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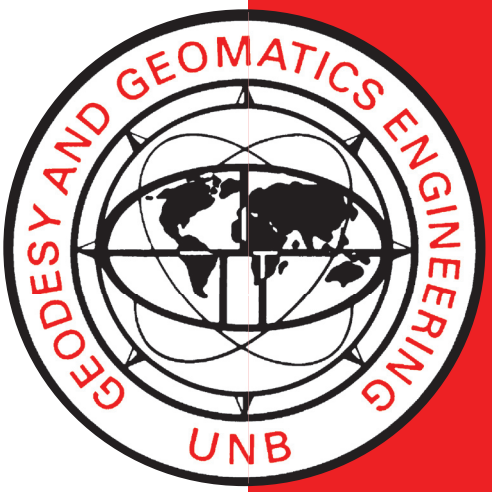

TECHNICAL REPORT
NO. 112

PREFACE

In order to make our extensive series of technical reports more readily available, we have scanned the old master copies and produced electronic versions in Portable Document Format. The quality of the images varies depending on the quality of the originals. The images have not been converted to searchable text.

EVALUATION OF CMA771 OMEGA RECEIVER PERFORMANCE ON PROJECT CESAR

BY

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1. INTRODUCTION

The Canadian Expedition to Study the Alpha Ridge (CESAR) took place between March and May of 1983 in the vicinity of latitude 86°N 110°W. Amongst the various navigation aids used was a Canadian Marconi CMA771 Omega Navigation System (ONS). Geodetic positions were displayed on the control display unit (CDU) and stored on cassette tapes.

Omega navigation positions from the CDU were manually logged every 12 hours during the operation of the receiver, and every 10 minutes during a 13-hour period (day 123-124).

Omega observation recordings on cassette tape were made during five, 24-hour time periods spread throughout the field program. Table 1 gives a list of the tapes accumulated and their approximate station locations, as derived from Transit satellite observations.

The 10-minute and 12-hour manually logged position determinations by the Omega receiver were compared with Transit positions and have been discussed in Wells [1984], thus are not repeated here. This report describes the processing and further investigations into the data stored on cassette tape at CMC. As of September 1984, 60% of the tapes had been analysed. This is sufficient to portray the performance of the CMA771 ONS at high latitudes. Presently, we at UNB do not have the capability to read the cassette tapes. Time limitations on the availability of the processing equipment at CMC makes it unlikely that the remainder of the tapes will be processed.

2. DATA PROCESSING

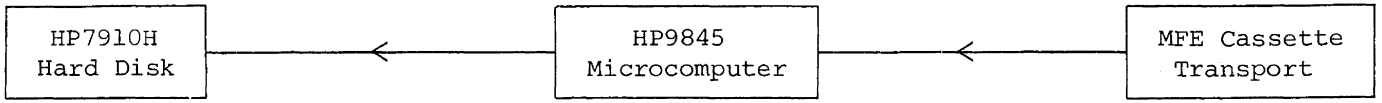
The cassette tapes at CMC were processed using the procedure and equipment outlined in Figure 1. The cassettes were read (using an MFE cassette transport model 250B) using the program NPDISC. The 30-second raw data frames were reformatted into various files. In addition to decoding the data, this program calculates and writes to disk differences between the assumed "true" position and the Omega-derived positions, along with differences between the predicted (from the "true" position) and observed Omega phase measurements. Processing time for one cassette tape is about 8 to 9 hours.

TABLE 1

CESAR Omega Data Cassette Log.

Session	Tape	Period (From/To)				Location	
		Day	Date (YY:MM:DD:HH:MM)	Day	Date (YY:MM:DD:HH:MM)	(N)	(W)
1	1	93	83:4: 3:10:02	93	83:4: 3:23:05	85°48!7	110°58!0
	2	93	83:4: 3:23:05	94	83:4: 4:12:50	85°48!5	110°50!0
2	1	103	83:4:13:02:15	103	83:4:13:15:14	85°45!7	110°51!3
	2	103	83:4:13:15:14	104	83:4:14:04:30	85°48!8	110°30!5
3	1	114	83:4:24:11:54	115	83:4:25:00:30	85°52!2	108°41!2
	2	115	83:4:25:00:30	115	83:4:25:15:30	85°52!2	108°41!2
4	1	123	83:5: 3:00:00	123	83:5: 3:13:37	85°51!4	108°39!7
	2	123	83:5: 3:13:38	124	83:5: 4:02:40	85°51!9	108°22!0
5	1	134	83:5:14:00:00	134	83:5:14:13:41	85°50!9	108°17!7
	2	134	83:5:14:13:42	135	83:5:15:02:30	85°50!5	108°23!1

NPDISC



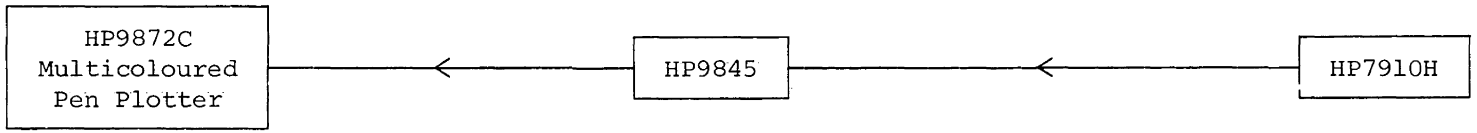
Compute

theoretical phases
phase errors
position errors
max-min values

Extract

diurnals (PPCs)
received phases
SNR, positions
log, geometric
quality and
accuracy

STUDYH



Compute

LOP errors
smoothed LOP errors
and SNRs

FIGURE 1

Processing Chart at CMC.

Several files are created by NPDISC on the hard disk. These files are then read by the program STUDYH, and graphs are plotted on the HP-9872C multicoloured pen plotter. Plotting time for the data from one cassette can be as long as 15 hours, but varies depending on the type of plots required. A standard set of plots for one cassette would be:

-- 1 location and world map
-- 1 flight profile
-- 1 lines of position errors: all frequencies, smoothed
-- 3 lines of position errors: single frequency, unsmoothed
-- 1 signal to noise ratio: all frequencies, smoothed
-- 3 signal to noise ratio: single frequency, unsmoothed
-- 1 diurnals: all frequencies.

The purpose of this software is to analyse the performance of the CMA771, including its built-in position fix algorithms. No fixes are recomputed in the post analysis--only the real-time results are presented. The results shown here have already been used by Canadian Marconi in the improvement of models and algorithms for their most recent Omega receivers [Baillie, 1984].

3. DESCRIPTION OF PLOTS

Program STUDYH is capable of displaying the recorded information in several predetermined formats. The program works out the plotting scale.

3.1 Flight Profile

The flight profile plot enables a general assessment of the performance of the receiver over a selected time span. It graphically portrays the quality and accuracy estimates based on the geometric configurations of the transmitting stations with respect to the receiver along with position and components of position differences between the adopted reference and observed positions.

3.2 SNR Index

The signal to noise ratios read from the cassette tapes portray the signal strength and quality. Effects of modal and local harmonic interferences are clearly displayed. The time constant, which represents

the smoothing parameter, can be varied. Unsmoothed ratios are obtained when the time constant falls below 10 seconds. In general, phase measurements are discarded (not used in the position fix) when their SNR falls below 7, and are used again when their SNR becomes greater than 13.

3.3 LOP Errors

The lines of position (LOP) errors are the differences between the predicted and observed range-difference (hyperbolic) lines of position for each Omega transmitter, with respect to one transmitter chosen as the reference station. As with the SNR index plots, a selectable time constant represents the smoothing parameter for the individual LOP errors. Unsmoothed LOP errors are plotted when the time constant falls below 10 seconds. In place of the LOP error plot for the reference station, the receiver station tracking log is displayed.

3.4 Diurnals

The diurnals are the predicted propagation corrections (PPC) that were computed by the receiver/processor and used to correct the propagation medium effects on the signal wave. Recorded phase measurements are uncorrected for diurnal effects.

3.5 World Map

In addition to the above, program NPOLE draws a map of the world with longitude and latitude lines on either the transverse Mercator or the polar stereographic projection. In addition, it has a long list of possible overlays on the world map. These include position markers, vectors to station sites and labels for receiver positions, highlighting ice shadow zones, and day and night lines.

4. DISCUSSION

Due to time and equipment access restrictions at CMC, only three of the five tape sessions have been processed. These are session 1, tape 1 and 2; session 2, tape 1 and 2; and session 4, tape 1 and 2 (see Table 1).

The flight profile for each of the tapes displays an overall summary of the Omega position estimates against an assumed stationary

"true" value for the CESAR camp position. The actual CESAR camp motion between the beginning and end of these three Omega observing sessions was 1.5 km, 7.3 km, and 3.1 km for sessions 1, 2, and 4 respectively (extracted from SATNAV positions [Wells, 1984]).

The observed Omega-derived positions exhibited position changes (with respect to the assumed stationary CESAR position) which are less than 10 km, except for session 1.

For session 1, the difference between Omega and reference position changes from an offset of about 3 km at the start of the session to about 35 km at the end of the session. This progressive deterioration of position estimates could have been the result of long signal paths from southern hemisphere stations, having a low SNR, which would cause a rapidly changing tracking status (stations being included and excluded from the solution). Jumps in the radial displacements are observed whenever the station from Australia is included or excluded from the least-squares position estimates. No lane ambiguity resolution techniques are used, so lane slips are not detected, nor are "outliers" rejected from the solution. The effect of a lane slip is difficult to detect since it is diluted in the estimation process by all the other measurements. Selection or deselection of a station is dependent only upon its signal to noise ratio.

As a result, the SNR index plots, both smoothed and unsmoothed, give a complete history of the signal quality and strength of the received signals, as recorded by the CMA771 real-time software. Any station whose signal strength is above 13 is utilized by the receiver for fix computations. As the LOP errors are all relative to a reference station, the station with the highest SNR is selected as the reference station.

Often, common effects on the LOP errors from all the stations occur. These may be due to fluctuations in the reference station phases or to worldwide sudden propagation disturbances. It is important to distinguish between these two different causes, if possible.

One of the predominant factors that has to be accounted for when navigating at high latitudes is the rapid transition of the signal path from night to day or vice-versa. In the CMA771 receiver, this effect is characterized by a significant sharp variation in the LOP errors during the transition period. This is attributed to the modelling of the predicted propagation corrections (PPC) or diurnals in the receiver. The processor

computes a set of PPCs for all stations about once every 7 minutes. When the PPCs change significantly within this 7-minute period, as during day/night transitions, a stepped correction curve results. The delay in computing the PPCs, along with limitations in the PPC model used, results in large fluctuations in the LOPs during day/night transitions. At high latitudes, day/night transitions occur both more frequently and more rapidly.

Another error source in Omega-derived positions is multipath signals. These are usually characterized by a high frequency variation in the signal phase and amplitude, as exhibited on some of the SNR plots. In contrast to local harmonic interference (due to power supply, etc.), multipath affects signals from only some of the stations.

The speed, in knots, of the station, as portrayed by the flight profile plots, does not truly describe the station's motion. The physical movement of the station is far smaller than the noise in the position fixes. The discretization of the speed is primarily due to its representation as discrete three-knot increments in the data records.

From all three sessions we note that, with the exception of Argentina, all stations were tracked at one time or another. Norway, which was the closest station, was the best in terms of its SNR: hence its use as the reference station. The station in Liberia was intermittently tracked because CESAR lay in the Greenland "ice shadow zone" of this signal.

The southern hemisphere station transmissions exhibited greater variations in signal strength. In session 4, all northern station transmissions were at a steady SNR of about 96. In session 1 and 2, they were strong signals but with some multipath contamination. In terms of geometry alone, there is no difficulty in obtaining a well-conditioned position fix in the vicinity of the North Pole with the current configuration of Omega transmitting stations.

5. CONCLUSIONS

The effect of operating in a real-time mode necessitates a compromise between more accurate position estimates with complex PPC modelling and computational speed for real-time position estimates. The CMA771 ONS lacks both the computing power and the memory storage of some of

the more modern or upgraded receivers. No post-processing has been done on the CESAR cassette tapes to improve the solution estimates using better PPC models or data filtering. The setup at CMC is primarily designed to evaluate the real-time performance of their Omega system. New or upgraded Omega receivers (e.g., the CMA734) allow the implementation of more complex and extensive PPC models through the use of more memory and faster and more powerful microprocessors.

Within the Arctic Circle, the solution estimates are geometrically well conditioned. However, even with faster computations of PPCs, a small time lag in applying the correction results in a large variation in the LOP due to the rapid transition of the signal path from day to night or vice-versa. Deselection of the weaker and long signal path stations, e.g., those from the southern hemisphere, coupled with the avoidance of signal paths crossing day/night lines, should improve accuracies considerably. Deselection, in the real-time mode, can either be achieved manually or through deselection maps stored inside the processors.

The effect of modal interference is quite evident from some of the SNR plots. This translates to a periodic shift in lines of position and position estimates.

Most of the factual information about the receivers and conclusions was drawn from discussions with Bob Baillie of CMC. They were entirely based on the plots contained in this report. What is lacking here is the ability to further improve the position estimates through post-processing techniques. Since time and phase information is recorded on cassette tape, it would be possible to post-process the data using smoothing techniques and more complete PPC models to generate better position estimates with formal error estimates. Such an analysis would highlight the true limitations of the system rather than those due to limited computing power and real-time navigation. In addition, if the accuracy of the navigation solution is dependent on the PPC modelling, then differential Omega should allow the recovery of errors due to incomplete PPC modelling and sudden propagation disturbances.

Real-time differential Omega techniques are capable of producing position estimates with an accuracy of about 450 metres over 180 km [Zajac, 1982]. With post-processing, this figure should drop further.

Currently at high latitudes, for programs such as the Canadian ice

island, there is a void for continuous, quick (less than one hour), low cost and accurate (less than 100 m) relative positioning techniques with a range of 100 km or more. Transit satellite positioning is intermittent, and requires several passes and accurate ice velocity knowledge for its position estimates. GPS is still limited to a few hours' availability per day by the present 6-satellite constellation. Other radio positioning systems, such as Syledis or Decca, require a sufficiently long baseline to enable geometrically well-conditioned position estimates.

The use of differential Omega in a non-real-time environment, if proven feasible and sufficiently accurate, would enable the observation of cost effective and rapid (less than one hour) relative position estimates. It may be feasible to consider using Omega receivers, in a non-real-time differential mode. For example, one receiver (at a reference site) would be calibrated by Transit and/or GPS. The other (identical) roving receiver would occupy remote sites for up to one hour. The data from both would then be post-processed at the reference site.

In order to establish whether acceptable differential accuracies may be achieved in this way, it will be necessary to establish to what extent the errors shown here arise from receiver-specific causes (measurement resolution), and local spatial signal variations, and to what extent these errors would be correlated over separations of a few 100 kilometres. A differential Omega test at high latitudes may well be necessary.

REFERENCES

Baillie, B. (1984). Personal communication. Canadian Marconi Company.

Wells, D.E. (1984). "CESAR radiopositioning analysis." CESAR contribution No. 1. Department of Surveying Engineering, University of New Brunswick, Fredericton, N.B., March.

Zajac, S. (1982). "Differential Omega - review of status, advantages, and problems." Proceedings of Omega Workshop, Atlantic City, May.

APPENDIX I

For each of the three sessions, the following plots are presented:

1. World map displaying CESAR's position, Omega transmitting stations, and the day/night terminators at varying hours.
2. Smoothed SNR plots for all 3 frequencies.
2. Smoothed LOP error plots for all 3 frequencies.
4. Unsmoothed SNR plots for the 10.2 KHz channel.
5. Unsmoothed LOP error plots for the 10.2 KHz channel.
6. Unsmoothed SNR plots for the 11.3 KHz channel.
7. Unsmoothed LOP error plots for the 11.3 KHz channel.
8. Unsmoothed SNR plots for the 13.6 KHz channel.
9. Unsmoothed LOP error plots for the 13.6 KHz channel.
10. Computed PPC or diurnals for each of the Omega stations.

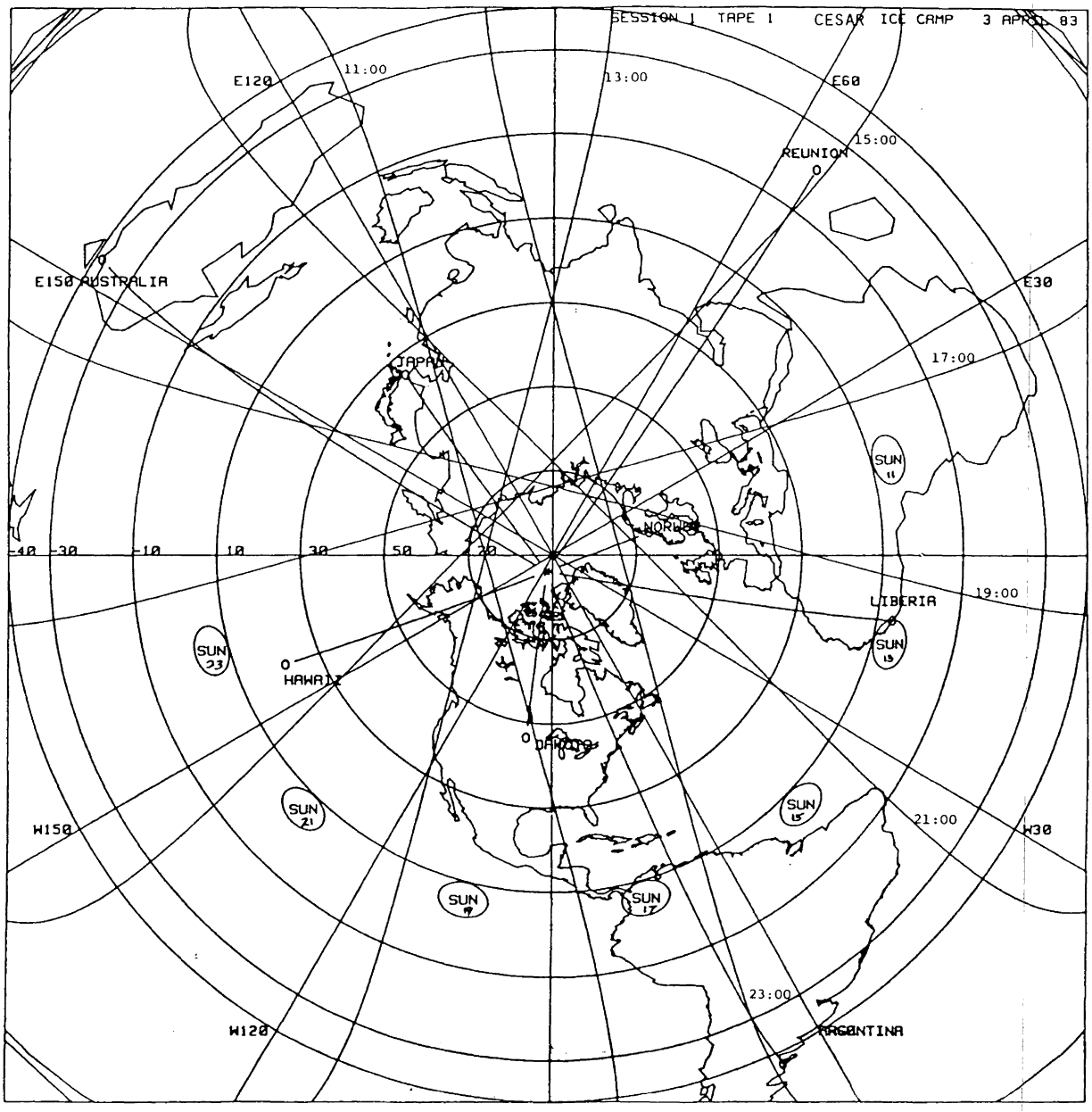
As the original plots are in colour and of size 15 1/2" by 11", the plots had to be reproduced in two halves and annotated to distinguish between the different frequencies in the absence of colour.

APPENDIX I.1

Session 1 Tapes 1 and 2

Time span: 10:02 April 3, 1983 to 12:50 April 4, 1983.

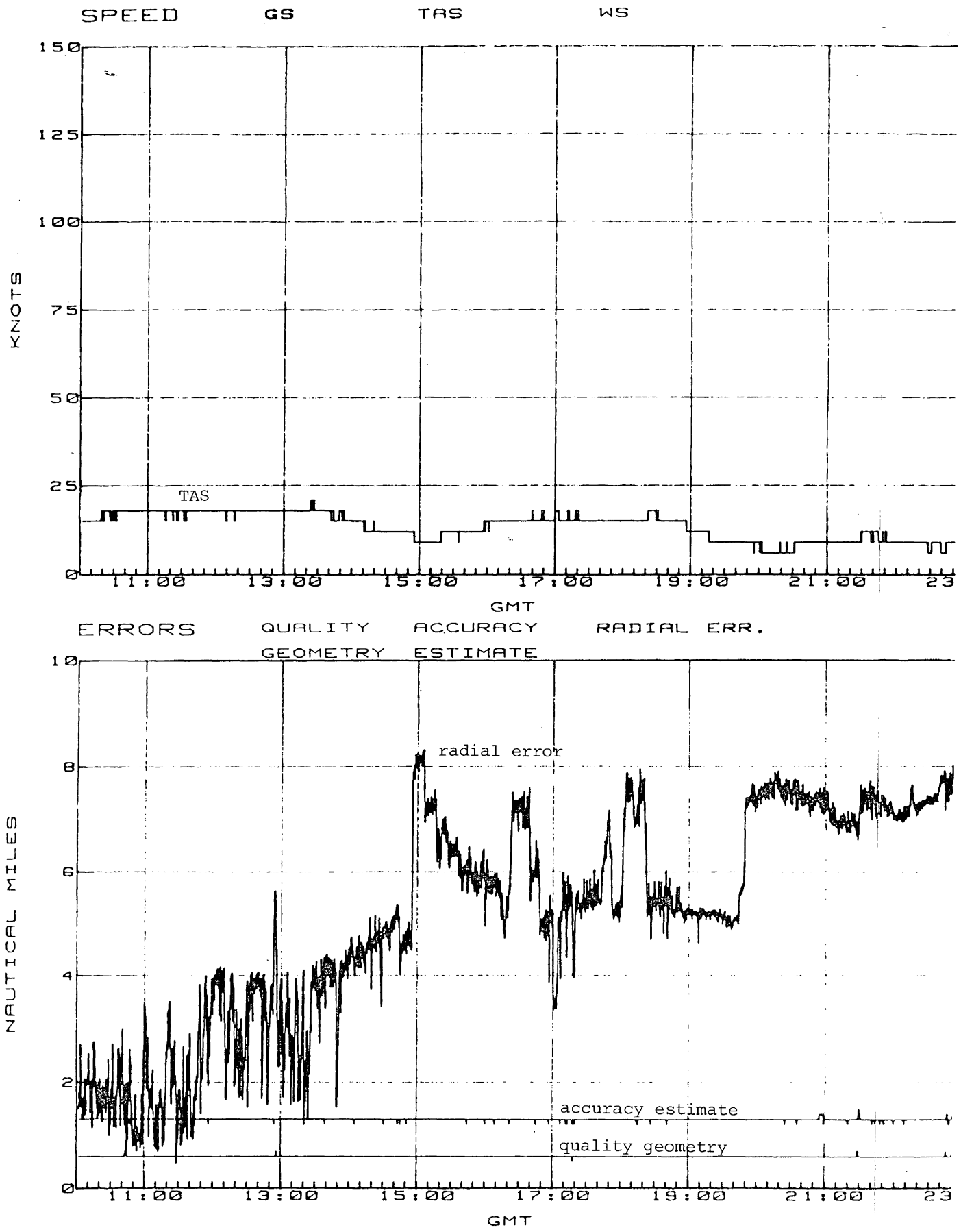
Approximate position: 85^{o} 48.6' (N)
110^{o} 54.0' (W)



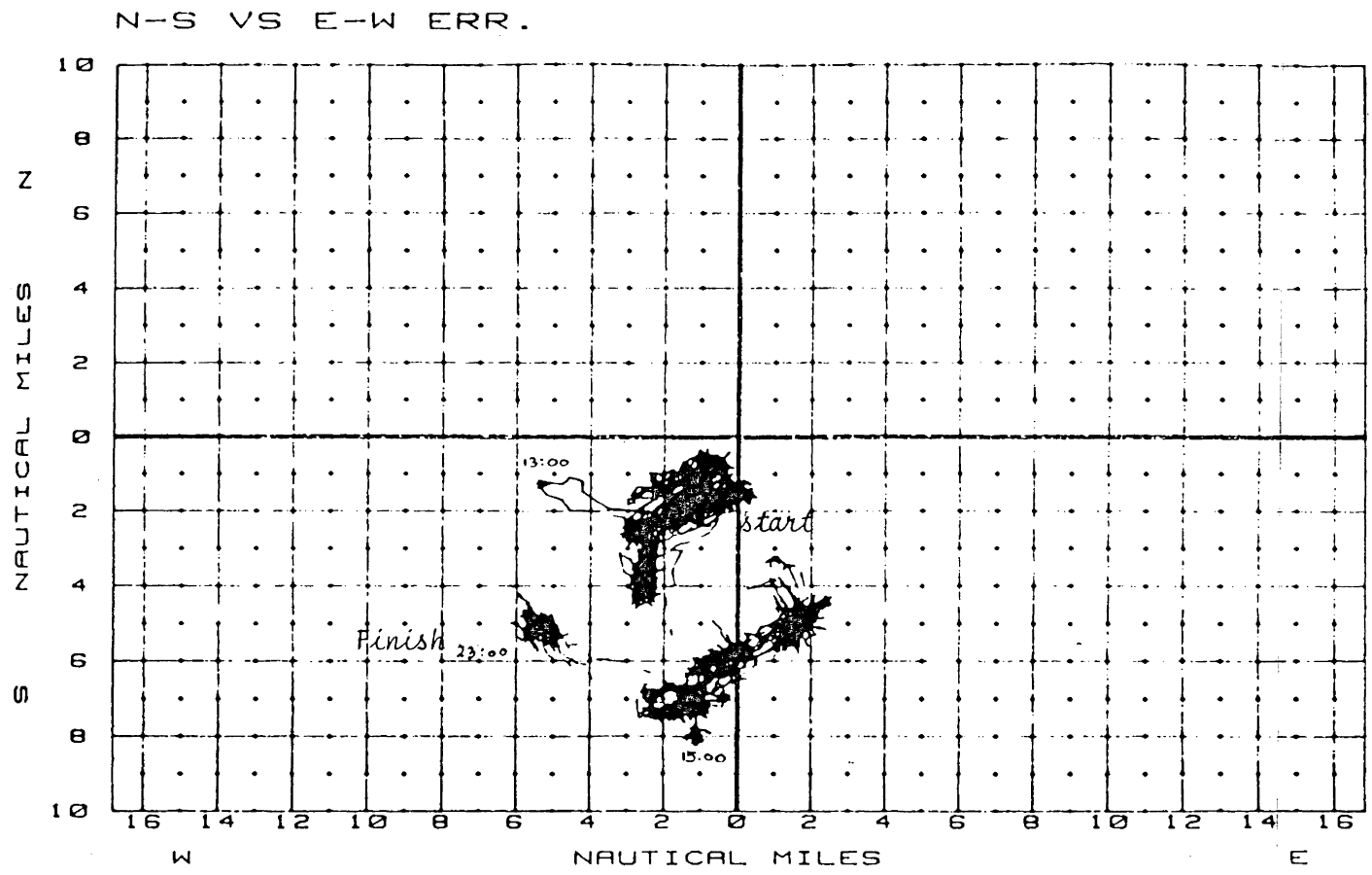
SESSION 1 TAPE 1

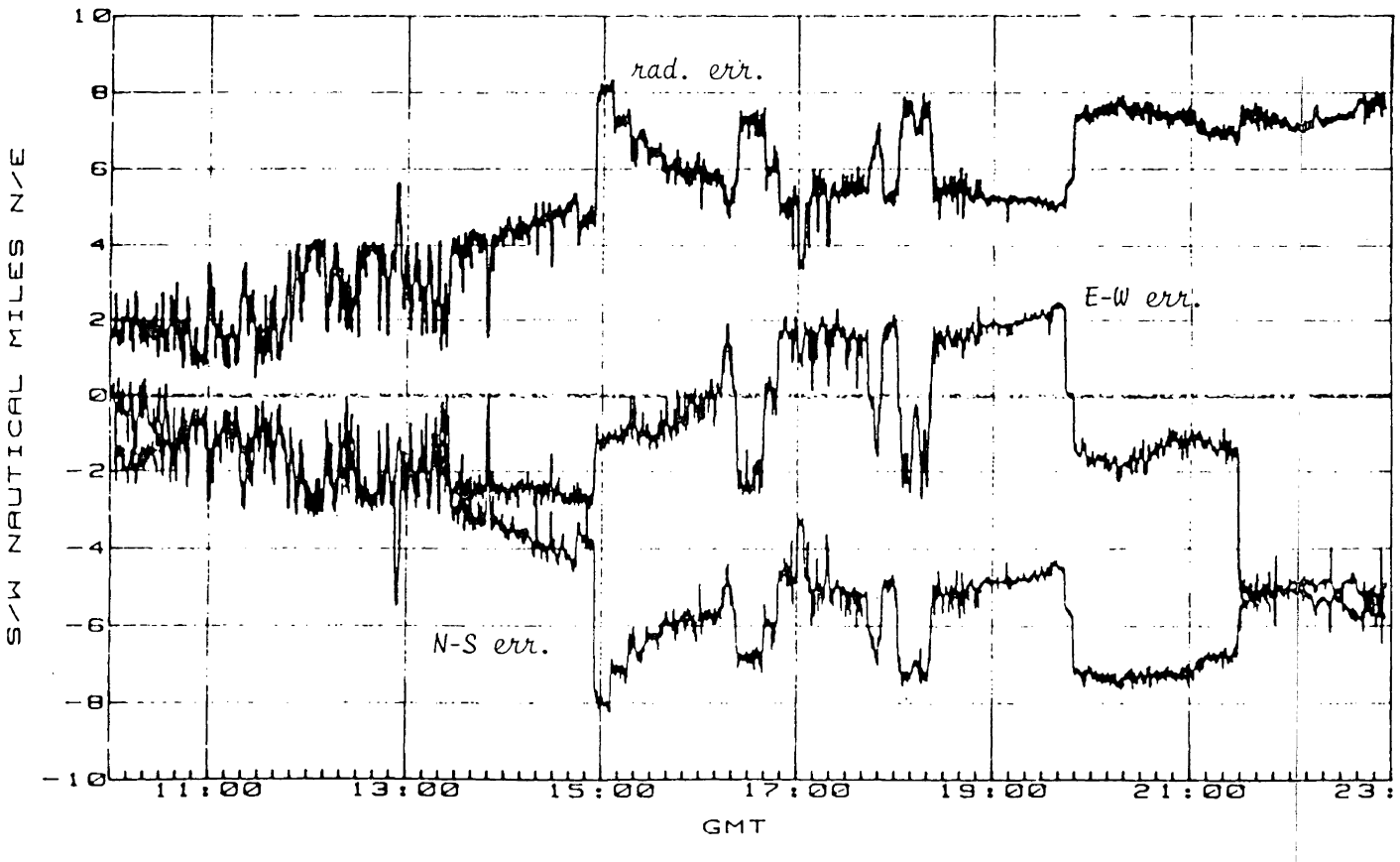
World map displaying CESAR's position, Omega transmitting stations and day/night terminators.

SESSION 1 TAPE 1 CESAR ICE CAMP DATE OF

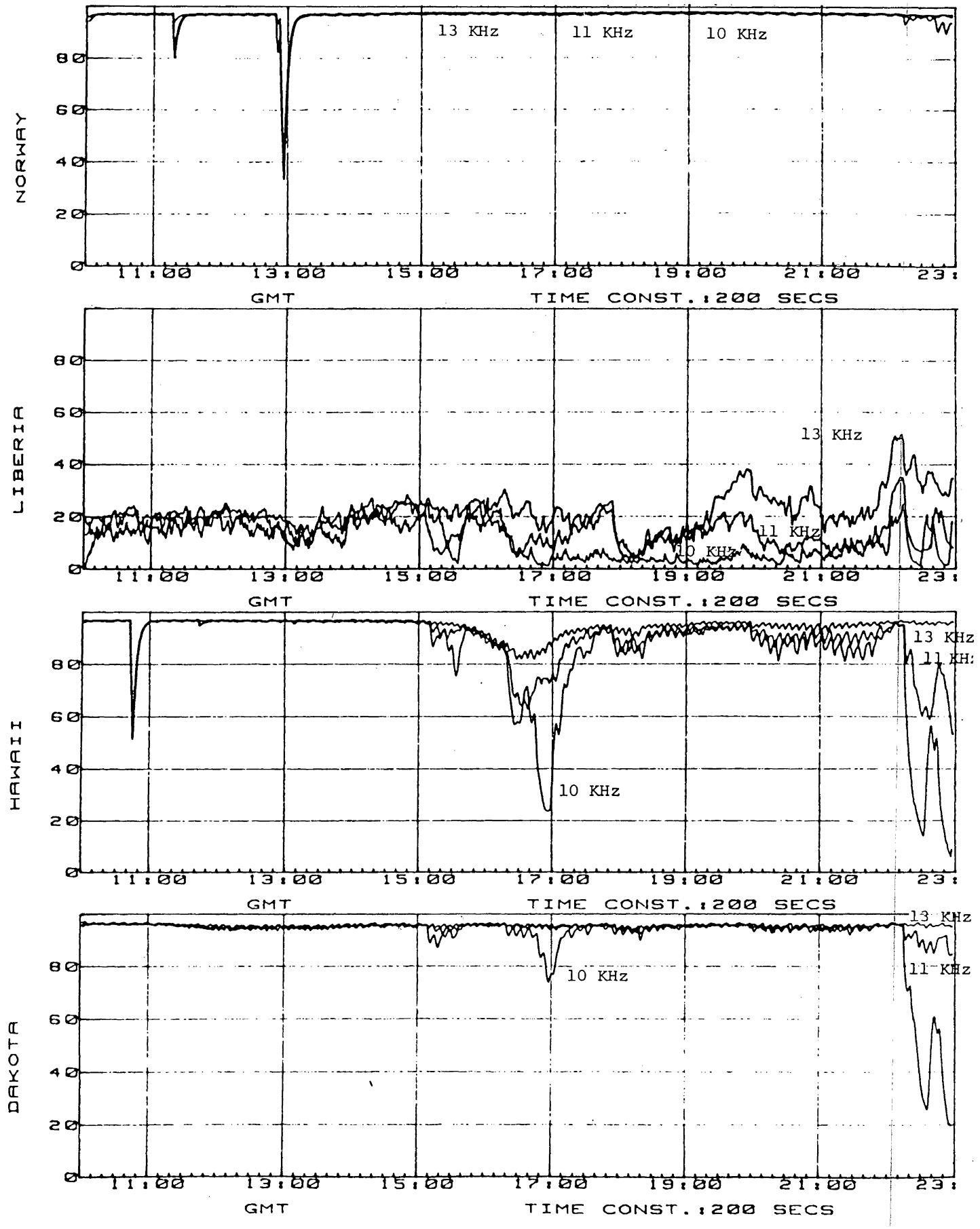


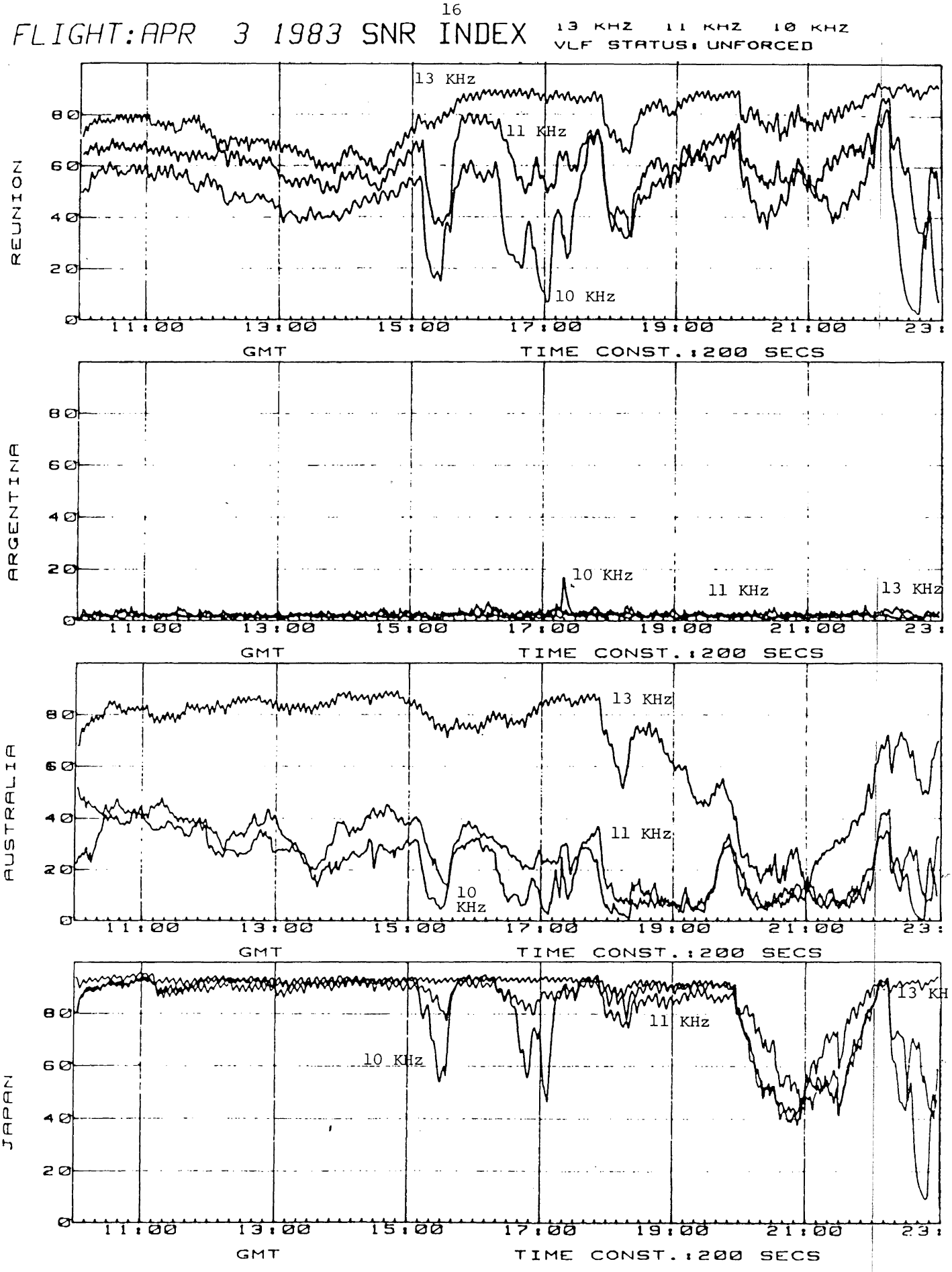
FLIGHT: APR 3 1983



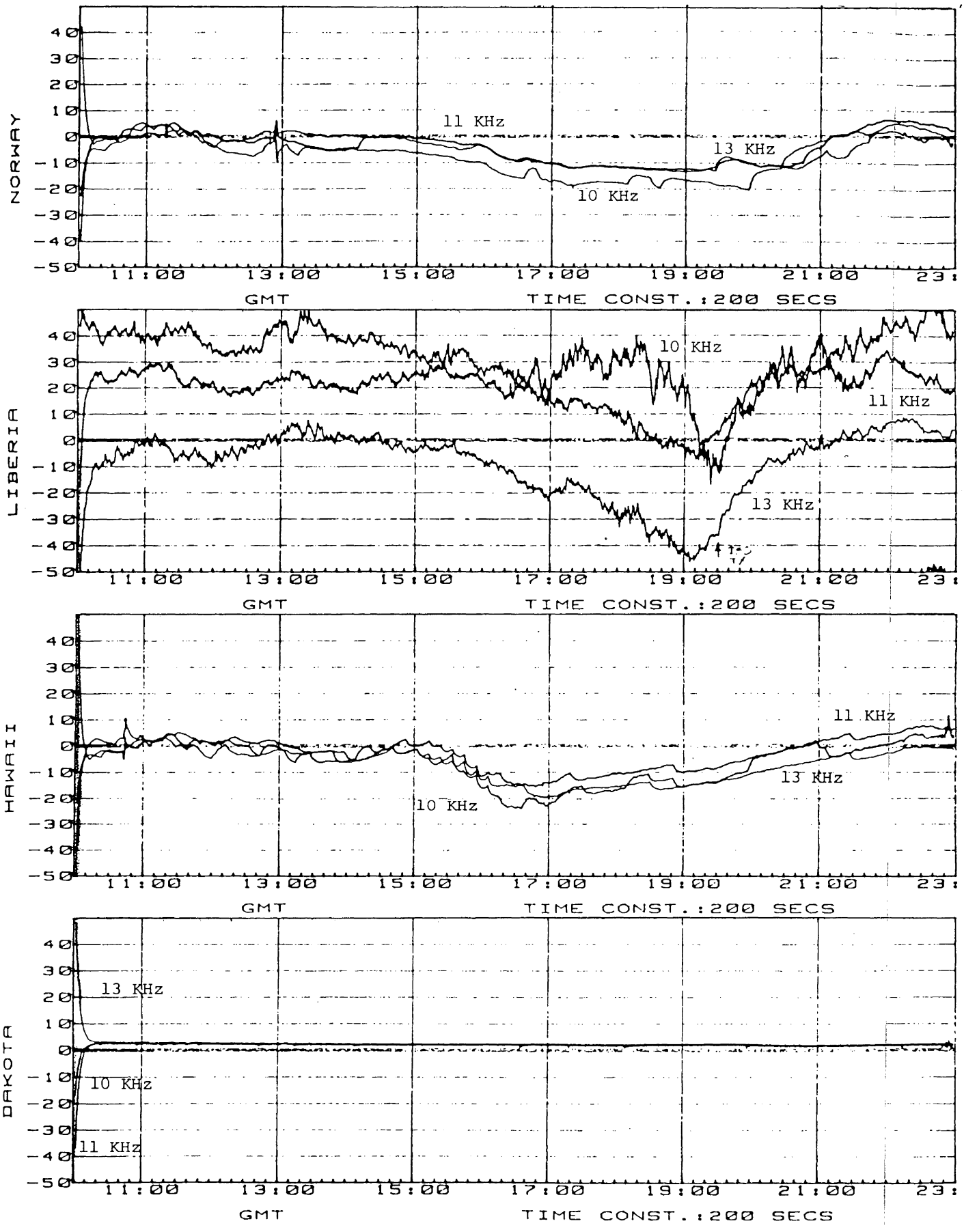


SESSION 1 TAPE 1 CESAR ICE CAMP DATE OF F



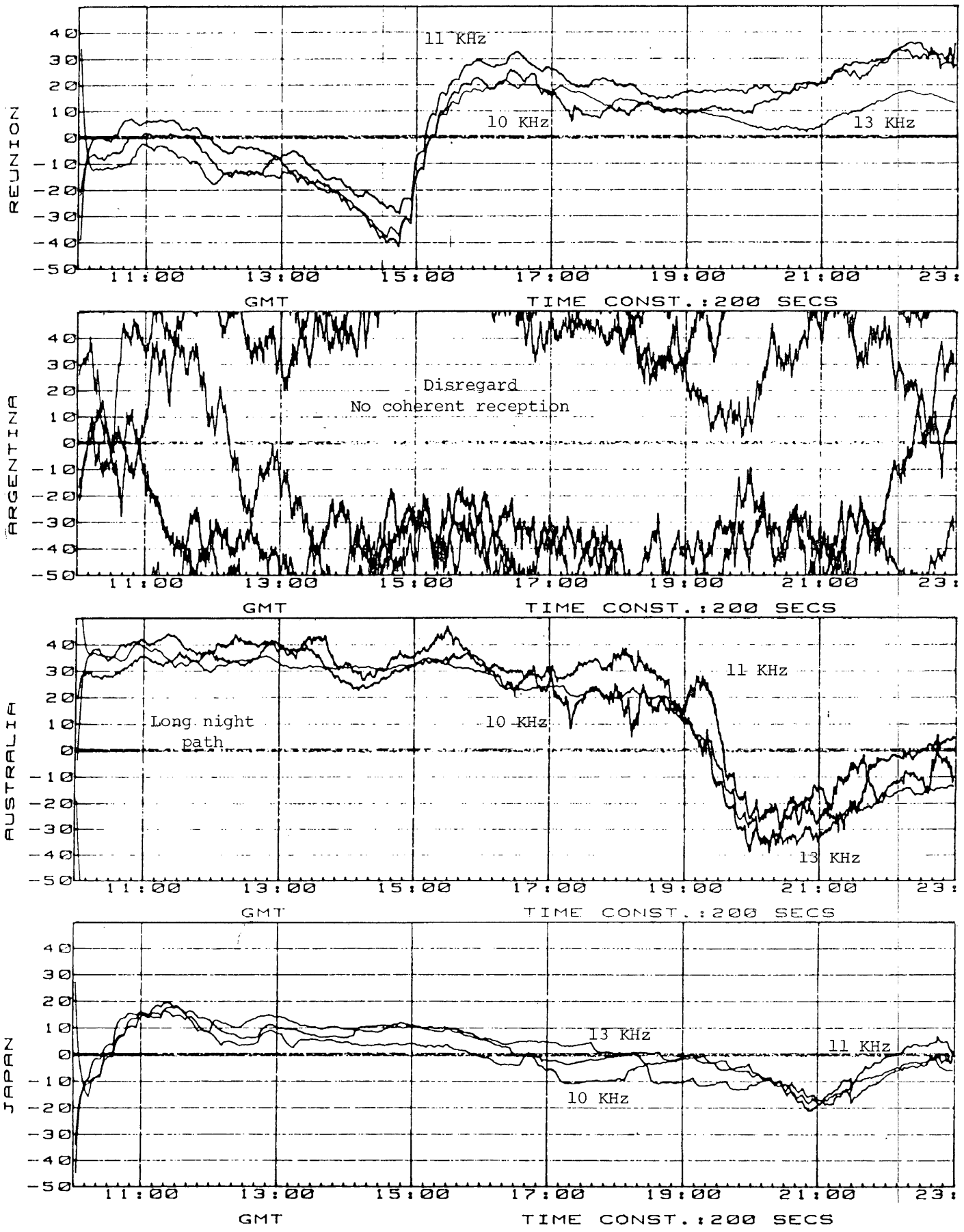

FLIGHT: APR 3 1983 SNR INDEX
13 KHZ 11 KHZ 10 KHZ
VLF STATUS: UNFORCED
REUNION
13 KHz
11 KHz
10 KHz
ARGENTINA
10 KHz
11 KHz
13 KHz
AUSTRALIA
13 KHz
11 KHz
10 KHz
JAPAN
10 KHz
11 KHz
13 KH
0
20
40
60
80
11:00
13:00
15:00
17:00
19:00
21:00
23:
GMT
TIME CONST.: 200 SECS

SESSION 1 TAPE 1 CESAR ICE CAMP DATE OF

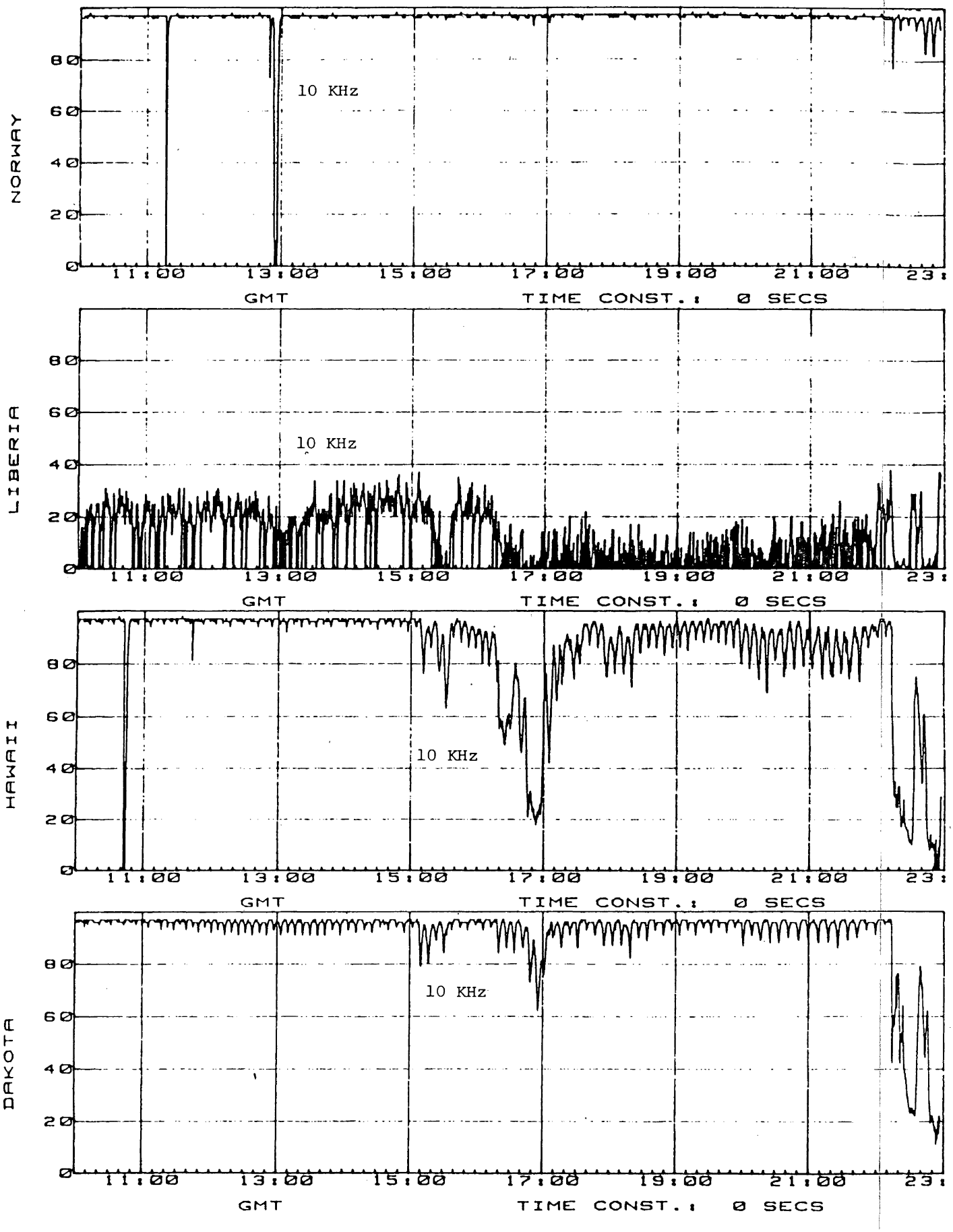


FLIGHT: APR 3 1983 LOP ERR

13 KHZ 11 KHZ 10 KHZ



SESSION 1 TAPE 1 CESAR ICE CAMP DATE OF F



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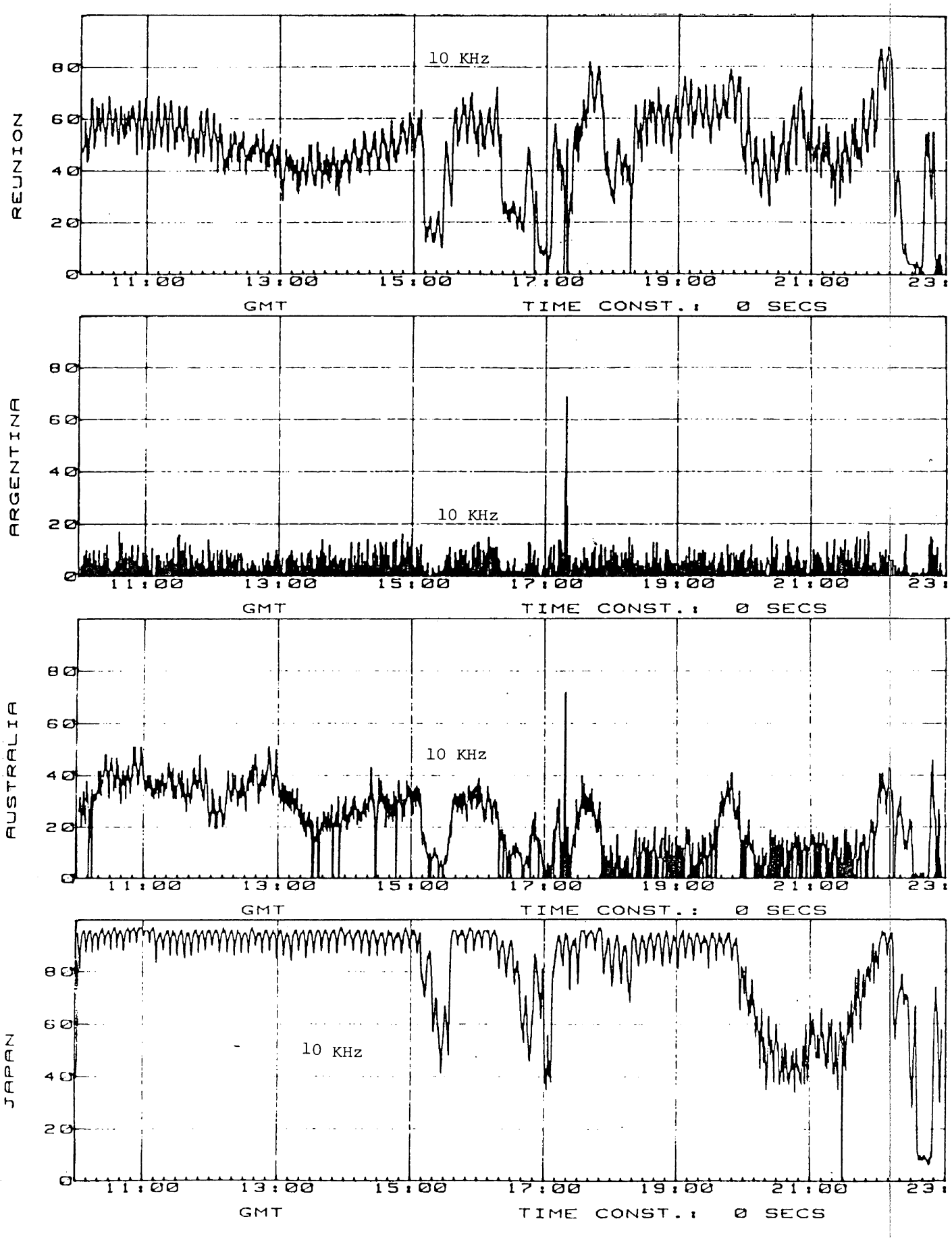
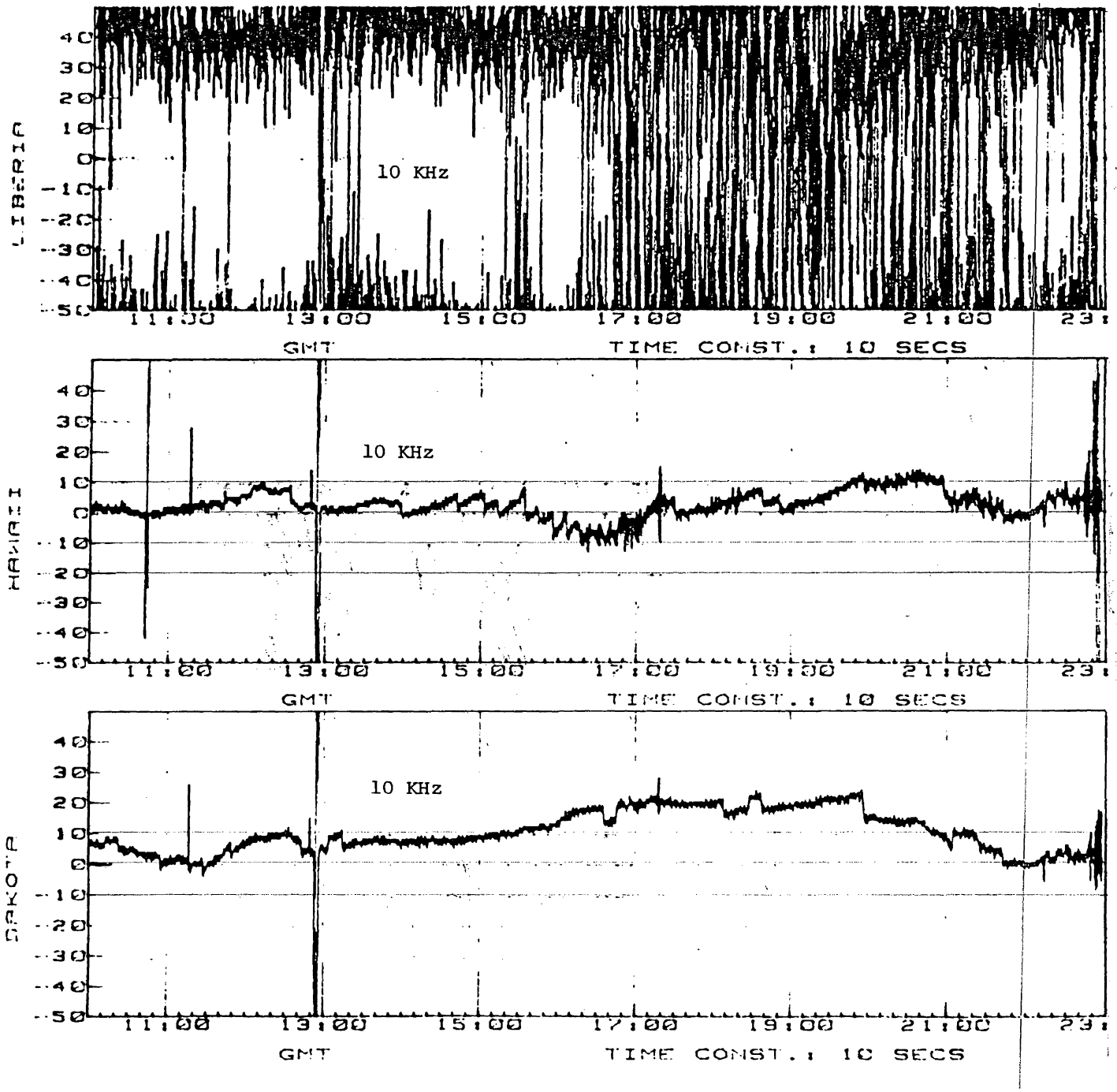
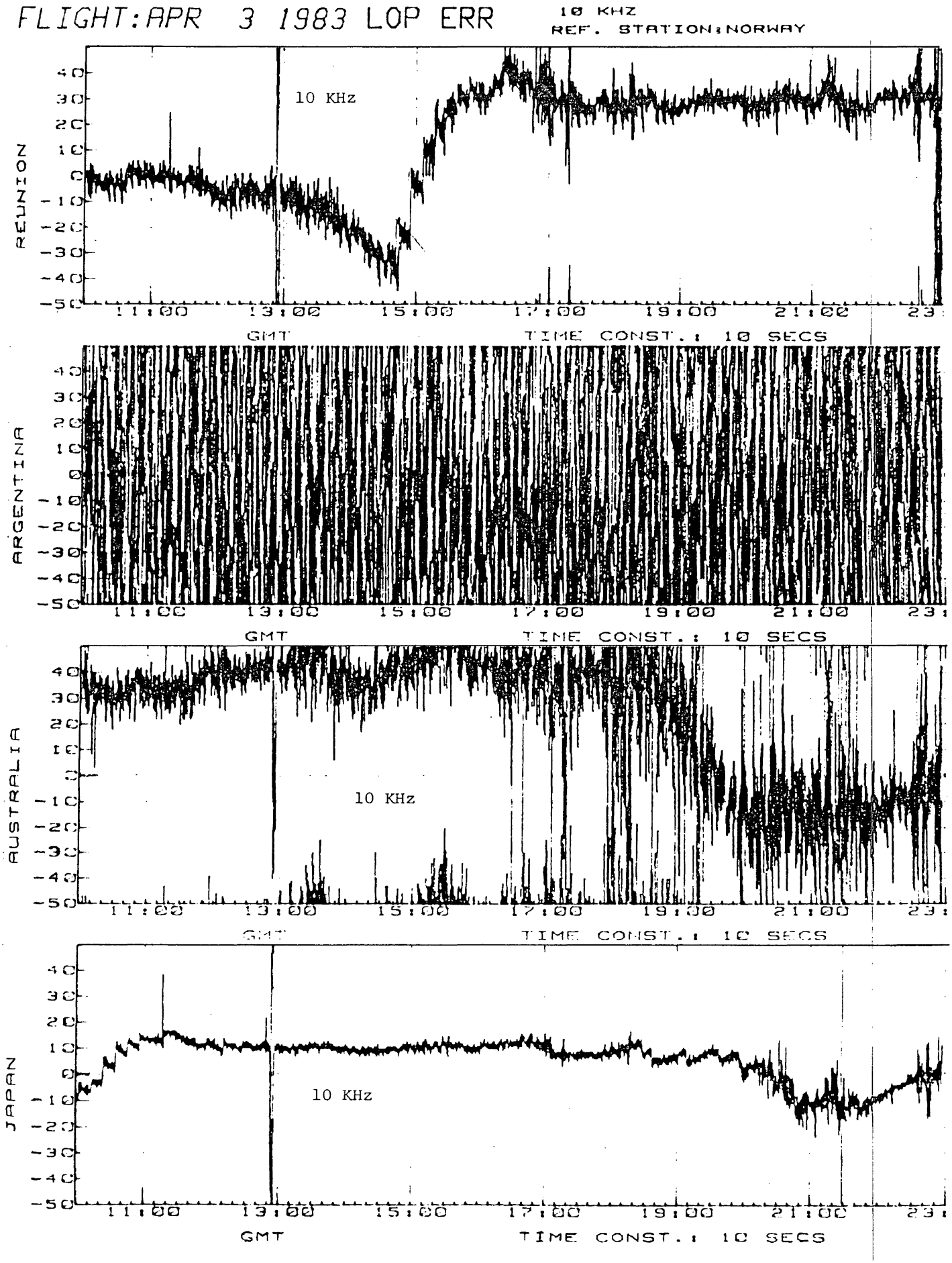
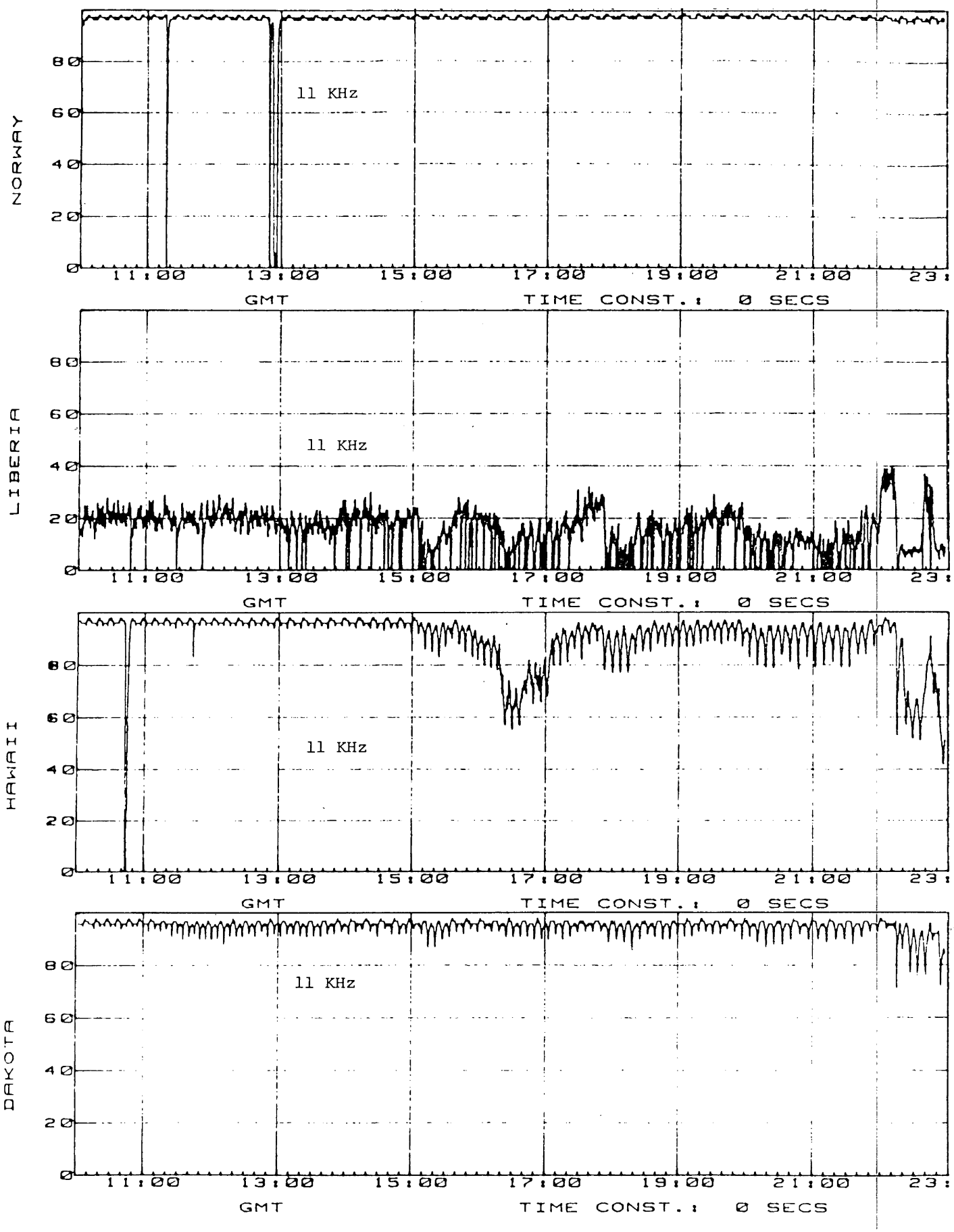


SESSION 1 TAPE 1 CESAR ICE CAMP DATE OF F

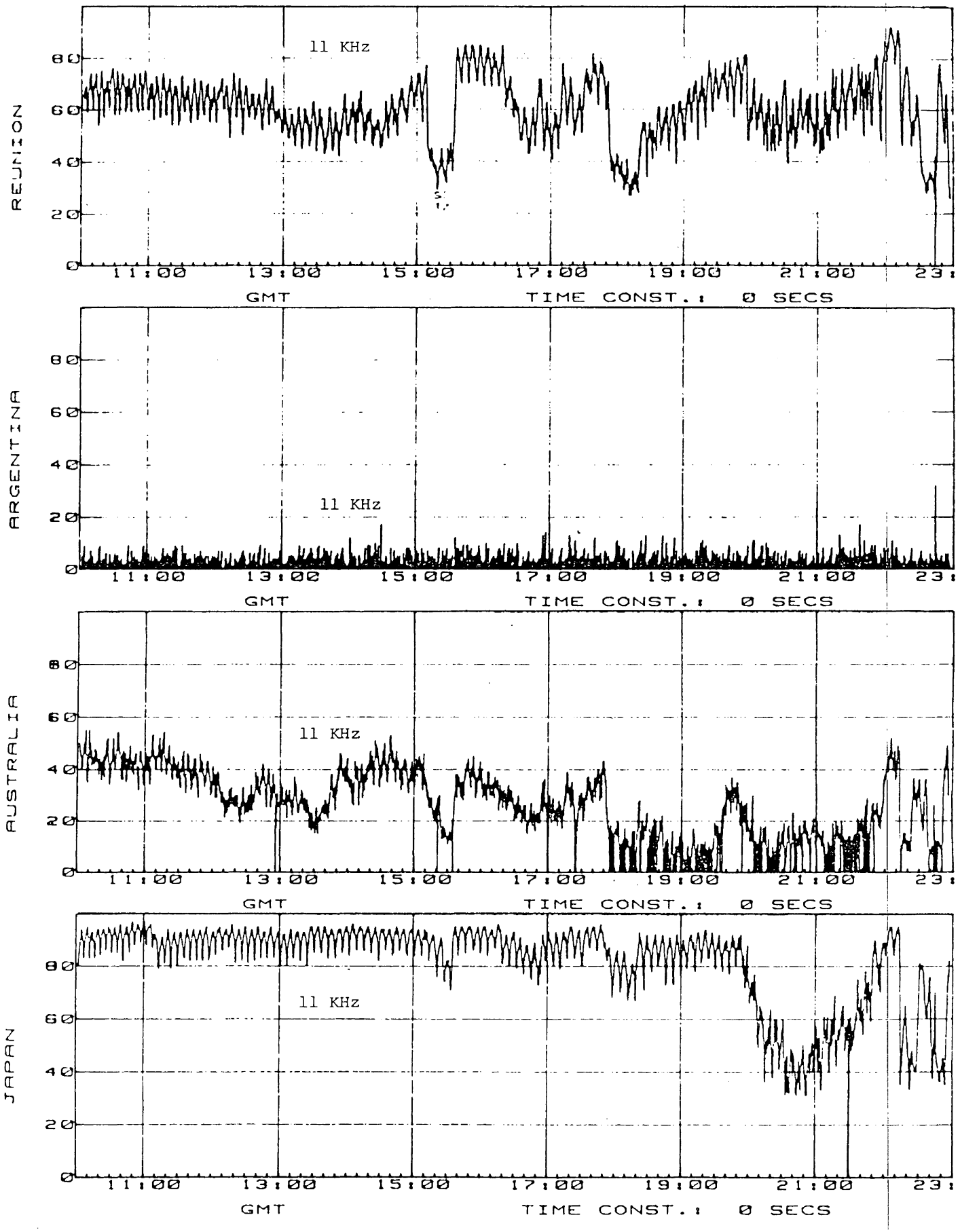



FLIGHT: APR 3 1983 LOP ERR
10 KHZ
REF. STATION: NORWAY
REUNION
10 KHz
40
30
20
10
0
-10
-20
-30
-40
-50
11:00
13:00
15:00
17:00
19:00
21:00
23:
GMT
TIME CONST.: 10 SECS
ARGENTINA
AUSTRALIA
10 KHz
JAPAN
10 KHz

SESSION 1 TAPE 1 CESAR ICE CAMP DATE OF



F FLIGHT:APR 3 1983 SNR INDEX 11 KHZ



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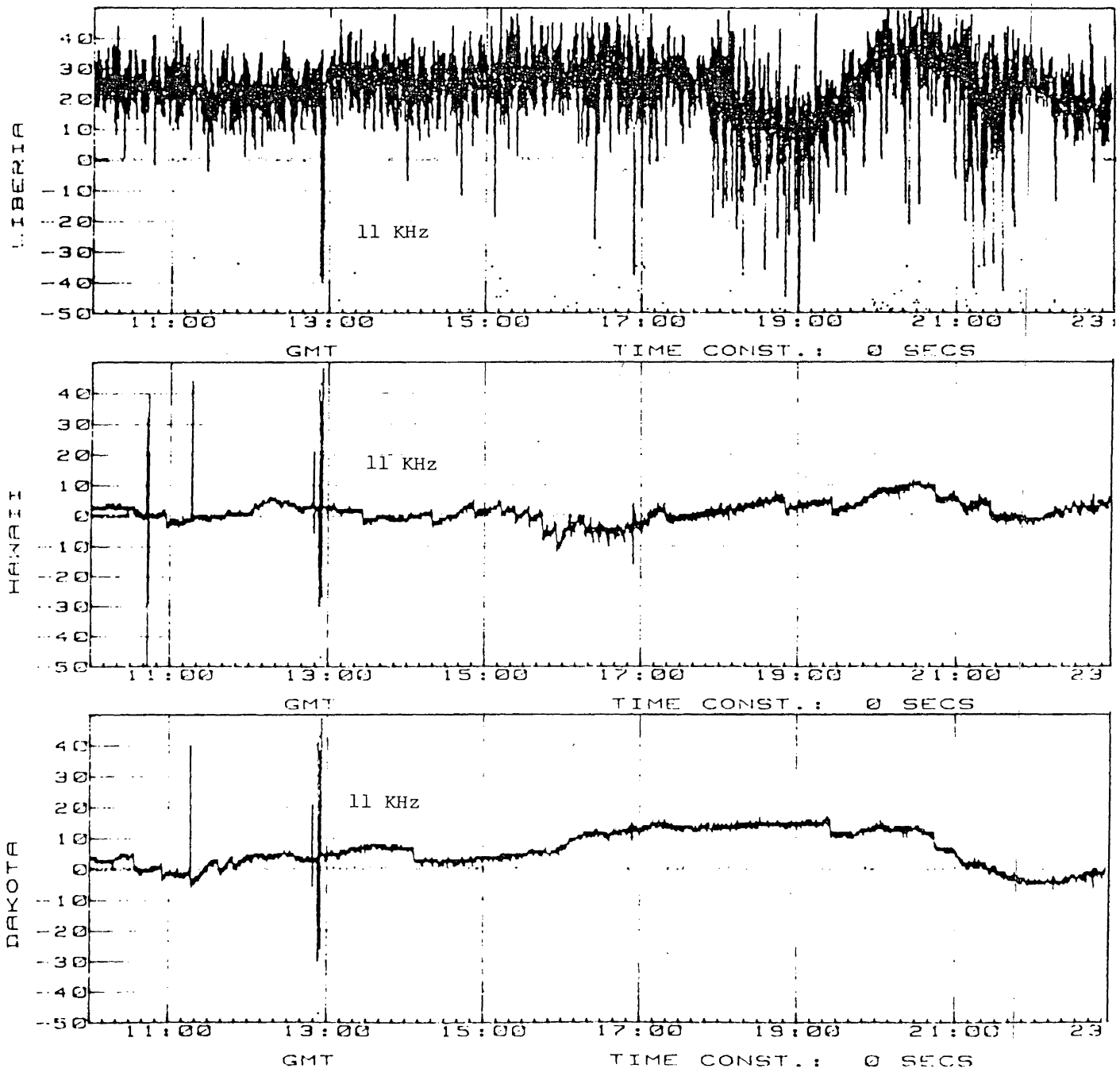
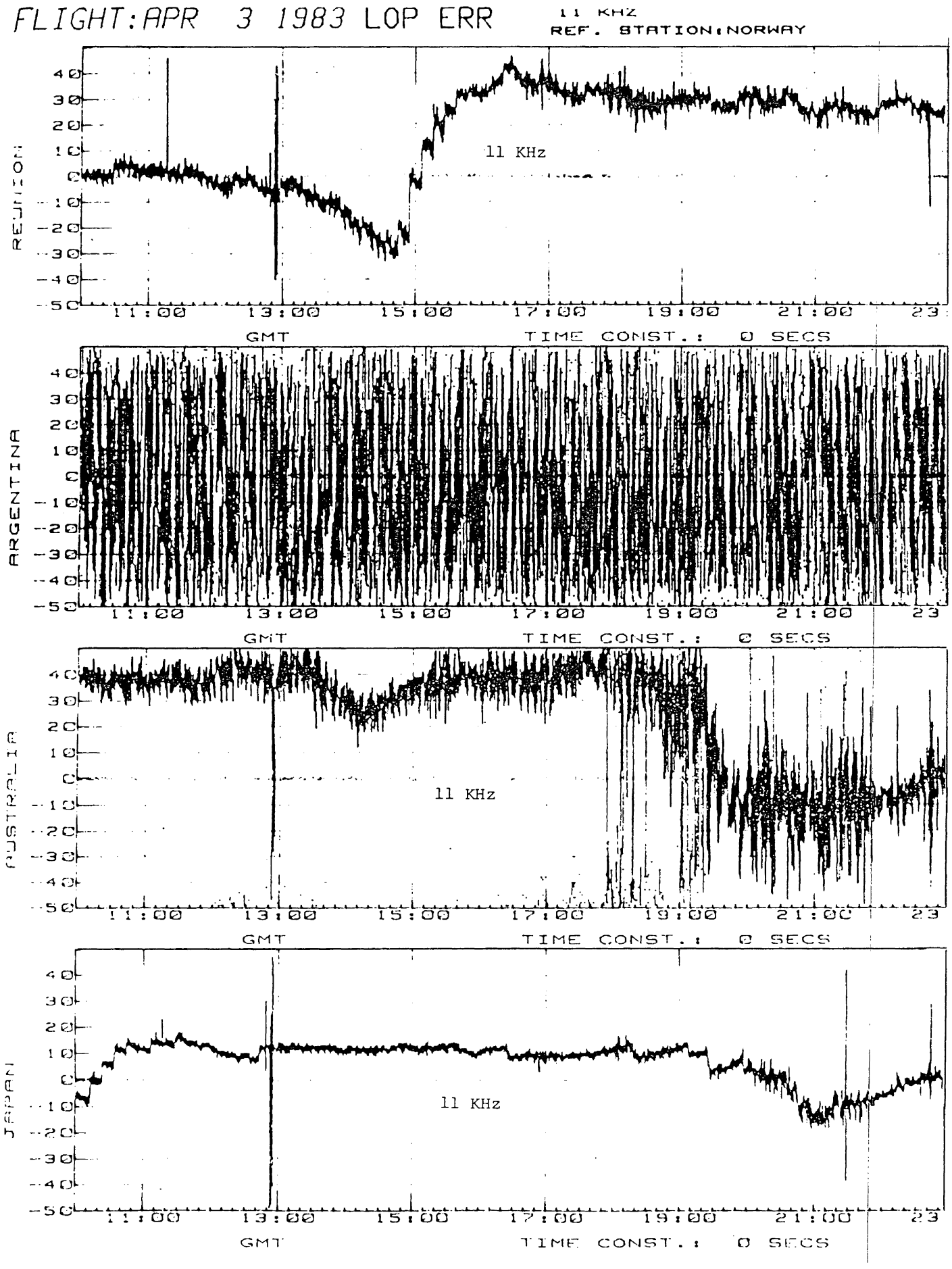
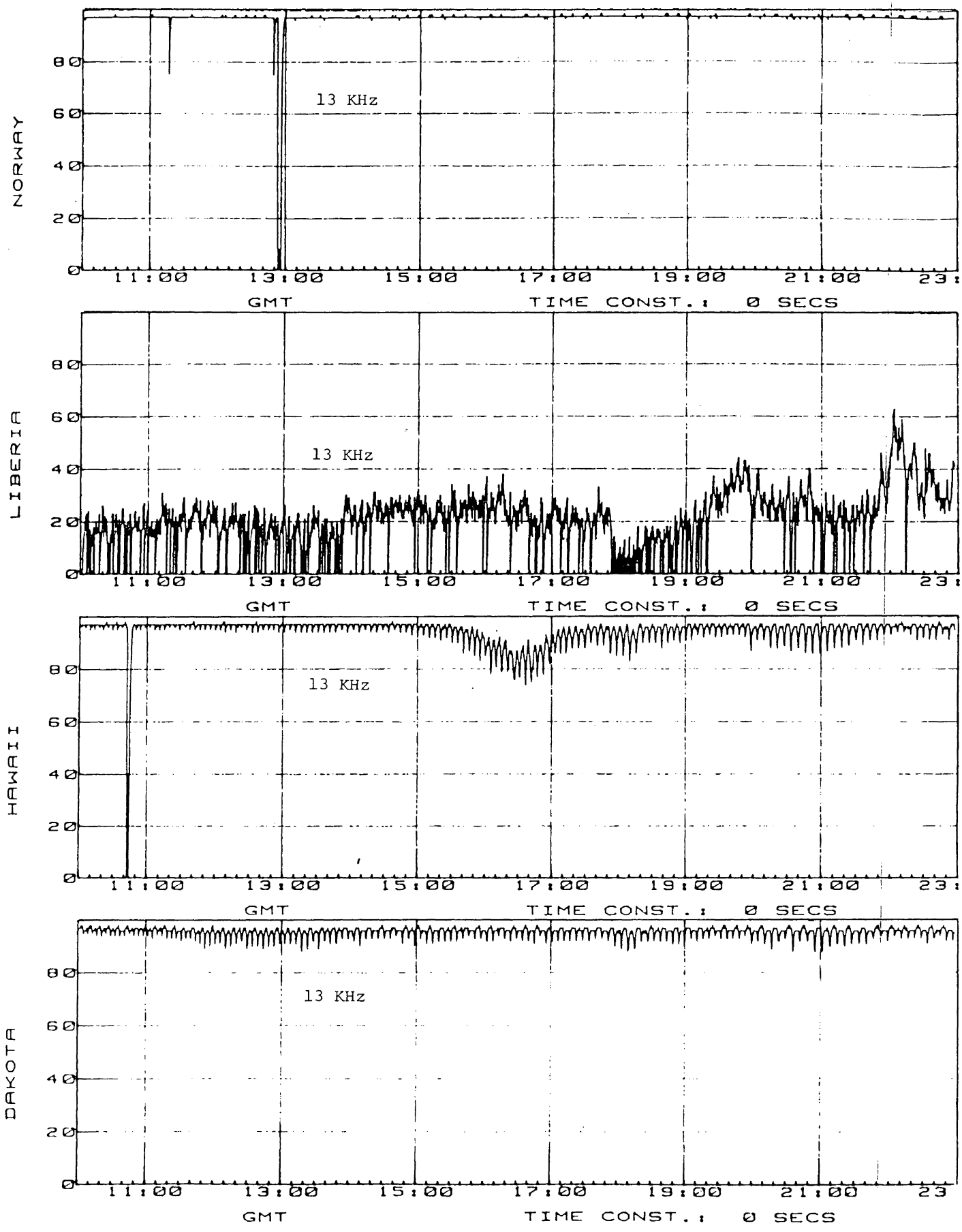
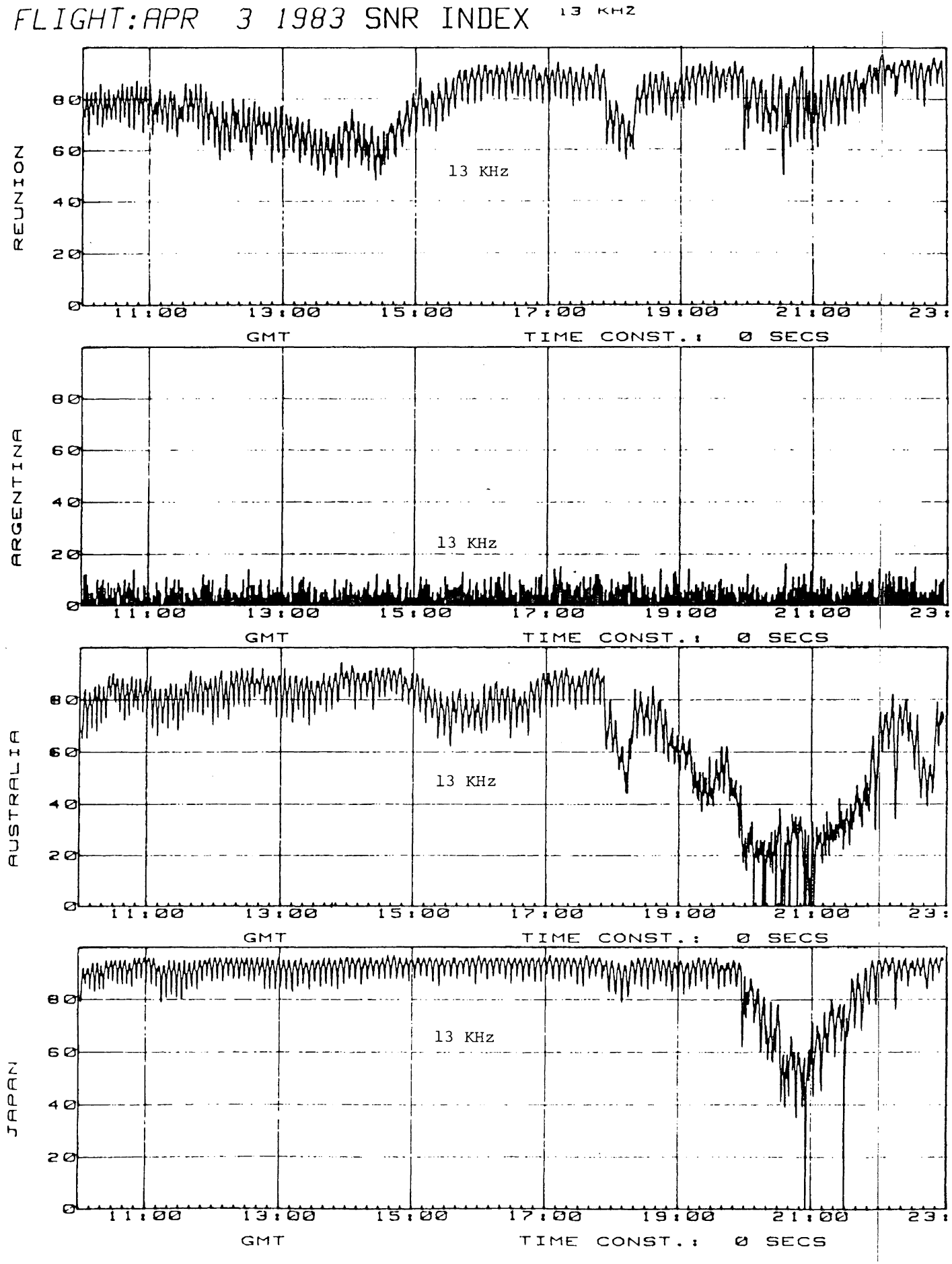



FLIGHT: APR 3 1983 LOP ERR
11 KHZ
REF. STATION: NORWAY
REUNION
11 KHz
40
30
20
10
0
-10
-20
-30
-40
-50
11:00
13:00
15:00
17:00
19:00
21:00
23
GMT
TIME CONST.: 0 SECS
ARGENTINA
11 KHz
AUSTRALIA
11 KHz
JAPAN
11 KHz

SESSION 1 TAPE 1 CESAR ICE CAMP DATE OF

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REUNION
13 KHz
0
20
40
60
80
11:00
13:00
15:00
17:00
19:00
21:00
23:
GMT
TIME CONST.: 0 SECS
ARGENTINA
13 KHz
0
20
40
60
80
11:00
13:00
15:00
17:00
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21:00
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GMT
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AUSTRALIA
13 KHz
0
20
40
60
80
11:00
13:00
15:00
17:00
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21:00
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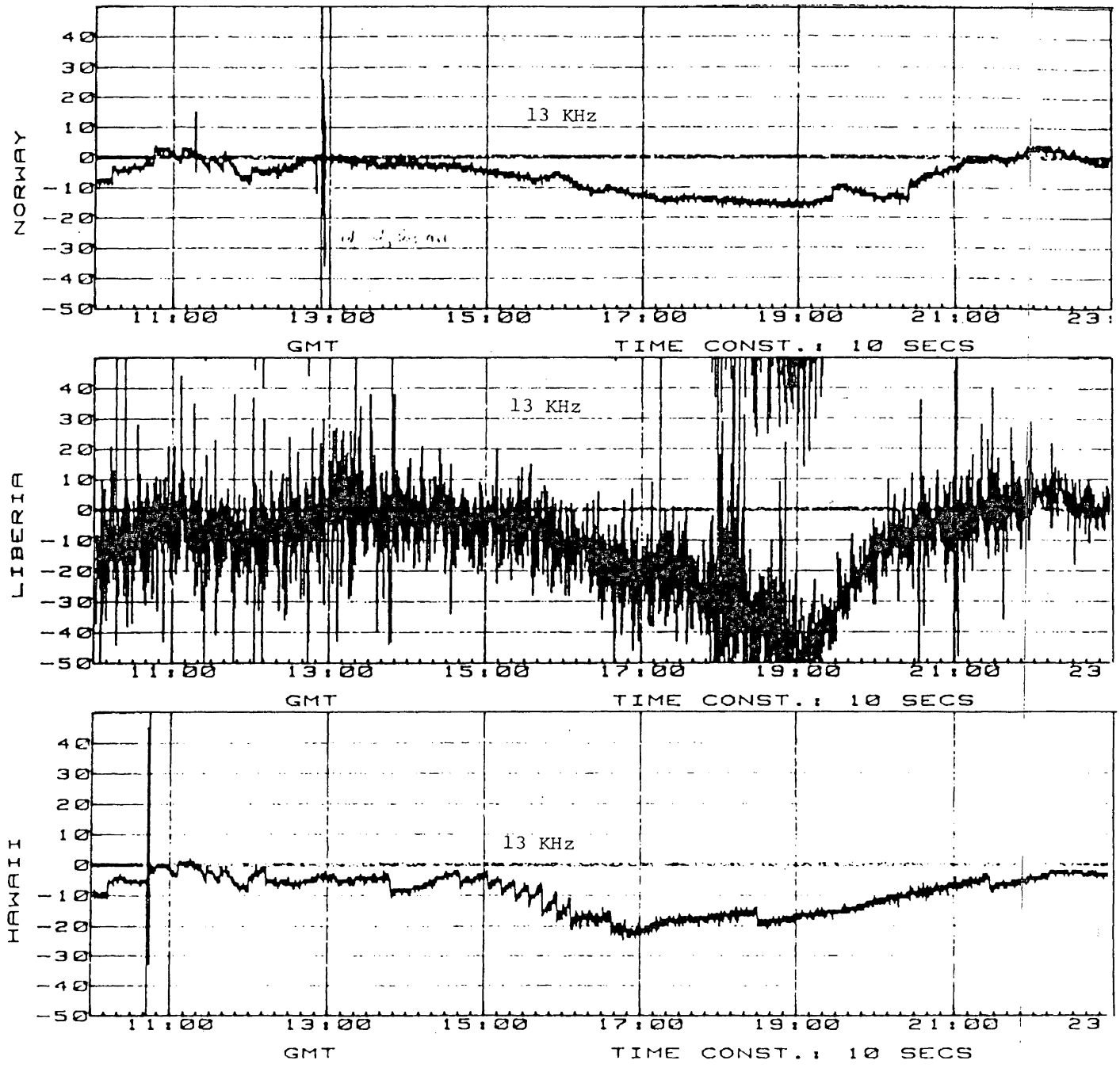
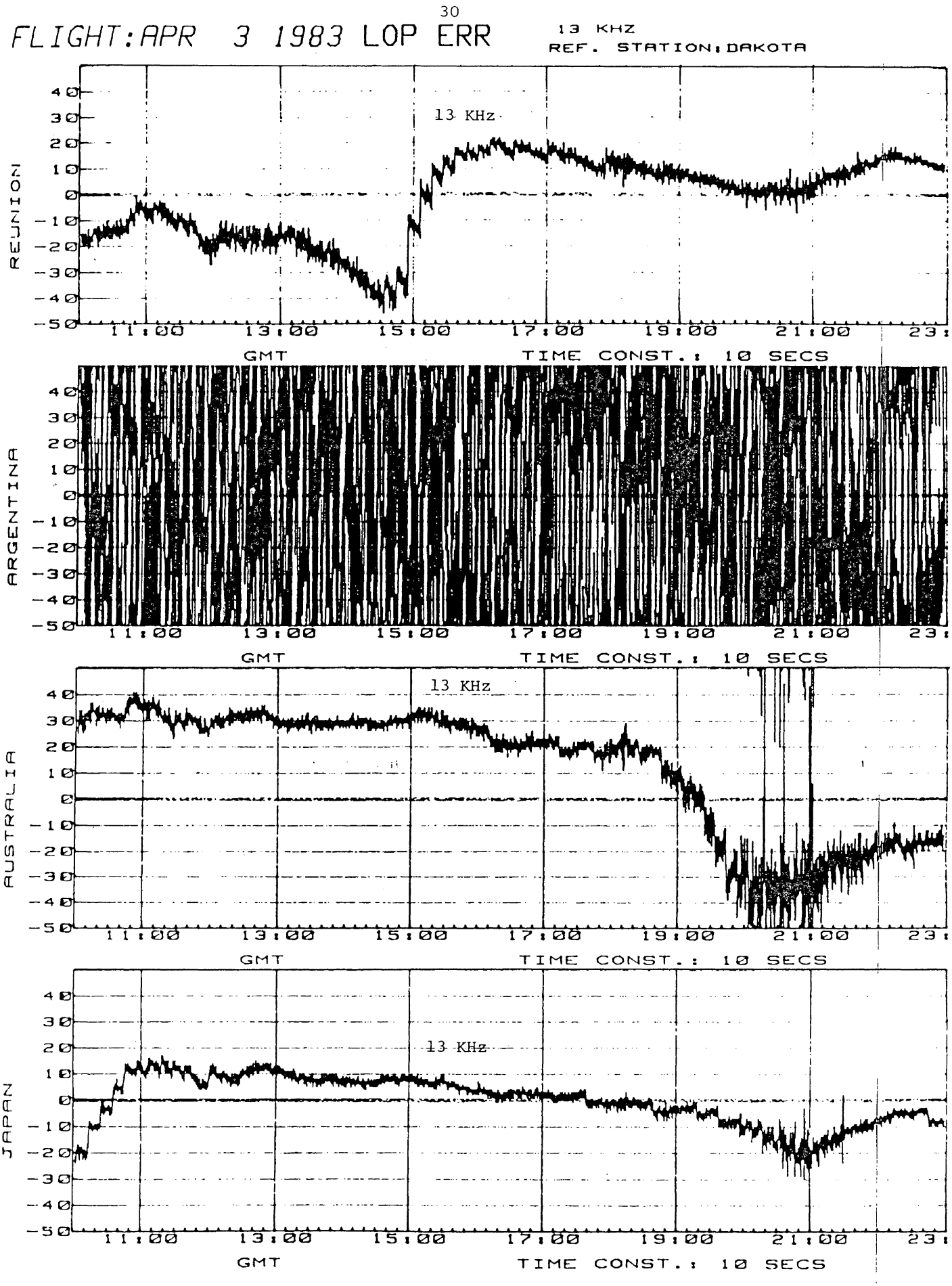
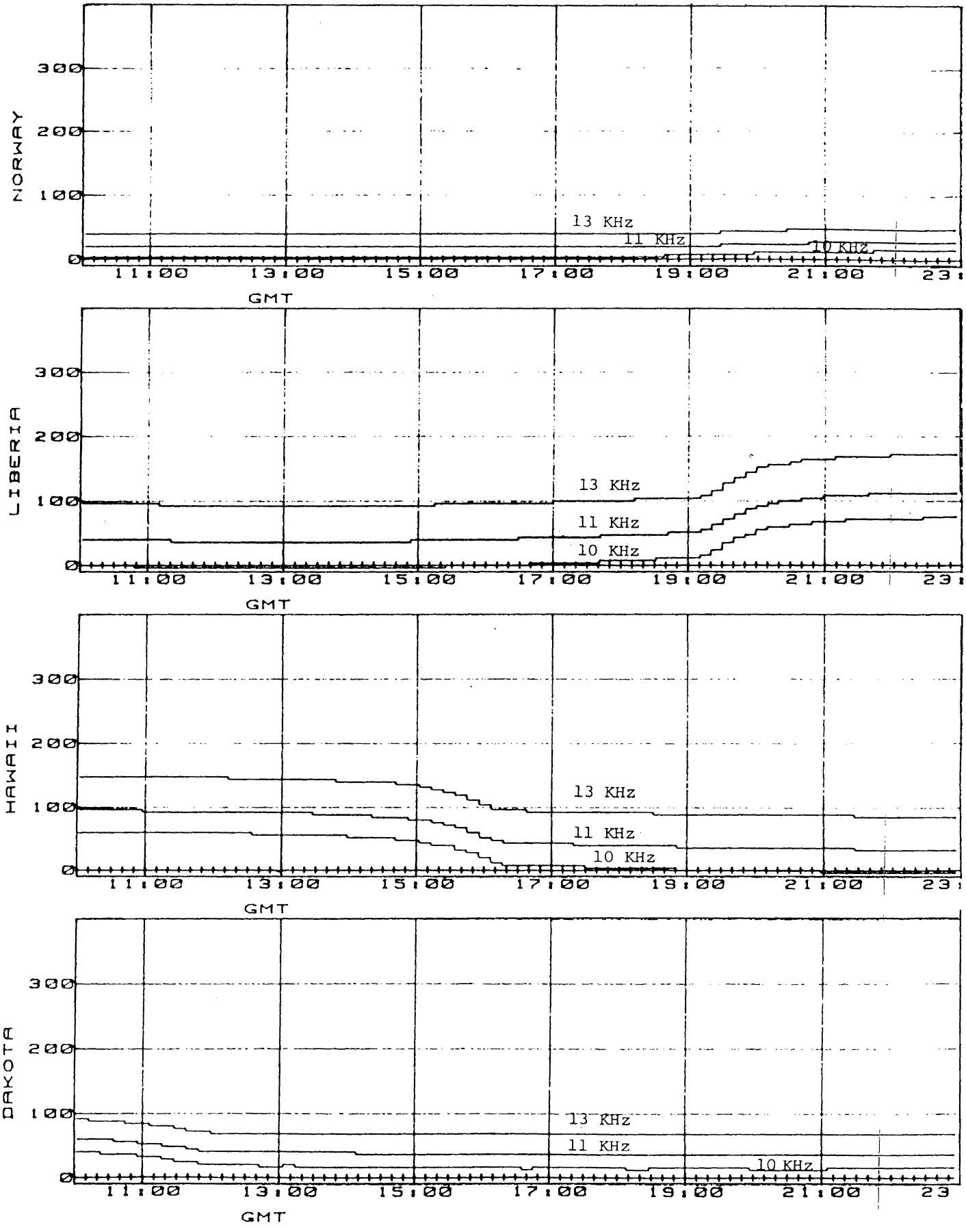
GMT
TIME CONST.: 0 SECS
JAPAN
13 KHz
0
20
40
60
80
11:00
13:00
15:00
17:00
19:00
21:00
23:
GMT
TIME CONST.: 0 SECS

SESSION 1 TAPE 1 CESAR ICE CAMP DATE OF



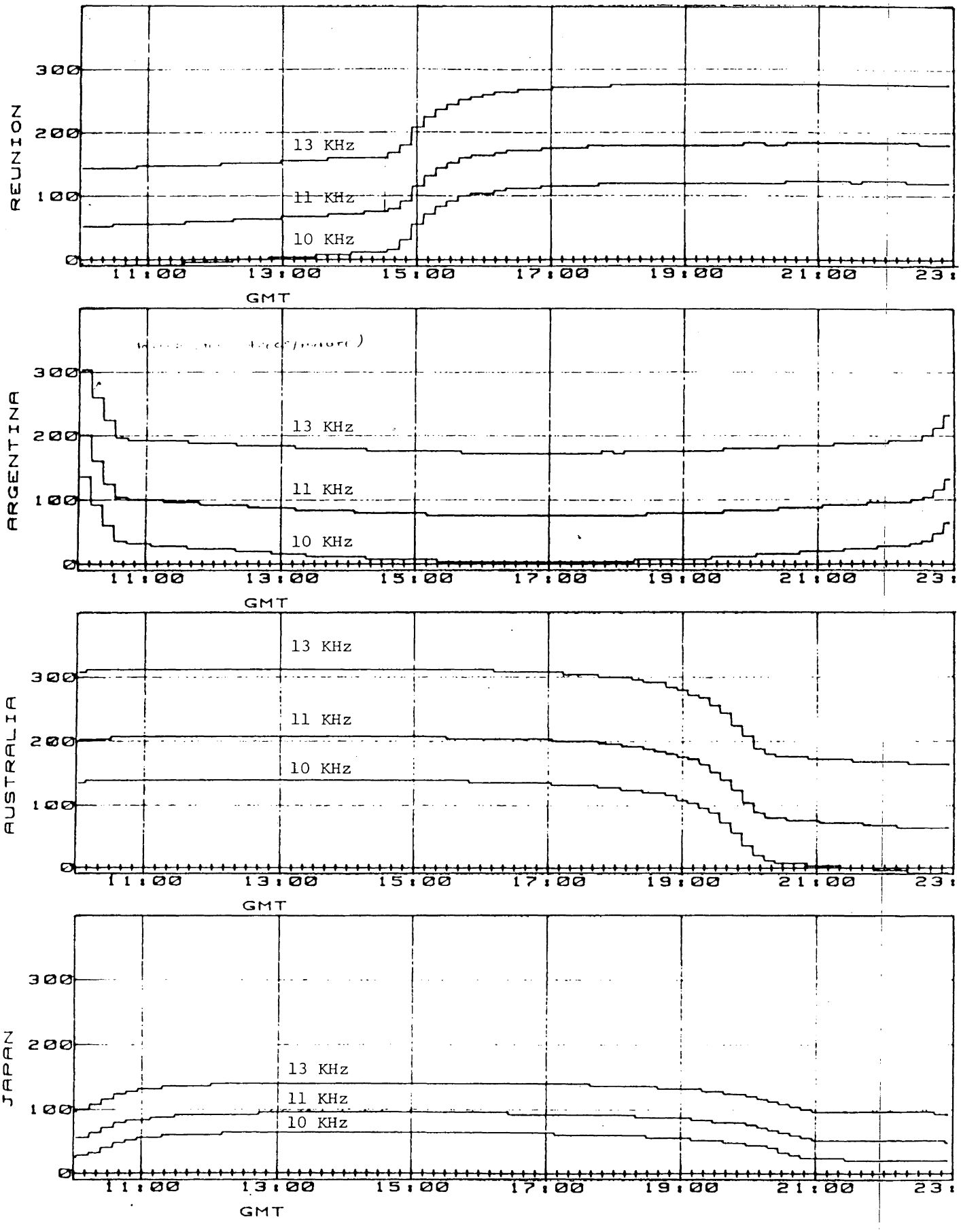

FLIGHT: APR 3 1983 LOP ERR
13 KHZ
REF. STATION: DAKOTA
REUNION
13 KHz
ARGENTINA
AUSTRALIA
13 KHz
JAPAN
13 KHz
40
30
20
10
0
-10
-20
-30
-40
-50
11:00
13:00
15:00
17:00
19:00
21:00
23:
GMT
TIME CONST.: 10 SECS

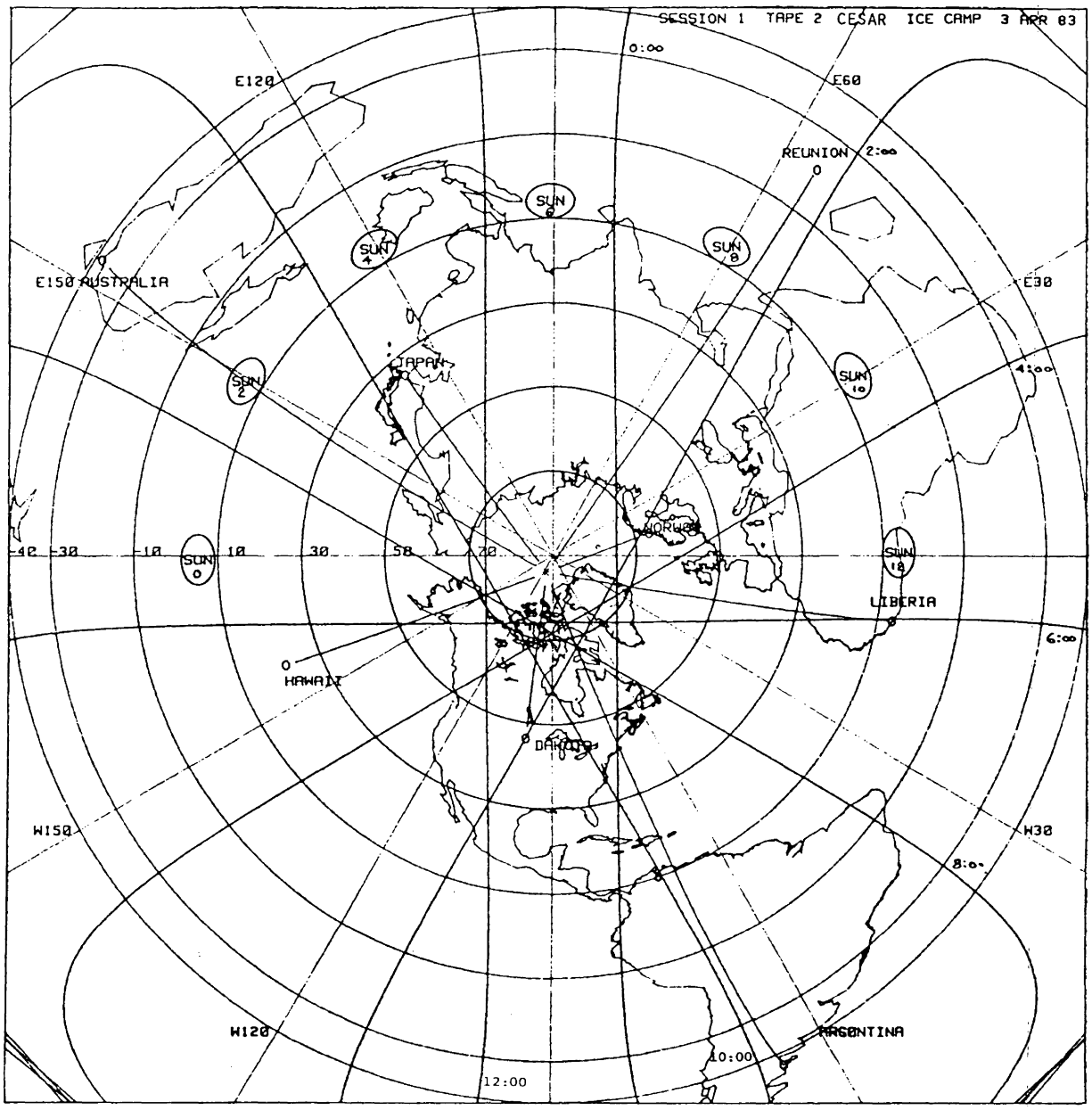
SESSION 1 TAPE 1 CESAR ICE CAMP DATE OF



FLIGHT: APR 3 1983 DIURNALS

13 KHz 11 KHz 10 KHz
VLF STATUS: UNFORCED

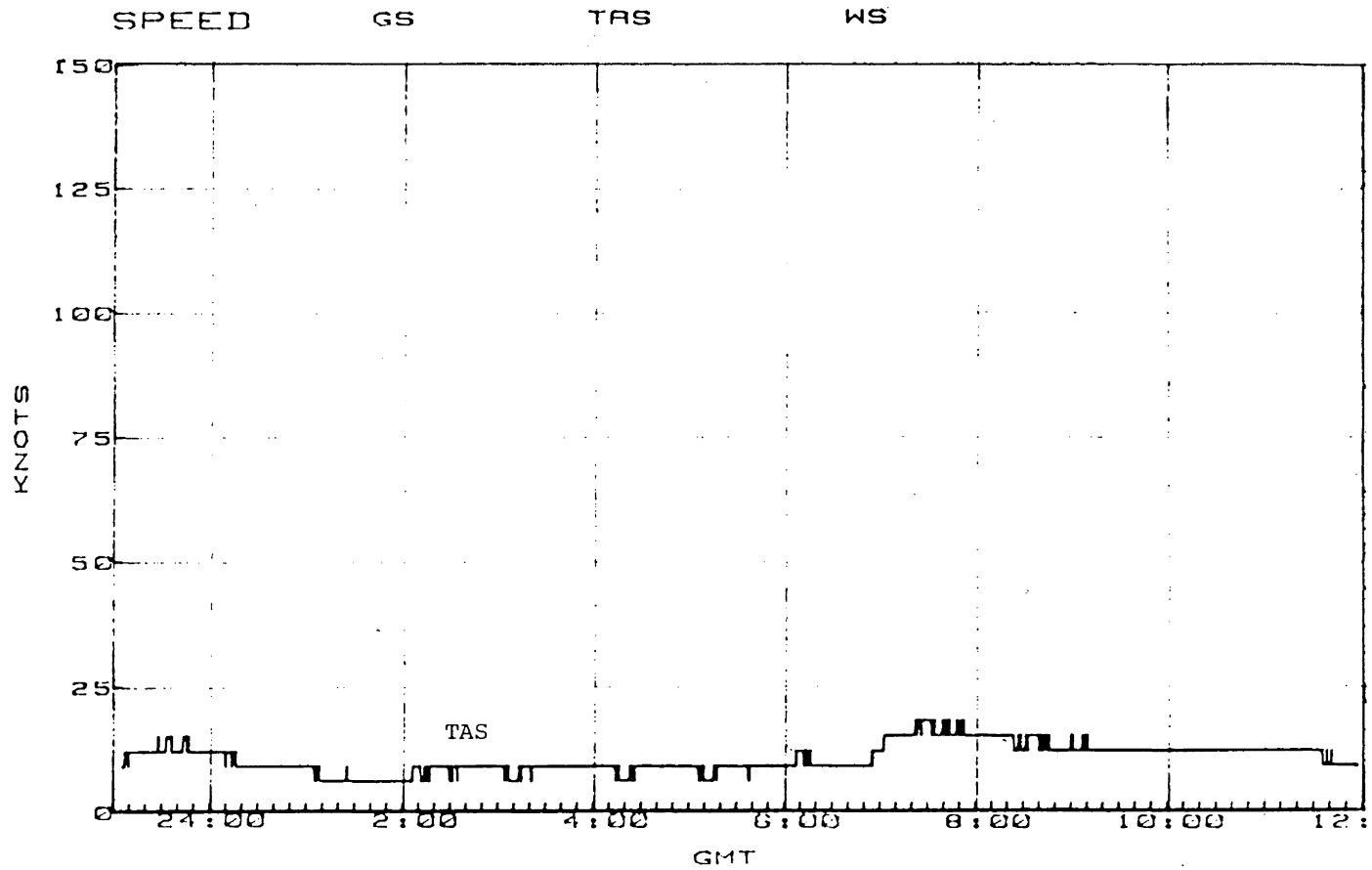


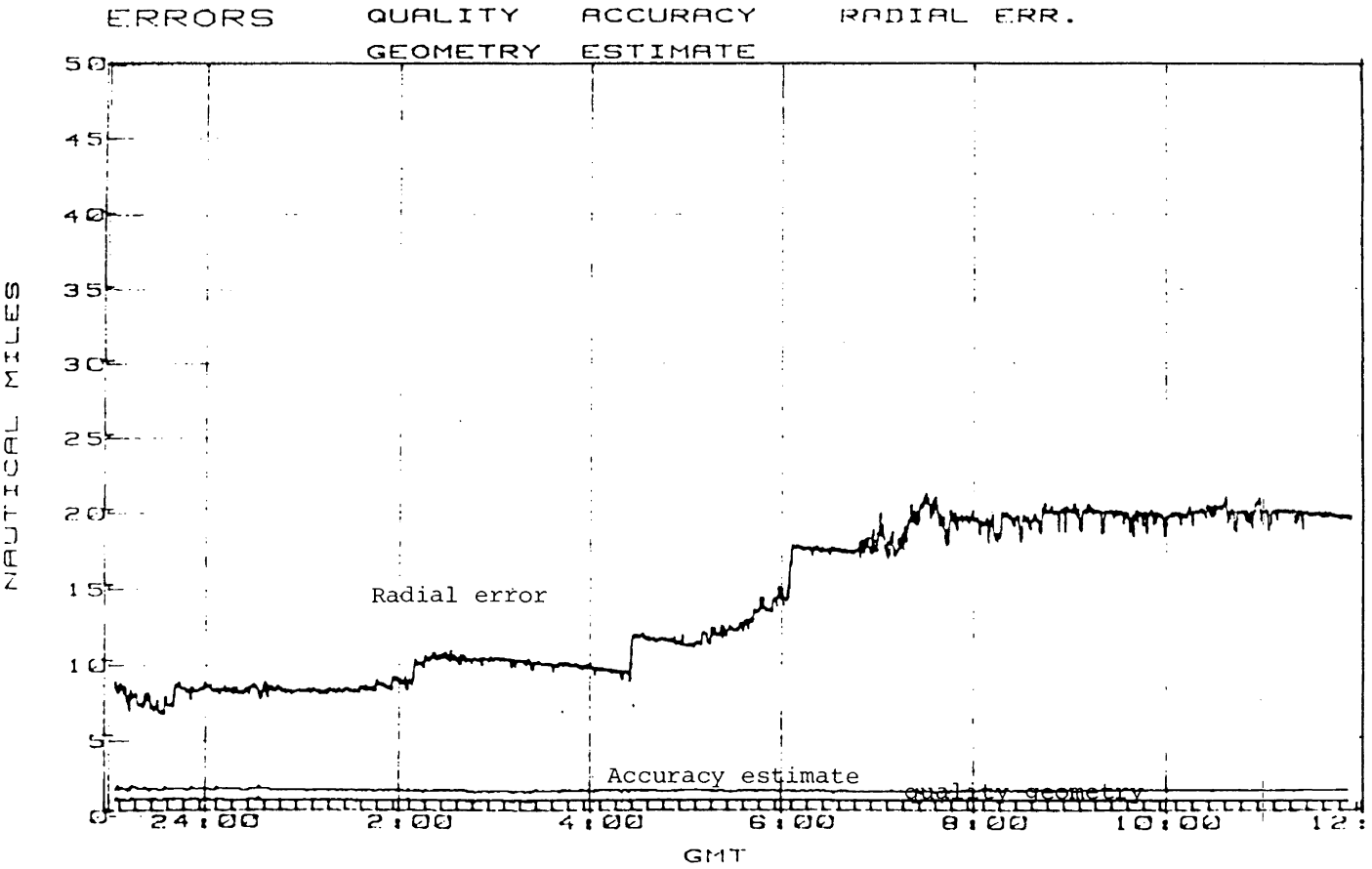


SESSION 1 TAPE 2

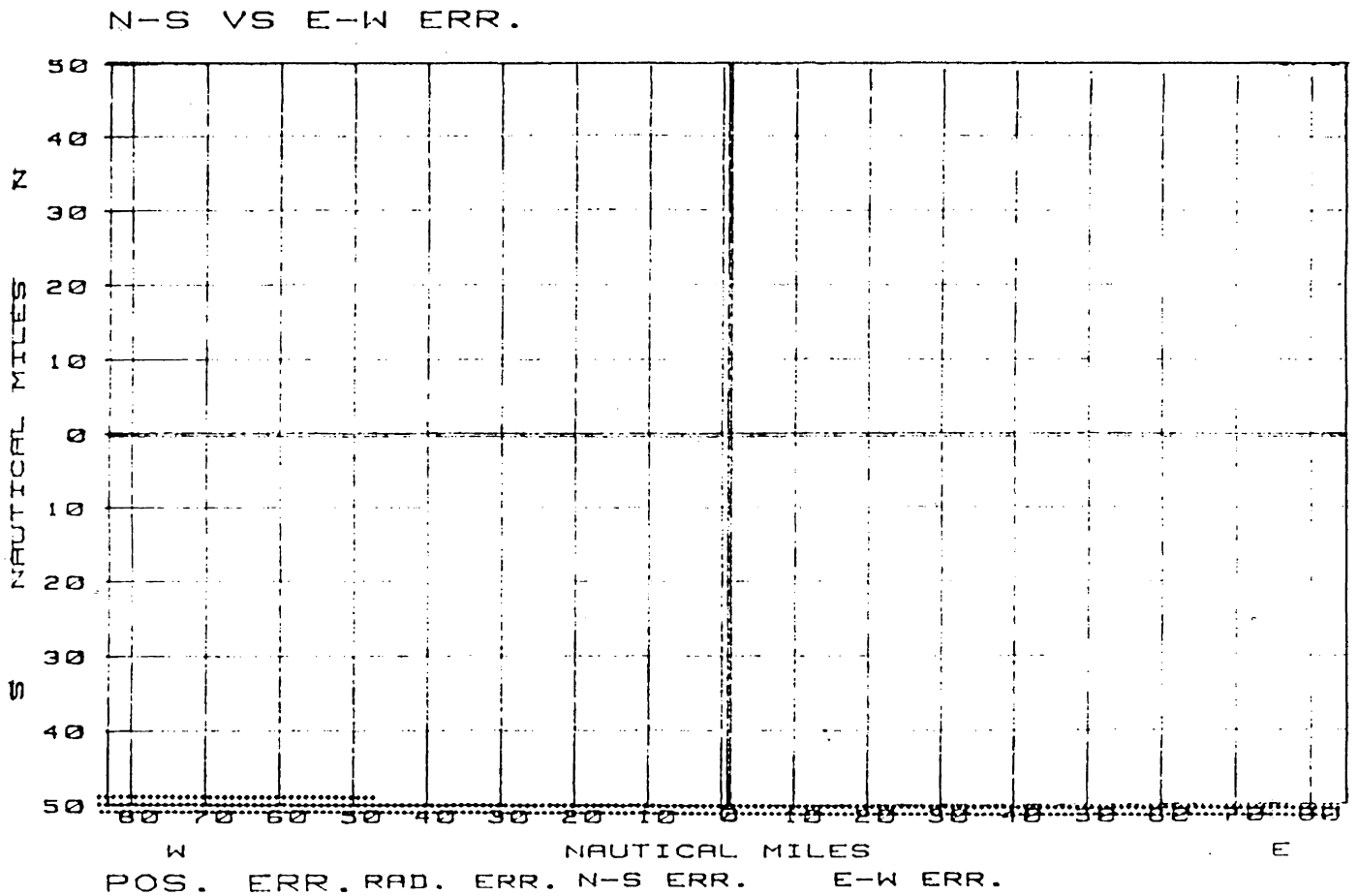
World map displaying CESAR's position, Omega transmitting stations and day/night terminators.

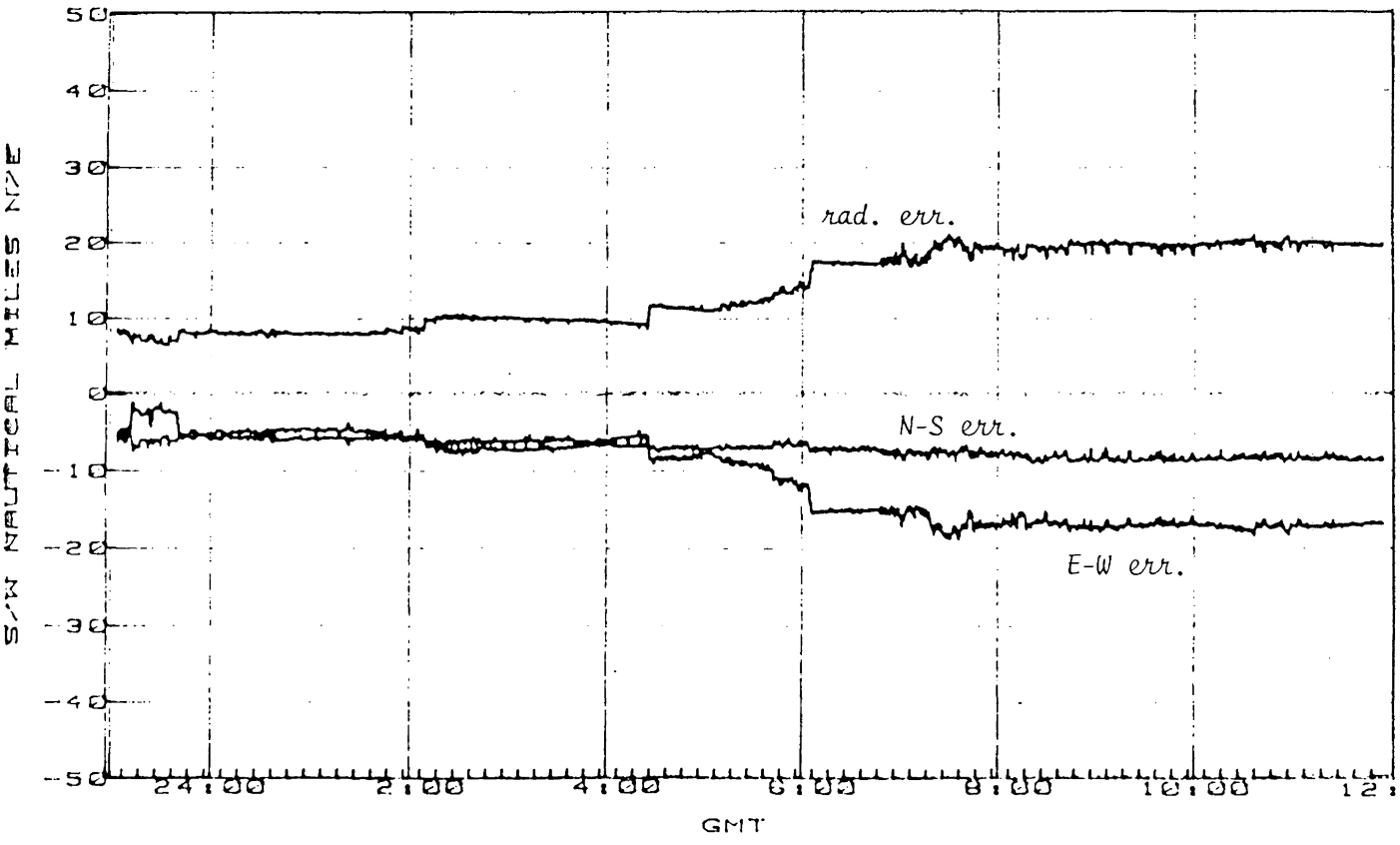
SESSION 1 TAPE 2 CESAR ICE CAMP DATE OF



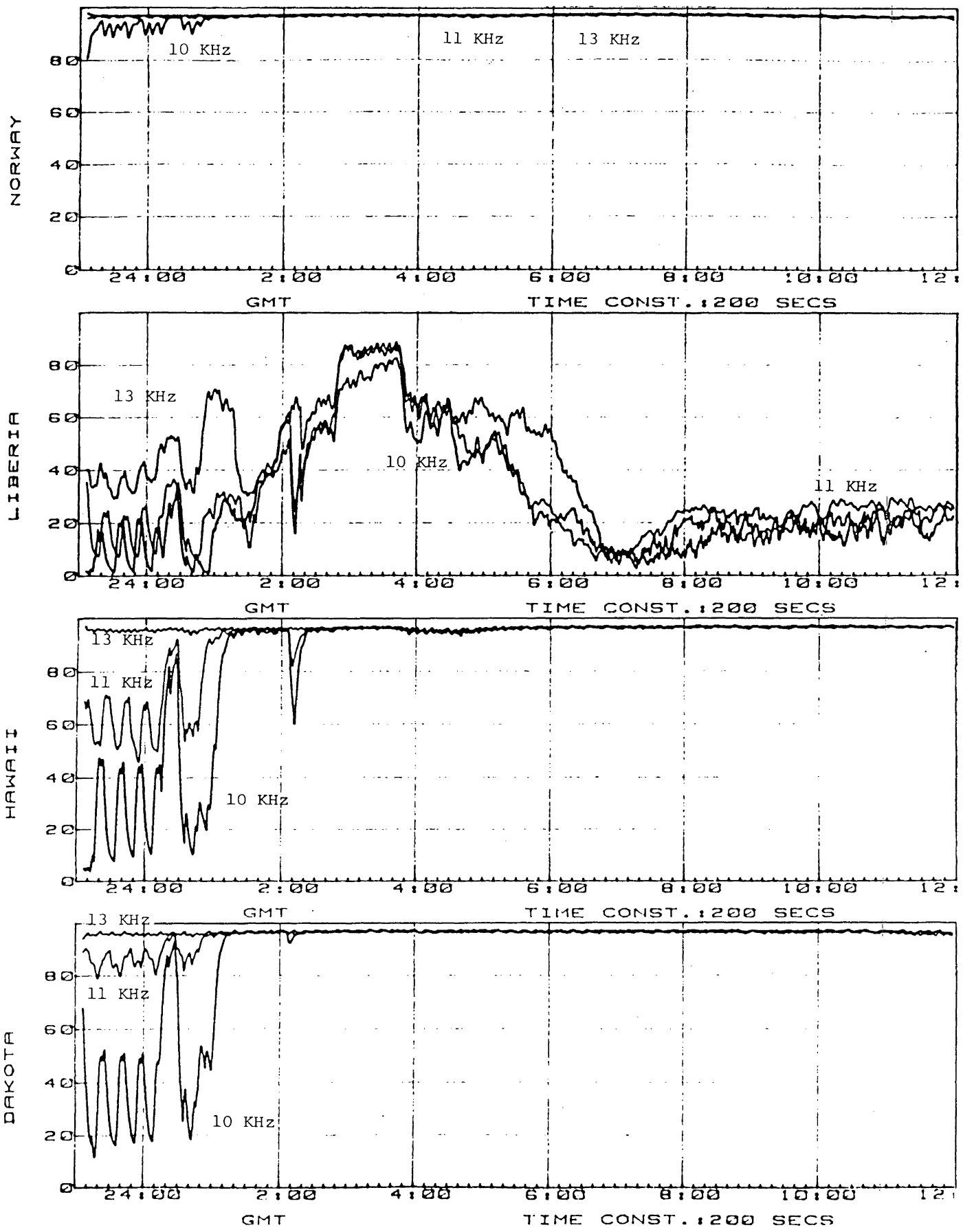


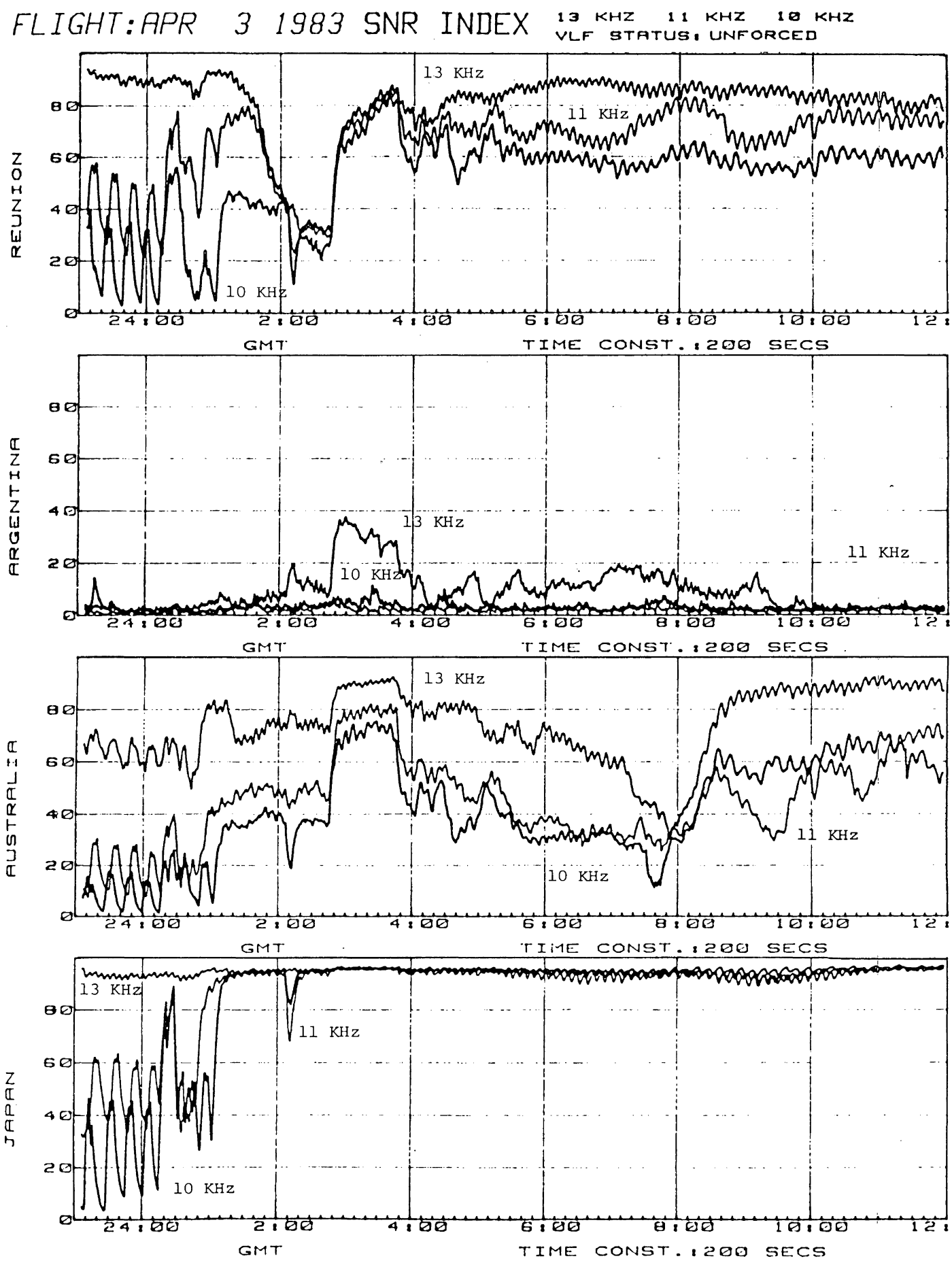
FLIGHT: APR 3 1983



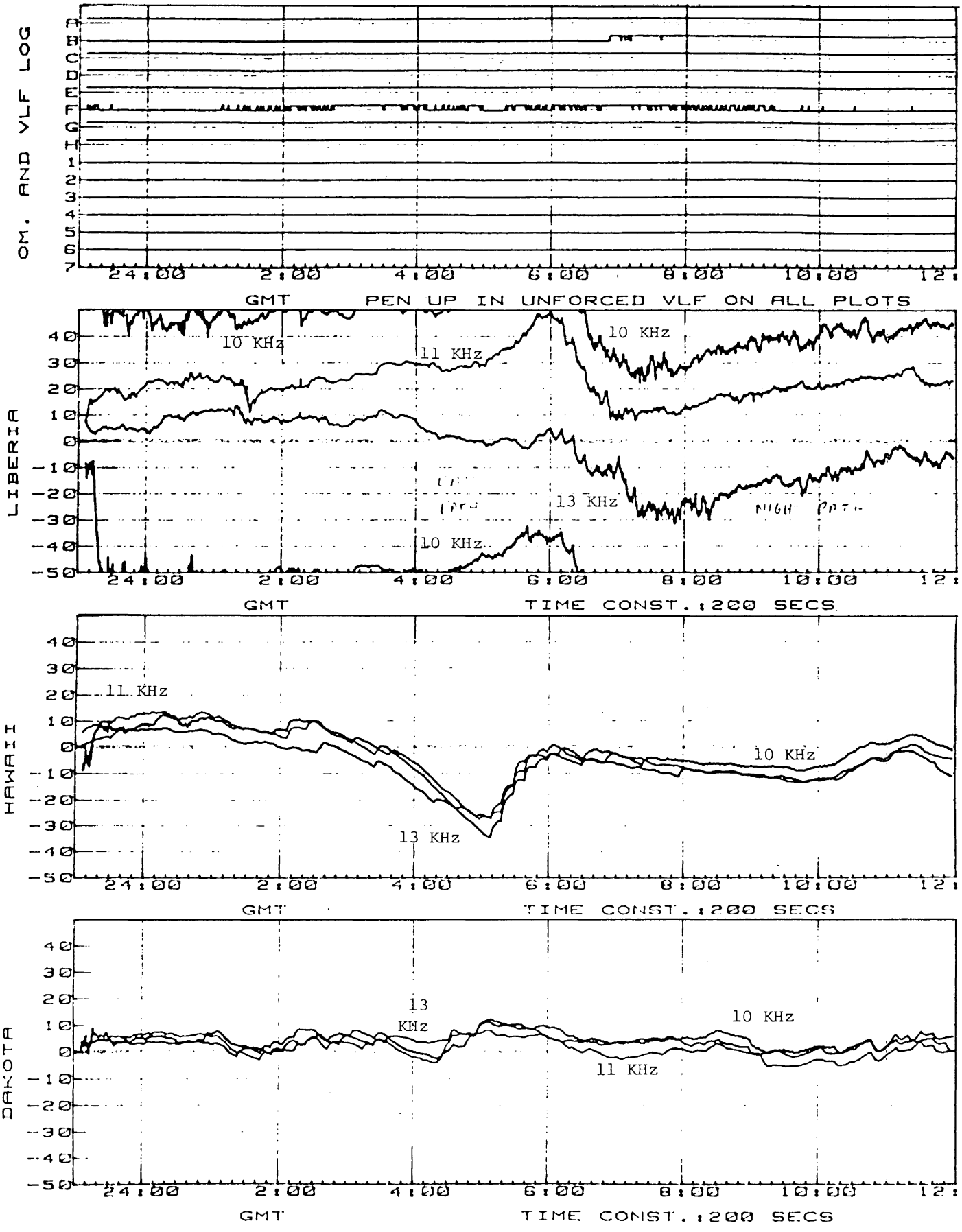


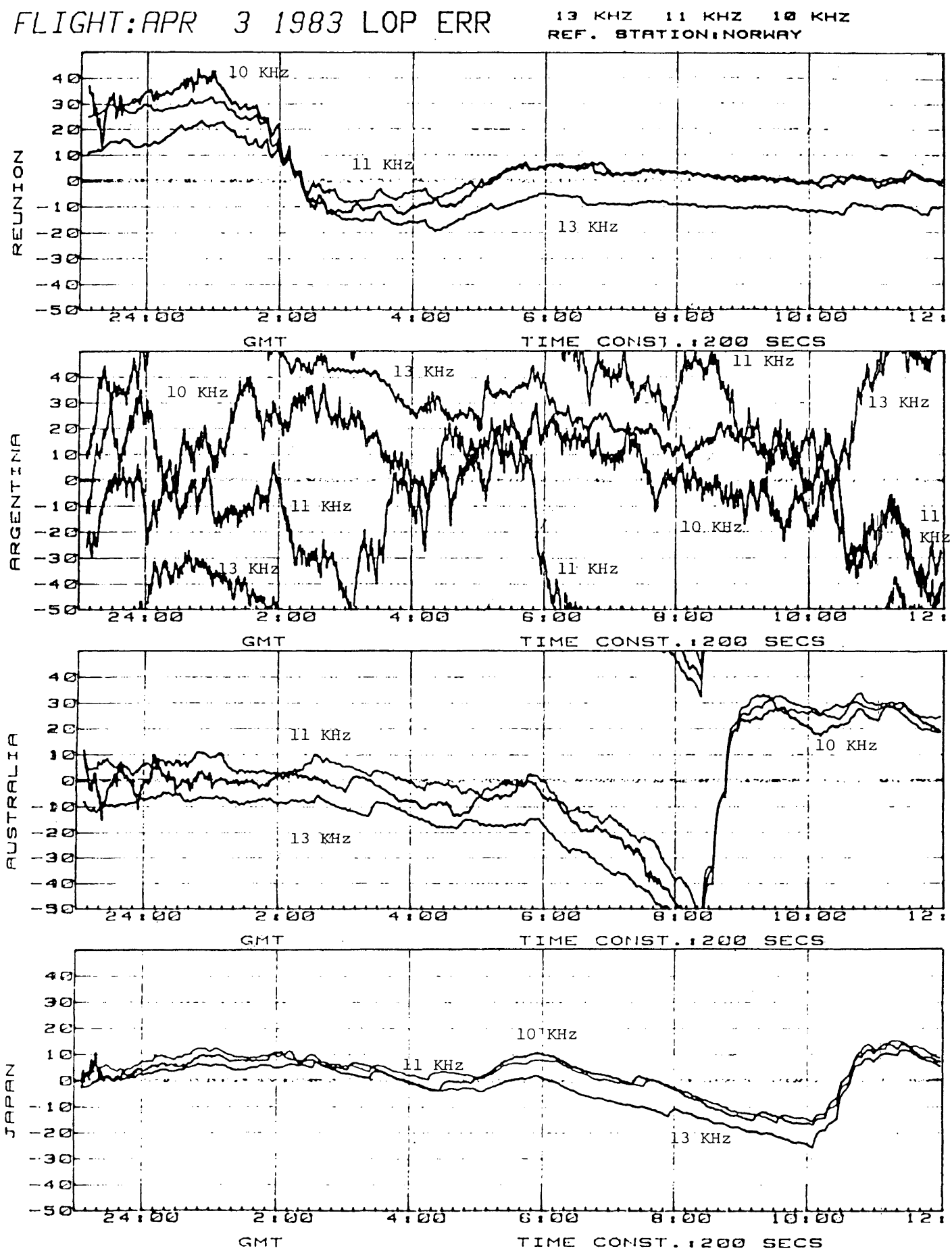
SESSION 1 TAPE 2 CESAR ICE CAMP DATE OF



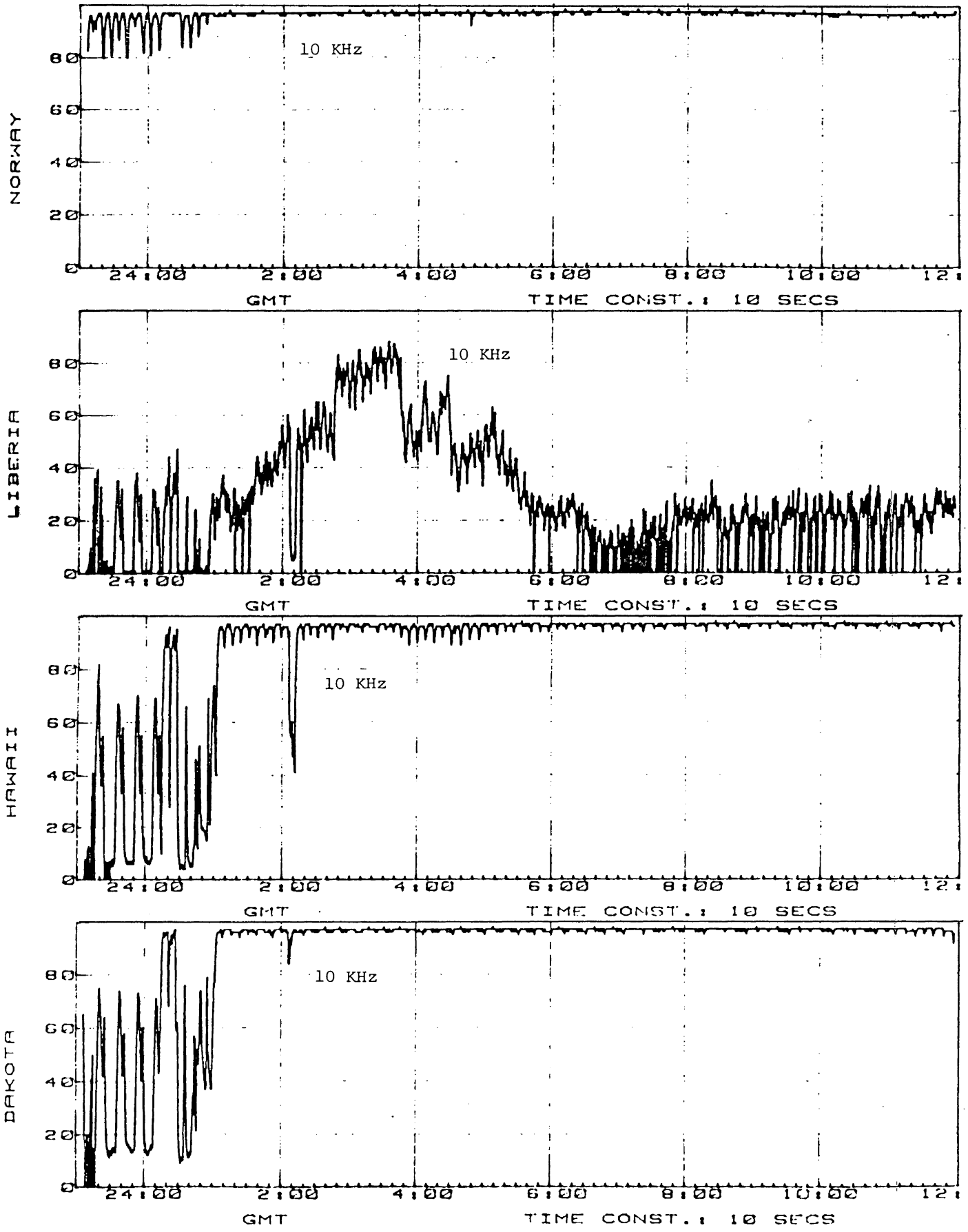

FLIGHT:APR 3 1983 SNR INDEX
13 KHZ 11 KHZ 10 KHZ
VLF STATUS: UNFORCED
REUNION
13 KHz
11 KHz
10 KHz
ARGENTINA
13 KHz
11 KHz
10 KHz
AUSTRALIA
13 KHz
11 KHz
10 KHz
JAPAN
13 KHz
11 KHz
10 KHz
0
20
40
60
80
24:00
2:00
4:00
6:00
8:00
10:00
12:
GMT
TIME CONST.:200 SECS

SESSION 1 TAPE 2 CESAR ICE CAMP DATE OF

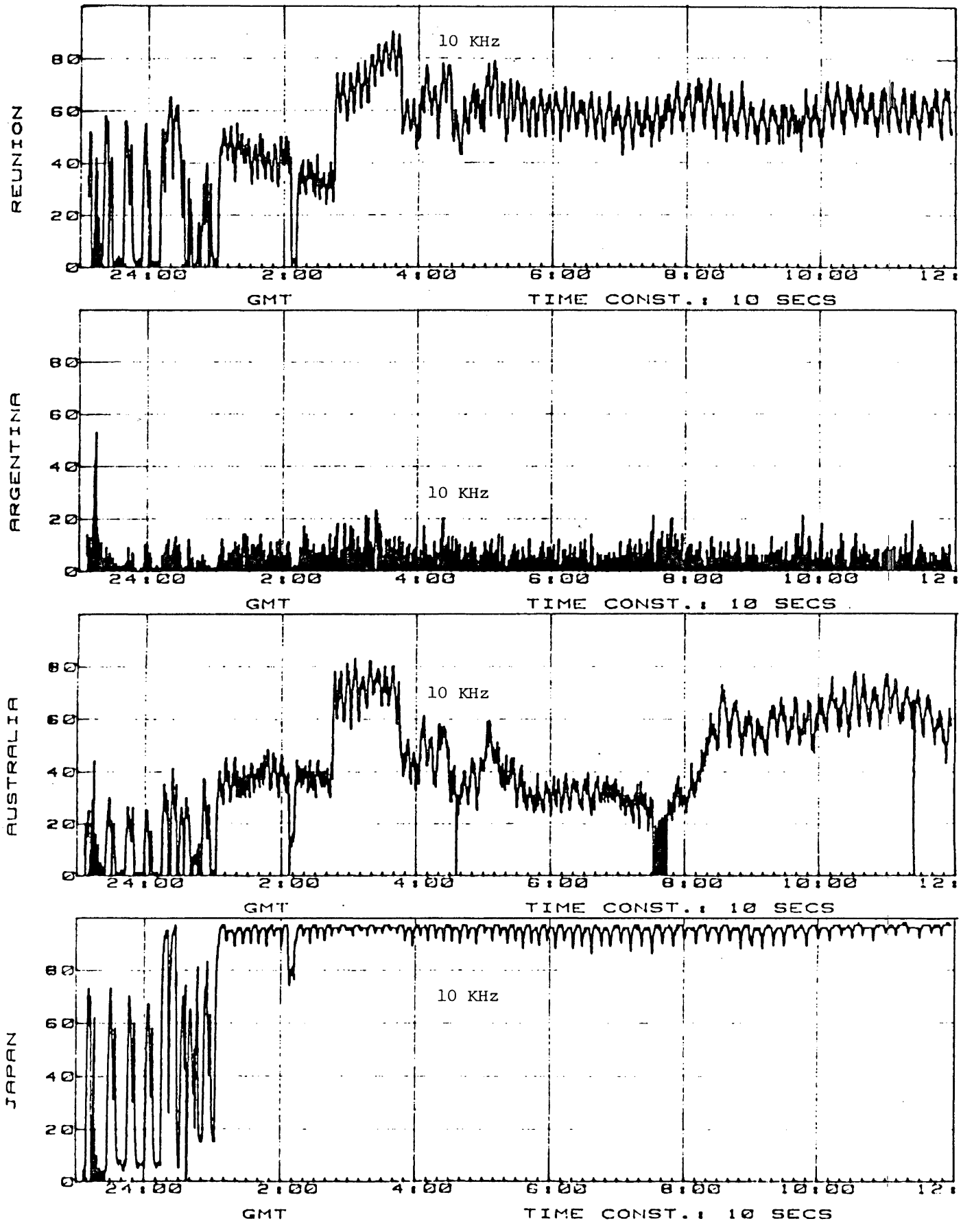



FLIGHT:APR 3 1983 LOP ERR
13 KHZ 11 KHZ 10 KHZ
REF. STATION:NORWAY
REUNION
10 KHz
11 KHz
13 KHz
GMT
TIME CONST.:200 SECS
ARGENTINA
10 KHz
13 KHz
11 KHz
13 KHz
11 KHz
10 KHz
11 KHz
13 KHz
11 KHz
GMT
TIME CONST.:200 SECS
AUSTRALIA
11 KHz
10 KHz
13 KHz
GMT
TIME CONST.:200 SECS
JAPAN
10 KHz
11 KHz
13 KHz
GMT
TIME CONST.:200 SECS

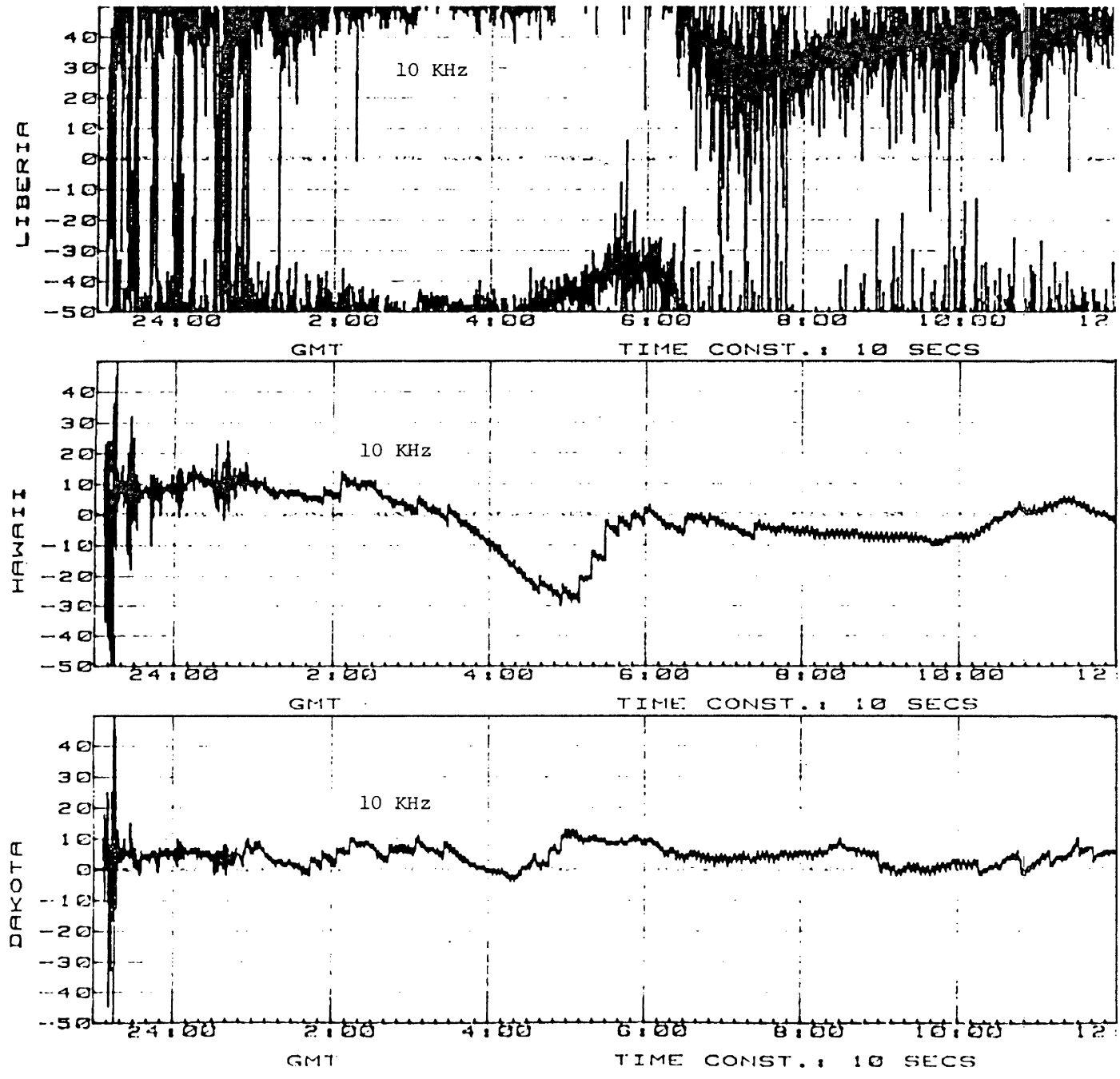
SESSION 1 TAPE 2 CESAR ICE CAMP DATE OF



F FLIGHT: APR 3 1983 SNR INDEX 10 KHZ

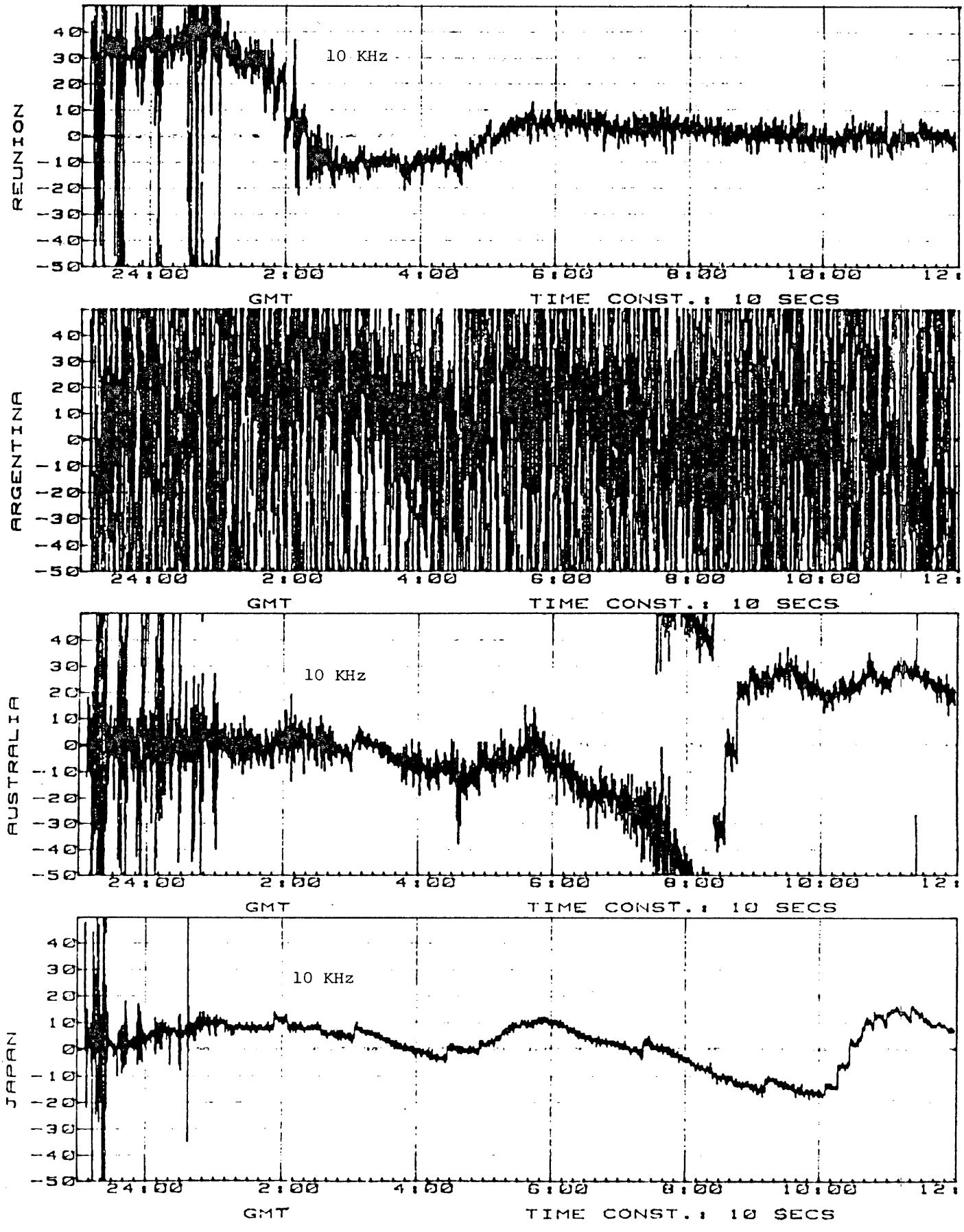


SESSION 1 TAPE 2 CESAR ICE CAMP DATE OF

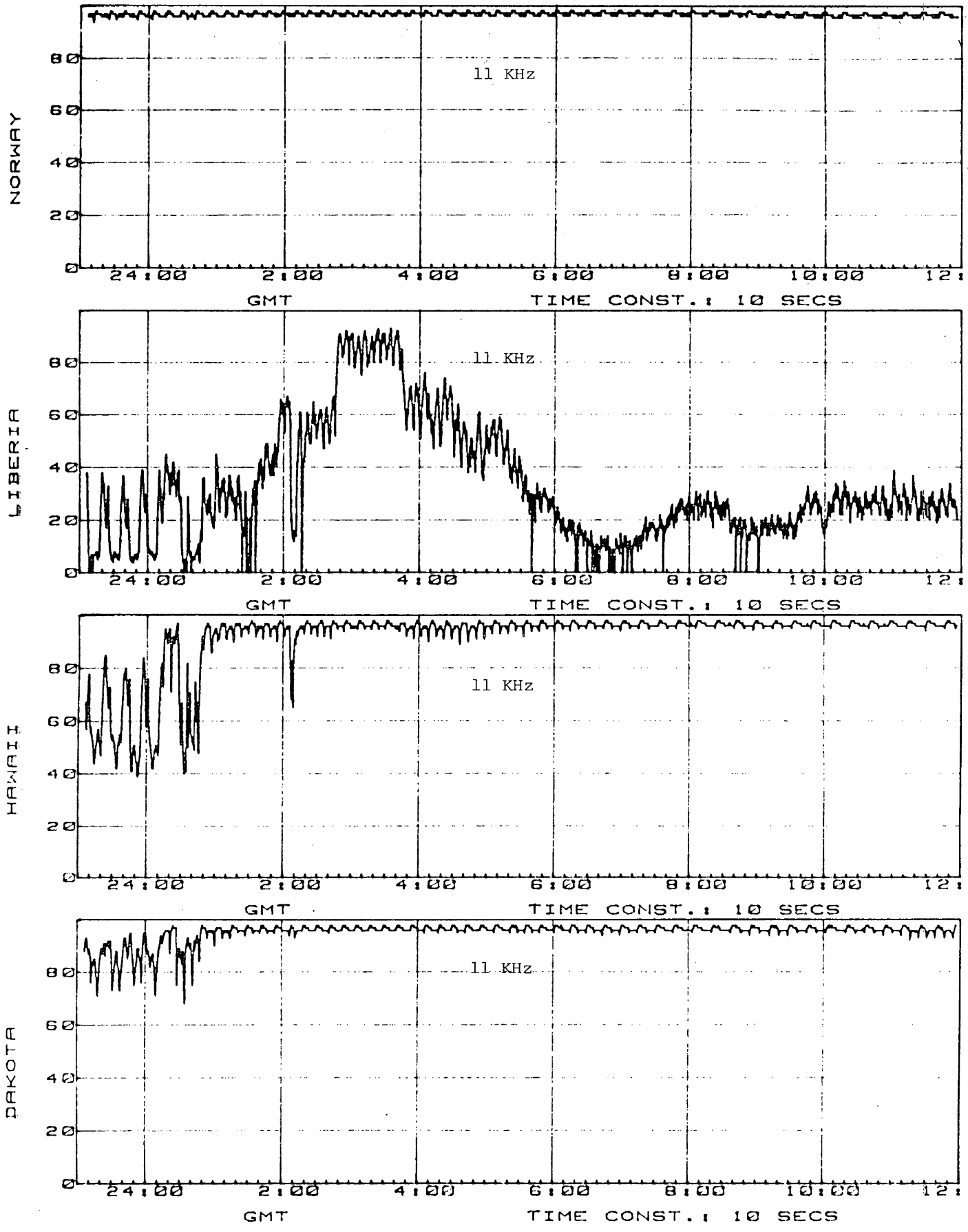


OF FLIGHT: APR 3 1983 LOP ERR

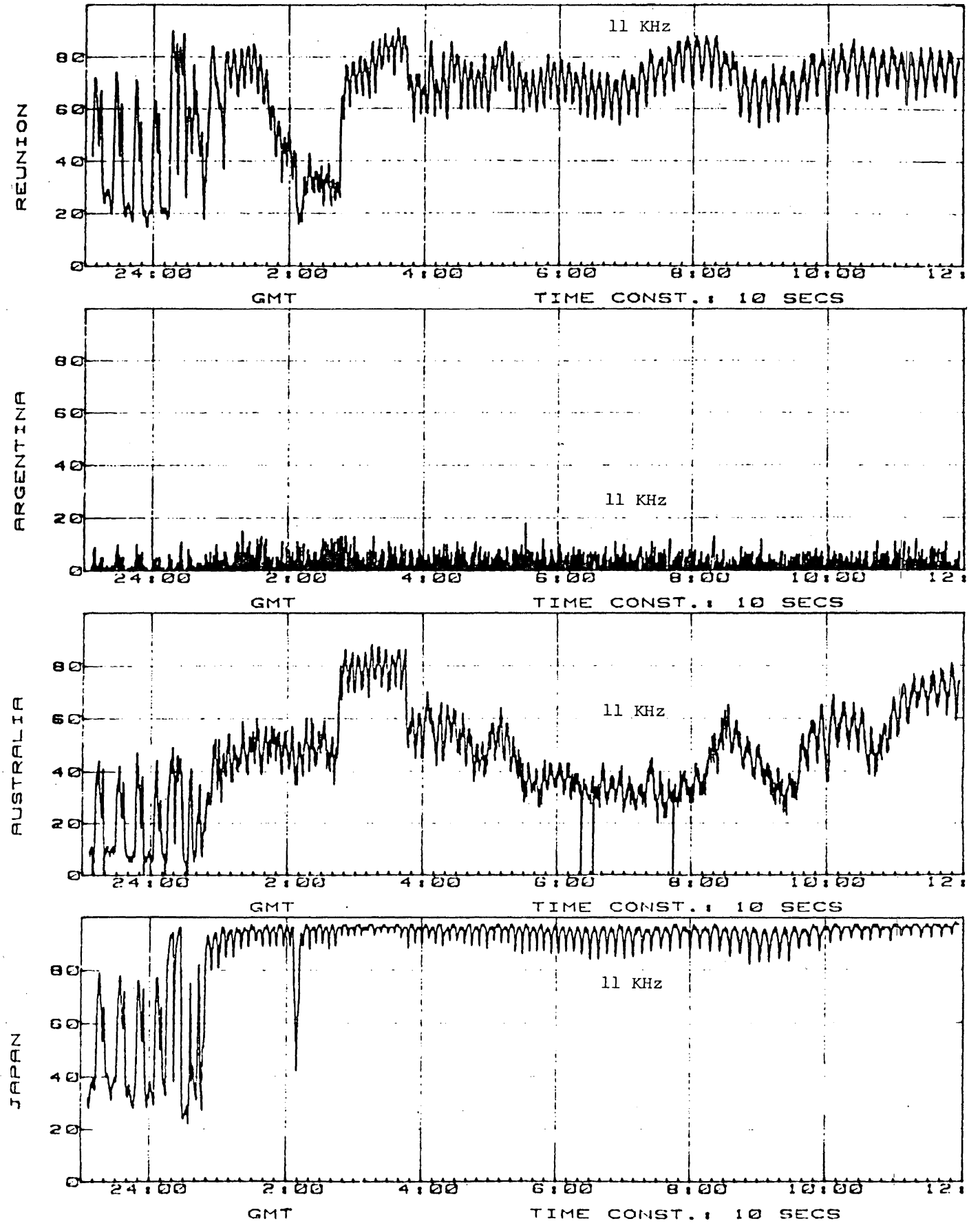
10 KHZ
REF. STATION: NORWAY



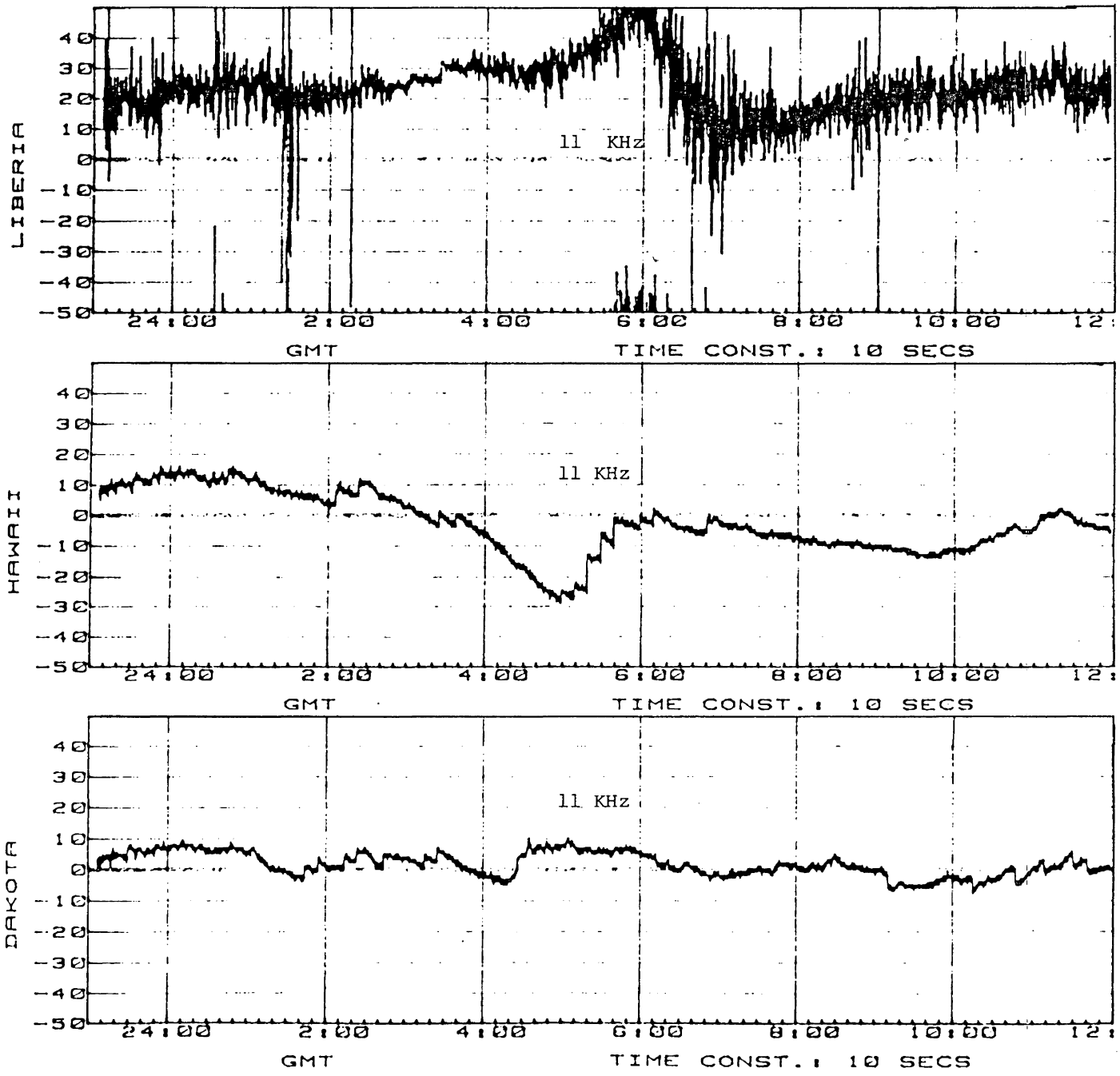
SESSION 1 TAPE 2 CESAR ICE CAMP DATE OF FL

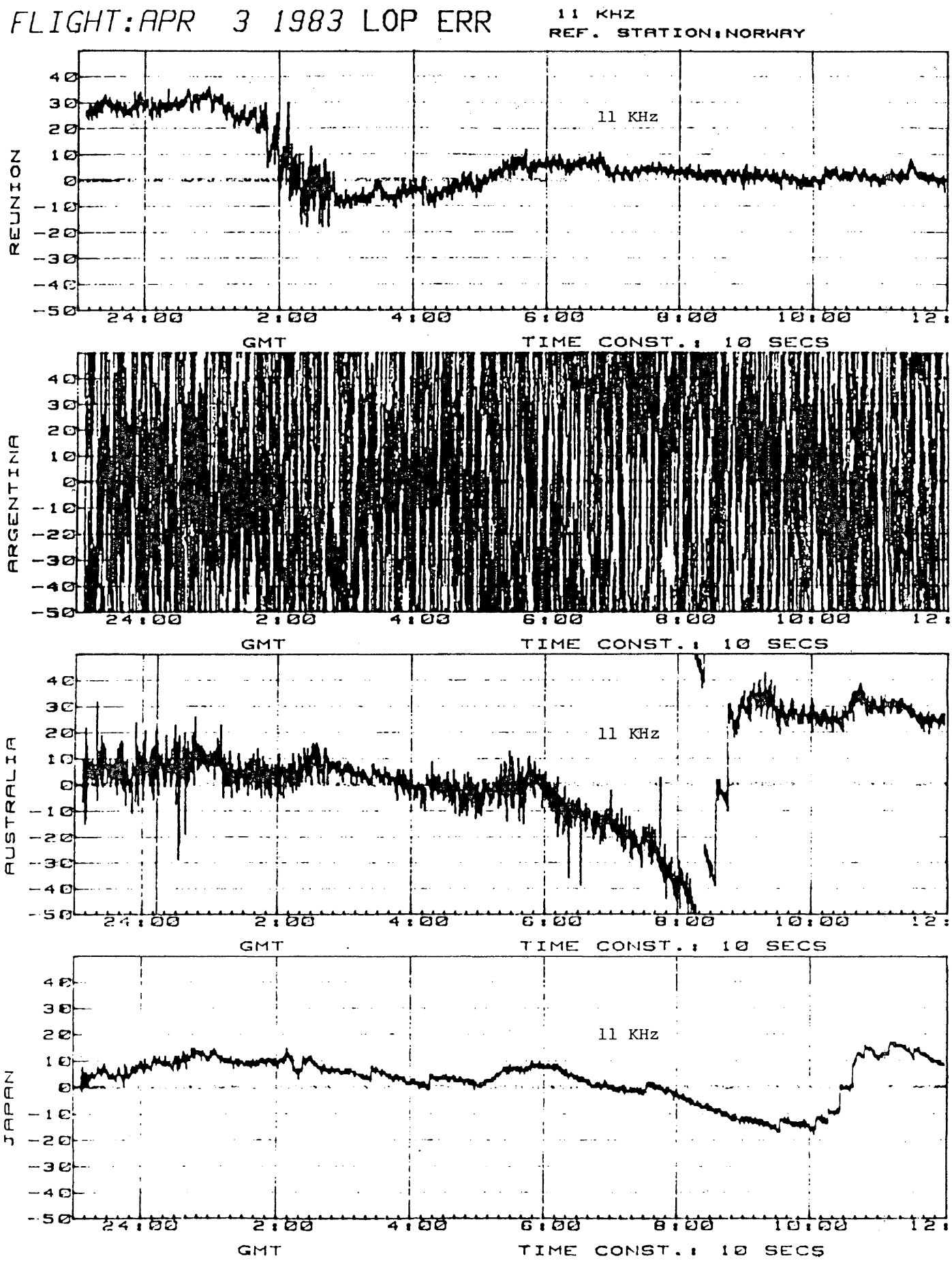


FLIGHT:APR 3 1983 SNR INDEX 11 KHz

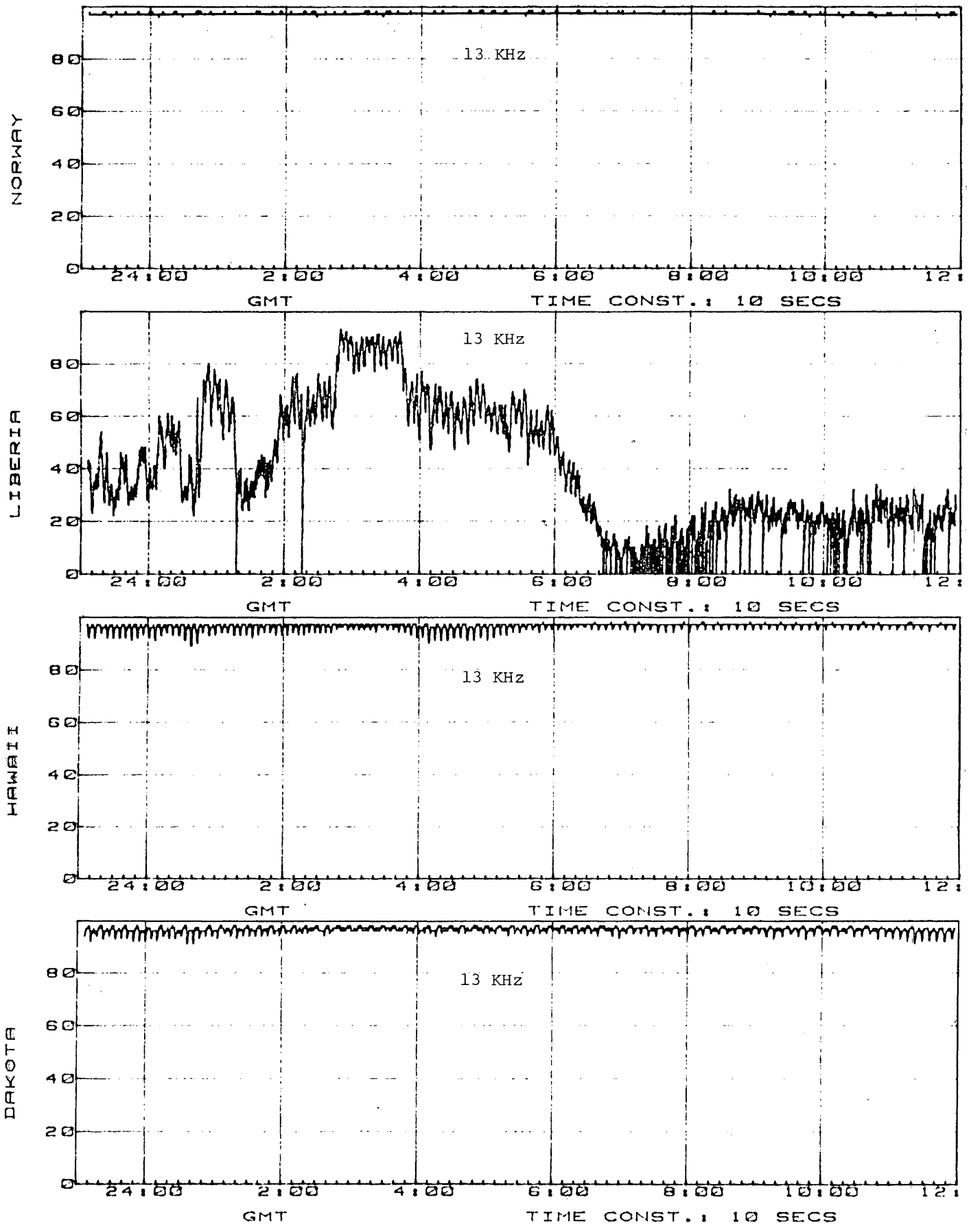


SESSION 1 TAPE 2 CESAR ICE CAMP DATE OF

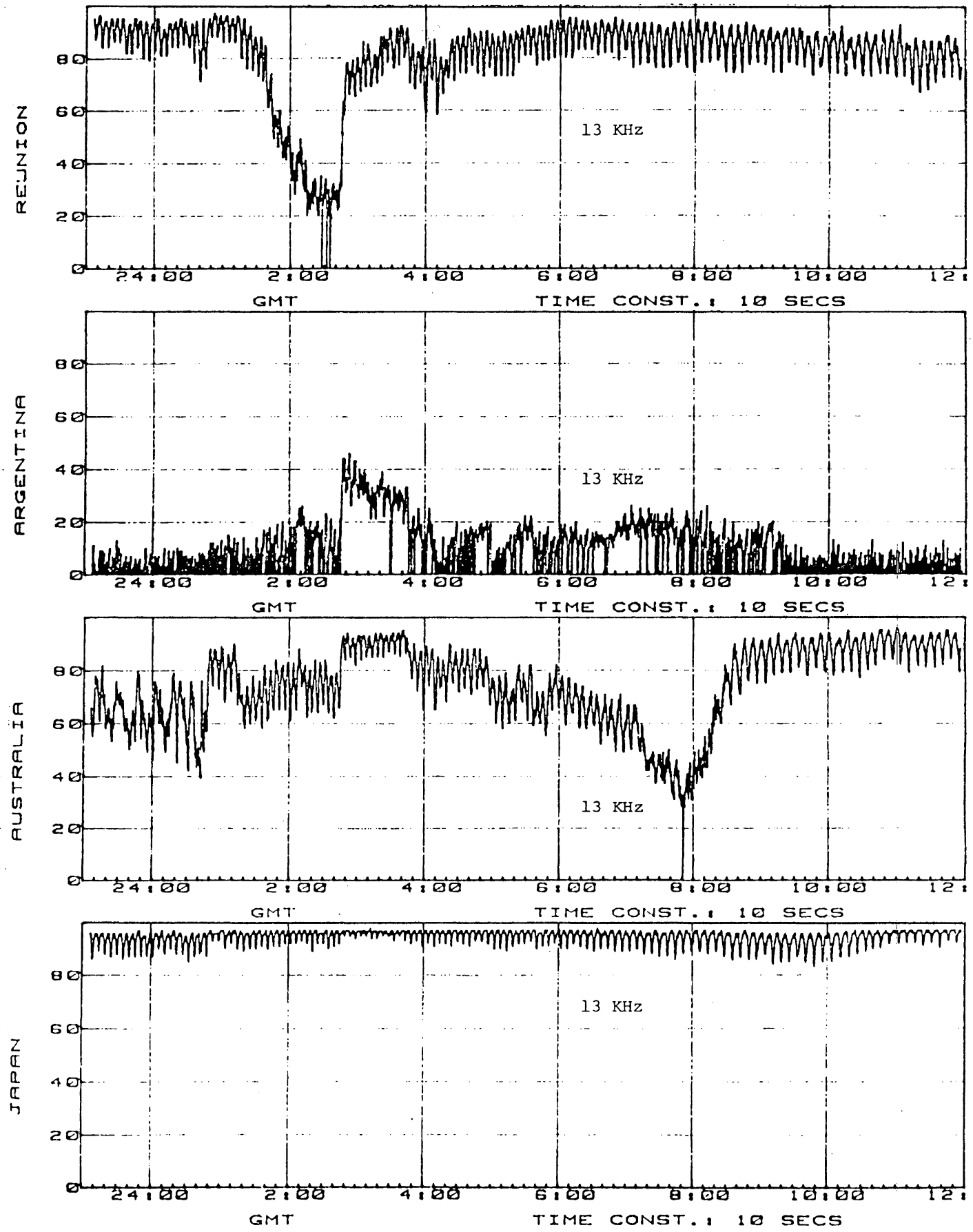



FLIGHT:APR 3 1983 LOP ERR
11 KHZ
REF. STATION:NORWAY
REUNION
11 KHz
GMT
TIME CONST.: 10 SECS
ARGENTINA
GMT
TIME CONST.: 10 SECS
AUSTRALIA
11 KHz
GMT
TIME CONST.: 10 SECS
JAPAN
11 KHz
GMT
TIME CONST.: 10 SECS

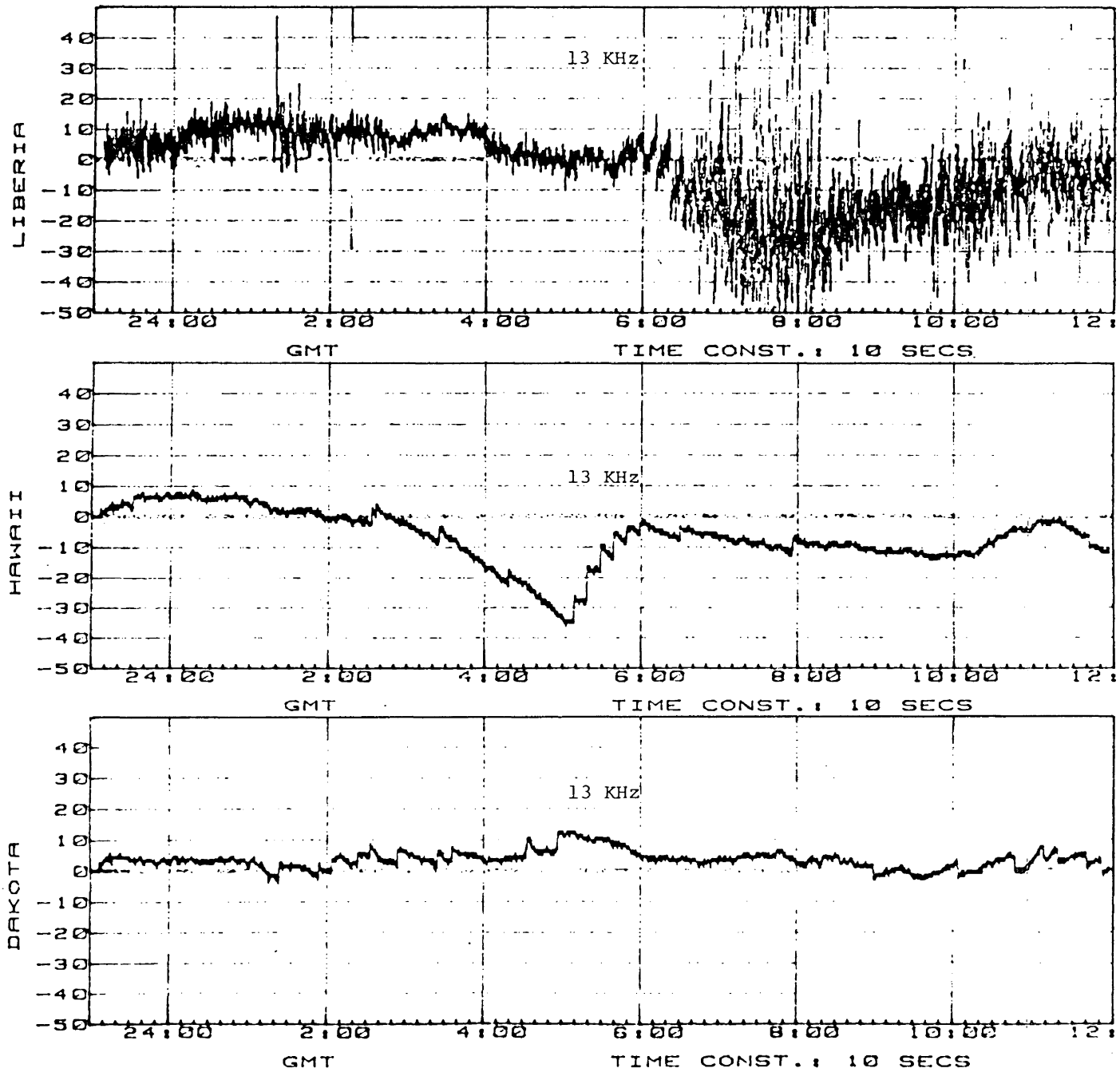
SESSION 1 TAPE 2 CESAR ICE CAMP DATE OF F



OF FLIGHT:APR 3 1983 SNR INDEX 13 KHZ

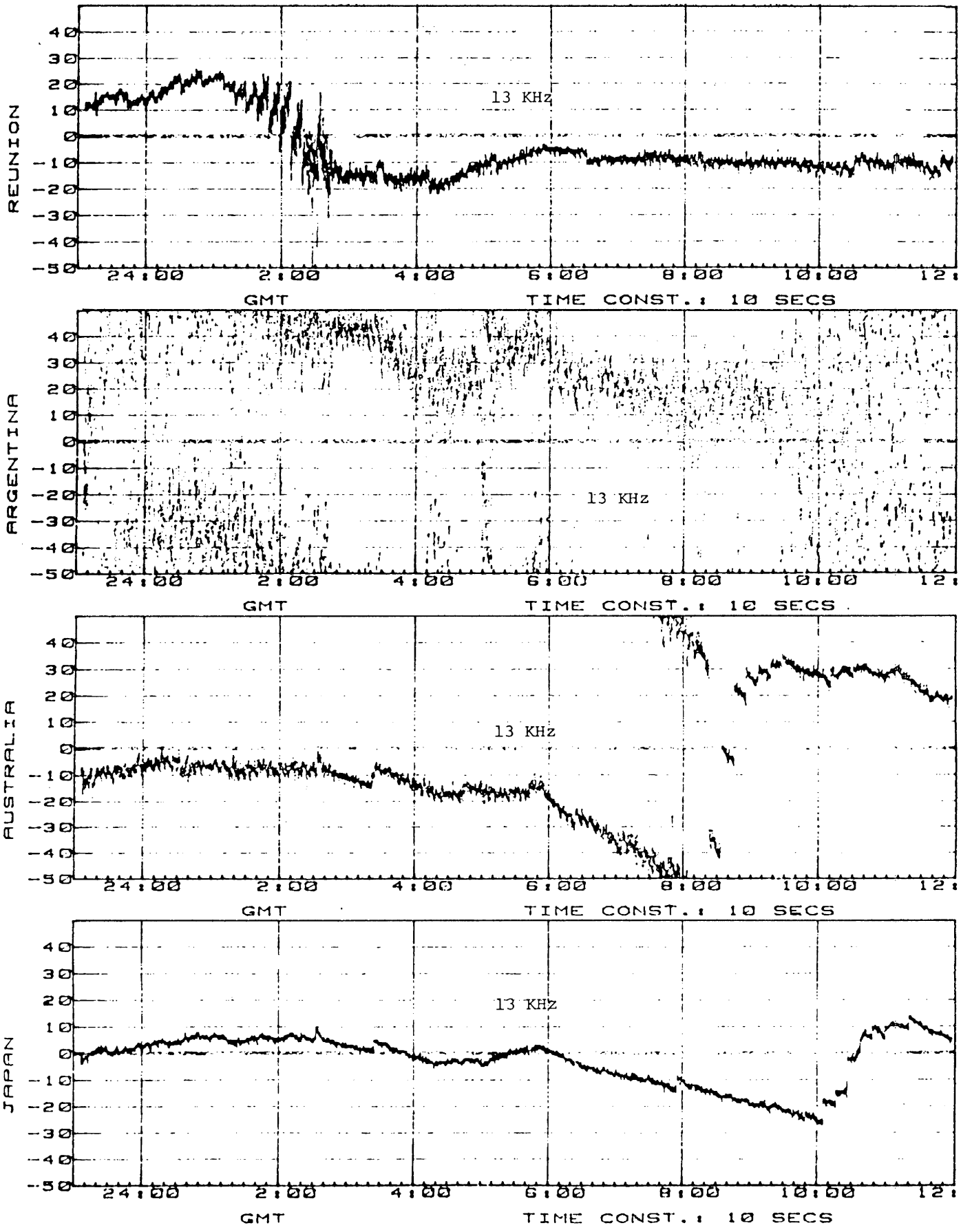


SESSION 1 TAPE 2 CESAR ICE CAMP DATE OF

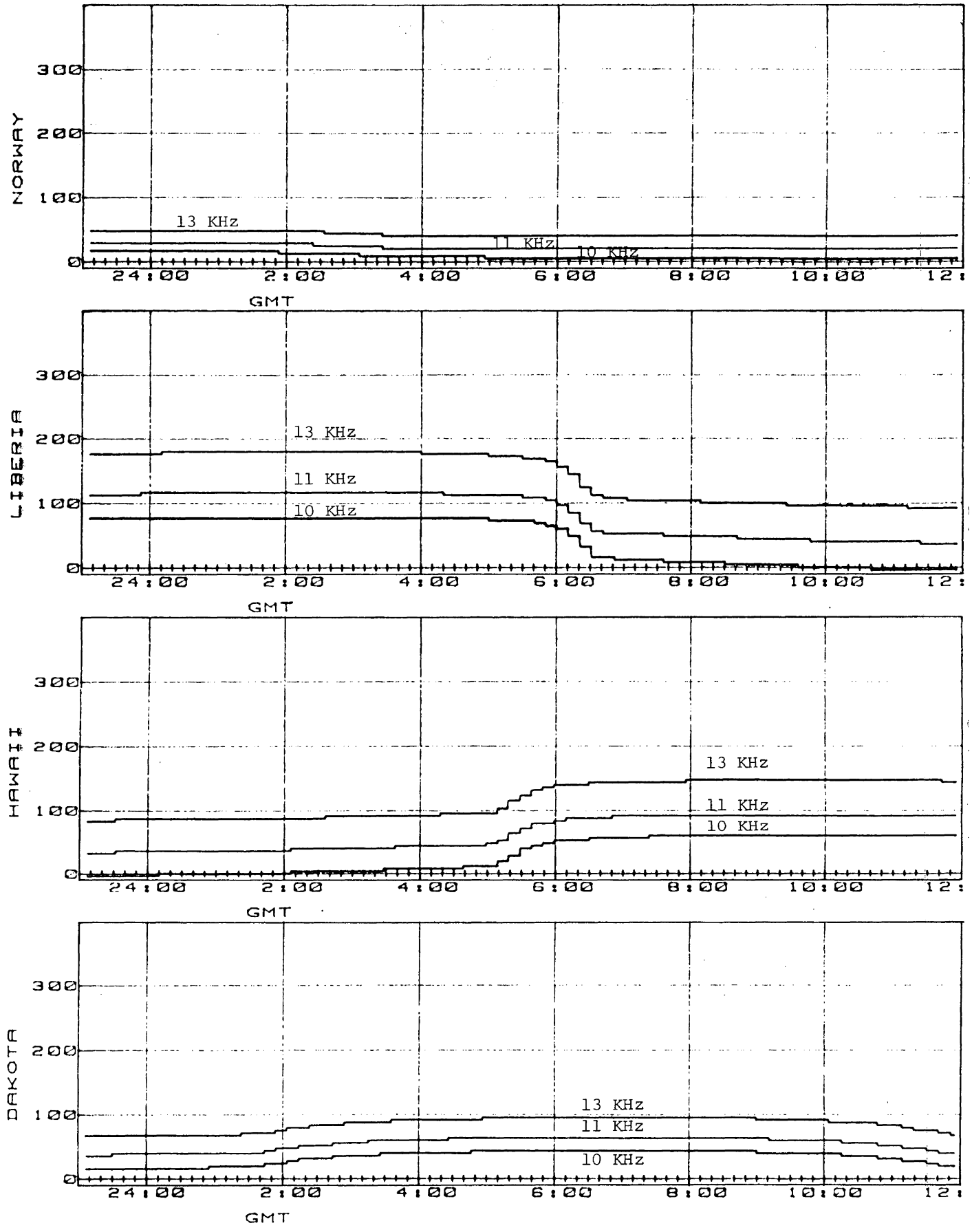


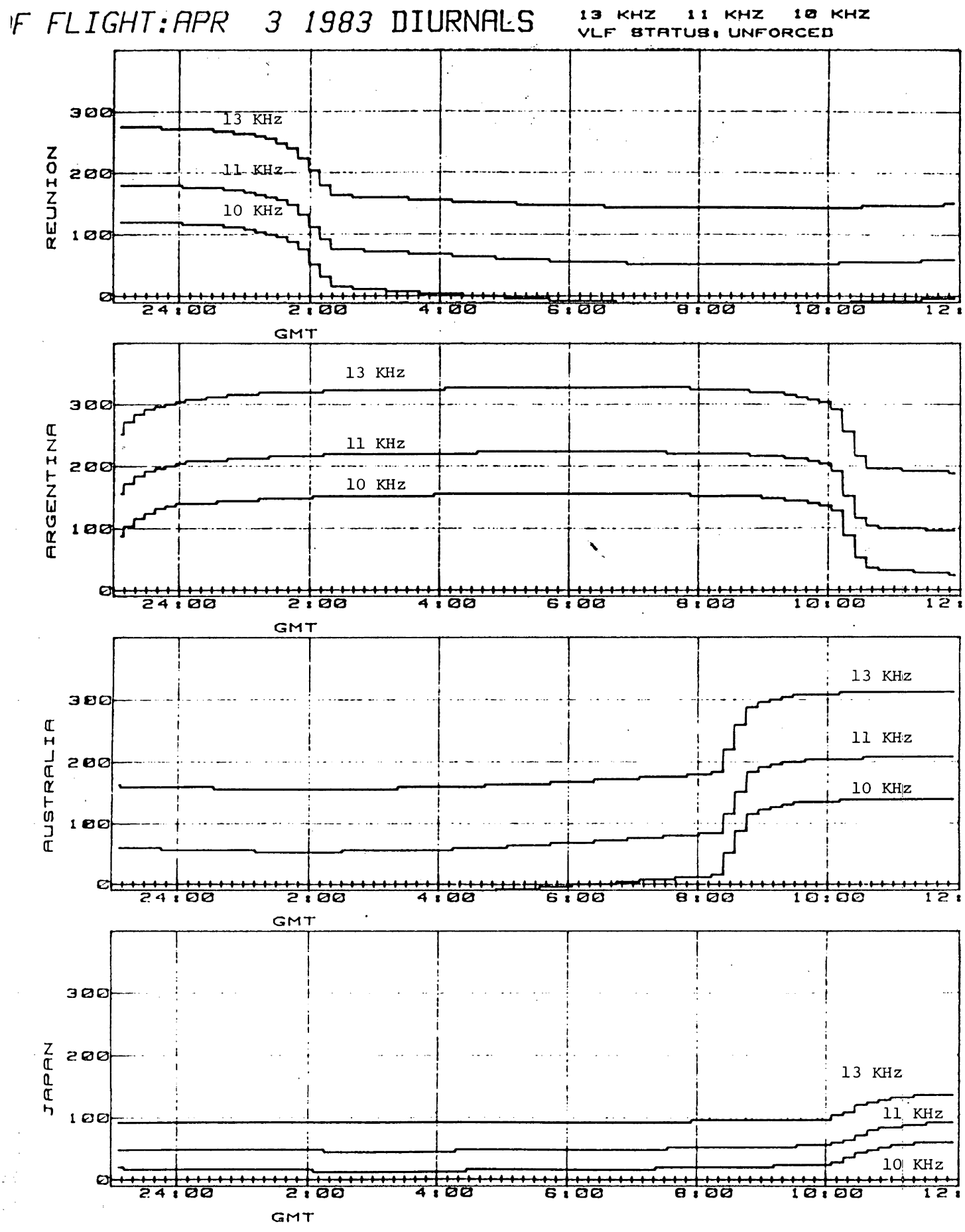
)F FLIGHT:APR 3 1983 LOP ERR

13 KHZ
REF. STATION:NORWAY



SESSION 1 TAPE 2 CESAR ICE CAMP DATE OF FL



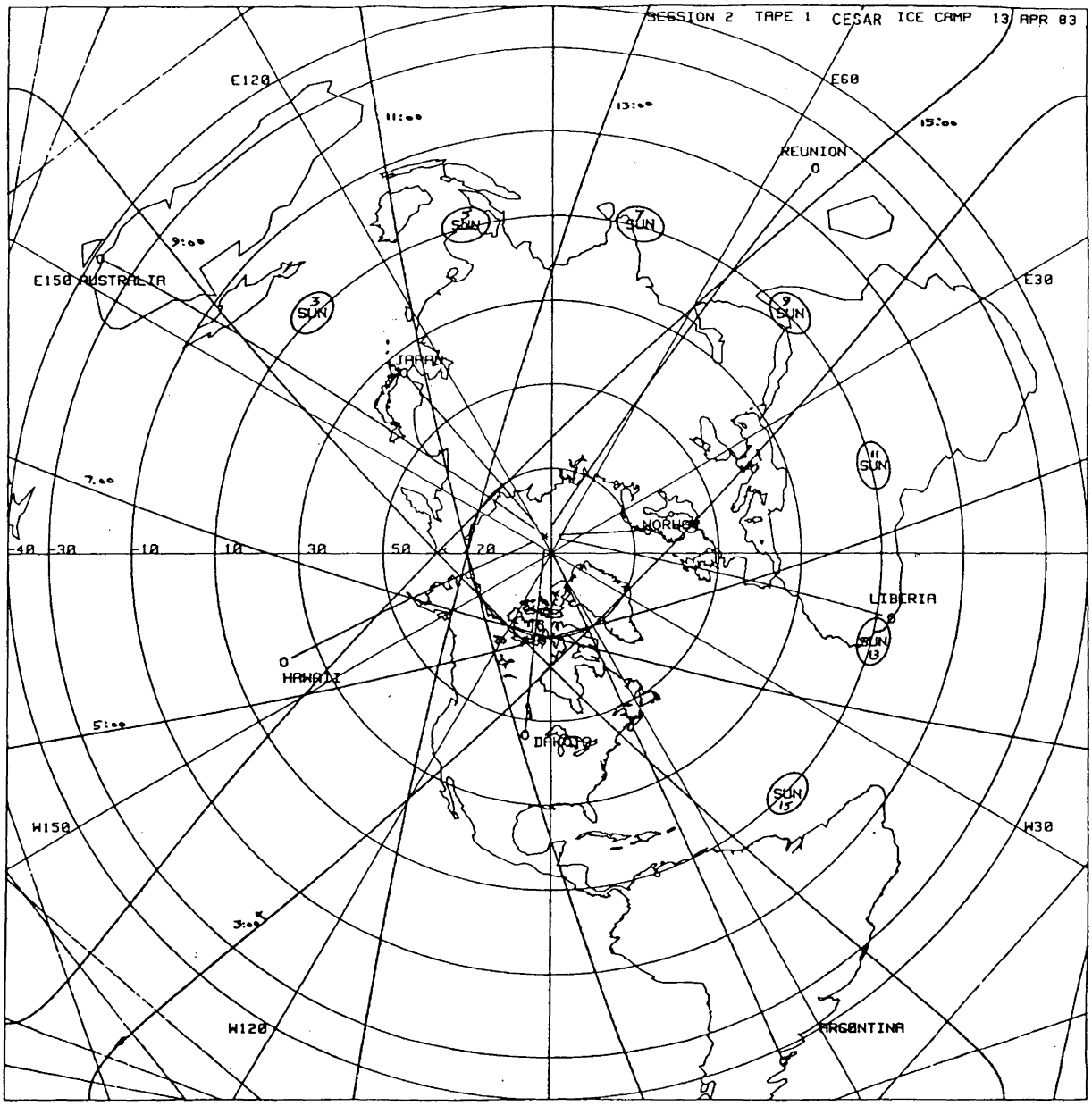

F FLIGHT:APR 3 1983 DIURNALS
13 KHZ 11 KHZ 10 KHZ
VLF STATUS: UNFORCED
REUNION
300
200
100
0
13 KHz
11 KHz
10 KHz
24:00
2:00
4:00
6:00
8:00
10:00
12:
GMT
ARGENTINA
300
200
100
0
13 KHz
11 KHz
10 KHz
24:00
2:00
4:00
6:00
8:00
10:00
12:
GMT
AUSTRALIA
300
200
100
0
13 KHz
11 KHz
10 KHz
24:00
2:00
4:00
6:00
8:00
10:00
12:
GMT
JAPAN
300
200
100
0
13 KHz
11 KHz
10 KHz
24:00
2:00
4:00
6:00
8:00
10:00
12:
GMT

APPENDIX I.2

Session 2 Tapes 1 and 2

Time span: 02:15 April 13, 1983 to 04:30 April 14, 1983.

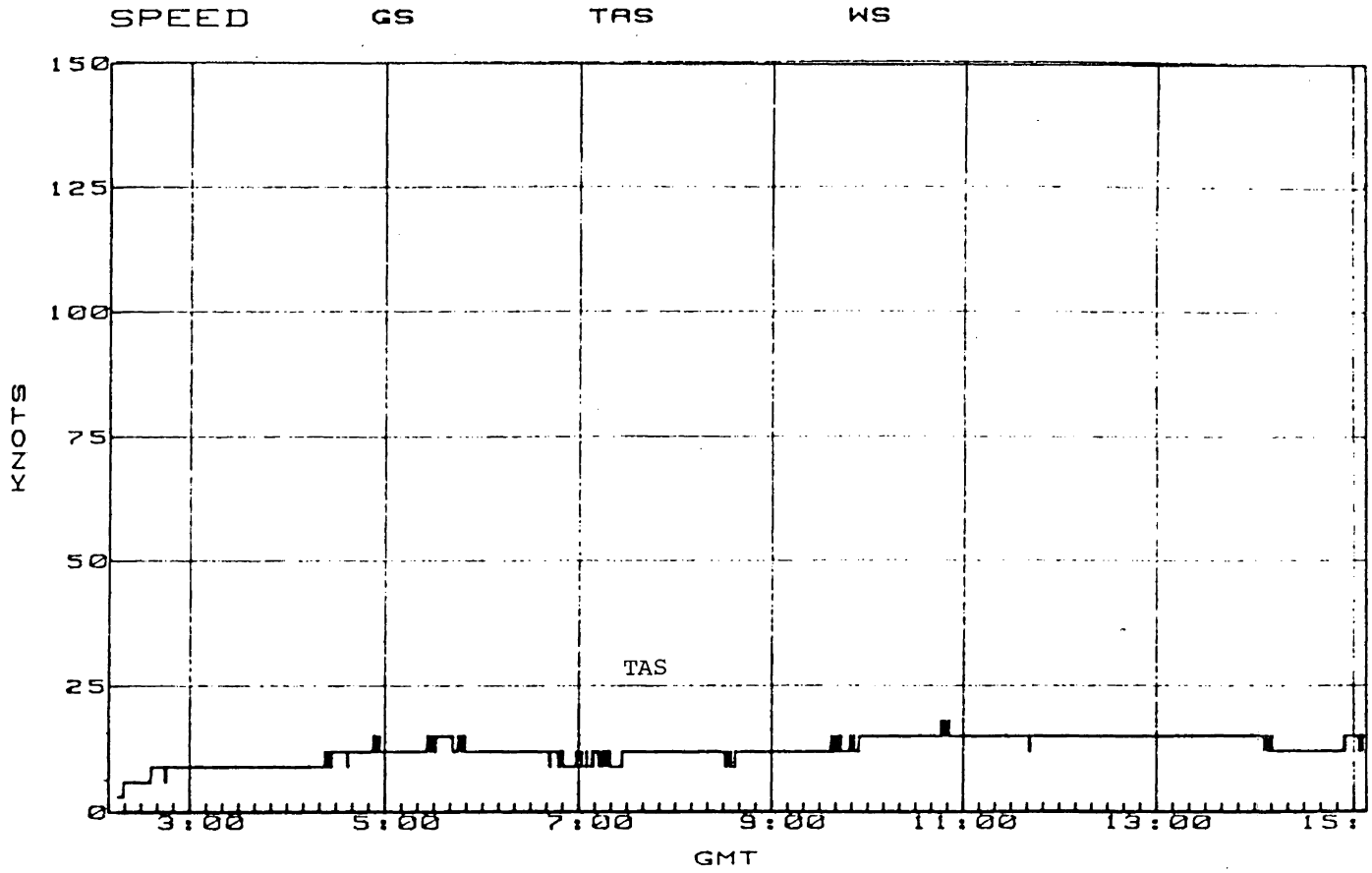
Approximate position: 85^{o} 47.3' (N)
110^{o} 40.9' (W)

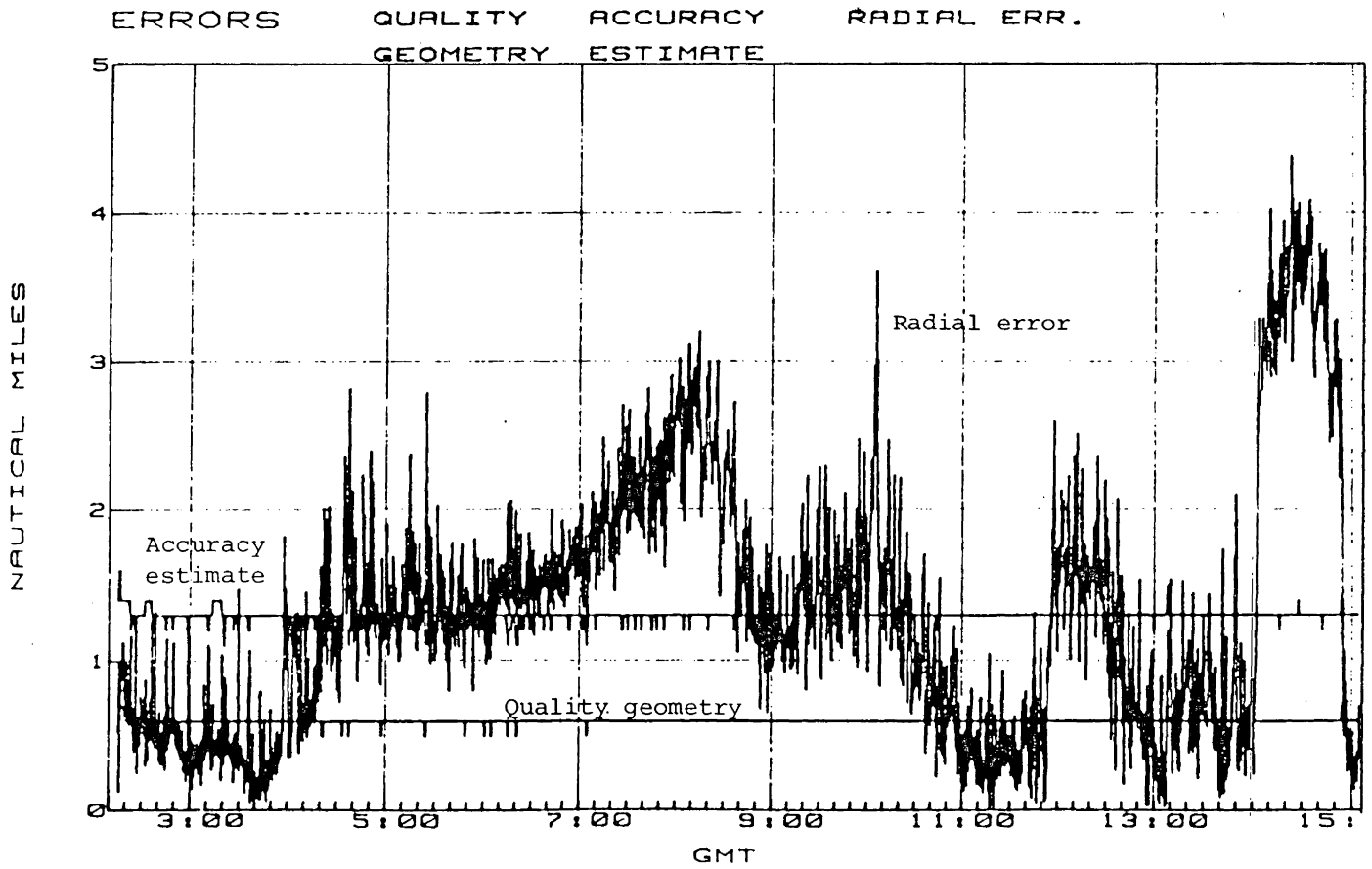


SESSION 2 TAPE 1

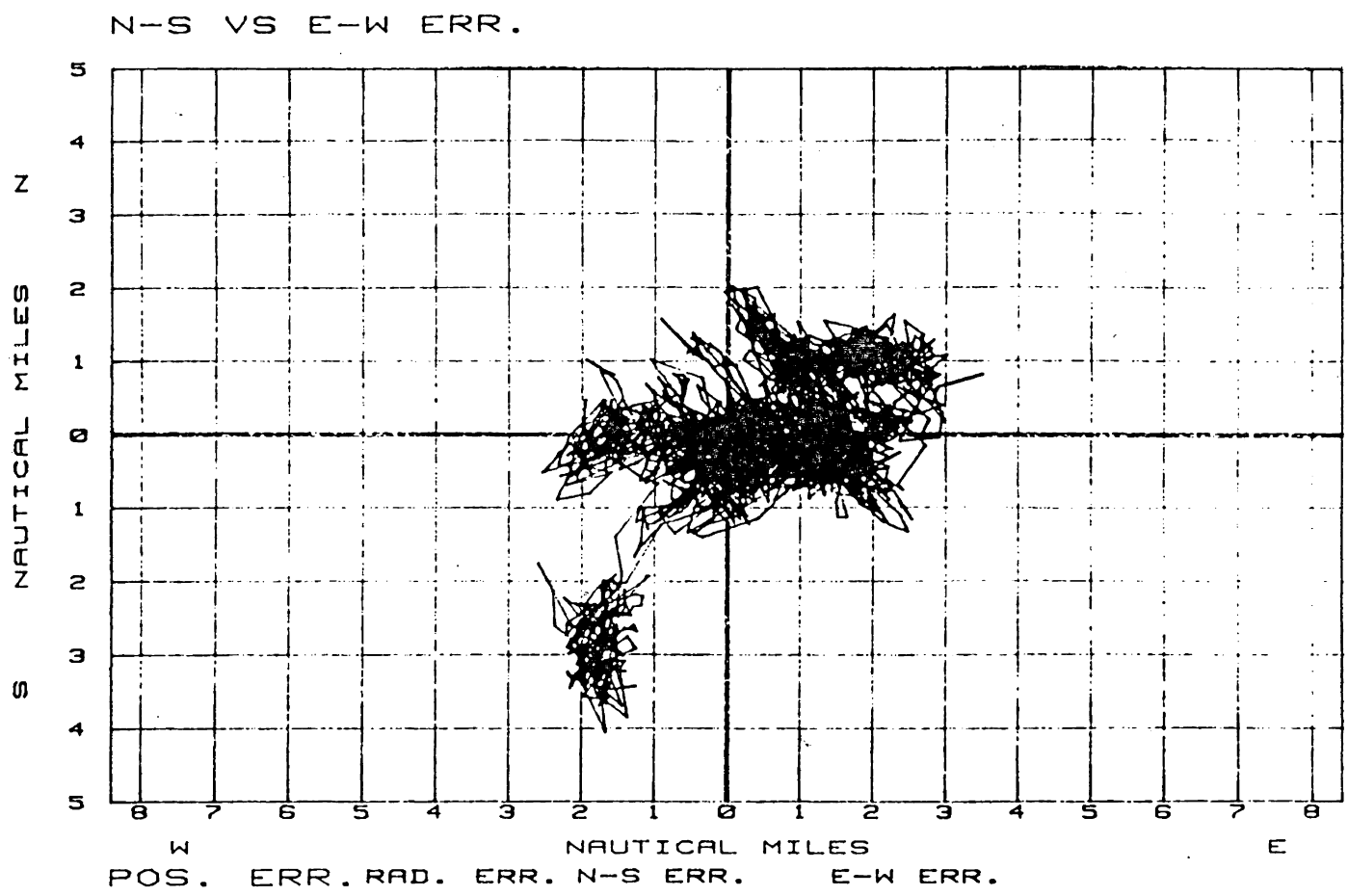
World map displaying CESAR's position, Omega transmitting stations and day/night terminators. (Note that CESAR's position is incorrect due to an input error in its coordinates to program NPOLE)

SESSION 2 TAPE 1 CESAR ICE CAMP DATE OF

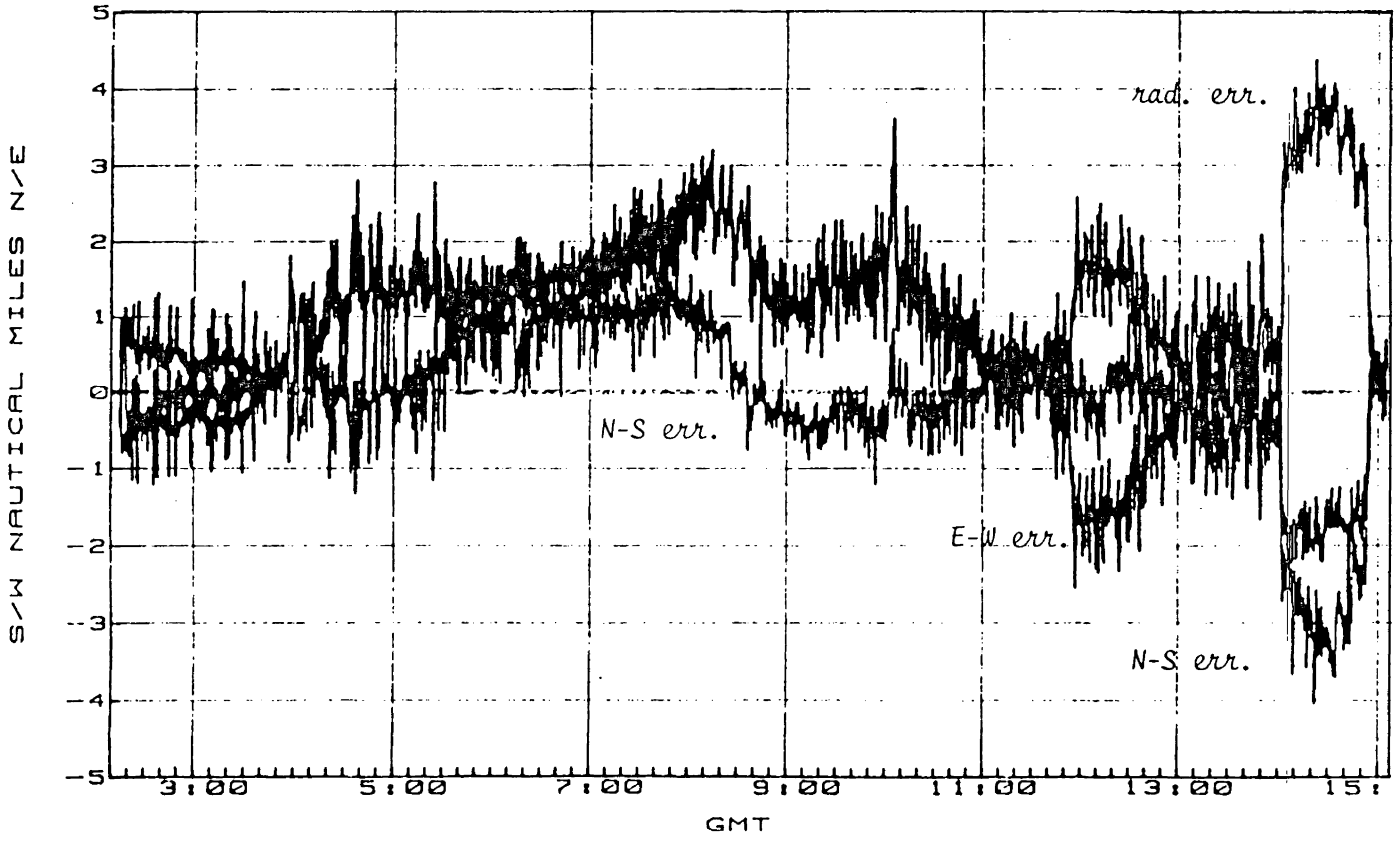




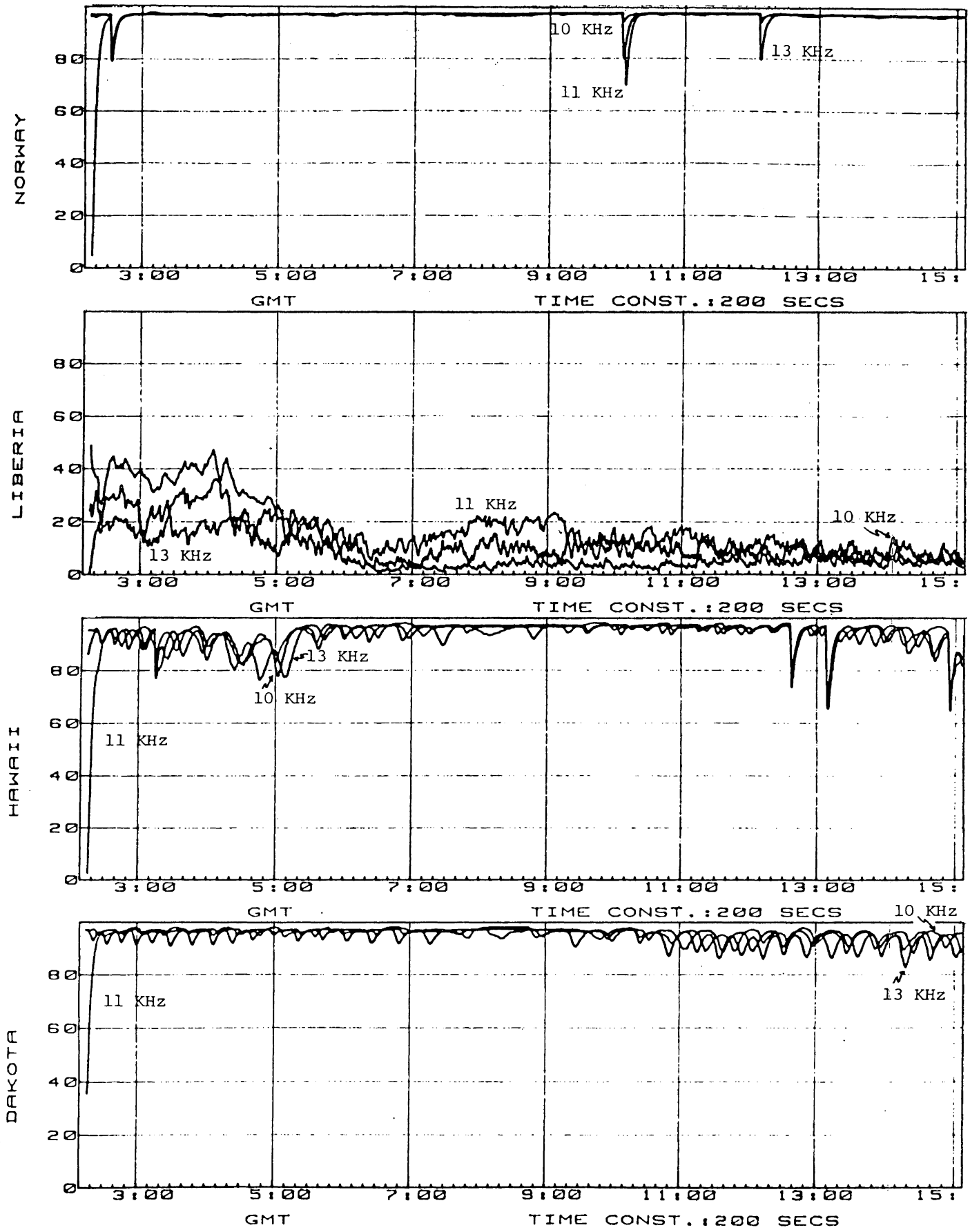
F FLIGHT: APR 13 1983

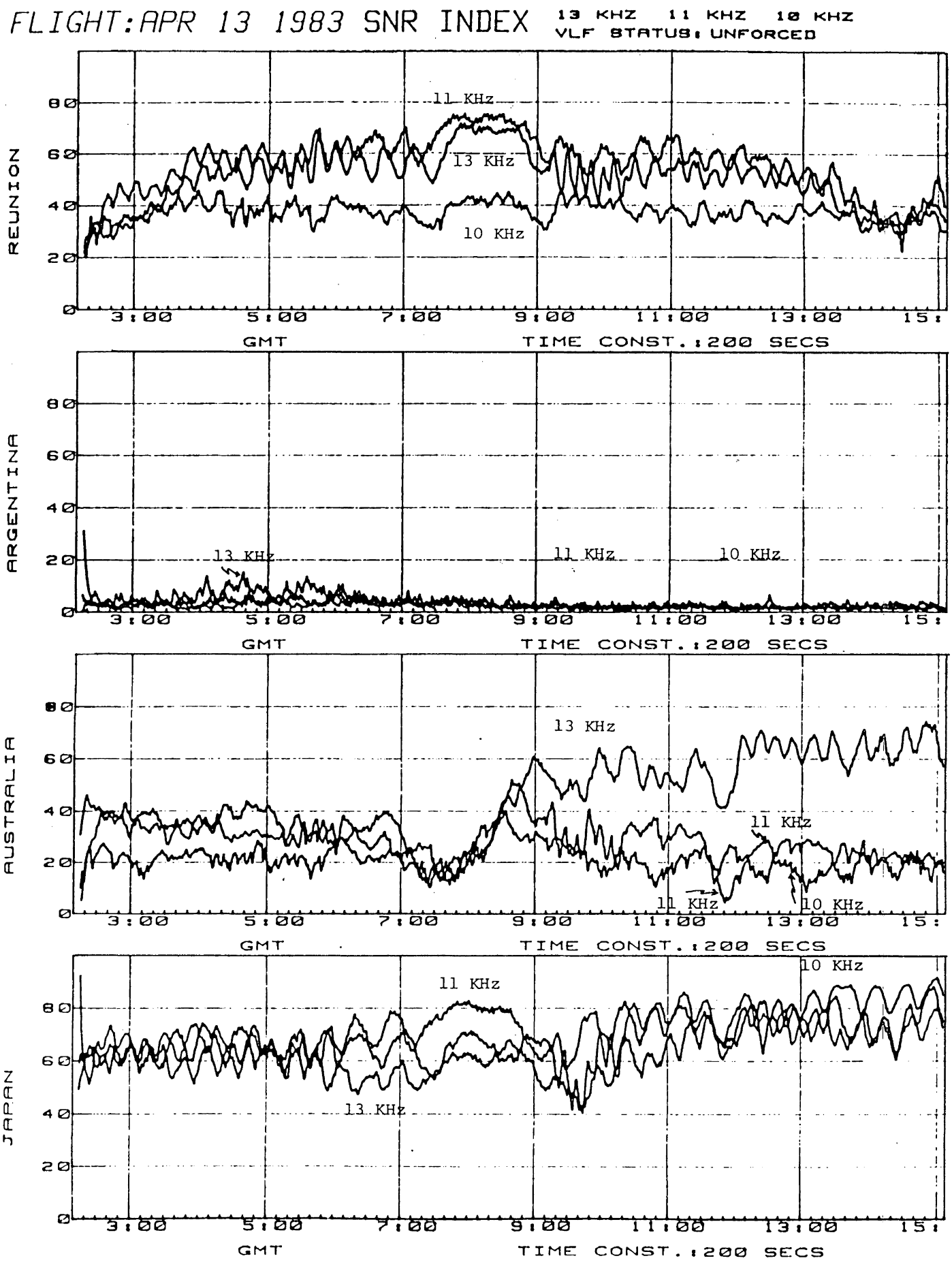


POS. ERR. RAD. ERR. N-S ERR. E-W ERR.

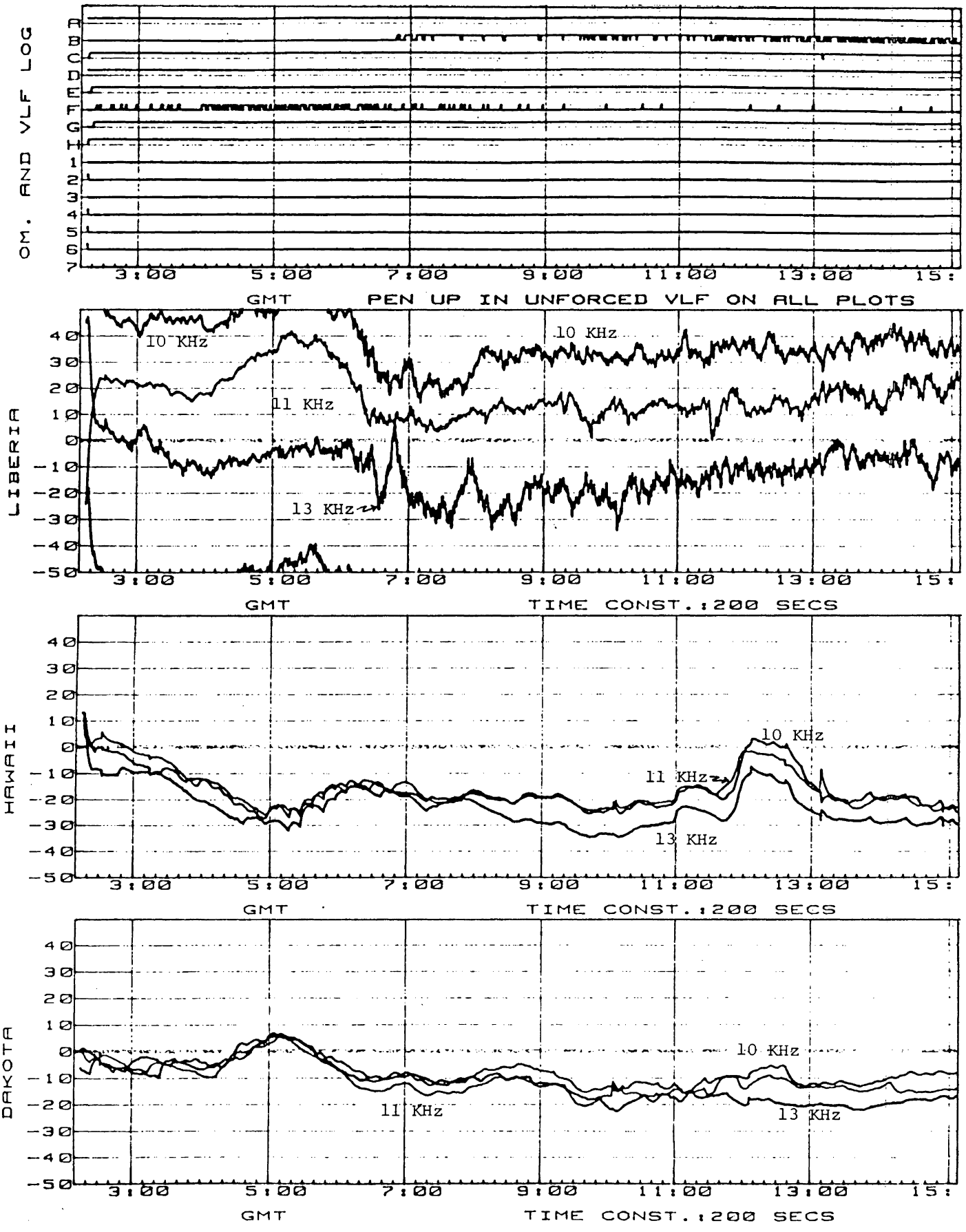


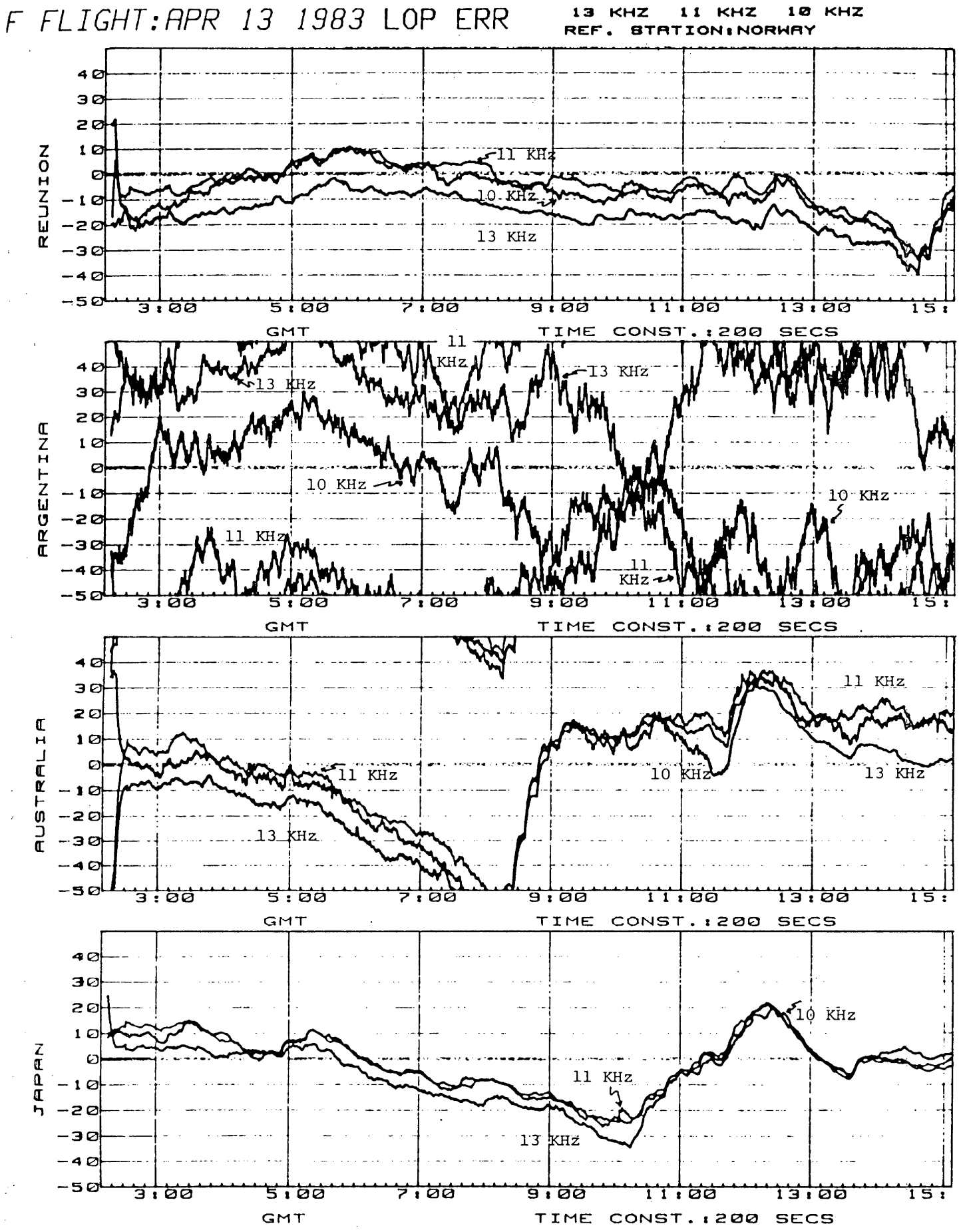
SESSION 2 TAPE 1 CESAR ICE CAMP DATE OF



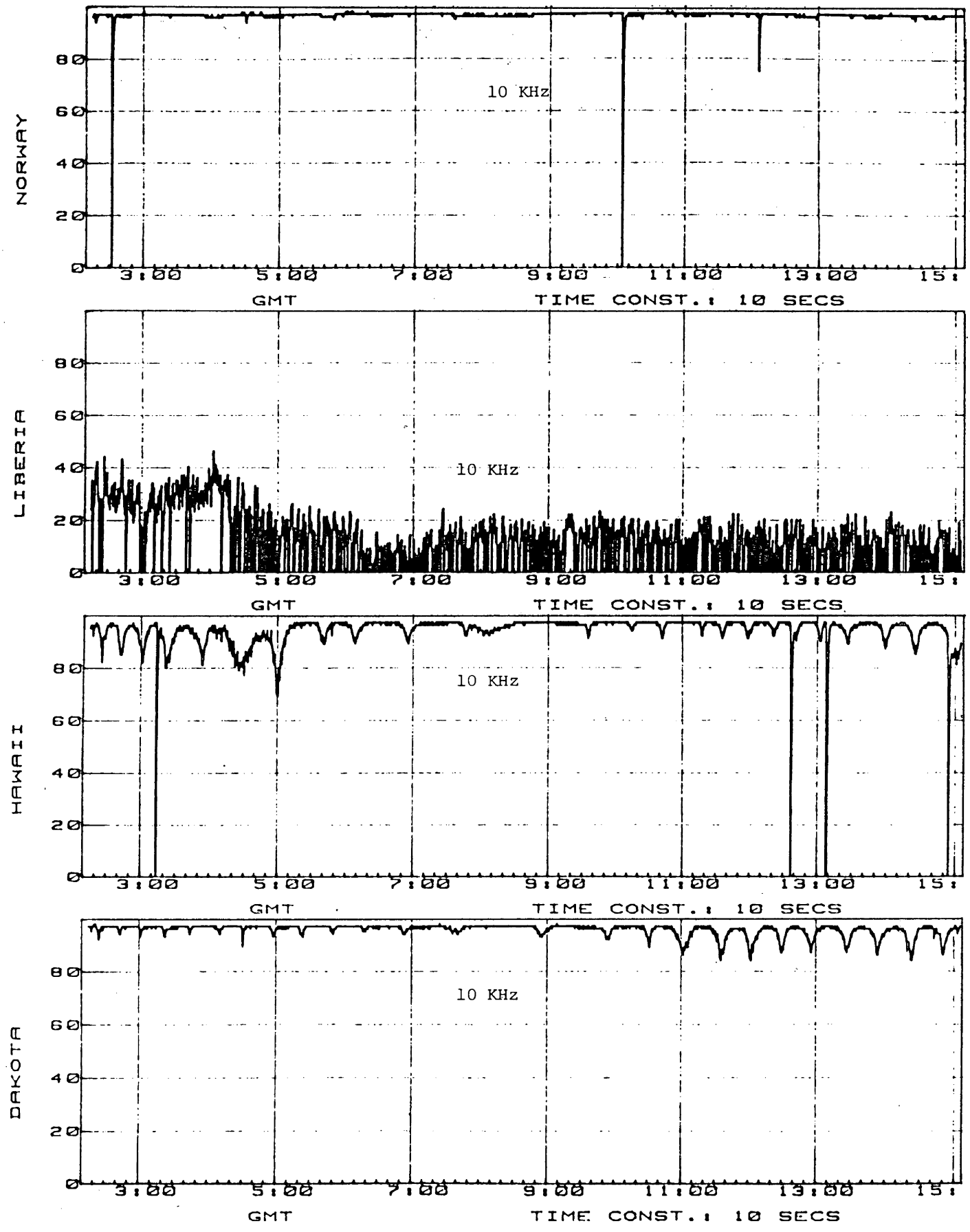

F FLIGHT:APR 13 1983 SNR INDEX
13 KHZ 11 KHZ 10 KHZ
VLF STATUS: UNFORCED
REUNION
11 KHz
13 KHz
10 KHz
GMT
TIME CONST.:200 SECS
ARGENTINA
13 KHz
11 KHz
10 KHz
GMT
TIME CONST.:200 SECS
AUSTRALIA
13 KHz
11 KHz
11 KHz
10 KHz
GMT
TIME CONST.:200 SECS
JAPAN
11 KHz
10 KHz
13 KHz
GMT
TIME CONST.:200 SECS

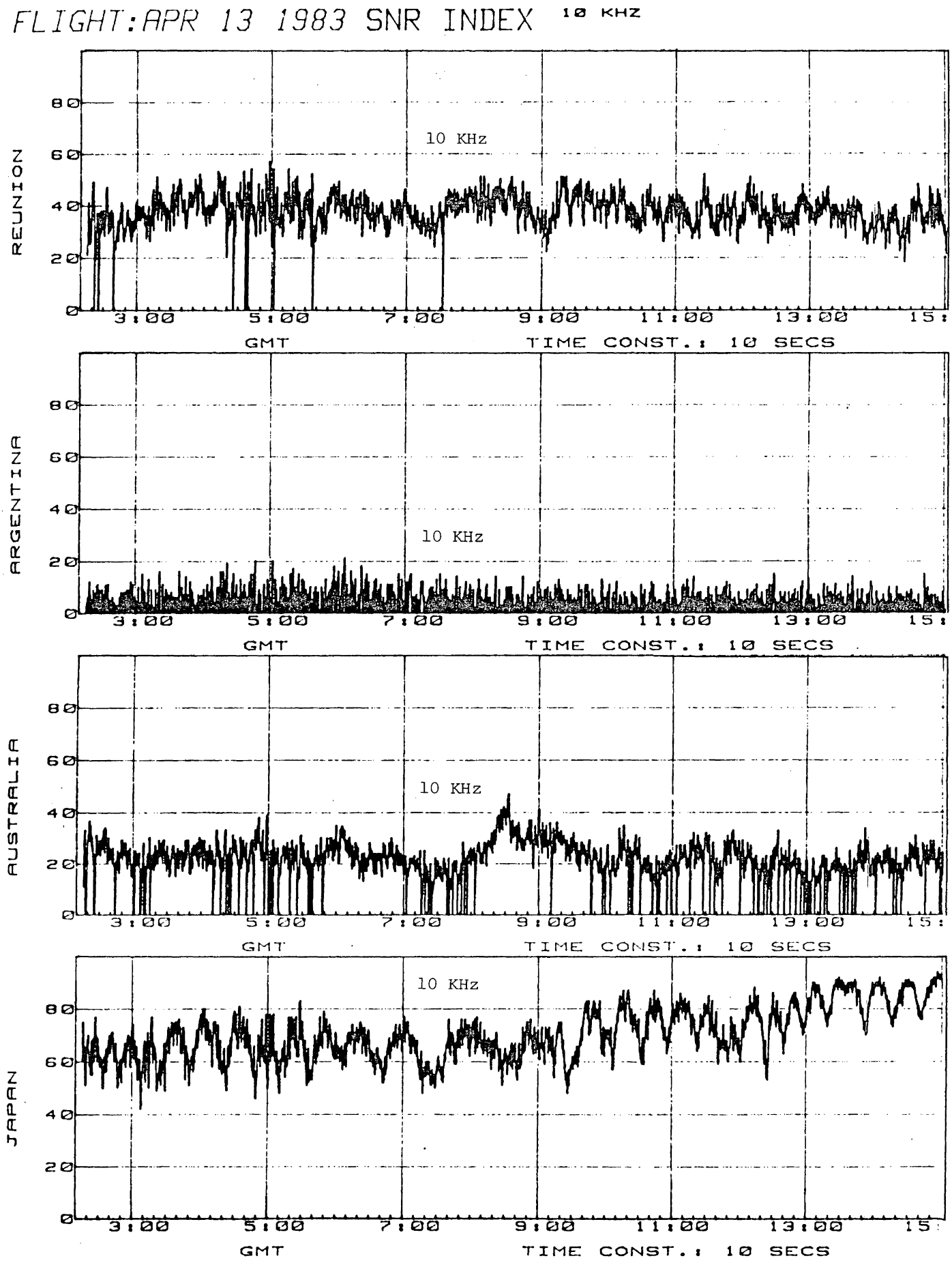
SESSION 2 TAPE 1 CESAR ICE CAMP DATE OF

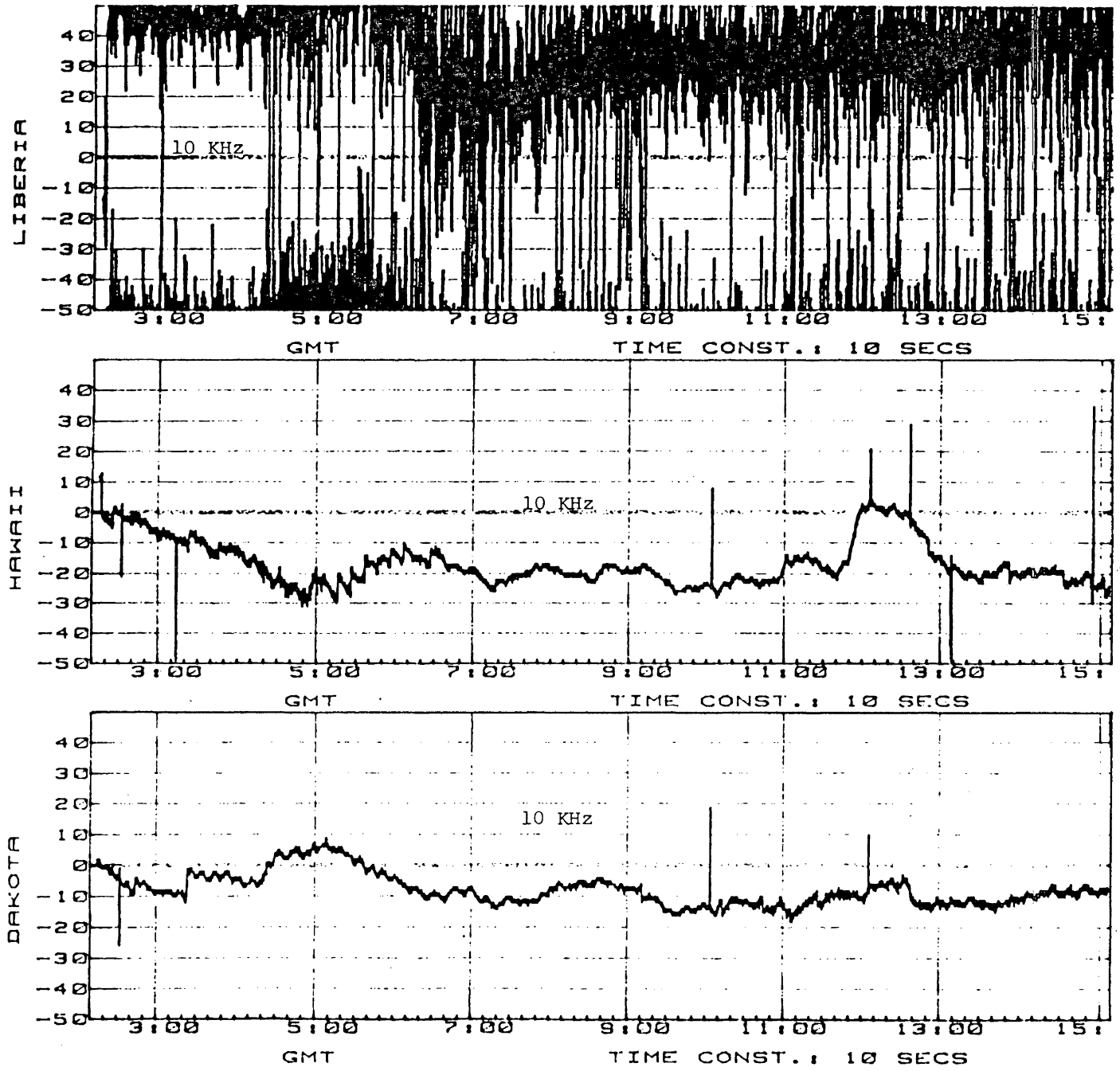


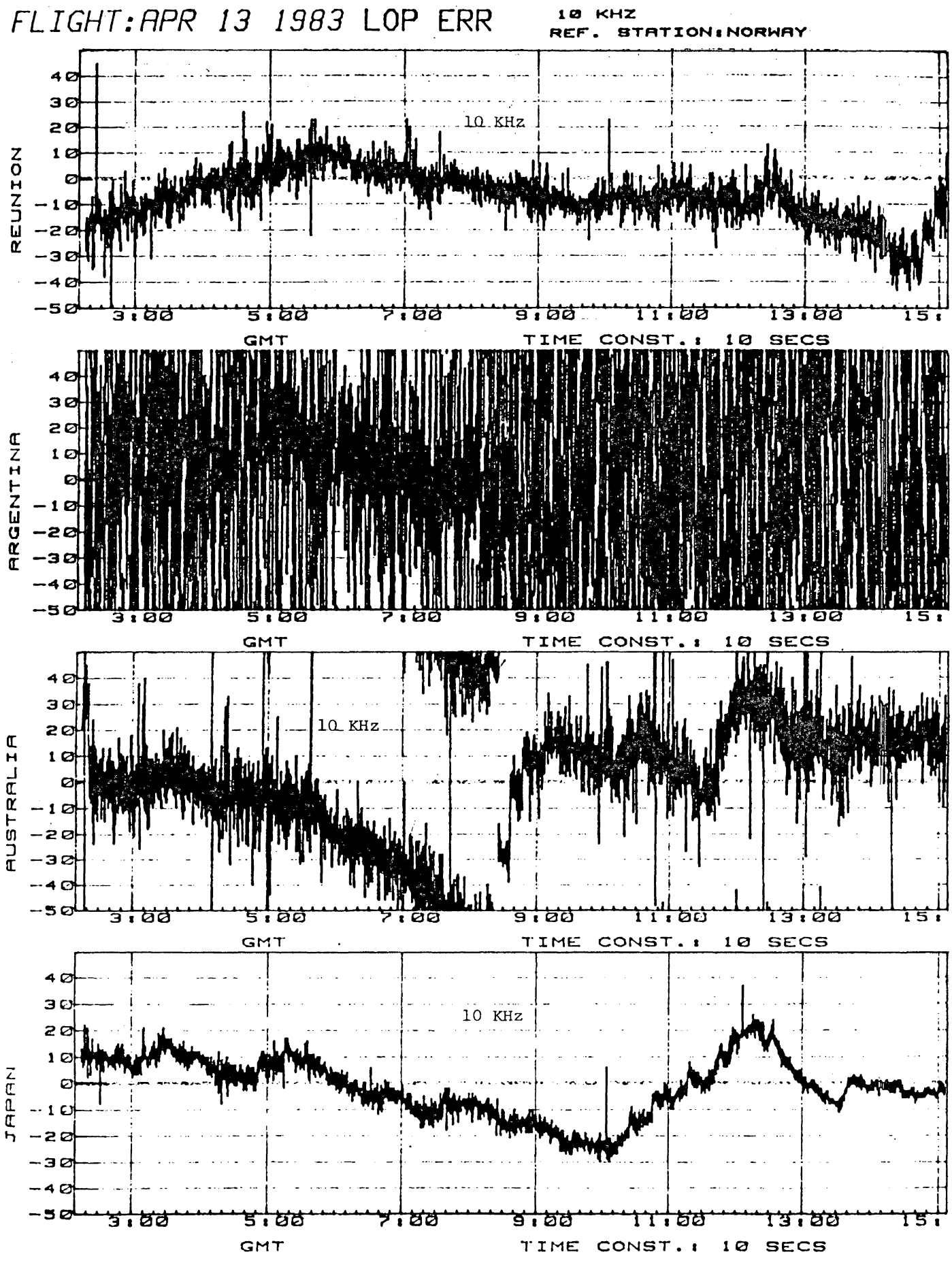

F FLIGHT:APR 13 1983 LOP ERR
13 KHZ 11 KHZ 10 KHZ
REF. STATION:NORWAY
REUNION
11 KHz
10 KHz
13 KHz
GMT
TIME CONST.:200 SECS
ARGENTINA
11 KHz
13 KHz
10 KHz
GMT
TIME CONST.:200 SECS
AUSTRALIA
11 KHz
10 KHz
13 KHz
GMT
TIME CONST.:200 SECS
JAPAN
10 KHz
11 KHz
13 KHz
GMT
TIME CONST.:200 SECS

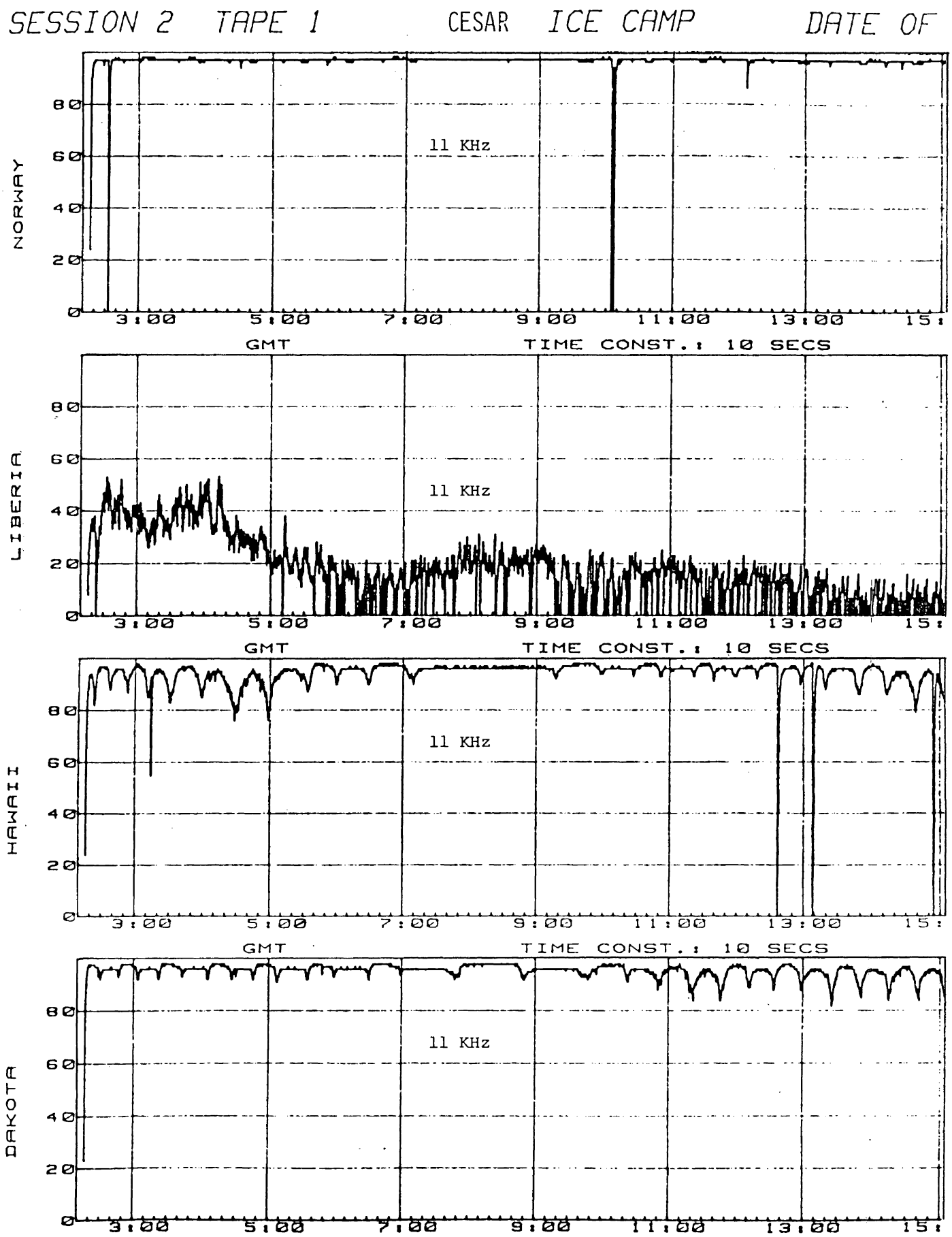
SESSION 2 TAPE 1 CESAR ICE CAMP DATE OF

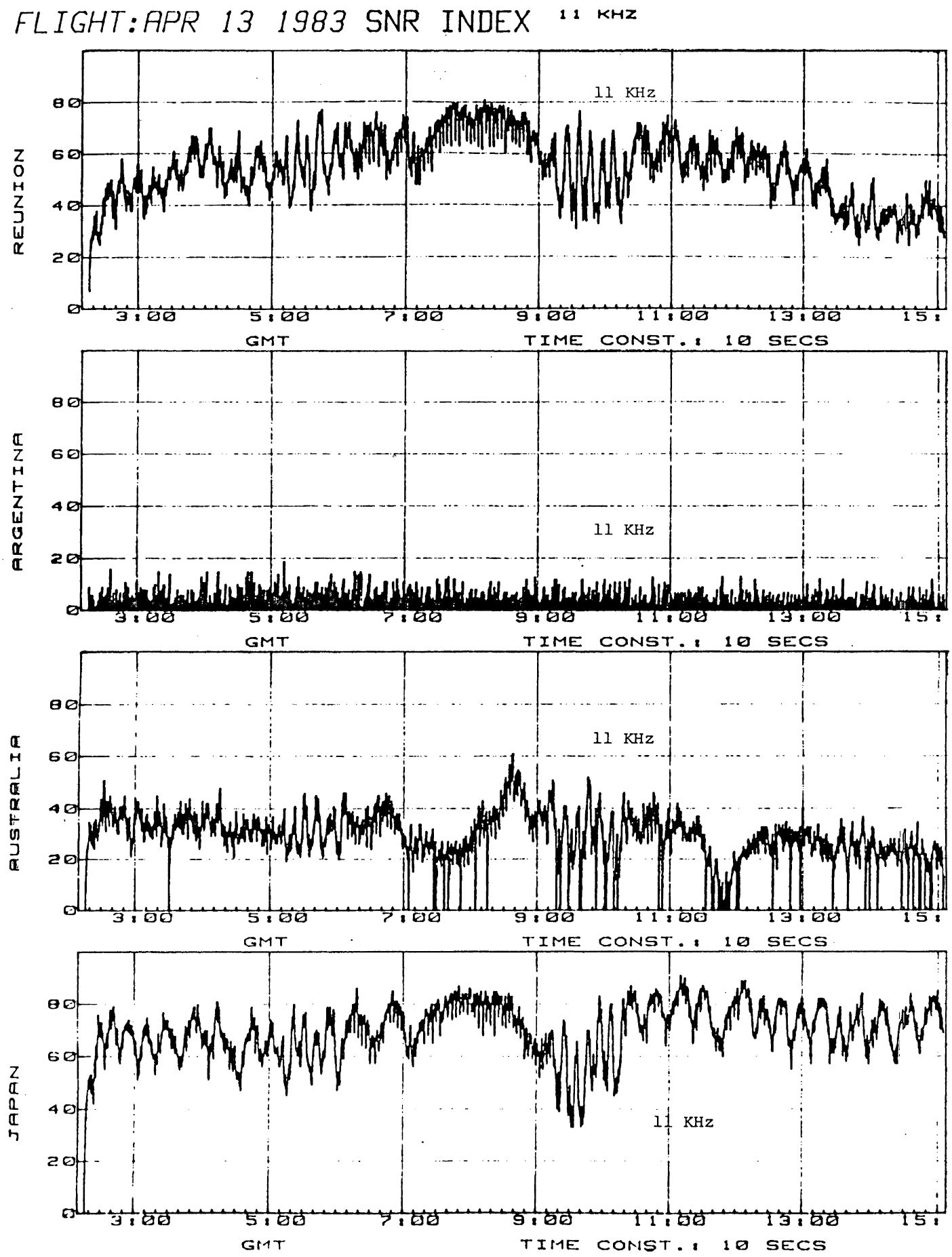



F FLIGHT:APR 13 1983 SNR INDEX 10 KHZ
REUNION
10 KHz
ARGENTINA
10 KHz
AUSTRALIA
10 KHz
JAPAN
10 KHz
0
20
40
60
80
3:00
5:00
7:00
9:00
11:00
13:00
15:
GMT
TIME CONST.: 10 SECS

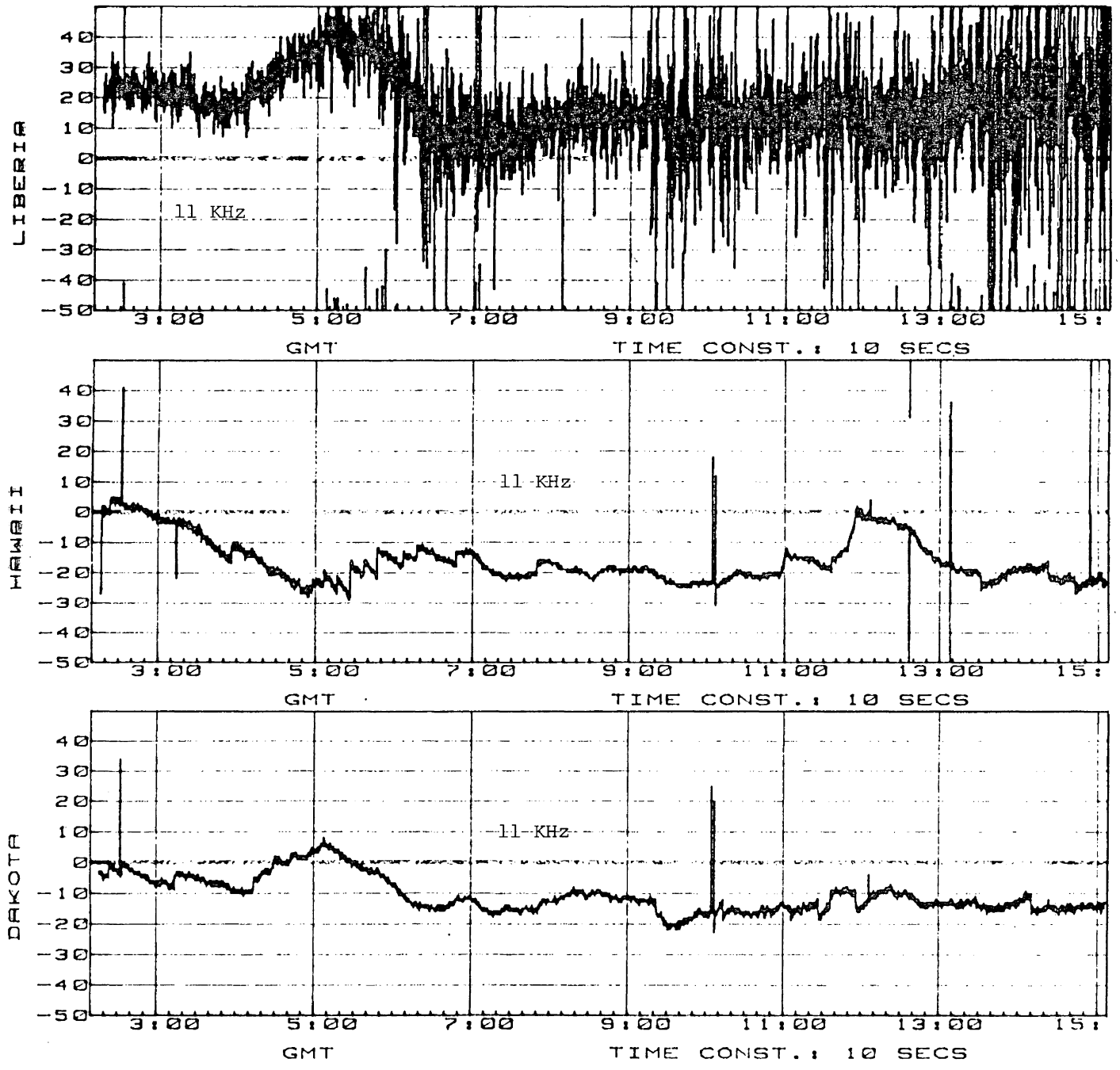

LIBERIA
10 KHz
40
30
20
10
0
-10
-20
-30
-40
-50
3:00
5:00
7:00
9:00
11:00
13:00
15:
GMT
TIME CONST.: 10 SECS
HAWAII
10 KHz
GMT
TIME CONST.: 10 SECS
DAKOTA
10 KHz
GMT
TIME CONST.: 10 SECS

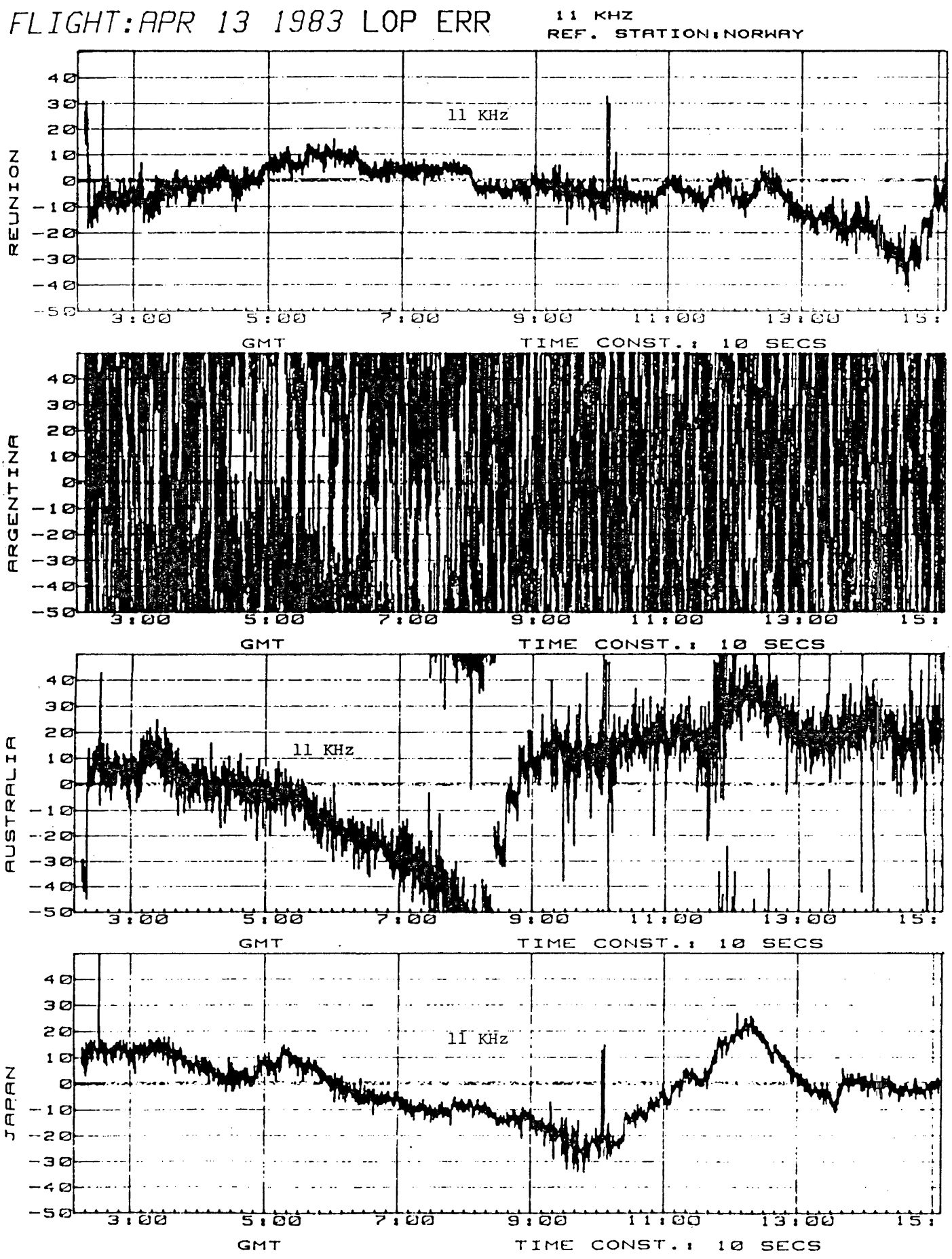

F FLIGHT:APR 13 1983 LOP ERR
10 KHZ
REF. STATION:NORWAY
REUNION
10 KHz
ARGENTINA
AUSTRALIA
JAPAN
40
30
20
10
0
-10
-20
-30
-40
-50
3:00
5:00
7:00
9:00
11:00
13:00
15:
GMT
TIME CONST.: 10 SECS


SESSION 2 TAPE 1 CESAR ICE CAMP DATE OF
NORWAY
11 KHz
GMT
TIME CONST.: 10 SECS
LIBERIA
11 KHz
GMT
TIME CONST.: 10 SECS
HAWAII
11 KHz
GMT
TIME CONST.: 10 SECS
DAKOTA
11 KHz
0
20
40
60
80
3:00
5:00
7:00
9:00
11:00
13:00
15:

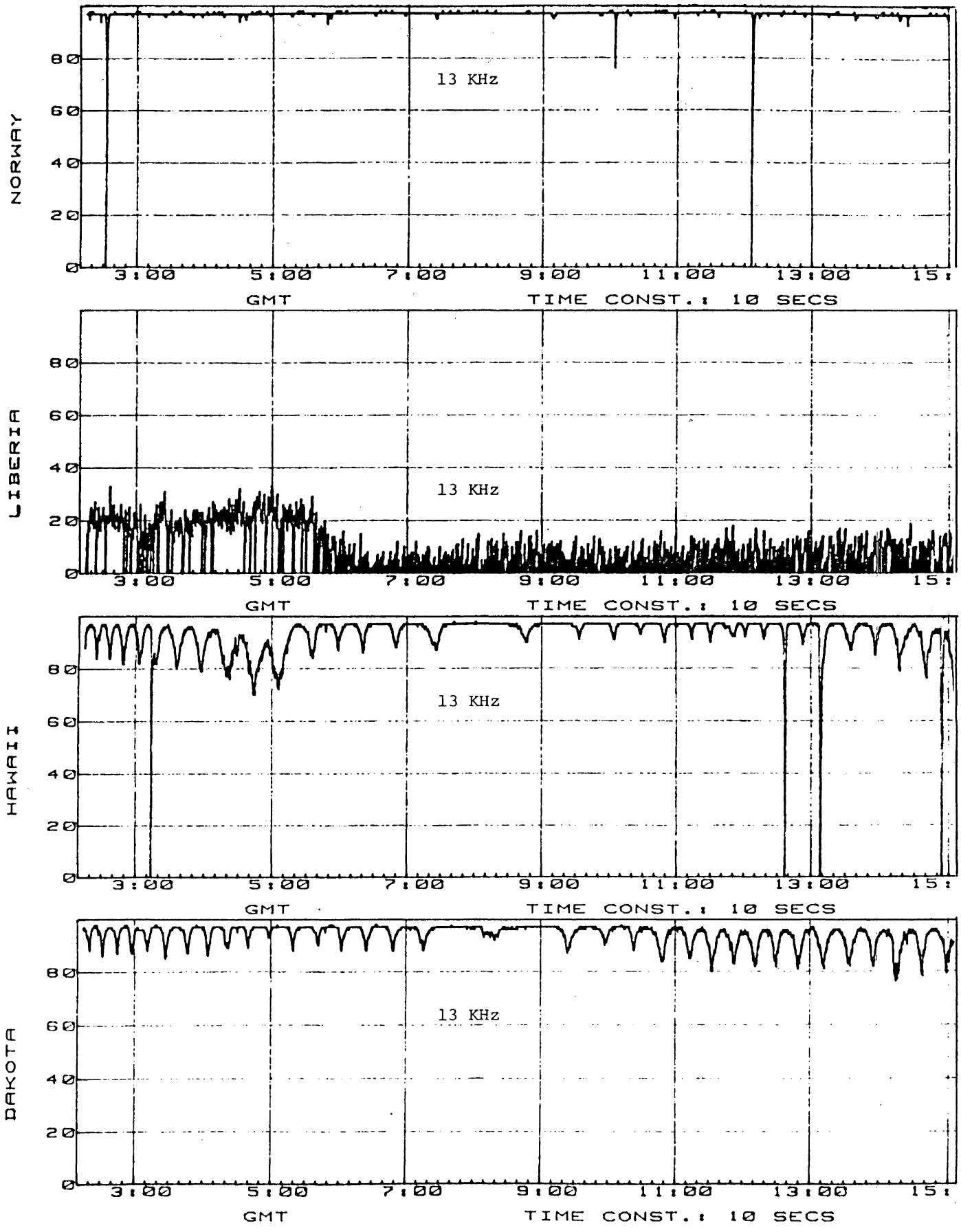

FLIGHT:APR 13 1983 SNR INDEX 11 KHZ
REUNION
11 KHz
0
20
40
60
80
3:00
5:00
7:00
9:00
11:00
13:00
15:
GMT
TIME CONST.: 10 SECS
ARGENTINA
11 KHz
AUSTRALIA
11 KHz
JAPAN
11 KHz

SESSION 2 TAPE 1 CESAR ICE CAMP DATE OF FL

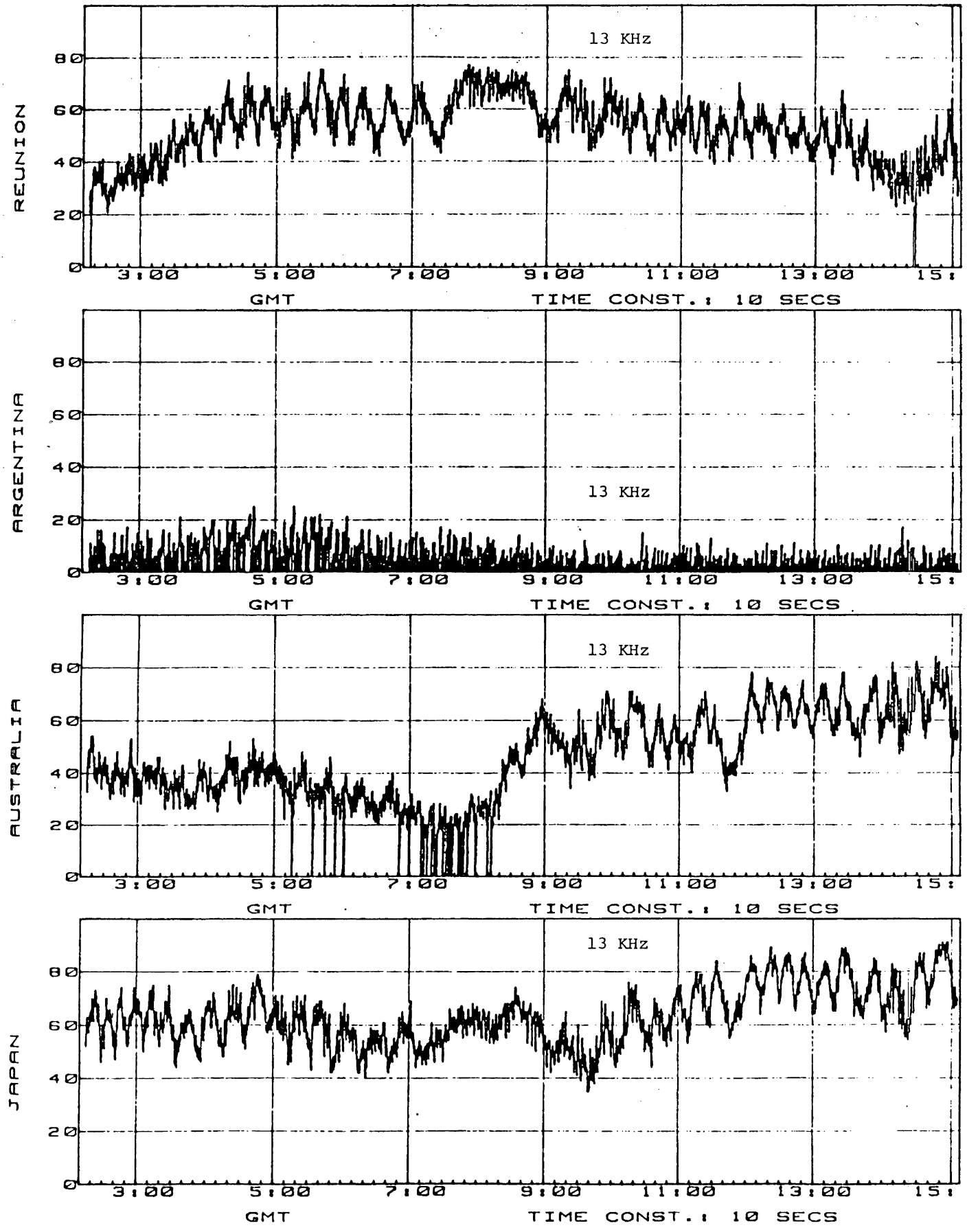



FLIGHT: APR 13 1983 LOP ERR
11 KHZ
REF. STATION: NORWAY
REUNION
11 KHz
40
30
20
10
0
-10
-20
-30
-40
-50
3:00
5:00
7:00
9:00
11:00
13:00
15:
GMT
TIME CONST.: 10 SECS
ARGENTINA
GMT
TIME CONST.: 10 SECS
AUSTRALIA
11 KHz
GMT
TIME CONST.: 10 SECS
JAPAN
11 KHz
GMT
TIME CONST.: 10 SECS

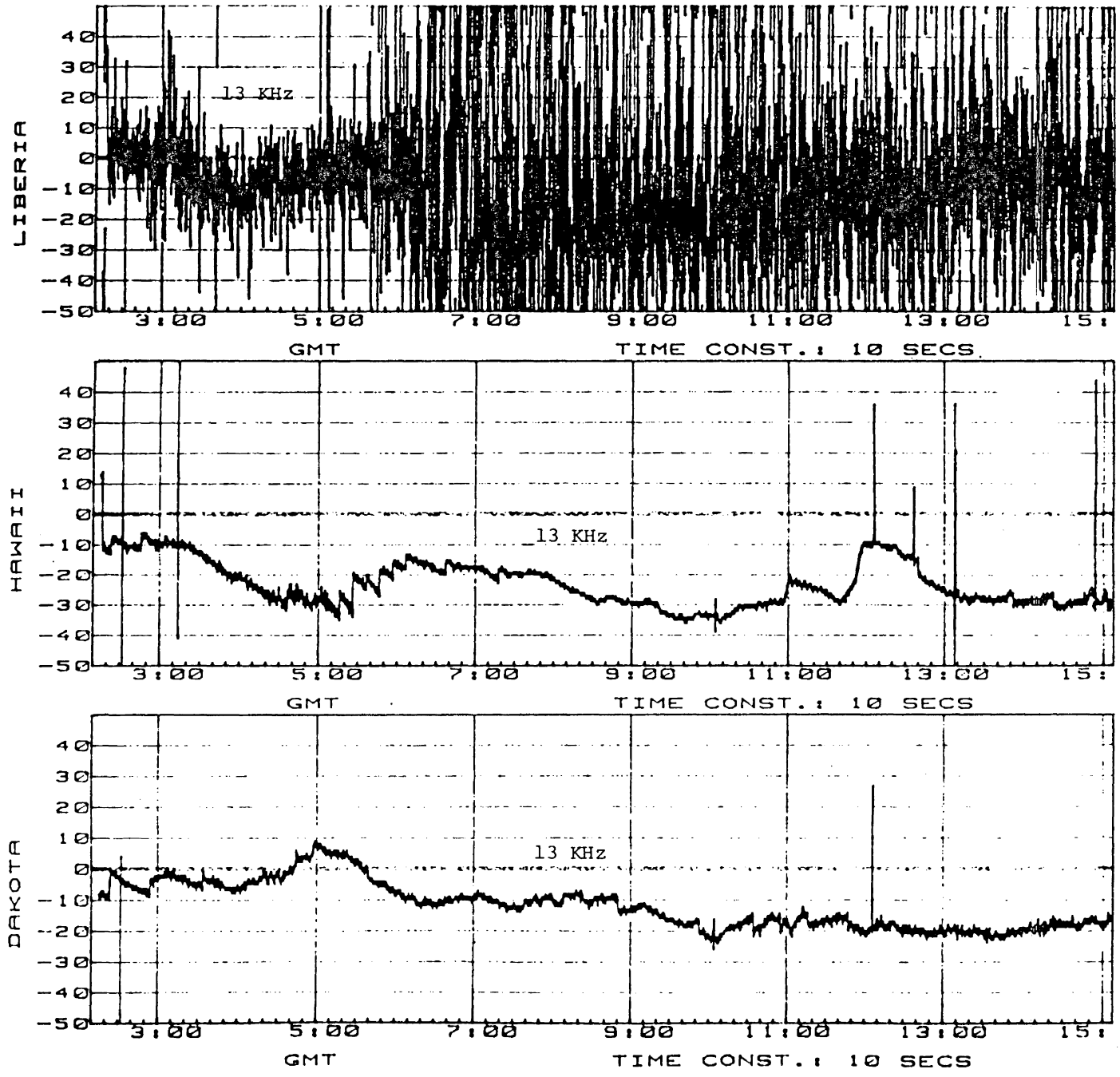
SESSION 2 TAPE 1 CESAR ICE CAMP DATE OF



)F FLIGHT:APR 13 1983 SNR INDEX 13 KHZ

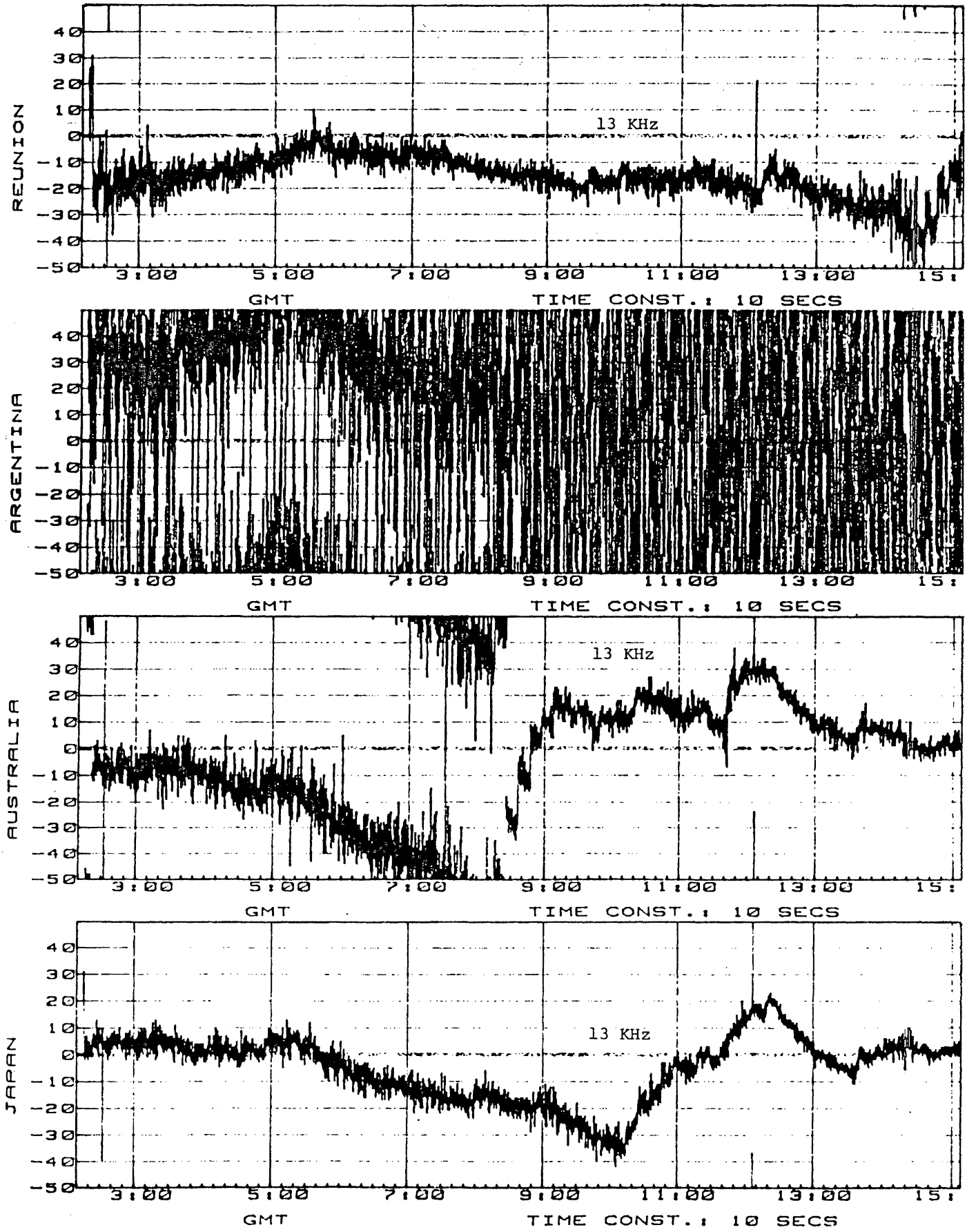


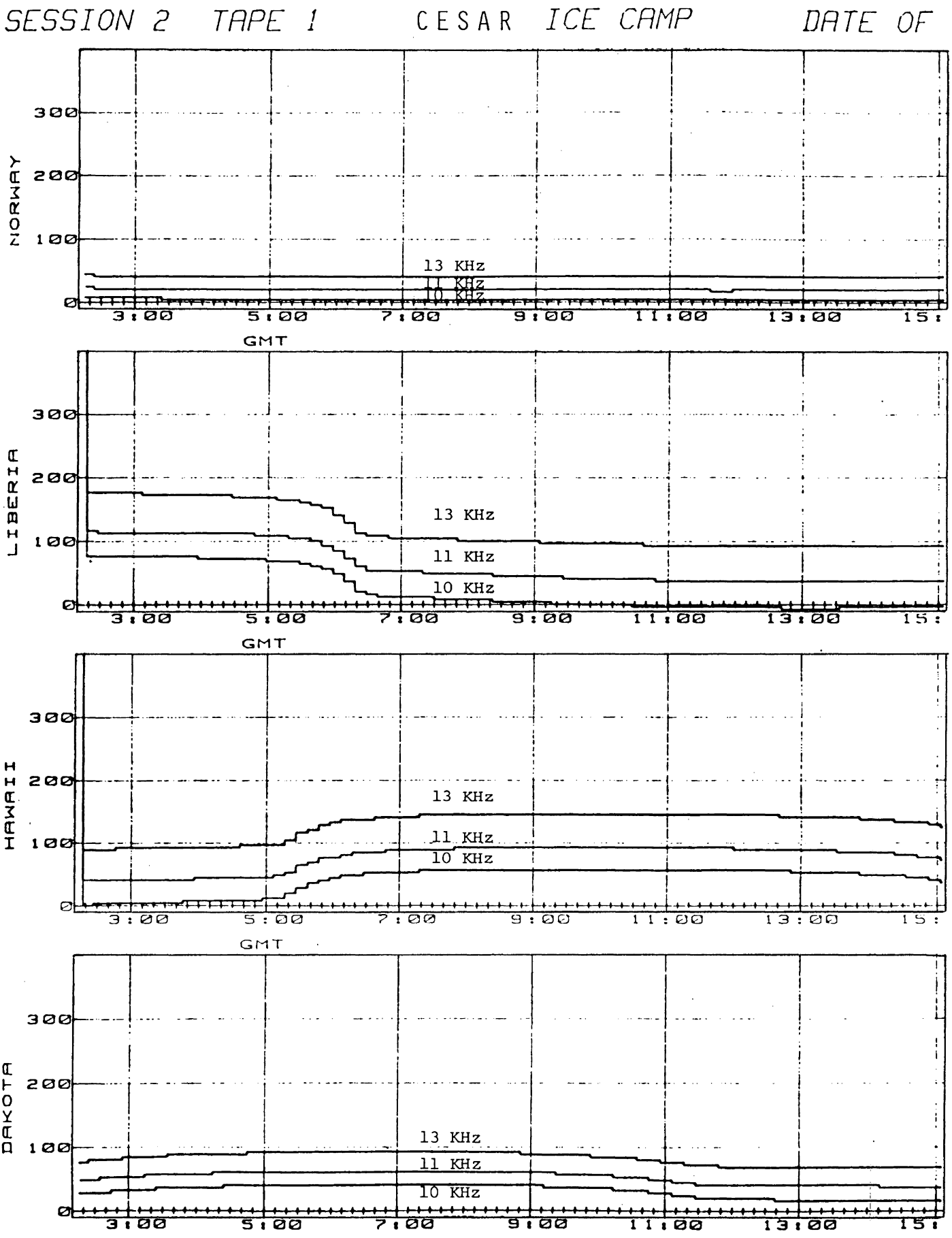
SESSION 2 TAPE 1 CESAR ICE CAMP DATE OF



F FLIGHT:APR 13 1983 LOP ERR

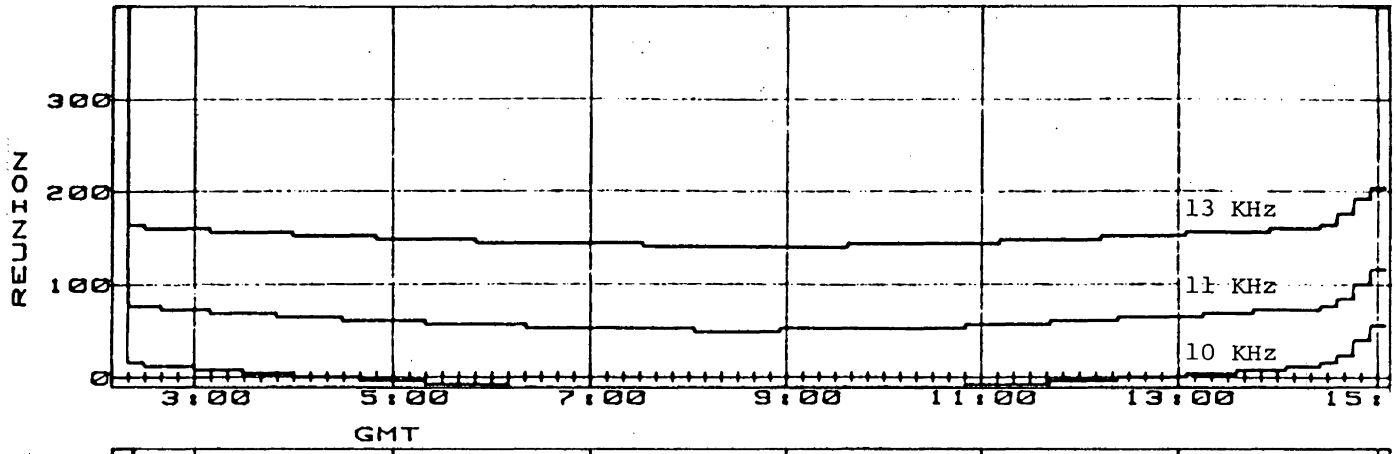
13 KHZ
REF. STATION:NORWAY

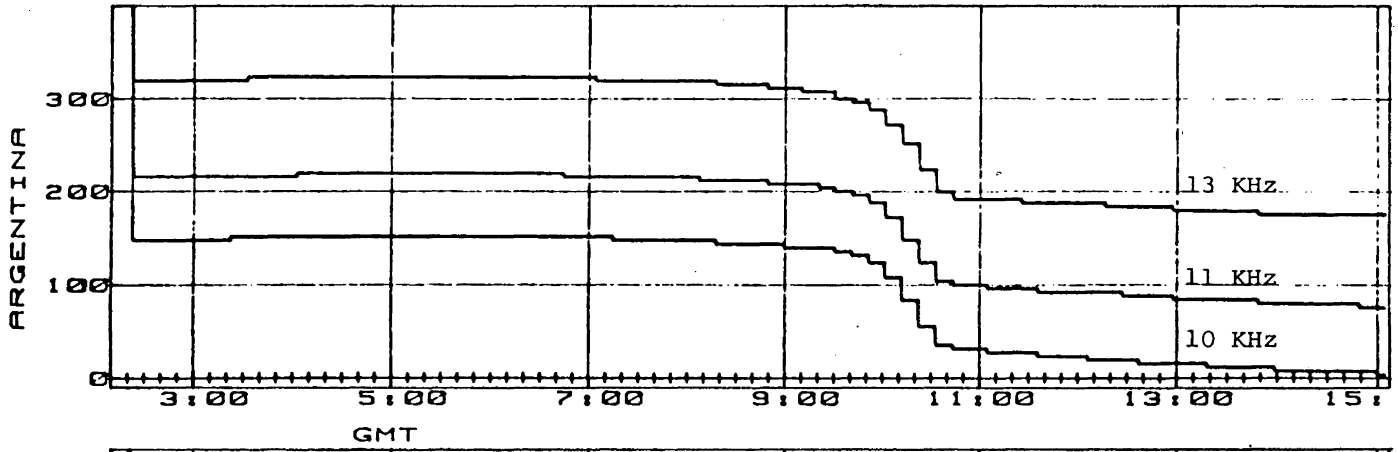


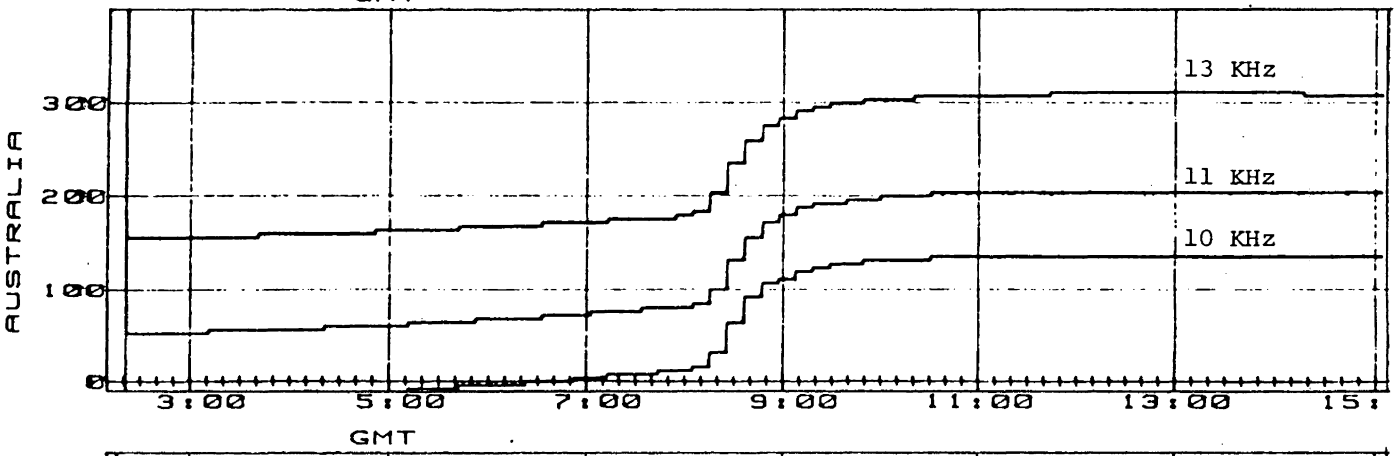

SESSION 2 TAPE 1 CESAR ICE CAMP DATE OF
NORWAY
300
200
100
0
13 KHz
11 KHz
10 KHz
3:00
5:00
7:00
9:00
11:00
13:00
15:
GMT
LIBERIA
300
200
100
0
13 KHz
11 KHz
10 KHz
3:00
5:00
7:00
9:00
11:00
13:00
15:
GMT
HAWAII
300
200
100
0
13 KHz
11 KHz
10 KHz
3:00
5:00
7:00
9:00
11:00
13:00
15:
GMT
DAKOTA
300
200
100
0
13 KHz
11 KHz
10 KHz
3:00
5:00
7:00
9:00
11:00
13:00
15:

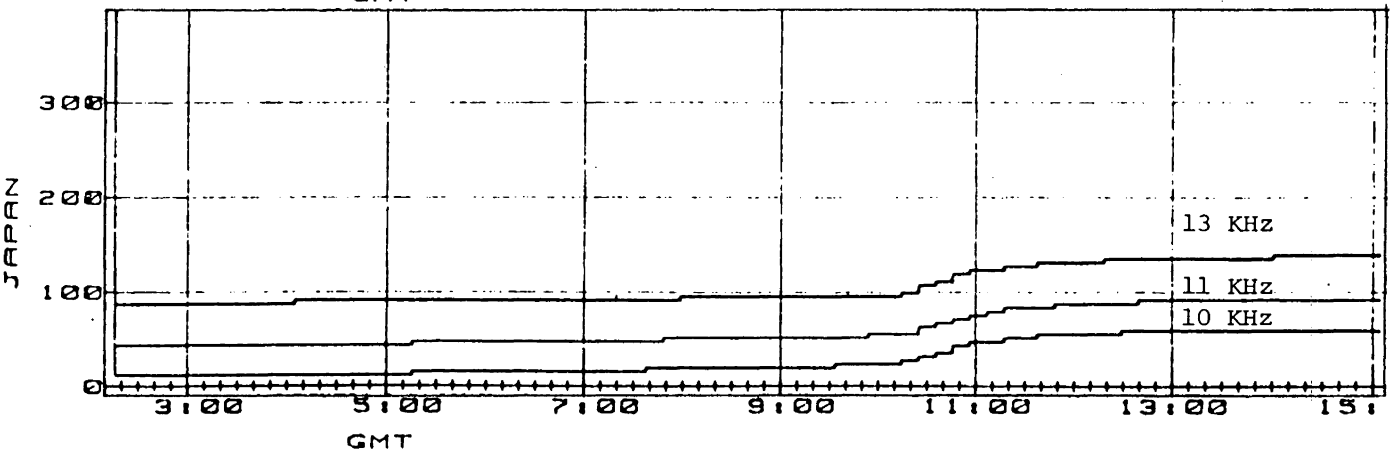
FLIGHT:APR 13 1983 DIURNALS

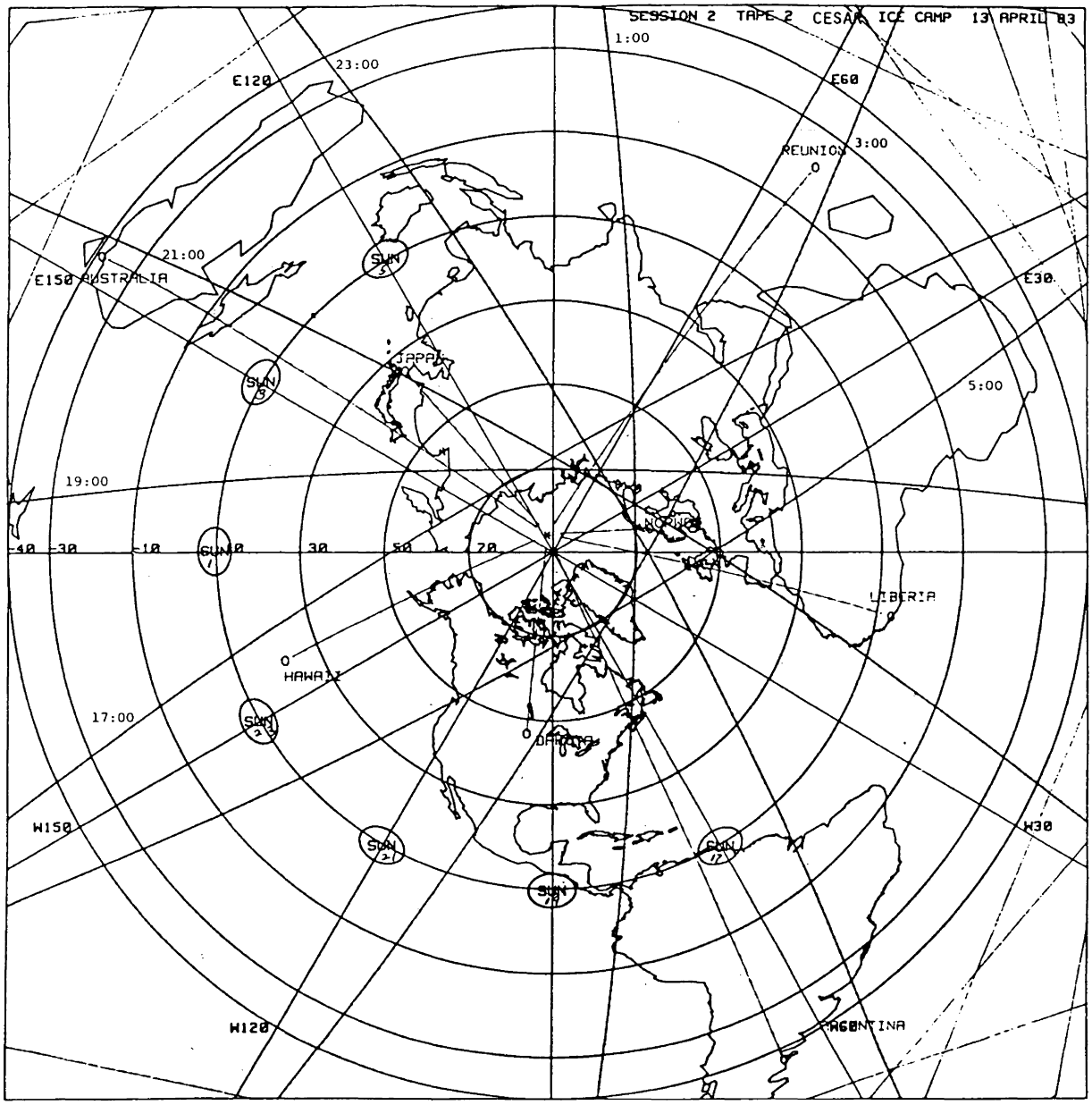
13 KHZ 11 KHZ 10 KHZ
VLF STATUS: UNFORCED







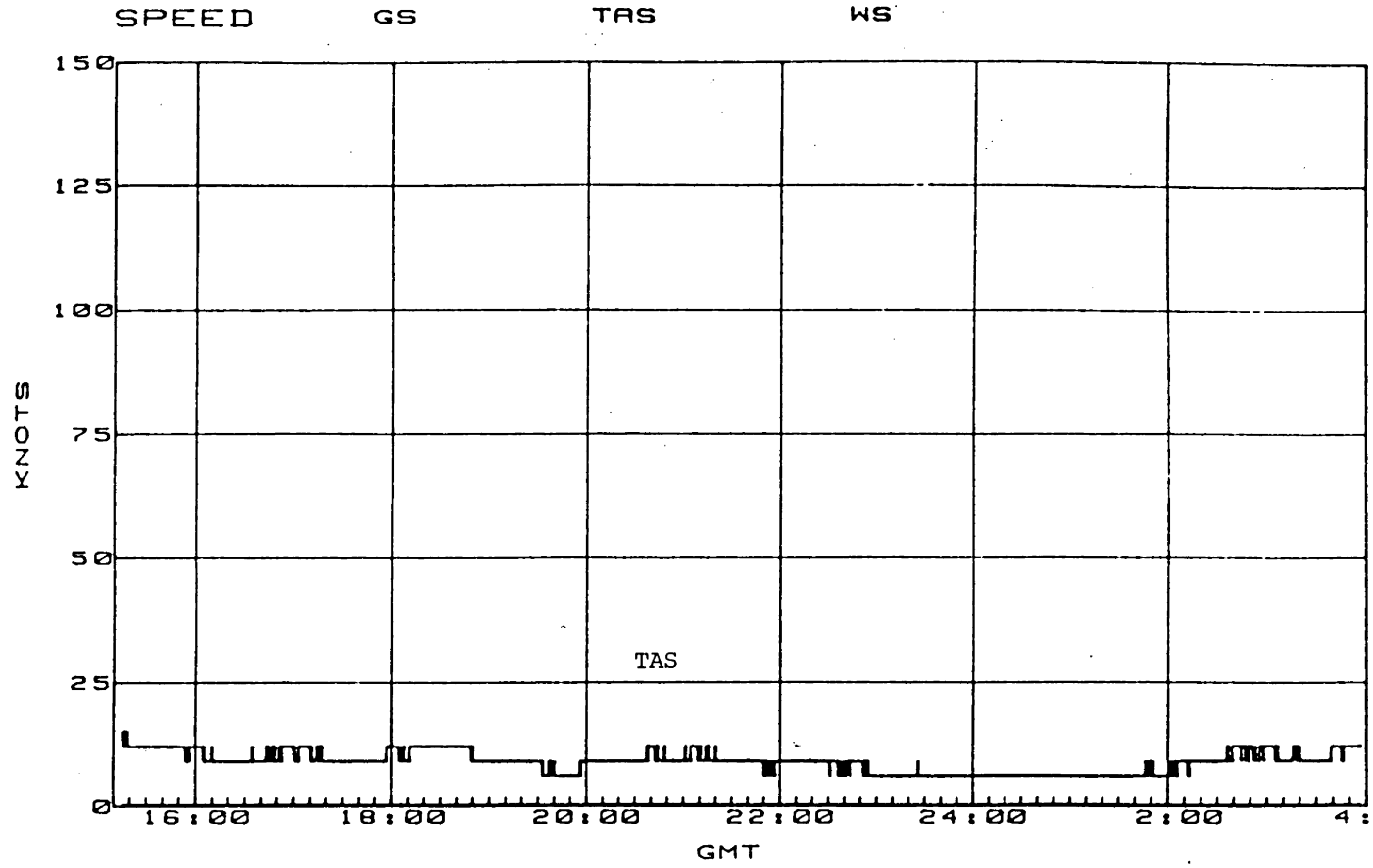


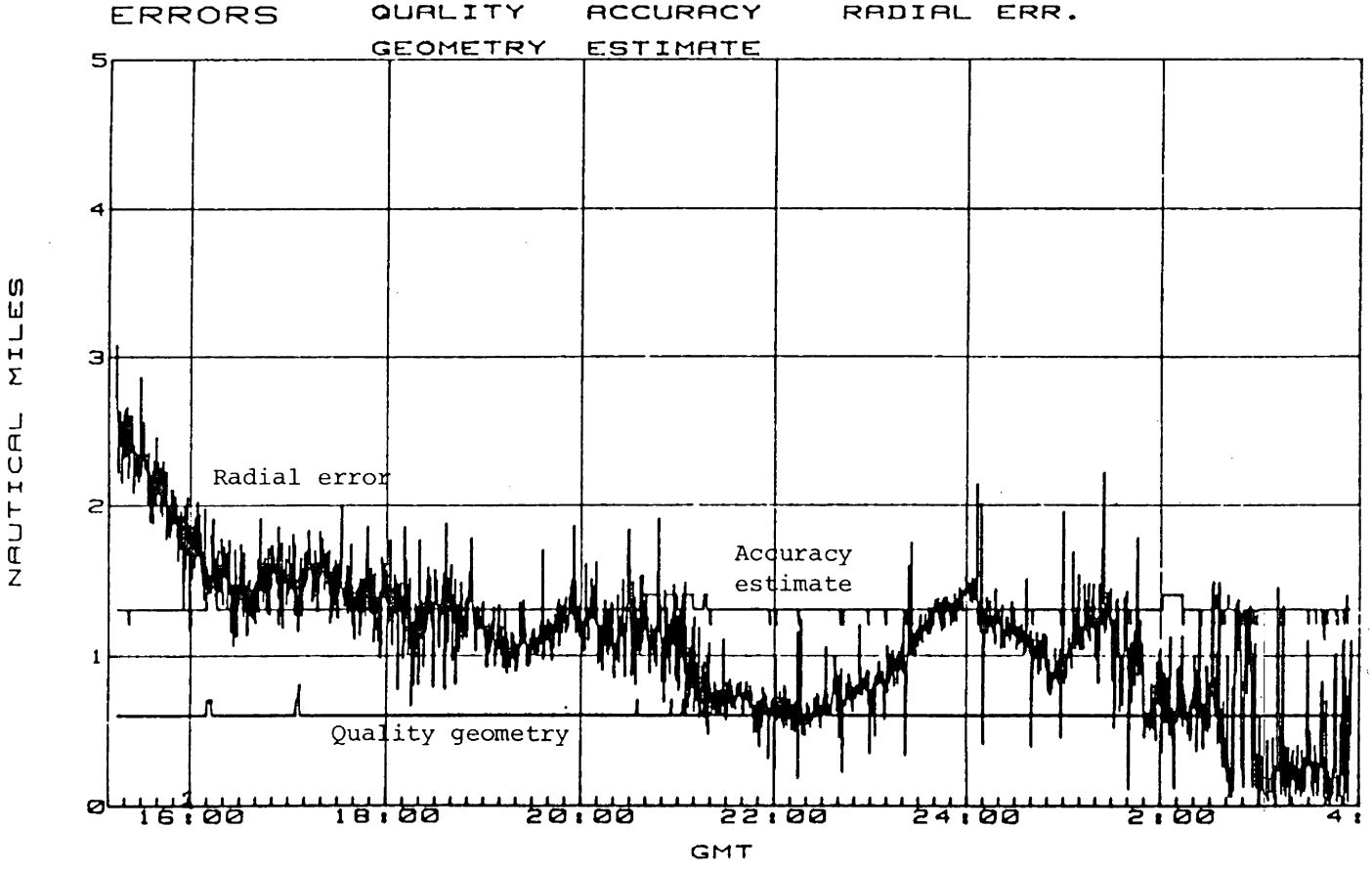


SESSION 2 TAPE 2

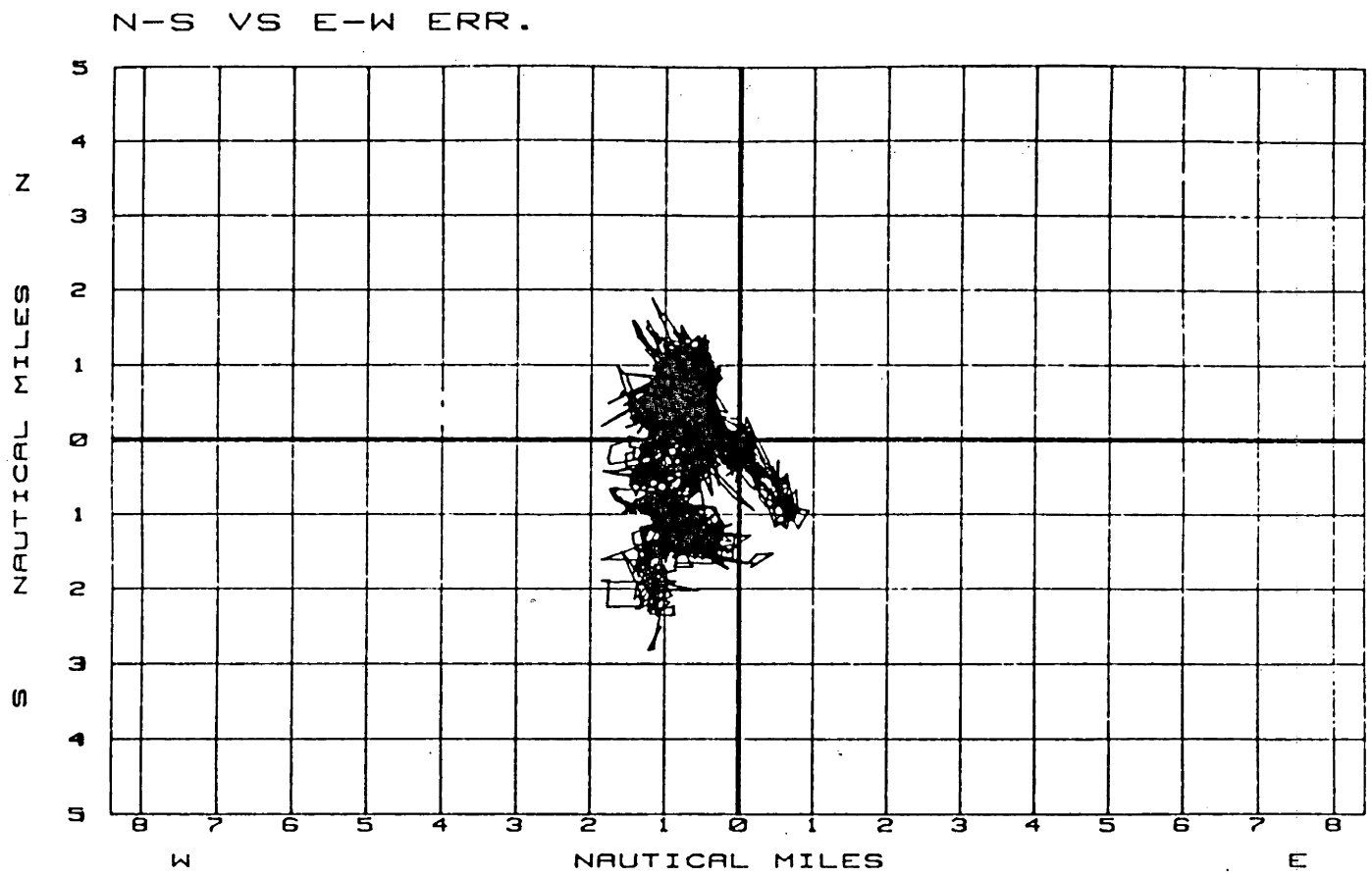
World map displaying CESAR's position, Omega transmitting stations and day/night terminators. (Note that CESAR's position is incorrect due to an input error in its coordinates to program NPOLE)

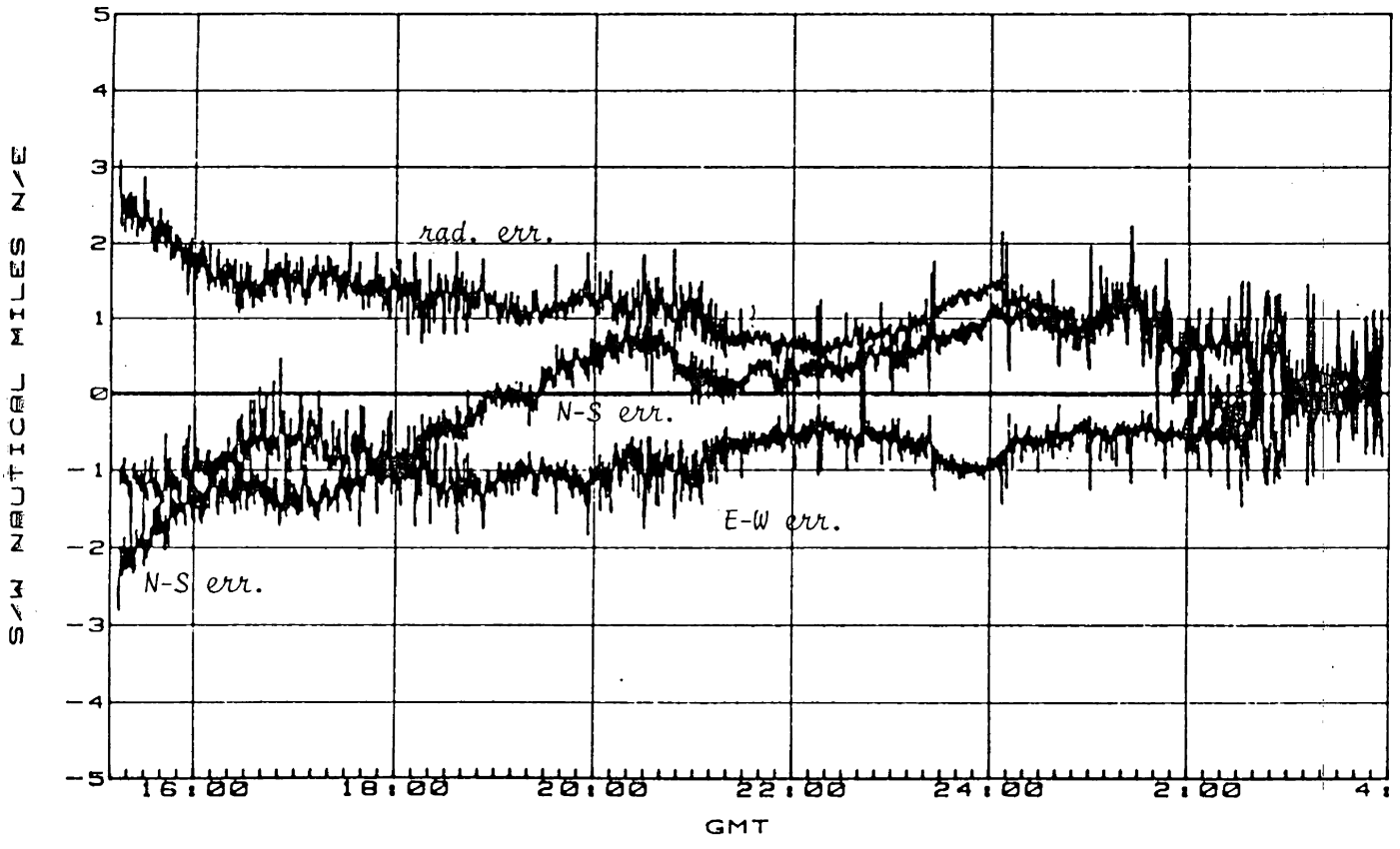
SESSION 2 TAPE 2 CESAR ICE CAMP DATE OF



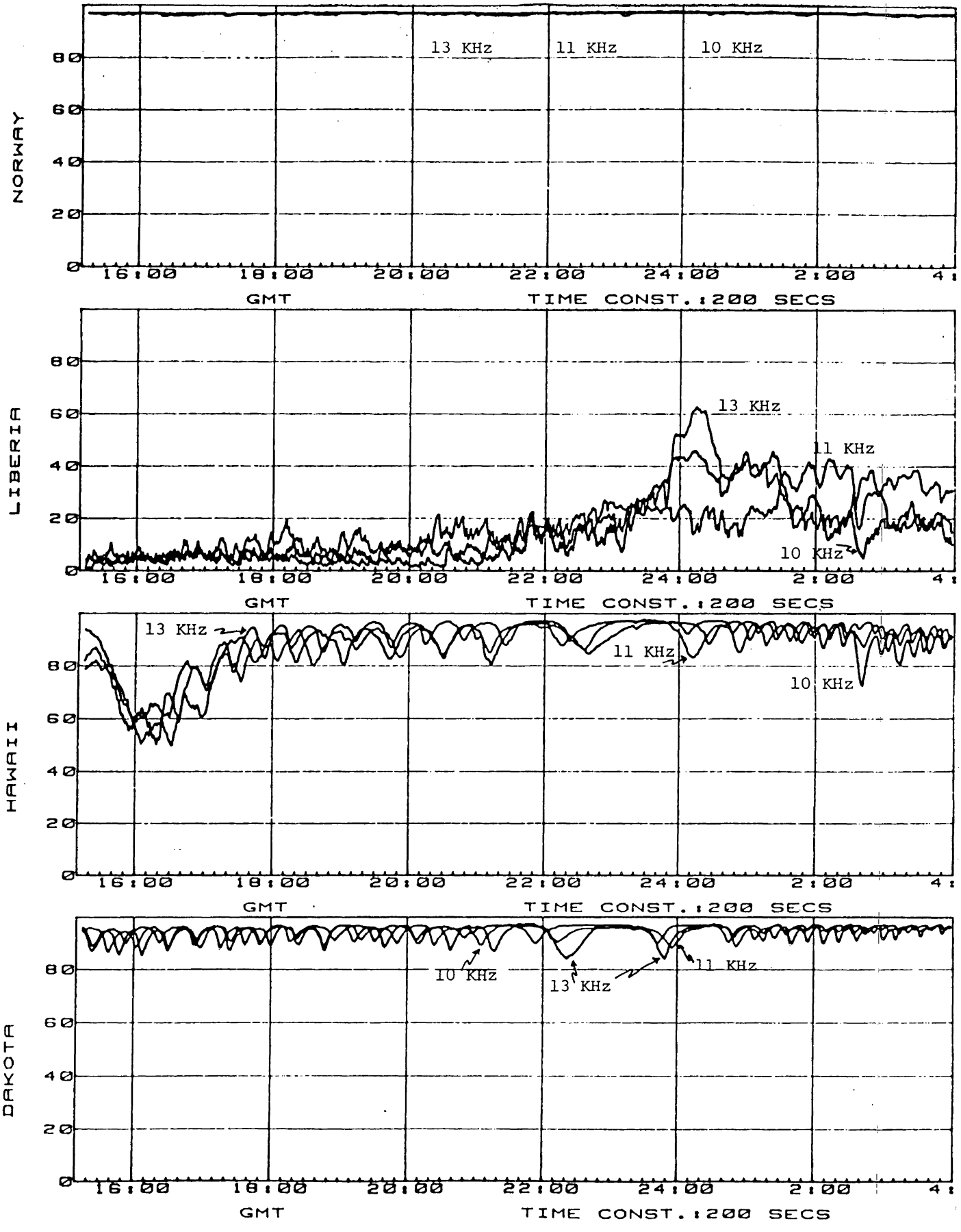


FLIGHT: APR 13 1983



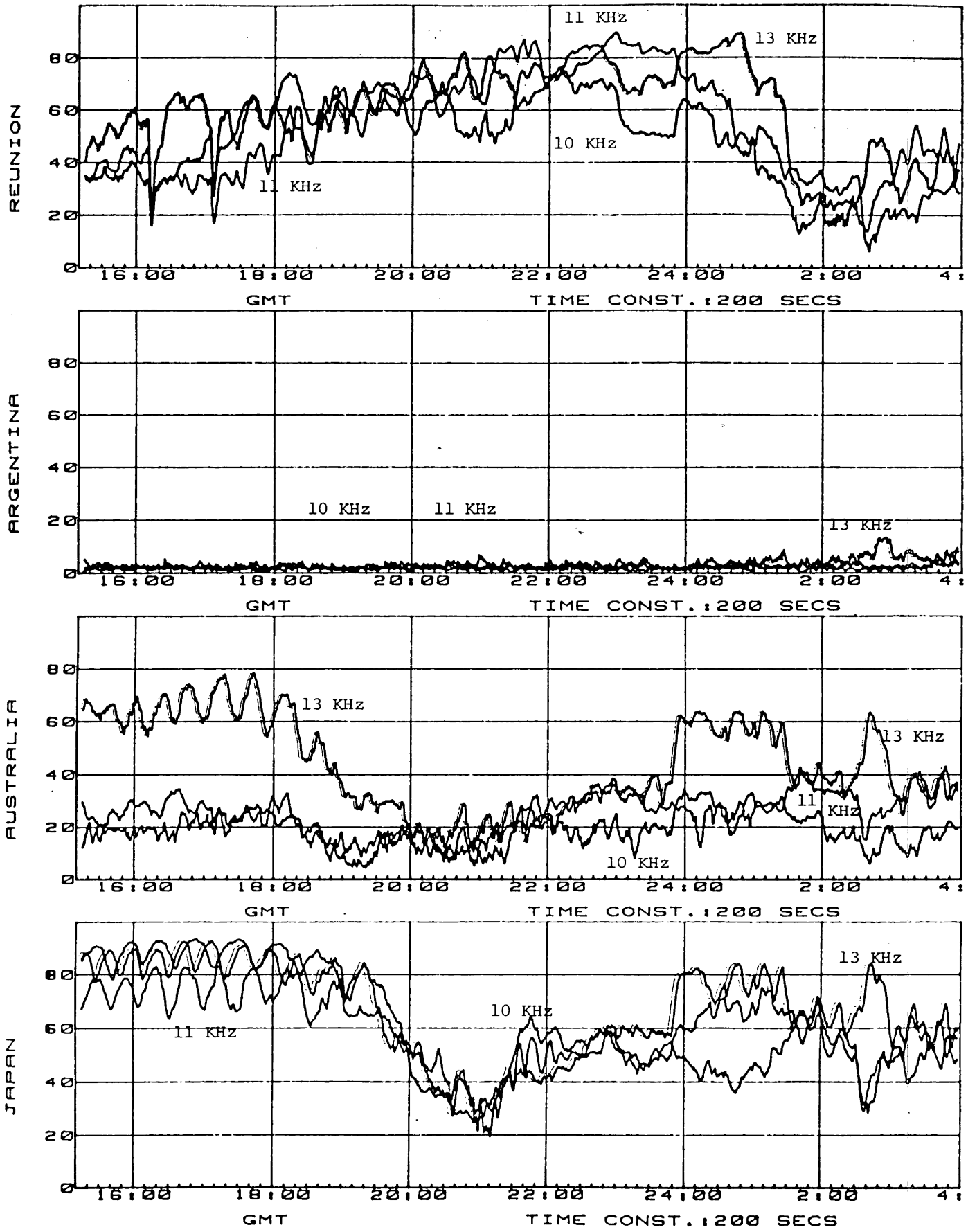


SESSION 2 TAPE 2 CESAR ICE CAMP DATE OF

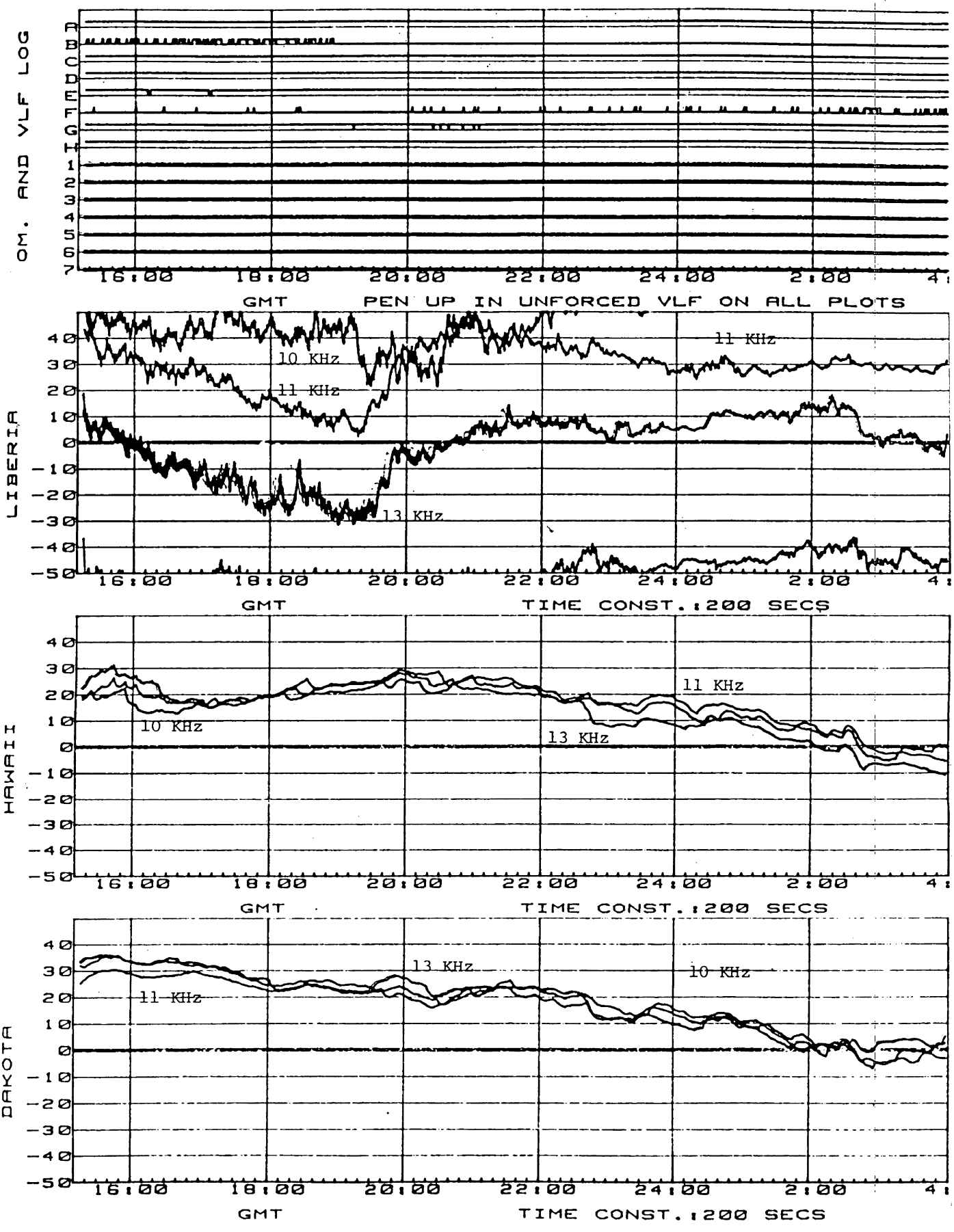


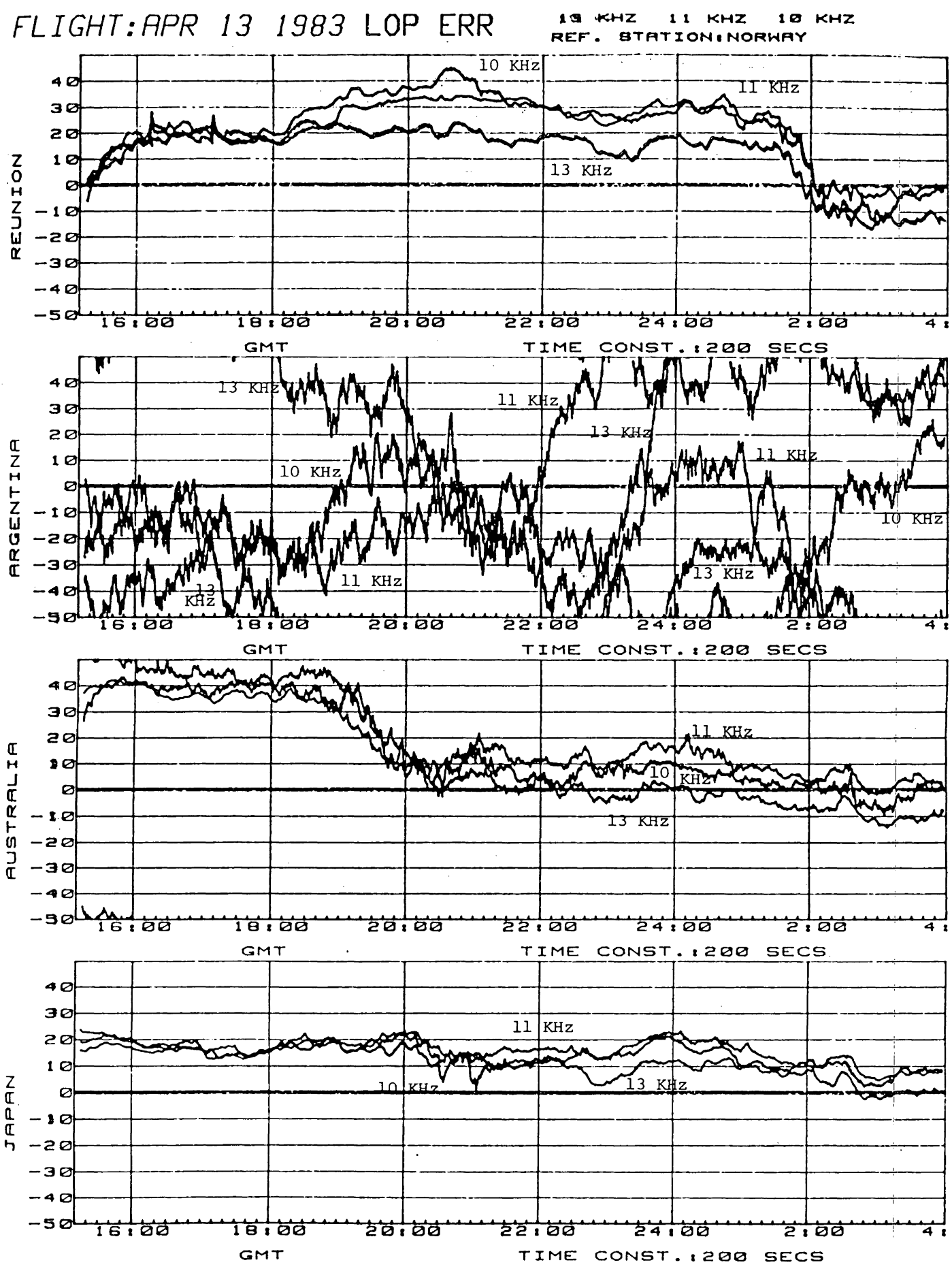
F FLIGHT: APR 13 1983 SNR INDEX

13 KHZ 11 KHZ 10 KHZ
VLF STATUS: UNFORCED

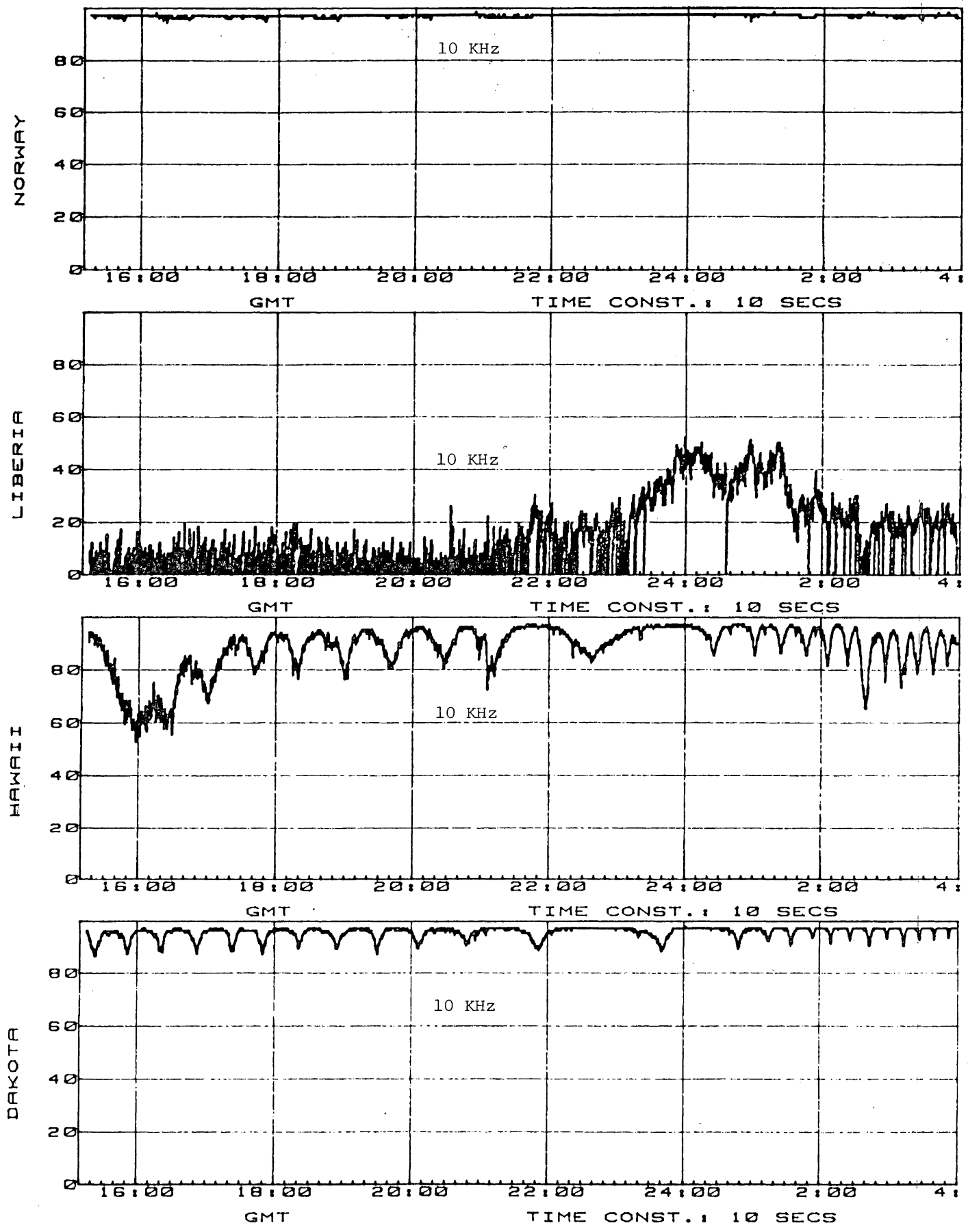


SESSION 2 TAPE 2 CESAR ICE CAMP DATE OF

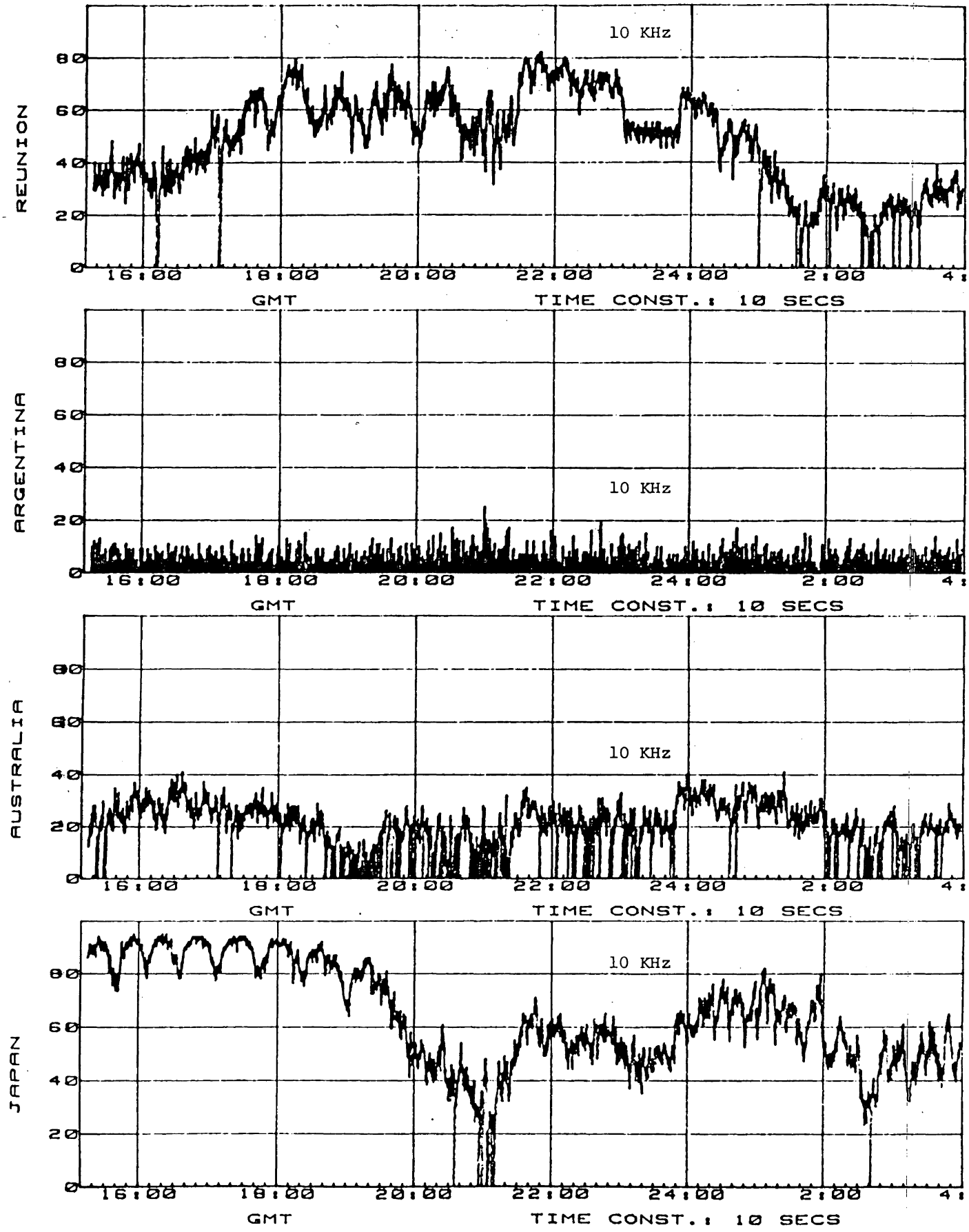



FLIGHT:APR 13 1983 LOP ERR
13 KHZ 11 KHZ 10 KHZ
REF. STATION:NORWAY
REUNION
10 KHz
11 KHz
13 KHz
ARGENTINA
13 KHz
11 KHz
13 KHz
11 KHz
10 KHz
10 KHz
13 KHz
11 KHz
AUSTRALIA
11 KHz
10 KHz
13 KHz
JAPAN
11 KHz
10 KHz
13 KHz
40
30
20
10
0
-10
-20
-30
-40
-50
16:00
18:00
20:00
22:00
24:00
2:00
4:
GMT
TIME CONST.:200 SECS

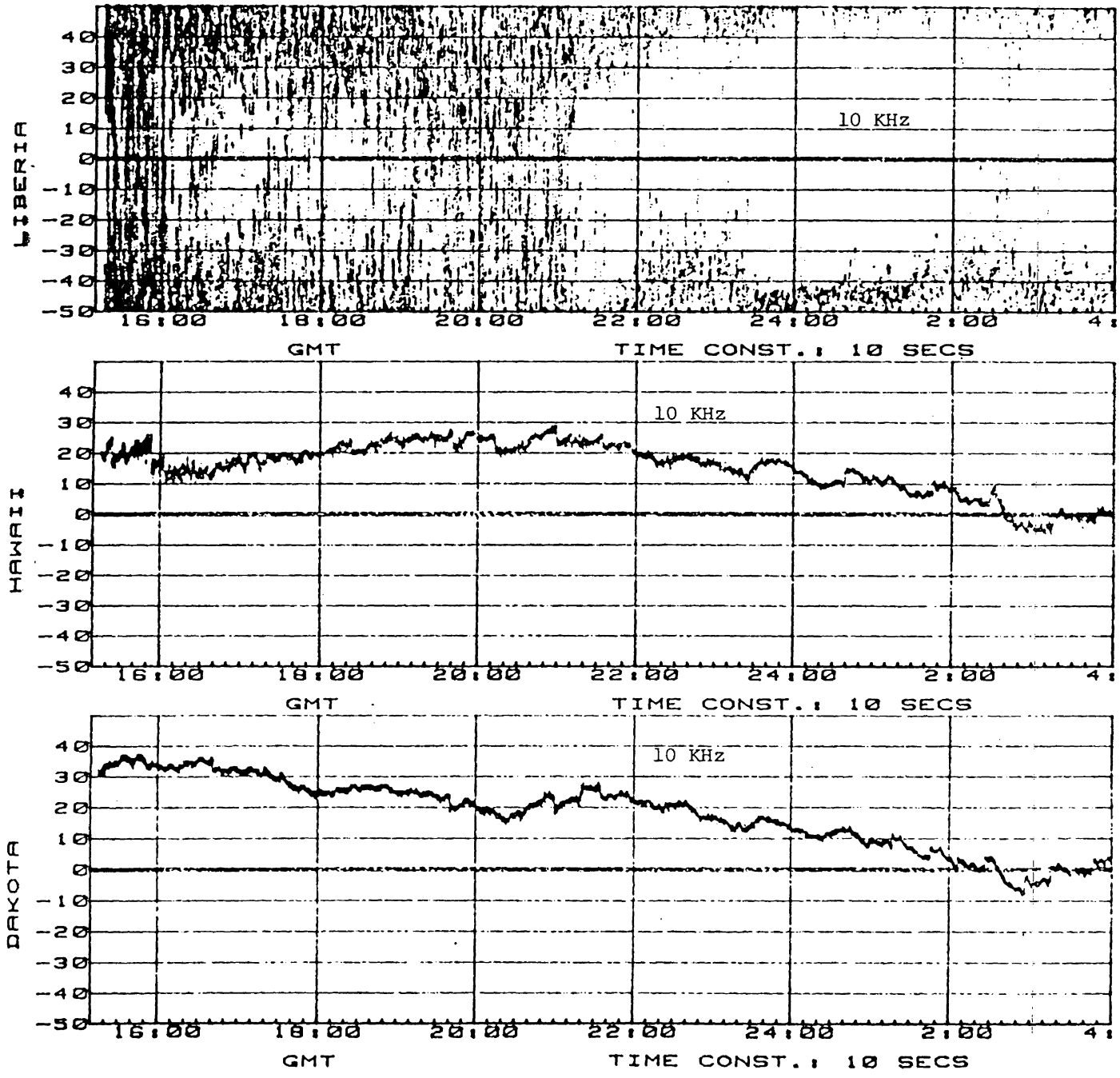
SESSION 2 TAPE 2 CESAR ICE CAMP DATE OF FL

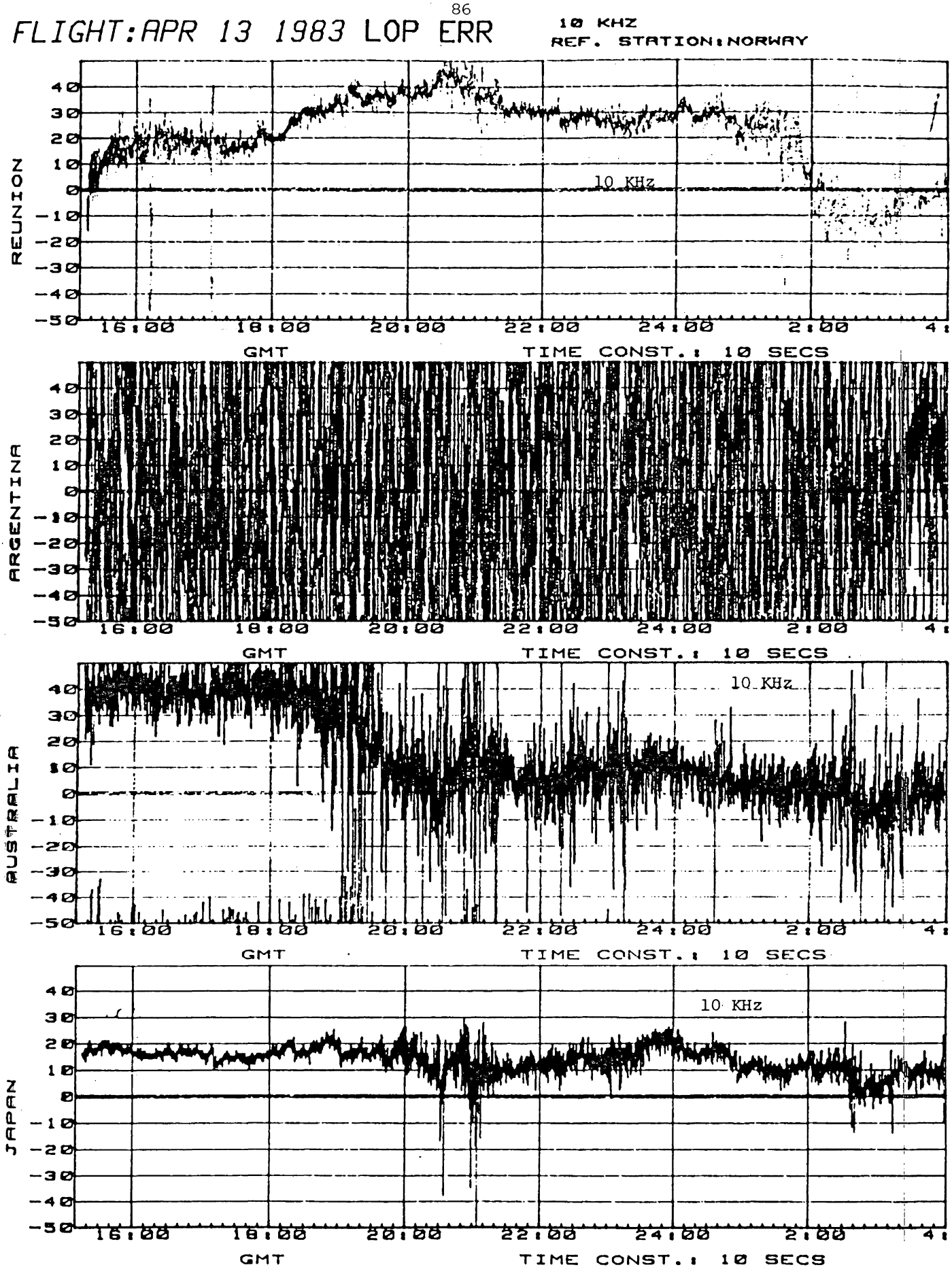


FLIGHT: APR 13 1983 SNR INDEX 10 KHZ

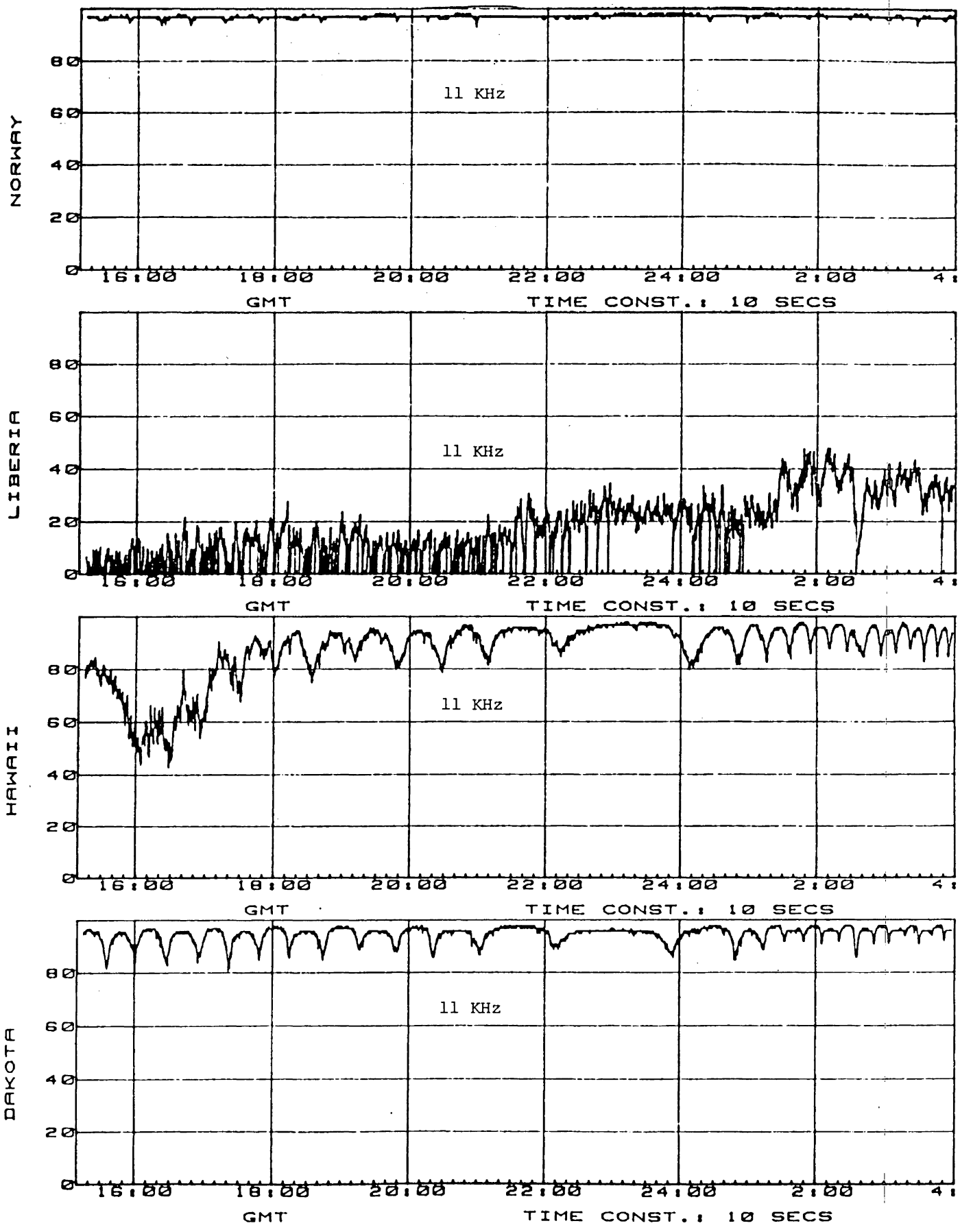


SESSION 2 TAPE 2 CESAR ICE CAMP DATE OF

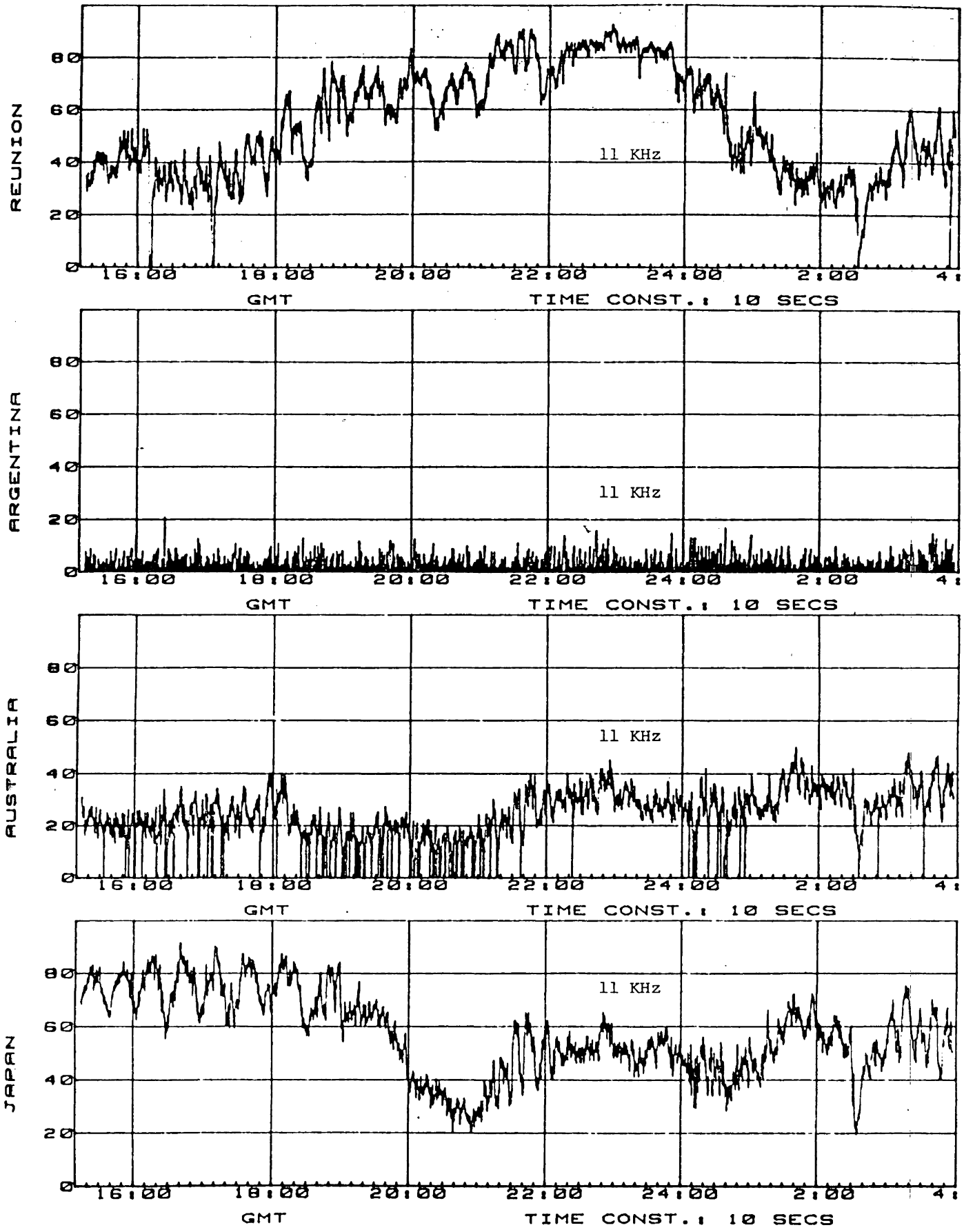



FLIGHT: APR 13 1983 LOP ERR
10 KHZ
REF. STATION: NORWAY
REUNION
ARGENTINA
AUSTRALIA
JAPAN
10 KHz
40
30
20
10
0
-10
-20
-30
-40
-50
16:00
18:00
20:00
22:00
24:00
2:00
4:
GMT
TIME CONST.: 10 SECS

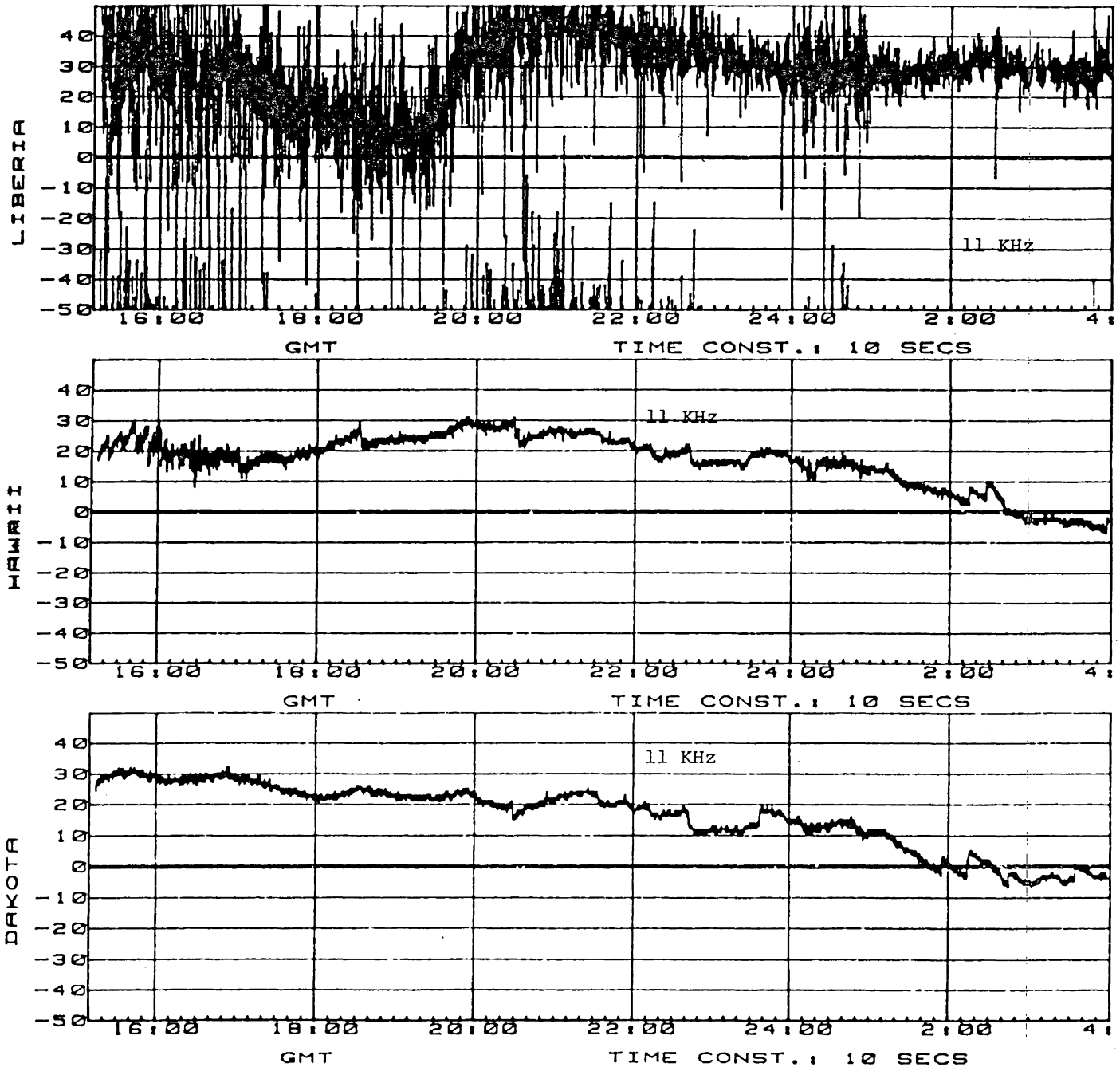
SESSION 2 TAPE 2 CESAR ICE CAMP DATE OF



FLIGHT: APR 13 1983 SNR INDEX 11 KHZ

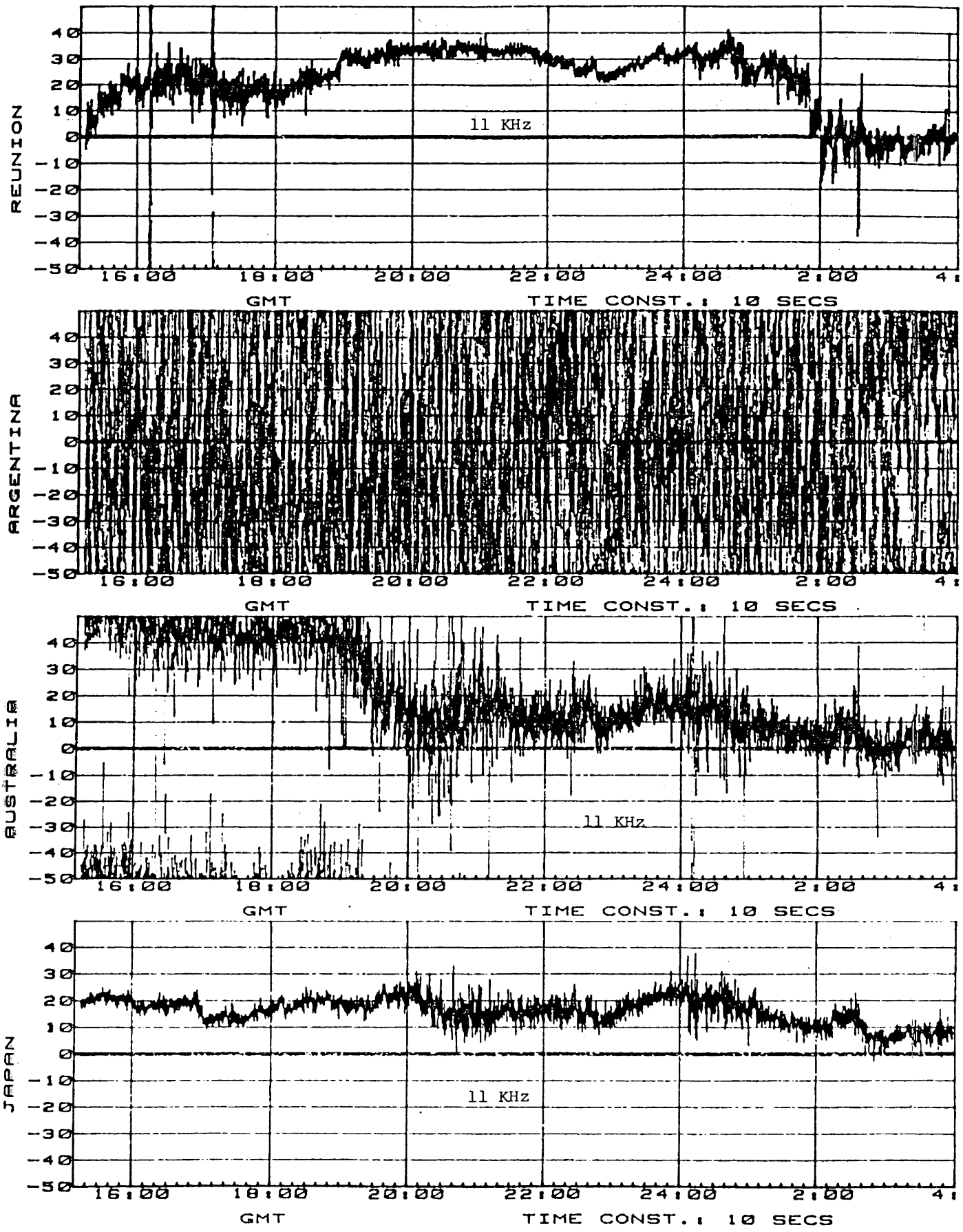


SESSION 2 TAPE 2 CESAR ICE CAMP DATE OF

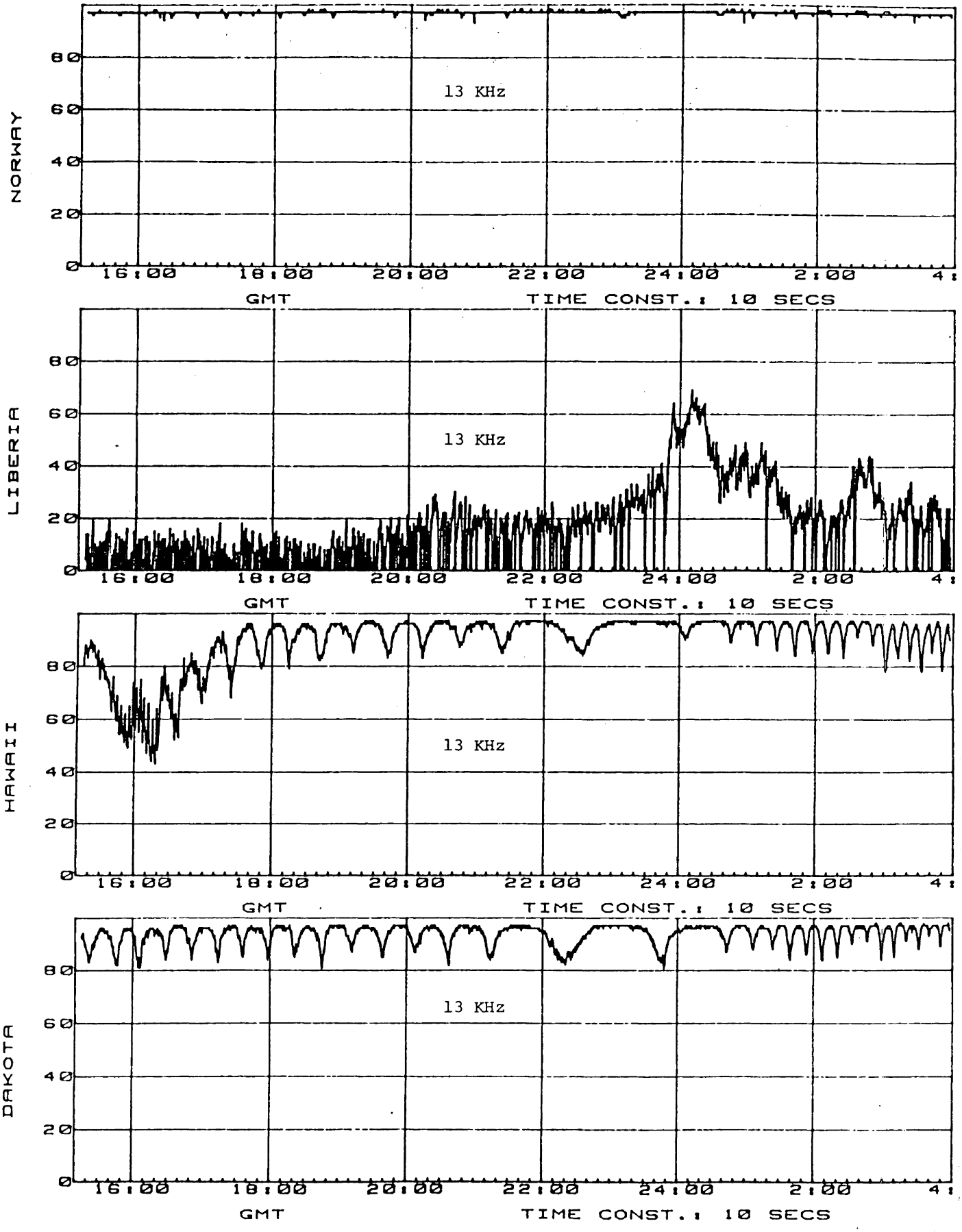


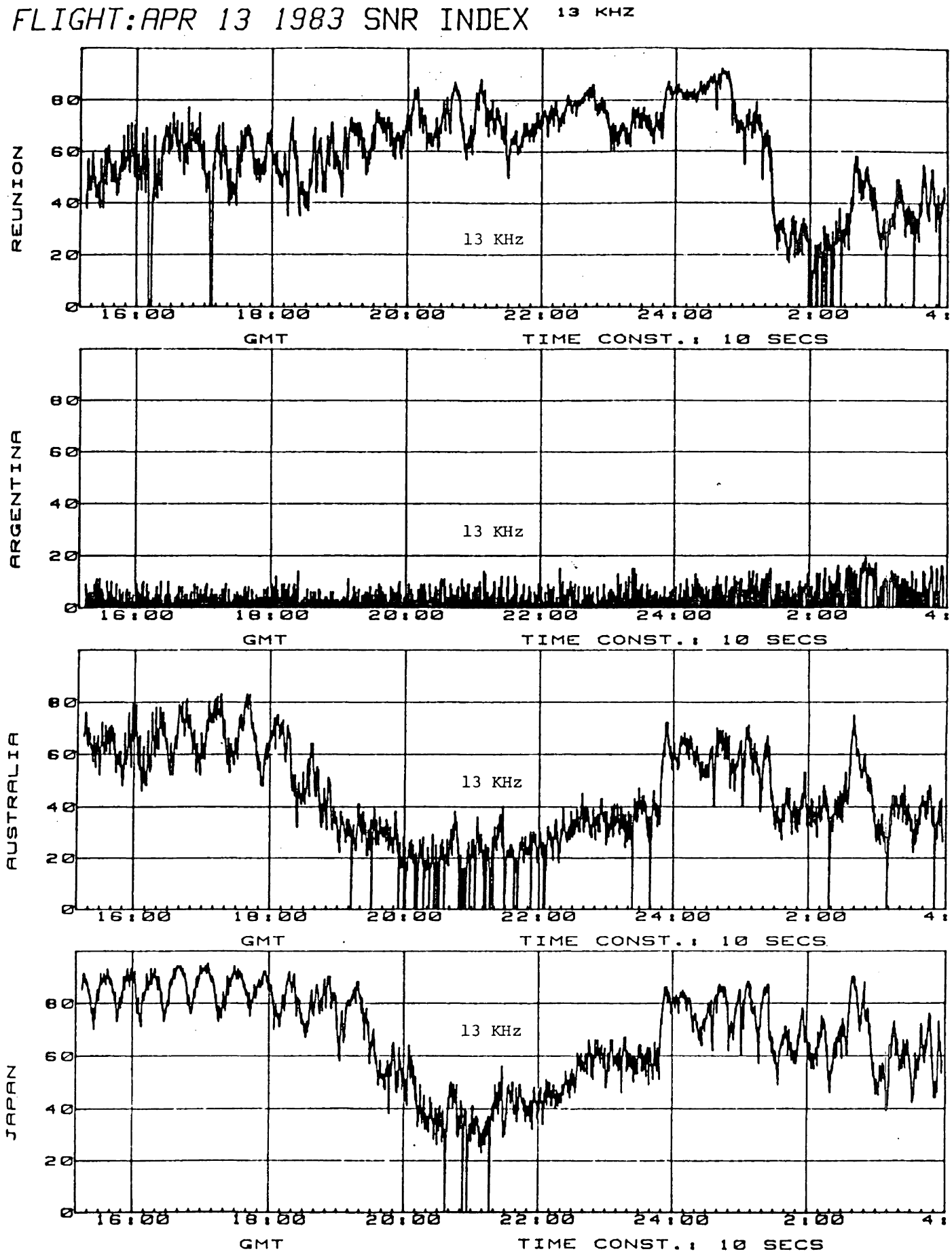
F FLIGHT:APR 13 1983 LOP ERR

11 KHZ
REF. STATION:NORWAY

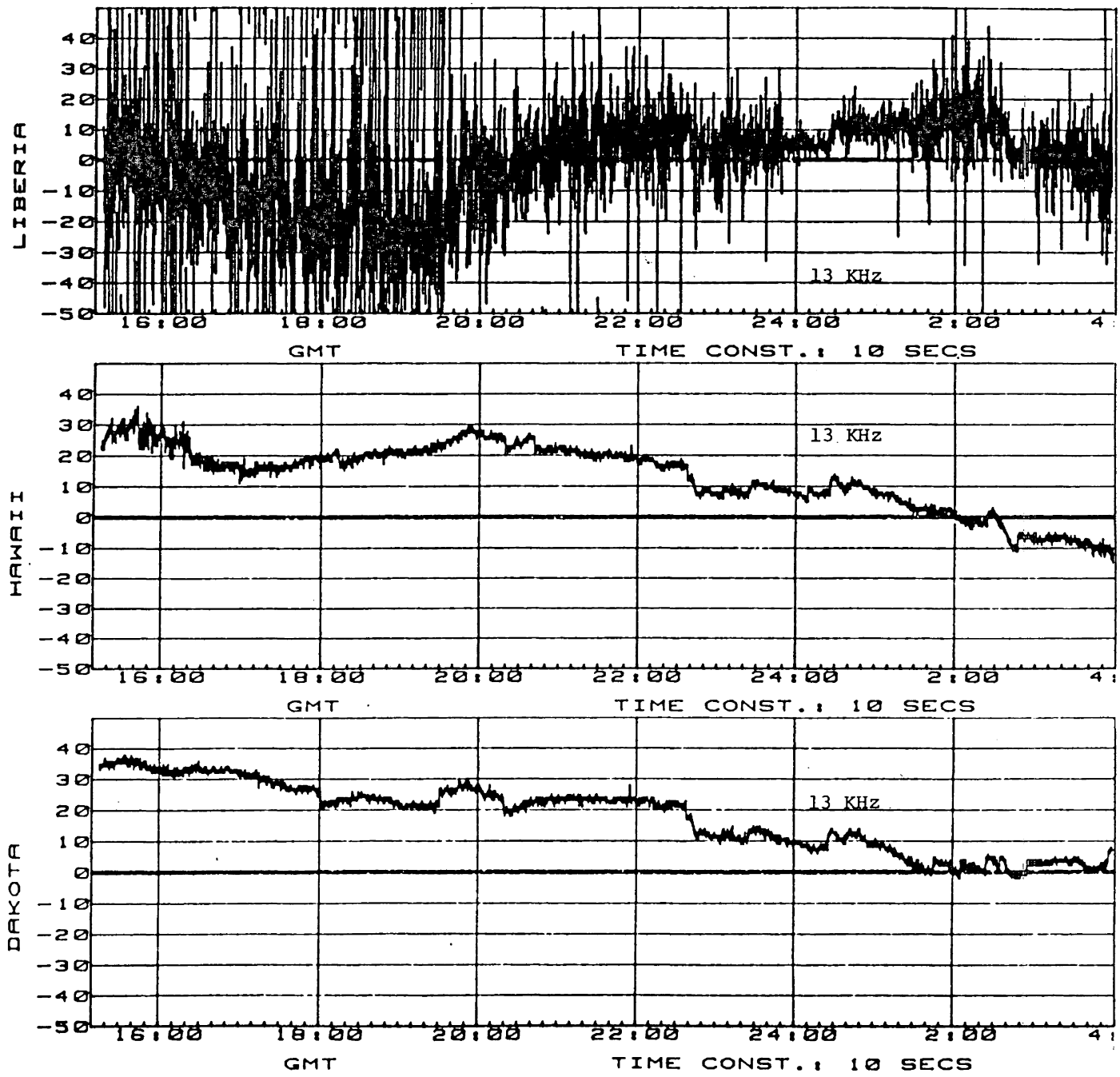


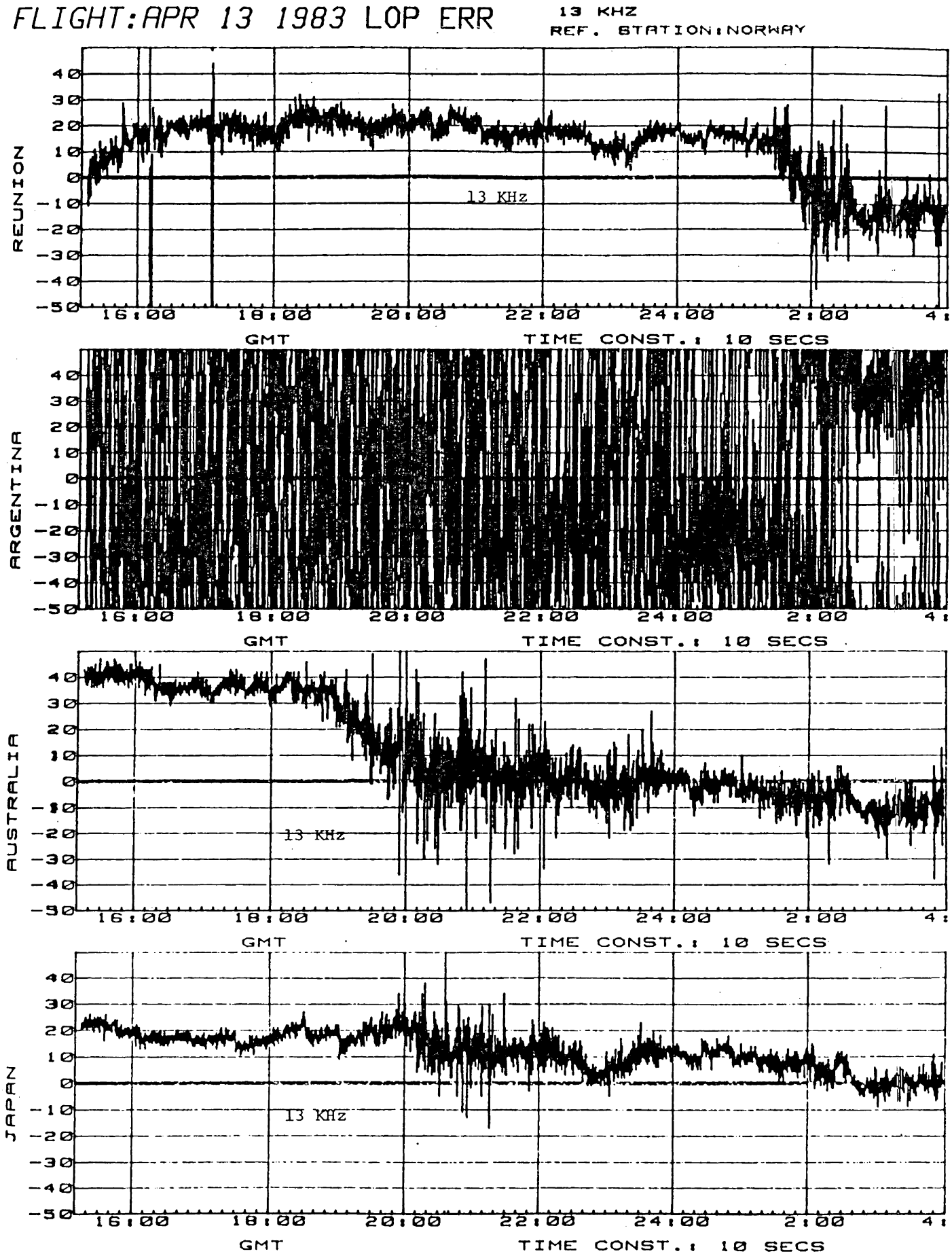
SESSION 2 TAPE 2 CESAR ICE CAMP DATE OF



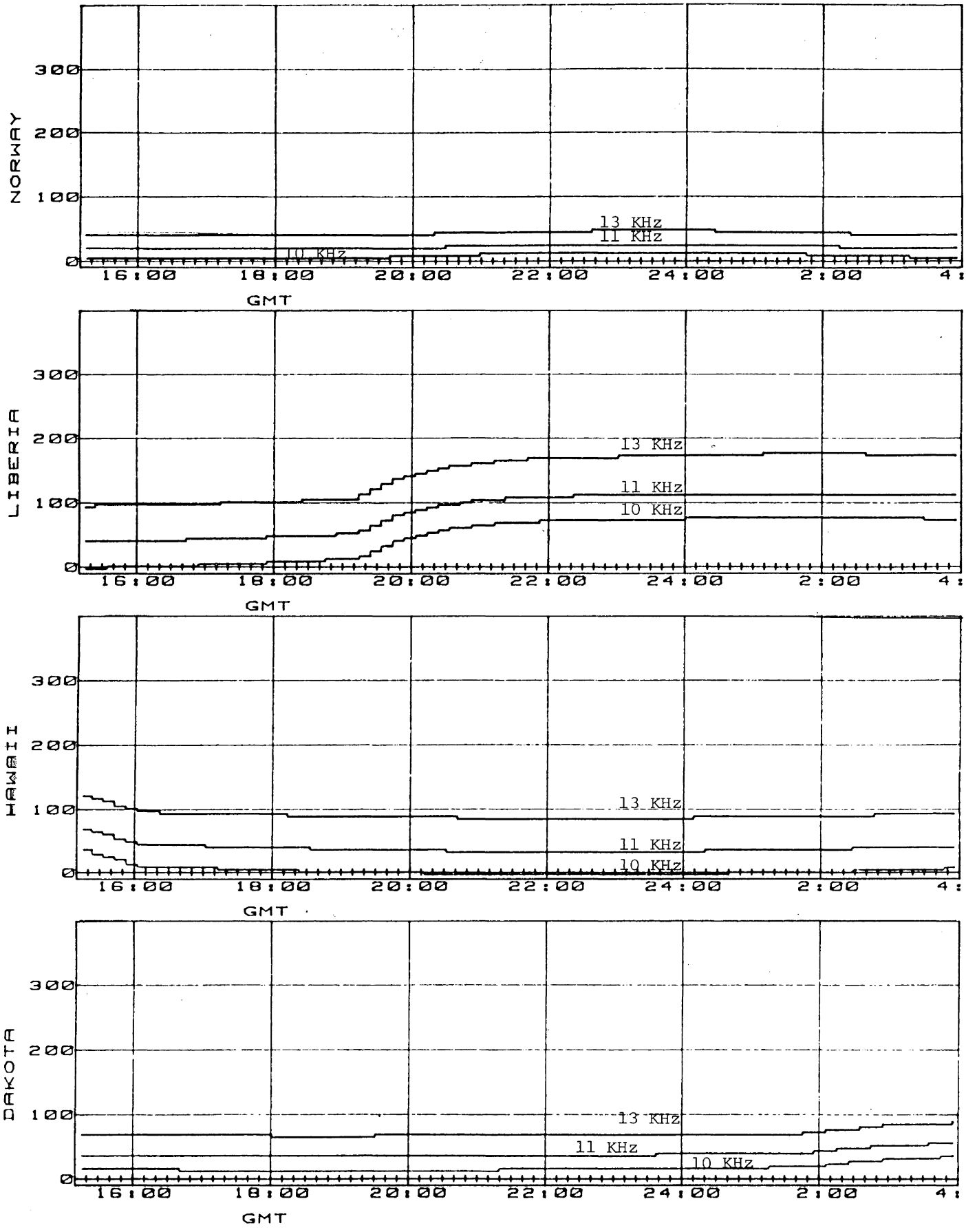

F FLIGHT:APR 13 1983 SNR INDEX 13 KHZ
REUNION
13 KHz
0
20
40
60
80
16:00
18:00
20:00
22:00
24:00
2:00
4:
GMT
TIME CONST.: 10 SECS
ARGENTINA
13 KHz
AUSTRALIA
13 KHz
JAPAN
13 KHz

SESSION 2 TAPE 2 CESAR ICE CAMP DATE OF



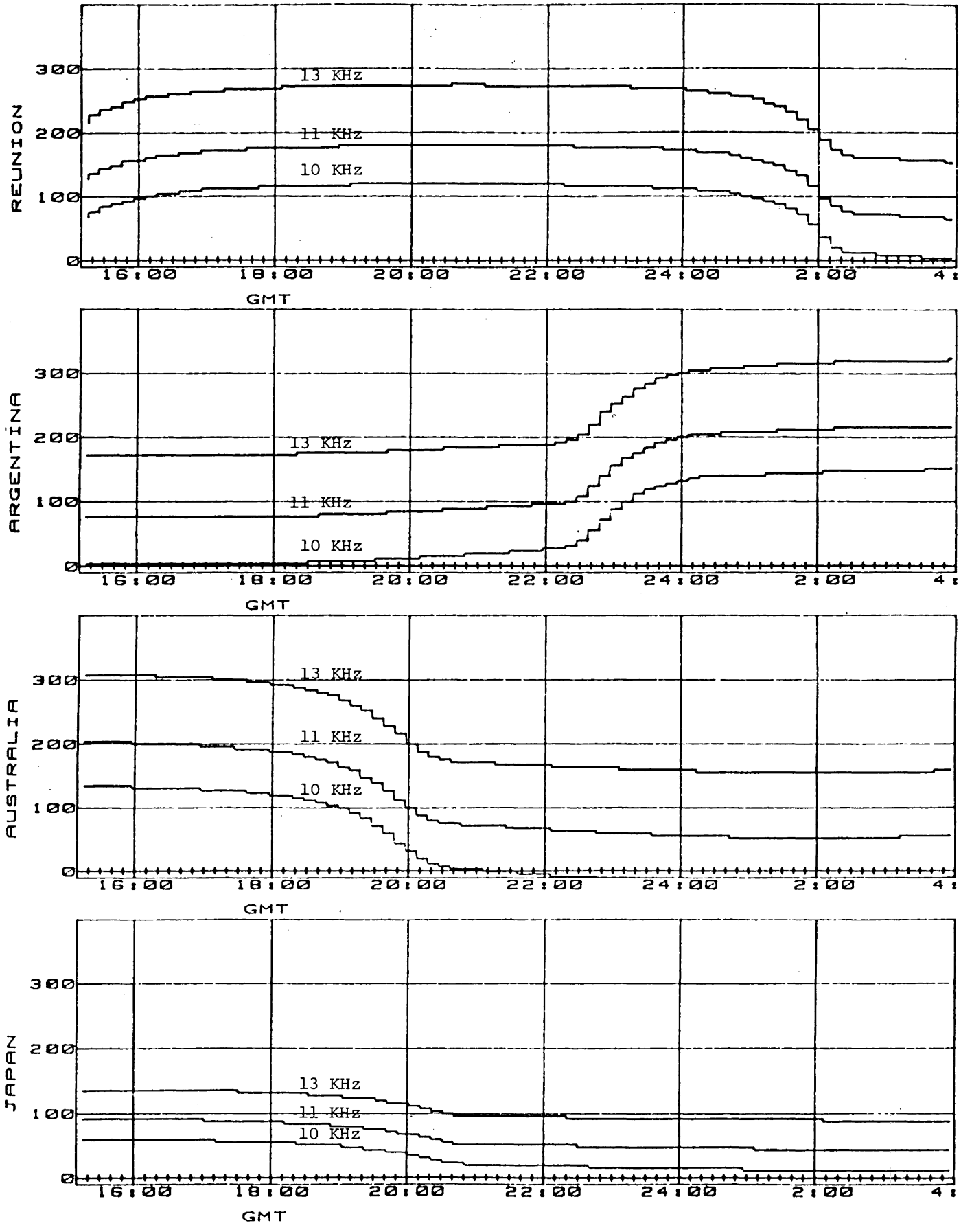

F FLIGHT:APR 13 1983 LOP ERR
13 KHZ
REF. STATION:NORWAY
REUNION
13 KHz
ARGENTINA
AUSTRALIA
13 KHz
JAPAN
13 KHz
40
30
20
10
0
-10
-20
-30
-40
-50
16:00
18:00
20:00
22:00
24:00
2:00
4:
GMT
TIME CONST.: 10 SECS

SESSION 2 TAPE 2 CESAR ICE CAMP DATE OF F



F FLIGHT: APR 13 1983 DIURNALS

13 KHZ 11 KHZ 10 KHZ
VLF STATUS: UNFORCED

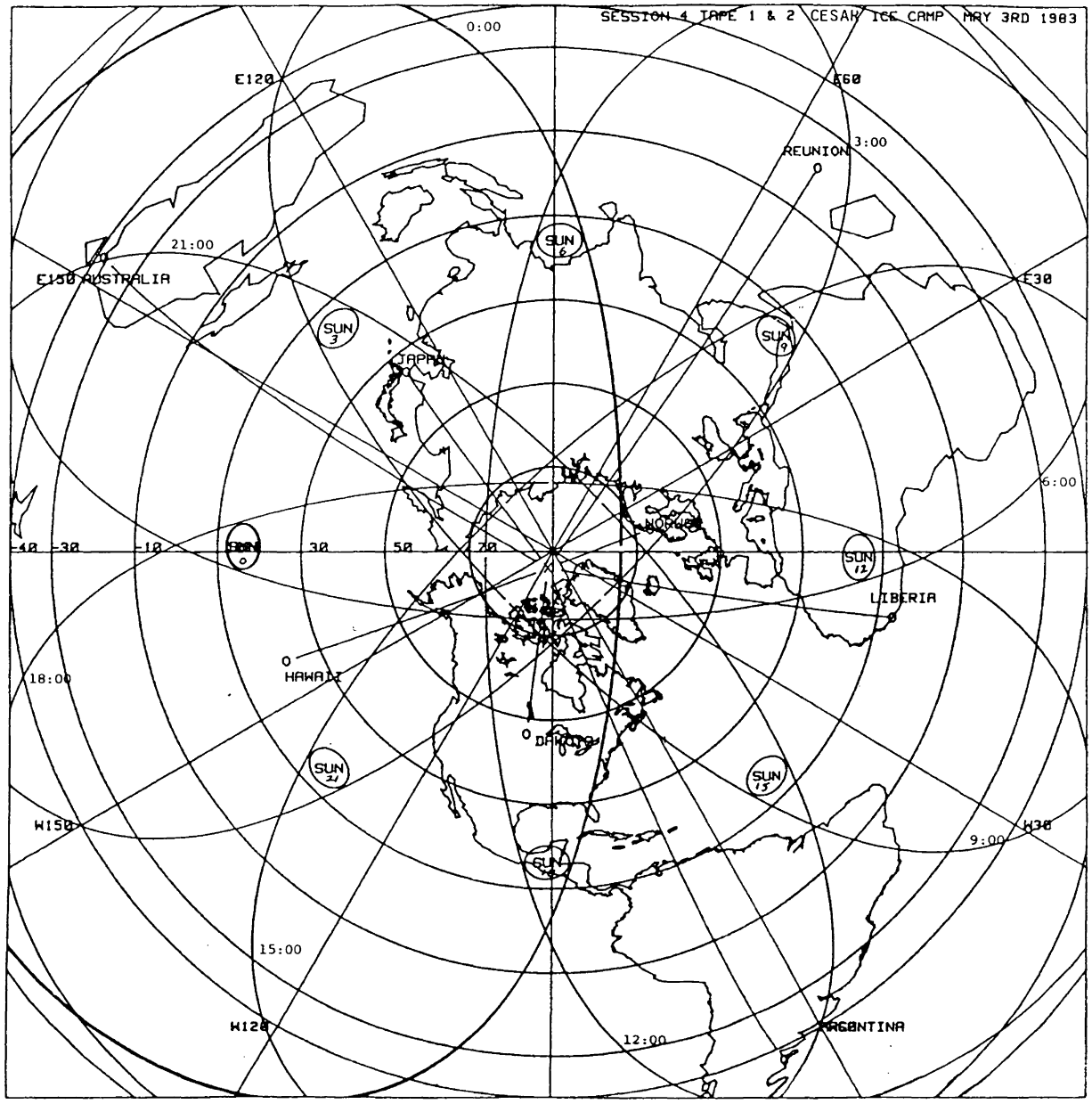


APPENDIX I.3

Session 4 Tapes 1 and 2

Time span: 00:00 May 3, 1983 to 02:40 May 4, 1983.

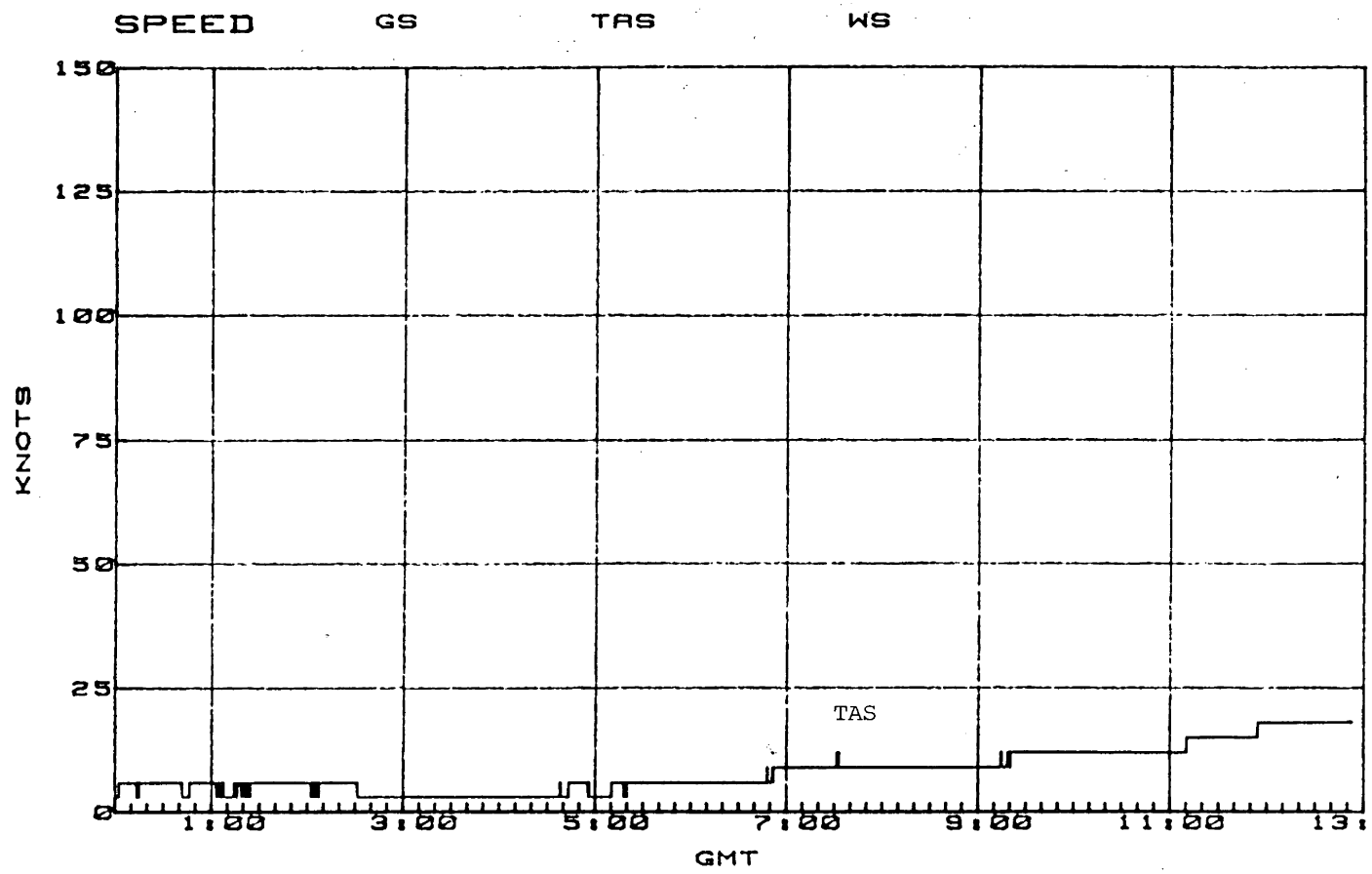
Approximate position: 85^{o} 51.7' (N)
108^{o} 30.9' (W)

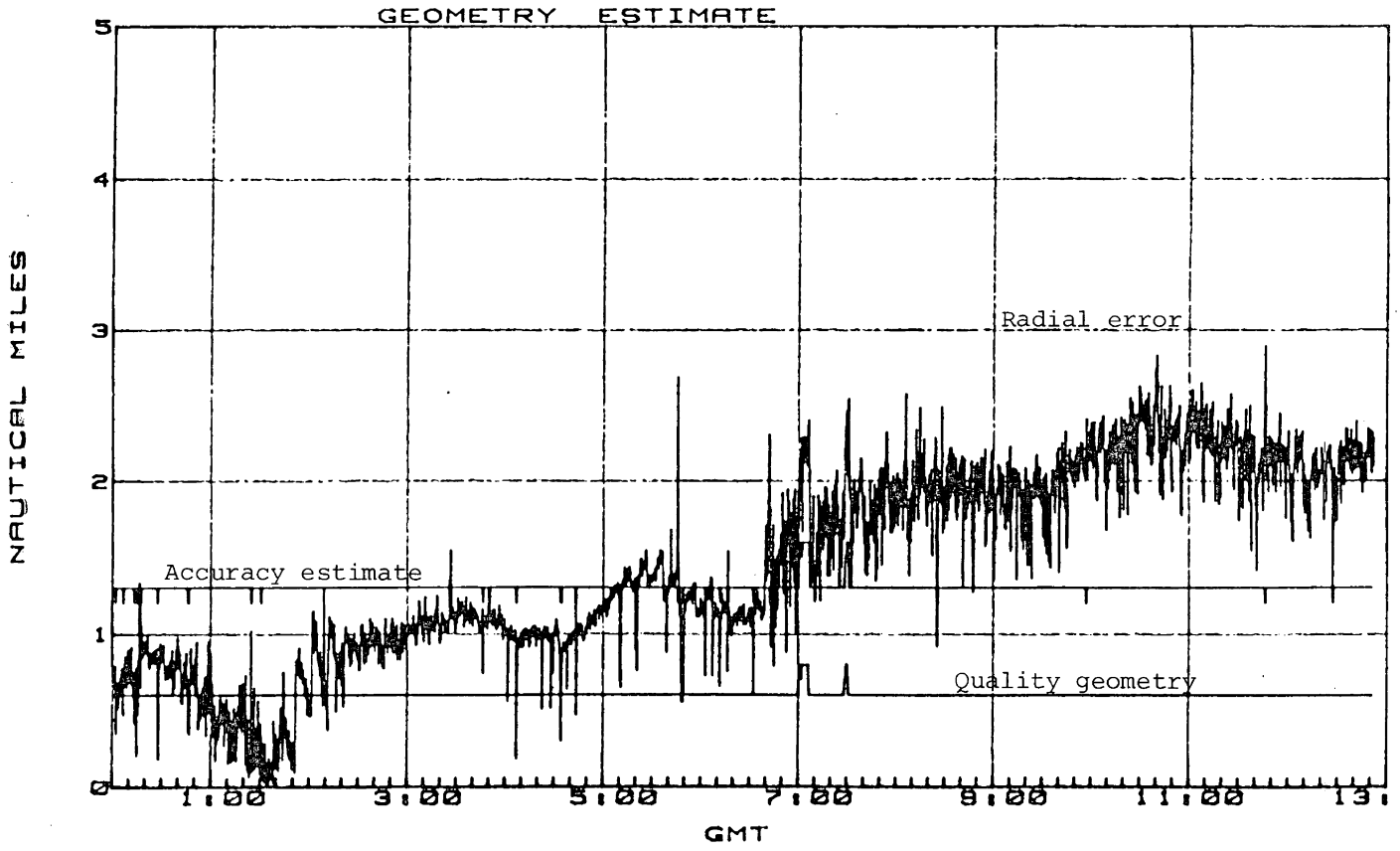


SESSION 4 TAPE 1 & 2

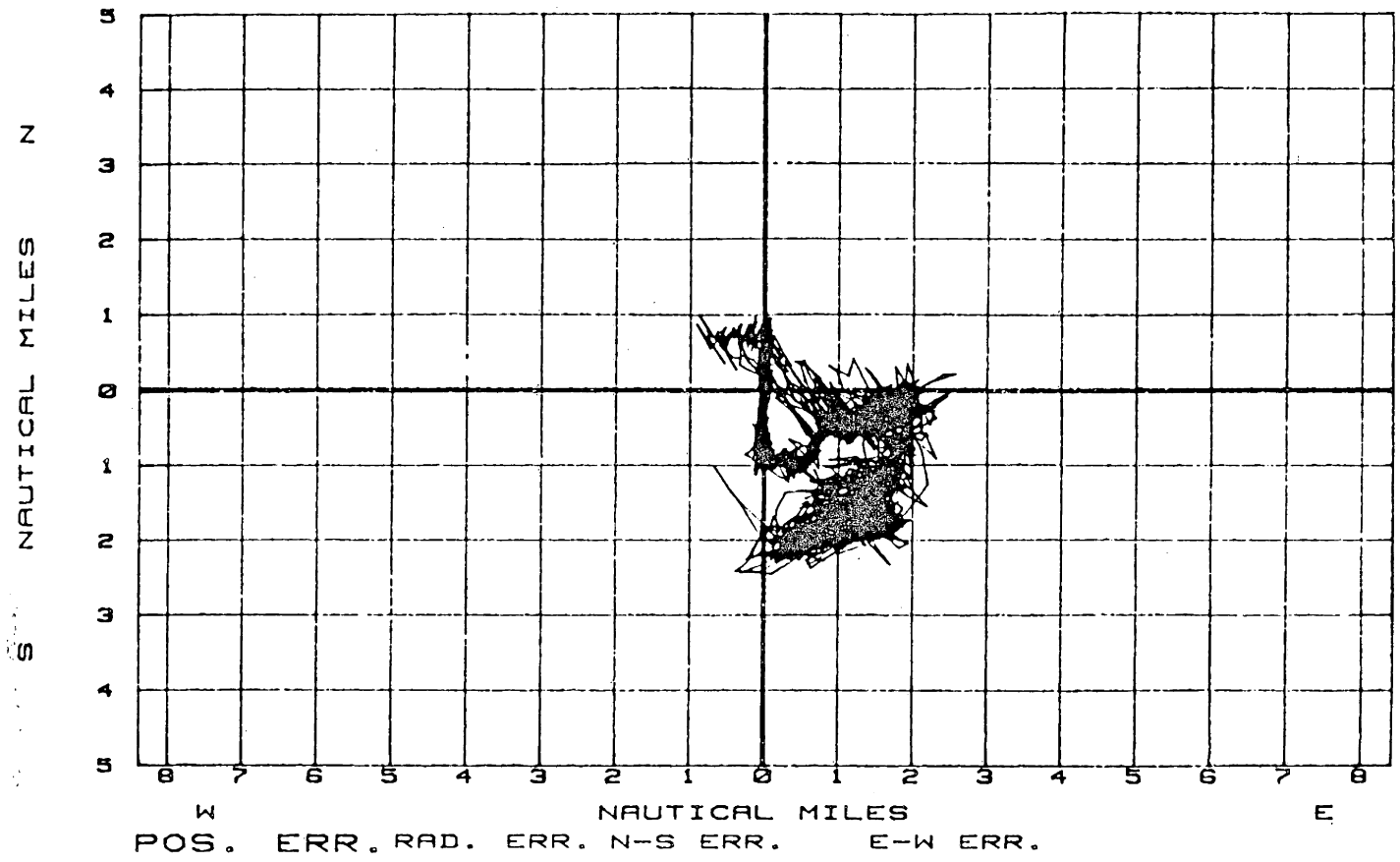
World map displaying CESAR's position, Omega transmitting stations and day/night terminators.

SESSION 4 TAPE 1 CESAR ICE CAMP DATE OF F

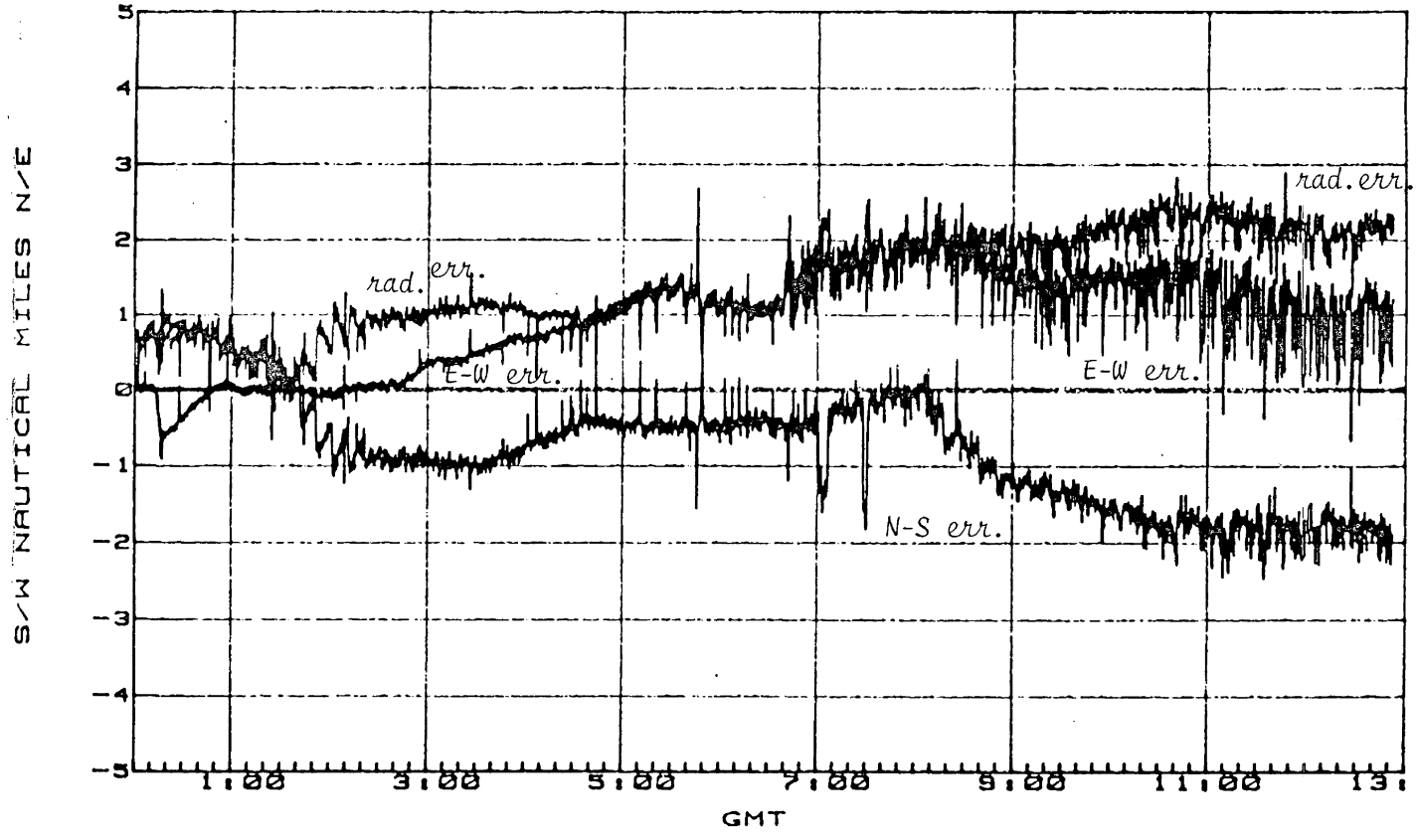




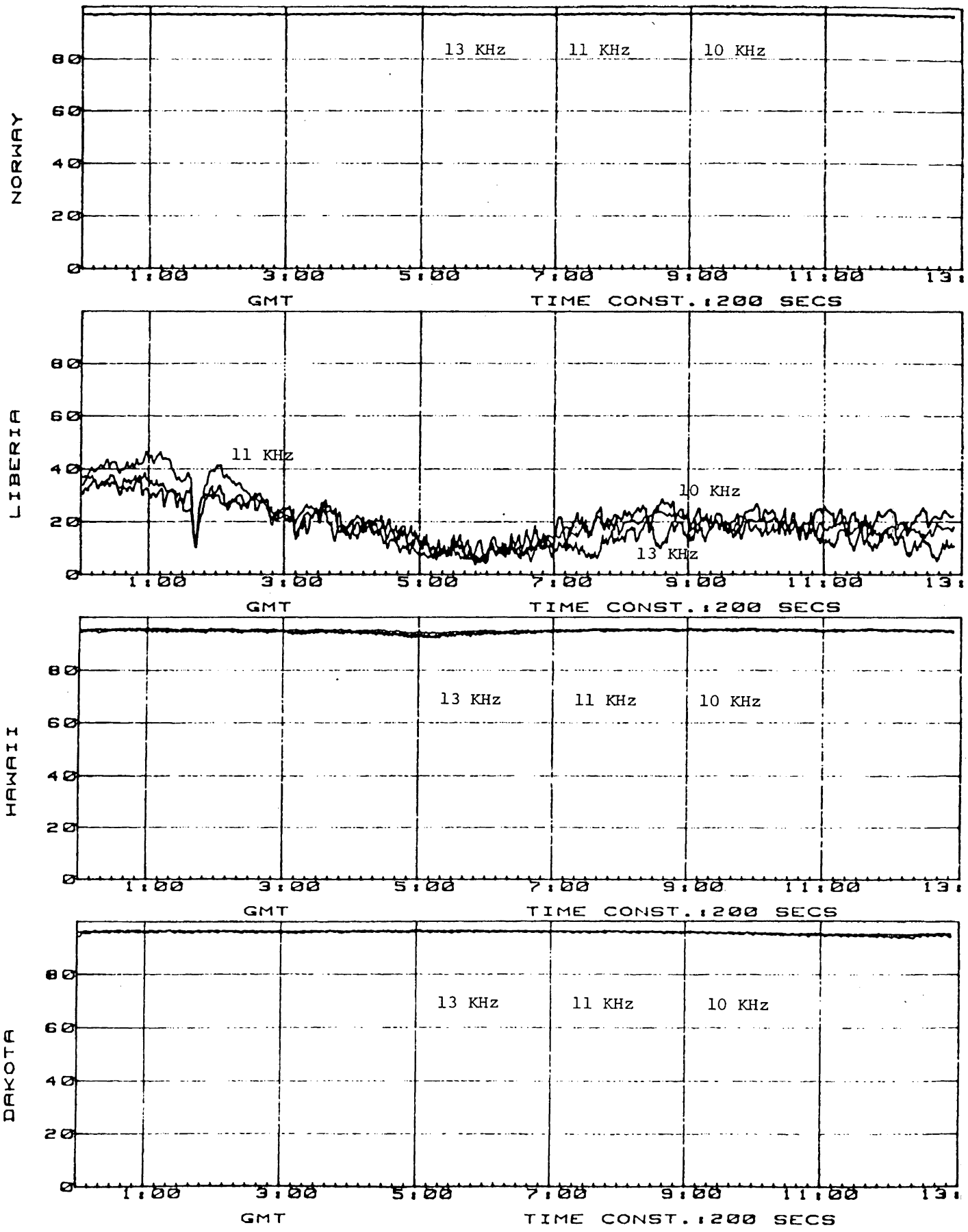
FLIGHT: MAY 3 1983



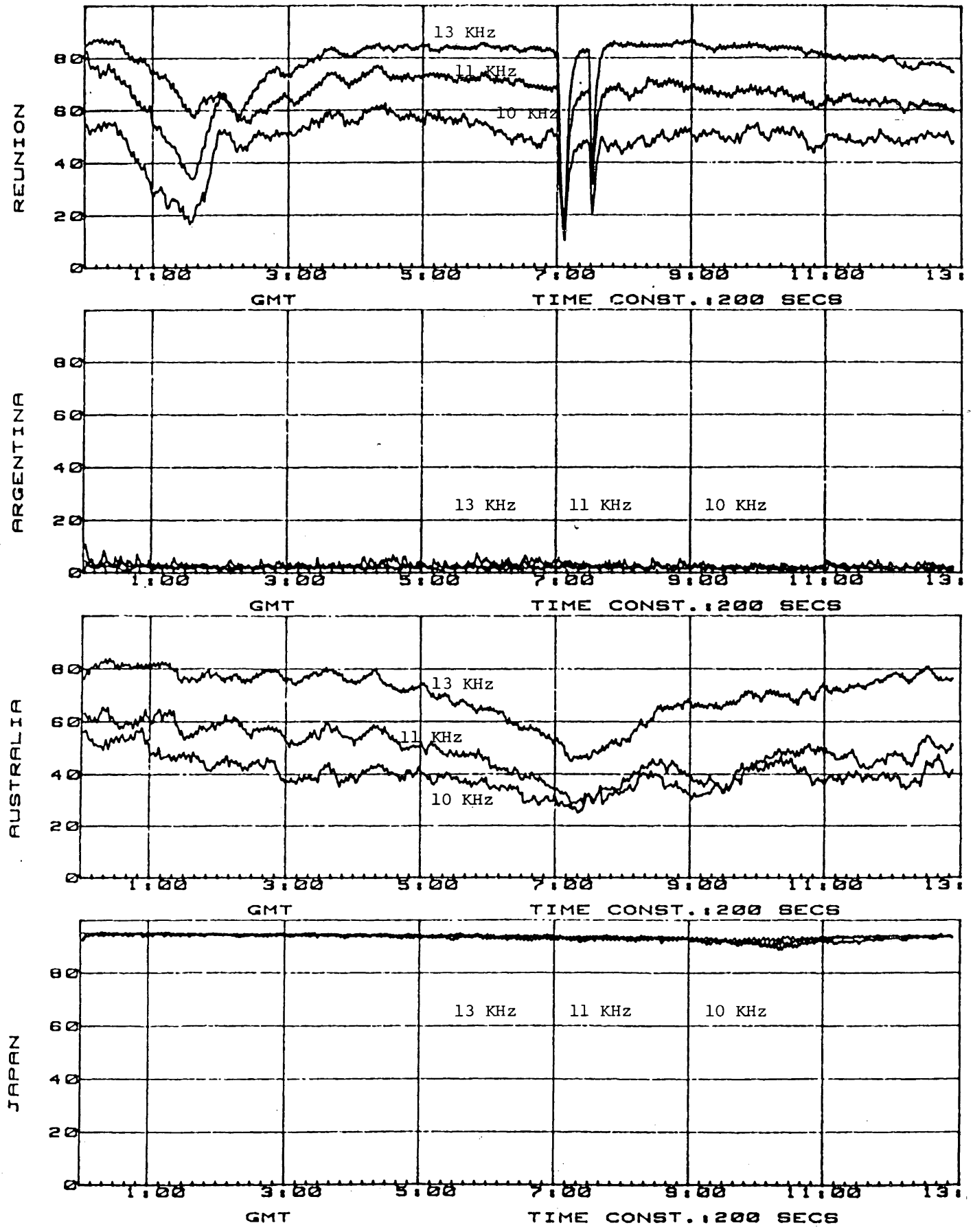
POS. ERR. RAD. ERR. N-S ERR. E-W ERR.

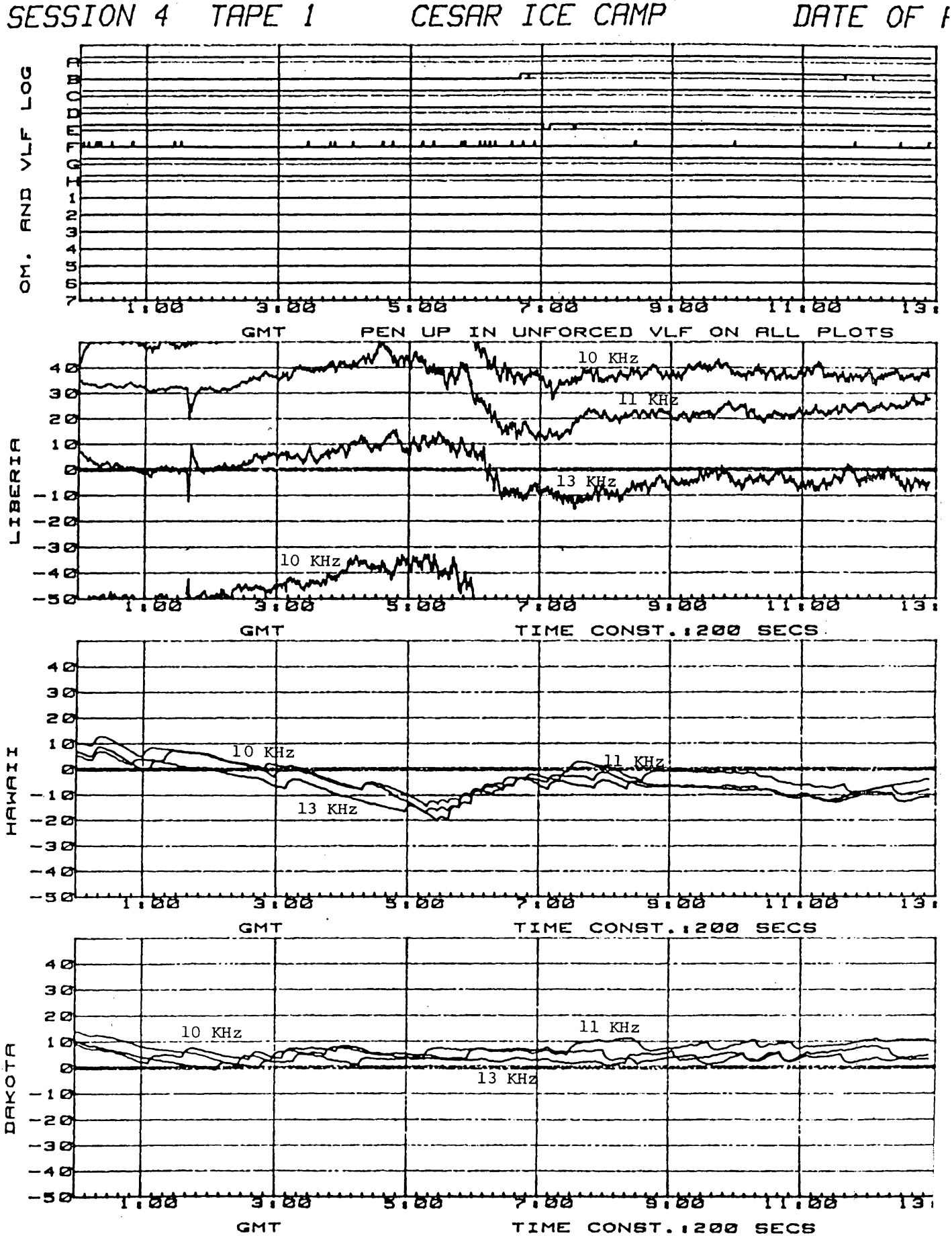


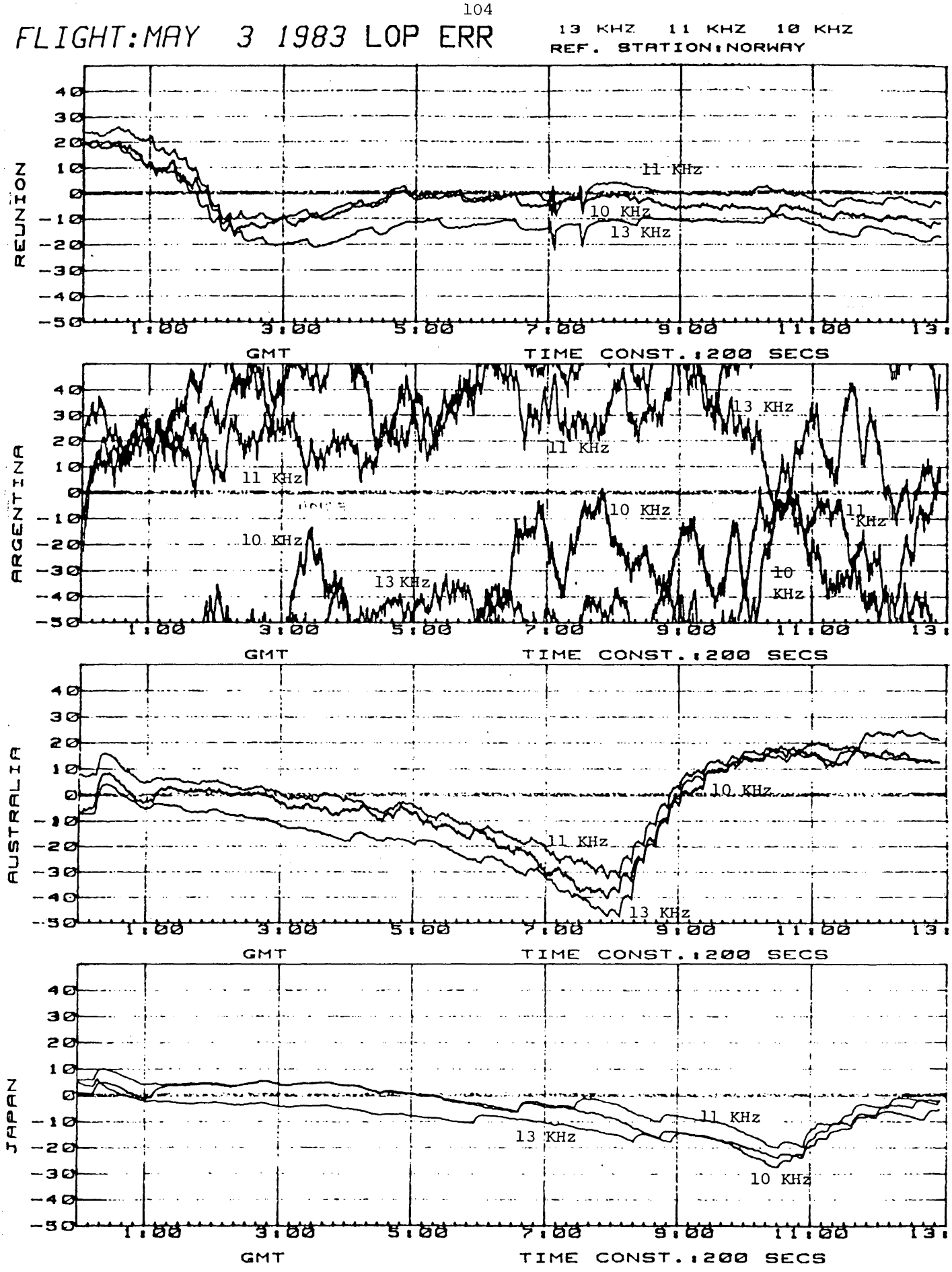
SESSION 4 TAPE 1 CESAR ICE CAMP DATE OF



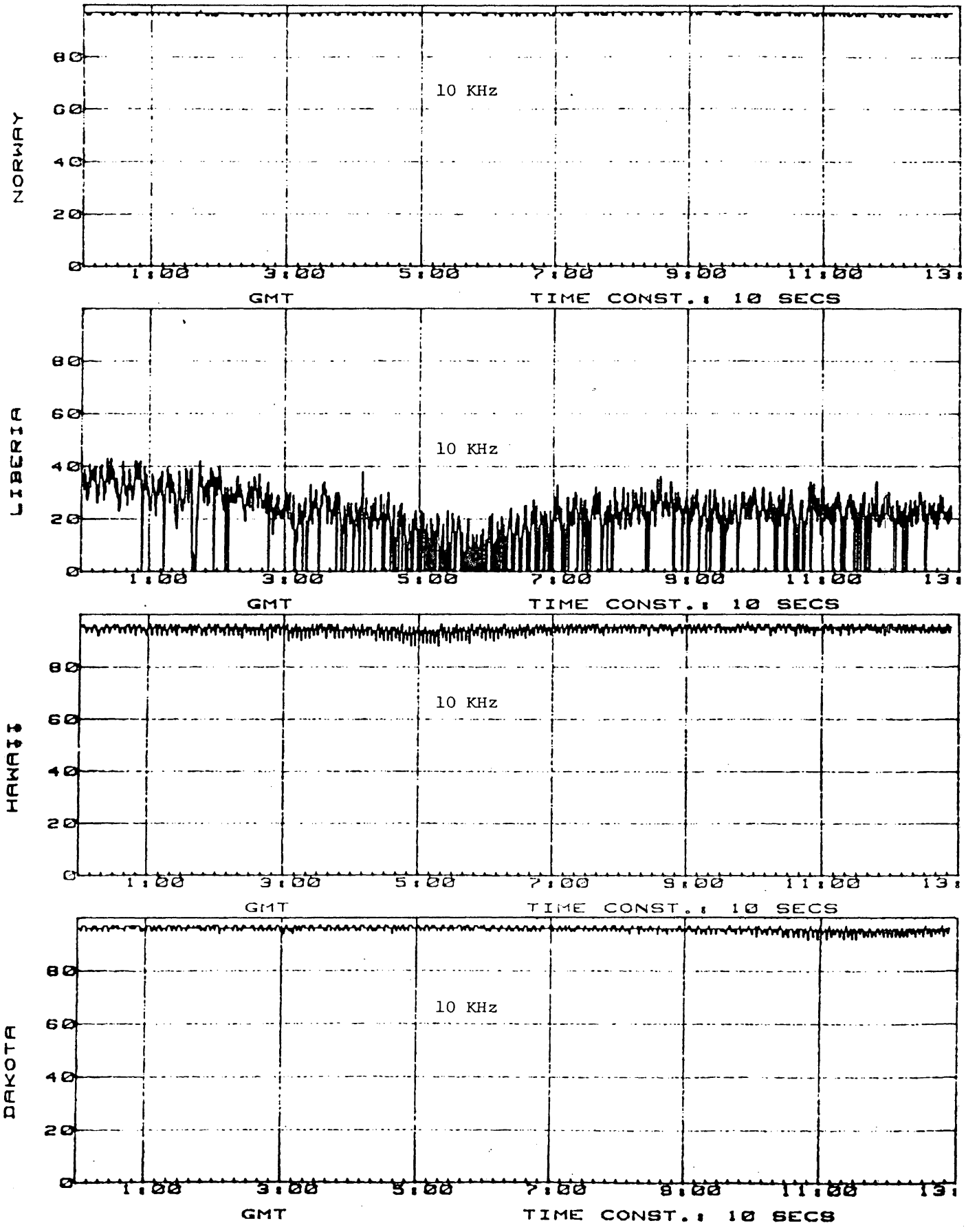
'F FLIGHT:MAY 3 1983 SNR INDEX 13 KHZ 11 KHZ 10 KHZ
VLF STATUS: UNFORCED

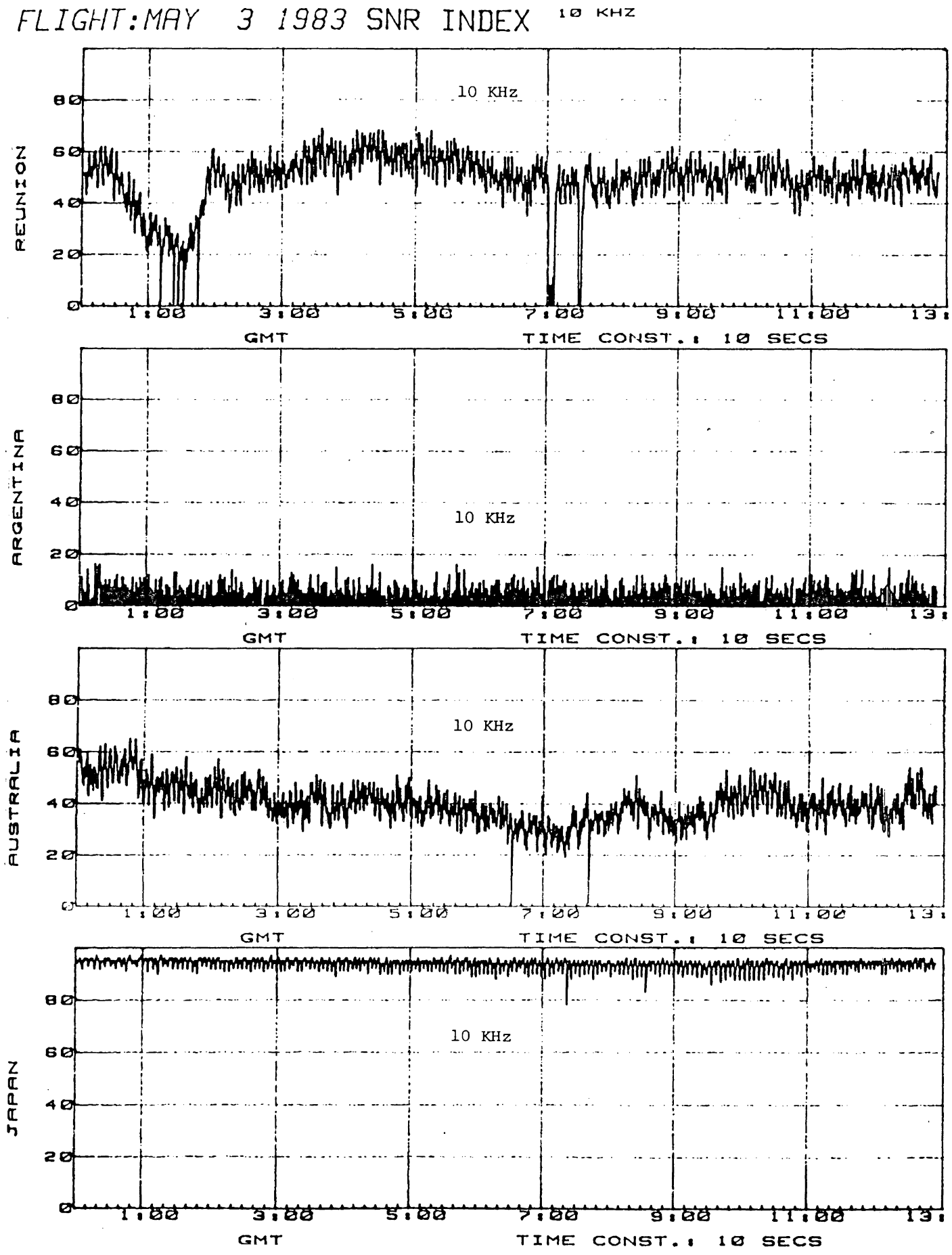



SESSION 4 TAPE 1 CESAR ICE CAMP DATE OF
OM. AND VLF LOG
A
B
C
D
E
F
G
H
1
2
3
4
5
6
7
1:00
3:00
5:00
7:00
9:00
11:00
GMT
PEN UP IN UNFORCED VLF ON ALL PLOTS
LIBERIA
10 KHz
11 KHz
13 KHz
10 KHz
40
30
20
10
0
-10
-20
-30
-40
-50
GMT
TIME CONST.:200 SECS
HAWAII
10 KHz
11 KHz
13 KHz
GMT
TIME CONST.:200 SECS
DAKOTA
10 KHz
11 KHz
13 KHz
GMT
TIME CONST.:200 SECS

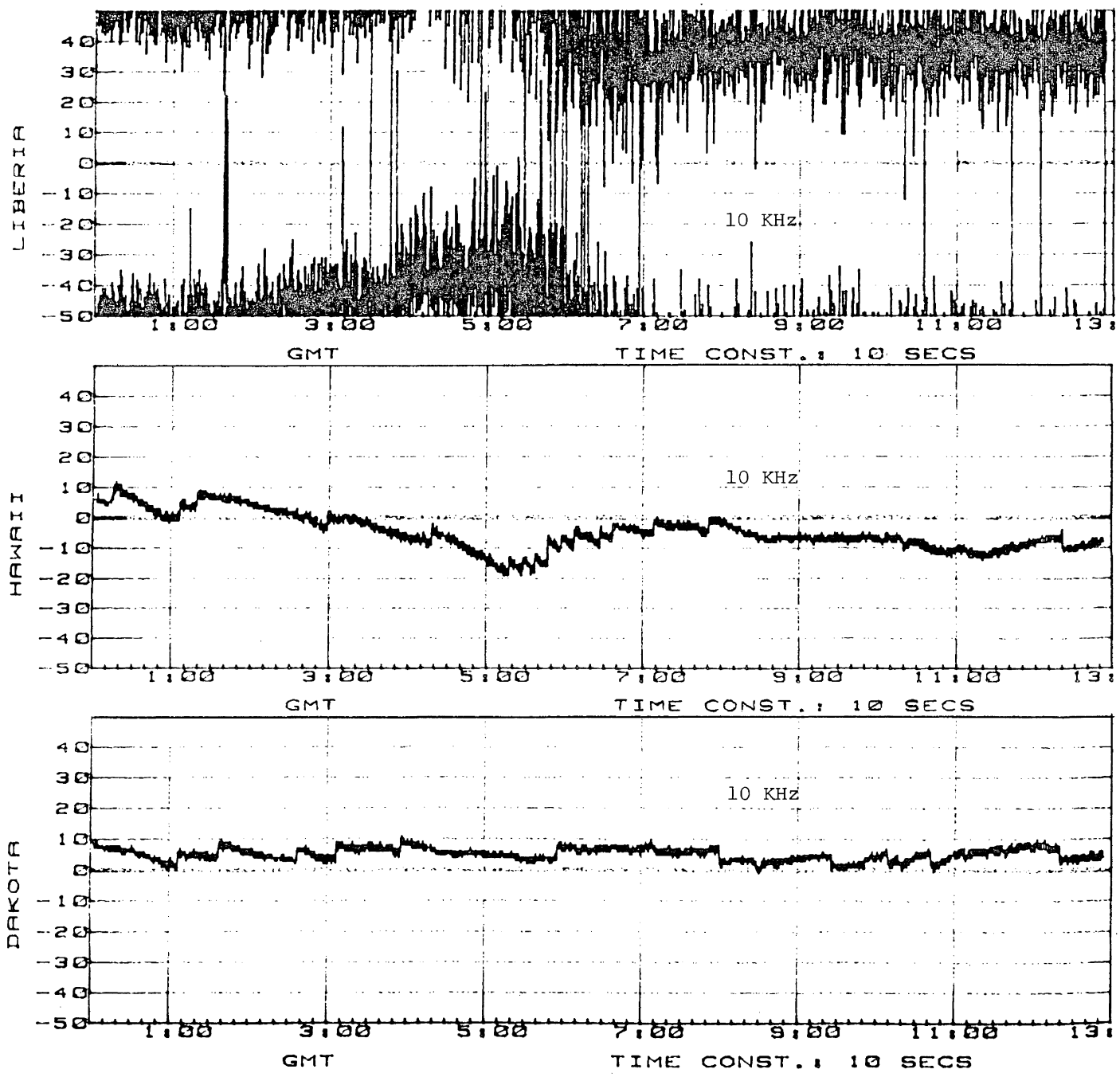

FLIGHT:MAY 3 1983 LOP ERR
13 KHZ 11 KHZ 10 KHZ
REF. STATION:NORWAY
REUNION
11 KHz
10 KHz
13 KHz
GMT
TIME CONST.:200 SECS
ARGENTINA
13 KHz
11 KHz
11 KHz
10 KHz
10 KHz
11 KHz
13 KHz
10 KHz
GMT
TIME CONST.:200 SECS
AUSTRALIA
10 KHz
11 KHz
13 KHz
GMT
TIME CONST.:200 SECS
JAPAN
11 KHz
13 KHz
10 KHz
GMT
TIME CONST.:200 SECS

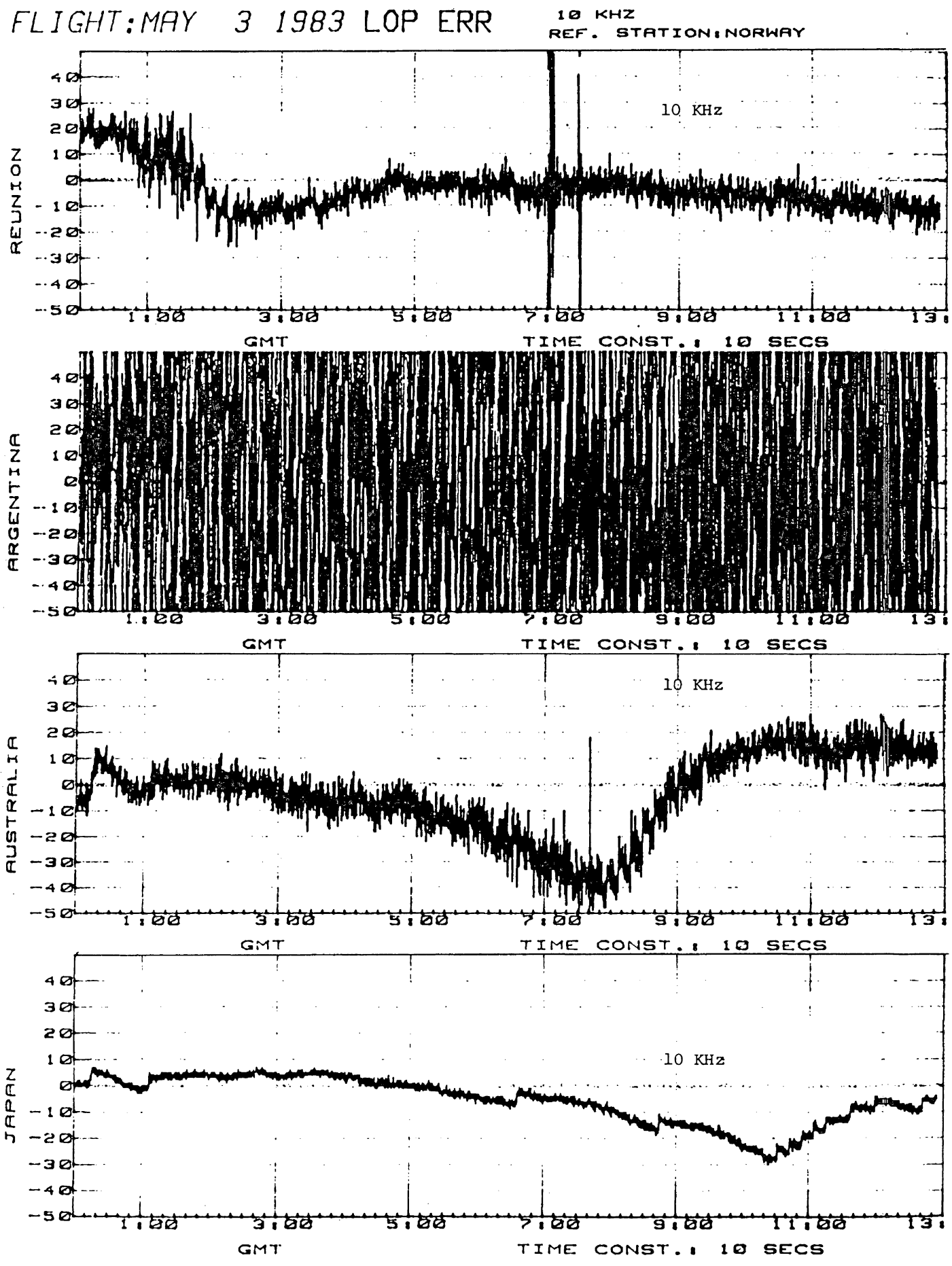
SESSION 4 TAPE 1 CESAR ICE CAMP DATE OF



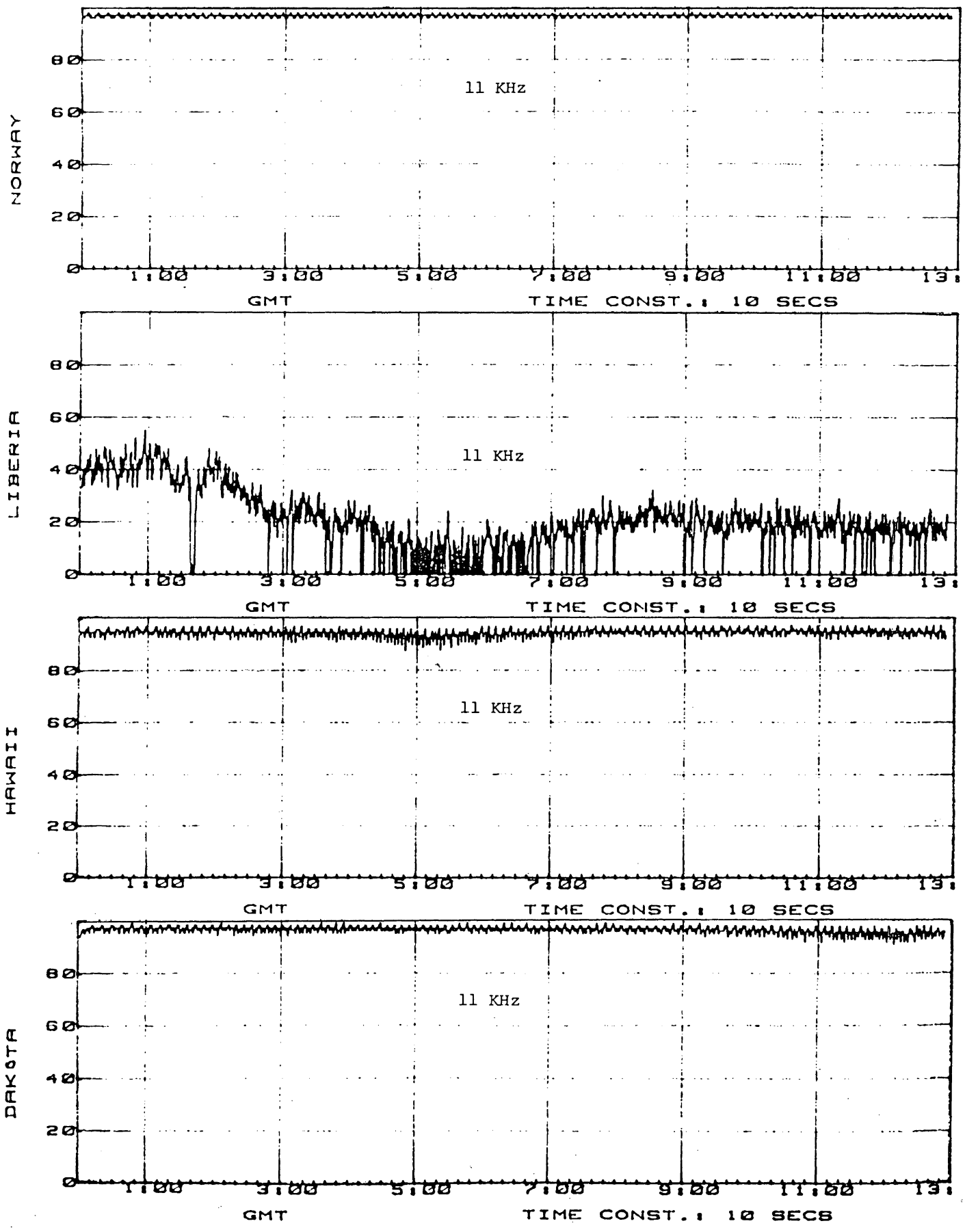

FLIGHT:MAY 3 1983 SNR INDEX 10 KHZ
REUNION
10 KHz
0
20
40
60
80
1:00
3:00
5:00
7:00
9:00
11:00
13:
GMT
TIME CONST.: 10 SECS
ARGENTINA
10 KHz
GMT
TIME CONST.: 10 SECS
AUSTRALIA
10 KHz
GMT
TIME CONST.: 10 SECS
JAPAN
10 KHz
GMT
TIME CONST.: 10 SECS

SESSION 4 TAPE 1 CESAR ICE CAMP DATE OF

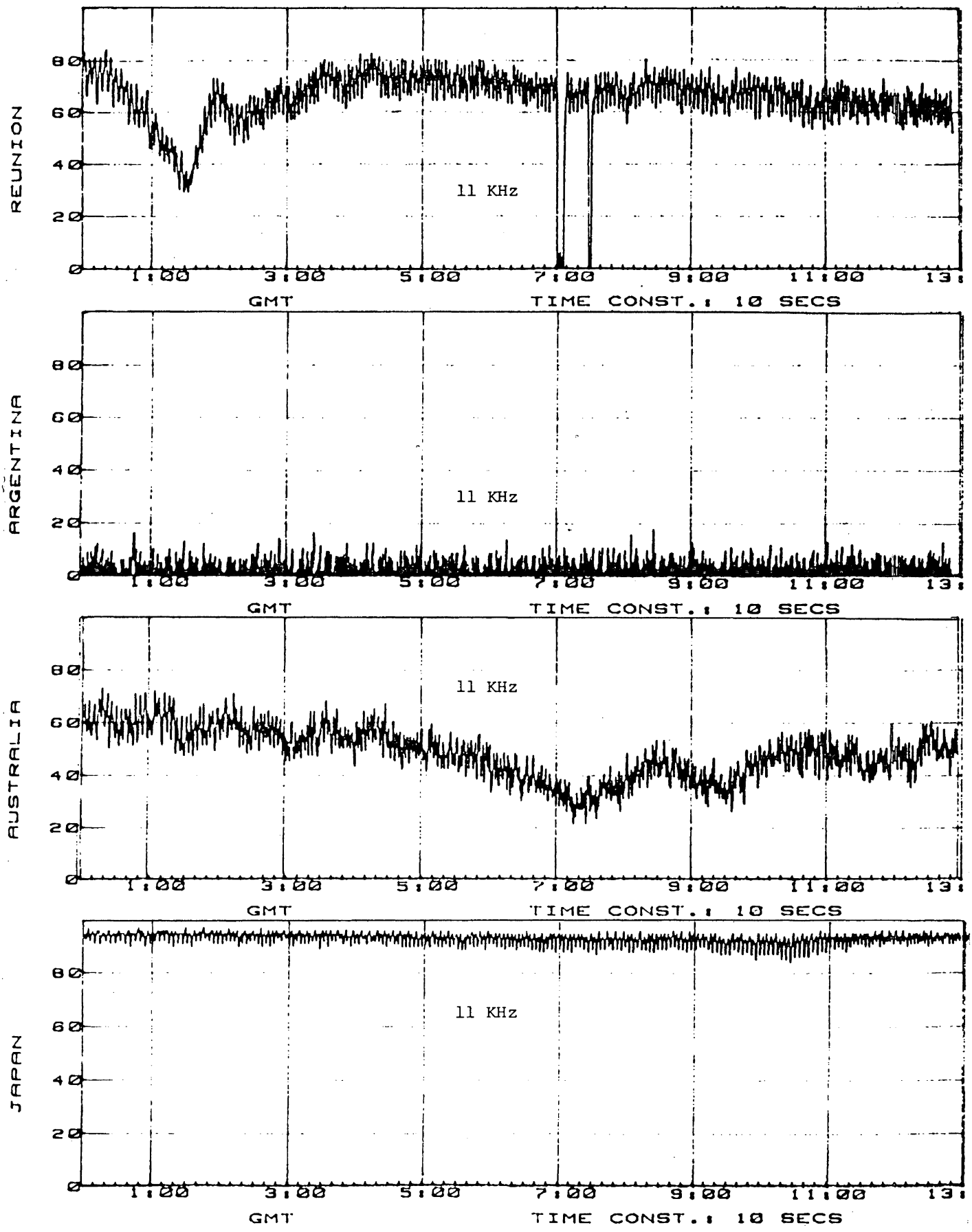



F FLIGHT:MAY 3 1983 LOP ERR
10 KHZ
REF. STATION:NORWAY
REUNION
10 KHz
GMT
TIME CONST.: 10 SECS
ARGENTINA
GMT
TIME CONST.: 10 SECS
AUSTRALIA
10 KHz
GMT
TIME CONST.: 10 SECS
JAPAN
10 KHz
GMT
TIME CONST.: 10 SECS

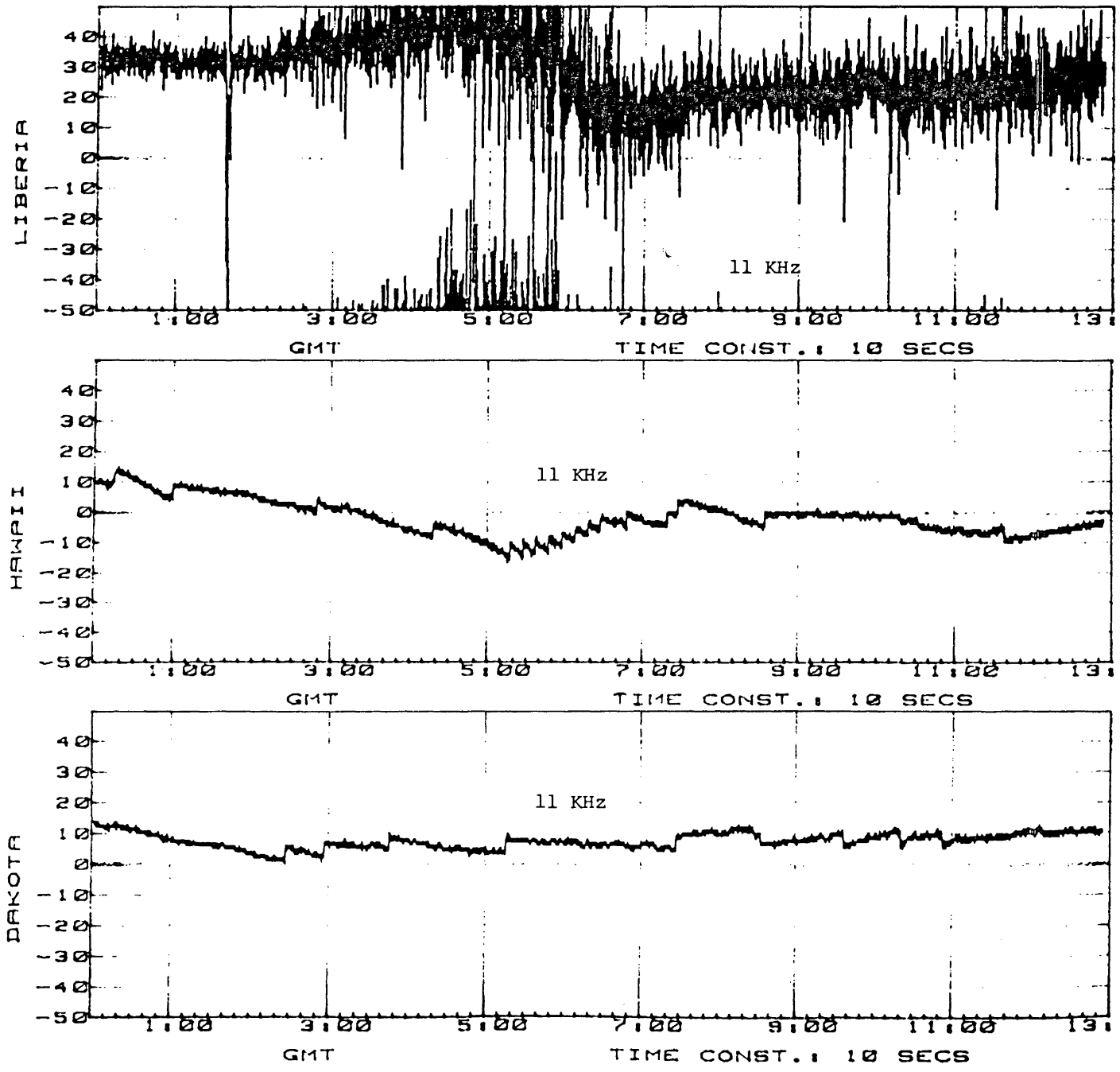
SESSION 4 TAPE 1 CESAR ICE CAMP DATE OF



)F FLIGHT:MAY 3 1983 SNR INDEX 11 KHZ

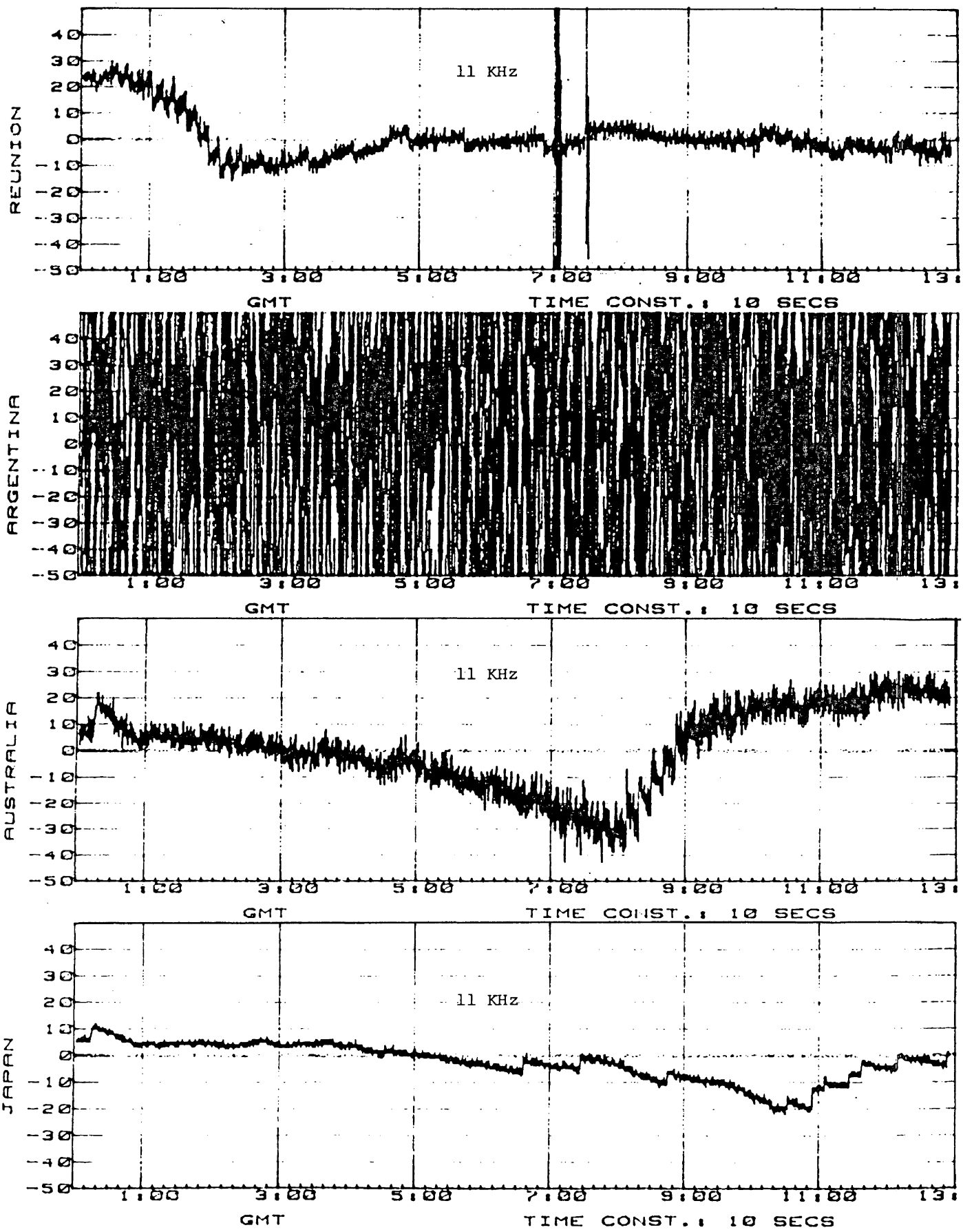


SESSION 4 TAPE 1 CESAR ICE CAMP DATE OF

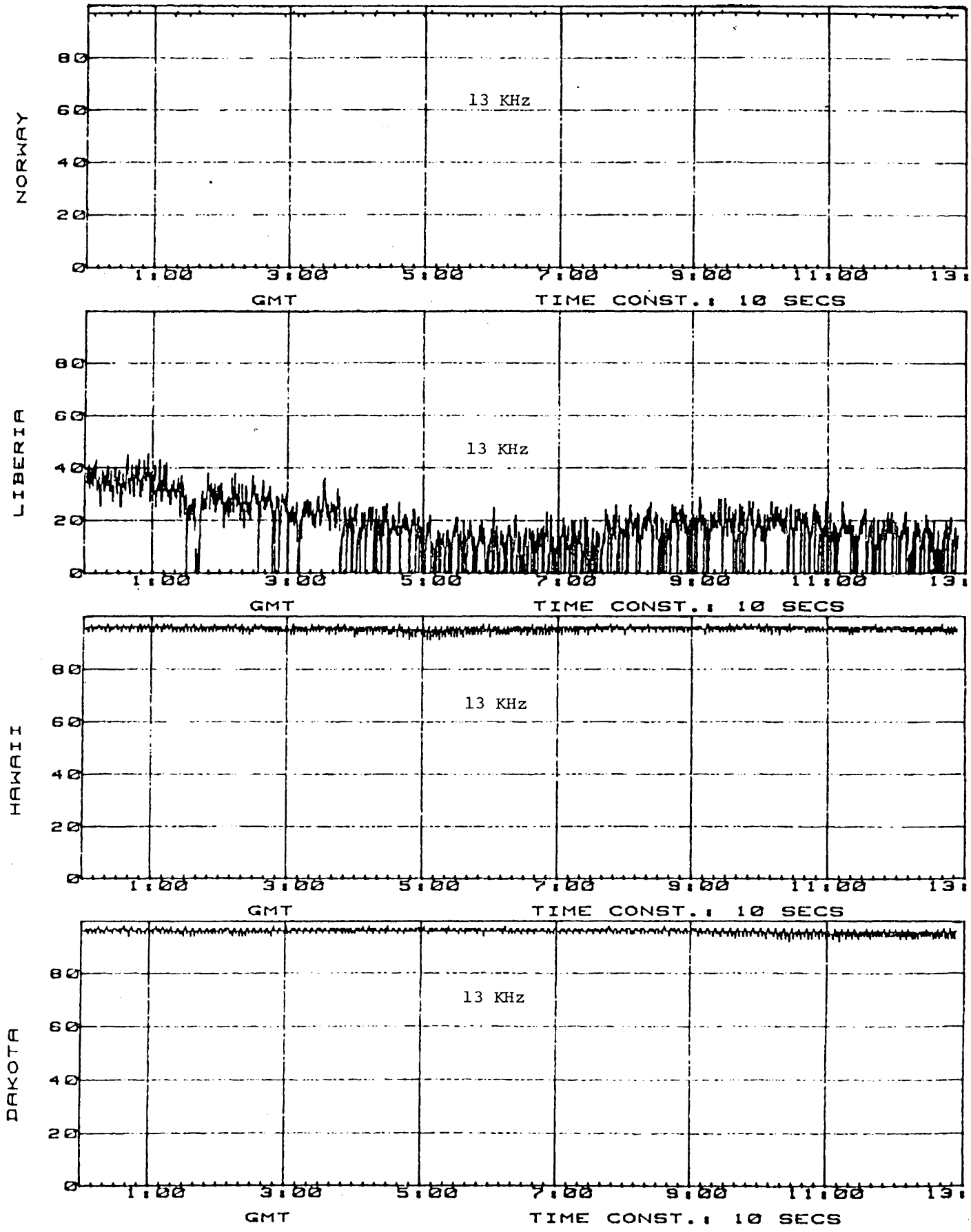


)F FLIGHT: MAY 3 1983 LOP ERR

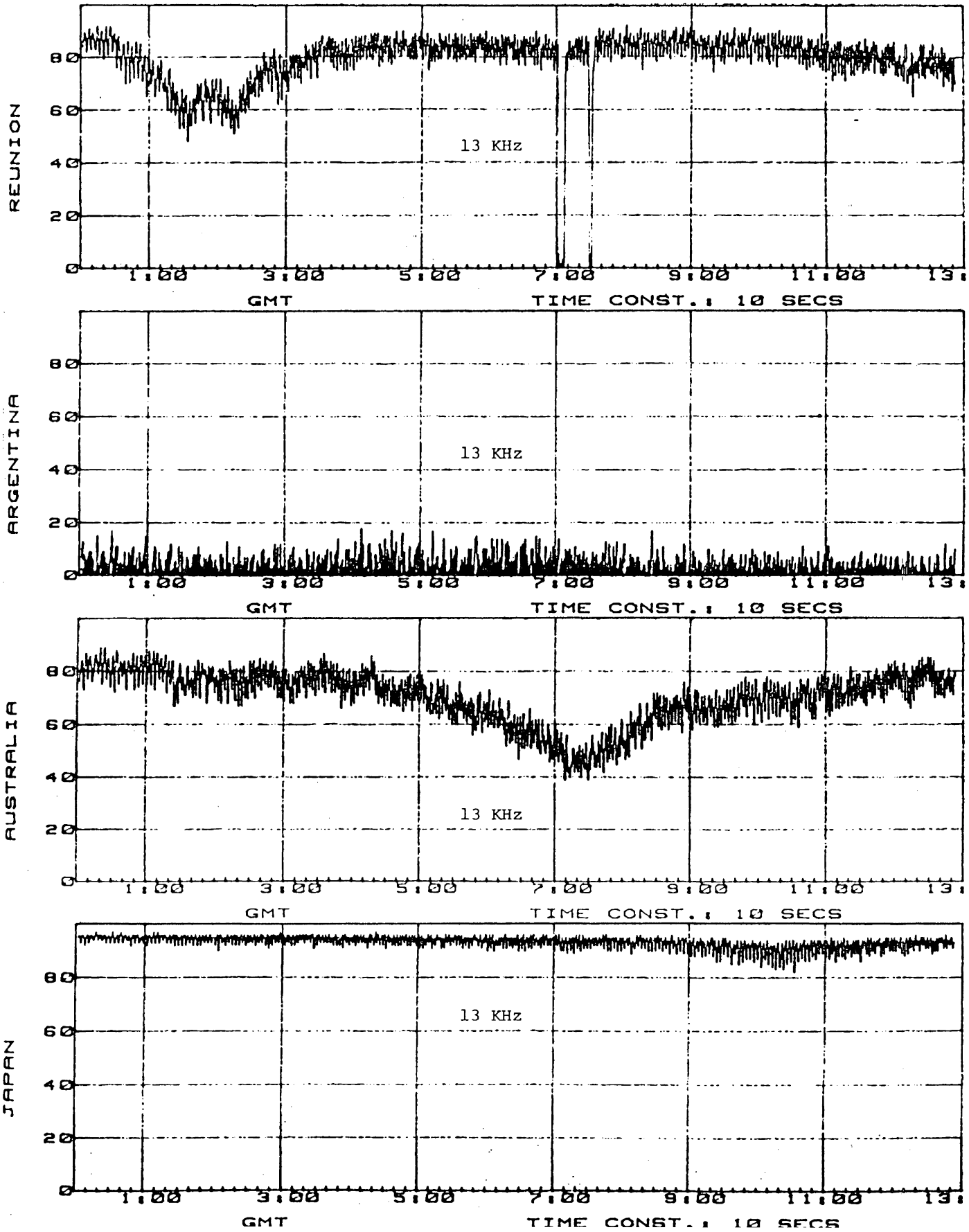
11 KHZ
REF. STATION: NORWAY



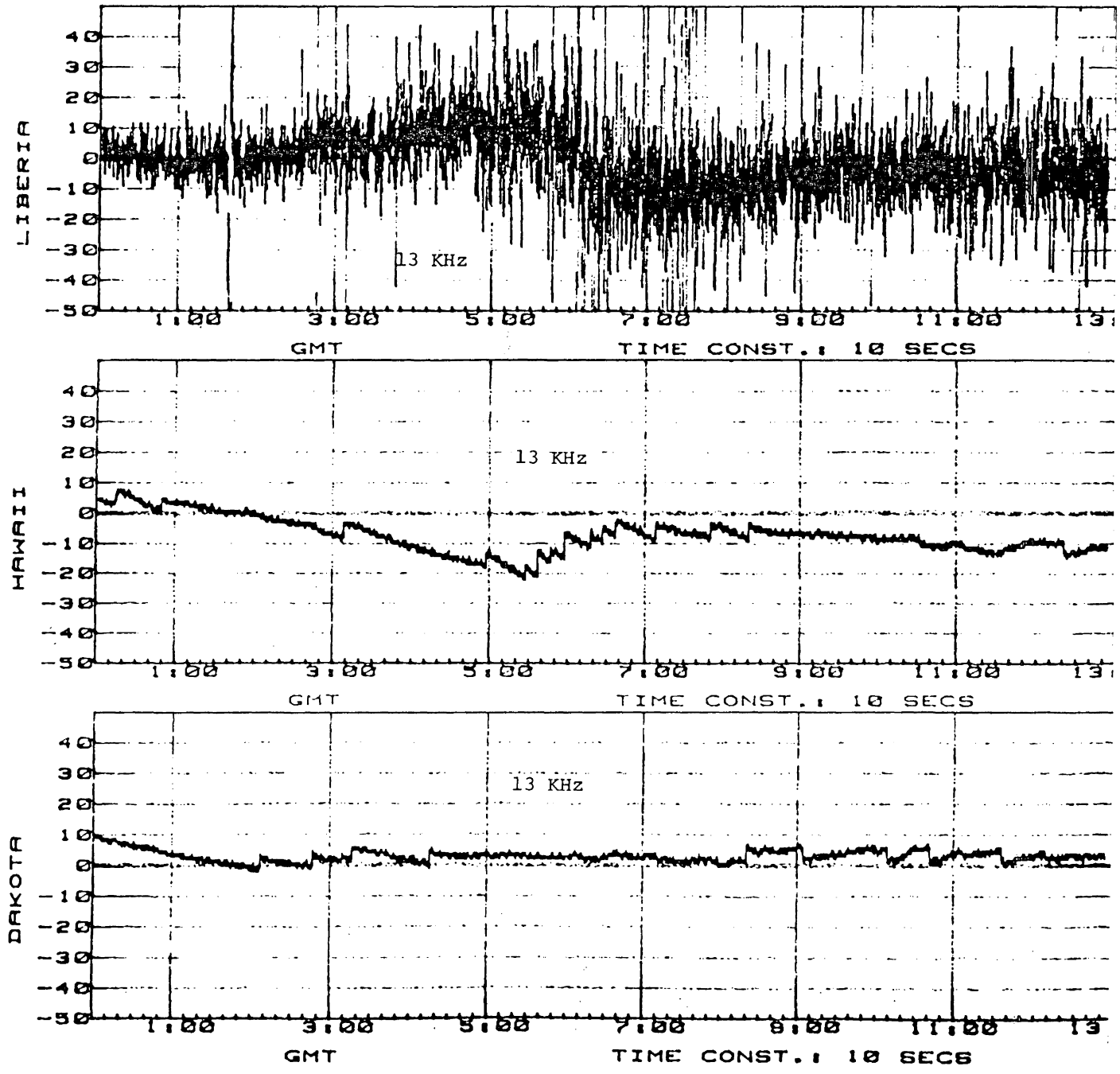
SESSION 4 TAPE 1 CESAR ICE CAMP DATE OF



F FLIGHT: MAY 3 1983 SNR INDEX 13 KHZ

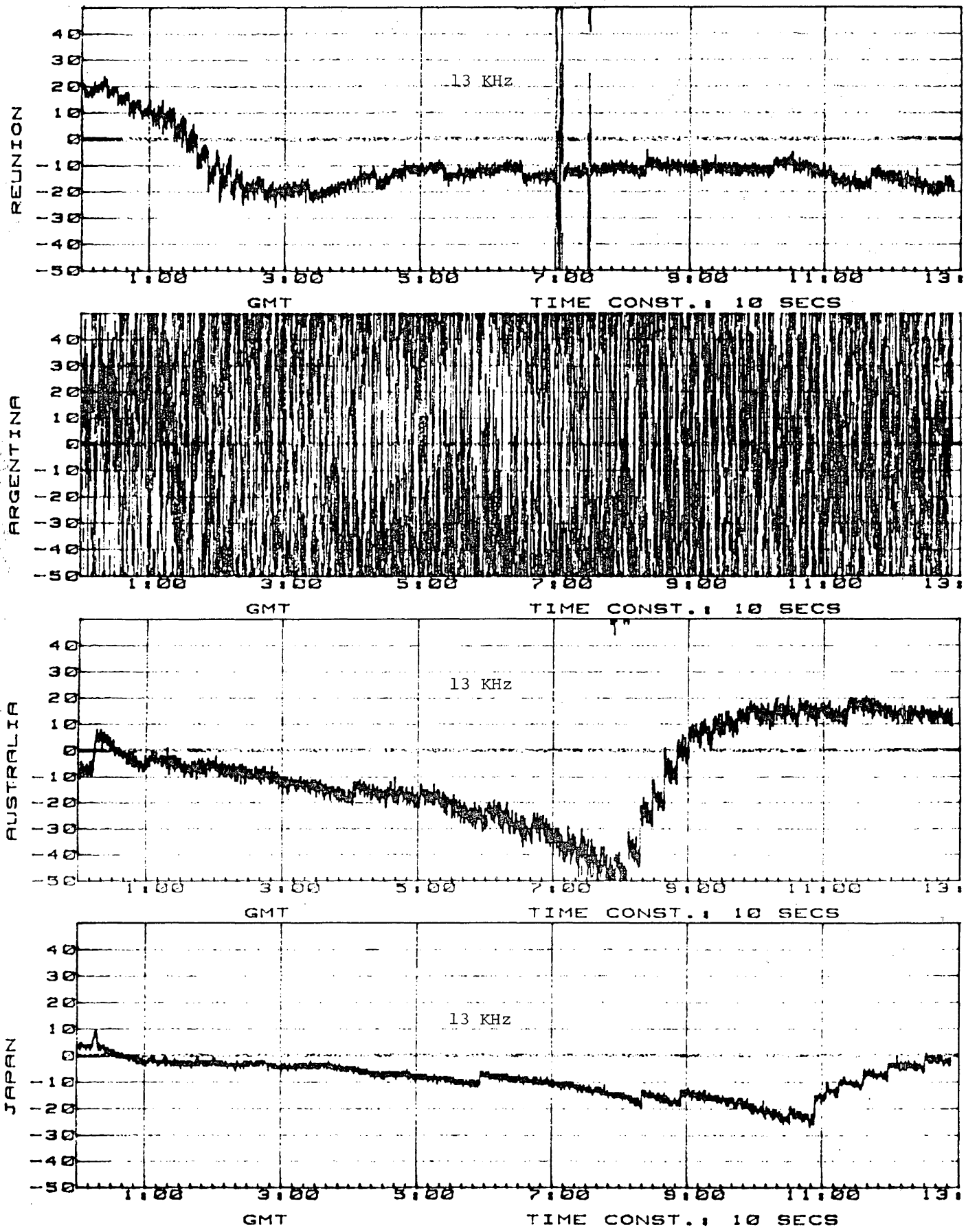


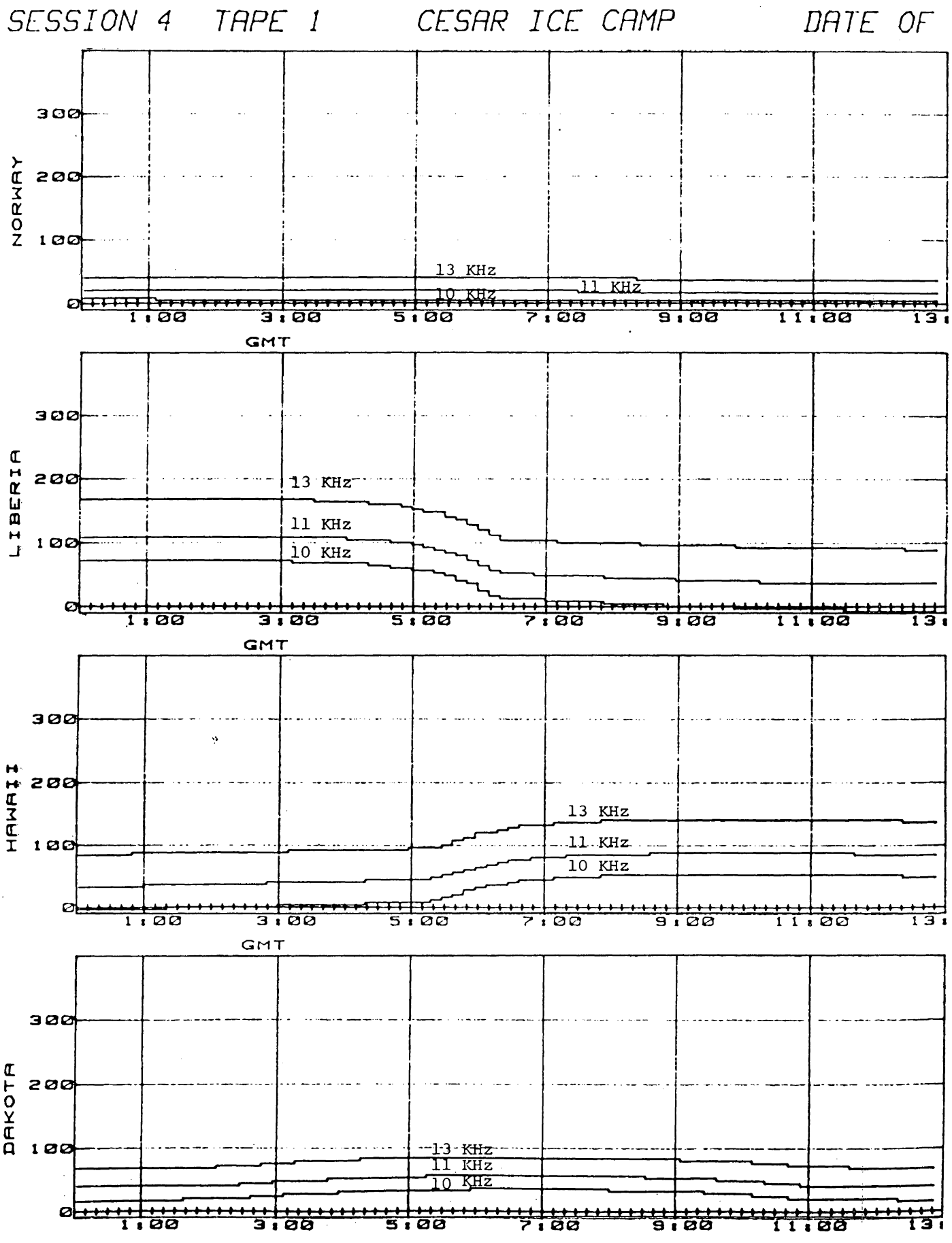
SESSION 4 TAPE 1 CESAR ICE CAMP DATE OF



OF FLIGHT:MAY 3 1983 LOP ERR

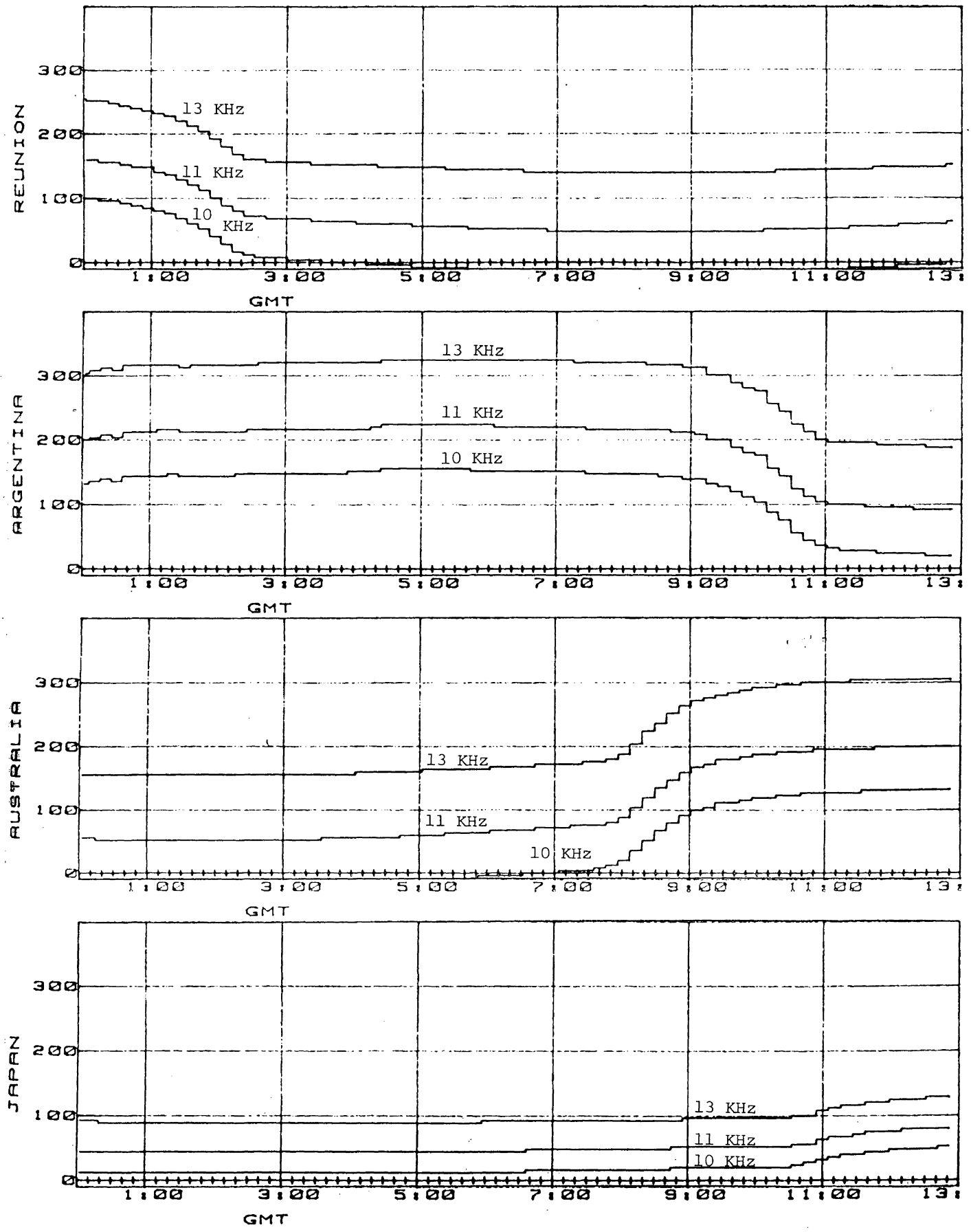
13 KHZ
REF. STATION:NORWAY



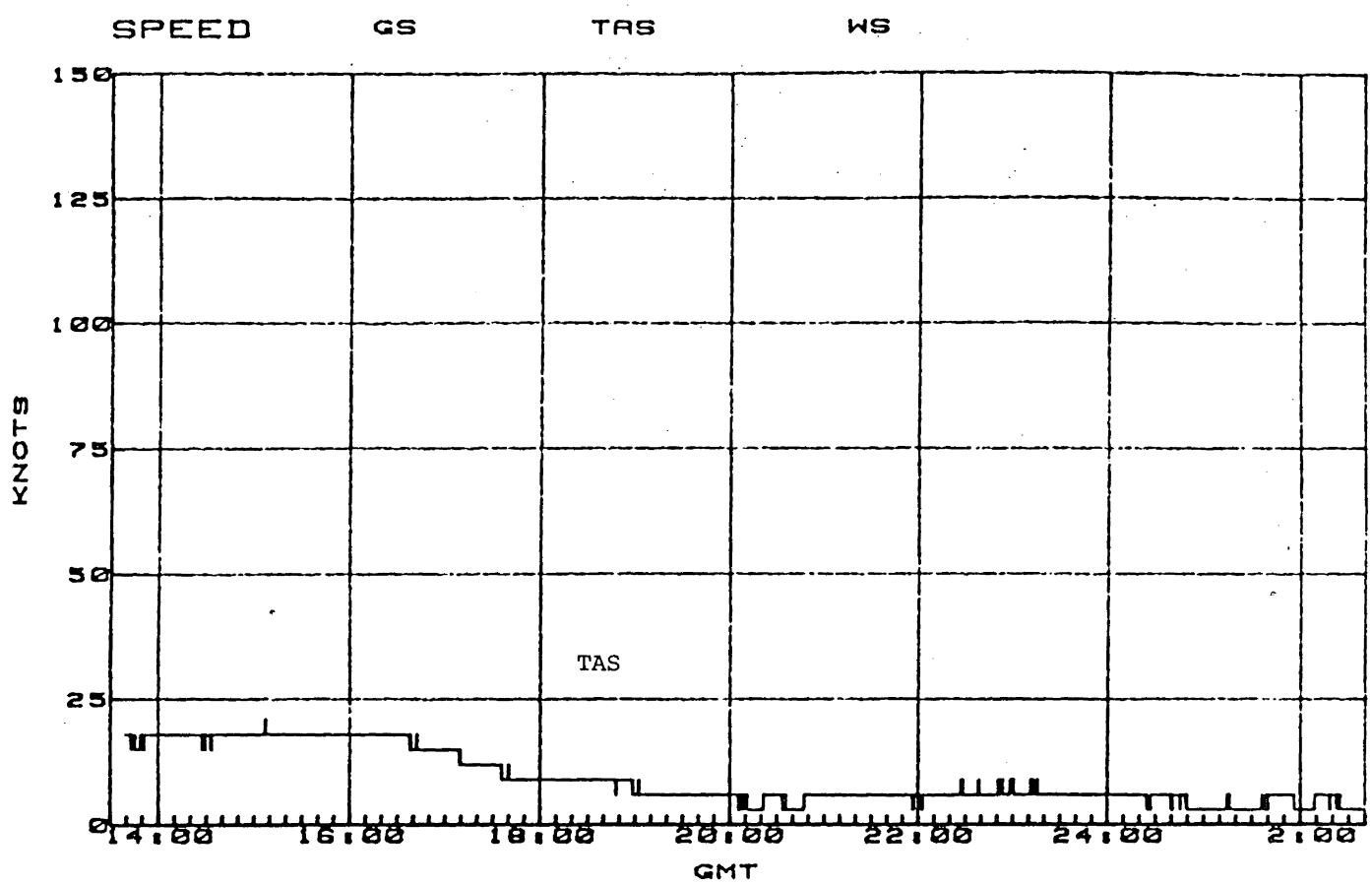

SESSION 4 TAPE 1 CESAR ICE CAMP DATE OF
NORWAY
300
200
100
0
13 KHz
10 KHz
11 KHz
1:00
3:00
5:00
7:00
9:00
11:00
GMT
LIBERIA
13 KHz
11 KHz
10 KHz
HAWAII
13 KHz
11 KHz
10 KHz
DAKOTA
13 KHz
11 KHz
10 KHz

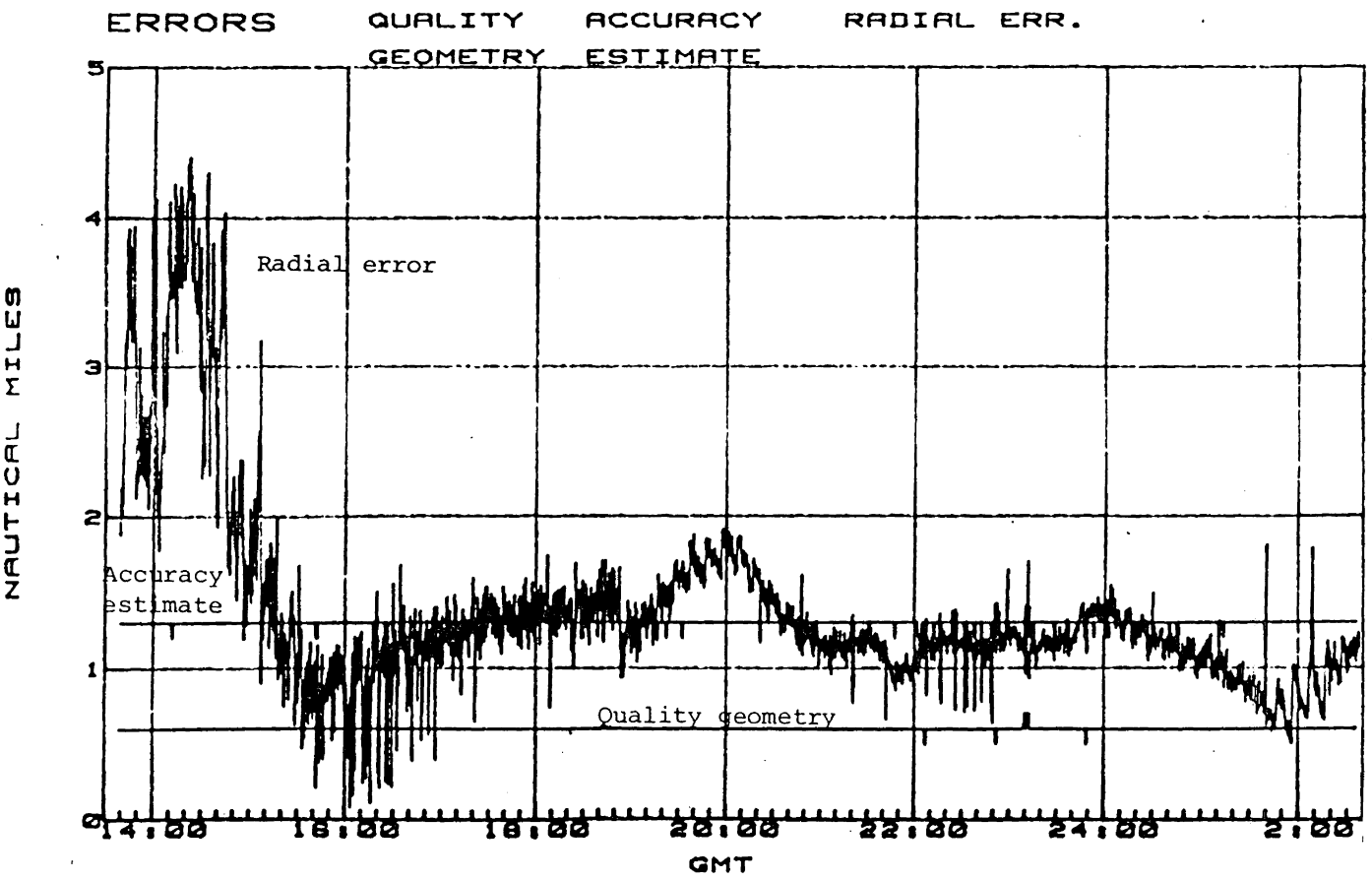
OF FLIGHT: MAY 3 1983 DIURNALS

13 KHZ 11 KHZ 10 KHZ
VLF STATUS: UNFORCED

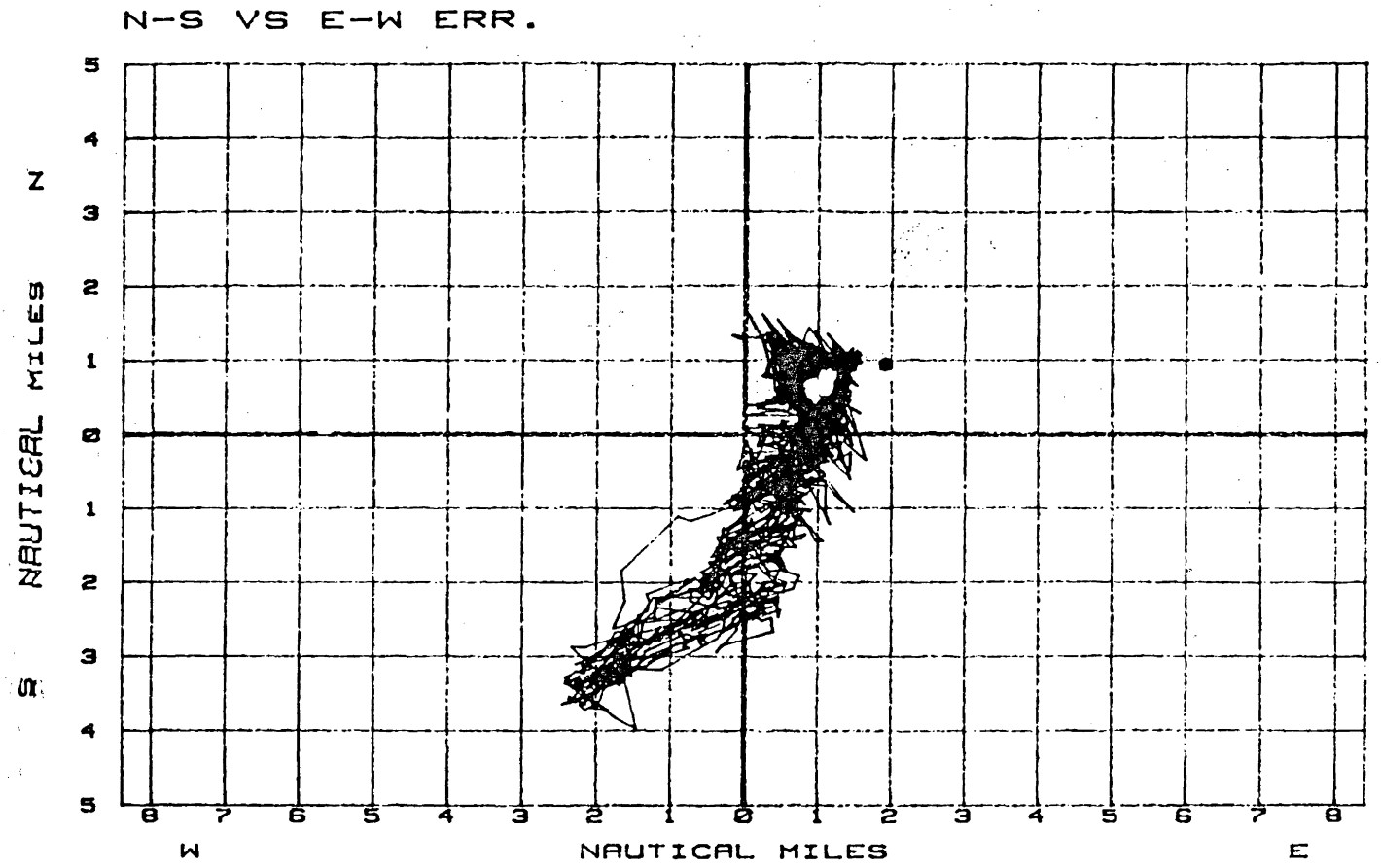


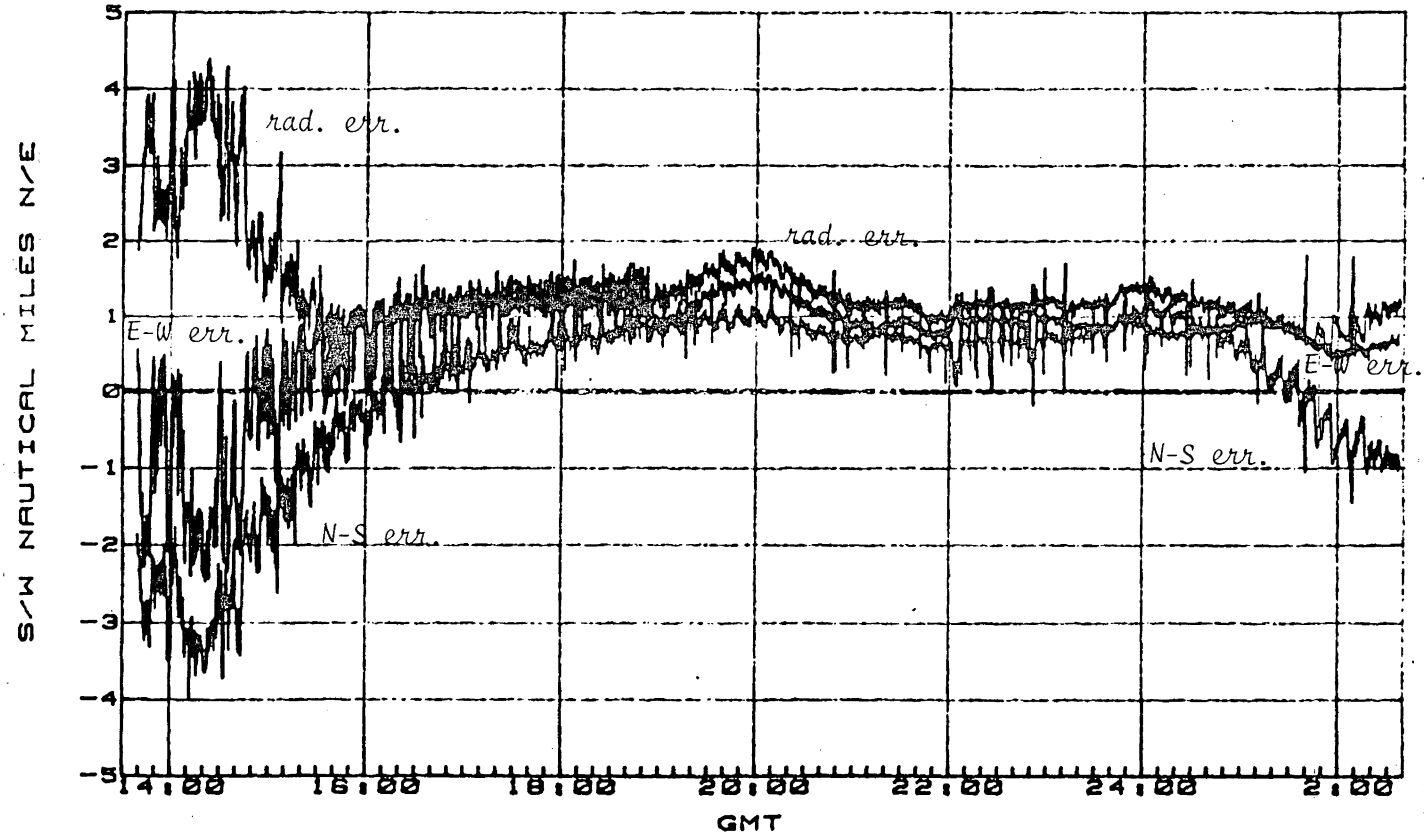
SESSION 4 TAPE 2 CESAR ICE CAMP DATE OF F



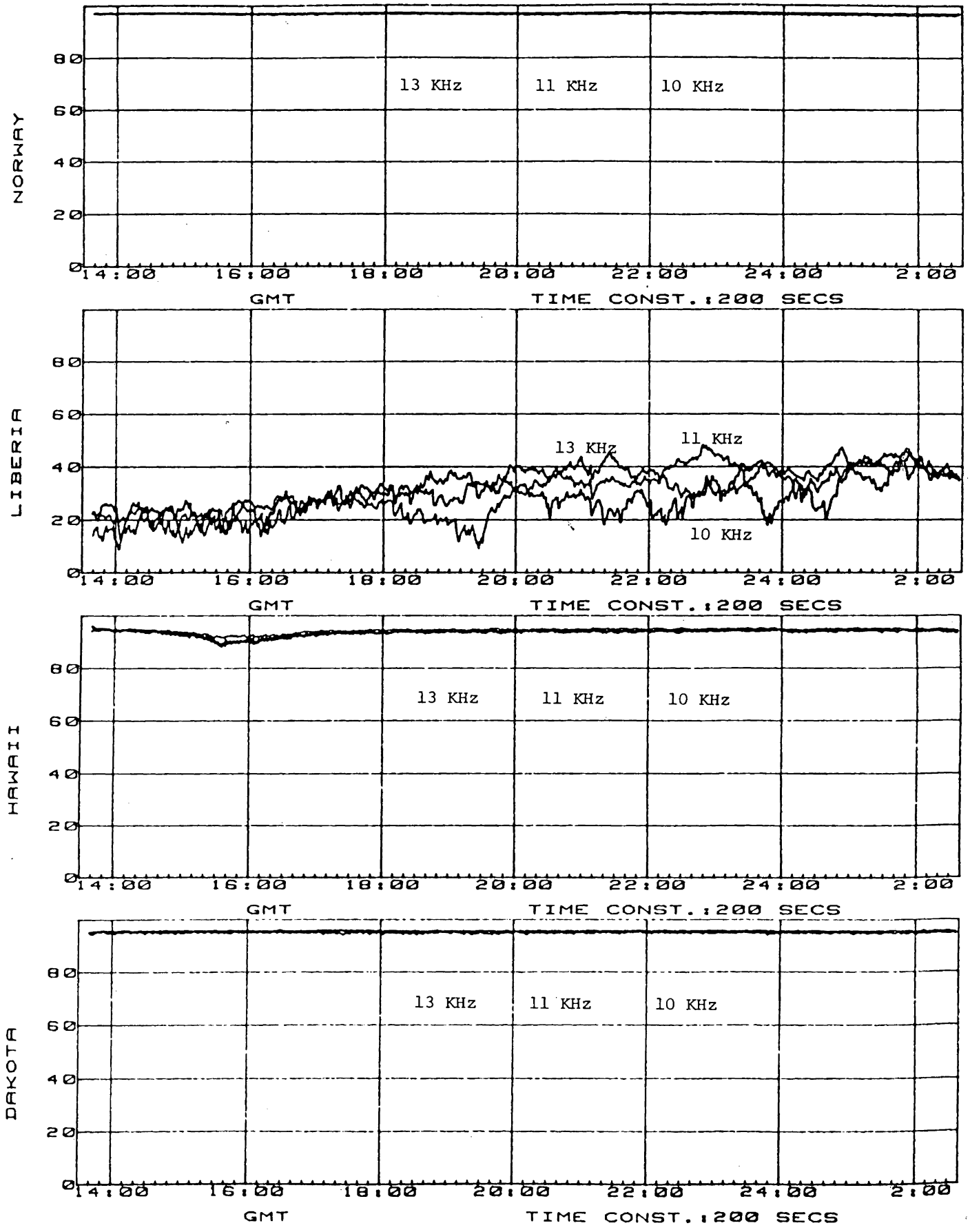


OF IFLIGHT: MAY 3 1983



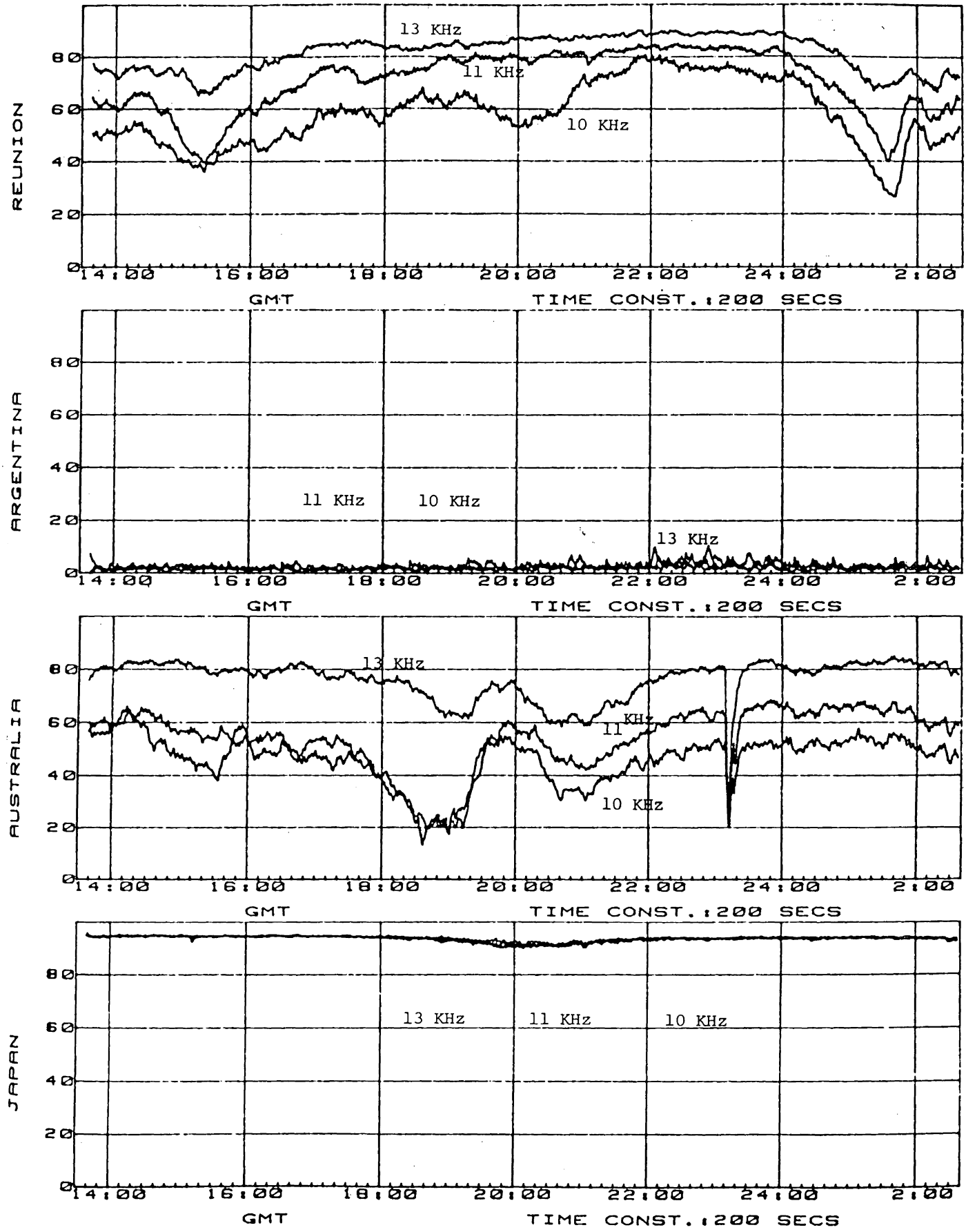


SESSION 4 TAPE 2 CESAR ICE CAMP DATE OF F

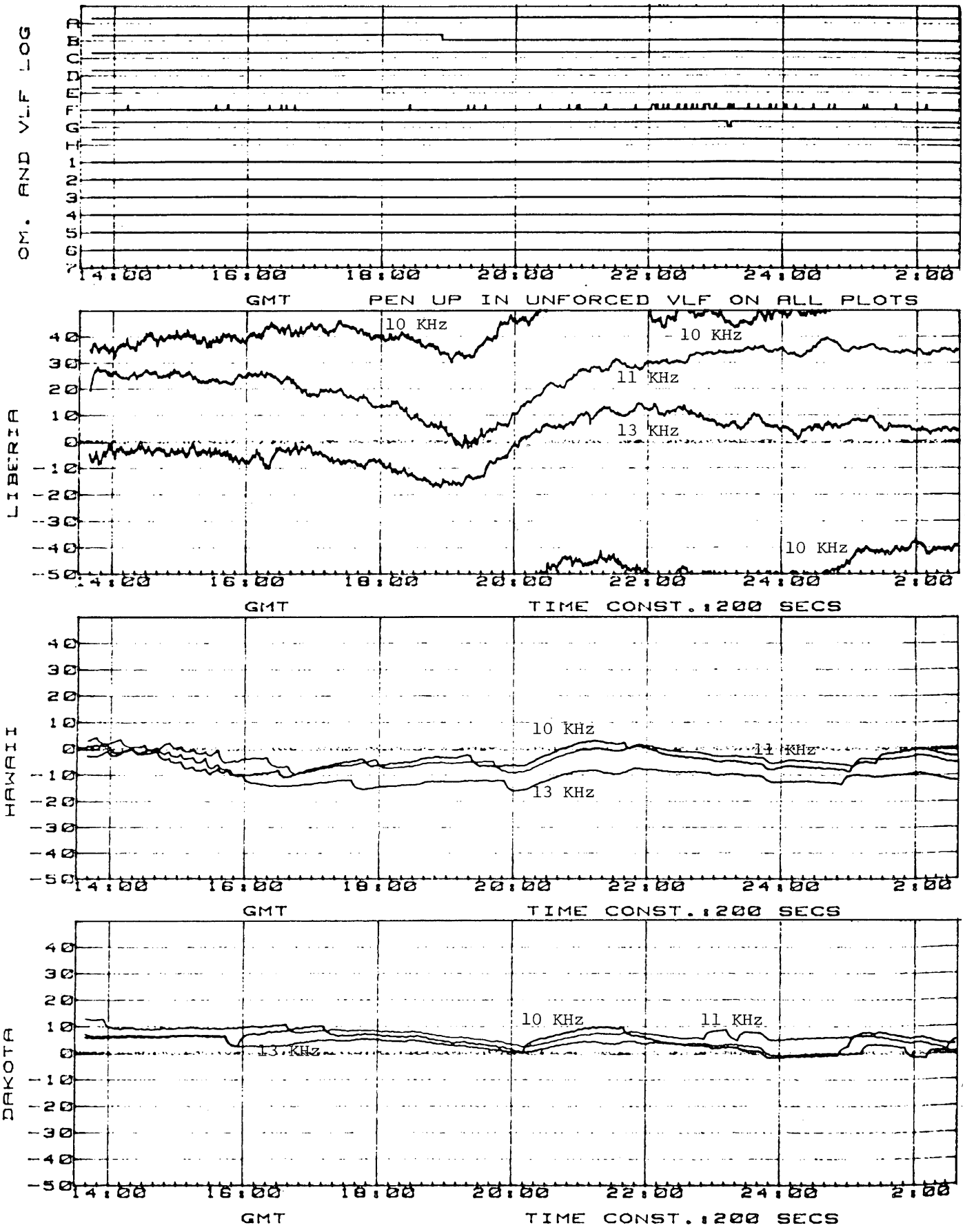


FLIGHT: MAY 3 1983 SNR INDEX

13 KHZ 11 KHZ 10 KHZ
VLF STATUS: UNFORCED

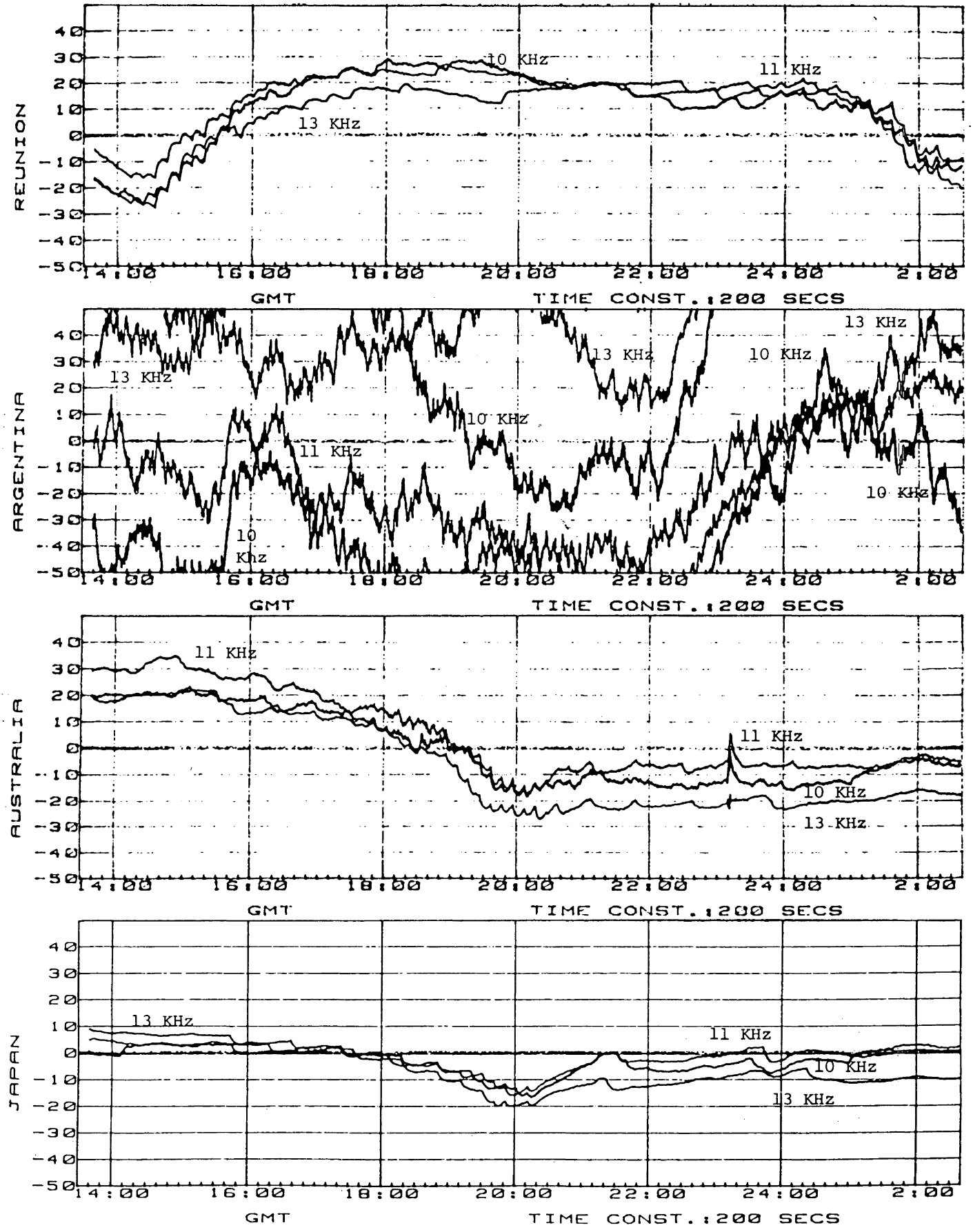


SESSION 4 TAPE 2 CESAR ICE CAMP DATE OF

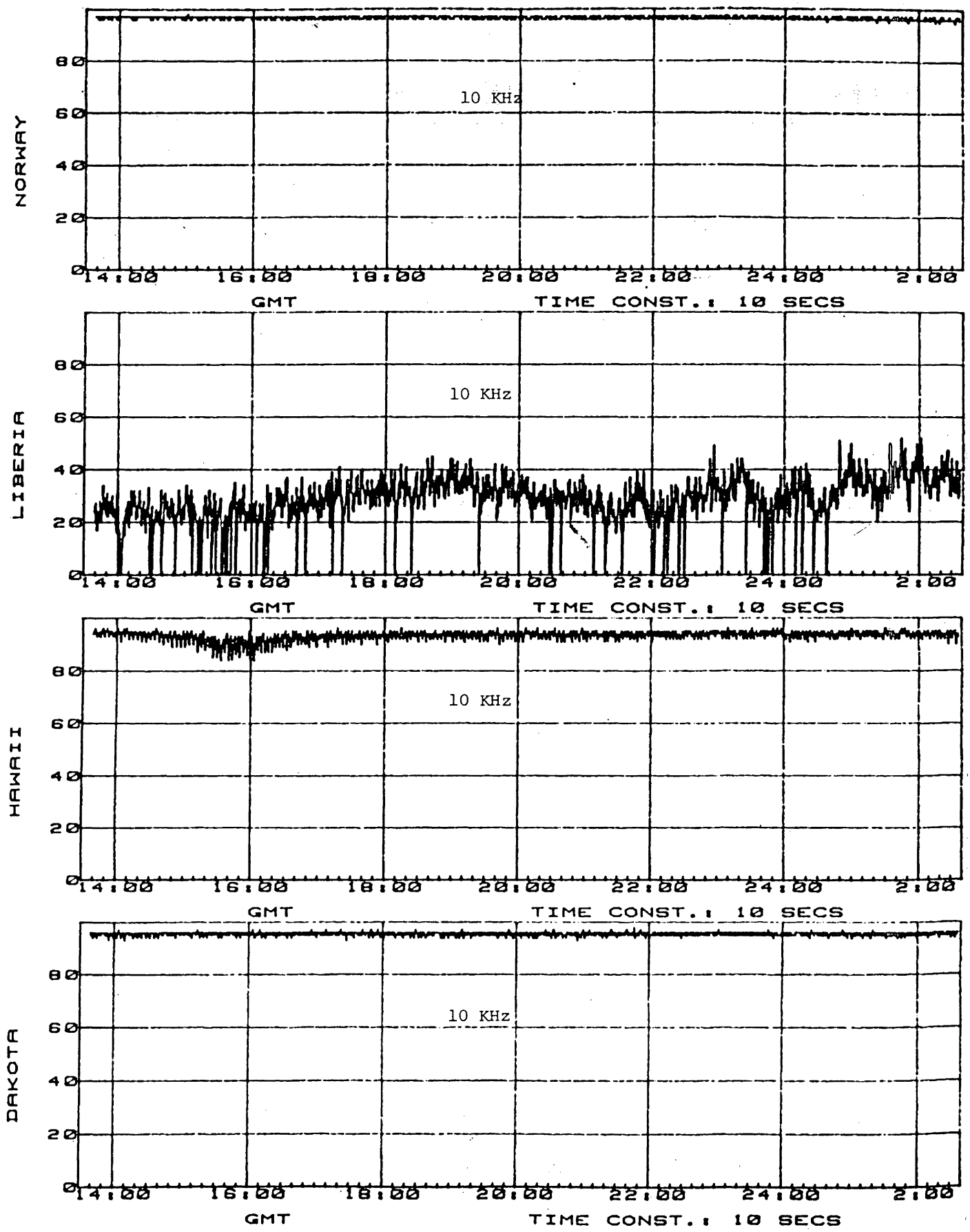


OF FLIGHT: MAY 3 1983 LOP ERR

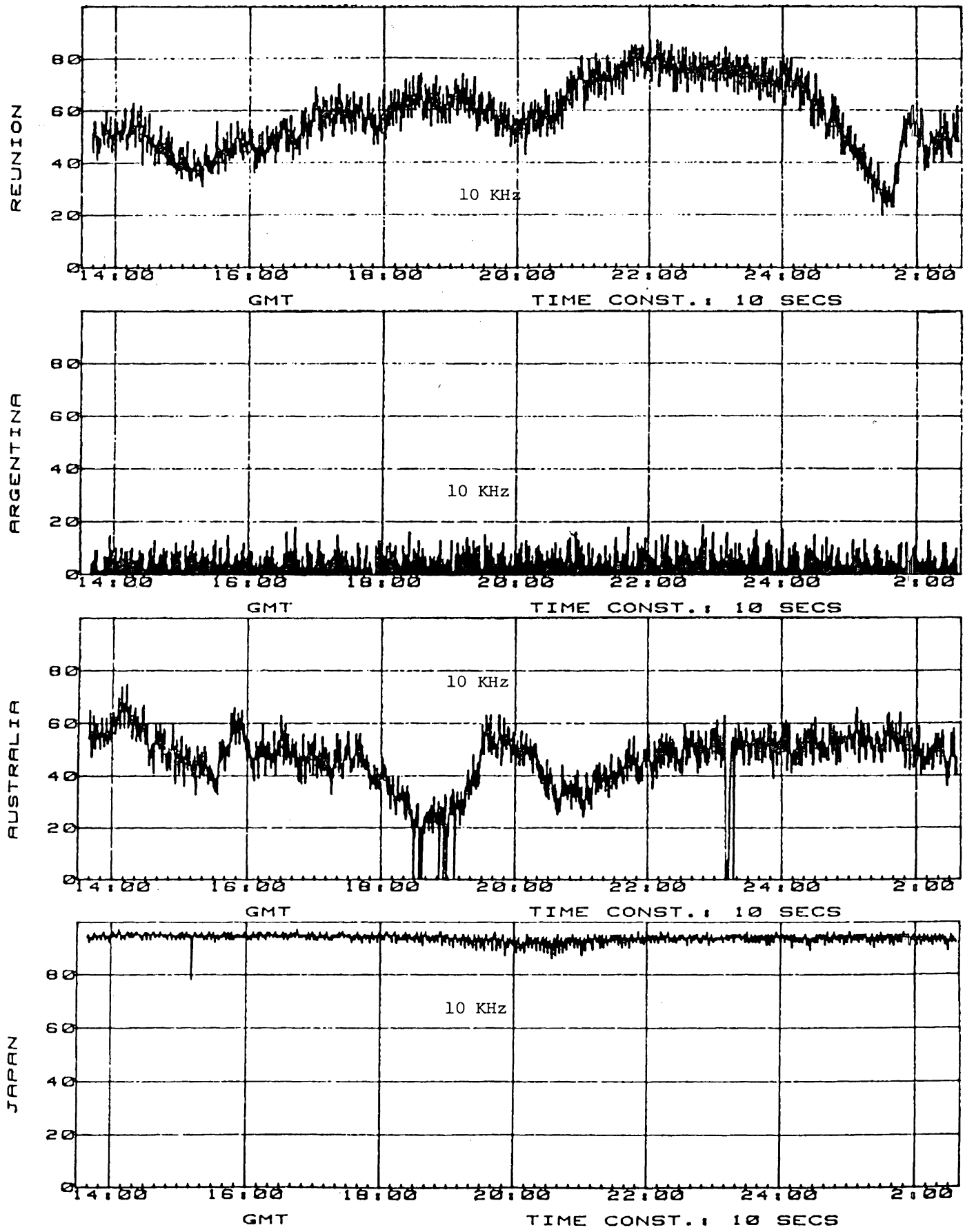
13 KHZ 11 KHZ 10 KHZ
REF. STATION: NORWAY



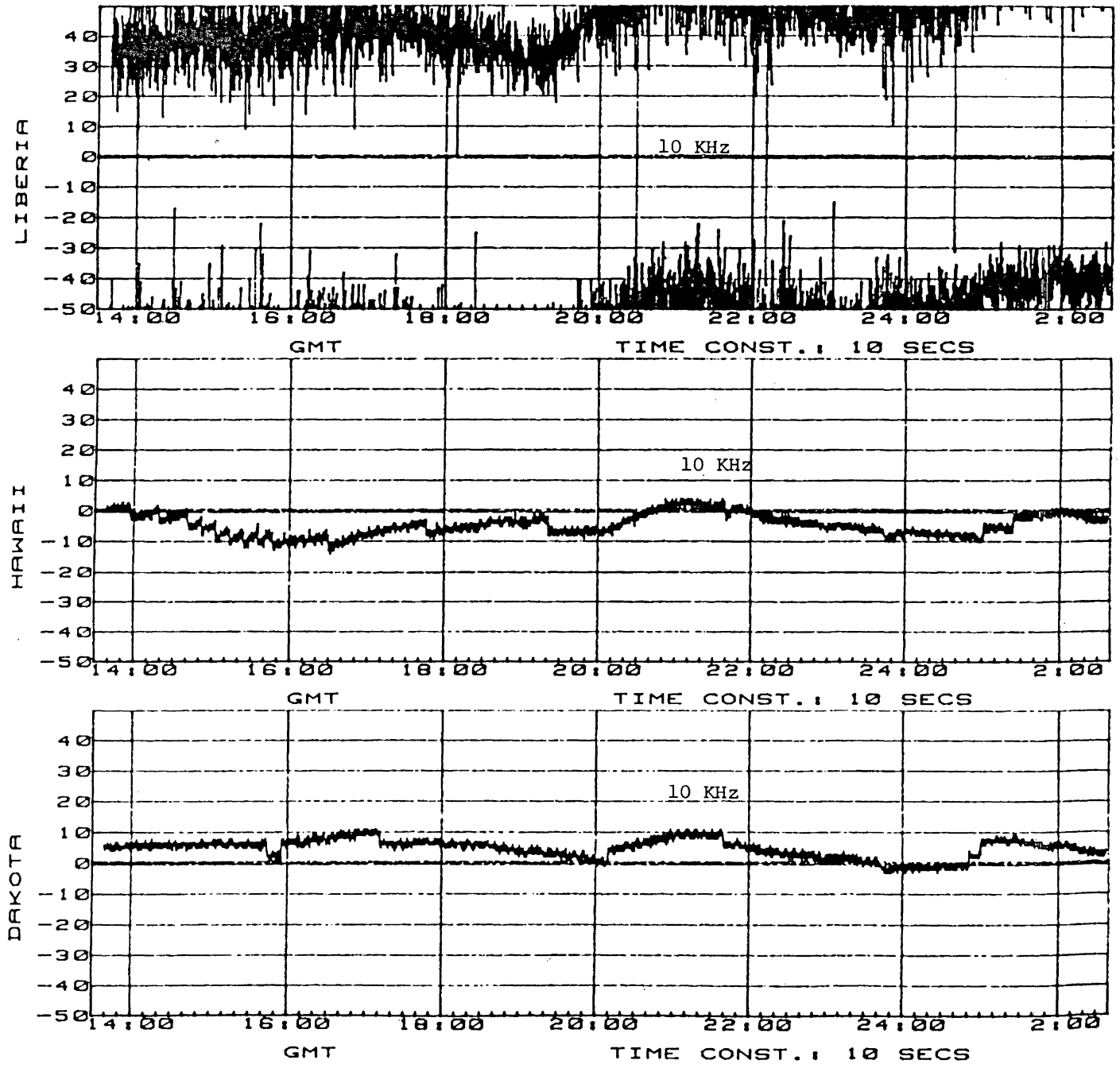
SESSION 4 TAPE 2 CESAR ICE CAMP DATE OF



F FLIGHT:MAY 3 1983 SNR INDEX 10 KHZ

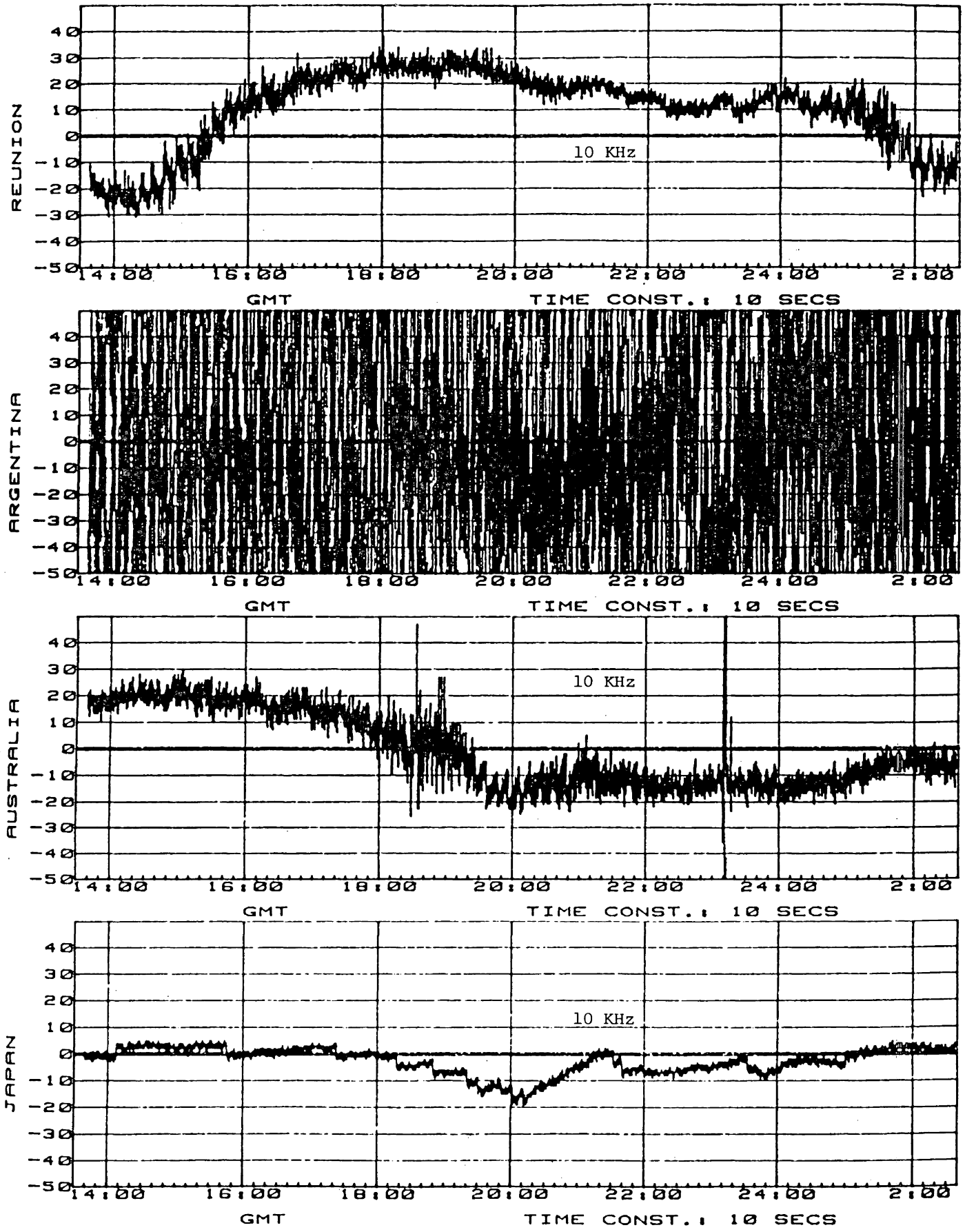


SESSION 4 TAPE 2 CESAR ICE CAMP DATE OF F

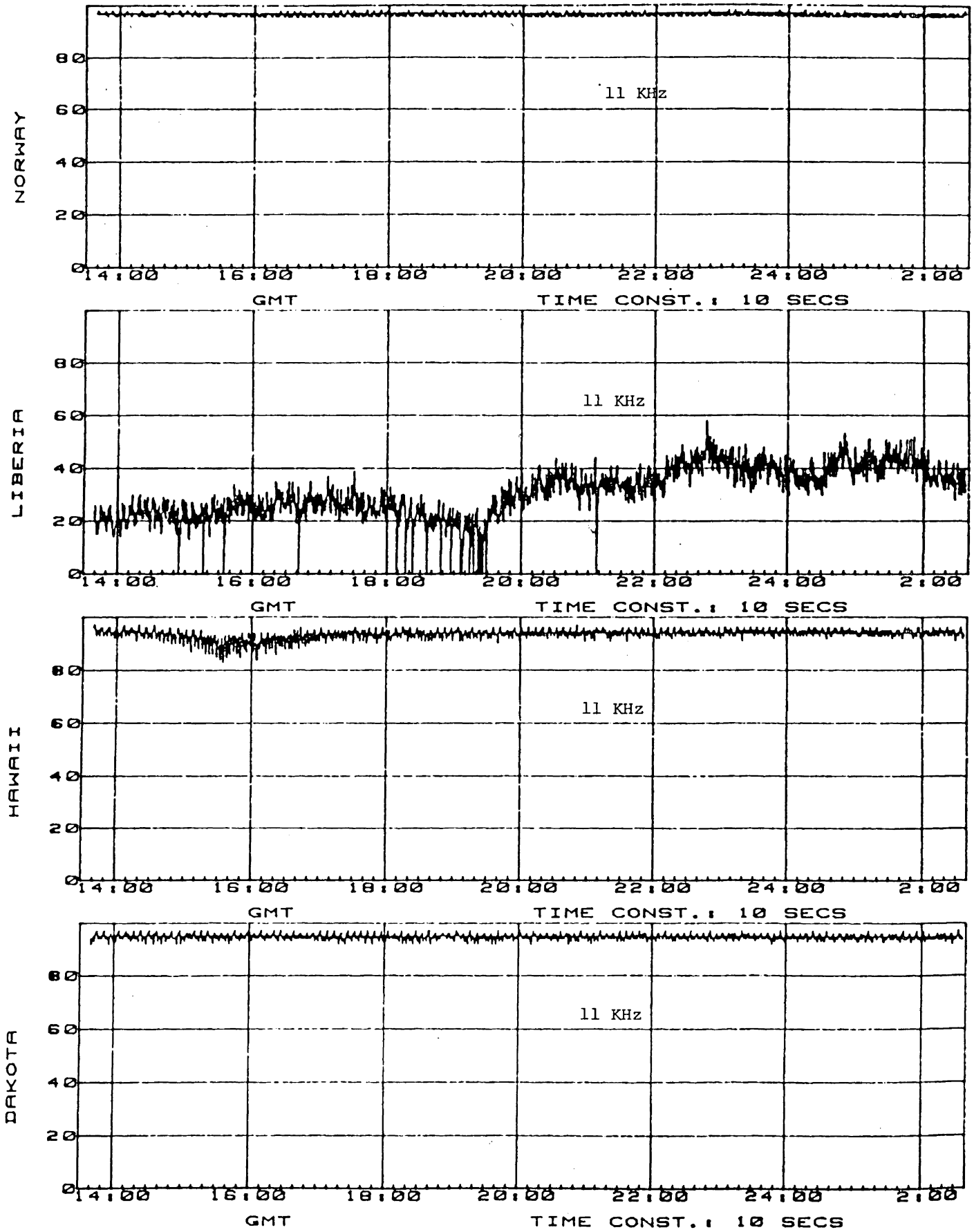


F FLIGHT: MAY 3 1983 LOP ERR

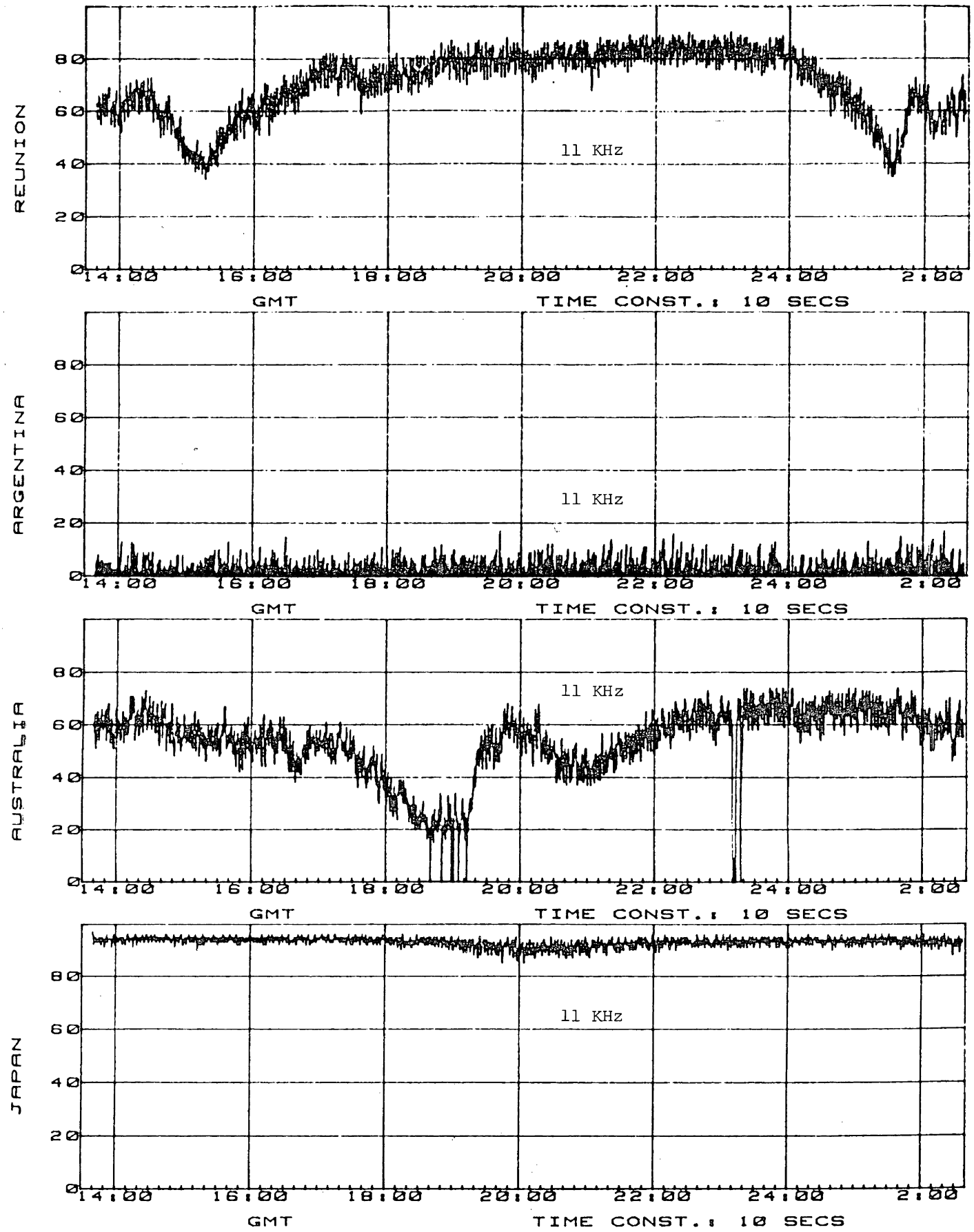
10 KHZ
REF. STATION: NORWAY



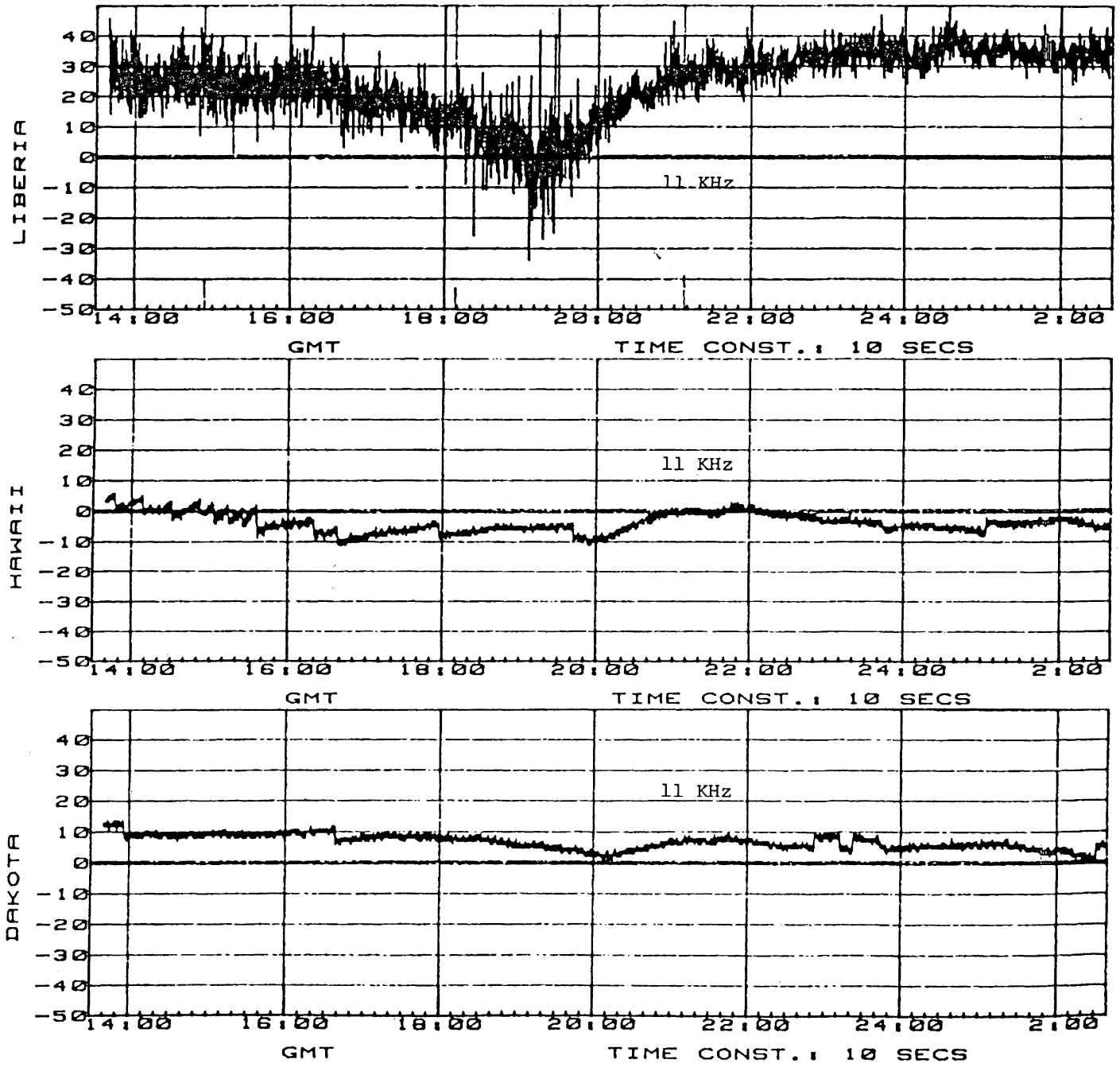
SESSION 4 TAPE 2 CESAR ICE CAMP DATE OF F



OF FLIGHT: MAY 3 1983 SNR INDEX 11 KHZ

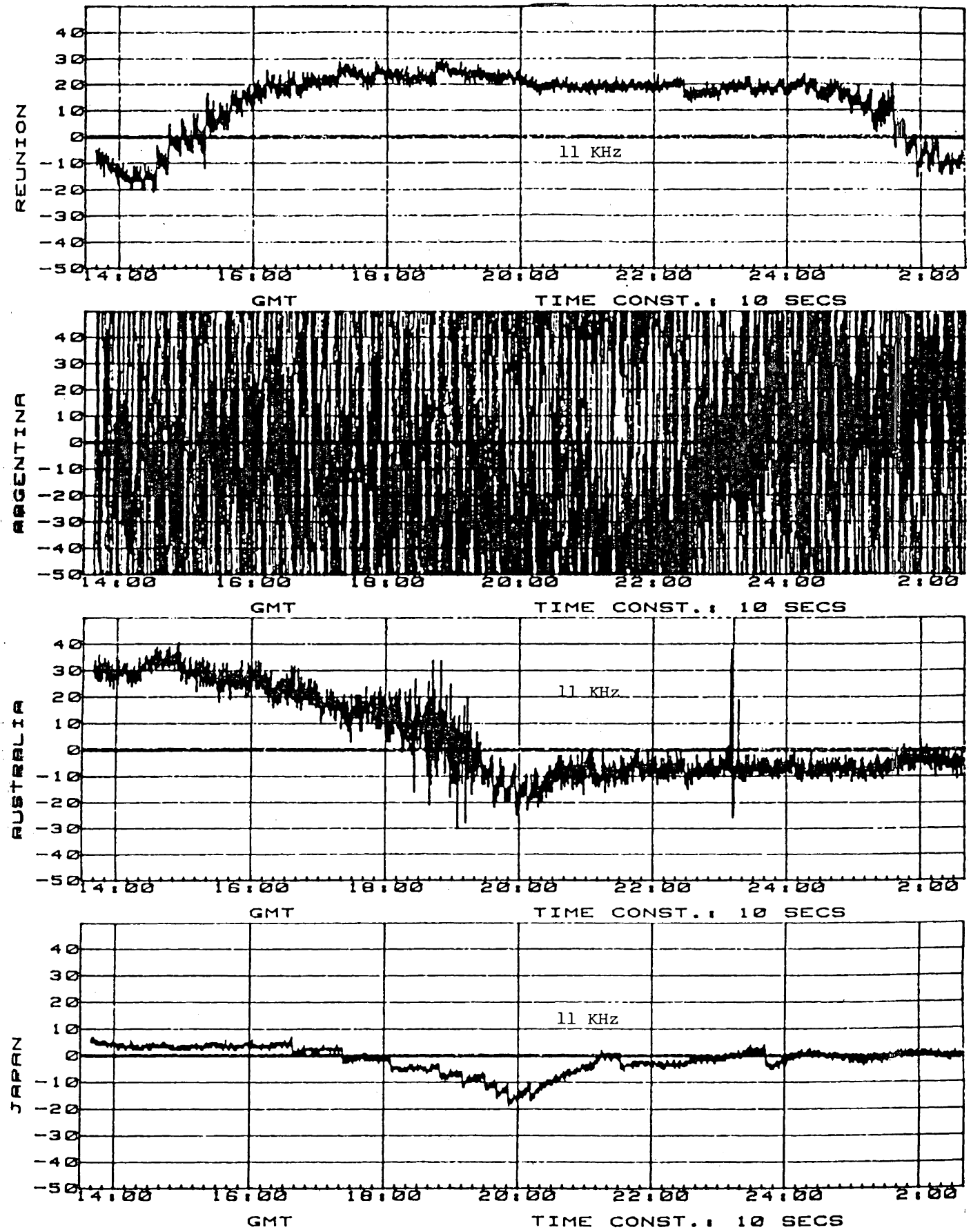


SESSION 4 TAPE 2 CESAR ICE CAMP DATE OF F

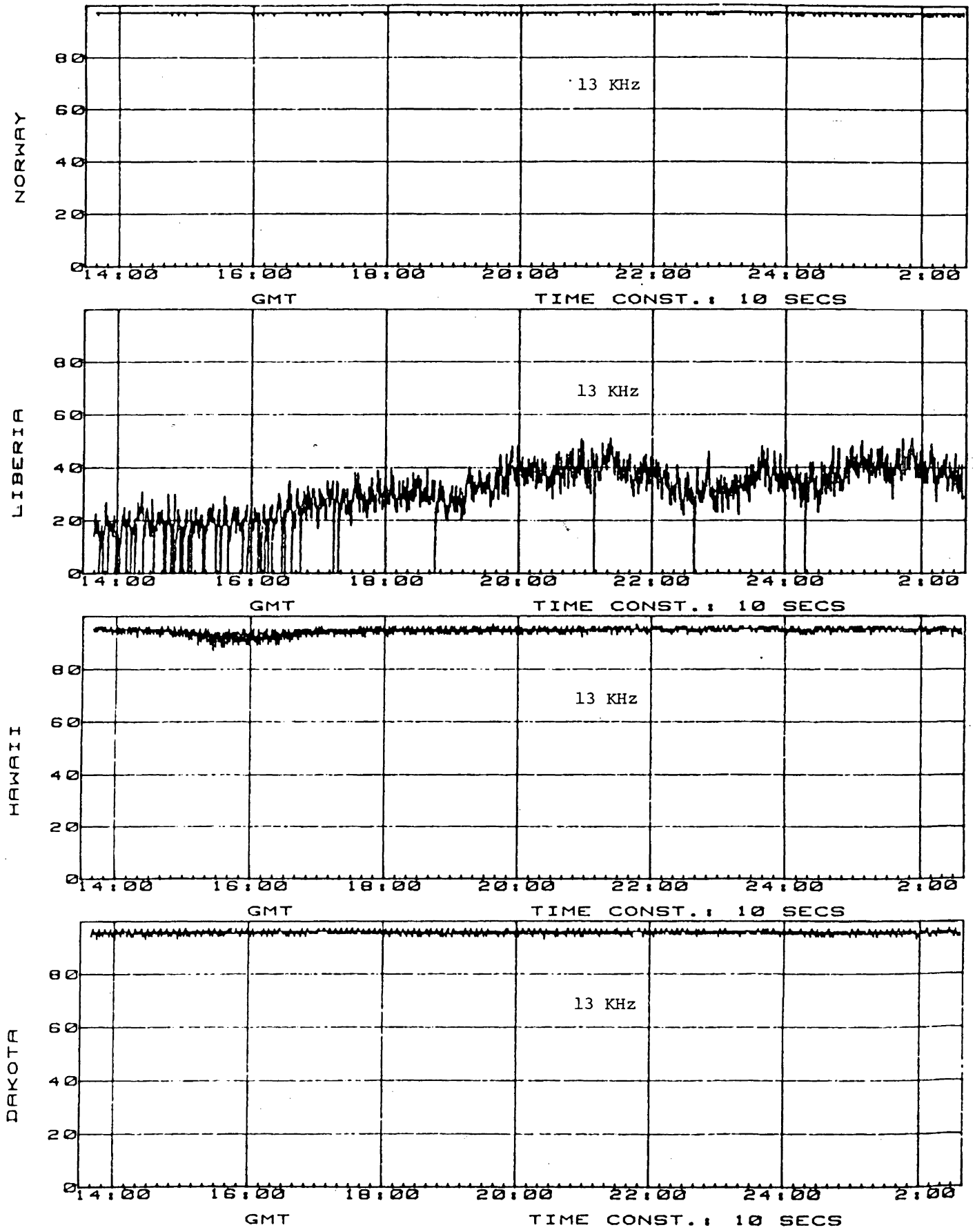


OF FLIGHT:MAY 3 1983 LOP ERR

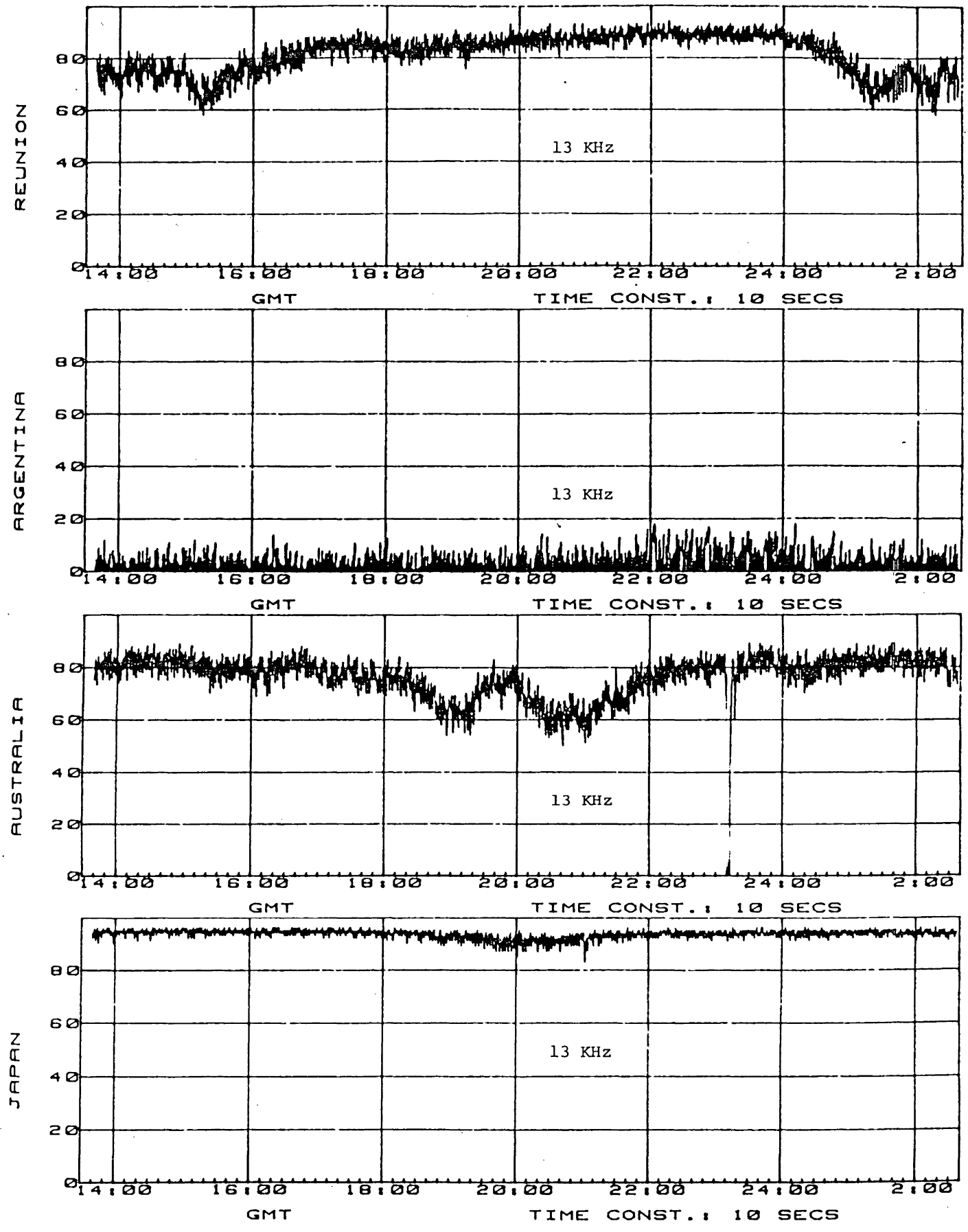
11 KHZ
REF. STATION:NORWAY



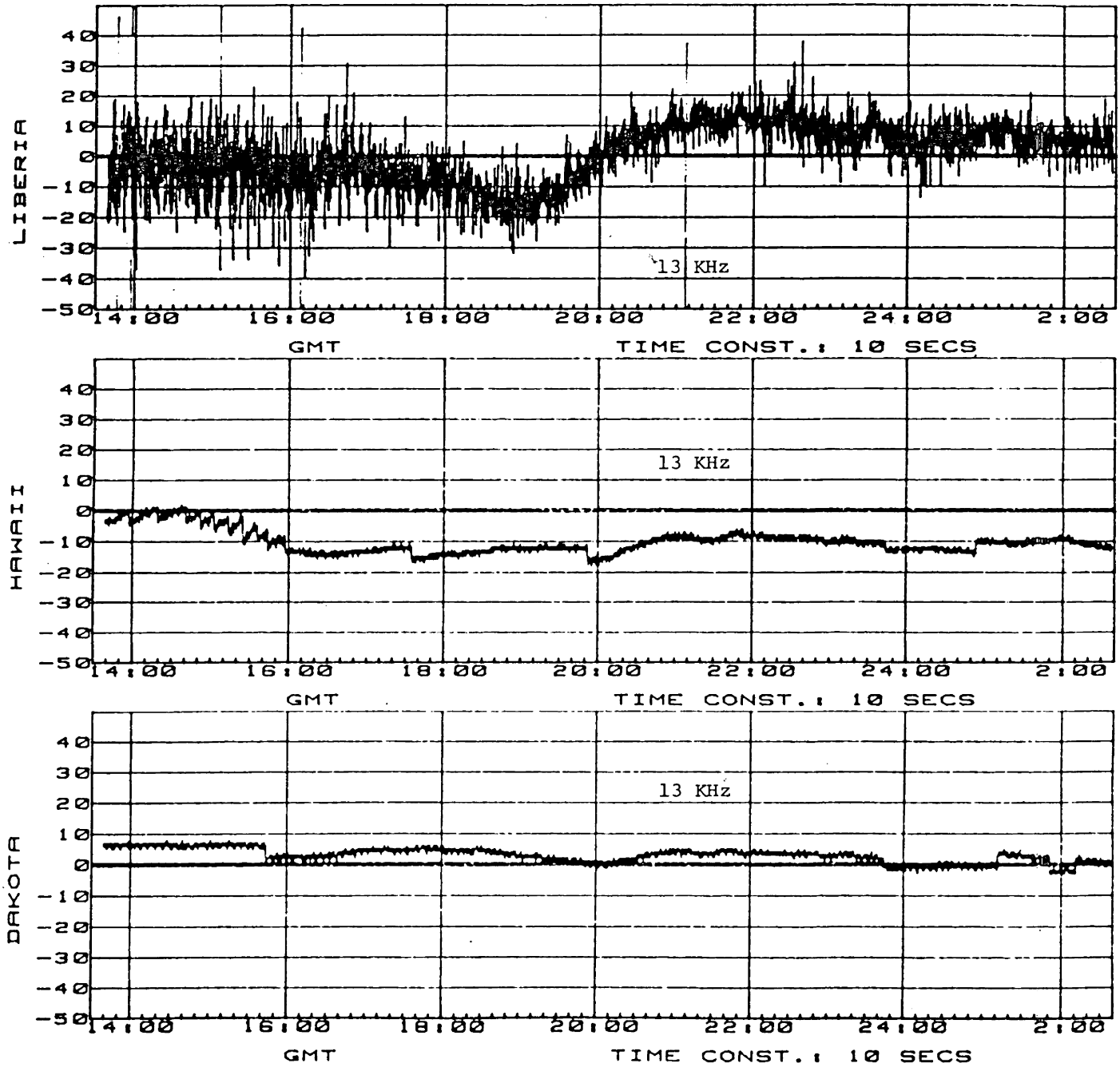
SESSION 4 TAPE 2 CESAR ICE CAMP DATE OF

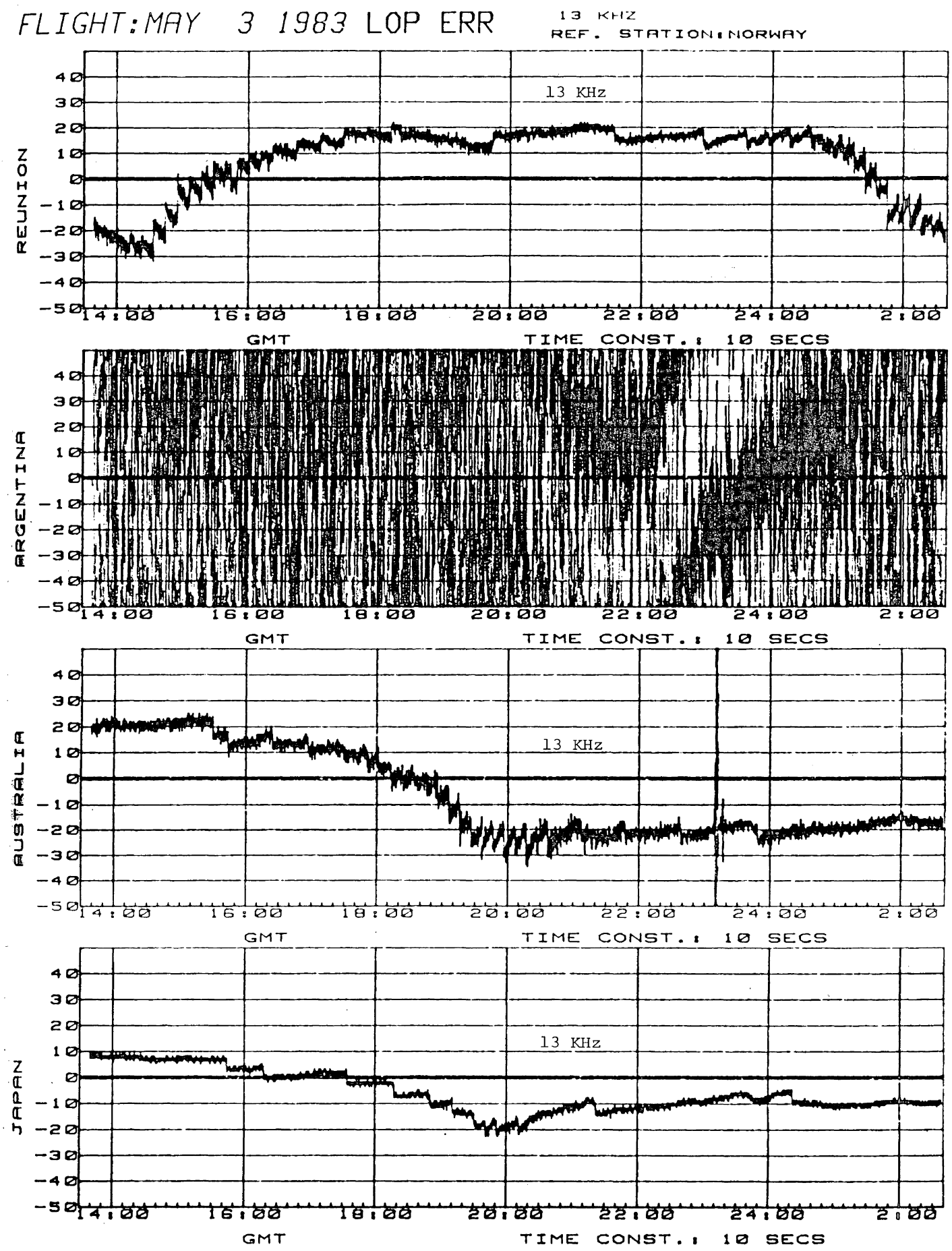


OF FLIGHT: MAY 3 1983 SNR INDEX 13 KHZ

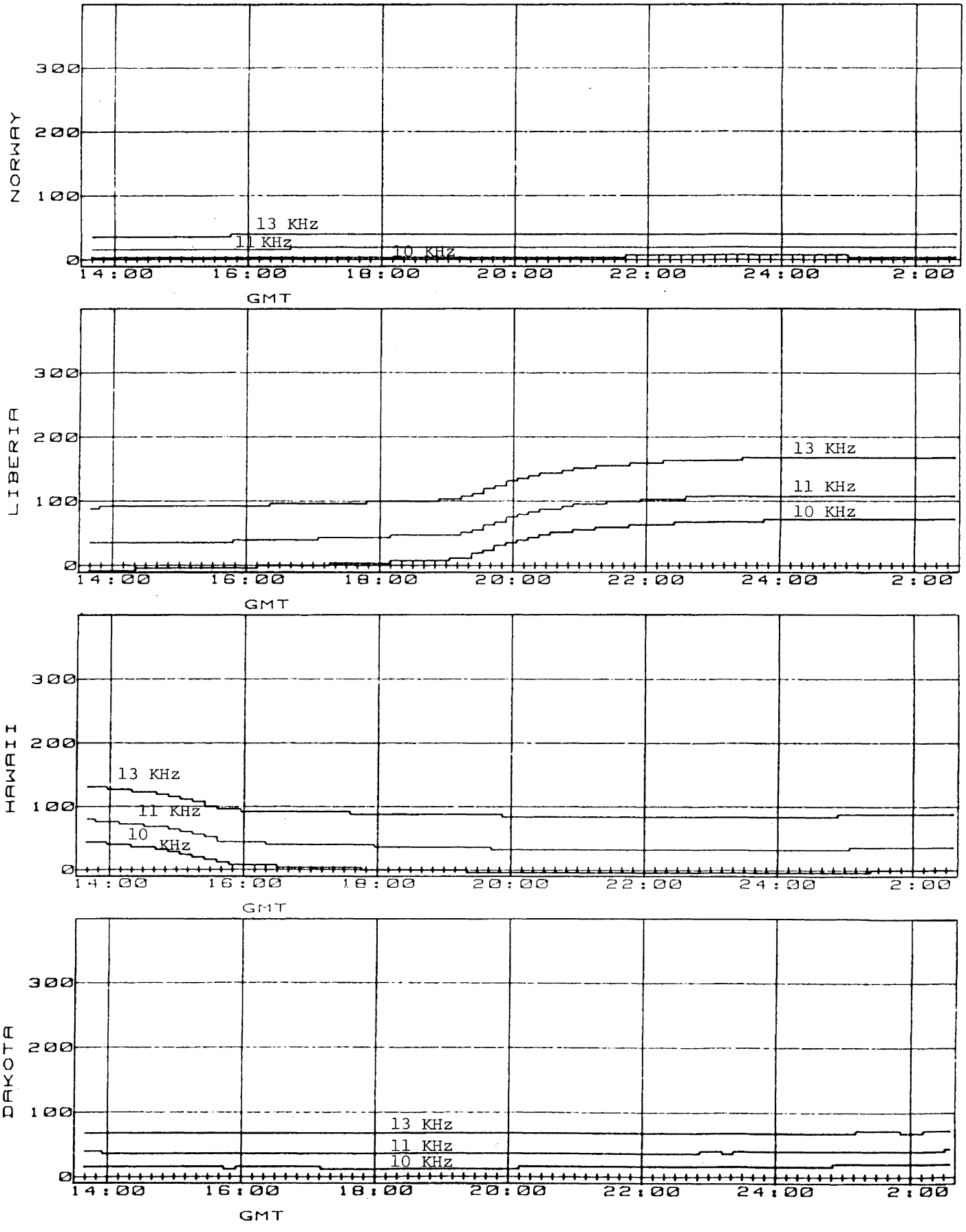


SESSION 4 TAPE 2 CESAR ICE CAMP DATE OF




FLIGHT:MAY 3 1983 LOP ERR
13 KHZ
REF. STATION:NORWAY
REUNION
13 KHz
40
30
20
10
0
-10
-20
-30
-40
-50
14:00
16:00
18:00
20:00
22:00
24:00
2:00
GMT
TIME CONST.: 10 SECS
ARGENTINA
AUSTRALIA
JAPAN

SESSION 4 TAPE 2 CESAR ICE CAMP DATE OF



OF FLIGHT: MAY 3 1983 DIURNALS

13 KHZ 11 KHZ 10 KHZ
VLF STATUS: UNFORCED