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Regional-Scale Downscaling of Typhoon Hazards under Changing Climate

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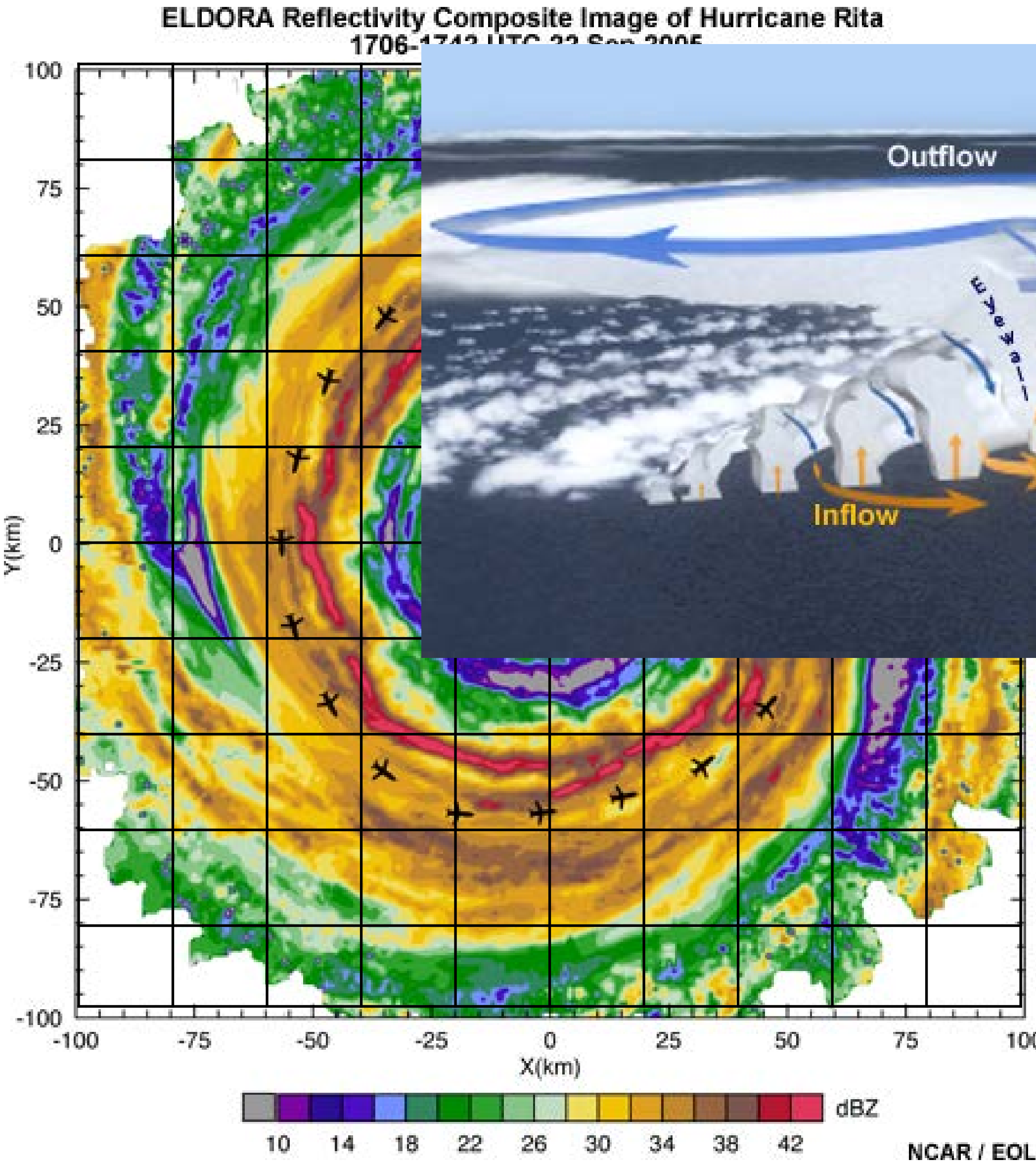
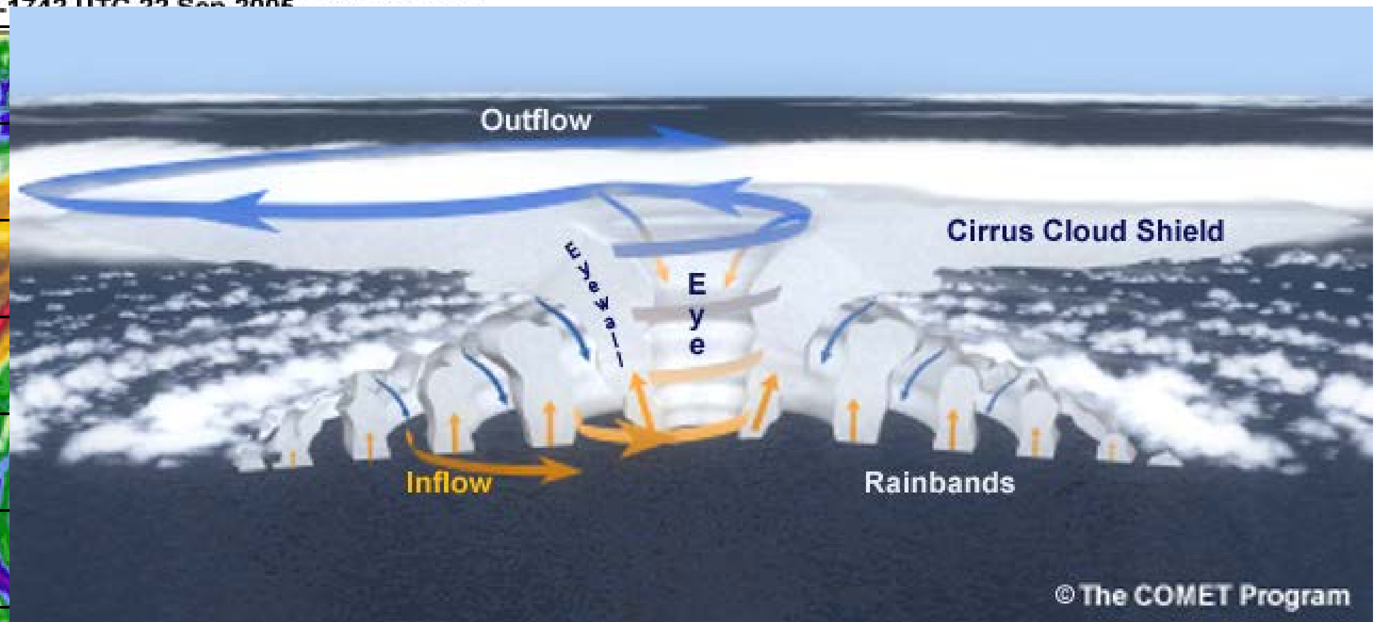
Assessing typhoon hazards at regional-scales

- Typhoon hazard is one of the major meteorological hazards in the western North Pacific region.
  - Coastal regions/island regions – Storm surge, high wave
  - Land regions – Heavy rainfall/high wind, often topographically induced
- Hazards depend on regional geographical characteristics.
  - Complex topography, climatology
- Quantitative assessment on the impacts from hazards is required for disaster prevention and mitigation.
  - Amount of rainfall, wind speed – Warning, Controlling flood, inundation, outside operation/activity
- Assessment of typhoon impacts under global warming is important for disaster mitigation and adaptation planning.
  - Changes in the severity of category-5 tropical cyclones and the resulting hazards under global warming

Typhoon has a meso-$\alpha/\beta/\gamma$-scale structure

200 km





200 km

Analysis requires a multi-scale point of view.

How to assess the impacts of typhoon hazards?

Hazards can be assessed by considering worst-class scenarios.

- Past disaster-spawning cases are regarded as a baseline for the hazard assessment

Downscaling experiments with a regional numerical weather prediction model are vital for quantitatively representing convective-scale processes.

- Cloud-resolving/permitting resolution

Effective use of climate prediction experiments is important.

- High-resolution GCM data
- Pseudo-global warming (PGW) experiments: worst-case scenario under global warming

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Downscaling experiments for worst-class typhoons

Typhoon Haiyan (2013)

Typhoon Vera (1959) (Isewan Typhoon)

Typhoon Songda (2004)

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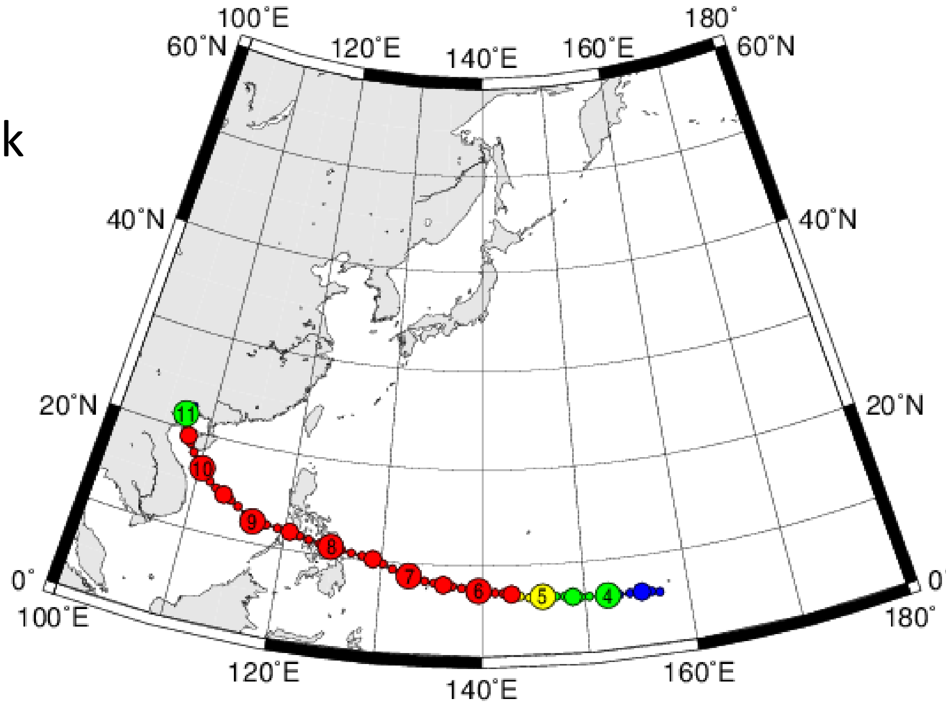
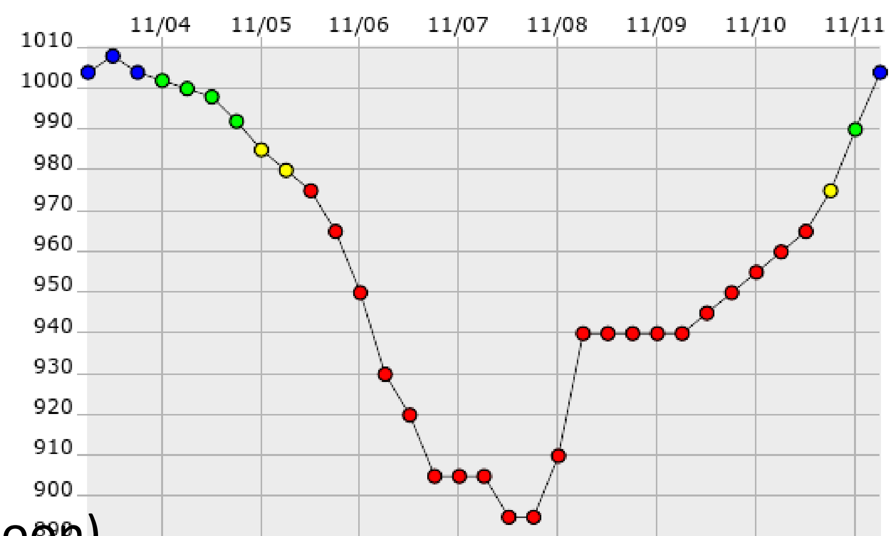
Super Typhoon Haiyan (2013)

Track



Central pressure



Maximum intensity

Central pressure:
895 hPa

Max wind speed: 65 m/s

(best track)

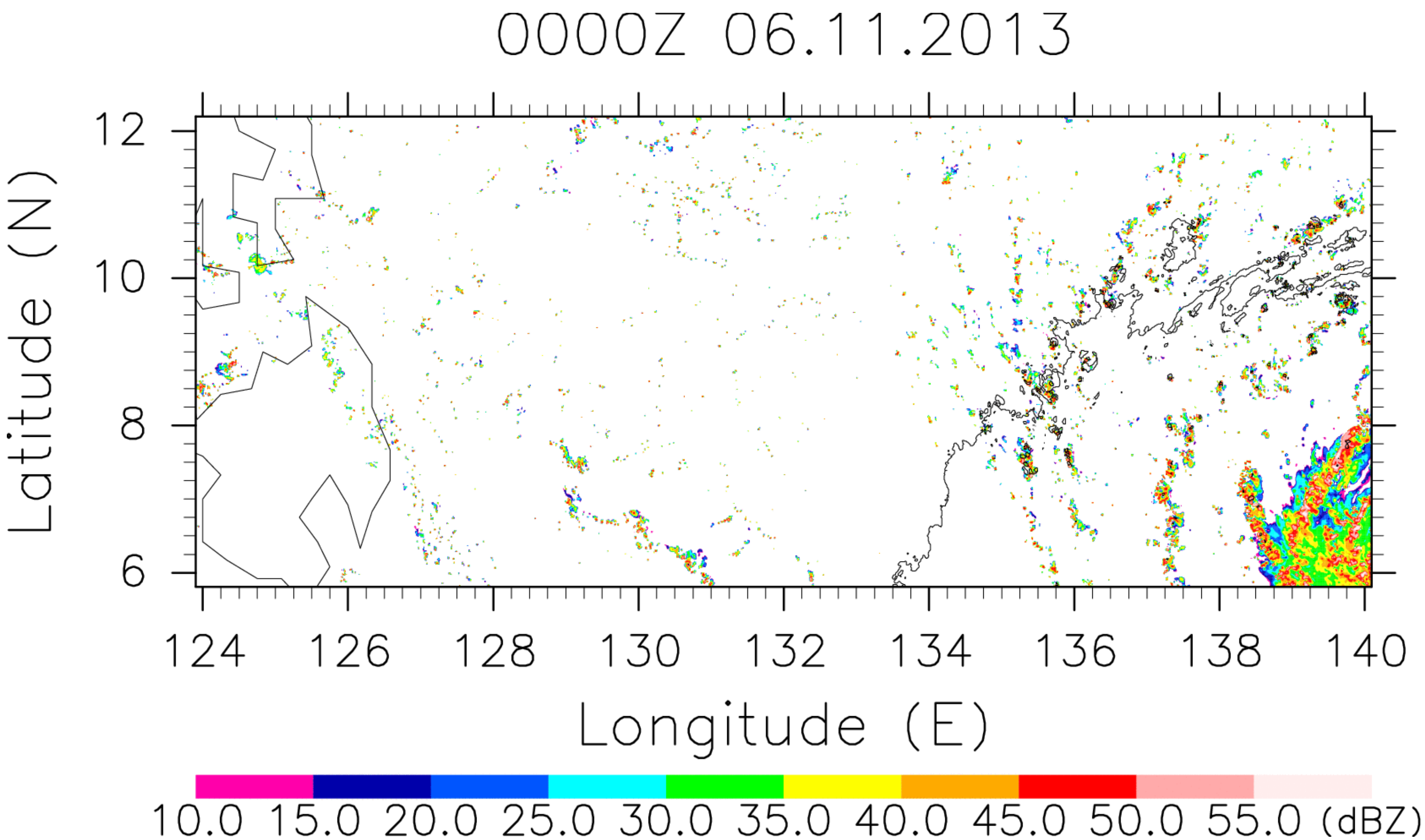
(From Digital Typhoon)

Model and experimental settings

- Model: WRF/ARW Version 3.3.1
- Initial and boundary conditions:
  - Atmosphere: NCEP Final Analysis (FNL)
  - SST: NCEP FNL or JMA MGDSST
- Domain & resolution: 3 km/1 km
  - Domain 1 (3 km): 4000 km x 2000 km
  - Domain 2 (1 km): 2000 km x 700 km, and etc.
  - Vertical levels: 56
  - Model top: 20 hPa
- Simulation period:
  - 0000 UTC 5 Nov – 0000 UTC 10 Nov 2013

Typhoon Haiyan (2013): Simulation with WRF

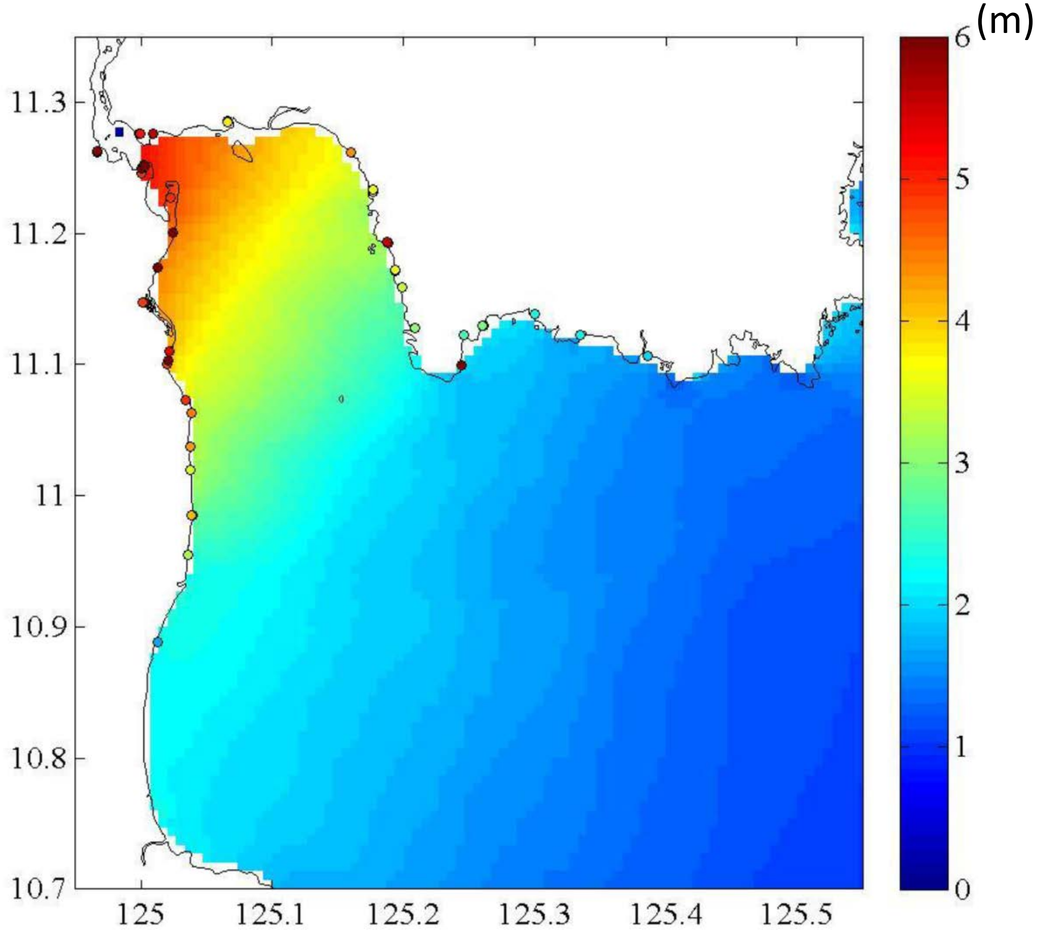
Regional simulation with the Weather Research and Forecasting (WRF) model at 1-km resolution



Simulation of storm surge in Leyte Gulf

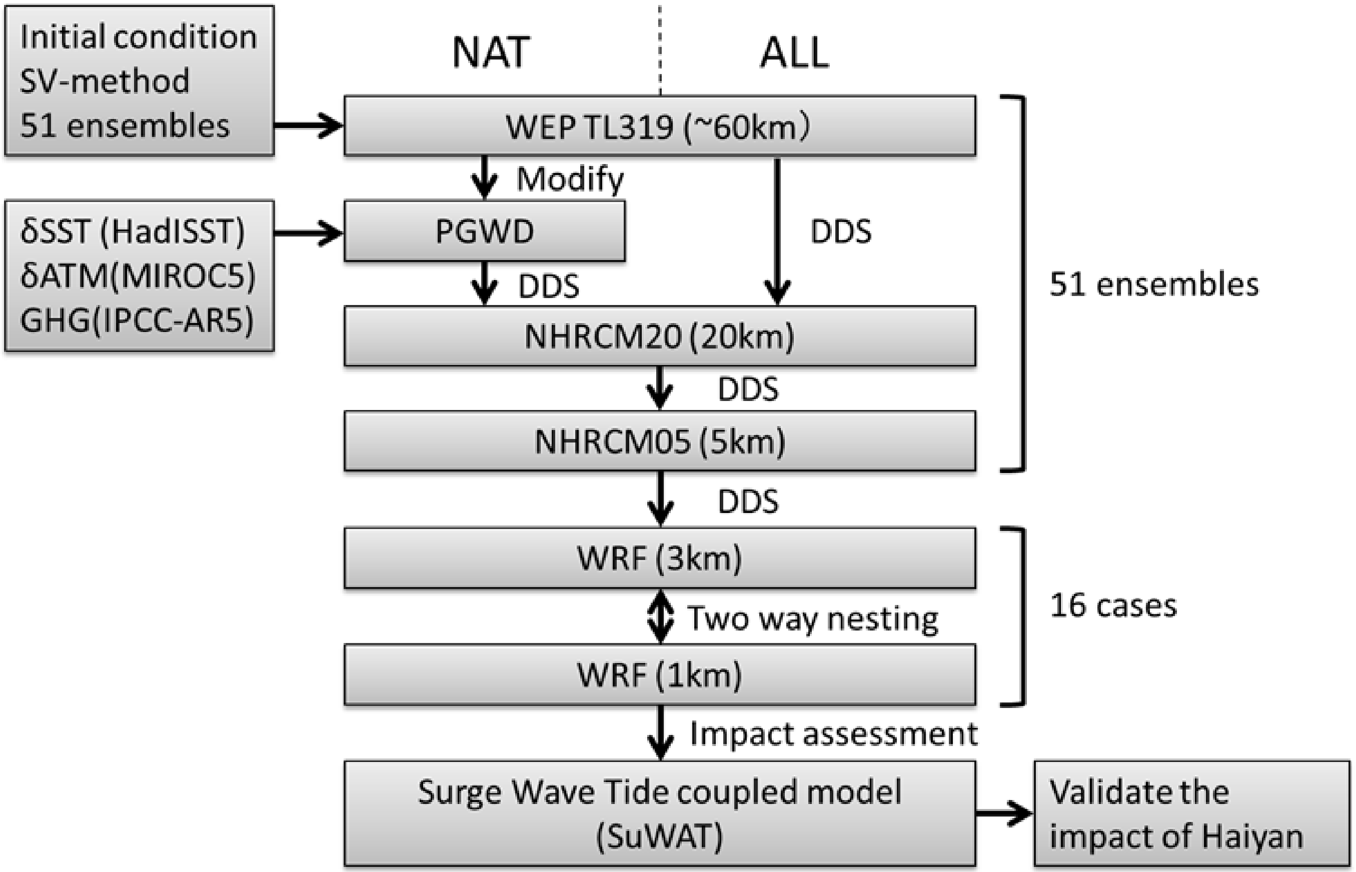
Maximum water surface elevation with the use of the WRF outputs

Circle points indicate the measurements.



(Mori et al. 2014)

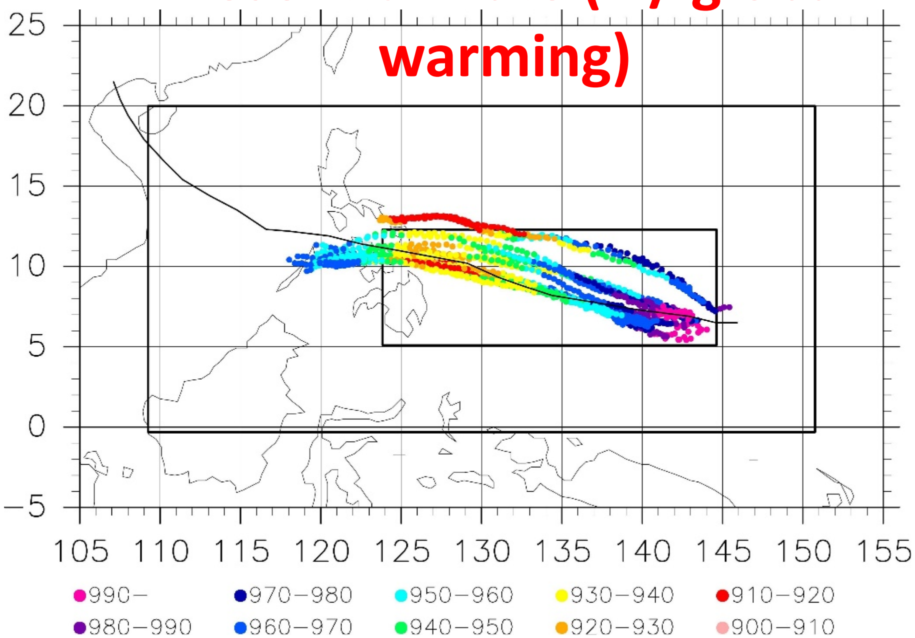
Effects of climate change on worst storm surge



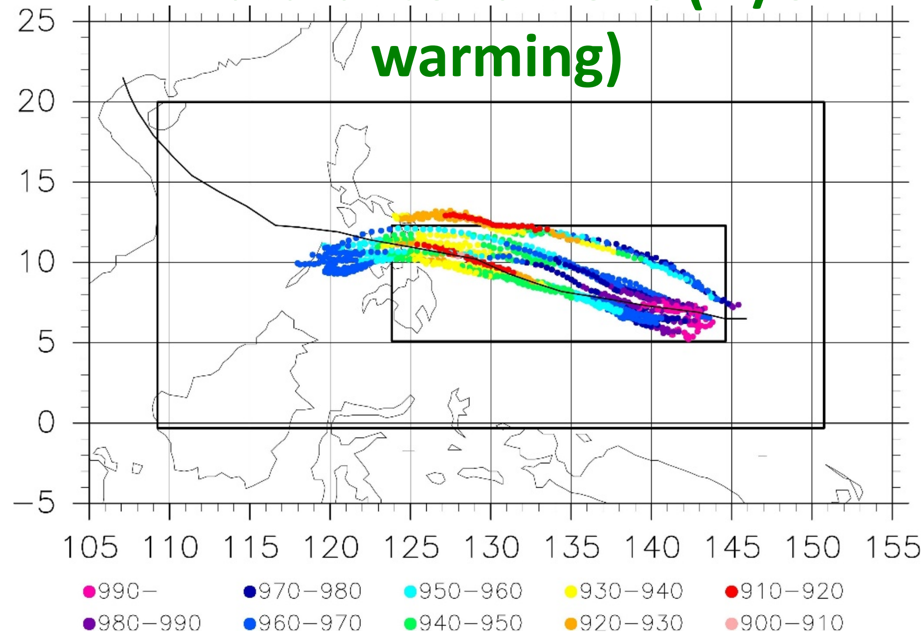
Takayabu, I., K. Hibino, H. Sasaki, H. Shiogama, N. Mori, Y. Shibutani, T. Takemi, 2015: Climate change effects on the worst-case storm surge: a case study of Typhoon Haiyan. *Env. Res. Lett.*, **10**, 064011

Intensity of tropical cyclones

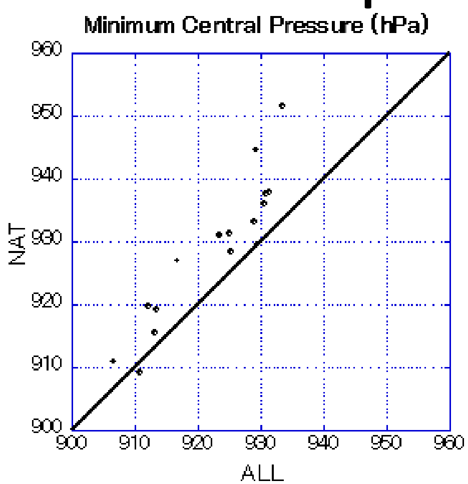
Present climate (w/ global warming)



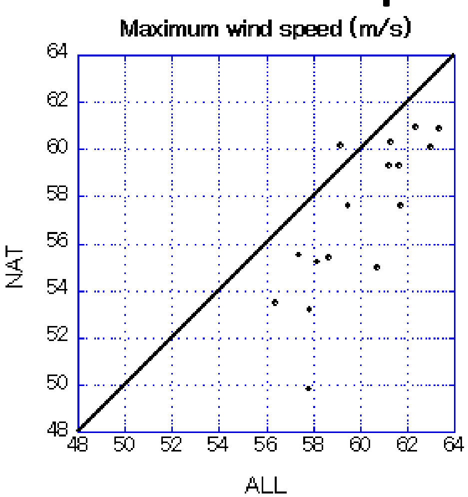
Natural conditions (w/o warming)



Minimum central pressure



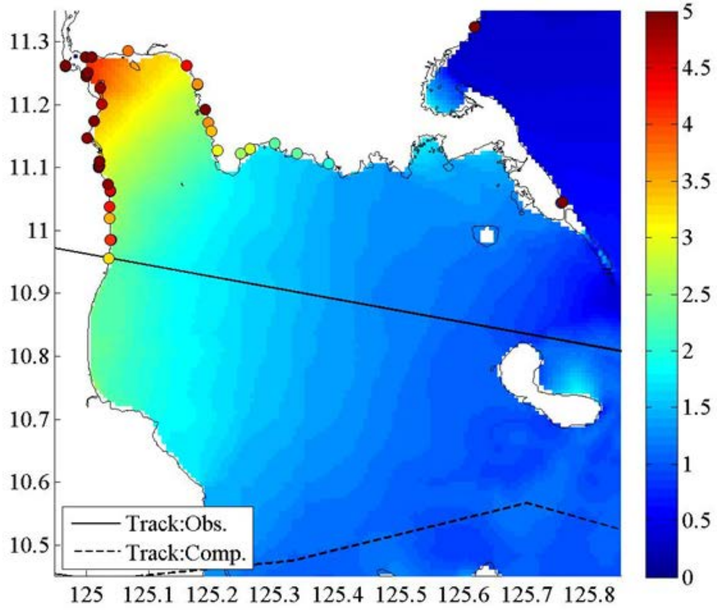
Maximum wind speed



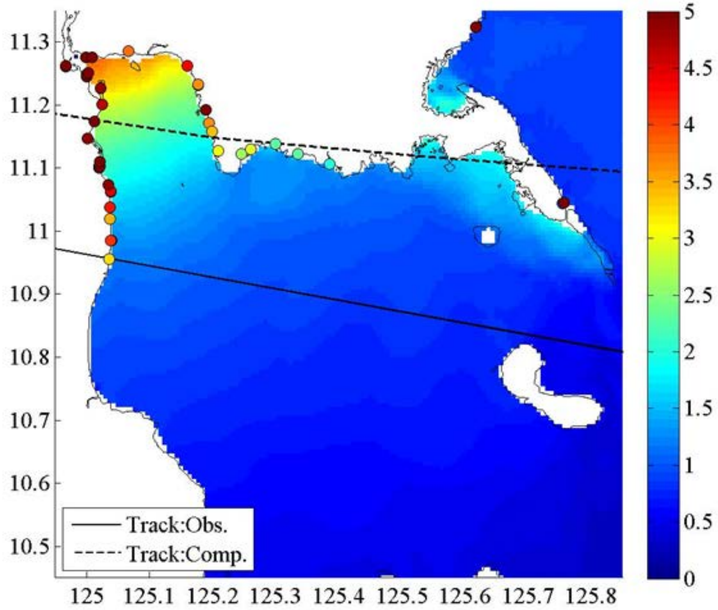
Takayabu, I., et al. 2015, *Env. Res. Lett.*, **10**, 064011

Storm surge

Present climate (w/ global warming)



Natural conditions (w/o warming)



Increase the water level by 10—20 % due to global warming for the worst-case storm surge from a Haiyan-class typhoon

Takayabu, I., et al. 2015, *Env. Res. Lett.*, **10**, 064011

Typhoon Vera (1959): “Isewan Typhoon”

- Downscaling experiments with the WRF model
  - Initial and boundary conditions: JRA-55
- Typhoon Vera (1959) “Isewan Typhoon”: September 1959
  - Minimum central pressure: 895 hPa
  - Storm surge/high waves in the Ise Bay
  - River discharge in the Yodo River basin
  - The highest resolution of the nested domains: 1km
- Assessing the impacts of global warming
  - Pseudo-global warming (PGW) experiments
    - † Climate change increment between future and present climate simulated by MRI-AGCM3.2S

Pseudo-global warming experiment

Global warming increment

Future changes in temperature, pressure, sea surface temperature from GCM climate prediction data

Increment = (GCM future climate) – (GCM present climate)

Past analysis

Long-term reanalysis dataset: JRA-55 (available from 1958)

Add global warming increment to past analysis fields

Example: Vera-class extreme typhoon under global warming

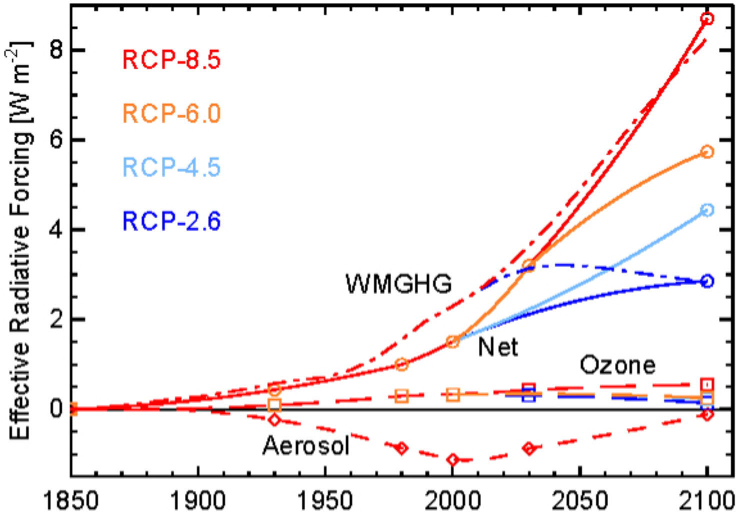
(Pseudo-global warming climate)

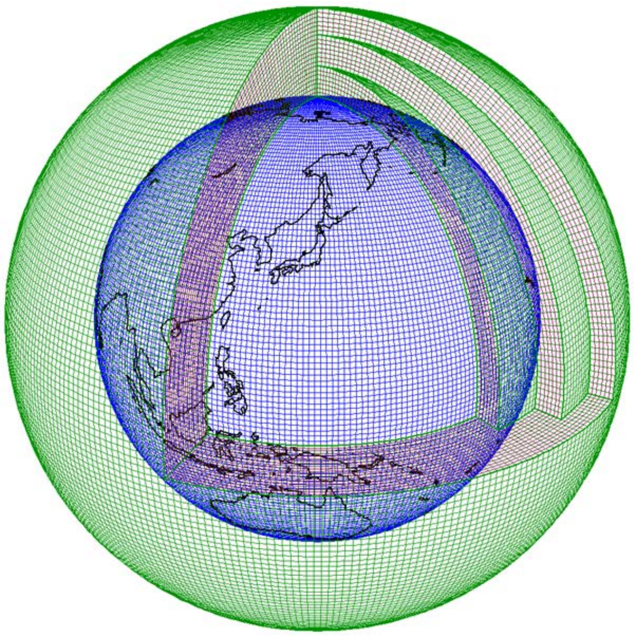
= (Sep 1959 reanalysis) + (Sep monthly mean GW increment)

Climate prediction data

- Climate simulation data by JMA/MRI-AGCM3.2 (Atmospheric General Circulation Model Version 3.2)
  - Present climate: 1979-2003
  - Future climate: 2075-2099 under various Representative Concentration Pathways (RPCs) (CO2 emission scenario)
  - Spatial resolution: 20 km and 60 km

Effective radiative forcing corresponding to CO2 increase

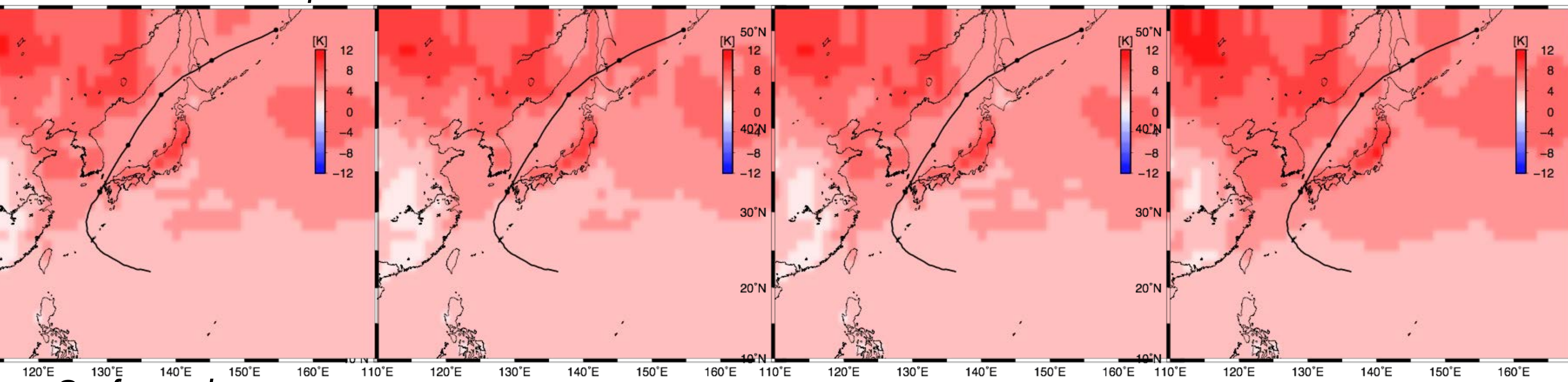




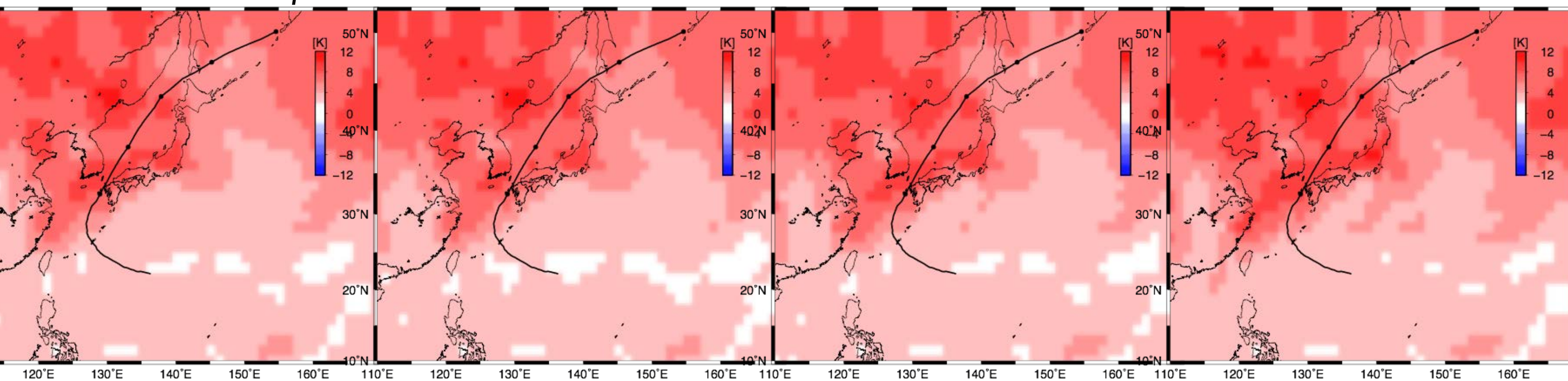
Global warming increment in September

All cluster | *Cluster 1* | *Cluster 2* | *Cluster 3*

Sea surface temperature

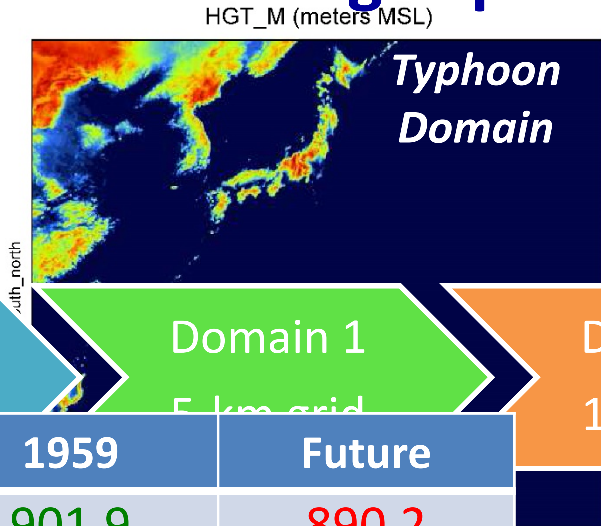


Surface air temperature

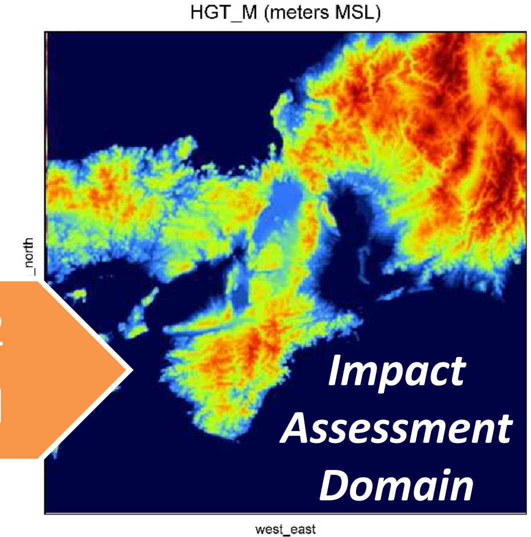


Downscaling experiments

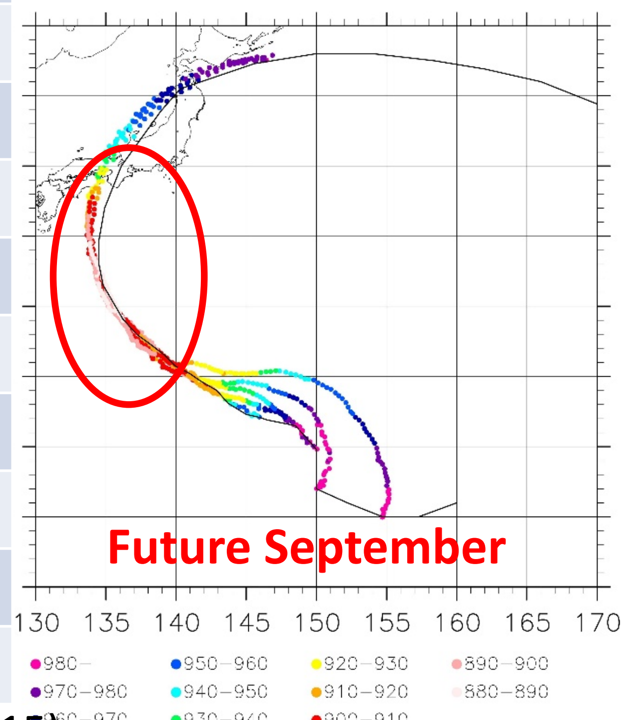
Downscaling by the WRF model



JRA55 → Domain 1 → Domain 2
1-km grid



	Initial time	1959	Future
MCP (hPa)	1200 9/22	901.9	890.2
	0000 9/22	901.8	893.0
	1200 9/21	899.5	898.1
	0000 9/21	904.9	886.0
	1200 9/20	909.0	879.4
MWS (m/s)	1200 9/22	58.3	65.3
	0000 9/22	58.4	65.5
	1200 9/21	57.9	66.2
	0000 9/21	55.4	65.6
	1200 9/20	61.8	66.1



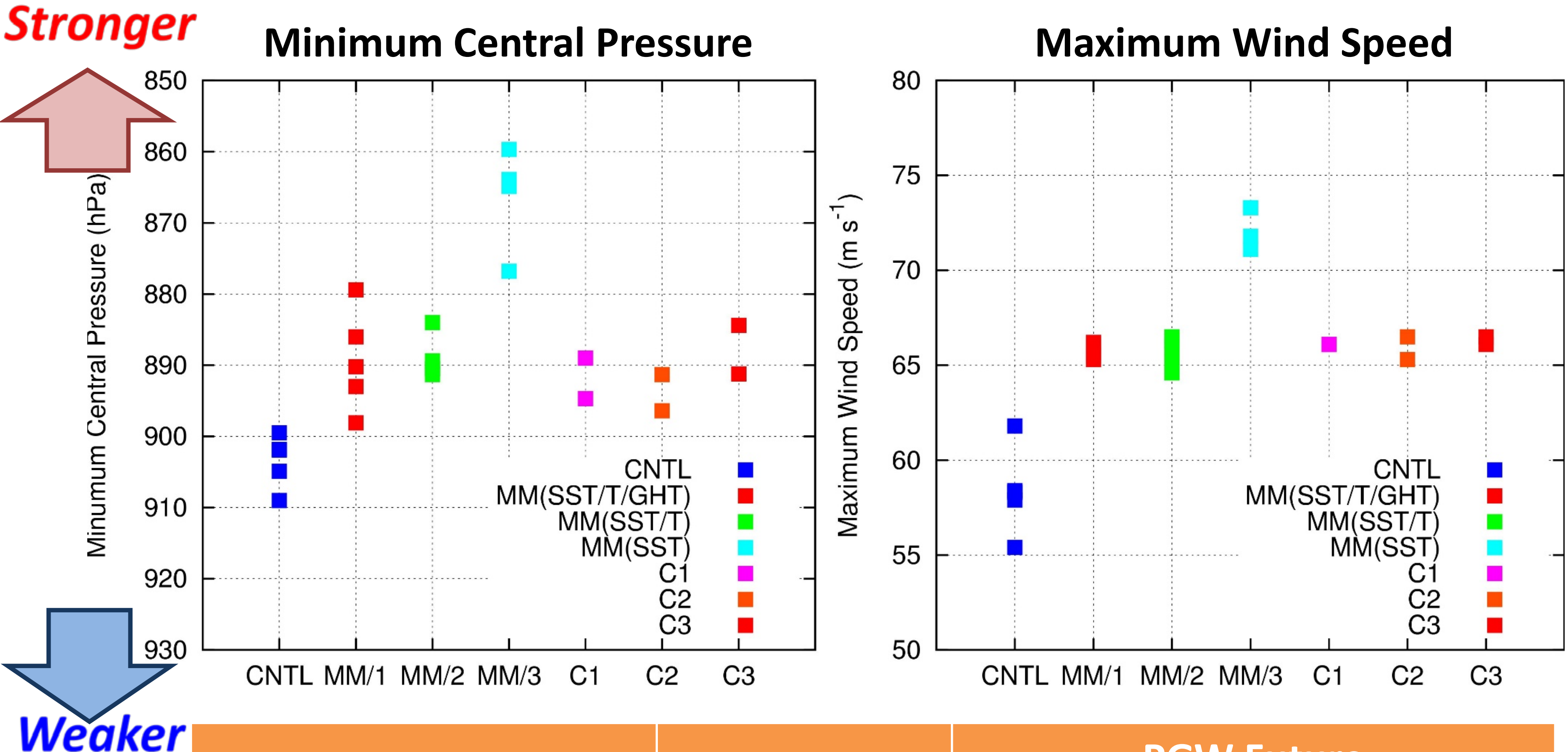
(Mori and Takemi 2015)

Pseudo-global warming (PGW) experiments

- **CNTL**: Sep 1959 condition; initialized at 5 different times
- **PGW**: Four different SST conditions (Mizuta et al. 2014)
  - CMIP5 multi-model ensemble mean SST
  - Three SST patters from cluster analysis (Cluster 1, 2, and 3)

		Added vars	9/22 12UT	9/22 00UT	9/21 12UT	9/21 00UT	9/20 12UT
1959 Exp (CNTL)			case001	case002	case003	case004	case005
Pseudo-global warming (PGW)	SST MM	SST, T, GHT	case101	case102	case103	case104	case105
		SST, T	case111	case112	case113	case114	case115
		SST	case121	case122	case123	case124	case125
	SST C1	SST, T, GHT		case202			
		SST, T	case211				
	SST C2	SST, T, GHT		case302			
		SST, T	case311				
	SST C3	SST, T, GHT		case402			
		SST, T	case411				

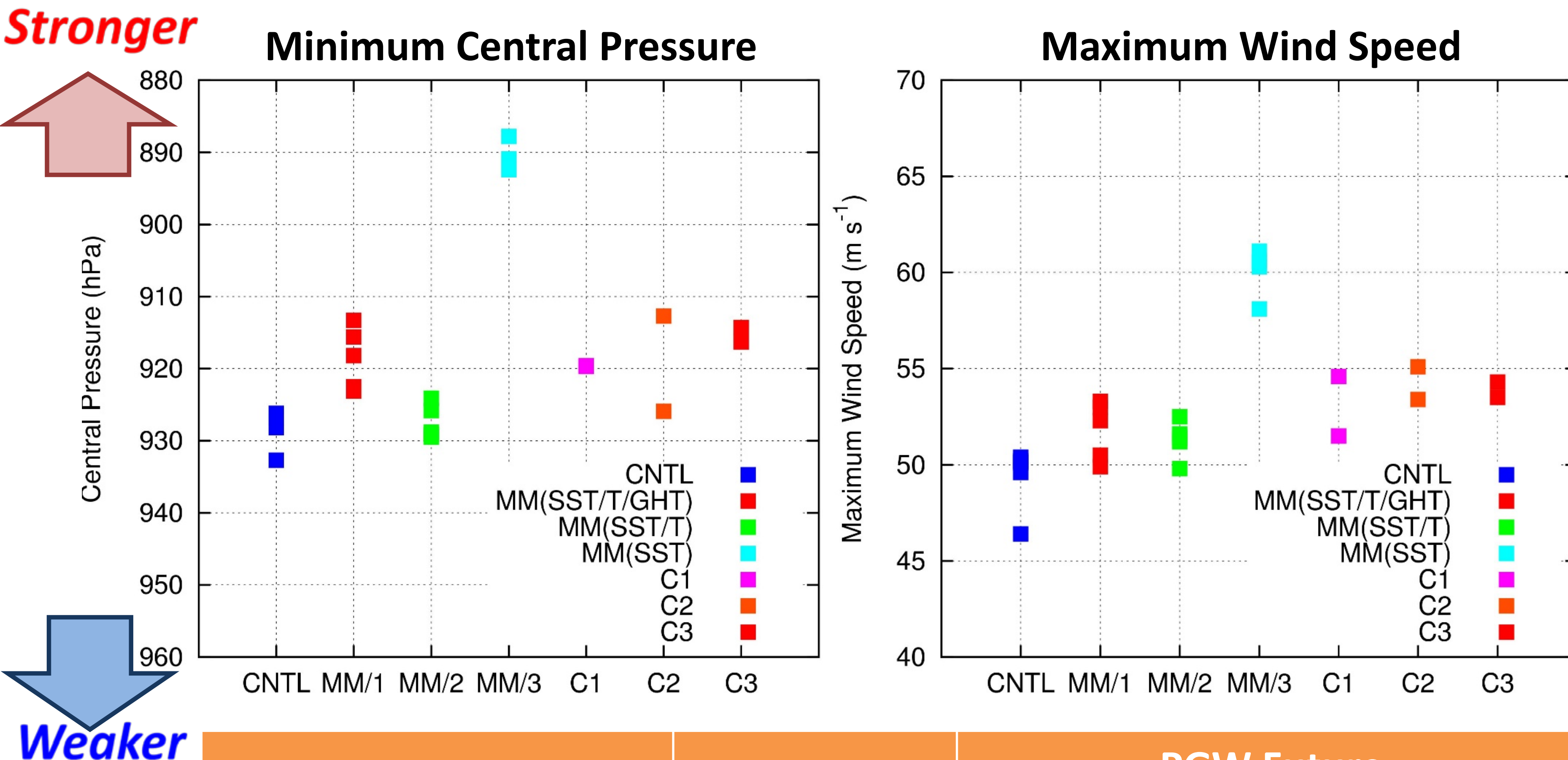
Intensification of Isewan Typhoon under GW



	Present	PGW Future	
		SST + 3D atm	SST
Min central pressure (hPa)	899.5 – 909.0	879.4 – 898.1	859.7 – 876.8
Max wind speed (m/s)	55.4 – 61.8	64.6 – 66.5	71.1 – 73.3

Cf: In Haiyan case, min central pressure decreases by 6.44 hPa.

Changes in typhoon intensity at landfall



	Present	PGW Future	
		SST + 3D atm	SST
Min central pressure (hPa)	926.2 – 932.7	912.7 – 929.5	887.8 – 892.4
Max wind speed (m/s)	46.4 – 50.4	49.8 – 55.1	58.1 – 61.1

Typhoon disaster in northern Japan

Typhoon Marie (1954) “Toyamaru Typhoon”

Shipwreck of “Toyamaru” over the Tsugaru Straits: 1139 deaths

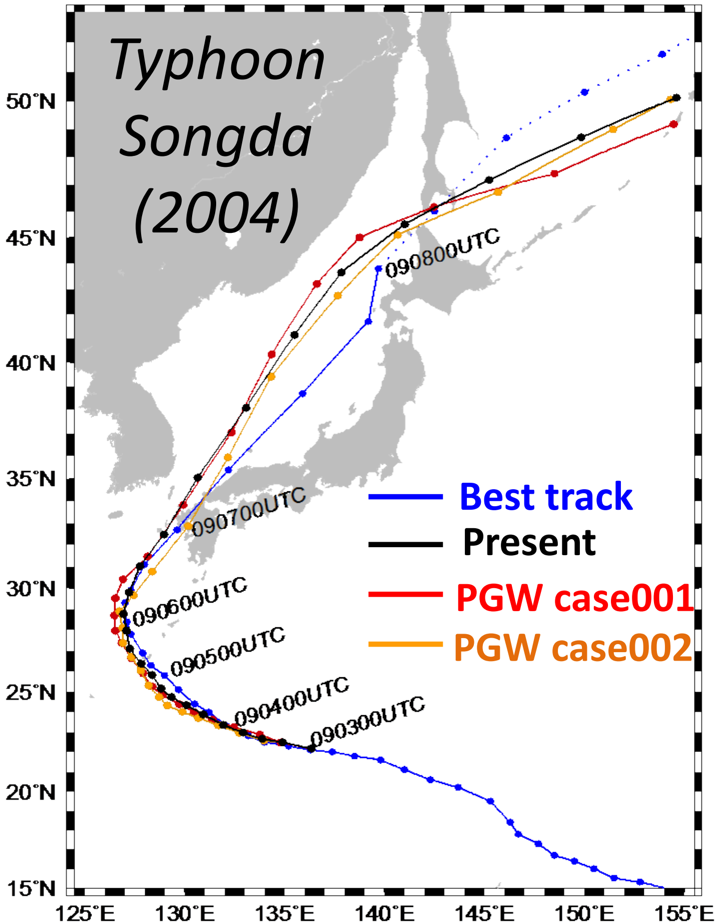
Typhoon Mireille (1991)

Significant damages to agriculture (e.g., apple trees in Aomori Prefecture)

Typhoon Songda (2004)

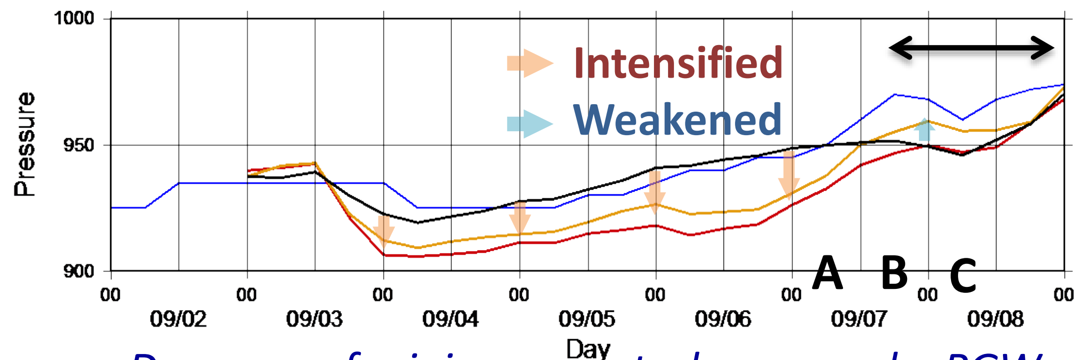
Forest damages over Hokkaido

Changes in typhoon hazard in northern Japan



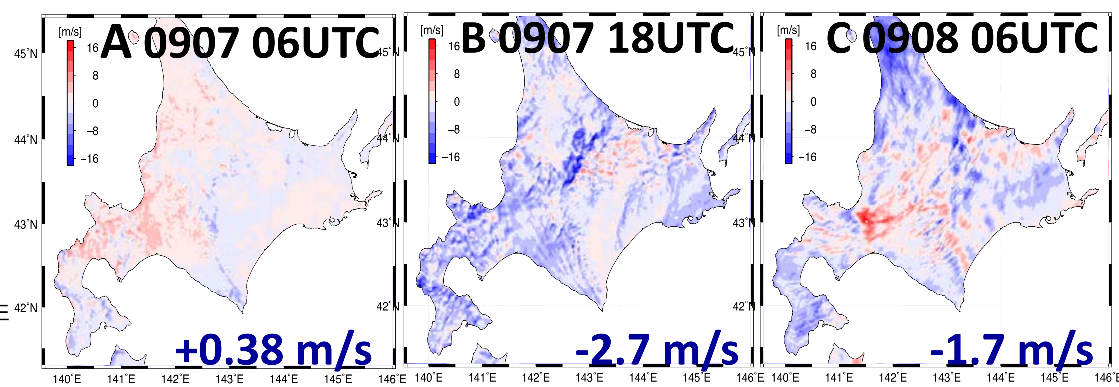
Time series of central pressure

Approaching Hokkaido



Decrease of minimum central pressure by PGW
case001: -28hPa; case002: -22hPa

Changes in wind speed by PGW

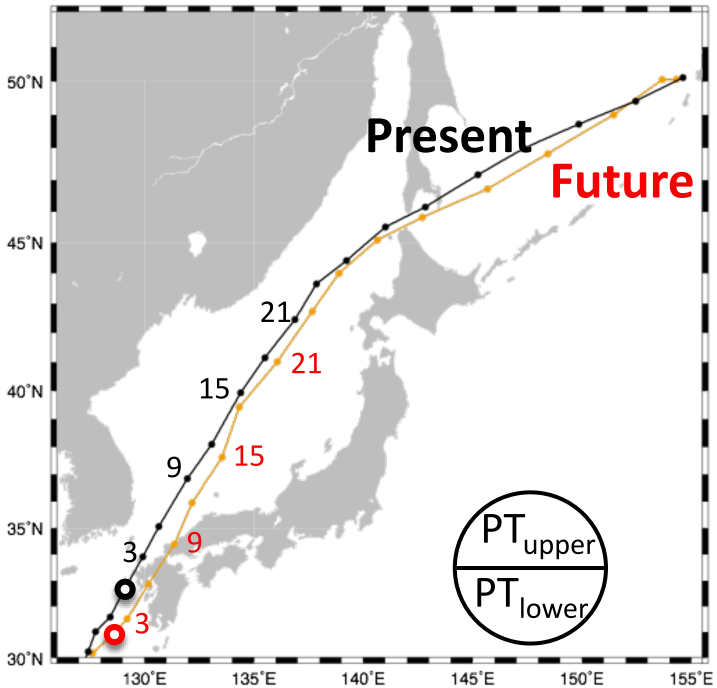


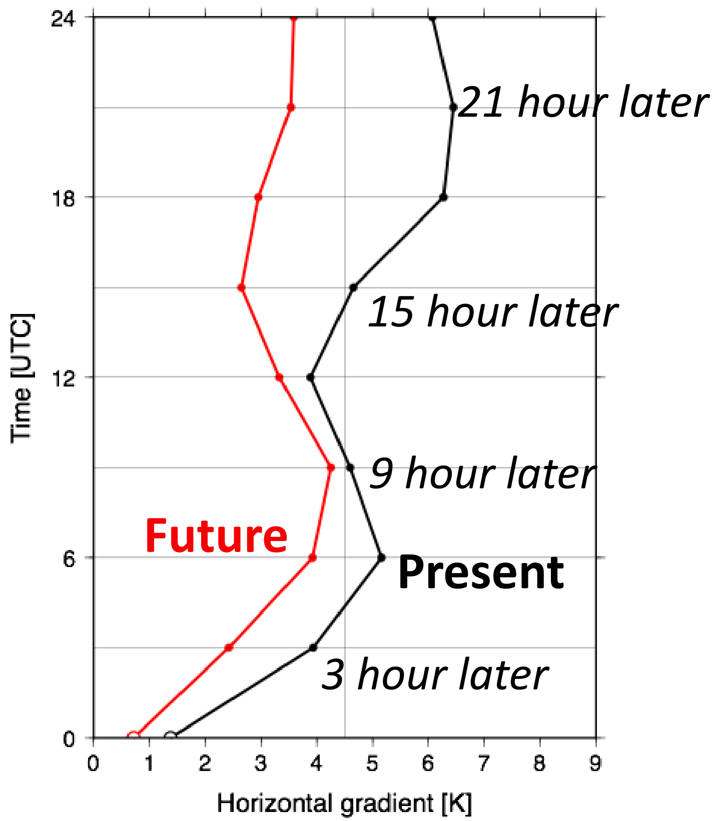
Decrease in wind speeds due to typhoon under PGW condition

(Ito et al. 2016)

Environmental control on the typhoon change

North-south gradient of temperature along the typhoon track

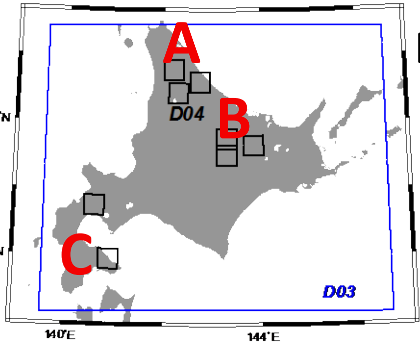




Decrease in the temperature gradient → Decrease in baroclinicity → Reduce the re-intensification due to extratropical transition

(Ito et al. 2016)

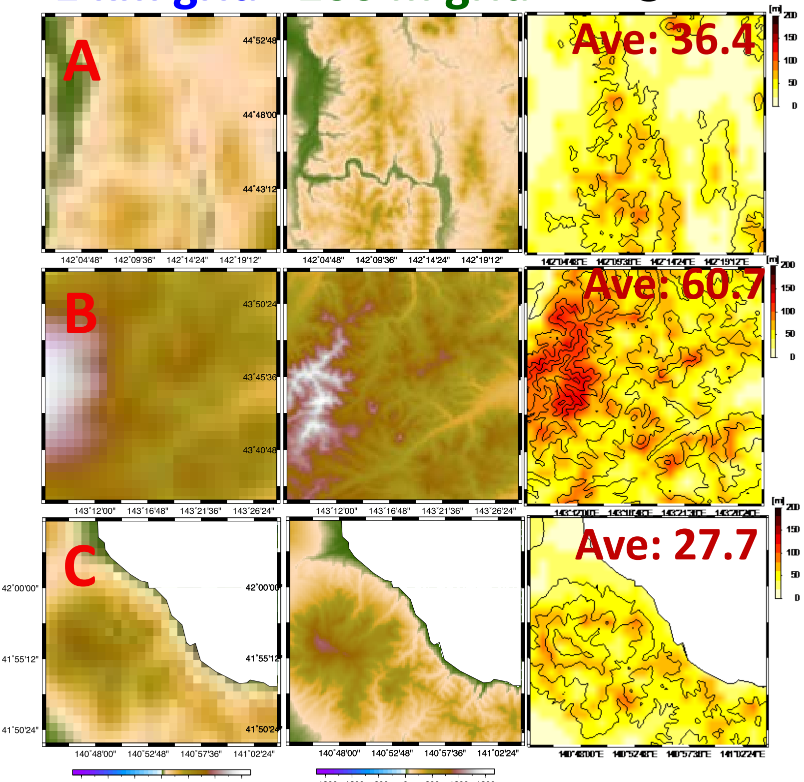
Added-values in higher-resolution simulations



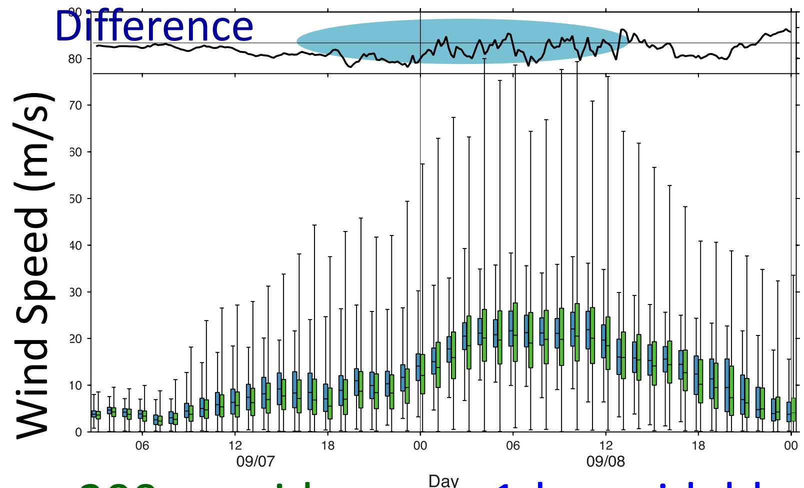
Degree of terrain complexity (Jimenez and Dudhia 2012)

$$\sigma_{sso} = \sqrt{\frac{1}{N_{d04}} \sum_{i=1}^{N_{d04}} (h_i - \bar{h})}$$

1 km grid **200 m grid** **σ**

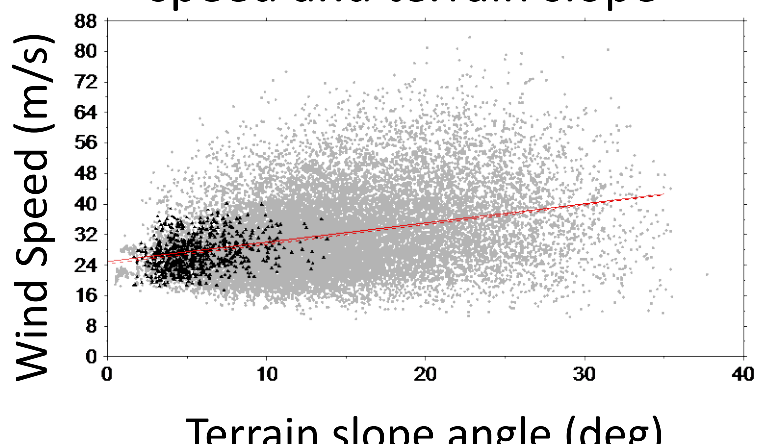


Time series of area-mean and variability of wind speed in Region B



200-m grid: green; 1-km grid: blue

Relationship between wind speed and terrain slope



(Ito et al. 2016)

Summary

Conduct downscaling numerical experiments of extreme typhoons

- Haiyan (2013), Vera (1959), Songda (2004)
- Quantitative estimation of the severity of typhoon is important for better assessment of resulting hazards.

Assess impacts of climate change on the severity of typhoons

- Pseudo-global experiment is a useful approach to consider how a past extreme typhoon will change under future global warming.

Typhoon hazards under global warming may depend on the latitudinal region

- Despite the increased intensity at its mature stage, typhoon may quickly weaken in the northern part of Japan, decreasing the severity of hazard.

DPRI-KU

Precise Impact Assessments on Climate Change

Climate change projection contributing to stabilization target setting (JAMSTEC)

Prediction and diagnosis of imminent global climate change (U Tokyo)

Climate prediction data

Development of basic technology for risk information on climate change (MRI)

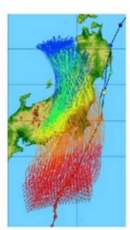
PI: Prof. E. Nakakita (DPRI, Kyoto U)
Kyoto U, PWRI, U Tokyo, Tohoku U, Nagoya U, Hokkaido U

Precise impact assessments on climate change

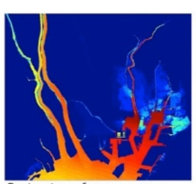
Natural disaster (DPRI, Kyoto U)
Water resources (DPRI, Kyoto U)
Ecosystem (Tohoku U)

Projection and Uncertainty of Natural Hazard

Socio-Economic Impact



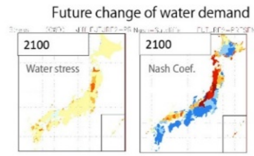
Super Typhoon

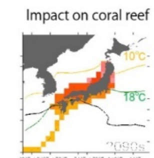


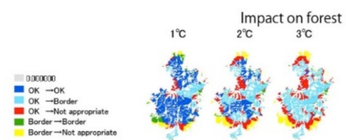
Projection of storm surge

SOUSEI-D

Risk for Water Resources







Socio-Economic Impact

Worst Class Scenario for Natural Harzards

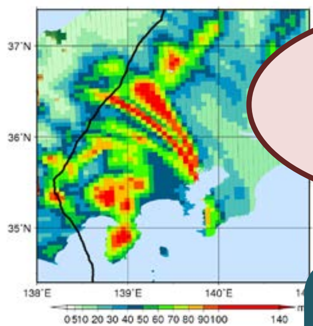
Impact on Ecosystem and Biodiversity

Risk assessment of meteorological disasters in SOUSEI-D

Climate model output (GCM, RCM) (CMIP5, Kakushin, Sousei)

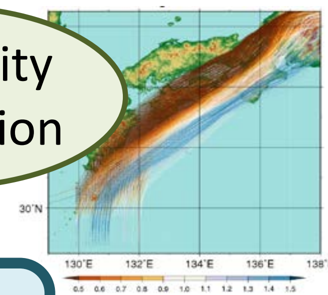
Extreme events (Typhoon, rain, wind)

Dynamical downscaling



Worst-case scenario

Statistical downscaling



Probability information

Downscaling to regional-scales (river basin, coastal area)

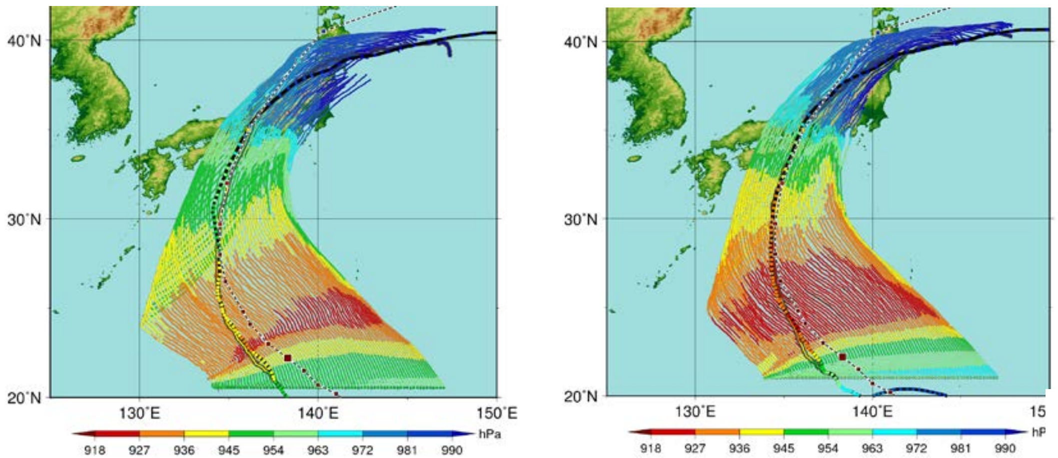
- Sufficient resolution for engineering assessment
- Probability information based on ensemble simulations
- Meteorological disaster risk in worst-case scenarios

Socio-economic impact assessment

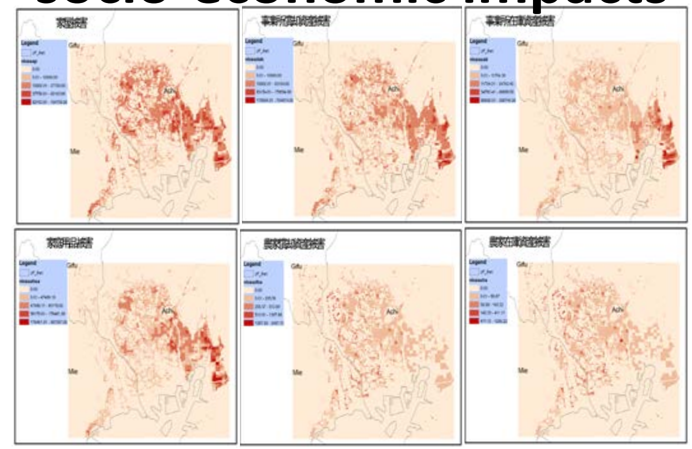
Impacts on natural disasters/water resources

Typhoon hazard assessment

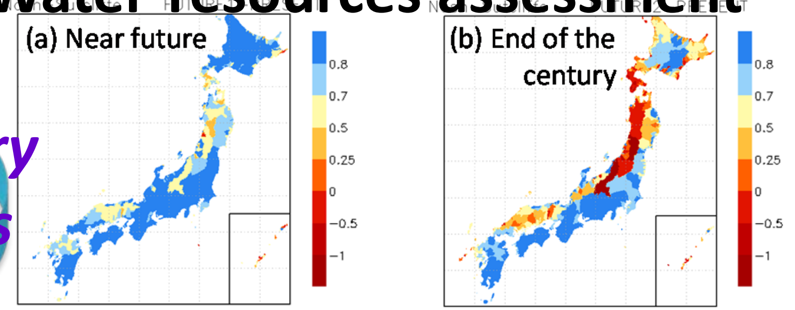
1959 September condition **Future September condition**



socio-economic impacts

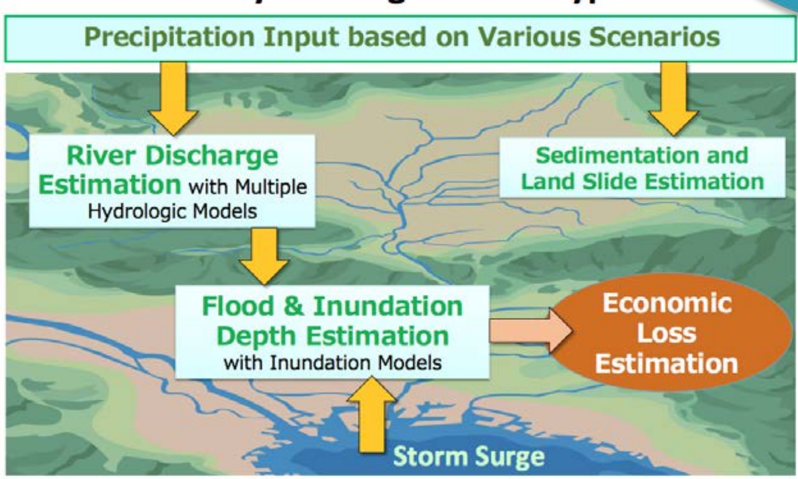


Water-resources assessment

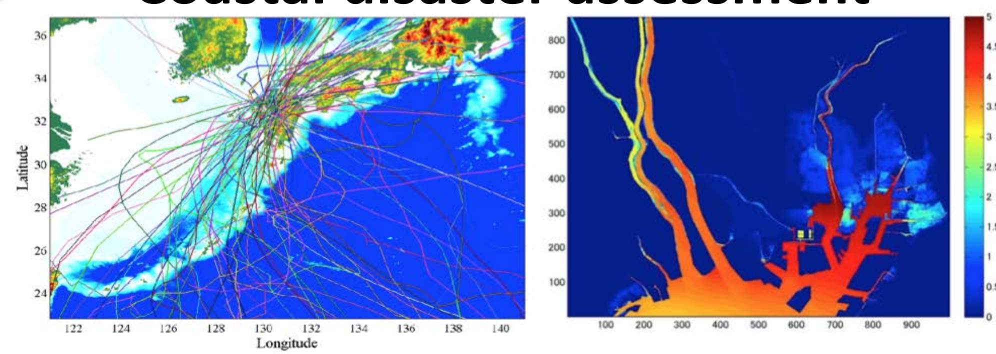


Water-related disaster assessment

Comprehensive Economic Loss Estimation Caused by the Largest Class Typhoon



Coastal disaster assessment



確率台風モデルで計算された台風コース

伊勢湾を対象とした擬似温暖化
＋最悪コース条件下での高潮氾濫