Evaluation of the Boundary Layer Characteristics and Pollutants in Mexico City Predicted by WRF

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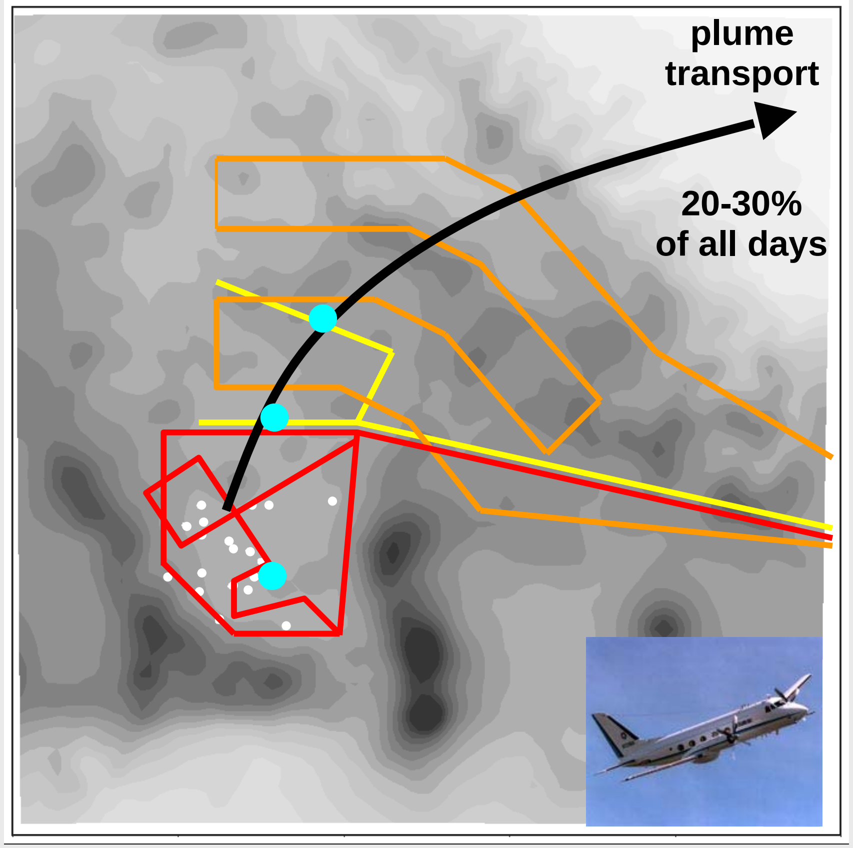
Motivation: 2006 Field Campaigns

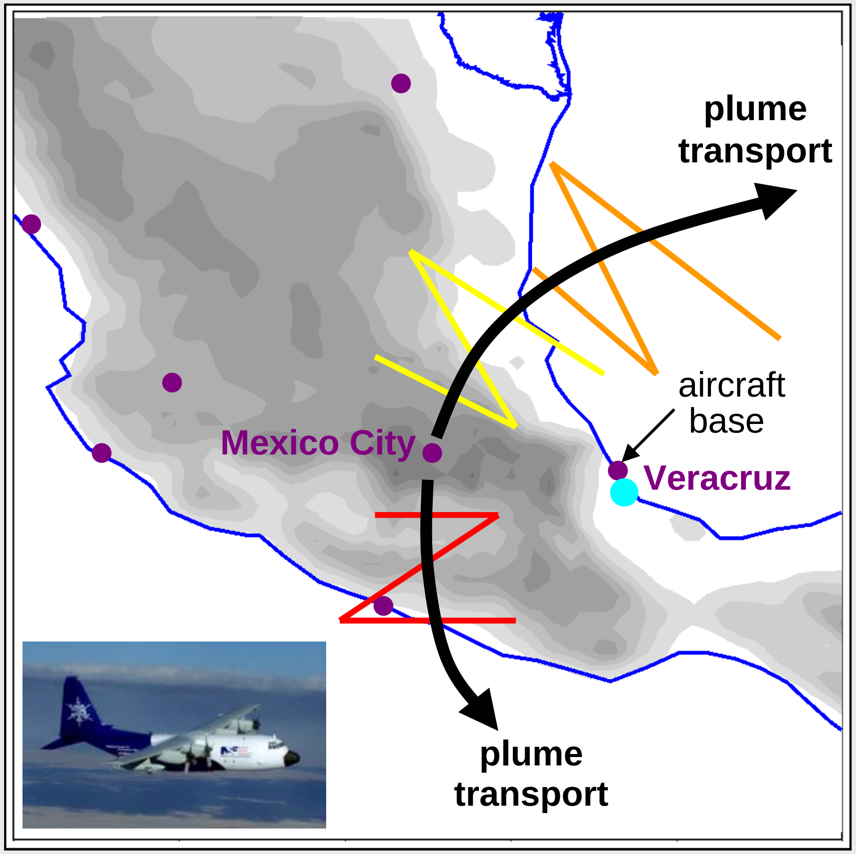
- MIRAGE-Mex - supported by NSF] March 2006
- MAX-Mex - supported by DOE
- improve understanding oxidants and particulates downwind of a megacity
- meteorological and chemical transport models to support aircraft operations

Expected DOE G-1 Flight Paths



● NSF and/or DOE meteorology/chemistry sites
○ operational ozone monitors

Expected NSF C-130 Flight Paths



● NSF and/or DOE meteorology/chemistry sites
● operational rawinsondes

Modeling Prior to Field Campaigns

Objectives:

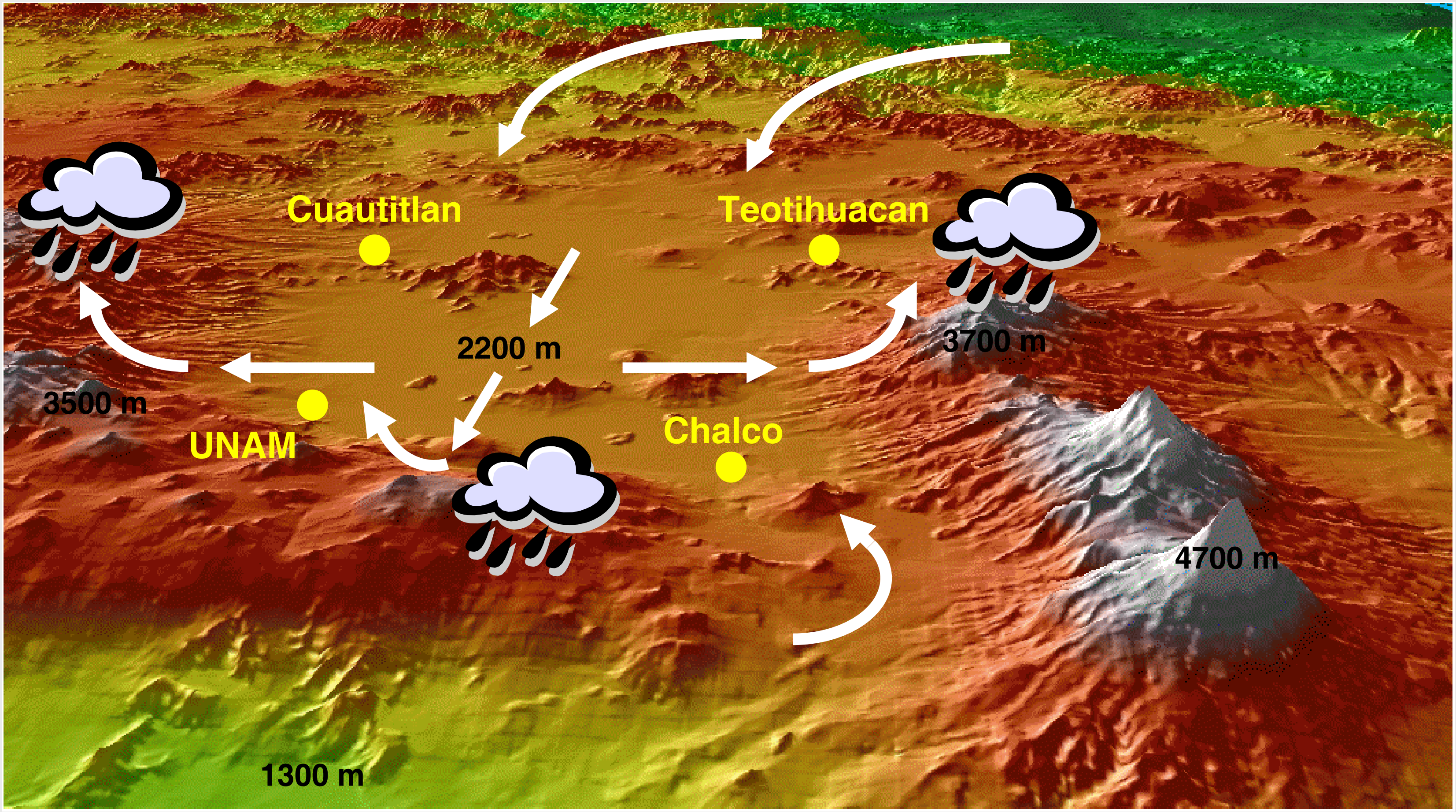
- use data from a previous field campaign to evaluate WRF forecasts
- determine the sensitivity of WRF forecasts to boundary-layer and land-use schemes and their effect on downwind pollutant transport
- learn forecast characteristics prior to the 2006 field campaigns

Rationale:

- operational data, field campaigns, modeling studies have shown how local circulations affect the distribution of surface ozone and particulates, but …
- little is known about the interaction of local and ambient circulations and their effect on venting pollutants into the free atmosphere
- the CBL can be up to 4 km deep so pollutants can be mixed directly into the mid-troposphere; therefore, …
- accurately simulating boundary layer evolution may be critical in forecasting pollutant transport downwind of Mexico City

IMADA 1997 Field Campaign

- February - March 1997
- 4 boundary layer sites: 915 mHz radar wind profilers, up to 5 soundings / day
- various trace gas and particulate measurements throughout the city



thermally-driven circulations:

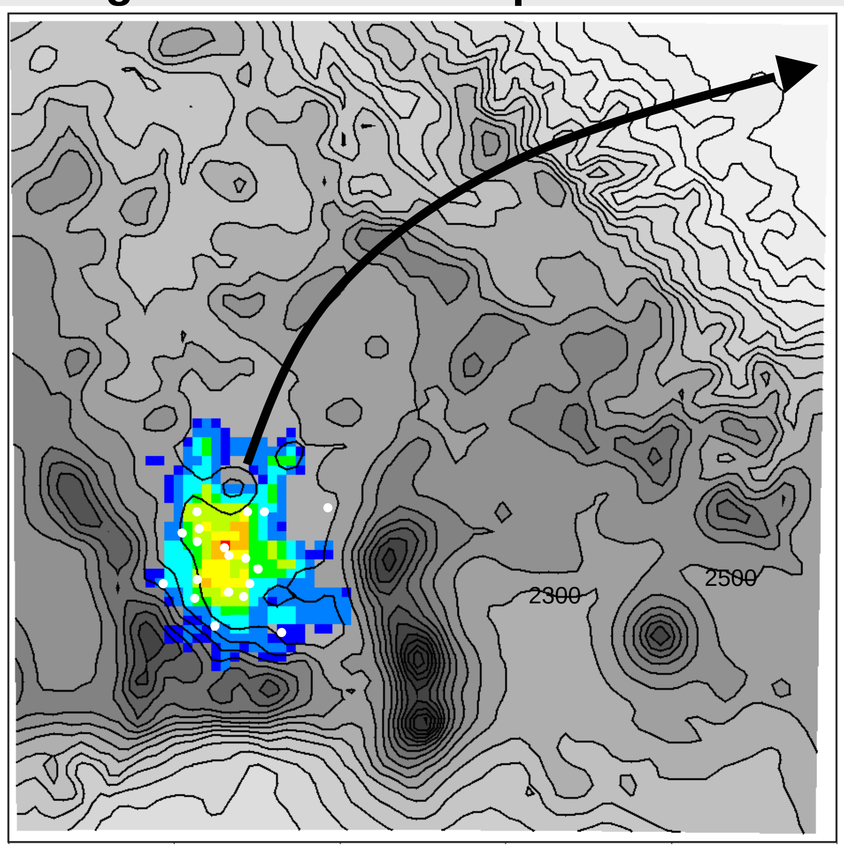
1) slope flows
[Jauregui, Atmosfera, 1988]

2) gap wind
[Doran and Zhong, JAM, 2000]

3) density current
[Bossert, JAM,1997]

WRF-chem Configuration

Domain 3
Designed for NE Transport Scenarios



225 km

topography - gray
CO emissions - color
emission rates based on 2000 inventory

Tracer Mode

- CO transport and mixing only
- IC and BC based on NARR analyses
- 3 grids: 22.5, 7.5, 2.5 km
- simulations / land-use / PBL

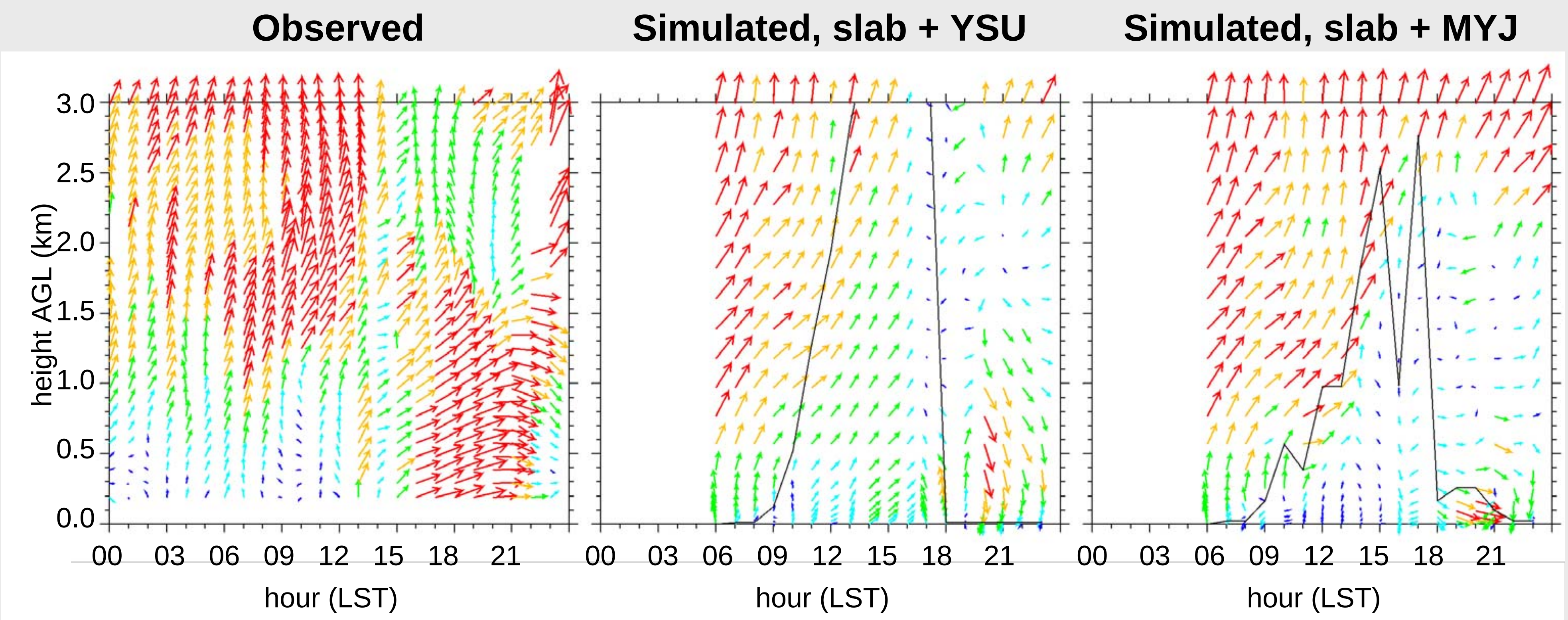
simulations	land-use	PBL
1	slab	YSU
2	slab	MYJ
3	NOAH	YSU
4	NOAH	MYJ

- eight 48-h simulation periods, weak to strong synoptic forcing

Full Chemistry Mode

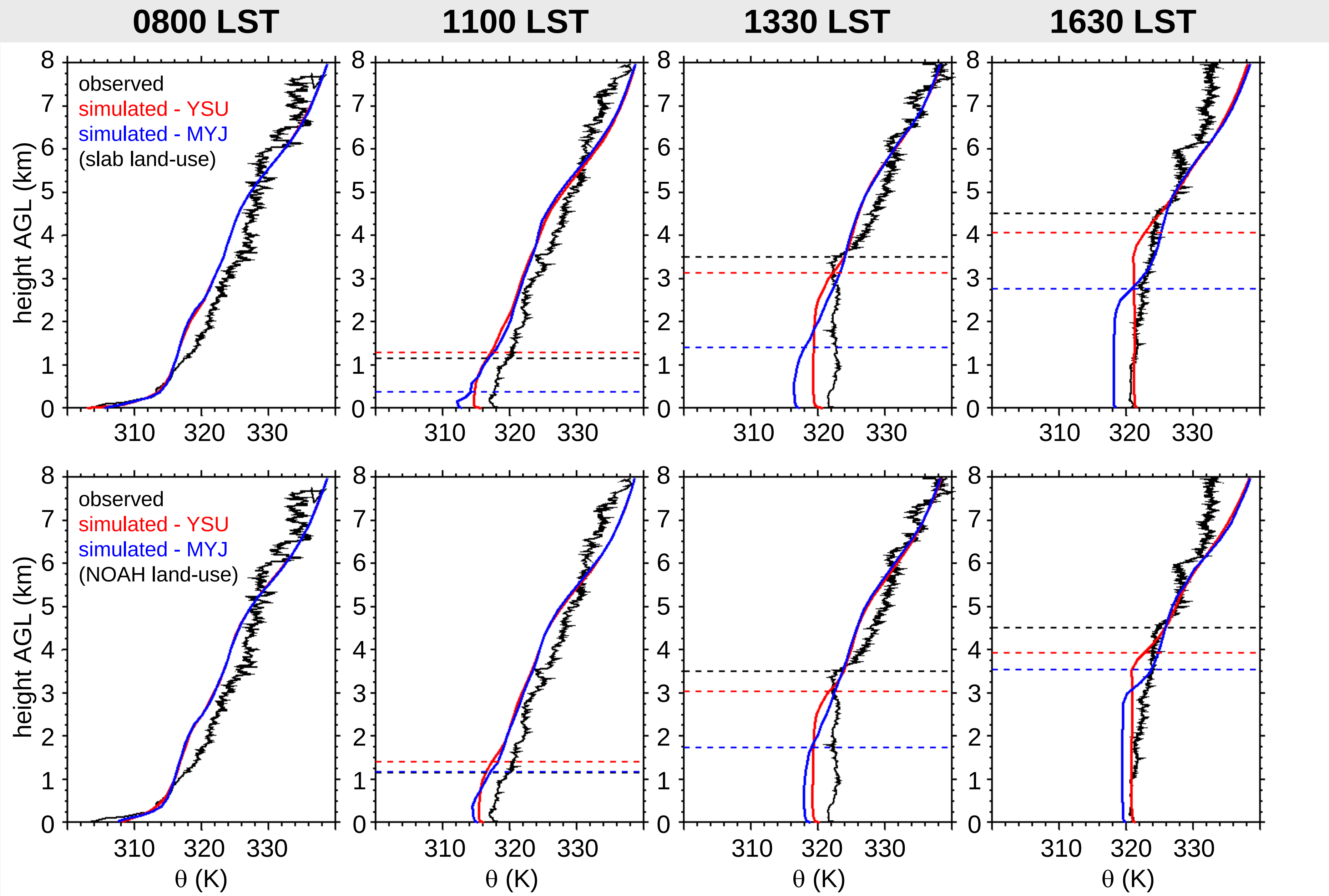
- trace gas chemistry
- configuration same as tracer mode
- select periods only

Winds at Cuautitlan on 1 March

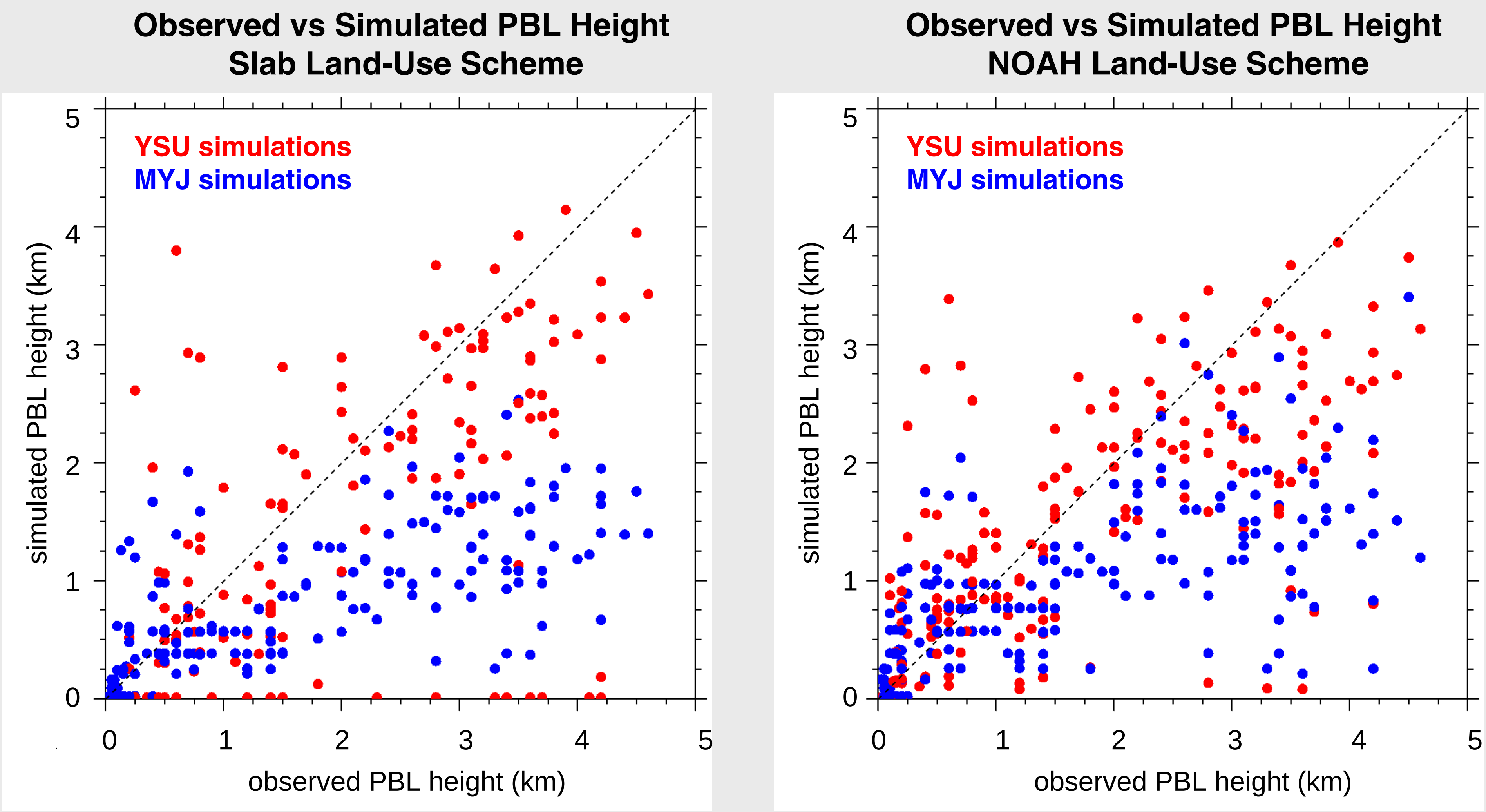


blue = 0 - 2 light blue = 2 - 4 green = 4 - 6 orange = 6 - 8 red > 8 m s^{-1}

Temperatures at Cuautitlan on 1 March



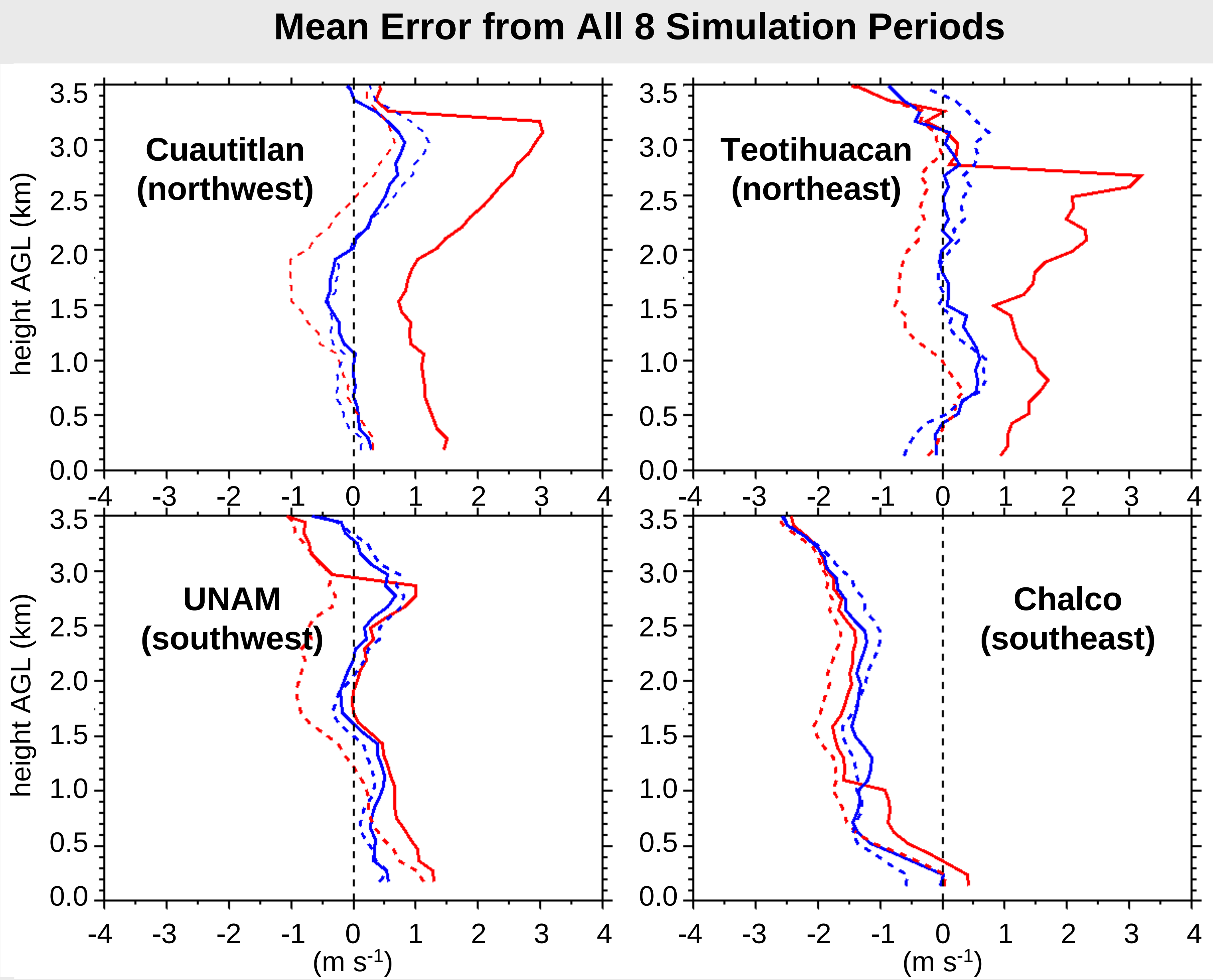
CBL Height Evaluation



YSU simulations: bias = -411 m, r =0.71
MYJ simulations: bias = -833 m, r = 0.77

YSU simulations: bias = -279 m, r =0.78
MYJ simulations: bias = -715 m, r = 0.70

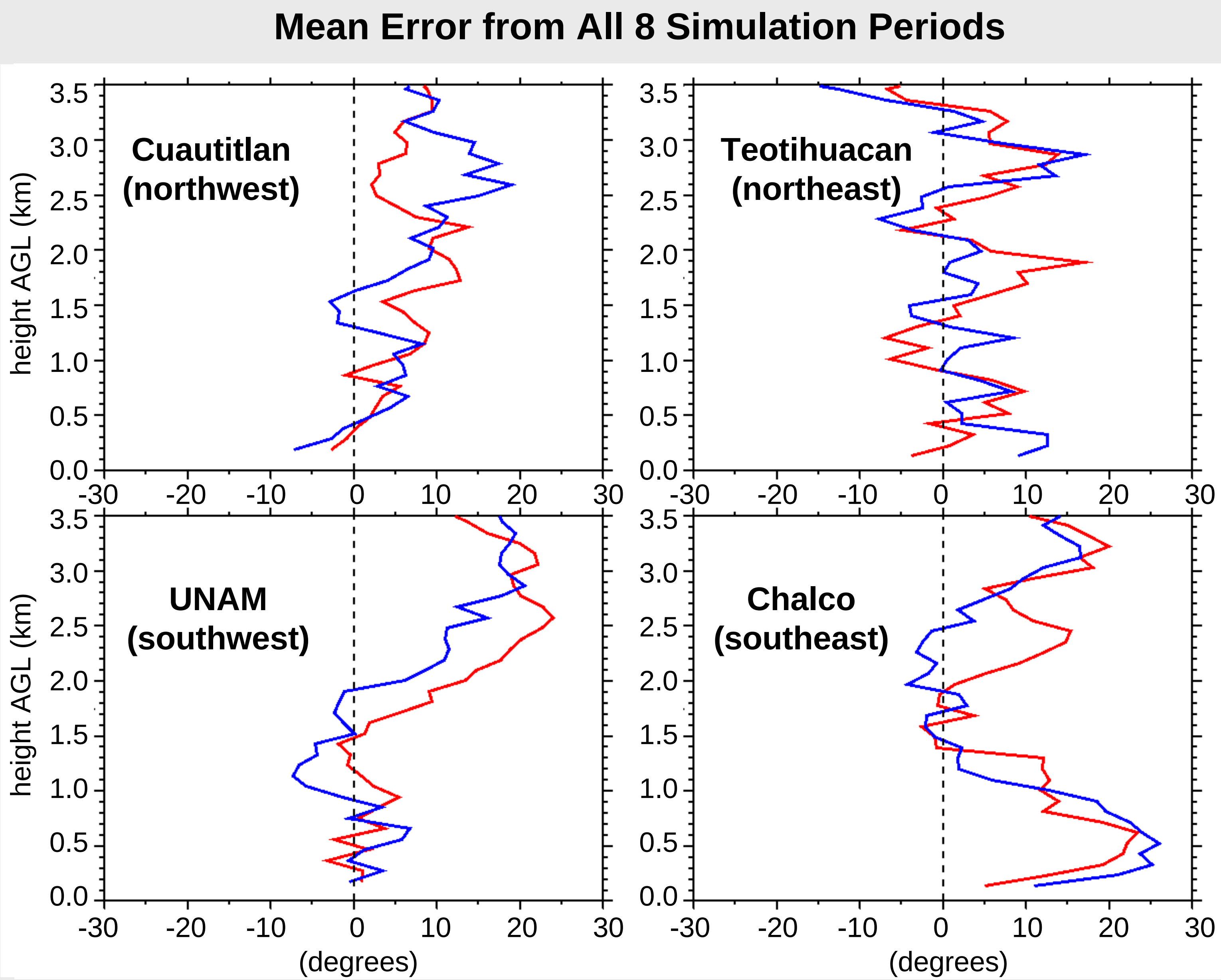
Speed Statistics: Mean Error



PBL simulations:
red = YSU
blue = MYJ

land-use simulations:
solid = slab
dashed = NOAH

Direction Statistics: Mean Error



PBL simulations:
red = YSU
blue = MYJ

both employ NOAH land-use scheme

(similar statistics obtained for slab land-use scheme)

Impact on Downwind Pollutant Dispersion

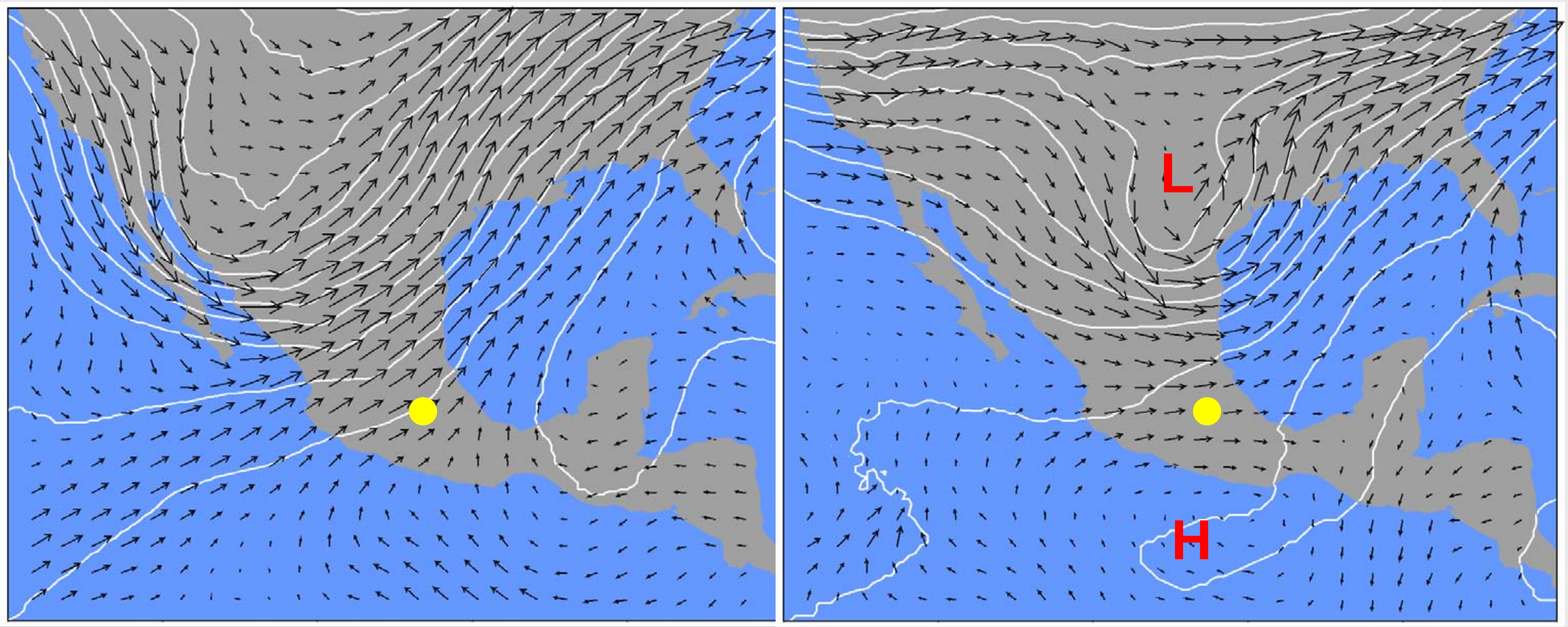
- PBL depth from both PBL schemes too low, but YSU closer to observations in general
- wind statistics between YSU and MYJ simulations different when using slab land-use scheme, otherwise winds similar when using NOAH
- YSU and MYJ simulated winds often different, even if statistics seem similar
- WRF qualitatively produces the 3 types of thermally-driven circulations
  - YSU simulations produced larger wind speeds in the boundary layer
  - MYJ simulations produced stronger afternoon northerly flow into the valley
- there are often large errors in wind speed and direction in the valley atmosphere (< 3 km AGL) among all simulations
  - large-scale analyses used for IC & BC may be poor as a result of few operational soundings over Mexico

Do these differences in boundary layer depth and winds produce significant differences in tracer transport?

Synoptic Conditions: 1 - 2 March

600 hPa Geopotential Heights and Winds

12 UTC 1 March, 1997 **12 UTC 2 March, 1997**

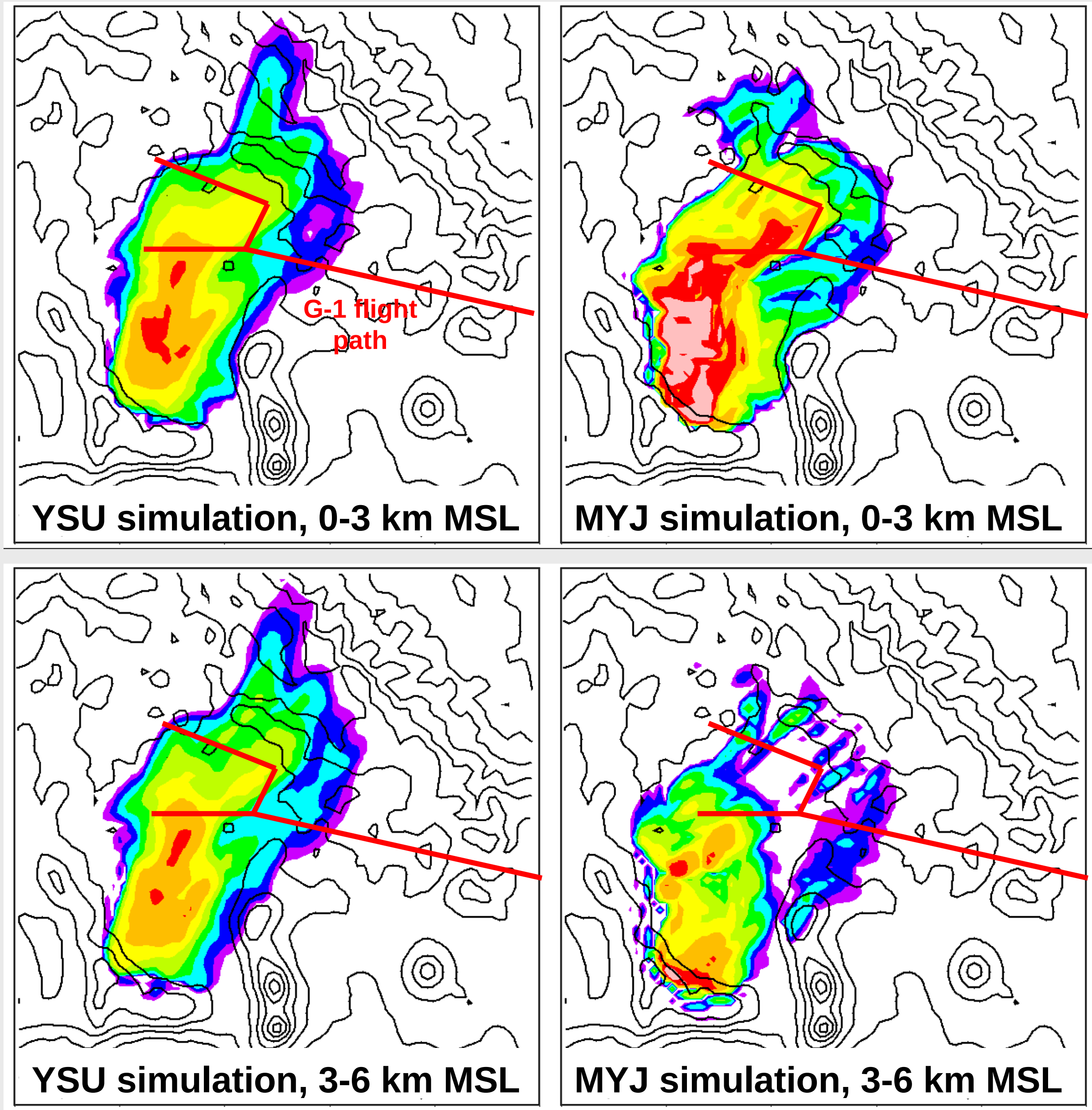


propagating trough over southern U.S.

NARR consistent with radar wind profiler data over Mexico City

conditions appear to be favorable for transport toward the NE, at least on the first day

Tracer Transport: 1 - 2 March



Day 1 Forecast
19 UTC (01 LST) 1 March
CO Footprint

southerly ambient winds

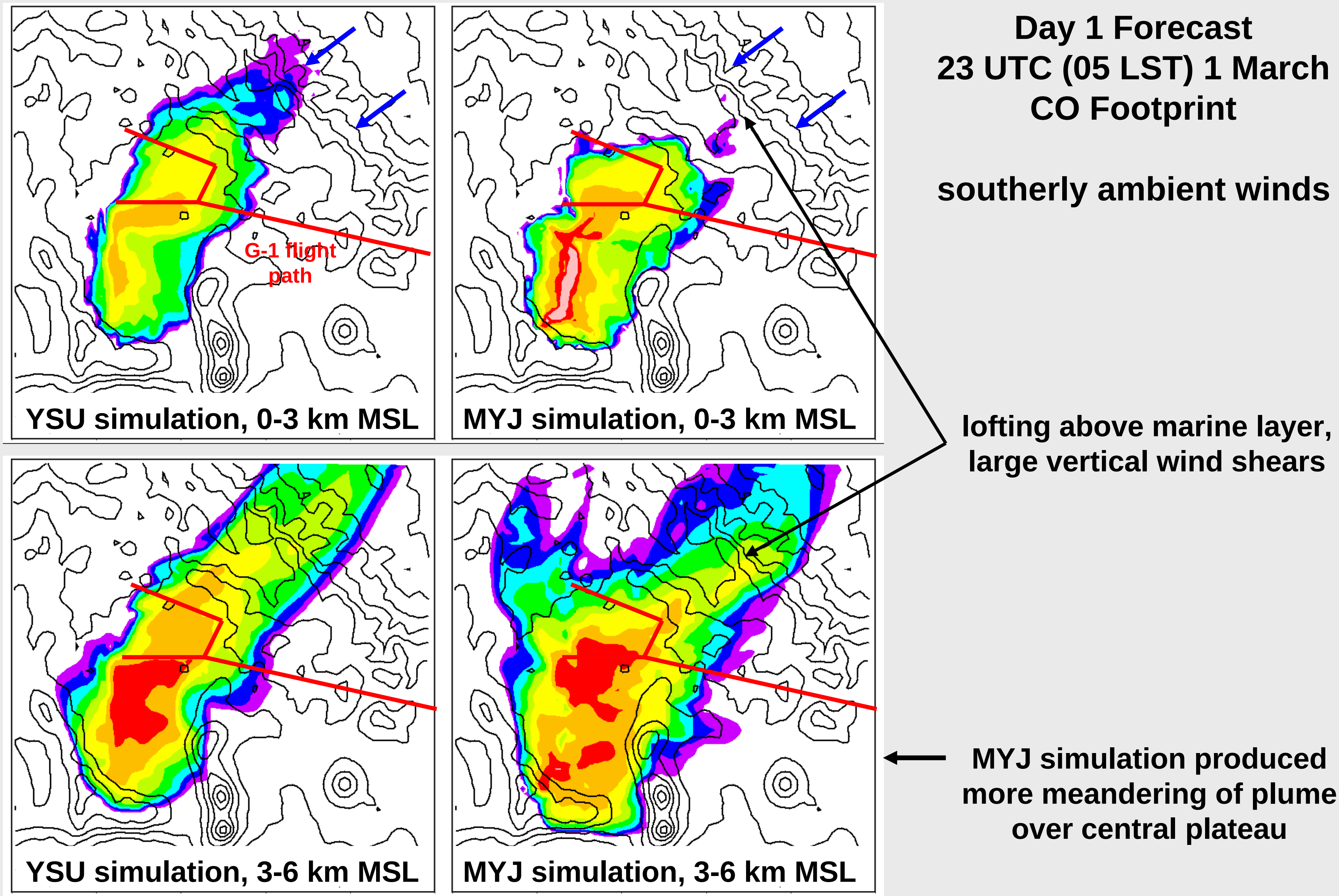
CO tracer "footprint" (color)

lower troposphere:
integrate CO between 0 and 3 km MSL

middle troposphere:
integrate CO between 3 and 6 km MSL

PBL depth from MYJ simulation resulted in higher near-surface concentrations and lower concentrations aloft

Tracer Transport: 1 - 2 March



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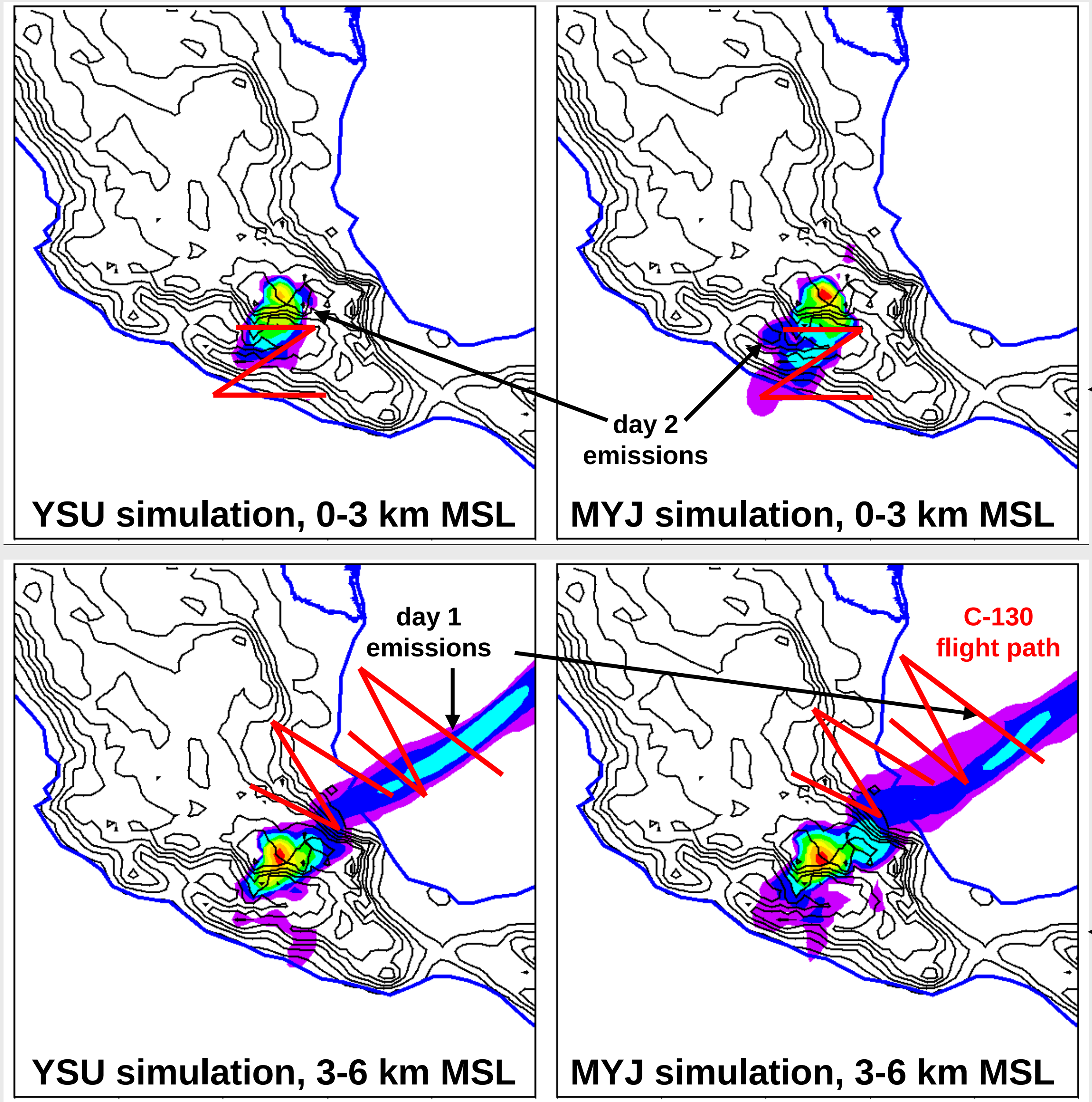


Day 2 Forecast
23 UTC (05 LST) 2 March
CO Footprint

westerly ambient winds

plume from MYJ simulation transported further south

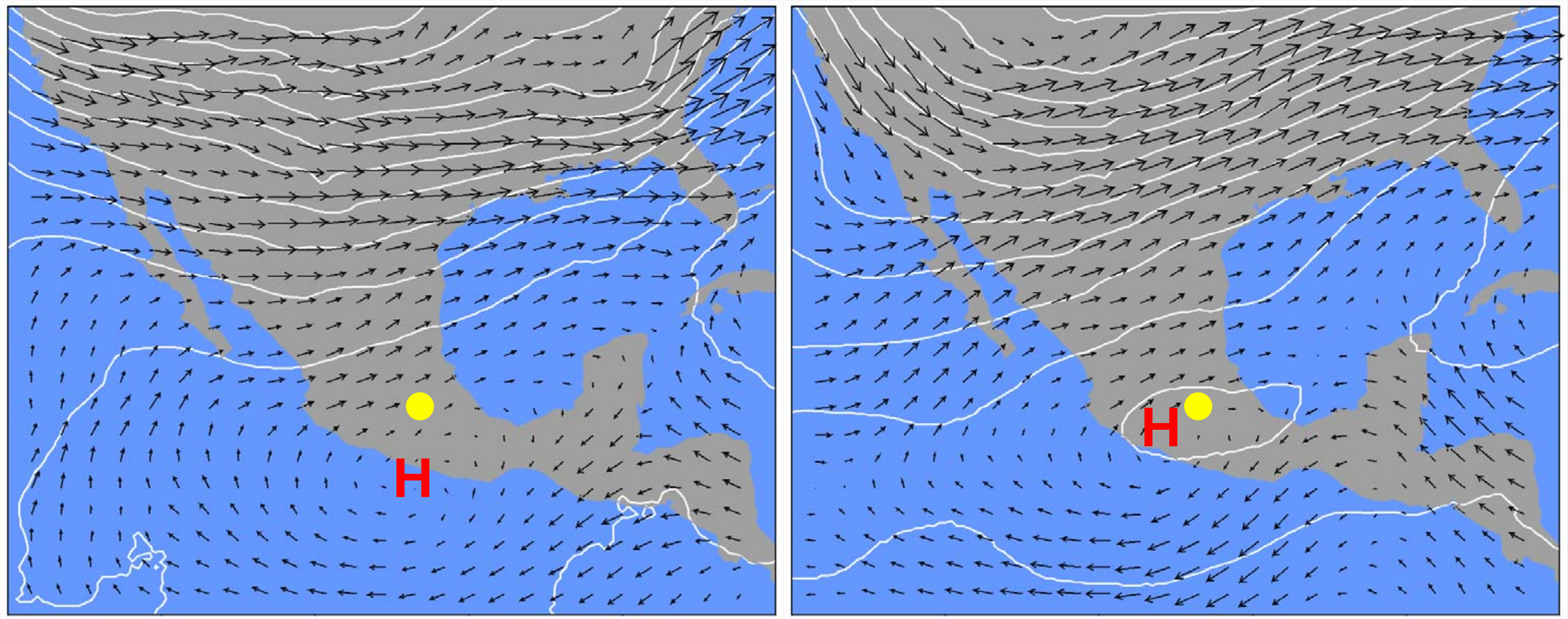
0.5 - 2 km deep
between 3.5 and 6 km MSL
YSU peak at 4.3 km
MYJ peak at 4.4 km

plume from YSU simulation a little farther north with higher concentrations

Synoptic Conditions: 3 - 4 March

600 hPa Geopotential Heights and Winds

12 UTC 3 March, 1997 | **12 UTC 4 March, 1997**

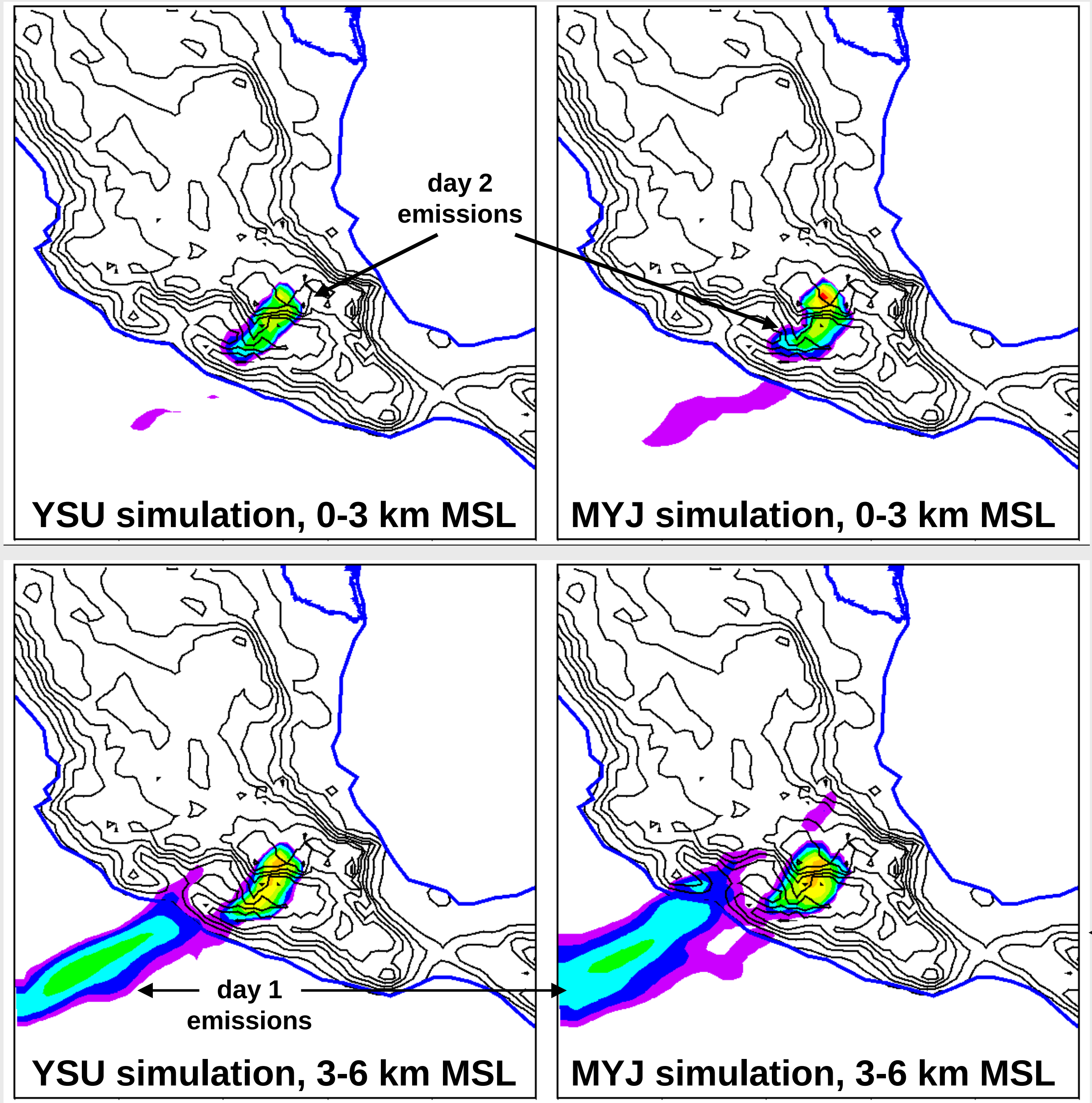


weak synoptic forcing over central Mexico

NARR not consistent with radar wind profiler data in Mexico City - observed NE winds at 6 - 10 m s^{-1}

conditions favorable for transport toward the NE ??

Tracer Transport: 3 - 4 March



Day 2 Forecast
23 UTC (05 LST) 4 March
CO Footprint

northeasterly ambient winds

1 - 2 km deep
between 3 and 5 km MSL
YSU peak at 4 km
MYJ peak at 3.7 km

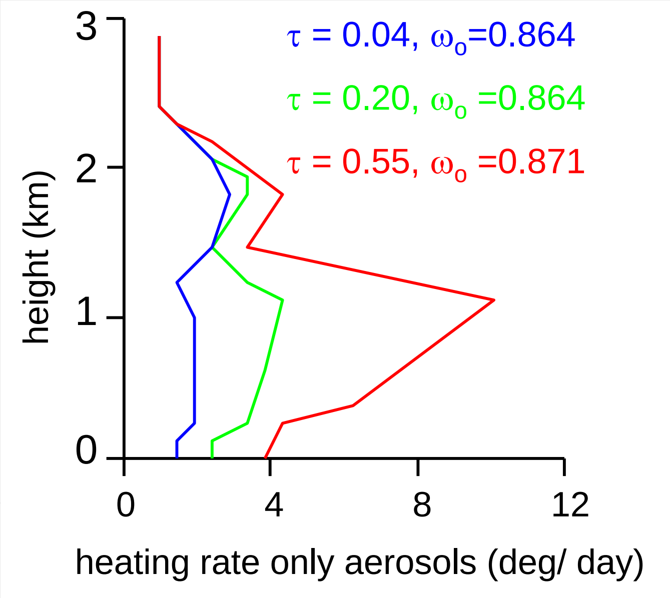
← **plume from MYJ simulation**
a little farther north

Summary

- sensitivity of tracer transport and mixing to PBL parameterization
  - large differences in spatial distribution of tracers in the valley …
  - but relatively small differences in downwind spatial tracer distribution - this is encouraging from a forecasting perspective for aircraft operations
- pre-field campaign simulations will be extended to include
  - additional periods during the 1997 IMADA field campaign
  - chemistry and aerosols and evaluated with data in Mexico City
  - data assimilation - initial 3DVAR tests improved winds aloft but not within 1 - 2 km of the surface
- effect of forecast errors on downwind tracer transport remains unknown - aircraft data will be the ultimate test of the model
- real-time forecast modeling efforts for 2006 field campaigns will be coordinated with Ernesto Caetano (UNAM) and Benjamin de Foy (MIT)
  - ensemble approach ?

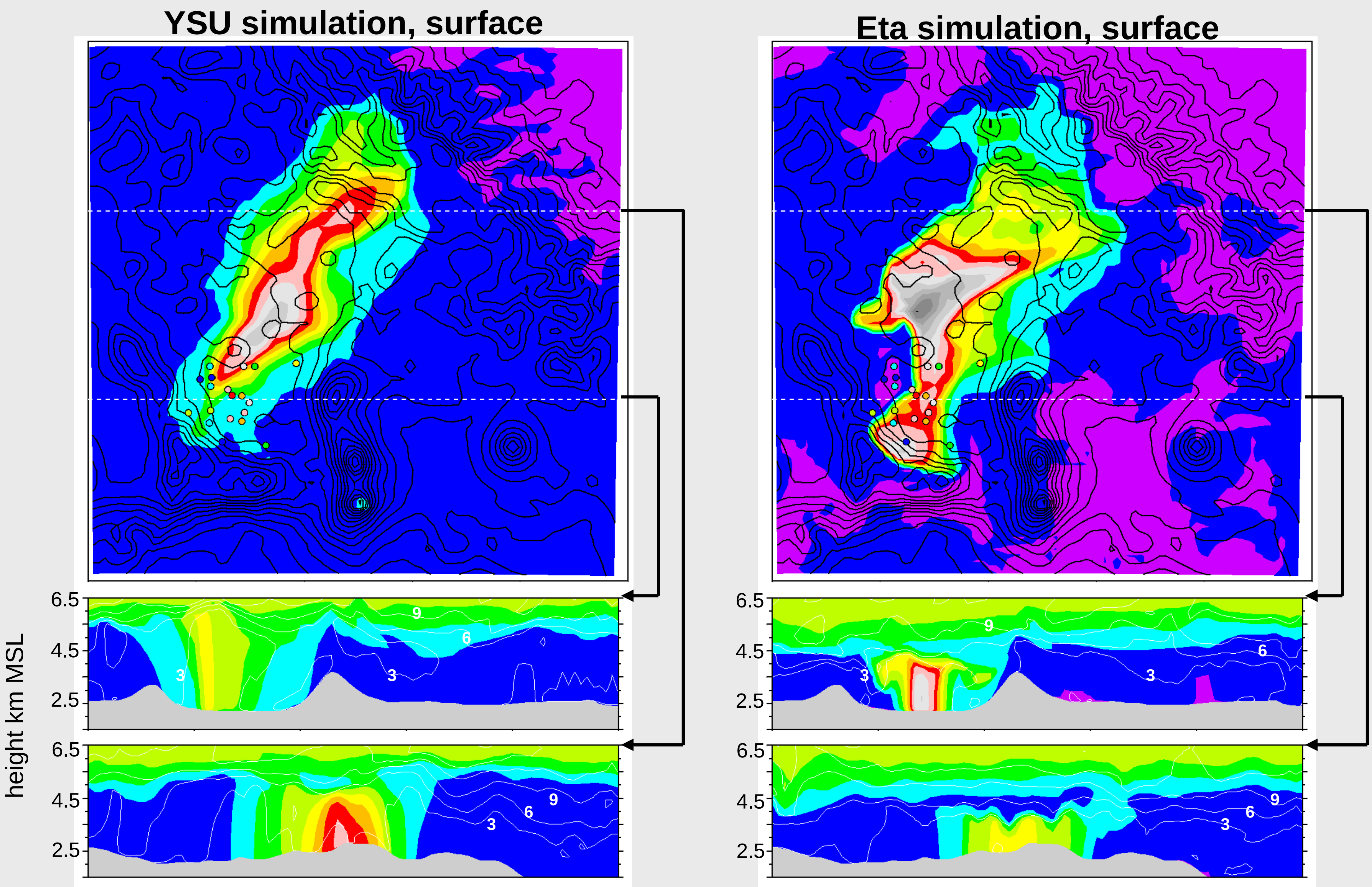
Future Plans

- after the field campaign, use 2006 measurements and WRF-chem to determine urban to regional-scale aerosol evolution and direct radiative feedbacks
  - evidence that PBL characteristics have been changing, correspond to growth of Mexico City [Magana, 2000]
  - vertical particulate distributions estimated to produce 0.4 K h^{-1} at the top of the CBL [Raga et al., 2001] - what is the effect on CBL evolution?
  - particulate layers reduce surface photolysis rates, but enhance rates at the top of the CBL [Castro et al. 2001] - what is the effect on ozone formation ?

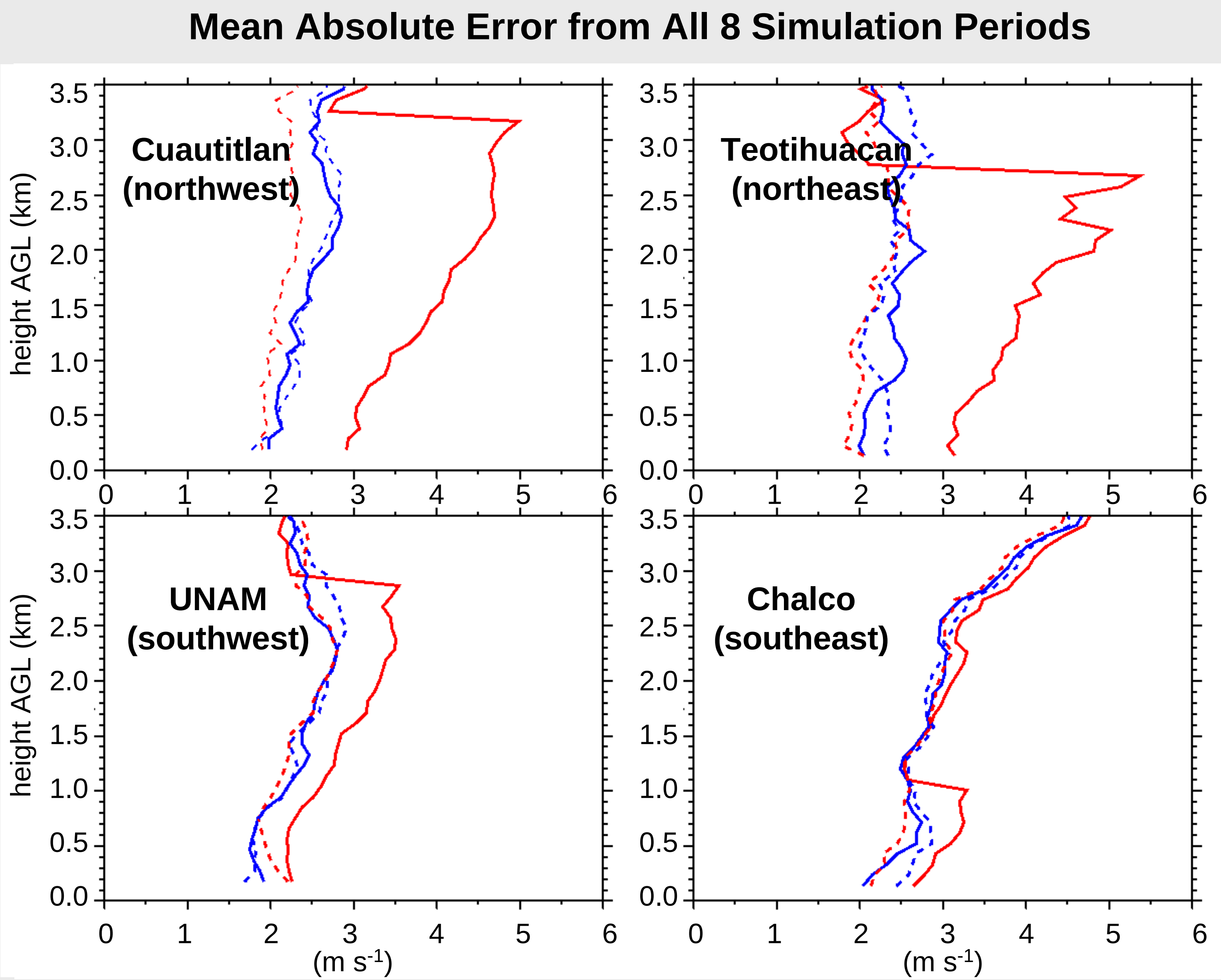


- *Acknowledgements:* This work is supported by the U.S. Department of Energy's Atmospheric Sciences Program (ASP)

Ozone Formation: 21 UTC 1 March



Speed Statistics: Mean Absolute Error



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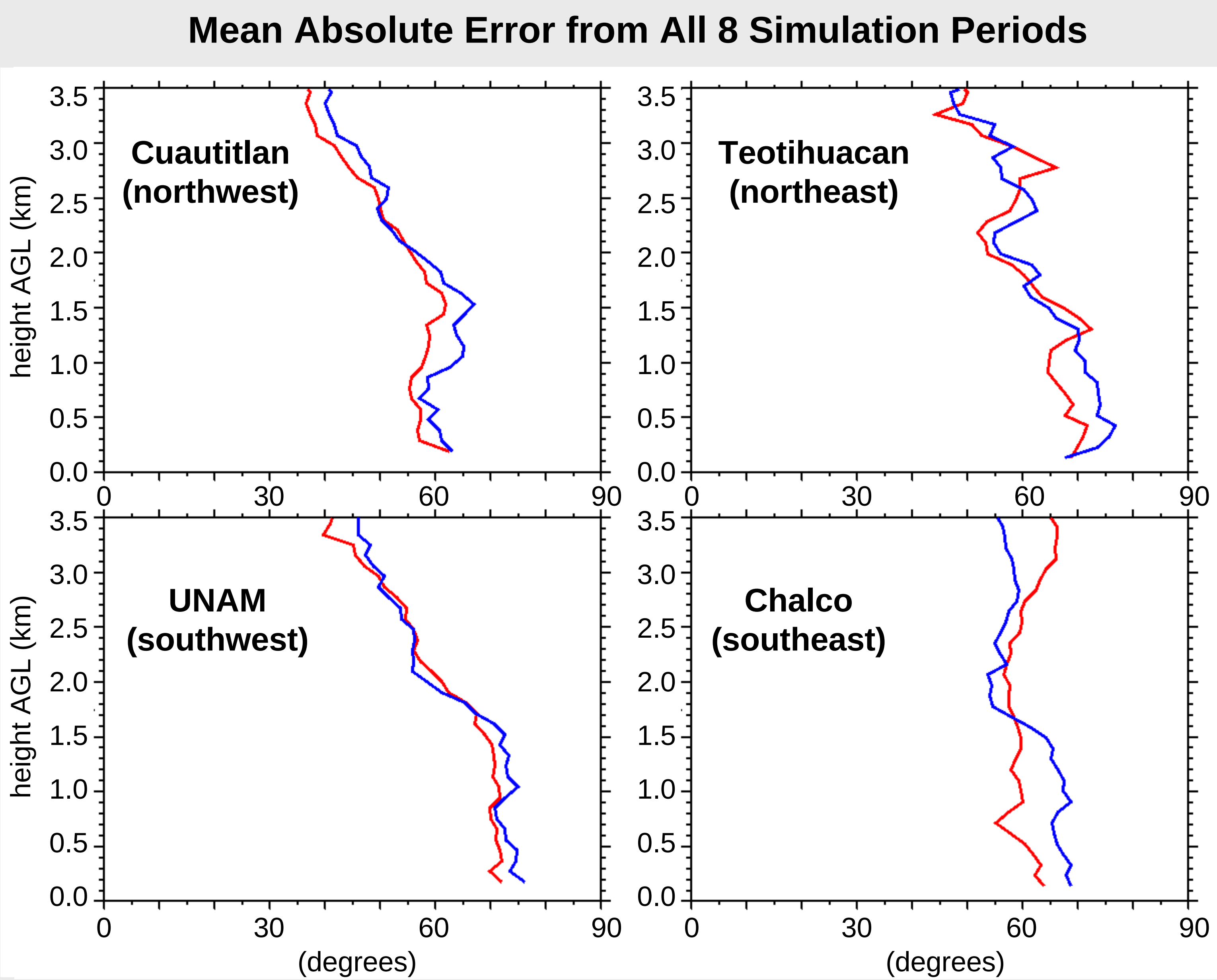

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