Sequential Variational Assimilation for Near-Space Temperature Based on the Space-Time Multiscale Analysis System Method

*Xinyi Du[1], Wenbin Chen[1,2], Xiong Hu[3,4], Junfeng Yang[3,4], Zhijin Li[5,6], Shuai Lu[1,2], Zewei Wang[7,8], Cunying Xiao[7,8]

1. School of Mathematical Sciences, Fudan University, Shanghai 200433, China, 2. Shanghai Key Laboratory for Contemporary Applied Mathematics, Fudan University, Shanghai 200433, China, 3. State Key Laboratory of Space Weather, National Space Science Center, Chinese Academy of Sciences, Beijing 100045, China, 4. Key Laboratory of Science and Technology on Environmental Space Situation Awareness, National Space Science Center, Chinese Academy of Sciences, Beijing 100045, China, 5. Department of Atmospheric and Oceanic Sciences, Institute of Atmospheric Sciences, Fudan University, Shanghai 200438, China, 6. Shanghai Key Laboratory of Ocean-land-atmosphere Boundary Dynamics and Climate Change, Shanghai 200438, China, 7. School of Physics and Astronomy, Beijing Normal University, Beijing 100875, China, 8. Institute for Frontiers in Astronomy and Astrophysics, Beijing Normal University, Beijing 102206, China

The near-space region is of strategic importance for aerospace activities. However, accurate temperature analyses remain challenging due to sparse observations and multi-scale spatial structure. In this study, a sequential multi-scale variational assimilation framework Space-Time Multiscale Analysis System (STMAS) is applied to near-space temperature analysis using the Mass Spectrometer and Incoherent Scatter (MSIS) empirical model as the background field and TIMED/SABER temperature observations. The multi-scale strategy is implemented through sequential iterations with different decorrelation length scales and scale-dependent background error to represent error characteristics at different spatial scales. A series of observing system simulation experiments (OSSEs) based on synthetic observations and real SABER temperature observations experiments are conducted to evaluate the performance of STMAS algorithm relative to a single-scale data assimilation (SSDA) Best Linear Unbiased Estimation (BLUE) scheme. Results from three stages of OSSEs demonstrate that STMAS more effectively propagates observational information across scales and achieves improved error reduction compared to the SSDA-BLUE method, reducing the RMSE from 3.000 K in the background to 2.203 K and 2.004 K, respectively. Using real SABER temperature observations, additional quantitative evaluations against independent validation data further indicate that STMAS yields lower RMSE and bias and higher correlations than the single-scale scheme, confirming its practical applicability for near-space temperature analysis. These results demonstrate that STMAS framework provides an effective extension of traditional variational assimilation method for near-space applications, offering improved multi-scale error correction in observation-sparse environments.

Keywords: data assimilation, multi-scale algorithm, near-space, sequential variational assimilation