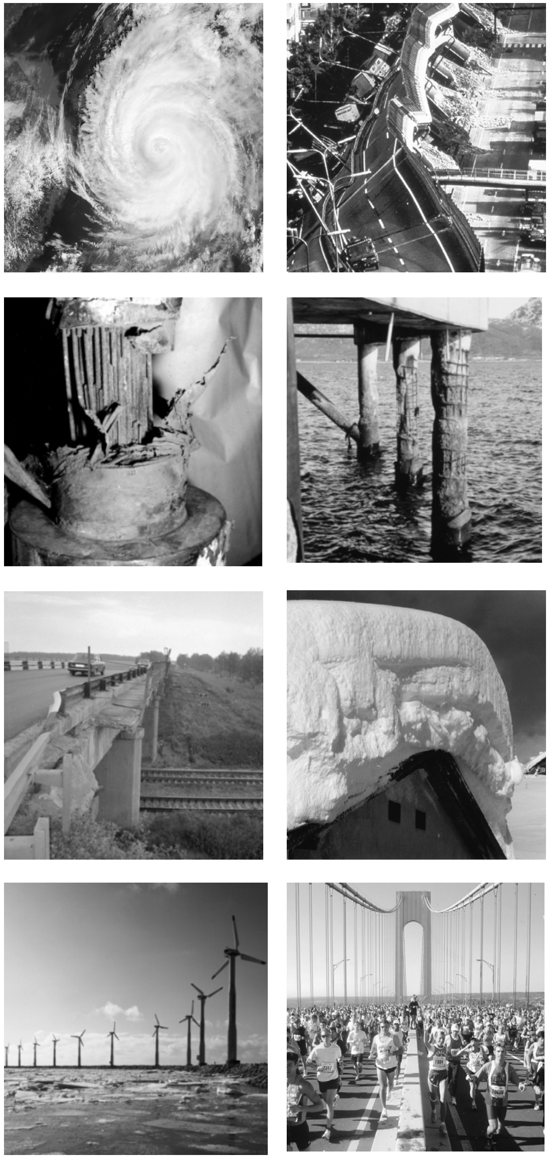
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zürich

Institute of Structural Engineering
Group Risk and Safety



Seminars on aspects of integral risk management in engineering

A platform for discussions and knowledge transfer for researchers within an outside the ETH domain.

Seminars take place on a regular basis,

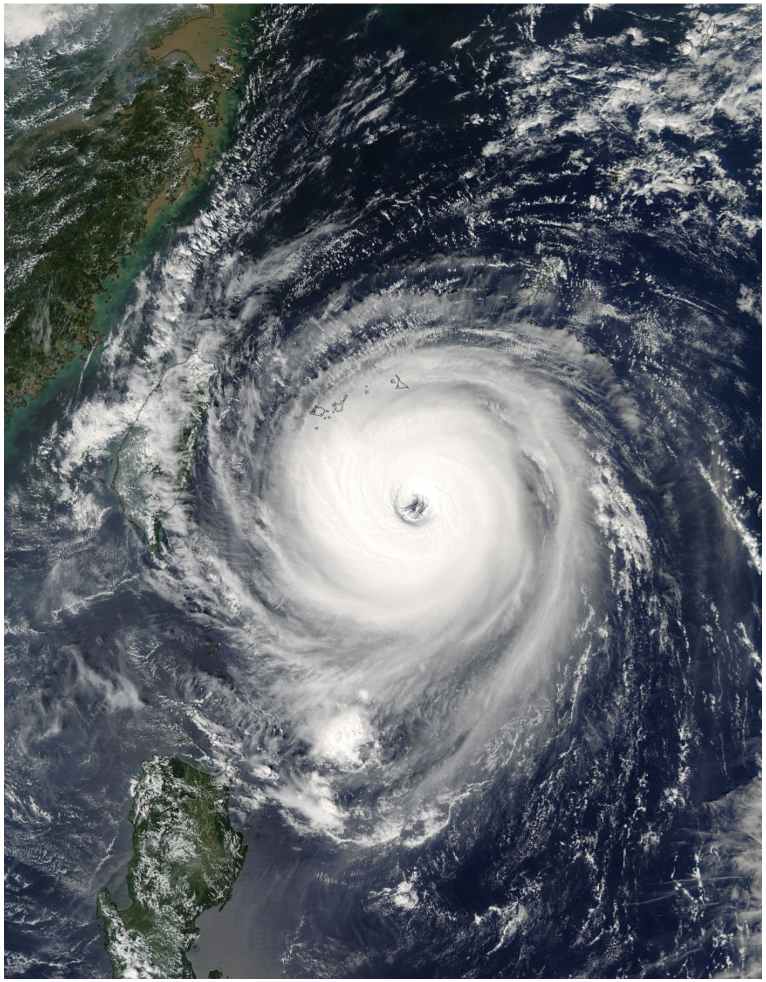
every first Monday per month, 1700h at HIL E6 (with exceptions)

Schedule (this year):

Today: Mathias Graf, Typhoon Risk Modelling.

2.11.09: Jianjun Qin, Risk management of large concrete structural systems.

30.11.09: Tbd



TYPHOON RISK MODELING

Mathias Graf, Kazuyoshi Nishijima and Michael Havbro Faber
ETH Zurich, Institute for Structural Engineering, Group Risk & Safety

Contents

- Introduction of the typhoon model developed.
- Risk assessment of insurance portfolios using the typhoon model
- Assessment of the effect of global warming on structural reliability using the typhoon model.
- Real-time decision making using the typhoon model

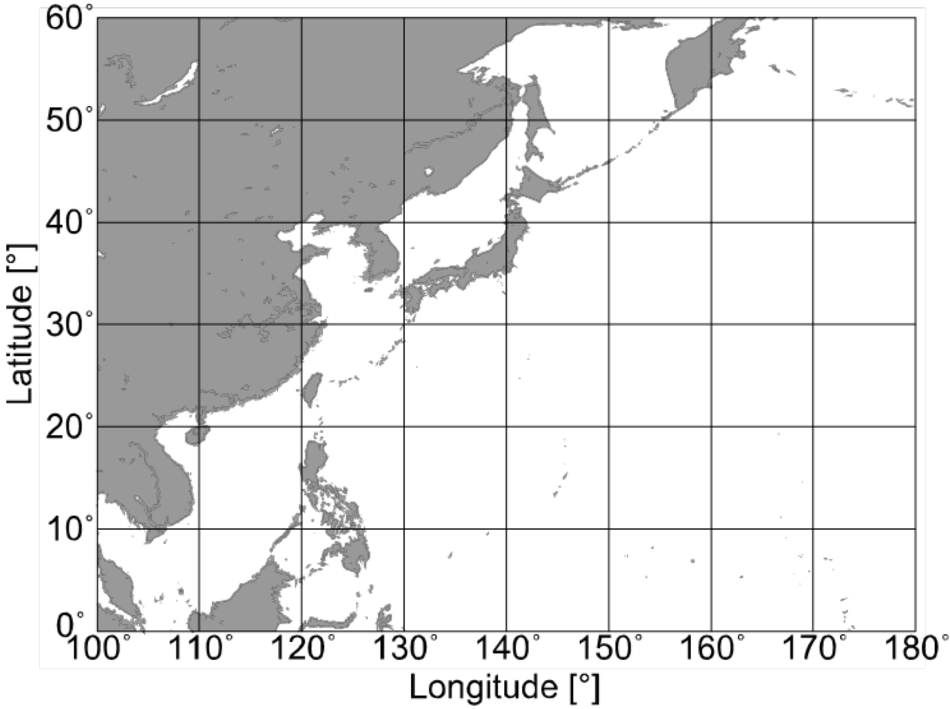
Main features of typhoon model

- Typhoon events are modeled for the entire life of typhoons, i.e. from occurrence to dissipation
- The effects of sea surface temperature on the evolution of typhoon events are accounted for.
- Seasonal differences of the probabilistic characteristics of the transition of typhoons are accounted for.

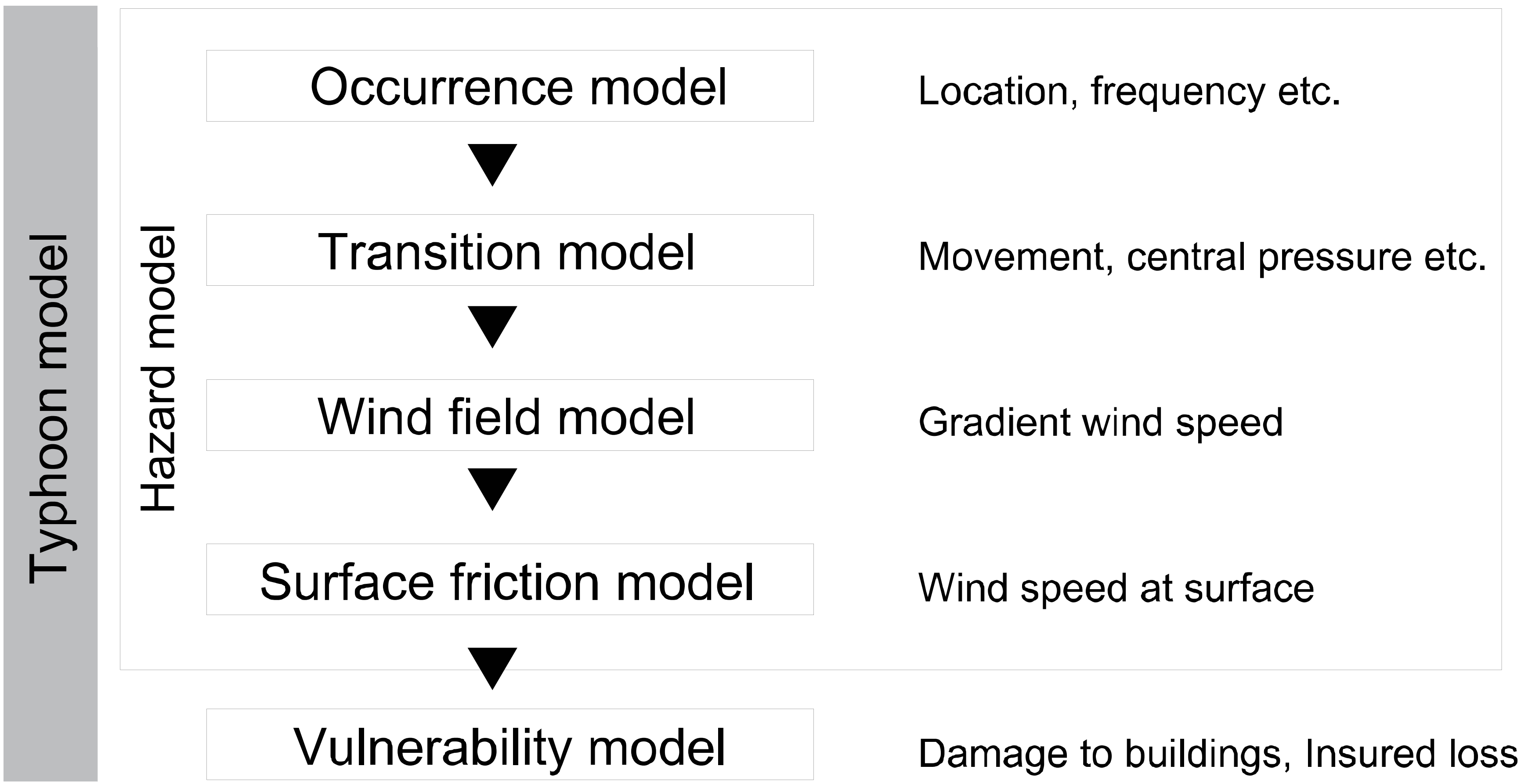
Main features of typhoon model

- The developed typhoon model can, in principle, represent the wind hazards due to typhoons in the northwest Pacific region.

- The developed typhoon model is verified and validated primarily for the area of the Japanese islands.

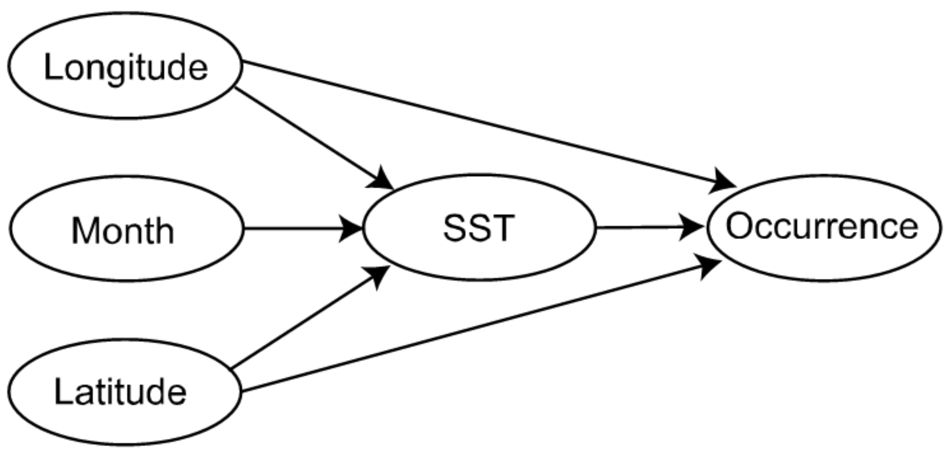


Components of typhoon model



Occurrence model

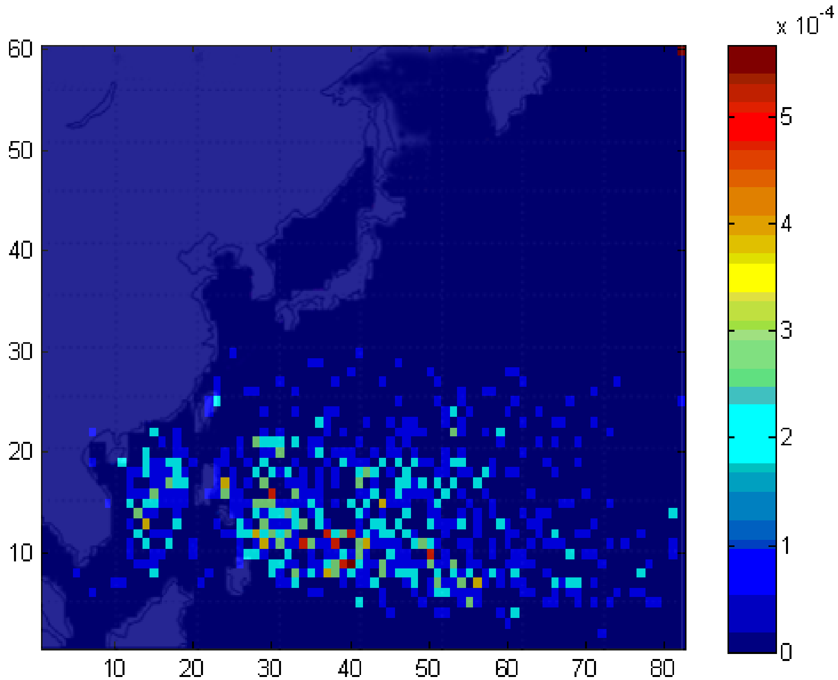
- The occurrence rate of typhoons depends on the location, season and sea surface temperature (SST).

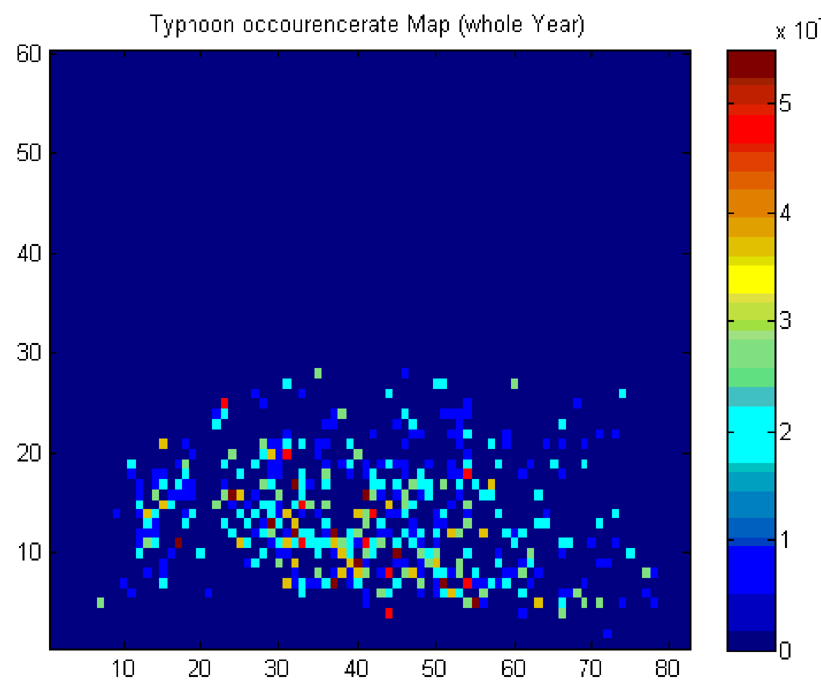


The Bayesian network representing the occurrence model.

Occurrence model

Comparison between historical data and simulation results

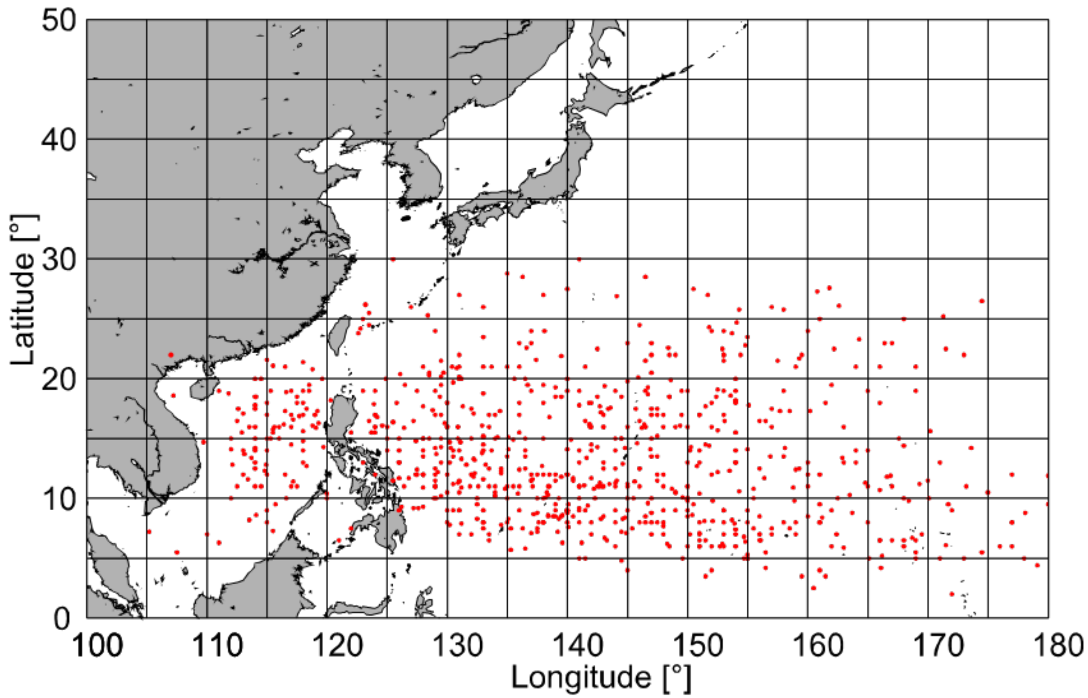




Occurrence rates (left: historical data, right: simulation results).

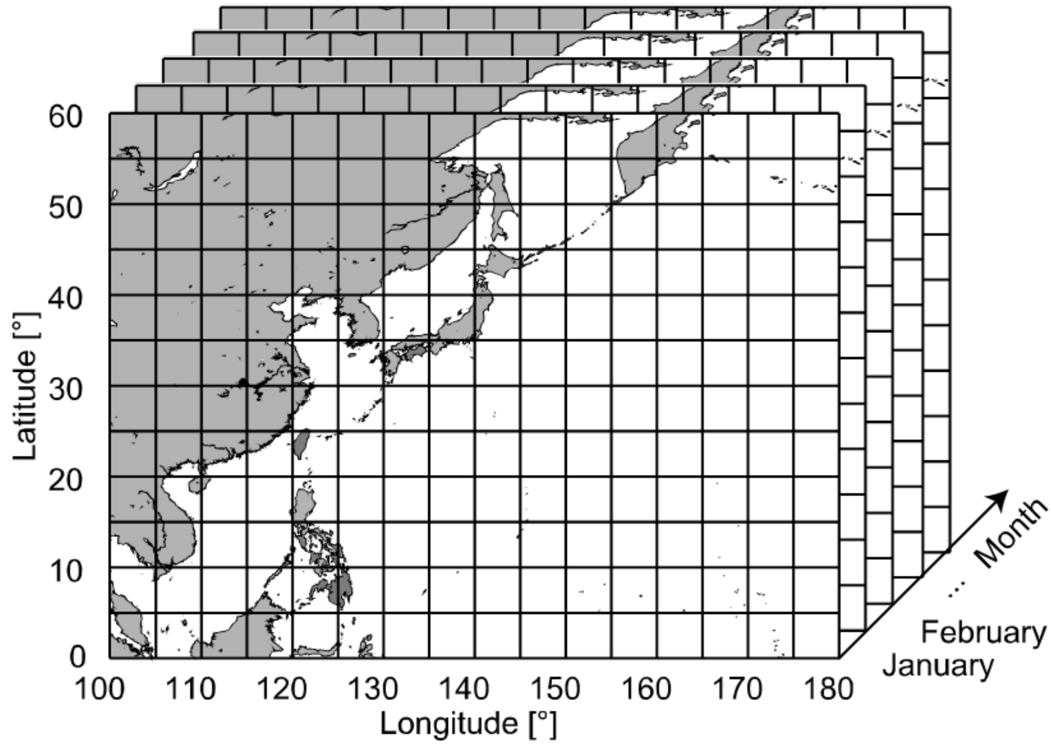
Occurrence model

- Resampling historical data
- Defining occurrence of a typhoon
- The best typhoon track data are used



Transition model

- Translation speed
- Translation angle
- Central pressure



One set of parameters for each 5° x 5° grid and for each month.

The best typhoon track data are used to establish the model.

Transition model

- Translation speed and angle

$$\Delta \ln V_i = a_1 + a_2 \ln V_i + a_3 \Phi_i + \varepsilon_V$$

$$\Delta \Phi_i = b_1 + b_2 V_i + b_3 \Phi_i + b_4 \Phi_{i-1} + \varepsilon_\Phi$$

$V_i =$ translation speed $[km/h]$ at time step i

$\Phi_i =$ translation angle [°] at time step i

$\varepsilon_V \sim N(0, \sigma_{\varepsilon_V})$

$\varepsilon_\Phi \sim N(0, \sigma_{\varepsilon_\Phi})$

Transition model

- Central pressure

$$P_{i+1} = c_1 + c_2 P_i + c_3 P_{i-1} + c_4 P_{i-2} + c_5 T_i + c_6 \Delta T_i + \varepsilon_P$$

P_i = Central pressure [hPa] at time step i

T_i = Sea surface temperature [°C] at time step i

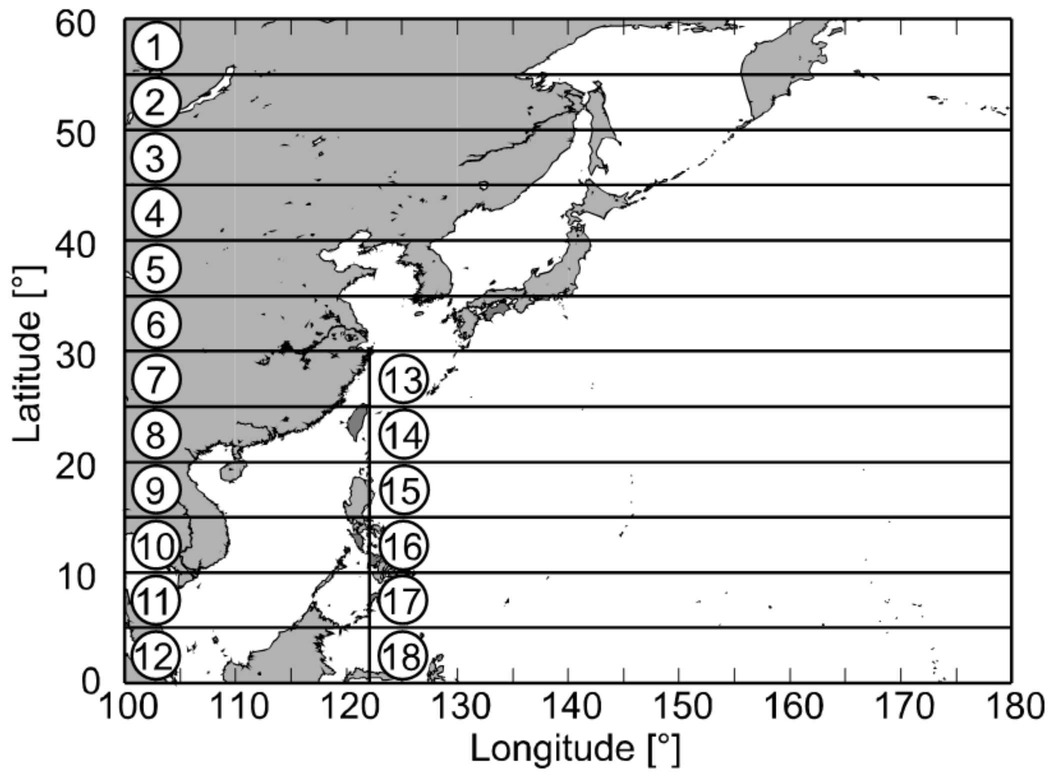
Note that when typhoons make the landfall, filling models are applied.

Transition model

- Central pressure

More parameters than for the estimation of the speed and direction change

Different spatial discretization



One set of parameters for each of the 18 zones and for each month.

Transition model

- Central pressure (the filling model)

$$\Delta P_t = \Delta P_0 \cdot \exp\left(-\left(d_1 + d_2 \Delta P_0\right) t\right)$$

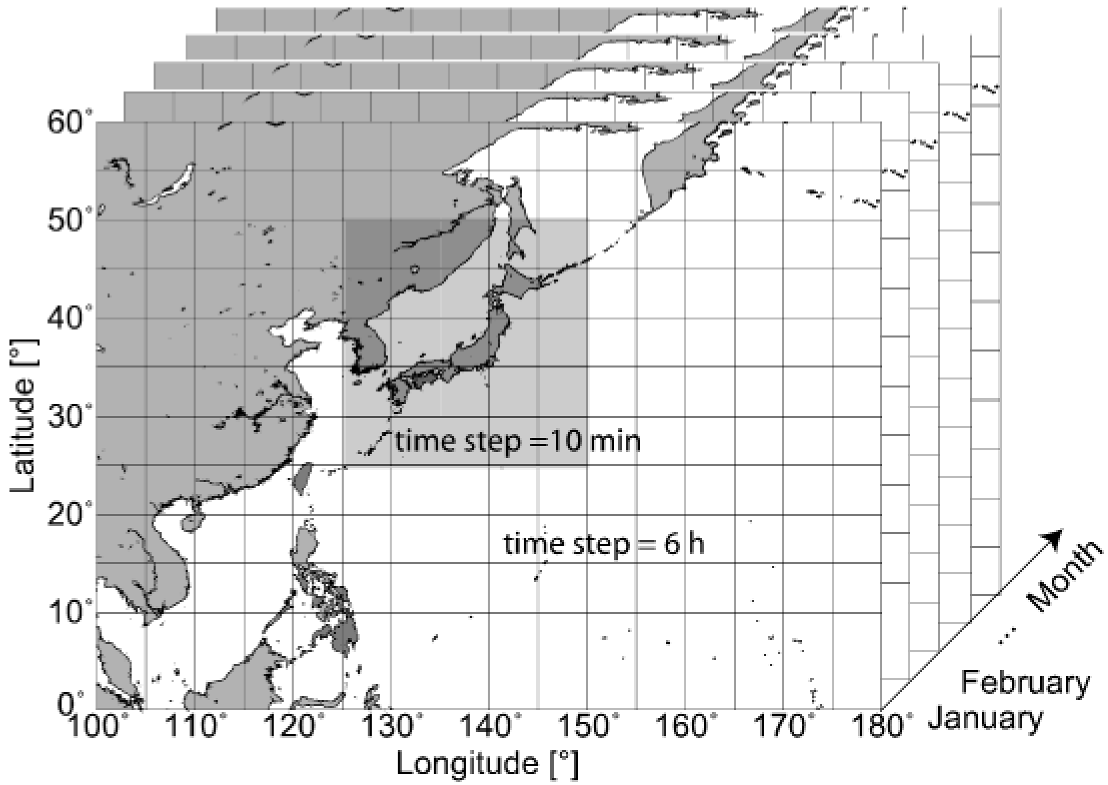
$\Delta P_t =$ (peripheral pressure)* - (central pressure at time t [h] after the landfall)

$\Delta P_0 =$ (peripheral pressure)* - (central pressure at landfall)

* (peripheral pressure) = 1013 [hPa]

Transition model

- One time step correspond to 6 h
- If the typhoon is on land or close to Japan the time step interval is changed to 10min



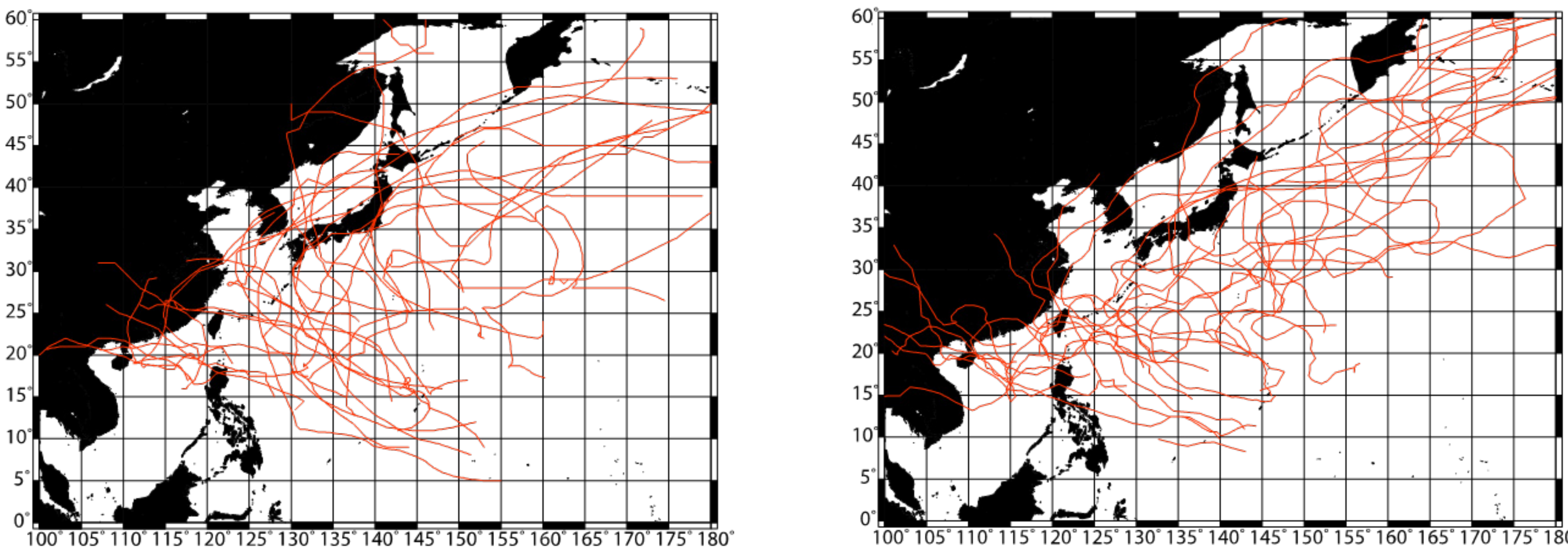
Transition model

A typhoon is terminated if

- the central pressure exceeds a certain threshold
- the typhoon is a certain number of time steps on land
- the typhoon leaves the region of interest

Transition model

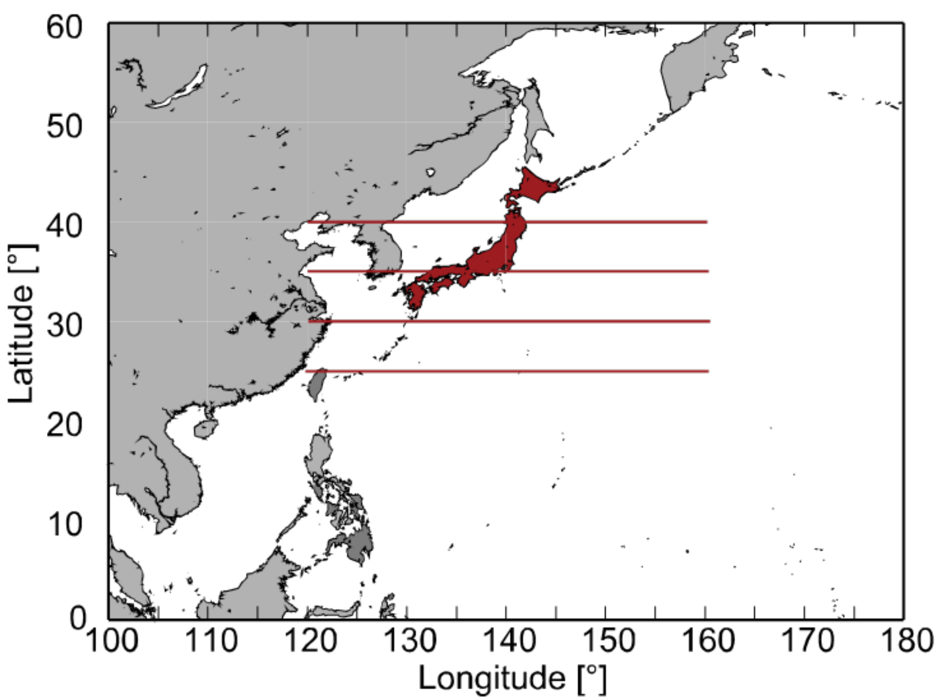
Comparison between historical data and simulation results

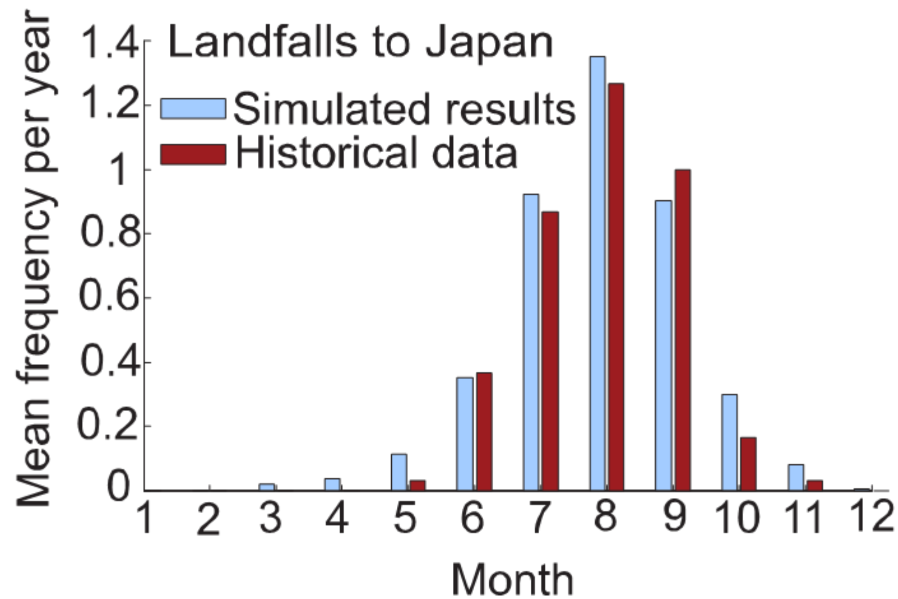


Typhoon tracks in August
(left: historical results, right: simulation data).

Transition model

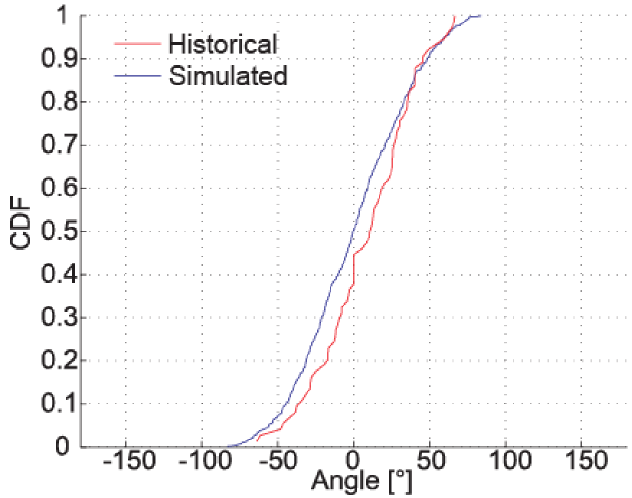
Comparison between historical data and simulation results

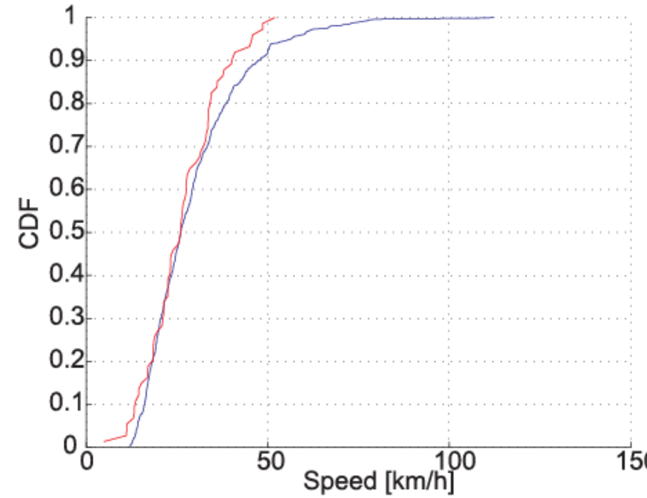


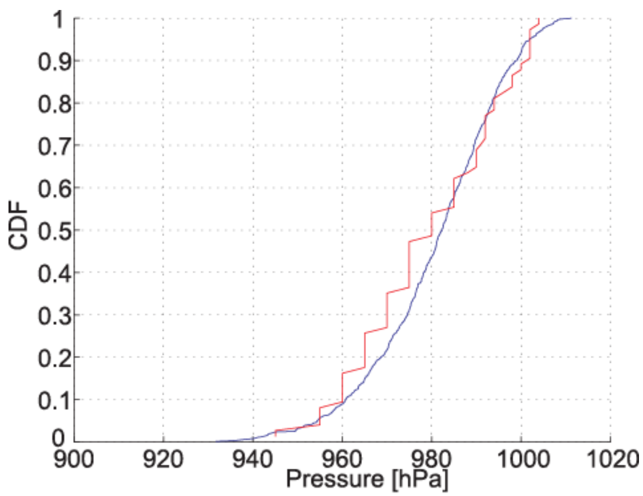


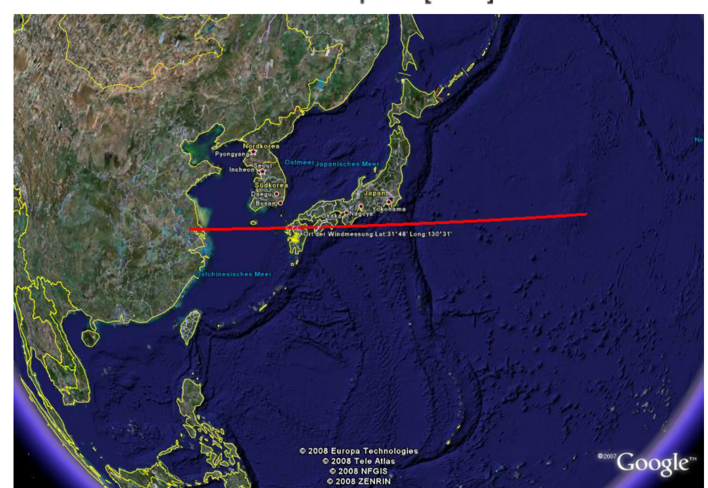
Transition model

Comparison between historical data and simulation results



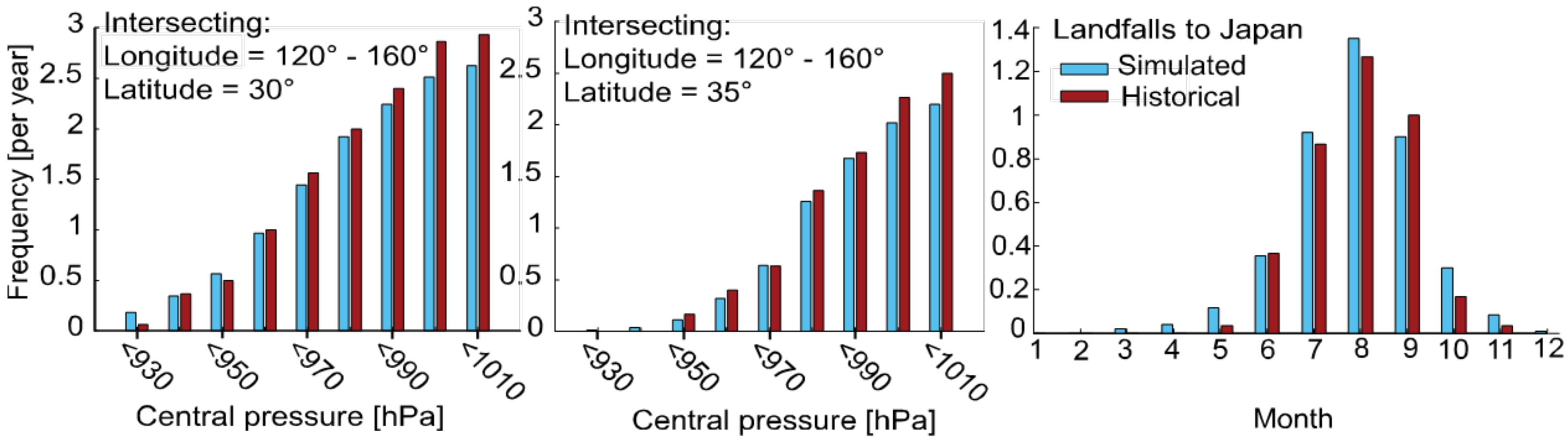






Transition model

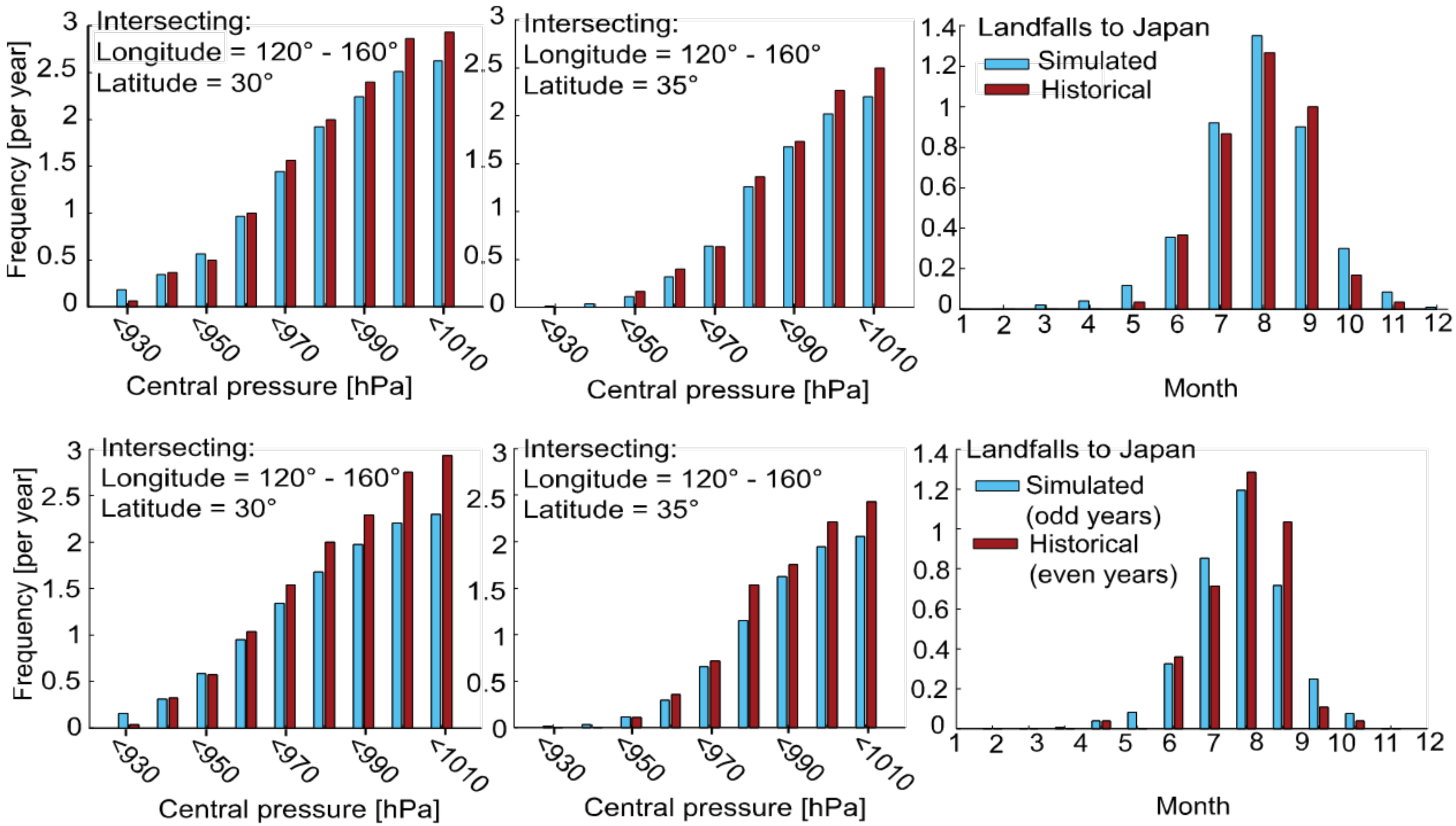
Comparison between historical data and simulation results



Using the odd years of the historical data to establish the transition model and compare it to the historical data of the even years.

Transition model

Comparison between historical data and simulation results



Wind field model

- Modeling of pressure field is required.

- Wind field is modelled at gradient height.

Wind field model

- Modelling of pressure field (Schloemer (1954))

$$p(r) = p_C + \Delta p \cdot \exp\left(-\frac{r_M}{r}\right)$$

r_M = Radius of maximum wind speed

r = Distance

$p(r)$ = Pressure at distance r

p_C = Central pressure

Δp = Peripheral pressure (1013 [hPa]) - central pressure

R.W. Schloemer (1954). " Analysis and synthesis of hurricane wind patterns over Lake Okeechobee, Florida ", *Hydrometeorological Report, USWB, No. 31, 49pp.*

Wind field model

- Modelling of wind field (Meng et al., 1995)

$$\tilde{u}(r,\alpha) = \frac{V\sin\alpha - fr}{2} + \sqrt{\left(\frac{V\sin\alpha - fr}{2}\right)^2 + \frac{r}{\rho}\frac{\partial p(r)}{\partial r}}$$

$\tilde{u}(r,\alpha) =$ Wind speed at considered loaction

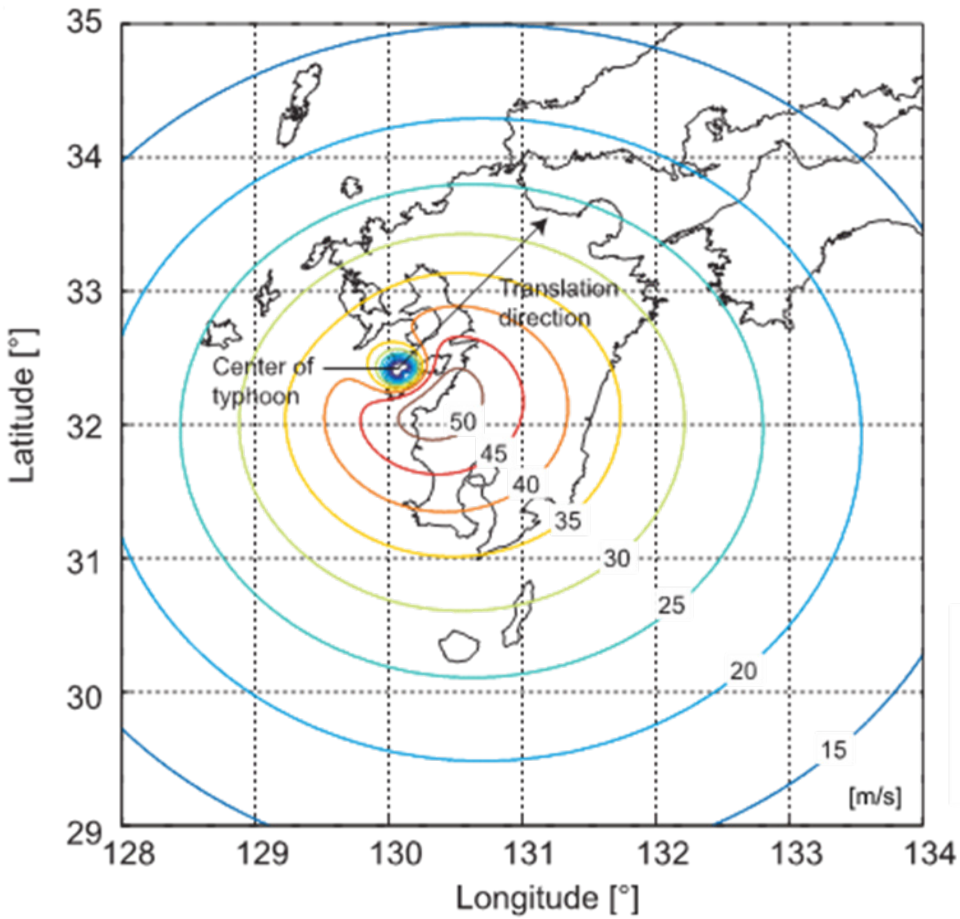
$V =$ Translation speed

$f =$ Coriolis parameter

$\rho =$ Air density

Meng, Y., Matsui, M. & Hibi, K. (1995), "An analytical model for simulation of the wind field in a typhoon boundary layer", *Journal of Wind Engineering and Industrial Aerodynamics, Vol. 56, pp. 291-310.*

Wind field model

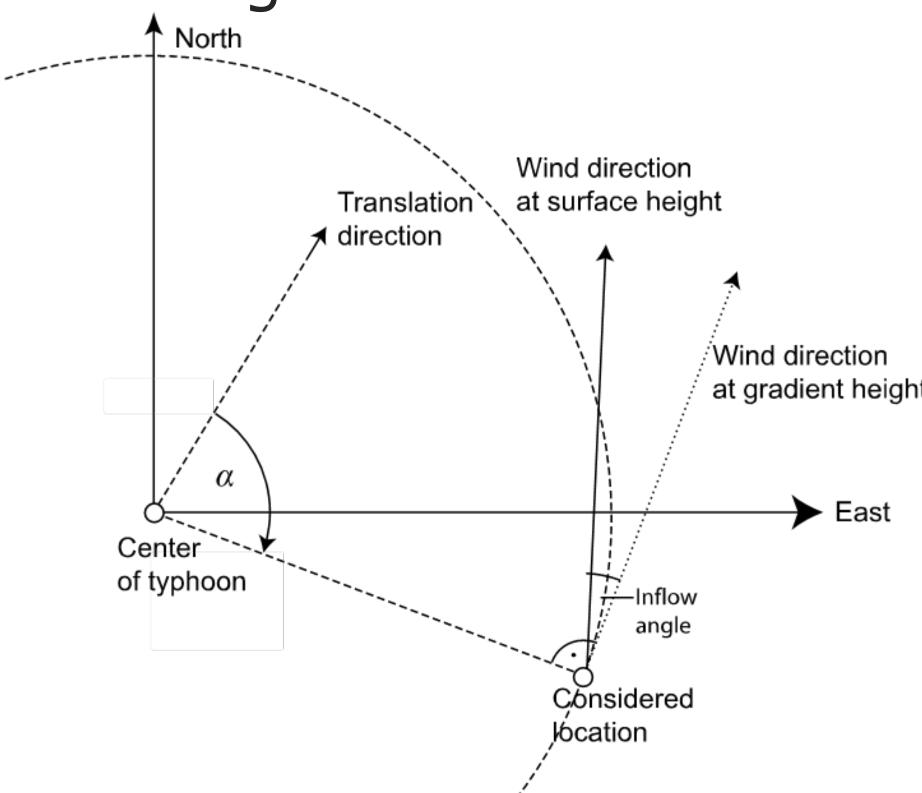


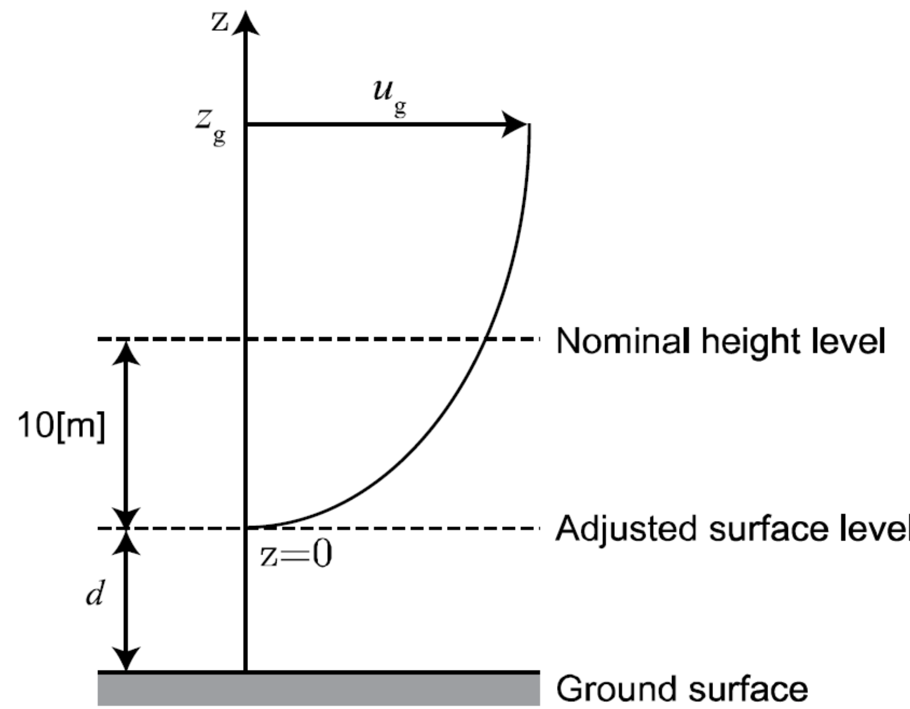
Typhoon Bart (199918)
4:30 JST 24 Septeber 1999
Latitude = 32.4° Logitude = 130.1°
Central pressure = 940 hPa
Translations speed = 40 km/h
Radius of maximum wind speed = 42 km

The wind field of typhoon Bart at gradient height reproduced using the model.

Surface friction model

Converts wind speed and direction at gradient height to wind speed and direction at surface as a function of roughness.





Surface friction model

Converts wind speed u_g and direction at gradient height to wind speed $u(z)$ and direction at surface as a function of roughness length z_0 .

Wind speed at height z:

$$u(z) = u_g \left(\frac{z}{z_g} \right)^a$$

Inflow angle at height z:

$$\gamma(z) = \gamma_s \left(1 - 0.4 \frac{z}{z_g} \right)^{1.1}$$

Y. Meng, M. Matsui, K. Hibi (1997),“A numerical study of the wind field in a typhoon boundary layer“, Journal of Wind Engineering and Industrial Aerodynamics, Vol 67&68, Pages 437-448.

Surface friction model

Wind speed at height z: $$u(z) = u_g \left(\frac{z}{z_g} \right)^a$$

Inflow angle at height z: $$\gamma(z) = \gamma_s \left(1 - 0.4 \frac{z}{z_g} \right)^{1.1}$$

Whereby:

$$a = 0.27 + 0.09 \log_{10} z_0 + 0.018 \left(\log_{10} z_0 \right)^2 + 0.0016 \left(\log_{10} z_0 \right)^3$$

Gradient height:

$$z_g = 0.052 \frac{u_g}{f_\lambda} \left(\log_{10} Ro_\lambda \right)^{-1.45}$$

Inflow angle at (h = 10m):

$$\gamma_S = \left(69 + 100\xi \right) \left(\log_{10} Ro_\lambda \right)^{-1.13}$$

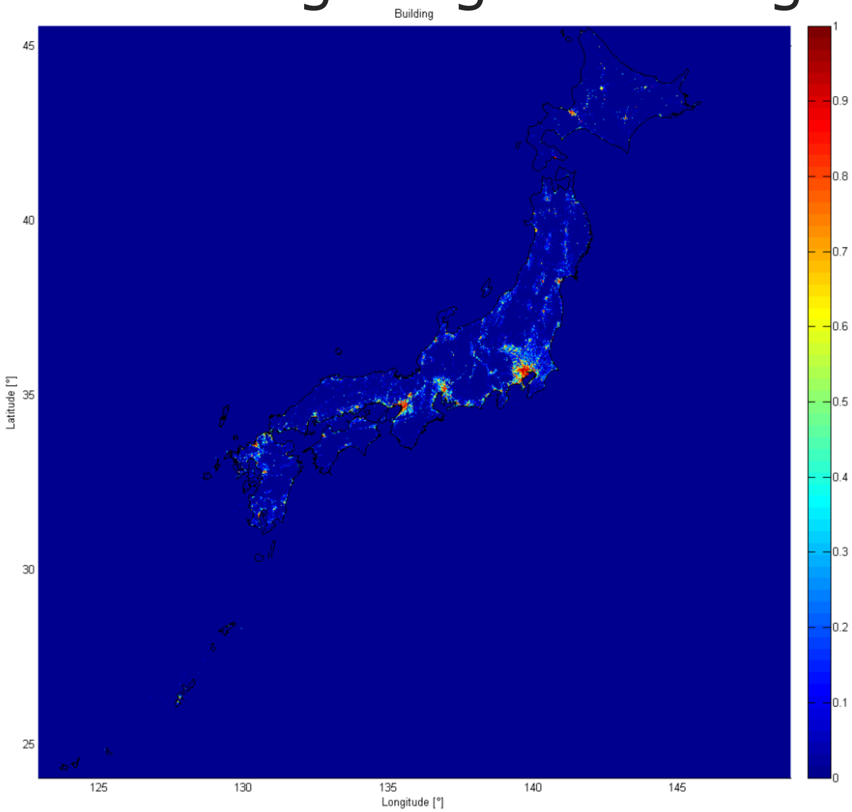
Modified Rossby number:

$$Ro_\lambda = u_g / \left(f_\lambda \cdot z_0 \right)$$

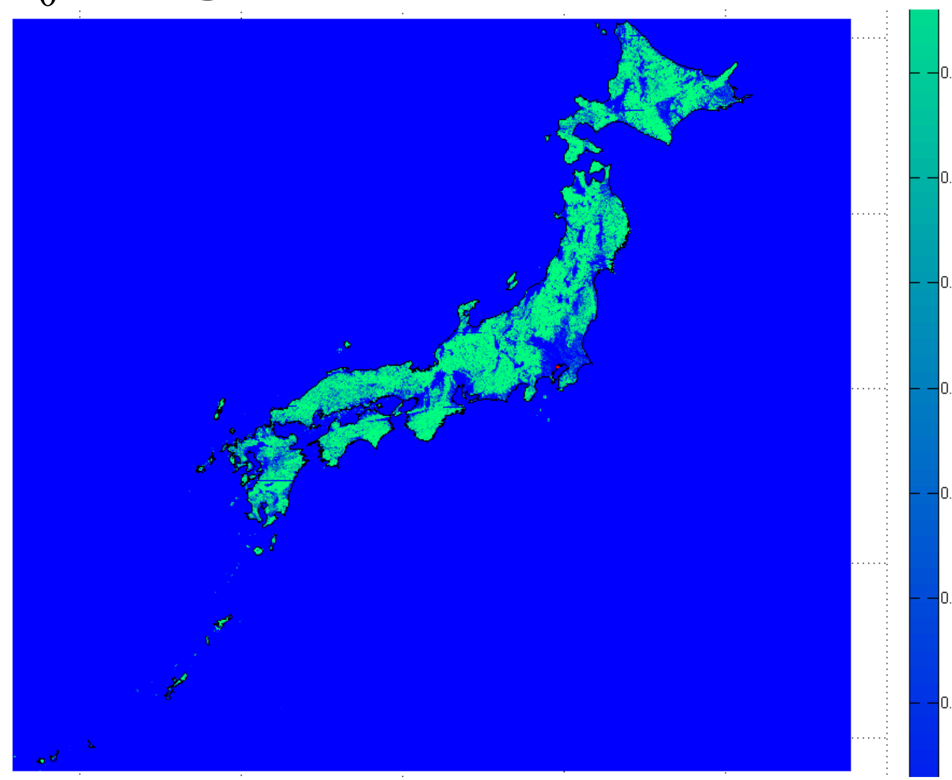
Y. Meng, M. Matsui, K. Hibi (1997),"A numerical study of the wind field in a typhoon boundary layer", Journal of Wind Engineering and Industrial Aerodynamics, Vol 67&68, Pages 437-448.

Surface friction model

Estimating roughness length z_0 using land use data



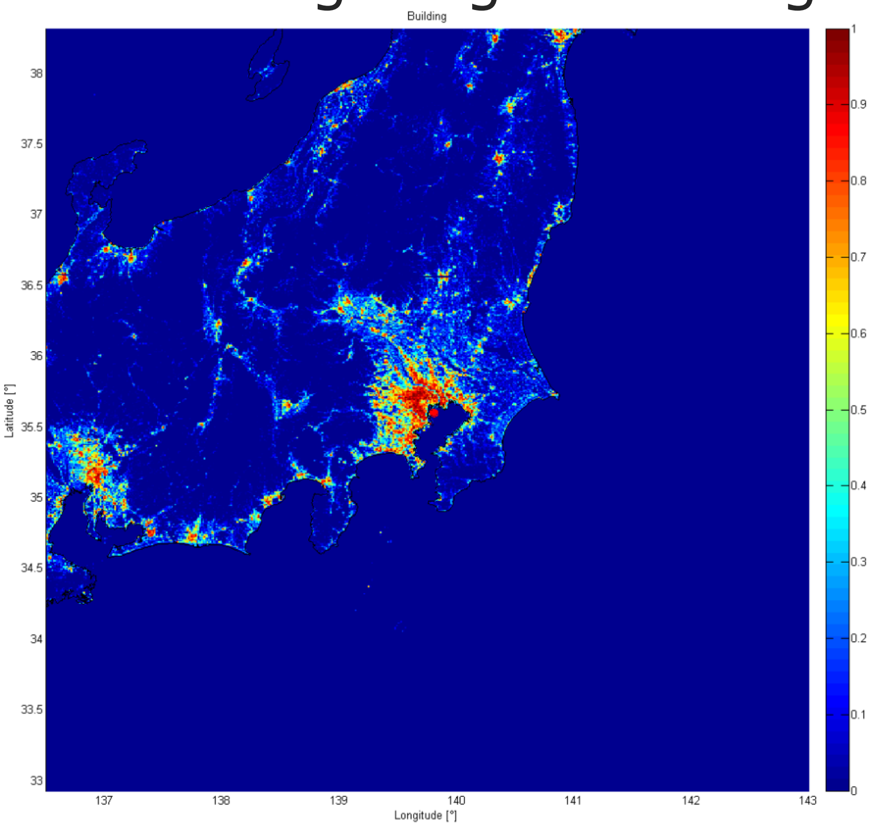
% of buildings per km2



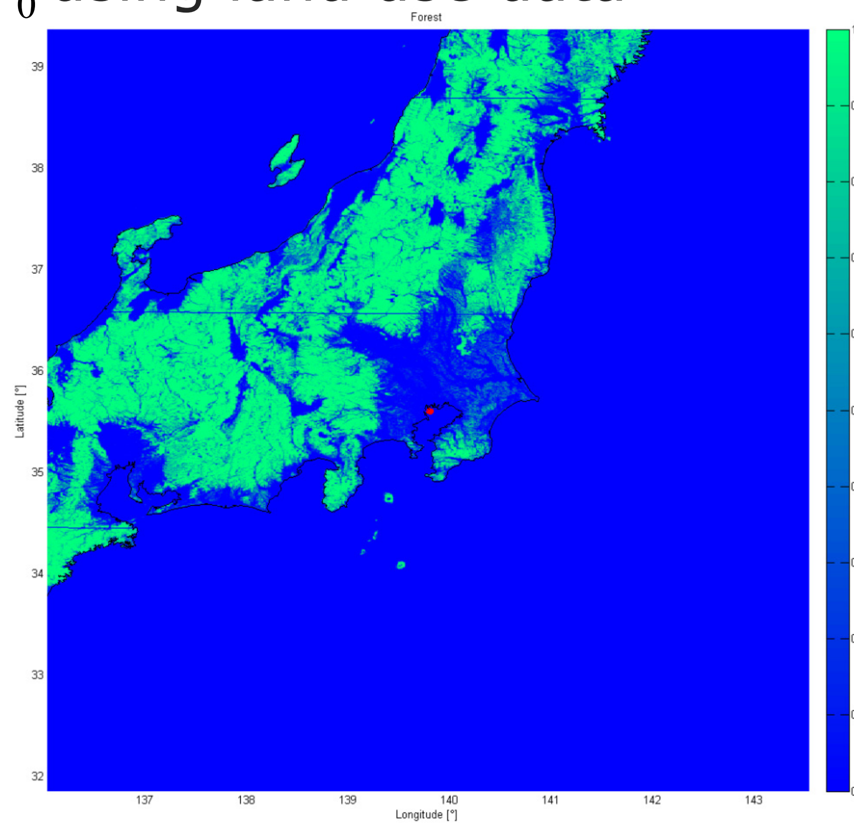
% of forest per km2

Surface friction model

Estimating roughness length z_0 using land use data



% of buildings per km2



% of forest per km2

Surface friction model

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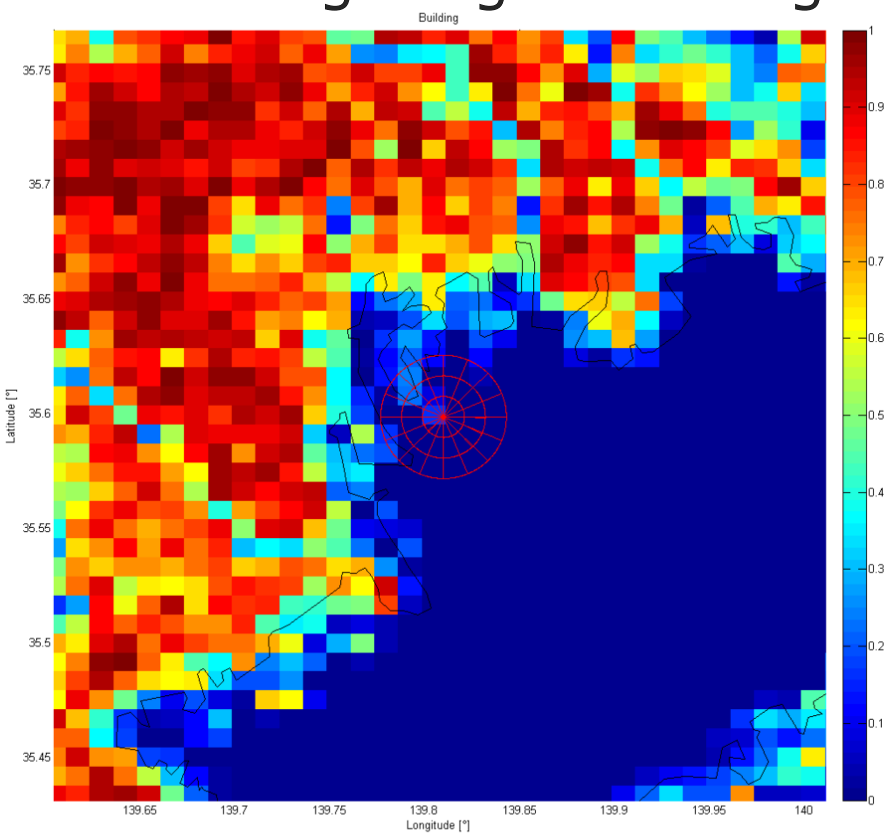
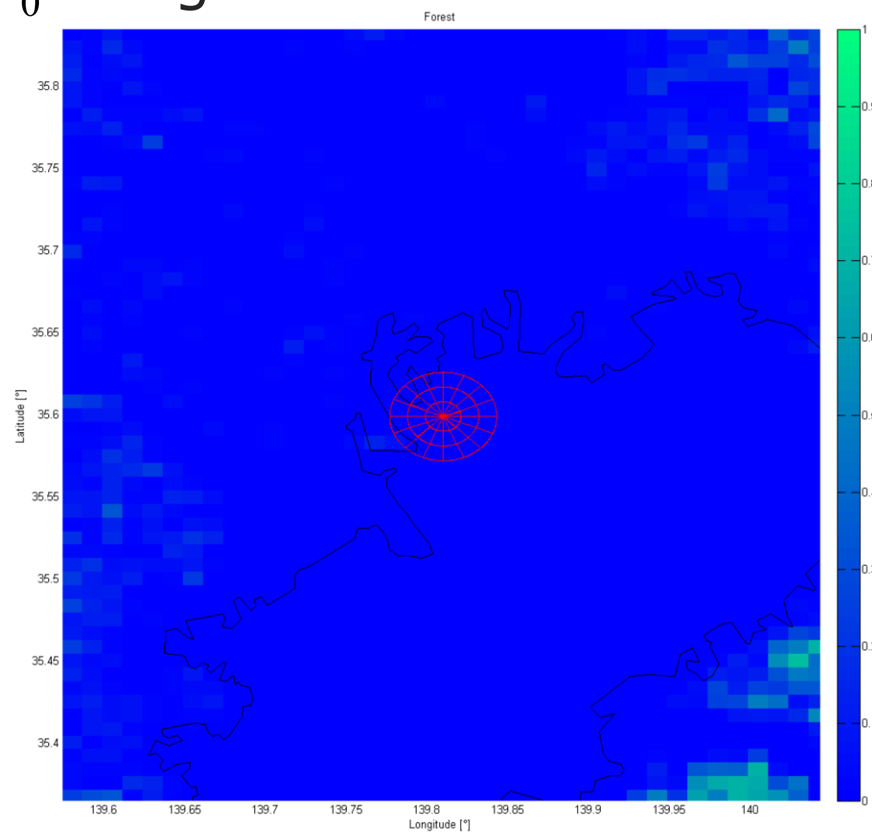


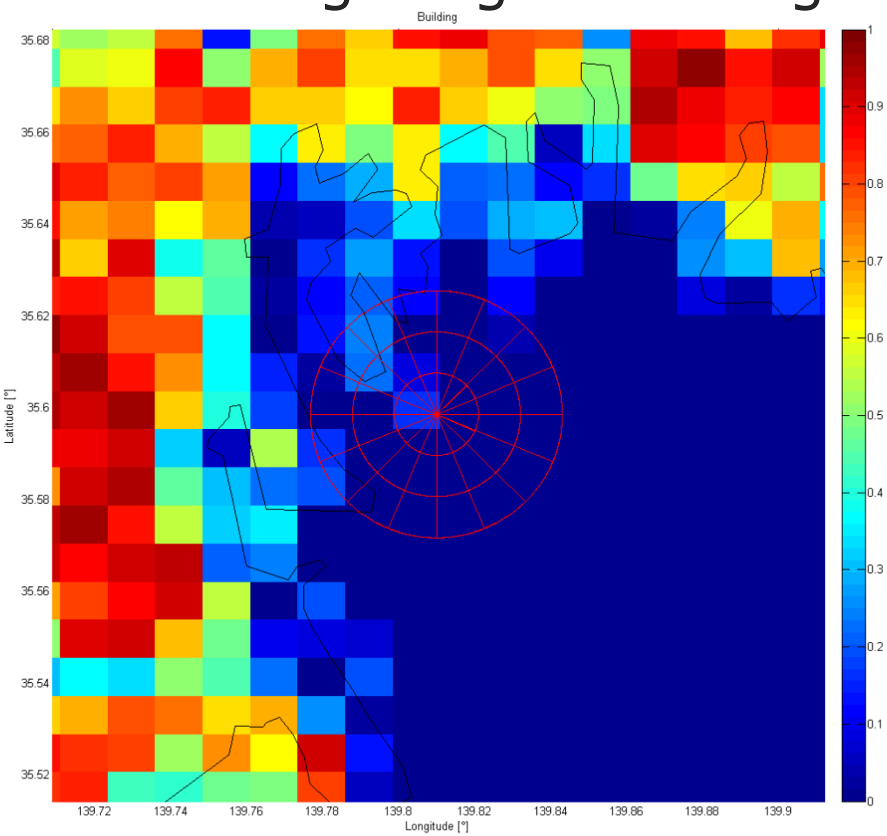


% of buildings per km2

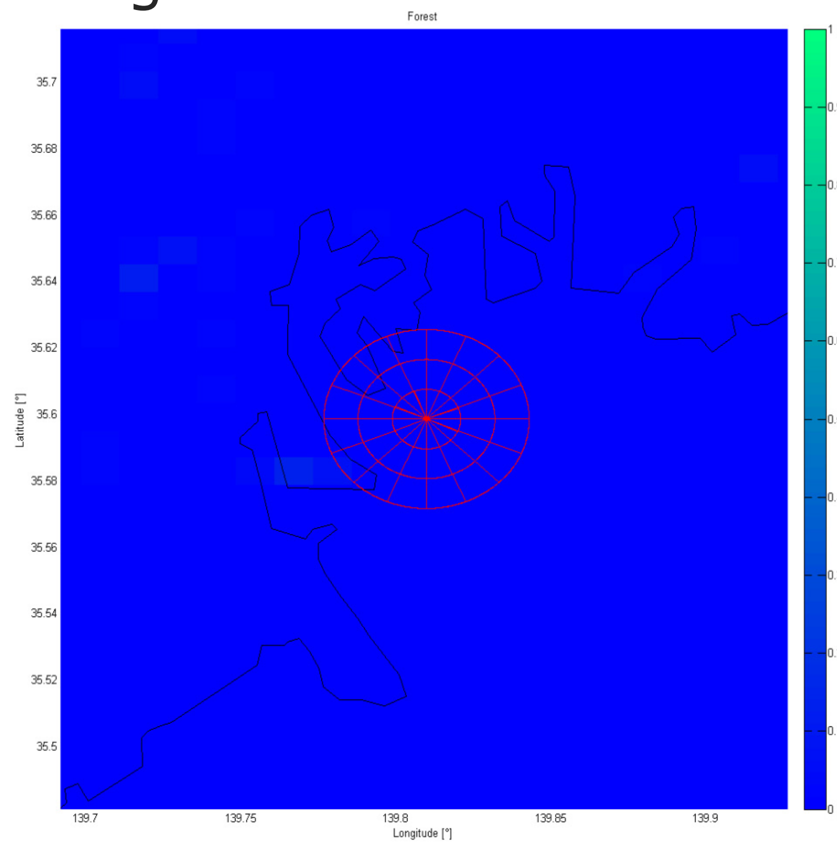
% of forest per km2

Surface friction model

Estimating roughness length z_0 using land use data



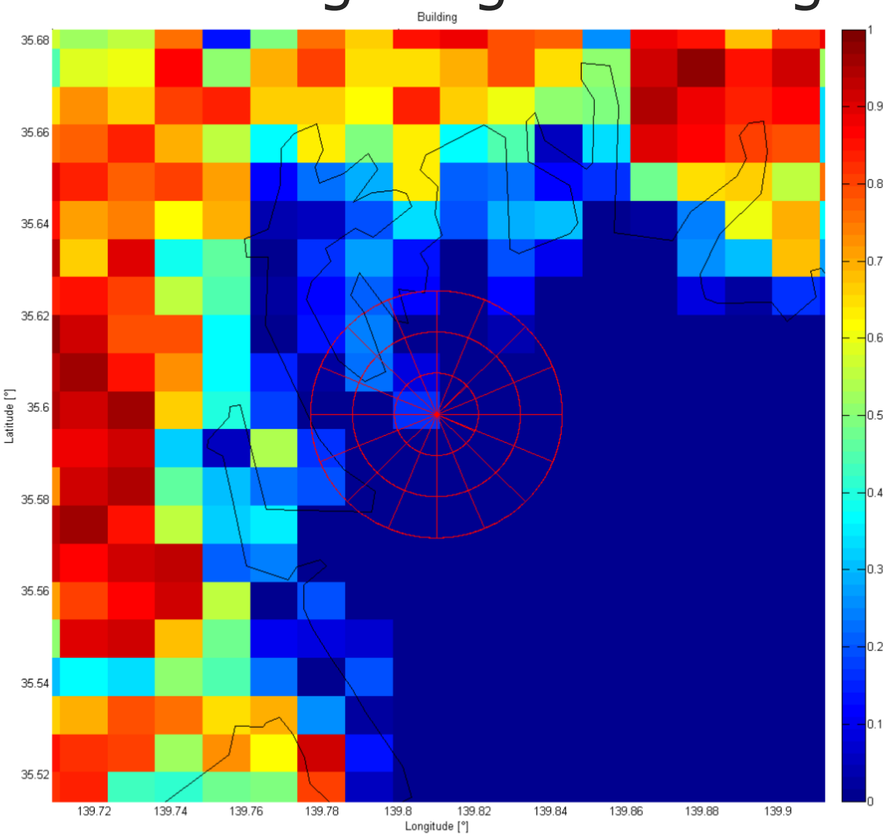
% of buildings per km2



% of forest per km2

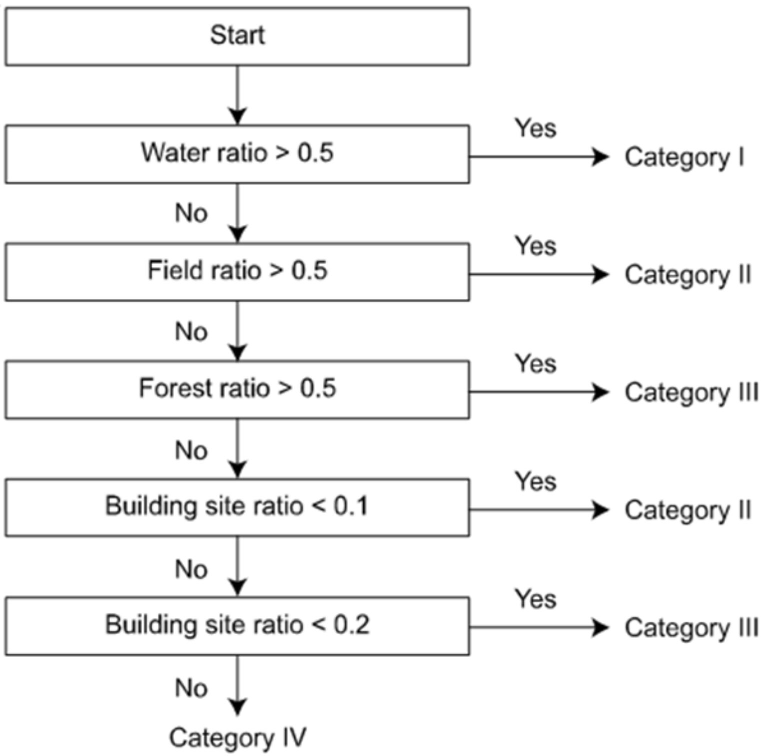
Surface friction model

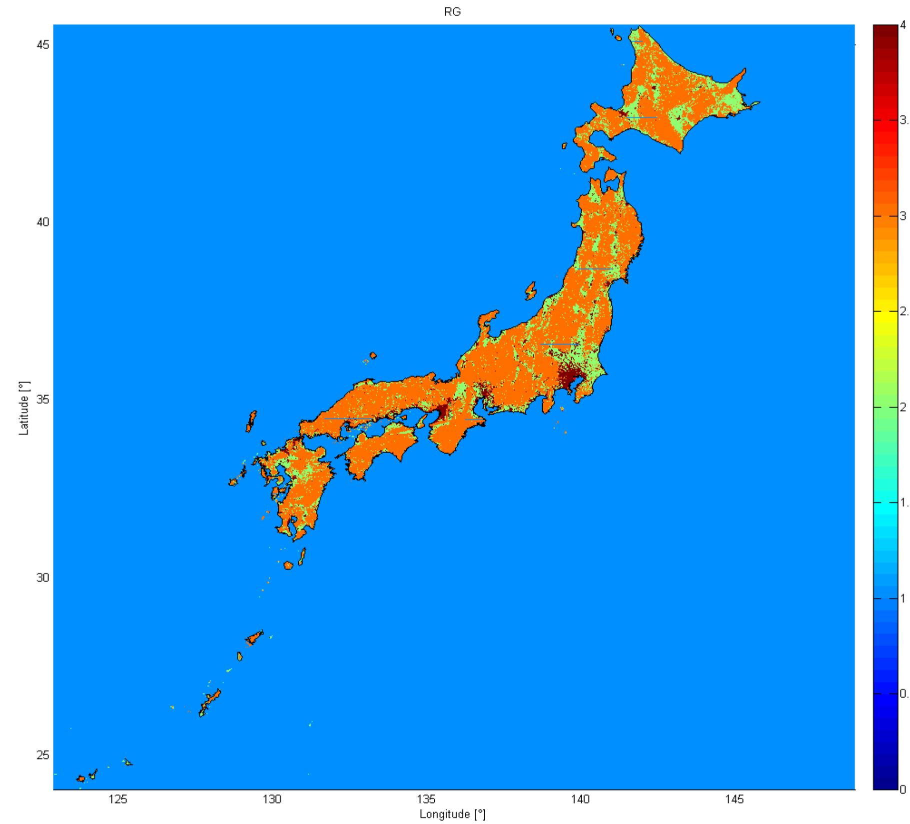
Estimating roughness length z_0 using land use data



% of buildings per km2

Surface friction model

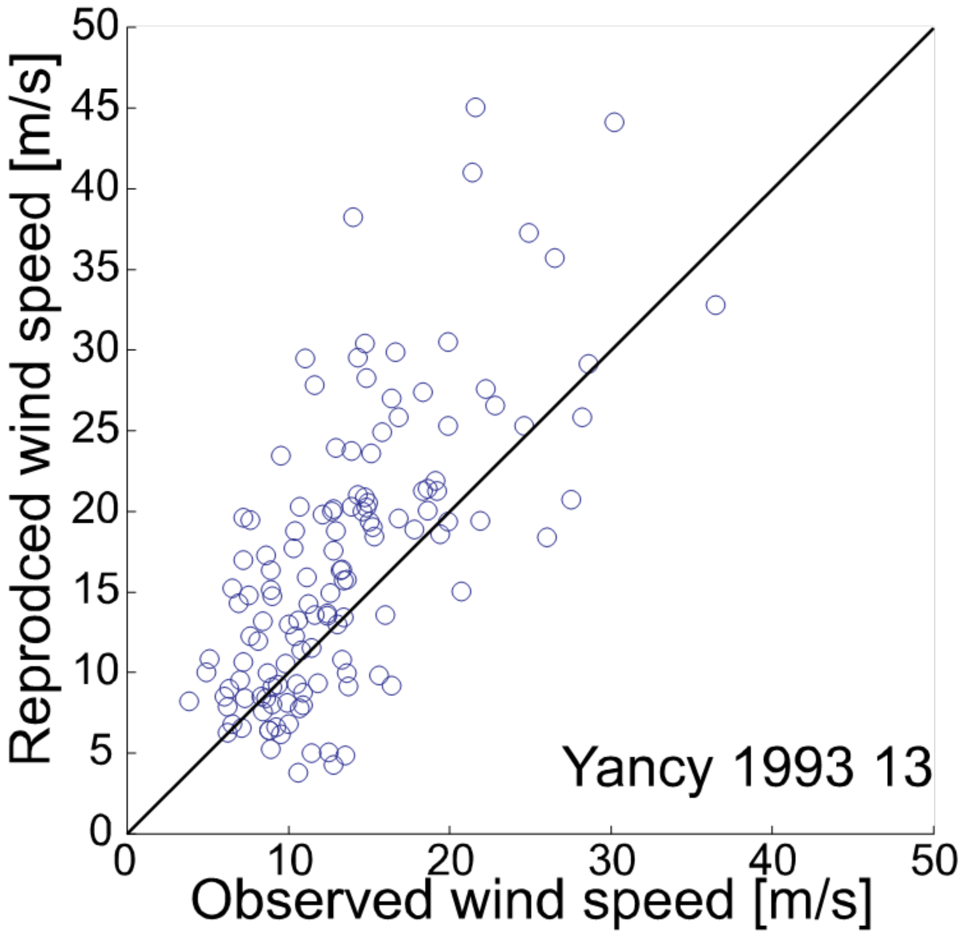


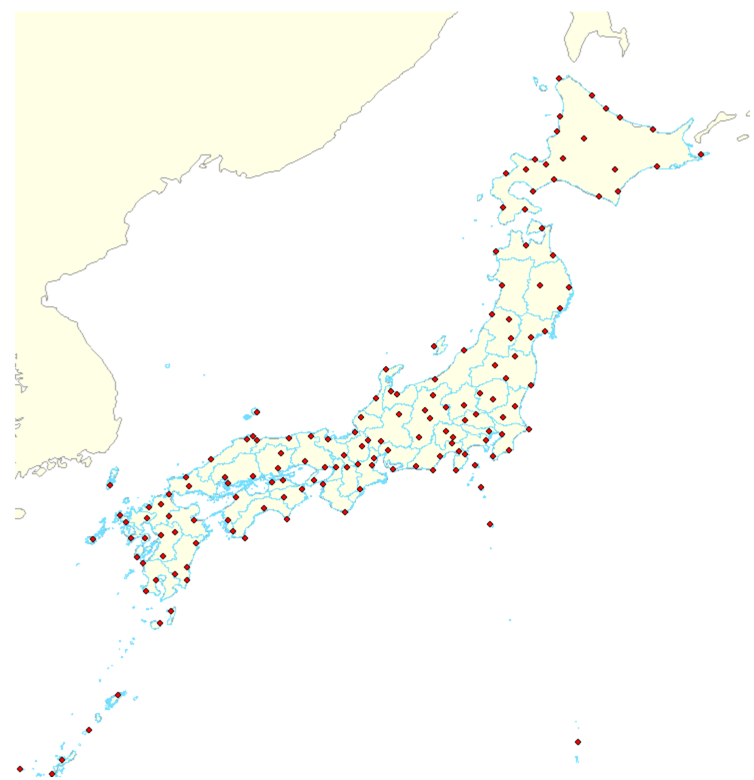


Roughness category	Terrain type	Roughness lenght [m]
I	Very flat terrain	0.0042
II	Open terrain (grassland, few trees)	0.047
III	Suburban terrain (buildings, 3-5[m])	0.42
IV	Dense urban (buildings, 10-30[m])	2.46

Surface friction model

Comparison between observed maximum wind speed and reproduced maximum wind speed

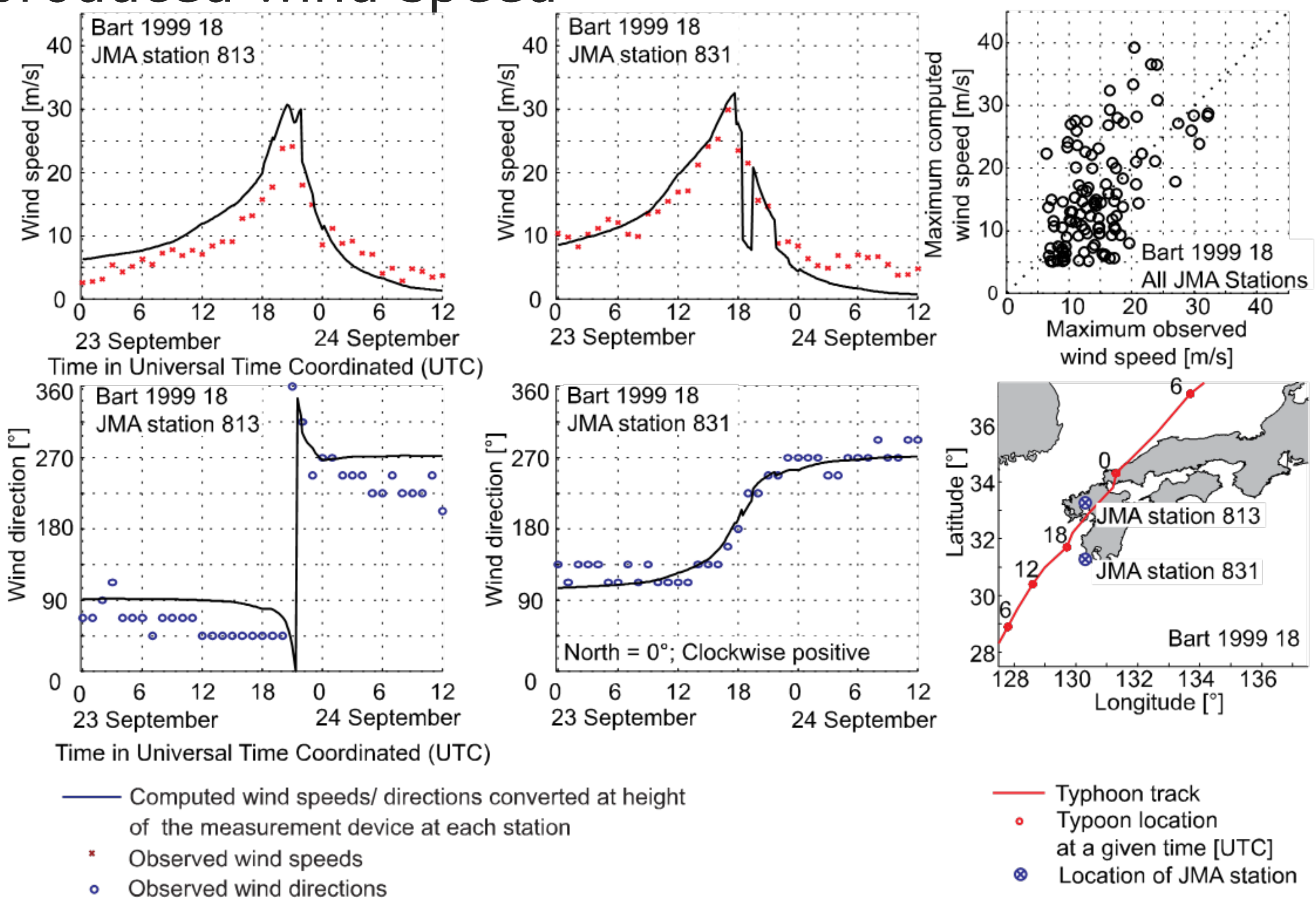




Locations of the meteorological stations.

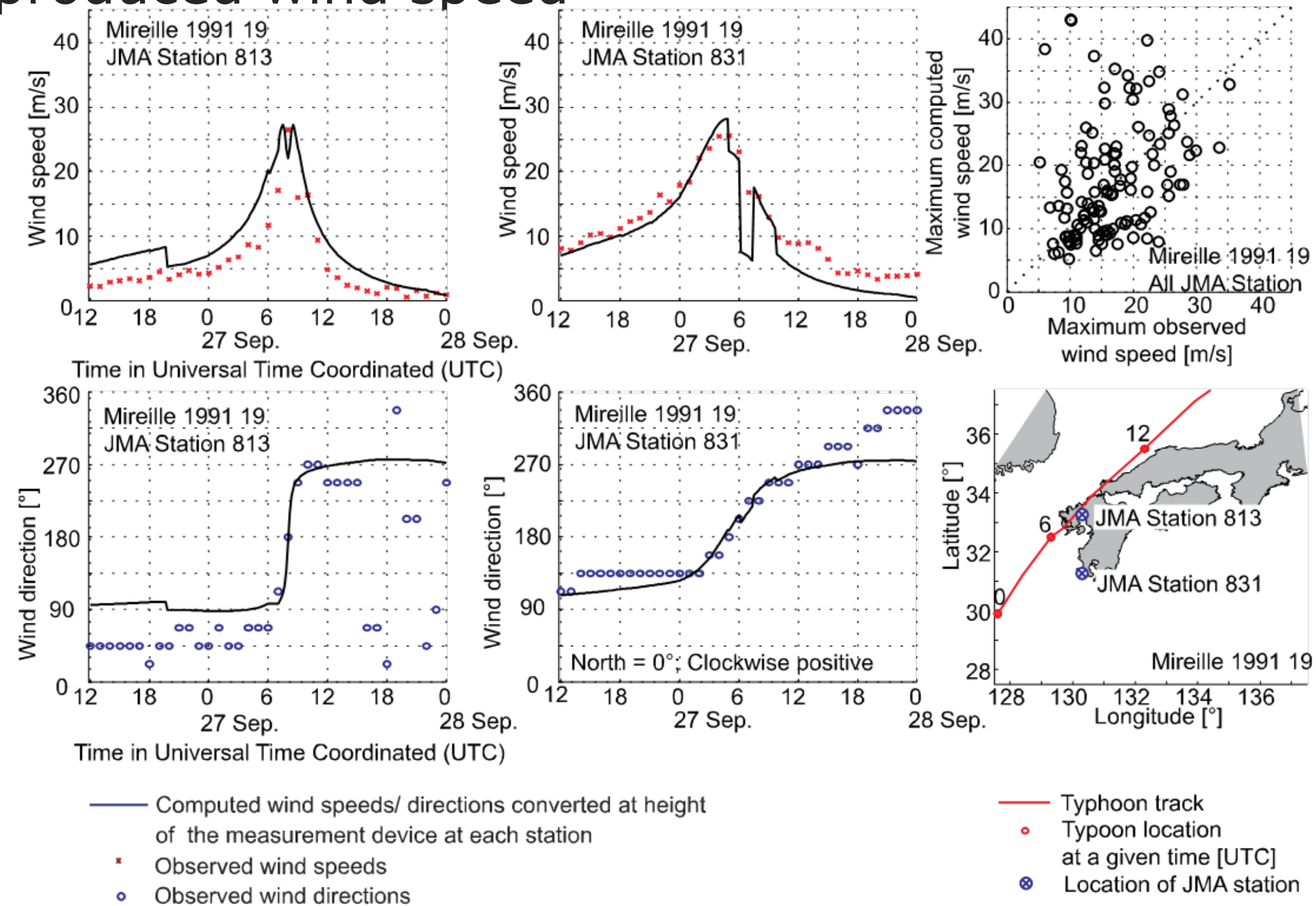
Surface friction model

Comparison between observed wind speed and reproduced wind speed



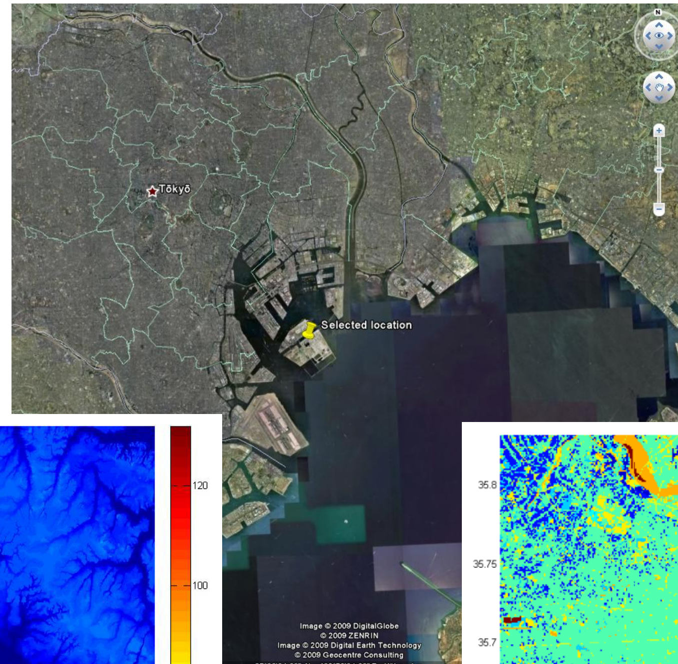
Surface friction model

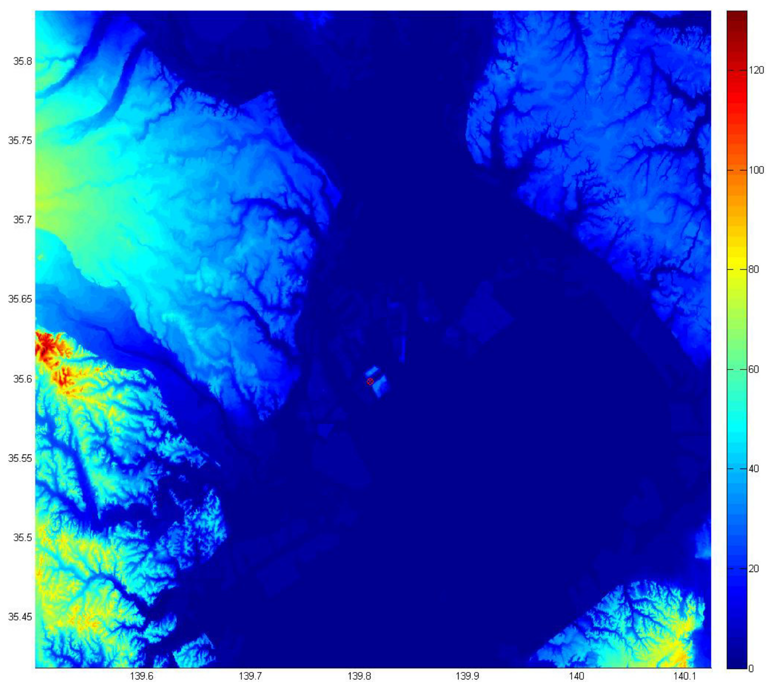
Comparison between observed wind speed and reproduced wind speed

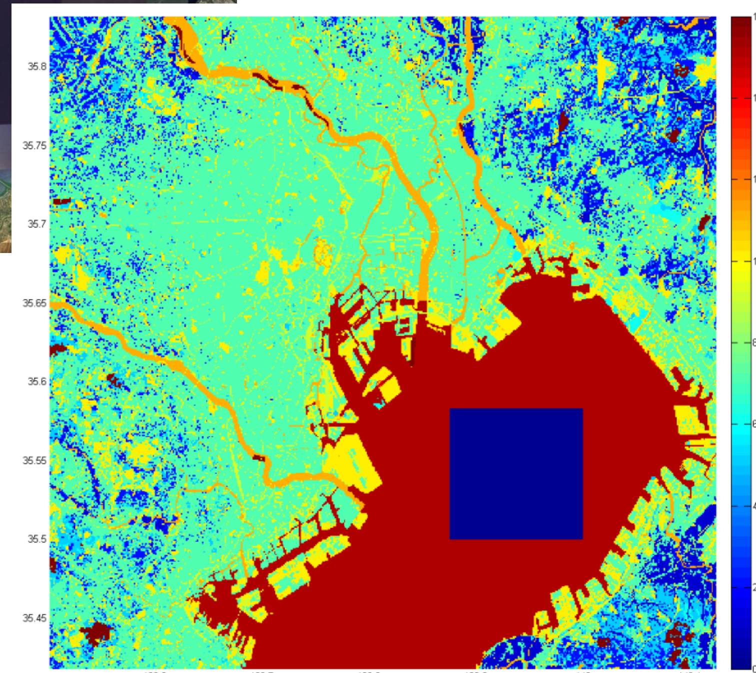


Surface friction model

Improving the estimation of z_0

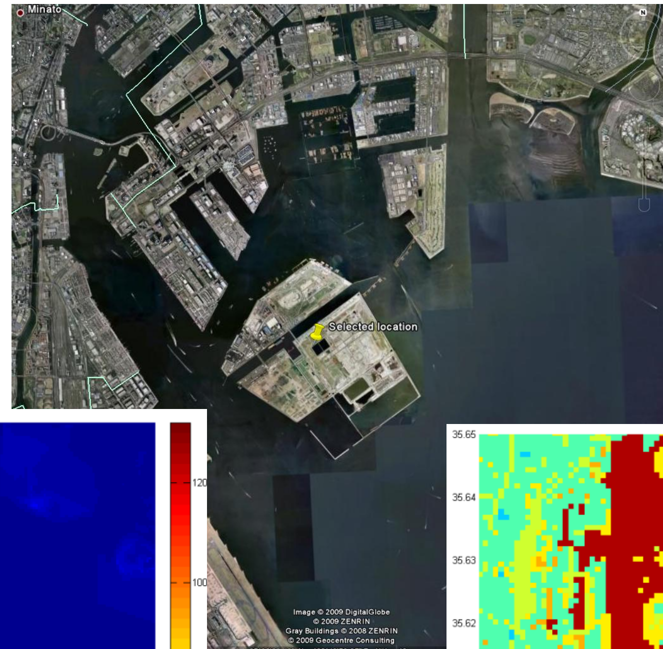


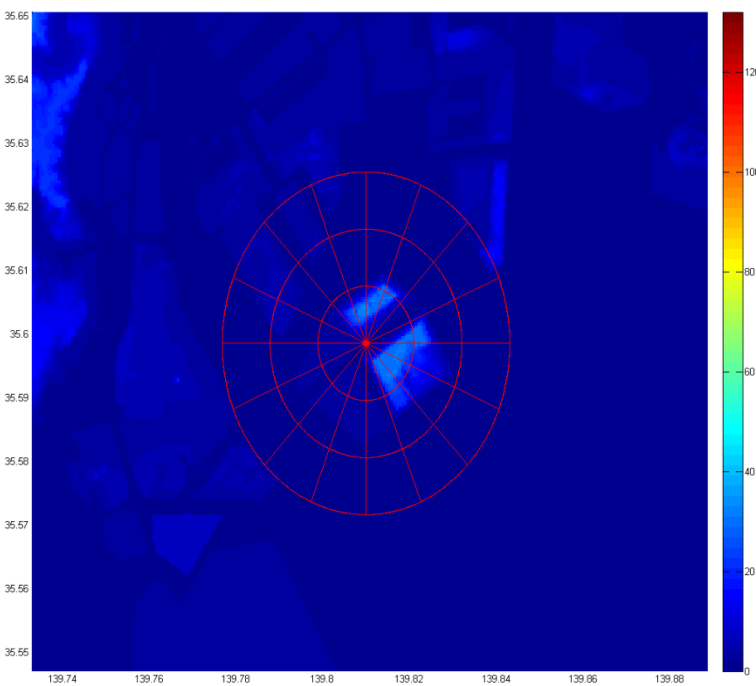


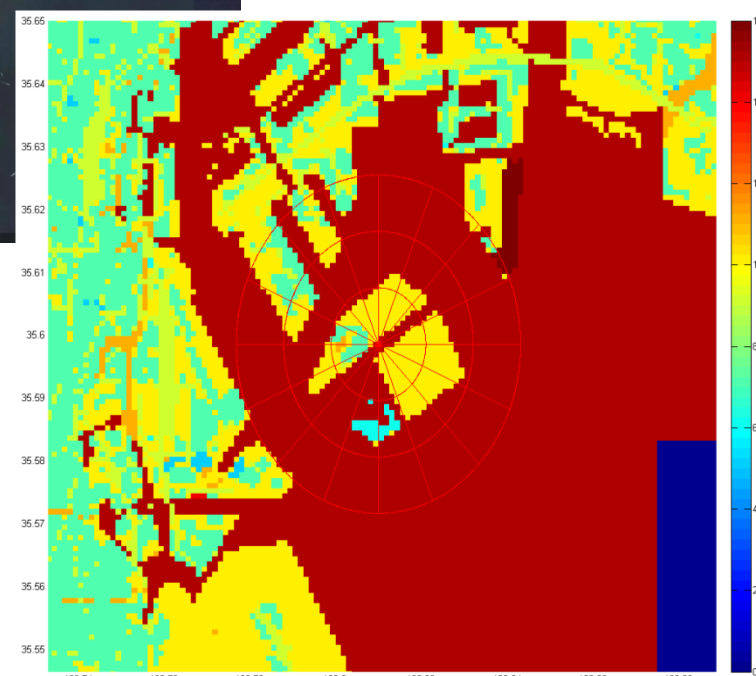


Surface friction model

Improving the estimation of z_0







Hazard model
Comparison with the hazard map of AIJ

Location	100-year wind speeds		500-year wind speeds	
	ETH	AIJ	ETH	AIJ
Hokkaido	30	32	35	36
Miyagi	32	32	36	36
Toyama	33	32	37	36
Chiba	34	36	38	38
Saitama	34	36	38	38
Kochi	35	37	40	41
Kumamoto	36	38	40	42
Okinawa	41	50	46	58

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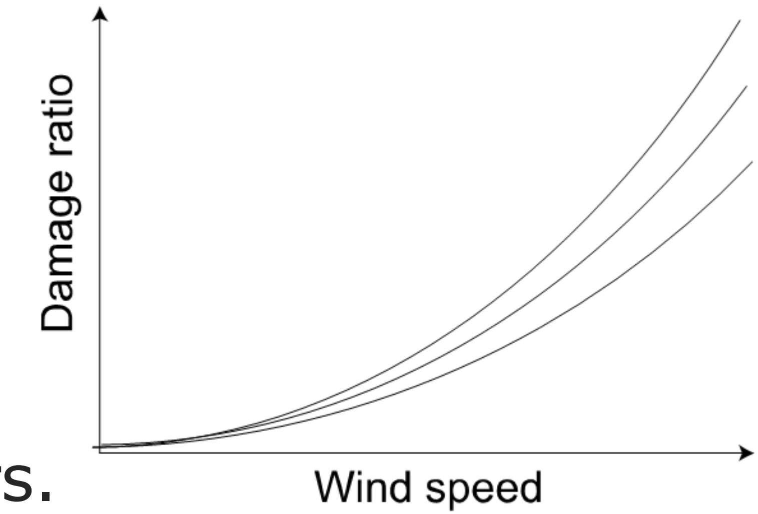
Portfolio risk assessment

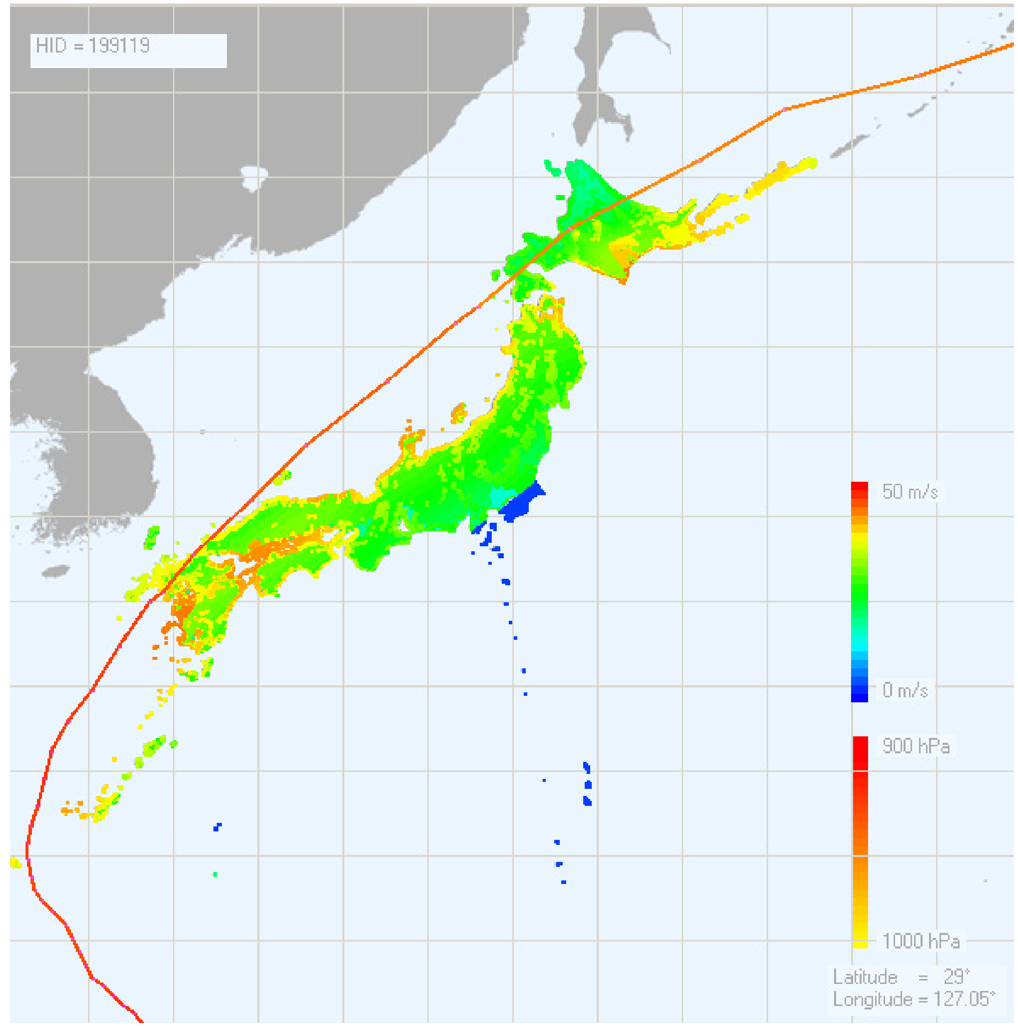


Vulnerability model

- Probability that a loss occurs.
- Distribution of the loss ratio conditioned that a loss occurs.
- Modeled as a function of the wind speed
- For different causes (Windstorm and flood)
- For different building types
- Taking the insurance payment conditions into account

Vulnerability model

- Reproducing wind field of historical typhoons
- Combining wind field with insurance portfolio and loss data.

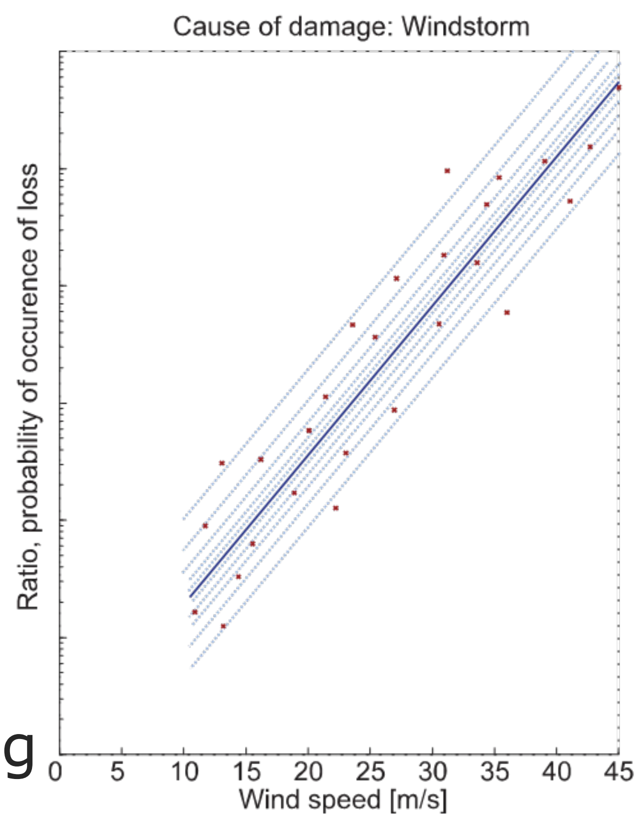


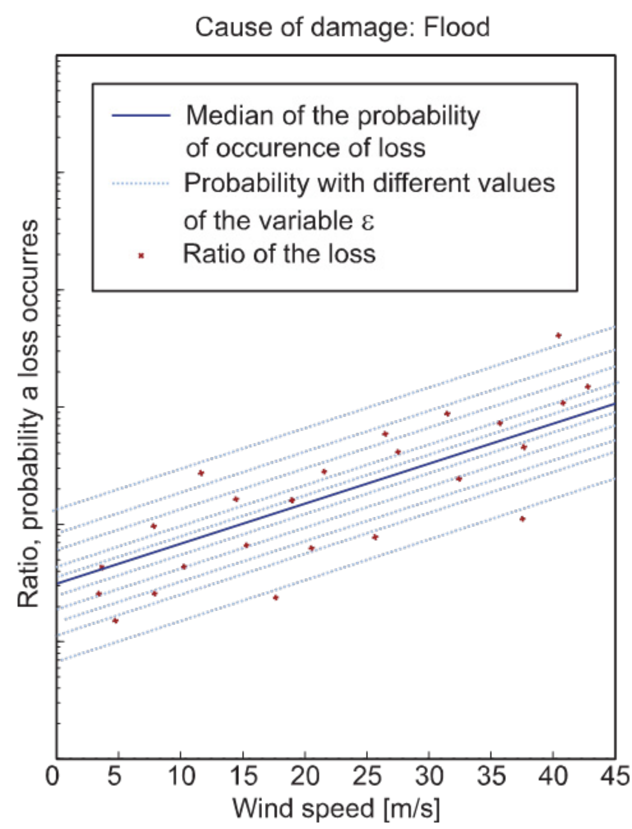
Vulnerability model

Estimating the probability that a loss occurs

Modeled as a function of the wind speed

For different Causes and for different building types



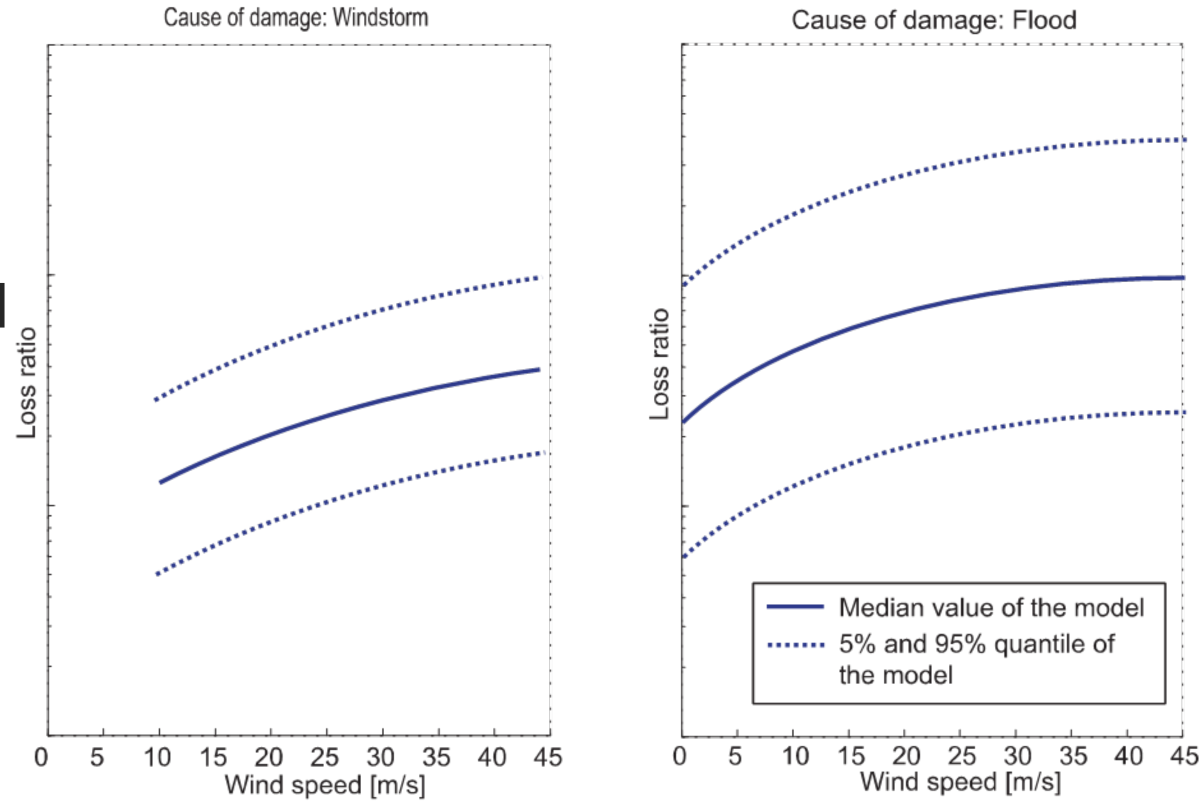


Logitfunction

$$P = \frac{1}{1 + e^{-a + b \cdot windspeed}} \cdot \varepsilon$$

Vulnerability model

Estimating the probability distribution of loss ratio conditioned that a loss happens



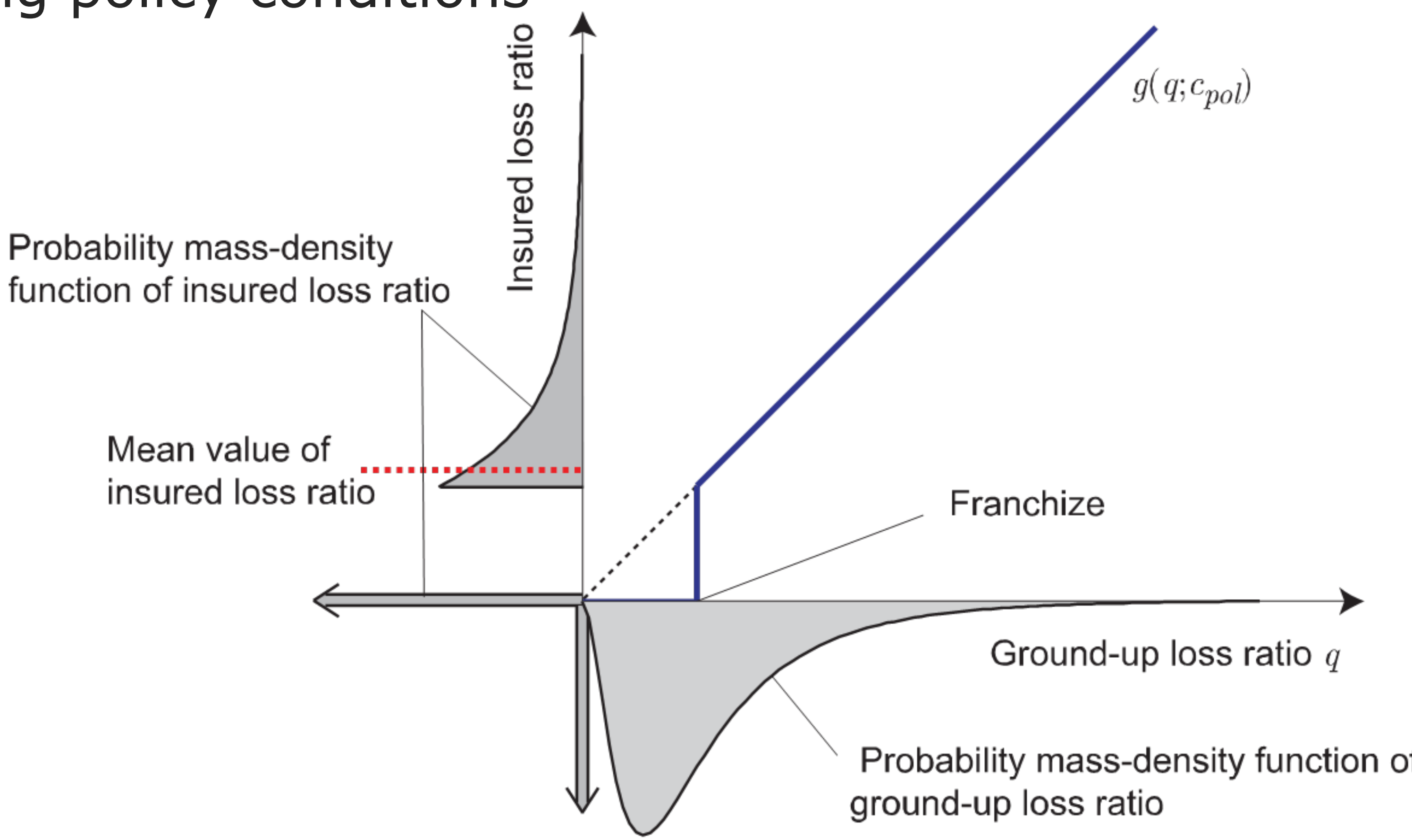
Loss ratio distribution modeled as Lognormal distribution.

$$\log(LossRatio) \sim N(lamda, tau)$$

$$lamda = \log(a1 + a2 \cdot WindSpeed)$$

Vulnerability model

- Aggregating ground-up loss ratio probability distribution
- Applying policy conditions



Portfolio risk assessment

Software tool:

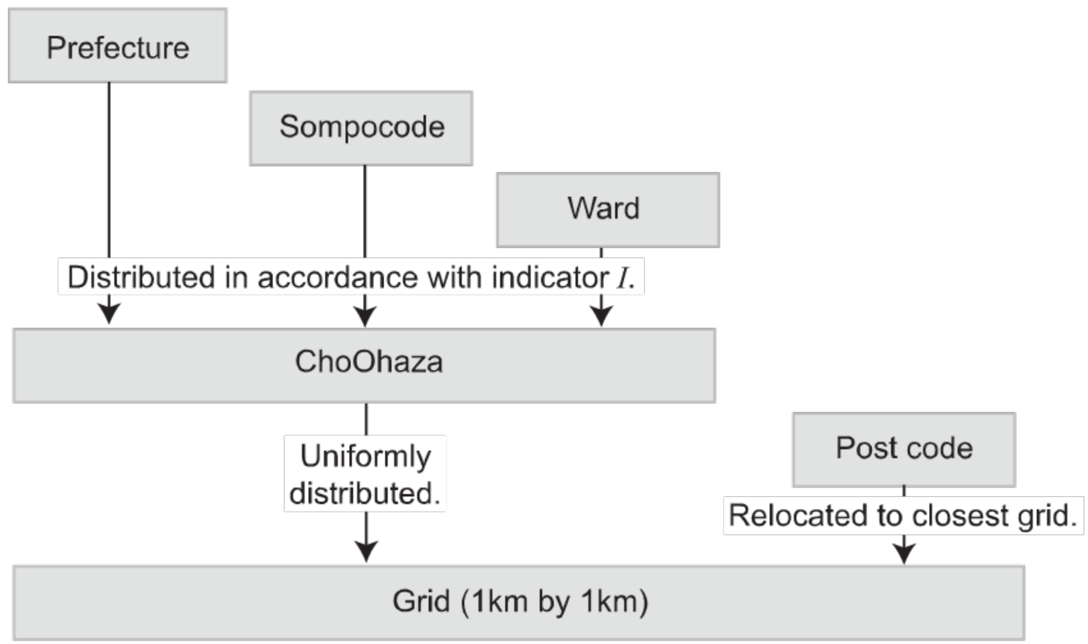
Hazard model is utilized to simulate the probabilistic typhoon events.

Loss of the portfolio due to the typhoons of the event set is calculated by applying the vulnerability model.

Portfolio risk assessment

Software tool:

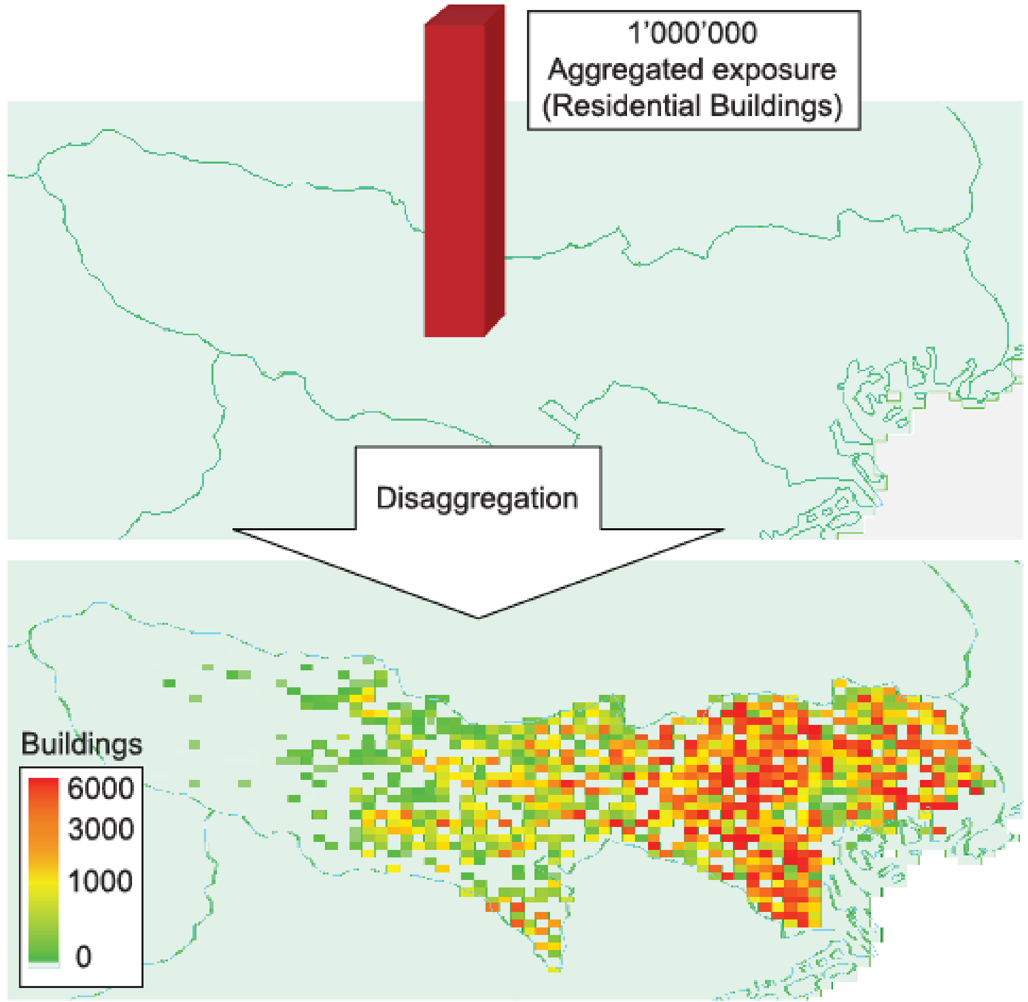
Disaggregation of the portfolio



Portfolio risk assessment

Software tool:

Disaggregation of the portfolio



Portfolio risk assessment

Considering the different seasons (months) during the development of the hazard model enables

to assess the risk of a portfolio for a certain period e.g. September till the end of the year.

Contents

- Introduction of the typhoon model developed.
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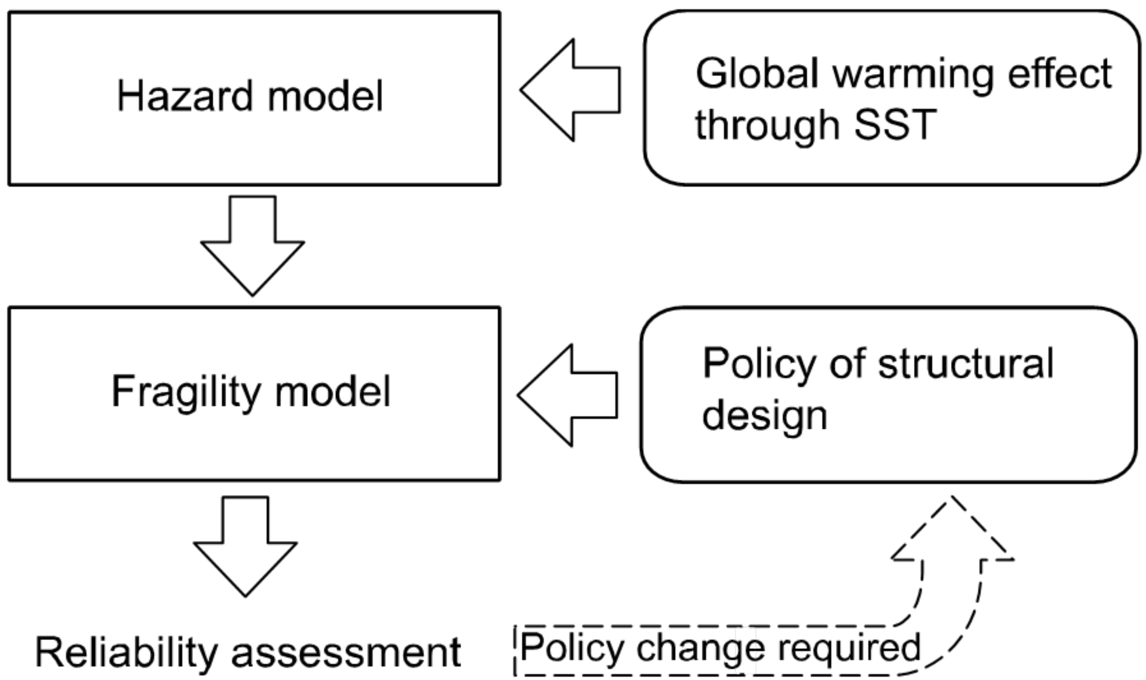
- Real-time decision making using the typhoon model

Assessing the effect of global warming on structural reliability



Graf, M., Nishijima, K. & Faber, M.H. (2008). Adaption of Typhoon Risk Modeling to Climate Changes. In *IDRC 2008.* Davos.

Assessing the effect of global warming on structural reliability

Incorporation of the global warming effect into the typhoon model

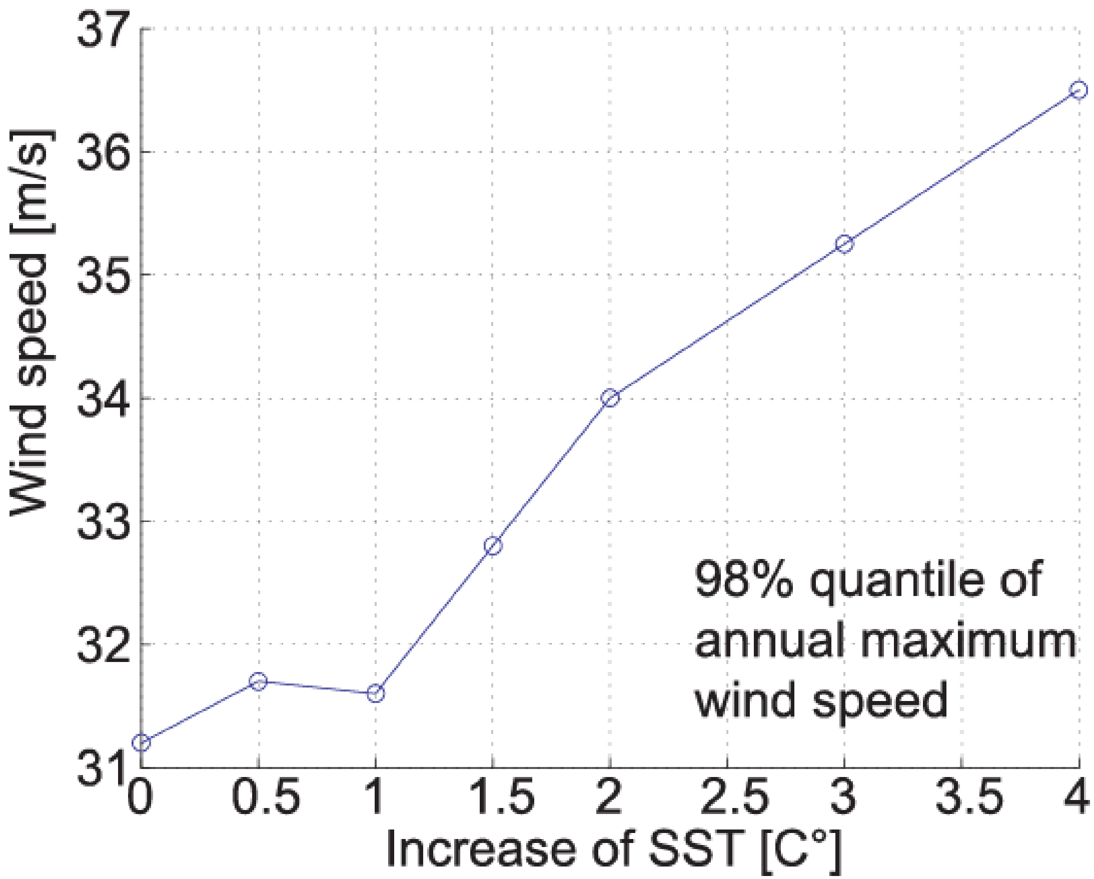
- The global warming effect is considered through the change of the sea surface temperature (SST).

→ SST is the input to the transition model.

- However, the occurrence rate of typhoons is assumed not to change.

Assessing the effect of global warming on structural reliability

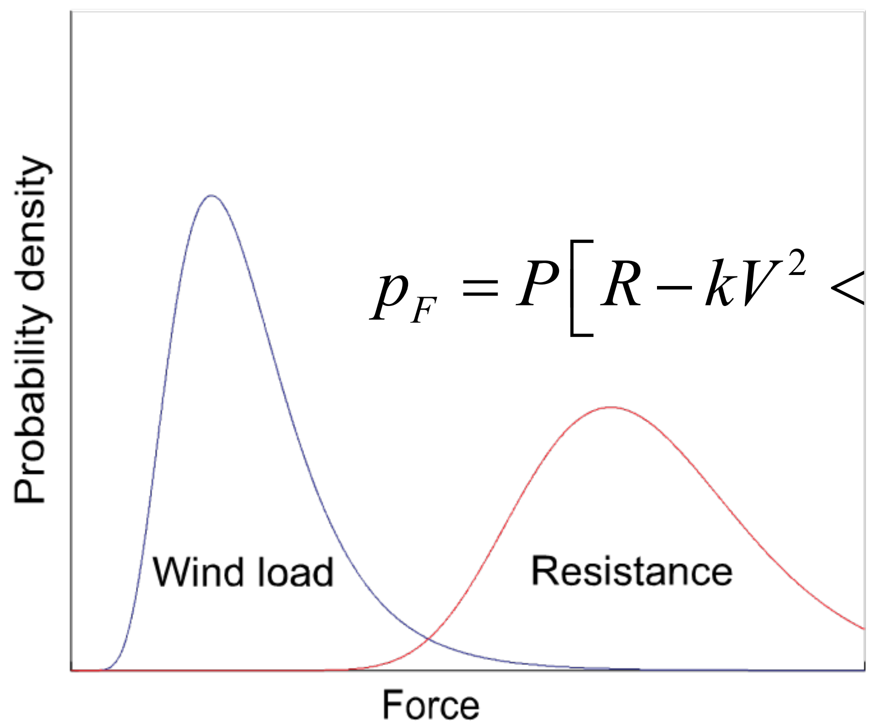
Change of the characteristic value (98%-quantile value) of annual maximum wind speed



Assessing the effect of global warming on structural reliability

Design problem:

Target probability of failure: $p_F \approx 10^{-5} \left[1/year\right]$

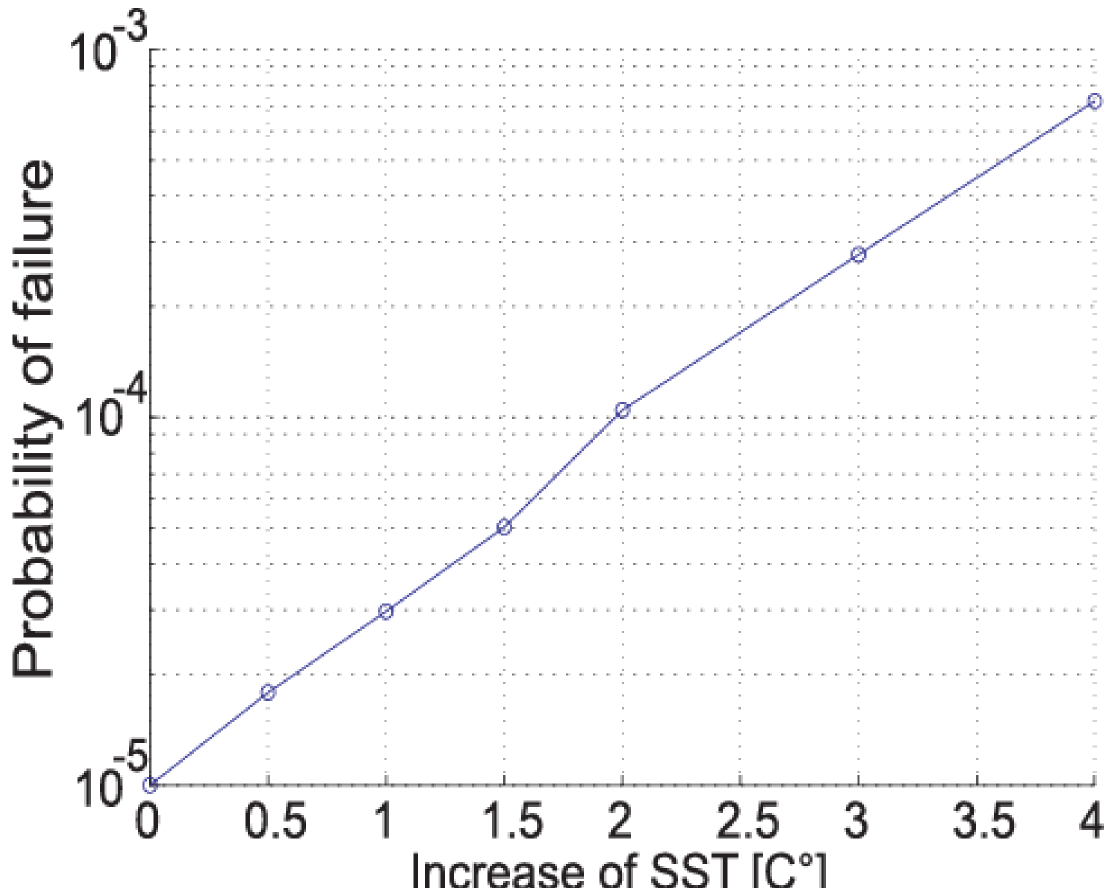


$$p_F = P\left[R - kV^2 < 0\right]$$

JCSS Probabilistic Model Code (2002). http://www.jcss.ethz.ch

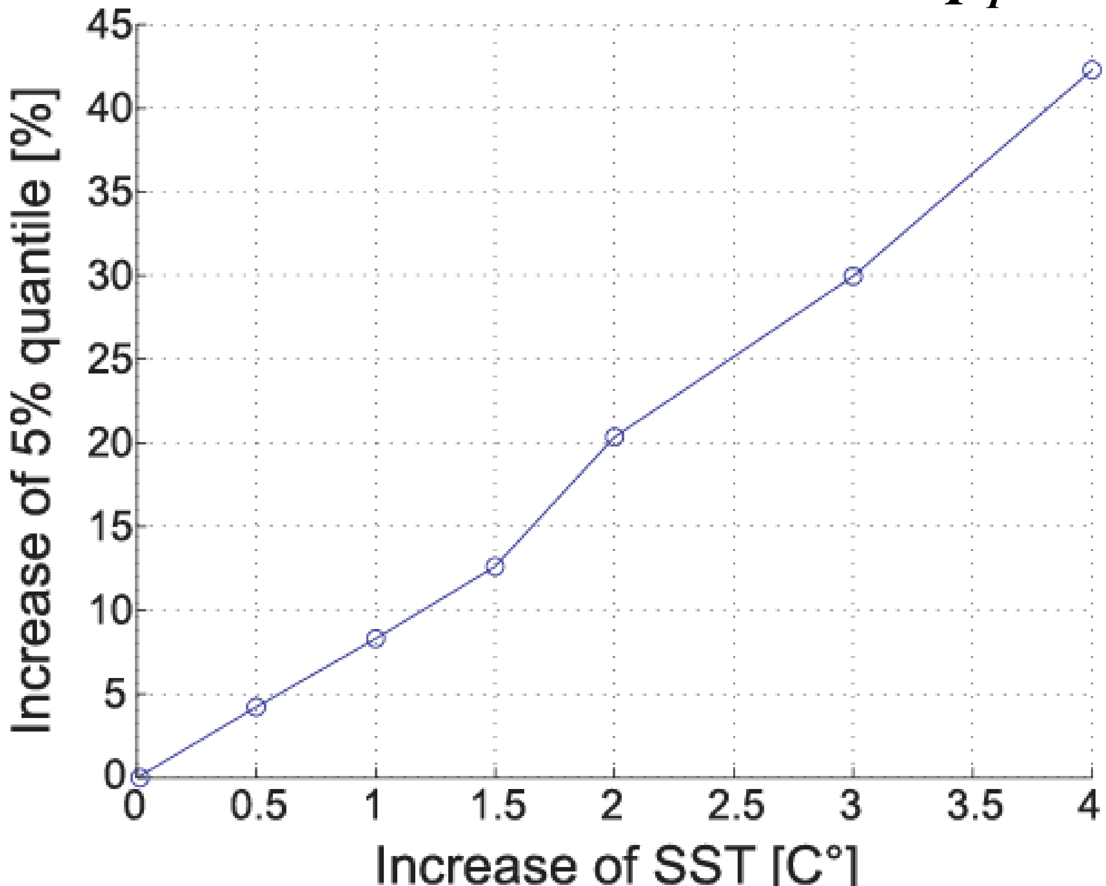
Assessing the effect of global warming on structural reliability

Change of the probability of failure



Assessing the effect of global warming on structural reliability

Required change of the characteristic value (5%-quantile value) to maintain the target reliability $p_F \approx 10^{-5} \left[1/year\right]$



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Real-time decision making

Modeling the typhoon events for the entire life of typhoons and

accounting for the seasonal differences of the probabilistic characteristics of the transition of typhoons

enables to integrate actual information on a approaching typhoon and simulate possible developments of this typhoon event.

Real-time decision making

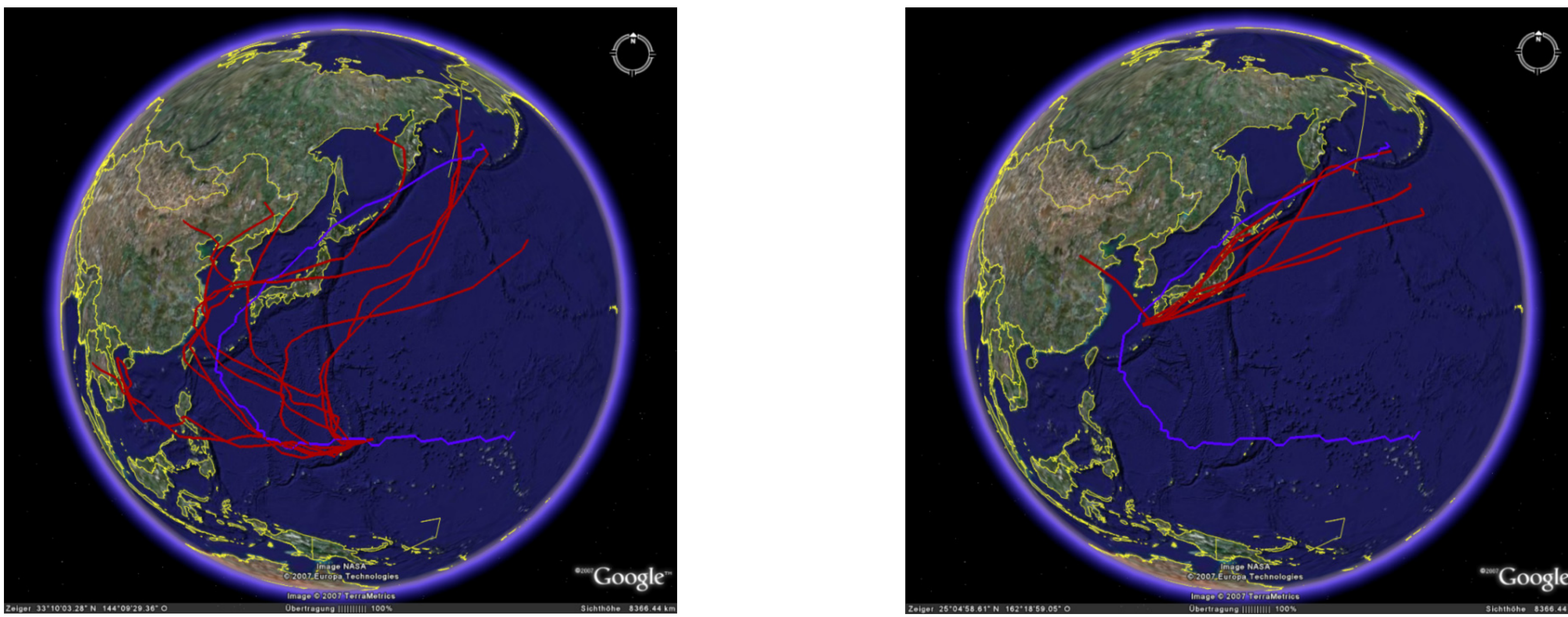
Actual information:

- Measurements at observation stations
- Satellite images and aerial photos
- Estimated developments from weather forecast

Real-time decision making

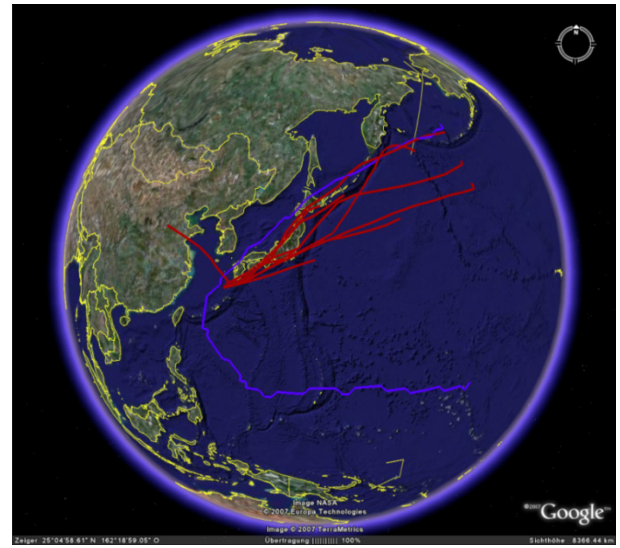
Conditional simulation

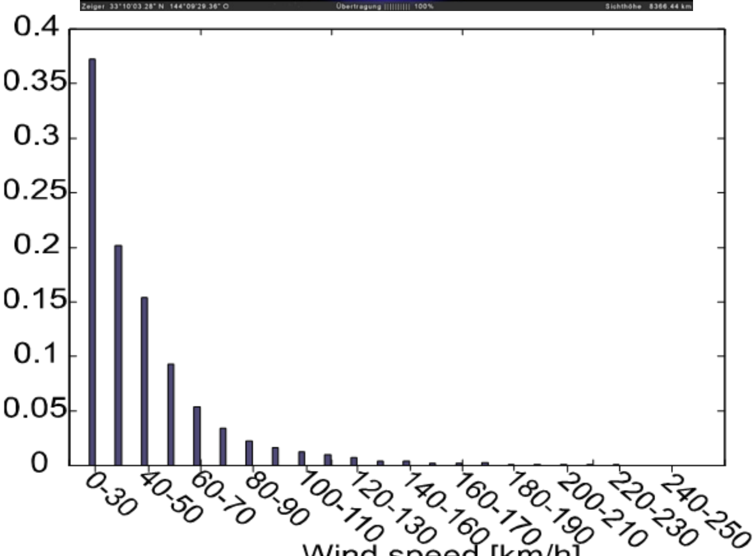
- enables to estimate the loss due to approaching typhoons in near-real time (near-real time updating).

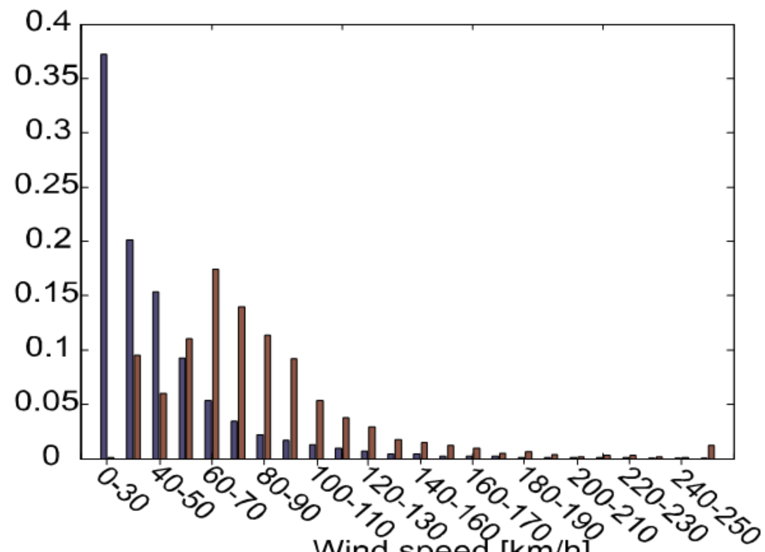


Conditional simulations when the typhoon is far from Japan (left) and close to Japan (right).

Real-time decision making

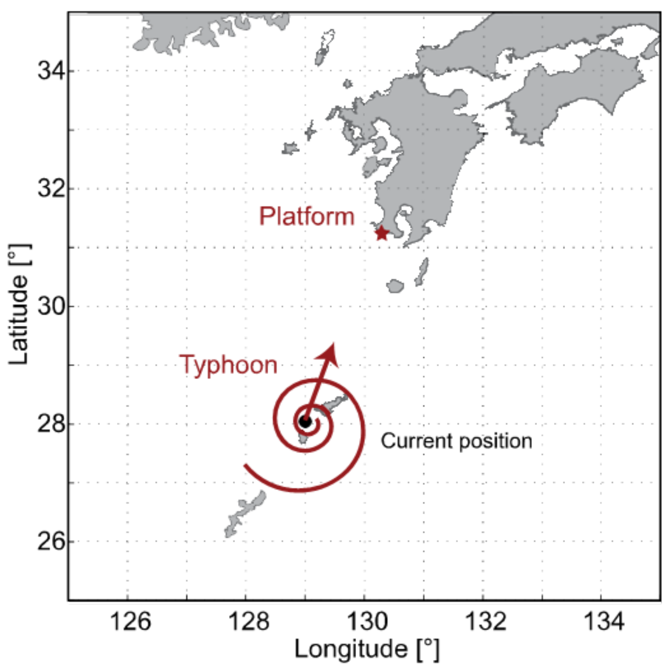






Real-time decision making

Optimal evacuation and shut-down decisions in the face of emerging natural hazards



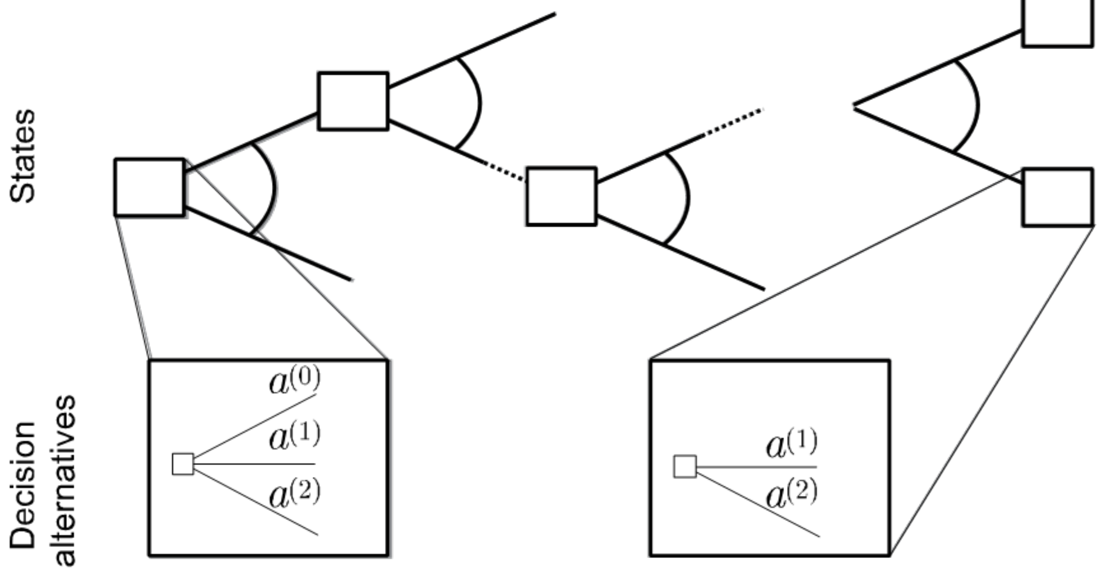
Continue or stop the operation on the platform?

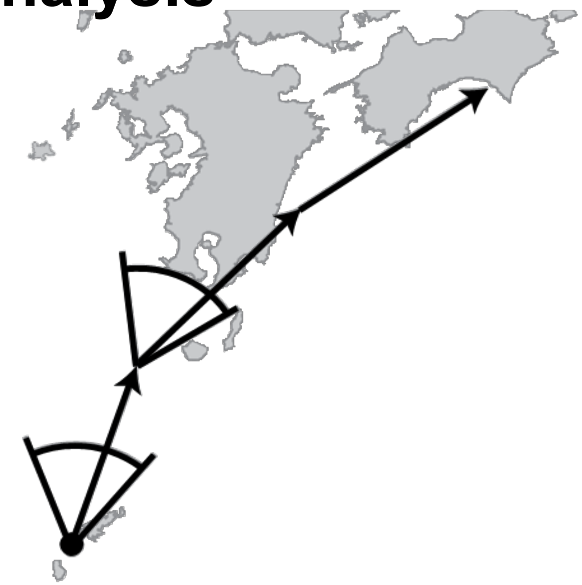
If yes, when to stop?

Nishijima, K., Graf, M. & Faber, M.H. (2009). Optimal evacuation and shut-down decisions in the face of emerging natural hazards. In *ICOSSAR 2009.* Osaka, Japan.

Real-time decision making

Methodology: Pre-posterior decision analysis





Reducing uncertainties by:

- (epistemic) collecting more information at costs
- (aleatory) “waiting”, which may result in being too late.


Thank you for your attention.