A 4.85 GHz SKY SURVEY. III. EPOCH 1986 AND COMBINED (1986+1987) MAPS COVERING $0°<\delta<+75°$

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ABSTRACT

The NRAO seven-beam receiver was used on the 91 m telescope in Green Bank, WV during 1986 November to survey the declination band $0°<\delta<+75°$ at 4.85 GHz. We made sky maps from the 1986 data alone, primarily for comparison with the epoch 1987 maps [Condon *et al.*, AJ, **97**, 1064 (1989)] to allow variability studies of a large, unbiased sample of sources selected at 4.85 GHz. The 1986 and 1987 data sets were combined, reedited, and mapped to yield maps fully covering the $\Omega=6.07$ sr region $0°<\delta<+75°$ with noise and position uncertainties divided by nearly $\sqrt{2}$. The 1986 and combined (1986+1987) maps are available on FITS-format tapes.

1. INTRODUCTION

The 91 m Green Bank telescope made three 4.85 GHz continuum surveys of the declination band $0°<\delta<+75°$ in 1986 November, 1987 October, and 1988 November. The 1987 data were mapped first (Condon *et al.* 1989, hereafter referred to as Paper I), and the 87GB catalog of radio sources (Gregory & Condon 1991) was extracted from these maps. The 1988 data were reduced but could not be mapped satisfactorily because the 91 m telescope pointing was gradually changing throughout the 1988 observing run.

This paper describes maps made from the 1986 data plus maps made from the combined 1986 and 1987 data sets. The new 1986 maps are similar to the published 1987 maps, and they can be used to select unbiased samples of highly variable and transient sources stronger than about 25 mJy at 4.85 GHz. The 1986 and 1987 edited data sets were corrected for known position offsets, combined, reedited, and mapped. These combined maps cover the entire $\Omega=6.07$ sr declination band $0°<\delta<+75°$ with no gaps, and they have significantly lower noise and position errors than either the 1986 or 1987 maps.

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2. THE 1986 MAPS

2.1 Equipment and Observations

The 1986 observations were made between November 7 and December 13. The receiver, telescope, and observing techniques were the same as those employed in 1987 and described in Paper I. Briefly, the 91 m telescope was scanned in elevation at $\pm 10° \text{ min}^{-1}$. The total-power outputs from both circular polarizations in the seven beams were integrated and sampled every 0.1 s. Interleaved scans were made to ensure full Nyquist sampling for both the north- and south-going scans. Most scans with known interference or bad baselines caused by rain were repeated.

2.2 Data Reduction

The methods already used to reduce the 1987 data (see Paper I for a detailed description) were applied to the 1986 data with only minor modifications. Data on the telescope tapes were converted to FITS table format (Harten *et al.* 1988) for processing by the Astronomical Image Processing System (AIPS). In AIPS the tables were converted to a pseudo (u,v) data format in which the equatorial coordinates (α,δ) replace (u,v). Baselines were subtracted in two stages. The elevation-dependent spillover baselines were more accurately fit by a cubic spline instead of the piecewise linear approximation applied to the 1987 data. Running-median baselines 40 samples=40 arcmin in length were subtracted to remove the remaining baseline fluctuations; this tends to suppress emission extended more than about 20 arcmin in declination. Next the data were flagged automatically to eliminate impulsive interference (all 14 channels were flagged if the levels in successive samples from at least ten channels increased and decreased by more than 10 mK), noisy receiver channels (if the two channels from one beam differed by more than ≈0.1 Jy and 10% of their average, they were flagged), and "holes" deeper than about −0.1 Jy. The preflagged data were projected onto a plane and mapped (gridded and convolved with a restoring function). All maps are sine projections 1024 pixels×40″ pixel^{-1}≈11.4° on a side. A total of 288 maps were made centered on the eight B1950 declinations 0°, +10°,...,+70° and the 36 B1950 right ascensions 0^h20^m, 1^h00^m,...,23^h40^m. The preliminary 1986 maps were blinked against the 1987 maps and edited interactively. No sources were rejected simply because they appeared on one map but not the other. We also used map pairs made from the north-going and south-going 1986 scans separately to locate bad data.

The edited 1986 data were remapped, and these maps were "self-calibrated;" that is, calibration sources in the maps were used to recalibrate the maps in both position and intensity. Gaussian fits to 148 strong ($S \gtrsim 1$ Jy) point sources with accurately known positions from the VLA calibrator list were used to measure the map point-source response and position offsets. Likewise, fits to 29 unresolved steep-spectrum sources from the Kühr *et al.* (1981) list checked the flux-density scale. Small corrections to the 1986 map headers were made to compensate for systematic position errors and to bring the map flux densities onto the Baars *et al.* (1977) scale, the basis of the Kühr *et al.* (1981) flux densities.

2.3 The 1986 Map Characteristics

The 1986 maps are similar to the 1987 maps (Paper I). The main differences are: (1) Some scans affected by interference or atmospheric emission fluctuations were not reobserved in 1986. Consequently, there are a number of narrow blanked strips in the edited 1986 maps. (2) The Sun was near $\alpha=16^h$, $\delta=-20°$ during the 1986 observations, so far south that no 1986 maps had to be rejected because of severe solar interference. The three 1987 maps covering $12^h40^m < \alpha < 14^h40^m$, $0° < \delta < +5°$ were rejected for this reason. Weak solar interference from radiation reflected off the feed support legs also appears at declinations approximately 60° (the feed support apex angle) north of the Sun. This affected the 1986 maps near $\alpha=16^h$, $\delta=+40°$ and the 1987 maps near $\alpha=13^h40^m$, $\delta=+50°$. (3) The 1986 observations were made in colder, cloudier weather than the 1987 observations. Consequently, telescope pointing errors caused by solar heating were very small in 1986. The peak position shifts were $\Delta\alpha=\pm1\overset{s}{.}6$, $\Delta\delta=-8''$ centered on $\alpha=16^h$ in 1986, in contrast to $\Delta\alpha=\pm5\overset{s}{.}5$, $\Delta\delta=-28''$ centered on $\alpha=13^h40^m$ in 1987 (see Fig. 8 of Paper I). These pointing errors were measured and removed from both sets of maps during the self-calibration process.

The 1986 map point-source response is nearly an elliptical Gaussian. The FWHM diameters θ_α, θ_δ in the east–west and north–south directions are approximately

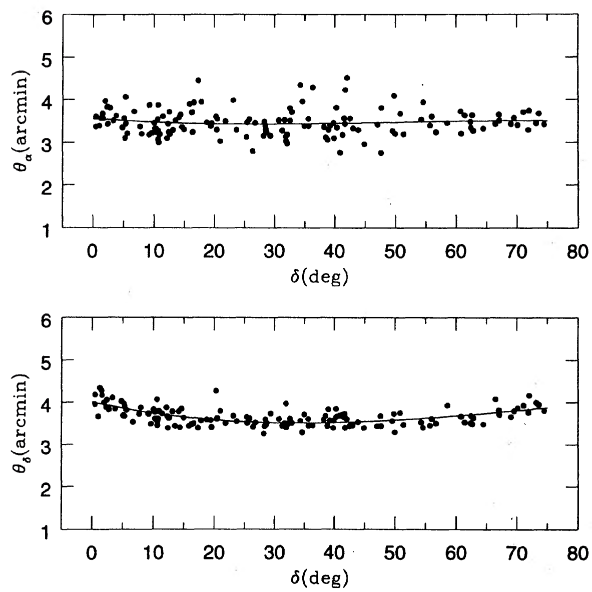

FIG. 1. The east–west and north–south FWHM widths θ_α and θ_δ of the 1986 map point-source response are nearly independent of right ascension and vary slowly with declination. Abscissae: declination (deg). Upper ordinate: east–west FWHM beamwidth (arcmin). Lower ordinate: north–south FWHM beamwidth (arcmin).

$$\theta_\alpha(\text{arcmin})=3.44+1.98\times10^{-3}(\delta-38°)+6.38\times10^{-5}(\delta-38°)^2-1.92\times10^{-6}(\delta-38°)^3 \quad (1a)$$

$$\theta_\delta(\text{arcmin})=3.51+2.23\times10^{-3}(\delta-38°)+3.03\times10^{-4}(\delta-38°)^2-2.64\times10^{-6}(\delta-38°)^3, \quad (1b)$$

where δ is the declination in degrees. The rms deviations in individual measured values of θ_α and θ_δ are 19″ and 10″, respectively (Fig. 1).

The rms uncertainty σ_S in the fitted peak flux density S of a point source can be treated as the quadratic sum

$$\sigma_S=[\sigma^2+(\gamma S)^2]^{1/2}, \quad (2)$$

where σ is the rms map fluctuation and γ is the intensity-proportional error coefficient. If the Kühr *et al.* (1981) flux densities have no errors and if the 29 steep-spectrum calibration sources have not varied during the last decade, then the differences between their flux densities and our map flux densities yield an estimate for γ; otherwise they yield an upper limit. We find $\gamma \lesssim 0.11$ for peak flux densities measured on the 1986 maps.

The rms map fluctuation σ is the quadratic sum of the rms noise and the rms confusion from unresolved galactic emission and faint extragalactic sources. The value of $\sigma=(\sigma_n^2+\sigma_c^2)^{1/2}$ can be estimated directly from the observed probability distribution $P(D)$ of map brightness "deflections" D (mJy beam^{-1}). The $P(D)$ distribution has an ill-defined rms dominated by the contributions of strong sources. Therefore we estimated σ by measuring the FWHM

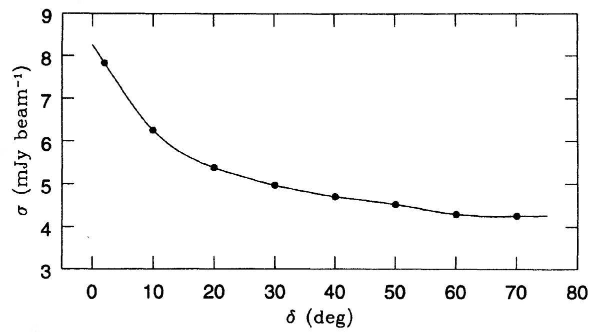

FIG. 2. The measured 1986 map noise plus confusion σ averaged over all right ascensions decreases with declination as shown by the filled symbols. Abscissa: declination (deg). Ordinate: rms noise plus confusion (mJy beam^{-1}) averaged over all right ascensions.

of its nearly Gaussian core and dividing by $(8 \ln 2)^{1/2}$. The declination dependence of σ is shown in Fig. 2. The noise is highest at low declinations because (1) gravitational deformation of the telescope at large zenith angles $|\delta-38°|$ causes astigmatism that reduces the aperture efficiency and (2) the density of samples on the sky is proportional to sec δ. The variation of σ with right ascension is too small to measure because solar heating did not deform the telescope significantly in 1986.

We approximated the 1986 self-calibrated map position uncertainties with the formulas (cf. Ball 1975)

$$\sigma_\alpha=\{\epsilon_\alpha^2+[\sigma\theta_\alpha/(2S)]^2\}^{1/2}, \tag{3a}$$

$$\sigma_\delta=\{\epsilon_\delta^2+[\sigma\theta_\delta/(2S)]^2\}^{1/2}. \tag{3b}$$

The rms pointing uncertainties ϵ_α and ϵ_δ were estimated from the map position errors $\Delta\alpha$, $\Delta\delta$ of the 148 strong VLA calibration sources (Fig. 3). They are $\epsilon_\alpha \approx \epsilon_\delta \approx 9''$. They do not vary significantly with right ascension or solar hour angle

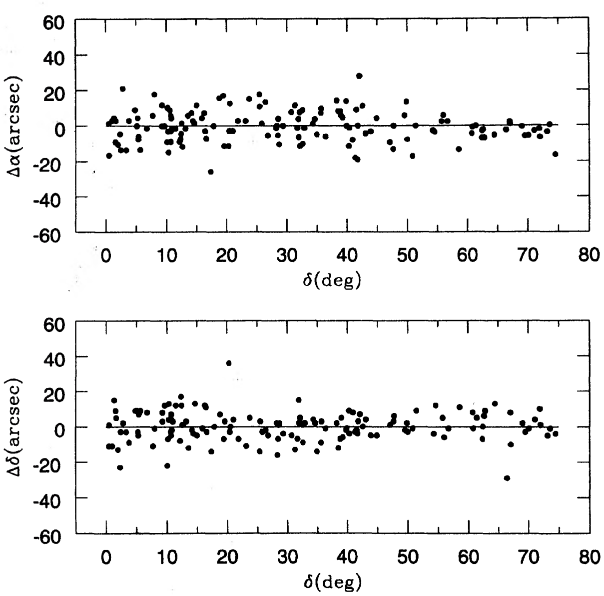

FIG. 3. Final 1986 map position errors of 148 strong point sources, averaged over all right ascensions. Abscissae: declination (deg). Upper ordinate: right-ascension error (arcsec). Lower ordinate: declination error (arcsec).

because solar heating was so weak during the 1986 observations.

3. THE (1986+1987) COMBINED MAPS

3.1 Data Reduction

Combining the epoch 1986 and epoch 1987 (u,v) data should yield maps in which the random noise and position errors are divided by about $\sqrt{2}$. Systematic errors (baseline and confusion errors, for example) are not reduced, so the actual errors on the combined maps are about 0.75 of those in the 1986 or 1987 maps, rather than 0.71. Extra observations of those scans lacking adequate 1986 coverage were made in 1987, and there are no regions of sky affected by solar interference in both epochs. Therefore the maps made from the combined data have significantly more uniform and complete coverage, and they are the best choice for most uses. However, the combined (1986+1987) maps do not correspond to the sky at any one epoch, but represent an average of two epochs.

The calibrated (but not self-calibrated) and edited (u,v) data used to make the 1986 and 1987 maps are not in perfect position agreement. We therefore applied the 1986 and 1987 self-calibration corrections directly to these (u,v) data before combining them. The combined 1986 and 1987 (u,v) data were remapped. The combined maps were compared with the original 1986 and 1987 maps, and a small amount of additional editing was performed. This final editing eliminated data lightly contaminated by solar interference in one but not both epochs, which had been kept in the single-epoch maps because a slightly noisy map is better than no map at all at that epoch. However, it is better to flag the slightly noisy data from one epoch instead of combining them directly with excellent data from the other. No sources were removed because they appeared at only one epoch. By far the most striking case is the strong ($S=3.0$ Jy) source 87GB B0137+0830; it appears in the 1987 but not the 1986 maps. Furthermore, it appeared in only one of the 1987 scans, so it must be either transient or not fixed in equatorial coordinates (e.g., interference from a nearly geostationary satellite).

As before, Gaussian fits to 148 strong point sources from the VLA calibrator list were used to measure the point-source response and position offsets in the combined maps, and fits to 29 unresolved steep-spectrum sources from the Kühr *et al.* (1981) list checked the flux-density scale. The mean position errors were found to be $<1''$ in both coordinates, and the flux-density scales agreed within 1%, so no further corrections were made.

3.2 The Combined (1986+1987) Map Characteristics

The combined (1986+1987) maps have a nearly Gaussian point-source response with FWHM angular diameters given by

$$\theta_\alpha(\text{arcmin})=3.36-1.08\times10^{-3}(\delta-38°)+1.02\times10^{-4}(\delta-38°)^2 \tag{4a}$$

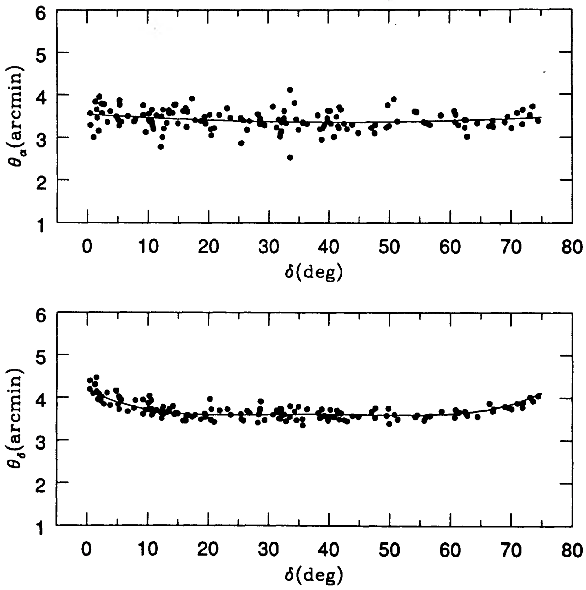

FIG. 4. The combined (1986+1987) map point-source response is independent of right ascension but varies slowly with declination. Abscissae: declination (deg). Upper ordinate: east–west FWHM beamwidth (arcmin). Lower ordinate: north–south FWHM beamwidth (arcmin).

$$\theta_\delta(\text{arcmin}) = 3.61 - 1.6\times10^{-4}(\delta - 38°)^2 + 3.9 \times 10^{-7}(\delta - 38°)^4, \tag{4b}$$

where δ is the declination in degrees. The rms scatter in individual measurements of θ_α is 14″, of θ_δ, 7″. The variation of θ_α and θ_δ with declination is plotted in Fig. 4.

The rms map fluctuations σ were measured from the map brightness distributions $P(D)$ (Fig. 5) as described in Sec. 2.3. An offset of +0.0005 Jy beam^{-1} has been added to all of the maps to ensure that the Gaussian cores of their $P(D)$ distributions have zero mean, as shown in Fig. 5. The values of σ vary primarily with declination (Fig. 6). The three maps covering $12^h40^m < \alpha < 14^h40^m$, $0° < \delta < +5°$ were made from epoch 1986 data only, so their rms is nearly 8 mJy beam^{-1}. Maps in the right-ascension range $11^h < \alpha < 17^h$ are slightly (about 7%) noisier, and maps outside this right-ascension range are typically about 2% less noisy, than the average over all right ascensions shown in Fig. 6. The rms intensity-proportional error coefficient γ [see Eq. (2)] is $\gamma \lesssim 0.09$.

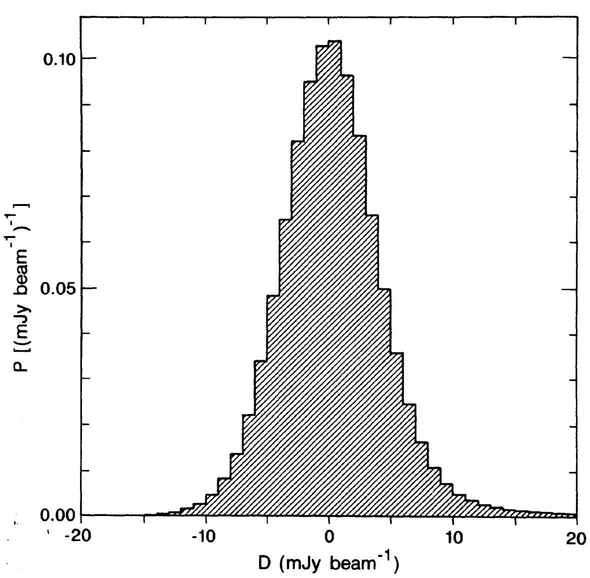

FIG. 5. Pixel brightness distribution for the combined (1986+1987) map centered on $\alpha = 1^h40^m$, $\delta = +30°$. Abscissa: brightness (mJy beam^{-1}). Ordinate: normalized probability [(mJy beam^{-1})$^{-1}$].

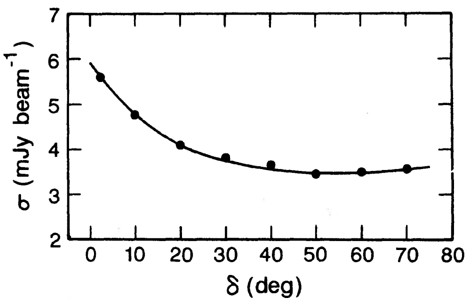

FIG. 6. The combined (1986+1987) map noise plus confusion σ averaged over all right ascensions decreases with declination as shown by the filled symbols. Abscissa: declination (deg). Ordinate: rms noise plus confusion (mJy beam^{-1}) averaged over all right ascensions.

The combined (1986+1987) map pointing uncertainties ϵ_α and ϵ_δ [see Eq. (3)] were estimated from the position errors measured for 148 strong VLA calibrators (Fig. 7).They appear to decrease slowly with declination, as expected since the density of observations increases as sec(δ). Thus we assumed that both are proportional to $\sqrt{\cos\delta}$ and fitted to ob-

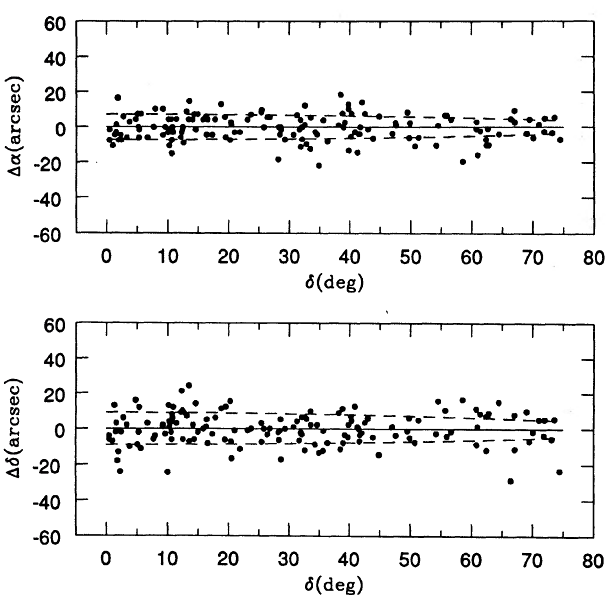

FIG. 7. Combined (1986+1987) map position errors of 148 strong point sources, averaged over all right ascensions. Dashed lines indicate the rms pointing uncertainties $\pm\epsilon_\alpha$ and $\pm\epsilon_\delta$. Abscissae: declination (deg). Upper ordinate: right-ascension error (arcsec). Lower ordinate: declination error (arcsec).

tain $\epsilon_\alpha = 7''3\sqrt{\cos\delta}$ and $\epsilon_\delta = 9''0\sqrt{\cos\delta}$. These fits are shown as dashed lines in Fig. 7.

4. MACHINE-READABLE MAPS

The Green Bank 4.85 GHz surveys were made as a service to the astronomical community. We claim no proprietary rights to the survey maps, and J. J. C. will distribute machine-readable copies at cost. You may use and copy them for any nonprofit educational or research use. The 288 self-calibrated 1986 maps covering $0°<\delta<+75°$ are available in FITS format (Grosbøl *et al.* 1988) on a single 4 mm DAT tape for the cost of the blank tape plus shipping. The 288 combined (1986+1987) maps are also available on one 4 mm DAT tape. The 285 self-calibrated 1987 maps are available on a CD-ROM for $10.

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