5A.6 STOCHASTIC MODELING OF TROPICAL CYCLONE TRACK DATA

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1. INTRODUCTION

Damages that can be caused by meteorological phenomena, particularly tropical cyclones, pose a major financial risk to insurance and reinsurance companies. It is therefore necessary for these companies to assess the frequencies and intensities of tropical cyclones hitting areas with insured objects as precisely as possible to estimate their losses. The approach taken in this paper is to create a model for the tracks of tropical cyclones and the maximum wind speeds attained on these tracks. This model is almost entirely stochastic and based on historical data; it incorporates only a few very basic meteorological properties. The purpose of this is to reduce very complex meteorological events to simpler mathematical objects, which allows for the simulation of a large number of synthetic cyclone tracks. A numerical model can then be applied to these tracks and the respective maximum wind speeds to calculate wind speeds in areas affected by the storms. From these wind speeds, the required risk assessments can be made. Recent approaches based on similar ideas have been introduced by Emanuel (2005) and Hall (2005).

2. DATA

The proposed model is based on historical cyclone track data from the western North Pacific. The data consists of the location and the maximum wind speed of every known tropical cyclone in that area from the period 1945–2004, recorded at intervals of 6 hours. The data set is a composite of best track data in the western North Pacific compiled by Munich Reinsurance Company using track data provided by the Japanese Meteorological Agency (JMA), Joint Typhoon Warning Center (JTWC) and Unisys Weather. Figure 2 shows the tracks of all the 1,519 storms considered.

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3. CLASSIFICATION

As can be seen in figure 2, the considered cyclones show some strong inhomogeneities. For example, while most storms (but not all) initially move westward, some later curve around to the east and make their way across Japan; others head straight for the South China Sea without making a curve. Thus, before creating a simulation from the observed data, the historical cyclones are first separated into more homogeneous classes. For this purpose, the observation window is segmented into 4 zones; see figure 3. Then, the historical cyclones are assigned to different classes according to the combinations of zones they started or ended in or moved across during their life span. The tracks of the cyclones in the 6 obtained classes are shown in figures 4 through 9. The respective class sizes can be found in table 1. For example, the storms curving eastward across Japan are now contained in class 2 (see figure 6), while those heading straight for the South China Sea are contained in class 1 (see figure 5). All subsequent steps of the modeling process are now performed separately for the 6 different storm classes.

4. INITIAL POINTS

Since the initial points (or points of genesis) of the considered cyclones can be viewed as random points within the observation window, they are modeled as a random point process. One of the simplest examples is the Poisson point process. As can clearly be seen from figures 10 through 15, the distribution of the points is rather inhomogeneous within the observation window. Therefore, an inhomogeneous Poisson point process is used to model the distribution of genesis points; see e. g. Stoyan (1994), pp. 228ff.

The characteristics of an inhomogeneous Poisson point process are determined by its intensity field. Thus, for the intended model, such intensity fields must be estimated from the historical data, i. e. the historical points of genesis. For this, a generalized-nearest-neighbor approach is employed; see Silverman (1986), pp. 96ff. The required kernel function is chosen to be the Epanechnikov kernel, because of certain quality characteristics of this kernel; see Silverman (1986), pp. 42f. In addition, a likelihood cross validation method has shown some advantage for the Epanechnikov kernel over a Gaussian kernel in fitting the data; compare e. g. Hall (2005d).

For obvious reasons, at points situated over land and points outside of the genesis region for the respective storm class, the intensity of the inhomogeneous Poisson point process (and in doing so, the probability for the genesis of a storm at these points) is set to zero. The obtained estimators for intensity fields are shown in figures 10 through 15; the used color scale is given in figure 1. The intensity is clearly seen to be higher where there are more historical genesis points, as intuition would suggest. Note that, due to the nature of the generalized-nearest-neighbor approach, the probability for storm genesis is low in regions with few historical initial storm points, but does not reach zero. This is intended, because there is no reason to completely exclude the possibility of storm genesis in these regions. The adequacy of this approach to modeling the initial points of the tropical cyclones can be assessed using a statistical Monte Carlo testing technique (see e. g. Baddeley (2006) and the references therein).

5. TRACKS

To model cyclone movement from the points of genesis, a traveling direction and a translation speed are needed. A density for the initial direction of a cyclone is estimated from the data using kernel techniques. The same is done for the change in the cyclone's direction on subsequent steps. An analogue procedure is employed for the modeling of translation speed and maximum wind speed. Note that these values have to be restricted by certain boundary conditions, for example being no less than zero.

Every cyclone is modeled in 6-hour steps to correspond with the historical data. After each step, the changes in direction, translation speed, and wind speed are sampled independently from the respective estimated densities and then added to the previous values of these characteristics to calculate their new values, thus constituting a generalized random walk. In this model prototype, any potential dependencies between direction, translation speed, wind speed, and location of the cyclone or autocorrelations of these characteristics are not yet considered.

The termination (or death) of a tropical cyclone is also modeled as a random variable. Depending on its location and maximum wind speed, the cyclone is assigned a certain termination probability after each step. By generating a uniformly distributed random number it is then determined whether the cyclone will end or more steps in the track will be generated.

With a Monte Carlo technique analogous to the one used to examine the initial points (see section 4.), the adequacy of the model for the simulation of the tracks can be tested by comparing the point patterns of the second points, third points, etc. of synthetic cyclones with the corresponding historical data.

6. SIMULATION

The programming work for the simulations has been done in JAVA, partially using methods from the GeoStoch library. This library comprises software tools designed to analyze image data with methods from stochastic geometry; see Mayer (2004) and *http://www.geostoch.de* . It is important to note that for generating the actual event sets of cyclone tracks, an acceptance-rejection method is used: after generating a storm track originating from one of the initial points, the obtained track is classified to determine whether a track has been produced that matches the class of its initial point (see section 3.). If this is not the case, the track is rejected and a new track is generated, until a track with the correct classification is generated. Examples of the generated synthetic cyclone tracks are shown in figures 16 through 21. Each figure shows synthetic cyclones from one of the storm classes for a time period that spans the same length of time as the historical data; see section 2.

7. WIND FIELDS AND RISK ASSESSMENT

Using this model, typhoon tracks with a frequency covering a time period of 10,000 years are generated. The model creates the position of the typhoon's eye, the translation speed and the maximum wind speed at intervals of six hours.

These parameters are used to calculate a two-dimensional wind field along each track using a wind profile developed by Munich Reinsurance Company. In this wind profile, the radius of gale force winds and the radius of maximum winds are calculated from the maximum wind speed at that time. A correlation between wind speed and damage is then used to calculate the damage caused by every event. The risk assessment is finally done by assigning a return period to each loss.

8. CONCLUSION

As can be seen from figures 16 through 21, the introduced model produces encouraging results in modeling the tracks of tropical cyclones in the western North Pacific. Still, there are various possibilities for model enhancements, such as making the changes in a cyclone's direction, translation speed and maximum wind speeds dependent on its current location and state; cf. e. g. Emanuel (2005) and Hall (2005). Other improvements may include a more precise way of modeling the termination probability of a cyclone; cf. e. g. Hall (2005).

Class (i)	Number of Storms in class (n_i)	Number of recorded points
0	115	1939
1	470	11958
2	470	14695
3	178	4086
4	84	2032
5	202	2667
Total	1519	37377

Table 1: Class sizes of the storm classes

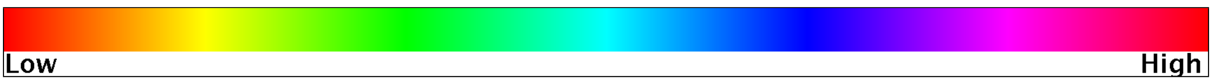

Figure 1: Color scale for figures 10 through 15

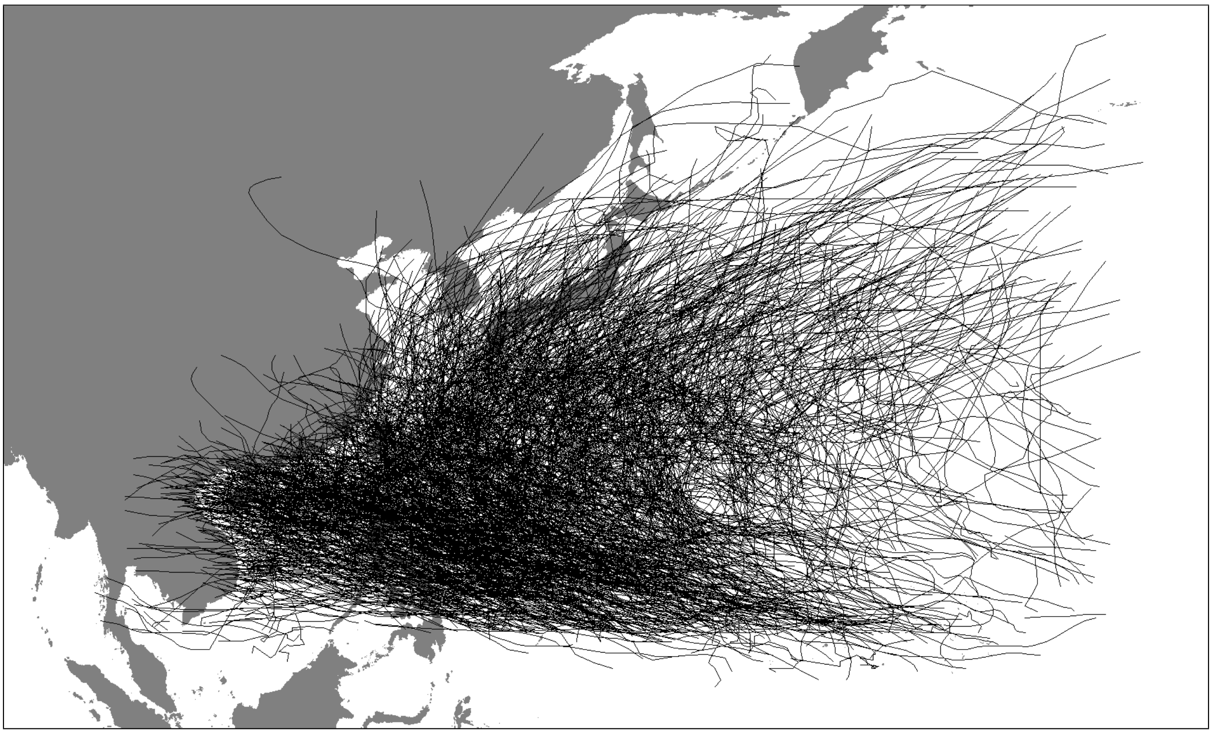

Figure 2: Storm tracks in the western North Pacific from 1945–2004

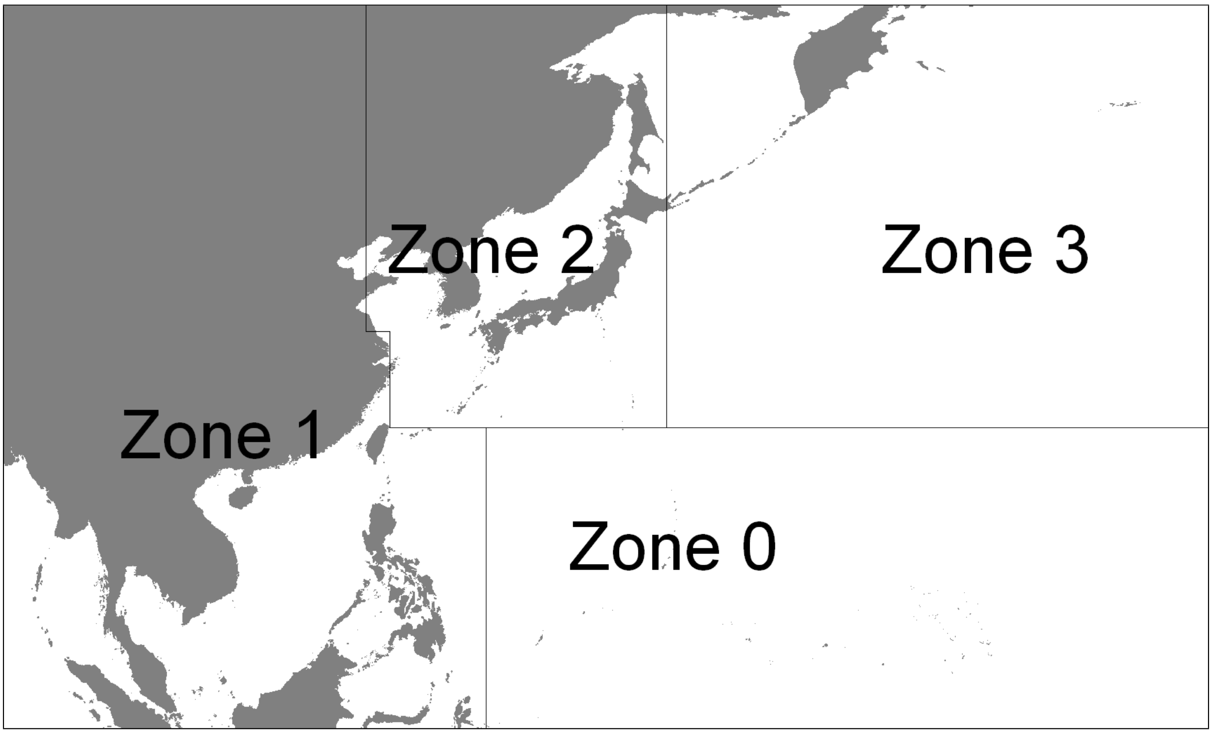

Figure 3: Zones used for the classification of storms

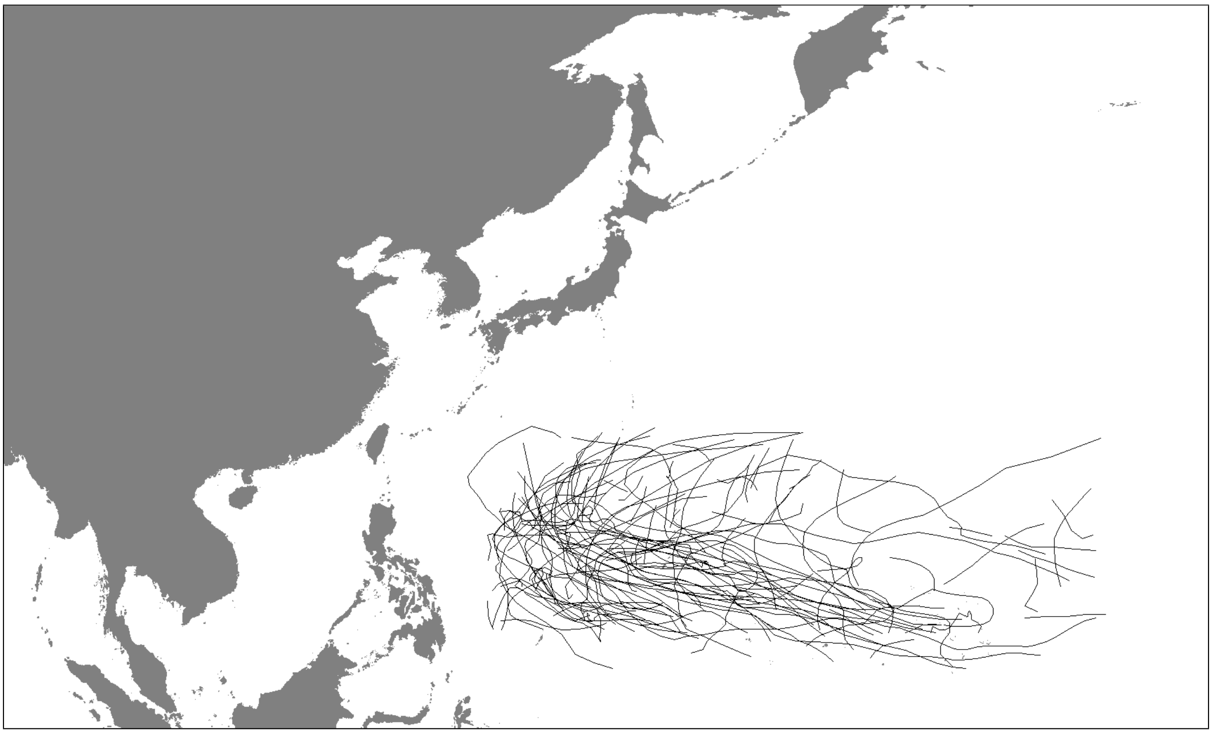

Figure 4: Tracks of all storms falling into class 0

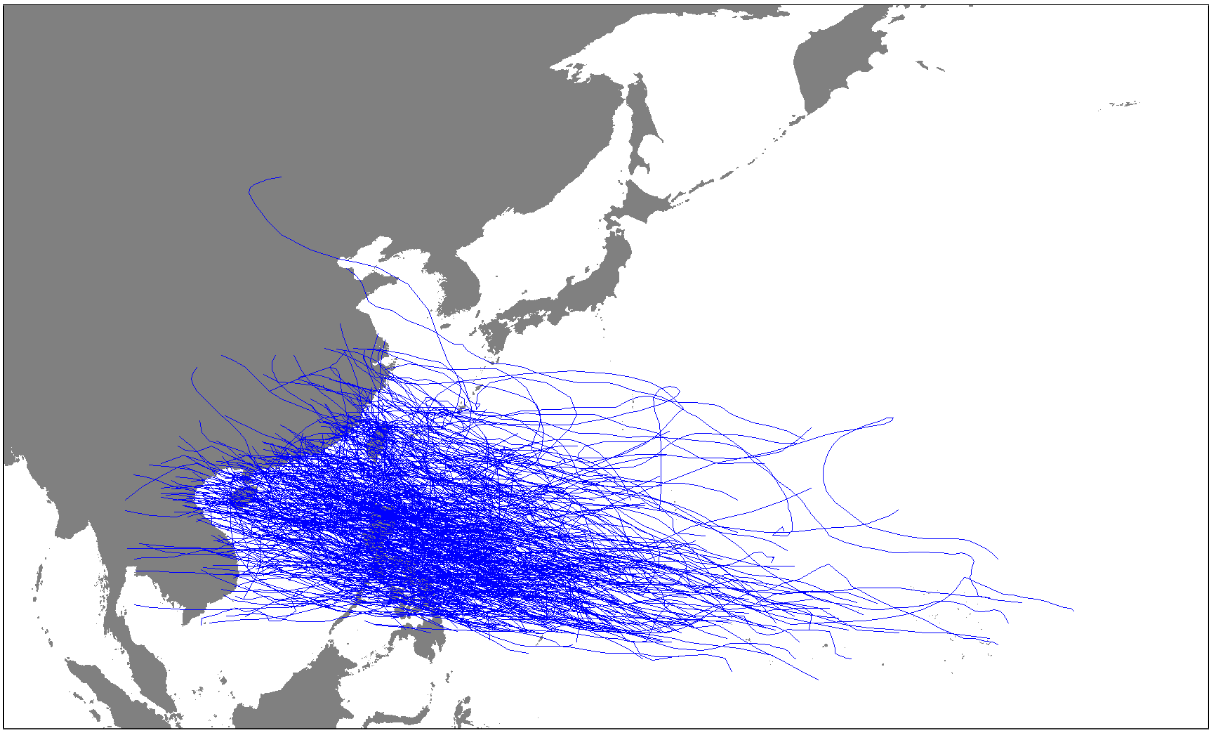

Figure 5: Tracks of all storms falling into class 1

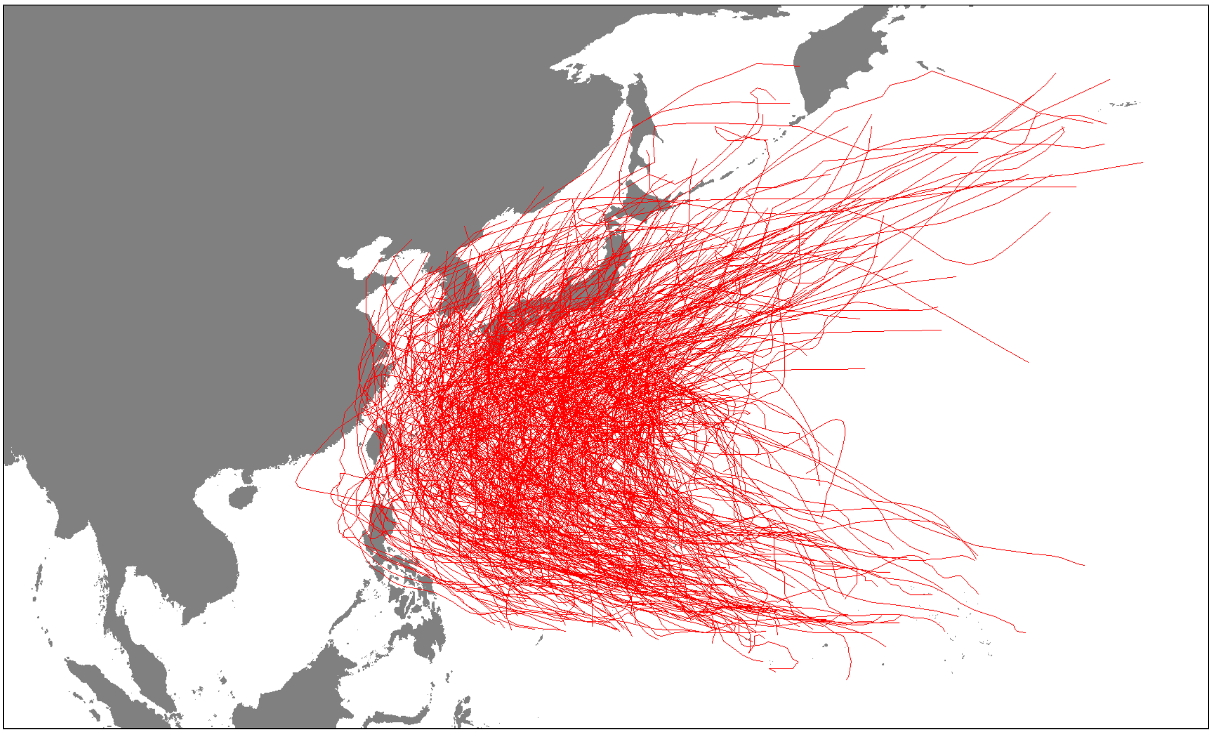

Figure 6: Tracks of all storms falling into class 2

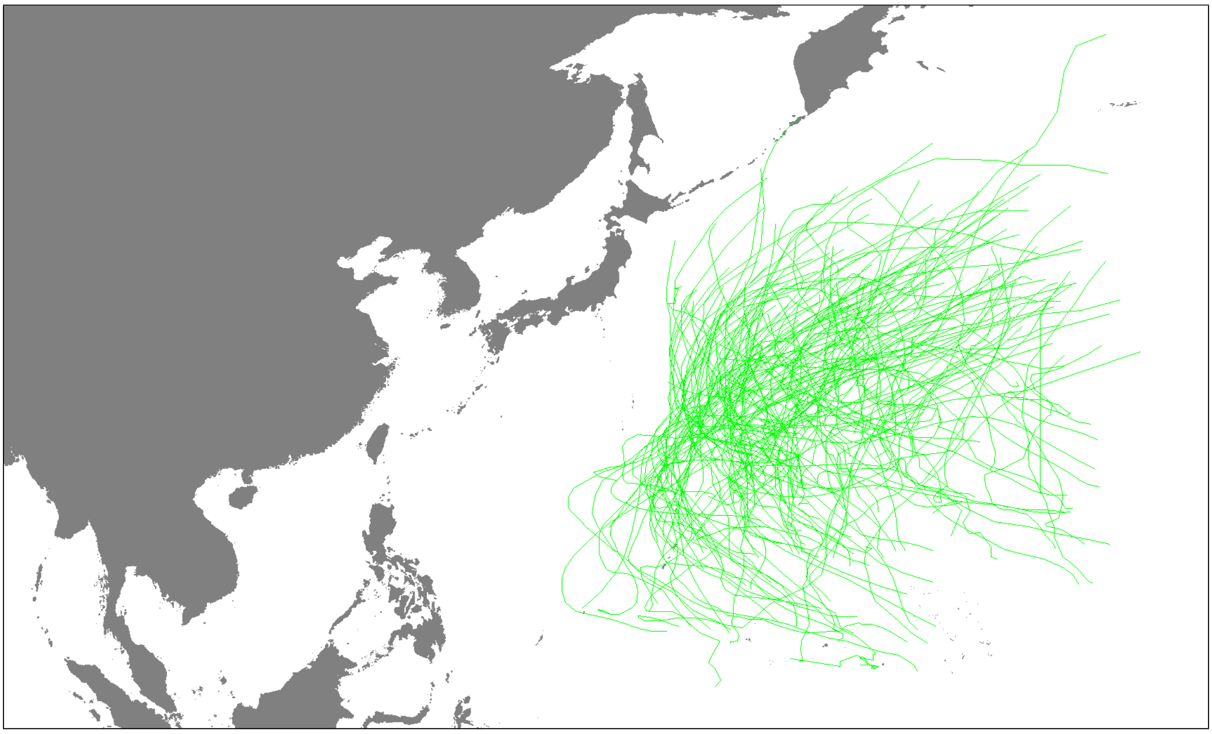

Figure 7: Tracks of all storms falling into class 3

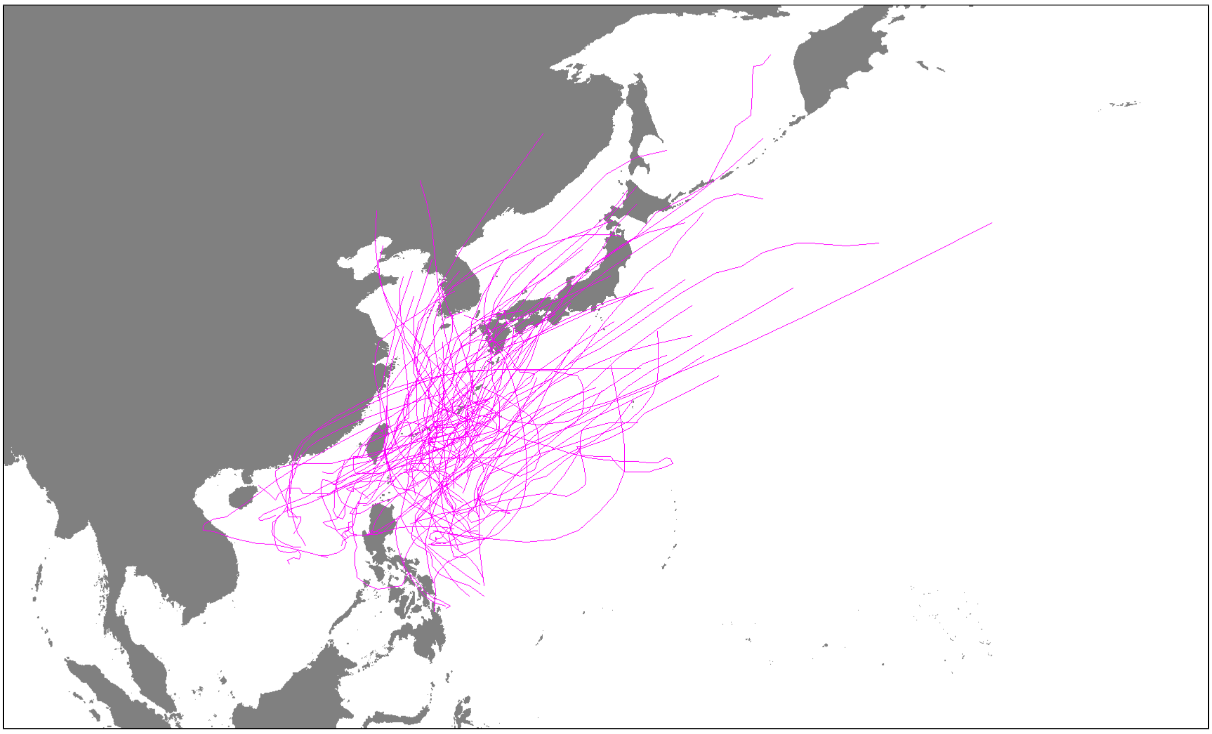

Figure 8: Tracks of all storms falling into class 4

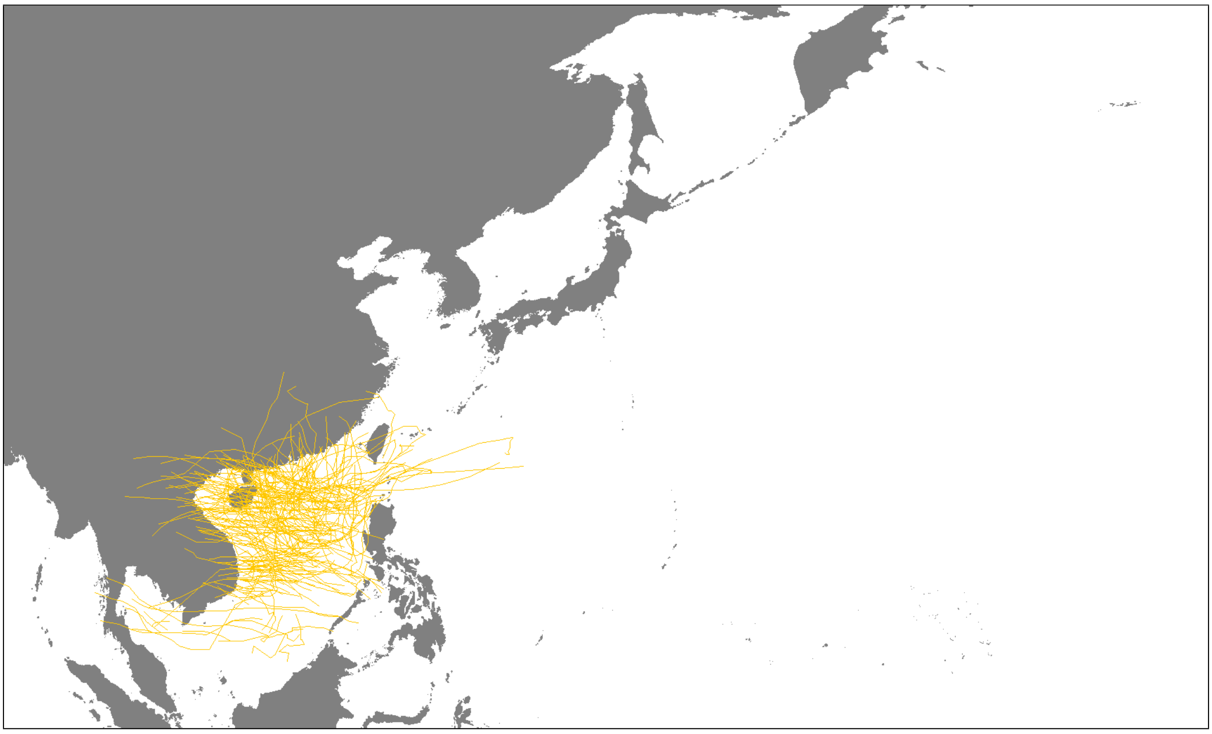

Figure 9: Tracks of all storms falling into class 5

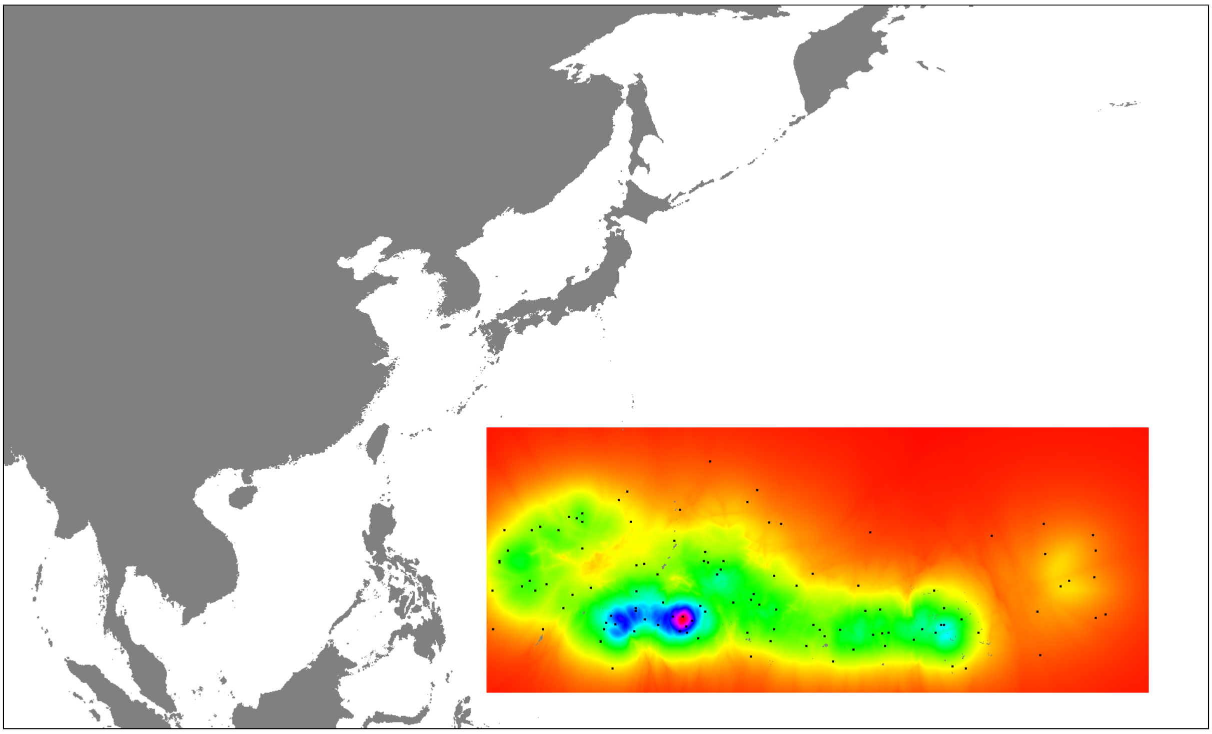

Figure 10: Points of genesis of all storms falling into class 0

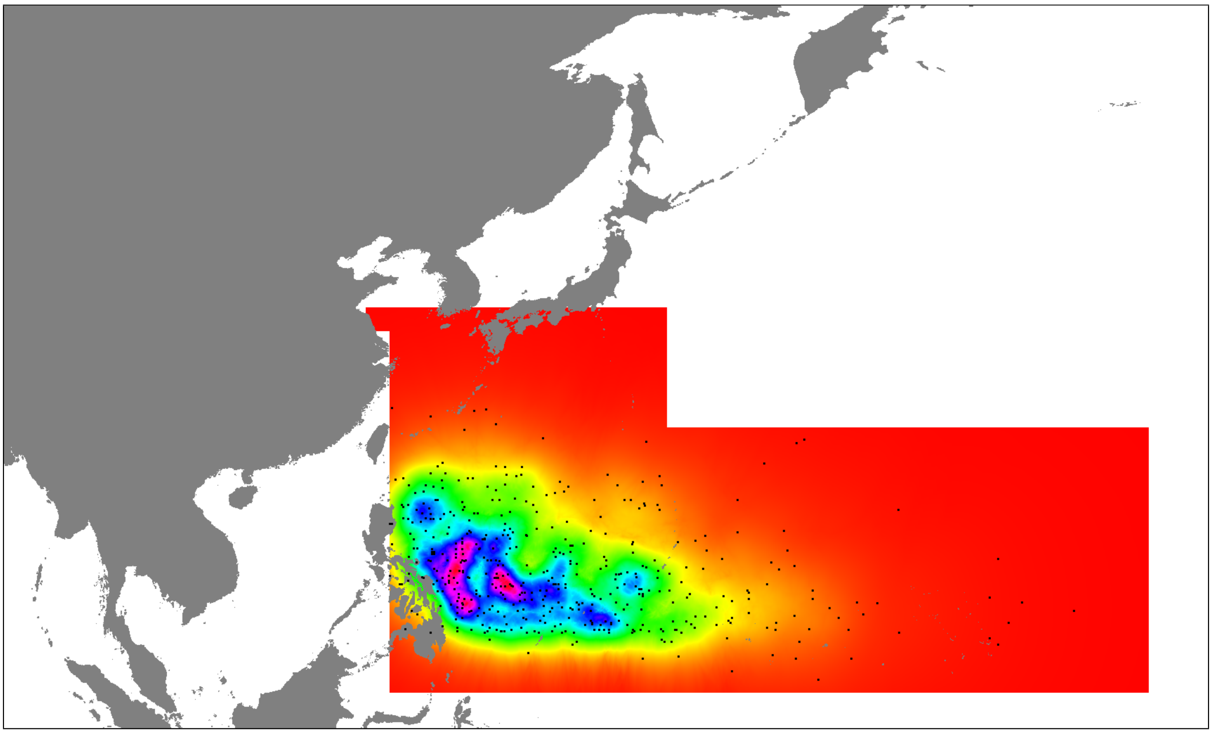

Figure 11: Points of genesis of all storms falling into class 1

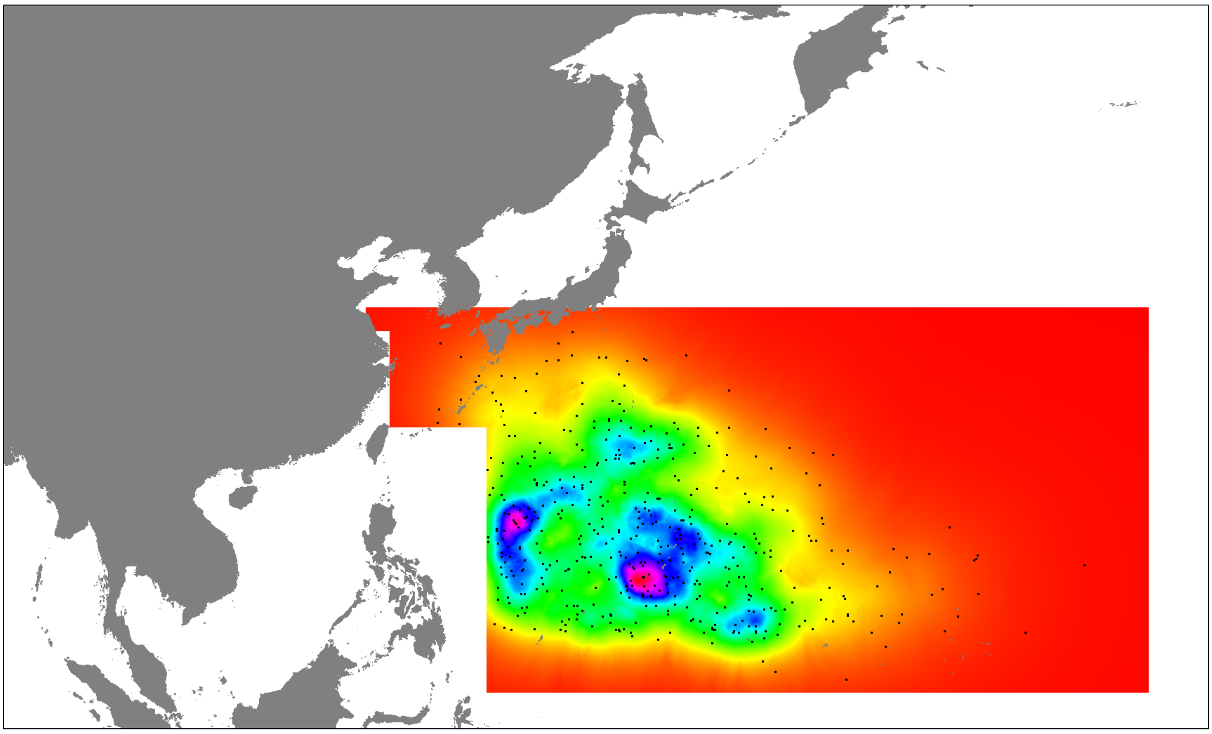

Figure 12: Points of genesis of all storms falling into class 2

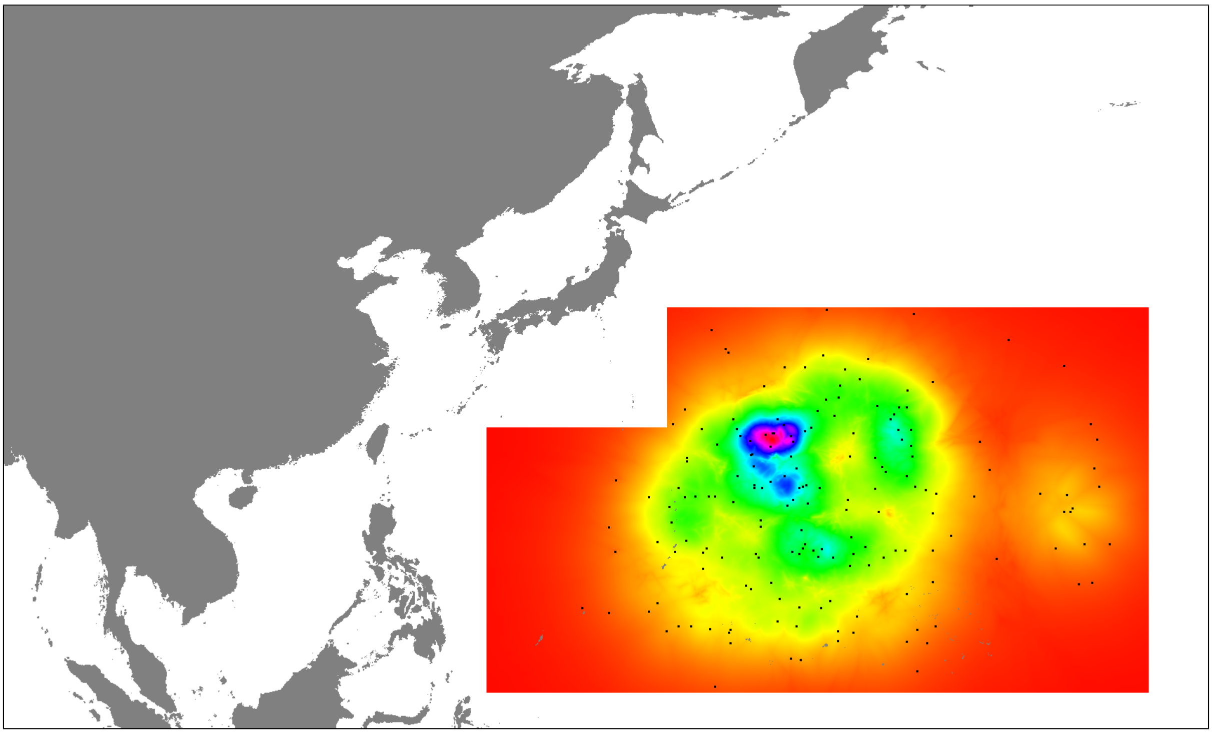

Figure 13: Points of genesis of all storms falling into class 3

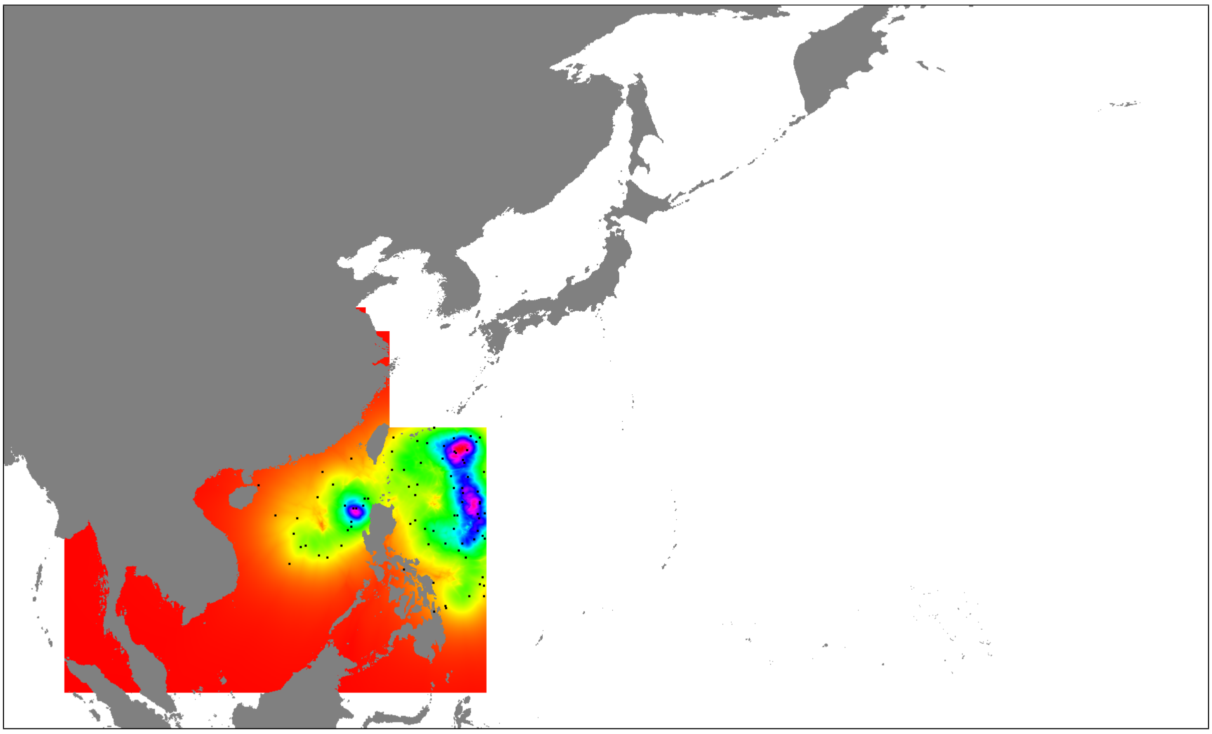

Figure 14: Points of genesis of all storms falling into class 4

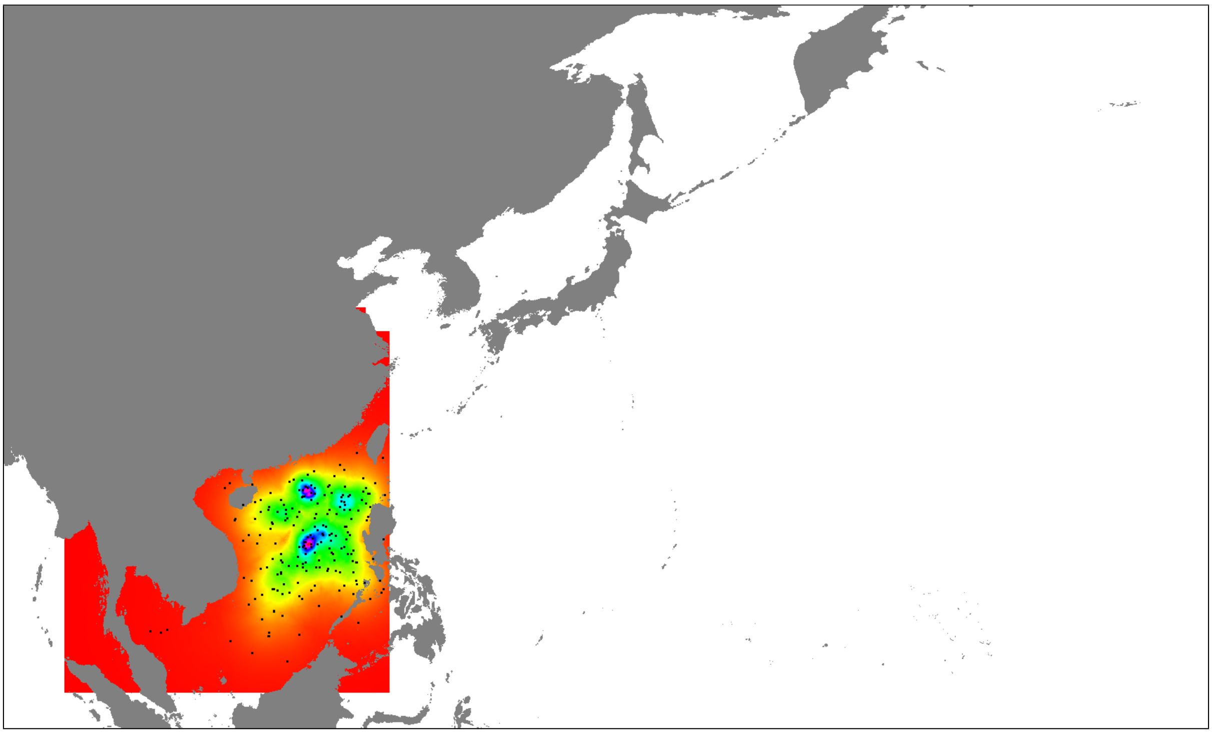

Figure 15: Points of genesis of all storms falling into class 5

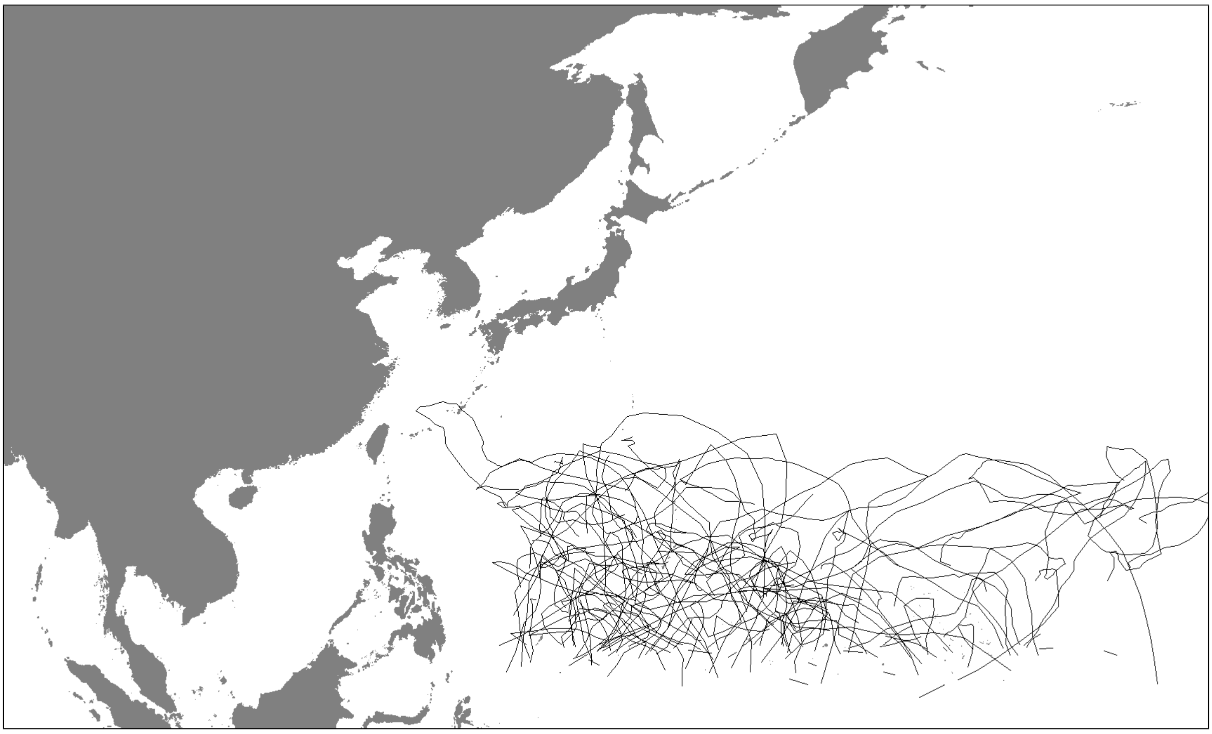

Figure 16: Synthetic tracks of storms falling into class 0

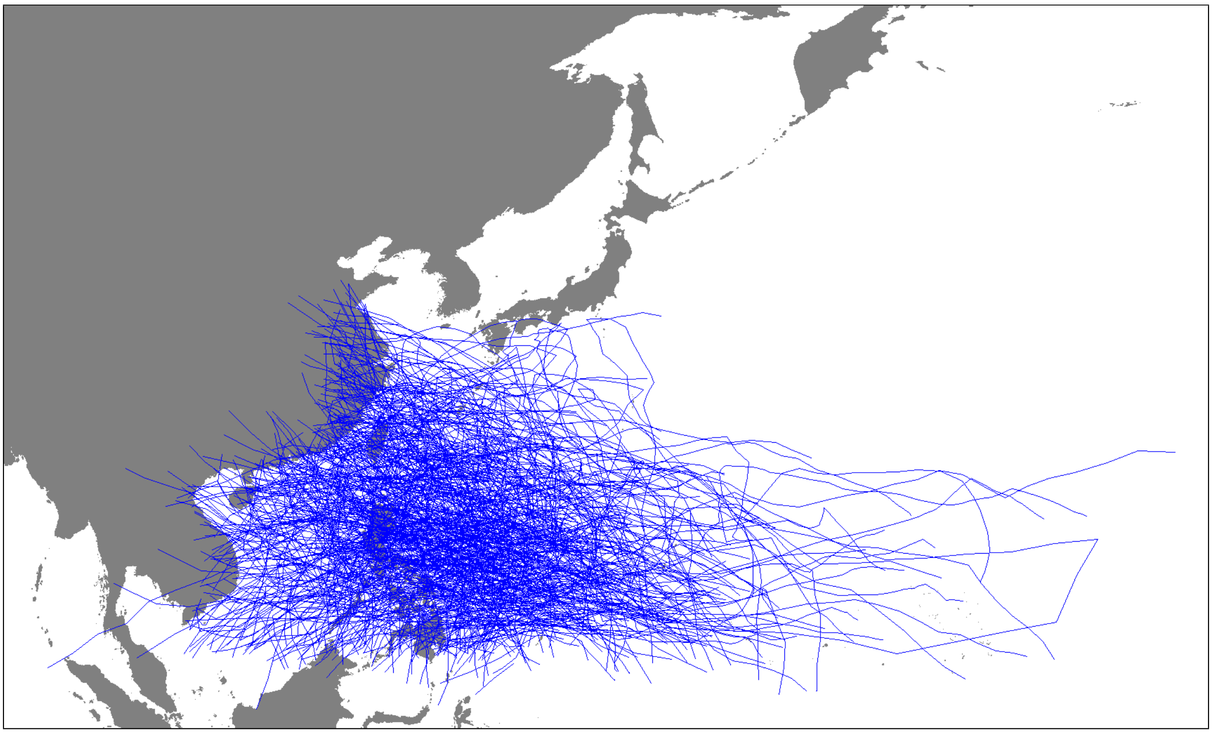

Figure 17: Synthetic tracks of storms falling into class 1

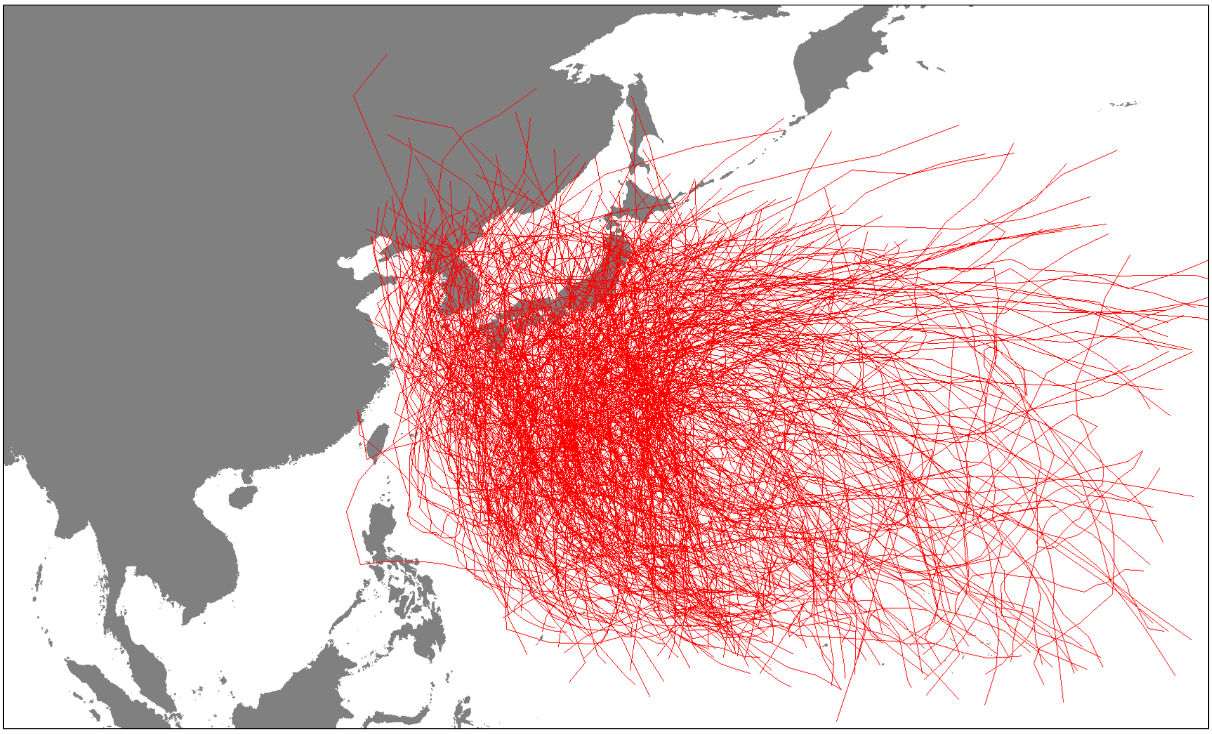

Figure 18: Synthetic tracks of storms falling into class 2

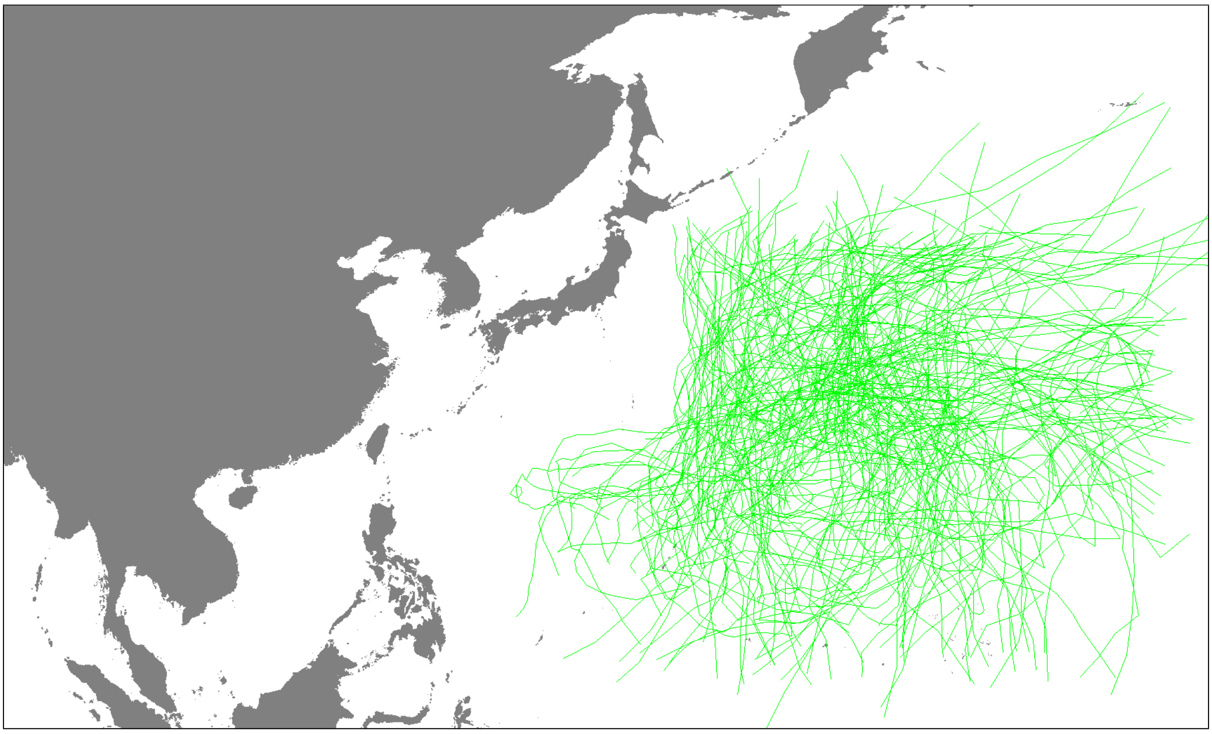

Figure 19: Synthetic tracks of storms falling into class 3

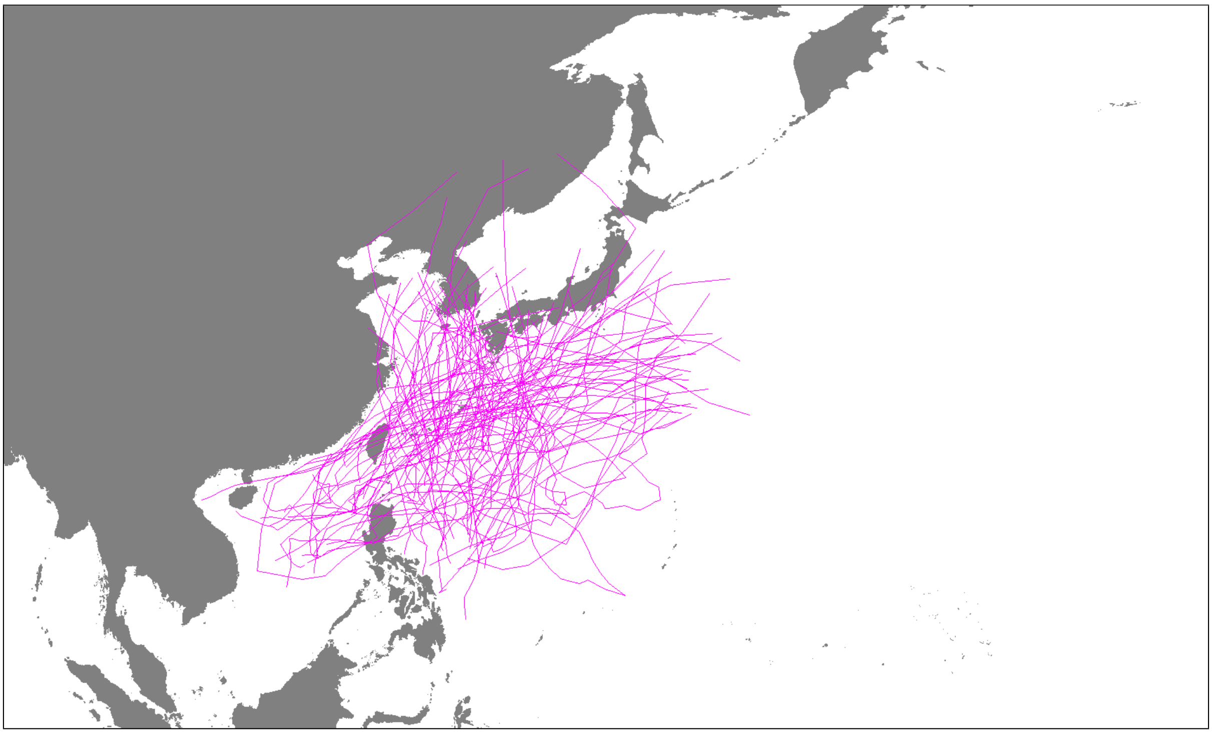

Figure 20: Synthetic tracks of storms falling into class 4

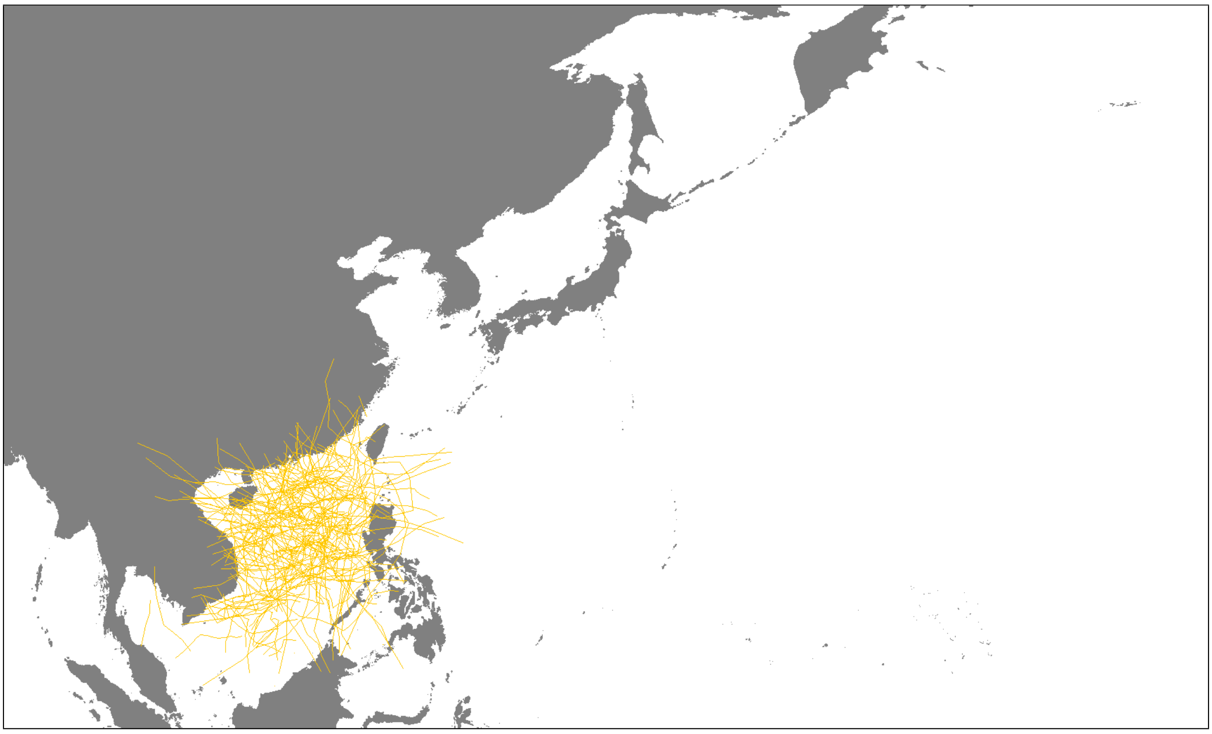

Figure 21: Synthetic tracks of storms falling into class 5

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