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Software Enhancements to the IVSEM Model of the CTBTO IMS

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Abstract

Sandia National Laboratories (SNL) developed the Integrated Verification System Evaluation Model (IVSEM) to estimate the performance of the International Monitoring System (IMS) operated by the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO). IVSEM was developed in several phases between 1995 and 2000. The model was developed in FORTRAN with an IDL-based user interface and was compiled for Windows and UNIX operating systems. Continuing interest in this analysis capability, coupled with numerous advances in desktop computer hardware and software since IVSEM was written, enabled significant improvements to IVSEM run-time performance and data analysis capabilities. These improvements were implemented externally without modifying the FORTRAN executables, which had been previously verified. This paper describes the parallelization approach developed to significantly reduce IVSEM run-times and the new test setup and analysis tools developed to facilitate better IVSEM operation.

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ACRONYMS

CTBTO	Comprehensive Nuclear Test Ban Treaty Organization
GUI	Graphical User Interface
IMS	International Monitoring System
ISS	International Scientific Studies (conference)
IVSEM	Integrated Verification System Evaluation Model
rms	root mean square
SNL	Sandia National Laboratories
VI	Virtual Instrument

1. INTRODUCTION

This report describes tools and techniques developed to improve the performance and usability of the Integrated Verification System Evaluation Model (IVSEM.) Sandia National Laboratories (SNL) developed IVSEM to estimate the performance of the International Monitoring System (IMS) operated by the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO). The IMS is a global monitoring system consisting of seismic, hydroacoustic, infrasound, and radionuclide stations. IVSEM was developed in several phases between 1995 and 2000. The model was developed in FORTRAN with an IDL-based user interface and was compiled for Windows and UNIX operating systems. The work described in this paper applies to IVSEM version 2.0 for Windows, but the concepts can be applied to the UNIX version.

1.1 IVSEM Overview

This section presents a brief overview of the IVSEM software. For detailed description of the software, refer to [1] and [2].

IVSEM is a simple “top level” modeling tool which estimates the performance of the CTBTO IMS system. One of IVSEM’s unique features is the integration of the results from the different monitoring technologies. This enables investigations of the synergies between technologies. IVSEM estimates the detection effectiveness (probability of detection), location accuracy, and identification capability of the integrated system and for the individual technologies.

IVSEM has two basic modeling capabilities: single event and global coverage. In single event mode, IVSEM simulates the system response to a nuclear detonation at a specific location with specific parameters. Single event simulations generate an output file called SPLOT. Single event simulations run rapidly on a standard desktop so no effort was made to speed up these simulations or process the SPLOT output files. However, some of the tools and concepts described for global simulations could be applied to single event simulations if needed.

Global coverage simulations model the ability of the IMS to detect nuclear detonations using an evenly spaced grid over a specified longitude and latitude range. Global coverage simulations can be run for a single month or for a year. The system response generated for the annual global coverage is an average of 12 monthly coverage simulations. IVSEM generates an output file called CPLOTOUT¹ that contains the detection effectiveness, location accuracy, and identification values for each subsystem at each grid point. Global coverage simulations can take significant amounts of time and many of these runs were needed in recent studies. The large number of relatively long global coverage simulation runs led us to develop the IVSEM tools described in this report.

¹ Reference [2] calls this file CPLOTEFF

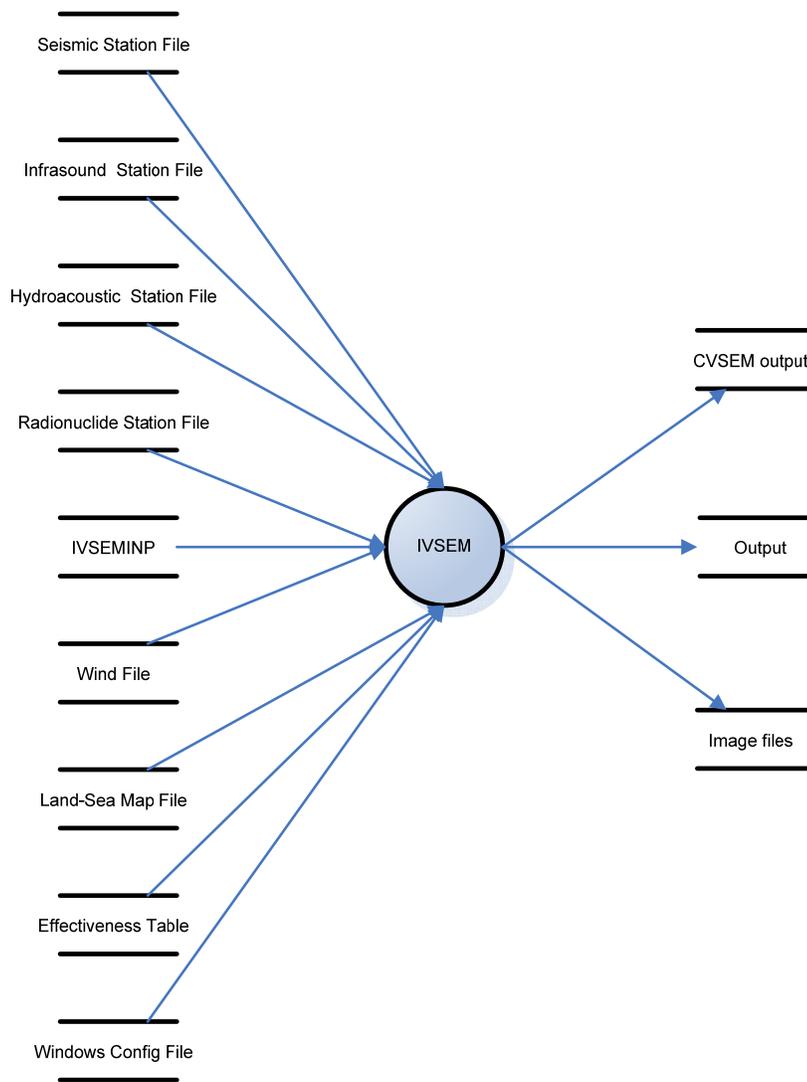


Figure 1. IVSEM Global Coverage Inputs and Outputs

There are three major elements of the IVSEM software: a Graphical User Interface (GUI) to setup the input parameters for a simulation, the model executable, and a GUI to review the results from a simulation. Figure 1 shows a top level dataflow diagram for IVSEM; input files are shown on the left and output files on the right. The top-most input files are modified to make different simulations while the bottom four files are not typically modified.

The seismic (szm-ims.dat), infrasound (isn-ims.dat), hydroacoustic (hyd-ims.dat) and radionuclide (rdn-ims.dat) station files contain detailed information about the stations for each technology. Individual stations can be turned on and off by setting a field within the station record. This allows data for a station to be retained in the file even if the station is not used in a single simulation. These station files are typically located in the C:\IVSEM20\data\defaults directory.

The *ivseminp* file contains the model control (single event or global coverage), event specification (yield, altitude, location and others), and flags to turn the different monitoring technologies on or off. This file must be located in a separate folder for each simulation run.

The weather file (*wind5.dat*) has monthly average wind speeds at 14 altitudes for 5 degree by 5 degree sections of the Earth's surface. The wind file is used by both the infrasound and radionuclide modules.

The land-sea map file (*landsea1.dat*) divides the Earth's surface into a 1-degree-by-1-degree grid and describes the surface in each grid cell with an integer value.

The effectiveness table file (*eftab001.dat*) specifies the weighting for combinations of different sensors from different monitoring technologies.

A Windows configuration file, called *ivsemwin.cfg*, contains output display parameters for the IVSEM GUI. Some of these parameters can be modified with the IVSEM GUI and others must be edited with a text editor.

IVSEM generates different output files for single event and global coverage simulations. Results for global coverage simulations are stored in a file titled *cplotout* along with contents of the station files and the effectiveness table. Single event simulation results are stored in a file called *splotout*. The output files are stored in the same directory as the *ivseminp* input file for the simulation.

The IVSEM analysis GUI can generate GIF or bitmap images of the simulation results. The user sets up the display and then interactively saves the file. Figure 2 shows a sample IVSEM output image for a global coverage simulation.

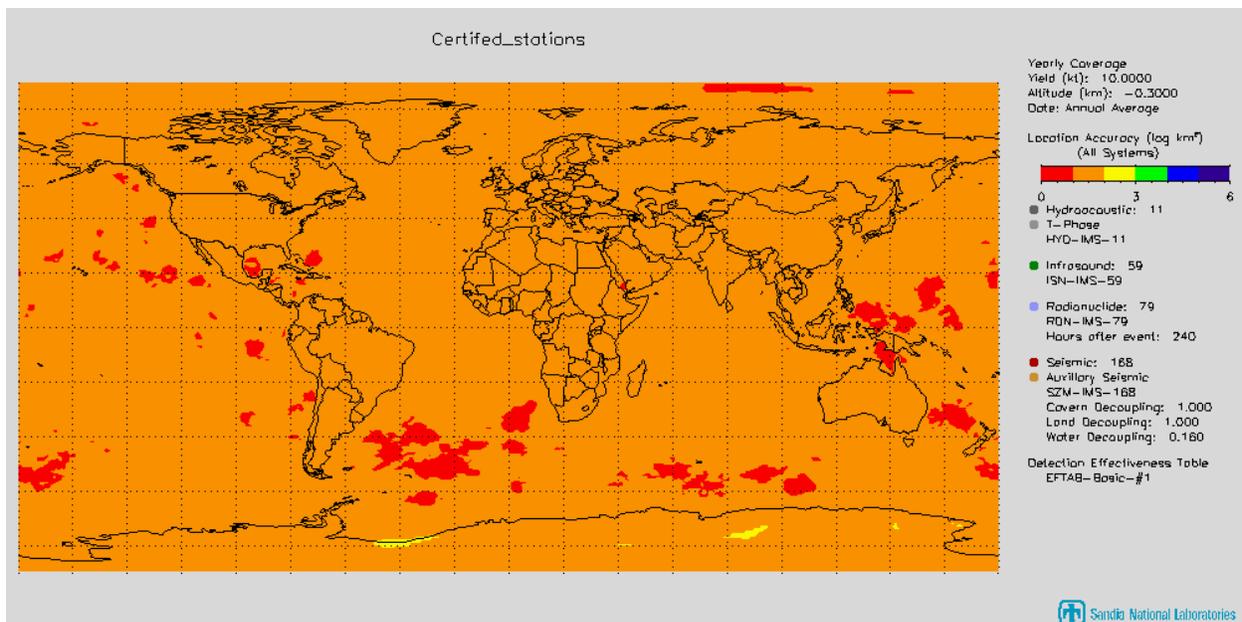


Figure 2. Example of IVSEM Output GIF Image

1.2 Motivation

Renewed interest in the Comprehensive Test Ban Treaty has created new demand for tools like IVSEM. In 2009, IVSEM results were published in a conference paper from the CTBTO sponsored International Scientific Studies (ISS) conference in Vienna. The IVSEM analysis performed for this conference paper revealed several issues with the model:

- Run times for high resolution models took roughly 3 hours on a basic desktop computer.
- The GUI for simulation setup was error prone.
- The GUI for display of simulation outputs was outdated and difficult to use.
- IVSEM setup and analysis were interactive and difficult to automate.

The ISS simulations were run using an existing IVSEM executable that was compiled July 25, 2000. While the source code is available, we did not attempt to modify or recompile the source code since this could require a significant effort to verify the new executable.

Our approach to improving the IVSEM performance and usability focused on developing tools to manually or programmatically generate input files and automatically process the simulation output files. The existing Windows executable can be used interactively from the GUI or programmatically from the command line to process the input files and generate outputs for simulations.

1.3 IVSEM Parallelization Approach

The IVSEM runtime performance showed that the executable used only one core of a multi-core Windows computer and used 100% of that core's CPU cycles. This led us to search for ways to use all cores to speed up execution of the IVSEM simulations.

Analysis of the output file showed that a simulation covering a broad range of longitudes could be split into several simulations covering smaller contiguous longitude ranges. This is possible because results from one part of the globe do not depend on results from other parts. When multiple IVSEM executables are started concurrently, Windows distributes them across different cores to spread the processor load. The output files from these smaller longitudinal ranges could be easily recombined into a single output file that could still be displayed in the IVSEM analysis GUI. Figure 3 and Figure 4 show the east and west halves from a simple test where a full earth coverage run was split in half. Figure 5 shows the merged results of the full earth coverage run.

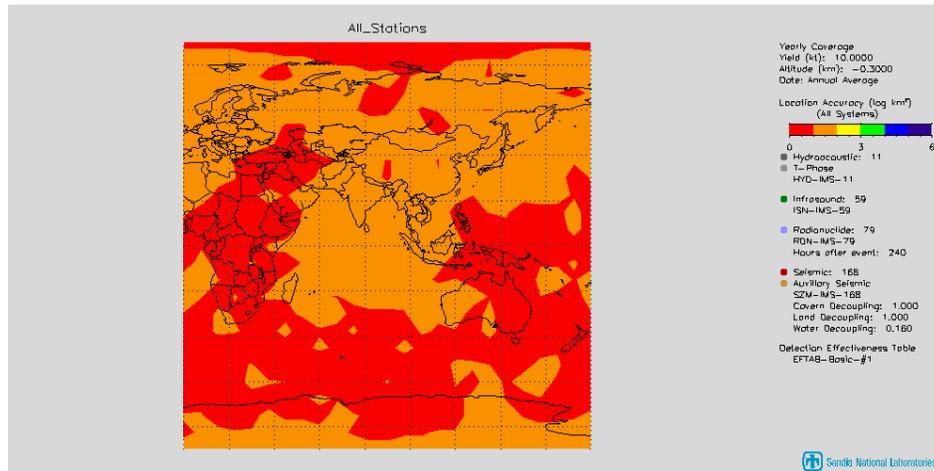


Figure 3. East Half of a Split IVSEM Global Coverage Simulation

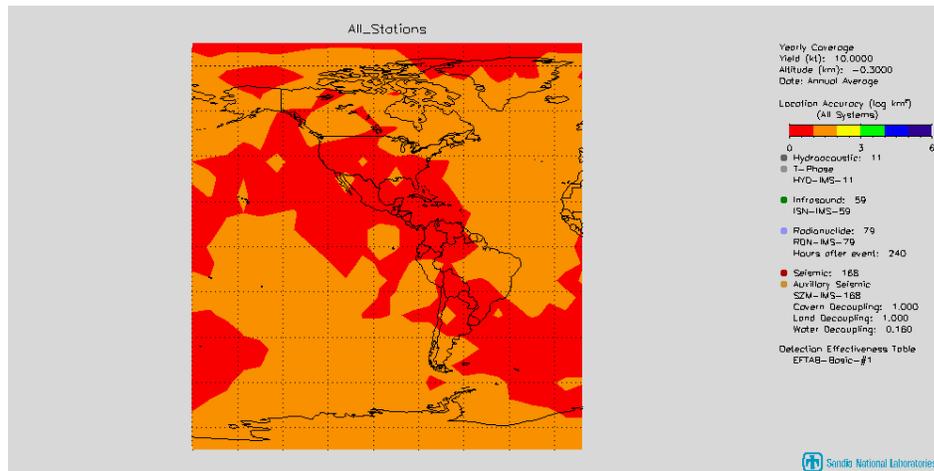


Figure 4. West Half of a Split IVSEM Global Coverage Simulation

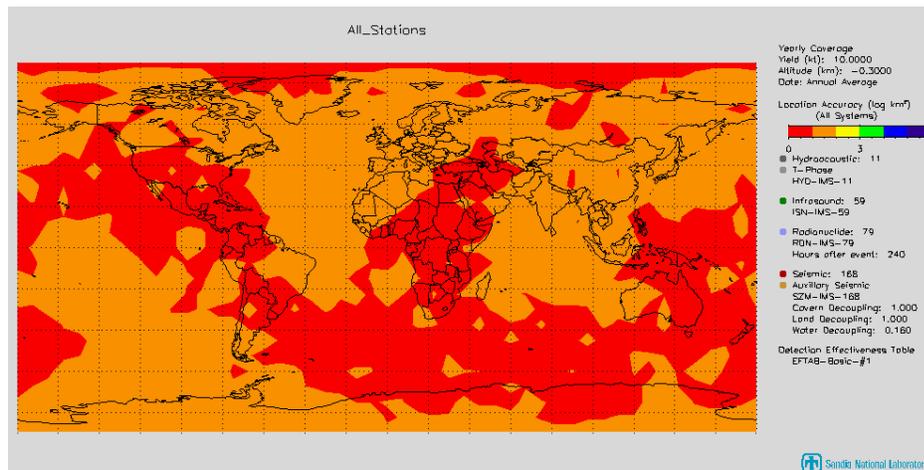


Figure 5. Merged Results of Split IVSEM Global Coverage Simulation

Table 1 shows runtimes for the same IVSEM simulation with different degrees of parallelism. The “# of Instances” column specifies the degree of parallelism used. These measurements were made on a dual quad core (8 cores total) Windows XP system.

Table 1. IVSEM Parallelization Runtimes

#Instances	Runtime (seconds)	□ Runtime (seconds)	% Speedup
1	6695		
2	3749	2946	44
4	1926	4769	71
8	1018	5677	85
16	982	5713	85

The performance improvements like those shown in Table 1 led us to develop several tools to automate IVSEM analyses. These tools are described below.

2. PROTOTYPE JAVA-BASED “BATCHER” INTERFACE

A prototype Java-based front-end GUI with the capability to launch parallel IVSEM instances was developed. This “Batcher” application provides a modern interface that reads and writes IVSEM input files. The application also launches two types of parallelized IVSEM global coverage simulations. A single IVSEM simulation is split longitudinally into multiple parallel simulations that execute concurrently. The Batcher allows users to set up and launch a series of IVSEM simulations by varying one of several key parameters. The Batcher maintains a thread pool that feeds the series of simulations to the processor cores as they complete previous simulations.

The Batcher application provides a modern interface for setting up an IVSEM simulation. It has numeric controls with bounds checking, pre-populated pull down menus for enumerated data, and check boxes for Boolean inputs. These features prevent simple editing errors in the *ivseminp* file.

The Batcher application is described in Section 2.1.

2.1 Setting Up an IVSEM Simulation with the Batcher

The Batcher is a Java application and requires that the Java Run Time Environment is installed before it will run.

2.1.1 Setting the Batcher

The Batcher application is started by double-clicking on the *testUIDelegate.jar* file. While this file can be installed anywhere on the user computer, it expects the IVSEM application and files to be installed in the folder path:

C:\IVSEM20\

2.2 The Batcher File Menu

The File menu allows users to select or create an *ivseminp* file, save changes to the simulation setup, and quit the Batcher application. Figure 6 shows the Batcher File menu options.

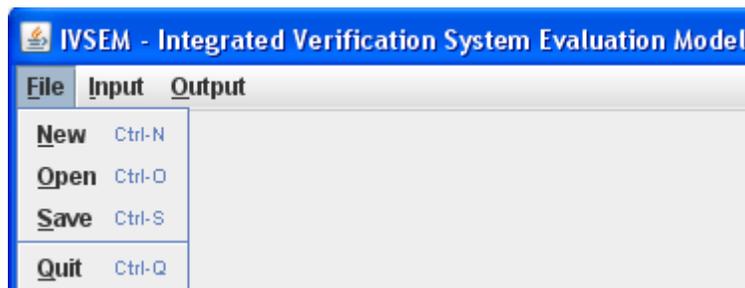


Figure 6. Batcher File Menu Options

The first thing a user needs to do after starting the Batcher is to specify the input file. A new file can be created or an old file opened.

To avoid problems when working with IVSEM files and folders, the user should heed the following guidance:

- File and folder names should have no spaces; spaces are not handled by the IVSEM application.
- Save each IVSEM simulation in its own folder because IVSEM will overwrite previous output files (the Batcher enforces this rule).
- Once a file is created or opened, another file cannot be created or opened. Restart the application to change input files.
- File dialog does not show actual file names.

2.2.1 Creating a New IVSEM Input File

Selecting **New** from the File menu allows the user to create a new IVSEM project with an input file. The user is prompted to name the project and specify the directory for the project folder. The user enters a project name and browses the file system for the folder that will hold the project folder. Figure 7 shows the New File dialog box.

The browse button allows users to select the folder for the new file; selecting it opens a file dialog box as shown in Figure 8. This Java dialog allows the user to navigate the directory and create a new folder. The file dialog defaults to the IVSEM data directory (C:\IVSEM20\data) Folders can be nested within this folder to any depth. As noted above, a new folder should be created for a new project file. Click the “New Folder” icon  in the upper right corner to create the new folder and give it a valid name (with no spaces); then click “Open” to select this folder for the project file.

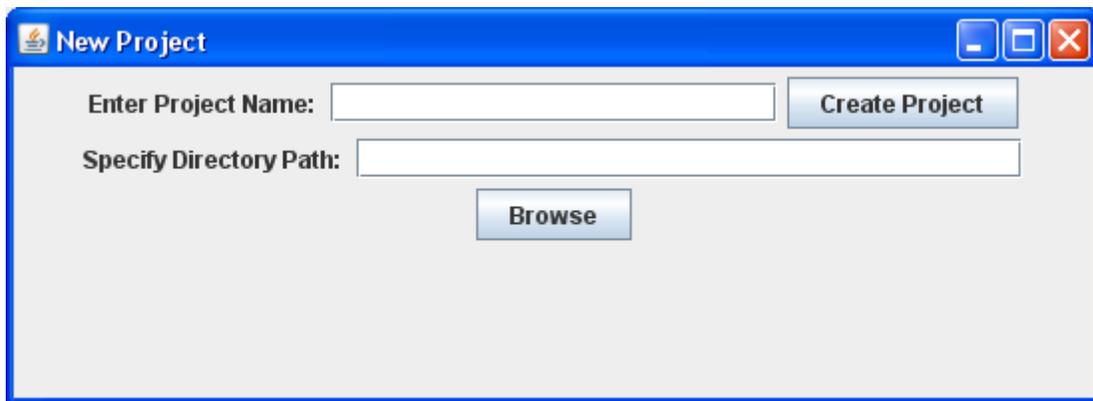


Figure 7. New File Dialog Box

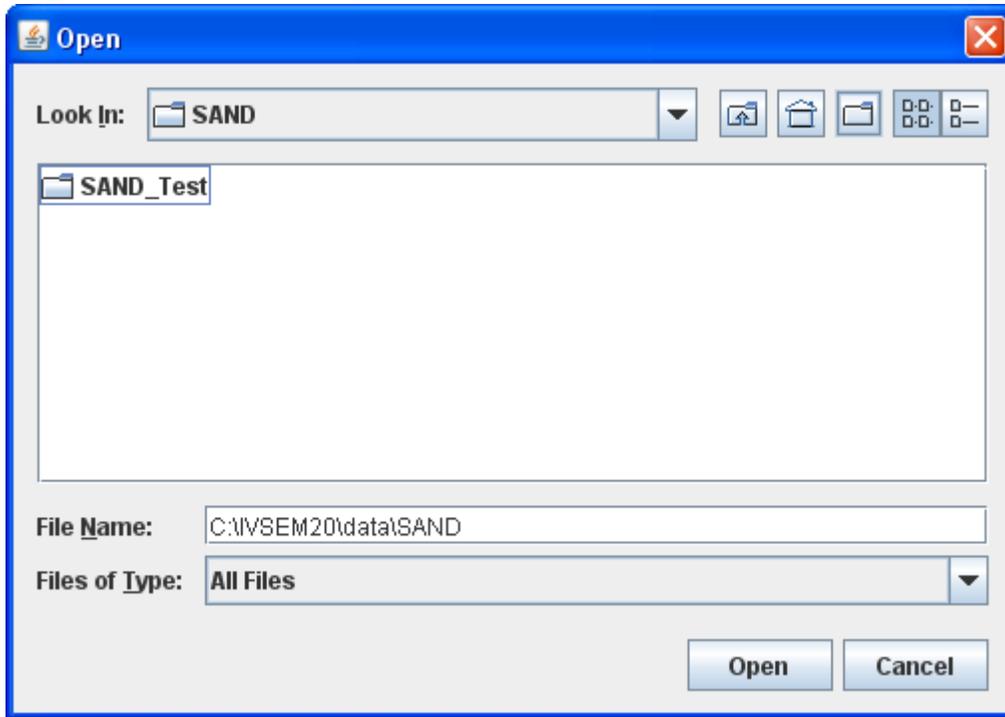


Figure 8. Batcher File Dialog Box

When the “Create Project” button is clicked, the Batcher creates a folder with the Project Name that is located in the folder selected with the file browser. A partial *ivseminp* file is created in the newly created folder. This *ivseminp* file contains default values for the event but needs to be populated with information from the station files and effectiveness table data before a simulation can be run. This data is entered with the various options in the Input menu, which is described in Section 2.3.

2.3 Batcher Input Menu Operations

The Batcher Input menu allows the user to setup IVSEM simulations. The Input menu options, shown in Figure 9, include the setup of the simulation event; the hydroacoustic, infrasound, radionuclide, and seismic stations; and the options for batch mode operation. These options are described in Section 2.3.1 through Section 2.3.6.

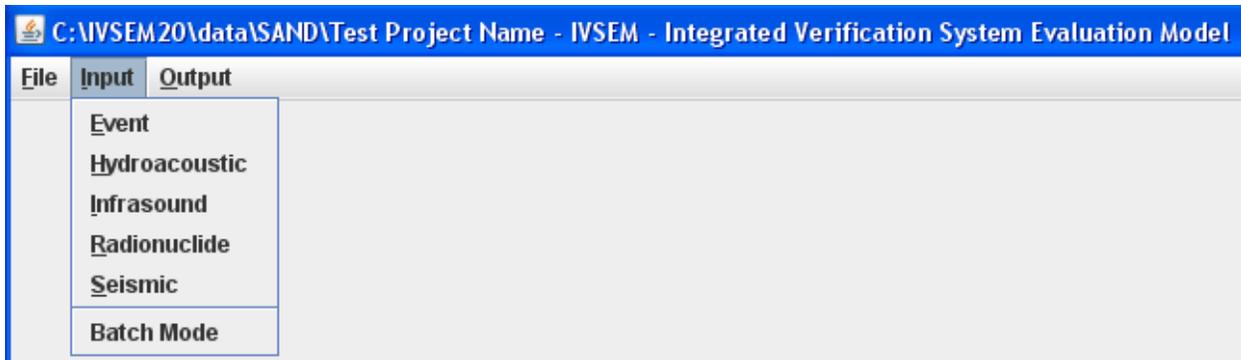


Figure 9. Batcher Input Menu Options

2.3.1 Event Options Setup

Selecting “**Event**” from the Input menu displays the window shown in Figure 10. This window allows the user to setup event and simulation specific parameters.

- The top row of parameters includes the Yield and Altitude for the simulated detonation. Yield must be positive; altitude can be positive for an atmospheric test, or negative for an underground test.
- The next row of parameters specifies the latitude and longitude for a single event simulation.
- The third row of parameters specifies the range of latitudes for global coverage simulations. The left latitude should be less than the right value. Enter “-90.0” and “90.0” for a full range of coverage. A more limited range of coverage can be entered.
- The fourth row of parameters specifies the range of longitudes for global coverage simulations. The left longitude should be less than the right value. Enter “-180.0” and “180.0” for a full range of coverage. A more limited range of coverage can be entered (this is how simulations are split into smaller simulations for parallel runs.)
- The fifth row of parameters includes the grid resolution and the coverage format options for the simulation. The grid resolution can be set to 1 degree or more. For faster but lower resolution simulations, set the resolution to greater values. This can be useful for a quick check on parameters. The coverage format options are shown in Figure 11. The coverage format options specify the type of simulation run by IVSEM. Selecting “Single Event” will simulate the system response to a nuclear detonation with yield, altitude, longitude and latitude specified with the other parameters, whereas selecting one of the "Global" options will model the ability of the IMS to detect nuclear detonations evenly spaced at the specified grid resolution over the specified range of longitudes and latitudes. Selecting “Global One Month” will simulate the IMS global response to the specified explosion over a one month period starting with the date and time specified on the Event Options page. Selecting “Global 12 Month” will simulate the IMS response for an average of 12 monthly coverage simulations.
- The last parameters in the Event Options window are the detection effectiveness table values. These values represent synergy among technologies by specifying the combination of sensors for each technology responding to an event that constitute a detection. Detailed discussion of this topic can be found in [1]. The detection effectiveness table can be read from an effectiveness file by clicking the “Select File”

button. This leads to a file dialog box which opens with the IVSEM default effectiveness file. The effectiveness table values can also be edited in this window.

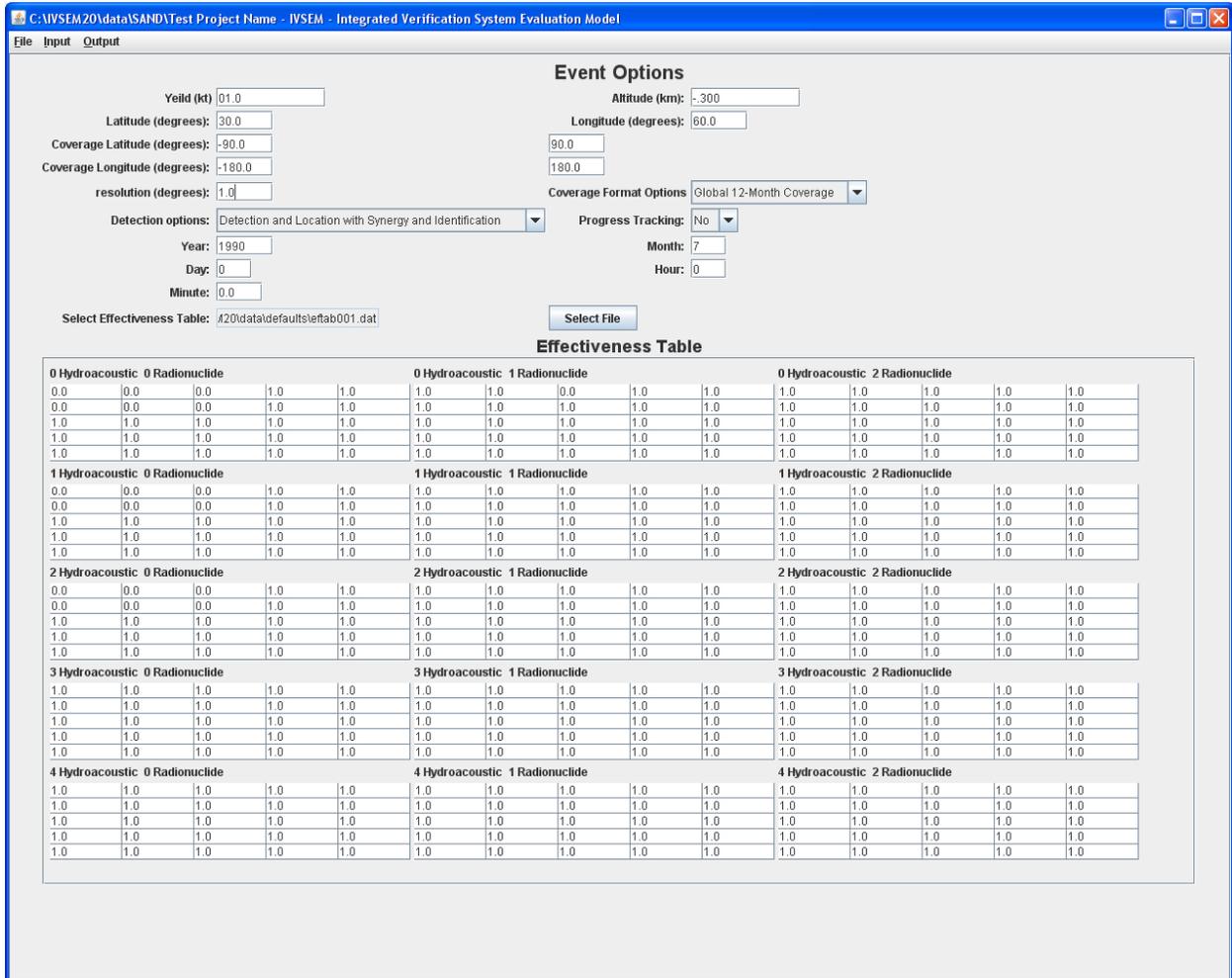


Figure 10. Event Options Setup



Figure 11. Coverage Format Options

2.3.2 Hydroacoustic Station Options

Selecting “**Hydroacoustic**” from the Input menu (Figure 9) opens the window shown in Figure 12. This window allows the user to set up the hydroacoustic stations and related options.

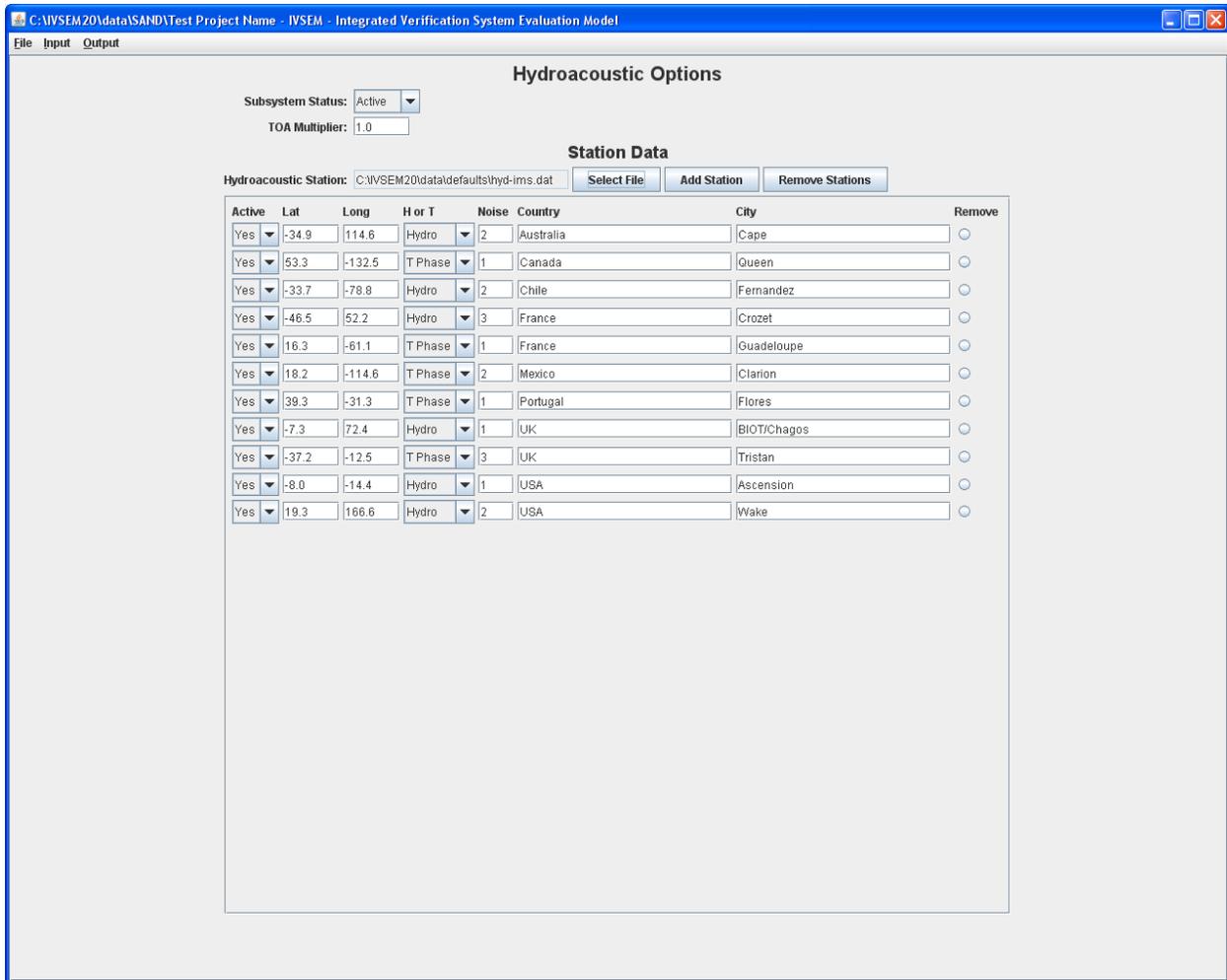


Figure 12. Hydroacoustic Station Options

- The Subsystem Status pull down allows the user to turn off hydroacoustic detection for the simulation.
- The TOA Multiplier sets the multiplier for the time of arrival error for which [2] provides this description:

The built-in rms signal arrival time error is multiplied by this parameter. The built-in rms arrival time error is the square root of the sum of two squared errors. The first error is a constant pick-time error of 1 sec. for hydroacoustic stations and 5 sec. for island T-phase stations. Pick-time error is the error associated with selecting an arrival time from a signal profile. The second error is a travel time error and is assumed to be 0.02 times the square root of station-to-event distance. The input parameter's default value is 1.0 which does not alter the built-in error.

The Station Data table contains data for each station. The table includes the following selection options and data displays:

- The “Select File” button opens a file browser which allows the user to specify the hydroacoustic station file.

- The “Add Station” button adds a new station with default values from the Cape Leeuwin station.
- The “Remove Station” button allows the user to remove any stations which have their “Remove” button selected.
- The “Active” selection allows the individual station to be turned on or off. Turning a station off allows the station data to remain in the file, but the data is excluded from simulations.
- The “Lat” and “Long” numeric values specify the station location.
- The “H or T” selector specifies whether the station is Hydroacoustic (in the water) or T-phase (land-based seismic stations which measure seismic P waves induced by hydroacoustic waves at the ocean-island interface.). Both types of stations participate in both detection and location.

2.3.3 *Infrasound Station Options*

Selecting “**Infrasound**” from the Input menu (Figure 9) opens the Infrasound Options window shown in Figure 13.

The Subsystem Status pull down allows the user to turn off infrasound detection for the simulation.

The TOA Multiplier is described in [2] as follows:

The ... parameter is a location accuracy parameter for arrival time errors. The arrival time error built into the model is multiplied by this parameter. The built-in error is an rms arrival time error which is assumed to be 2% of signal travel time. The default value of the input parameter is 1.0 which does not alter the built in error.

The Bearing Error multiplier is described in [2] as follows:

The ... parameter is a location accuracy parameter for bearing errors. The bearing error built into the model is multiplied by this parameter. The built-in error is an rms bearing error, and it is equal to 1.8 degrees for station-to-event distances between 0 and 3000 km; it increases linearly to 7.0 degrees for distances between 3000 and 10,000 km; it increases linearly to 20 degrees for distances between 10,000 and 15,000 km; and it is 20 degrees beyond 15,000 km. The default value of the input parameter is 1.0 which does not alter the built-in error.

The Threshold to Noise Ratio is described in [2] as follows:

The... parameter is the threshold value which the signal-to-noise ratio must exceed to get a station detection. If the signal-to-noise ratio is equal to the threshold value, the probability of a station response to the event is 0.5. The threshold’s default value is 1.5.

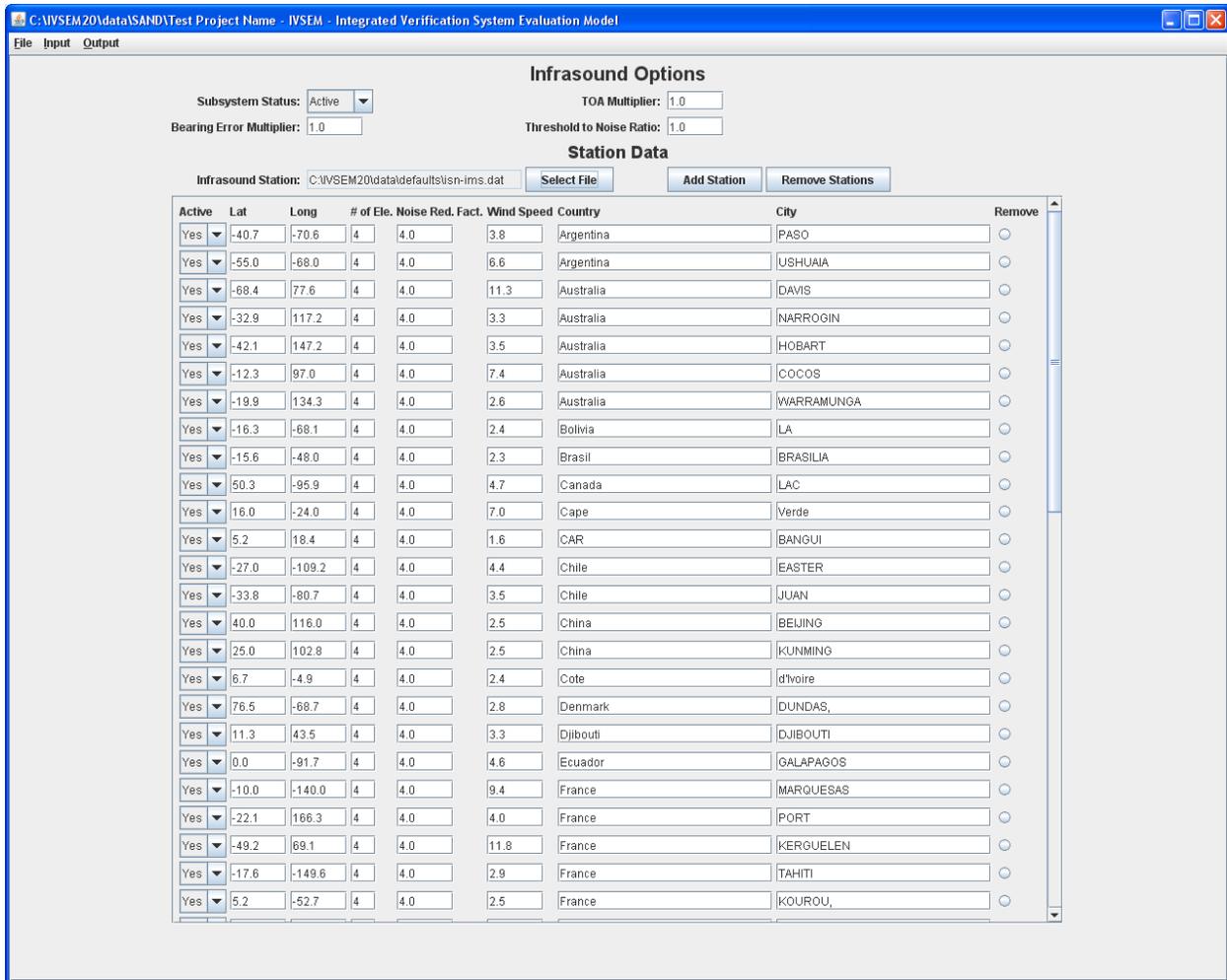


Figure 13. Infrasound Station Options

The Station Data table contains data for each station. The table includes the following selection options and data displays:

- The “Select File” button opens a file dialog that allows the user to choose a station file.
- The “Add Station” button adds a new station to the end of the list; the new station has a default setting from the Paso Flores station.
- Individual stations can be removed by selecting the “Remove” button for each station to remove and then clicking the “Remove Stations” button.
- The “Active” selection allows the individual station to be turned on or off. Turning a station off allows the station data to remain in the file, but it is excluded from simulations.
- The “Lat” and “Long” numeric values specify the station location.
- The “# of Ele” parameter is the number of elements used at the station. A greater number of elements will result in a larger signal. Four elements is the default.
- The “Noise Red Fact.” parameter is a noise reduction factor for the station. In real stations, noise reduction may be accomplished by a “spider” or hoses. The default noise reduction is 4.0.

- The “Wind Speed” parameter is the average wind speed at the site in m/s. The average wind speed is used to calculate the station's noise. If the wind speed is set to the flag value of 99.0, the infrasound module computes average monthly wind speed from surface wind data in the wind data file based on the station’s regional location. The average monthly surface wind speed computed from the wind data file may or may not be the best average wind speed to use because the actual location may have an average local wind speed that is significantly lower than the average regional wind speed.

Actual values for some of these parameters are published on the CTBTO website.

2.3.4 Radionuclide Station Options

Selecting “Radionuclide” from the Input menu (Figure 9) opens the Radionuclide Options window shown in Figure 14.

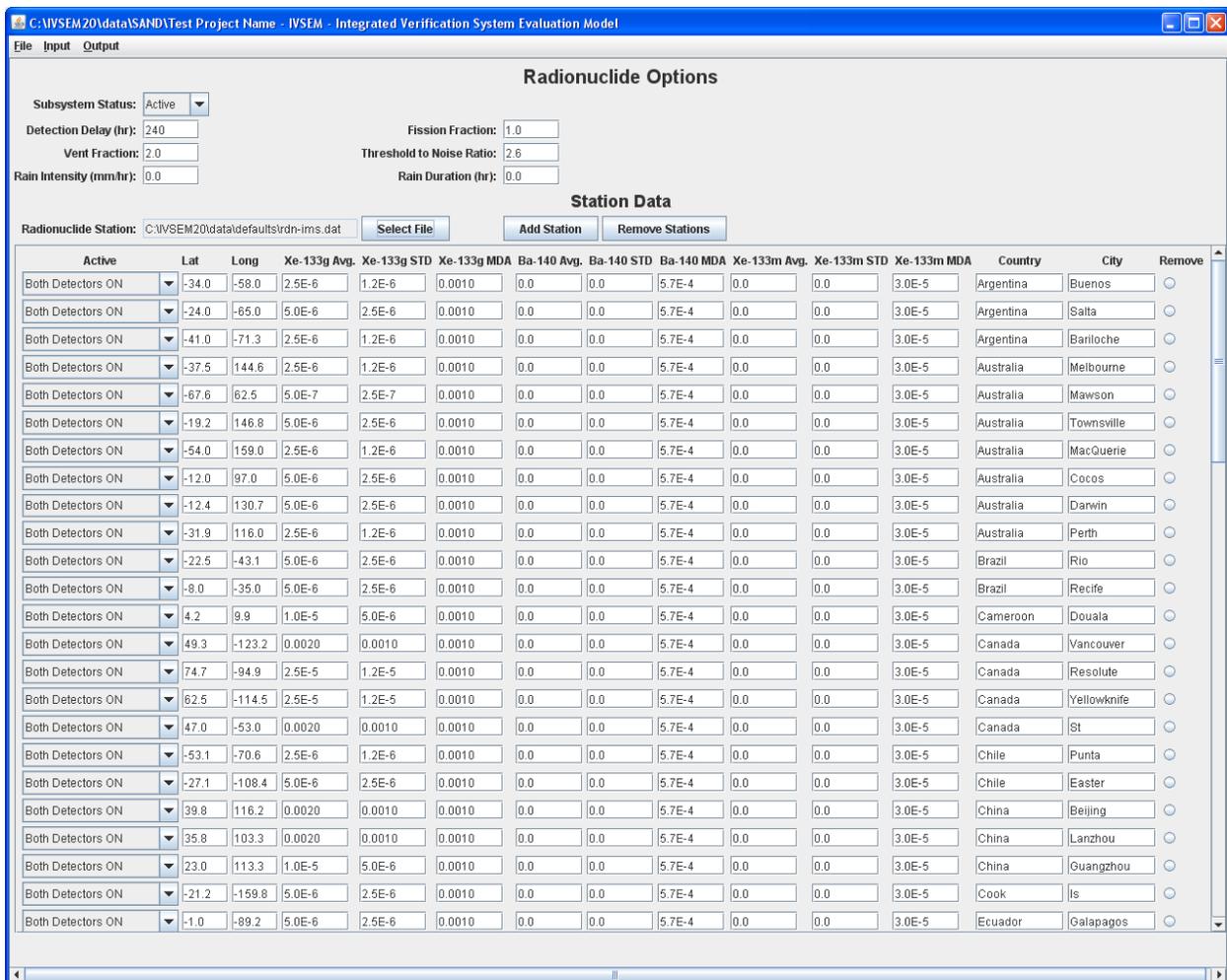


Figure 14. Radionuclide Station Options

The Subsystem Status pull down allows the user to turn off radionuclide detection for the simulation.

The Detection Delay parameter is described in [2] as follows:

The ... parameter is the maximum allowed detection time which is the length of time (in hours) after an event in which the radionuclide subsystem is allowed to get a detection. The default is 240 hours (10 days). For this default value, a detection occurs if radiation from any 24 hour sample within the 10-day period exceeds the specified threshold value. Smaller or larger values can be used, and execution time is directly dependent on maximum allowed detection time.

Reference [2] states the Fission Fraction parameter

“specifies the fraction of fissions generated from fission neutrons in contrast to the fraction generated from fusion neutrons. This parameter has a small effect on the source term. We use a default value of 1.0 to indicate a fission weapon.”

The Vent Fraction description in [2] states:

[Vent Fraction] is the fraction of fission product material assumed to vent immediately from an underground or underwater detonation. If a value greater than 1 (2 is the default) is specified, the model computes a value that depends on scaled depth of burst. If a value between 0 and 1 is specified, the model uses that value as the vent fraction. Radionuclides which are assumed to vent immediately become a part of the elevated debris cloud which may ultimately trigger sensors. Radionuclides that vent slowly are assumed to become part of a diffuse, low concentration, ground cloud which does not trigger sensors because ground winds have low speed and the cloud will probably not reach a sensor before the radionuclides decay.

The Threshold to Noise Ratio description in [2] states:

The ... parameter is a threshold which the sample activity must exceed to get a station detection. Every station site is given an average and a standard deviation of preexisting background radiation for each radionuclide. The default threshold of 2.6 specifies that the signal (which includes background radiation) must be 2.6 standard deviations above the average background radiation to get a sensor response probability of 0.5. The default value of 2.6 gives roughly 1.7 false alarms per year (for a 24 hour sample period).

The Rain Intensity parameter is entered in mm of rain per hour. The description from [2] states:

The sixth parameter is rain intensity in mm/hr. Our default value is 0. A heavy rain might be 40 mm/hr. Rain removes aerosols from the atmosphere. A long, light rain will remove aerosols more effectively than a short, heavy rain if the total rainfall is the same for both.

The Rain Duration parameter specifies the hours of rain. The default is 0.

The Station Data table contains data for each station. The table includes the following selection options and data displays:

- The “Select File” button opens a file dialog that allows the user to choose a station file.
- The “Add Station” button adds a new station to the end of the list; the new station has a default setting from the Paso Flores station.

- Individual stations can be removed by selecting the “Remove” button for each station to remove and then clicking the “Remove Stations” button.
- The “Active” selection allows the individual station to be turned on or off. Turning a station off allows the station data to remain in the file but excluded from simulations.
- The “Lat” and “Long” numeric values specify the station location.
- The “Xe-133g Avg”, “Xe-133g STD”, and “Xe-133g MDA” parameters are described in [2] as “the average and standard deviation of local background radiation levels and the minimum detectable activity, respectively, for each station in Bq/m³ for Xe-133g. Notice that the background values are higher in the northern hemisphere than in the southern hemisphere, a result of nuclear power generation and fuel processing site locations.”
- The “Ba-140 Avg”, “Ba-140 STD”, and “Ba-140 MDA” parameters descriptions in [2] state “the average and standard deviation of local background radiation levels and the minimum detectable activity, respectively, for each station in Bq/m³ for Ba-140. (To date, we have used Ba-140 background levels of 0.0 for all stations.)”

2.3.5 Seismic Station Options

Selecting “**Seismic**” from the Input menu(Figure 9) opens the Radionuclide Options window shown in Figure 15.

The Subsystem Status pull down allows the user to turn off radionuclide detection for the simulation.

The “TOA Multiplier” parameter is described in [2] as follows:

The ... parameter is a location accuracy parameter. The signal arrival time error built into the model is multiplied by this parameter. If the input parameter is given a value of 1.0, the built-in error will be used; if it is given a value of 1.7, the built-in error will be multiplied by 1.7. The built-in error is an rms arrival time error and is the square root of the sum of two squared errors. The first error is a constant error of 0.75 seconds. The second error is 0.15 seconds divided by signal-to-noise ratio minus 1. The default value for the location accuracy parameter is 1.0 which does not alter the built-in error.

The “Cavity Decoupling Factor” default value is 1. Decoupling increases with greater values for this parameter.

The “Land Decoupling Factor” models the type of medium surrounding the detonation. The default value is 1.

The “Water Decoupling Factor” default value is 0.16.

The “Threshold to Noise Ratio” parameter is described in [2] as follows:

The ... parameter is the threshold-to-noise ratio which the signal-to-noise ratio must exceed to get a station detection. Seismologists currently use a value of 3, which we have adopted as our default value. If the signal-to-noise ratio is equal to this threshold, the response probability is 0.5.

The “False Identifications Allowed per Year” parameter is described in [2] as follows:

The ... parameter specifies the number of earthquakes which are allowed to be falsely identified as explosions each year. This parameter sets the threshold value for discriminating between earthquakes and explosions. If the value is set lower, there will be fewer earthquakes mistakenly identified as explosions, but the probability of “missing an explosion—falsely identifying a nuclear explosion as an earthquake—becomes greater.

The Station Data table contains data for each station. The table includes the following selection options and data displays:

- The “Select File” button opens a file dialog that allows the user to choose a station file.
- The “Add Station” button adds a new station to the end of the list; the new station has a default setting from the Paso Flores station.
- Individual stations can be removed by selecting the “Remove” button for each station to remove then clicking the “Remove Stations” button.
- The “Active” selection allows the individual station to be turned on or off. Turning a station off allows the station data to remain in the file, but it is excluded from simulations.
- The “Lat” and “Long” numeric values specify the station location.
- The “Primary” pull-down selector specifies whether the seismic station is a primary or auxiliary station. The parameter description in [2] adds:
Only primary stations are used for event detection. Both primary and auxiliary stations are used for location accuracy estimation if the verification system detects the event.
- The “# of Ele.” is the number of elements used at the station. If the number of elements exceeds one, the station is called an array.
- The “Teleseismic Noise” parameter is the noise value in nanometers for teleseismic distances. The description in [2] notes, “Different stations will have different noise values; however, in the absence of specific station data, we use uniform noise values.”
- The “Intermediate Noise” and “Regional Noise” parameter descriptions in [2] state
The ... parameters are noise values for intermediate distances (1111 to 2500 km for stable regions, 500 to 2000 km for tectonic regions) and regional distances (less than 1111 km for stable regions, less than 500 km for tectonic regions), respectively.
- The “Surf. Wave Noise” parameter is the noise value, in nanometers, for surface waves used in the identification analysis.

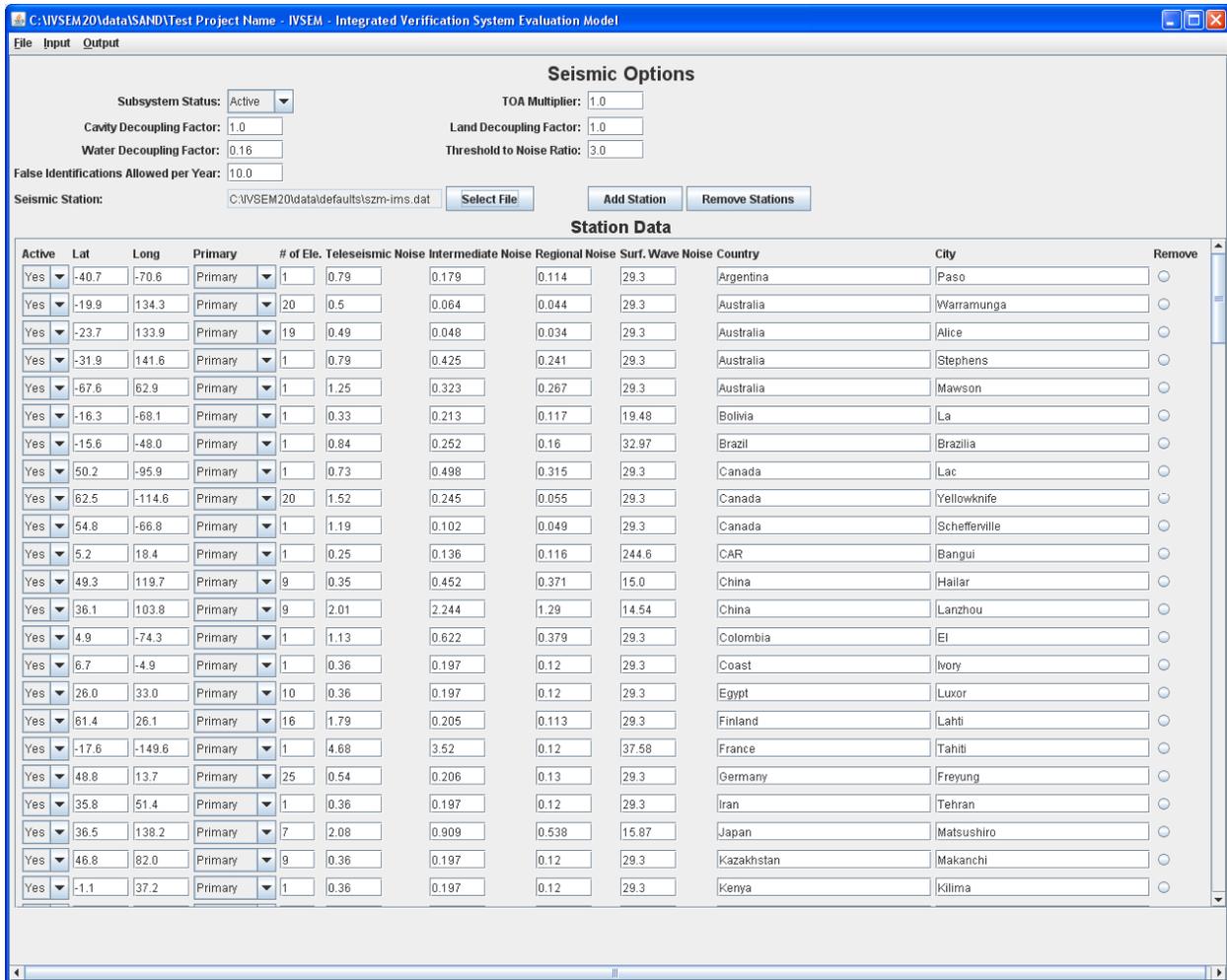


Figure 15. Seismic Station Options

2.3.6 Batch Mode Setup Parameters

The Input menu also includes the setup of batch mode runs; this window is shown in Figure 16. A batch mode run takes the active *ivseminp* file and creates a set of *ivseminp* files each with a different value for the specified parameter. The batch mode simulation input files are each stored in folders named with the name of the variable parameter and the value for the particular run (ex. Yield20.000).

The parameter to vary is selected with the “Parameter” pull down shown in Figure 16. The parameters that can be varied in batch mode include yield, altitude, resolution, and vent fraction. The “Min. Value” and “Max. Value” parameters set the lower and upper bounds for the selected parameter, and the “Increment” parameter sets the amount of change between each run.

The “Batch Mode ON” box must be selected for the batch mode to be executed.

The batch mode run can be executed by selecting “Run” from the Output menu (Figure 9). The batch mode runs are executed in parallel with each IVSEM executable assigned to a processor

core. The Batcher manages a thread pool that starts new IVSEM executables when a previous one finishes. This continues until all simulations in the batch run are complete.

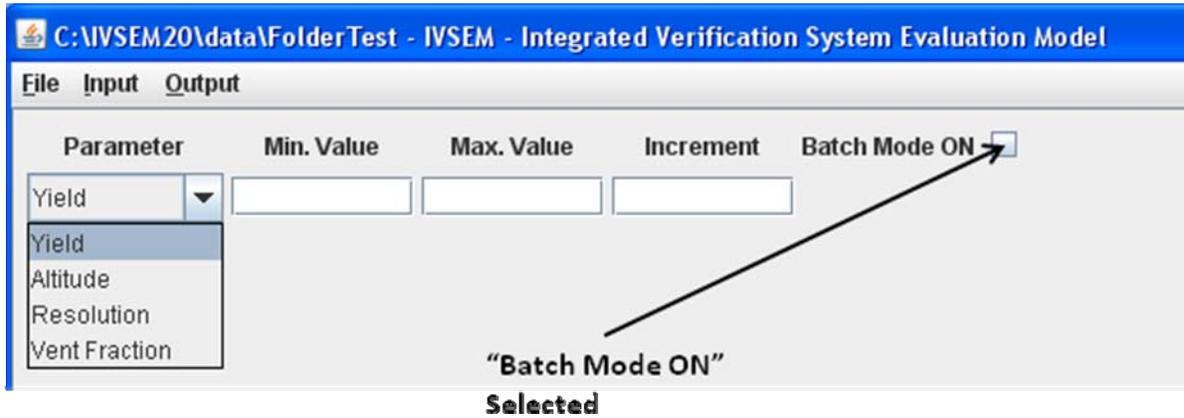


Figure 16. Batch Mode Setup Window

2.4 The Batcher Output Menu Operations

The Batcher Output Menu allows the user to start an IVSEM simulation and specify whether or not the simulation will be run in parallel mode.

2.4.1 Run

Selecting “**Run**” from the Output Menu launches a single, non-parallel IVSEM execution unless a valid batch mode simulation has been setup up. If the “Batch Mode ON” box was selected, the batch of simulations will be run in parallel with each IVSEM executable assigned to a processor core. The Batcher manages a thread pool that starts new IVSEM executables when a previous one finishes. This continues until all simulations in the batch run are complete.

2.4.2 Run Parallel

Selecting “**Run Parallel**” from the Output Menu will start a parallel execution of the selected *ivseminp* file. The Batcher splits the IVSEM simulation into eight multiple smaller simulations and launches each in parallel. A folder is created for each of the smaller simulation and the corresponding *ivseminp* file is written there. The simulation writes the output file to the same folder. After the smaller simulations complete, the Batcher combines the outputs to create the output file for the original simulation. The folders created for each simulation are then deleted along with their contents.

3. STATION SENSITIVITY ANALYSIS TOOLS

About 75% of the IMS stations have been certified; the remaining stations are either under test, under construction, or planned. In addition to building out the remainder of the IMS, the CTBTO must maintain the existing network, so it is useful to know the capability impact of individual stations to help prioritize spending on certification and maintenance. A series of station sensitivity simulations was performed to evaluate the contributions of the uncertified stations. This section describes the station sensitivity analysis approach and provides a guide to the setup and execution of a station sensitivity analysis. The main software components used in this analysis are discussed. This code can be modified to produce other IVSEM analyses.

3.1 Station Sensitivity Analysis Overview

The station sensitivity analysis used a 12-month global coverage simulation with the certified stations as a baseline scenario. The sensitivity for individual uncertified stations was calculated by running a series of simulations with only one uncertified station added to the baseline certified stations, and the same simulation scenario was repeated. The output for each simulation was analyzed to generate images of the station sensitivity results graphs for each technology and for the “all systems” synergistic results.

3.1.1 Simulation Folder and File Structure and Setup

The analysis was setup from a master *ivseminp* file with only the certified stations turned on; this file is stored in a root folder for the analysis. For each simulation run with a master *ivseminp* file, the software creates a folder named with the date and time in a *yyyymmddhhmmss* format. Within this folder, a folder titled *baseline* is created and the master *ivseminp* file is copied there. The software creates a new folder for each of the uncertified stations (i.e., those that are not enabled in the master file) and writes a modified version of the master *ivseminp* file with all the certified stations along with the uncertified station turned on. The *ivseminp* file for each of the uncertified stations is written to a folder named with the technology (*szm*, *hyd*, *isn* or *rdn*) and the latitude and longitude. The folder structure is shown in the left side of Figure 17. This figure also shows the input, output, and images files for a station’s analysis.

3.1.2 Executing the Simulation

The software creates the full path for the baseline folder and all uncertified station folders to a queue. Once the queue is populated with all folder names, parallel instances of code to launch the simulations are started. Each parallel instance reads a path from the queue, passes the path information to an IVSEM executable with a Windows system *exec* call, and waits for the simulation to complete. A semaphore limits access to the IVSEM *exe* to only one of the parallel instances to prevent file access errors that caused some simulations to fail. When the simulation completes, the code reads another path from the queue and launches another simulation. When the queue is empty, the parallel code stops.

IVSEM writes the *cplotout*, *cvsemout* and *status* files to each station folder. Only the *cplotout* file is used for analysis.

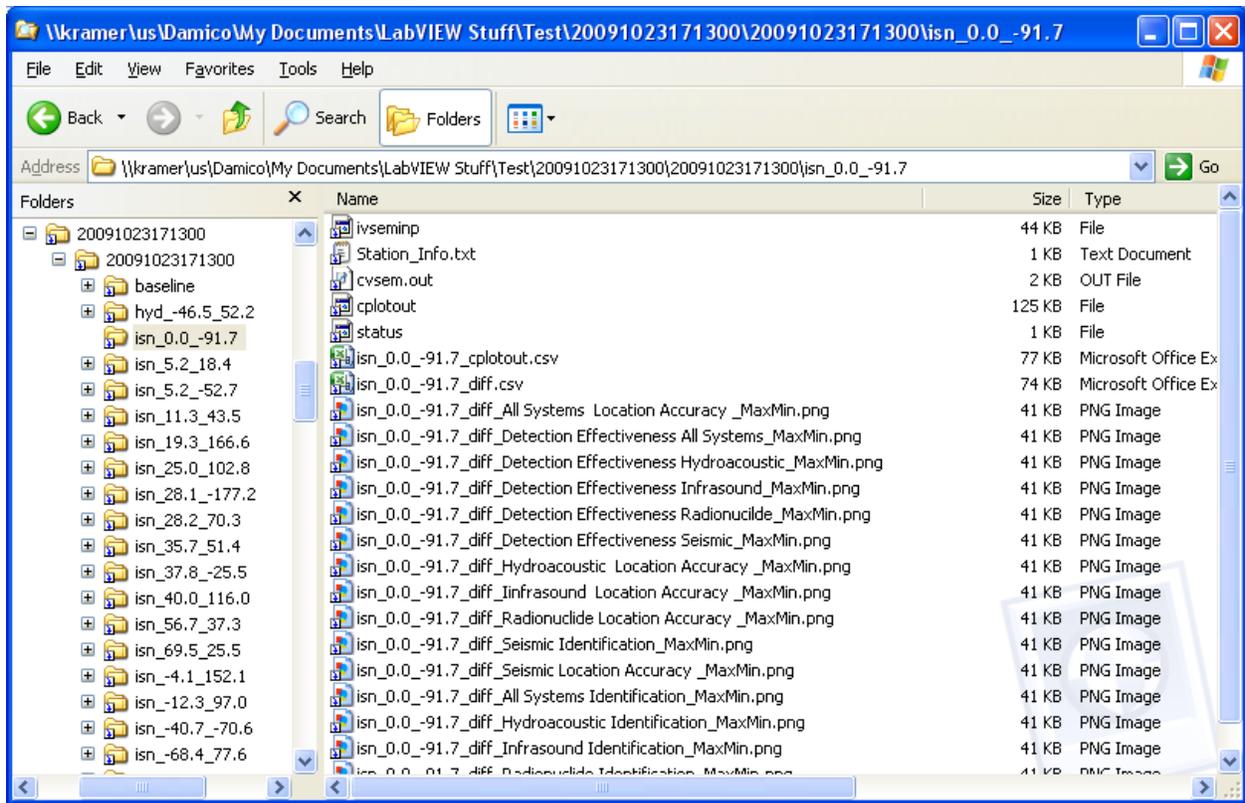


Figure 17. Example Station Sensitivity Folder

3.1.3 Analyzing the Simulation Results

The analysis software reads the *cplotout* file for each simulation and converts the simulation results to a comma-separated value (csv) spreadsheet file named with the technology, latitude and longitude. An example of one of these filenames is *isn_-68.4_77.6_cplotout.csv*. (Note that the baseline *cplotout* file is converted to a csv file called *baseline.csv*.) The csv files are used for all further calculations and can also be used for further analysis or display with other tools.

The baseline results are subtracted from the results of the baseline plus the single uncertified station to calculate the single station sensitivity. This calculation is performed to estimate the location accuracy and detection effectiveness for each technology (seismic, hydroacoustic, infrasound, and radionuclide) and for the all-technologies with synergy. A csv formatted difference file is created by subtracting the *baseline.csv* file from all the stations csv results files. These difference files are named with the station technology, latitude, and longitude. An example is *isn_-68.4_77.6_diff.csv*.

3.1.4 Analysis Outputs

The output of the analysis on all stations is summarized in a spreadsheet that lists the maximum, minimum, and average changes for all systems detection effectiveness (AS_DE) and location accuracy (AS_LA). Figure 18 shows an example of an output spreadsheet. The percentage of changed cells is listed in the “%Diff” column for each of these calculations. This value is hyperlinked to an image of the related graph. The Station column is hyperlinked to the folder containing the results for that that station; clicking it will open the folder for browsing and

display of results images thumbnails. The spreadsheet can be sorted by column to aid in analyzing the results.

1	Station	AS DE_Max	AS DE_Min	AS DE_Avg	AS DE	% Diff	AS LA_Max	AS LA_Min	AS LA_Avg	AS LA	% Diff	AS ID_Max	AS ID_Min	AS ID_Avg	AS ID	% Diff
28	rdn -8.0 -35.0	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
29	rdn 13.8 100.5	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
30	rdn 18.0 13.0	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
31	rdn 2.6 101.5	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
32	rdn 23.0 113.3	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
33	rdn 28.0 -113.0	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
34	rdn 28.0 -177.0	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
35	rdn 32.5 15.0	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
36	rdn 35.0 52.0	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
37	rdn 38.0 103.3	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
38	rdn 39.8 116.2	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
39	rdn 43.7 131.9	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
40	rdn 49.3 -123.2	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
41	rdn 5.5 42.7	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
42	rdn 68.0 166.4	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
43	rdn 69.0 88.0	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000
44	szm 51.7 103.6	0.0000	0.0000	0.0000		0.0000	0.0300	-0.0500	-0.0100		1.0000	0.0000	0.0000	0.0000		0.0000

Figure 18. Sample Station Sensitivity Analysis Summary Spreadsheet

The analysis software also automatically generates images of intensity graphs for each station and technology where the “%Diff” is greater than zero. Figure 19 shows a sample intensity graph. The units are log km².

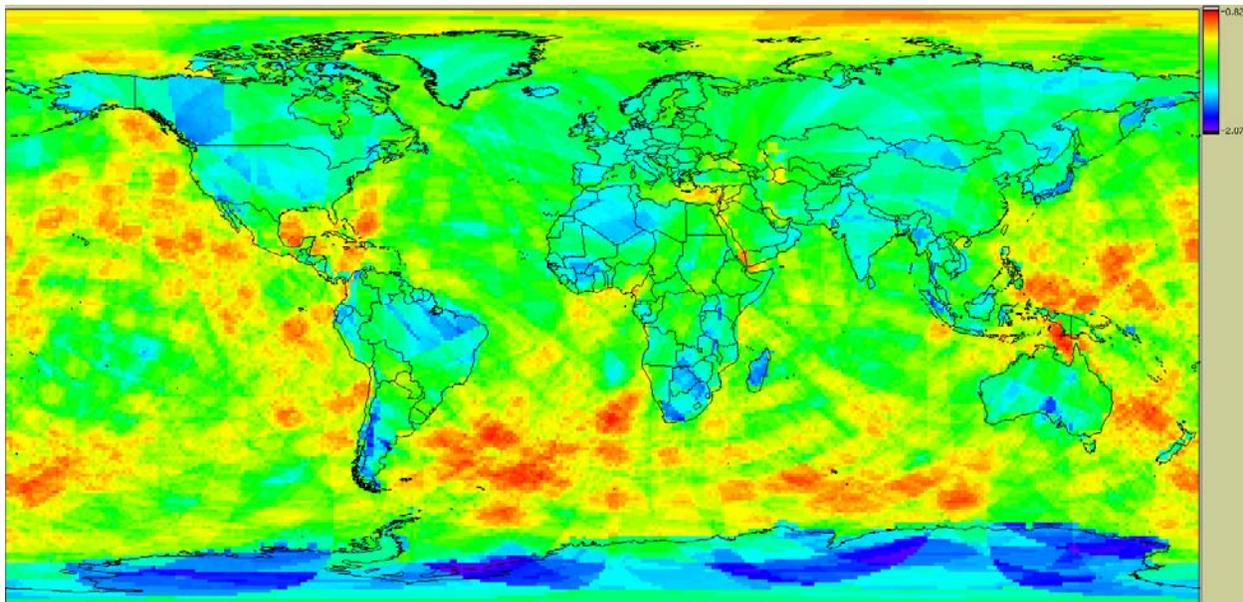


Figure 19. Sample Image of Station Location Accuracy Sensitivity

3.1.5 Other Station Sensitivity Analyses

The station sensitivity analysis described above measured the impact of adding an uncertified station to a baseline set of all certified stations. Other variations are possible, but were not performed. Another possible analysis could measure the difference of removing a station from a larger set (all stations for example) of IMS stations.

3.2 Running a Station Sensitivity Analysis

3.2.1 Setting Up the IVSEM Master File

The first step in setting up a station sensitivity analysis is the definition of the master *ivseminp* file. This file can be generated or modified with the IVSEM or Batchter GUI. All event, technology, and station parameters for the simulation should be set in the master file. The baseline set of monitoring stations should be turned on and all other stations turned off. Any stations that are not desired in the analysis should be completely edited out of the master file since turning them off in the master file ensures they will be turned on for a simulation. This master file should be placed in a folder accessible by IVSEM (remember IVSEM expects data to be on the C: drive with file paths without any spaces.)

Simulations can be repeated with the same master file; the software will create a folder alongside the master file each time it is used for a station sensitivity analysis.

3.2.2 Running the Station Sensitivity Simulations

The Station Sensitivity Analysis code is written in LabVIEW 2009. A LabVIEW program or subroutine is called a Virtual Instrument, or VI. These files have a file extension of “.vi” on Windows systems.

To start the analysis, open LabVIEW and then run the Run Station Sensitivity Analysis.vi file.

The analysis code will prompt the user for the baseline input file (the master file discussed above). The code then displays a dialog window that allows the user to select the IMS technologies to use in the analysis. All technologies are on by default; turn off any undesired technologies and then click the “OK” button to finalize the selections and close the dialog.

The analysis code creates the simulation folder structure and populates each folder with a modified version of the master *ivseminp* file. The path to each of these input files is placed on a queue for execution.

Cloned versions of the “Run Queued IVSEM Instances.vi” run in parallel. This simple VI checks the queue for a file path to process and then parses the file path to create the input parameter strings for launching an IVSEM simulation with the system exec call. A semaphore shared between the parallel instances allows only one simultaneous launch of the executable file since file access collisions have been observed occasionally and result in flawed results. Each instance waits for the semaphore and then delays several milliseconds after acquiring the semaphore before it launches the IVSEM system exec call. The semaphore is released and the VI loops until the *cplotout* file is closed indicating the IVSEM simulation is complete. The VI then loops back and checks the queue for a new input file path. The VI terminates when the queue is empty.

The Run Station Sensitivity Analysis.vi monitors the queue size while the parallel simulations are running. This gives the user some indication of progress in the series of simulations. The VI terminates when the queue is empty and all of the parallel instances have terminated.

3.2.3 Automated Analysis of the Station Sensitivity Results

The large number of simulation files led to the development of automated tools for basic analysis.

Subtract IVSEM Output Directory Differences.vi takes the baseline output file, converts its system response results into a spreadsheet-compatible comma-separated values (csv) file. It then traverses the directories for each station, converts the output file for each station to a csv file, and then subtracts this file from the baseline csv file to create a differences csv file. This VI can be used to generate a difference csv file for any two IVSEM output files as long as they are placed in adjacent folders.

Create Station Sensitivity Report 2.vi takes the location of the baseline folder and then traverses all station folders and computes the maximum, minimum, and average values for each difference file's technology results. The fraction of changed cells is also calculated. This VI then generates Portable Network Graphic (PNG) images of intensity graphs computed for all output and difference csv files. Finally, the summary spreadsheet is populated with summary data and hyperlinks to the images and folders created in the analysis. This VI can generate graph images from any .csv files generated by the Subtract IVSEM Output Directory Differences.vi.

4. ANIMATION TOOLS FOR IVSEM RESULTS

The .png intensity graph images for a series of IVSEM simulation results can be combined into a simple animation that aids the visualization of the simulation results. These animations are particularly useful for visualizing the system performance changes with a varying parameter such as those modeled with a Batchter batch job. For example, one animation shows the system detection effectiveness changes with varying yields.

The Image Magick software freeware package provides the necessary functions to convert the .png images into an animated GIF image, which plays an animation. While .png files are best suited for generating .mng animations, .mng players are not standard Windows software so GIF animations are used here. Note that Image Magick can also generate .mng files if desired. Image Magick is a command line tool that can be called with a Windows system exec call. Image Magick must be downloaded, installed, and configured on the system where it will be used. See www.imagemagick.org for downloads and help with this software.

The IVSEM animations have been created manually from the Windows command line. The .png files are first copied into a temporary folder with sequential file names. Using the windows cmd window, the working directory should be set to the temp directory containing the .png files. The Image Magick system exec is then called with several parameters specifying the desired operation.

A sample Image Magic system exec call has the form

```
convert -delay 100 *Seis*Loc*.png seis_movie.gif
```

where

convert specifies the Image Magick conversion function

-delay specifies the delay between the animation images in milliseconds (100 mS in this call)

***Seis*Loc*.png** specifies the input filenames (these are assumed to be in the current working directory. Wildcards are allowed; in this case, seismic location files would be selected.)

seis_movie.gif specifies the filename for the output file

Image Magick interprets the file types from the parameters and applies the correct image conversions to generate the output file.

5. CONCLUSION

The IVSEM model is a valuable tool for investigating the response of the CTBTO IMS under different scenarios. The tools and techniques described in this report improve the IVSEM run-time performance without modifying the IVSEM executable by utilizing the multi-core capabilities of modern personal computers. These tools also provide modern user interfaces to simplify the setup and execution of parallel IVSEM runs.

The setup automation tools and parallel IVSEM execution enables the generation of large data sets that require automated analysis tools. The analysis tools described in this report convert the IVSEM outputs to a more common .csv file format and generate difference .csv files. New graphing routines were developed to process these .csv files and generate PNG image files of the graphs. Simple animations of changing system response can be created with these PNG images and the free Image Magick toolkit.

It is hoped that the tools and techniques described here will allow further application of the IVSEM model.

6. REFERENCES

- [1] M.W. Edenburn, M.L. Bunting, A.C. Payne, Jr, R.R. Preston, and C. Lawrence, *CTBT Integrated Verification System Evaluation Model*, SAND97-2518. Sandia National Laboratories, Albuquerque, NM, October 1997.
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