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Precipitation Statistics for the Deep Space Network

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This article presents statistics characterizing the frequency of precipitation at each Deep Space Communications Complex (DSCC). Monthly statistics derived from 10 to 17 years of observations are given for rain, snow, thunderstorms, and fog. Selection of reliable data sources and appropriate statistical measures are discussed. A framework is established for these statistics to be applied to existing telecommunications models. Sources of biases and errors are described and assessed. Yearly statistics show that the daily frequencies of rain at the Spanish and Australian DSCCs are similar. However, rainstorms in Australia last longer and have a very different seasonal dependence. Each year, the number of hours of measurable precipitation is 40 percent greater in Australia than in Spain. Daily precipitation at Goldstone is roughly a third of that reported by the other two DSCCs, with a mean incidence of 39 days of precipitation per year. Goldstone also has the greatest difference between hourly and daily occurrence statistics, yielding the shortest storms with an average of 4 hours per precipitation event. As expected, all three DSCCs show strong seasonal variations in precipitation patterns.

I. Introduction

The atmosphere is a window through which we communicate with space. Precipitation can obscure that view, restricting the performance of space communication systems. Rain, snow, and hail can severely attenuate and depolarize signals as well as emit significant amounts of radio noise. Precipitation also deposits moisture on antenna mirrors and radomes, compromising their operating characteristics. The upper limit or high-end attenuation and noise exceedence statistics for telecommunication systems are dictated by the incidence and characteristics of precipitation at each Deep Space Station (DSS).

Deriving high-end attenuation and noise exceedence statistics requires a long-term database of either propagation or meteorological measurements. Since there is not a suitable database of propagation measurements, meteorological data can be used to augment the existing telecommunication models. In fact, precipitation measurements are routinely used to derive high-end propagation statistics. The availability of long-term meteorological records makes their use attractive. However, precipitation is difficult to model because it is characterized by a wide range of spatial and temporal structure. Rain, snow, and hail display a wide range of yearly, monthly, daily, and minute-to-minute variability. Modeling the effect of snow and hail requires assumptions about their thermodynamic state because propagation effects depend on the liquid content. (In theory, snow and hail should not impair radio propagation, because the dielectric constant of ice is negligible. However, falling snowflakes and hailstones develop a thin coat of melt water that degrades signal propagation.) Finally, specifics of a communication link's implementation dictate the appropriate statistical measures for assessing the impact of precipitation on link performance. This article will report precipitation statistics for the three Deep Space Communications Complexes (DSCCs) comprising the Deep Space Network (DSN).

II. Data Sources

Characterization of attenuation and noise exceedence statistics can be assisted with a variety of data types [1]. The DSN currently makes radiometric measurements of atmospheric radio noise, Global Positioning System (GPS) measurements of propagation delay, and meteorological measurements that could be used for developing telecommunications models. Since the GPS is insensitive to liquid water (it has sensitivity to water vapor), GPS data are inappropriate for this study; however, the other two data types could be useful.

Radiometric measurements of atmospheric noise are valuable because they provide a direct measure of line-of-sight attenuation and noise. This technique can provide accurate attenuation measurements to 15 dB, corresponding to near-ambient noise temperatures [1]. Currently, the DSN makes routine measurements of atmospheric noise using water vapor radiometers (WVRs) at Goldstone, California, and Madrid, Spain. Unfortunately, there are a couple of reasons why these data cannot be used to generate precipitation-related propagation statistics. First, the data series are limited, and longer time series are needed to reduce biases introduced by year-to-year variability. At present, available WVR data include only six years of data from Spain, one and one-half years of data from Goldstone, and less than a year of data from Australia. In fact, the Australian 32-GHz (Ka-band) noise model has been primarily inferred from the Spanish data set. The second reason for not using WVR data to generate high-end statistics is that the existing WVRs were not designed for all-weather operation. These WVRs were originally developed for retrieving water-vapor-induced radio path delay during short-term very long baseline interferometry (VLBI) and GPS campaigns. Although they have been adapted for providing 32-GHz statistics under most weather conditions, they are not designed to provide reliable noise temperature estimates during precipitation.

As stated earlier, rain gauge data have been favored for developing telecommunication models because of the availability of long time series. There are a few disadvantages associated with these data, including uncertainties about their correlation with propagation parameters. Ground-based meteorological data provide a measure of attenuation at a single point, not averaged along a propagation path [1]. For localized storms, a slant propagation path can sometimes intercept a storm cell that will not be detected by a local rain gauge. Conversely, precipitation at a ground station may have minimal propagation effects if the body of the rainstorm is not in line with the Earth-to-space communication path. The importance of spatial variability depends on the nature of the storm system. To infer attenuation and noise from rain gauge measurements requires assumptions about the rain cloud height and horizontal extent [2]. In spite of these difficulties, standard methods have been developed to incorporate rain gauge data in telecommunications models.[1]

Rain gauge measurements are subject to a variety of error sources. Globally, gauge measurements tend to underestimate precipitation due to wind-induced turbulence at the gauge orifice, wetting losses on gauge walls, splashing, and evaporation [3]. Monthly biases in rain gauge measurements are thought to range between 5 and 40 percent, with the largest errors occurring during snowfall [4]. It is estimated that the long-term global average of precipitation has been underestimated by 11 percent, due primarily to turbulence and wetting losses. [3].

Selection of a reliable and accurate source of long-term data is essential. Preferably, it should record data hourly and be located near the DSCC. Although the DSN has installed rain gauges at each DSCC,

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[1] There is a considerable body of literature on the correlation between rain statistics and telecommunication link parameters. As a starting point, the reader is directed to the June 1993 issue of the *Proceedings of IEEE*, vol. 81, no. 6, which contains a series of articles on atmosphere-induced propagation effects on satellite communications links.

the rain data have never been validated or archived for general use.[2] Therefore, the National Climate Data Center (NCDC) database was consulted for nearby meteorological stations. In California, four stations were considered: Edwards Air Force Base (AFB), Daggett Airport, Bakersfield, and China Lake Air Station. Edwards AFB was selected because it maintains the most comprehensive and detailed records of meteorological phenomena. In Spain, two stations that are located within a few miles of each other were considered. The records from the Spanish station in Madrid were chosen because of apparent errors in the compilation of daily rain statistics from the meteorological station at the U.S. Torrejon AFB. This will be discussed in more detail in the next section. Finally, in Australia, the meteorological (met) station in Canberra was chosen because it is clearly the closest to the DSCC in Tidbinbilla. The locations of the 70-m DSSs and the associated meteorological stations are given in Tables 1 and 2. These meteorological stations are close enough to the DSCC to be subject to the same weather patterns and storm systems. However, some biases will be introduced because of orographic effects and altitude differences between the meteorological sites and DSSs. Except for frozen precipitation, the size and sign of this bias cannot be accurately estimated without a better understanding of local weather patterns or reliable meteorological data from the DSCC. For snow, hail, and freezing rain, the lower altitude will decrease the reported total because, at these altitudes, the frozen precipitation is more likely to melt and turn to rain. Summary meteorological data from these stations are available from the NCDC on CD-ROM [5]. The *International Station Meteorological Climate Summary (ISMCS)* CD-ROM [5] contains comprehensive surface meteorological statistics for 2200 stations and less detailed statistics for another 5000 stations. These meteorological summaries are computed from the data archives maintained by the NCDC. The breadth of this database allowed identification and comparison of appropriate meteorological stations. Since precipitation time series are not provided, the types of statistical analyses that can be employed are somewhat limited. These NCDC summary data are the source of statistics reported in this article.

Table 1. Locations of the DSN 70-m antennas.

70-m DSN site	Latitude	Longitude	Elevation, m MSL
DSS 14, Goldstone, California	35° 25′ 28″	243° 06′ 35″	993
DSS 43, Canberra, Australia	−35° 24′ 09″	148° 58′ 51″	670
DSS 63, Madrid, Spain	40° 25′ 41″	355° 45′ 15″	812

Table 2. Locations of the meteorological stations.

Meteorological station	Latitude	Longitude	Elevation, m MSL
Edwards AFB, California, WMO[a] 723810	35° 41′	243° 08′	701
Canberra, Australia, WMO 949260	−35° 18′	149° 11′	577
Madrid, Spain, WMO 082210	40° 27′	357° 27′	582

[a] World Meteorological Organization.

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[2] H. Royden, personal communication, Jet Propulsion Laboratory, Pasadena, California, March 1995.

III. Precipitation Statistics

Precipitation-induced link failures are best correlated with the precipitation rate [6]. Since the rate at which precipitation falls displays a tremendous amount of minute-to-minute variability, it cannot be measured reliably and reported in an operational setting. The two measures of precipitation routinely reported are the total daily precipitation and the number of hours each day during which precipitation falls. From these data, precipitation can be quantified using statistical measures such as the mean, median, standard deviation, maximum, and minimum values. Currently, the DSN uses a yearly weather model and does not quantify the variance associated with its model [7]. Therefore, mean values are most useful in validating the DSN high-end attenuation and noise exceedence statistics. Since plans to expand the existing atmospheric noise model to include seasonal variations have been discussed, monthly precipitation statistics will be given.

The mean frequencies of rain, snow, fog, and thunderstorms for each station are listed in Tables 3, 4, and 5, corresponding to Edwards AFB, Madrid, and Canberra, respectively. These statistics are expressed as a percentage of the frequency of mean occurrence. This statistical measure is best illustrated with an example. Assume a 720-hour month (30 days); then a 1-percent precipitation occurrence corresponds to a mean monthly incidence of 7.2 hours. These statistics indicate the fraction of time that space communication availability may be restricted due to precipitation. The “observations with precipitation, percent” column is the total percentage of precipitation frequency. This does not always coincide with the sum of the frequencies given in the “thunderstorm, percent,” “rain and/or drizzle, percent,” and “snow, sleet, and/or hail, percent” columns because thunderstorm conditions can occur without precipitation, both frozen and liquid precipitation can occur during a given hour, and round-off errors can affect the summation at the tenth-of-a-percent level.

Table 3. Precipitation and fog statistics for the Edwards AFB meteorological station—the percentage frequency of hourly weather conditions observed between 1979 and 1989.

Month	Thunderstorms, percent	Rain and/or drizzle, percent	Snow, sleet, and/or hail, percent	Observations with precipitation, percent	Fog, percent
January	0.0	3.0	1.3	3.0	1.4
February	0.0	3.2	0.4	3.7	2.3
March	0.0	5.0	0.5	5.0	0.9
April	0.2	1.2	0.0	1.3	0.1
May	0.3	0.5	0.0	0.5	0.1
June	0.3	0.5	0.0	0.5	0.0
July	0.7	0.6	0.0	0.6	0.0
August	0.7	0.8	0.0	0.8	0.1
September	0.7	1.0	0.0	1.0	0.4
October	0.3	1.1	0.0	1.1	0.5
November	0.1	1.5	0.1	1.6	0.2
December	0.0	2.3	0.7	3.0	4.0
Yearly average	0.3	1.7	0.1	1.8	0.8

Table 4. Precipitation and fog statistics for the Madrid meteorological station—the percentage frequency of hourly weather conditions observed between 1973 and 1993.

Month	Thunderstorms, percent	Rain and/or drizzle, percent	Snow, sleet, and/or hail, percent	Observations with precipitation, percent	Fog, percent
January	0.0	8.2	0.4	8.4	15.6
February	0.0	9.8	0.4	10.2	7.7
March	0.2	6.5	0.1	6.9	2.3
April	0.3	10.0	0.1	10.9	2.3
May	1.3	6.9	0.0	7.5	1.6
June	1.9	4.2	0.0	4.3	1.2
July	1.7	1.8	0.0	1.8	0.1
August	1.3	1.6	0.0	1.6	0.2
September	0.9	3.0	0.0	3.1	1.0
October	0.3	6.9	0.0	7.6	3.8
November	0.1	8.6	0.0	9.3	12.2
December	0.0	10.0	0.4	10.8	18.0
Yearly average	0.7	6.4	0.1	6.8	5.5

Table 5. Precipitation and fog statistics for the Canberra meteorological station—the percentage frequency of hourly weather conditions observed between 1973 and 1990.

Month	Thunderstorms, percent	Rain and/or drizzle, percent	Snow, sleet, and/or hail, percent	Observations with precipitation, percent	Fog, percent
January	0.9	7.2	0.0	7.1	1.8
February	0.9	6.1	0.0	6.1	1.9
March	0.6	8.0	0.0	7.9	4.3
April	0.4	11.4	0.0	11.4	9.1
May	0.1	11.3	0.0	11.2	14.5
June	0.0	10.9	0.0	10.8	16.8
July	0.0	11.5	0.1	11.6	13.9
August	0.2	12.9	0.1	12.9	9.3
September	0.2	11.8	0.1	11.9	8.6
October	0.4	11.5	0.1	11.5	5.3
November	0.4	8.5	0.0	8.5	3.9
December	1.2	7.6	0.0	7.5	2.4
Yearly average	0.5	9.9	0.0	9.9	7.7

The use of the frequency of occurrence as opposed to precipitation totals makes telecommunication modeling less sensitive to rain gauge measurement errors. Errors in frequency of occurrence due to rain gauge underestimates happen primarily during very light rain. Usually these errors occur when not enough rain has fallen to register on the gauge. Since light rain is rarely correlated with communication link failure, the use of frequency of occurrence reduces the impact of rain gauge errors on deriving high-end attenuation and noise exceedence statistics.

An indication of geographical variability and statistical reliability can be gleaned from a comparison of Table 3, which lists statistics for Edwards AFB, and Table 6, which lists statistics for Daggett Airport. The incidence of rainfall agrees to within 1 percent for all months except March, which exhibits a 2.5-percent difference. Since the sampling periods for the two underlying data sets are different, this could be the result of several extended rain events occurring during years not considered in the calculation of the Edwards AFB statistics. There is also a consistent difference in the reported snowfall. Snowfall at Daggett Airport is consistently less than snowfall observed at Edwards AFB. Some of this difference can be attributed to the station altitudes: Daggett Airport is at 588 m with respect to mean sea level (MSL) and Edwards AFB is at 701-m MSL, thus illustrating the earlier point about biases in frozen precipitation statistics caused by differences in station altitude. However, the magnitude of this snowfall difference is too great for station altitude alone to explain and requires consideration be given to other mechanisms, such as orographic effects and snow measurement errors. It is important to note that the frozen precipitation is still measured and reported, only it is reported as rain. A comparison was also made of statistics reported by the two stations in Madrid, and differences were on the order of a percent or less.

The daily incidences of precipitation are listed in Tables 7 through 9. These statistics are also expressed as a percentage of frequency of mean occurrence. The difference in these statistics is that daily precipitation records were used in the calculations. Therefore, assuming a 30-day month, a 3.3-percent occurrence

Table 6. Precipitation and fog statistics for the Daggett Airport meteorological station—the percentage frequency of hourly weather conditions observed between 1973 and 1993.

Month	Thunderstorms, percent	Rain and/or drizzle, percent	Snow, sleet, and/or hail, percent	Observations with precipitation, percent	Fog, percent
January	0.0	3.0	0.1	3.0	2.9
February	0.0	2.4	0.1	2.4	1.0
March	0.1	2.6	0.0	2.7	0.3
April	0.1	1.0	0.0	1.0	0.0
May	0.2	0.6	0.0	0.6	0.0
June	0.4	0.3	0.0	0.3	0.0
July	1.3	1.0	0.0	1.0	0.0
August	1.3	1.0	0.0	1.0	0.2
September	0.7	0.9	0.0	0.9	0.2
October	0.3	0.7	0.0	0.7	0.1
November	0.0	0.8	0.0	0.8	0.3
December	0.0	2.0	0.1	2.1	1.5
Yearly average	0.4	1.4	0.0	1.4	0.6

Table 7. Precipitation and fog statistics for the Edwards AFB meteorological station—the percentage frequency of daily weather conditions observed between 1979 and 1989.

Month	Thunderstorms, percent	Rain and/or drizzle, percent	Snow, sleet, and/or hail, percent	Observations with precipitation, percent	Fog, percent
January	0.2	17.0	3.4	18.7	9.7
February	0.4	16.4	2.0	17.1	6.4
March	0.6	17.4	2.7	17.9	4.4
April	1.0	12.0	0.6	12.0	1.5
May	2.0	6.3	0.1	6.3	1.1
June	2.3	3.0	0.1	3.0	0.4
July	4.6	7.4	0.1	7.4	0.2
August	6.3	7.3	0.1	7.3	0.6
September	3.5	7.3	0.1	7.3	1.7
October	1.9	6.8	0.3	6.8	3.1
November	0.7	11.0	0.5	11.1	3.7
December	0.2	13.5	2.3	14.5	7.6
Yearly average	2.0	10.4	1.0	10.8	3.3

Table 8. Precipitation and fog statistics for the Madrid meteorological station—the percentage frequency of daily weather conditions observed between 1973 and 1993.

Month	Thunderstorms, percent	Rain and/or drizzle, percent	Snow, sleet, and/or hail, percent	Observations with precipitation, percent	Fog, percent
January	0.0	28.0	2.8	28.7	43.1
February	0.9	36.2	3.7	37.0	31.4
March	2.6	28.2	1.4	28.5	15.0
April	4.8	40.4	0.3	40.4	14.7
May	14.2	39.2	0.0	39.3	12.3
June	17.8	27.8	0.0	27.8	8.3
July	14.0	14.1	0.0	14.1	0.9
August	11.8	13.1	0.0	13.1	2.4
September	10.2	18.7	0.0	18.9	6.1
October	3.3	32.0	0.0	32.0	20.5
November	0.8	29.3	0.3	29.3	41.0
December	0.3	33.6	2.2	33.9	44.4
Yearly average	6.7	28.4	0.0	28.6	20.0

Table 9. Precipitation and fog statistics for the Canberra meteorological station—the percentage frequency of daily weather conditions observed between 1973 and 1990.

Month	Thunderstorms, percent	Rain and/or drizzle, percent	Snow, sleet, and/or hail, percent	Observations with precipitation, percent	Fog, percent
January	4.9	22.1	0.0	22.1	9.5
February	4.8	17.9	0.0	17.9	9.2
March	2.7	26.3	0.0	26.3	19.4
April	2.1	30.5	0.0	30.5	34.4
May	0.6	30.3	0.2	30.5	43.3
June	0.0	30.6	0.0	30.6	40.7
July	0.2	31.7	0.7	32.2	37.1
August	0.9	35.1	0.4	35.1	29.0
September	1.1	32.4	0.4	32.8	31.7
October	2.2	34.7	0.2	34.7	22.8
November	5.8	28.0	0.0	28.0	18.0
December	4.2	23.9	0.0	23.9	11.4
Yearly average	2.4	28.7	0.2	28.8	25.6

would correspond to a day. Comparison of these statistics with the hourly statistics reveals a two- to six-fold increase in precipitation incidence. The source of this difference can be explained with an example. If during a week in a given month, a 2-hour thunderstorm occurs each afternoon, then the percentage frequency of hourly precipitation occurrence would be 1.9 percent (2 hours × 7 days/720 hours). In contrast, the percentage frequency of daily precipitation occurrence would be 23 percent (7 days/30 days). Since rain rarely lasts all day, the daily occurrence statistics will always be greater than the hourly occurrence.

As stated in the previous section, there appears to be an error in the Madrid Torrejon AFB daily statistics. As compared with the Spanish station, the meteorological station at Torrejon AFB reports roughly twice the daily occurrence of precipitation. This difference yields a 63-percent mean annual percentage of days with observed precipitation at Torrejon AFB. This is clearly wrong since no other Spanish meteorological records are able to substantiate that it rains more than half the days in Madrid. Since the hourly statistics for both stations are in excellent agreement, a calculation error is assumed in the Torrejon AFB daily statistics. Due to these discrepancies, the Spanish station rain records were chosen for this study.

A listing of the occurrences of total daily rainfall and snowfall amounts for Edwards AFB are given in Tables 10 and 11. These tables are broken down by month.

IV. Discussion

Rain, snow, fog, and thunderstorm statistics from meteorological stations near the DSCCs have been presented. Yearly statistics show that the daily frequency of rain at the Spanish and Australian DSCCs are similar. In contrast, daily precipitation at Goldstone is roughly a third of that reported by the other DSCCs, with a mean incidence of 39 days of precipitation per year. When hourly occurrence

Table 10. Precipitation statistics for Edwards AF— the percentage frequency of daily precipitation total observed between 1946 and 1989.

Precipitation total	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.	Annual
None	81.9	81.7	81.1	87.1	93.8	97.2	93.0	93.2	93.0	92.7	88.4	83.9	88.9
Trace < 0.01	5.4	5.9	6.5	6.1	4.0	1.3	4.5	3.6	4.1	2.9	4.0	6.6	4.6
0.01	0.8	1.5	1.4	1.1	0.4	0.2	0.7	0.3	0.4	0.6	0.7	0.8	0.7
0.02–0.05	2.4	2.4	2.5	1.7	0.5	0.6	0.8	1.0	0.9	1.1	1.9	2.2	1.5
0.06–0.10	2.2	1.5	2.0	1.1	0.7	0.2	0.5	0.5	0.3	0.8	0.6	1.1	1.0
0.11–0.25	3.3	2.8	3.3	1.8	0.6	0.4	0.4	0.5	0.6	1.0	1.7	2.0	1.5
0.26–0.50	2.3	2.4	1.9	0.7	0.0	0.1	0.1	0.5	0.4	0.4	1.4	2.1	1.0
0.51–1.00	1.4	1.3	1.1	0.3	0.1	0.0	0.0	0.3	0.2	0.3	1.2	1.0	0.6
1.01–2.50	0.2	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.1
2.51–5.00	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>5.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	12.6	12.4	12.4	6.8	2.3	1.5	2.6	3.2	2.8	4.4	7.6	9.5	6.5

Table 11. Snowfall statistics for Edwards AF— the percentage frequency of daily precipitation total observed between 1946 and 1989.

Precipitation total	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.	Annual
None	97.0	98.4	97.7	99.8	100.0	100.0	100.0	100.0	100.0	100.0	99.6	97.6	99.2
Trace < 0.01	1.7	1.2	1.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.6	0.6
0.1–0.4	0.3	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1
0.5–1.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1
1.5–2.4	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
2.5–3.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
3.5–4.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
4.5–6.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
6.5–10.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>10.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Measured amount	1.3	0.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.3
Greatest snowfall total	11.5	2.6	1.4	Trace	0.0	0.0	0.0	0.0	0.0	0.0	3.8	8.6	11.5

statistics are examined, differences in rainfall patterns become apparent. The average precipitation event in Australia lasts 40-percent longer than the average event in Spain, causing a marked difference in the hourly frequency of occurrence. Goldstone has the greatest difference between hourly and daily occurrence statistics, yielding the shortest storms with an average of 4 hours per precipitation event. Not surprisingly, precipitation at all three DSCCs exhibits seasonal variations.

It was shown that biases inherent in standard methods for measuring precipitation will cause a slight underestimate in the occurrence of rain. However, use of percentage frequency of occurrence as a statistical measure reduces the impact of rain gauge errors on precipitation associated with high-end noise and attenuation statistics. An indication of the repeatability of these statistics, given the errors inherent in measurement techniques, was given by comparisons of nearby stations. It was shown that the variance in the percentage frequency of hourly occurrence statistics agreed to 1 percent each month. In contrast, evidence was presented that the reported incidence of frozen precipitation could be severely underestimated due to differences in DSS and meteorological station altitudes and to difficulties in measuring snowfall. This should have a small impact on telecommunication modeling because the frozen precipitation was most likely reported as rain at the meteorological stations.

These statistics may provide some insight on a recent study showing that monthly rainfall totals are not well correlated with monthly averages of the atmospheric noise temperature exceedence statistics.[3] A possible explanation for the poor correlation is that this technique attempts to correlate short-term precipitation events with monthly average atmospheric brightness temperatures. The study used data collected in Madrid, where the ratio between the mean frequency of daily precipitation occurrence and the mean frequency of hourly precipitation occurrence is four; so, the average precipitation event lasts a quarter of a day. Therefore, the correlation of monthly rainfall with monthly atmospheric brightness temperatures on average seeks to connect repeated 6-hour events with a monthly average. The existence of a correlation would only become apparent if there were a strong correlation between total precipitation and precipitation duration. If this were the case, then higher rainfall totals would yield longer precipitation-induced increases in atmospheric brightness temperature. The results of the above-mentioned recent study indicate that this correlation, if it exists, is not very strong.[4] Given these results, it is worth revisiting this effort with an examination of the correlation between monthly precipitation total as measured by percentage frequency of hourly occurrence with the monthly average brightness temperature.

This article provides the statistics necessary to validate and improve the high-end exceedence statistics for existing DSN telecommunication models. For future models, it would be worthwhile to obtain the raw precipitation time series from these meteorological stations to develop a measure of the year-to-year variance in precipitation. Additional improvements could be obtained from a comparison of calibrated DSN rain gauge data with meteorological station measurements to quantify the size of biases that are being introduced by orographic and regional weather effects.

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