Appendix A

Pointing Equations for the 12m Telescope

A.1 Primary Pointing Equations

The basic pointing model in use at the 12m is much the same as that described by Ulich (1981, Int. J. Infrared & Millimeter Waves, 2, 293); much of this discussion is excerpted from that paper. The azimuth and elevation terms used to correct the nominal encoder positions are given by the equations

$$\Delta A = A_0 + C_0 \sec(E_s) + C' \tan(E_s) + I_a \tan(E) \sin(A_s - A_{ta}) + A_{obs} \sec(E_s) \quad (A.1)$$
$$\Delta E = E_0 + B_0 \cos(E_s) + I_e \cos(A_s - A_{te}) + E_{obs} + R_0 f(E_s) \quad (A.2)$$

where A_s and E_s are the azimuth and elevation of the source and

ΔA is the total azimuth encoder correction,

A_0 is the azimuth encoder zero offset (AZOFF),

C_0 is the collimation error of the electromagnetic axis (C),

C' is the collimation error of the mount (CPRIME),

I_a and I_e are two independent estimates of the tilt of the azimuth axis from the zenith (TILTAZ and TILTEL),

A_{ta} and A_{te} are two independent estimates of the azimuth toward which the azimuth axis is tilted (AZAZ and AZEL),

A_{obs} is the observer-applied azimuth correction,

ΔE is the total elevation encoder correction,

E_0 is the elevation encoder zero offset (ELOFF),

B_0 is the gravitational flexure correction at the horizon (BEND),

E_{obs} is the observer-applied elevation correction,

R_0 is the weather dependent term to the atmospheric refraction correction (REF),

$f(E)$ is the elevation dependence of the atmospheric refraction correction.

The terms in parentheses are the associated variable names in the actual pointing model.

The weather-dependent refraction coefficient, which is practically independent of wavelength, is given by Liebe & Hopponen (1977, IEEE Trans. Antennas Propagation, AP-25, 336, equation 9) as

$$\begin{aligned} N_0 &= (n-1) \times 10^6 \\ &= R_0(radians) \times 10^6 \\ &= 103.56\frac{P_d}{T_s} + 95.5\frac{P_w}{T_s} + 499500\frac{P_w}{T_s^2} \quad ppm \end{aligned} \tag{A.3}$$

and is given similarly by Crane (in *Methods of Experimental Physics*, volume 12, part B, page 186, equation 2.5.1) as

$$N_0 = 103.43\frac{P_d}{T_s} + 96.0\frac{P_w}{T_s} + 499835\frac{P_w}{T_s^2} \quad ppm \tag{A.4}$$

where I have ignored the partial pressure contribution due to carbon dioxide (only $\sim 0.03\%$ of the total pressure), n is the complex index of refraction, and the pressures and temperatures are as defined below. A similar expression to the two given above can also be found in Allen (1963, "Astrophysical Quantities", page 120). Taking the Liebe & Hopponen relation (Equation A.3) for N_0 and solving for R_0 in arcseconds yields

$$R_0 = 21.36\frac{P_s}{T_s} - 1.66\frac{P_w}{T_s} + 103029.27\frac{P_w}{T_s^2}, \tag{A.5}$$

where

P_d is the partial pressure of dry gases in the atmosphere (in Torr),

P_w is the partial pressure of water vapor at the surface (in Torr),

P_s is the total surface barometric pressure (in Torr), which is equal to $P_d + P_w$, and

T_s is the surface ambient air temperature (in Kelvin).

P_s must be measured by a barometer at the telescope site. P_w may be calculated from the expression

$$P_w = RH\frac{e_{sat}}{100}, \tag{A.6}$$

where RH is the surface relative humidity (in percent) and e_{sat} is the surface saturated water vapor pressure (in Torr) and is given by Crane (in *Methods of Experimental Physics*, volume 12, part B, page 187, equation 2.5.3) as

$$\log(e_{sat}) = 24.67 - \frac{2990.14}{T_s} - 5.31\log(T_s). \tag{A.7}$$

Note that Ulich (1981) quotes a similar expression for $\log(e_{sat})$, but does not give a reference.

The weather-dependent term R_0 is calculated using the on-site weather station, and is recalculated every time the surface temperature changes by more than 1.5°, the surface relative humidity changes by more than 5%, or the surface barometric pressure changes by more than 1 Torr. R_0 usually remains in the range $48''$ to $60''$. A plot of R_0 as a function of T_s and relative humidity for a constant total surface barometric pressure is shown in Figure A.1. The elevation dependence of the refraction correction is given by

$$f(E) = \frac{\cos(E)}{\sin(E) + 0.00175\tan(87.5 - E)}. \tag{A.8}$$

This term is recomputed for each elevation of observation.

The 12m staff determines the pointing coefficients regularly. To derive a new pointing model a campaign of optical and radio pointing sources measurements are made. Both the optical and radio pointing sources are observed at as many azimuth and elevation positions as possible and the corrections necessary to receive peak flux from the sources are measured. The corrections are then input to a fitting program and the coefficients are determined. The total rms of the fit is typically $3''$– $5''$.

A.1.1 Secondary Pointing Corrections

In addition to the primary pointing corrections, a set of secondary pointing corrections are used at the 12m. In azimuth, these corrections are given by the equation

$$\Delta A_1\cos(E) = A_1\cos(E) + C_1, \tag{A.9}$$

where the left-hand side of the equation corresponds to the "cross-elevation" azimuth correction on the sky, given at a particular elevation by the observer-applied azimuth correction. In elevation, the secondary correction is

$$\Delta E_1 = B_1\cos(E) + E_1, \tag{A.10}$$

These terms correspond to the linear (in $\cos(E)$) terms in the principal pointing equations given above: A_1 is the supplemental azimuth encoder offset, C_1 is the supplemental electromagnetic collimation error correction, B_1 is the supplemental gravitational bend error, and E_1 is the supplemental elevation encoder offset.

Each of the four receiver bays have their own set of these secondary coefficients to compensate for slight differences between feed and mirror alignments in each bay. The intent of these pointing coefficients is to keep the required pointing offsets as close to zero

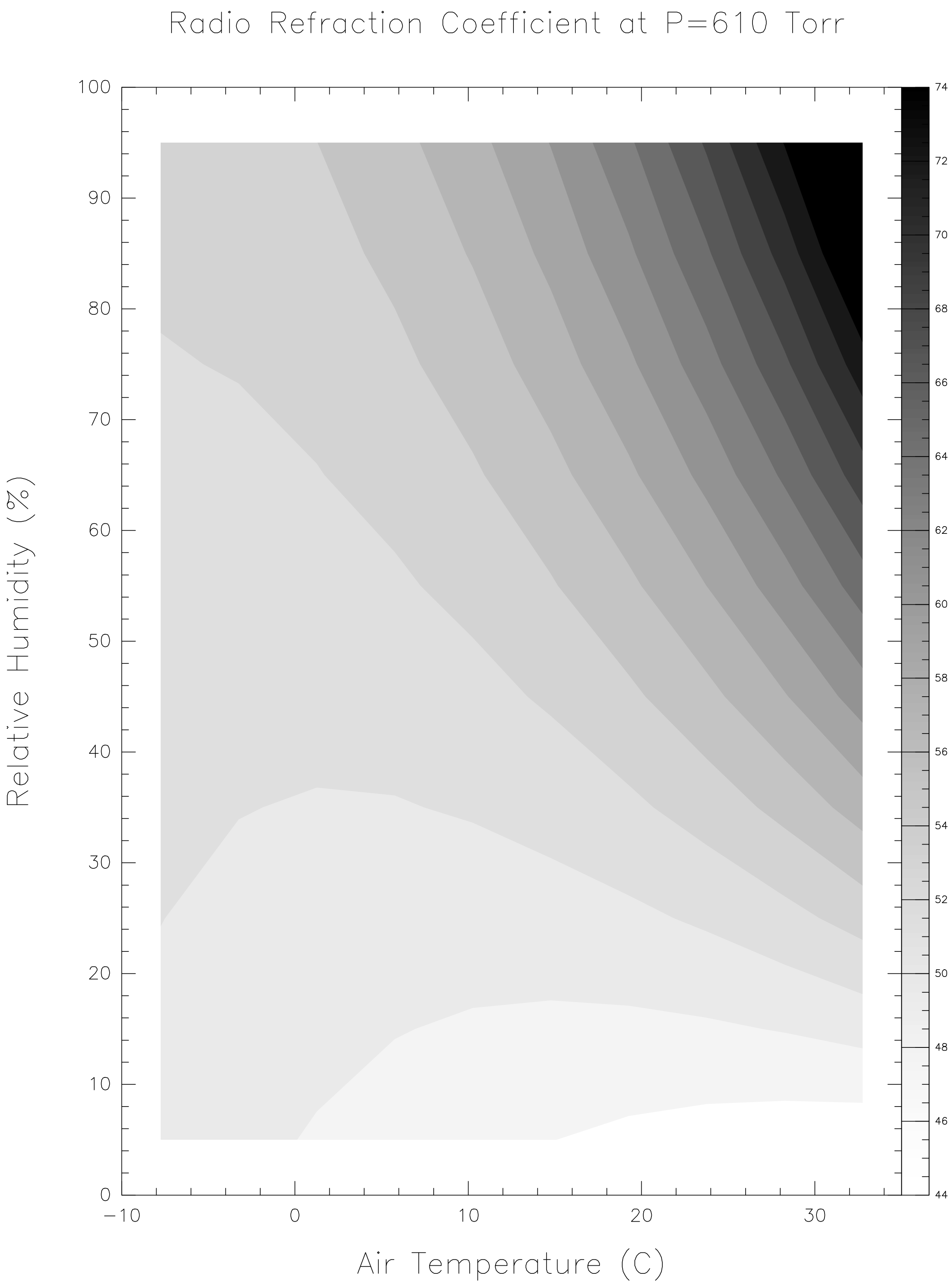

Figure A.1: R_0 as a function of T_s and relative humidity for a constant total barometric pressure of 610 Torr.

as possible. The determination of these coefficients requires much less data than the main pointing equations and can thus be adjusted on a more frequent basis.