Systematic Evaluation of Errors Induced by Different Spatial Grids in Regional and Global Air Quality Models

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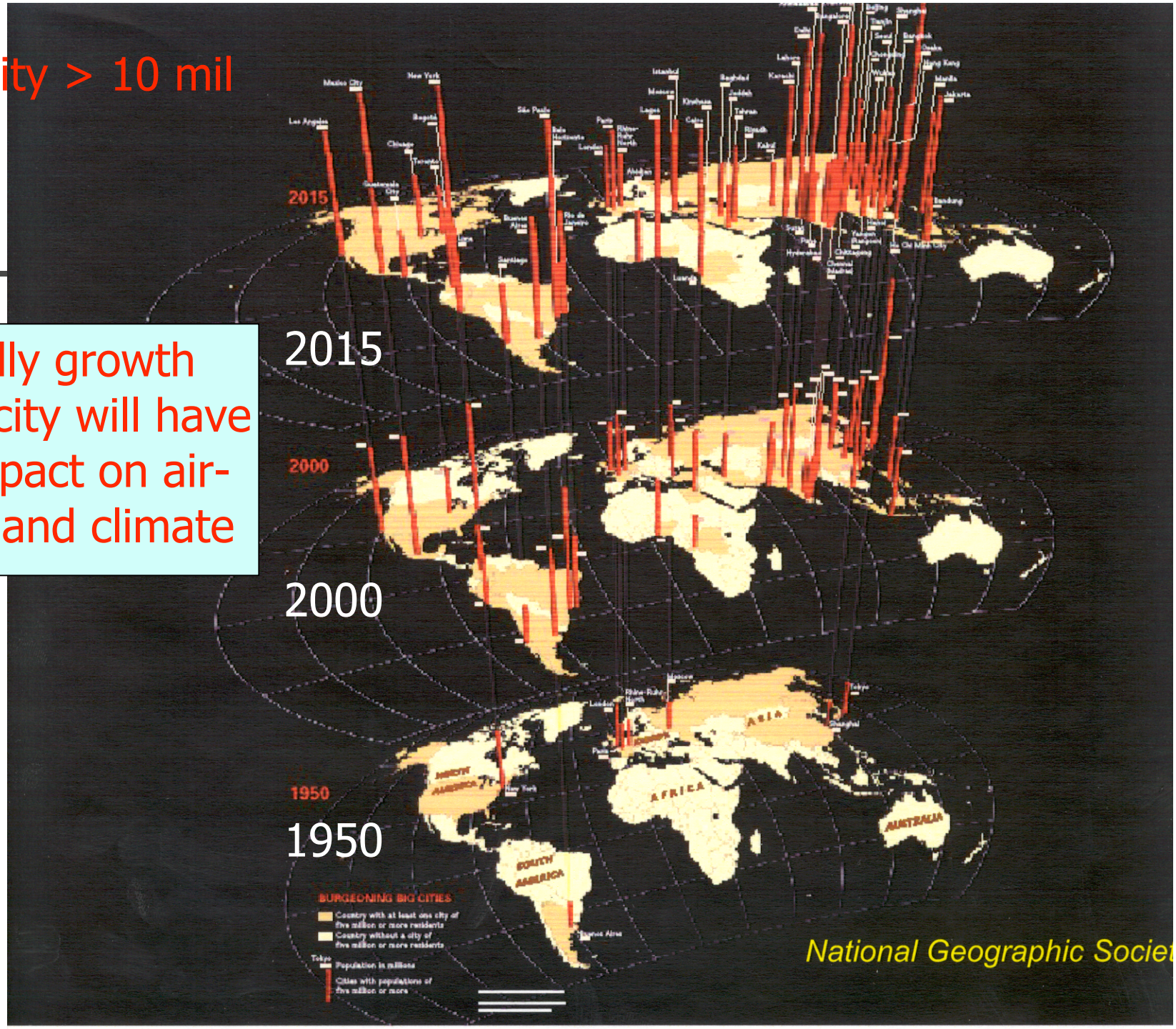
Outline

(I) Overall motivation
(II) Outline of the problem
(III) WRF-Chem regional model
(Description and results)
(IV) Scientific issues
(V) Summary

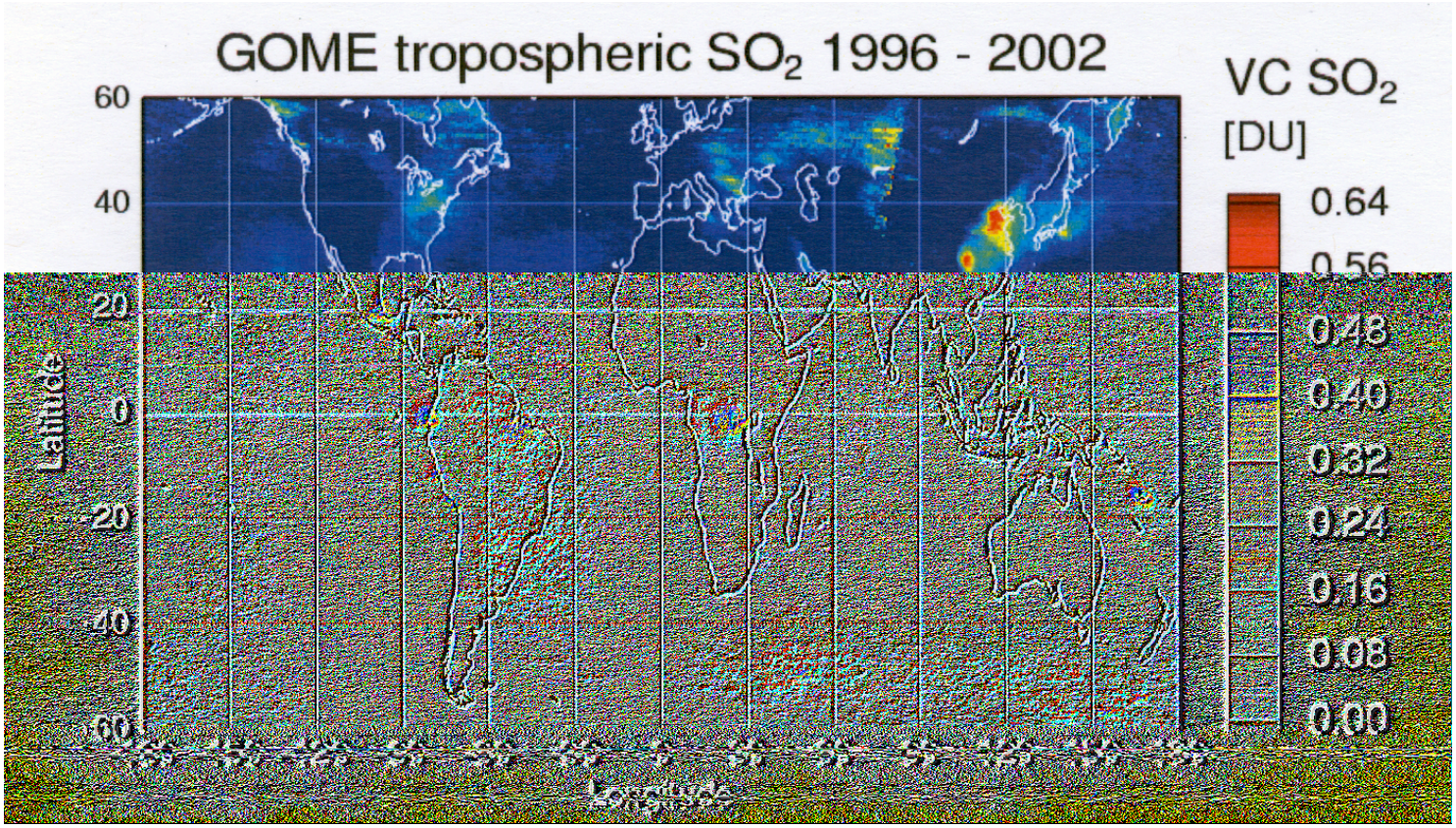
(I) Overall Motivation

Mega City > 10 mil

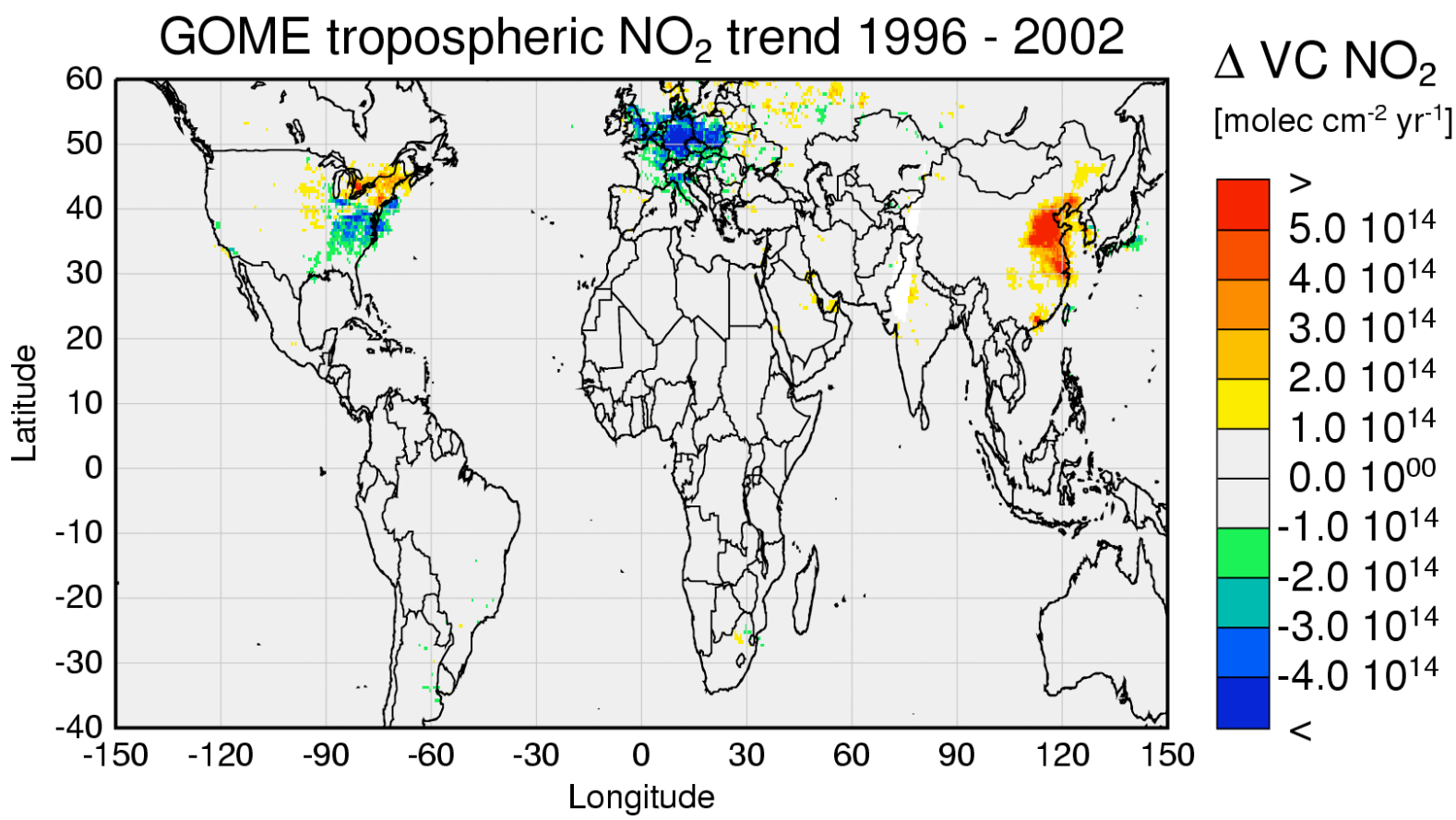
The rapidly growth in mega city will have global impact on air-pollution and climate



Satellites are beginning to detect high pollution levels near urban areas



The air pollution rapidly increases in the newly developed mega cities such as in Eastern Asia.



Megacity air pollution is a regional and global problem.

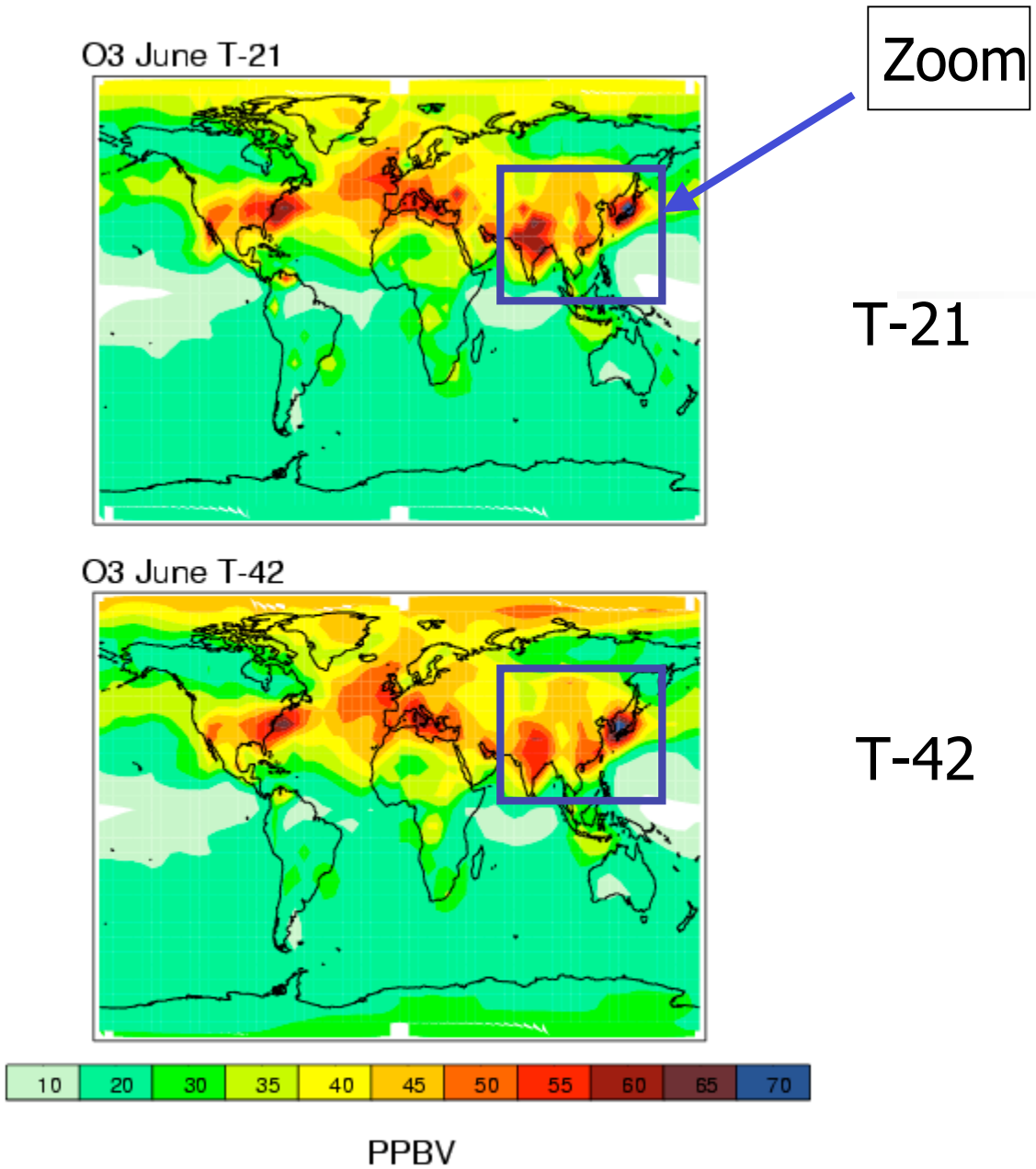
Questions:

(1) How do the mega cities affect regional air quality and ultimately global chemistry?

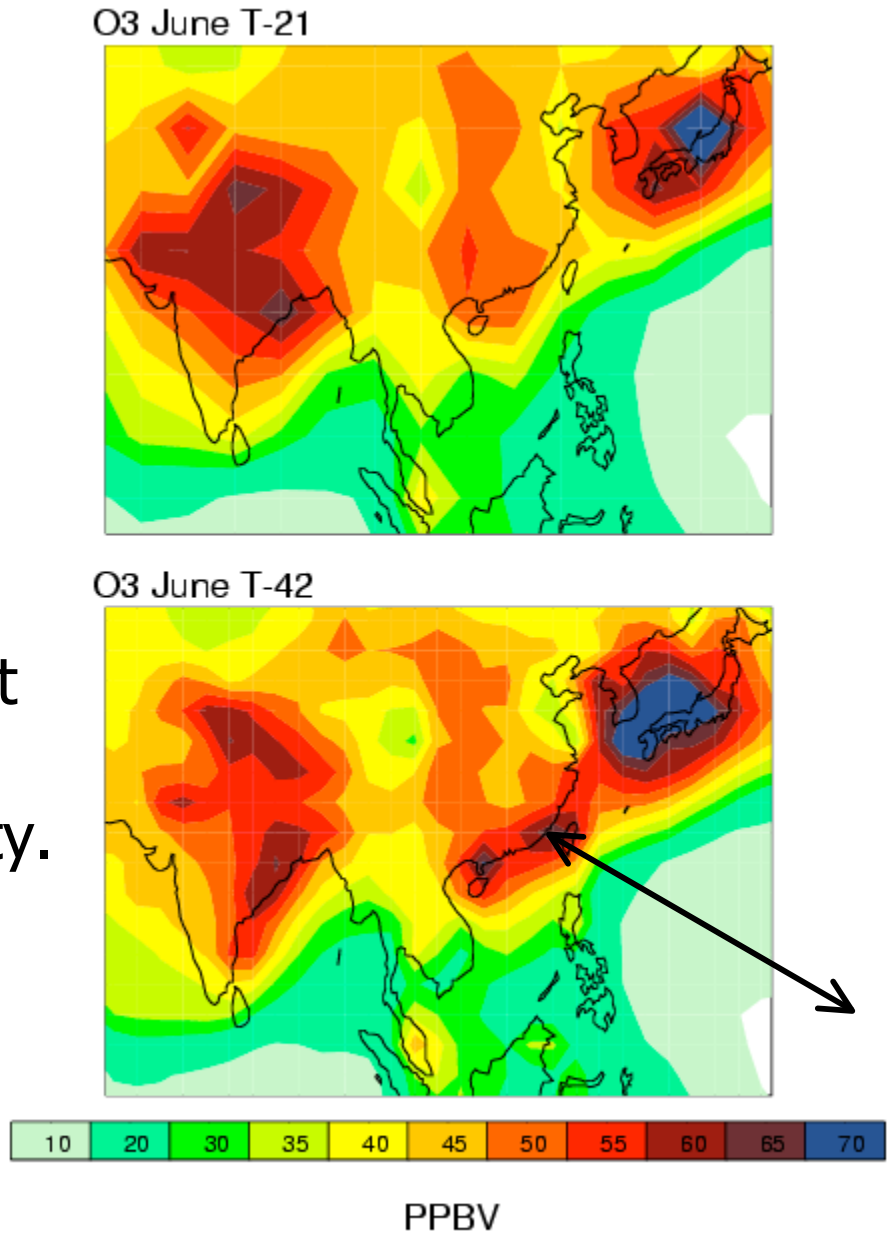
(2) How does megacity air pollution affect the local dynamics (CCN, cloud, convection, etc.) → climate?

(3) Can we use a global chemical transport model to calculate regional air quality? How much error is induced when a coarse-resolution global model is used to predict the regional air quality?

MOZART-2 Runs
Surface O_3 in June



Grid resolution significantly affect the prediction of regional air-quality.



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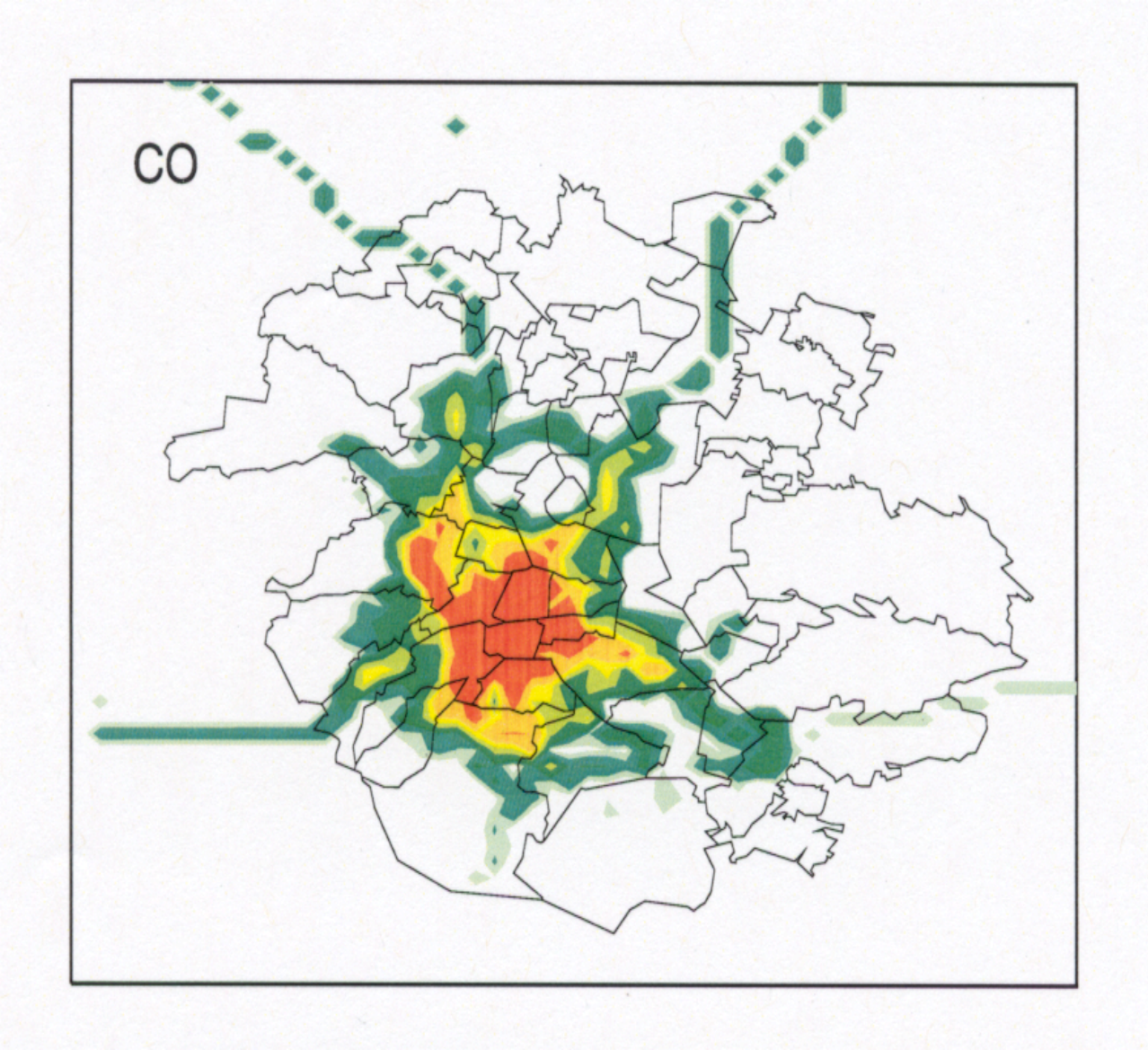
Large city

(II) Outline of the problem

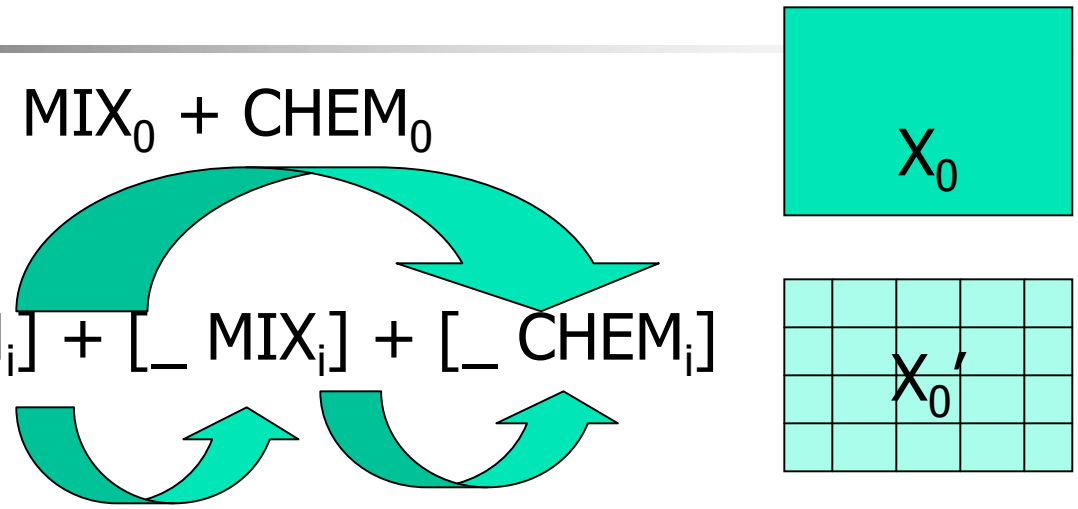
A coarse grid (1x1 degree) with 4x4 km resolution emission in Mexico City area



X_0 = averaged concentration in a coarse cell
X_0' = averaged concentration in a coarse cell with fine resolution

(Coarse) $X_0 \sim EM_0 + MIX_0 + CHEM_0$

(Fine) $X_0' \sim [_\ EM_i] + [_\ MIX_i] + [_\ CHEM_i]$



Because of the non-linearity of chemistry and non-uniformed mixing in the sub-grids

$$X_0 \neq X_0'$$

Example: the non-linear ozone chemistry

[Liu et al.,1987]

$$T[O_3] = E_{NOx}\, P[O_3]/L[NO_x] = E_{NOx}\, _[O_3]$$

Where ozone production efficiency

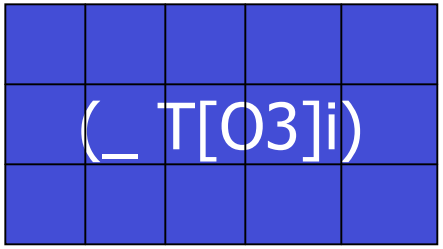
$$_[O_3] = kr/kn\ [RH]/[NO_2]$$

$T[O_3]$

$E_{NOx} = (_E_{NOxi})$

$_[O_3] \neq (_\ _[O_3]_i)$

$T[O_3] \neq (_\ T[O_3]_i)$



(III) Main Tool - Regional Chemical/transport model WRF-Chem

Meteorology: On-line calculated from the WRF model

Chemistry: RADM-2 chemistry with on-line photolysis (TUV) (36 species, including ethene, alkane, olefins, isoprene, toluene, xylene etc.)

Aerosols: Black carbon, sulfate, organic carbon, and nitrate (three modes and three moments)

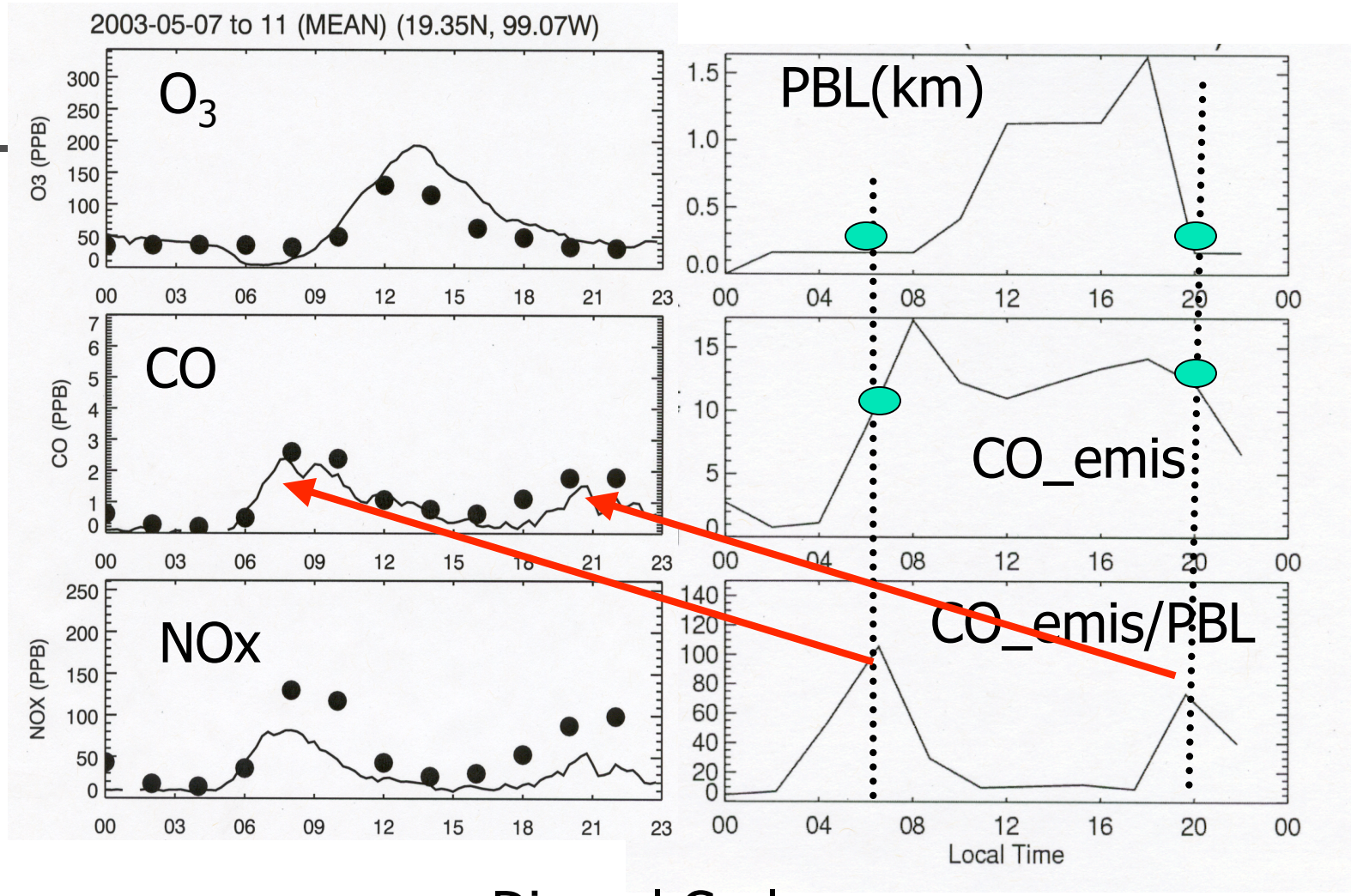
Other processes

Advection, Convection, Boundary Layer Diffusion
Dry and wet deposition, Surface Emissions

Advantages:

The fine temporal resolution of dynamics is consistent with the chemical calculation and easy to change resolution.
The model is fully parallelized.
The model is also easily portable to different regions.

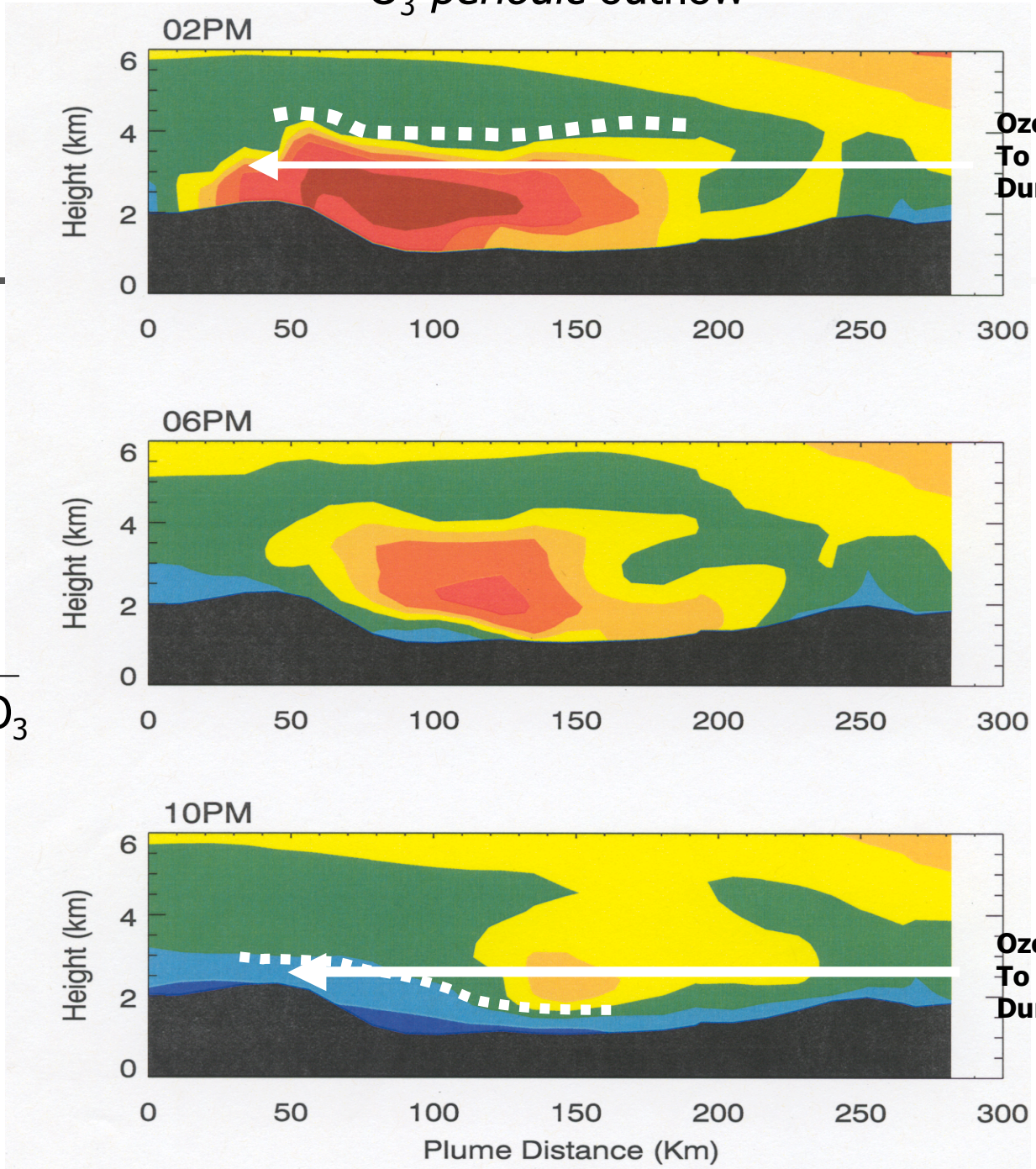
5-day Simulation in the Center of Mexico City



Diurnal Cycle

O_3 *periodic* outflow

O_3



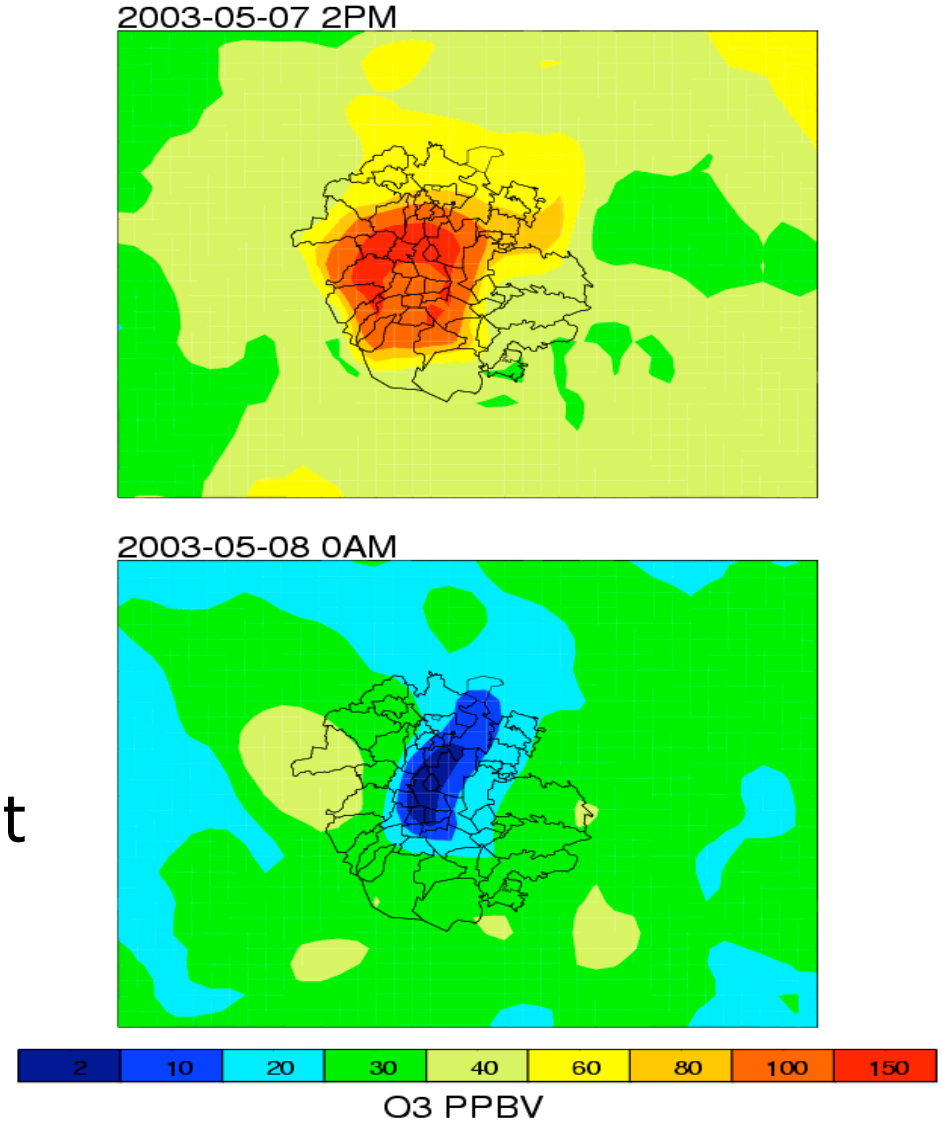
Ozone production due To NO and VOC emis During Day

Ozone destruction due To NO emission During Night

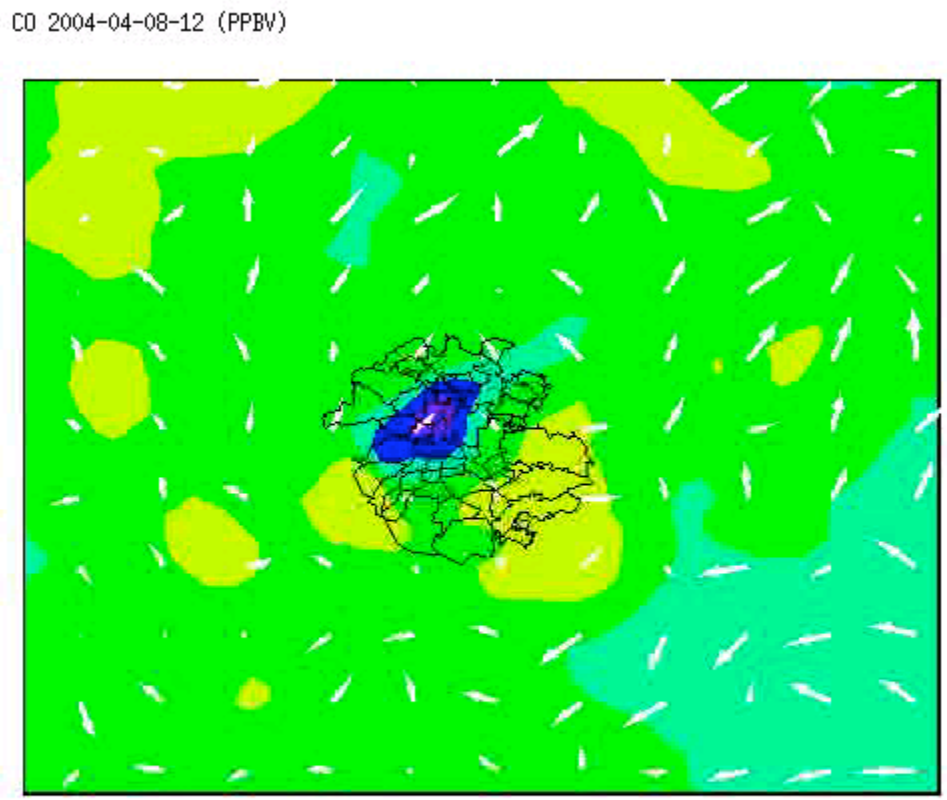
Calculated surface O_3 in Mexico City (WRF-Chem)

Day

Night



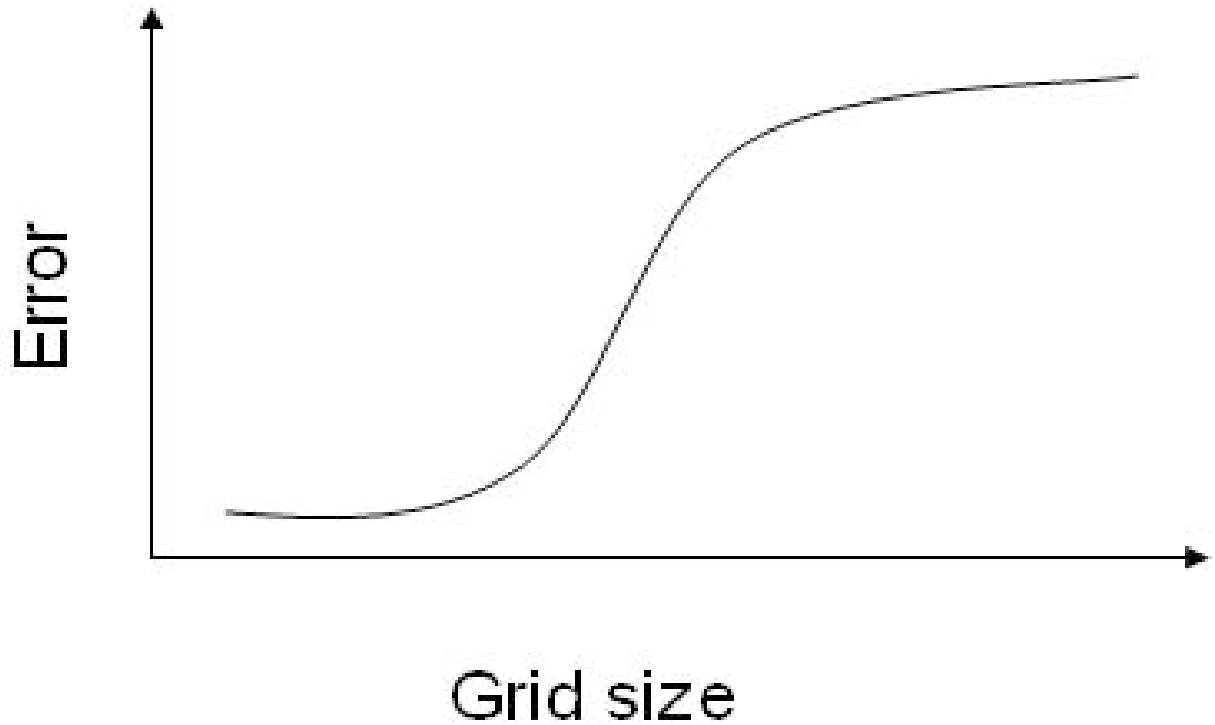
5-day simulation of O_3 movie



(VI) Scientific Issues

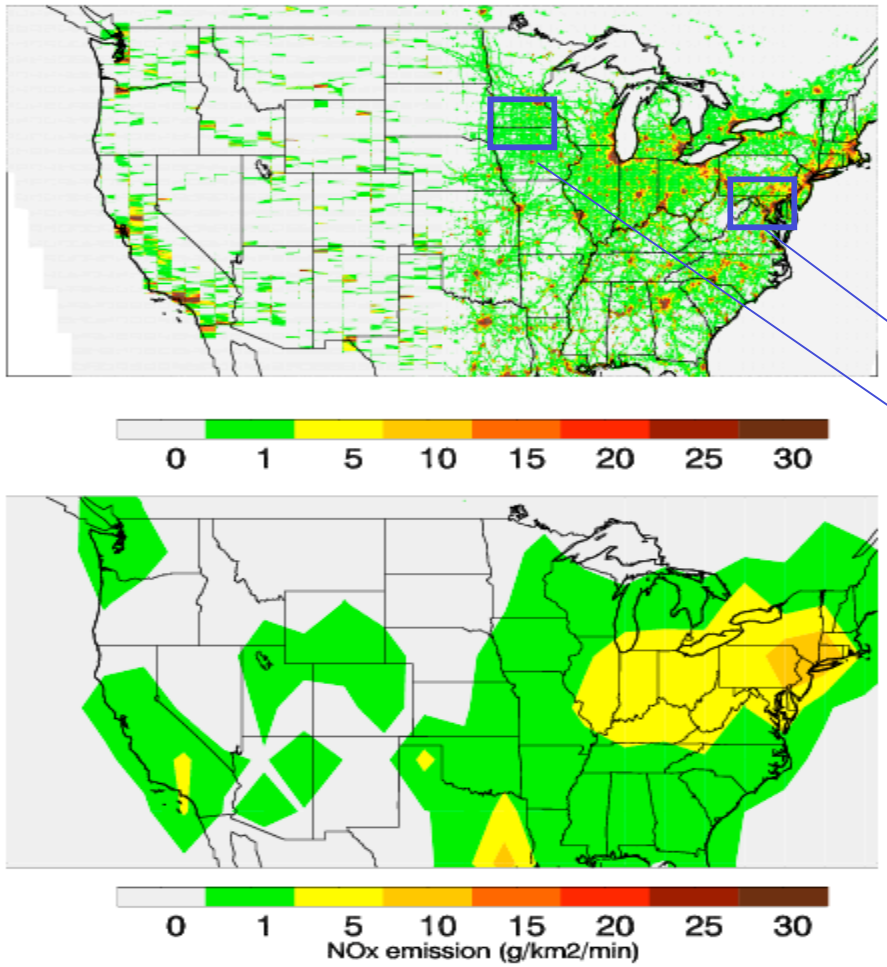
- Determine the growth of grid-related errors as the grid size of the model is increased.
- Isolate and quantify the relative contribution to grid-related errors from poorly resolved emissions and poorly resolved transport.
- Identify those geographic regions that are most likely to be impacted by grid-related errors.
- Exploratory parameterizations of sub-grid emissions and chemistry to improve the regional air-quality prediction in global models.

Try to determine the
error growth curves as a function of grid size



To run WRF-Chem with resolutions (Lf), e.g., Lf = 4, 8, 16, 32, 64 km, ... in different simulations.

Relative contribution to grid-related errors from poorly resolved emissions



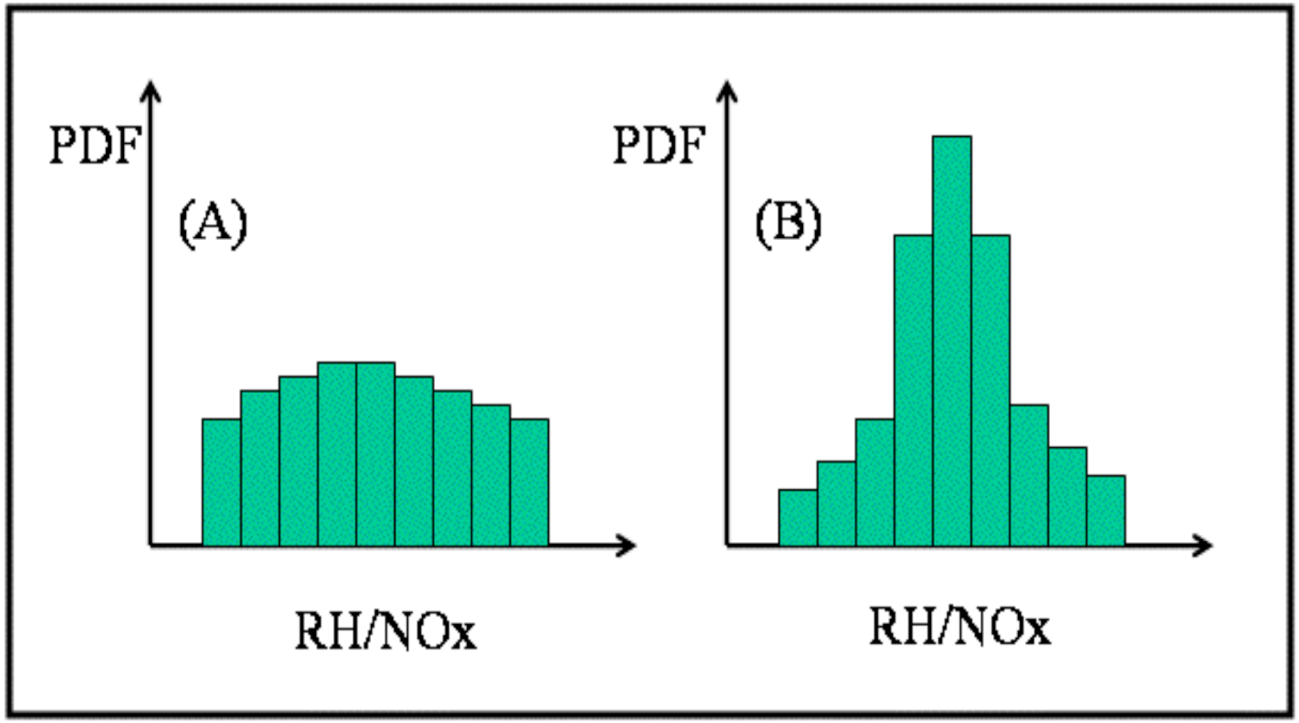
8x8 km
(6.9 TgN/yr)

(A)
(B)

2.8x2.8 Degree
(6.6 TgN/yr)

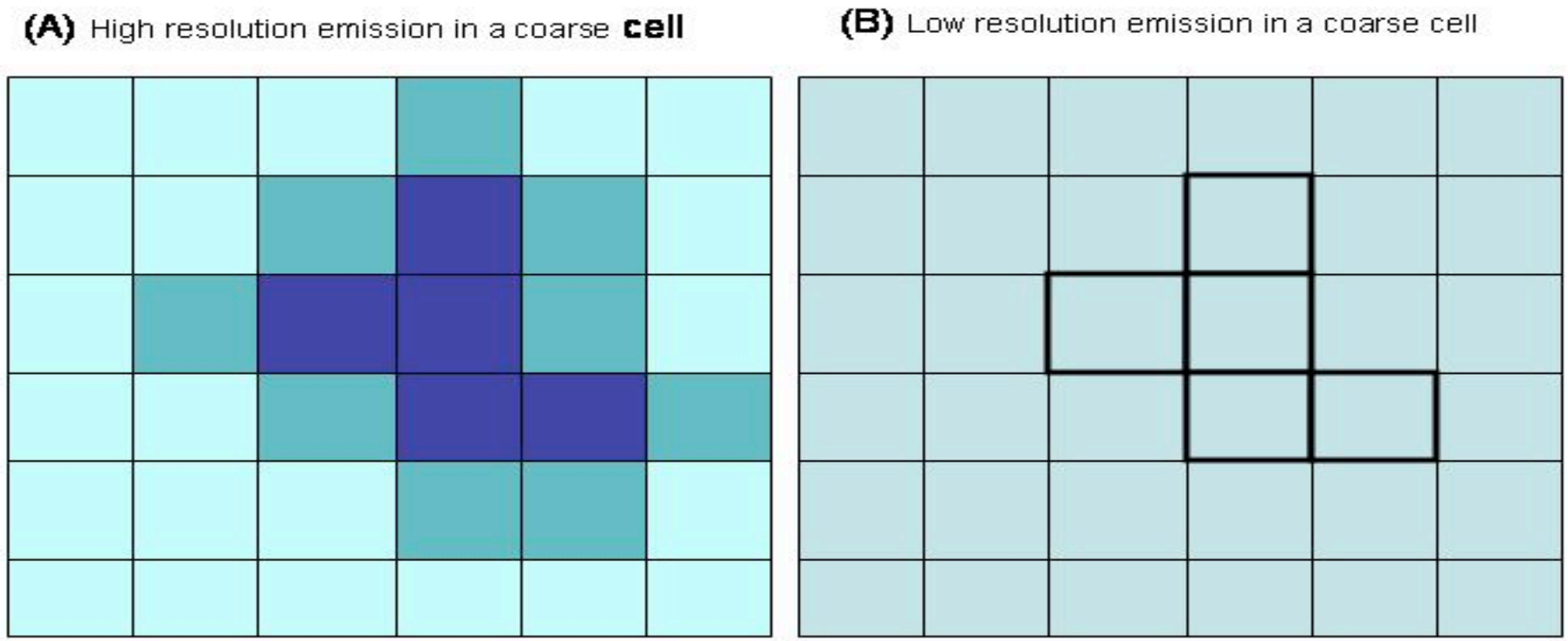
- Identify those geographic regions that are most likely to be impacted by grid-related errors.

Illustration of probability distribution functions (PDFs) of fine-grid RH/NOx (emission ratio) within a coarse grid, for two different regions.



The broad PDF of region (A) is expected to lead to more severe grid-related errors than the peaked PDF of region (B).

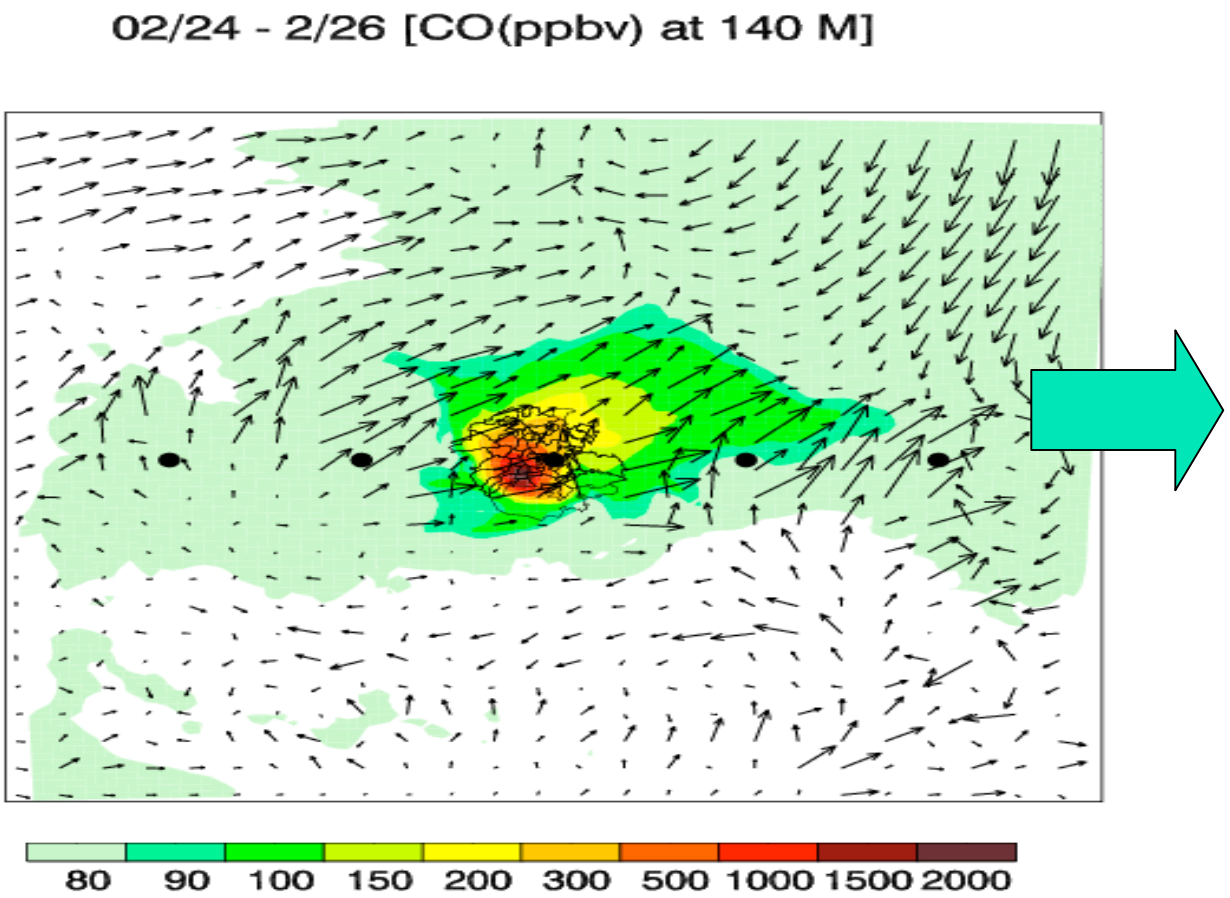
Relative contribution from poorly resolved emissions (coupled with non-linear chemistry).



Run-A
Emission in fine grid
Transport in fine grid

Run-B
Emission in coarse grid
transport in fine grid

Transport: To isolate the effects of resolution on transport, we will carry out a number of WRF-Chem simulations at different resolution, but with only non-reactive tracers being emitted and no chemical processing.



Flux with different resolution

Exploratory parameterizations of sub-grid emissions and chemistry

Effective emission factors: Assumption: the chemical loss is roughly equal to the emission EM in a large grid cell:

$$EM \sim LOSS$$

For fine grid resolution (averaged in the same large cell)

$$EEM \sim _(LOSS_i)$$

Because $_(LOSS_i) \neq LOSS$, $EEM \neq EM$. EEM = effective emission

Then an emission modification function f will be calculated as

$$f = EEM/EM = _(LOSS_i) / EM$$

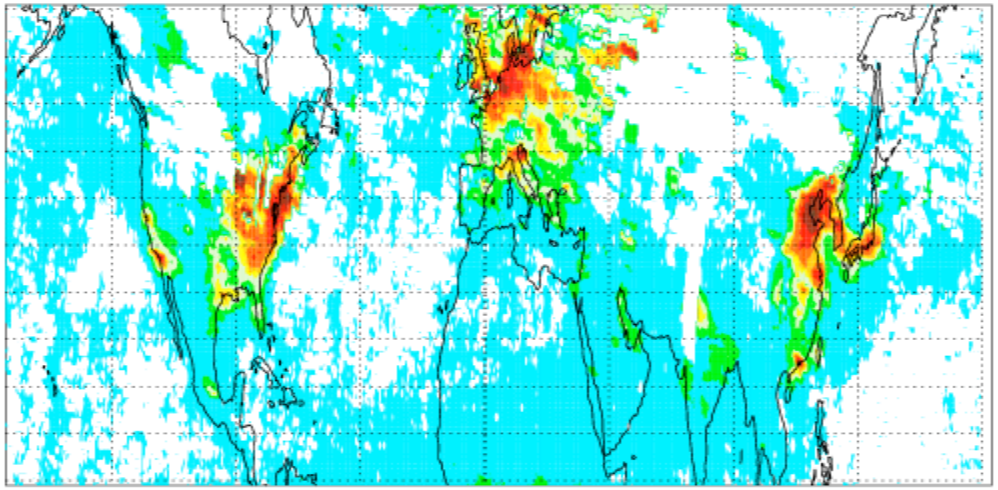
The value of f will be a function of sub-grid resolution, location, season, PDF, etc.

To construct maps of the emission modification factor f for both NOx and RH emissions.

A similar modification function f approach will also be tested for Kinetic adjustment factors: For example, the reaction $OH + NO_2 \rightarrow HNO_3$.

If either (or both) of these parameterizations yield satisfactory results in the WRF-Chem, we will implement them in global models (such as GMI). We will also compare the global model results with satellite-derived data

GOME column NO2 (DEC/2000)



Summary

- Rapidly increasing urbanization will be a major environmental driving force in the 21st century, affecting air quality on all scales – local, regional, and global.
- Because urbanization is occurring on every continent, global chemical transport models (CTMs) must be used to understand fully the impacts on tropospheric air quality. However, errors in regional air quality predictions that result from the use of coarse spatial grids in large-scale (e.g. global) chemistry-transport models need to be understood.
- Systematic evaluation of errors induced by different spatial grids in regional and global air quality models - proposed in this work.