SCIENCE AND TECHNOLOGY FORESIGHT FOR THE PROVISIONAL TECHNICAL SECRETARIAT OF THE COMPREHENSIVE NUCLEAR-TEST-BAN TREATY ORGANIZATION

Patrick Grenard and Philippe Steeghs

Provisional Technical Secretariat of the Comprehensive Nuclear-Test-Ban-Treaty Organization

ABSTRACT

The Provisional Technical Secretariat (PTS) of the CTBTO has engaged in a Technology Foresight exercise aiming to mobilize the wider science and technology community in support of its mission to nurture and grow the technological capabilities of its verification systems and operations. In this context the PTS is currently working towards the establishment of a technology development strategy and a plan for the implementation of that strategy. The primary objective of the strategy is to structure the current portfolio of technology development activities as well as to provide guidance for future initiatives. A second objective is to promote communication and create a common understanding of technology development issues between the PTS and the wider science and technology community. The starting point is an evaluation of the results of the International Scientific Studies (ISS) project that were presented at the ISS Conference in June 2009. In addition, a critical technology study is being carried out in order to identify relevant wider scientific and technological trends and developments. This paper reports on the status of the Technology Foresight project and outlines the technology development strategy that is currently being formulated by the PTS.

OBJECTIVES

The primary goal of the technology development strategy is to grow the capabilities of the CTBT verification regime and to promote the efficient utilization of advances in science and technology. However, a number of issues that are pertinent to the mission and operations of the CTBTO need to be taken into consideration. Firstly, the PTS needs to prepare itself for the unique challenges and opportunities that are emerging from long-term continuous monitoring operations on a global scale. The IMS/IDC infrastructure is unique in the scope and scale of its mission, which brings some very specific challenges for the adoption of new technologies. Requirements on the longevity of infrastructure and continuity of operations are examples. Technology development should also contribute to increasing the efficiency and sustainability of systems and operations. Expanding the capabilities of the CTBT verification system needs to go hand-in-hand with efforts towards greater efficiency and sustainability. In addition, the technology development strategy should persistently express that transparency, neutrality, and reliability of CTBT verification technology and methods are central themes. The mission of the CTBTO requires the highest standards with respect to the validation and quality of data and products.

TECHNOLOGY FORESIGHT

Questions related to the positioning of CTBTO within a changing environment go well beyond the initial “bottom-up” approach of looking into emerging technologies of relevance to CTBTO’s mission. Most likely, such an activity would require some scenario development work with more than just the CTBTO community in order to better specify potential future requirement profiles of CTBTO to which the evolution of the Science &Technology portfolio of CTBTO would then have to respond and conform.

In order to develop a broader perspective of the future role of the CTBTO verification regime within a changing global context, the PTS is engaging in an extended effort to reach out to, and to incorporate scientific and technological expertise from, the CTBTO community as well as personnel outside of CTBTO.

This Technology Foresight effort is essentially based on four elements: a collaborative electronic forum, focused surveys, technology workshops and bibliometric studies.

Technology Foresight Communication System

A new interactive forum for the exchange of information and ideas on Technology Foresight related to CTBTO has been developed and is available for use. The forum, called the Technology Foresight Communication System (TFCS), can be found at http://www.ctbto.org/expert-area/technology-foresight-communicationsystem/. It contains information, documents, surveys and discussion boards related to the PTS technology foresight effort.

Surveys

As part of the Technology Foresight effort, the PTS is conducting surveys to solicit expert opinions on the future of technology related to the IMS. The first of these surveys was carried out on modeling and computing applications across all the IMS technologies. Subsequent rounds of surveys are planned that will further investigate specific applications of modeling and computing, as well as more general trends, in particular technological fields including seismology, infrasound, and atmospheric sciences. Surveys evaluating the relevance and functionality of OSI techniques applied to different scenarios are also planned.

Technology Workshops

Technology workshops sponsored by external institutions and supported by the PTS have proved to be very effective at bringing together groups of experts from science, technology and industry to focus on topics of particular interest to the PTS. Workshops specific to each of the four monitoring technologies, Seismic, Hydroacoustic, Infrasound and Radionuclide, have been held over the years, typically with a declared theme to focus attention on a particular topic. There have been a number of OSI broad technical workshops as well. A new series of Science and Technology Foresight Workshops are planned, focused not on individual monitoring technologies, but on cross-cutting topics of relevance to the PTS. The output of these workshops will be in the form of advice and recommendations to the PTS on key developments in science and technology that should be considered for adoption by the PTS over the next decade, as they mature. The following topics of interest have already been identified: sources of energy, sensors and digitizers, wave propagation, automation and information processing, human system interfaces, and modeling.

Other forums are necessary, such as contracted studies and design competitions, to ensure that the PTS continues to engage with the applied science and technology communities.

Bibliometric Analysis

A particularly successful element of the Technology Foresight efforts has been the adoption of Bibliometric Survey & Analysis of the world's scientific literature. This foresight method systematically identifies highly relevant articles from many thousands of possible publications, whose authors represent key clusters of experts who could assist the CTBTO in technology foresight. To date, bibliometric analyses have been done on two topics: modeling of propagation phenomena related to event characterization and development of autonomous marine measurement systems with special consideration of hydroacoustics. In addition, a bibliometric analysis of technical and scientific underground nuclear explosion literature has been carried out in the OSI field, which has resulted in a portfolio of OSI-relevant technical background information.

TECHNOLOGY DEVELOPMENT

In the phase of the build-up of the verification systems and operations, technology development has been largely requirements based: technology needs to be developed and deployed to meet the requirements that have been the outcome of the design and specification process. On the whole, the aims and scope of technology development are narrowly defined by what is dictated by the operational requirements.

In the coming years the technology development will gradually shift from the present focus on meeting requirements towards increasing capabilities and preparing for the adoption of new technologies. This shift requires awareness of on-going scientific developments as well as the ability to identify promising new technology at an early stage. This awareness needs to come from involvement with the scientific community. In addition, mechanisms need to be in place to provide active support for the deployment of promising new technologies. In technology areas that have a significant application outside the nuclear explosion monitoring area, especially in seismology, rapid technological progress is being made. The efforts of the PTS will be largely directed towards how to leverage this progress for increasing the capabilities of its systems and operations. In other areas, there may be limited or only incremental progress because of an absence of commercial markets and/or limited application besides nuclear explosion monitoring. In these areas the PTS seeks to serve as a catalyst for developments and be an active supporter of innovation.

For the first phases of new technology development, the PTS depends on the work carried out at universities and institutions that engage in basic research. Key contributions are provided by the nuclear explosion monitoring research that takes place in national laboratories and research networks. However, the PTS also seeks to stimulate technology development by instrumentation providers. Thus, in early stage technology development the PTS takes the role of a potential end-user. In the later phases of technology development the PTS has the possibility to intensify its involvement. For instance, demonstration and validation projects can make use of PTS test facilities and data, such as the recently opened infrasound test-bed at the Conrad Observatory. In addition, the PTS seeks to contribute with its continually increasing experience gained from operating and sustaining its verification systems.

Ultimately the robustness and the performance of an evolving infrastructure integrating new developments will be evaluated within the PTS Performance Monitoring and Testing Framework. While still under development this framework provides a structure for testing and monitoring the verification system processes and elements, ultimately leading to their commissioning.

Scenarios and Major Challenges for Technology Development

At the current stage of development of the monitoring infrastructure, the design of the majority of system components is reaching maturity. Significant improvements in overall system performance can be expected to emerge through exploitation of synergies between monitoring technologies. In the long-term, major improvements may arise from integration of the measurement process with data exploitation using sophisticated modeling and automated learning strategies. The main challenge that lies ahead is to develop the methodology and tools to support this development.

However, integrating measurements and information extraction will require a major overhaul of certain parts of the system. At the same time, backward compatibility needs to be guaranteed. For instance, the current way the waveform database is structured does not lend itself very well to application of advanced Machine Learning methods. However, changing the structure of the database without compromising other parts of the system holds a formidable design challenge.

Improvements in sensors will not only result in better data quality but will at the same time result in a significant increase in data rates and number of detections that need to be processed. Specifically, for hydroacoustic and infrasound data processing, an important issue is reduction of environment noise and the development of an effective approach to signal classification. A similar challenge lies ahead for the radionuclide technologies, where there exists a great need for better background and signature models.

For the On-Site Inspection (OSI) component of the verification regime the main goal for further technology development is the development of mechanisms to take systematic and evidence-based decisions in the planning and execution of an inspection. The creation of signature models that can be used to reliably parameterize geophysical measurements for an underground nuclear explosion is still a hard problem. In addition there is a need to integrate the different technologies with the operational concepts for an on-site inspection, e.g., the establishment of criteria, tools, and methods for choosing data acquisition parameters and effective sampling strategies.

Exploiting Synergies and Integration

The current global monitoring system is set-up as a one-way serial “pipeline” process in which data are created from measurements, followed by data transmission from the sensor station to the data center. In the second stage the information is extracted and reviewed. At several instances models are being used, for instance earth models from which seismic travel time corrections are derived. At present, the measurements and information derived from the data are not explicitly incorporated in the models or used to update and refine models. As a consequence, there is no formal strategy to utilize the vast amount of information from the present and past measurements to improve the monitoring system. The same applies to on-site inspection technologies, where an integration of the measurements coming from the different technologies into the OSI search logic is needed. A central theme of the technology development strategy is the transition from a sequential, “stovepipe” approach into an interconnected system, with several feedback loops. In the shorter term, improvements can be realized through partial integration. An example of a first step in a more integrated approach is to implement data fusion algorithms at an early stage of the data processing pipeline. For instance, joint infrasound and seismic data exploitation may result in significant gains in efficiency of the event screening process.

Beyond the current development horizon one could foresee a transition into a deeply integrated monitoring system operating in a closed loop that links the utilization of sophisticated environmental models in data exploitation with adaptive sensing and automated instrument calibration. Such an integrated system would support an implicit learning process: the sensor and environment models are continuously updated with information that is contributed by new data interpretation and background noise measurements.

At present, the integration of the data from the different sensor types takes place in the last stage of the process. A more effective data exploitation could be achieved if measurements from one sensor could be used to cue a detection and classification process for another sensor. For instance, earthquakes and explosions near the surface can be detected both in seismic and infrasound data. If event detections in both seismic and infrasound measurements could be associated as coming from the same source in an early stage this could result in reduction of the effort needed in the event screening phase. A similar concept could be envisaged for joint exploitation of seismic and hydroacoustic data. This would represent a big improvement when considering the information to be facilitated to the operations support center in a very brief time lapse in case of an OSI.

Another example of improvements that may be realized through further integration is in using additional measurements to improve instrument performance. For instance, atmospheric pressure variations can in certain cases have a detrimental effect on seismometer noise performance. The barometric pressure is measured by infrasound sensors, and hence data from a collocated infrasound sensor may be used to attribute and correct for this effect of the atmospheric pressure on seismometer performance. Similar synergies may be attainable in the integration of the atmospheric modeling—currently performed in support of the interpretation of radionuclide measurements—and the creation of infrasound propagation models. For the particular case of an OSI, the systematic integration of the analysis of the different geophysical techniques allowed by the Treaty would constitute a major development.

Goals for Technology Development

In follow-up to the present strategy development, an implementation plan will be established. Although the PTS is still in the early phase of the Technology Foresight project, some of the intermediate and end-goals of the technology development are already taking form.

Example long term goals: Establishment of a deeply integrated system with long-term memory, utilizing sophisticated models that are generated and maintained using measurements taken by the system itself.

Example intermediate term goals: Waveform event detection and classification takes place using advanced Machine Learning methods. Sophisticated earth, atmosphere, and ocean models are used in support of detection and localization. Creation of a comprehensive spatial and temporal radionuclide background model.

Example short term goals: Establishment of the groundwork for implementation of a Machine Learning approach. Initiate and evaluate data fusion strategies. Implement modern waveform classification tools for infrasound and hydroacoustic data.

CONCLUSIONS AND RECOMMENDATIONS

The PTS is currently reviewing its technology development strategy. Apart from laying the groundwork for sustaining and growing the technological capabilities of its verification systems, a major goal of the Technology Foresight project is to further build relations with the scientific community and to intensify its participation in the nuclear explosion monitoring research networks.

One long-term goal for technology development may be aimed at transitioning the present sequential and highly modular data acquisition and exploitation process into an integrated system that utilizes its own measurements and data to guide autonomous and highly automated operations. Several promising areas for research and development to support such a transition have been identified. For instance, promising results have been obtained with Machine Learning methods in data exploitation, which makes this a key area for further development. Other areas that have been targeted for further analysis are concepts for autonomous platforms, sensors with highly automated self-calibration and noise mitigation capabilities. A general issue that has been singled out as important is the utilization of sophisticated modeling concepts and tools throughout the system.

In the shorter-term there are significant gains to be expected from focused efforts to deploy available technologies and to exploit synergies between the different verification technologies. An example is to work towards more effective tools to support event screening through the joint exploitation of seismic, hydro-acoustic, and infrasound data, or the development of mechanisms for the integration of on-site inspection technologies.

In the first stages of implementation, growing the technology development capabilities and infrastructure will be highly placed on the agenda. With the establishment of a seismic and infrasound test facility at Conrad Observatory in Austria and the creation of an open access virtual Data Exploitation Center (vDEC) in the foreseeable future the first steps have been taken to build the infrastructure to support and stimulate cooperative technology development activities

REFERENCES

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