Noise in Wireless Systems Produced by Solar Radio Bursts

B. Bala[1], L. J. Lanzerotti[1], D. E. Gary[2]
and D. J. Thomson[1]

[1] Bell Labs, Lucent Technologies, Murray Hill, NJ 07974

[2] New Jersey Institute of Technology, Newark, NJ 07102

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Abstract

We have carried out an investigation of 40 years of solar radio burst data in a wide range of frequencies that have been reported by observing stations around the world during 1960–1999. The data were compiled by the NGDC of NOAA. This period covers three full and two partial solar cycles. We find that the number of bursts per day with amplitudes $> 10^3$ solar flux units (SFU) falls as an approximate power law with increasing flux level for the frequency bands investigated (1–10 and 10–20 GHz). Also, the number of events with peak flux density $> 10^3$ SFU varies, as expected, with the solar cycle in the bands investigated (1–2, 2–4, and 4–10 GHz). We discuss the rate of occurrence of events ($> 10^3$ SFU) in the context of the noise levels in typical wireless communications systems. We find that statistically, depending upon wireless system parameters, several solar events per year are likely to occur that could cause severe interference in a given cell site during solar maximum periods.

1 Introduction

The first measurements of radio noise from the quiet Sun were made in 1942 and 1943 by Southworth [1945] and in 1943 and 1944 by Reber [1944]. The first (inadvertent) detections of solar radio bursts were made by radar systems at the time of large solar flares in 1942 during the Second World War [Hey, 1946]. Working with an experimental 24 GHz radar at the Bell Labs, Southworth [1945] showed that the radio diameter of the Sun was larger than its optical diameter. Following these pioneering studies, and the end of the war, solar radio studies became an active field of astronomical research.

Early studies in this area established that solar radio emissions exhibit a wide range of spectral shapes and intensity levels [e.g., Reber, 1944; Kundu, 1965; Castelli et al., 1973; Guidice and Castelli, 1975]. In addition to the intrinsic interest for obtaining a better understanding of the Sun and the physical processes going on, this research often had underlying practical motivations as well. These included prediction of solar energetic particle events that could affect the Earth's space environment [e.g., Castelli et al., 1967; O'Brien 1970; Castelli et al., 1973; Cliver, 1985], and the possibility of solar emissions being a cause of interference in wireless communications and other radio systems [Barron et al., 1985; Castelli et al., 1973].

The rapid growth in wireless communications around the world at GHz frequencies in the last decade and continuing to date calls for a revisit of solar noise levels at such frequencies. Kakinuma et al. [1969] examined solar radio burst statistics at four microwave frequencies measured in Japan during 1957–1962. Most of the existing longer-term statistical results have used data acquired during solar cycles 19 and 20 [Barron et al., 1980; Barron et al., 1985], work that was motivated by the solar radio patrol network the U. S. Air Force established around the world.

This Brief Report presents the initial results of an analysis of four decades of solar radio burst data in the context of noise levels existing in wireless communications systems.

2 Data Set

The solar radio burst data that are analyzed for this study were obtained from the National Geophysical Data Center (NGDC) of NOAA (National Oceanic and Atmospheric Administration), Boulder, Colorado. The original data set was a compilation of solar radio burst measurements supplied to NGDC by various solar radio observatories around the world during 1960 through 1999. During this forty–year interval the number and location of radio observatories have changed, as did the frequencies observed. Further, over this period, it is likely that instrumentation has improved considerably, leading to a higher level of the sensitivity of detection, among other improvements. Thus, the data set could suffer from several types of bias, including local time coverage, sensitivity levels, and frequency coverage. However, calibration uncertainties are not likely to be significant because even in the first inadvertent detection by British radars, the reported flux was as high as $\sim 10^5$ SFU (1 SFU $= 10^{-22}$ W/m^2/Hz).

A more serious bias may arise due to attenuation of the data caused by saturation of receivers on large bursts. The receiver saturation occurs because the usual solar radio bursts are at low levels and the instrumentation is designed accordingly. It is important to keep this and the other caveats in mind as the results presented here are discussed. Nevertheless, to the best of our knowledge, this is the best (and only) set of data of its kind available for such a long time span. Therefore, it is useful to investigate the data set in order to determine what might be concluded about the past occurrences of large ($> 10^3$ SFU) solar burst events, especially in the context of the noise levels of contemporary wireless communications technologies.

Table 1. Total number of events during 1960–1999. The percentages given in brackets are for the non-overlapping events.

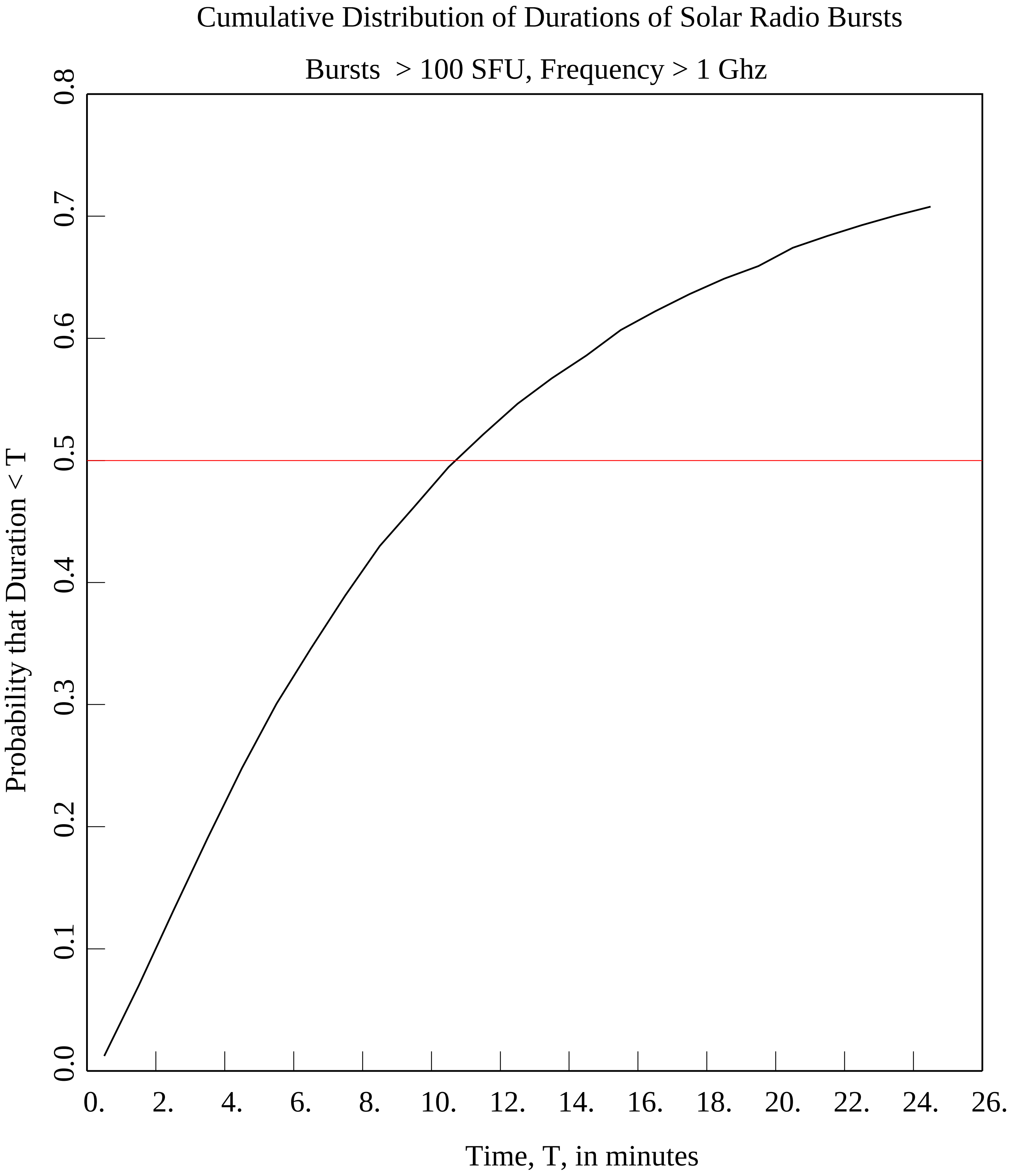

Figure 1

Figure 1: The cumulative probability distribution of duration of events less than time T (in min). This is for events with peak flux density > 100 SFU and frequency > 1 GHz (See text for details).

Table 1 Total number of events during 1960–1999. The percentages given in brackets are for the non-overlapping events.

Peakflux (SFU)	Freq. Range (GHz)	1960–1999	1964–1975 Cycle 20	1976–1985 Cycle 21	1986–1995 Cycle 22
$> 10^3$	1 – 10	2882 (72%)	624 (80%)	1164 (71%)	996 (68%)
	10 – 20	720 (77%)	103 (91%)	270 (81%)	329 (71%)

The original data set received from the NGDC was reorganized to have easy access for categorization in terms of observing station, frequency, time of acquisition, duration of the bursts, peak flux, time at which the peak flux was detected, etc. The entries are listed chronologically (in UT) according to the starting time of each burst. Since there was little coordination in observation among the stations, many events were reported by more than one station, often at different observing frequencies. Therefore, the next task was to identify those reports belonging to a given event within the desired frequency range. For this we adopted the following procedure. As a first step, we "defined" an event using a time window of 12 minutes. That is, if the starting time of two successive entries in the data are separated by more than 12 minutes, then they are counted as two separate events. Each event is then assigned a label and the events are numbered sequentially. All the entries within 12 min are considered to belong to the same event and they all bear the same event label. As the second step, data with peak flux density $\geq 10^3$ SFU and frequency between 1–20 GHz were selected. Finally, for entries with the same event label and frequency (called duplicate events), only that event with the largest amplitude, viz. the peak flux density, is chosen. Thus, each event is uniquely identified.

The selection of the width of the time window, 12 min, that is used here is based on several statistical studies of the data set. Shown in Figure 1 is the cumulative probability distribution of the duration T of solar radio burst events. The distribution shown is for events with peak flux density > 100 SFU and for frequencies > 1 GHz. The cumulative probability distribution shows that the 50% probability line falls between T $\sim$ 10–12 min. That is, $\sim$ 50% of the events lasted for 12 minutes. The probability of multiple detections of the same event by different observatories is highest during the time interval in which the event existed. Therefore, a time window of 12 min should eliminate all the duplicate events. However, independent events can also occur within this 12 min interval. Moreover, the other 50% of the population have durations greater than 12 min, which implies that perhaps not all duplicate events are eliminated. A time window greater than 12 min will eliminate more real events whereas a time-window less than 12 min will include more duplicate events. Thus, the use of 12 min for the present analysis is a trade off between the elimination of more real events and the inclusion of more duplicate events.

In this study, only those events in the frequency range 1–20 GHz were examined. Results for events with amplitudes $> 10^3$ and $> 10^4$ SFUs are shown. The analysis was carried out for (a) the entire period, 1960–1999, (b) solar cycle 20 (1964–75), (c) solar cycle 21 (1976–85) and (d) solar cycle 22 (1986–95). The number of events during each of these periods is presented in Table 1. These number of events are a fraction of the total events recorded at the end of Step 2 of the filtering process outlined above, and these fractions are listed as percentages in parentheses.

3 Results

Figure 2 depicts a histogram of the number of events per day for (top to bottom panel): (a) the entire period 1960–1999 (b) solar cycle 20, covering a period from 1964 through 1975 (c) solar cycle 21, starting from 1976 to 1985 inclusive and (d) solar cycle 22; 1986–1995. Here, only those events with peak fluxes $> 10^3$ SFU are shown. Events in the frequency band 1–10 GHz are plotted in the left hand column of panels whereas events in the frequency band 10–20 GHz are shown in the right hand panels. In all cases, the bin sizes have been taken as 0.1 in the log scale.

From Figure 2 it is clear that the occurrence distributions for events with amplitudes $> 10^3$ SFU decrease with amplitude (peak flux density) approximately as an inverse power law. These distributions and the possible implications for solar radio emission mechanisms will be addressed in a subsequent work in preparation. In both the frequency bands, most events have amplitudes $< 10^5$ SFU. There was only one event with amplitude $> 10^5$ SFU during the entire period of study. This event occurred on July 4, 1974. It was reported from Kiel, Germany, at 1 GHz (2.6×10^5 SFU) and at 1.42 GHz (8×10^5 SFU).

The number of larger events ($> 10^4$ SFU) in the frequency range 1–10 GHz appear to increase in number with solar cycle (see also Table 1). This is also true in the frequency band 10–20 GHz. The physical implication of this inference is not clear at this stage. The possibility of an increase in the dynamic range of instrumentation cannot be ruled out, a situation that would permit the recording of larger events without saturation. A parallel examination of the data showed that there are differences in the number of observatories during the four decades analyzed. Some longitudes showed a decrease in reporting stations whereas some other locations have an increased number with time. This aspect is also under further investigation.

The yearly dependence of the daily number of events was investigated for the 40-year interval and this result is shown in Figure 3. The upper and lower panels show events with peak flux density $> 10^3$ and $> 10^4$ SFU respectively. The results are plotted with solid, dotted and dashed lines representing the different frequency ranges, 1–2, 2–4 and 4–10 GHz, respectively.

The 11-year sunspot cycle is clearly seen in both panels of Figure 3. Here again the marked increase in the daily occurrence rate of larger events (lower panel) in later solar cycles can be seen. Also, the number of events/day shows an increase with increase in frequency. This may be an indication of the increasing flux density due

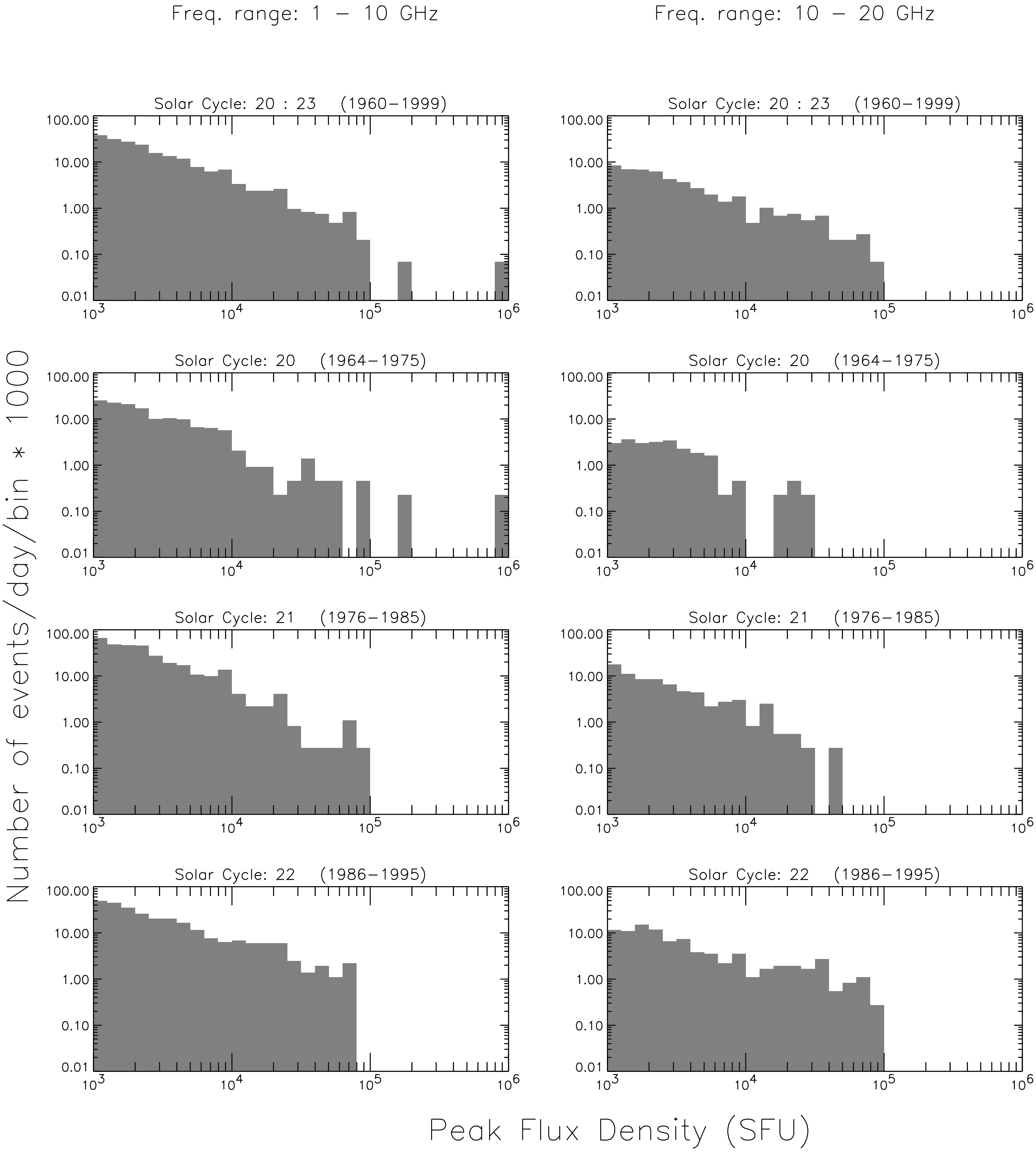

Figure 2

Figure 2: Number of events per day with amplitudes $> 10^3$ SFU for 40 years (panel a) and for cycles 20 (panel b), 21 (panel c), and 22 (panel d). The frequency ranges are 1–10 GHz (excluding 10 GHz) shown in the left panels and 10–20 GHz (excluding 20 GHz) in the right panels. Here, the number of events/day/bin is multiplied by 1000.

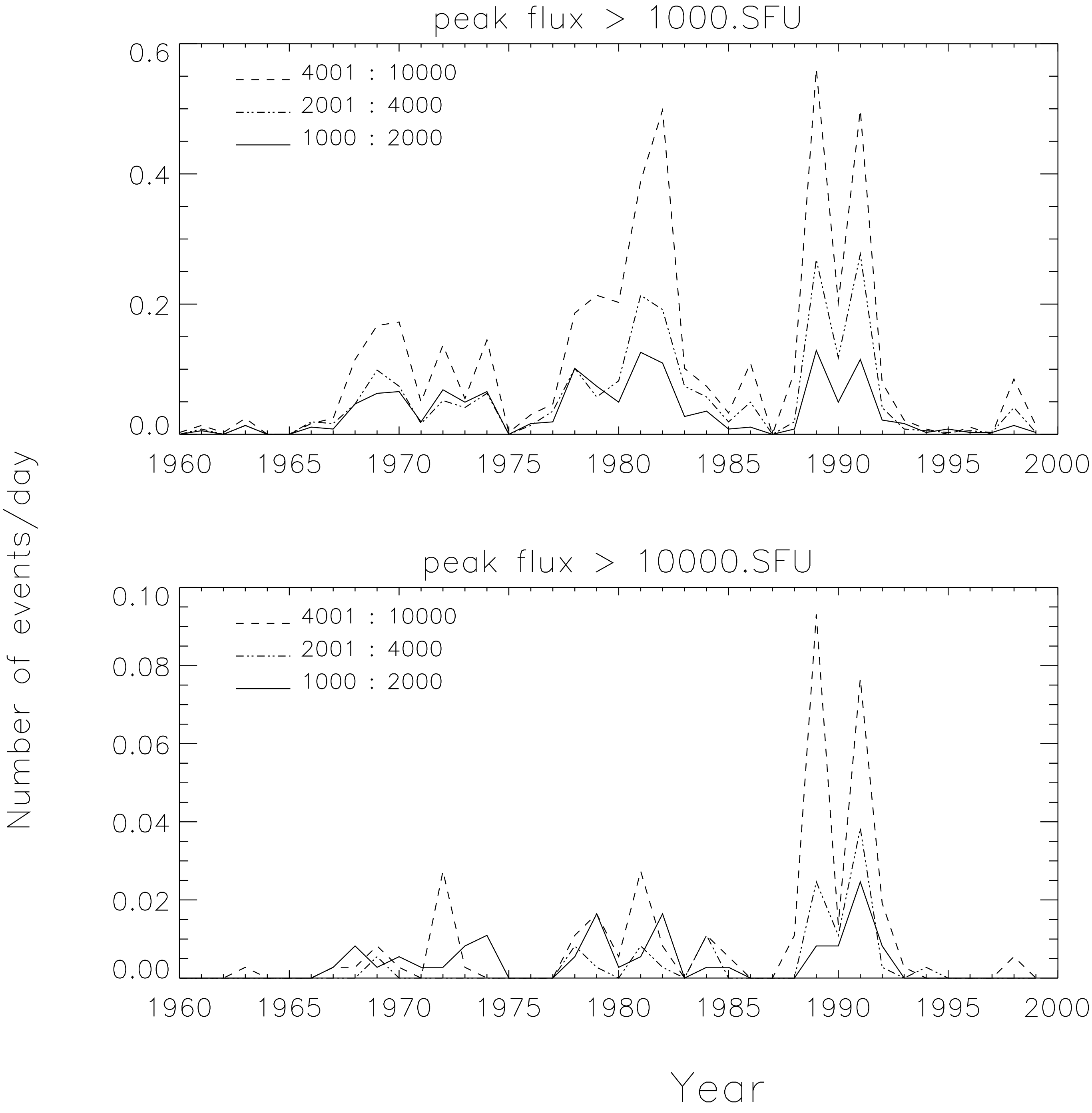

Figure 3

Figure 3: Total number of events/day as a function of time in years for peak flux $> 10^3$ SFU shown in the Upper Panel, and peak flux $> 10^4$ SFU in the Lower Panel. The frequency ranges are 1–2, 2–4 and 4–10 GHz.

to the gyrosynchrotron mechanism, which is responsible for the bulk of the emission at the frequencies investigated here [Dulk, 1985]. Another interesting aspect is the clear double peak in the number of events that is seen in the last (22^{nd}) solar cycle, which had its maximum around 1990. A similar behaviour is clearly evident in storm sudden commencements in the 22^{nd} cycle and somewhat less evident in the number of sunspots [see Solar Geophysical Data, 2000]

4 Discussion

The increasing use of wireless as a mode of communication requires a study of the possible effects of solar activity in the radio frequency ranges that are used and projected for use in wireless systems. In this Brief Report, we presented the initial results of a statistical analysis of solar radio bursts recorded in the frequency band 1–20 GHz by various stations around the world. The data covers a period of 40 years from 1960 through 1999; part of solar cycle 19, full solar cycles 20, 21 and 22, and the rising phase of 23. There have been a number of modifications including increased sophistication of the observing techniques and in the quality of data acquisition over these four decades. Therefore, the results could have some biases, but we do not believe these should negate the overall conclusions.

The receiver noise at a wireless cell site at ambient temperature is 3.8×10^{-21} W/Hz (given by kT, where, k is the Boltzmann constant and T = 273 K). For a bandwidth B = 1 Hz, this is amounts to ~ -174 dBm. A single polarization antenna of gain G (typically, about 10–30) in an isotropic radio flux of F $\mathrm{W/m^2/Hz}$ gives a receiver power $\mathrm{P_R}$ [Kummer and Gillespie, 1978]:

$$\mathrm{P_R} = \frac{1}{2}\mathrm{G}\frac{\lambda^2}{4\pi}\mathrm{F} \qquad \mathrm{W/Hz} \tag{1}$$

where, λ is the wavelength received. Now, define an “equivalent” solar flux $\mathrm{F_{eq}}$

where the thermal and the solar noise levels are equal.

$$\mathrm{kTB} = \frac{1}{2}\mathrm{GB}\frac{\lambda^2}{4\pi}\mathrm{F_{eq}} \tag{2}$$

$$= \frac{1}{2}GB\frac{\lambda^2}{4\pi}10^{-22} \tag{3}$$

where $\mathrm{F_{eq}}$ is expressed in SFU. $\mathrm{F_{eq}}$ can be determined from Eq. 3. for any wireless system with frequency equal to $1/\lambda$. For example, for a cellular base station operating at 900 MHz ($\lambda^2 \sim 0.1\mathrm{m}^2$) and G $\sim$ 10, the equivalent flux $\mathrm{F_{eq}}$ will be $\sim$ 960 SFU. This is more than twice the thermal noise power. For a base station operating at 2.4 GHz, ($\lambda^2 \sim 1.6 \times 10^{-2}$) and G $\sim$ 10, $\mathrm{F_{eq}}$ will be $\sim$ 6000 SFU.

In the above, the receiver noise figure, typically a few dB, has been ignored. Most current cellular systems operate well above thermal noise since the bit error rate changes rapidly with the signal to power ratio. For example, a change of 0.75 dB can produce a change of as much as a factor of 10 in the bit error rate [e.g., Gordon and Morgan, 1993].

If a solar flux level of 10^3 SFU can be taken as a context "threshold" for interpreting the statistical results presented here, Figure 3 indicates that there can be of the order of one event of this size or larger every 10–20 days or so on average per year. Of course, the event occurrence rate will be larger during solar maximum periods and smaller during minimum periods. Further, whether antenna interference at a cell site will actually occur will depend upon the orientation of the antenna. It can be expected that the probability for interference will be larger during local mornings and evenings than at local noon for those antennas pointed towards the east and west horizons, respectively.

Considering that an antenna at a given cell site is most susceptible for $\sim$ 3 hours each, around local mornings and evenings, then the chances would reduce to perhaps one event with peak flux density 10^3 SFU or larger every 40–80 days, or a few times every year at a given cell site. However, it should be noted that numerous sites will be pointing in the solar direction at the same time and, therefore, a large service area could be affected by a single burst event.

It is also of interest to note that radio frequency microbursts (with durations of the order of tens of msec) often occur within a solar radio burst event [Benz, 1986; Csillaghy and Benz, 1993]. Such microbursts may not have been included in the data set analyzed. It is not uncommon for microburst amplitudes to exceed the overall burst amplitude by factors of 10 to 10^3. Thus, the probability for a solar burst to interfere with a wireless cell site is undoubtedly larger than that estimated here.

In summary, this analysis of a compilation of solar noise bursts measured over the last four decades indicates that it is very likely that a wireless cell site could suffer severe interference from a solar radio burst on several occasions in a year, especially during solar maxima.

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