

Modelling the dynamics of ambient dose rates induced by radiocaesium in the Fukushima terrestrial environment

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Abstract. Since the Fukushima accident, Japanese scientists have been intensively monitoring ambient radiations in the highly contaminated territories situated within 80 km of the nuclear site. The surveys that were conducted through mainly airborne, airborne and in situ gamma-ray measurement devices, enabled to efficiently characterize the spatial distribution and temporal evolution of air dose rates induced by Caesium-134 and Caesium-137 in the terrestrial systems. These measurements revealed that radiation levels decreased at rates greater than expected from physical decay in 2011-2012 (up to a factor of 2), and dependent on the type of environment (i.e. urban, agricultural or forest). Unlike airborne measurements that may have been strongly influenced by the decontamination of road surfaces, no obvious reason can be invoked for airborne measurements, especially above forests that are known to efficiently retain and recycle radiocaesium.

The purpose of our research project is to develop a comprehensive understanding of the data acquired by Japanese, and identify the environmental mechanisms or factors that may explain such decays. The methodology relies on the use of a process-based and spatially-distributed dynamic model that predicts radiocaesium transfer and associated air dose rates inside/above a terrestrial environment (e.g., forests, croplands, meadows, bare soils and urban areas).

Despite the lack of site-specific data, our numerical study predicts decrease rates that are globally consistent with both aerial and in situ observations. The simulation at a flying altitude of 200 m indicated that ambient radiation levels decreased over the first 12 months by about 45% over dense urban areas, 15% above evergreen coniferous forests and between 2 and 12% above agricultural lands, owing to environmental processes that are identified and discussed. In particular, we demonstrate that the decrease over evergreen coniferous regions might be due the combined effects of canopy decontamination (through biological and physical mechanisms) and the shielding of gamma rays emitted from the forest floor by vegetation. Our study finally suggests that airborne surveys might have not reflected dose rates at ground level in forest systems, which were predicted to slightly increase by 5 to 10% during the same period of time.

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Modelling the dynamics of Ambient Dose Rates in Fukushima terrestrial environments

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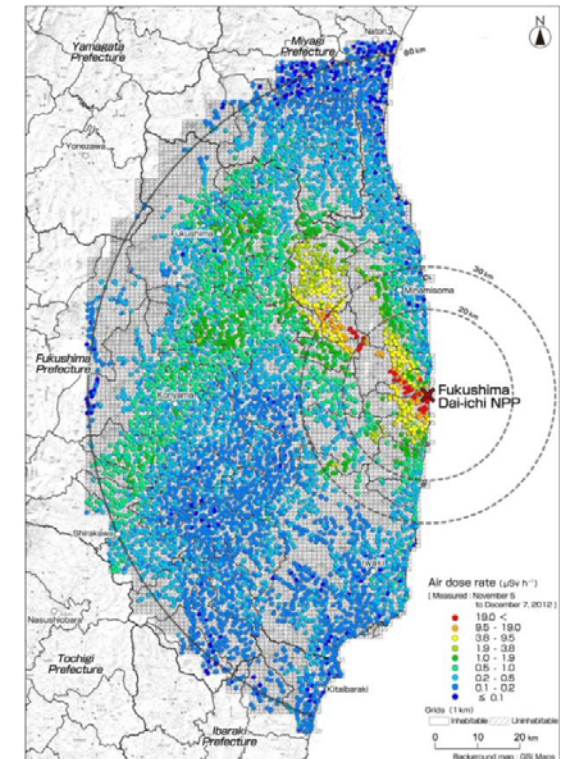
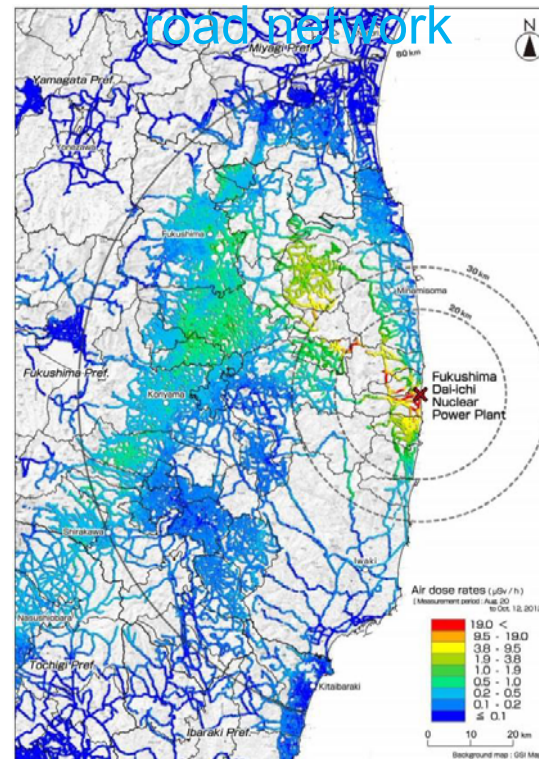
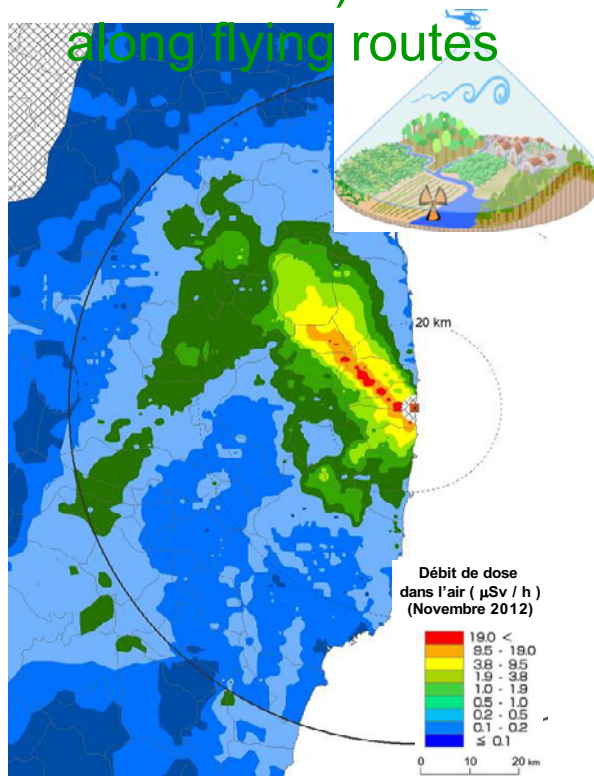
Field surveys of Ambient Dose Rates (ADRs)

Coordinated by the Japanese Nuclear Regulatory Authority / Atomic Energy

Agency

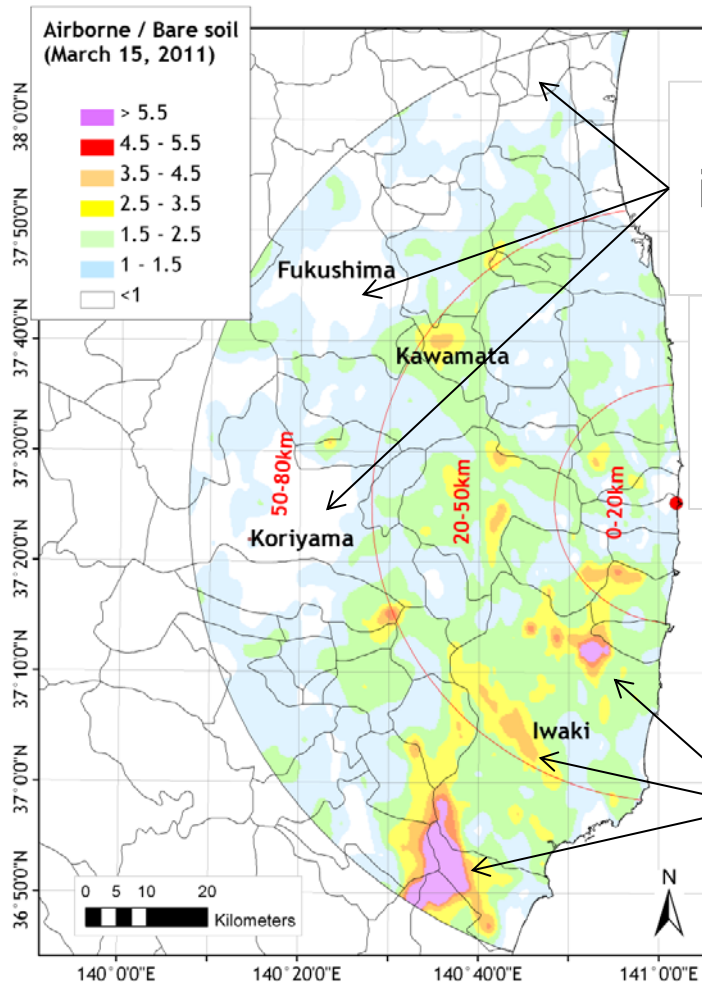
Carbone (dec. 2012) along

In situ (dec. 2012) of undisturbed bare soils



Sanada et al., 2012; Sanada et al. 2014a,b; Tsuda and Tsusumi, 2012; Tsuda et al. 2014; Tanigaki et al., 2013; Kinase et al., 2014; Andoh et al., 2014; Mikami et al., 2014a; Mikami et al., 2014b; Onda et al., 2014; Saito et al., 2014a; Saito et al., 2014b; Matsuda et al., 2014

Aerial versus in situ (Oct. 2011)

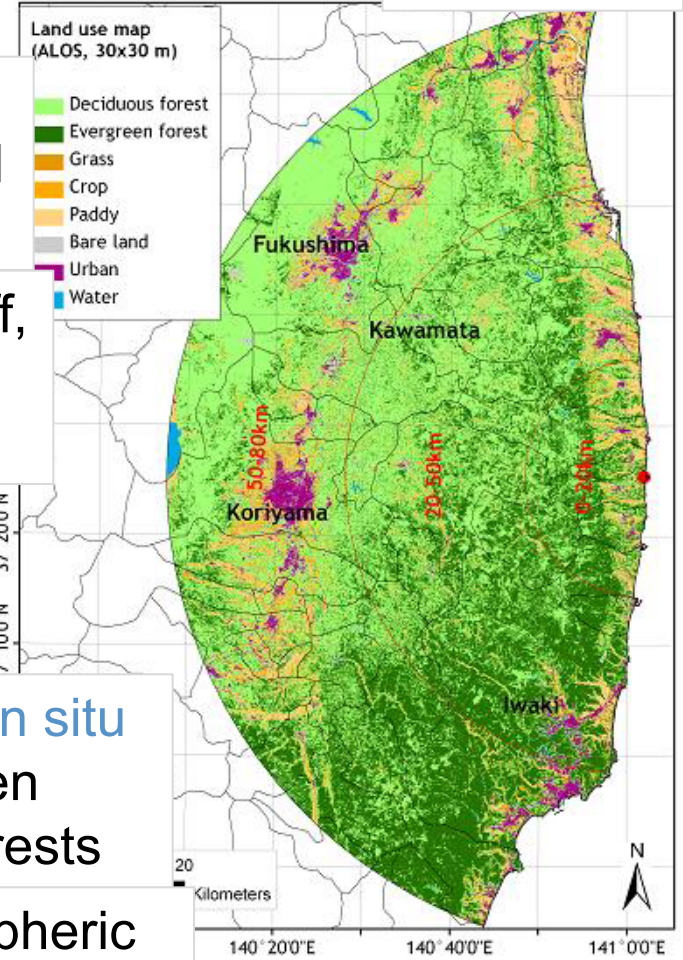


airborne < in situ
in densely inhabited
areas

⇒ natural wash-off,
traffic erosion &
decontamination

airborne > 3× in situ
in evergreen
coniferous forests

⇒ dry atmospheric
deposition

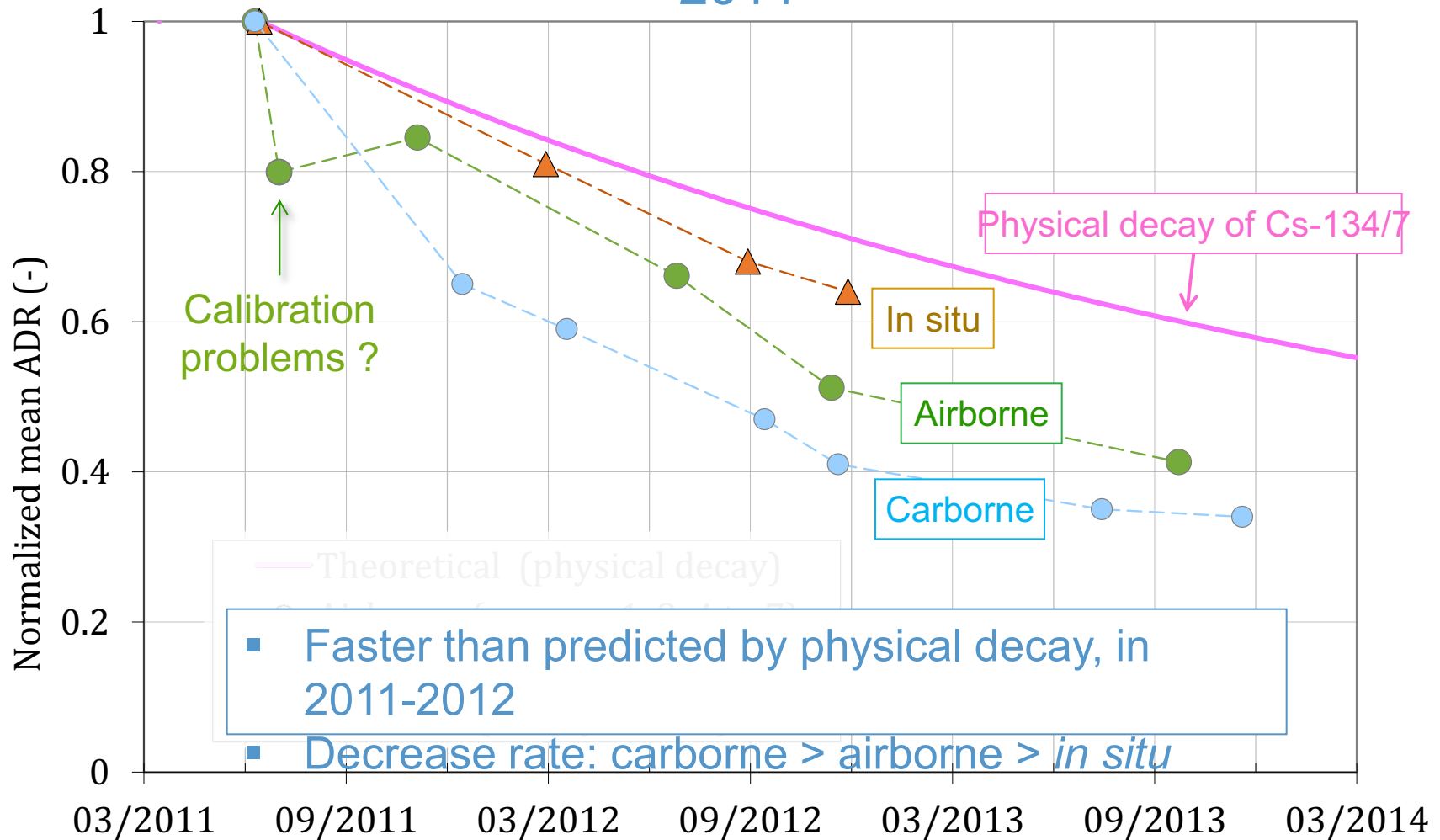


Landuse map

Gonze et al., ES&T 2014

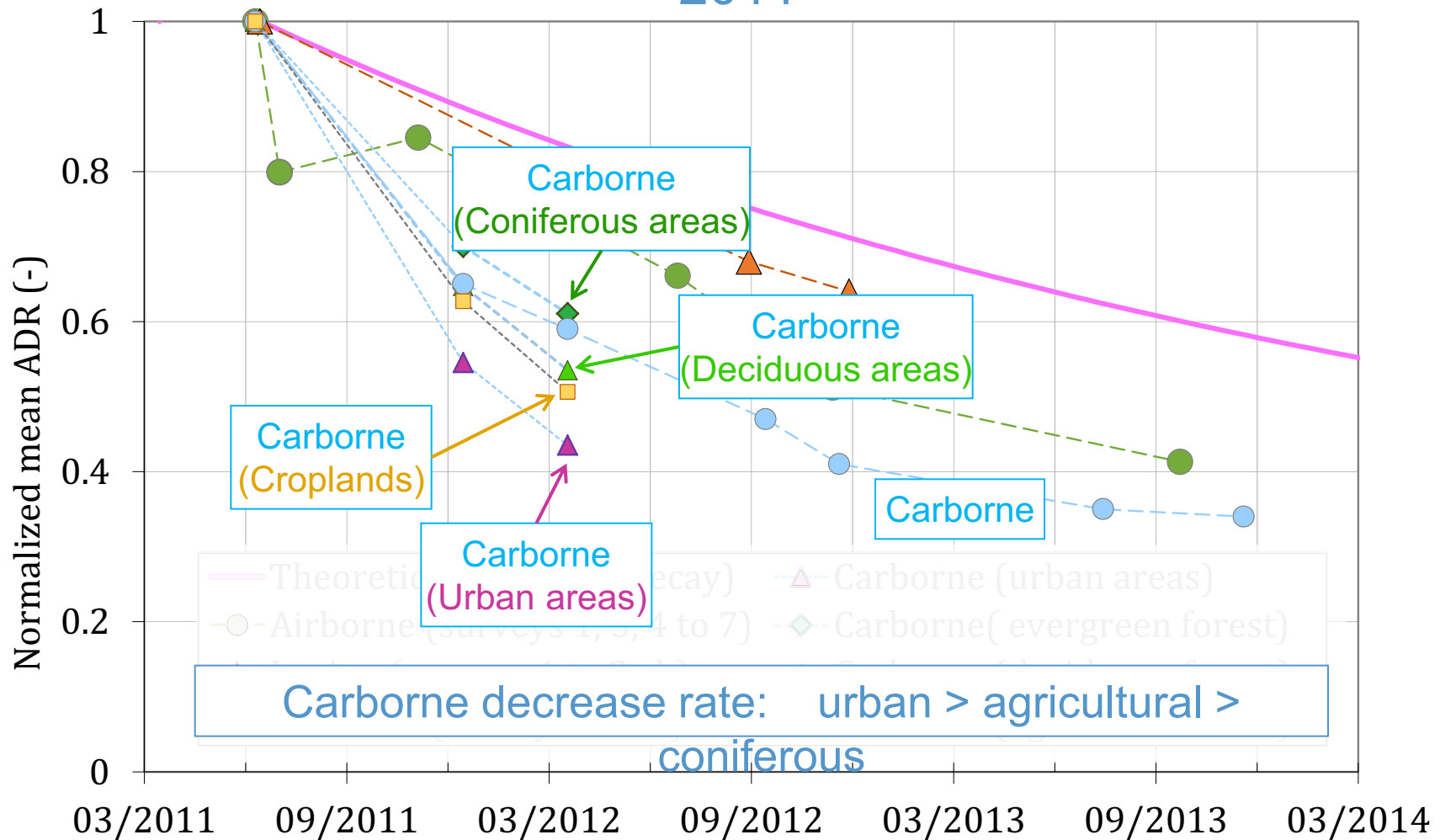
Time decrease of ADRs (1m height)

... averaged within 80 km & normalized by its value in June 2011



Time decrease of ADRs (1m height)

... averaged within 80 km & normalized by its value in June 2011



Ongoing research projects

Open questions

- Which environmental processes could explain such a variability in ADRs ?
- To what extent can forest vegetation modify ADRs inside/above forests ?
- Can we gain further understanding from process-based & dynamic models ?

AMORAD project (2013-2019)

Improvement of models for predicting radionuclide transfer in biosphere, with one focus put on forest systems



French National Research Agency

EDOFU project (2014-2016)

Improvement of models for predicting γ ADRs in a multimedia and patchy environment



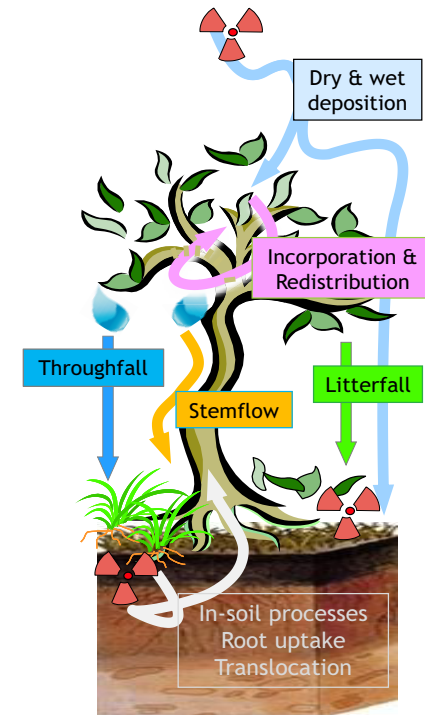
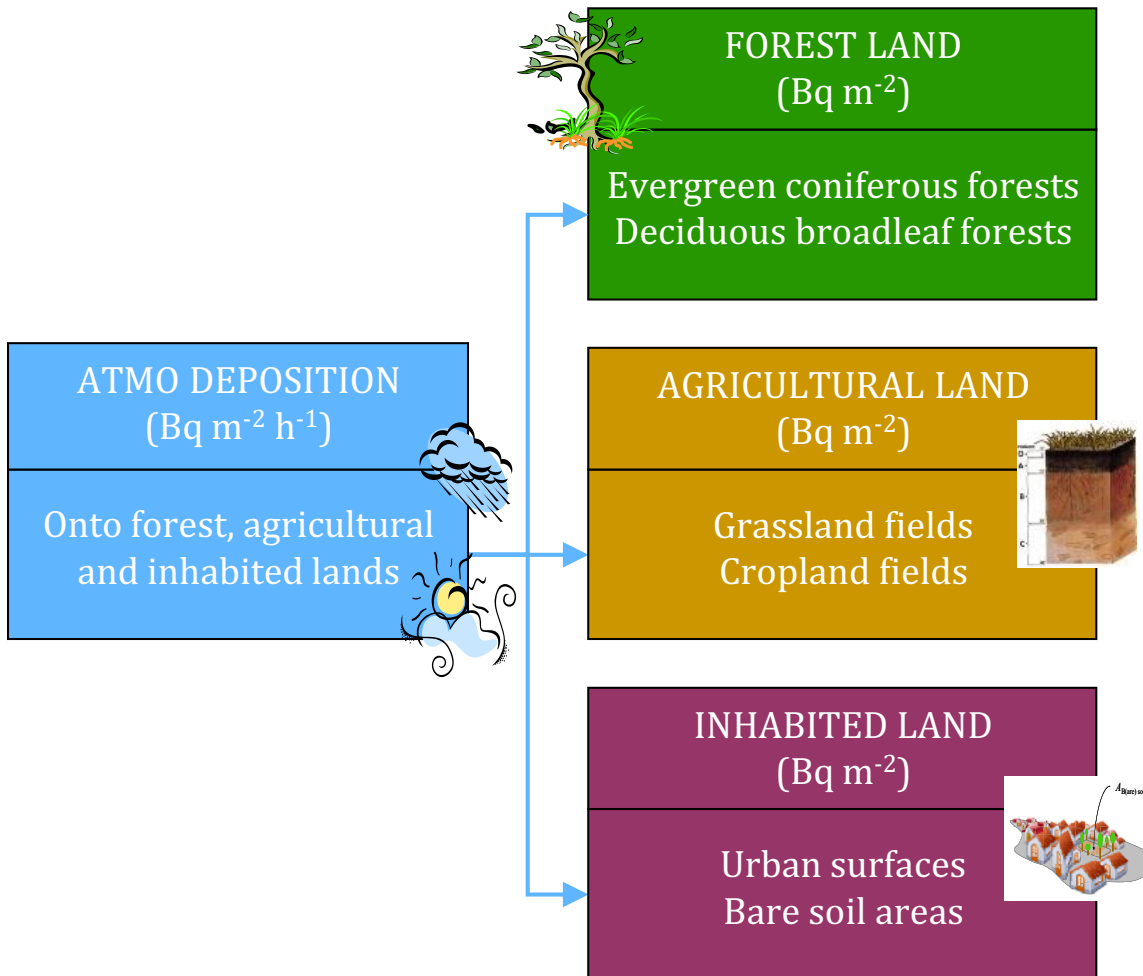
Electricité de France

<http://www.irsn.fr/EN/Research/Research-organisation/Research-programmes/Pages/Research-programmes-2966.aspx>

Modeling Cs transfer ...

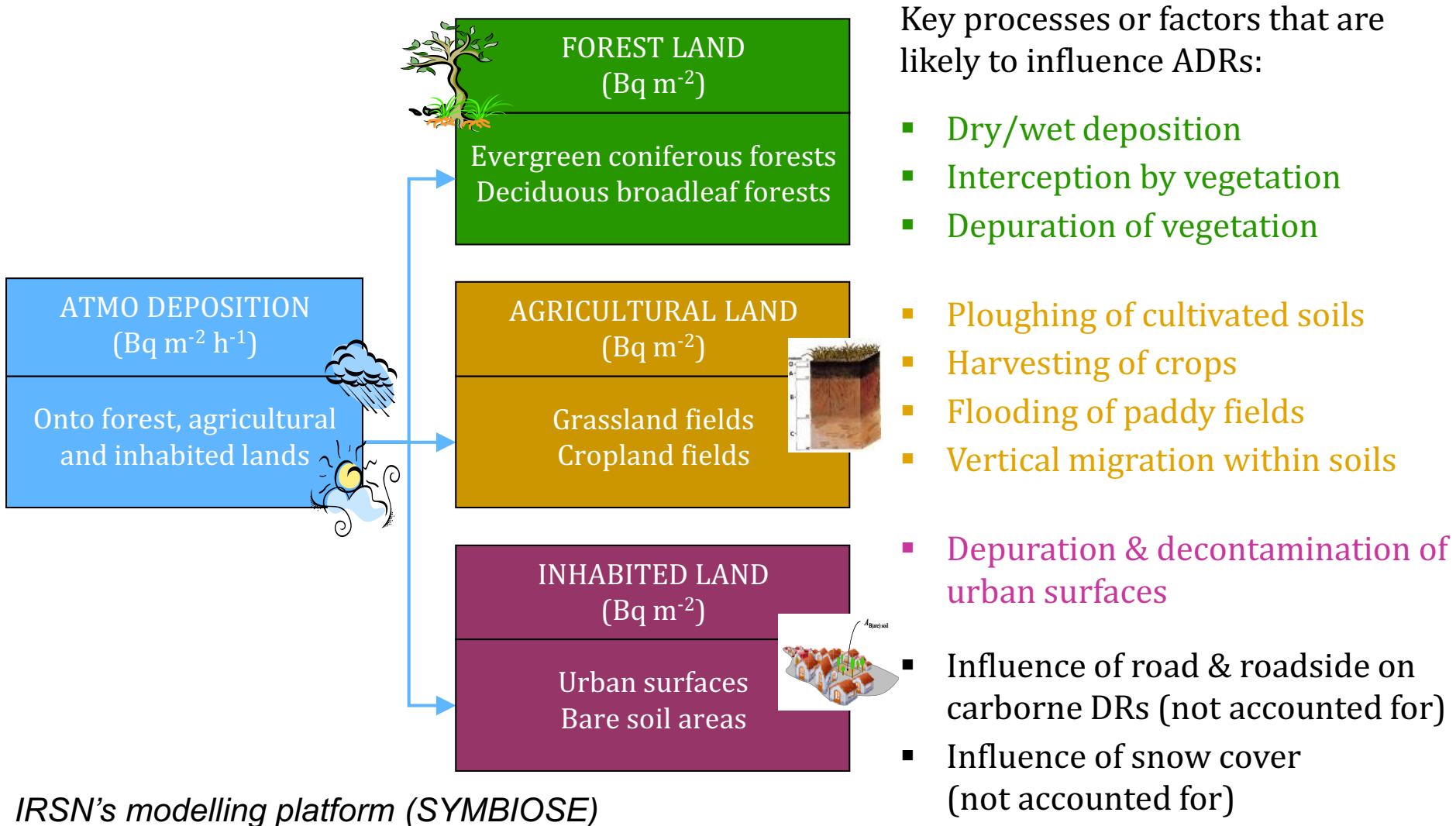
Key processes or factors that are likely to influence ADRs:

- Dry/wet deposition
- Interception by vegetation
- Depuration of vegetation

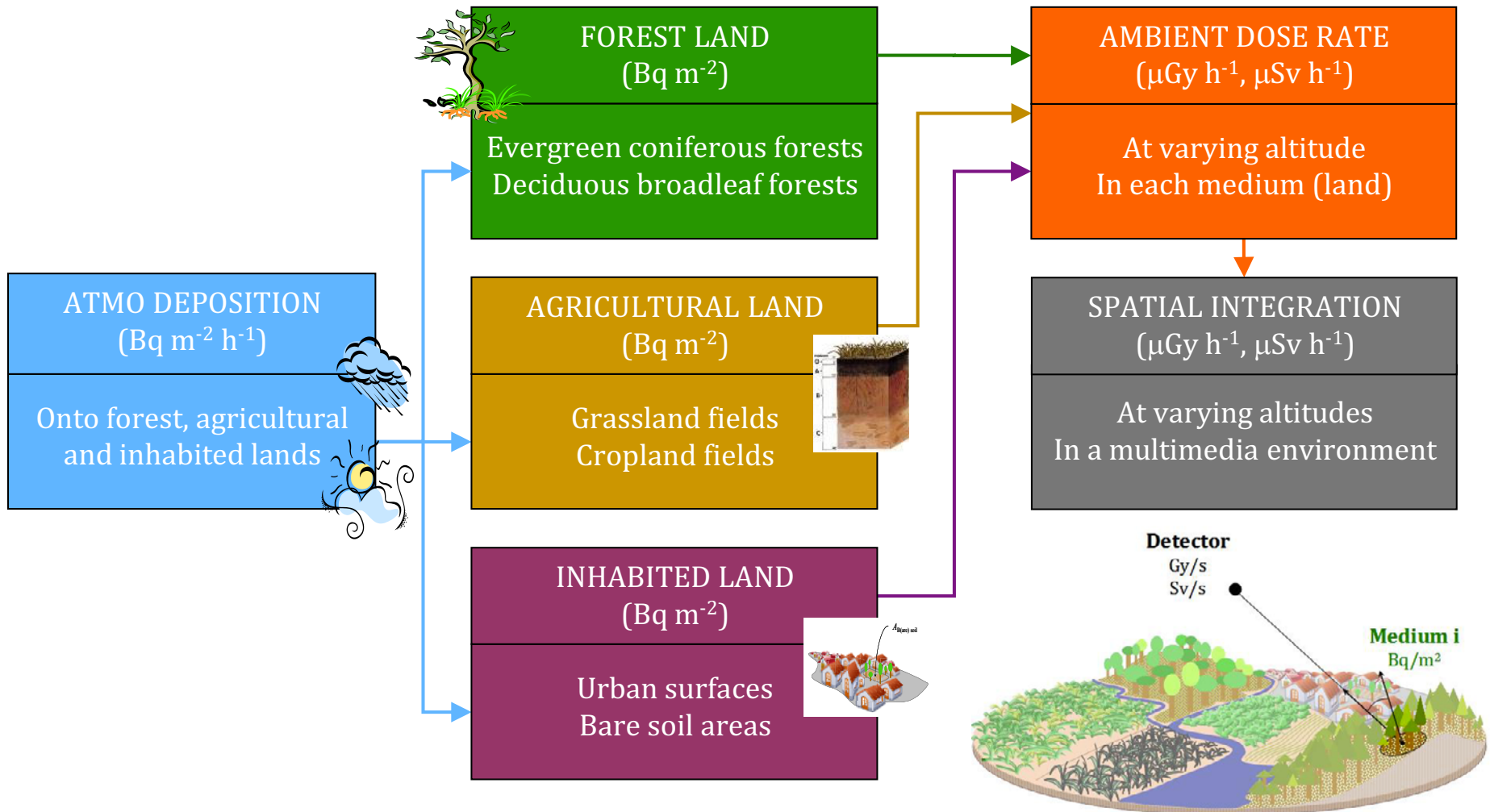


IRSN's modelling platform (SYMBIOSE)

Modeling Cs transfer ...



... and ADRs



IRSN's modelling platform (SYMBIOSE)

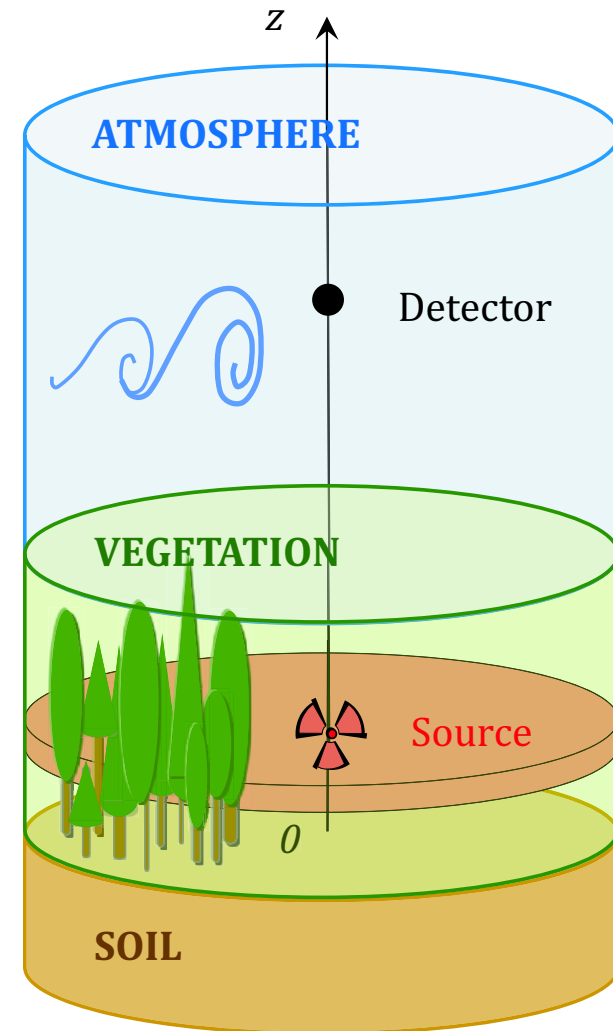
ADR coefficients for a soil-vegetation medium

Use of :

- ADR coefficients expressed in $(\text{Gy/h})/(\text{Bq/m}^2)$
- Pre-calculated with MCNP code
- Depending on detector altitude, depth of source and medium characteristics (e.g., geometry, density & elemental composition)

Equivalent Medium assumption

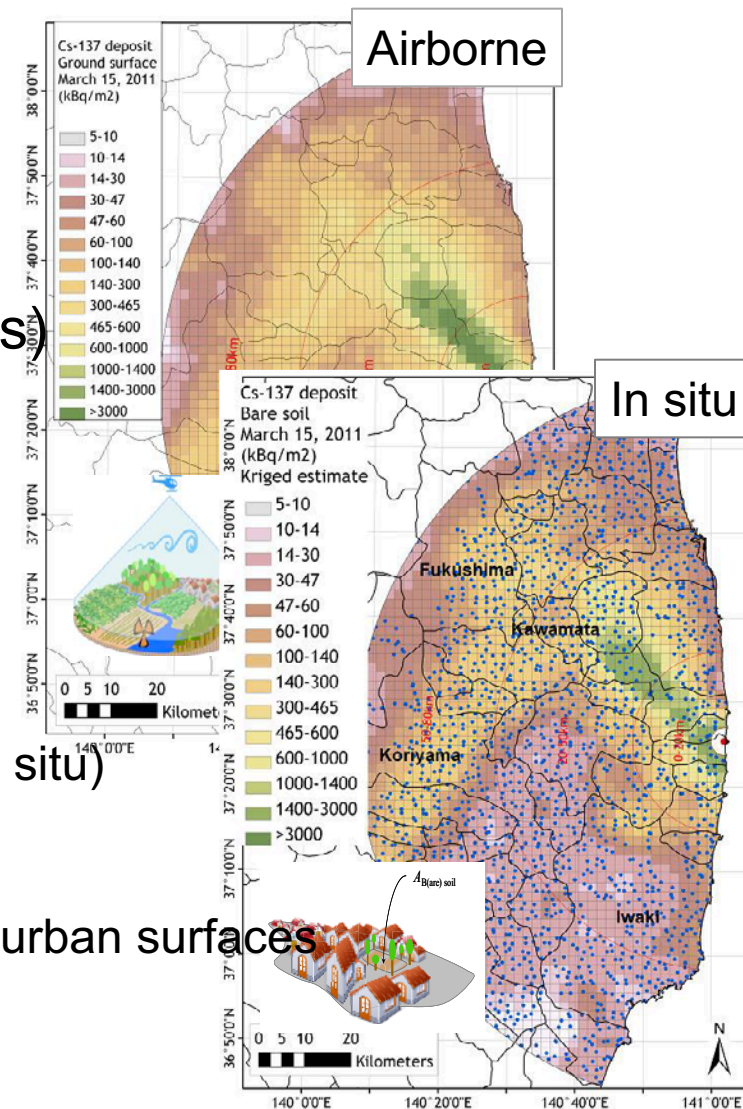
- Soil, vegetation & atmosphere layers with homogeneous properties
- Plane or volumetric radioactive source of homogeneous intensity



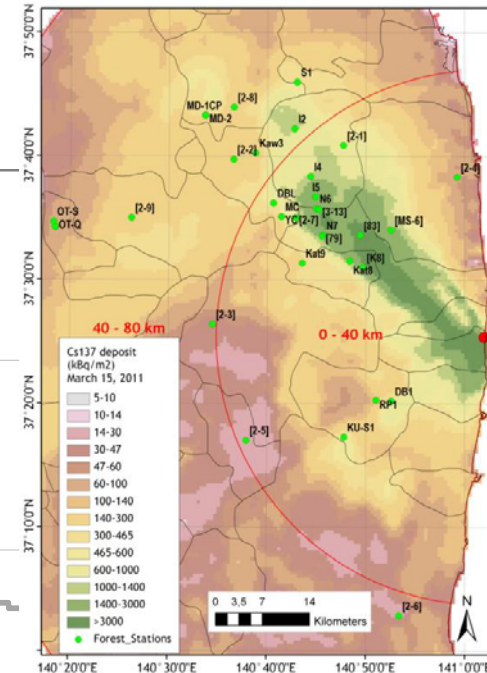
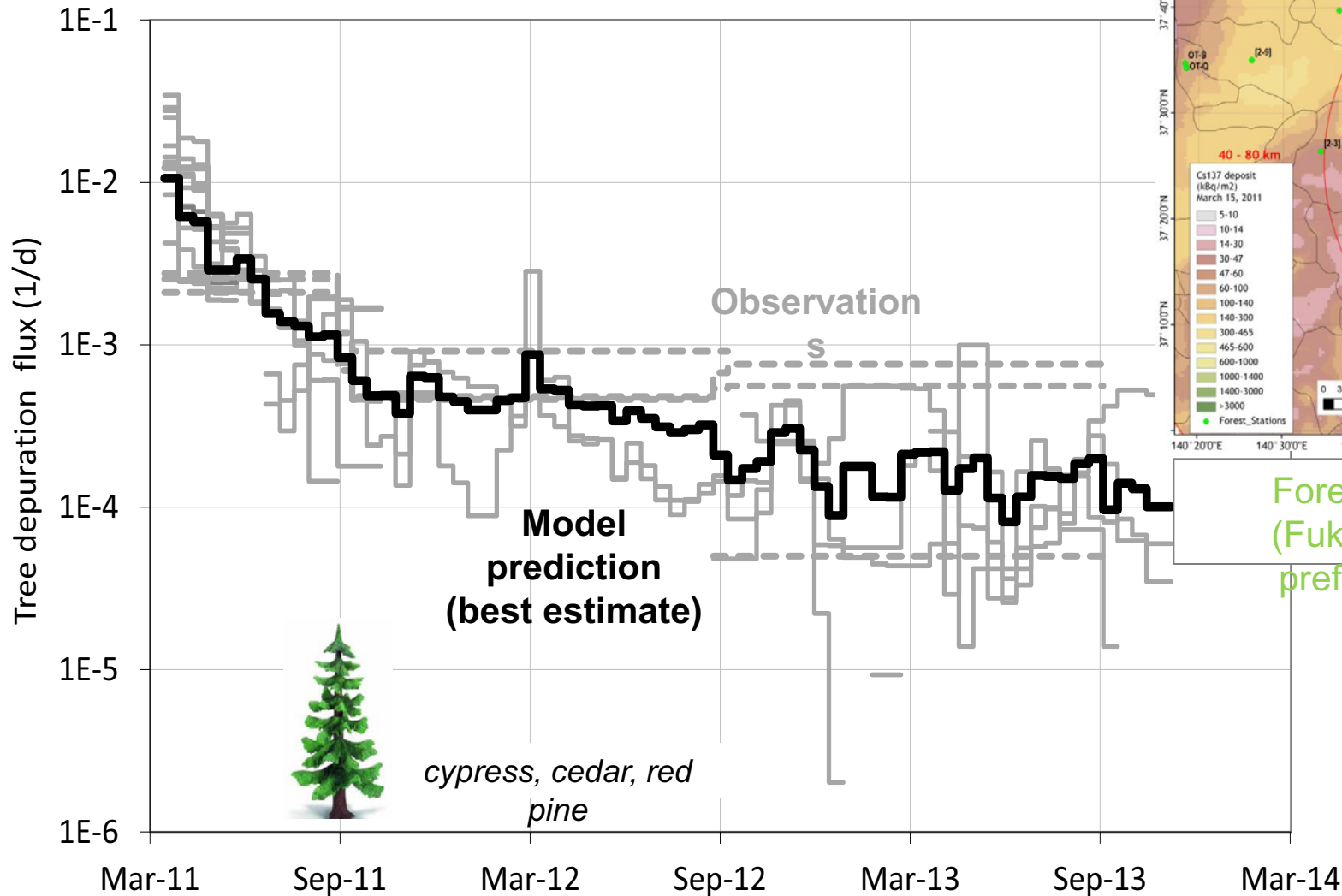
Regional simulations

- Spatio-temporal domain
 - 80 km from FDNPP
 - Computational regular grid
 - March 2011 to March 2014 (3 years)

- Environmental parameters
 - Mostly generic
 - A few site-specific
 - Land use map
 - Cs contamination maps (airborne & in situ)
 - Seasonal climatic data
 - Agricultural practices
 - Depuration/decontamination rates for urban surfaces
 - Depuration of forest vegetation
 - ...

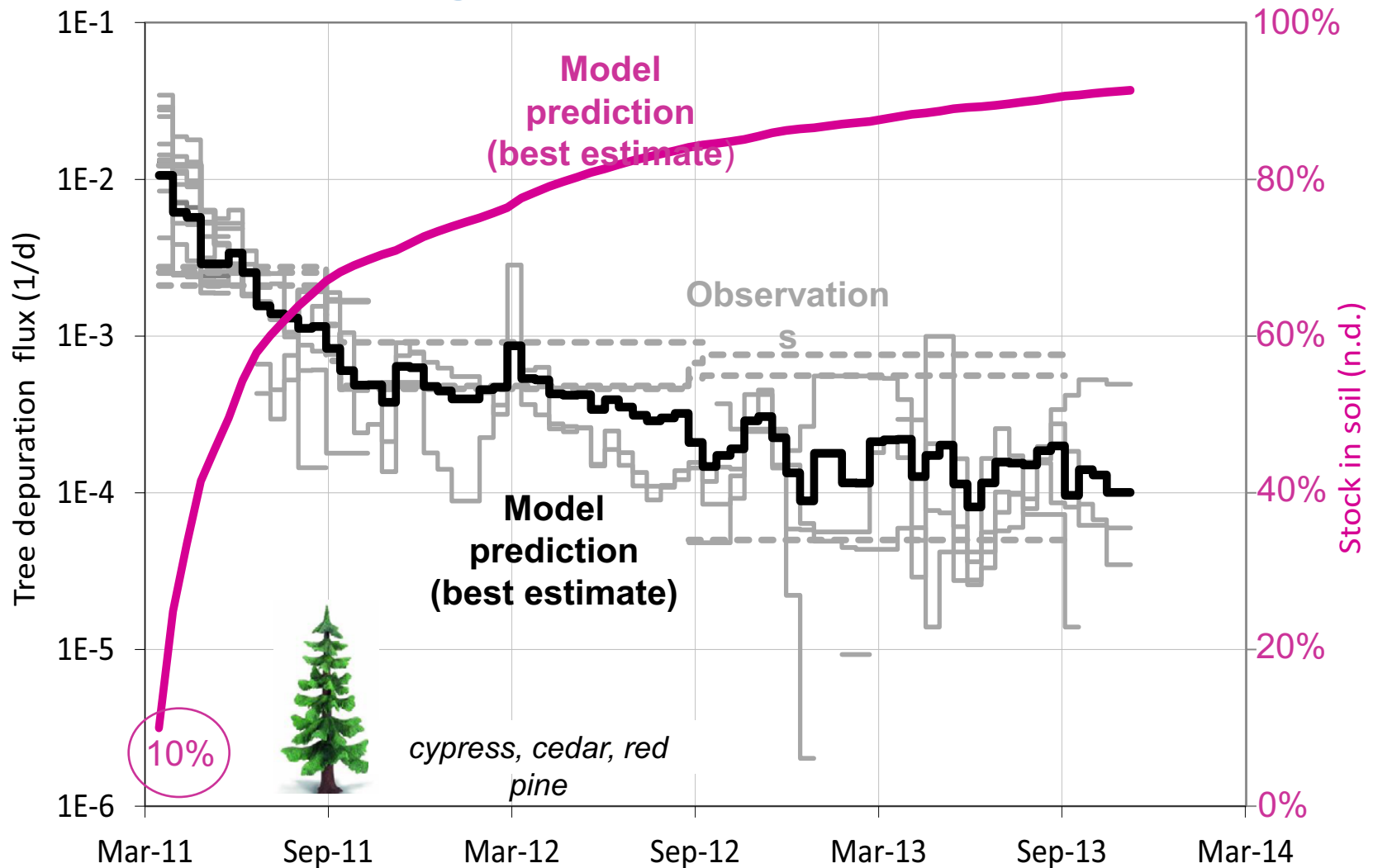


Tree depuration flux at 21 evergreen coniferous sites

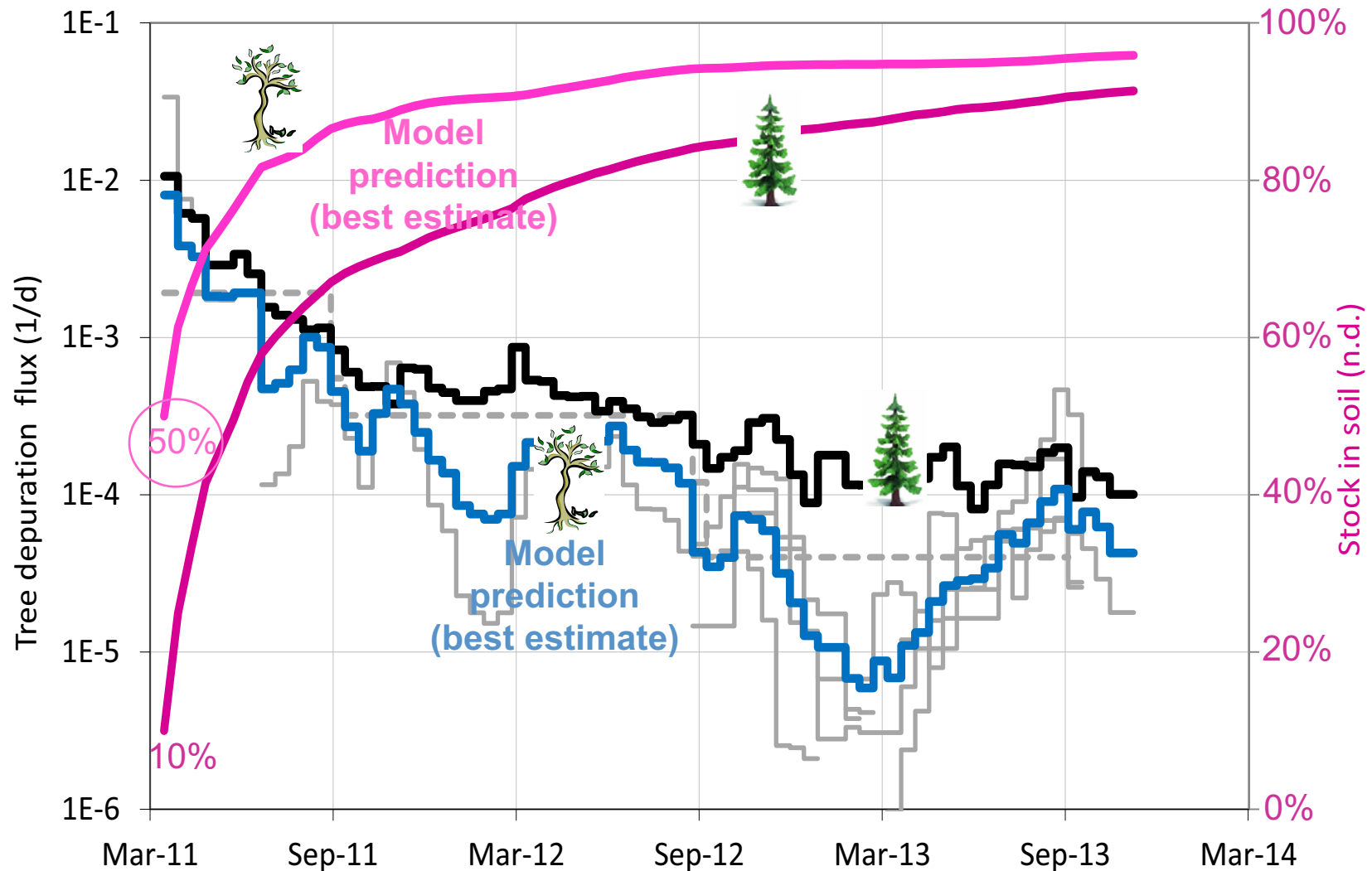


Forest sites
(Fukushima
prefecture)

... and inventory in soil at 21 evergreen coniferous sites

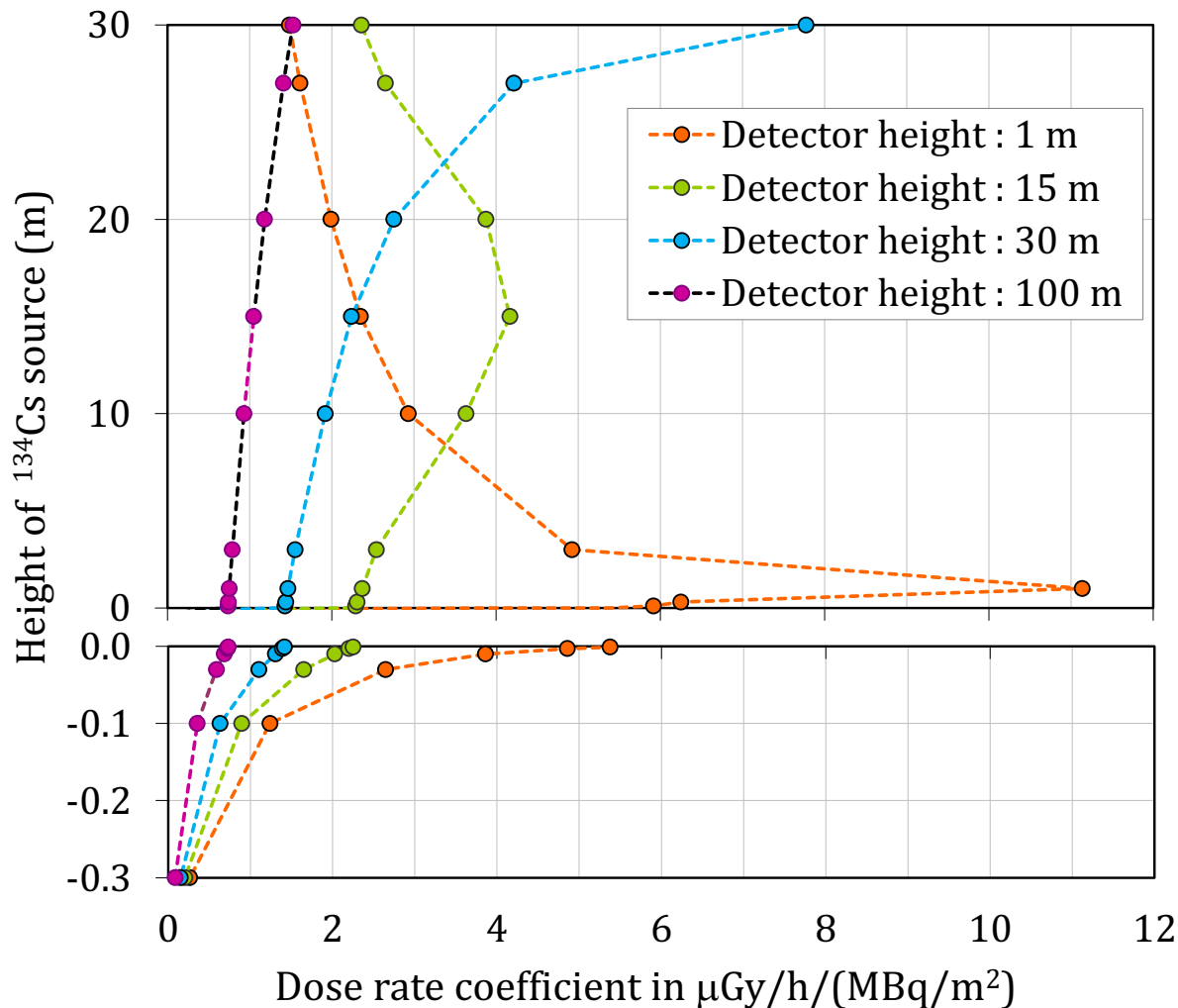


Deciduous broadleaf forests (4 sites)



ADR coefficient in a coniferous forest

... for a plane source of ^{134}Cs of increasing height

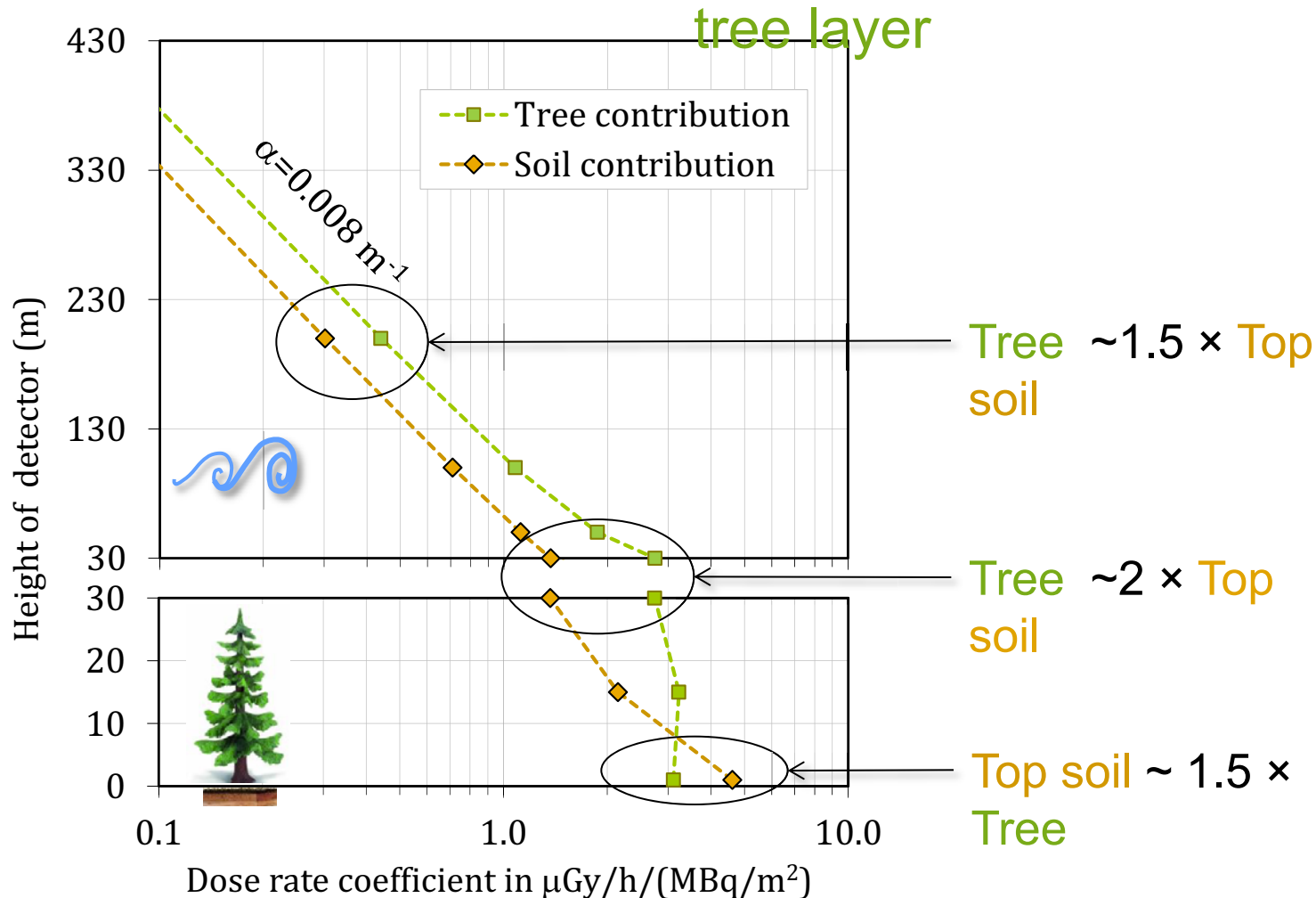


30 m tree layer

30 cm soil layer

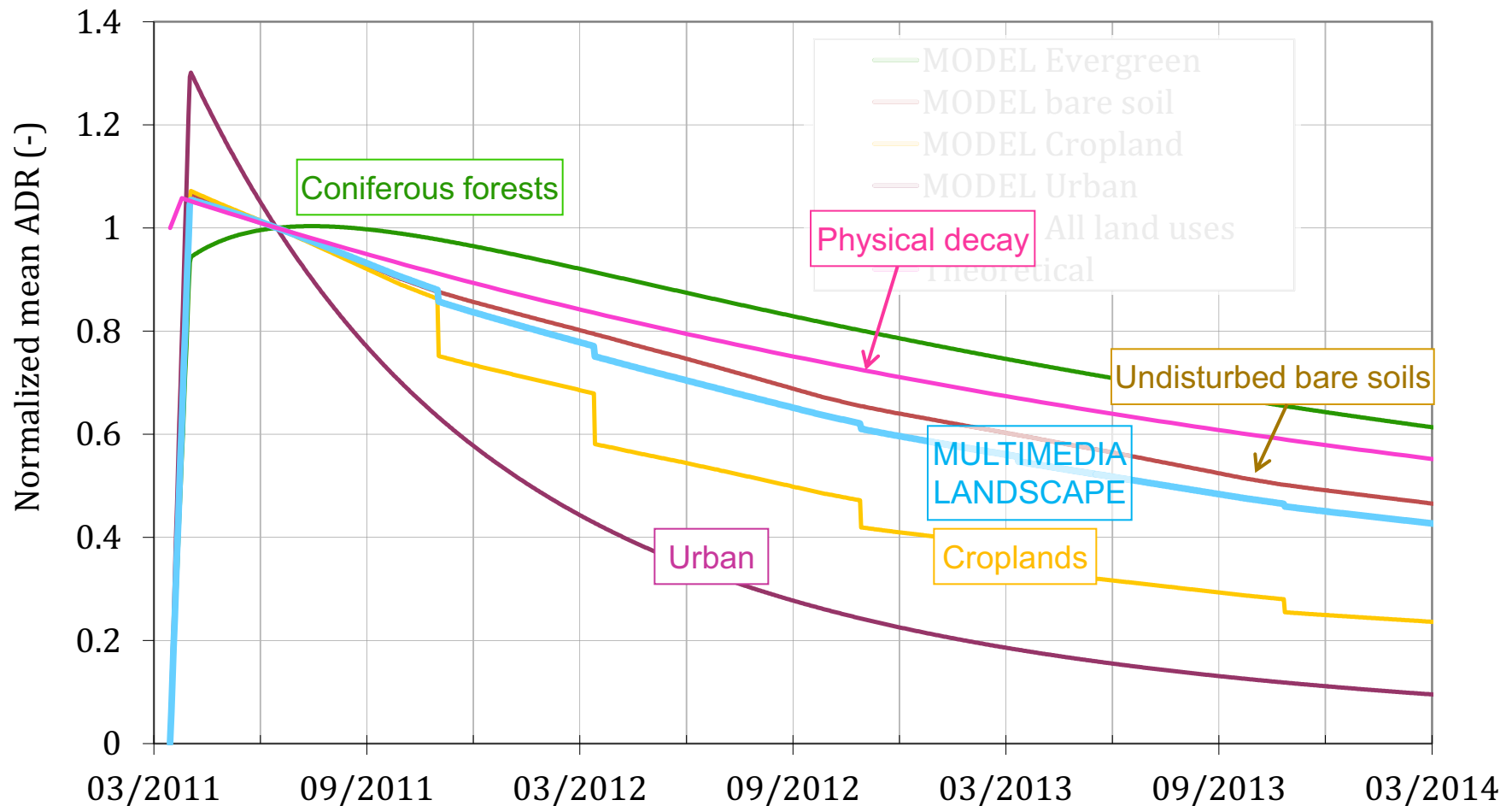
ADR coefficients in a coniferous forest

for a volumic source of ^{134}Cs in the top 1cm soil layer or 30m tree layer



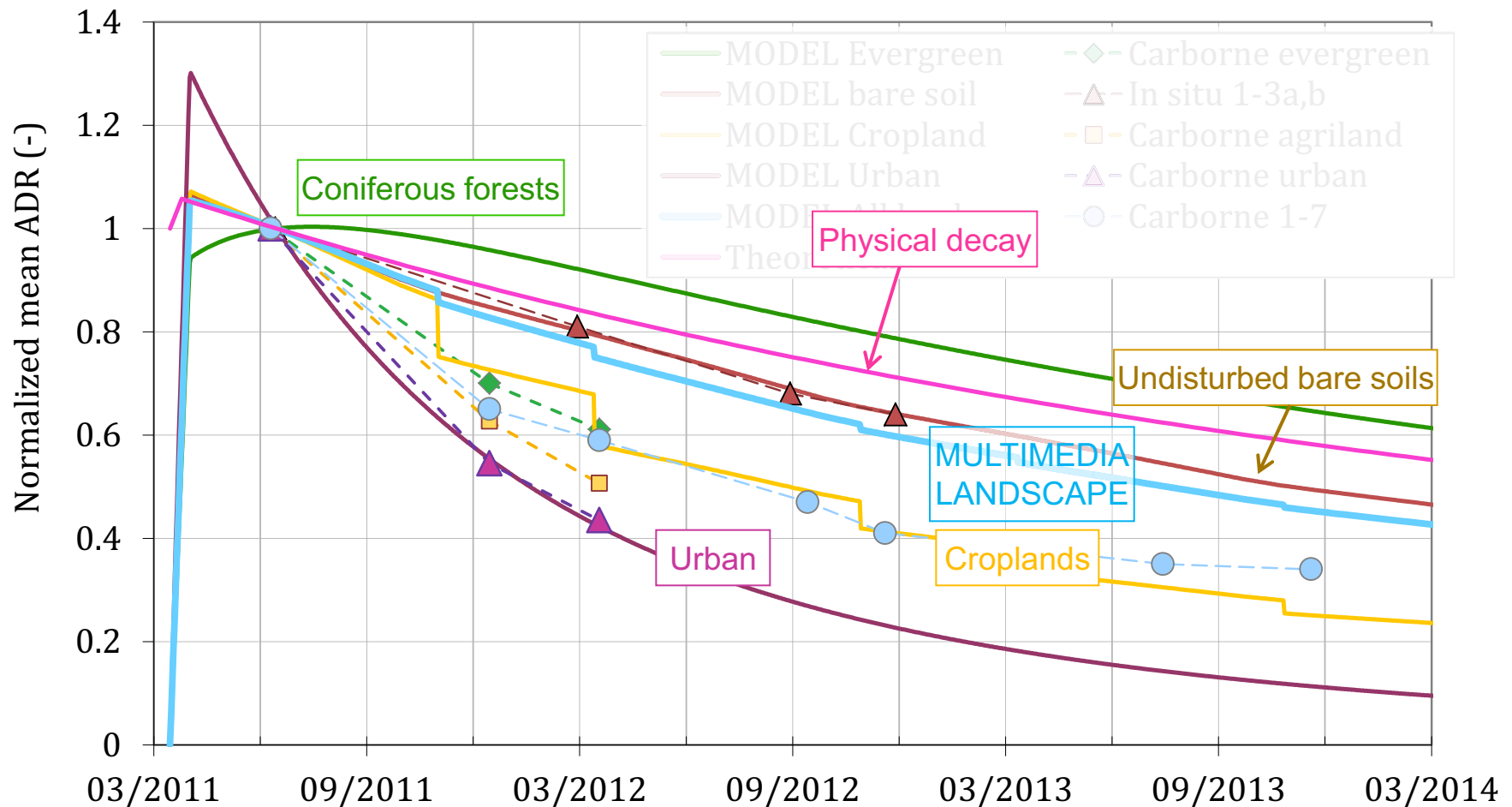
Predicted ADRs at ground level ($^{134+7}\text{Cs}$)...

Mean value within the 80 km region and normalized by its value in June 2011



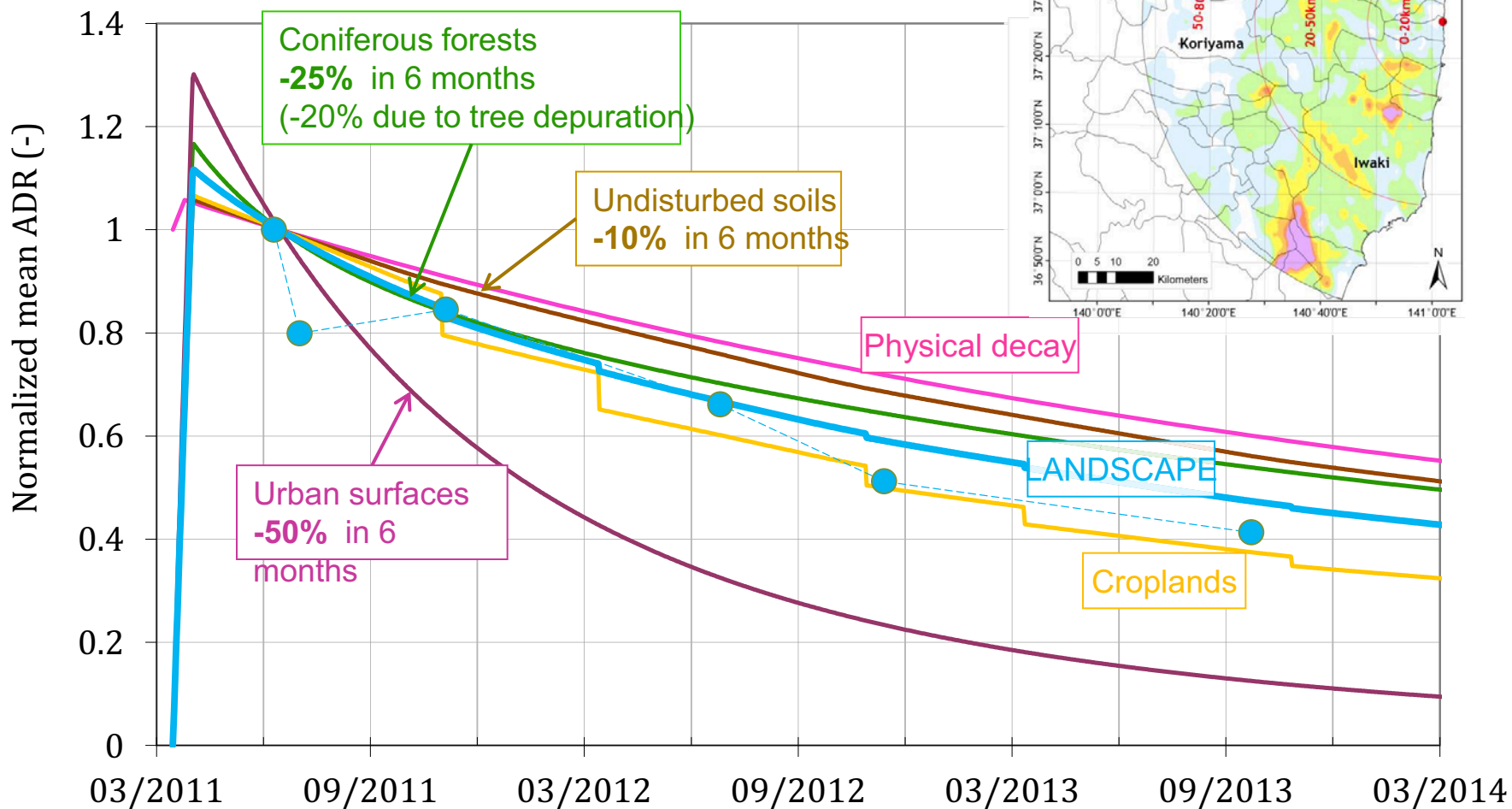
...versus in situ & carborne data

Mean value within the 80 km region and normalized by its value in June 2011



Predicted ADRs at 200m vertical data

Mean value within the 80 km region and normalized by



Further

Science of the Total Environment 529 (2015) 30–39



Contents lists available at ScienceDirect

Science of the Total Environment

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Modeling the early-phase redistribution of radiocesium fallouts in evergreen coniferous forest after Chernobyl and Fukushima accidents

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HIGHLIGHTS

- Transfer of radiocesium atmospheric fallout in evergreen forests was modeled.
- The model was tested using observations from Chernobyl and Fukushima accidents.
- Model predictions of canopy interception and depuration agree with measurements.
- Unexpectedly high contribution of litterfall for the Japanese forest is discussed.
- Meteorological conditions and tree species characteristics are sensitive factors.

details in...



ENVIRONMENTAL Science & Technology

Assessment of Dry and Wet Atmospheric Deposits of Radioactive Aerosols: Application to Fukushima Radiocaesium Fallout

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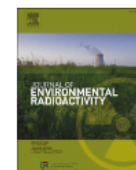
Journal of Environmental Radioactivity xxx (2015) 1–13



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ICRS-15 & RSP-2016 Conference, Paris, Oct. 2016

ident led to massive the land surfaces. The Japanese authorities for the monitoring surveys of bare soil areas (since differences exist between these differences can be largely based relationships ecology, which has been in 80-km of the nuclear and wet deposits that are simulations from the Institute of Radioprotection



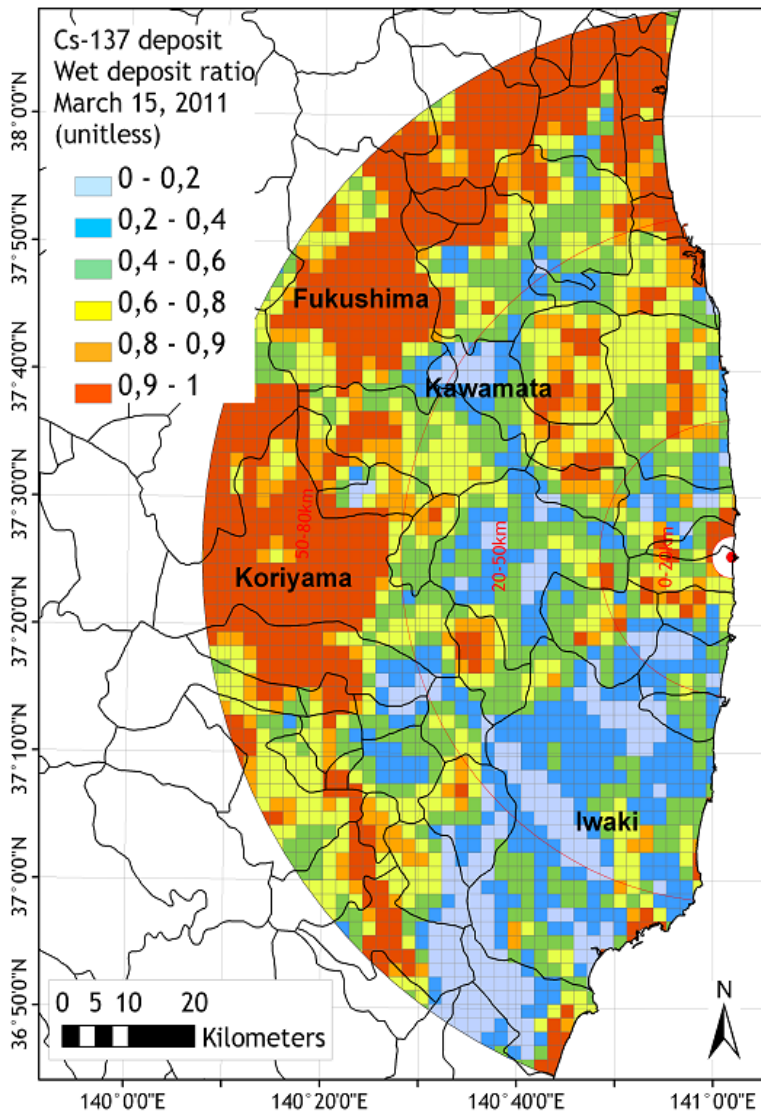
Compilation & analysis of monitoring observations in Japanese forests to be published shortly



Summary

- Japanese data highly valuable for improving our understanding of post-accidental consequences in terrestrial systems
- Despite the lack of site-specific data & uncertainties on deposition characteristics, predicted ADRs globally consistent with field observations (thanks to some models improvement & calibration)
- This study suggests that:
 - Disagreement with carborne observations mostly attributed to road & roadside effects (not accounted for in our modelling study)
 - Airborne observations above vegetation may not be representative of ground ADRs, due to tree depuration & shielding of gamma rays
 - Influence of forest vegetation should be accounted for when converting counting rates (for especially low flying altitudes)
=> this requires assumptions on radionuclide distribution !

Predicted wet deposition ratio



Wet fraction > 0.8
Intense wet deposition might have occurred in the Abukuma valley & to the NW of FDNPP

Wet fraction < 0.4
Noticeable dry deposition might have occurred in S/SW regions = high forested areas of the Abukuma mountains