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Chandra Long-Term Trending and Prognostication Tools

Bradley D. Spitzbart and Scott J. Wolk

Chandra X-ray Center, Smithsonian Astrophysical Observatory, 60 Garden St., Cambridge, MA 02138, USA

Abstract. The *Chandra X-Ray Observatory* was launched in July 1999, and is thus in its fifth year on-orbit. The Monitoring and Trends team at the *Chandra X-Ray Center* (CXC) is charged with tracking observatory performance parameters to optimize the mission's science return. We have built from scratch an IDL-based system, called "dtrend" (derivative trending), for visualizing and quantifying long-term trends. Data are input from our databases of over 600 engineering mnemonics, averaged on 5 minute intervals over the course of the entire mission. Dtrend computes the mean, standard deviation, first derivative and second derivative for each parameter. The derivatives are then used to predict the next 6 month cycle. Output is presented via web pages with statistical summary tables and graphics color-coded to highlight threat level or potential problems. This paper will discuss the algorithms and metrics used to predict future behavior based on previous trends and how the CXC can efficiently identify, track, and possibly curtail problems to extend the length and quality of the *Chandra* science mission.

1. Overview

The *Chandra* Monitoring and Trends Analysis (MTA) team is part of the Science Operations Team and works with the Flight Operations Team engineers to identify and monitor problems on-board and to ensure the continued, efficient, and safe operation of the Observatory. We monitor and report limit violations on a daily, weekly, monthly, and mission-length basis. MTA uses automated e-mail alerts, web pages and an SQL database to report and track any and all limit violations (Spitzbart 2002; Wolk 2002). Several problems, such as changes in thermal control, are currently known and could lead to compromised or at least altered instrument performance. Therefore it is becoming increasingly important to understand the sense and prognosis of any anomalies and to have metrics to track them. Herein the focus is on tools that plot trending and predictions for various Chandra subsystems over the long-term.

2. Software Design

Trending is run on a subset of the subsystems each night so that all the mnemonics are updated once a week. The schedule is balanced so that the software is

Table 1. General dtrend processing steps.

1	Extract new data from MTA databases using DataSeeker (5 minute averages).
2	Compute 1 hour averages (for faster run times and compressed storage), merge with previous data.
3	Read merged data into IDL.
4	Apply filters (e.g. 3-sigma clipping, handle NaNs and missing data).
5	Look-up defined limits to color-code output.
6	Scatter plot each data column.
7	Apply smoothing and calculate derivatives.
8	Overplot smoothed curve (blue) and fit line (color-coded by limits).
9	Overplot 6 month extrapolation.
10	Plot derivative.
11	Overplot fit line (second derivative).
12	Produce html statistical summary page.

active for about 4 hours each night. We have chosen a homegrown system to fit our very customized needs and for easy maintainability.

2.1. Processing Steps

Input comes from the MTA database of 5-minute averaged values through the DataSeeker interface (Overbeck 2002). DataSeeker can read from either the pipeline produced SQL database or from RDB text files. We use the RDB tables to prototype new tables or add additional data not yet available from the pipeline. DataSeeker can select data from user-specified time ranges or based on specific spacecraft states, then will merge data columns across different tables and deliver a FITS or RDB file. Our automated processing uses the command line version of DataSeeker, while a web-based interface is also available.

Processing is done with IDL code to take advantage of built-in or readily available FITS I/O, statistical, and plotting routines. Table 1 lists the key steps involved. Note, default values are listed for all constant parameters, such as sigma clipping level and extrapolation time frame, in this description. The code gives control of these values to the user through keywords.

Output is to World Wide Web pages for easy user access. See section 3.

2.2. Algorithms

We employ a simple boxcar algorithm for smoothing and derivative calculation. For each data point,(x_0, y_0), a least squares linear fit, $f(x) = m_0 x + b_0$, is computed to the subset of data points within some range ($|x - x_0| < r$, nominally $r = 30$ days). Thus, m_0 defines our instantaneous slope or derivative at that point. The data value interpolated from the fit at that point gives our smoothed curve. A straight line fit on the derivative array gives us a single metric to call

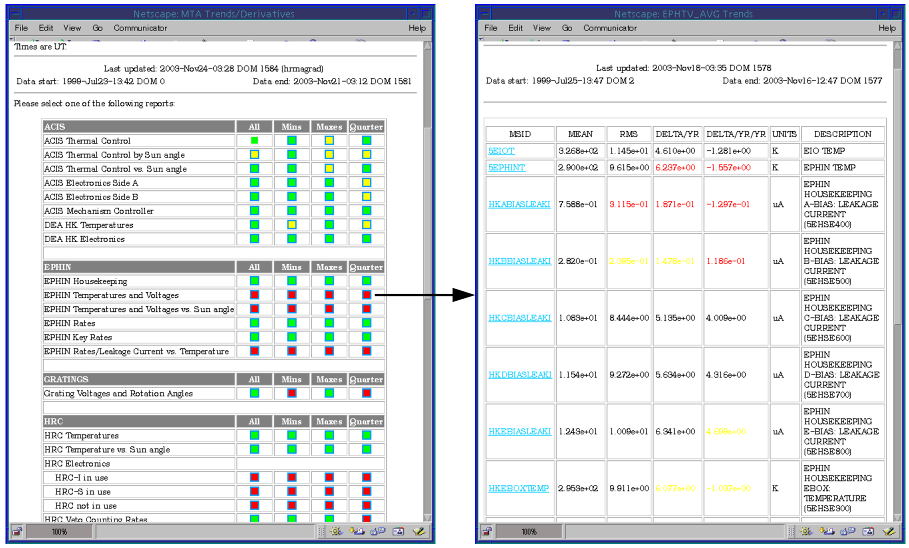

Figure 1. Example dtrend summary pages. Note columns 4 and 5 on the right, which show the linear fit slope of the data (first derivative) and the fit to the "instantaneous" slopes (second derivative), respectively.

the second derivative. With the first and second derivatives we can extrapolate out some length of time (nominally 6 months) to look for future limit violations.

3. Data Output/User Interface

The URL for SOT Trending is `http://cxc.harvard.edu/mta/DAILY/mta_deriv`.

Figure 1 shows example summary pages. On the left is the trending top level page. Here we present a table listing all the trended subsystems with links to the available analyses (total, daily minimum, daily maximum, and past quarter). The links are color-coded green, yellow, and red based on limit violations seen in the underlying pages to quickly identify the problem areas.

On the right is a subsystem summary and statistics page. Each link from the top level page expands to a statistical summary page. Here we list for each mnemonic the calculated mean, standard deviation, first derivative, and second derivative. These values are color-coded to easily identify the current or future problem areas. We also list units and a description of each mnemonic extracted from the limits look-up file for reference.

Figure 2 shows examples of our pop-up plotting windows. Each mnemonic links to a plot of the data. The top panel in each shows a scatter plot of the data with smoothed curve (blue) and fit line overplotted. Note the six month extrapolation plotted based on the second derivative. Any out-of-limit values are indicated with yellow or red colors.

There are several types of profiles commonly seen: On the left is a linear fit, $f(x) = mx + b$, for simple cases or as a first step in cases not yet understood.

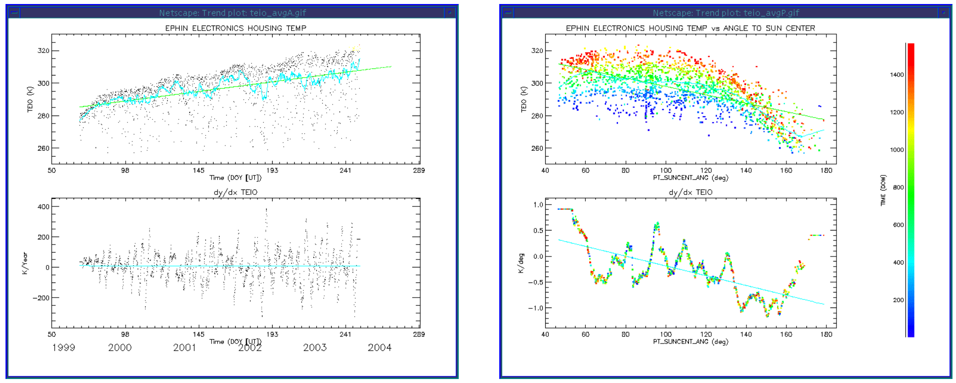

Figure 2. Examples of mnemonic vs. time (left) and correlation (right) plots. Each shows cleaned data, smoothed curve, and fit line on top along with first and second derivatives in bottom panel. The time-dependant plot has a six month extrapolation while the correlation features a color bar to indicate time.

The right-hand figure shows that we do not have to plot only versus time. Here we show temperature versus sun angle, with time indicated by the color of the data points. It is clear that the EPHIN housing heats up most at forward-sun attitudes, but the problem is getting worse over time due to the deterioration and darkening of insulating materials. This profile may be best fit with a higher order polynomial or exponential decay model, such as $f(x) = ax^2 + bx + c$ or $f(x) = (m_0x + b_0)\exp(\omega x) + (m_1x + b_1)$.

Other subsystems show more complicated structures, with multiple components. Solar array voltages, for instance, show an overall decreasing linear or exponential trend as well as seasonal sinusoidal variations. By carefully fitting both of these elements with something like $f(x) = (m_0x+b_0)\sin(\omega x)+(m_1x+b_1)$, we can glean more information on the system's behavior and better estimate its future performance.

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