RF-070 **Assessment of Climate Change Using Self-Organizing Map**
(Abstract of the Final Report)

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[Abstract]

We propose the use of a high-speed spherical self-organizing map (HSS-SOM) to visualize climate variability as a complementary alternative to empirical orthogonal function (EOF) analysis. EOF analysis, which is often used to extract leading climate variability patterns, with its production of linear mapping with only a low contribution rate may preclude producing any meaningful results. Due to computational limitations, however, conventional self-organizing maps are difficult to apply to huge climate dataset. The development of HSS-SOMs with dynamically growing neurons has helped reduce computational time. After demonstrating validity of our HSS-SOM using observational climate data and HSS-SOM effectiveness as a complementary alternative to the EOF, we extract dominant atmospheric circulation patterns from huge amounts of climate data in the general circulation model, in which both present and future climate are simulated. These patterns correspond to those obtained in previous studies, indicating the HSS-SOM's usefulness in climate research.

In addition, we propose a high speed non-empirical method to detect centers of tropical cyclones, which is useful to identify tropical cyclones in huge climatology data. In this method, centers of tropical cyclones are detected automatically by iteration of streamline with enhanced curvature in down-stream direction from some initial positions. Since this method is free from empirical conditions used in the conventional method, the accuracy is independent of these conditions. Moreover, because the proposed method does not need to check these at all grid points, computational cost is significantly reduced. The method is extended for risk-assessment of detected tropical cyclones. We compare the accuracy and effectiveness of the method with those of the conventional one for tropical cyclone identification task in the observational data. In addition, this method was useful for huge climatology data, since computational cost does not depend on the number of grid points.

1. Introduction

In the fields of climatology, the EOF analysis is often used to extract leading patterns of climate variability. However, since EOF analysis obtains a linear mapping only, sometimes we cannot obtain any meaningful result (Ito, 2002). On the other hand, because of computational limitation, it is also difficult to apply conventional self-organizing map (Kohonen, 2001) to huge climate data. Recently, one of the authors has developed HSS-SOM with dynamically growing neurons to reduce computational time (Tachibana et al., 2007). In the present study, we use this method to visualize climate variability. It is also of importance to assess climate models, since there are large uncertainties of the results of each climate model (IPCC, 2007). There are strong needs to evaluate climate models from the reproducibility of dominant modes in climate variability.

It is also suggested in several studies that global warming gives not only increase of global average temperature, but change of frequencies and intensities of extreme events, such as tropical cyclones. To simulate tropical cyclones in climate models, we have to use climate model with high resolution. However, it is very difficult to identify tropical cyclones in huge output data. In the conventional method for detecting tropical cyclones (Bengtsson et al., 1995), we have to check several empirical conditions at all grid points. It takes enormous computational cost. There is a room of exploring an alternative method to identify tropical cyclones effectively.

2. Research Objective

In the present study, we propose a high speed spherical self-organizing map (HSS-SOM) to visualize climate variability as a complementary and alternative method to empirical orthogonal function (EOF) analysis. Using this method, we extract dominant modes from the observational and climate model data. We quantify uncertainties of climate models evaluating the reproducibility of the dominant modes. We also give a strategy for developing future climate models with few uncertainties.

In addition, we propose a new method to detect center of tropical cyclones with high speed. We compare the effectiveness of the proposed method with those of the conventional one for tropical cyclone identification task in the observational data. We also apply this method to huge data provided from climate model with high resolution.

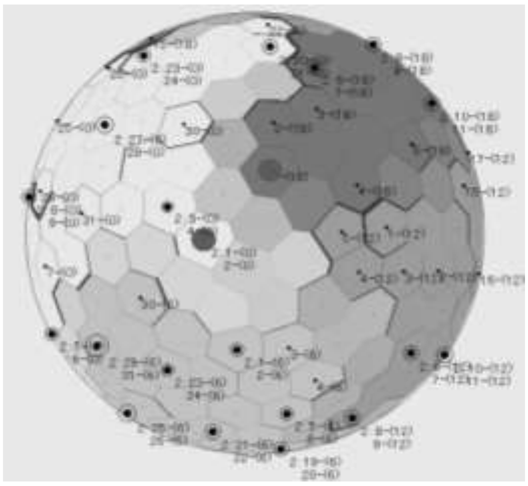

Fig. 1: Classification of observational daily temperature data. Hexagon shows each neuron and observations are plotted (day-time). Grey scale shows observational time.

3. Result

First, we apply HSS-SOM to the NCEP observational data. For monthly mean 500 hPa geopotential height data, HSS-SOM succeeded to classify huge data which are not classified clearly by the EOF analysis. For daily surface temperature data, HSS-SOM classifies data not only with regard to the dominant variability, but also the similarity of each pair (Fig. 1.). These results show HSS-SOM is a complementary alternative to the EOF analysis.

Next, we apply HSS-SOM to huge data of monthly mean 500 hPa geopotential height from climate model (NIES-AOGCM; K-1 Model Developers, 2001) with 3600 years run under pre-industrial condition. Our new HSS-SOM made it possible to classify these huge data with sufficiently large number of neurons (1884 neurons). We determined the center of cluster region on the SOM by use of U-matrix (average length of adjacent neurons). Obtained dominant atmospheric circulation pattern had PNA and NAO like structure (Fig. 2), which is well known patterns in natural variability.

In addition, climate data with 300 years run under global warming with a scenario SRES-A1B are analyzed. We detected the center of cluster region using U-matrix and obtained dominant atmospheric circulation pattern (Fig. 3.). Enhancement of AO pattern is clearly seen. This result is consistent with the previous studies which usually used other kind of methods.

Finally, we analyze datasets of several climate models which are used for IPCC-AR4. We extracted dominant modes from datasets under the past and future climate under global warming (SRES-A1B). Then,

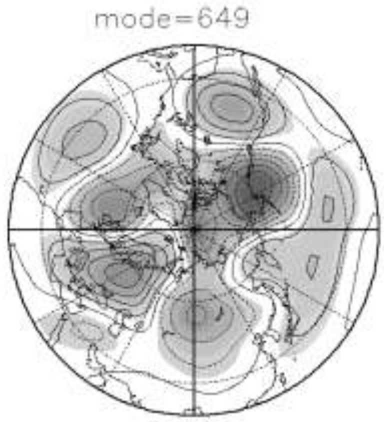

Fig. 2: Structure of dominant mode extracted from climatology data under pre-industrial condition. Northern hemisphere is shown.

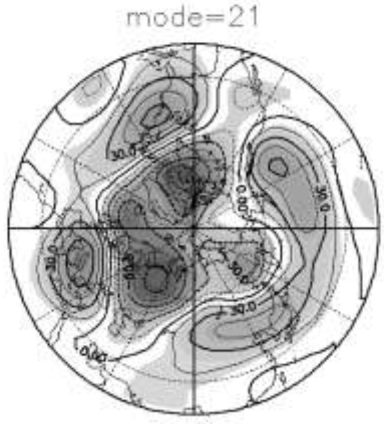

Fig. 3: Structure of dominant mode extracted from climatology data under global warming (SRES-A1B). Northern hemisphere is shown

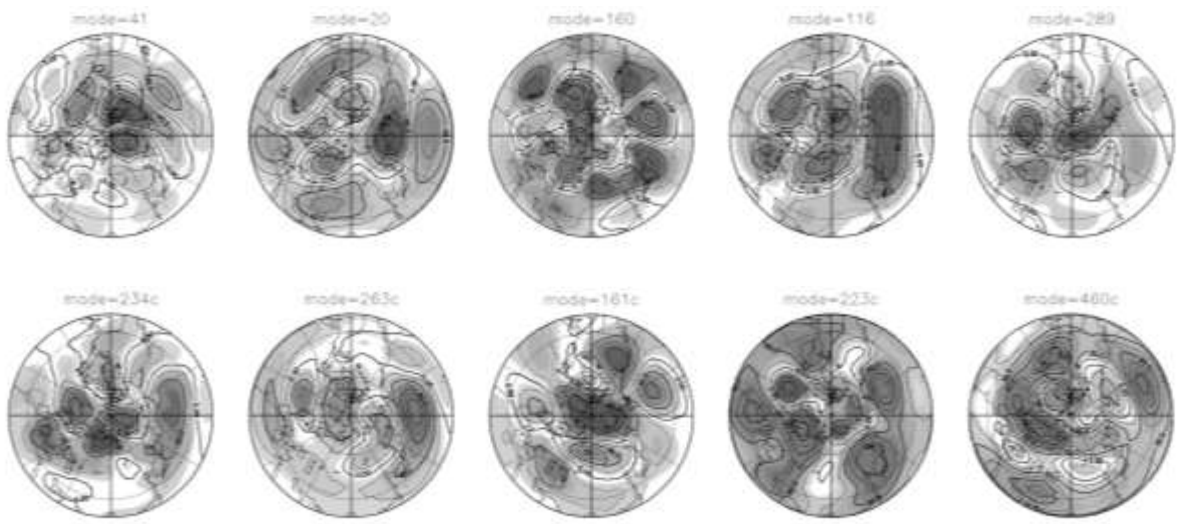

Fig. 4: Structure of dominant mode extracted from climatology datasets in the past (upper panels) and future climate in several climate models. Northern hemisphere is shown. Climate models are ECHAM, MIROC, NCAR, UKMO, GFDL, respectively.

dominant atmospheric circulation patterns of climate models are different from each other (Fig. 4.), which indicated large uncertainties of climate models.

We also proposed a new method to detect the center of tropical cyclones with high speed. In the method, centers of vortices are detected automatically by iteration of streamline in down-stream direction from some initial positions. We also bend the path of streamline successively to converge on the center of vortex rapidly. This method is independent of empirical conditions. Moreover, since we do not need to check these at all grid points, computational cost is significantly reduced.

To evaluate the effectiveness of the proposed method, we made several comparison experiments using the NCEP observational data. Although the data are too coarse to define tropical cyclones, the proposed method automatically detected almost all tropical cyclones some of which were not identified by the conventional method. While our method was robust for initial positions, we could obtain better results using lower level (1000hPa).

We also extend the method to evaluate intensities and influence ranges of detected vortex. Figure 5 shows a snapshot of the vortex risk-assessing method using the observational data. Besides, strong cyclones which brought severe disaster were also detected by the proposed method. Risk-assessment of detected vortices works successfully to rank dangerous vortex.

In addition, we apply this method to huge data provided by the climate models with high resolution (MRI-AGCM, Oouchi et al., 2006). Figure 6 shows a snapshot. Since our method does not need to be checked at all grid points, computational cost does not increase for the climate model with high resolution. It would be important to study statistics of tropical cyclones and cyclones under future warmer climate predicted by next generation climate models with finer grid by use of the proposed method.

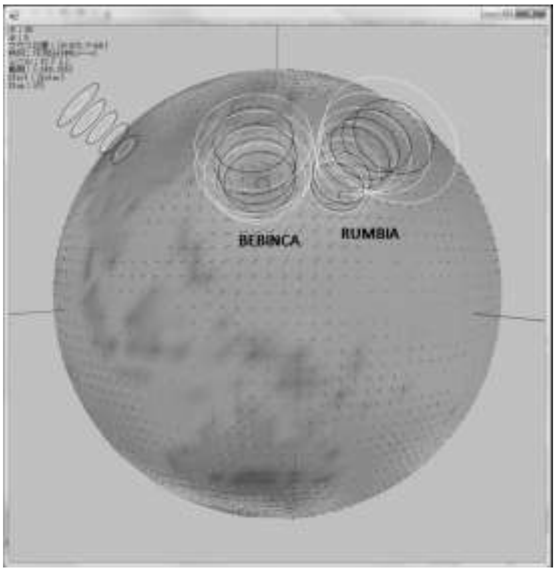

Fig. 5: Snapshot of risk-assessment of detected vortices. White circles denote influence ranges, and the radii of black circles indicate maximum wind velocities.

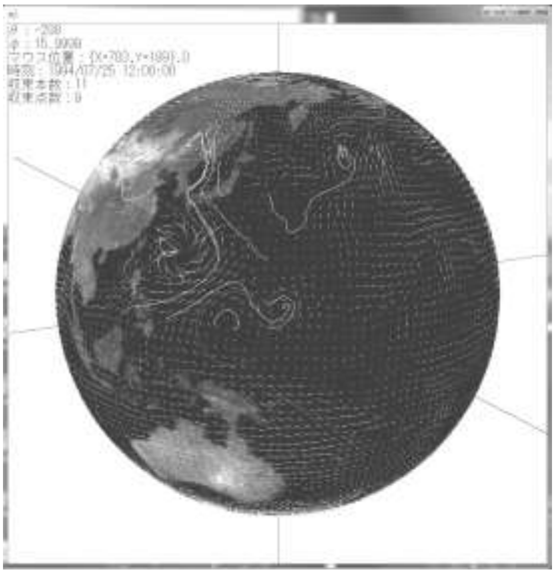

Fig. 6: Snapshot of detection of vortices from data with high resolution climate model. White lines denote route of detection of enhanced streamline.

4. Summary

In this research, we proposed two high speed methods for the analysis of huge climate data. One is a high-speed spherical self-organizing map (HSS-SOM) with dynamically growing neurons and the other is high speed non-empirical method to detect centers of tropical cyclones. In the analysis of the observational data, HSS-SOM is a complementary alternative to the EOF. In the analysis of the climate model data, HSS-SOM extracts dominant atmospheric circulation patterns from huge data under pre-industrial and global warming conditions. We also evaluated several climate models from the reproducibility of dominant modes. Besides, high speed non-empirical method detected the centers of tropical cyclones automatically by iteration of streamline in down-stream direction. This method is free from empirical conditions, and has high accuracy with small computational cost. We further extended the method for automatic risk-assessment of detected tropical cyclones. The proposed method was also useful for huge data provided by climate model with high resolution.

For future work, we will study the change of the frequencies and patterns of atmospheric dominant circulation regimes with an effect of anthropogenic forcing. In addition, we will quantify uncertainties of climate models using results of the dominant modes of several climate models. For the method to detect tropical cyclones, we will apply the method to datasets of several climate models. We evaluate climate models from the reproducibility of tropical cyclones. It would be interesting to predict course and development of the tropical cyclone by using a revealed 3-dimensional structure. This would be also important for risk management for future climate.

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Major Publications

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3) N. Sugimoto, T. M. Pham, K. Tachibana, T. Yoshikawa, and T. Furuhashi: High speed non-empirical tropical cyclone identification method in huge climatology data, *"Hurricanes and Climate Change", J. B. Elsner and T. H. Jagger (Eds.), Proceedings of 1st International Summit on Hurricanes and Climate Change, Springer-Verlag*: 251-263, (2008b).

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5) N. Sugimoto, T. M. Pham, K. Tachibana, T. Yoshikawa, and Takeshi Furuhashi: High speed method of detecting vortex without empirical conditions - Application to risk-assessment of tropical cyclone -, *Theoretical and Applied Mechanics Japan*, Vol.57: 297-307, (2009a).

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