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Atmospheric Refraction Correction for Ka-Band Blind

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An analysis of the atmospheric refraction corrections at the DSS-13 34-m diameter beam waveguide antenna for the period covering July through December 1990 is presented. The current DSN atmospheric refraction model and its sensitivity with respect to sensor accuracy are reviewed. Refraction corrections based on actual atmospheric parameters are compared with the DSS-13 station default corrections for the six-month period. Average blind-pointing improvement during the worst month would have amounted to 5 mdeg at 10 deg elevation using actual surface weather

testing would enable assessment of the reduction of actual elevation pointing errors. Unfortunately, only a limited number of measurements were made at the lower elevation angles, and they appeared to be of only marginal quality. Due to the nonrepeatable nature and poor quality of these

$$\Delta EL = f(P, T, RH, EL) \tag{1}$$

where

$\Delta EL =$ change in elevation pointing difference between the two sensors for all days was computed to be

Pressure: 0.0493 mbar (σ = 0.0791 mbar)

Temperature: 0.0710 deg C (σ = 0.1428 deg C)

Relative humidity: 3.9 percent (σ = 3.7 percent)

Both the pressure and temperature sensor pairs agreed extremely well during this period, while at least one relative humidity probe appeared to be biased. The differences also display large variations. To illustrate the variability in the humidity sensors, Fig. 2 shows the average daily difference between the humidity observations for days 267 through 321. The readings from sensor 2 are always larger than those registered by sensor 1. The true relative humidity value may lie between the sensor readings, or one or both of the sensors may be biased high or low. These discrepancies in humidity can map into significant differences in refraction correction, especially at low elevation angles. To minimize the impact on the refraction correction analysis, the atmospheric measurements were filtered in the following manner: Points were eliminated when the difference between the two measurements from each of the sensors was greater than twice the stated DSS-13 accuracy specification. Approximately twenty percent of the data points were removed in this manner.

B. Sensor Error Propagation

As noted, uncertainties in all three surface weather measurements will propagate into errors in the computed refraction corrections. To quantify the correction degradation, the sum of the squares of the partial derivatives of the refraction model with respect to each input parameter were computed.

A first-order approximation to the Lanyi model, which is adequate for sensitivity analysis, is given by

$$\Delta EL = \frac{\chi_0 - Z_{tot}/\left(R\sin^2(EL)\right)}{\tan(EL)} \tag{2}$$

where

$$\chi_0 = \chi_{dry} + \chi_{wet} = \text{ total surface refractivity}$$

$$Z_{tot} = Z_{dry} + Z_{wet} = \text{ total zenith path delay}$$

$$R = \text{ Earth radius}$$

$$EL = \text{ the uncorrected elevation angle}$$

The dry and wet surface refractivities and dry and wet zenith path delays can be determined from surface measurements of pressure, temperature, and relative humidity. The DSS-13 weather instrumentation specifications were then input as uncertainties and yielded an error of 0.71 mdeg in the computed refraction correction at 10 deg elevation. Thus, the sensor error propagation would not be a major problem in this current study if all the sensors were within their accuracy limits.

Figure 3 shows the DSS-13 rss refraction correction error at 10 deg elevation due to relative humidity uncertainty, using the default weather parameters and the given pressure and temperature sensor specifications. It is seen that when the sensor error increases above 3 percent, refraction error correction on the millidegree level is unachievable.

IV. Refraction Correction Analysis

A. Computed Refraction Corrections

Refraction corrections were computed at 1-hr intervals for the atmospheric measurement set spanning the six months (3446 points). In order to examine the variability of the computed corrections over this period, the extreme ranges of the sensor readings are considered. By setting two of the three input variables (pressure, temperature, and relative humidity) to the DSS-13 default values and entering the extreme points listed below into the refraction model, the correction ranges listed in Table 1, in millidegrees, are computed.

As seen in that table, the change in refraction correction due to relative humidity is about 17 times greater than that due to pressure and about 3 times greater than that due to temperature.

B. Effect on Gain

The absolute differences between the default refraction corrections and those corresponding to actual weather parameters were computed. The resultant values are assumed to be improvements in the beam-pointing accuracy for blind pointing if the real-time surface weather observations were used in the refraction correction for the six-month period. For all the hour-interval atmospheric measurements, the absolute difference is computed at elevation increments of 5 deg. Figure 4 illustrates the differences for the month of October 1990, which had the highest average refraction difference from the default refraction values.

Note that for this particular month, very few actual refraction corrections equaled the default corrections (absolute difference = 0). Thus, rarely would good blind pointing be achieved, and the average pointing errors at low elevation angles would be rather large (4.8 millidegrees). Expected beam-pointing improvement (using real weather inputs) increases significantly as the elevation angle is decreased.

To summarize the whole six-month period, statistics were computed for the entire data set at 5-deg increments. Figure 5 shows the means and standard deviations of the absolute differences. At 10 deg elevation, the refraction pointing error should, on the average, be reduced by 4 mdeg, with a 2.4-mdeg 1-σ variation. The expected DSS-13 Ka-band gain degradation corresponding to the average differences is shown in Fig. 6. X-band gain loss would be less than 0.1 dB. The large magnitude of the average gain loss at the lower elevations stresses the need for accurate, real-time weather inputs for refraction correction during Ka-band tracking operations.

Figure 7 shows the means of the absolute correction ... of August and October, when actual atmospheric conditions best in August and worst in October.

V. Conclusions

An analysis of the atmospheric refraction correction at the DSS-13 BWG antenna for the period covering July through December 1990 has been presented. The Lanyi refraction model and its sensitivity with respect to sensor error were reviewed. It was shown that the present specifications on the DSS-13 weather instrumentation are sufficient to provide submillidegree refraction correction, however, performance will sharply degrade when the relative humidity sensors fail to meet their specified accuracy.

Refraction corrections based on actual atmospheric parameters from the six-month period were computed and compared with the DSS-13 station default corrections. The average worst-month differences between the corrections was 5 mdeg at 10 deg elevation (Fig. 7). The corresponding average Ka-band gain loss expected using the DSS-13 default weather parameters during this period was thus 1.1 dB at that elevation (Fig. 8). The X-band gain

Table 1. Effect of measured weather extremes on calculated refraction correction.

Parameter	Refraction correction, mdeg		
	10-deg elevation	20-deg elevation	30-deg elevation
Pressure, 883 to 907 mbar	83.6–85.6	41.7–42.7	26.5–27.1
Temperature, −9.7 to 37.7 deg C	84.3–95.1	42.1–47.4	26.7–30.1
Relative humidity, 4 to 99 percent	75.2–109.7	37.6–54.6	23.9–34.6

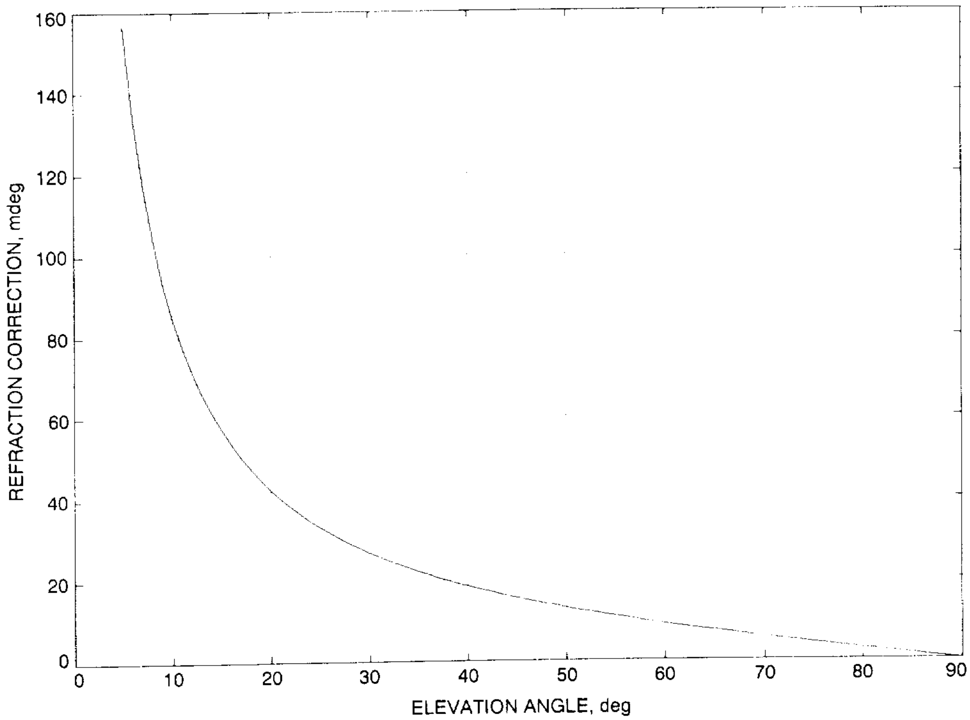

Fig. 1. Lanyi angular refraction correction model for DSS-13 default atmospheric parameters.

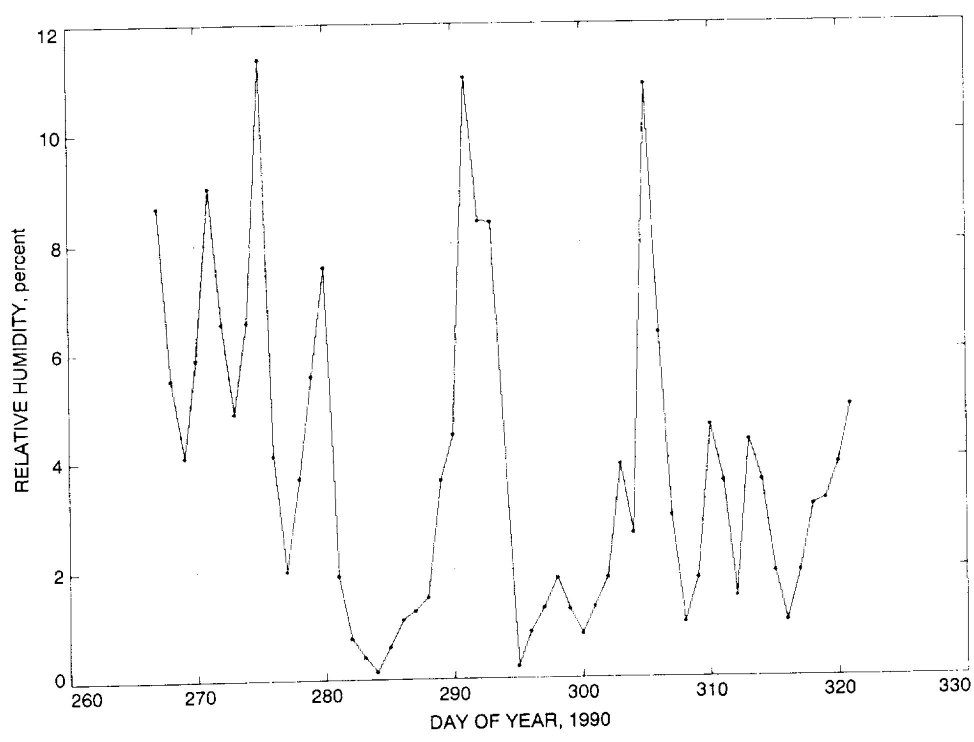

Fig. 2. Daily average difference between relative humidity probe readings.

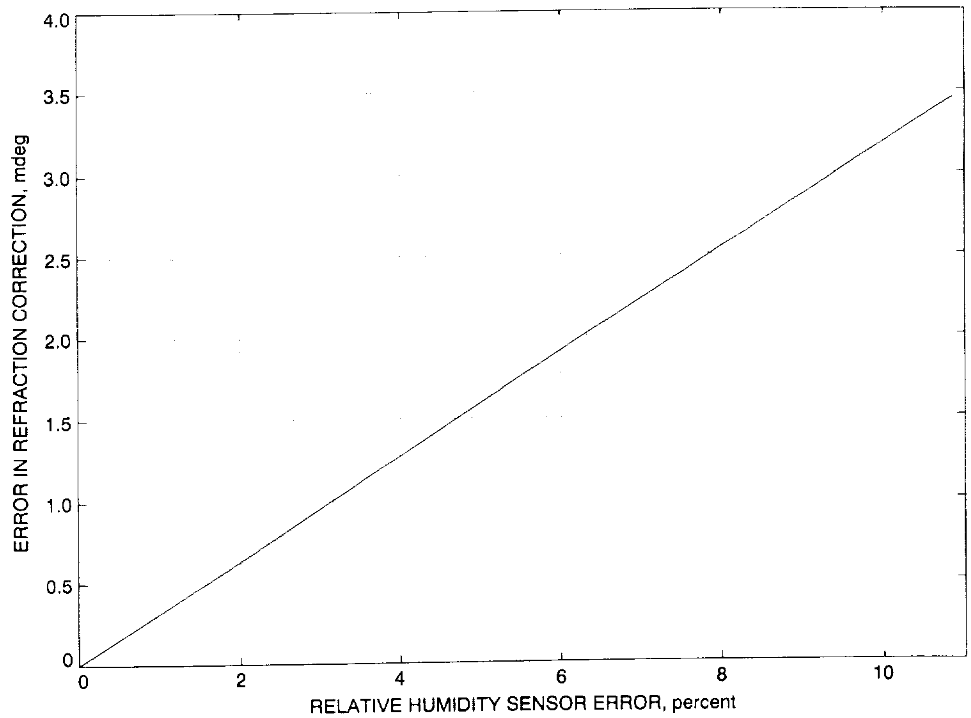

Fig. 3. Error in computed correction at 10 deg elevation, due to relative humidity instrument error, using default parameters.

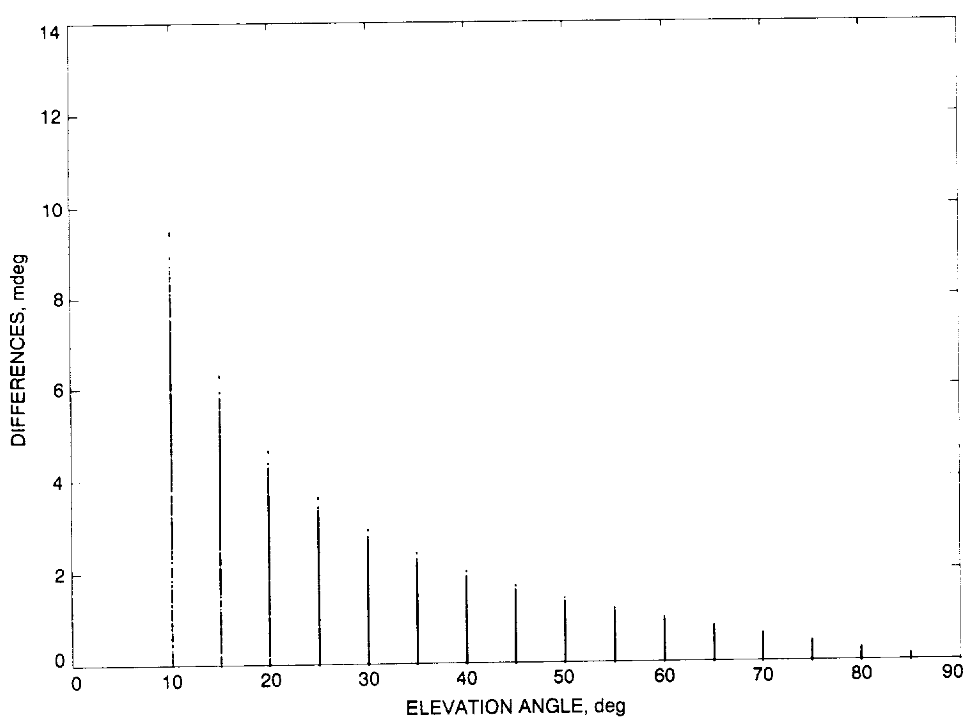

Fig. 4. Absolute difference between actual weather-based refraction corrections and default corrections for October 1990.

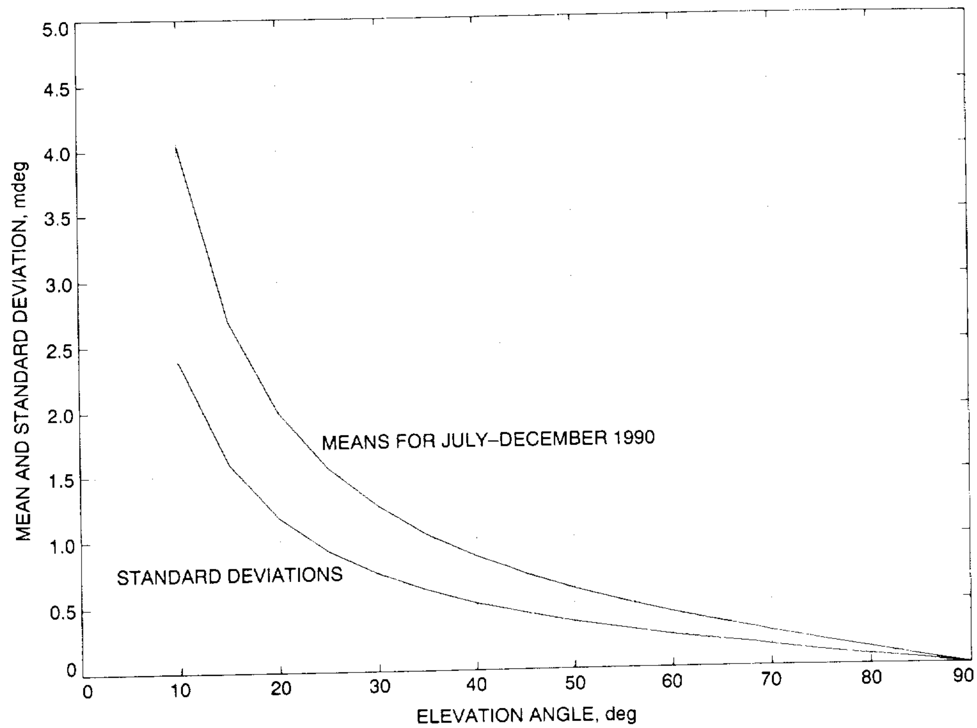

Fig. 5. Mean and standard deviation of the absolute difference between default and actual refraction corrections during July–December 1990.

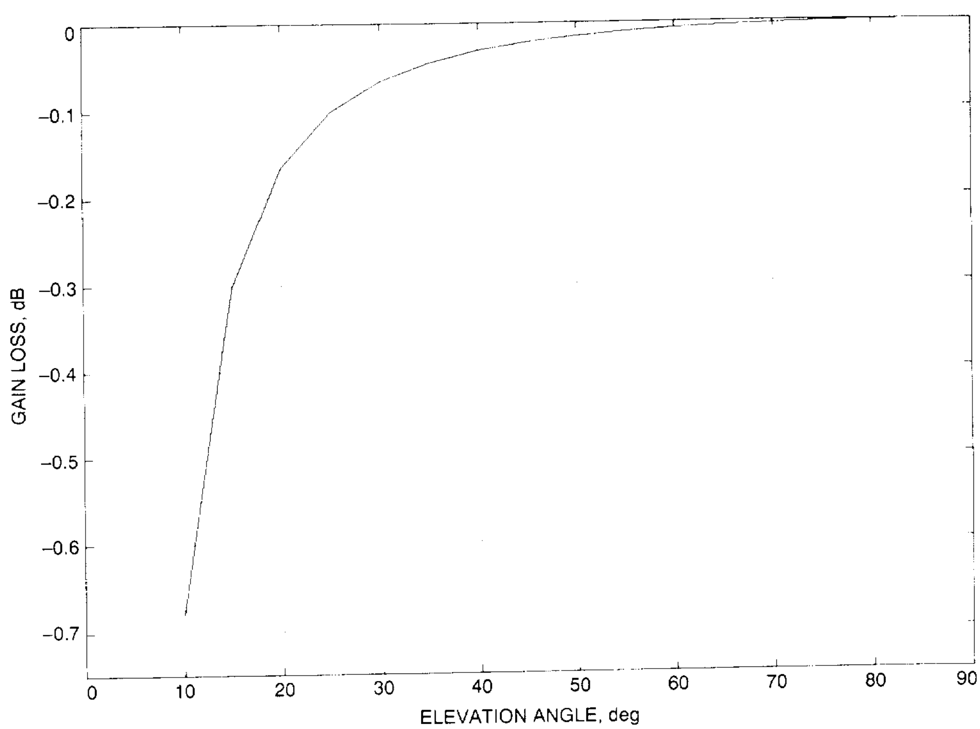

Fig. 6. Gain loss for refraction pointing error, July–December 1990.

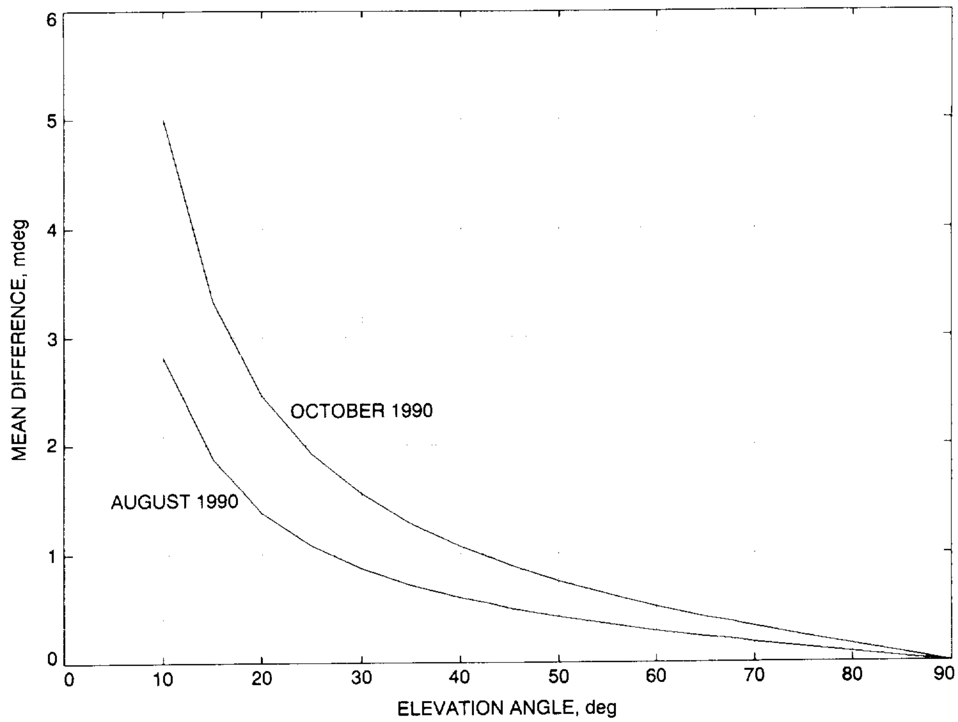

Fig. 7. Mean of the absolute difference between default and absolute refraction corrections, August and October 1990.

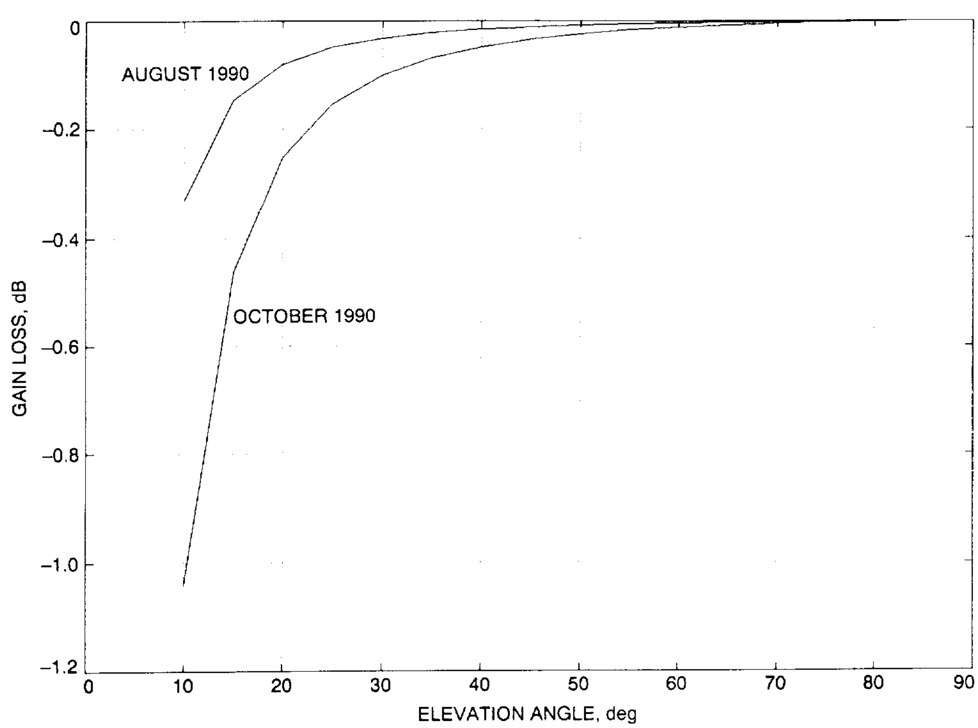

Fig. 8. Gain loss for refraction pointing error, August and October 1990.