What Happened from the Accidental Release of Radioactive Materials from the Fukushima Dai-Ichi Nuclear Power Station on March11 in 2011?

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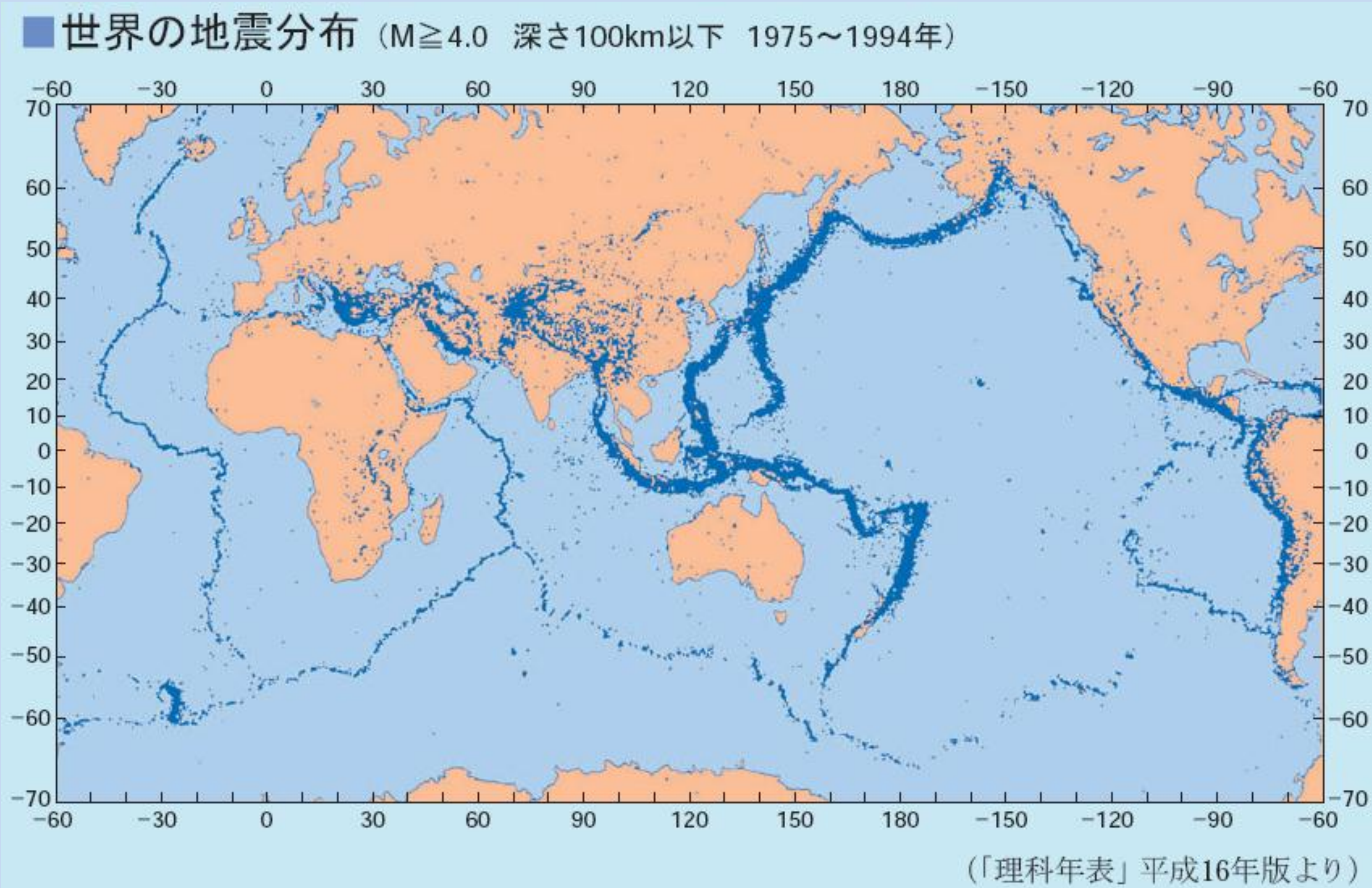
1. Earthquake and Tsunami
2. Release of Radio Active Materials
3. Evacuation
4. Numerical simulations
5. How should we use models in emergency response?

1. Earthquake and Tsunami

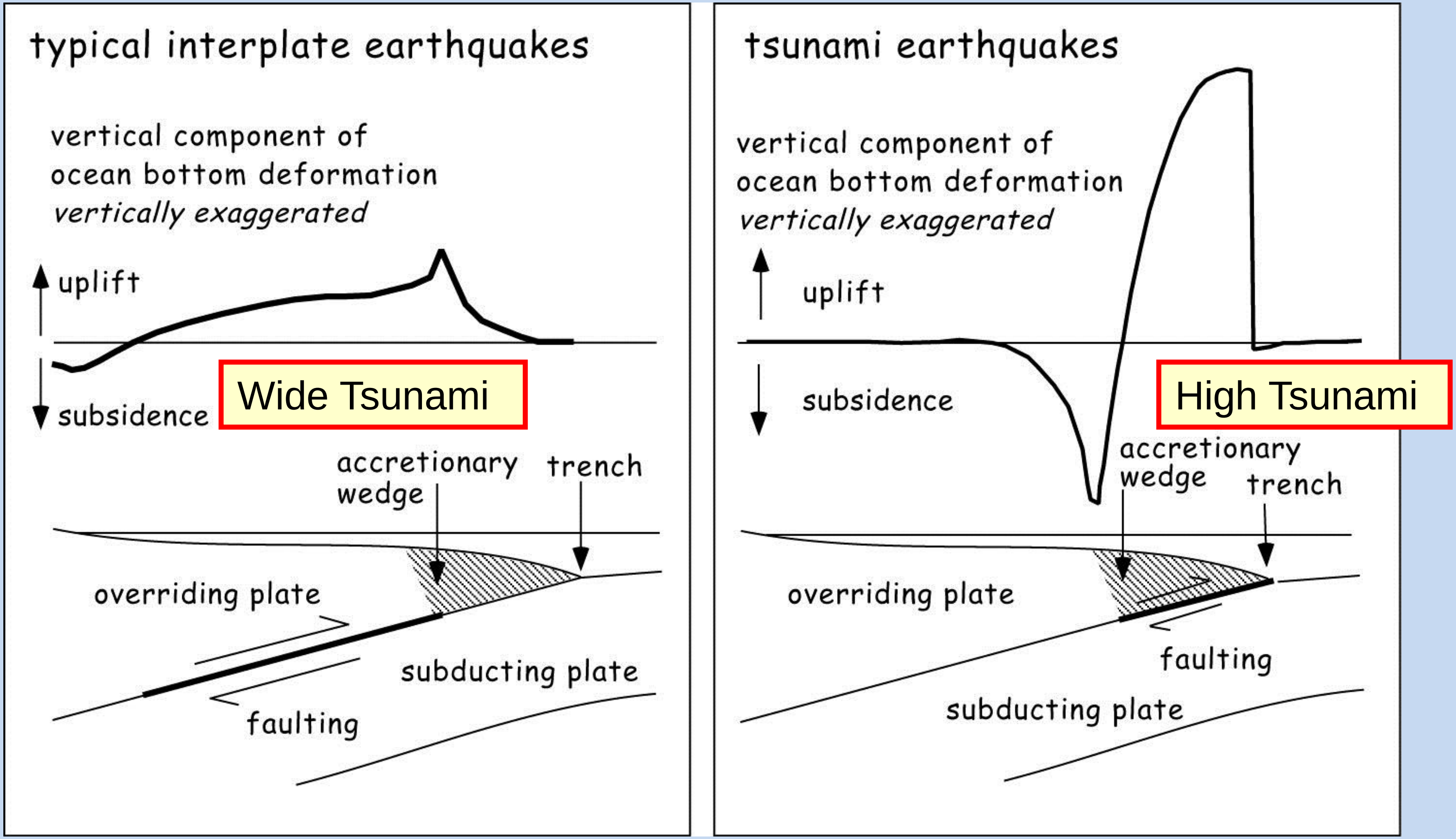
Epicenter Distribution in the World



M ≥ 4.0, h ≤ 100km, 1975-1994

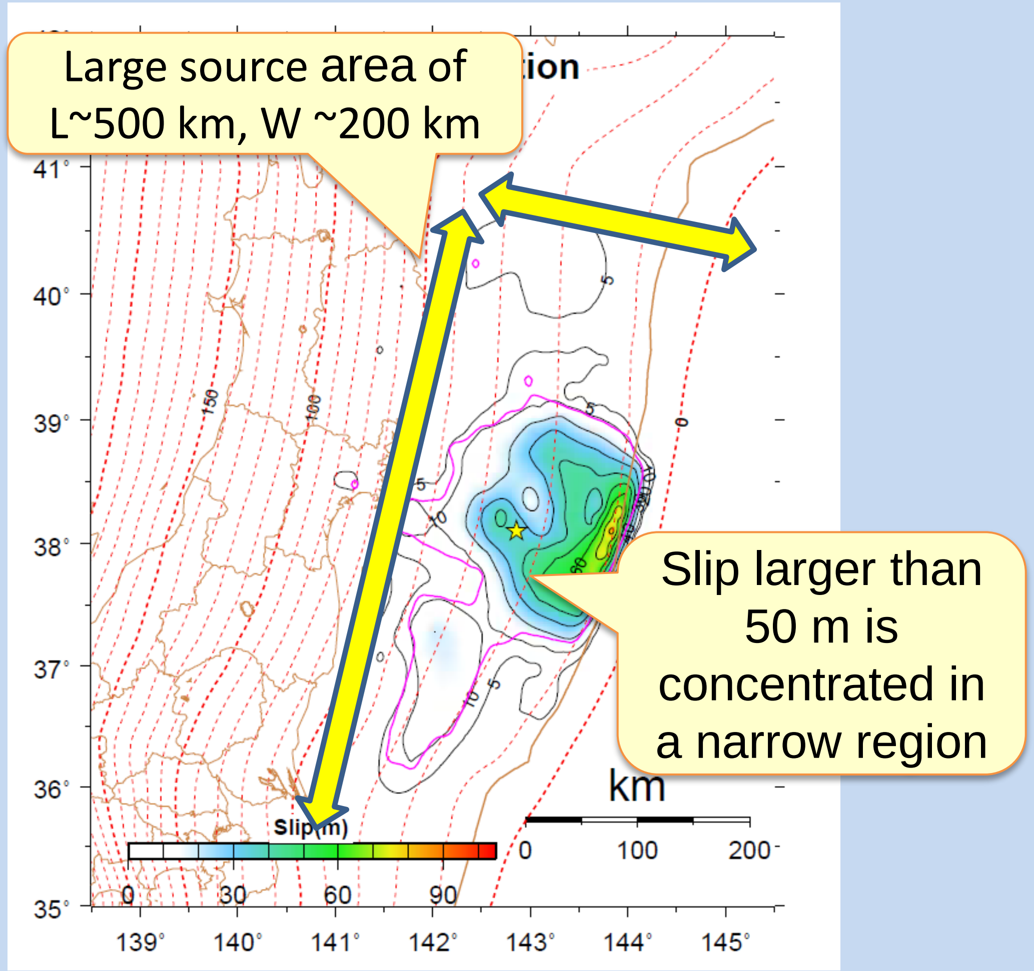
MEXT (2004)

Tsunamigenic and Tsunami Earthquakes



Satake and Tanioka (1999, Pageoph)

Slip distribution of Great East Japan Earthquake



14:46JST/March 11/2012

M: 9.0

Epicenter
130 km from the East coast of Miyagi prefecture

This occurred since Jougan earthquake (M: 8.3-8.7) in 869

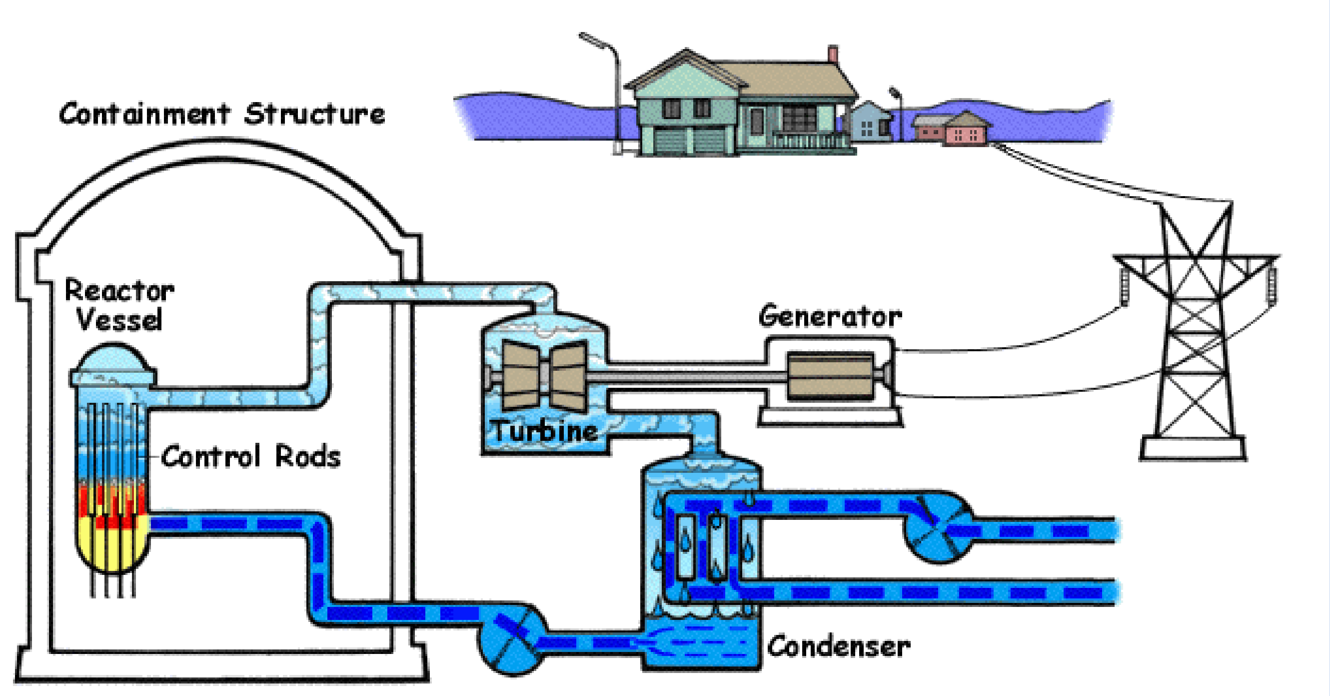
Both land and ocean-bottom data are used

Iinuma et al. (2012)

2. Release of radioactive materials

Fukushima Daiichi Nuclear Power Station

Tokyo Electronic Company



Mark 1
Boil water reactor
Unit1: 1971
Unit2: 1974
Unit3: 1976
Unit4: 1978
Unit5: 1978
Unit6: 1979

Vessel of Mark 1 is too small to control the pressure in emergency.

A 35-m hill was dug down to only 10 meters above sea level.
Emergency Diesel Power Generators were placed under the ground.
Fukushima NPS was not well prepared for Tsunami.

Lost of power supplies to Fukushima NPS

Earthquake broke down the Power Supply Cable from outside.
Tsunami broke down all Emergency Diesel Power Generators.
Back-up batteries were damaged by Tsunami and ran down 8 hours later.   Heavy traffic jam prevented transportation of batteries.
All the power supplies were completely lost.

Accidental release of radioactive materials

Electric failure stopped the circulation of reactor coolant water.

In the unit 1, 2 and 3 reactors, coolant water was boiled away and the nuclear fuel was melt down in a few days.

Reactors increased temperature and pressure, and generated hydrogen gas through reactions of zirconium and vapor.

Accidental release of radioactive materials

Hydrogen explosions occurred on 12 in unit 1, on 14 in unit 3 and on 15 in unit 4. To prevent explosions, ventilations were also conducted.

A huge amount of radioactive materials were released through the explosions, ventilations and leaks from broken containments.

Explosions/Ventilations

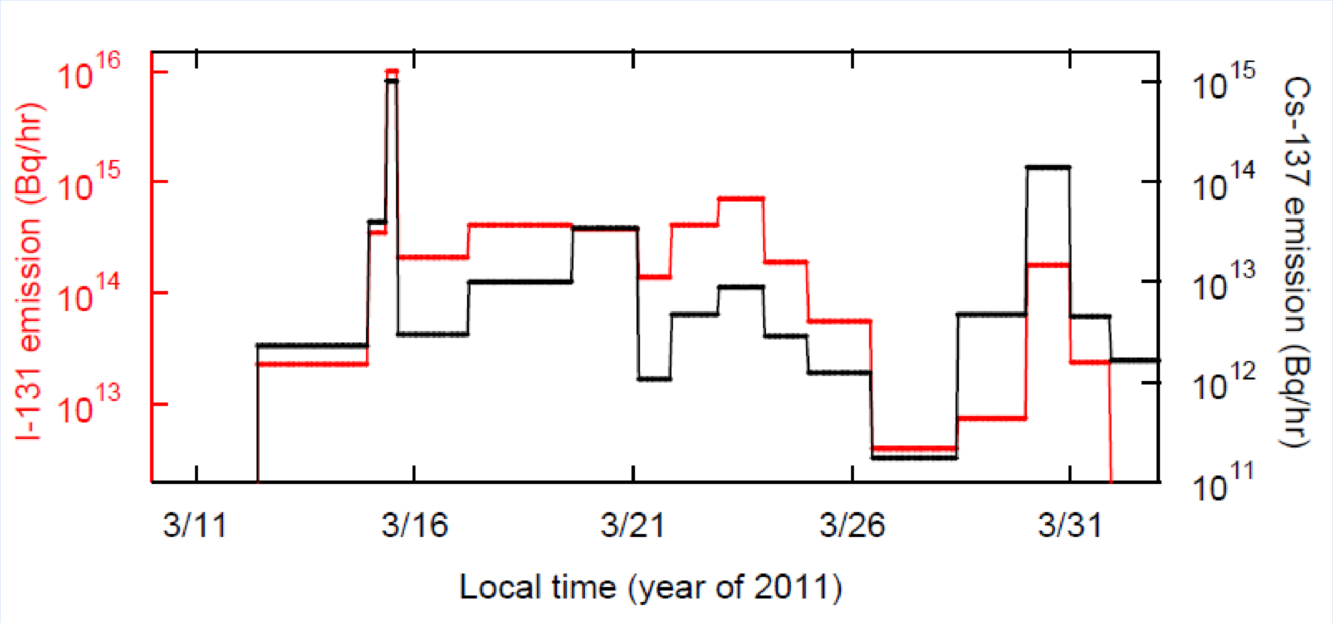
March 11:	14-15jst	Earthquake and Tsunami
March 12:	10jst, 14jst	Ventilation (unit 1)
	15jst	Explosion (unit 1)
March 13:	08jst	Ventilation (unit 3)
	11jst	Ventilation (unit 2)
March 14:	05jst	Ventilation (unit 3)
	11jst	Explosion (unit 3)
March 15:	00jst	Ventilation (unit 2)
	06jst	Fire/Explosion (unit 4)

Continuous leak may remain after explosions/ventilations

Emission Intensity

Emission intensity is to be estimated in the Emergency Response Support System (ERSS). In this accident, however, this system could not work well due to the lack of reactor information.

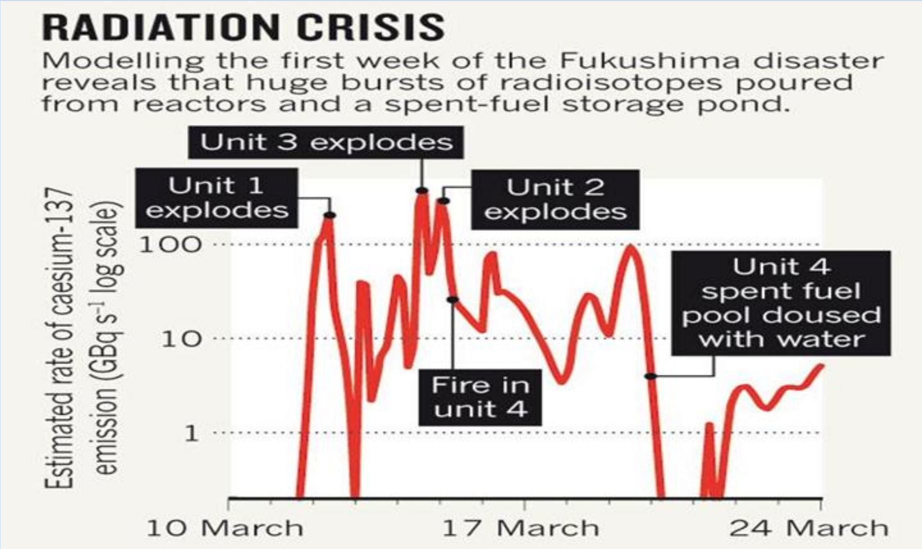
Uncertainty of Emission Intensity



Emission intensity was inversely estimated with transport models from radiations at monitoring posts around NPS (Chino et al., 2011)

The number of monitoring posts was limited. Most of materials were transferred toward the Pacific Ocean following westerlies, so that they could hardly be observed at land stations.

Uncertainty of Emission Intensity



Another inverse estimation was made using a global monitoring network of CTBTO (Stohl et al., 2011)

However, network of CTBTO is very sparse over the globe.

CTBTO: Comprehensive Test Ban Treaty Organization

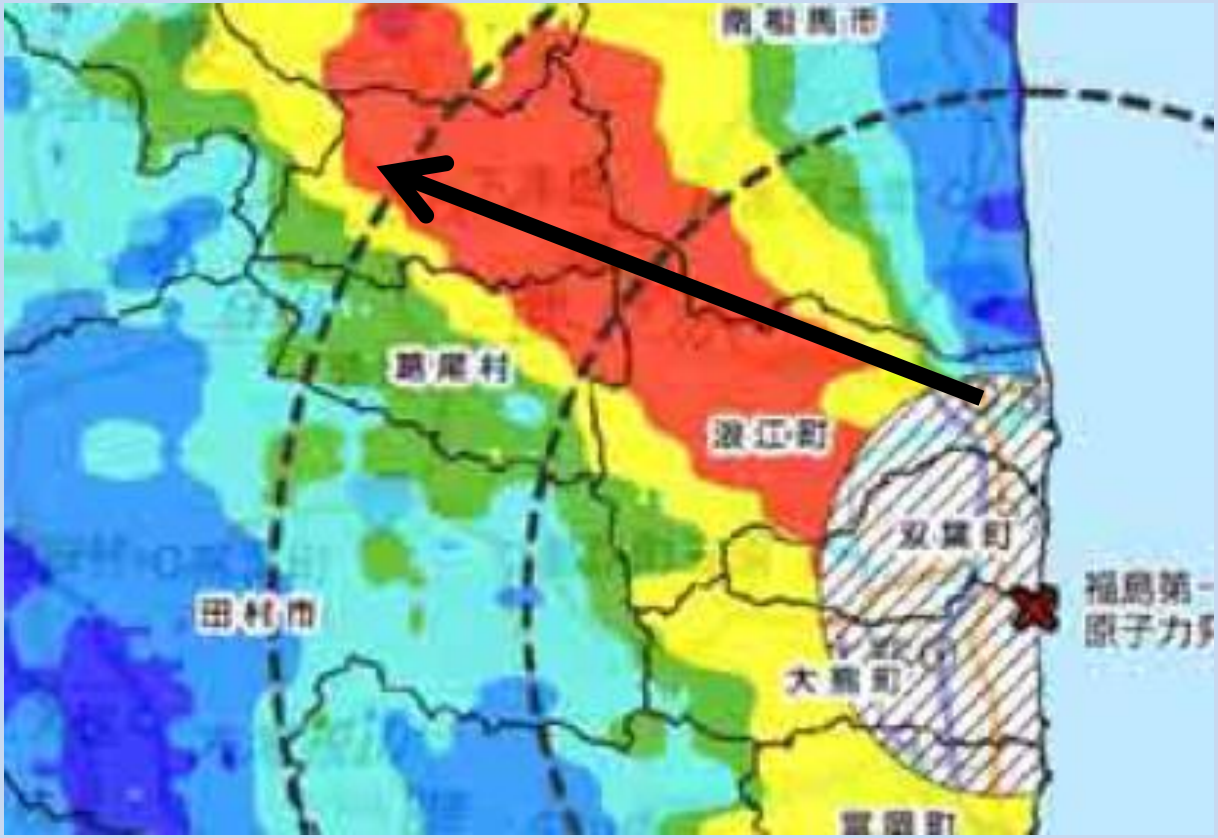
3. Evacuation

Evacuation orders

The government issued evacuation orders based on concentric circles,
They did not use numerical model predictions for evacuations.

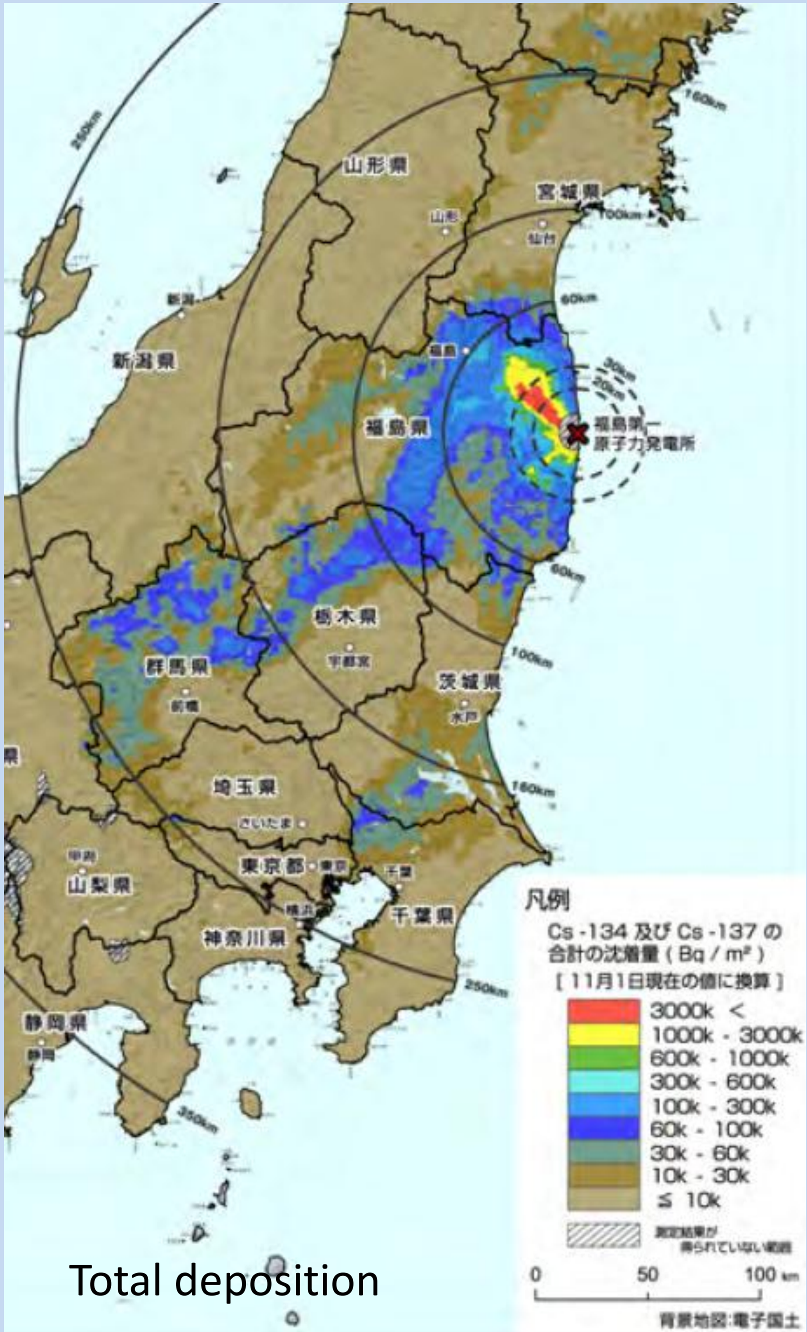
March 11: Evacuation order with a 3 km radius and
stay-indoors order within 3 to10km.
March 12: Evacuation-order within a 10km radius.
March 14: Evacuation-order within a 20km radius.
March 15: Stay indoors within a 20-30km radius.
March 25: Recommend deliberate evacuation to those who lived
within a 20-30km radius.
April 22: Designate evacuation planning zone outside 30km,
which was not a circle but strong-radiation areas
based on the monitoring results.

People in Namie-town evacuated to stronger-radiation area without any information except for a radius from NPS.



Air dose rate

Concentric evacuation zones were not adequate in this case.
Anisotropy of material transport should have been considered.



Total deposition

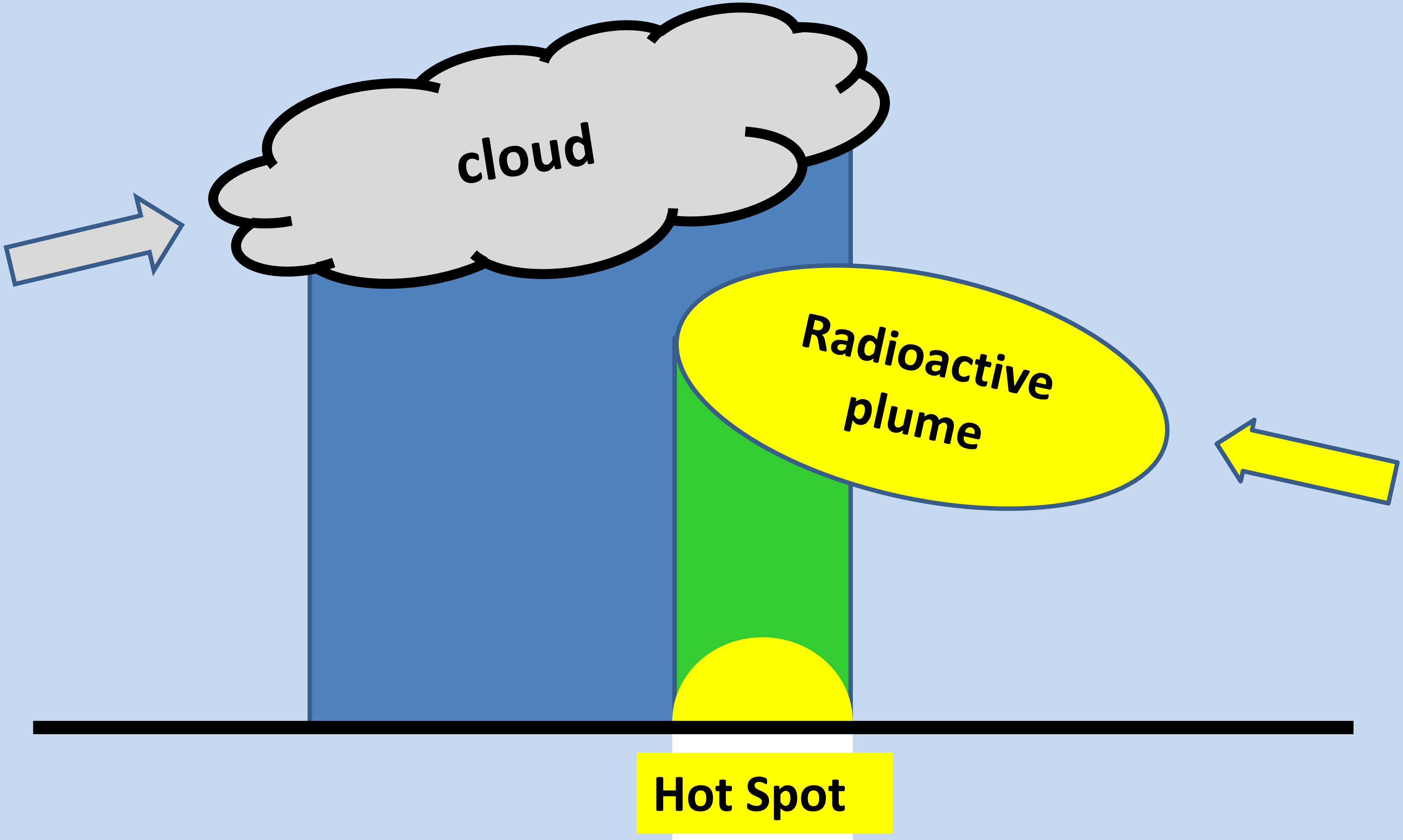
Evacuation order within 20 km is not enough in some directions.

Evacuation orders mainly considered internal exposure caused by inhaled radioactive materials. It depends on low-level air concentration of radioactive material. The low-level concentration decreases rapidly with a distance along the trajectories.

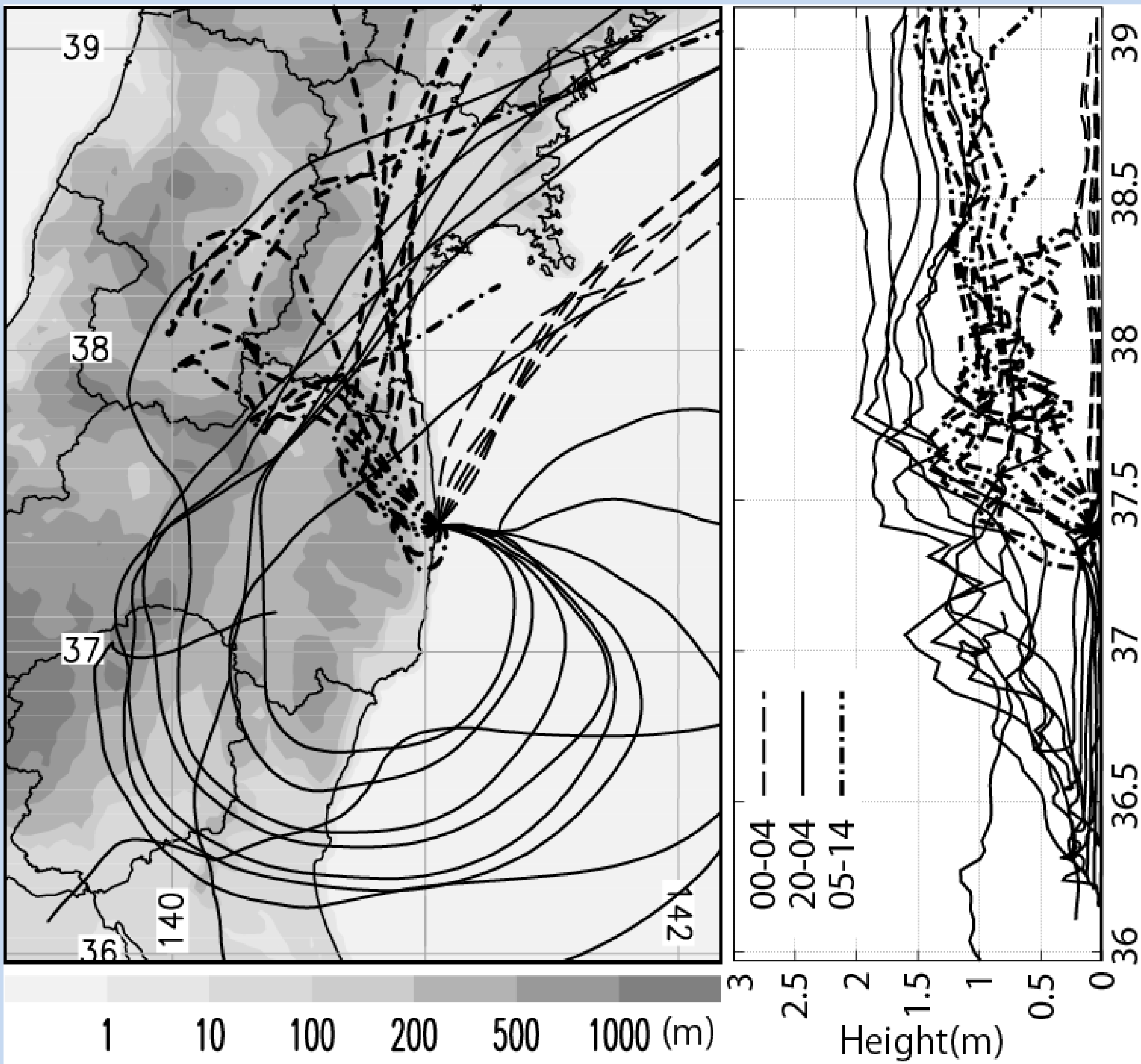
Besides, hot spots are formed far away from NPS by wet depositions.

However, no special evacuation order is issued for wet depositions.

Hot spot formations due to wet depositions

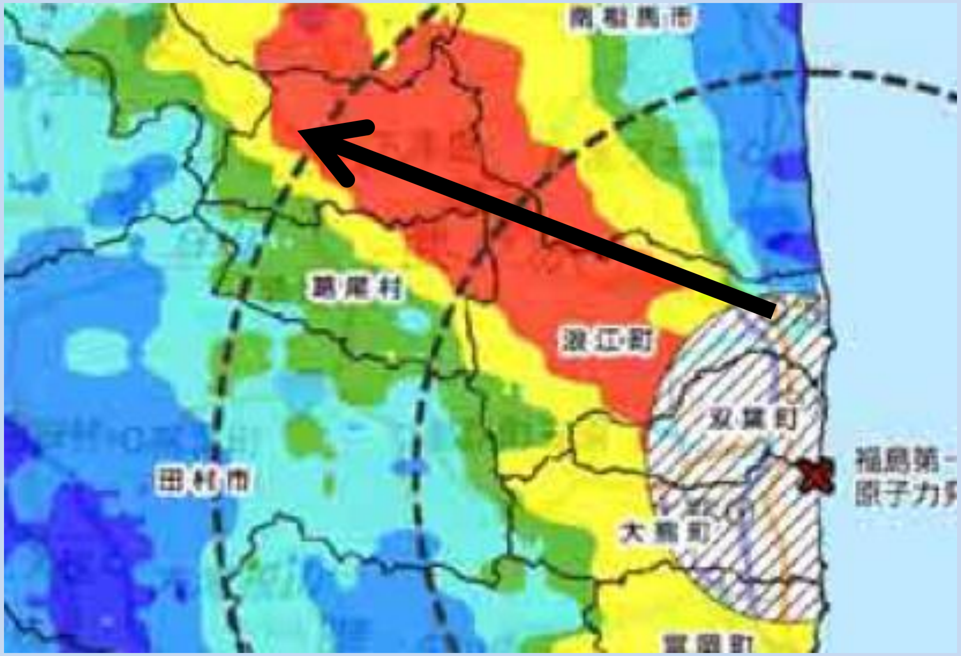


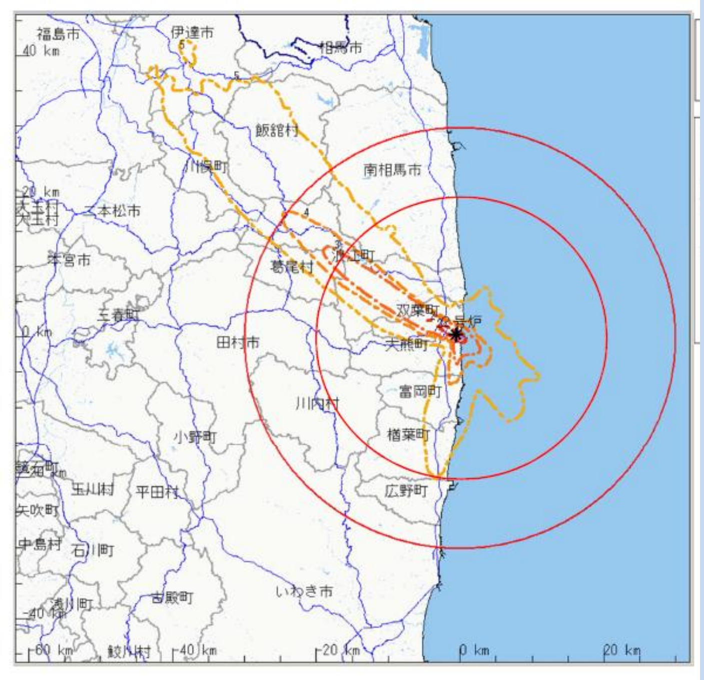
Horizontal and vertical trajectories released from Mar 19 to Mar 20 19



4. Numerical Simulations

SPEEDI





SPEEDI

System for Prediction of Environmental Emergency Dose Information

High resolution dispersion model, SPEEDI, was prepared to disseminate radiation information for emergency cases.

In this accident, Emergency Response Support System (ERSS) could not estimate the emission intensity due to the lack of reactor information. Thus, no information on emission intensity was given to SPEEDI.

JMA

In the framework of RSMC (Regional Specialized Meteorological Center) for emergency response, JMA operated a global dispersion model and provided its results from unit releases to neighboring countries. However, its products are too coarse to utilize for evacuation of local people in Fukushima.

Dissemination of Model Predictions

SPEEDI had been run many times since the first hours after the earthquake and tsunami, based on initial conditions of unit releases. Its predictions were, however, not disclosed to the public.

The government officials explained that the early SPEEDI data were incomplete and inaccurate, especially due to the lack of emission intensity. In fact, the government had withheld the data for fear of "creating a panic." People complained that the SPEEDI predictions were not provided for evacuations.

The government apologized for the failure of timely disclosure and opened full model outputs on May 2, 50 days after the accident.

5. How should we use models?

1. The numerical dispersion models may be useful for giving warnings/orders to mitigate both internal and external exposures. Warning/order of evacuation should be issued by making use of numerical dispersion model forecasts.

2. Wet depositions make hot spots on the ground even far away from the source. Areas of higher radioactivity cause external exposures from the ground and internal exposure through having contaminated water and foods. Numerical models are expected to give some information on the wet depositions. However, the prediction of wet depositions may have large uncertainty that will arise from precipitation forecast.

5. How should we use models?

3. Particular attention must be paid to predictability. In dispersion models, errors come out through processes of diffusions and depositions, in addition to errors of general-purpose NWP models.

4. Multi-model ensemble approach seems to be promising in order to reduce the uncertainty and to consider the worst-case scenario.

5. Comprehensive advisories are necessary to make a maximal use of model results for crisis management.

6. Thank you for international friendship during emergency cases !