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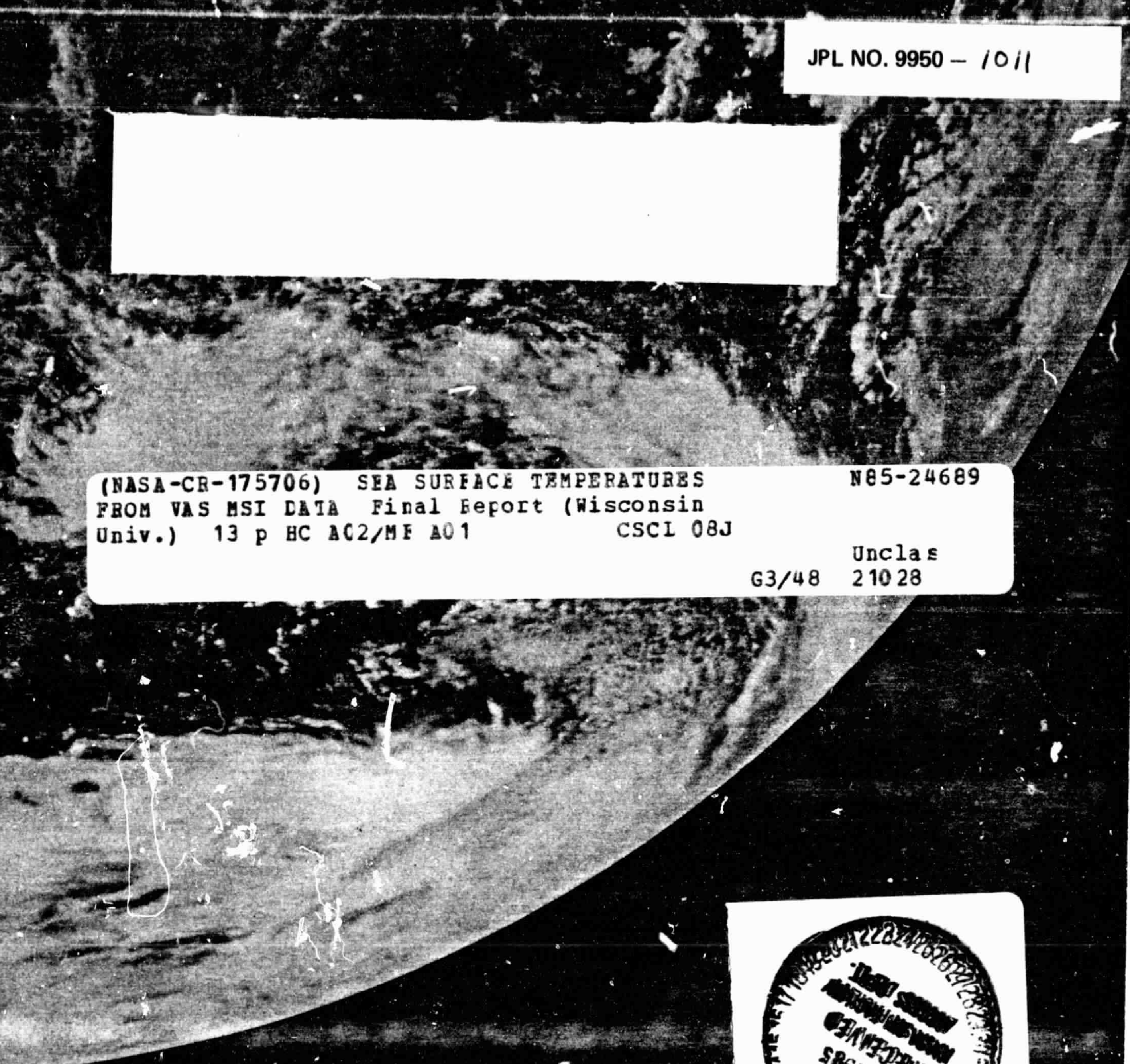

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A REPORT

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Sea surface temperatures from VAS MSI data

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Final Report

by

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This report contains no new technology.

Abstract

A procedure is developed for estimating sea surface temperatures (SST) from multispectral image data acquired from the VISSR atmospheric sounder on the geostationary GOES satellites. Theoretical regression equations for two and three infrared window channels are empirically tuned using clear field of view satellite radiances matched with reports of SST from NOAA fixed environmental buoys. The empirical regression equations are then used to produce daily regional analyses of SST. Monthly mean SST's for the western North Atlantic and the eastern equatorial Pacific during March and July 1982 were produced for use in the SST Intercomparison Workshop Series. Workshop results showed VAS SST's have a scatter of 0.8-1.0°C and a slight warm bias with respect to the other measurements of SST. The VAS SST's show no discernible bias in the region of El Chichón volcanic aerosol cloud.

1. Introduction

The results of the SST intercomparison workshop series (JPL, 1983) are the first examination of monthly mean SST's derived from MSI data provided by the VAS instrument on the GOES series satellites. While VAS instruments are currently only on the U.S. geostationary satellites, limiting coverage to the western hemisphere, it is hoped that the success of VAS will encourage the European Space Agency, Japan, and India to consider installing a VAS instrument on their future geostationary satellites.

Because the procedure to derive SST's from VAS data is still in the developmental stage, several changes in the procedure were made between the processing of data for March 1982 and processing the data for July 1982. The most significant change was the use of the three window channel algorithm (3.9, 11.0, and 12.6 μm) in the processing of the July data as opposed to the use of only the two window channel (11.0/12.6 μm) algorithm for the March data. Initially only the two channel algorithm was used in order to extend the analysis of SST into areas of sunglint in the tropics. However, the analysis of the March data showed that little additional data was gained by doing this. In addition, further satellite/buoy matches indicated that the triple window channel algorithm showed a smaller standard deviation than the two window channel algorithm and was less sensitive to the effects of volcanic aerosol contamination and low level inversion conditions. This is due to the smaller brightness temperature attenuation by aerosols and water vapor at 3.9 μm than at 11.0 and 12.6 μm. Thus, the decision was made to use the best product (i.e., the three window channel algorithm) for processing the July data.

2. March 1982 Results

Two large regions were chosen for analysis of VAS data from GOES-East, one in the western North Atlantic and one in the eastern Tropical Pacific. Since ship observations of surface layer temperature provide the only long-term climatology of SST, Reynolds (1982) climatology has been used as a standard from which satellite SST monthly mean anomaly fields were produced. Data from all sensors were binned on a two by two degree latitude/longitude grid for each month. SMMR data were required to be more than 600 km from land in order to avoid contamination from land. Thematic contour charts of sensor anomaly fields from climatology for March are shown in Figure 1. VAS, AVHRR, and ship data all show a pattern of cold to warm to cold to warm proceeding southeast off the U.S. east coast; however the VAS data have a warm bias of 0.5 to 1.0°C. In the South Pacific, the VAS data show only a slight warm bias and again are highly correlated with the AVHRR, ships, and XBT's. In particular, the VAS and AVHRR thematic contour anomaly charts show similar patterns with warm water along the coast from 20° to 30°S and extending to the west along 30°S, a pool of cold water along the coast from 0 to 10°S, another cold anomaly offshore, and near normal conditions elsewhere. The HIRS data show generally weaker anomaly patterns and a warm bias near the coastlines due to problems in accurately specifying the land/water boundaries (Susskind, personal communication). The HIRS data do show a warm anomaly along 30°S in the eastern South Pacific and a large warm anomaly in the western North Atlantic. Little correlation in patterns is found between the VAS and the SMMR product.

Table 1 summarizes the cross correlation statistics for each satellite verses ship-of-opportunity measurements for March 1982. Matches with ships were limited to a time window of ±12 hours and a space window of ±50 km from the satellite observation. VAS estimates of SST show a warm bias relative to ships for all regions ranging from +0.35 to 1.73°C. The largest biases (1.73°C and 1.05°C) are found with the lowest numbers of matches (21 and 53) and also occur at the largest satellite zenith angles (North Pacific region 20-56°N and South Pacific region 20-56°S). This indicates that the magnitude of the warm bias for the two channel algorithm may increase with increasing satellite zenith angle but also suggests that noisy ship data may be partly responsible for some of the bias.

The uniform warm bias in all regions, however, indicates a diurnal sampling bias and a possible bias in the matches used to tune the emperical algorithm. Satellite/buoy matches are continuing to be collected in order to ensure that a seasonally and geographically diverse set of matches is used to update the coefficients for the emperical algorithms. It does appear though that the diurnal sampling of VAS data is largely responsible for the warm bias. VAS data were generally processed at 1530 and 1830 GMT (1030 and 1330 LST at the GOES-East subpoint) and only cloud-free observations were used. Thus, VAS SST's might be expected to have a warm bias relative to estimates of SST that average day and night data. Diurnal heating of the ocean skin temperature as observed by satellite infrared data has also been reported by Strong (1984) and by Deschamps and Frouin (1984). Future intercomparisons must take into account possible diurnal sampling biases of each sensor.

Additional cross correlation statistics for March show VAS with a scatter relative to ships of 0.79-1.24°C. The statistics show VAS well correlated with ships, and shows regional correlations very similar to those of the AVHRR. The one exception is the far South Pacific region (20-56°S). This again is the region of fewest matches and thus should be given little weight.

3. July 1982 Results

In the thematic anomaly charts for July (Figure 2), the effects of the El Chichon volcanic aerosol are very evident in the AVHRR data as a zonal band of cold anomalies from 10-30°N. VAS data, however, do not show an analagous anomaly in those latitudes. This result is due to differences in the spectral channels of the VAS and AVHRR, differences in the processing algorithms, and differences in the average viewing geometry. The VAS, SMMR, and ship data all show a warm anomaly in the eastern tropical Pacific.

In the North Atlantic VAS region, the VAS data appears to be slightly warmer than the ship data, but again shows similar patterns. The VAS and AVHRR data show some correlation near the coast of the U.S., but meaningful comparisons between the two are hampered by the volcanic aerosol contamination in the AVHRR data. The anomaly patterns are much the same in a comparison the the VAS/SMMR data, however the SMMR data is contaminated by "cold" instrument warmup noise in much of the North Atlantic (Milman, personal communication). In the VAS region of the Pacific, the VAS, SMMR, and ship data all show warming. Here, the VAS and SMMR data show a high correlation with a pattern of warm anomalies along the coast and extending westward along the equator. In contrast, the HIRS data, while not showing any consistent bias in the El Chicón region, does show a large cold anomaly in this region.

Cross correlation statistics for July 1982 are summarized in Table 2. VAS SST's again show a slight warm bias in all regions. The very large warm bias at large local zenith angles evident in the March 1982 data, however, has been eliminated by the use of the three window channel algorithm. Little bias is evident in the region of the El Chichon volcanic aerosol (approximately 10-30°N). In this region, the AVHRR data show a cold bias of 0.50-0.75°C relative to ships. The VAS standard deviations are also generally smaller in July than in March due to the use of the three window channel algorithm. The cross correlations of VAS data with ship data, however, are much weaker in July than March.

After SST Intercomparison Workshop III, additional cross correlation tables were generated to try to answer some of the questions raised during the workshop. Most important to the interpretation of VAS data was the stratification of AVHRR data into day and night so that the daytime only VAS data could be directly compared to daytime only AVHRR data. Although the new cross correlation tables are masked to include only data greater than 600 km from land (to normalize the comparison between SMMR and the other sensors, but greatly reducing the number of VAS/ship matches), some trends are clearly evident. In March 1982, AVHRR shows a global average day minus night difference relative to ships of +0.43°C. This reduces the VAS minus AVHRR day bias to +0.23°C. The VAS verses ship biases remain unchanged since ships measure SST at some depth beneath the surface and are relatively insensitive to diurnal heating of the ocean skin. In July, on a global basis, the AVHRR day product is 0.43°C warmer than ships while the AVHRR night product is 0.72°C colder than ships. There is no discernable bias between AVHRR day SST's and VAS SST's outside the El Chichon zone (i.e., in the South Pacific and North Atlantic), while within the El Chichon zone (the mid-Pacific) AVHRR day is 0.69°C colder than VAS and 0.50°C colder than ships. These data clearly show that the diurnal heating of the ocean skin is being detected by VAS and AVHRR, and demonstrates that most of the VAS warm bias relative to the other sensors is due to this diurnal variability.

4. Evaluation of Other Products

4a. AVHRR

The AVHRR MCSST is the only operational satellite SST analysis currently and is the most accurate and consistent product evaluated at the workshop series. As with all SST data sources, care and understanding must be used when evaluating and applying this data. Studies such as that by Legeckis and Pichel (1984) are particularly useful in interpreting the weekly MCSST analyses. Users must also understand the nature and variability of ocean surface skin temperature measurements as opposed to ship bulk surface layer measurements. For example, the MCSST analysis for March 1982 has been criticized for showing a warm anomaly along the equator from the western Pacific into the western Indian Ocean; an area where ship climatology shows little monthly variability. The AVHRR day-night thematic contour analysis (not shown), however, shows that this warm anomaly may be the result of diurnal warming of the ocean surface. In fact, the AVHRR day-night analyses show a distinct diurnal pattern of solar heating from December 1981 to March 1982 to July 1982. In December 1981, a consistent zonal band of warm daytime SST anomalies is found from about 30-50°S, in the southern (summer) hemisphere. In March 1982, the warm anomaly has become more diffuse and shows the largest anomalies on the equator. By July 1982, the warm anomaly evident as a zonal band in the northern (summer) hemisphere. Diurnal variability of the oceans skin is being measured by satellite sensors, as is evident from the analysis of AVHRR day-night measurements.

4b. SMMR

The problems with the SMMR SST product are largely due to instrumental difficulties. The SMMR antenna biases are large and vary in time and space, and side-lobe interference requires observations to be greater than 600 km from land. In spite of these difficulties, SMMR analyses of the Pacific and Indian Oceans appear reasonable. Unfortunately, the antenna problem makes it difficult to evaluate the problem of microwave emmissivity changes of the ocean surface with wind speed, while the land mask restricts analysis of the important boundary currents. The SMMR/ship product is an improvement on SMMR alone, but it does not take full advantage of all the different sensors for measuring SST.

4c. HIRS/MSU

Evaluation of the HIRS/MSU product is difficult because of changes in the product from one time to the next and because the data were presented late. The HIRS/MSU anomaly patterns generally look noisy and weaker than the anomaly patterns of the other sensors. In March 1982, the HIRS/MSU shows no correlation with any of the other products and a standard deviation from climatology of about 1°C. The July 1982 statistics are better, but the anomaly patterns are inconsistent, showing an overall cool bias. Particularly troublesome is a cool anomaly in the eastern Equatorial Pacific where all the other sensors show a warm anomaly.

5. Recommendations

5a. Improvements in infrared sensors

Recent theoretical and emperical studies of the infrared portion of the earths spectrum have revealed that neither VAS nor AVHRR have the optimal channel selection for SST detection. Studies are now underway to determine which window regions using a filtered radiometer would yield the most accurate SST's. In the long term, though, an infrared spectrometer interferometer instead of a filtered radiometer will be a much better instrument since it would permit use of all portions of the infrared window regions to be utilized.

5b. A combined product

Efforts should begin on a combined satellite SST product that takes advantage of the benefits of each sensing system discussed in the workshop series. Such an approach should use the raw data from each instrument, not just the finished products such as the SMMR/Ship composite. The McIDAS system has the capability of processing raw data from all sensors used in the workshop series. It is time to begin a program to produce an operational SST analysis.

5c. Research panel on SST sensing

A research panel to set research program goals, evaluate present systems, and recommend areas for further study should be set up under the direction of NSF or other appropriate agency. This panel should coordinate efforts between ongoing ocean research programs and the remote sensing community. This panel could also serve as the focus for the development of a combined SST product.

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TABLE 1

CROSS CORRELATIONS OF SATELLITE SST ESTIMATES VERSUS
SHIP SST ESTIMATES FOR MARCH 1982

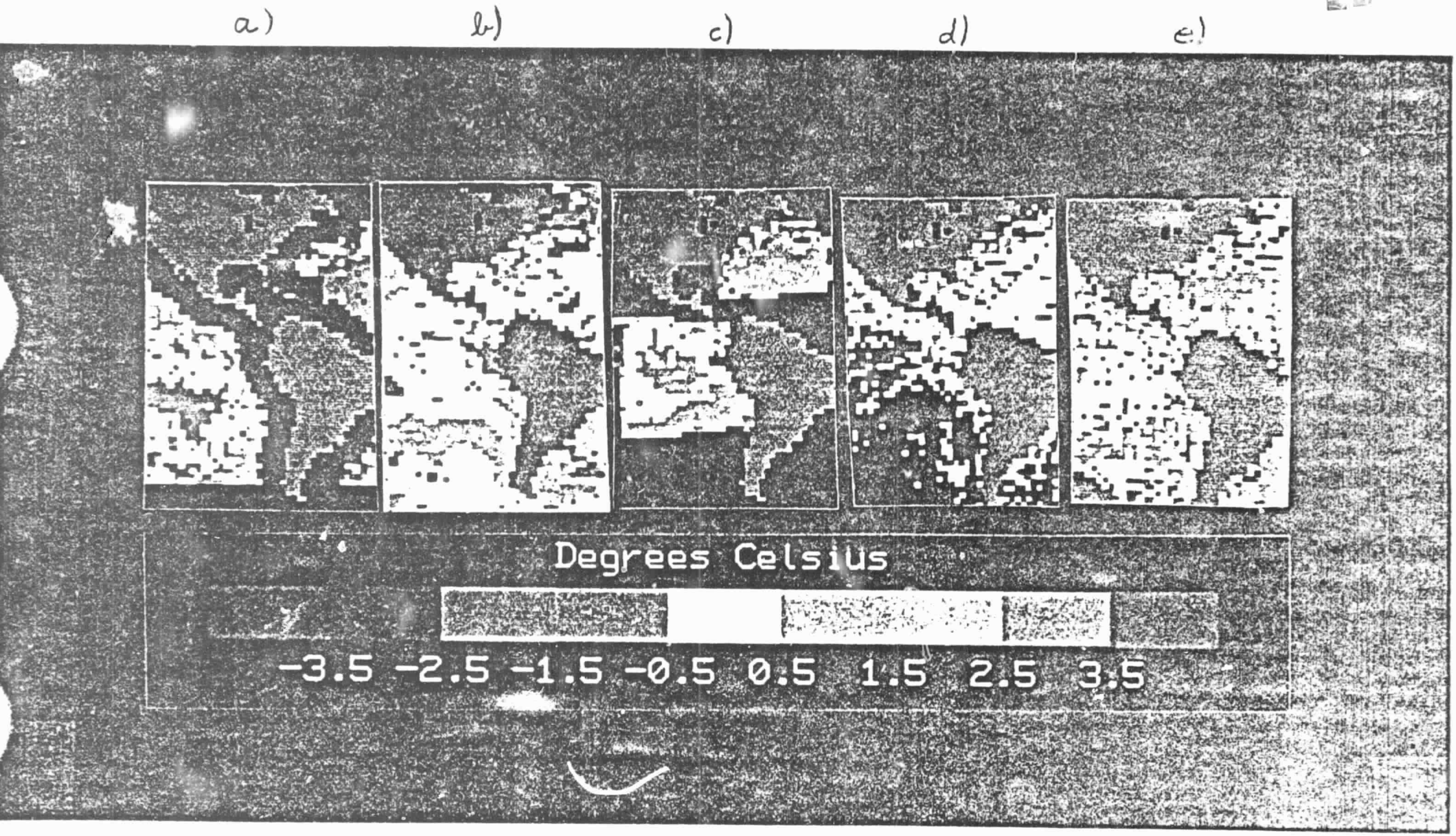
	Number of Matches				Bias				Standard Deviation				Cross Correlation			
	AVHRR	SMMR	HIRS	VAS	AVHRR	SMMR	HIRS	VAS	AVHRR	SMMR	HIRS	VAS	AVHRR	SMMR	HIRS	VAS
Global	4322	1972	-	425	-0.06	-0.01	-	+0.63	0.81	1.20	-	0.96	0.58	0.25	-	0.59
North Pacific (0-56°N)	1563	815	-	127	-0.26	-0.05	-	+0.52	0.67	0.99	-	0.92	0.64	0.29	-	0.61
North Pacific (20-56°N)	1033	529	1054	53	-0.39	-0.01	+0.54	+1.05	0.65	1.03	1.07	0.89	0.60	0.36	0.28	0.63
Tropical Pacific (20°N-20°S)	837	412	858	165	+0.10	-0.22	+0.23	+0.20	0.73	0.87	0.93	0.90	0.13	0.08	0.03	0.10
South Pacific (20-56°S)	535	202	541	21	+0.24	+0.55	+0.05	+1.73	0.78	1.19	1.11	1.24	0.42	0.08	0.28	-0.39
South Pacific (0-56°S)	984	328	-	112	+0.26	+0.17	-	+0.52	0.80	1.14	-	1.20	0.29	0.11	-	0.23
VAS Pacific Region (14°N-30°S)	178	81	-	181	+0.06	-0.16	-	+0.35	0.89	0.91	-	1.06	0.23	-0.08	-	0.03
Global AVHRR El Chichon Mask	2214	1088	2229	211	+0.03	+0.12	+0.20	+0.55	0.86	1.11	1.04	1.12	0.48	0.29	0.20	0.41
North Atlantic (0-56°N)	715	315	-	186	-0.33	-0.92	-	+0.76	0.61	1.18	-	0.79	0.58	-0.02	-	0.65

TABLE 2

CROSS CORRELATIONS OF SATELLITE SST ESTIMATES VERSUS SHIP SST ESTIMATES FOR JULY 1982

	Number of Matches				Bias				Standard Deviation				Cross Correlation			
	AVHRR	SMMR	HIRS	VAS	AVHRR	SMMR	HIRS	VAS	AVHRR	SMMR	HIRS	VAS	AVHRR	SMMR	HIRS	VAS
Global	3962	1826	-	437	-0.54	-0.18	-	+0.60	0.90	1.08	-	0.85	0.44	0.38	-	0.26
North Pacific (0-56°N)	1368	708	-	116	-0.69	+0.26	-	+0.91	0.95	0.89	-	0.80	0.41	0.46	-	0.17
North Pacific (20-56°N)	514	221	-	26	-0.18	+0.11	-	+0.40	0.64	1.13	-	1.25	0.50	0.24	-	-0.10
Tropical Pacific (20°N-20°S)	779	366	-	165	-0.69	+0.10	-	+0.77	0.83	0.83	-	1.00	0.30	0.27	-	0.07
South Pacific (20-56°S)	958	480	-	51	-0.54	-0.31	-	+0.61	0.98	0.92	-	0.50	0.46	0.44	-	0.11
South Pacific (0-56°S)	883	359	-	126	-0.23	+0.06	-	+0.50	0.67	1.03	-	1.05	0.41	0.26	-	0.00
VAS Pacific Region (14°N-30°S)	162	104	-	174	-0.38	+0.16	-	+0.68	0.81	1.10	-	1.08	0.25	0.05	-	0.01
Global AVHRR El Chichon Mask	2305	1112	-	216	-0.20	+0.02	-	+0.49	0.77	1.08	-	0.90	0.49	0.41	-	0.25
North Atlantic (0-56°N)	695	324	-	195	-0.81	-1.06	-	+0.49	0.87	1.06	-	0.67	0.38	0.21	-	0.40

Figure 1. Thematic contour SST anomaly charts for March, 1982, for a) SMMR, b) AVHRR, c) VAS, d) Ships, and e) HIRS-MSU. (Original figures can be found in JPL publication Satellite-derived Sea Surface Temperature Intercomparison: Workshop III.)



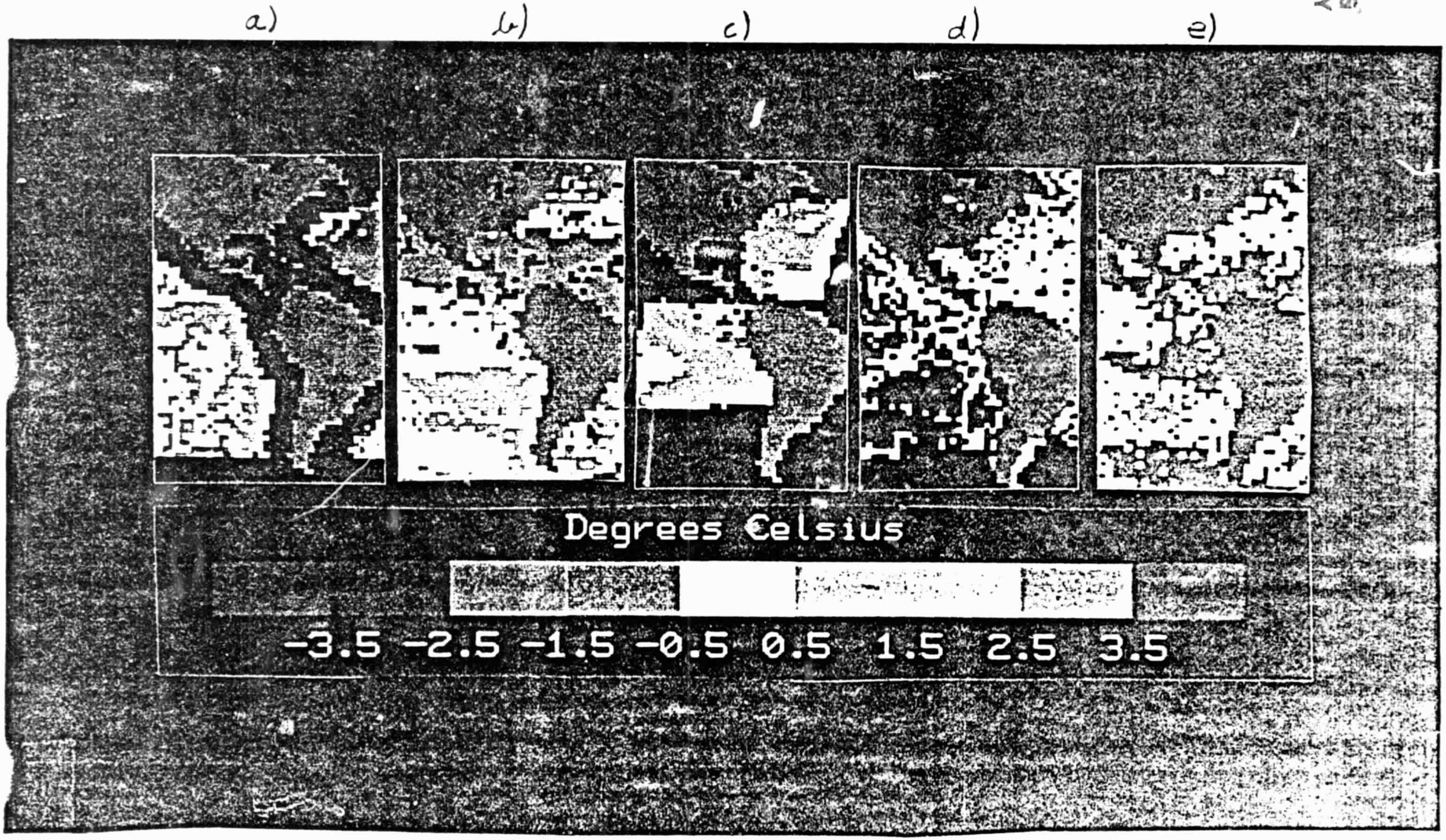


Figure 2. Thematic contour SST anomaly charts for July, 1982, for a) SMMR, b) AVHRR, c) VAS, d) Ships, and e) HIRS-MSU. (Original figures can be found in JPL publication Satellite-derived Sea Surface Temperature Intercomparison: Workshop III.)