1 Localization method

In order to 'cut-off' the spurious correlation in the background covariance matrix $\mathbf{P}^f$, a correlation matrix $\mathbf{L}$ filled with local supports is introduced. Local support is a term meaning that the function is only non-zero in a local region and is zero elsewhere. The local support function is set as:

$$5 \quad \mathbf{S}_{i,j} = \frac{\mathbf{D}_{i,j}}{L_{thres}} \tag{1}$$

$$\mathbf{L}_{i,j} = \begin{cases} 1 - \frac{5}{3}\mathbf{S}_{i,j}^2 + \frac{5}{8}\mathbf{S}_{i,j}^3 + \frac{1}{2}\mathbf{S}_{i,j}^4 - \frac{1}{4}\mathbf{S}_{i,j}^5, & \mathbf{S}_{i,j} < 1 \\ -\frac{2}{3}\mathbf{S}_{i,j}^{-1} + 4 - 5\mathbf{S}_{i,j} + \frac{5}{3}\mathbf{S}_{i,j}^2 + \frac{5}{8}\mathbf{S}_{i,j}^3 - \frac{1}{2}\mathbf{S}_{i,j}^4 + \frac{1}{12}\mathbf{S}_{i,j}^5, & 1 \leq \mathbf{S}_{i,j} < 2 \\ 0, & \mathbf{S}_{i,j} \geq 2 \end{cases} \tag{2}$$
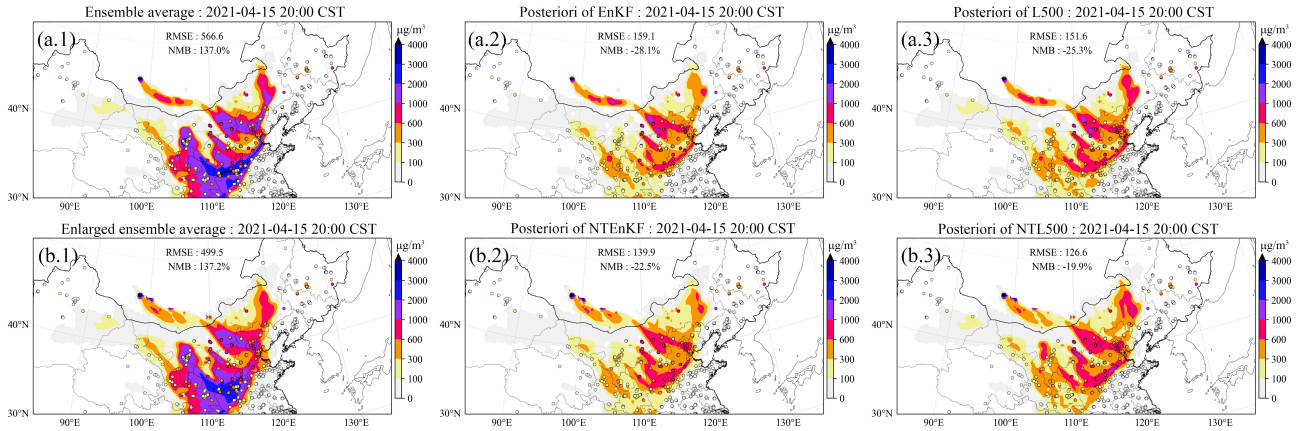
Figure S1. Spatial distribution of ground-based BR-PM$_{10}$ observations (scatter) and simulated dust plume (SDP) on surface from central time ensemble model mean (**a.1**), the posterior SDP updated by EnKF (**a.2**), the posterior SDP updated by EnKF with localization distance of 500 km (**a.3**), central and neighboring time ensemble model mean (**b.1**), the posterior SDP updated by NTEnKF (**b.2**), the posterior SDP updated by NTEnKF with localization distance of 500 km (**b.3**) at 20:00, 15th April 2021 (CST). BR-PM$_{10}$:baseline-removed PM$_{10}$
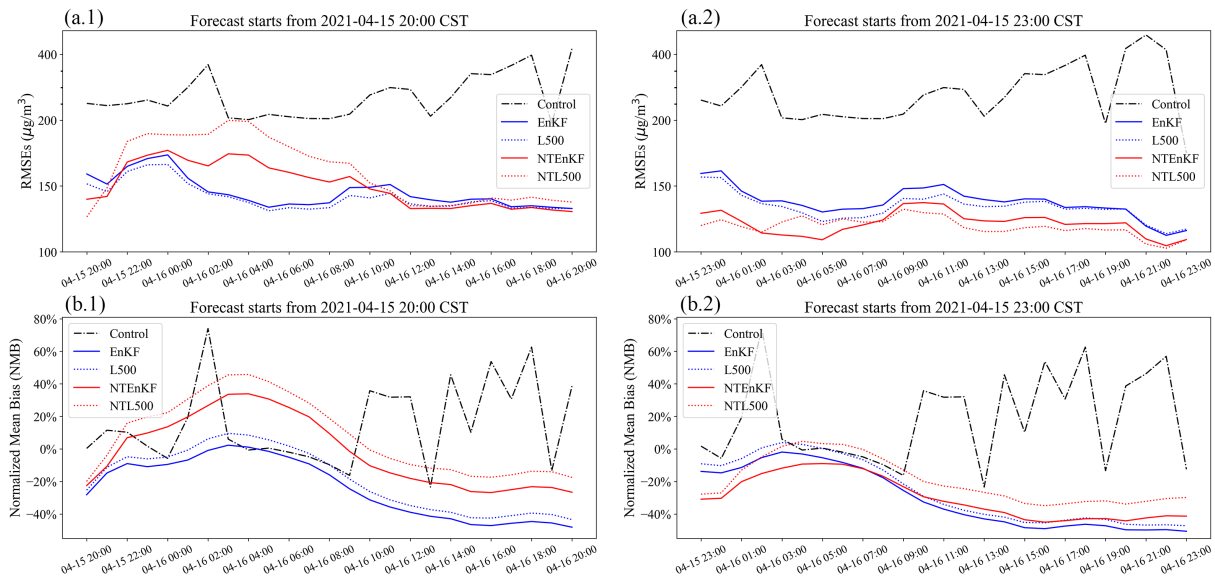
Figure S2. Variation of 24 hours forecast RMSEs starting from 20:00 (**a.1**), 23:00 (**a.2**) and normalized mean bias (NMB) starting from 20:00 (**b.1**), 23:00 (**b.2**) on 15th April 2021.