not available before. Analysis of the totality of data from the worldwide network of recording stations obtained no significant changes in these characteristics, so this portion of the "new" model is the same as the current CCIR Report 322 model.

Crichlow et al. (1960a) developed a "model" or method for obtaining the APD of the received atmospheric noise envelope from the measured statistical moments V_d and L_d, defined previously. A "most likely" subset of this model became the "CCIR 322" model. Section 4 reviews this model and presents a numerical representation, including bandwidth relationships, since the received APD is a function of receiver bandwidth.

Section 5 then gives a brief summary and Section 6 contains the references. Various computer algorithms (programs) are given throughout the report, where appropriate, that will reproduce all the atmospheric noise characteristics. These programs are given in FORTRAN.

2. THE NEW 1 MHz ATMOSPHERIC RADIO NOISE F_{am} ESTIMATES

As noted in the last section, the existing estimates of atmospheric noise levels and characteristics are contained in CCIR Report 322. These estimates were obtained from measurements made by a worldwide network of 16 recording stations (Figure 3). The measurements were made in a 200 Hz bandwidth on frequencies of essentially .013, .051, .160, .495, 2.5, 5, 10, and 20 MHz. There were some small variations in these frequencies between stations and not all stations had all frequencies for the entire period of measurement. The measurements made from July 1957 through October 1961 were used to produce Report 322. The network continued to operate through November 1966 and longer still for some locations. All these data are contained in the series of NBS Technical Notes No. 18 (July 27, 1959) through 18-32 (October, 1967). This means that there is a great deal of additional analyzed data available from this network to use in producing an updated "322." Data from portions of the network exist past November 1966, but only the analyzed data contained in the NBS Technical Note Series (July 1957-November 1966) are used here. Also, after the publication of Report 322, it was shown that the data from Thule, Greenland, and Byrd Station, Antarctica, were generally contaminated by high levels of local man-made noise. Therefore, data from Thule and Byrd Station were not used in this present analysis.

For a number of years the Soviet Union operated a network of ten noise measurement stations. Data from these measurement locations within the Soviet Union are available from the World Data Center (National Oceanic and Atmospheric Administration, Boulder, Colorado 80303). Raw data are available on microfilm for periods of time from mid-1958 through 1965. The parameters that were measured were different from those discussed above and the analysis and use of the Soviet data are discussed next. The worldwide network locations and the new locations are given in Table 1. Figure 7 is a repeat of Figure 3, but with the new locations added.

2.1 Analysis of the Soviet Data

The Soviet atmospheric noise measurement program was organized and controlled by Dr. Ja. I. Likhter (Izmiran, P. O. Akademgorodok, Moscow Region, USSR). Dr. Likhter kindly supplied detailed information on the measurement equipment used and the definitions of the various parameters measured. On each measurement frequency (specified later) a measurement lasted approximately 2 minutes and measurements were taken 3 hours apart each day. There were often many days in any given month when no measurements were taken. The voltage levels (given in field strength, μV/m) that were exceeded 2, 10, 20, 30, 40, 50, 60, 70, 80, and 90 percent of the time were recorded. These levels are noted by $E_{0.02}$ to $E_{0.9}$. Because of averaging in the receiving and, perhaps, the short measurement time, this set of measurements, unfortunately, does not appear to be an APD measurement (as defined earlier) and they do not correspond to other Soviet APD results (e.g., Remizov, 1981, the references therein, and Likhter and Terina, 1960). Also, most of the energy in the atmospheric noise process is contained at levels that occur less than two percent of the time. The peak value was also recorded. The data also give a parameter, noted E_{on}. This parameter has no physical meaning in itself but is a level set by the equipment operator, below which the other levels ($E_{0.02}$, etc.) were recorded. As detailed below, it turns out the E_{on} serves as a good approximation to the rms level (f_a) and the parameter E_{on} is the parameter used in the analysis here. This is based on the following analysis and observations:

a) In 1960, Likhter and Terina developed a model for the APD of atmospheric noise based on measurements. Using this model, they developed a technique to determine the rms level from the measured median level $E_{0.5}$. This was done for 12, 25, 36, and 60 kHz. These authors used this technique to compare some Soviet measurements at Moscow to the CCIR estimates contained in CCIR Report 65 (the predecessor to Report 322), that is, to F_{am}. Using this technique, we always obtained, for the sample case studies, a value that was always within 4 dB of E_{on}, and usually much closer. It was assumed that this would perhaps be true, therefore, at all frequencies.

Table 1. Atmospheric noise measurement locations.

WORLDWIDE NETWORK LOCATIONS (CCIR 322)

Balboa, Canal Zone	79.5W, 9.0N
Bill, Wyoming	105.2W, 43.2N
Boulder, Colorado	105.1W, 40.1N
Byrd, Antarctia	120.0W, 80.0S
Cook, Australia	130.4E, 30.6S
Enkoping, Sweden	17.3E, 59.5N
Front Royal, Virginia	78.2W, 38.8N
Ibadan, Nigeria	3.9E, 7.4N
Kekaha, Hawaii	159.7W, 22.0N
New Delhi, India	77.3E, 28.8N
Ohira, Japan	140.5E, 35.6N
Pretoria, South Africa	28.3E, 25.8S
Rabat, Morocco	6.8W, 33.9N
San Jose, Brazil	45.8W, 23.3S
Singapore	103.8E, 1.3N
Thule, Greenland	68.7W, 76.6N

NEW LOCATIONS

Laem Chabang, Thailand	100.9E, 13.05N
Alma Ata, USSR	76.92E, 43.25N
Ashkhabad, USSR	58.3E, 37.92N
Irkutsk, USSR	104.5E, 52.0N
Khabarovsk, USSR	135.0E, 50.0N
Kiev, USSR	30.3E, 50.72N
Moscow, USSR	37.32E, 55.47N
Murmansk, USSR	35.0E, 69.0N
Simferopol, USSR	34.03E, 45.02N
Sverdlovsk, USSR	61.07E, 56.73N
Tbilisi, USSR	40.0E, 41.72N

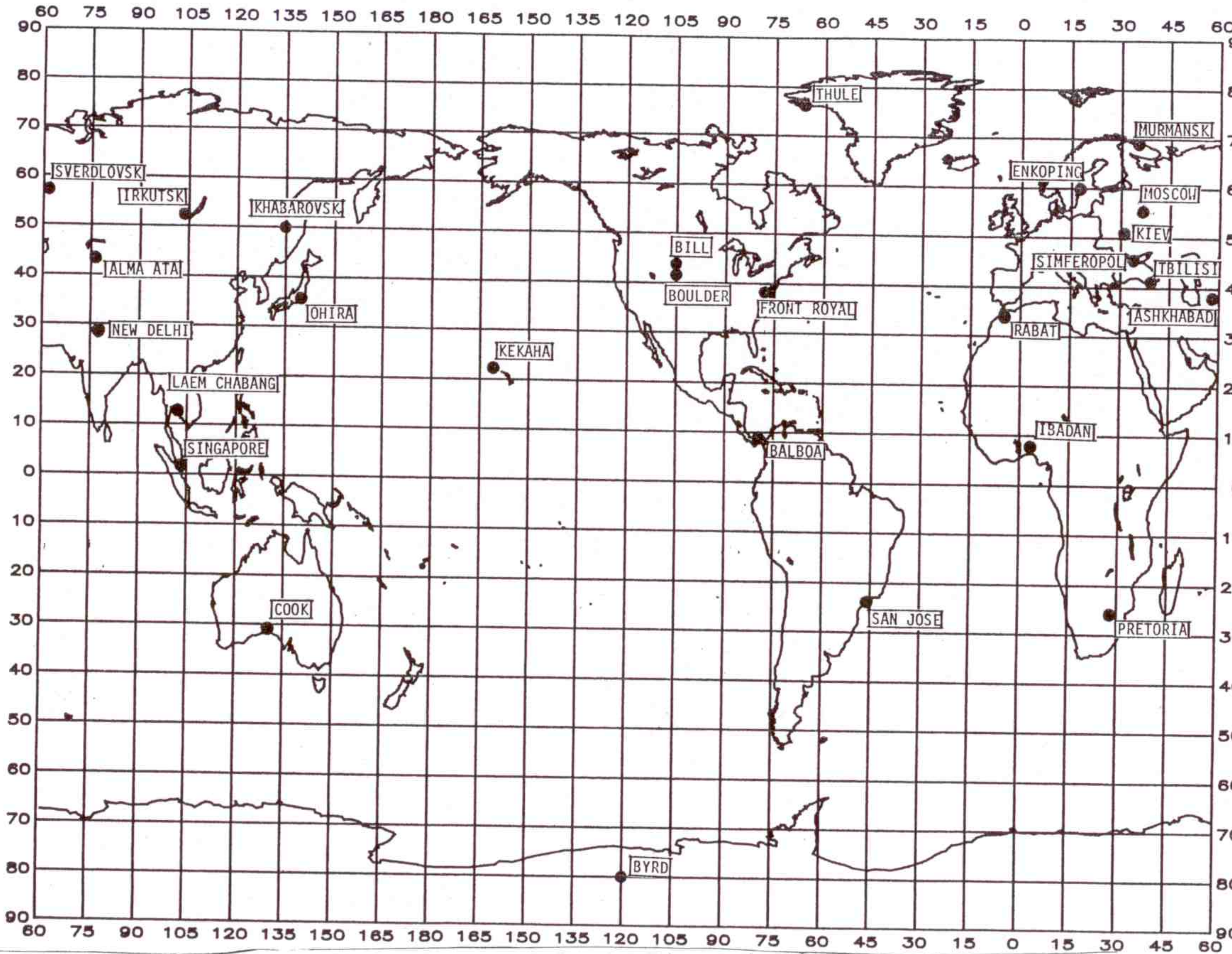

Figure 7. Radio noise recording station locations used in the present analysis.

b) The atmospheric noise is low within the USSR, especially the eastern part, and the measurements appear to be of mostly man-made noise for a good portion of the time at the higher frequencies. The parameter E_{on} leads to levels and variation with frequency that correspond quite closely to levels measured at quiet receiving sites in the worldwide network; that is, comparison of man-made noise levels check.

c) Finally, the analysis to obtain new estimates is based on determining correction factors at each measurement location (corrections to CCIR 322). Correction factors developed using E_{on} at Murmansk and at the close F_a measurement location, Enkoping, Sweden, were always quite similar, both in magnitude and direction.

Based on the above, the median value of E_{on} was determined for all measurements at a given location and for a given measurement frequency for the hours and months within each of the twenty-four 3-month/4-hour time blocks. This median value of E_{on} is in μV/m. The antennas used at the Soviet measurement locations were 5 meter vertical rods over a ground plane. Equation (3), therefore, is used to go from field strength to F_{am}. The bandwidths used were approximately 250 Hz at frequencies below 1.5 MHz, and 1000 Hz at frequencies at or above 1.5 MHz, with some variation at some of the measurement stations; for example, a 1000 Hz bandwidth was sometimes used at .750 and 1 MHz. The measurement frequencies and other information are summarized below for each of the measurement locations.

Alma Ata: Data are available from September 1958 through December 1965. The measurement frequencies at the start were .75, 1, 2.5, 5, 7.5, and 10 MHz. In May 1962 the measurement frequencies were changed to 12, 25, 35, 60, 350, 750, 1000, 2500, 5000 kHz.

Ashkhabad: Data are available from November 1958 through December 1965. The measurement frequencies were 12.5, 50, 100, 350, 750, 1000, 2500, 5000, 7500, and 10000 kHz. In March 1962, they were changed to 12, 25, 35, 60, 100, 750, 2500, 5000 kHz.

Irkutsk: Data are available from November 1958 through December 1965. The measurement frequencies were initially 12.5, 50, 100, 350, 750, 1000, 2500, 5000, 7500, 10000 kHz. In February 1963 they were changed to 12.5, 25, 35, 60, 100, 350, 750, 1000, 7500, 5000, 7500, 10000 khz. In 1964 and 1965 only the lower frequencies were used, essentially up to 60 kHz, with a few measurements at higher frequencies.

Khabarovsk: Data are available from December 1958 through December 1965. The measurement frequencies were initially 12.5, 50, 100, 350, 750, 1000, 2500, 5000, 7500, 10000 kHz. In February 1961, they were changed to 12.5, 25, 35, 50, 100, 350, 750, 1000, 2500, 7500, 10000 kHz. As with Irkutsk, the lower frequencies were then emphasized.

Kiev: Data are available from August 1960 through December 1965. The initial frequencies were 2500, 5000, 7500, and 10000 kHz, but were changed to 12, 25, 35, 50, 750, 1000, 2500, 5000, 7500, and 10000 kHz in December 1960. The frequency 350 kHz was also occasionally used.

Moscow: Data are available from March 1958 through December 1964. The frequencies were 12, 25, 35, 60, 100, 350, 750, 1000, 2500, 5000, 7500, and 10000 kHz. In October 1962 the frequencies 3, 5, and 8 kHz were added. Starting in February 1964, there are also data at the additional frequencies of 15, 20, 30, 40, 50, and 70 kHz.

Murmansk: Data are available from May 1959 through November 1965. The frequencies were 12.5, 25, 35, 50, 100, 350, 750, 1000, 2500, 5000, 7500, and 10000 kHz throughout.

Simferopol: Data are available from August 1958 through December 1965. The initial frequencies were 750, 1000, 2500, 5000, 7500, and 10000 kHz. In August 1963, 12, 25, 35, 60, 100, and 350 kHz were added.

Sverdlovsk: Data are available from March 1959 through December 1965. The initial frequencies were 750, 1000, 2500, 5000, 7500, and 10000 kHz. In April 1964, 12, 25, 35, 60, 100, and 350 kHz were added.

Tbilisi: Data are available from November 1959 through December 1965. The frequencies were 12.5, 25, 35, 50, 100, 350, 750, 1000, 2500, 5000, 7500, and 10000 kHz. In January 1963, 50 kHz was changed to 60 kHz.

The above summarizes the Soviet data. Throughout these data, there are missing months, times, frequencies, some months with only a few days of measurements, etc. All in all, however, there is a large body of usable data. Some of the data were analyzed by the Institute for Telecommunication Sciences (ITS) in Boulder, Colorado, but most of the data were analyzed by David Sailors and his colleagues at the Naval Ocean Systems Center (NOSC) in San Diego, California. This analysis represents a very large and time consuming effort.

The analysis involved determining, at each frequency, for each 3-month period and 4-hour time block, the median value of all the data. (A large number of other statistical parameters were also determined, since the analysis employed standard computer statistical analysis algorithms.) These median values at the various frequencies were then used to determine the appropriate 1 MHz F_{am} value and this value was then used to obtain a correction value to the current CCIR Report 322 value. Figure 8 shows an example for Moscow for June, July, August (Northern Hemisphere Summer) and 1600-2000 hours. A computer algorithm was developed that determined the frequency variation curve that "best" fit the data. However, since the median value at some frequencies was based on much more data than the value of other frequencies (due to missing data and some frequencies being stressed at some locations), this "fitting" process was generally done by hand (visually). On Figure 8, the "best" frequency law curve was determined to be 72 dB. The current CCIR 322 value is 65 dB, resulting in a correction of +7 dB. As mentioned earlier, most of the data at higher frequencies were measurements of man-made noise, rather than atmospheric noise. Figure 9 shows an example for Moscow for the period November, December, January, 0800-1200 hours. Atmospheric noise would be expected to be low during this period (winter morning). Note that the higher frequencies, 350 kHz and above, give a typical man-made noise curve at a level expected for quiet receiving sites. Using the data at the lower frequencies, the frequency law curve for 31 dB was determined. The CCIR value is 29 dB, resulting in a required correction of +2 dB.

2.2 Corrections to CCIR Report 322 1 MHz F_{am} Values

The above procedure (Figures 8 and 9) was followed for all the data available worldwide (noted above) and corrections were obtained for each location and for each 3-month/4-hour time block.

Tables 2 through 5 give the corrections determined by the above procedure used in the analysis. The "correction" is the difference between the current CCIR Report 322 1 MHz F_{am} value and the corresponding value determined from the above data. Note there are no correction values for Thule, Greenland, or Byrd Station, Antarctica, as explained earlier. There are also no corrections for Ibadan, Nigeria, since there are no data from Ibadan past the publication date of Report 322. The corrections for Bill and Boulder were essentially identical, so only Boulder is used. Corrections are also given for only 6 Soviet locations (rather than 10) since Simferopol, Svendlovsk, Tbilisi, and Kiev had only small amounts of usable low frequency data (needed to determine the proper 1 MHz F_{am} value, as explained

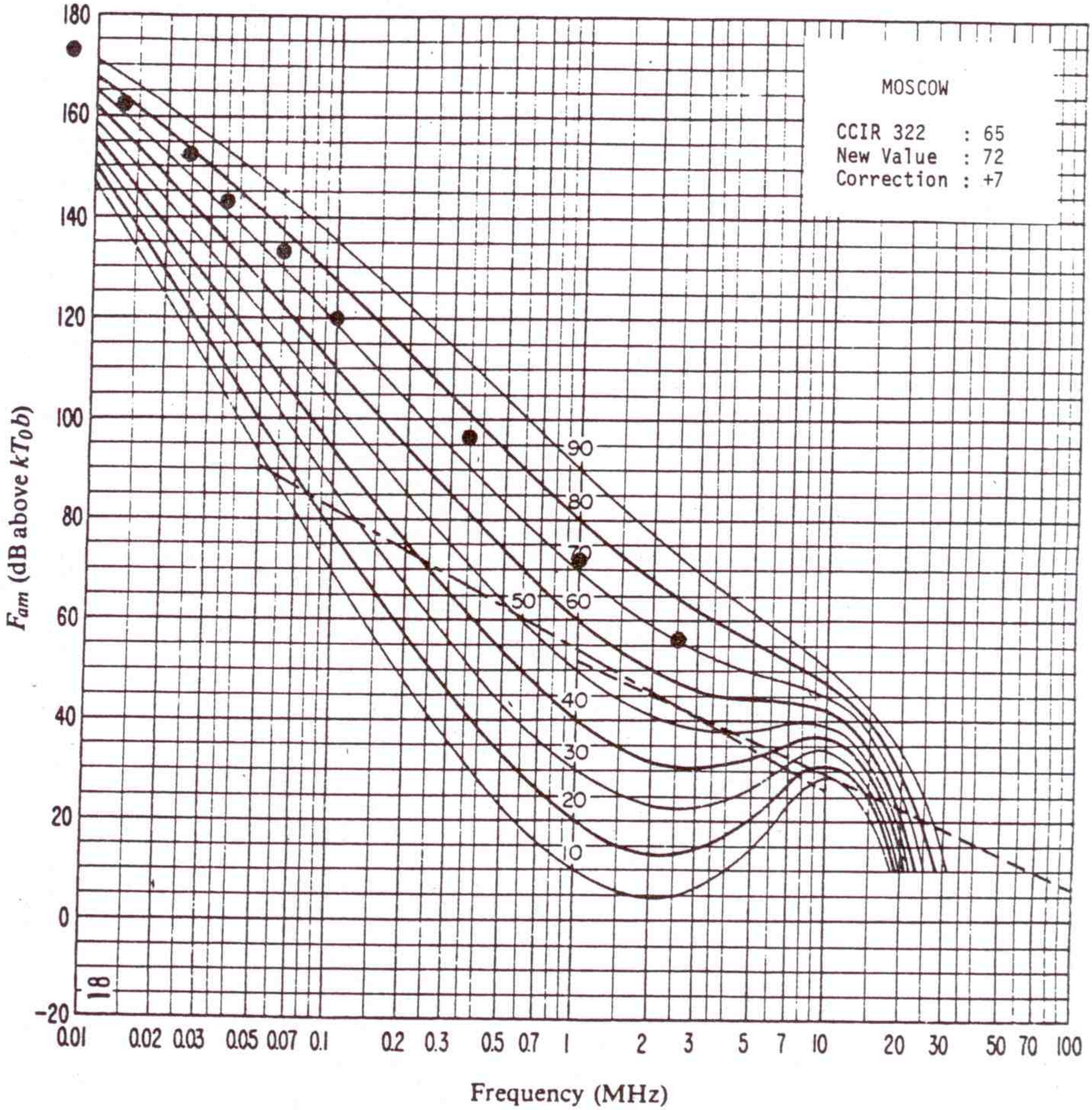

Figure 8. Determination of 1 MHz F_{am} value for Moscow, June, July, August, 1600-2000 hours.

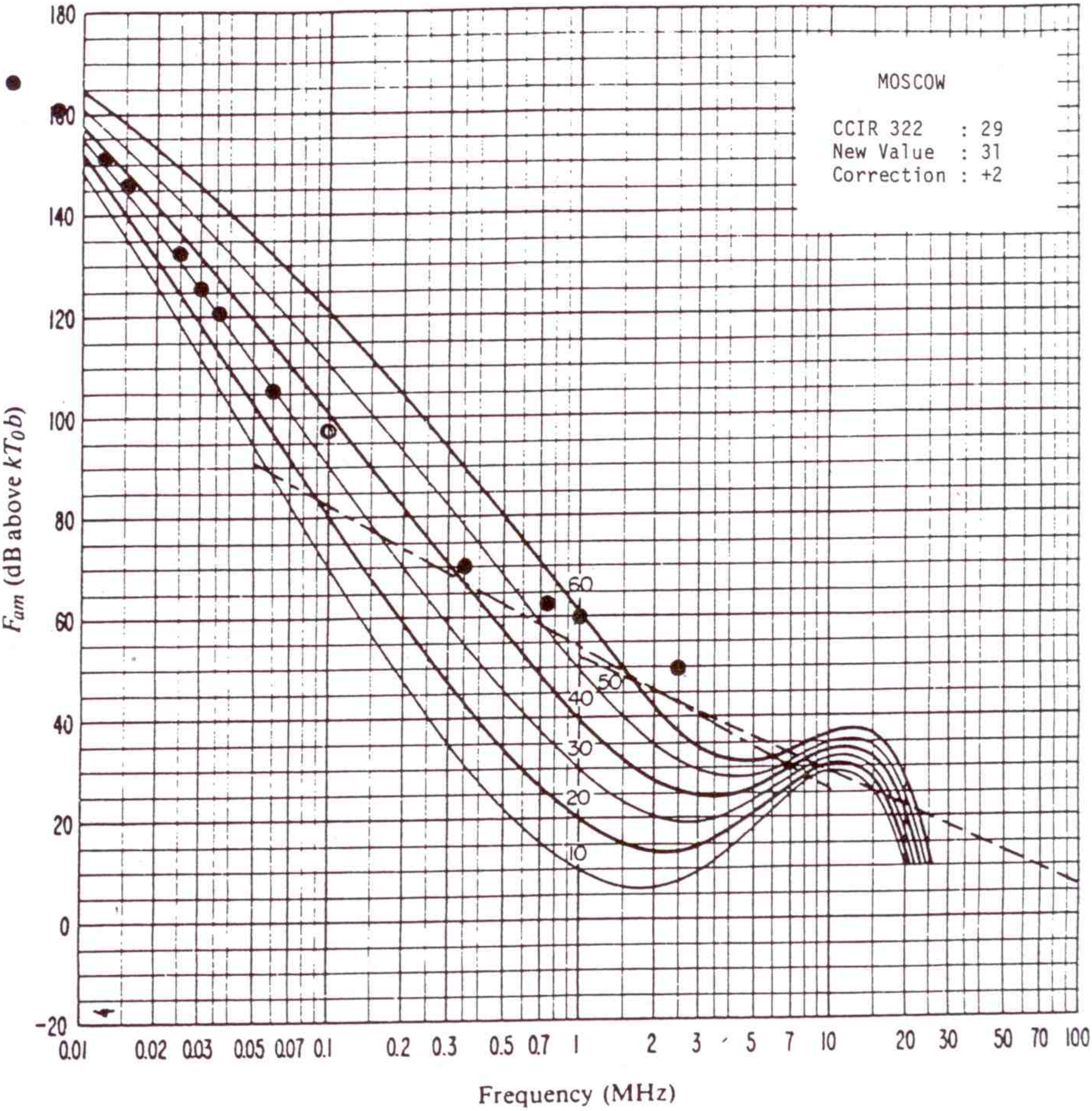

Figure 9. Determination of 1 MHz F_{am} value for Moscow, December, January, February, 1000-1200 hrs.

Table 2. Corrections (dB) to CCIR Report 322 1 MHz F_{am} values for December, January, and February.

PLACE	LOCATION	00-04	04-08	08-12	12-16	16-20	20-24
Alma Ata	76.9E,43.2N	-7	-6	+6	+5	-3	-6
Irkutsk	104.5E,52.0N	-21	-25	-7	-15	-25	-25
Khabarovsk	135.0E,50.0N	-19	-15	-8	-7	-20	-20
New Delhi	77.3E,28.8N	-13	+7	+17	+17	+8	+11
Ohira	140.5E,35.6N	+7	+7	+8	+12	+11	+11
Thailand	100.9E,13.0N	+14	+15	+24	+18	+17	+15
Singapore	103.8E, 1.3N	0	+6	+12	+9	+5	+1
Kekaha	159.7W,22.0N	+5	+10	+8	+15	+5	+6
Boulder	105.1W,40.1N	+5	+4	+7	+14	+7	+8
Front Royal	78.2W,38.8N	-1	+2	+3	+8	0	0
Balboa	79.5W, 9.0N	+3	+6	+7	+9	+7	+2
Rabat	6.8W,33.9N	+2	+4	+3	+8	+2	+4
Enkoping	17.3E,59.5N	+12	+10	-1	+8	+7	+7
Murmansk	35.0E,69.0N	+8	+5	+7	+9	+7	+7
Moscow	37.3E,55.5N	+4	+3	+2	+4	0	-1
Ashkhabad	58.3E,37.9N	-9	-1	-5	-5	-6	-12
Cook	130.4E,30.6S	+2	-3	+6	+1	+6	+3
San Jose	45.8W,23.3S	+2	0	+2	+2	+4	+3
Pretoria	28.3E,25.8S	-4	+8	-4	+1	+5	-8

Table 3. Corrections (dB) to CCIR Report 322 1 MHz F_{am} values for March, April, and May.

PLACE	LOCATION	00-04	04-08	08-12	12-16	16-20	20-24
Alma Ata	76.9E,43.2N	-7	-4	-5	-8	-2	-5
Irkutsk	104.5E,52.0N	-12	-7	-5	+5	+4	-14
Khabarovsk	135.0E,50.0N	-15	-6	-7	+1	-1	21
New Delhi	77.3E,28.8N	+6	+10	+15	+9	+12	+7
Ohira	140.5E,35.6N	+2	+4	+15	+12	+7	+2
Thailand	100.9E,13.0N	+6	+9	+14	+17	+10	+8
Singapore	103.8E, 1.3N	+3	+5	+16	+13	+10	+5
Kekaha	159.7W,22.0N	+6	+8	+11	+13	+5	+6
Boulder	105.1W,40.1N	+3	+5	+7	+2	+8	+3
Front Royal	78.2W,38.8N	-3	-1	-5	-5	-3	+1
Balboa	79.5W, 9.0N	+4	+5	+9	+5	+6	+4
Rabat	6.8W,33.9N	+1	+4	+3	-5	0	0
Enkoping	17.3E,59.5N	0	0	+3	-1	-5	+2
Murmansk	35.0E,69.0N	+3					+4
Moscow	37.3E,55.5N	+4	0	0	-2	+0	-4
Ashkhabad	58.3E,37.9N	+2	+1	-3	+2	-4	+2
Cook	130.4E,30.6S	+3	+9	+5	+8	+4	+5
San Jose	45.8W,23.3S	+2	+3	+5	+7	+3	+7
Pretoria	28.3E,25.8S	+3	+2	+11	+9	+11	-1

Table 4. Corrections (dB) to CCIR Report 322 1 MHz F_{am} values for June, July, and August.

PLACE	LOCATION	00-04	04-08	08-12	12-16	16-20	20-24
Alma Ata	76.9E,43.2N	-4	0	-8	-6	-2	-3
Irkutsk	104.5E,52.0N	-20	-6	-11	0	-4	-15
Khabarovsk	135.0E,50.0N	-10	-4	-8	+1	+2	-12
New Delhi	77.3E,28.8N	+8	+17	+11	+4	+10	+8
Ohira	140.5E,35.6N	+2	+5	+11	+10	+9	+3
Thailand	100.9E,13.0N	+11	+15	+15	+18	+13	+8
Singapore	103.8E, 1.3N	+4	+11	+15	+15	+10	+2
Kekaha	159.7W,22.0N	+9	+6	+2	+2	-6	+4
Boulder	105.1W,40.1N	+2	+8	+7	+10	+12	+6
Front Royal	78.2W,38.8N	-8	-4	+4	-11	-10	-1
Balboa	79.5W, 9.0N	-10	+9	+12	+1	+3	+4
Rabat	6.8W,33.9N	0	+3	+2	-16	-4	0
Enkoping	17.3E,59.5N	+5	+6	-4	-7	-4	-7
Murmansk	35.0E,69.0N	-2	+8	-1	+5	+10	-2
Moscow	37.3E,55.5N	-2	0	-2	+2	+7	-6
Ashkhabad	58.3E,37.9N	+2	-4	-7	-8	-3	-3
Cook	130.4E,30.6S	+5	+7	+12	+11	+10	+6
San Jose	45.8W,23.3S	-4	+5	+11	+10	+9	0
Pretoria	28.3E,25.8S	+12	+11	+20	+22	+16	+17

Table 5. Corrections (dB) to CCIR Report 322 1 MHz F_{am} values for September, October, and November.

PLACE	LOCATION	00-04	04-03	08-12	12-16	16-20	20-24
Alma Ata	76.9E,43.2N	-4	-3	-2	-8	-7	-9
Irkutsk	104.5E,52.0N	-22	-20	-15	-15	-20	-20
Khabarovsk	135.0E,50.0N	-19	-10	-8	-9	-12	-18
New Delhi	77.3E,28.8N	+5	+8	+9	-4	+6	+5
Ohira	140.5E,35.6N	+6	+4	+12	+9	+9	+7
Thailand	100.9E,13.0N	+5	+11	+20	+12	+9	+7
Singapore	103.8E, 1.3N	+7	+11	+20	+14	+7	+7
Kekaha	159.7W,22.0N	+1	+5	0	+2	0	+2
Boulder	105.1W,40.1N	+2	+7	+12	+10	+9	+3
Front Royal	78.2W,38.8N	-2	+3	+4	-1	-2	-1
Balboa	79.5W, 9.0N	0	+4	+14	+12	+5	0
Rabat	6.8W,33.9N	+5	+9	+11	+3	+6	+5
Enkoping	17.3E,59.5N	+2	+4	0	+4	0	+3
Murmansk	35.0E,69.0N	-5	+2	-2	+3	+1	-2
Moscow	37.3E,55.5N	0	+3	+3	-2	-2	+2
Ashkhabad	58.3E,37.9N	+3	+5	-6	-4	-2	0
Cook	130.4E,30.6S	-1	+2	+11	+10	+4	+4
San Jose	45.8W,23.3S	+4	+6	+12	+6	+3	+2
Pretoria	28.3E,25.8S	+3	+9	+9	+6	+8	+4

earlier) and/or were close to other measurement locations. The data at these four locations were analyzed to ascertain that the corrections agreed with those used at nearby locations, especially Moscow and Ashkhabad. For Murmansk, March, April, and May, for the four time blocks 0400-0800, 0800-1200, 1200-1600, and 1600-2000 hours, the data were highly irregular and confusing, so it was decided not to attempt to obtain any correction values for Murmansk for those four periods (Table 3).

As noted previously, the CCIR Report 322 1 MHz F_{am} contour maps were obtained directly from a grid of equally spaced 84 longitude and 100 latitude points. The next step in the analysis was to obtain a corresponding grid of 84 x 100 correction values to add point by point to the grid of original data. To do this, we used a method of C^1 (continuous first partial derivatives) interpolation to scattered data over a sphere developed by Dr. Charles L. Lawson (1982) of the Jet Propulsion Laboratory (JPL). The method first constructs a triangular grid over the surface of a sphere (the Earth, here) using a given set of points as vertices (the 19 data points, Tables 2 through 5). First partial derivatives are estimated at each vertex using local quadratic least squares approximates to given data values at nearby vertices. The derived method for C^1 interpolation then uses six Hermite cubic interpolations along arcs of great circles. This approach has been implemented using the JPL structured FORTRAN preprocessor, SFTRAN3, and was used by JPL in the analysis of the gravity field of Venus. Dr. Lawson supplied SFTRAN3 and all the algorithms (programs) for the interpolation, along with complete documentation. The structured FORTRAN preprocessor was installed on the Department of Commerce Boulder Laboratories' computer (CYBER 170/750) and grids (84 x 100) of correction values were generated. Figures 10 through 33 are contour maps of these 24 (four 3-month periods, six 4-hour time blocks) correction grids. These maps show, at a glance, the changes from the current model (CCIR Report 322). Note that substantial corrections (on the order of 20 dB in some cases) are indicated for some areas, especially around the "new" measurement locations. This is also shown, of course, on Tables 2 through 5. Also note that the correction maps are presented in terms of 3-month periods rather than in terms of seasons (which results in a discontinuity at the equator) as in Report 322.

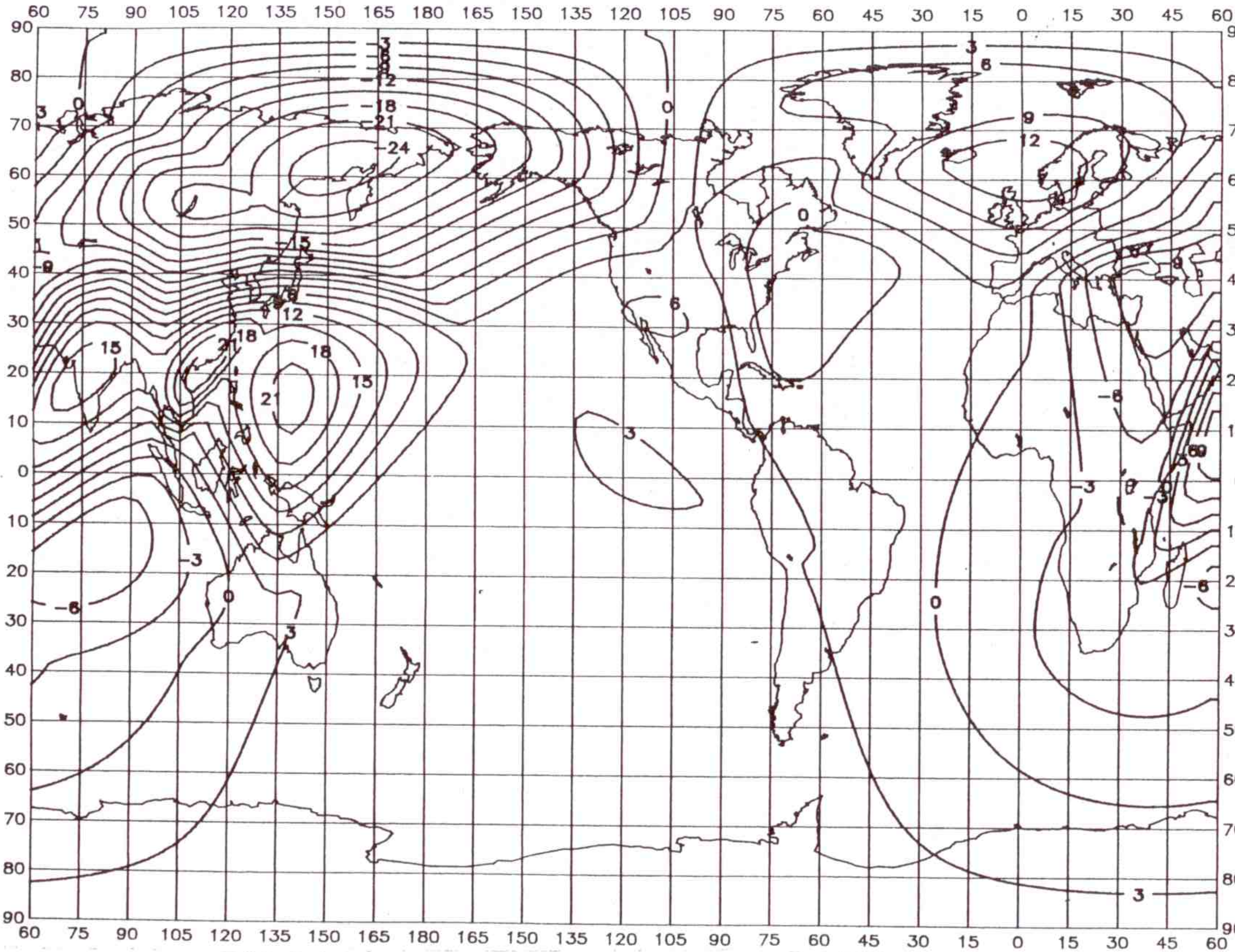

Figure 10. Corrections (dB) to current CCIR Report 322 1 MHz F_{am} estimates, December, January, February, 0000-0400 hours.