Preliminary Analysis of the Microwave Weather Project Data for CY 1971

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The Weather Project forms part of an overall Radio Systems Development Project which seeks to optimize the spacecraft-to-ground communications link. Statistical correlations of weather and communications capability at X- and K-bands are needed to provide practical predictions of link performance. Thus the objective of the Weather Project is the statistical prediction of the performance of the DSN at X-band and, in the future, at K-band. A previous article discussed the general approach of the Weather Project, the measurements, calibrations, equipment, and methods. Problems encountered were also discussed as well as proposed future work. This article reports on a preliminary analysis of the Weather Project data for calendar year 1971. These results are presented in tabular form. Cumulative frequency distributions of percentages of excess system temperature are tabulated as a function of time (whole year and quarterly periods) and of antenna elevation angle (four elevation ranges and all elevation angles). Averages, standard deviations, and confidence limits are tabulated, and the experimental results are compared with the data from a theoretical study based on estimated and observed cloud cover effects.

I. Introduction

The Weather Project forms part of an overall Radio Systems Development Project which seeks to optimize the spacecraft-to-ground communications link. Statistical correlations of weather and communications capability at X- and K-bands are needed to provide practical predictions of link performance. Thus the objective of the Weather Project is the statistical prediction of the performance of the DSN at X-band and, in the future, at K-band. A previous article (Ref. 1) discussed the general approach of the Weather Project, the measurements, calibrations, equipment, and methods. Problems encountered were also discussed as well as proposed future work. This article reports on a preliminary analysis of the Weather Project data for calendar year 1971. These results are presented in tabular form. Cumulative frequency distributions of percentages of excess system temperature are tabulated as a function of time (whole year and quarterly periods) and of antenna elevation angle (four elevation ranges and all elevation angles). Averages, standard deviations, and confidence limits are tabulated, and the experimental results are compared with the data from a theoretical study (Ref. 2) based on estimated and observed cloud cover effects.

II. Discussion of the Tables

The results for calendar year 1971 are presented in tabular form. Table 1 is a cumulative frequency distribution of percentages of excess system temperature due to atmospheric conditions and other unknowns as a function of antenna elevation angle. The excess system temperatures have been divided into increments of 10 K. Four antenna elevation angle ranges have been considered: 6 to 14.99, 15 to 24.99, 25 to 44.99, and 45 to 90 deg. The table consists of percentages of time that the excess system temperature was less than the nominal magnitude for the various antenna elevation angles. Thus for 88.4 percent of the time that the antenna's elevation angle was in the range 6 to 15 deg, the excess system temperature was under 10 K. The column on the right lists percentages for all elevation angles.

The frequency distribution shown in Table 1 is for the whole of calendar year 1971. The table lists percentages of time, in each antenna elevation angle range, that the excess system temperature was less than the value given in the left-hand column. Tables 2 through 5 are similar tables for quarterly periods. Table 4, for example, is the frequency distribution for June through August 1971.

The total number of minutes of good data recorded in each category is listed at the bottom of each of the above tables. In Table 1, for example, which refers to the whole of calendar year 1971, the total number of minutes of good data recorded is listed as 172,000 out of a possible 529,000 minutes. This means that good data were obtained for only 33% of the year. The reasons for missing or bad data are several. Data were lost when scheduled X-band radio science experiments were carried out, or when the X-band system was undergoing frequency changes, development or diagnostic work, or when equipment failed. The unusable or "bad" data were recorded when the X-band system suffered from S-band transmitter fourth harmonic interference, noise burst interference, or when calibration was lost due to equipment or operator error, etc.

The usable or "good" data, however, are also subject to some error. The most common sources of error in the good data are inaccuracies in the scale calibrations due to drifts in the equipment and an insufficiently determined fair weather baseline. These sources of error are being investigated.

Table 6 shows averages, standard deviations, and confidence intervals on measured excess system temperatures for the whole year and for the year divided into separate quarters. In each period the data have been divided into the same antenna elevation intervals as in the previous tables. The results have been computed taking one data point per minute of recorded data. The mean values of the excess system noise temperature for the various periods and elevation angles are shown in the second column. The next column lists the standard deviation of the data. This column shows that there is a considerable spread in the data, particularly at low elevation angles and for the winter months. The next two columns list the 95 and 50% confidence intervals, computed from the measured data, on the mean values of the excess system temperatures. These confidence intervals were calculated assuming all errors are random and neglected the effects of any bias in any of the measurements. Bias errors would degrade the calculations by widening the intervals for a fixed confidence. Hence, neglecting bias errors and assuming the same conditions held for next year (same equipment, same weather, etc.), one would expect to obtain a mean excess near 5.6 K with a probability of about 0.95.

The mean value can be calculated with good resolution since one data point per minute is recorded and used in the calculations; hence N, the total number of data points, is large. The sample mean converges fairly rapidly, approximately as $\sigma/\sqrt{N}$, where σ is the standard deviation of the data. The sample mean converges as $\sigma/\sqrt{N}$ if the data are gaussian distributed, which is only approximately true in this case.

Tables 7 and 8 are a comparison between experimental and calculated data for 0.90 and 0.99 probability conditions. The experimental data are the frequency distribution tables of excess system noise temperatures, Tables 1 through 5, and the calculated results are based on a theoretical study of cloud cover (Ref. 2). The agreement is not good at 0.99 probability but is somewhat better at 0.90 probability. There are several possible reasons for this. The theoretical study was based on observed and estimated cloud cover of the Goldstone area for a time period of a few years prior to the start of the Weather

Project. One would expect that as the elevation angle of the antenna is lowered, the probability of a cloud intercepting the beam of the antenna would increase, resulting in a higher expected noise temperature. Hence the calculated results show a steady increase in excess system temperature with decrease in elevation angle.

The statistics from the experimental data are a little more uneven. The experimental results include all elements that affect the system noise temperature such as clouds, rain, snow, and all the effects and errors not related to the atmosphere and described above. Furthermore, the 0.99 probability level is extremely sensitive to the actual data. Roundoff errors, the choice of antenna elevation channel size, and in some cases such as low elevation angles, the relatively few data points all lead to these uneven results. The 0.90 probability level should be more reliable since a fairly large amount of data falls above the 0.90 probability level.

It must be noted that:

(1) Measured results are based on one year of data only. It is not possible to derive meaningful statistics from one year of recorded data.

(2) The calculated values are based on cloud cover only, whereas the measured values are for all atmospheric effects.

(3) For the measured results the underlying data are only approximately gaussian distributed (as indicated by a test for normality), and therefore the use of confidence intervals is suspect.

(4) More measured data are required before meaningful statistics can be deduced.

(5) A more accurate baseline must be determined.

References

1. Reid, M. S., "A Description of the Weather Project," in *The Deep Space Network Progress Report,* Technical Report 32-1526, Vol. X, pp. 116–122. Jet Propulsion Laboratory, Pasadena, Calif., Aug. 1972.

2. Smith, T. B., and Chien, C. W., "Cloud Cover Effects on Signal Attenuation at DSN Sites," Subcontract No. 952757, Meteorology Research Inc., Altadena, Calif., April 1970.

Table 1. Cumulative percentage probabilities of excess system temperature for CY 1971

Excess system temperature less than, K	Range of antenna elevation angle, deg				
	6–15	15–25	25–45	45–90	6–90
10	88.4	94.4	95.3	97.1	96.3
20	91.1	96.1	96.6	97.8	97.2
30	93.1	96.4	97.2	98.2	97.7
40	94.8	96.7	97.6	98.4	98.0
50	95.3	96.7	97.8	98.5	98.2
60	96.6	97.0	98.0	98.5	98.3
70	96.6	97.3	98.3	98.6	98.4
80	97.0	97.6	98.4	98.7	98.5
90	97.0	97.9	98.5	98.9	98.7
100	97.0	98.2	98.8	99.2	99.0
110	97.0	98.2	98.8	99.3	99.1
120	97.0	98.7	98.9	99.3	99.2
130	97.8	99.0	99.2	99.4	99.4
140	97.8	99.3	99.4	99.4	99.5
150	98.6	99.6	99.5	99.4	99.6
160	98.6	99.9	99.6	99.4	99.7
170	99.0	99.9	99.6	99.5	99.8
180	99.0	100.0	99.8	99.6	99.9
190	99.4	100.0	100.0	99.7	100.0
200	99.4	100.0	100.0	100.0	100.0
210	99.8	100.0	100.0	100.0	100.0
220	99.8	100.0	100.0	100.0	100.0
270	100.0	100.0	100.0	100.0	100.0

Antenna elevation angle was:

6–15 deg 4.61% of the time.
15–25 deg 6.40% of the time.
25–45 deg 16.75% of the time.
45–90 deg 72.24% of the time.

Total number of minutes of good data recorded was 172,000 out of a possible 529,000 minutes.

Table 2. Cumulative percentage distribution of excess system temperature for CY 1971 (December, January, February)

Excess system temperature less than, K	Range of antenna elevation angles, deg				
	6–15	15–25	25–45	45–90	6–90
10	77.2	92.6	92.7	90.4	89.6
20	82.6	92.6	93.5	91.1	90.8
30	88.0	92.6	94.3	92.9	92.7
40	92.0	92.6	94.3	93.9	93.8
50	93.3	92.6	94.3	94.6	94.4
60	96.0	92.6	94.3	95.0	95.0
70	96.0	92.6	94.3	96.0	95.7
80	97.3	95.1	94.3	96.3	96.1
90	97.3	97.6	94.9	96.5	96.5
100	97.3	100.0	96.6	97.5	97.6
110	97.3	100.0	96.6	97.9	97.9
130	100.0	100.0	96.6	98.1	98.3
150	100.0	100.0	97.1	98.1	98.4
160	100.0	100.0	97.9	98.1	98.5
180	100.0	100.0	99.4	98.1	98.8
190	100.0	100.0	100.0	98.5	99.2
200	100.0	100.0	100.0	99.4	99.8
210	100.0	100.0	100.0	100.0	100.0

Antenna elevation angle was:

6–15 deg 10.25% of the time.
15–25 deg 5.59% of the time.
25–45 deg 17.92% of the time.
45–90 deg 66.24% of the time.

Total number of minutes of good data recorded was 21,830 of a possible 129,750 minutes.

Table 3. Cumulative percentage distribution of excess system temperature for CY 1971 (March, April, May)

Excess system temperature less than, K	Range of antenna elevation angles, deg				
	6–15	15–25	25–45	45–90	6–90
10	98.4	98.2	99.5	99.3	99.3
20	100.0	100.0	100.0	99.8	99.8
30	100.0	100.0	100.0	100.0	100.0
40	100.0	100.0	100.0	100.0	100.0

Antenna angle was:

6–15 deg 2.13% of the time.
15–25 deg 2.71% of the time.
25–45 deg 11.52% of the time.
45–90 deg 83.63% of the time.

Total number of minutes of good data recorded was 43,345 out of a possible 133,400 minutes.

Table 4. Cumulative percentage distribution of excess system temperature for CY 1971 (June, July, August)

Excess system temperature less than, K	Range of antenna elevation angles, deg				
	6–15	15–25	25–45	45–90	6–90
10	80.5	93.1	92.4	92.9	92.3
20	83.9	93.1	92.5	94.9	93.9
30	86.6	93.1	92.5	95.2	94.2
40	86.6	93.1	94.7	95.4	94.7
50	87.2	93.1	95.8	95.6	95.1
60	87.2	93.1	95.8	95.6	95.1
70	87.2	93.1	96.3	95.6	95.2
80	87.2	93.1	96.3	95.8	95.4
90	87.2	93.1	96.3	96.6	96.0
100	87.2	93.1	96.8	97.3	96.6
110	87.2	93.1	96.8	97.5	96.8
120	87.2	95.1	97.3	97.6	97.1
130	87.2	96.1	98.9	97.8	97.6
140	87.2	97.1	100.0	98.0	98.0
150	91.4	98.1	100.0	98.1	98.3
160	91.4	99.1	100.0	98.3	98.6
170	93.5	99.1	100.0	98.9	99.1
180	93.5	100.0	100.0	99.4	99.5
190	95.6	100.0	100.0	99.5	99.7
210	97.7	100.0	100.0	99.5	99.8
220	97.7	100.0	100.0	100.0	99.9
270	100.0	100.0	100.0	100.0	100.0

Antenna elevation angle was:

6–15 deg 4.07% of the time.
15–25 deg 8.69% of the time.
25–45 deg 16.0% of the time.
45–90 deg 71.23% of the time.

Total number of minutes of good data recorded was 34,866 out of a possible 132,900 minutes.

Table 5. Cumulative percentage distribution of excess system temperature for CY 1971 (September, October, November)

Excess system temperature less than, K	Range of antenna elevation angles, deg				
	6–15	15–25	25–45	45–90	6–90
10	96.4	94.9	95.7	99.6	98.2
20	97.3	97.9	98.0	99.7	99.0
30	97.3	98.4	99.0	100.0	99.5
40	98.6	98.9	99.0	100.0	99.6
50	98.6	98.9	99.0	100.0	99.6
60	100.0	99.4	99.4	100.0	99.8
70	100.0	100.0	99.7	100.0	100.0
80	100.0	100.0	100.0	100.0	100.0
90	100.0	100.0	100.0	100.0	100.0
100	100.0	100.0	100.0	100.0	100.0
110	100.0	100.0	100.0	100.0	100.0

Antenna elevation angle was:

6–15 deg 4.65% of the time.
15–25 deg 7.76% of the time.
25–45 deg 19.93% of the time.
45–90 deg 67.66% of the time.

Total number of minutes of good data recorded was 71,904 out of a possible 132,500 minutes.

Table 6. Averages, standard deviations, and confidence intervals on excess system temperature for CY 1971

Period	Range of antenna elevation angles, deg	Excess noise temperature mean value, K	Standard deviation, K	95% confidence level, K	50% confidence level, K
CY 1971 January through December	6–15	11.0	32.1	±0.71	±0.24
	15–25	7.9	21.8	±0.41	±0.14
	25–45	6.4	18.3	±0.21	±0.07
	45–90	5.6	17.1	±0.10	±0.03
	All angles	6.1	18.6	±0.09	±0.03
December January February	6–15	11.6	26.0	±1.07	±0.18
	15–25	7.2	23.6	±1.32	±0.37
	25–45	9.8	34.7	±1.09	±0.46
	45–90	9.0	31.2	±0.51	±0.37
	All angles	9.3	31.0	±0.41	±0.14
March April May	6–15	4.0	5.2	±0.34	±0.12
	15–25	3.1	5.0	±0.29	±0.10
	25–45	2.1	4.2	±0.12	±0.04
	45–90	3.9	5.2	±0.05	±0.02
	All angles	3.7	5.1	±0.05	±0.02
June July August	6–15	30.6	63.0	±3.30	±1.13
	15–25	15.5	35.5	±1.26	±0.44
	25–45	11.6	24.9	±0.65	±0.22
	45–90	11.6	27.3	±0.34	±0.12
	All angles	12.7	30.3	±0.32	±0.11
September October November	6–15	4.2	9.1	±0.31	±0.11
	15–25	5.0	8.9	±0.23	±0.08
	25–45	4.9	8.6	±0.14	±0.05
	45–90	2.7	4.7	±0.04	±0.01
	All angles	3.4	6.4	±0.05	±0.02

Table 7. Comparison of cumulative probabilities derived from calculated and measured results for 0.99 probability conditions (Probability of 0.99 excess noise temperatures will be less than value tabulated)

Period	Elevation angle, deg	Calculated results, K	Measured results, K
CY 1971 January through December	6–15	75	170
	15–25	40	130
	25–45	25	123
	45–90	17	93
December January February	6–15	110	116
	15–25	60	96
	25–45	40	167
	45–90	25	195
September October November	6–15	45	53
	15–25	25	52
	25–45	18	30
	45–90	14	< 10

Table 8. Comparison of cumulative probabilities derived from calculated and measured results for 0.90 probability conditions (Probability of 0.90 excess noise temperatures will be less than value tabulated)

Period	Elevation angle, deg	Calculated results, K	Measured results, K
CY 1971 January through December	6–15	35	16
	15–25	18	< 10
	25–45	10	< 10
	45–90	6	< 10
December January February	6–15	50	35
	15–25	25	< 10
	25–45	15	< 10
	45–90	9	< 10
September October November	6–15	25	< 10
	15–25	12	< 10
	25–45	7	< 10
	45–90	4	< 10