Off-line Air Quality Coupling System:

WRF-CMAQ Simulation of Houston High Ozone Event

Fong Ngan, Daewon Byun and Soontae Kim
IMAQS, University of Houston, Houston, TX

Introduction

- WRF-ARW (Advanced Research WRF)
  new generation operational & research weather forecasting model
  Providing met. input for air quality modeling

- CMAQ (Community Multiscale Air Quality model)
  state-of-science air quality model developed by US EPA
  designed for multiple-pollutant modeling
  use fully compressible eq. written in generalized coordinates

Off-line air quality modeling system

Meteorological and chemical models are treated independently.

Through the Meteorology-Chemistry Interface Processor (MCIP version 3) hourly meteorological data is transformed into the CMAQ.

Complex air quality issues are studied by examining individual scientific problems of meteorology, chemical transport, emission etc independently.

Introduction

Off-line modeling for air quality assessment with WRF-CMAQ

WRF-ARW was demonstrated to have accurate numerics and high quality mass conservation characteristics.

The governing set of equations, coordinate system, numerical algorithms, and computational framework of WRF-ARW are closer to CMAQ than MM5.

Objective

➢ Improve WRF simulation for air quality studies:

Sensitivity tests have been performed to obtain better results representing the boundary layer parameters that are critical for air quality simulations.

1) employing the update of PBL scheme and LSM in version 2.1

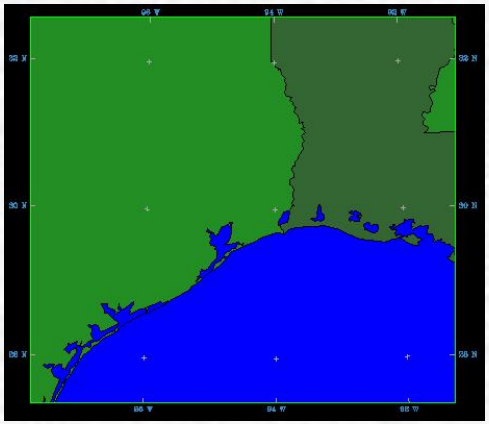
2) tuning on Grell-Devenyi ensemble scheme to capture temperature decrease caused by the development of clouds.

➢ Evaluate WRF-CMAQ results with TexAQS 2000 experiment data:

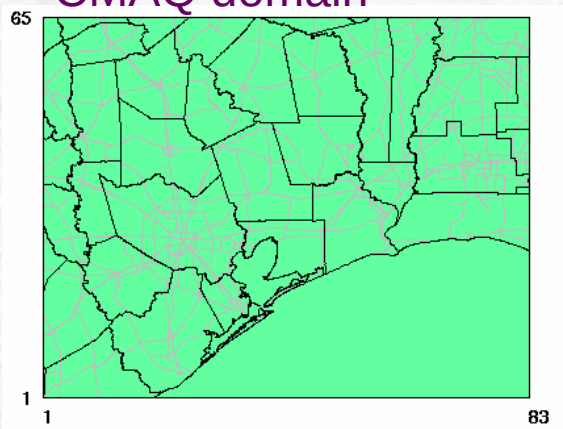
The WRF-ARW simulations were utilized for the offline modeling of air quality with CMAQ for high ozone events in Houston. The simulation results were evaluated with the OBS during the TexAQS 2000 experiment.

Model Configuration

WRF domain



CMAQ domain



Time period: 2000/8/22 00UTC ~ 9/2 00UTC
IC/BC: From 40 km Eta reanalysis data (AWIP)
Grid size: 161*145*43 layers (WRF)
83*65*23 layers (CMAQ)
Resolution: 4 km
Nudging: None

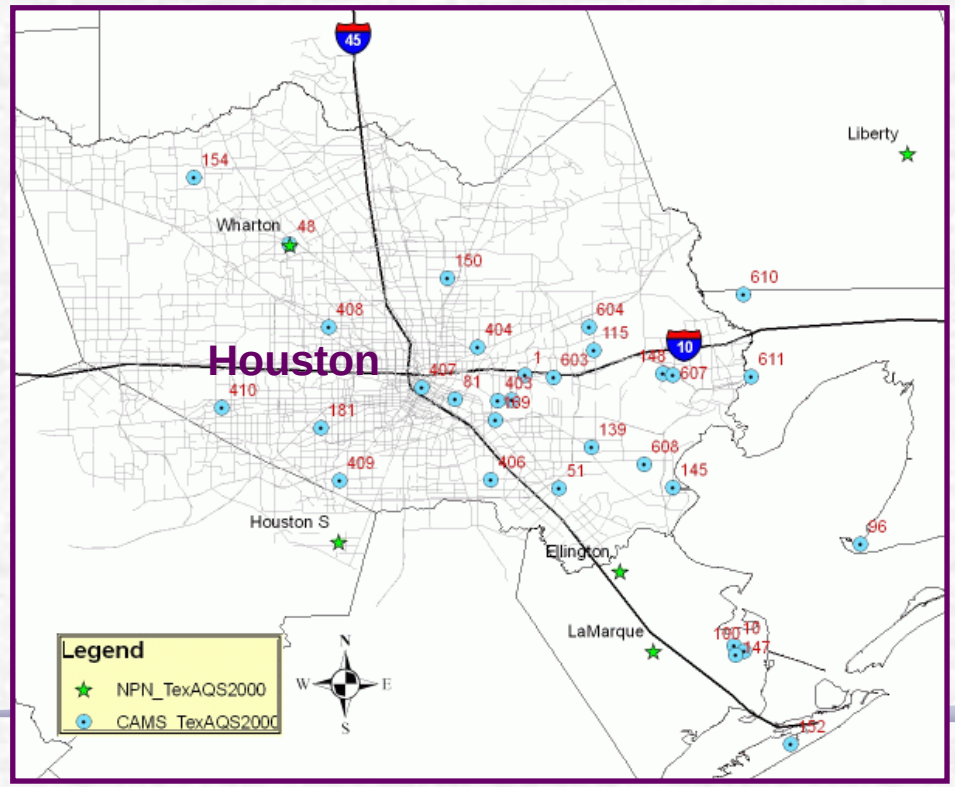
Physical options for control run
Microphysics: WSM 3-class simple ice scheme
Radiation: RRTM (longwave), Dudhia (shortwave)
Surface layer: Monin-Obukhov scheme
LSM: Noah land-surface model
PBL: MRF scheme
Cumulus: None

Simulations Design

Description	ARW-WRF	CMAQ
Control run of v2.0.3.1	W_v2	CMAQ1
Control run of v2.1 (No sub-grid cloud & MRF PBL scheme)	W_v2.1	CMAQ2
WRF v2.1 with Grell-Devenyi ensemble & YSU scheme	W_v2.1_cu	/

Anthropo. Emission
generated by SMOKE v2.1 with CB4 and NEI 99 v3 of base EI.
plume rise from SMOKE laypoint
Biogenic Emission
generated by BEIS 3.12 in SMOKE
~provided by Dr. Soontae Kim

OBS of temp, wind & O3 conc.
Continuous Ambient Monitoring Stations (CAMS), TCEQ
OBS of PBL height
NOAA Profiler Network (NPN)



Review the comparison of MM5 & WRF

Mulit-nesting simulation failed because of the lack of grid-nudging tool in the ARW-WRF model.

WRF is able to simulate comparable meteorological features as MM5 when the same physical options and inputs are used in the simulations..

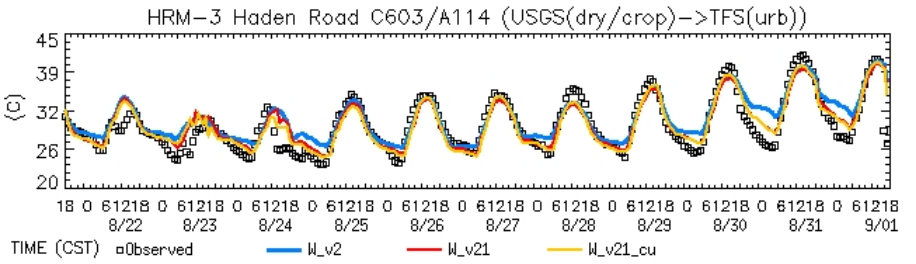
- *Larger warm bias in 2m temperature simulated by WRF than MM5.*
- *Both models overestimated PBL heights, WRF's result was closer to OBS.*
- *Both models simulated similar wind patterns; had difficulties simulating correct wind directions under light wind conditions.*

Root mean square error (RMSE) & mean gross bias (BIAS) for all OBS in TexAQS 2000 during the simulation period				
	WRF		**MM5**	
	RMSE	BIAS	RMSE	BIAS
2m temperature	2.05	0.56	1.92	0.79
10m wind speed	1.35	0.21	1.3	0.5
10m wind dir	85.54	-5.75	86.37	-7.31
PBL height	374.05	189.19	424.69	247.69

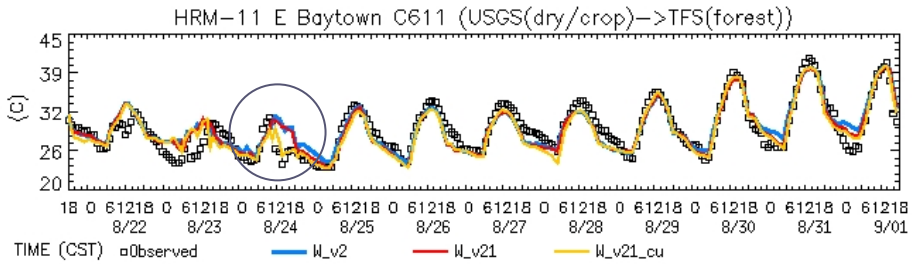
Comparison of different WRF versions
Time-series of 1.5m Temperature

Different runs: v2.0.3.1, v2.1, v2.1 using GD ensemble & YSU scheme

Urban site

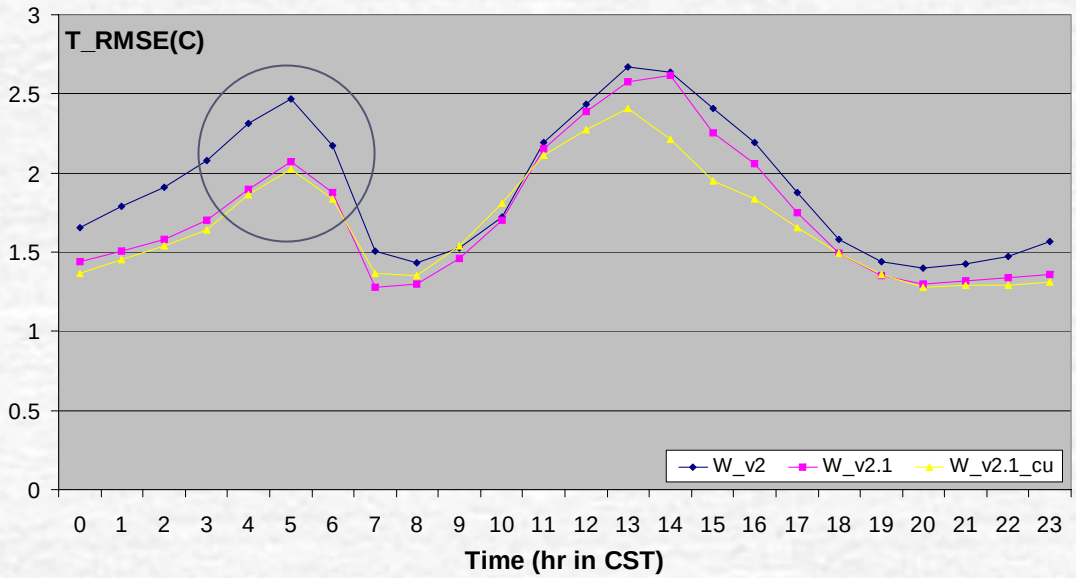


Rural site



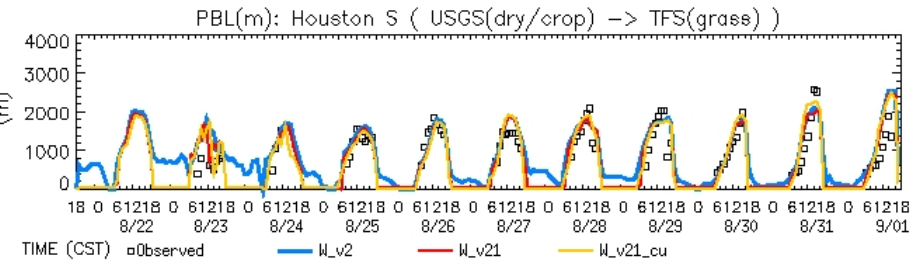
Nighttime cold bias was reduced substantially in v2.1
It affected the urban area (C603) more than the rural area (C611)

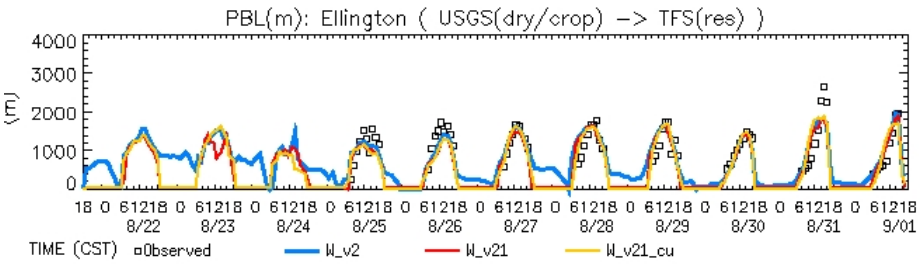
In the run W_v2.1_cu, temperature dropped in the afternoon on August 24th due to the thunderstorm activities simulated.



Comparison of different WRF versions
Time-series of PBL Height

Different runs: v2.0.3.1, v2.1, v2.1 using GD ensemble & YSU scheme

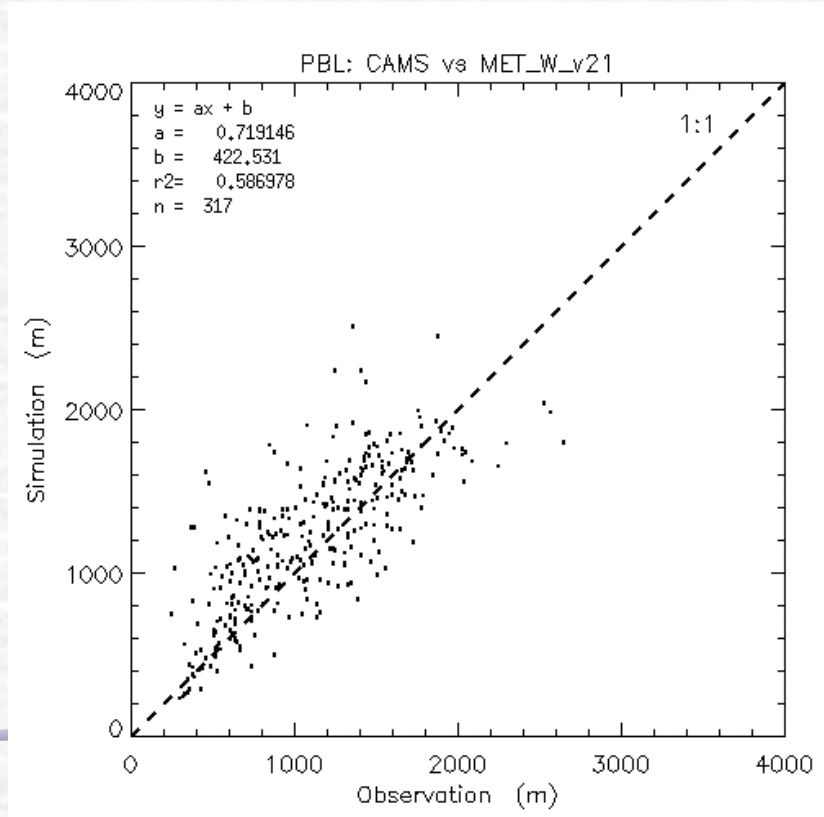




During the stable condition, PBL top was reported to be the height of the first layer, around 34 m (sigma=0.996).

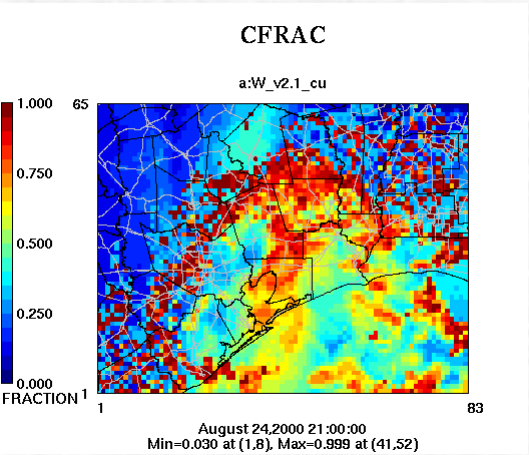
At daytime, all versions simulated development of PBL height well; W_v2.1 showed the best agreement with OBS.

	RMSE	BIAS
W_v2	374.05	189.19
W_v2.1	**334.28**	**115.56**
W_v2.1_cu	355.23	139.09

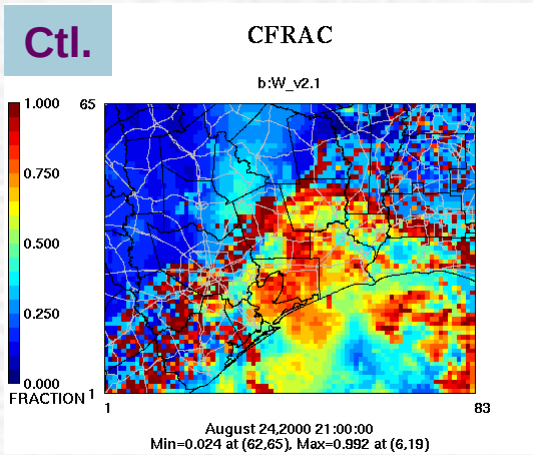


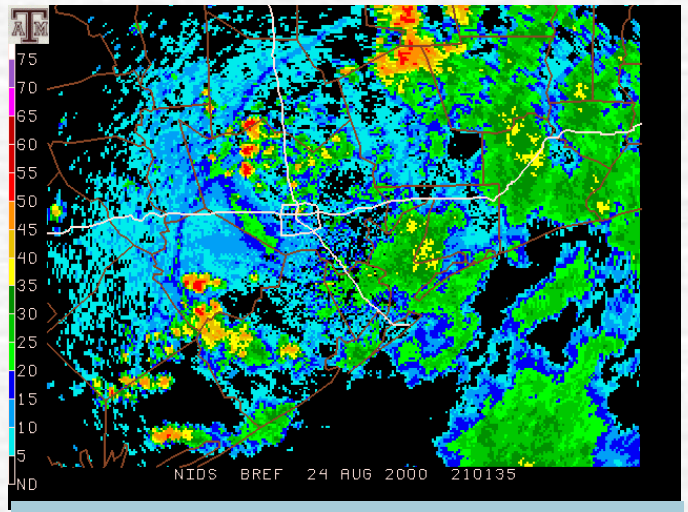
Comparison of W_v2.1_cu & W_v2.1
Spatial plot of cloud fraction & horizontal wind at 21 UTC on 8/24

Thunderstorm on 8/24, 2000
At the afternoon larger area of shower moved to Houston from SE.



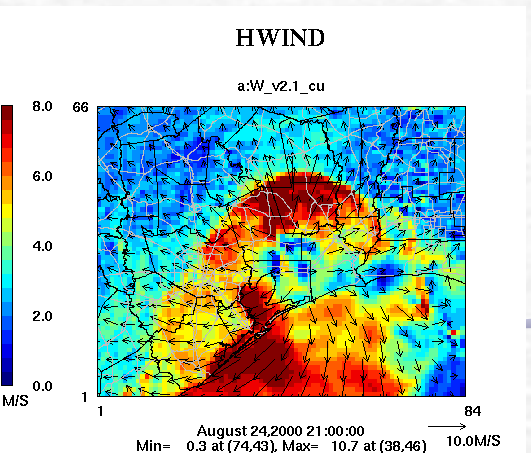
Ctl.





Radar imagery at 21 UTC 8/24

More clouds were generated & area covered by thunderstorm was larger with W_v2.1_cu.
➔ lower PBL height at the north-western edge of Harries County
gust front moved further north



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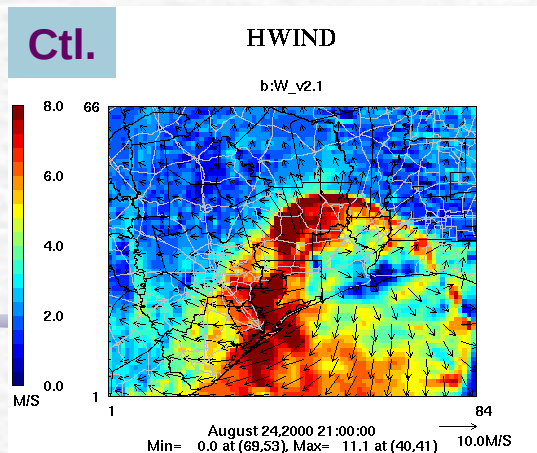

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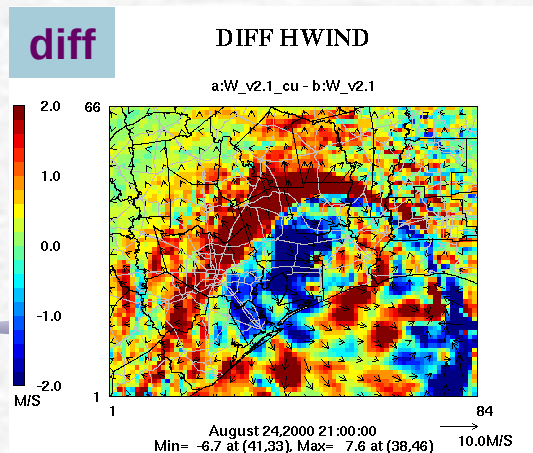
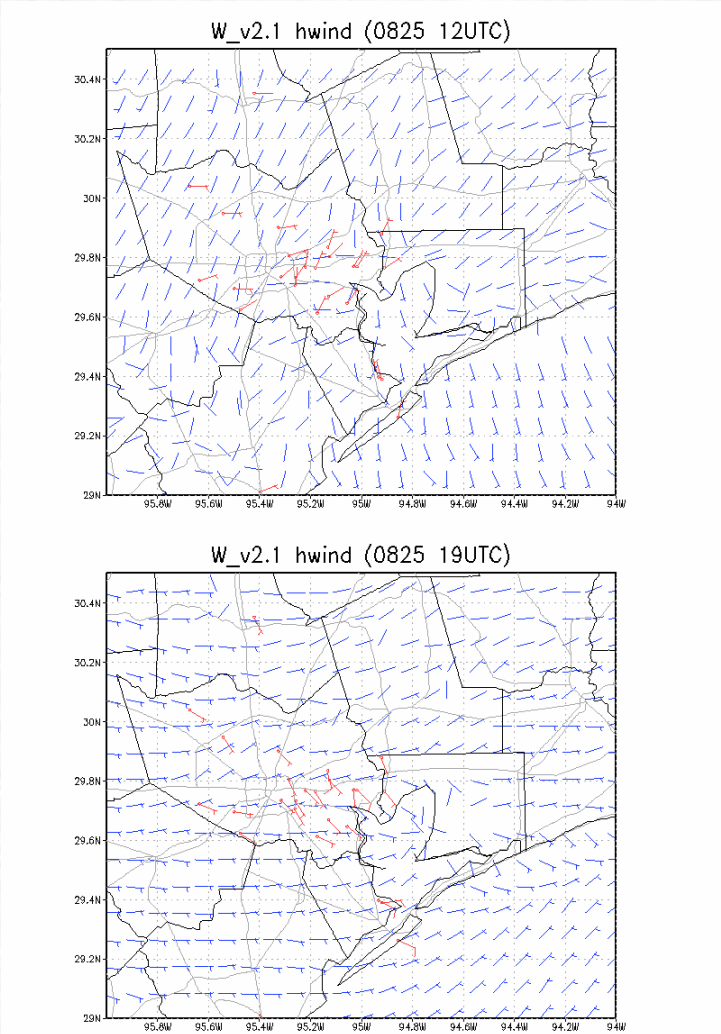
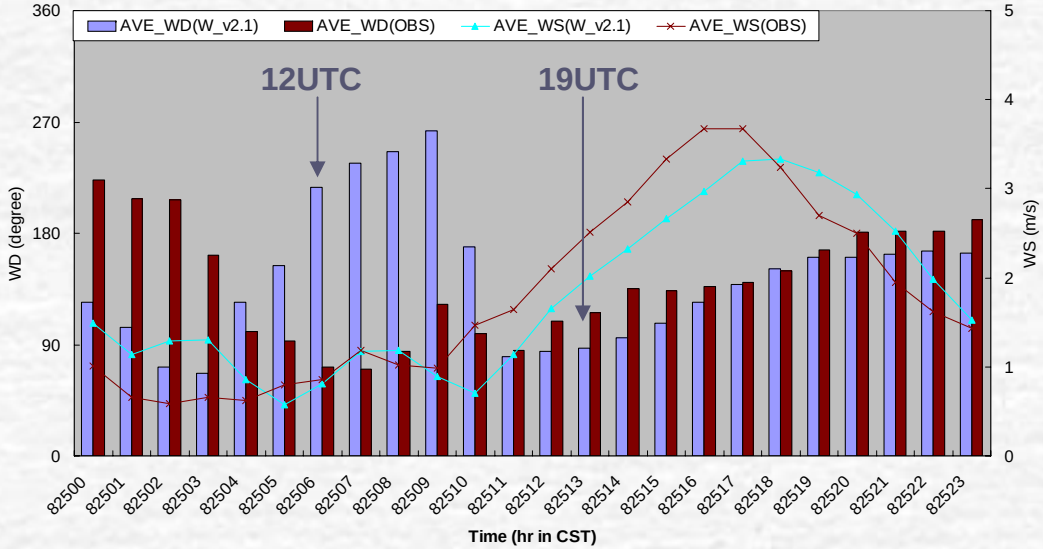


Variation of wind on 8/25 in Ctl. run of v2.1

Snap shot of simulated wind and OBS



Time-series of wind speed & direction on 8/25

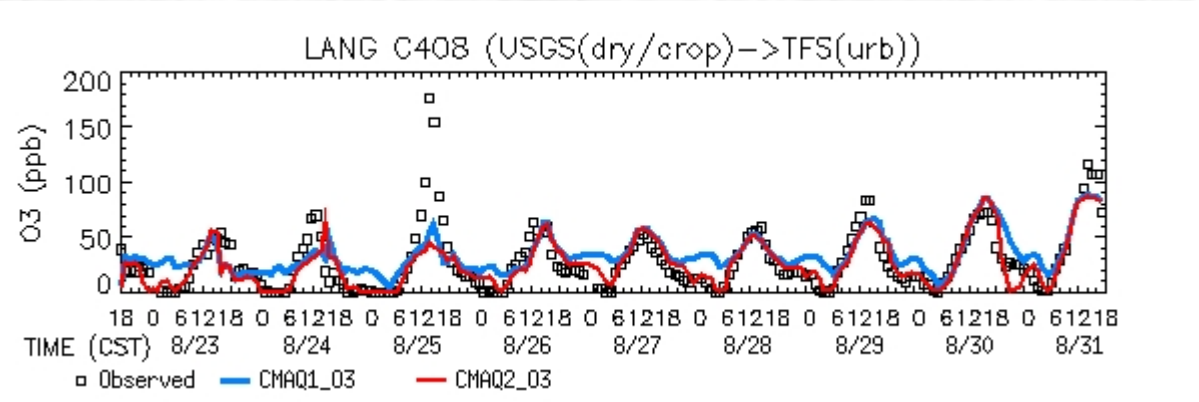


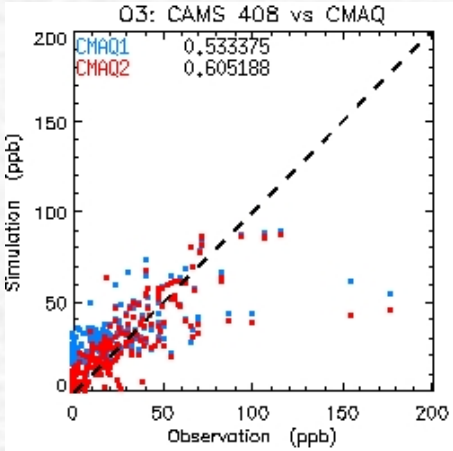
Lack of northerly component in the morning.

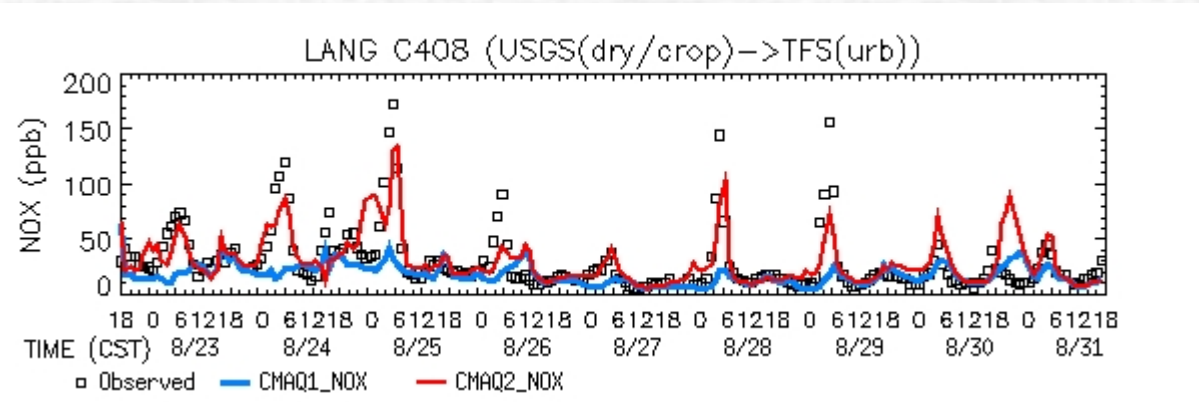
Delay in tuning of wind direction from E to SE in the afternoon

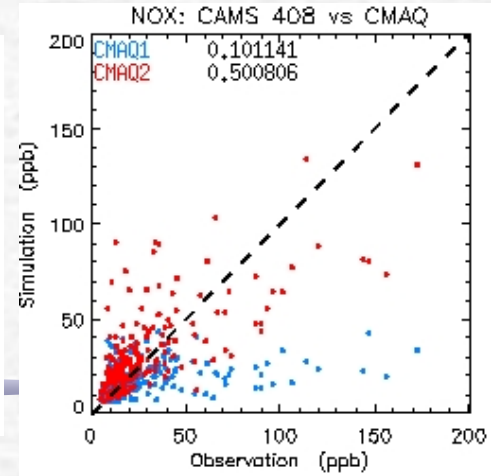
Comparison of CMAQ simulations with WRF v2.0 & v2.1
Time-series of O3 & NOx

The CMAQ1 run with WRF old version estimated PBL height at nighttime too high that maybe one of the reason causing nighttime ozone bias.
In CMAQ2 run, the nighttime O3 bias was reduced at urban sites (C22, C120, C53, C408).
Due to low PBL top (height of lowest layer) assigned by ARW-WRF v2.1
➔ increased titration of ozone with nitrogen oxides (NOx).







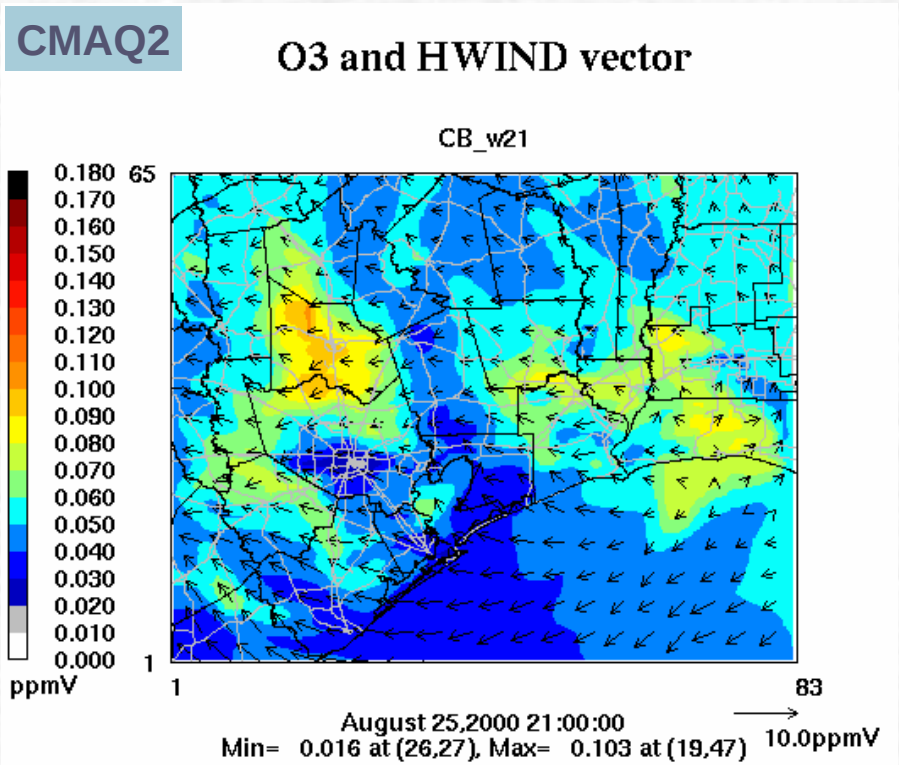


Comparison of CMAQ simulations with WRF v2.0 & v2.1
Spatial plot of O3 at 21 UTC on 8/25

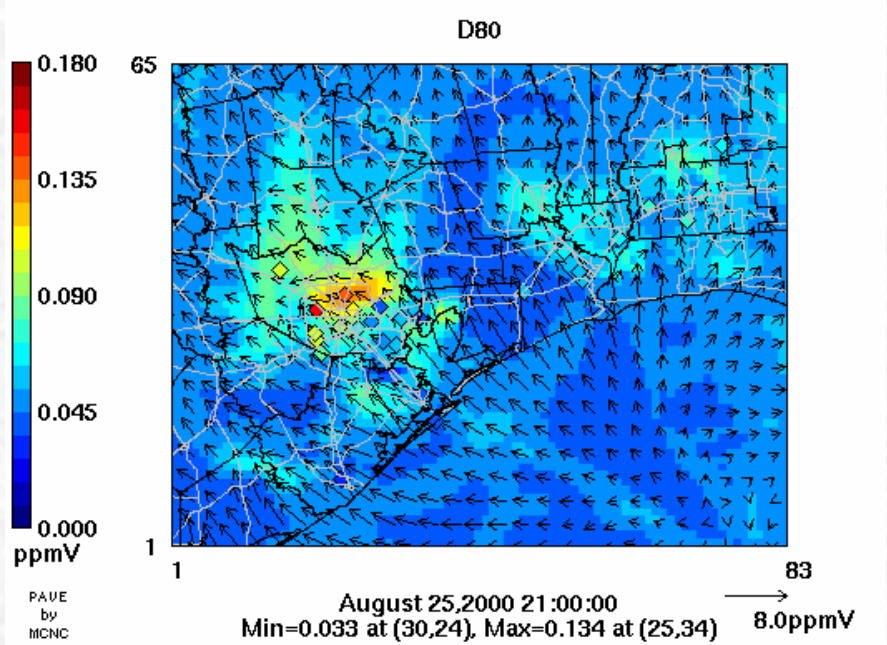
The simulations could capture the general changes of ozone observed during the period. O3 peak, such as a very high ozone level observed at some of the CAMS sites in Houston downtown area on August 25th, was underestimated.

Max O3 was predicted at north of Houston instead of Houston downtown where was recorded O3 peak by CAMS sites.

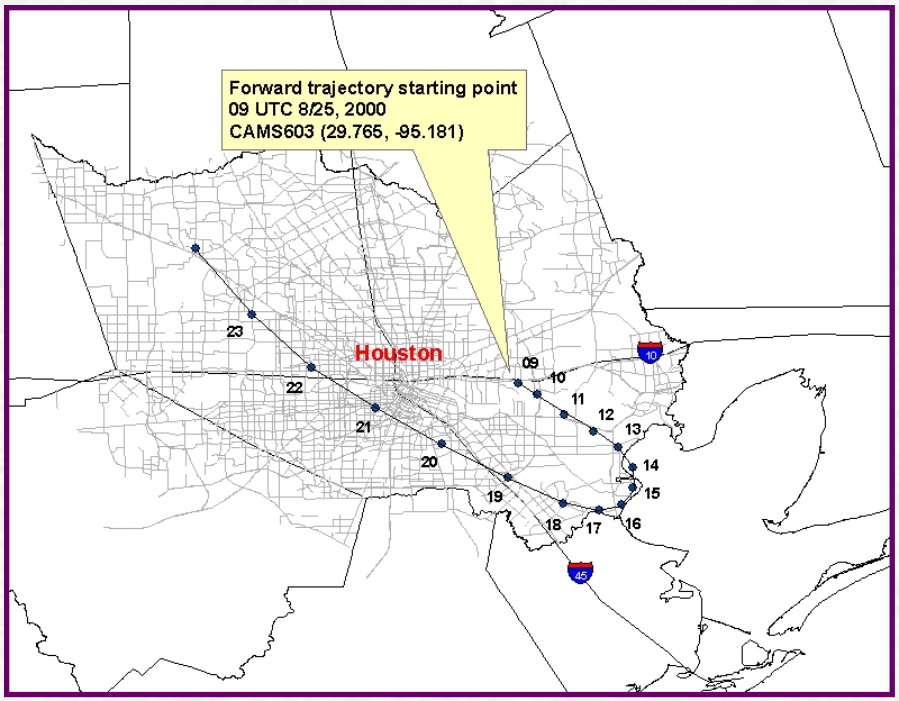
CMAQ2



CMAQ with multi-nesting MM5
~ provided by Fang-Yi Cheng



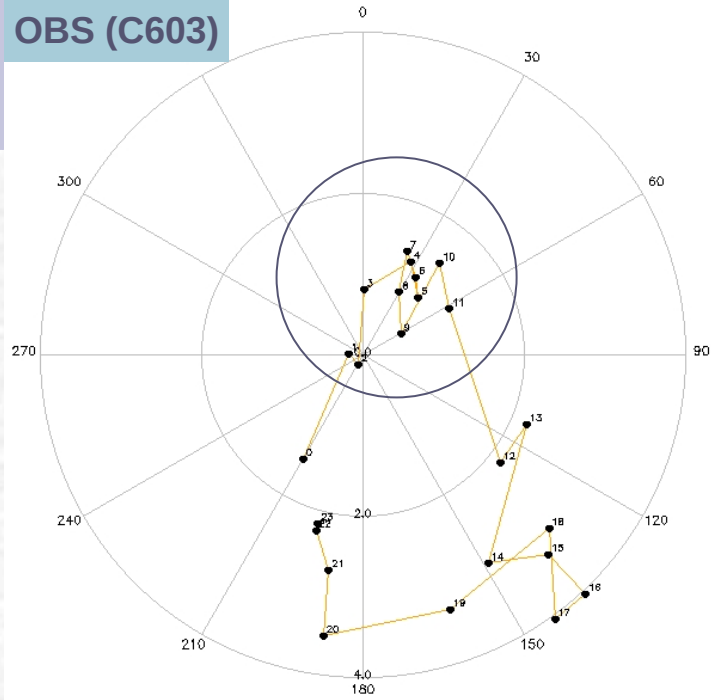
High O3 event on 8/25



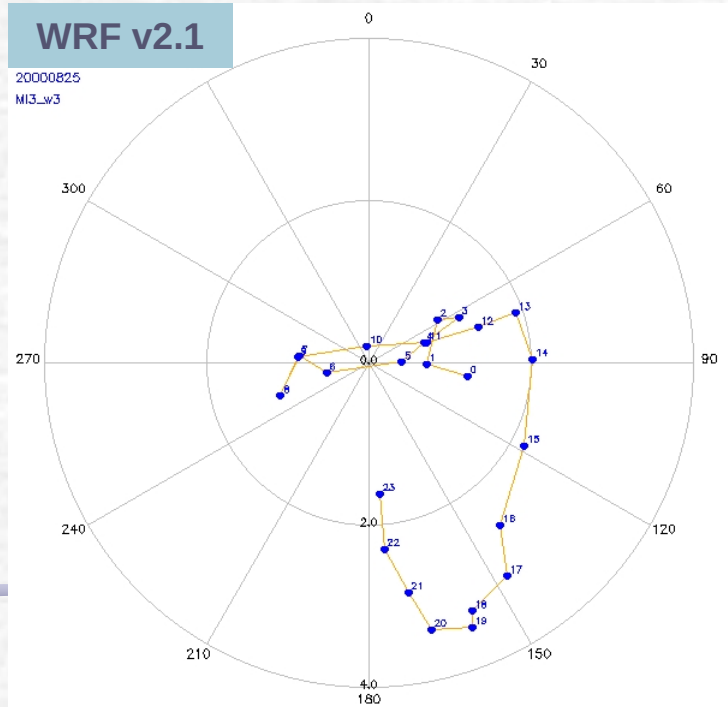
The high O3 event was caused by emissions sent out to the Galveston Bay and Gulf areas by the land breeze in the morning then returned by the sea breeze in the afternoon.

Turning of wind direction in the morning was not simulated properly caused the underestimation of ozone peak.

OBS (C603)



WRF v2.1



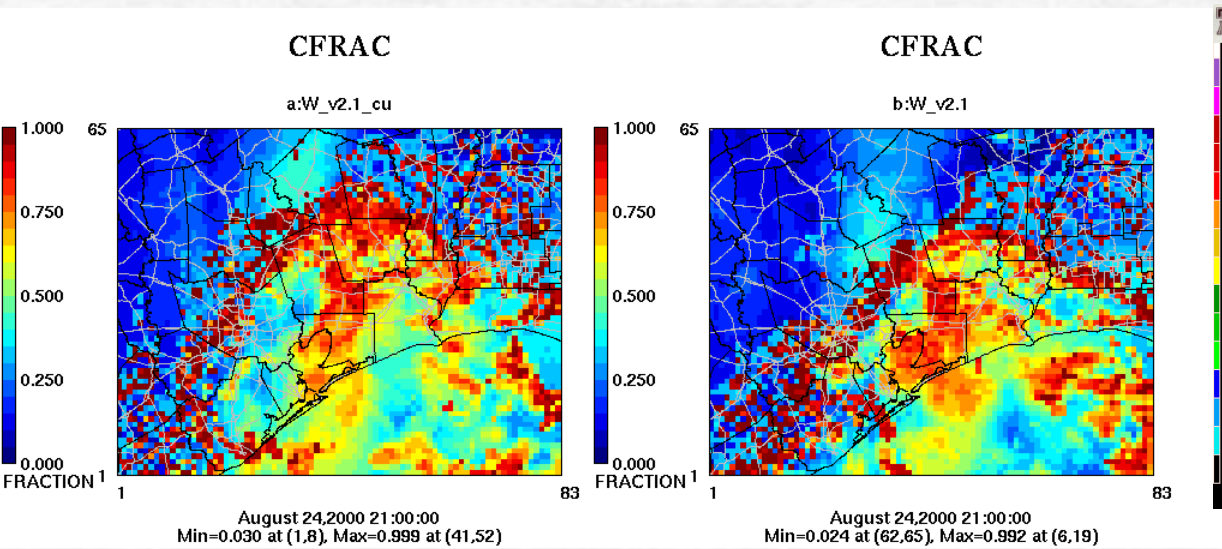
Summary

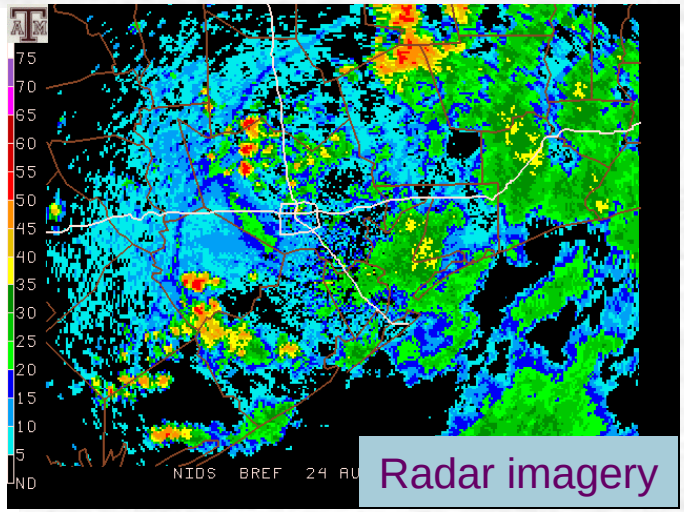
- In WRF v2.1, nighttime cold bias was reduced
  PBL height was reported as the height of first layer under stable conditions.

- CMAQ result revealed that the estimation of ozone level was sensitive to the surface temperature, wind and PBL height.
- **Off-line coupling system is able to isolate failure of air quality predictions caused by inadequate meteorological modeling.**
- Nighttime high PBL height bias from ARW v2.0.3.1 caused unrealistic high ozone at night.
- Prediction of light wind in the morning is critical for the estimation of maximum value and location of O3 concentration.

- lack of grid-nudging tool in the ARW model is one of critical shortcomings for air quality assessment study.

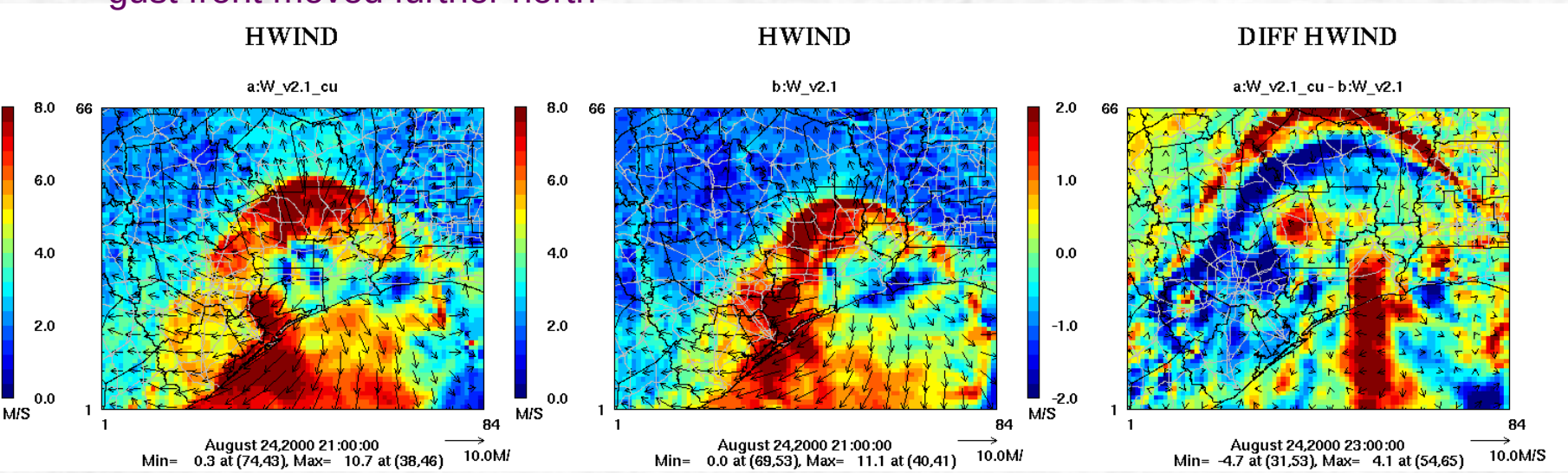
Comparison of W_v2.1_cu & W_v2.1
Spatial plot of cloud fraction & horizontal wind on 8/24





More clouds were generated & area covered by thunderstorm was larger with W_v2.1_cu.

➔ lower PBL height at the north-western edge of Harries County
gust front moved further north



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Spatial plot of PBL height & horizontal wind at 21 UTC on 8/24

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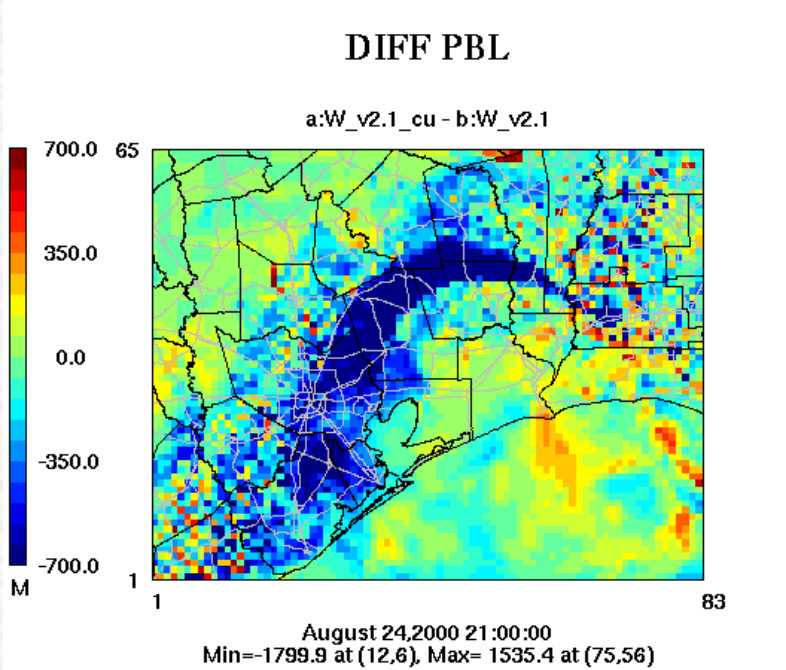

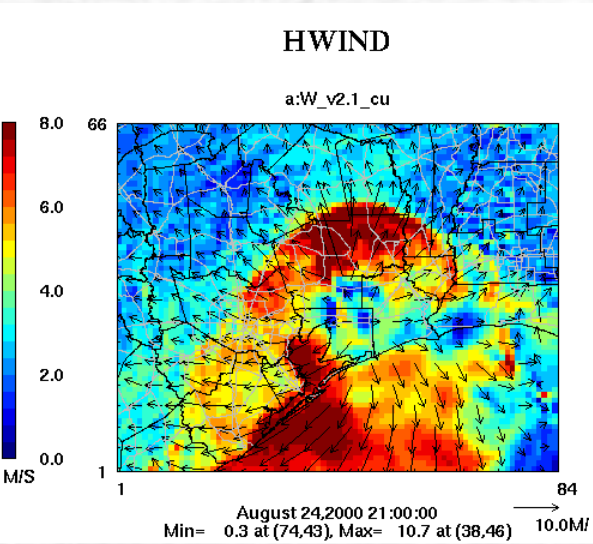

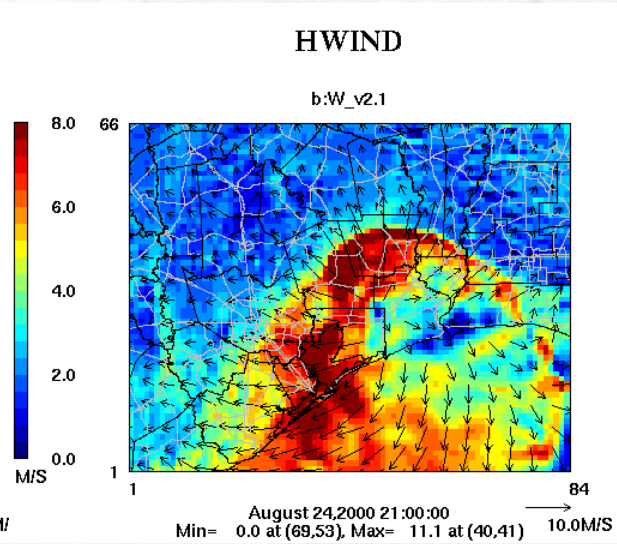

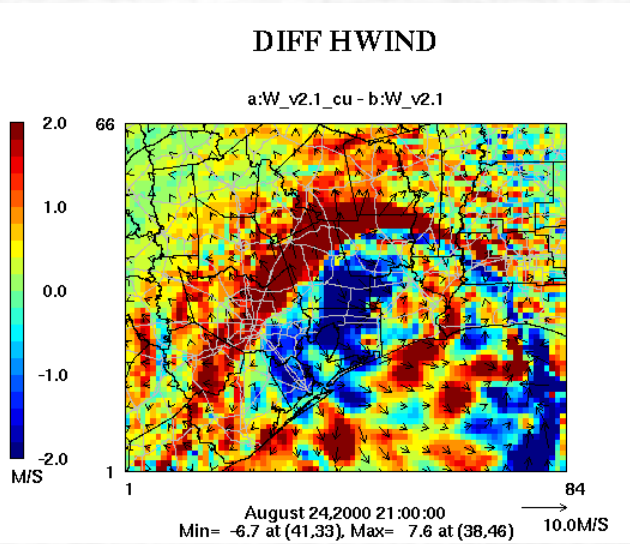

Content:

Introduction – objective, introduce CMAQ, emphasize advantage linking WRF to CMAQ, show benefit to use off-line system for Houston high O3 which met involved much. (2p)

Review previous study – no nudging no nesting, WRF generates comparable met field as MM5, show statistical analysis, conclusions are consistent with CA study. (1p)

Domain configuration & physics settings (1p)

Numerical experiment & OBS, emission is provided by STkim(1p)

Time-series of TEMP1P5 & PBLH – improvement of nighttime temperature, PBLH in new WRF, better match to OBS of temp drop on 8/24 (1p)

Spatial plot of CFRAC & HWIND 8/24 – show satellite & radar imagery (1p)

Spatial plot of HWIND – 8/25 new version WRF have faster wind at afternoon. Wind tuning problem on 8/25 (2p)

CMAQ time-series of O3, NOx, – OBS records of peak, improvement of nighttime bias (1p)

Spatial plot at nighttime of O3, NOx (1p)

Conclusion (1p)

Future work (1p)