Multi-scale Mechanisms Affecting Hemispheric Chemistry & Transport

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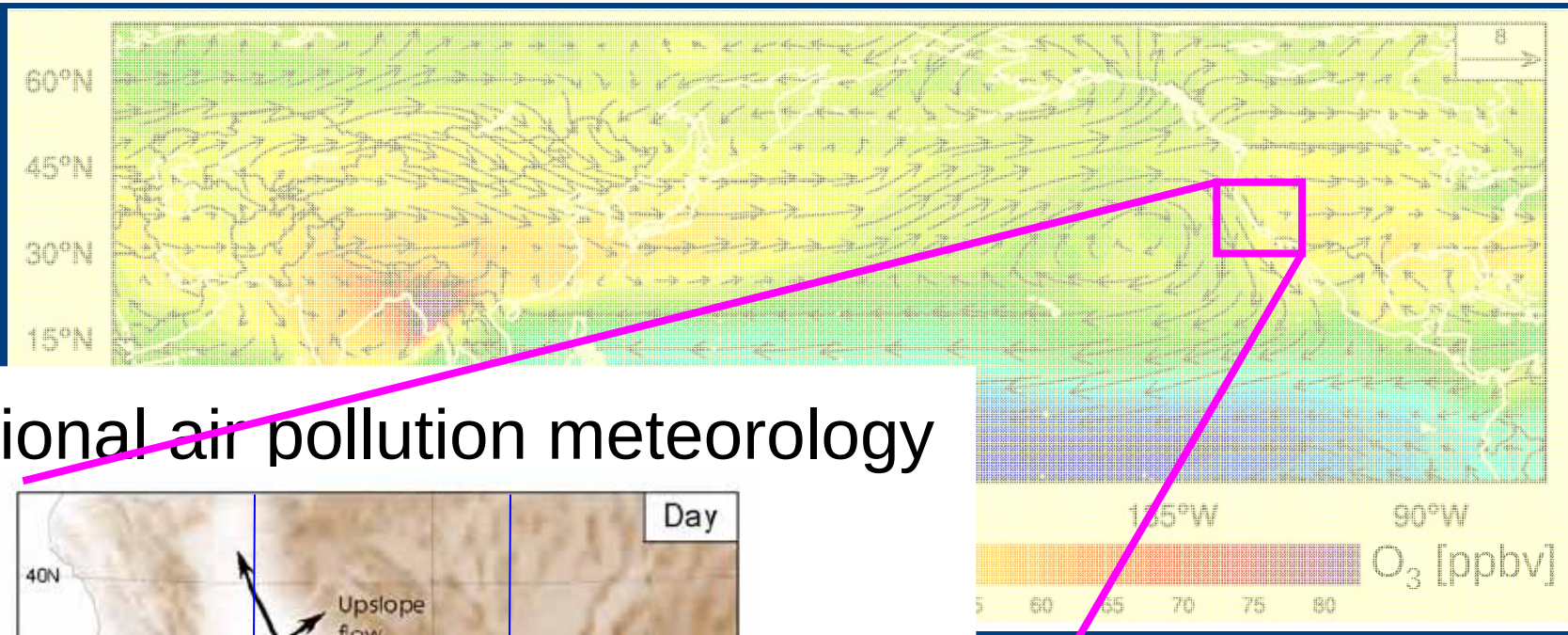
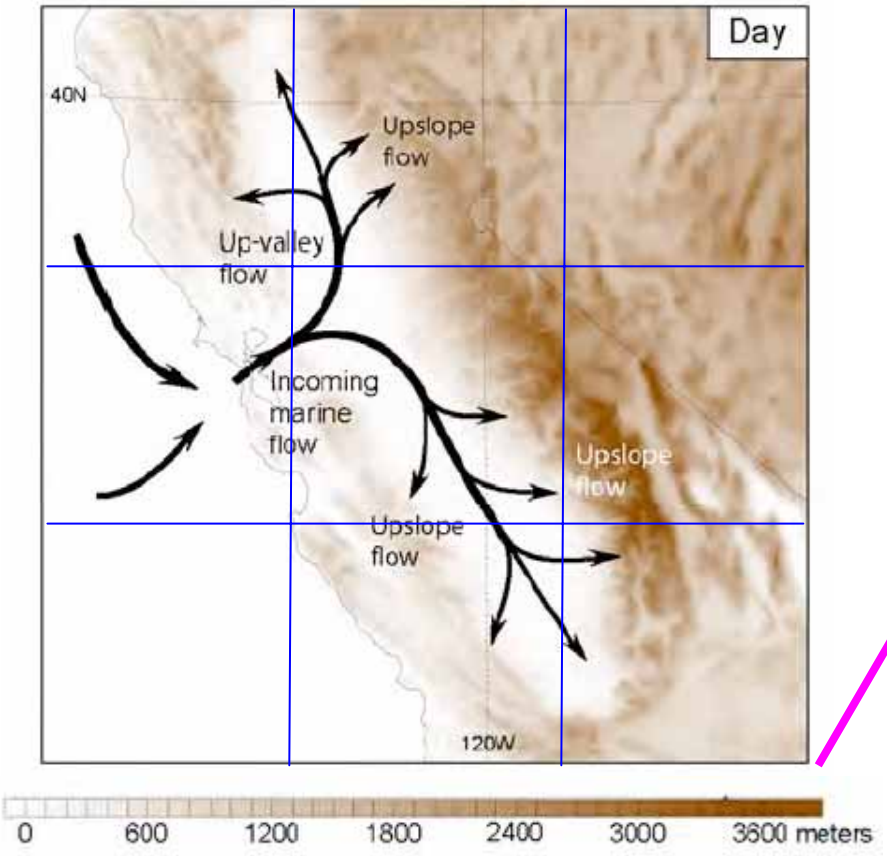
NOAA GFDL & Princeton University

Regional air pollution meteorology



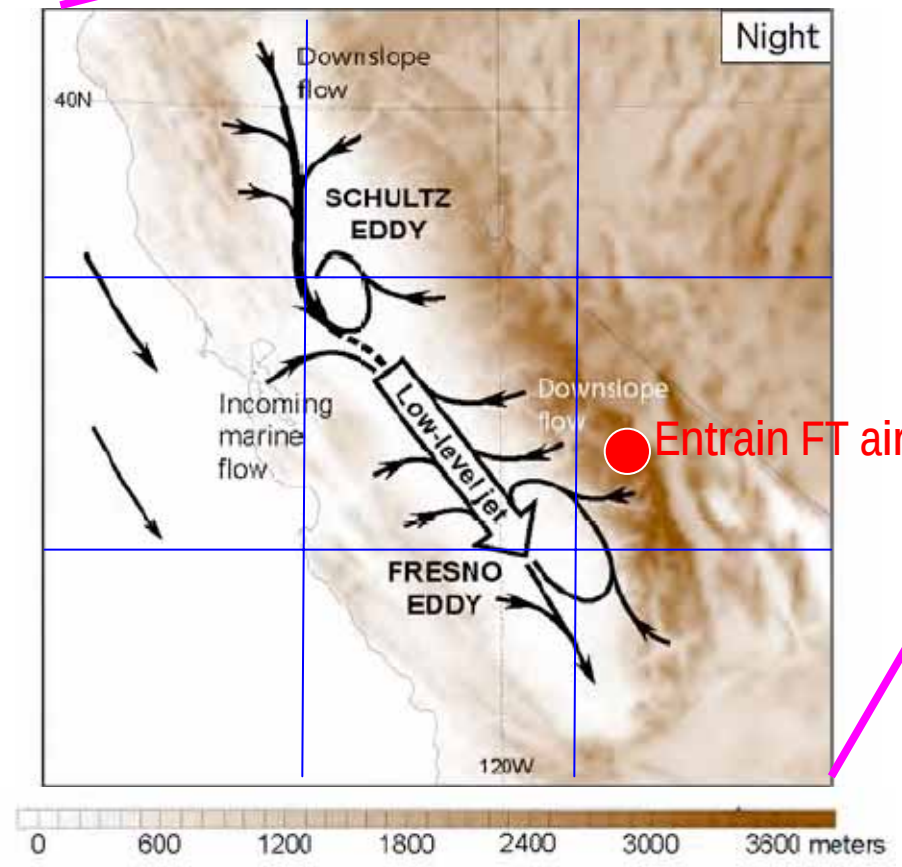


Adapted from NOAA CalNex 2008

Day

- Enhanced incoming marine flow by sea breezes
- Pollution lofting through upslope/ up-valley flow

Regional air pollution meteorology



Adapted from NOAA CalNex 2008

Night

- Low-level jet
- Interacts with downslope
- Entrain possibly polluted FT air to BL

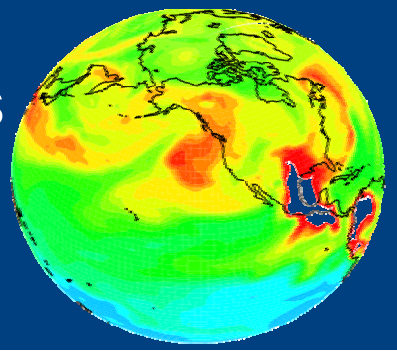
Challenges in evaluating air quality impacts from large-scale GCM-CTMs

Strengths:

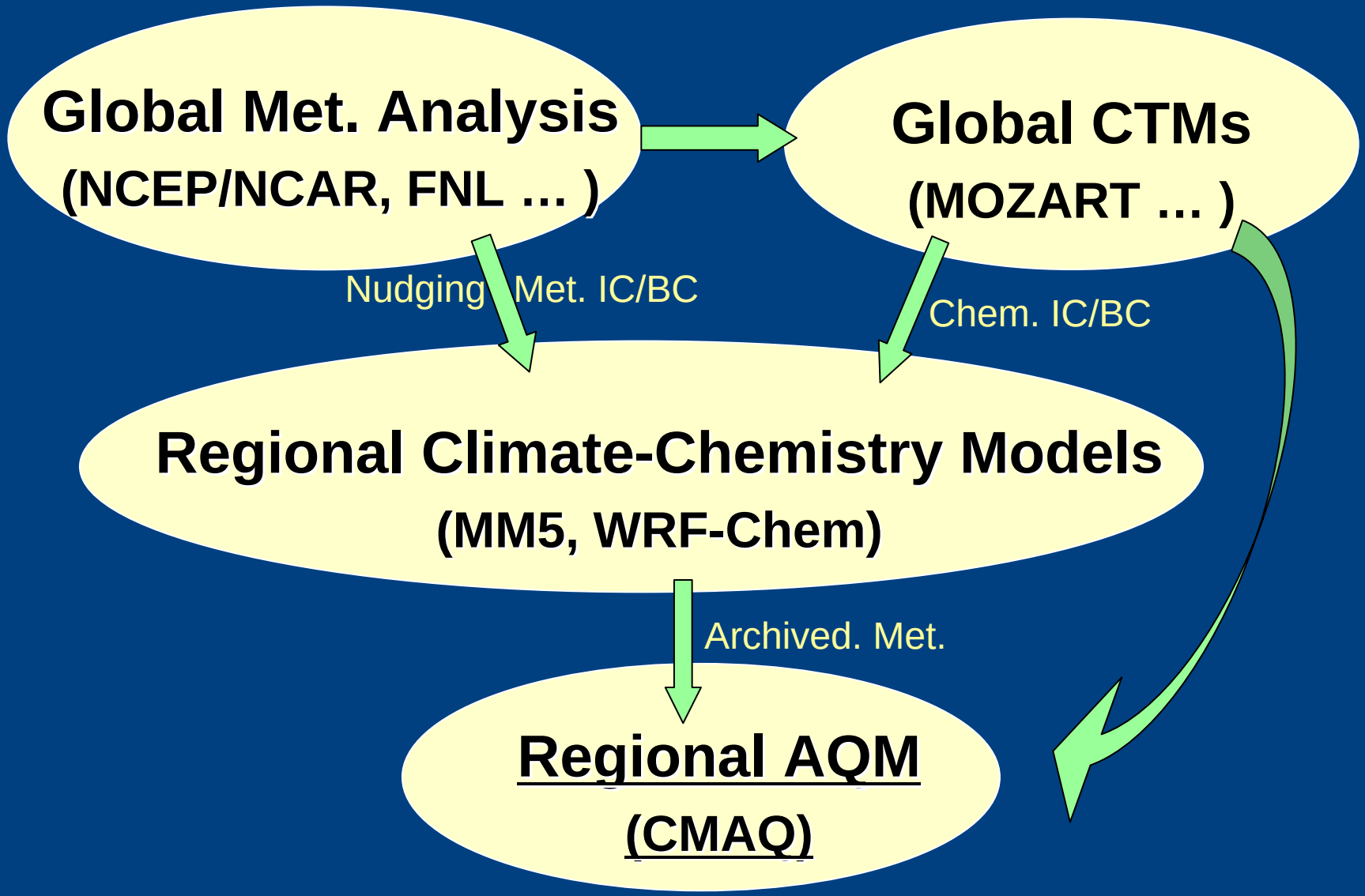
- General atmospheric circulations
- Describe changes in the background and in intercontinental transport

Limitations & Challenges:

- Coarse spatial/temporal resolutions
- Possibly simplified model physics
- Inadequate to simulate small-scale met. features and its sensitivity to climate change
- Inadequate to resolve chemical non-linearities relevant to air quality



Dynamic downscaling with RCM-CTMs



Motivating Questions:

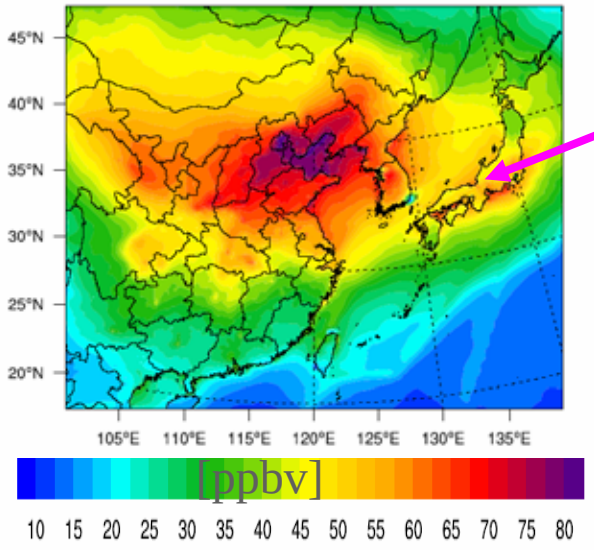
How do regional atmos. processes affect
-urban air quality
-pollution export/import
-effect of climate change?

- Correlations of ozone with regional weather
- Surface pollutants export processes
- Transpacific transport & chemical evolution

Vertical stratification of urban pollution

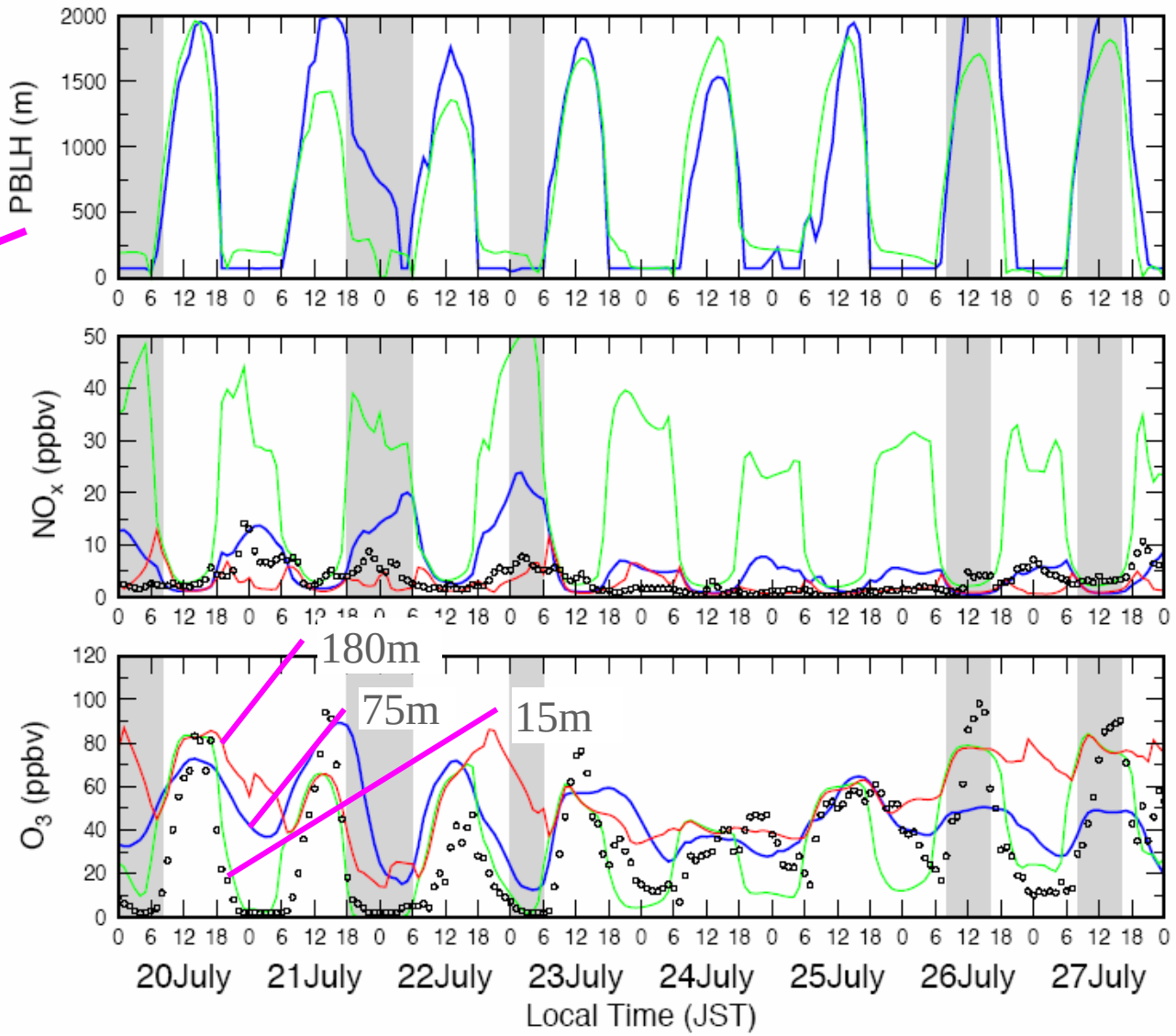
WRF-CMAQ at ~15m **MM5-CMAQ at ~75m** **WRF-CMAQ at ~180m**

Afternoon O_3 in June



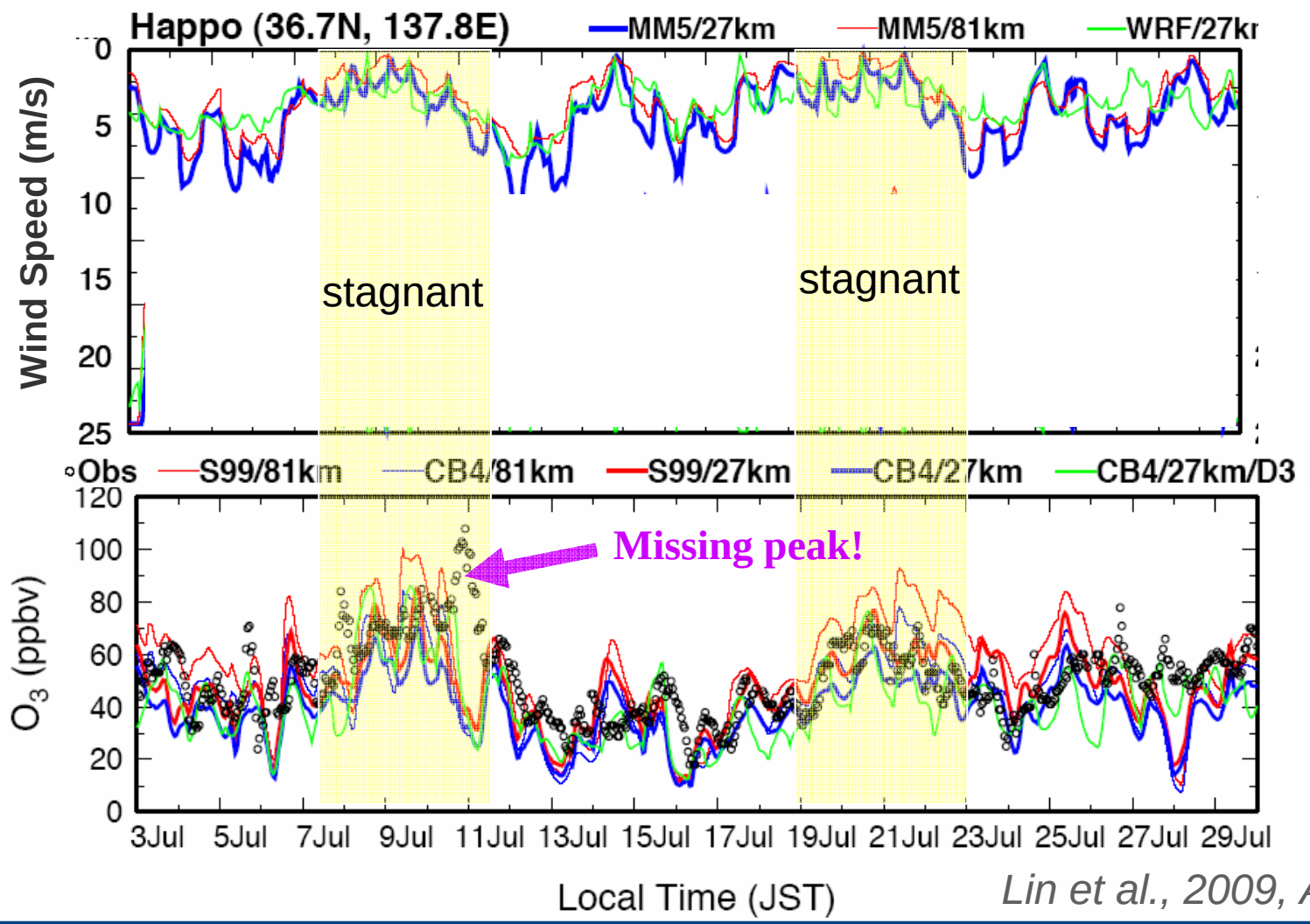
Nighttime chemistry:

- Nocturnal VOC oxidation
- N_2O_5 hydrolysis
- Ozone loss and formation of secondary aerosols



Lin et al., 2009, ACP

Strong correlation of elevated ozone with stagnant weather

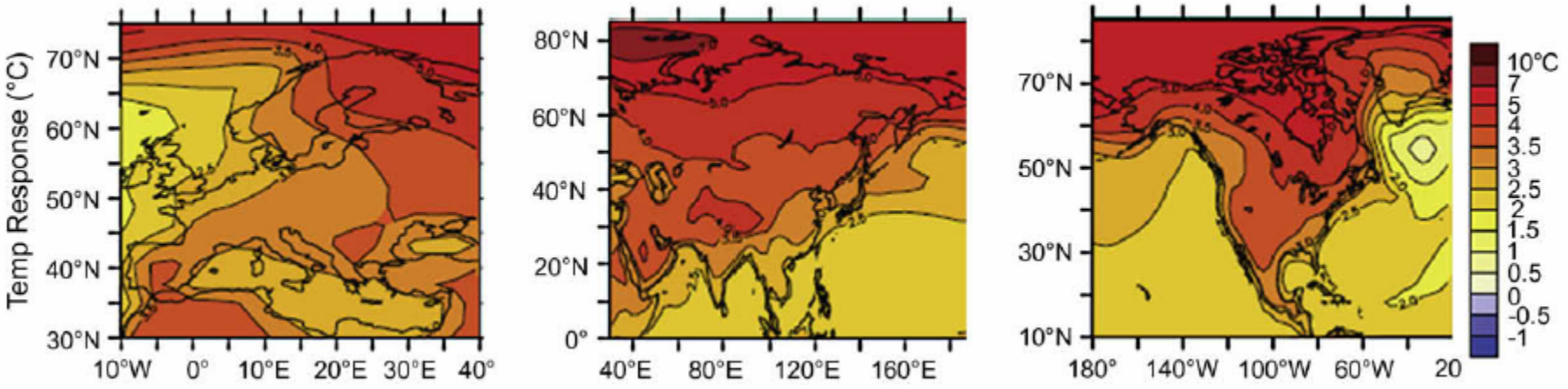


Lin et al., 2009, ACP

- Influence of up-slope/up-valley polluted airflow during the day
- De-couple of dry dep. at mountain sites above the nocturnal inversion

21st century climate change

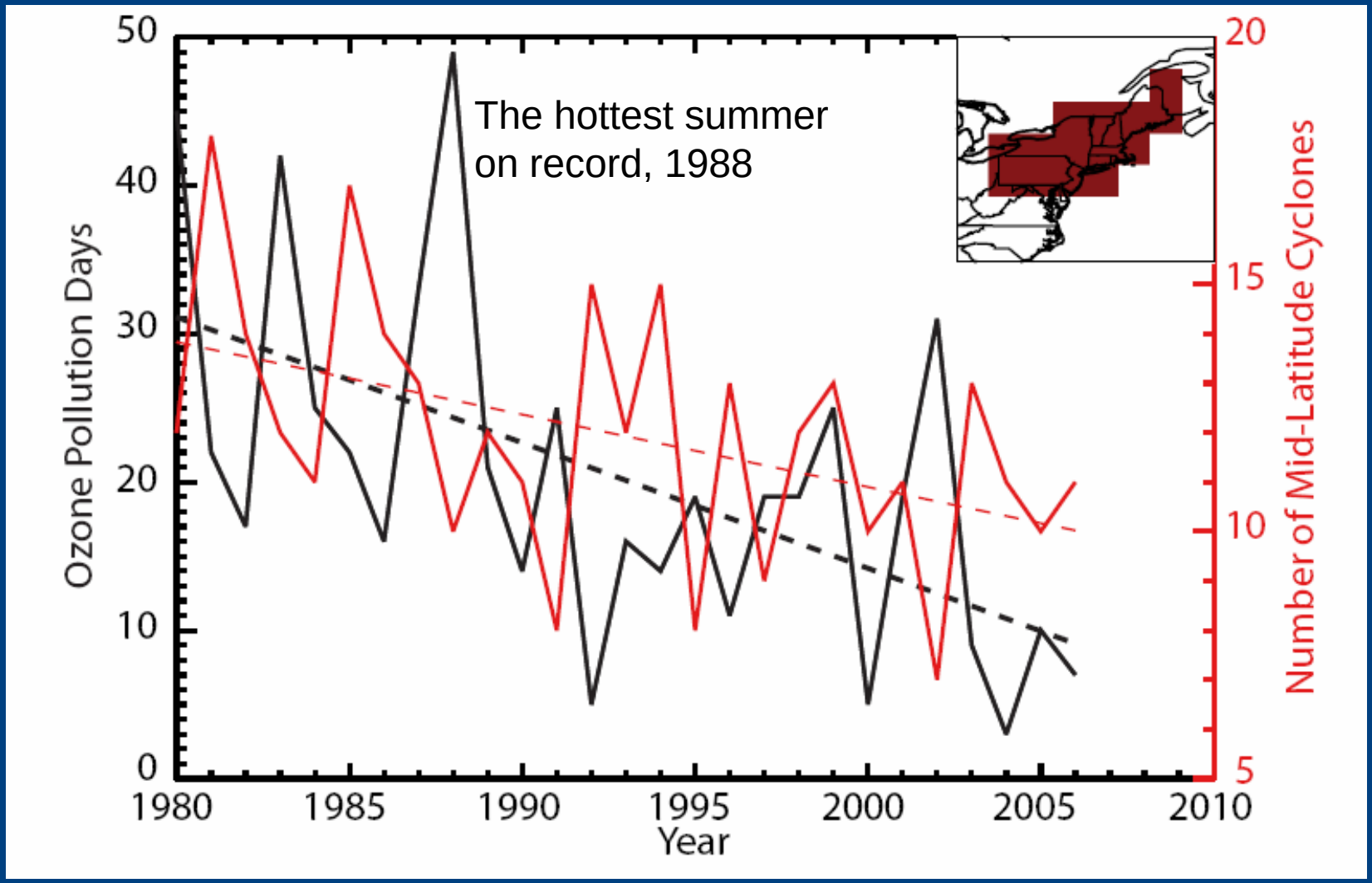
- Decrease in mid-latitude cyclone frequency
- Increase in the frequency and duration of stagnation/heat wave episodes



Differences in annul mean surface temperatures for 2080-2099 vs. 1980-1999

IPCC AR4 (Climate Change 2007: The Physical Science Basis)

Effect of climate change on ozone in polluted regions



D. J. Jacob and D. A. Winner, 2009

Implications for ozone changes in polluted regions

- Climate change increases surface ozone in polluted regions
- Stronger emission controls will be needed to meet a certain air quality standard

But how many? Uncertainties in large-scale models?

- Missing extreme events?
- Non-linear chemical processing?
- Nocturnal inversion & nighttime chemistry

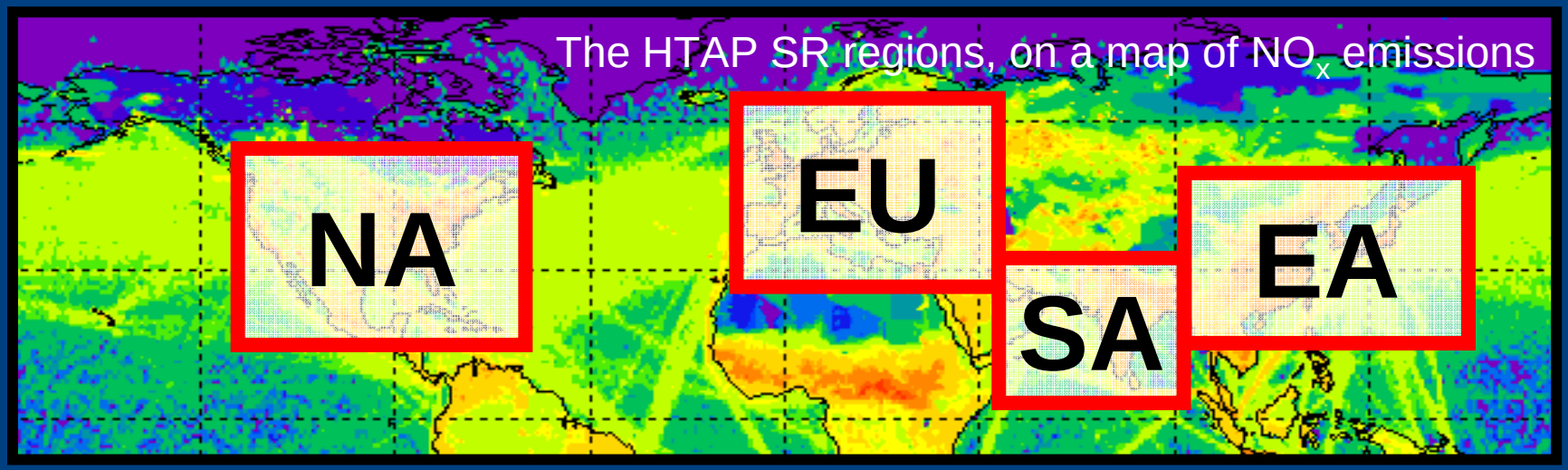
Changes in the background?

Surface-to-free troposphere exchange affecting continental outflow from Asia

(MOZART vs. WRF-Chem)

United Nations Task Force on Hemispheric Transport of Air Pollution (HTAP; www.htap.org)

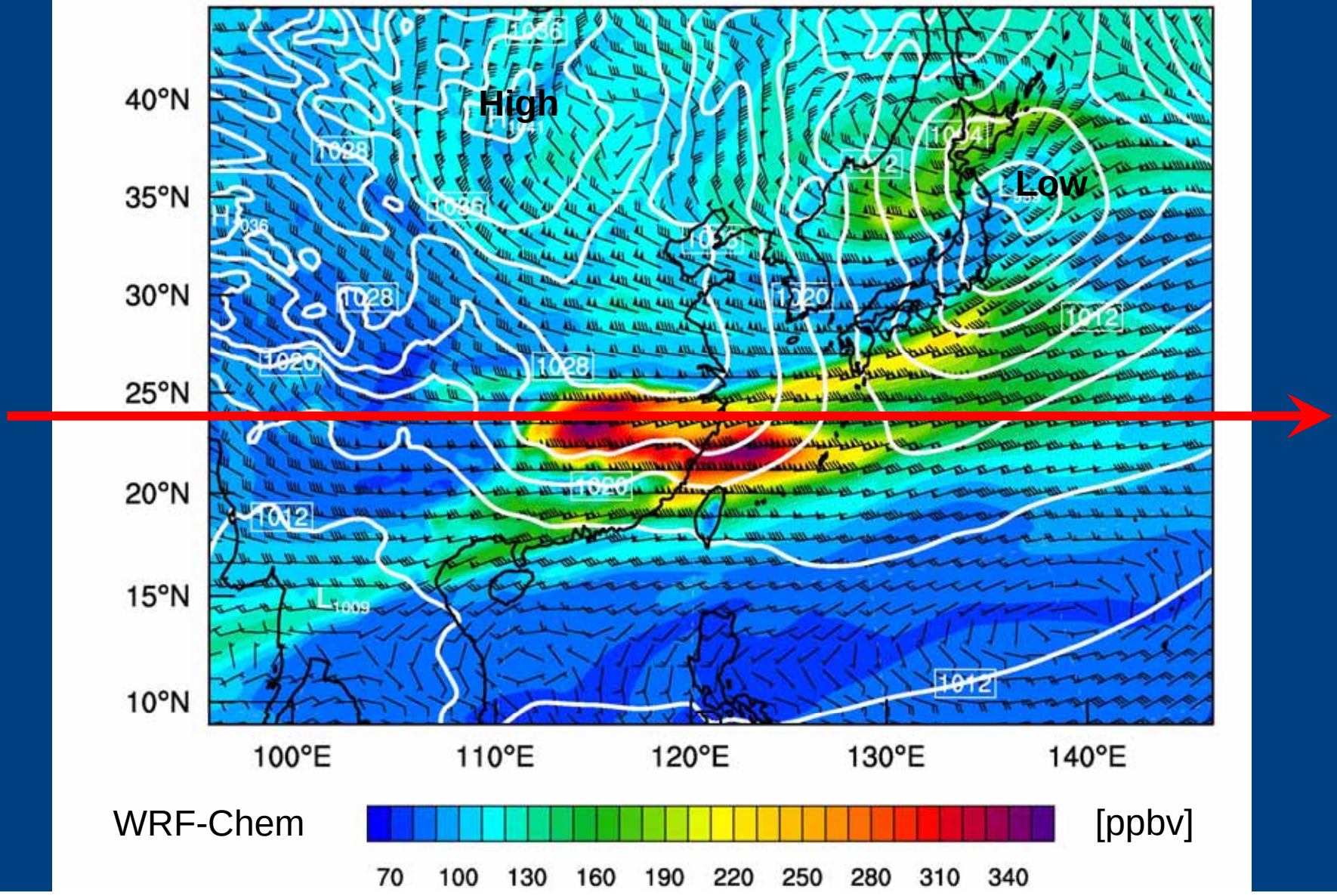
- ~20 global models participated in the HTAP source-receptor relationships experiments



- Will S/R relationships change if we use high-resolution models?

Mid-latitude cyclones & pollutants lofting

CO mixing ratios and horizontal flux at 5-km, 2001-03-07



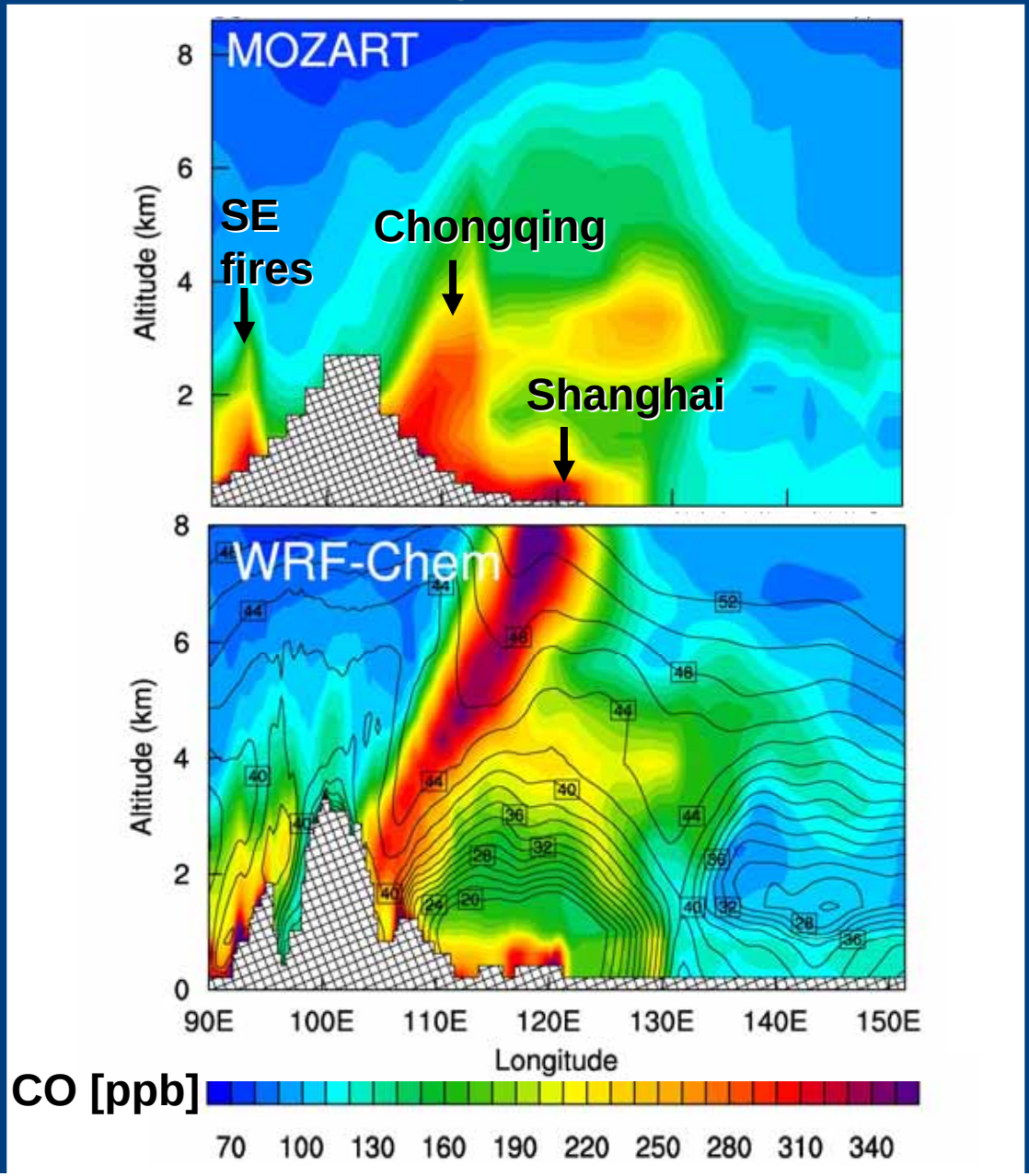
Enhancement of deep convection in the leading edge of the convergence band is missing in MOZART

Global Model

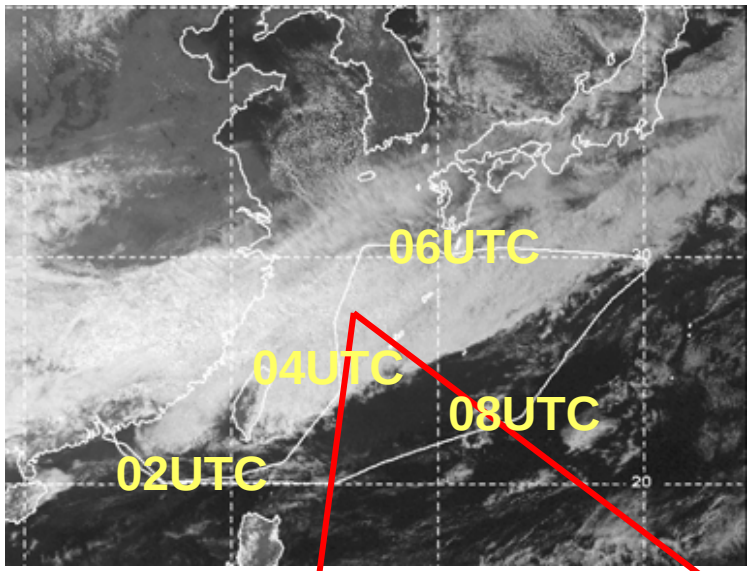
(2x2°, driven with 6-hr NCEP reanalysis)

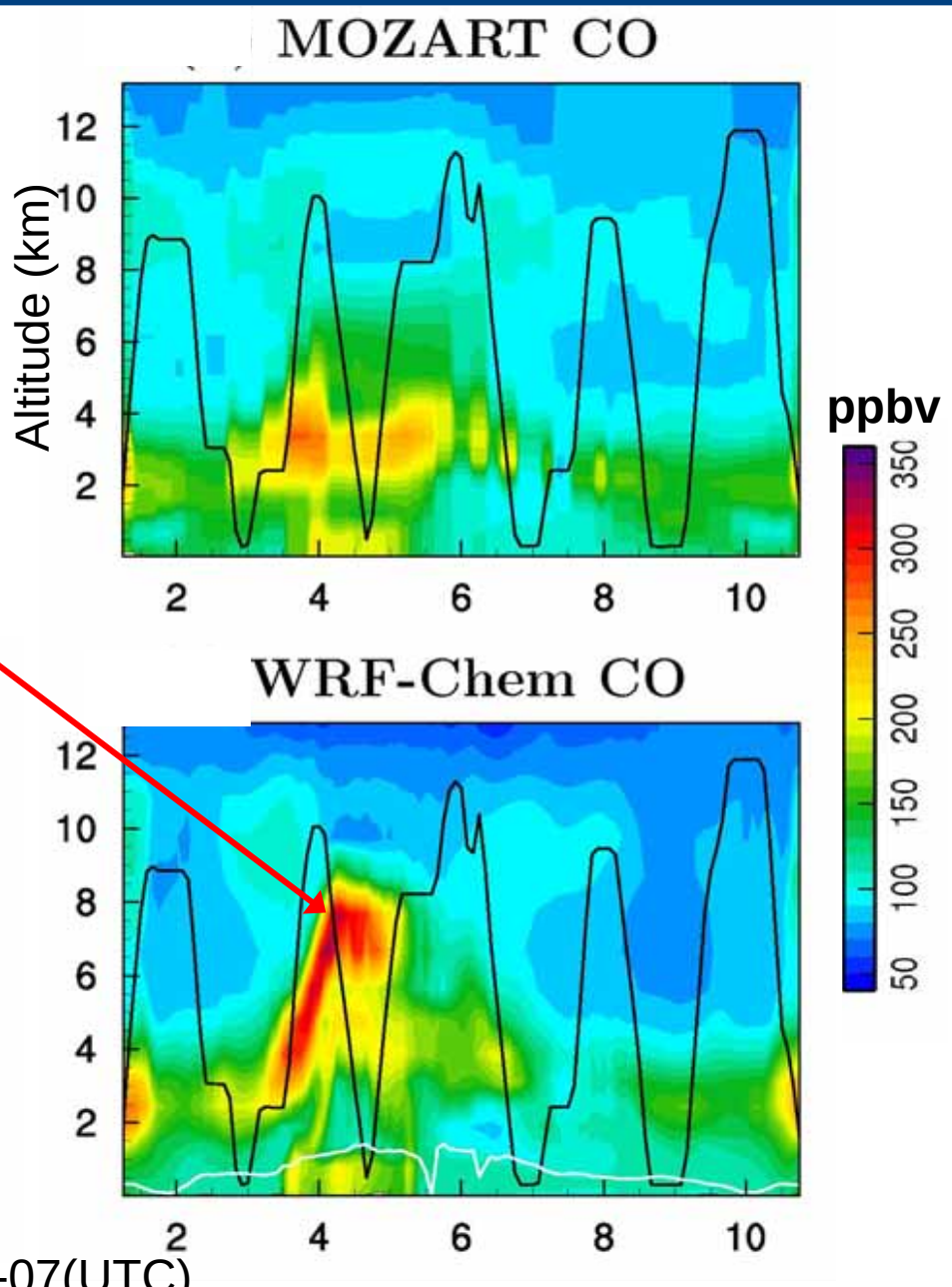
Online Regional Model

(36x36 km, 3-min climate modeling driven with 6-hr NCEP FNL analysis)



Comparison with TRACE-P measurements





Differences in zonal fluxes in the middle & upper troposphere

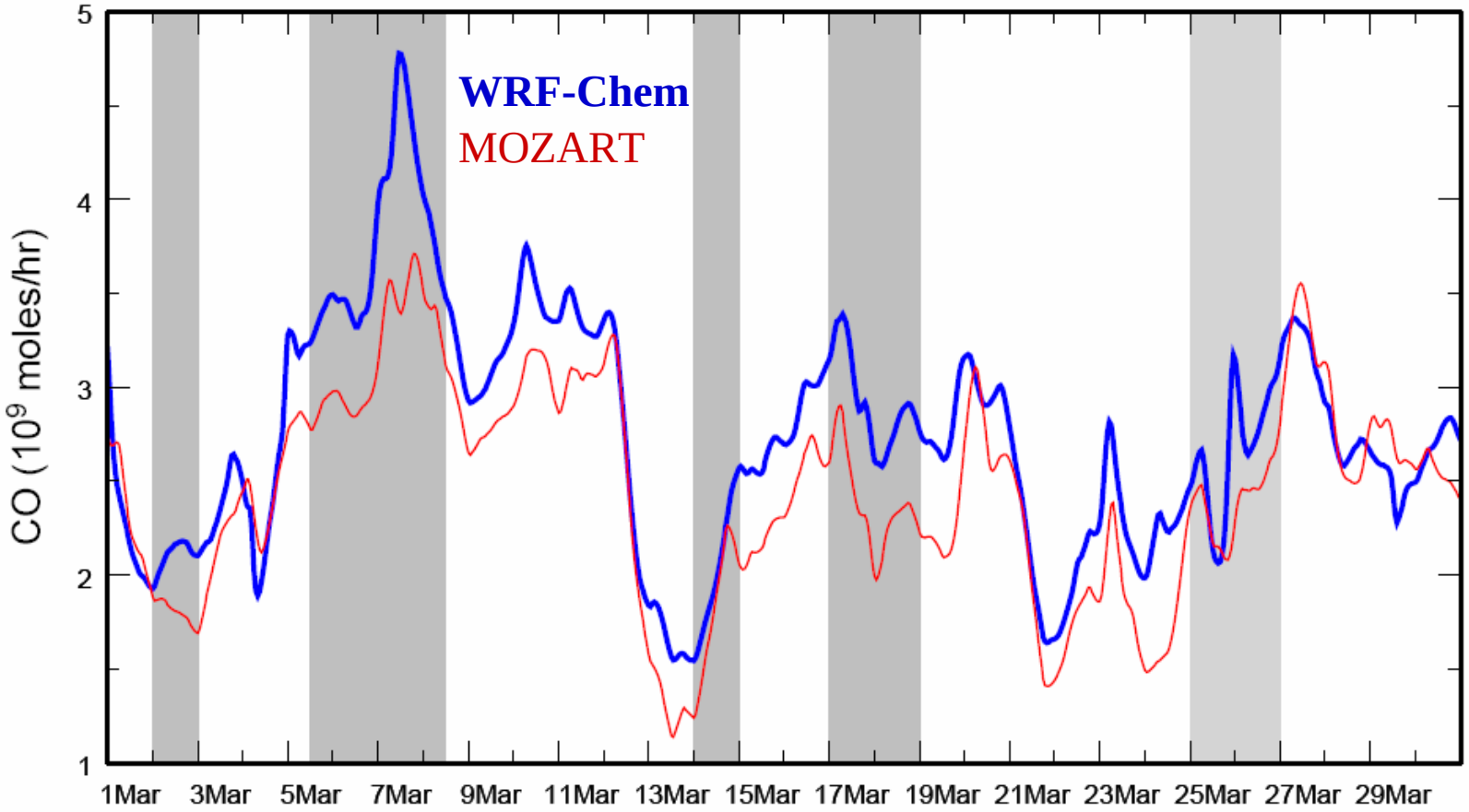
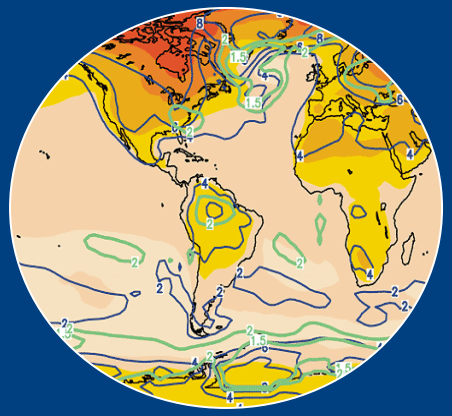


Figure 2. Comparison of MOZART and WRF-Chem calculated zonal fluxes of CO and PAN along 140°E that is integrated over 4-8.5km altitudes and 25°-40°N latitudes. Episodes of cold frontal passages in March 2001 are highlighted in gray.

Lin et al., 2009, ACP



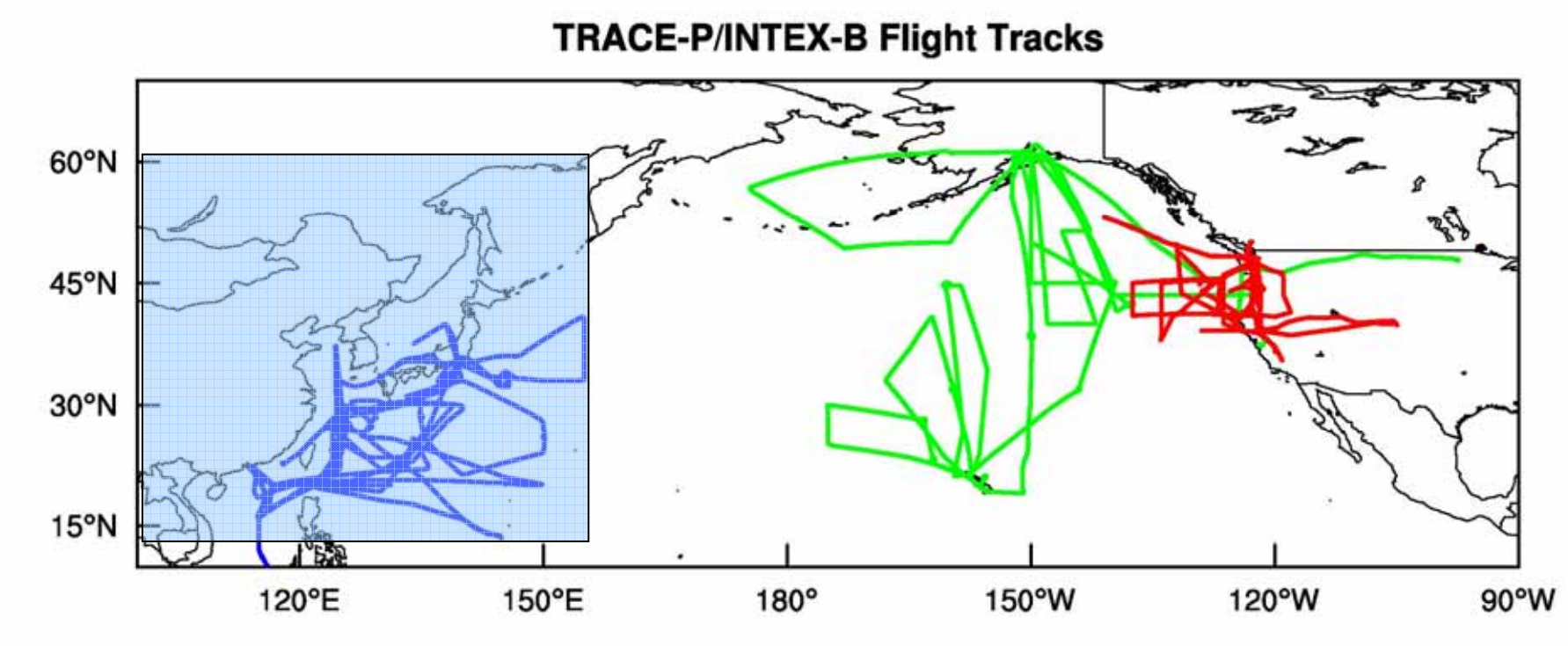
Implications for changes in the background

- Large-scale models tend to underestimate Asian outflow through rapid convective transport.
- The pollutants lofted to the upper troposphere can undergo long-range transport.
- The range of intercontinental S-R estimates with global models is likely to underestimate the true uncertainty

For details, please refer to:

Lin, M., Holloway, T., Carmichael, G., Fiore, A., 2009, ACP, to be submitted

Transpacific Transport & Chemical Evolution



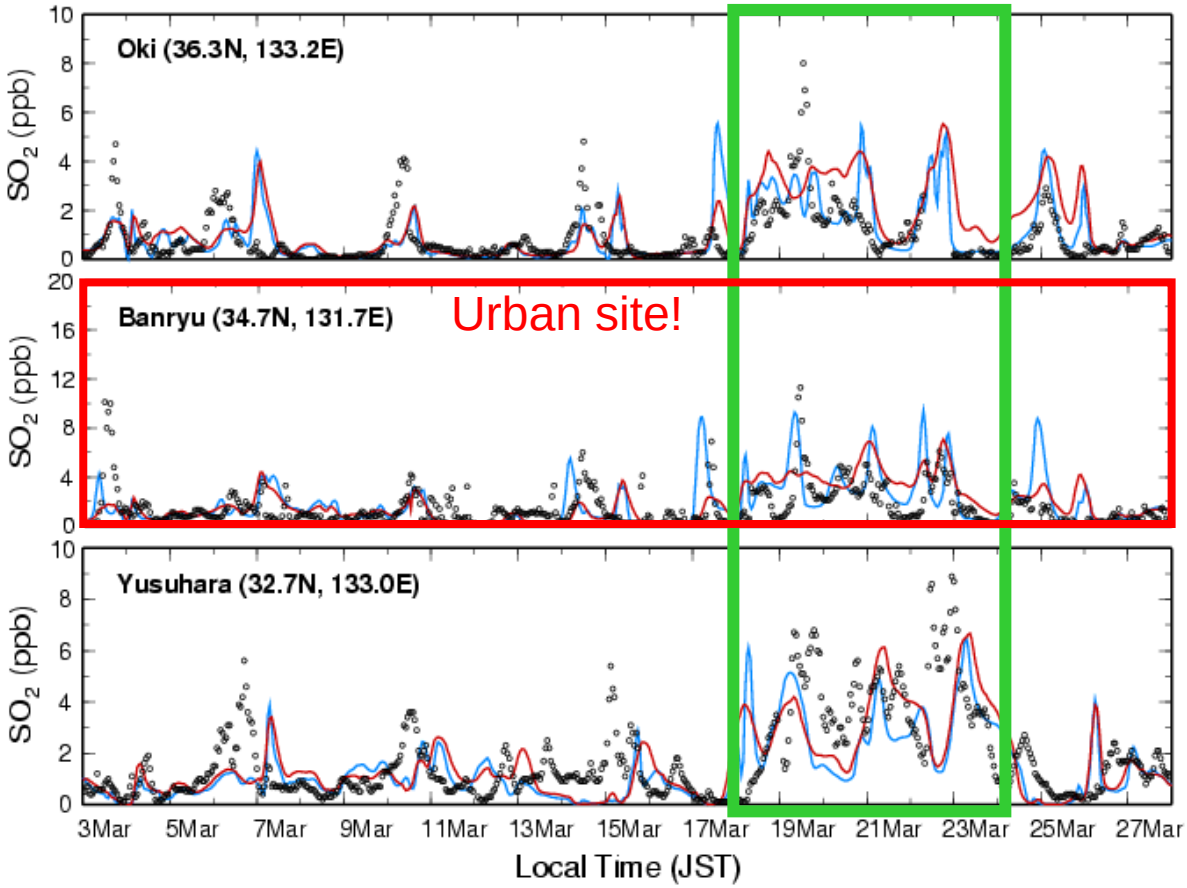
- Cold frontal passages
- Orographic forcing
- Deep convection
- Escape of SO_2 from cloud processing

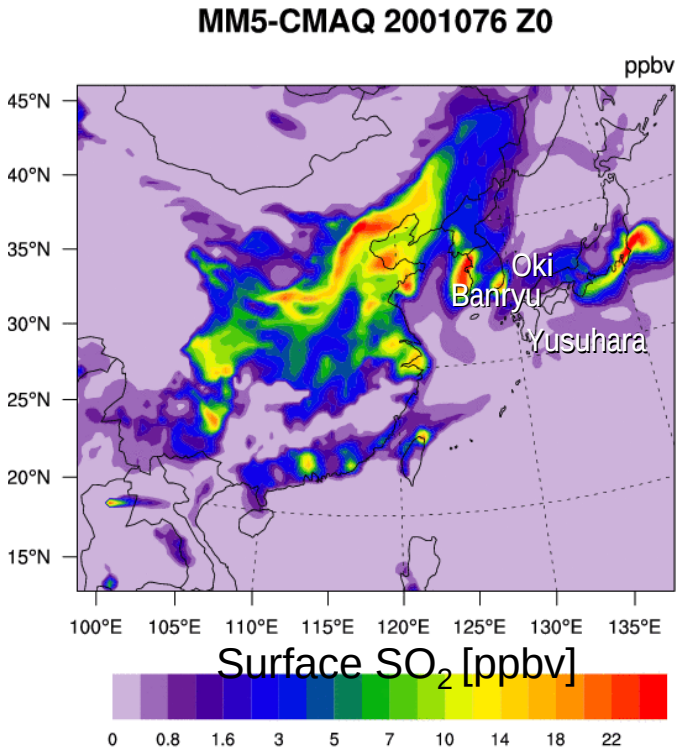
Low-level (altitude) outflow of SO_2 from China

- EANET Obs

MM5-CMAQ/81km

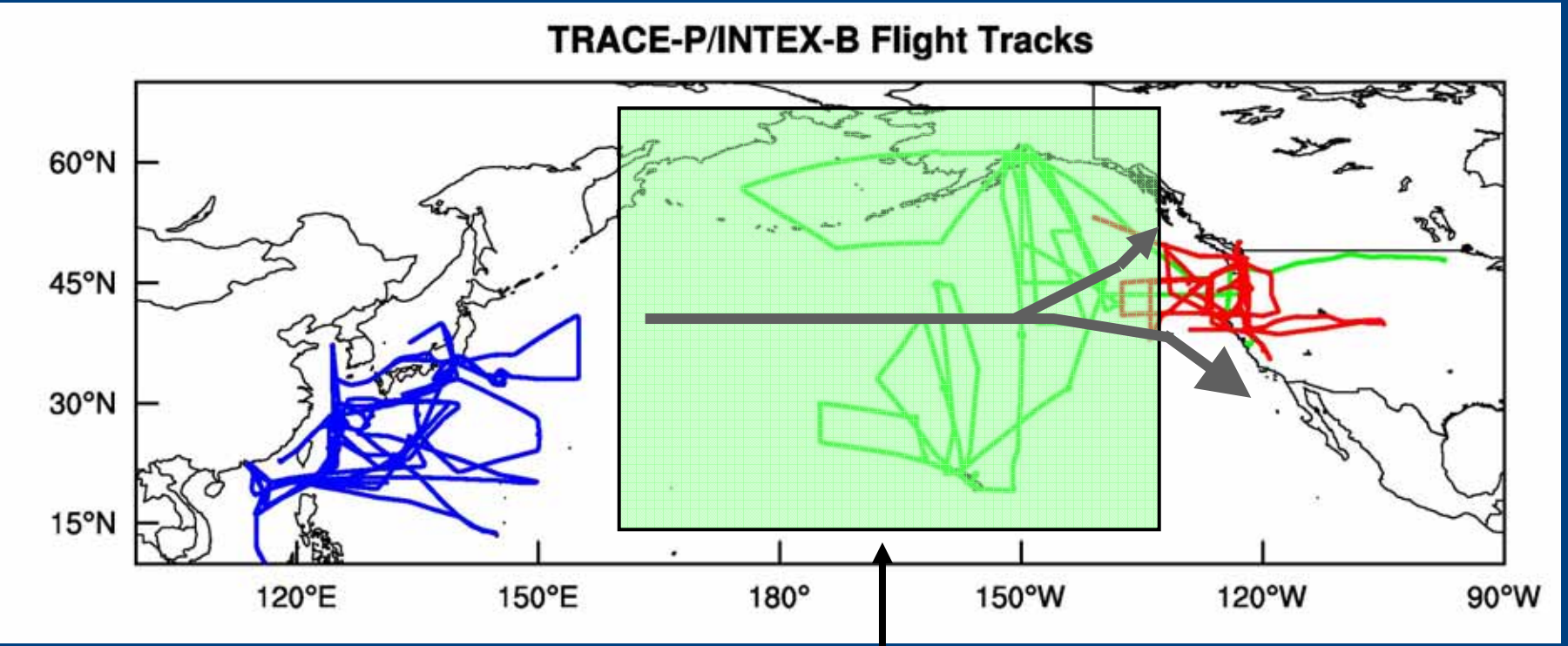
Nested MM5-CMAQ/27km





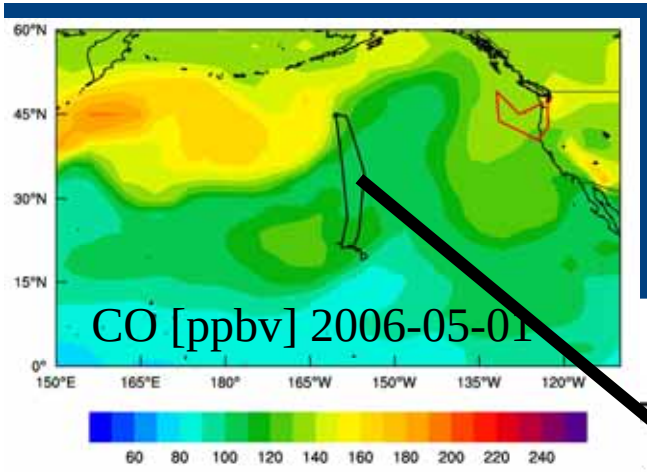
Lin et al. 2008a, AE

Transpacific Transport & Chemical Evolution

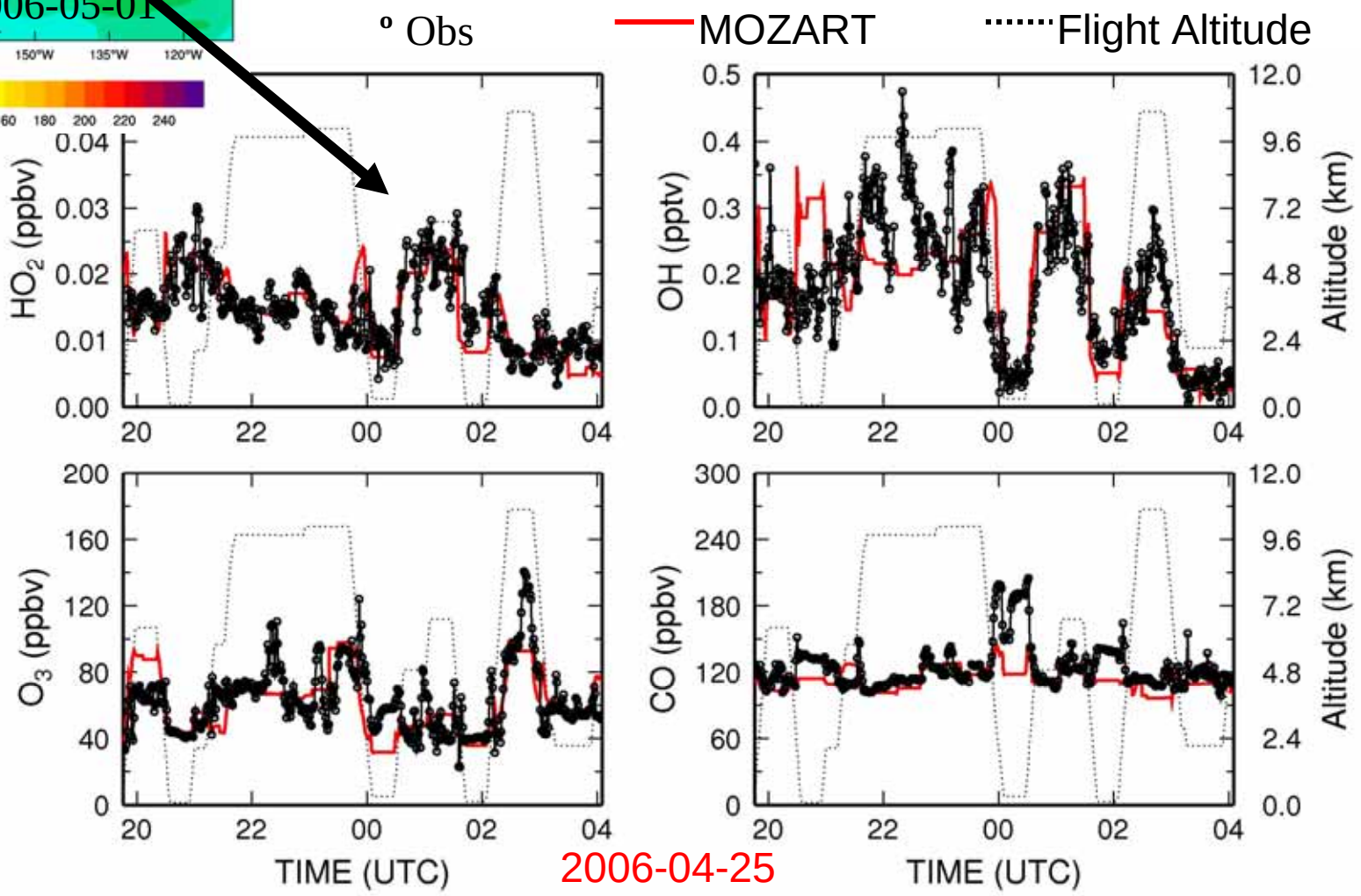


- Transport in the warm conveyor belts
- Splitting over the northeast Pacific
- Additional O_3 production driven by PAN decomposion

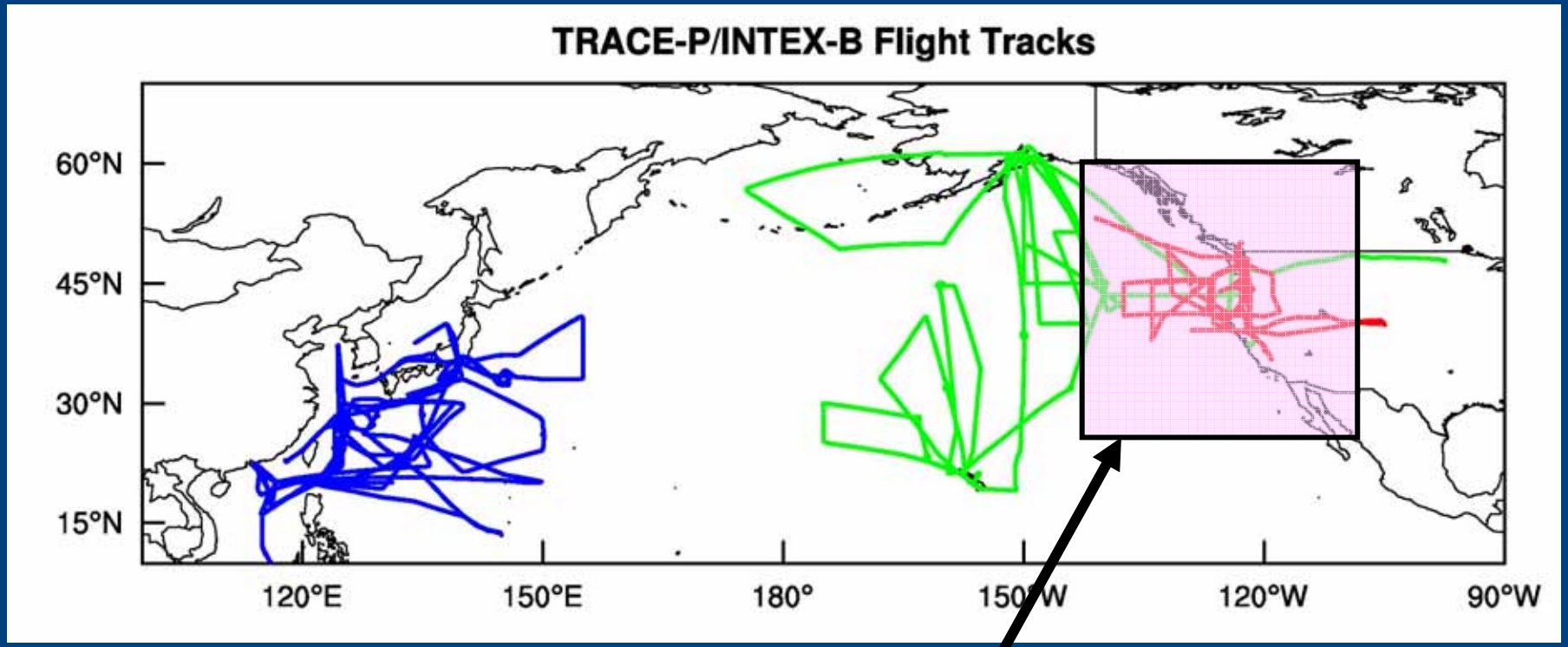
Chemical evolution over the Pacific



INTEX-B April–May 2006

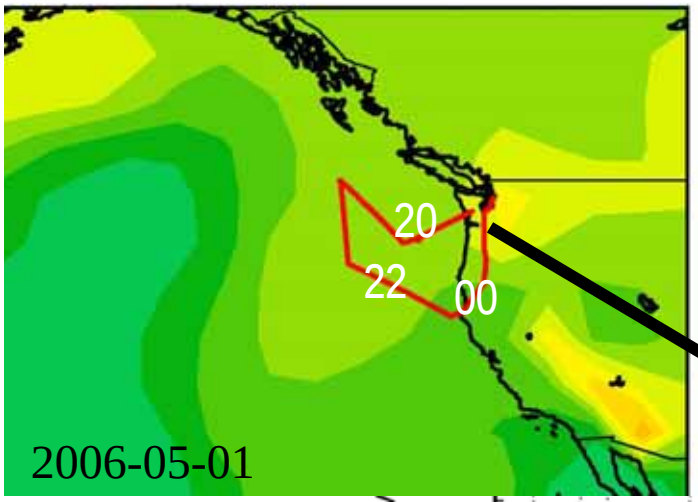


Transpacific Transport & Chemical Evolution



- Orographic effects
- Recirculation through land-ocean breezes
- FT→BL entrainment
- Mixing with local short-lived species

Asian pollutant plumes over the NA west coast



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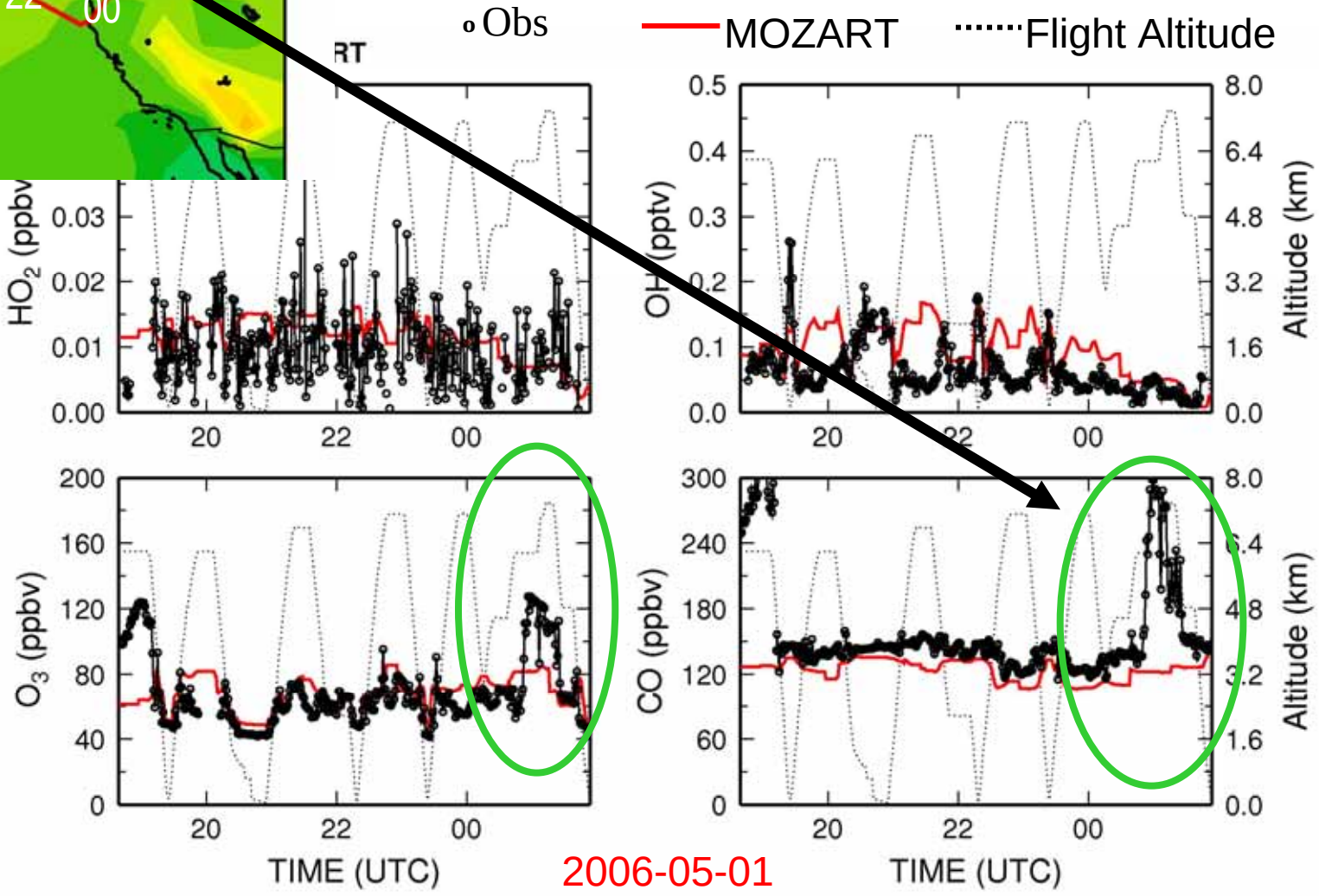
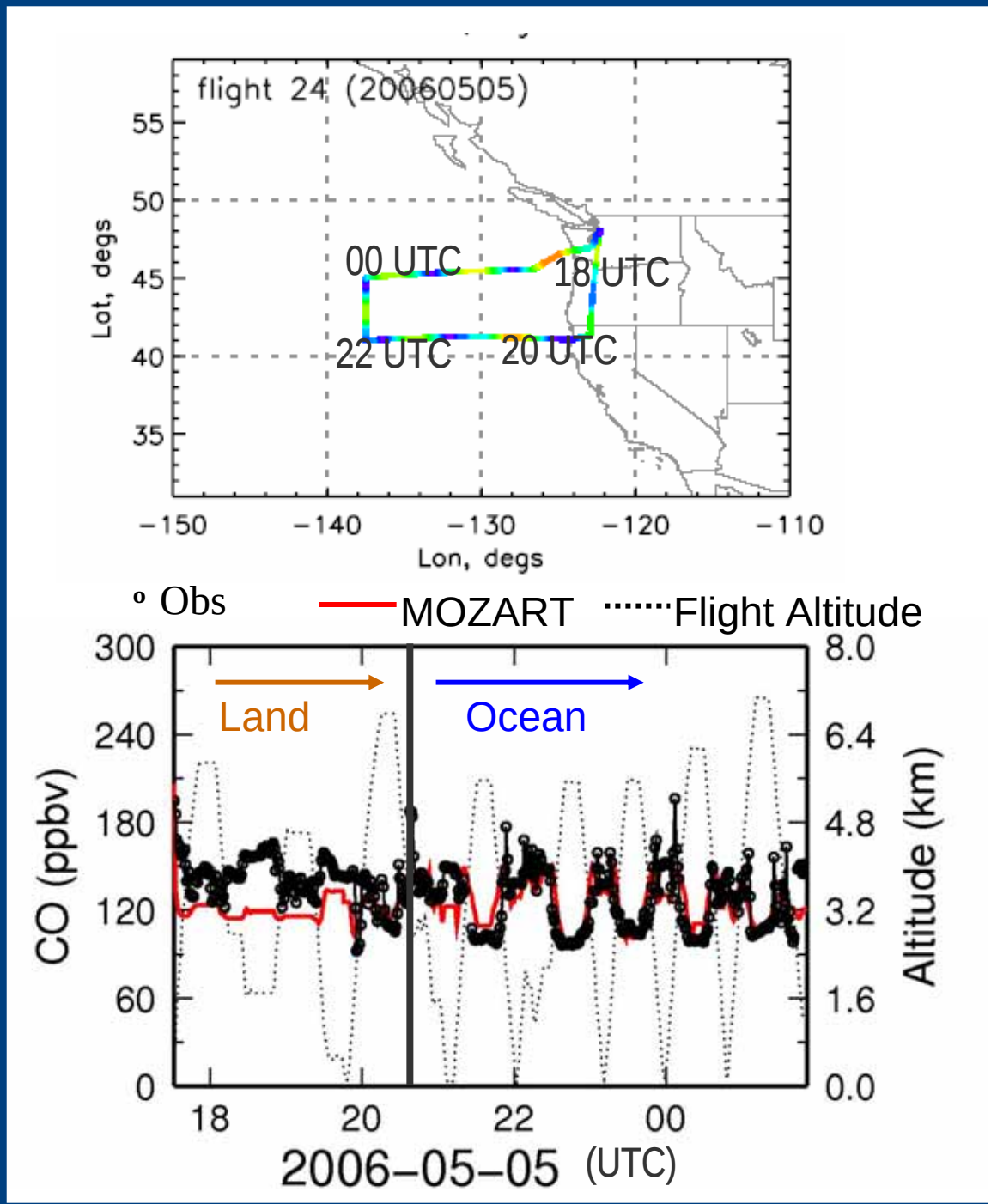
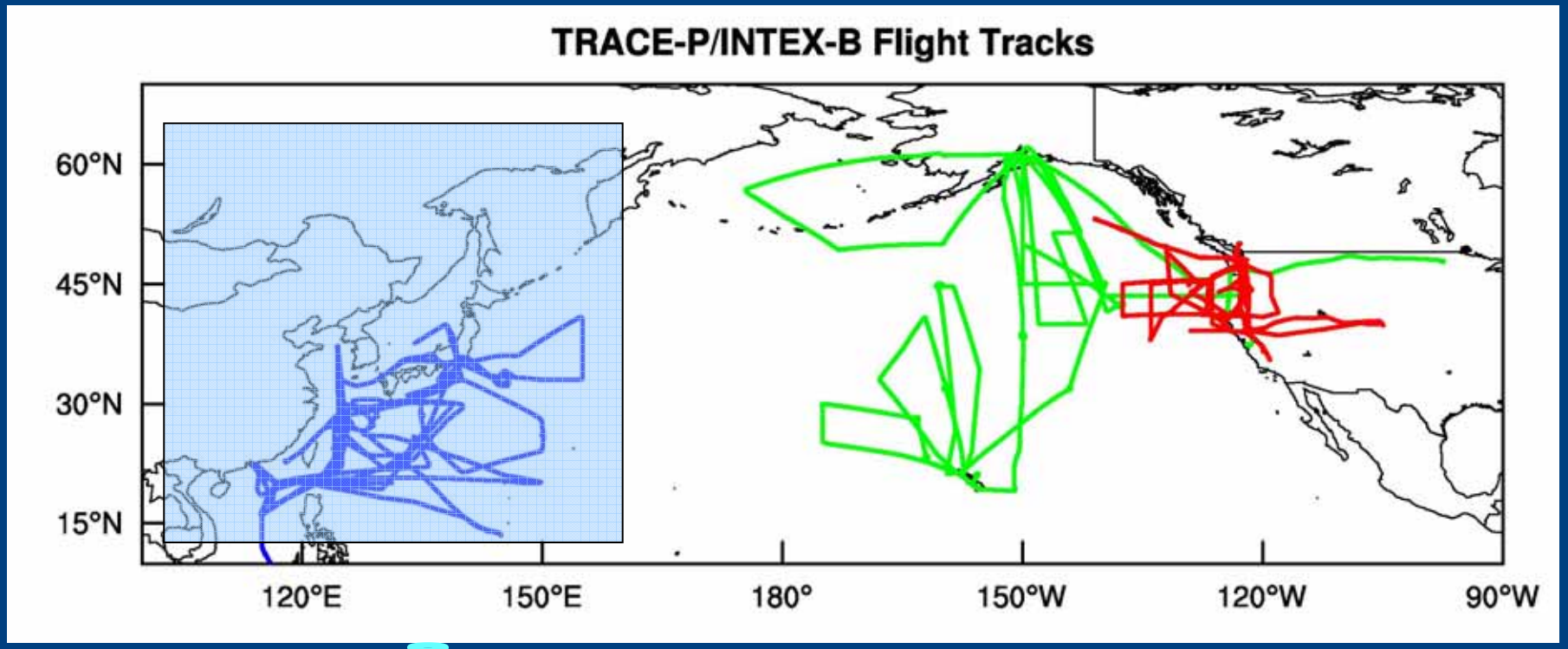


Remarkable difference in model performance over land and ocean

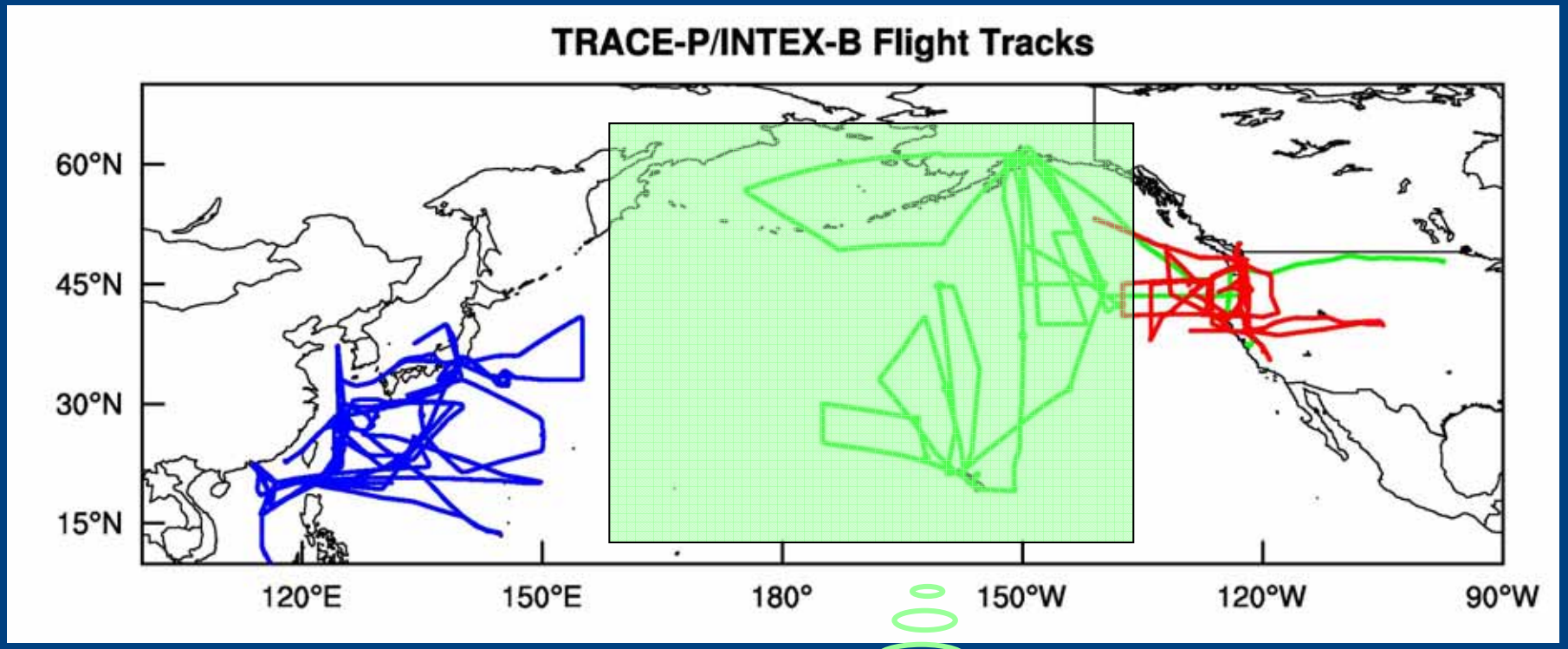


Uncertainties in hemispheric transport



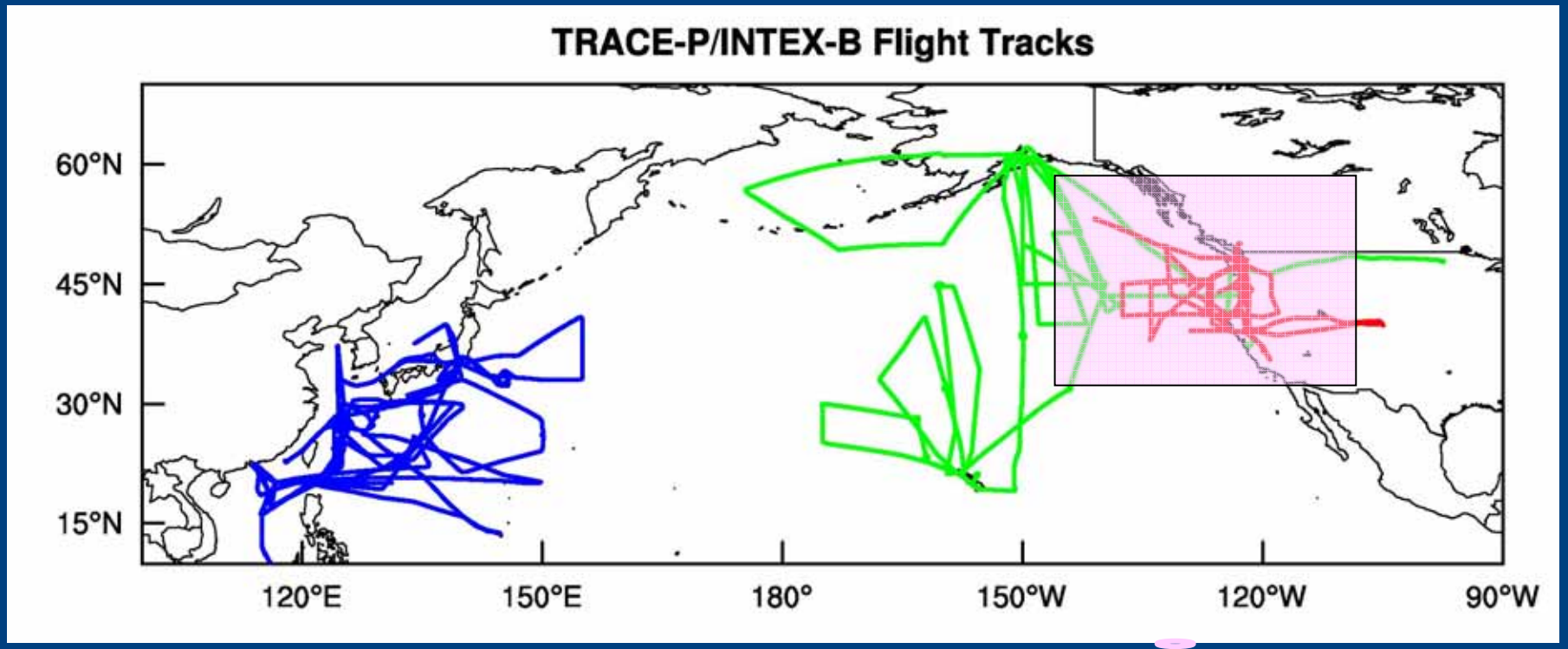
Likely underestimate

Uncertainties in hemispheric transport



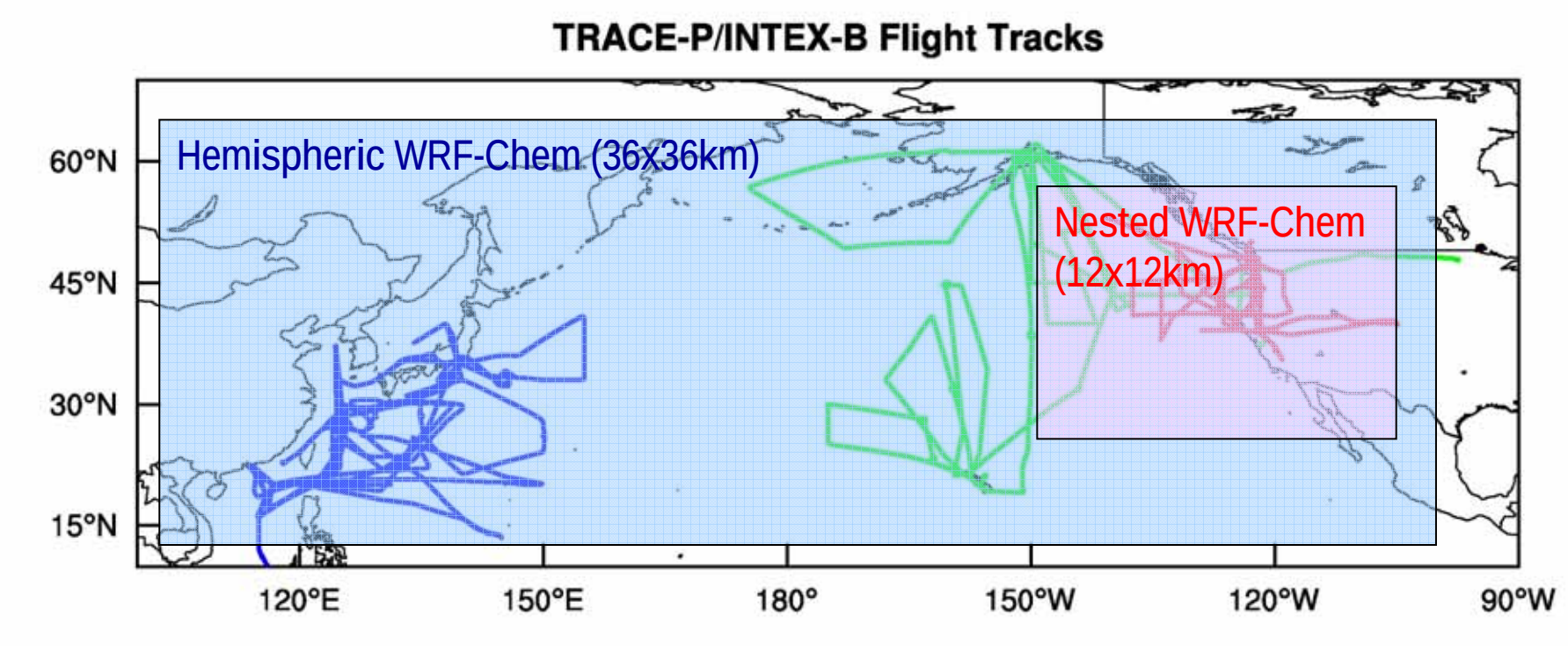
Generally well reproduced

Uncertainties in hemispheric transport



Not well understood

Uncertainties in hemispheric transport



Conclusions

- Strong correlation of air quality with regional/local meteorology & non-linear chemistry
- This presents a particular challenge in evaluating the effect of climate change on regional air quality using GCM-CTMs

  -- sensitivities in regional climate

  -- air quality effects in polluted regions

  -- changes in the background

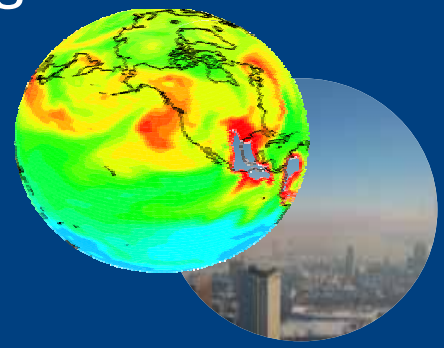
Recommended approaches for future research

- Global high-resolution GCM-CTMs

  -resolution vs. physics induced uncertainties
- Dynamic downscaling with RCM-CTMs

  - two-way nesting

  - maintain consistency in model physics



Thank You!

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- Holloway group, *University of Wisconsin – Madison*
- Arlene Fiore, *NOAA Geophysical Fluid Dynamics Laboratory*
- Louisa Emmons, *National Center for Atmospheric Research*
- Peter Hess, *Connell University*
- Greg Carmichael, *University of Iowa*
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- EANET / ADORC, Japan