Koopman operator analysis: application in short-term precipitation forecasts

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Improving the accuracy of precipitation prediction is one of the major issues in meteorology; it is also important from the viewpoint of mitigating weather disasters. Using a numerical forecasting method decreases the prediction accuracy in a short lead time due to the spin-up time. On the other hand, a kinematic extrapolation method cannot express the development or decay of cloud in principle. Therefore, for both these schemes, improving precipitation prediction accuracy in the lead time around 30 minutes to an hour is a major issue.

With this aim, the development of data-driven methods for weather forecasting has become a recent trend. However, this approach potentially has problems such as the reflection of knowledge regarding physical phenomena and the interpretation of computation processes. This study proposes a new precipitation forecast method based on Koopman operator analysis, which is a more recent type of data-driven method, in order to address these issues. Koopman operator analysis is a methodology to reproduce and predict the temporal evolution of nonlinear dynamic phenomena using observation datasets. As the theoretical basis of the analysis assumes the causal laws of phenomena, such a data-driven model is suitable for predicting physical phenomena such as precipitation.

Koopman operator analysis decomposes nonlinear dynamic phenomena into multiple spatial modes that oscillate while evolving or attenuating in the time domain and obtains the characteristics of each mode using observation data. However, it is difficult to apply this method to transient phenomena that comprise spatial movement. Therefore, in this study, we propose a model to decompose the temporal evolution of weather states into global spatial movement and the evolution or attenuation of state, and to predict the former by kinematic manipulation and the latter by Koopman operator analysis. A numerical experiment was performed wherein the precipitation was predicted for a certain lead time based on the observation records in XRAIN. From the experimental results, it was verified that the proposed model shows high accuracy as compared to Conv-LSTM, a precipitation prediction model that uses deep learning, and basic models such as the persistent prediction and simple kinematic extrapolation models.

Keywords: short-time precipitation forecast, Koopman operator analysis, nonlinear dynamics, data-driven analysis

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