Quantifying Sub-Grid Variability of Trace Gases & Aerosols

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1. Motivation

Sub-grid treatments for aerosols and their climate forcing are understudied, whereas sub-grid treatments for meteorological processes in atmospheric models have been studied extensively.

- Need to quantify trace gas and aerosol sub-grid variability and document the severity of the issue.
- What processes contribute most to sub-grid aerosol variability, e.g. terrain, relative humidity differences, emissions, non-linearity of chemical reactions?
- What impact does neglected sub-grid aerosol variability have on climate simulations?

WRF-Chem PBL Height, 5-30 March 2006

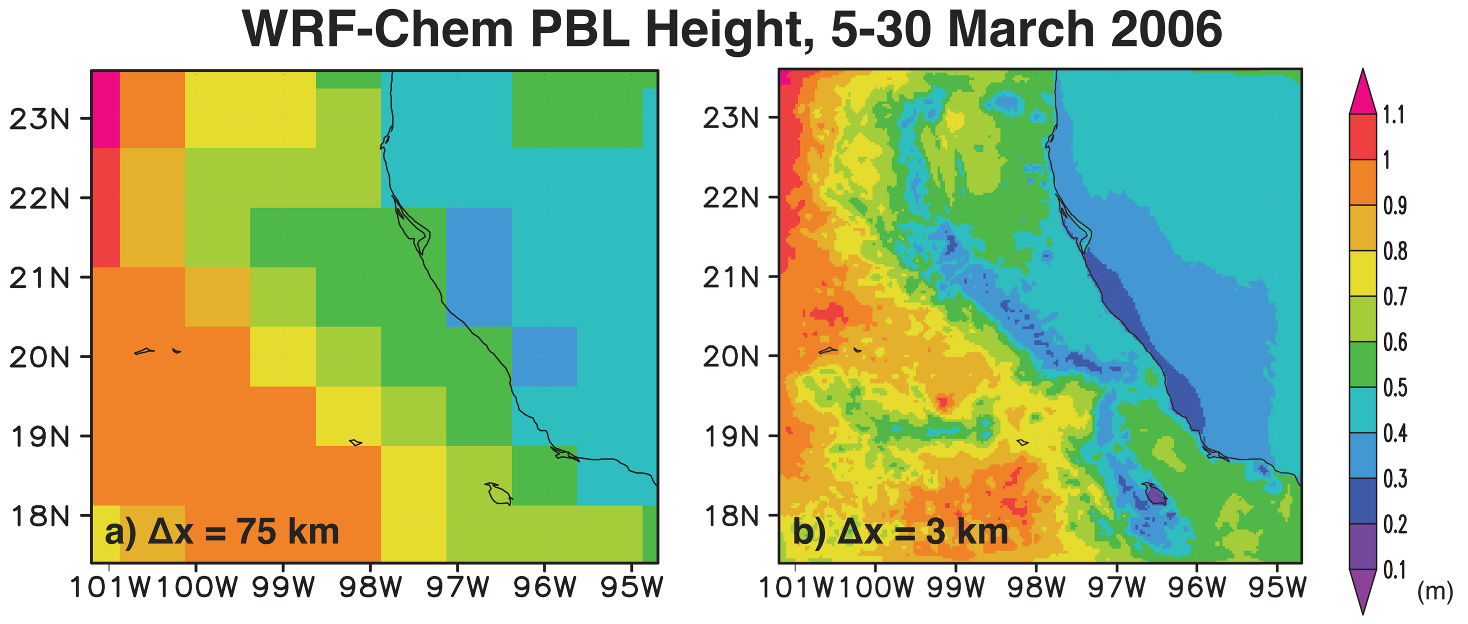


Figure 1. Simulated PBL height averaged over 5-30 March 2006 for the (a) 75-km and (b) 3-km domains used in this study. Added topographic complexity locally alters pollutant concentrations significantly. But, what is the net effect to the region as a whole?

2. Methodology

Used WRF-Chem to simulate differences in variability between two grid spacings, one with spacing on the order of a climate model and one on the order of a cloud-scale resolving model. The high resolution domain serves as a proxy for added variability that would be present in the real world. The simulations are for the MILAGRO field campaign during March 2006.

Terrain Height for WRF-Chem Domains

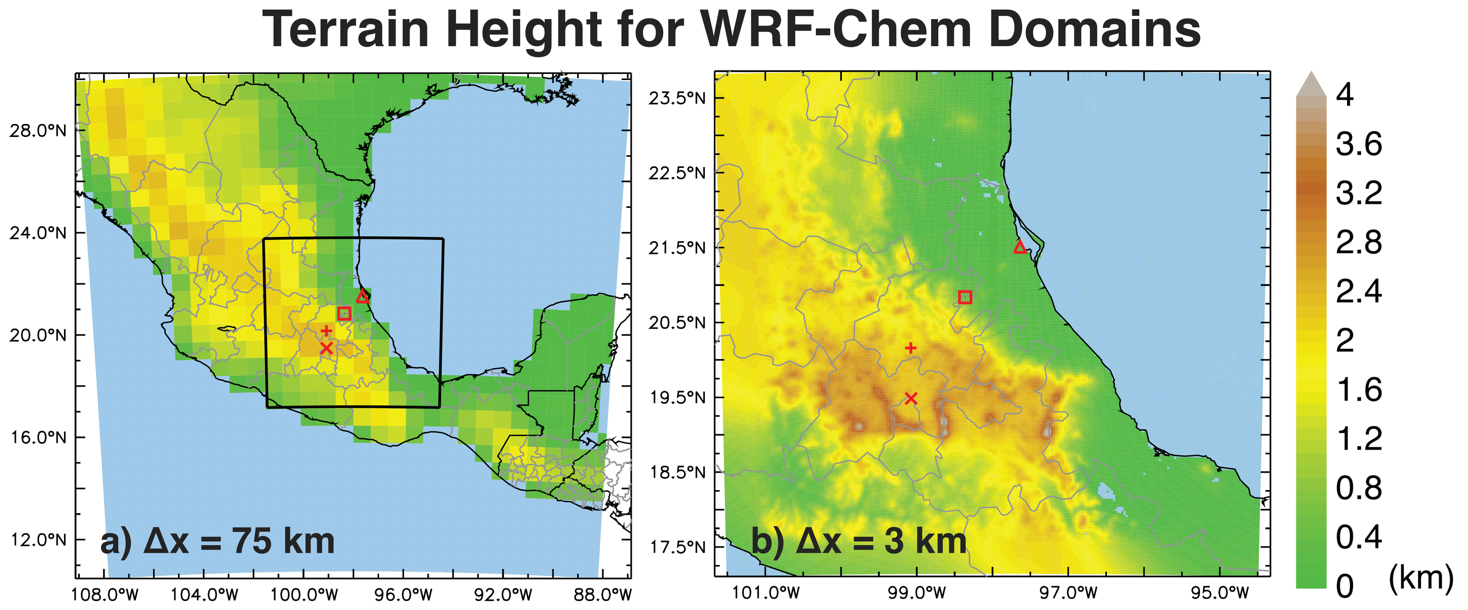


Figure 2. Terrain height for the (a) 75-km and (b) 3-km domains used in this study. The red markers denote the sites T1 (x), T2 (+), T3 (☐), and T4 (Δ).

3. Spatial Variability in a GCM Grid Box

Model grids are aligned such that cell edges match every 75 km. This allows easy comparison between grids and averaging of the high-resolution grid to compare with the coarse grid.

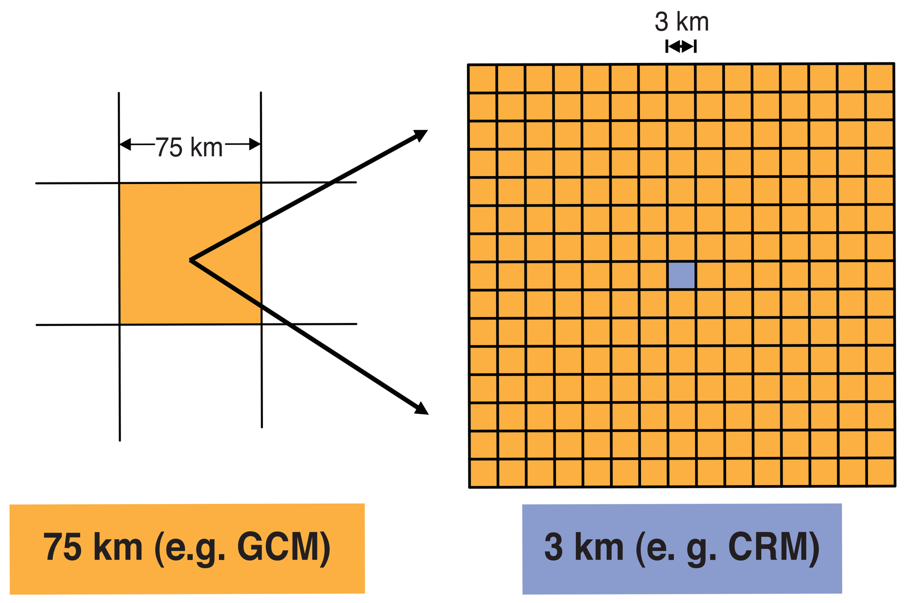


Figure 3. Within each 75-km grid cell lies 625 3-km grid cells. For clarity, not all of the 25 3-km cells are shown in each direction.

Variability of a value within the area of a GCM grid box can be expressed using probability density functions (PDFs). The PDFs show the variability of the high resolution grid cell values that reside within the GCM cell.

PDFs for 3-km Grid Cells in 75-km Cell at Site T1

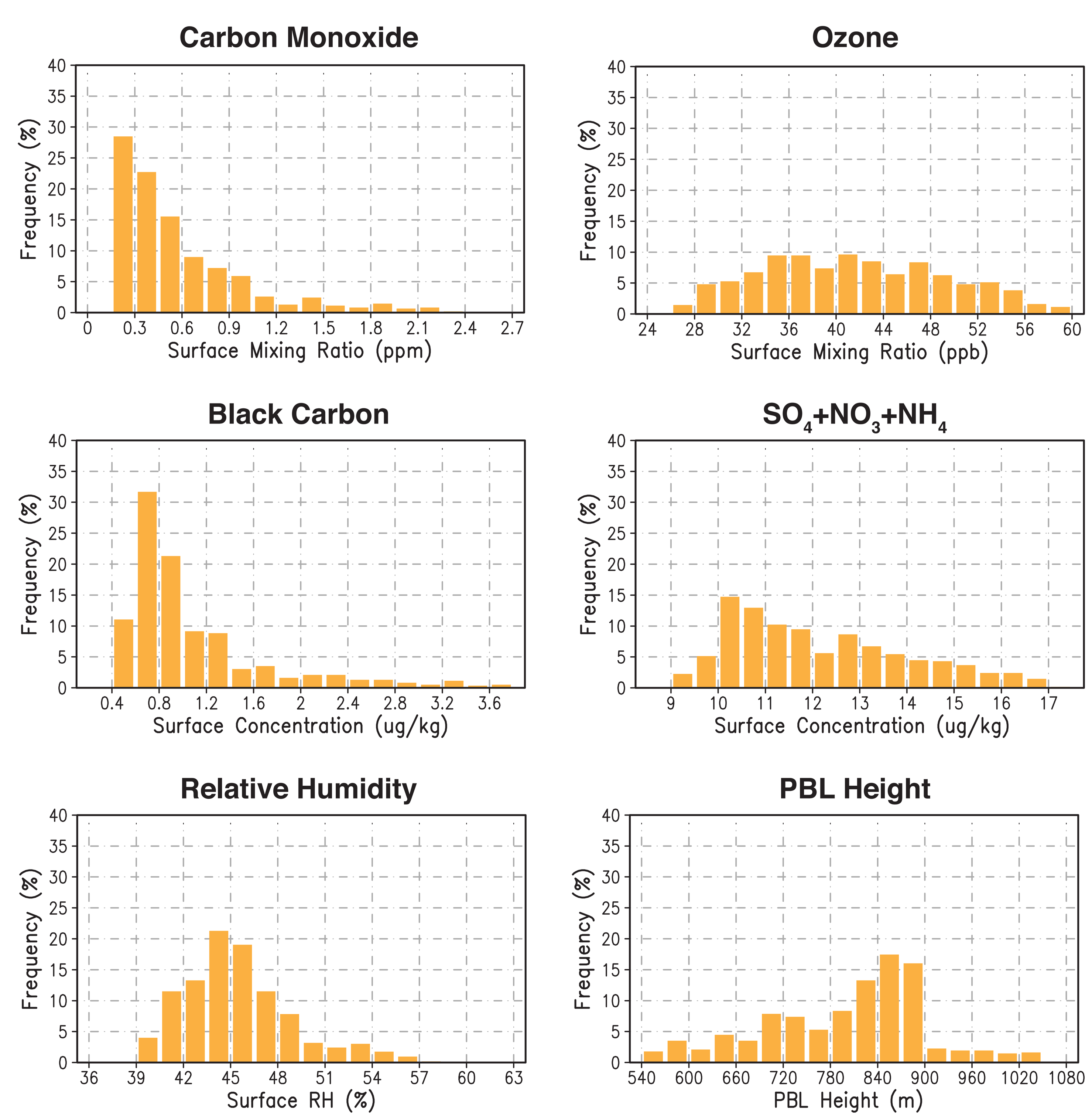


Figure 4. PDFs of various values for coincident cells from the 3-km grid within the 75-km grid for the T1 site close to Mexico City. The PDFs include values from 5-30 March 2006.

Results: Spatial variability for inert species (CO & BC) has a larger relative range of values and is skewed compared to more reactive species (O_3 and secondary aerosols, e.g. SO_4+NO_3+NH_4).

4. Sub-Grid Variability Index

Sub-grid variability is quantified using a "sub-grid variability index":

$$SGV = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}}{\bar{x}}$$

where x_i is a grid point value on the high resolution domain, N is the number of points on the high resolution domain that reside within a given coarse domain grid point, e.g. 625 points per time from the 3-km domain reside in each 75-km domain grid point, and $\bar{x}$ is the mean. Note that N optionally includes multiple times.

Lowest Level SGV

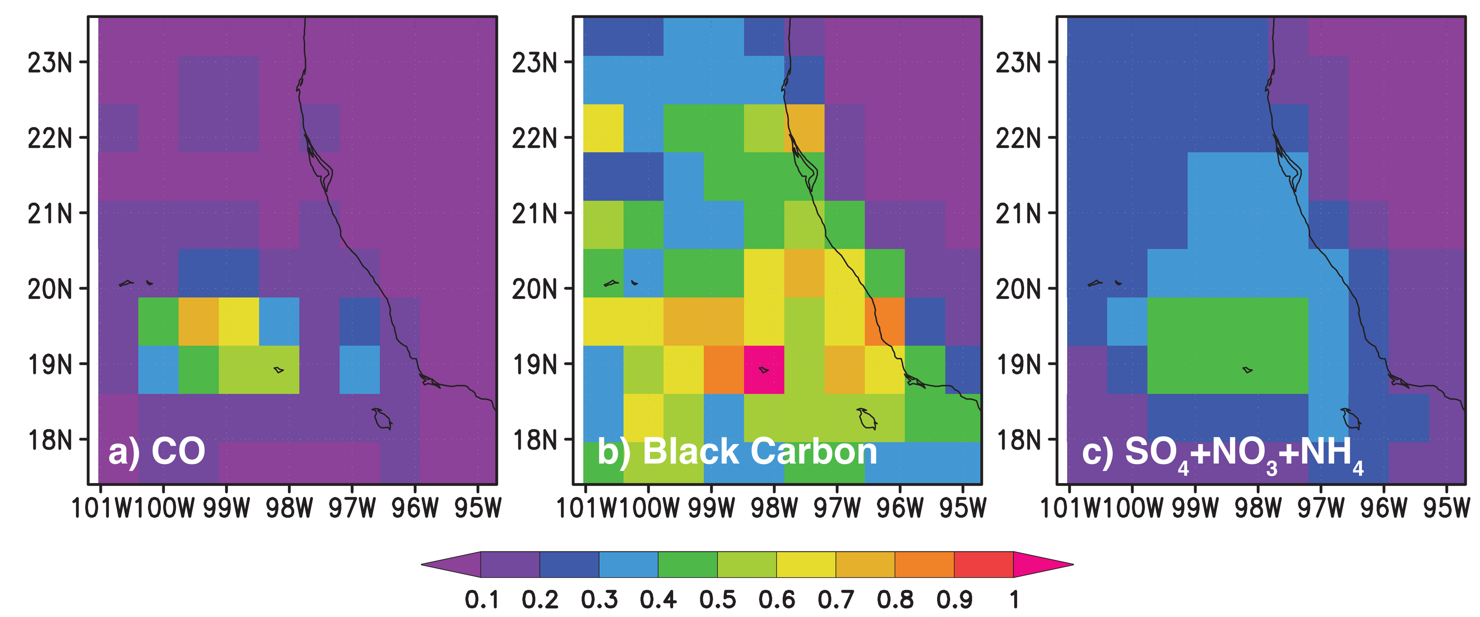
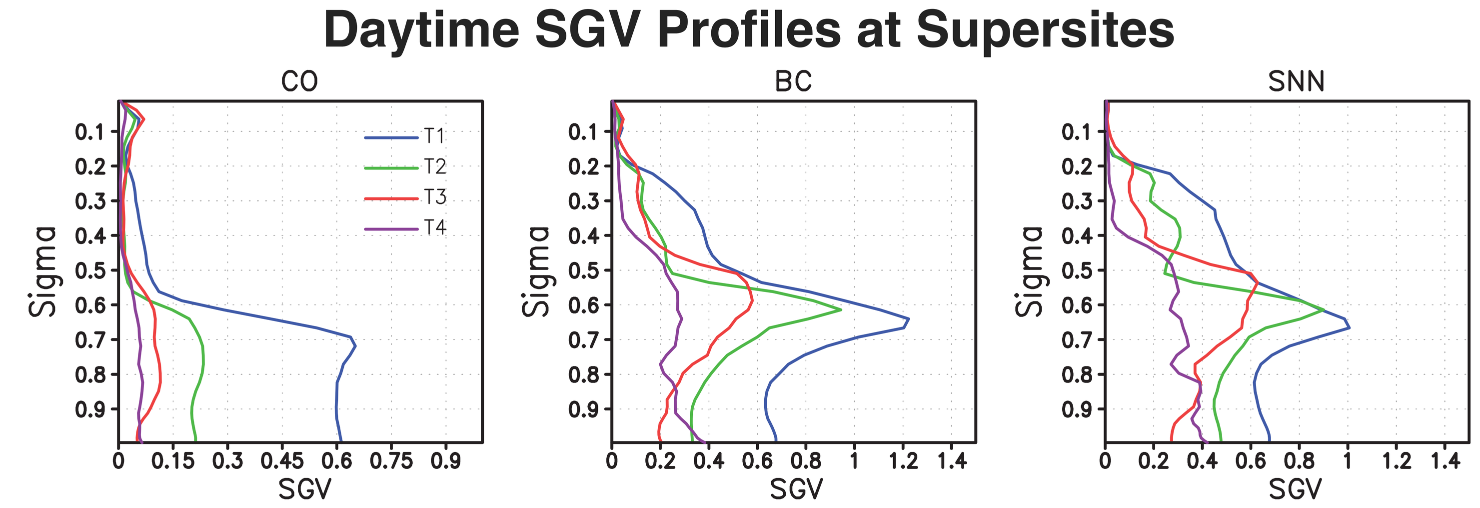


Figure 5. Sub-grid variability (SGV) for 3-km vs. 75-km domains over 5-30 March 2006 at the lowest model level. Variables shown are (a) carbon monoxide, (b) black carbon, and (c) secondary aerosol species.

Daytime SGV Profiles at Supersites



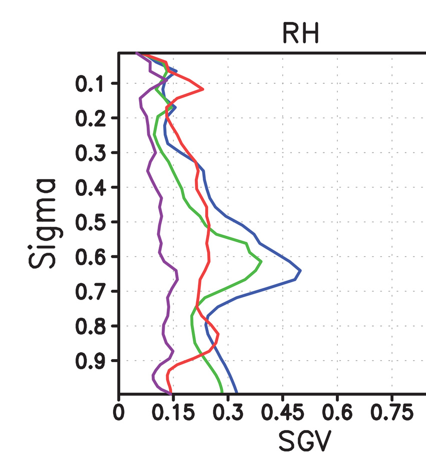


Figure 6. Profiles of sub-grid variability (SGV) for 3-km vs. 75-km domains over 5-30 March 2006 calculated at 15 local time (daytime). The four sites are indicated in Figure 2 and represent successively more remote locations from the main Mexico City emission region.

Results: SGV varies greatly by variable, height, and location:

- SGV generally largest near emissions sources
- Fluctuations in the PBL height lead to larger SGV near PBL top
- Relative to primary species, secondary species generally have lower SGV near emission regions but larger SGV farther downwind

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