

3rd model intercomparison projects of atmospheric dispersion model for ^{137}Cs emitted from Fukushima Daiichi Nuclear Power Plant, and application of MIPs' results for usage in an emergency

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Acknowledgement :

- Project of Environmental Restoration and Conservation Agency, Japan (JPMEERF2018100)

What we have done in this study?

1. 3rd Model Intercomparison Project (MIP) of ATDM for ^{137}Cs emitted from FDNPP (Sato et al. 2020)
2. Discussion about how to use ATDM's results in emergency situation

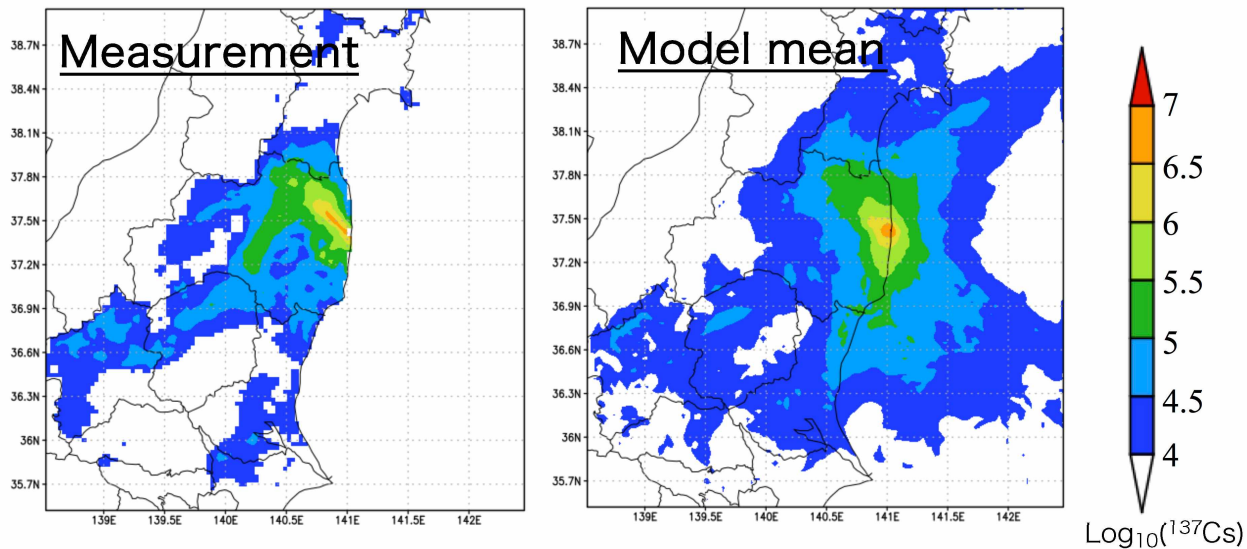
My presentation in EGU 2018

2nd Atmospheric Model Intercomparison Project for Fukushima Daiichi Nuclear Power Plant Accident on March 2011 ~ 2nd FDNPP-MIP

Poster number : EGU2018-2882

Yousuke Sato, Nagoya University

Cumulative deposition amount of Cs-137 during March 2011



Purpose and Participants in 2nd MIP (Sato et al. 2018)

Participants

Purpose

- Estimate uncertainties originated from physical components of the model
- Obtain multi-model ensemble mean for atmospheric concentrations of Cs-137 emitted from FDNPP

Unique point of this MIP

- Identical meteorological data
(3 km, 10 min)
- Identical emission
(Katata et al. 2015)
- Same grid resolution (3km)

Model name	Institute	Reference
AIST-MM	AIST	Kondo (2001)
Pello	FOI	Schoenberg et al. (2014)
HIRAT	Fukushima Univ.	Hirao et al. (2013)
IdX	IRSN	Mathieu et al. (2012)
GEARN	JAEA	Katata et al. (2015)
WRF-Chem	JAMSTEC	Grell et al. (2005)
NHM-Chem	MRI	Kajino et al. (2013)
WRF-CMAQ	NIES	Morino et al. (2013)
SCALE	Nagoya Univ.	Nishizawa et al. (2015)
Polyphemus/ WRF-Chem	Tsinghua Univ.	Brandt et al. (2002)/ Hu et al. (2014)
NICAM-Chem	U-Tokyo	Uchida et al. (2017)

Purpose and Participants in 3rd MIP (Sato et al. 2020)

Participants

Purpose

- Estimate uncertainties originated from **physical components** of the model
- Obtain **multi-model ensemble mean** for atmospheric concentrations of Cs-137 emitted from FDNPP

Unique point of this MIP

- Identical meteorological data
(1 km, 1 hour)
- Identical emission
(Katata et al. 2015)
- Same grid resolution (1 km)

Model name	Institute	Reference
AIST-MM	AIST	Kondo (2001)
Pello	FOI	Schoenberg et al. (2014)
IdX	IRSN	Mathieu et al. (2012)
GEARN	JAEA	Katata et al. (2015)
WRF-Chem	JAMSTEC	Grell et al. (2005)
NHM-Chem	MRI	Kajino et al. (2013)
WRF-CMAQ	NIES	Morino et al. (2013)
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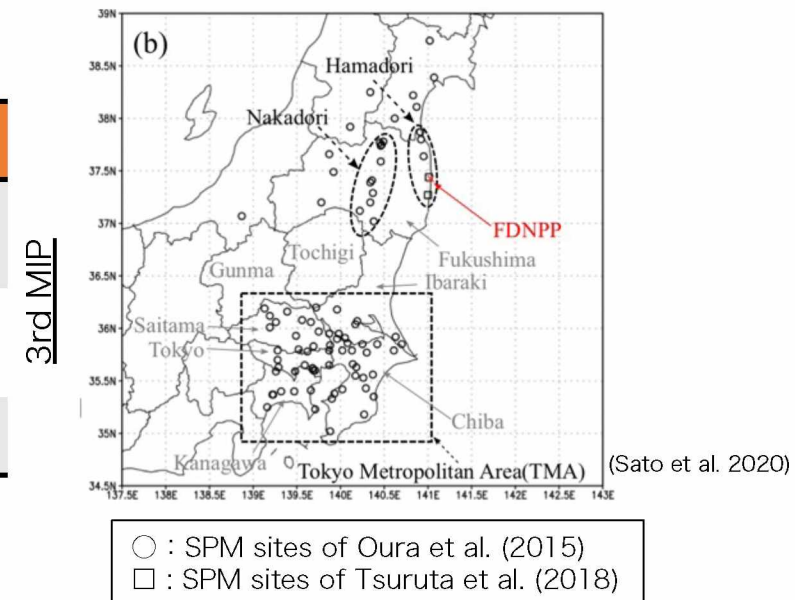
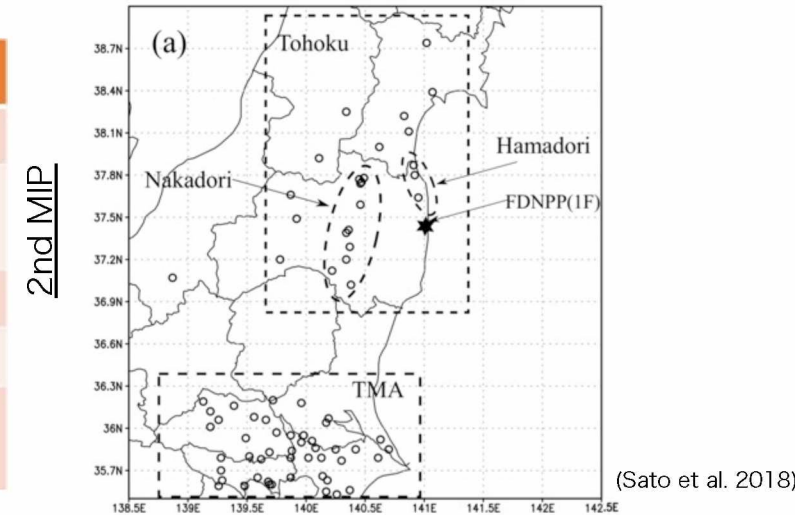
Difference between 2nd and 3rd MIP

List of configuration of MIPs

	3rd MIP	2nd MIP
Domain size	Left figure (b)	Right figure (a)
Initial/Lateral condition	NHM-LETKF ($dx=1km$) (Sekiyama and Kajino 2020)	NHM-LETKF ($dx=3km$) (Sekiyama et al. 2015)
Emission	Katata et al. (2015)	
Calculation Period	2011, Mar. 11 ~ Mar. 31	2011, Mar. 11 ~ Mar. 23
Horizontal grid spacing	1 km	3 km

Data	
Atmospheric Concentration of ^{137}Cs	SPM [hourly] (Oura et al. 2015, Tsuruta et al. 2018)
Deposition amount of ^{137}Cs	Aircraft measurement over land (MEXT 2011)
Meteorological field	AMeDAS operated by JMA

Calculation domain



Evaluation for Deposition amount

Score for evaluation

$$\text{RANK} = \text{CC}^2 + \left(1 - \left|\frac{\text{FB}}{2}\right|\right) + \frac{\text{FMS}}{100} + \left(1 - \frac{\text{KSP}}{100}\right)$$

(Draxler et al. 2015)

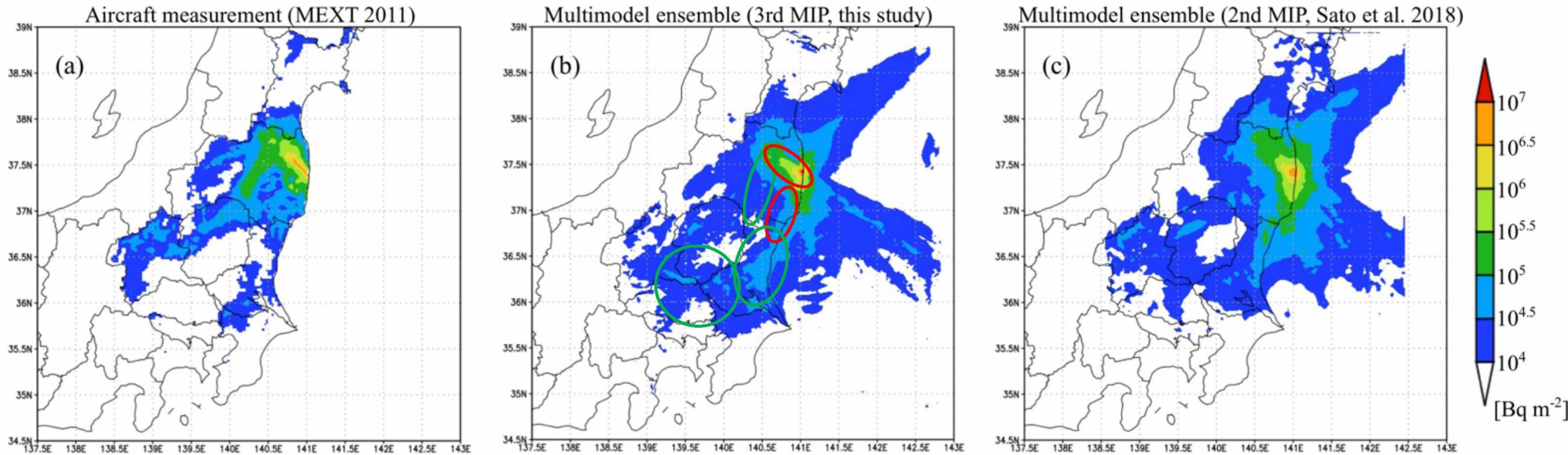
$$\text{CC} = \frac{\Sigma(D_{\text{model}} - \overline{D_{\text{model}}})(D_{\text{obs}} - \overline{D_{\text{obs}}})}{\sqrt{\Sigma(D_{\text{obs}} - \overline{D_{\text{obs}}})^2 \Sigma(D_{\text{model}} - \overline{D_{\text{model}}})^2}},$$

$$\text{FB} = 2 \times \frac{\overline{D_{\text{model}}} - \overline{D_{\text{obs}}}}{\overline{D_{\text{model}}} + \overline{D_{\text{obs}}}},$$

$$\text{FMS} = 100 \times \frac{A_{\text{obs}} \cap A_{\text{model}}}{A_{\text{obs}} \cup A_{\text{model}}},$$

$$\text{KSP} = \text{Max} |P_{\text{obs}}(D_{\text{ksp}}) - P_{\text{model}}(D_{\text{ksp}})|,$$

Deposition (Multimodel ensemble)



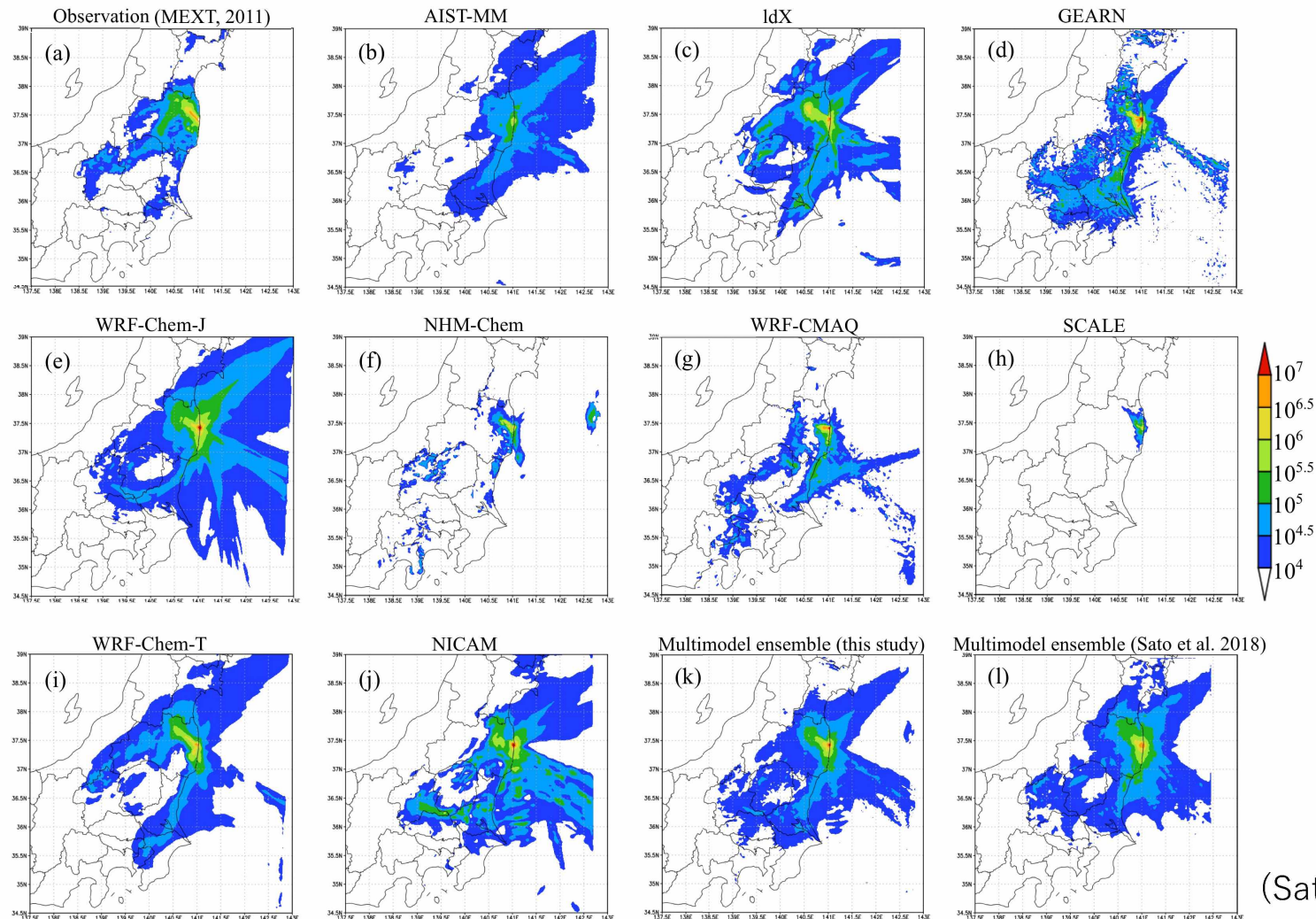
Improvement in deposition distribution from 2nd MIP to 3rd MIP

- Reproduce narrow distribution of northwest of FDNPP
- Reduce overestimation of south of FDNPP

Poor performance of the model in both MIPs

- Underestimation of Nakadori-area
- Overestimation over Ibaraki, Saitama, south of Tochigi.

Deposition amount by each model and by aircraft measurement



Large variability even if the identical met. data and source term were used (as in 2nd MIP)

RANK for total deposition amount

Model	RANK	
	2nd (Sato et al. 2018)	3rd (Sato et al. 2020)
AIST-MM	2.78	1.88
IdX	2.75	2.88
GEARN	2.86	2.65
WRF-Chem-J	2.98	2.63
NHM-Chem	1.90	1.64
WRF-CMAQ	2.38	1.92
SCALE	0.73	0.92
WRF-Chem-T	2.93	2.95
NICAM	2.57	2.50
Ensemble	3.21	2.72

The performance in 3rd MIP was worth than 2nd MIP
Multimodel ensemble showed better score than whole models

Evaluation of models for each plume

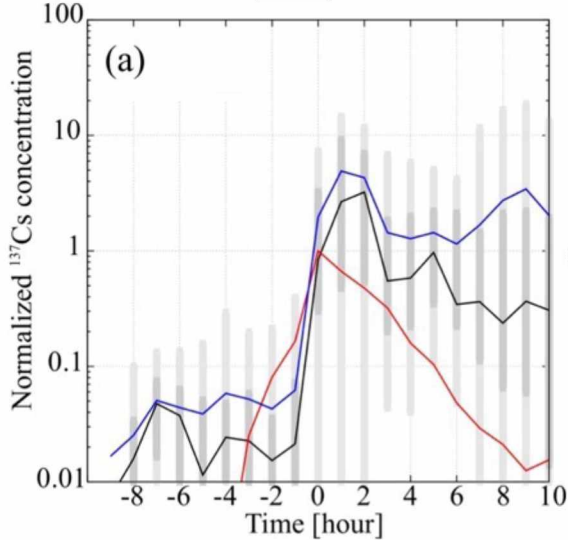
Score for evaluation

$$\text{RANK2} = \frac{\text{FA2}}{100} + \frac{\text{CAPTURE}}{100} + F \times \left(1 - \frac{\text{OVERSESTIMATE}}{100}\right), \quad F = \begin{cases} 0 & (\text{OVERESTIMATE} = 0) \\ 1 & (\text{OVERESTIMATE} \neq 0) \end{cases}$$

(Sato et al. 2018)

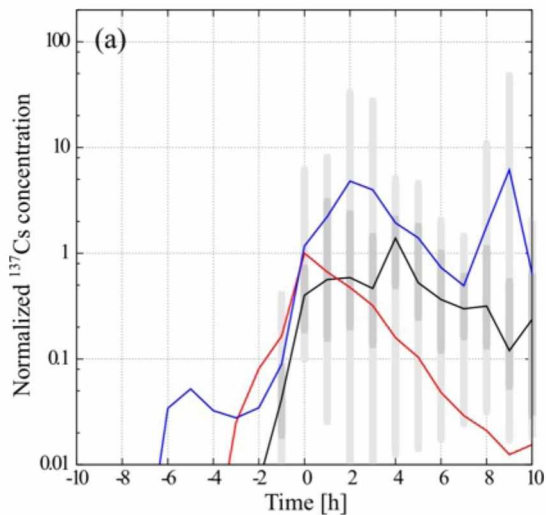
Plume arrival time and Score for atmospheric concentration

2nd



Red : Observation
 Blue: Mean (ensemble)
 Black: Median
 Grey: Range

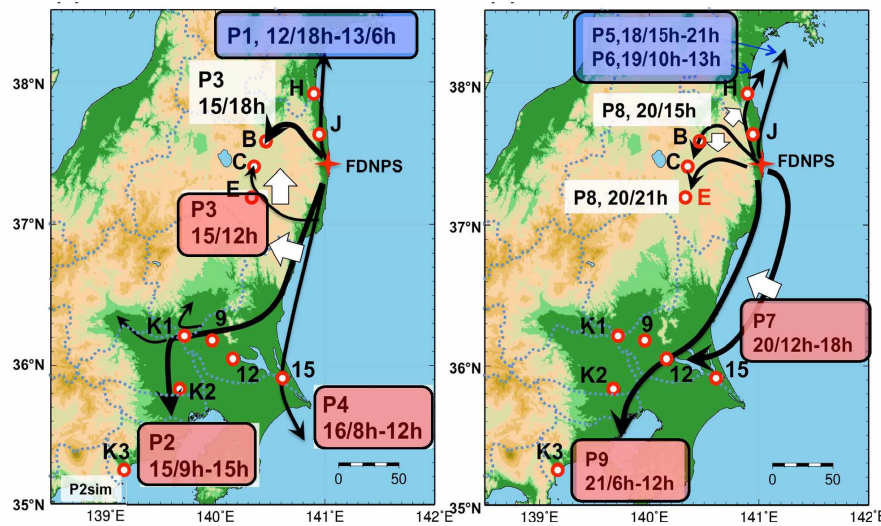
3rd



Model name	3rd RANK2 Sato et al. (2020)	2nd RANK2 Sato et al. (2018)
AIST-MM	1.88	2.78
ldX	2.88	2.75
GEARN	2.65	2.86
WRF-Chem-J	2.93	2.98
NHM-Chem	1.64	1.90
WRF-CMAQ	1.92	2.38
SCALE	0.92	0.73
WRF-Chem-T	2.95	2.93
NICAM-Chem	2.50	2.57
Ensemble	2.72	3.21

- The multimodel ensemble reproduced plume arrival time with 2~3 hours delay
 - The performance in 3rd MIP was worse than 2nd MIP
 - Bad performance of some models was cancelled by good performance of others
- Multimodel ensemble showed better score than each model in both 2nd and 3rd MIP.

Overview of 9 plumes (Tsuruta et al. 2014)



Plume measured near FDNPP (P1, P5, and P6) were not discussed in 2nd MIP due to the coarse grid horizontal resolution in 2nd MIP (Sato et al. 2018)

Nakajima et al., PEPS, 2017.

RANK for each plume (ensemble)

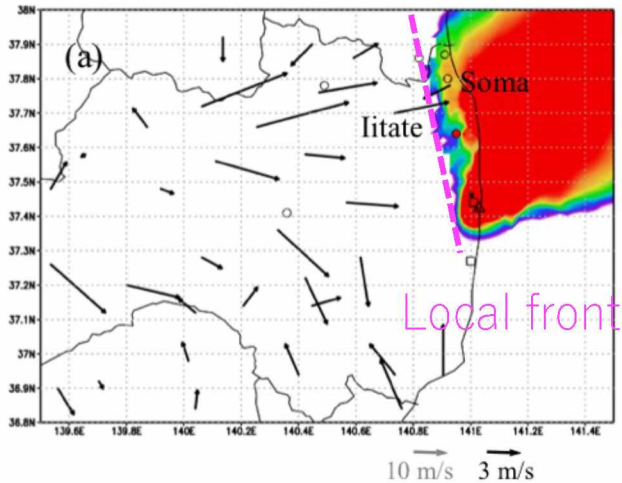
Plume	RANK2
P1	1.42
P2	1.61
P3	1.07
P4	1.24
P5	1.10
P6	1.76
P7	0.78
P8	1.57
P9	0.14

Wind field was not reasonably reproduced for these plumes

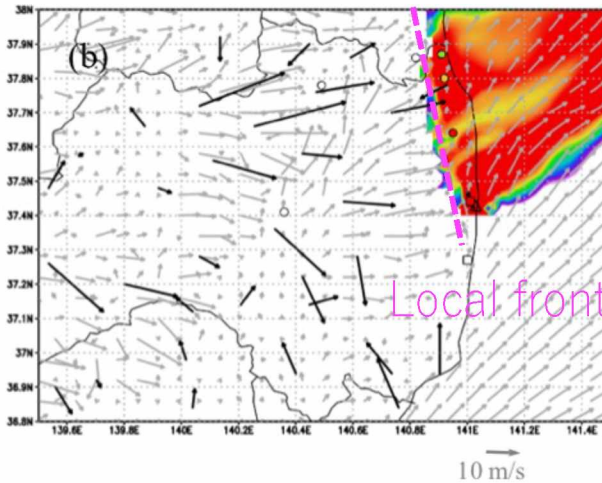
Meteorological field is most critical for reproducing observed ¹³⁷Cs

Plume measured near FDNPP (Plume 1) (Plume 6 was similar characteristics)

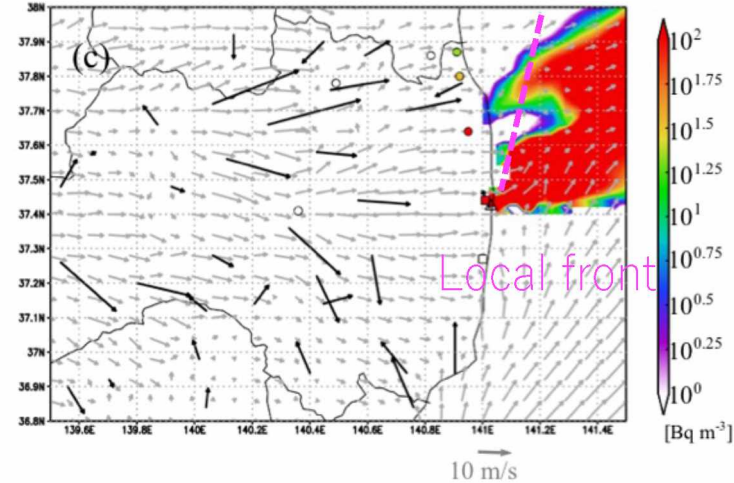
Multimodel ensemble



Model with good performance(SCALE)



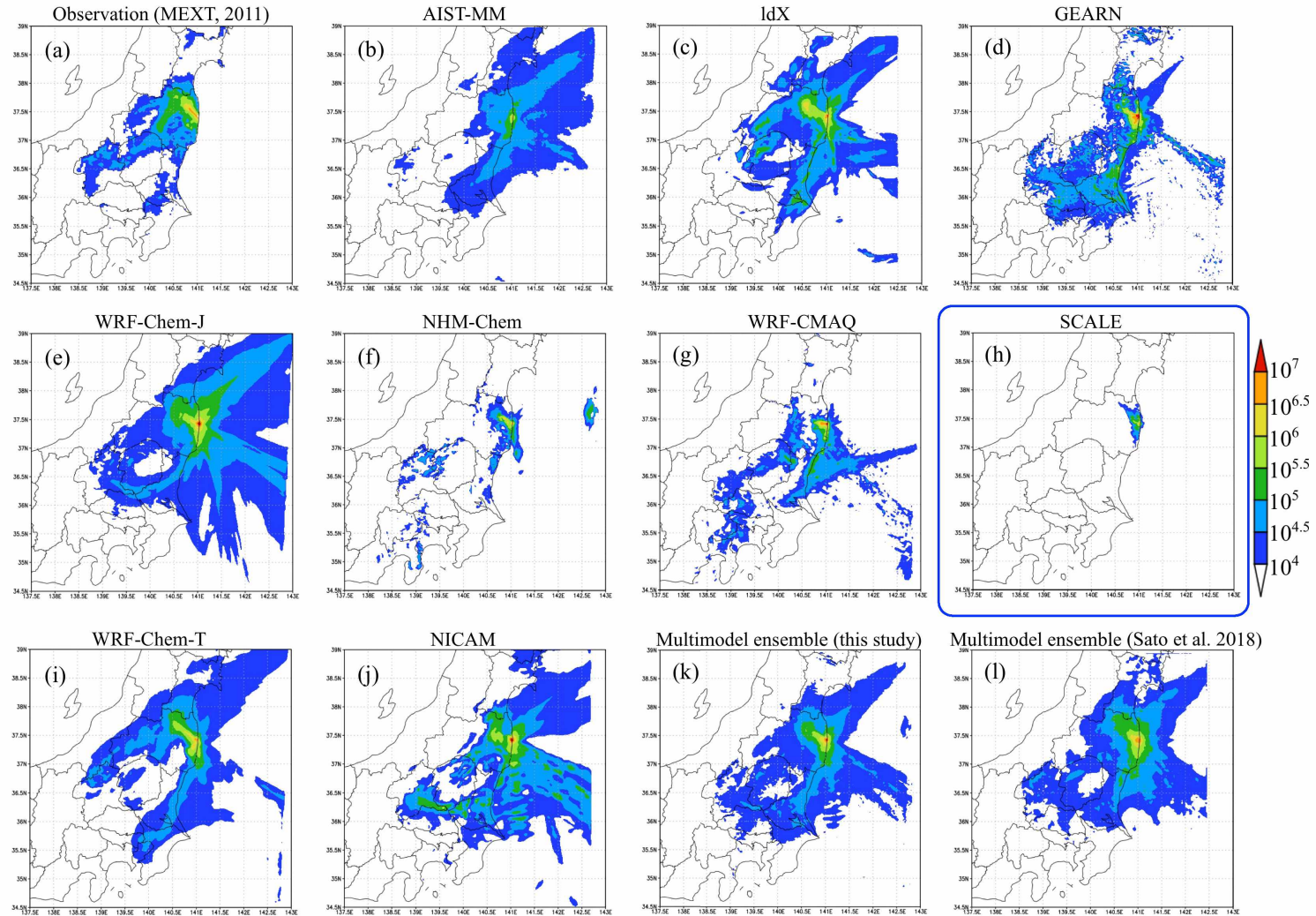
Model with poor performance



(Sato et al. 2020)

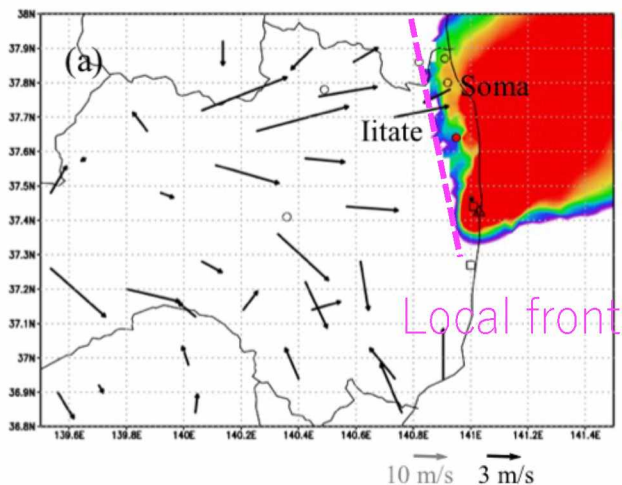
1. Model with good performance reasonably simulated local front around the coastal area
→ Meteorological field is most critical for reproducing observed ^{137}Cs
2. Good performance of some models cancelled poor performance of others

Deposition amount by each model and by aircraft measurement (3rd MIP)

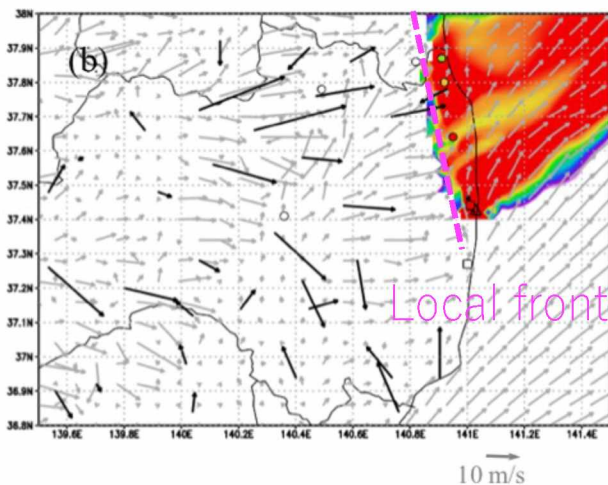


Plume 1 (Plume 6 was similar characteristics)

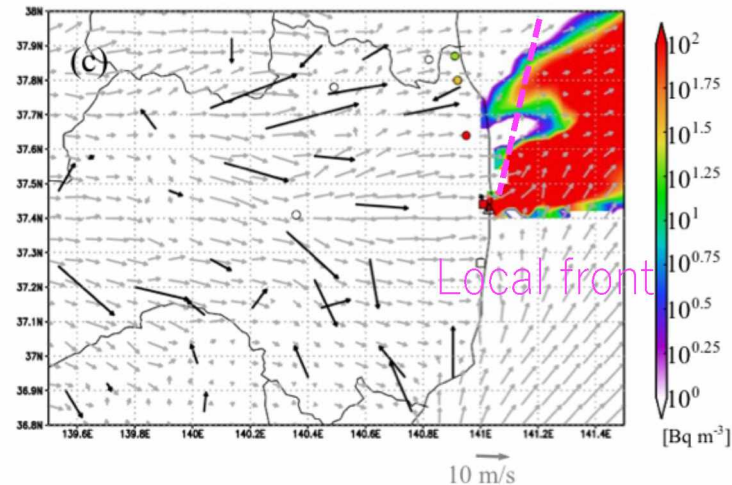
Multimodel ensemble



Model with good performance(SCALE)



Model with poor performance

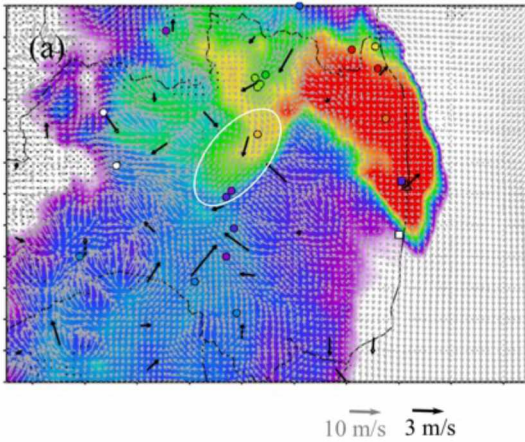


(Sato et al. 2020)

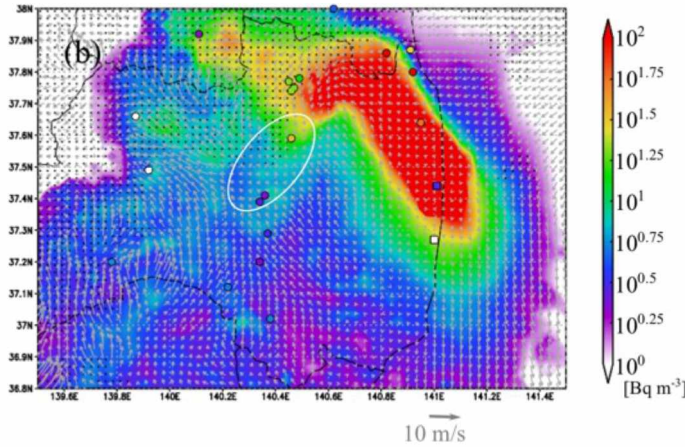
1. Model with good performance reasonably simulated local front around the coastal area
→ Meteorological field is most critical for reproducing observed ^{137}Cs
2. Good performance of some models cancelled poor performance of others
3. Model with good performance for air concentration does not always show good performance for deposition amount

Advantage of using fine grid resolution (Plume 8)

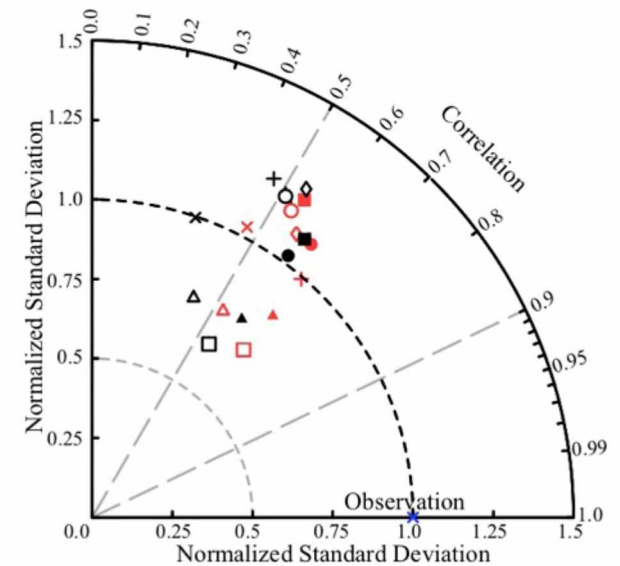
Mutimodel ensemble(3rd)



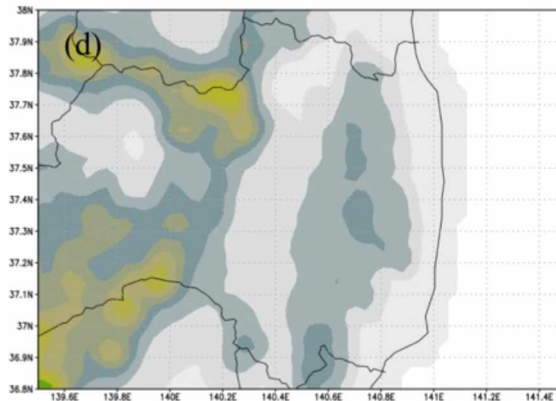
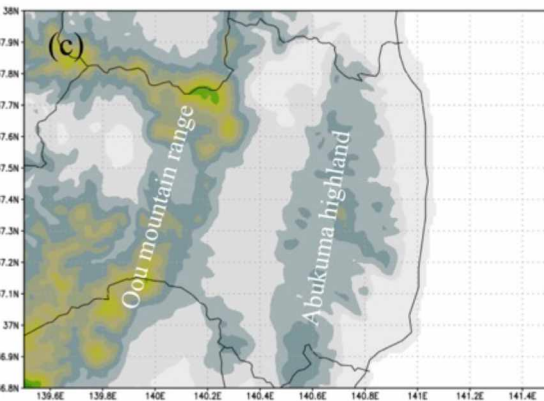
Mutimodel ensemble(2nd)



Taylor diagram for wind field



- Red: 3rd MIP (This study)
- Black: 2nd MIP (Sato et al. 2018)
- + : AIST-MM
- : GEARN
- : WRF-Chem-J
- : NHM-Chem and IdX
- : WRF-CMAQ
- × : SCALE
- ◇ : WRF-Chem-T
- △ : NICAM
- ▲ : Ensemble



Using fine grid resolution, “valley wind” was well reproduced and resulted in good performance of the model

Summary of part 1

1. Performance of the models was evaluated for the plume measured near FDNPP (P1, P5, and P6)
2. In the vicinity of FDNPP, meteorological field and atmospheric dispersion calculations with a fine (1 km or less) grid resolution are needed to evaluate and investigate the atmospheric behavior of atmospheric ^{137}Cs .
3. Good performance of some models can improve the performance of the multimodel ensemble, highlighting the advantage of using a multimodel ensemble.
4. Model with good performance for atmospheric concentration of ^{137}Cs does not always show the good performance in deposition amount of ^{137}Cs .
5. Fine grid spacing does not always result in the good performance, but fine grid spacing is required for simulating events measured in vicinity of FDNPP.

What we have done in this study?

1. 3rd Model Intercomparison Project (MIP) of ATDM for ^{137}Cs emitted from FDNPP (Sato et al. 2020)
2. Discussion about how to use ATDM's results in emergency situation

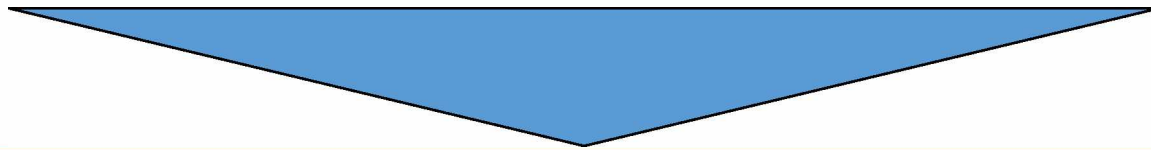
How to use ATDM's results in emergency situation?

□ The advantages of prediction by ATDM

- Predictable in advance
- Possible to grasp spatiotemporal distribution
- Possible to operate at a remote center

□ Disadvantages of prediction by ATDM

- Uncertainty in terrain reproducibility, meteorological data, source information
- Uncertainty in model and input data



- ✓ Consideration of usage so that uncertainty does not increase the risk of exposure

Discussion about the usage of the ATDM's results in emergency situation

□ Target area for the discussion

- ✓ To examine the performance of model ensemble plume prediction for the area within 30 km.

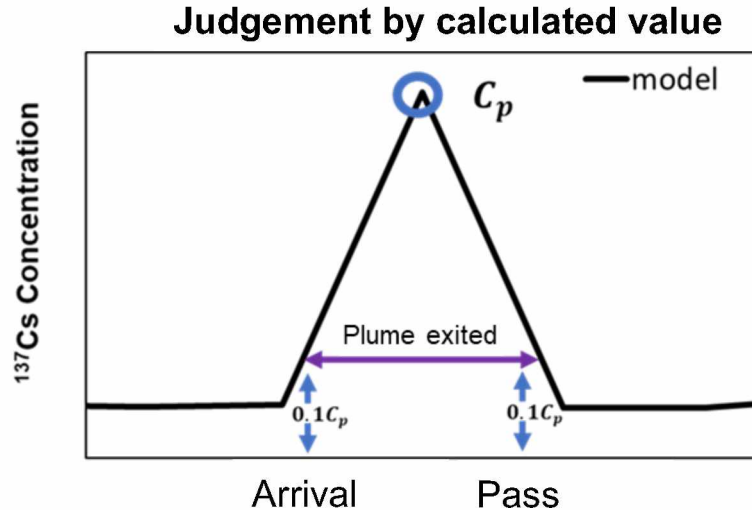
□ Data for examination

- ✓ Results of 9 models participated in the 3rd MIP

How to judge plume arrival and passage

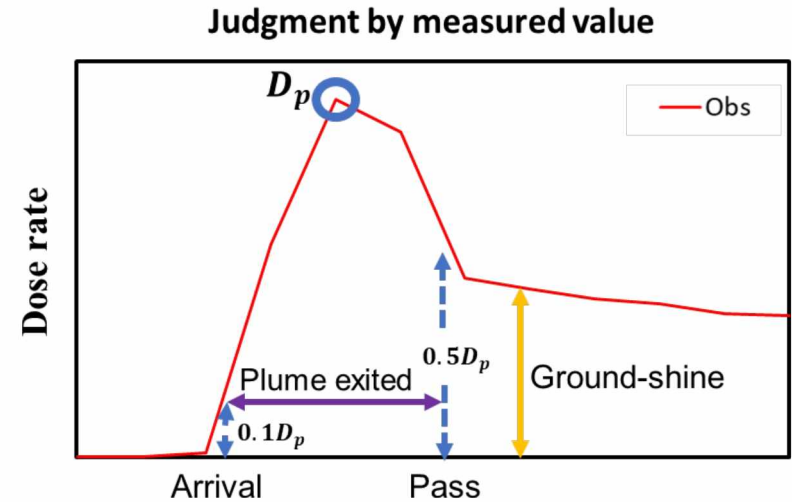
✓ Prediction method (model calculation)

Judgment from time series of ^{137}Cs Concentration at the surface level



✓ Verification method (measured values)

Judgment from time series of air dose rate

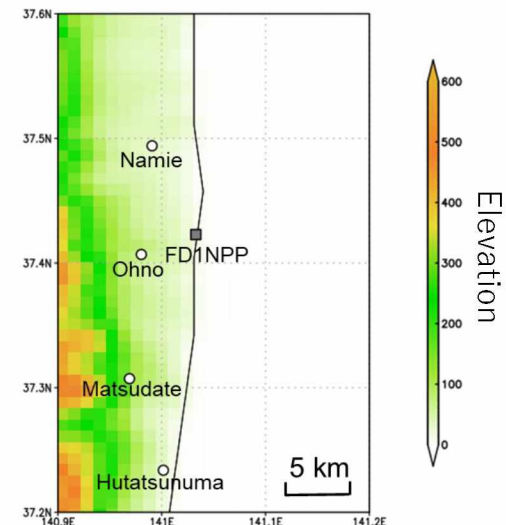


✓ Target points

4 MP points within 30km from FD1NPP

✓ Evaluation period

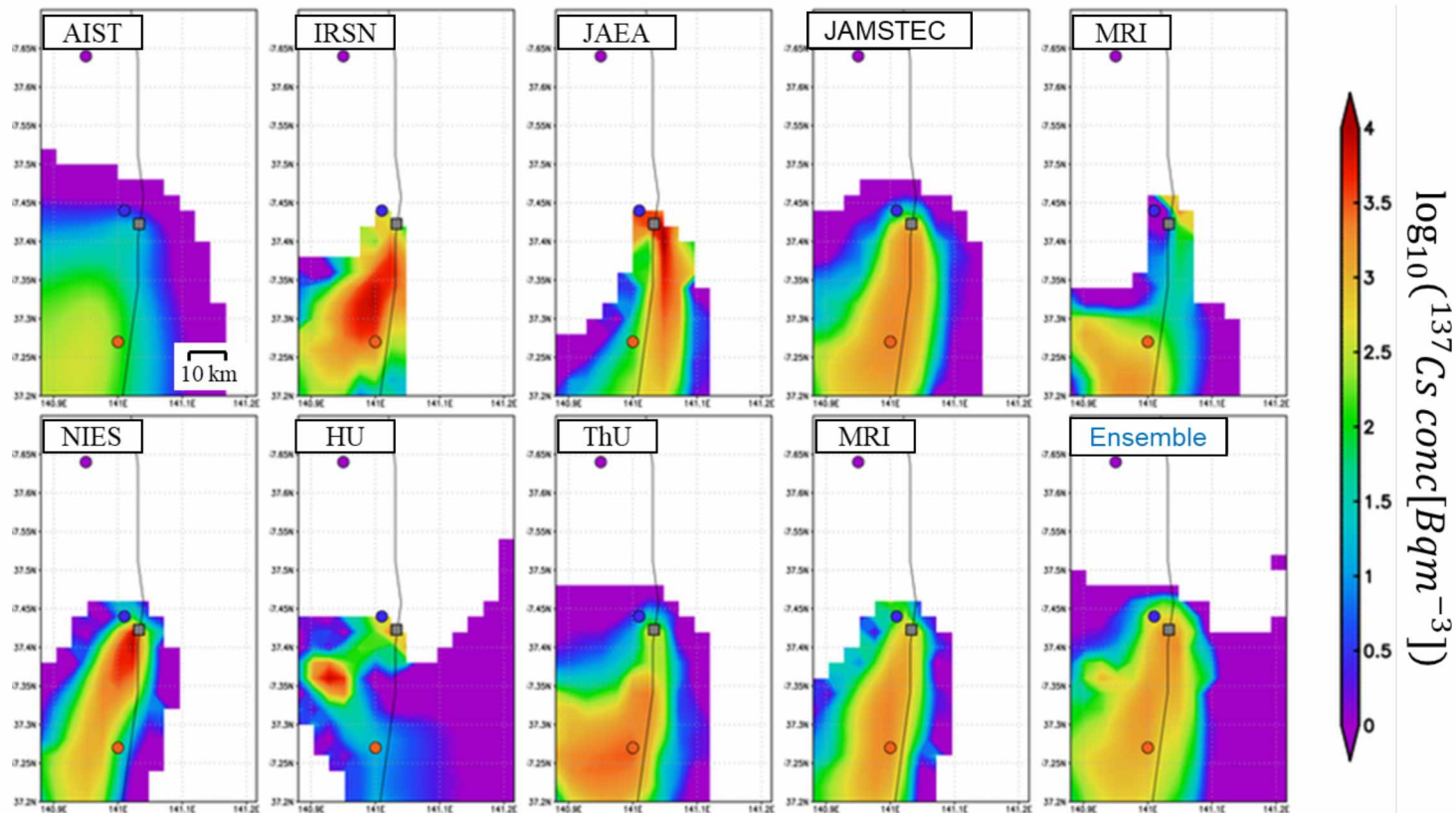
3/12 14:00~ 3/24 8:00 (JST)



Ensemble mean

- ◆ Ensemble mean...The average value of the concentration of each grid
- ◆ Ensemble members are 9 models submitted to the 3rd MIP.

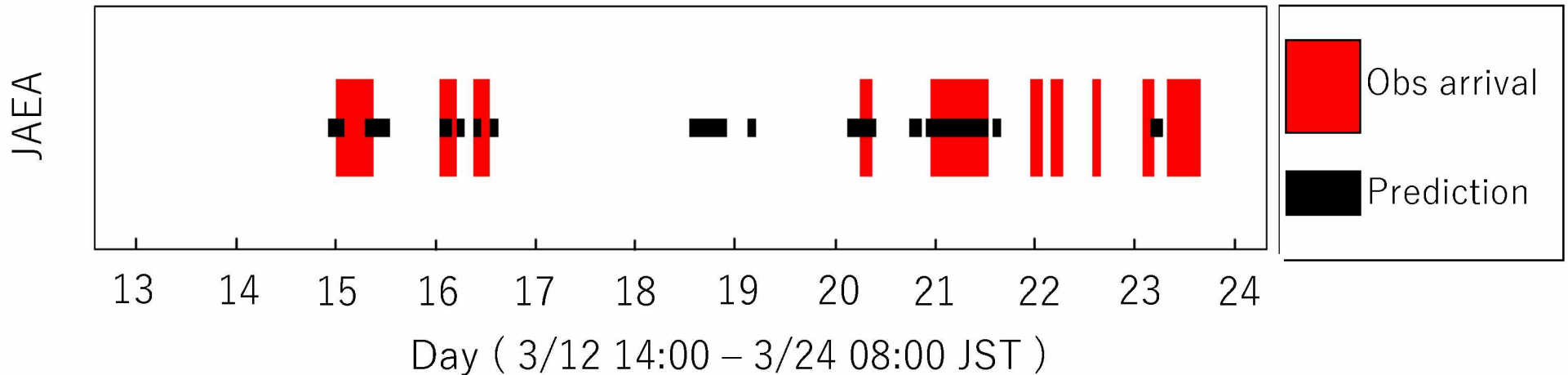
Concentration of ^{137}Cs by each model and its ensemble mean (2011 3/15 01:00 JST)



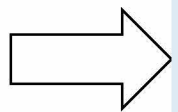
- ✓ Ensemble mean encompass overall features of each model

Plume arrival prediction with a single model

Comparison of arrival prediction and measurement at Hutatsunuma



- The model may predict absence of plume for the cases where plume actually arrived.
- There is a time lag in the plume arrival prediction.

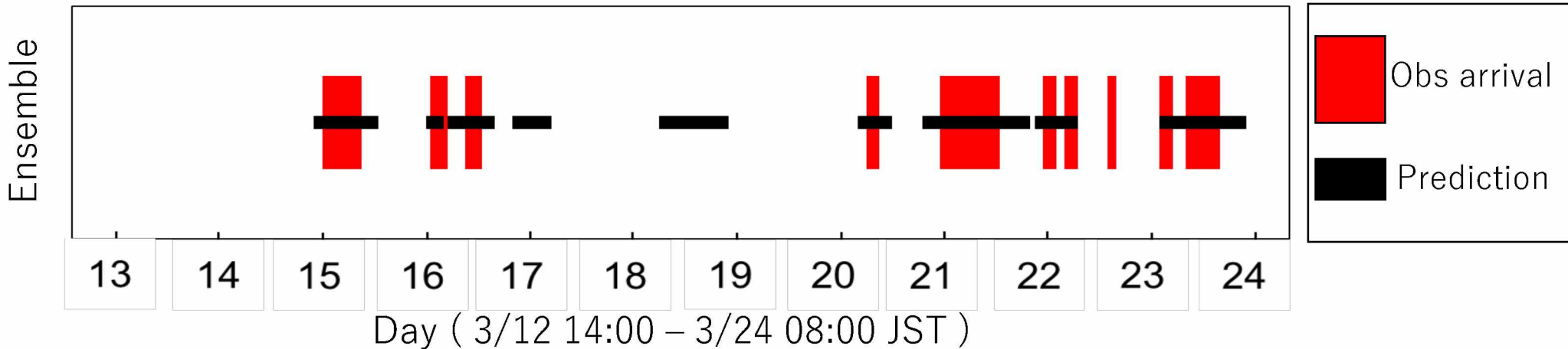


✓ Arrival prediction with a single model is not sufficient.

Plume arrival prediction with multiple models

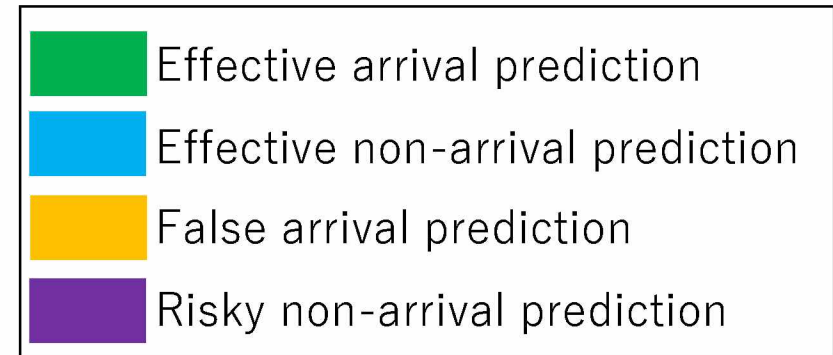
□ Evaluation of plume arrival prediction of model ensemble

Comparison of plume arrival prediction and measurement at Hutatsunama



Evaluation of plume arrival at all 4 points (time fraction)

		Model.	
		Plume	No
Obs.	Plume	0.152	0.033
	No	0.280	0.534



✓ Plume arrival can be fairly accurately predicted by the ensemble mean

○ Effective arrival prediction + Effective non-arrival prediction 69%

× Risky non-arrival prediction 3.3% → Necessary to be reduced

Consideration for model uncertainty

□ Uncertainty of model

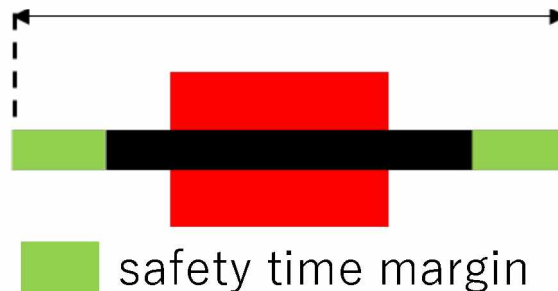
- ✓ Model validation results (Sato et al., 2020, Nakamura, 2021)
 - Time lag of 2 to 3 hours in the plume arrival
 - The axis of plume may deviate by about 1 compass point (22.5°)



□ Use of safety time margin

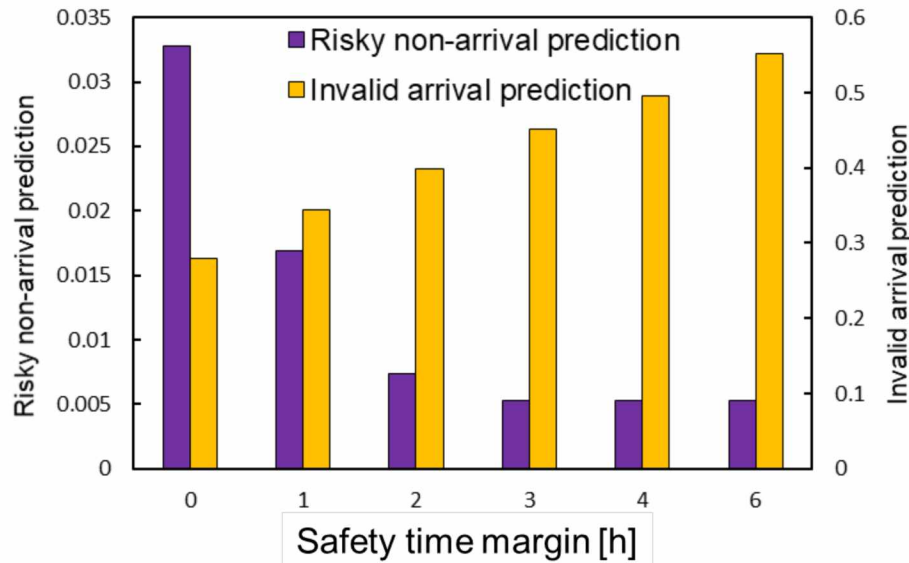
- ✓ Setting safety time margin before and after the periods of plume arrival prediction

Regarded as period of plume existence



Examination of appropriate safety margin

□ Evaluation results of all 4 points ✓ Setting a longer safety margin...



Evaluation of plume arrival at all 4 points with safety margin of 3 h (time fraction)

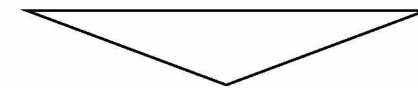
		Model.	
		Plume	No
Obs.	Plume	0.180	0.005
	No	0.452	0.363

→ Risky non-arrival prediction decreased

→ False arrival prediction increased

✓ Beyond 3 h safety margin ...

→ No decrease in risky non-arrival prediction



There is no benefit of setting it longer than 3 hours.

✓ With 3 h of safety margin

Risky non-arrival prediction 3.3% → 0.5%

Effective non-arrival prediction 53% → 36%

Summary of part 2

We verified the emergency usage of the atmospheric dispersion model using the data from FD1NPP accident. We clarified the following.

□ Conclusion

- ✓ It is Insufficient to predict plume arrival with a single model, even one of the best models.
- ✓ Highly accurate arrival prediction is possible by using the ensemble mean.
- ✓ By setting the safety time margin, safer prediction became possible.

□ Future tasks

- ✓ Examination including MP points that were not selected this time to confirm the universality of the present results