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NetCAP Status Report for the End of Fiscal Year 2010

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Abstract

The Network Capability Assessment Program (NetCAP) is a software tool under development at Sandia National Laboratories used for studying the capabilities of nuclear explosion monitoring networks. This report discusses motivation and objectives for the NetCAP project, lists work performed prior to fiscal year 2010 (FY10) and describes FY10 accomplishments in detail.

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Technical discussions and collaborations with colleagues in the ground based nuclear explosion monitoring (GNEM) programs at LANL and LLNL have been extremely useful throughout NetCAP's development.

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NOMENCLATURE

DOE	Department of Energy
GNEM	Ground Based Nuclear Explosion Monitoring
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
SNL	Sandia National Laboratories

1. INTRODUCTION

Fiscal year 2010 (FY10) is the second full year of NetCAP development and the first full year devoted largely to new feature development rather than the reimplementation of existing capabilities found in NetSim (Sereno et al., 1990). Major tasks completed this year include:

- Addition of hydroacoustic simulation
- Addition of event Identification simulation
- Initial design and preparation for infrasound simulation

2. BACKGROUND

The Network Capability Assessment Program (NetCAP) was initially conceived in 2008 as a rewrite of the NetSim seismic network simulation software to provide a fresh, extendable codebase and a more user friendly interface. A major requirement was that NetCAP make comparable event detection and location assessments as NetSim when both applications are configured to use the same file inputs for specifying networks of stations, instrument noise estimates, phase propagation models, event source characteristics, and so on. That requirement was met within the first year of development, and NetCAP's scope has since expanded both in the monitoring technologies that can be simulated (hydroacoustic and infrasound have been added) as well as in the type of monitoring capabilities that can be simulated (location simulation has been significantly upgraded and event identification has been added).

3. PRIOR ACCOMPLISHMENTS - FY10 BEGINNING OF YEAR STATUS

A version of NetCAP with seismic event detection capability assessment was first delivered in January 2009 and essentially reproduced the NetSim functionality for calculating the probability of detecting body waves generated by fixed size events as well as the minimum event size detectable by a seismic network at a fixed fidelity. These results were shown to match NetSim calculations with high accuracy.

A version of NetCAP with seismic event location capability assessment was demonstrated to users on August 19 and 20th, 2009 and was the last major milestone of FY09. Rather than using a direct port from NetSim for event location estimates, which would limit the fidelity of the location simulations, NetCAP's location module uses Sandia's LocOO event location software, which has been extensively benchmarked against the operational event location code used by the U.S. monitoring authority. LocOO in turn uses Sandia's powerful PGL observation prediction library, also benchmarked against operational code, for calculating seismic phase travel times. PGL can calculate travel times through 1D, 2D, or 3D models, and can further increase accuracy by applying kriged empirical data correction surfaces, if they are available. Leveraging LocOO and PGL provides a sound basis for high fidelity location assessments in NetCAP. NetCAP also includes extensions for using the Magnitude Distance Amplitude Calibration (MDAC -- Walter and Taylor, 2001) technique for calculating regional amplitudes, a broad band based detector to better match operational procedures (in addition to the default high signal to noise ratio (SNR) detector used in NetSim), and amplitude estimation for Rayleigh surface waves (LR) based on the Ms(VMAX) technique (Russell, 2006).

Beyond the use of better geophysical algorithms, other major accomplishments in the NetCAP project have been the production of a modern codebase written in Java and the introduction of a powerful graphical user interface to improve the user experience over previous tools that are based on command line interfaces.

4. MAJOR ACCOMPLISHMENTS IN FY10

Hydroacoustic simulation, event identification, and initial design and development of infrasonic simulation capabilities were the primary focus in FY10. Other tasks include improved documentation and improved steps to provide confidence in analyzing NetCAP simulation results.

4.1 Hydroacoustic Simulation

Hydroacoustic signals are generated by events occurring within or near the surface of the Earth's oceans. Due to the oceanic Sound Fixing and Ranging (SOFAR) waveguide, these signals can propagate long distances with very limited attenuation (in the absence of physical blockages along propagation paths), thus oceanic events can be well monitored using a relatively small number of sensors. Simulating hydroacoustic networks is vital to assess oceanic event monitoring capabilities.

4.1.1 Approach

High fidelity hydroacoustic event simulation is already available in the HydroCAM (Hydroacoustic Coverage Assessment Model) package developed by BBN (Farrell et al., 1997), HydroCAM includes algorithms and models directly suitable for NetCAP and since the NetCAP team lacks expertise in hydroacoustic monitoring and the calculations are complex, NetCAP's approach to simulating network capability involves processing the sensor signal to noise ratio (SNR) grids created by HydroCAM simulation runs to find network capability estimates. HydroCAM's explicit focus is in predicting the detection and location performance of explosion monitoring networks for sub- and near-surface events. HydroCAM can simulate both hydroacoustic and T-phase (a type of seismic phase created when a hydroacoustic signal converts to ground motion on collision with a landmass) signal propagation and instrumentation, but T-phase simulation is not currently considered of high enough quality for inclusion in NetCAP. HydroCAM characterizes the SOFAR waveguide, uses bathymetry models to compute blockages and signal refraction, and accurately computes signal loss.

4.1.2 Simulation Details

HydroCAM outputs frequency and event size dependent SNR outputs for a set of defined sensors for a specified grid of event locations. The grid covers event locations visible to each sensor, which are largely dependent on line of sight. For production of the grid output files for NetCAP use, HycroCAM is run without sensor ambient noise so the grid outputs for each sensor actually contain observed signal amplitude, not SNR. NetCAP loads the HydroCAM grid files and also loads its own hydroacoustic sensor noise information and performs the SNR calculation internally. This allows users to use different noise files to capture phenomena such as seasonal variation in cultural and natural noise levels without having to rerun HydroCAM. The standard NetCAP release contains a set of HydroCAM files for the stations in the IMS hydroacoustic network for 1 kiloton signals propagating at 10.0Hz. Additional production of HydroCAM sensor grids is required if a new station is to be added to the simulation, or if additional event size or frequency sampling is needed.

Hydroacoustic monitoring networks are typically composed of stations containing multiple sensors that are perhaps located at different depths or focused at different angles. It is also common for a station to have multiple groups of sensors that are capable of detecting events from drastically different regions of the ocean. For example, one set of sensors might be placed on the northern side of island and a second set placed on the southern side. NetCAP allows users to organize sensors into stations without constraint, which gives the simulation the flexibility required to define simulated monitoring networks as they are actually deployed. NetCAP's current approach defines a station's detection capability according to the component sensor with the best detection characteristics.

NetCAP provides the ability to assess detection probability for a fixed event size as well as to find minimum event sizes detectable at a fixed confidence level. Since HydroCAM signal amplitude calculations are performed offline and thus the event size sampling is fixed, interpolation between grids of different event sizes is used to estimate results for event sizes not directly represented in the supplied HydroCAM grids.

Lawrence Livermore National Laboratory (LLNL) has been a key partner in developing NetCAP's hydroacoustic simulation capabilities. The HydroCAM event grid sensor outputs used by NetCAP were all calculated by LLNL. Separate work at LLNL resulted in a set of historic IMS hydroacoustic station noise observations that can be used as input to NetCAP.

4.2 Event Identification

NetCAP takes two approaches to simulating network event source identification capability. The first is to determine the probability that individual discriminants can be applied, which answers questions about events that are observed with sufficient clarity to be used in network identification calculations. The second approach is to actually apply discriminants to assess how well a network can identify events.

4.2.1 Probability of Discriminant Application Calculations

Certain data quality constraints such as the minimum SNR for observations, minimum number of observing stations, and maximum azimuthal gap between two observing stations must be met in order for a discriminant to be applied. Finding the probability that a network meets these constraints provides analysts with information about where on the Earth, and for what types and sizes of events, discriminant calculations can be made. Hence, this information shows where it is feasible to distinguish between explosions and earthquakes (without actually identifying the source). NetCAP extensions to support these sorts of calculations include calculating the probability that station observations meet an azimuthal gap requirement, separating identification

SNR from detection SNR criteria, and allowing the simulator to make and display multiple probability calculations during a single run. This last step is important as it allows NetCAP to simultaneously provide color overlays and contours for network probabilities of detecting events, applying individual discriminants, applying a group of discriminants, and of applying discriminants where events can be detected.

Discriminant capability assessment setup is available through the NetCAP GUI and is written to disk for preservation across NetCAP runs.

4.2.2 Discriminant Calculations

Two seismic discriminants have been implemented: the regional P/S family that ratios signal amplitudes of a regional P phase (Pg, Pn) with a regional S phase (Sn, Lg), and mb:Ms that ratios teleseismic body wave (P) and surface wave (LR) magnitudes. In addition, we have begun to work on implementation of the depth-from-location discriminant, that is based on the idea that events occurring below a certain depth cannot be explosions due to limitations in drilling and mining technologies. The depth-from-location discriminant requires events to actually be located (as opposed to simply calculating location uncertainty ellipses), a feature provided by the LocOO utility that NetCAP uses, which was unavailable in NetSim.

Regional P/S and mb:Ms discriminants can be simulated as either network or single station discriminants. In a network based discriminant, individual observations can occur at any station in a network. The network result is an average value, but there are two ways to form the average. As an example, consider a network based regional P/S discriminant. The first approach is to average the P-type amplitude from all observing stations, average the S-type amplitude from all observing stations, and then find their ratio. This approach does not require each station to have observable amplitudes for both phases; each phase contributes separately and a missing phase is not problematic so long as at least one station has an observable phase. The second approach is to ratio the P-type observation and S-type observation at each station, then average those results. This approach implies that each station must have observable amplitudes for both phases to contribute to the average. The same data quality constraints for the number of observing stations, azimuthal gap, and SNR apply in both cases.

4.2.3 Monte-Carlo Simulation

Network based discriminants follow the framework designed for use with MDAC calibrations (Anderson et al., 2009) for regional phase discrimination that fully attributes residuals between observations and predictions to two normally distributed error event and station terms and a bias due to source type. Variances from the error terms are used in the discriminant calculations, but also can be used to provide populations that can be sampled. Doing so allows simulated amplitudes to realistically vary while maintaining consistency with empirical observations. Perturbing amplitudes in this way lets users evaluate various monitoring scenarios at a high level of fidelity and can help identify features such as stations or individual discriminants that are most important for making event identifications in particular regions. This sort of information can also reveal shortcomings in monitoring networks.

Another advantage of this randomized approach to computing observed amplitudes is related to calculating observed event magnitudes. Since magnitude is an input to NetCAP to generate predicted amplitudes, following a deterministic process to estimate amplitudes and then solving for magnitude results in observed magnitudes that are equal to the inputs. This does not provide useful information for the mb:Ms discriminant since the ratio could just as easily be performed on the input values. Using observed amplitudes randomly perturbed with error terms to solve for magnitude yields observed magnitudes useful for discrimination while more closely matching the monitoring scenario, since physical events have fixed sizes but, due to un-modeled source effects, propagation effects, and measurement error, generally do not have observed station amplitudes that perfectly match predictions.

An optional Monte-Carlo method for computing source amplitudes using the MDAC variances has been implemented. Users select the desired number of realizations for each source grid position and then NetCAP computes that many arrivals for each station in the network. Each realization is expected to have different observed amplitudes at each station, meaning each realization has a unique set of network observations. Since realization results are carried through the seismic location and discrimination modules, this gives insight into the various monitoring scenarios that are possible for a given event position and size.

4.2.4 Event Characterization Matrix

The Event Characterization Matrix (ECM) is a robust, rigorous statistical method for combining multiple discriminants to make an event source identification (Anderson et al., 2007). It can combine very different types of discriminants (e.g. seismic and hydroacoustic), can gracefully drop discriminants that are either unobserved or do not meet data quality constraints, and can easily accommodate the addition of new discriminants. ECM has been implemented in NetCAP at a monitoring technology independent level. This means that even though only seismic discriminants have been implemented to date, NetCAP is designed to make source identifications using results from seismic, hydroacoustic, and infrasound simulation modules.

NetCAP provides full graphical setup of the ECM matrix and associated parameters. These are stored to disk for persistence across NetCAP runs.

Los Alamos National Laboratory (LANL) has been a key collaborator in helping to design NetCAP's event identification module.

4.3 Infrasound simulation

NetSim was not designed for infrasound simulation, but it has been used for infrasound simulation by substituting in appropriate parameter files for source type, propagation, and station noise. However, this approach suffers from a major shortfall relating to a fundamental difference in signals propagating through the earth vs. those propagating through the air: seismic signals travel through a static medium (on the time scales of interest to us) while infrasonic signals travel though a medium with significant time based fluctuations both diurnally and seasonally. It is well known that infrasonic event detection capability at a station for events at a fixed location can vary by several orders of magnitude over the course of a year, depending on prevailing wind direction and speed (Le Pichon et al., 2008). The main shortfalls of NetSim's approach to infrasound simulation are the inability to account for time based fluctuations in signal propagation and no means to deal with time varying noise, other than manually updating references to noise input files. Fortunately, the complexity of the calculations required to account for these effects is not significant, so we were able to extend to NetCAP to account for them by taking advantage of the ready availability of global wind models.

The Horizontal Wind Model 2008 (HWM08) is a respected climatological model of wind velocity. Using this model gives NetCAP access to the seasonal fluctuations in atmospheric conditions affecting infrasound signal propagation. When combined with station noise estimates of the desired fidelity (time of day, season, month, etc.), NetCAP will correctly account for time variance in infrasonic monitoring network capability.

NetCAP will initially only consider stratospheric returns (infrasound signals turned back towards the Earth due to the temperature gradient at the stratosphere-mesosphere boundary (approximately 50km above the Earth's surface). Whitaker's (Le Pichon et al., 2008) well established event yield to observed signal amplitude relationship -- which accounts for average wind speed along the propagation path -- will be used to compute the station observations that form the basis for network assessments.

Planning and initial development for this work occurred in FY10 and will continue in FY11. LANL is providing technical guidance for this aspect of NetCAP.

4.4 Other Accomplishments

Many other small NetCAP tasks were completed during FY10. Major highlights include:

4.4.1 Documentation

NetCAP documentation improved significantly during FY10. The March release included a user's guide and tutorial describing how to use NetCAP. This was a first step towards extending the NetCAP user base.

Additionally, a preliminary document describing in a single source all of the calculations implemented in NetCAP was written in the fourth quarter. This document aims to improve user understanding of the calculations made by NetCAP. This should help build confidence in simulation correctness, point out model limitations, and help prevent misunderstandings about NetCAP's functionality.

4.4.2 Introspection

A further step to improve understanding of NetCAP while also validating and providing a proof of correctness is NetCAP's new introspection tool that is available after a simulation has been run. This tool allows users to select a station and epicenter and then displays the various calculations that NetCAP used to compute the selected station's monitoring capability for the selected event. The display starts with the highest level equations, and users can then drill down through the individual terms to see successively lower level (and therefore more detailed) views of calculations involved in the station's simulation. Introspection is currently limited to seismic detection calculations. Extending to seismic location, discrimination, and other monitoring technologies is straightforward and will occur (dependent on positive feedback from users) as focus shifts away from NetCAP's seismic detection module.

4.4.3 Corrected Surface Wave Simulation

Users discovered discrepancies between observed and NetCAP simulated LR surface wave amplitudes. This was traced to NetCAP's SNR calculation incorrectly using the noise power spectral density while signal amplitude as computed in Ms(VMAX) is in displacement. The correction involved converting noise estimates from power spectral density to root mean squared (RMS) noise amplitude before forming the ratios.

4.4.4 Access to LocOO3D for Seismic Location

NetCAP had used the LocOO software written in C++, and which had only been compiled successfully on the Sun Solaris OS, hence limiting NetCAP to that platform. NetCAP has now been modified to use Sandia's new LocOO3D software written purely in Java, making NetCAP computing platform independent, while still providing access to 1D, 2D, and 3D travel time models. Using LocOO3D makes it possible for NetCAP to be deployed on Windows and Linux machines as well as Sun machines.

4.4.5 IMS Seismic Simulations

To better guide the ongoing NetCAP development, Sandia has begun to calculate our own simulations of the IMS seismic network using historical noise estimates. This effort is transitioning Sandia from being solely a software provider to also being a user. Having local users with expertise in seismology and explosion monitoring will result in improved testing and validation of software before it is delivered to other users, serves as a test bed for formulating software extensions, and makes it possible to perform network assessments at Sandia.

4.4.6 System Effectiveness

System effectiveness calculations are an idea borrowed from the IVSEM tool (Edenburn et al., 1997). A system effectiveness calculation combines results from independent simulations of an event into a single numeric output representing overall system capability. This allows seismic, hydroacoustic, and infrasound simulations to run independent of one another.

4.4.7 Software Release

The only release of NetCAP in FY10 was delivered to users in March, 2010.

5. PLANS FOR FY11

Work on NetCAP was put on hold for most of the fourth quarter of FY10 in order to preserve funding for carryover into FY11 to compensate for funding reductions across the GNEMRD program. This caused a delay in completing event discrimination work and put infrasound simulation development on hold until the first or second quarter of FY11. Initial development work in FY11 will focus on these areas.

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