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Evaluation of a temperature-based HST Focus Model

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ABSTRACT

A study of the history of the HST focus measurements compared to the predictions of the DiNino (2008) model was recently performed covering a time period from March 2003 to December 2010. Arising from this analysis, an improvement to the secular part of the model has been implemented and the inter-camera offsets have been revised. The model performance is good, falling within 2 microns of the measured values of the secondary mirror displacement 80% of the time. A web page with a link to the model has been supplied to display the measurement and modeling results and these are linked to a method for calculating point-spread functions using Tiny Tim. Point-spread functions can be calculated using the focus offset given by the focus model.

Introduction

Maintaining the HST focus has long been a fairly complex procedure. The focus changes over the long term because of outgassing and shrinking of the metering truss and in the short term because of temperature variations during HST's orbit and the changing illumination from the Sun and Earth. A full discussion of the difficulties and attempts to overcome them is given in Lallo et al. (2005). Several attempts to model the focus variations have been made over the years (Hershey, 1998), (Di Nino et al., 2008) with steadily increasing success. Following the installation of new instruments during the servicing mission SM4 in May 2009, we have revisited the focus model to include measurements made with the new Wide Field Camera 3.

Measurements

Using a phase-retrieval analysis method formulated for the HST (Krist and Burrows, 1995) and recently updated to include current cameras (Niemi et al., 2010), this study uses focus measurements made approximately every month since March 2003. Initially the cameras used were the ACS/HRC and WFPC2/PC. The HRC provided the best sampled measurements with its small pixel size of 0.025 arc-seconds compared to the point spread function width of about 0.1 arc-seconds at the best focus. The HRC became inoperable in January 2007 because of an HST electronics failure, and has never been recovered. Measurements continued using the PC with its pixel scale of 0.043 arc-seconds until May 2009 when WFPC2 was removed and replaced by WFC3 with its UVIS camera having a similar pixel size of 0.04 arc-seconds. Since August 2009 both WFC3/UVIS and ACS/WFC with a 0.05 arc-second pixel size have been used.

The model currently used for predicting the long-term behavior and planning for secondary mirror moves uses the thermal prediction derived in Di Nino et al. (2008). The measured values are adjusted by subtracting the thermal prediction thereby leaving just the long-term function. We then fit this with an exponential function of time given in Niemi et al., 2010. If we restrict the analysis to the period since March 2003 a single exponential fits quite well. Then, combining the long-term function with the thermal prediction gives us our final estimate. In this document and related focus models the results are expressed as microns of secondary mirror axial displacement. One micron displacement at the secondary mirror induces an RMS wavefront error in defocus of 6.2 nm.

Figure **1** gives two examples showing how well the model performs. The second example is admittedly unusually good but the first plot is typical, in which the model follows the general shape of the measurement but is occasionally a micron or two displaced. It is worth noting that these are recent measurements that match well to the temperature model developed from data gathered in 2004 and 2005.

Figure 2 shows the result of applying the composite model to measurements of the HRC between days 4724 and 6115 after launch, or March 31st, 2003 to January 21st, 2007. The standard deviation between the model and the measurements is 1.7 microns.

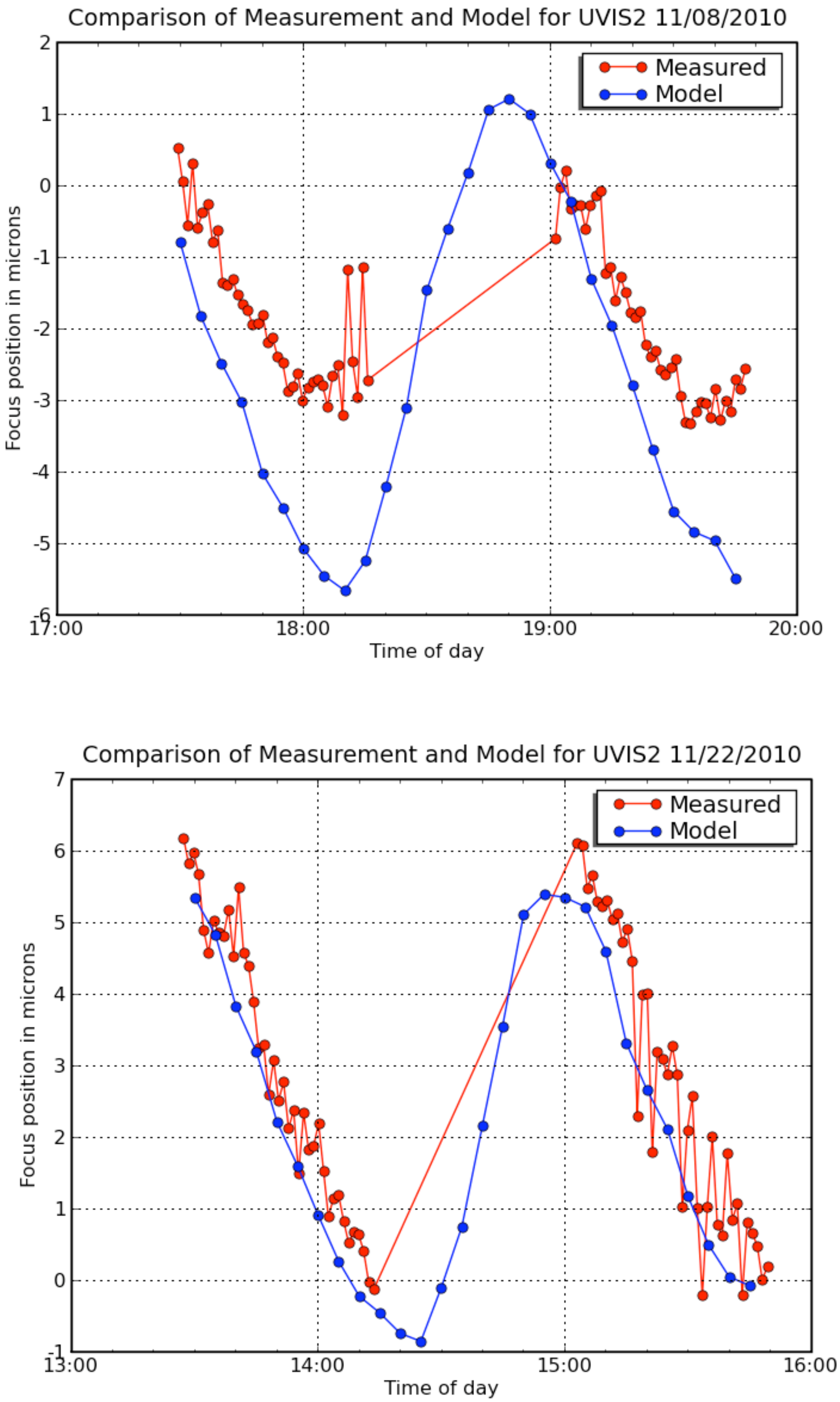

Figure 1 Examples of measurement and model comparison.

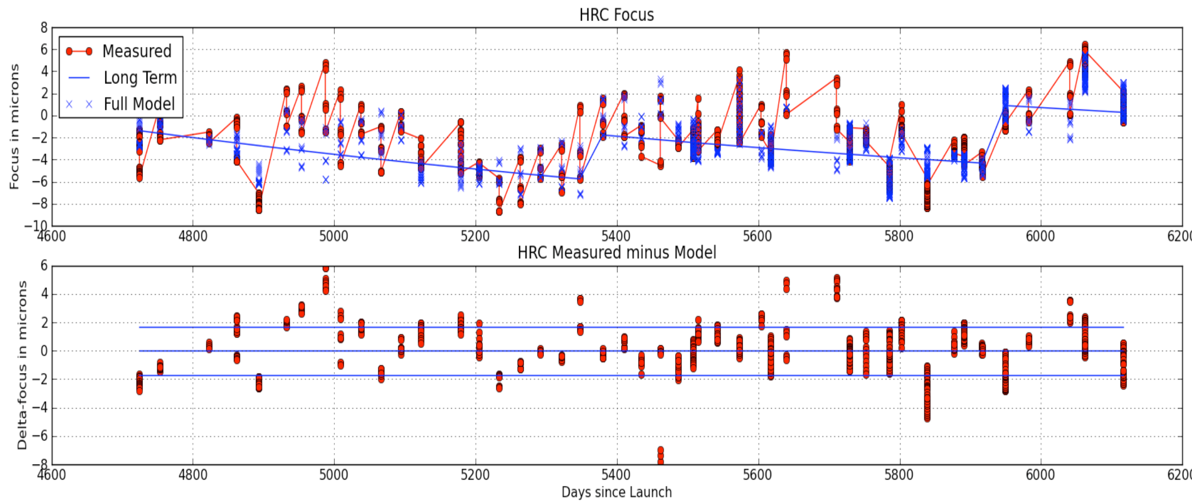

Figure 2. A history of the HRC focus. The upper plot shows the measured values (Lallo et al. 2010), the secular model and the full composite model. The secular model includes steps corresponding to the occasional adjustments made to the secondary mirror position. The lower plot shows the difference between the measured and modeled values. The blue lines indicate the mean value and one standard deviation above and below the mean.

Small focus offsets are measured between the Science Instruments (SIs) as shown in Table 1. This is the residual amount of non-confocality remaining after the SI's initial focusing during commissioning. Within an SI we found that ACS WFC1 & WFC2 exhibit ~0.5 micron focus offset between them while WFC3 UVIS1 & UVIS2 differed by ~1.3 microns. These defocus values are expressed as physical motion at the Secondary Mirror which implies physical displacements of the chips in question on order of ~100 microns, far too large to be plausible. We know that real differences in PSF width due (for example) to differing charge diffusion between the chips, or the known spherical aberration gradient across them, can be interpreted by our phase retrieval techniques as focus change, given the undersampled and nearly in-focus PSFs measured in this way. For these reasons, we currently assume confocality within an SI by taking the mean position of WFC1 and WFC2 as the focus value for both chips and applying the same method to UVIS1 and UVIS2.

Instrument	Mean offset	Standard Deviation	Standard Error
HRC	0.076	1.714	0.056
PC	0.549	1.721	0.051
WFC1	0.832	1.303	0.135
WFC2	0.303	1.301	0.135
UVIS1	-0.487	1.221	0.180
UVIS2	0.648	1.423	0.100

Table 1 Instrument offsets from initial model value

The distribution of the measured deviations from the updated model is illustrated by the following histograms in which each column is one micron in width. So the central column covers from -0.5 to +0.5 microns deviation.

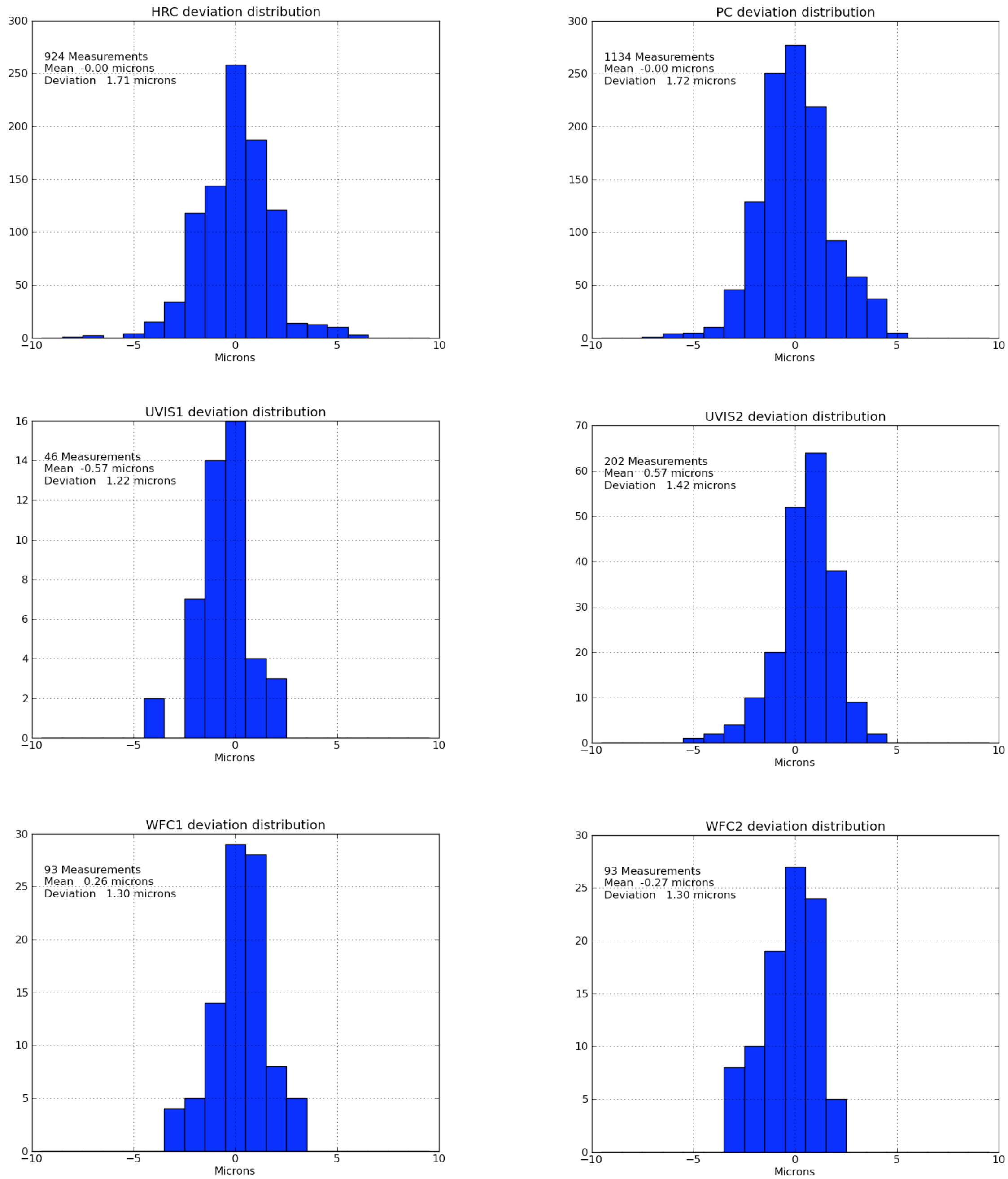

Figure 3 Distributions of the deviations of measured focus positions from modeled values. The HRC and PC have mean values of zero because the model has been adjusted to match the history. The WFC and UVIS are at equal positive and negative distances from the newly applied instrument average positions.

Another way of illlustrating the model performance is to consider what proportion of deviations fall within various values. Figure **4** shows the fraction of events for which the deviation is included within the given distance. About 50% of the deviations are smaller than one micron and more than 80% fall within two microns.

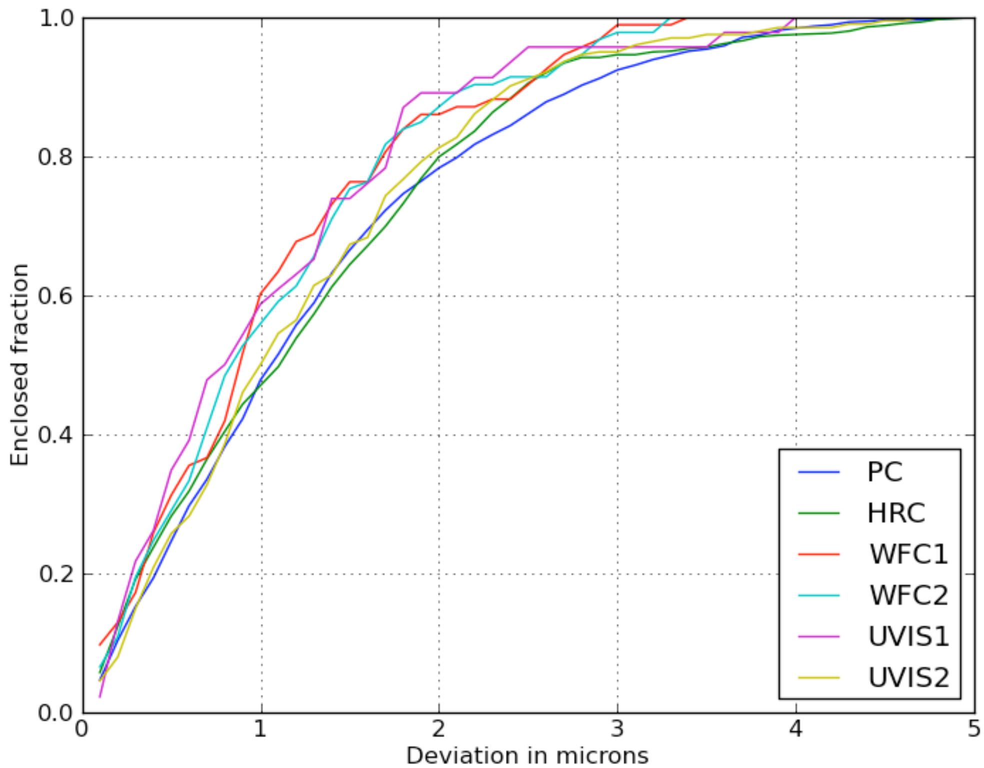

Figure 4 Included fraction of measurements falling within given deviation from the model.

Application

Simply knowing that an instrument was somewhat out of focus during a particular observation might be of some use in understanding properties of the data. We now supply a detailed web page that provides access to the modeling software and a link to the point-spread function (PSF) calculation software in Tiny Tim (Krist 1995). Focus values derived from the model may be incuded in the input parameters to Tiny Tim which will then calculate the appropriate out-of-focus PSF.

Conclusions

The focus model behaves well, supplying a focus estimate within two microns of the actual position over 80% of the time. This despite the fact that the focus can vary by six microns or more within an orbit. Results for any instrument and for any time period within a single day may be viewed and retrieved by means of a utility provided at http://focustool.stsci.edu/cgi-bin/control.py This supplies plots like those in Figure **1**. For periods when actual focus measurements were made, about one hour per month, the results may be displayed or compared with the model calculations. The modelled focus shifts maybe used in the on-line Tiny Tim PSF modelling software at http://tinytim.stsci.edu/cgi-bin/tinytimweb.cgi The resulting PSF may then be used for a variety of image analysis tasks. For further information on using the HST focus and PSF modeling tools, see http://www.stsci.edu/observatory/focus

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