Field Data Report for Radiobrightness Energy Balance Experiment 0 (REBEX-0), August 1992--September 1992, UM Matthaei Botanical Gardens

Edward J. Kim and Anthony W. England

August, 1996

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Abstract

Radiobrightness Energy Balance Experiment 0 (REBEX-0) was conducted at the University of Michigan's Matthaei Botanical Gardens in Ann Arbor, Michigan from August 19, 1992 to September 8, 1992. This represented the first field use of the Tower Mounted Radiometer System (version 1), a set of microwave radiometers operating at Special Sensor Microwave/Imager (SSM/I) frequencies, along with a suite of micrometeorological instruments.

Acknowledgement

We thank the staff of the Matthaei Botanical Gardens for their assistance during REBEX-0.

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1 Introduction

Our Radiobrightness Energy Balance Experiment 0 (REBEX-0) was conducted locally at the University Botanical Gardens beginning in August, 1992, as a shakedown test of the Tower Mounted Radiometer System (version 1). This was in preparation for REBEX-1, our first full-length experiment, which was scheduled to begin in September in Sioux Falls, South Dakota [3]. During REBEX-0, we were concerned with learning how to deploy and operate TMRS-1 under field conditions, as we had never done either before, and were originally not so worried about getting useful data.

As it turned out, there were no major deployment problems, and we did get about 20 days of useful data. The experience from REBEX-0 helped make REBEX-1 deployment quick and fairly straightforward. While REBEX-0 and REBEX-1 were both conducted at grassy sites, and thus similar in many respects, the differences were complementary and should improve our understanding of land-atmosphere interactions in such areas.

A brief description of the Botanical Gardens site is given in Chapter 2. Chapters 3 and 4 describe the instruments and observations, respectively, and the Appendices contain summary plots of the field data.

2 Site Description

2.1 Matthaei Botanical Gardens

The Botanical Gardens site (42°17.7' N, 83°40.5' W) consisted of a field with a fairly uniform grass cover similar to that of unmowed lawn grass (for a close-up, see Figure 1). Detailed measurements of the grass canopy density and moisture profiles were made at a later time [1]. Figure 2 presents a view of the experimental area looking north. Electrical power was obtained from outlets within the fenced research enclosure. A telephone line was extended from a shed within the enclosure. All measurements were made within a semi-circular area with a radius of approximately 15 m centered on the tower (see Figure 3). The site was flat throughout this area.

Low mounds ($<$ 1 m high) about 50 m to the east and the fenced area to the immediate north were the primary nearby wind obstructions. The fetch to the south and to the west was at least 200 m (see Figure 4).

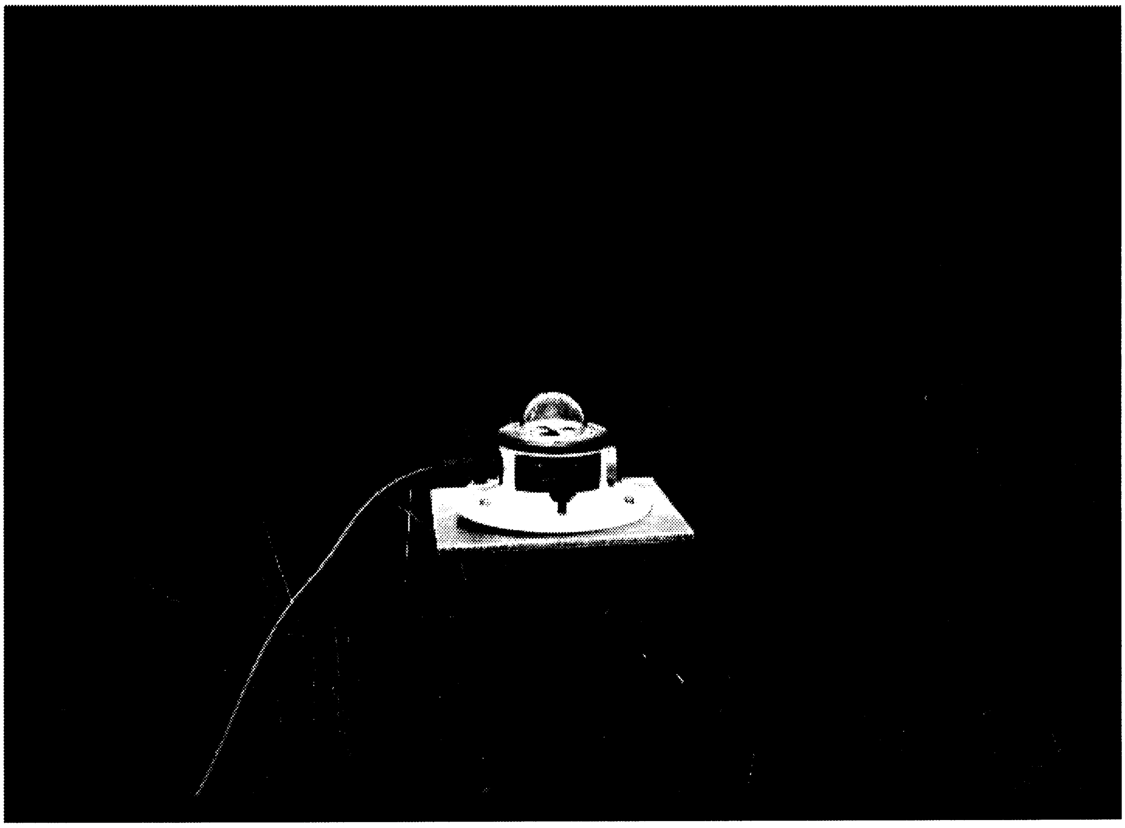

Figure 1: Pyranometer with dew and close-up of grass.

Figure 2: REBEX-0 site, looking north.

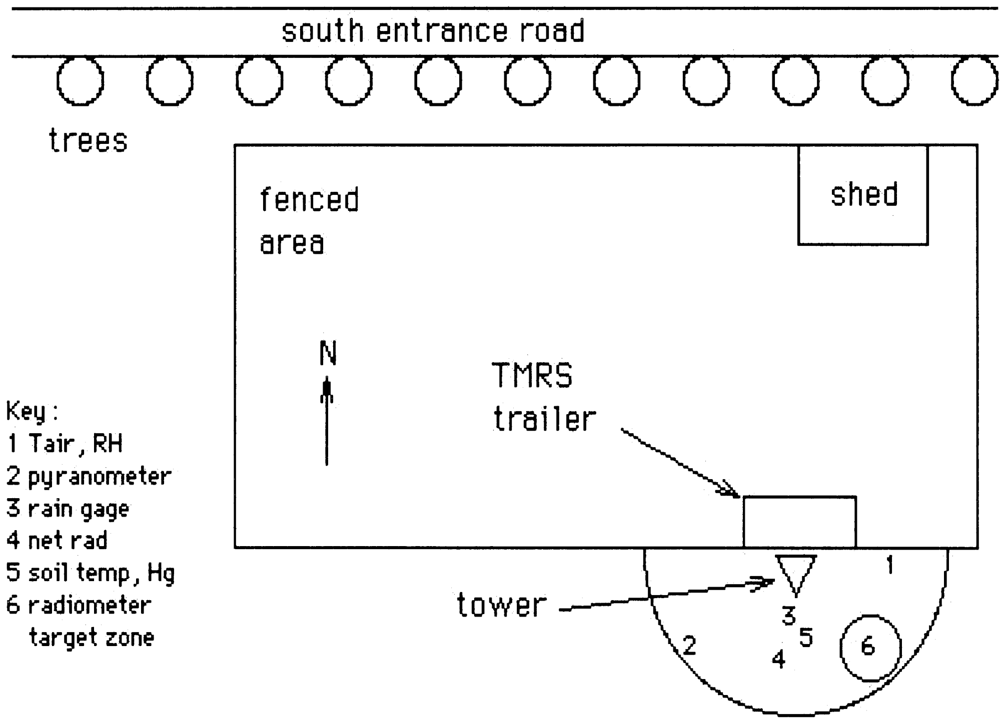

Figure 3: Plan view of the REBEX-0 site (not to scale).

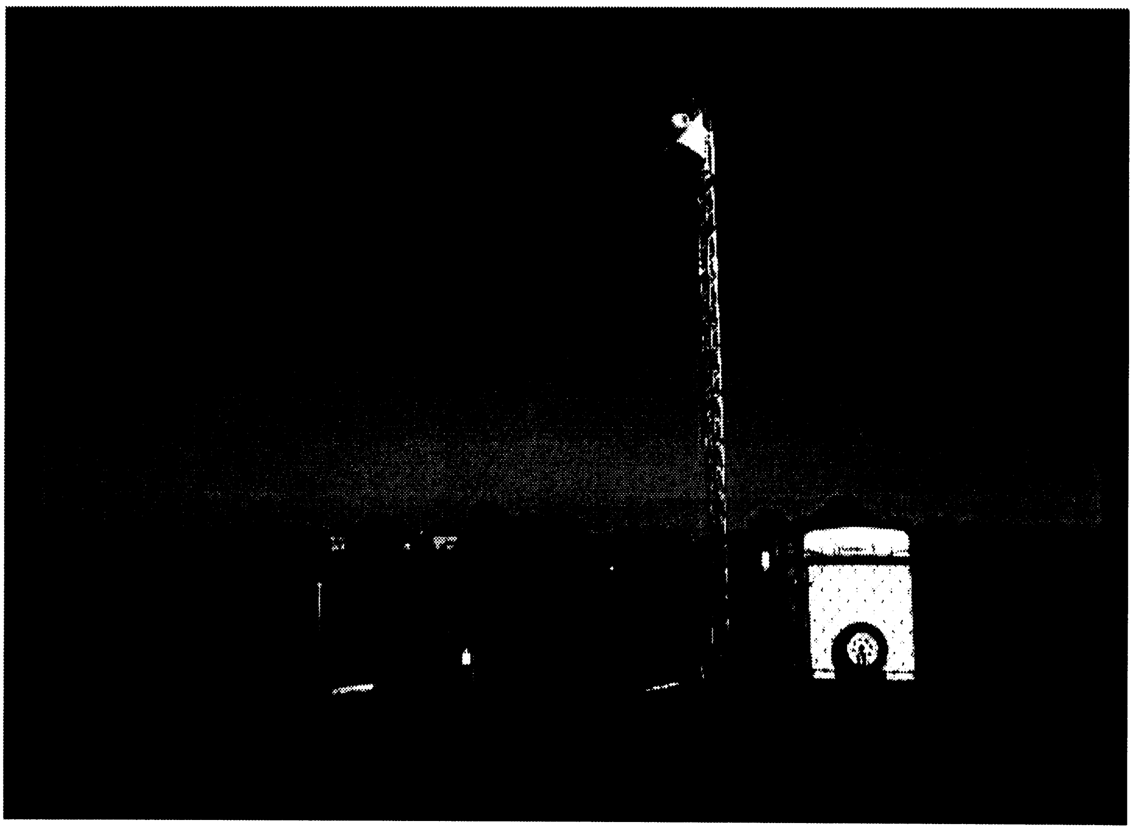

Figure 4: REBEX-0 site, looking west.

2.2 Differences between REBEX-0 and REBEX-1

REBEX-0 differed from REBEX-1 in the following significant respects:

- Qualitatively, the REBEX-0 grass was essentially long lawn grass with scattered "weeds," while the REBEX-1 grass more closely resembled prairie vegetation or an agricultural crop such as wheat. And, the REBEX-0 canopy was shorter and much less uniform in height, orientation, and composition. The soil at the REBEX-0 site was sandier and had less humus than the rich Great Plains soil at the REBEX-1 site. Quantitatively, the REBEX-0 grass had a lower column density [2].

- REBEX-0 took place toward the end of the growing season, well before senescence, while REBEX-1 *began* just before the vegetation became sensescent.

- Twice-daily soil and vegetation samples were collected during a large part of the REBEX-0 period compared with 7 samples during all of REBEX-1.

- Estimates of cloud cover in the direction of the sky radiobrightness observations were made each time soil and grass samples were taken. Cover was subjectively estimated to the nearest 10 % between 0.0 (no clouds) to 1.0 (completely overcast). Color photos were also taken.

3 Instruments

The instruments used during REBEX-0 were identical to those used during REBEX-1. They are listed and described briefly in this section, but for more detailed descriptions, including sensor specifications, the reader is referred to [3].

3.1 Radiometers

"Radiometers" here refer to the microwave and infrared radiation sensors, not the solar shortwave and net radiation sensors, which are also called "radiometers" by some. The TMRS-1 radiometers were located in a metal housing at the top of a 10-meter tower. There were three single-polarization microwave radiometers at the 19.35, 37.0, and 85.5 GHz SSMI/I frequencies. For REBEX-0, these observed horizontally-polarized ground and sky radiation (see section on "sky brightnesses" below). The infrared sensor observed thermal IR "skin" temperatures with an assumed target emissivity of 0.95.

3.2 Micrometeorological instruments

The TMRS-1 suite of micrometeorological sensors was designed to measure quantities which determine the surface energy balance. These included solar and net radiation, soil heat flux, soil temperature at 6 depths, wind speed (but not direction), precipitation, air temperature, and relative humidity.

3.3 Other equipment

A 83 mm (3.25 in) diameter coring tool was used to take soil samples for determining near-surface moisture and bulk density.

4 Observations

Weather conditions were generally hot and humid, with dew formation nearly every night. Significant precipitation fell on day 240 and days 241–242. Prior to day 240, conditions had been dry and fairly constant from day to day for several days. After day 242, little additional precipitation was received until day 246. Thus, the REBEX-0 period includes initially dry conditions, then strong precipitation followed by a dry-down—a very interesting and informative sequence of events.

In the remainder of this report, times will be given in the format "*jjj//hhmm*" where *jjj* is the 1992 Julian Day (001 = 1 Jan 92) *hhmm* is the time of day in 4-digit, 24-hour format. Occasionally, the format "*jjj.fff*" will also be used where *fff* is the time of day expressed as a decimal portion of a day. All times are with respect to US Eastern Daylight Savings Time (EDT), which is 4 hours behind Universal Coordinated Time (UTC) for our purposes [5].

4.1 Automatic Measurements

Every 10 minutes, all of the instruments were read automatically, and the output values were recorded. These "experiments" began at 0, 10, 20, 30, 40, and 50 minutes past the hour and lasted 3 minutes. Experiments began on 231//2122 (18 Aug 92) and ended on 252//0600 (8 Sep 92). The first experiment with a complete set of readings (radiometric and meteorological) was the 232//2033 experiment. The last experiment with a complete set of readings was the 247//1252 experiment, however, meteorological readings continued until 251//1020.

The 3-dB antenna beamwidths of the microwave radiometers were all 10°, which corresponds to a 4 m × 2 m target area on the ground. The IR radiometer beamwidth was 15°, which corresponds to a 6 m × 3 m target area. The site was flat and uniform over these areas. Radiometer integration time was 6 seconds.

4.2 Soil and Vegetation Samples

As mentioned earlier, one of the strengths of REBEX-0 was the relatively frequent sampling of the soil and grass. The sampling was intended to provide a coarse indicator of diurnal moisture variations without resorting to a truly statistically robust (both spatially and temporally) and manpower-intensive sampling strategy.

The grass (including the thatch) immediately above each soil coring location was cut with a sharp knife at the level of the soil surface. For grass-like vegetation canopies with well-developed near-surface root systems, the "surface" can be difficult to determine. For REBEX-0 we defined the surface to be the plane below which significant amounts of solid soil particles begin to occur—approximately the stopping plane as one presses down firmly with one's palm). Grass samples were stored in sealed plastic bags and weighed. The sample bags were later opened and the grass baked in an oven at 40° C (simulating a hot daytime temperature) for 3 days, then weighed again. The results of the vegetation sampling are listed in Table 1 along with dew and cloud cover observations. These data were noisy in general and are included here mainly for completeness.

The soil coring process is depicted in Figures 5–7. The 0–2, 2–4, and 4–6 cm segments were sliced off and placed in paper cups (Figure 6). Each slice had a volume of 107 cm^3. These sample cups were then weighed within 15 minutes. The samples were later baked in their cups (plastic covers removed) in an oven at 100° C for one day, then weighed again.

The results of the soil sampling are tabulated in Table 2. The morning samples were intended to be taken while dew was still present on the grass in an attempt to obtain a maximally-wet soil sample each day before significant evaporation from the soil. The afternoon samples were taken at the approximate time of peak soil temperature in an attempt to obtain a maximally-dry soil sample. Samples were not taken during rain because it was deemed too likely that the soil core would be contaminated with rainwater (puddles covered the ground).

Day_no_	Time24	Dew_	Veg_Wet	Veg_Dry	Vgrv	Vmix	clouds
235.6	1500	0	6.89	2.97	0.57	1.32	0.1
236.3	800	1	10.2	4.22	0.59	1.42	0
236.6	1500	0	6.13	3.97	0.35	0.54	0.6
237.3	800	2					
237.6	1500	0	7.98	3.79	0.53	1.11	0.9
238.3	800	1	17.19	6.43	0.63	1.67	0.7
238.6	1430	1	12.35	7.33	0.41	0.68	0.9
239.3	800	- 9					
239.6	1500	0	11.78	6.31	0.46	0.87	0.9
240.4	900	1	28.07	9.02	0.68	2.11	1
240.6	1500	2					
241.3	800	2					
241.6	1500	1	33.95	14.37	0.58	1.36	1
242.4	830	1	25.43	9.39	0.63	1.71	0
242.6	1500	0	9.16	4.11	0.55	1.23	1
243.4	945	0	13.87	5.98	0.57	1.32	0.9
243.8	1800	0	20.81	8.13	0.61	1.56	0
244.3	800	- 9					
244.7	1730	0	14.14	7.69	0.46	0.84	0.3
245.4	900	1	13	5.67	0.56	1.29	0
245.6	1430	0	7.88	4.32	0.45	0.82	0.3
246.3	800	1	14.48	7.64	0.47	0.90	0.1
246.6	1500	0	10.17	5.45	0.46	0.87	1

Table 1: Vegetation sample data. Masses are in grams. Key for "dew" column: 0 = no dew, 1 = dew, 2 = rain, -9 = no sample taken. "Veg_Wet" and "Veg_Dry" are the wet and dry sample mases, respectively. "Vgrv" is the gravimetric moisture, and "Vmix" is the moisture mixing ratio. See text for description of "clouds" index.

Figure 5: Soil sampling: pounding the coring tool into the ground.

Figure 6: Soil sampling: slicing the core using the rings as a guide.

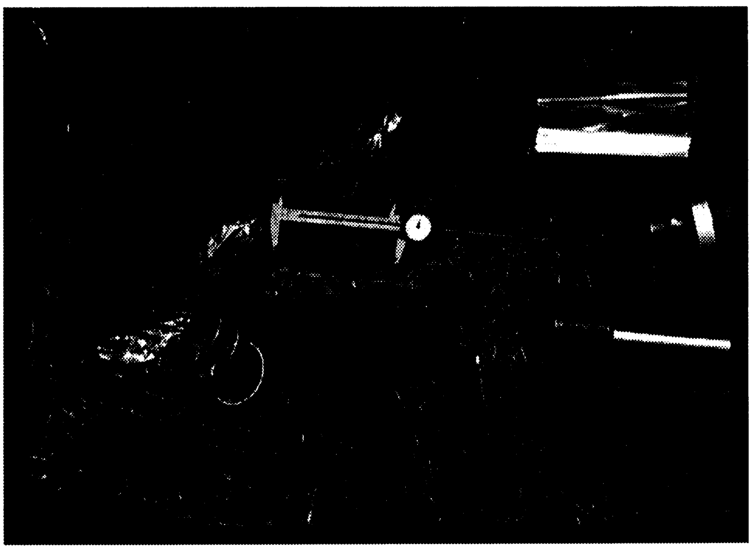

Figure 7: Soil sampling: a soil core shown with rings removed.

Day_nd	Time24	Dew	Top_Wet	Top_Dry	Tvol	Tgrv	Tmix	Mid_Wet	Mid_Dry	Mvol	Mgrv	Mmix	Bot_Wet	Bot_Dry	Bvol	Bgrv	Bmix
235.6	1500	0	12.02	8.3	0.03	0.31	0.45	35.11	30.45	0.04	0.13	0.15	121.89	111.9	0.09	0.08	0.09
236.3	800	1	13.15	9.62	0.03	0.27	0.37	44.85	39.19	0.05	0.13	0.14	101.29	94.14	0.07	0.07	0.08
236.6	1500	0	32.01	27.31	0.04	0.15	0.17	108.45	98.39	0.09	0.09	0.10	135.18	125.58	0.09	0.07	0.08
237.3	800	2															
237.6	1500	0	51.63	46.13	0.05	0.11	0.12	102.25	92.96	0.09	0.09	0.10	108.49	100.48	0.07	0.07	0.08
238.3	800	1	36.18	31.23	0.05	0.14	0.16	53.83	47.48	0.06	0.12	0.13	103.53	93.89	0.09	0.09	0.10
238.6	1430	1	34.92	30.37	0.04	0.13	0.15	93.66	86.38	0.07	0.08	0.08	108.74	101.79	0.06	0.06	0.07
239.3	800	-9															
239.6	1500	0	34.22	30.17	0.04	0.12	0.13	95.74	88.41	0.07	0.08	0.08	110.63	104.01	0.06	0.06	0.06
240.4	900	1	44.33	34.95	0.09	0.21	0.27	75.81	65.04	0.13	0.14	0.17	132.05	115.46	0.16	0.13	0.14
240.6	1500	2															
241.3	800	2															
241.6	1500	1	34.8	27.81	0.07	0.20	0.25	92.36	76.21	0.15	0.17	0.21	130.22	110.95	0.18	0.15	0.17
242.4	830	1	36.91	25.37	0.11	0.31	0.45	88	71.35	0.16	0.19	0.23	119.77	101.35	0.17	0.15	0.18
242.6	1500	0	27	18.99	0.07	0.30	0.42	98.93	81.85	0.16	0.17	0.21	122.47	100.73	0.20	0.18	0.22
243.4	945	0	47.35	32.63	0.14	0.31	0.45	99.63	79.26	0.19	0.20	0.26	142.9	119.5	0.22	0.16	0.20
243.8	1800	0	57.81	44.33	0.13	0.23	0.30	122.19	101.08	0.20	0.17	0.21	137.36	118.49	0.18	0.14	0.16
244.3	800	-9															
244.7	1730	0	43.11	35.89	0.07	0.17	0.20	72.57	59.8	0.12	0.18	0.21	85.76	70.76	0.14	0.17	0.21
245.4	900	1	27.82	21.41	0.06	0.23	0.30	80.56	68.22	0.12	0.15	0.18		103.68			
245.6	1430	0		44.31					80.76					108.41			
246.3	800	1	20.85	15.13	0.05	0.27	0.38	59.49	48.24	0.11	0.19	0.23	120.72	105.3	0.14	0.13	0.15
246.6	1500	0	12	8.7	0.03	0.28	0.38	28.78	23.96	0.05	0.17	0.20	67.96	58.77	0.09	0.14	0.16

Table 2: Soil sample data. Masses are in grams. Key for "dew" column: 0 = no dew, 1 = dew, 2 = rain, –9 = no sample taken. "*_Wet" and "*_Dry" are the wet and dry soil mases, respectively, where * indicates abbreviations for "Top", "Middle", and "Bottom". "*vol", "*grv", and "*mix" refer, respectively, to the volumetric, gravimetric, and mixing ratio moisture measures.

Soil moisture is most commonly expressed as either a gravimetric or a volumetric ratio. In addition, we previously used a third measure: the moisture mixing ratio. These three different definitions of "soil moisture" are shown in Equations 1–3. Note that ρ_{H_2O} can conveniently be set equal to 1 through careful choice of mass and volume units (e.g., grams and milliliters). The lower limits correspond to the case of all soil particles and no water (maximally dry), while the upper limit corresponds to the extreme case of all water and no soil particles (maximally wet).

$$m_g = \frac{mass\ of\ H_2O}{mass\ of\ wet\ soil}; \quad 0 \leq m_g \leq 1 \tag{1}$$

$$m_v = \frac{volume\ of\ H_2O}{volume\ of\ wet\ soil} = \frac{mass\ of\ H_2O}{\rho_{H_2O} \times (sample\ volume)}; \quad 0 \leq m_v \leq 1 \tag{2}$$

$$m_m = \frac{mass\ of\ H_2O}{mass\ of\ dry\ soil}; \quad 0 \leq m_m < \infty \tag{3}$$

We note that m_g and m_m are related by

$$\frac{1}{m_g} = 1 + \frac{1}{m_m}, \tag{4}$$

and m_v can be related to the other two measures through the fact that

$$m_v = \frac{mass\ of\ H_2O}{constant}. \tag{5}$$

For comparison purposes, soil moisture was computed using each of the three different methods. These are plotted in Figures 8–10.

The close relationship of the gravimetric moisture and the mixing ratio are evident in the plots. The significant increase in moisture following the heavy rain of days 240–242 is reflected in all 3 plots. However, note that the *bottom* samples (4–6 cm) have the highest volumetric moistures while the *top* samples (0–2 cm) have the highest gravimetric and mixing ratio moistures. Here we see the effect of bulk density on the latter two moisture measures: while the volumetric moisture depends only on the amount of water within the sample volume (for same-size sample volumes), the other measures also depend on the mass of the soil within the volume (i.e., the bulk density). As we might expect, the bulk density increases with depth. Thus, both the gravimetric and mixing ratio moistures are "attenuated" with depth. If the bulk density vs. depth were not monotonic or if the bulk density varies greatly vs. depth, the moisture values would be strongly affected.

It is worth noting that only single samples were taken to determine each moisture value, so the experimental uncertainty of the values is not known.

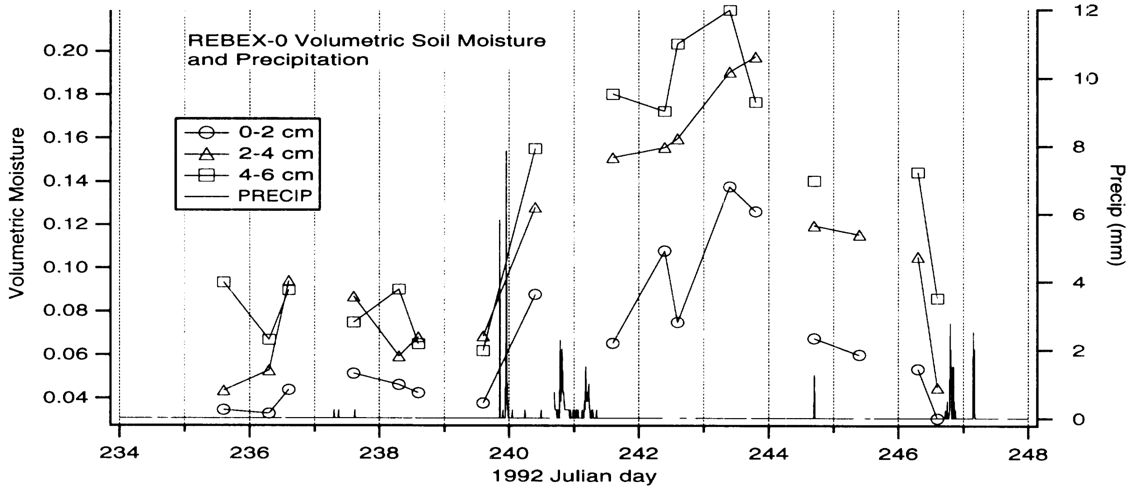

Figure 8: Volumetric soil moisture.

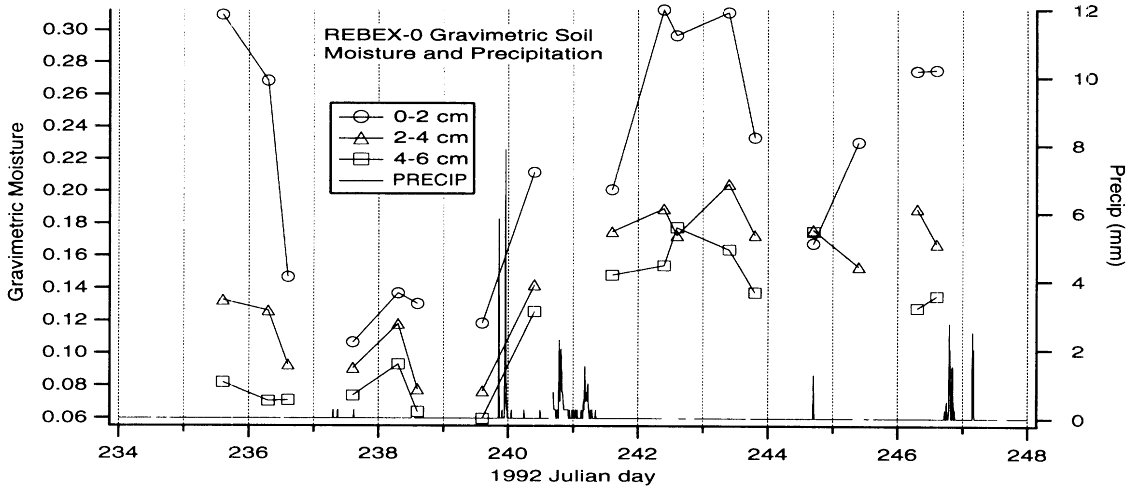

Figure 9: Gravimetric soil moisture.

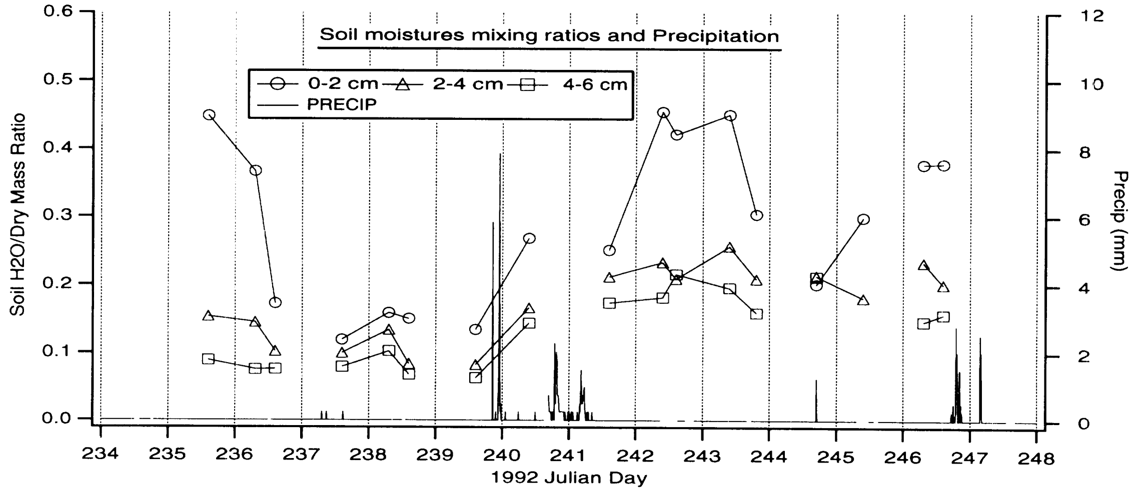

Figure 10: Soil moisture mixing ratio.

The top slices of the first 2 soil samples were taken from too shallow a location in the respective cores, resulting in underestimated wet and dry masses and overestimated gravimetric and mixing ratio moistures. These high values can be seen in the plots. Note that the corresponding volumetric moistures appear to be consistent with adjacent values during the dry period prior to day 240. Also note that the middle and bottom moistures do not appear to have been severely affected by the problem with the top slices.

The average bulk densities of the top (excluding the first 2 samples), middle, and bottom samples were 0.278, 0.670, and 0.958 g/cm^3, respectively.

4.3 Calibration and Data Cleaning

Calibrations:

Hot/cold calibrations of the microwave radiometers were performed before the start of REBEX-0 and on days 234, 236, 238, 242, and 245 (19 GHz and 85 GHz only since 37 GHz was down). The hot load was a piece of microwave absorber at ambient temperature, and the cold load was a piece of absorber soaked in liquid nitrogen. At the beginning of REBEX-0, calibrations were performed every other day in order to check radiometer stability. After approximately the day 238 calibration, stability appeared to be adequate, and the frequency of calibrations was reduced.

Cleaning bad data points:

The general assumption was that most variables, especially thermal quantities, could not change rapidly. Thus, isolated points that differed significantly from adjacent values were examined. If they were considered to be out of range or unlikely deviations from surrounding trends, they were deleted. Other related variables were used as consistency checks. Unphysical data was usually easy to identify (e.g., negative temperatures, solar radiation at night).

Both uninterpolated data files (with data gaps) and files with gaps filled by interpolated or curve-fitted values have been archived. Consult the associated README file.

Known problems or limitations:

Rs Data is clipped at about 973 W/m^2 on days 243–5 and day 250. The instrumentation amp circuit gain or the A/D gain may have been too high. Prior to day 242, the nighttime values are 6–9 W/m^2 above zero. No good explanation for this could be found, so these values were left as is. Compared to the near-1000 W/m^2 daytime peak values for those days, the integrated effect of even 10 W/m^2 of nighttime shortwave radiation should be negligible.

Hg Prior to 234//1723, the software-programmable gain for this sensor was initially too low by a factor of 10. Earlier values were corrected, but may not have the resolution of later values.

Clouds The cloudiness values were determined subjectively by the observer to the nearest 10% at the time of each soil/vegetation sampling. When the cloudiness was not uniform across the sky, the cloudiness in the direction of the radiometer sky measurement was recorded. Color photographs of the sky in this direction were also taken each time (35 mm SLR with 50 mm lens). Cloud type or height were not recorded.

Dew The presence or absence of dew or water on the grass at the time of the soil/vegetation samples was recorded.

Rain Quantitative measurements of precipitation were made by the rain gage. Precipitation during a soil/vegetation sample time was also noted.

The integrated precipitation for days with significant rainfall was as follows:

- squall on day 240: 21.1 mm (0.83 in)
- rain on days 241–242: 29.7 mm (1.17 in)
- total rain for days 240–242: 51.3 mm (2.02 in)
- rain on days 246–248: 17.0 mm (0.67 in)

The integrated precipitation for the entire REBEX-0 period was 78.9 mm (3.1 in).

IR data The reported values of the ground and sky thermal IR temperatures are "skin" (i.e., physical) temperatures with an assumed IR emissivity of 0.95.

37 GHz radiometer The 37 GHz radiometer was off-line beginning on day 242 until day 245 for repairs. The 19 and 85 GHz radiometers were also off-line on day 242 until the problem was isolated to the 37 GHz unit.

Amp oven The post-detector amplifiers for the three microwave radiometers were co-located in a temperature-stabilized oven located in the TMRS trailer. Until day 241, when a tarp was erected over the trailer as a sun shield, the oven would occasionally overheat. The extent of the problem is not known since TMRS-1 did not record diagnostic temperature data. However, the ground brightness temperatures prior to day 241 appear to be reasonable.

Sky brightnesses The TMRS-1 tower housing door was intended to be used (among other things) as a reflector to obtain microwave and thermal IR sky brightness temperatures. However, several problems were discovered with the design:

- The reflector was not large enough to prevent the sidelobes of the microwave radiometers from picking up direct and/or diffracted ground emission.

- Microwave and thermal IR emission from housing components could be reflected into the field of view of the radiometers by parts of the door mechanism.
- Emission from any water or dirt on the door surface could be sensed by the radiometers.

Microwave sky brightness temperatures under non-cloudy conditions are typically low at the SSM/I frequencies, and reflection from grass vegetation is small [2, 4]. So, the contribution of ground brightness leakage and emission from (hot) housing components to the "sky" brightnesses observed by the radiometers could be quite significant. No attempt to correct IR or microwave sky temperature values for door-related problems was made for REBEX-0 data. The uncorrected sky brightness values are presented in this report for completeness and for use in other work for which they may be useful (e.g., studies of sky emission). A correction scheme was presented in the REBEX-1 report [3] and may be applied directly to REBEX-0 data as the exact same housing configuration was used for both experiments.

Rounding and significant figures The precision of each data variable is reflected in the number of significant figures retained in the archived data files—consult the README file. Rounding was performed as necessary.

References

[1] Dahl, P., J. Judge, J. Gallo, and A. W. England, "Vertical distribution of biomass and moisture in a prairie grass canopy," UM Radiation Laboratory Technical Report RL-902, November 1993.

[2] England, A.W. and J.F. Galantowicz, Moisture in a Grass Canopy from SSM/I Radiobrightness, Proc. 2nd Topical Symposium on Combined Optical-Microwave Earth and Atmos. Sensing, Atlanta, pp.12–14, Apr. 3–6, 1995.

[3] Galantowicz, J., Field Data Report for the First Radiobrightness Energy Balance Experiment (REBEX-1), October 1992-April 1993, Sioux Falls, South Dakota, UM Radiation Laboratory Report RL-913, February, 1995.

[4] Kim, E.J. and A.W. England, Radiobrightness Thermal Inertia Sensing of Soil and Canopy Moistures for Grassland Areas, Proc. 2nd Topical Symposium on Combined Optical-Microwave Earth and Atmos. Sensing, Atlanta, pp.39–41, Apr. 3–6, 1995.

[5] Observer's Handbook 1993, R.L. Bishop, ed., Royal Astron. Society of Canada, Toronto, 1992.

A REBEX-0 Julian Day chart

	1992	
	AUG	SEP
1		245
2		246
3		247
4		248
5		249
6		250
7		251
8		252
9		
10		
11		
12		
13		
14		
15		
16		
17		
18	231	
19	232	
20	233	
21	234	
22	235	
23	236	
24	237	
25	238	
26	239	
27	240	
28	241	
29	242	
30	243	
31	244	

Table A-1: REBEX-0 Julian day to calendar date conversion chart. 1992 was a leap year.

B Graphs

Summary graphs of the non-interpolated data are presented in this section. All graphs cover the day 232–252 period including any initial or final data gaps.

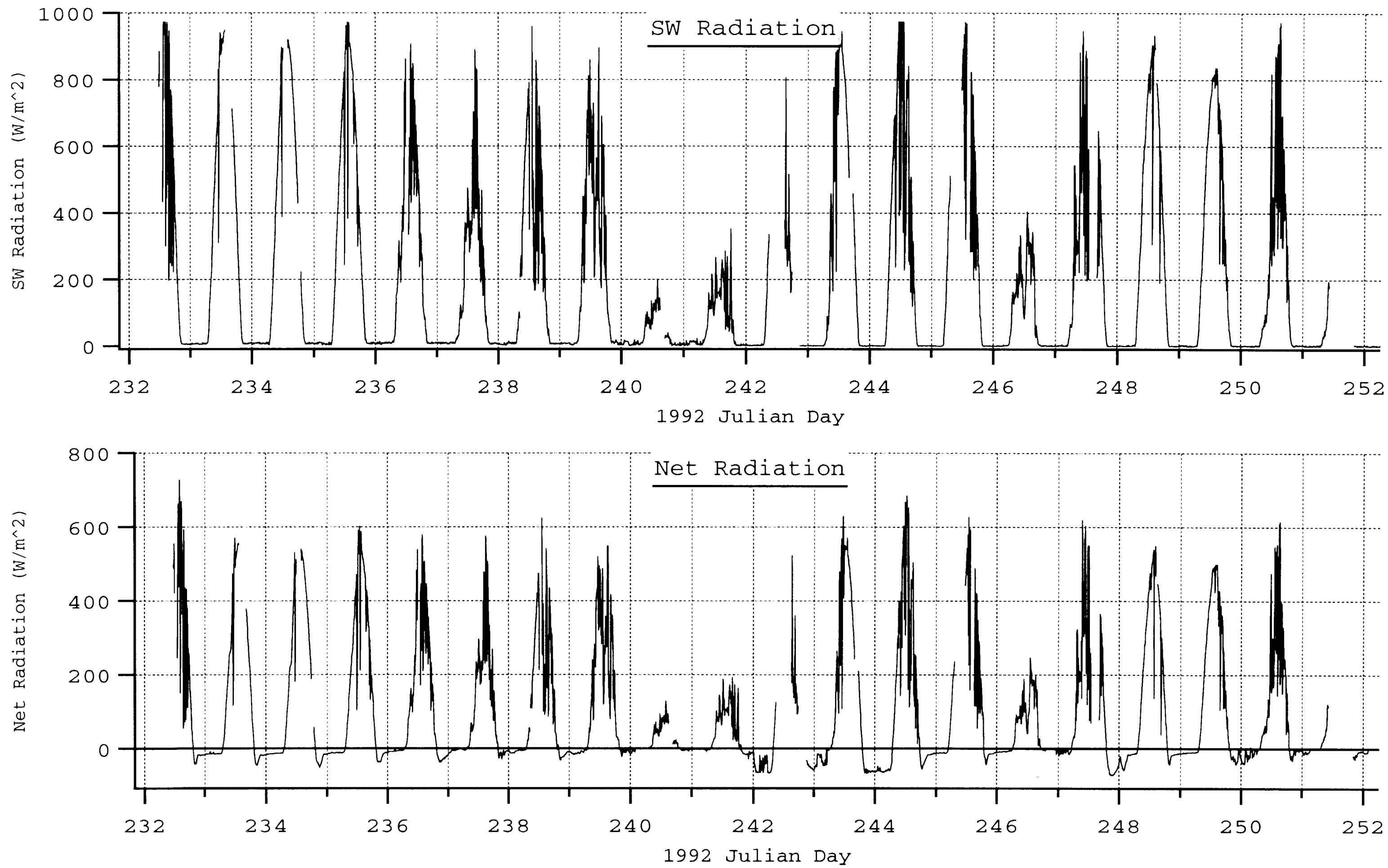

Figure 11: Solar and net radiation.

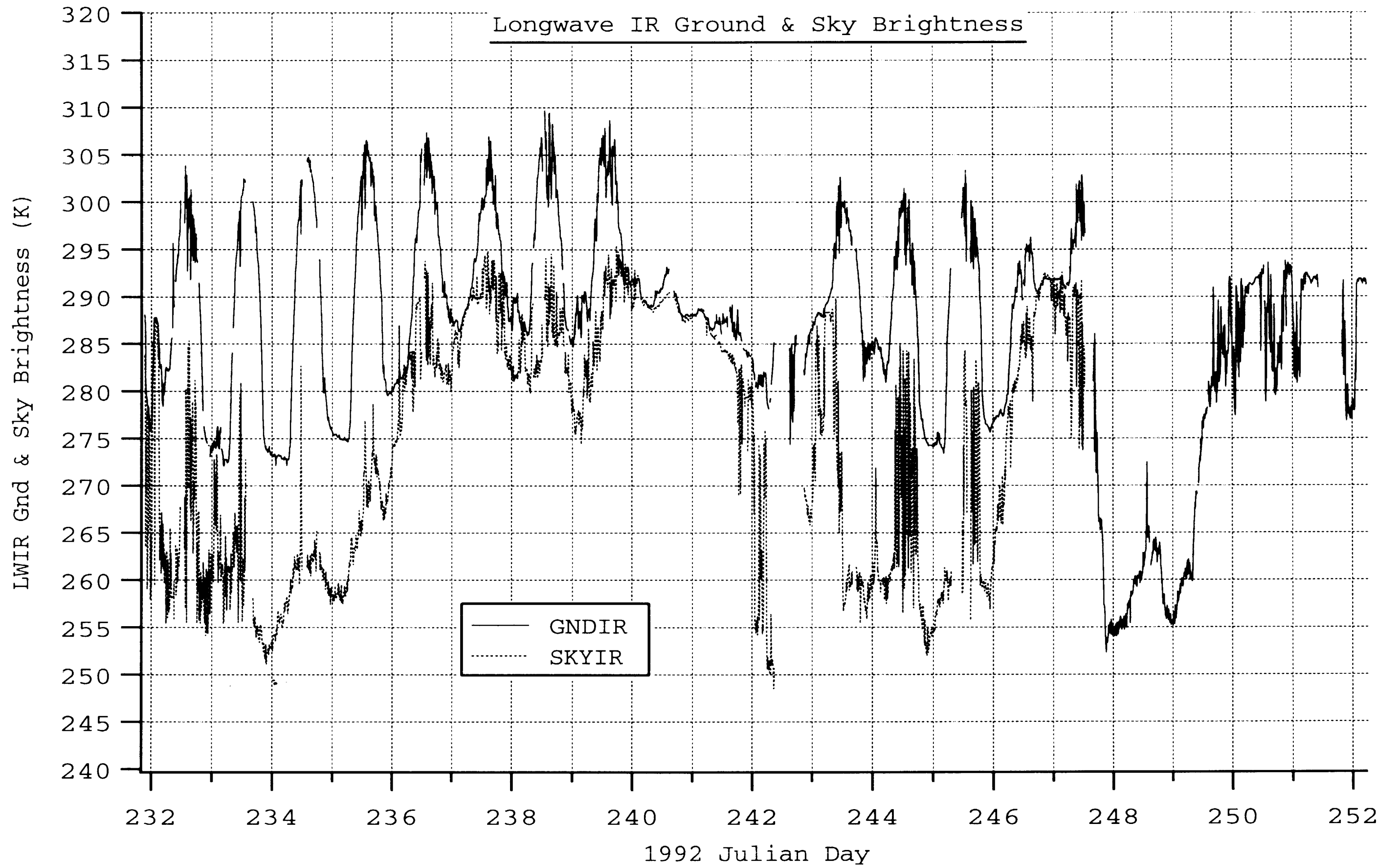

Figure 12: Longwave IR ground and sky brightnesses.

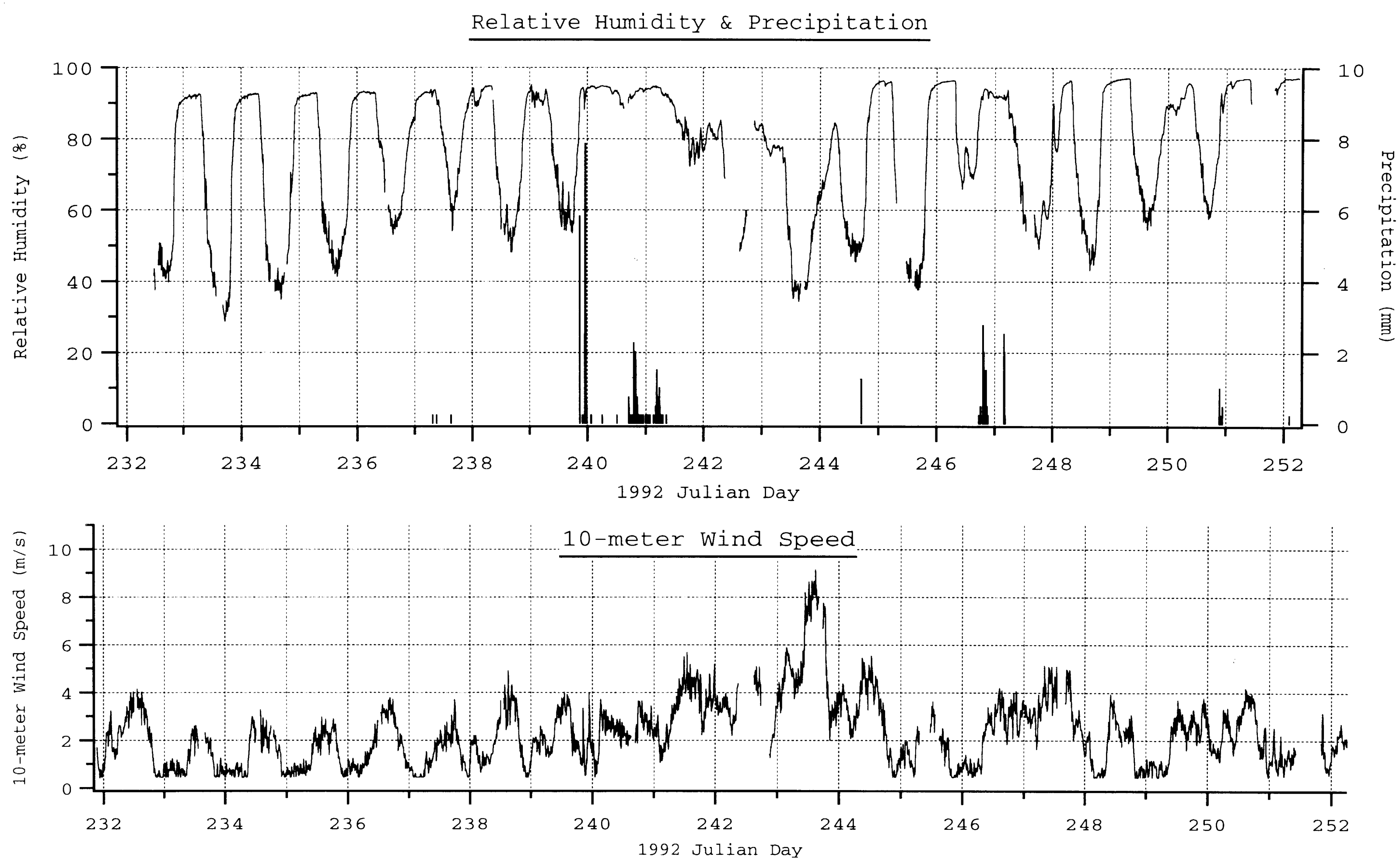

Figure 13: Relative humidity, precipitation, and wind.

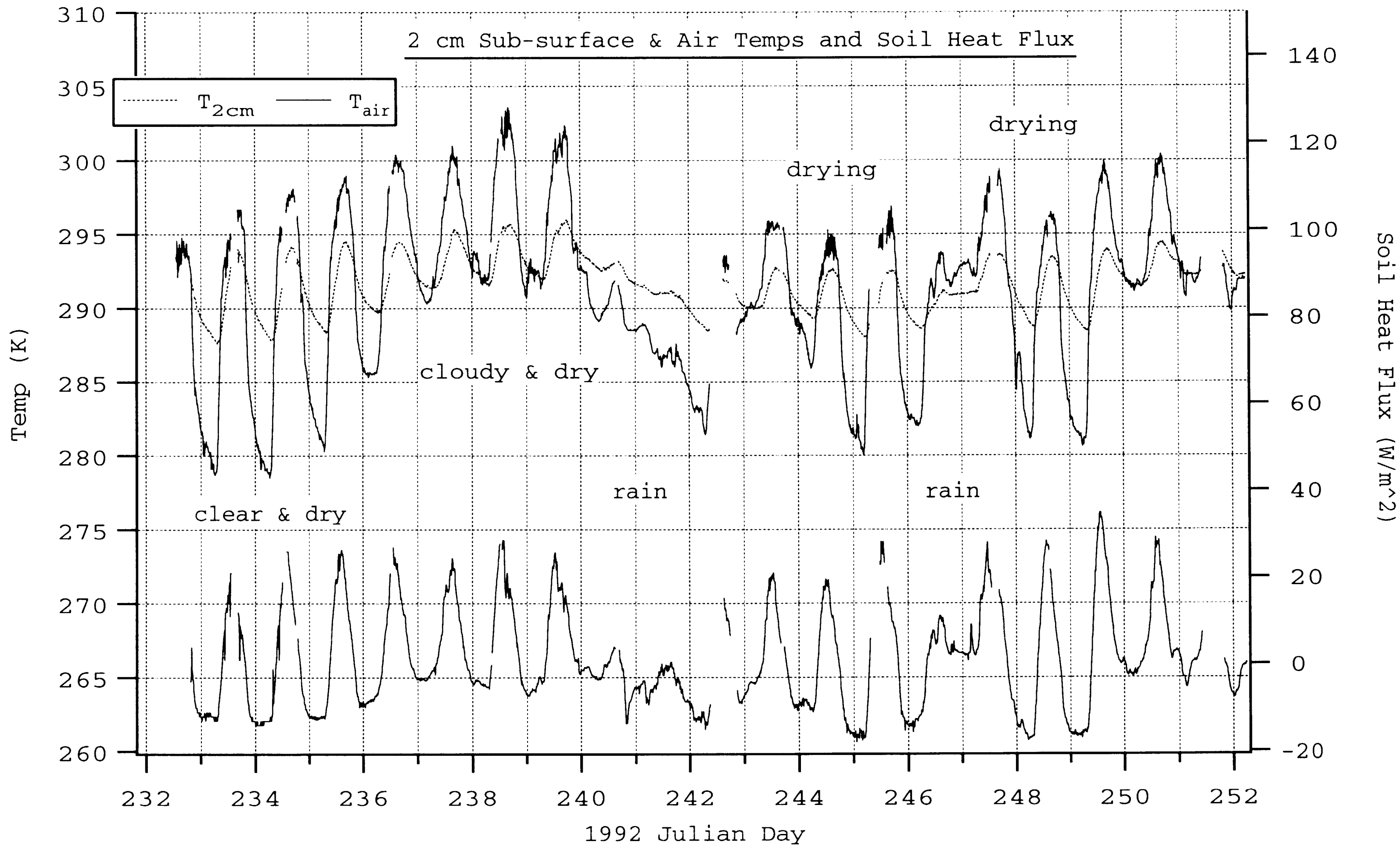

Figure 14: "Surface" temperature comparison 1 and soil heat flux.

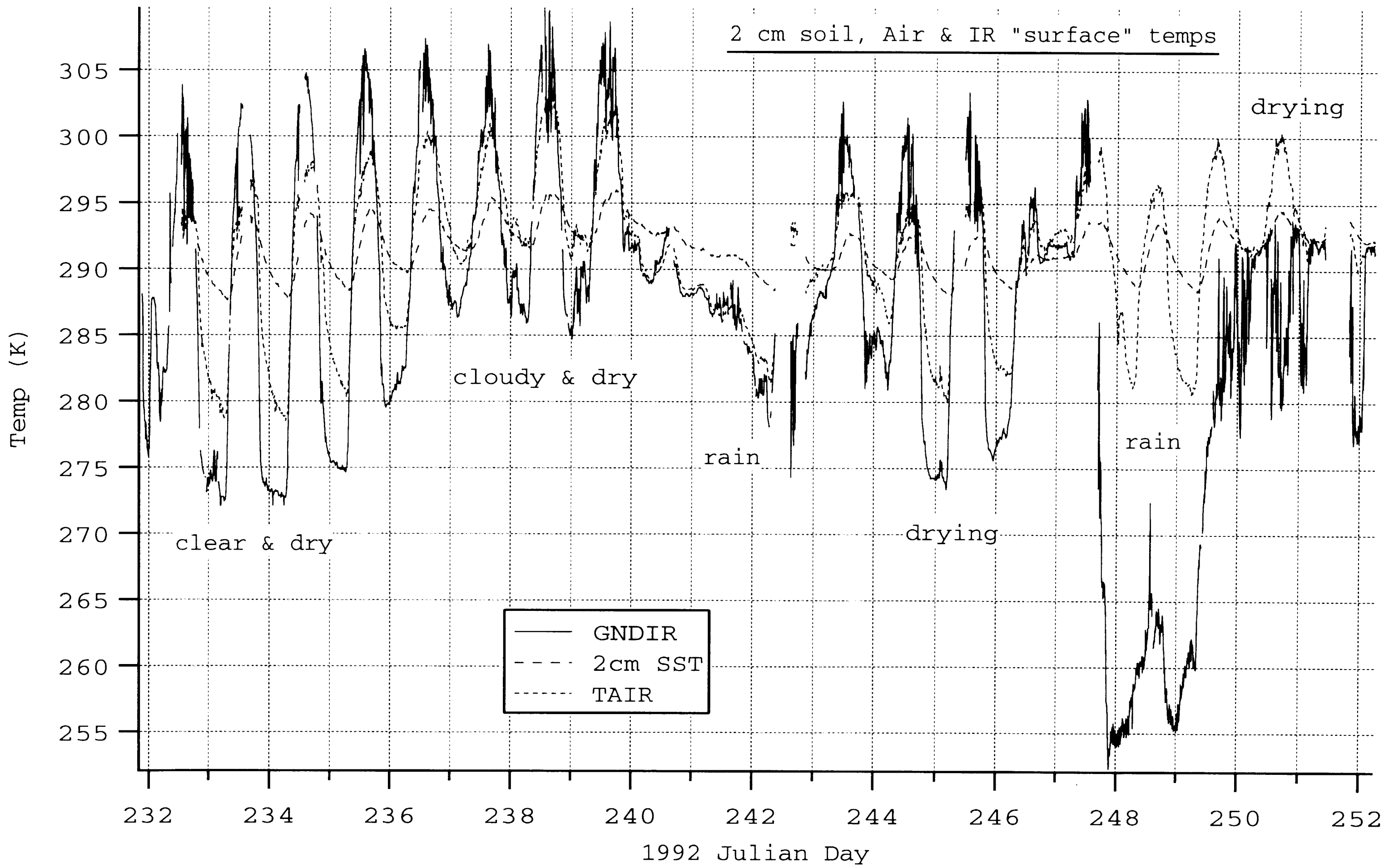

Figure 15: "Surface" temperature comparison 2.

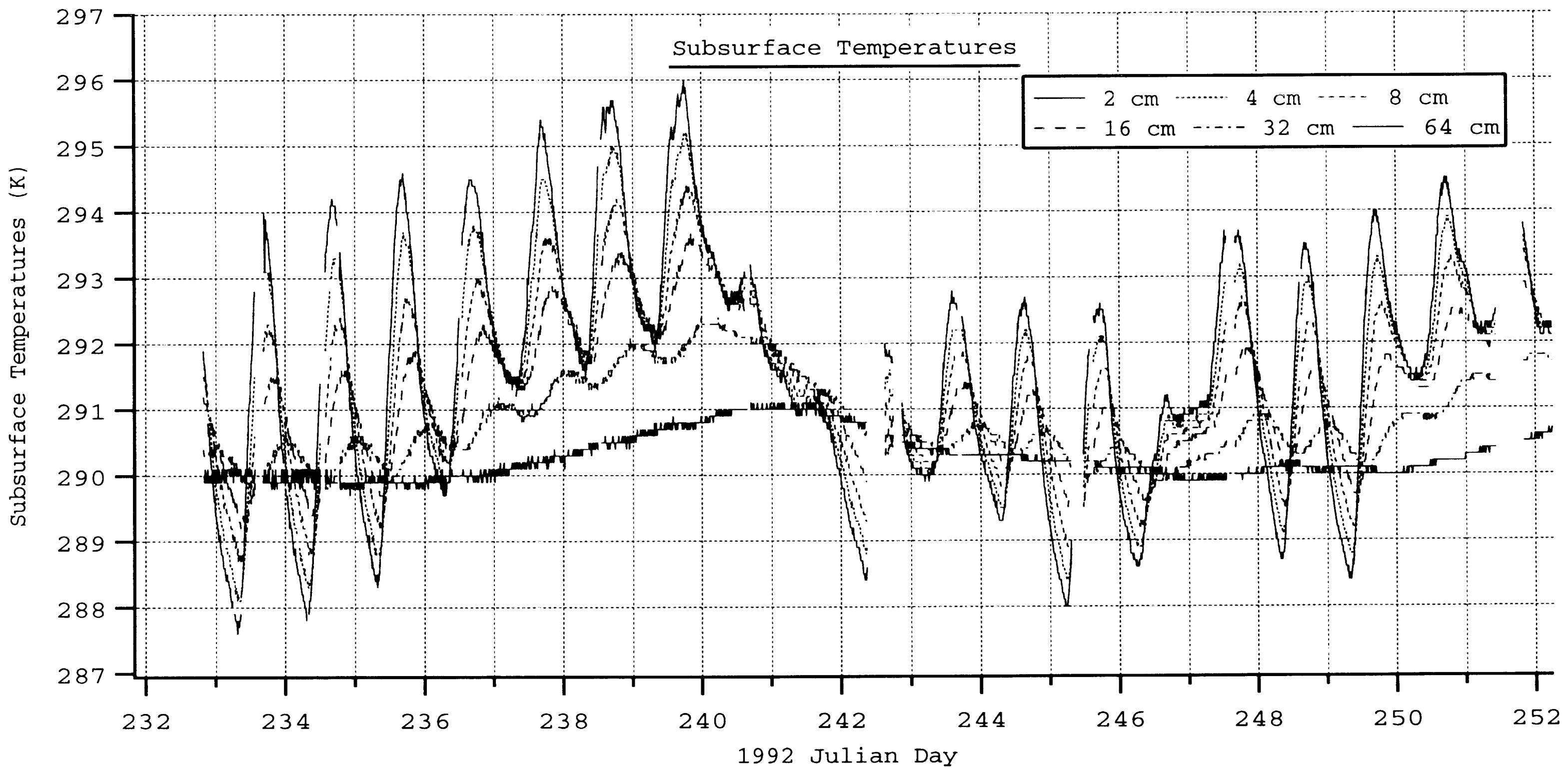

Figure 16: Subsurface temperatures.

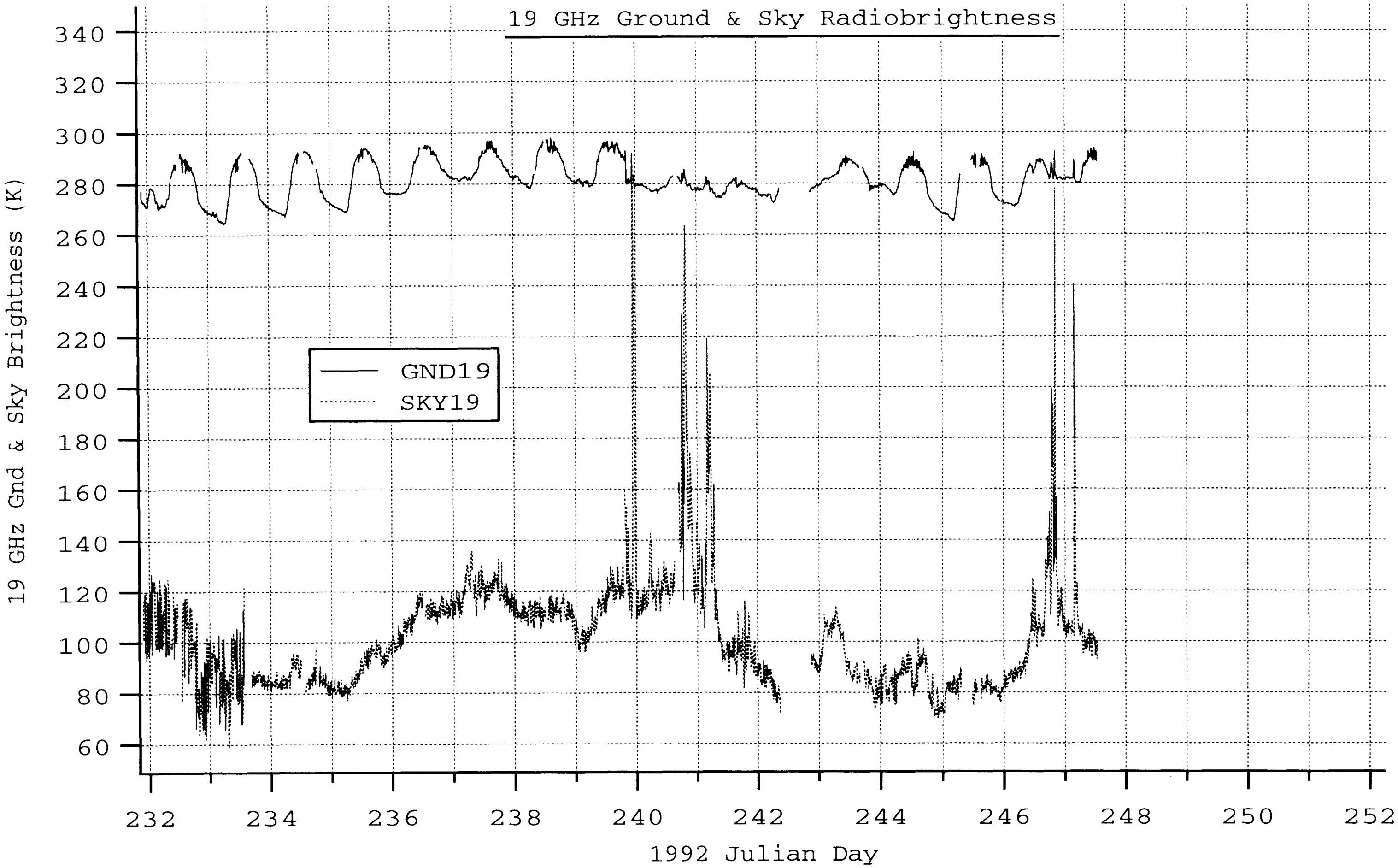

Figure 17: 19.35 GHz ground and sky radiobrightnesses.

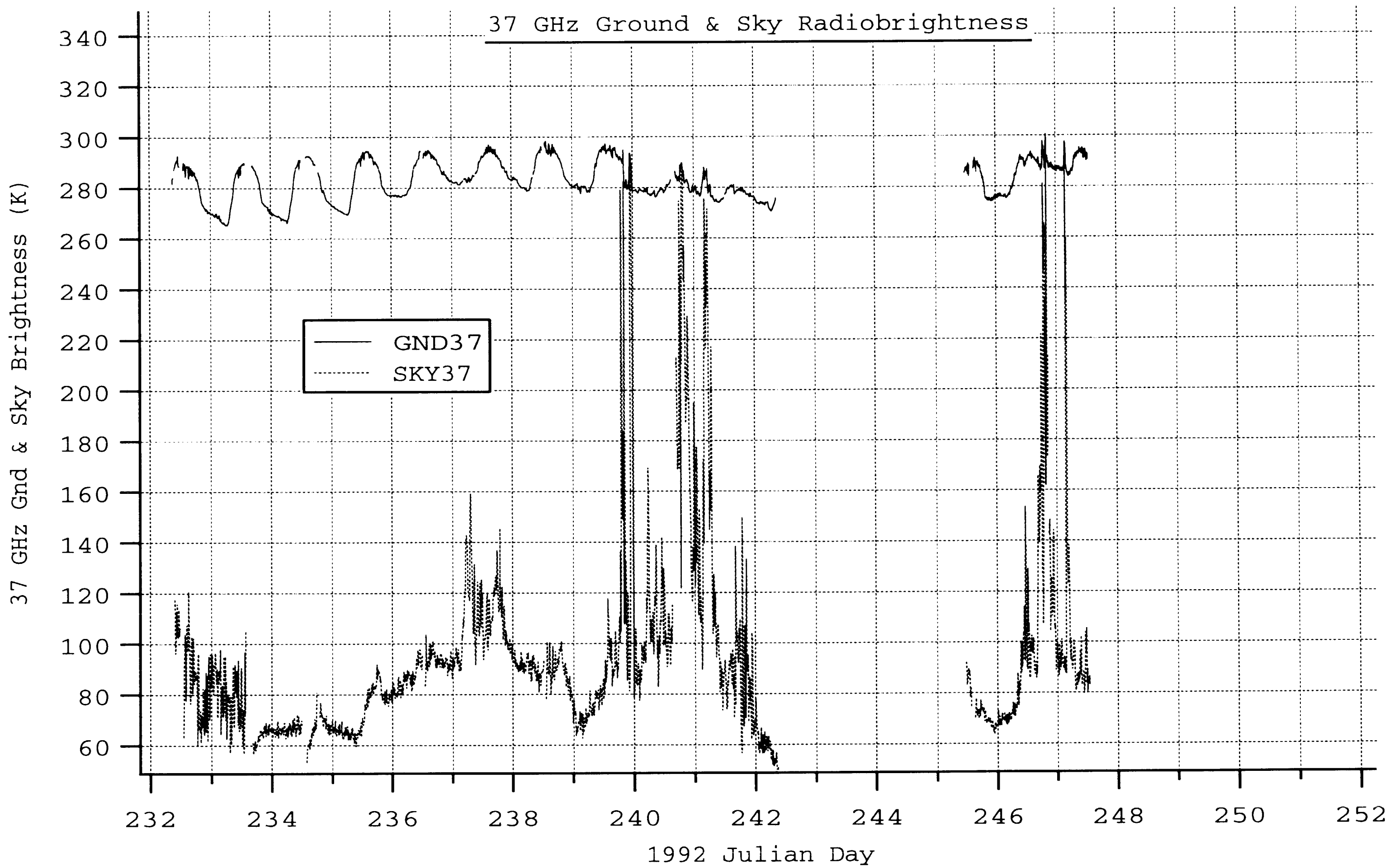

Figure 18: 37.0 GHz ground and sky radiobrightnesses.

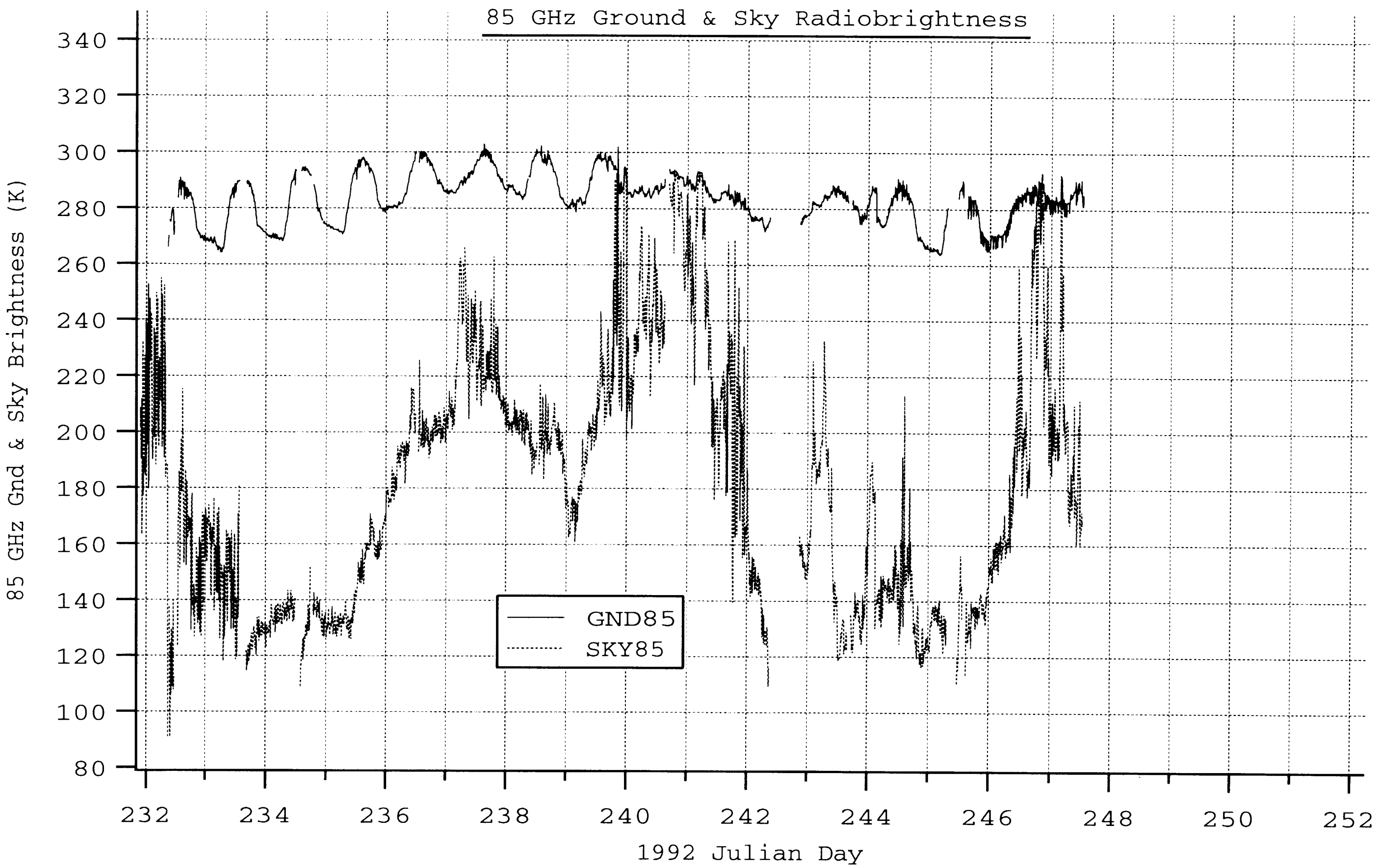

Figure 19: 85.5 GHz ground and sky radiobrightnesses.

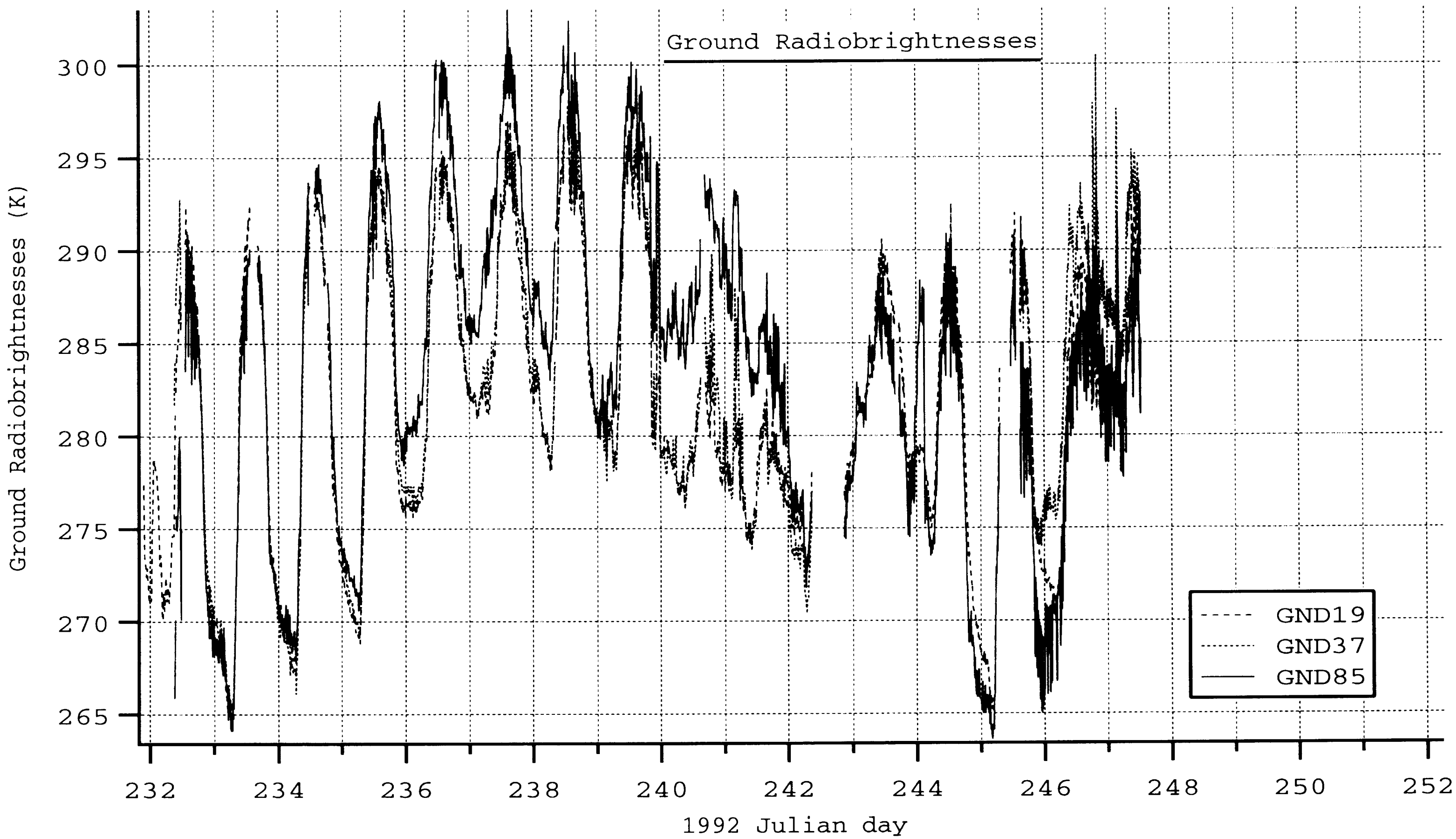

Figure 20: 19.35, 37.0, and 85.5 GHz ground radiobrightnesses.

REBEX-0 Report Errata RL-916

Ed Kim 1/28/98

The soil coring tool ID was 7.2 cm, not 8.255 cm. Thus, numeric values that depend on coring tool ID should be corrected as follows:

pages	section	old value	new value
5	3.3	83	72
5	3.3	3.25	2.83
6	4.2	107	81.4
9	Table 2	Tvol,Mvol,Bvol	mult by 1.314
11	Figure 8	soil moistures	mult by 1.314