An Overview of the Current Distribution of Radionuclides Released to the Environment Following the Fukushima Accident

Kimiaki Saito

Fukushima Environmental Safety Center

Japan Atomic Energy Agency (JAEA)

Estimated radioactive releases into the atmosphere from the Fukushima accident (Bq)

Nuclide	Half life	Reactor 1	Reactor 2	Reactor 3	Total
Xe-133	5.2 d	3.4×10^{18}	3.5×10^{18}	4.4×10^{18}	1.1×10^{19}
Cs-134	2.1 y	7.1×10^{14}	1.6×10^{16}	8.2×10^{14}	1.8×10^{16}
Cs-137	30 y	5.9×10^{14}	1.4×10^{16}	7.1×10^{14}	1.5×10^{16}
Sr-89	50.5 d	8.2×10^{13}	6.8×10^{14}	1.2×10^{15}	2.0×10^{15}
Sr-90	29.1 y	6.1×10^{12}	4.8×10^{13}	8.5×10^{13}	1.4×10^{14}
Te-129m	33.6 d	7.2×10^{14}	2.4×10^{15}	2.1×10^{14}	3.3×10^{15}
Pu-238	87.7 y	5.8×10^{08}	1.8×10^{10}	2.5×10^{08}	1.9×10^{10}
Pu-239	24065 y	8.6×10^{07}	3.1×10^{09}	4.0×10^{07}	3.2×10^{09}
Pu-240	6537 y	8.8×10^{07}	3.0×10^{09}	4.0×10^{07}	3.2×10^{09}
Pu-241	14.4 y	3.5×10^{10}	1.2×10^{12}	1.6×10^{10}	1.2×10^{12}
I-131	8 d	1.2×10^{16}	1.4×10^{17}	7.0×10^{15}	1.6×10^{17}

Nuclear Industry Safety Agency （June 6, 2011）

Contamination mapping projects

- In order to estimate the impact of the Fukushima accident and take appropriate countermeasures, it has been necessary to obtain precise information on the contamination conditions.
- The Ministry of Education, Culture, Sports, Science and Technology (MEXT) commissioned JAEA to construct detailed contamination maps based on reliable environmental monitoring.
- JAEA has completed three series of mapping projects in collaboration with many organizations.
- The 4th project is in progress being commissioned by the Nuclear Regulation Authority (NRA).

Tasks of mapping projects

1. Mapping of radionuclide deposition and dose rates in air
2. Studies on radionuclide migration in natural environment
3. Construction of a database
4. Prediction of contamination conditions in future

Contents

1. Distribution of radionuclide ground deposition densities (Bq/m^2)
2. Distribution of air dose rates ($\mu Sv/h$)
3. Depth profiles of radiocesium in ground (Bq/kg, relaxation depth β)

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Locations

- Undisturbed flat fields for 1, 2, 3
- Car-borne survey on roads over wide areas for 2

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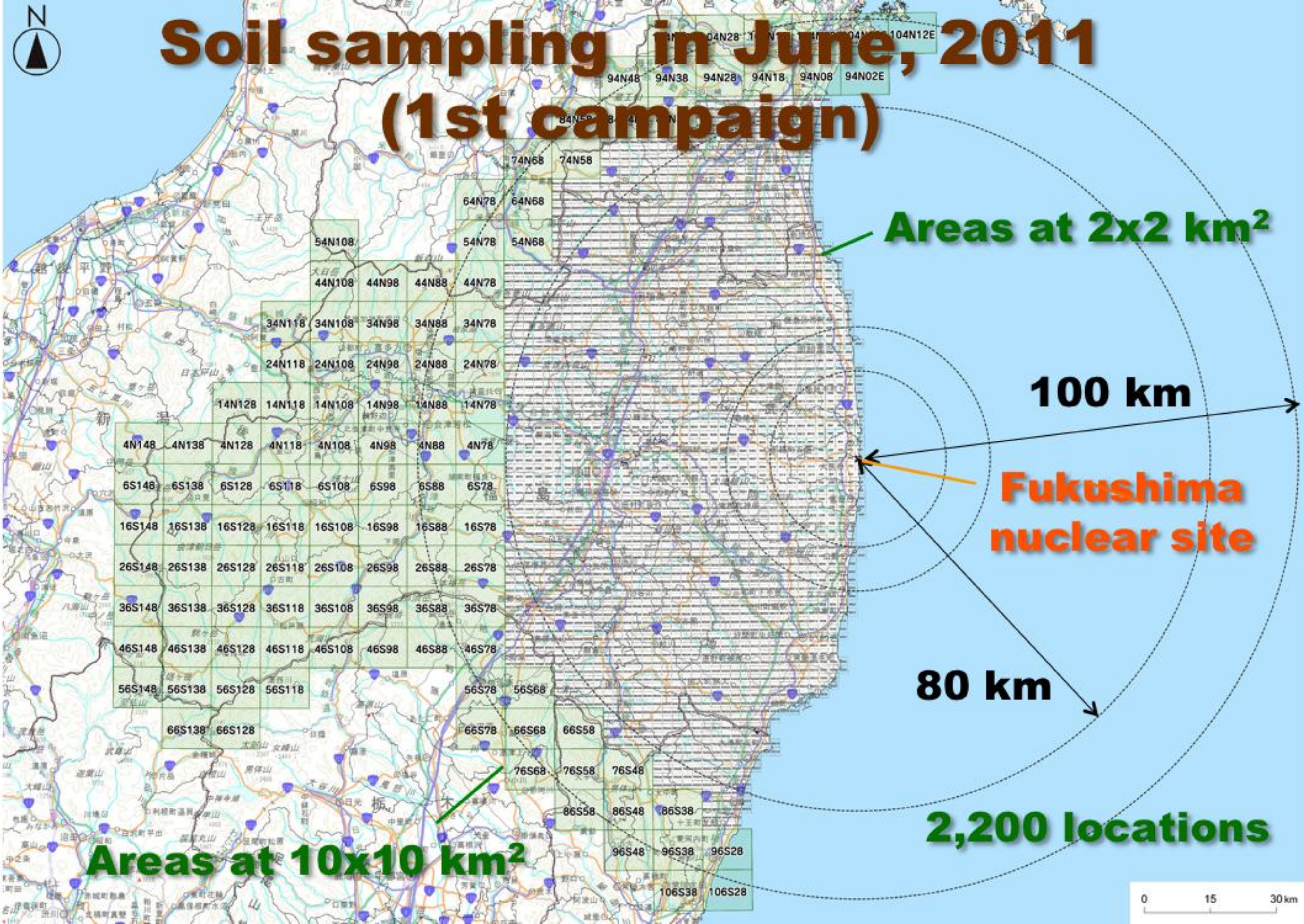
Soil sampling in June, 2011 (1st campaign)



Collection procedures of a soil sample

- **Top 5 cm soil**
- **Sufficient mixing**
- **U8 plastic container**
- **11,000 samples at 2,200 locations in 1st campaign**
- **Analyzed at 21 laboratories**

In-situ measurement using a portable Ge detector

In-situ measurements have been used to determine deposition density of radionuclides since December 2011.

Radionuclide deposition maps

1. Gamma-ray emitting nuclides

- Cs-137 (30.2 y) •Cs-134 (2.06 y)
- I-131 (8.02 d)
- Te-129m (33.6 d) •Ag-110m (250 d)

2. Alpha-ray emitting nuclides

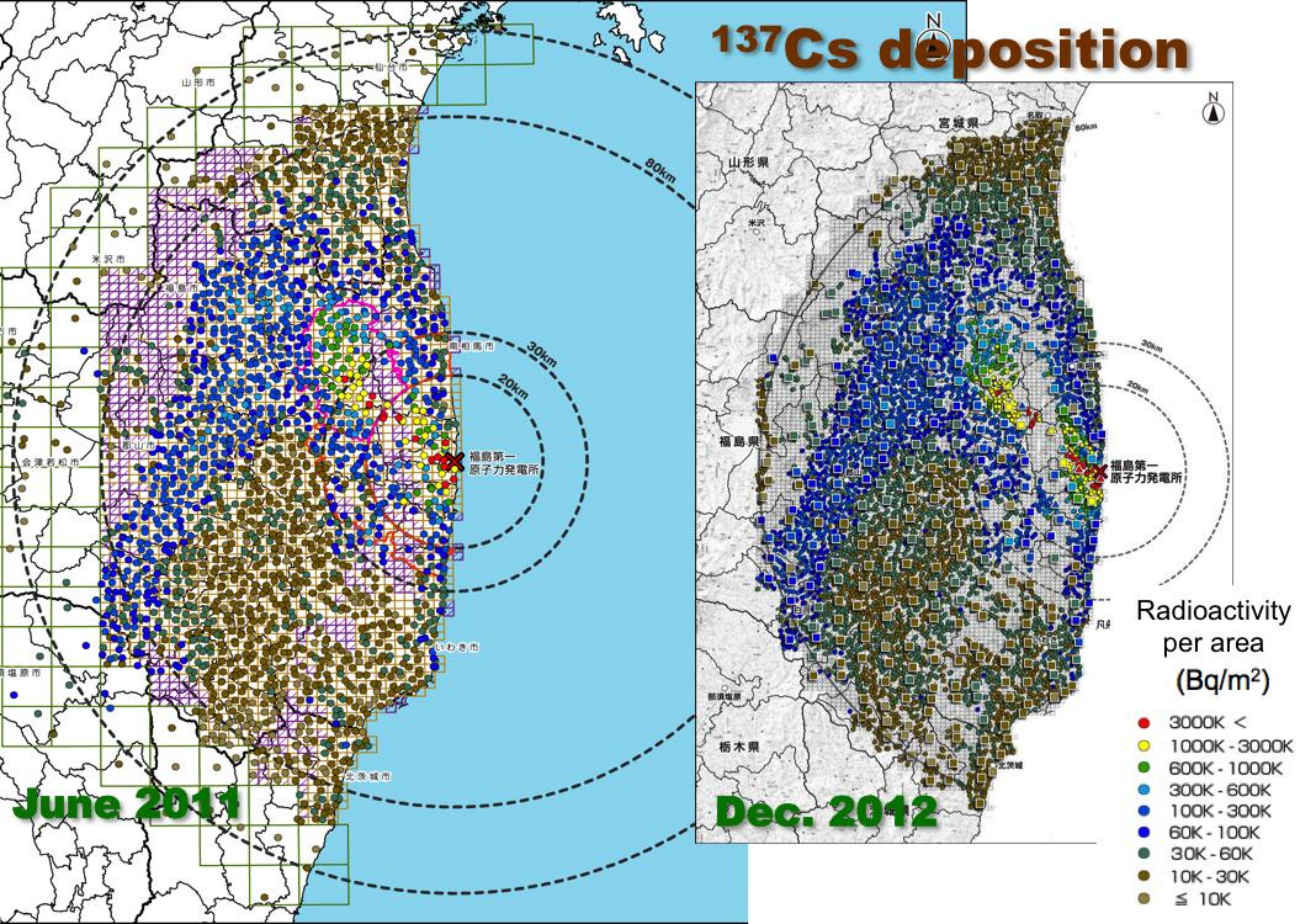
- Pu-238 (87.7 y)
- Pu-239 (24,100 y) + Pu-240 (6,564 y)

3. Beta-ray emitting nuclides

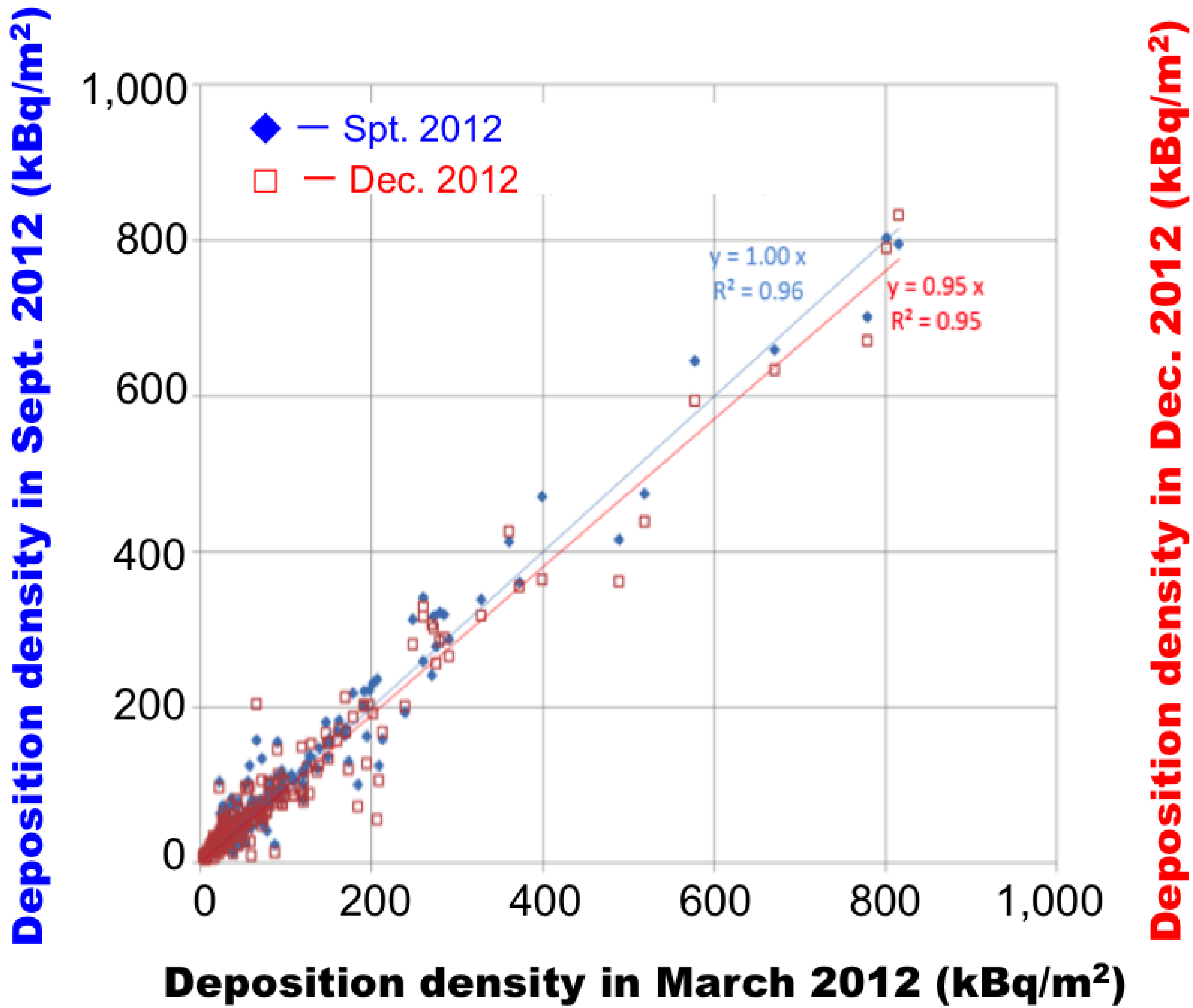
- Sr-89 (50.5 d)
- Sr-90 (28.8 y)

(half life)

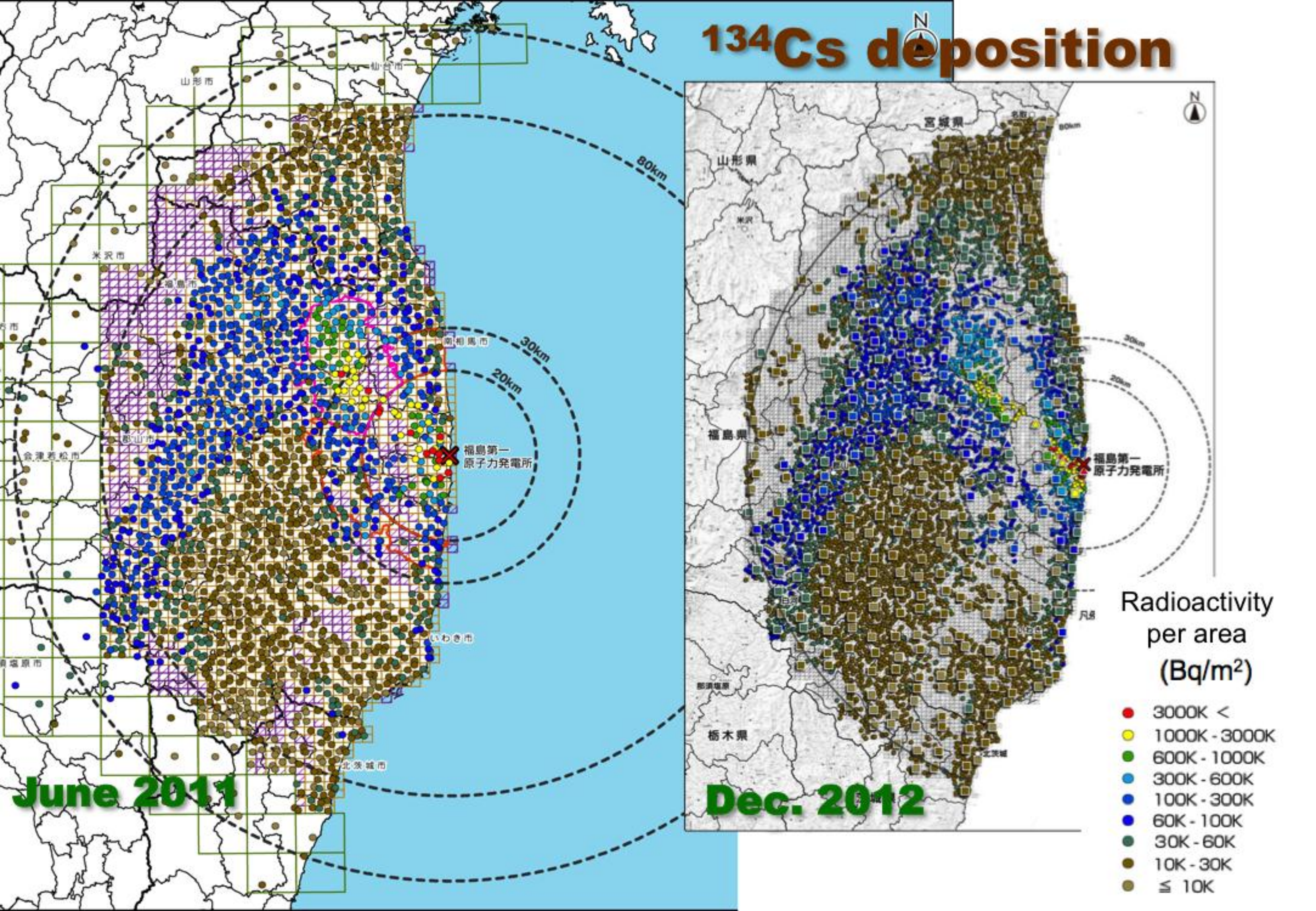
^{137}Cs deposition



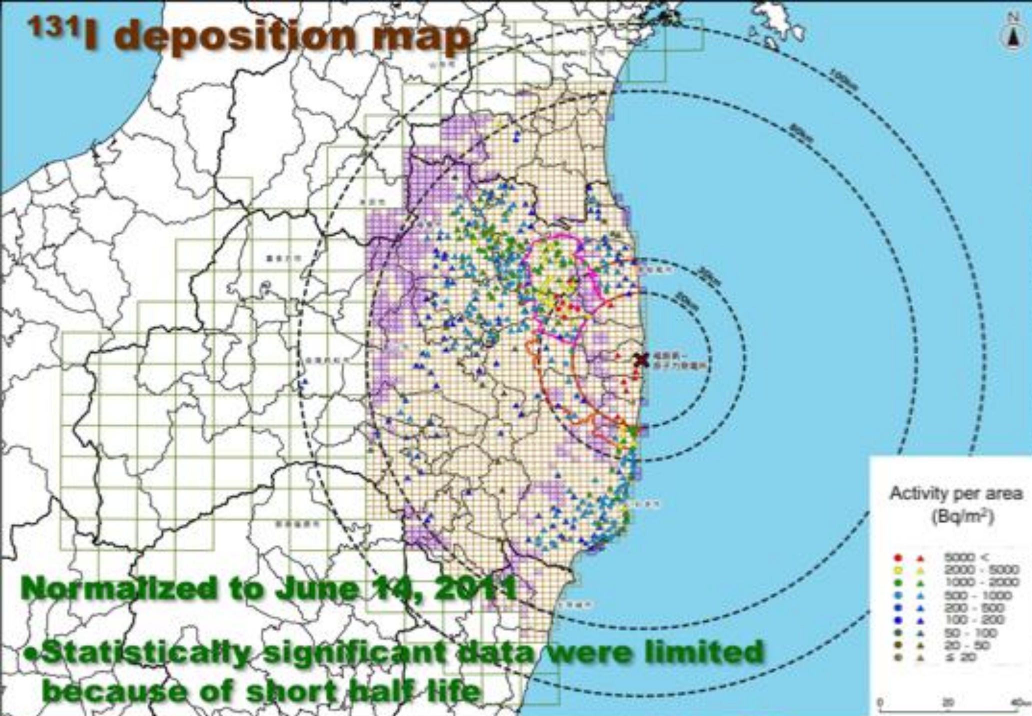
Temporal change in Cs-137 deposition density



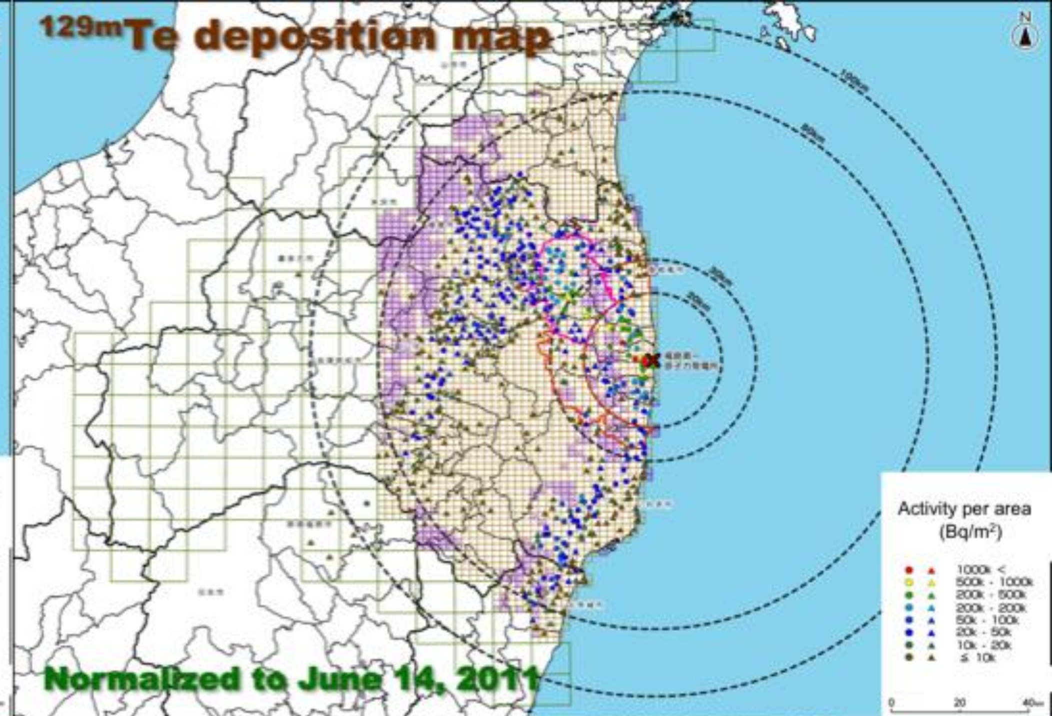
●Cs-137 deposition densities have not changed much in undisturbed flat fields.



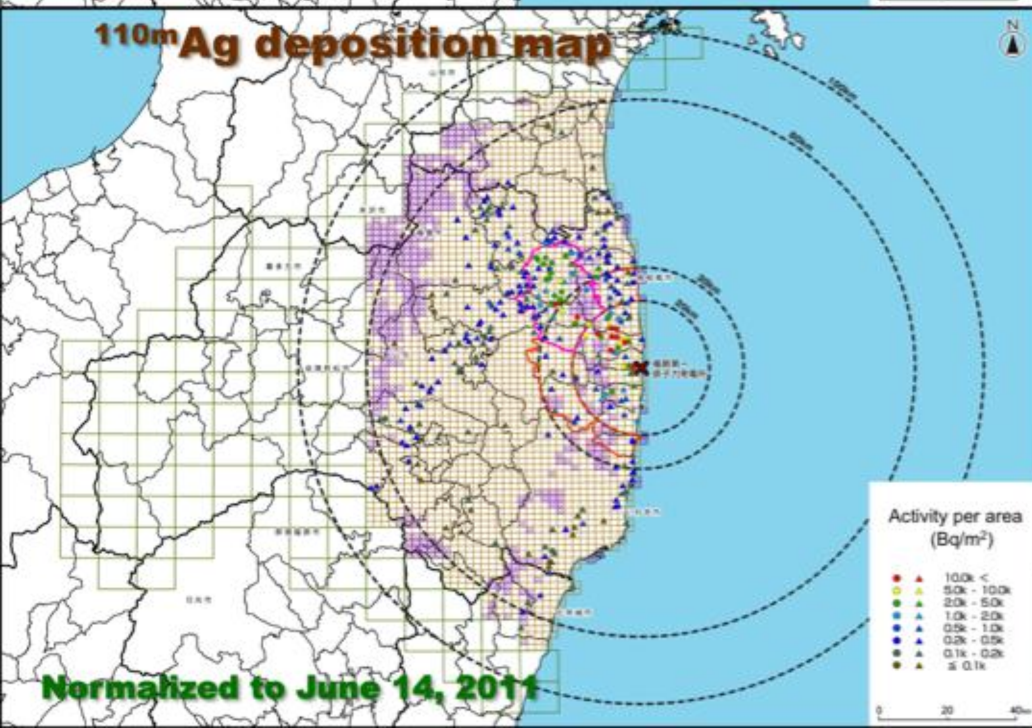
134Cs deposition
June 2011
Dec. 2012
山形市
仙台市
米沢市
福島市
郡山市
会津若松市
南相馬市
いわき市
北茨城市
80km
30km
20km
福島第一
原子力発電所
宮城県
山形県
福島県
栃木県
Radioactivity per area (Bq/m²)
3000K <
1000K - 3000K
600K - 1000K
300K - 600K
100K - 300K
60K - 100K
30K - 60K
10K - 30K
≦ 10K



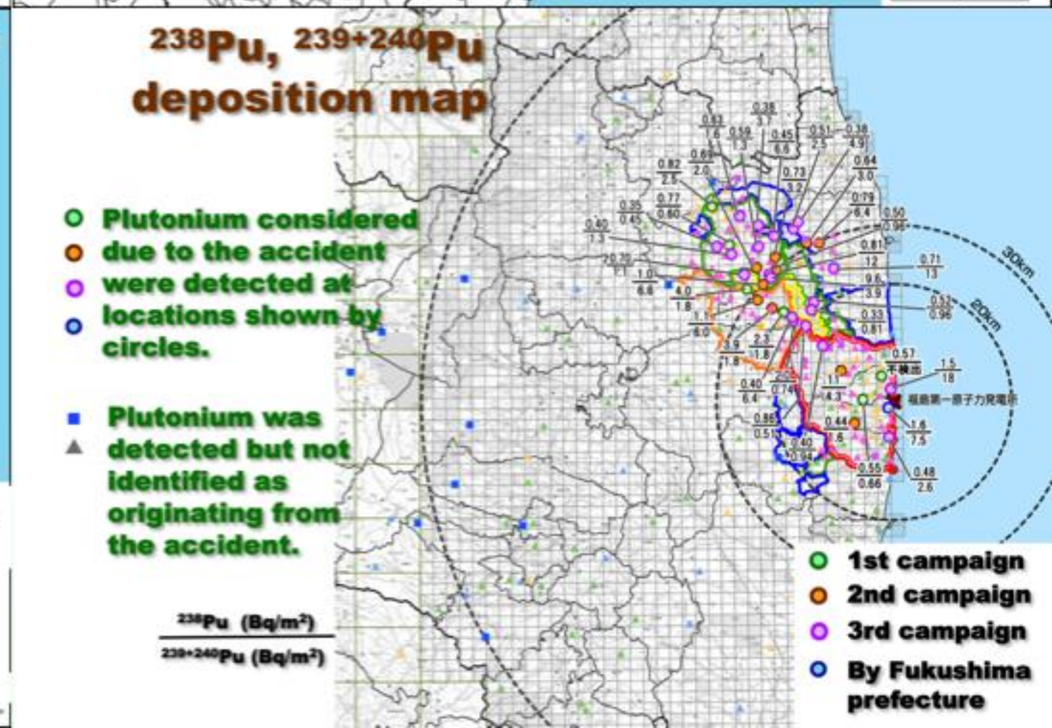
131I deposition map
Activity per area (Bq/m2)
5000 <
2000 - 5000
1000 - 2000
500 - 1000
200 - 500
100 - 200
50 - 100
20 - 50
≤ 20
0 20 40km
Normalized to June 14, 2011
•Statistically significant data were limited because of short half life



129mTe deposition map
Activity per area (Bq/m2)
1000k <
500k - 1000k
200k - 500k
100k - 200k
50k - 100k
20k - 50k
10k - 20k
≤ 10k
0 20 40km
Normalized to June 14, 2011



110mAg deposition map
Activity per area (Bq/m2)
10.0k <
5.0k - 10.0k
2.0k - 5.0k
1.0k - 2.0k
0.5k - 1.0k
0.2k - 0.5k
0.1k - 0.2k
≤ 0.1k
0 20 40km
Normalized to June 14, 2011



238Pu, 239+240Pu deposition map
Plutonium considered due to the accident were detected at locations shown by circles.
Plutonium was detected but not identified as originating from the accident.
238Pu (Bq/m2) / 239+240Pu (Bq/m2)
30km
20km
福島第一原子力発電所
1st campaign
2nd campaign
3rd campaign
By Fukushima prefecture

Evaluation of accumulated effective doses for 50 years from June 2011

- Maximum nuclide deposition densities (Bq/m^2) were used.
- External exposures and inhalation due to re-suspension were evaluated.

Nuclide	Half life	Maximum concentration (Bq/m2)	Effective dose for 50 years	
			Conversion coef. (μSv/(Bq/m^2))	Dose (mSv)
Cs-134	2.065 y	1.4×10^7	5.1×10^{-2}	710
Cs-137	30.167 y	1.5×10^7	1.3×10^{-1}	2000(2.0Sv)
I-131	8.02 d	5.5×10^4	2.7×10^{-4}	0.015
Sr-89	50.53 d	2.2×10^4	2.8×10^{-5}	0.00061 (0.61 μSv)
Sr-90	28.79 y	5.7×10^3	2.1×10^{-2}	0.12
Pu-238	87.7 y	4	6.6	0.027
Pu-239+240	2.411×10^4 y	15	8.5	0.12
Ag-110m	249.95 d	8.3×10^4	3.9×10^{-2}	3.2
Te-129m	33.6 d	2.7×10^6	2.2×10^{-4}	0.6

(Dose coefficients from TECDOC-1162)

Summary on radionuclide deposition

1. Cesium is much more important than other nuclides from the viewpoint of exposure doses in future.
2. Plutonium and Strontium originating from the accident were detected; the radioactivities were not large.
3. Cs-137 deposition densities have not decreased much; while, Cs-134 deposition densities have certainly decreased due to physical decay.
4. Radioactivity ratios of I-131, Te-129m and Ag-110m to Cs-137 have regional dependency.

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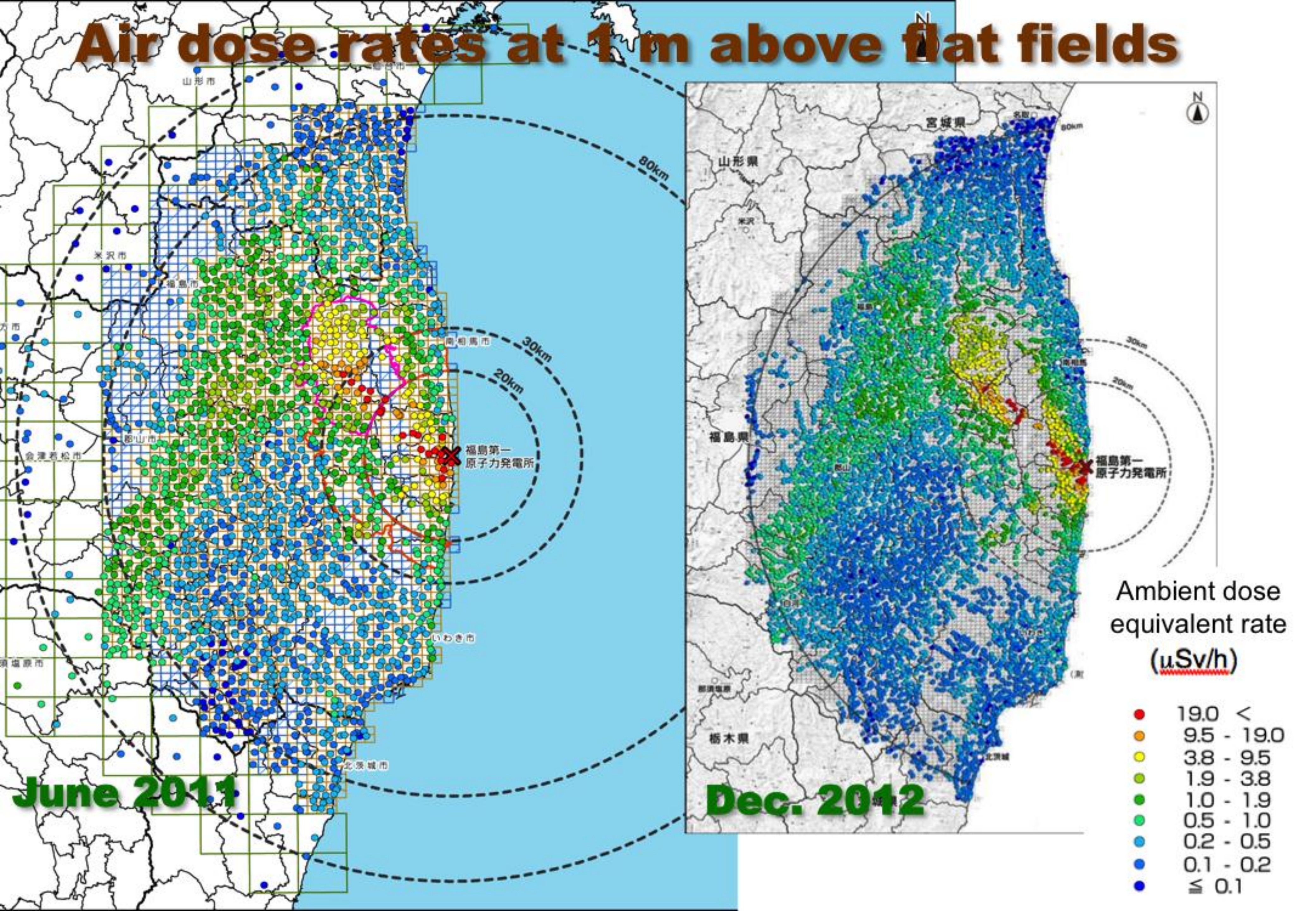
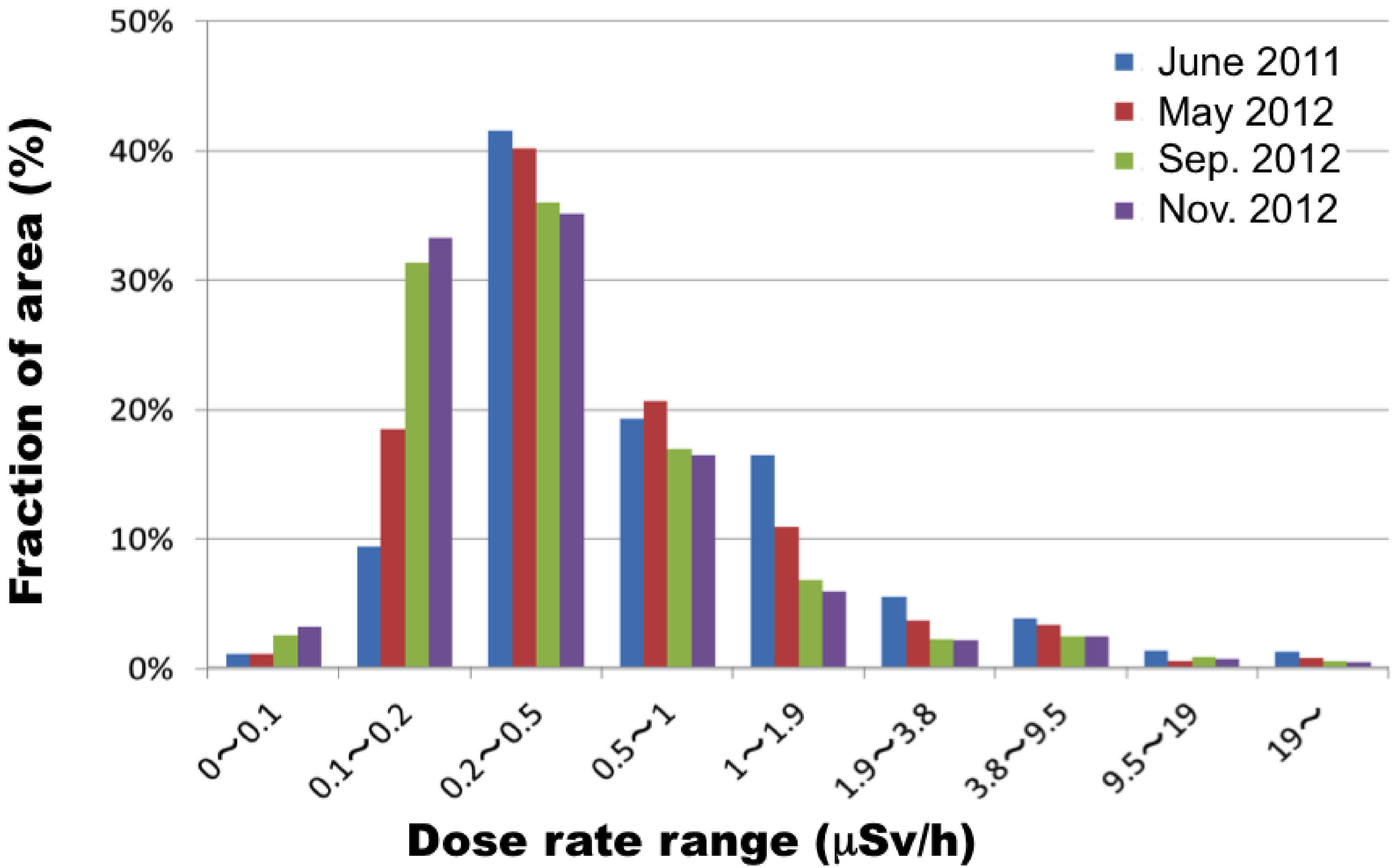
Air dose rates at 1 m above flat fields

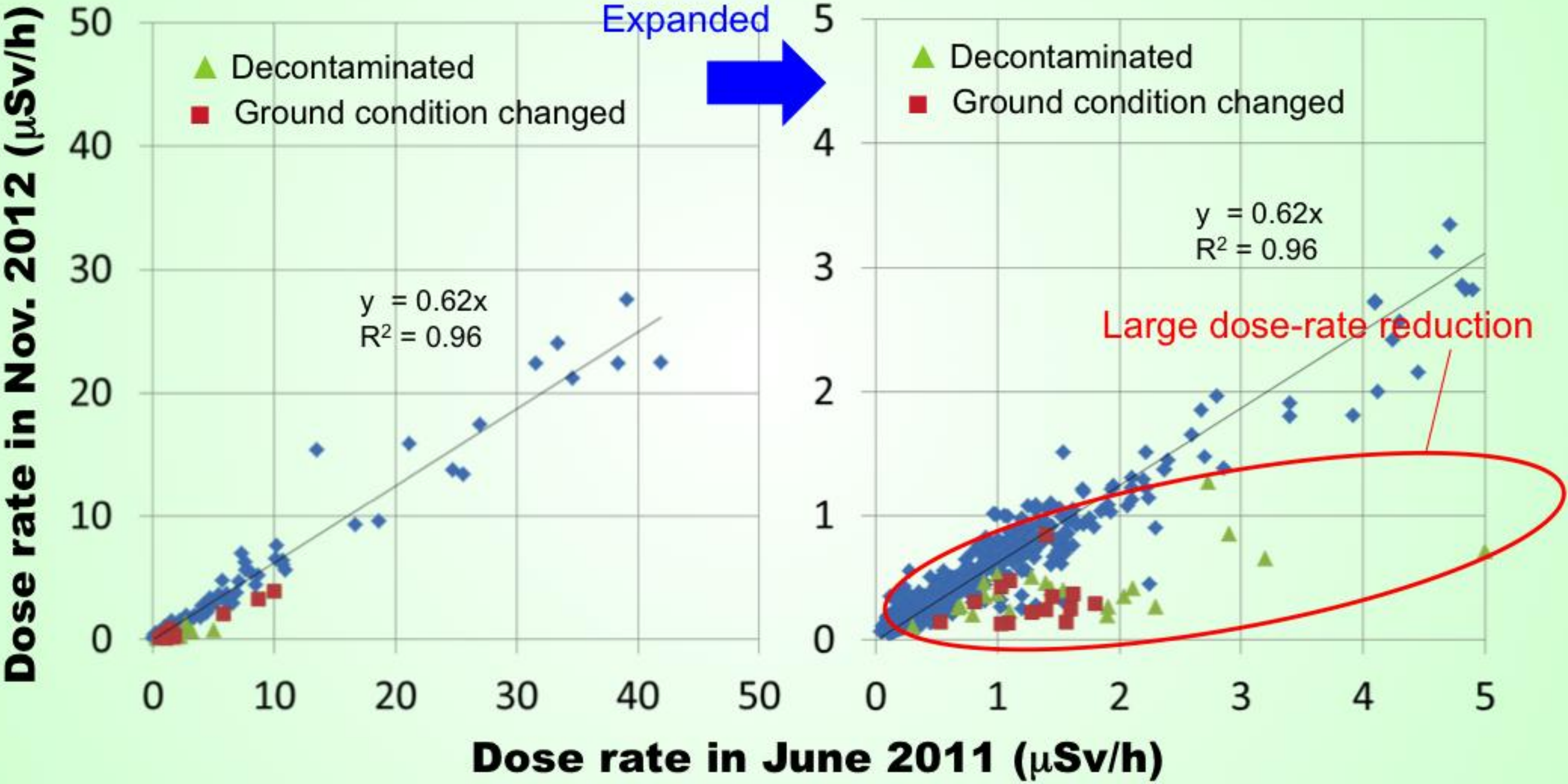


Distribution of areas having different dose rate ranges within the 80 km zone

- **Areas more than 0.2 μSv/h are decreasing, less than 0.2 μSv/h increasing.**
- **Nearly 70% of the total area has dose rates below 0.5 μSv/h.**

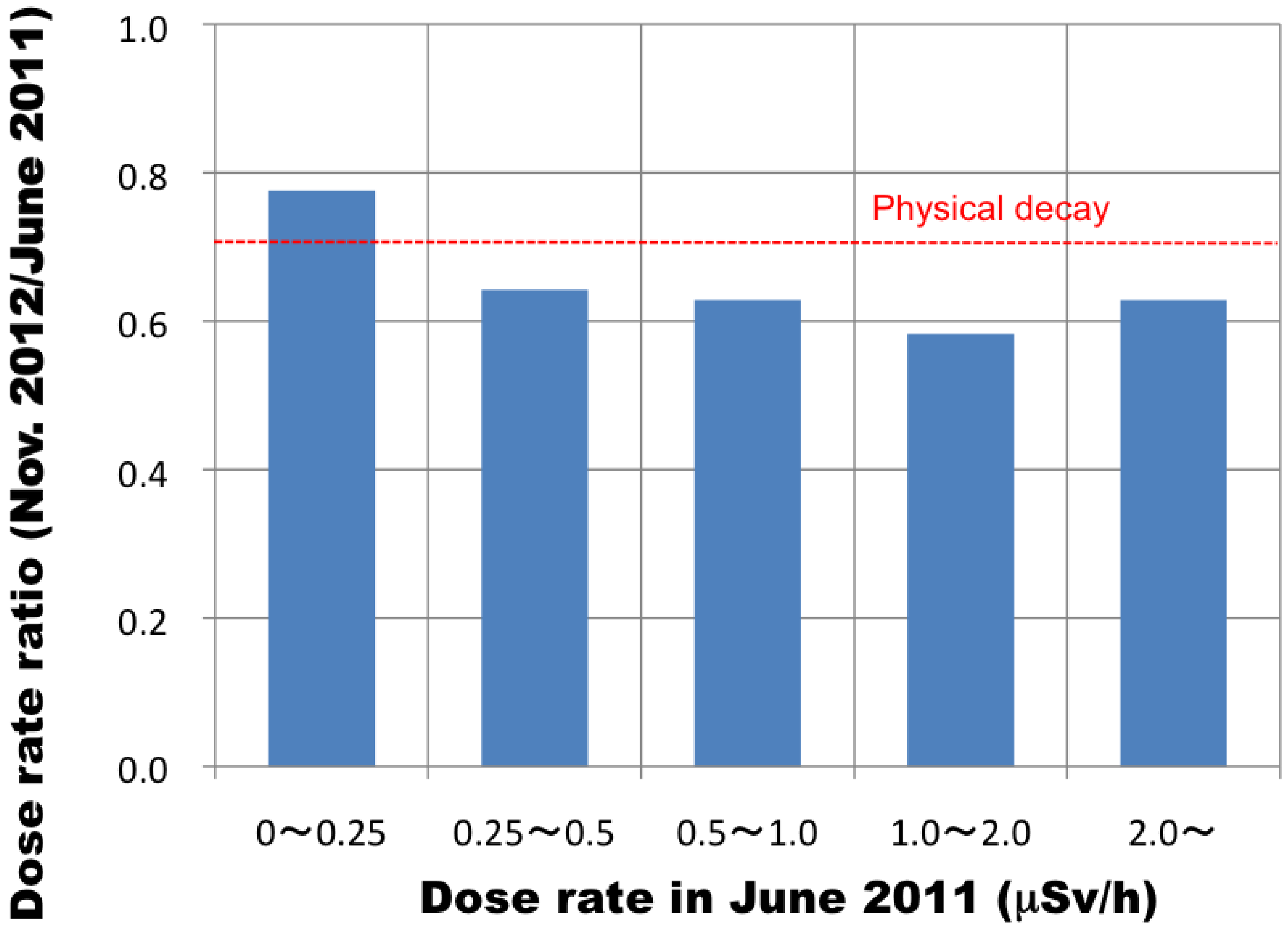


Comparison of dose rates in air at 1 m between June 2011 and Nov. 2012



- **Dose-rate reduction was smaller than 40%. (Physical decay : 29%)**
- **There exist locations showing large dose-rate reduction.**

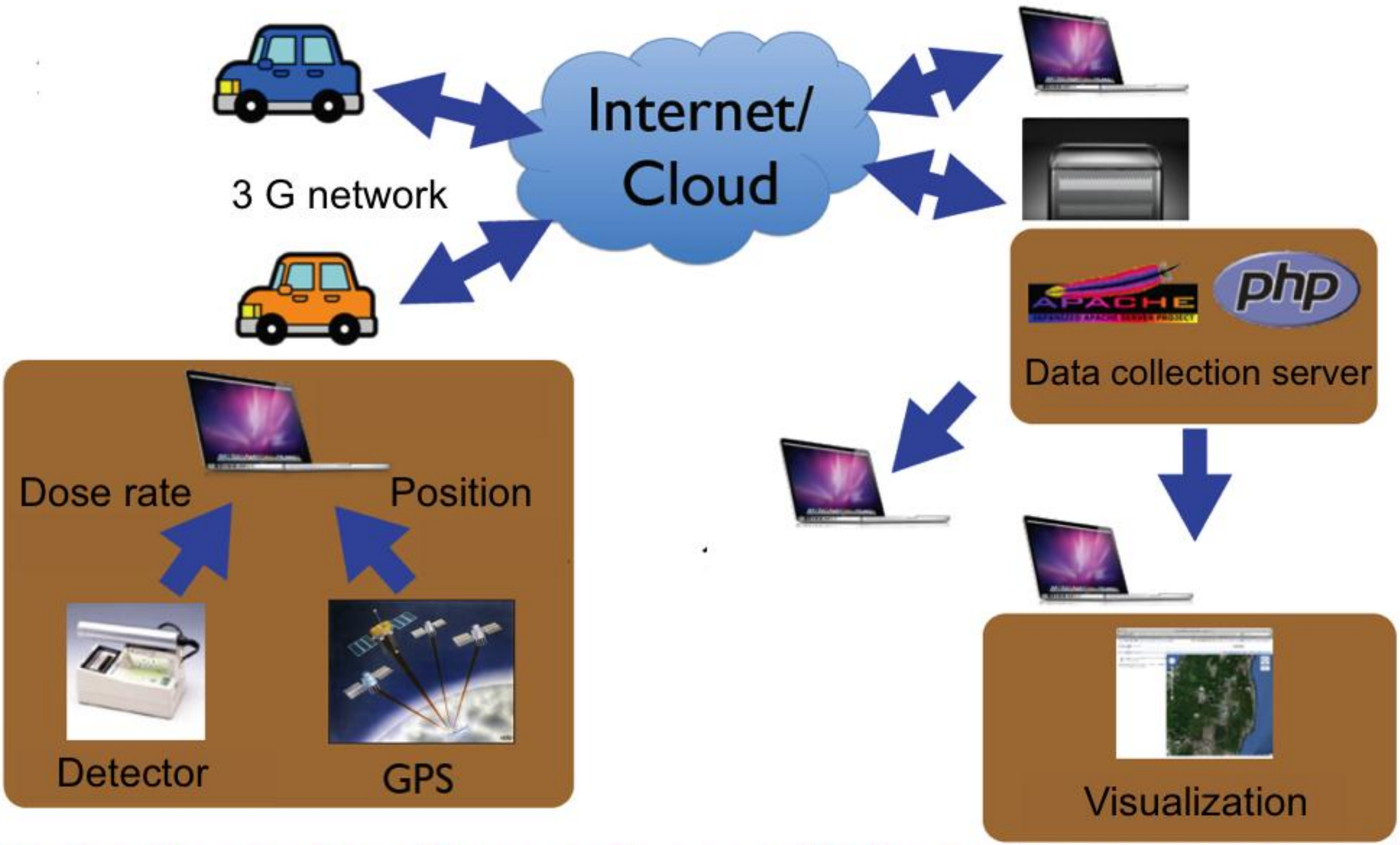
Comparison of dose rates in air at 1 m between June 2011 and Nov. 2012



BG was subtracted

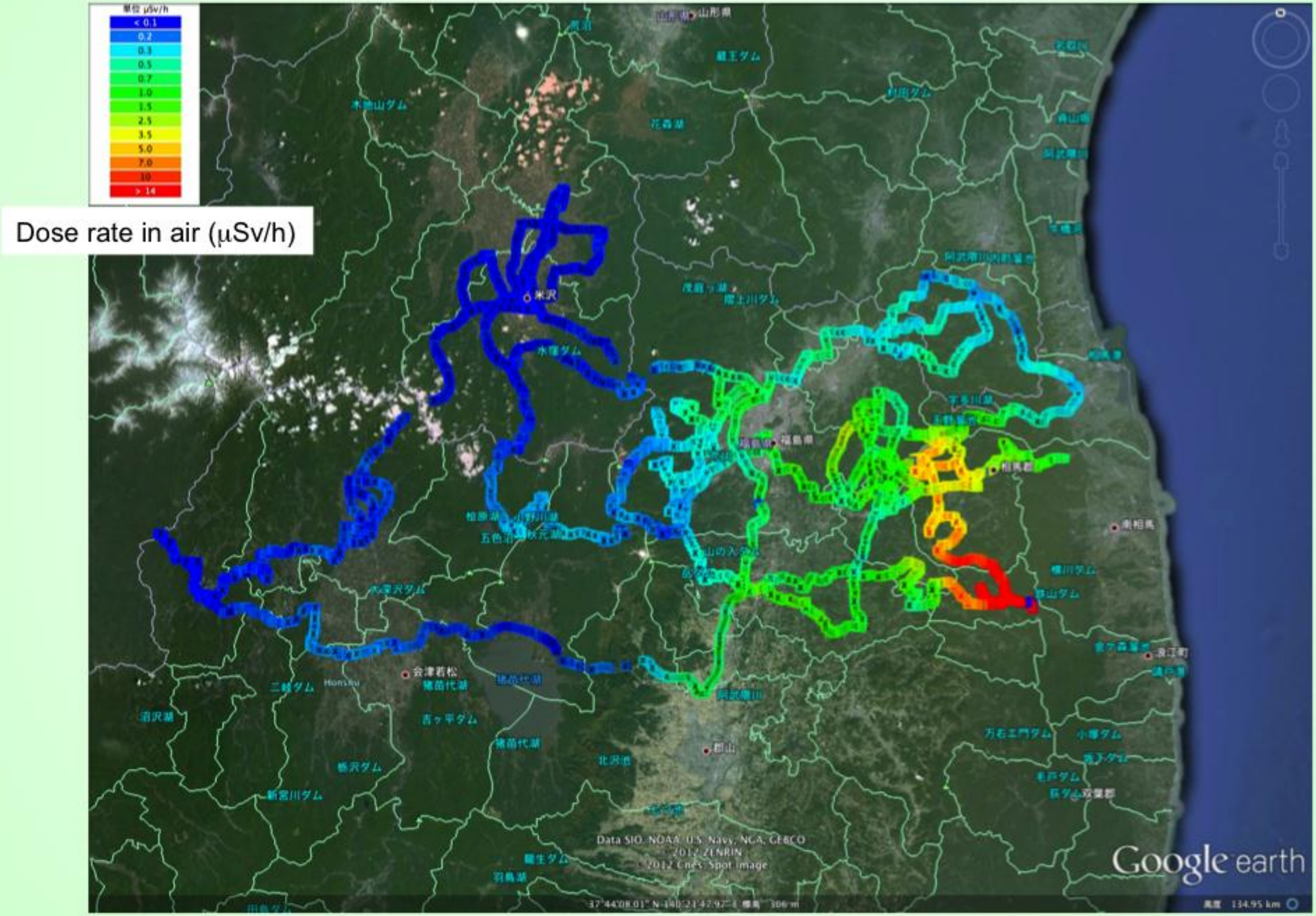
- **Dose-rate reduction has an initial dose rate dependency.**

Car-borne survey using KURAMA system
(developed at Kyoto Univ.)



- **Data transfer through a cellular phone network**

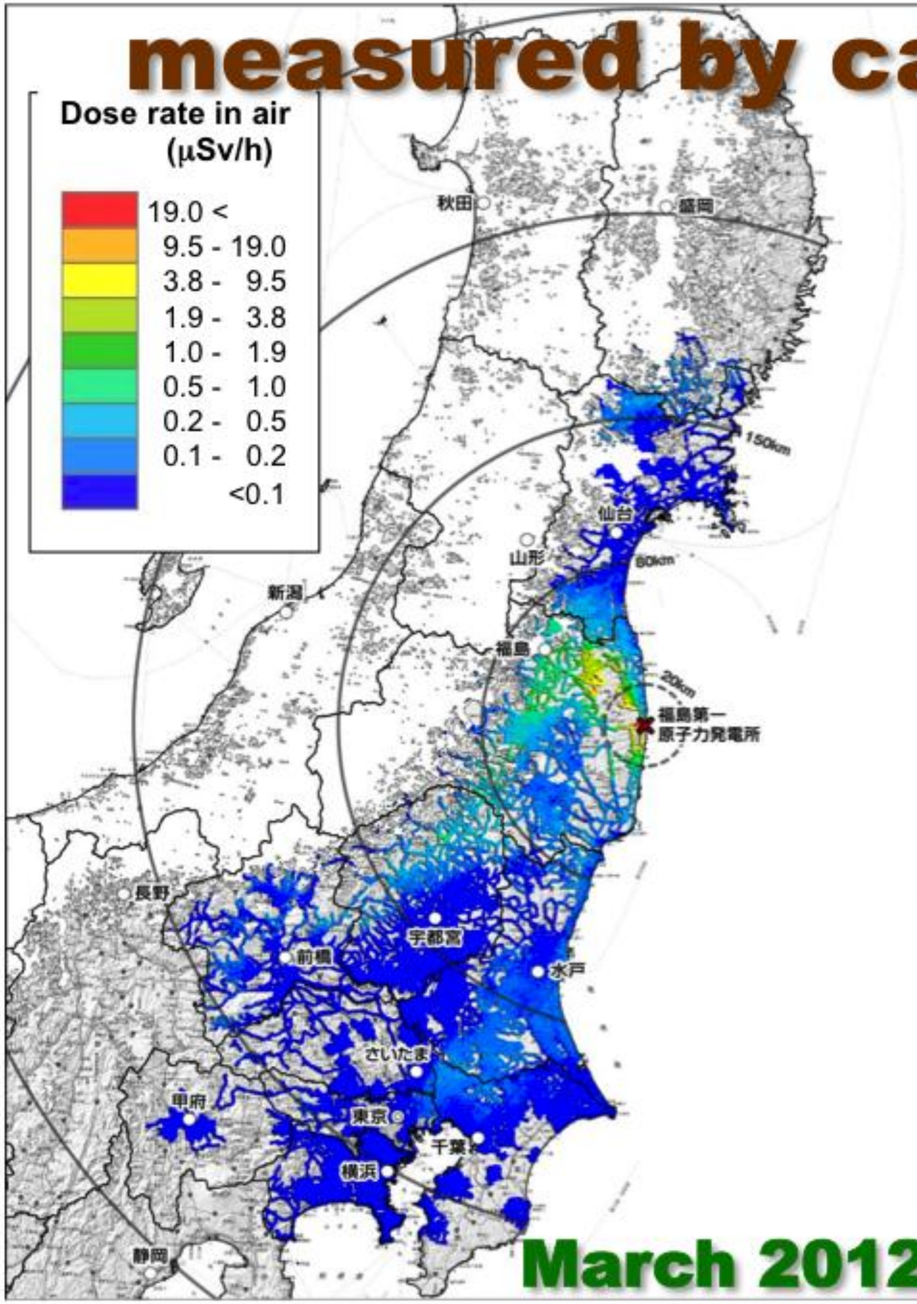
Real-time display of car-borne survey data



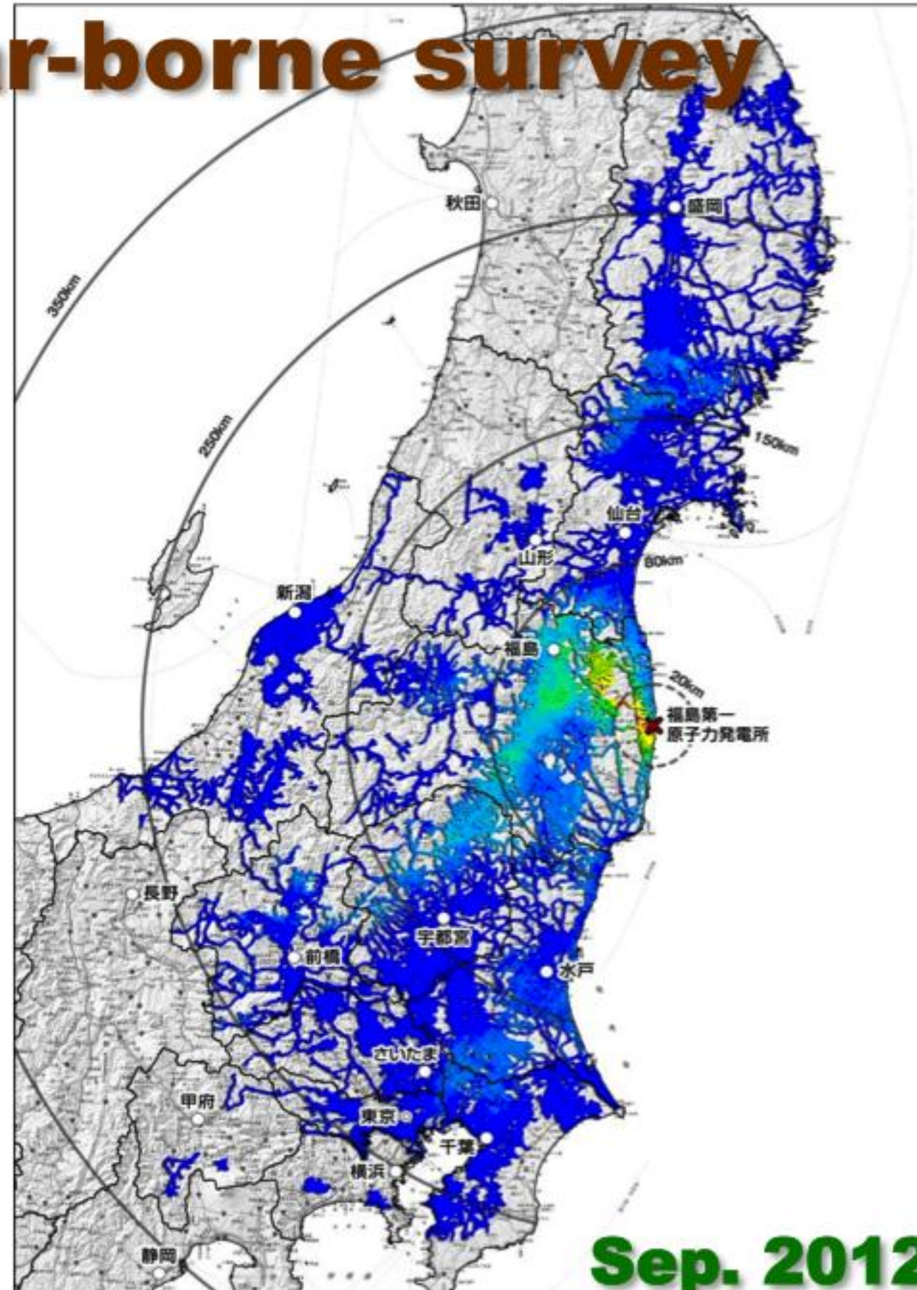
KURAMA-II system

- Compact •Easy to operate
- Distribute 100 systems to about 200 local governments
- Each local government makes a survey as it would like.

Distribution of dose rates in air measured by car-borne survey

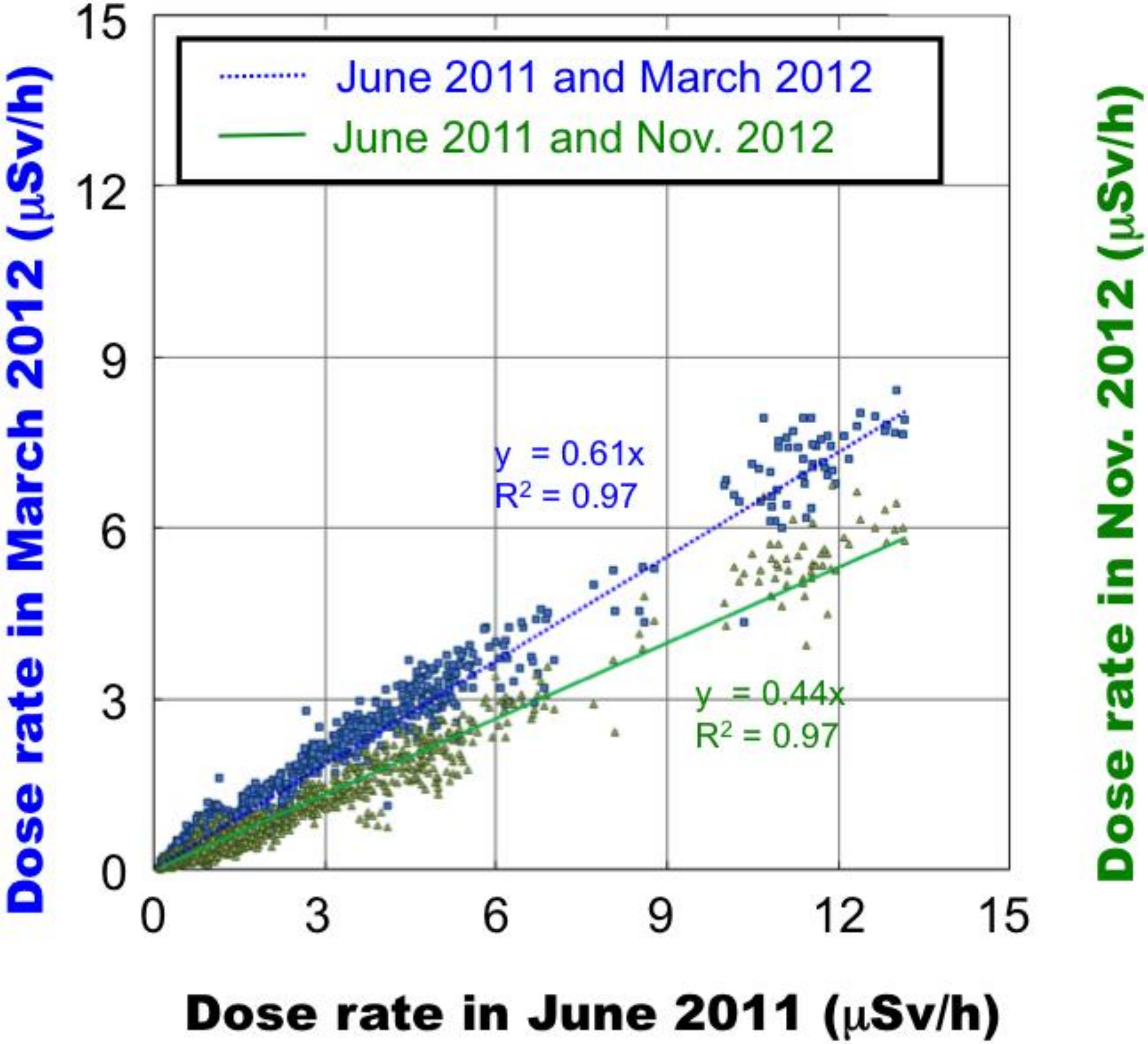


March 2012



Sep. 2012

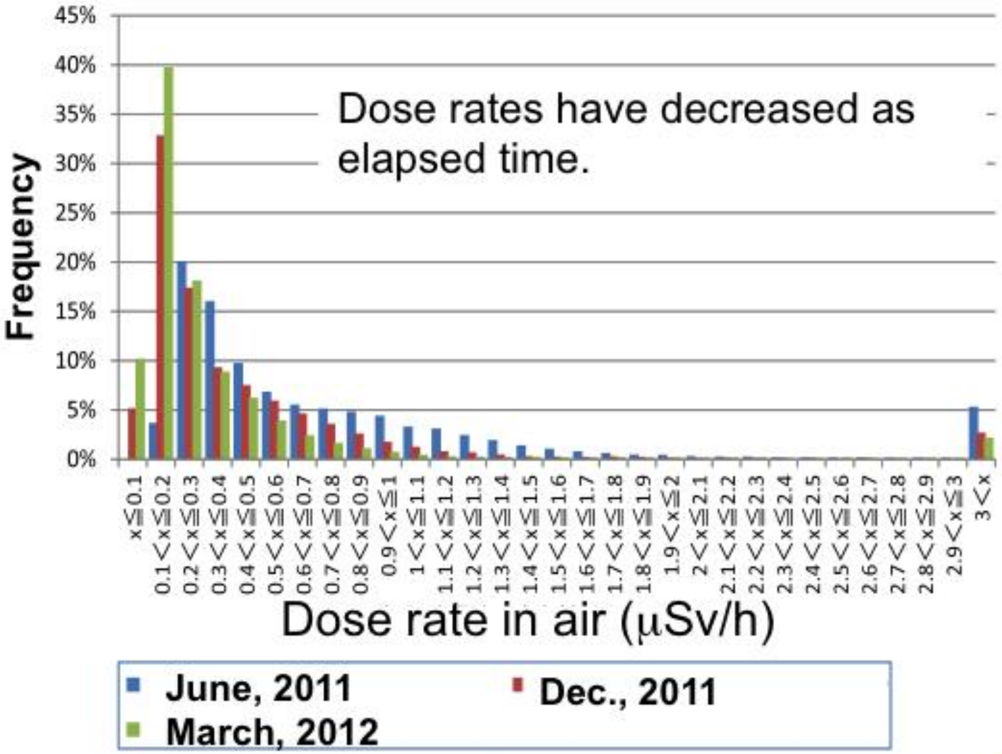
Comparison of dose rates in air measured by car-borne survey

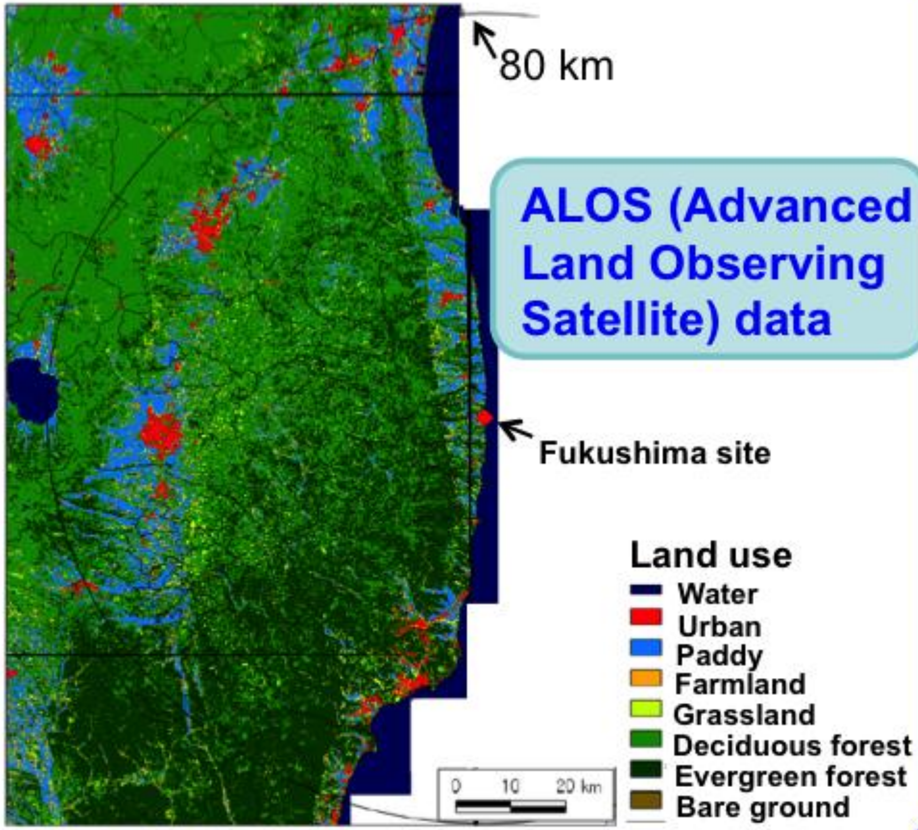


- **Dose rates decreased by about 40% from June 2011 to March 2012. (Physical decay 20%)**
- **Dose rates decreased by more than 55% from June 2011 to Nov. 2012. (Physical decay 29%)**

Analyses based on land uses

Car-bone survey data



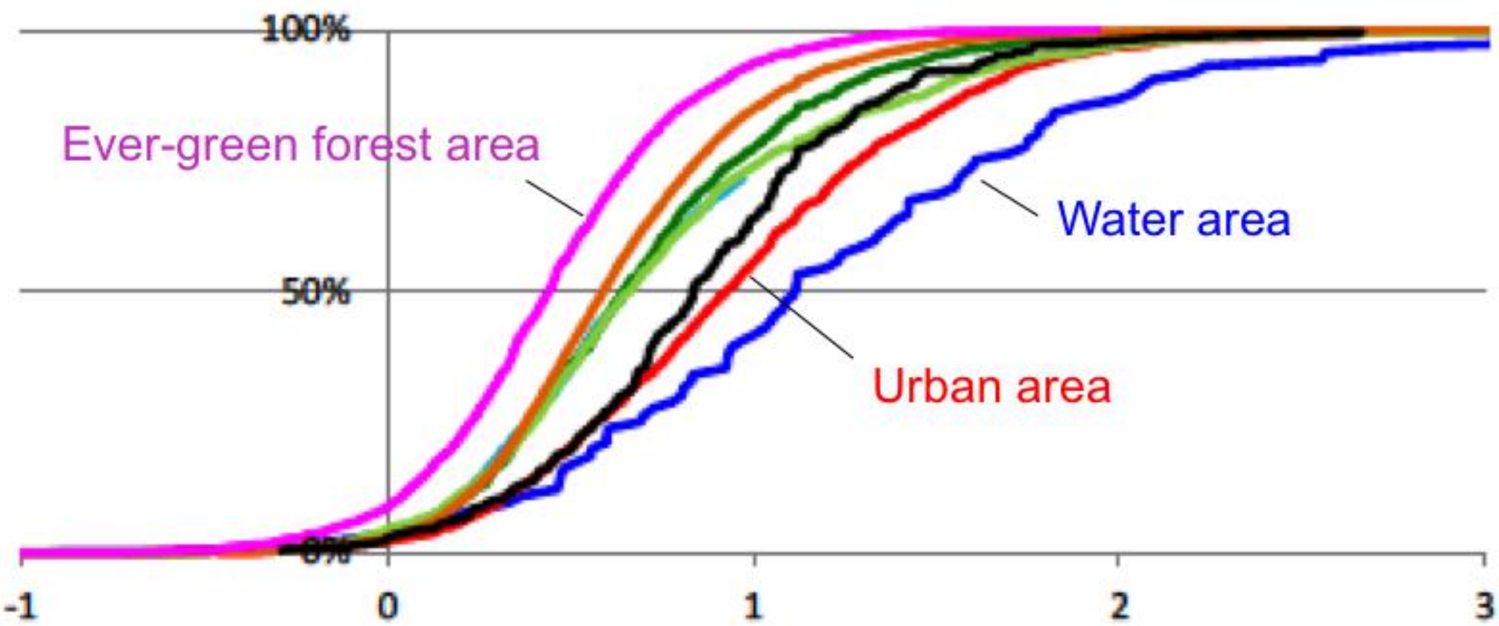


- **Dose rate reduction tendency was analyzed in connection with different land uses**

Dose rate reduction tendency for different land uses

- Slow in ever-green forest area
- Fast in urban and water areas

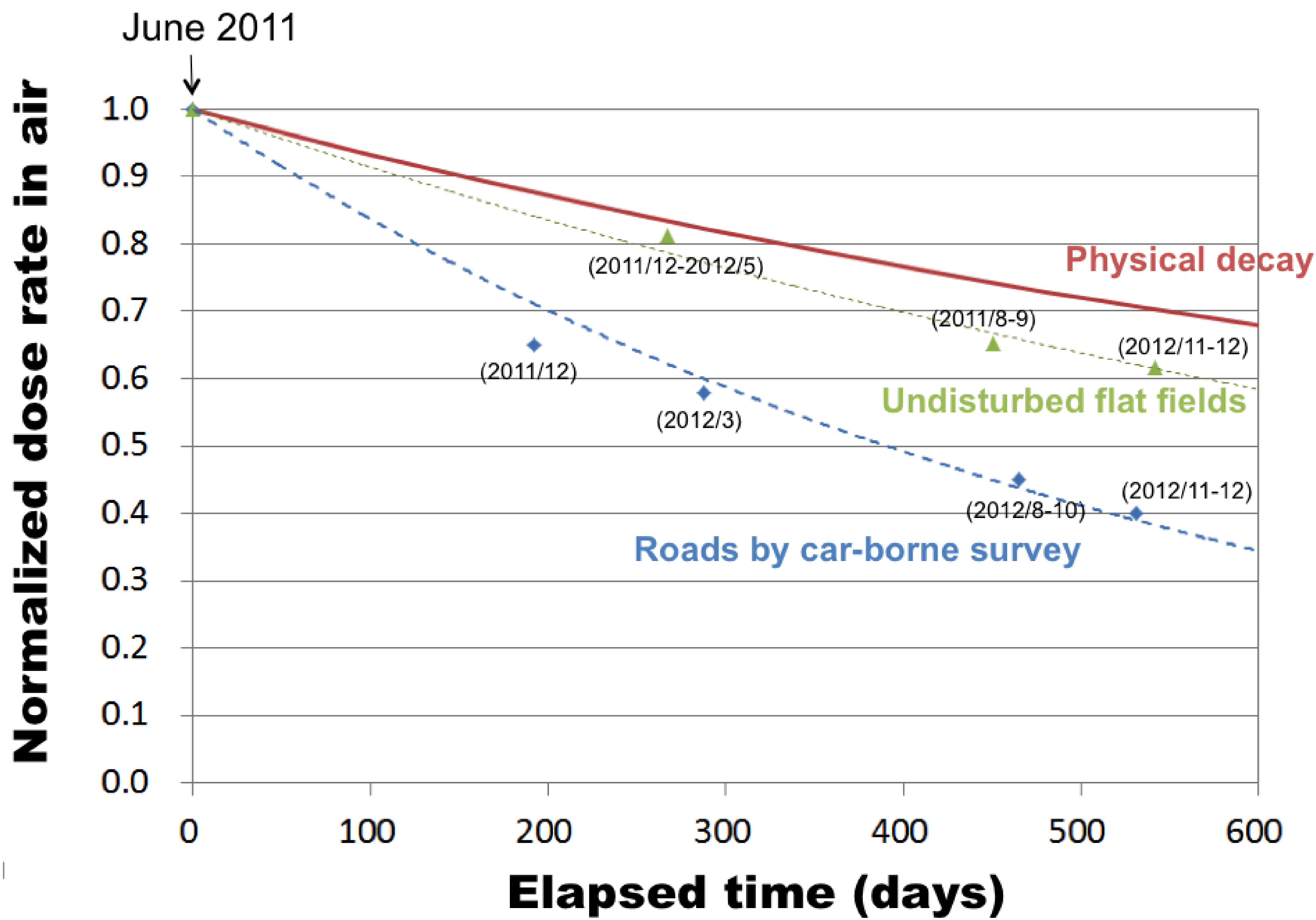
Cumulative Distribution Frequency of environmental decay rate



Environmental decay rate (1/y)

Excluding physical decay

Temporal change of dose rates in air



Summary on dose rates in air

1. Dose rates in air above roads have decreased much faster than those at undisturbed flat fields.
2. Dose-rate reduction tendency depends on
   a) land-use: fast in urban, slow in forest,
   b) magnitude of initial air dose rate,
   c) local distribution of contamination.
3. Decontamination is considered to reduce dose rates in air by a factor of 2-5

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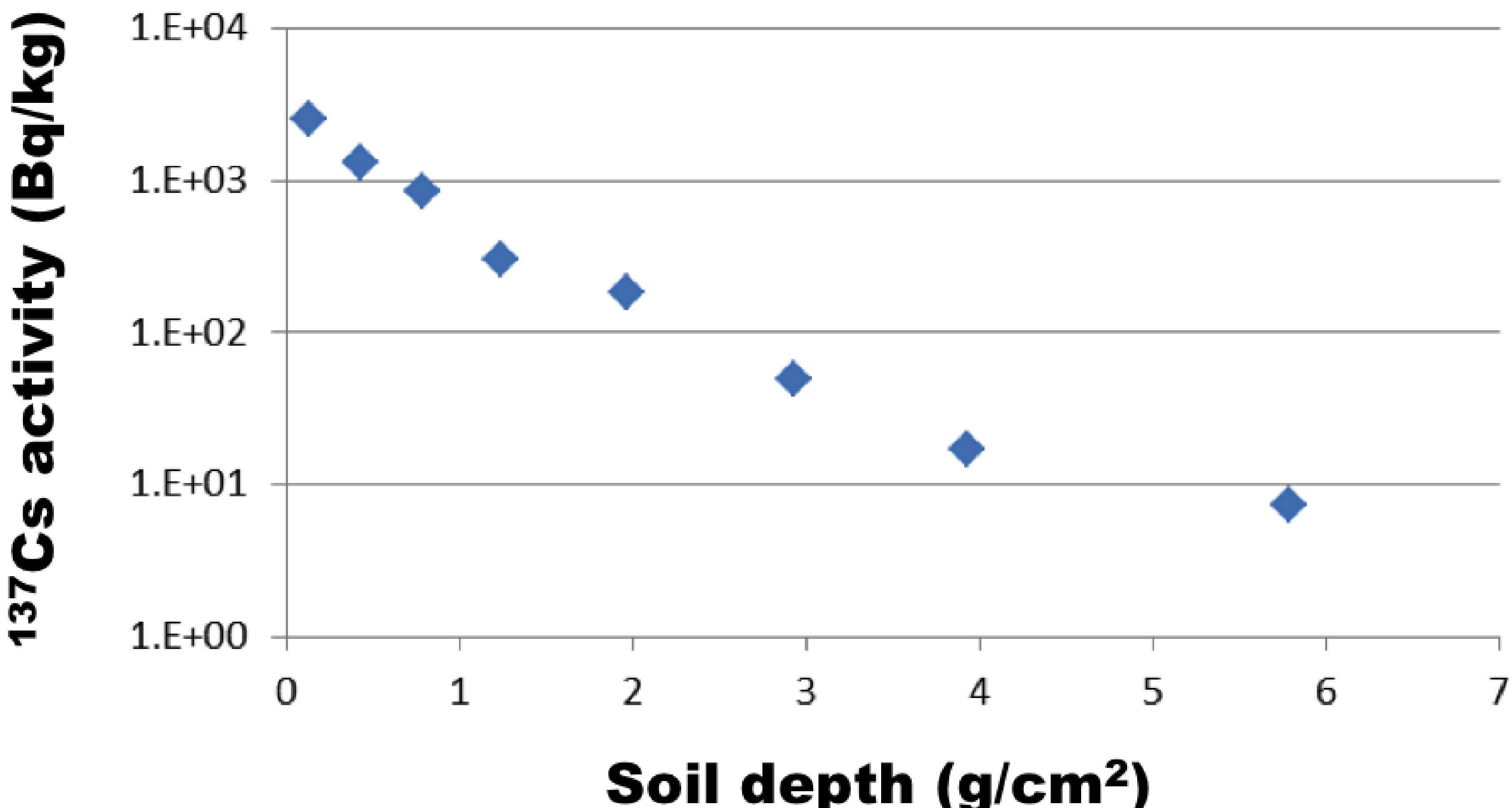
Soil sampling for investigating depth profiles

- Soil was sampled at 85 locations using scraper plates in:
  1) Dec. 2011,
  2) Aug. 2012,
  3) Dec. 2012.

Example of ^{137}Cs depth profile in soil

- **Most depth profiles could be approximated by exponential distribution**

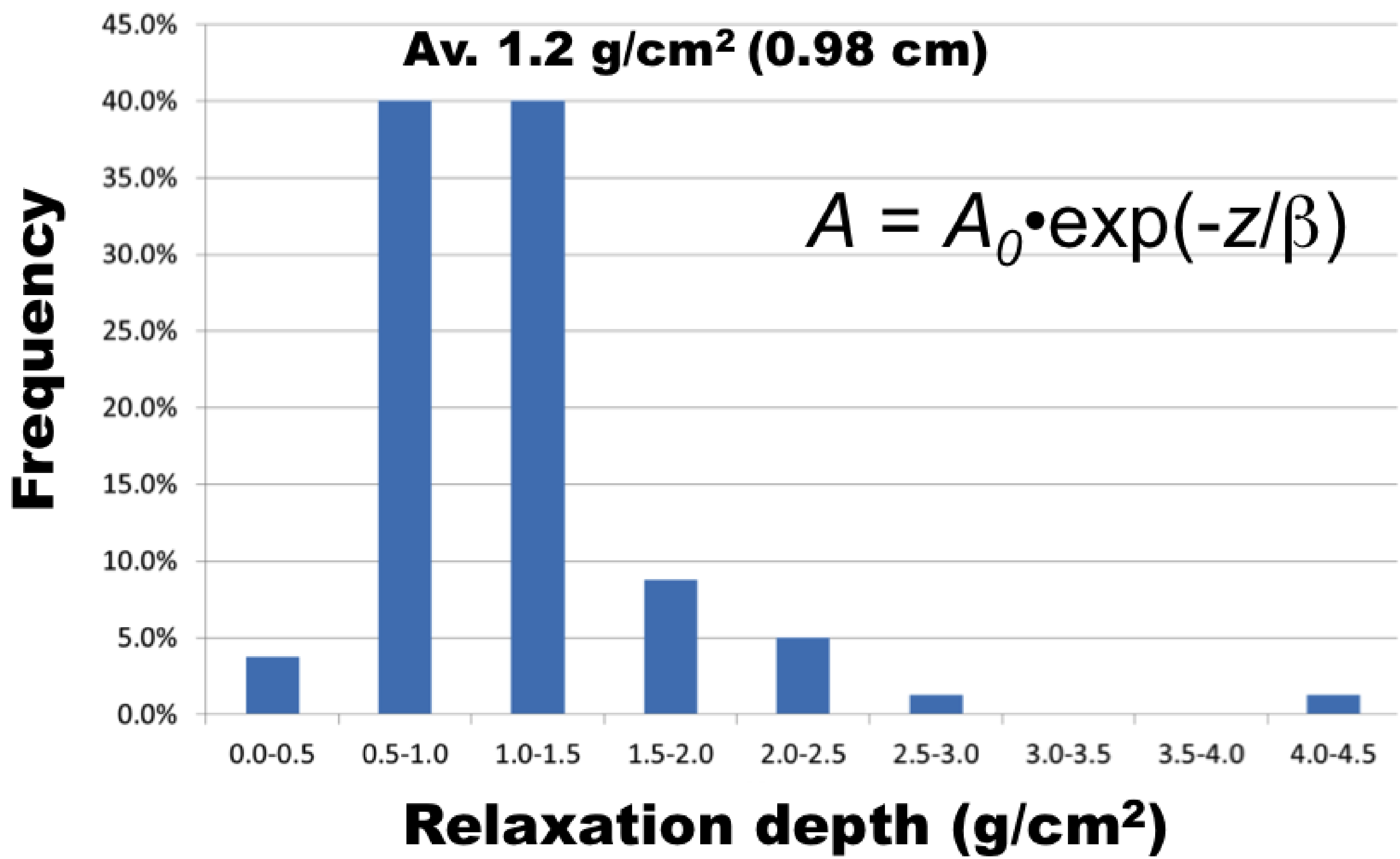


(December, 2011)

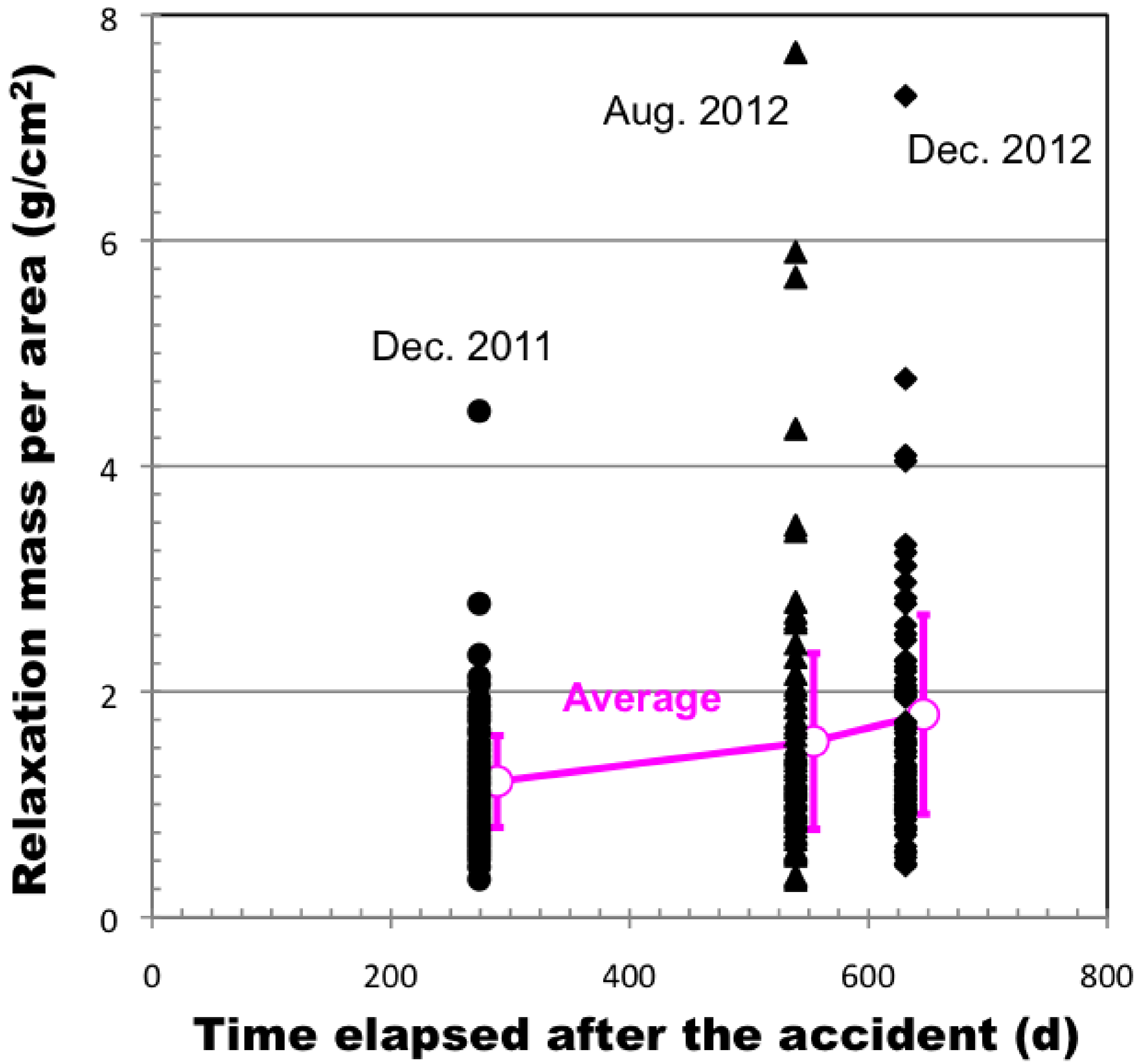
Distribution of relaxation depth β

- **Indicator of radionuclide migration into soil**

(Dec. 2011)



Temporal change of relaxation depth β



$$A = A_0 \bullet \exp(-z/\beta)$$

Average β

- ● **1.2 ± 0.4 g/cm²** **(Dec. 2011)**
- ▲ **1.6 ± 0.8 g/cm²** **(Aug. 2012)**
- ◆ **1.8 ± 0.9 g/cm²** **(Dec. 2012)**

- **β has gradually increased with time.**
- **Most cesium exists within 5 cm depth**

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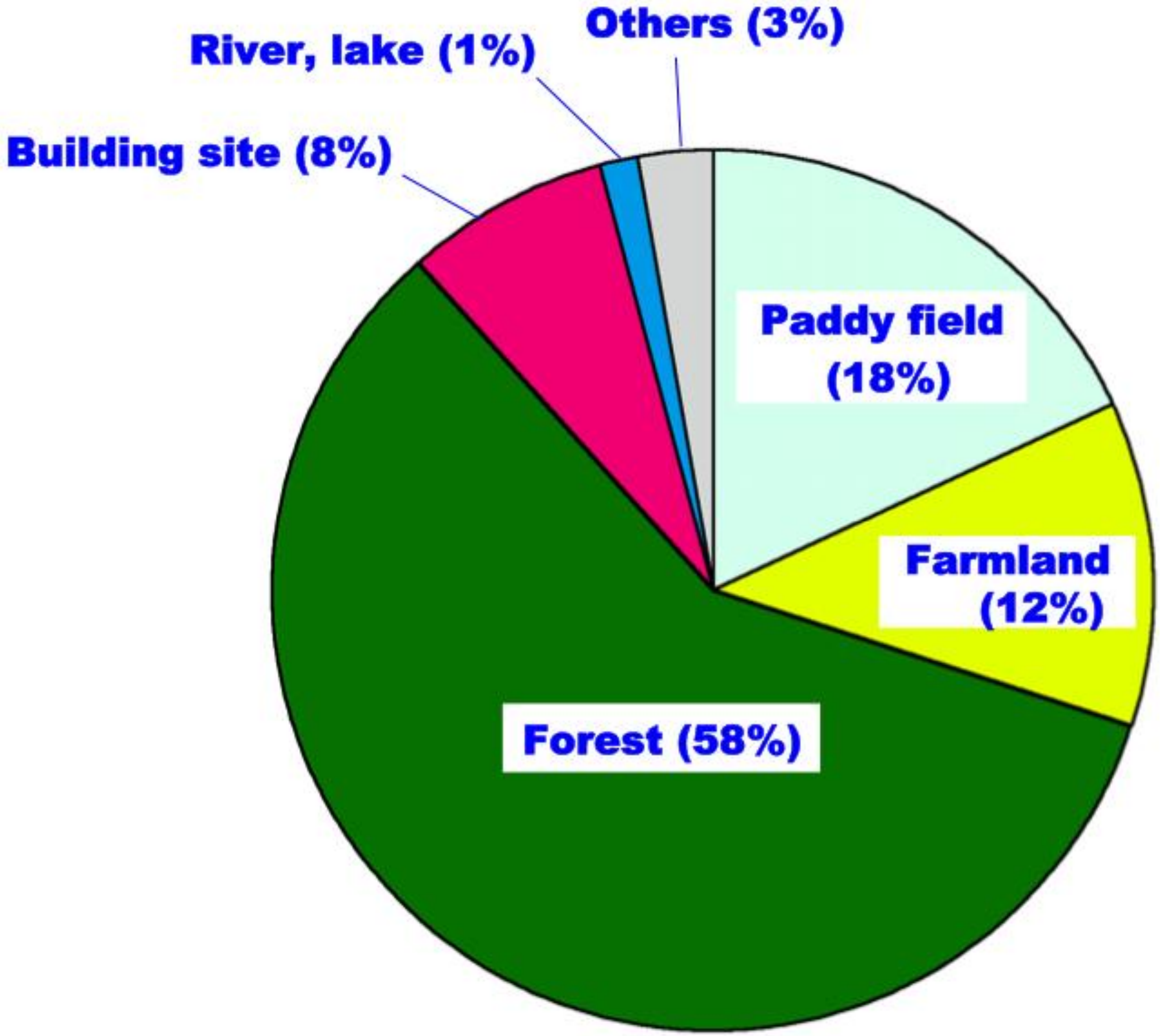
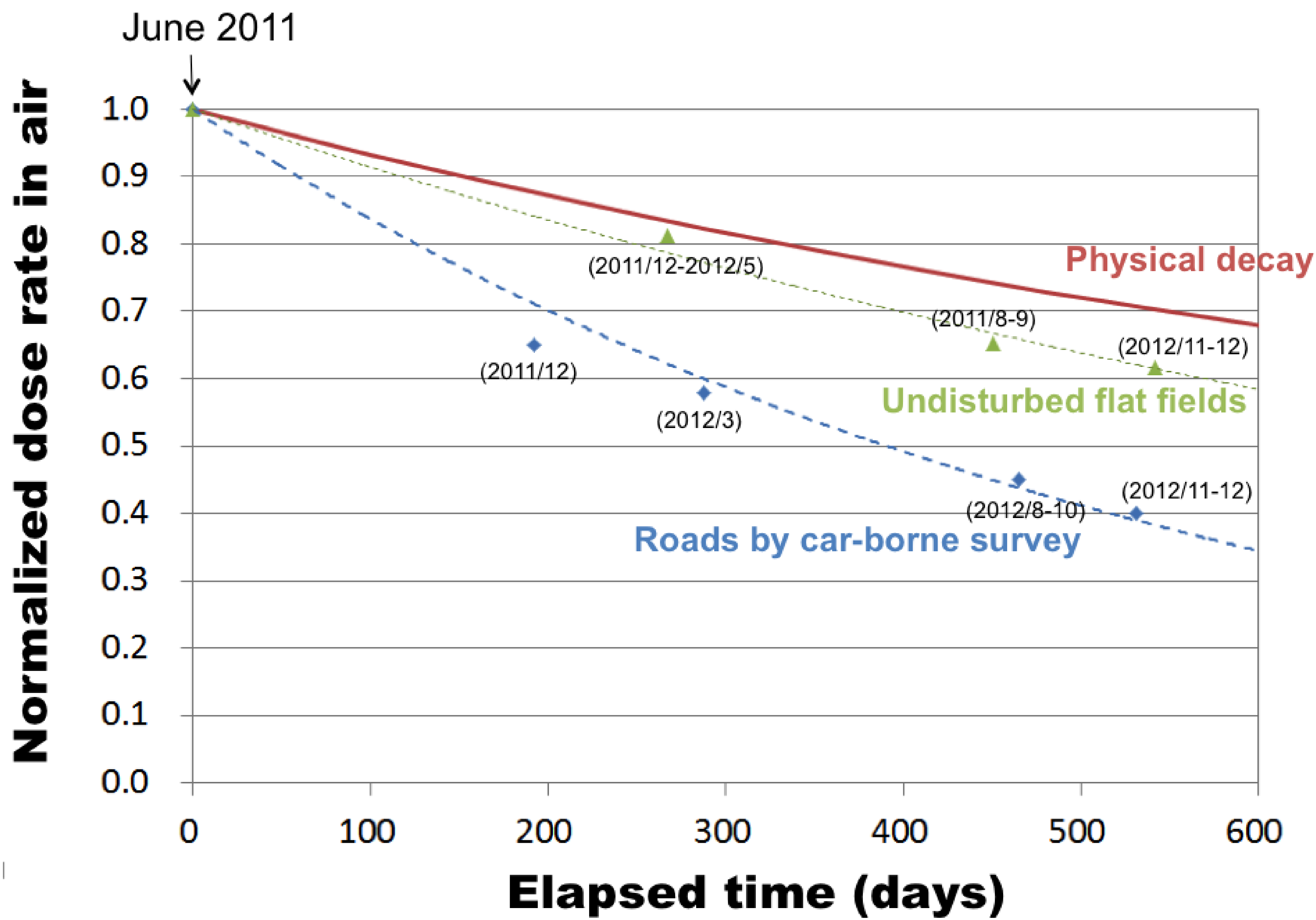
Fractions of Cs-137 deposition for different land uses within the 80 km zone



- Evaluated based on deposition densities measured in undisturbed fields in Dec. 2012.
- Assumed that the density does not change within 1 km square.

(Dec. 2012)

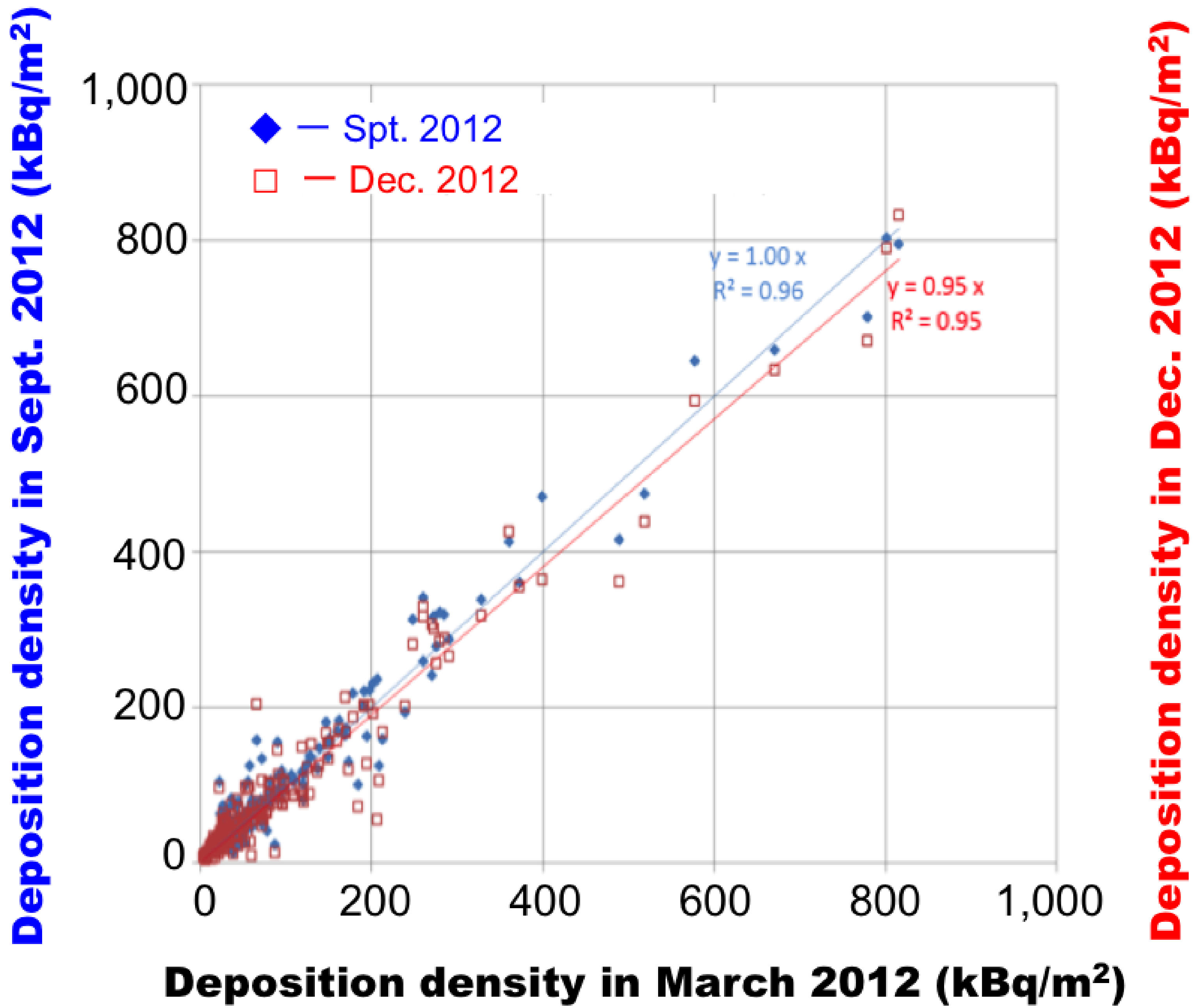
Temporal change of dose rates in air



Undisturbed fields

1. Dose rates in air have decreased a little faster than the physical decay.
2. Movement of cesium in horizontal directions seems small.
3. Cesium has gradually penetrated into deeper parts in the ground: the excess decrease in dose rates can be explained by this penetration.
4. Yet small amount of cesium is considered to have moved in horizontal directions into low-contaminated areas.

Temporal change in Cs-137 deposition density



●Cs-137 deposition densities have not changed much in undisturbed flat fields.

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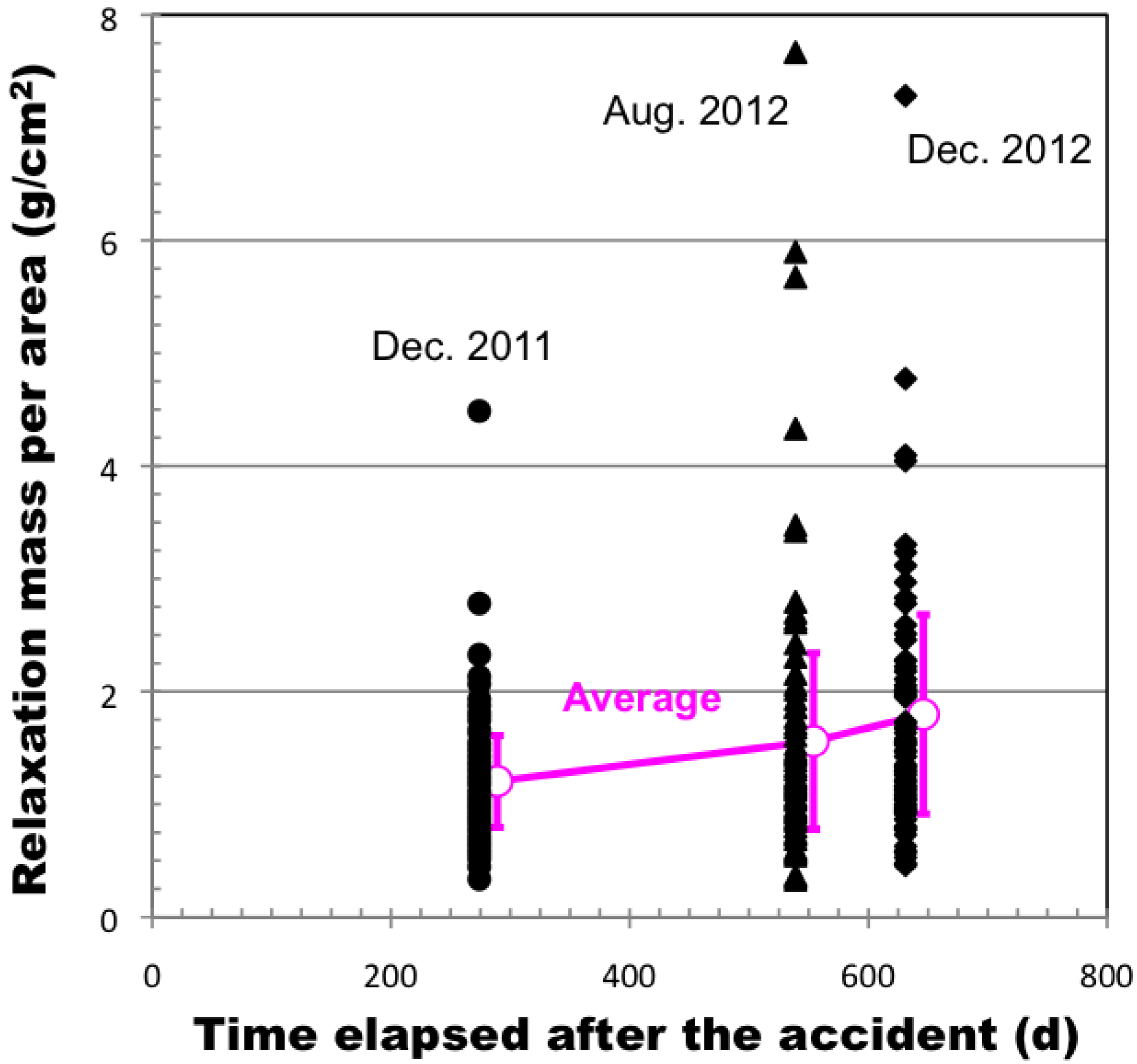
Temporal change of relaxation depth β



$$A = A_0 \cdot \exp(-z/\beta)$$

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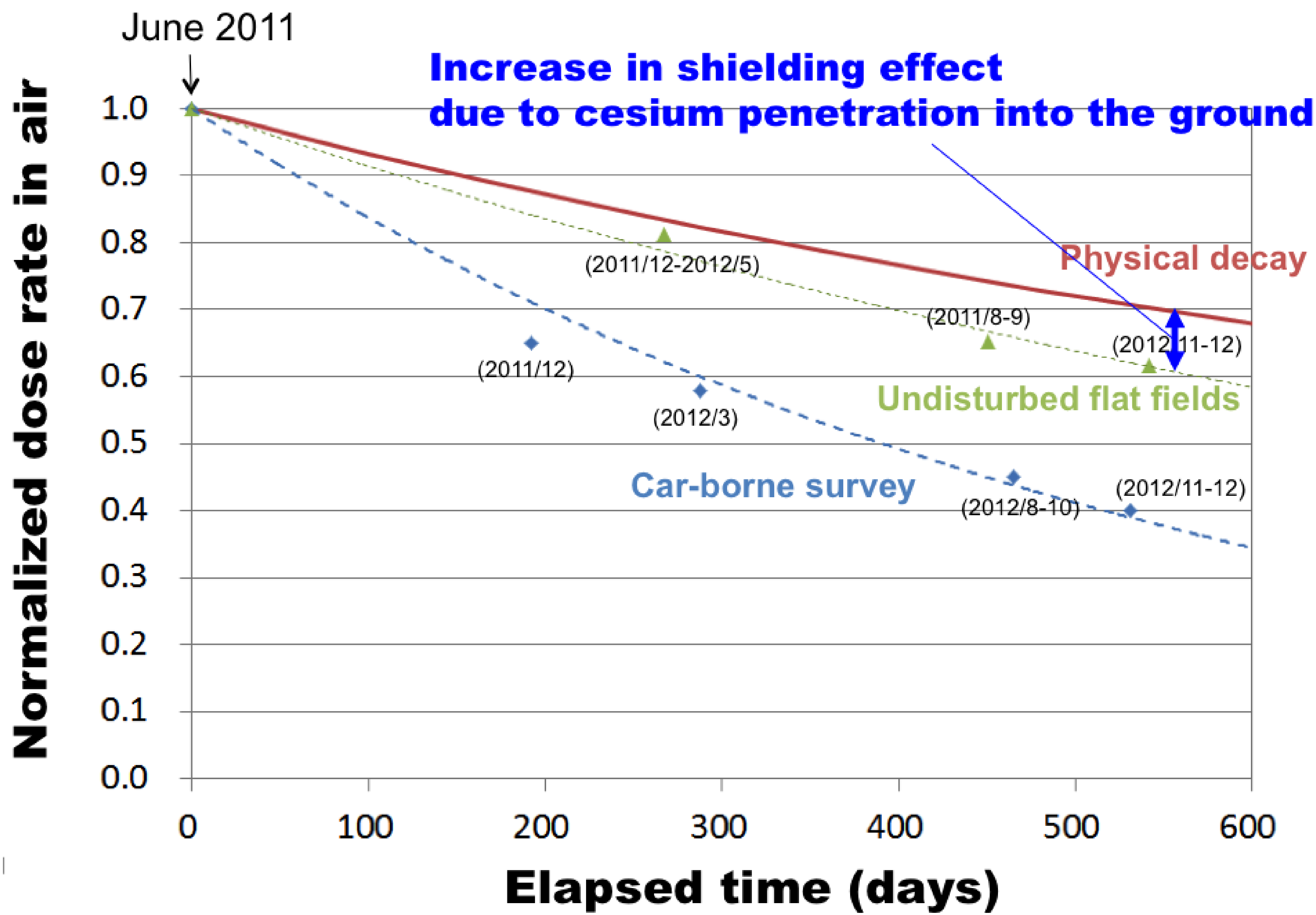
Temporal change of dose rates in air



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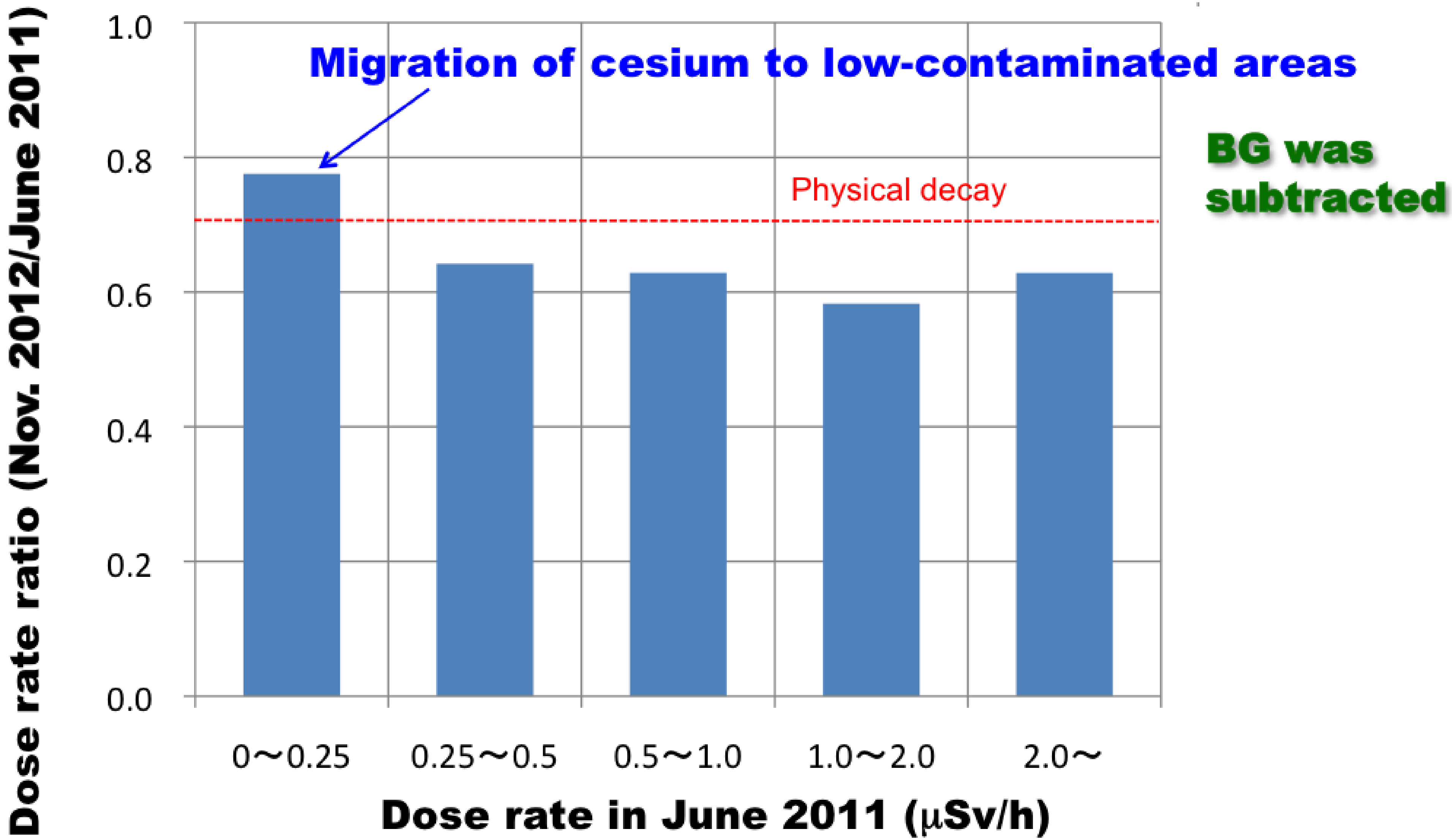
Comparison of dose rates in air at 1 m between June 2011 and Nov. 2012

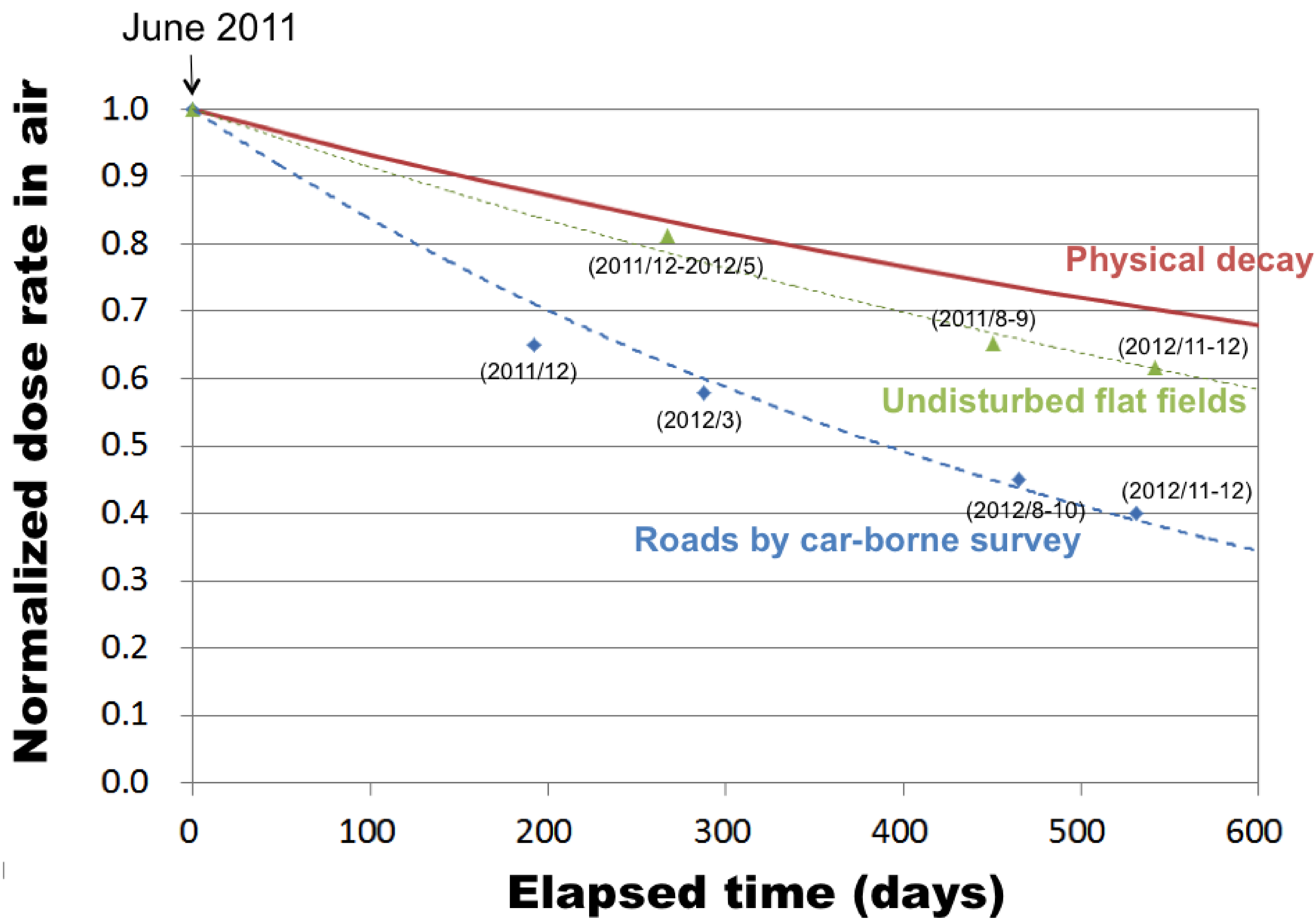


- Dose-rate reduction has an initial dose rate dependency.

Car-borne survey on roads

1. **Air dose rates above roads have decreased much faster than the physical decay.**
   a) Cesium on roads is easily washed away.
   b) Cesium around roads is inferred to have been removed somehow.
2. Air dose rate reduction is slow in forest area, and fast in urban and water areas.
   a) Cesium is being kept in the forest system.
   b) Flooding plays an important role in removing cesium.

Temporal change of dose rates in air



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Dose rate reduction tendency for different land uses

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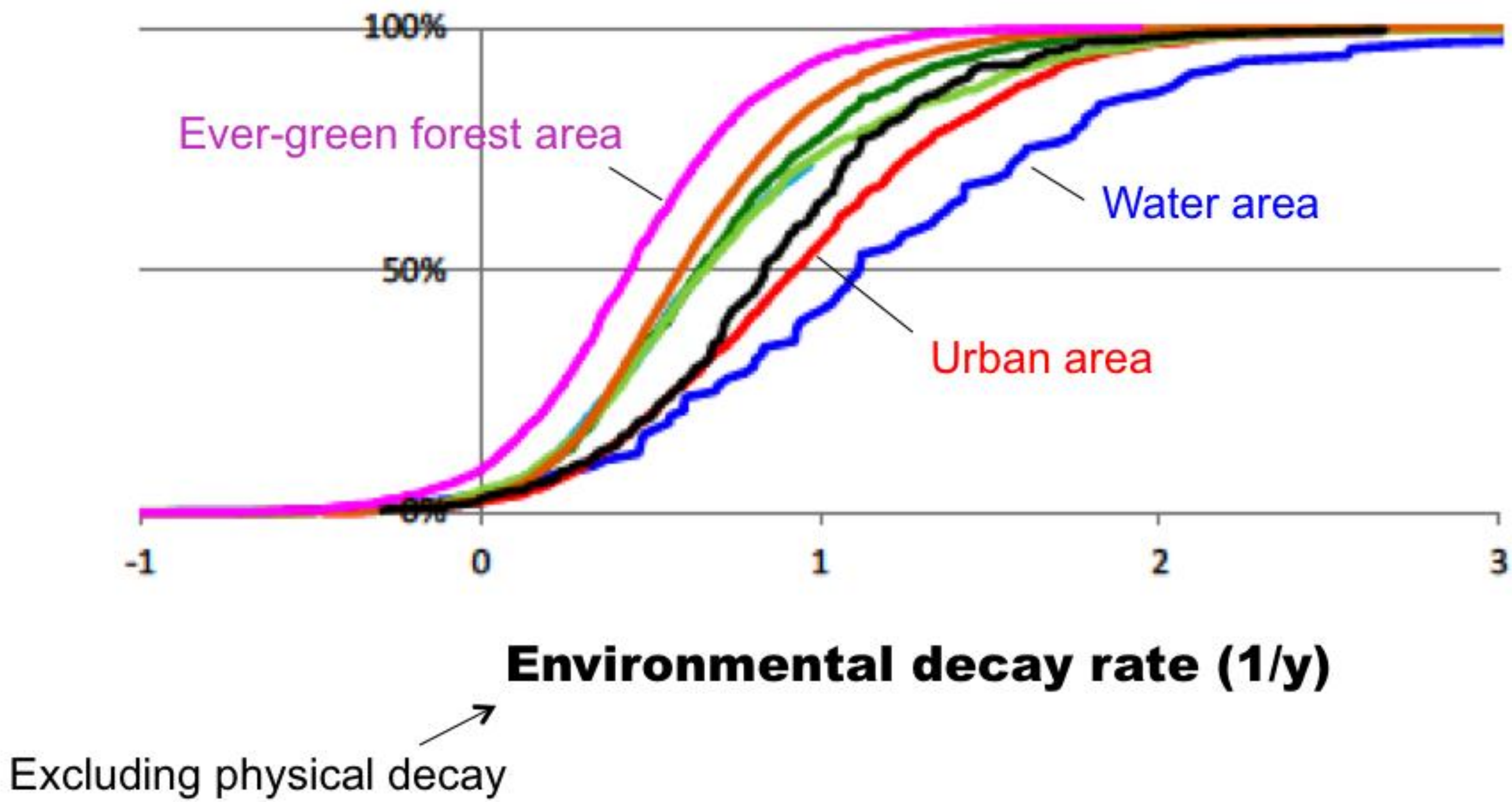
- Fast in urban and water areas

Cumulative Distribution Frequency of environmental decay rate



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Air dose rate reduction

Slow

Forest

Undisturbed field

Fast

Near road

Air dose rate reduction

Slow | **Fast**

Forest

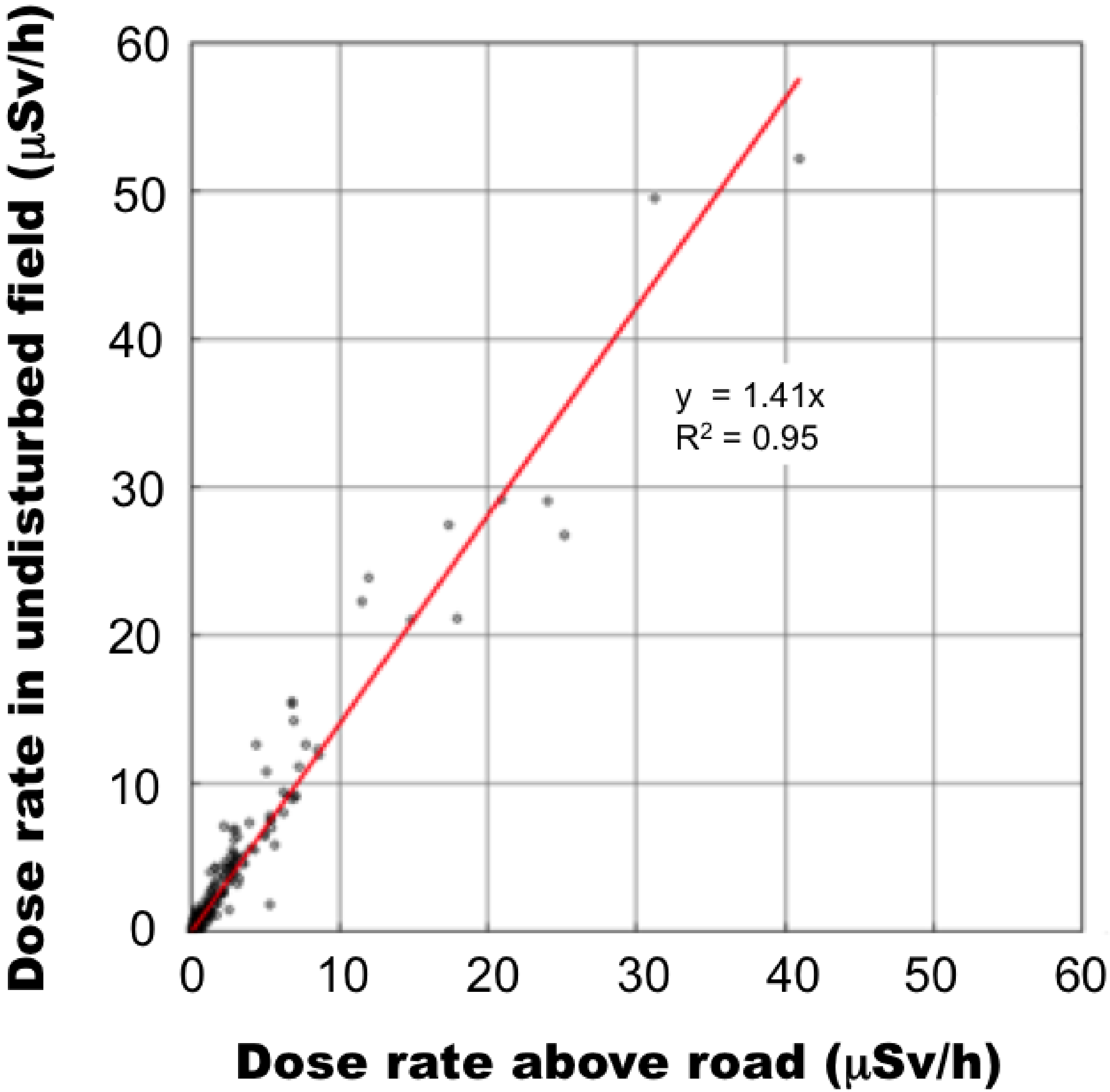
Undisturbed field

Near road

High | **Low**

Air dose rates

Comparison of dose rates between roads and undisturbed field



Dose rates in undisturbed fields are several tens percent higher than those by car-borne survey.

(Nov. 2012)

Air dose rate reduction

Slow — **Fast**

Forest

Undisturbed field

Near road

High — **Low**

Air dose rate

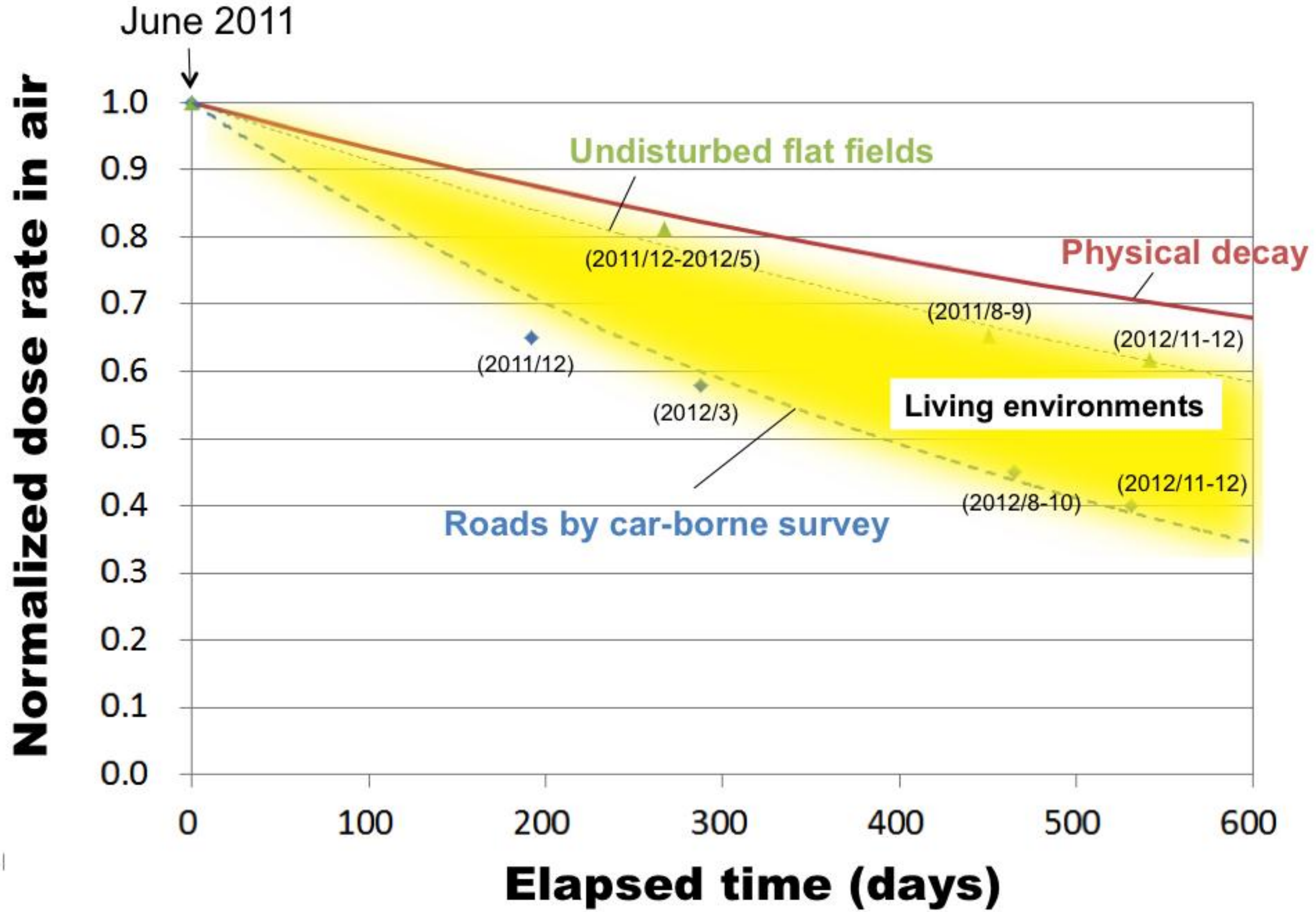
How about in intermediate areas?

Farmland

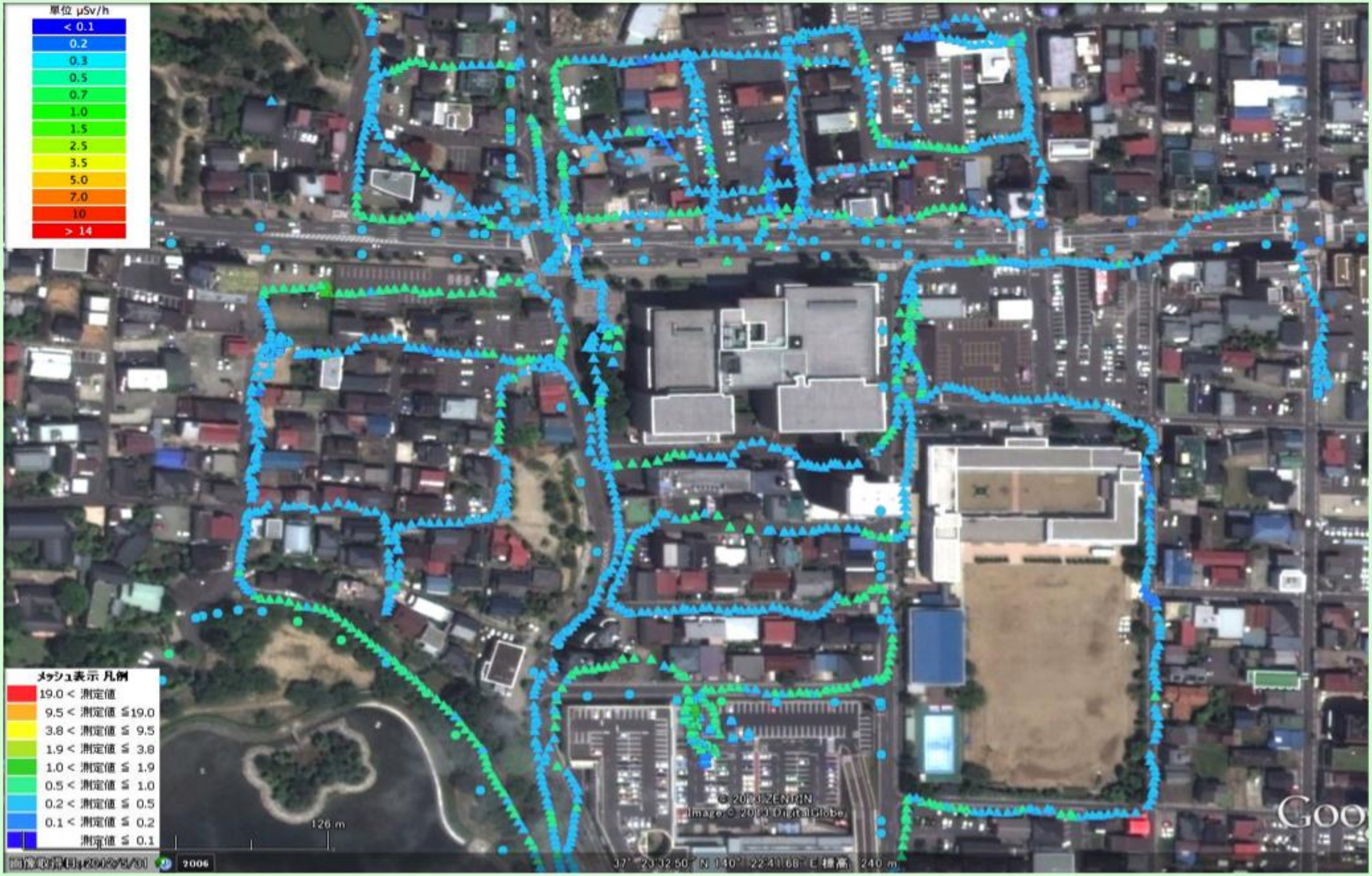
Residence

Town

Temporal change of dose rates in air



Example of man-borne survey



Example of man-borne survey

Ongoing program

1. Man-borne survey

a) Examine detailed distributions of air dose rates in living environment

b) Find out the relation of the dose rates to those in undisturbed fields and above roads

2. Prediction model

a) Semi-empirical model assuming two components indicating time-dependent reduction (fast and slow) in air dose rates

b) Determine the parameters on the basis of statistical analysis of large amount of air dose data

Thank you for your attention