Sensitivities Analyses of Atmospheric Radiocesium Simulation based on Atmospheric Concentration and Deposition

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-Transfer of science from academic to operational models- Fukushima University, 2 Mar 2015

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CONTENTS of this talk

- ✓ **INTRODUCTION**
  - ✓ Activities of atmospheric modelers
  - ✓ Current research themes
- ✓ **METHODOLOGY**
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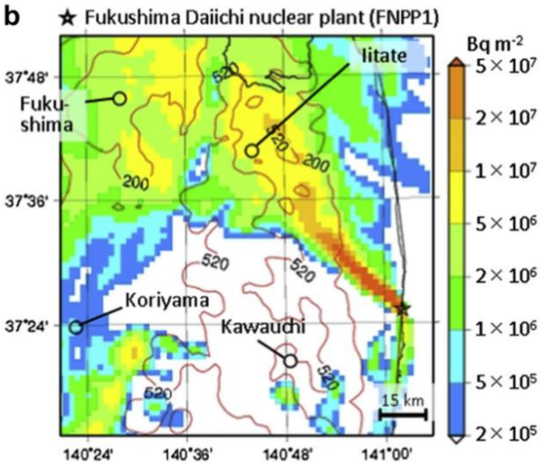
  - ✓ Modelling
- ✓ **UNCERTAINTY ANALYSES** of atmospheric models
  - ① **Source term** scenarios
  - ② **Wet deposition** modules
  - ③ **Meteorological** schemes

ACTIVITIES of atmospheric modelers after the Fukushima accident

- ✓ **Forecast** of radioactive plumes
  [*SPEEDI and other models*]
- ✓ **Inverse analysis** of radionuclides' **release rates**
  [e.g., *Chino et al*., 2011; *Stohl et al*., 2012; *TEPCO*, 2012]
- ✓ Understanding of **radionuclides' behaviors**
  [e.g., *Katata et al*., 2012; *Morino et al*., 2011; *Takemura et al*., 2011]
- ✓ Provide deposition data to land/ocean modelers
  [e.g., *Tsumune et al*., 2013; *Kobayashi et al*., 2013]
- ✓ Estimate of public radiation exposure
  [e.g., *Ten Hoeve et al*., 2012; *Itubo et al*., 2013]
- ✓ Support of revision of disaster prevention plan
  [Japanese local governments, including *Hyogo prefecture* (2013)]

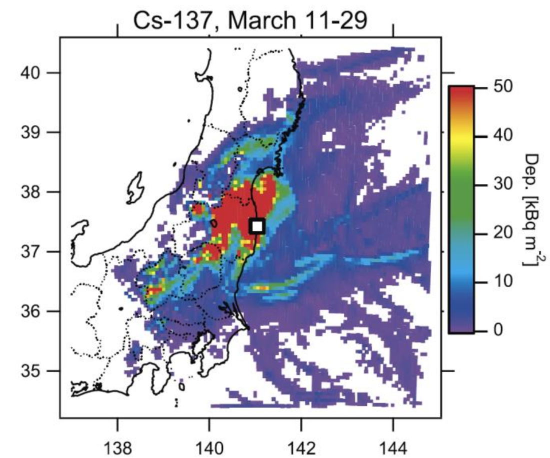
ATMOSPHERIC SIMULATIONS of radionuclides after the Fukushima accident (within half a year)

① Local scale (～100km)
Released in June 2011



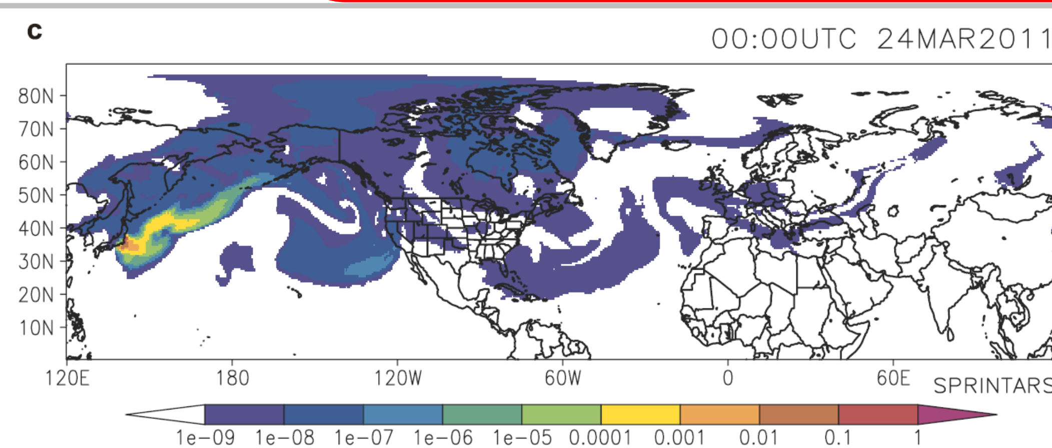
Katata et al., JER, 2012 (JAEA)

②Regional scale (～500km)
Released in August 2011



Morino et al., GRL, 2011 (NIES)

③ Global scale
Released in June 2011



Takemura et al., SOLA, 2011 (Kyusyu Univ.)

Current RESEARCH THEMES of atmospheric modelers after the Fukushima accident

- ✓ Refinement of **release rate** estimation
- ✓ **Model inter-comparison** for model evaluation
- ✓ **Uncertainty analyses** of atmospheric models
- ✓ Reproduction of **initial radionuclides' fields**
- ✓ Estimate of **re-suspension from ground**

Current RESEARCH THEMES of atmospheric modelers after the Fukushima accident

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- ✓ Reproduction of **initial radionuclides' fields**

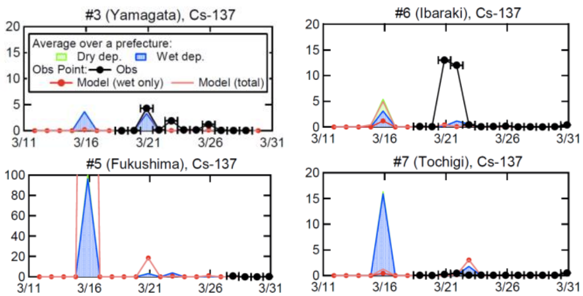
OBJECTIVES of this study

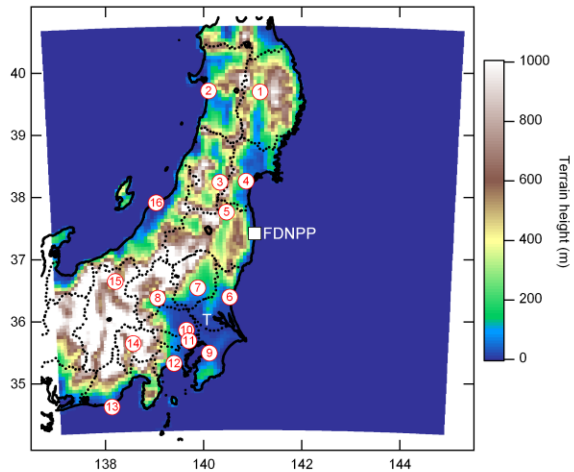
Evaluations of model performance in simulating **both atmospheric concentrations and depositions** of radiocesium.

OBSERVATIONAL DATA – atmospheric deposition

Monitoring of surface deposition (MEXT, 2011)

- Bulk samplers
- Sampling duration: 1 day

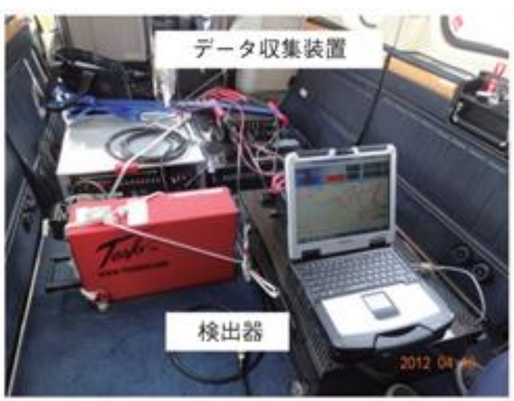


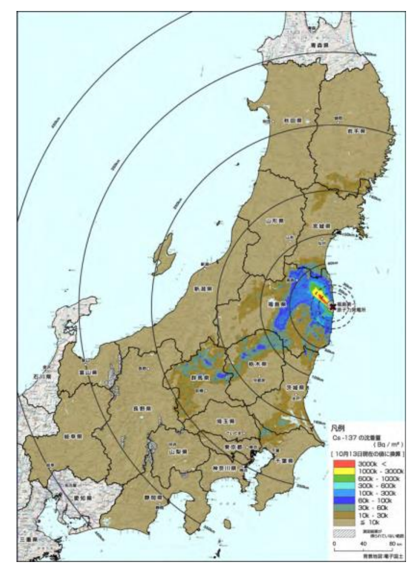


北海道立衛生研究所
http://www.iph.pref.hokkaido.jp/eiken_housyanou/radinst.pdf

Aircraft monitoring over Eastern Japan (MEXT, 2011)

- Monitoring : Aug-Nov 2011
- Space of flight path: 1.8～3 km





日本原子力研究開発機構 http://jolisfukyu.tokai-sc.jaea.go.jp/fukyu/mirai/2012/1_6.html

OBSERVATIONAL DATA – atmospheric concentration

① Measurement at several stations using high-volume samplers

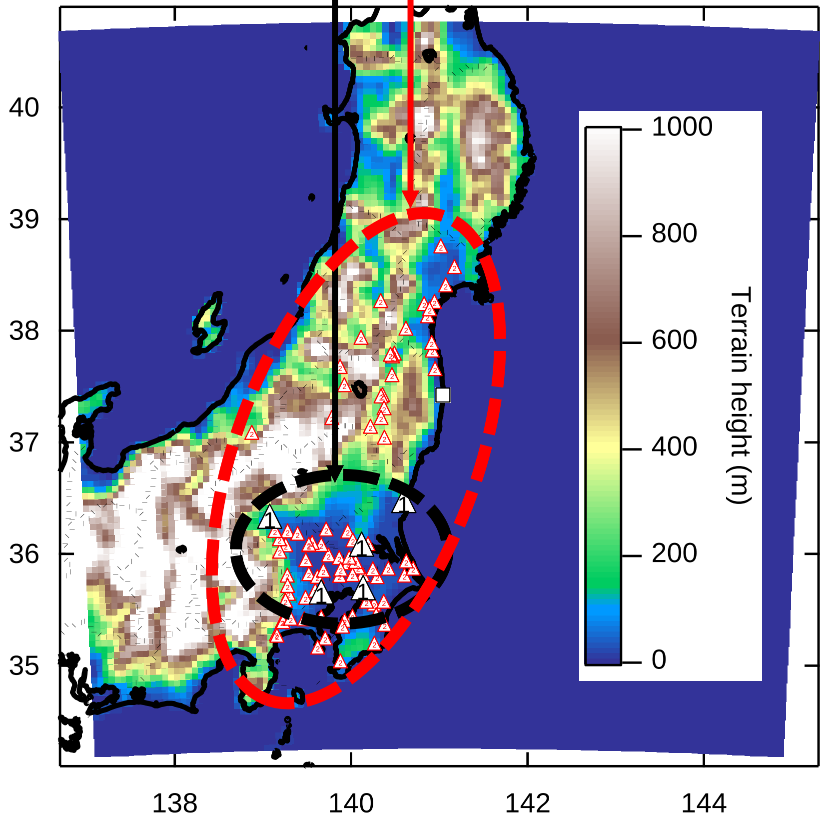
- ～5 sites
- sampling duration: 1hr～several days (mostly ≥24 hr)

② Filter-tapes of operational air pollution monitoring stations

- ～90 *sites*
- sampling duration: 1-hr

Tsuruta et al. (2014)

国立環境研究所
http://www.nies.go.jp/shinsai/measurement.html



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http://www.toadkk.co.jp/product/env/ap/dub.html

MODEL SETUPS —atmospheric simulation model

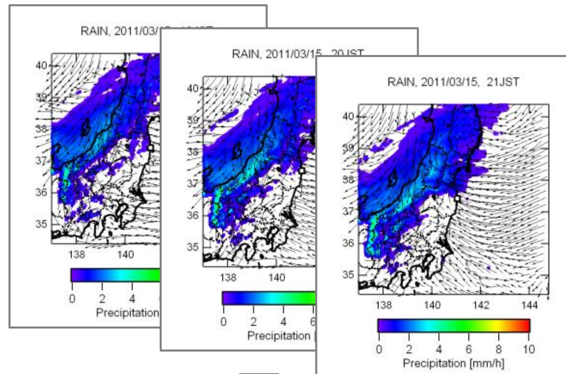
- Meteo. Model:
  WRF v3.1 (JMA/MSM)
- CTM : CMAQ v4.6
- Grid : 237 x 237 x 34
- Δx, Δy : 3km

- Dry dep: Wesely (1989)
- Wet dep:
  Binkowski and Roselle (2003)
- Properties of ^{137}Cs:
  - Particles of 1μm
- Properties of ^{131}I
  - Gas:particle = 8:2
  - Particles of 1μm
  - V_d of gas-^{131}I: same as SO_2

Morino et al. *ES&T* (2013)

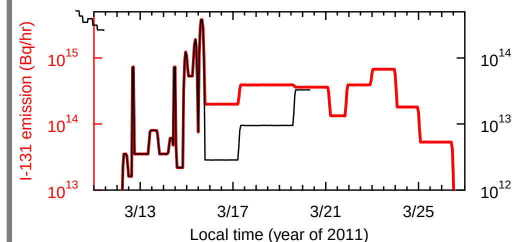
Meteorological model (WRF)

Wind field, precipitation, etc.



Emission (JAEA)

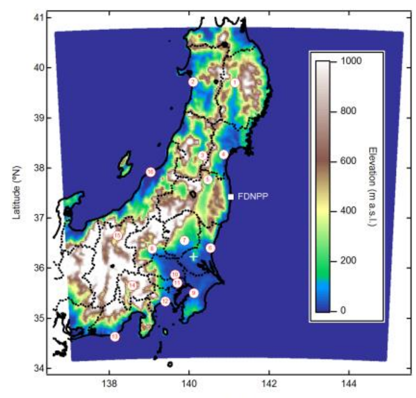
Release rates of ^{131}I and ^{137}Cs



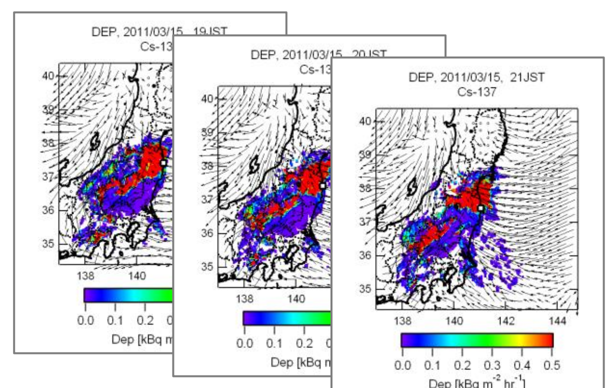
Chemical transport model (CMAQ)

Process: emission, transport, deposition, and radioactive decay.

Simulation domain



Concentration/Deposition of ^{131}I/^{137}Cs



METHODOLOGY

MODEL SETUPS — UNCERTAINTY ANALYSES

- Meteo. Model:
  WRF v3.1 (JMA/MSM)
- CTM：CMAQ v4.6
- Grid：237 x 237 x 34
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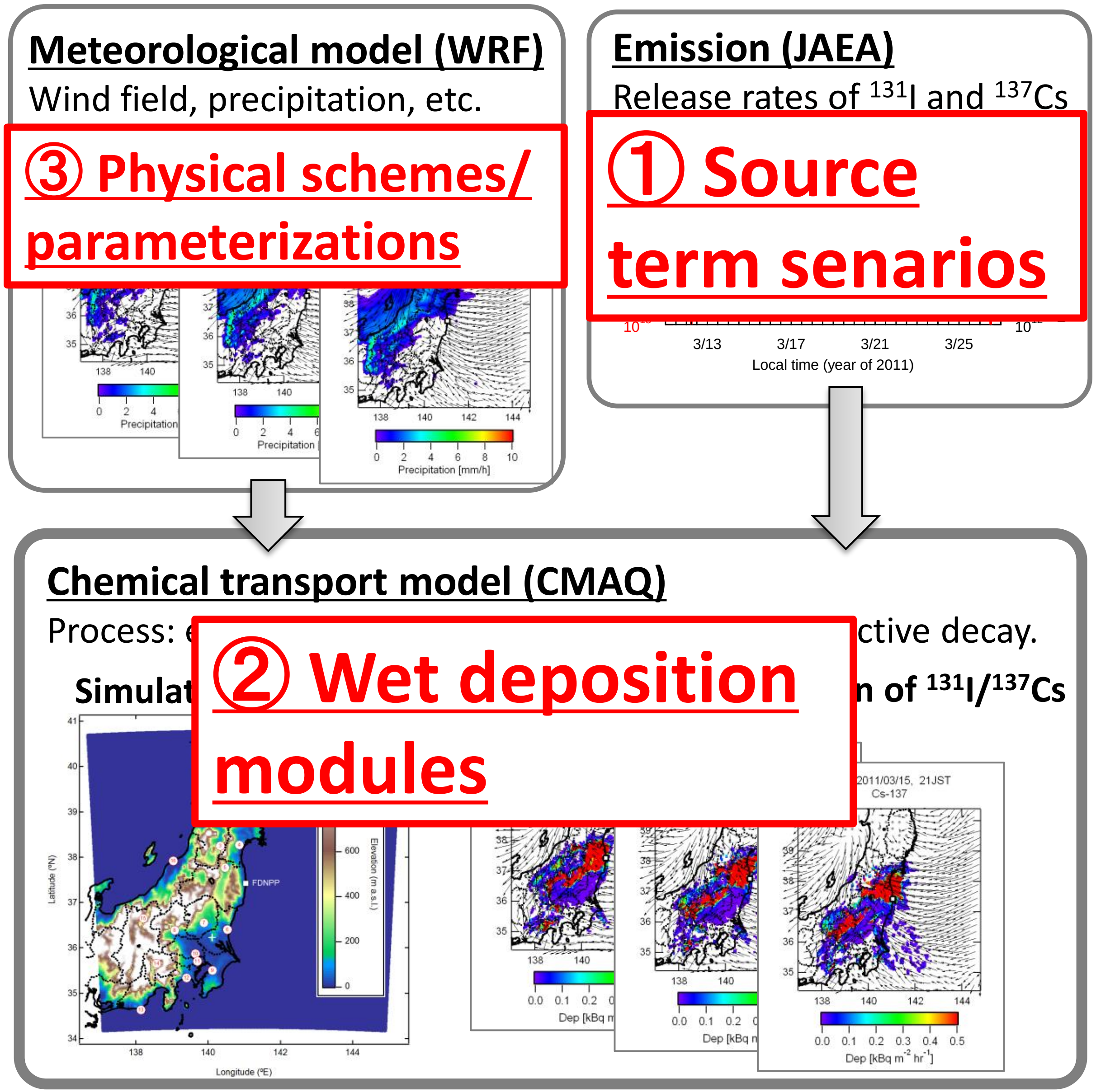
  - V_d of gas-^{131}I: same as SO_2



Morino et al. *ES&T* (2013)

MODEL SETUPS —Sensitivity simulations

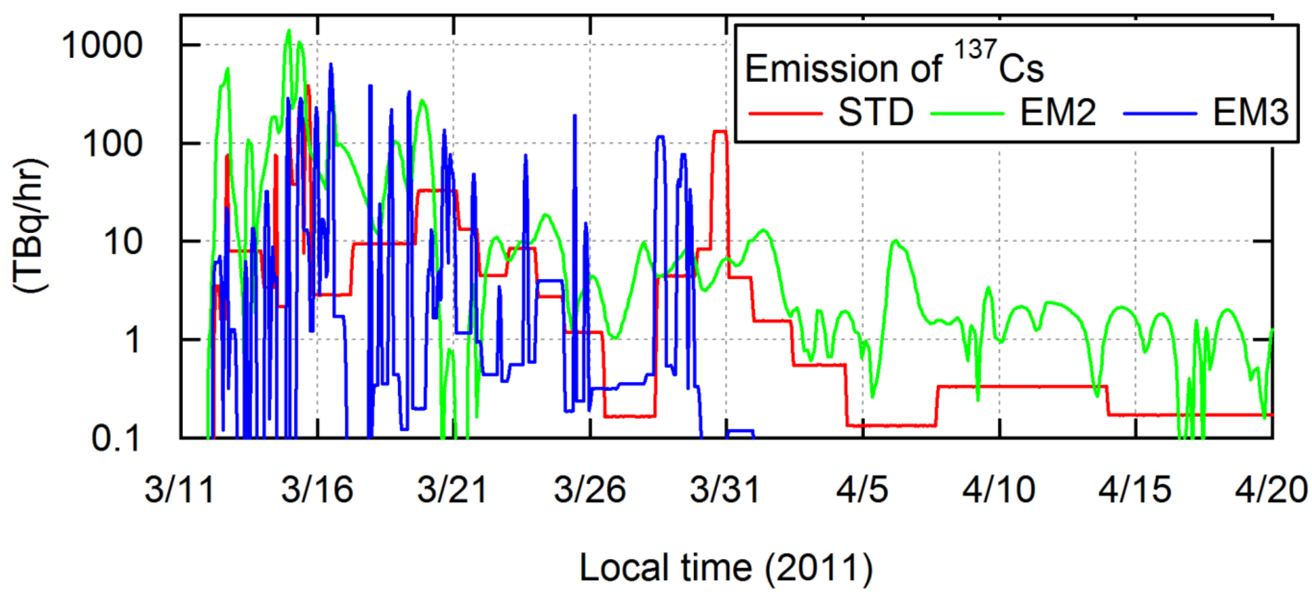
Table 1. Setup Parameters Used for Ten Model Simulations

simulation	emissions[a]	wet deposition[b]	particle diameter
STD	JAEA[7]	CMAQ[11]	1 μm
EM2	NILU[2]	CMAQ	1 μm
EM3	TEPCO[3]	CMAQ	1 μm
WD2	JAEA	Scav. coeff.[7]	1 μm
E2W2	NILU	Scav. coeff.	1 μm
E3W2	TEPCO	Scav. coeff.	1 μm
WD3	JAEA	Scav. coeff. × 10	1 μm
E2W3	NILU	Scav. coeff. × 10	1 μm
E3W3	TEPCO	Scav. coeff. × 10	1 μm
DD2	JAEA	CMAQ	Kaneyasu et al.[15]

Morino et al. *ES&T* (2013)

Available ^{137}Cs SOURCE TERM

	JAEA	NILU	TEPCO
Model	WSPEEDI	FLEXPART	DIANA
Scale	Local/Regional (Δx=3km)	Global	Local (Δx=1km)
ObsPoint	Eastern Japan (conc. and dep.)	World-wide (6 in Japan, 5 in N-Pacific, 12 in N-America)	Fukushima (monitoring car)
^{137}Cs (PBq)	8.8	36.6	10.0
References	*Terada et al.*, 2012	*Stohl et al.*, 2012	*TEPCO*, 2012



Morino et al. *ES&T* (2013)

RESULTS

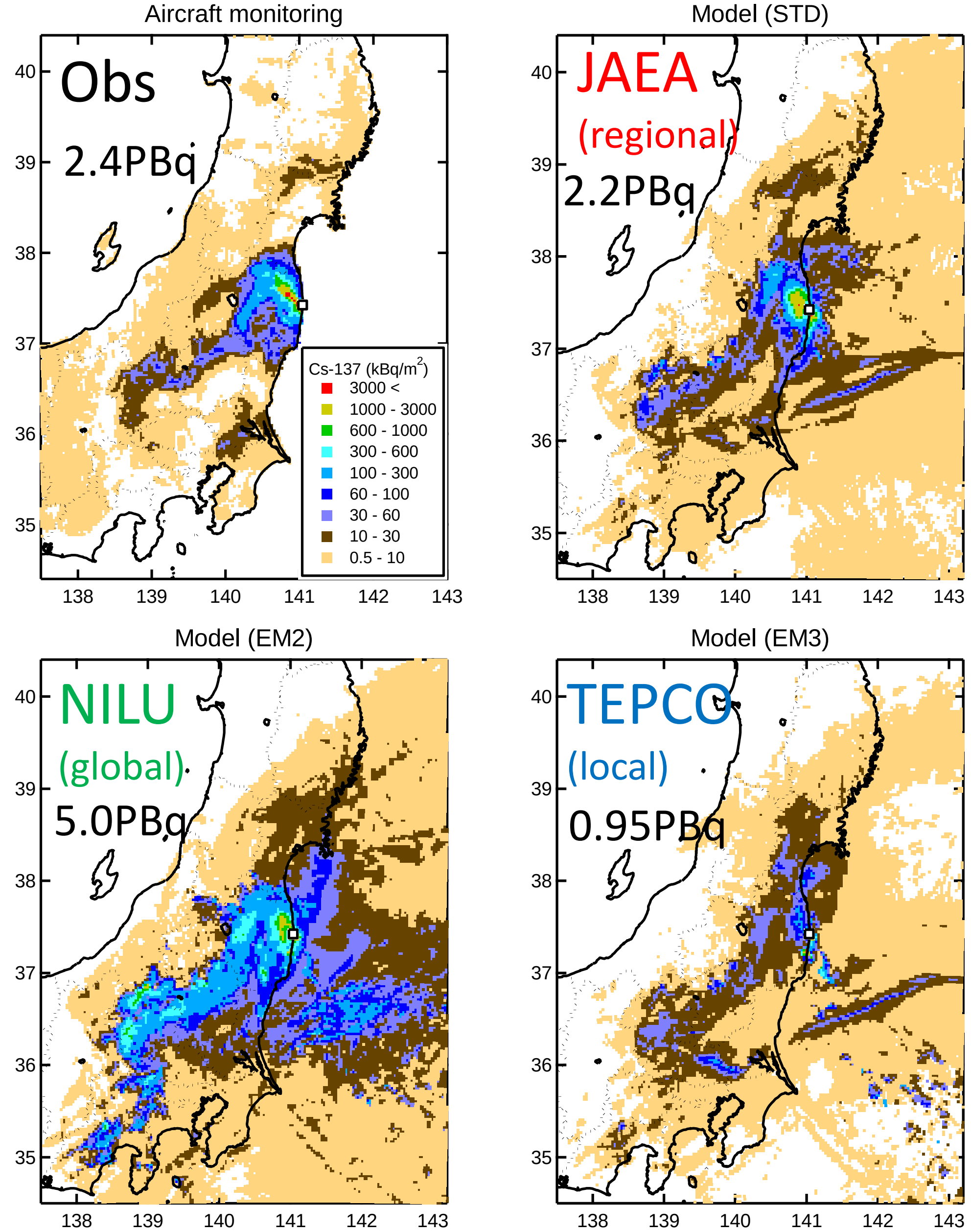
^{137}Cs deposition

—Sensitivity to **SOURCE TERM**

JAEA: Deposition patterns was generally reproduced

NILU: largely overestimated

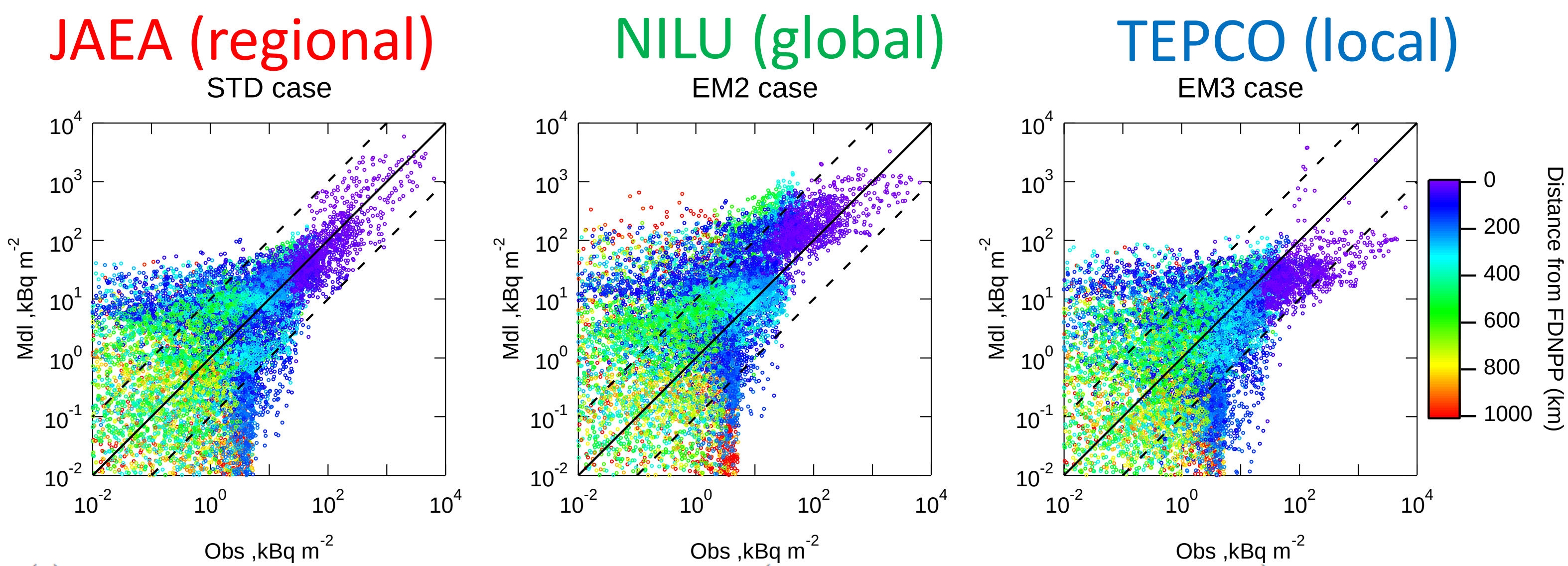
TEPCO: large underestimation in Fukushima and different spatial patterns



Morino et al. *ES&T* (2013)

RESULTS

^{137}Cs deposition —Sensitivity to SOURCE TERM



(c) Comparison with airborne monitoring (cutoff[b]: 10 kBq m^{-2}, n=2448)

	STD	EM2	EM3	WD2	WD3	DD2
FA2 (%) Agreement within a factor of 2	57.0	34.6	40.0	44.9	54.9	56.8
FA10 (%) Agreement within a factor of 10	95.6	87.8	88.9	98.7	99.6	95.5
r Correlation coefficients	0.663	0.526	0.308	0.639	0.720	0.663

(e) Budget analysis (PBq)

	STD (JAEA)	EM2 (NILU)	EM3 (TEPCO)	WD2	WD3	DD2	Obs[d]
Emission	8.79	36.63	10.04	8.79	8.79	8.79	
Total deposition over land	2.21	4.98	0.95	2.03	3.19	2.19	2.40

Morino et al. *ES&T* (2013)

WET DEPOSITION modules of atmospheric models

CMAQ (Byun and Ching, 1999)

$$\frac{dQ}{dt} = Q\left(\frac{\exp(-\tau_{cld}/\tau_{washout})-1}{\tau_{cld}}\right)$$

$$\tau_{washout} = \frac{W_T \Delta z}{\rho_{H2O}\, p_0}$$

Water in cloud and rain

Precipitation rate

Q is in-cloud concentrations,
τ_{cld} is the cloud timescale
$\tau_{washout}$ is washout time
W_T is the mean total water content
Δz is the cloud thickness,
ρ_{H2O} is the density of water
p_0 is precipitation rate

WSPEEDI (Terada et al., JNST, 2005)

$$\frac{dQ}{dt} = -\Lambda Q$$

Q: Conc. in cloud
Λ: Scav. coeff.(1/s)

$$\Lambda = A p_0^{B}$$

Precipitation rate

Q is in-cloud concentrations,
Λ is scavenging coefficient (1/s)
p_0 is precipitation rate (mm/hr)
A and B are empirically determined parameters
(**$A = 5.0 \times 10^{-5}$ and $B=0.8$** for ^{137}Cs)

Morino et al. *ES&T* (2013)

SCAVENGING COEFFICIENTS (Λ) in previous studies

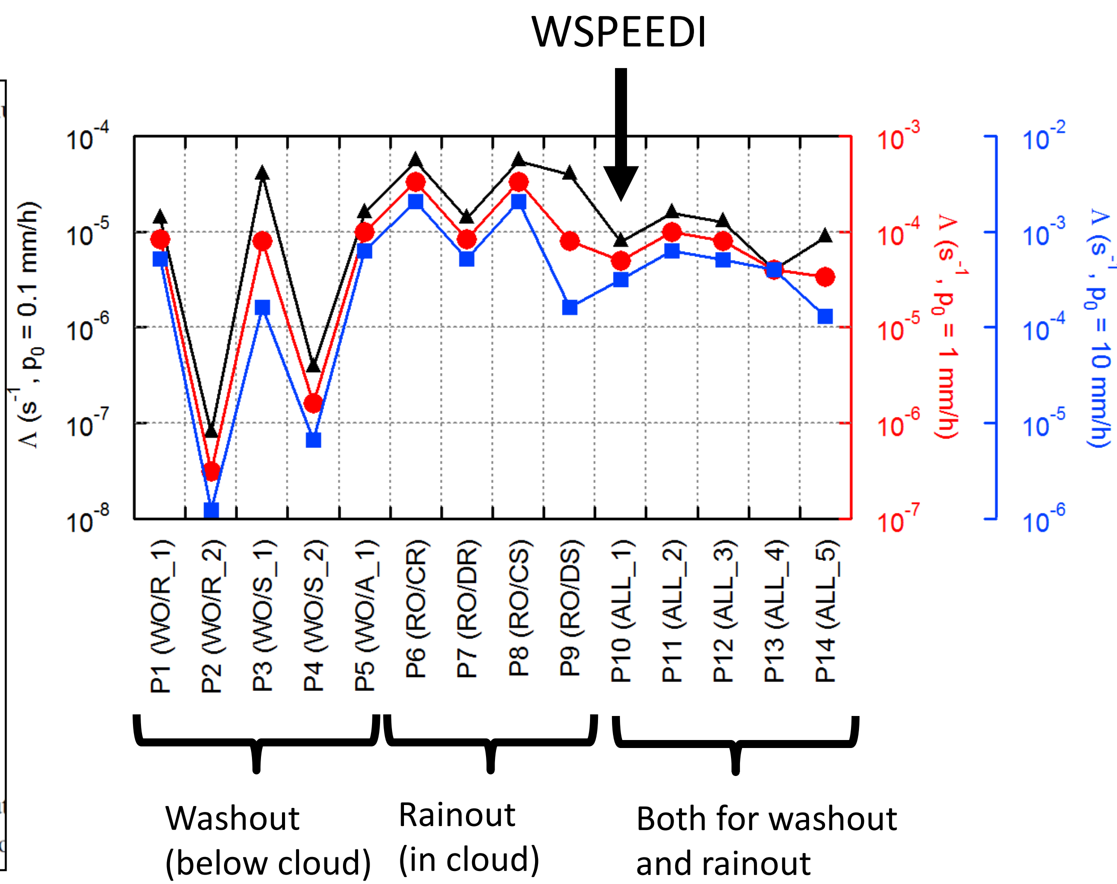
$$\Lambda = A p_0^{\,B}$$

Precipitation rate

Table S1. Parameters for scavenging coefficient calculation of particles, incl
(A and B in an equation S4).

	Cases	Rain or snow	A	B
Washout (below cloud)	P1[S5]	Rain	8.40×10^{-5}	0.79
	P2[S6]	Rain	3.14×10^{-7}	0.6
	P3 [S5]	Snow	8.05×10^{-5}	0.305
	P4 [S6]	Snow	1.60×10^{-6}	0.62
	P5[S7]	Both[a]	1.00×10^{-4}	0.8
Rainout (in cloud)	P6 [S5]	Rain (conv.[b])	3.35×10^{-4}	0.79
	P7 [S5]	Rain (dyn.[c])	8.40×10^{-5}	0.79
	P8 [S5]	Snow (conv.)	3.35×10^{-4}	0.79
	P9 [S5]	Snow (dyn.)	8.05×10^{-5}	0.305
Both[d]	P10[S2]	Both	5.00×10^{-5}	0.8
	P11[S8]	Both	1.00×10^{-4}	0.8
	P12[S9]	Both	8.00×10^{-5}	0.8
	P13[S10]	Both	4.00×10^{-5}	1
	P14[S11]	Both	3.40×10^{-5}	0.59

[a] This parameterization is applied both for rain and snow, [b] convective rainou
dynamic rainout, [d] this parameterization is applied both for washout and rainc



Morino et al. *ES&T* (2013)

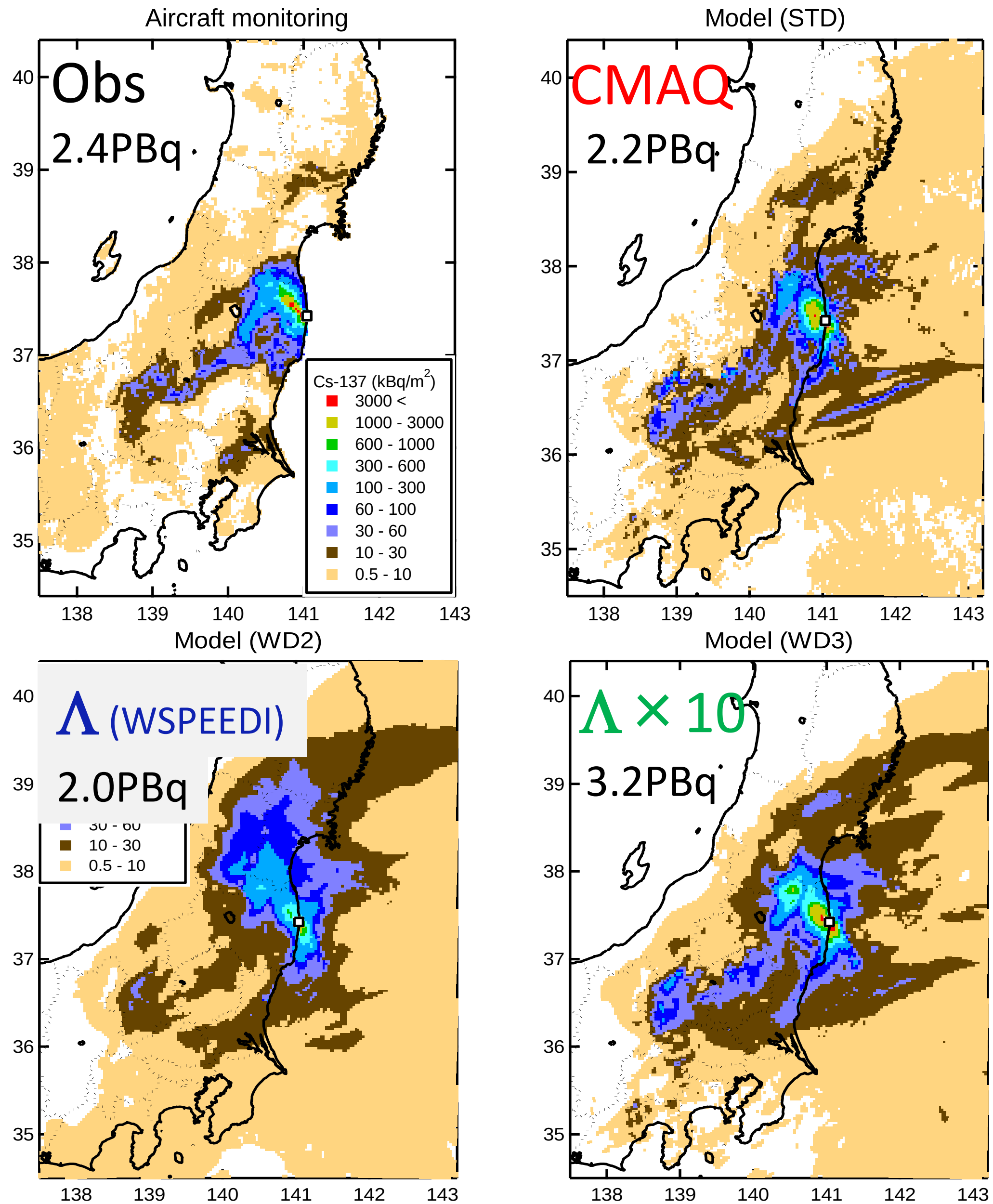
RESULTS

^{137}Cs deposition —Sensitivity to **WET DEPOSITION** modules

STD: wet-dep. module in CMAQ

WD2 (wet dep. module of WSPEEDI): deposition amount is smaller and deposition areas are far from NPP

WD3 (wet dep. module of WSPEEDI: $\Lambda \times 10$): similar to standard case



Morino et al. *ES&T* (2013)

RESULTS

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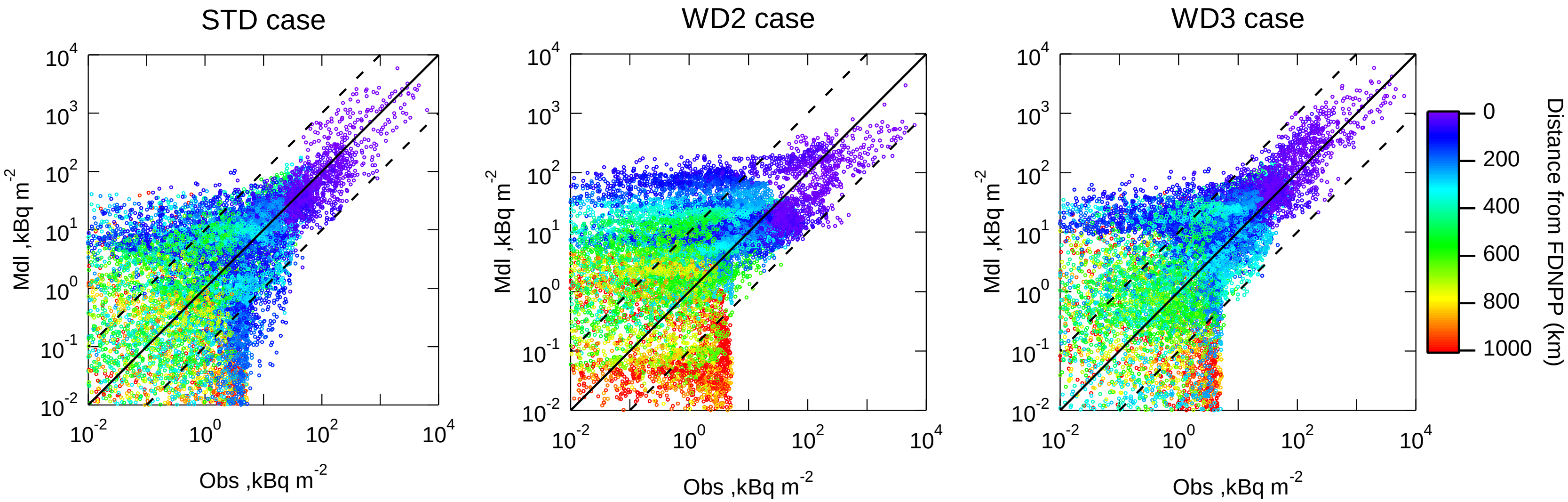

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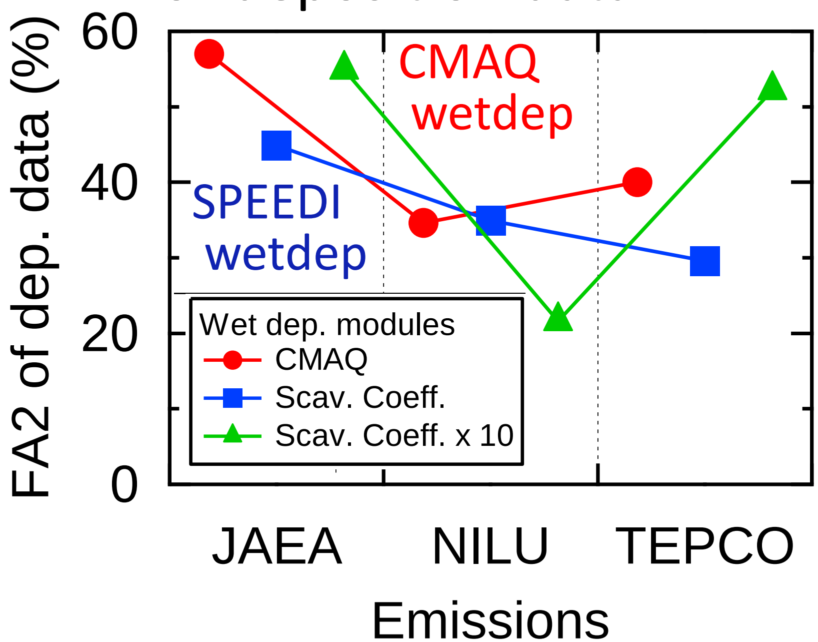
Morino et al. *ES&T* (2013)

MODEL EVALUATION using atmospheric deposition/concentration data

FA2 (% of 0.5<Model/Obs<2)

for deposition data

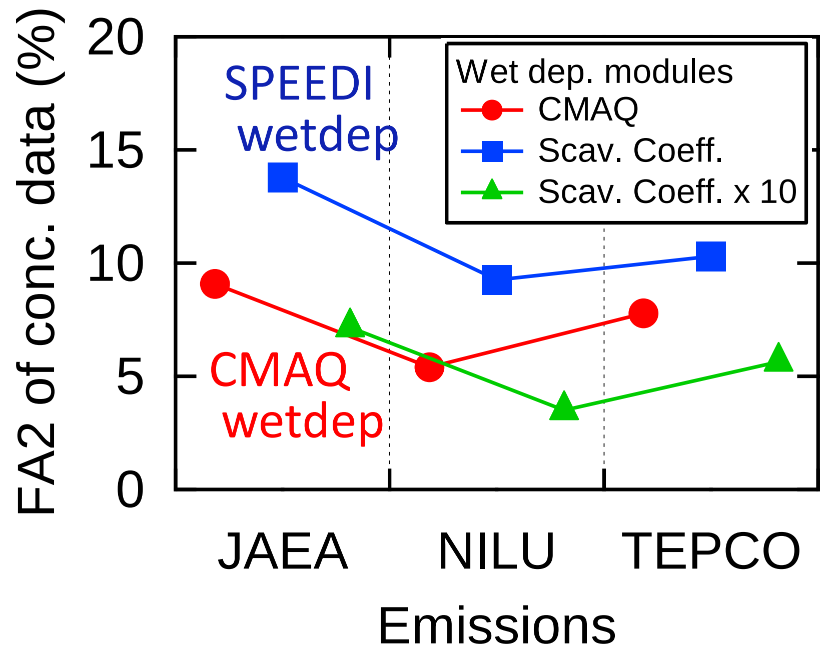


Reproduced best by

- CMAQ wetdep
- JAEA emissions

FA2 (% of 0.5<Model/Obs<2)

for concentration data



Reproduced best by

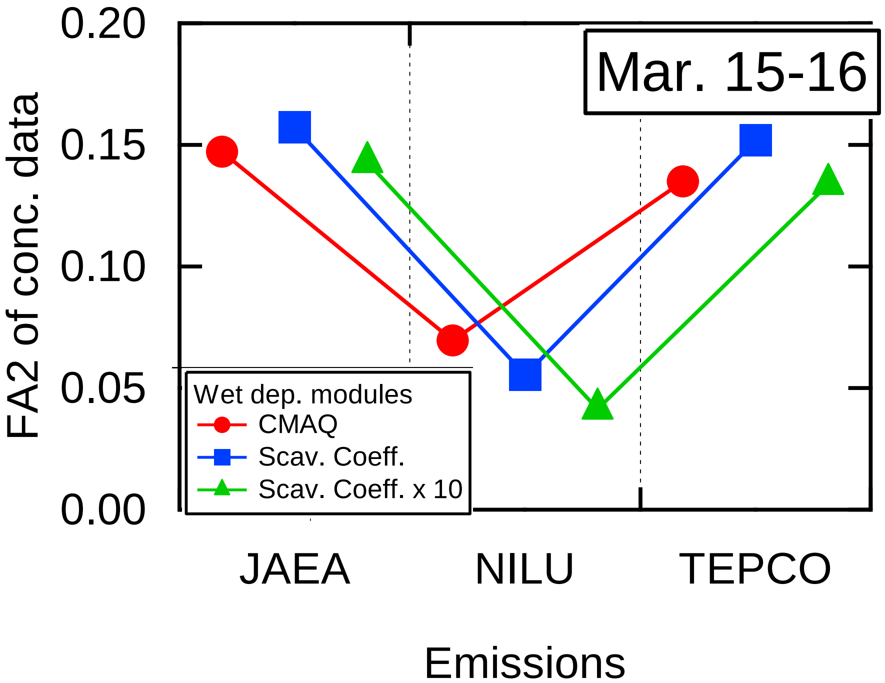
- SPEEDI wetdep
- JAEA emissions

Best setup is different between deposition and concentration data

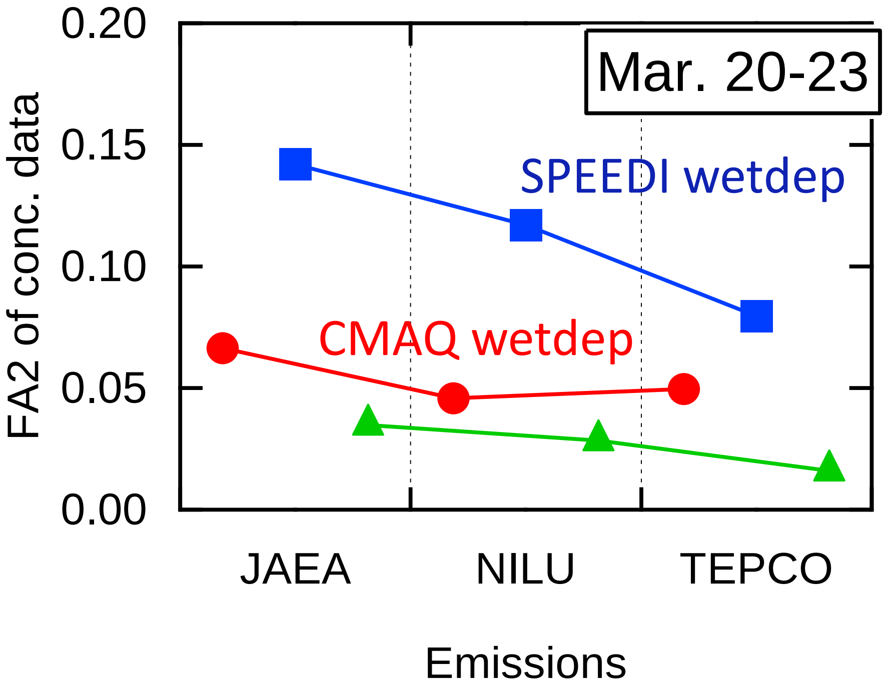
RESULTS

MODEL EVALUATION using atmospheric deposition/concentration data

FA2 (% of 0.5<Model/Obs<2) for concentration data



Low sensitivity to wetdep modules



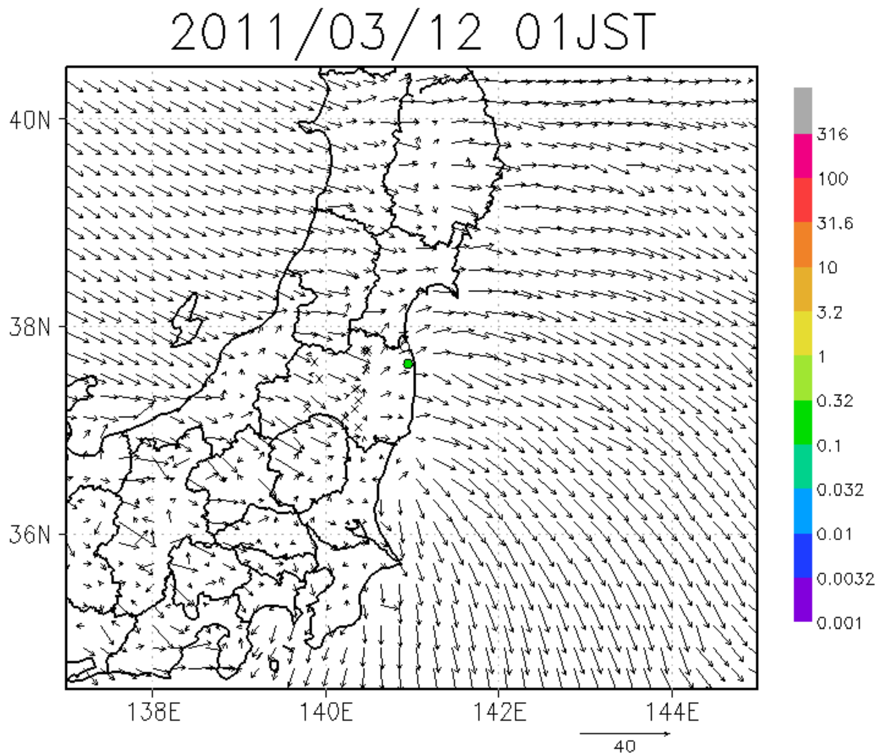
Best reproduced by SPEEDI wetdep

Sensitivity to wet deposition modules is very different between the two events.

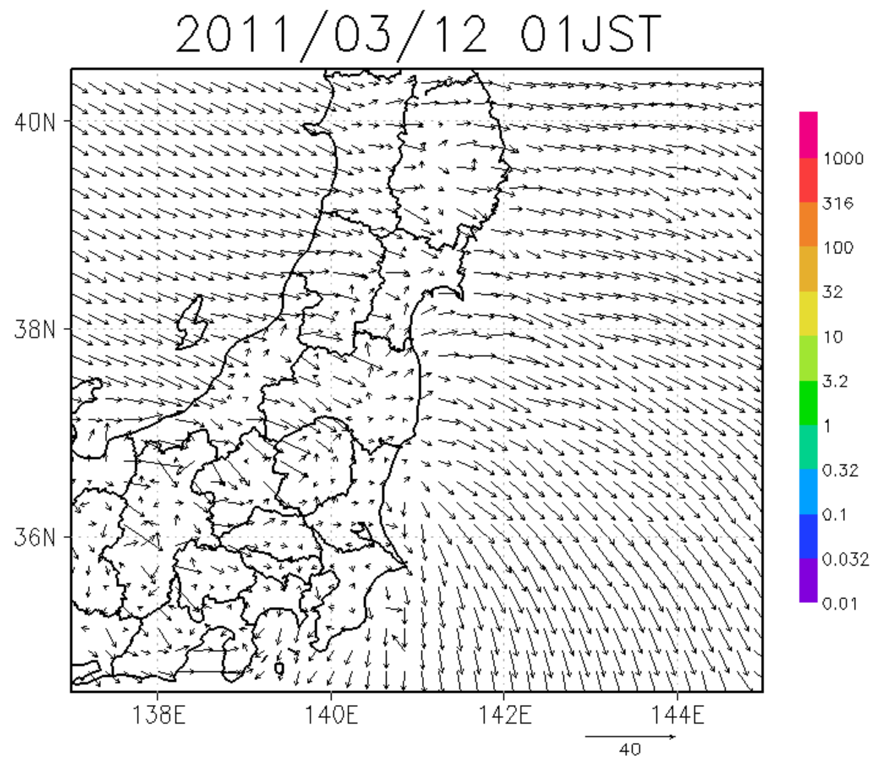
RESULTS

MODEL RESULTS of standard simulation

Concentration of ^{137}Cs [Bq/m^3]



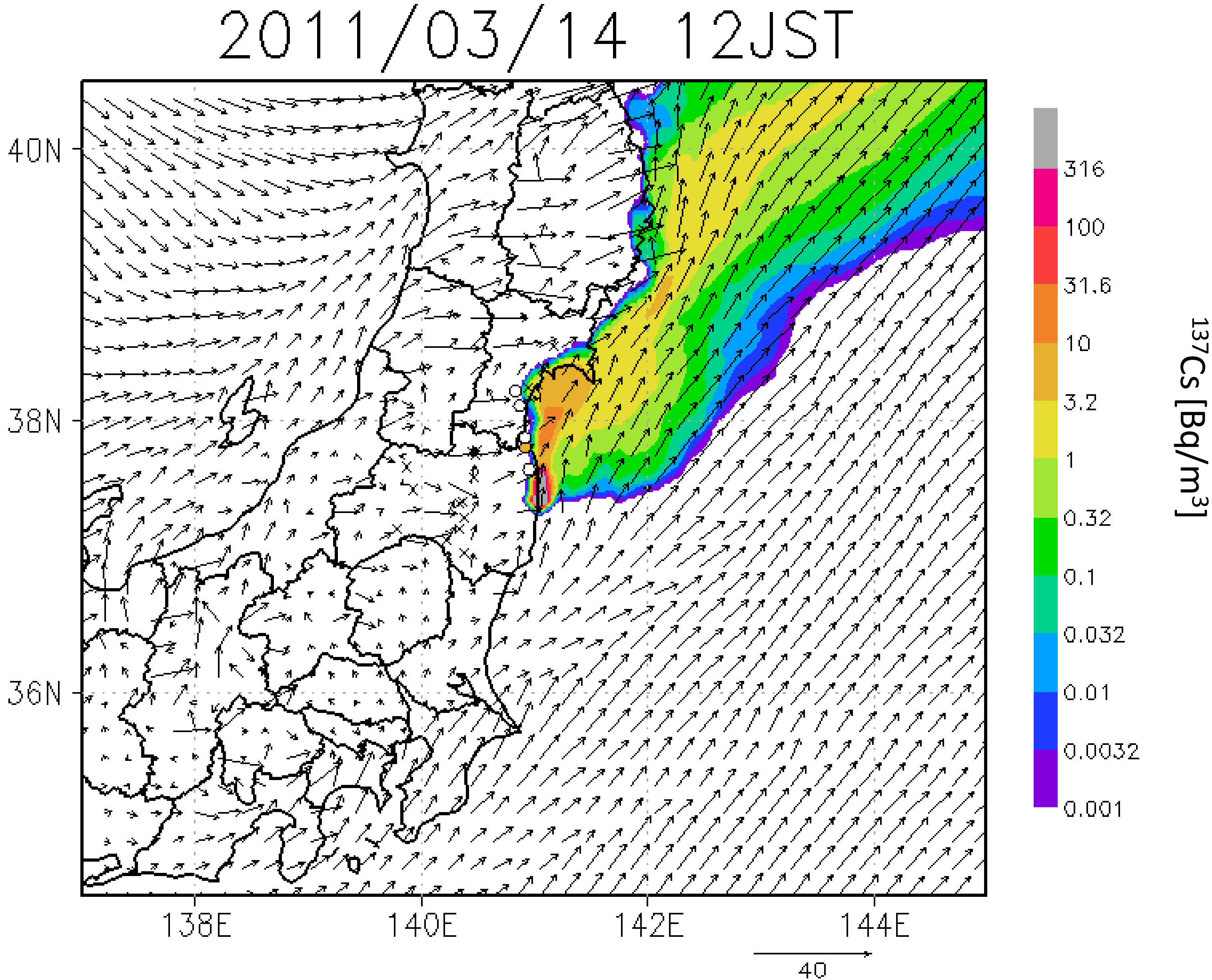
Accumulated deposition of ^{137}Cs [Bq/m^2]



RESULTS

ATMOSPHERIC CONCENTRATIONS

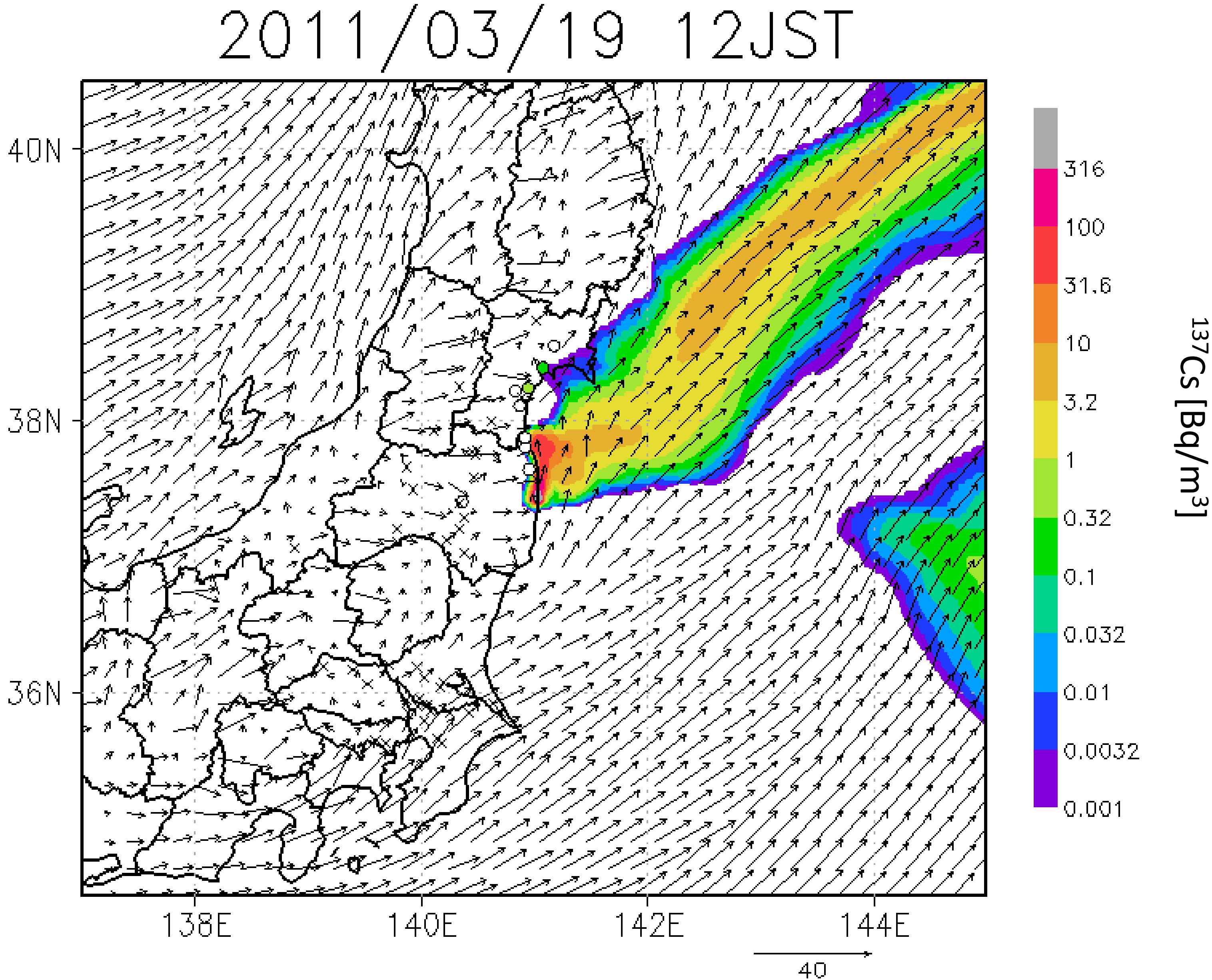
by the standard simulation during MARCH 14-16, 2011



RESULTS

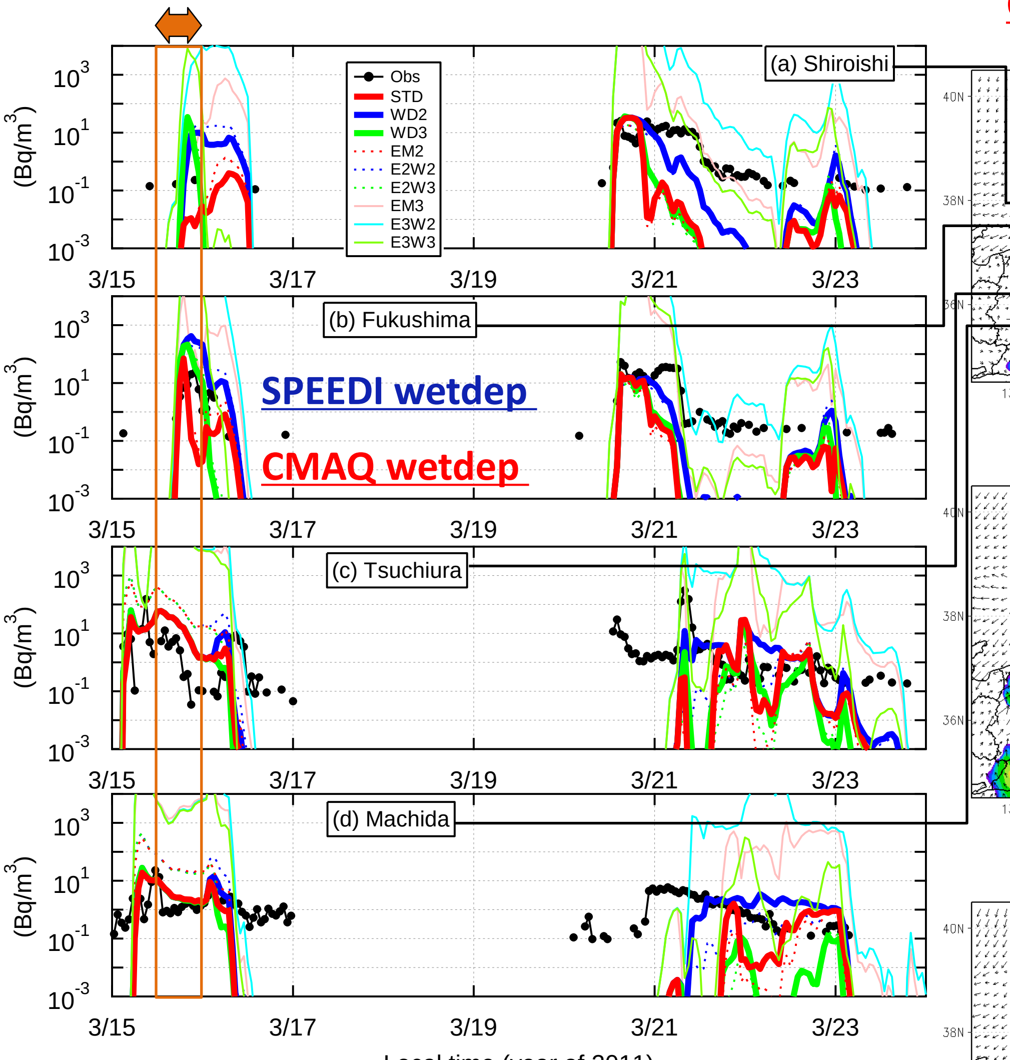
ATMOSPHERIC CONCENTRATIONS

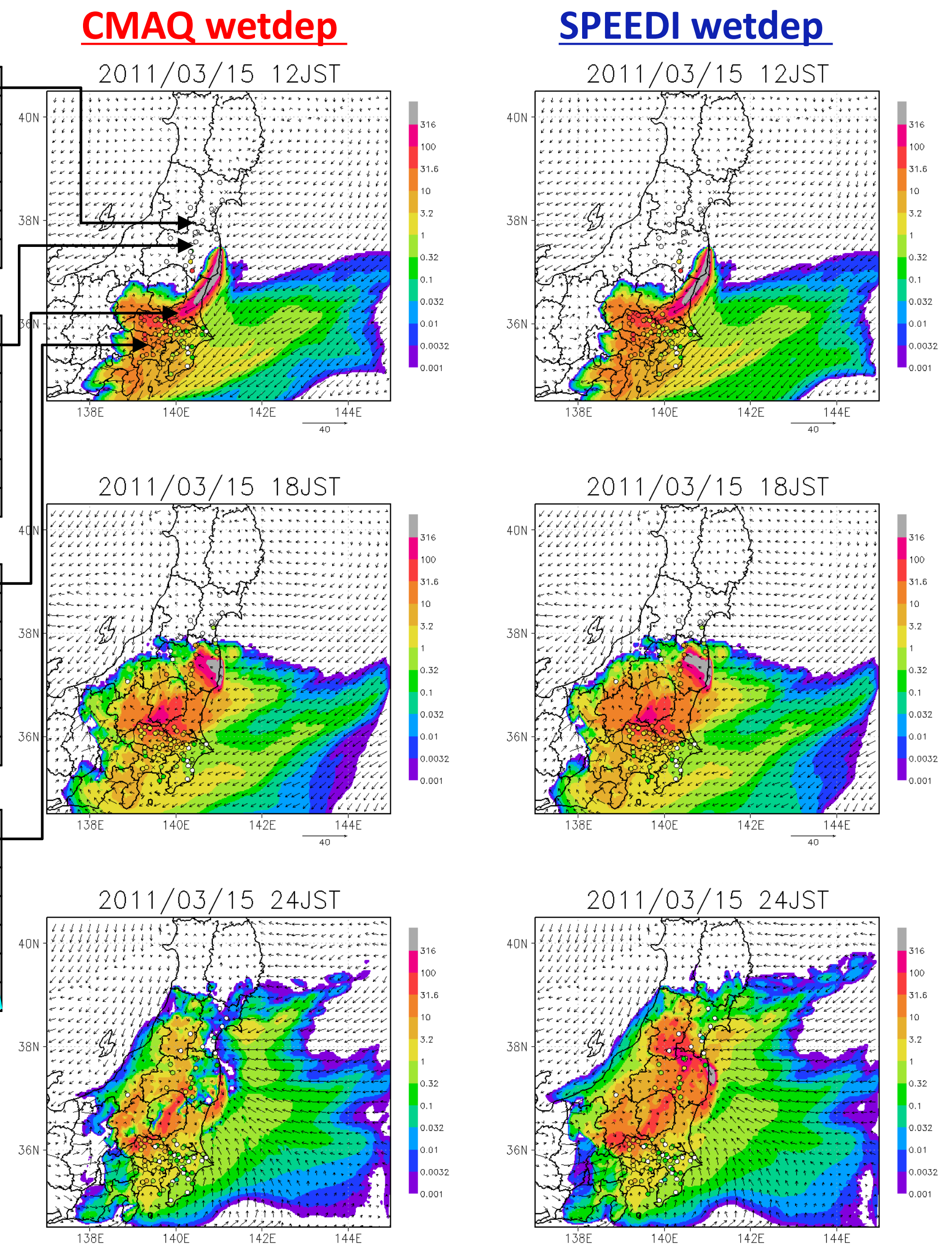
by the standard simulation during MARCH 19-23, 2011



RESULTS

ATMOSPHERIC CONCENTRATIONS on MARCH 15, 2011

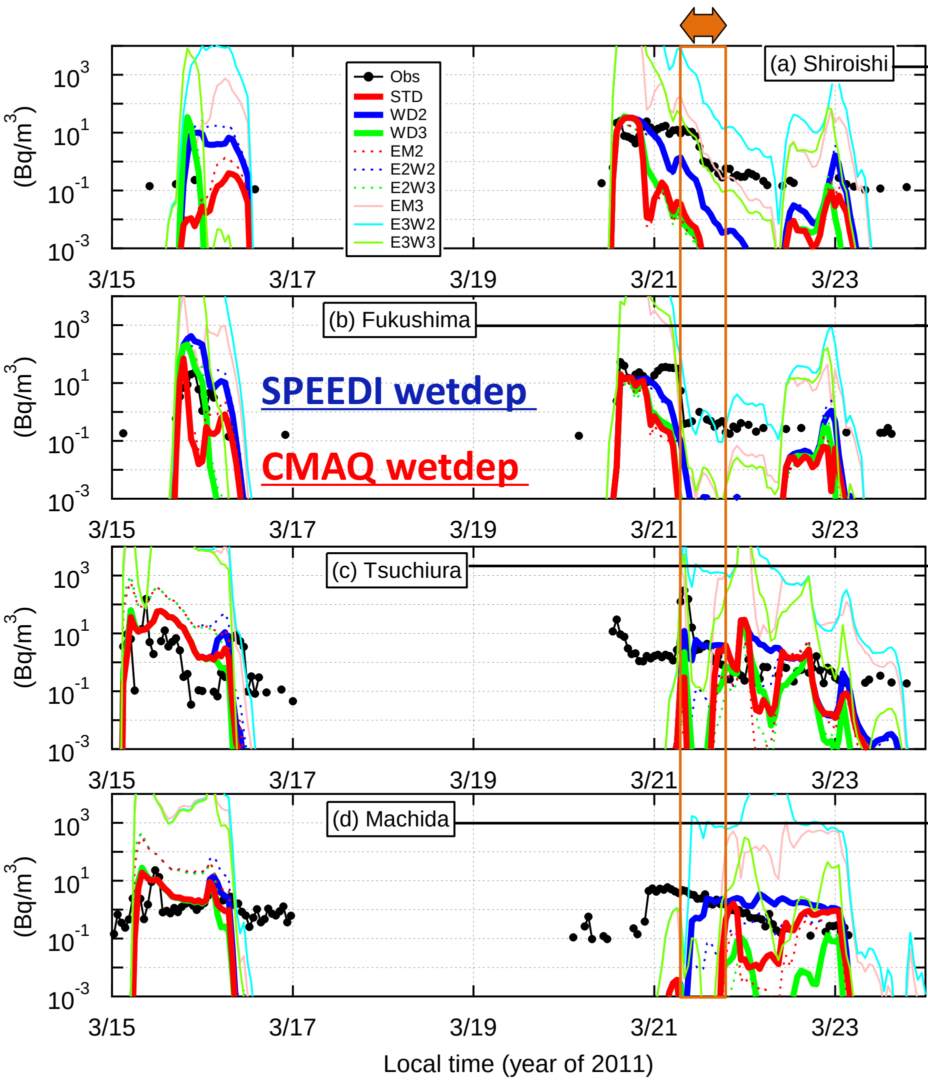


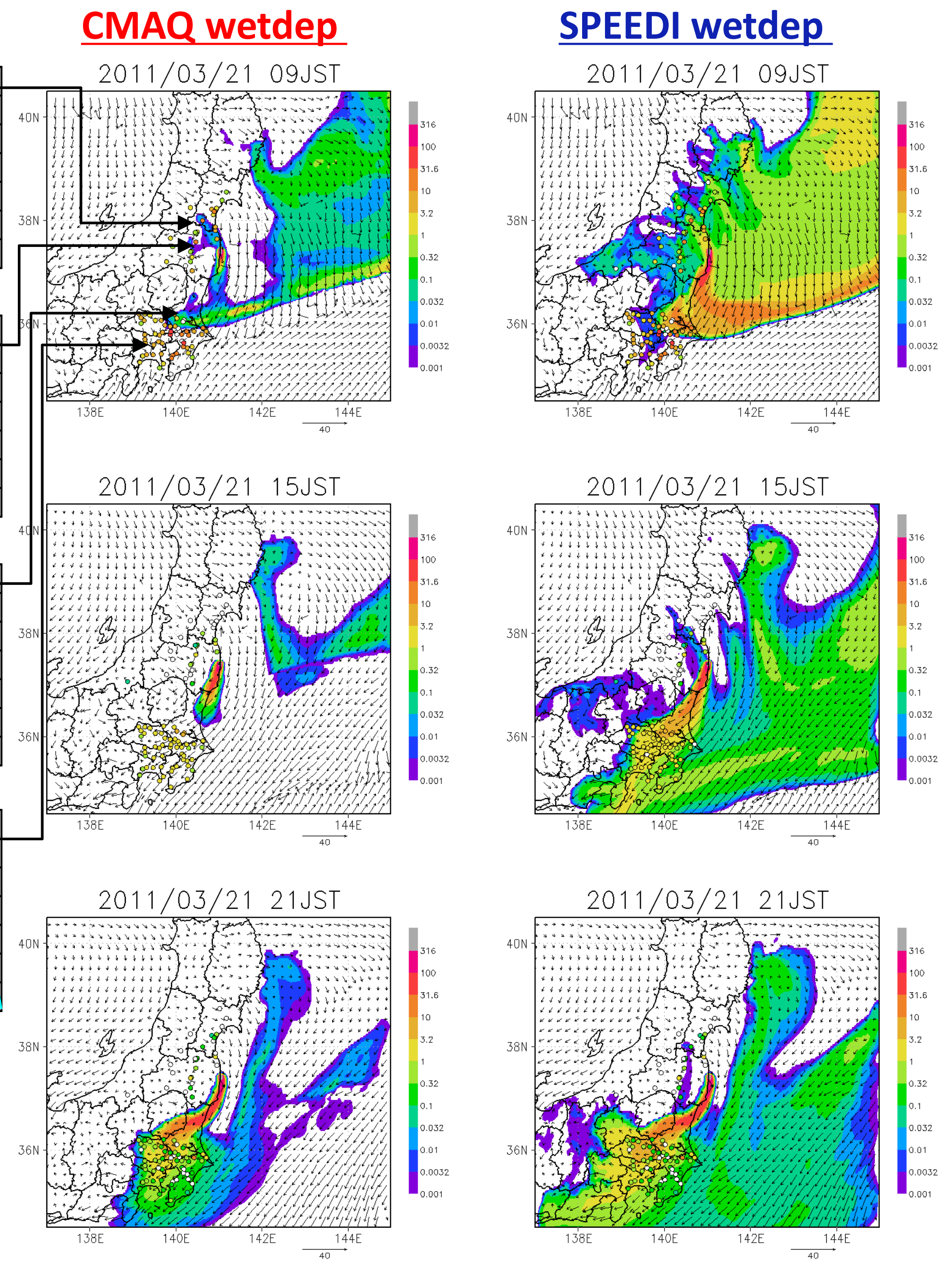


Differences between the two simulations in north of FDNPP

RESULTS

ATMOSPHERIC CONCENTRATIONS on MARCH 21, 2011



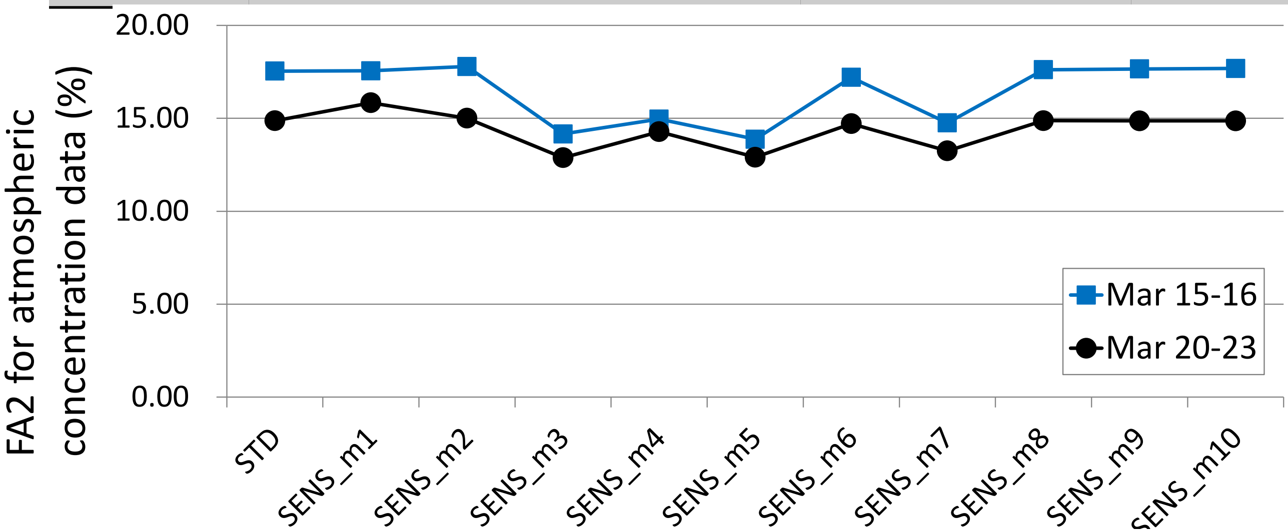


Highly sensitive to wet deposition modules

RESULTS

Sensitivities to setups of a METEOROLOGICAL MODEL

	Microphysics	PBL	Surface-layer	Land-surface	Cumulus	Nudging
STD	**WSM 5-class**	**Mellor-Yamada-Janjic (Eta) TKE**	**Monin-Obukhov (Janjic Eta)**	**unified Noah land-surface model**	**Grell-Devenyi ensemble**	**guv=2.5e-4 (PBL off)**
SENS_m1	STD	STD	STD	STD	STD	OBSGRID
SENS_m2	**WRF double moment, 5-class**	STD	STD	STD	STD	STD
SENS_m3	STD	**YSU**	**MM5 Monin-Obukhov**	STD	STD	STD
SENS_m4	STD	**ACM2 (Pleim)**	**MM5 Monin-Obukhov**	STD	STD	STD
SENS_m5	STD	**ACM2 (Pleim)**	**Pleim-Xiu**	**Pleim-Xiu**	STD	STD
SENS_m6	STD	STD	STD	STD	**Kain-Fritsch (new Eta)**	STD
SENS_m7	STD	STD	STD	STD	**Betts-Miller-Janjic**	STD
SENS_m8	STD	STD	STD	STD	STD	**guv=2.5e-4 (PBL on)**
SENS_m9	STD	STD	STD	STD	STD	**guv=2.5e-3 (PBL on)**
SENS_m10	STD	STD	STD	STD	STD	**guv=0.01 (PBL on)**



Low sensitivity to physical modules and nudging parameters of WRF

WRF v3.3 was used (instead of WRF v3.1)

Summary

- We evaluated sensitivities of model setups (**source-term, wet deposition and meteorological schemes**) to simulations of atmospheric depositions and concentrations of radiocesium.
- Simulation using emissions estimated with a **regional-scale model (JAEA)** and **a diagnostic wet deposition module (CMAQ)** better reproduced the **observed deposition pattern** in eastern Japan.
- However, wet deposition module using **scavenging coefficients (SPEEDI)** better reproduced **observed atmospheric concentrations**.
- Simulated concentration was **not sensitive** to physical modules and parameterizations of a **meteorological model**.