Comparing 2MASS positions with UCAC

Norbert Zacharias
2002 Oct 27

1 Data input

From Rae Stiening I received an extract of the 2MASS point source catalog, which is in preparation for the final data release. The DVD1 contained star ID, positions, 3–band photometry, all with associated formal errors, of 148.5 million stars. Only sources with nearest neighbors $\geq$ 8 arcsec are included, which also have "good" astrometry and reliable 3–band photometry (J,H,Ks). The 2MASS was constructed without any input from UCAC data, thus the following is a truly external comparison.

The extended r10 run of the UCAC data was used, including survey observations obtained up to 2002 September 23. It contains more survey observations beyond the r10 run of April this year, with the same data reduction procedures applied. This position catalog, the basis for the upcoming UCAC2 release, contains 56,389,237 stars, which all have at least 2 detections. Stars with neighbors within 3 arcsec have been excluded. These UCAC data completely cover the declination range $-90° \leq \delta \leq +40°$, with some areas up to $+50°$.

Most areas up to about $+25°$ declination were observed from Cerro Tololo (CTIO), Chile, with a zenith distance up to about $+55°$. Areas further north were generally observed from the Naval Observatory Flagstaff Station (NOFS) in Arizona.

Both catalogs are on the Hipparcos system, utilizing Tycho-2 reference stars. Positions of both catalogs are for the mean epoch of their observations. Both projects observed almost at the same epoch, with the largest epoch differences being on the northern hemisphere, where 2MASS observed earlier than UCAC by about 2 years.

UCAC observations are made in a 579–643 nm bandpass, which is between V and R. The expected differential color refraction is about ± 5 mas for a zenith distance of $45°$ and extreme spectral types of B5 and M5. The positions of stars in UCAC (mostly without known color) are calculated as if they were of the average color of the reference stars (Tycho-2) in a given field of about 1 square degree.

Field distortion corrections were applied to the UCAC data based on the reference star residuals (Tycho-2). Systematic error correction of UCAC positions as a function of magnitude times x or y coordinate (CTE effect) were performed based on dedicated calibration observations (flip of the telescope) without the use of external catalog data. Large systematic errors are in the raw UCAC data mainly for the RA component (charge transfer efficiency problem of the CCD along the x–coordinate). These newly calibrated UCAC data, intended for the upcoming 2nd release, are believed to still show systematic errors on the 10 mas level, but hopefully not significantly more than that.

2 Match

No proper motions are available at this point. The comparison was performed with the given catalog positions.

All UCAC stars were taken one by one and the 2MASS data were searched for a match in position. A match distance of 0.5 arcsec was used for each coordinate ($\Delta\alpha \cos\delta$ and $\Delta\delta$). The match was based on position only without limits on photometry.

Because of the size of the files, the data was split at the equator. This is close to the split of the 2MASS observational data (CTIO vs. Arizona observations), however, is NOT the CTIO vs. NOFS split (see above). In the following "s" and "n" represents the southern and northern part of the comparison, respectively.

In the south, 25.0 million stars were matched out of the 39.4 and 81.3 million available entries from the UCAC and 2MASS data, respectively. This is only a 63% match success, likely due to the strict restrictions used for the 2MASS data extraction (only 1/3 of the available 2MASS point sources were extracted for this comparison). For the northern hemisphere, 13.2 million matches were found for 17.0 and 50.6 million input entries form UCAC and 2MASS, respectively (77% match success).

3 Results

3.1 Overall numbers

The following 2 tables give the results of the comparison over all stars, split by magnitude, for the southern and northern celestial sphere, respectively. Unit is milliarcsecond (mas).

``` 
*** southern celestial hemisphere ****  (mas)
```

UCAC	posit. diff.		std.err.		RMS diff.		number of
mag	x	y	x	y	x	y	stars
7.0	-54.4	326.2	138.9	157.1	145.9	360.3	20
7.5	-24.0	92.2	101.9	159.0	104.4	183.4	181
8.0	-9.1	15.3	98.0	114.5	98.4	115.5	3893
8.5	-10.8	3.0	89.7	100.9	90.4	100.9	18001
9.0	-11.1	1.6	84.8	96.6	85.6	96.6	36979
9.5	-8.7	-0.4	79.6	91.2	80.1	91.2	61955
10.0	-4.6	-5.1	73.6	83.5	73.7	83.6	103763
10.5	-1.3	-7.8	69.0	77.2	69.0	77.6	167884
11.0	2.4	-11.0	65.0	70.4	65.1	71.3	266881
11.5	4.4	-12.1	63.1	67.1	63.3	68.2	413208
12.0	5.3	-12.6	62.4	65.5	62.6	66.7	619702
12.5	5.7	-12.6	61.8	64.9	62.1	66.1	895112
13.0	6.0	-12.4	61.5	64.3	61.8	65.5	1241283
13.5	6.0	-12.4	61.7	64.4	61.9	65.6	1663067
14.0	6.0	-12.4	62.7	65.3	63.0	66.5	2464785
14.5	5.8	-12.2	65.7	68.0	65.9	69.1	3367006
15.0	5.5	-12.1	70.6	72.2	70.8	73.2	3829140
15.5	4.4	-12.4	78.9	79.9	79.1	80.8	4804849
16.0	3.2	-13.1	92.7	92.7	92.8	93.6	4235478
16.5	3.4	-13.6	110.0	108.9	110.1	109.8	770517
17.0	4.2	-12.9	131.3	129.4	131.3	130.0	4553

The UCAC magnitude (between V and R) is used. The magnitude bins are centered, thus the line for 9.0 includes stars of 8.75 to 9.24999... mag. The next 2 columns give the (UCAC–2MASS) position differences for $\Delta\alpha \cos\delta$ and $\Delta\delta$, respectively. The columns "std.err." give the standard error of the position differences around the mean (within the magnitude bin), i.e. the average position offset as given in the previous 2 columns has been taken out. The columns "RMS" give the straight root-mean-square position differences, thus all systematic catalog differences are included. The last column in the tables give the number of stars used.

`*** northern celestial hemisphere ****   (mas)`

UCAC mag	posit. diff. x	posit. diff. y	std.err. x	std.err. y	RMS diff. x	RMS diff. y	number of stars
7.0	-60.3	-47.7	208.2	65.6	180.4	71.7	3
7.5	2.8	-29.5	127.7	148.5	127.3	150.9	137
8.0	-0.5	-27.4	122.0	128.3	122.0	131.1	2308
8.5	0.4	-26.6	112.0	113.1	112.0	116.2	10683
9.0	-0.1	-23.8	106.0	108.0	106.0	110.6	22146
9.5	0.3	-22.5	97.5	100.0	97.5	102.5	36516
10.0	0.0	-23.5	90.7	93.2	90.7	96.1	60908
10.5	-1.3	-23.8	85.1	87.4	85.1	90.6	97733
11.0	-1.4	-23.7	80.3	81.7	80.3	85.0	155672
11.5	-2.0	-24.0	78.1	79.5	78.1	83.1	237923
12.0	-1.7	-23.8	76.8	78.6	76.9	82.1	351274
12.5	-1.8	-23.0	75.3	77.7	75.3	81.1	504639
13.0	-2.1	-22.9	73.8	76.4	73.8	79.7	693969
13.5	-2.2	-22.6	73.1	75.9	73.1	79.2	915163
14.0	-2.3	-22.4	73.0	76.0	73.1	79.3	1257034
14.5	-2.4	-22.2	74.7	77.6	74.7	80.7	1798197
15.0	-2.7	-22.2	78.7	81.5	78.8	84.4	1959792
15.5	-3.1	-22.1	86.3	88.4	86.3	91.1	2303507
16.0	-3.5	-22.0	99.0	100.0	99.0	102.4	2191623
16.5	-3.3	-21.8	114.1	114.7	114.2	116.8	616173
17.0	-1.8	-23.0	136.9	135.7	136.9	137.6	10528

3.2 Function of magnitude and declination zone

Figure 1 shows an example of the position differences ($\Delta\alpha \cos\delta$ and $\Delta\delta$) as a function of UCAC magnitude, here for the -90 to $-30°$ declination zone. One dot is the average over 4000 stars. The 11 to 16 mag range is incredibly flat, showing no magnitude equation. This result is extremely helpful for the UCAC work. Stars brighter than 11 are significantly worse. The overall offsets are very small (order 10 mas).

Taking the magnitude–binned averages of a figure like Figure 1 results in a line in the Δposition vs. mag plots. Several of these lines are shown in Figure 2, one for each declination zone. Here the full range is presented, including southern and northern data. The top diagrams are for right ascension, the bottom for declination. On the left hand side the position differences are shown, on the right hand side the corresponding standard errors (around the mean position offsets).

The position differences show a significant trend as a function of declination zone. For right ascension the offsets are small (within $\pm$ 10 mas). For declination the offsets show 2 groups: a constant -10 to -14 mas for all the southern hemisphere, and about -22 to -30 mas for the northern zones. There is a significant jump in the average position offset right at the equator. Data for stars brighter than about UCAC magnitude 8 show likely problems due to overexposure, particularly for the RA component.

The minimum for the standard errors is in the UCAC magnitude range of 11 to 14.5. Again, there is a variation with declination. The errors are smallest for the $-90°$ to $-20°$ area, with a slight preference for the -60 to -40 zone. The lowest standard errors are about 62 mas for each coordinate. Assuming an error contribution of 20 mas for the UCAC data, this gives a peak performance of the 2MASS positions of 59 mas (standard error, after average UCAC–2MASS offsets = f(mag) are taken out).

Towards the north, the standard errors increase and don't go below 70 mas. Because the mean offsets in the positions have been taken out already, this increase in the errors is a true increase in scatter, likely due to larger epoch differences in combination with unknown proper motions.

At 16th magnitude, the standard errors are about 95 to 100 mas for each coordinate. Assuming an UCAC error of 70 mas at that magnitude, I derive about 68 mas for the intrinsic 2MASS error, which is only slighly worse than at 13th UCAC magnitude.

For stars brighter than about 10.5 the errors steeply increase, for declination worse than for RA (southern zones), and even worse (but equal for RA and Dec) for the northern zones. At 9th magnitude we see errors from 90 mas (RA south) to 115 mas (both coordinates, north). Assuming an UCAC error of 30 to 40 mas here, the error budget has to be dominated by the 2MASS contribution in any case. For stars brighter than about 8th magnitude even the UCAC gets unreliable and no conclusions should be drawn here other than that we are in the overexposure range here.

3.3 Slices along right ascension and declination

Figure 3 shows position differences vs. UCAC magnitude with data split along 2 hour wide RA slices. The solid and dotted lines are for the southern and northern sky, respectively.

The data follow the general trend (e.g. average large negative $\Delta\delta$ offset), but also significant variations are seen as a function of RA. For the same RA the southern and northern data are offset as well.

Figure 4 and 5 show the position differences for the stars of the RA slices along declination, for the southern and norther part, respectively. Significant variations with location in the sky are seen. The $\Delta\delta$ differences for RA=20 to 22 h and northern declinations (Fig. 5, lower left) shows an almost periodic pattern of about 5 degrees period and a peak-to-peak amplitude of about 20 mas.

Figure 6 and 7 similarly show position differences of stars in 6 declination zones plotted along RA. The $\Delta\alpha\cos\delta$ differences show a "seasonal" pattern which is bent one way for far southern declinations, than flattens out for about -45 to $0°$ declination, and goes the other way for northern declinations.

The $\Delta\delta$ component shows a distinct change for far south declinations as a function of RA, spanning a range of over 30 mas. Sharp peaks are visible at other declination zones, for example in the -15 to -10 zone for RA=18.5 hour, and in the $+15$ to $+20$ zone for RA = 7 and 19 hours. In the latter case, these are the crossings of the galactic plane, suggesting a correlation with the density (average magnitude?) of the reference star catalog (Tycho-2).

3.4 Function of color

Figure 8 and 9 show the position differences as a function of color (UCAC r $-$ 2MASS J) for different declination zones. Each dot represents the mean over 4000 stars (from the 9.5 to 16.5 UCAC mag range). Generally there is only a small variation with color (± 5 mas), exceptions are $\Delta\alpha\cos\delta$ for the most northern zone. Off hand, I can't think of an easy explanation for this. There is also a slight slope for $\Delta\delta$ in several zones, most noticeably for -15 to -10, 0 to $+5$, and $+15$ to $+20$. This could be differential color refraction, at least for the northern zones, where UCAC observations were made from CTIO and 2MASS observations from Arizona, with extreme zenith distance differences. The slope in $\Delta\delta$ for the -15 to -10 zone (-20 to 0 mas for (r–J) from 1 to 5) can't be explained by differential color refraction.

4 Conclusions

This investigation is meant as a supplement to a similar effort by Howard McCallon (http://spider.ipac.caltech.edu/staff/hlm/2mass/catvsuc/catvsuc.html).
The 2 investigations agree, showing slightly different aspects.

This is a truly external position comparison, showing generally only very small systematic differences (on the 10 mas level) with the most noticeable exception of an about -25 mas offset in right ascension (UCAC – 2MASS) for declinations north of the equator. The largest epoch differences in the entire comparison are for northern declinations. More conclusive results should be obtained in the future by using proper motions (e.g. USNO B).

The standard error of 2MASS positions show a minimum around 60 to 65 mas (each coordinate) for 11 to 14.5 mag (UCAC) stars in the southern hemisphere, getting slightly worse (70 mas) at 16th UCAC magnitude, with the assumption of 70 mas UCAC positional errors. Thus at the faint end of UCAC (16th mag) the positional accuracy of both catalogs are about equal.

The fact that the (average offset = f(mag) corrected) results are the same for both coordinates leads to the conclusion that variations in the external RMS differences for both coordinates are dominated by the mean offsets, which vary with declination zone. However, the intrinsic precisions for both coordinates seem to be very similar.

Overexposure effects appear around UCAC magnitude 10, with large systematic differences (order 100 mas or more) showing at 8th magnitude. Systematic differences in the 8 to 10th magnitude range are likely caused by 2MASS data.

Variations as a function of the location in the sky can be larger (20 mas level). There seems to be a "seasonal" variation (function of RA) which could be correlated with the density of reference stars (galactic latitude).

Overall the agreement of the 2 catalogs is extremely good, showing small systematic position differences (typically 10, up to 25 mas) and confirming 2MASS positions to be on the 60 to 70 mas level for the 11 to 16 UCAC mag range.

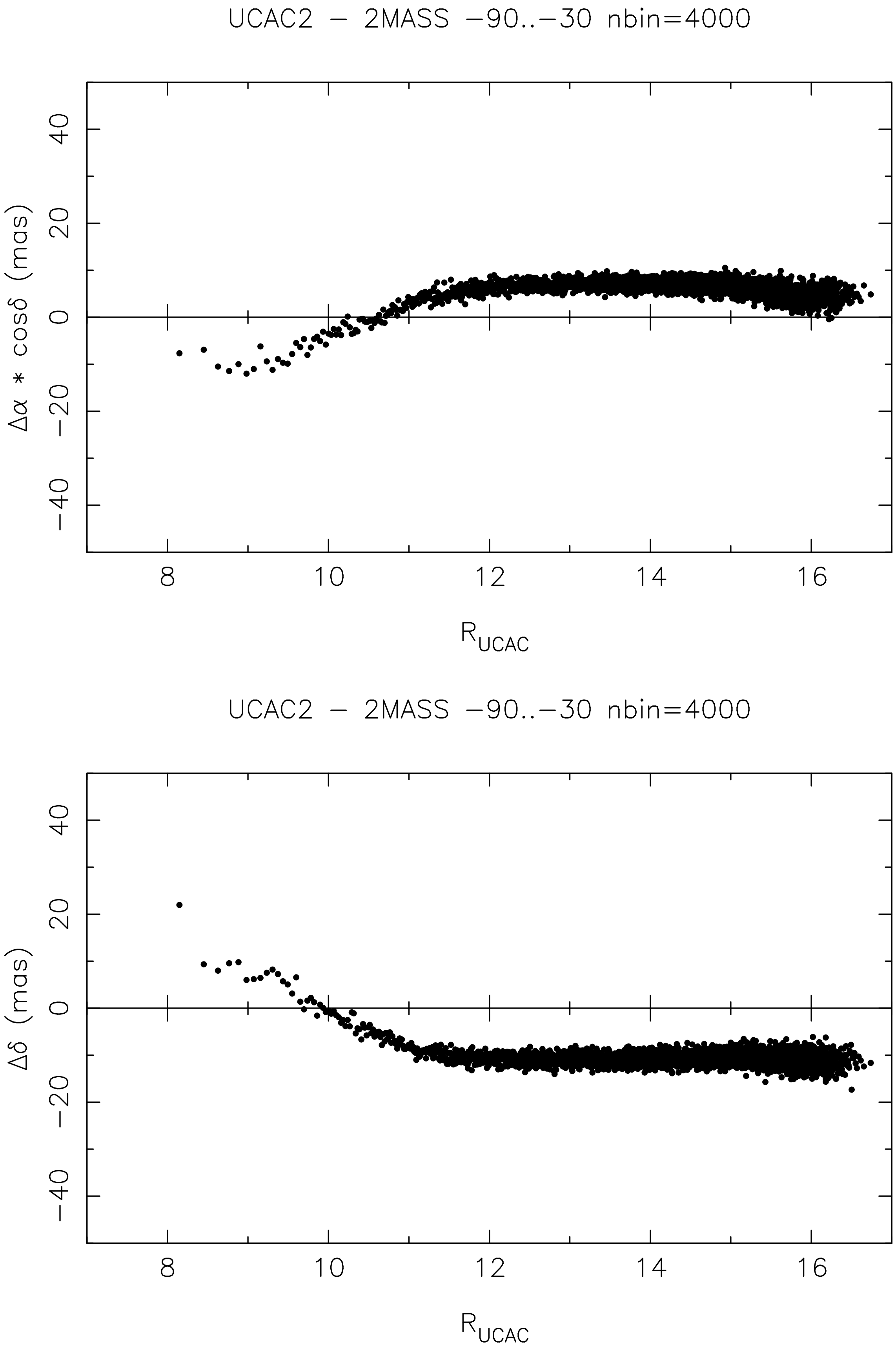

Figure 1: UCAC–2MASS position differences as a function of magnitude for the $-90^\circ \leq \delta \leq -30^\circ$ zone.

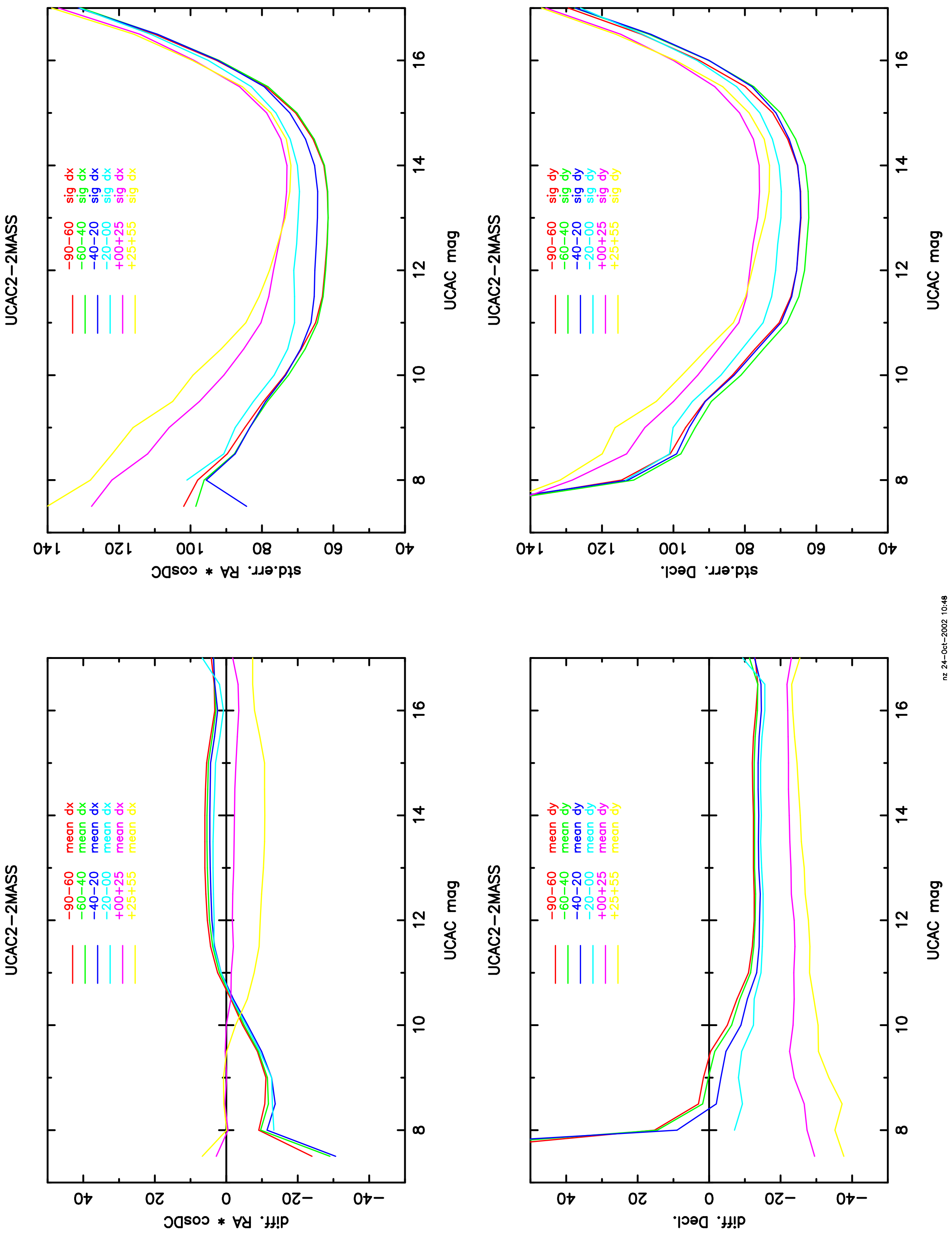

Figure 2: Average UCAC–2MASS position differences as a function of magnitude for all declination zones.

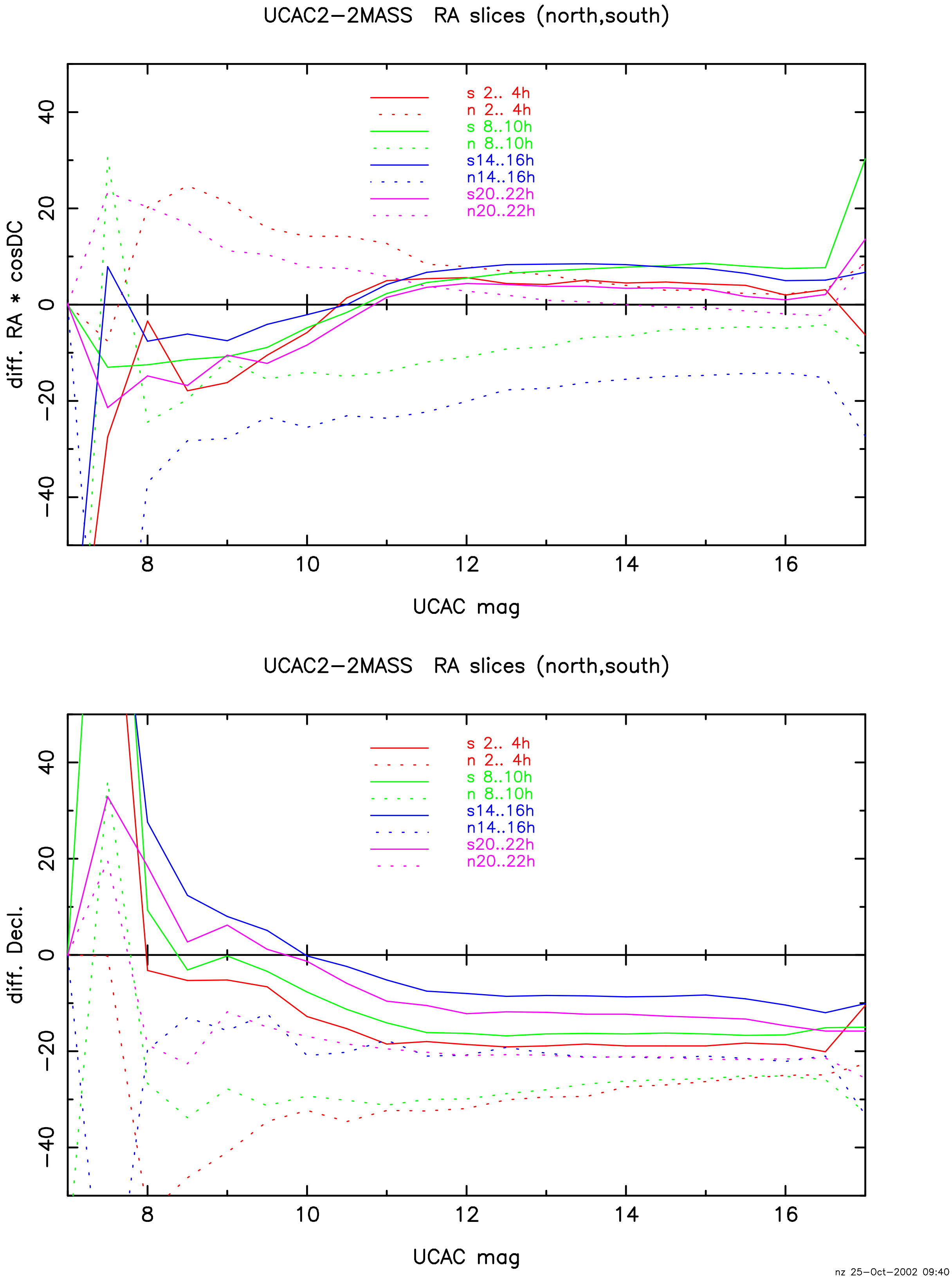

Figure 3: Average UCAC–2MASS position differences as a function of magnitude for slices along right ascension. Solid and dotted lines are for the southern and northern declinations, respectively.

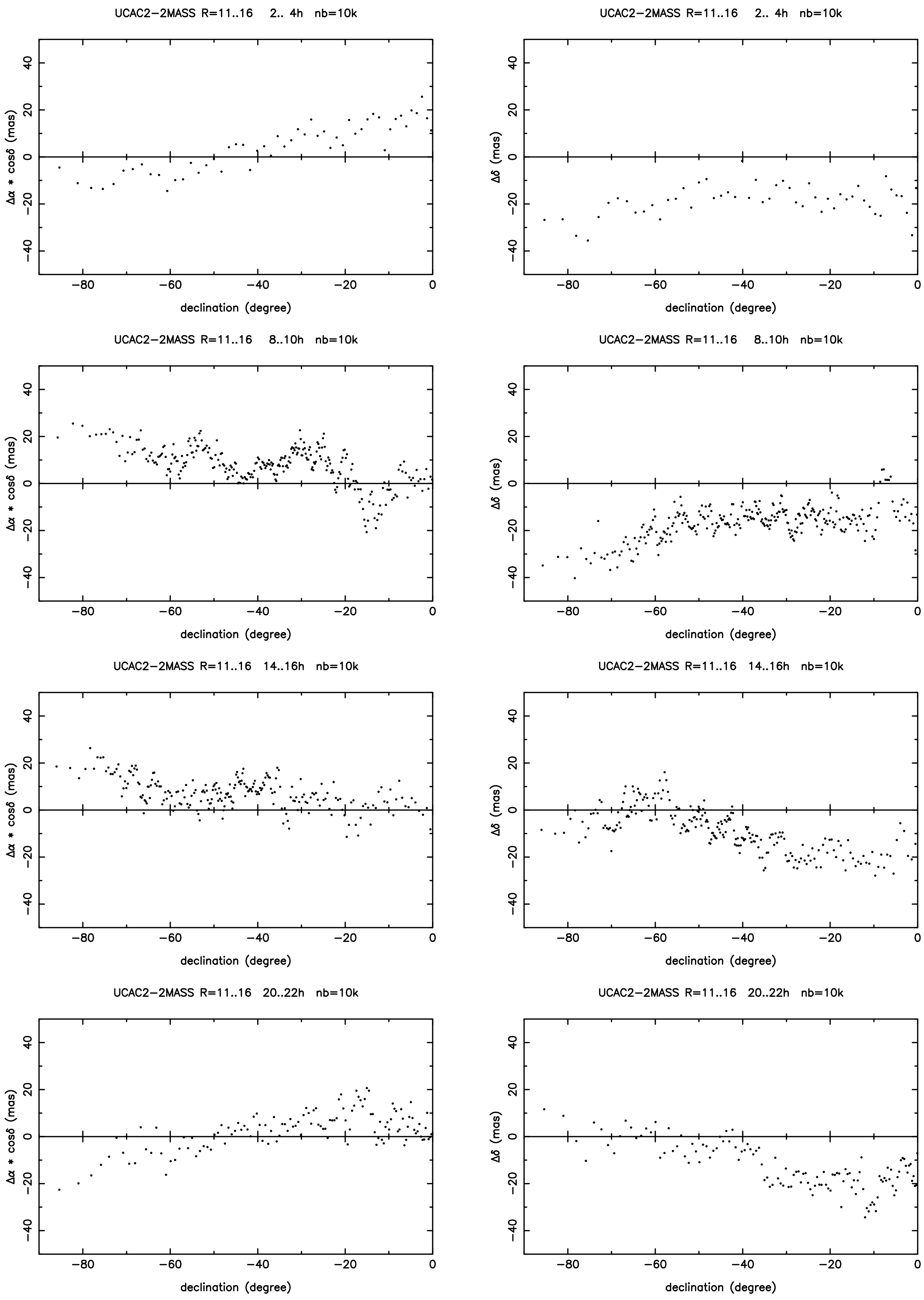

Figure 4: UCAC–2MASS position differences as a function of declination for 4 slices along RA (southern hemisphere). One dot is the average over 10,000 stars.

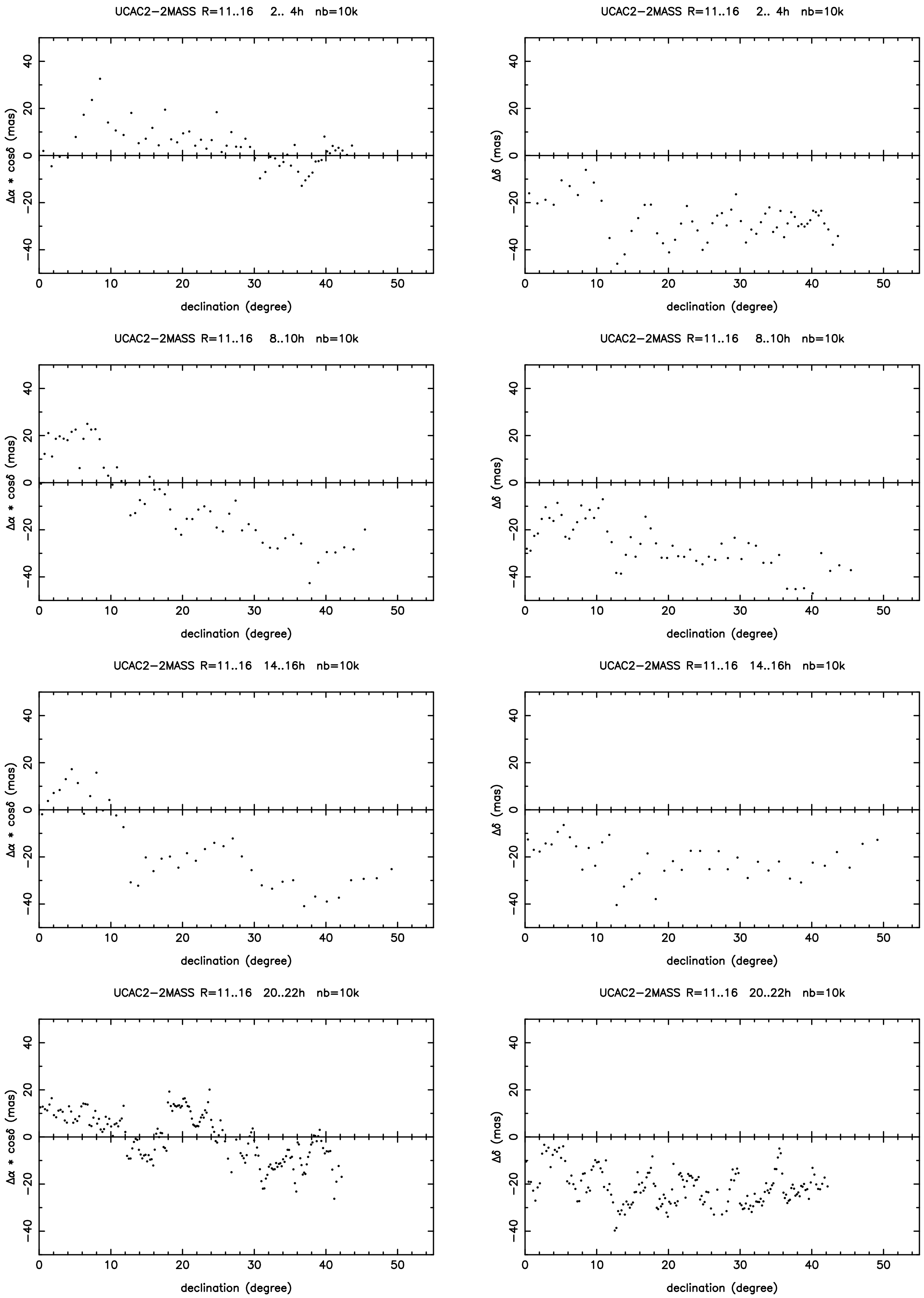

Figure 5: Same as before, for northern declinations.

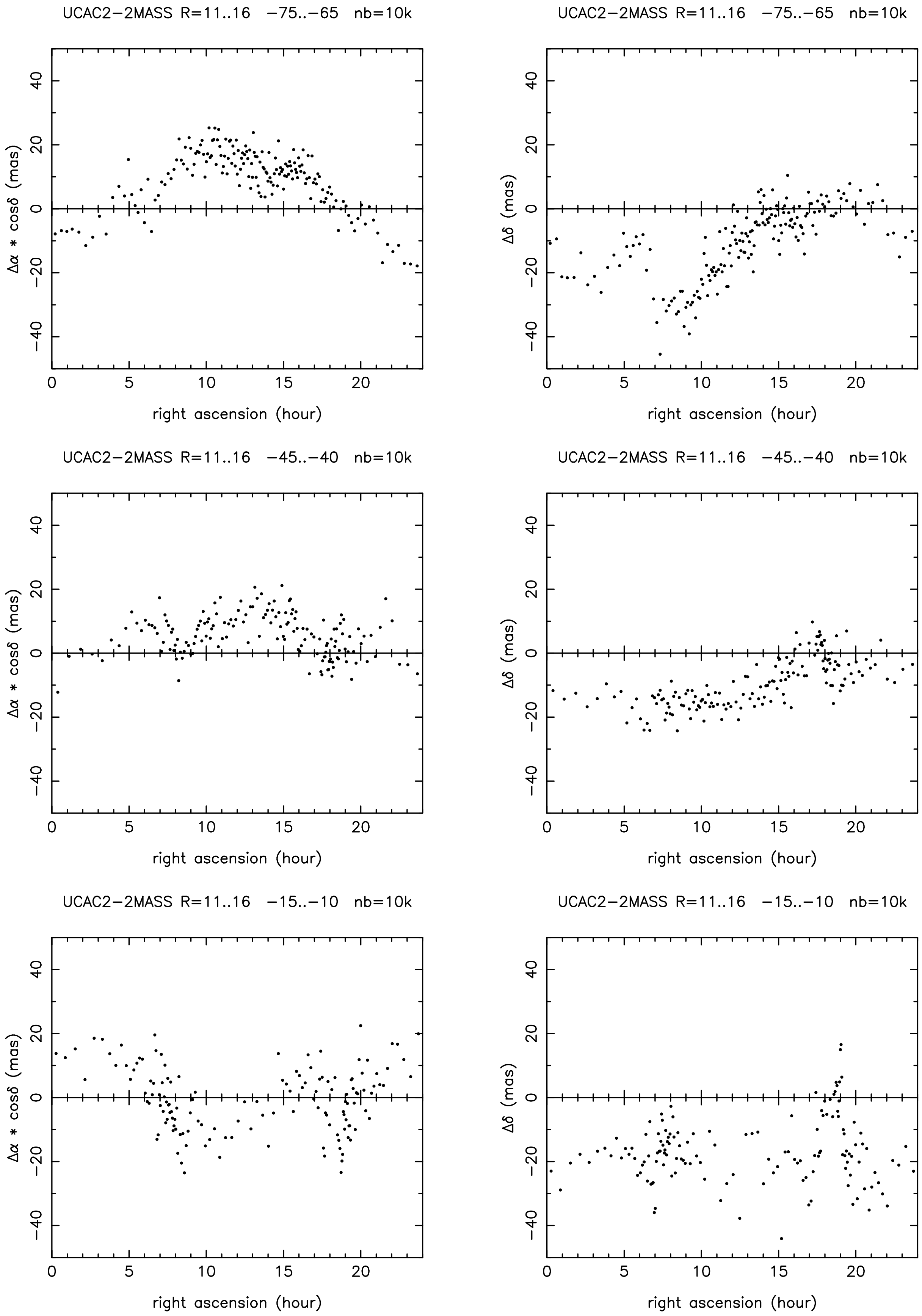

Figure 6: UCAC–2MASS position differences as a function of right ascension for 3 declination zones in the south.

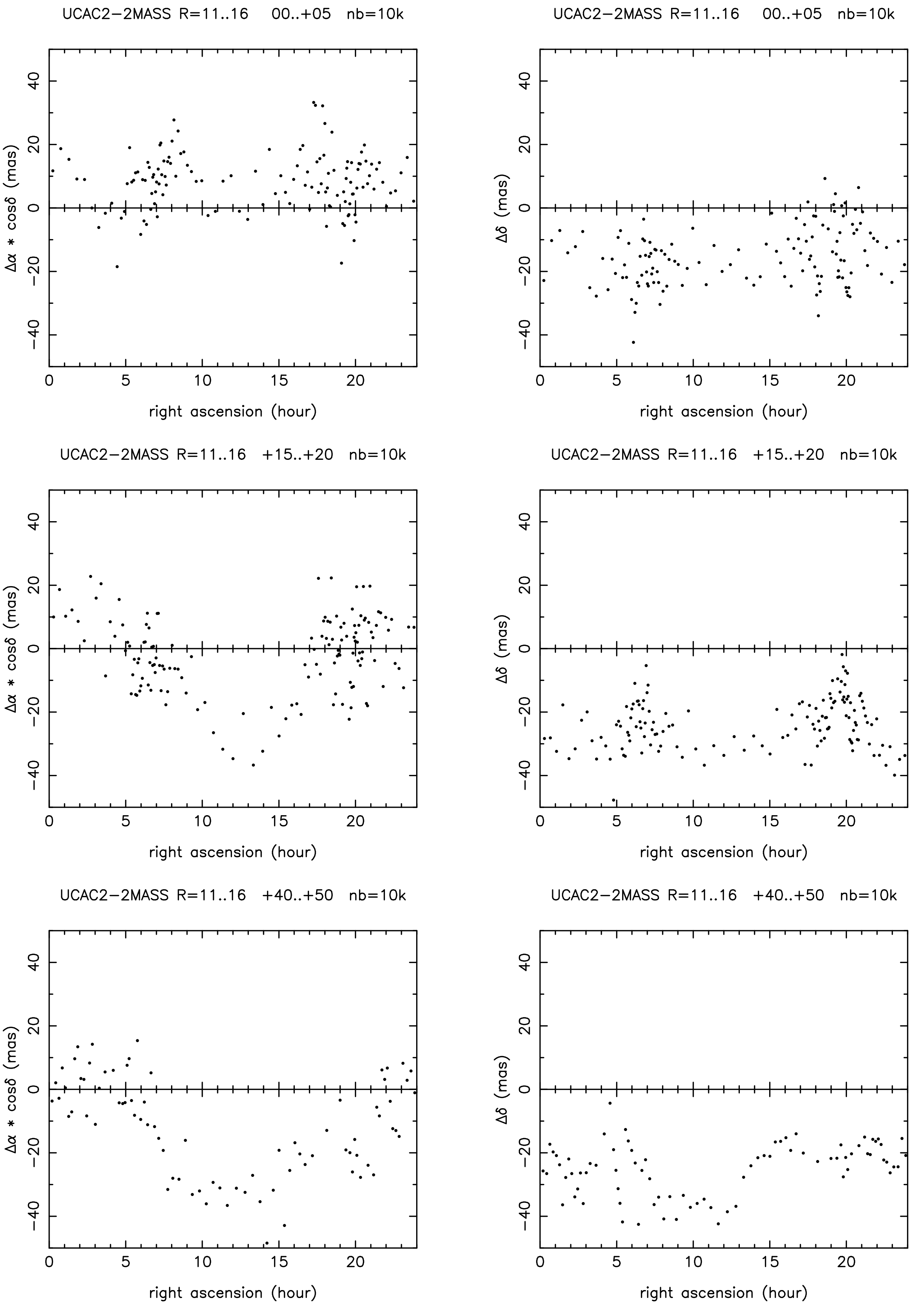

Figure 7: Same as before for 3 northern declination zones.

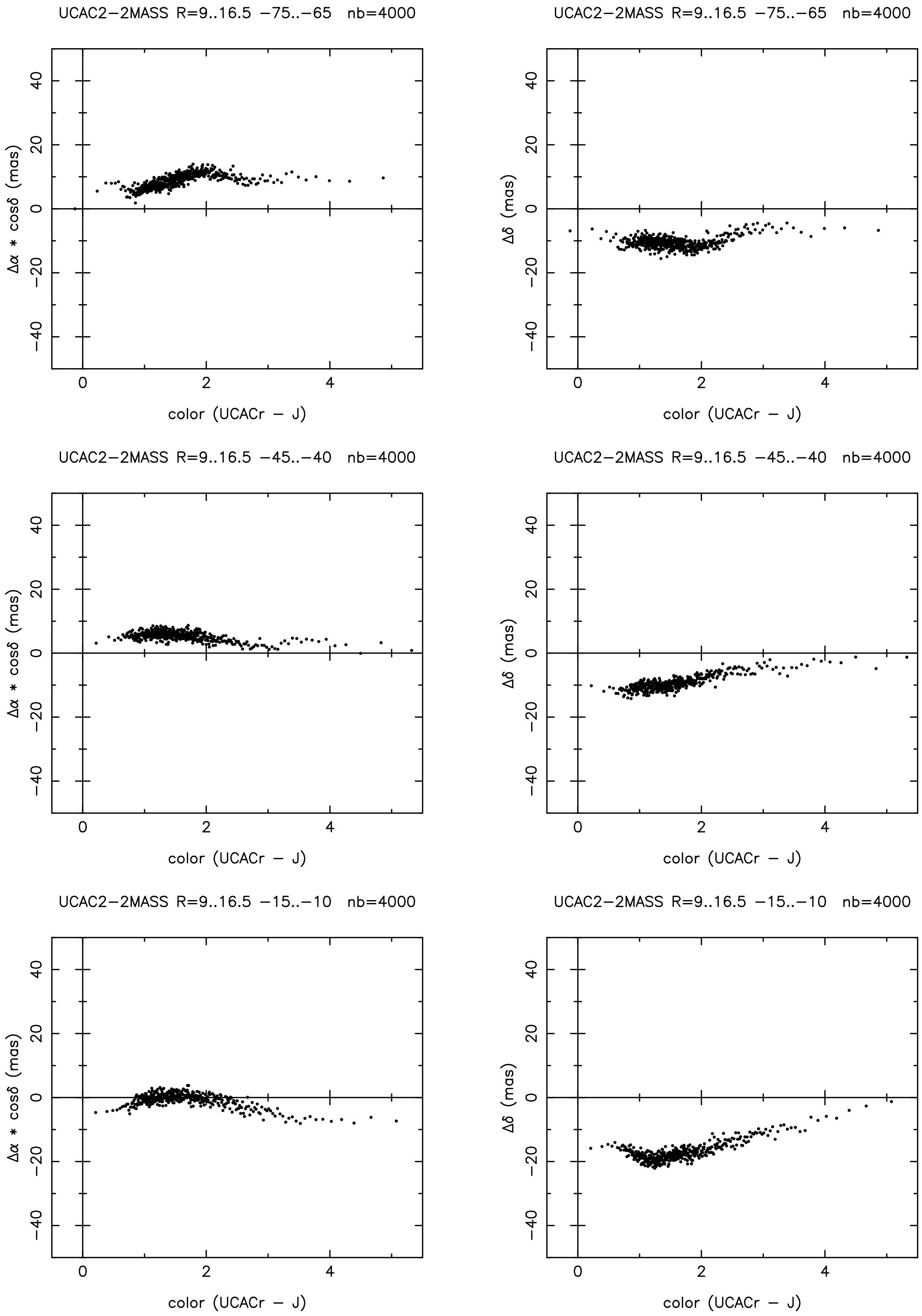

Figure 8: UCAC–2MASS position differences as a function of color (UCAC mag - 2MASS J mag) for 3 declination zones in the south.

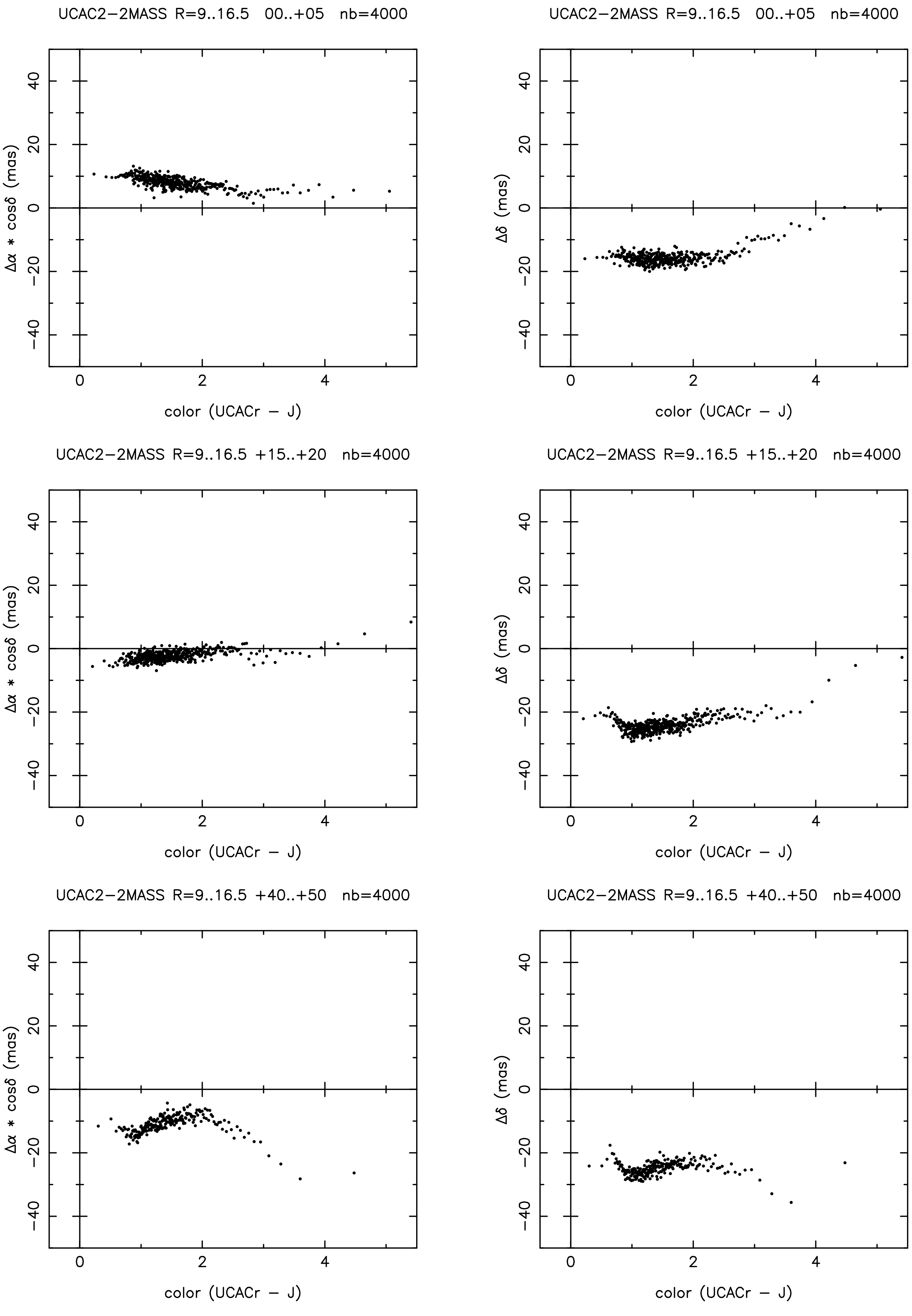

Figure 9: Same as before for 3 zones in the north.