AC 2008-2558: ON THE USE OF JAVA-DSP IN EARTH SYSTEMS

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ON THE USE OF J-DSP IN EARTH SYSTEMS

1. Introduction

Java-Digital Signal Processing (J-DSP) is a web-based, platform-independent, visual programming environment that enables users to perform online signal processing calculations and simulations. J-DSP was built from the ground up in Java to provide free and universal access to an array of signal processing functions that can be used for research and education[1]. All signal manipulation functions appear in J-DSP as "blocks" that are brought into the simulation environment by a *drag-n-drop* process. Signal and data flow is established by linking the blocks. Original J-DSP functionality targeted engineering algorithms for signal processing[2], imaging[3], controls[4], time-frequency analysis[5] and communications[6] applications.

There is a strong need for introducing the basics of signal and data analysis tools to the students in earth systems and geology science courses. While research of time-dependent processes is becoming more prevalent, students lack training and hands-on experiences in the modeling and analysis of natural signals and data obtained from geological systems. J-DSP can be tailored to perform analysis and visualization of time-varying signals and data acquired in earth system and geological science. A new J-DSP Earth Systems Edition (J-DSP/ESE) has been developed through a partnership of Arizona State University (ASU), Johns Hopkins University (JHU) and Purdue University (PU). J-DSP/ESE has access to earth systems data which is generated using a data generation function. Customized interpolation, time-frequency analysis and filtering functions have been integrated into the new J-DSP/ESE program and are described in Section 2.

Modules that use the new J-DSP/ESE infrastructure have been developed for introduction to students in the DSP class at Arizona State University to earth systems and geology applications. Additional modules and exercises have been created for use in Earth systems classes at Johns Hopkins University. Below, we describe some of these modules and we provide details on the software extensions that were developed in J-DSP/ESE from the core J-DSP environment.

2. Earth Systems Signals and J-DSP/ESE

Sampling dynamical Earth systems may involve "real-time" monitoring of natural phenomena, such as river flow, atmospheric pressure, or Earth orientation. Here "real-time" is the term used by geologists to describe the events that are happening now or in the relatively recent past, and is not to be confused with the definition of "real-time" electrical engineering. Sampling can also involve collection of "deep-time" proxy data that are representative of past Earth systems behavior. "Real-time" geoscientists tend to be highly trained in math and physics, and have assembled and/or developed algorithms and software to service their needs on a community-wide basis. "Deep-time" geoscientists are versed more in geology, biology and chemistry, and tools customized for their science are comparatively unavailable.

Typical needs to support J-DSP/ESE include procedures for re-sampling, interpolation, de-noising, signal frequency evaluation, and correlation. Accordingly, the current version of J-DSP/ESE includes functions for generating the Earth systems data and performing *depth-time transformation*, interpolation/re-sampling, filter design, windowing, fast Fourier transforms (FFT/IFFT), and time-frequency analysis. The current version of JDSP/ESE has the capability to handle long signals (up to 8192 points) that are typical of Earth systems data. For visualizing data and accepting user inputs, JDSP/ESE uses time and frequency units that are familiar to geoscientists, e.g., kiloyears (Kyr) and cycles/Kyr, instead of the units in terms of samples that are widely used by electrical engineers.

A screenshot of the J-DSP/ESE block diagram is shown in Figure 1. Each block is associated with Java code that operates on specified data, and produces the necessary graphs and visualization modules. By double clicking on each block, a dialog with a menu and graphics appears.

3. J-DSP/ESE Application to Global Change Science

The causes and consequences of global change are the most important societal issues of our time. Global change science involves study of the physical, chemical and biological processes that regulate the Earth system. In particular, global change science focuses on the time-evolutionary behavior of Earth system processes; this requires application of signal processing techniques to extract information from sampled time series measurements of processes. We apply J-DSP/ESE to the problem of past global climate change to demonstrate the power of the tool's functions in exposing paleoclimate signal frequencies traceable to long-term variations in Earth's orientation relative to the Sun.

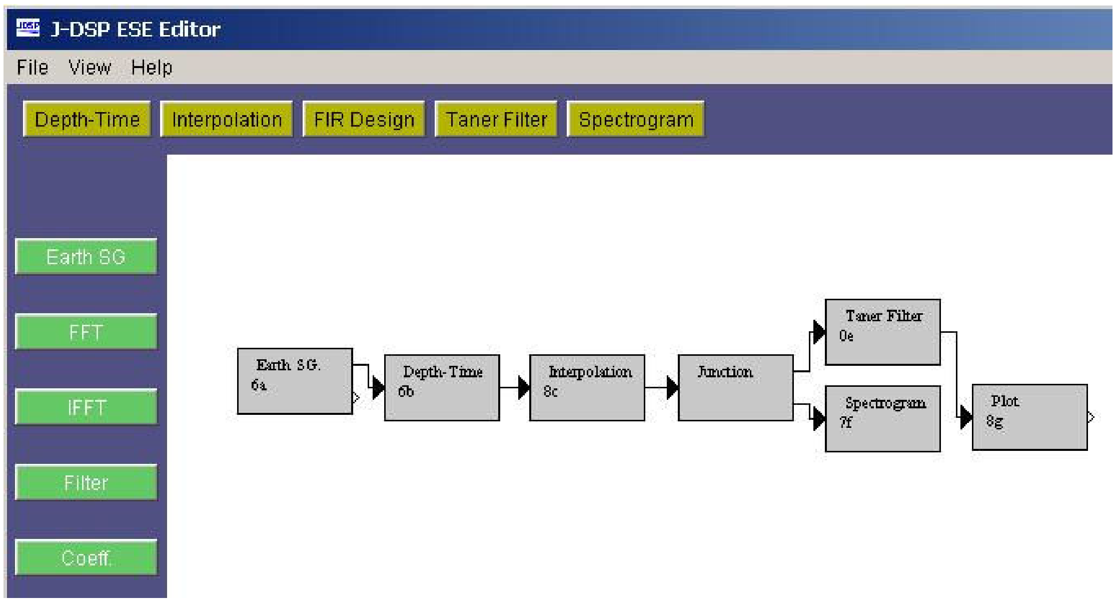

Figure 1: Basic J-DSP/ESE block diagram.

3.1 Examples of Earth System Data

Three Earth system data sets are used to demonstrate J-DSP/ESE. Each has a different probability distribution (Gaussian, non-Gaussian, and binary). The first (Gaussian) data set is Core RC11-120, a data series from the paleoclimatological SPECMAP ("Spectral Mapping") dataset, which tracks the global flux of oxygen isotopes between ocean waters and continental (ice) reservoirs over the past 800,000 years[7]. The second (non-Gaussian) data set is the composite biogenic silica record from Lake Baikal over the past 2 million years[8]. The third data set is the data from the Trubi Marls formation in Sicily, obtained by sampling alternating limestone beds and is binary in nature[9]. All the three data sets were originally sampled in a depth scale as they were obtained by drilling ocean beds, lake beds or rock beds. They carry significant astronomical information that needs to be extracted through signal processing techniques. In the following sections we will limit our discussion to SPECMAP data only.

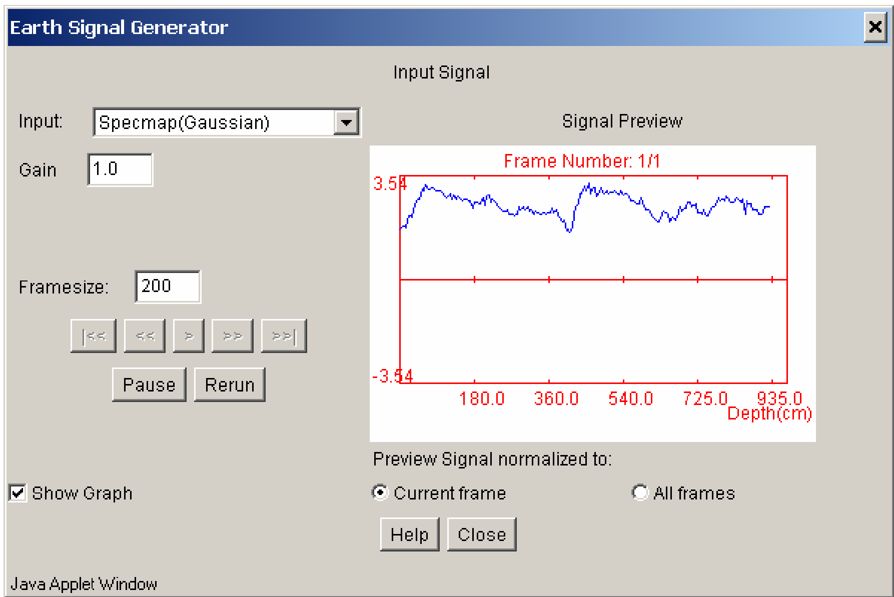

Figure 2: Earth signal generator with Earth data sets.

J-DSP/ESE has incorporated all three data sets in the "Earth Signal Generator" block. This block consists of two pins, one through which the generated signal is output frame-by-frame and another through which the signal is output as a whole. The signal can be previewed in depth scale and for the frame-by-frame output, the frame size can be fixed by the user. The user interface for the block is shown in Figure 2.

3.2 Converting the Data Sets to Time Scale

The depth scale at which the data is sampled corresponds to a time scale corresponding to years BP (Before Present). The data can be converted to the time scale using user-specified age models and is accomplished by the "Depth-Time Transformation" block.

The user can select the standardized age model to be used for converting the depth scale to time scale and this user interface as shown in Figure 3.

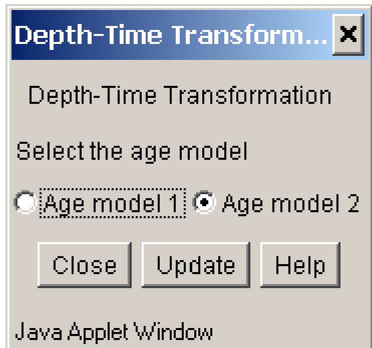

Figure 3: Conversion of depth scale to time scale.

3.3 Interpolation and Uniform Re-sampling of Data

The data obtained after the depth to time transformation is typically non-uniformly sampled. This is because while the original depth scale is usually uniformly sampled,

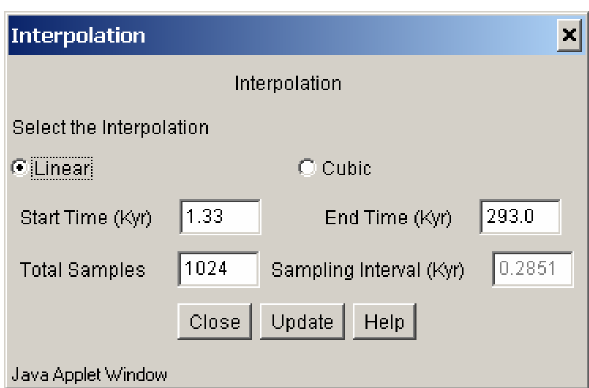

Figure 4: Interpolation and uniform re-sampling.

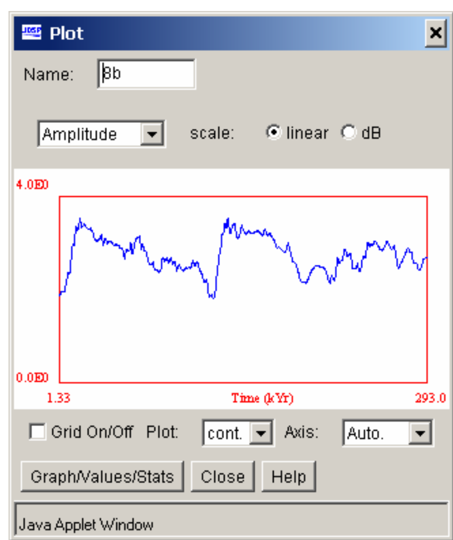

Figure 5: Plot of the interpolated and re-sampled SPECMAP data set.

there exists a non-linear relationship between depth and time scales as the result of variable depositional rate of sediment in nature. This problem requires that the time series be interpolated and uniformly re-sampled before further processing. In the J-DSP/ESE interpolation block the user can select the start and end time of the time series and the number of points for interpolation. The block currently supports two commonly used interpolation methods – linear and cubic. Figure 5 shows the time series of SPECMAP data set, transformed using Age Model 2 and linearly interpolated and re-sampled over 1024 points. The data are now ready for processing by the subsequent signal processing blocks.

3.4 Filtering the Data

The Earth's astronomical variations that affect changes in solar radiation have three basic origins: Earth's orbital eccentricity E (cycle periods of 400,000 and ~100,000 years), axial tilt T (cycle period at 41,000 years), and precession P (principal cycle periods of 23,000 and 19,000 years). The three effects can be represented as a single "ETP" model signal. The spectrum of all low frequency components in the SPECMAP signal is shown in Figure 7. Our objective is to design filters in JDSP/ESE that could capture the signal frequencies from this Earth system data that are related to those of Earth's astronomical variations.

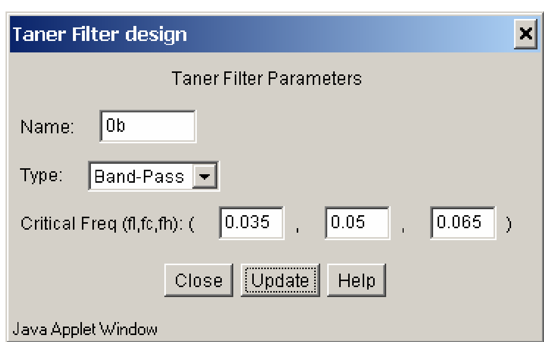

Figure 6: Taner bandpass filter.

To address this, a filter known as the Taner filter[10] that has desirable characteristics in terms of minimum leakage and zero phase response has been implemented in J-DSP/ESE. We bandpass filter the data with lower and upper cutoff frequencies as 0.035 and 0.065 cycles/Kyr to recover the precession (with cycle periods ranging from 0.043 cycles/Kyr and 0.052 cycles/Kyr). Figure 6 shows the Taner filter interface and Figure 8 shows the filtered signal in the time and frequency domain. Three dominant frequency components 0.041, 0.051 and 0.061 cycles/Kyr that correspond to precession can be observed in Figure 8b.

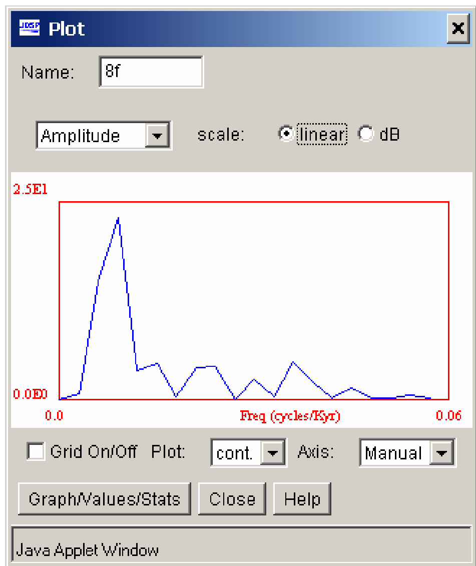

Figure 7: Low frequency components in SPECMAP data.

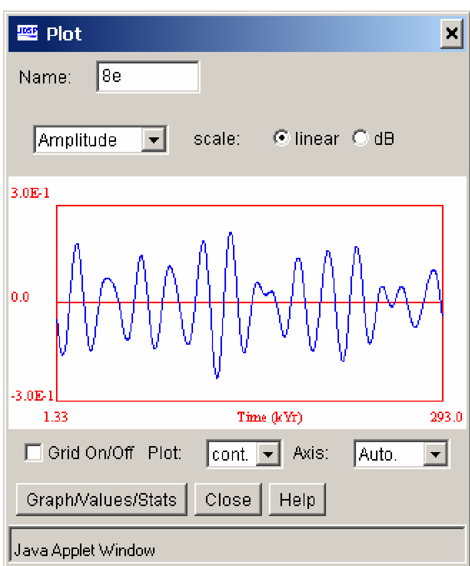

Figure 8a: Precession in time domain.

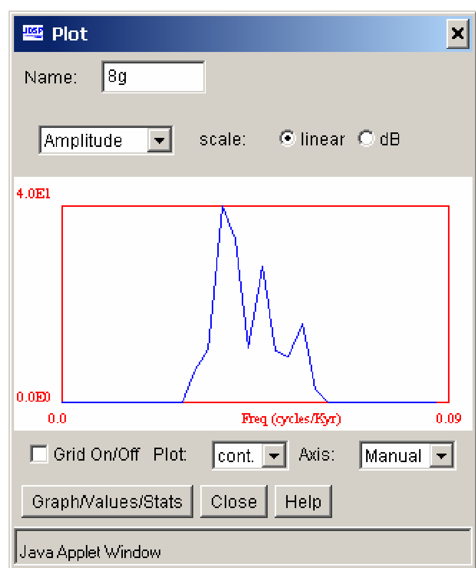

Figure 8b: Precession in frequency domain.

3.5 Time Frequency Analysis of the Data

Time-frequency analysis is done on Earth data sets to identify the presence of the ETP frequencies. The spectrogram block is used here to perform the time-frequency analysis of the data. The window length can be chosen in Kyr and depending on the sampling interval the window length in samples will be displayed. The time-frequency analysis of the SPECMAP data set indicates the presence of E, T and P frequencies near 0.01, 0.024 and 0.04 cycles/Kyr as shown in Figure 9.

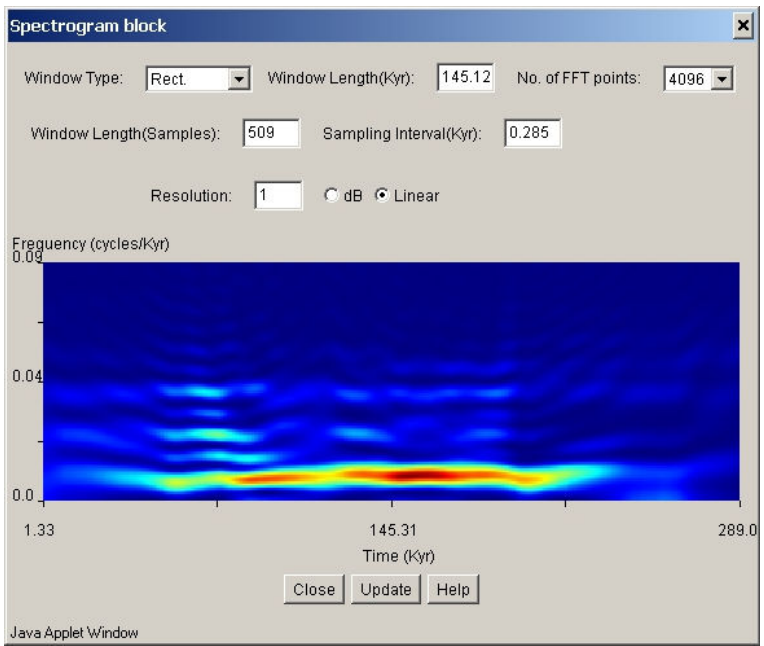

Figure 9: Spectrogram of SPECMAP data set.

4. Utility in Interdisciplinary Education

J-DSP/ESE is used as a computational and visualization tool for generating and processing of Earth systems data. The readily available signal processing functions like FFT, windows, filter design, and time-frequency analysis functions tailored with special functions needed by geoscientists, such as depth-time transformation and interpolation, can be easily used by the geology students to experiment with Earth systems data. The example illustrated above for identification of ETP frequencies can be administered as an exercise for students in general Earth systems classes. Students are thus exposed to the signal processing techniques that can be successfully used to analyze Earth systems data.

The tool can also be used to expose electrical engineering students to the interdisciplinary areas where DSP techniques can be applied. A typical exercise for students in a DSP class would be to analyze the effect of different windowing techniques in the filtering and time-frequency analysis of Earth systems data. Students in the class are asked to develop a J-DSP/ESE block diagram which does windowing and filtering of the data and also shows the spectrogram. By varying the type and length of the window the different frequency and time characteristics of the Earth systems data are studied. The students are also asked to provide their observations regarding the considerations that are required for the analysis of Earth systems data when compared to the analysis of speech signals. Assessment of the new J-DSP/ESE will be conducted in both Earth systems (Johns Hopkins University) and DSP classes (Arizona State University), and the results will be presented at the conference.

5. Conclusion

J-DSP software extensions have been developed to create the new J-DSP/ESE version for use in earth systems and geology education and research. J-DSP/ESE has basic functions that can be used to process Earth systems data. Future editions of J-DSP/ESE will include sophisticated functions like innovative graphics for tuning to an astronomical target curve for depth to time transformation, multi-tapered method (MTM) power and line spectra, coherency/cross-phase spectra and demodulation. Earth systems are associated with a rich set of signals that can be use to expose electrical engineering students and researchers to this area and to current issues in climate change prediction. J-DSP/ESE will be used in geology classes to introduce students to basic DSP concepts, and to provide hands-on experiences with the analysis, processing, and interpretation of earth systems data.

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