University of Wisconsin Participation in the VOCAR Experiment at Pt Mugu, California

Preliminary Results

3 September 1993

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TABLE OF CONTENTS

1. OVERVIEW

The University of Wisconsin participation in the Aug-Sept 1993 VOCAR (Variation of Coastal Atmospheric Refractivity) experiment under sponsorship of the NOARL and the U.S. Department of the Navy is decribed in this report. Since the VOCAR experiment is still continuing at the time of writing, this report will necessarily be limited to preliminary results obtained using the 'real-time' data analysis software employed during by the University of Wisconsin during the experiment. Preliminary analysis of data collected during VOCAR have been performed in order to address the primary goal of the experiment, namely, the measurement of the variation of atmospheric refractivity in a coastal environment.

The University of Wisconsin deployed the latest (and most advanced) version of the Ground-Based High-resolution Interferometer Sounder (GBHIS) at the Naval Air Station on Pt Mugu near Oxnard, California. The GBHIS is a passive infrared "sounder" which determines the temperature and moisture profile above the instrument at ten minute intervals in an automated manner. The GBHIS measures directly the downwelling infrared spectrum at a spectral resolution of 0.5 cm-1 (a resolving power of about 1000) over the spectral region 18.2 to 3.3 microns. Using an atmospheric model to relate infrared wavelength and atmospheric optical depth, atmospheric state parameters which provide the "best fit" to the measured radiance are derived from the downwelling spectra. The measurement technique combines state of the art radiometric observations and sophisticated nonlinear least squares fitting techiques to obtain the vertical profiles needed to study atmospheric radar refractivity.

The instrument used during VOCAR '93 is the third generation of a series of groundbased instruments under development at the University of Wisconsin. It should be noted that the two earlier generations have also obtained coastal refractivity measurements during the Naval Post Graduate cruises aboard the NFS ship the Pt Sur in 1991 and 1992. The GBHIS instrument used at VOCAR goes under the name AERI-01 (Atmospheric Emitted Radiance Interferometer #01) and was developed by the UW (Dr. Henry Revercomb, PI) for the Department of Energy Atmospheric Radiation Measurement (ARM) program. The VOCAR '93 experiment was the first field deployment of the AERI-01 system. Several new features of the AERI-01 to enhance the automation of the system were succesfully tested during VOCAR, including a liquid nitrogen autofill system for the infrared detector dewar. These advances have allowed nearly continuous operation of the GBHIS from 18 August through 3 Sept 1993.

The retrieval software used during VOCAR '93 is a substantially improved version of code developed by Prof. William L. Smith at the University of Wisconsin. The current version breaks new ground in three areas: (1) simultaneous use of both longwave (15 micron) and shortwave (4.3 micron) carbon dioxide and water vapor channels, (2) greatly improved cloud detection allowing retrieval during partly cloudy conditions, and (3) retrieval of marine aerosol amount (visibility). The VOCAR '93 experiment was the first opportunity to test this new algorithm in the marine environment. VOCAR data is especially valuable for the study of the elevated temperature inversion which is such a persistent feature along the California coast but rarely occurs in the continental U.S. where most of our data have been obtained. Results of using this prototype retrieval software are presented elsewhere in section 3.

2. GBHIS OPERATIONS AT PT MUGU

The GBHIS measures the downwelling infrared radiance on an automated schedule. The time interval between measured spectra is about 9 minutes (of which 3.5 minutes is sky dwell). Every measured spectrum potenially could provide an atmospheric sounding. Note however that the atmospheric sounding is from the ground to the cloud base since cloud water droplets block the infrared emission above the cloud from reaching the instrument.

The GBHIS was deployed the week before the intensive observing period (23 Aug - 3 Sept) and began operation on 18 August 1993 adjacent to the Geophysics building on the Navy Air Station at Point Mugu, CA. The following table indicates the number of potential soundings that were observed during the deployment at Pt Mugu. Examples of the soundings obtained with the realtime processing software are given in the next section. Note that almost all the down periods were at night during low overcast or fog conditions.

Table 1. GBHIS Operations

#	DATE	Number of Spectra (Max=160)	Up-time Percentage
1	930818	152	95 %
2	930819	120	75 %
3	930820	107	67 %
4	930821	155	97 %
5	930822	152	95 %
6	930823	158	99 %
7	930824	159	99 %
8	930825	115	72 %
9	930826	160	100 %
10	930827	155	97 %
11	930828	159	99 %
12	930829	110	69 %
13	930830	158	99 %
14	930831	156	98 %
15	930901	158	99 %
16	930902	158	99 %
17	930903	>100	--
	TOTAL	2430(+)	> 91 %

3. CASE STUDY (26-28 August)

A three day period during the VOCAR experiment has been identified as a particularly good period for analysis of GBHIS data. The period 26, 27, and 28 August (UTC) was nearly cloud-free with a persistent elevated inversion and strong marine layer. Ducting conditions were indicated from both GBHIS and raob (MRS) data. In particular, the radar duct was observed to lower in height on the 27th sufficiently so as to interfere with microwave and other communications.

Data collected during this period is presented in the following pages. Note that MRS radiosondes were launched at Pt Mugu on four hour intervals at 0, 4, (missing 8), 12, 16, and 20 UTC daily during this period. The GBHIS observations are at about 10 minute intervals and thus have a 24 times higher temporal resolution than the raob. However, the GBHIS measurements are derived from the passive infrared and thus have an inherently smoother vertical profiling capability (less vertical resolving power) compared to the in-situ raob.

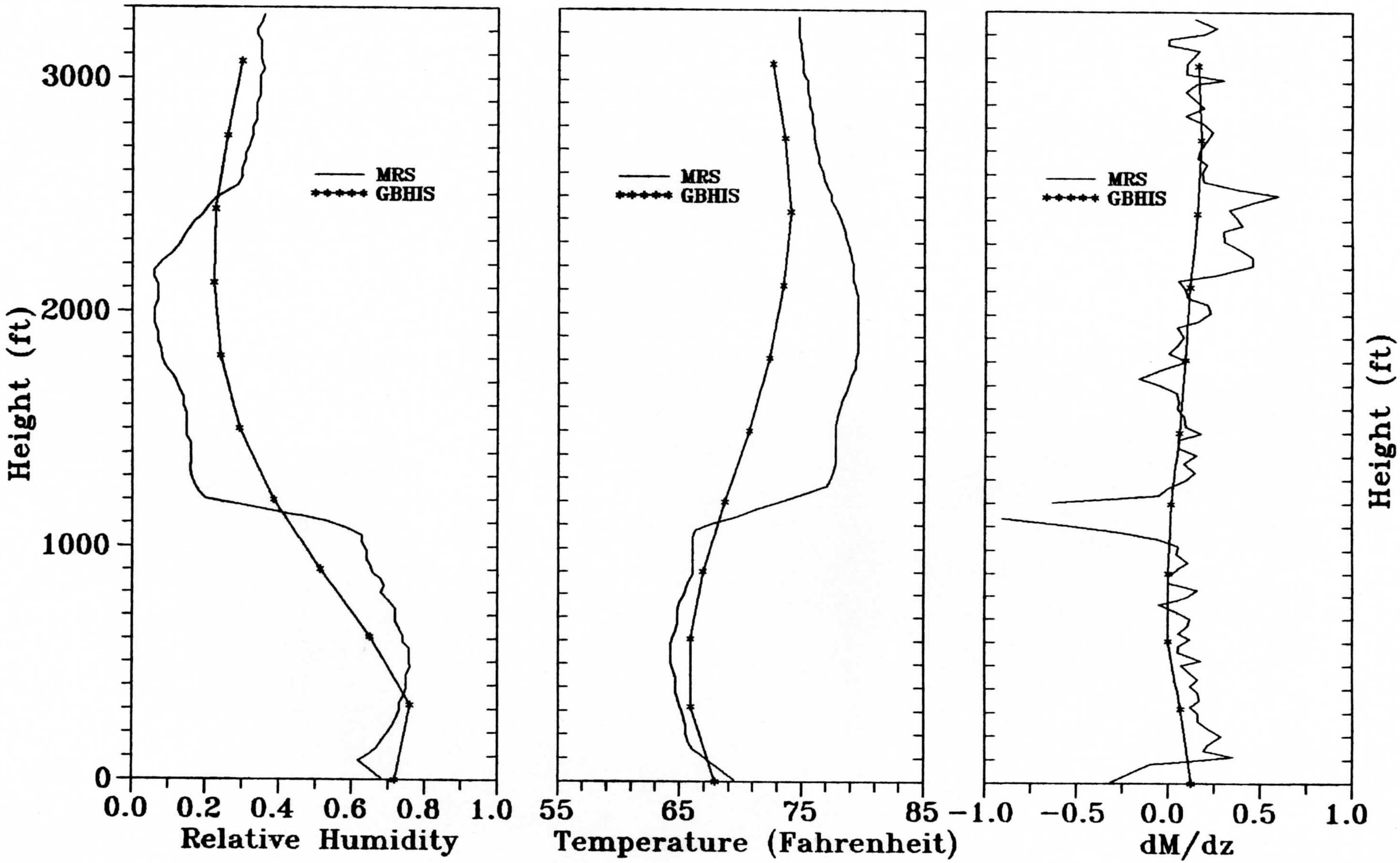
Note that the utility of the GBHIS is in detection of relative changes over time by continuous monitoring of the downwelling infrared using a low power passive technique. The GBHIS retrieval software was operated with a first guess made from heavily smoothing the 0 UTC raob for each day to initialize the retrieval at the beginning of each UTC day (1700 PDT). From that point the retrieval ran undisturbed in "real-time" while the data was being collected. Note especially that these preliminary results are from on-site real-time analysis with a 486 PC and though they are representative of the performance of the infrared GBHIS system, they are expected to be improved through post-experiment data processing.

Of particular interest are the comparison of the vertical derivative of the modified radar refractivity (dM/dz) between the MRS balloon sonde (using Vaisala sensors) and the passive IR GBHIS instrument. This quantity (dM/dz) is a measure of the bending that would be induced on the propogation of radar waves. The equations used to compute this quantity are given below:

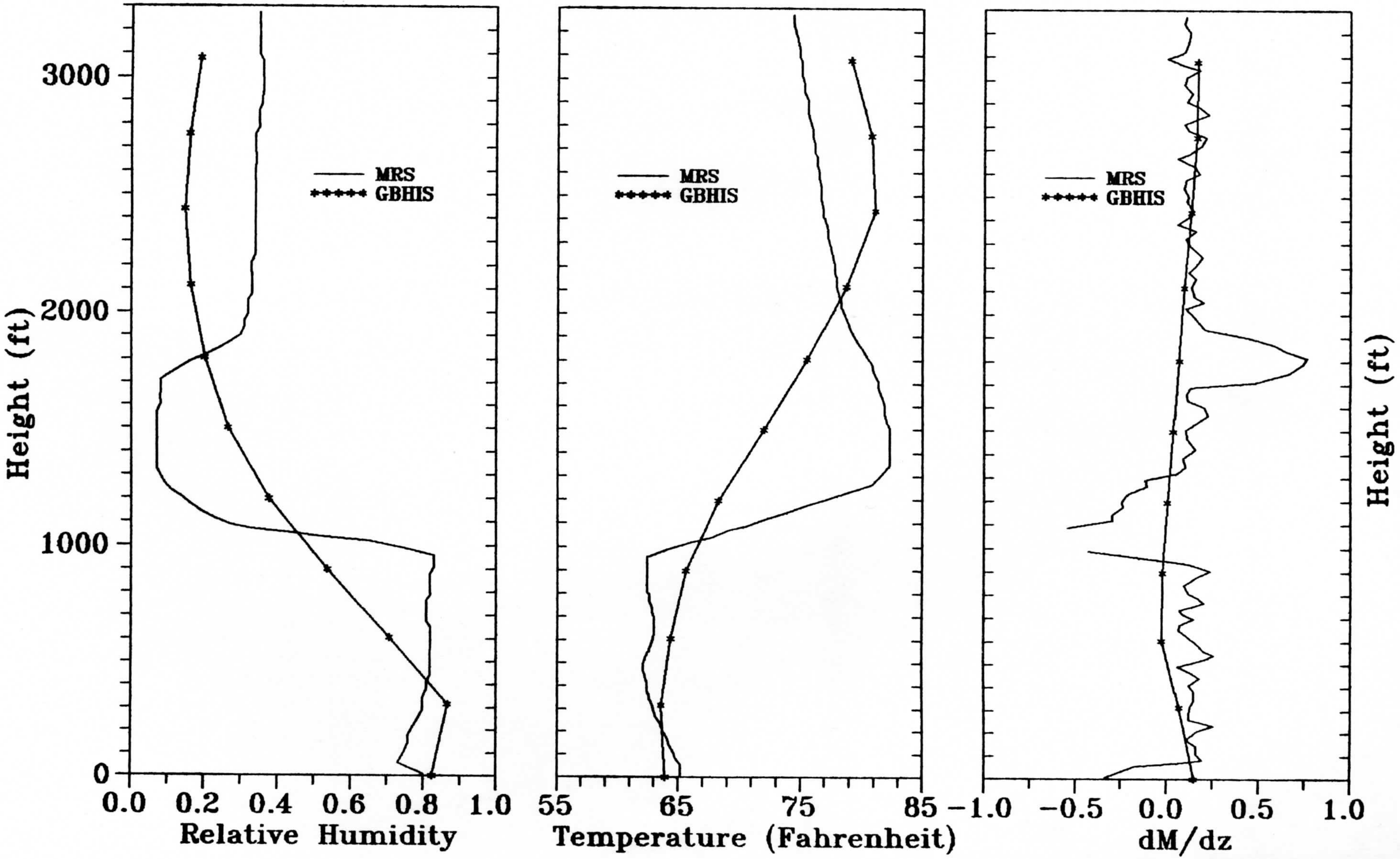
$$N = (P/T) * (77.6 + 3.73E5*q/(0.622*T)),$$
$$M = N + 0.157*Z,$$

where P = pressure (mb), T = temperature (K), q = H2O mixing ratio (kg/kg), and Z = height (m). Naturally, dM/dz for the GBHIS is obtained from the retrieved temperature and moisture profiles while the dM/dz for the MRS sounding is obtained from the 2 second in-situ temperature and moisture measurements. The comparison shows that the IR sensor is not able to resolve the very high resolution features seen in the raob data, in fact it appears to represent a smooth mean of the somewhat noisy looking raob data. The GBHIS does however indicate the ducting condition (in a vertically smoothed sense) and it does capture the decrease in height with time during the 27th August.

VOCAR Experiment at Pt Mugu
26 August 1993 00 UTC



VOCAR Experiment at Pt Mugu
26 August 1993 04 UTC



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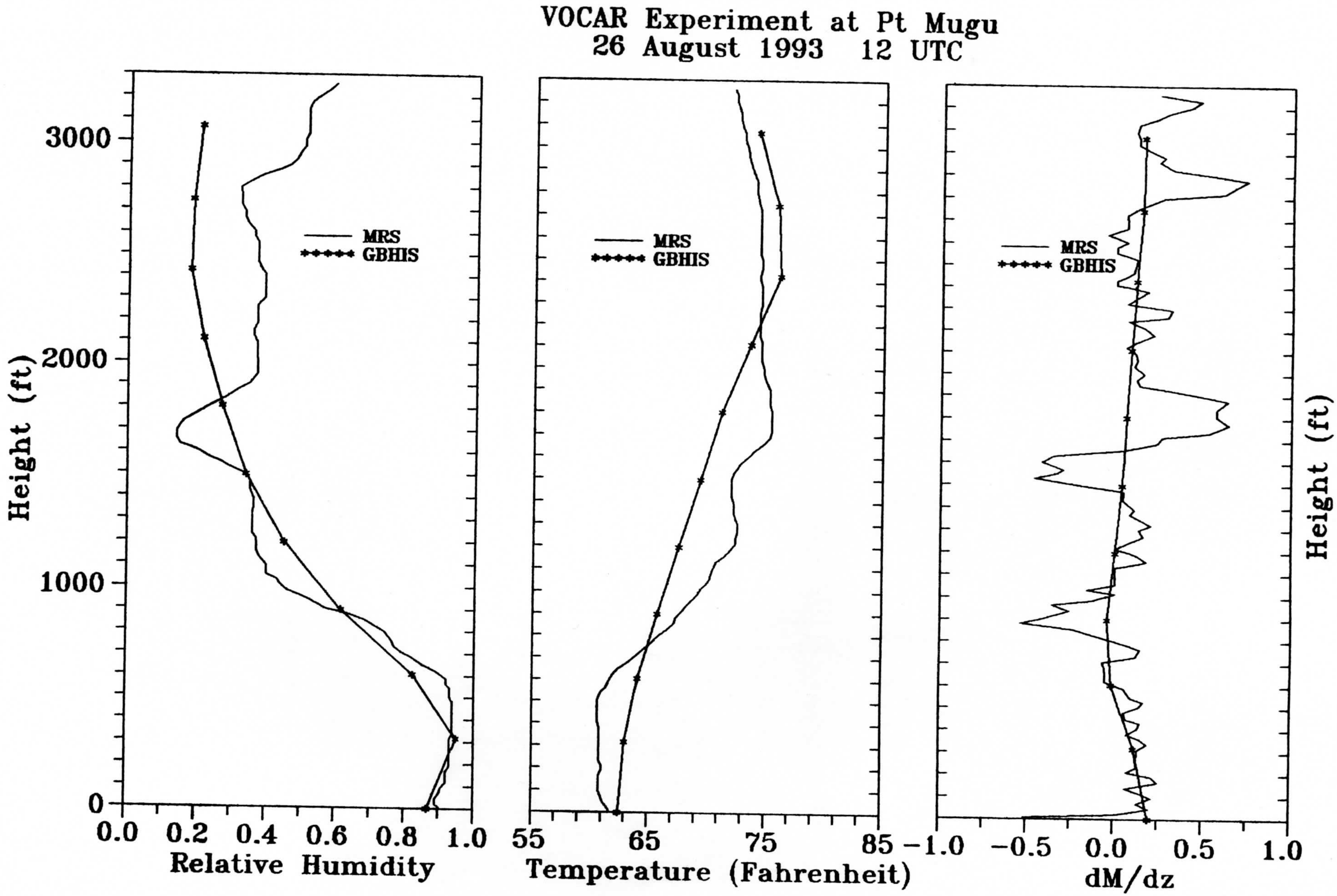
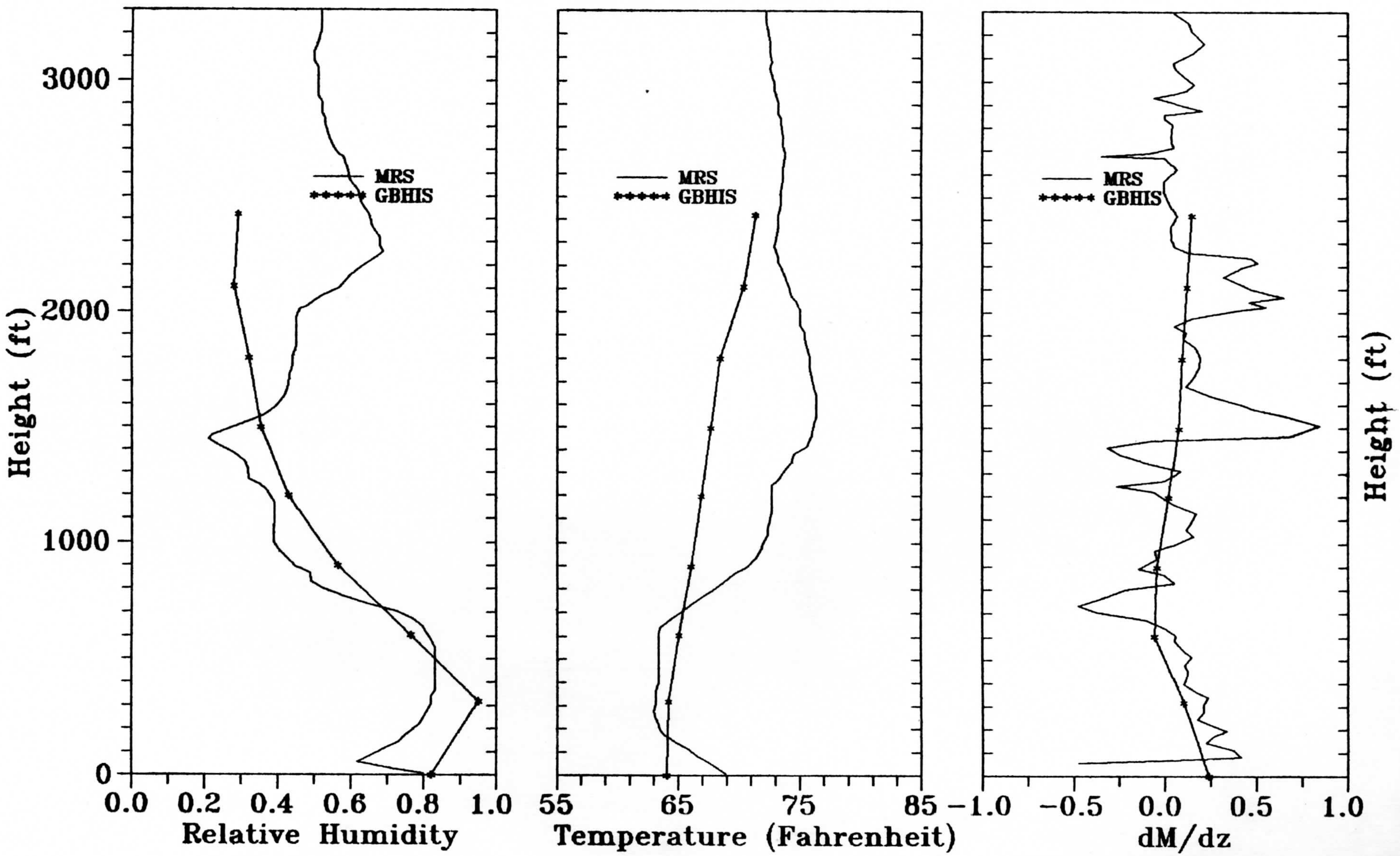

VOCAR Experiment at Pt Mugu
26 August 1993 12 UTC
Height (ft)
3000
2000
1000
0
MRS
GBHIS
0.0
0.2
0.4
0.6
0.8
1.0
Relative Humidity
55
65
75
85
Temperature (Fahrenheit)
−1.0
−0.5
0.0
0.5
1.0
dM/dz
Height (ft)

VOCAR Experiment at Pt Mugu
26 August 1993 16 UTC



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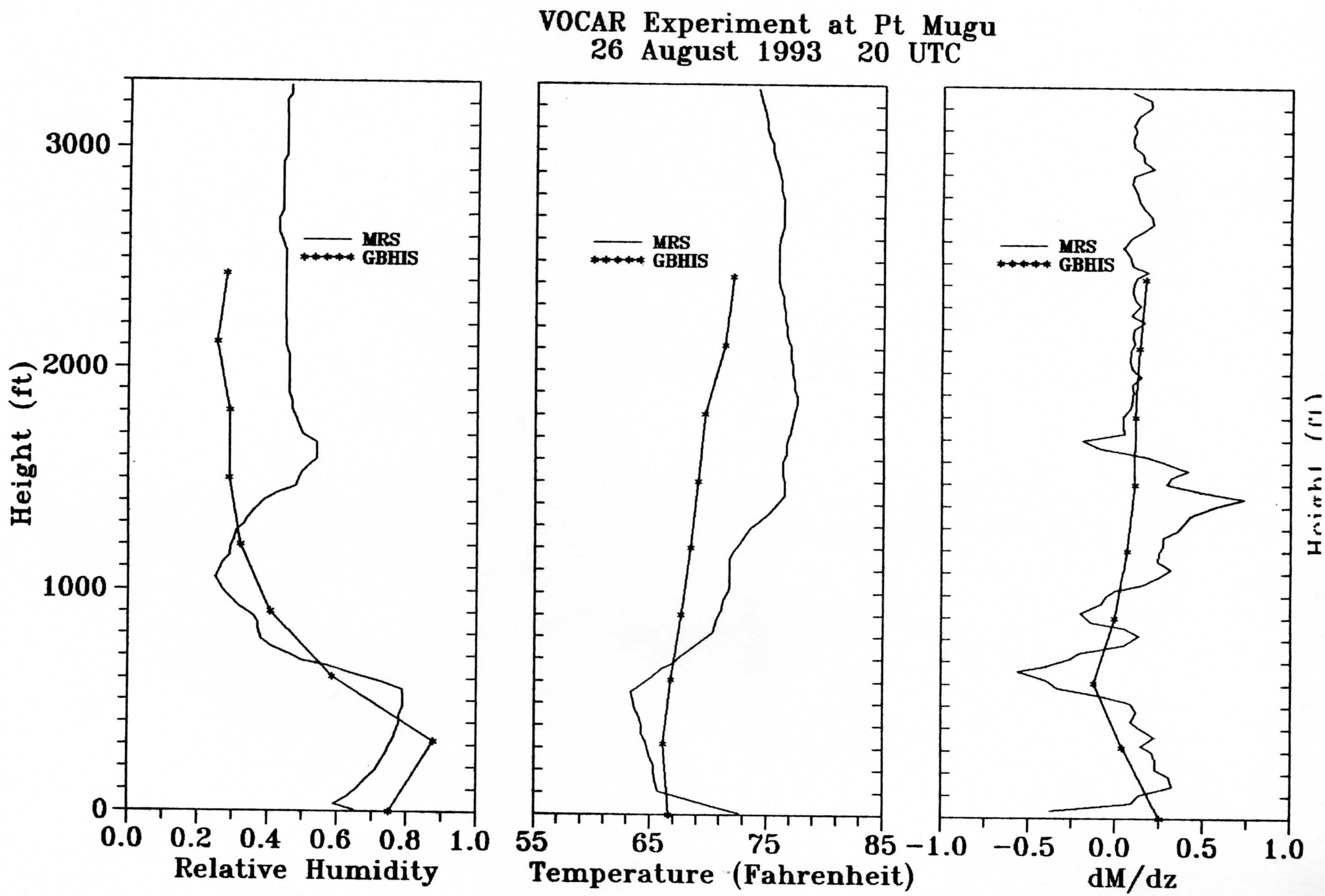

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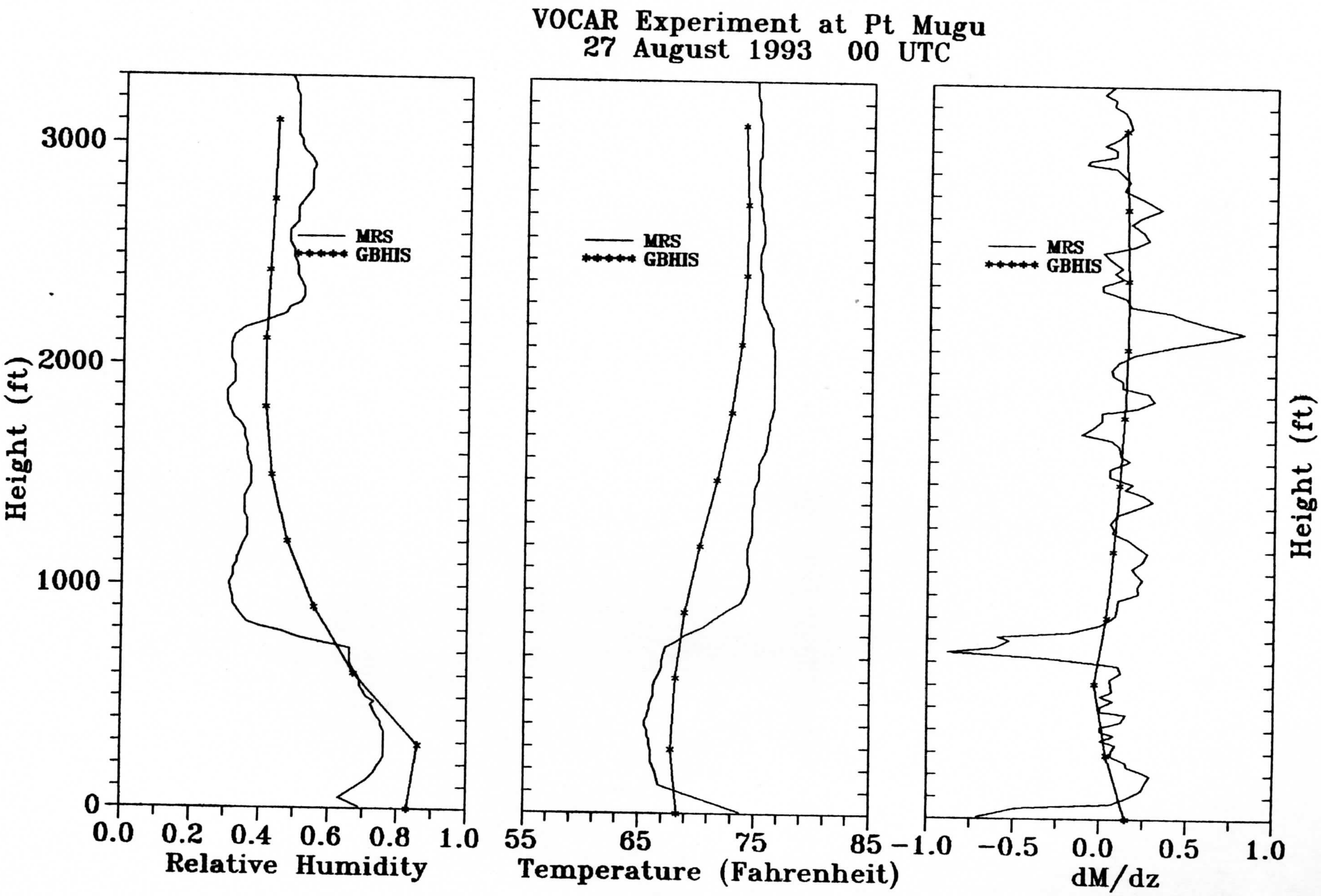
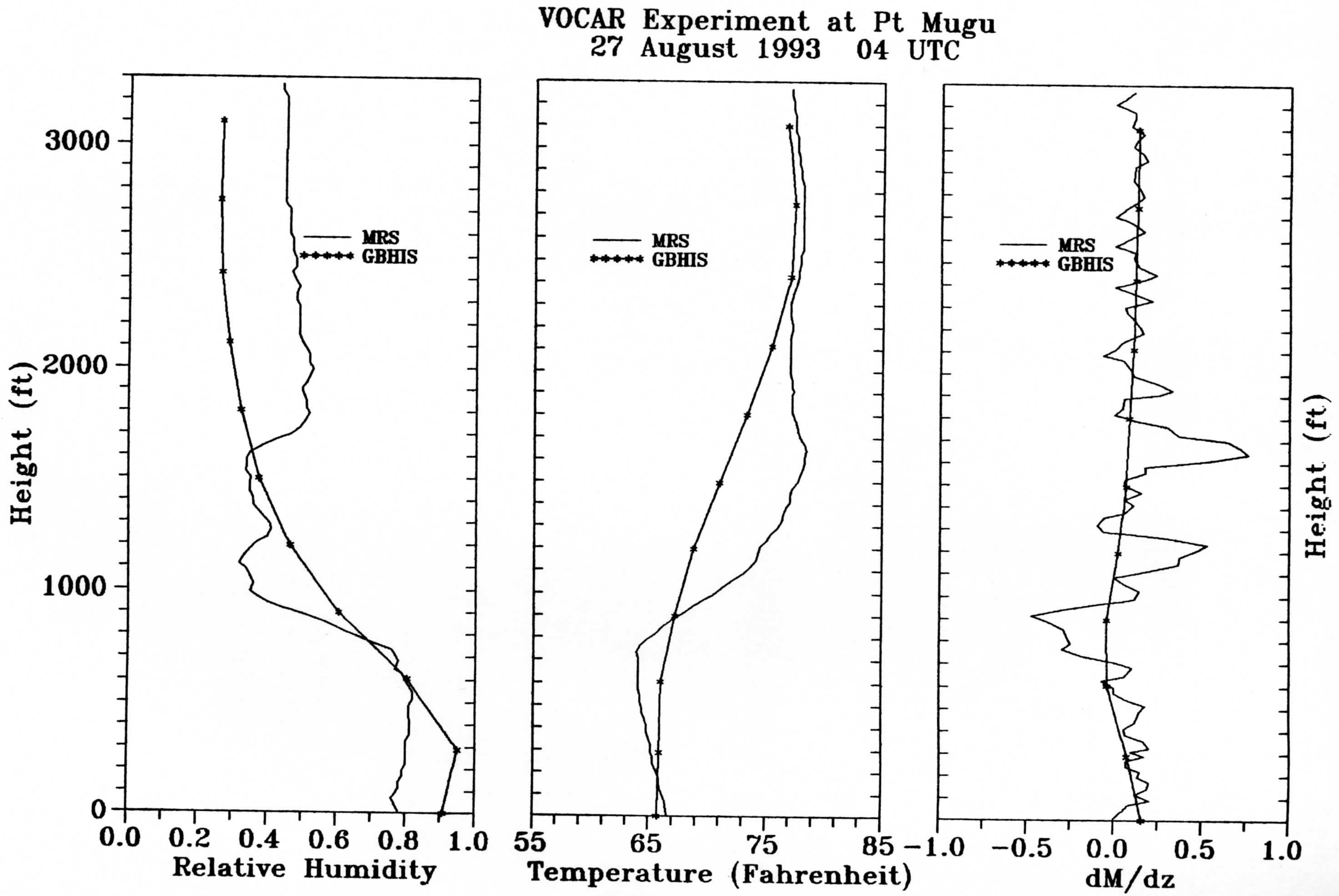

VOCAR Experiment at Pt Mugu
27 August 1993 00 UTC
Height (ft)
3000
2000
1000
0
0.0
0.2
0.4
0.6
0.8
1.0
Relative Humidity
MRS
GBHIS
55
65
75
85
Temperature (Fahrenheit)
MRS
GBHIS
−1.0
−0.5
0.0
0.5
1.0
dM/dz
MRS
GBHIS
Height (ft)



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rB

VOCAR Experiment at Pt Mugu
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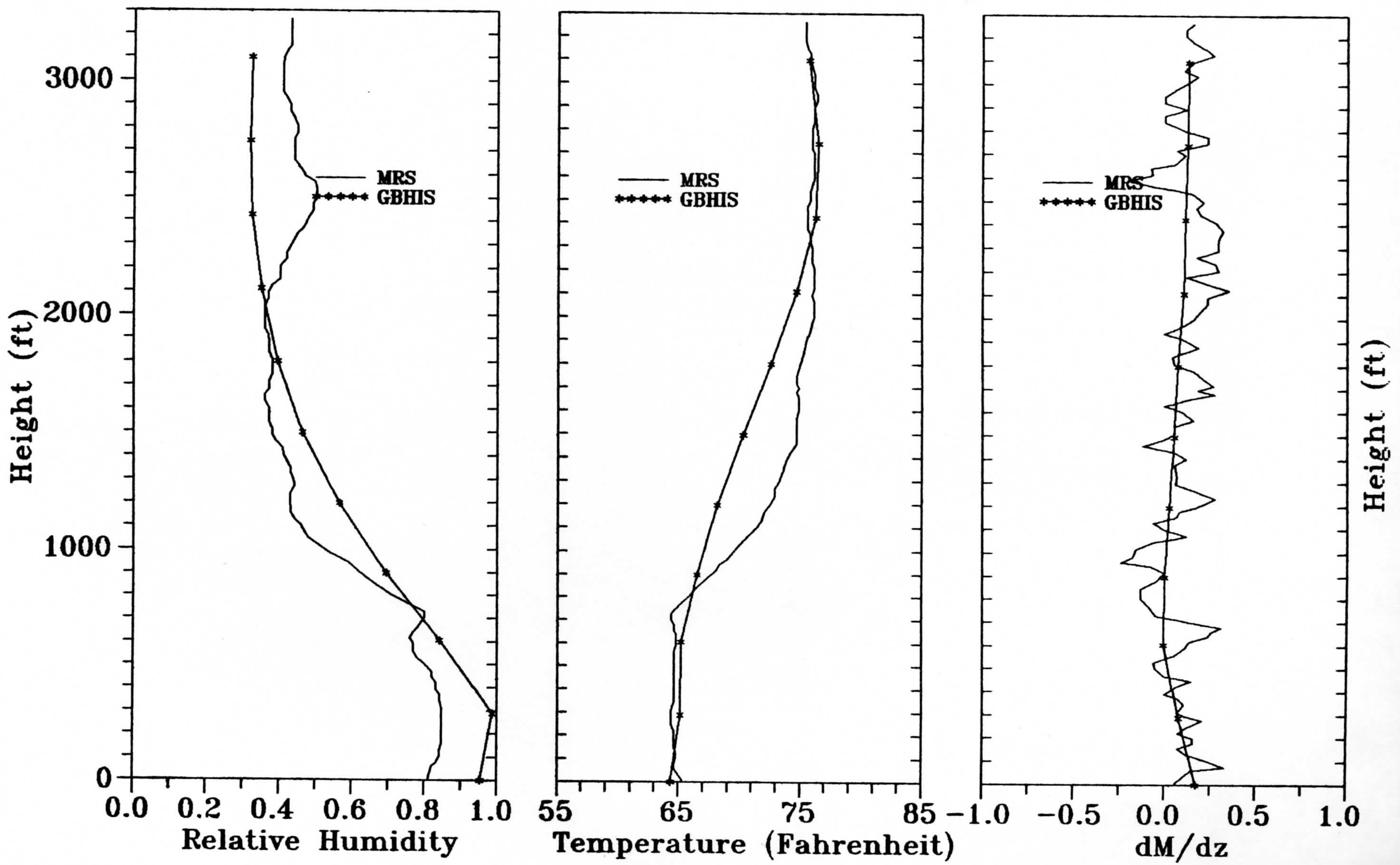

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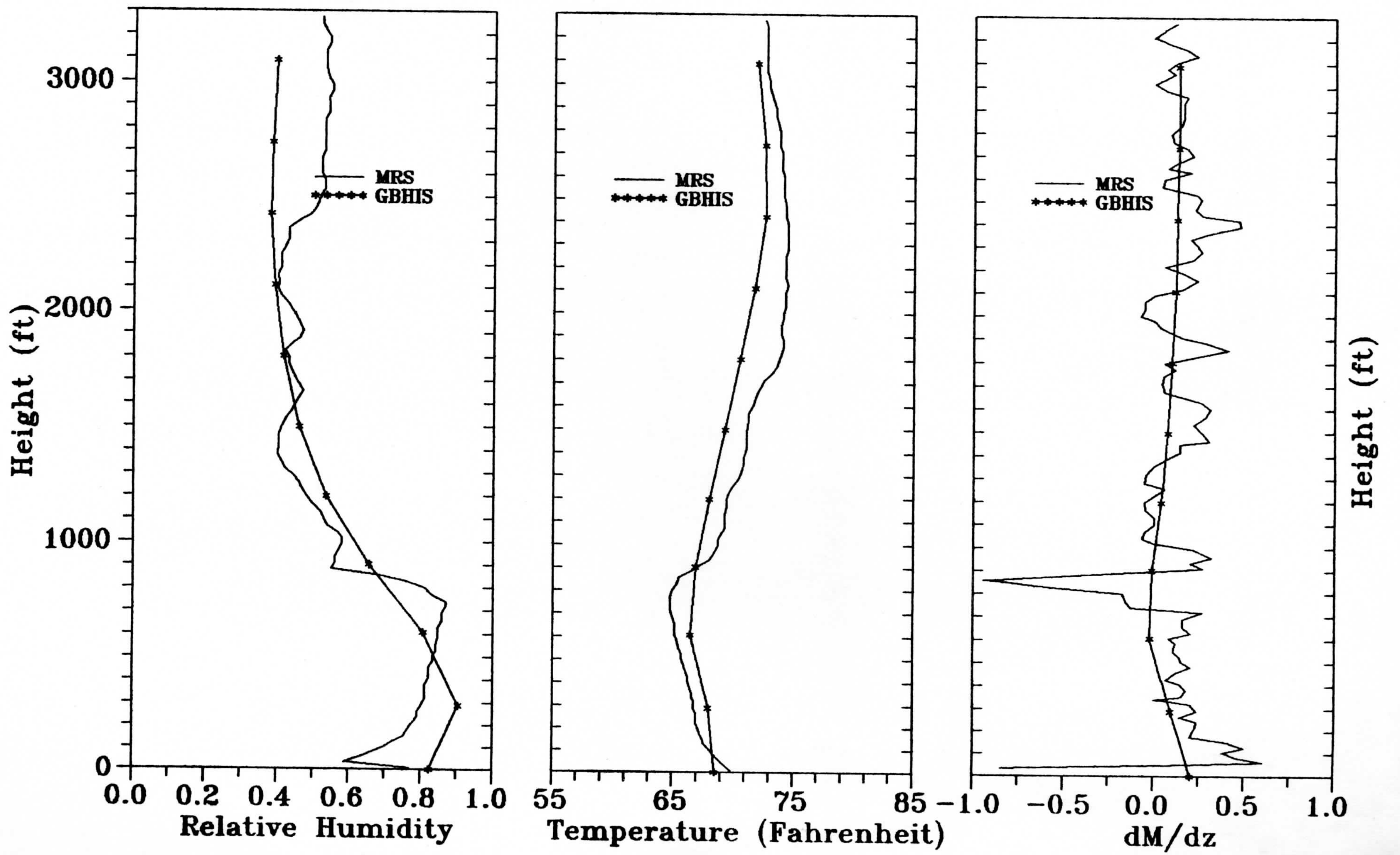
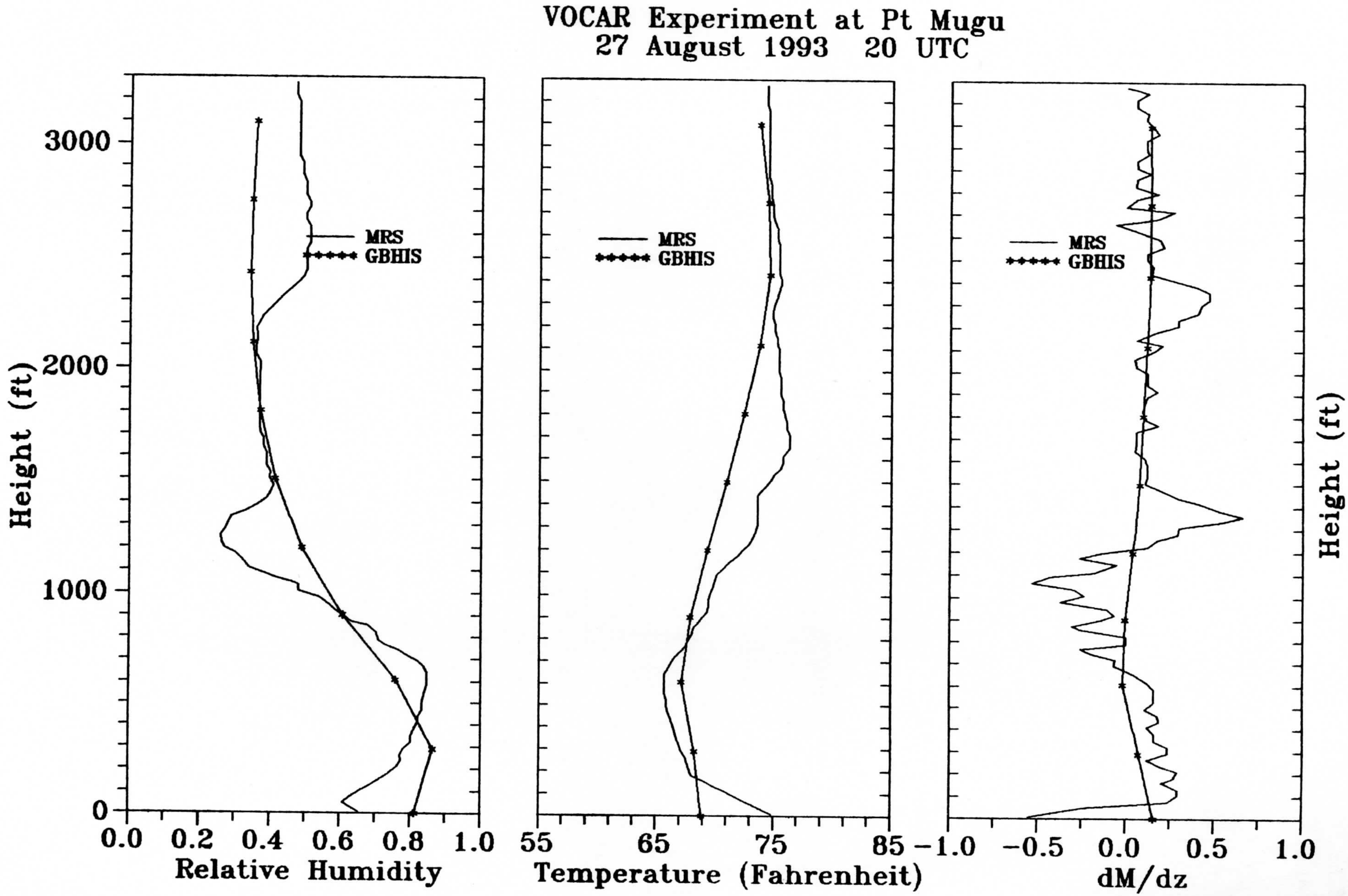
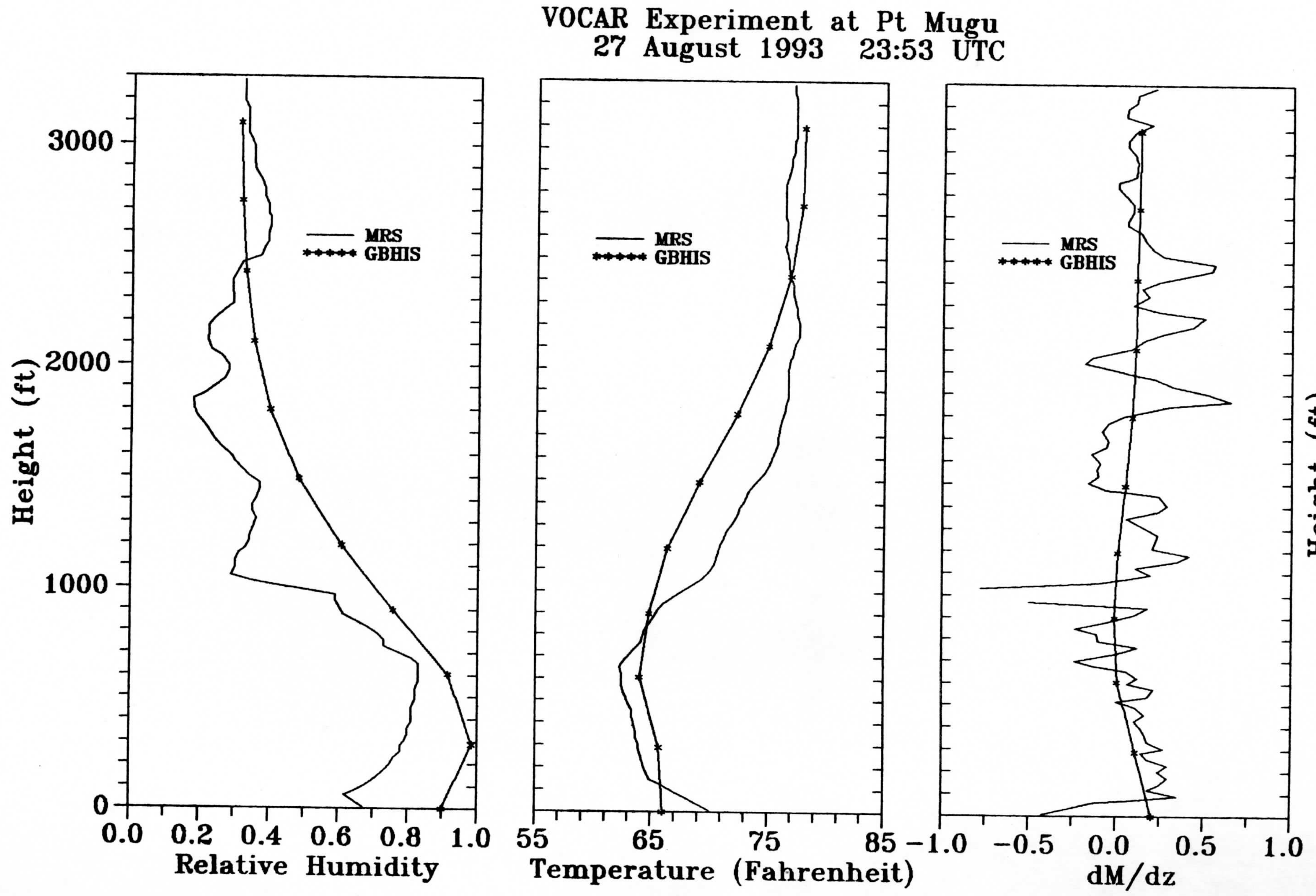
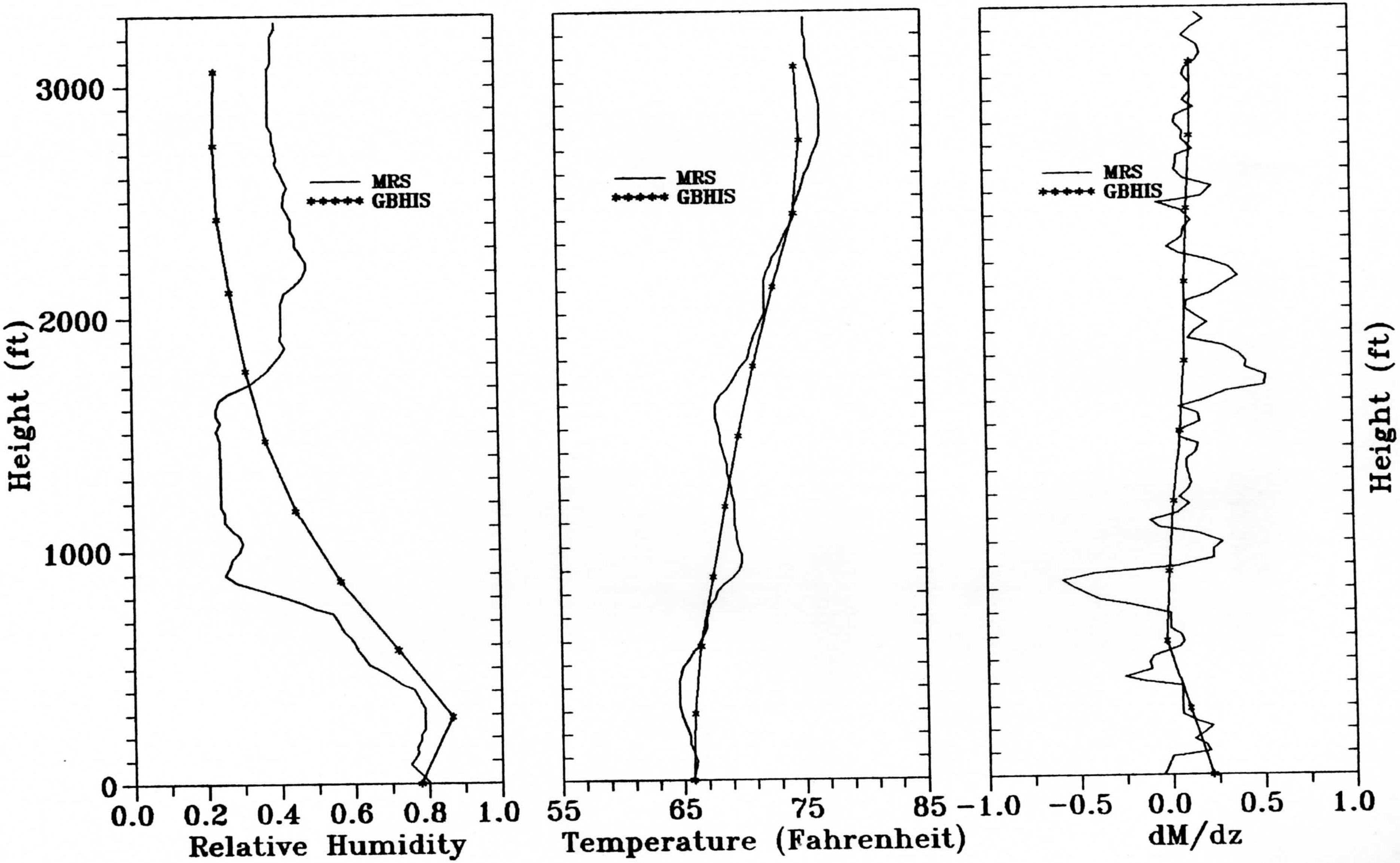
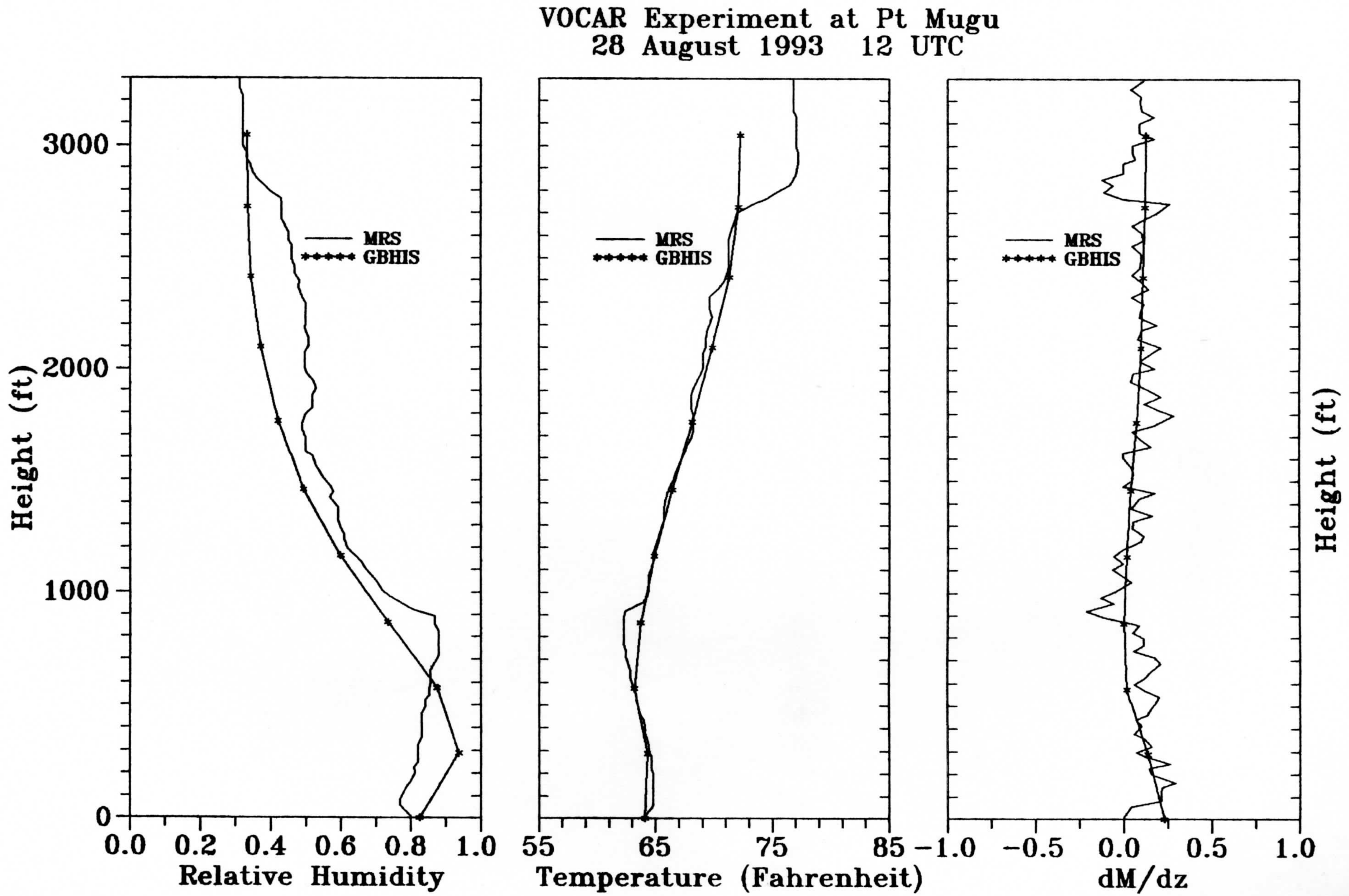



VOCAR Experiment at Pt Mugu
27 August 1993 20 UTC
Height (ft)
3000
2000
1000
0
MRS
GBHIS
0.0
0.2
0.4
0.6
0.8
1.0
Relative Humidity
55
65
75
85
Temperature (Fahrenheit)
−1.0
−0.5
0.0
0.5
1.0
dM/dz
Height (ft)

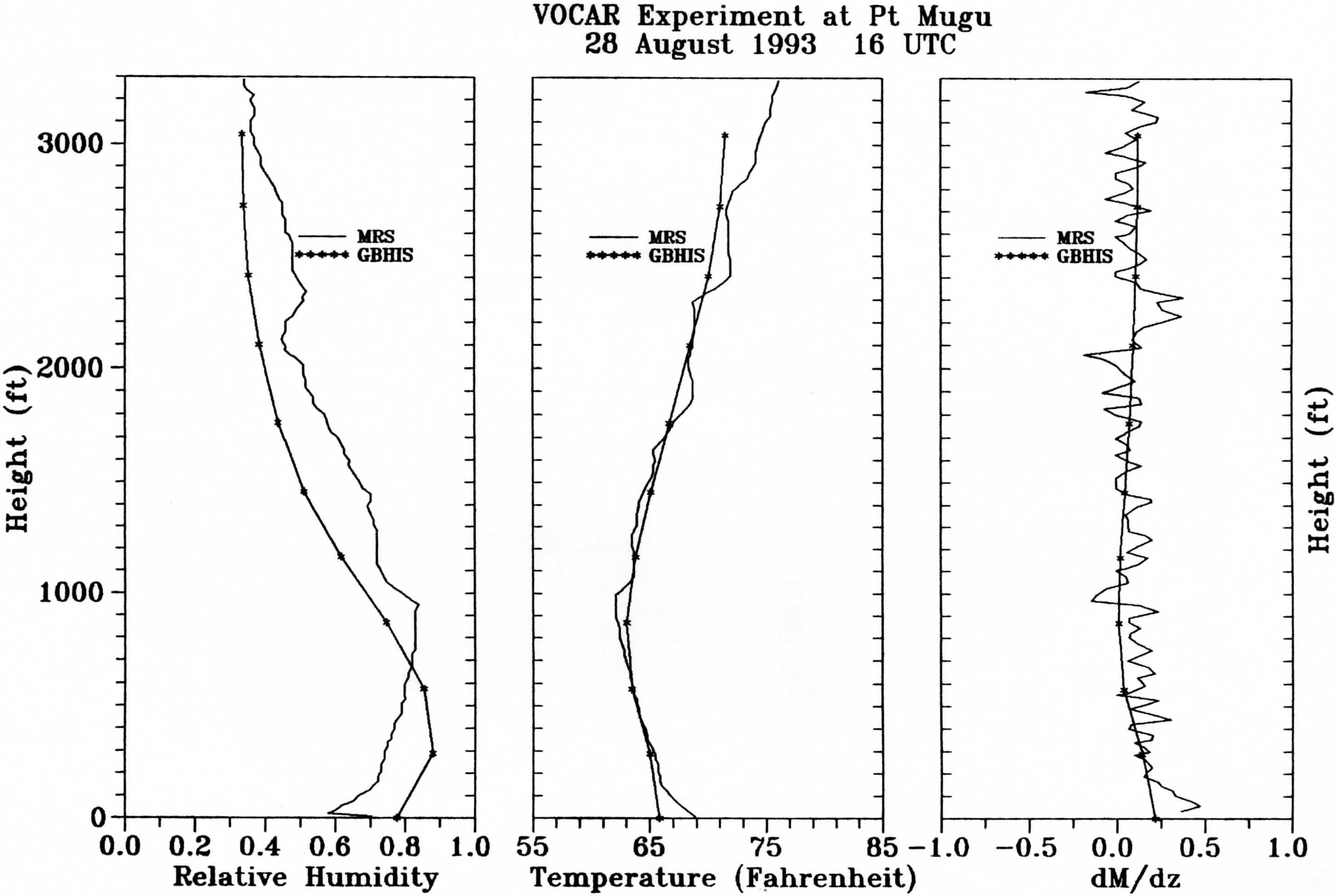

VOCAR Experiment at Pt Mugu
27 August 1993 23:53 UTC
Height (ft)
3000
2000
1000
0
MRS
GBHIS
0.0
0.2
0.4
0.6
0.8
1.0
Relative Humidity
55
65
75
85
Temperature (Fahrenheit)
−1.0
−0.5
0.0
0.5
1.0
dM/dz
Height (ft)

VOCAR Experiment at Pt Mugu
28 August 1993 04[redacted] UTC

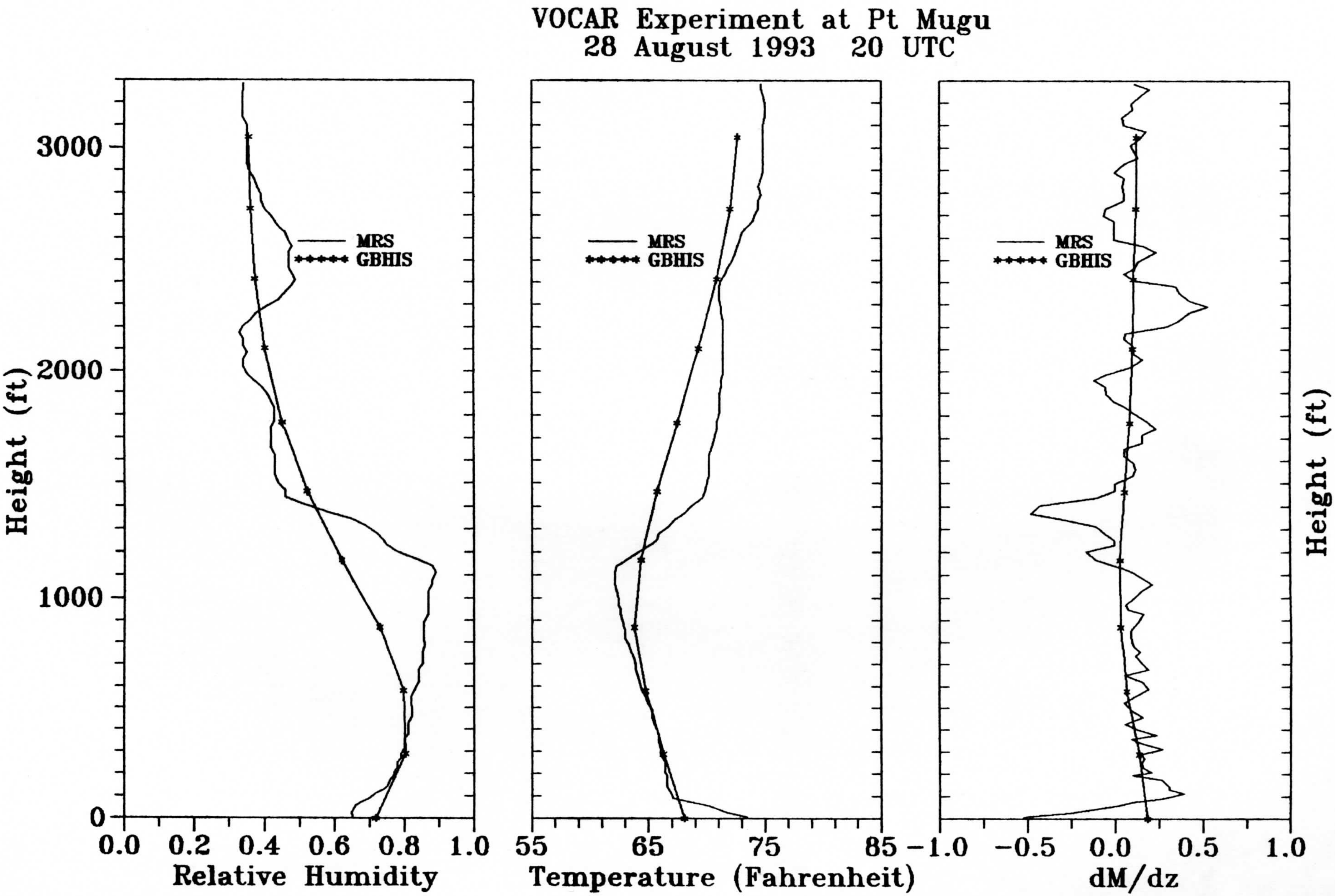


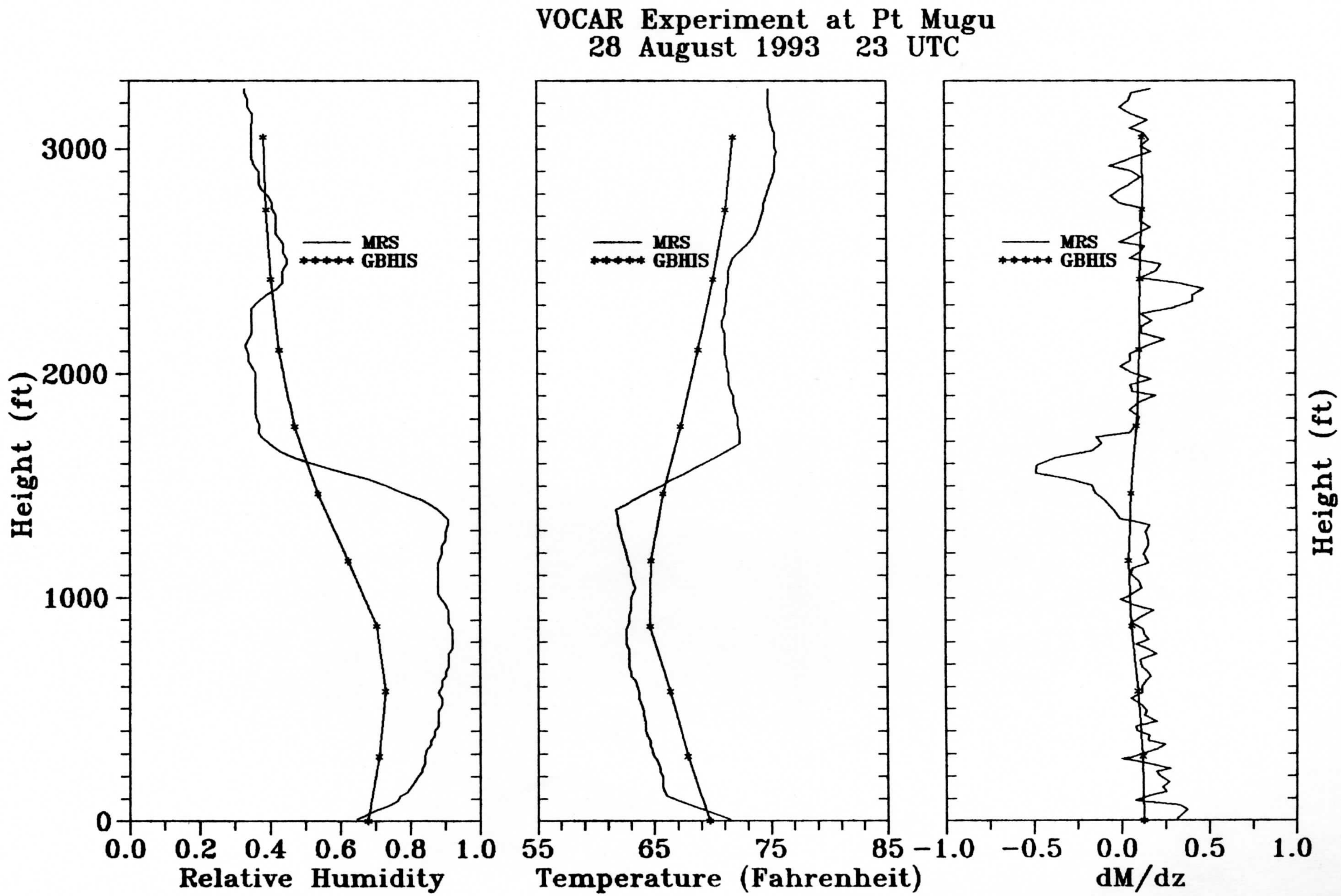


VOCAR Experiment at Pt Mugu
28 August 1993 12 UTC
Height (ft)
3000
2000
1000
0
0.0 0.2 0.4 0.6 0.8 1.0
Relative Humidity
MRS
GBHIS
55 65 75 85
Temperature (Fahrenheit)
MRS
GBHIS
−1.0 −0.5 0.0 0.5 1.0
dM/dz
MRS
GBHIS
Height (ft)



VOCAR Experiment at Pt Mugu
28 August 1993 16 UTC
Height (ft)
3000
2000
1000
0
MRS
GBHIS
0.0
0.2
0.4
0.6
0.8
1.0
Relative Humidity
55
65
75
85
Temperature (Fahrenheit)
−1.0
−0.5
0.0
0.5
1.0
dM/dz
Height (ft)

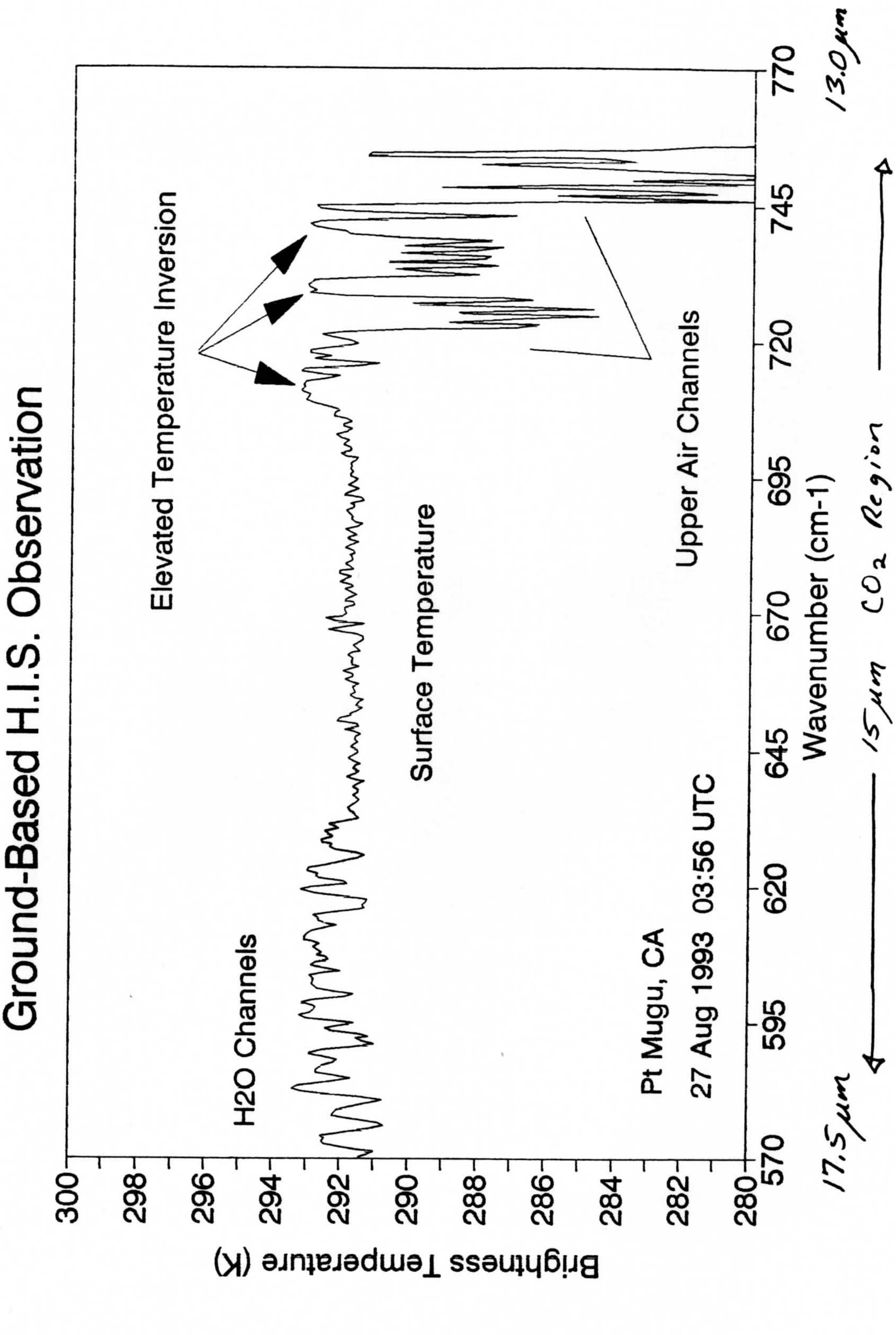

VOCAR Experiment at Pt Mugu
28 August 1993 20 UTC
Height (ft)
3000
2000
1000
0
MRS
GBHIS
0.0
0.2
0.4
0.6
0.8
1.0
Relative Humidity
55
65
75
85
Temperature (Fahrenheit)
−1.0
−0.5
0.0
0.5
1.0
dM/dz
Height (ft)


VOCAR Experiment at Pt Mugu
28 August 1993 23 UTC
Height (ft)
MRS
GBHIS
Relative Humidity
Temperature (Fahrenheit)
dM/dz
Height (ft)

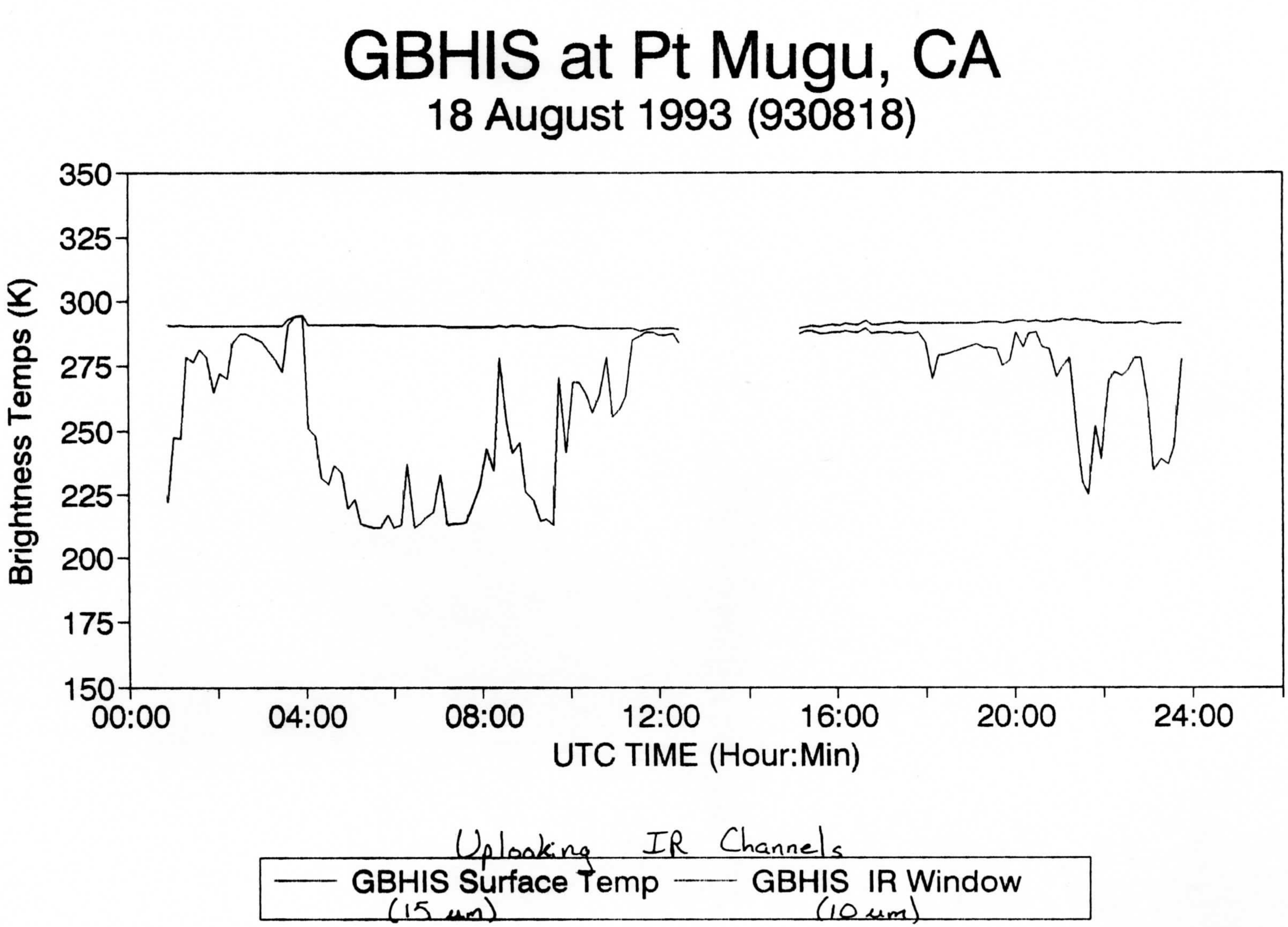
4. GBHIS INFRARED OBSERVATIONS

The GBHIS instrument measures the downwelling infrared spectrum with high radiometric and wavelength accuracy from 18.2 to 3.3 microns with a spectral resolution (unapodized) of 0.5 cm-1. An example of a small portion of the observed spectrum is given in a figure on the next page which indicates some of the channels used to detect the elevated temperature inversion. In this figure, note that 667 cm-1 is the center of the 15 micron CO_2 band and thus the emission from this region is representative of the near surface temperature. Channels at wavelengths on either side of this band center are increasing transparent in the IR and thus allow radiation from greater heights to reach the groundbased instrument. It is the relation between wavelength and optical depth (using an atmospheric model such as FASCODE) which is used in the retrieval of vertical temperature and moisture profiles.

On subsequent pages a record of the operations of the GBHIS is given in the form of a time series plot of two infrared channels (out of about 5000) converted to equivalent brightness temperature. One channel is representative of the temperature just above the instrument (15 micron) and the other channel (10 micron) is in the IR window and is sensitive to H_2O water continuum, marine aerosol, and low to mid level clouds. Clouds can be seen passing over the instrument in the IR window channel data. The most common feature of the data is the low stratus deck which almost always was present from midnight to noon local time. Gaps in the time series represent times when the instrument was not operating. Nearly all the down periods are during low overcast conditions for which analysis of the GBHIS data is not very exciting.

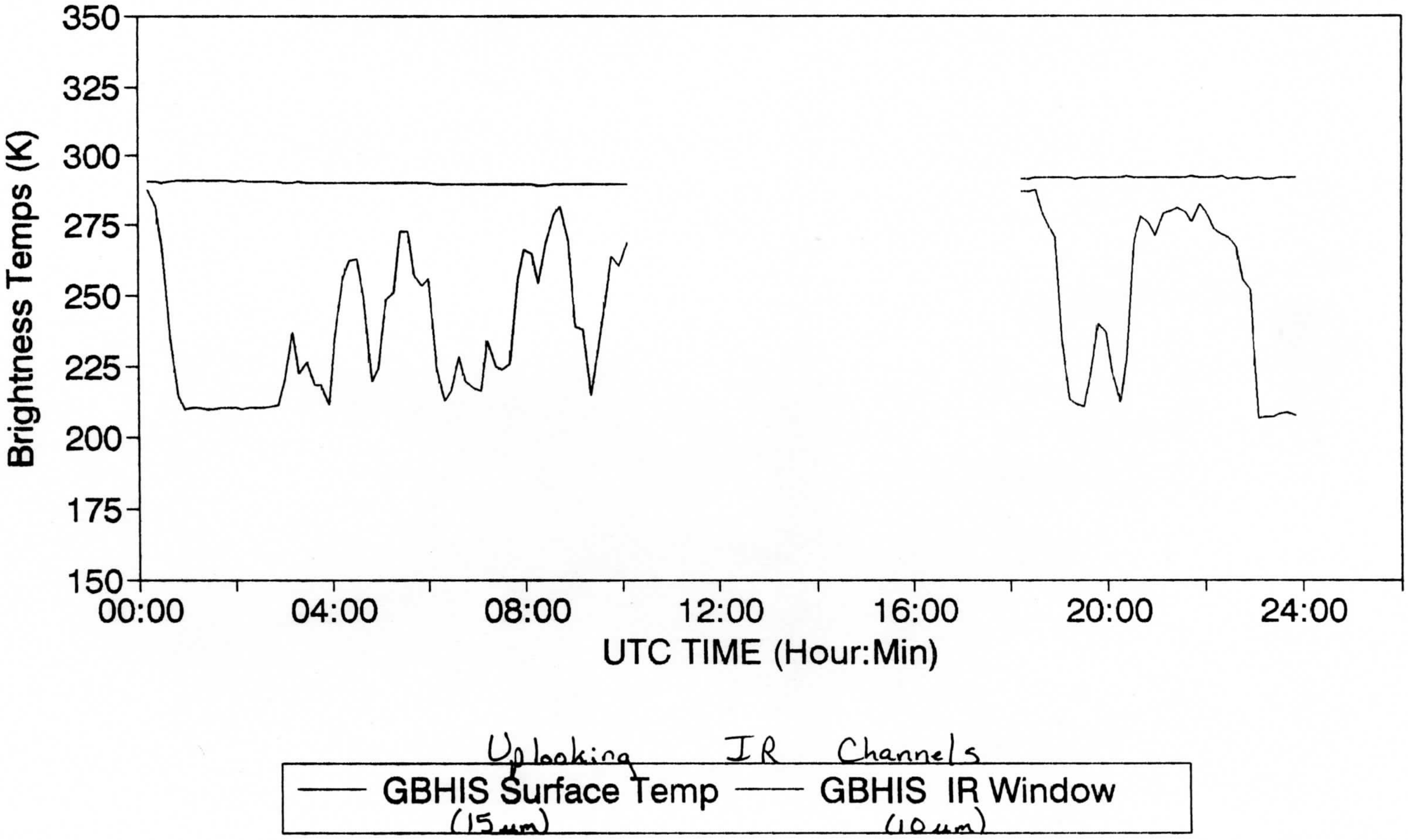


- GBHIS Measurement Characteristics -


GBHIS at Pt Mugu, CA
18 August 1993 (930818)
Brightness Temps (K)
350
325
300
275
250
225
200
175
150
00:00
04:00
08:00
12:00
16:00
20:00
24:00
UTC TIME (Hour:Min)
Uplooking IR Channels
GBHIS Surface Temp
(15 um)
GBHIS IR Window
(10 um)

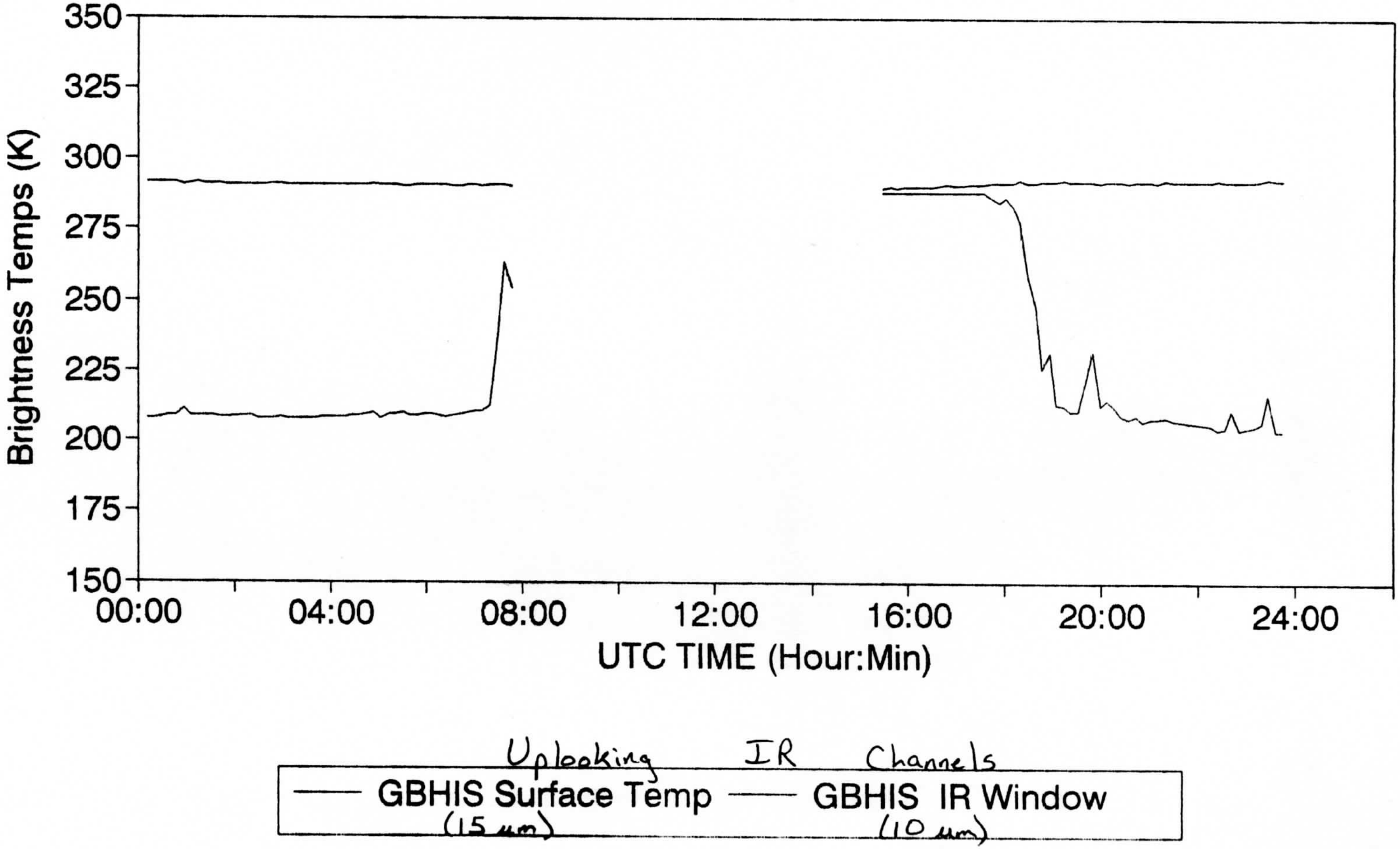
GBHIS at Pt Mugu, CA

19 August 1993 (930819)



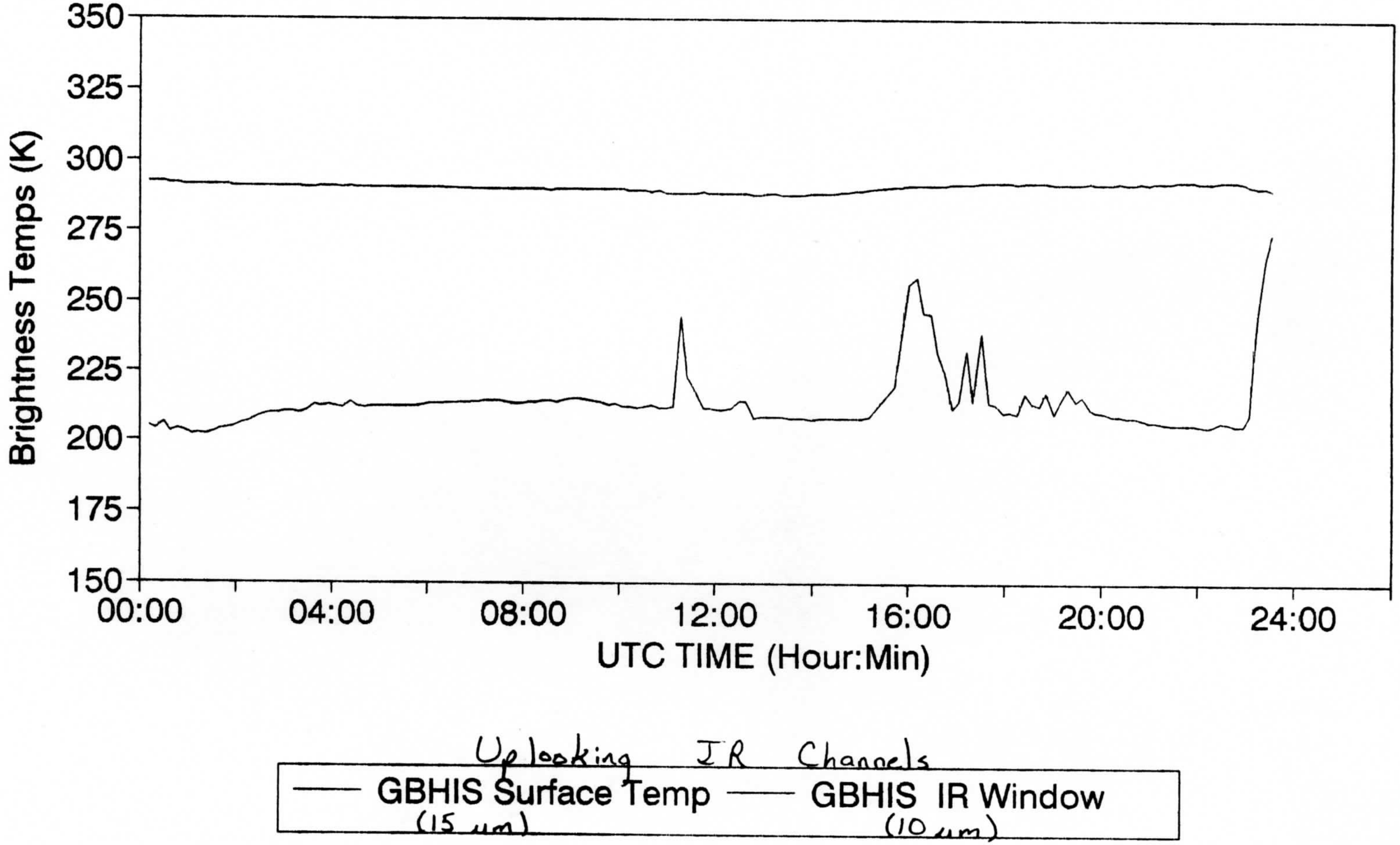
GBHIS at Pt Mugu, CA

20 August 1993 (930820)



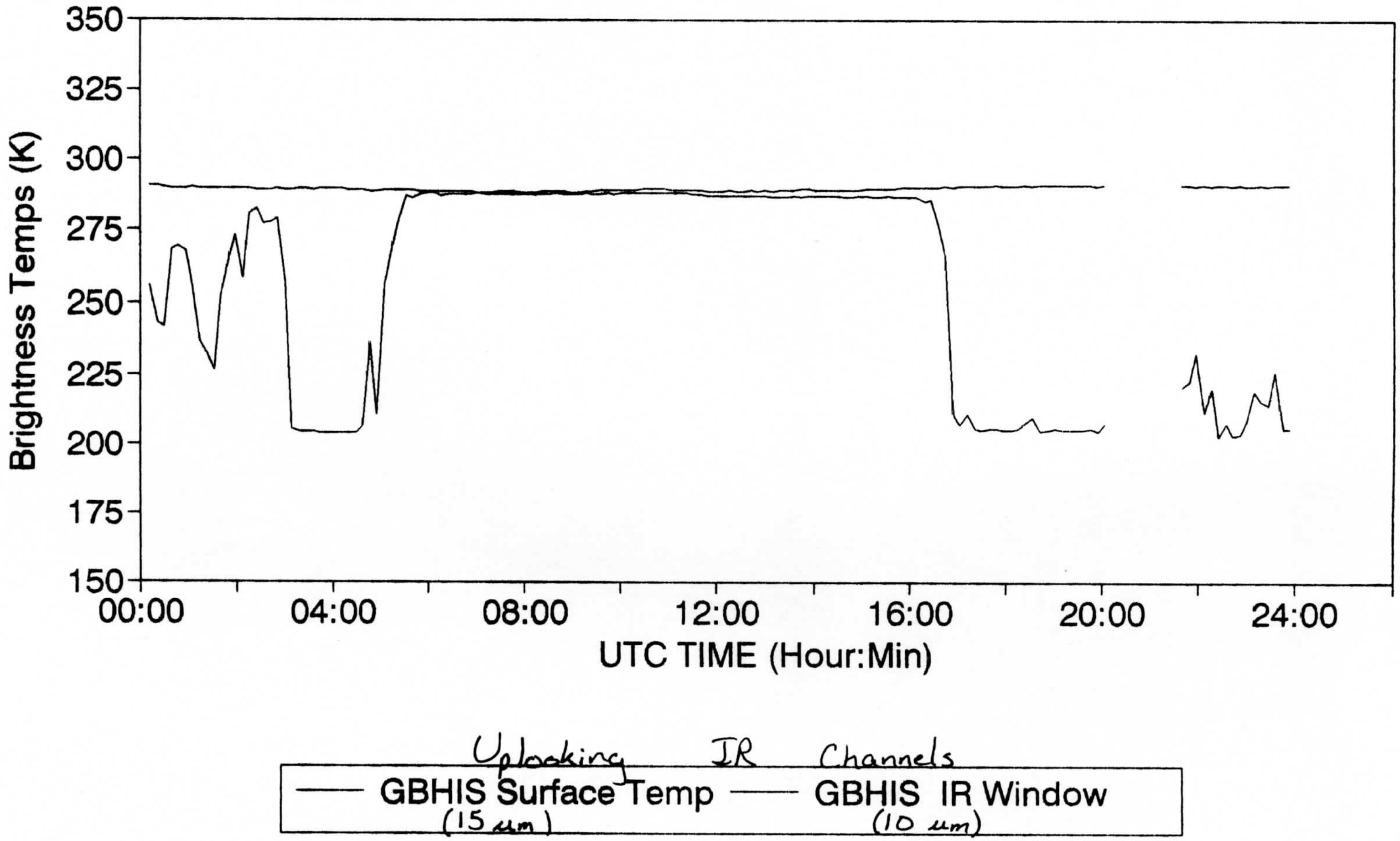
GBHIS at Pt Mugu, CA

21 August 1993 (930821)



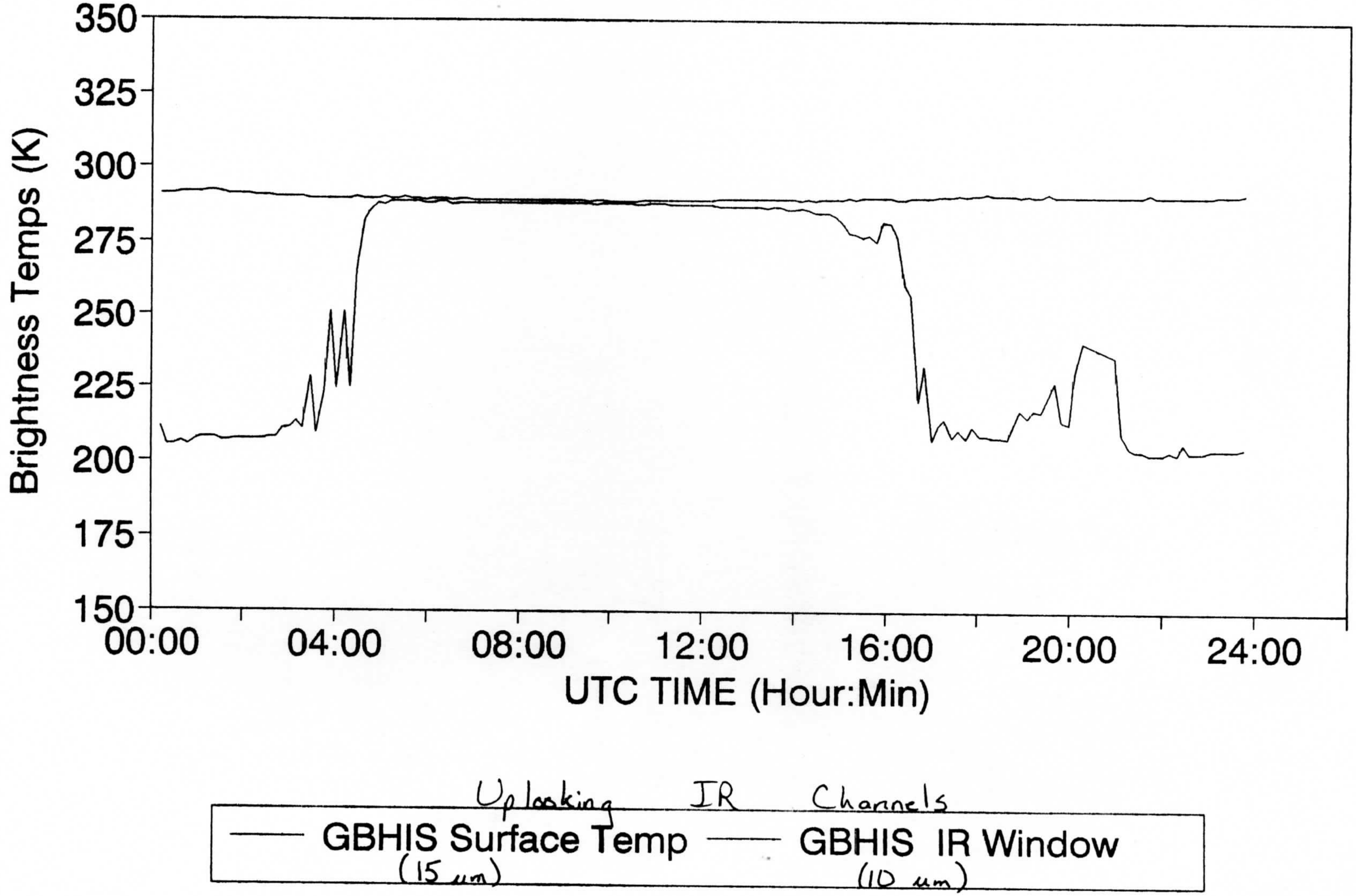
GBHIS at Pt Mugu, CA

22 August 1993 (930822)



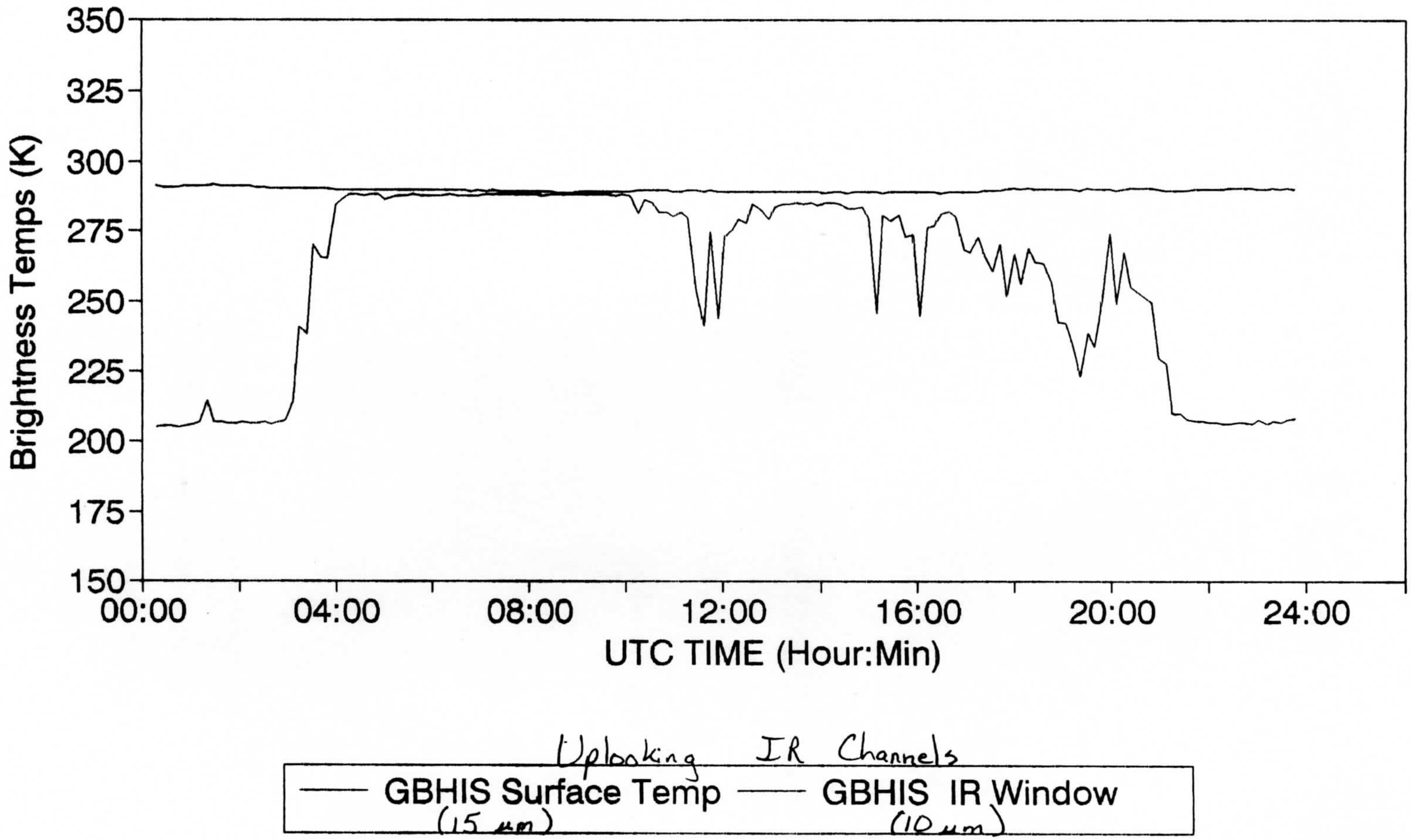
GBHIS at Pt Mugu, CA

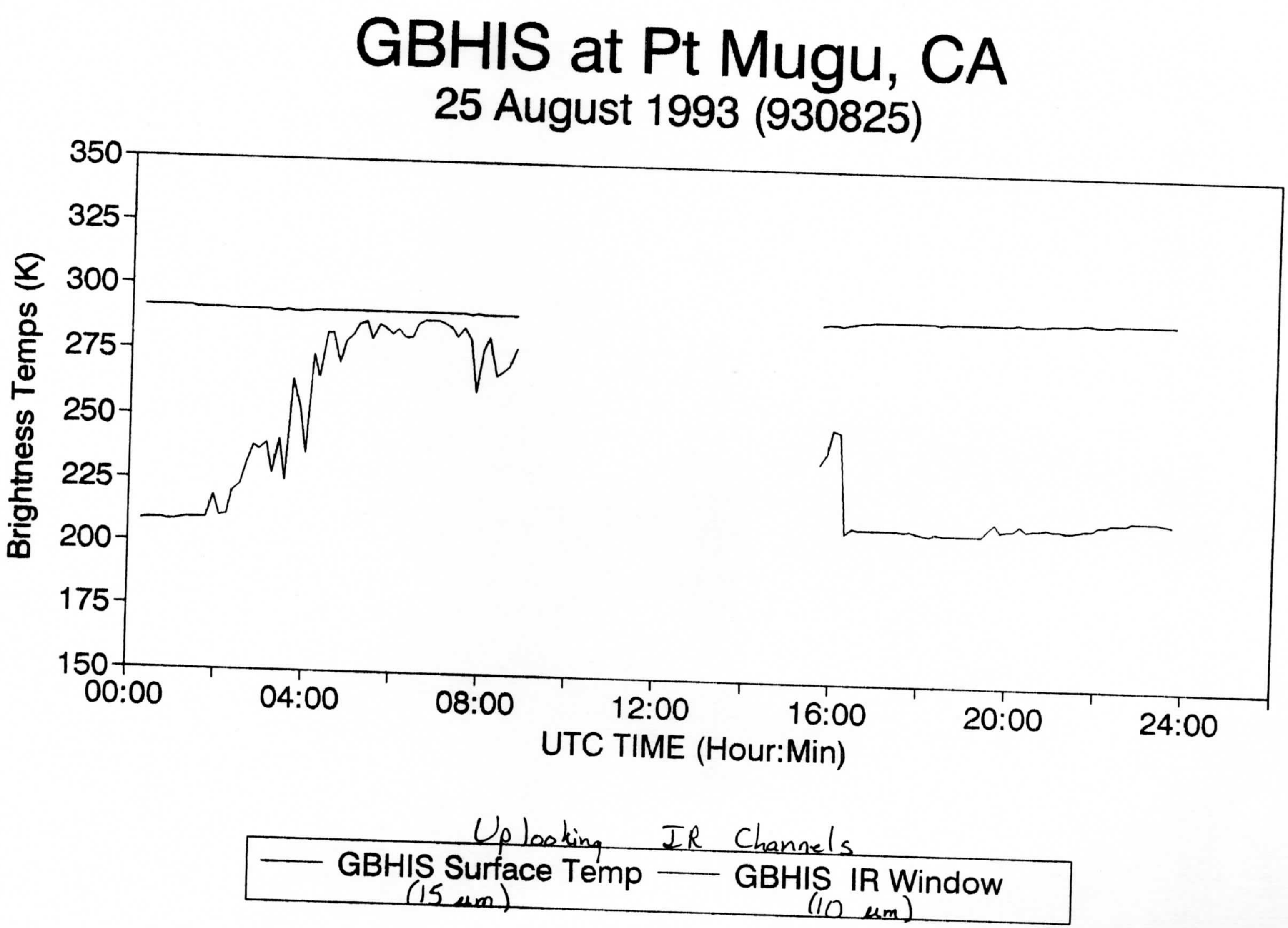
23 August 1993 (930823)



GBHIS at Pt Mugu, CA

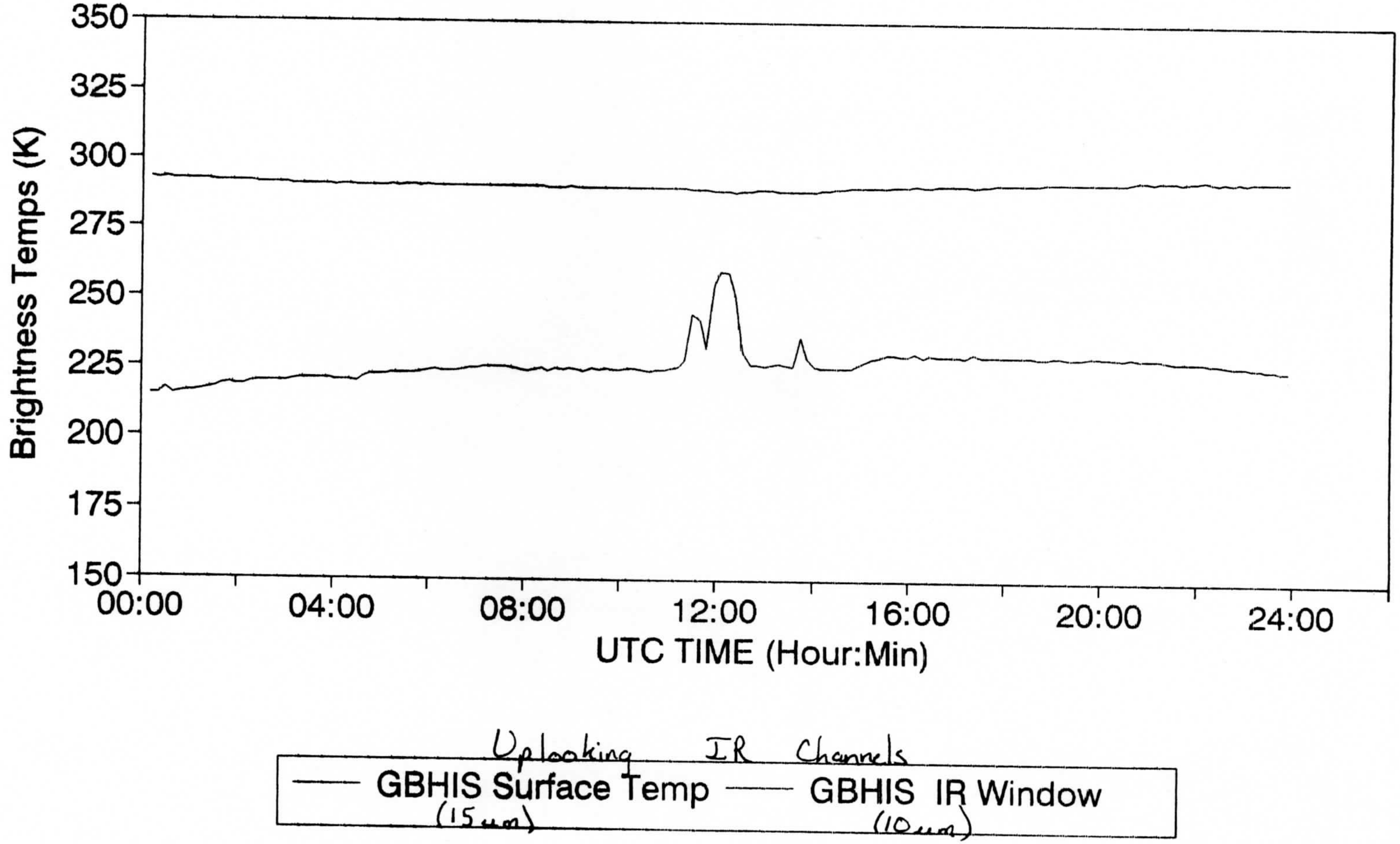
24 August 1993 (930824)




GBHIS at Pt Mugu, CA
25 August 1993 (930825)
Brightness Temps (K)
350
325
300
275
250
225
200
175
150
00:00
04:00
08:00
12:00
16:00
20:00
24:00
UTC TIME (Hour:Min)
Uplooking IR Channels
GBHIS Surface Temp (15 µm)
GBHIS IR Window (10 µm)

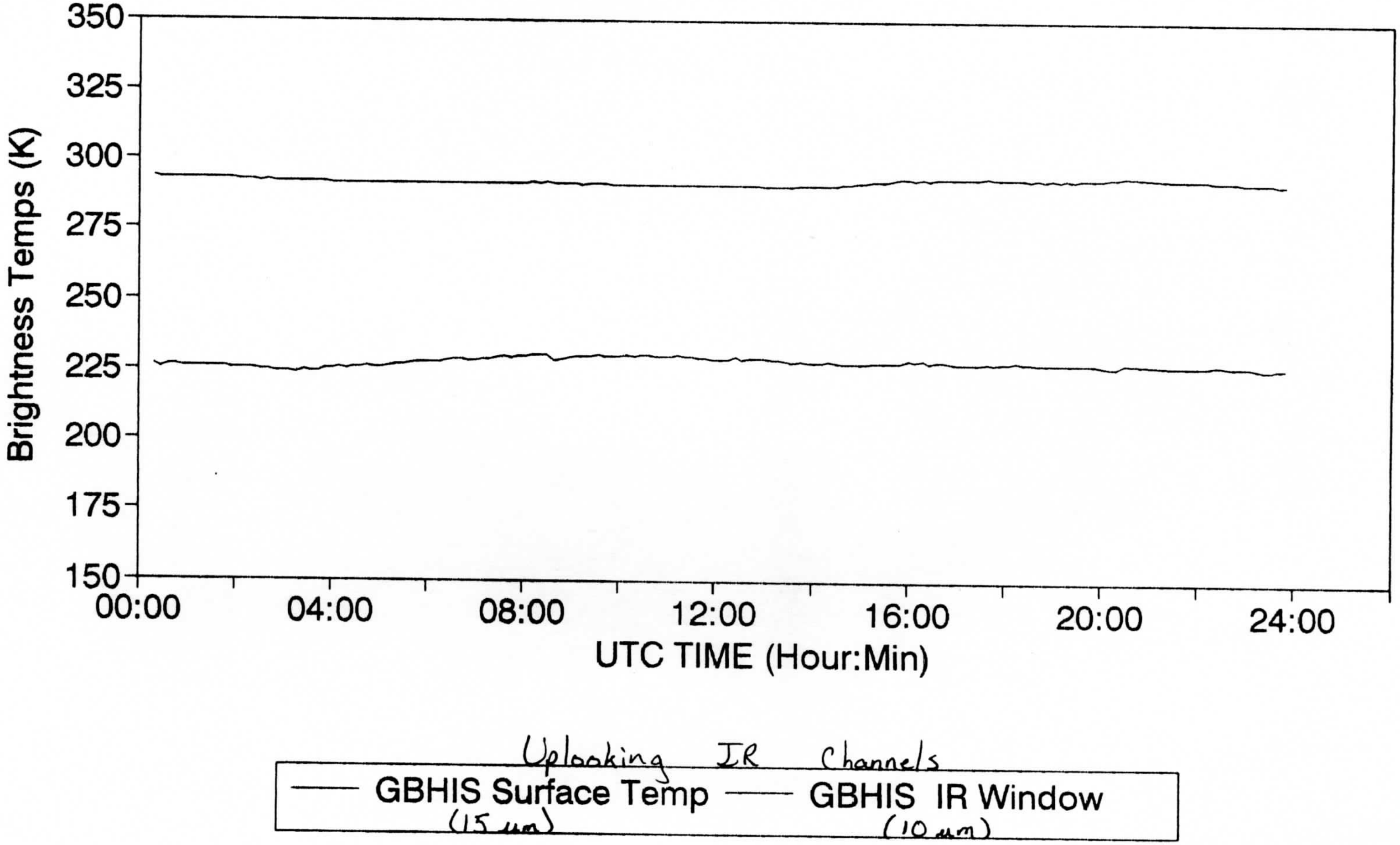
GBHIS at Pt Mugu, CA

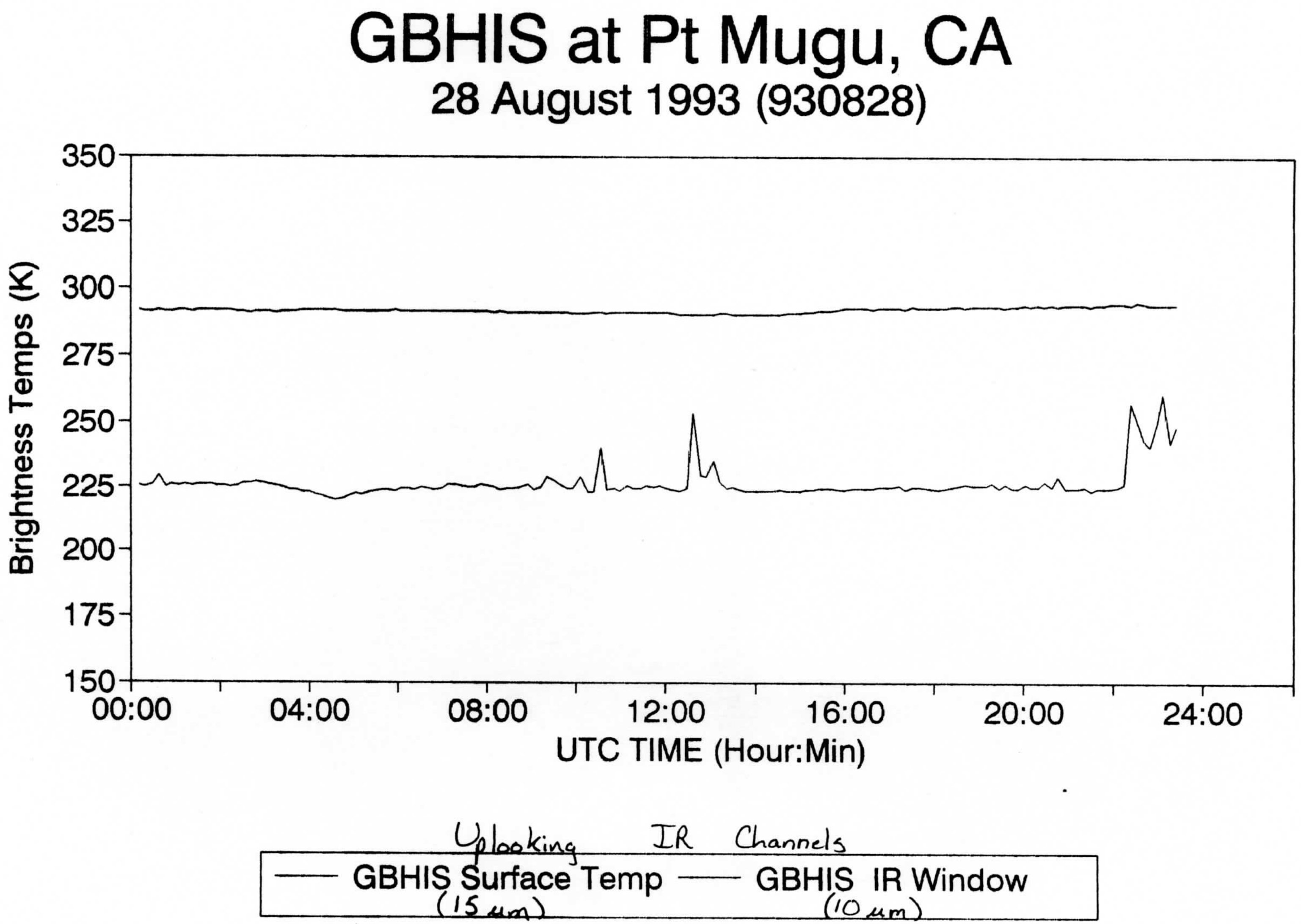
26 August 1993 (930826)



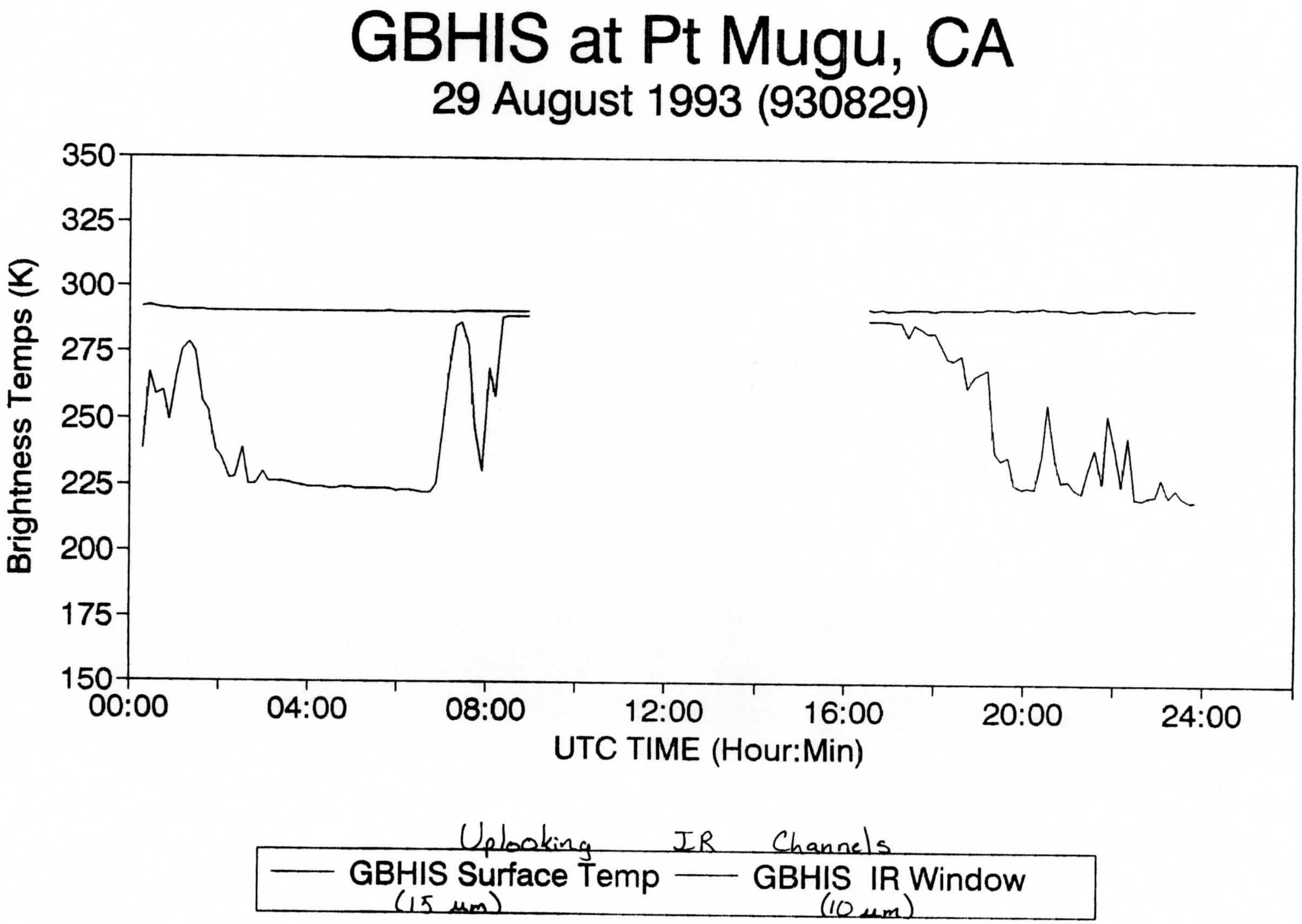
GBHIS at Pt Mugu, CA

27 August 1993 (930827)



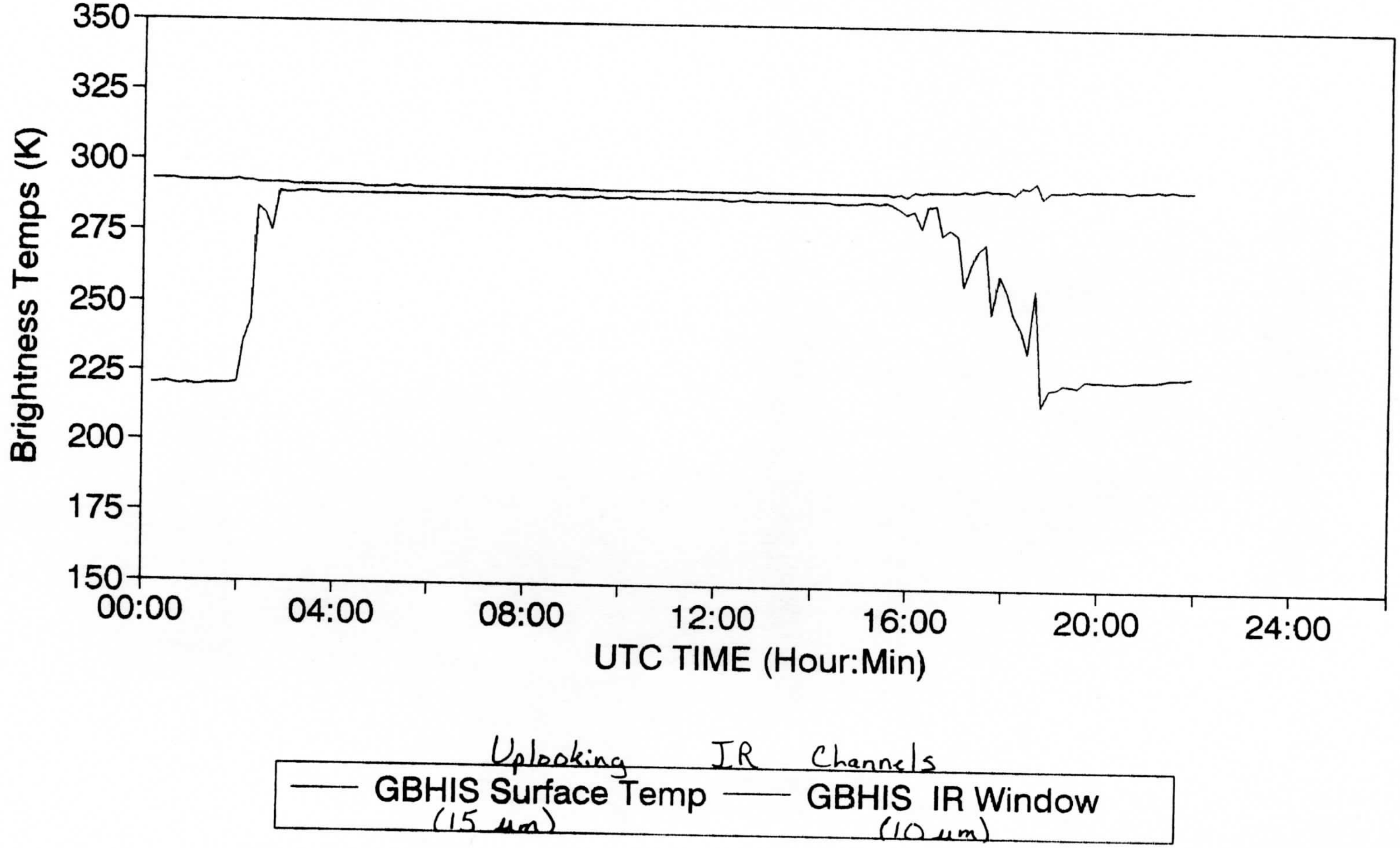


GBHIS at Pt Mugu, CA
28 August 1993 (930828)
Brightness Temps (K)
350
325
300
275
250
225
200
175
150
00:00
04:00
08:00
12:00
16:00
20:00
24:00
UTC TIME (Hour:Min)
Uplooking IR Channels
GBHIS Surface Temp (15 µm)
GBHIS IR Window (10 µm)


GBHIS at Pt Mugu, CA
29 August 1993 (930829)
Brightness Temps (K)
350
325
300
275
250
225
200
175
150
00:00
04:00
08:00
12:00
16:00
20:00
24:00
UTC TIME (Hour:Min)
Uplooking IR Channels
GBHIS Surface Temp
(15 um)
GBHIS IR Window
(10 um)

GBHIS at Pt Mugu, CA

30 August 1993 (930830)



GBHIS at Pt Mugu, CA

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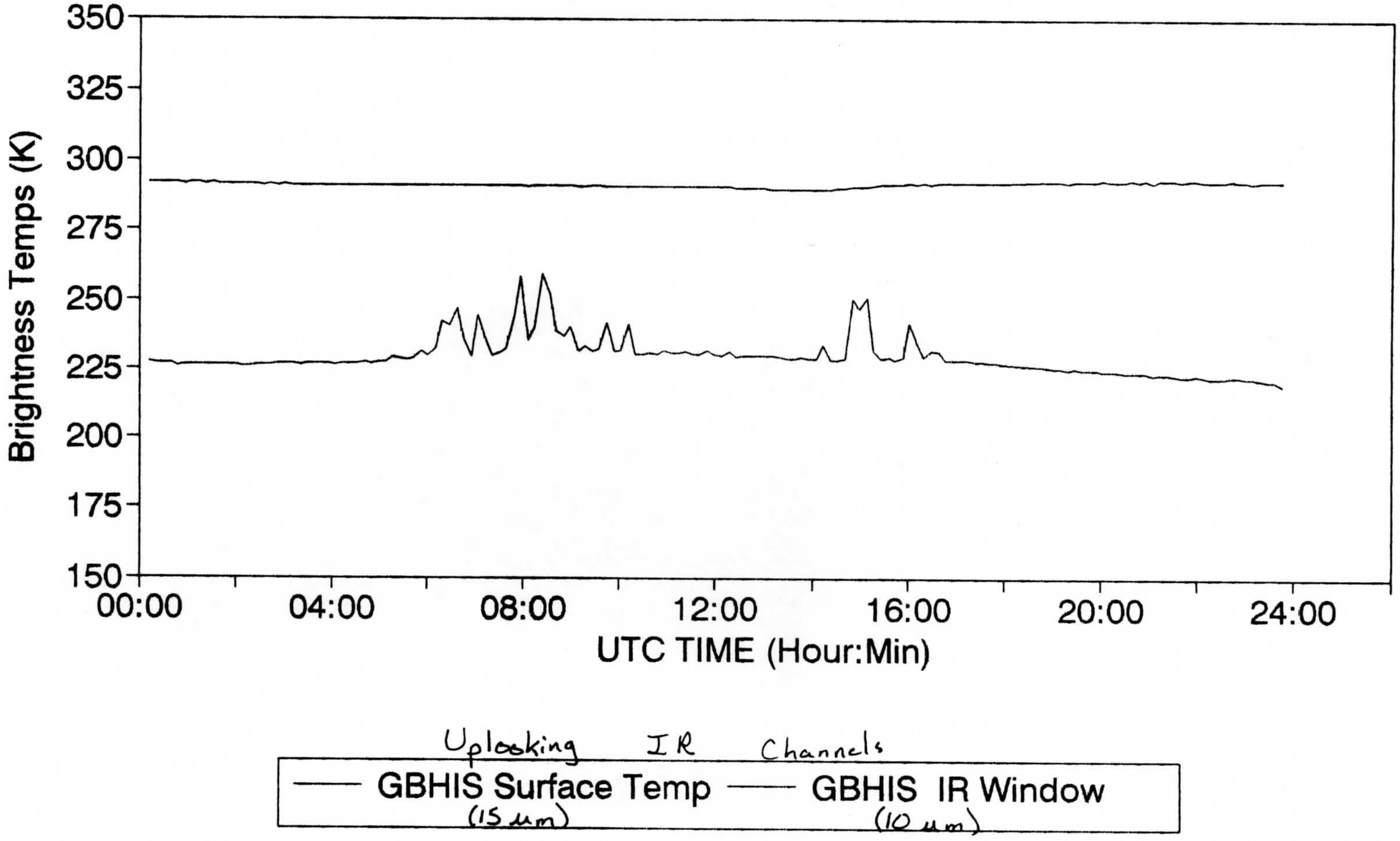
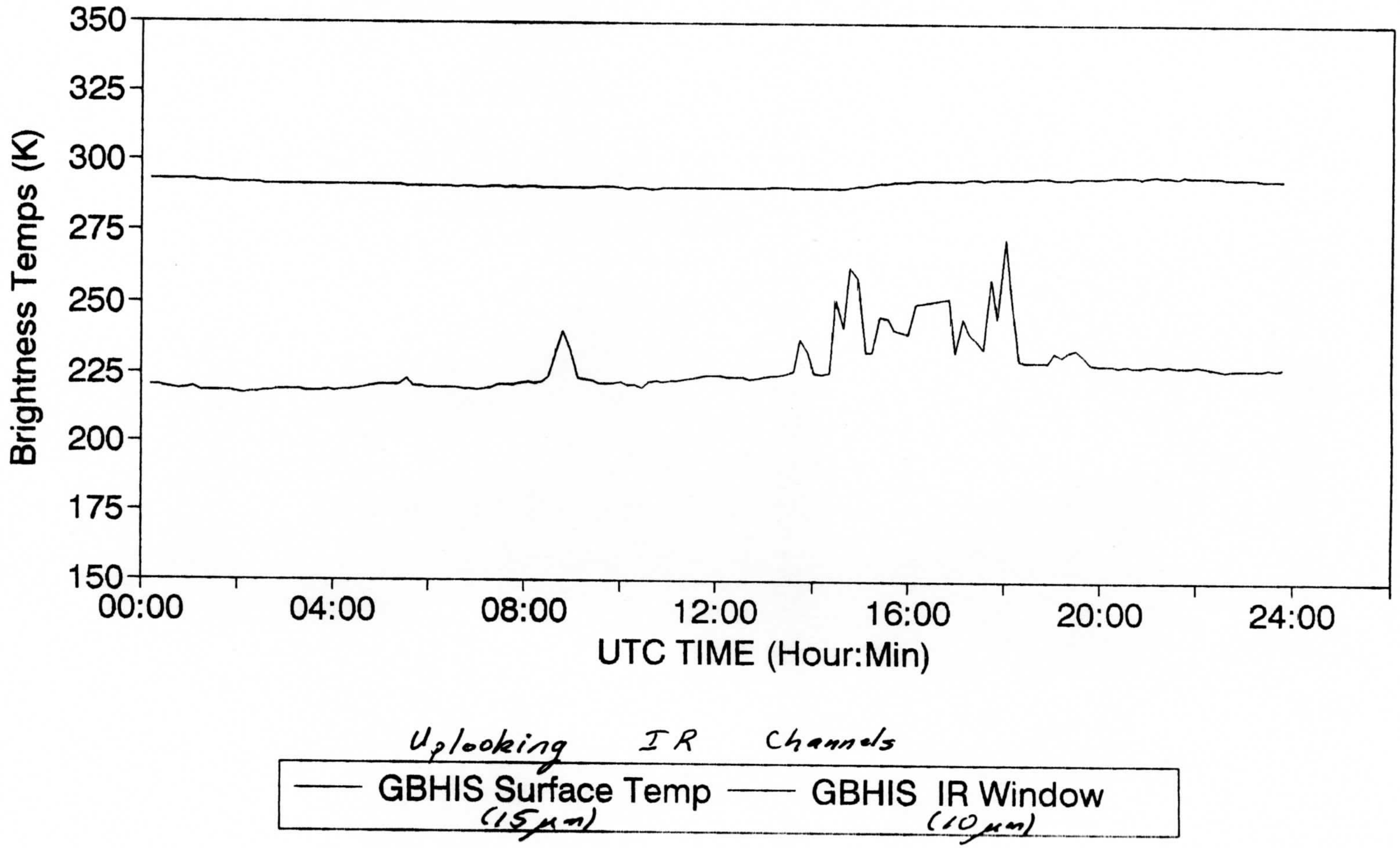


GBHIS at Pt Mugu, CA

1 September 1993 (930901)



GBHIS at Pt Mugu, CA

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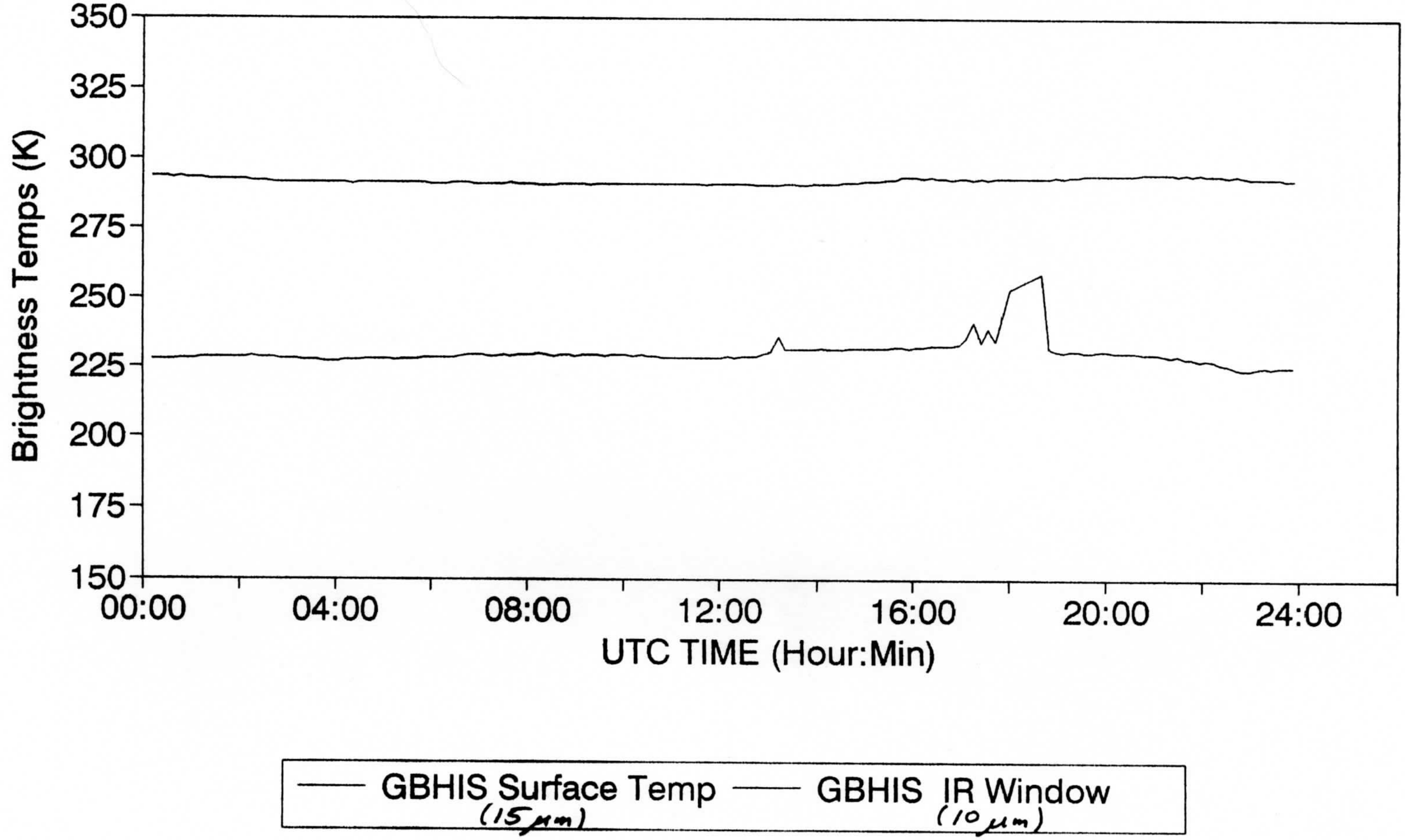
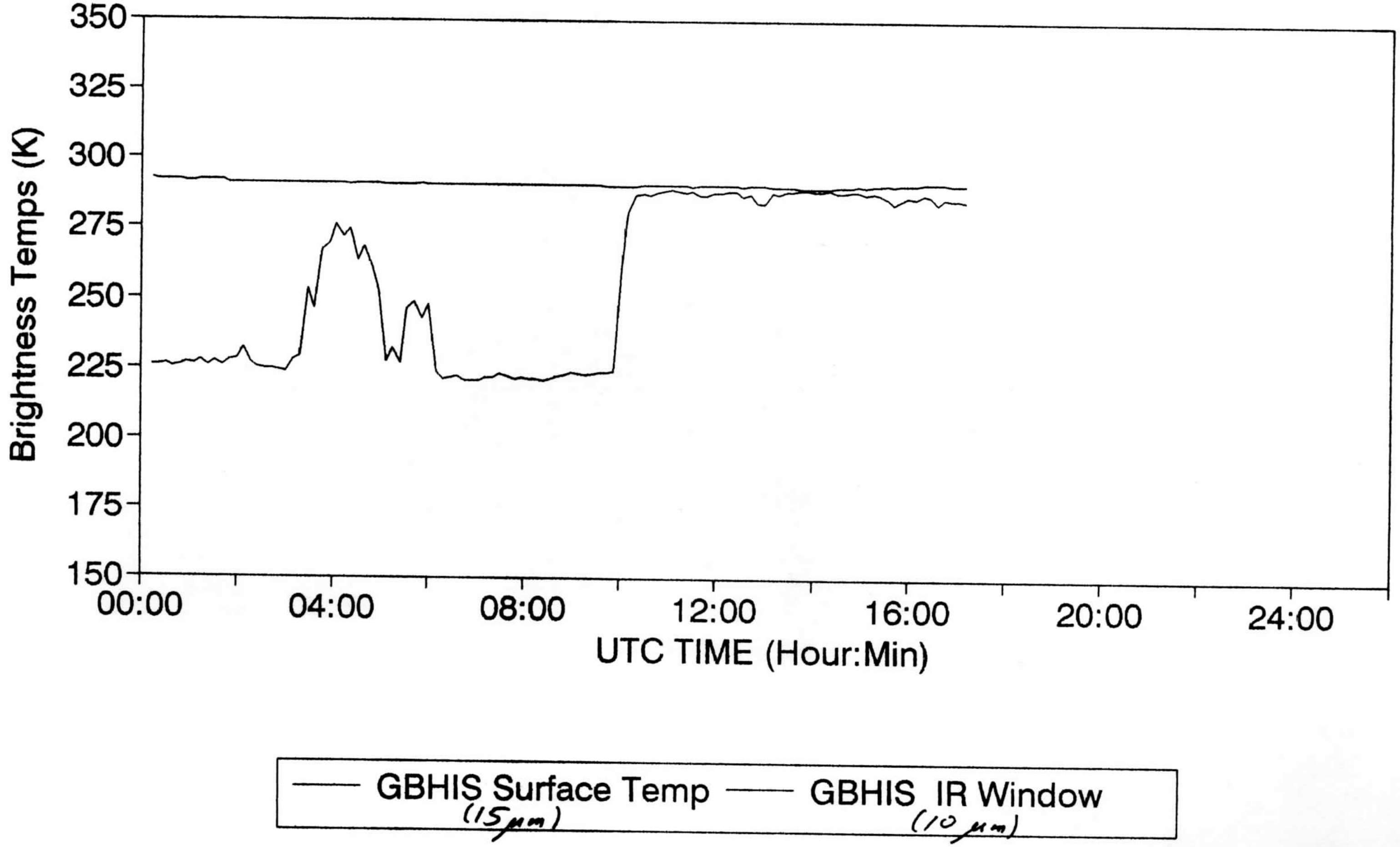


GBHIS at Pt Mugu, CA

3 September 1993 (930903)



5. PRELIMINARY CONCLUSIONS

The GBHIS system as deployed during VOCAR at Pt Mugu shows promise as a passive monitor of changes in radar refractivity in the coastal environment. The GBHIS has considerable skill in observing "layered average" vertical variations in radar refractivity and has the advantage of high temporal frequency with a completely passive device. A key question for the Navy is the accuracy and vertical resolving power required for adequate characterization of inputs needed for propogation models and how frequently those inputs need to be updated.

University of Wisconsin participation in VOCAR has resulted in the collection of a unique dataset for further research into optimizing retrieval of temperature and moisture profiles in the marine environment, especially with respect to aerosols. It is anticipated that the combination of GBHIS infrared, JPL microwave, and the RAMAN lidar data will provide a realistic picture of the relative merits of remote sensing system as applied to this application.