

NICMOS Focus and HST Breathing

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ABSTRACT

The program 7608 monitored on a biweekly basis NICMOS camera foci from June 9, 1997, through February 18, 1998. Each of the biweekly observations included 17 measurements of focus position (focus sweeps), individually for each of the three cameras. The measurements for camera 1 and camera 3 foci covered one or two HST orbital periods. Comparison of these measurements with the predictions of the three OTA focus breathing models has shown the following. (1). Focus variations seen in NICMOS focus sweeps correlate well with the OTA focus thermal breathing as predicted by breathing models (“4–temperature”, “full–temperature”, and “attitude” models). Thus they can be attributed mostly to the HST orbital temperature variation. (2). The amount of breathing (breathing amplitude) has been found to be on average larger in the first orbit after a telescope slew to a new target. This is explained as being due to additional thermal perturbations caused by the change in the HST attitude as the telescope repoints to a new target. (3). In the first orbit, the amount of focus change predicted by the 4-temperature model is about the same as that seen in the focus sweeps data (breathing scale factor ~ 1). However the full-temperature model predicts a two times smaller breathing amplitude (breathing scale factor ~ 1.7). This suggests that the light shield temperatures are more responsive to the attitude change than temperatures from the other temperature sensors. The results of this study may help to better understand the HST thermal cycles and to improve the models describing the impact of those on both the OTA and NICMOS focus.

1. Introduction

HST focus is known to experience quite noticeable variations on the orbital time scale which are attributed to thermal contraction/expansion of the HST optical telescope assembly (OTA) as the telescope warms up during its orbital day and cools down during orbital night (Bely 1993, Hasan & Bely 1994). These short term focus variations are usually referred to as “OTA breathing” or “HST breathing” or just “focus breathing”. Using a limited data set, Bely (1993) had found that focus breathing correlates well with the

temperatures measured by the four light shield temperature sensors. He took this correlation as a basis for a phenomenological “four temperature” breathing model, or “*4T-model*” (i.e., based on temperature information), which has been used since then to convert the measured light shield temperature variations to the corresponding OTA secondary mirror shifts. This model has been extended by Hershey (1998) to include measurements from other temperature sensors, along with a few other modifications (“*full temperature*”, or “*full-T model*”). Finally, Hershey (1998) has developed an independent “breathing” model based on a physical relationship between HST thermal conditions and the telescope attitude (“*attitude-based model*”). Unlike the temperature models, the attitude model can also predict the Secondary Mirror position variations once the observation schedule, hence telescope attitude, becomes known.

Accurate characterization of HST focus breathing is quite important for both HST data reduction and instrument monitoring. For example, thermally induced HST focus variations were found to have a substantial effect upon high precision WFPC2 photometry (Suchkov & Casertano 1997). Another example is the NICMOS focus monitoring program where breathing turned out to be important in tracking the unstable NICMOS focus (Burrows & Krist 1997). Therefore further understanding and quantification of HST breathing remains a topical issue.

The three breathing models mentioned above have been tested using a sparse time series of actual focus measurements which are mostly the results of phase retrieval analysis of WFPC2 images from the WFPC2 photometric monitoring program. Unfortunately, those scarce data are insufficient to differentiate between the models in terms of which of them are better and in what sense. Hershey (1998) has shown that there is a good degree of agreement between the predictions of all three models. At the same time, the differences are also quite noticeable in some time intervals, especially between the attitude model and the temperature-based models.

A unique opportunity to test the breathing models and gain a new insight into the HST thermally induced focus variations is now provided by the results of the NICMOS focus monitoring programs 7608 and 7901 obtained in 1997 through 1998. The two programs have a slightly different setup. The program 7608 measured bi-weekly the “*best focus*” position in all three NICMOS cameras 17 times over a period which covered one or two visibility periods in the case of camera 1 and camera 3 (camera 2 data cover a much shorter period). A program observation for each of the cameras is implemented as a “*focus sweep*” in which each of the 17 exposures executes at a different focal plane position relative to camera’s detector. The focal plane is moved using NICMOS Pupil Adjustable Mechanism (PAM). The “*best focus*” is derived from the PAM defocused images using the *phase retrieval* technique developed by Krist & Burrows (1995). The observed variations in the “*best*” focus during each orbit are interpreted as being due mostly to OTA breathing. Thus the program provides the data to test directly predictions of the breathing models

against the actually observed focus variations. Given a very good sampling of the orbital period by the data (cameras 1 and 3 only) and a large number of orbits measured over more than a one year period (proposal 7608 executed from June 9, 1997, through February 1, 1998), the NICMOS focus results may be expected to catch even subtle differences between the three available breathing models. In what follows, we use the results of the NICMOS focus monitoring program 7608 to confront the predictions of the breathing models and the actual NICMOS focus variations observed on the HST orbital time scale.

2. Results and Discussion

Figures 1 and 2 display the relationship between cameras 1 and 3 focus (measured relative to the mean focus during the observation), respectively, and breathing as predicted by the three breathing models. The panels in the first row show the correlation coefficient for the linear regression of the measured camera focus variation during a focus sweep on the breathing values predicted by the breathing models for the times at which focus was measured. The second row of panels displays the slope, or *breathing scale factor*, of the regression line. The panels in the third row give the breathing amplitude predicted by the models for the time period of the focus sweep in a particular observation (visit). The mean values of all the parameters as averaged over all observations are given in the panel legends as well as in Table 1 in which are also given the corresponding results for camera 2.

Correlation between orbital variation of NICMOS focus and breathing

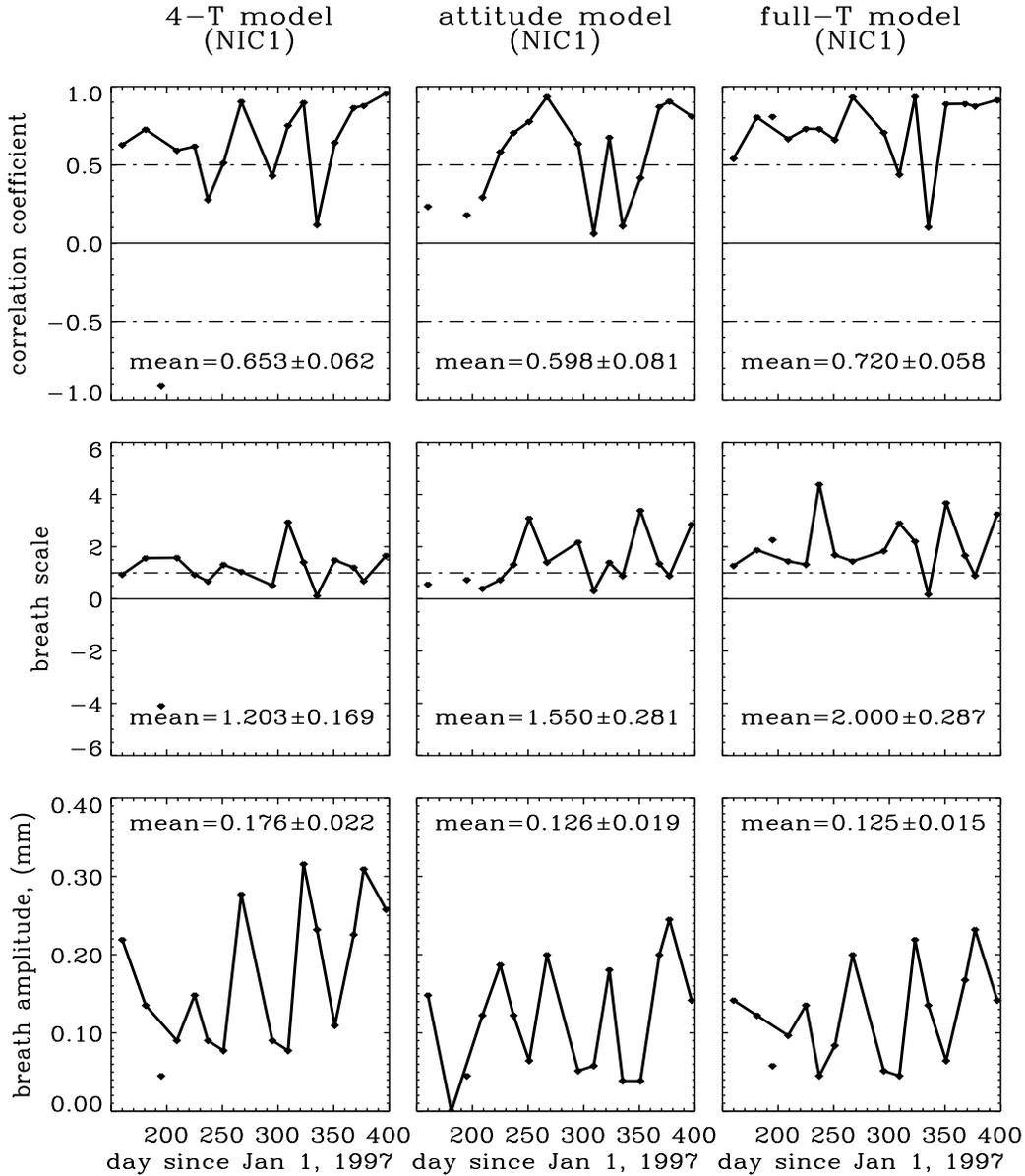
The total time of one focus sweep is ~40 min for camera 1 and ~35 min for camera 3. Typically a sweep for at least one of the cameras is split between two orbits. As mentioned above, the focus position is measured 17 times during that time. Thus the focus sweep data sample very well an orbital period, and the observed focus variation should be expected to provide a good tracking of the OTA breathing. For camera 2, the time of a focus sweep is about two times smaller than that for camera 1, and the exposures are split between the orbit less often. Therefore breathing effects in camera 2 focus sweep data are expected to be much less pronounced.

Inspection of Figure 1 immediately reveals that there is a high degree of correlation between the observed camera 1 focus variation in a focus sweep and focus variation predicted by the breathing models. The correlation coefficient for individual visits is in most of the cases larger than 0.5, with the mean of about 0.7 for the two temperature models. Correlation coefficient close to 1 is seen in quite a number of cases. Thus there is no doubt that the bulk of camera 1 focus variation observed over the orbital period is due to the OTA thermal breathing.

There is a marginal evidence that breathing based on the full-temperature model correlates with the observed focus better than the 4-temperature model. Breathing based on the attitude model yields a slightly worse correlation. The latter is hardly surprising

because, unlike the two temperature models, the attitude model is merely predictive, not using any observed parameters from the spacecraft.

Figure 1: Relationship between NICMOS focus variations and predictions of the breathing models: camera 1 data.



Comparison of Figure 1 and Figure 2 reveals a significant difference between the cameras 1 and 3 results (see also Table 1). In the first place, the correlation between focus variation and breathing for the camera 3 data looks in general worse than for camera 1, with a few correlation coefficient values being negative at all. A clue to this difference seems to be provided by breathing amplitude shown at the bottom in Figures 1 and 2. Breathing amplitude is defined here as a half of the difference between the maximum and the minimum of the breathing values. One can see that four of the five negative correla-

tions were obtained when breathing amplitude was very small, less than 0.08 mm in PAM space. In these cases the correlation might be dominated by errors and/or other factors which may cause focus variation additional to that associated with OTA breathing. If only large breathing amplitudes are considered, the mean correlation coefficient gets well above 0.5, implying that whenever we see a large temperature swing during a focus sweep, we can always ascribe most of the NICMOS focus variation to OTA breathing.

Figure 2: Relationship between NCIMOS focus variations and predictions of the breathing models: camera 3 data.

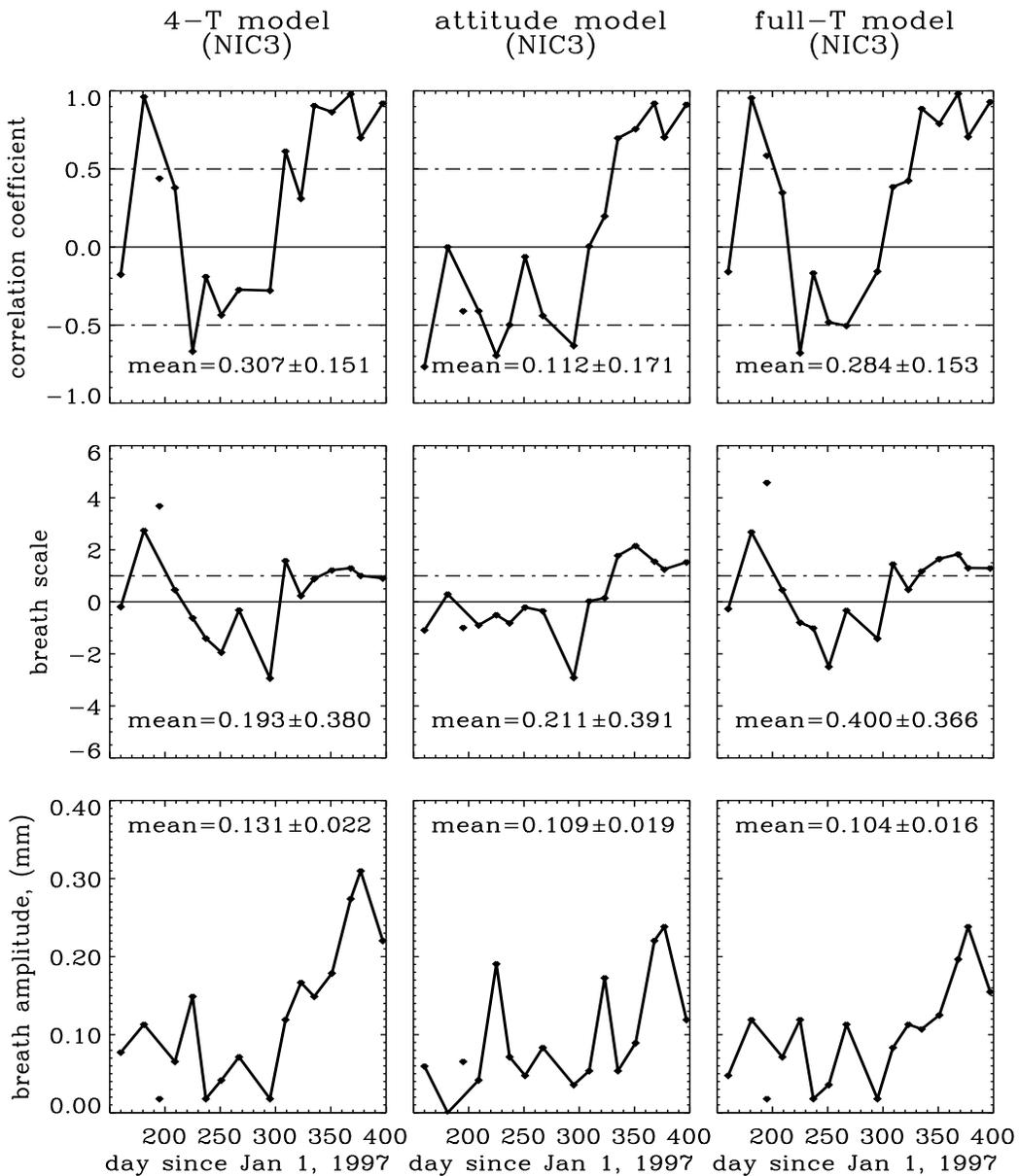


Table 1. NICMOS focus variation vs. predictions of the breathing models: mean correlation coefficient, breathing scale factor, and breathing amplitude for the data displayed in Figures 1 and 2 and the respective data for camera 2 not shown in those figures.

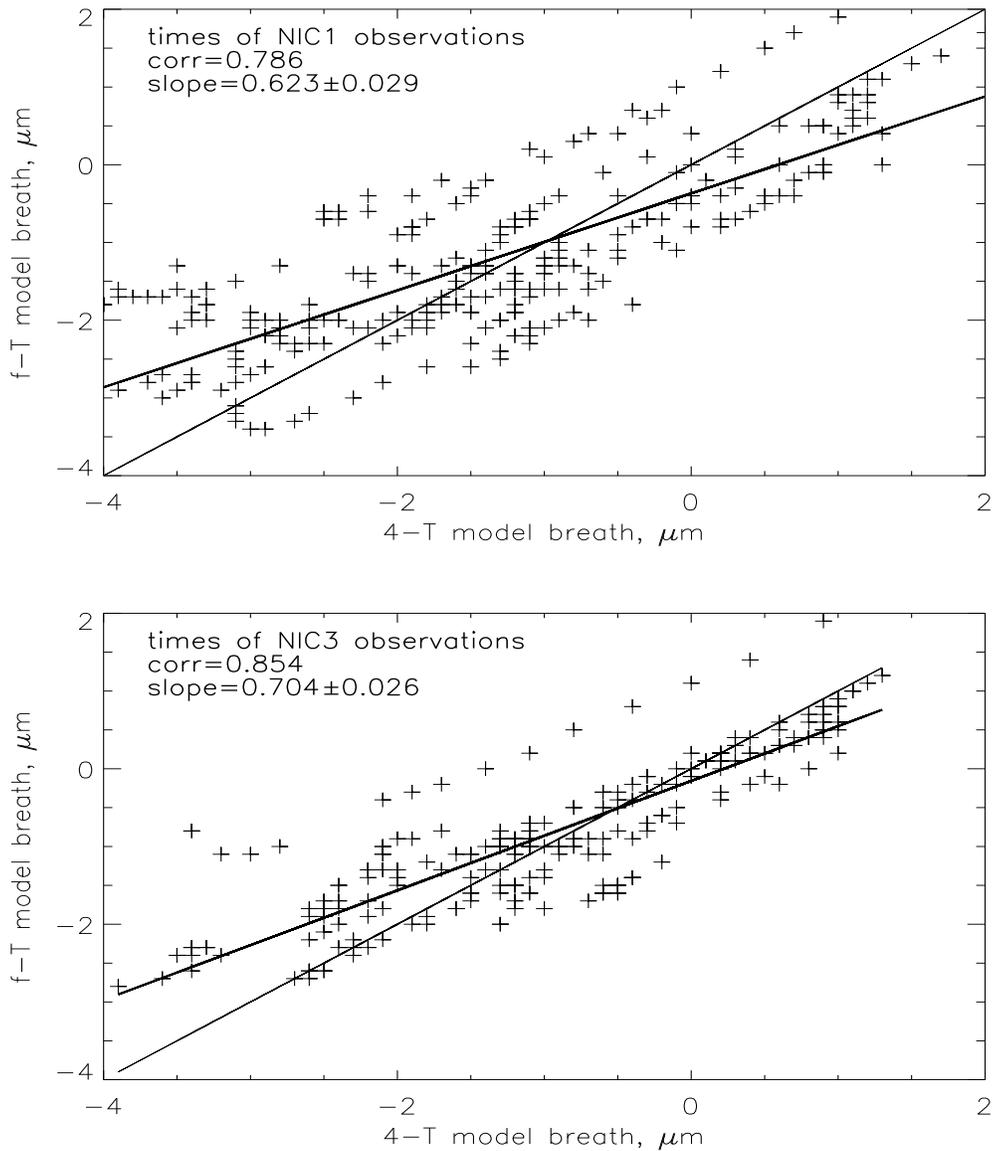
	NIC1	NIC2	NIC3
Mean Correlation Coefficient			
4-T model	0.653	-0.012	0.308
error	± 0.063	± 0.118	± 0.152
attitude model	0.598	-0.035	0.112
error	± 0.081	± 0.133	± 0.172
full-T model	0.721	-0.036	0.284
error	± 0.058	± 0.130	± 0.153
Mean Breathing Scale Factor			
4-T model	1.203	0.288	0.193
error	± 0.169	± 0.996	± 0.380
attitude model	1.550	0.117	0.211
error	± 0.282	± 0.644	± 0.392
full-T model	2.000	-1.874	0.400
error	± 0.287	± 1.801	± 0.366
Mean Breathing Amplitude, mm (PAM space)			
4-T model	0.177	0.105	0.131
error	± 0.023	± 0.020	± 0.023
attitude model	0.127	0.086	0.109
error	± 0.020	± 0.012	± 0.020
full-T model	0.125	0.087	0.104
error	± 0.016	± 0.016	± 0.016

Breathing amplitude and breathing scale factor

Smaller breathing amplitude in general during camera 3 focus sweeps is quite obvious from comparison of the bottom panels in Figures 1 and 2. This fact can partially be attributed to a smaller total exposure time for camera 3 focus sweeps. However camera 3 exposures are often split between two orbits, which makes the difference in the exposure time less important. Larger breathing during camera 1 sweeps is rather due to the fact that this camera observed always immediately after the telescope had slewed from a previous target to the proposal target while camera 3 observations followed an orbit or two after

that. In the first orbit, the telescope temperature variation has the regular orbital component plus a component associated with the changed telescope attitude. One orbit seems to be enough for the thermal perturbations caused by the attitude change to relax. Thus the temperature variation, hence breathing, in the second or third orbit should typically be less than in the first orbit.

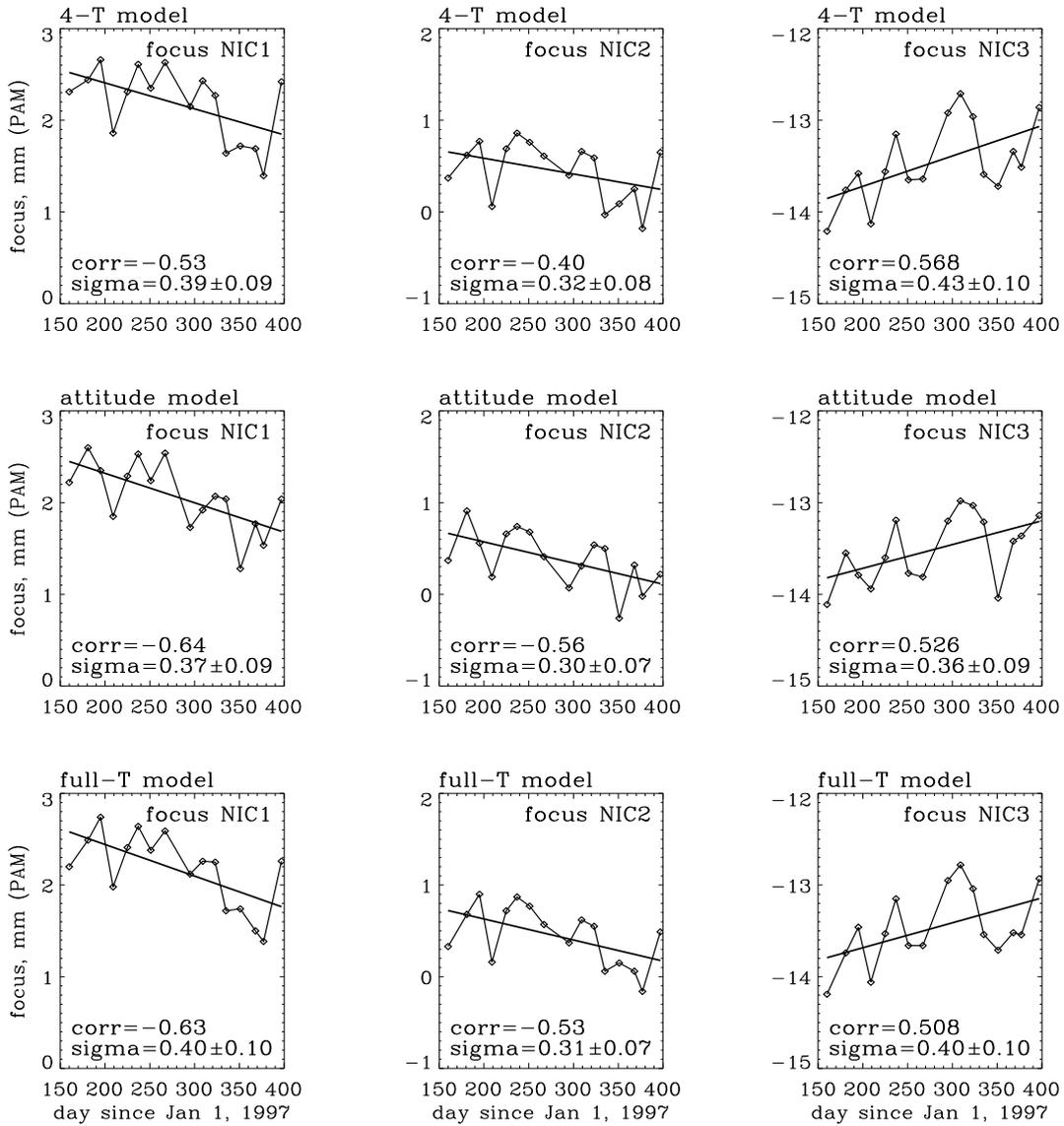
Figure 3: Relationship between the predictions of the 4-temperature model and the full-temperature model immediately after the telescope attitude change (first orbit, times of NIC1 observations) and an orbit after that change (subsequent orbits, times of NIC3 observations). The thick line is the linear regression, the thin line is the $slope = 1$ line. The correlation coefficient and the slope of the regression line are indicated.



The difference between the predictions of the two temperature models persists however into the second and third orbits after the telescope slew. Figure 3 shows the

correlation between the model predictions for the time of camera 1 observations (i.e., the first orbit, occasionally including a part of the second orbit) and camera 3 observations (i.e., the second orbit, sometimes also a part of the third orbit). In both cases, the slope is significantly below unity.

Figure 4: NICMOS focus history from June 9, 1997, through February 18, 1998, with breathing corrections from the three breathing models. Correlation coefficient (*corr*) and standard deviations (*sigma*) are indicated.



Another difference between the attitude and temperature models is that the former defines focus breathing as focus deviations from an average taken over many orbits rather than a one-orbit (4-temperature model) or two-orbit (full-temperature model) average.

Therefore we may expect this model to reflect HST focus variations on a time scale larger than the orbital period. The NICMOS focus history plots in Figure 4 seem to support this expectation: the focus scatter about the trend line is always smaller if breathing corrections are used from the attitude model, although the difference is only marginally significant in each individual case.

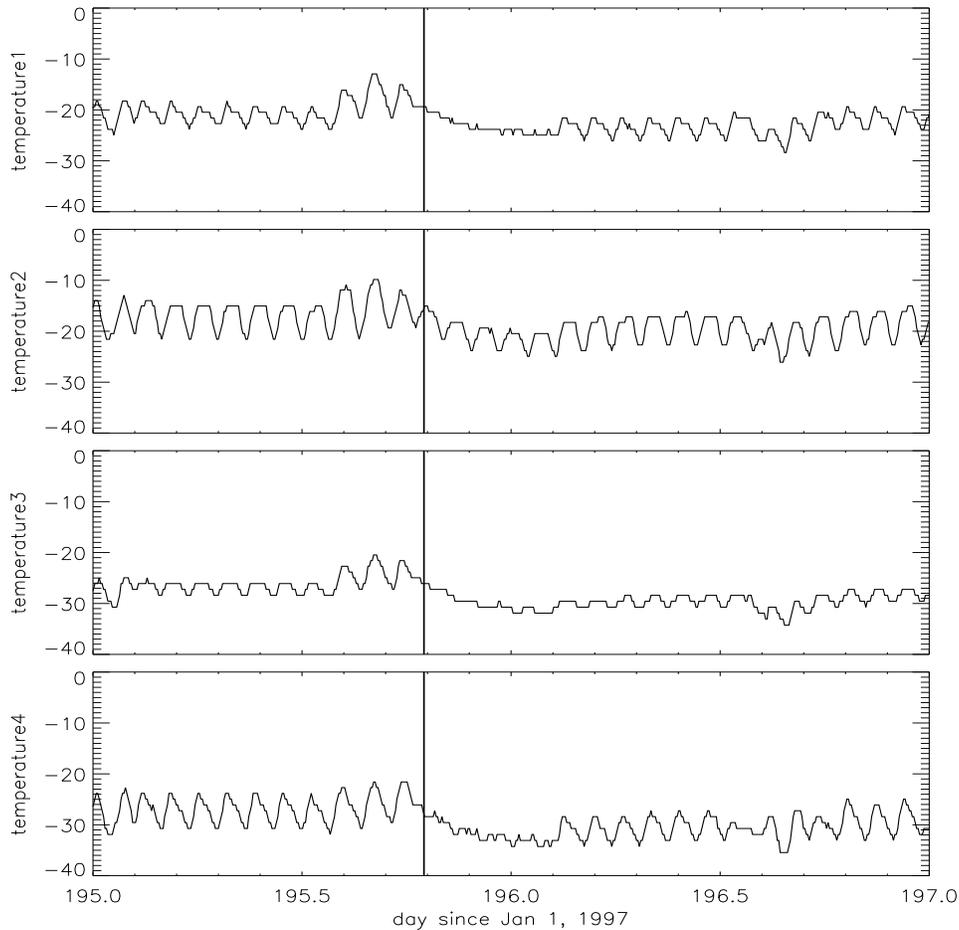
The downward trend seen in camera 1 and camera 2 data in Figure 4 can be attributed to the general HST focus drift caused by water desorption in the metering truss while the upward trend in camera 3 focus probably reflects the NIC3 detector motion caused by a gradual relaxation of mechanical tensions within the camera. Those tensions were originally induced by the dewar anomaly. The oscillatory pattern about the trend lines was found to correlate with the NICMOS fore-optic temperature variations. It seems to have a time scale of about one precessional period and thus can be tracked down to a systemic component in the HST attitude associated with the HST orbit precession (Suchkov 1998).

Anomalies in temperature data

A noticeable outlier in Figures 1 and 2 is the data point corresponding to the day 195 (visit of July 14, 1997). It was rejected as the numbers in Table 1 were generated. We have checked the telemetry data to see what temperatures were reported by the temperature sensors on that day. As seen from the results presented in Figure 5, the light shield temperatures immediately after the start of the proposal 7608 visit on that day turn out to be quite anomalous. The major unusual feature is the absence of orbital temperature oscillations as reported by three of the four temperature sensors, T1, T3, and T4. At the same time, T2 showed quite normal oscillations, with a modulation mostly likely caused by the change in the telescope attitude as the spacecraft re-pointed to the proposal target. Also unusual is the fact that the data from the other three sensors do show the same multi-orbit modulation. The latter seems to rule out just a glitch in telemetry or corruption of data.

We do not know what is the nature of that temperature anomaly. Whatever it was, the temperature data for the July 14 visit look at this point unreliable, and we have dropped them from our analysis. It may well be possible that such an anomaly is not a one-time event. It may be worthwhile to check at some point the rest of the temperature data, especially given that now we know what to look for.

Figure 5: Light shield temperatures during July 14 through July 16, 1997. The start of the proposal 7608 visit for which anomalous breathing was reported is indicated by the vertical line.



3. References

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