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# ELF PVS Field Strength Measurements, April 1977

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Newport, Rhode Island / New London, Connecticut

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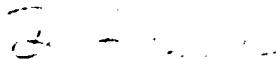
### **Preface**

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The analysis and write up of this report was performed while the author was occupying the Research Chair in Applied Physics at the Naval Postgraduate School, Monterey, CA. The author would especially like to thank Professors Otto Heinz and John Dyer and Dean Bill Tolles for recommending him to occupy this post and NAVSEA (Code 63R) for sponsoring the Chair.

The Technical Reviewer for this report was Raymond F. Ingram.

**Reviewed and Approved: 3 February 1983**



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similar paths. As expected, the presence of the ice cap had no adverse effect on ELF reception.


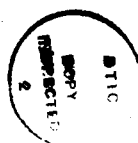


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GLOSSARY OF ABBREVIATIONS

|       |                                  |
|-------|----------------------------------|
| ELF   | Extremely low frequency          |
| EW    | East-west                        |
| GMT   | Greenwich Mean Time              |
| MSK   | Minimum shift keying             |
| NS    | North-south                      |
| NUSC  | Naval Underwater Systems Center  |
| PVS   | Propagation validation system    |
| SNR   | Signal-to-noise ratio            |
| S RTP | Sunrise transition period        |
| SSTP  | Sunset transition period         |
| STIU  | Signal timing and interface unit |
| TTY   | Teletype                         |
| WTF   | Wisconsin Test Facility          |



## ELF PVS FIELD STRENGTH MEASUREMENTS, APRIL 1977

## INTRODUCTION

The ELF\* propagation validation system (PVS) is composed of the U. S. Navy's extremely low frequency (ELF) Wisconsin Test Facility (WTF) and ELF receivers (AN/BSR-1) installed on submarines and at certain land sites. The WTF is located in the Chequamegon National Forest in north-central Wisconsin, about 8 km south of the village of Clam Lake. It consists of two 22.5 km antennas; one antenna is located approximately in the north-south (NS) direction and one is located approximately in the east-west (EW) direction. Each antenna is grounded at both ends. At 76 Hz, the electrical axis of the NS antenna is 14 deg east of north, while the electrical axis of the EW antenna is 114 deg east of north.<sup>1</sup> The WTF antenna array can be steered electrically toward any particular location. Its radiated power is approximately 1 W.

The AN/BSR-1 receiver is composed of an AN/UYK-20 minicomputer, a signal timing and interface unit (STIU), a rubidium frequency time standard, two magnetic-tape recorders, and a preamplifier. The message output is on a teletype (TTY), which is used to control the receiver. The submarine receiving antenna is a buoyant cable 1.6 cm in diameter with electrodes spaced 300 m apart on a 580 m transmission line.

The system uses minimum shift keying (MSK) modulation with a center frequency of 76 Hz. The signalling scheme uses block orthogonal coding to make maximum use of the limited transmitter power available. The scheme provides the most efficient use of the transmitter for short messages.

During April 1977, the submarine involved in testing was located under the ice in the Greenland-Sea area at a range of approximately 4.5 Mm from WTF. Signal-strength, effective-noise, and signal-to-noise ratio (SNR) data were recorded automatically whenever the ELF receiving antenna was streamed, though no special operational posture was adopted to provide ELF reception. Unfortunately, because of an erroneous receiver setting, the relative-phase information obtained was in error.

In the submarine data, the depth and orientation are automatically accounted for by the receiver. The submarine data analyzed in this report have been taken at essentially constant depth and orientation for considerable periods of time. We also have a substantial amount of unreduced (as far as signal amplitude and phase are concerned) submarine data where the speed, depth, and orientation of the submarine were varying considerably. These particular data are not too useful for obtaining accurate signal amplitude and

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\*ELF (formerly called SANGUINE/SEAFARER) is an arbitrary designation applied to ongoing extremely low frequency research by the U. S. Navy. The term designates work directed toward the implementation of an ELF shore-to-ship radio communication system.

phase information. However, they are very useful for obtaining information on messages received during submarine maneuvers.

In this report, we will discuss the results of these April 1977 submarine and Connecticut measurements and will compare them with previous measurements taken over similar paths.

#### APRIL 1977 RESULTS

During this time period, data were obtained on 15 days from the submarine in the Greenland-Sea area and from the Connecticut site on 25 days. The daily plots of signal strength, effective noise,\* and SNR versus Greenwich Mean Time (GMT) are presented in appendix A for submarine data and in appendix B for Connecticut data.

The WTF antenna phasing angle ( $\psi$ ) was 291 deg during April and the transmitting frequency was  $76 \pm 4$  Hz.

Presented in table 1 are the April 1977 Greenland-Sea-area submarine daily field-strength averages. These data are broken up into four time periods, which should be representative of

1. Nighttime propagation conditions (-0200 to 0600 GMT),
2. Sunrise transition period (SRTP) propagation conditions (-0600 to 1200 GMT),
3. Daytime propagation conditions (-1200 to 2100 GMT), and
4. Sunset transition period (SSTP) propagation conditions (-2100 to 0200 GMT).

Referring to table 1, we see that there is a considerable day-to-day variation in the received field strengths. That is, the average field strength sometimes changes by 2 to 4 dB from one day to the next. This phenomenon is typical of ELF propagation on northern-latitude paths.<sup>3,4</sup>

The 4 through 26 April average field-strength, SNR, and effective-noise values are plotted in figure 1† versus GMT. From this figure, we see that the highest field strengths were measured during the latter part of the sunrise and sunset transition periods (1000 to 1200 and 2330 to 0130 GMT), while the lowest field strengths were measured during the latter part of the nighttime period (0400 to 0600 GMT). The average daily effective-noise variation was approximately 5 dB with the minimum values measured during the early morning

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\*The effective-noise spectrum level (in  $\text{dBA/m} \cdot \sqrt{1 \text{ Hz}}$ ) is defined as the spectrum level of ELF noise at the signal frequency divided by the improvement (in SNR) using nonlinear processing.<sup>2</sup>

†Figures have been placed together at the end of this report or in the applicable appendix.

Table 1. April 1977 Greenland-Sea-Area Submarine  
Daily Field-Strength Averages

| Date            | Night $H_{\phi}$<br>(dBA/m) | SRTP $H_{\phi}$<br>(dBA/m) | Day $H_{\phi}$<br>(dBA/m) | SSTP $H_{\phi}$<br>(dBA/m) |
|-----------------|-----------------------------|----------------------------|---------------------------|----------------------------|
| 4/4             | -153.5                      | -150.8                     | -                         | -149.7                     |
| 4/5             | -151.4                      | -150.0                     | -                         | -149.8                     |
| 4/6             | -152.3                      | -150.7                     | -149.9                    | -158.2                     |
| 4/7             | -155.9                      | -155.5                     | -153.2                    | -15                        |
| 4/8             | -152.1                      | -151.0                     | -150.6                    | -15                        |
| 4/9             | -152.2                      | -150.6                     | -                         | -                          |
| 4/10            | -151.8                      | -153.1                     | -150.0                    | -14                        |
| 4/11            | -152.6                      | -                          | -                         | -                          |
| 4/12            | -152.2                      | -150.8                     | -                         | -                          |
| 4/15            | -                           | -151.5                     | -                         | -                          |
| 4/16            | -152.0                      | -149.6                     | -149.9                    | -                          |
| 4/18            | -                           | -                          | -150.2                    | -151.4                     |
| 4/21            | -150.9                      | -151.3                     | -                         | -                          |
| 4/22            | -151.2                      | -152.0                     | -152.6                    | -150.1                     |
| 4/24            | -155.2                      | -151.6                     | -152.5                    | -                          |
| 4/26            | -151.5                      | -150.3                     | -                         | -151.5                     |
| Monthly Average | -152.4                      | -151.2                     | -151.1                    | -150.6                     |

hours (0300 to 0500 GMT) and the maximum values measured during the late afternoon hours (1800 to 2100 GMT).

A plot of the April 1977 Greenland-Sea-area SNR distribution ( $N = 338$  30-min samples) is presented in figure 2. From this curve, we see that the predetection (in a 1-Hz bandwidth) SNR at optimum heading was greater than -8 dB 50 percent of the time and greater than -14 dB 98 percent of the time. The postdetection SNR (after 30 min integration time) was greater than 24.5 dB 50 percent of the time and greater than 18.5 dB 98 percent of the time.

During both January and March 1977, field-strength measurements were taken in Connecticut and aboard submarines located in the North-Atlantic/Norwegian-Sea

area. The daytime and nighttime attenuation rates inferred from these measurements were 1.25 and 0.9 dB/Mm, respectively, while the excitation factors were -1.0 dB during the day and -3.8 dB at night.<sup>5,6</sup> These values are consistent with previous measurements taken over similar propagation paths.<sup>7,8</sup>

Referring to table 1, we see that the average April Greenland-Sea-area (~4.5 Mm from WTF) daytime, transition-period, and nighttime measured field strengths were -151.1, -150.9, and -152.4 dBA/m, respectively. Based on the abovementioned values of attenuation rate and excitation factor, the predicted field strengths at a range of 4.5 Mm are -151.2, -151.8, and -152.5 dBA/m, respectively. Note that there is excellent agreement between the measured and predicted Greenland-Sea-area daytime and nighttime field strengths. On the other hand, the measured transition-period field strengths were approximately 1 dB greater than predicted.

The most unusual field-strength and effective-noise variations measured on the submarine in the Greenland-Sea area occurred on 6 and 7 April. During this time, the average measured field strengths were 3 to 7 dB lower than during the preceding or succeeding days (see table 1). The 0000-1200 measured effective noise was approximately 8 dB lower than the monthly average.

Presented in figure 3 are the 6 and 7 April 1977 Greenland-Sea-area submarine data versus GMT. Here, we see that, from 2000 to 0030, the field strength decreased ~12 dB while the effective noise decreased ~11 dB. The signal strength then increased ~9 dB from 0030 to 0330, while the noise only increased about 2 dB. Both the signal and noise then remained fairly constant until the beginning of the daytime propagation period where they both increased.

On the other hand, the 7 April Connecticut nighttime field strengths were fairly constant. However, the night-to-day relative-phase variation ( $\Delta\phi$ ) was only 13 deg compared to the monthly average of 23 deg, which implies a lower nighttime reflection height (and increased nighttime excitation factor). This is further borne out by the fact that the 7 April 0400 to 0800 nighttime field strengths were 1 to 2 dB greater than those during the preceding or succeeding nights (see appendix B).

Because some previous ELF field-strength variations appeared to be correlated with geomagnetic activity,<sup>9-12</sup> it would be of interest to compare the April measurements with geomagnetic activity. Presented in figure 4 are the daily comparisons of the average SSTP, nighttime, and SRT<sub>r</sub> field strengths (measured from 4 to 12 April) with the geomagnetic  $A_k$  index for Fredericksburg, VA. (Note that minus  $H_\phi$  is plotted versus day of month.)

It is readily apparent from figure 4 that, during this particular period, increases in geomagnetic activity were accompanied by decreases in the SSTP, nighttime, and SRT<sub>r</sub> field strengths. In particular, during 7 April, when the magnetic activity was the greatest, the measured field strengths were the lowest.

## CONCLUSIONS

The average daytime and nighttime field strengths measured aboard a submarine located under the ice in the Greenland-Sea area during April 1977 are in excellent agreement with previous ELF measurements over similar paths. As expected, the presence of the ice cap had no adverse effect on ELF reception.

Anomalous ELF field-strength and effective-noise variations were also correlated with geomagnetic activity. That is, increases in geomagnetic activity were usually accompanied by decreases in the received field strengths.

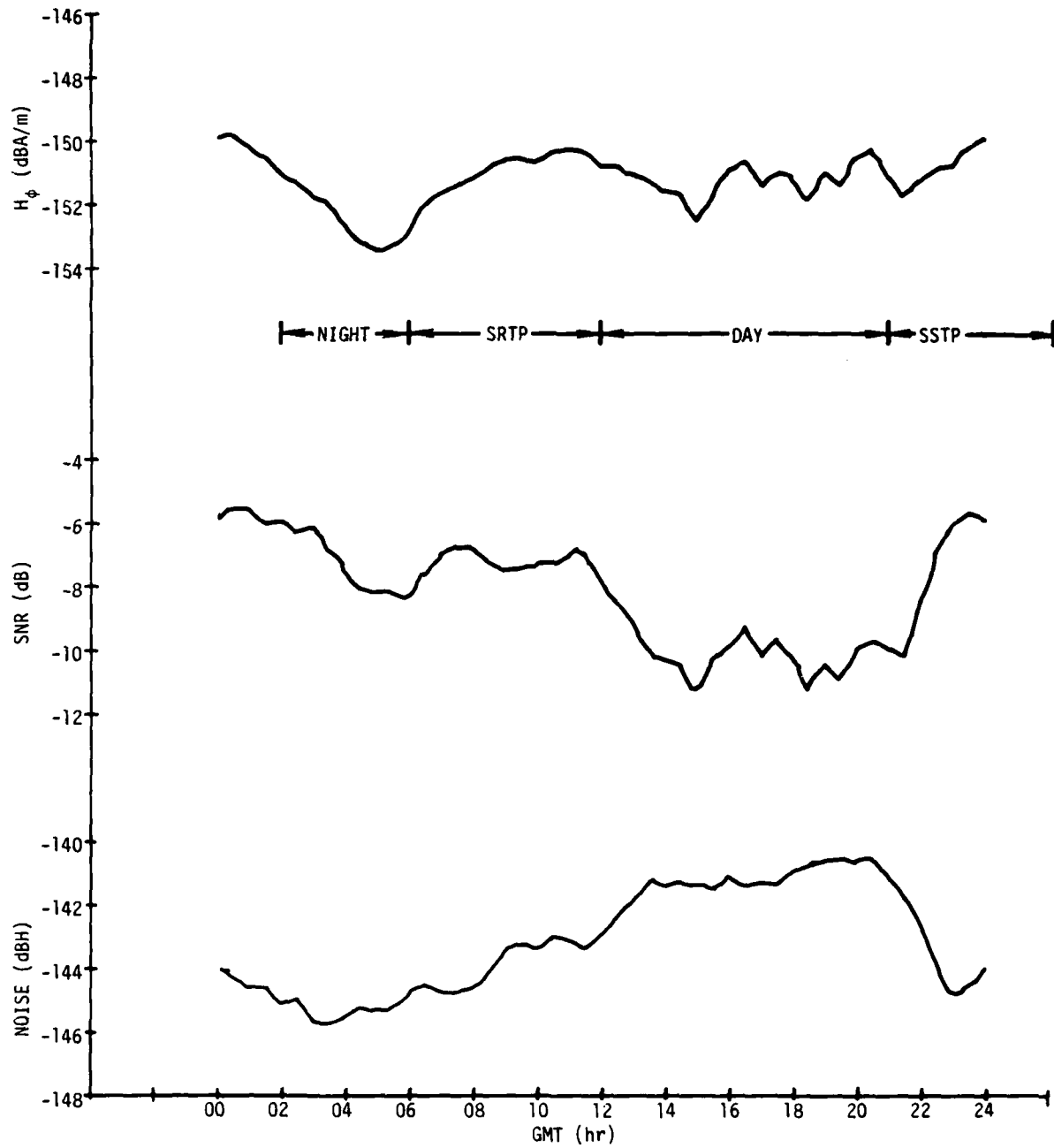


Figure 1. Greenland-Sea-Area Average Data Versus GMT ( $\psi = 291$  deg), 4 to 26 April 1977

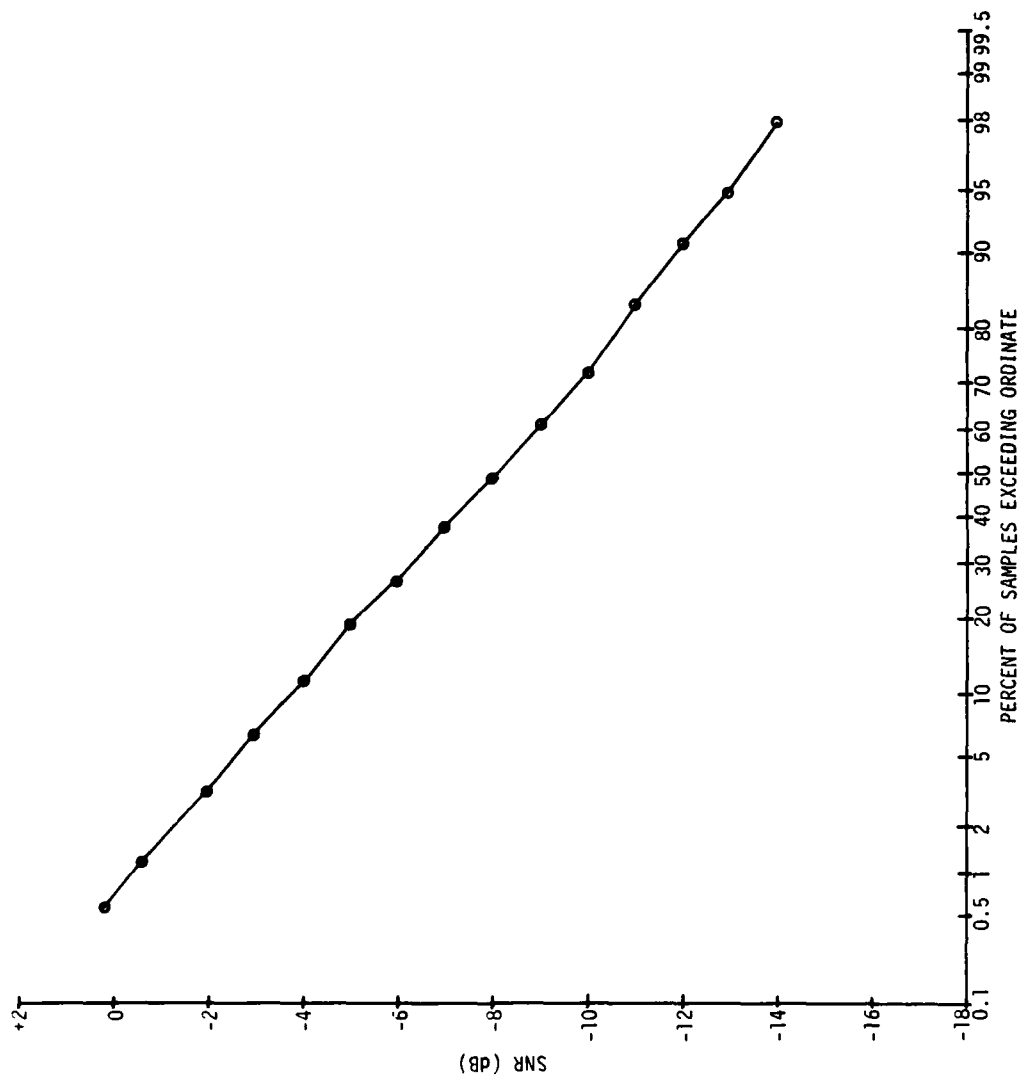


Figure 2. Greenland-Sea-Area SNR Distribution  
( $\psi = 291$  deg,  $N = 338$ ), April 1977

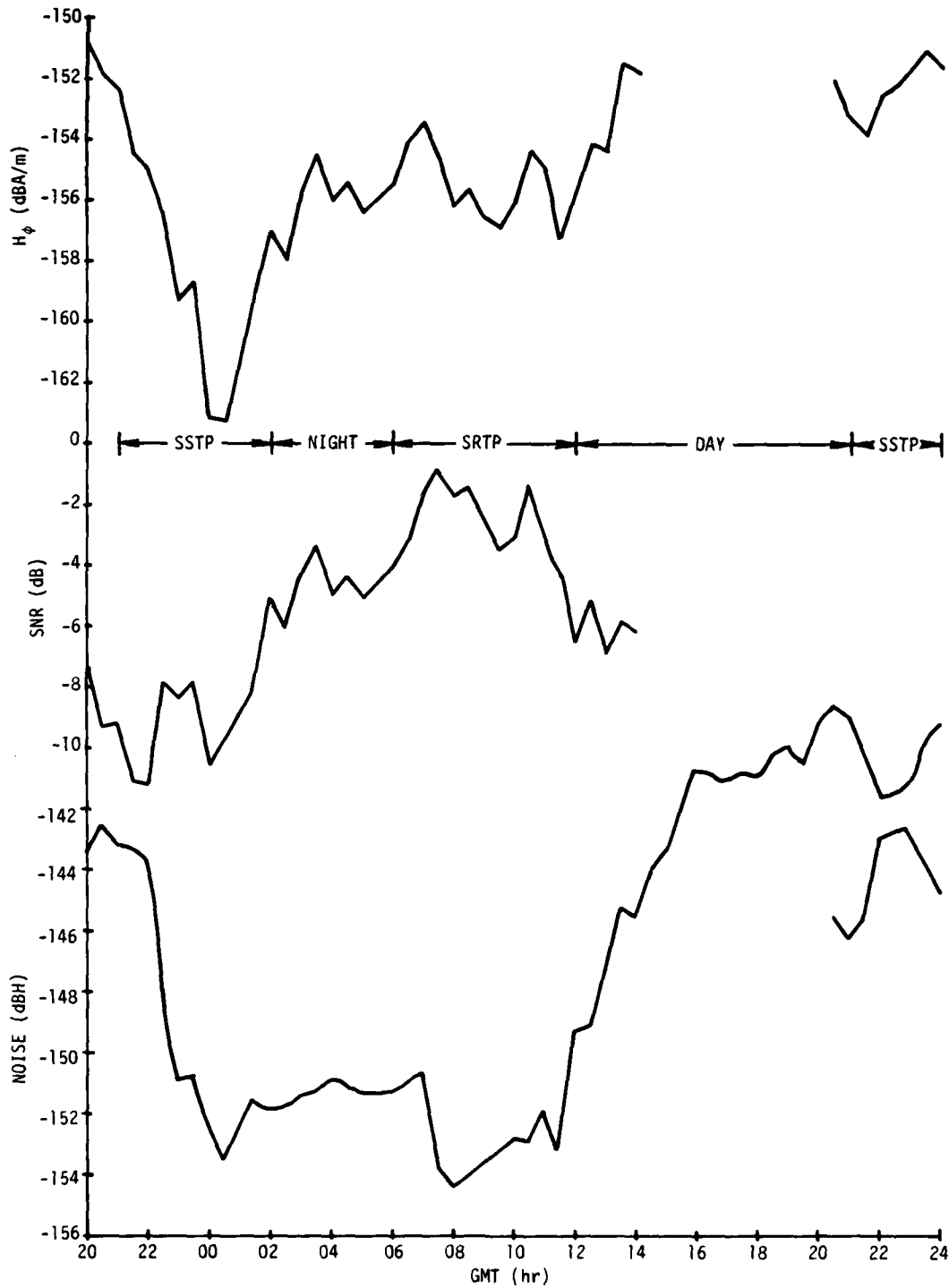


Figure 3. Greenland-Sea-Area Submarine Data Versus GMT ( $\psi = 291$  deg), 6 and 7 April 1977



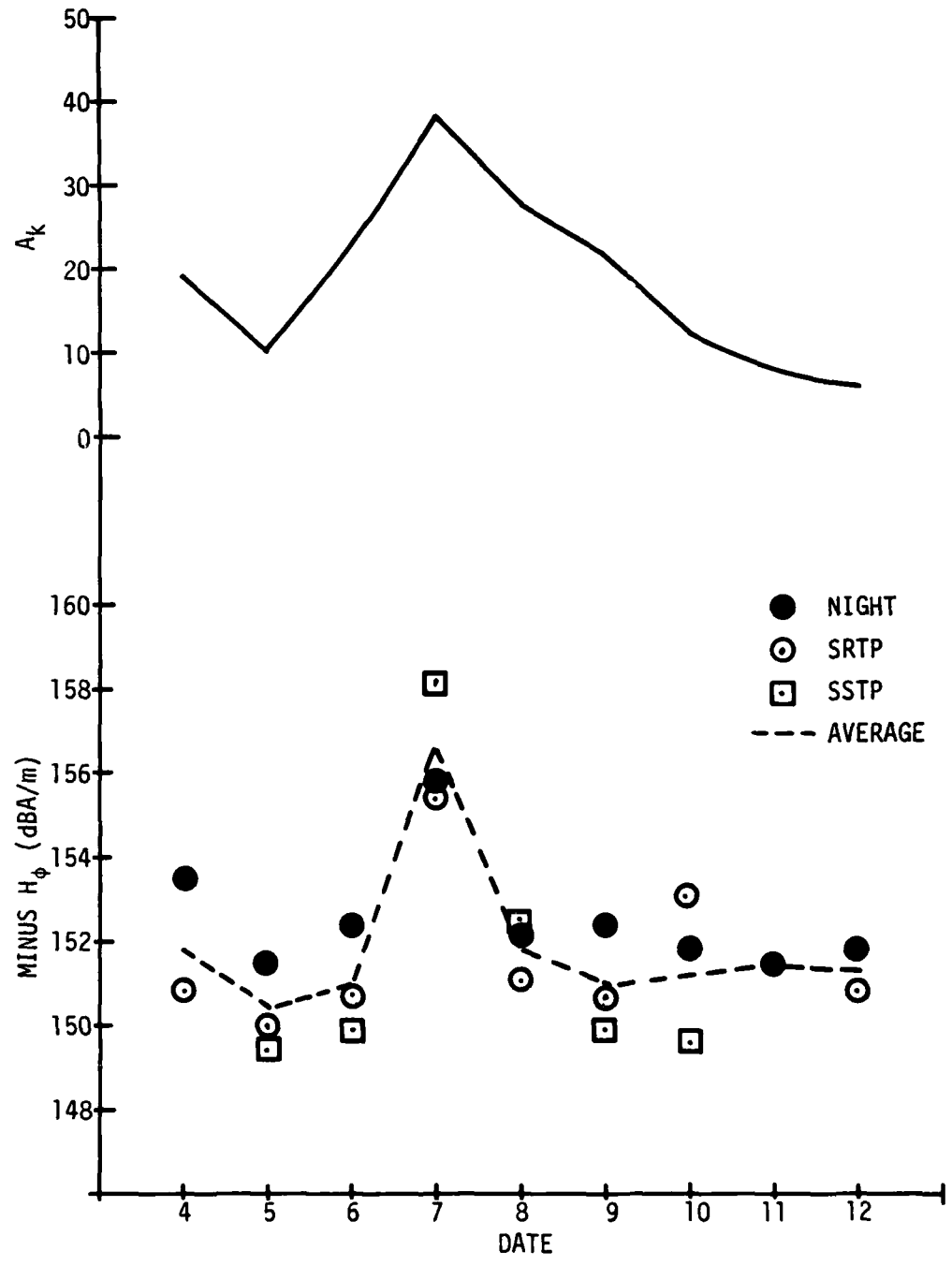


Figure 4. Daily Comparison of Average SSTP, Nighttime, and SRTP Field Strengths With Geomagnetic Behavior, 4 to 12 April 1977

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## Appendix A

## GREENLAND-SEA-AREA SUBMARINE DAILY DATA

Daily field-strength, effective-noise, and SNR values for Greenland-Sea-area submarine data are plotted versus GMT in this appendix as figures A-1 through A-13. The WTF antenna phasing angle ( $\psi$ ) was 291 deg during April and the transmitting frequency was  $76 \pm 4$  Hz.

We can see that, with the exception of the 22 and 26 April data (figures A-11 and A-13), amplitude peak-to-trough variations of 5 dB or greater occurred during each day that included a nighttime measurement period. The largest variation (8.5 dB) during the nighttime measurement period (0200 to 0600 GMT) occurred on 9 April (figure A-5), while the largest variation measured (12.4 dB) occurred during the sunset transition period of 6/7 April (figure 3).

The field-strength behavior during 5, 8, 11, 12, 15, 16, 18, and 26 April was very close to the monthly average ( $\pm 1$  dB). On 4 April (figure A-1), the nighttime field strength was approximately 2 dB lower than the monthly average, as was the 0400 to 0600 GMT nighttime field strength measured on 9 April (figure A-5).

The field strength measured during a 2-hr portion of the SRTP was approximately 4 dB lower than the monthly average on both 10 and 21 April (figures A-6 and A-10), while the 22 April daytime field strength (figure A-11) was approximately 1.5 dB lower throughout the whole daytime period.

During 24 April (figure A-12), the nighttime field strength was -3 dB lower than the monthly average. During the sunrise transition period, the field strength and SNR were characterized by 3 to 4 dB variations between successive samples, while the effective noise was essentially constant. The daytime field strength was also 1.5 dB lower than the monthly average.

It should be noted that all of the submarine effective-noise data presented in this report are contaminated to some degree by submarine-generated noise (external or internal to the submarine). Thus, the effective-noise values presented here are on the high side.

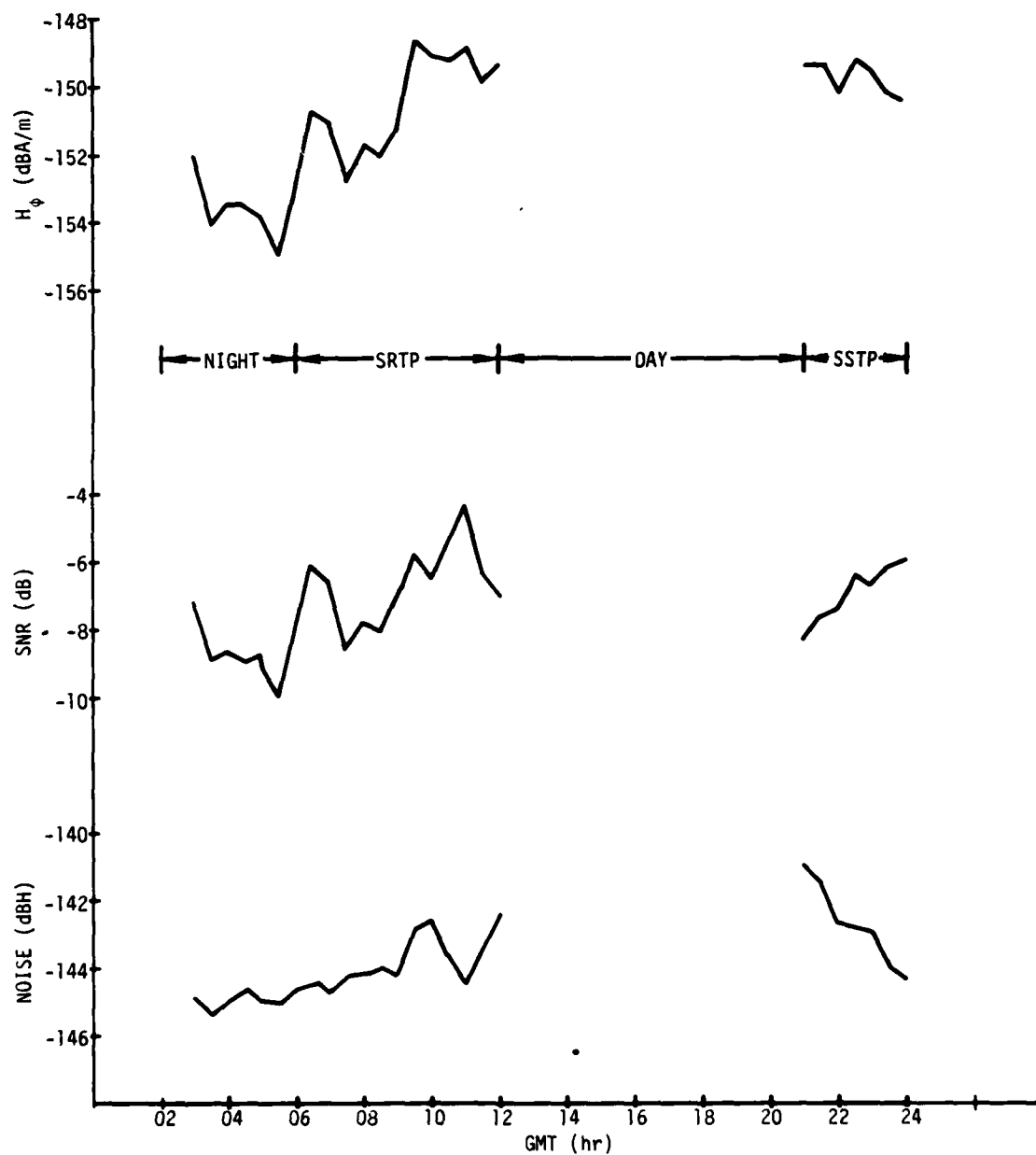


Figure A-1. Submarine Data Versus GMT ( $\psi = 291$  deg), 4 April 1977

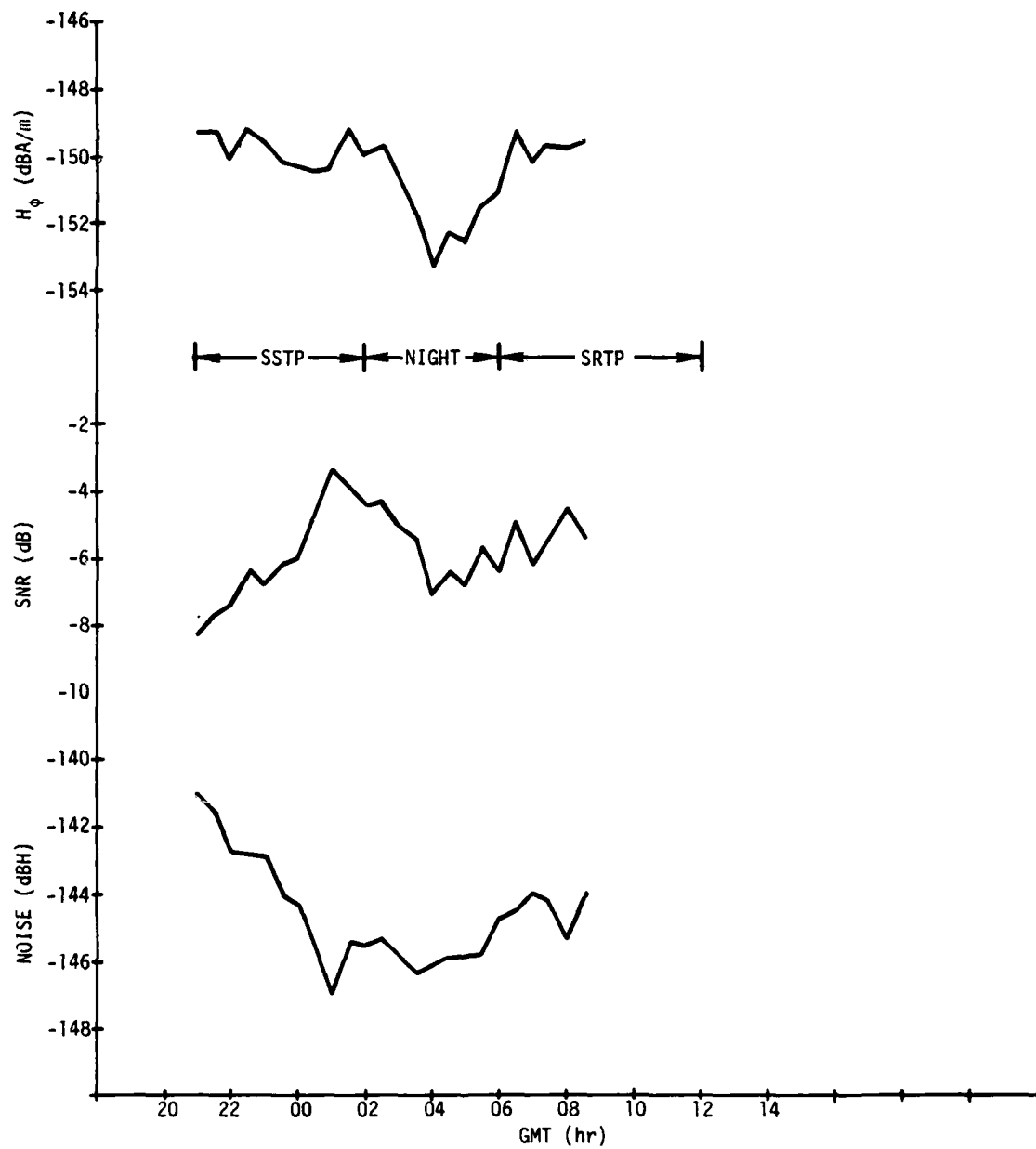


Figure A-2. Submarine Data Versus GMT ( $\psi = 291$  deg), 5 April 1977

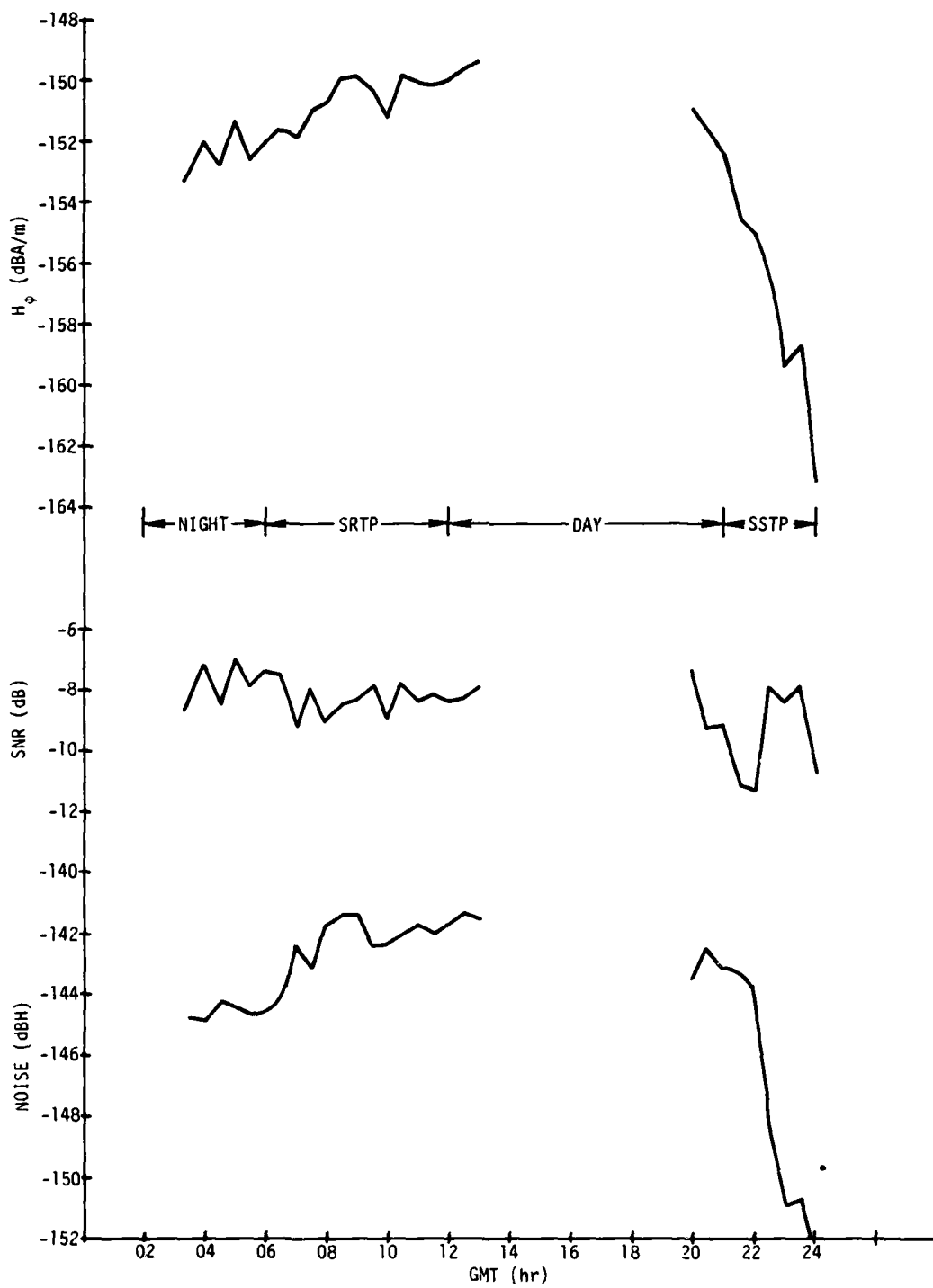


Figure A-3. Submarine Data Versus GMT ( $\psi = 291$  deg), 6 April 1977

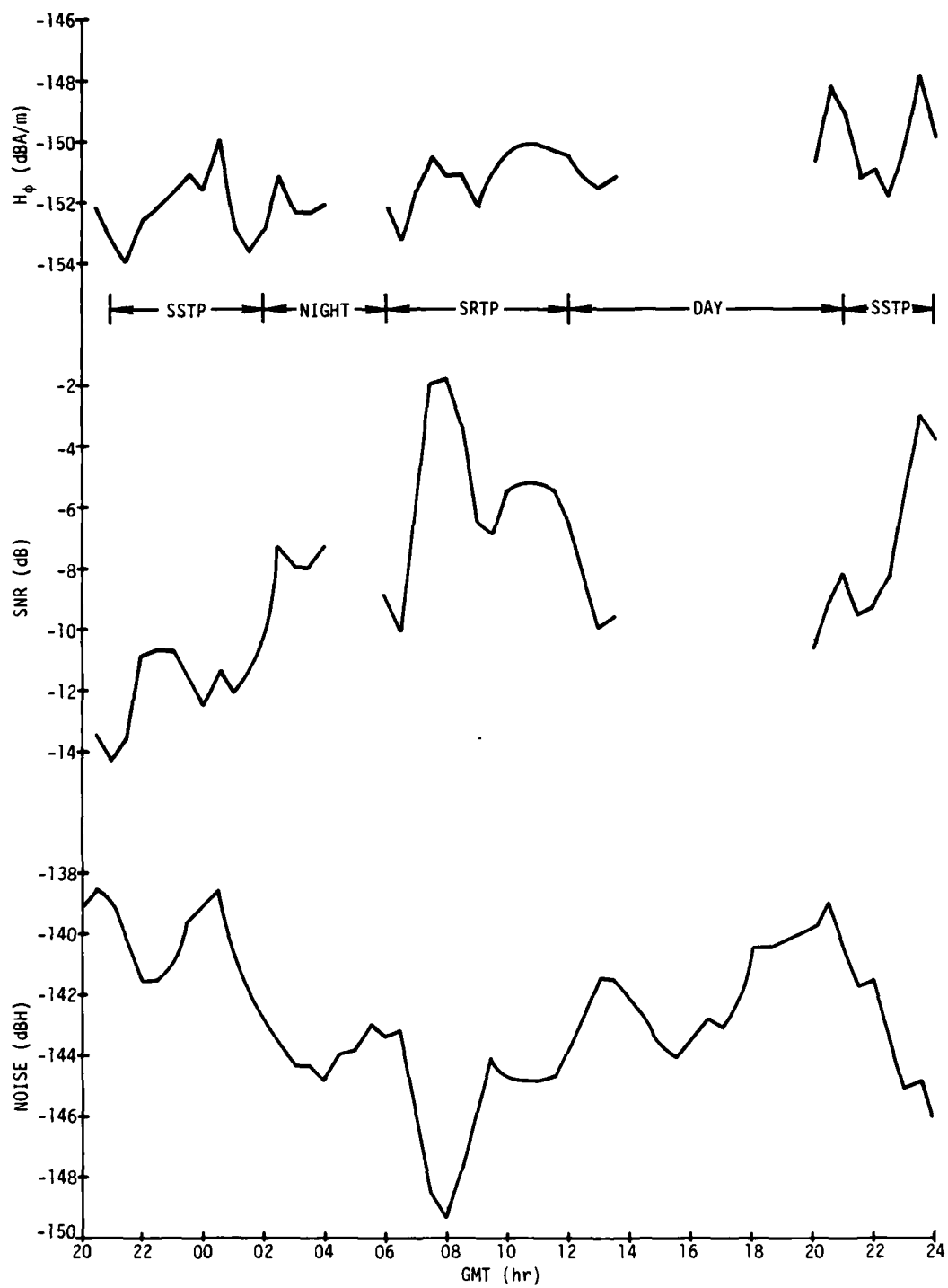


Figure A-4. Submarine Data Versus GMT ( $\psi = 291$  deg), 8 April 1977

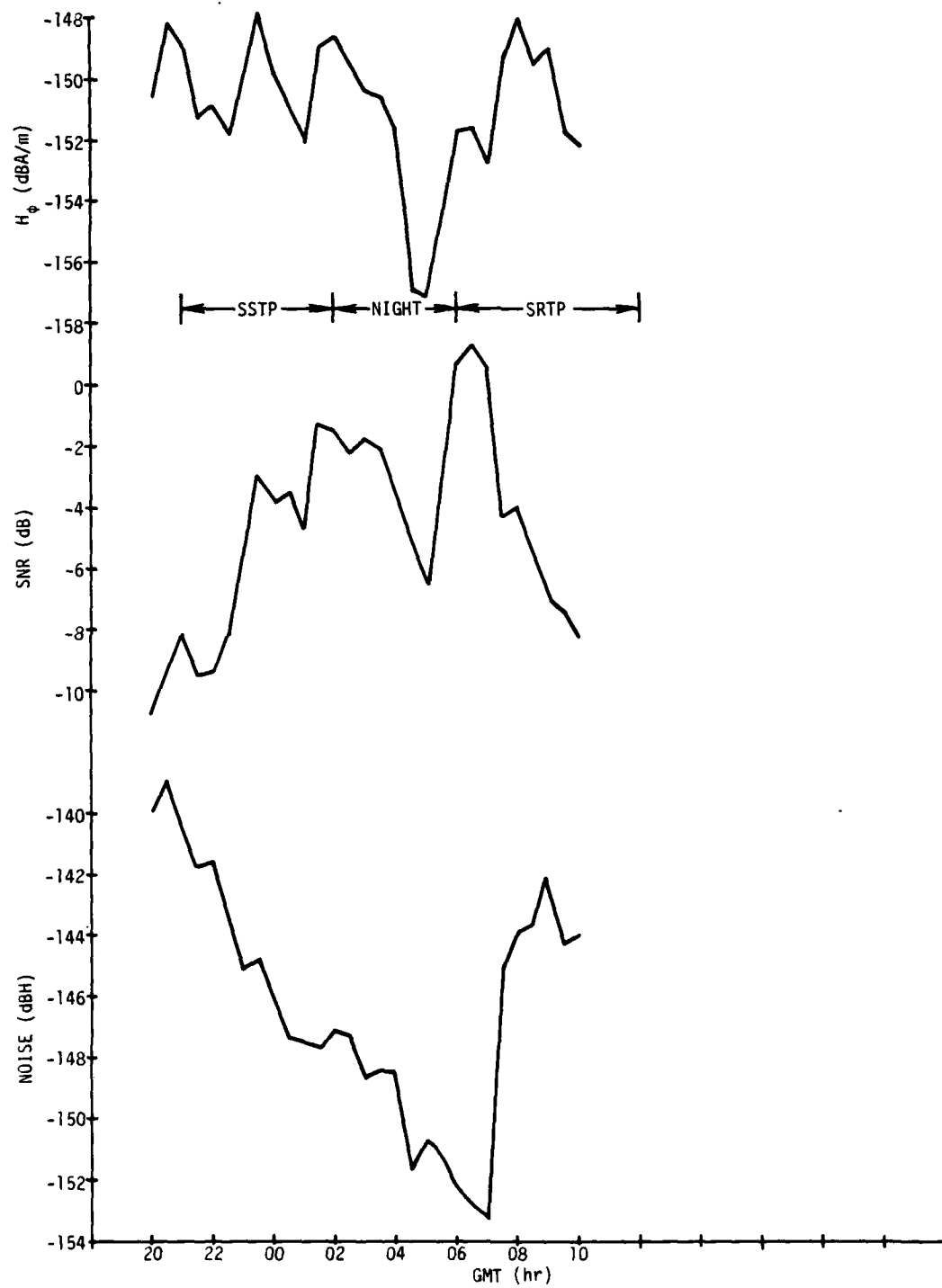


Figure A-5. Submarine Data Versus GMT ( $\psi = 291$  deg), 9 April 1977



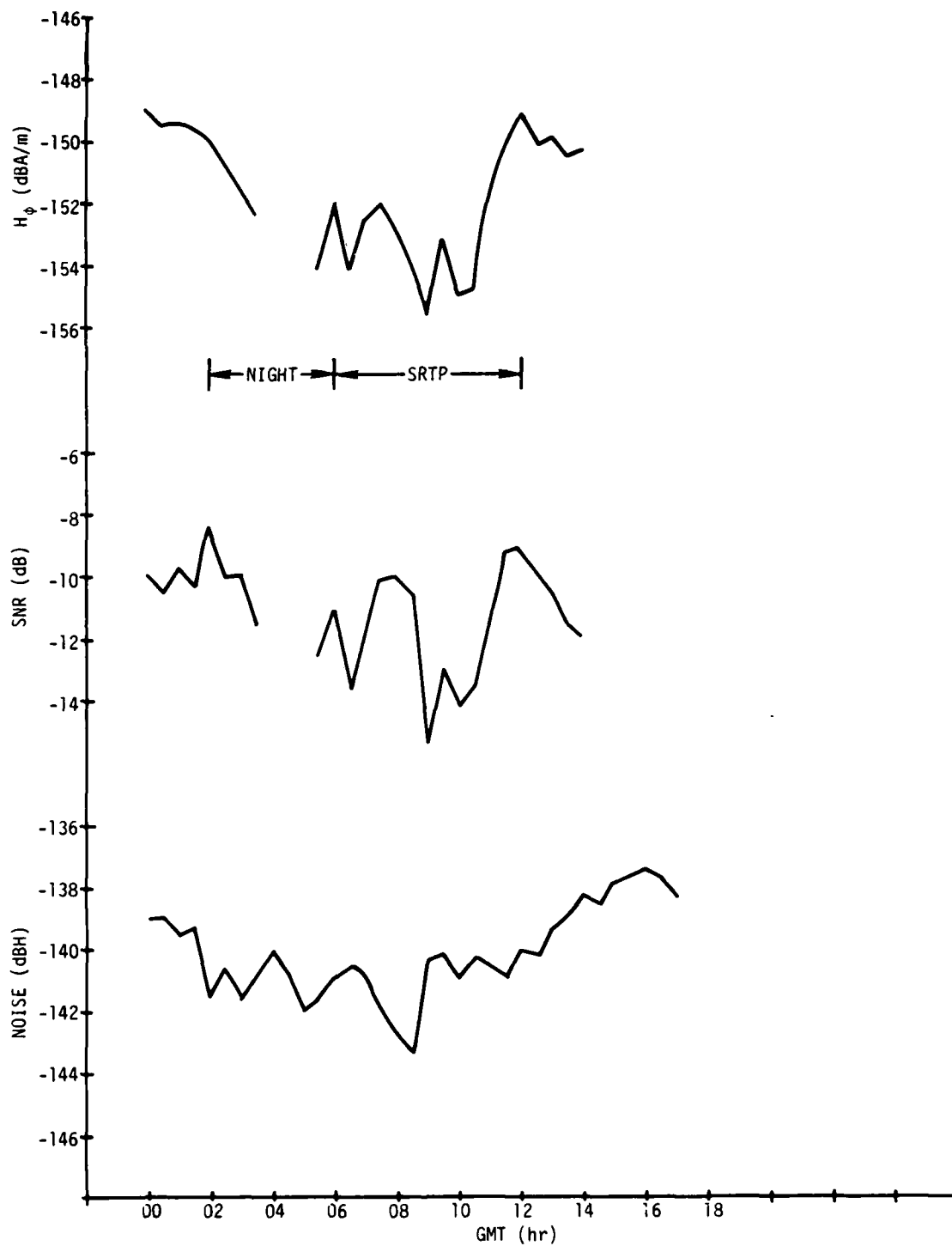


Figure A-6. Submarine Data Versus GMT ( $\psi = 291$  deg), 10 April 1977

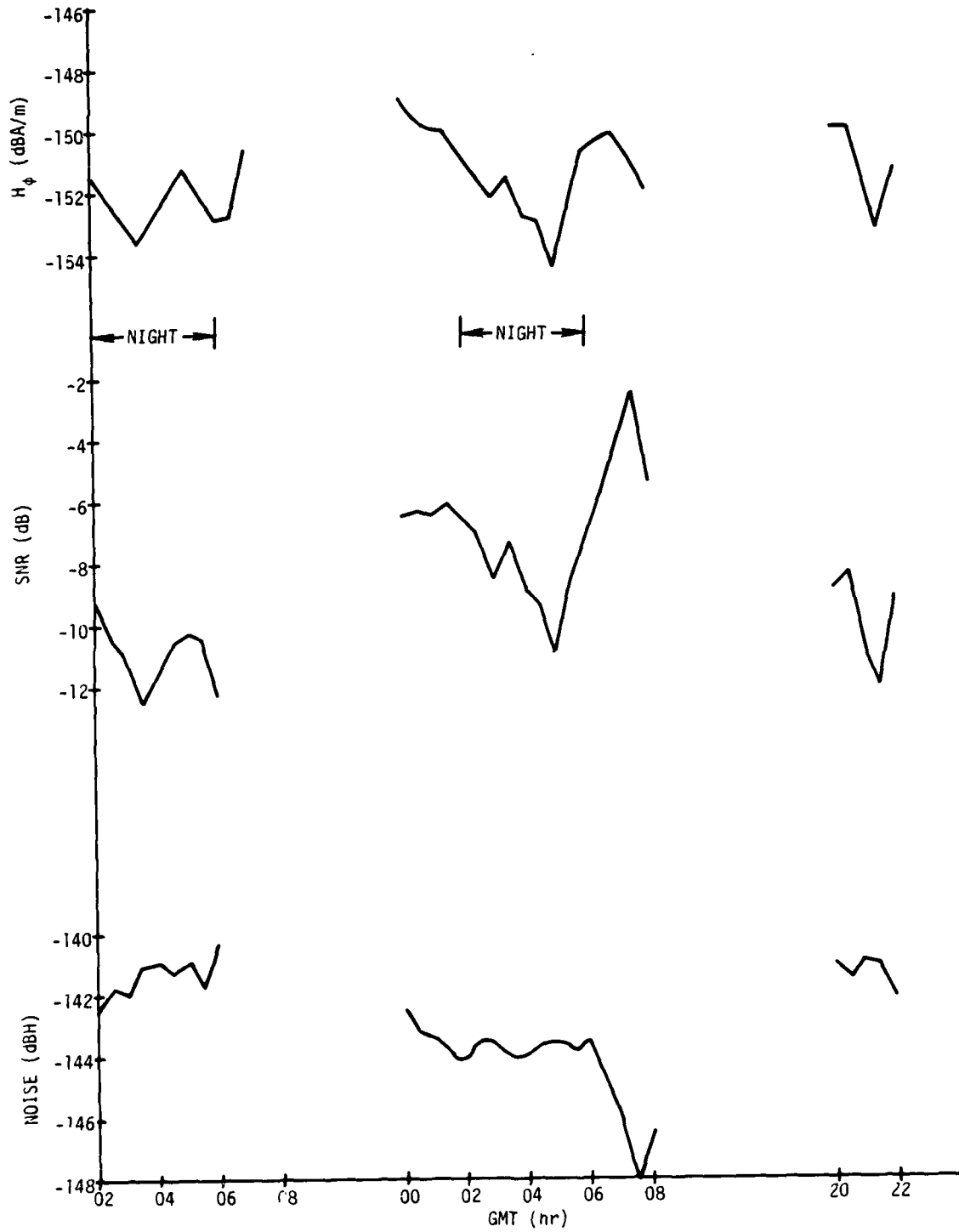


Figure A-7. Submarine Data Versus GMT ( $\psi = 291$  deg),  
11 and 12 April 1977

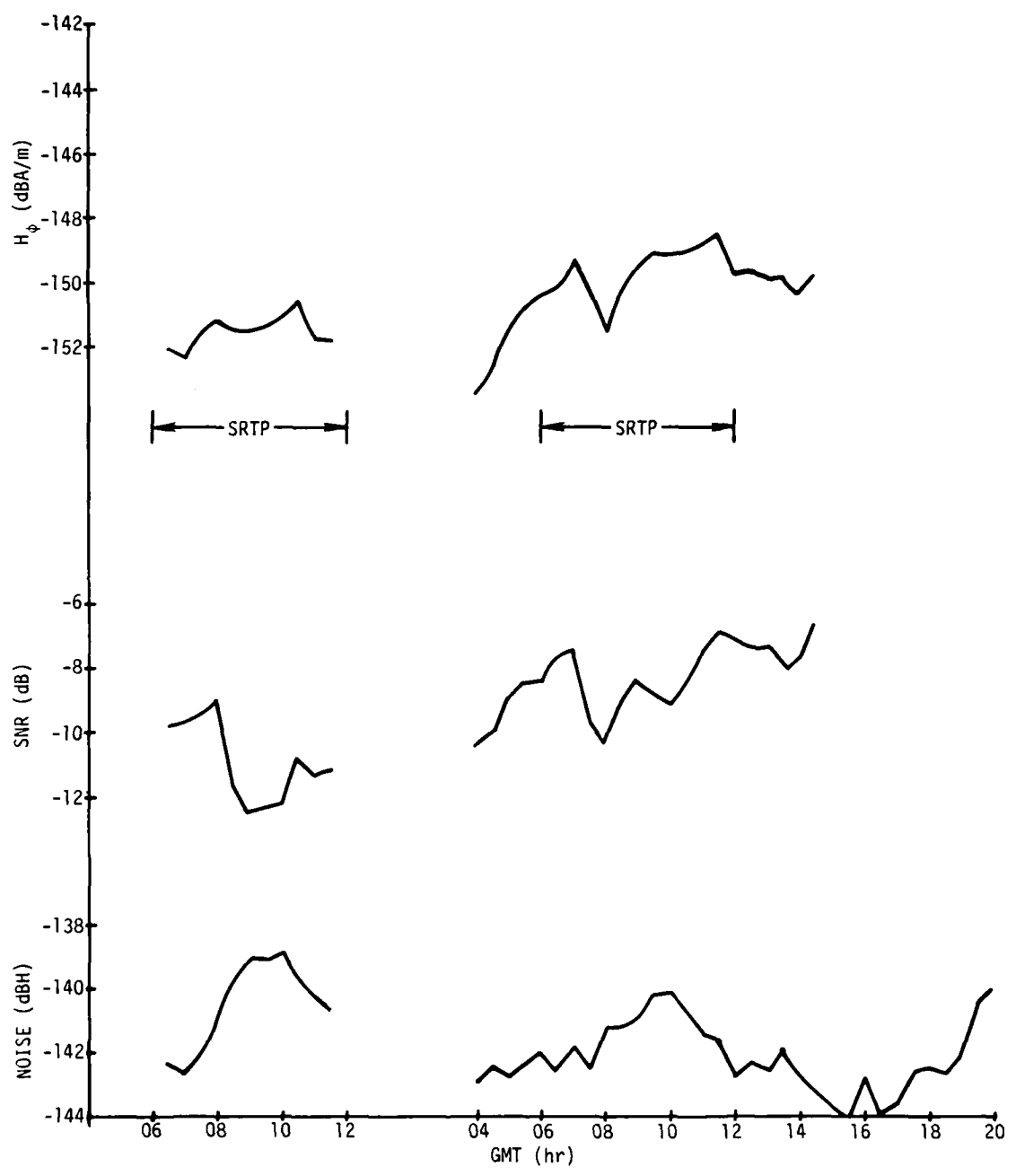


Figure A-8. Submarine Data Versus GMT ( $\psi = 291$  deg),  
15 and 16 April 1977

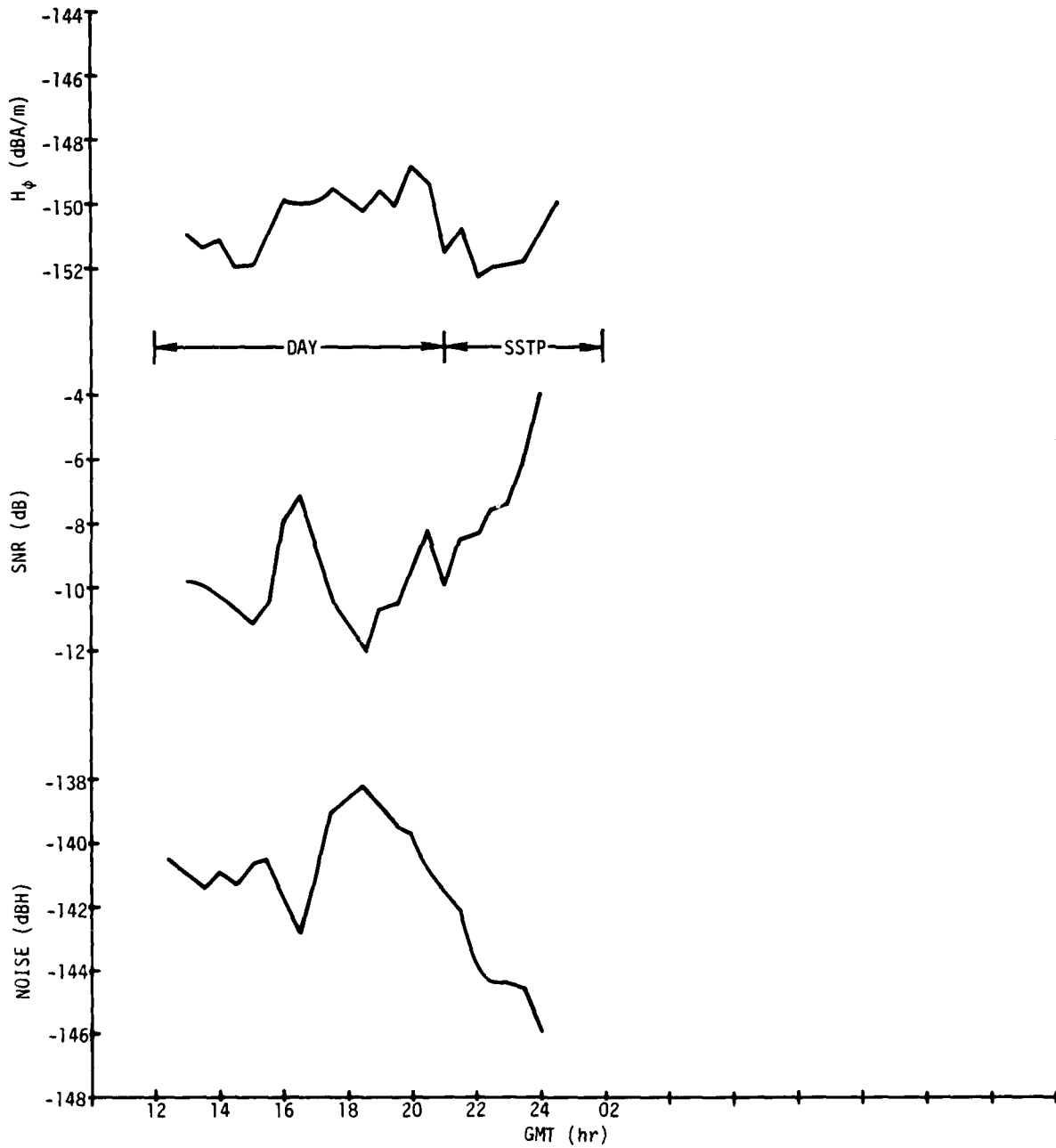


Figure A-9. Submarine Data Versus GMT ( $\psi = 291$  deg), 18 April 1977

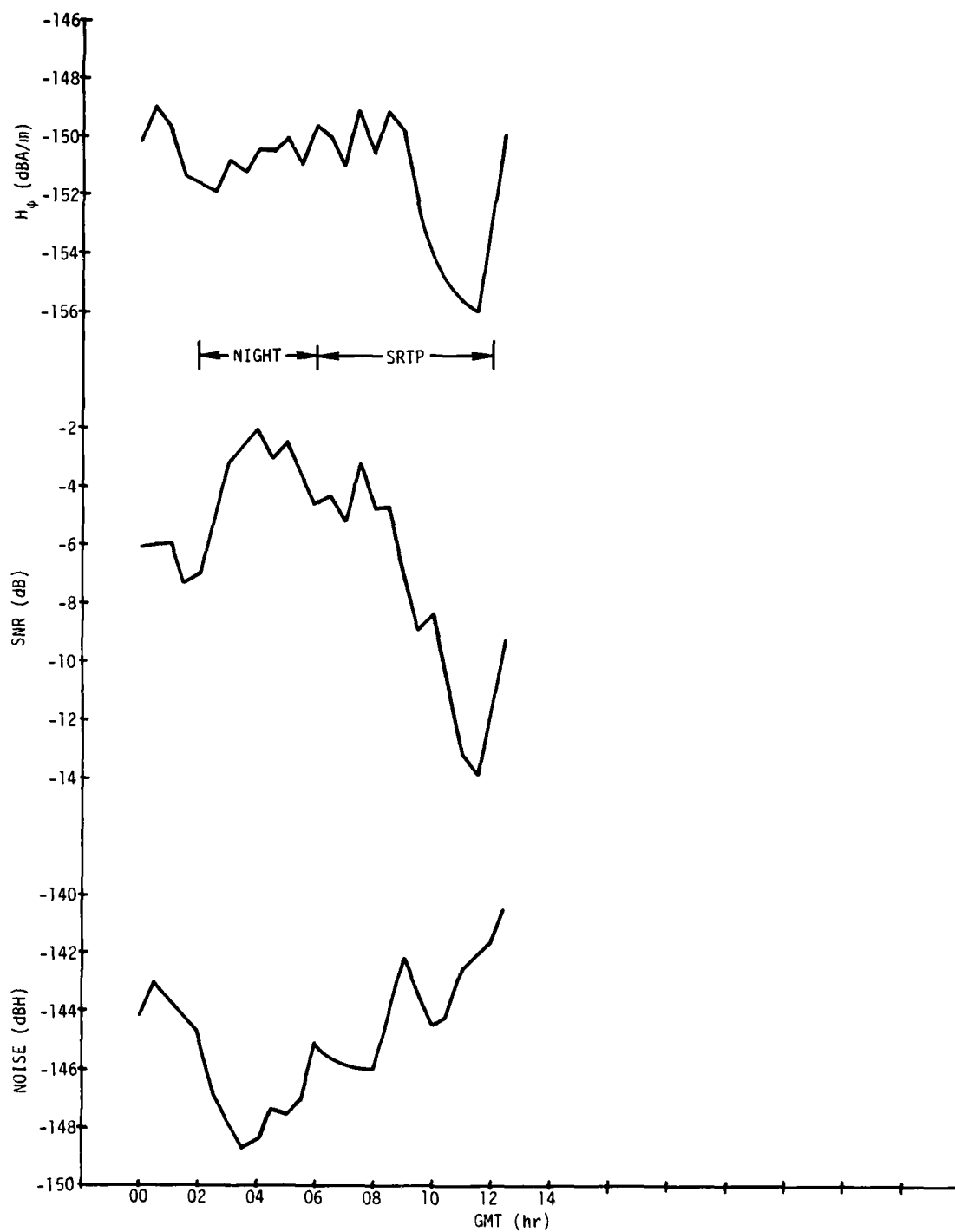


Figure A-10. Submarine Data Versus GMT ( $\psi = 291$  deg), 21 April 1977

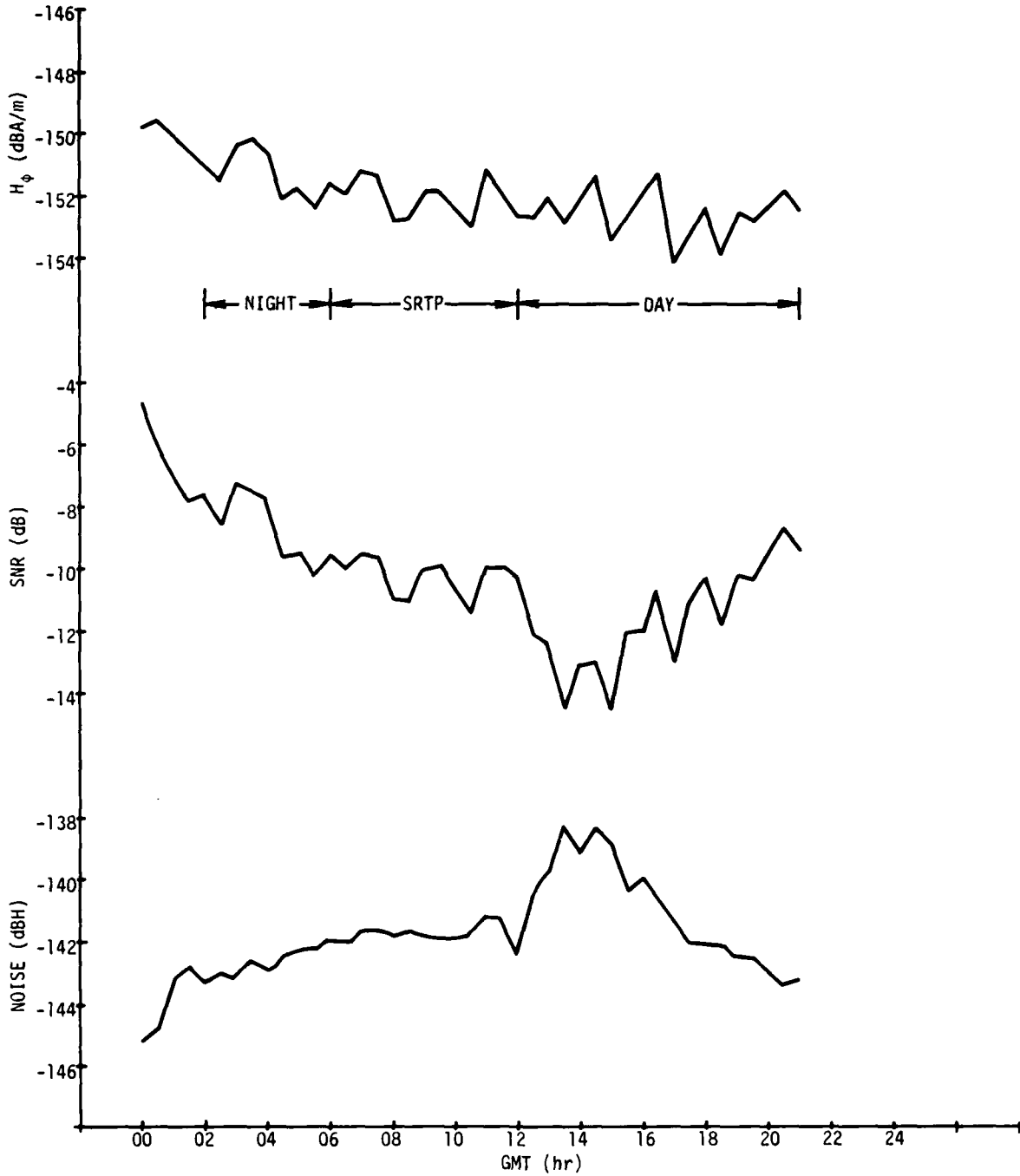


Figure A-11. Submarine Data Versus GMT ( $\psi = 291$  deg), 22 April 1977

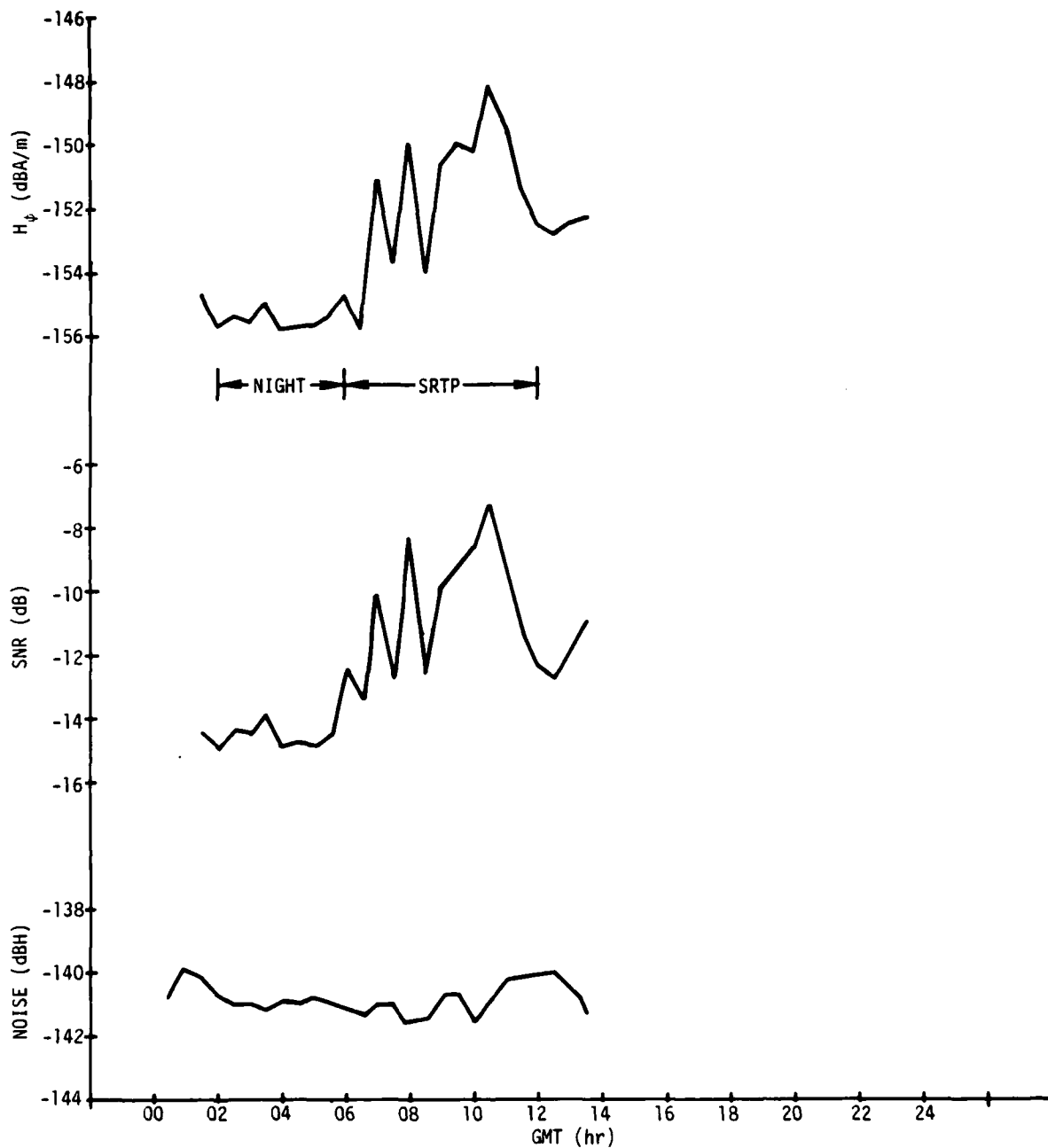


Figure A-12. Submarine Data Versus GMT ( $\psi = 291$  deg), 24 April 1977

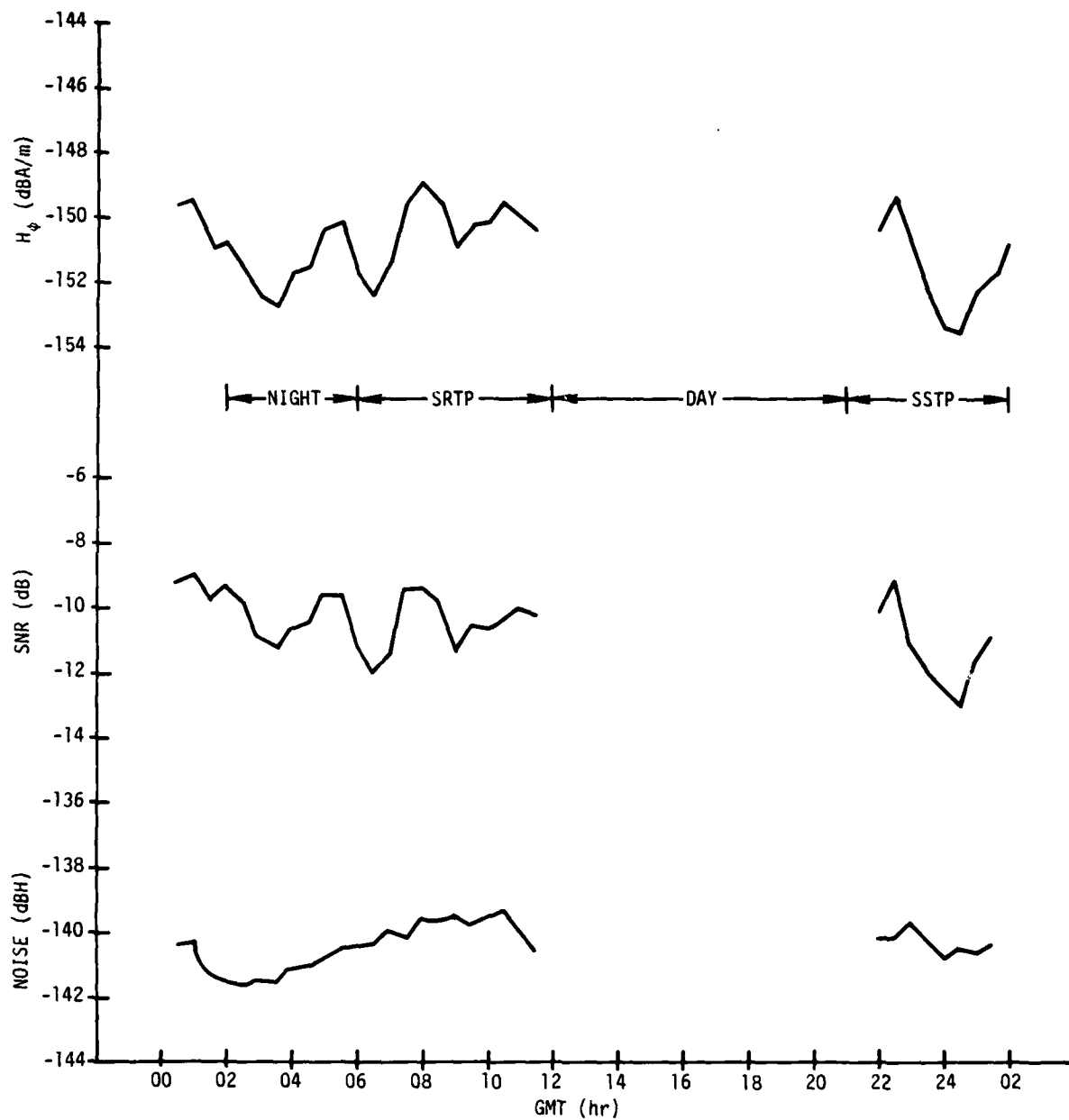


Figure A-13. Submarine Data Versus GMT ( $\psi = 291$  deg), 26 April 1977



## Appendix B

## APRIL 1977 CONNECTICUT DAILY DATA

For the Connecticut measurements, the AN/BSR-1 receiver is located in Room 3111, Building 80, at the Naval Underwater Systems Center (NUSC), New London, CT. The loop receiving antenna is located at Fishers Island, NY (about 10 km from New London). The receiver and receiving antenna are connected by means of a microwave link from Fishers Island to NUSC. The receiving antenna is located approximately 50 m from an NUSC building at Fishers Island that houses the ELF preamplifier and associated circuitry.

As was previously mentioned,<sup>5</sup> the Connecticut effective-noise measurements are sometimes contaminated by industrial noise. Thus, the effective-noise values presented in this appendix are on the high side.

The April daily field-strength (both amplitude and relative phase), effective-noise, and SNR values are plotted versus GMT in this appendix. The WTF antenna phasing angle ( $\psi$ ) was 291 deg during April and the transmitting frequency was  $76 \pm 4$  Hz.

For a WTF antenna phasing angle of 291 deg, the average Connecticut field strength should equal  $-143.3$  dBA/m during the day and  $-145.5$  dBA/m at night. Referring to figures B-1 through B-25, we see that, with the exception of the nighttime minimum-field-strength period, the field-strength levels are about as expected.

Amplitude peak-to-trough variations of 5 dB or greater occurred during 9 of the 25 days measured (April 1, 2, 4, 6, 14, 16, 18, 28, and 29). The largest variation ( $-6.5$  dB) occurred on 1 and 18 April (figures B-1 and B-14).

The April night-to-day relative-phase variation was  $23 \pm 5$  deg, with the largest variation (31 deg) measured on 2 April (figure B-2) and the smallest (13 deg) measured on 7 April (figure B-5).

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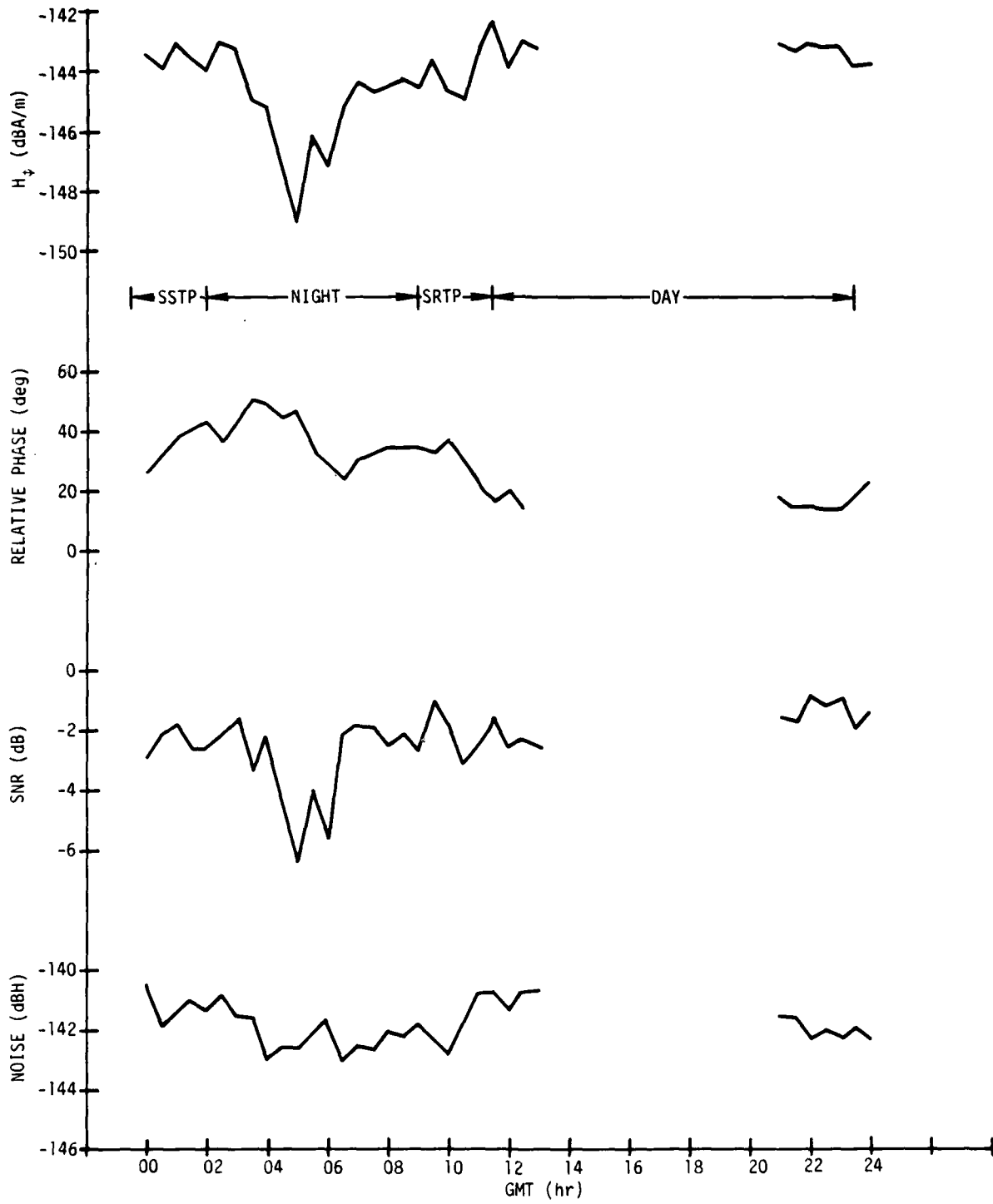


Figure B-1. Connecticut Data Versus GMT ( $\psi = 291$  deg), 1 April 1977

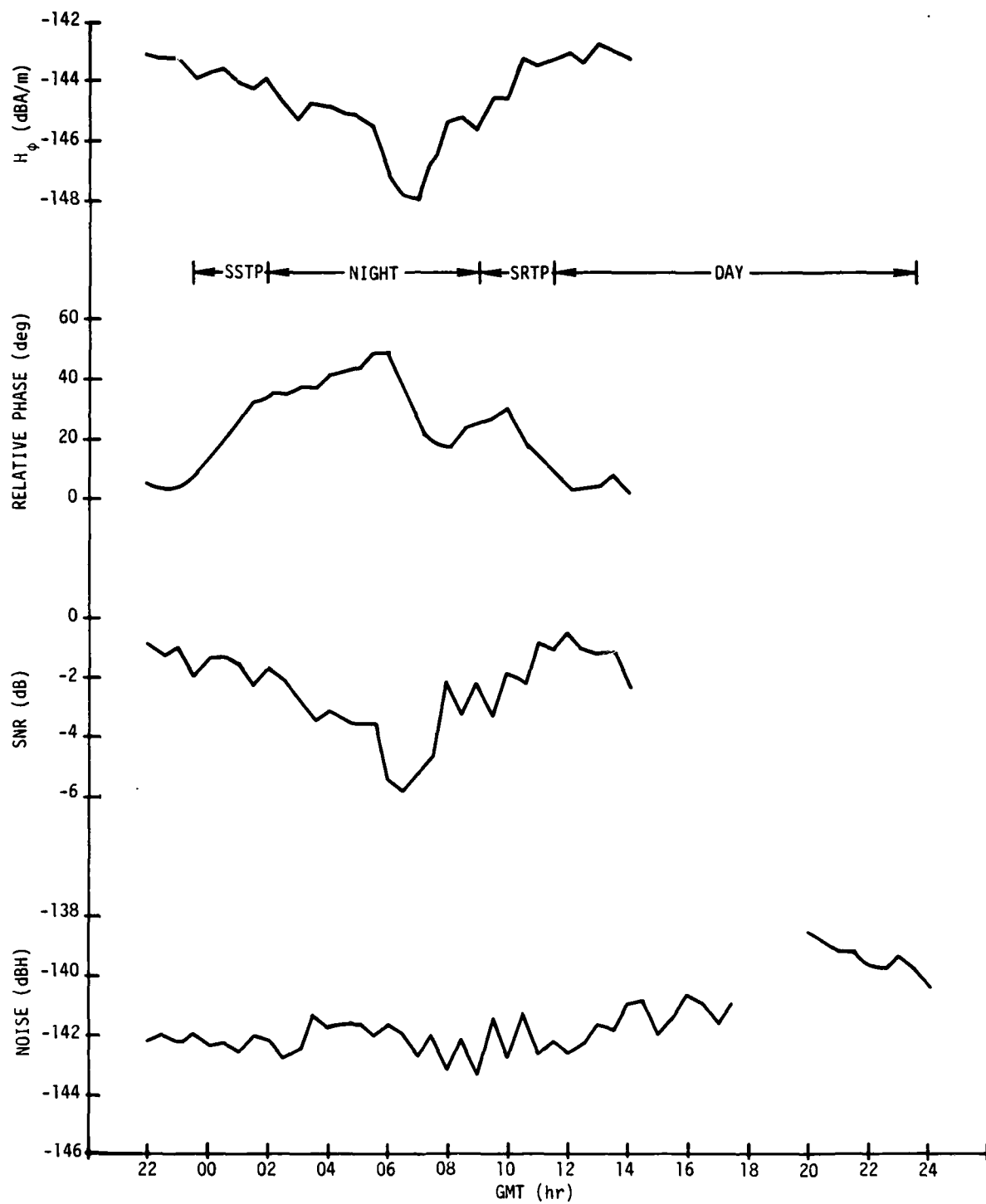


Figure B-2. Connecticut Data Versus GMT ( $\psi = 291$  deg), 2 April 1977

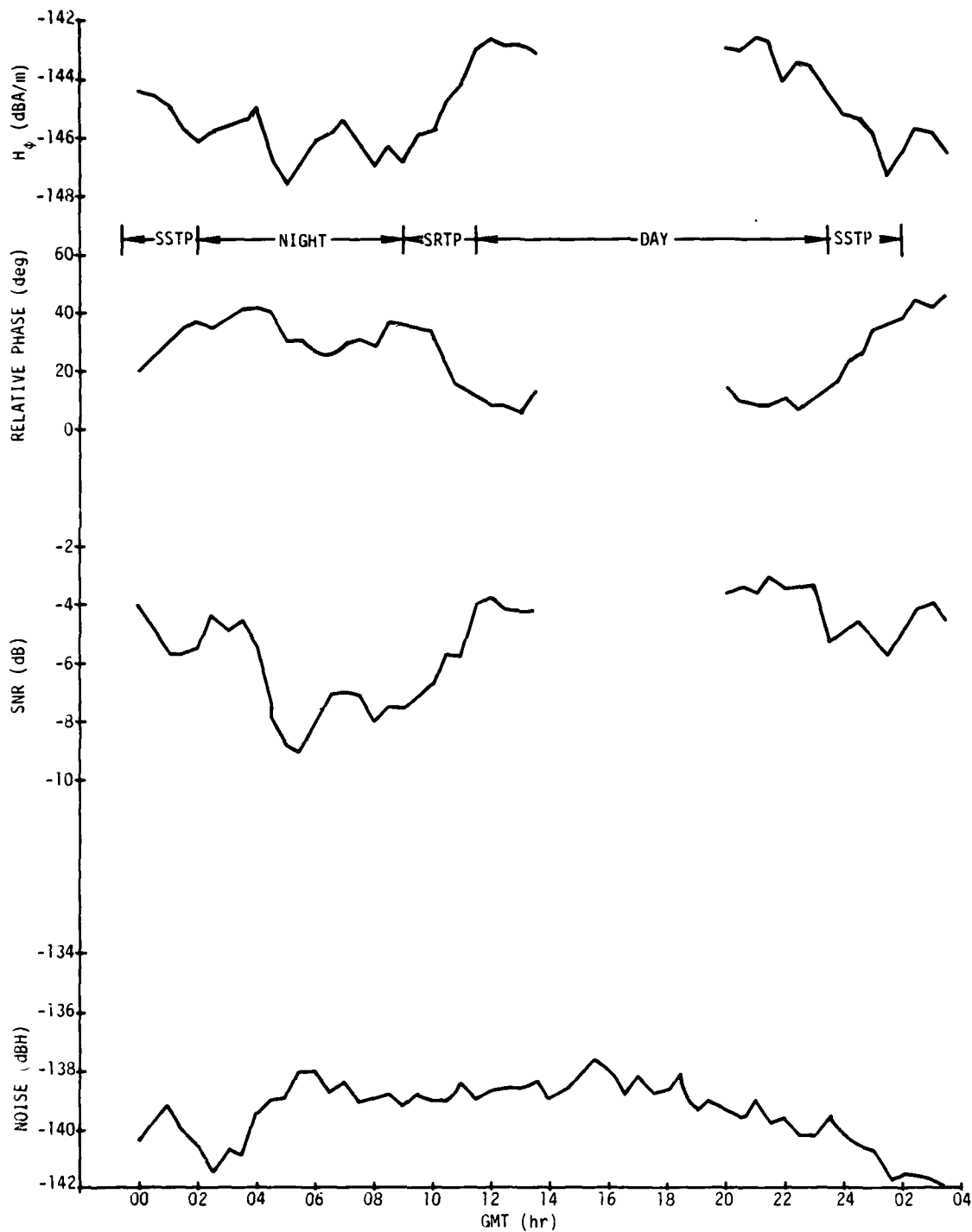


Figure B-3. Connecticut Data Versus GMT ( $\psi = 291$  deg),  
3 and 4 April 1977

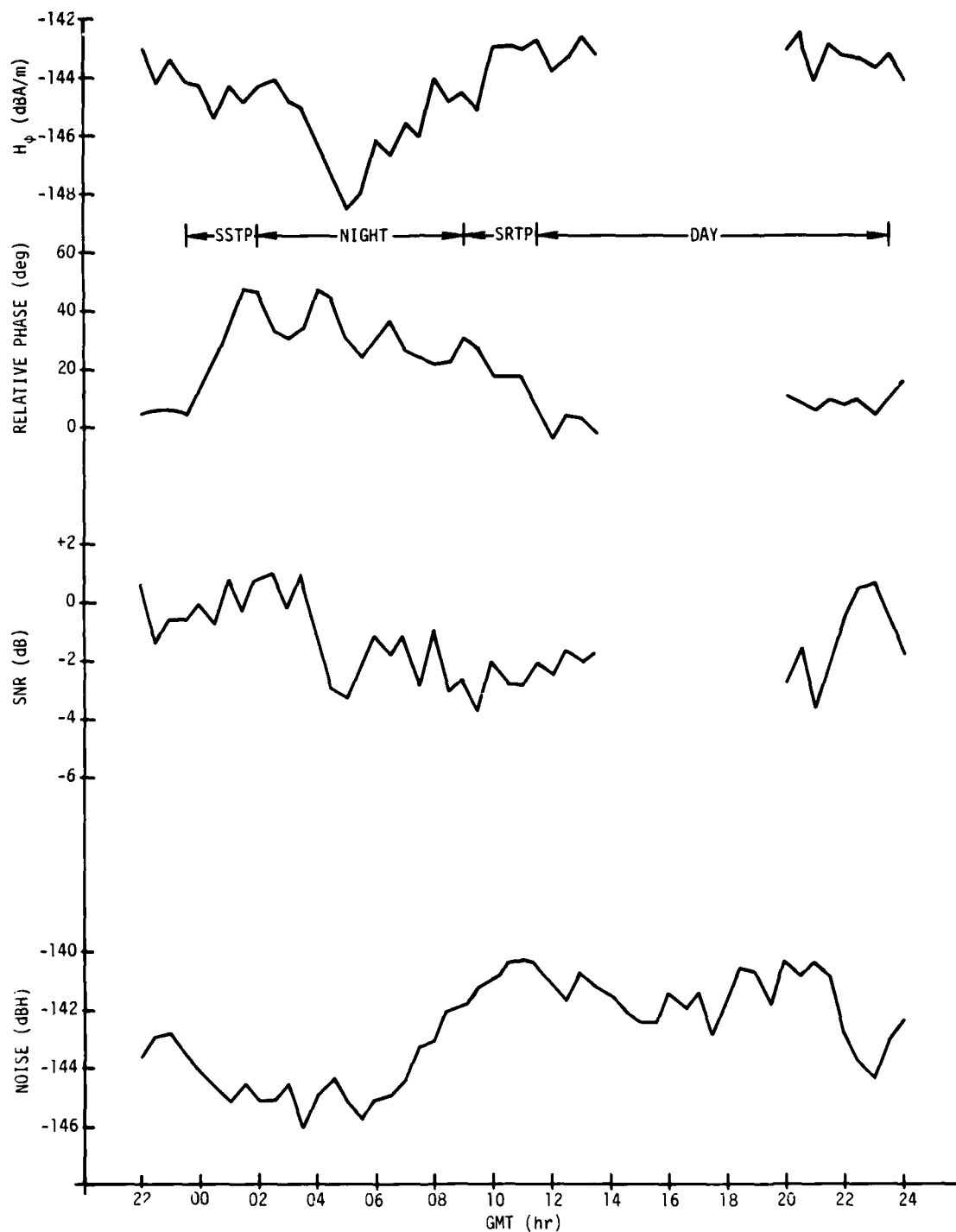


Figure B-4. Connecticut Data Versus GMT ( $\psi = 291$  deg), 6 April 1977

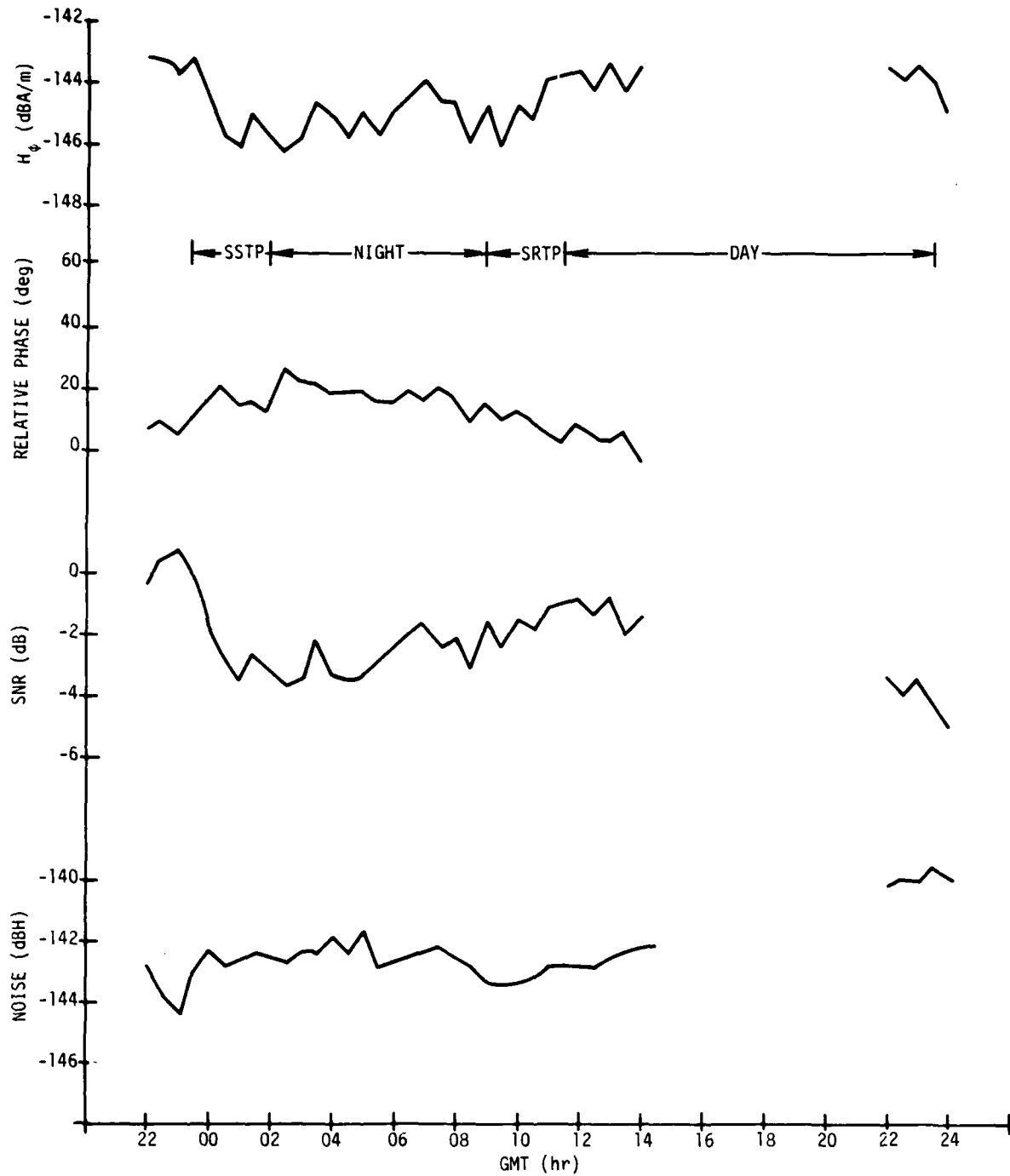


Figure B-5. Connecticut Data Versus GMT ( $\psi = 291$  deg), 7 April 1977

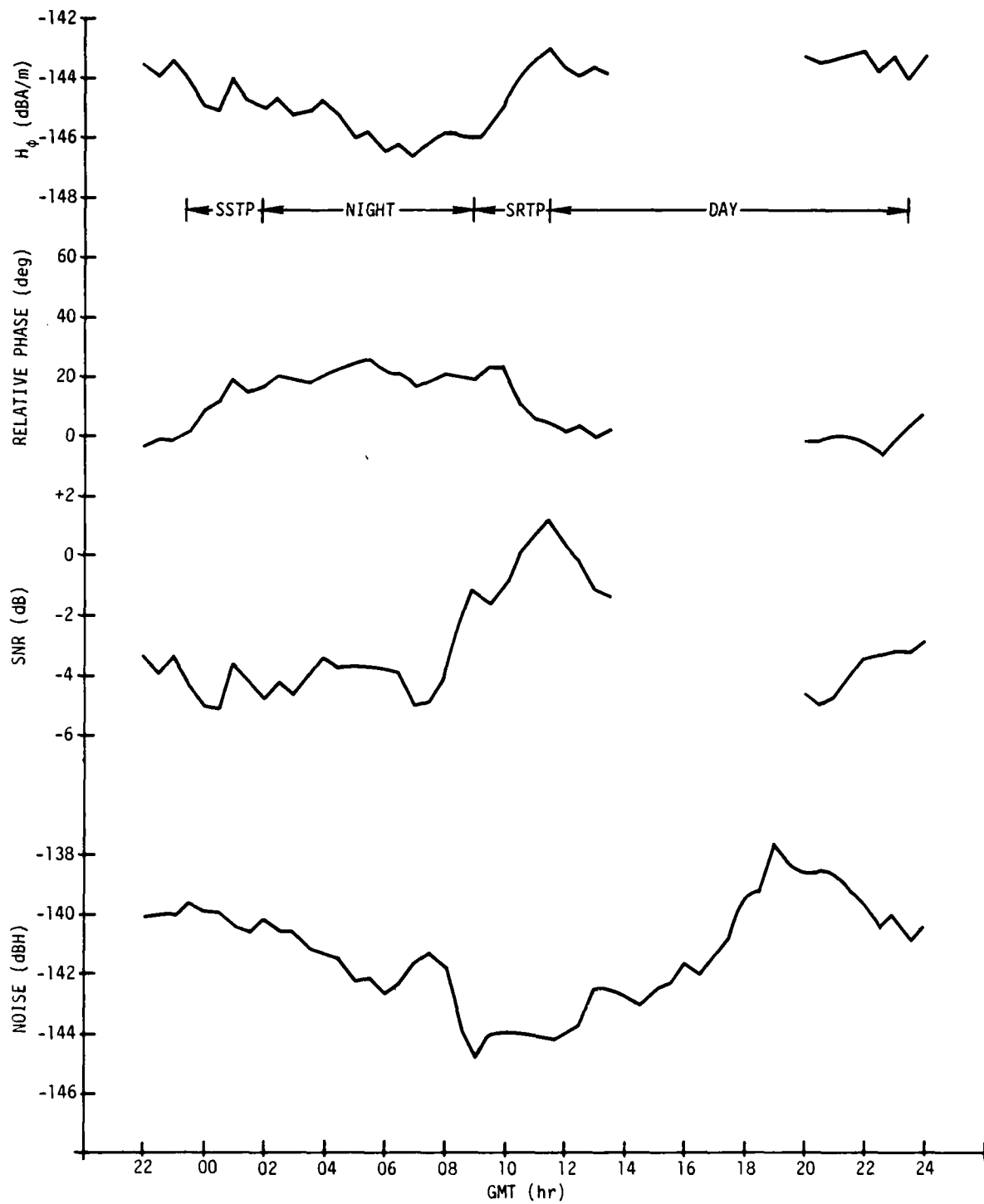


Figure B-6. Connecticut Data Versus GMT ( $\psi = 291$  deg), 8 April 1977

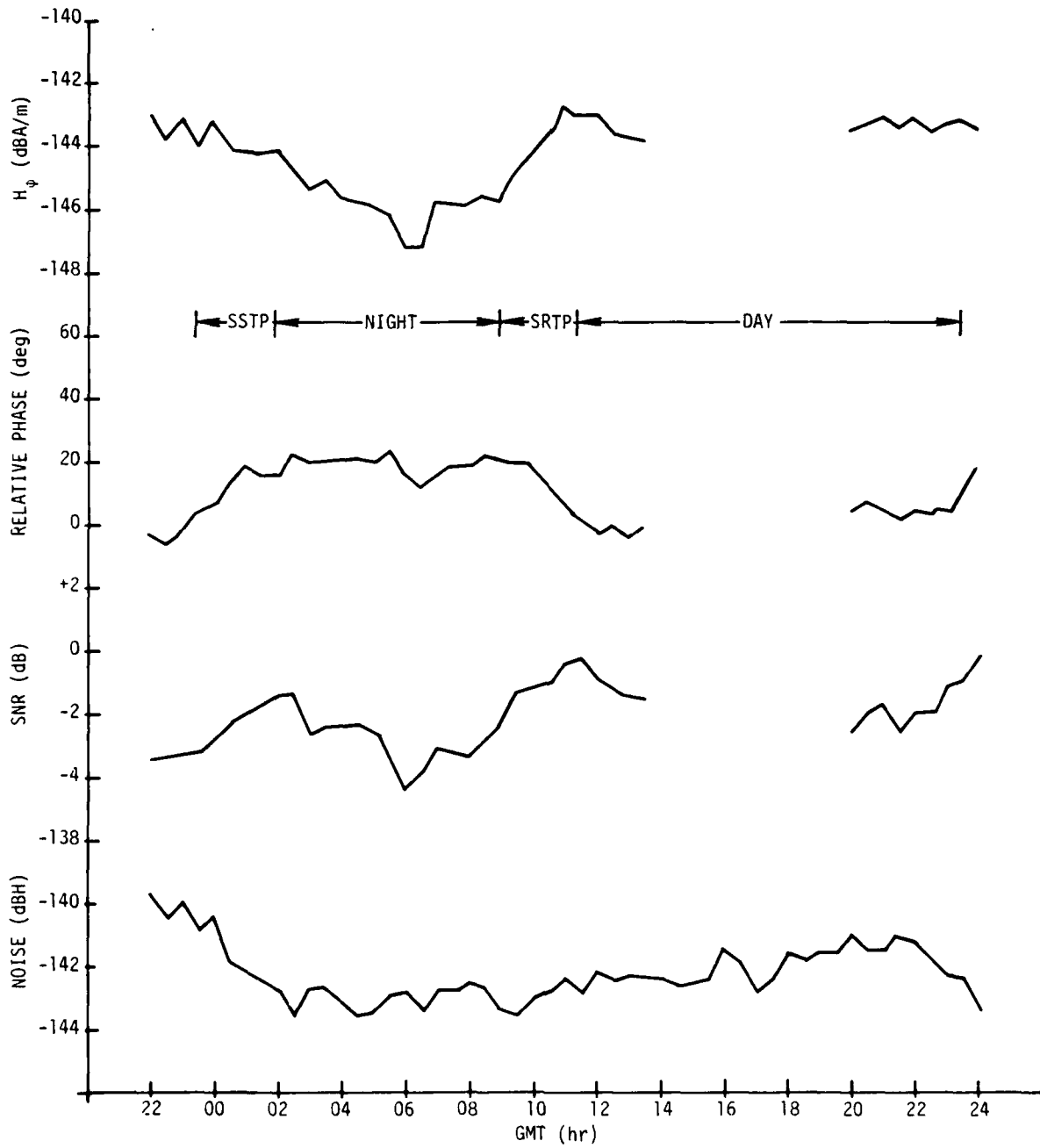


Figure B-7. Connecticut Data Versus GMT ( $\psi = 291$  deg), 9 April 1977



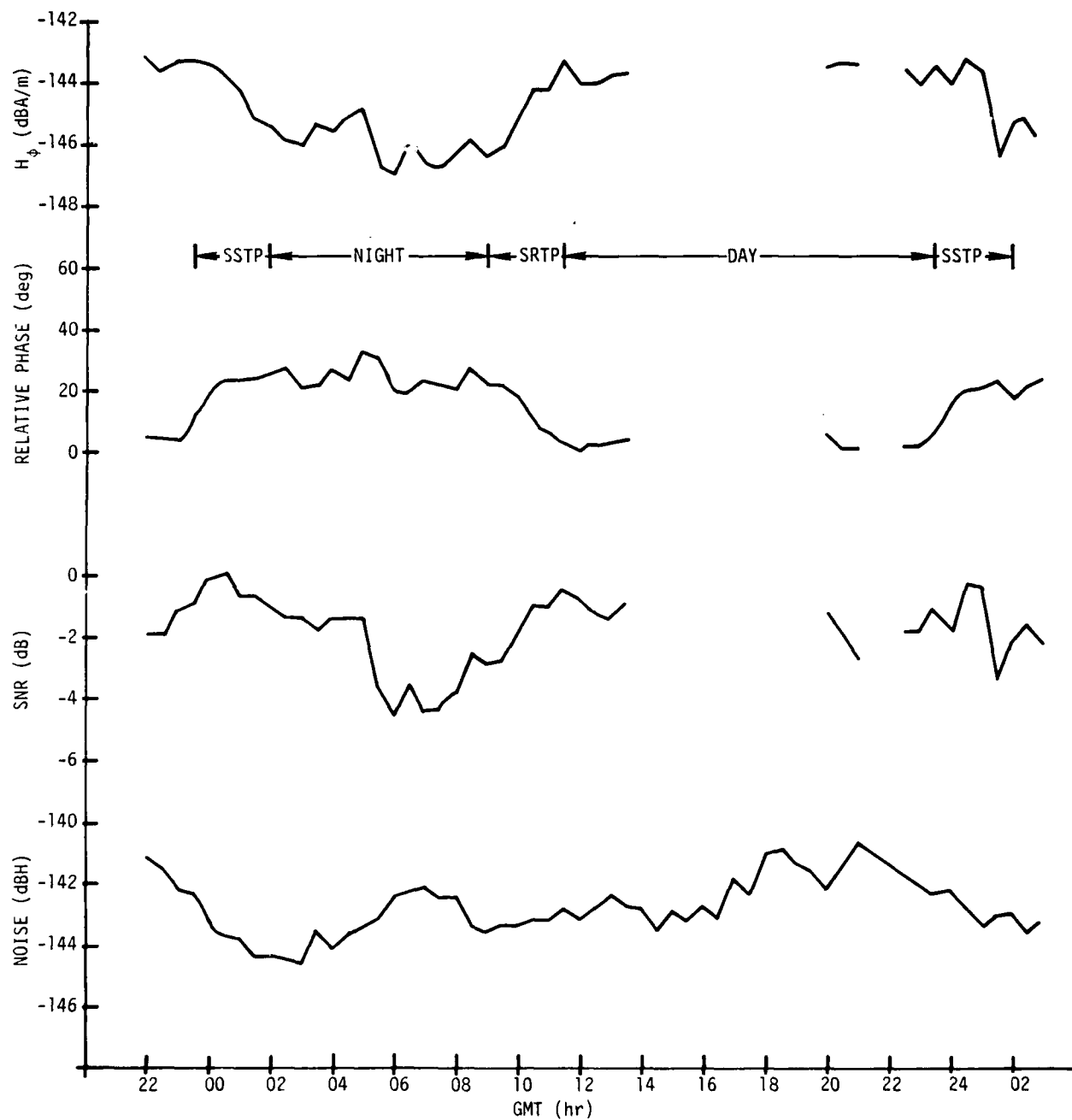


Figure B-8. Connecticut Data Versus GMT ( $\psi = 291$  deg), 10 April 1977

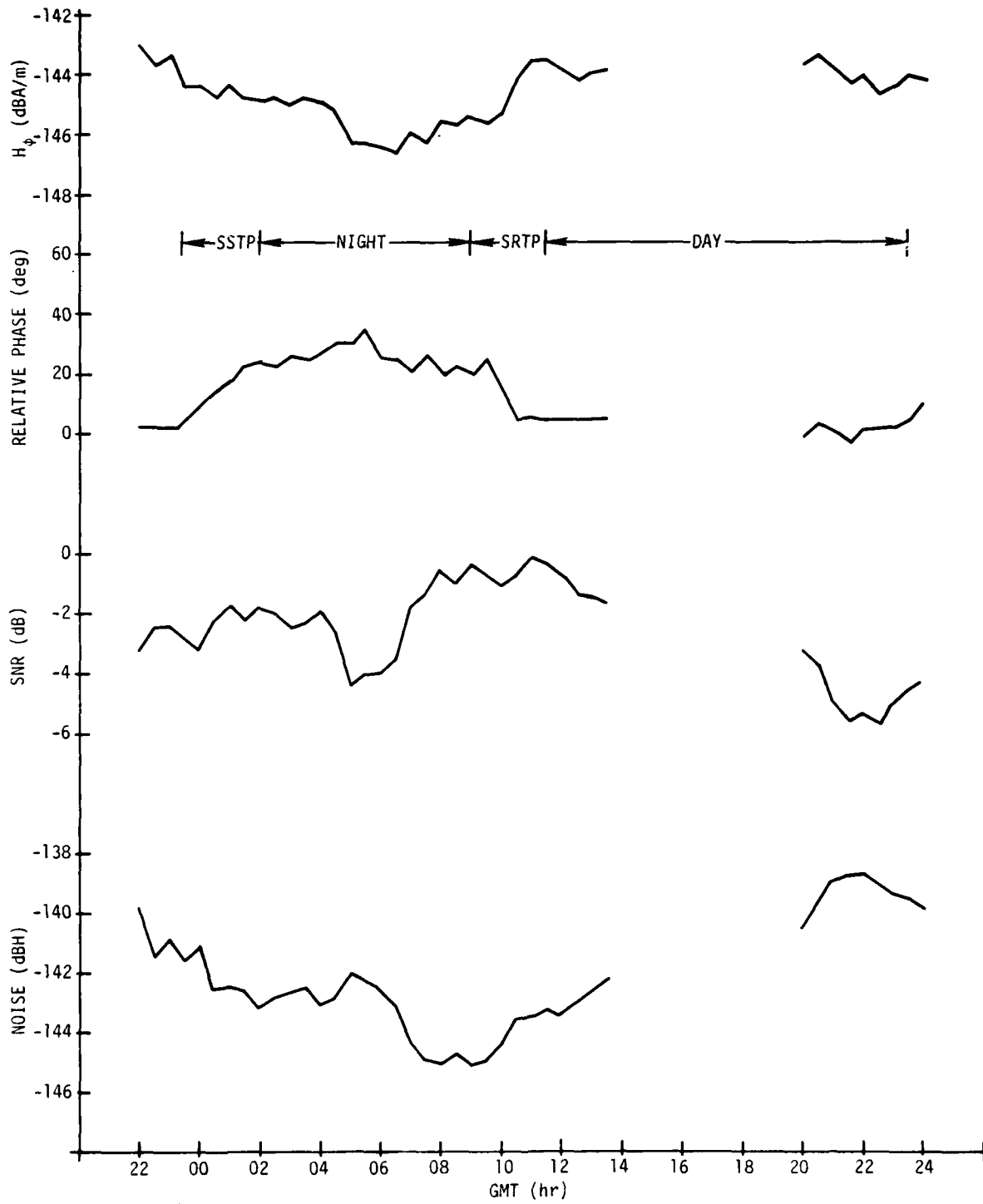


Figure B-9. Connecticut Data Versus GMT ( $\psi = 291$  deg), 12 April 1977

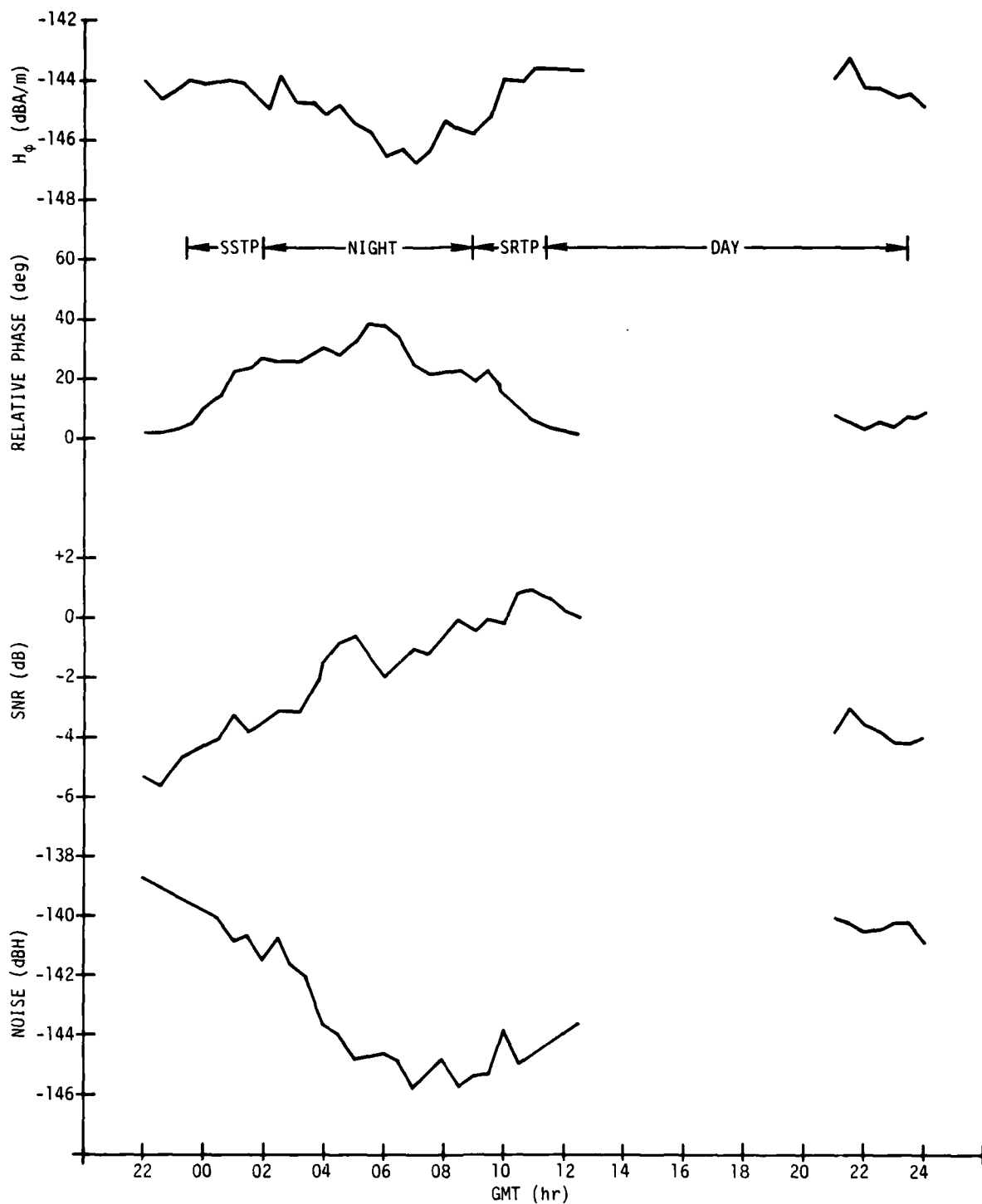


Figure B-10. Connecticut Data Versus GMT ( $\psi = 291$  deg), 13 April 1977

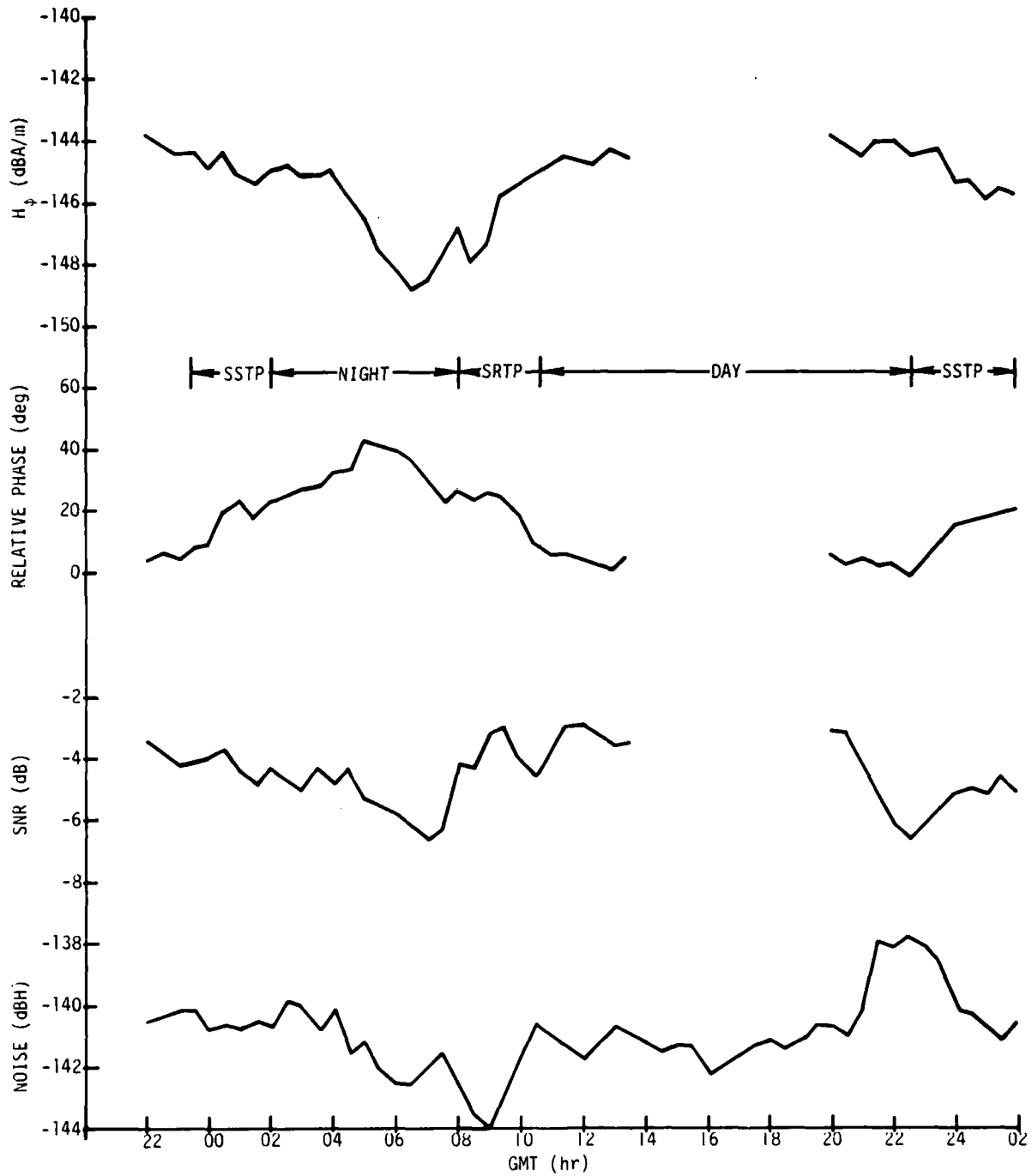


Figure B-11. Connecticut Data Versus GMT ( $\psi = 291$  deg), 14 April 1977

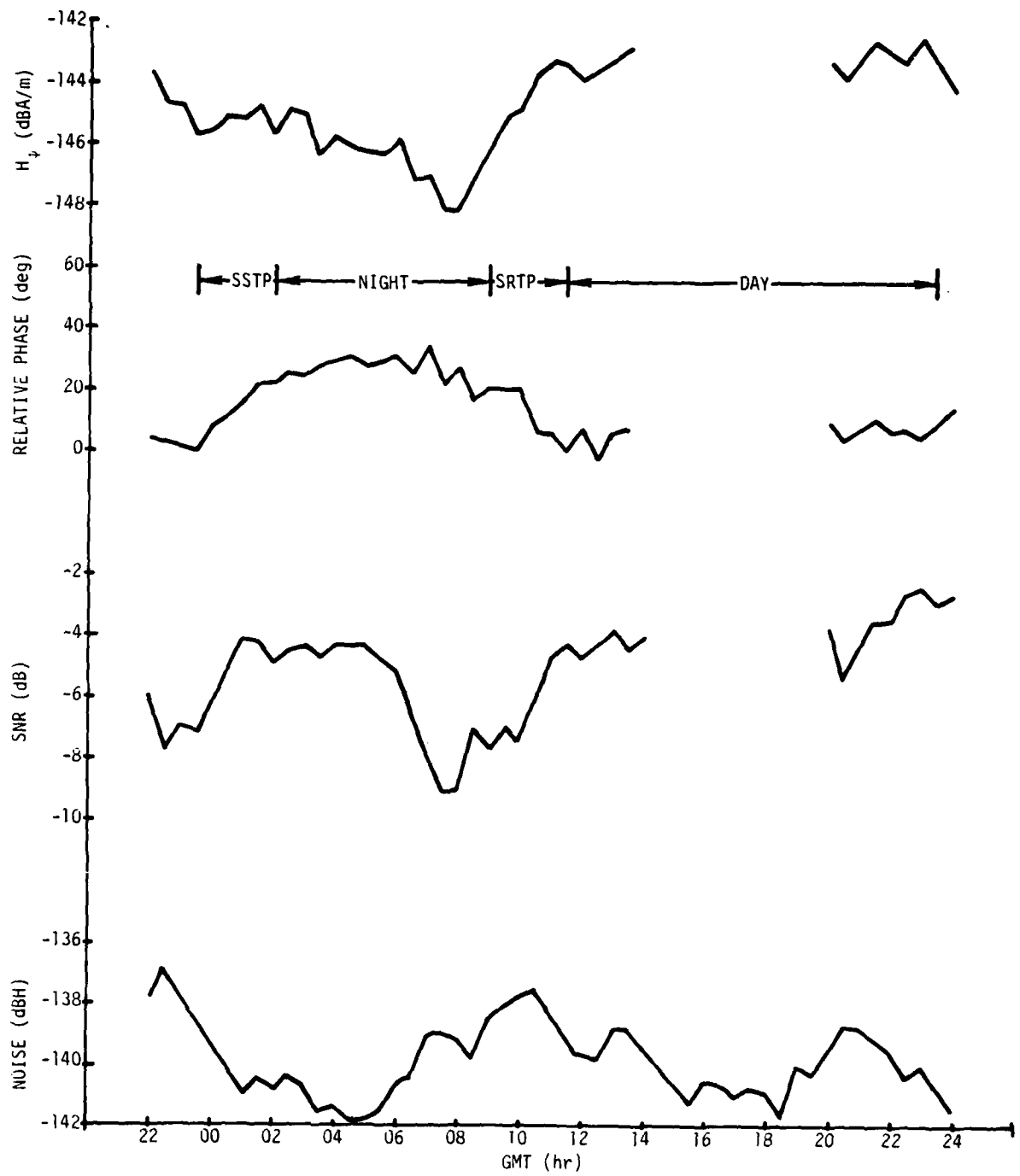


Figure B-12. Connecticut Data Versus GMT ( $\psi = 291$  deg), 16 April 1977

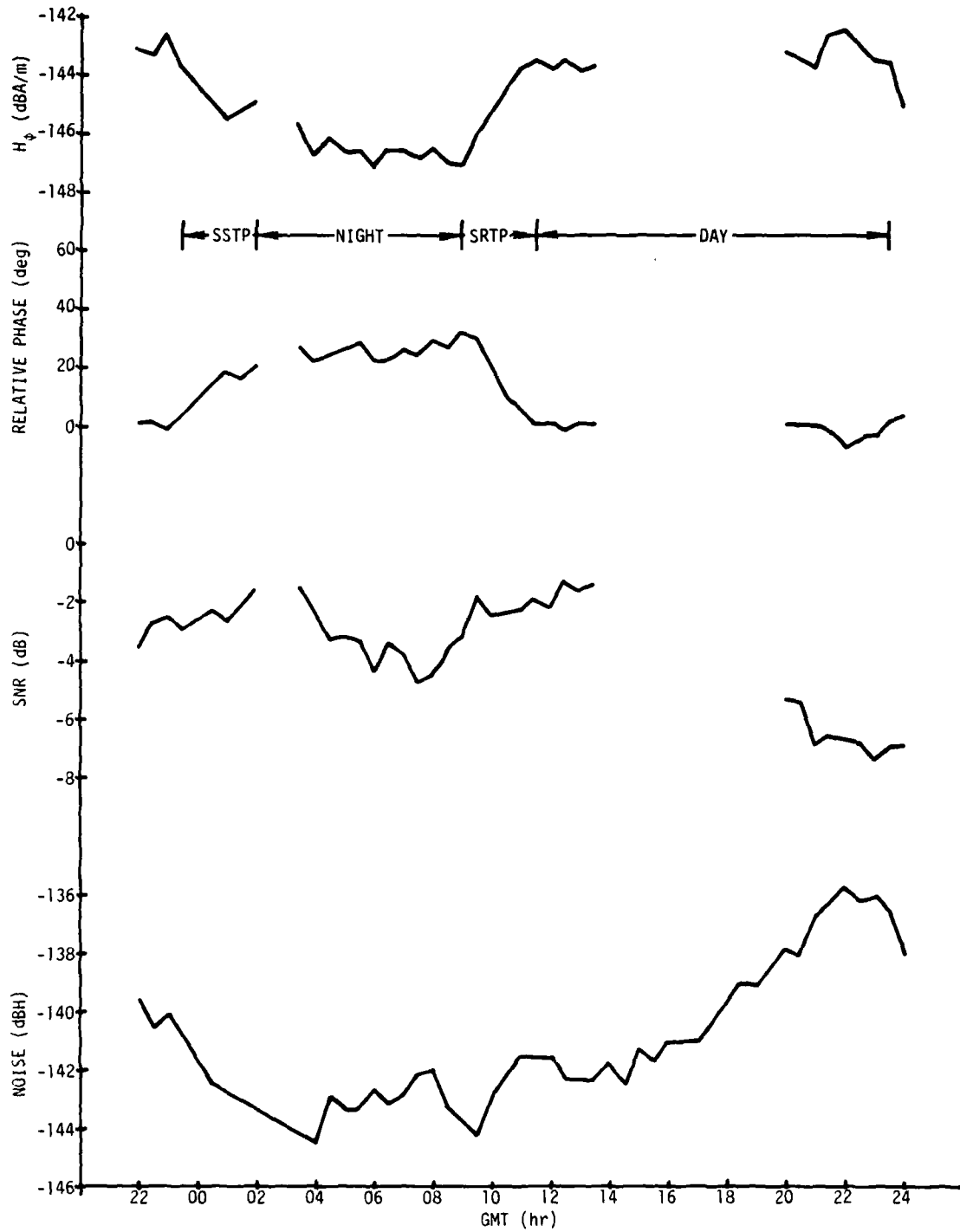


Figure B-13. Connecticut Data Versus GMT ( $\psi = 291$  deg), 17 April 1977

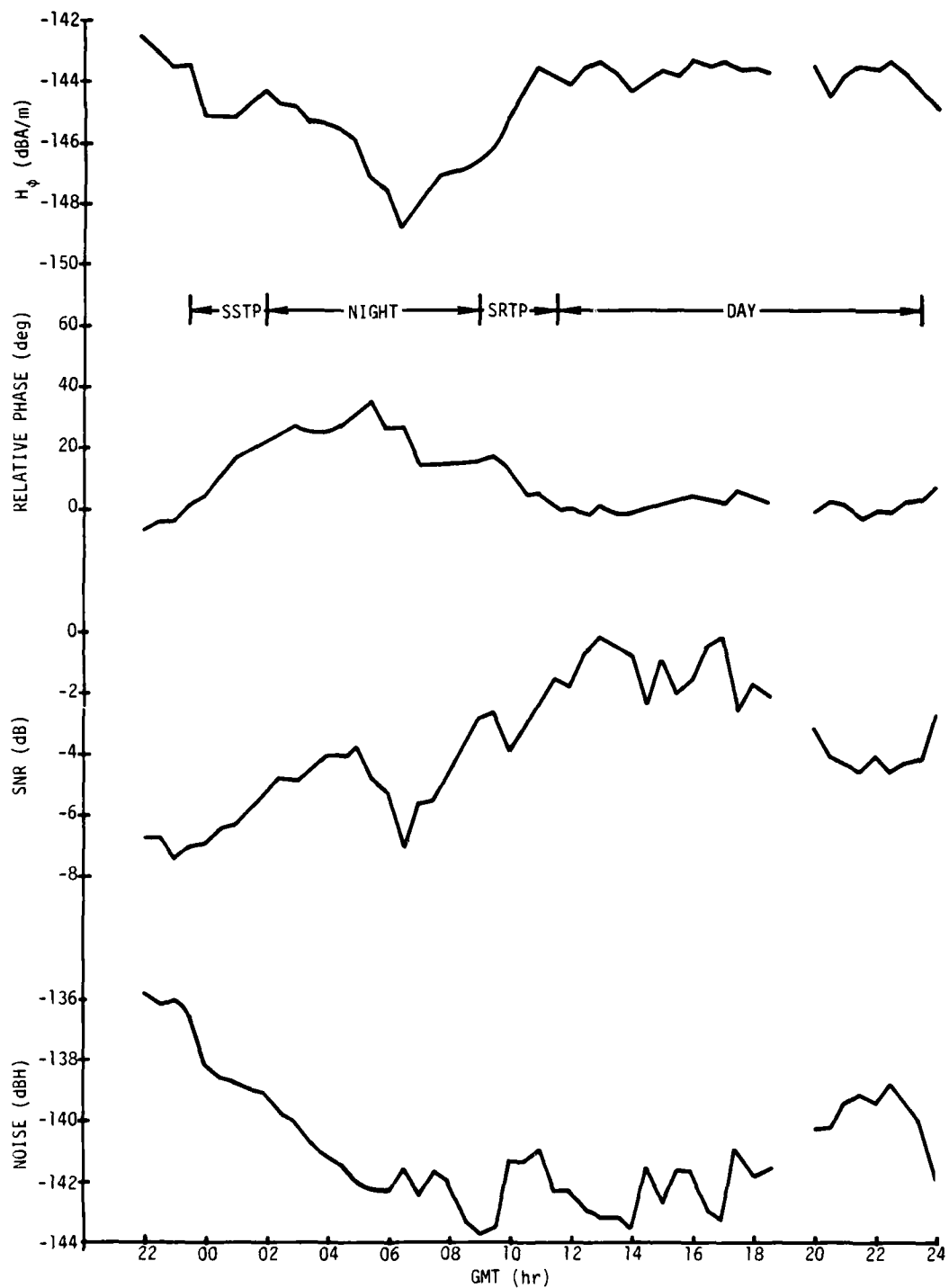


Figure B-14. Connecticut Data Versus GMT ( $\psi = 291$  deg), 18 April 1977

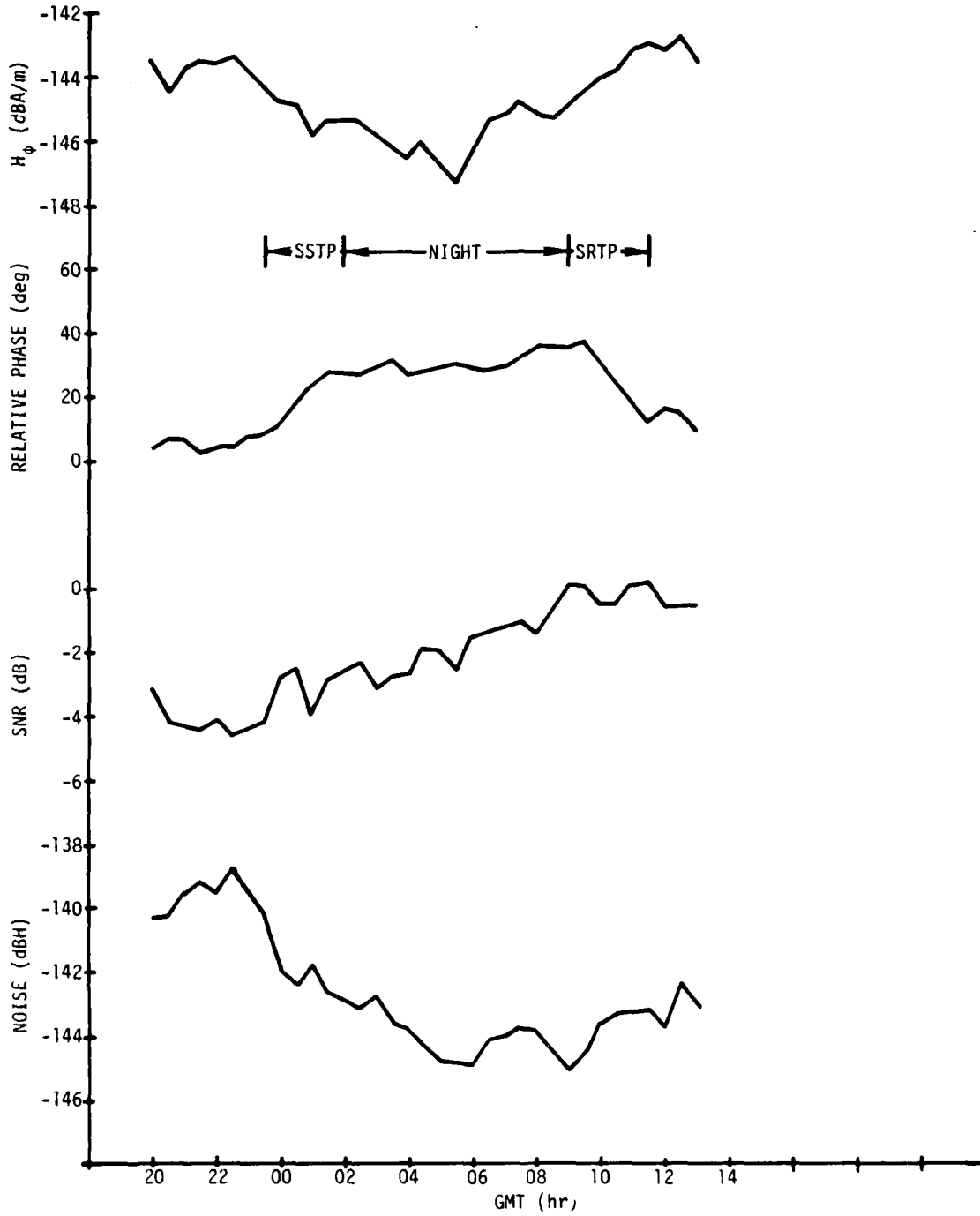


Figure B-15. Connecticut Data Versus GMT ( $\psi = 291$  deg), 19 April 1977



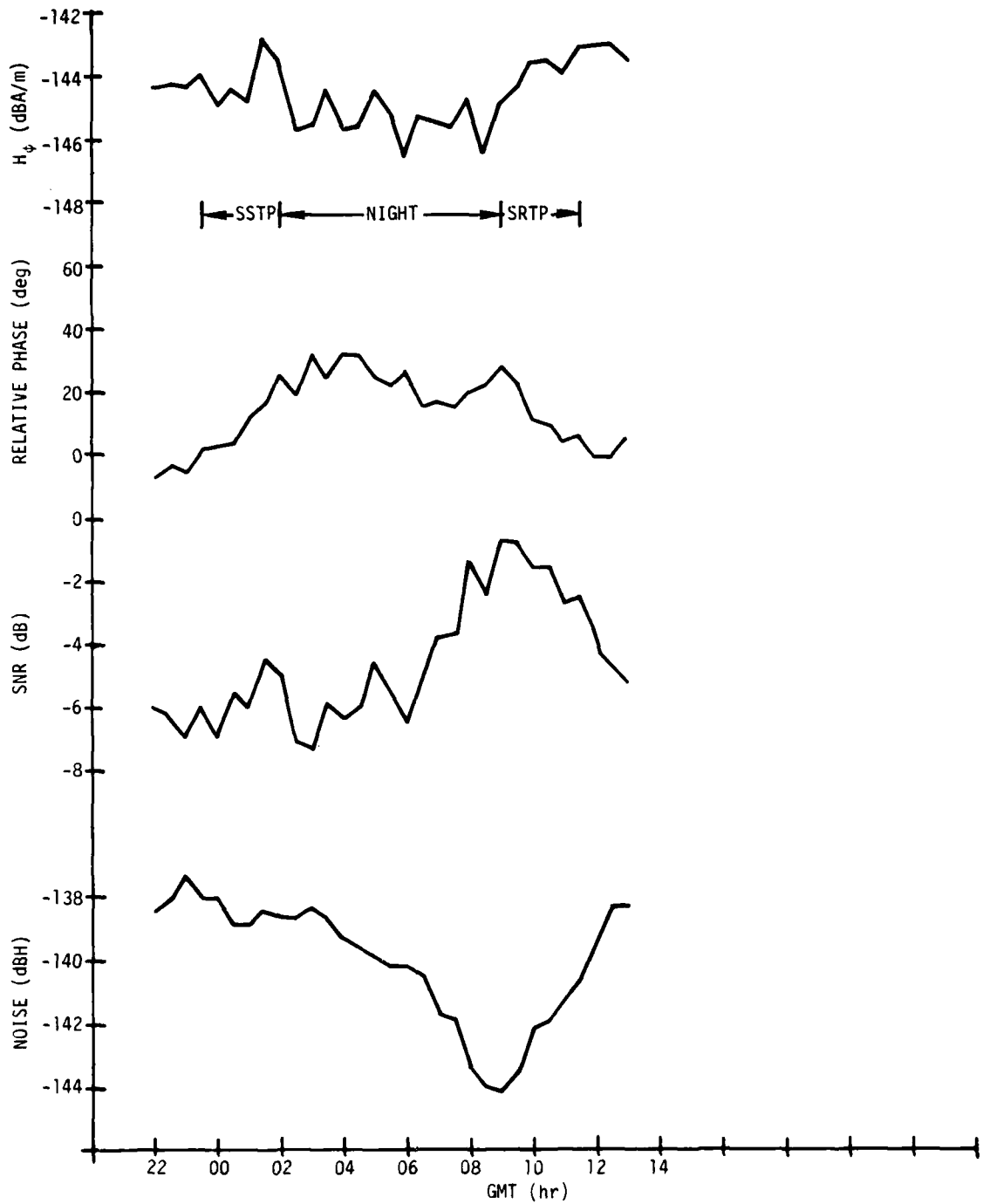


Figure B-16. Connecticut Data Versus GMT ( $\psi = 291$  deg), 20 April 1977

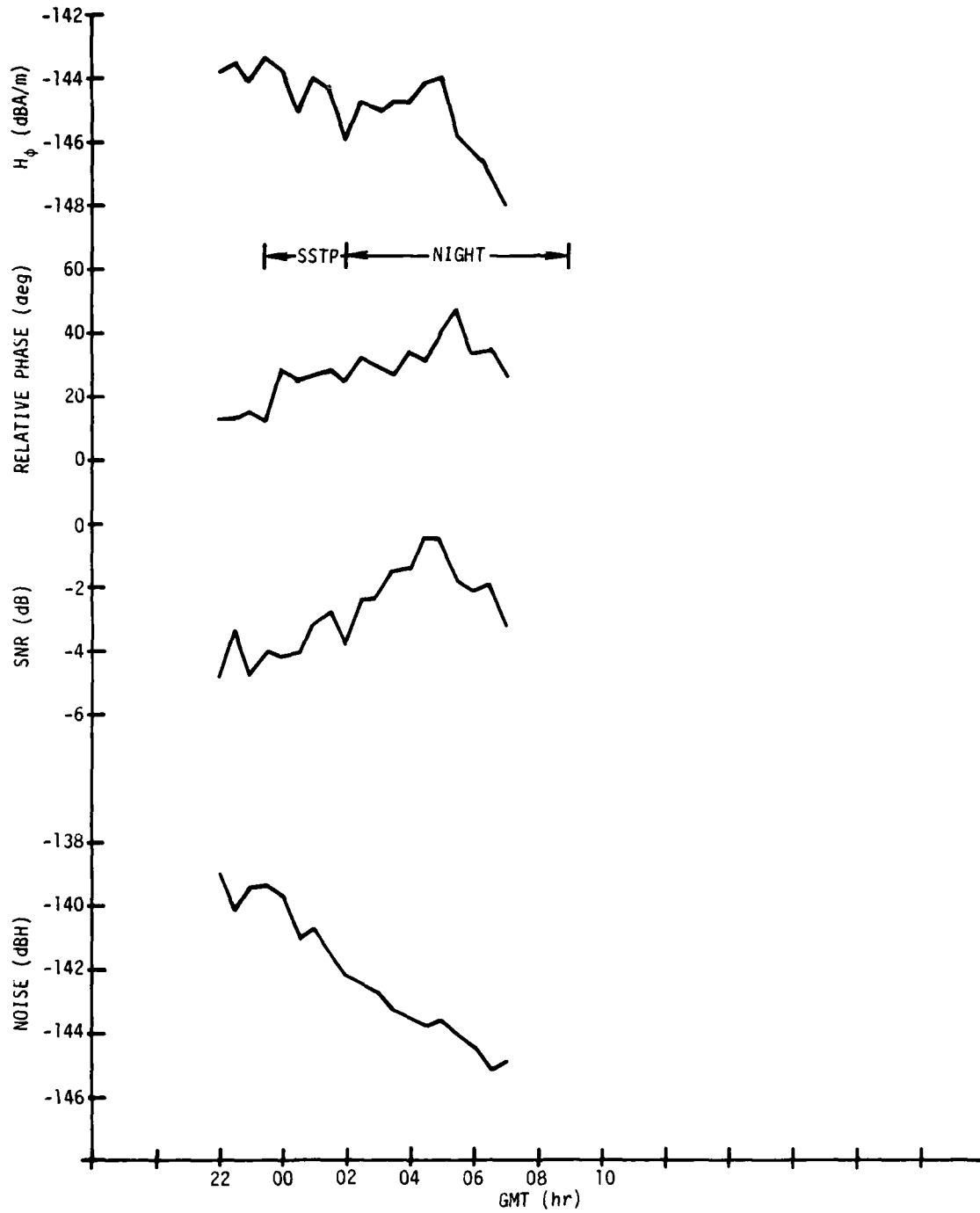


Figure B-17. Connecticut Data Versus GMT ( $\psi = 291$  deg), 21 April 1977

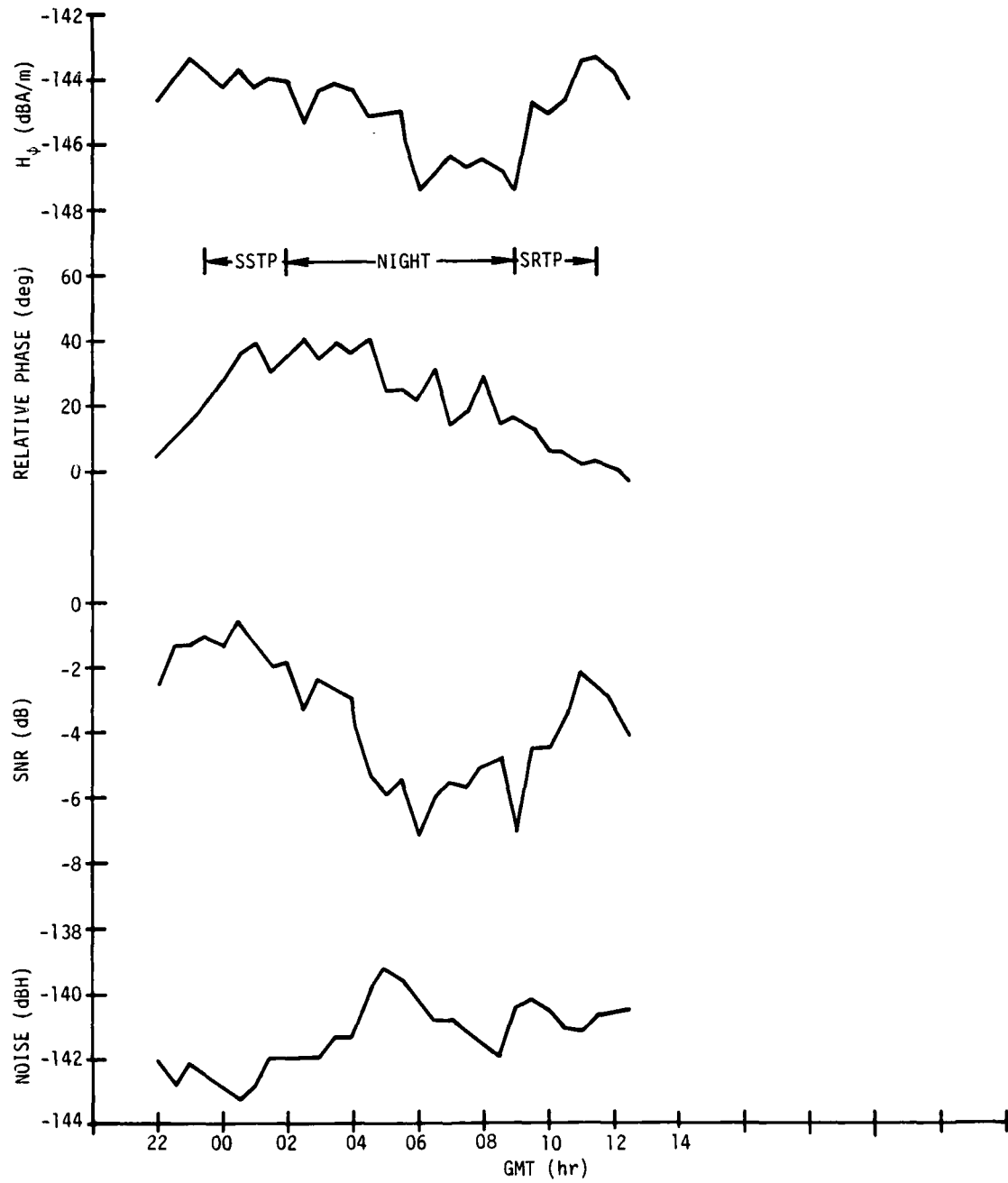


Figure B-18. Connecticut Data Versus GMT ( $\psi = 291$  deg), 22 April 1977

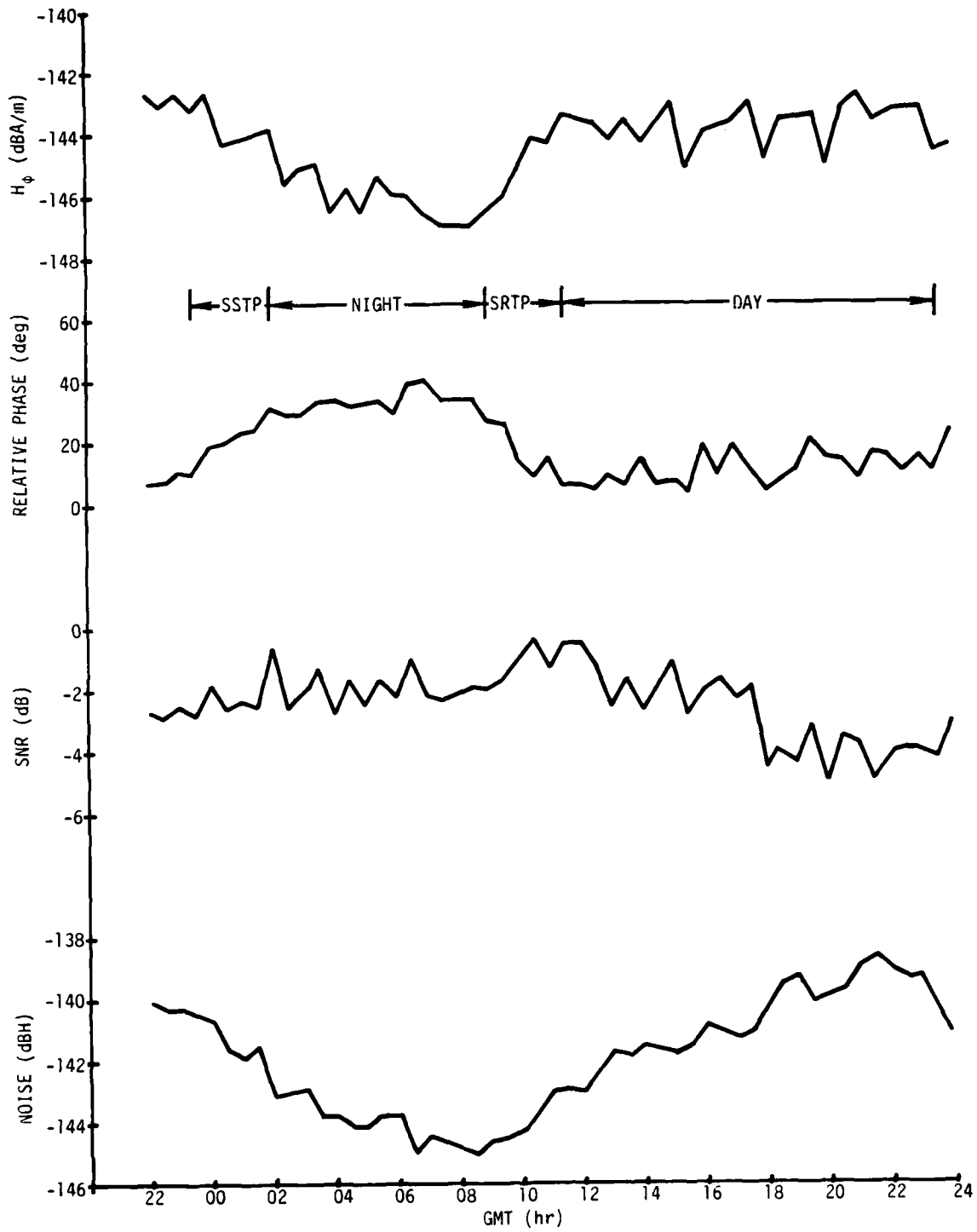


Figure B-19. Connecticut Data Versus GMT ( $\psi = 291$  deg), 23 April 1977

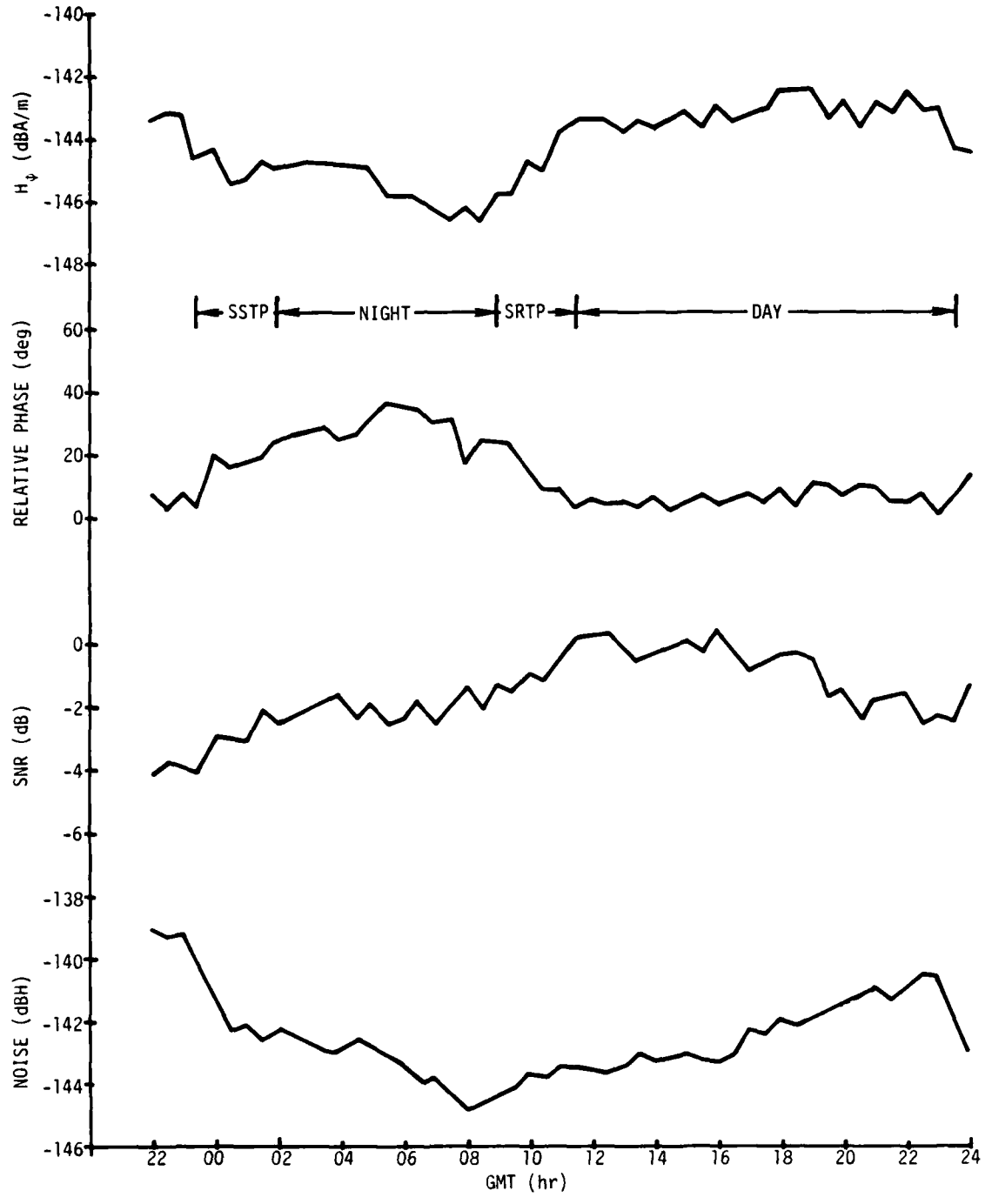


Figure B-20. Connecticut Data Versus GMT ( $\psi = 291$  deg), 24 April 1977

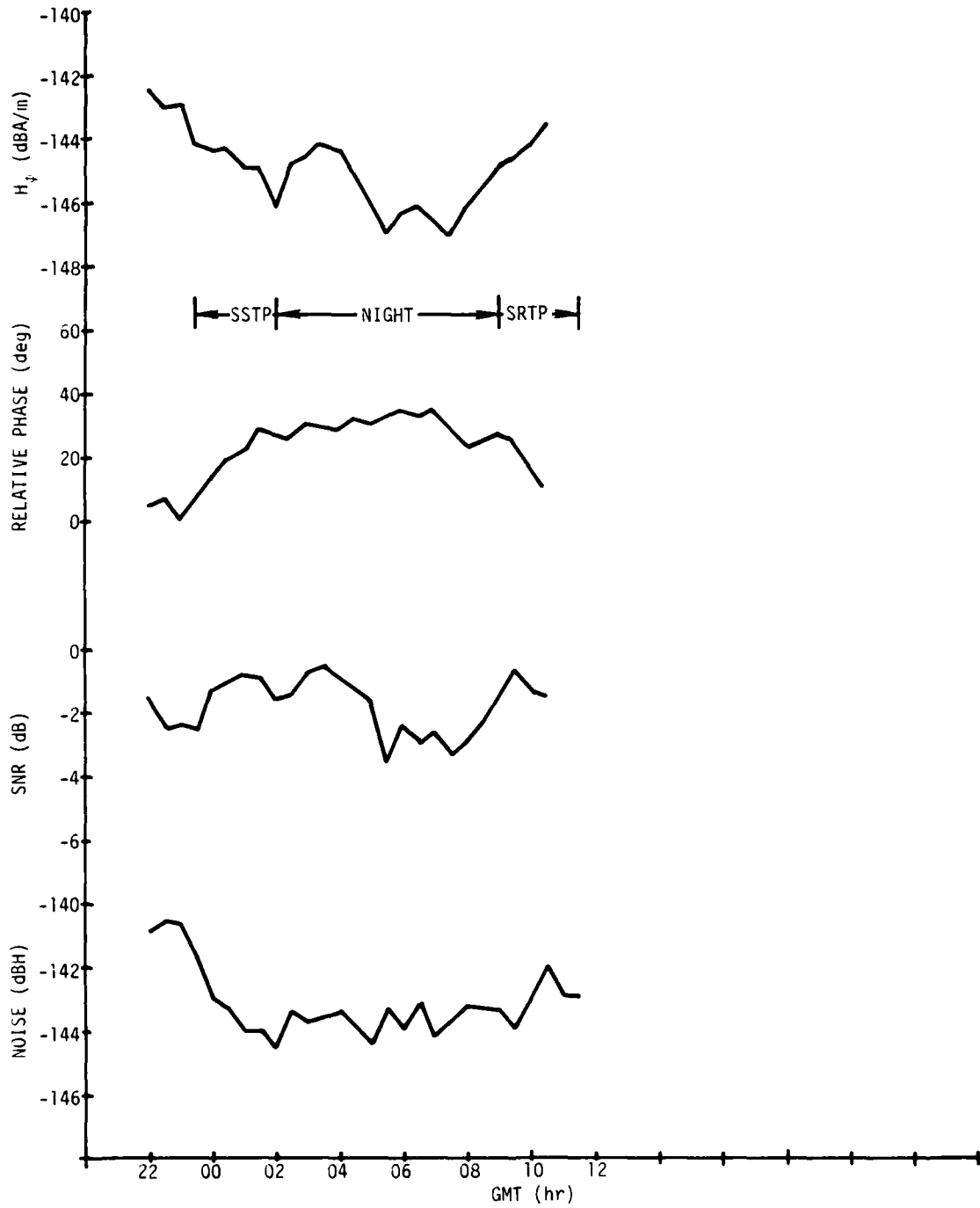


Figure B-21. Connecticut Data Versus GMT ( $\psi = 291$  deg), 25 April 1977

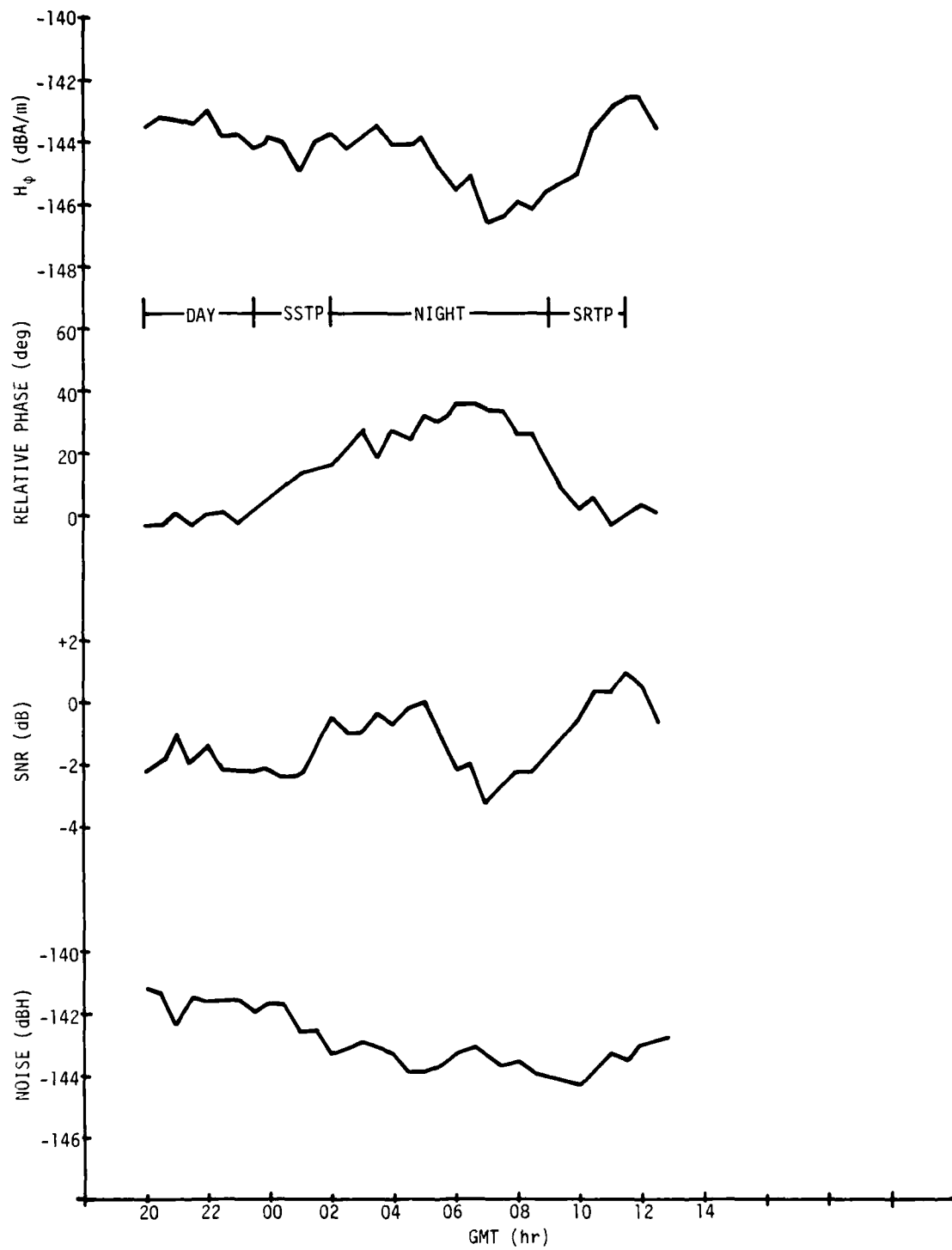


Figure B-22. Connecticut Data Versus GMT ( $\psi = 291$  deg), 26 April 1977

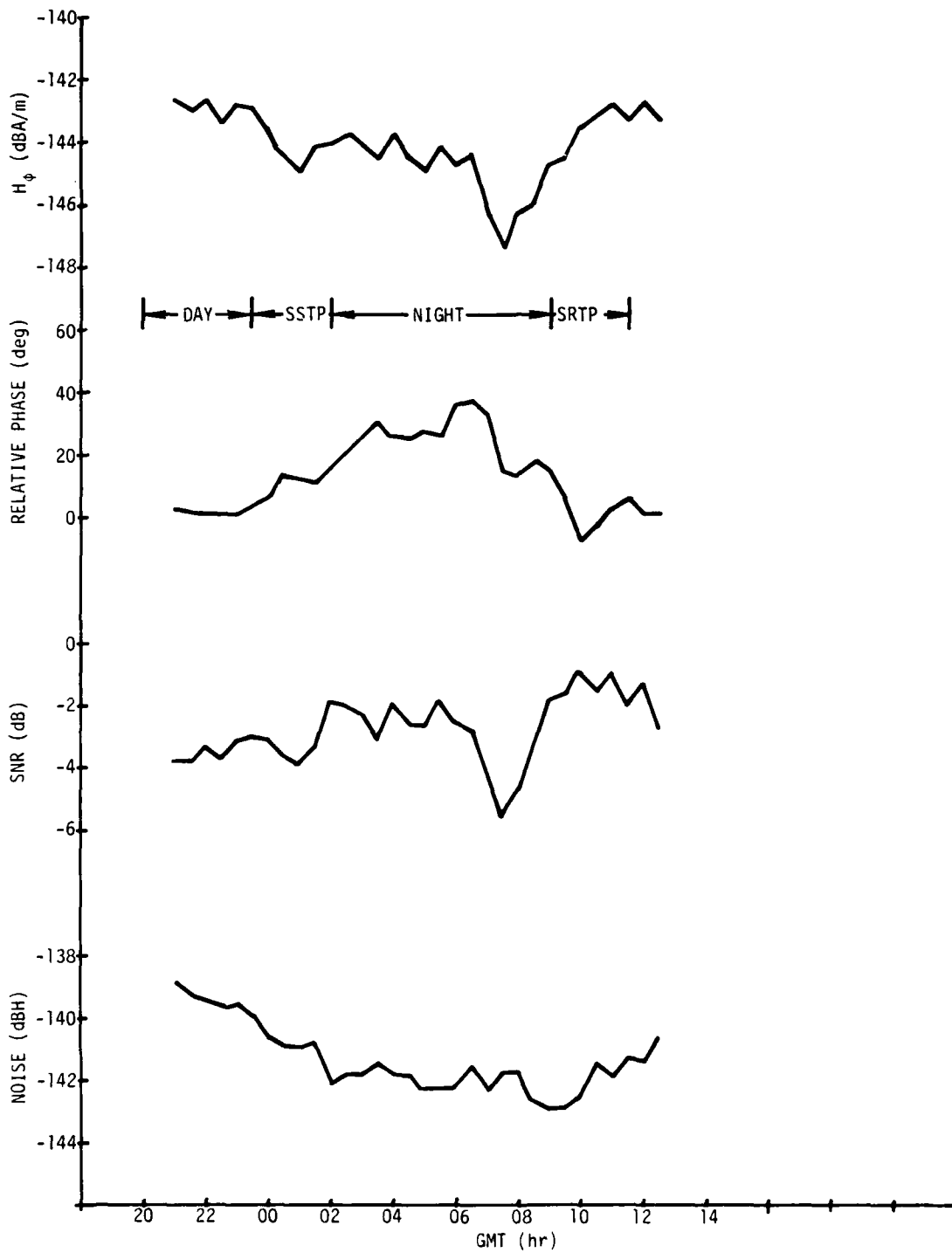


Figure B-23. Connecticut Data Versus GMT ( $\psi = 291$  deg), 27 April 1977



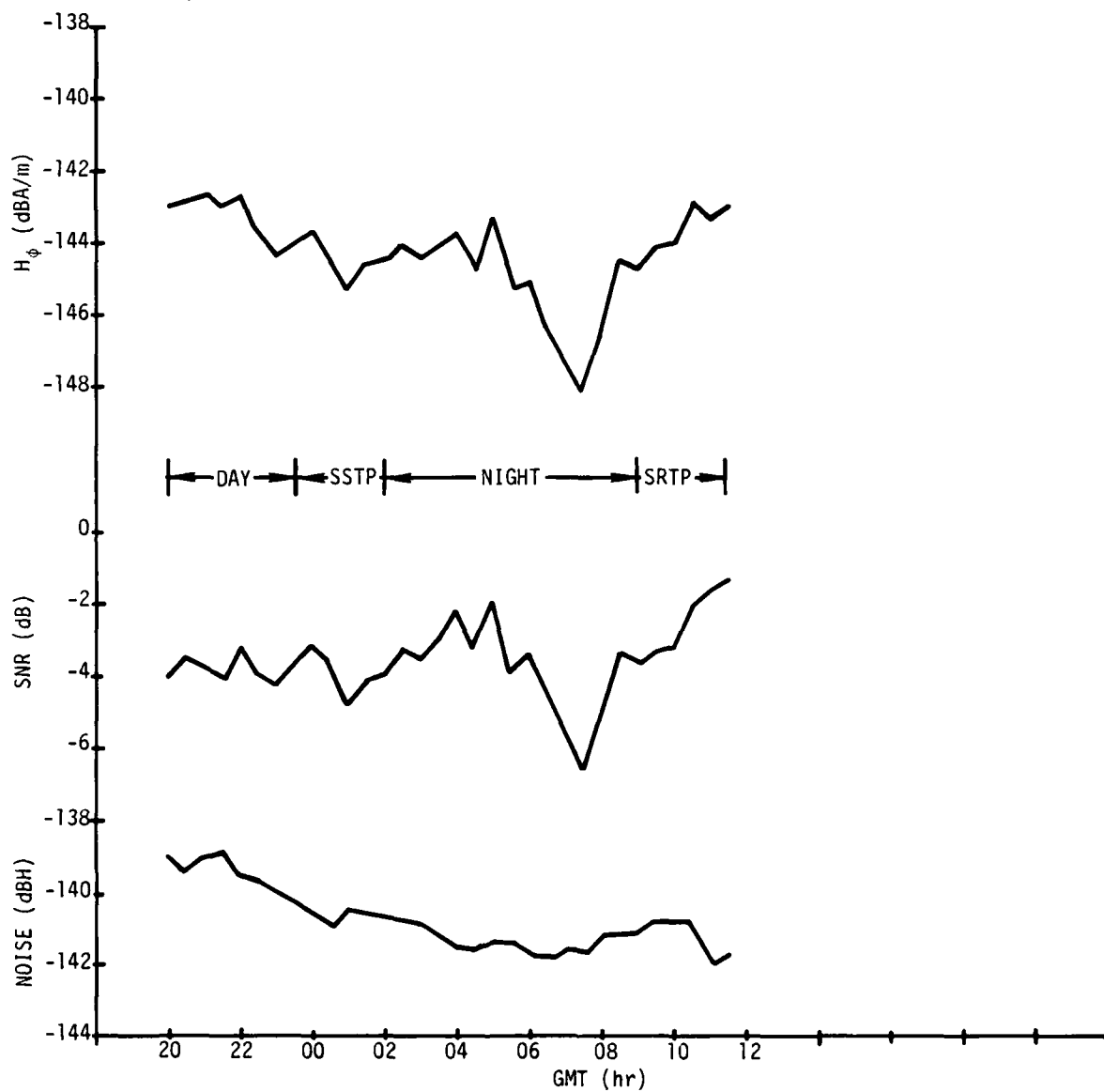


Figure B-24. Connecticut Data Versus GMT ( $\psi = 291$  deg), 28 April 1977

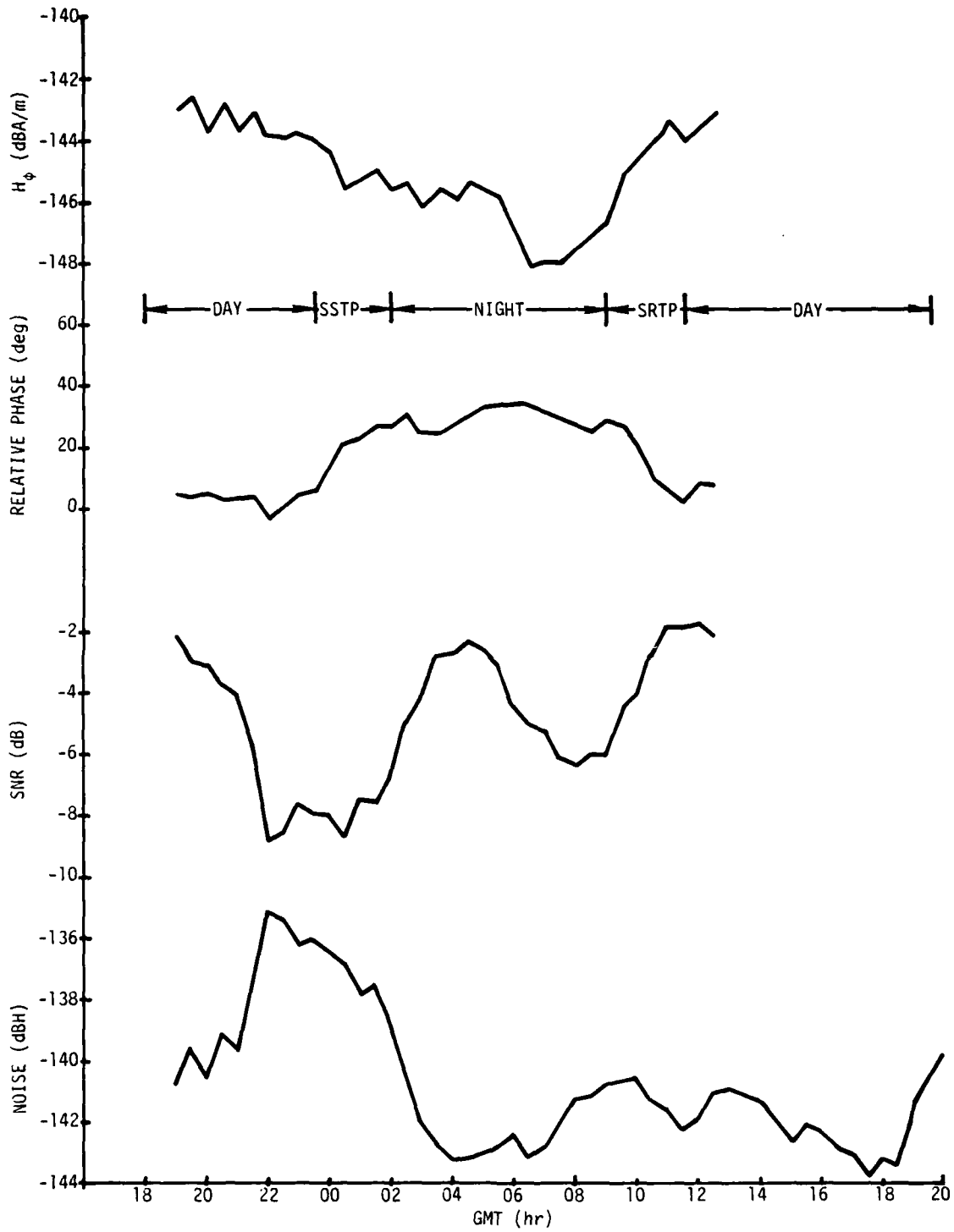


Figure B-25. Connecticut Data Versus GMT ( $\psi = 291$  deg),  
28 and 29 April 1977

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