R&D item

3. Dimension Reduction

Progress until FY2023

1. Outline of the project

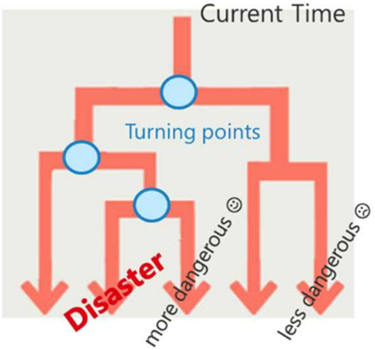

Fig. 1

The goal of this research project is to prevent heavy rainfall damage on land by generating torrential rain over the sea. To achieve this, we need to redirect weather scenarios from causing heavy rain on land to reducing atmospheric water vapor over the sea, preventing damage. Comprehensive meteorological data, such as temperature, humidity, and wind direction, result in ultra-high-dimensional data, making prediction and control challenging. However, if weather conditions lead to several typical patterns, with one being undesirable, we can effectively describe these abstracted meteorological conditions to improve control efficiency. In Research Item 3, we aim to extract essential low-dimensional degrees of freedom, that we call as latent space representation, crucial for these branching points. We investigate three approaches to acquire latent space representations beneficial for weather control: reservoir computing, Koopman mode decomposition, and landscape analysis.

2. Outcome so far

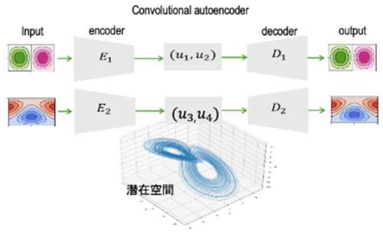

Fig. 2

For reservoir computing, we studied data dimensionality reduction using deep learning and nonlinear time series prediction methods. We explored dimensionality reduction for meteorological fields in predicting linear rainbands using deep learning, examining Autoencoders and Convolutional Networks, and listing key references for technology development. Based on this, we obtained preliminary results on predicting nonlinear convective phenomena in FY 2024 (Fig. 2).

For Koopman mode decomposition, we studied dimensionality reduction techniques using Koopman mode and dynamic mode decomposition. We confirmed the Prony method's effectiveness for periodic data and the Original and Exact methods for quasi-periodic data, listing effective techniques for meteorological applications (Fig. 3).

Original method • Schmid (2009) • SVD and POD-based • Initially applied to fluid data	**Arnoldi-type method** • Rowley et al. (2009) • Companion matrix-based • Initially applied to fluid data
Exact method • Tu et al. (2013) • SVD-based • Widely used in literature	**Prony method** • Susuki & Mezic (2016) • Hankel matrix-based • Delay embedding utilized
Kernel-based method • Williams et al. (2014); Kawahara (2016) • Gaussian kernel normally used • Applied to SST data in Navarra et al (2021)	**Sparsity-based method** • Jovanovic et al. (2014) • L1 norm-based penalization • Initially applied to fluid data

Fig. 3

For landscape analysis, we detected a meteorological landscape reflecting the essential flow of meteorological fields by decomposing it into potential and rotational flows using graph Hodge decomposition. Applying the landscape analysis to typhoon track prediction data, we successfully extracted essential trajectories and its separatrix (Fig. 4).

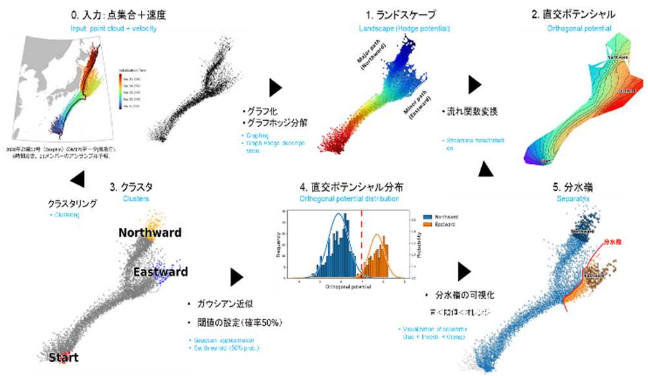

Fig. 4

3. Future plans

Next year, we plan to use the knowledge from this year's investigation to formulate methods for acquiring latent space representations of meteorological phenomena more concretely. We will also apply these methods to more complex data, including real meteorological data, to verify their effectiveness.

Japan Science and Technology Agency