Decadal variation of heavy rainfall frequency in Kyushu, Japan and associated synoptic weather patterns

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(Dated: 26 August 2011)

I. INTRODUCTION

Climate change has affected human life, food production, and many ecosystems, etc in the world, and may give serious damages to them accompanying future anticipated global warming. This issue is one of the most important concerns in Japan. Therefore, it is important to diagnose climate change and associated weather situation.

However, in spite of serious issue that significant signals obtained from such situations cannot be easily recognized because of too many and complicated meteorological information, there are few systematic reports that what kind of synoptic patterns have affected temporal variability of heavy rainfall for decade in Japan. Many studies focused on a case study relating to individual storm, the statistical analysis of rainfall only (Fujibe and Kobayashi, 2007).

Therefore, the aim of this study is to investigate decadal variation of heavy rainfall frequency in Kyushu area (target area) located in the west of Japan and, subsequently, to visually demonstrate significant relationships between decadal variation of heavy rainfall and synoptic field patterns recognized by using the Self-Organizing Map (SOM) developed by Kohonen (1995). The pattern recognition technique is a kind of unsupervised artificial neural networks (ANNs) technique in the field of information science. The SOM provides useful information for helping the interpretation of non-linear complicated features by classifying a set of high-dimensional data into the units (patterns) arranged regularly on a two-dimensional space that can be *easily* and *visually* recognized by '*human eye*'. The SOM has been widely applied to many fields that requires pattern recognition. For the analysis of synoptic meteorology, Nishiyama et al. (2007), Crimins (2006), Hope et al. (2006), Cassano (2006) , etc. were applied.

II. METHODOROGY

The main task of this study is to construct synoptic field patterns corresponding to decadal variation (30 years : 1979-2008) of heavy rainfall by applying the SOM. The methodology available for the analysis of synoptic meteorology is summarized by Hewitson and Crane (2002). According to their suggestion, the first step of the methodology is to conduct the pattern recognition of high-dimensional synoptic situations (e.g. spatial distribution of geo-potential height, wind, temperature, moisture). The next step is to construct visualized relationships on the two-dimensional SOM space between formed patterns and independent local variables (e.g. extreme high and low temperature, strong wind, heavy rainfall frequency) observed in a specific target area. The final step is to investigate the frequency of synoptic patterns, the frequency of independent local variable per each synoptic pattern, temporal variability in the frequency per each synoptic pattern, and so on.

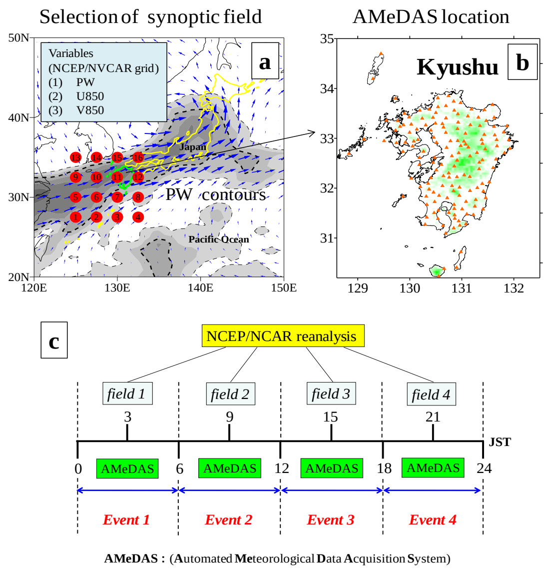

FIG.1:
(a) NCEP/NCAR Grid space (16 grids) specified for constructing synoptic field patterns using the variables (PW, U850, V850).
(b) Target area specified for obtaining AMeDAS rainfall data.
(c) Extraction of AMeDAS rainfall data within 6 hours interval centering at 0, 6, 12, 18 UTC to each synoptic field.

In this study, synoptic fields related to heavy rainfall in Kyushu, Japan, are represented by the spatial distribution of wind components at the 850 hPa level and Precipitable Water (PW) using NCAR-NCEP reanalysis data (4 times per a day). A data sample characterizing the pattern consists of 48 dimensions (16 grid points, 3 variables), as shown in FIG.1(a). On the other hand, for detecting heavy rainfall features, this study uses rainfall data recorded in Kyushu located in the west of Japan, as shown in FIG.1(b). The rainfall observation system is called as the Automated Meteorological Data Acquisition System (AMeDAS), which has been maintained by the Japan Meteorological Agency (JMA). The observational items of AMeDAS consist of rainfall, temperature, wind, and sun duration. Rainfall only

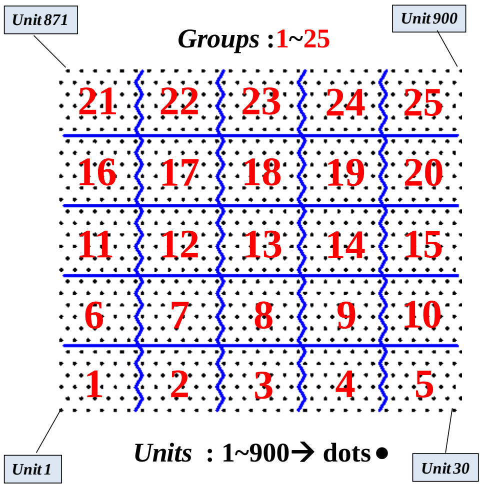

FIG.2: The structure of the SOM defined in this study. The SOM consists of 900 units (patterns). In addition, all the units are divided into 25 groups.

is observed as indispensable item at all the locations. Its resolution is very fine and equivalent to about 17 km, covering all areas in Japan. These data are recorded per 10 minutes and 1 hour. In this study, to investigate relationships between synoptic field and heavy rainfall, assuming that a synoptic field at T (=0, 6, 12, 18UTC) is dominant during 6 hours between T-3 and T+3, heavy rainfall frequency is calculated by summing up AMeDAS hourly rainfalls (>=30mm/h) recorded during 6 hours in the target area (Kyushu), as shown in FIG.1(c).

The training uses input samples (*total_num*=14648) obtained from the outputs (NCAR-NCEP reanalysis data) of 4 times (T=0, 6, 12, 18UT) per a day in the warm season (June-September) for 30 years. Here, it should be noted that rainfall data such as heavy rainfall frequency are not used for the SOM training. In other words, rainfall data is treated as a variable independent of synoptic field patterns classified by the SOM. As a result of SOM training, the input samples are classified into the 30 (x-axis) ×30 (y-axis) hexagonal units (FIG.2), in other words, 900 synoptic field patterns. Each unit includes a reference vector and the most similar input samples to it. The reference vector obtained by the SOM training shows a representative feature among the input samples classified in the unit. In addition, all the patterns formed by the SOM training are arbitrarily divided into 25 groups (36 units per a group), as shown in FIG.2.

As a result of the SOM training, similar input samples are classified into an identical unit on the map. In other words, each unit on the map can be interpreted as the assembly of similar input samples with a reference vector, which shows representative features among these input samples. Moreover, the neighboring units in the map are similar to each other while distant units are dissimilar on the map. Therefore, the SOM provides visually recognizable information for interpreting non-linear complicated features.

III. RESULTS AND CONCLUSIONS

FIG.3 shows the frequency of heavy rainfall caused by the synoptic situation of each unit (pattern) on the SOM map. The frequency is defined as the total number of heavy rainfall >= 50 mm/h observed in all the events classified in each unit. FIG.4 shows a histogram (a) and spatial distribution (b) of heavy rainfall frequency >=30 mm/h in each group together with synoptic pattern (c) of each group.

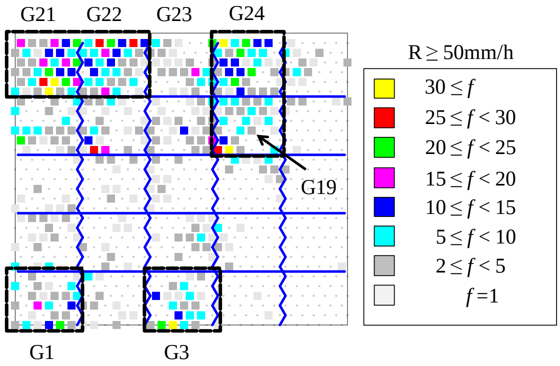

FIG.3: Heavy rainfall frequency of each unit (pattern). The number plotted on each unit shows frequency ≥ 50mm/h. The groups enclosed by black frames are *'heavy rainfall groups*'.

From these results, it is found that dominant heavy rainfall activity is related to the groups (G1 and 3) situated in the lower left of the SOM map, and the groups (G19, 21, 22, 24) situated in the upper of the map. Therefore, these six groups are recognized as '*heavy rainfall groups*'. Especially, G21, 22 and 24 among the heavy rainfall groups shows high frequency of heavy rainfall occurrence.

FIG.4(c) shows features of synoptic field patterns of the heavy rainfall groups. The patterns are obtained by averaging all the reference vectors included in each group. The common feature of these six heavy rainfall groups shows the existence of high PW (≥ 40 mm) area.

Focusing on G21, 22 and 24 showing the top 3 groups of heavy rainfall frequency, the common features are characterized by high PW distribution and strong wind, the Low Level Jet (LLJ) at 850hPa. G21 shows typical synoptic field pattern in a rainy season in Japan. G22 is similar to G21 in that Kyushu is affected by the dominant area of high PW, accompanying strong LLJ. However, G22 is characterized by eastward LLJ and a steep gradient of PW in the northern area of Kyushu. The steep PW gradient is related to frontal activity. G21 and 24 have common feature of high PW area in Kyushu with dominant northeastward LLJ. However, wind patterns of synoptic field in G24 are characterized by cyclonic motion in the northwest edge of the target area. The feature implies the passage of meso-scale low-pressure system formed frequently on a stationary front, or typhoons.

Moreover, The feature of G19 is basically the same as those of G24, which is characterized by the combination of high PW and cyclonic motion. However, the axis of high PW distributed from the southwest to the northeast in G19 is located in the north of the axis of high PW of in G24. On the other hand, heavy rainfall of G1 and 3 are related to cyclonic motion of typhoons. The feature of G1 shows that a typhoon moves northward around the East China Sea situated in the west of Kyushu. The feature of G3 shows the approach of a typhoon towards Kyushu from the south.

Decadal variation (FIG.5(a)) of heavy rainfall frequency is characterized by high frequency (especially, 1999, 2006, 2007) in the recent period after 1999. FIG.5(b) shows what kinds of groups contribute to the formation of the decadal trend. G19, G22 and G24 have remarkable

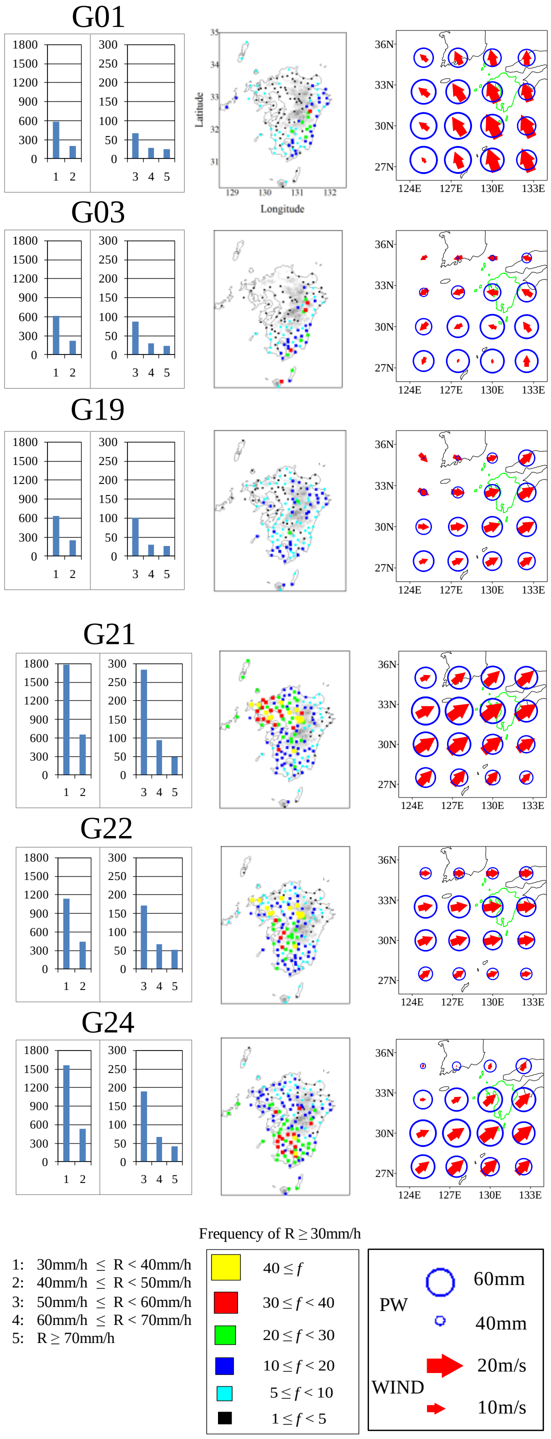

FIG.4: The left and central figures show the histogram and spatial distribution of heavy rainfall frequency ≥ 30mm/h per a group, respectively. The right figure shows average features of synoptic patterns included in each group.

peaks in 2007, 2006 and 1999, respectively. G19 and G22 have higher frequency of heavy rainfall in the recent period. G19 is highly related to typhoon passing through Kyushu. The peak of G19 in 2007 shows typhoon attack (Typhoon No.5) to southern Kyushu. The peak of G22 in 2006 shows the enhancement and stagnation of frontal activity in Kyushu.

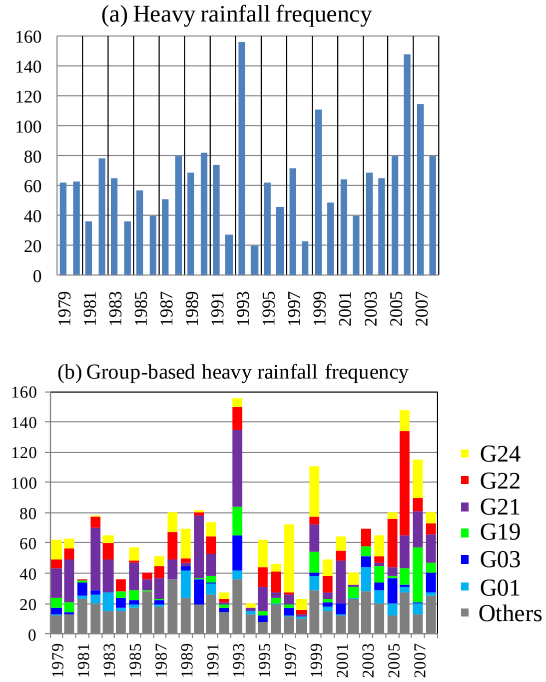

FIG.5: (a) Temporal variation in heavy rainfall frequency (>=50mm/h) in Kyushu, Japan. (b) Contribution of six HR groups and the other groups to heavy rainfall frequency shown by FIG.5 (a).

The peak of G24 in 1999 shows small scale cyclonic activity. On the other hand, G21, which is typical heavy rainfall group characterized by dominant LLJ with high PW area, does not contribute to the formation of recent period after 1999. The group affected heavy rainfall in 1993.

From these results, it could be clearly understood that what kinds of groups contributed to the formation of decadal variation. It was found that the SOM is available for pattern-based analysis of heavy rainfall trend.

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