Evaluating NOAA Satellite Products for Global Climate Monitoring

59-43
171300

by
John J. Bates
NOAA Climate Monitoring and Disgnostics Laboratory

N94-23604

1. Validation criteria for satellite products
2. Long-term global validation examples
3. Lessons of history - Applications to the EOS era

1. Validation criteria for satellite products

1.1. Are the physics of the radiative transfer sound?

1.2. How do the means and higher moments compare with in situ measurements?

1.3. How do the spatial and temporal variations in the satellite data compare with other observations and hydrodynamic models?

The Forward and Inverse Problems in Remote Sensing of the Environment

The Forward Problem

Using radiative transfer theory and relavent geophysical variables, model the upwelling and scattered radiance that a particular instrument should measure

Interpreters - Required to specify a base state around which the radiative transfer equation is linearized

Class1	A priori information dependent Hydrodynamic model dependent
Class 2	A priori information dependent Hydrodynamic model independent
Class 3	A priori information independent Hydrodynamic model independent

The Inverse Problem

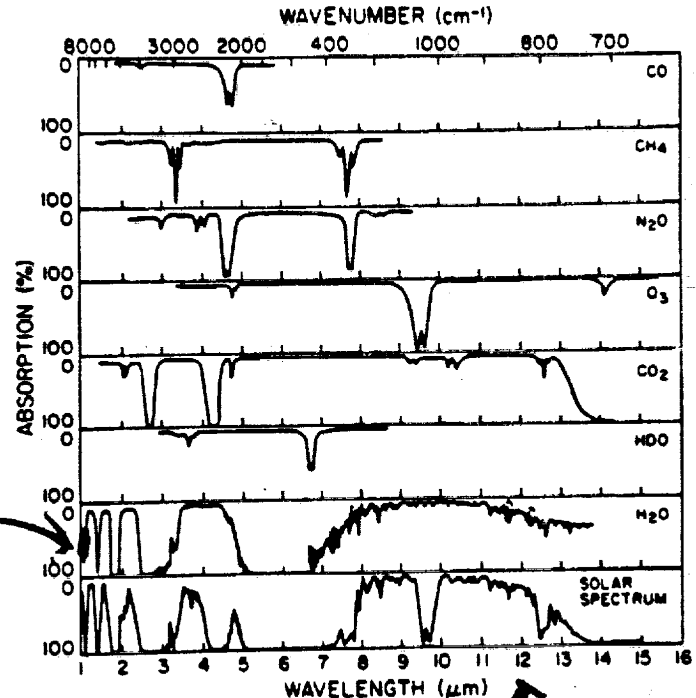
Using upwelling and scattered radiances, invert the radiative transfer equation to retrieve geophysical variables

$$R_\nu = \varepsilon_s B_\nu(T_s)\,\tau_\nu(p_s)$$ — Surface → Cloud EMISSION

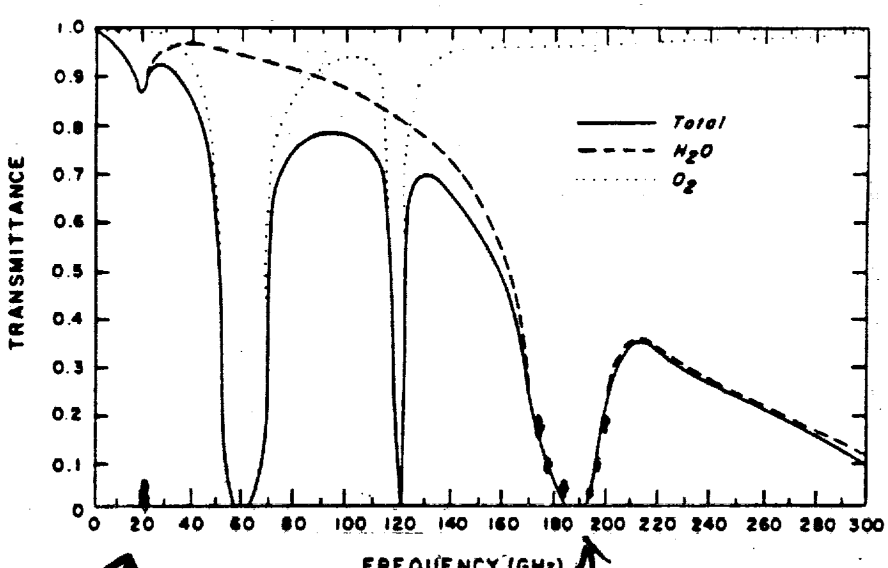
$$+ \int_{p_s}^{0} B_\nu(T(p))\,\frac{d\tau_\nu(p)}{dp}\,dp$$ — ATMOSPHERIC TERM

$$+ (1-\epsilon_s)\int_{0}^{p_s} B_\nu(T(p))\,\frac{d\tau^{*}_\nu(p)}{dp}\,dp$$ — REFLECTED ATMOSPHERIC TERM

INFRARED



MICROWAVE



2. Long-term global validation examples

2.1. Sea surface temperature

2.1.1. The JPL intercomparison workshops

2.1.2. Evaluation of the operational MCSST product

2.2. Global water vapor content

2.2.1. TOVS study conference comparisons

2.2.2. HIRS channel 12 brightness temperature climatology

2. Long-term global validation examples

2.1. Sea surface temperature

2.1.1. The JPL intercomparison workshops

2.1.2. Evaluation of the operational MCSST product

2.2. Global water vapor content

2.2.1. TOVS study conference comparisons

2.2.2. HIRS channel 12 brightness temperature climatology

JPL SST INTERCOMPARISON WORKSHOP

(p) July 1982, Global

Two Degree Average SST Anomaly Cross Correlations
Region: 56.0 deg N to 56.0 deg S, 0.0 deg E to 360.0 deg E

At least 1 observation(s) at common grid points
(C--Cross Correlation, B--Bias, S--Standard Deviation
about bias, N--Number of common valid observations)
Bias is average over column temperatures minus row temperatures

	NOAA AVHRR DAY JUL	NOAA AVHRR NIGHT	NOAA AVHRR	SUSSKIND HIRS	SUSSKIND HIRS WEIGHTED	MILMAN SMMR NIGHT CELL 234	WILHEIT/MAN SMMR/SHIP COMPOSITE	BATES VAS	PAZAN SHIPS >5/CELL	PAZAN SHIPS >20/CELL	TRANSPAC XBT	CLIMATOL
NOAA AVHRR DAY JUL	..	C 0.82 B -0.12 S 0.36 N 1652	C 0.95 B -0.06 S 0.19 N 1600	C 0.60 B -0.10 S 0.47 N 1600	C 0.59 B -0.33 S 0.50 N 1600	C 0.39 B 0.08 S 0.77 N 1422	C 0.55 B 0.04 S 0.51 N 946	C 0.56 B 0.06 S 0.40 N 183	C 0.83 B -0.79 S 0.52 N 74	C 1.00 B -0.40 S 0.50 N 2	..	C 0.00 B [illegible] S 0.59 N 1600
NOAA AVHRR NIGHT	..	..	C 0.90 B 0.05 S 0.17 N 2409	C 0.60 B 0.12 S 0.66 N 2602	C 0.69 B -0.14 S 0.60 N 2604	C 0.69 B 0.27 S 0.64 N 2641	C 0.59 B 0.41 S 0.61 N 1906	C 0.00 B 0.67 S 0.54 N 247	C 0.81 B 0.67 S 0.36 N 269	C 0.09 B 0.56 S 0.40 N 7	C -0.06 B 0.69 S 0.47 N 3	C 0.00 B 0.36 S 0.83 N 2409
NOAA AVHRR	..	..	..	C 0.66 B 0.06 S 0.60 N 2721	C 0.69 B -0.19 S 0.59 N 2721	C 0.65 B 0.21 S 0.67 N 2644	C 0.55 B 0.34 S 0.63 N 2016	C 0.46 B 0.67 S 0.53 N 249	C 0.70 B 0.35 S 0.52 N 274	C 0.90 B 0.45 S 0.43 N 7	C -0.90 B 0.10 S 0.77 N 3	C 0.00 B 0.30 S 0.82 N 2727
SUSSKIND HIRS	..	..	..	..	C 0.90 B -0.26 S 0.14 N 4009	C 0.45 B 0.15 S 0.77 N 2883	C 0.53 B 0.21 S 0.52 N 2101	C 0.24 B 0.05 S 0.53 N 254	C 0.70 B -0.09 S 0.38 N 327	C 0.00 B -0.15 S 0.80 N 7	C -0.90 B 0.09 S 0.61 N 3	C 0.00 B 0.26 S 0.52 N 4009
SUSSKIND HIRS WEIGHTED	..	..	..	..	..	C 0.44 B 0.29 S 0.77 N 2883	C 0.54 B 0.48 S 0.56 N 2101	C 0.17 B 1.06 S 0.60 N 254	C 0.79 B 0.26 S 0.30 N 327	C 0.25 B 0.22 S 0.23 N 7	C -0.95 B 0.42 S 0.61 N 3	C 0.00 B 0.52 S 0.60 N 4009
MILMAN SMMR NIGHT CELL 234	..	..	..	..	..	..	C 0.07 B 0.20 S 0.35 N 1760	C 0.50 B 0.52 S 0.65 N 243	C 0.56 B 0.69 S 0.60 N 230	C -1.00 B 1.01 S 0.09 N 2	C 0.00 B 0.61 S 0.00 N 1	C 0.00 B 0.03 S 0.06 N 2071
WILHEIT/MAN SMMR/SHIP COMPOSITE	..	..	..	..	..	..	..	C 0.73 B 0.42 S 0.34 N 211	C 0.06 B 0.10 S 0.27 N 137	..	C 0.00 B 0.04 S 0.00 N 1	C 0.00 B -0.01 S 0.57 N 2190
BATES VAS	..	..	..	..	..	..	..	..	C 0.42 B -0.55 S 0.27 N 40	..	..	C 0.00 B -0.05 S 0.47 N 254
PAZAN SHIPS >5/CELL	..	..	..	..	..	..	..	..	..	C 1.00 B 0.00 S 0.00 N 7	C -0.97 B 0.06 S 0.80 N 2	C 0.00 B 0.70 S 0.63 N 336
PAZAN SHIPS >20/CELL	..	..	..	..	..	..	..	..	..	..	..	C 0.00 B 0.72 S 0.71 N 7
TRANSPAC XBT	..	..	..	..	..	..	..	..	..	..	..	C 0.00 B 0.65 S 0.23 N 3
CLIMATOL	..	..	..	..	..	..	..	..	..	..	..	..

ORIGINAL PAGE IS OF POOR QUALITY

INTERPRETING MULTI-CHANNEL SEA SURFACE TEMPERATURES

FOR AN INFRARED WINDOW CHANNEL

$$R_i = B_i(T_s)\tau_i + B_i(T_a)(1-\tau_i)$$

CONVERT FROM RADIANCE TO BRIGHTNESS TEMPERATURE AND USE WEAK ABSORPTION APPROXIMATION

$$T_i - T_s = k_i X(\bar{T} - T_s)$$

FOR TWO WINDOWS i AND j

$$T_s = T_i + \frac{k_i}{k_j - k_i}(T_i - T_j)$$

WHERE k_i + k_j ARE ABSORPTION COEFFICIENTS ASSUMING A <u>SINGLE</u> ABSORBING GAS VARIES

IN THE TWO WINDOWS

AVHRR/2 CHANNELS 4 + 5

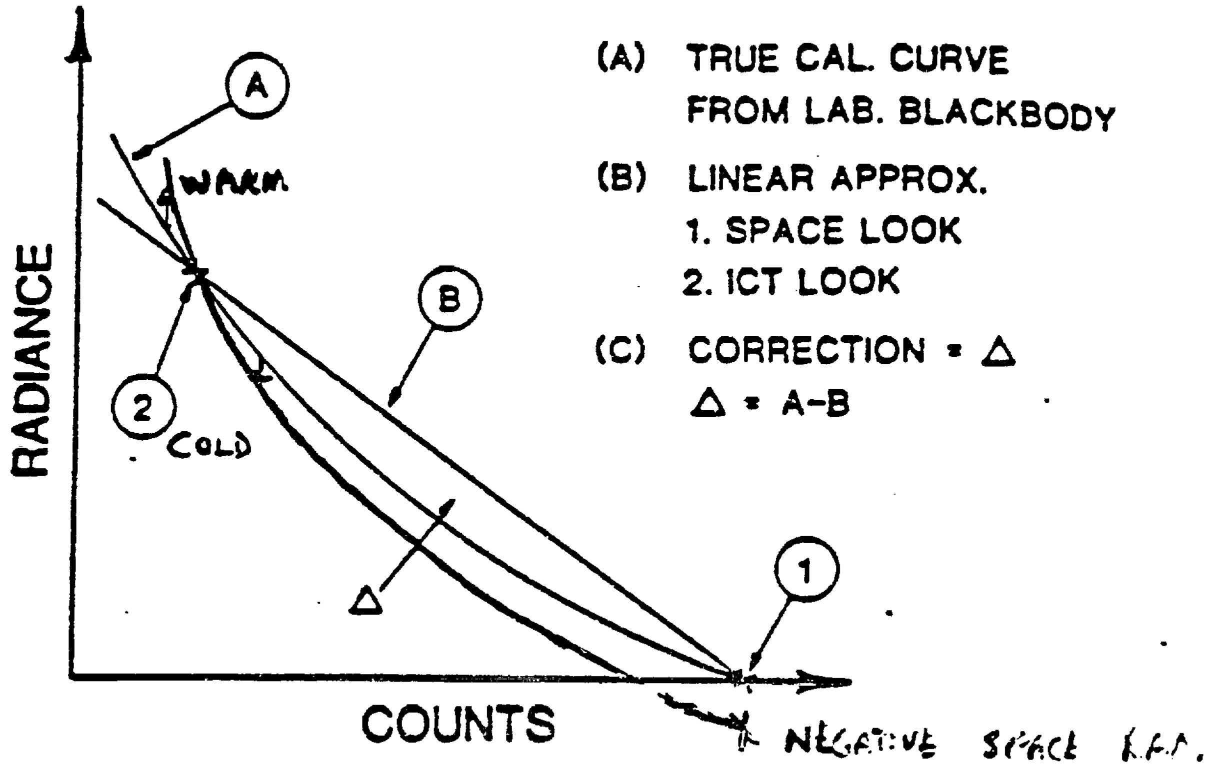
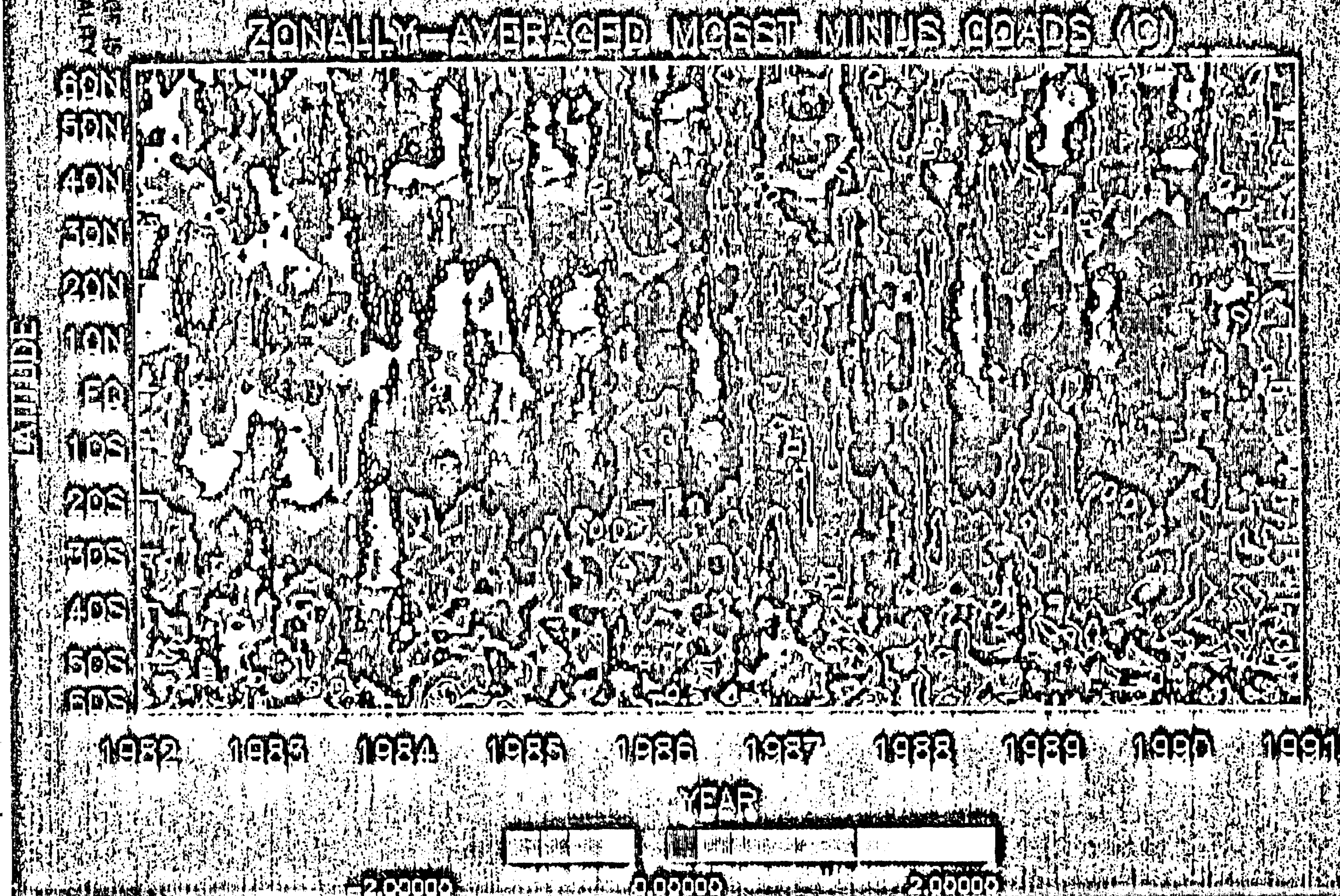
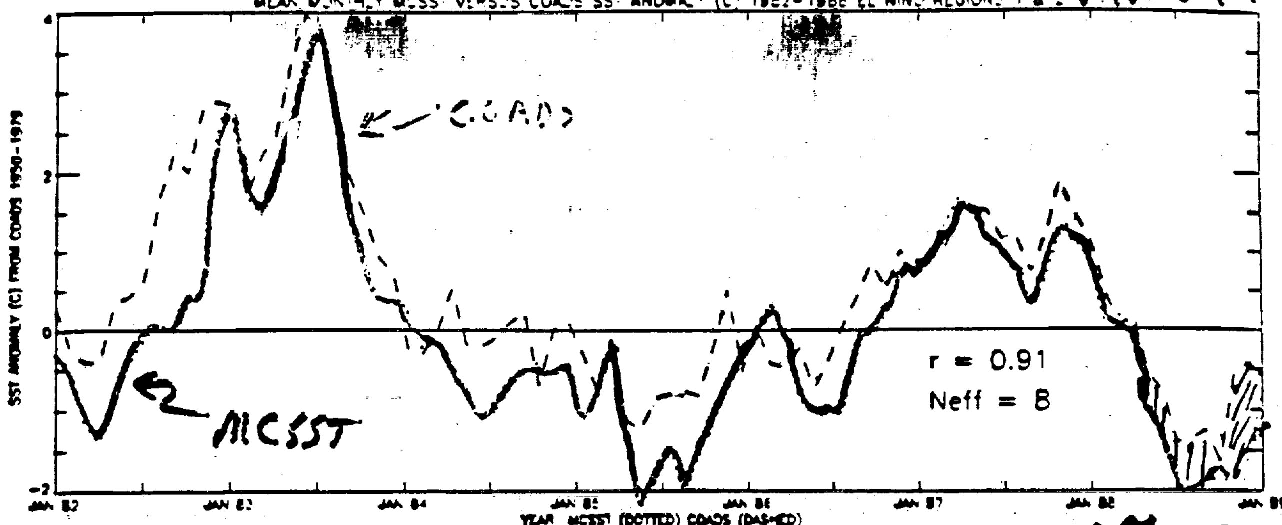


Fig. 3. Illustration of how nonlinearity correction terms are computed.

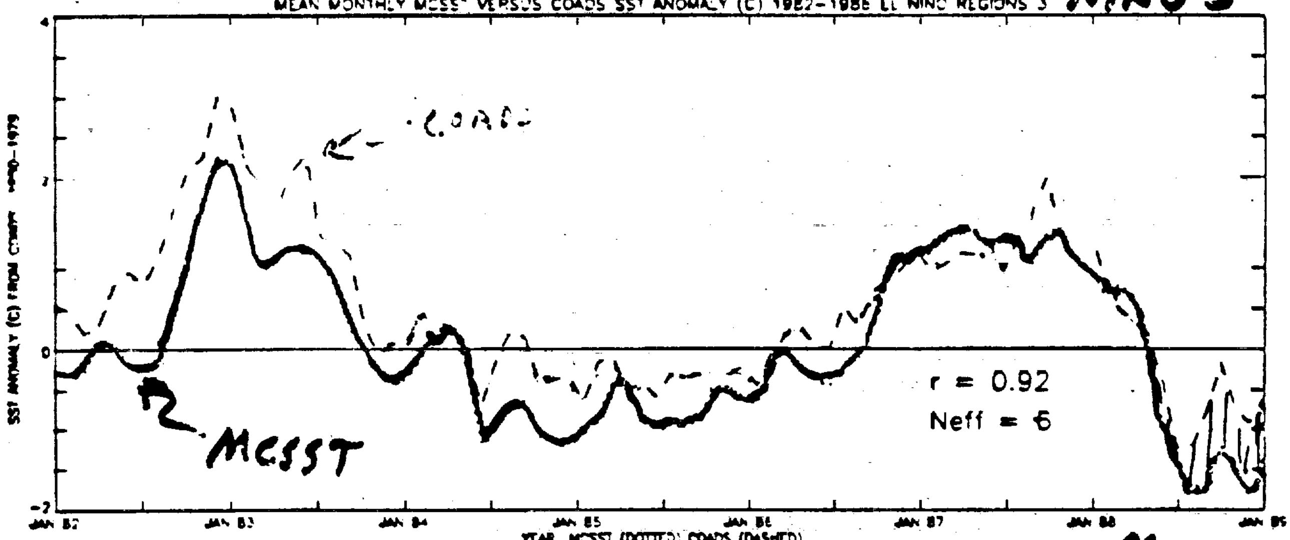

ZONALLY-AVERAGED MCSST MINUS COADS (C)
LATITUDE
60N
50N
40N
30N
20N
10N
EQ
10S
20S
30S
40S
50S
60S
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
YEAR
-2.00000
0.00000
2.00000

EL NIÑO REGIONS

MEAN MONTHLY MCSST VERSUS COADS SST ANOMALY (C) 1982-1988 EL NINO REGIONS 1 & 2 NIÑO 1 & 2



MEAN MONTHLY MCSST VERSUS COADS SST ANOMALY (C) 1982-1988 EL NINO REGIONS 3 NIÑO 3



MEAN MONTHLY MCSST VERSUS COADS SST ANOMALY (C) 1982-1988 EL NINO REGIONS 4 NIÑO 4

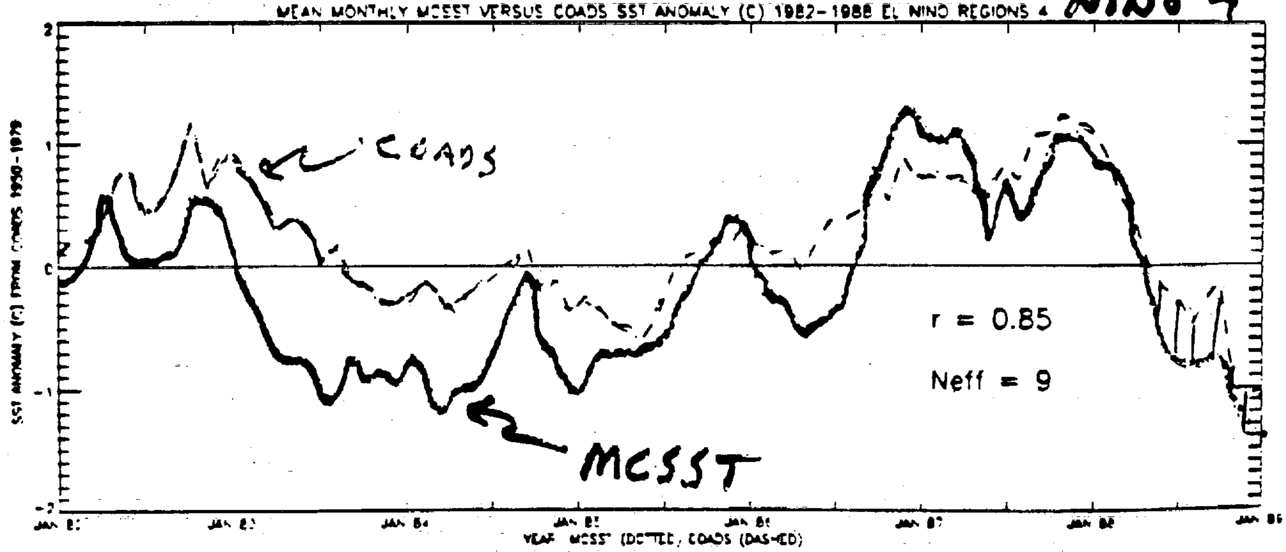


Fig. 8

ORIGINAL PAGE IS
OF POOR QUALITY

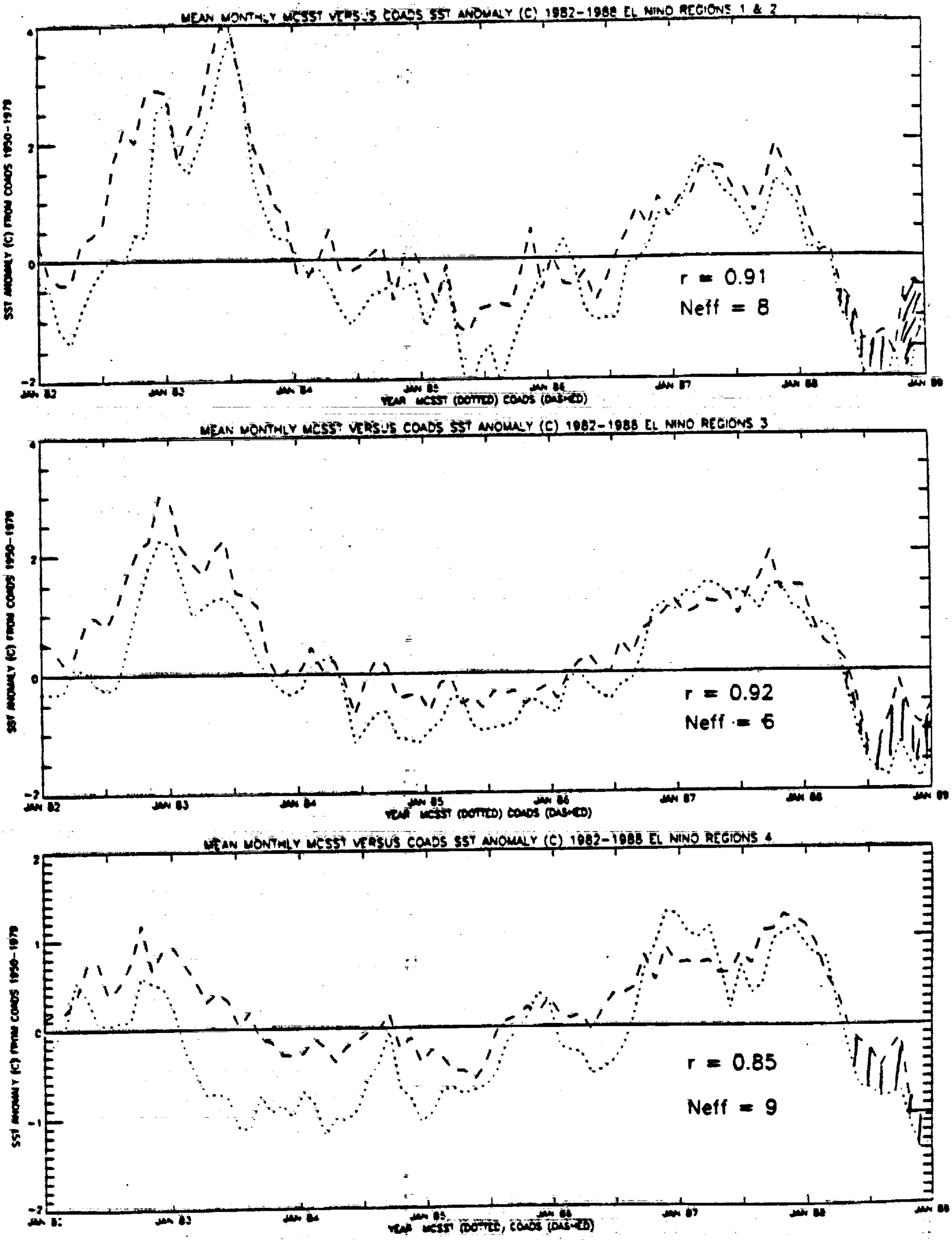

MEAN MONTHLY MCSST VERSUS COADS SST ANOMALY (C) 1982-1988 EL NINO REGIONS 1 & 2
SST ANOMALY (C) FROM COADS 1950-1979
YEAR MCSST (DOTTED) COADS (DASHED)
r = 0.91
Neff = 8
MEAN MONTHLY MCSST VERSUS COADS SST ANOMALY (C) 1982-1988 EL NINO REGIONS 3
SST ANOMALY (C) FROM COADS 1950-1979
YEAR MCSST (DOTTED) COADS (DASHED)
r = 0.92
Neff = 6
MEAN MONTHLY MCSST VERSUS COADS SST ANOMALY (C) 1982-1988 EL NINO REGIONS 4
SST ANOMALY (C) FROM COADS 1950-1979
YEAR MCSST (DOTTED), COADS (DASHED)
r = 0.85
Neff = 9

FIG 8

SOUTH ATLANTIC OCEAN

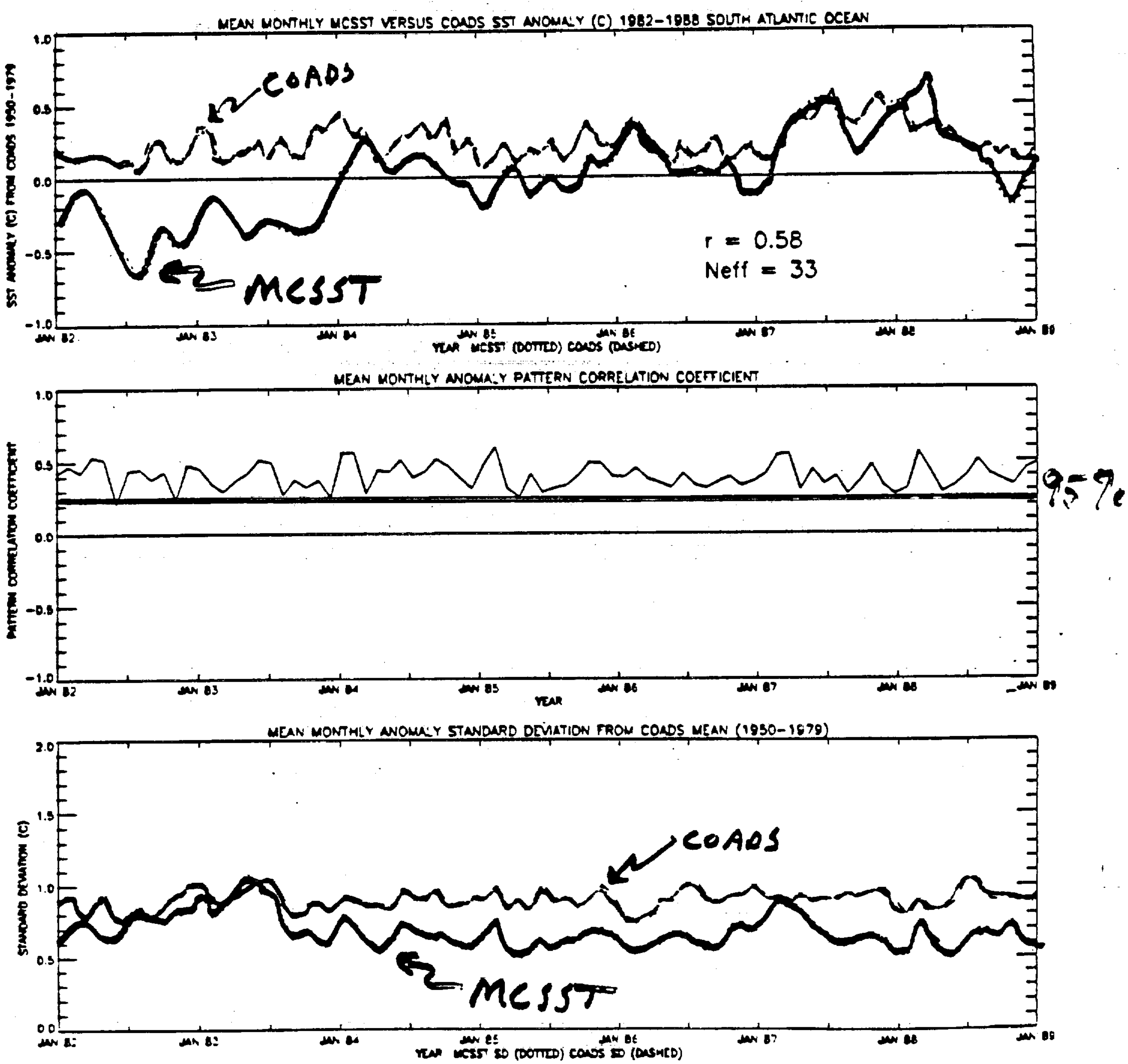


FIG (7)

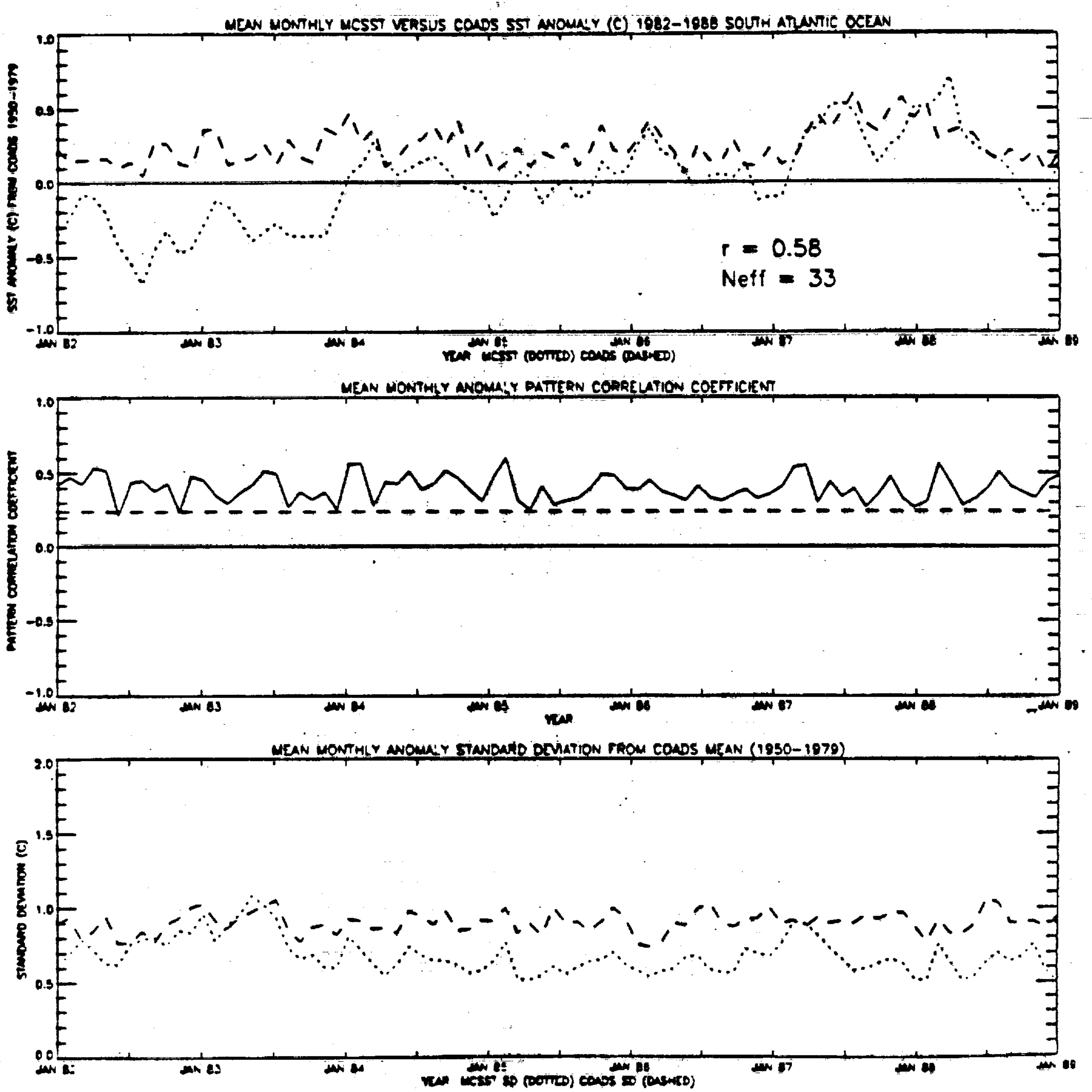

MEAN MONTHLY MCSST VERSUS COADS SST ANOMALY (C) 1982–1988 SOUTH ATLANTIC OCEAN
SST ANOMALY (C) FROM COADS 1950–1979
r = 0.58
Neff = 33
YEAR MCSST (DOTTED) COADS (DASHED)
MEAN MONTHLY ANOMALY PATTERN CORRELATION COEFFICIENT
PATTERN CORRELATION COEFFICIENT
YEAR
MEAN MONTHLY ANOMALY STANDARD DEVIATION FROM COADS MEAN (1950–1979)
STANDARD DEVIATION (C)
YEAR MCSST SD (DOTTED) COADS SD (DASHED)
JAN 82
JAN 83
JAN 84
JAN 85
JAN 86
JAN 87
JAN 88
JAN 89

FIG 7

SST SUMMARY STATISTICS

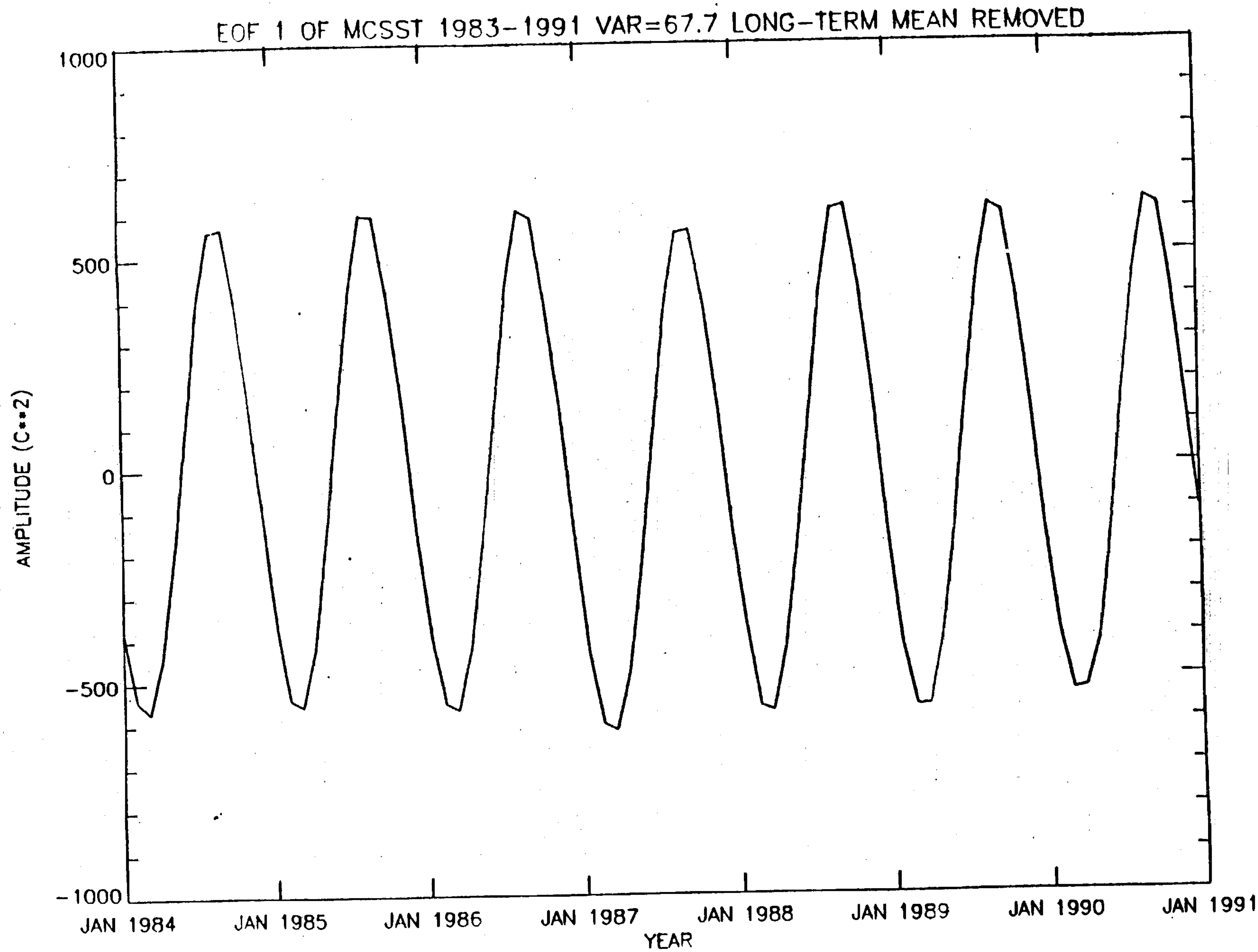
Ocean Basin or Region	Anomaly Cross Correlation	Effective Degrees of Freedom	Signal-to-Noise Variance Ratio	First Monthly Difference Cross Correlation	Mean MCSST Anomaly (°C)	Mean COADS Anomaly (°C)	Mean MCSST Standard Deviation(°C)	Mean COADS Standard Deviation(°C)
Global 60°N-60°S, 0°-360°	0.65 *	19	1.14	0.02	-0.16	0.13	0.75	0.84
Northern Hemisphere 0°-60°N, 0°-360°	0.55 *	40	0.56	0.21	-0.32	0.03	0.74	0.76
Southern Hemisphere 0°-60°S, 0°-360°	0.67 *	22	2.42	0.16	0.04	0.23	0.70	0.92
Indian Ocean 20°N-60°S, 30°E-120°E	0.70 *	21	2.93	0.30 *	0.06	0.32	0.60	0.81
North Pacific Ocean 0°-60°N, 120°E-90°W	0.66 *	26	0.59	0.23	-0.34	0.01	0.79	0.86
South Pacific Ocean 0°-60°S, 120°E-80°W	0.62 *	27	2.21	0.03	-0.04	0.15	0.70	0.95
North Atlantic Ocean 0°-60°N, 0°-90°W	0.43	20	0.49	0.36 *	-0.33	0.04	0.66	0.63
South Atlantic Ocean 0°-60°S, 0°-80°W	0.63 *	28	2.86	0.57 *	0.00	0.25	0.68	0.90
El Niño 1 & 2 0°-10°S, 80°W-90°W	0.89 *	23	4.69	0.58 *	-0.03	0.50	0.75	1.19
El Niño 3 6°N-6°S, 90°W-150°W	0.93 *	17	4.67	0.50 *	0.08	0.50	0.67	1.12
El Niño 4 6°N-6°S, 160°E-150°W	0.91 *	12	1.97	0.25	-0.17	0.22	0.62	0.89
North Pacific Region 1 50°N-60°N, 155°W-175°W	0.43 *	26	1.27	0.25	-0.14	0.17	0.34	0.37
North Atlantic Region 1 30°N-40°N, 60°W-80°W	0.69 *	23	0.51	-0.13	-0.17	0.01	0.66	0.58
North Atlantic Region 2 15°N-25°N, 40°W-60°W	0.50	23	0.34	0.51 *	-0.59	0.05	0.29	0.46

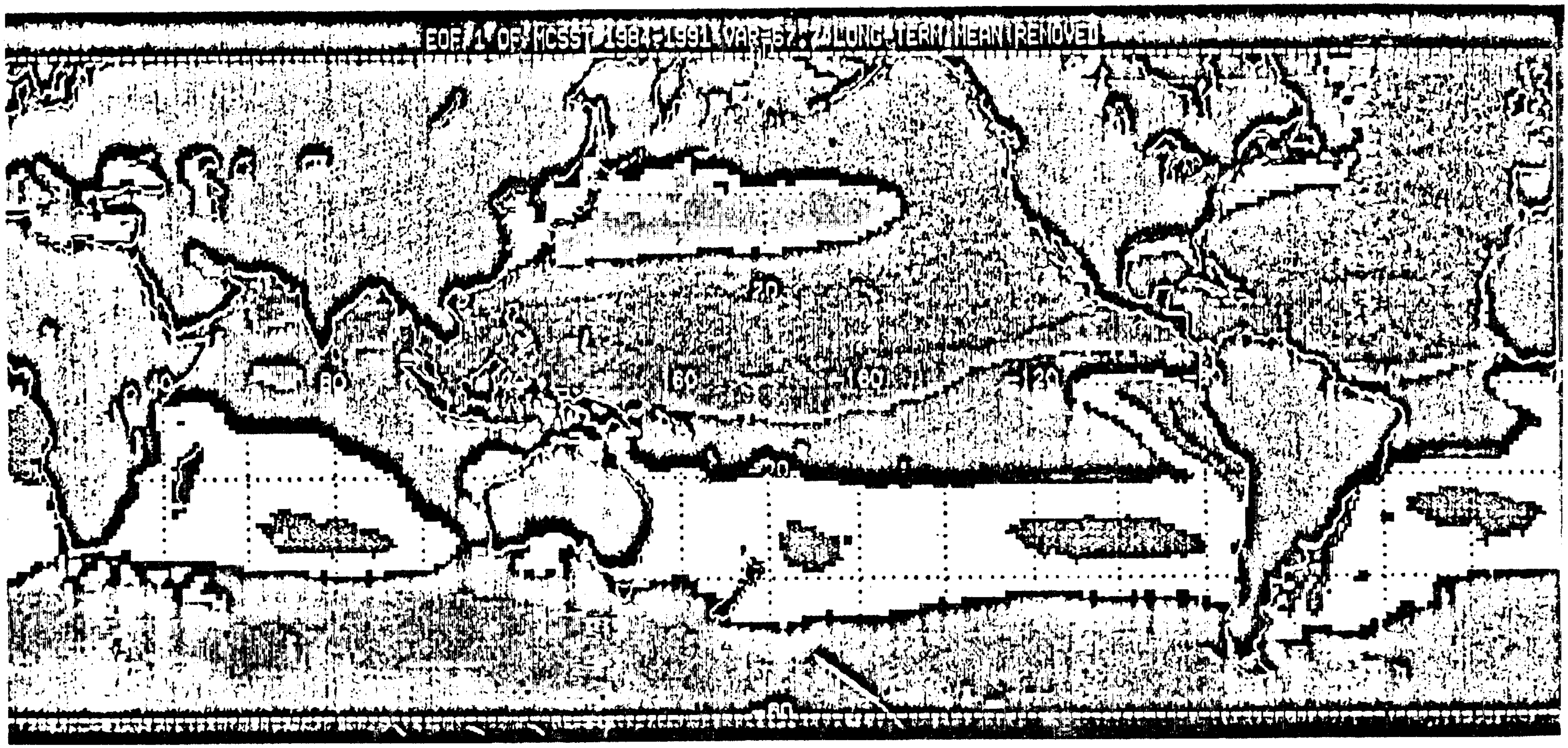
Table 3. Summary statistics for MCSST and COADS 1984-1988 anomaly cross correlations, means, and standard deviations. All anomaly cross correlations are significant at the 95% level except the North Atlantic Ocean and North Atlantic Region 2.

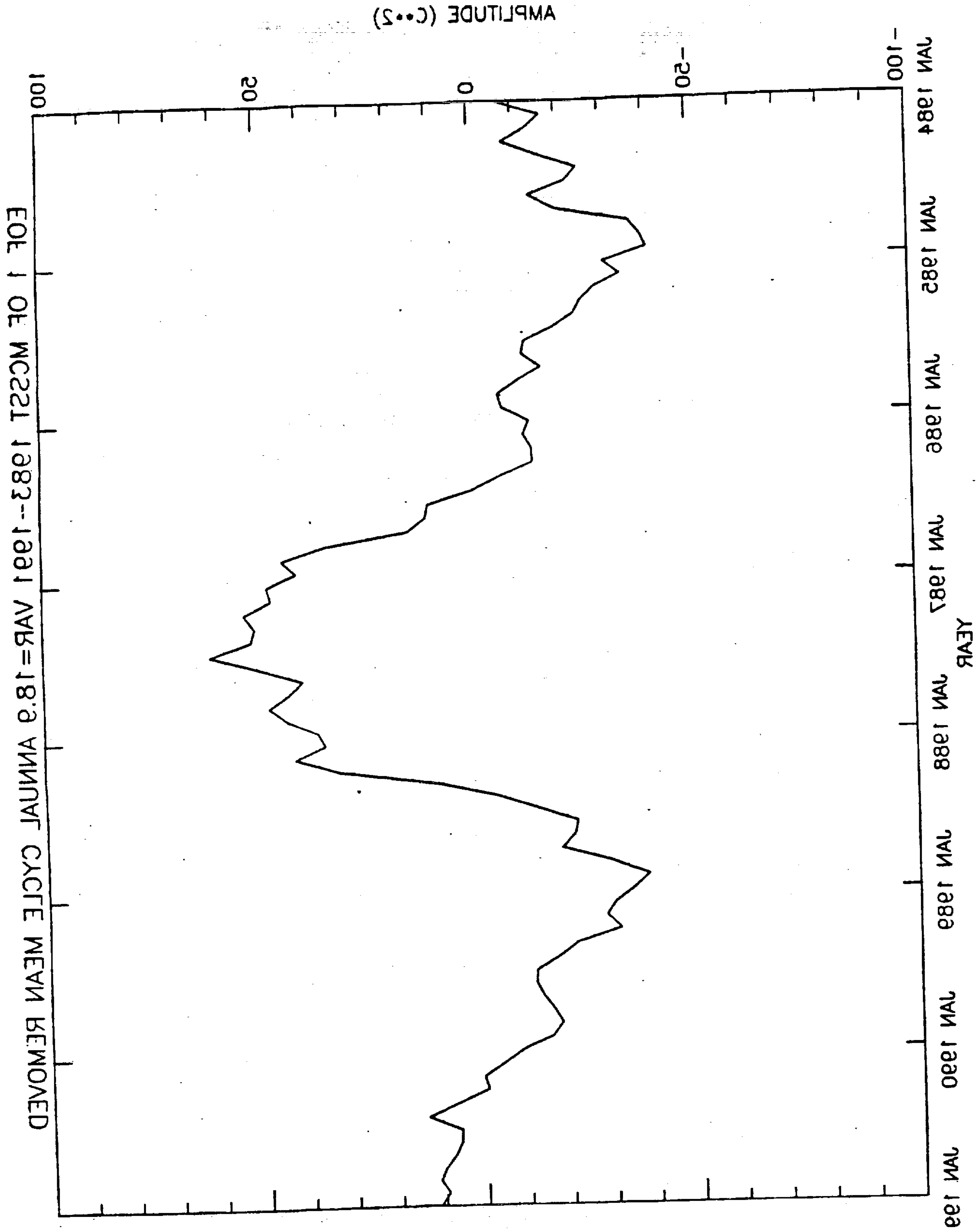
* SIGNIFICANT AT 95% FOR N_{EFF}

Ocean Basin or Region	Anomaly Cross Correlation	Effective Degrees of Freedom	Signal-to-Noise Variance Ratio	First Monthly Difference Cross Correlation	Mean MCSST Anomaly (°C)	Mean COADS Anomaly (°C)	Mean MCSST Standard Deviation(°C)	Mean COADS Standard Deviation(°C)
Global 60°N-60°S, 0°-360°	0.65	19	1.14	0.02	-0.16	0.13	0.75	0.84
Northern Hemisphere 0°-60°N, 0°-360°	0.55	40	0.56	0.21	-0.32	0.03	0.74	0.76
Southern Hemisphere 0°-60°S, 0°-360°	0.67	22	2.42	0.16	0.04	0.23	0.70	0.92
Indian Ocean 20°N-60°S, 30°E-120°E	0.70	21	2.93	0.30	0.06	0.32	0.60	0.81
North Pacific Ocean 0°-60°N, 120°E-90°W	0.66	26	0.59	0.23	-0.34	0.01	0.79	0.86
South Pacific Ocean 0°-60°S, 120°E-80°W	0.62	27	2.21	0.03	-0.04	0.15	0.70	0.95
North Atlantic Ocean 0°-60°N, 0°-90°W	0.43	20	0.49	0.36	-0.33	0.04	0.66	0.63
South Atlantic Ocean 0°-60°S, 0°-80°W	0.63	28	2.86	0.57	0.00	0.25	0.68	0.90
El Niño 1 & 2 0°-10°S, 80°W-90°W	0.89	23	4.69	0.58	-0.03	0.50	0.75	1.19
El Niño 3 6°N-6°S, 90°W-150°W	0.93	17	4.67	0.50	0.08	0.50	0.67	1.12
El Niño 4 6°N-6°S, 160°E-150°W	0.91	12	1.97	0.25	-0.17	0.22	0.62	0.89
North Pacific Region 1 50°N-60°N, 155°W-175°W	0.43	26	1.27	0.25	-0.14	0.17	0.34	0.37
North Atlantic Region 1 30°N-40°N, 60°W-80°W	0.69	23	0.51	-0.13	-0.17	0.01	0.66	0.58
North Atlantic Region 2 15°N-25°N, 40°W-60°W	0.50	23	0.34	0.51	-0.59	0.05	0.29	0.46

Table 3. Summary statistics for MCSST and COADS 1984-1988 anomaly cross correlations, means, and standard deviations. All anomaly cross correlations are significant at the 95% level except the North Atlantic Ocean and North Atlantic Region 2.


EOF 1 OF MCSST 1983-1991 VAR=67.7 LONG-TERM MEAN REMOVED
1000
500
0
-500
-1000
AMPLITUDE (C**2)
JAN 1984
JAN 1985
JAN 1986
JAN 1987
JAN 1988
JAN 1989
JAN 1990
JAN 1991
YEAR


EOF 1 OF MCSST 1984-1991 VAR=67.% LONG TERM MEAN REMOVED


EOF 1 OF MCSST 1983--1991 VAR=18.9 ANNUAL CYCLE MEAN REMOVED
AMPLITUDE (C**2)
100
50
0
-50
-100
JAN 1984
JAN 1985
JAN 1986
JAN 1987
JAN 1988
JAN 1989
JAN 1990
JAN 1991
YEAR

Evaluating NOAA Satellite Products for Global Climate Monitoring

by
John J. Bates
NOAA Climate Monitoring and Disgnostics Laboratory

1. Validation criteria for satellite products

2. Long-term global validation examples

3. Lessons of history - Applications to the EOS era

EOF #1 OF MCSST 1984-1991 VAR=18.9 ANNUAL CYCLE REMOVED

1. Validation criteria for satellite products

1.1. Are the physics of the radiative transfer sound?

1.2. How do the means and higher moments compare with in situ measurements?

1.3. How do the spatial and temporal variations in the satellite data compare with other observations and hydrodynamic models?

TOVS Study Conference Summary

TABLE 1

Summary of contributions to the intercomparison study. (Note T represents temperature data, Z represents thickness data and P represents precipitable data, ITPP1, ITPP2, and ITPP3 represents International TOVS Processing Package 1, 2 and 3 respectively, RFG represents regression first guess, CFG represents climatology first guess, MFG represents first guess fields derived from a forecast model, SD indicates the use of surface data in the retrieval scheme. AVHRR represents the use of locally generated regression coefficients and NRC indicates the use of NESDIS regression coefficients.)

DATA ORIGIN	ALPEX	CONTENT	DATA	TOT. NOBS	NOBS (CLEAR)	RET. SCHEME
British Met. Office	ALUK	T, Z, P	clear, cloudy, and microwave	*695	*420	Statistical (Modified ITPP1, NRC)
CIMSS/NOAA-NESDIS Wisconsin	ALWI1	T, Z, P	clear only	*1719	*1719	Physical (Iterative, ITPP2, RFG, SD)
	ALWI2	T, Z, P	clear, cloudy, and microwave	*1819	*1333	Physical (One step, ITPP3, CFG, SD)
	ALWI3	T, Z, P	clear only	*1828	*1828	Physical (One step, ITPP3, RFG, SD)
DFVLR West Germany	ALDF	T, Z, P	clear only	*1389	*1389	Physical (Iterative, modified ITPP2, RFG, SD)
Laboratoire de Meteorologie Dynamique France	ALFR	T, Z	clear, cloudy, and microwave	*4180	*1879	Physical/ Statistical
NASA/GLAS United States	ALNA	T, Z, P	clear, cloudy, and microwave	*903	*614	Physical (Relaxation, MFG)
NOAA/NESDIS Washington	ALNE	T, Z	clear only	*223	*223	Statistical (Operational Algorithm)
University of Bologna Italy	ALIT1	T, Z, P	cloudy only	*1517	-	Physical (Iterative, modified ITPP2)
	ALIT2	T, Z, P	clear only	*1757	*1757	Physical (Iterative, modified ITPP2, SD)
Western Australian Institute of Tech.	ALWA	T, Z, P	clear, cloudy, and microwave	*2808	*1757	Statistical (Modified ITPP1, NRC)
DATA ORIGIN	**TASMAN**	**CONTENT**	**DATA**	**TOT. NOBS**	**NOBS (CLEAR)**	**RET. SCHEME**
Bureau of Meteorology Australia	TAAU	T, Z, P	clear, cloudy, and microwave	*2037	*859	Physical (Modified ITPP3, RFG)
CIMSS/NOAA-NESDIS	TAWI	T, Z, P	clear only	*1626	*1626	Statistical (ITPP2, RFG, SD)
NOAA-NESDIS	TANE	T, Z	clear only	*229	*229	Statistical (Modified ITPP1, NRC)
New Zealand Meteorological Service	TANZ	T, Z, P	clear, cloudy, and microwave	*2049	*1329	Statistical (Operational Algorithm)
DATA ORIGIN	**US**	**CONTENT**	**DATA**	**TOT. NOBS**	**NOBS (CLEAR)**	**RET. SCHEME**
Atmospheric Environment Services (AES) Canada	USCA	T, P	clear, cloudy, and microwave	*192	*95	Statistical (Modified ITPP1, NRC)
British Met. Office	USUK	T, Z, P	clear, cloudy, and microwave	*163	*83	Statistical (Modified ITPP1, NRC)
CIMSS/NOAA-NESDIS	USWI	T, Z, P	clear, cloudy,	*134	*42	Physical (Iterative, AVHRR)

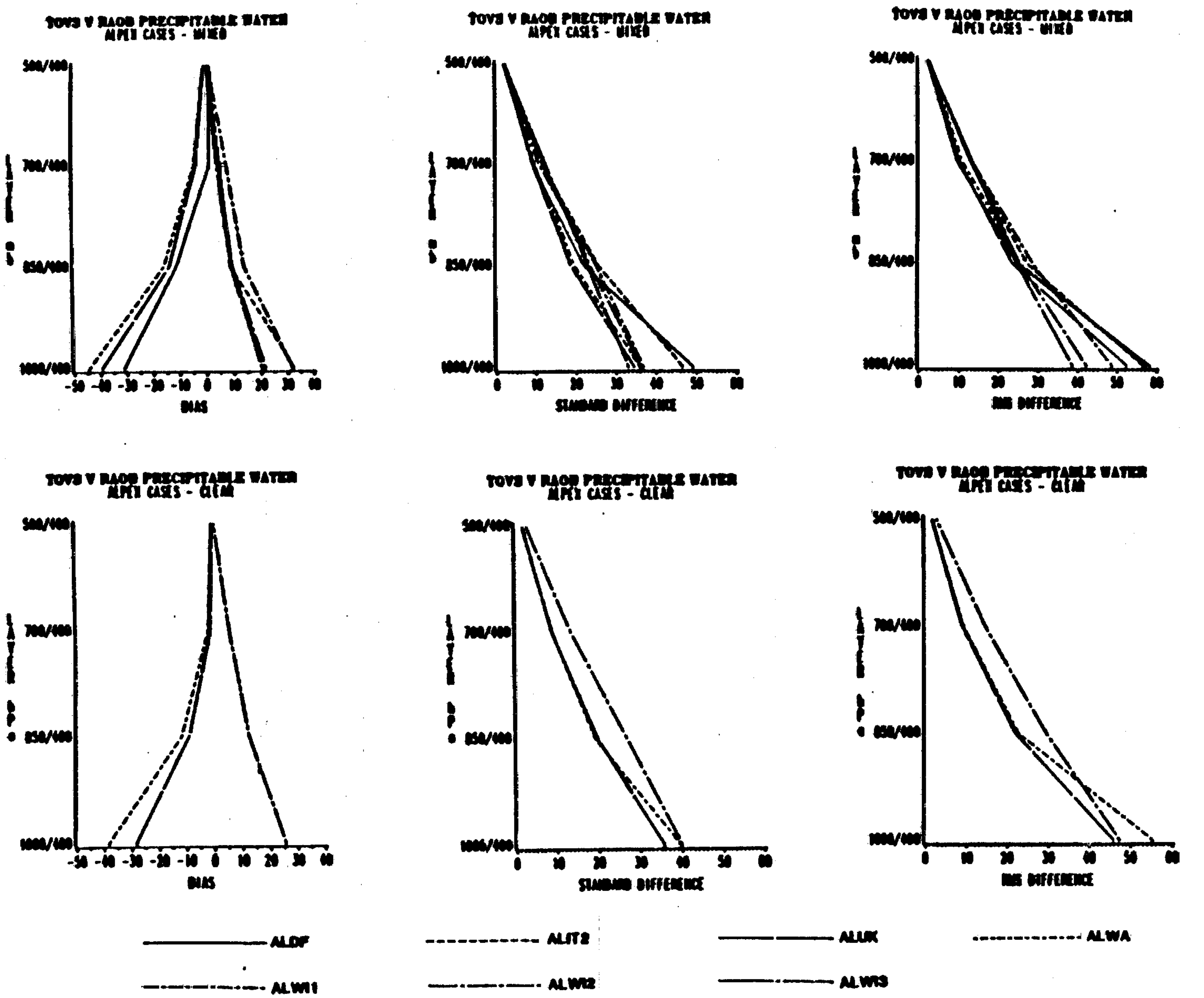


Figure 9. Basic statistics for TOVS retrievals compared with radiosondes for precipitable water observations for both the mixed and clear case. Precipitable water units (cm x 100)

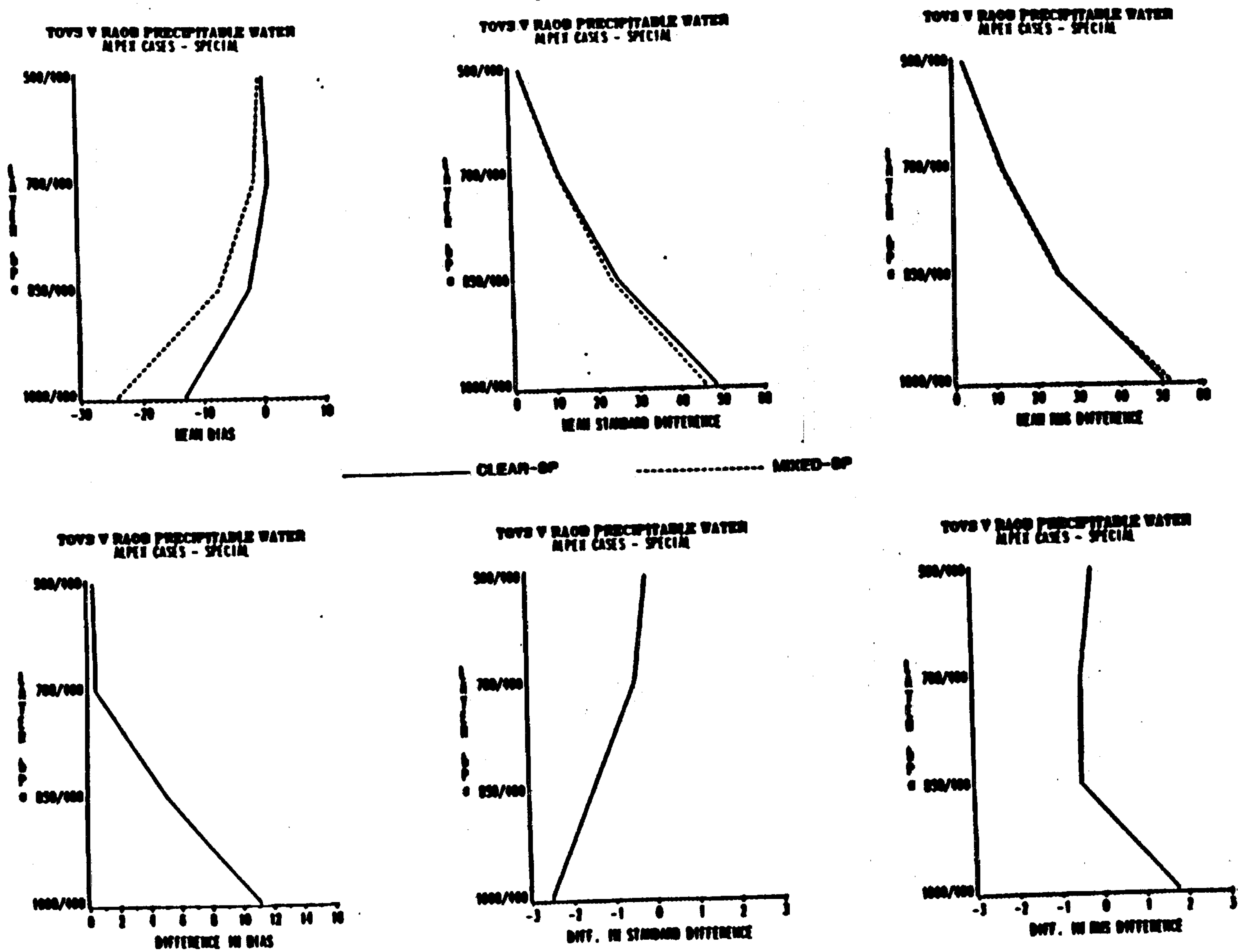
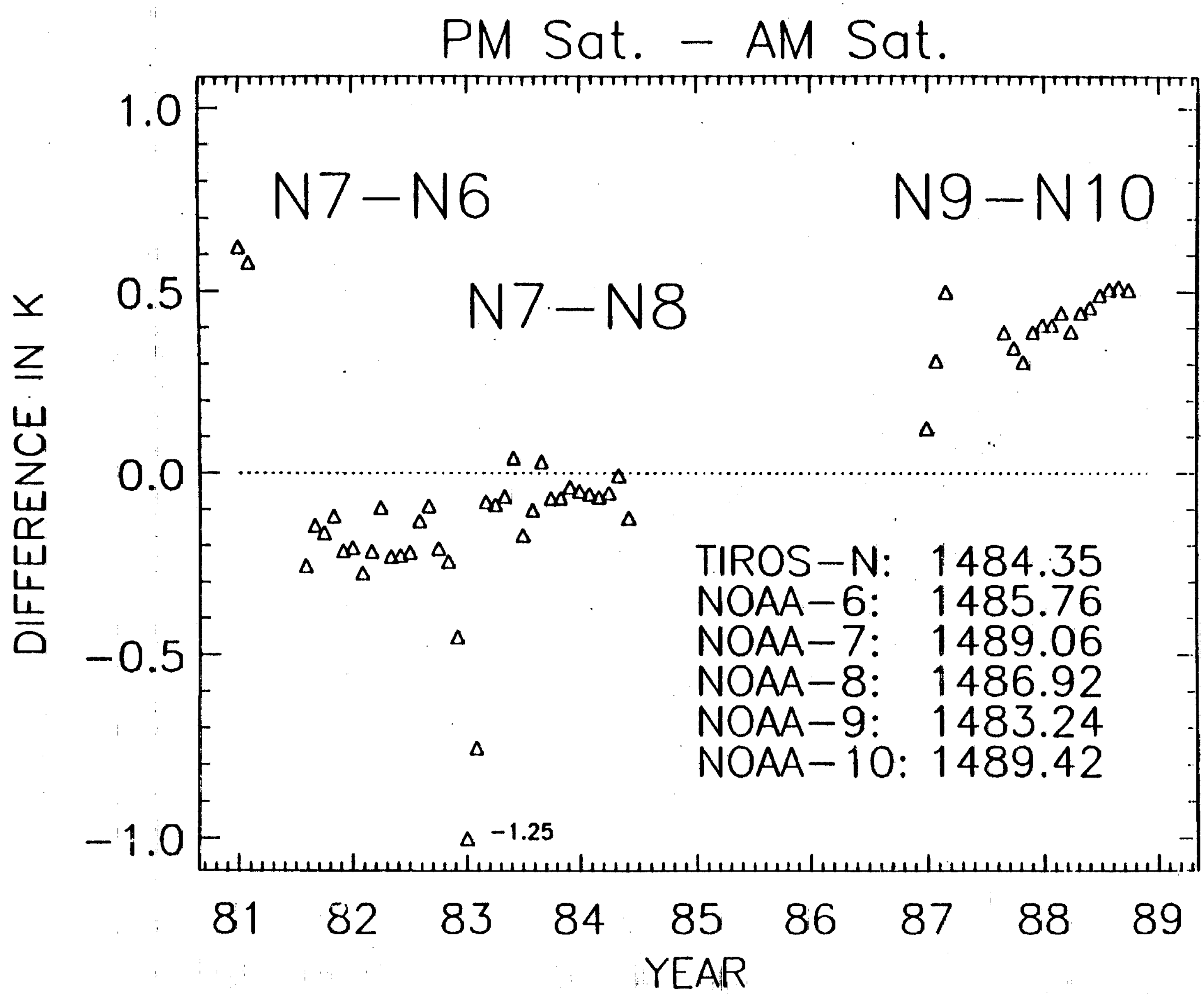
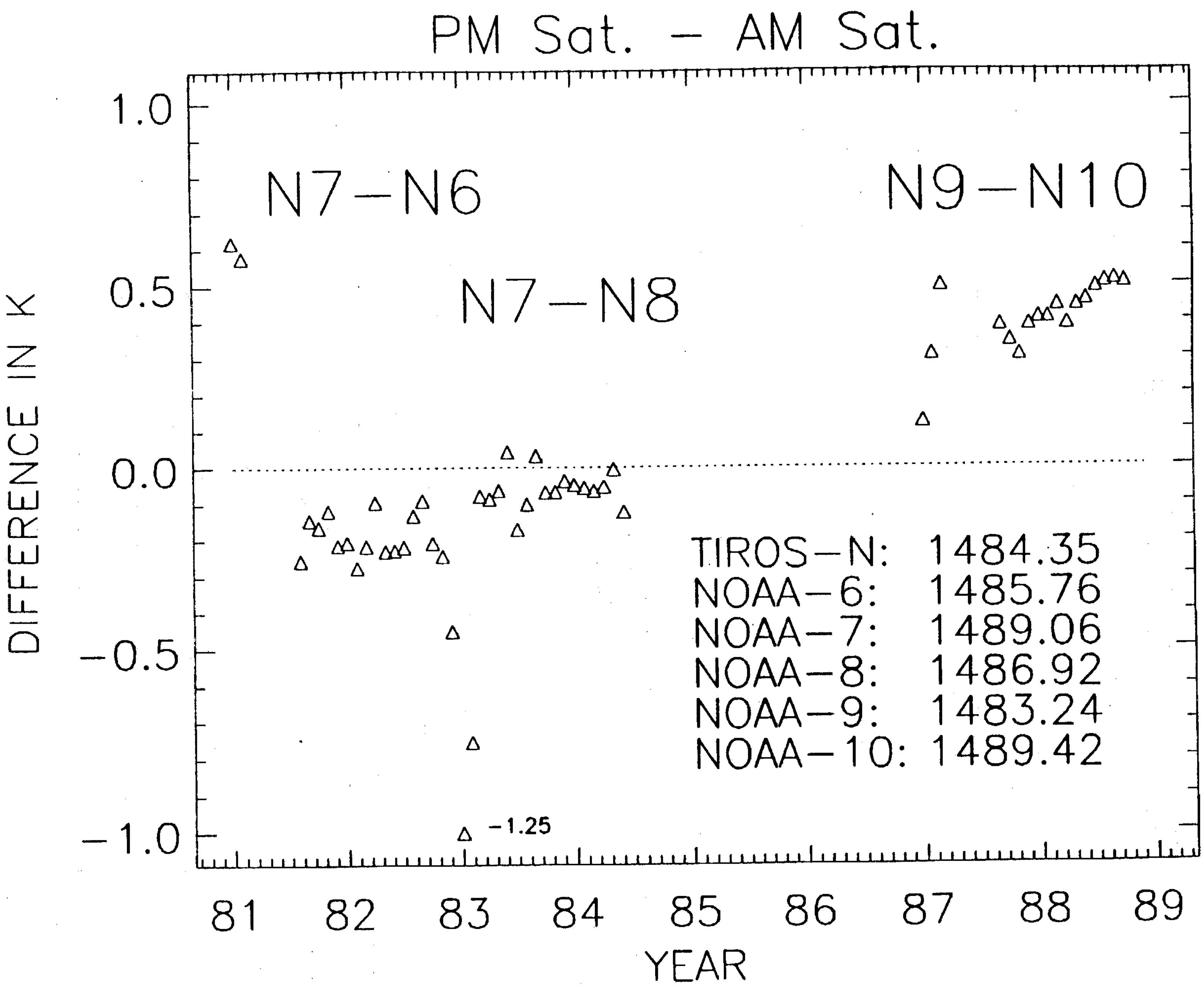
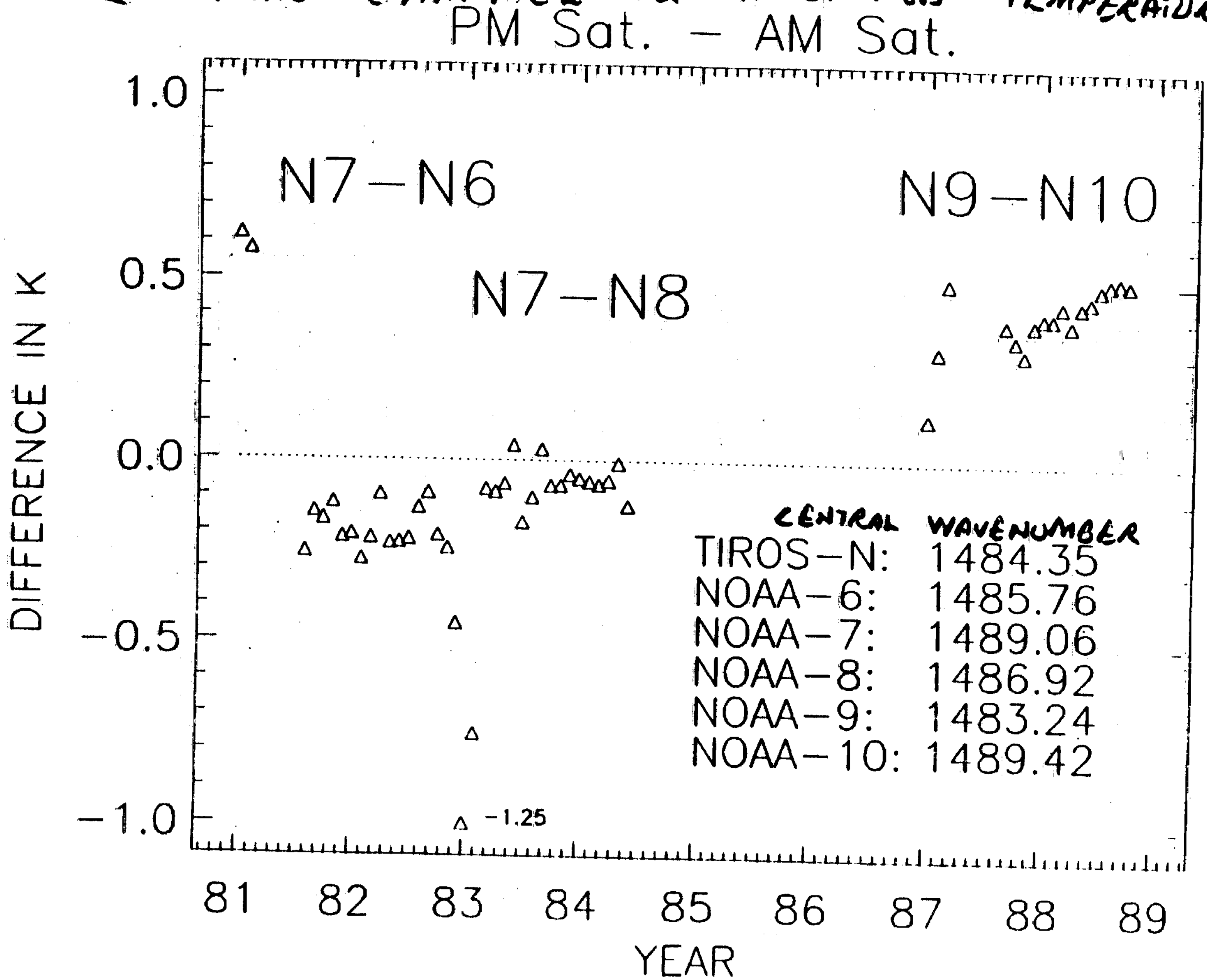


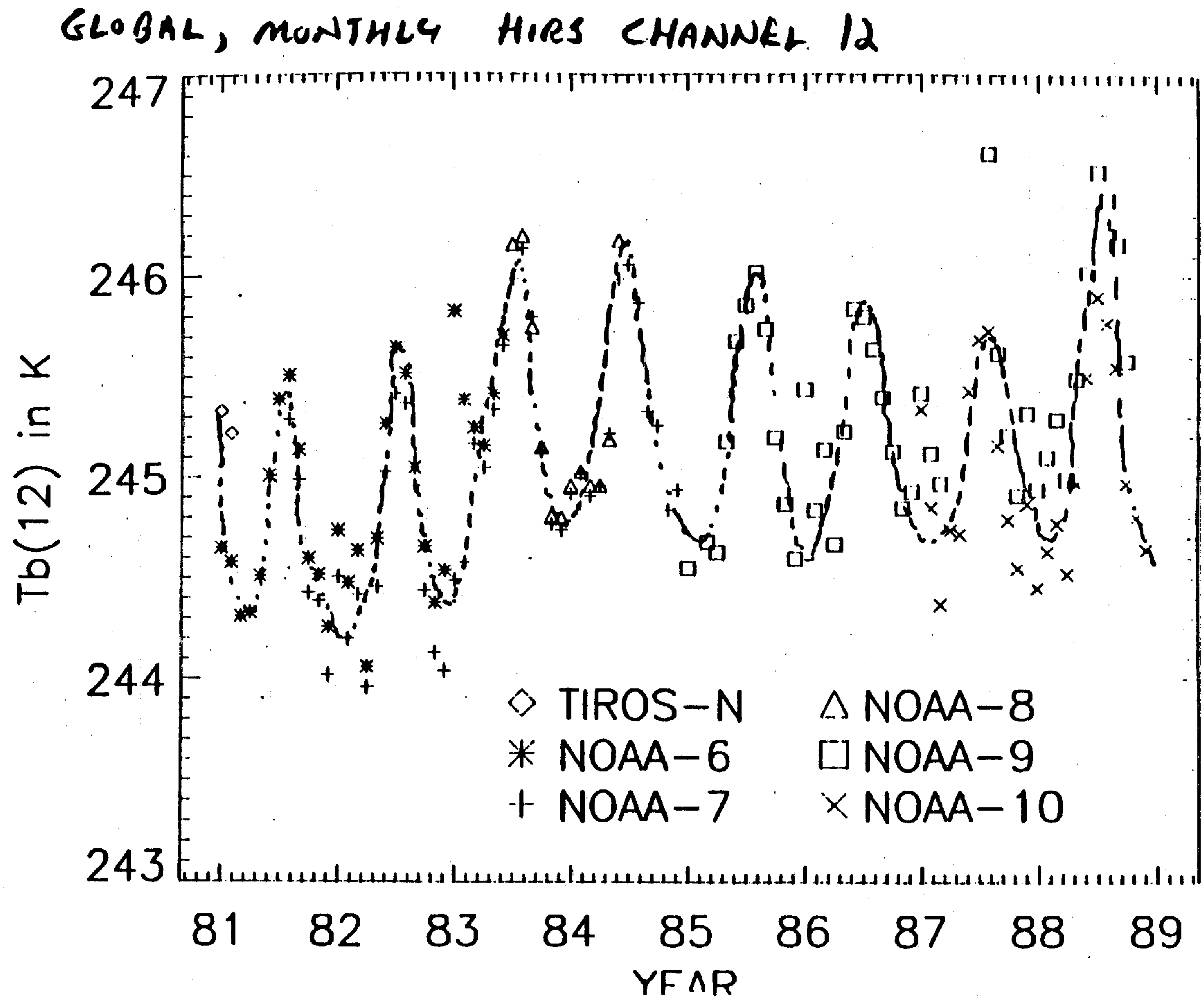
Figure 10. Mean statistics and the difference in mean statistics for precipitable water for the ALUK, ALWA and AL[illegible]2 cases.


PM Sat. – AM Sat.
N7–N6
N7–N8
N9–N10
−1.25
TIROS–N: 1484.35
NOAA–6: 1485.76
NOAA–7: 1489.06
NOAA–8: 1486.92
NOAA–9: 1483.24
NOAA–10: 1489.42
DIFFERENCE IN K
YEAR

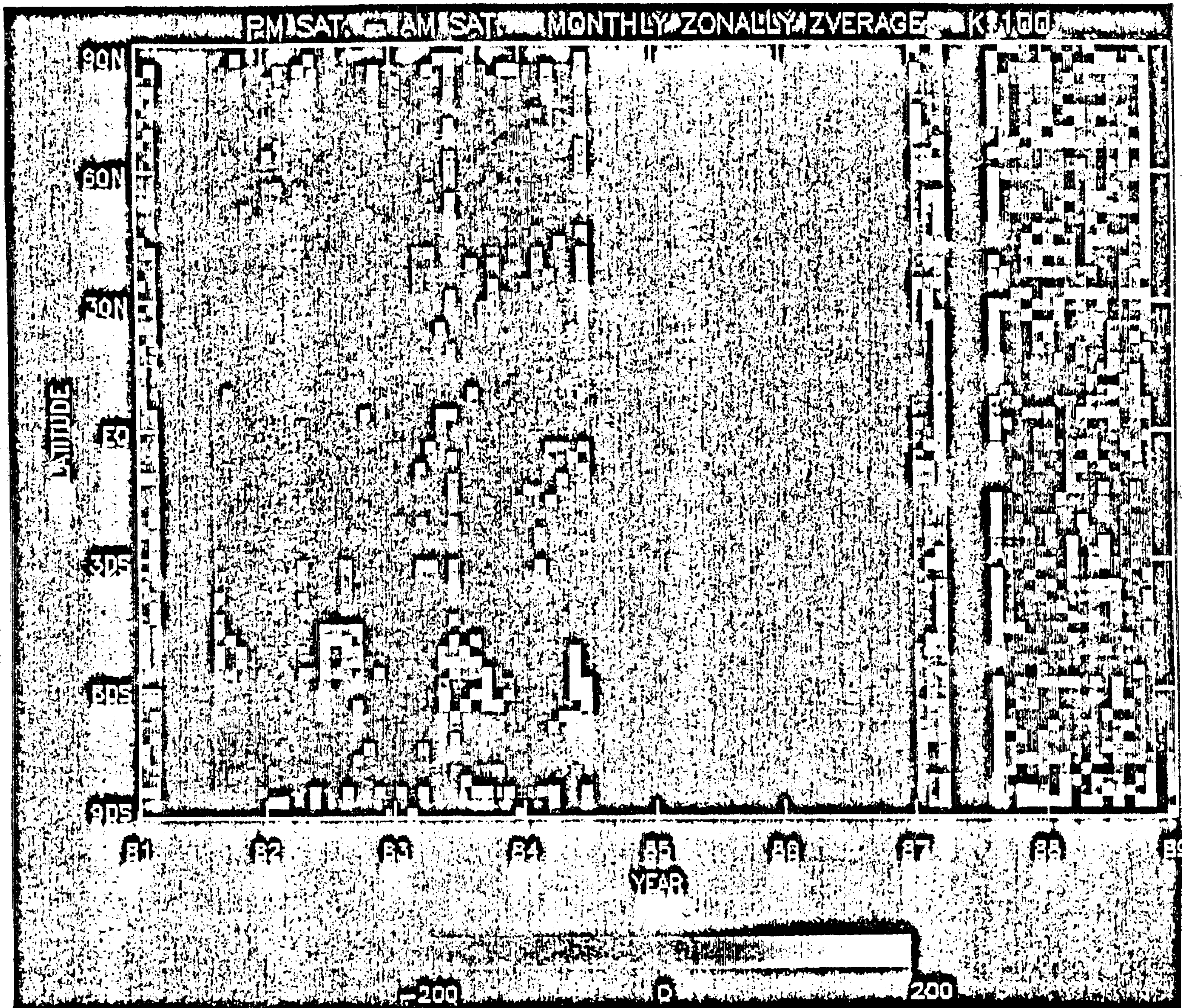

PM Sat. – AM Sat.
N7–N6
N7–N8
N9–N10
TIROS–N: 1484.35
NOAA–6: 1485.76
NOAA–7: 1489.06
NOAA–8: 1486.92
NOAA–9: 1483.24
NOAA–10: 1489.42
–1.25
DIFFERENCE IN K
YEAR
1.0
0.5
0.0
–0.5
–1.0
81
82
83
84
85
86
87
88
89

GLOBAL HIRS CHANNEL 12 BRIGHTNESS TEMPERATURE

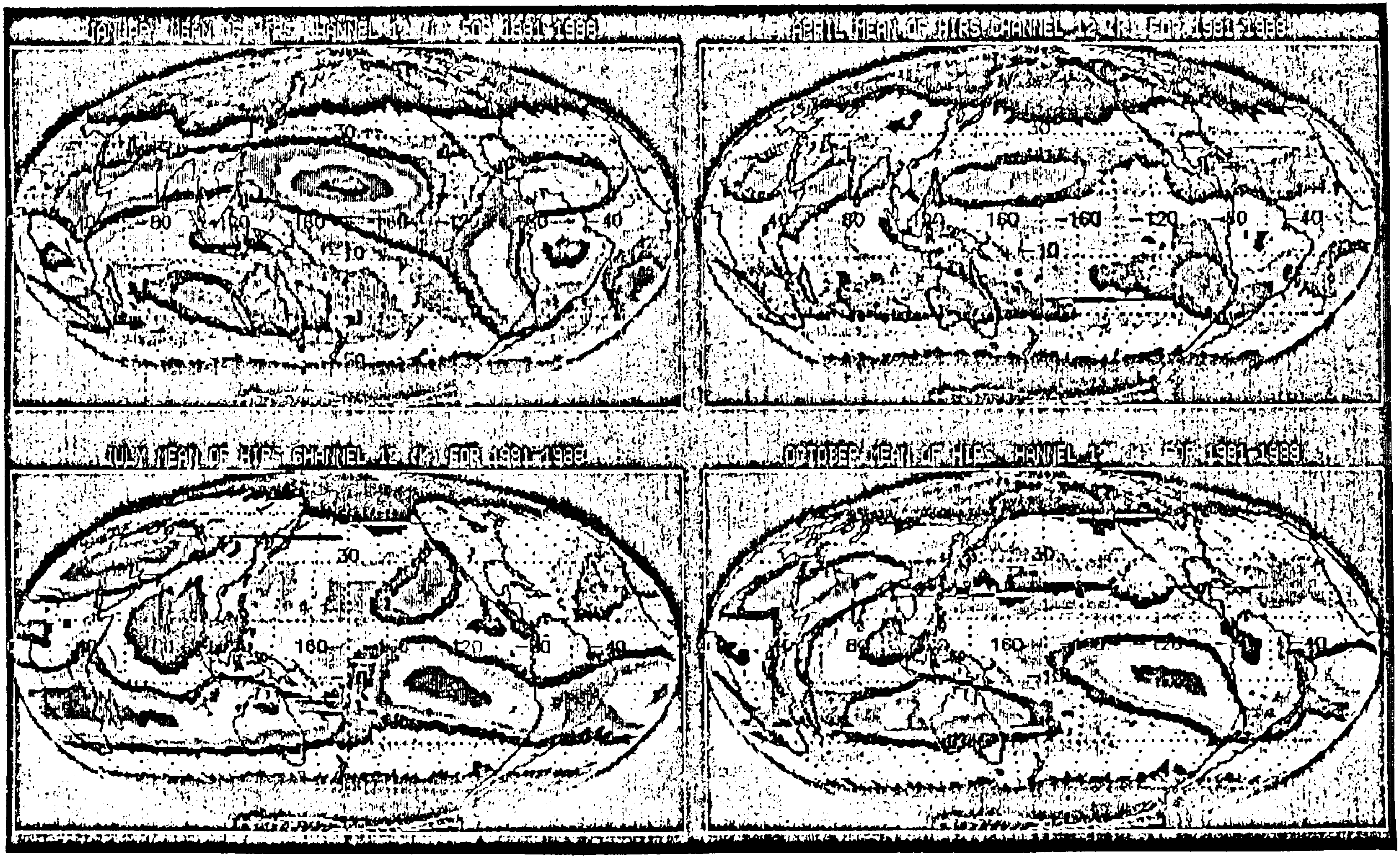


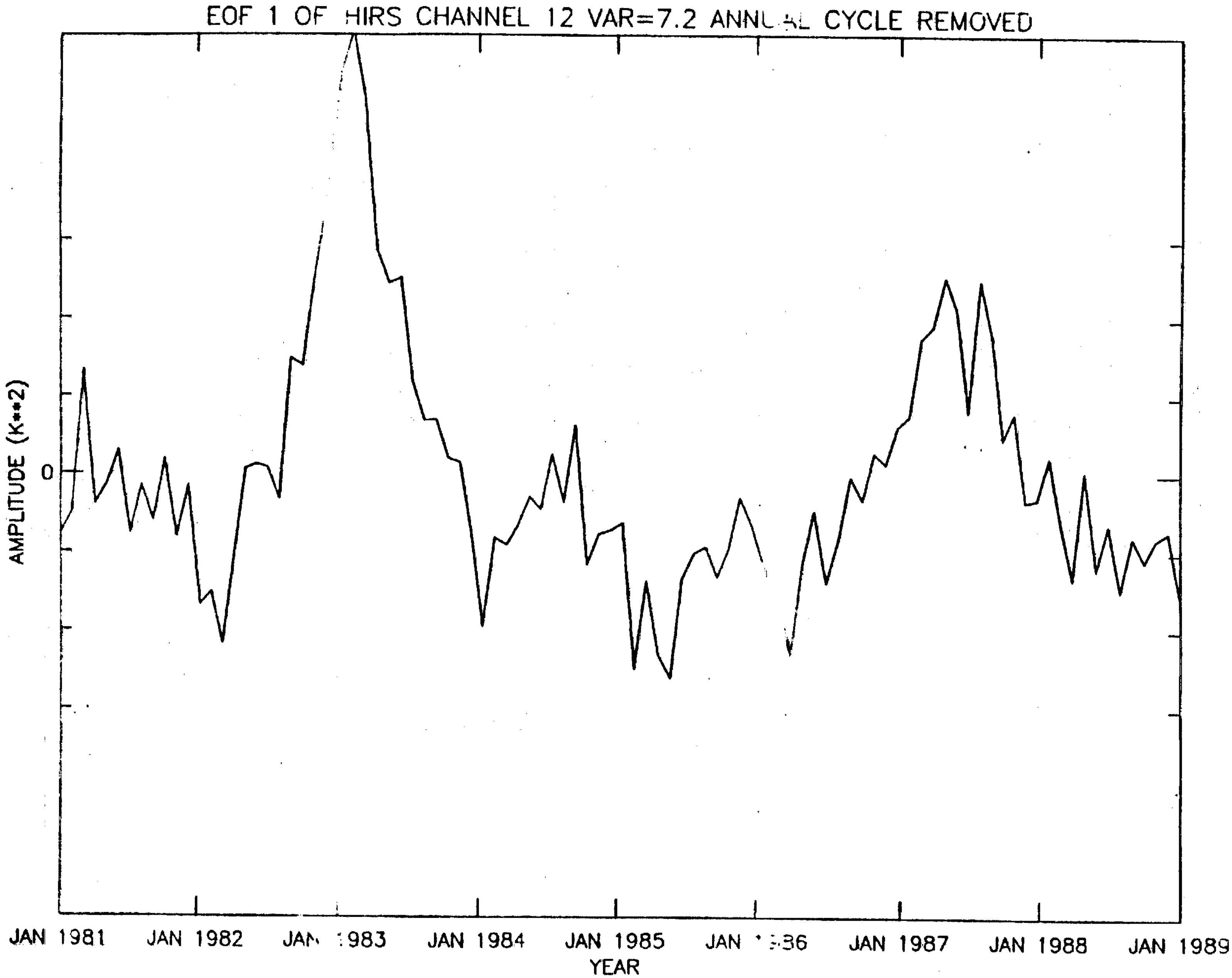


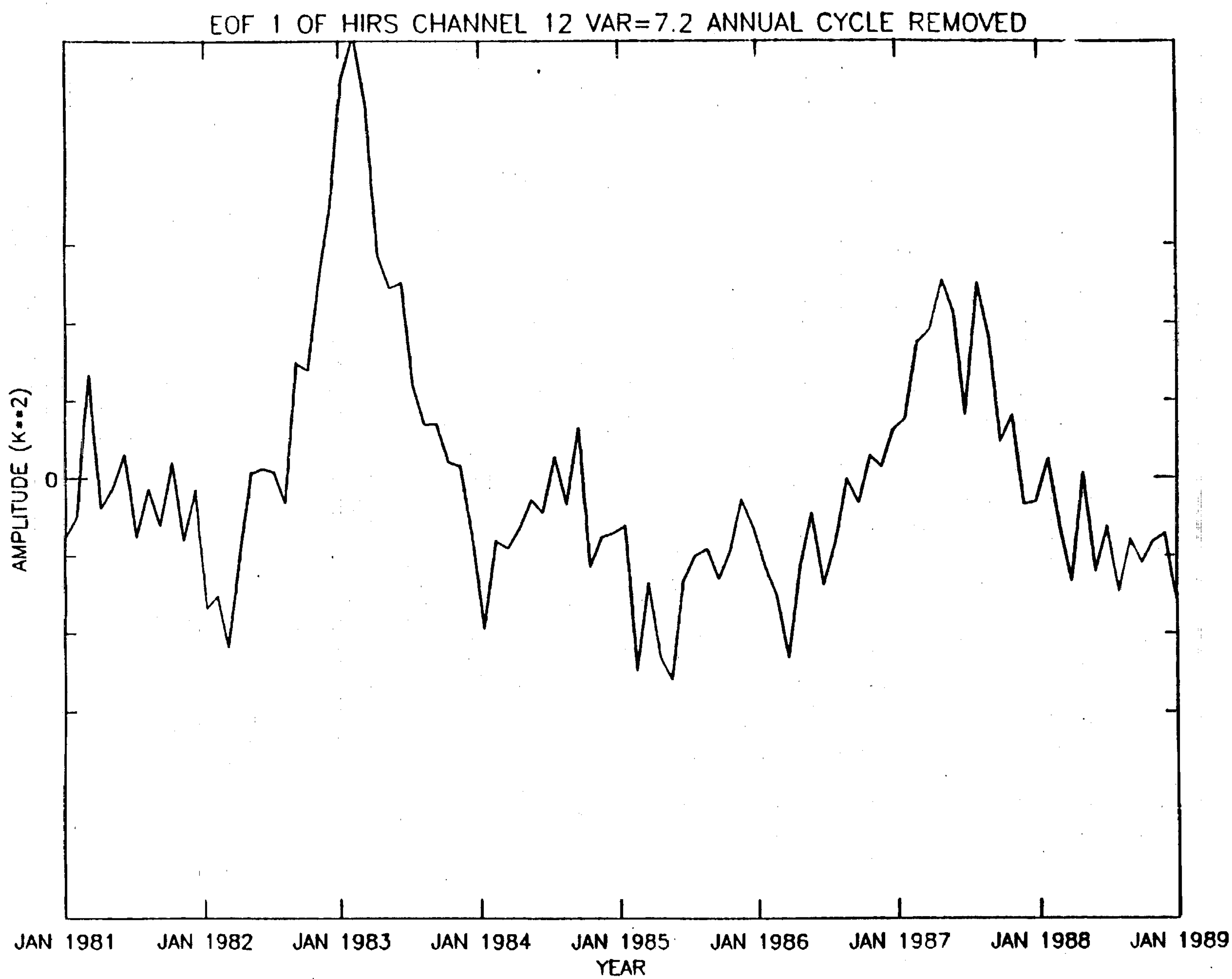
GLOBAL, MONTHLY HIRS CHANNEL 12
Tb(12) in K
247
246
245
244
243
81
82
83
84
85
86
87
88
89
YEAR
TIROS−N
NOAA−6
NOAA−7
NOAA−8
NOAA−9
NOAA−10

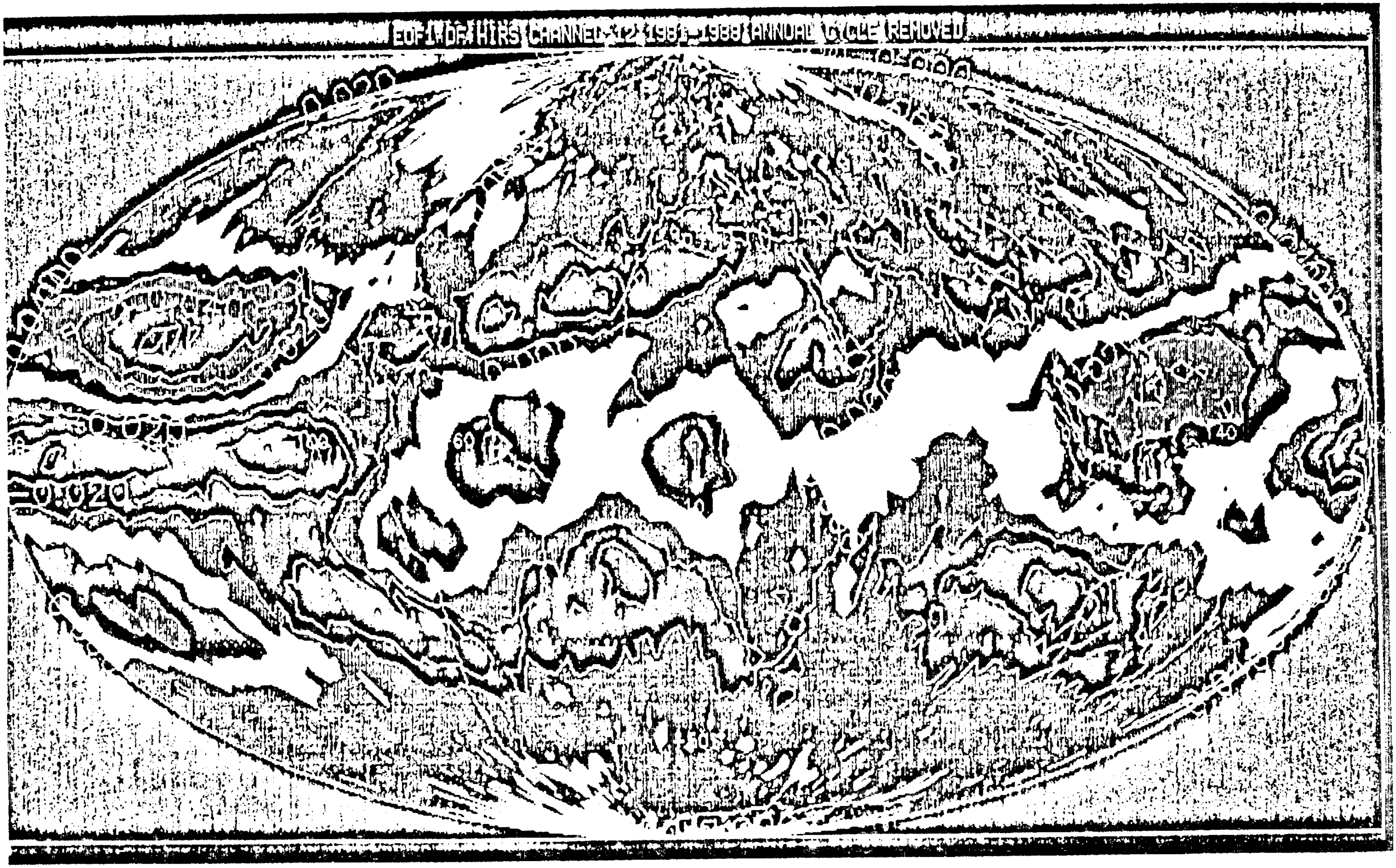


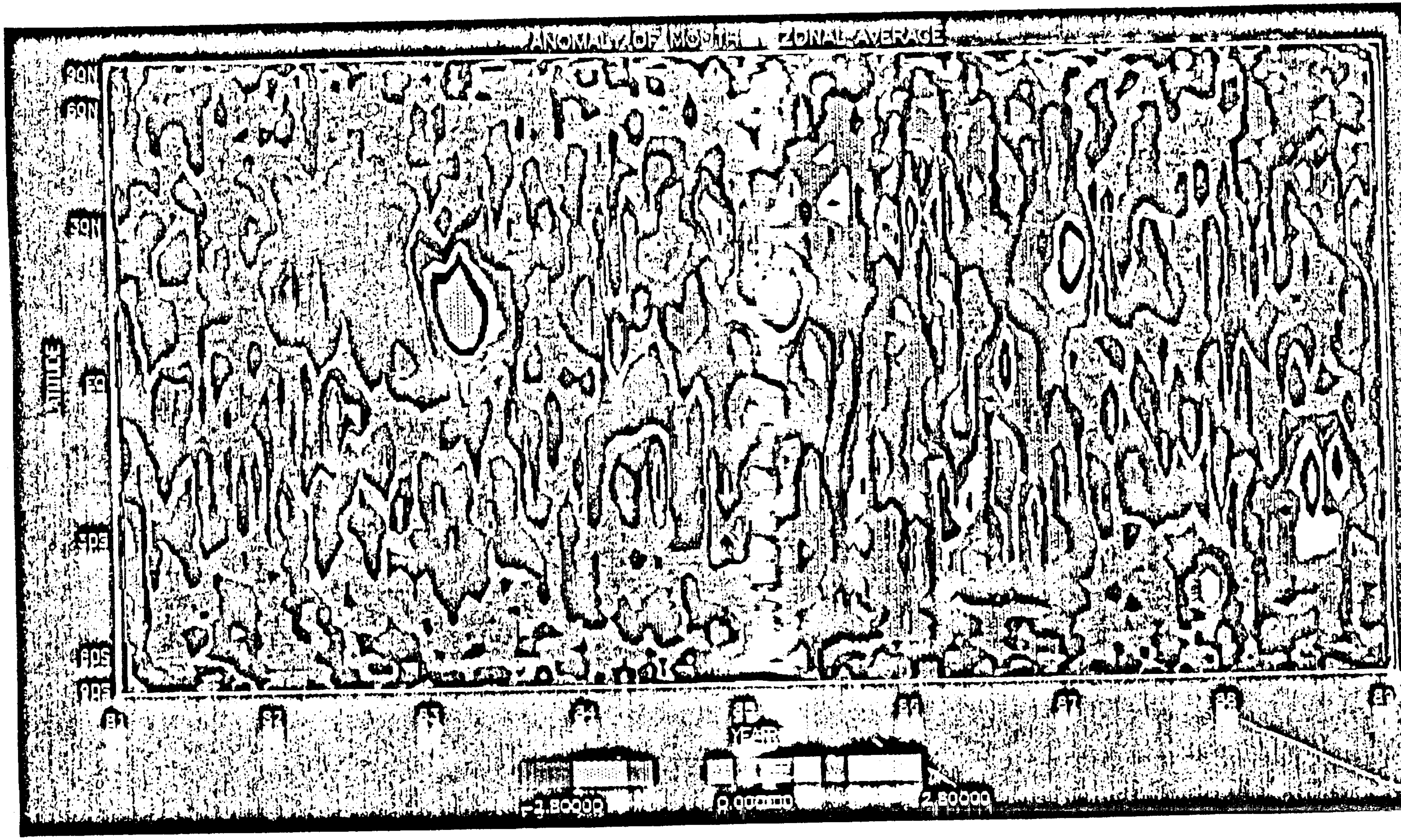
ORIGINAL PAGE IS OF POOR QUALITY


JANUARY MEAN OF HIRS CHANNEL 12 (K) FOR 1981-1988
APRIL MEAN OF HIRS CHANNEL 12 (K) FOR 1981-1988
JULY MEAN OF HIRS CHANNEL 12 (K) FOR 1981-1988
OCTOBER MEAN OF HIRS CHANNEL 12 (K) FOR 1981-1988


EOF 1 OF HIRS CHANNEL 12 VAR=7.2 ANNUAL CYCLE REMOVED
AMPLITUDE (K**2)
0
JAN 1981
JAN 1982
JAN 1983
JAN 1984
JAN 1985
JAN 1986
JAN 1987
JAN 1988
JAN 1989
YEAR


EOF 1 OF HIRS CHANNEL 12 VAR=7.2 ANNUAL CYCLE REMOVED
AMPLITUDE (K**2)
0
JAN 1981
JAN 1982
JAN 1983
JAN 1984
JAN 1985
JAN 1986
JAN 1987
JAN 1988
JAN 1989
YEAR


EOF1 OF HIRS CHANNEL 12 1981-1988 ANNUAL CYCLE REMOVED
0.020


ANOMALY OF MONTH ZONAL AVERAGE
90N
60N
30N
EQ
30S
60S
90S
LATITUDE
YEAR

3. Lessons of history - Applications to the EOS era

3.1. We must establish long-term, global validation programs based on the three principles of validation

3.2. Both satellite and in situ data must be subject to rigorous quality control and continuous monitoring

3.3. Extend and examine the overlap periods of similar instruments on different satellites

3.4. Sampling of most fields must extend over several ENSO cycles, since most fields show large interannual variability related to ENSO.

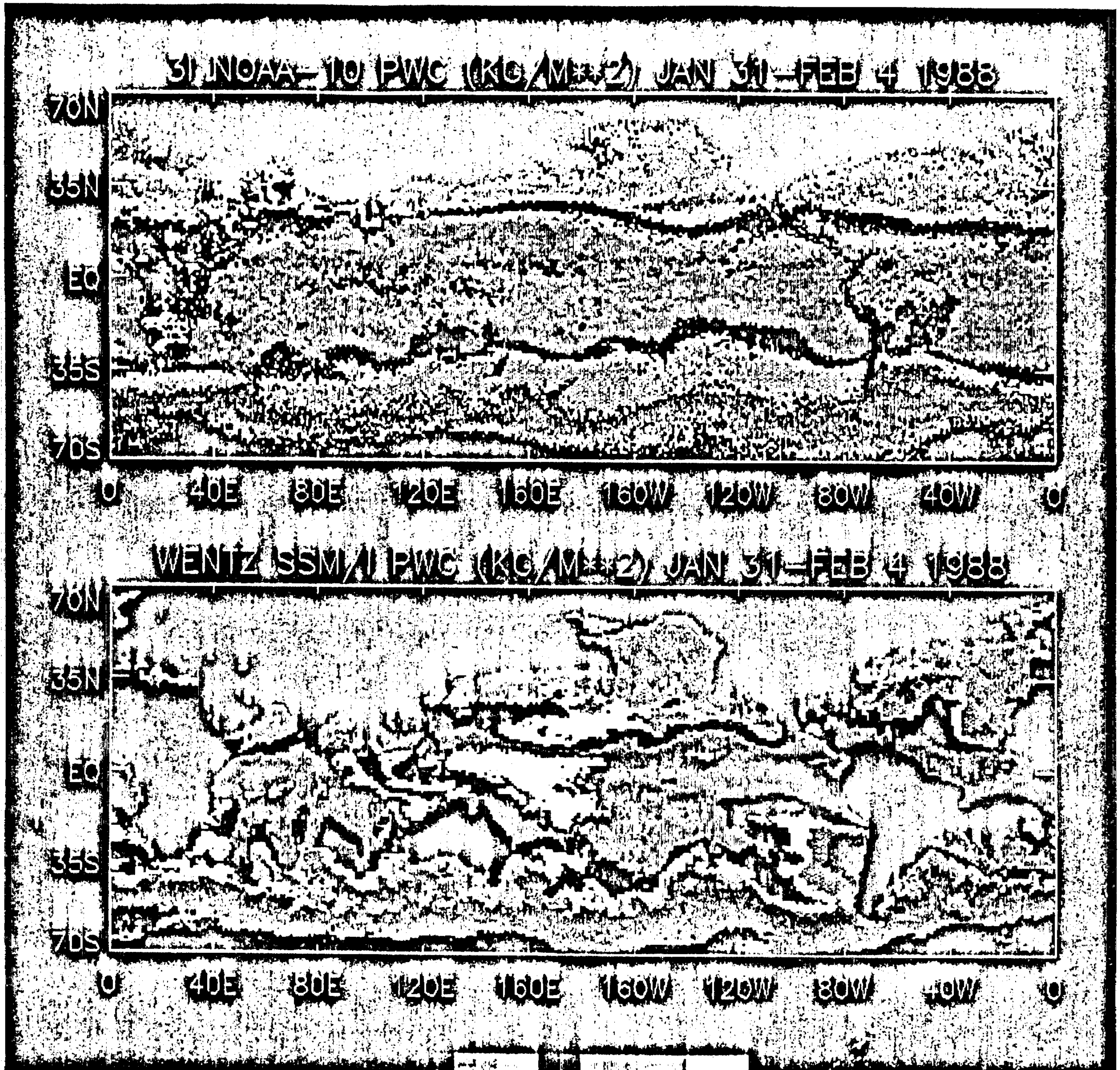
3. Lessons of history - Applications to the EOS era

3.1. We must establish long-term, global validation programs based on the three principles of validation

3.2. Both satellite and in situ data must be subject to rigorous quality control and continuous monitoring

3.3. Extend and examine the overlap periods of similar instruments on different satellites

3.4. Sampling of most fields must extend over several ENSO cycles, since most fields show large interannual variability related to ENSO.


3) NOAA-10 PWC (KG/M**2) JAN 31-FEB 4 1988
70N
35N
EQ
35S
70S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
WENTZ SSM/I PWC (KG/M**2) JAN 31-FEB 4 1988
70N
35N
EQ
35S
70S
0
40E
80E
120E
160E
160W
120W
80W
40W
0