THE SRS CATALOG OF 20,488 STAR POSITIONS
CULMINATION OF AN INTERNATIONAL COOPERATIVE EFFORT

C.A. Smith[1], T.E. Corbin[1], J.A. Hughes[1], E.S. Jackson[1], E.V. Khrutskaya[2], A.D.Polozhentsev[3], D.D. Polozhentsev[2], L.I. Yagudin[2], M.S. Zverev[2]

[1] U.S. Naval Observatory, Washington, DC, U.S.A.
[2] Pulkovo Observatory, Leningrad, U.S.S.R.
[3] Leningrad State University, Leningrad, U.S.S.R.

ABSTRACT

A major international effort to observe and compile the results of observations from many transit circle programs into a single catalog of positions referred to the FK4 system came to a conclusion with the completion and distribution of the Southern Reference Star (SRS) catalog of 20,488 stars. Previous discussions focussed on the adjustments to the observational material to refer it to the FK4 system and on the random errors as estimated from residual differences. In the present discussion, we give the results of internal comparisons which have been made between the individual contributing catalogs and the final combined SRS catalog. Also, results of a comparison between the SRS catalog and the AGK3R catalog are given where they overlap in the declination zone from +5 to -5 degrees. The possibility of magnitude equation and color error in the SRS catalog is discussed.

The reduction procedure used to transform the version of the SRS catalog based on the FK4/B1950.0 system to the version based on the FK5/J2000.0 system is given.

INTRODUCTION

In 1961, a program of observations was started which, by the time it ended in 1973, was to involve six transit circle telescopes in the southern hemisphere and seven in the north. In the southern hemisphere, observations were made from Argentina, Australia, Chile and South Africa. Observations in the northern hemisphere were made from France, Japan, Rumania, Spain, the USA and the USSR.

A list of stars from -90 to -30 degrees declination was chosen at the Cape Observatory. At the U.S. Naval Observatory a list of stars from -30 to -5 degrees declination was chosen. The combination of those two lists and the AGK3R stars in the declination zone from -5 to +5 degrees comprised the list of about 20,500 stars called the Southern Reference Star (SRS) catalog. The selection of stars was made in accordance with guidelines coordinated through the SRS Committee of Commission 8 of the International Astronomical Union. The principal criteria for selection were that the visual magnitudes of the stars should lie mostly in the range from 7.5 to 9.5 with excursions outside of that range as necessary to achieve a uniform distribution on the celestial sphere of about 1 star

J. H. Lieske and V. K. Abalakin (eds.), Inertial Coordinate System on the Sky, 457–463.

per square degree. Stars with good observational histories were given preference in order to improve the proper motions.

The compilation of the observations into a single catalog of positions referred to the fundamental system of the FK4 catalog was carried out jointly at the Pulkovo Observatory and at the U.S. Naval Observatory. Results of observations from the participants were received over an eight year period from 1974 to 1982. Work on the compilation of the SRS catalog was completed in December 1987. Distribution of the catalog was made in April 1988 after a review of procedures and comparisons with other catalogs had been completed. Preliminary proper motions were distributed with the SRS catalog, but should not be regarded as a part of it. See Corbin (1974,1978) for a discussion of the work on the proper motions of the SRS stars.

There was general agreement that a version of the SRS catalog referred to the FK5 system should also be made available. The question of the proper technique for accomplishing the transformation is still under discussion, but an approach was adopted and justified as closely paralleling the technique used at the Astronomisches Rechen-Institut for the reduction of the FK4 to the FK5 system.

The SRS catalog is the reference catalog for the 2nd Cape Photographic Catalog (CPC2), the first example of a modern photographic catalog taken in the visual spectral range (5300-6400 Å). The plates were measured on the automatic measuring machine, GALAXY. The measurement program is described in Nicholson(1978). Reductions at Hamburg Observatory for the individual plates using the SRS catalog referred to the FK5/J2000 system are nearly finished, and preparations for a complete plate overlap solution are underway. The accuracy of the CPC2 is estimated at $0\overset{''}{.}06$. For further details see Nicholson et al.(1984), de Vegt(1988) and de Vegt(1989).

COMPARISON OF THE SRS CATALOG WITH THE INDIVIDUAL CONTRIBUTORS

Evidence of a small but significant magnitude equation in the declination differences between a preliminary version of the CPC2 realized in early 1989 and depending on a single plate solution and the SRS in the declination zone from -5 to +3 degrees has been noted by de Vegt (personal communication). From those differences alone, it is not possible to conclude with certainty from which catalog the magnitude equation comes.

However an analysis of the differences between the declinations of the individual SRS contributors and the SRS catalog could be expected to indicate something about the extent to which magnitude related differences exist among them. The following table (Table I) shows the differences in declination collected in half-magnitude intervals for the seven catalogs which contributed to the SRS catalog in the -5 to +3 degree zone of declination.

It is quite clear from the table that each of the participants, with the exception of Perth and Washington, show some systematic behavior at the 0.1 to 0.2 arcsec level over the magnitude range from 6.5 to 9.0. Unfortunately, there being no reliable standard known to be free of magnitude equation, it is not possible to free the SRS catalog of the residual effects of the magnitude equation of the individual contributors, which, it appears, can be rather substantial.

Table I
Magnitude Dependent Systematic Differences in Declination
Individual Catalog Minus SRS Catalog
in the Declination Zone -5 to +3 Degrees

unit = arcsec

	6.5	7.0	7.5	8.0	8.5	9.0 mag
Abbadia	0.198+	0.198+	0.032+	0.079+	0.020+	0.040+
(me)	57	22	7	2	3	3
(N)	16	45	80	197	260	147
Bordeaux	0.151+	0.100+	0.047+	0.054+	0.042+	0.037+
	30	6	3	2	4	3
	21	63	89	186	281	132
Bucharest	0.234+	0.167+	0.110+	0.048+	0.075+	0.034+
	31	14	6	4	1	6
	17	55	93	187	272	134
Leoncito	0.153-	0.040-	0.037-	0.047-	0.014-	0.007+
	8	3	2	1	1	1
	59	216	330	738	1063	526
Nicolaiev	0.172-	0.003-	0.027+	0.012-	0.054-	0.133-
	22	8	7	1	2	2
	25	93	134	318	495	250
Perth	0.030-	0.036-	0.011+	0.015+	0.034+	0.041+
	13	2	2	0	0	1
	58	207	328	735	1064	540
Washington	0.002+	0.020-	0.021-	0.004-	0.009-	0.027-
	8	1	1	0	0	1
	59	222	333	757	1100	555

Although no significant magnitude equation in right ascension between the preliminary CPC2 and SRS catalogs was noticed, an internal analysis of the SRS catalog differences with respect to the SRS contributors was made. Only the Nicolaiev right ascensions showed significant systematic behaviour, being rather strongly positive at the 0.1 arcsec level in the brightest and faintest SRS catalog magnitude limits, and zero or slightly negative in the middle of the magnitude range.

When the comparisons are extended over the full declination range of the SRS catalog, from -90 to +5 degrees, vestiges of the behavior in the -5 to +3 degree zone persist, but are greatly diminished. It is clear that observations in the equatorial zone are the most seriously affected.

Residual differences in right ascension and declination were examined for a color equation correlated with spectral type. No significant variation was found.

COMPARISON OF THE SRS CATALOG WITH THE AGK3R CATALOG

A comparison of the SRS and the AGK3R catalogs in the zone of overlap between -5 and +5 degrees in declination was made. There were about 3,300 stars in common or more than 300 per one degree zone of declination. The AGK3R position was brought to the mean epoch of the SRS position using the NIRS (also known as AGK3RN) catalog proper motions of T. Corbin. One outlying difference in right ascension was rejected. No differences in declination were rejected. The average difference in epoch between the SRS and AGK3R catalogs is about 10 years.

Taking the differences globally and forming the mean differences in right ascension and declination over the entire zone in the sense (SRS minus (AGK3R + NIRS proper motion)) gave a systematic difference of +0.02 arcsec in each coordinate. The greatest regional difference in the right ascension coordinate occurred in the declination zone from -4 to -5 degrees, where the difference was +0.06 arcsec with a mean error of 0.02 arcsec for 307 differences. The greatest regional difference in the declination coordinate occurred between +3 and +4 degrees where the difference was +0.07 arcsec with a mean error of 0.01 arcsec for 347 differences. The following table gives differences collected by magnitude interval.

Table II. SRS-(AGK3R+NIRS Prop. Motions) in the Decl. Zone -5 to +5 Deg.

Avg. Mag.	Avg. RA Diff.	ME	N	Avg. DEC Diff.	ME	N
6.25	-0".053	0".029	34	0".036	0".028	34
6.75	-0.028	9	217	37	14	217
7.25	-0.015	7	330	22	10	330
7.75	-0.007	7	471	21	9	471
8.25	0.003	5	932	12	7	932
8.75	0.051	5	986	25	7	987
9.25	0.080	10	322	19	13	322

ME denotes the mean error, N denotes the number of stars.

In right ascension, Table II shows a small, but well determined magnitude equation. On the other hand, the comparison of the SRS with the preliminary CPC2 by deVegt shows no significant magnitude equation. In declination, Table II shows no magnitude equation, but de Vegt's comparison of SRS with the preliminary CPC2 shows a well determined magnitude equation.

Our interpretation of these conflicting results is that despite the results given in Table I, where a magnitude equation is found in the individual transit circle catalogs in declination, neither the SRS nor AGK3R has a serious magnitude equation in declination since it is not evident in their differences. The potential for a serious magnitude equation in the SRS declinations from a few northern hemisphere catalogs has been avoided by a strong contribution from the southern hemisphere catalogs.

We restate the result that no significant magnitude equation in right ascension is found among the SRS contributing catalogs. We may also conclude that, since no magnitude equation is found between the CPC2 and SRS right ascensions, the SRS right ascensions are essentially free of magnitude equation. This implies that the magnitude equation found in the SRS-AGK3R differences comes mainly from the AGK3R catalog.

It is significant that problems of magnitude equation occur in the equatorial zone. This is where all of the transit circles participating in the SRS (and AGK3R) programs observed at extremes of zenith distance. Image quality as affected by seeing and the consequent increase in the diameter of the seeing disk could produce a magnitude equation. It is not surprising that everywhere else in the southern hemisphere, at more modest zenith distances, no significant magnitude equation is found, either among the catalogs contributing to the SRS catalog, or between the SRS and preliminary CPC2.

An analysis using NIRS positions instead of AGK3R positions was also tried, but as expected, no significant change was noted.

TRANSFORMATION OF THE SRS CATALOG TO THE FK5/J2000.0 SYSTEM

The SRS positions are the combined results of observations of all participants in the SRS observing campaign from 1961 to 1973. Preliminary catalogs were compiled at both the U.S. Naval Observatory (Washington) and the Pulkovo Observatory (Leningrad). The two compilations were compared, reconciled and combined to give the SRS catalog. The proper motions are given principally as a means to take into account the small differences in epoch of observation between the SRS and the CPC2, which are at most about two years.

Because of the inhomogeneous nature of the proper motion sources, and the likely presence of magnitude-related systematic errors in the proper motions, they may not safely be used to extend the SRS system of positions very far from the mean epoch of observation, which is about 1968. A discussion by T. Corbin of all the SRS observations, including those made before and after the 1961 to 1973 campaign, and their reduction to the FK4 system is in an advanced stage of preparation and will yield the desired high quality proper motions required for transferring the system to more distant epochs.

Two sets of positions and proper motions are given. One set is referred to the equator and equinox of B1950.0 and the other to the equator and equinox of J2000.0. The positions are referred to the mean epoch of observation in both cases. The B1950.0 positions were linked directly to the FK4 system by observational techniques.

The SRS catalog has been referred to the FK5 system and the epoch and equinox of J2000.0 in accordance with the IAU 1976 conventions described in Resolution No. 1 of the IAU Sixteenth General Assembly (Trans. IAU XVIB, 56, 58).

The precise SRS positions and approximate proper motions are given for the equator and equinox of B1950.0 and are referred to the FK4 system. The SRS was reduced to the FK5 system by using coefficients of H. Schwan (Astronomisches Rechen-Institut, Heidelberg) communicated to us as part of a computer subroutine package described in Schwan (1988). The coefficients represent the systematic differences between the FK4 and FK5 catalog positions and proper motions for the mean epoch and equinox of B1950.0 and are given in the system of the FK4 catalog.

The arguments needed as input to the computer subroutine are the right ascension, declination and magnitude. The subroutine returns systematic corrections to the FK4 positions and proper motions. In general, the magnitudes of the SRS lie outside the range of magnitudes of the stars in the FK4 catalog and are therefore inappropriate to use as arguments, because the magnitude-related error of the FK4 system is not defined outside the magnitude range of the FK4 stars. The problem was resolved by adopting as the magnitude argument the mean magnitude of the FK4 stars within 10 degrees of declination and two hours of right ascension of a given SRS position. For stars within 10 degrees of either pole, ALL of the FK4 stars within 20 degrees of the pole and within two hours of right ascension of the SRS star were used to compute the mean FK4 magnitude used as the input argument.

After the SRS positions and proper motions had been referred to the FK5 system by using the procedure described above, they were transformed from the equinox B1950.0 basis to J2000.0 using the algorithm given in the 1988 edition of the Astronomical Almanac, p. B42. The algorithm was applied with the foreshortening terms set equal to zero. By the use of that algorithm, elliptic terms in aberration are removed, the IAU 1976 precession is introduced, the FK4 equinox error in the right ascension position and proper motion system is corrected, and the time scale for the proper motions is shifted from units of tropical centuries to Julian centuries of exactly 36,525 days.

This transformation procedure gives a first order reduction from the FK4 to the FK5 system. A more precise reduction of many of the SRS catalogs observed from 1961 to 1973 is possible from a re-discussion of the FK4 star observations made concurrently with the SRS observations on a nightly basis. A program to reduce first the SRS and then the AGK3R to the FK5 system as directly as possible, going back to the observations of FK4/FK5 stars when they are available, is now in progress at the observatory in Washington.

REFERENCES

Corbin, T.E. 1974 *Astron. J.* **79**, p. 885.

Corbin, T.E. 1978 Proc. IAU Coll. 48, *Modern Astrometry*, ed. Prochazka, F.V. and Tucker, R.H., Inst. of Astronomy (University Observatory) Vienna, p. 505.

de Vegt, C., Zacharias, N., Penston, M.J. and Murray, C.A. 1988 Proc. IAU Symp. 133, *Mapping the Sky*, ed. Debarbat, S., Eddy, J.A., Eichhorn, H.K. and Upgren, A.R., Kluwer Acad. Publ., Dordrecht, p. 415.

de Vegt, C., Zacharias, N., Murray, C.A. and Penston, M.J. 1989 *Star Catalogues: A Centennial Tribute to A.N. Vyssotsky*, Contr. of the Van Vleck Observatory No. 8, ed. Philip, A.G.D. and Upgren, A.R., L. Davis Press, Schenectady, N.Y., p. 45.

Nicholson, W. 1978 Proc. IAU Coll. 48, *Modern Astrometry*, ed. Prochazka, F.V. and Tucker, R.H., Inst. of Astronomy (University Observatory) Vienna, p. 515.

Nicholson, W., Penston, M.J., Murray, C.A., and de Vegt, C. 1984 *Mon. Not. R. Ast. Soc.* **208**, p. 911.

Schwan, H. 1988 *Astron. and Astrophys.* **198**, p. 363.

Discussion

RÖSER: You made the comparison SRS – NIRS and SRS – (AGK3R + NIRS pm) in the zone –5° to +5° in order to study the possible magnitude equation in SRS. May I ask Tom Corbin, how large is the weight of AGK3R in NIRS at epoch 1958? If it's rather large, then both comparisons are almost the same and it is not surprising that the results are the same.

SMITH: We were not surprised that the results are the same.

CORBIN: AGK3R had high weight in the proper motions. There are other late epoch catalogs of high weight in this zone also: PFKSZ, Larink's Schwacher Sternen, Semirot's Bordeaux 50, and Bucharest KSZ +11° to –11°. However, only AGK3R contains all of the AGK3R stars.

CORBIN: Did Bucharest observe with screens?

[*Several people respond that they do not know*]

CORBIN: It should be noted that the six-inch Washington instrument makes rigorous use of screens and could be used as a standard as well as the Perth results.

SMITH: The Seven-inch transit circle at Leoncito also used screens and yet it shows a significant magnitude equation. Which one should we believe?

DÉBARBAT: I do not know the answer for Bucharest regarding the use of a screen, but I know that in Paris they used screens for their meridian observations for developing catalogues. Have you looked at the spectral type for a magnitude effect?

SMITH: We find no systematic effects correlated with spectral type.

BRONNIKOVA: The biggest contribution to magnitude equation in declination is from the Bucharest catalog. If you did not consider it when you put together the initial catalog, then do you still have that dependency left?

Smith: All of the catalogs were included with weights. Bucharest was not excluded, but contributed about 15% of the total weight.

HØG: The magnitude equation of the Perth catalogue was determined by means of some observations made through a neutral filter. The equation was found to be zero within certain limits and was published by Nikoloff and Høg in the Perth 75 catalogue, pages 14 and 15. Have you made use of this result in your discussion?

SMITH: No. This discussion is confined to the problem of SRS observations made within a few degrees of the equator.