CTBTO radionuclide detections in the aftermath of Fukushima and a necessity for improved source inversion algorithms

International Workshop

on Source Term Reconstruction Methods

for Estimating the Atmospheric Radiation Release

from the Fukushima Daiichi Nuclear Power Plant

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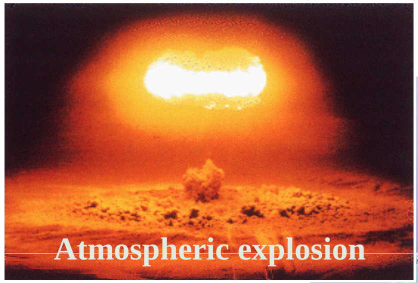
Outline

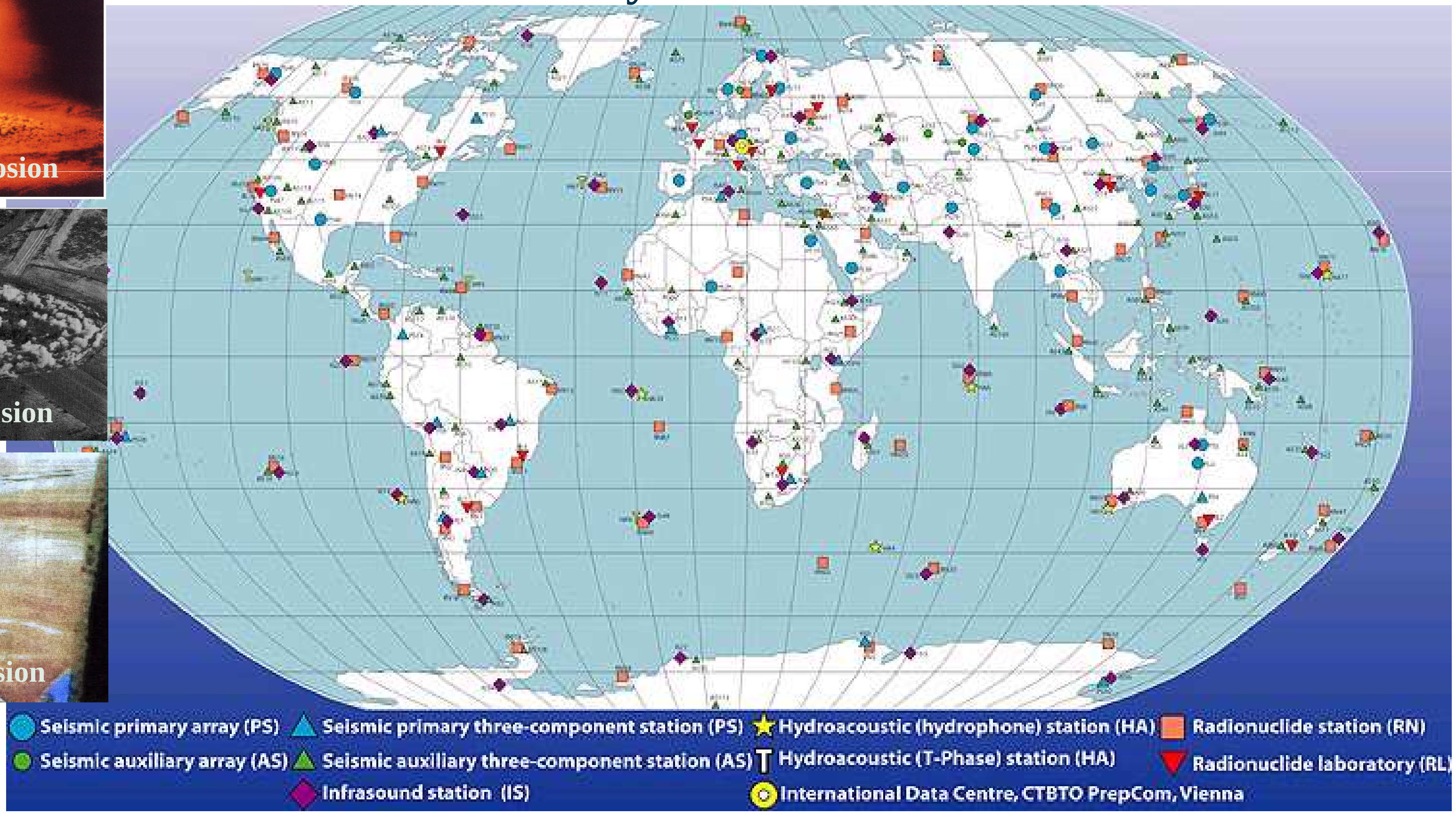
- CTBTO
- Radionuclide network, measurement technology and atmospheric transport modelling in support of radionuclide measurements
- Source location method
- Fukushima detections by the International Monitoring System of CTBTO
- vDEC platform

CTBT (**Comprehensive Nuclear-Test-Ban Treaty**) bans all nuclear explosions
CTBTO(Comprehensive Nuclear-Test-Ban Treaty Organization) operates a system (International Monitoring System) monitoring compliance with the CTBT

Monitoring based on four technologies

Seismic Infrasound Hydroacoustic Radionuclide





CTBTO: IMS radionuclide network

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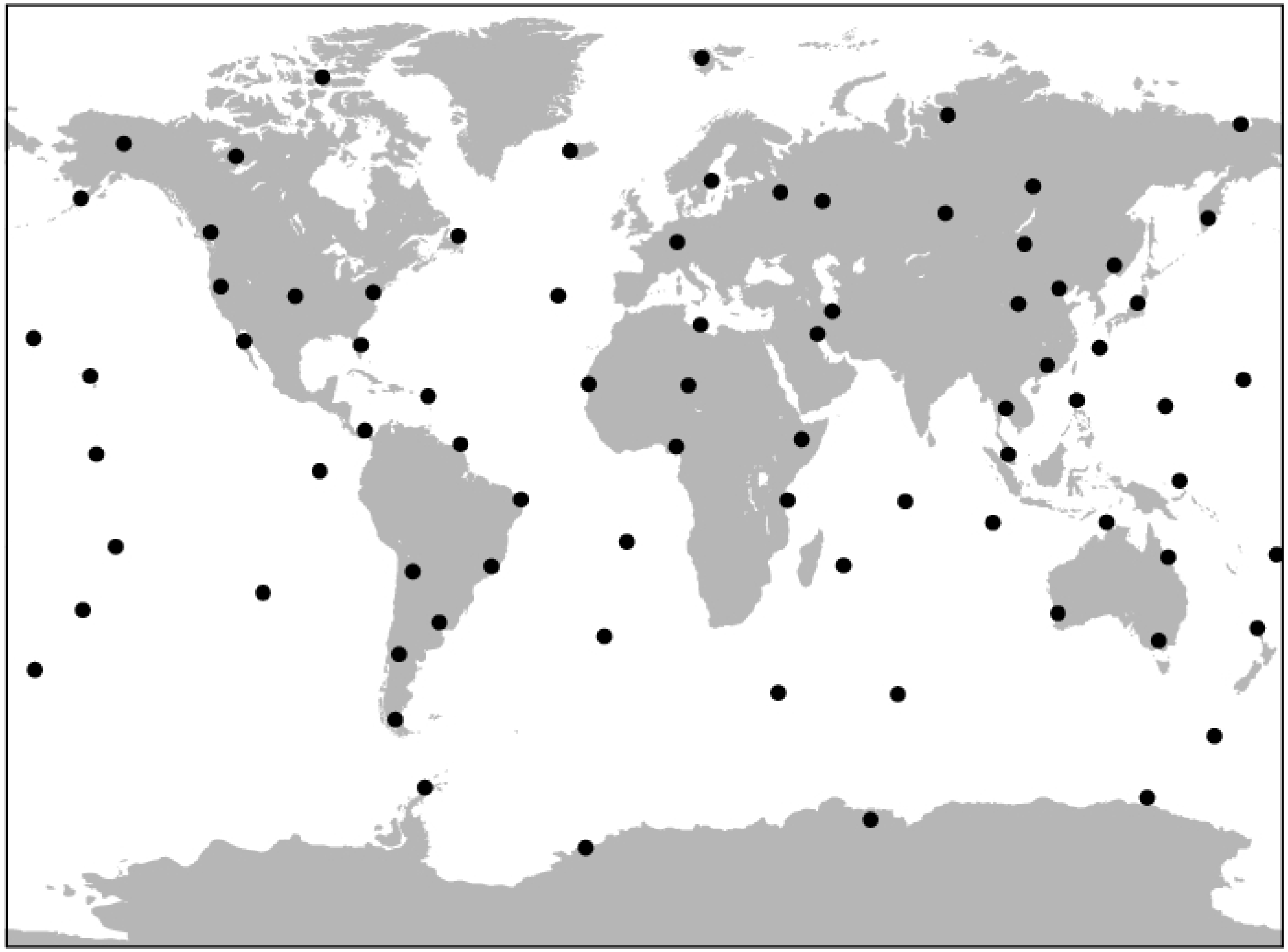
RN station locations of the International Monitoring System

(79 of 80 currently determined)



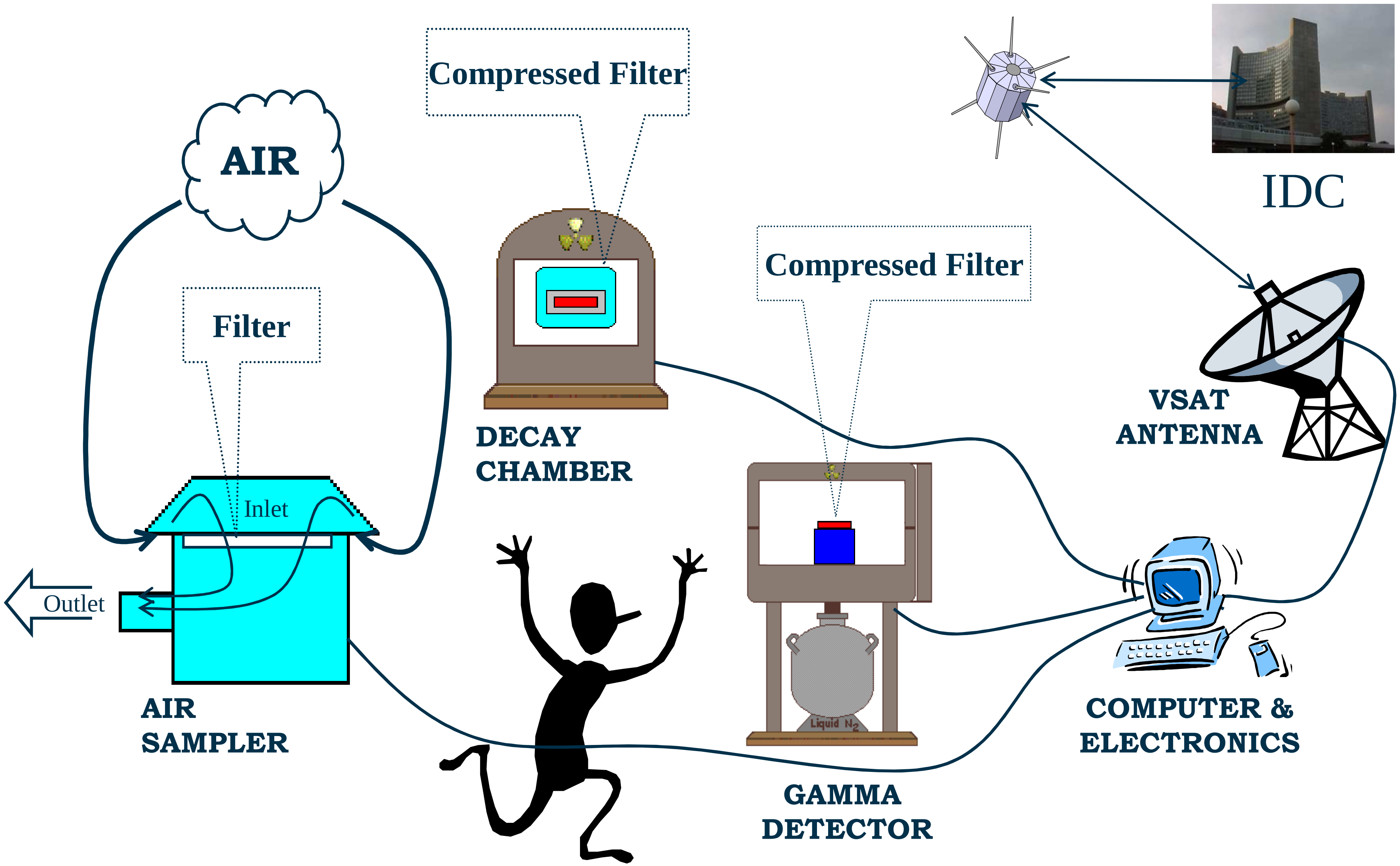
Network performance:

Detect debris from a 1 kt nuclear explosion within 14 days of an event with 90 % probability

All stations will be equipped with an aerosol sampling system (high volume sampling) and high-purity Germanium detectors

50% of the stations will, in addition, be equipped with a noble gas sampling system

Radionuclide technology:
Particulate sampling station



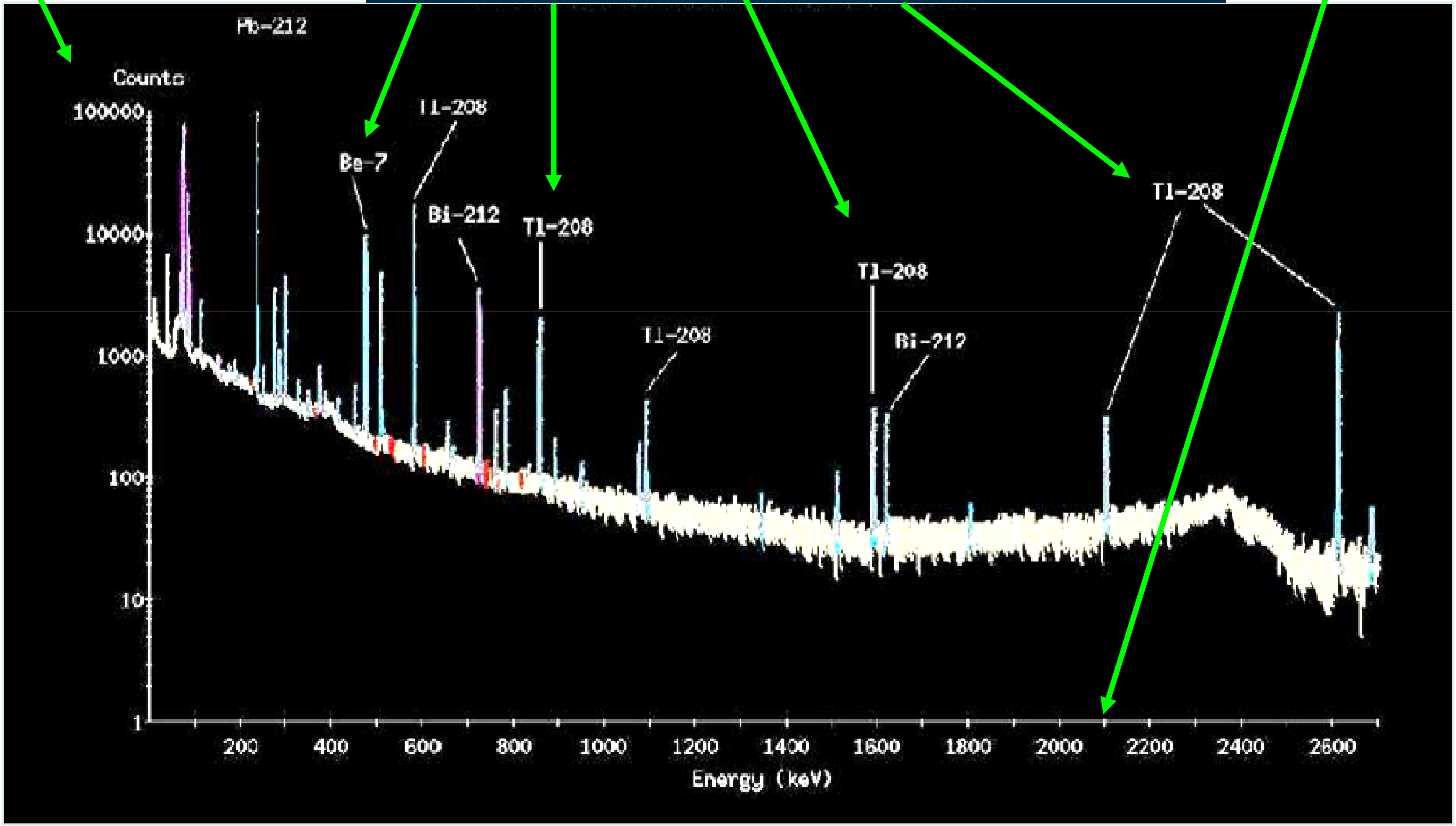
Slide courtesy: Mika Nikkinen

Example of station sample spectra

Number of γ-photons collected in the detector

What energy do they have?

What radionuclides and how much are in the sample?



Slide courtesy: Mika Nikkinen

Source receptor relationship concept

- Source Receptor Sensitivity (SRS) field $M_{k\,ijn}$ or retro-plume or dilution factor field [m^{-3}] is specific to each radionuclide sample

- A retro-plume is simulated by running an atmospheric transport model backward in time with “releases” corresponding to radionuclide samples

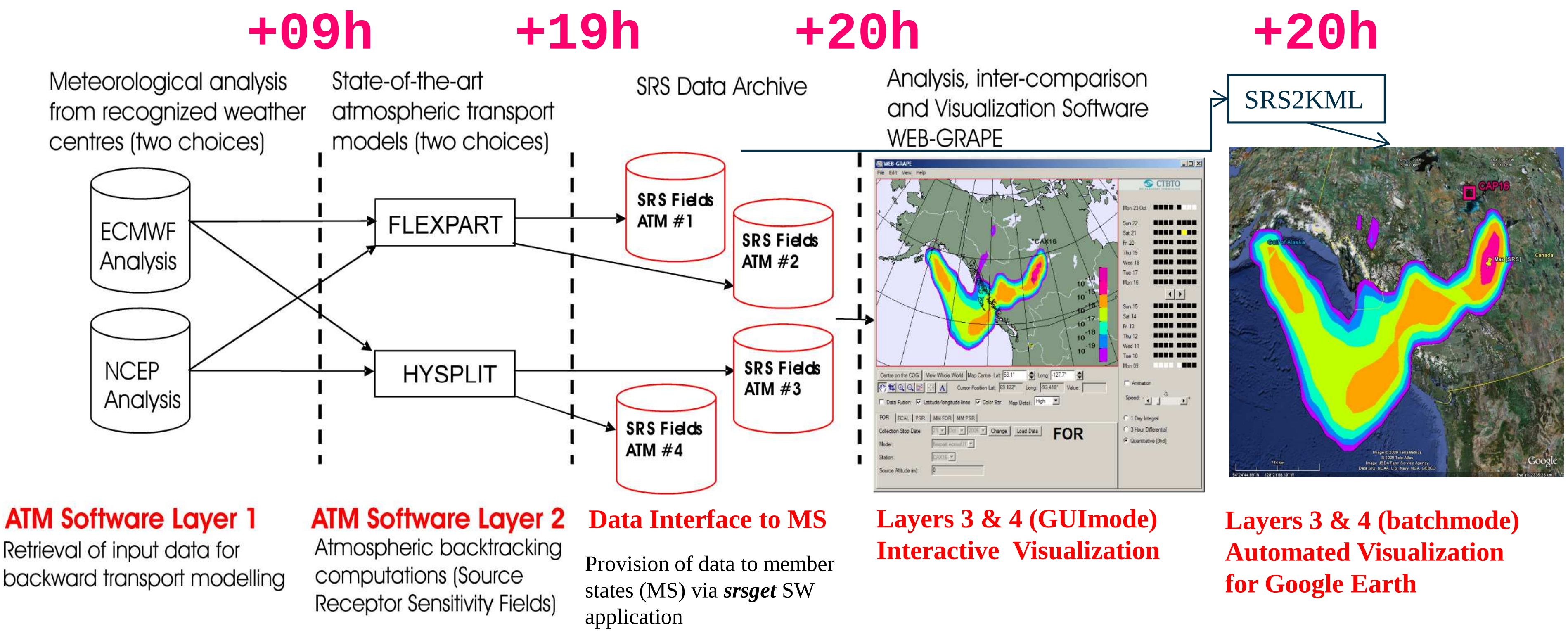
- SRS translates any **grid point** release at position *i,j* and transport time from source to receptor *n* [Bq] into the activity concentration c_k [Bqm^{-3}] for the *kth sample* :

$$\boxed{c_k = M_{k\,ijn} \cdot S_{ijn}}$$

Slide courtesy: Andreas Becker

ATM workflow

(with hours elapsed since end of a considered day)



Adopted from Figure 5 of Kalinowski, et al. (2008)

Flow chart of the 4-layer ATM system operated at IDC. Note: The final analysis tool WEB-GRAPE is also capable to export any visualization into zipped kml (=kmz) files for import into Google Earth. SRS2KML automates this process.

Source Location Algorithm

Step 1: **source hypothesis field *S(i,j,n)*** is folded for each sample with the related SRS field M_k yielding a vector of calculated concentrations for the *k* stations affected:

$$\boxed{c_k\left[S_{ijn}\right] = M_{kijn} \cdot S_{ijn}} \qquad (1)$$

Step 2: For each of the geo-temporal source possibilities (permutations of *i,j,n*) a regression of the calculated vector elements $c_k[S(i,j,n)]$ against the vector of the *k* measurements m_k according to equation (2) yields the so-called "Possible Source Region", in terms of a geo-spatial distribution of correlation coefficients:

$$\boxed{m_k = c_0 + PSR_{ijn} \cdot c_k[S_{ijn}]} \qquad (2)$$

The geo-temporal location of *max[PSR(i,j,n)]* is then the location where the single grid cell source *S(i,j,n)* would cause calculated concentrations c_k at the *k* stations being most consistent with the vector of actually measured ones, m_k.

Slide courtesy: Andreas Becker

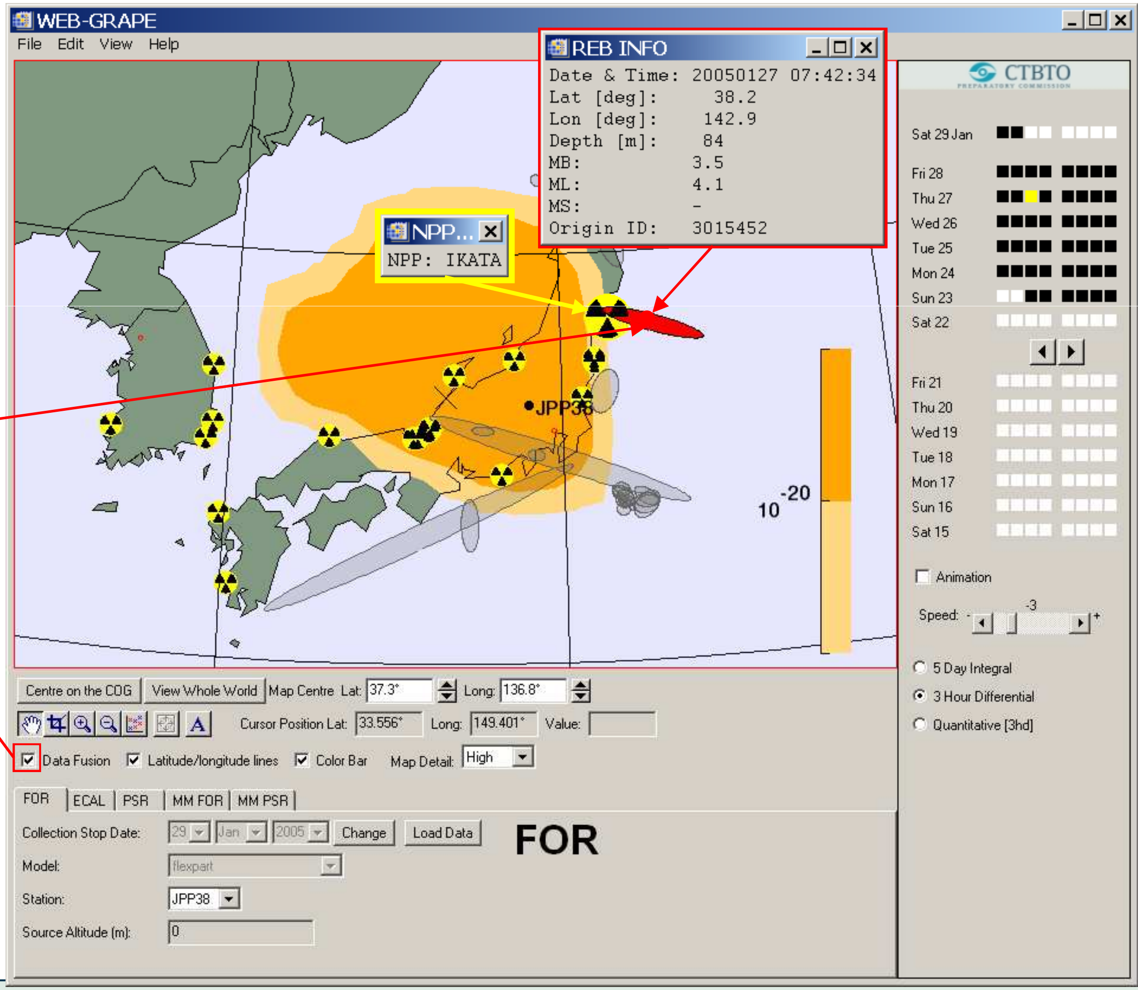
All ATM Products can be generated by ONE software: WEB-GRAPE

WEB-GRAPE is a piece of software that can be used to analyze the relation between a detection in the radionuclide network and possible emission points on the globe.

The WEB-GRAPE utilizes dispersion calculations at the CTBTO to conveniently make interactive map products on demand.

It also provides a fusion function as waveform error ellipses can be co-displayed for the corresponding time slices.

Also co-display of other potential nuclear sources can be configured.



Slide courtesy: Andreas Becker

CTBTO: why interest in source location methods?

- CTBTO provides a set of independent data (monitoring) but CTBT verification is in the hands of States Signatories

- CTBTO is responsible for enhancing characterization of verification parameters. Contribution of non Treaty-relevant sources of radionuclides needs to be assessed

- The known sources originate mainly from emissions of noble gases by the radiopharmaceutical industry. And those emissions are not precisely known

- Need to infer as much source information as possible from the radionuclide detections in conjunction with an atmospheric transport model

- Need to perform source reconstruction – location and strength (quantity of the released material)

- May also need to have an upper boundary for a potential non-detected release

Effects of Earthquake, Tsunami, and Fukushima NPP in CTBTO network

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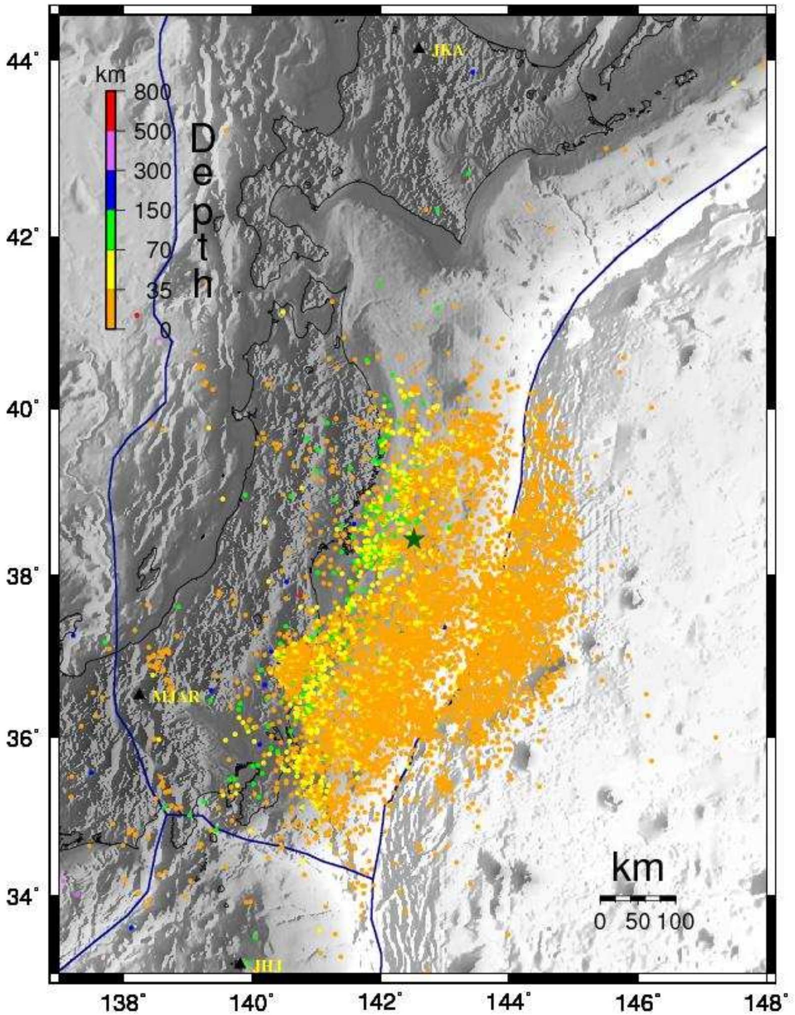
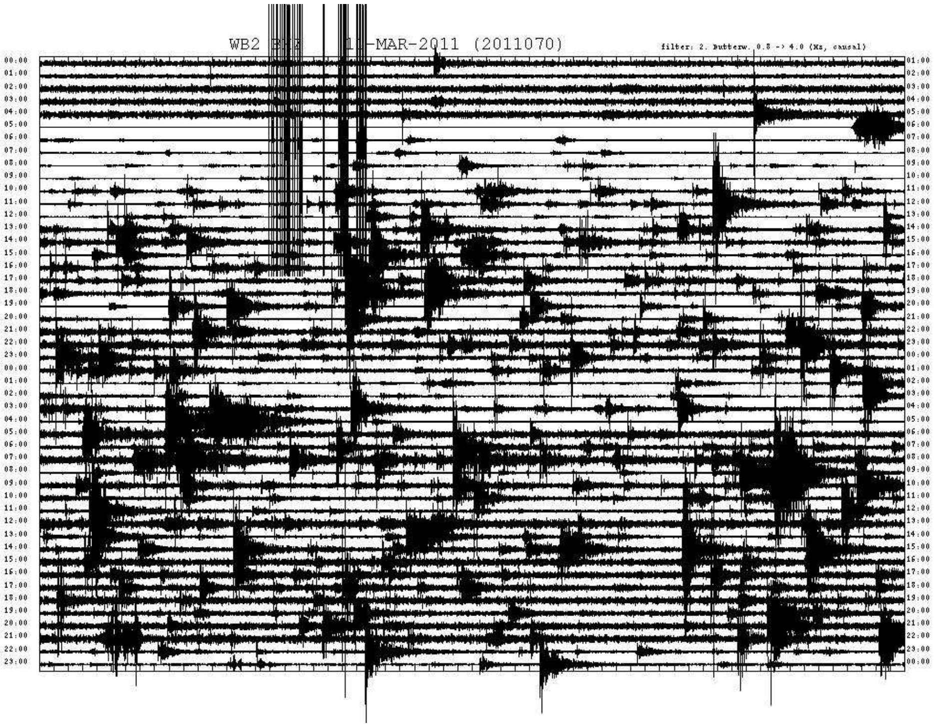
This series of events was tragic, but unprecedented all-inclusive stress test of data gathering, processing, and distribution:

- Seismic detection of Earthquake of magnitude nine March 11 2011 and subsequent ten thousand aftershocks
- Hydroacoustic detection showing the rupture forming under the sea
- Infrasound detections showing the explosions in the Fukushima NPP
- Subsequent radioactivity measurements in all the particulate and noble gas stations in the Northern Hemisphere and some in the Southern Hemisphere
- Atmospheric transport modeling played an important role as there was a need to see which stations are going to be affected by the release

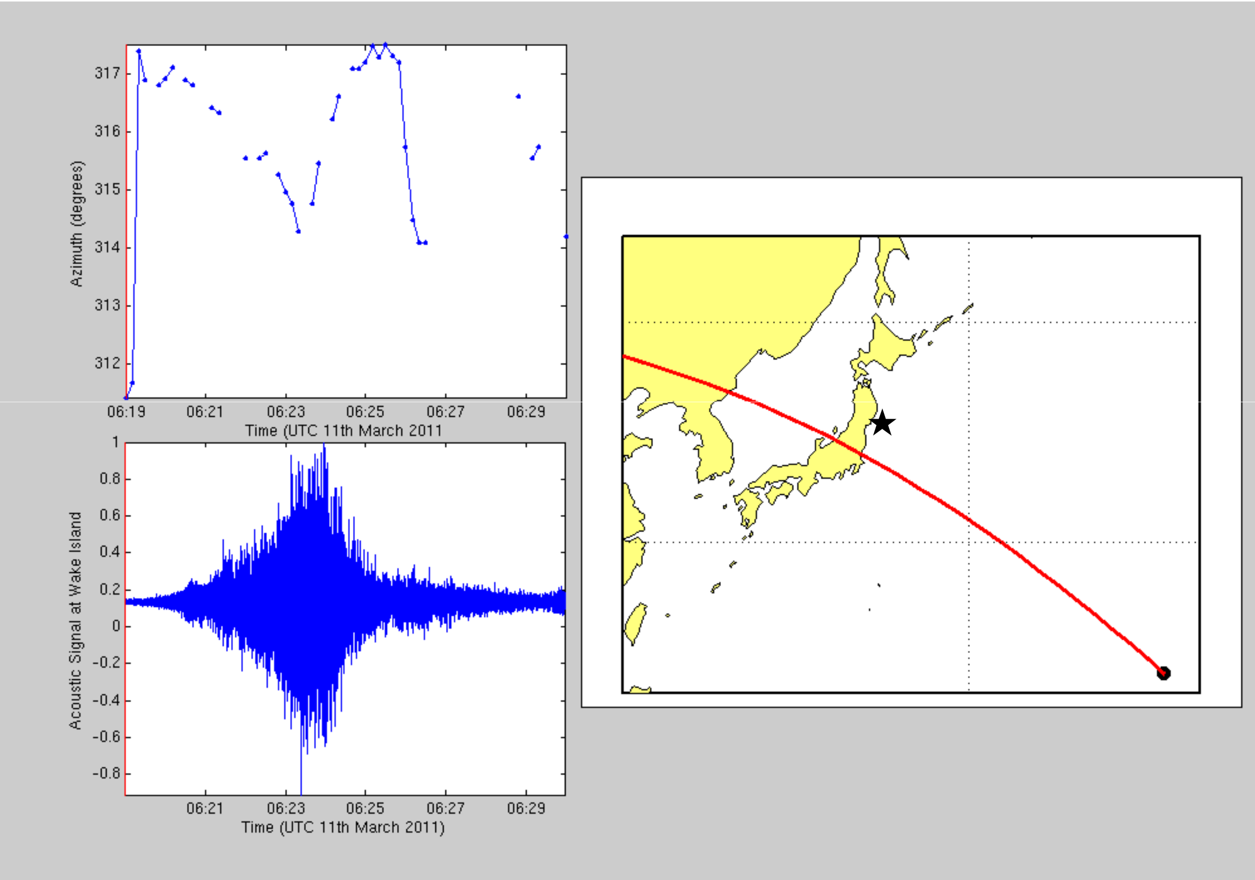
Seismic: Japan earthquake 11 March 2011, Magnitude 9 earthquake and 9800 aftershocks





Slide courtesy: Spilio Spiliopulos

Hydroacoustics: evidence of fault rupture after 11 March 2011 earthquake



Plot shows arrival angle versus time, measured at Wake Island hydroacoustic station, during reception of T-phase from main event

Epicentre is at 316 degrees, variation from 312 to 317 degrees

Slide courtesy: Mark Prior

Infrasound: evidence of 11 March 2011 earthquake and 12 March 2011 NPP explosion

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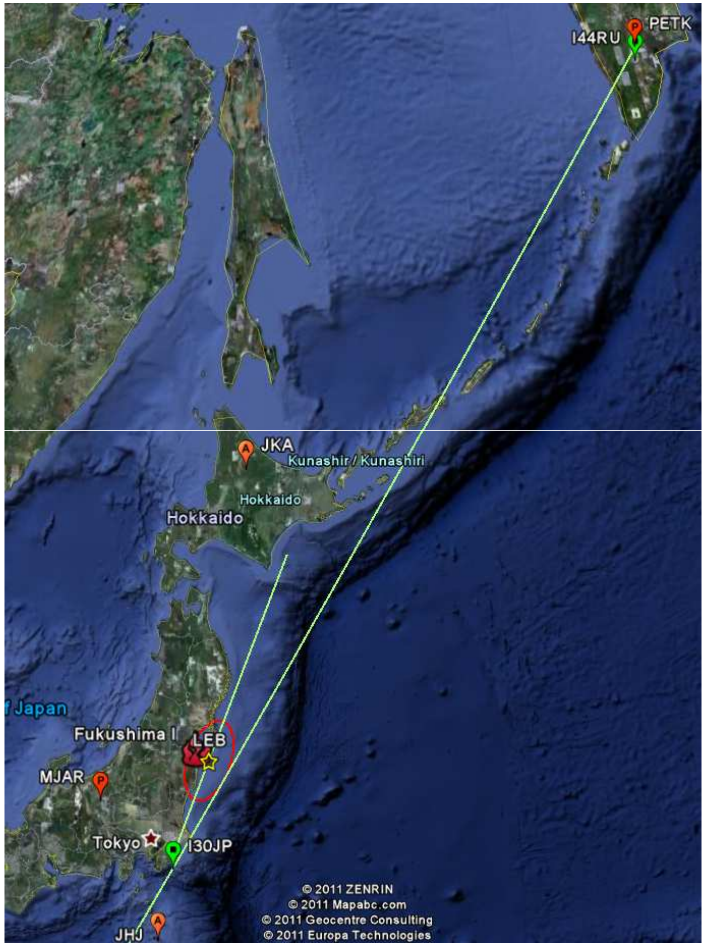
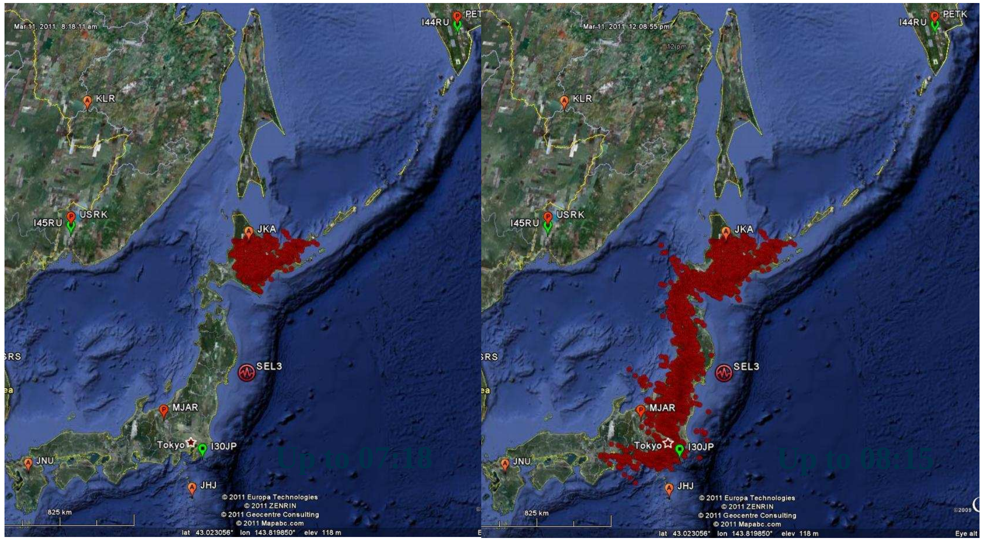
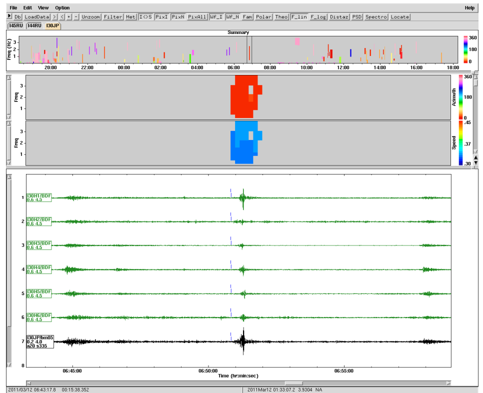




Infrasound signals generated in Japan on 11. March 2011 by earthquakes and tsunami as seen at I44RU (Kamchatka).

Detection of explosion at Fukushima Nuclear Power Plant



Ev=7290356 (orid 7291372) 2011/03/12 06:35:21 37.60N 141.39E 0.0km Ell=109/53/19 NEAR EAST COAST OF HONSHU, JAPAN

Allocated to: lombe Infra Review : none

Arid	Sta	Delta	Phase	Arrival time	Tres	Az	Azres	Tr.Vel	Cel	CFreq	Fstat	SNR	Dur	nPix
66163261	I30JP	2.4	I	2011/03/12 06:50:50	2.1	20.3	-0.2	335 m/s	292 m/s	1.47	14.3	2.2	70s	47
66166766	I44RU	19.2	I	2011/03/12 08:36:10	-2.6	221.2	-1.5	333 m/s	294 m/s	1.66	3.1	0.5	170s	28

Slide courtesy: Pierrick Mialle

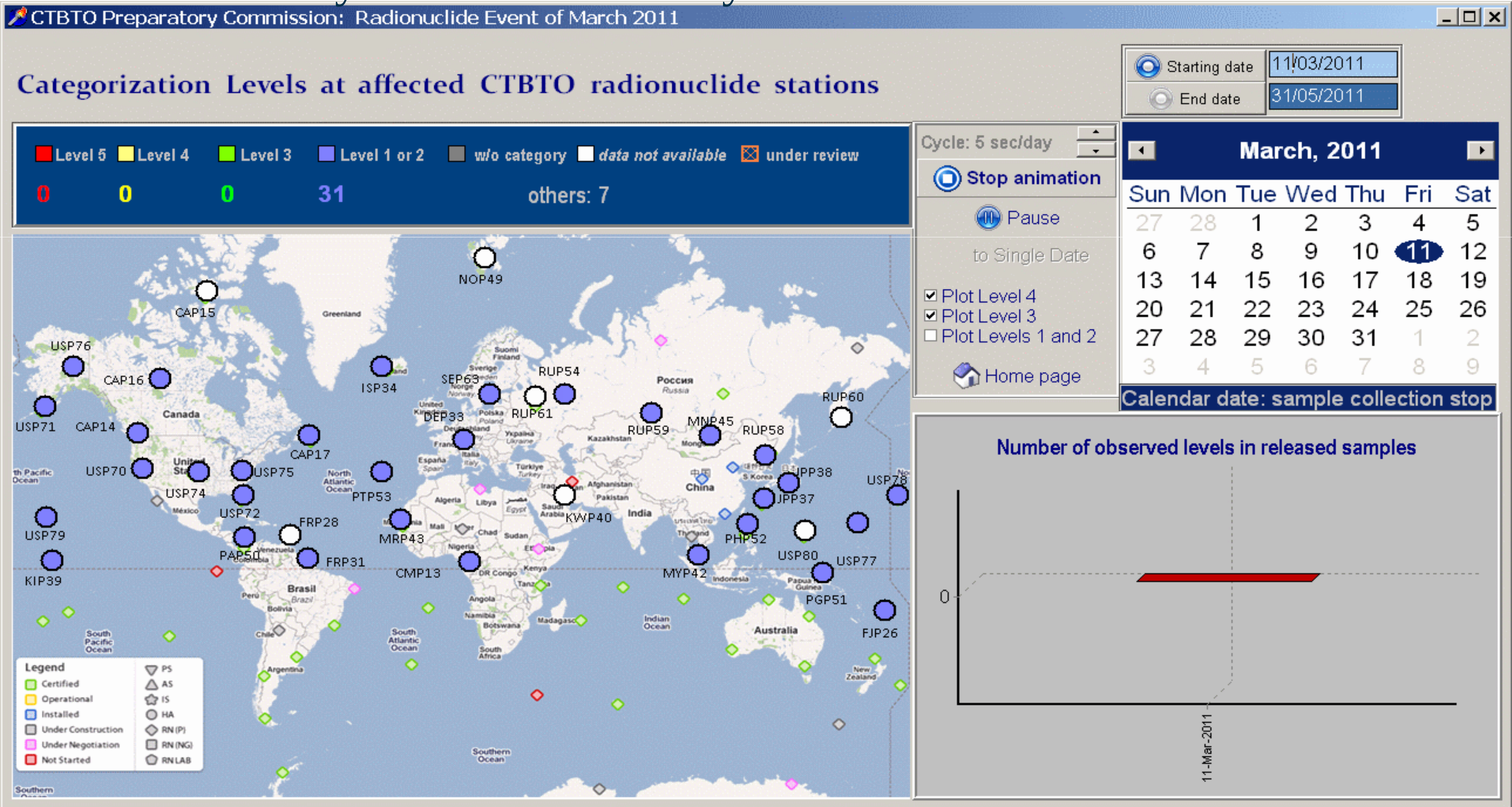
Dynamics of particulate network detections originating from Fukushima

This picture show time development of detections for each day after the accident.

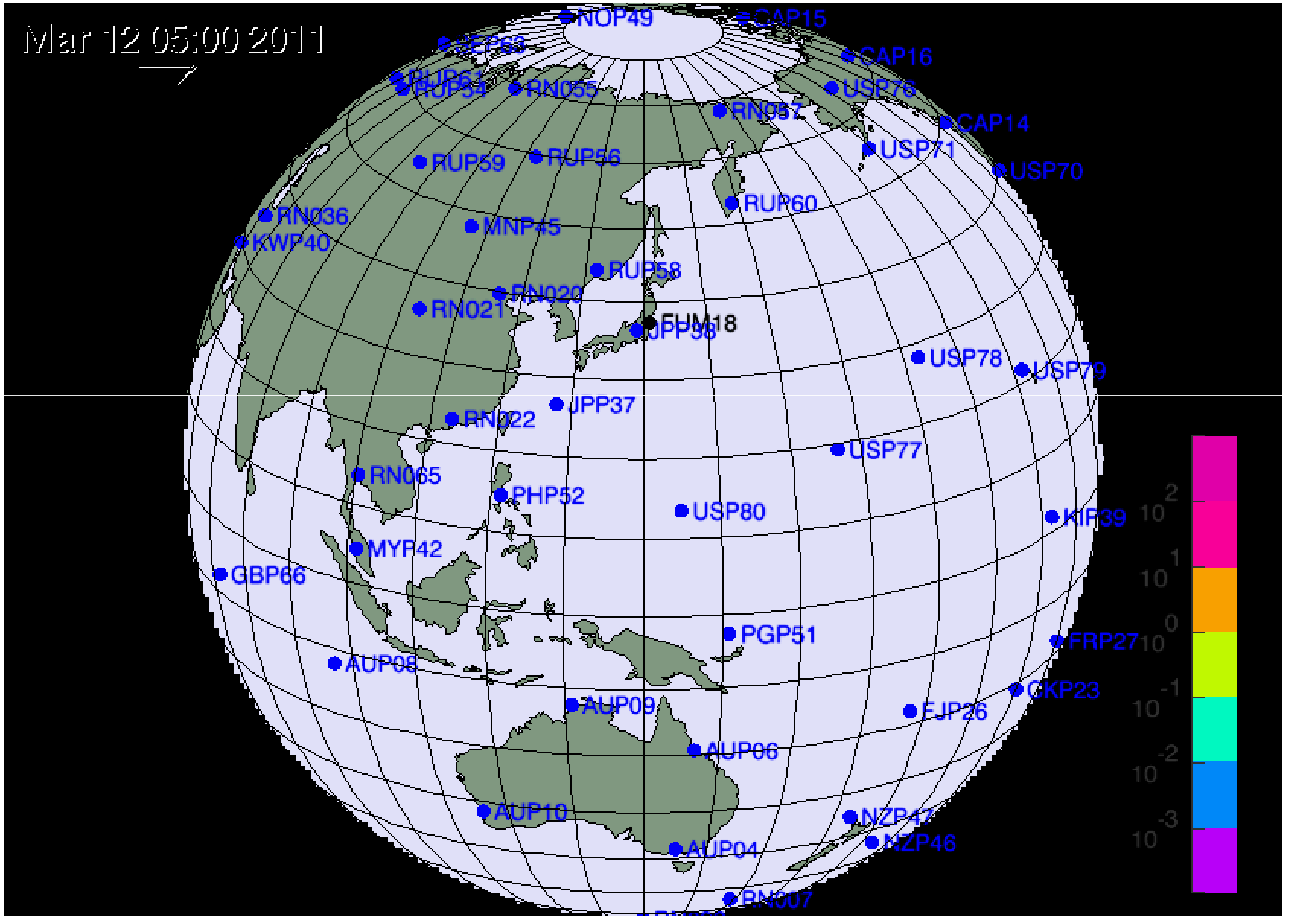
Level 5 = multiple fission products detected, **Level 4** = one fission product detected,

Level 3 = fission products typical for the station detected

Level 1 and 2 = only natural radioactivity detected



ATM simulations for Fukushima



Particulate network detections.
Stations which detected radioactive particles originating from Fukushima

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Network availability 90-95%

All these stations detected at least radioactive iodine from Fukushima in March and April 2011

Slide courtesy: Mika Nikkinen

Noble gas network detections. Stations which detected radioactive xenon originating from Fukushima

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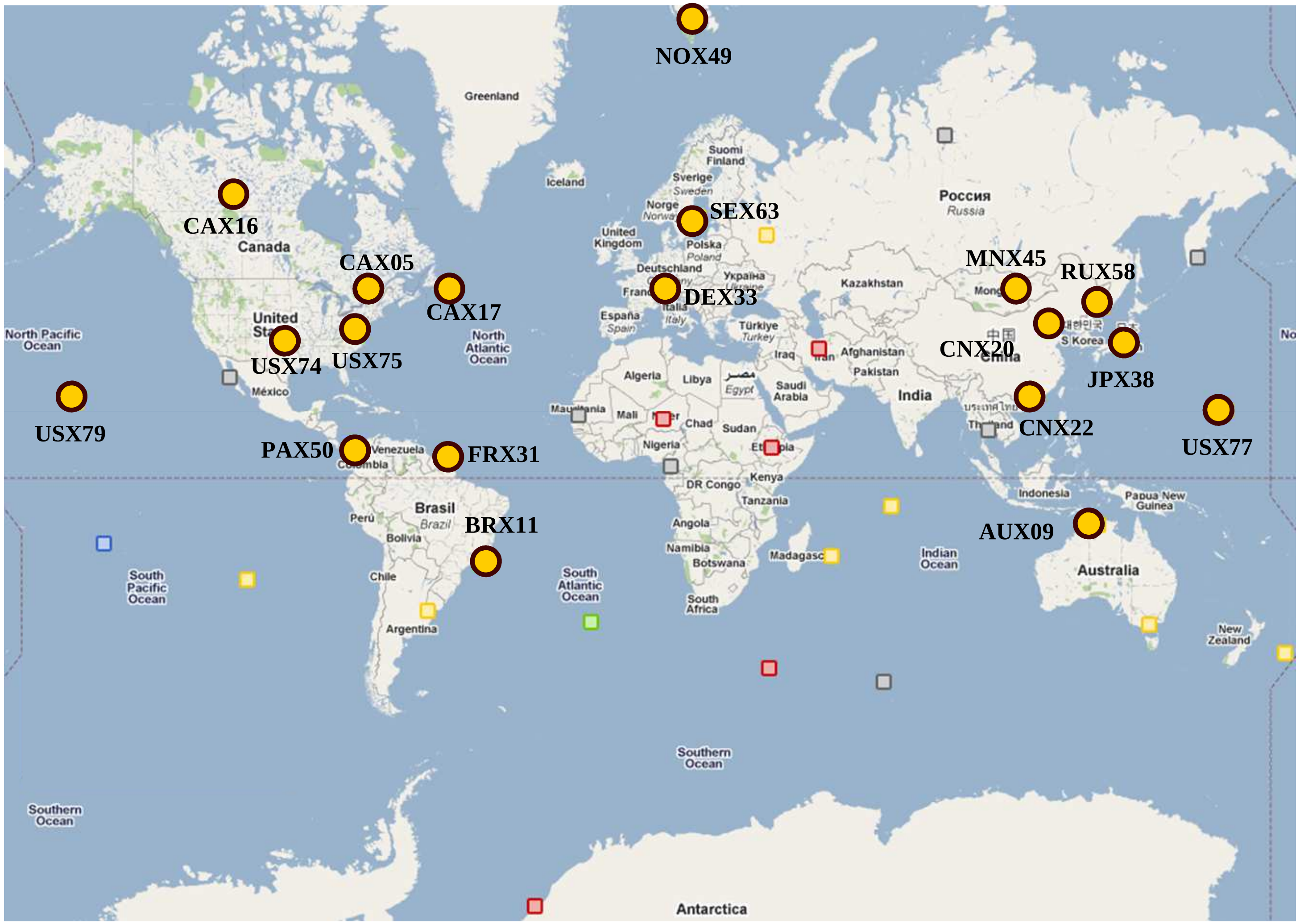


Network availability 85-90%

All these stations detected at least radioactive Xe-133 From Fukushima in March and April 2011

Slide courtesy: Mika Nikkinen

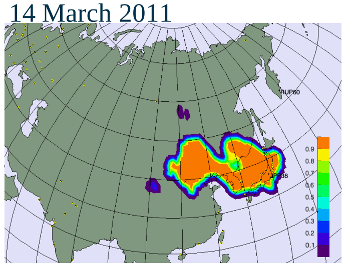
Examples of data analysis for Fukushima

Scientific research could stem from the analysis of detections at the IMS radionuclide stations. In-depth analysis is required to infer information on :

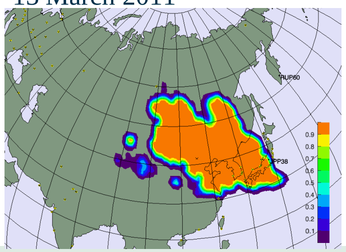
- source location
- temporal profile of the emission
- quantities of the released radionuclides

Some examples of what can be done using the SRS fields computed by the CTBTO and the Regional Specialised Meteorological Centres of WMO

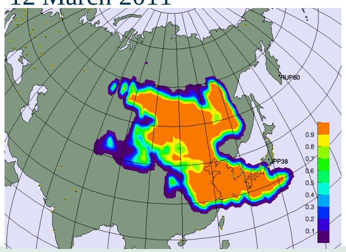
14 March 2011



13 March 2011

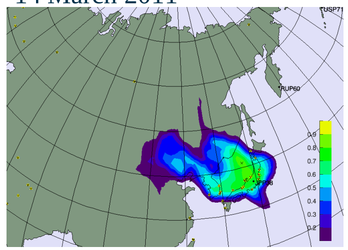


12 March 2011



PSRs for detections at JPP38/RUP60/USP70/USP74/CAP14/CAP17/USP75/USP74/USP71/USP79 between 15 and 19 March 2011. Left: PTS. Right: RSMCs

14 March 2011



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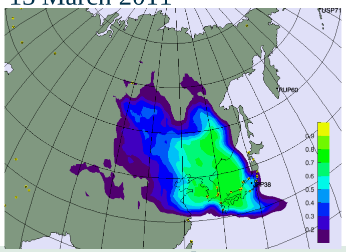

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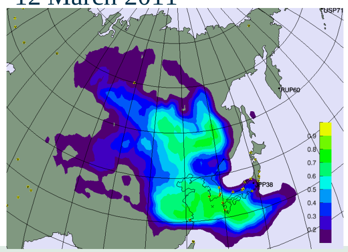
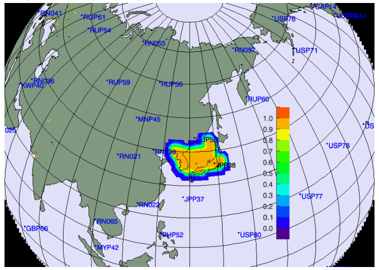
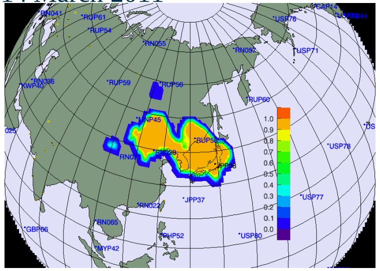


Example of data analysis for Fukushima

15 March 2011



14 March 2011



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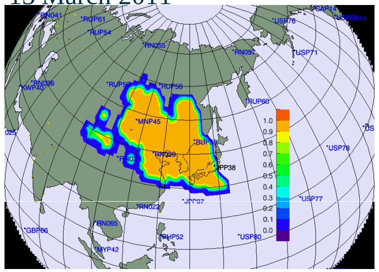

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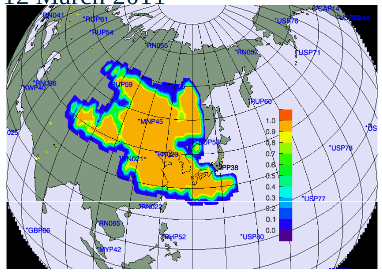
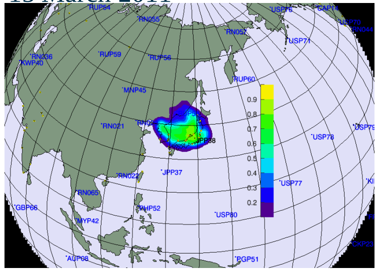


PSRs for detections at JPP38 between 15 and 19 March 2011. Left: CTBTO. Right: RSMCs

15 March 2011



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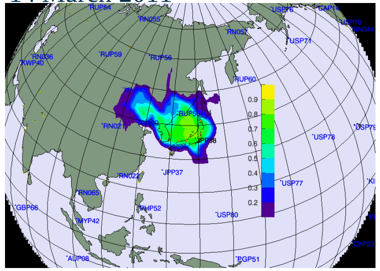

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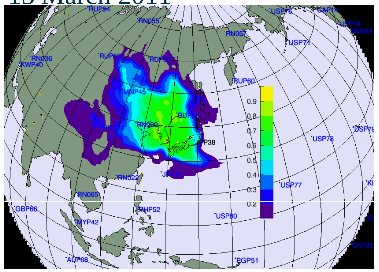

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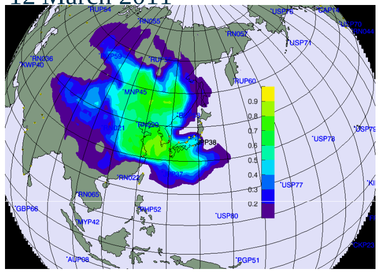

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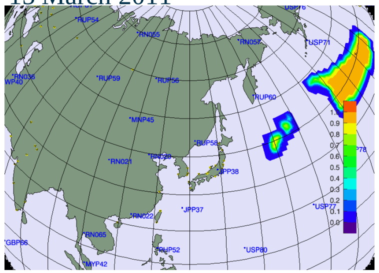

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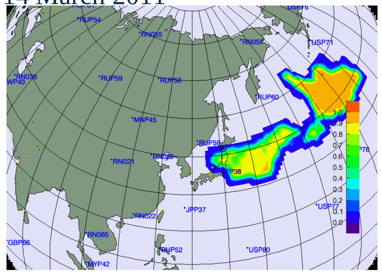

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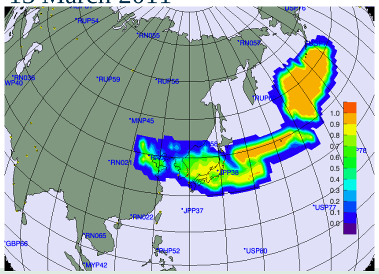

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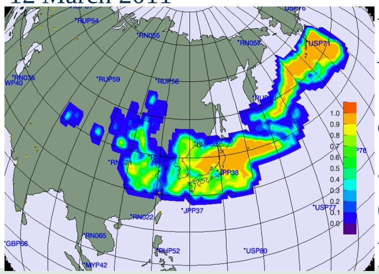
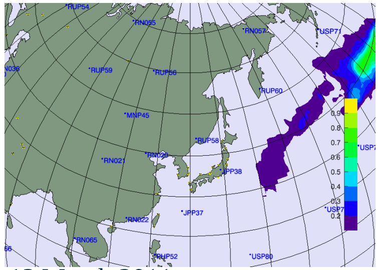


PSRs for detections at USP70 between 15 and 19 March 2011. Left: CTBTO. Right: RSMCs

15 March 2011



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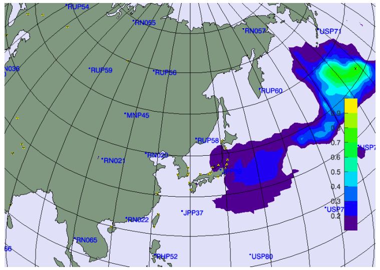

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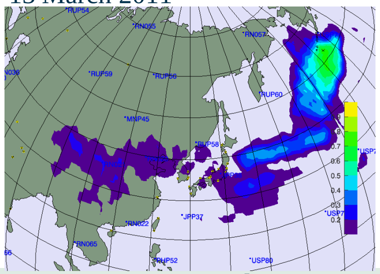

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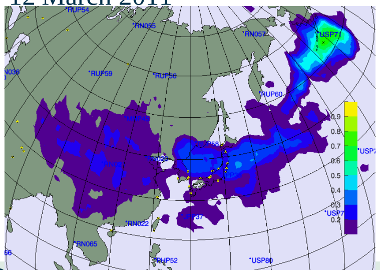

virtual Data Exploitation Centre (vDEC) Establishment Project

CTBTO PREPARATORY COMMISSION

- Purpose
  - Provide a mechanism for a structured partnership and cooperation between the external community (academia, contractors, national institutes, international organizations) and CTBTO

- Mechanism
  - Virtual machine on powerful cluster of servers made available to users
    - Legal framework for zero-cost, confidentiality-bound contracts
    - CTBTO software and archive installed
    - Helpdesk available
    - Collaborative wiki installed

- Status
  - Pilot Project FEI (False Events Identification) used vDEC platform to access data
    - FEI software integrated and being tested on the Development LAN
  - EU Council Decision funds to be used for CTBTO posts (e.g. for vDEC maintenance & operation)
  - Currently a few years of waveform data (seismic, hydroacoustic, infrasound)
  - Three months of radionuclide data (March – May 2011)

Access to vDEC

- Automatic access for NDCs

- Access for external Contractors when needed

- Zero-cost contracts

- Any research group can request access with a short proposal justifying the use of the platform

- CTBTO-internal process of evaluation of short proposal in place

- Fourteen requests received for access. Four contracts signed with university groups

- Requests can be sent to support@ctbto.org, enquiring about vDEC

Thank You!