Chapter 46

WF/PC-1 Error Sources and Data Analysis

In This Chapter...

In this chapter, we provide details about residual effects that may be affecting the robustness of the calibrated WF/PC-1 data, including:

- Effect of Decontaminations.
- Scattered light.
- Persistent measles.
- Hot pixels.
- Cosmic rays.
- Flatfield anomalies.
- Photometry.
- Plate distortion.

Additionally, we provide information for deconvolving WF/PC-1 images.

Further, these sections contain suggestions for further improving upon the calibration and analysis of WF/PC-1 data. A more general discussion of various image plotting and manipulation tasks is described in the STSDAS chapter of this book; please refer to that section for details on how to work with the positional information in the image, use metric, use **synphot** to re-derive the flux scale, and remove cosmic rays and image defects.

46.1 Effect of Decontaminations

The structure of the WF/PC-1 flatfields and the UV throughput was changed by any decontamination (decon) procedure. Decontaminations were normally done to:

- Improve blue performance.
- Reduce internal scattered light.
- Temporarily restore UV transmission and reduce contaminations.

See “Flatfield Anomalies” on page 46-7 below and “Photometry” on page 46-9 for corrections to apply to the data to compensate for the decons; note, too, that **synphot** can be used to determine and apply a contamination correction (use the CONT keyword in the OBSMODE; see *WF/PC-1 ISR* 96-02).

Decons were performed under either of two conditions: 1) after every WF/PC-1 or HST safe mode entry which turns off the WF/PC-1 Thermal Electric Coolers (TECs) or 2) after about 9 or more months of continuous cold operation. Table 46.1 summarizes the WF/PC-1 decon activities.

46.2 Scattered Light

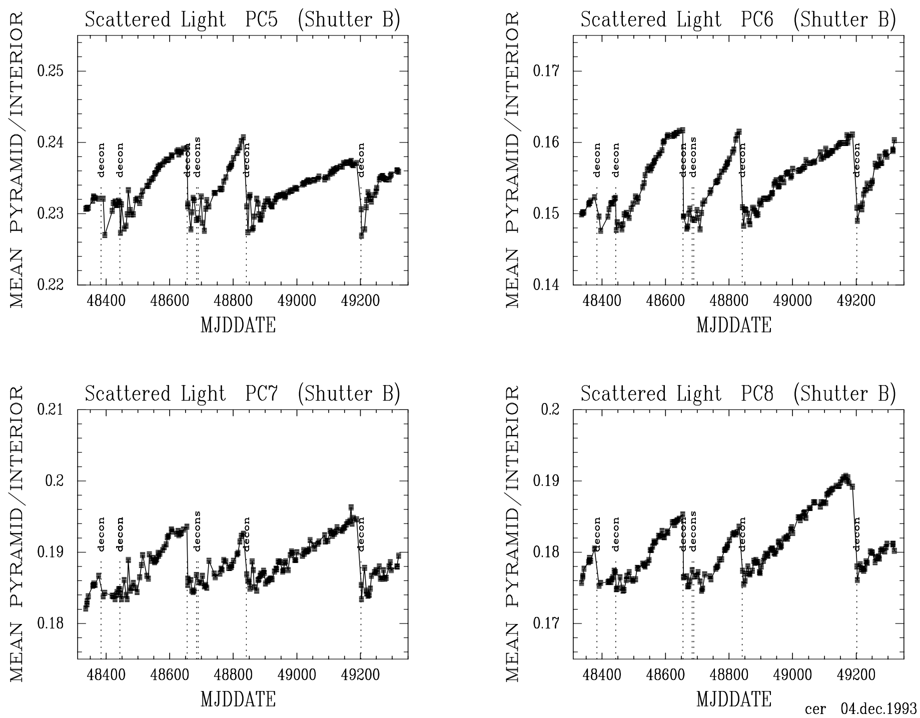
The WF/PC-1 cameras are known to suffer from a time-dependent loss of throughput as well as an increase in scattered light during the time periods following a decontamination procedure. Both effects are believed to be due to the slow growth of contaminants on the field flattening windows in front of the CCDs. The scattered light changes are estimated from internal flatfields, by determining the ratio of the intensity beyond the pyramid vertex to the intensity at chip center. The figure below summarizes the scattered light behavior of all eight chips since early 1991; decontamination episodes are marked with the vertical dotted lines.

46.3 Persistent Measles

The WF/PC-1 camera heads were decontaminated on February 3, 1992 (day 034), following a long period of continuous cold operation of the WF/PC-1 CCD

Figure 46.1: Scattered Light Versus Time

Planetary Camera Chips



Wide Field Camera Chips

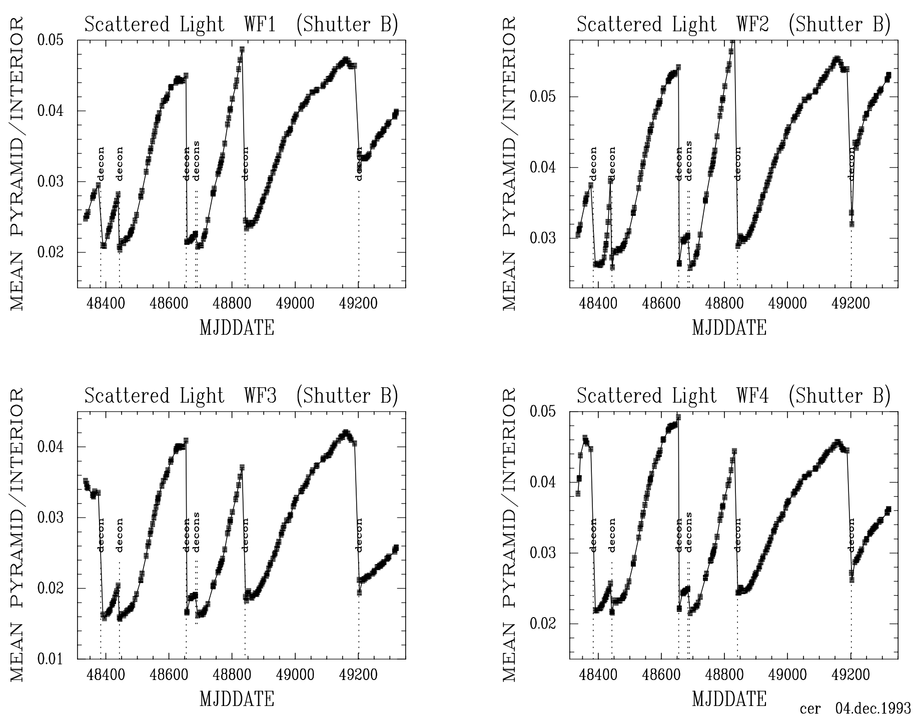


Table 46.1: WF/PC-1 Decontamination Events

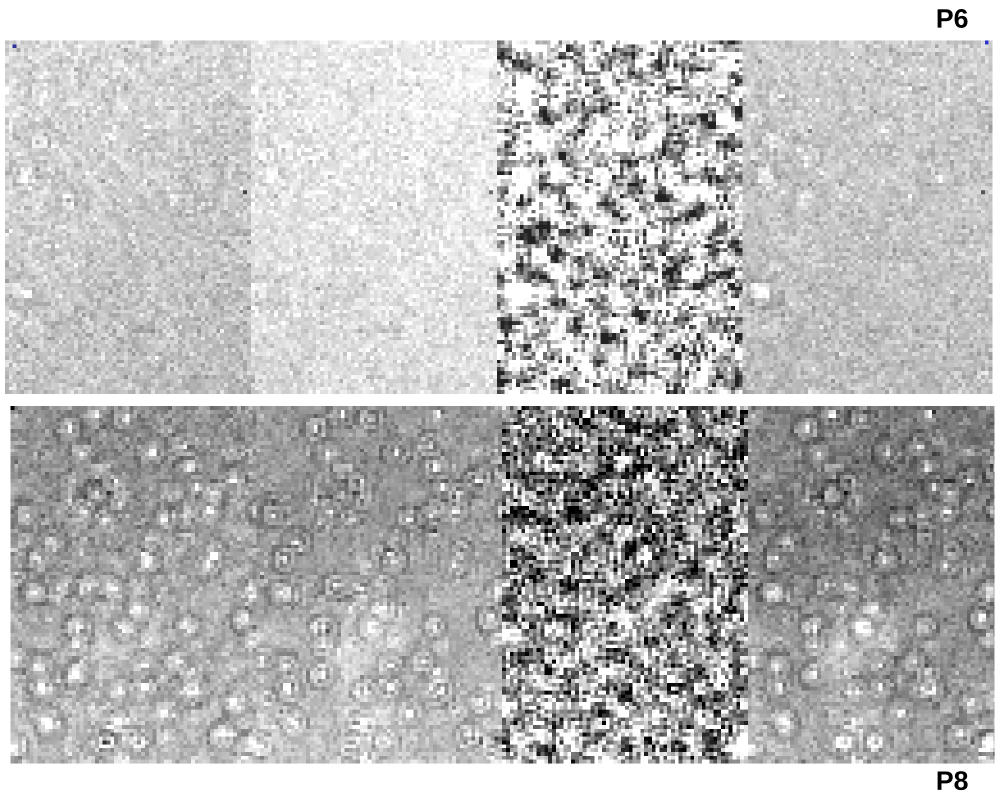
Date		DOY	Activity
1990	Dec 31	365	Telescope safes (FGE 3 bit flip); UV flood
1991	Jan 2	002	Mini-low-temp decon
	Jan 26	026	De-ice decon (-82C)—failed to remove daisies
	Jan 28	028	Mini-low temp (-20C)—removed daisies, created measles
	Jan 29	029	Low-temp decon (-15C)—removed measles
	May 2	122	PSEA hardware safe mode, CCDs at -35 for 80 hours, created measles
	May 8	128	Hot-junction decon (+12C)—removed measles
	Jul 3	184	WIDLE turned WFC TEC off for 7 hours WFC reached -25C, created measles
	Jul 5	186	Flash decon (+6C)—removed measles
1992	Feb 3	03/4	Flash decon—restored UV transmission, removed scattering but made persistent measles
	Feb 4	035	Flash decon (same as day 034)—p.measles still present
	Mar 3	063	Hot junction decon—p. measles still present
	Mar 8	68	Flash decon—persistent measles still present
	Aug 7	220	Flash decon (CCDs +3.5C to +8.5)
1993	Aug 2	214	Modified flash decontamination

detectors during which many science observations were obtained. The decontamination procedure restored UV transmission (temporarily), blue performance, and reduced the internal scattered light. It also made the expected small changes in the flatfield structure but did not re-introduce QEH.

However, unlike previous decontaminations, the February 3,1992 procedure caused the re-appearance of the measles contaminant. These permanent spot-like features, dubbed *persistent measles*, are generally a few pixels in radius; some have light cores, some have dark cores but all appear surrounded by one or more weaker rings. On an uniformly illuminated source (i.e., flatfield) they produce a 1.1% rms modulation with a 4 to 5% peak amplitude in their cores. Optical modelling finds them to be consistent with 10–15 μm sized particles on the field flattening windows. A likely cause of persistent measles is the usage of the pyramid motor without a sufficient cool down period between motions. This often occurred during the SV flatfield observations (fourth quarter of 1991); the waiting period between pyramid motions was increased after the problem was recognized.

Detectors WFC2 and PC6 were the least affected CCDs while PC7 and PC8 were probably the most affected. Figure 46.2 shows a 100 x 100 region of the PC6 and PC8 detectors (divided by a flat taken before the measles problem appeared) at 4 epochs. The third from the left is after an HST safing event and illustrates the *post-safing measles* which the decontamination procedures regularly removed. The display range in Figure 46.2 is about +/– 10% about the mean.

Figure 46.2: Persistent Measles



Precision photometry and astrometry of images with measles will be degraded. Applying an appropriate delta flat may partially correct for the measles; however, because the measles are out-of-focus features, a delta flat will not completely remove their effect. In addition, image deconvolution can actually enhance the measles, since they are roughly the same size as the PSF. In this case, delta flats may prove useful as a template, to allow differentiation of target features and measles.

46.4 Hot Pixels

A hot pixel has been defined as a pixel whose dark current exceeds 0.01 DN/sec (usually few hundred per chip). Time variability has been seen in the hot pixels (*Instrument Science Report* 93-01) with the following characteristics:

- The number of hot pixels gradually increases over time (about 30 new pixels per month per CCD).
- The number of hot pixels decreases (by 10–30%) after decontamination procedures.
- Individual pixels evolve: some undergo large variations in count rate, others remain constant in time, a very few decrease at times other than decons.

The pipeline calibrates the data with time averaged dark files: these files have improved signal-to-noise, but don't correct for time variations in the hot pixels. If hot pixels are more of a concern than signal-to-noise, an custom dark file could be generated from dark frames taken close in time to the observation, and that alternate dark used to recalibrate the data. Some alternate dark reference files have been generated and are listed in the WWW WF/PC-1 Reference File Memo. It is also possible to generate a more appropriate reference file from a set of individual dark frames available through the STScI Archive; this can be done using **crrej**.

Through April 1993, two dark frames were usually obtained each month. As of May 1993, additional darks were taken, for a total of about 12 per month for each camera. By calibrating with a reference file generated from dark frames taken within one month of the science observation, it is possible to reduce the number of residual hot pixels by nearly an order of magnitude. Suspect pixels can be compared with new lists of known hot pixels which are kept on WWW.

46.5 Cosmic Rays

The WF/PC-1 Investigation Definition Team (IDT) (*OV/SV Report*, 1992) analyzed several different cases, based on specific pixel threshold levels; two of these are summarized in the short table below.

Table 46.2: Cosmic Ray Events by Threshold Level

Threshold	Count Rate of Cosmic Ray Events Above Threshold	Average Number per Event
9 DN	4.7 pixels/sec/CCD	2.7 pixels
20 DN	3.2 pixels/sec/CCD	1.88 pixels

The event rate is estimated at about 1.7 events per second per CCD. As expected, long observations are most affected by cosmic ray events. Generally any exposure longer than 10 minutes is split into multiple integrations unless it was specified otherwise by the observer. The STSDAS task **crrej** may be used to correct a series of images for cosmic rays.

46.6 Flatfield Anomalies

The photometric accuracy of the data is often limited by the quality of the flatfield used to calibrate the data (see “Determining the “Best” Reference Files” on page 45-14 as well as the WWW Reference File and Closure Flat Memos). Details of the flatfields and delta flats available for calibration were discussed in “Determining the “Best” Reference Files” on page 45-14. In this section, we summarize residual features that may remain; we recommend experimenting with different flatfields to determine which are best for the data (see “Improving the Flatfield Correction” on page 46-15).

- ***Changes due to decontaminations.*** The flatfields are relatively stable between decontamination procedures; however, they do undergo some incremental changes across decontaminations. These changes are usually at the few percent level and so, may not be important for some observations[1]; if necessary, the changes may be corrected using an appropriate delta flat (see “Choosing and Generating Delta Flats” on page 45-18).
- ***Time variability due to scattered light changes.*** Following a decontamination, the gradual buildup of contaminants causes an increase in the scattered light (see “Scattered Light” on page 46-2); the corners of the internal flatfields used to monitor the instrument performance are seen to droop relative to the chip centers. Note also that the dust features change character in response to the increase in scattered light.
- ***UV throughput decreases over time.*** The buildup of contaminants responsible for the increase in scattered light also causes a corresponding decrease in throughput (see “Photometry” on page 46-9 and *WF/PC-1 Instrument Science Report* 93-02).
- ***Persistent measles after February 1992.*** These features are at the ~1% rms level, although the cores can deviate by up to 5% or more. See “Persistent Measles” on page 46-2 for more details.
- ***Large gradients caused by F122M.*** Due to the Earth’s albedo, some broadband filters had to be taken in conjunction with a neutral density filter (either F8ND or F122M) to obtain sufficient numbers of unsaturated earthflat observations for creating reference files. The F122M filter, designed as a short wavelength pass filter, had a red leak that was used to provide neutral density at long wavelengths. The filter consisted of a very weak MgF lens, with a dielectric short pass filter deposited on the side closest to the pick-off mirror. However, the dielectric coating was non-uniform, resulting in a *25-30% brightness gradient* running across the WF field, which is very weakly dependent on wavelength within the visual range. There were also several small pinholes in the F122M filter, which caused wavelength dependent “doughnuts” (images of camera relay optics pupils) to appear in the flats with strengths of 2% to 5%.

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1. *WF/PC-1 ISR* 92-4.

- ***Anomalies due to the F8ND filter.*** In other flatfields, the F8ND filter was used as the neutral density filter; it consisted of a strongly curved, thin meniscus whose center of curvature was at the pyramid apex. The surface was coated with a highly reflective metal film, which provided a neutral density uniform to less than 1% in intensity. The problem was that strong reflections could occur when F8ND was crossed with certain other filters. The strongly curved surface, together with its high reflectivity, caused light reflected from other filters to be strongly concentrated in a circular pattern centered near the pyramid apex. These reflections were formed by light passing through F8ND, reflecting off the other filter, reflecting from the curved surface of F8ND, and then passing through the other filter and onto the CCD. The strength of the circular reflection depended on the filter composition, and varied from <1% to ~30%. These reflections caused the F8ND filter to be dismissed as unusable early in the mission, though more recent tests show it is capable of giving near-perfect flats in certain filters. For filters which consist only of anti-reflection coated colored glass (polarizers, F555W, F569W, F725LP, F785LP, and F850LP), the intensity of the filter reflection is less than 1%. Certain other filter constructions gave very weak reflections, such as F336W, where the UG-11 colored glass component had a low throughput and was between F8ND and the F336W thin film component; in this case, the filter reflection is reduced to 1-2% in intensity (depending on field position).

Note that the neutral density filter effects have not been removed from the SV and the non-SV epoch flatfields; to avoid the problem, use a flatfield close in wavelength that was not generated with the F122M filter or use a *closure* or a high fidelity flat[2]. For further suggestions on improving the flatfields, see “Data Accuracies and Problem Solving” on page 46-13 (see also *OV/SV Report*, Faber et al., 1992, Chapter 6, and Closure Flatfield Memo on WWW).

- ***Individual filter anomalies - short exposure reciprocity effects.*** For exposures shorter than 1 second, the sensitivity of the CCD corners tends to increase. The effect is largest in the blue (~5%), and diminishes towards red wavelengths. The effect is strongest for 0.11 second exposures, and is nearly gone for exposure times of over 1 second. Hence it is useful to optimize the exposure times of the flats to match the data being flat-fielded; the Closure Flatfield Memo lists flats optimized to short and longer exposures.

2. Note that the use of a different flat will affect the photometric calibration.

46.7 Photometry

The photometry keywords (PHOTFLAM, PHOTZPT, PHOTPLAM, PHOTBS, and PHOTMODE) in the `.c0h` header are populated by the **calwfp** task; the header keywords are updated but the data are not changed (see “Converting Counts to Flux or Magnitude” on page 3-15). There are four effects that to be aware of when converting from DN to flux:

- The time-dependent throughput.
- The effect of the source spectrum.
- Use of an alternate flatfield.
- Gradients (~20-30%) in broadband flats taken through neutral density filters.

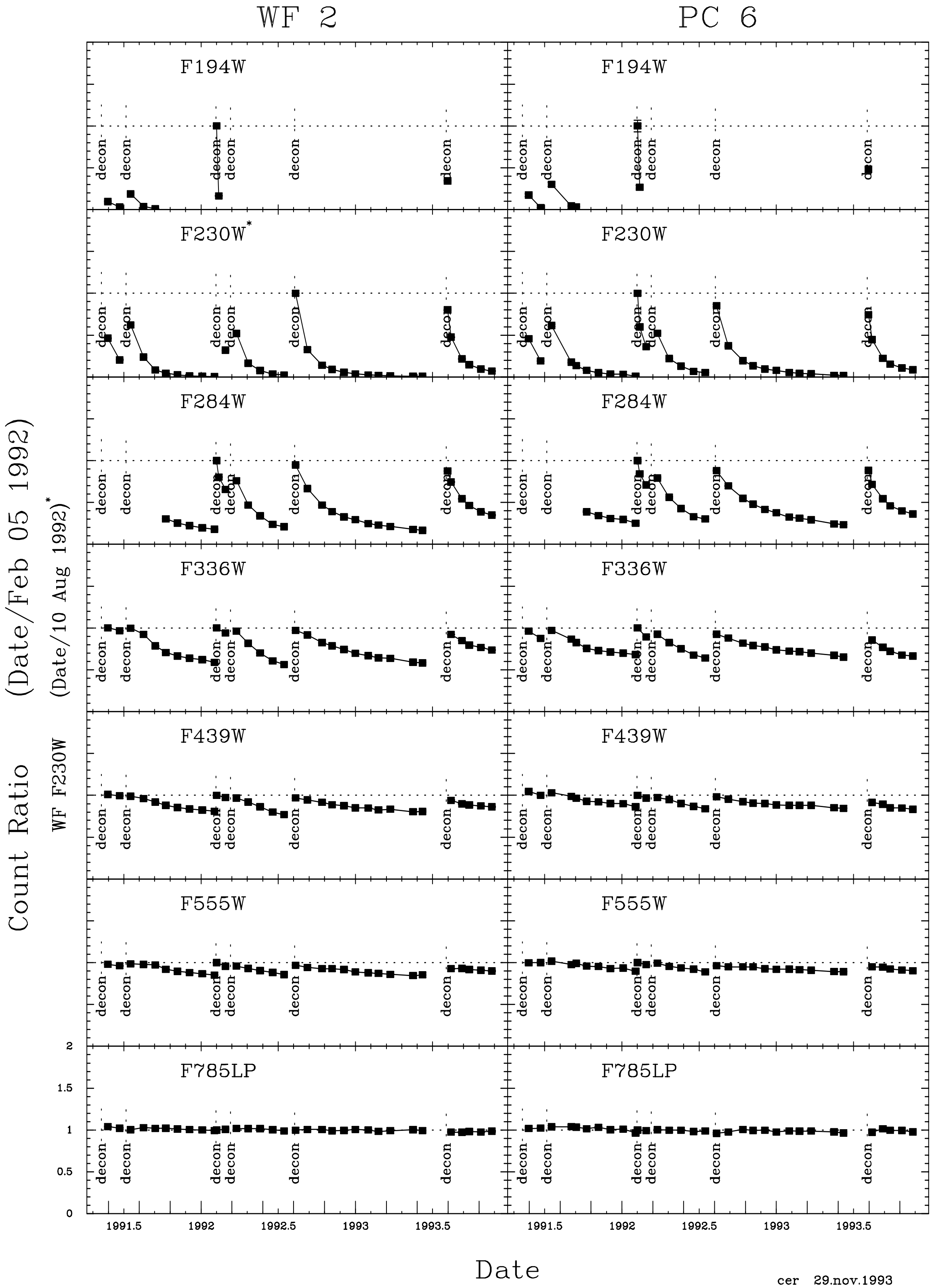
The absolute sensitivity does not account for the temporal variations in throughput which follow each decontamination. Contamination is—as discussed on page 21-2—the gradual buildup of contaminants after a decontamination procedure and gives rise to a corresponding decrease in photometric throughput over time. On-orbit observations indicate that the attenuation is apparent to at least 5000 Å. Figure 46.3 summarizes the photometric monitoring of BD+75D325 done in WF 2 and PC 6; counts for each date are normalized to those from a set of observations taken in February 1992 immediately following a decontamination procedure (except for WFC, F230W, which is ratioed to July 1991, which was about 10 days after a decontamination). Decontaminations are indicated with vertical, dotted lines.

Users should correct their fluxes for the decrease in sensitivity that may have occurred during the time between the observation and the decontamination done before the observation was taken.[3] (See the list of decontamination events in Table 46.1). The necessary correction can be estimated from Figure 46.3 or by using **synphot** (e.g., the **calcphot** task), which can now accommodate the time-dependent throughput via the CONTAM keyword which is specified as part of the OBSMODE (*WF/PC-1/WFPC2 Instrument Science Report* 96-02).

The absolute sensitivity calculation in WF/PC-1 is done assuming a flat spectrum (constant flux per wavelength); if the spectrum of the source is not flat, the STSDAS **synphot** package can be used to recalibrate the flux (see Chapter 3). Finally, corrections to the conversion factors (PHOTFLAM) may need to be applied if an alternate flatfield is used; use the photometry appropriate for the filter through which the observation was taken, regardless of the flatfield filter.

3. For more information about photometric modeling, see *WF/PC-1 ISR* 93-02.

Figure 46.3: Relative Quantum Efficiency Versus Time



46.8 PSFs

When dealing with the spherical aberration, point spread function (PSF) images are often an important element in the deconvolution of WF/PC-1 data. Characteristics of the WF/PC-1 PSF include:

- A sharp, 0.1 arcsecond radius core which contains about 15% of the energy.
- Broad, extended wings out to about 4".
- Strong position dependance due to camera vignetting.
- Wavelength dependance due to diffraction effects.
- Time variability due to dependance on the telescope's focus position.
- Shutter diffraction effects for exposures of less than 1/2 second.
- OTA focus variations and image motion on short time scale (< 1 hour).
- Spacecraft jitter.

Ideally, PSFs should be observed in a variety of positions on each chip, in all filters used and close in time to the observation, a time-consuming process. In addition, the shorter exposures needed to avoid saturating the PSF cores generally provide insufficient S/N in the wings. For these reasons, model PSFs will generally be needed to supplement the available observed PSFs. The Tiny Tim software package, which can be used to generate model PSFs, is available at:

`http://scivax.stsci.edu/~krist/tinytim.html`

Observed PSF Library

Deconvolution of WF/PC-1 observations is supported through a library of observed WF/PC-1 point spread function (PSF) images that can be found in the STScI Calibration DataBase (CDBS). Rather than storing entire WF/PC-1 datasets that already reside in the HST Archive, the library consists of smaller (typically 256 x 256) sub-sections, usually centered on the PSF star. Any PSF can be retrieved from StarView in the same manner as reference files (the file type is `CDB`). A complete PSF image name consists of the PSF rootname as provided in DATA_FILE column of the tables in the WWW memo plus the suffixes `.r7h` for the ASCII header and `.r7d` for the binary data file. The memo listing all available observed PSFs in the library is regularly updated on WWW.

Header keywords from a typical PSF image are described in Table 46.3. The secondary mirror actuator position keywords were populated using the results presented in the *OTA Instrument Science Report #7*.

Table 46.3: PSF Header Keywords

Keyword	Sample Value	Definition
Keywords Listed in WWW Memo		
filtnam1	F785LP	First STSCI filter name
camera	PC	WF or PC
detector	6	1–4 for WF, 5–8 for PC
rootname	W0MN0A02T	Rootname of observation with PSF image
data_fil	C3U1428IW.R7H	Name of the PSF image file
targname	SAO107200	Target name
spectral	unknown	Spectral type of source, if known
exptime	0.23	Exposure time in seconds
date_obs	23/06/91	UT date
xcorner	502	X pixel of (1,1) corner in PSF image
ycorner	38	Y pixel of (1,1) corner in PSF image
xcenter	630	X coordinate of PSF center on the chip
ycenter	166	Y coordinate of PSF center on the chip
Keywords in Headers, but not Listed in WWW Memo		
filtnam2	F122M	Second STScI filter name
mode	FULL	Full or area
origin	HST	Data source, e.g., HST, TIM or other
mjd	48430.	Modified Julian date (JD-2400000.5)
calibrat	T	Was image calibrated (see Chapter 45)?
flatfile	c1916444w	Name of flatfield image (or INDEF)
psfscale	1.	Divisor used to normalize PSF (1 if none)
obsmode	PC,6,F,DN,F785LP	Observation mode (for **synphot**)
refspec	CRCALSPEC: AGK_81D266_002.TAB	Reference spectrum
actuat25	-1492	Position of secondary mirror actuator 25 (and actuator keywords 26 through 30)

PSF Limitations and Effect of Jitter

Due to the limited dynamic range of the WF/PC-1, observed PSFs that are properly exposed in the core will have low signal-to-noise in the wings and will not reflect the true PSF. In addition, exposures shorter than 0.17 second (*OV/SV Report*, Chapter 9, Faber et al., 1992) suffer from diffraction effects which are caused by the shutter obscuring some of the light beam during flight time.

Except for very short exposures, both the observed and modeled PSFs will not perfectly match WF/PC-1 images due to the *jitter* in the HST pointing. The jitter is primarily caused by the motion of the telescope in response to the solar array oscillations, and possibly oscillations of the aperture door and the high gain antennas as well (*SESD Report* 92-15). The effect is greatest during earth terminator crossings, but is present at other times as well. On April 12, 1992, software called *SAGA II* was installed to correct for some of the jitter, effectively reducing it by about 50%. That is, the rms jitter dropped from 17 mas to 7 mas entering orbital day and fell from 12 mas to 6 mas entering orbital night.

The effects of the remaining 5–10 mas jitter, while not predictable, can be partially determined for observations taken in Fine Lock, via some of the associated engineering data. (Note that this is engineering data which is not part of the standard WF/PC-1 image set; users must submit a special request to `help@stsci.edu` to obtain more information on a particular observation from the Observation Monitoring System[4].) For images obtained on Coarse Track, the effects of jitter can only be estimated.

46.9 Plate Distortion

Calibrated WF/PC-1 data from the pipeline are left with a residual geometric distortion; across a chip, from corner to corner, there is roughly a 1 pixel distortion in positional accuracy. This distortion can be removed, using the **wmosaic** task, which joins the four images into a single, correctly aligned and geometrically rectified, image; the residual distortion is about 0.1 pixels in both cameras. Note however, that **wmosaic** uses linear interpolation so the photometric accuracy of the image it produces is reduced. Thus, we recommend using the unrectified images for accurate photometry wherever possible. The task **metric** can be used to determine accurate RA and Dec for sources (correcting for the geometric distortion) directly from the uncorrected single chip images which make up the groups of the `.c0h` file. See “Basic Astrometry” on page 3-9 for more details.

46.10 Data Accuracies and Problem Solving

In this section we characterize the accuracy obtainable with WF/PC-1 data and suggest steps to take to achieve the best accuracy from the data. The table below summarizes the estimated calibration accuracies and the following sections offer some final suggestions on improving the calibration.*

4. This information became part of the standard pipeline products delivered with science data after June 1994.

Table 46.4: Estimated WF/PC-1 Calibration Accuracies

Attribute	Estimated Accuracy	Comments
Bias	0.2–0.3 DN	Files `d8c08261w`, `d8c0826nw`
Dark	~0.0006 DN/sec	Files `dac14274w`, `dae14273w`; worse on hot pixels
Preflash	~0.5 DN	Assuming 8 sec preftime for PC, 30 sec for WF (files `d8c0*`)
Flatfields, in general	~3%	Small scales (<<1”)
	~25–30%	scales > 1” if flat contains F122M or F8ND (includes most broad band filters)
	~5–10%	scales > 1” if flat contains no ND filter (includes most narrow band filters)
	~1–2%	scales > 1” if high-fidelity flat used
Flatfields, additional effects	up to 5–7%	Short exposure reciprocity problem, if flat and data have very different exposure times. To minimize, use flat with same exptime as data.
	~1% rms (4–5% peak)	Measle effects, partially correctible (see text)
	few percent	changes caused by decon; reduced with deltaflats
Relative photometry	5–30%	Depending on flat used
Absolute photometry	5–30%	*Strongly* dependent on flat used (see “Flatfield Anomalies” on page 46-7 and “Improving the Flatfield Correction” on page 46-15)
Plate Scale	WFC: 0.1016” +/- ~0.0001” PC: 0.0439” +/- ~0.0001”	

46.10.1 Improving Bias, Preflash, and Dark Calibration

- Near the end of the WF/PC-1 mission, high quality bias and preflash files were generated and installed in the archive; these are listed in the WWW Reference File memo. We suggest verifying that these were used in the calibration (e.g., BIASFILE, PREFFILE keywords) and if not, recalibrating.
- Check that the CTE correction was correctly applied for observations that were not preflashed. That is, the header keywords should be set as follows: PREFCORR=YES, PREFTIME=0, and PREFFILE=FILENAME. Note that the CTE correction was sometimes not applied where it should have been due to a bug in the PODPS pipeline. Use the preflash files that contain the updated versions of the CTE correction.
- Review the HISTORY records in the dark file used for calibration: Was it generated from individual dark frames taken close in time to the science image? If not, recalibrate with a more appropriate dark reference file from the Archive. If necessary, a new dark reference file can be generated for recalibration, by identifying dark frames that were taken close in time to the science data (e.g., with StarView), retrieving them from the Archive, then combining and normalizing them into a reference file for use in **calwfp**.

- If hot pixels are a concern, check the WWW memo for the locations of hot pixels or see the *WF/PC-1 Instrument Science Report* 93-02 for a discussion of the evolution and treatment of WF/PC-1 hot pixels.
- Verify the DARKTIME keyword value; for more accurate dark calibration, darktime value can be recomputed (*WF/PC-1 Instrument Science Report* 93-01). Also note that for interrupted observations (perhaps due to loss of lock), the dark current continues to accumulate even when the shutter was closed. A bug in the PODPS pipeline caused only the shutter open time to be used to compute the darktime.

46.10.2 Improving the Flatfield Correction

Apply a Delta Flat

A delta flat correction may be necessary if there was a decontamination procedure between the epoch of the flatfield and the epoch of the science data, particularly for PC8 data. One of the archived delta flats could be used or a new one created from individual internal flatfield exposures (see “Choosing and Generating Delta Flats” on page 45-18).

Experiment with Flatfields

After the end of the WF/PC-1 mission, Closure and high-fidelity flatfields, as well as deltaflats, were generated and archived; these flats cover ~85% of the nearly 8000 external WF/PC-1 science images in the archive. Any of these flats may be retrieved from the Archive and used for recalibrations; the reference file memo on WWW lists all of the WF/PC-1 reference files available from the archive. Small scale errors in the flatfields are normally around 3% (the high-fidelity flatfields are generally good to nearly 1%) while 10% errors can be expected on larger scales. In addition, those flatfields which were generated from Earth calibration observations taken with the neutral density filter F122M are known to have 25% gradients across the four WF CCDs. The following suggestions may improve the flatfielding.

- Select an alternate version of the flatfield used; many filter / camera combinations have more than one possible flatfield. Look for the *closure or high fidelity flatfields* (Cycle 2 and 3) which have been generated and installed in the Archive in 1994 or try the “Super-Sky Flatfields” from the MDS (Medium Deep Survey) group. The WWW memos provide pointers to all these files. Closure flatfields can be *back-corrected* with a delta flat and applied to data taken before August 1993. WWW memos are available at:

```
http://www.stsci.edu/ftp/instrument_news/WFPC/
wfpc1_memos.html
```

- Try a flatfield close in wavelength to the science observation; for example, use narrow band flatfields to flatfield images of emission line targets taken with broadband filters.

- Remove the neutral density filter pattern if the flatfield was taken with F122M or F8ND (or use high-fidelity flats). Alternatively, if a high signal to noise target is small and close to the center of particularly WF2 or PC6, the neutral density filter gradient may not be significant.

- Generate high-fidelity flatfields for those observation modes lacking such a flatfield; these would include WF in F439W, F702W, F547M, and others, as well as PC in F889N, F850LP, and F502N (the prospects for improving the UV flats are not good, since there are few or no on-orbit earthflats). For example, a F555W, WF high fidelity flat (accuracy better than 2%) can be computed by correcting the Closure F569W flatfield reference file for wavelength dependent effects; the correction is obtained from F122M filter Earth flats, since the F122M pattern varies slowly with wavelength. That is:

  newflat (F555W) = flat(F569W+F8ND) *
  [flat(F555W+F122M) / flat(F569W+F122M)]

  In this case the flats are Cycle 3 flats taken through the indicated filters. The ratio of the flats crossed with F122M corrects for any wavelength dependent effects between 555nm and 569nm, and is applied to the F569W+F8ND Earth flat, which is known to be quite good. In practice, this can be done by identifying the appropriate filenames using the WWW Closure Flatfield memo, retrieving them from the archive, and using **imcalc** to perform the computation. For example:

  ```
  imcalc input=e751348dw.r6h,e6d10291w.r6h,e6d1028sw.r6h output=newflat.r6h
  equals=”im1*im2/im3” pixtype=”real”
  ```

  The flatfield data quality file may be updated as well:

  ```
  imcalc input=e751348dw.b6h,e6d10291w.b6h,e6d1028sw.b6h output=newflat.b6h
  equals=“max(max(im1,im2),max(im2,im3))” pixtype=”short”
  ```

- Account for exposure time dependencies in the flatfields, which can be a signficant effect; for example, we have found that flatfields based on Earth flats with exposures shorter than 1 sec, when applied to science exposures much longer than 1 sec, will result in 5–7% errors. As noted in their header HISTORY records, the input flats used in the example above (e75*, e6d*) were generated from Earth flat exposures which were ~8 sec long and so, the resulting flat is optimized for long exposures. The flatfield can, however, be optimized for short exposures by including a wavelength-independent correction factor; in this case, the factor can be determined from the F588N+F122M Closure flatfield (generated from 400 sec Earth flats) and the F588N Closure flatfield (generated from 0.18 sec F588N Earth flats). That is:

  newflat(F555W,short) = newflat(F555W)*[flat(F588N)*flat(F569W+F122M)] /
  [flat(F588N+F122M)*flat(F569W+F8ND]

  In this case, newflat(F555W,short) is the new flatfield appropriate for short exposures, newflat(F555W) is the flatfield computed in the previous step, and the other flatfields are Closure flatfields taken through the noted filters. This final high-fidelity flatfield can then be used directly in calwfp. In a similar manner, Closure flatfields based on short exposure times could be optimized for longer exposure times.

- Also be aware that many of the raw earth observations (from which the flatfield reference files are generated) and the INTFLATs (from which the delta flats are generated) contain small numbers of cosmic rays.
- Check for features in the flatfield which could degrade the science data; the delta flats may be used to identify the positions of measles.

46.10.3 Improving the Photometric Calibration

The resultant relative photometry at visible and far-red wavelengths should be good to 5–15% in the PC and WF2, and 10–30% for the full field of the WFC. Somewhat better accuracy is possible for narrow and medium band filters if the flats were not observed through neutral density (ND) filters; in these cases, the accuracy will be around 5–10% for all cameras. If core photometry is used in conjunction with a linear magnitude correction (*WF/PC-1 ISR* 92-02), and corrections are made for throughput variations and flatfield problems (ND filter gradients, edge droop, measles, etc.), an accuracy around 3–5% should be possible. The accuracy for absolute photometry will ultimately be limited by the accuracy of the absolute calibration, which is around 5% (see *WF/PC-1 ISR* 92-09).

- The uniform contamination layer has been shown to decrease the throughput in F555W by 10–15% about 6 months after a decontamination procedure; the degradation is worse toward blue. The effects can be corrected one of two ways:
  - Read the correction from the plots of the stellar monitoring results. (See Figure 46.3 and *WF/PC-1 ISR* 93-02).
  - Use the CONTAM keyword in **synphot**, which uses the date of the science observation to interpolate between data points in the CDBS stellar photometry table to arrive at the correction (see *WFPC ISR* 96-02).
- The uniform layer of contamination is also known to scatter and absorb light. This scattered light effect is particularly evident in the Earth observations (from which the flatfield reference files are generated) and in the internal flats (from which the delta flats are generated) as an edge-droop. Due to the different illumination pattern, the edge-droop is not likely to be present to the same extent in the science observation.
- The non-uniform contamination (persistent measles) will have small scale effects (2–5%) which may be partially corrected with the application of a delta flat.
- Note that the WF/PC-1 photometric calibration, in the form of the STSDAS Synphot tables, is based on the Cycle 1 (SV) flats and standard star observations made during Cycle 1 (the contamination correction tables *have* been updated through the end of the mission and may be used to estimate the

effect of the contamination layer). If the data has been recalibrated with the improved reference files discussed in previous sections, and the photometric information in the header keywords (e.g., PHOTFLAM) will be used, the synphot tables should be updated in order to make them consistent with the closure flatfields. The updates would require measuring statistics on all the final flatfields and adjusting the tables accordingly, before running **calwfp** or **synphot**. An ideal set of calibration data with which to verify any changes made would be the photometric sweep (proposal #4785), which was taken near the end of the WF/PC-1 mission.