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WL-TR-92-1050

ELEVEN YEARS OF IONOSPHERIC SCINTILLATION FADING DATA FROM TWENTY GREENLANDIC STATIONS

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Information Transmission Branch
System Avionics Division

May 1992

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Radio communications in the polar region are subject to periodic outages due to rapid density fluctuations in the Arctic ionosphere. In order to evaluate the effect of solar activity on these outages, the messages from an extensive network of unmanned automatic meteorological stations in Greenland were recorded. In a joint project between the Danish Meteorological Institute and the U.S. Air Force Wright Laboratory, the recorded data were reduced and analyzed to derive bit-error-rate and missed message statistics. These data are summarized in hourly, daily, monthly, and yearly plots for 20 mid-latitude, auroral, and polar station around Greenland. This report describes the results of the experiment. The Appendices (WL-TR-92-1051) contains 100 station years of data.

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FOREWORD

The work reported in this Technical Report was accomplished between 1985 and 1991 under the Advanced Space Communications Work Unit, 12270126. This effort was based on the data and support provided by the Danish Meteorological Institute in Copenhagen, Denmark. The assistance of Flemming Jensen, Kris Damgaard, and Jorgen Taagholt was essential in the successful completion of this effort. The data analysis assistance of Roger Miniard and Steve Brown of the 4950th Test Wing, Test Analysis Division, WPAFB OH was also essential in completing the study.

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SECTION 1
INTRODUCTION

Radio communications in the polar region are subject to periodic outages due to rapid density fluctuations in the Arctic ionosphere. In order to evaluate the effect of solar activity on these outages, it is necessary to study the sub-auroral, auroral, and polar regions of the Arctic over at least one complete, 11-year solar cycle. A long-term measurement campaign designed exclusively for ionospheric measurements would be very expensive. An alternate approach investigated was the use of an extensive network of unmanned automatic meteorological stations operated by the Danish Meteorological Institute (DMI) in Greenland. These stations transmitted weather information periodically on 400 MHz to the Argos Data System aboard polar orbiting satellites. The satellite collected the data and relayed it to a ground station in Greenland where it was recorded.

An extensive network of Greenlandic stations in the sub-auroral, auroral, and polar regions has been in operation since 1980, providing over 100 station-years of data. In a joint project between the Danish Meteorological Institute and the US Air Force Wright Laboratory, the recorded data were reduced and analyzed to derive Bit Error Rate (BER) and missed message statistics. This report describes the results of the experiment.

SECTION 2

METEOROLOGICAL SYSTEM DESCRIPTION

Since 1925, manned weather stations in Greenland have provided meteorological observations to the Global Weather Center (Jensen, 1980). To supplement the manned weather stations around coastal Greenland, the DMI initiated an experiment in the 1970s with an unmanned meteorological observatory (Taagholt, 1982). The unmanned station was designed to collect information on air pressure, air temperature, wind speed, wind direction, and relative humidity. The collected information was digitized and periodically transmitted, via satellite, back to a ground station for processing and distribution.

After the initial test in the mid-70s proved successful, DMI implemented an Unmanned Geophysical Observatory (UGO) in a self-contained, battery powered station designed for operation in remote locations. At present 20 of these UGOs, housed in fiberglass caravans, Figure 1, are positioned from the southern to the northern tips of Greenland, Figure 2 (Johnson and Taagholt, 1985).

The meteorological measurements are made eight times a day, starting at midnight Universal Coordinated Time (UTC). The analog measurements are digitized by a data logger and stored in digital form, Table 1 (Nehring, 1988).

Over the next 3-hour period, a 300 bit message is transmitted every 100 seconds. Each station transmits a unique station identifier number along with its meteorological information. A 1-watt solid-state transmitter and an omni-directional antenna are used to relay the data at approximately 400 MHz to a polar-orbiting collection satellite.

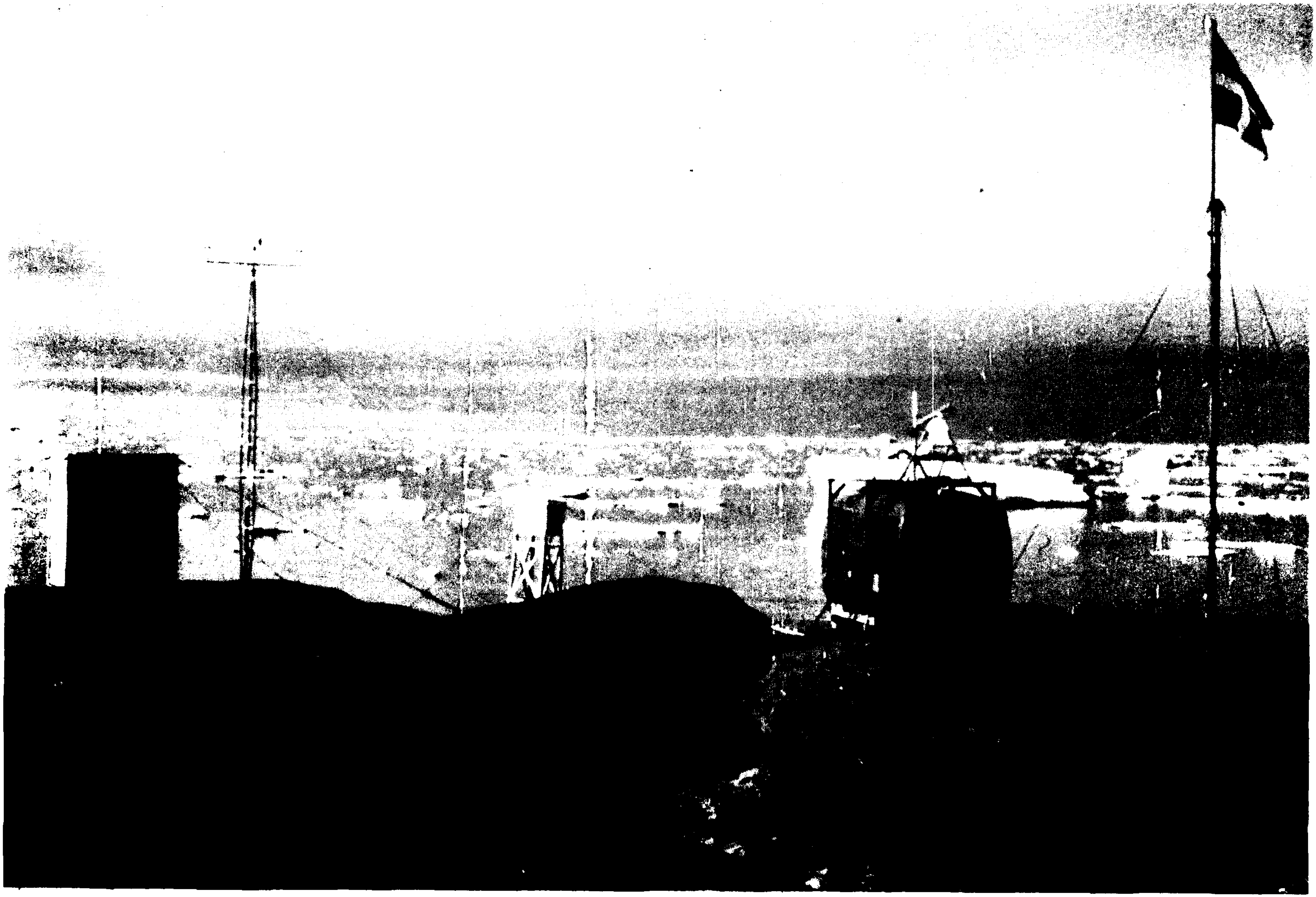
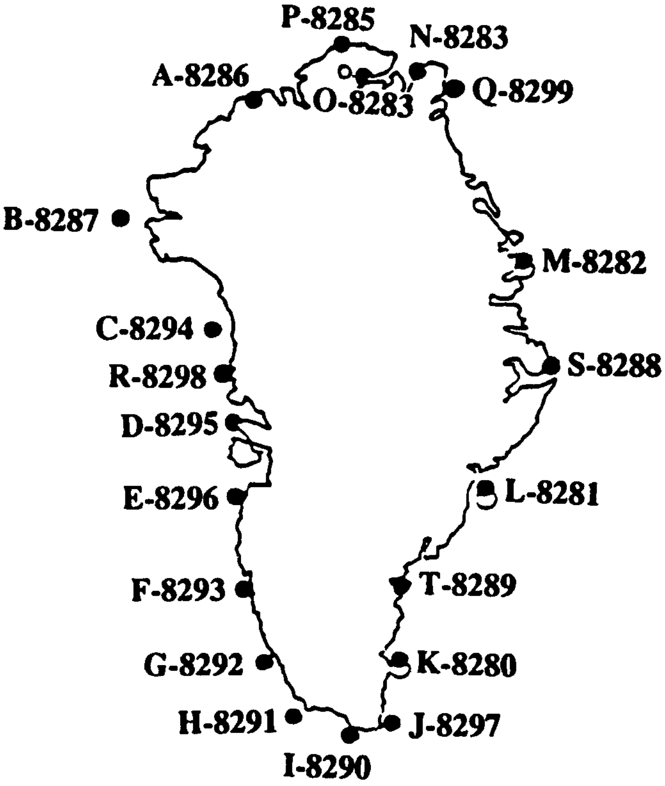


Figure 1. Danish Unmanned Geophysical Observatory



	Station	Location	WMO-NR	Argos-NR	Established
A-	Hall Land	81°44'N,59°00'W	04-207	8286	Jul.1982
B-	Carey Øer	76°38'N,73°00'W	04-203	8187	Aug.1979
C-	Edderfugleøer	74°02'N,57°49'W	04-208	8294	Sep.1981
D-	Nugssuaq	70°41'N,54°37'W	04-214	8295	Aug.1982
E-	Agto	67°47'N,53°58'W	04-228	8296	Aug.1983
F-	Sioralik	65°01'N,52°33'W	04-242	8293	Jun.1983
G-	Frd.håbs Isblink	62°34'N,50°25'W	04-253	8292	Jun.1982
H-	Nunarssuit	60°46'N,48°25'W	04-266	8291	Jun.1981
I-	Angissoq	59°59'N,45°12'W	04-285	8290	Jun.1981
J-	Prins Chr.sund	60°02'N,43°07'W	04-390	8297	Okt.1982
K-	Ikermiarssuk	61°56'N,42°04'W	04-381	8280	Aug.1978
L-	Aputiteq	67°47'N,32°18'W	04-351	8281	Aug.1978
M-	Daneborg	74°18'N,20°13'W	04-330	8282	Aug.1978
N-	Station Nord	81°36'N,16°40'W	04-312	8283	Sep.1979
O-	Kap Harald Moltke	82°09'N,29°53'W	04-305	8284	Aug.1979
P-	Kap Morris Jessup	83°40'N,33°22'W	04-301	8285	Jul.1979
S-	Kap Tobin	70°25'N,21°58'W	04-340	8288	Aug.1985
T-	Ikermit	64°47'N,40°18'W	04-373	8289	Okt.1986
Q-	Krøyers Holme	80°41'N,13°55'W	04-313	8299	Jul.1984
R-	Upernavik	72°47'N,56°10'W	04-209	8298	Aug.1984

Figure 2. Locations of ARGOS Stations in Greenland

Table 1. Synoptic Data from Meteorological Station

		PARAMETER	UNIT	TYPICAL RANGE	RES.	msb BITS TRANSMITTED lsb
LATEST SYNOP	1	GMT	min.	0 to 23⁵⁰	10	1 2 3
	3	Air press.1	mb	904 to 1077	0.17	9 10
	2	Day no.	-	1 to 365	1	19 20
	12	Reference	-	0 to 31	1	28
	4	Wind speed 1	knots	0 to 137	0.39	33 34
	10	Wind speed 2	knots	0 to 137	0.39	41 42
	7	Air press.2	mb	904 to 1077	0.17	49
	11	Wind direct.	deg.	0 to 360	5.63	59
	8	Air temp.	°C	-58 to 33	0.09	65
	6	Wind direct.	deg.	0 to 360	5.63	75
	13	Aux 1	-	-	0.48	81
	14	Com. box	-	1 - 35	1	89
	15	Aux 3	-	-	0.18	97
	16	Aux 4	-	-	0.18	
	9	Rel.humidity	%	0 to 100	0.78	
	5	Indoor temp.	°C	-58 to 33	1.8	

SECTION 3

ARGOS SATELLITE DESCRIPTION

The Argos System is a satellite-based data collection system for collecting environmental data (Argos, 1984). Argos is a cooperative project between the Centre National d'Etudes Spatiales (CNES, France); the National Aeronautical Space Administration (NASA, USA); and the National Oceanic and Atmospheric Administration (NOAA, USA). Argos consists of two polar-orbiting satellites and three ground stations for collection, processing, and relaying of the environmental information, Figure 3. The environmental data are picked up from seaborne buoys, boats, balloons, and fixed stations called Platform Transmitter Terminals (PTTs). From the PTTs, the data are uplinked to the Television Infrared Observation Satellites (TIROS-Ns). The data received at the satellite are processed and relayed real-time or stored for future relay to ground stations, Figure 4.

The TIROS-Ns are in a circular orbits, at 830-kilometers altitude, with an inclination of 98.7 degrees to the equator. This orbit has a period of approximately 101 minutes, which provides 14 satellite passes per day. The orbital planes of the two operational satellites are offset by approximately 75 degrees, Figure 5.

From their 830-kilometer altitude each satellite can see approximately a 5,000-kilometer diameter circle on the earth, Figure 6. Because of their visibility area and orbital perimeters, PTT at the equator can see three successive passes of each satellite each day, Table 2. If the PTT latitude is farther from the equator, it will see more satellite passes per day. PTTs above 75 degrees north (or south) can see all 14 daily passes of each satellite. Since there are two satellites, each PTT will see from 6 to 28 satellite passes per day, depending on their latitude.

To operate with the Argos System fixed-data format, the PTT must transmit a short, unmodulated carrier; followed by a preamble; a short format sync; an initialization bit; a group identifier; a station identifier; and from 32 to 256 bits of sensor information, Table 3. The system employs split phase modulation, a form of binary phase shift keying. The entire message can vary from 80 to 304 bits of information.

While there may be thousands of PTTs, the Argos System is able to receive and process only four signals simultaneously. System operation depends on random transmission times,

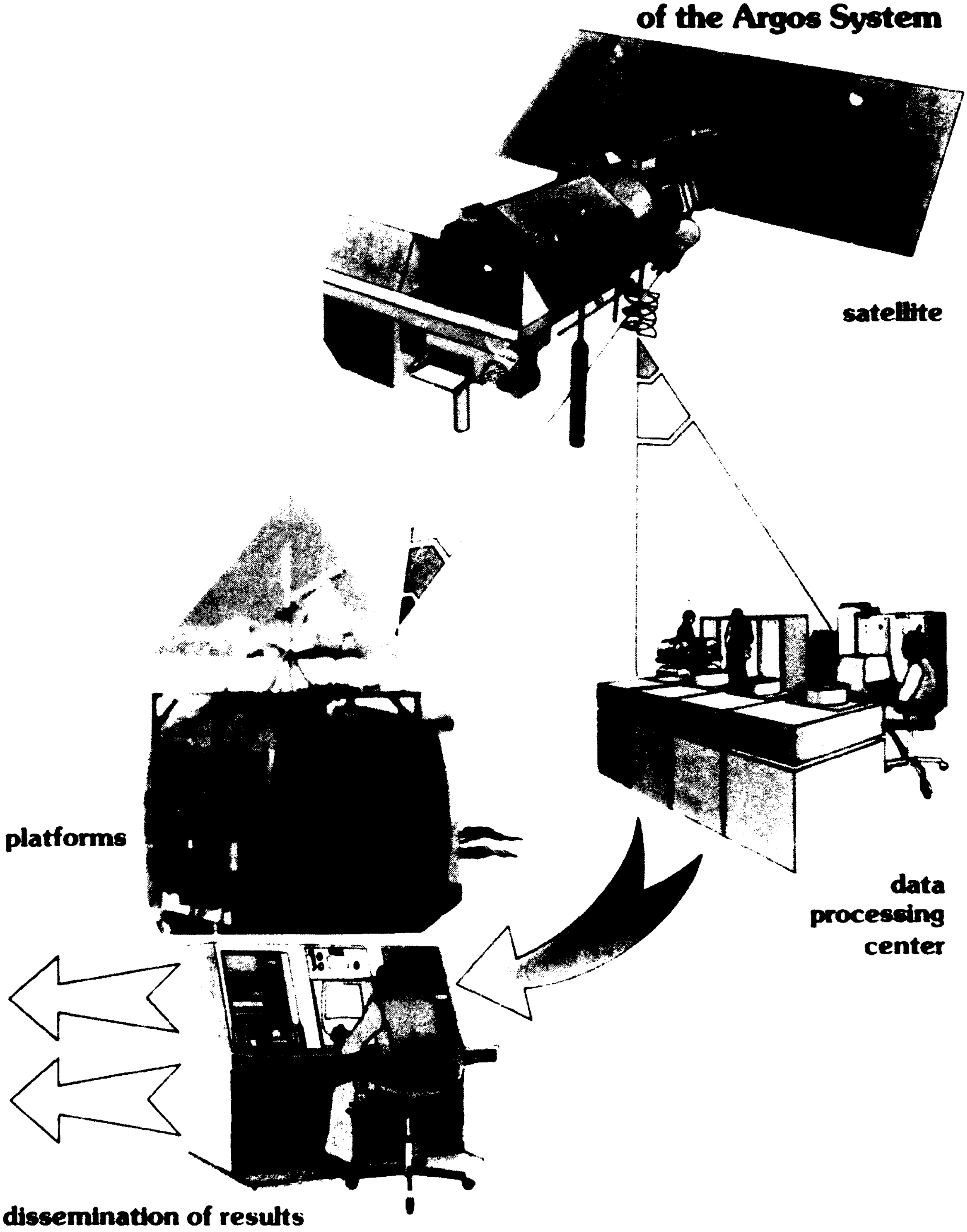


Figure 3. Composition of the ARGOS System

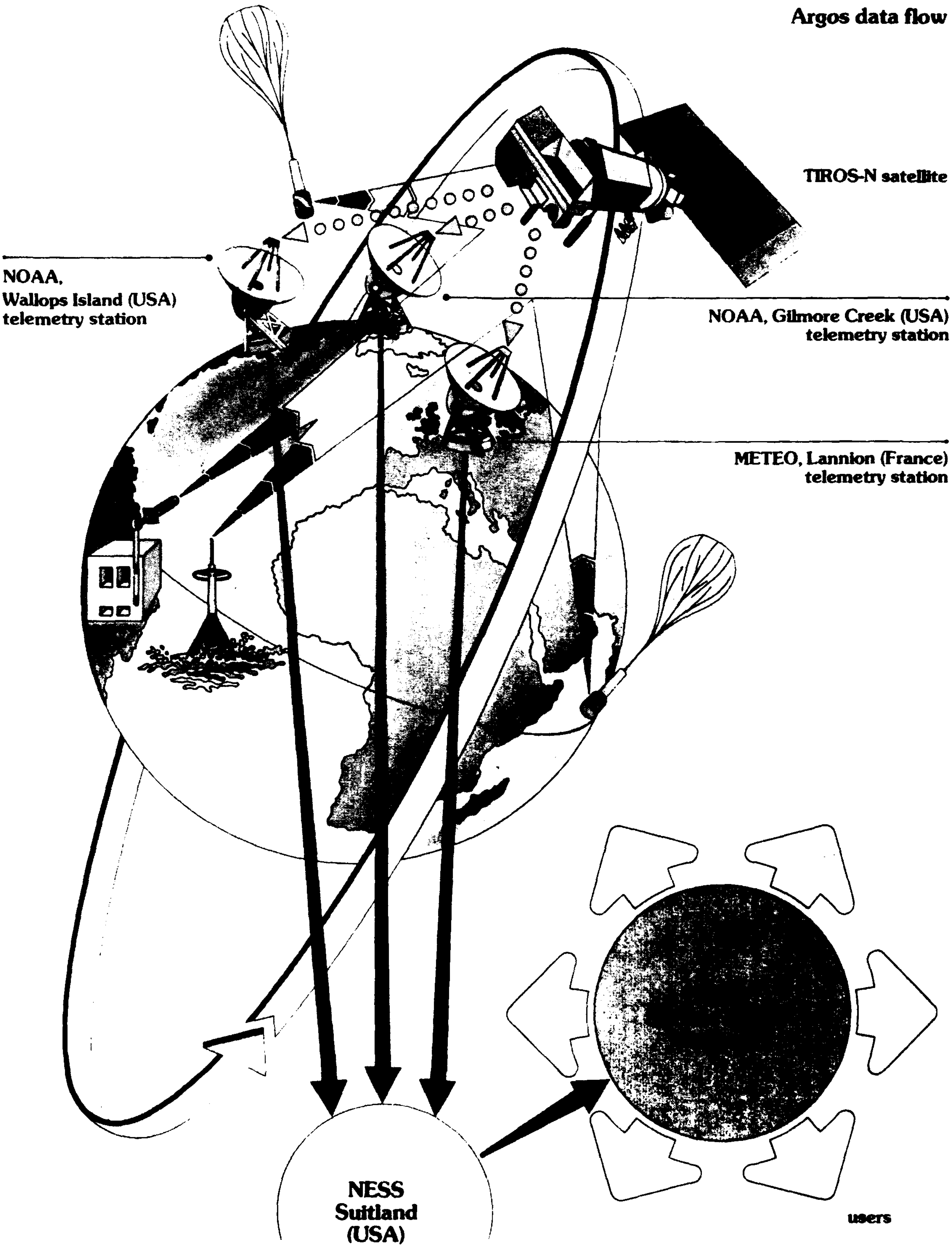


Figure 4. ARGOS System Data Flow

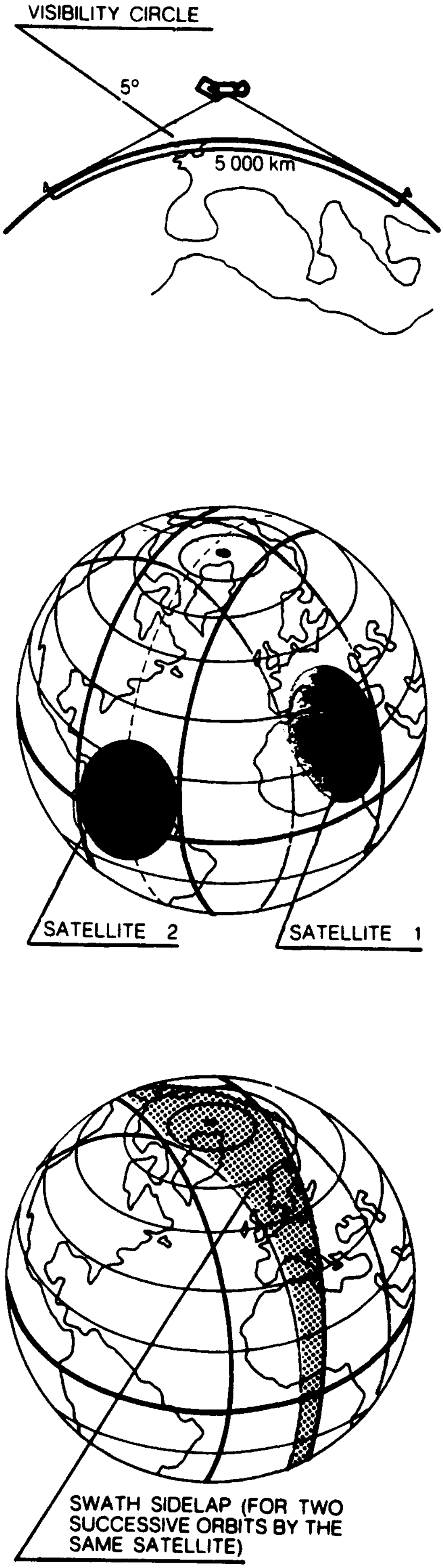


Figure 5. Geometry of ARGOS Satellite Orbits

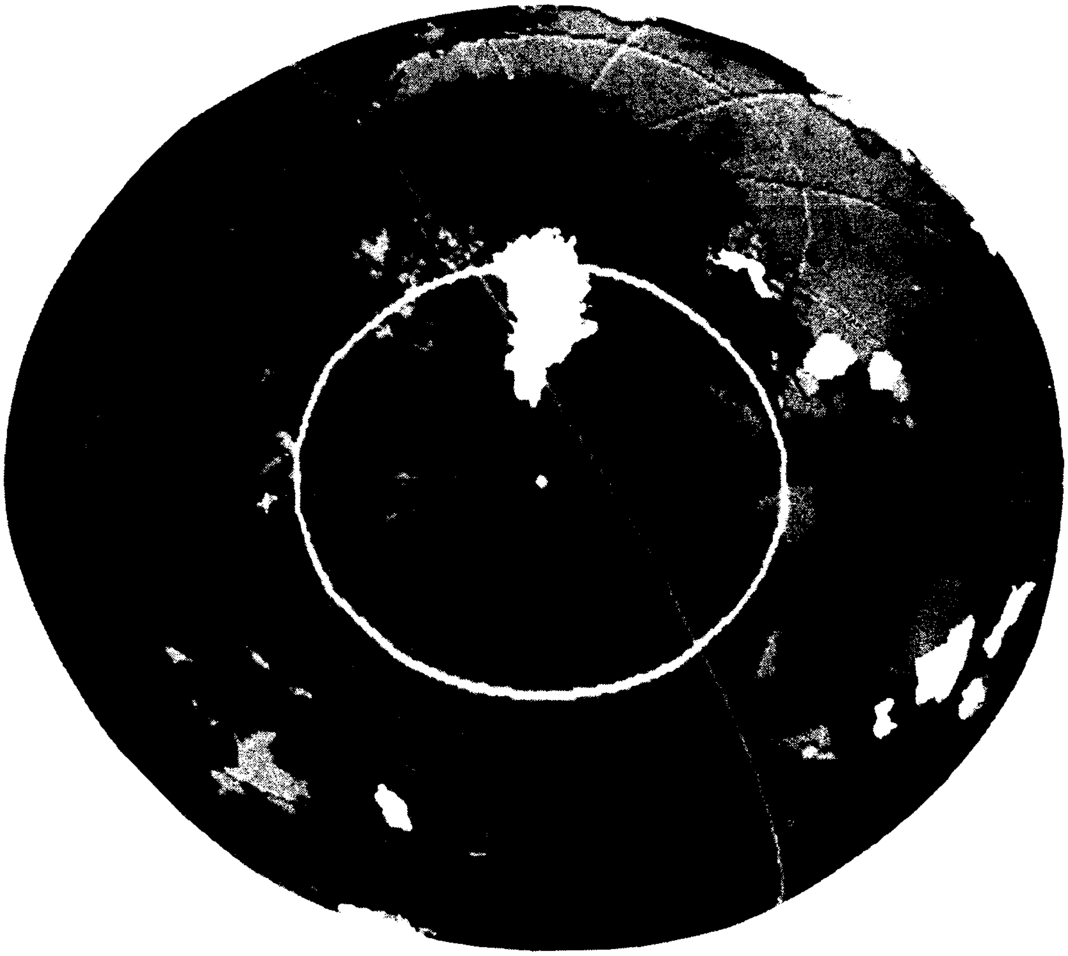


Figure 6. Visibility Circle from ARGOS System Satellite

Table 2. Two Satellite Pass Frequency and Duration of Visibility

PTT LATITUDE	CUMULATIVE VISIBILITY OVER 24 HOURS minutes	MINIMUM NUMBER OF PASSES PER 24 HOURS	MEAN NUMBER OF PASSES PER 24 HOURS	MAXIMUM NUMBER OF PASSES PER 24 HOURS
0°	80	6	7	8
± 15°	88	8	8	9
± 30°	100	8	9	12
± 45°	128	10	11	12
± 55°	170	16	16	18
± 65°	246	21	22	23
± 75°	322	28	28	28
± 90°	384	28	28	28

Table 3. Platform Transmitter Terminal Message Structure and Format

UNMODULATED CARRIER LENGTH T1	MODULATED CARRIER : LENGTH T2					
	PREAMBLE	FORMAT SYNC.	INITIALIZATION	NUMBER OF 32-BIT GROUPS	ID N° (+ Check bits)	SENSOR DATA
T1 = 160 ms ± 2.5 ms	15 bits (= 1)	8 bits (00010111)	1 bit (= 1)	4 bits	20 bits	$N \times 32$ bits ($1 < N < 8$)

random frequencies, and random visibility of the PTTs in order to separate the thousands of potential users. Since the satellite can only see 3% of the earth at any one time, there are only a limited number of mutually visible PTTs competing for access. Each PTT transmits with a fixed period, but the period is chosen in a random fashion to be from 40 to 200 seconds apart. Transmitting at 400 bits per second, each transmission lasts for 1 second or less. While all transmitting frequencies are nominally 401.650 MHz, differences in crystal frequency drift, terminal temperature, and Doppler to the satellite results in sufficient frequency shift to separate simultaneously transmitting PTTs.

Each PTT is in view of the satellite from 10 to 13 minutes, depending upon the elevation angle of the satellite paths over the PTT. To increase their data reception reliability, the DMI UGOs send the same data message for the entire 3 hours synoptic update period. If there should be interference on a single transmission, there is a high probability that the subsequent transmissions will be received by the satellite without interference from another PTT transmission.

The Argos System is designed so that the data from one PTT have a probability of 80% of being received by the satellite without interference from another PTT. With three repeats of the message, the probability of noninterference rises to better than 99%. The Argos System parameters are chosen to provide a 10^{-4} BER for the data.

A buffer memory in the satellite stores the uplink data and makes it available for immediate retransmission on a Very High Frequency (VHF) downlink or later retransmission on a Ultra High Frequency (UHF) downlink to the Argos ground stations. The primary downlink from the satellite is transmitted on approximately 1.7 GHz to three receiving stations in the United States and France. In the case of the Greenlandic data, DMI has established a ground station in Sondrestrom, Greenland, to receive the meteorological data. The data are recorded and passed back, via the geo-stationery International Telecommunications Satellite (INTELSAT) to Denmark for data processing and distribution to the international meteorological community.

SECTION 4

DATA ANALYSIS TECHNIQUE

In addition to the interference caused by simultaneous transmissions from other PTTs and man-made interference, the 400 MHz link from a PTT to the satellite may be disturbed by ionospheric irregularities (Aarons et al., 1981). Ionospheric scintillation fading can be especially severe in the polar regions. Recent tests of a satellite system at 250 MHz showed 25-35 dB peak-to-peak fading for 90% of the 24-hour day, Figures 7 and 8 (Johnson, 1990). While the effects of ionospheric scintillation fading decrease with increased frequency, it is still severe at the Argos System 400-MHz uplink frequency.

In a cooperative experiment between the Danish Meteorological Institute (DMI) and the Wright Laboratory (WL), the Greenlandic data were collected on separate monthly magnetic tapes by DMI. The data tapes were then provided to WL for processing. The magnetic tapes were scanned for station identifiers and all the data from each station were processed and analyzed to provide monthly station statistics. Since a repetitive message was sent for a 3-hour period from each synoptic station, the data reduction software collected all the messages from one station for that 3-hour period and through a voting process, determines what a single "correct" 256-bit message should be, Figure 9. It then compared all of the messages from that 3-hour block with the "correct" message to determine the BER. Note that the second message in Figure 9 has an error at the top of the right-hand column. The hexadecimal 2C should have been 3C. Since there was a possibility of interference or clock drift on the messages, each message was first scanned to determine its validity. If the error rate was higher than 10%, it was considered a corrupted message and rejected from the analysis process. Separate statistics were kept on rejected message count. The BER for each 3-hour block was computed and then summarized into daily, monthly, and yearly statistics for each station.

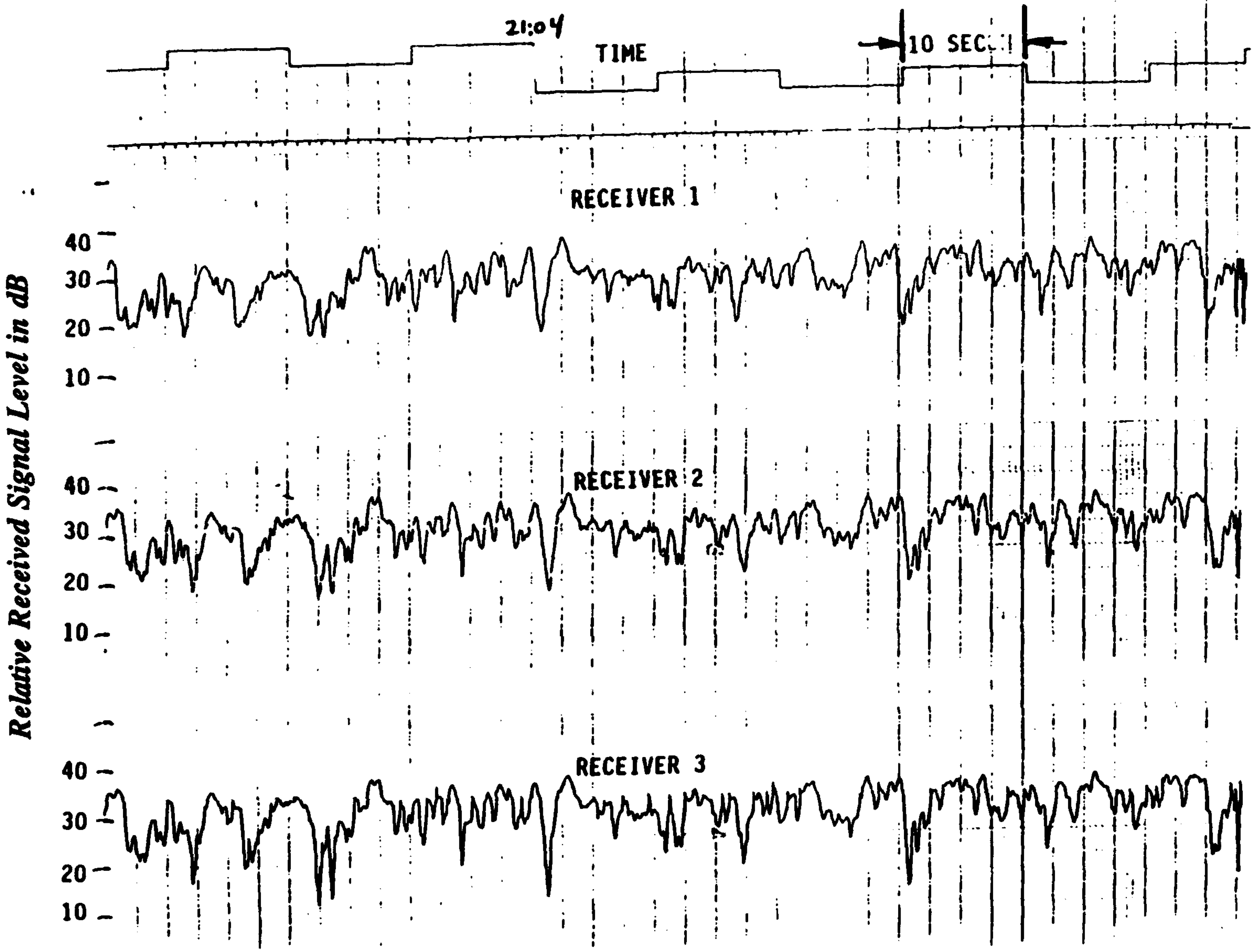


Figure 7. The 250 MHz Ionospheric Scintillation Fading in Greenland

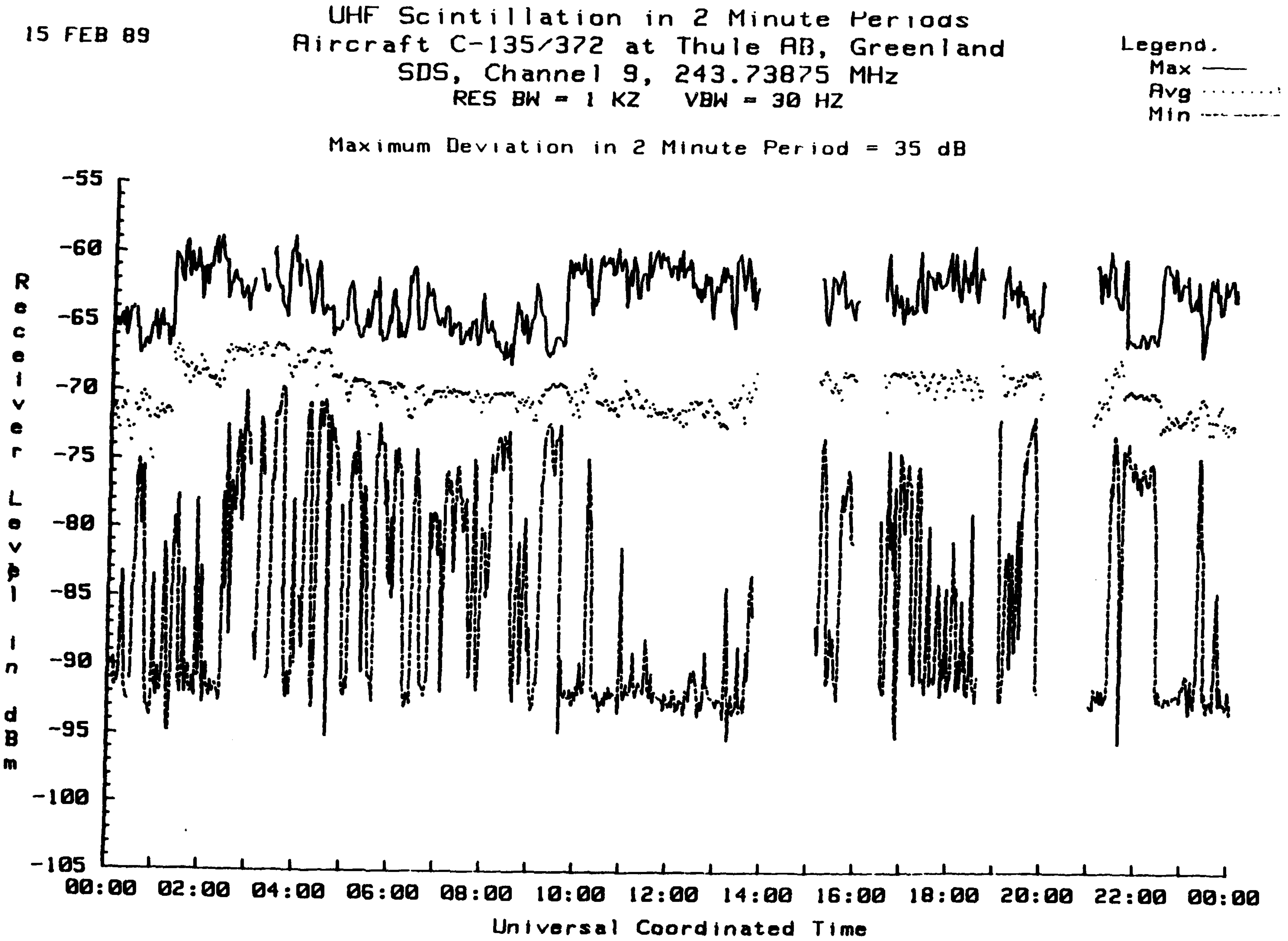


Figure 8. Summary of UHF Scintillation Fading Levels For 15 February 1989

```
309   0272 13149 12 09 28 02  78            82             80          3C
310   0272                    01            00             7F          30
311   0272                    7C            1C             00          F9
312   0272                    00            00             0F          2F
313   0272                    5A            7F             40          3C
314   0272                    01            00             7C          7F
315   0272                    7A            FE             00          FA
316   0272                    00            00             0F          2F
317   0272   18 08280 32 12205 83       00 00 00 0   -1 1     000000 401650000
318   0272      0      61.917 317.917          .000        .000   000000 401650000
319   0272 13149 12 32 37 01  78            82             80          2C
320   0272                    01            00             7F          30
321   0272                    7C            1C             C0          F9
322   0272                    00            00             0F          2F
323   0272                    5A            7F             40          3C
324   0272                    01            00             7C          7F
325   0272                    7A            FE             00          FA
326   0272                    00            00             0F          2F
327   0272 13149 12 37 58 03  78            82             80          3C
328   0272                    01            00             7F          30
329   0272                    7C            1C             00          F9
330   0272                    00            00             0F          2F
331   0272                    5A            7F             40          3C
332   0272                    01            00             7C          7F
333   0272                    7A            FE             C0          FA
334   0272                    00            00             0F          2F
```

Figure 9. Corrected UGO Synoptic Data Message

SECTION 5

DATA ANALYSIS RESULTS

Data from one complete 11-year solar cycle, Figure 10, was collected and analyzed for bit-error-rate and error-free-message rate. Bit-error-rate plots and error-free-message plots of data from a representative mid-latitude station, auroral station, and polar station are shown in Figures 11 - 16. The data show an increase in bit-error-rate during years of high solar activity, Figure 12, and a decrease in the error-free messages, Figure 15. Plots of the data from all stations are shown in Appendix A for bit-error-rate and Appendix B for error-free-message rate.

To analyze the monthly variations, the monthly bit-error-rate data for 1988 was plotted, Figures 17 - 19. Those plots show an increase in the bit-error-rate throughout the year, as the solar activity increases, Figure 18. To further investigate the diurnal variation of the bit-error-rate, the monthly data for 1989 were plotted for a noon period and a midnight period, Figures 20 - 22. The diurnal data show no diurnal effect for the mid-latitude station, Figure 20, a daytime minimum during the equinox for the auroral station, Figure 21, and a nighttime peak in the summer for the polar station, Figure 22. The noon-midnight data were also plotted for 1985, a year near the solar minimum, Figures 23 - 25. Analysis of quiet solar conditions in 1985/86 indicates that the Argos data collection system, as implemented by DMI's UGOs, has an overall BER floor of approximately 1 X 10^{-3}, Figures 11, 12, and 13. Under periods of high sunspot activity the monthly BER rises to 4 X 10^{-3}. The complete collections of the monthly data for 1985, 1988, 1989, and 1990 are presented in Appendices C, D, E, and F.

In order to investigate the short-term scintillation statistics, the daily scintillation results were plotted for January 1990, Figures 26 - 28. The daily bit-error-rate tended to follow the daily solar flux intensity, Figure 27. The daily diurnal dependence of scintillation fading was investigated further by plotting the noon period and midnight period bit-error-rate for October, 1990, Figures 29 - 31. An even finer time analysis was made by plotting the bit-error-rate for 3-hour periods on 15 - 16 October 1990, Figures 32 - 34. The 3-hour data were compared with field-test data collected at Sondrestrom AB Greenland for a ground-truth test. The station closest to Sondrestrom was Agto (#8296). A comparison of the ionospheric scintillation fading at Sondrestrom from a 250-MHz satellite downlink and the bit-error-rate of the 400-MHz

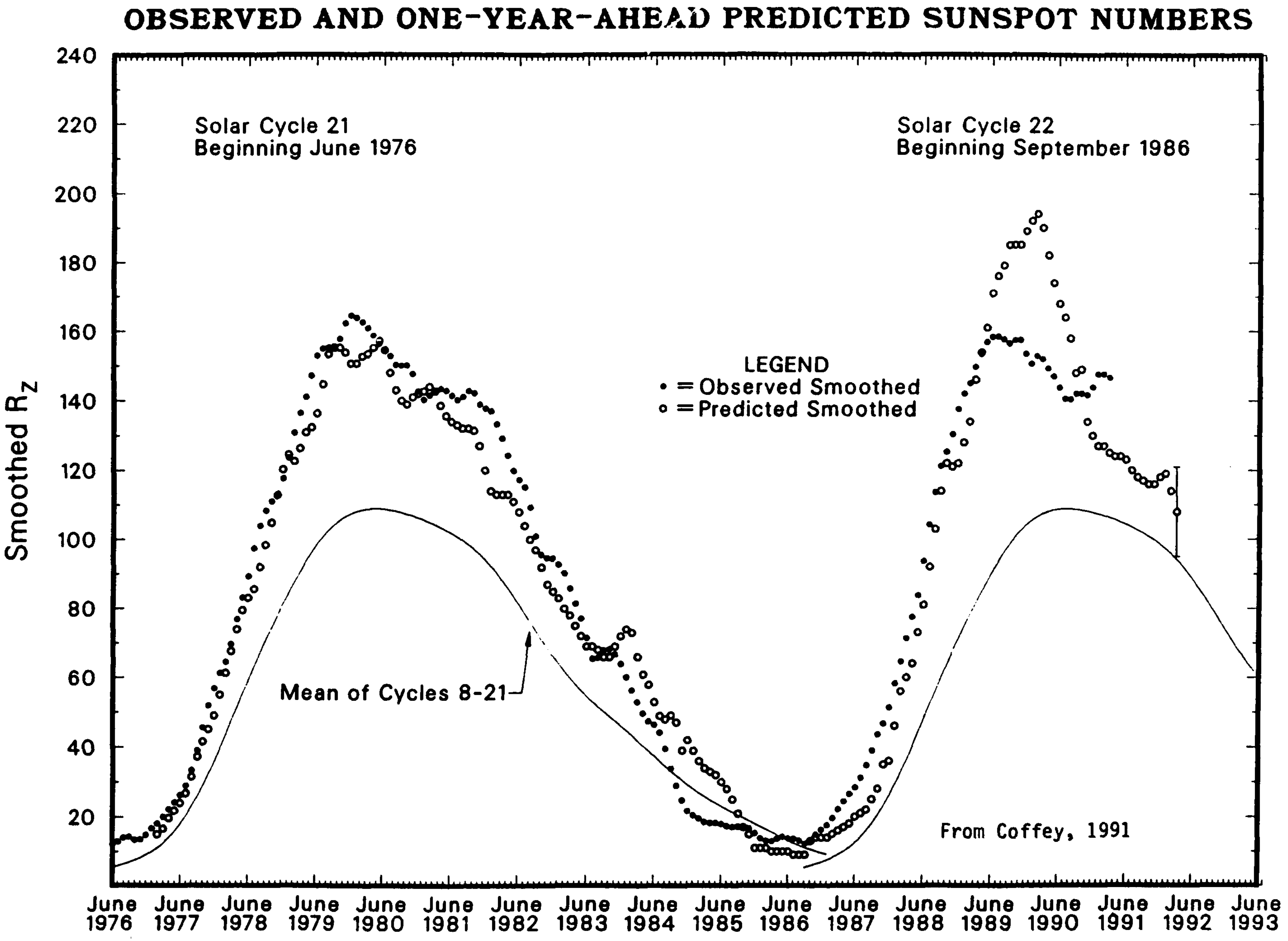


Figure 10. Observed and 1-Year-Ahead Predicted Sunspot Numbers

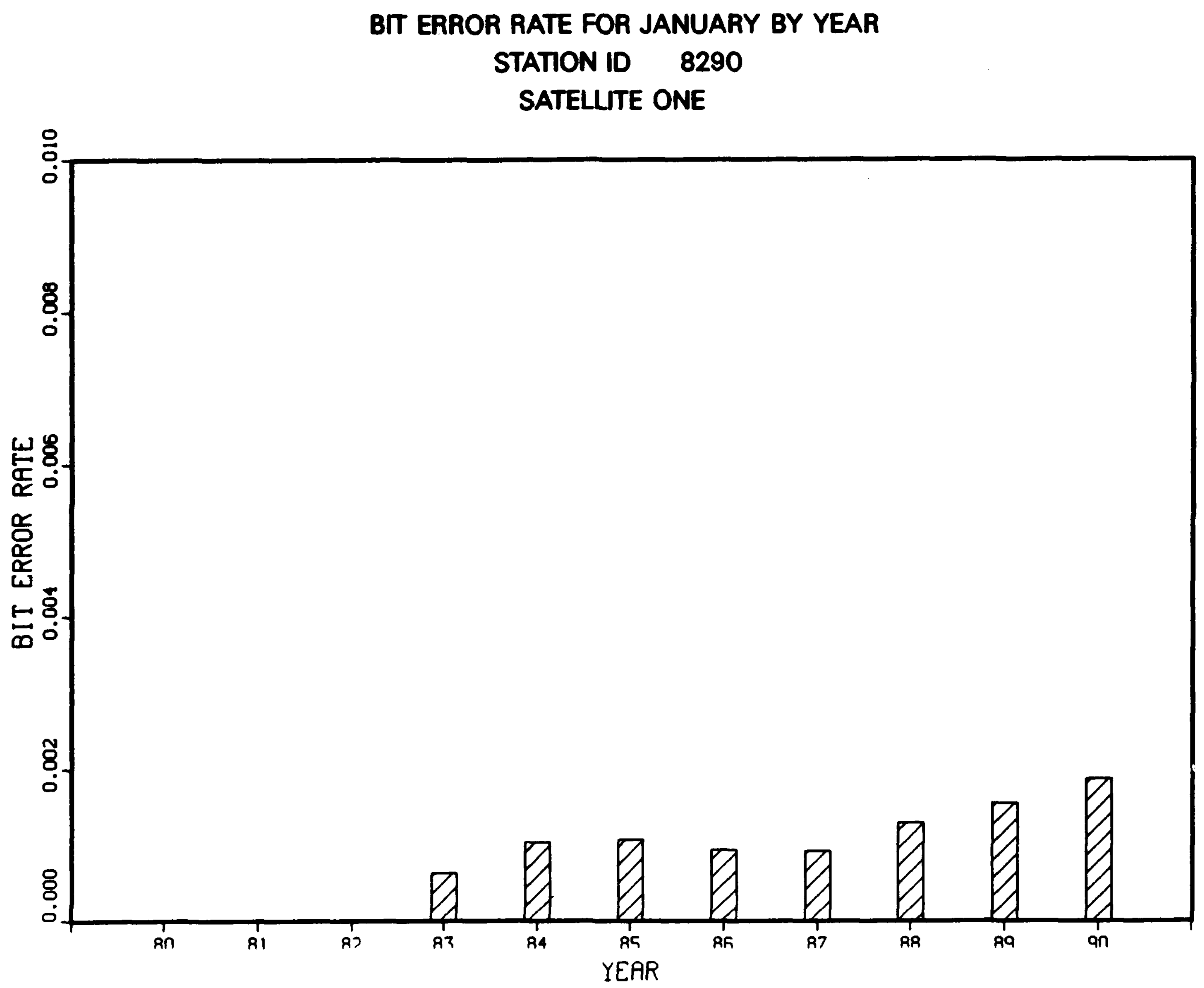


Figure 11. *Yearly Bit-Error-Rate For Mid-Latitude Station*

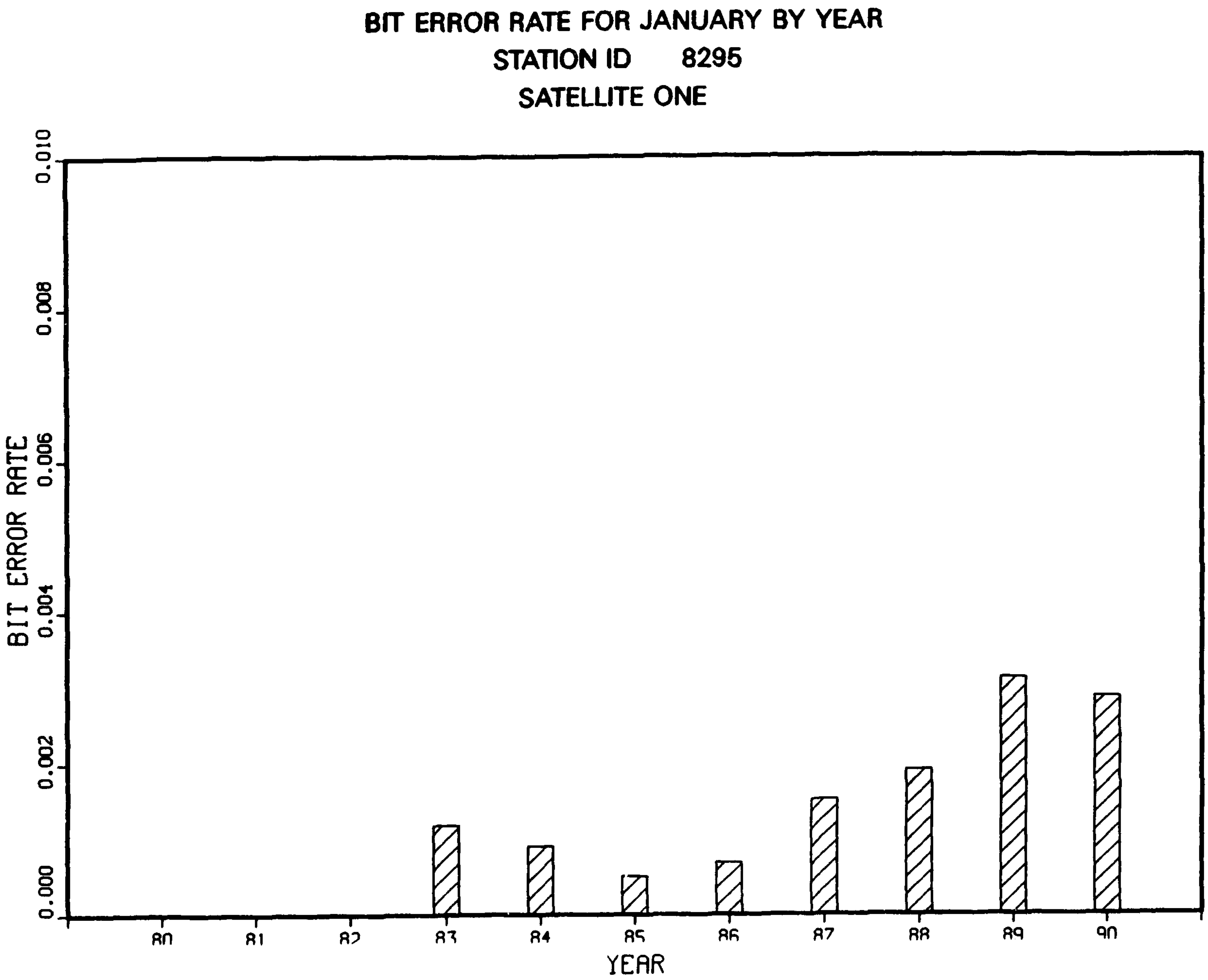


Figure 12. Yearly Bit-Error-Rate For Auroral Station

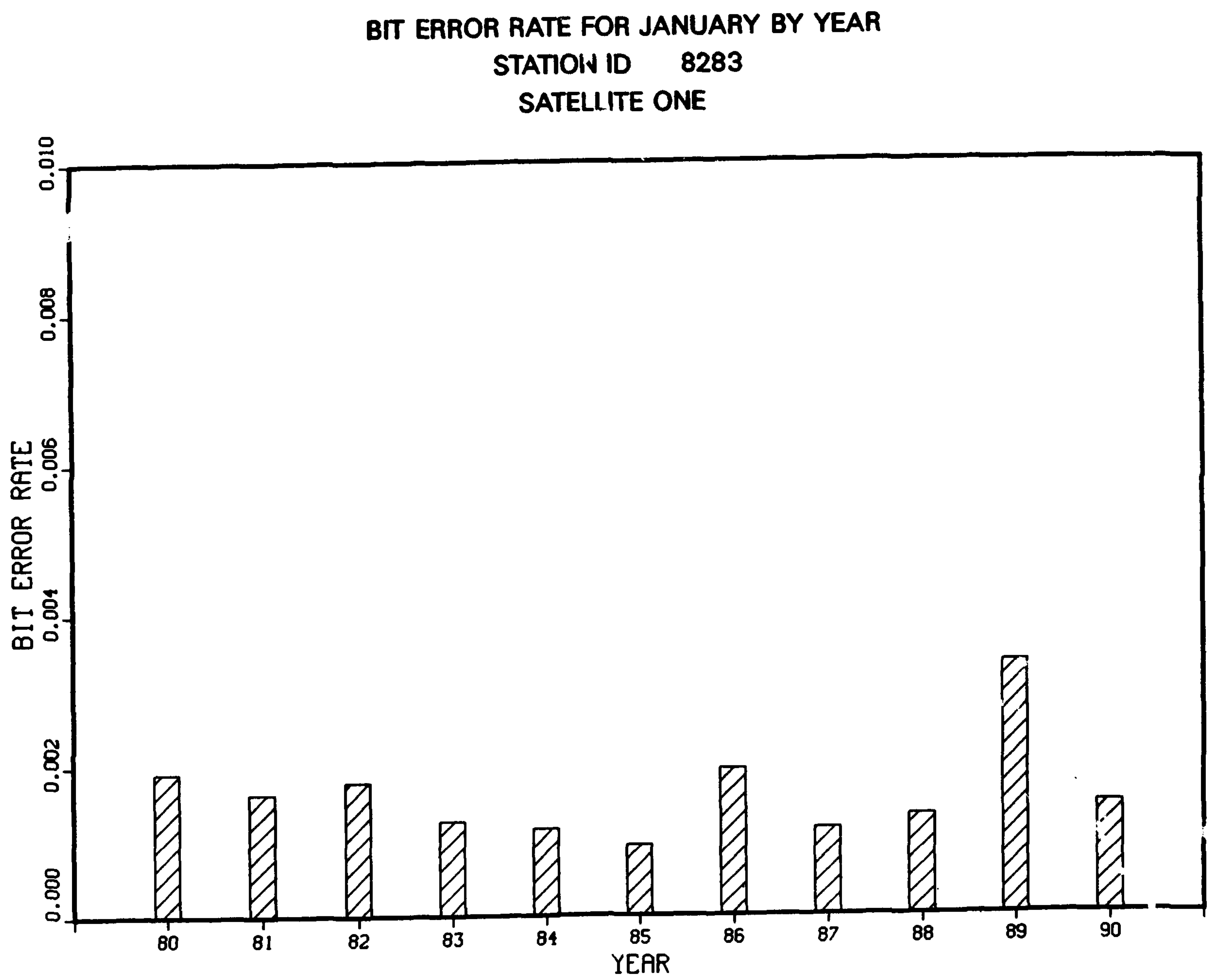


Figure 13. Yearly Bit-Error-Rate For Polar Station

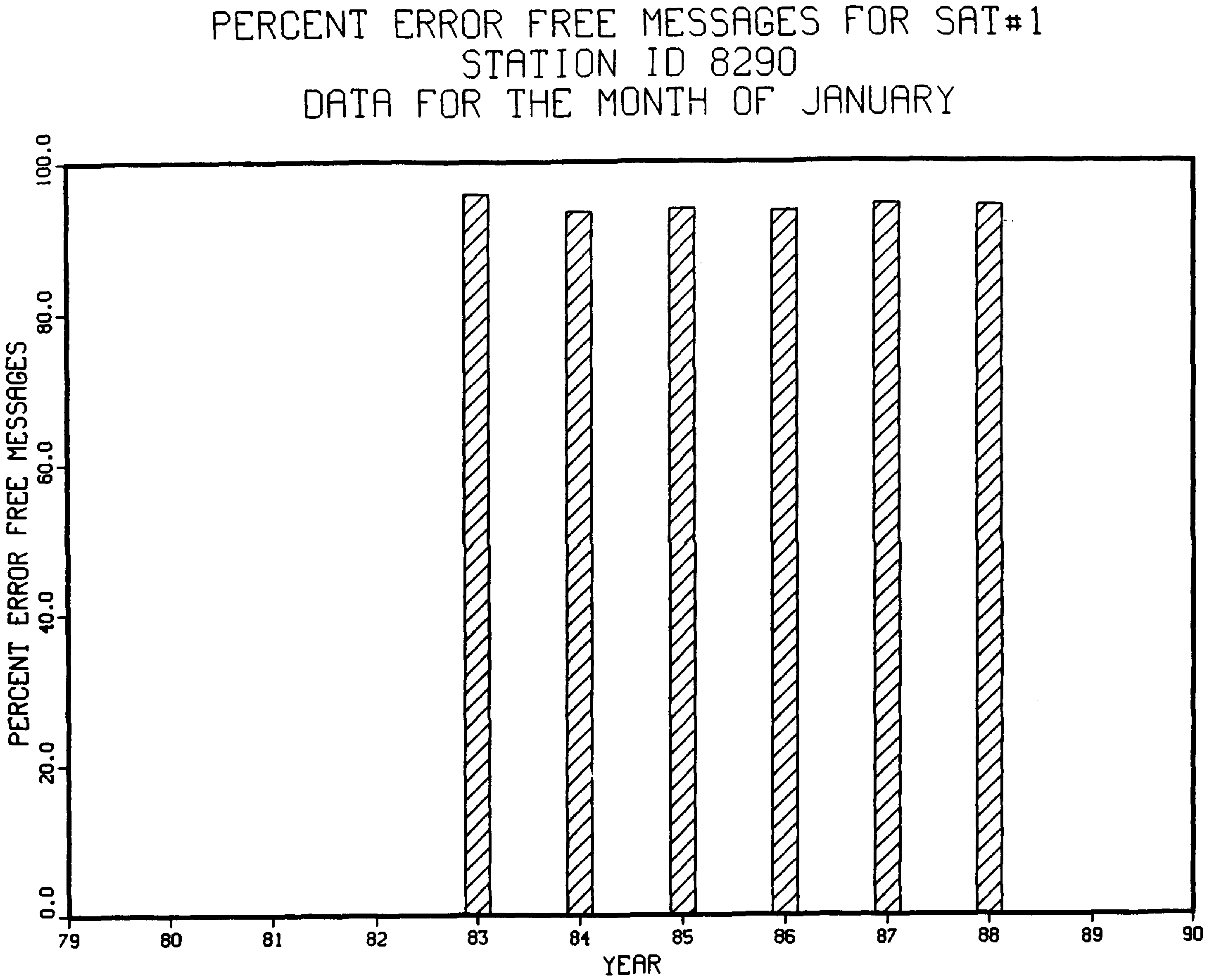


Figure 14. Yearly Percent Error-Free-Messages For Mid-Latitude Station

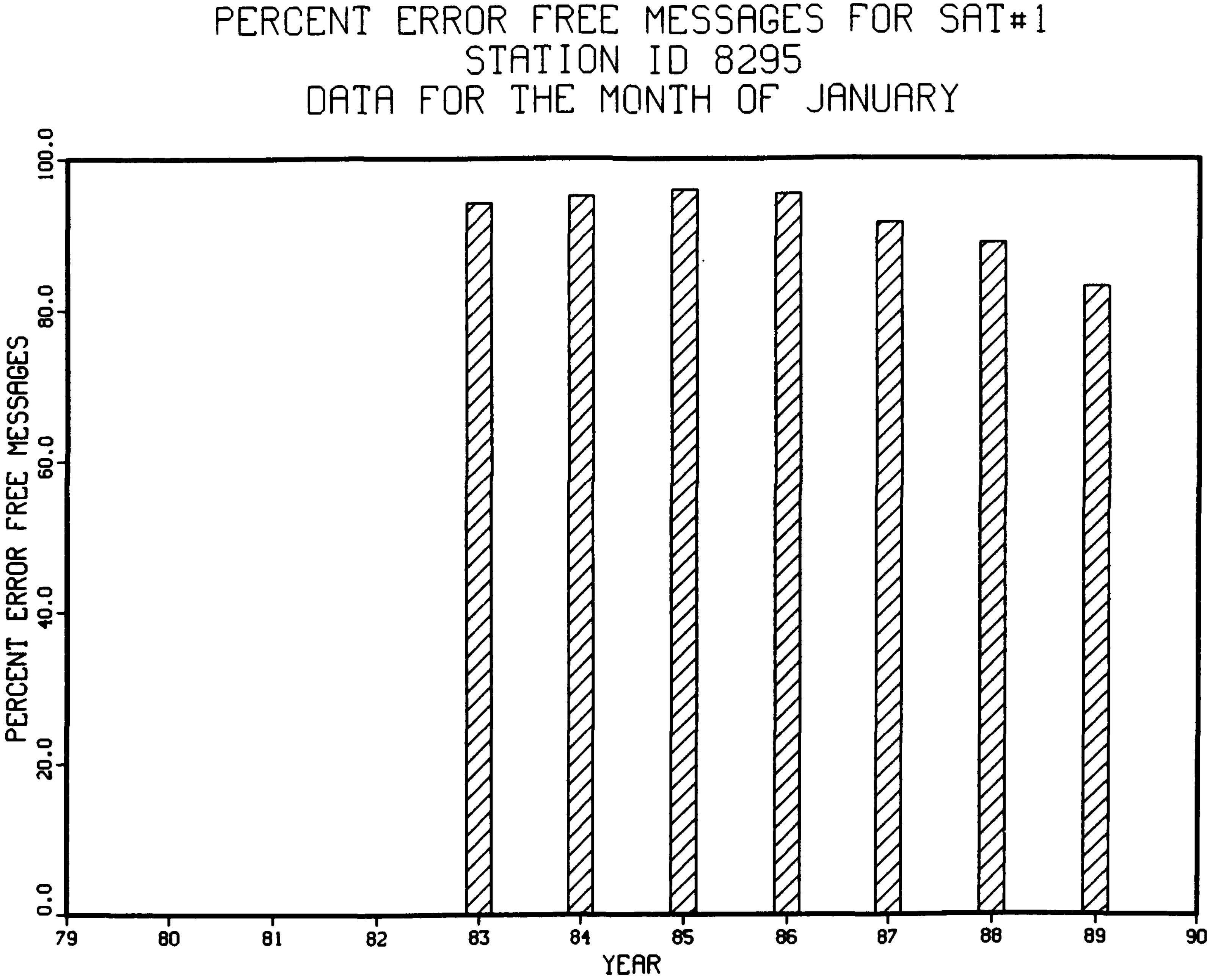


Figure 15. Yearly Percent Error-Free-Messages For Auroral Station

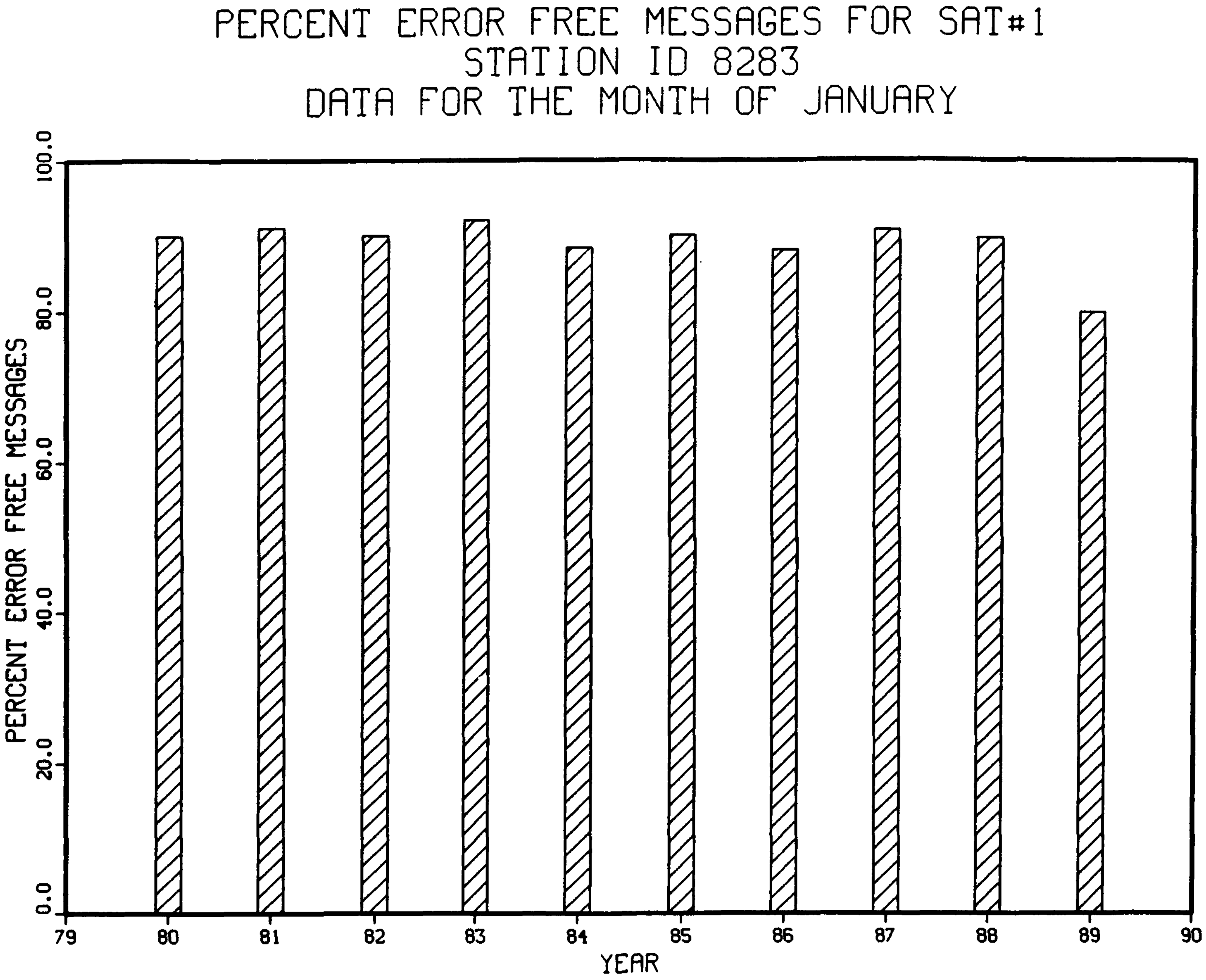


Figure 16. Yearly Percent Error-Free-Messages For Polar Station

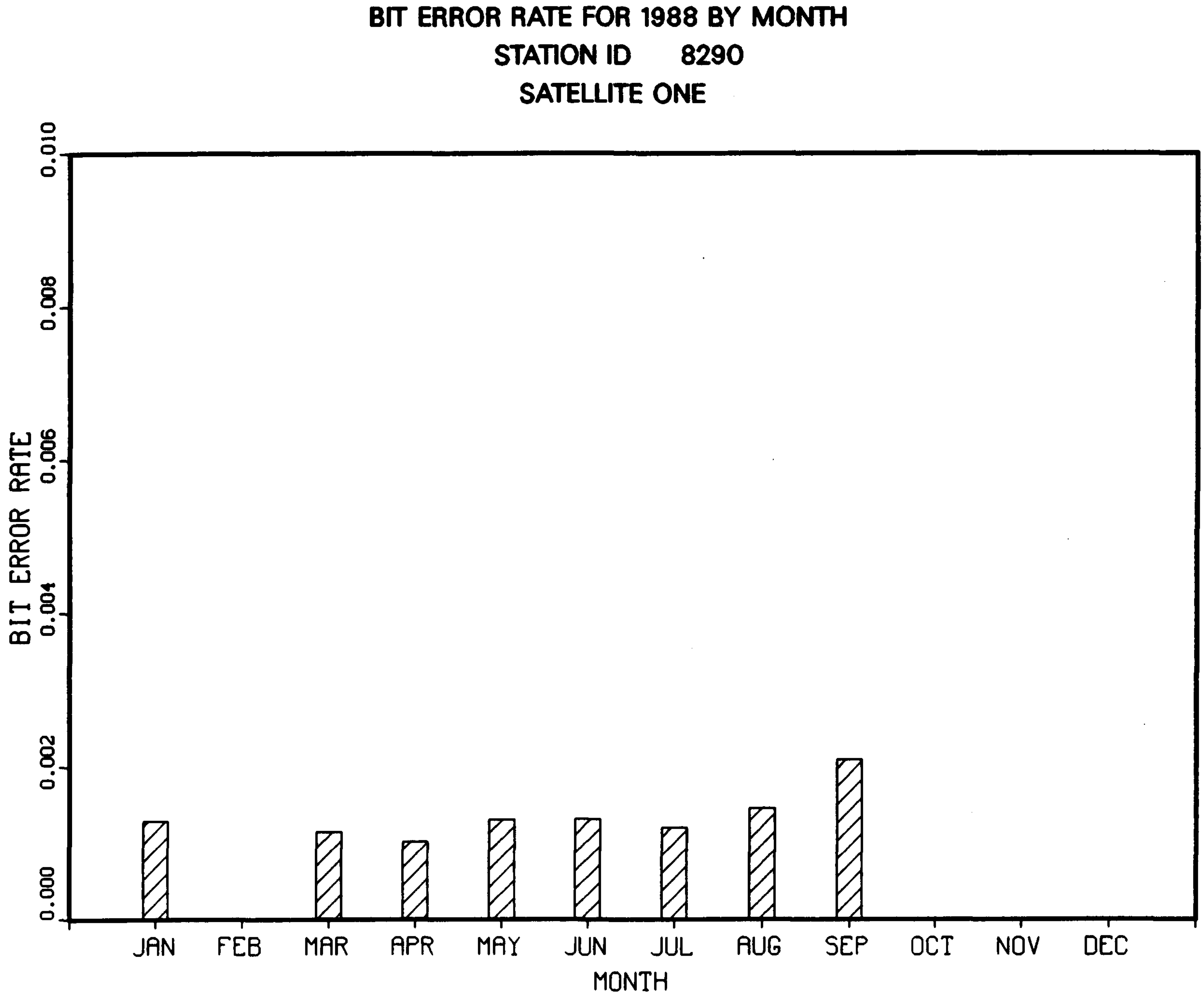


Figure 17. Monthly Bit-Error-Rate For Mid-Latitude Station

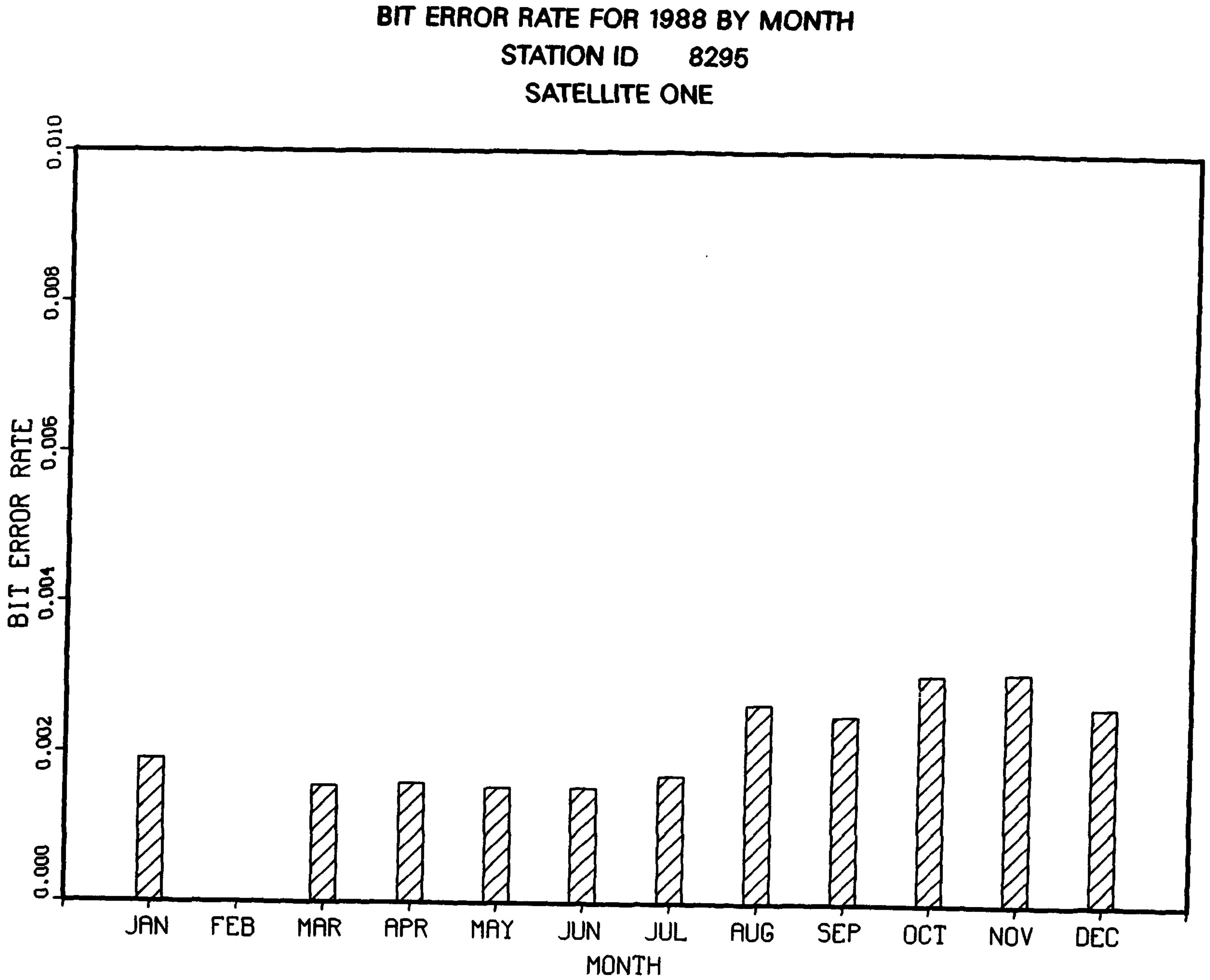


Figure 18. Monthly Bit-Error-Rate For Auroral Station

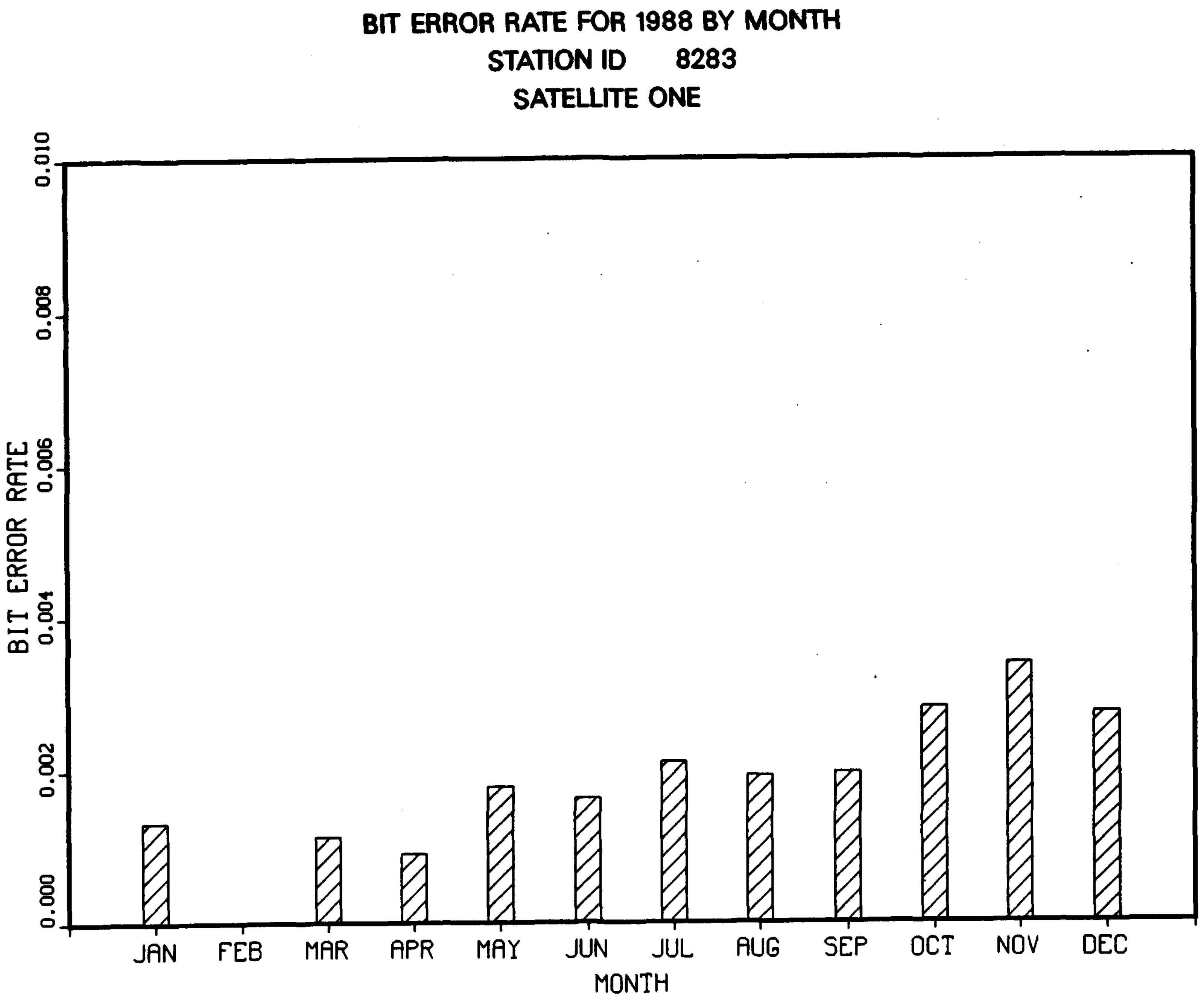


Figure 19. Monthly Bit-Error-Rate For Polar Station

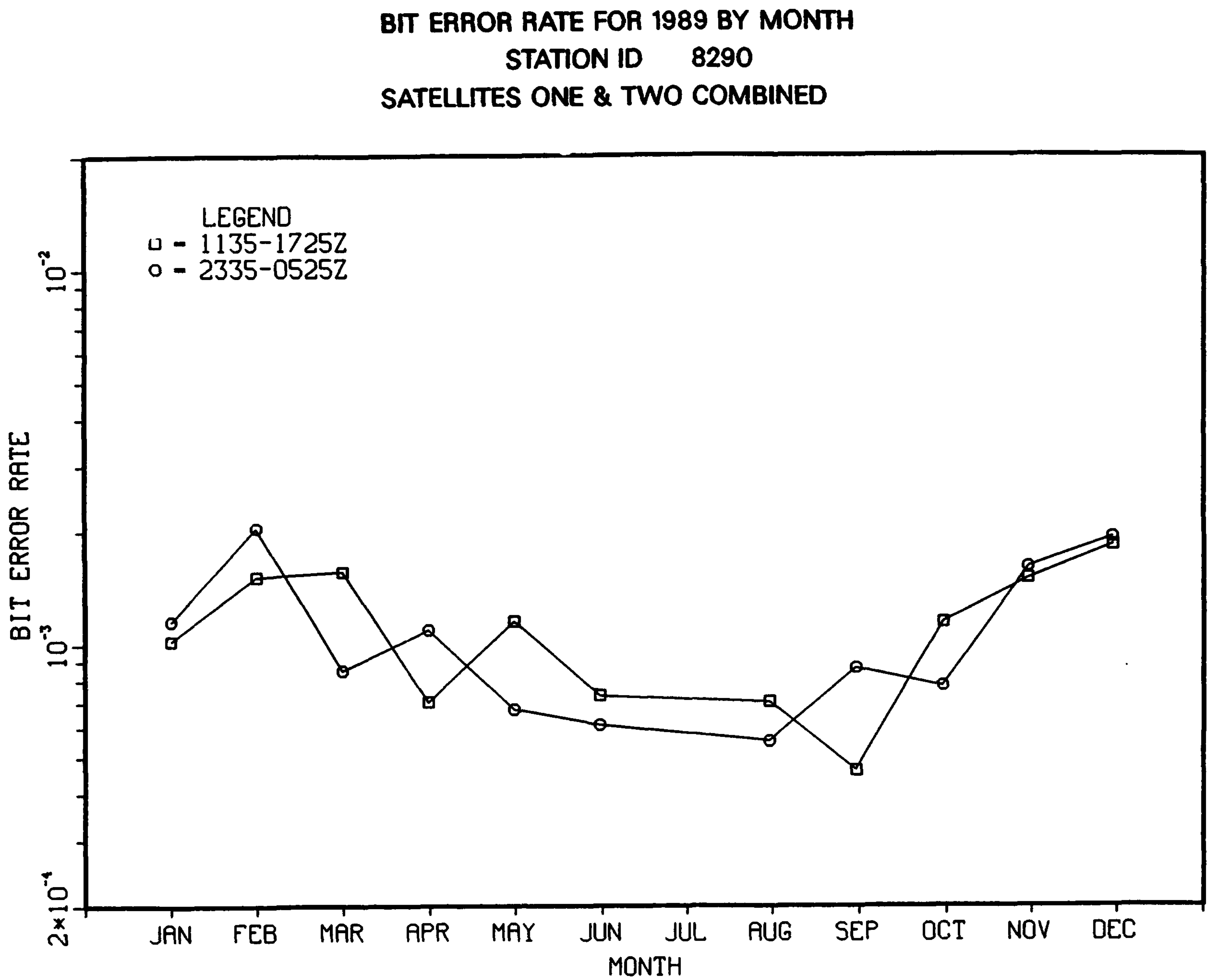


Figure 20. Diurnal Variation of Monthly Bit-Error-Rate For Mid-Latitude Station

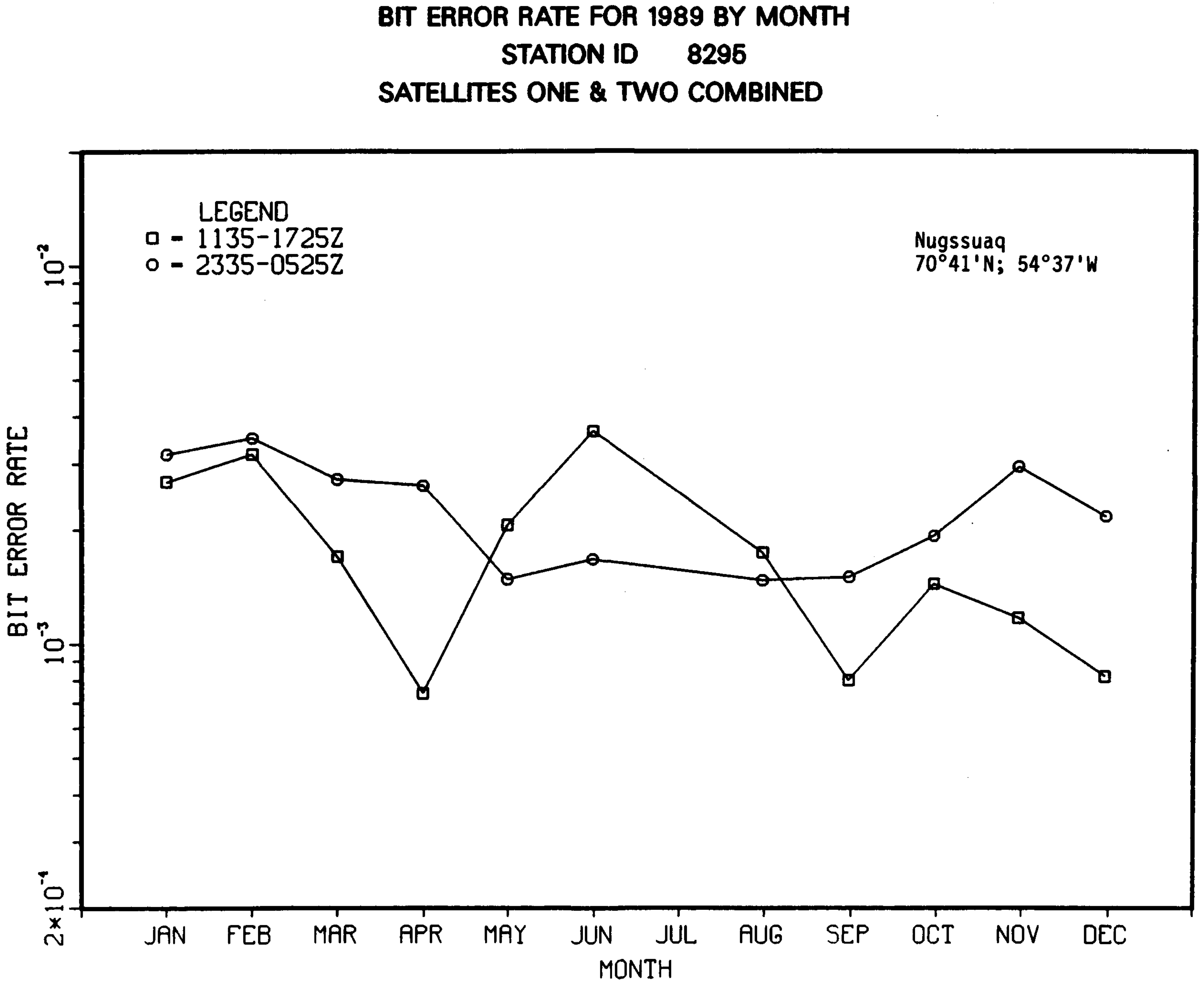


Figure 21. Diurnal Variation of Monthly Bit-Error-Rate For Auroral Station

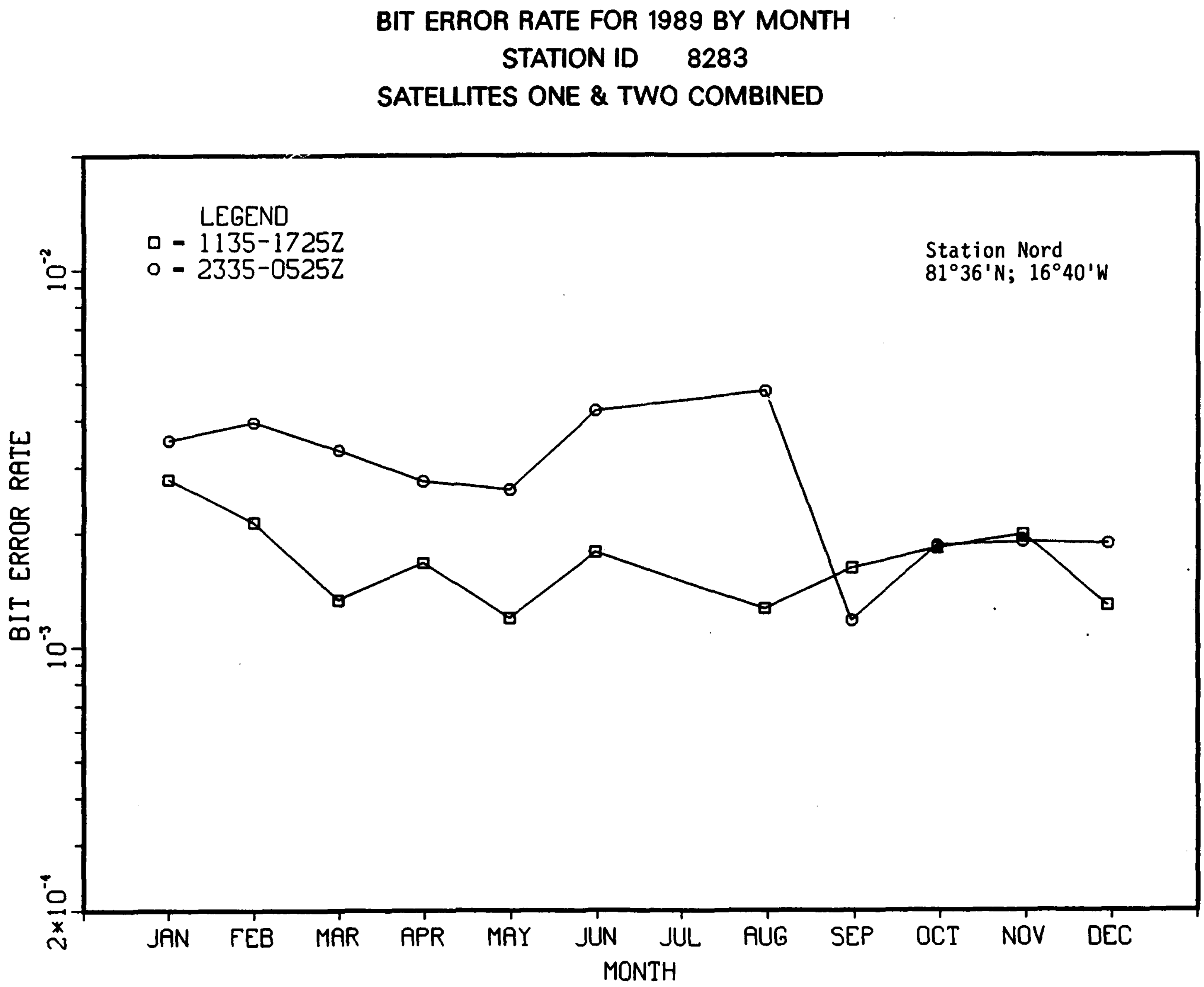


Figure 22. Diurnal Variation of Monthly Bit-Error-Rate For Polar Station

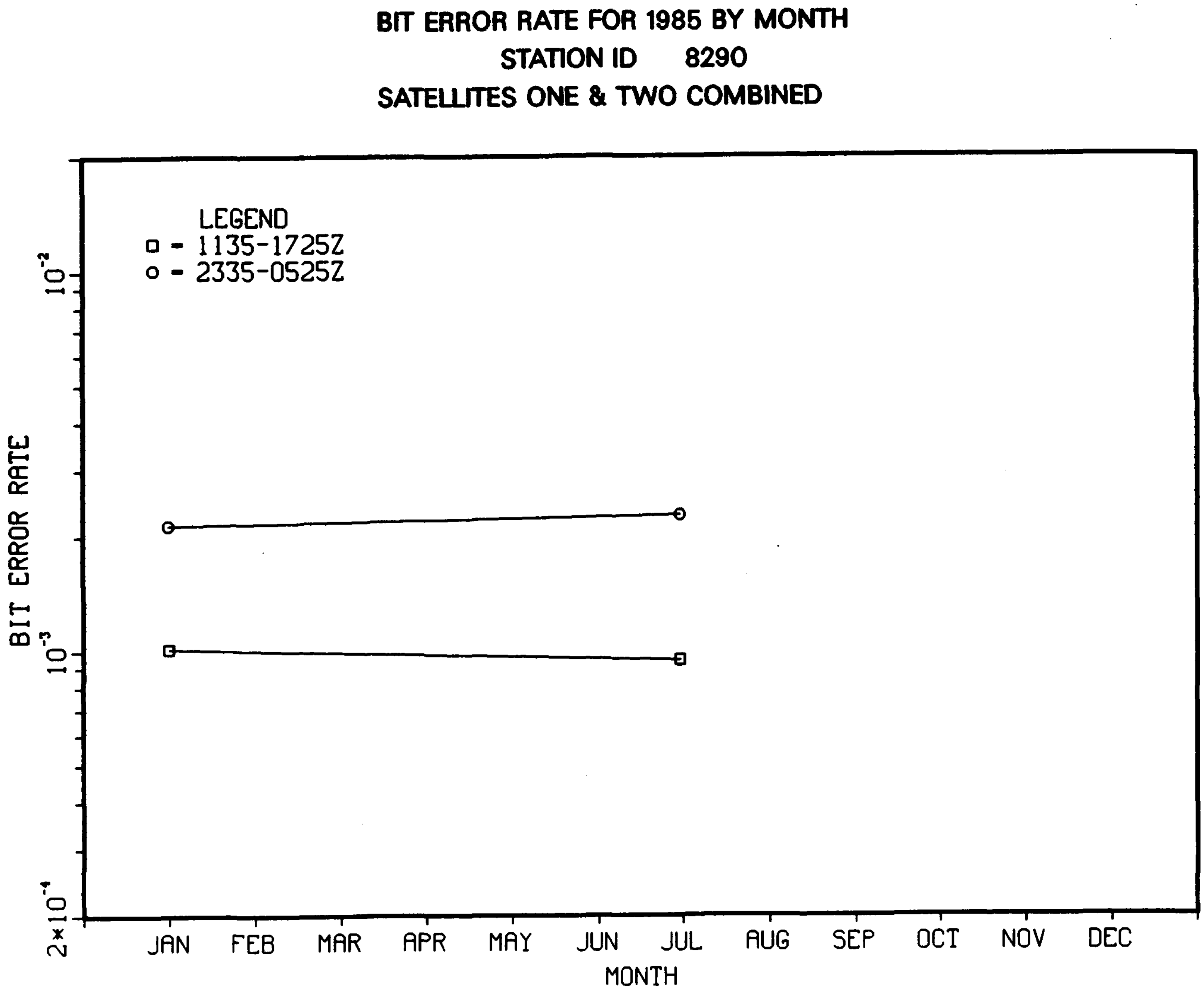


Figure 23. Diurnal Variation of Monthly Bit-Error-Rate For Mid-Latitude Station - Solar Minimum

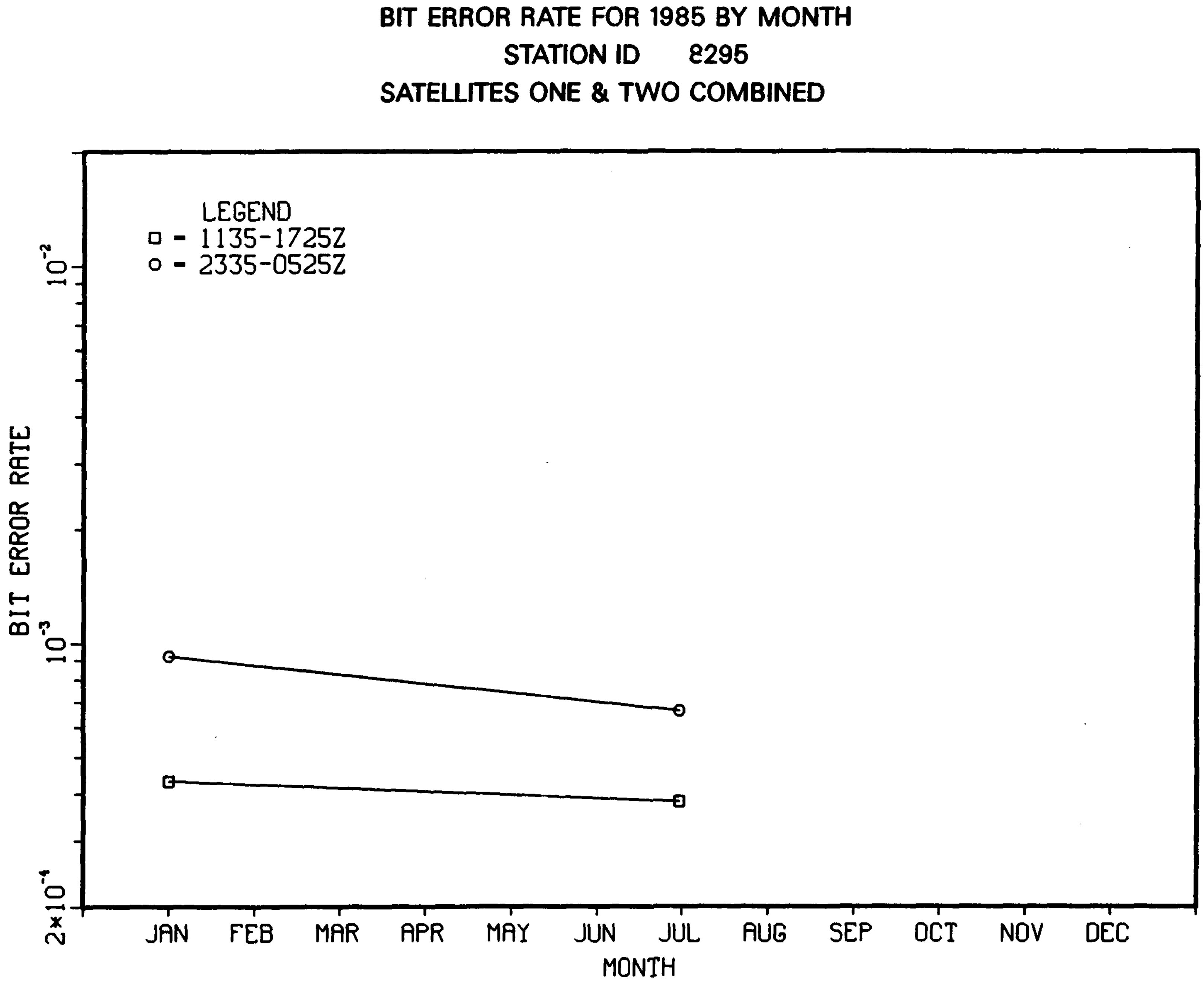


Figure 24. Diurnal Variation of Monthly Bit-Error-Rate For Auroral Station - Solar Minimum

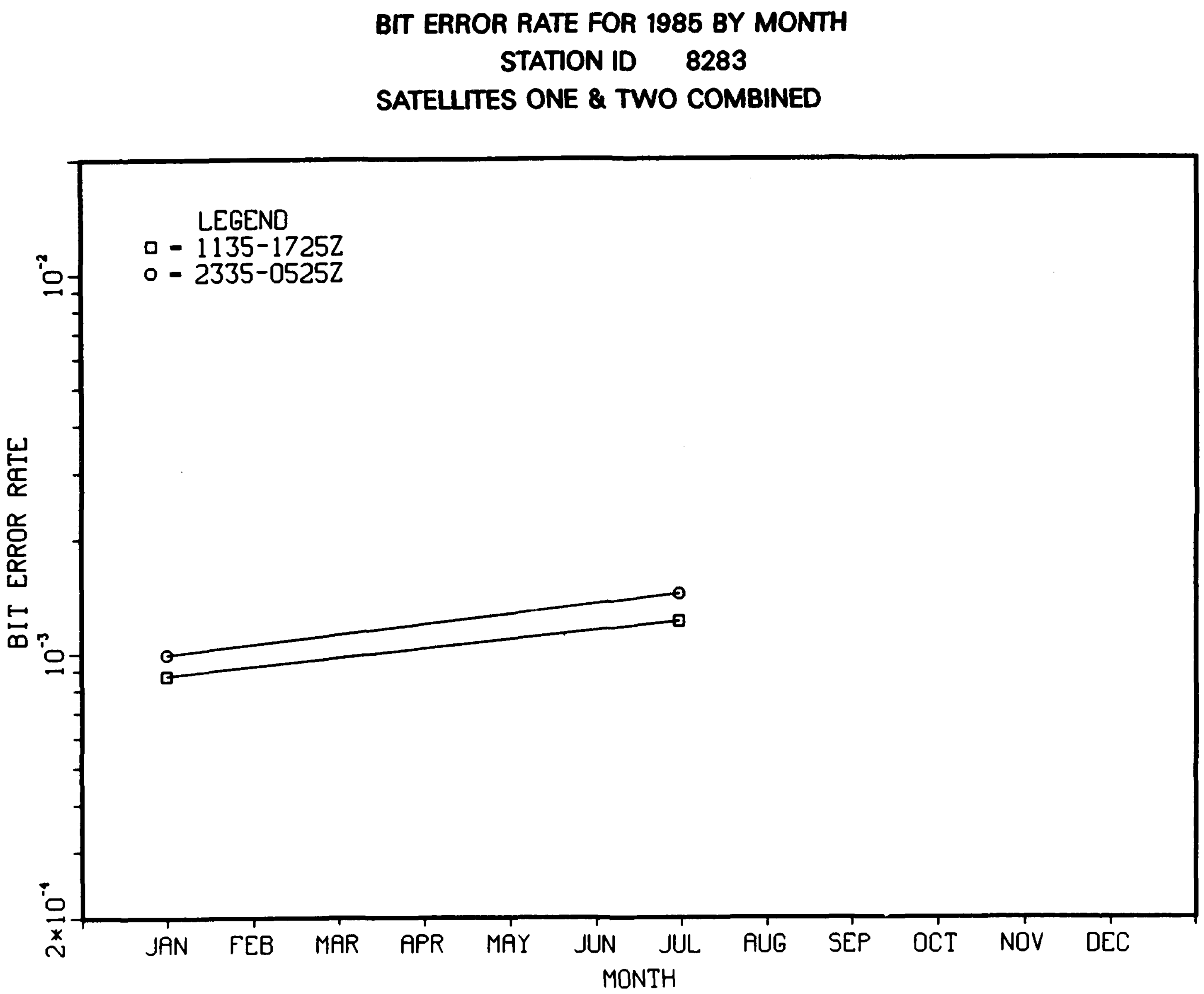


Figure 25. Diurnal Variation of Monthly Bit-Error-Rate For Polar Station - Solar Minimum

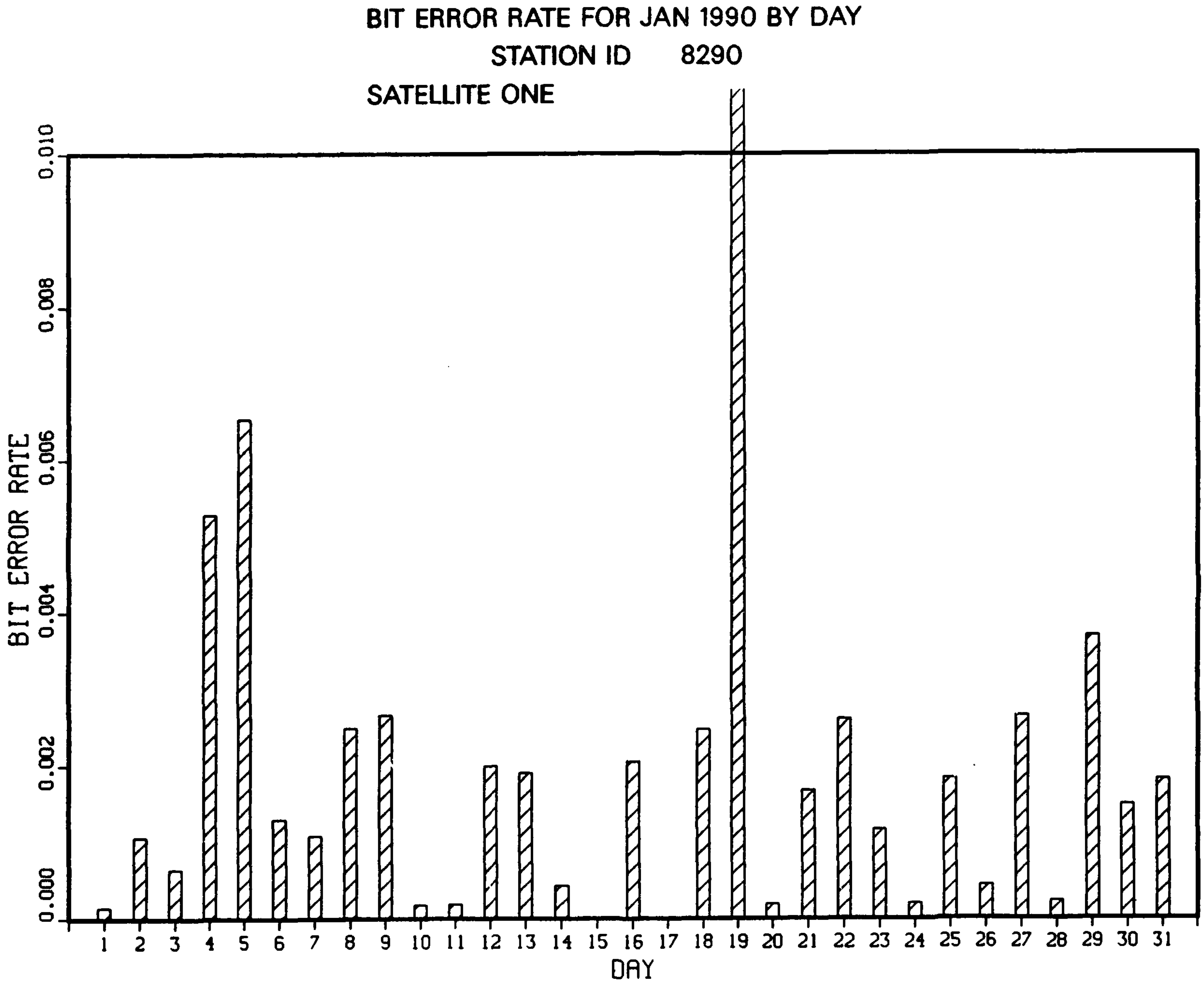


Figure 26. Daily Bit-Error-Rate For Mid-Latitude Station

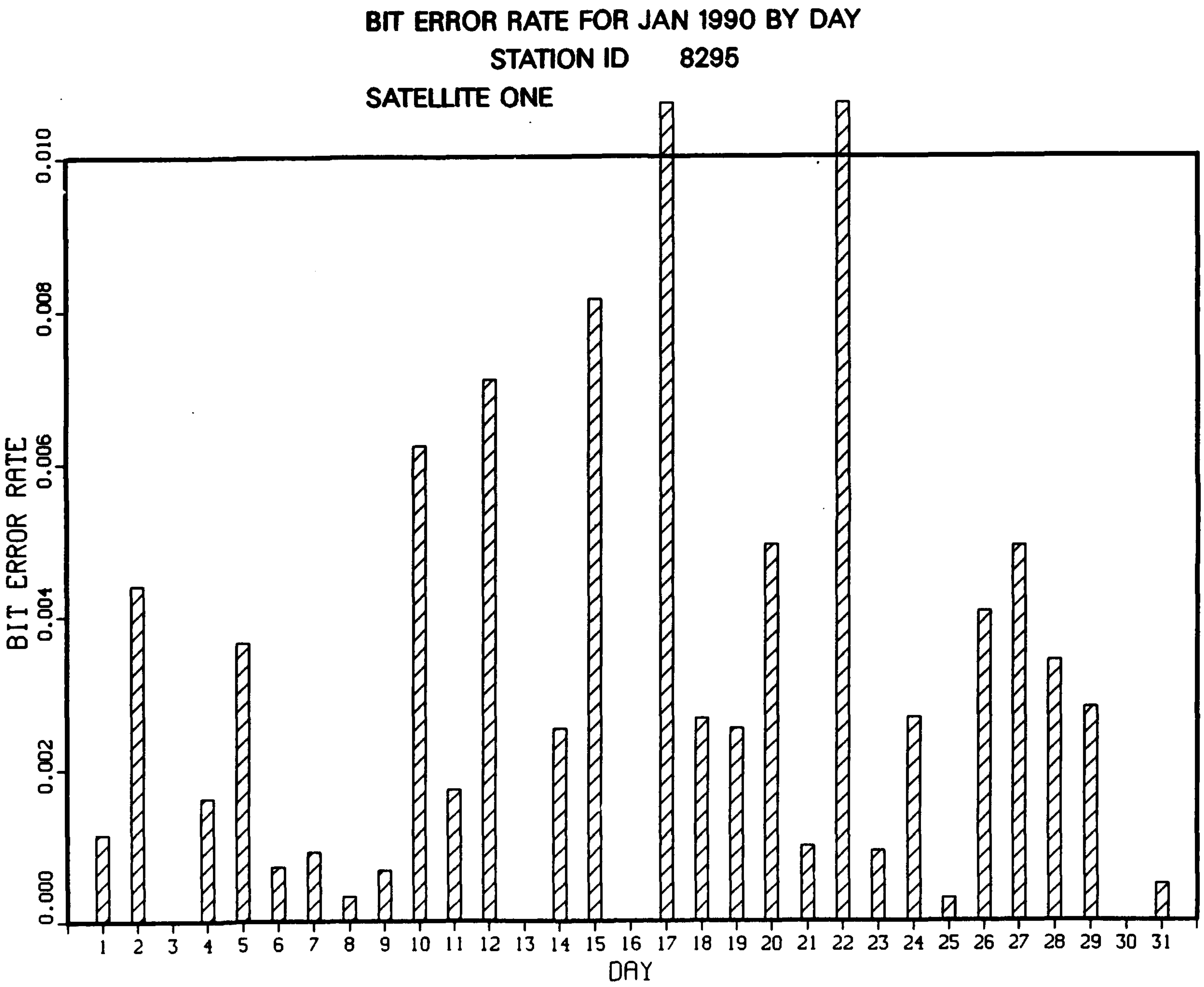


Figure 27. Daily Bit-Error-Rate For Auroral Station

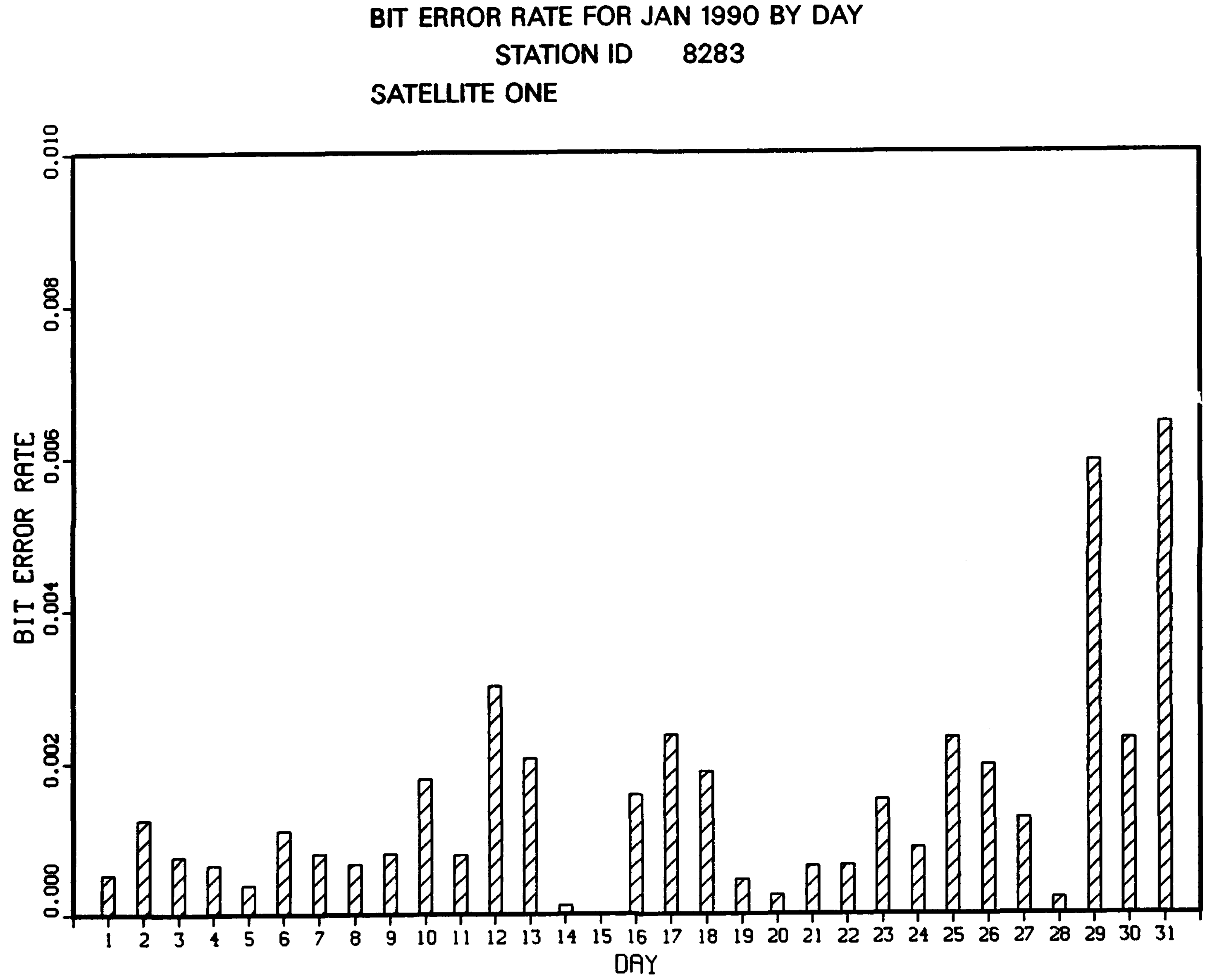


Figure 28. Daily Bit-Error-Rate for Polar Station

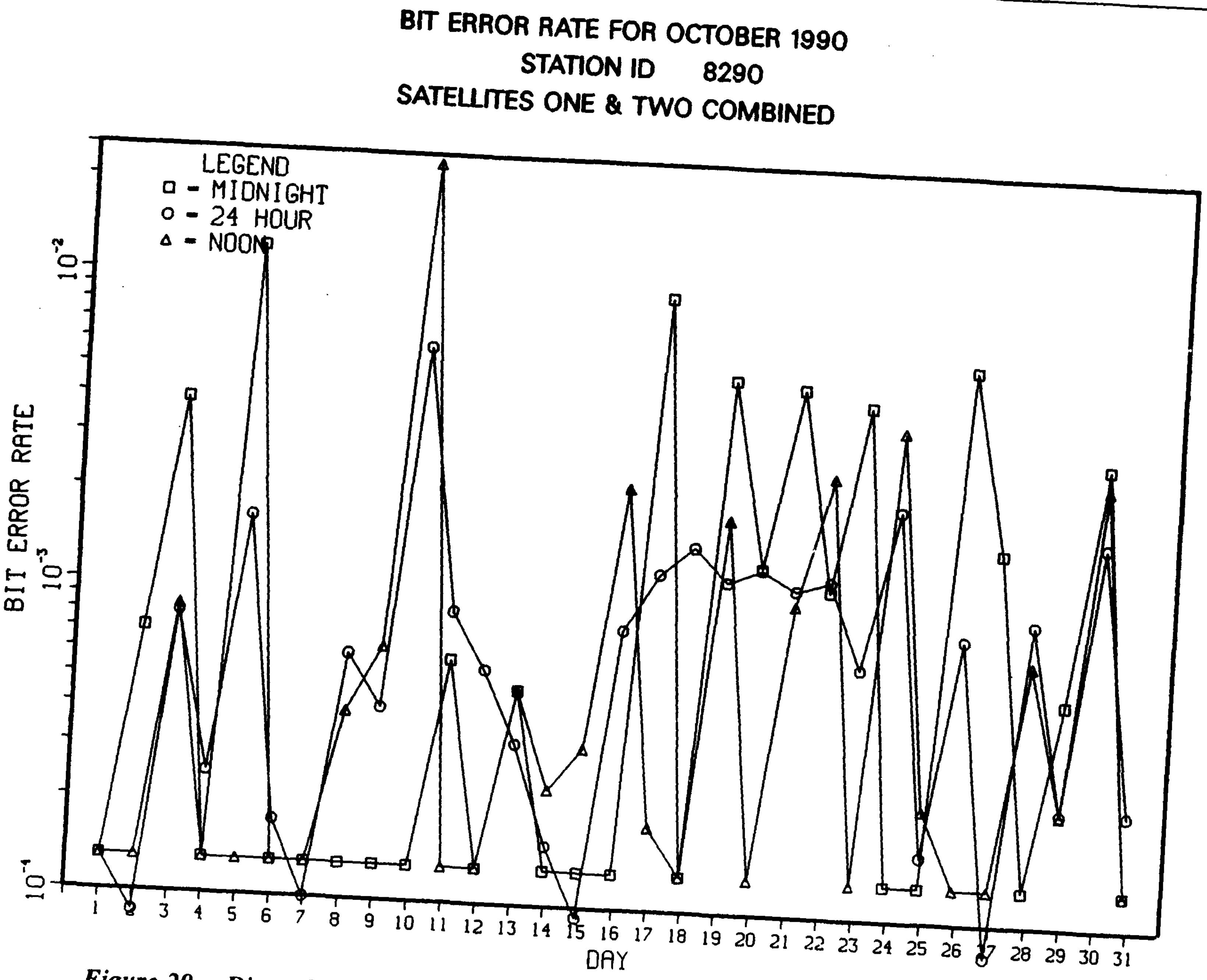


Figure 29. Diurnal Variation of Daily Bit-Error-Rate For Mid-Latitude Station

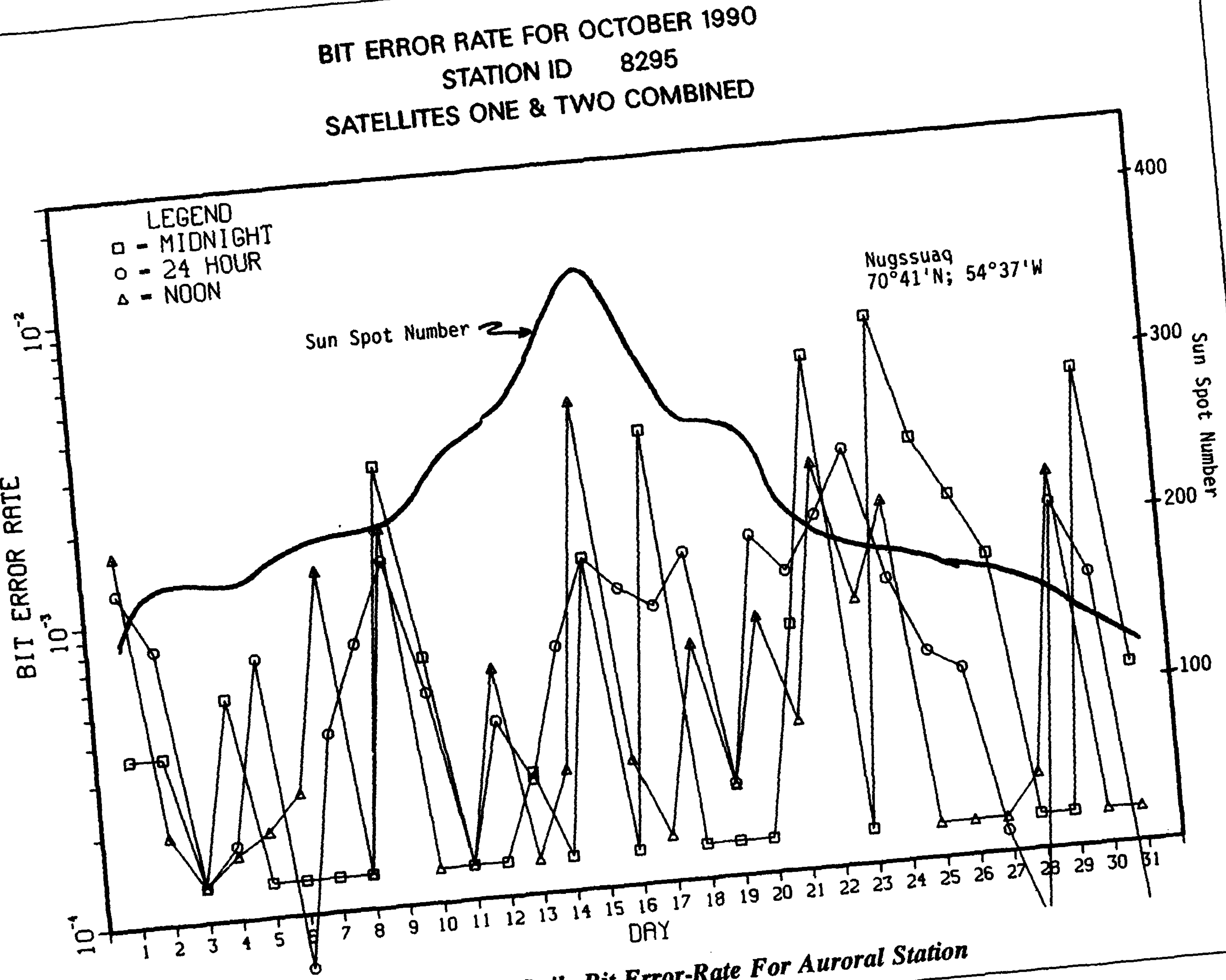


Figure 30. ***Diurnal Variation of Daily Bit-Error-Rate For Auroral Station***

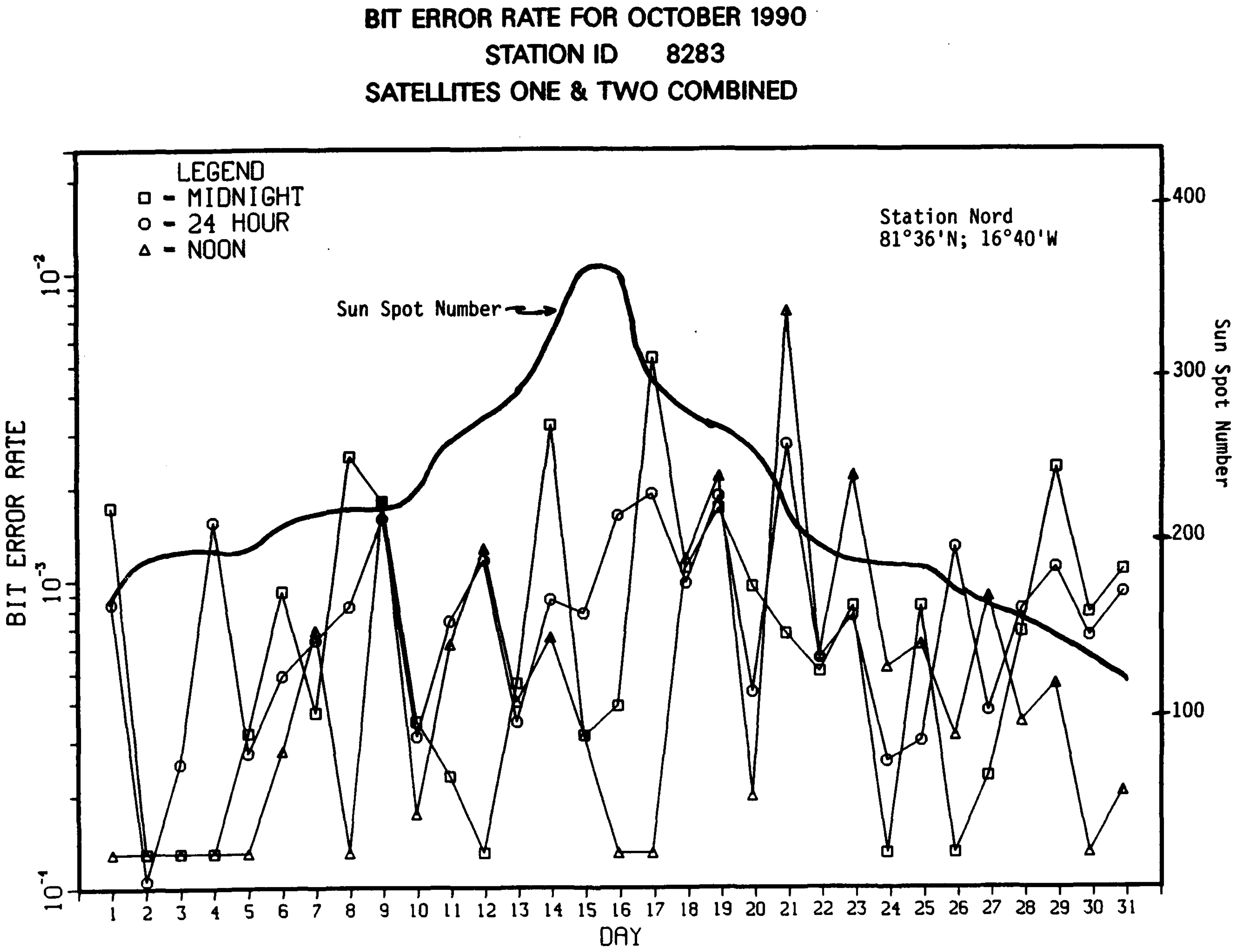


Figure 31. Diurnal Variation of Daily Bit-Error-Rate For Polar Station

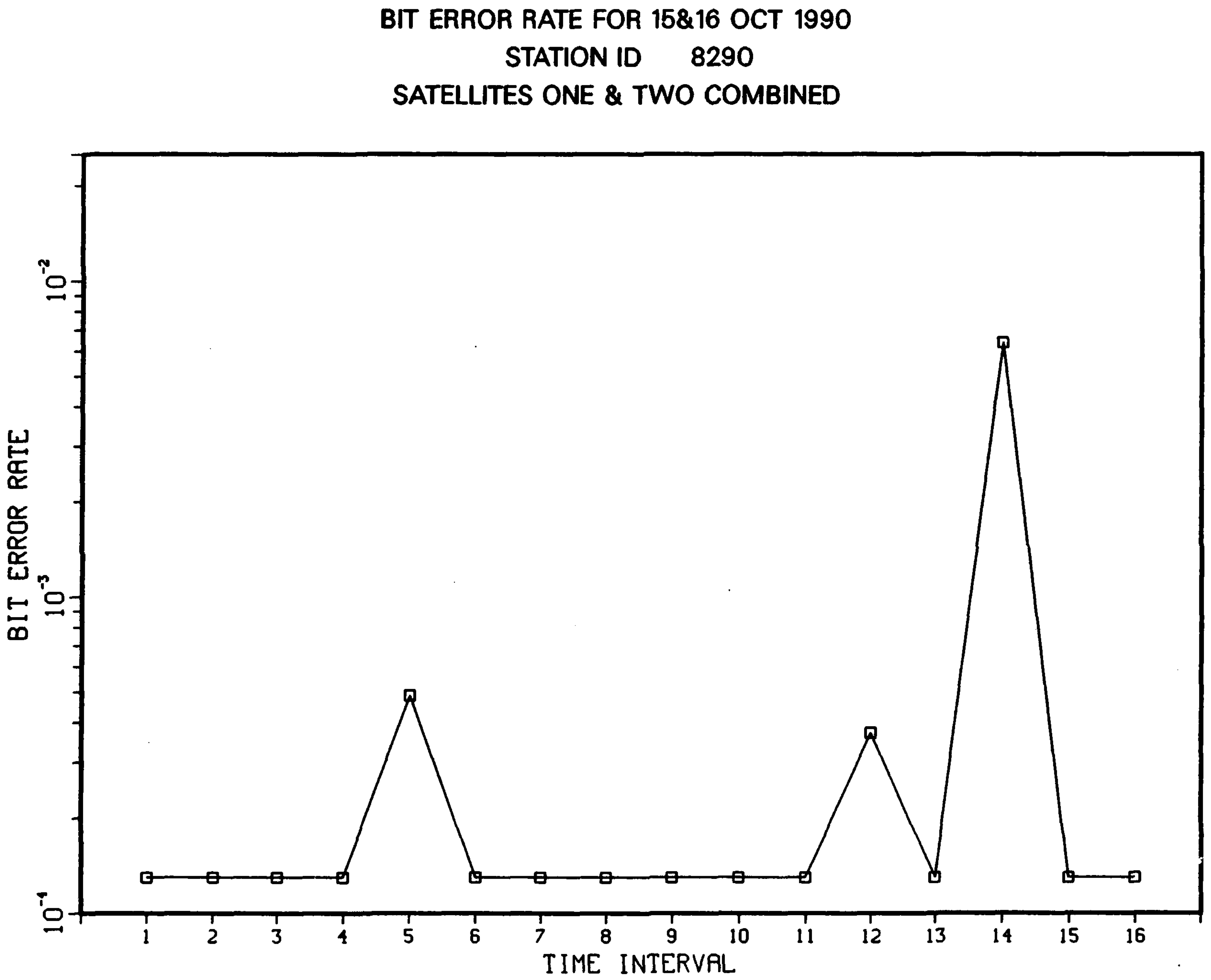


Figure 32. Hourly Bit-Error-Rate For Mid-Latitude Station

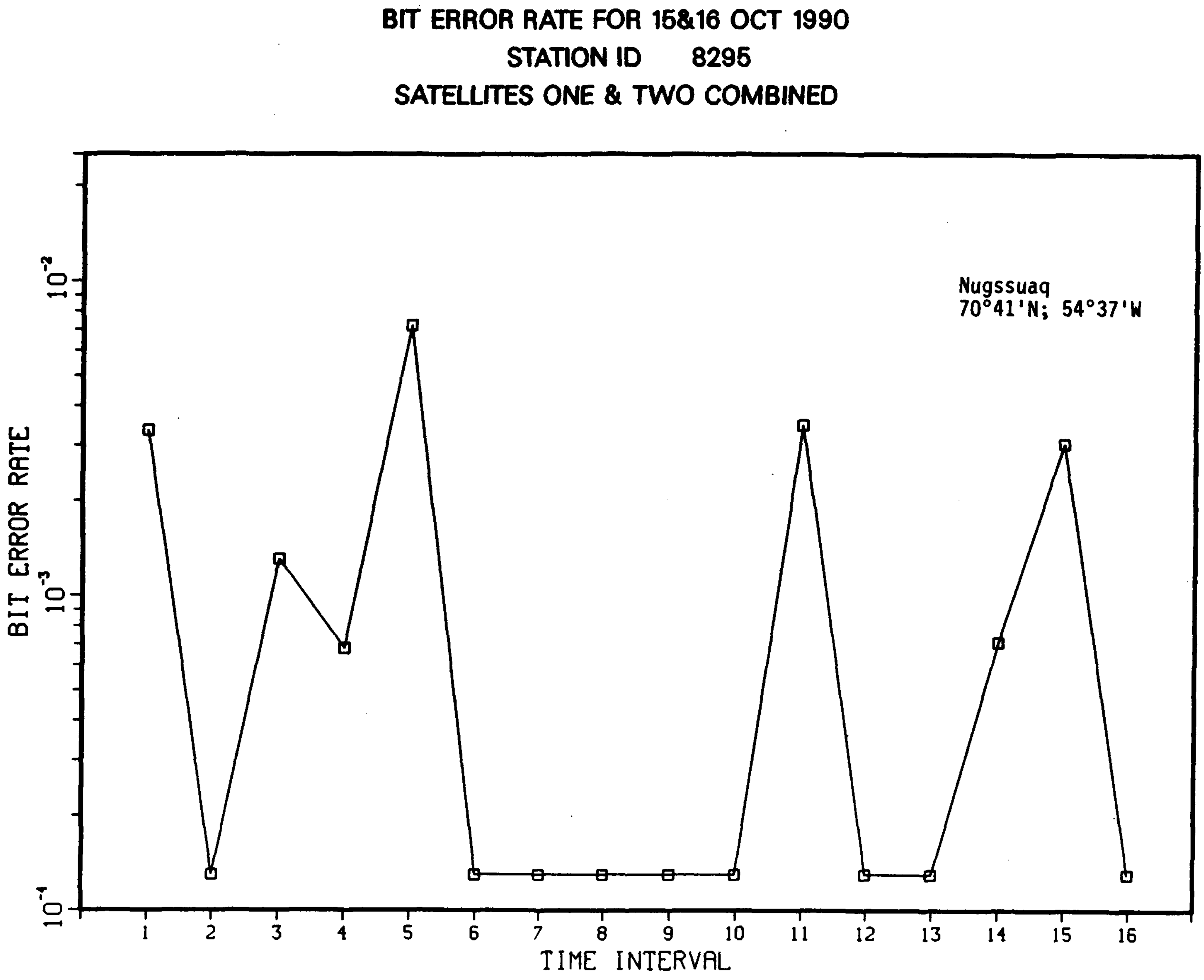
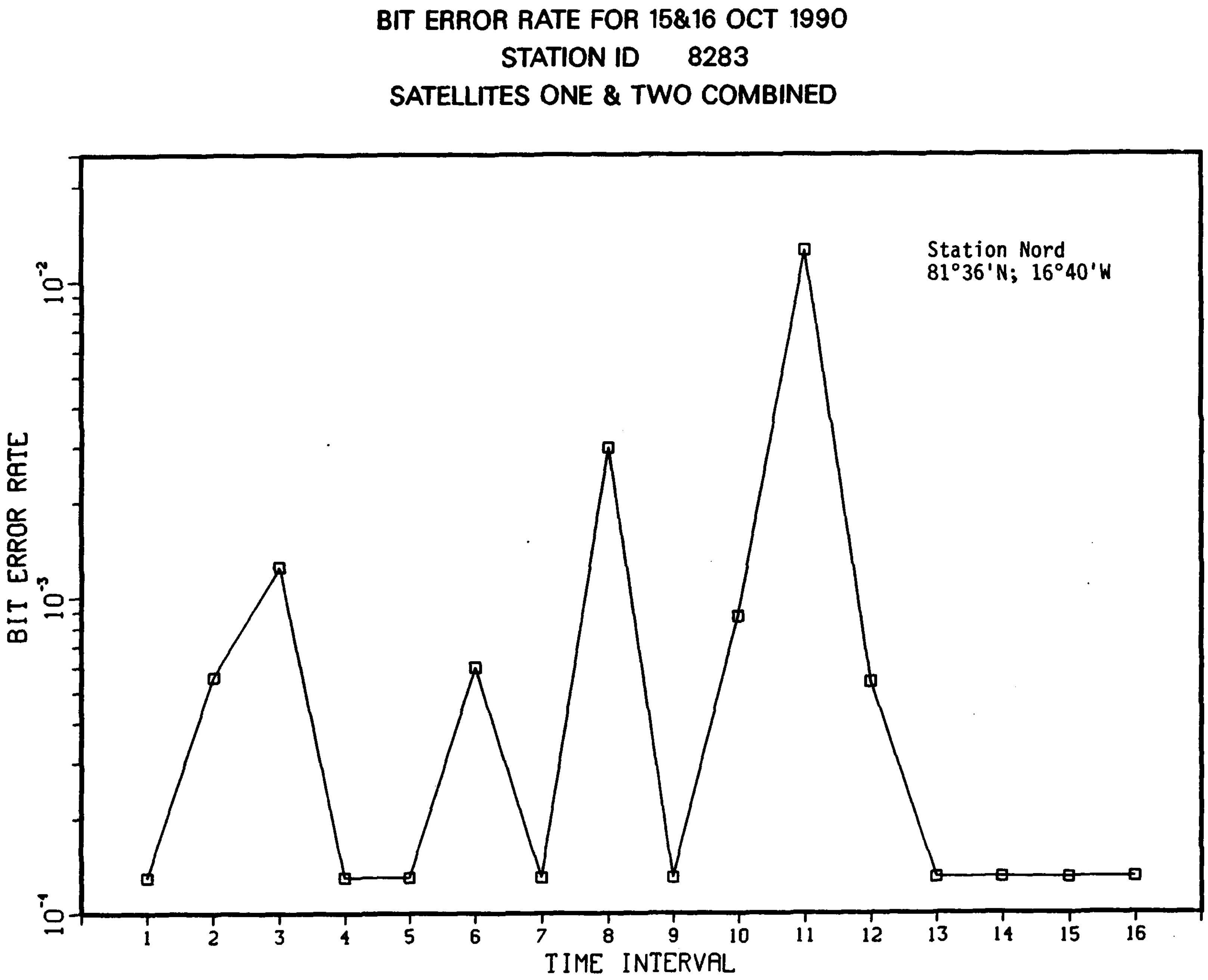


Figure 33. Hourly Bit-Error-Rate For Auroral Station



BIT ERROR RATE FOR 15&16 OCT 1990
STATION ID 8283
SATELLITES ONE & TWO COMBINED

Figure 34. Hourly Bit-Error-Rate For Polar Station

meteorological satellite uplink from Agto are shown in Figure 35. The correlation of the data from the two satellites is surprisingly good. The complete daily bit-error-rate data are presented in Appendices G, H, and I.

BIT ERROR RATE FOR 15&16 OCT 1990
STATION ID 8296
SATELLITES ONE & TWO COMBINED

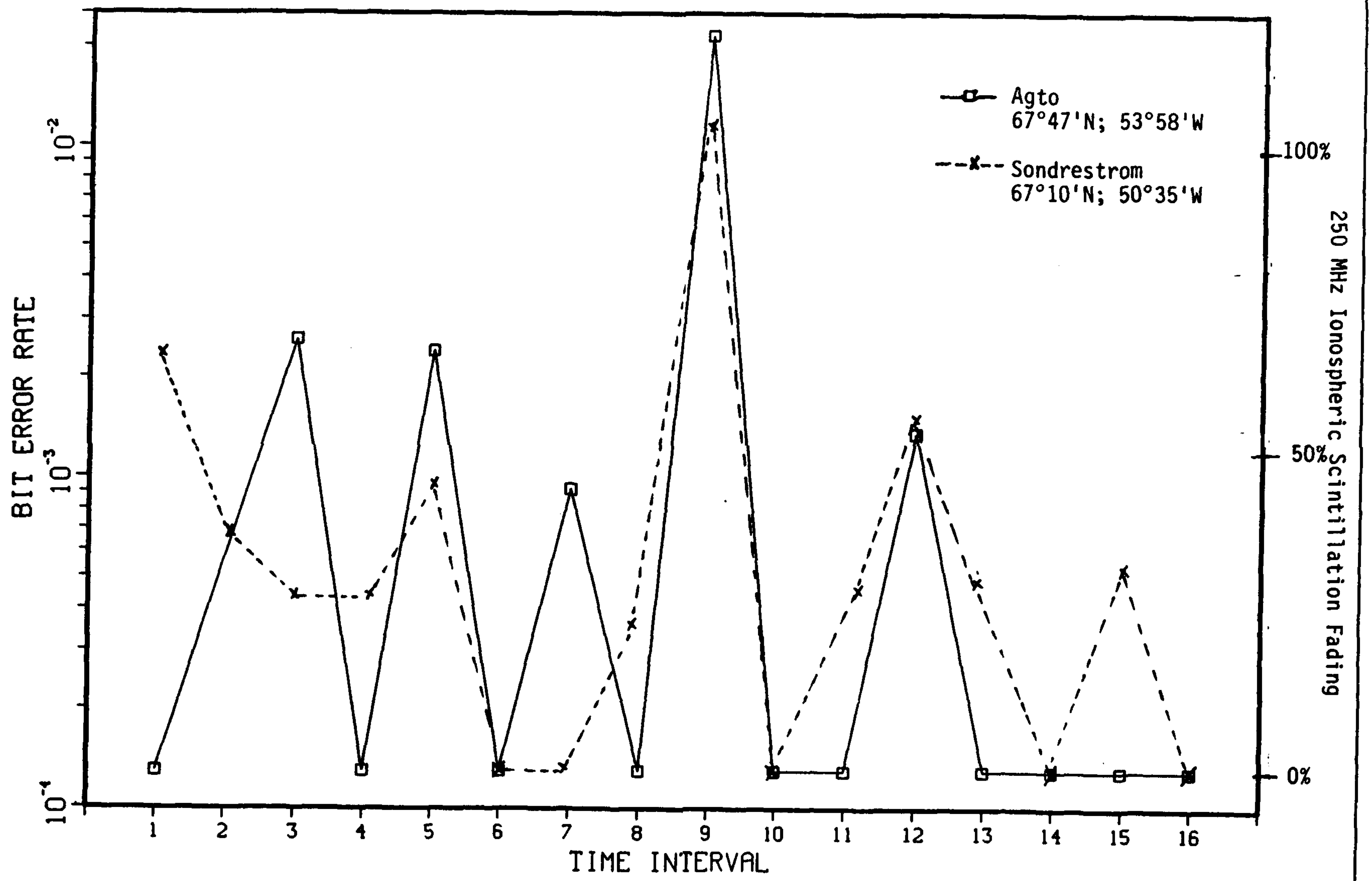


Figure 35. Comparison of Hourly Bit-Error-Rate At Agto and Fading At Sondrestrom

SECTION 6
CONCLUSIONS

The analysis of the Danish Meteorological Institute data collected through the Argos System has provided ionospheric scintillation fading data from a geographically diverse area over an extended time period at a reasonable cost. This technique could be expanded to provide world-wide information on ionospheric irregularities.

The collection of 11 years of ionospheric scintillation fading information from 20 sub-auroral, auroral, and polar stations around Greenland provides an enormous data base for future analysis. Various hypotheses concerning ionospheric scintillation fading could be tested against the data base. Investigators interested in using the Greenland data base should contact the author.

BIBLIOGRAPHY

Aarons, J., J. Mullin, H.E. Whitney, A.L. Johnson, and E.J. Weber, "UHF Scintillation Activity over Polar Latitudes," Geophysical Research Letters, Vol 8, No. 3, pp 277-280, March 1981.

Argos, "Location and Data Collection Satellite System," Users Guide, Service Argos, Suitland MD, May 1984.

Coffey, H.E. (Editor), "Solar-Geophysical Data," Prompt Report Number 566, Part 1, National Oceanic and Atmospheric Adm, Boulder CO, October 1991.

Jensen, F., "Application of the Argos Data Collection System for Automatic Meteorological Observations in Arctic Regions," Argos User's Conference, Quebec City Canada, October 1980.

Johnson, A.L. and J. Taagholt, "Ionospheric Effects on C3I Satellite Communications Systems in Greenland," Radio Science, Vol 20, No. 3, pp 339-346, May-June 1985.

Johnson, A.L., "Polar Ionospheric Scintillation Measurements Using Widely Distributed Operational Stations," URSI Beacon Satellite Symposium, Tucamon Argentina, 27 March 1990.

Nehring, C., "Decoding of Data From Argos," Report IR-020, Danish Meteorological Institute, Copenhagen Denmark, 1988.

Taagholt, J., "Northeast Greenland Weather Data," NIMBUS-6 Random Access Measurement System Applications Experiments, NASA SP-457, Washington DC, 1982.

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