Science Data Visualization Tools for the Tropospheric Emissions Spectrometer Ground Data System[1]

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Abstract - The Tropospheric Emissions Spectrometer (TES) instrument seeks to analyze the chemical composition of the atmosphere based on the transmission of radiation. Meeting the scientific objectives requires demanding analysis of the data being collected and processed. Visualization tools will assist in the understanding of the data and of the effects of the various types of processing being performed.

The TES visualization tools are designed to verify correct functioning of the instrument, provide early detection of potential problems, and report on the quality and validity of the science data for drawing scientific conclusions. Visualization displays include the Level III tools for displaying the end result of all the processing, merged and georeferenced for display relative to maps or global images, and displays for characterizing the behavior of the science processing algorithms and exploring the effects of implementation decisions. Displays of interest include plots of spectra and profiles, animations showing variations in the data along spatial or temporal axes, and results of various operations on the data.

Together, these tools provide a visualization suite for more rapidly analyzing the science results of the TES instrument and detecting and identifying problems in the instrument or processing system.

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1.0 INTRODUCTION

The Tropospheric Emissions Spectrometer (TES) instrument seeks to analyze the chemical composition of the atmosphere based on the transmission of radiation. Meeting the scientific objectives requires demanding analysis of the data being collected and processed. Visualization tools will assist in the understanding of the data and of the effects of the various types of processing being performed.

The visualization tools for TES may be categorized as belonging to one of three areas. The first includes tools for monitoring the performance of the data processing modules executing within the Production Facility. The second includes fault isolation tools that would be used to inspect data being processed to identify and classify a problem that has shown up in the monitoring tools. The third category is science analysis tools that would include visualization of the science data products as well as more detailed analysis of intermediate products in an experimental environment such as the Science Computing Facility (SCF).

Process monitoring tools may be described as methods for verifying the day to day operations of the system in processing data over long periods of time. The visualization tools examine log files and other metadata describing the data within the system and display this information to the user/operator in a meaningful way. Note that there are two classes of users viewing this information, the engineers and the scientists. The engineers are most concerned that the system is operating correctly and doing what it is supposed to be doing. The scientists are most concerned that the data being collected and processed is valid and usable for drawing scientific conclusions. While there is overlap between these two domains, different displays will be of most interest to each group. Please note that this paper does not attempt to describe the various tools for monitoring health and functionality of the spacecraft or the instrument from the telemetry. Instead it describes how the partially or fully processed science data can be visualized in order to draw conclusions about the functioning of the instrument. Each level of processing provides additional information about the instrument that can be used for diagnosing possible problems.

The fault isolation tools may be described as methods for determining more detail about system performance in the operating environment. These tools can be used to display spectra or interferograms or other types of data to determine what the system is doing or why it is not doing what is expected. They are more specialized in tracking down the activities of the system and examining the effects of the system upon the data. These tools will be able to display virtually any type of data found within the system and perform simple comparison operations.

The science analysis tools fall into two subcategories. The

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first includes the Level III visualization tools for displaying the end result of all the processing, merged, gridded, and georeferenced for display relative to maps or global images. The second includes the tools for use in the SCF for characterizing the behavior of the science processing algorithms and exploring the effects of implementation decisions. Displays of interest will include plots of spectra and profiles, animations showing variations in the data along spatial or temporal axes, and results of various operations on the data.

Together, these tools provide a visualization suite for more rapidly analyzing the science results of the TES instrument and closing the loop back to instrument engineering for improved operations. They draw strongly on the experiences of the Multi-angle Imaging Spectral Radiometer (MISR) science team at JPL and on the TES science processing prototype system for visualization.

2.0 THE SCIENTIST AND THE ENGINEER

The TES visualization tools are designed for use by two different groups of individuals, the scientists and the engineers. These two groups have very different views of the system and its functionality. The engineers want to know that the system is functioning correctly, that it is collecting the right data at the right time, that problems are understood and corrected or worked around, and that the instrument does what it was designed to do. The scientists want all this also but their viewpoint is that the data collected must be valid and usable for drawing scientific conclusions.

The engineers will have a variety of quite powerful tools for monitoring spacecraft and instrument health and functionality. However, these tools are disconnected from the science data processing and analysis that happens once the data is on the ground. The results of the science data processing can help to alert the operators to potential problems and assist in the process of identifying the problem and possible solutions. As a simple example, consider the effects of heavy cloud cover. Clouds obscure the Earth and typically cause failed retrievals for those observations. However, clouds are ubiquitous and seeing clouds is normal and within operational parameters. While the spacecraft and instrument might be able to detect that clouds are present, based on the observations, they cannot detect that a problem is causing readings that appear to be clouds. However, a trend showing that a typical 20% of retrieval failures due to clouds has suddenly jumped to 90% will point to an instrument problem immediately.

Typically, engineers will want to see data visualized relative to events affecting the spacecraft and instrument. These include time, orbital position and orientation, and spacecraft and instrument telemetered events. Failed retrievals for four hours after a thruster burn could indicate that the propellant cloud is obscuring the instrument and requires four hours to sufficiently disperse and may require more than four hours for the retrievals to be valid. All telemetry shows a completely healthy instrument but the scientists will realize immediately that something is wrong.

The scientists will want to see much of the same data as the engineers and they will also want to see their data relative to natural phenomena that could affect the validity of the data. This type of visualization will show the correspondences between science data and such factors as cloud cover, sun glint, and surface temperature, and events such as volcanic eruptions. Each of these factors could affect the validity of the retrieval results and reduce the value of the scientific conclusions.

3.0 PROCESS MONITORING TOOLS

The process monitoring tools are the first line of analysis and visualization tools for determining the validity and quality of the science data. Since the processing of the data is highly automated in a batch environment, the monitoring tools will rely on flags and notes logged by the individual processes during execution. An automated batch process will read the logs and generate a variety of diagnostic information on performance, trends, error rates, and other factors. Statistical analyses of the logged data can be performed to identify out-of-range conditions and generate alarm messages to direct attention to particular problems. A comprehensive list of the data items logged is outside the scope of this document but includes successful and failed retrievals, number of retrievals attempted per orbit, number of iterations to converge, variation between initial state and final state, etc. As an example, the percentage of failed retrievals over various time intervals can be plotted, both in absolute numbers and as a trend plot to identify both short term problems as well as slower developing problems.

The process monitoring tools will run in two different modes, batch and interactive. The batch mode tools will run on a regular basis, perhaps hourly or daily, to generate a variety of plots for rapid review of the previous period's performance. The tools may also be run in an interactive mode to display information about performance at any time as well as to display information collected but not deemed critical or meaningful enough for automatic output.

4.0 FAULT ISOLATION TOOLS

The fault isolation tools are designed to burrow down into the data to allow the scientist or engineer to track a problem down to its roots. These tools provide access to the data products and metadata in the batch processing environment in order to trace specific data items from source to destination and locate problems in their processing.

A useful type of display is plotting science data analysis results versus spacecraft telemetry. An example of this is shown in Figure 1. This display visualizes what might happen when an event such as a thruster firing affects retrieval success rates. The vertical green bars in the upper section of the display represent a telemetered event or reading such as attitude which changes during the firing. The middle section of the display represents the count of successful retrievals which falls significantly during the firing and stays low for more than an hour afterward. The bottom section of the display shows the time period that is being displayed, in this case about one and one-half hours.

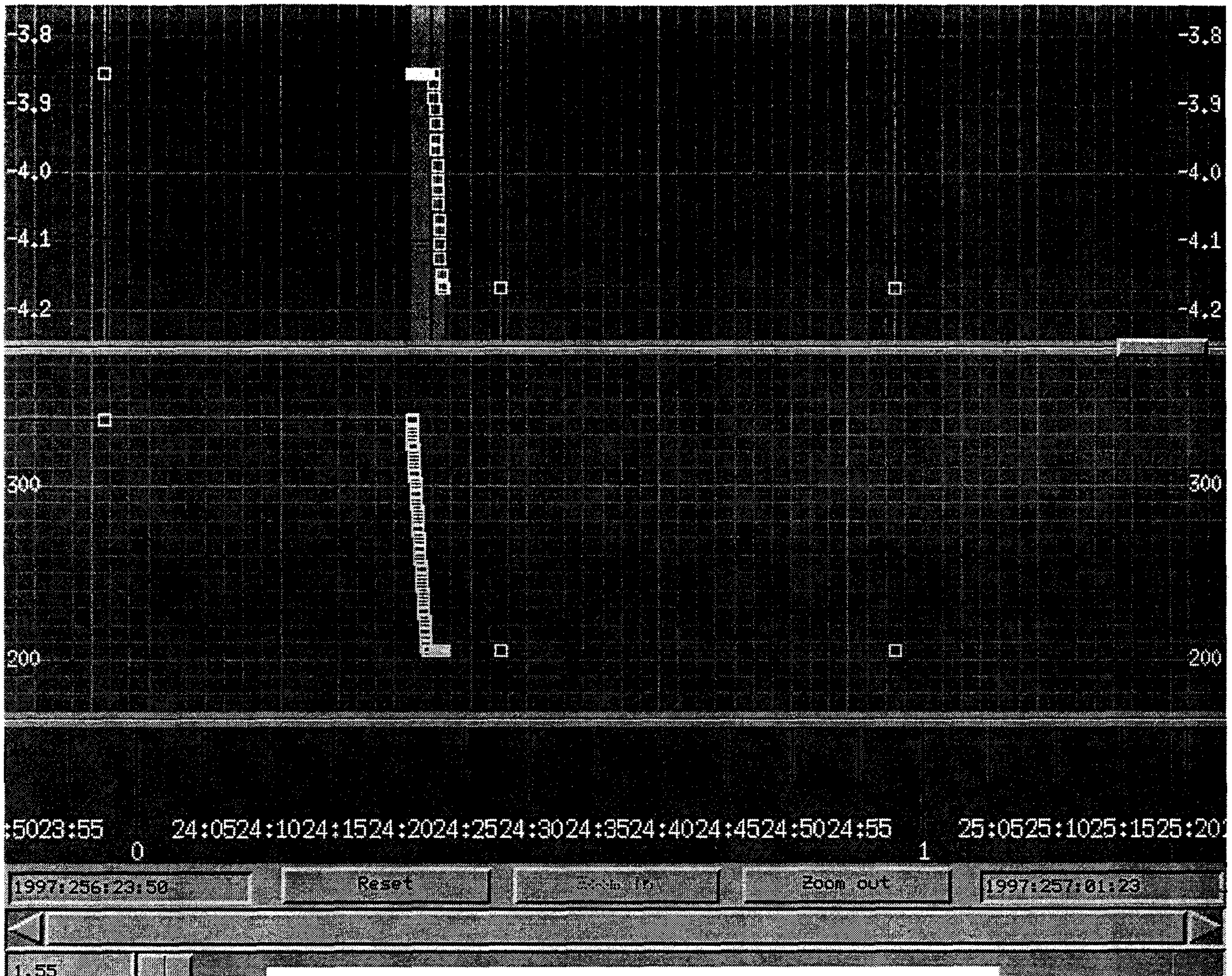

Figure 1 - Plot of Spacecraft Events and Retrieval Counts versus Time

Various controls allow the operator to zoom in and examine short timeframes or zoom out to rapidly review the data for unreasonable values. Alarm limits can be specified for any channel, displayed as horizontal red lines, and automatically detected and collected in a file for rapid analysis. The alarm limit values can be dynamic and change over the life of the mission.

Another important type of display is the visualization of retrieval failure versus geographic position. Once the collected data has been geolocated, it can be overlaid on a variety of maps and imagery in the correct position and time. Figures 2 and 3 shows how data from a partial orbit can be overlaid onto a nautical chart from the National Oceanic and Atmospheric Administration (NOAA) to reference against such features as coastlines and islands (this example chart appears courtesy of BSB Electronic Charts). Figue 2 shows a large-scale, low-resolution view of the map of the northeastern Pacific Ocean to provide an overall picture. Figure 3 shows a zoomed in view of the Aleutian Islands in Alaska.

Data of this type can also be displayed on a GOES weather satellite image for reference to cloud layers as shown in figure 4. This example demonstrates how failed retrievals can be related to cloud coverage using a subset of the sample data from the previous figure. Since GOES imagery is captured on regular intervals and at high resolution, it can be combined with georeferenced TES data to produce animations showing instrument and data states relative to moving cloud and storm patterns.

5.0 Science Analysis Tools

The science analysis tools are designed to burrow down into the data as deeply as a scientist or engineer wishes, make changes to the data, and process or reprocess the data within the SCF. In particular, these tools provide the capability to visualize and change ancillary data as well as standard and special data products and metadata to allow experimentation with the data processing algorithms. Particular data types are appropriate for each level of processing but each data type may be visualized within a common visualization

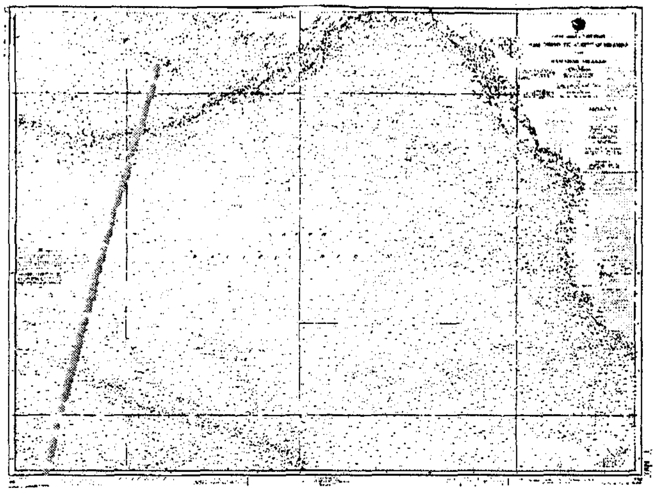

Figure 2 - Retrieval Data Overlaid on NOAA Chart

environment.

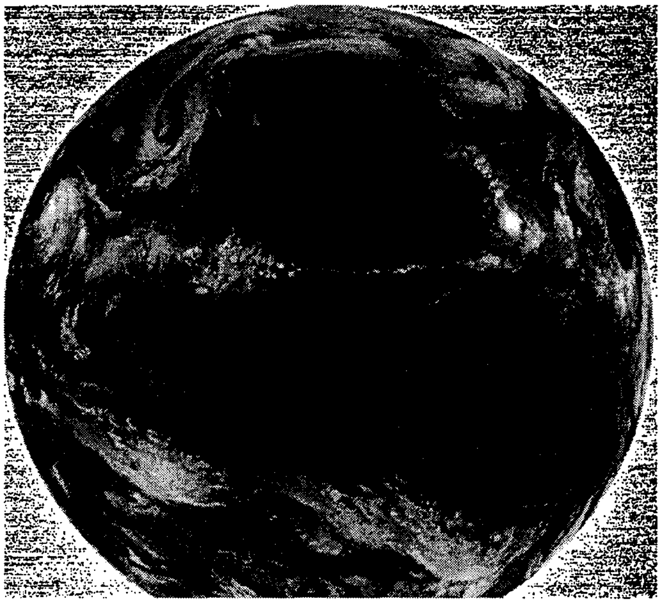

Figure 4 - Retrieval Data Overlaid on GOES Image

5.1 Level 0

The Level 0 processing for TES involves accepting downlinked data and packetizing the data appropriately. During processing, logs will be generated that record packet rates, various statistics on the packetization process, and errors occurring during the process. Plots of numeric values and trends will be generated in batch mode for process monitoring. The science analysis tools will be able to display these plots, incoming and packetized data streams, and interact with the data to perform regression tests on the Level 0 functionality as well as trace data from input to output.

5.2 Level I

The Level I processing for TES involves processing the packet stream into interferograms and metadata, performing gain and calibration operations, and then performing a

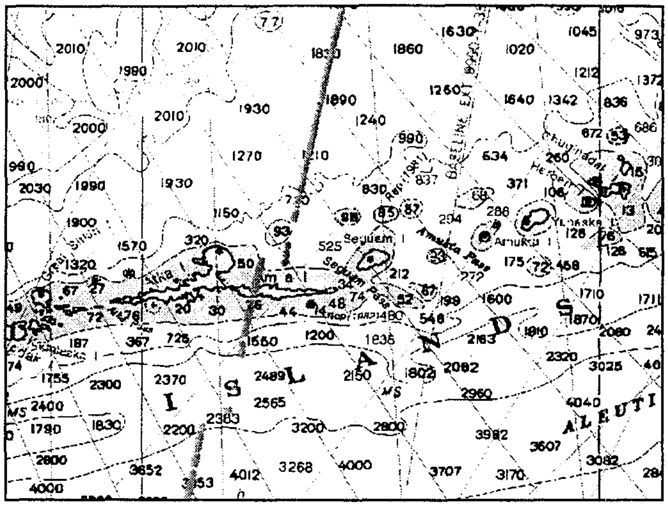

Figure 3 - Zoomed In View of Retrieval Data on NOAA Chart

Fourier transform of the interferograms into spectra. Processing logs will record information on metadata statistics, calibration results, and missing data/packet errors. Visualization tools will plot the numeric and statistical data as well as the interferograms and resulting spectra. Figure 5 shows an example plot of a spectrum. The visualization tools will provide the mechanism for tweaking the interferogram data, computing the resulting spectrum, and comparing the results to that for the original interferogram. While this may not be an attractive method to experiment with the spectra computation process, it may be very useful for attempting to determine why a particular interferogram could not complete the process of retrieving a profile. For example, a high level of noise might make an interferogram unusable but experimentation with filters would be useful to determine additional desired processing to make use of the data.

5.3 Level II

The Level II processing for TES involves performing retrievals on the spectra to generate profiles of various constituents within the atmosphere. Processing logs will record information on unsuccessful retrievals, statistics on iterations for successful retrievals, and a variety of metadata describing the characteristics of the Jacobians and other intermediate processing data elements. The visualization tools will provide the capability to plot and analyze trends of logged data, display, compare, and modify spectra and profiles, and display and modify the Jacobian matrices. Figure 6 shows a displayed Jacobian as an image for the entire matrix as well as slices through the matrix in either direction. The blue lines on the associated slice displays indicate the slice plane values. The slice planes for the Jacobian may be animated to rapidly peruse and understand the character of the matrix.

The visualization tools provide a variety of operators that may be used to modify and compare data. These operators include difference and percent difference calculators, absolute value and negate operators, and specialized operators such as black body temperature calculators. In addition to the

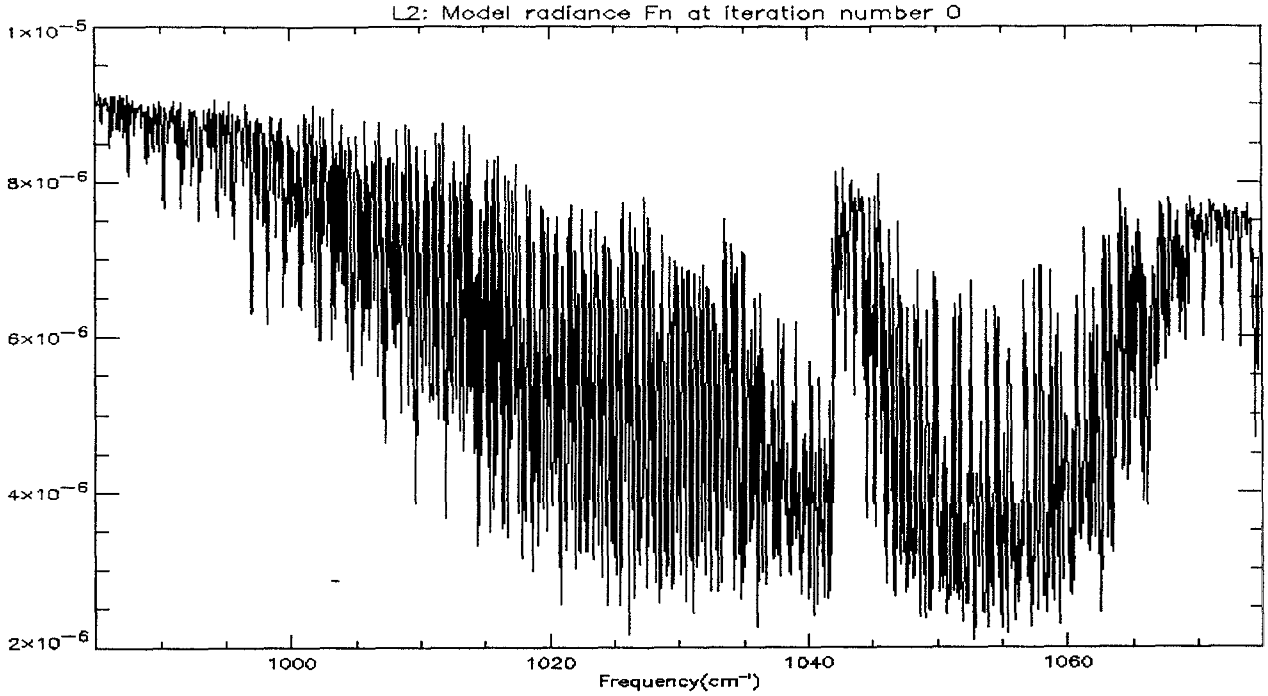

Figure 5 - Example Plot of a Spectrum

prespecified operators, scientists may create their own operators and add them to the list of available tools as a plugin. This provides the capability to enhance the visualization system beyond the original requirements.

5.4 Level III

The Level III processing for TES involves sampling a time period's worth of profile data onto a three-dimensional grid for easier access, analysis, and visualization. There is a variety of visualization techniques available for 3D gridded data. Key visualization tools for TES will include plotting the data onto a global map image, taking slices through the data in arbitrary directions, and animating slices and views over time, constituent, and location. Figure 7 shows a display of one level of gridded data over a global map with continental outlines. The data plotted reflects retrieved temperature at a chosen pressure level with higher temperatures near the equator.

Another useful capability for visualizing mesoscale phenomena is isosurface extraction using a method such as Marching Cubes [1] or newer adaptations [2]. For phenomena such as large volcanic plumes, using an isosurface extraction method can provide excellent visualization of extent, density, and velocity of constituent masses. The orbital characteristics of the TES instrument preclude close monitoring of smaller phenomena but larger events over several days and hundreds of kilometers can be

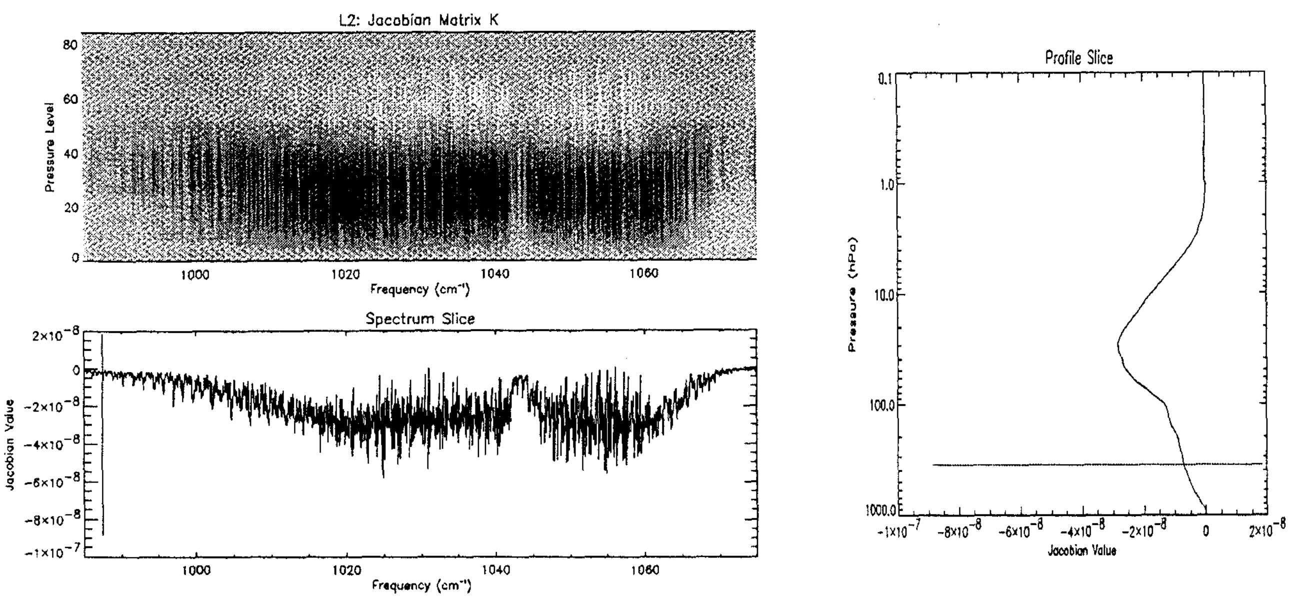

Figure 6 - Display of Jacobian Matrix with Horizontal and Vertical Slices

monitored and visualized.

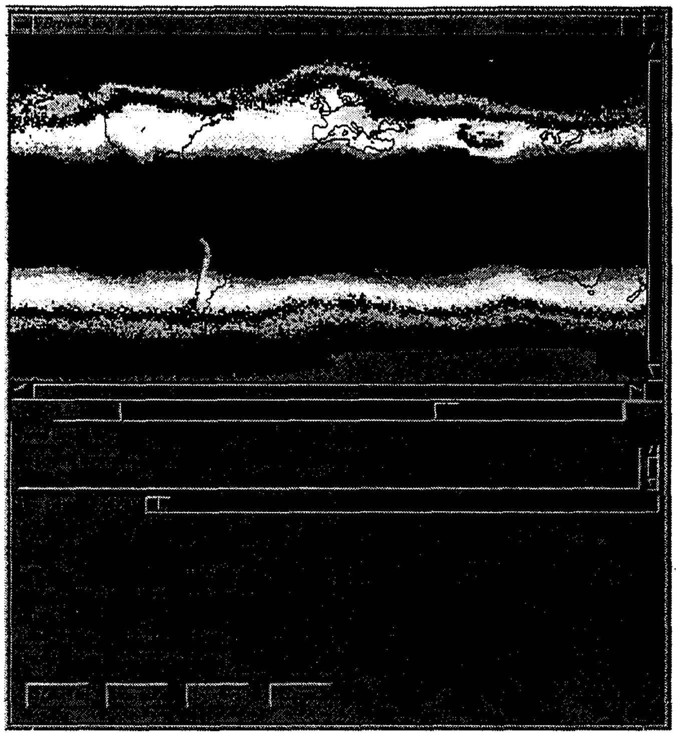

Figure 7 - Gridded Temperature Displayed Over Continental Outlines

6.0 Use Cases

Use cases provide a method to describe the expected behavior of a system under particular circumstances. They are often used to generate requirements and to tie requirements to particular operating aspects of the system being designed. The examples described here are included to illustrate how the visualization tools might be used to detect and identify problems in the instrument or system.

6.1 Example 1

In this example, the first thing noticed is that the successful retrieval percentage for the past 24 hours is below normal. An individual might then examine the trend plot for retrieval percentage as well as successful retrieval counts over smaller intervals of time. In this example, the trends do not show any decline until the time period in question. However, the plots over smaller time intervals show a sudden, drastic decline at a particular time followed by a slow rise back to normal levels. The sudden decline would indicate that a particular event probably caused the problem rather than natural conditions such as cloud cover. The next item to display would be a plot of successful retrievals compared to a display of spacecraft events. In this example, the telemetry plots show a small thruster firing for an orbital adjustment. The conclusion is that the thruster firing interfered with the instrument and data collection. The slow return to normal operation would likely indicate that the gas cloud from the firing was the culprit rather than attitudinal, electrical, or computational problems on board and that future firings should be coordinated with instrument down times to avoid data loss.

6.2 Example 2

In this example, the first thing noticed is that the successful retrieval percentage for the past 24 hours is below normal. An individual might then examine the trend plot for retrieval percentage as well as successful retrieval counts over smaller intervals of time. In this example, the trends do not show any decline until the time period in question. However, the plots over smaller time intervals show a number of periods with low retrieval success interspersed with higher success rates. The overall rate is not much below normal so the likely problem is natural phenomena. The next step might be to examine recent GOES satellite imagery and compare cloud areas to unsuccessful retrievals. In this example, there is a large storm in the Atlantic and multiple orbits were affected but the plots show that most of the unsuccessful retrievals were indeed coincident with the heavy cloud cover. The indication is that the instrument is functioning normally.

7.0 Conclusions

The visualization tools described in this paper are designed to assist the engineer and scientist in evaluating the science data being returned from the TES instrument and processed on the ground. These evaluations can lead to detection and identification of problems in the instrument or spacecraft or in the processing stream. Of particular importance to the scientist is a measure of the quality of the data or its validity for drawing scientific conclusions. Display of science data relative to spacecraft events is crucial for identifying instrument problems while display relative to world maps and imagery is crucial for determining validity of results.

Acknowledgements

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References

[1] W. E. Lorenson and H. E. Cline. Marching Cubes: A High Resolution 3D Surface Construction Algorithm. *Computer Graphics*, 21(4):163-169, 1987.

[2] K. Engel, R. Westermann, and T. Ertl. Isosurface Extraction Techniques for Web-based Volume Visualization. *Proceedings of IEEE Visualization '99*, pages 139-146, October, 1999.

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