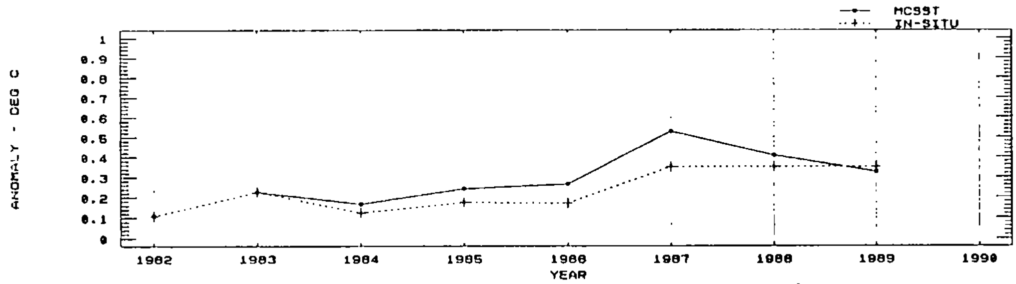


Figure 3 Same as Fig. 1 except for Southern Hemisphere only.

TABLE 1

AREA	SLOPE - DEG/YEAR		STANDARD ERROR	
	MCSST	IN-SITU	MCSST	IN-SITU
Global	0.042	0.036	0.014	0.009
Northern Hem	0.040	0.044	0.018	0.009
Southern Hem	0.034	0.021	0.015	0.012
North Pacific	0.046	0.046	0.019	0.015
South Pacific	0.054	0.046	0.016	0.014
North Atlantic	0.060	0.075	0.018	0.014
South Atlantic	0.077	0.063	0.015	0.018
Indian	-0.054	-0.061	0.038	0.036
ZONALS				
60N	0.059	0.030	0.044	0.015
50N	-0.057	-0.032	0.033	0.028
40N	0.080	0.079	0.044	0.033
30N	0.104	0.080	0.022	0.010
20N	0.042	0.050	0.032	0.019
10N	0.020	0.034	0.047	0.032
EQ	-0.058	-0.032	0.081	0.045
10S	0.035	0.026	0.040	0.028
20S	0.076	0.054	0.028	0.017
30S	0.086	0.050	0.011	0.014
40S	0.051	0.040	0.029	0.015
50S	-0.076	-0.097	0.022	0.034

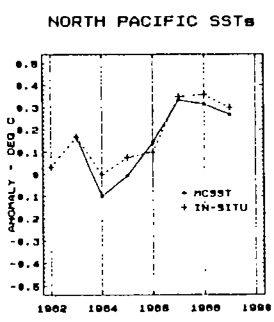
Table 1. Regional and Zonal variations in SST for both satellite and in-situ data. Standard errors for the slope calculations are included.

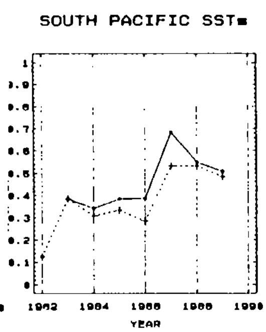
3. RESULTS

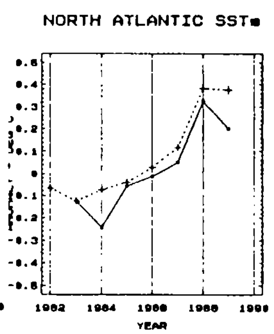
Eight-year tendencies are presented for global, Northern Hemisphere, Southern Hemisphere SSTs in Figures 1, 2, and 3, respectively. In general, more variability is seen in the MCSST than in the in-situ SST year-to-year anomalies. MCSST data show warmer conditions during the 1987 El Niño and, in the Northern Hemisphere, lower SSTs following the 1982/3 and 1987 El Niño than shown by the in-situ data. Nevertheless, using annual data, the upward trends in both data sets in Table 1 do not show any statistically significant differences, i.e. their standard errors all overlap. Interestingly, although concern has been expressed that MCSST values have been erroneously too high at times, the Northern Hemisphere results (Fig. 2) are now revealing in-situ data that exceed the MCSST levels using these processing procedures. Furthermore, the upward trend in the in-situ data over the Northern Hemisphere show the most significant upward trend during this eight-year period (Table 1). Significant also, in this record is the somewhat faster increase in SST over the Northern Hemisphere compared to the Southern Hemisphere, particularly shown by the in-situ data.

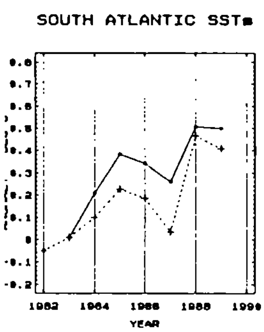
Further observations can be made about the following basins: North and South Pacific Ocean, Figures 4/5; North and South Atlantic Ocean, Figures 6/7; and Indian Ocean, Figure 8. There is good overall correspondence between the two data sets in virtually all areas. Note how well the large excursions seen in the Indian Ocean anomalies are supported by both satellite and conventional SSTs. Both excursions are undoubtedly a function of the El Niños of the 1980s and provide further evidence of air-sea teleconnections between the Indian and Pacific Oceans.

Remembering that most of the drifting buoys used to establish the MCSST algorithms resided in the Southern Hemisphere, we note that the best correspondence between the two data sets is found in the Northern Hemisphere, where data density for the ship and buoy data set is highest. Possibly the greater discrepancies between conventional and MCSST annual values in the Southern Hemisphere is due to reduced data coverage from in-situ sources. From these present-ations, it can be seen that greatest SST increases during this period over the Northern Hemisphere are occurring in the North Atlantic -- with the in-situ annual means increasing slightly faster, although not significantly so, than the satellite means. Again, as with the earlier hemispheric and global cases, Table 1 shows that all tendencies have "standard error bars" that overlap, suggesting there is no significant disagreement between these two data sets. Other than this larger Atlantic Ocean change, perhaps the most noteworthy observation is the observed decrease recently seen in the Indian Ocean trend, clearly associated with the decrease in SST following the 1987 El Niño. Temperatures over the Indian Ocean during 1988 and 1989 have been averaging annually below anything observed during the rest of this past decade. When reviewing this basin's annual time series over the period it is apparent that the extreme scatter from the two high-anomaly spikes, coinciding









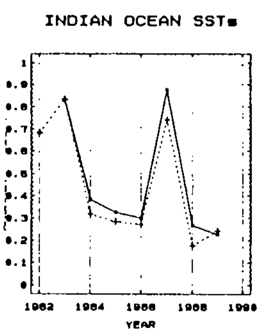


Figure 4 Same as Fig. 1 except for North Pacific basin only.

Figure 5 Same as Fig. 1 except for South Pacific basin only.

Figure 6 Same as Fig. 1 except for North Atlantic basin only.

Figure 7 Same as Fig. 1 except for South Atlantic basin only.

Figure 8 Same as Fig. 1 except for Indian Ocean basin only.

responsible for the greater standard errors derived over this region.

From the eight-year trends summarized in Table 1, the most significant rises over this relatively short period are on both sides of the equator in the Atlantic Ocean. Here upward tendencies are seen that are nearly double the rate seen on the global ocean scale. It is apparent that the Indian Ocean, whose surface area represents 21% of the global oceans, has been cooling, helping to offset some of the overall effect of a more rapidly warming Western Hemisphere (and Northern) during the 1982-89 period. Although much of the area of the Indian Ocean lies in the Southern Hemisphere (approximately 90%), both the trend and year-to-year variations in anomaly bear no resemblance to those being seen in the other two oceans of the Southern Hemisphere.

Displaying SST tendencies zonally provides another way to monitor our ocean's variabilities and trends. This is useful because for the most part the planet's climate regimes are best categorized zonally. Zonal slices from the data sets used here have been selectively analyzed for every ten degrees of latitude from the 2.5 degree latitude/longitude oceanic grid. Figure 9 presents these twelve zones from 60N to 50S for the satellite and conventional SST data sets. Trends and standard errors of these tendencies are summarized in Table 1. Although more annual variability is often obvious when the data are broken out zonally, with expected lower overall significance, certain features that collectively could become significant may be worth noting. Figure 10 illustrates the similarities in short-term tendencies at approximately the same latitudes in each hemisphere. Although the only error bars that do not overlap occur at 30S, that higher trends are seen at <u>both</u> 30N and 30S may

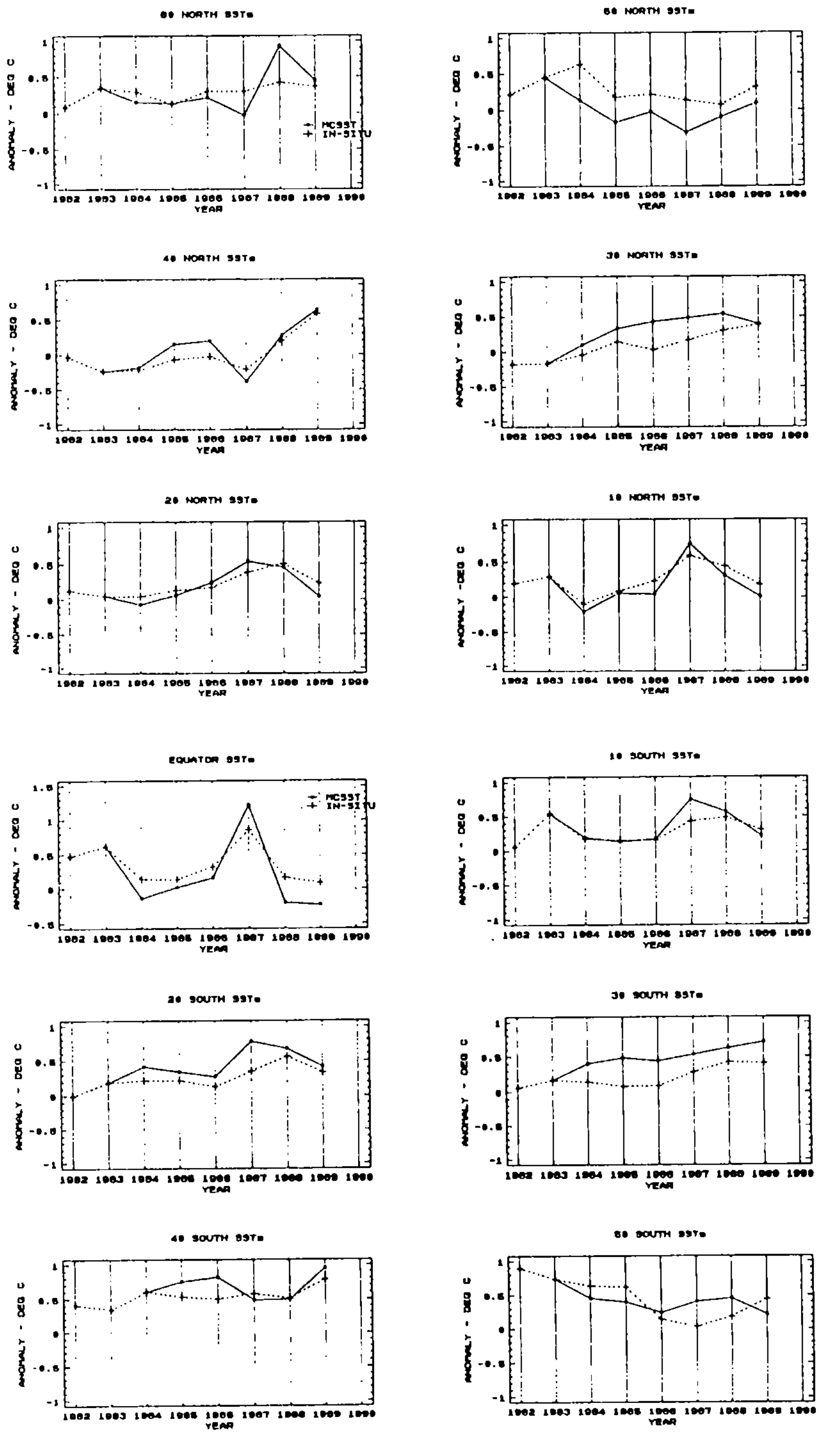


Figure 9 Annual zonal MCSST and in-situ SST departures from climatology (°C) between 60N and 50S from 1982 to 1989.

somewhat more than 0.5°C increases over the decade. Our tendencies over this area are not significantly different.

Possibly the biggest surprise in our findings is the strong apparent correlation between the Indian Ocean SST tendencies and El Niño events in the tropical eastern Pacific. The two warm events from the 1982/3 and 1987 El Niños are mirrored strongly in the average Indian Ocean basin anomalies. Walker[12] and Berlage[13] argue that a strong coupling exists between the atmospheres over the South Pacific and the Indian Ocean. Pressures of the lower atmosphere over these two regions correlate strongly, but negatively, in a "seesaw"[14] effect that points to a strong inter-relationship between these two large ocean areas.

Incorporation of additional MCSST data during the 1990s should help reduce the dependency of trends in these time series resulting from the periodic and far reaching effects of El Niño events. It has been suggested that considering only grid locations with coincident satellite and in-situ values would help remove much of the remaining discrepancies between the two global data sets. If that turns out to be the situation, an excellent case can be made for continuing and maintaining this MCSST time-series to adequately monitor our entire planet's SST, particularly in the Southern Hemisphere.

5. ACKNOWLEDGMENTS

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give more credence to the trends seen in these areas than otherwise. It should be noted that these are regions that are dominated by large anti-cyclones in the atmosphere, and they overlie large oceanic anticyclonic gyres in the respective ocean basins.

With the recent discussions of tropical surface warming[8] Figures 9 and 10 indicate both in-situ and satellite data sets show similar but slightly cooling equatorial surface tendencies, which are in opposition to the warming found at subtropical latitudes. At higher latitudes in both hemispheres, these overall SST increases can be seen to fall off, the trends becoming negative at 50N and 50S. Again, what appears most significant from these data sets is the symmetry in tendency apparent over both hemispheres. Poor in-situ SST coverage over the Southern Hemisphere around 30S may help to explain the largest discrepancies between the MCSST and in-situ trends. Development of the operational MCSST algorithms have extensively employed drifting buoys from this ocean region.

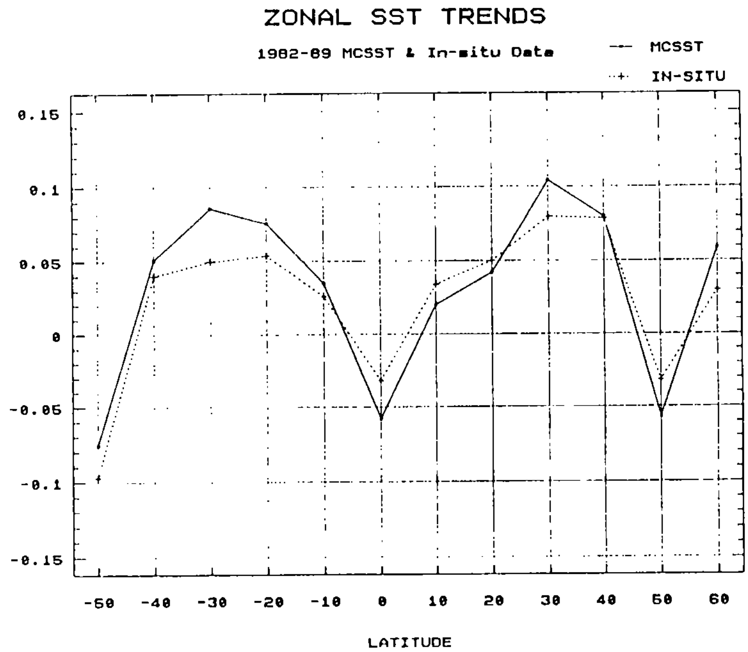

Figure 10 Zonal tendencies from satellite and conventional data sources between 1982 and 1989 as a function on latitude. See Table 1 for standard errors accompanying each location and data type. (All overlap except 30S location.)

4. DISCUSSION

If a case can be made for any increase in SSTs during the 1980s from these analyses, it would be for the subtropical ocean regions -- 20-40° N and S and the Atlantic Ocean. Regions along the Equator, at least globally, appear to show small cooling tendencies as does the entire Indian Ocean. Zonally, the higher latitudes around 50N and S exhibit negative trends during the decade. Provided these trends continue in a similar fashion over the next decade, there are implications for some significant redistributions of heat over the planet's oceans.

As climatologists continue to watch both oceans and atmosphere for signals of changing temperatures from predicted "greenhouse" related adjustments in our coupled air-sea environment, the questions are where should we watch and what should we expect to observe? Recently some sophisticated models have begun to point to certain zones and regions where responses might be most notable. NOAA's GFDL(Geophysical Fluid Dynamics Laboratory) results[9,10] from their coupled ocean-atmosphere model reveal that little change in SST is expected due to global warming in the region of the Antarctic Convergence -- even some decrease in SST could occur. Their model predicts considerably larger increases should be seen over the Northern Hemisphere where a higher land/sea ratio exists than over the Southern. The results presented here appear to be consistent with these preliminary GFDL findings.

Results from the NASA/GISS (Goddard Institute for Space Science) three-dimensional model[11] target the "low-latitude" oceans for significant warming from augmented greenhouse conditions. The region of 30S exhibits notable warming over the oceans by the 1990's in their "Scenario B". The Northern Hemisphere warming zonal band appears around 40N in the GISS results. Our zonally stratified calculations for tendencies during the 1980s are qualitatively consistent with the findings from the GISS model. Quantitatively, their model shows these ocean areas could expect