Signal Time of Arrival based on the Kolmogorov-Smirnov Test

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J. C. Orum

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Algorithm Name

Time of arrival based on a Kolmogorov-Smirnov goodness-of-fit hypothesis test, or simply: time of arrival, KS method.
Implemented as Matlab programs `toa_ks`, `toa_ks_plots`, which do the same thing, but without and with plots respectively.

Author: Chris Orum
Affilitaion: Los Alamos National Laboratory, Statistical Sciences, D-1
Contact information: orumc@lanl.gov, 606-0480
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Status: short time-scale exploratory research; extendable.

The algorithm described here has its origins in the DDMA Threaded Assembly Workshop held in Santa Fe, Oct. 30 through Nov. 1, 2005.

Description

The algorithm takes as input a vector of data values which contains an initial segment of noise followed by the arrival of a signal. The algorithm returns an estimate of the time of arrival of the signal along with a binary random variable `conf` indicating the credibility of the estimate: $\mathsf{conf} = 1$ indicating a level of confidence, $\mathsf{conf} = 0$ indicating no confidence in the estimate.

For the purpose of describing the algorithm we use the notation

$$X_1, X_2, X_3, \ldots, X_{30,000} \tag{1}$$

for the recorded amplitudes, and use the indices to describe time. An interval of time indices $\{a, a+1, \ldots, b\}$ is denoted $[a, b]$. "Data" generally refers to the recorded amplitudes, although the actual data is the vector $(X_1, X_2, X_3, \ldots)$ and a vector of real time values $(T_1, T_2, T_3, \ldots)$.

The algorithm works by assuming that the signal arrives after an initial period in which the data points are independent and normally distributed (i.e. discrete white noise), or that actual data are the realization of a Gaussian or more general stochastic process for which this is a reasonable approximation. The change point τ is treated as a random variable that is to be estimated from the data, and that it is known that $\tau > N$ for some N:

$$\underbrace{X_1, X_2, \ldots, X_{\tau-1}}_{\text{noise}}, \underbrace{X_\tau, X_{\tau+1}, X_{\tau+2}, \ldots}_{\text{noise and signal}}. \tag{2}$$

Our estimate of τ is denoted $\widehat{\tau}$. It is computed by first applying the Kolmogorov-Smirnov test on increasing initial segments of the data

$$[1,k], [1,k+1], \ldots \quad k \geq N \tag{3}$$

suitably normalized. This is a hypothesis test that the data are independent samples from a $\mathcal{N}(0,1)$ distribution; rejection is supposed to indicate that the onset of the signal has already occurred. The normalization is as follows: let $Y_i^{(n)}, i = 1, \ldots, n,\ n > N \approx 200$ denote elements in a triangular array whose nth row is defined by

$$Y_i^{(n)} = \frac{X_i - \bar{X}}{\hat{\sigma}_n}, \quad 1 \leq i \leq n. \tag{4}$$

Here

$$\bar{X} = \frac{1}{n} \sum_{i=1}^{n} X_i$$

denotes the sample mean and $\hat{\sigma}_n = \hat{\sigma}(X_1, \ldots, X_n)$ the sample standard deviation, based on the first n data points. Then each row contains entries that are distributed approximately $\mathcal{N}(0,1)$.

Note: even if the X_n were independent draws from a normal $\mathcal{N}(\mu, \sigma^2)$ distribution, the $Y_i^{(n)}$ would not really be $\mathcal{N}(0,1)$ because the data are used to estimate the mean and variance; the result is related to a t-distribution. However, the normal approximation is used because (i) it is completely dominated by other approximations made in fitting the real world data into this framework, (ii) in the hypothesis test the significance level α is very small, so that *extreme* departures from normality are required for the null hypothesis to be rejected.

By itself this test has an inherent detection delay. That is, if we let $t(\alpha)$ denote the rejection time at confidence level α (the time that the null hypothesis of normality is rejected at a certain confidence level α) then for the values of α typically operative in the algorithm, $\alpha \approx .00005$, we observe that $t(\alpha) > \tau$. To accommodate this, the estimator $\widehat{\tau}$ is computed by a subroutine that finds when the normalized data first gets above and stays above a certain threshold in the interval $[1, t(\alpha)]$ (the last exit time for a certain threshold value). The subroutine is this: let

$$Z_n = Y_n^{(n)}, \quad n = N, \ldots, t(\alpha) \tag{5}$$

and compute

$$\widehat{\tau} = \inf\big\{i \in [N, t(\alpha)] : |Z_i|, |Z_{i+1}|, \ldots, |Z_{t(\alpha)}| > \beta^{-1}|Z_{t(\alpha)}|\big\}. \tag{6}$$

Here β^{-1} is a factor going into computation of the threshold: typically $\beta \approx 5$.

The algorithm is not robust against departures from the white noise assumption on the data. In real world noise, patterns do appear which can look like the onset of a signal leading to $\widehat{\tau}$ being much sooner than the actual τ. In order to assess the confidence of the estimate $\widehat{\tau}$ the following test is performed based on mixing the data with a white noise process and recomputing:

$$X_i' = \frac{1}{2}(X_i + \xi_i), \quad \xi_i \sim \mathcal{N}(0, \hat{\sigma}_{\widehat{\tau}}), \quad \xi_1, \xi_2, \ldots \ \textit{i.i.d.} \tag{7}$$

Here $\hat{\sigma}_{\widehat{\tau}}$ is the sample standard deviation of $X_1, \ldots, X_{\widehat{\tau}}$. This is supposed to double the noise to signal ratio. Let $\widehat{\tau}_1$ denote the new estimate of τ but using the modified data

$$X_1', X_2', X_3', \ldots \tag{8}$$

and the same algorithm described above. If $\widehat{\tau}_1$ is not too different than $\widehat{\tau}$ the estimate $\widehat{\tau}$ is considered good and confidence is reported along with $\widehat{\tau}$. If $\widehat{\tau}_1$ is much different that $\widehat{\tau}$ then $\widehat{\tau}$ is reported along with an indication of no confidence, meaning that the data needs closer examination. The cut-off between close and not close is somewhat arbitratry: currently it is based on $t(\alpha)$. Confidence is reported according to the indicator function

$$C = \mathbf{1}[\widehat{\tau}_1 \le t(\alpha)].$$

Mathematical Principles

The Kolmogorov-Smirnov test statistic is the largest absolute difference between the empirical distribution function $\hat{F}_n(x)$ of the samples $X_1, \ldots, X_n$ and the hypothesized distribution $F_0(x)$:

$$D_n = \sup_{-\infty < x < \infty} \big|\hat{F}_n(x) - F_0(x)\big|. \tag{9}$$

An example of an empirical cumulative distribution function (stair-step) and the normal cumulative distribution function is shown in Figure 1. It is a theorem that D_n is independent of $F_0(x)$. The large sample behavior D_n has been studied: $\sqrt{n}D_n$ has a limiting distribution under the null hypothesis [1, p. 379].

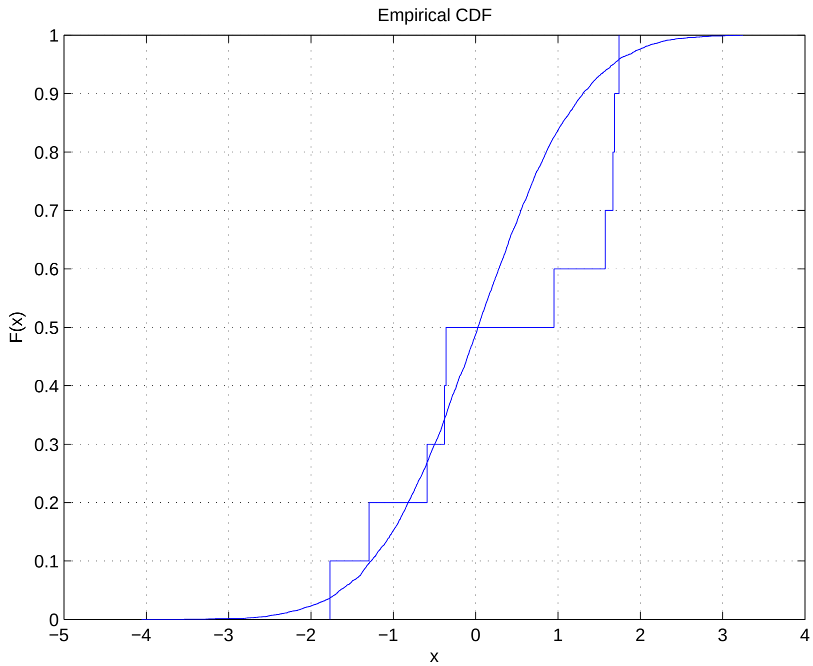

Figure 1: Example of an empirical cumulative distribution function $\hat{F}_n(x)$ (stair-step) and normal cdf. The test statistic D_n is the absolute value of the largest vertical distance between the normal cdf and empirical cdf. Here n is the number of data points used in computing $\hat{F}_n(x)$.

Illustration of Algorithm

Figure 2 shows an example of the computation of $t(\alpha)$ (top arrow), which is the value of k where the Kolmogorov-Smirnov hypothesis test first indicates that the normalized data $Y_1, \ldots, Y_k$ are not standard normal at significance level α. (That is, D_n as illustrated in Figure 1 is large enough so that the null hypothesis of $Y_1, \ldots, Y_k$ being standard normal is rejected. Here α is set very low (e.g. $\alpha = .00005$) to ensure that spurious things in the data do not give a false indication of "onset of signal". That would happen with the traditional $\alpha = .05$. Also shown is the estimate $\widehat{\tau}$ (lower arrow) where the absolute value of the normalized data $|Z_i|$ first gets above and stays above a certain threshold. (This is illustrated in Figure 3.) Thus $\widehat{\tau}$ is backed-off from $t(\alpha)$. Note that $t(\alpha)$ is computed with $Y_1, \ldots, Y_k$ as k increases, while $\widehat{\tau}$ is computed with $Z_N, \ldots, Z_{t(\alpha)}$.

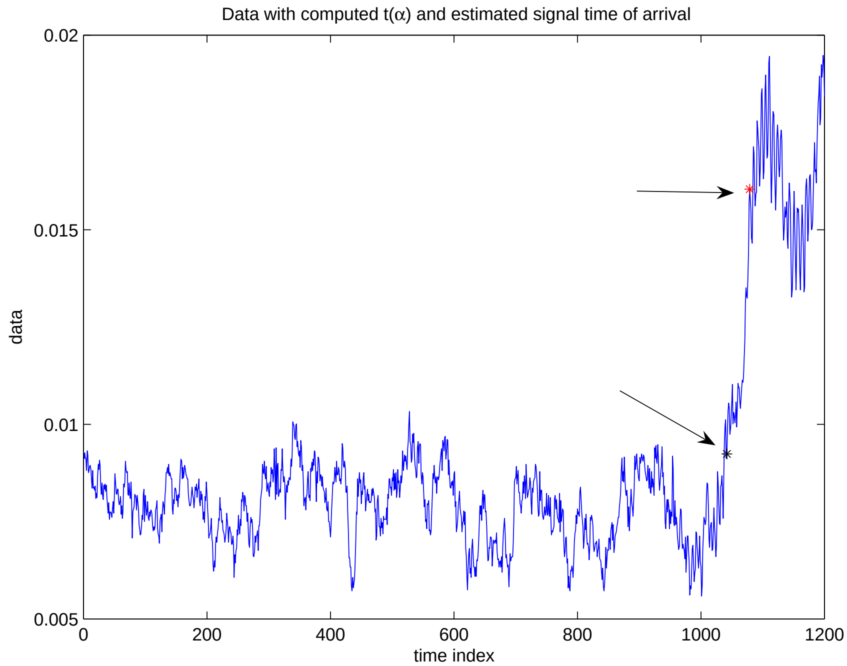

Figure 2: The minimal k for which the null hypothesis (regarding $Y_1, \ldots, Y_k$) is rejected at significance level $\alpha = .00005$ is denoted $t(\alpha)$. The estimated time of arrival $\widehat{\tau}$ is somewhat earlier. Data set: SG304T32XRAW

Figure 3 shows $|Z_n|$ for $n > N = 200$. (Here N is a time index for which it is known that $\tau > N$.) We have defined

$$Z_n = Y_n^{(n)}, \quad n = N, \ldots, t(\alpha). \tag{10}$$

The upper arrow points to $\big(t(\alpha), Z_{t(\alpha)}\big)$. The threshold is $\beta^{-1} Z_{t(\alpha)}$. The lower arrow points to where the sequence $Z_N, \ldots, Z_{t(\alpha)}$ first gets above and stays above this threshold. The time of this occurrence is the estimated time of arrival: $\widehat{\tau}$.

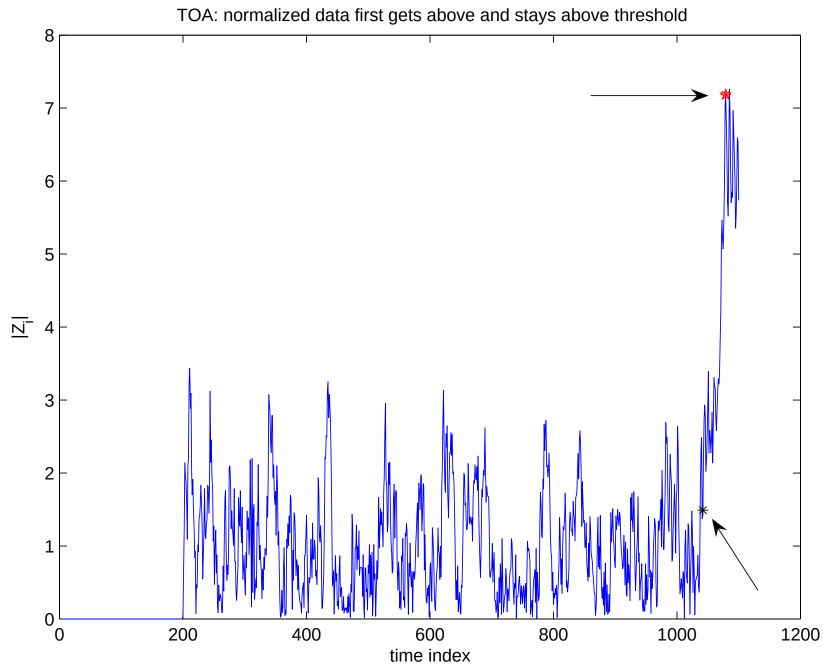

Figure 3: The estimate $\hat{\tau}$ is made by finding where $|Z_n|$ first *exceeds and stays above the threshold* $\beta^{-1} Z_{t(\alpha)}$. Here $\beta = 5$.

Figure 4 shows a confidence check on the estimate $\hat{\tau}$. The same procedure that is illustrated in Figure 2 is repeated, but this time with the data and added noise. The lower arrow points to $\hat{\tau}_1$. Since this has not moved too much from the original $\hat{\tau}$, (i.e. it does not exceed the value of $t(\alpha)$ computed from the original data) the estimate is considered stable and confidence is indicated. The idea here is that the original $\hat{\tau}$ could be far too early due to spurious patterns in the noise, and this would be washed out with added noise, causing a large difference between $\hat{\tau}$ and $\hat{\tau}_1$. On the other hand if $\hat{\tau}$ is close to the real τ and if the signal to noise ratio is large, then added noise should not cause a large difference between $\hat{\tau}$ and $\hat{\tau}_1$.

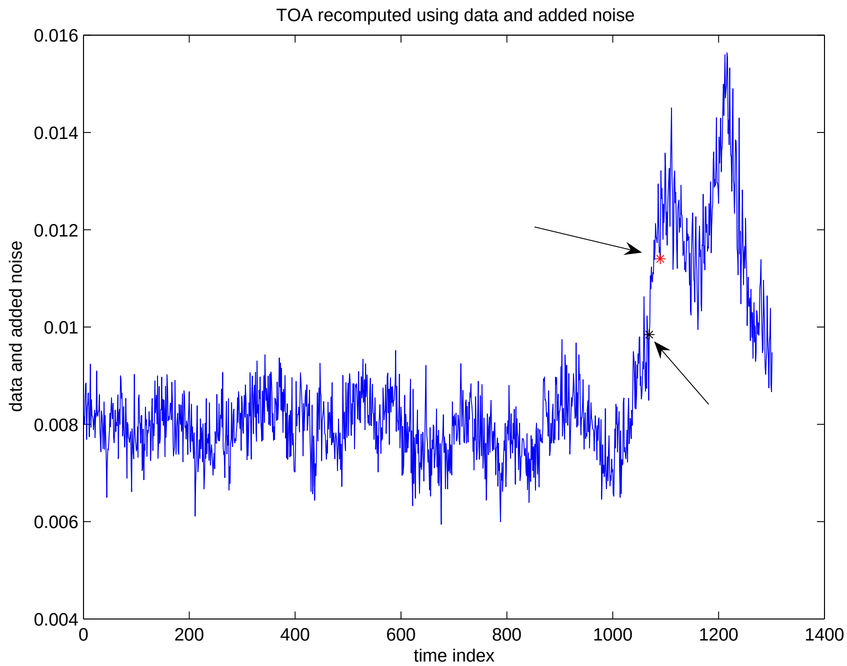

Figure 4: Using data with added noise, $t(\alpha)$ and $\widehat{\tau}$ are recomputed. These are denoted $t_1(\alpha)$ (top arrow) and $\widehat{\tau}_1$ (bottom arrow). Since $\widehat{\tau}_1 < t(\alpha)$ (not shown) the algorithm returns the original estimate $\widehat{\tau}$ along with $\mathsf{conf} = 1$.

Physical and Engineering Principles

A graph of the p-values from the Kolmogorov-Smirnov test on the normalized data sets

$$\{Y_1^{(n)}, \ldots, Y_n^{(n)}\} \tag{11}$$

as a function of n, typically shows that the p-values make a final sharp drop to zero at the onset of the signal. This illustrates one reason for setting the significance level α so low: this final drop is captured with a low value of α, with less probability of error, than with a higher value of α.

Similarly there is typically a sharp rise in the values of

$$|Z_N|, \ldots, |Z_i|, |Z_{i+1}|, \ldots, |Z_{t(\alpha)}| \tag{12}$$

right at the signal onset. (See Figure 3). In this situation the algorithm is fairly robust against changing β. For example, here are computations with the data set SG403T22XRAW using different values of β:

$$\begin{array}{lll}
\beta = 2 & \widehat{\tau} = 664 & \widehat{\tau}_1 = 667 \\
\beta = 3 & \widehat{\tau} = 662 & \widehat{\tau}_1 = 664 \\
\beta = 4 & \widehat{\tau} = 660 & \widehat{\tau}_1 = 662 \\
\beta = 5 & \widehat{\tau} = 660 & \widehat{\tau}_1 = 663 \\
\beta = 6 & \widehat{\tau} = 660 & \widehat{\tau}_1 = 662 \\
\beta = 7 & \widehat{\tau} = 660 & \widehat{\tau}_1 = 662 \\
\beta = 8 & \widehat{\tau} = 660 & \widehat{\tau}_1 = 663 \\
\beta = 12 & \widehat{\tau} = 659 & \widehat{\tau}_1 = 660
\end{array}$$

However, β is still a parameter that may be adjusted.

Usage

[t, conf, tn] = toa_ks(data, beta, N, upper)
[t, conf] = toa_ks(data, beta, N, upper)

toa_ks_plots does the same thing as toa_ks except it also draws plots. Use toa_ks_plots for individual data set analysis.

The inputs:

data is the vector of data values $X_1, X_2, X_3, \ldots, X_{30,000}$.
beta is β, the threshold factor ≈ 5; see equation (6).
N is N, a time point for which it is known that $\tau > N$.
upper is an estimate of how far the algorithm should look for τ, that is upper should be set (with a good guess) so that $\tau <$ upper, and not too much above τ in order to save on computation. However, if upper is set too low, the algorithm automatically adjusts it upward.

The outputs:

toa_est is $\widehat{\tau}$, the estimate of τ, the index where the onset of the signal occurs.
conf is a zero-one indicator of the confidence of the estimate t: conf = 1 indicates a level of convidence.
tn is $\widehat{\tau}_1$, the recomputed value of toa_est, using noise added to the signal. It is an optional part of the output and gives somewhat more information than conf alone, in that a small difference between toa_est and tn indicates the results are robust against the addition of the noise.

Note that both tn and conf are random, in that they are based on simulation: noise is added. But they tend to be stable because of the central limit theorem.

References

[1] Peter J. Bickel and Kjell A. Doksum. *Mathematical statistics*. Holden-Day Inc., San Francisco, Calif., 1976. Basic ideas and selected topics, Holden-Day Series in Probability and Statistics.

Matlab code

Code for toa_ks

```
function [toa_est, conf, tn] = toa_ks(data, thresh_factor, N , upper)
% TOA_KS returns an estimate of the time of arrival of a
% signal within a data set along with an indication
% of the credibility of the estimate in the form of the
% binary variable CONF. Chris Orum (606-0480) orumc@lanl.gov.
%
% USAGE
% [toa_est, conf ] = toa_ks(data, thresh_factor, N , upper)
% [toa_est, conf, tn] = toa_ks(data, thresh_factor, N , upper)
%
% NOTE: Comments in code refer to pdf file Toaks.pdf;
% the LaTex $...$ refers to variables explained in Toaks.pdf
%
% INPUTS
%
% DATA is the vector of data values
% $X_1$, $X_2$, $X_3$ ...
%
% BETA is $\beta$, the threshold factor.
% Should be set to somewhere around BETA = 5.
%
% N is $N$, a time point for which it is known
% that $\tau > N$. Here $\tau$ is the signal onset,
% estimated by output TOA_EST.
%
% UPPER is an estimate of how far the algorithm should
% look for $\tau$, that is UPPER should be set
% (with a good guess) so that $\tau < UPPER,
% and not too much above $\tau$, in order to
% save on computation. However, if UPPER is set too low,
% the algorithm automatically adjusts it upward.
%
% OUTPUTS
%
% TOA_EST is $\widehat{\tau}$, the estimate of $\tau$,
% the index where the onset of the signal occurs.
%
% CONF is a zero-one indicator of the confidence
% of the estimate TOA_EST: CONF = 1 indicates a level
% of convidence.
%
% TN is $\widehat{\tau}_1$, the recomputed value of
```

```
% TOA_EST, using noise added to the signal. It is an optional
% part of the output and gives somewhat more information
% than CONF alone, in that a small difference between
% TOA_EST and TN and indicates the results are robust against
% the addition of the noise.
%
% Note that both TN and CONF are random, in that they
% are based on simulation: noise is added.  But they tend
% to be stable because of the central limit theorem.

% t_a is $t(\alpha)$:
t_a = [];
while isempty(t_a),
    p = zeros(1,upper);
    h3 = zeros(1,upper-N+1);
    % norm_data_initial will be filled in with the values
    % $Z^{(k)}_k$ for k = N,...,UPPER
    norm_data_initial = zeros(1,upper);
     for k = N:1:upper;
     % init is the vector [ $Y^{(k)}_1$, ..., $Y^{(k)}_k$ ]
     init = (data(1:k)-mean(data(1:k)) )./std(data(1:k));
     % norm_data_initial(k) is the value $Z^{(k)}_k$
     norm_data_initial(k) = init(k);
     % Kolmogorov-Smirnov test with indicated significance level
     % which is the third argument of KSTEST.
     [h3(k-N+1) p(k)] = kstest(init, [], .00005);
     end
    t_a = N-1+find(h3 ==1, 1);
    upper = upper + 100;
end
    % Find where norm_data_initial gets above
    % and stays above the threshold:
    thresh = abs(norm_data_initial(t_a))/thresh_factor;
    indices_over_thresh = ...
        find(abs(norm_data_initial(1:t_a)) > thresh);
    backoff = find(fliplr(indices_over_thresh) == ...
        (t_a:-1:t_a-length(indices_over_thresh)+1),1,'last');
    % t is the estimate $\widehat{\tau}$:
    toa_est = t_a - backoff + 1;

    % Figure out how much noise to add:
    s =std(data(1:toa_est));
    m=mean(data(1:toa_est));
    data = (data(1:2*upper)+ m+s*randn(2*upper,1))/2;

%%%%%%% Repeat with data with added Gaussian noise %%%
```

```
% t_an is $t_1(\alpha)$:
t_an = [];
while isempty(t_an),
    p = zeros(1,upper);
    h3 = zeros(1,upper-N+1);
    norm_data_initial = zeros(1,upper);
     for k = N:1:upper;
     init = (data(1:k)-mean(data(1:k)) )./std(data(1:k));
     norm_data_initial(k) = init(k);
     h3(k-N+1) = kstest(init, [], .00005);
     end
    t_an = N-1+find(h3 ==1, 1);
    upper = upper+101;
end
    % Find where norm_data_initial gets above
    % and stays above the threshold:
    thresh = abs(norm_data_initial(t_an))/thresh_factor;
    indices_over_thresh = ...
        find(abs(norm_data_initial(1:t_an)) > thresh);
    backoffn = find(fliplr(indices_over_thresh) == ...
        (t_an:-1:t_an-length(indices_over_thresh)+1),1,'last');
    % tn is $\widehat{\tau}_1$:
    tn = t_an - backoffn + 1;
    conf = (tn <= t_a);
```

Code for toa_ks_plots

```
function [toa_est, conf, tn] = toa_ks_plots(data, thresh_factor, N , upper)
% TOA_KS_PLOTS is the same as TOA_KS except it makes
% some plots as well.  Use TOA_KS for mass data analysis.
% Use TOA_KS_PLOTS for individual data set analysis.
%
% TOA_KS returns an estimate of the time of arrival of a
% signal within a data set along with an indication
% of the credibility of the estimate in the form of the
% binary variable CONF. Chris Orum (606-0480) orumc@lanl.gov.
%
% USAGE
% [toa_est, conf ] = toa_ks(data, thresh_factor, N , upper)
% [toa_est, conf, tn] = toa_ks(data, thresh_factor, N , upper)
%
% NOTE: Comments in code refer to pdf file Toaks.pdf;
% the LaTex $...$ refers to variables explained in Toaks.pdf
```

```
%
% INPUTS
%
% DATA is the vector of data values
% $X_1$, $X_2$, $X_3$ ...
%
% BETA is $\beta$, the threshold factor.
% Should be set to somewhere around BETA = 5.
%
% N is $N$, a time point for which it is known
% that $\tau > N$. Here $\tau$ is the signal onset,
% estimated by output T.
%
% UPPER is an estimate of how far the algorithm should
% look for $\tau$, that is UPPER should be set
% (with a good guess) so that $\tau < UPPER,
% and not too much above $\tau$, in order to
% save on computation. However, if UPPER is set too low,
% the algorithm automatically adjusts it upward.
%
% OUTPUTS
%
% TOA_EST is $\widehat{\tau}$, the estimate of $\tau$,
% the index where the onset of the signal occurs.
%
% CONF is a zero-one indicator of the confidence
% of the estimate TOA_EST: CONF = 1 indicates a level
% of convidence.
%
% TN is $\widehat{\tau}_1$, the recomputed value of
% TOA_EST, using noise added to the signal. It is an optional
% part of the output and gives somewhat more information
% than CONF alone, in that a small difference between
% TOA_EST and TN and indicates the results are robust against
% the addition of the noise.
%
% Note that both TN and CONF are random, in that they
% are based on simulation: noise is added.  But they tend
% to be stable because of the central limit theorem.

% t_a is $t(\alpha)$:
t_a = [];
while isempty(t_a),
    p = zeros(1,upper);
    h3 = zeros(1,upper-N+1);
    % norm_data_initial will be filled in with the values
```

```
    % $Z^{(k)}_k$ for k = N,...,UPPER
    norm_data_initial = zeros(1,upper);
     for k = N:1:upper;
     % init is the vector [ $Y^{(k)}_1$, ..., $Y^{(k)}_k$ ]
     init = (data(1:k)-mean(data(1:k)) )./std(data(1:k));
     % norm_data_initial(k) is the value $Z^{(k)}_k$
     norm_data_initial(k) = init(k);
     % Kolmogorov-Smirnov test with indicated significance level
     % which is the third argument of KSTEST.
     [h3(k-N+1) p(k)] = kstest(init, [], .00005);
     end
    t_a = N-1+find(h3 ==1, 1);
    upper = upper + 100;
end
    % Find where norm_data_initial gets above
    % and stays above the threshold:
    thresh = abs(norm_data_initial(t_a))/thresh_factor;
    indices_over_thresh = ...
        find(abs(norm_data_initial(1:t_a)) > thresh);
    backoff = find(fliplr(indices_over_thresh) == ...
        (t_a:-1:t_a-length(indices_over_thresh)+1),1,'last');
    % t is the estimate $\widehat{\tau}$:
    toa_est = t_a - backoff + 1;
    %plots:
    plot(data(1:upper),'b'); hold
    plot(t_a, data(t_a), 'r*');
    plot(toa_est, data(toa_est), 'k*'); hold
    title(...
    'data with t(\alpha) (top mark), estimate of \tau (bottom mark)');
    figure
    plot(1:upper-100,p),
    title('plot of p-values from KSTEST');
    figure
    plot(1:upper-100, abs(norm_data_initial)); hold
    plot(t_a, abs(norm_data_initial(t_a)), 'rp');
    plot(t_a, abs(norm_data_initial(t_a)), 'r*');
    plot(toa_est, abs(norm_data_initial(toa_est)), 'k*'); hold
    title('plot of the |Z_i|');

    % Figure out how much noise to add:
    s =std(data(1:toa_est));
    m=mean(data(1:toa_est));
    data = (data(1:2*upper)+ m+s*randn(2*upper,1))/2;

%%%%%%% Repeat with data with added Gaussian noise %%%
```

```
% t_an is $t_1(\alpha)$:
t_an = [];
while isempty(t_an),
    p = zeros(1,upper);
    h3 = zeros(1,upper-N+1);
    norm_data_initial = zeros(1,upper);
     for k = N:1:upper;
     init = (data(1:k)-mean(data(1:k)) )./std(data(1:k));
     norm_data_initial(k) = init(k);
     h3(k-N+1) = kstest(init, [], .00005);
     end
    t_an = N-1+find(h3 ==1, 1);
    upper = upper+101;
end
    % Find where norm_data_initial gets above
    % and stays above the threshold:
    thresh = abs(norm_data_initial(t_an))/thresh_factor;
    indices_over_thresh = ...
        find(abs(norm_data_initial(1:t_an)) > thresh);
    backoffn = find(fliplr(indices_over_thresh) == ...
        (t_an:-1:t_an-length(indices_over_thresh)+1),1,'last');
    % tn is $\widehat{\tau}_1$:
    tn = t_an - backoffn + 1;
    conf = (tn <= t_a);
    % final plot:
    figure
    plot(data(1:upper),'b'); hold
    plot(t_an, data(t_an), 'r*');
    plot(tn, data(tn), 'k*'); hold
    title('data with added noise, t_1(\alpha), and the recomputed estimate of \tau')
```

Results Format

Here is the format of the results given in the file on results:

name	$\widehat{\tau}$	conf	$\widehat{\tau}_1$	$T_{\widehat{\tau}}$
SG201T11XRAW	446	1	474	$7.4500e-05$
SG201T12XRAW	549	1	549	$8.4800e-05$
...				
SG202T11XRAW	359	0	484	$6.5800e-05$

Results

```
SG201T11XRAW     446 1    484   7.450000e-05
SG201T12XRAW     549 1    547   8.480000e-05
```

SG201T13XRAW	469	1	469	7.680000e-05
SG201T21XRAW	512	1	523	8.110000e-05
SG201T22XRAW	521	1	528	8.200000e-05
SG201T23XRAW	494	1	495	7.930000e-05
SG201T31XRAW	592	1	600	8.910000e-05
SG201T32XRAW	533	1	536	8.320000e-05
SG201T33XRAW	489	1	490	7.880000e-05
SG201T41ARAW	561	1	561	8.600000e-05
SG201T41BRAW	571	1	571	8.690000e-05
SG201T42XRAW	503	1	502	8.020000e-05
SG201T43XRAW	534	1	535	8.330000e-05
SG202T11XRAW	359	1	451	6.580000e-05
SG202T12XRAW	596	1	605	8.950000e-05
SG202T13XRAW	523	0	541	8.220000e-05
SG202T21XRAW	553	1	567	8.520000e-05
SG202T22XRAW	619	1	621	9.180000e-05
SG202T23XRAW	549	1	557	8.480000e-05
SG202T31XRAW	620	1	623	9.190000e-05
SG202T32XRAW	603	0	629	9.020000e-05
SG202T33XRAW	564	1	564	8.630000e-05
SG202T41ARAW	631	0	664	9.300000e-05
SG202T41BRAW	620	1	631	9.180000e-05
SG202T42XRAW	538	1	549	8.370000e-05
SG202T43XRAW	600	1	600	8.990000e-05
SG203T11XRAW	453	1	484	7.520000e-05
SG203T12XRAW	882	0	932	1.181000e-04
SG203T13XRAW	793	1	797	1.092000e-04
SG203T21XRAW	848	0	896	1.147000e-04
SG203T22XRAW	840	0	902	1.139000e-04
SG203T23XRAW	834	1	834	1.133000e-04
SG203T31XRAW	897	1	906	1.196000e-04
SG203T32XRAW	855	1	857	1.154000e-04
SG203T33XRAW	803	1	818	1.102000e-04
SG203T41ARAW	877	1	892	1.176000e-04
SG203T41BRAW	905	1	919	1.203000e-04
SG203T42XRAW	824	1	827	1.123000e-04
SG203T43XRAW	875	0	903	1.174000e-04
SG204T11XRAW	484	0	497	7.830000e-05
SG204T12XRAW	1005	1	1007	1.304000e-04
SG204T13XRAW	910	1	917	1.209000e-04
SG204T21XRAW	959	1	967	1.258000e-04
SG204T22XRAW	971	1	989	1.270000e-04
SG204T23XRAW	854	0	952	1.153000e-04
SG204T31XRAW	791	0	1033	1.090000e-04
SG204T32XRAW	991	1	991	1.290000e-04
SG204T33XRAW	947	1	949	1.246000e-04

SG204T41ARAW	998	1	998	1.297000e-04
SG204T41BRAW	1015	1	1026	1.313000e-04
SG204T42XRAW	952	1	954	1.251000e-04
SG204T43XRAW	821	0	993	1.120000e-04
SG205T11XRAW	423	0	485	7.220000e-05
SG205T12XRAW	759	0	909	1.058000e-04
SG205T13XRAW	827	1	841	1.126000e-04
SG205T21XRAW	836	1	841	1.135000e-04
SG205T22XRAW	853	1	869	1.152000e-04
SG205T23XRAW	818	1	820	1.117000e-04
SG205T31XRAW	790	0	908	1.089000e-04
SG205T32XRAW	865	1	870	1.164000e-04
SG205T33XRAW	821	1	821	1.120000e-04
SG205T41ARAW	874	1	876	1.173000e-04
SG205T41BRAW	899	1	920	1.197000e-04
SG205T42XRAW	839	1	845	1.138000e-04
SG205T43XRAW	852	0	876	1.151000e-04
SG206T11XRAW	412	1	485	7.110000e-05
SG206T12XRAW	615	1	626	9.140000e-05
SG206T13XRAW	542	1	543	8.410000e-05
SG206T21XRAW	573	1	586	8.720000e-05
SG206T23XRAW	569	1	572	8.680000e-05
SG206T31XRAW	652	1	651	9.510000e-05
SG206T32XRAW	600	1	613	8.990000e-05
SG206T33XRAW	554	1	562	8.530000e-05
SG206T41ARAW	630	1	636	9.290000e-05
SG206T41BRAW	651	1	652	9.490000e-05
SG206T42XRAW	551	0	580	8.500000e-05
SG206T43XRAW	601	1	610	9.000000e-05
SG301T11XRAW	337	1	343	6.360000e-05
SG301T12XRAW	550	1	554	8.490000e-05
SG301T13XRAW	471	0	494	7.700000e-05
SG301T21XRAW	513	1	517	8.120000e-05
SG301T22XRAW	518	1	528	8.170000e-05
SG301T23XRAW	504	1	503	8.030000e-05
SG301T31XRAW	248	0	579	5.470000e-05
SG301T32XRAW	539	1	541	8.380000e-05
SG301T33XRAW	511	1	513	8.100000e-05
SG301T41ARAW	554	1	553	8.530000e-05
SG301T41BRAW	574	1	577	8.720000e-05
SG301T42XRAW	489	1	500	7.880000e-05
SG301T43XRAW	533	0	551	8.320000e-05
SG302T11XRAW	331	1	347	6.300000e-05
SG302T13XRAW	544	1	545	8.430000e-05
SG302T21XRAW	638	1	640	9.370000e-05
SG302T22XRAW	590	1	597	8.890000e-05

SG302T23XRAW	580	1	581	8.790000e-05
SG302T31XRAW	723	1	732	1.022000e-04
SG302T32XRAW	608	1	611	9.070000e-05
SG302T33XRAW	570	1	570	8.690000e-05
SG302T41ARAW	608	0	641	9.070000e-05
SG302T41BRAW	632	1	641	9.300000e-05
SG302T42XRAW	529	1	531	8.280000e-05
SG302T43XRAW	595	1	598	8.940000e-05
SG303T11XRAW	358	1	363	6.570000e-05
SG303T12XRAW	862	1	873	1.161000e-04
SG303T13XRAW	644	0	834	9.430000e-05
SG303T21XRAW	1004	0	1235	1.303000e-04
SG303T22XRAW	994	1	1013	1.293000e-04
SG303T23XRAW	859	0	954	1.158000e-04
SG303T31XRAW	784	0	1083	1.083000e-04
SG303T32XRAW	965	1	1019	1.264000e-04
SG303T33XRAW	542	1	543	8.410000e-05
SG303T41ARAW	917	1	960	1.216000e-04
SG303T41BRAW	952	1	957	1.250000e-04
SG303T42XRAW	386	0	975	6.850000e-05
SG303T43XRAW	894	0	939	1.193000e-04
SG304T11XRAW	345	0	392	6.440000e-05
SG304T12XRAW	1067	1	1085	1.366000e-04
SG304T13XRAW	990	1	996	1.289000e-04
SG304T21XRAW	1038	1	1044	1.337000e-04
SG304T22XRAW	1036	1	1046	1.335000e-04
SG304T23XRAW	1027	1	1026	1.326000e-04
SG304T31XRAW	1085	0	1110	1.384000e-04
SG304T32XRAW	1042	1	1042	1.341000e-04
SG304T33XRAW	543	0	1011	8.420000e-05
SG304T41ARAW	1085	1	1091	1.384000e-04
SG304T41BRAW	1053	1	1083	1.351000e-04
SG304T42XRAW	217	0	1028	5.160000e-05
SG304T43XRAW	1055	1	1066	1.354000e-04
SG305T11XRAW	200	0	324	4.990000e-05
SG305T12XRAW	713	0	1209	1.012000e-04
SG305T13XRAW	200	0	886	4.990000e-05
SG305T21XRAW	200	0	1669	4.990000e-05
SG305T22XRAW	860	1	862	1.159000e-04
SG305T23XRAW	838	1	840	1.137000e-04
SG305T31XRAW	799	0	919	1.098000e-04
SG305T32XRAW	869	1	870	1.168000e-04
SG305T33XRAW	549	1	550	8.480000e-05
SG305T41ARAW	887	1	891	1.186000e-04
SG305T41BRAW	878	1	906	1.176000e-04
SG305T42XRAW	844	1	918	1.143000e-04

SG305T43XRAW	891	0	939	1.190000e-04
SG306T11XRAW	357	1	357	6.560000e-05
SG306T12XRAW	660	1	660	9.590000e-05
SG306T13XRAW	576	1	576	8.750000e-05
SG306T21XRAW	463	0	609	7.620000e-05
SG306T22XRAW	629	0	710	9.280000e-05
SG306T23XRAW	579	1	582	8.780000e-05
SG306T31XRAW	669	0	715	9.680000e-05
SG306T32XRAW	640	1	635	9.390000e-05
SG306T33XRAW	597	1	599	8.960000e-05
SG306T41ARAW	631	0	685	9.300000e-05
SG306T41BRAW	643	1	644	9.410000e-05
SG306T42XRAW	608	1	613	9.070000e-05
SG306T43XRAW	608	1	632	9.070000e-05
SG401T11XRAW	490	1	490	7.890000e-05
SG401T12XRAW	644	1	650	9.430000e-05
SG401T13XRAW	536	1	542	8.350000e-05
SG401T21XRAW	669	1	670	9.680000e-05
SG401T22XRAW	572	0	619	8.710000e-05
SG401T23XRAW	552	1	556	8.510000e-05
SG401T31XRAW	733	1	741	1.032000e-04
SG401T32XRAW	581	1	602	8.800000e-05
SG401T33XRAW	557	1	559	8.560000e-05
SG401T41ARAW	572	0	615	8.710000e-05
SG401T41BRAW	668	1	672	9.660000e-05
SG401T42XRAW	561	1	562	8.600000e-05
SG401T43XRAW	592	1	592	8.910000e-05
SG402T11XRAW	330	1	364	6.290000e-05
SG402T12XRAW	667	1	669	9.660000e-05
SG402T13XRAW	406	0	563	7.050000e-05
SG402T21XRAW	665	1	666	9.640000e-05
SG402T22XRAW	640	1	640	9.390000e-05
SG402T23XRAW	578	1	581	8.770000e-05
SG402T31XRAW	749	1	754	1.048000e-04
SG402T32XRAW	628	0	711	9.270000e-05
SG402T33XRAW	578	1	575	8.770000e-05
SG402T41ARAW	597	0	635	8.960000e-05
SG402T41BRAW	691	1	691	9.890000e-05
SG402T42XRAW	585	1	585	8.840000e-05
SG402T43XRAW	615	1	616	9.140000e-05
SG403T11XRAW	417	0	488	7.160000e-05
SG403T12XRAW	684	1	684	9.830000e-05
SG403T13XRAW	579	1	580	8.780000e-05
SG403T21XRAW	697	1	706	9.960000e-05
SG403T22XRAW	660	1	663	9.590000e-05
SG403T23XRAW	596	1	602	8.950000e-05

SG403T31XRAW	776 1	790	1.075000e-04
SG403T32XRAW	654 1	654	9.530000e-05
SG403T33XRAW	599 1	602	8.980000e-05
SG403T41ARAW	620 1	622	9.190000e-05
SG403T41BRAW	713 1	715	1.011000e-04
SG403T42XRAW	606 1	610	9.050000e-05
SG403T43XRAW	637 1	640	9.360000e-05
SG404T11XRAW	490 1	490	7.890000e-05
SG404T12XRAW	711 1	711	1.010000e-04
SG404T21XRAW	730 1	731	1.029000e-04
SG404T22XRAW	690 1	690	9.890000e-05
SG404T23XRAW	624 1	624	9.230000e-05
SG404T31XRAW	784 0	829	1.083000e-04
SG404T32XRAW	671 0	772	9.700000e-05
SG404T33XRAW	624 1	629	9.230000e-05
SG404T41ARAW	636 1	671	9.350000e-05
SG404T41BRAW	740 1	740	1.038000e-04
SG404T42XRAW	634 1	636	9.330000e-05
SG404T43XRAW	662 1	663	9.610000e-05
SG502T11XRAW	497 1	498	7.960000e-05
SG502T12XRAW	704 1	708	1.003000e-04
SG502T13XRAW	683 1	684	9.820000e-05
SG502T21XRAW	692 1	695	9.910000e-05
SG502T22XRAW	673 1	675	9.720000e-05
SG502T23XRAW	677 1	681	9.760000e-05
SG502T31XRAW	695 1	696	9.940000e-05
SG502T32XRAW	742 1	742	1.041000e-04
SG502T33XRAW	676 1	678	9.750000e-05
SG502T41ARAW	706 1	705	1.005000e-04
SG502T41BRAW	718 1	721	1.017000e-04
SG502T42XRAW	655 1	658	9.540000e-05
SG502T43XRAW	727 1	730	1.026000e-04
SG503T11XRAW	348 0	418	6.470000e-05
SG503T12XRAW	938 1	939	1.237000e-04
SG503T13XRAW	901 1	905	1.200000e-04
SG503T21XRAW	916 1	923	1.215000e-04
SG503T22XRAW	899 1	899	1.198000e-04
SG503T23XRAW	909 1	906	1.208000e-04
SG503T31XRAW	714 0	728	1.013000e-04
SG503T32XRAW	975 1	978	1.274000e-04
SG503T33XRAW	894 1	900	1.193000e-04
SG503T41ARAW	913 1	929	1.212000e-04
SG503T41BRAW	932 1	943	1.231000e-04
SG503T42XRAW	886 1	886	1.185000e-04
SG503T43XRAW	819 0	937	1.118000e-04
SG504T11XRAW	496 1	499	7.950000e-05

SG504T12XRAW	944	1	945	1.243000e-04
SG504T13XRAW	919	1	921	1.218000e-04
SG504T21XRAW	933	1	933	1.232000e-04
SG504T22XRAW	900	1	908	1.199000e-04
SG504T23XRAW	850	1	852	1.149000e-04
SG504T31XRAW	719	0	958	1.018000e-04
SG504T32XRAW	991	1	995	1.290000e-04
SG504T33XRAW	916	1	919	1.215000e-04
SG504T41ARAW	934	1	934	1.233000e-04
SG504T41BRAW	948	1	956	1.247000e-04
SG504T42XRAW	897	1	897	1.196000e-04
SG504T43XRAW	819	0	930	1.118000e-04
SG505T11XRAW	398	1	395	6.970000e-05
SG505T12XRAW	719	1	725	1.018000e-04
SG505T13XRAW	645	0	689	9.440000e-05
SG505T21XRAW	707	1	710	1.006000e-04
SG505T22XRAW	690	1	690	9.890000e-05
SG505T23XRAW	697	1	697	9.960000e-05
SG505T31XRAW	720	0	733	1.019000e-04
SG505T32XRAW	765	1	767	1.064000e-04
SG505T33XRAW	692	1	692	9.910000e-05
SG505T41ARAW	704	1	705	1.003000e-04
SG505T41BRAW	722	1	722	1.021000e-04
SG505T42XRAW	676	1	680	9.750000e-05
SG505T43XRAW	752	1	752	1.051000e-04
SG506T11XRAW	481	0	612	7.800000e-05
SG506T12XRAW	565	1	564	8.640000e-05
SG506T13XRAW	546	1	366	8.450000e-05
SG506T21XRAW	550	1	550	8.490000e-05
SG506T22XRAW	533	1	534	8.320000e-05
SG506T23XRAW	540	1	540	8.390000e-05
SG506T31XRAW	561	1	561	8.600000e-05
SG506T32XRAW	606	1	607	9.050000e-05
SG506T33XRAW	538	1	538	8.370000e-05
SG506T41ARAW	547	1	546	8.460000e-05
SG506T41BRAW	568	1	569	8.670000e-05
SG506T42XRAW	522	1	525	8.210000e-05
SG506T43XRAW	590	1	592	8.890000e-05
SG701T11XRAW	340	1	342	6.390000e-05
SG702T11XRAW	346	1	341	6.450000e-05
SG702T12XRAW	693	1	693	9.920000e-05
SG702T13XRAW	668	1	673	9.670000e-05
SG702T21XRAW	678	1	678	9.770000e-05
SG702T22XRAW	652	1	656	9.510000e-05
SG702T23XRAW	664	1	664	9.630000e-05
SG702T31XRAW	272	1	271	5.710000e-05

SG702T32XRAW	727	1	730	1.026000e-04
SG702T33XRAW	657	1	659	9.560000e-05
SG702T41ARAW	683	1	690	9.820000e-05
SG702T41BRAW	699	1	705	9.980000e-05
SG702T42XRAW	646	1	650	9.450000e-05
SG702T43XRAW	718	1	721	1.017000e-04
SG703T11XRAW	334	1	344	6.330000e-05
SG703T12XRAW	896	1	912	1.195000e-04
SG703T13XRAW	890	1	895	1.189000e-04
SG703T21XRAW	898	1	902	1.197000e-04
SG703T22XRAW	872	1	878	1.171000e-04
SG703T23XRAW	876	1	884	1.175000e-04
SG703T31XRAW	722	0	783	1.021000e-04
SG703T32XRAW	944	1	947	1.243000e-04
SG703T33XRAW	870	1	879	1.169000e-04
SG703T41ARAW	904	1	909	1.203000e-04
SG703T41BRAW	925	1	926	1.224000e-04
SG703T42XRAW	868	1	869	1.167000e-04
SG703T43XRAW	809	0	948	1.108000e-04
SG704T11XRAW	363	1	379	6.620000e-05
SG704T12XRAW	920	1	921	1.219000e-04
SG704T13XRAW	891	1	894	1.190000e-04
SG704T21XRAW	911	1	913	1.210000e-04
SG704T22XRAW	884	1	897	1.183000e-04
SG704T23XRAW	893	1	899	1.192000e-04
SG704T31XRAW	722	0	929	1.021000e-04
SG704T32XRAW	970	1	974	1.269000e-04
SG704T33XRAW	895	1	897	1.194000e-04
SG704T41ARAW	421	0	929	7.200000e-05
SG704T41BRAW	934	1	943	1.233000e-04
SG704T42XRAW	467	0	891	7.660000e-05
SG704T43XRAW	450	1	456	7.490000e-05
SG705T11XRAW	371	1	379	6.700000e-05
SG705T12XRAW	700	1	701	9.990000e-05
SG705T13XRAW	676	1	674	9.750000e-05
SG705T21XRAW	685	1	690	9.840000e-05
SG705T22XRAW	671	1	674	9.700000e-05
SG705T23XRAW	678	1	680	9.770000e-05
SG705T31XRAW	696	1	700	9.950000e-05
SG705T32XRAW	745	1	748	1.044000e-04
SG705T33XRAW	669	1	676	9.680000e-05
SG705T41ARAW	693	1	695	9.920000e-05
SG705T41BRAW	700	1	713	9.990000e-05
SG705T42XRAW	654	1	656	9.530000e-05
SG705T43XRAW	725	1	727	1.024000e-04
SG706T11XRAW	327	1	344	6.260000e-05

SG706T12XRAW	546	1	546	8.450000e-05
SG706T13XRAW	528	1	528	8.270000e-05
SG706T21XRAW	538	1	539	8.370000e-05
SG706T22XRAW	480	0	514	7.790000e-05
SG706T23XRAW	529	1	530	8.280000e-05
SG706T31XRAW	546	1	546	8.450000e-05
SG706T32XRAW	593	1	595	8.920000e-05
SG706T33XRAW	521	1	521	8.200000e-05
SG706T41ARAW	415	0	540	7.140000e-05
SG706T41BRAW	559	1	559	8.580000e-05
SG706T42XRAW	473	0	507	7.720000e-05
SG706T43XRAW	471	0	579	7.700000e-05
SG801T11XRAW	320	1	321	6.190000e-05
SG801T12XRAW	553	1	563	8.520000e-05
SG801T13XRAW	414	1	417	7.130000e-05
SG801T21XRAW	560	1	563	8.590000e-05
SG801T22XRAW	538	1	544	8.370000e-05
SG801T23XRAW	551	1	553	8.500000e-05
SG801T31XRAW	414	0	569	7.130000e-05
SG801T32XRAW	612	1	615	9.110000e-05
SG801T33XRAW	546	1	546	8.450000e-05
SG801T41ARAW	416	1	416	7.150000e-05
SG801T41BRAW	532	0	569	8.310000e-05
SG801T42XRAW	529	1	530	8.280000e-05
SG801T43XRAW	474	0	598	7.730000e-05
SG802T11XRAW	338	0	390	6.370000e-05
SG802T12XRAW	533	1	534	8.320000e-05
SG802T13XRAW	421	1	421	7.200000e-05
SG802T21XRAW	525	1	525	8.240000e-05
SG802T22XRAW	480	1	480	7.790000e-05
SG802T23XRAW	501	0	510	8.000000e-05
SG802T31XRAW	532	1	532	8.310000e-05
SG802T32XRAW	555	1	554	8.540000e-05
SG802T33XRAW	506	1	506	8.050000e-05
SG802T41ARAW	413	1	413	7.120000e-05
SG802T41BRAW	535	1	536	8.340000e-05
SG802T42XRAW	472	1	475	7.710000e-05
SG802T43XRAW	563	1	565	8.620000e-05
SG803T11XRAW	369	1	383	6.680000e-05
SG803T12XRAW	498	1	499	7.970000e-05
SG803T13XRAW	418	0	481	7.170000e-05
SG803T21XRAW	490	1	490	7.890000e-05
SG803T22XRAW	423	0	464	7.220000e-05
SG803T23XRAW	421	0	479	7.200000e-05
SG803T31XRAW	200	0	541	4.990000e-05
SG803T32XRAW	498	0	538	7.970000e-05

SG803T33XRAW	473 1	474	7.720000e-05
SG803T41ARAW	408 1	412	7.070000e-05
SG803T41BRAW	431 0	501	7.300000e-05
SG803T42XRAW	452 1	452	7.510000e-05
SG803T43XRAW	467 0	527	7.660000e-05