Supplementary Materials

S.1. Study area

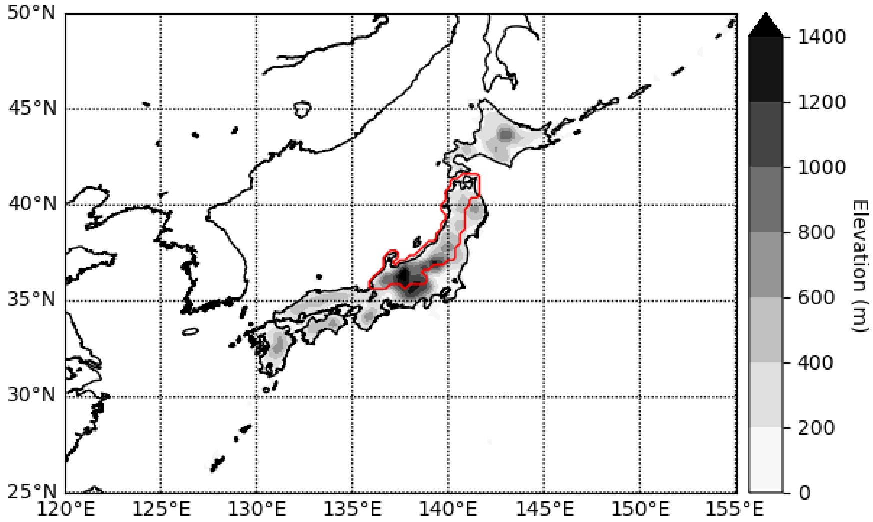

Figure S1. Topography of the study region. Shading indicates surface elevation (m) across Japan. The red outline delineates northwestern Japan, which serves as the target study area for the precipitation and environmental analysis in this research.

S.2. Tracking algorithm for quasi-stationary linear rainbands (QSLRB), referred to as "Senjo-Kousuitai" in Japanese (Hirockawa et al. 2020)

We identified quasi-stationary linear rainbands (QSLRB) using the Radar/Raingauge-Analyzed Precipitation observation data (RA data), over northwestern Japan. Being consistent with the previous studies (Hirockawa et al., 2020) and to reduce small-scale noise, the original 1-km precipitation data were spatially aggregated to a 5-km resolution prior to analysis. This resolution is sufficient to resolve most meso-β scale convective systems, whose typical horizontal scales range from approximately 20 to 200 km, while also ensuring computational efficiency and consistency with previous similar studies. Using the upscaled dataset, accumulated three-hour precipitation (RAP3), produced at one-hour intervals, was calculated and used as the basis for detecting heavy rainfall areas (HRAs), as three-hour accumulation effectively captures persistent mesoscale rainfall structures.

The extraction of Heavy Rainfall Areas (HRAs) was based on the procedure originally proposed by Hirockawa et al. (2020). First, grid cells exceeding the precipitation threshold (**60** mm) for HRA identification were detected at each analysis time. Spatially contiguous rainfall regions were then identified using four-connected component labeling, in which grid cells sharing a common side were considered connected. Second, rainfall regions detected at consecutive time steps were aggregated into a single HRA when the spatial overlap between them exceeded 40%. This aggregation allows quasi-stationary rainfall systems that persist over time with minor spatial displacement to be treated as a single event. Third, geometric properties of rainfall regions were evaluated prior to aggregation to preserve the structural characteristics of individual rainfall elements.

Aggregated HRAs were classified as QSLRBs when they satisfied linearity and stationary criteria. Specifically, an HRA was identified as a linear HRA when at least one of its constituent rainfall regions exhibited an aspect ratio of 2.5 or greater, where the aspect ratio is defined as the ratio of the major axis length to the minor axis length of the rainfall area. The HRA was identified as stationary HRA when the persist period was five hours or longer and the aggregated total area fell between 625 and 12,500 km^2. These criteria enable objective identification of elongated, band-shaped rainfall systems that remain nearly stationary over several hours, which correspond to QSLRBs.

References:

Hirockawa, Y., Kato, T., Tsuguti, H., & Seino, N. (2020). Identification and classification of heavy rainfall areas and their characteristic features in Japan. Journal of the Meteorological Society of Japan. Ser. II, 98(4), 835-857.