以人工智慧為基礎之數值天氣預報未解析尺度強迫項統計估計

AI-Based Statistical Estimation of Unified Unresolved-Scale Forcing in Numerical Weather

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摘　要

數值天氣預報模式僅能解析尺度大於網格間距3-5倍以上之過程，而無法被解析的較小尺度過程對可解析尺度大氣狀態的效應則是透過物理參數化方法來表示。傳統物理參數化方法將未解析過程區分為對流、微物理及邊界層等不同強迫項，因而各種未解析過程的交互影響無法被完整表示。

本研究基於「未解析尺度對解析尺度之強迫本質上為統計問題」之觀點，發展一套整合式 AI 物理架構，以單一強迫項來表示各種未解析過程的綜合效應。關鍵創新在於引入局地化小波嵌入（localized wavelet embedding）技術，以動力相關之多尺度小波特徵作為強迫項的估算條件。實務上，本研究訓練神經網路學習 6 小時純動力預報與再分析場(真值)之差異量，並將此差異量視為未解析過程於 6 小時時間窗區內之綜合效應。透過AI物理模型整合不同尺度與不同物理過程之資訊，本研究預期即便是較粗解析度之全球模式，亦能有效改善熱帶波動之模擬，進而提升展期天氣預報能力。

關鍵字：單一強迫項、局地化小波嵌入

Abstract

Numerical weather prediction (NWP) models explicitly resolve only processes at scales larger than about 3–5 times the model grid spacing, while the effects of unresolved-scale processes on the resolved-scale atmospheric states are represented through physical parameterization schemes. These schemes separate inherently interacting unresolved processes, such as convection, microphysics, and boundary-layer processes, into distinct forcing terms. As a result, interactions among unresolved processes may not be fully represented.

This study explores a unified AI-based physics framework that statistically represents the combined effects of unresolved processes as a unified forcing term. A key innovation is the use of localized wavelet embedding, which conditions the estimation of this forcing on dynamically relevant multiscale features affecting each grid column. In practice, we train a neural network to predict the difference between a 6-hr dynamics-only forecast and the verifying reanalysis. This difference is interpreted as the integrated effect of unresolved processes within a 6-hr time window. By integrating information across scales and processes, this research is expected to improve the simulation of tropical

waves, even in coarse-resolution global models. Improved simulations of tropical waves may in turn enhance extended-range prediction skill.

Key words : unified forcing, localized wavelet embedding