Probable maximum damage estimation of the tropical cyclone in future climate

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Impact assessment studies in DPRI

It is required to assess the impacts of extreme weather in future environment.

The DPRI is conducting a comprehensive disaster estimation using the output from very high resolution JMA/MRI AGCM (AGCM20, 20-km in spatial and 1 hour in time resolution), which is running under the KAKUSHIN Program (Innovative Program of Climate Change Projection for the 21st Century) of MEXT (the Ministry of Education, Culture, Sports, Science, and Technology, Japan).

In this presentation we introduce a procedure to assess impacts of strong Typhoon emerged in the Global Warming experiment conducted by MRI.

Topics

1. Identification method of extreme event with high societal impact
2. Dynamical downscaling of the identified extreme typhoon to estimate its possible maximum wind speed and precipitation

Identification method

It is assumed that the societal damage due to extreme weather depends on three factors, **strength of the extreme event**, **potential loss of society** and **the vulnerability** of the society.

Disastrous Event Potential Index (DEPI), $I(n)$, is a measure of the extreme weather to the society.

DEPI for wind *(u can be displaces by precipitation for rain hazard)*

$$I(n) = \sum_{i,j} \sum_{k} p(i,j) q(i,j,k) u(i,j,k)$$

$u(i, j, k)$ is the wind speed at the location (i, j) with historical order k.
$p(i, j)$ is a weighting function of location (i, j) reflecting potential loss.
$q(i, j, k)$ is a weighting function of ranking k at (i, j) reflecting vulnerability.

Top 7 synoptic scale event

rank	event	DEPI score	person		building	
			death	injured	damaged	flooded
1	typhoon T9119 Sep. 1991	689	62	1,499	107,447	22,965
2	typhoon T7920 Oct. 1979	560	111	478	7,523	37,450
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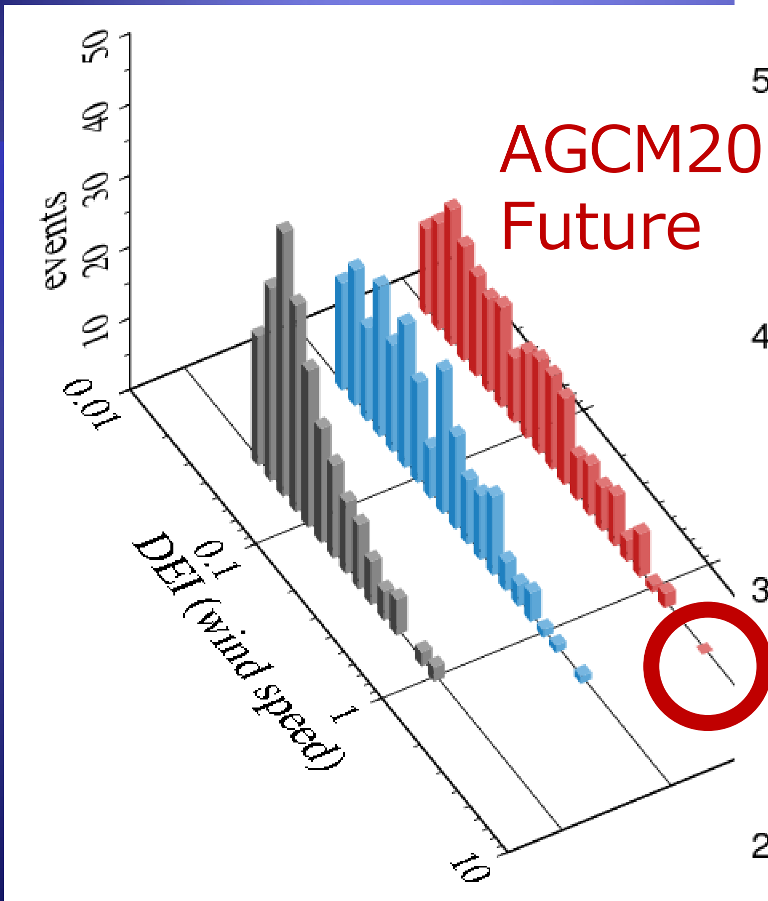
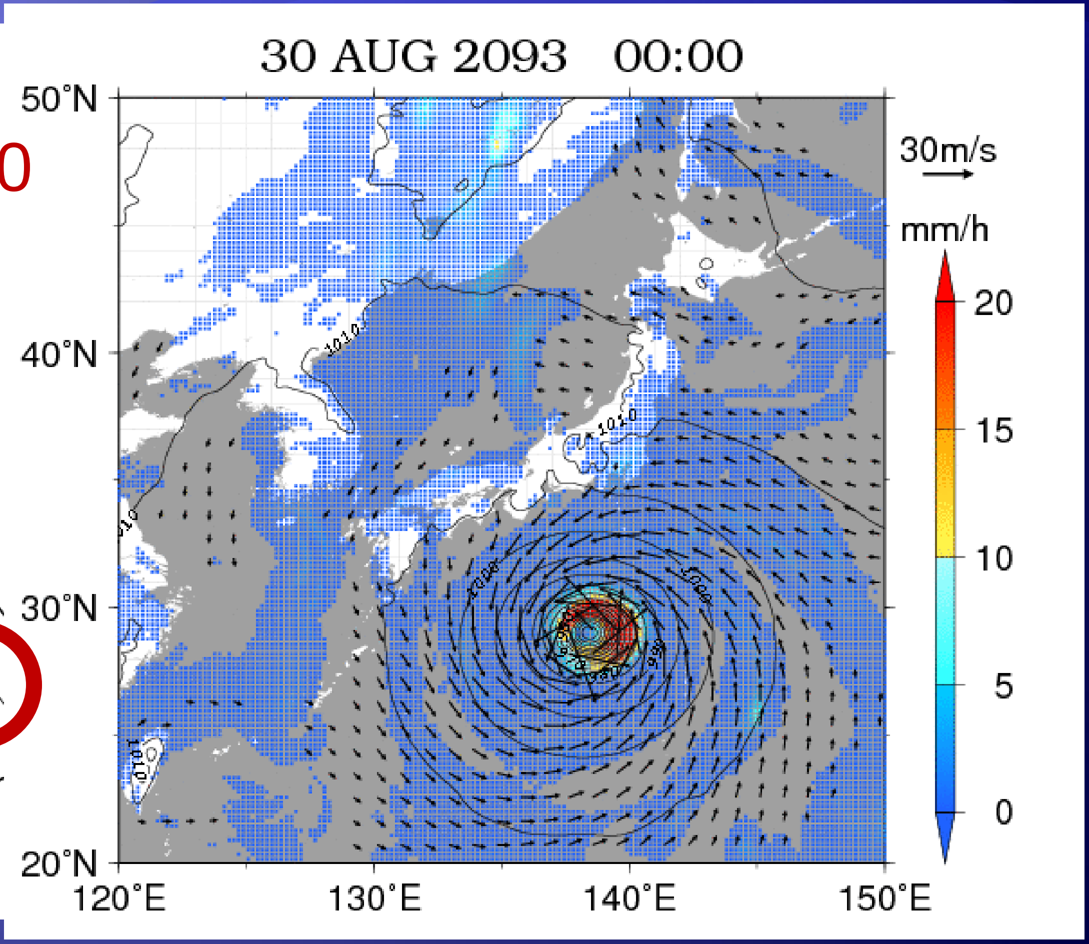
All of them are recorded as a significant event in the reports published by the government agency.

Extreme event in AGCM20 future

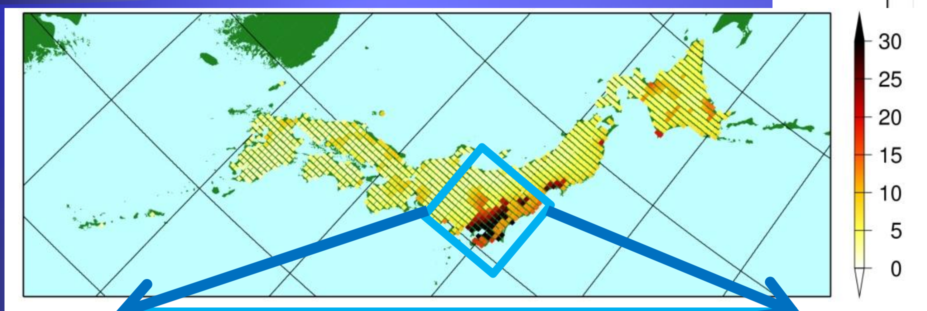


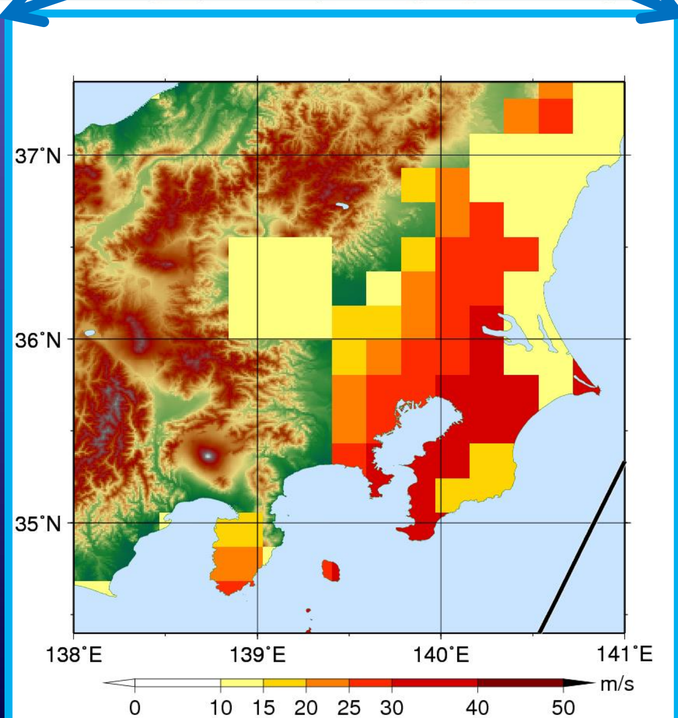


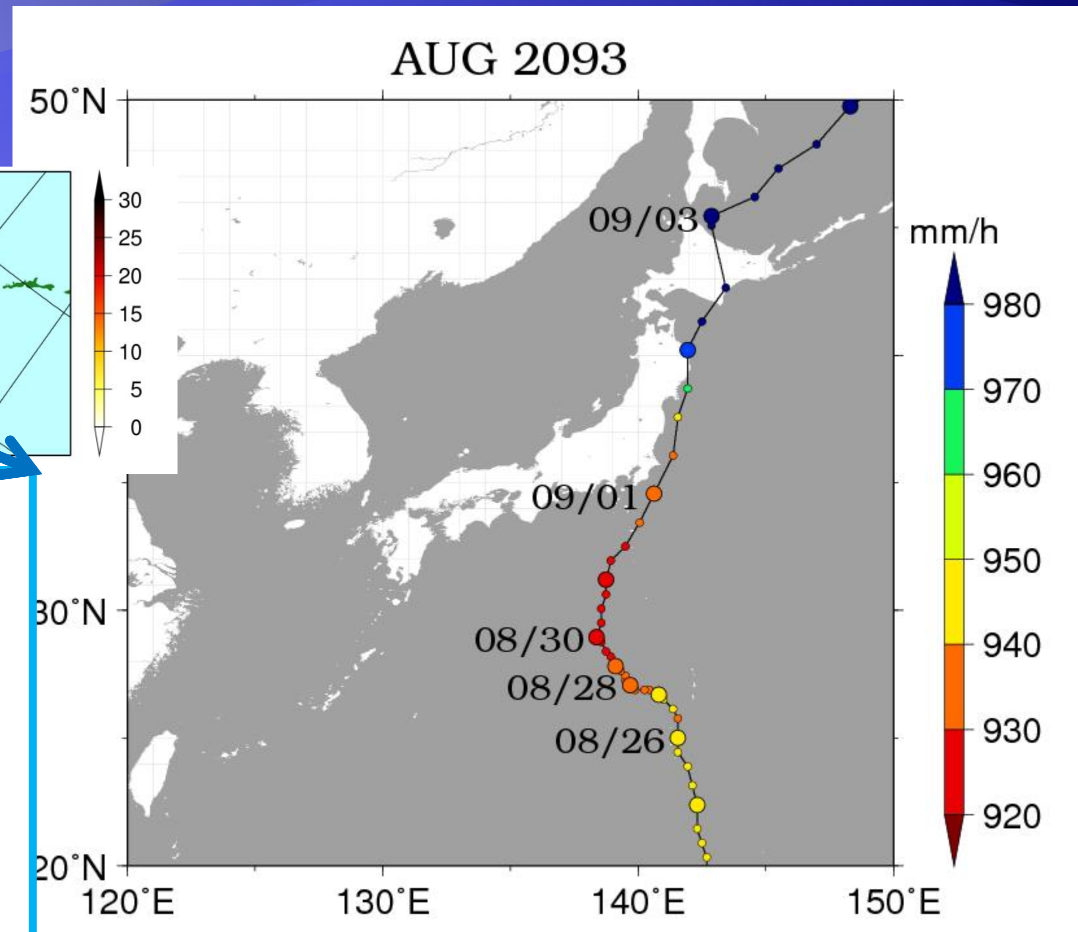
The highest DEPI event in the future climate is a typhoon.

Extreme typhoon in the future

Maximum wind speed distribution
during typhoon period

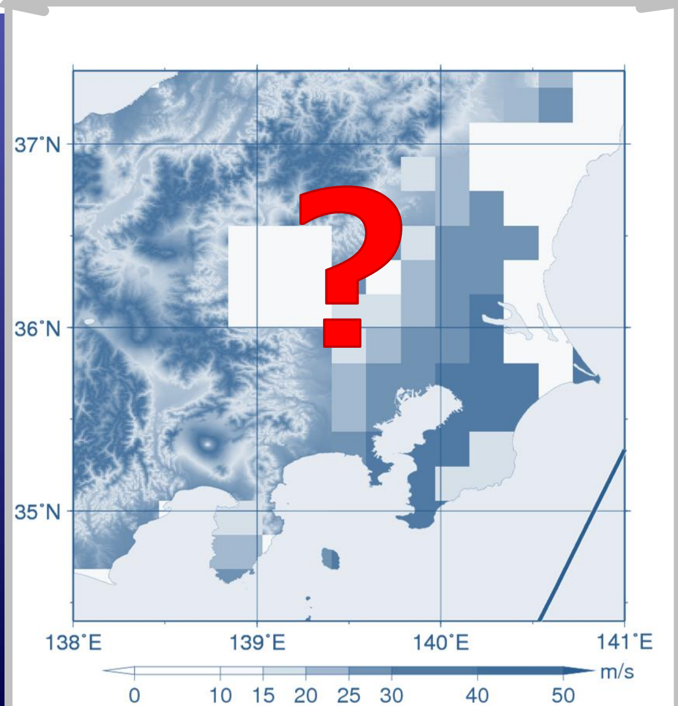


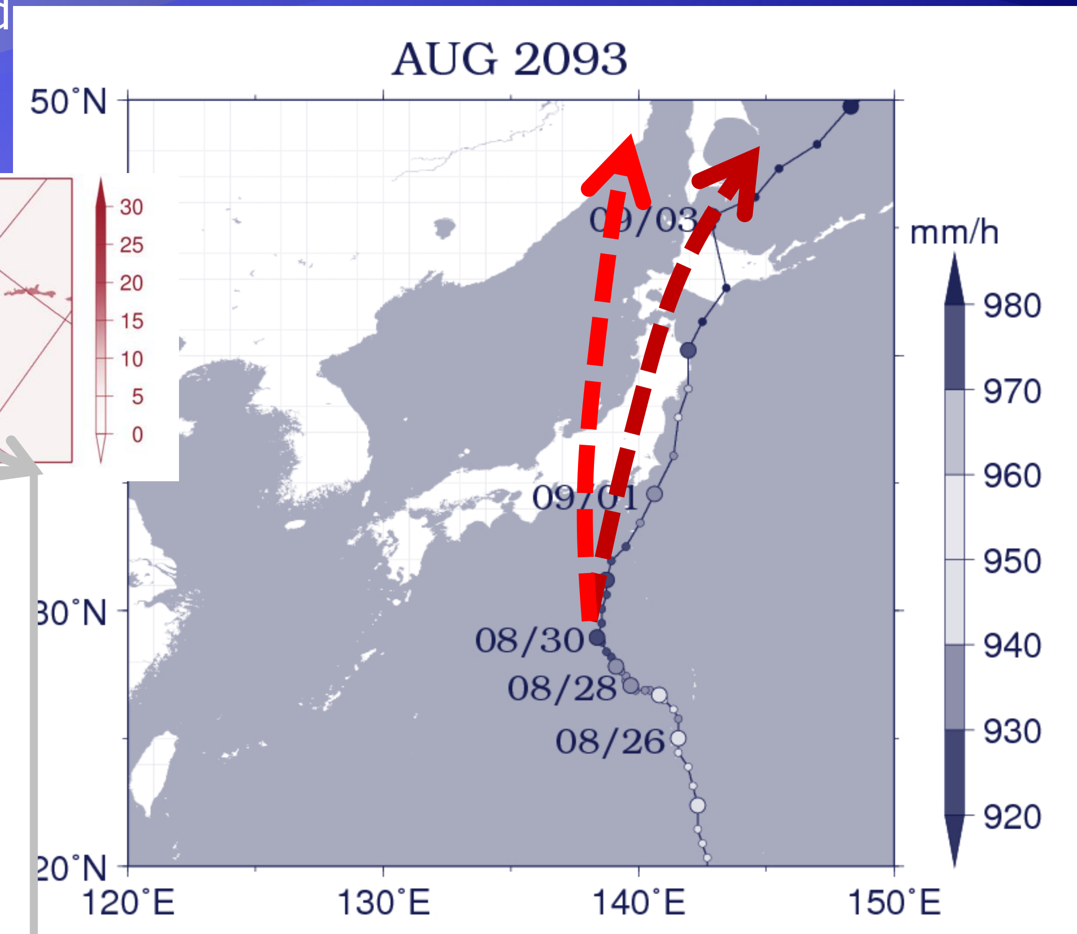




if typhoon track shifts …

How the maximum wind speed distribution during typhoon passage changes?





Dynamical downscaling with a modified initial condition are conducted.

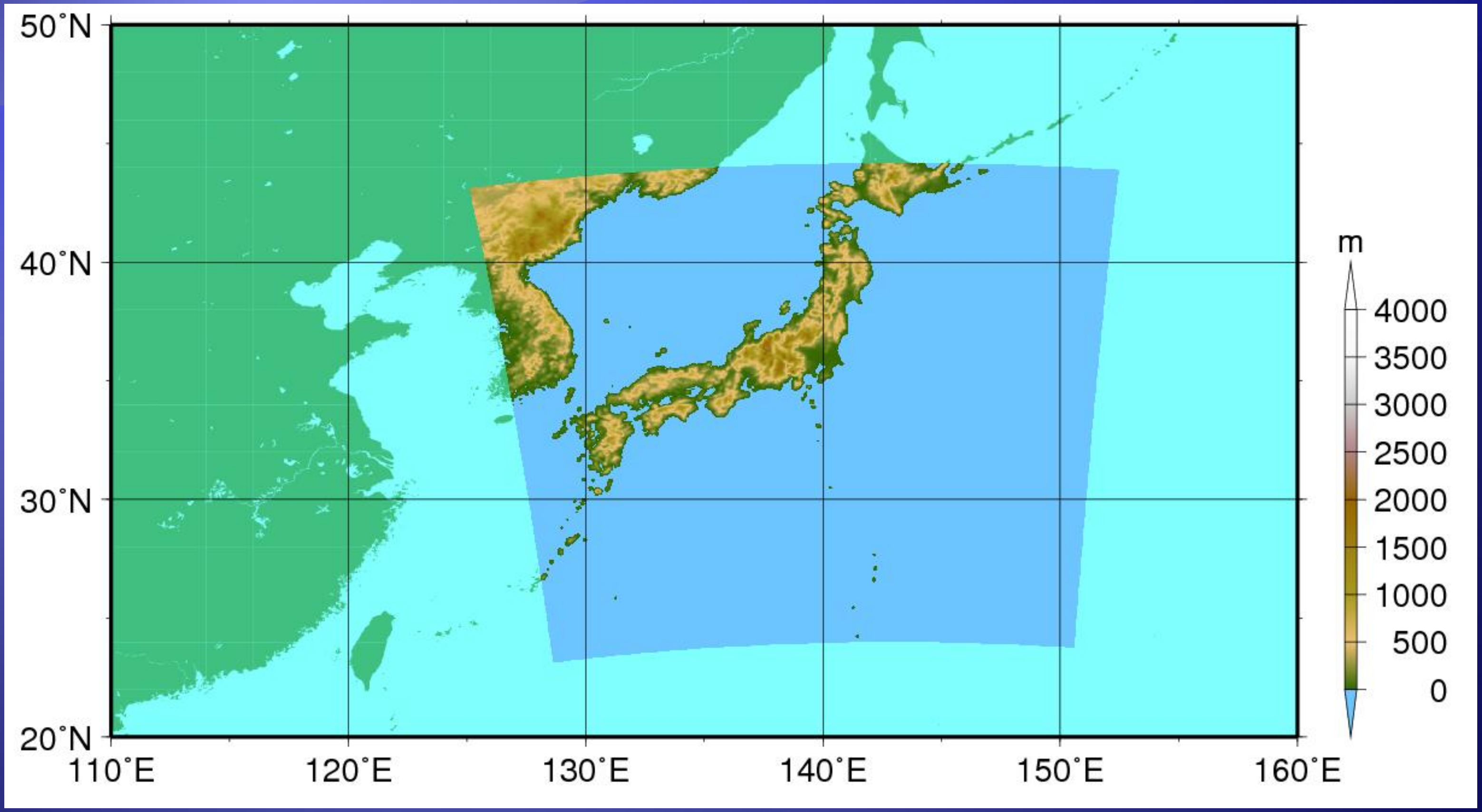
Topics

1. Identification method of both meteorologically and sociologically extreme typhoon in the future climate
2. Dynamical downscaling of the identified extreme typhoon to estimate its possible maximum wind speed and precipitation

Model settings

WRF-ARW ver3.0.1.1	
grid resolution Δx	5km
grids	453 x 453 x 50
time step Δt	30sec.
initial time	2093/08/30 06UTC
analysis period	2093/08/31 06UTC ~ 09/02 00UTC
boundary input	JMA/MRI GSM (AGCM20)
cumulus scheme	Kain-Fritsch
microphysics	WSM6
PBL sheme	MYJ Level 2.5
outputs	wind speed at 10m (1min.) precipitation, surface pressure (5min.) others (60min.)

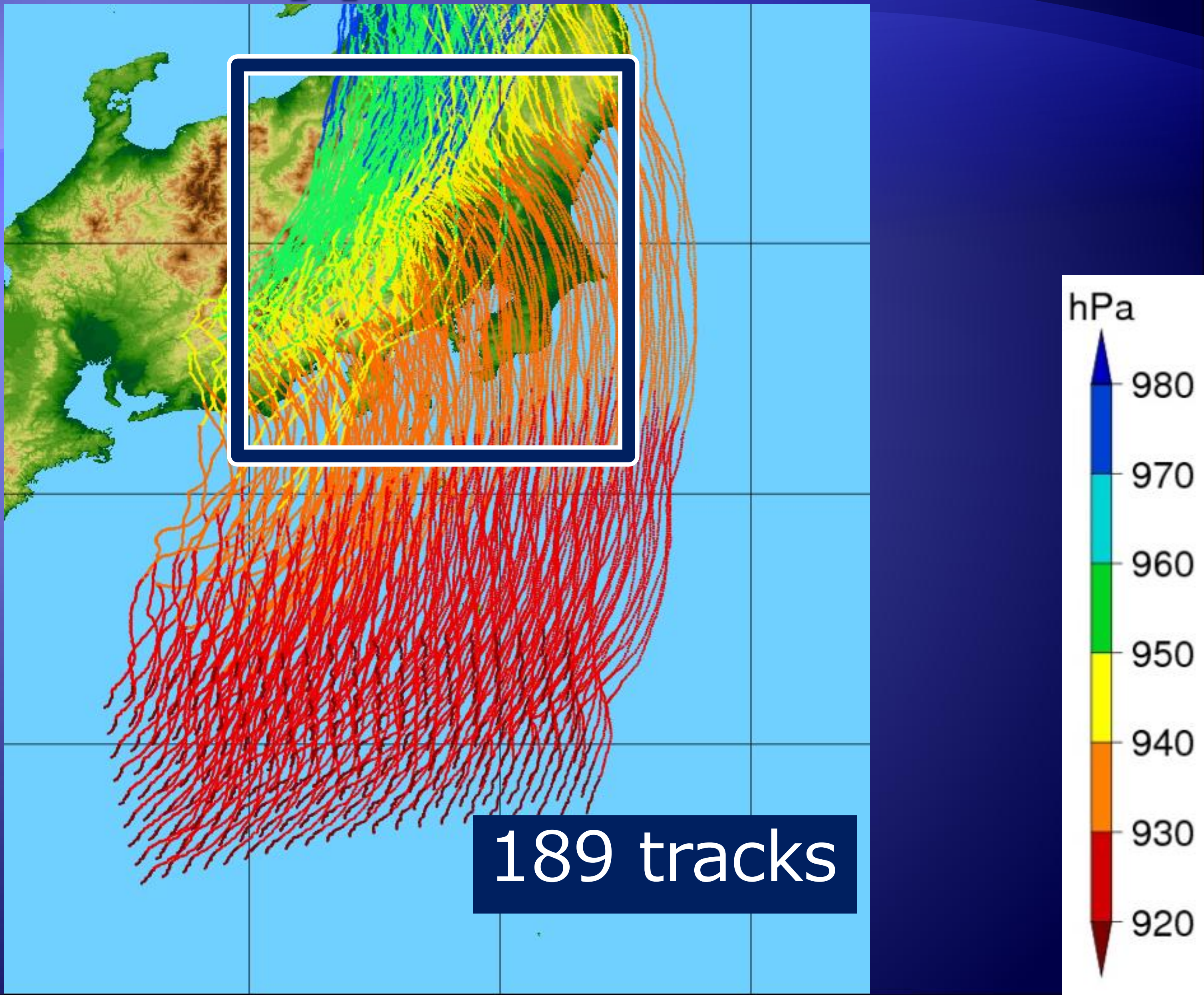
Model domain



Δx=5km

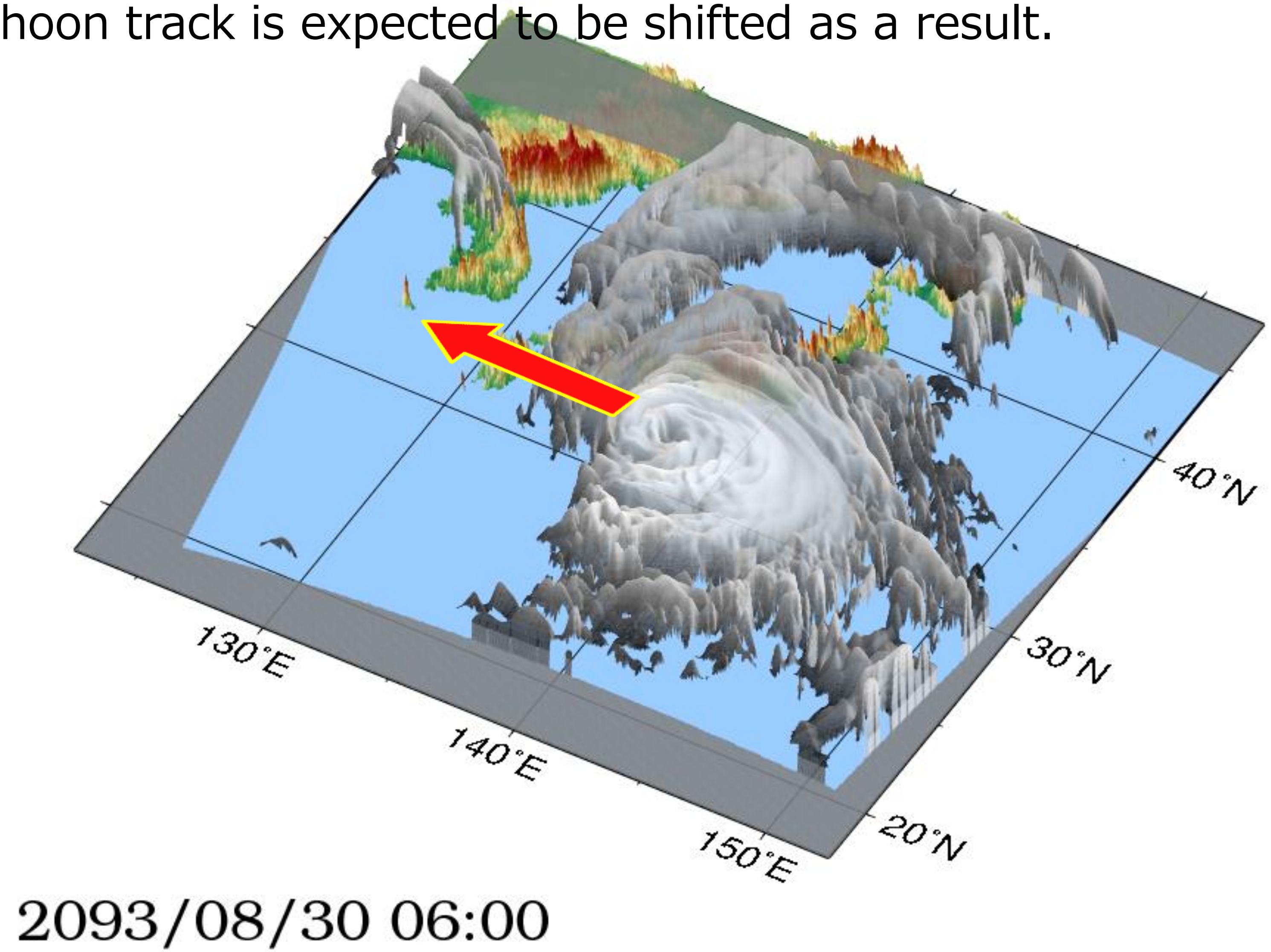
453 x 453 x 50 grids

Simulated typhoon tracks

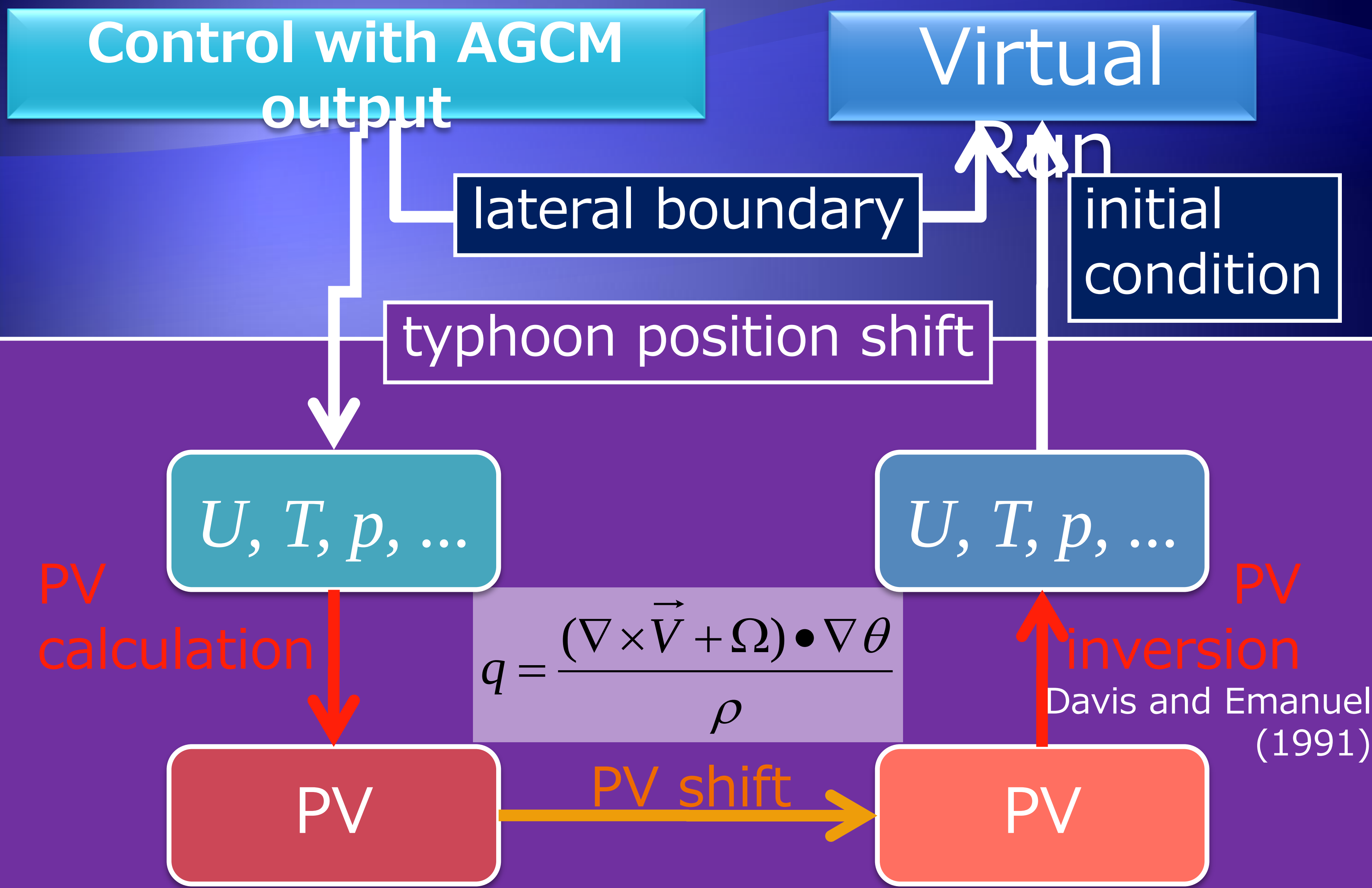


Initial data modification

If the typhoon's initial position can be shifted to various locations, typhoon track is expected to be shifted as a result.

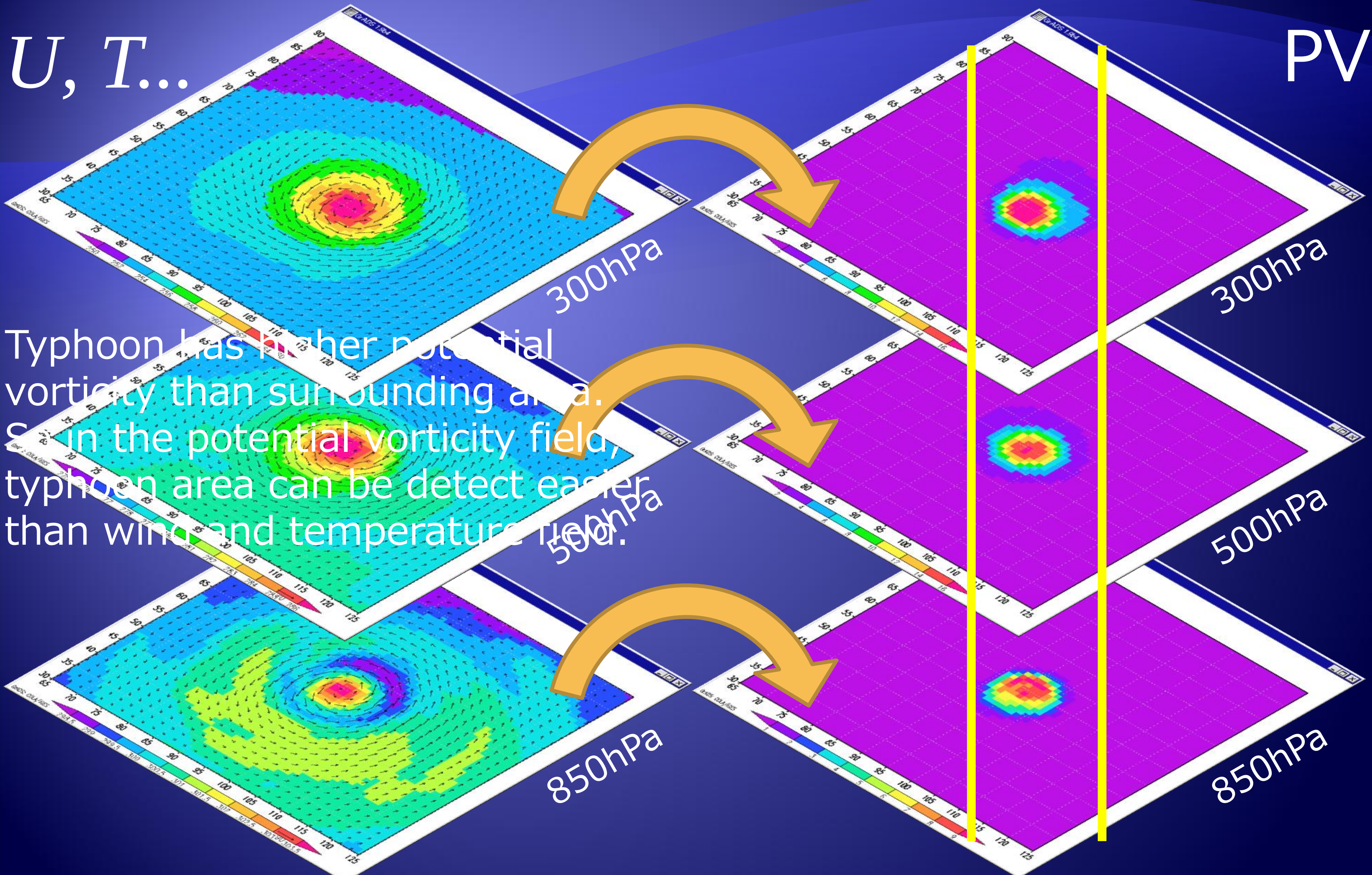


Data input procedure



PV calculation

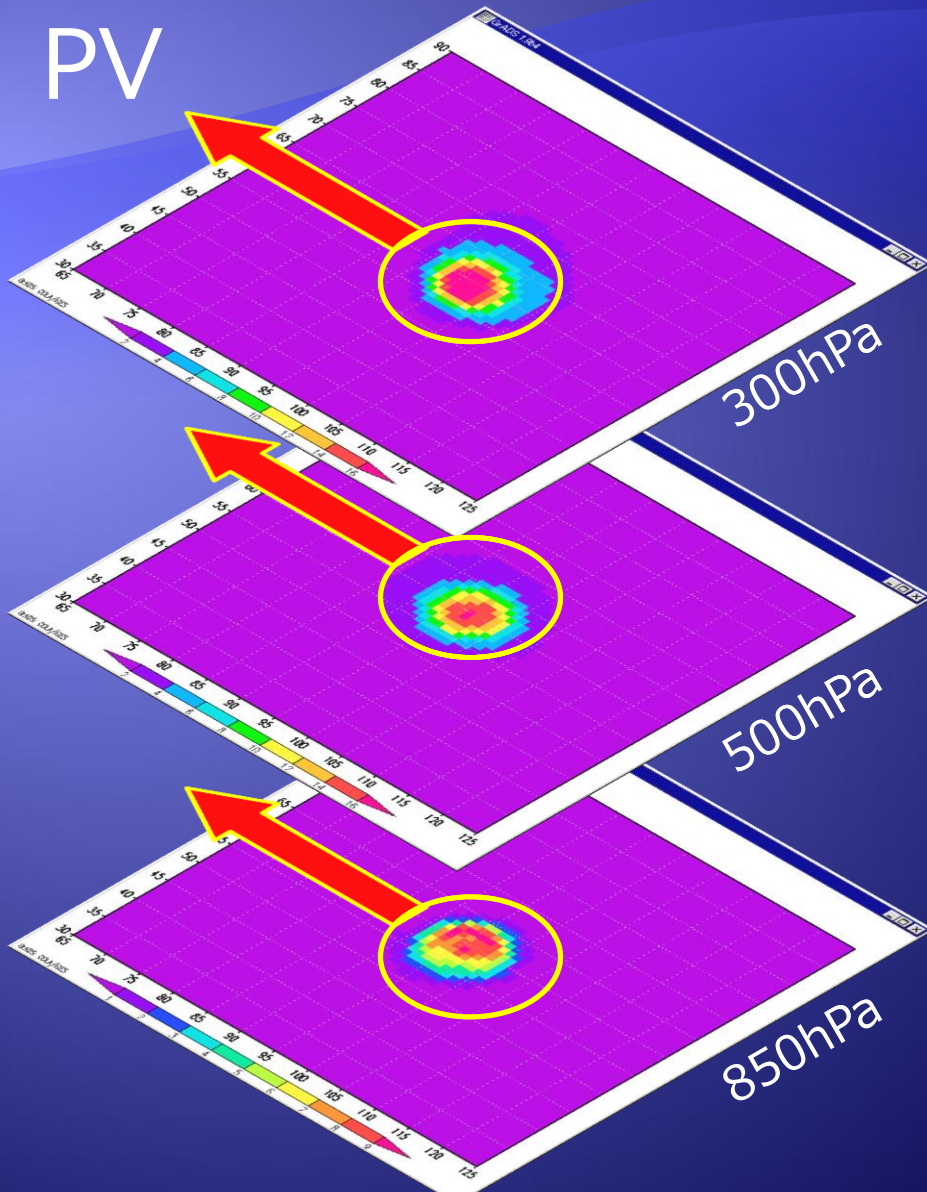
At first, potential vorticity is calculated in each pressure level.



Typhoon has higher potential vorticity than surrounding area. So, in the potential vorticity field, typhoon area can be detect easier than wind and temperature field.

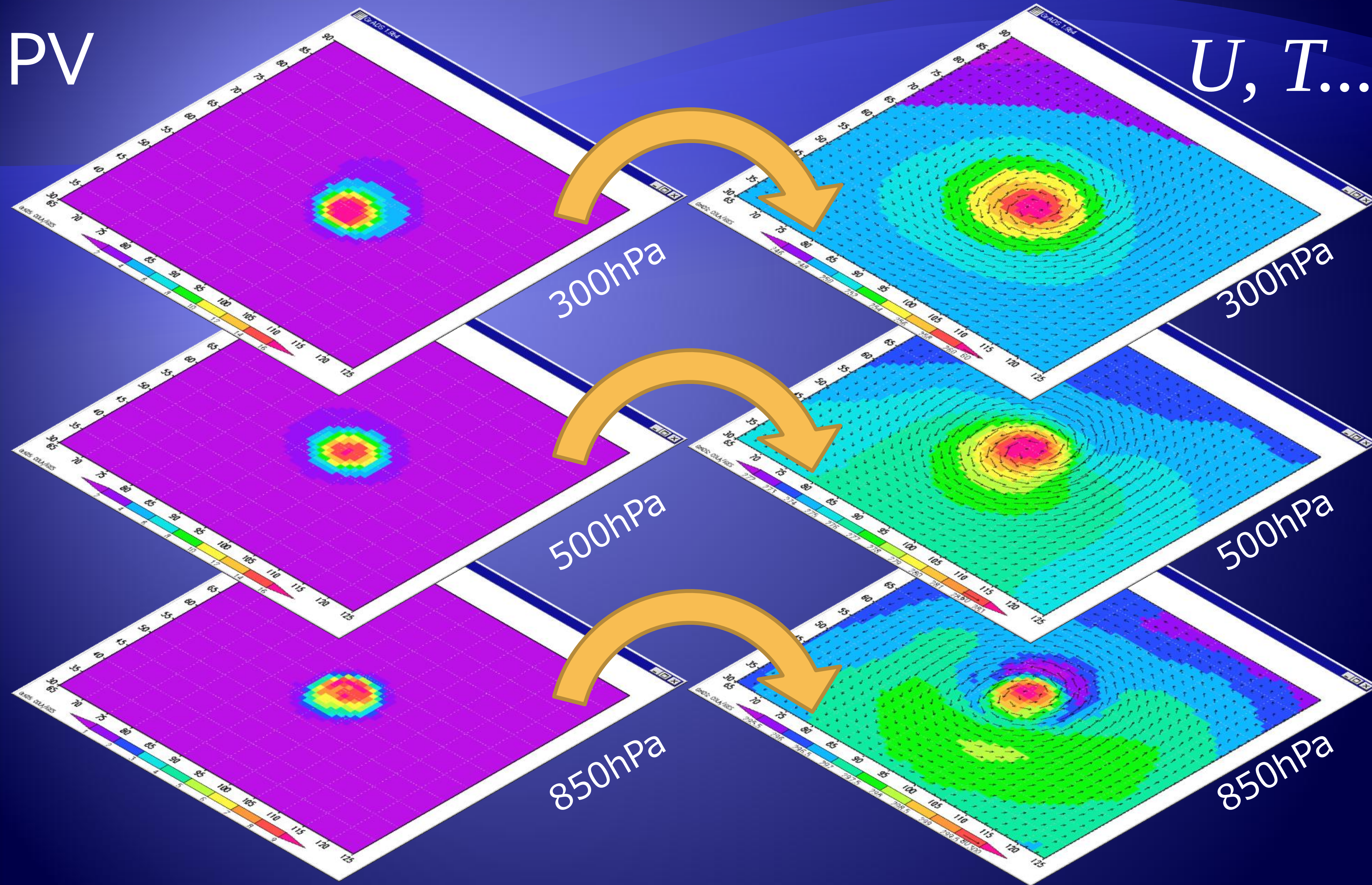
PV shift

The higher potential vorticity area is shifted to another area.



PV inversion

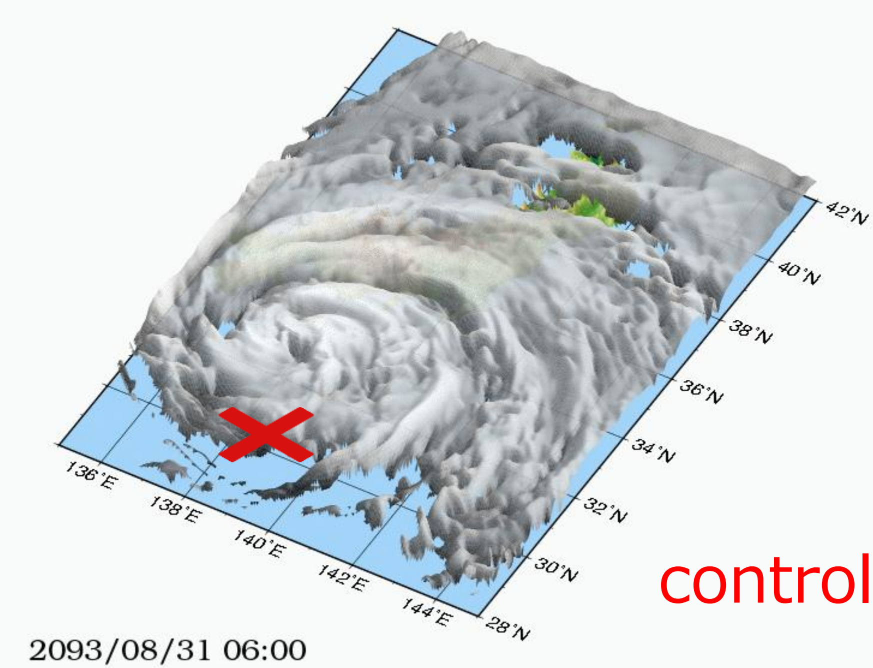
And then meteorological field is calculated by potential vorticity inversion technique.



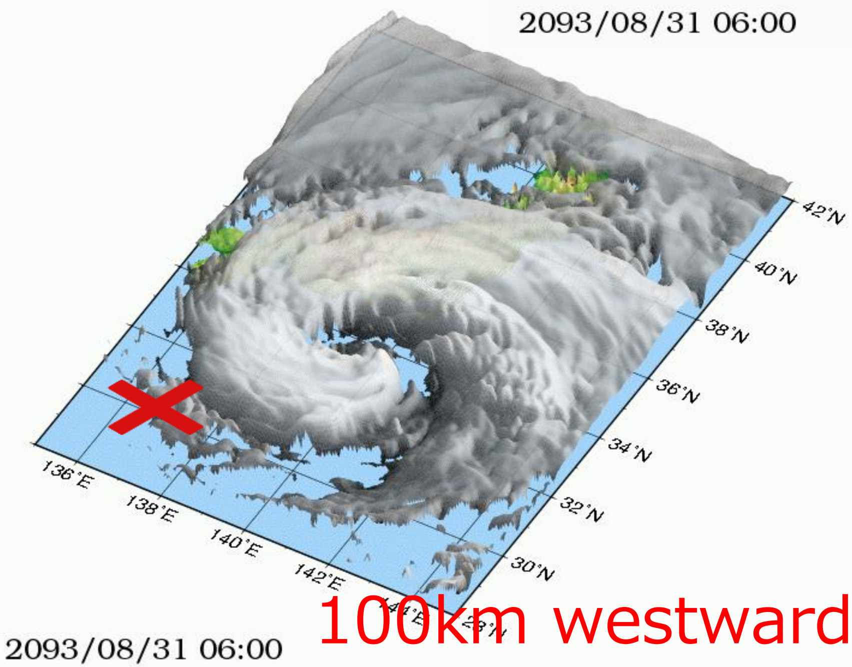
sample

OLR

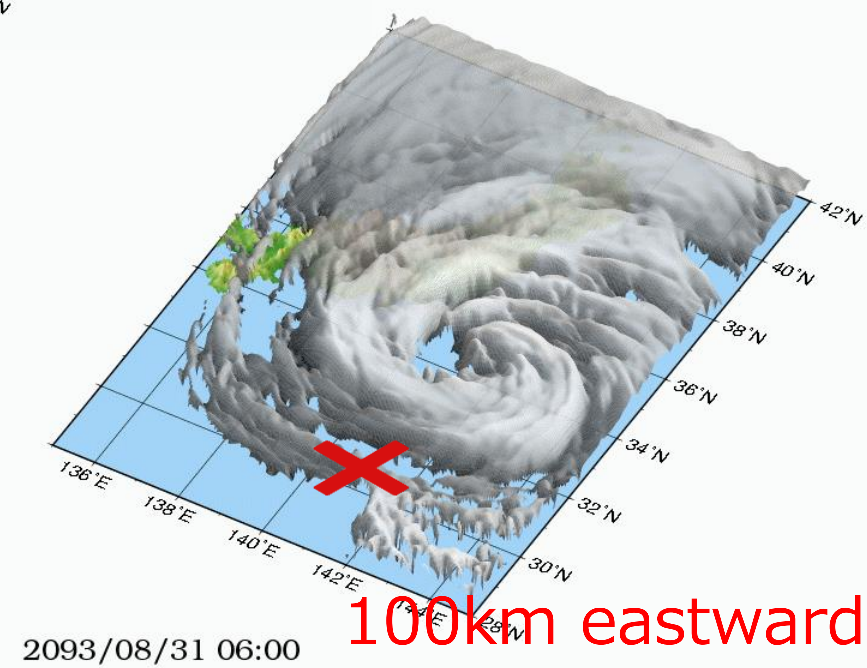
cloud image



control

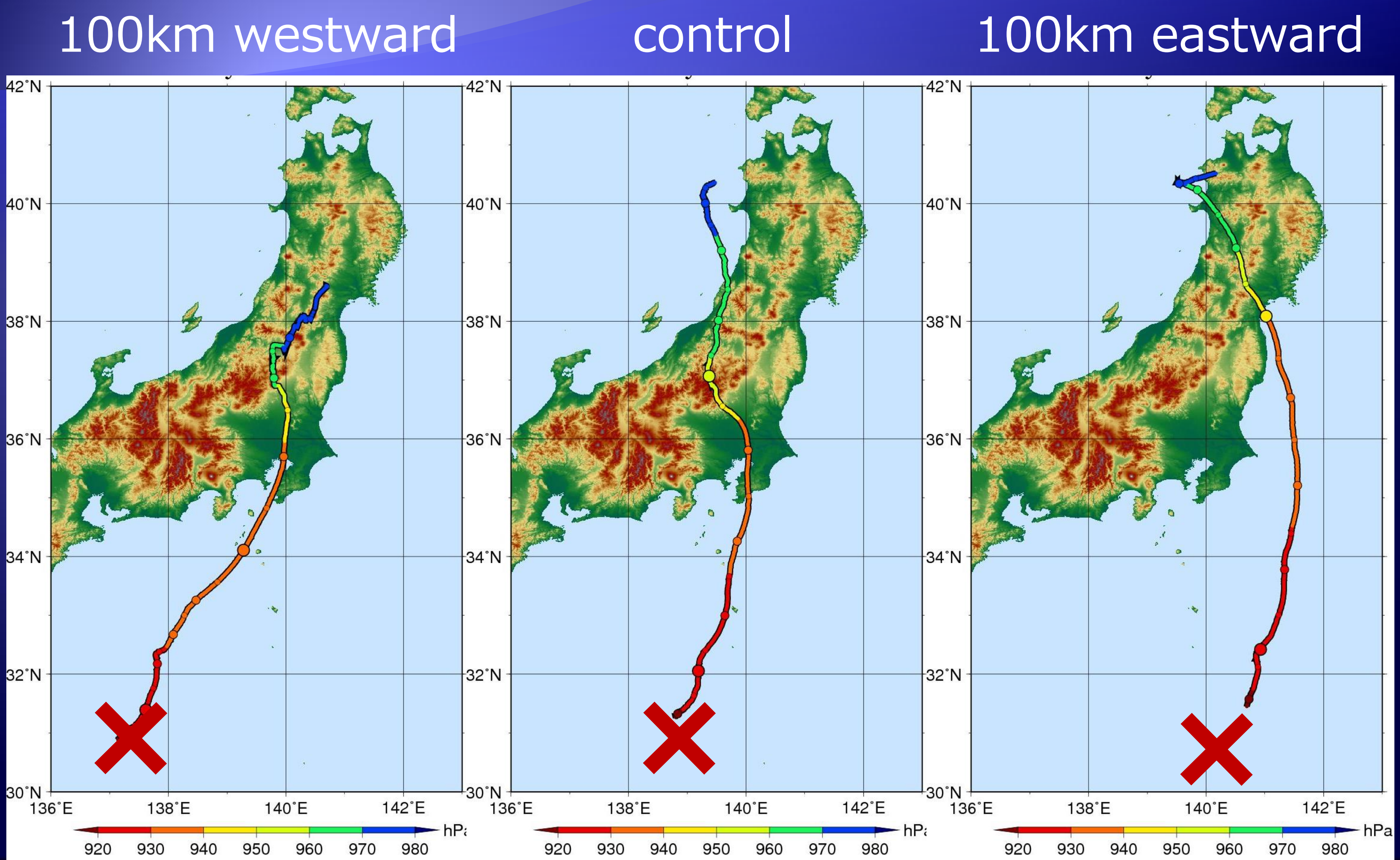


100km westward



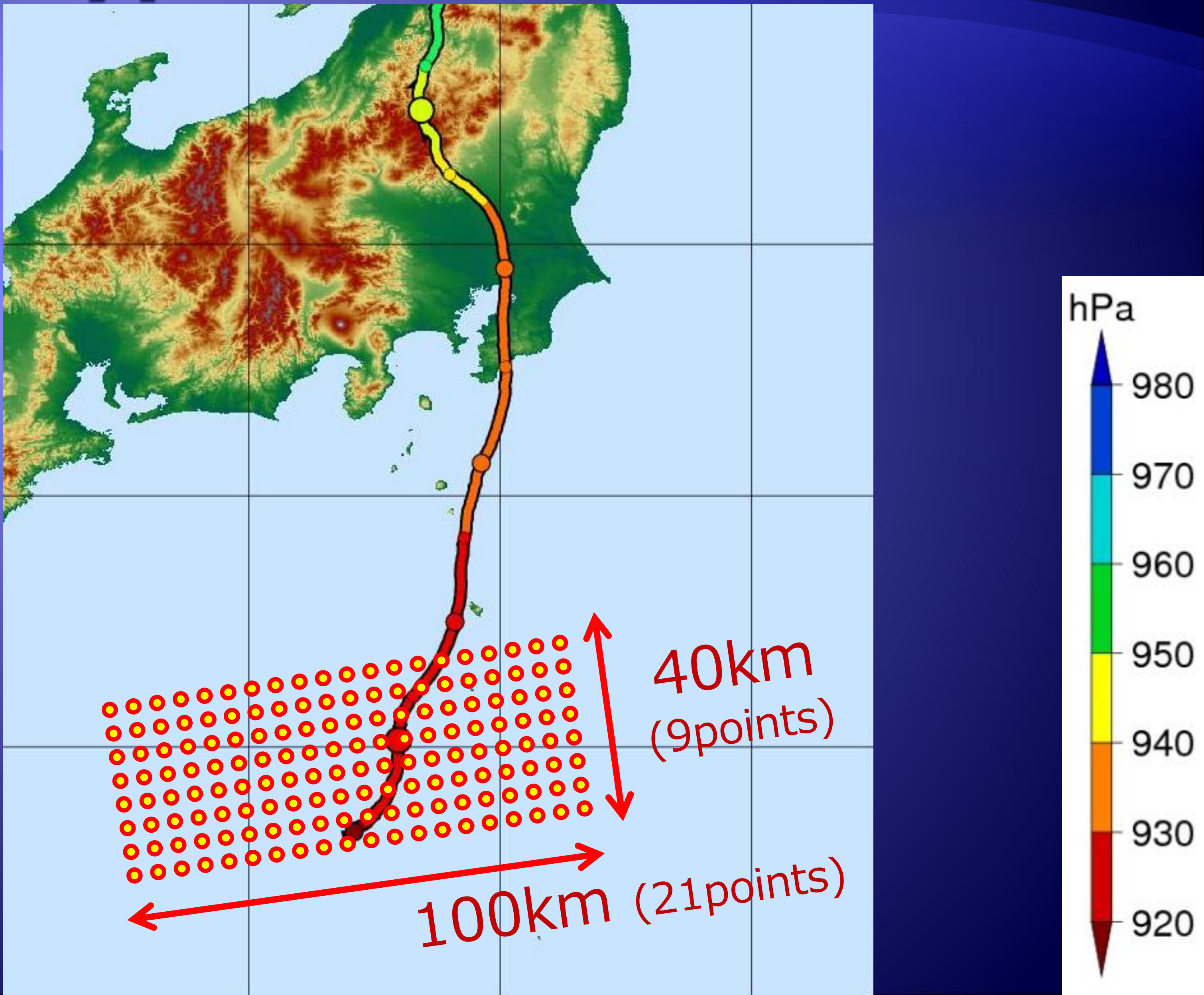
100km eastward

sample

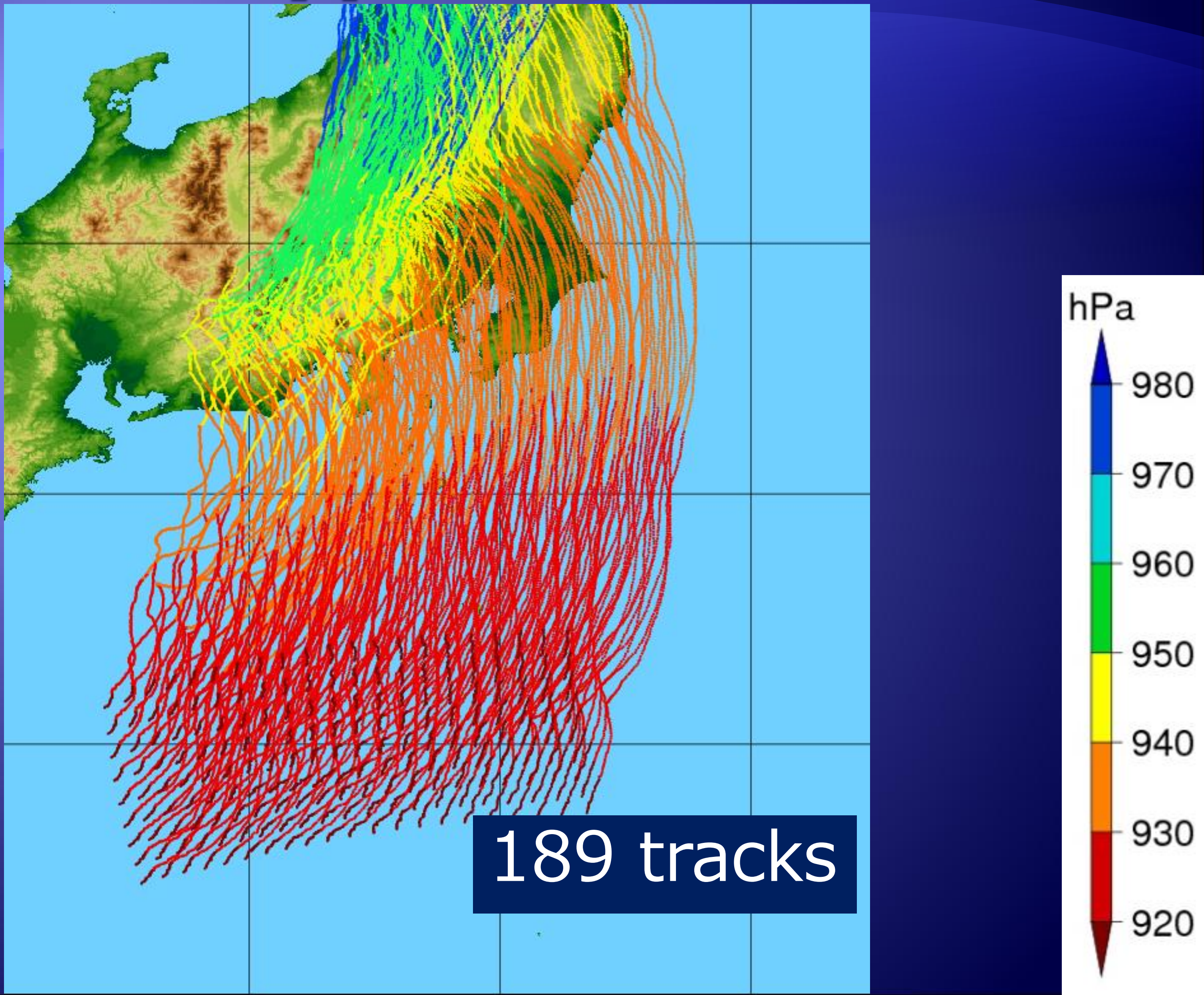


100km westward
control
100km eastward
42°N
40°N
38°N
36°N
34°N
32°N
30°N
136°E
138°E
140°E
142°E
hPa
920 930 940 950 960 970 980

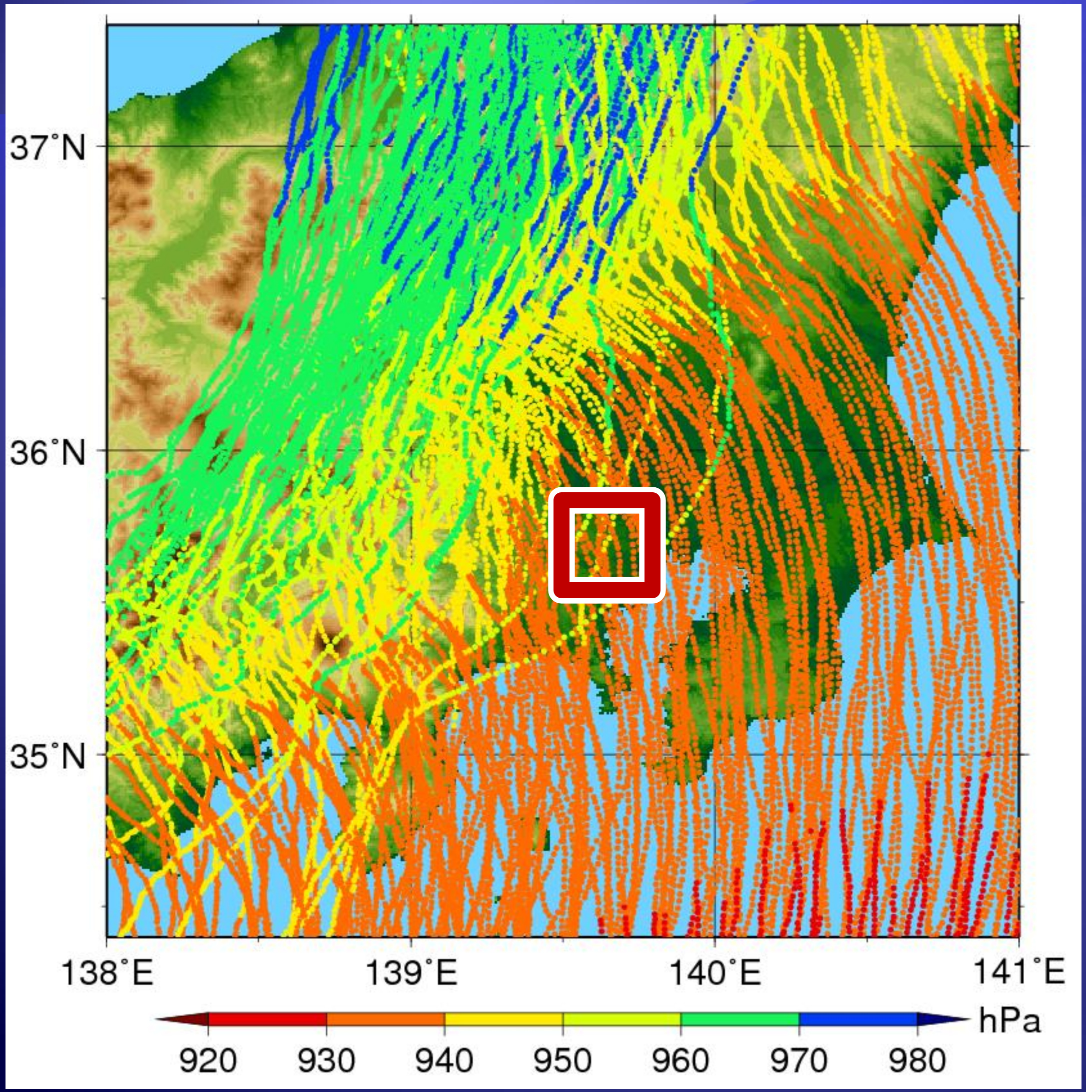
Initial typhoon location



Simulated typhoon tracks



Which track is the worst?

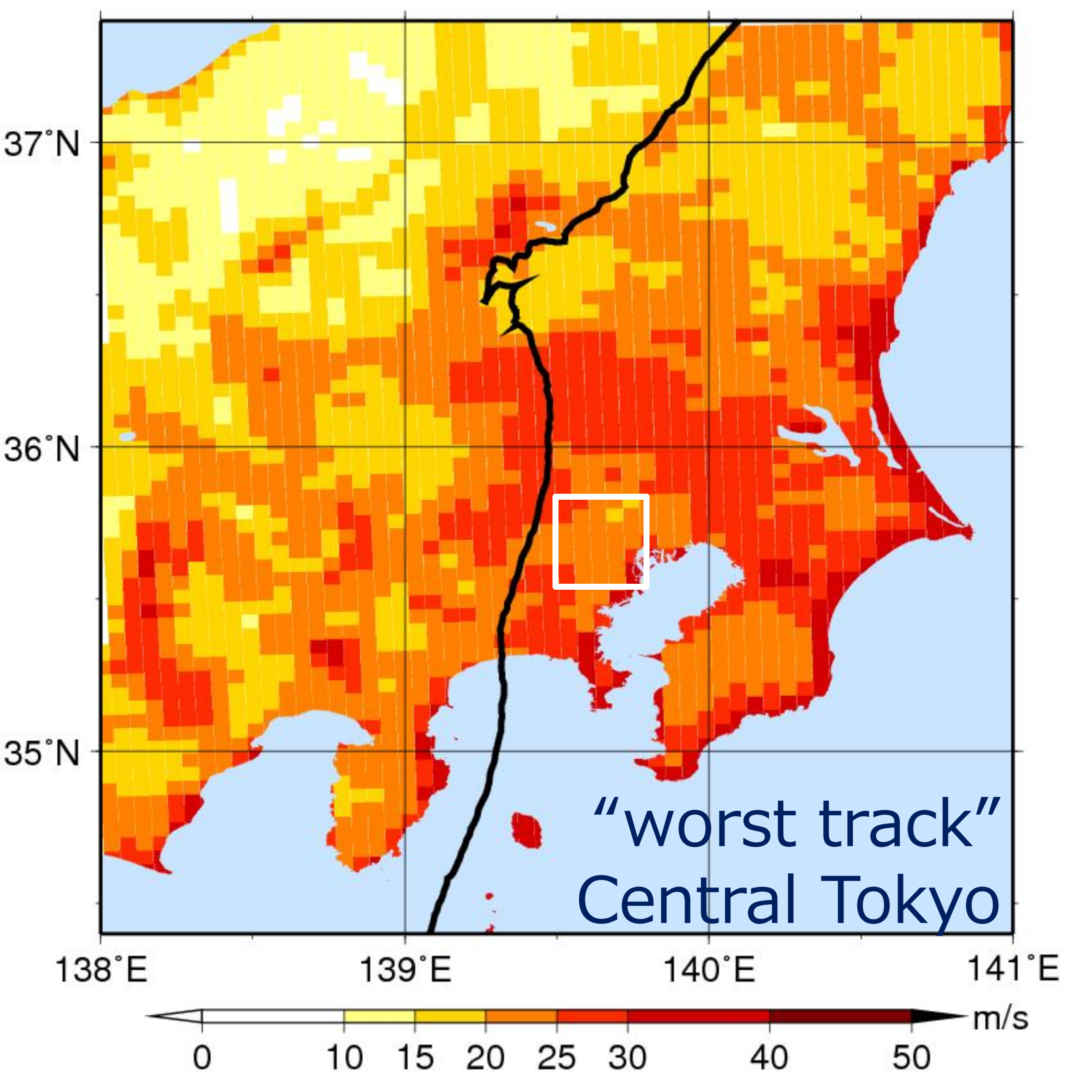


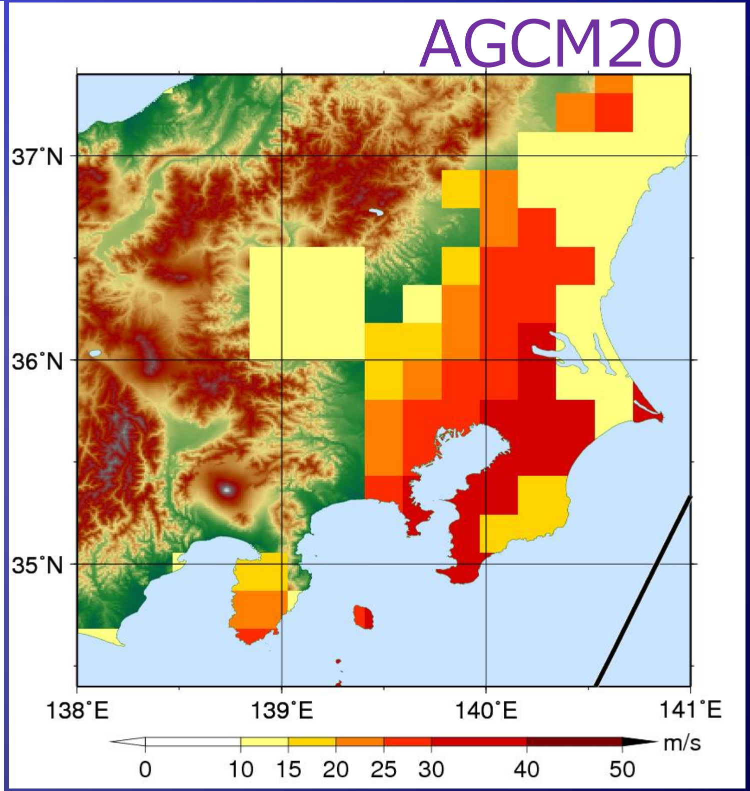
Which track is the "worst track" for the central Tokyo?

The maximum wind speed in the central Tokyo during typhoon period is estimated every track.

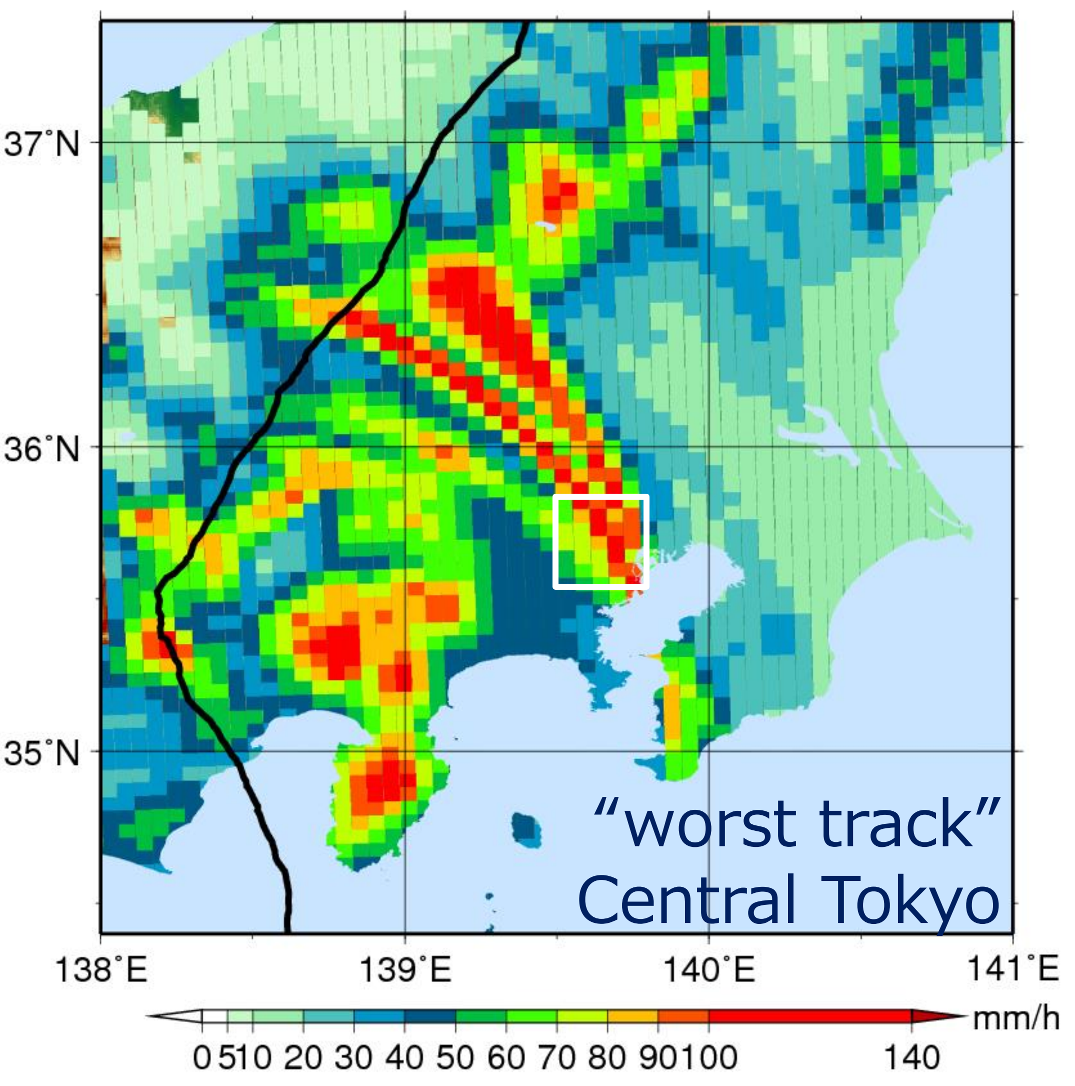
"worst track" is determined as the maximum of the maximum wind speed.

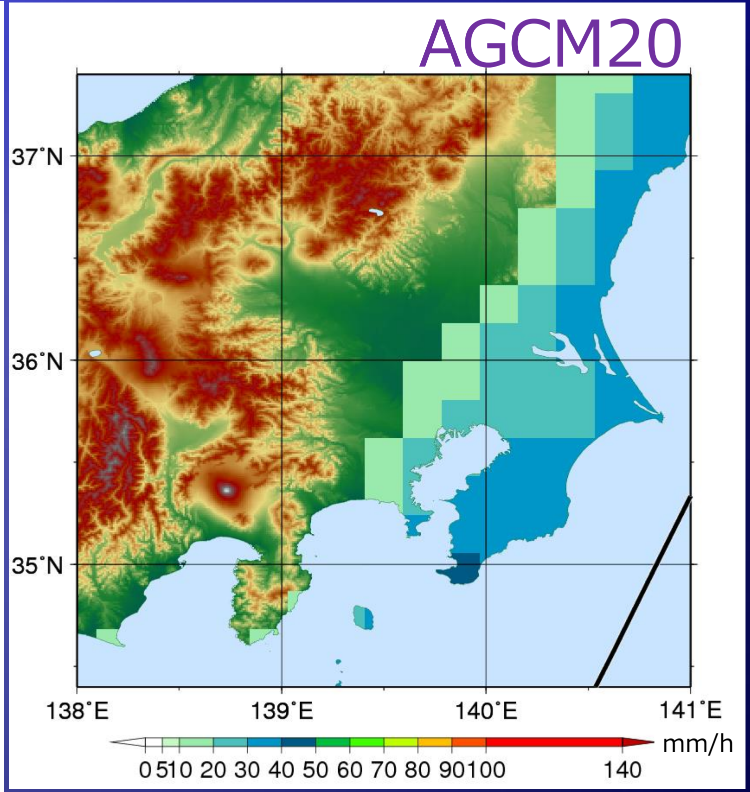
Probable maximum Wind speed



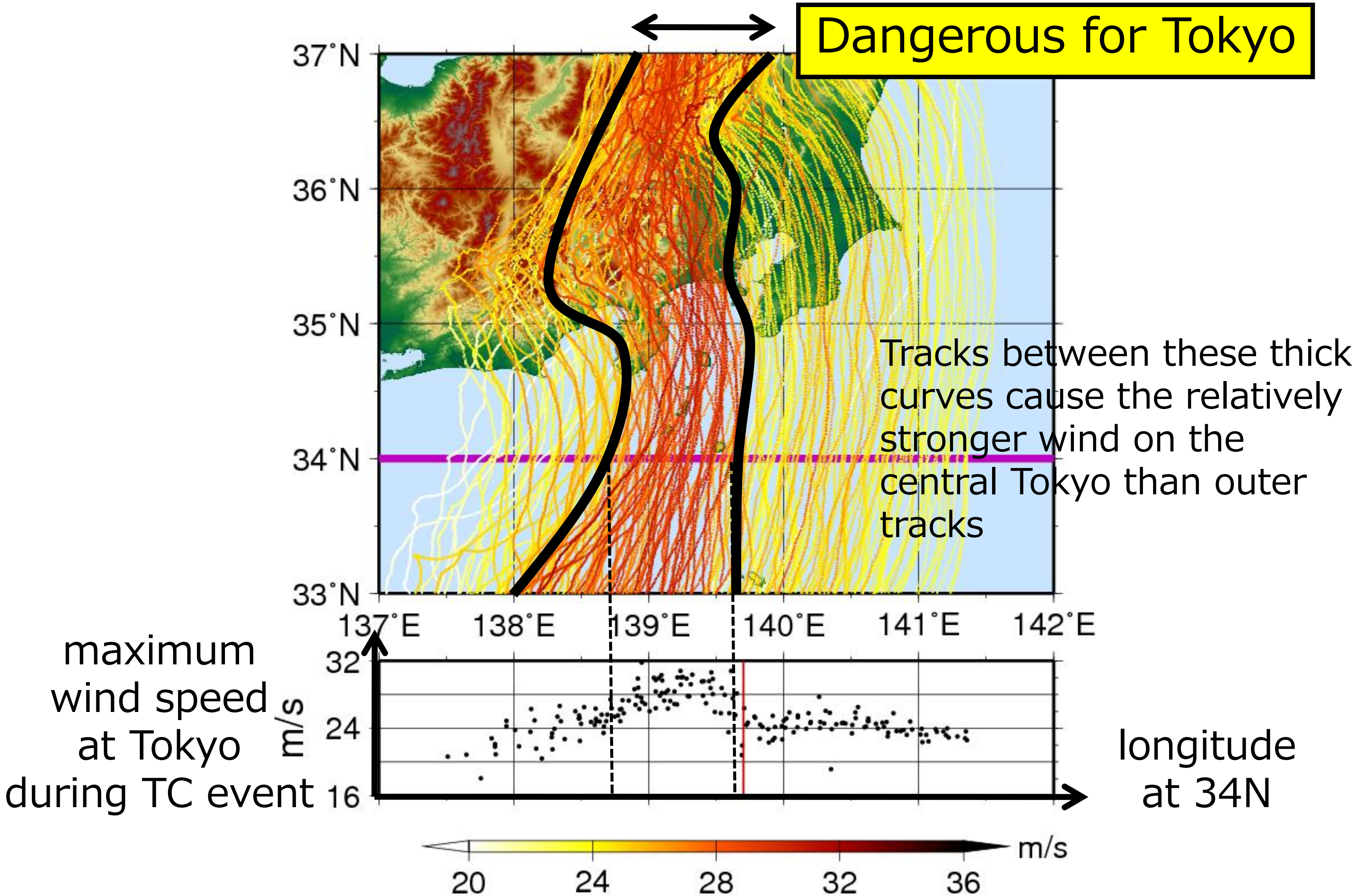


Probable maximum hourly precipitation

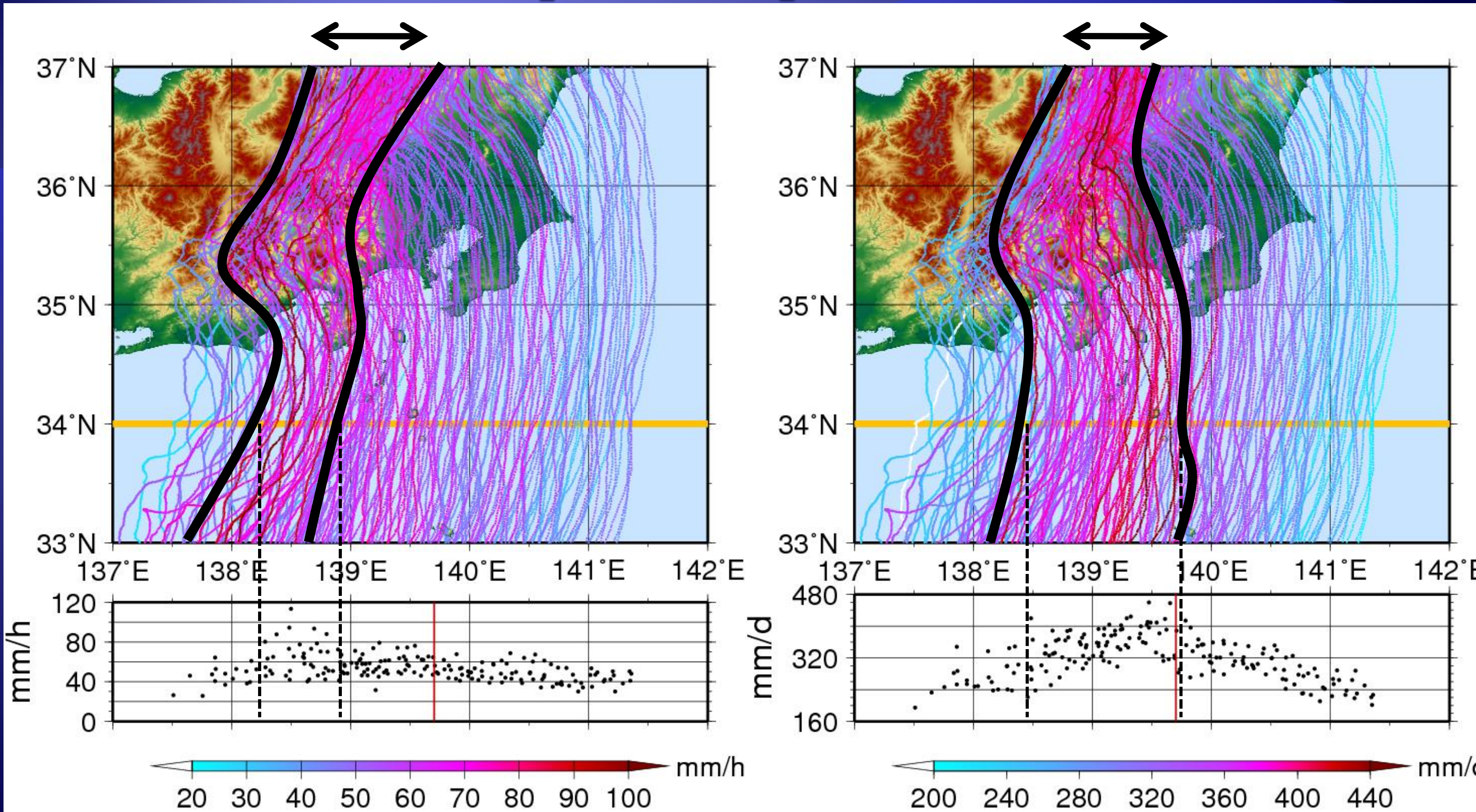




Track and wind speed



Track and precipitation



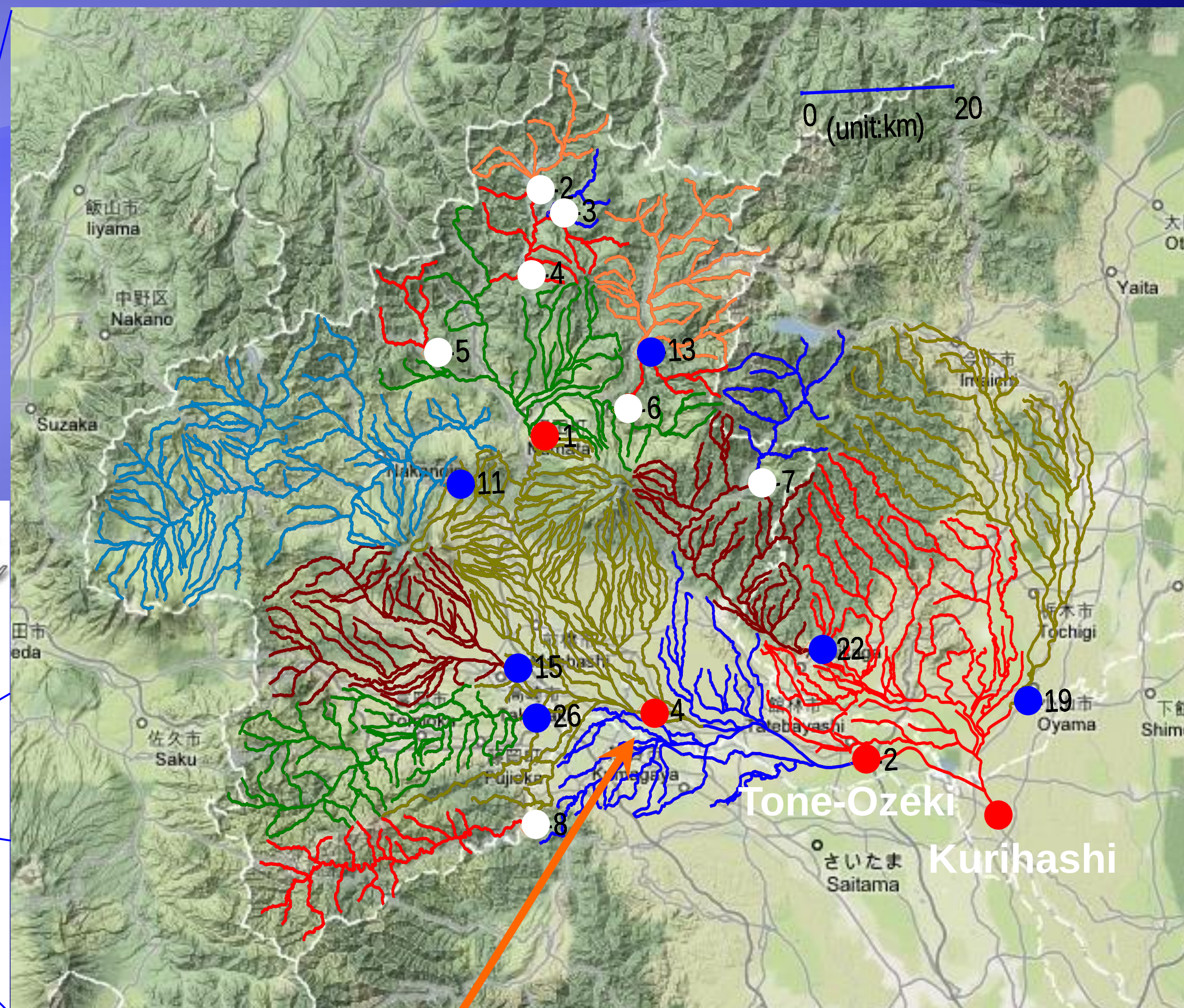
hourly precipitation   daily precipitation

Simulation of River Discharge using Precipitation Output （Tone River Basin）

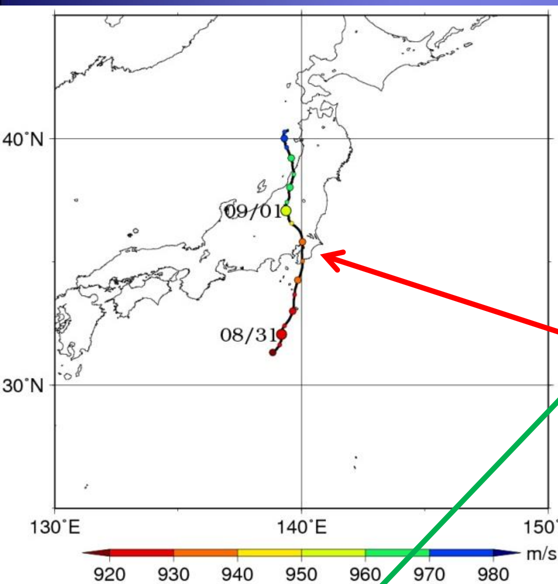
Main Points
- Yakatahara (1677.5 km²)
- Yattajima (5133.6 km²)
- Tone-Ozeki (6058.8 km²)
- Kurihashi (8772.2 km²)

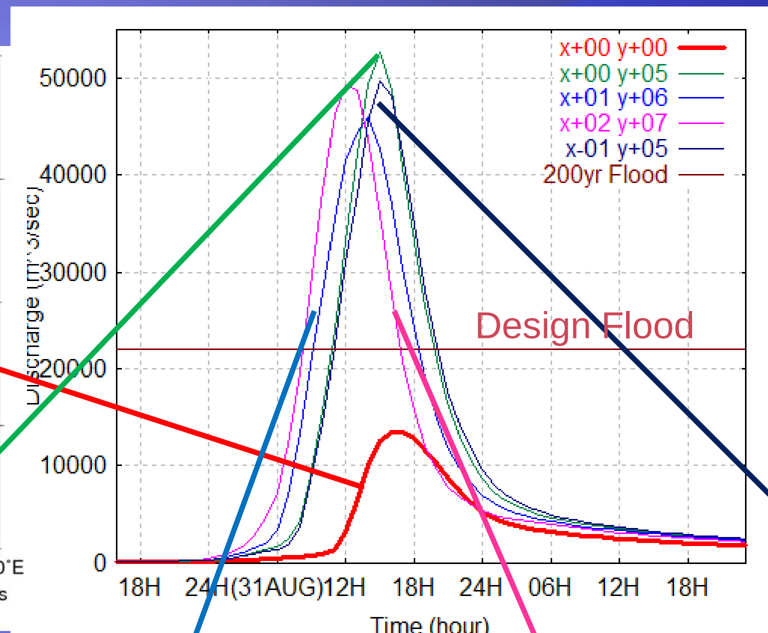
Dam Points
- Yagisawa Dam
- Naramata Dam
- Fujiwara Dam
- Aimata Dam
- Sonohara Dam
- K
- S

(



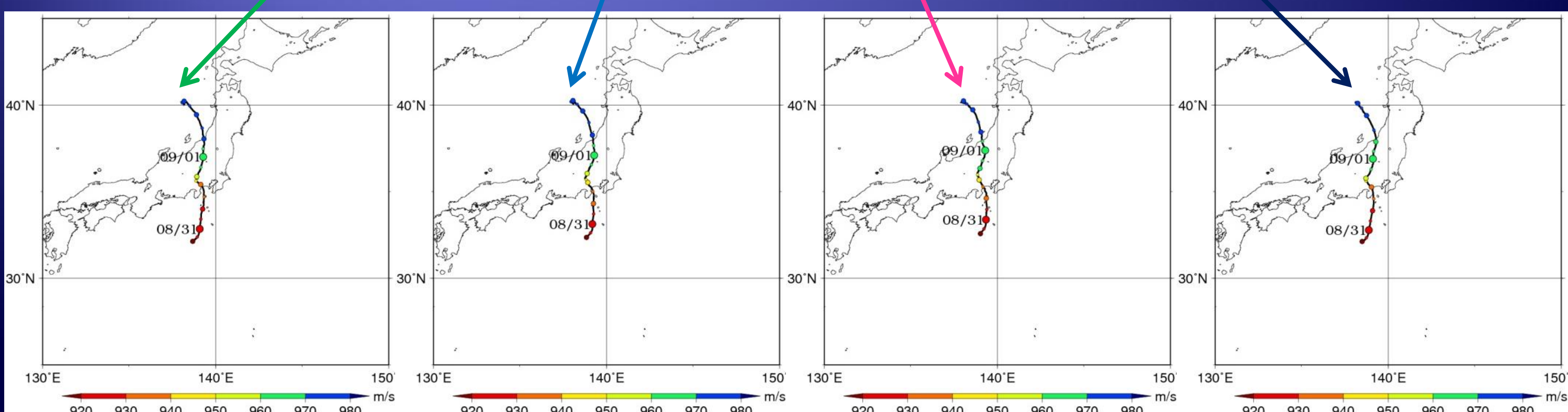
Yattajima （八斗島）
Design Flow Rate：22,000 m^3/s （200years）



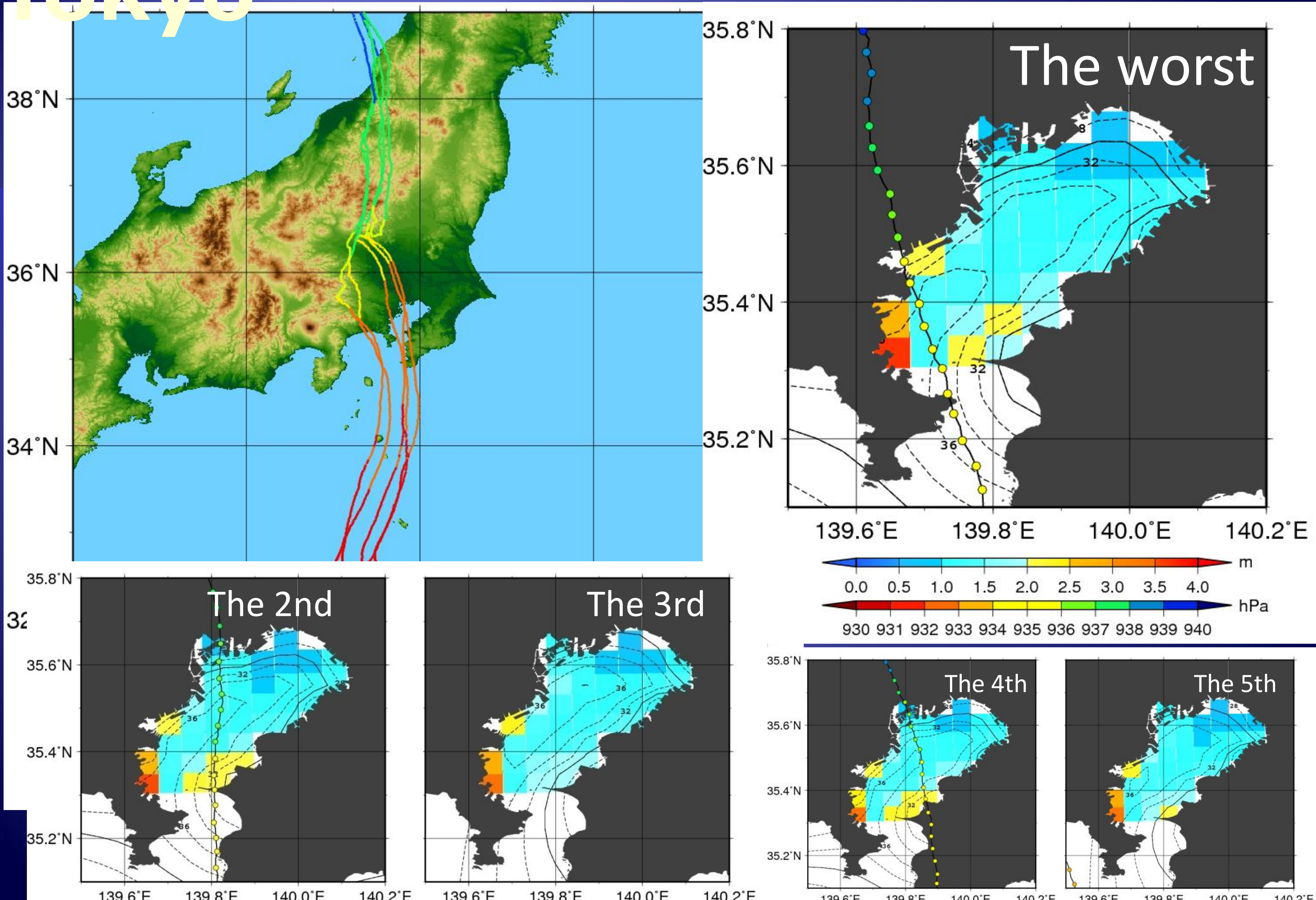


At the Yattajima Station:

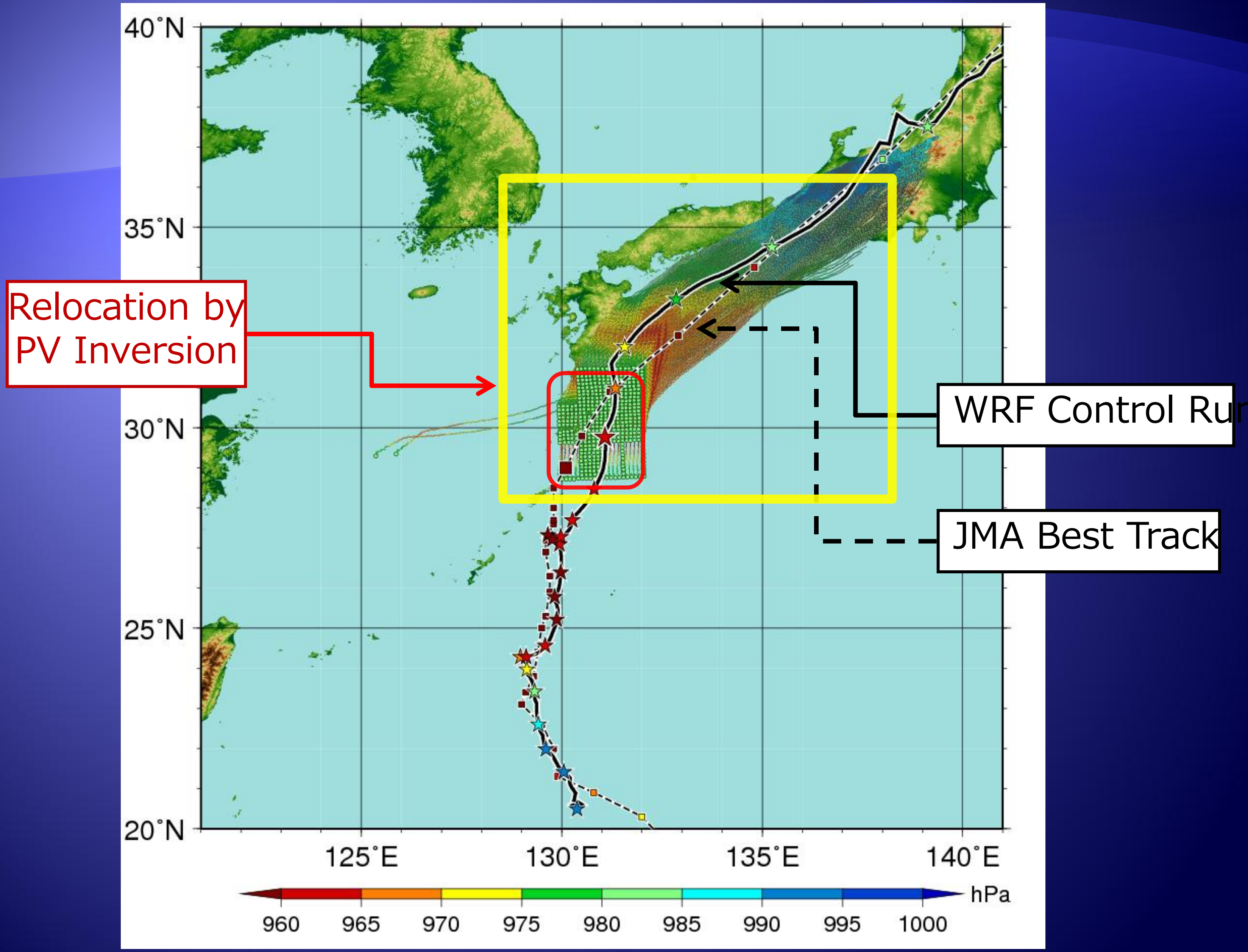
- 13,540 ton/sec of Peak Discharge with the original route of the Typ.
- Over 45,000 ton/sec of Peak Disch. with the modified routes.
- # Dam operation for flood control is NOT included in the given results!!



Storm surge in the Bay of Tokyo



Virtual-realization of T7918



Summary

KAKUSHIN

Identification method of both meteorologically and sociologically extreme synoptic scale event has been developed. The extreme typhoon in the future climate is identified from AGCM20 outputs. Dynamical downscaling with vortex relocation has been conducted to estimate its probable maximum wind speed and precipitation.

Quantifying both probable maximum damage and its probability is important in the impact assessment.

This study does not touch the probability this typhoon event occurs. It should be emphasized that the scenario based discussion may help to consider the countermeasure to the disaster beyond the design base.

DPRI-KU

To realize this, it is important to prepare a physically based scenario by the physically based virtual shifting of typhoon's track and the dynamic downscaling.

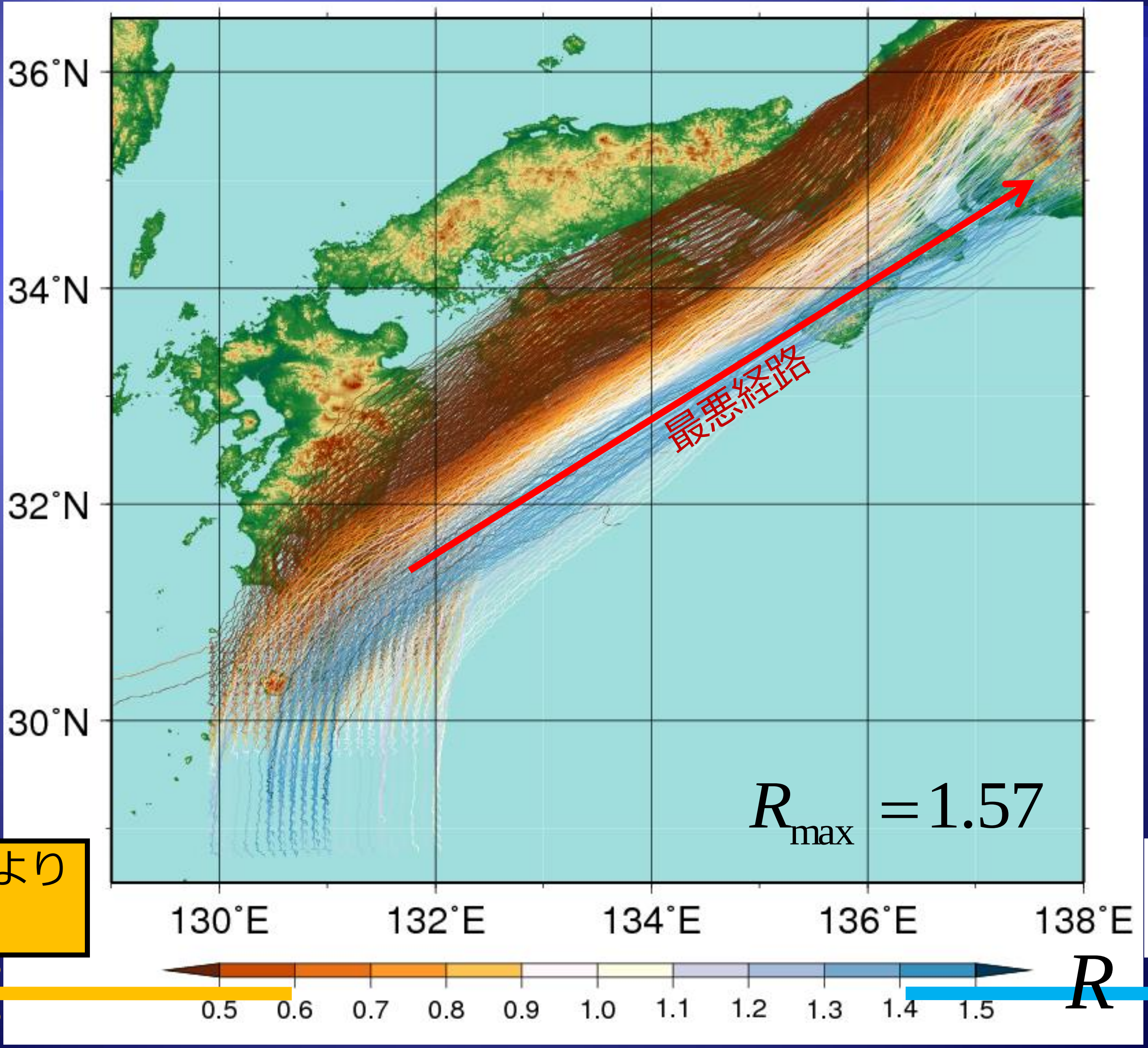
Thank you for your attention

Acknowledgement

This study was supported by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) under the framework of the "KAKUSHIN" program.

Numerical simulations were performed using the Large-Scale Computation of The Academic Center for Computing and Media Studies (ACCMS) and Institute for Information Management and Communication (IIMC), Kyoto University.

積算降水量の比較



観測値より少ない

観測値より多い

Topics

1. Identification method of extreme event with high societal impact
2. Dynamical downscaling of the identified extreme typhoon to estimate its probable maximum wind speed and precipitation

Disaster due to typhoon

Typhoon is one of the most hazardous meteorological disturbances affecting Japan.

AGCM20 resolves lots of typhoons in the northwest Pacific Ocean. However, in the impact assessment studies, strong typhoons do not necessarily have severe impact on our society.

> For example, if the climatologically extreme typhoon approached the area where nobody lives or any social infrastructures do not exist, there would be few social impacts.

In order to estimate the impact of extreme weather, we propose a new index.

Identification method

It is assumed that the damage due to extreme weather depends on three factors, strength of the extreme event, potential loss of society and the vulnerability of the society.

Disastrous Event Potential Index (DEPI), $I(n)$, is a measure of the extreme weather to the society.

DEPI for wind *(u can be displaces by precipitation for rain hazard)*

$$I(n) = \sum_{i,j} \sum_{k} p(i,j) q(i,j,k) u(i,j,k)$$

$u(i,j,k)$ is the wind speed at the location (i,j) with historical order k.
$p(i,j)$ is a weighting function of location (i,j) reflecting potential loss.
$q(i,j,k)$ is a weighting function of ranking k at (i,j) reflecting vulnerability.

$$I(n)=\sum_{i,j}\sum_{k}p(i,j)q(i,j,k)\underline{u(i,j,k)}$$

Since the duration of a synoptic-scale meteorological event over mid-latitude region is generally about from 1 week to 10 days, wind speed records involving each event can be assumed to have **<u>an appearance time within 10 days</u>**.

reference time of event $n=1$

location (i, j)

time	m/s
. . .	. . .
1991/09/25 02:00	22.1
1991/09/25 03:00	30.1
1991/09/25 04:00	30.2
1991/09/25 05:00	29.3
1991/09/25 06:00	21.9
1991/09/25 07:00	17.1
1991/09/25 08:00	11.8
. . .	. . .

k	m/s	time	n
1	30.2	1991/09/25 04:00	1
2	30.1	1991/09/25 03:00	1
3	29.9	1986/08/02 09:00	2
4	29.7	2001/07/12 16:00	3
5	29.3	1991/09/25 05:00	1
6	29.2	2001/07/11 22:00	3
. .	. . .	. . .	. . .
k_0	28.1	1987/02/21 18:00	311
. .	. . .	. . .	. . .

identified as event $n=1$

How to define function $q(i, j, k)$?

$$k < k_0 : q(i, j, k) = \frac{u(i, j, k) - u(i, j, k_0)}{u(i, j, 1) - u(i, j, k_0)}$$

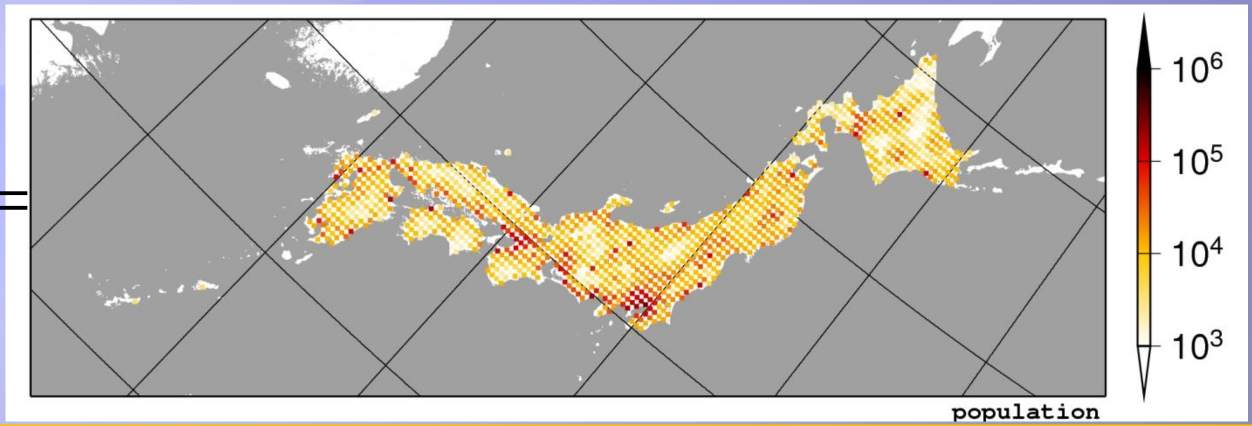
$$k \geq k_0 : q(i, j, k) = 0.$$

The rarer strong wind is expected to make a larger contribution to DEPI. $u(i, j, k_0)$ is a threshold; if wind speed is smaller than $u(i, j, k_0)$, $q(i, j, k)$ becomes 0 which brings no contribution to DEI. In this study, 99.9%-ile value is used as $u(i, j, k_0)$.

$$I(n) = \sum_{i,j} \sum_{k} p(i, j) \underline{q(i, j, k)} u(i, j, k)$$

How to define function $p(i, j)$?

$$p(i, j) =$$



A number of human damages is relatively expected to be larger in the urban area than in rural area if observed strong wind speed is same.

$p(i, j)$ is defined by the population as an proxy of sociological parameter.

$$I(n) = \sum_{i,j} \sum_{k} \underline{p(i, j)} q(i, j, k) u(i, j, k)$$

Performance verification

Before identification of an extremely disastrous synoptic-scale event from outputs of AGCM20, it is necessary to verify the presented method can detect disastrous events actuary occurred.

For this purpose, ground based surface meteorological point data are converted to horizontally homogeneous distributed grid data, and then DEPI estimated from those grid data is compared with magnitude of damages ever recorded in the reports published by government agencies.

In this study, hourly AMeDAS observation data from 1979 to 2003 are used. This 25-year period is consistent with the present climate of time-slice experiments conducted by AGCM20.

Top 7 synoptic scale event

rank	event	DEPI score	person		building	
			death	injured	damaged	flooded
1	typhoon T9119 Sep. 1991	689	62	1,499	107,447	22,965
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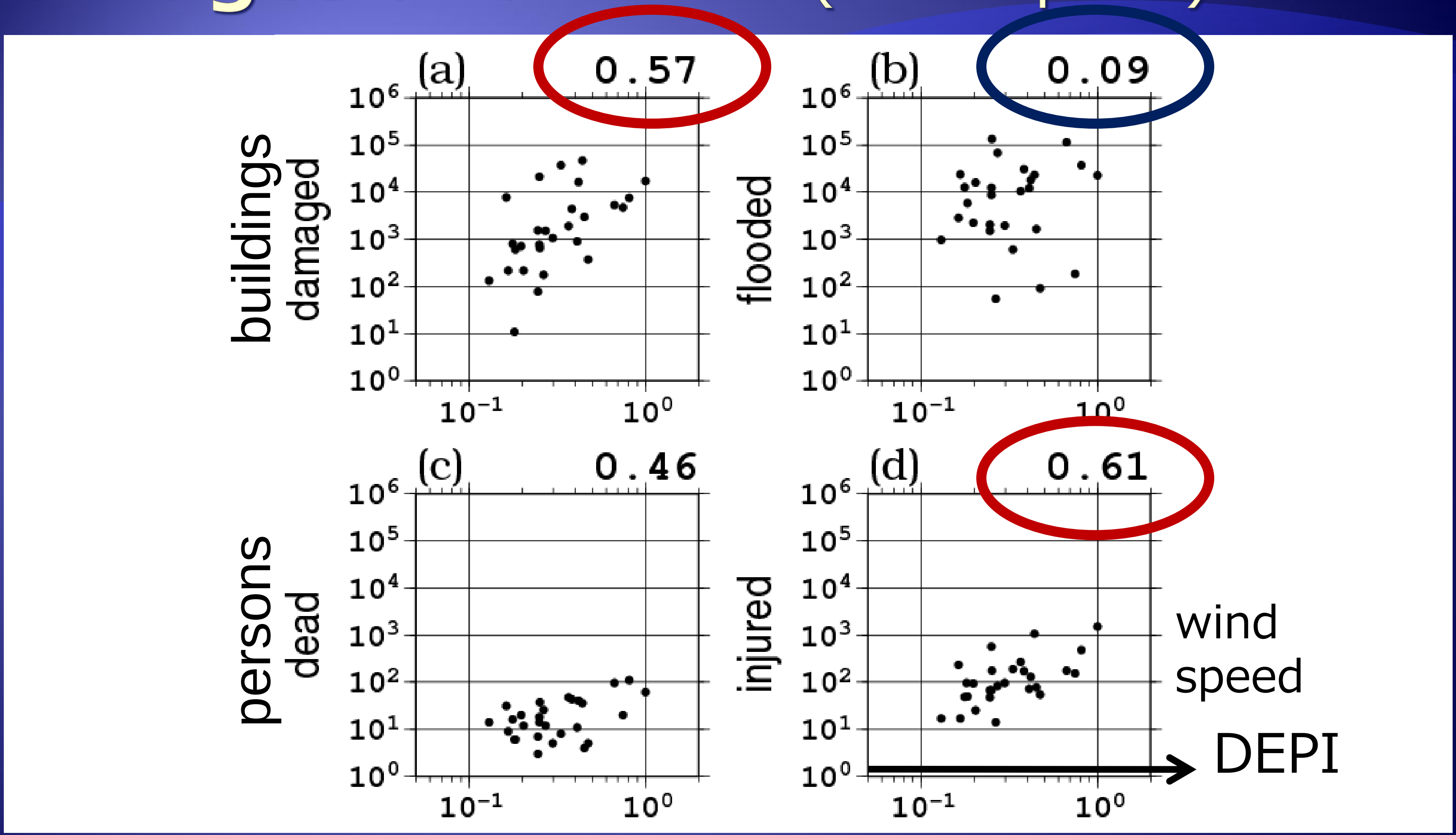
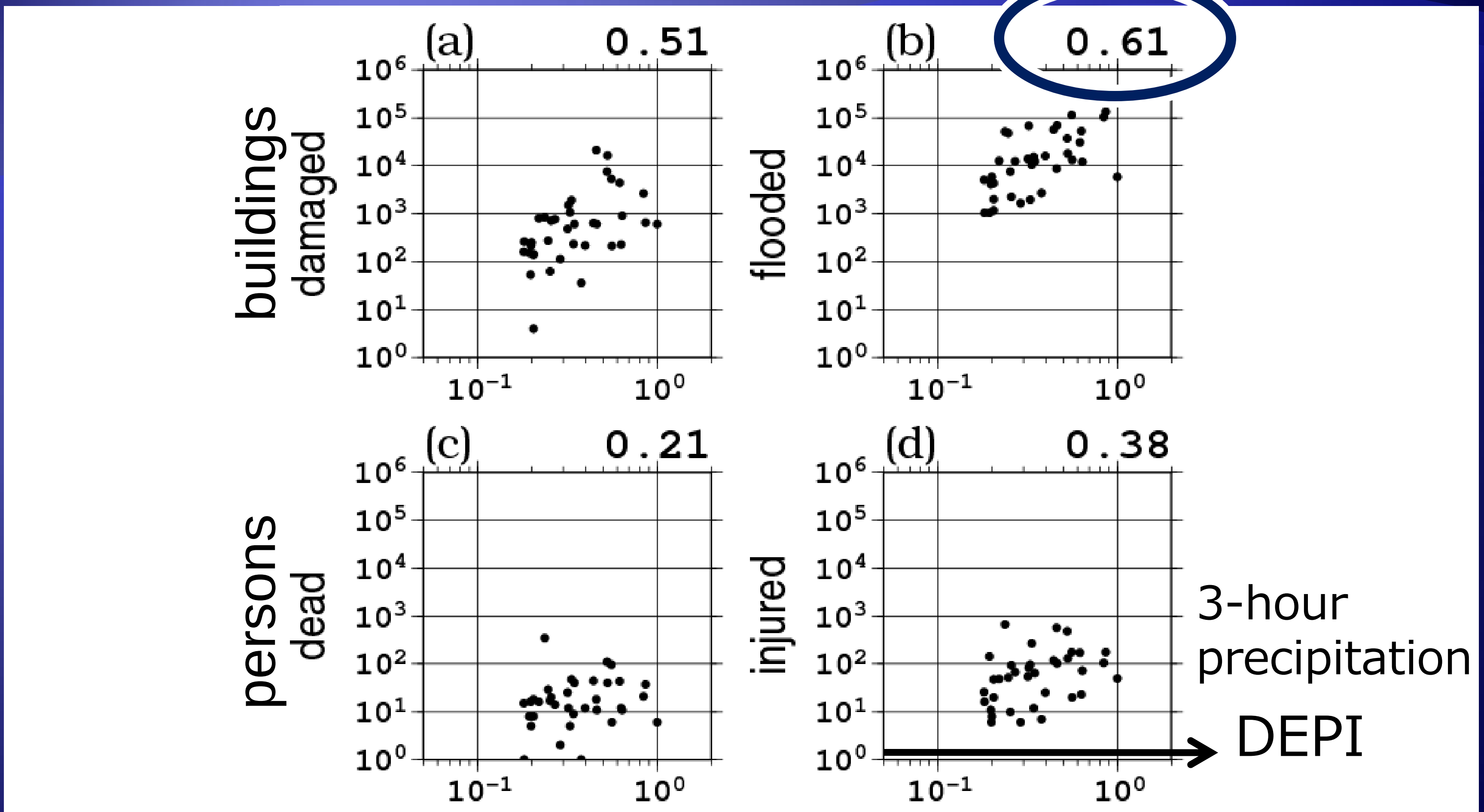
All of them are recorded as a significant event in the reports published by the government agency.

Damages and DEPI (wind speed)



Roughly log-linear relationship can be seen between DEPI values and numbers of damaged buildings and injured persons. Since DEPI values have been estimated from wind speed, number of flooded buildings is not correlated.

Damages and DEPI (3-hour precipitation)



Number of flooded buildings is well correlated with DEPI estimated from 3-hourly precipitation.

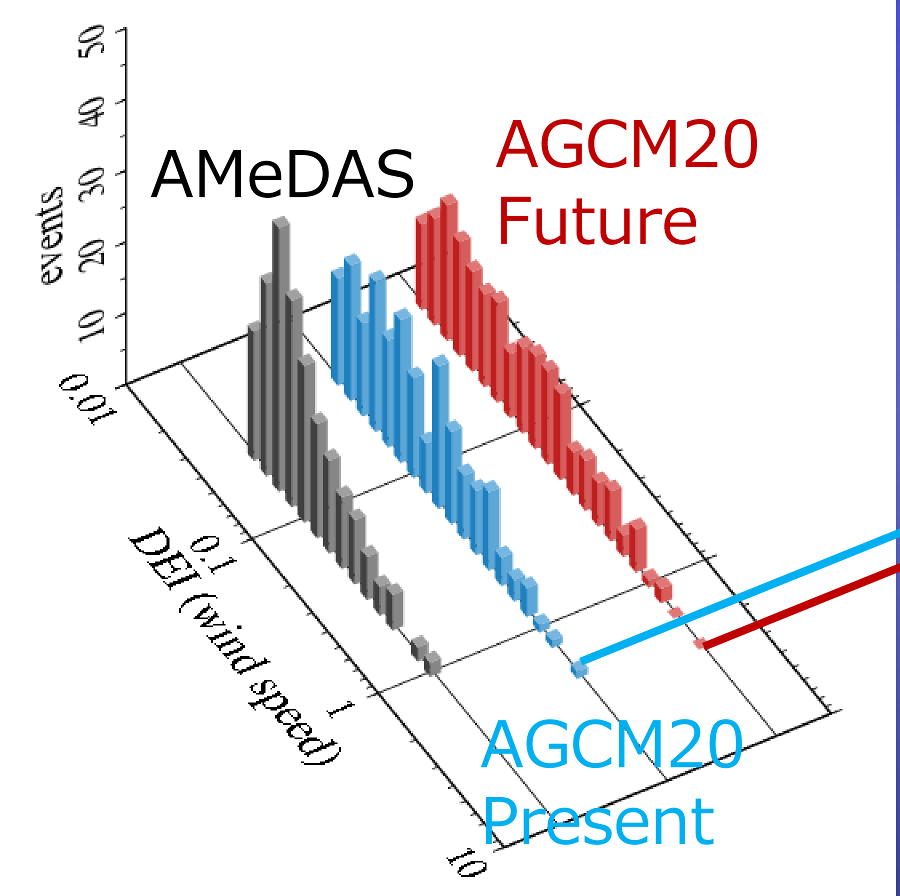
DEI estimation from AGCM20 data

It is reasonable to suppose that amount of damage can be roughly explained by DEPI. It can be concluded that an extremely disastrous synoptic-scale event is able to be determined as the highest DEPI.

This method is applied to AGCM20 outputs.

Input data: hourly wind speed
Present climate: 1979-2003
Future climate: 2076-2099

DEPI estimation from AGCM20 Data



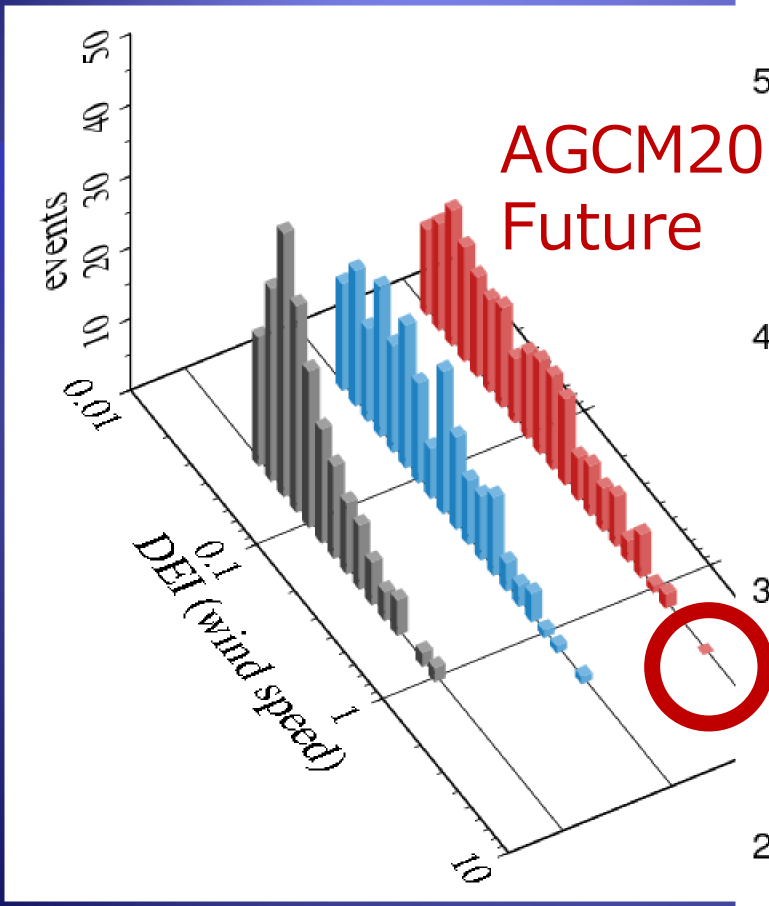
Frequency count distributions of synoptic-scale events classified by DEPI

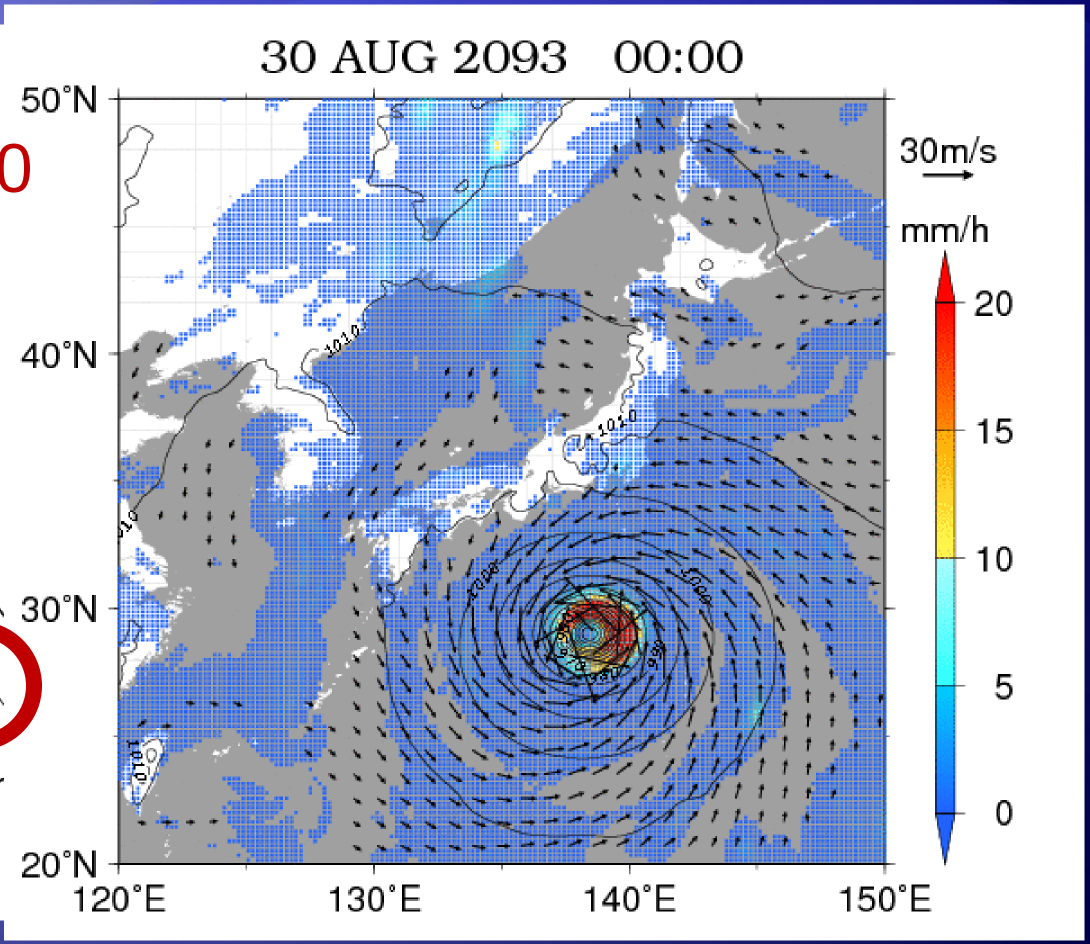
The maximum DEPI during the future climate period is larger than that in the present.

$DEPI_{max}$ present < $DEPI_{max}$ future

This result indicates the extreme synoptic-scale event in the future climate is stronger than that in the present.

Extreme event in AGCM20 future

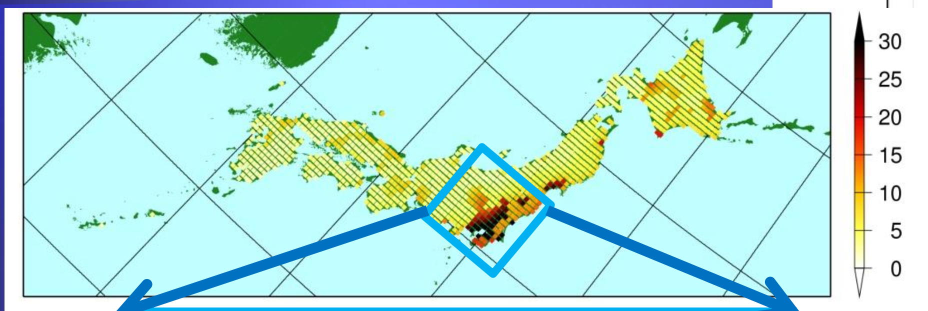


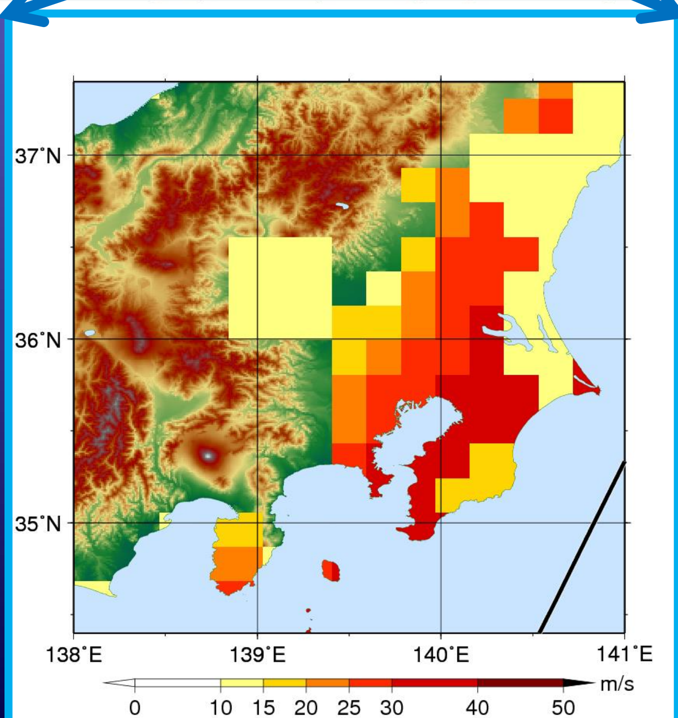


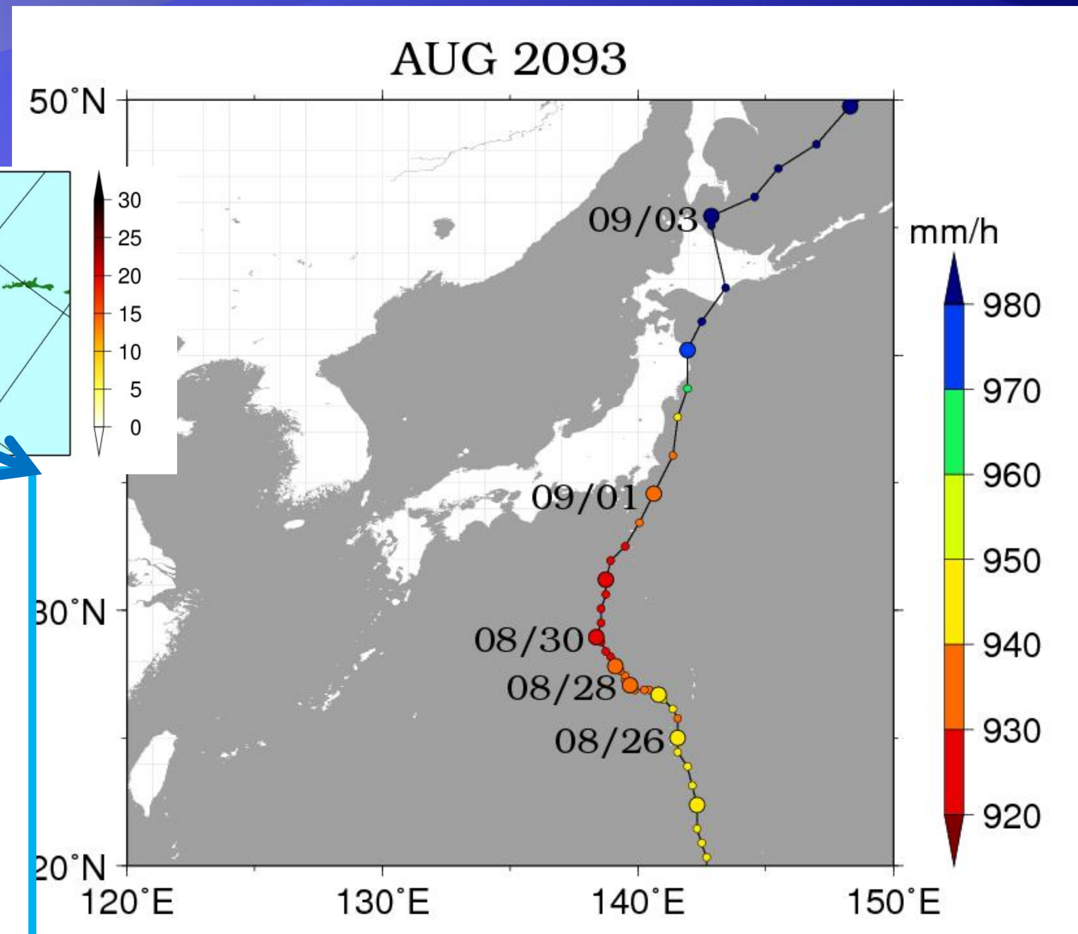
The highest DEPI event in the future climate is a typhoon.

Extreme typhoon in the future

Maximum wind speed distribution during typhoon period







Ertel's Potential Vorticity Inversion

Ertel's Potential Vorticity

$$q = -g\kappa \frac{\pi}{p}\left[\left(f + \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)\frac{\partial \theta}{\partial \pi} - \frac{\partial v}{\partial \pi}\frac{\partial \theta}{\partial x} + \frac{\partial u}{\partial \pi}\frac{\partial v}{\partial y}\right]$$

Non-Divergence and Hydrostatic Equilibrium

$$q = g\kappa \frac{\pi}{p}\left[\left(f + \nabla^2 \Psi\right)\frac{\partial^2 \Phi}{\partial \pi^2} - \frac{\partial^2 \Psi}{\partial \pi \partial x}\frac{\partial^2 \Phi}{\partial \pi \partial x} - \frac{\partial^2 \Psi}{\partial \pi \partial y}\frac{\partial^2 \Phi}{\partial \pi \partial y}\right]$$

Balance Equation

$$\nabla^2 \Phi = \nabla \cdot f \nabla \Psi + 2\left[\frac{\partial^2 \Phi}{\partial x^2}\frac{\partial^2 \Psi}{\partial y^2} - \left(\frac{\partial^2 \Psi}{\partial x \partial y}\right)^2\right]$$

unknown: Φ(geopotential), Ψ(balanced wind steam function)

EPVI (cont.)

given: Φ(geopotential), Ψ(balanced wind steam function)

Ertel's Potential Vorticity

1 $$\frac{d}{dt}\left(q = g\kappa \frac{\pi}{p}\left[\left(f + \nabla^2\Psi\right)\frac{\partial^2\Phi}{\partial\pi^2} - \frac{\partial^2\Psi}{\partial\pi\partial x}\frac{\partial^2\Phi}{\partial\pi\partial x} - \frac{\partial^2\Psi}{\partial\pi\partial y}\frac{\partial^2\Phi}{\partial\pi\partial y} \right] \right)$$

Balance Equation

2 $$\frac{d}{dt}\left(\nabla^2\Phi = \nabla\cdot f\,\nabla\Psi + 2\left[\frac{\partial^2\Phi}{\partial x^2}\frac{\partial^2\Psi}{\partial y^2} - \left(\frac{\partial^2\Psi}{\partial x\partial y}\right)^2 \right] \right)$$

unknown:

q_t (potential vorticity),

χ (irrotational wind), ω (vertical velocity),

Φ_t (geopotential), Ψ_t (balanced wind steam function)

EPVI (cont.)

EPV tendency

3 $$\frac{dq}{dt} = -\mathbf{V}_{\mathrm{h}} \cdot \nabla q - \omega \frac{\partial q}{\partial \pi} + g\kappa \frac{\pi}{p}\left[\vec{\eta} \cdot \nabla\left(\frac{d\theta}{dt}\right)\right]$$

$$\mathbf{V}_{\mathrm{h}} \equiv \mathbf{V}_{\Psi} + \mathbf{V}_{\chi}$$

unknown:

q_t (potential vorticity),

χ (irrotational wind), ω (vertical velocity),

Φ_t (geopotential), Ψ_t (balanced wind steam function)

EPVI (cont.)

$$\nabla^2(\text{thermodynamic eq.}) - f\frac{\partial}{\partial \pi}(\text{balanced vorticity eq.}) - \frac{\partial}{\partial \pi}(2)$$

$$f\eta\frac{\partial}{\partial \pi}\left[\pi^{1-1/\kappa}\frac{\partial}{\partial \pi}\left(\pi^{1/\kappa-1}\omega\right)\right] + \nabla^2\left(\frac{\partial^2\Phi}{\partial \pi^2}\omega\right)$$
$$- f\frac{\partial}{\partial \pi}\left(\frac{\partial^2\Psi}{\partial x\partial \pi}\frac{\partial \omega}{\partial x} + \frac{\partial^2\Psi}{\partial y\partial \pi}\frac{\partial \omega}{\partial y}\right) + \left(f\frac{\partial \eta}{\partial \pi}\frac{1/\kappa - 1}{\pi} - f\frac{\partial^2\eta}{\partial \pi^2}\right)\omega$$
$$= \nabla^2\left(\mathbf{V}_\mathrm{h}\cdot\nabla\theta\right) + f\frac{\partial}{\partial \pi}\left(\mathbf{V}_\mathrm{h}\cdot\nabla\eta\right) - \frac{\partial}{\partial \pi}(J) - \nabla f\cdot\nabla\left(\frac{\partial^2\Psi}{\partial \pi\partial t}\right) + \nabla^2\left(\frac{d\theta}{dt}\right)$$

Iversen and Nordeng (1984)

4 $$F\left(q_\mathrm{t}, \Phi_\mathrm{t}, \Psi_\mathrm{t}, \chi, \omega\right) = 0$$

q_t (potential vorticity),

unknown: χ (irrotational wind), ω (vertical velocity),

Φ_t (geopotential), Ψ_t (balanced wind steam function)

EPVI (cont.)

mass continuity

5 $$\nabla^2 \chi + \pi^{1-1/\kappa} \frac{\partial}{\partial \pi}\left(\pi^{1/\kappa-1}\omega\right) = 0$$

unknown: q_t (potential vorticity),

χ (irrotational wind), ω (vertical velocity),

Φ_t (geopotential), Ψ_t (balanced wind steam function)

Impact assessment studies in DPRI