Calibration of WFCAM data from 2MASS: an investigation and implications for observing strategy

Authors: Simon Hodgkin, Mike Irwin, Paul Hewett

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Abstract

This report considers the photometric calibration of the WFCAM camera from the 2MASS point-source catalogue. We analyse photometry of the UKIRT faint standards measured on 20 photometric nights. We conclude that a calibration based on 2MASS meets the UKIDSS requirements for photometric accuracy.

1 Introduction

Currently, observations with WFCAM are interspersed, approximately hourly, with observations of UKIRT faint standard stars[1]. There is growing evidence to suggest that the 2MASS survey may offer an alternative route to calibration that is at least as good as one based on the UKIRT faint standards and reaches the specified UKIDSS survey goals of 2% photometric accuracy.

Nikolaev et al. (2000) claim that the 2MASS all-sky point-source catalogue has photometry that is globally consistent to $\sim 1\%$. In Figure 7 of Nikolaev et al., the scatter in the differences between 2MASS and Persson/UKIRT standards is ± 0.02 mag, which includes some intrinsic scatter due to errors in the primary standards.

In this report, We address how well we can calibrate WFCAM images from 2MASS data alone. In particular, we attempt to tackle the follwing questions:

- On photometric nights, how well can we calibrate the photometry: both (i) using a 'whole night' solution and (ii) calibrating each frame using the 2MASS stars within that frame – a 'by frame' calibration.
- Can we confirm the quality of the UKIRT Faint Standards and their calibration in the WFCAM system ?
- Do we need to observe standard fields in non-photometric conditions ?
- Can we reduce the frequency with which we observe standard fields ? Do we need to observe them at all ?

Two other questions we do not address in this report, but will be tackled in the immediate future are: How well can we calibrate photometry from 2MASS taken in non-photometric conditions? How well can we calibrate the Z and Y filters from 2MASS? For now, we assume that the transformation from JHK(2MASS) to Y and Z ought to be stable, and it follows that if we can calibrate J, H and K from 2MASS, then Y and Z calibration is also achievable.

There are still some remaining issues regarding spatial systematics and their possible variations as a function of time that need further work. However, since these can be assessed and quantified directly from 2MASS residuals they do not directly impact decisions on policies for observing standards.

We conclude this report with a statement to JAC and the UKIDSS community on the feasibility of 2MASS as a reference for photometric calibration. We also make a recommendation for what we feel the minimum calibration observing strategy should be for WFCAM.

[1] http://www.jach.hawaii.edu/UKIRT/astronomy/calib/phot_cal/fs_izjhklm.dat

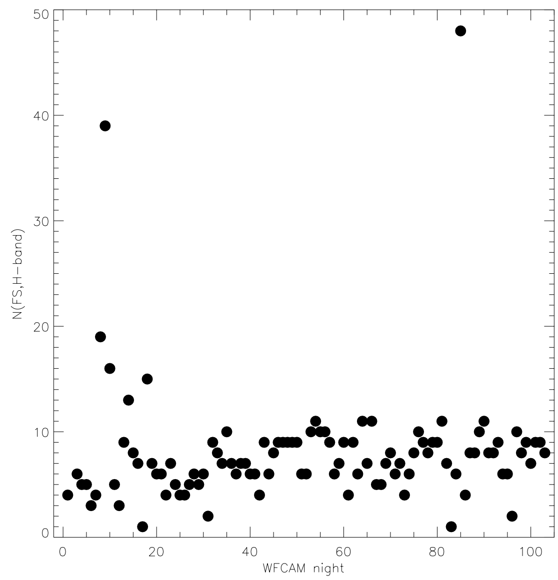

Figure 1: The number of H-band UKIRT FS stars measured on each night with WFCAM data processed to date by CASU.

2 Current observing strategy

We are currently observing between 5 and 10 UKIRT FS stars per night. Given that the average night is some 11 hours (between March and October, the dataset under analysis), we are observing standards every 1–2 hours (see Figure 1). Hourly calibration adds an overhead to WFCAM observing. Members of UKIDSS have questioned the need for hourly calibration fields, especially during non-photometric conditions. The elapsed time to measure one standard field in YZJHK filters is approximately 7 mins, of which some 75 seconds is spent taking dark frames. This 7 mins does not include slew time to reach the standard field. Without performing a detailed analysis of the timings, it looks like we are spending some 10 mins out of every 1–2 hours on standard fields, i.e. 8–17% of the avilable time. Typically a focus is also performed when the telescope slews to a standard field.

3 Calibration from 2MASS

Within routine CASU processing, a zeropoint is first derived for each frame by comparison with objects in the 2MASS PSC. The photometry for each 2MASS source is transformed into the WFCAM system using the colour terms[2], and corrected to account for the radial varitaion in plate-scale (objects at the corners of the array appear $\sim 1.5\%$ brighter than if they were at the rotator centre[3]. MAGZPT is the median difference between the aperture-corrected magnitude (APCOR3: 1 arcsecond radius aperture) and the corrected 2MASS magnitude for all 2MASS sources (with $\sigma_{J2MASS} \leq 0.1$, $\sigma_{H2MASS} \leq 0.1$, $\sigma_{K2MASS} \leq 0.1$), corrected for extinction (using a default extinction of 0.05 mags per unit airmass, assumed for all nights and all filters). MAGZPT is averaged over all four chips, i.e. has a single value per pointing. The nightly zeropoint for each filter is simply the median over all these per-

[2]http://www.ast.cam.ac.uk/vdfs/docs/reports/sv/index.html
[3]http://www.ast.cam.ac.uk/vdfs/docs/reports/wfcam_photcal_report/index.html

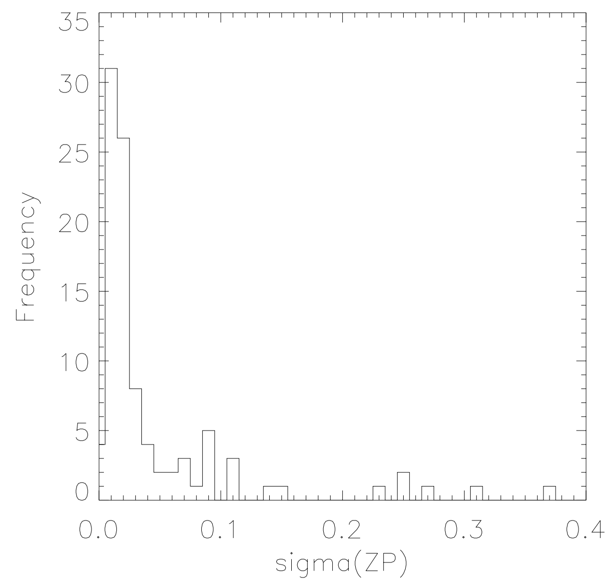

Figure 2: A histogram of the frequencey of photometric nights observed with WFCAM as measured by the standard deviation in the zeropoints for the nights. For each night we count the maximum of σ_J, σ_H, and σ_K. The entire sample comprise 103 nights of data measured in semesters 05A and 05B.

frame measurements. Tests using a larger aperture (4 arcsecond diameter) for the calculation of the zeropoint show no difference.

19 photometric nights were identified by visual examination of the DQC plots[4] from a total sample of 103 nights. A number of frames, identified by isolated significantly discrepant zeropoints in a plot of MAGZPT versus time, were found to be of poor quality, and were rejected from further analysis. Typically they show streaking (the telescope was moving during the exposure), or other artefacts. The photometric zeropoints for these nights all have $\sigma \leq 0.03$ mag (derived from the median absolute deviation), see Figure 2.

We restrict the analysis to a study of the UKIRT Faint Standards measured on these 19 nights. In summary, the data comprise 600 images (catalogues) in J, H and K filters spread over 19 nights containing 46 unique standard stars. The UFTI standards have published photometric errors in the range 0.01–0.02 mag for most stars.

3.1 By-night versus by-frame calibration

In Figures 3, 4 and 5 we plot the difference in magnitude for each observation of a UKIRT faint standard calibrated by-frame and by-night, i.e. mag(by-frame)–mag(by-night). This is therefore independent of the UFTI photometry and can be used to ascertain the quality of the data sample. Note that we always plot against J-band magnitude (rather than J, H and K) to facilitate comparison between the figures.

These figures show the following:

1. The RMS scatter in the per-frame vs per-night calibrations is around 1% in J, 1.5% in H and 2% in K. It's not clear why the scatter should be larger at K than J.

[4] http://apm15.ast.cam.ac.uk/wfcam/

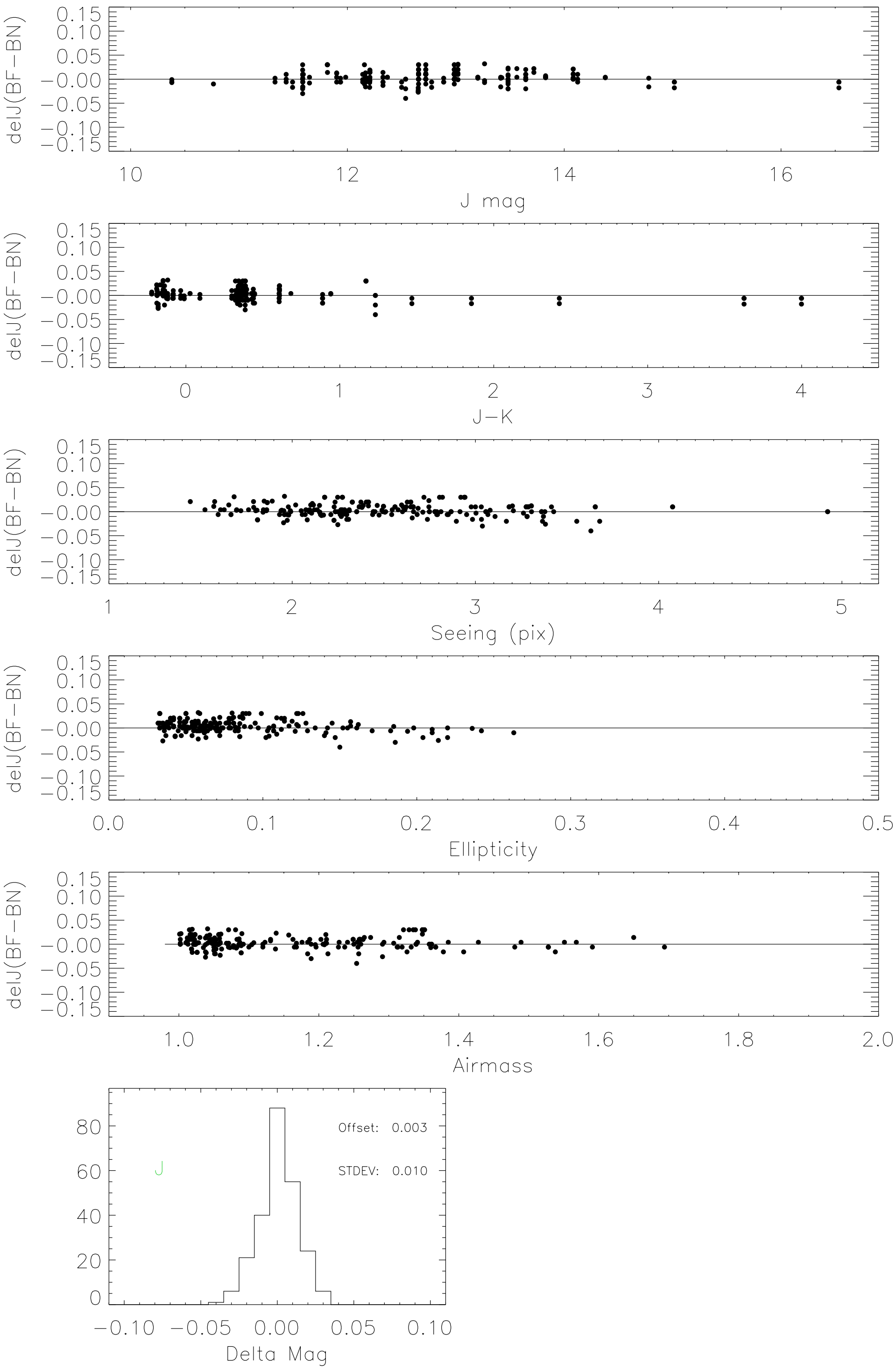

Figure 3: J-band Δmag, mag(by-frame)-mag(by-night), for UKIRT FS stars, versus J(UFTI), J-K(UFTI), seeing, ellipticity, and airmass.The histograms at the bottom collapse the data along the Y-axis.

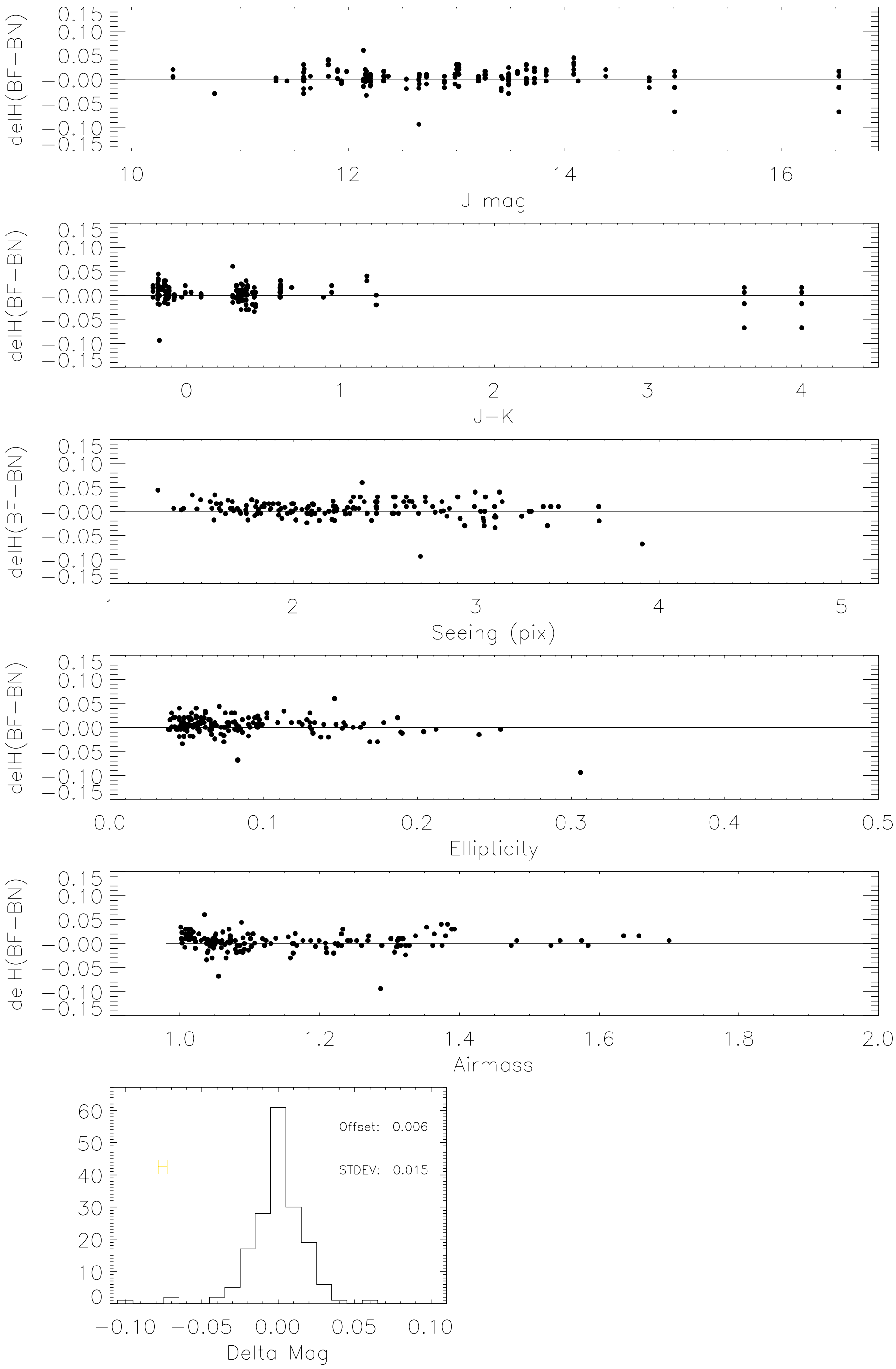

Figure 4: H-band Δmag, mag(by-frame)-mag(by-night), for UKIRT FS stars, versus J(UFTI), J-K(UFTI), seeing, ellipticity, and airmass.The histograms at the bottom collapse the data along the Y-axis.

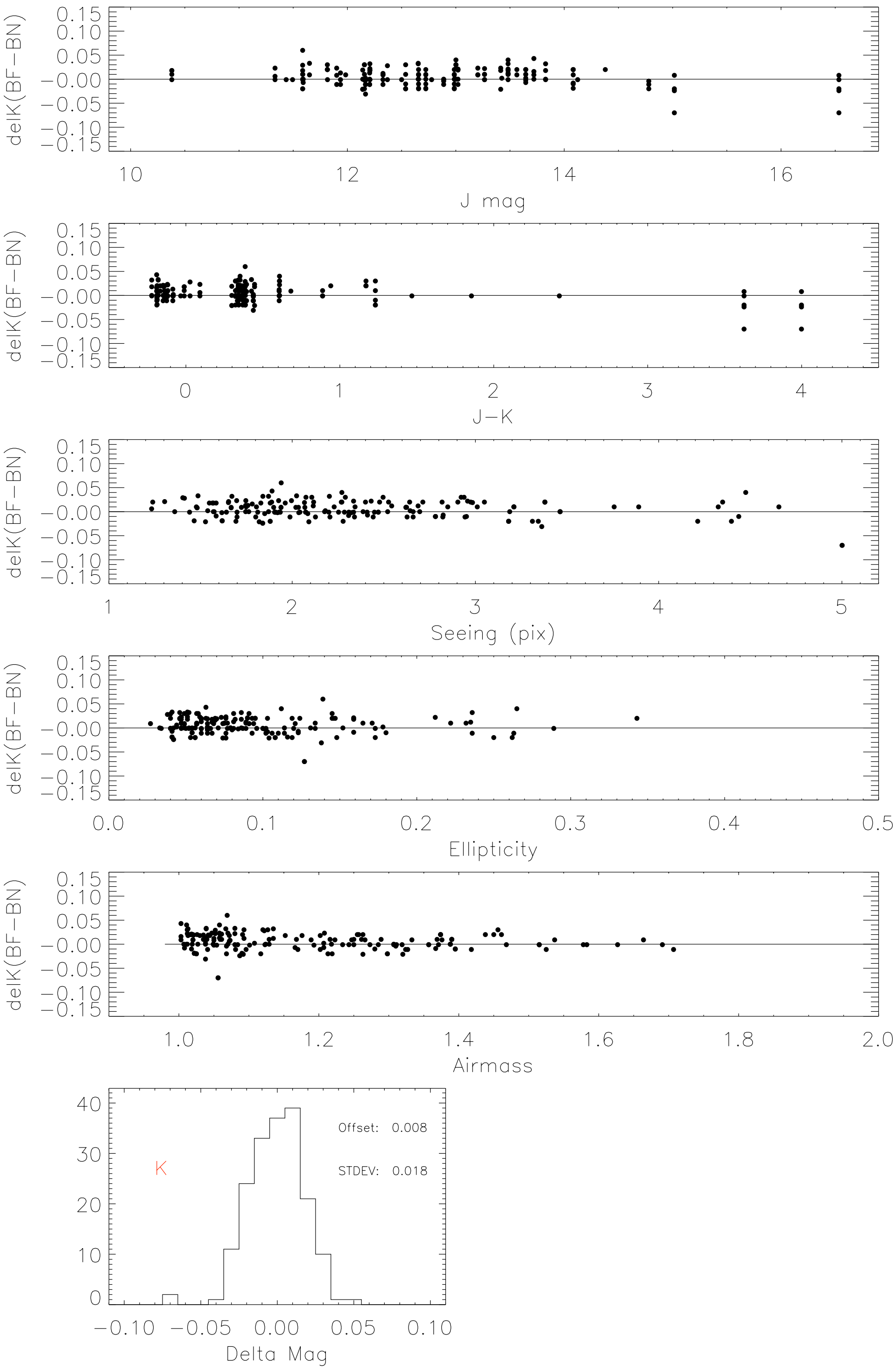

Figure 5: K-band Δmag, mag(by-frame)-mag(by-night), for UKIRT FS stars, versus J(UFTI), J-K(UFTI), seeing, ellipticity, and airmass.The histograms at the bottom collapse the data along the Y-axis.

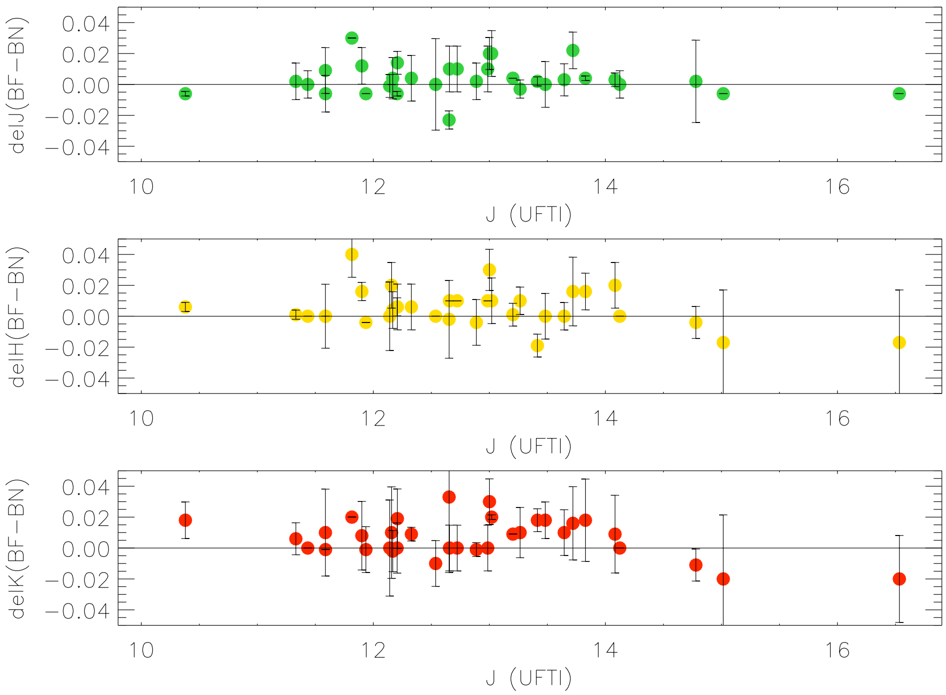

Figure 6: Median Δmag, mag(by-frame)–mag(by-night) plotted as a function of J(UFTI).

2. There are no signifcant trends between the different calibrations as a function of seeing, ellipticity, airmass, and the magnitude and colour of the faint standard. A slight correlation between Δmag and seeing may be visible in J.

3. The lack of a residual trend with airmass in any filter suggests that the approximation that extinction=0.05 mags/airmass in each filter is reasonable on photometric nights, even for observations at high airmass (≤ 1.7).

4. Most of the UKIRT faint standards are not significantly offset between the per-frame and per-night calibrations.

The last point (above) is important. If the stars in a field containing a UKIRT FS star were systematically off in the 2MASS system with respect to the global calibration, then this would manifest itself as a shift in the measurements of that FS star. In Figure 6, we plot the offsets for each UKIRT faint standard star. The offset is the median over all measurements, the error bars in the plot are a robust estimate of the standard deviation (derived from the median of the absolute deviation). This diagram clearly illustrates the quality of the 2MASS calibration. There are very few data points with a systematic error larger than 2% confirming that the 2MASS global systematics are close to the claimed accuracy. For interest, the standard deviations of these distributions are $\sigma_J = 0.004, \sigma_H = 0.006, \sigma_K = 0.009$, which agrees well with the Nikolaev et al. accuracy of 1%.

3.2 Comparison with UFTI measurements

In Figures 7, 8 and 9 we plot the differences between the 2MASS calibrate magnitudes and the UFTI magnitudes for the UKIRT Faint Standards. We show the by-night and by-frame calilbrations on the same plots.

We make the following observations:

1. The per-frame calibration achieves 1σ errors of 2% for the UFTI standard stars.
2. The per-night calibration is slightly poorer, with 1-sigma errors of 2.5%. This slightly increased scatter could have a number of causes: (i) non-photometric behaviour within apparently photometric nights, (ii) residual contamination of the sample of images by some with trailing or other image quality issues.
3. The J-band calibration has no offset with respect to the UFTI system. There is no obvious trend with J-band magnitude, seeing, ellipticity or airmass. There is a hint that there may be a residual colour term in the second panel. Alternatively, looking at the first panel, we may actually be seeing small shifts between our measurements and the UFTI photometry on a star by-star basis. We note that the UFTI standards have quoted errors of around 1–2% and typically 2–4 measurements per star.
4. The H-band calibration is systematically off by 1%. We suggest that this is caused by a minor 1% error in the correction applied to the 2MASS stars (currently there is an H-band, colour-independent offset of 4% applied, this should probably be reduced to 3%)[5]. Again we see no obvious trend with colour, but there are systematic shifts between the stars.
5. In the K-band we see no systematic offset nor colour-dependent trend. There are significant offsets in some of the UKIRT faint stanards.

In summary, this preliminary comparison with UFTI indicates that on photometric nights, a 2MASS calilbration can be used to calibrate WFCAM observations measure in J, H and K filters into the UFTI(MKO) system to 2%. This is very like the level of agreement found by Nikolaev et al., and as with their analysis, our analysis may be limited by errors in the fiducial measurements of the standard stars. In the next section we attempt to minimize these effects and see if we can do better than 2%.

4 Repeatability of fiducial stars

In the previous section, we found that there are offsets between the published UFTI(MKO) magnitudes for UKIRT faint standards, and those we derived from an analysis based on observations of 2MASS stars using WFCAM(MKO).

In Figure 10 we plot the median Δmag for each star as a function of J-band magnitude to highlight this effect. Figure 10 should be compared to Figure 6 where the differences between the by-frame and by-night calibrations for the same stars are plotted. If an object was discrepent in Figure 10 because the individual frames were poorly calibrated then it should also be offset in Figure 6, for example if the frames were measured in non-photometric conditions, or if the 2MASS calibration for these fields was not in agreement with the global solution. This is not the case, and Figure 6 shows that we have found intrinsic differences between the WFCAM(MKO) and published UFTI(MKO) magnitudes for a number of stars. Further investigation is required before we can comment on the causes of these differences.

In order to remove this effect from our analysis, and to examine the repeatability of the measurements of a set of fiducial starss, we corrected the magnitudes of the faint standards to minimise the dispersion in the WFCAM(MKO) system. UFTI J, H and K magnitudes

[5] http://www.ast.cam.ac.uk/vdfs/docs/reports/sv/index.html

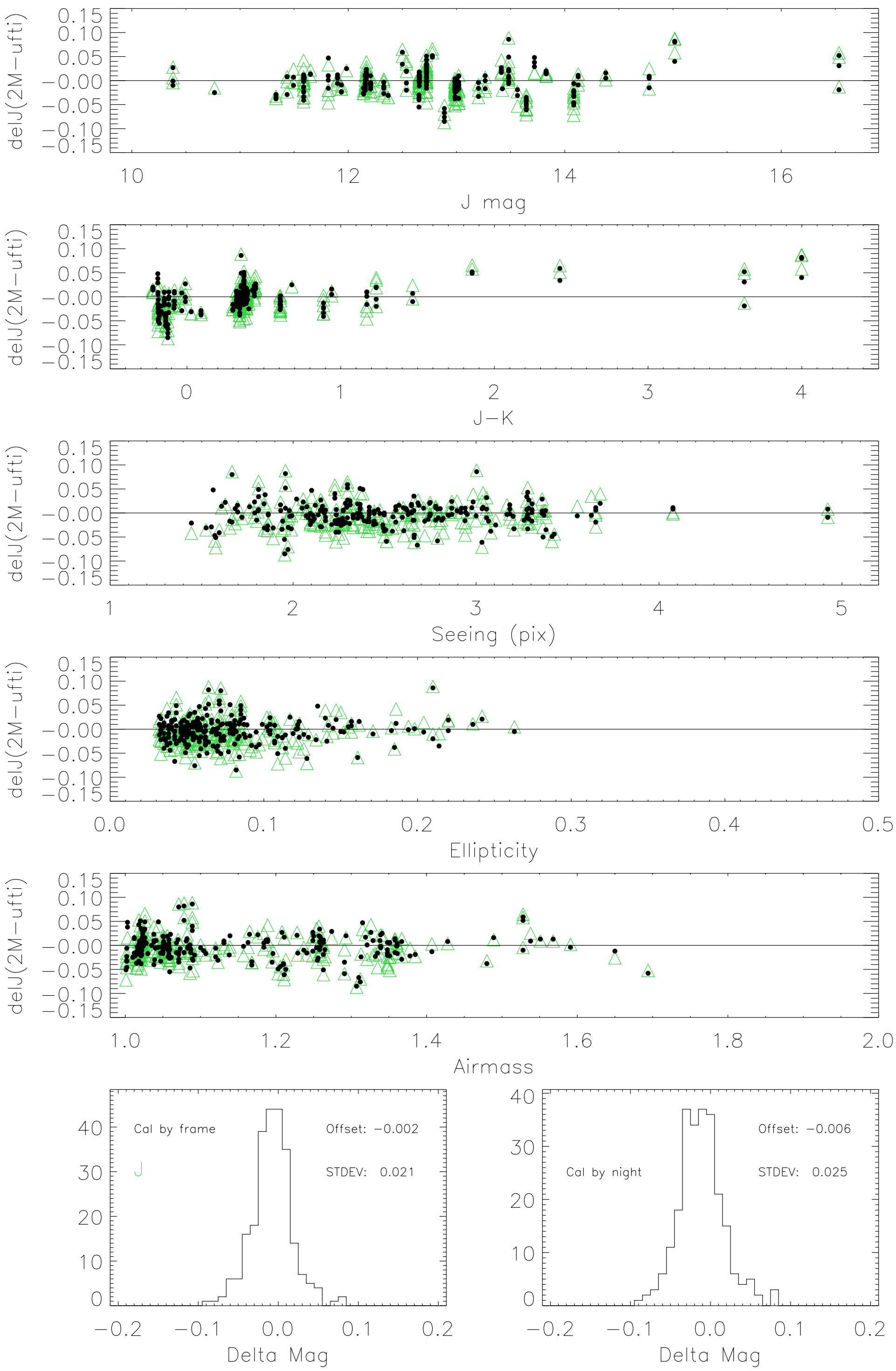

Figure 7: J-band Δmag (2MASS calibration–UFTI) for UKIRT faint standard stars observed with WFCAM. Measurements calibrated with a per-frame zeropoint, MAGZPT, are black dots, while measurements calibrated with a by-night zeropoint are green triangles. The histograms at the bottom collapse the data along the Y-axis for the by-frame (LHS) and by-night (RHS) calibrations.

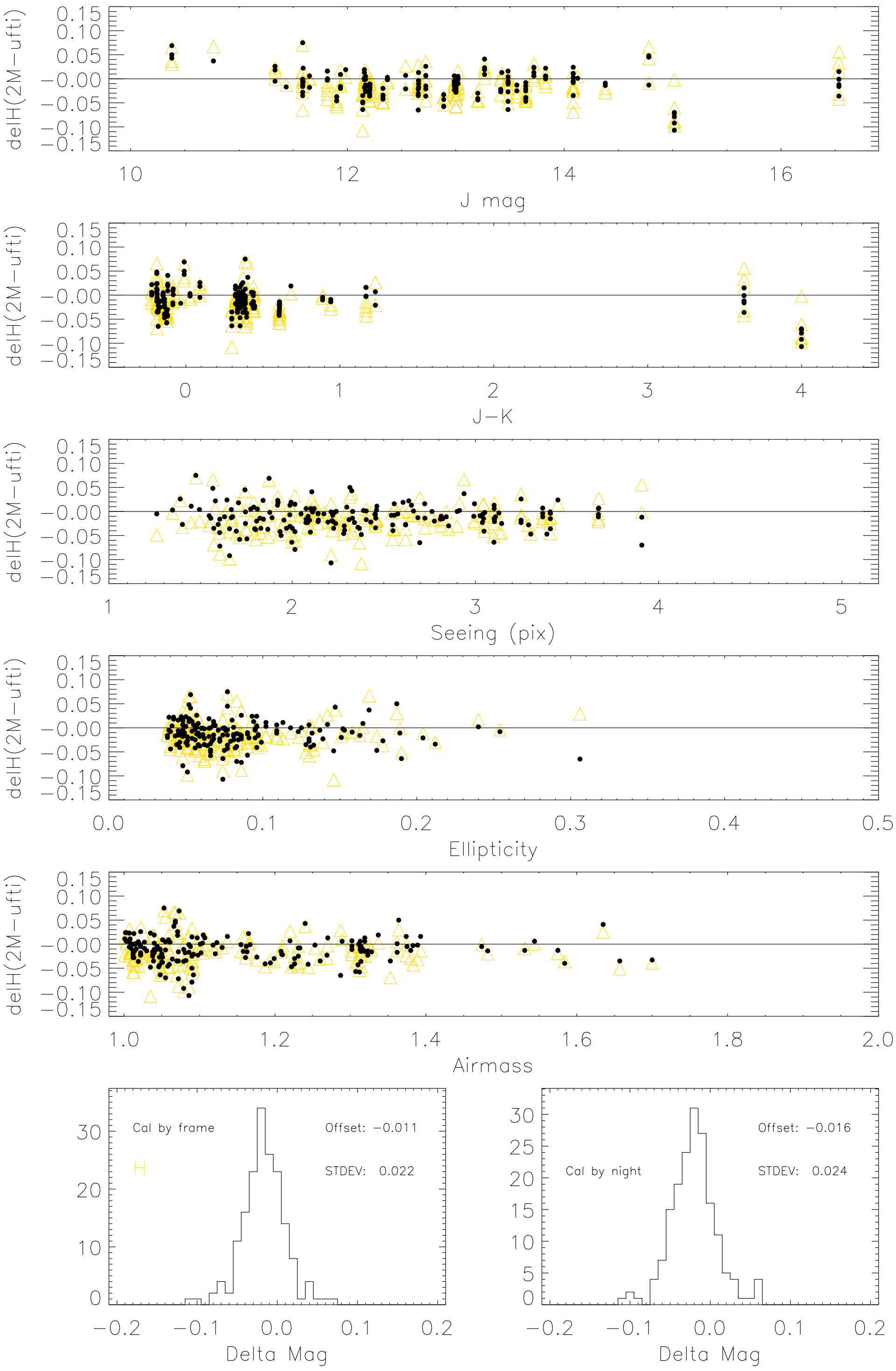

Figure 8: H-band Δmag (2MASS calibration–UFTI) for UKIRT faint standard stars observed with WFCAM. Measurements calibrated with a per-frame zeropoint, MAGZPT, are black dots, while measurements calibrated with a by-night zeropoint are yellow triangles. The histograms at the bottom collapse the data along the Y-axis for the by-frame (LHS) and by-night (RHS) calibrations.

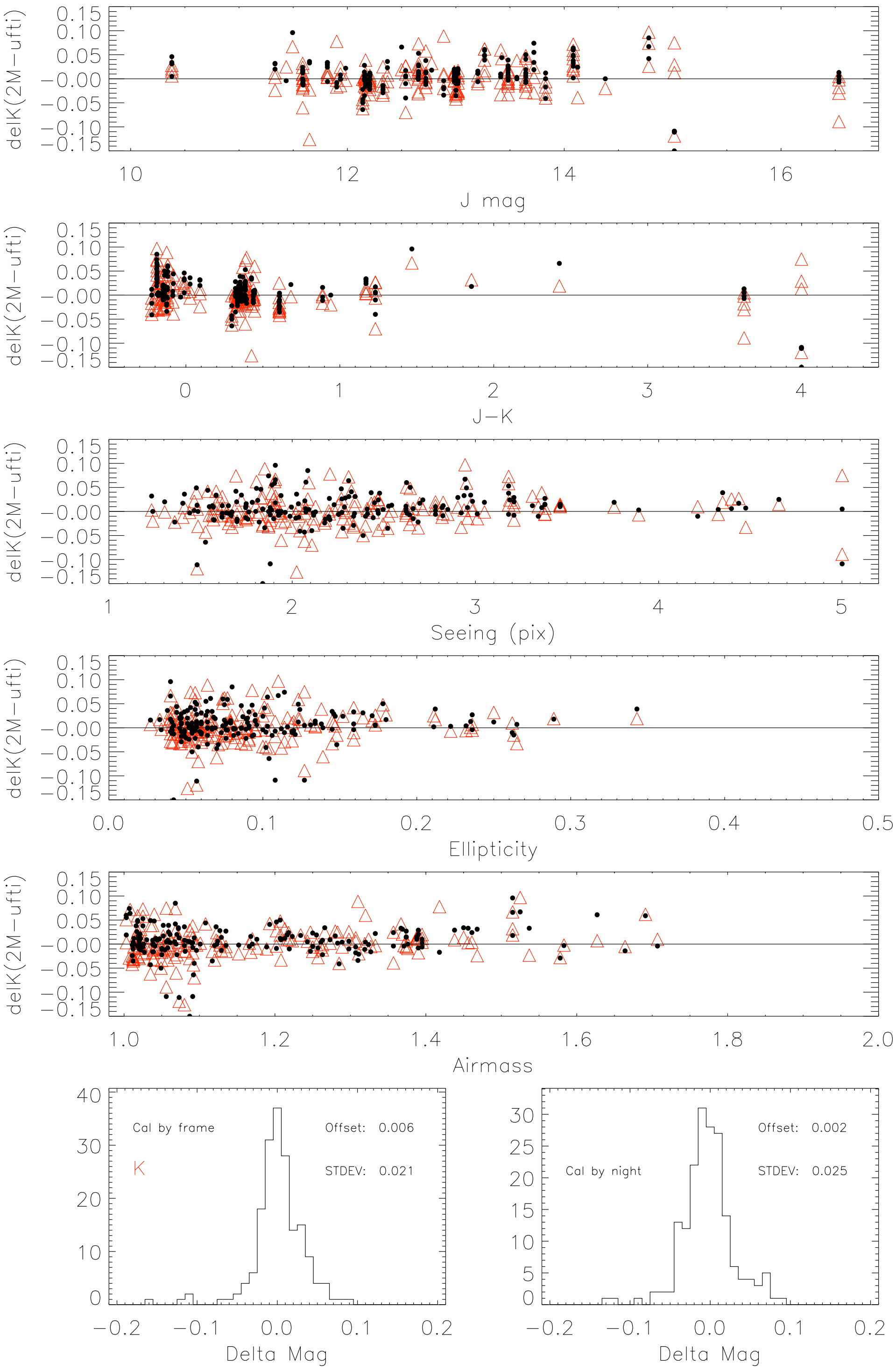

Figure 9: J-band Δmag (2MASS calibration–UFTI) for UKIRT faint standard stars observed with WFCAM. Measurements calibrated with a per-frame zeropoint, MAGZPT, are black dots, while measurements calibrated with a by-night zeropoint are red triangles. The histograms at the bottom collapse the data along the Y-axis for the by-frame (LHS) and by-night (RHS) calibrations.

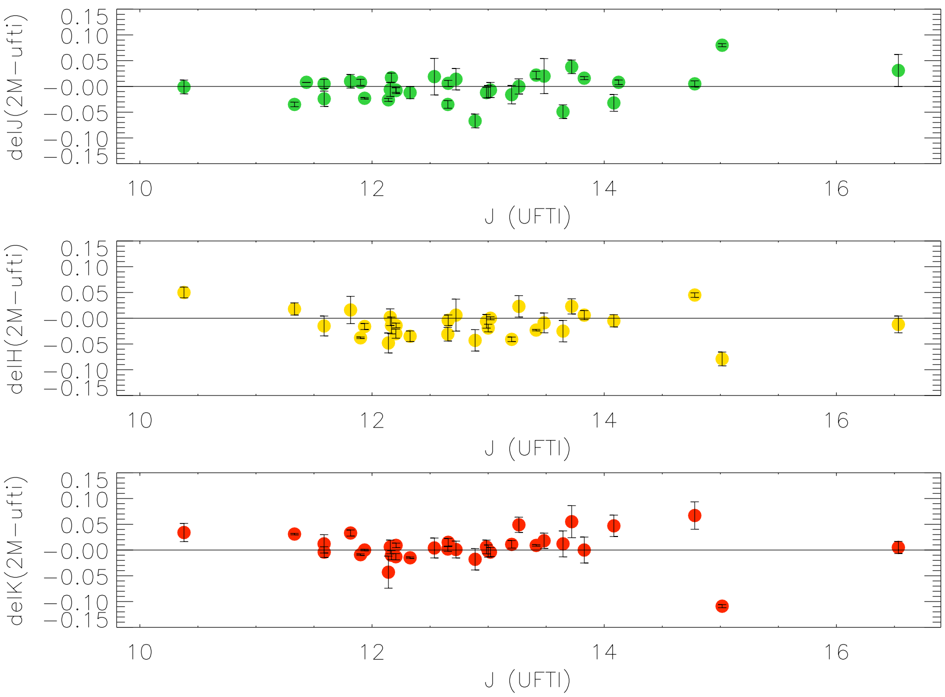

Figure 10: Median Δmag (2MASS calibration - UFTI published magnitude) plotted as a function of J(UFTI) for the J, H and K filters (top to bottom).

were therefore re-calibrated from the measured offsets (only for stars with ≥ 3 measurements in the filter). The by-frame calibration was then re-analysed as in Section 3. The results are shown in Figure 11.

This analysis shows a significant reduction in scatter in the 2MASS calibration of the UKIRT faint standards. After correcting the 2MASS faint standards, we can calibrate to $< 2\%$ (Figure 11 displays the standard deviations measured from the distributions of Δmag (with no clipping); a robust estimate of the standard deviation, derived from the median absolute deviation, puts the standard deviation in each filter to be 0.010 mag.

5 Conclusions

The original purpose of observing the UKIRT faint standards was to provide the primary WFCAM calibration, with the byproduct of a set of well-calibrated secondary standards in these fields. However, it is apparent that direct 2MASS calibration satisfies the photometry requirements more readily than reliance on sparsely time-sampled observations of standard fields.

Producing well-calibrated standard fields is still worth pursuing to provide an independent check on the 2MASS calibration and to provide single shot checks on spatial systematics.

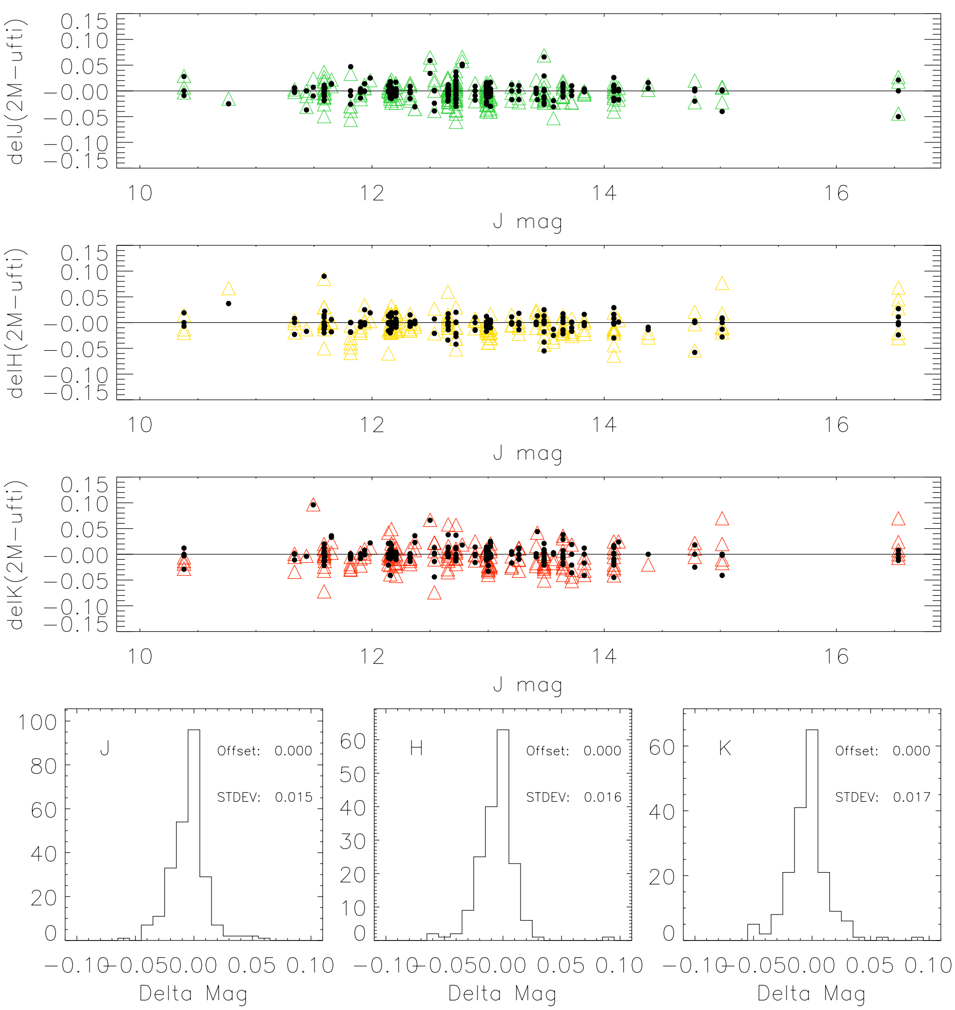

Figure 11: Δmag (2MASS calibration–recalibrated UFTI mags) for UKIRT faint standard stars, i.e. after applying the offsets shown in Figure 10. J, H and K from top to bottom. Measurements calibrated with a per-frame zeropoint, MAGZPT, are black dots, while measurements calibrated with a by-night zeropoint are coloured triangles. The histograms at the bottom collapse the data along the Y-axis. The standard deviation for each filter/histogram is shown on the plot.

6 Recommendations

1. We should continue to observe UKIRT FS stars in photometric conditions (i) to enable an independent (from 2MASS) calibration of WFCAM data and (ii) to ensure repeat observations of 'touchstone' fields.

2. Calibration MSB frequency can be reduced on photometric nights. We suggest that the minimum interval between calibrations be set to $\sim$2 hours.

3. On non-photometric nights, calibration MSBs are not particularly useful. A better calibration will be obtained from the per-frame 2MASS zeropoint.