A survey of polarization in the JVAS/CLASS flat-spectrum radio source surveys: I. The data and catalogue production

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ABSTRACT

We have used the very large JVAS/CLASS 8.4-GHz surveys of flat-spectrum radio sources to obtain a large, uniformly observed and calibrated, sample of radio source polarizations. These are useful for many investigations of the properties of radio sources and the interstellar medium. We discuss comparisons with polarization measurements from this survey and from other large-scale surveys of polarization in flat-spectrum sources.

Key words: techniques:polarimetric – radio continuum:general – surveys – galaxies:active

1 INTRODUCTION

Polarization measurements are potentially important because they provide information about magnetic fields and the media between source and observer. Radio emission from active extragalactic objects is generated by relativistic electrons spiralling around magnetic field lines, either close to the active centre or in the radio jets ejected from it. Radio waves passing through a magnetised plasma suffer Faraday rotation whose magnitude depends on the magnetic field and electron density along the path; this can occur within the synchrotron-producing region, in the interstellar medium of the emitting galaxy or in passage through our own Galaxy. It is also important to measure the polarization of large numbers of discrete radio sources in order to remove their contribution from future measurements of the polarization of the cosmic microwave background radiation.

Studies of radio polarization in extragalactic sources have yielded important results in the past, including support for orientation models of active galaxies (Laing 1988; Garrington et al. 1988). They have also been used to investigate the physics of radio jets on kiloparsec scales, which can be polarized by tens of percent and whose polarization structure can give information on magnetic fields and jet confinement (e.g. Laing et al. 2006; Leismann et al. 2005; Hardee 2003; Gizani & Leahy 2003; Ferrari 1998; Laing 1996) down to parsec scales close to the central black hole (e.g. Lister & Homan 2005; Hughes 2005; Lyutikov, Pariev & Gabuzda 2005; Fraix-Burnet 2002).

The subject of this paper is the radio polarization of core-dominated, flat-spectrum, radio sources. At flux density levels of >100 mJy at frequencies of a few GHz, these sources are predominantly quasars and BL Lac objects in which the bipolar jets are oriented close to the line of sight. Consequently, the radio emission from the approaching jets is enhanced by Doppler beaming, leading to associated observable effects such as strong variability and apparent superluminal motion caused by the relativistic motion close to the line of sight. The integrated polarization in these flat-spectrum sources is typically a few per cent (e.g. Saikia, Kodali & Swarup 1985; Okudaira et al. 1993). The physics is somewhat complicated, since flat-spectrum “cores”, when observed with milliarcsecond resolution, consist of multiple synchrotron components of different sizes and hence with different frequencies at which the emission becomes optically thick and below which the spectrum suffers a self-absorption turnover. The integrated rotation measure is usually quite low, often less than a few tens of rad m$^{-2}$ (e.g. Rudnick & Jones 1983, but see also Zavala & Taylor 2004).

Over and above these astrophysical inferences, occasional attempts have been made to investigate the hypothesis that observations of apparently ordered polarizations can be used to make cosmological inferences. Amongst these are chiral effects on the propagation of light (Nodland & Ralston 1997; see also Carroll & Field 1997), coupling of light pseudoscalars, such as axions, to the photons (Raffelt & Stodolsky 1988), and universal rotation (Birch 1982). More recently, Hutsemékers et al. (2005) have claimed alignments on large angular scales of the optical polarization position angles of quasars. Our data can be used to place constraints on effects of this nature and these are discussed in more detail in Paper II of this series.
In this paper we describe the data calibration and analysis for the largest survey of polarization in compact radio sources to date, namely the JVAS and CLASS surveys (Patnaik et al. 1992; Browne et al. 1998; Wilkinson et al. 1998; Myers et al. 2003; Browne et al. 2003). We discuss the steps that need to be taken to ensure clean polarization measurements with low systematics in these large samples. In subsequent papers we address uses of this sample. In Paper II we discuss cosmological alignments prompted by the claims of Hutsemékers et al. (2005) of extreme-scale alignments of quasar optical polarization vectors. In Paper III we will present further polarization observations of a subset of the JVAS/CLASS sources.

2 OBSERVATIONS AND DATA ANALYSIS

2.1 The JVAS/CLASS surveys

The prime motivation for JVAS (the Jodrell-VLA Astrometric Survey) was to identify sources suitable for use as interferometer phase calibrators and to measure accurate positions for them. A secondary aim was to look for any sources that might have been gravitationally lensed. For both these objectives, pre-selecting sources which one might expect a priori to have compact radio structures was desirable. For this reason only those sources with known flat radio-spectra ($S_{\nu}^{1.4 \, \text{GHz}} > -0.5$) were selected. Spectral selection for JVAS was initially carried out using the 5-GHz 87GB survey (Gregory & Condon 1991) and the 1.4-GHz Green Bank survey (White & Becker 1992). Each JVAS source was then observed for 2 min with the VLA in its A-configuration at a frequency of 8.4 GHz. A full description of the sample selection process and the observational details can be found in Patnaik et al. (1992). In three separate observing sessions, each separated by around 15 months, 2720 sources stronger than ~200 mJy at 5 GHz were successfully observed in the region of sky with declination $\geq 0^\circ$ and $|b| \geq 2.5^\circ$. The observations in each session were typically divided into blocks of time lasting for $\geq 12$ hr, each of which was calibrated and analysed separately.

The CLASS survey (Cosmic Lens All-Sky Survey) consisted of 30-second snapshot observations at 8.4 GHz of all sources with a 5-GHz flux density of $>30$ mJy which had not already been observed as part of JVAS. In addition, some sources below 30 mJy were observed, down to the GB6 survey limit of $\sim 20$ mJy and using newer surveys (GB6, Gregory et al. 1996; WENSS, Rengelink et al. 1997; NVSS, Condon et al. 1998). Full observing details and a more complete description of sample selection can be found in Myers et al. (2003). Four observing sessions in 1994, 1995, 1998 and 1999 covered the whole sky between declinations of $0^\circ$ and $70^\circ$, with the more southerly regions being observed later in the programme. 13783 sources were observed, making a total of 16503 sources for the whole JVAS/CLASS programme.

2.2 Calibration

The original purpose of the CLASS survey was to identify gravitational lens systems. The analysis was done using a DIFMAP script (Shepherd 1997) for automatic mapping and identification of candidates. For the present work we have re-edited, recalibrated and re-imaged the datasets as described below. This is because we have found that bad data on individual telescopes or calibration errors which do not cause major problems for lens identification can become serious impediments to accurate polarization calibration and mapping. All analysis was done using the NRAO Astronomical Image Processing System (AIPS). Because we want to be able to perform statistical analysis on large samples of sources with low levels of polarization, the polarization calibration is crucial, and we therefore describe it in some detail. Errors in the antenna polarization calibration at one epoch of observations will show up as correlated polarizations with similar position angles in the patch of sky observed at that epoch.

After careful editing of bad data, phase and amplitude solutions were obtained using point-source phase calibrators which were typically observed every 15-20 minutes during the CLASS observations, and more frequently in the case of JVAS. These solutions were inspected, edited where necessary to remove discrepant points, and interpolated before application to the data on the target sources.

2.2.1 Instrumental polarization terms

Instrumental polarization terms were then estimated using the AIPS task PCAL. For this process it is necessary to find a calibrator which either has a known polarization, or has an unknown polarization but which has been observed at a range of parallactic angles; this allows its polarization at the time of observation to be calculated. For the majority of epochs of CLASS data the unpolarized source 3C84 (J0319+415) was observed. Aller, Aller & Hughes (2003) present monitoring results for 3C84 over 17 years and quote a 14.5-GHz polarization of 0.12±0.01%, which is well within the error to which we are able to determine instrumental terms. We have therefore assumed 3C84 to be completely unpolarized. In some cases we have used OQ208 as a zero-polarization calibrator which has been observed on numerous occasions with the WSRT (A.G. de Bruyn, private communication). In a few cases, particularly in many of the CLASS observations from 1994, we do not have a suitable instrumental term calibrator and have therefore excluded these observations from our analysis. This results in a sparse sampling of some of the sky, in particular for areas north of declination $45^\circ$.

For one observing session in 1991, we have observations of both the unpolarized calibrator OQ208 and observations of a strong polarized calibrator, B1611+343, taken at a range of parallactic angles. In Figure 1 we show the instrumental terms derived from each of these two observations. They are entirely consistent with each other giving us confidence in the use of OQ208 as an unpolarized calibrator. Figure 2 shows the resulting polarizations derived for 150 target sources using the two methods. Little difference is evident. If significantly polarized sources are considered (polarized flux density $>1$ mJy), the rms deviation in position angles between the two calibrations is $6^\circ$. We have also experimented with the use of the solution interval for the determination of instrumental term solutions (between 15s and 60s, a standard value of 30s being eventually chosen), as well as choice of reference antenna, and find that the result is...
robust to these choices. In practice, the mean instrumental term for each telescope was normally between 1% and 2%. Excursions outside this range could nearly always be traced back to bad data in one or more telescopes which upsets the overall solution.

2.2.2 Polarization angle determination

After the instrumental terms were determined, the corrections were applied to observations of a polarized source of known position angle in order to determine the relative phase of the left-hand and right-hand polarization channels. This is necessary in order to rotate the phases for all baselines within each polarization channel so that the average phases on the left-hand and right-hand channels are consistent with each other and also with the known linear polarization angle of the position-angle calibrator. We used 3C286 (position angle 33°) and 3C48 (position angle −70°) for this purpose (Myers & Taylor 2006).

We have checked that the phase rotations applied to left- and right-hand data in each epoch within a season do not differ significantly, although some drift is expected resulting from system changes and which the phase rotation is designed to remove. In most cases this was true to within 20° (r.m.s. deviation between epochs was 19° in 1995 and 14° in 1998), apart from a significant change which occurred between 1998 April 5 and 1998 May 21.

When the instrumental polarization term correction and the L-R phase rotation are both determined, a polarization angle can be derived for each baseline from observations of the polarized calibrator. Ideally, there should be a small scatter between baselines of less than 10° in these measurements, giving a very small error in the overall polarization angle averaged over ~300 baselines. In some epochs, all from the CLASS part of the survey, this desirable level of scatter is exceeded by factors of 3-4. However, in such epochs where two polarized calibrators (3C48 and 3C286) are available, we can determine the L-R phase corrections from one source and use them to attempt to recover the polarization angle for the other source. In these cases, and in other cases where two polarized calibrators are available, the angle is recovered to within 10° of that expected, suggesting that there is no major systematic problem in the use of data from these epochs and in particular that derived polarization angles have systematic calibration errors of ≤10°. In most of the survey, including all the JVAS observations and the CLASS observations from 1998 March and April, the reliability is likely to be significantly better than this.

Table 1 shows the JVAS/CLASS epochs with the calibrators used for each, together with the important polarization parameters which have been derived for each epoch.

2.3 Imaging and the derivation of position angles

The calibrated datasets were mapped using an automatic procedure implemented using an AIPS runfile. A shift was applied to the phases of the \( u - v \) data in order to centre the observations on the brightest point source found in the earlier automated analysis described in Myers et al. (2003). Sources were not included if they were not detected in the previous analysis, or if a source was located but judged to be extended on the basis of angular sizes (defined as being fitted by a Gaussian FWHM of 0.5 or greater). An initial map of 12′ × 12′ was produced using natural weighting. If the source had previously been detected by the Myers et al. (2003) analysis with a flux density of 40mJy or greater, the initial map was used as an input for phase self-calibration using clean components brighter than the first negative; in cases where the flux density is greater than 80mJy one iteration of amplitude self-calibration was also applied, using the results from the initial phase self-calibration as an input model. For the purposes of visual inspection, final images in Stokes \( I, Q \) and \( U \) were then made using the CLEAN algorithm (Högstrom 1974) using the task AIPS IMAGR, and combined into polarization level and position angle maps.

Polarization parameters were extracted using fits to the processed (and in the case of strong sources, self-calibrated) \( u - v \) Stokes \( Q \) and \( U \) data using the task AIPS UVFIT. In order for this algorithm to converge successfully, the position of the centre of polarized flux is required. This was calculated by making a total-intensity map and using the brightest point in this map as the \( Q \) or \( U \) centre, on the assumption that these coincide.

We did not use the value derived from applying the CLEAN algorithm to the \( Q \) and \( U \) data, as this can cause the measured flux densities to be decreased by CLEAN bias (e.g. Condon et al. 1998). The model-fitting procedure is valid provided that there is no extended polarized structure such as a polarized radio jet, in which case it provides an averaged value.

We checked for the overall uniformity of the distribution of the model-fitted polarization position angles and found, as expected, that the position angles derived from direct fits to the data are statistically uniform in the range from 0° to 180°. In contrast, angles derived from CLEANed \( Q \) and \( U \) data show peaks at 0°, 45°, 90° and 135°, corresponding to CLEAN bias forcing the \( Q \) and \( U \) fluxes towards zero. This effect of CLEAN bias on polarization determinations is unexpected and potentially important; it will be discussed further in a future paper (Battye et al., in preparation).

In order to keep only significant polarization detections, we imposed a limit of 1 mJy in polarized flux in most subsequent analysis, corresponding to approximately 4σ; below these levels the derived polarized flux is increasingly affected by positive bias (e.g. Simmons & Stewart 1985). However, the polarization parameters for all sources are available in the electronic version of this paper. An extract from the first page of the data table is shown in Table 2 and includes the position of the source, the epoch of the data and the derived flux densities in Stokes \( I, Q \) and \( U \) together with the polarization percentage and position angle. The total number of sources in the catalogue with polarization measurements is 1255 of the total JVAS/CLASS sample of 16503. Of these, 4294 have significant detections of polarization, with a polarized flux density ≥1 mJy.
Figure 1. Instrumental polarization terms per telescope for the observations taken in 1991 as part of the JVAS survey. The scales on the axes run from $-3\%$ to $3\%$ of instrumental polarization. The length of each line gives the amplitude of the instrumental term; that is, the amplitude of polarization that this telescope would record for an unpolarized source. The angle gives the phase in such a way that a complete rotation on the diagram would rotate the polarization vector by $180^\circ$. The number attached to each arrow refers to the specific VLA antenna. On the left is the calibration achieved by using the polarized source 1611+343 observed at different parallactic angles, and on the right is the calibration made using the assumption that the source OQ208 is unpolarized. Note the similarity in the derived instrumental terms.

Figure 2. Comparison of derived polarization of 150 sources obtained using two different calibrations of instrumental polarization in observations from 1991 June 16. Axes represent $Q$ and $U$ as a percentage of Stokes $I$. Unfilled and filled circles represent calibrations using the polarized source 1611+343 and the unpolarized source OQ208. Larger symbols represent significant detections of polarization (>1 mJy in polarized flux density). The right-hand panel is a blowup of the inner region of the left-hand panel, indicated by a dotted line in the left-hand panel.

2.4 External comparisons with other data.

Do the CLASS$^*$ polarization position angles agree with other measurements? We have made comparisons, some direct and some indirect, that convince us that our CLASS polarization angles are reliable. Okudaïra et al. (1993) have used the Nobeyama 45-m telescope to measure the polarizations of 99 flat spectrum radio sources at 8.4 GHz and their sample has 76 objects in common with ours. We plot the histogram of position-angle differences in Fig. 3. There is a clear peak around zero degrees, with a rms dispersion of

$^*$ In this and subsequent sections we refer to the combined JVAS/CLASS surveys simply as “CLASS”.

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Table 1. Observing epochs for JVAS/CLASS. For each epoch we list the approximate sky area principally covered by the observation. The zero-polarization calibrator observed to calibrate the instrumental polarization terms is listed together with the derived instrumental polarization in columns 4 and 5; in most cases these can be brought below 1.5% with careful editing of bad data. The amplitudes of these terms are also given by the lengths of the vectors in Fig. 1. Column 6 lists the polarized calibrator used to determine L-R phase offsets as described in the text. The scatter between measurements of polarization angle for different baselines, derived from applying the instrumental polarizations to the polarized calibrator, varies widely between epochs.

| Epoch | RA       | Dec     | Zero-pol calibration | Instrumental polar. | Angle calibrator | L-R residual/° | Comments |
|-------|----------|---------|---------------------|---------------------|------------------|----------------|----------|
| 900219 | all      | >35     | 3C84                | 1.0%                | 3C286            | 2              |          |
| 910616 | all      | 20–35   | OQ208               | 1.0%                | 3C286            | 5              |          |
| 921017 | all      | <20     | 3C84                | 1.1%                | 3C286            | 2              |          |
| 940301 | 10–20h   | 45–53   | 3C84                | 1.6%                | 3C286            | 3              |          |
| 940404 | 7–10h    | 45–70   | 3C84                |                     |                  |                |          |
| 950813 | 6–15h    | 29–36   | 3C84                | 1.0%                | 3C286            | 16             |          |
| 950814 | 6–9h     | 45–70   | 3C84                | 1.5%                | 3C286            | 24             |          |
| 950829 | 6–10h    | >37     | 3C84                | 1.3%                | 3C286            | 43             |          |
| 950902A | 6–20h    | <10     | 3C84                | 1.3%                | 3C286            | 16             |          |
| 950902B | 6–20h    | 17–30   | 3C84                | 1.3%                | 3C286            | 31             |          |
| 980314A | 2–24h    | 8–17    | 3C84                | 1.3%                | 3C286            | 2              |          |
| 980314B | 2–12h    | <8      | 3C84                | 1.6%                | 3C286            | 2              |          |
| 980403 | 1–11h    | 17–28   | 3C84                | 1.3%                | 3C286            | 4              |          |
| 980510 | 12–24h   | <7      | OQ208               | 1.5%                | 3C286            | 44             |          |
| 980521 | 13–17h   | 28–45   | OQ208               | 1.2%                | 3C286            | 14             |          |
| 990816 | 12–20h   | 0–20    | 3C84                | 1.3%                | 3C286            | 45             |          |

Some spread is expected because many of the sources are known to be extremely variable both in their total intensity and polarization properties, position angles (e.g. BL Lac, 3C445, 3C454.3, etc.). In addition, the angular resolutions of the two sets of observations are very different. Resolution may make a difference because emission from optically thin, kiloparsec-scale jets, is generally more highly polarized, and sometimes at a different position angle, compared to that from the compact cores (e.g. Saikia & Salter 1988).

Another test is to compare the CLASS position angles with the intrinsic position angles, corrected for Faraday rotation, determined by Broten et al. (1988). Typical rotation measures arising from a combination of Galactic and internal Faraday rotation are ~20 rad m⁻² which means that most of the CLASS measured angles should be close to the intrinsic ones. The difference between the CLASS angles and those from Broten et al. (1998) for the 67 objects in common are also shown in Fig. 3. The spread is about the same (~40°) as that of the Okudaira et al. (1993) sample but there is a peak which a formal average of the data shows to be centred around (~7 ± 5)°.

A typical rotation measure of ~20 rad m⁻² will produce a rotation of ~50° at a wavelength of 21 cm which, if left uncorrected, would effectively smear out any record of the intrinsic position angle. There are, however, areas of sky at high Galactic latitudes where average rotation measures are significantly less than 20 rad m⁻² and hence one would expect to be able to see a correlation between the CLASS position angles and those measured at 21 cm in these regions. The NVSS survey, which was made at a wavelength of 21 cm, lists polarization information on all the sources (Condon et al. 1998). In Fig. 3 we show the histogram of position angle differences between CLASS and NVSS for the 1424 common sources in the region |b| > 30° and which have NVSS polarized flux density ≥2 mJy and CLASS polarized flux density ≥1 mJy. As expected there is a significant peak near zero degrees, although the mean value of the data is actually located at (3.9±1.2)°.

The offset in the peak from 0° in the CLASS-NVSS polarization angle difference is almost certainly due in part to large-scale rotation measure structure in the Galaxy. Simard-Normandin & Kronberg (1980) present RM measurements over the whole sky, and identify regions of 60°–90° in extent with correlated Galactic RM. To demonstrate that the observed offset in the peak is probably due to Galactic Faraday rotation, we have selected sources in regions found to have significant positive RM (defined by 90° < l < 165°, b > 0°; Simard-Normandin & Kronberg 1980) and significant negative RM (defined by δ > 0°, l < 130° and b < 0°, corresponding to Simard-Normandin & Kronberg’s region A). Plotting these separately (Fig. 4) clearly shows that the polarization differences are offset in different directions in these two regions of sky.
Finally we emphasize that seeing any peak in the CLASS-NVSS position angle histogram implies that the average integrated rotation measures of the sources in the sample must be \( \leq 20 \) rad m\(^{-2}\). This is somewhat surprising since in these flat-spectrum sources it is believed that most of the emission originates on parsec-scale structures, and it is now well established that the core regions detected in cm-wavelength VLBI observations typically have rotation measures of several hundreds of rad m\(^{-2}\) (e.g. Zavala & Taylor 2004). Indeed, the core rotation measures revealed by 7mm-2cm VLBI observations sometimes approach 1000 rad m\(^{-2}\) or more (Mutel et al. 2005; Gabuzda et al. 2006).

We have also performed an indirect test. It is known both statistically, and from detailed mapping of individual radio sources, that there is a correlation between the structure of radio jets and the magnetic field direction inferred from radio polarization measurements. In particular high-luminosity quasar jets tend to have dominant longitudinal magnetic fields (Bridle & Perley 1984; Cawthorne et al. 1993). Therefore we might expect to see a correlation between jet position angles and polarization angles. We have compiled a list of 157 sources which have VLBI elongation directions given in the tables of Taylor et al. (1994) and Henstock et al. (1995). In Figure 5 we show the histogram of the difference between structural and polarization position angles for these sources in common between the two samples. There is a clear excess around 90 degrees difference, as expected if magnetic field direction aligns with that of the radio jet.

### Table 2

| RA (hh mm ss) | Dec (dd mm ss) | I | SigI | Q | SigQ | U | SigU | PA/deg |
|---------------|---------------|---|------|---|------|---|------|---------|
| 00 00 07.0341 | +08 16 45.040 | 29.4 | 0.2 | -0.26 | 0.19 | +0.28 | 0.19 | 66.2 |
| 00 00 10.9098 | +30 55 59.420 | 20.0 | 0.3 | +0.18 | 0.20 | -1.40 | 0.20 | 138.7 |
| 00 00 14.8771 | +27 51 57.577 | 22.8 | 0.3 | +0.35 | 0.21 | +0.11 | 0.21 | 9.1 |
| 00 00 19.2833 | +02 48 14.657 | 81.8 | 0.3 | +1.21 | 0.32 | -1.66 | 0.33 | 153.1 |
| 00 00 19.5679 | +11 39 20.718 | 28.9 | 0.3 | +0.40 | 0.27 | +0.32 | 0.26 | 19.4 |
| 00 00 26.8395 | +44 31 11.700 | 5.4 | 0.2 | -0.27 | 0.20 | -0.14 | 0.21 | 103.8 |
| 00 00 27.0230 | +03 07 15.635 | 96.0 | 0.4 | +1.87 | 0.37 | -0.37 | 0.36 | 174.5 |
| 00 00 30.1085 | +47 16 43.313 | 16.3 | 0.3 | -0.03 | 0.24 | +0.46 | 0.28 | 65.1 |
| 00 00 35.1294 | +29 14 35.823 | 64.5 | 0.2 | +0.48 | 0.25 | -0.30 | 0.25 | 164.1 |
| 00 00 30.1085 | +24 20 11.799 | 51.4 | 0.3 | -3.18 | 0.28 | +0.66 | 0.29 | 84.1 |
| 00 00 35.1294 | +03 07 54.199 | 60.6 | 0.3 | +0.86 | 0.32 | -0.36 | 0.32 | 168.6 |
| 00 00 47.3761 | +32 52 57.109 | 13.5 | 0.3 | -0.39 | 0.28 | +0.46 | 0.28 | 65.1 |
| 00 00 56.0910 | +25 16 20.152 | 25.2 | 0.4 | -0.96 | 0.35 | +0.13 | 0.35 | 86.2 |
| 00 00 49.7361 | +02 43 09.588 | 60.3 | 0.2 | -0.30 | 0.18 | +0.50 | 0.18 | 60.5 |
| 00 00 14.3441 | +06 14 22.011 | 20.8 | 0.3 | -0.02 | 0.33 | +0.35 | 0.34 | 46.4 |
| 00 00 14.8643 | +23 58 50.617 | 117.1 | 0.5 | -0.30 | 0.36 | -0.25 | 0.36 | 110.1 |
| 00 00 21.6723 | +34 16 55.519 | 41.2 | 0.3 | -0.78 | 0.29 | -0.40 | 0.29 | 103.1 |
| 00 00 23.6573 | +06 32 30.966 | 33.9 | 0.3 | +0.88 | 0.19 | -0.52 | 0.19 | 164.8 |
| 00 00 32.2272 | +13 52 58.482 | 13.1 | 0.3 | +0.20 | 0.25 | -0.52 | 0.26 | 146.5 |
| 00 00 32.3700 | +21 13 36.216 | 99.2 | 0.4 | -0.83 | 0.32 | +1.16 | 0.32 | 62.8 |
| 00 00 34.4532 | +07 23 12.903 | 71.0 | 0.3 | +0.86 | 0.35 | +2.63 | 0.35 | 36.0 |
| 00 00 43.4710 | +07 01 23.570 | 50.3 | 0.3 | +0.11 | 0.22 | +0.38 | 0.22 | 37.1 |
| 00 00 46.2388 | +46 16 32.368 | 15.7 | 0.2 | -0.18 | 0.21 | -0.32 | 0.21 | 120.8 |

### 3 CONCLUSIONS

We have presented polarization determinations for the 76% of CLASS sources for which reliable polarization calibration is possible. Although systematic effects are important in determining low levels of polarization, we have quantified the systematic errors involved and compared the data with other surveys. Agreement is obtained which convinces us that the polarization angles are reliable to within a few degrees for sources with a significant (>1 mJy) polarized flux density.

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Figure 4. CLASS-NVSS polarization position angle differences for two regions of sky. On the left is the region $90^\circ < l < 165^\circ$, $b > 0^\circ$, found to have significant positive RM by Simard-Normandin & Kronberg (1980). On the right is the region of significant negative RM, $\delta > 0^\circ$, $l < 130^\circ$ and $b < 0^\circ$.

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Figure 3. Histogram of position angle differences, in degrees, between CLASS and other surveys. From top to bottom: Okudaira et al. (1993), Broten et al. (1988) and NVSS (Condon et al. 1998). In the case of NVSS we have required sources with significant polarization in each survey (>1 mJy for CLASS and >2 mJy for NVSS).

Figure 5. Histogram of position angle offsets, in degrees, between CLASS polarization vectors and VLBI structure from the observations of Henstock et al. (1995) and Taylor et al. (1994). Note the peak at about 90°.

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