Regionalization of Tornado Intensities Using Tornado Parameters and a Long-term High-resolution Reanalysis Data

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Background and Motivation

- A new regulatory guide has been issued for evaluating tornado effects on nuclear power plants. The design-basis tornado and tornado-generated missiles are needed to be determined.
- In United States, the regionalization of the design-basis tornado wind speeds on the order of 10^{-7} per year probability level (NUREG/CR-4461; Fig. 1). In Japan, however, no map for regionalization has been proposed.
- A climatology of model-derived supercell and tornado parameters is considered using our long-term high-resolution reanalysis dataset. The regionalization is discussed in terms of the frequency of favorable mesoscale conditions for the intense classes (F3-F5) of tornado.

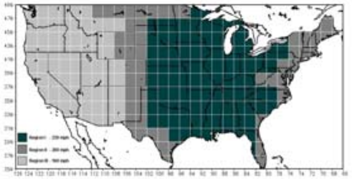

Fig. 1: Tornado intensity regions for the contiguous United States.

Geographical features of tornadoes in Japan

- Many tornadoes occurred in plain areas, especially near the coastline (Figs. 2 and 3). Almost of F3 (the most intense class in Japan) tornadoes have occurred in the Pacific side.
- The probability density of F3 tornado in a northern region is 1-2 order smaller than the one in a Pacific region (Fig.4), which implies that the southerly inflow of humid warm airmass from the Pacific Ocean tends to be blocked by inland high mountains.

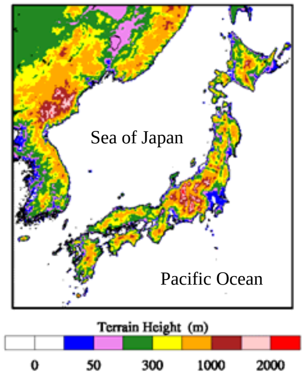

Fig. 2: Topography in and around Japan.

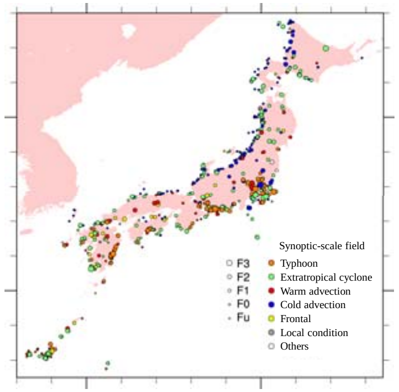

Fig. 3: Points of tornado outbreak (1961-2010)

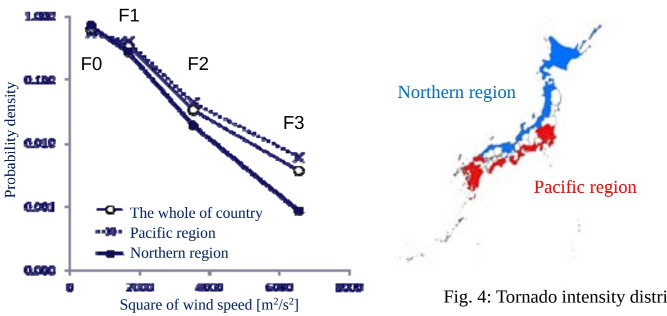

Fig. 4: Tornado intensity distribution

Supercell and tornado forecast parameters

- MUCAPE (Most unstable CAPE), 3-km SReH, and EHI are calculated on each grid point.
- Based on Rasmussen and Blanchard (1998, WF), the largest MUCAPE is selected within the proximity area with 15-km radius and the 90° section which is determined by the low-level inflow pattern. EHI is calculated using SReH and the largest MUCAPE.

WRF model simulation for F3 and F2 tornadoes

- WRF model simulation (5-km horizontal resolution) is performed for mesoscale analysis of each event.
- ERA-interim or ERA-40 reanalysis data from ECMWF is used for the initial and the boundary conditions.
- The maximum SReH, the maximum MUCAPE, and the maximum EHI in the 100 km square area centered at the tornado outbreak point are used for consideration of each event.
- It is found that both MUCAPE and SReH are relatively larger in F3 tornado cases. Meanwhile, F2 tornadoes could occur even if one of parameters has quite a small value (Fig. 6).
- The absolute value of (MU)CAPE in winter season (Nov. to April) is much smaller than in summer season (May to Oct.).

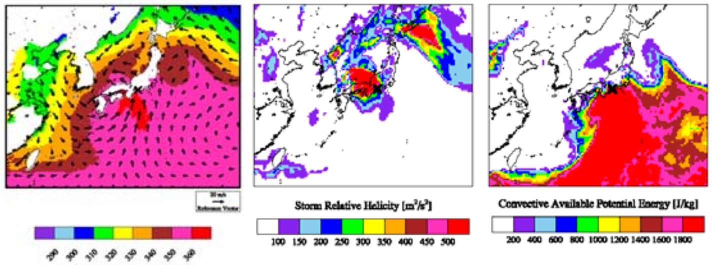

Fig. 5: WRF simulation for a F3 tornado (September 24, 1999) associated with a typhoon (Left: Horizontal wind vector and equivalent potential temperature (100 m ASL), Middle: 3-km SReH, Right: CAPE)

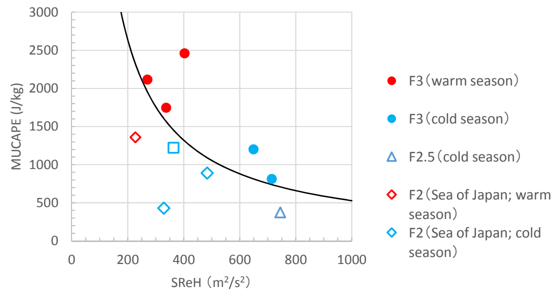

Fig. 6: Scatterplot of tornado parameters for F3 (the whole of country) and F2 (Sea of Japan side) events occurred in Japan.

A climatological consideration using a long-term high-resolution reanalysis data

- A 50-year reanalysis dataset is produced by a physical downscaling using WRF model, ERA-40, and ERA-interim reanalysis data. The temporal interval of data is 1 hour, and the horizontal resolution is 5 km.
- Favorability of occurrence of tornado is evaluated on each grid point from the frequency that both of tornado parameters and precipitation amount exceed their thresholds.

Results

- The latitude- and season-dependent variability of CAPE is found in Fig. 7, which suggests that the threshold of (MU)CAPE has to be set according to season.
- The points of past F3 tornado outbreak are included in high exceedance frequency regions (Figs 8 and 9) where both of MUCAPE and SReH exceed their thresholds specified from the results of WRF model analysis (Fig. 6).
- The exceedance frequency in the Pacific side is 1-2 order larger than in the Sea of Japan or in a northern region. This is consistent with the tornado intensity distribution in Fig. 4.
- This method could be applied to relatively large F-scale (F2-F5) tornadoes that are driven by forcings in larger scales.

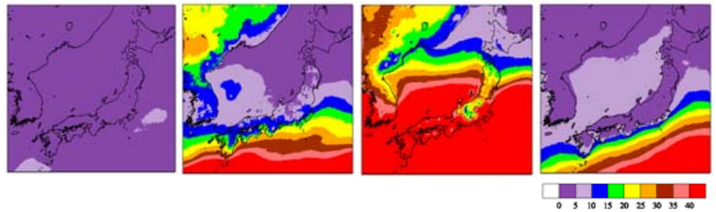

Fig. 7: Seasonal pattern of the exceedance frequency [%] (CAPE threshold of 250 J/kg)

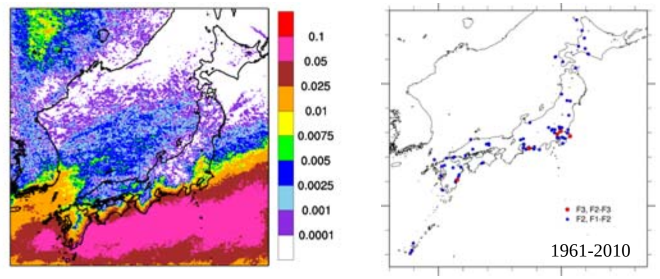

Fig. 8: Distribution of the exceedance frequency [%] (left) and points of F3 and F2 tornadoes (right) in warm season. (MUCAPE threshold of 1600 J/kg, SReH threshold of 250 m²/s², and precipitation threshold of 2 mm/hr)

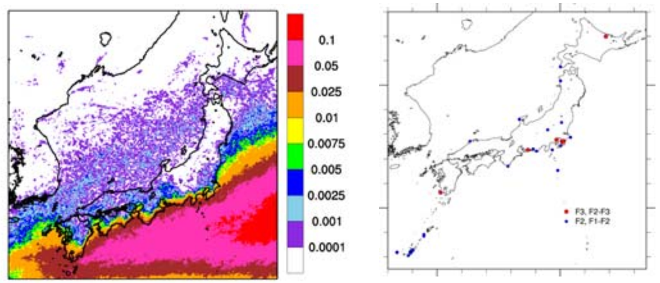

Fig. 9: Same as Fig. 8 but for winter season and with MUCAPE threshold of 600 J/kg.

Summary

- The pattern of exceedance frequency evaluated in this study is useful for the regionalization of the design-basis tornado intensity.
- The investigation of the usefulness of other tornado parameters and the application to other climatic regions including the contiguous United States are needed as the future research direction.