The CTBTO International Data Centre (IDC)

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Abstract

Following the negotiations on establishing The Comprehensive Nuclear-Test-Ban Treaty (CTBT) in Geneva from 1993 to 1996 and its opening for signature, The Provisional Technical Secretariat (PTS) has been since 17 March 1997 engaged in the establishment of a global verification regime to monitor compliance (prohibition of all nuclear test explosions in any environment). The treaty is yet to reach entry-into-force (EiF), pending mandatory signature and/or ratification of key States (Article IV and Annex 2 of the treaty).

The verification regime includes both non-technical and technical elements. While non-technical refers to diplomatic actions and confidence building measures within States Parties, the latter involves the construction of a complex system built on science, strategy and technology that is divided into three large components progressively being established: the International Monitoring System (IMS), the International Data Centre (IDC) and the On-Site Inspection (OSI).

The role of the IDC is to receive, collect, process, analyse, report-on and archive data from the IMS and other verification elements. Furthermore, to apply on a routine basis, automatic and manual data processing (in order) to produce and archive Standard IDC Products on behalf of all States Parties (provided at no cost) without prejudice to final judgments with regard to the nature of any event, which shall remain the responsibility of the States.

IDC operations began in 2000 with the release of the first global monitoring (automatic and manual) products. The progression of the building of the IMS (coverage) has progressively improved the IDC accuracy by lowering the statistical uncertainty of the parameters associated with the seismoacoustic event epicenters and radionuclide monitoring.

A parallel activity of the IDC is the adaptation of new methods for event detection, in particular the global association of phase arrivals as part of the building of the bulletins, completing the new suit of software for the automatic processing and the interactive review of radionuclide data analysis and the progression on software development in general.

Other functions of the IDC include the provision of open, equal, timely and convenient access to all IMS data, raw or processed (IDC Products), Technical assistance to individual States with a Capacity Building and Training (CBT) programme and engagement with the scientific community.

Key words: IMS, IDC, Nuclear Explosions, CTBT verification, data, products

1. Background

After more than 20 years of provisional operations, the IDC continues a steady progression of development towards being fully commissioned. Methods for IMS network operations and software applications for data analysis on a global monitoring scale have been established and processes continue to be improved. The creation of a Capacity Building and Training (CBT) programme to States Signatories (addressing treaty responsibilities) and the continuous engagement with the scientific community regarding new methods of analysis of data from IMS technologies, has made the IDC an evolved technical division of CTBTO.

Since the establishment of the CTBTO headquarters (1997) at the Vienna International Center (VIC) in Vienna, Austria, there has been no publication depicting the complete (programme oriented) functionality of the IDC. For historical purposes, while the IDC Commissioning continues, we consider it important to present the status of the IDC as of April 2023.

Beginning: The Group of Scientific Experts (GSE) was formally established on July 22, 1976 (after a process that started in 1958) by the Conference of the Committee on Disarmament (CDD) and provided a detailed first mandate (CCD/PV.714) for the experts to specify the characteristics of an international monitoring system. The twenty-year process of research and numerous sessions (held in Geneva, Switzerland, between 1976-1996) covered three GSE mandates (and their respective reports) and three large-scale Technical Tests of the components of the future monitoring system (GSETT-1, GSETT-2 and GSETT-3). While the first two tests were focused on the exchange (and collection) of data from participating seismic stations, the GSSET-3 aimed to develop a single centralized international data center to receive and process the data, and that could evolve and adapt to support future requirements. This test was conducted at the United States (after GSE accepted their generous offer) in Arlington, Virginia to become a Prototype International Data Centre (pIDC) (Dahlman et.al. 2020) and so, preparing the path to the IDC.

A previous (partial) status of development of the IDC was presented by R. Kebeasy in 2004 as part of the North Atlantic Treaty Organization (NATO) Science Series.

2. CTBTO Organigram

The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is an interim organization, whose main task is the building of a verification regime of the CTBT in preparation for the Treaty's EiF, as well as promoting the Treaty's universality.

The Commission consists of two main organs:

- A plenary body (Preparatory Commission - PrepCom) composed by all States Signatories (Member States). This is assisted by three groups: Working Group A (WGA) dealing with administrative and financial issues, Working Group B (WGB) dealing with verification-related issues and an advisory group.
- The Provisional Technical Secretariat (PTS), which assists the plenary body in carrying out its activities has five divisions of which three are technical: The International Monitoring System (IMS), the International Data Centre (IDC) and the On-Site Inspection (OSI) divisions. These are supported by two administrative: Legal and External Relations (LEG) and Administration (ADM) Divisions.

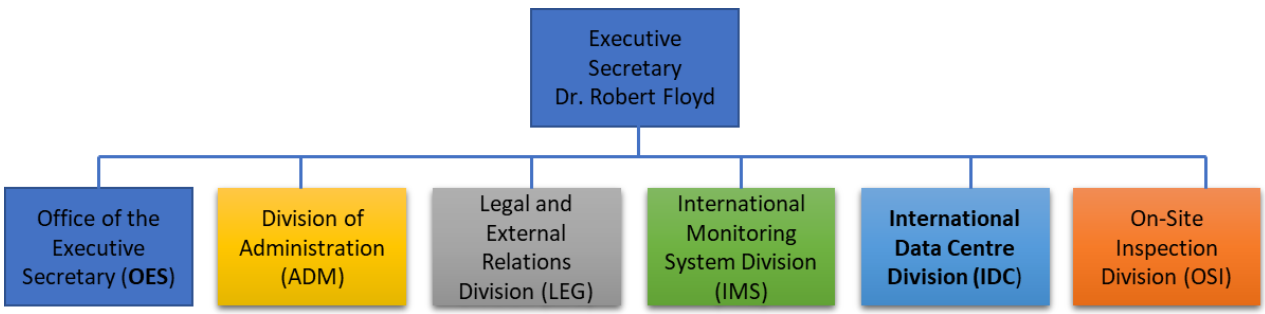


Figure 1. *Organigram of the PTS.*
On 1 August 2021, Dr. Robert Floyd began his tenure (elected) as Executive Secretary of the CTBTO.

The PTS has around 300 multi-disciplinary professional and support personnel from around 90 States. The CTBTO is led by an Executive Secretary and each of the five divisions by a director. The Gender balance of CTBTO is in the range of 35% (female).

The PTS structure employs a centralized authority and top-down decision making with well-defined divisional roles and responsibilities and a clear vertical chain of command. Similar to other international organizations, national institutions or large companies, there is direct managerial oversight through Section Chiefs and Unit Heads (small teams of officers with targeted areas of focus).

3. The IDC

The organigram in Figure 2 reflects the IDC three-tiered vertical structure. The Office of the Director is leading five sections which in turn are led by Chiefs and Unit Heads. Other Divisions in the PTS (shown in Figure 1) have structures with similar characteristics than that of the IDC.

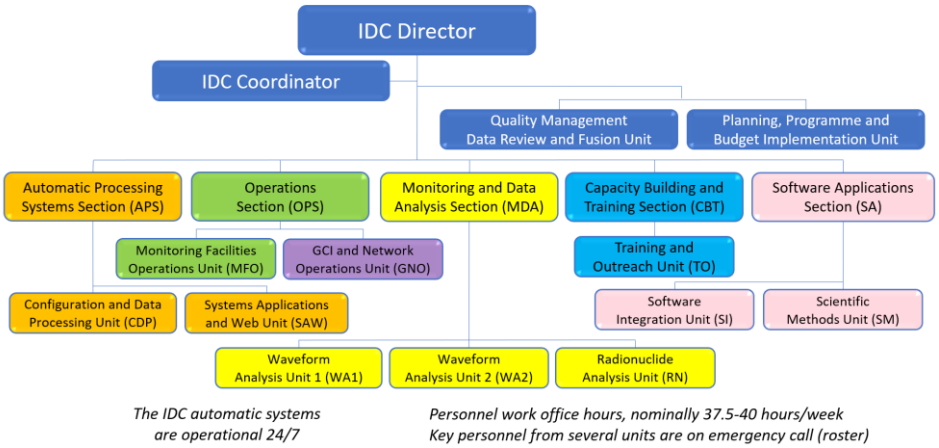


Figure 2. *Organigram of the International Data Centre (IDC).*

The IDC accounts for about 30% of the CTBTO/PTS personnel, distributed in the Office of the Director and five sections as indicated in Figure 2.

IDC is allocated about 50% of the CTBTO budget. About one third of the IDC budget is committed to Post Certification Activities (PCA), which relates to contracting services for local operations of the IMS Facilities (stations and radionuclide laboratories). Apart from its regular budget, the CTBTO also may receive voluntary contributions (VC), Contributions-in-Kind (CiK) and Cost-Free-Experts (CFE) from individual States and the European Union. The IDC benefits from this through support for PCA for some IMS station operations, for infrastructure and training to support National Data Centres (NDCs) and for software development. The NDCs are the technical entities of the States Signatories that engage with the IDC (on a technical level) for issues related to treaty verification or compliance.

3.1 IDC Office of the Director (IDC/OD)

The Director and the Programme and Project Coordinator are responsible for the management of the division, implementation of the IDC programme and technical coordination. The IDC/OD is supported by:

- *Quality Management, Data Review and Fusion Unit* focusing on enhancing the Quality Management System (QMS), performance monitoring, testing and reporting to advance the IDC progressive commissioning.

- *Planning, Programme and Budget Implementation Unit* assisting in the overall division administration and programme and budget planning, implementation and reporting.
- Information Security Manager ensuring the development and improvement of the security posture of the information assets of the PTS, provision of data surety and Public Key Infrastructure for authentication of IMS data and IDC products, including business continuity/disaster recovery plan solutions.
- Specialists working on short terms (according to the needs).

The IDC Director is responsible for addressing expert technical analysis of events of special interest (See Section 5).

3.2 Automatic Processing Systems (APS) Section

The APS Section is at the core of the IDC operations. It has to ensure the reliable operation of automatic data processing systems, including databases, the secure website, systems and application software and associated configurations aspects. Processes in all sections of the IDC require inputs and create outputs that interlace with other sections-tasks. The technical nature of the work requires large amount of computer resources, as it holds the key to the continuous operation of processing software systems, applications and database repositories (commercial applications and custom-made software).

3.3 Operations Section (OPS)

The operation of the IMS Network is the responsibility of the OPS Section. It has to ensure: the continuous data from IMS stations (data availability 98% for seismoacoustic and 95% for radionuclide data) and the telecommunication between the IMS and the IDC ($\geq$99.5% of the time, set as contractual limit, outsourced commercially). The OPS Section hosts the CTBTO Operations Centre, whose concept of operations describes the complete framework.

3.4 Monitoring and Data Analysis Section (MDA)

The MDA Section performs IMS Data (manual) analysis to ensure the efficient and timely availability of IDC reviewed products; the Reviewed Event Bulletin (seismoacoustic) and the Reviewed Radionuclide Report (See Section 4), under provisional operations. The data analysis teams use the automatically generated products as a starting point, with the objective of corroborating and fine tuning the event detections for seismoacoustic detections and radioactive particles and noble gases spectra.

Figure 3. *The CTBTO Operations Centre and Data Analysis Virtual Tour available at https://vrtours.ctbto.org/tours/opscentre*

3.5 Software Applications Section (SA)

The SA Section works on the design and development of IDC software and the corresponding scientific methods used in the applications in order to enhance and sustain the application software necessary for Treaty verification: Oversees the development of software for NDCs, to support their role in verification, the NDC in a Box (NIAB) package includes, software applications that allow replication of results obtained by the IDC data processing software. For IDC software, it includes its integration into the IDC data processing scheme (some software is provided as CiK from States). In addition, engages with the technical and scientific experts and communities from States institutions and international forums (see Section 3.6), seeking for advances in the technologies used in the IMS stations and the IDC data processing strategy and methods.

3.6 Capacity Building and Training Section (CBT)

The CBT Section supports States in fulfilling their functions as providers of IMS data and users of the data and IDC products and to raise their awareness of the relevance of the Treaty and their role in the operation and sustainment of the verification system: *a) maintaining and executing a technical training programme for SOs of the IMS facilities and NDC personnel, including provision of e-Learning, b) providing services to States Signatories (technical assistance and software), c) organizing technical workshops on IMS technologies and meetings of experts, including a major role in handling participant services for the biannual CTBTO Science and Technology conference (SnT) and d) managing the PTS Library Services*. The current design of the CBT Multi-Year Action Plan (MYAP) has ramped-up over the years to include (nominally) 25 training courses, 5-6 workshops, 0-1 SnT Conference and 5 technical and expert meetings per year. Services are provided to 145 established NDCs (for ~1800 Authorized Users).

3.7 IDC Progressive Commissioning Plan

In 1997, PrepCom set an initial plan of seven phases for the progressive commissioning of the IMS and the IDC. The plan also includes the GCI (see Section 4.1). In 2001, the IDC commissioning was reviewed, as a result, Phase 5 was divided into two groups (allowing for the IMS to make further progress). Since 2002, the PTS established a Medium-Term Plan (MTP) with 4-5 years periodical updates to identify and address areas of development foreseen in phases 5-7. Table 1 presents the status of the IDC Commissioning Plan.

IDC Progressive Commissioning Plan		
Phase	Timeline	Description
1	1-Apr-1997	IDC Design and Planning (VIC-Vienna remodeling for headquarters)
2	1-Oct-1997	Establishment of the initial Computer Facilities and Communications
3	1-Jun-1998	Establishment of the initial Operations at the Vienna IDC
4	1-Mar-1999	Initial Testing of the Vienna Hardware/Software
5	2001	Full Scale Testing of the Vienna IDC
5a	Completed March-2015	Preparation for Full-Scale testing of IDC Hardware/Software *Performance testing phase of the IMS/IDC/GCI System Wide Performance Test (SPT1)*
5b	2016, ongoing	Full Scale Testing of the IDC Hardware/Software *Experiments 1-4 (2016 – 2019)* *2023 Experiment (6-17 February 2023)* *2 further experiments planned for 2024 and 2025* *Full Scale Test (at end of Phase 5b)*
6	TBD	Validation and Acceptance of the IDC
7	TBD	Available for Full CTBTO Operations

Table 1. *The seven separate transition phases of IDC Commissioning*

4. The IMS, GCI, IMS Data and IDC Products

The IMS is a global network of 321 monitoring stations and 16 laboratories hosted by 89 countries (See Figure 4). To this date, around 90 percent of these 337 facilities are already installed and in operation, providing a steady flow of real-time "IMS Data". IMS station locations include some of the world's most remote and inhospitable environments, posing engineering challenges unprecedented in the history of arms control. There is a rigorous protocol for establishing and certifying IMS facilities (with prescriptive specifications). This ensures the provision of high-quality data. The IDC operates the IMS and performs automatic and manual analysis of the data, this results in a range of automatic and reviewed "IDC Products".

4.1 The Global Communications Infrastructure (GCI)

The telecommunication between the IMS and the IDC is established via the GCI, this allows for: transmission of data from stations in near real time to the IDC, distribution of the raw data, as well as the products of the data analysis to State Signatories and remote command and control operations of IMS stations (State of Health – SoH monitoring).

The communication links are established using geostationary satellites and frame relays. Over the years, the use of internet has become an additional (also for redundancy) resource (using VPN). This service is outsourced commercially under the supervision of the IDC/OPS/GNO Unit.

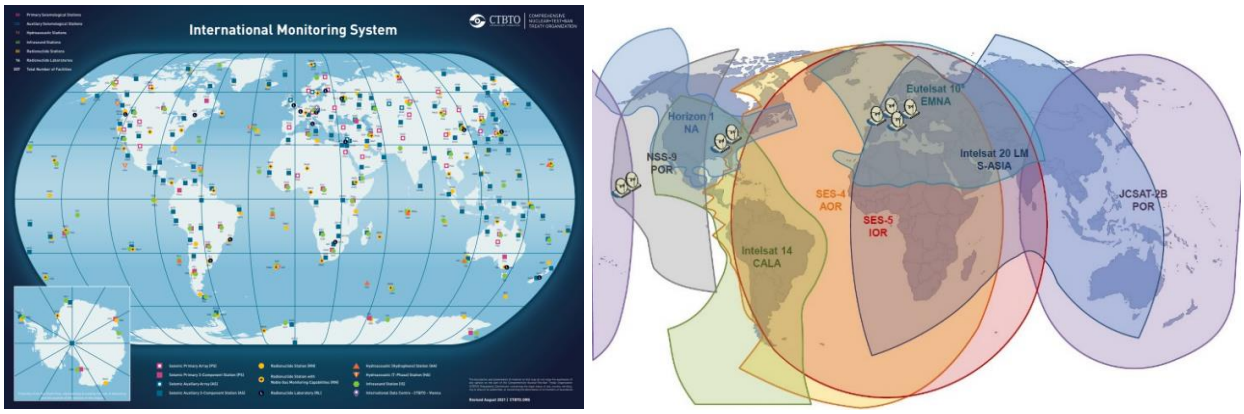


Figure 4. *The IMS and GCI*
Detailed version is available at https://www.ctbto.org/our-work/international-monitoring-system

4.2 IMS Data

The data acquired by the IMS stations comes from four complementary technologies (verification methods) with state-of-the-art instrumentation; although for some technologies, such as the infrasound and radionuclide, the CTBTO plays an important role in its development (edge technology). The 321 monitoring stations are distributed as follows:

- 50 primary (PS) and 120 auxiliary (AS) seismic stations to monitor for underground explosions by measuring shockwaves through the ground.
- 11 hydroacoustic (HA) stations to detect soundwaves through the ocean from an underwater explosion. Five of these are T-Phase stations.
- 60 infrasound (IS) stations to listen for ultra-low-frequency sound waves moving through the atmosphere at levels inaudible to the human ear.
- 80 radionuclide (RN) stations detect radioactive particles from atmospheric, vented by underground or underwater nuclear explosions (40 of these stations have equipment fitted that may also detect noble gases - NG). There is a standard list of CTBT relevant nuclides (84 particulate and 4 Xenon isotopes). The

particulate samples are categorized in 5 levels (See table 2). NG Spectra categorization is defined in three levels: A, B and C for non, typical and atypical detection of radioxenon respectively (for the sampling station, based on 365 days history).

- The 16 radionuclide (RNL) laboratories assist RN stations in corroborating relevant anomalous concentrations detected (samples with spectral analysis categorized level 5 and some level 4).

*The conglomerate of P**S**, AS, **H**A and **I**S stations is known as the IMS SHI waveform technology. The RN particulate and noble gas stations and laboratories are known as the IMS RN radionuclide technology.*

Categorization	Description of Sample content
Level 1: Typical Background	Typical concentrations of natural radionuclides.
Level 2: Anomalous Background	Anomalous concentrations of radionuclides (either natural or anthropogenic) which are not on the standard list of relevant radionuclides.
Level 3: Typical Anthropogenic	Typical concentrations of a fission or activation product(s) which is (are) on the standard list of relevant radionuclides.
Level 4: Anomalous Anthropogenic	anomalous concentration of either a single fission product or one (or more) activation product(s) which is (are) on the standard list of relevant radionuclides.
Level 5: Multiple anomalous Anthropogenic	multiple anthropogenic nuclides at anomalous concentrations, which are on the standard list of relevant radionuclides.

Table 2. *Radionuclide (RN) sample spectral analysis categorization (particulates)*

The IMS can detect very small level of radioactivity in the air (few uBq/m3 for the particulate technology, and few mBq/m3 for the NG technologies). There is a dependency on the movement of air masses. Atmospheric Transport Modelling (ATM) is used for correlating radioactive detections with possible sources (data fusion concept).

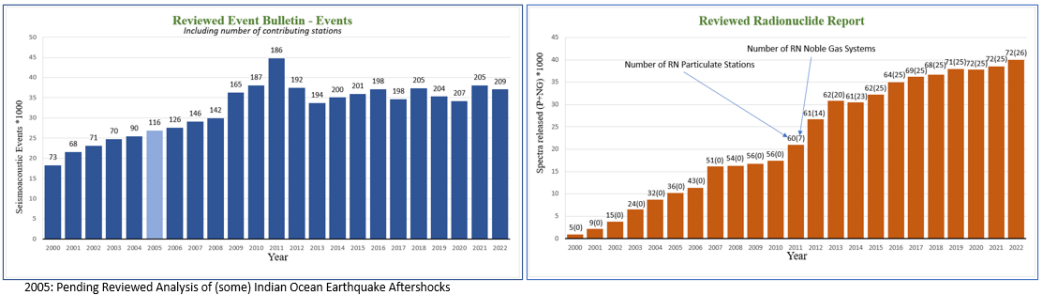
4.3 IDC Products

The Standard IDC Products are the results of both automatic and interactive analysis of the IMS Data. There is a reference to the products in the treaty protocol and specific details in the IDC draft Operational Manual. IMS Data and IDC products are available to States Signatories designated personnel (IDC Users). See Table 3

Product	Description (IDC draft Operational Manual)
SLSD	Standard List of Signal Detections, made automatically from seismic, hydroacoustic and infrasound data
SPHD	Sample pulse height data from radionuclide stations
SEL1, SEL2, SEL3	Standard Event Lists 1, 2 and 3, created automatically at different stages of processing from SLSD
ARR	Automatic Radionuclide Report, created automatically from the SPHD
REB	Reviewed Event Bulletin, created after interactive analysis
RRR	Reviewed Radionuclide Report, created after analyst review of the ARR
RLR	Radionuclide Laboratory Report, created from samples sent to laboratories for analysis
SEB	Standard Event Bulletin, created after adding screening parameters to events in the REB
SSEB	Standard Screened Event Bulletin, a subset of the SEB containing only those events not screened out
SSREB	Standard Screened Radionuclide Event Bulletin, created by computing event screening parameters for events in the RRR
Executive Summaries: EDS, EPS, EPOS	Executive Data, which summarizes information on the data acquired and archived by the IDC Executive Product, which summarizes the information on all IDC products Executive Performance and Operational, which summarizes the performance and operational status of the IMS facilities, communication links and IDC processing systems

Table 3. *Standard Products of the International Data Centre*

IDC Production (2000-2022): ~0.75M REB events and ~0.5M RRRs



2005: Pending Reviewed Analysis of (some) Indian Ocean Earthquake Aftershocks

Figure 5. *IDC Production of REB and RRR*

The progression of the IMS Commissioning and the MDA workload are reflected in the number of cumulative events per year for both REB seismoacoustic events (detections) and number of RRR reports issued.

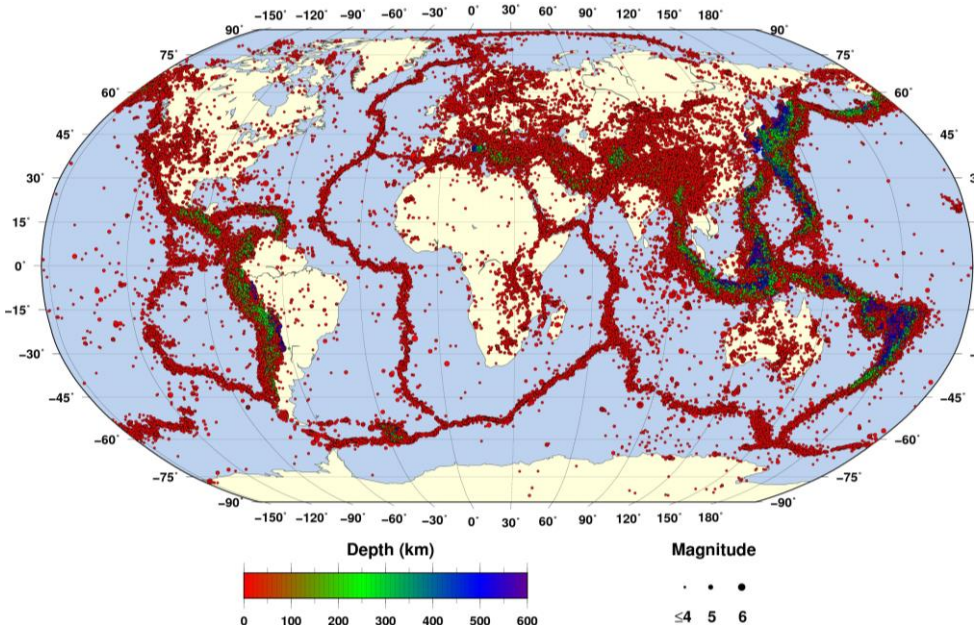


Figure 6. *IDC REB (2000-2022)*

4.3 The IDC Operational Pipeline

IMS Data and IDC Products are available in accordance with the schematic view in Figure 7, of the sequence of processing and timelines requirements of the IDC automatic and manual analysis of IMS Data and the corresponding Standard IDC Products.

The IDC relies on dozens of computer servers (running on Linux Operating System) enabling the automatic processing pipeline to function. The use of machine virtualization has become a norm worldwide and the IDC uses it for some processes (considered not a risk to core functions). The entire system (data and products) creates some 30GB information per day; there is a large capacity of storage in the organization (at least one Petabyte which could progressively be extended).

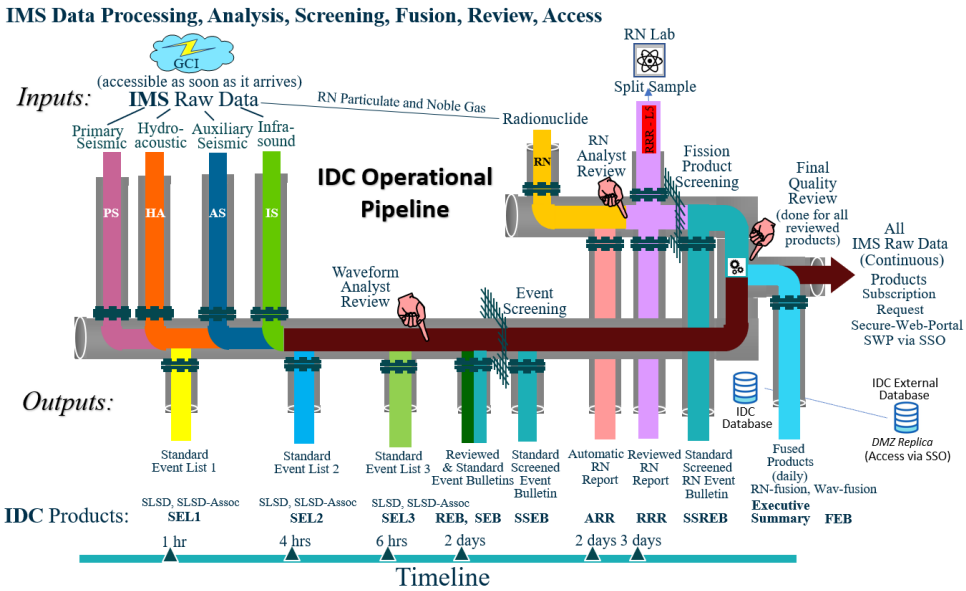
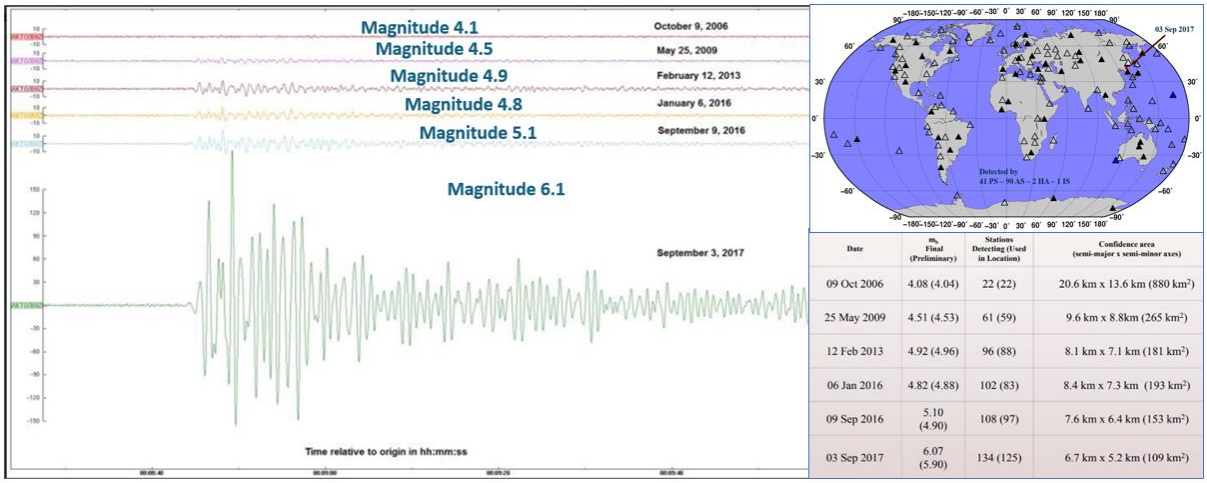


Figure 7. *The IDC Operational Pipeline*

5. Nuclear Explosion Detection

The IDC automatic processing detected all 6 announced nuclear tests from the Democratic People's Republic of Korea (DPRK). The system is capable of detecting 3.6 magnitude seismic events (globally) and as low as 2.7 in the northern hemisphere (mb-*IDC*). The IDC is alert at all times, focusing on events of special interest, for which expert technical analysis is performed.



Date	Mb_{Lg} Final (Preliminary)	Stations Detecting (Used in Location)	Confidence area (semi-major x semi-minor axes)
09 Oct 2006	4.08 (4.04)	22 (22)	20.6 km x 13.6 km (880 km²)
25 May 2009	4.51 (4.53)	61 (59)	9.6 km x 8.8km (265 km²)
12 Feb 2013	4.92 (4.96)	96 (88)	8.1 km x 7.1 km (181 km²)
06 Jan 2016	4.82 (4.88)	102 (83)	8.4 km x 7.3 km (193 km²)
09 Sep 2016	5.10 (4.90)	108 (97)	7.6 km x 6.4 km (153 km²)
03 Sep 2017	6.07 (5.90)	134 (125)	6.7 km x 5.2 km (109 km²)

Figure 8. *IDC Detection of the 6 announced DPRK's nuclear tests*

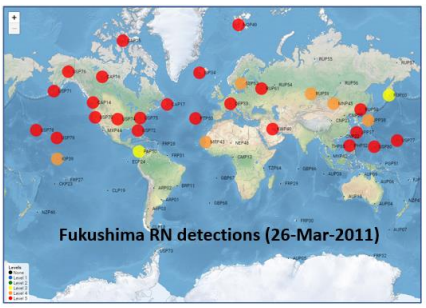
6. Use of IMS Data and IDC Products for non-CTBT verification

In 2000-2001, following the technical advice of WGB, the PrepCom granted procedures for access to IMS Data and IDC Products for scientific studies (which in turn could contribute to develop and optimize the IMS and IDC) under a policy approved by State Signatories. The scientific and technological community can obtain access via the Virtual Data Exploitation Centre "vDEC".

The IDC provides, since 2002, on ad hoc basis (also under approval of the policy making organs) the REB to the International Seismological Centre (ISC), for comparison and integration with other (scientific) global and regional networks for improving event location (including use of Ground Truth (GT) events for calibration).

Following the devastating 2004 Indian Ocean earthquake/tsunami, the CTBTO and UNESCO's Intergovernmental Oceanographic Commission (IOC) agreed to explore the potential generated by using IMS data for tsunami warning purposes. The positive outcome concluded with a CTBTO-UNESCO agreement (4 February 2010) to support Tsunami Warning Centers (TWCs). Currently, the IDC provides data from over 150 IMS stations to 20 TWCs in 19 States (>4TB data/year).

The IDC automatic and reviewed analysis encounters a variety of events generated from natural and non-natural sources.



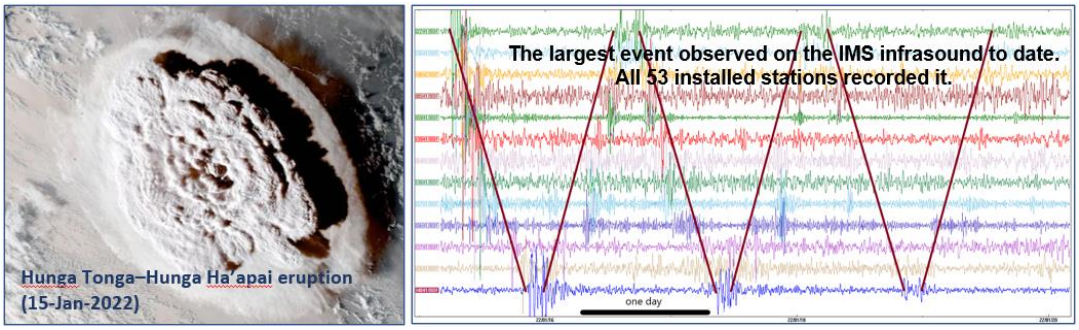


Figure 9. *IDC non-nuclear-tests Event Detections*

7. Conclusions

Since 1997, the IMS global network is being progressively build-up and it has reached ~90%. The IDC continues its enhancement at a steady pace, while in provisional operations. The IMS Data and IDC Products are continuously available since 2000 and reflect the progress of the commissioning of the IMS and IDC components.

Significant challenges had to be addressed and overcome as part of the ongoing progressive commissioning of the IDC. Several functionalities are being developed or enhanced: The SHI software (for the processing pipeline) is being re-engineered, and the operational tools continue to evolve. The milestones of Phase 5b of the IDC Progressive Commissioning are requirement based and not time bound.

The IDC detected all (six) Democratic People's Republic of Korea's announced nuclear tests between 2006 and 2017. In addition to this, it continuously records a wide range of seismoacoustic phenomena including earthquakes, volcanic eruptions and meteors (fireballs), as well as non-nuclear explosions such as the blast that devastated parts of Beirut, Lebanon in 2020. All of these contributed to close to one million events located across the globe over the past 22 years.

The automatic products are produced in accordance with Treaty requirements while the review performed by waveform and radionuclide analysts follows more relaxed requirements in accordance with provisional operations.

IMS data and IDC products can also be used for civil and scientific applications, as agreed by States Signatories. The contribution to the TWCs has provided a new resource for the world to mitigate the effects of devastating tsunamis.

The Technical Assistance to States Signatories is mostly focused on training activities, assisting countries to develop the capability to receive, process and analyse IMS Data at their NDCs.

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