CPC2 PLATE REDUCTIONS WITH HIPPARCOS STARS: FIRST RESULTS

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ABSTRACT

The Second Cape Photographic Catalog (CPC2) contains 276 131 stars covering the entire Southern Hemisphere in a 4–fold overlap pattern of 5687 plates. New plate reductions using Hipparcos stars have been done. The formal error of a Hipparcos star position at the mean epoch of the CPC2 (1968) is about 30 mas per coordinate, which is small compared to the x,y measuring precision. A standard error of unit weight of 90 mas has been obtained for an average plate solution as compared to 141 mas for the earlier solution based on the Southern Reference Stars (SRS). The same systematic field distortion patterns have been found in both solutions, but only the Hipparcos reference stars allow solving for magnitude dependent, systematic errors on a plate by plate basis. Using the Hipparcos Catalogue considerably improves the accuracy of the final CPC2, which is estimated to be about 45 mas per coordinate when reductions, including a global block adjustment, are completed later this year. Without significant systematic errors, this improved CPC2 will be a key catalogue for proper motion determinations of 9 to 11 magnitude stars in the Southern Hemisphere.

Key words: photographic astrometry; Hipparcos astrometry; proper motions; CPC2; systematic errors.

1. INTRODUCTION

The Second Cape Photographic Catalog (CPC2) is an astrometric survey of the Southern Hemisphere. A total of 276 131 stars were observed at mean epoch 1968. The first release of the CPC2 (de Vegt et al. 1993, Zacharias et al. 1992) was based on the Southern Reference Star (SRS) Catalog (Smith et al. 1990). Versions of the CPC2 for both the FK4 and FK5 system were produced. A preliminary version of the CPC2 significantly contributed to the Input Catalogue (INCA) of the Hipparcos mission. The CPC2 is also a major contributor to compiled astrometric catalogues such as the PPM–South (Bastian & Röser 1993) and the ACRS (Corbin & Urban 1990).

This paper describes the first results of a new reduction of the CPC2 data using Hipparcos reference stars (ESA 1997), as obtained from ESA for the 1982 INCA proposal 101. The CPC2 is important for deriving high precision proper motions, not only for the CPC2 stars themselves, but also for improving the proper motions of the Astrographic Catalogue (AC) stars. With the help of the CPC2, high precision reference stars for a new reduction of the AC data can be obtained. This will lead to better proper motions for the AC star and in turn will have implications for kinematical and dynamical studies of our Galaxy. The almost error free Hipparcos reference stars allow for detecting and removing systematic errors in the CPC2 data, which in turn significantly reduces systematic errors in the derived proper motions.

2. HISTORY OF THE CPC2 PROJECT

A summary of the project history is given in Table 1. Observations were made in a 4–fold overlap pattern at the Cape Observatory, South Africa. The original plan was to observe only the Cape Astrographic Catalogue Zone, which is between declination degrees −40 and −52. Because of its success, the project was extended, finally covering the entire Southern Hemisphere down to a limiting magnitude of about V=10.5.

Table 1. CPC2 project history.

1954			first plans for CPC2
1959			camera delivered
1962	–	1963	observations of zone $-40°$ to $-52°$
1966	–	1968	observations of zone $-30°$ to $-40°$
1967	–	1972	observations of all other zones
1978	–	1984	measurement of all plates at RGO
1984			publication of Cape Zone results
1985			all data at Hamburg Observatory
1987			block adjustment of Cape Zone
1990	–	1993	entire CPC2, release 1, publications
1992	–	1995	prep. for block adjustment, distortion analysis
1996	–	1997	reductions with Hipparcos stars

All plates were measured on the *Galaxy* machine at the Royal Greenwich Observatory (RGO), UK. The data were handed over to Hamburg Observatory for astrometric reductions. Details of the reductions can be found in Zacharias et al. (1992), while the history, observation and plate measuring process is described in de Vegt et al. (1993).

The CPC2 data were used for simulations (Zacharias 1992) of the block adjustment technique (Eichhorn 1960). Application of the Hamburg Block Adjustment Program Package (Zacharias 1987) to the real data showed problems with remaining systematic errors depending on the plate geometry. These field distortions are described in Zacharias (1995). A new intermediate version of the CPC2 data based on a block adjustment solution with the SRS stars was never published, because of the upcoming Hipparcos data in 1996. The final version of the CPC2 is in preparation. First results of a conventional plate adjustment with Hipparcos reference stars are shown here.

3. OBSERVATIONS

A 2–meter focal length astrograph was used for obtaining all plates. Some details of the instrument and the observations are given in Table 2. A visual spectral bandpass was used for the first time for such a photographic, astrometric project. Thus effects due to refraction and atmospheric dispersion were minimized as compared to older surveys using unfiltered blue sensitive plates.

Table 2. Some instrumental and observational details of the CPC2 project.

focal length	2090	mm
focal ratio	f/10	
field size	4.1	degree
bandpass	530 – 640	nm
exposures	2 per plate,	3 min each
overlap pattern	4–fold	= 8 images/star
number of plates	5687	used
plate centers	0° to −90°	

The measuring precision, σ_{xy} is 1.13 micrometer on average, thus 113 mas for a single image per coordinate. This precison ultimately limits the catalogue accuracy. The CPC2 release 1 catalogue precision is about 60 mas for a star coordinate. Various systematic errors could not be removed in that release due to significant errors in the reference star catalogue used for the reductions. Thus the accuracy of a CPC2 release 1 star coordinate is estimated to be on the 100 mas level plus system offsets caused by the local wobbles of the FK5 reference frame.

4. REDUCTIONS WITH HIPPARCOS STARS

As with the first release of the CPC2, the 2 exposures per plate were combined after a linear transformation. The resulting x,y data have been used for a conventional plate adjustment using only those Hipparcos stars flagged as suitable for astrometric reductions, thus excluding 'problem stars'.

4.1. Plate Solutions

A comparison of the old and new plate reduction results is given in Table 3.

Table 3. Summary of plate reduction results. A comparison is made between the release 1 solution based on SRS reference stars and preliminary results obtained with Hipparcos reference stars.

reduction with	SRS	Hipp.	
number of ref. stars/plate	14	38	
average field distortions	40	40	mas
precision of ref. stars	110	30	mas
mean sigma of plate adj.	141	≤ 90	mas
catalogue precision	60	≈ 45	mas
catalogue accuracy	≈ 100	≈ 45	mas

There are on average 2.7 times more Hipparcos than SRS stars per plate. The mean position error of a Hipparcos star at its central epoch (1991.25) is only about 1 mas. However, propagated back to the epoch of individual CPC2 plates (around 1968), the mean position error of a Hipparcos star is about 30 mas per coordinate. This is still negligible with respect to the x,y errors of the CPC2 data, which is 113 mas / $\sqrt{2}$ = 80 mas for the combined exposures on a single plate. Depending on the plate model used, an rms plate adjustment error of 87 to 91 mas has been obtained. This includes error contributions from the reference stars and the x,y errors as well as any yet unmodelled systematic errors.

The average standard error of a plate reduction using Hipparcos reference stars is a factor of 1.6 better than when the SRS catalogue was used. The SRS based field star positions contain a significant error contribution from the propagation of plate parameter errors due to the relatively poor and sparse reference stars used in the least–squares adjustment process. The Hipparcos based solution does not have this large additional random error for the field star positions. The mean catalogue position accuracy of a star in the Hipparcos based solution is very close to the limit given by the x,y precision. Furthermore, the Hipparcos based solution is much more accurate in a systematic sense (see below). The average accuracy of a CPC2 position in the final catalogue is estimated to be about 45 mas, as compared to about 100 mas in the release 1 catalogue.

4.2. Field Distortion Pattern

Figure 1 shows the residuals of the adjustment averaged in bins over the plate area. Here an 8–parameter plate model (linear plus plate tilt terms) was used with the x,y data pre–corrected for an average third order optical distortion term of 40 mas/degree^3. A

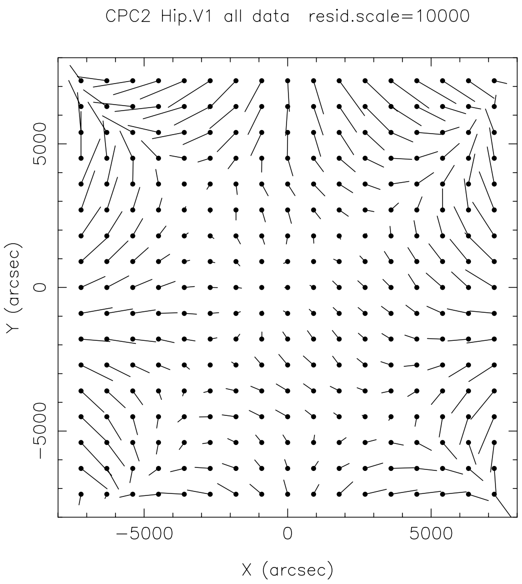

Figure 1. Field distortion pattern as obtained from the residuals of a conventional plate adjustment of all CPC2 data using Hipparcos reference stars. North is up and East to the right. The plate size is 4.07 degrees and the scale for the residuals is 10000. About 1000 individual residuals are averaged in each vector shown.

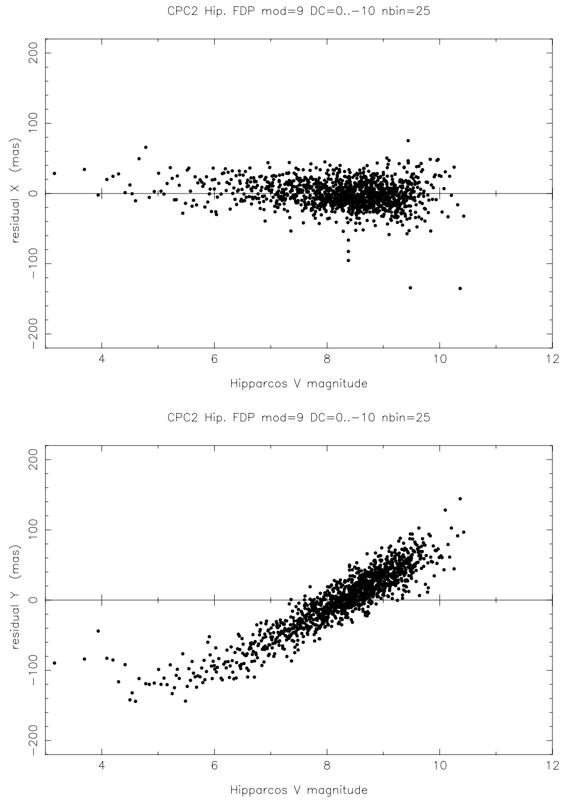

Figure 2. Systematic errors as a function of magnitude. Here the residuals of a conventional plate adjustment with Hipparcos reference stars are given for the declination zone −10 to 0 degrees. Diagrams for the x and y–component are shown (top and bottom, respectively). Each dot represents the mean over 25 individual residuals.

clear field distortion pattern (FDP) is visible. Tests with smaller grid steps revealed no additional fine structure.

Exactly the same plate model was used in the release 1 reductions using the SRS as reference star catalogue. The corresponding FDP is published in Zacharias (1995). Both diagrams are virtually identical despite the fact that very different reference star catalogues were used! This is an important result. The high precision Hipparcos stars are not required to obtain a map of these systematic errors depending on the geometry of the plate area. However, the Hipparcos stars gave the proof of this statement. Thus relatively poor and few reference stars are sufficient to obtain the FDP, providing the statistics are strong enough, i.e. there are enough x,y data with uniform systematic errors.

This is an important conclusion for future astrograph–type astrometric surveys, such as the UCAC-S project (Zacharias et al. 1997a), where a CCD detector will be used instead of photographic plates. For such future surveys the field of view will be small (only about 1 square degree in the case of the UCAC-S project), thus Tycho stars (ESA 1997) are required for a conventional plate adjustment instead of the Hipparcos stars used with photographic plates. The Tycho star positions, particularly at a future epoch, are relatively poor as compared to the x,y precision of CCD observations (Zacharias 1997, Zacharias et al. 1997b). Nevertheless the result obtained in this investigation gives confidence in the successful detection and removal of FDP–type systematic errors in CCD frame reductions using Tycho stars.

4.3. Magnitude Dependent Systematic Errors

The plate reductions for release 1 of the CPC2 revealed systematic errors as a function of magnitude between the x,y data and the reference star positions (Zacharias et al. 1992). At that time it was not obvious which part of the systematic errors were due to the photographic or reference star data, and no corrections were applied to the published CPC2 release 1.

Using the Hipparcos reference stars, very similar systematic errors were detected, indicating that the photographic data were systematically wrong. As an example, the residuals from all plate solutions with plate centers in the declination zone $-10° \leq \delta \leq 0°$ were plotted versus magnitude in Figure 2. For the y–component there is a strong magnitude equation, which is almost linear over the range of 4.5 to 10.5 magnitudes with a slope of about 40 mas/mag.

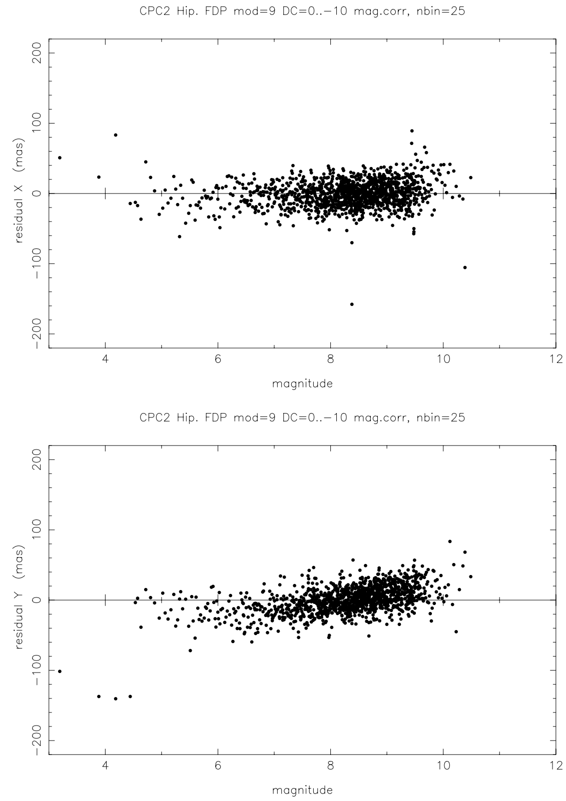

Figure 3. Same as Figure 2 but after a re–run with x,y data corrected for the systematic errors as a function of magnitude as obtained from Figure 2. The systematic errors are not fully corrected in one step. Each dot represents the mean over 25 individual residuals.

After correcting the x,y data for this systematic effect (for stars fainter than 4.5 mag), the reduction was repeated. Figure 3 shows the resulting residuals. Obviously the effect has not been fully corrected. Due to correlations, parameters used in the conventional plate adjustment 'take over' part of the systematic errors, thus Figure 2 does not show the full effect of the magnitude dependent systematic error inherent in the data. This explains the result shown in Figure 3. The additional 25 per cent systematic error can be removed by one more iteration step or by scaling the corrections to be applied by a factor of 1.25 in this case.

Figure 4 shows an example of residuals versus magnitude for the y–component on a plate by plate basis. It is possible to solve for a magnitude term on a plate by plate basis in the adjustment process. However, the scatter of individual residuals is large compared to the systematic effect. Some sort of averaging over many plates seems a better way of correcting for the magnitude dependent systematic errors. This is still work in progress. The Hipparcos data give the assurance of an almost perfect reference star catalogue to allow a proper handling of these systematic errors in the photographic data.

A previously unnoticed systematic error is shown in Figure 5. A coma term is significant in the Hipparcos based plate reductions, after pre–applied preliminary corrections for magnitude terms as a function of declination zone. The reduced level of random errors with the Hipparcos stars allowed the detection of this effect, which was invisible in the SRS based plate reduction results.

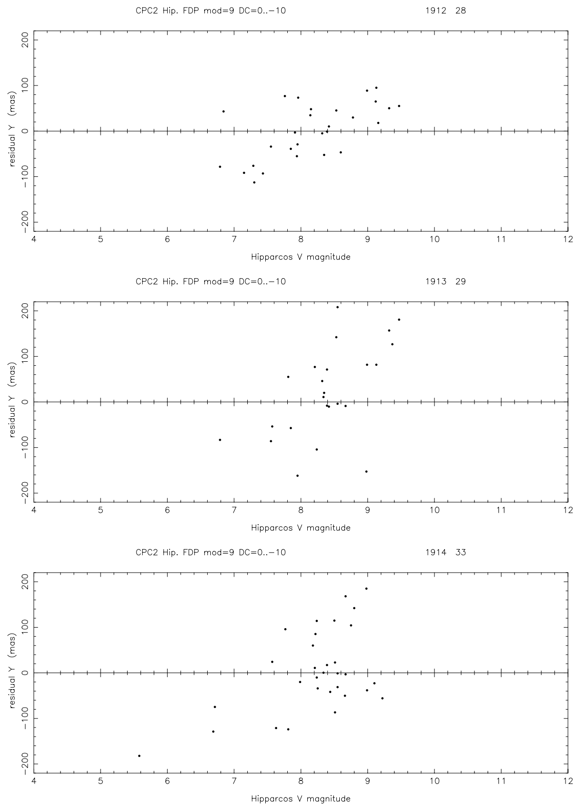

Figure 4. Individual residuals in y (declination) versus magnitude for 3 example plates, randomly selected from the −10 to 0 degree declination zone.

5. CURRENT STATUS OF REDUCTIONS

Preliminary corrections for FDP and magnitude dependent systematic errors have been applied to the x,y data. A conventional plate adjustment with Hipparcos reference stars has been made using a 9–parameter model, including linear terms, tilt terms and a free parameter for the third order optical distortion to allow for yet unmodelled variations as a function of declination zone. The resulting x,y residuals have been split up in radial and tangential components with respect to the plate center. Figure 6 shows these radial and tangential residuals as a function of the distance from the plate center. Not all systematic errors have been corrected sufficiently at this stage, wobbles with an amplitude of about 10 mas can be seen.

6. FUTURE

The publication of only one more release is planned for the CPC2 data. The first step toward this goal

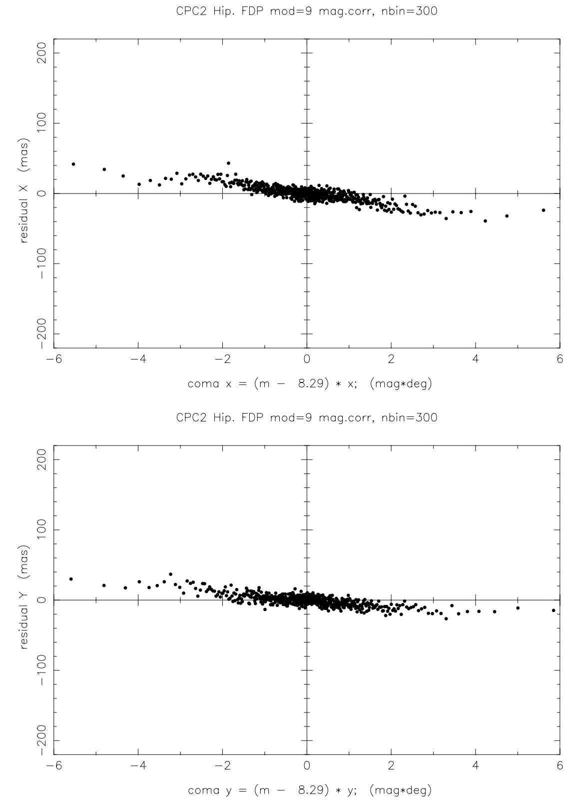

Figure 5. Coma term in the CPC2 photographic data. Residuals of x (top) and y (bottom) are plotted versus the product of magnitude and coordinate values. Each dot represents the mean over 300 individual residuals.

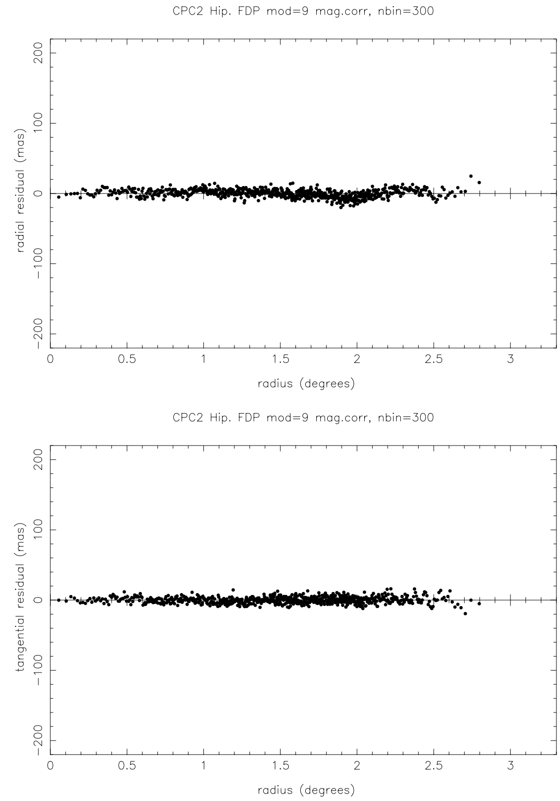

Figure 6. Radial (top) and tangential (bottom) residuals versus distance from the plate center (radius). Each dot represents the mean over 300 individual residuals. The diagrams show the results after preliminary corrections of the data for FDP and magnitude dependent systematic errors.

will be the final analysis of the systematic errors in the conventional plate adjustment process. Corrections for FDP, magnitude and coma terms will be applied and an 8–parameter plate model is likely to be used. All systematic errors seem to depend on declination zone. Finally a block adjustment of the entire data is planned to provide the release 2 catalogue. The CPC2 is most suitable for this procedure due to its 4–fold overlap pattern. However, the biggest improvement in the accuracy of the star positions has already been gained by using Hipparcos instead of SRS reference stars (see also Zacharias (1992)). The block adjustment will further reduce the errors by an estimated 5 to 10 per cent.

A distribution of the CPC2 release 2 on CD–ROM is planned. This will also include the release 1 version as well as the original x,y measures. A publication in 1998 is realistic.

The CPC2 data can be combined with the Tycho Catalogue to obtain highly accurate proper motions. The epoch difference of 19 to 29 years leads to an expected accuracy of the proper motions in the 2 to 3 mas/year range. Projected back to around 1900 the CPC2/Tycho data is able to provide a reference star catalogue with random errors less than 200 mas and nearly no systematic errors for the final reduction of the AC data in the Southern Hemisphere. The Northern Hemisphere would benefit most from a re–measurement of the AGK2 plates (de Vegt 1982), a project planned at Hamburg Observatory.

7. CONCLUSIONS

- The field distortion pattern can successfully be extracted from x,y data with relatively poor reference stars. The same result for FDP–type systematic errors has been obtained from plate adjustments using either the SRS or Hipparcos as the reference star catalogue.
- The Hipparcos reference stars allow a large reduction in random errors. The propagation of errors from the obtained adjustment parameters (plate constants) to the field star positions made up a considerable fraction of the error budget ($\approx$ 50 per cent) in the SRS based release 1 solution. The new reductions with the use of Hipparcos reference stars result in a small contribution ($\approx$ 5 to 10 per cent) for this type of error.
- The Hipparcos based solution is almost free of systematic errors. Systematic errors in the photographic data can be detected and removed much more efficiently than before.
- An additional block adjustment solution will give only a minor improvement: due to the high

accuracies of the Hipparcos star positions and large number of reference stars per plate, the conventional plate adjustment result with Hipparcos stars is already close to the limit given by the x,y data.

- Proper motions for all CPC2 stars can be obtained at least on the 2 to 3 mas/year level by combining the final CPC2 with the Tycho Catalogue and other data.
- The improved CPC2/Tycho catalogue will provide a vastly improved reference star catalogue for the final reduction of the AC data in the Southern Hemisphere.

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