Current Regional Air Quality Modeling Activities

10th MICS-Asia Workshop
at IIASA
February 18-19, 2008

Joshua Fu[1], Nicky Lam[1], Yuan Du[1], Roger Chuang[2], Roger Kwok[3], Qiang Zhang[6], Carey Jang[5], David Streets[6], Loretta Mickely[7], Daniel Jacob[7], Jimmy Fung[3] and Alexis Lau[3], Chung-Te Lee[2],

[1]University of Tennessee, USA
[2]National Center University, Taiwan
[3]Hong Kong University of Science and Technology, HK
[4]Tsinghai University, China
[5]U.S. Environmental Protection Agency, USA
[6]Argonne National Laboratory, USA
[7]Harvard University, USA

Current Regional Modeling Status

- **US** and East Asia **(global impacts)**
- **East Asia (O3, PM2.5, acid deposition, global impacts to Asia)**
- **YRD region (O3, PM2.5, acid deposition)**
- **Taiwan region (O3, PM2.5)**
- **PRD region (Sulfate)**

East Asia Regional Modeling Configuration

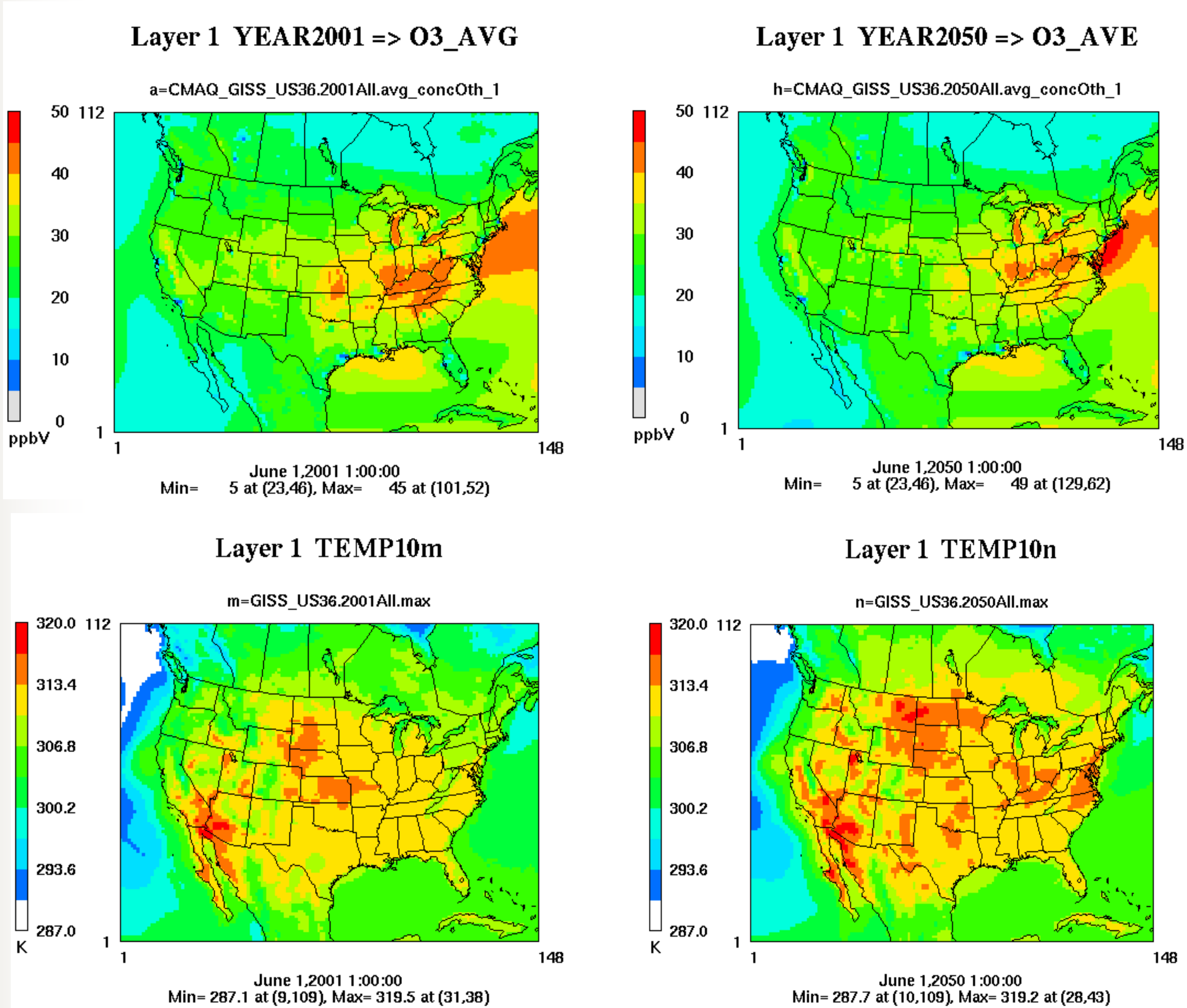
- **Features : Models-3/CMAQ One-Atmosphere (multi-pollutants) Modeling**
  - 2001, 2005 (2006) scenarios
  - US and Asia CMAQ Domains
- **Model Setup :**
  - NASA's TRACE-P and INTEX-B emission inventories and local emissions and GEIA biogenic emission inventory
  - Emissions Processing: Spatial allocation (GIS/Gridding) and SMOKE, Temporal, speciation needed for the M3/CMAQ simulations
  - 36-km, 12-km, 4-km and 40.5km, 13.5km, 4.5km and 1.5km, 14 and 27 vertical layers
  - Meteorology : MM5 V3.7
  - CMAQ V4.5.2 -> V.4.6.1
  - CB-IV, CB05, SAPRC99

CMAQ comparison

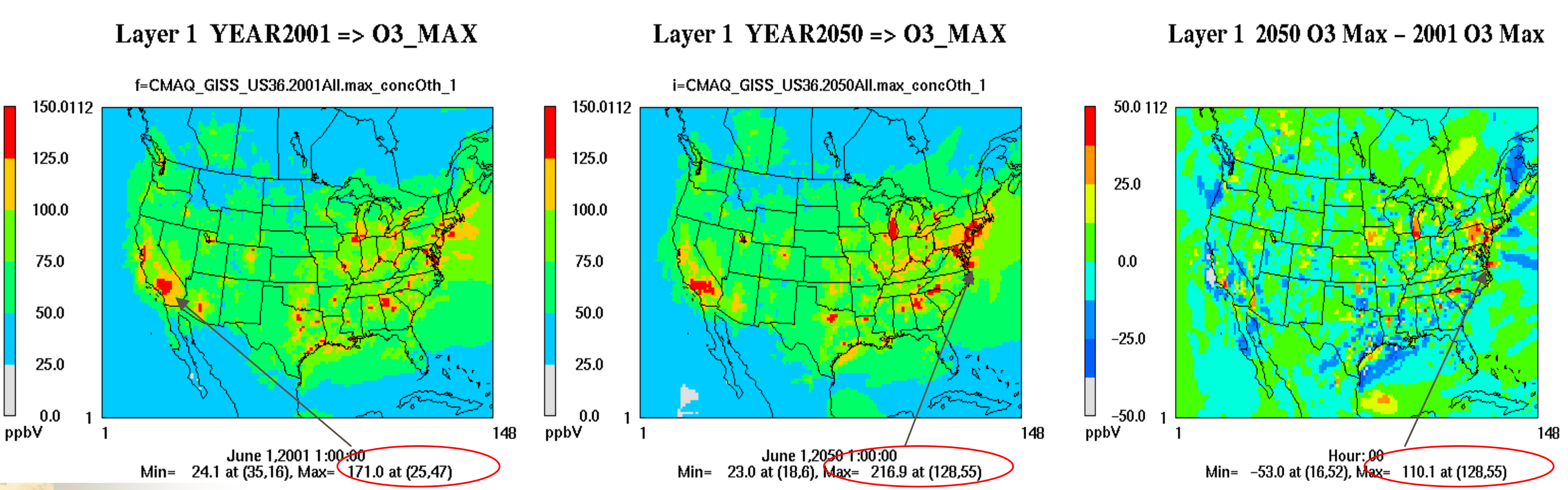
2001 GISS data

2050 GISS data

O_3 concentration vs. Temperature

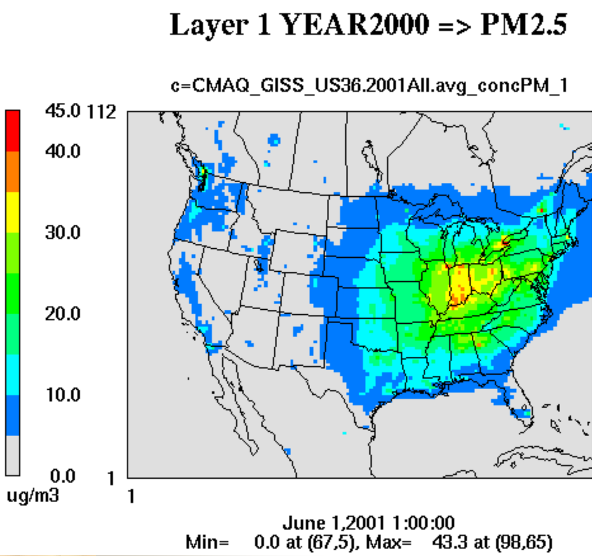


Maximum O_3

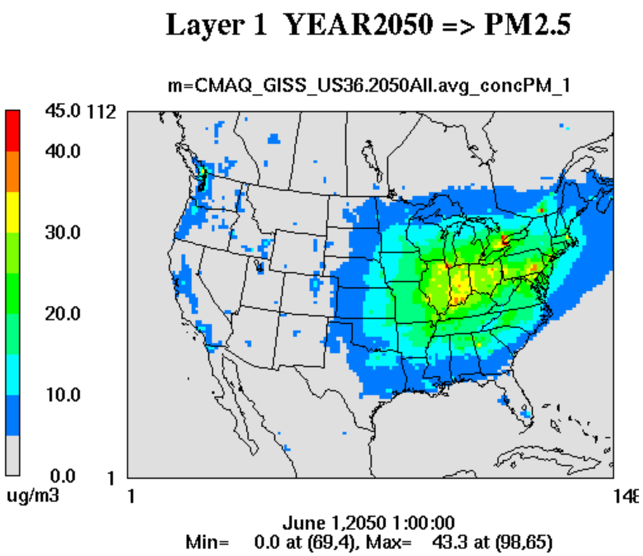


Layer 1 YEAR2001 => O3_MAX
f=CMAQ_GISS_US36.2001All.max_concOth_1
150.0112
125.0
100.0
75.0
50.0
25.0
0.0
ppbV
1
148
June 1,2001 1:00:00
Min= 24.1 at (35,16), Max= 171.0 at (25,47)
Layer 1 YEAR2050 => O3_MAX
i=CMAQ_GISS_US36.2050All.max_concOth_1
150.0112
125.0
100.0
75.0
50.0
25.0
0.0
ppbV
1
148
June 1,2050 1:00:00
Min= 23.0 at (18,6), Max= 216.9 at (128,55)
Layer 1 2050 O3 Max – 2001 O3 Max
50.0 112
25.0
0.0
–25.0
–50.0
ppbV
1
148
Hour: 00
Min= –53.0 at (16,52), Max= 110.1 at (128,55)

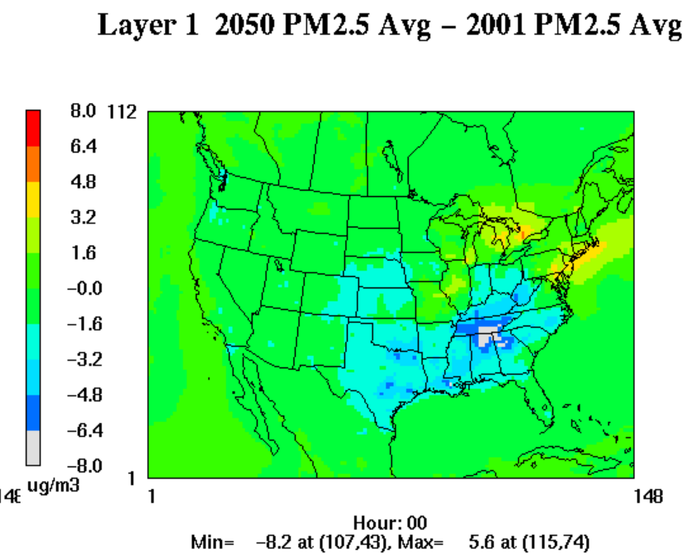
$PM_{2.5}$



Layer 1 YEAR2000 => PM2.5
c=CMAQ_GISS_US36.2001All.avg_concPM_1
45.0 112
40.0
30.0
20.0
10.0
0.0
ug/m3
1
1
June 1,2001 1:00:00
Min= 0.0 at (67,5), Max= 43.3 at (98,65)



Layer 1 YEAR2050 => PM2.5
m=CMAQ_GISS_US36.2050All.avg_concPM_1
45.0 112
40.0
30.0
20.0
10.0
0.0
ug/m3
1
1
148
June 1,2050 1:00:00
Min= 0.0 at (69,4), Max= 43.3 at (98,65)



Layer 1 2050 PM2.5 Avg – 2001 PM2.5 Avg
8.0 112
6.4
4.8
3.2
1.6
-0.0
-1.6
-3.2
-4.8
-6.4
-8.0
ug/m3
1
1
148
Hour: 00
Min= -8.2 at (107,43), Max= 5.6 at (115,74)

Average O3 Concentration

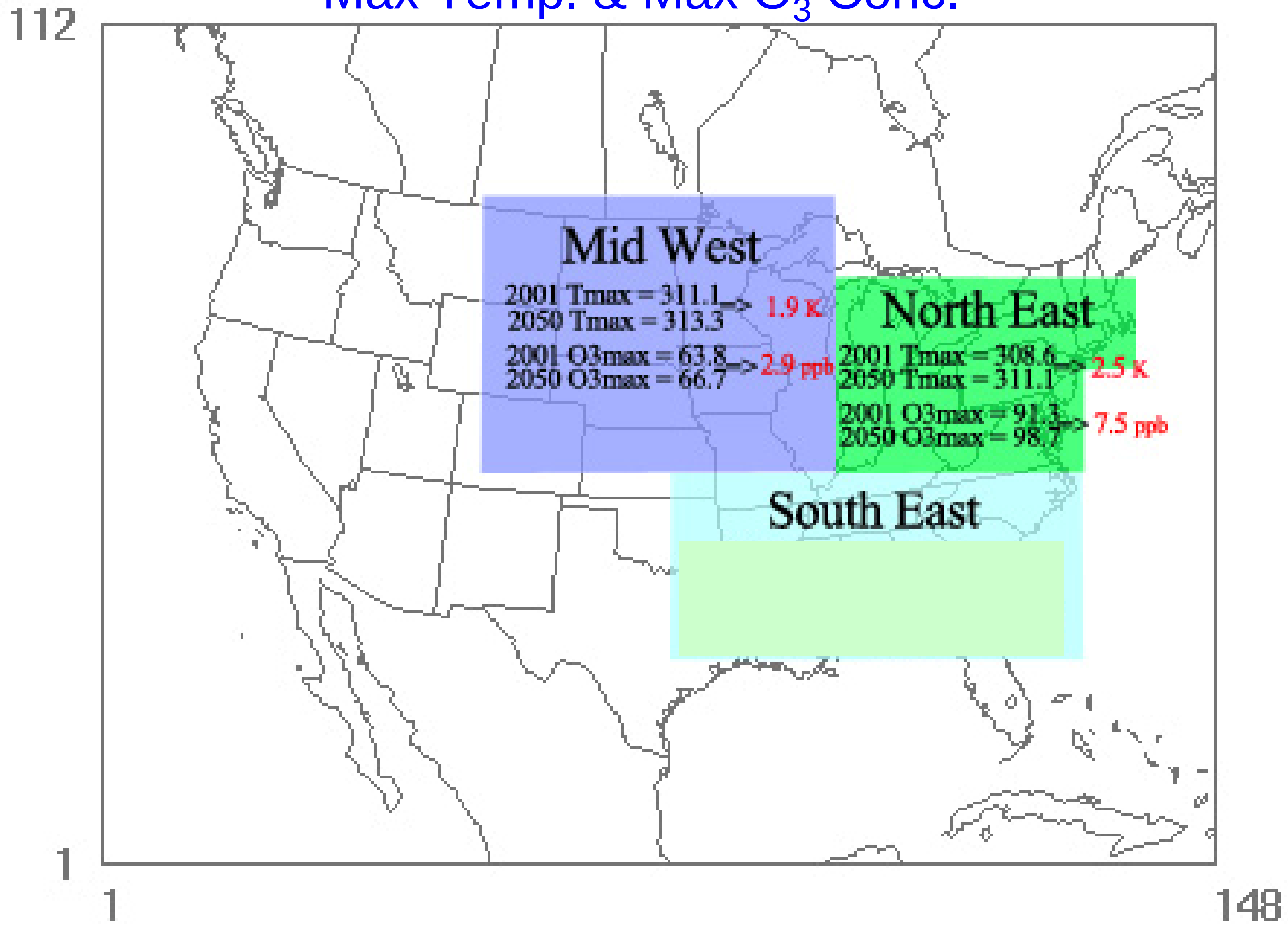
	Mid West	North East	South East	Full Domain
2001_Temp_AVG	299.4	298.6	302.7	297.4
2050_Temp_AVG	300.8	300.2	303.6	298.5
Diff	1.4	1.7	0.8	1.1

Maximum O3 Concentration

	Mid West	North East	South East	Full Domain
2001_Temp_MAX	311.1	308.6	309.9	305.6
2050_Temp_MAX	313.0	311.1	310.8	307.2
Diff	1.9	2.5	0.9	1.7
2001_O3_MAX	63.8	91.3	81.6	58.4
2050_O3_MAX	66.7	98.7	79.7	58.5
Diff	2.9	7.5	-1.9	0.1

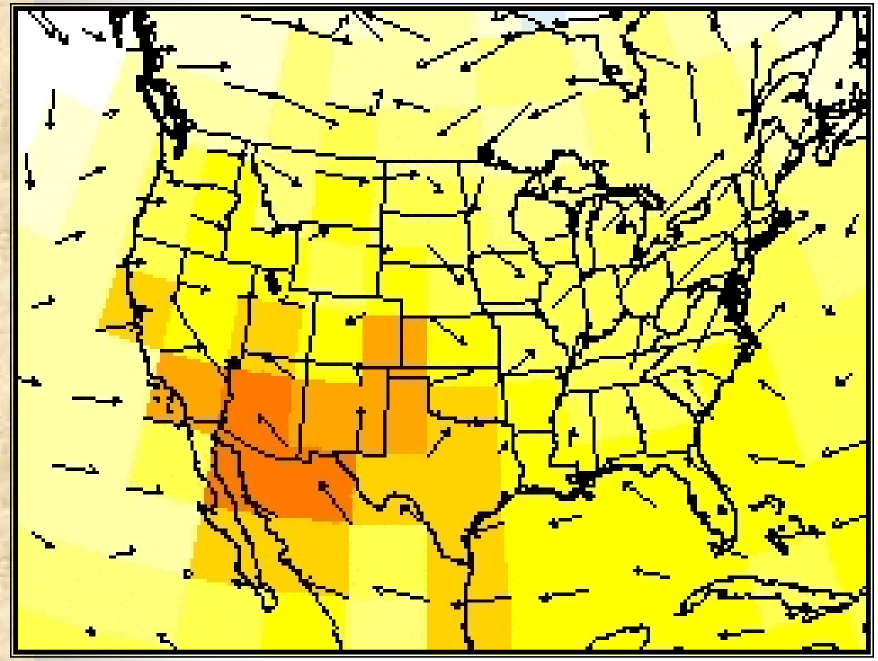
Comparison between 2050 and 2001 (2050 – 2001)

Max Temp. & Max O_3 Conc.

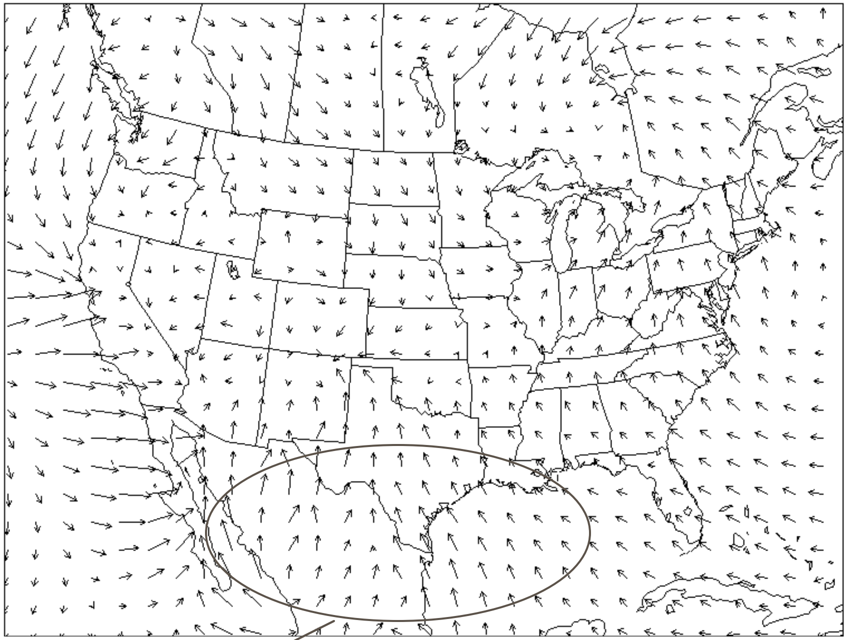


MM5 Output Comparisons - 1

GISS_Havard_20010630_00Hr_36km



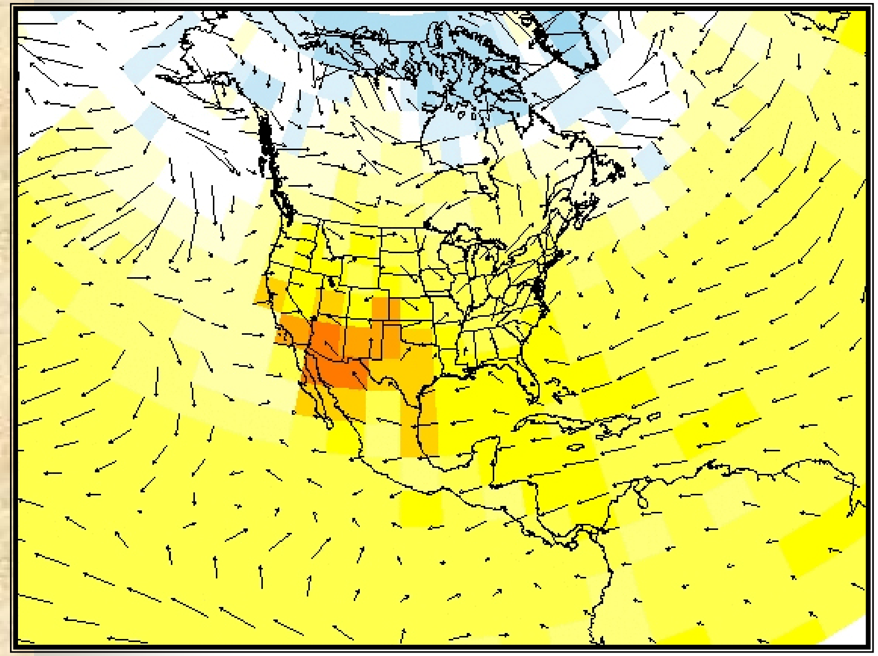
MM5_UTenn_20010701_00Hr_108km



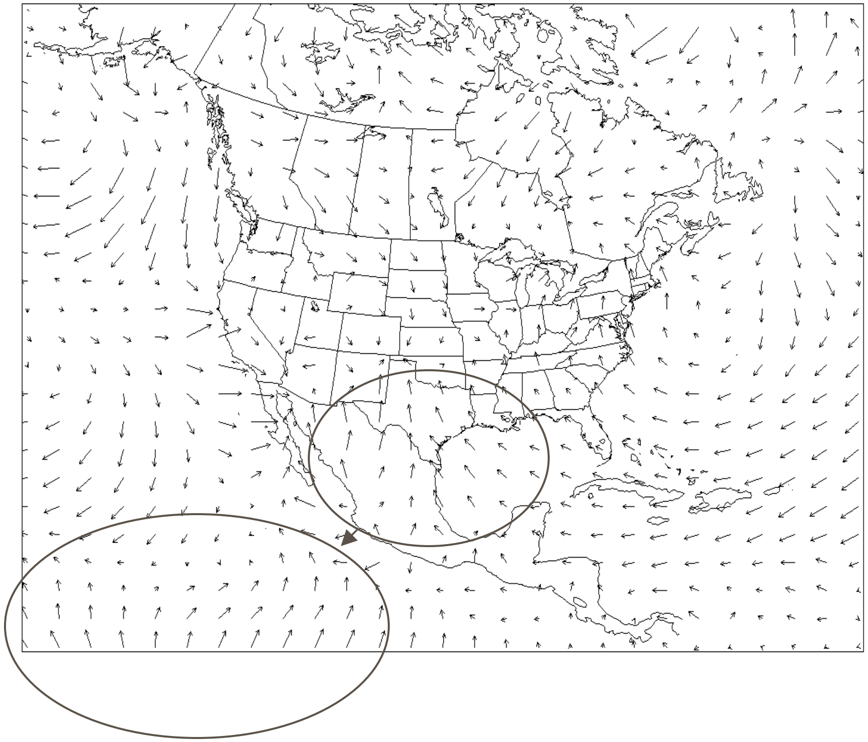
The Problem may be caused by the resolution of FDDA Data (4x5). The FDDA can not capture the actual scene of GISS data.

MM5 Output Comparisons - 2

GISS_Havard_20010630_00Hr_108km



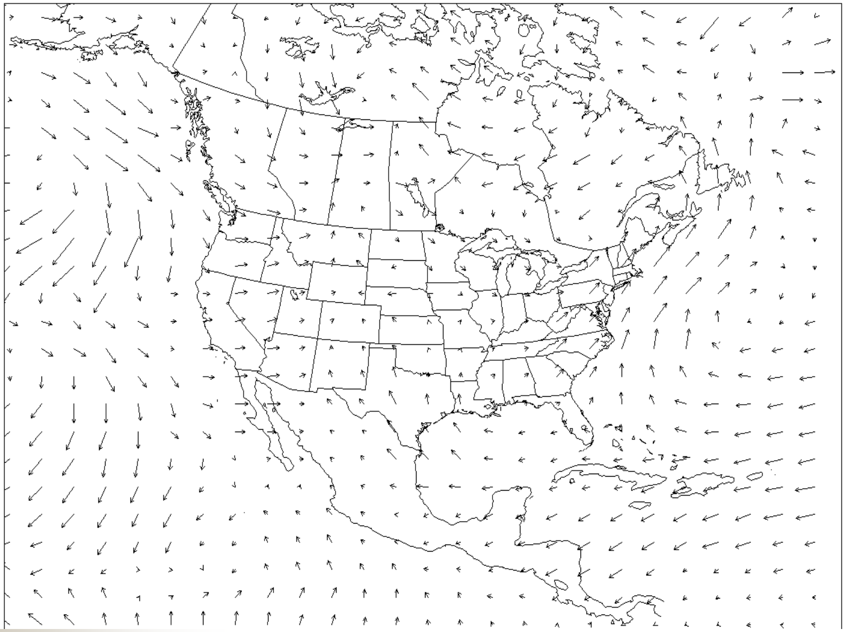
MM5_UTenn_20010701_00Hr_108km



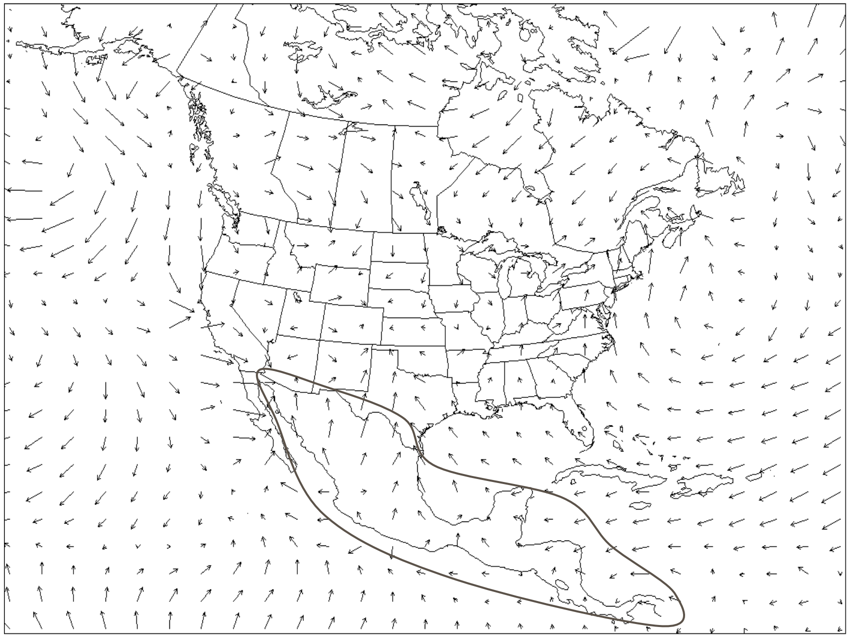
The Problem may be caused by the resolution of FDDA Data (4x5). The FDDA can not capture the actual scene of GISS data.

MM5 Output Comparisons - 3

GISS_Havard_20010701_00Hr_108km



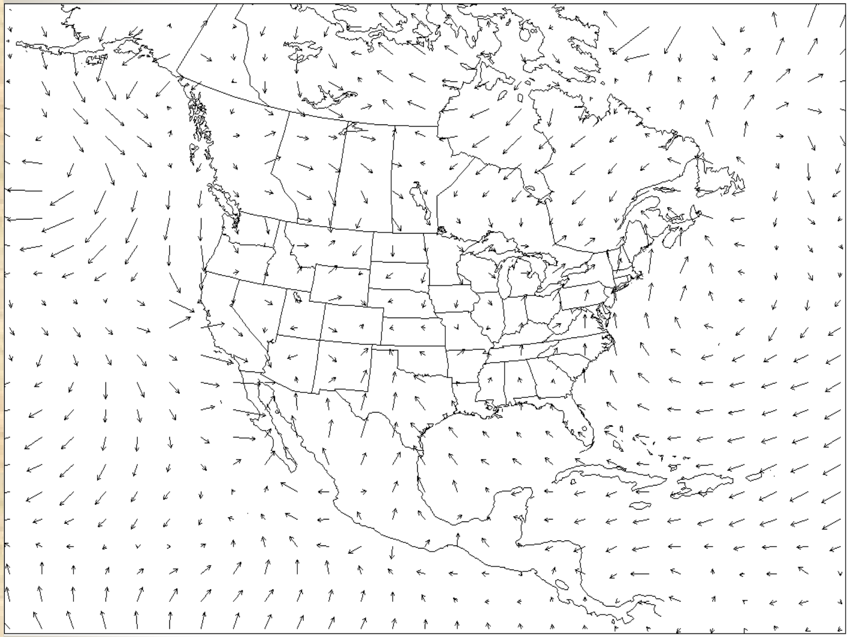
MM5_UTenn_20010701_00Hr_108km
with 0.3 x 0.3 resolution FDDA



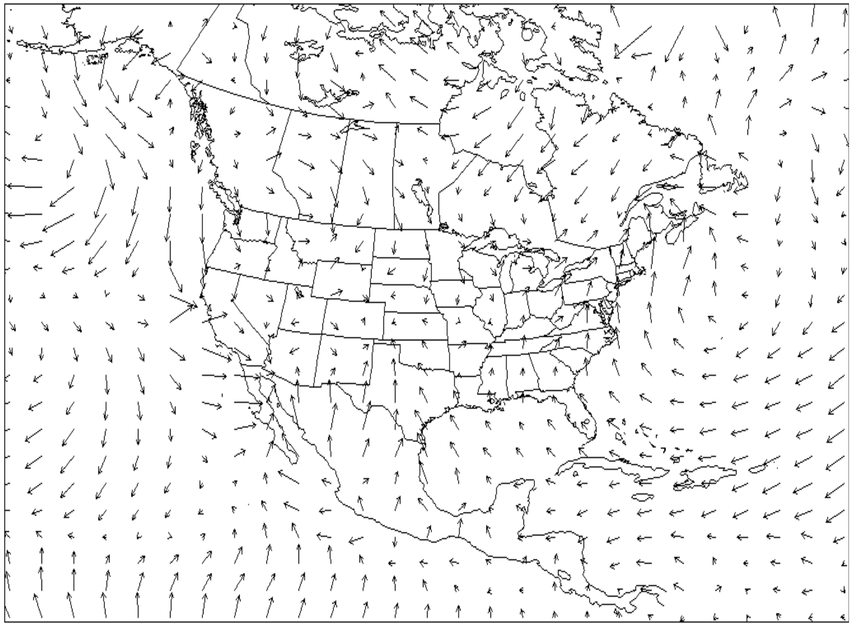
The problem is still existed, even though 0.3 x 0.3 resolution of FDDA data is used. It is believed that the land use model used in Mexico is caused the problem

MM5 Output Comparisons - 4

MM5_UT_20010701_00Hr_108km



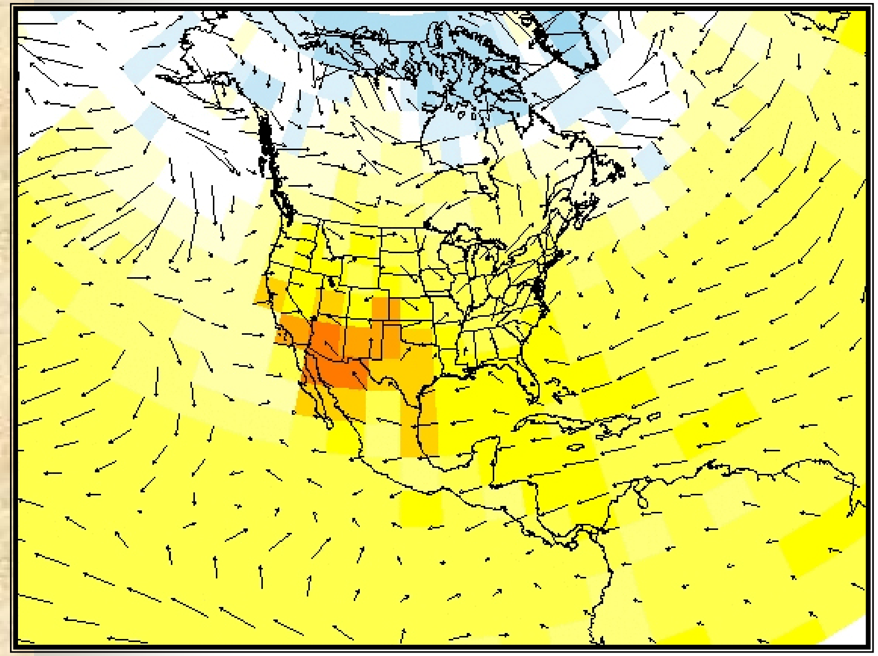
MM5_UTenn_20010701_00Hr_108km with 0.3 x 0.3 resolution FDDA _newTerrainInRegrid



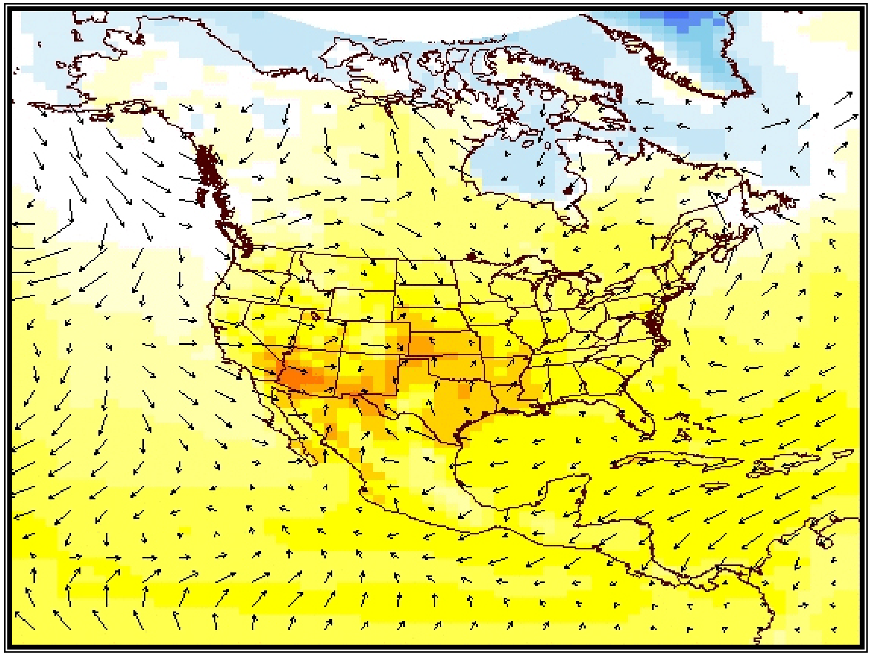
The problem is still existed, even though 0.3 x 0.3 resolution of FDDA data is used. It is believed that the land use model used in Mexico is caused the problem

MM5 Output Comparisons - 5

GISS_Havard_20010630_00Hr_108km

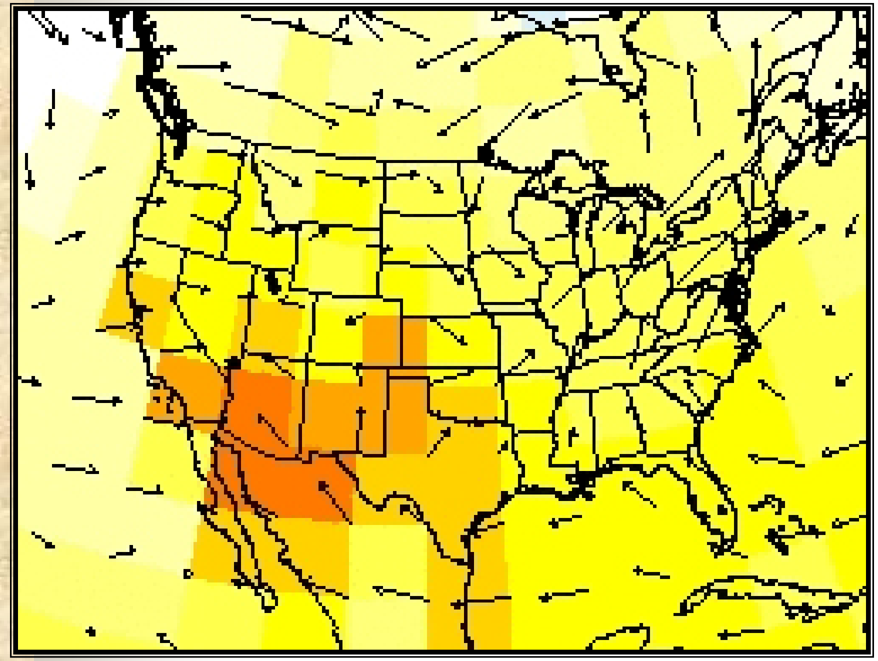


MM5_UTN_20010701_00Hr_108km

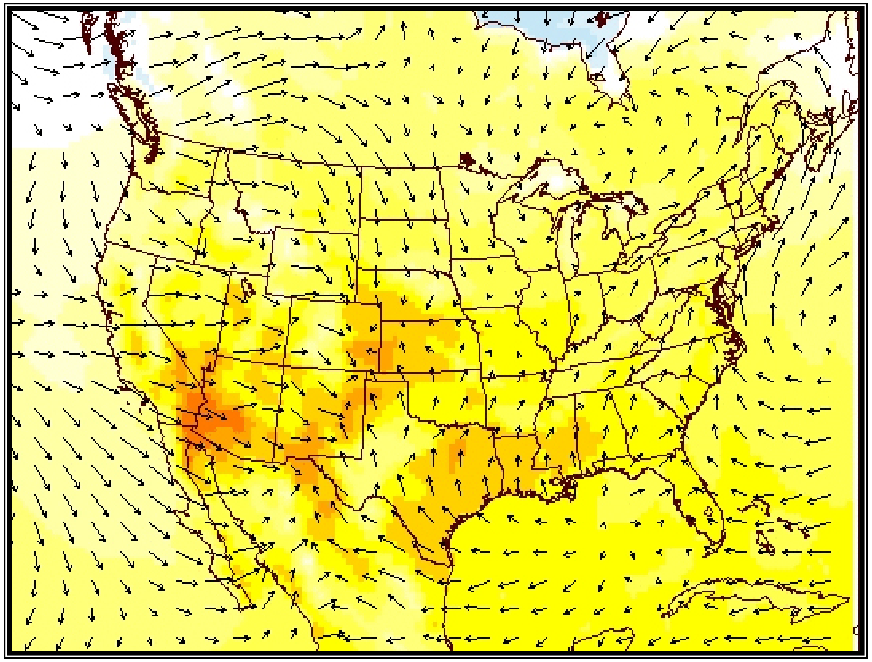


MM5 Output Comparisons - 6

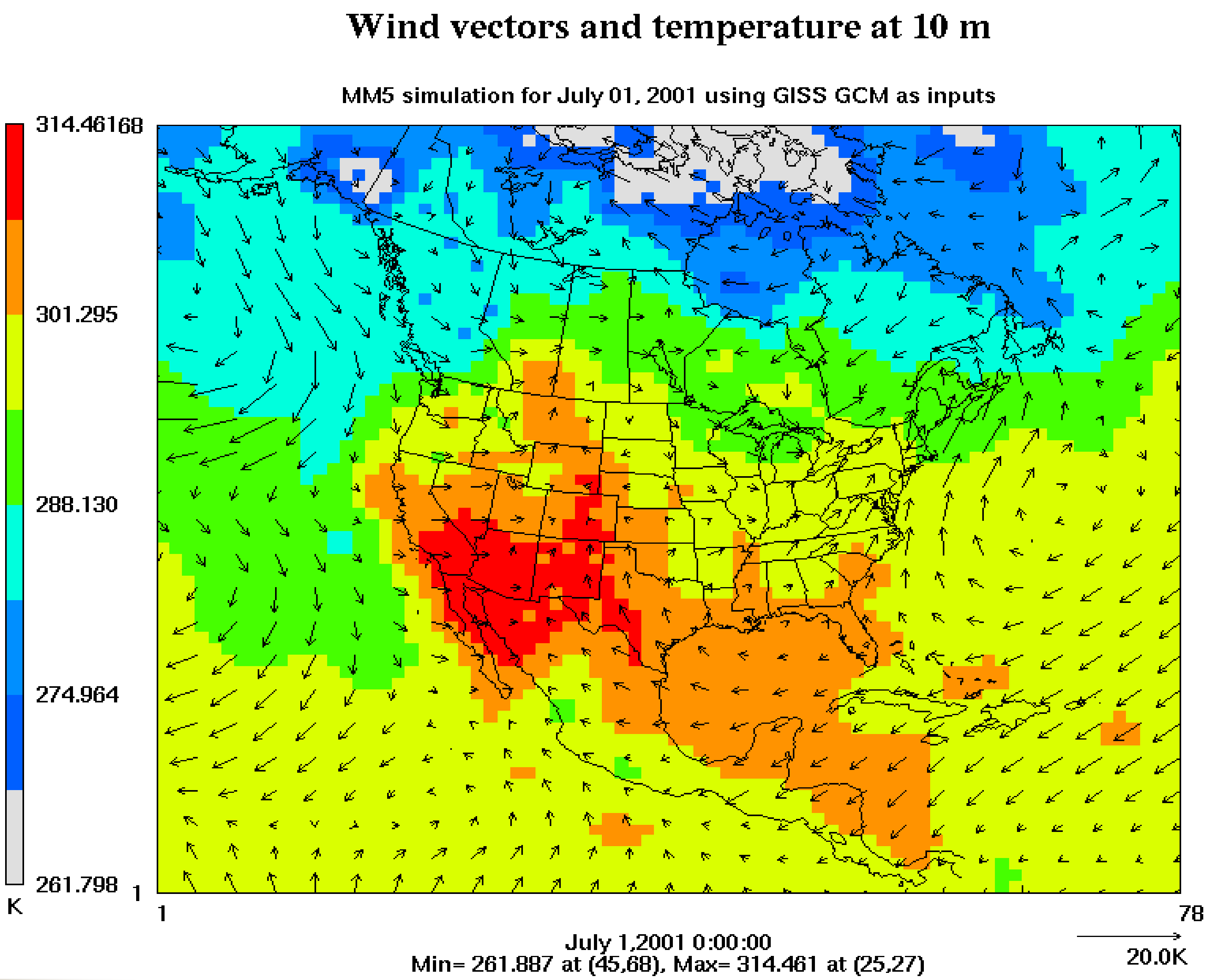
GISS_Havard_20010630_00Hr_36km



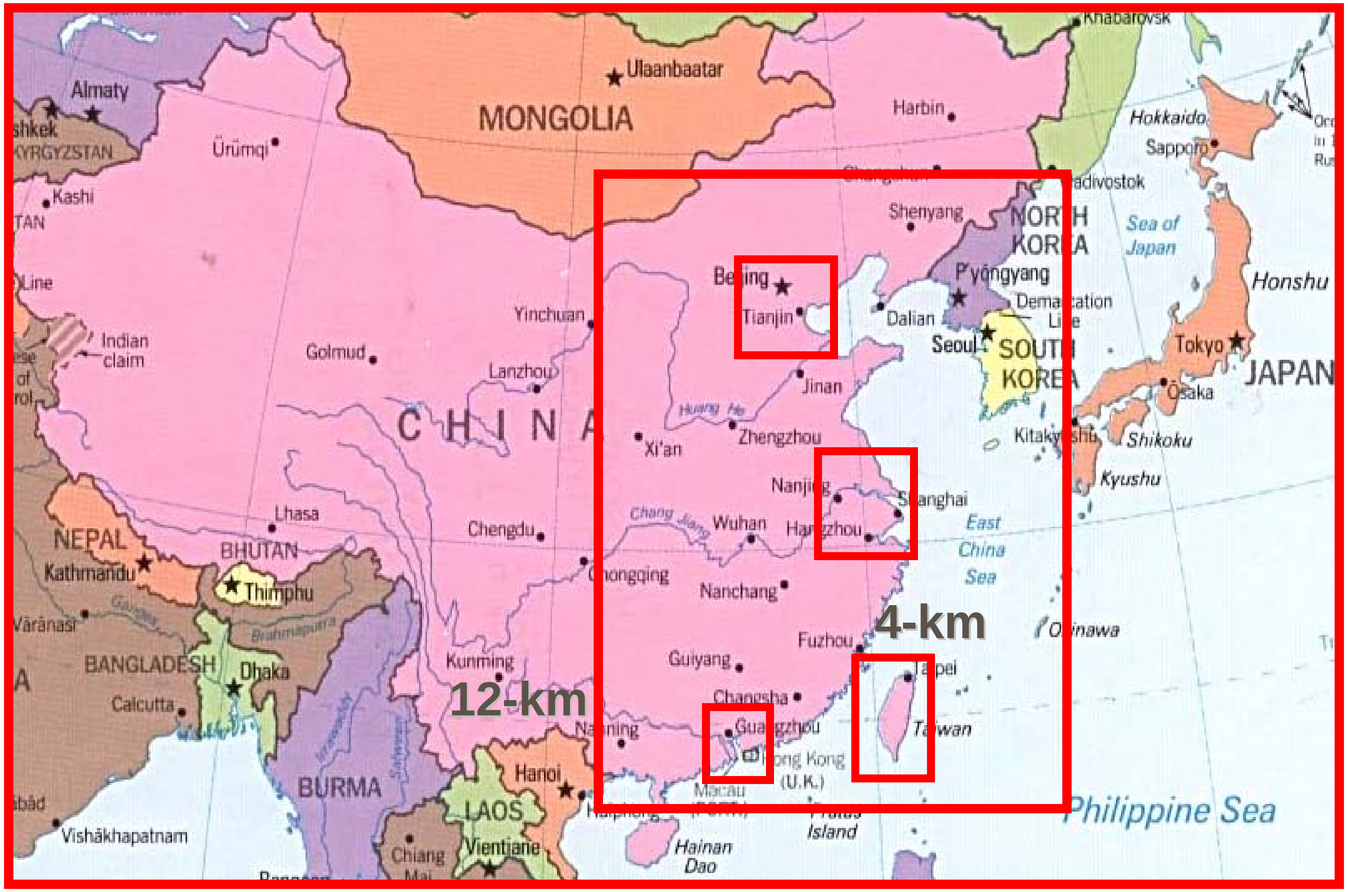
MM5_UTenn_20010701_00Hr_36km



Climatic Meteorology



Models-3/CMAQ Study Domains



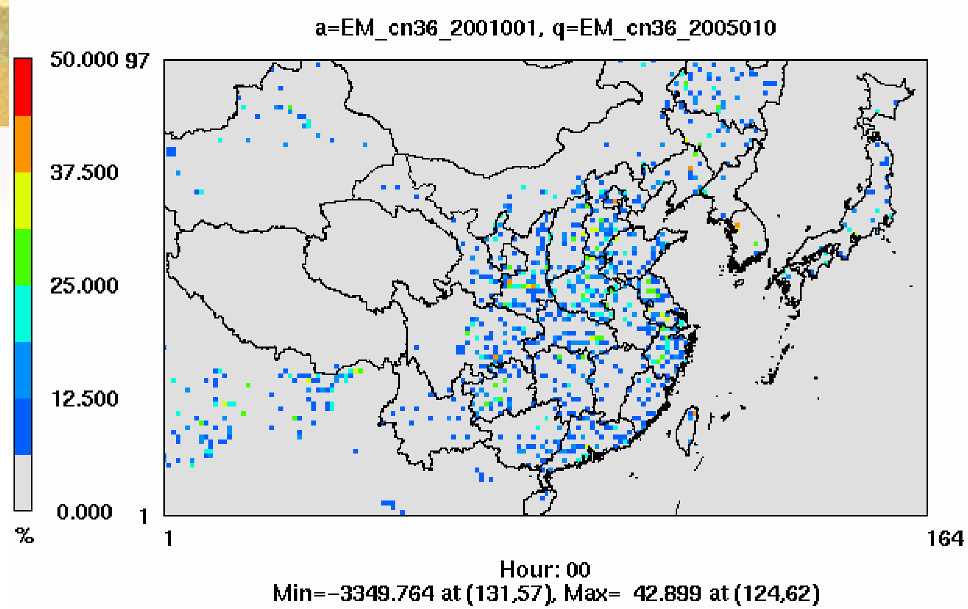
36-km

East Asia Emissions

- 2001 (2000)
- 2005 and 2006
- Comparisons

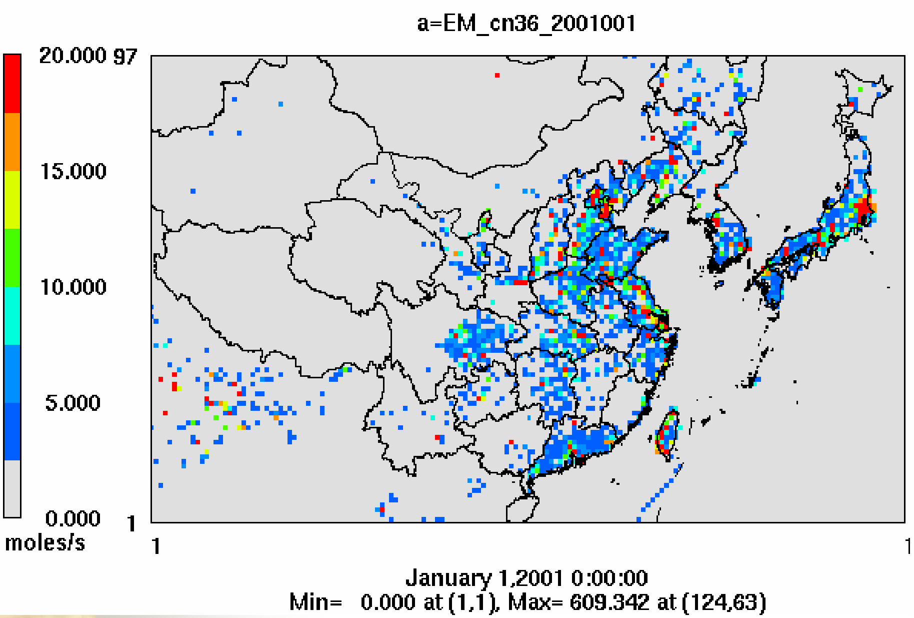
NO_x

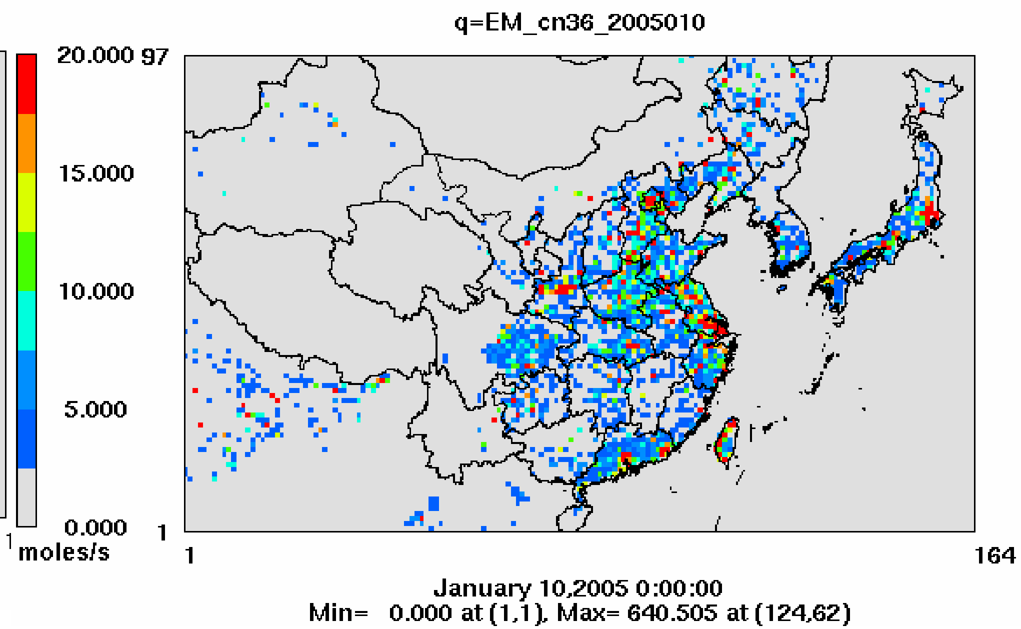
2001 vs. 2005



1-14-layer average:Layer 14 (NOa+NO2a)*14

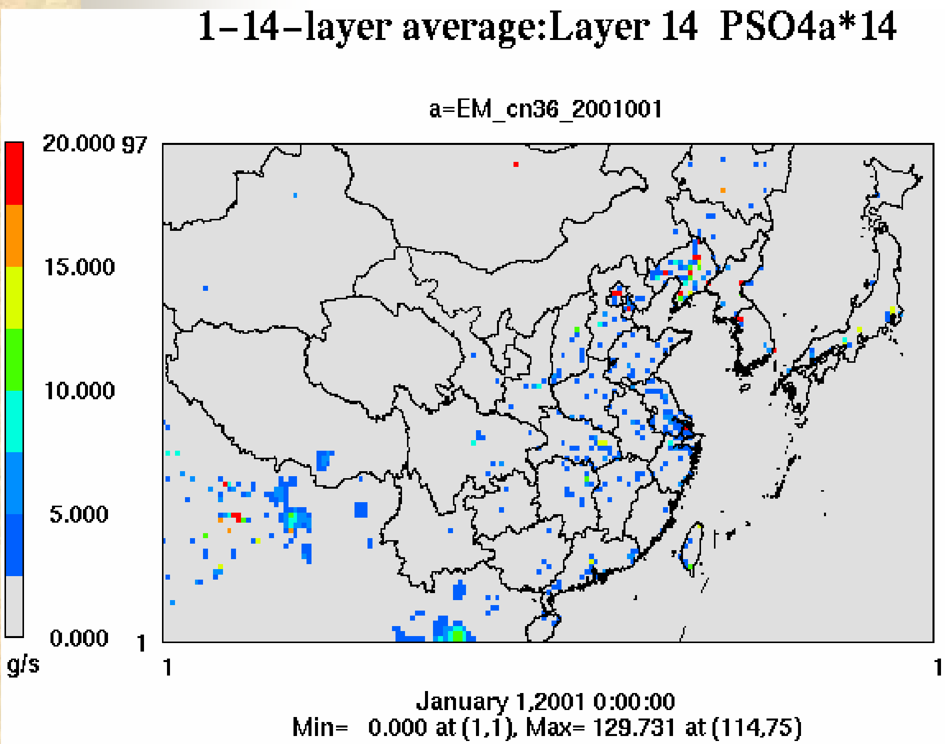
1-14-layer average:Layer 14 (NOq+NO2q)*14

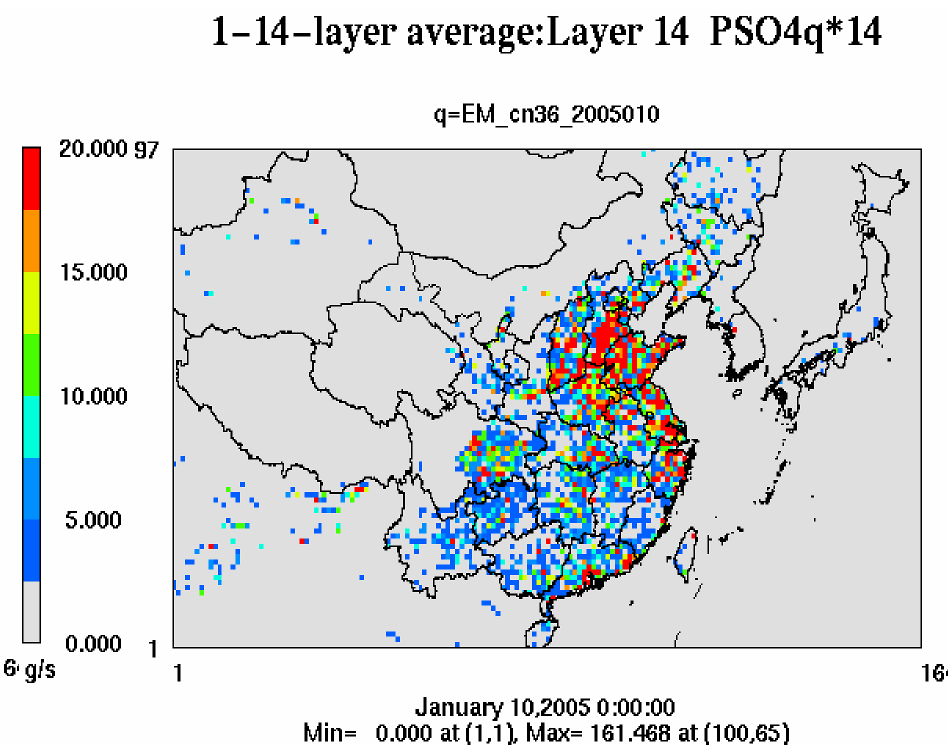


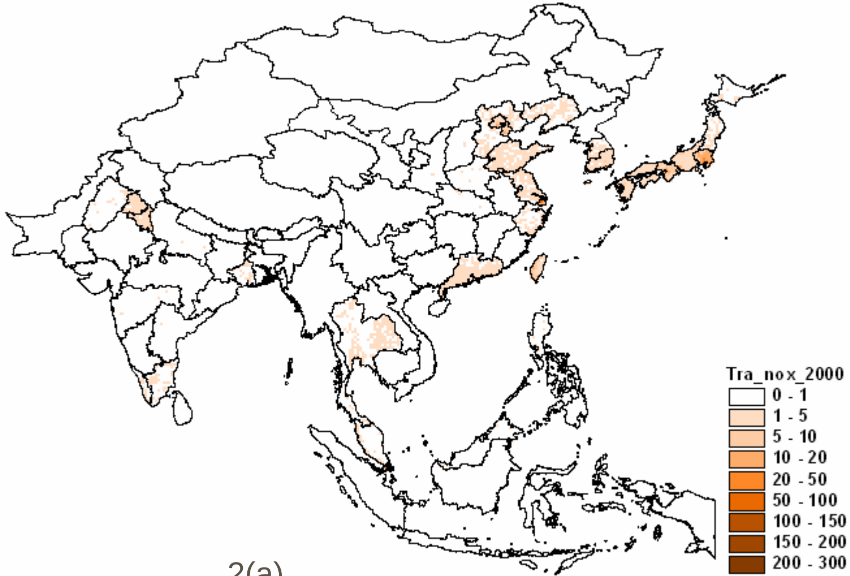


PSO_4

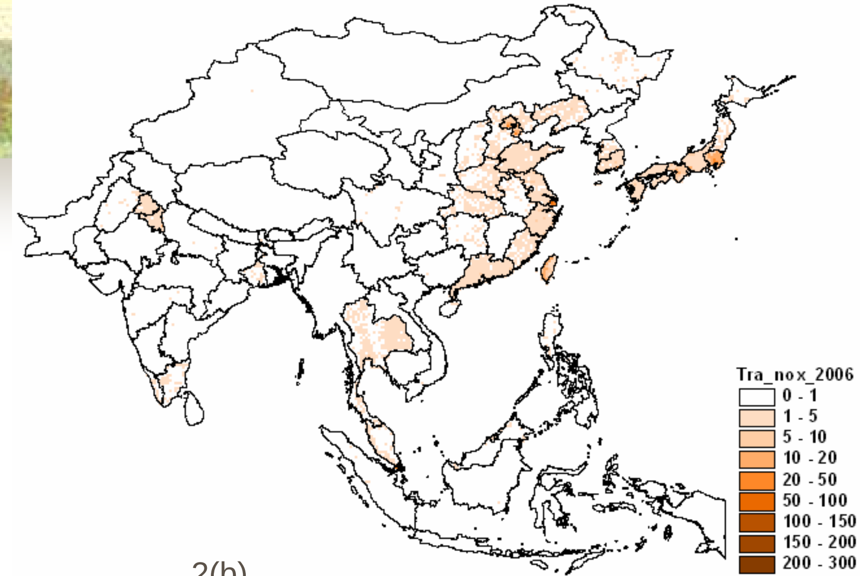
2001 vs. 2005



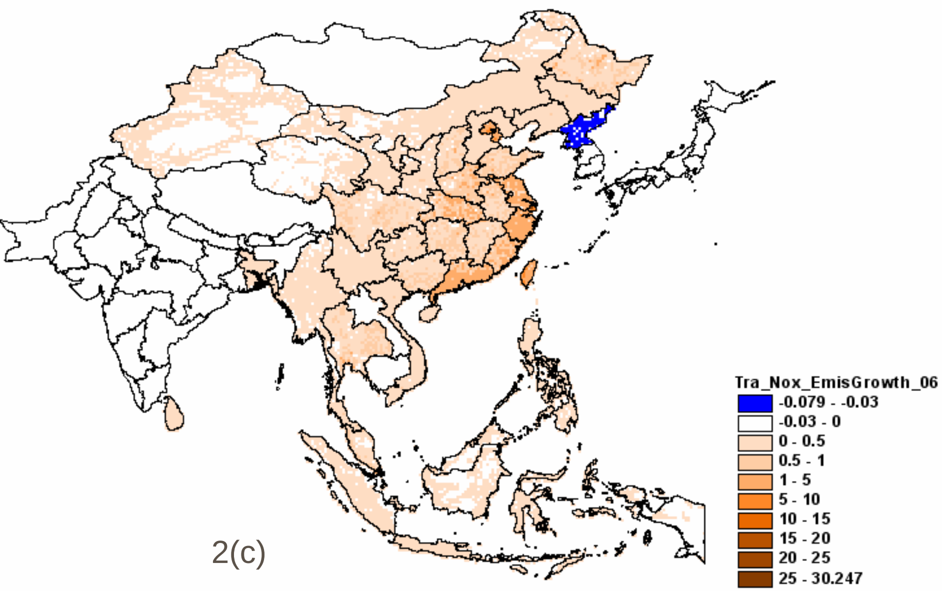




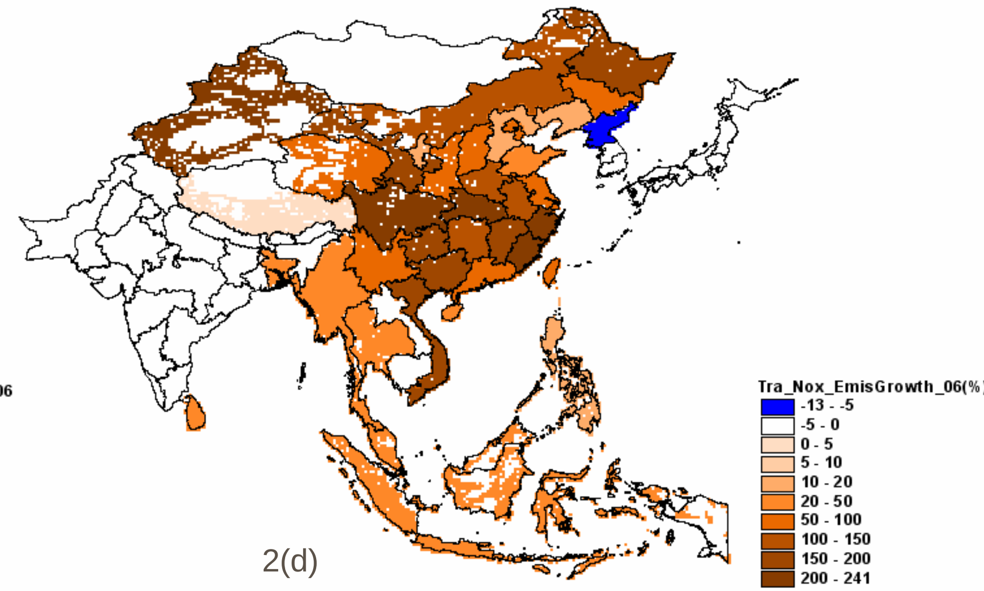
2(a)



2(b)



2(c)



2(d)

2001 vs. 2006

Shanghai Map (on-going)

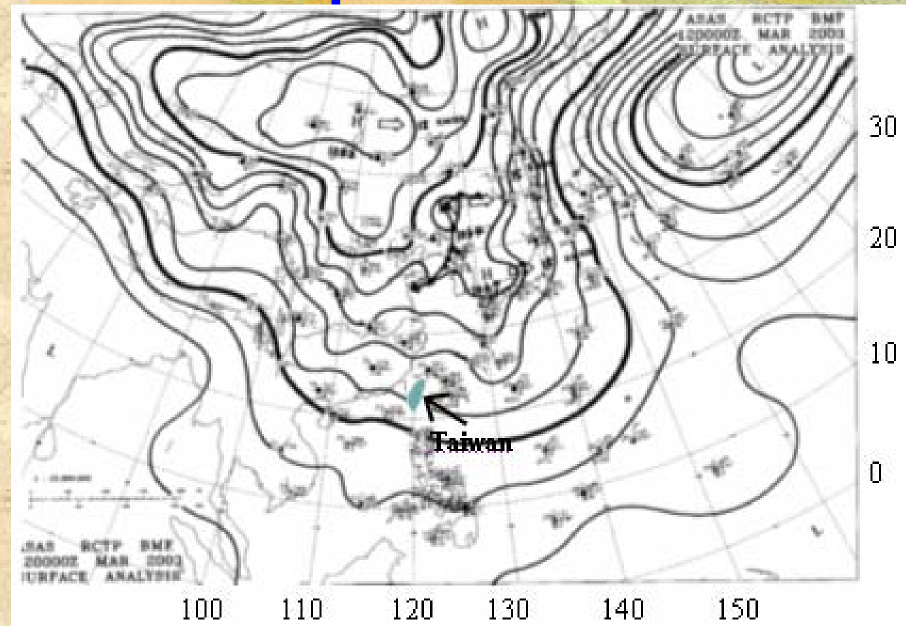
Sulfate Modeling Results in Taiwan

Focus of Study: Understanding high pressure system moved to Taiwan area

Case Study:

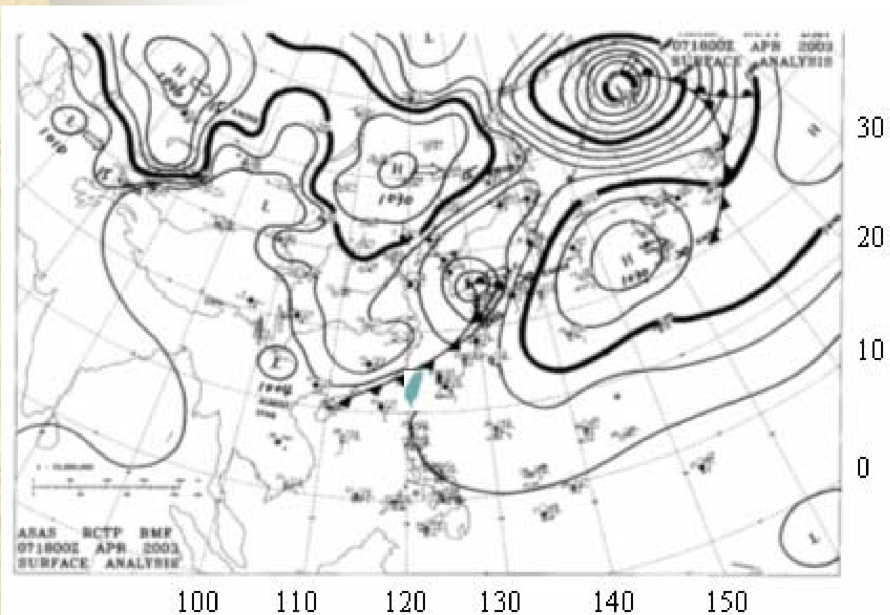
December, 2004 (Winter HPP case)

Main episode weather patterns in Taiwan



HPPC (High Pressure Peripheral Circulation pattern) :

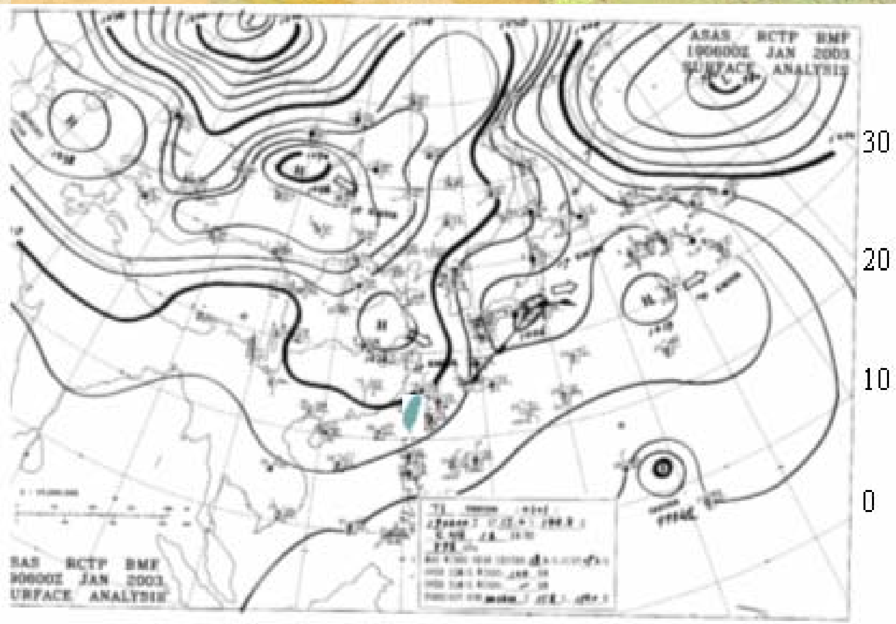
When the Asian continental high pressure system moves from China to the West Pacific, its peripheral circulation blows clockwise as to have the southeast wind around Taiwan.



WAF (Warm area Ahead of Front pattern) :

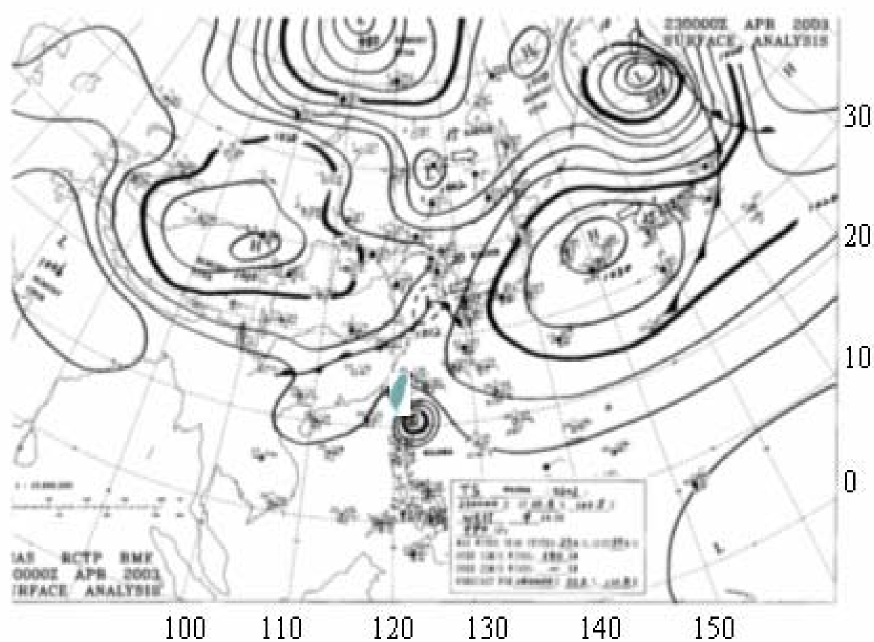
When the leading edge of the high-pressure air mass, i.e., the cold front or stagnant front gets very near Taiwan, Taiwan is located at the warm area ahead of the front.

Main episode weather patterns in Taiwan



HPP (High Pressure Pushing pattern) :

If the leading edge of Asian continental high pressure systems move fast from China to Taiwan, PM2.5 events will occur accompanied by a prevailing strong northeast wind which is observed at all sites in the greater Taipei area.



TYP (TYPhoon pattern) :

When the typhoon is located south or southeast of Taiwan, the peripheral circulation can be the southeast wind

Weather pattern	Event days	Non-valid days	$PM_{2.5}$ max	$PM_{2.5}$ min	$PM_{2.5}$ avg	$PM_{2.5}$ s.d.
HPPC	122	0	103	21	52	14
WAF	98	0	98	13	49	16
HPP	53	0	101	17	53	14
TYP	34	1	90	28	46	12
WHP	17	0	69	21	44	11
PHP	15	1	66	10	40	12
WSW	12	0	54	33	44	6
other	1	0	—	—	51	—
Non-event days in spring	150	2	46	8	25	9
Non-event days in summer	219	2	44	6	24	10
Non-event days in autumn	184	25	53	7	22	9
Non-event days in winter	150	10	50	7	22	9

Note: the unit of $PM_{2.5}$ concentration is in $\mu g\ m^{-3}$. A non-valid day is the one with fewer than 16 valid hourly values.

Weather pattern	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Total
HPPC	17	22	20	23	13	4	0	0	2	3	9	9	122
WAF	10	16	15	19	13	8	1	1	2	0	4	9	98
HPP	12	5	3	1	4	0	0	0	3	12	3	10	53
TYP	0	0	0	4	4	2	4	5	7	5	4	0	35
WHP	0	0	0	1	3	2	3	5	3	0	0	0	17
PHP	0	0	0	0	0	0	5	4	3	4	0	0	16
WSW	0	0	0	0	0	3	2	6	1	0	0	0	12
other	0	0	0	0	1	0	0	0	0	0	0	0	1

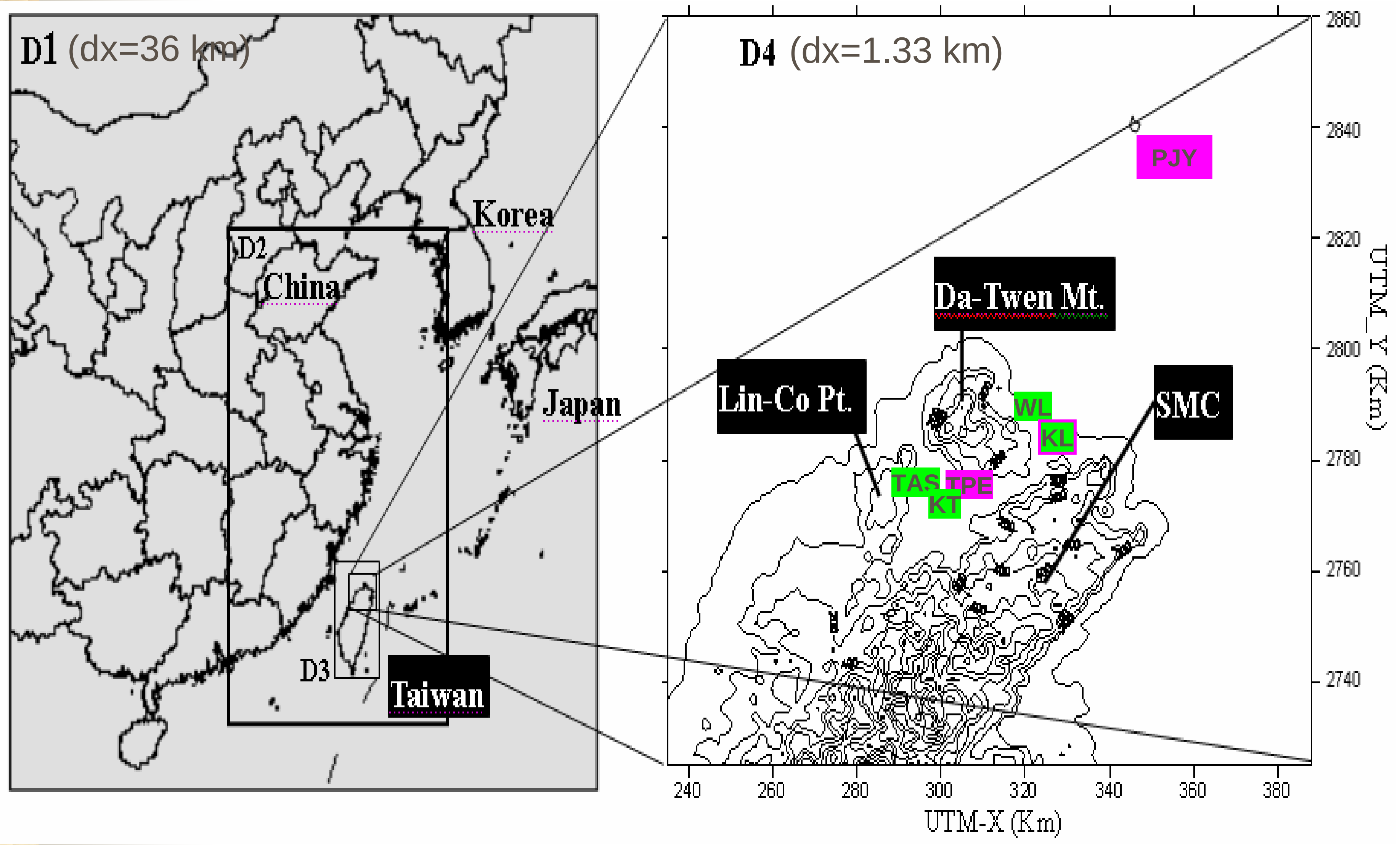
From Chuang et al. (2007), events were defined from 2002 to 2005

Station	Monitoring item	Weather pattern	Effective hours	Avg.	s.d.	Max.	Min.
TAS	$PM_{2.5}$ ($\mu g\ m^{-3}$)		937	54.1	23.8	148.3	6.5
	$PM_{2.5}$ sulfate ($\mu g\ m^{-3}$)		819	12.0	7.2	55.1	1.3
	$PM_{2.5}$ nitrate ($\mu g\ m^{-3}$)		806	2.6	2.0	14.9	0.4
	$PM_{2.5}$ OC ($\mu g\ m^{-3}$)		803	4.5	1.0	13.9	1.0
	$PM_{2.5}$ EC ($\mu g\ m^{-3}$)	HPP	524	1.7	0.8	8.6	1.0
TPE	Wind speed ($m\ s^{-1}$)		991	3.8	1.2	7.9	2.0
	Wind direction (degree)		991	87	31	—	—
	Surface pressure (mb)		991	1020.1	5.4	1031.2	1007.1
PJY	Wind speed ($m\ s^{-1}$)		1248	7.2	2.2	15.2	2.1
	Wind direction (degree)		1248	39	33	—	—
	Surface pressure (mb)		1248	1021.9	5.0	1032.8	1009.5
TAS	$PM_{2.5}$ ($\mu g\ m^{-3}$)		8250	22.6	11.4	64.5	5.0
	$PM_{2.5}$ sulfate ($\mu g\ m^{-3}$)		7662	4.7	3.5	28.5	0.4
	$PM_{2.5}$ nitrate ($\mu g\ m^{-3}$)		6717	1.4	1.1	20.2	0.4
	$PM_{2.5}$ OC ($\mu g\ m^{-3}$)		6747	3.5	1.7	18.0	1.0
	$PM_{2.5}$ EC ($\mu g\ m^{-3}$)	non-HPP*	2142	1.7	1.2	13.9	1.0
TPE	Wind speed ($m\ s^{-1}$)		9093	3.8	1.2	12.1	2.0
	Wind direction (degree)		9093	—	—	—	—
	Surface pressure (mb)		9093	1017.2	5.9	1033.8	989.9
PJY	Wind speed ($m\ s^{-1}$)		12482	7.7	2.9	37.3	2.0
	Wind direction (degree)		12482	—	—	—	—
	Surface pressure (mb)		12482	1018.4	6.0	1036.0	990.4

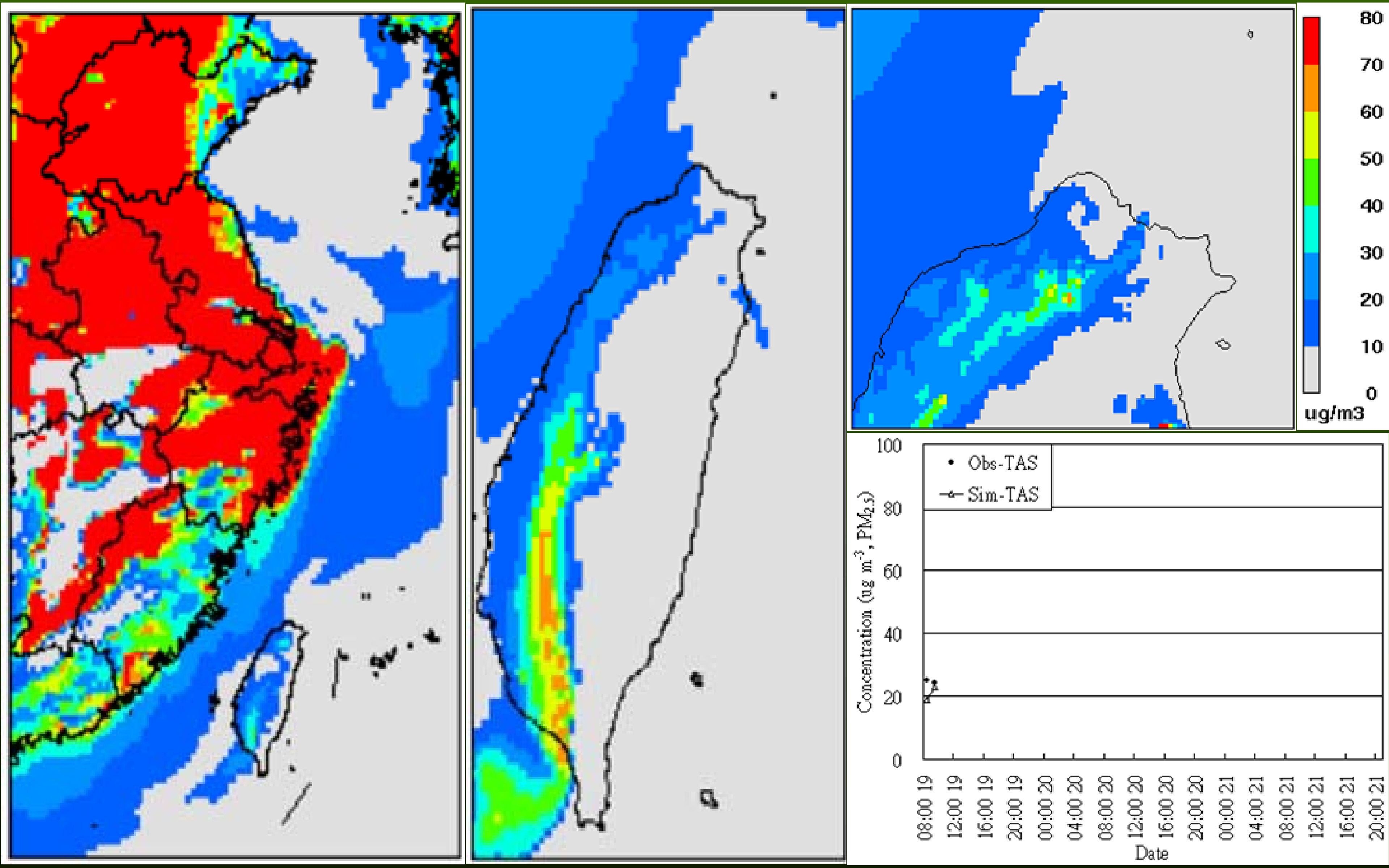
*Non-HPP time period is for days excluding June, July, August, and events time defined in Chuang et al. (2007) from 2002 to 2005.

159%

Simulation domain



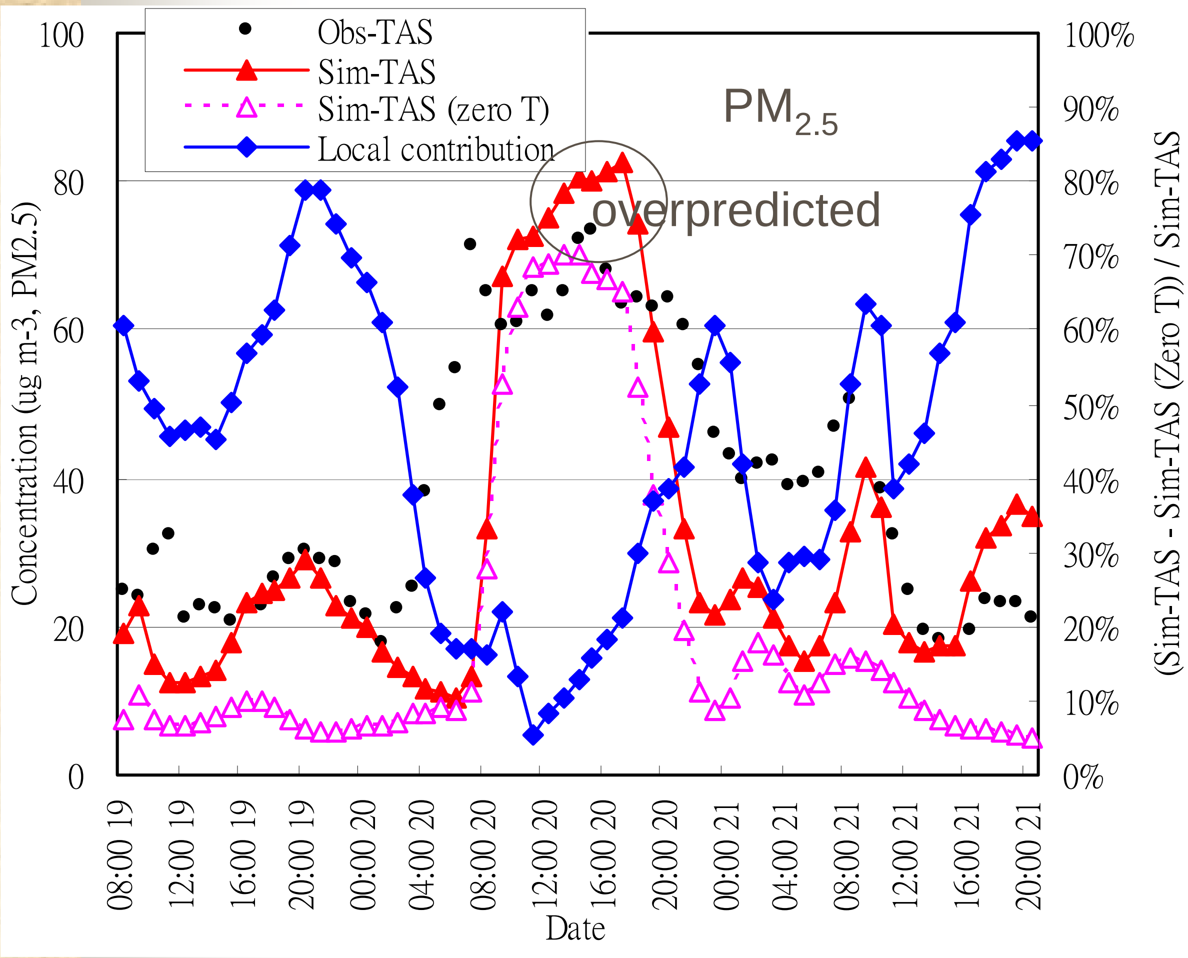
09:00 on day19



$PM_{2.5}$ long-range transport animation

- **The long-range transport episode on 20 December in 2004 was caused by a southward high pressure.**
- **A huge plume formed in China moved with the leading edge of the the southward high pressure.**

Contribution from long-range transport and local pollution



If the overpredicted nitrate is ignored, then local pollution contributed about 5% during the most intense influencing period of long-range transport.

Summary

- Long-range transport (LRT) from China to Taiwan occurred mainly in Fall, Winter, and Spring. PM2.5 level in episode period reached 54.1 $\mu g\ m^{-3}$. which was much higher than 22.6 $\mu g\ m^{-3}$ in non-episode period.
- In the study of simulation, episode occurred when Asia continental high pressure stretched southward to Taiwan. Fine particles accompanied with air mass moving and dominated air quality in Taipei.
- This study reveals that LRT from Asia continent to Taiwan (even West Pacific countries) should be valued and need more studies.

Sulfate Modeling Results in Hong Kong

Focus of Study: Understanding high sulfate in PRD-HK

Two cases run:

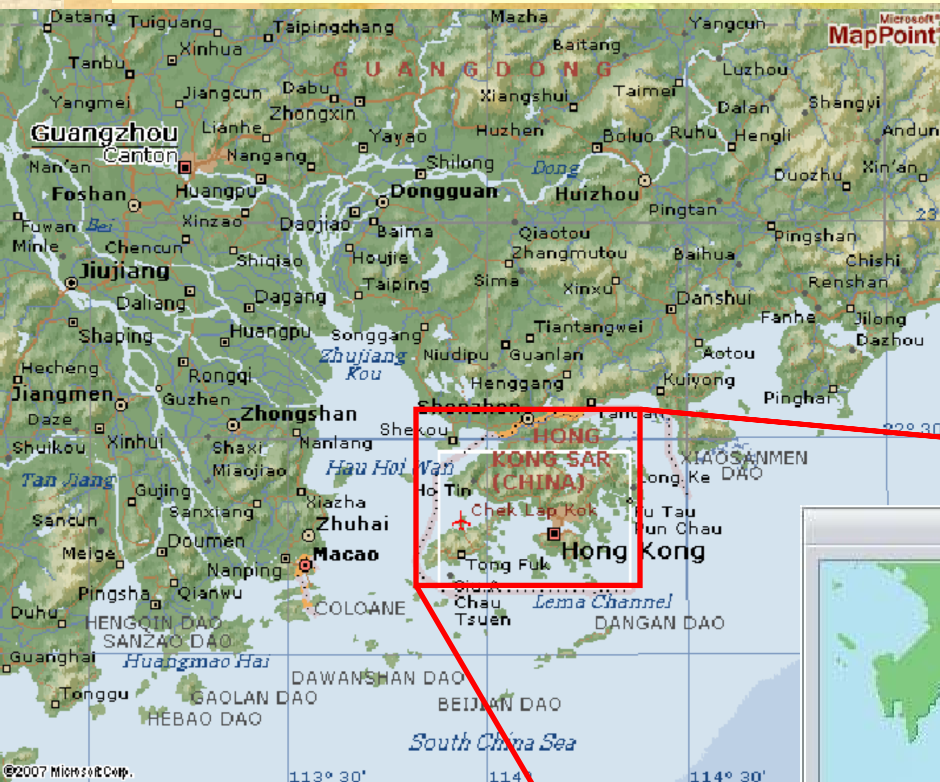
(1) July-August, 2004 (Summer case)

(2) September, 2004 (Fall case)

(3) December, 2004 (Winter case)

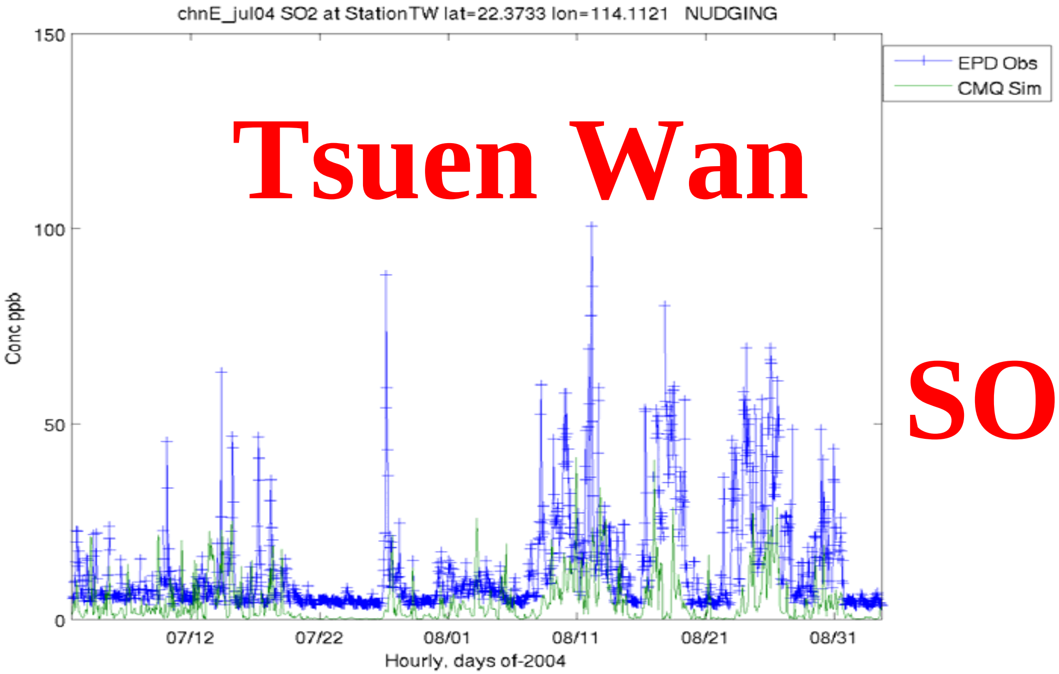
Model settings and inputs tabulated in the last two slices

Pearl River Delta And Hong Kong

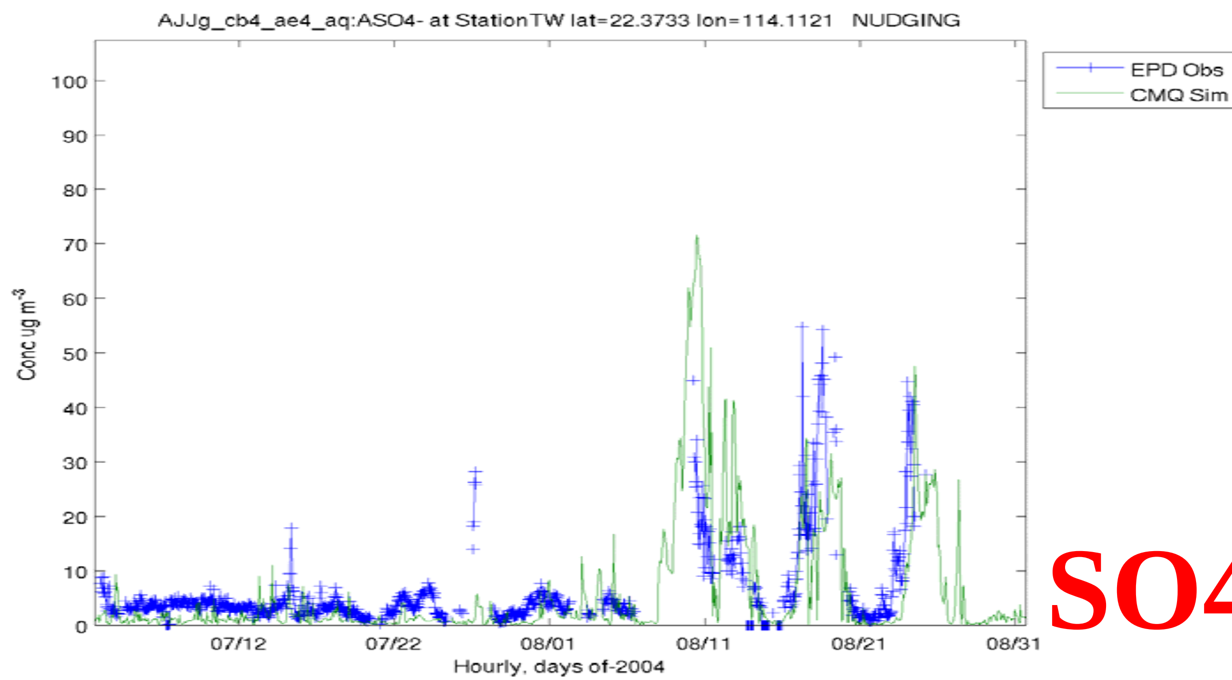


Case: July-August 2004

Tsuen Wan

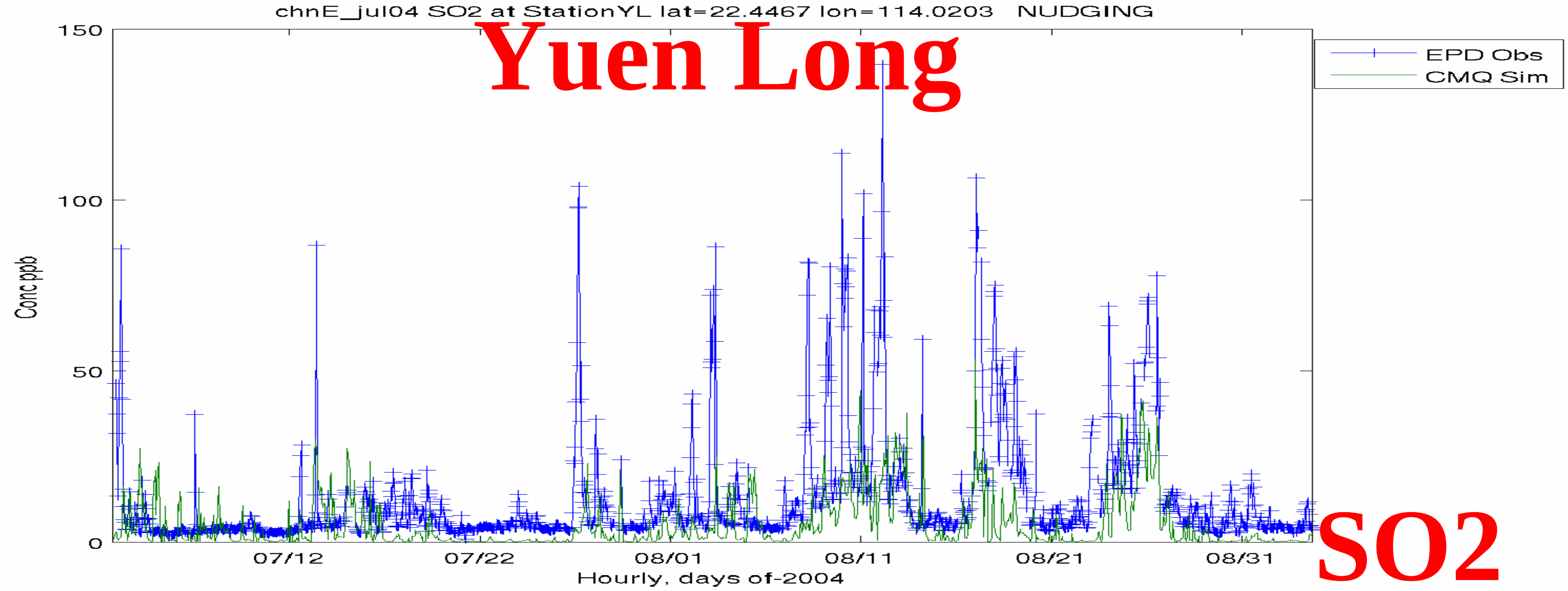


SO2

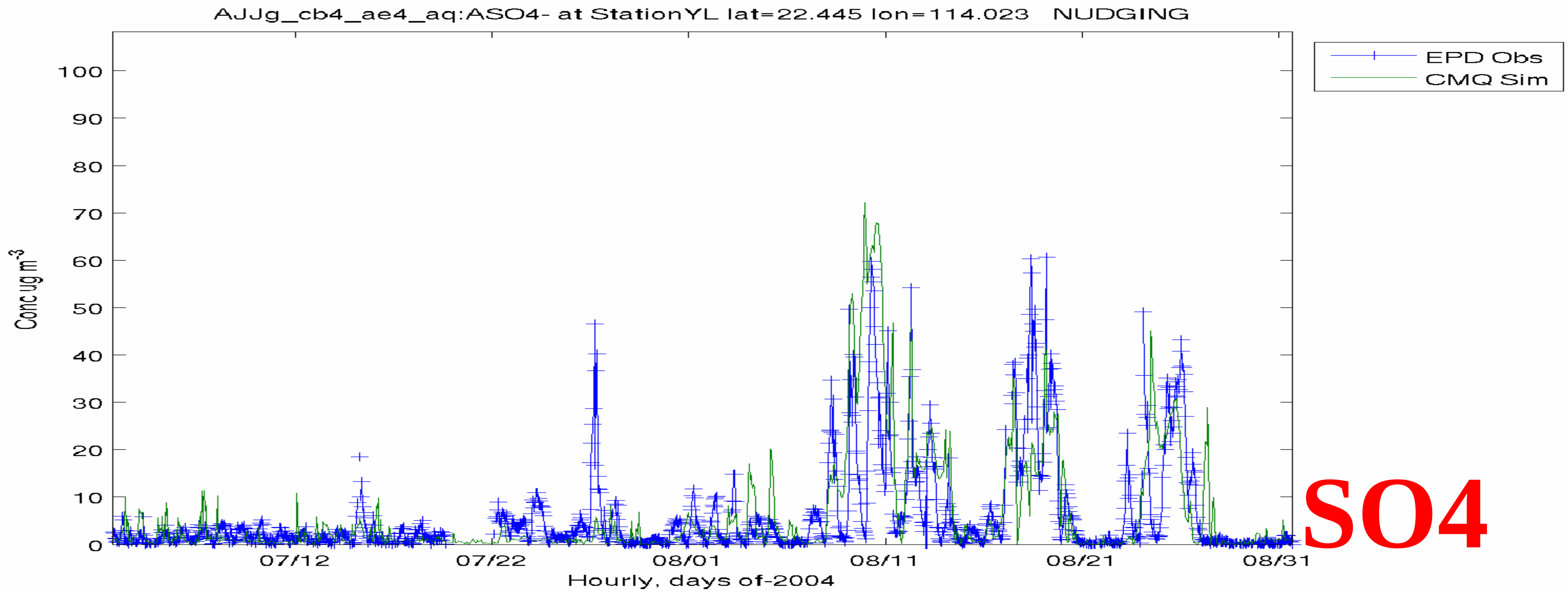


SO4

Yuen Long

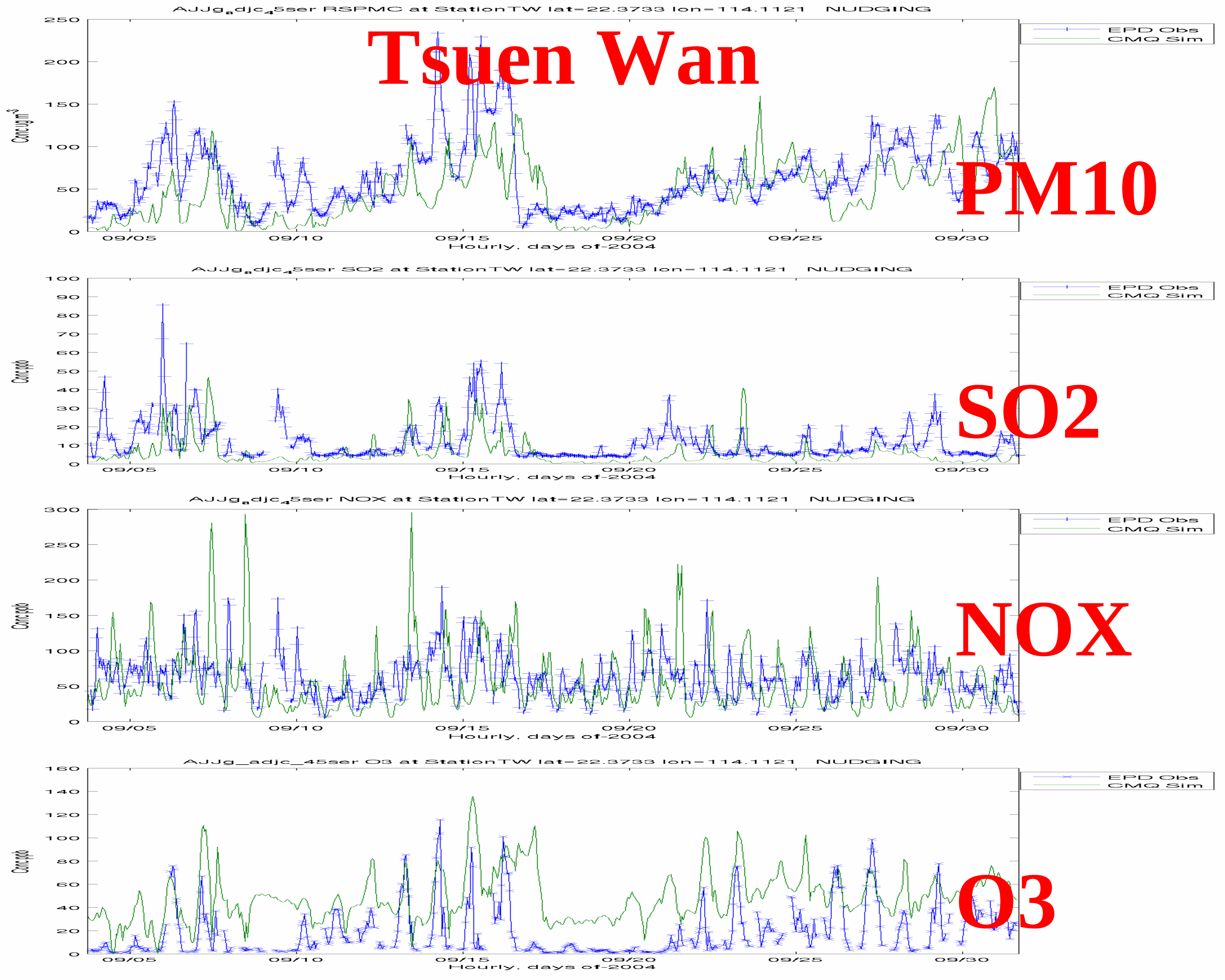


chnE_jul04 SO2 at StationYL lat=22.4467 lon=114.0203 NUDGING
EPD Obs
CMQ Sim
Conc ppb
150
100
50
0
07/12
07/22
08/01
08/11
08/21
08/31
Hourly, days of-2004
SO2

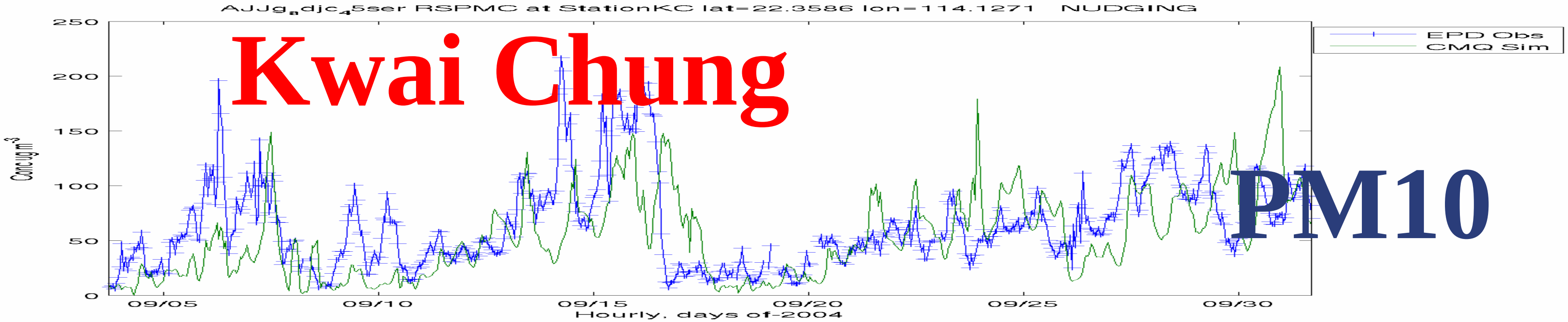


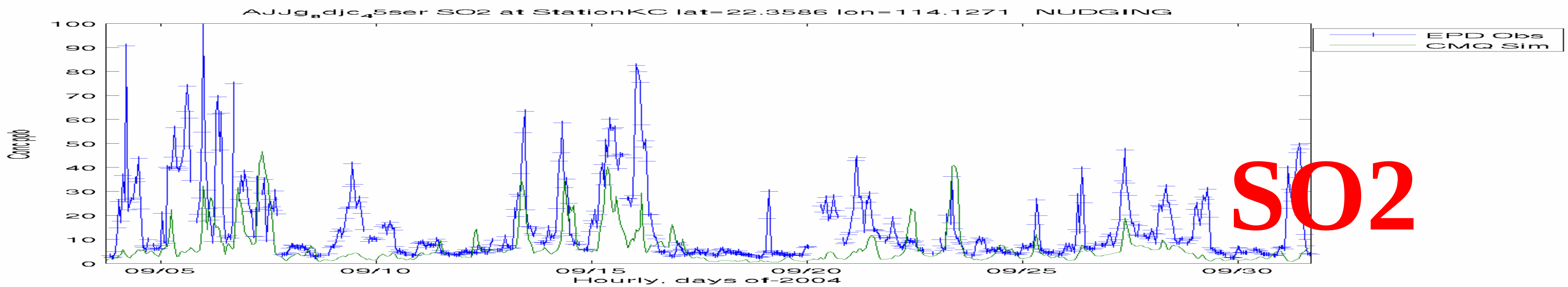
AJJg_cb4_ae4_aq:ASO4- at StationYL lat=22.445 lon=114.023 NUDGING
EPD Obs
CMQ Sim
Conc ug m-3
100
90
80
70
60
50
40
30
20
10
0
07/12
07/22
08/01
08/11
08/21
08/31
Hourly, days of-2004
SO4

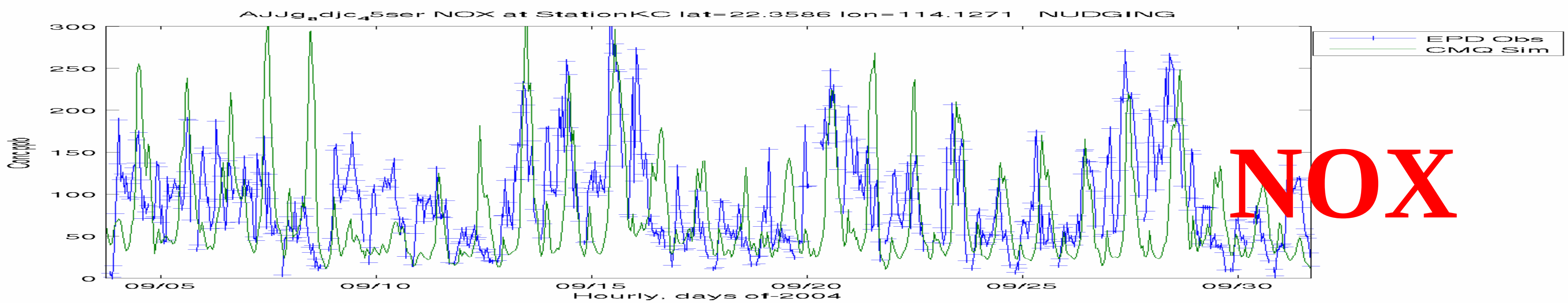
Case: Sep 2004

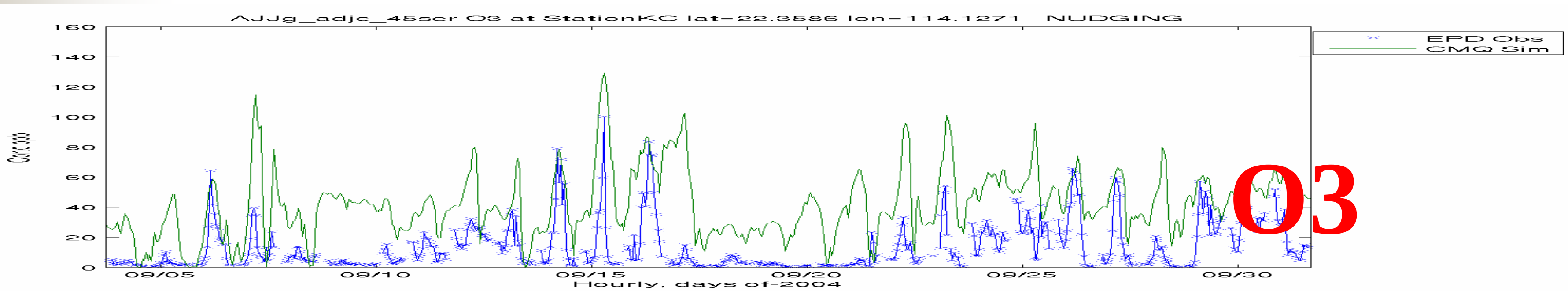


Tsuen Wan
AJJg_adjc_45ser RSPMC at StationTW lat=22.3733 lon=114.1121 NUDGING
EPD Obs
CMQ Sim
Conc ug m-3
Hourly, days of 2004
PM10
AJJg_adjc_45ser SO2 at StationTW lat=22.3733 lon=114.1121 NUDGING
Conc ppb
SO2
AJJg_adjc_45ser NOX at StationTW lat=22.3733 lon=114.1121 NUDGING
NOX
AJJg_adjc_45ser O3 at StationTW lat=22.3733 lon=114.1121 NUDGING
O3
09/05
09/10
09/15
09/20
09/25
09/30

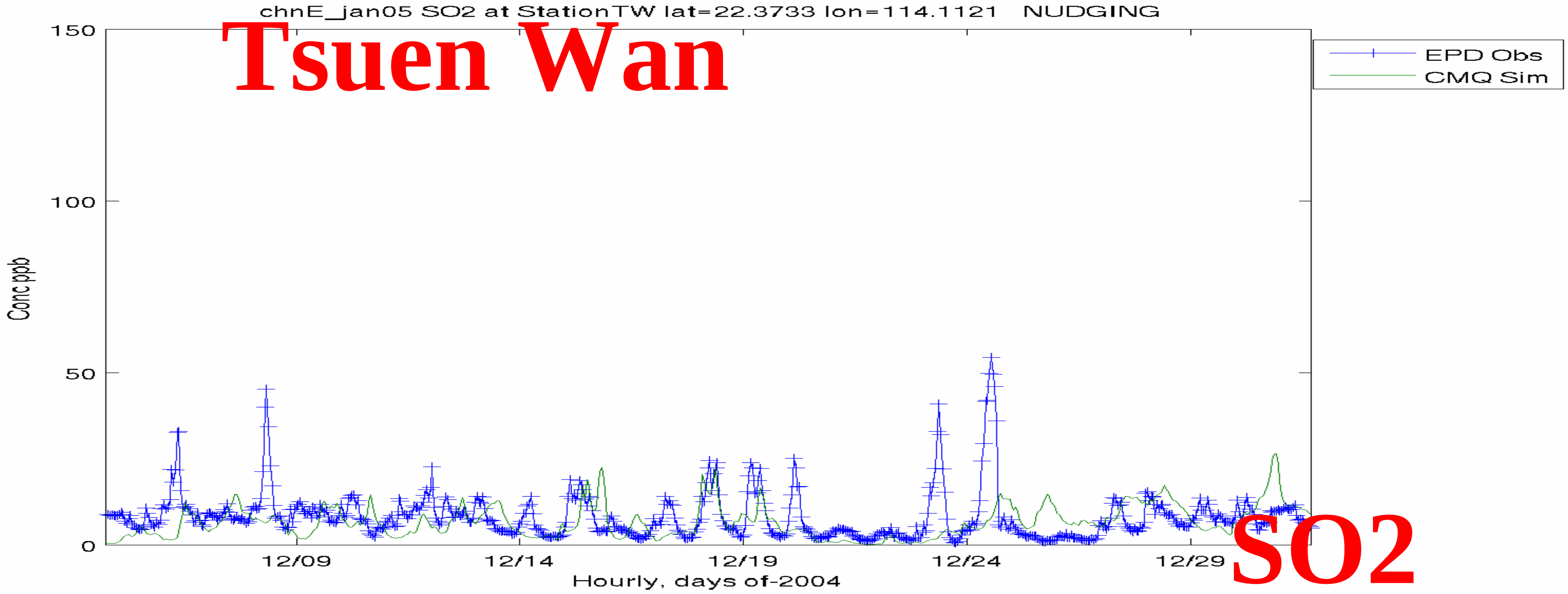

AJJg_adjc_45ser RSPMC at StationKC lat=22.3586 lon=114.1271 NUDGING
Kwai Chung
PM10
EPD Obs
CMQ Sim
Conc ug m-3
09/05
09/10
09/15
09/20
09/25
09/30
Hourly, days of-2004

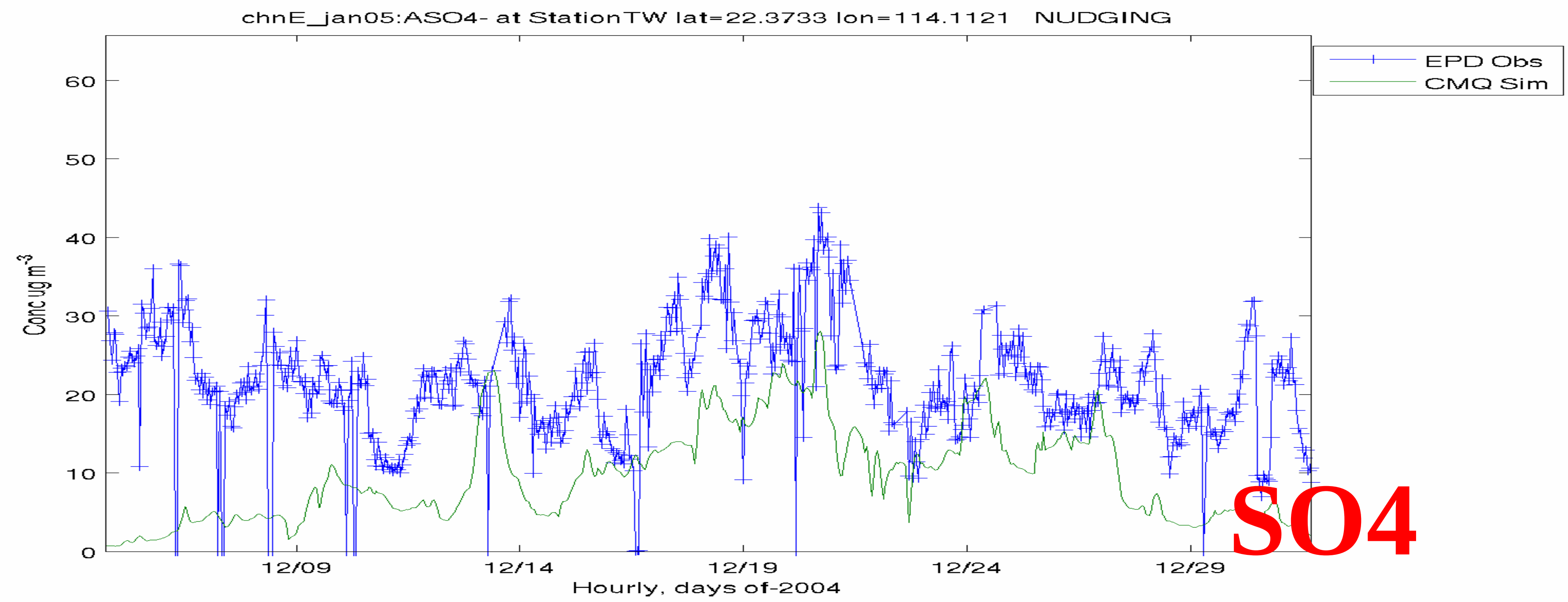

AJJg_adjc_45ser SO2 at StationKC lat=22.3586 lon=114.1271 NUDGING
SO2
EPD Obs
CMQ Sim
Conc ppb
09/05
09/10
09/15
09/20
09/25
09/30
Hourly, days of-2004

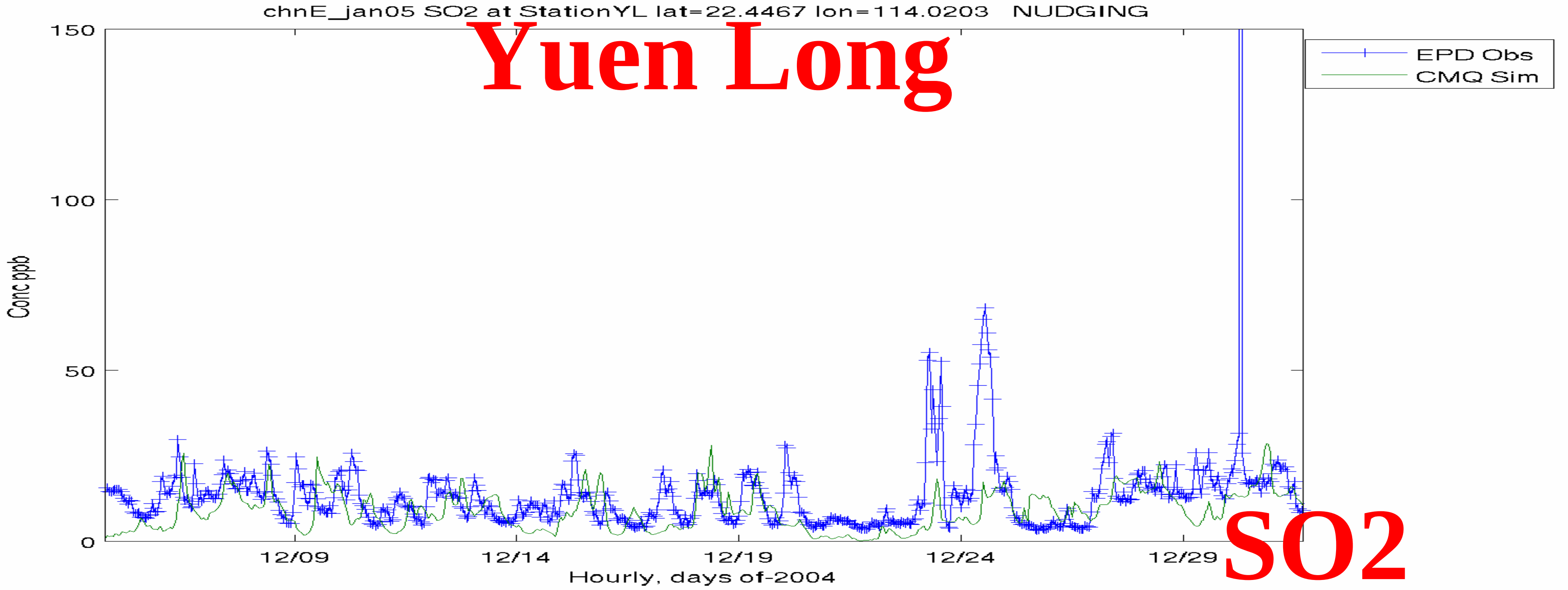

AJJg_adjc_45ser NOX at StationKC lat=22.3586 lon=114.1271 NUDGING
NOX
EPD Obs
CMQ Sim
Conc ppb
09/05
09/10
09/15
09/20
09/25
09/30
Hourly, days of-2004

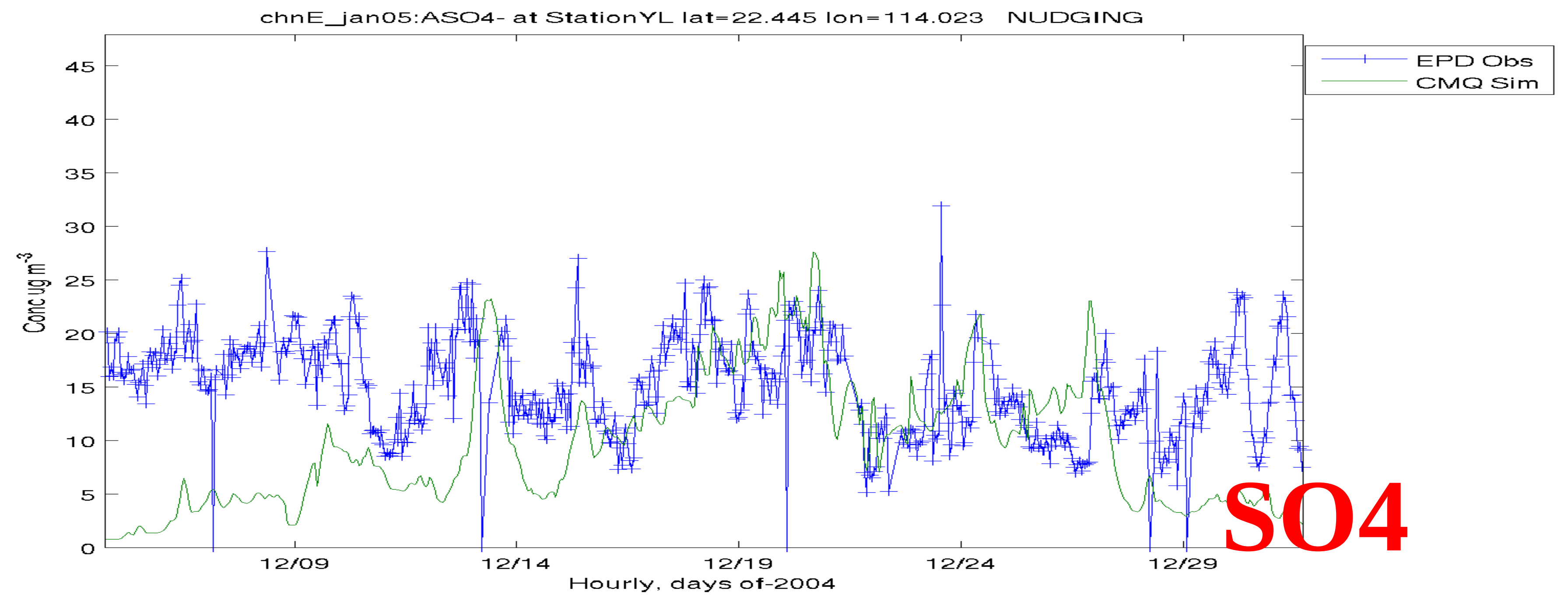

AJJg_adjc_45ser O3 at StationKC lat=22.3586 lon=114.1271 NUDGING
O3
EPD Obs
CMQ Sim
Conc ppb
09/05
09/10
09/15
09/20
09/25
09/30
Hourly, days of-2004

Case: December 2004


chnE_jan05 SO2 at Station TW lat=22.3733 lon=114.1121 NUDGING
Tsuen Wan
EPD Obs
CMQ Sim
Conc ppb
150
100
50
0
12/09
12/14
12/19
12/24
12/29
Hourly, days of-2004
SO2


chnE_jan05:ASO4- at Station TW lat=22.3733 lon=114.1121 NUDGING
EPD Obs
CMQ Sim
Conc ug m-3
60
50
40
30
20
10
0
12/09
12/14
12/19
12/24
12/29
Hourly, days of-2004
SO4


chnE_jan05 SO2 at StationYL lat=22.4467 lon=114.0203 NUDGING
Yuen Long
EPD Obs
CMQ Sim
Conc ppb
150
100
50
0
12/09
12/14
12/19
12/24
12/29
Hourly, days of-2004
SO2


chnE_jan05:ASO4- at StationYL lat=22.445 lon=114.023 NUDGING
EPD Obs
CMQ Sim
Conc ug m-3
45
40
35
30
25
20
15
10
5
0
12/09
12/14
12/19
12/24
12/29
Hourly, days of-2004
SO4

Sulfate Modeling Results in Hong Kong

- Oct. case looks at month-long PM (especially SO_4) variations.
- The 30-day Sept. case runs sensitivity studies of SO_4.
- All cases consistently underestimate SO_4 and SO_2.
- $PM_{2.5}$ (Sulfate PM) is still not well predicted

Next Steps – Regional Modeling

- Reprocess outside-GD emissions with the most update growth rates of SO2, NOx, and PM (Streets's 2005 and 2006)
- Analysis and sensitivity studies
- Additional model assessment in PRD
- Shanghai AQ modeling – meteorology
- High pressure system effects in Taiwan islands
- WRF-CMAQ

Next Steps – Scale of MICS and HTAP

- Evaluate the effects of resolution & BCs (ensemble data) on regional ozone and PM predictions.
- Analyze ozone and PM concentration metrics for Global CTM and Regional CTM calculations.
- Calculate import and export fluxes (across altitude & longitudes) for Global CTM and Regional CTM calculations.
- Explore subregional domestic perturbation experiments

Acknowledgment

- USEPA
- HKEPD
- University of Tennessee Office of Research
- Argonne National Laboratory
- University of Iowa
- Hong Kong University of Science and Technology
- Tsinghua University