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A Nesting Algorithm Used for Improving the Resolution of CMA Sand-Dust Forecasting Model(CUACE-Dust)

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Outline

- Introduction and Model Description
- Nesting Algorithm
- Testing and Operational Results
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Dust Storm


Saharan dust storm from Space Shuttle, 1992
Dead Sea
Big Spring, TX, 16.6.1997
Shanton, TX, 13.6.2002

Harm of Dust storm

14 June 2004, 5 PM-Beijing, Visibility < 1 km

Short dust-storm in St. Petersburg, 1998

Burningman 2001 - Dust Storm couple

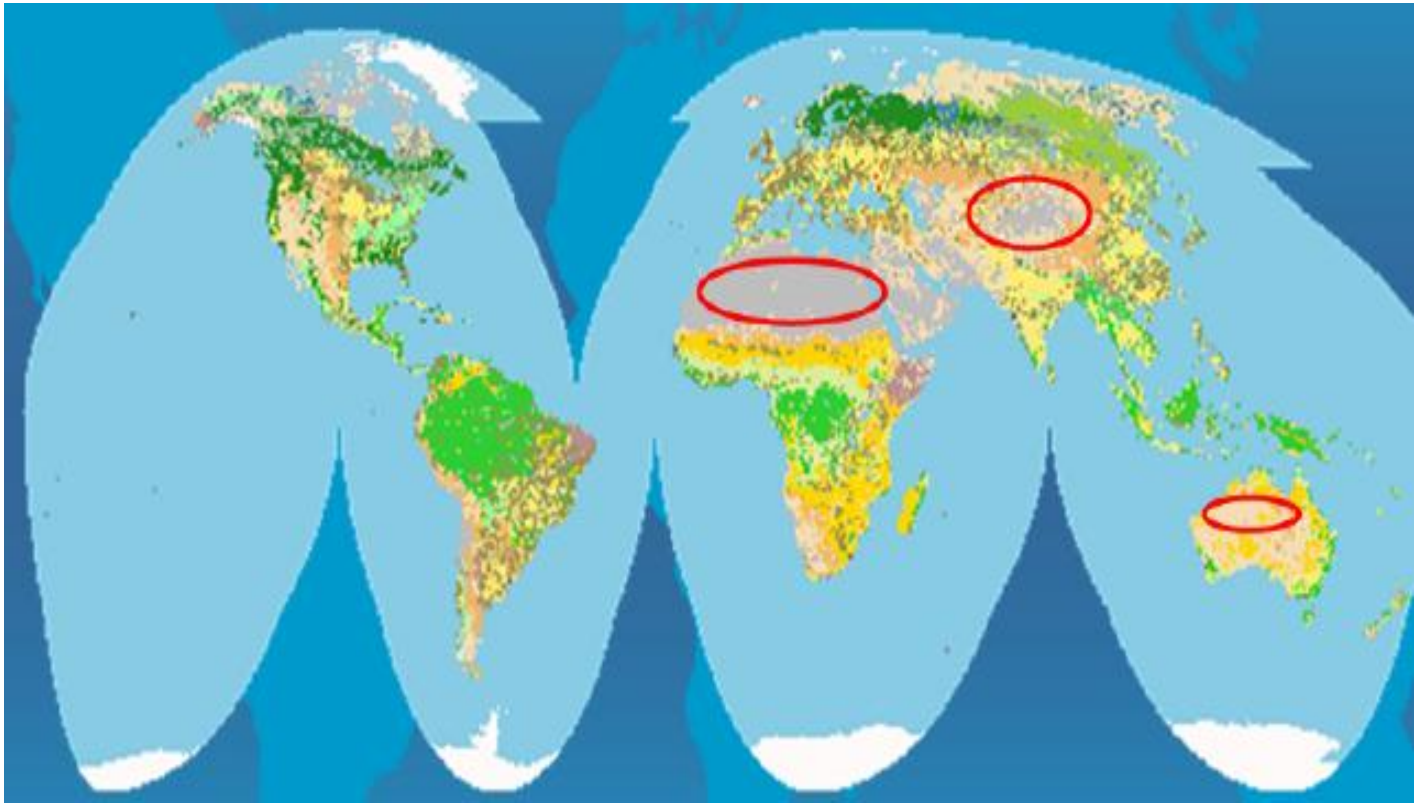
18 May 2004, 5 PM-Bayanhaote City, Inner Mongolia

SDS occurs every Spring in the Northeast Asia

Jinchang, Gansu Province, China

A huge dust storm broke out on 5, May 1993 in the northwestern desert area in China. In which More than 40 people died and many missing. Property damage was severe.

3 Major sourcelands



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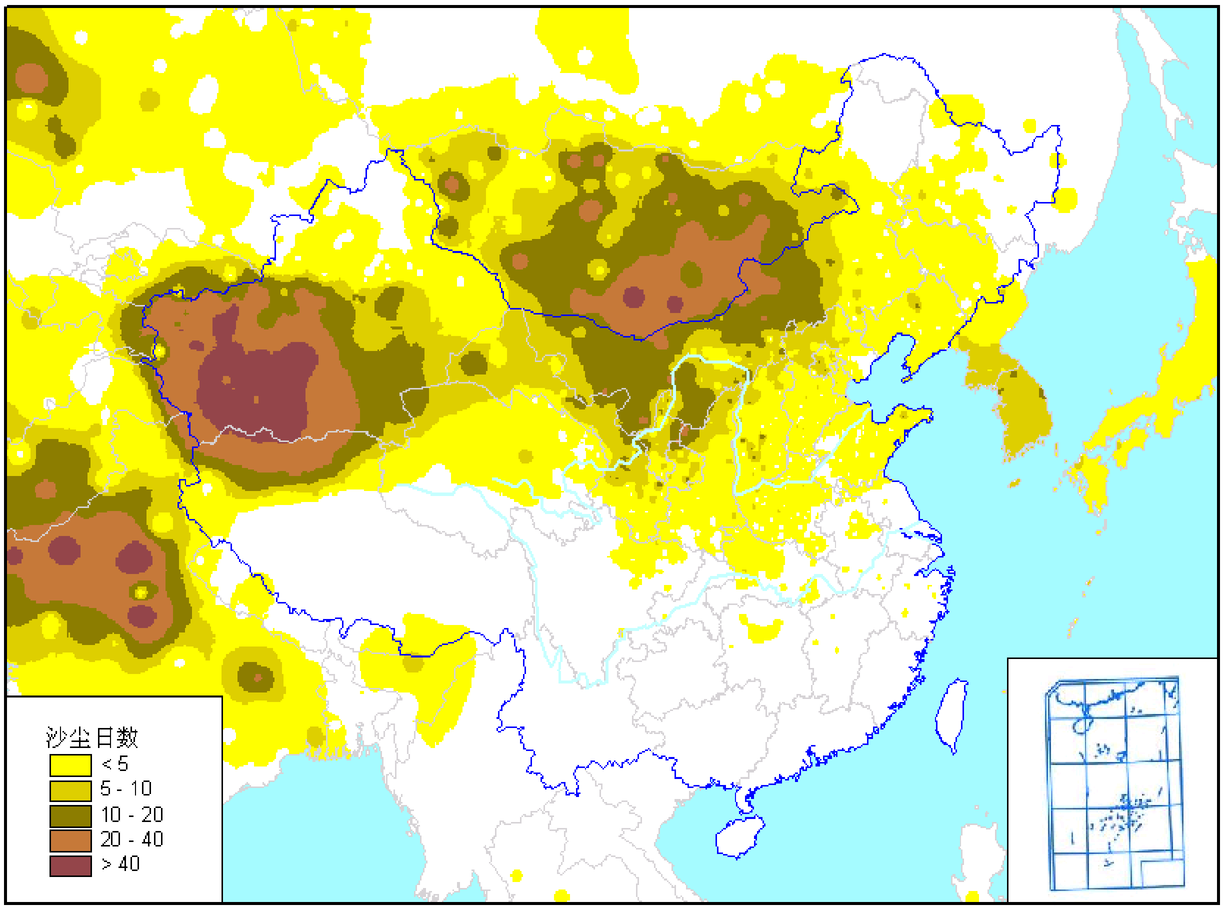
Sand-dust Storm in 2006



- Damages of sand-dust storm are severe, especially in northeast Asia.
- Tremendous storms damages can be prevented or mitigated if there is systematic early warning information.
- Numerical simulation and forecasting is the most effective method.
- We built an aerosol model CUACE-Dust(CMA Unfied Atmosphere Chemisty Environment-Dust).
- CUACE-dust has been used for real time forecasting in CMA.

Model mass balance equation

A size segregated prognostic equation in such a way that the spectrum of sand particle size is divided to 12 grads

$$\frac{\partial \chi_{ij}}{\partial t} = \frac{\partial \chi_{ij}}{\partial t}\Big|_{DYNAMICS} + \frac{\partial \chi_{ij}}{\partial t}\Big|_{SURFACE} + \frac{\partial \chi_{ij}}{\partial t}\Big|_{CLEARAIR} + \frac{\partial \chi_{ij}}{\partial t}\Big|_{DRY}$$

$$+ \frac{\partial \chi_{ij}}{\partial t}\Big|_{IN-CLOUD} + \frac{\partial \chi_{ij}}{\partial t}\Big|_{BELOW-CLOUD}$$

Surface Dust Emission

- Based on **DPM** model **(Alfaro and Gomes, 2001; Marticorena and Bergametti, 1995; Marticorena et al., 1997)**

- **Emission of soil sand-dust storm depends on two factors, (1) surface wind speed, and (2) soil surface properties(threshold friction velocity).**

$$N_i = \frac{\beta}{e_i} \int_r p_i \, dF_h(r)$$

$$F_{soil,i} = \frac{\pi \rho_p (MMD_i / 2)^3}{6} N_i$$

$$F_{sd} = \sum_{1}^{3} F_{soil,i}$$

Dynamics:Dust Transport

advection：

$$\frac{\partial C_i}{\partial t}\Big|_{con} = -\frac{\partial u^* C_i}{\partial x}$$

Turbulent diffusion：

$$\frac{\partial C_i}{\partial t}\Big|_{tur} = \frac{\partial^2 K_v C_i}{\partial^2 z}$$

Clear Air Cohesion

$$\frac{dN_i}{dt} = \sum_{k=1}^{[\frac{i}{2}]} K_{k,i-k} N_k N_{i-k} - N_i \sum_k K_{i,k} N_k$$

Dry sedimentation

$$\frac{\partial C_i}{\partial t}\Big|_{dry} = C_i\left[\exp\left(-\frac{\Delta t}{\Delta z}V_t\right) - 1\right]$$

cleanup

$$\frac{\partial C_i}{\partial t}\Big|_{below-clouds\ (in-clouds)} = f_{cld}\,\psi(r_i)\,C_i$$

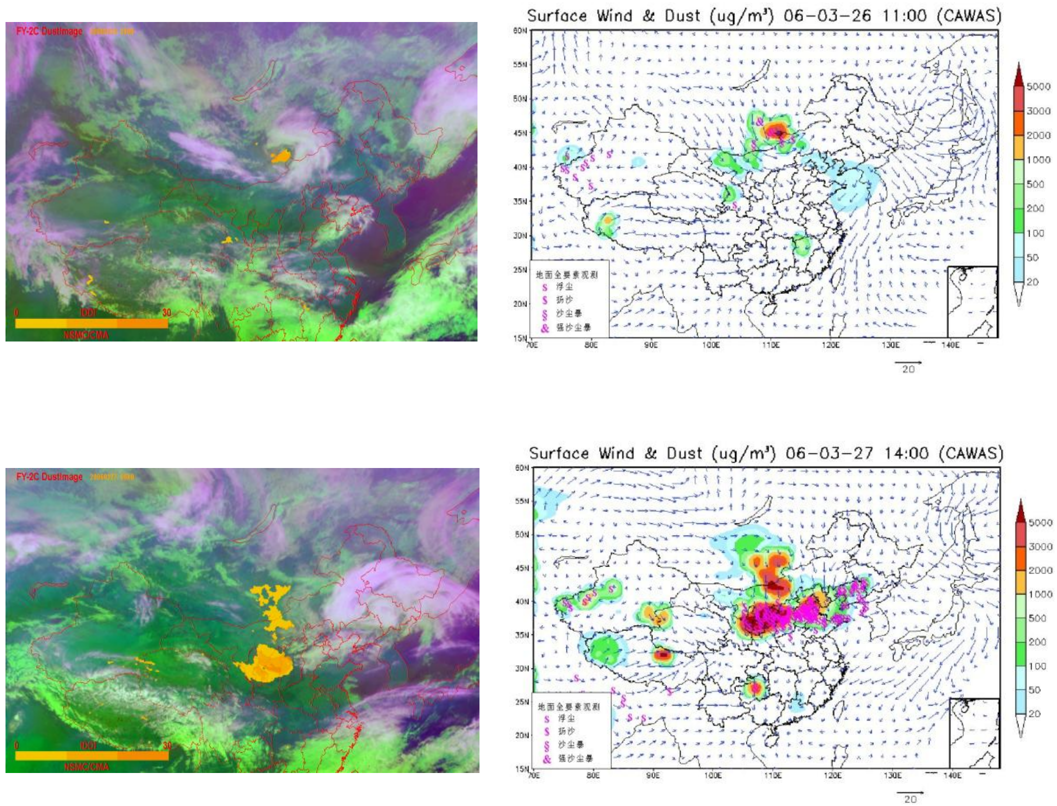


Figure: the position and intensity of the sand storm observing from meteorological satellite FY2C; and forecasting result by CUACE-Dust

- Horizontal resolution is 108km,time step is 54s.grids number is 67*85*23; forecasting period is 72 hrs.

- The execution time of main forecasting procedure is about 6.5mins using 64CPUs. The execution time of the total system is about 15mins,including pre-run and post-run data processing.

- The timeliness is as important as accuracy for a real time forecasting model.

- High resolution is desired,but it need much more calculation. The execution time grows cubically.

- If we want to improve the resolution to 12km,the execution time of the main calculation procedure need more than 80hrs.

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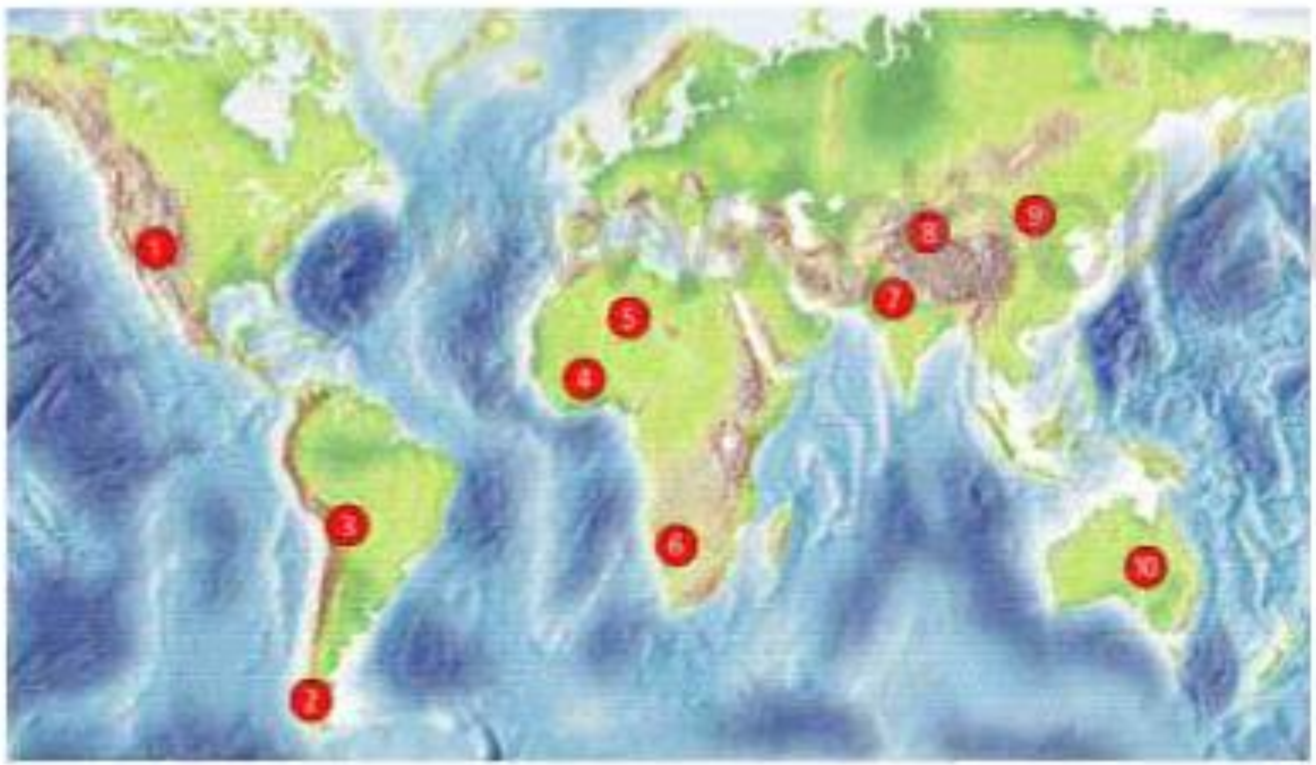
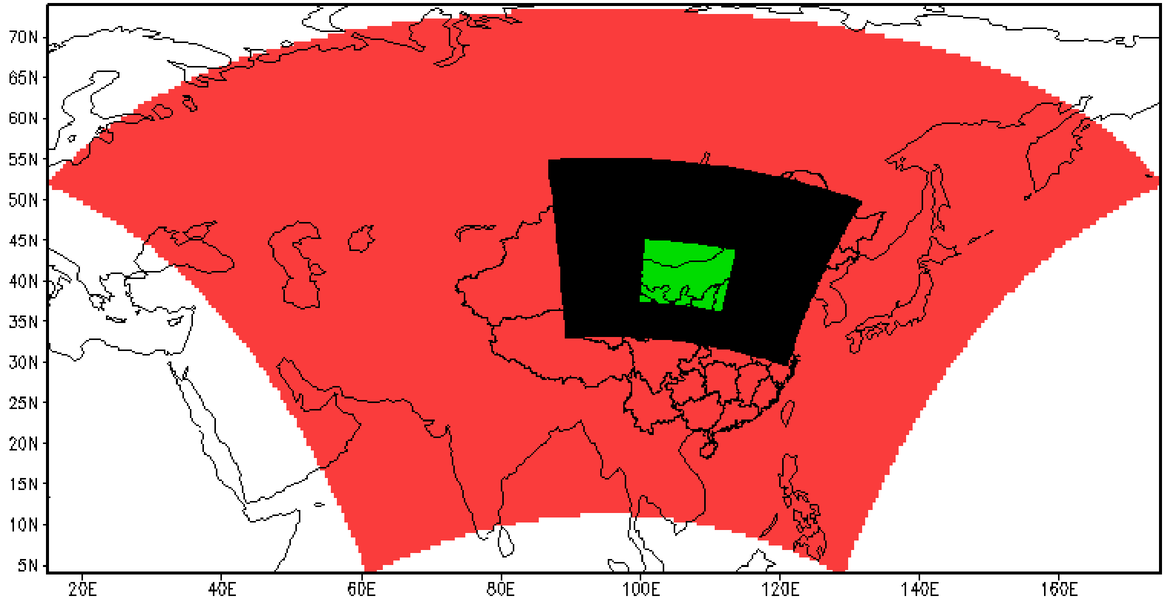
Source places




70N
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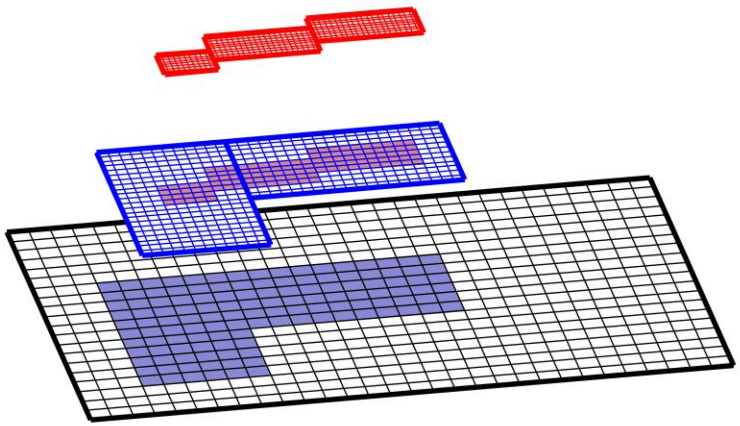
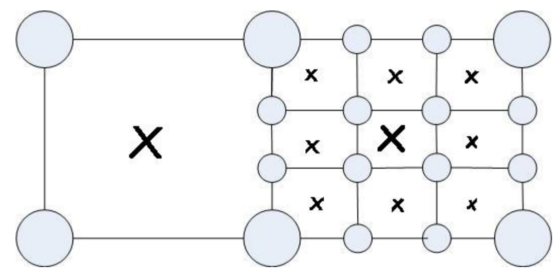
40E
60E
80E
100E
120E
140E
160E





- **computing grids**
  - several layers nesting grids.
  - fine grids(FG) nest in coarse grids(CG) by progressive refinement with ratio 3.
- **integration procedure**
  - Both CG and FG simulations run with the **same** program
  - CG integrates one coarse time step
  - FG get the boundary from CG at each coarse time step using FCT interpolation
  - FG integrates up to the same time.
  - feedback FG to CG

FCT Interpolation

$$\frac{\partial \phi}{\partial t} = -\frac{\partial u\phi}{\partial x},$$

$$\phi_i^{n+1} = \Phi_i^{n+1} - (\tilde{A}_{i+1/2} - \tilde{A}_{i-1/2}),$$

$$\Phi_i^{n+1} = \phi_{i_c}^{n} - (FL_{i+1/2} - FL_{i-1/2})$$

$$FL_{i+1/2} = \alpha\phi_i$$

$$\tilde{A}_{i+1/2} = min\left(1, \beta_i^{\downarrow}\right)\left[A_{i+1/2}\right]^{+} + min\left(1, \beta_i^{\uparrow}\right)\left[A_{i+1/2}\right]^{-}$$

$$\phi_i^{MAX} = max\left(\phi_{i-1}^{n}, \phi_i^{n}, \phi_{i+1}^{n}, \Phi_i^{n+1},\right) \; ; \; \phi_i^{MIN} = min\left(\phi_{i-1}^{n}, \phi_i^{n}, \phi_{i+1}^{n}, \Phi_i^{n+1}\right)$$

$$\beta_i^{\uparrow} = \frac{\phi_i^{MAX} - \Phi_i^{n+1}}{A_i^{IN} + \varepsilon} \; ; \; \beta_i^{\downarrow} = \frac{\Phi_i^{n+1} - \phi_i^{MIN}}{A_i^{OUT} + \varepsilon}, \qquad A_{i+1/2} = FH_{i+1/2} - FL_{i+1/2},$$

$$A_i^{out} = \left[A_{i+1/2}\right]^{+} - \left[A_{i-1/2}\right]^{-} \qquad A_i^{in} = \left[A_{i-1/2}\right]^{+} - \left[A_{i+1/2}\right]^{-}$$

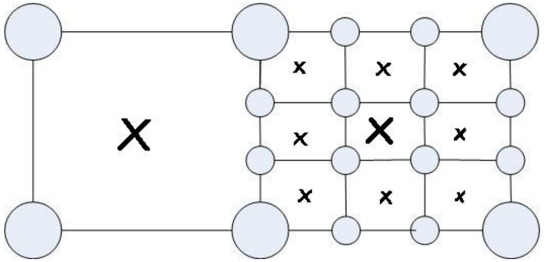
$$\begin{aligned} FH_{i+1/2} = \; & + \frac{\alpha}{12}(\phi_{i-1} - 7\phi_i - 7\phi_{i+1} + \phi_{i+2}) \\ & + \frac{\alpha^2}{24}(\phi_{i-1} - 15\phi_i + 15\phi_{i+1} - \phi_{i+2}) \\ & + \frac{\alpha^3}{12}(-\phi_{i-1} + \phi_i + \phi_{i+1} - \phi_{i+2}) \\ & + \frac{\alpha^4}{24}(-\phi_{i-1} + 3\phi_i - 3\phi_{i+1} + \phi_{i+2} \end{aligned}$$

Feedback

- **Point-Point feedback with smoother**

$$\begin{aligned}\bar{\alpha}(i,j) =& \alpha(i,j) \\ &+ \frac{\nu}{2}(1-\nu)(\alpha(i+1,j)+\alpha(i-1,j)+\alpha(i,j+1)+\alpha(i,j-1)+4\alpha(i,j)) \\ &+ \frac{\nu^2}{4}(\alpha(i+1,j+1)+\alpha(i+1,j-1)+\alpha(i-1,j+1)+\alpha(i-1,j-1)-4\alpha(i,j))\end{aligned}$$

- **9 points weighted average feedback**



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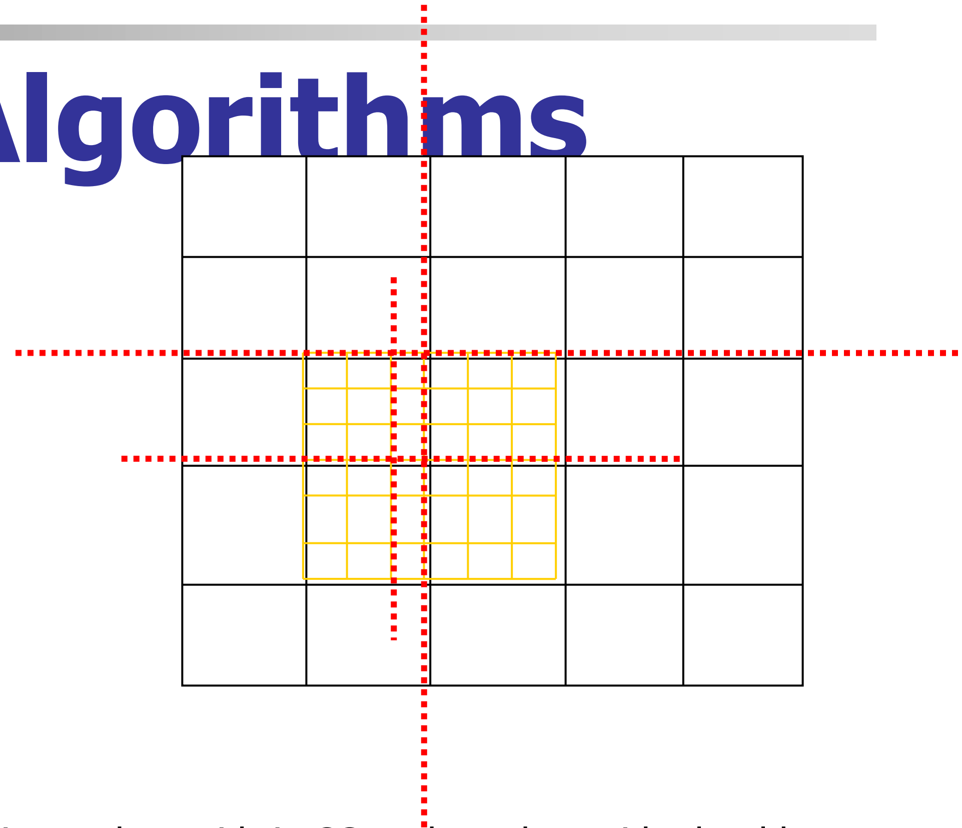
Parallel Algorithms



- **Domain decompsition**
  - CG and FG use the same CPUs group
- **CG and FG grids mapping**
  - FG in boundary should get information of its mother grids in CG,and mother grids should get information of its child grids,including the processor number.
- **FCT and feedback**
  - FCT calculation in CG and 9points weighted average calculation in FG.Smoother in CG.
- **parallel communication**
  - FCT, 9points weighted average and smoother need get data from neighbour CPUs
  - FG should get boundary from CG and CG get feedback data by communication according to grids mapping.

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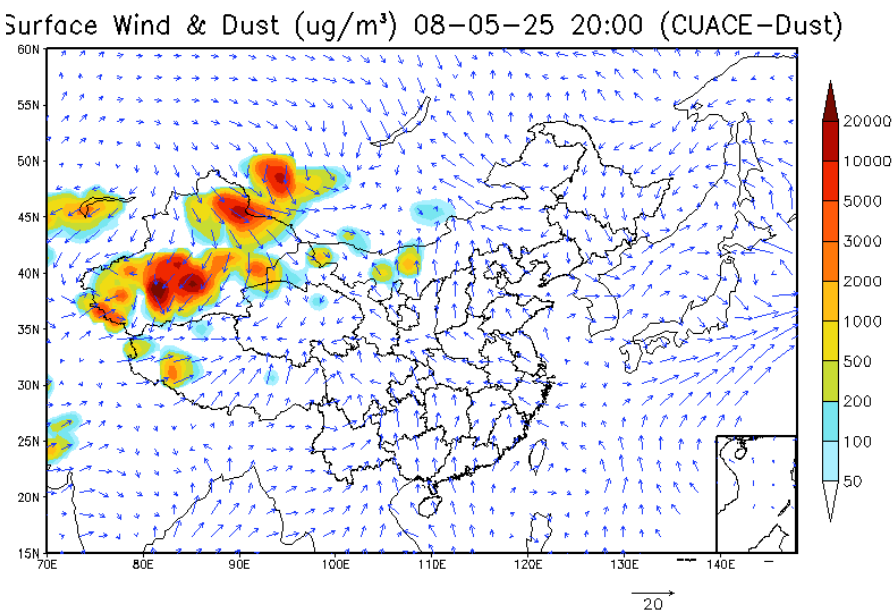
Surface Wind & Dust (ug/m³) 08-05-25 20:00 (CUACE-Dust)
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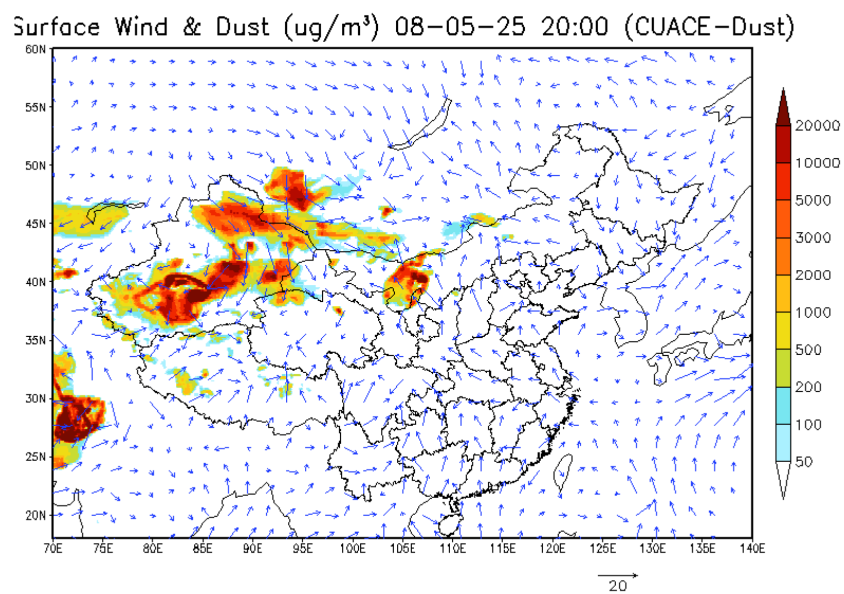
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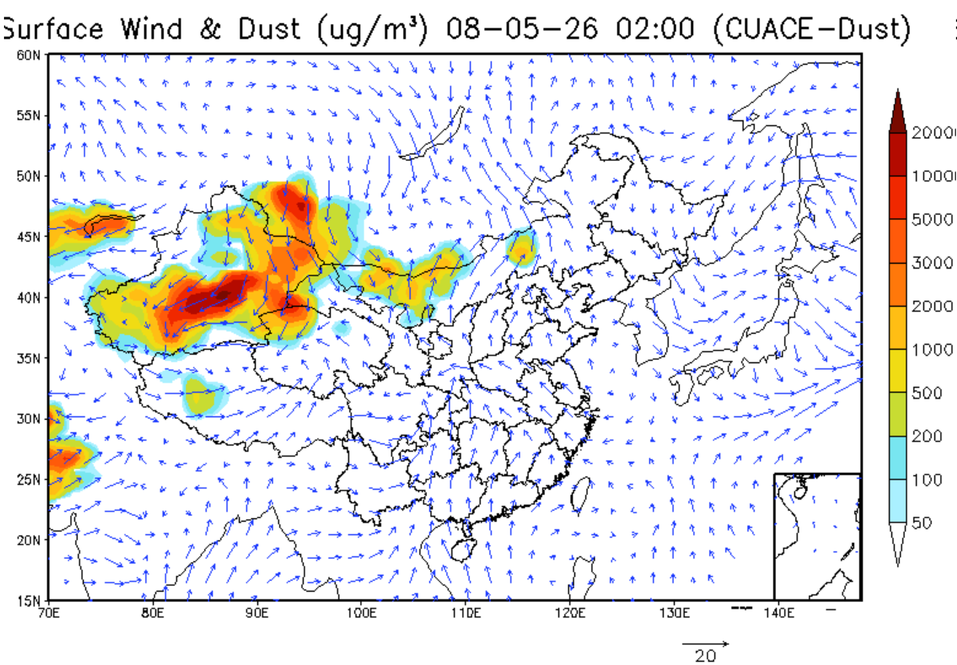

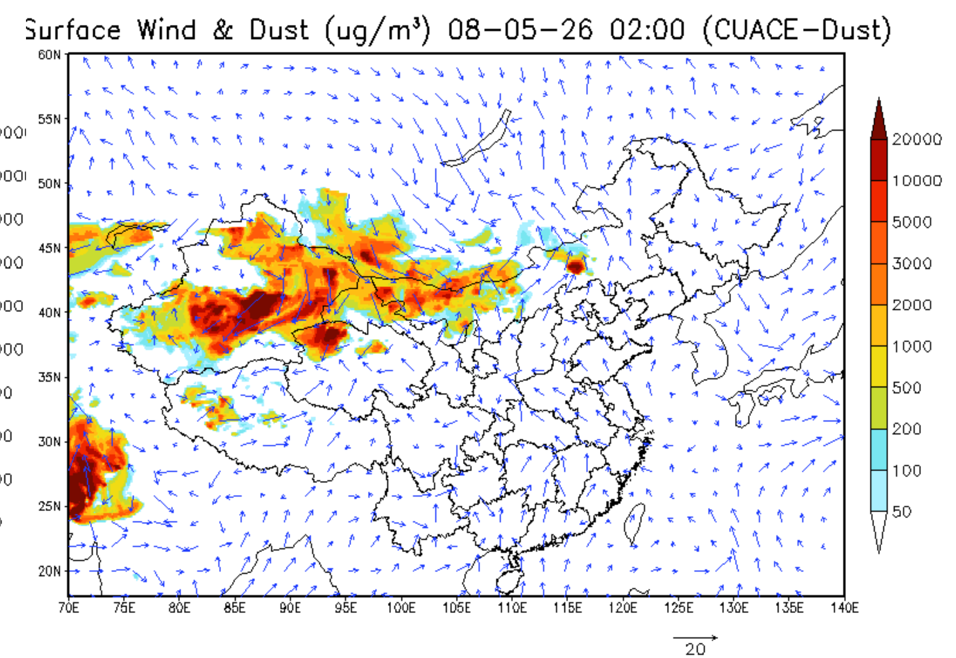

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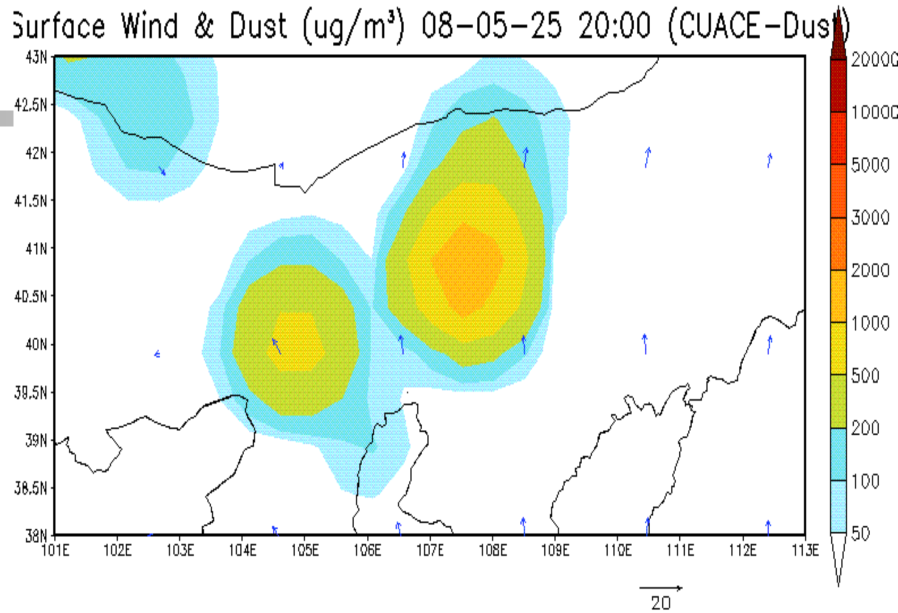

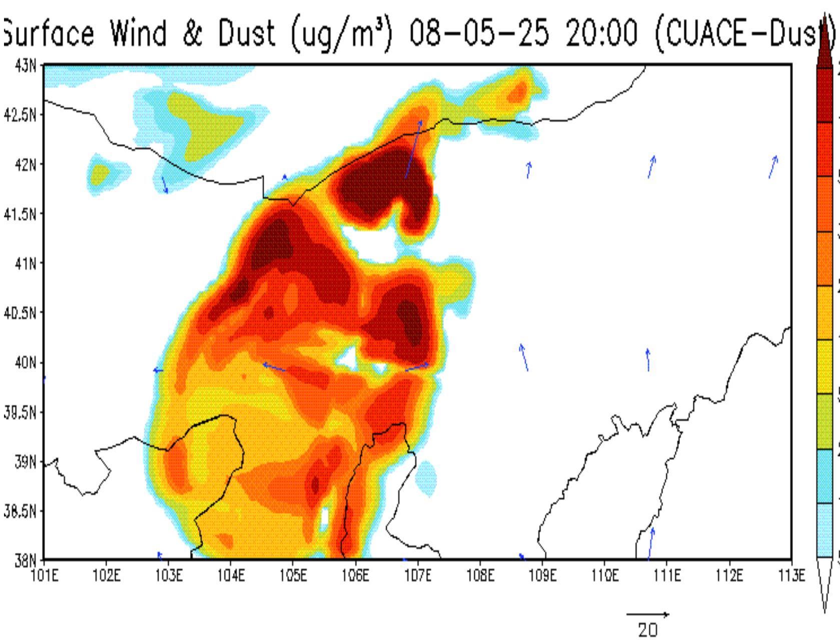

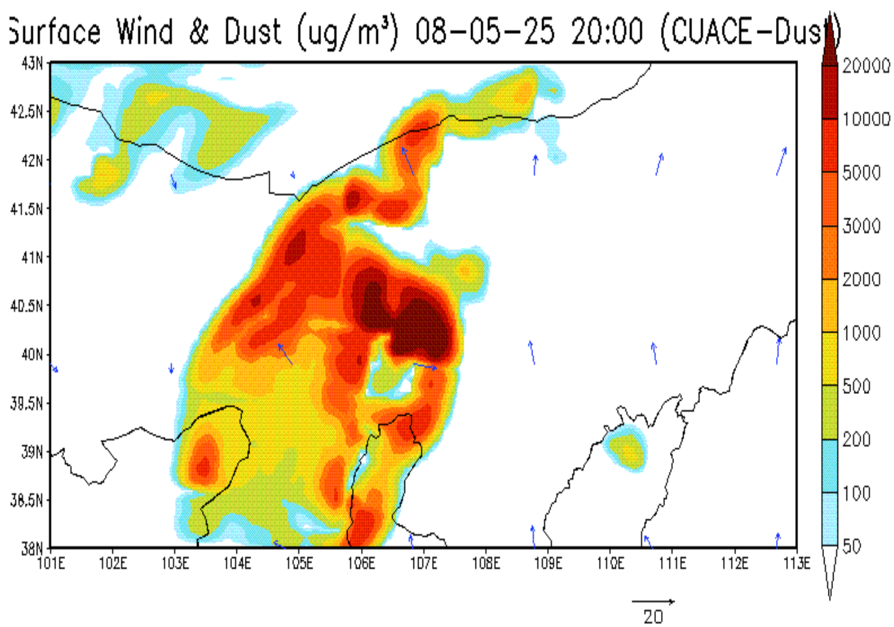

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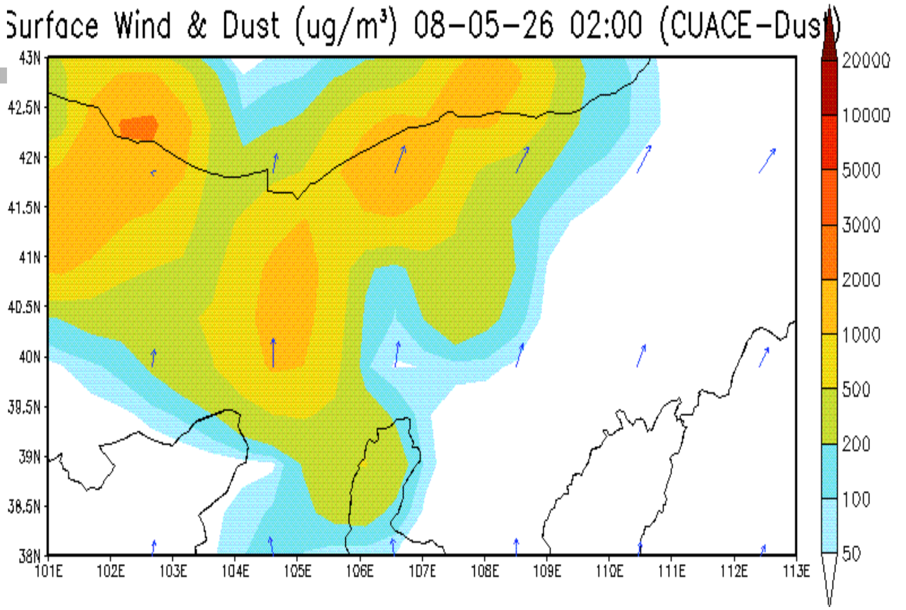

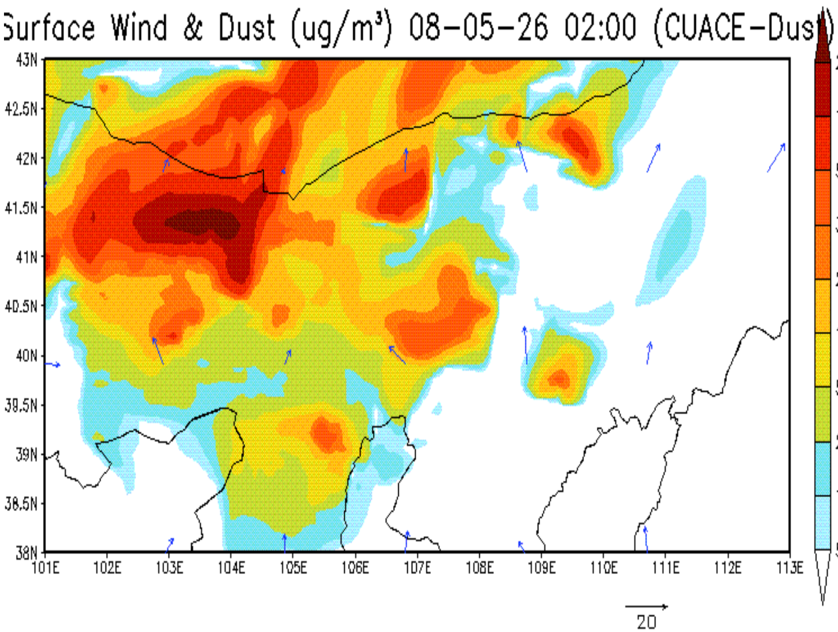

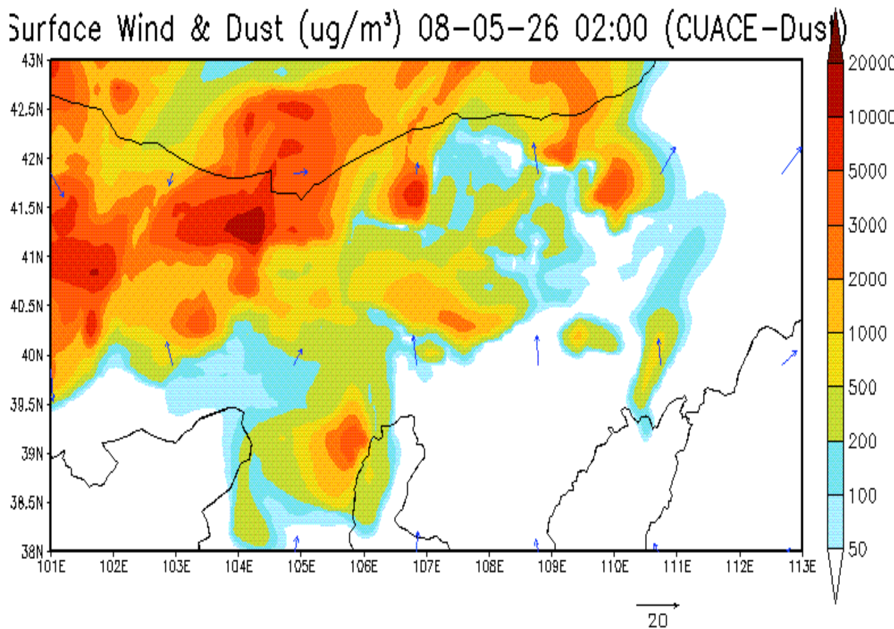

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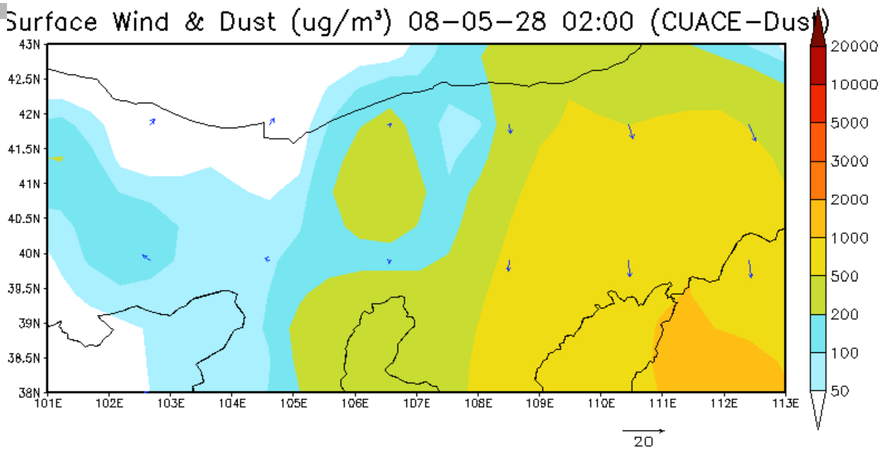

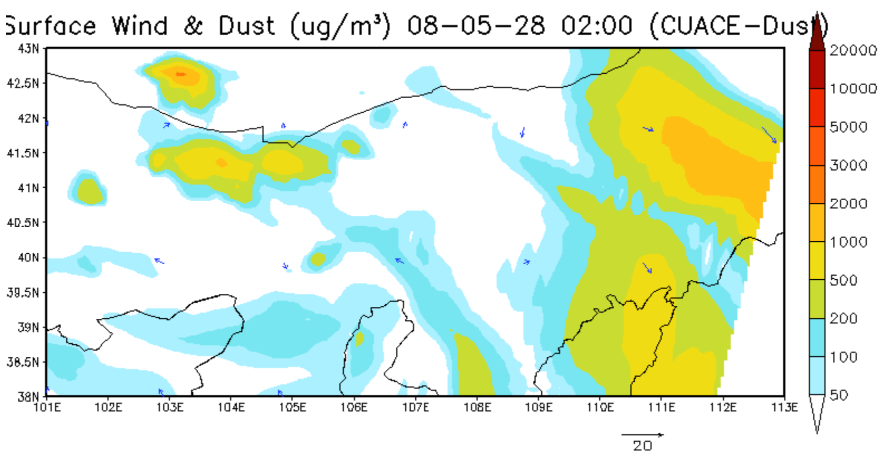

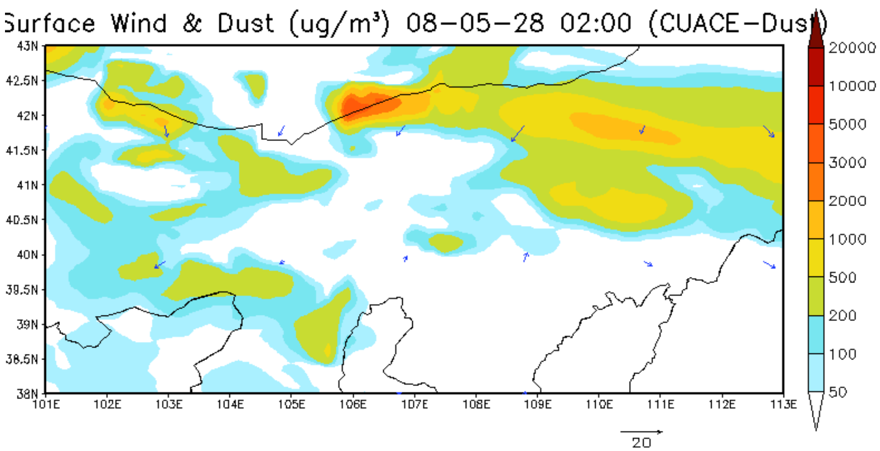

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Time Analysis

	12km/1 mesh	108km/1 mesh	12km/nesting
ideal runtime	277020s	380s	4940s
ratio	729	1	13
real runtime	298510s	380s	5599s
ratio	785.5	1	14.7

- The time complexity without nesting techniques is $T(N) = N^3 * t = O(N^3 * t)$
- The time complexity with nesting techniques is $T'(N) = (1 + 3 + \ldots + 3^L) * t$ $= (3N - 1) * t / 2 = O(3N * t / 2)$

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Summary

•Nesting Alogrithm works well for improving the resolution of CUACE-Dust.It's not a new method, but it is an efficient method.

•The error is small at the beginning of simulation,but bigger in the later stage.

•We want to apply it for global climate model,but there are some questions remaining.

Q&A

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