What We Can Learn from the Midlatitudes – Intercomparison Studies

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Ann Fridlind, Andy Ackerman, NASA/GISS
Jean-Pierre Pinty, Celine Mari, Lab. D'Aerologie, CNRS
Vlado Spiridonov, Hydrological Inst., Macedonia
John Helsdon, Richard Farley, SDSMT

Motivation

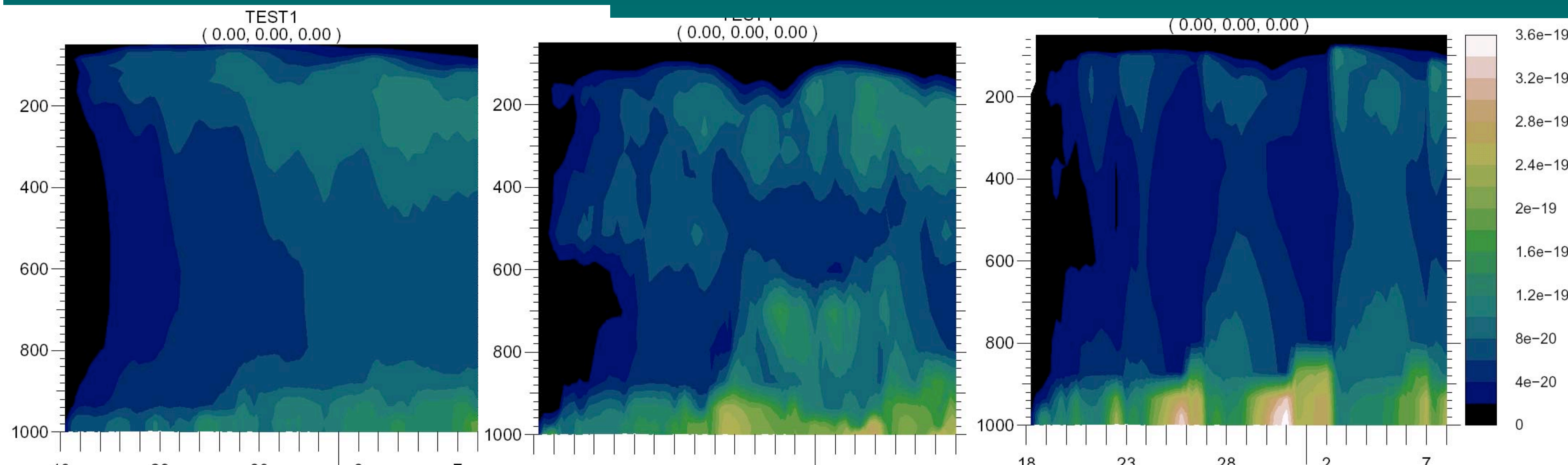
- Convective processing of chemical species is important to
  - Moving pollutants to upper troposphere
  - Cleansing the atmosphere (rain out)
- Large-scale models produce inconsistent results for convective transport of scalars

Results from the NCAR CCSM Using Different Convection Parameterizations

Emanuel, Stochastic mixing model

Standard, CCSM bulk formulation

Kain-Fritsch, Plume model



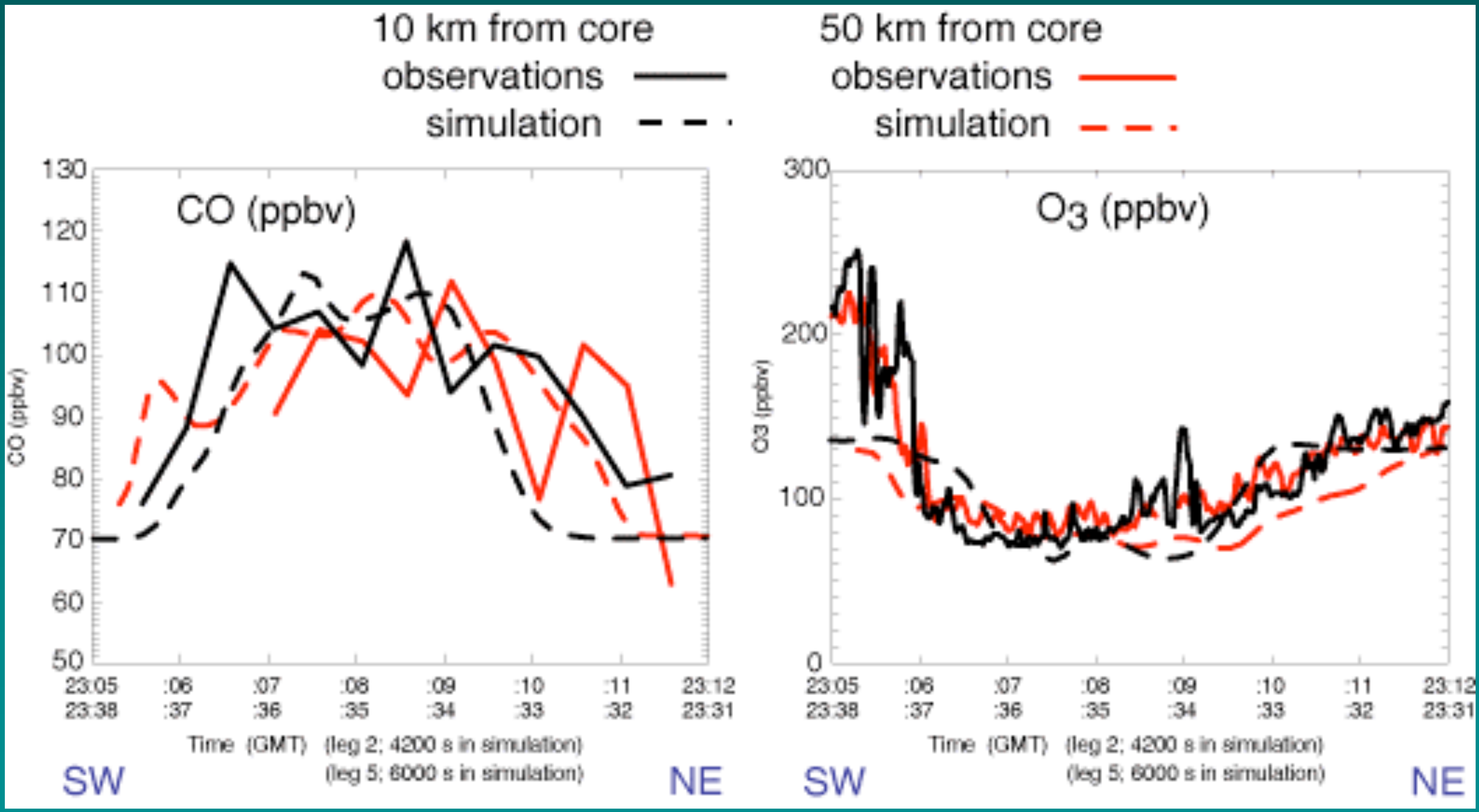
Mixing ratio of surface tracer averaged over the TOGA-COARE region as a function of day (December 18 – January 8) and pressure

From Phil Rasch, EGS talk, 2003

Motivation

- Convective processing of chemical species is important to
  - Moving pollutants to upper troposphere
  - Cleansing the atmosphere (rain out)
- Large-scale models produce inconsistent results for convective transport of scalars
- Convective-scale models produce reasonably represent convective transport

Results From the COMMAS Convective Cloud Model Coupled With Chemistry



From Skamarock et al. (2000)

Motivation

- To improve sub-grid convective transport and wet deposition in large-scale models
  - multiple convective-scale models can be used to obtain general characteristics of these processes.
- The Chemistry Transport in Deep Convection Intercomparison
  - means to *calibrate* a variety of convective-scale models coupled with chemistry.
- Determine what the variability among reputable cloud chemistry convective models is for a given storm.

Acknowledgment

The Chemistry Transport in Deep Convection Intercomparison

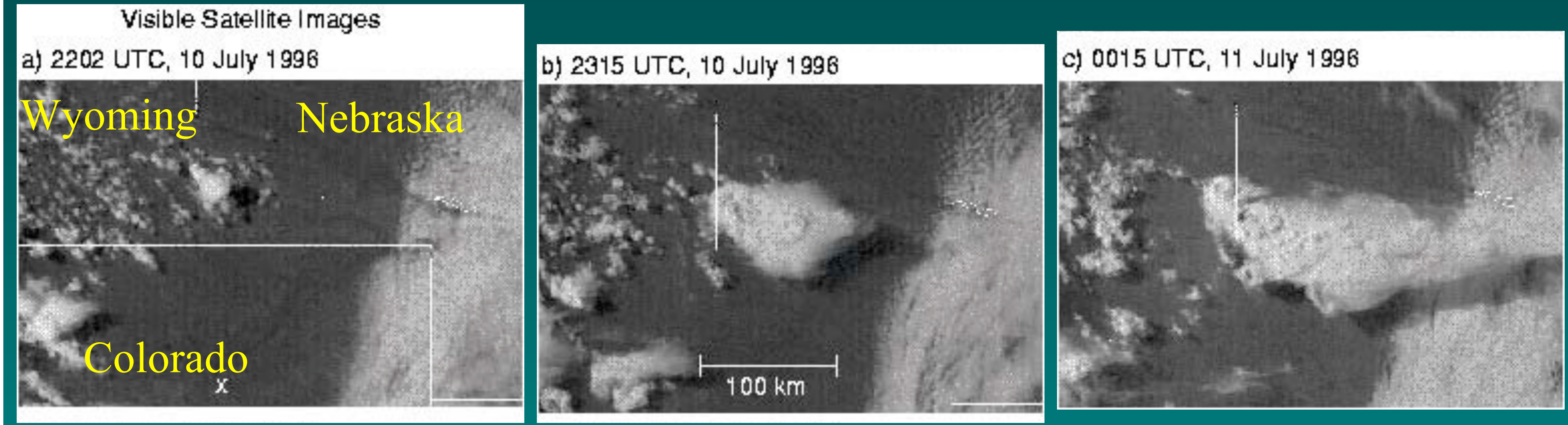
6th International Cloud Modeling Workshop

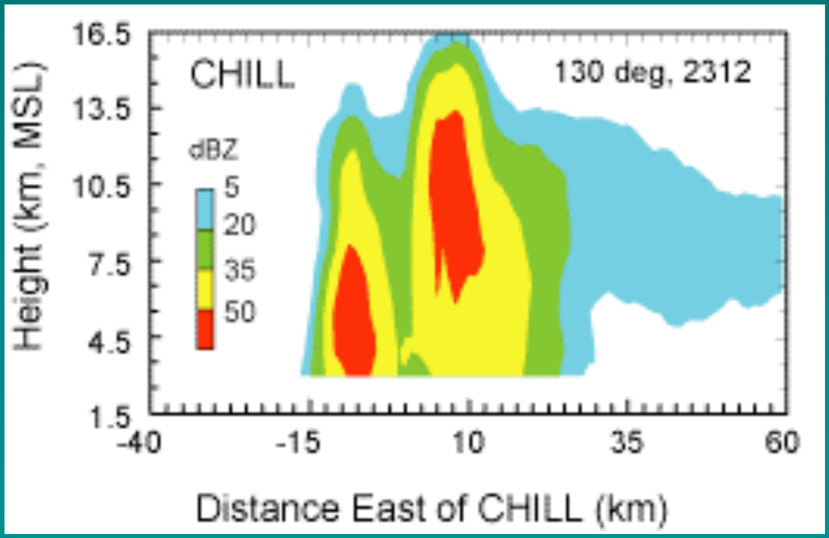
July 2004

Hamburg, Germany

WMO

Simulate the 10 July 1996 STERAO storm





Chemistry Transport by Deep Convection

Primary Species:

Ozone (O_3) – tracer

Carbon monoxide (CO) – tracer

Nitrogen oxides ($NOx = NO + NO_2$) – enhanced by lightning

Soluble species:

Nitric acid (HNO_3)

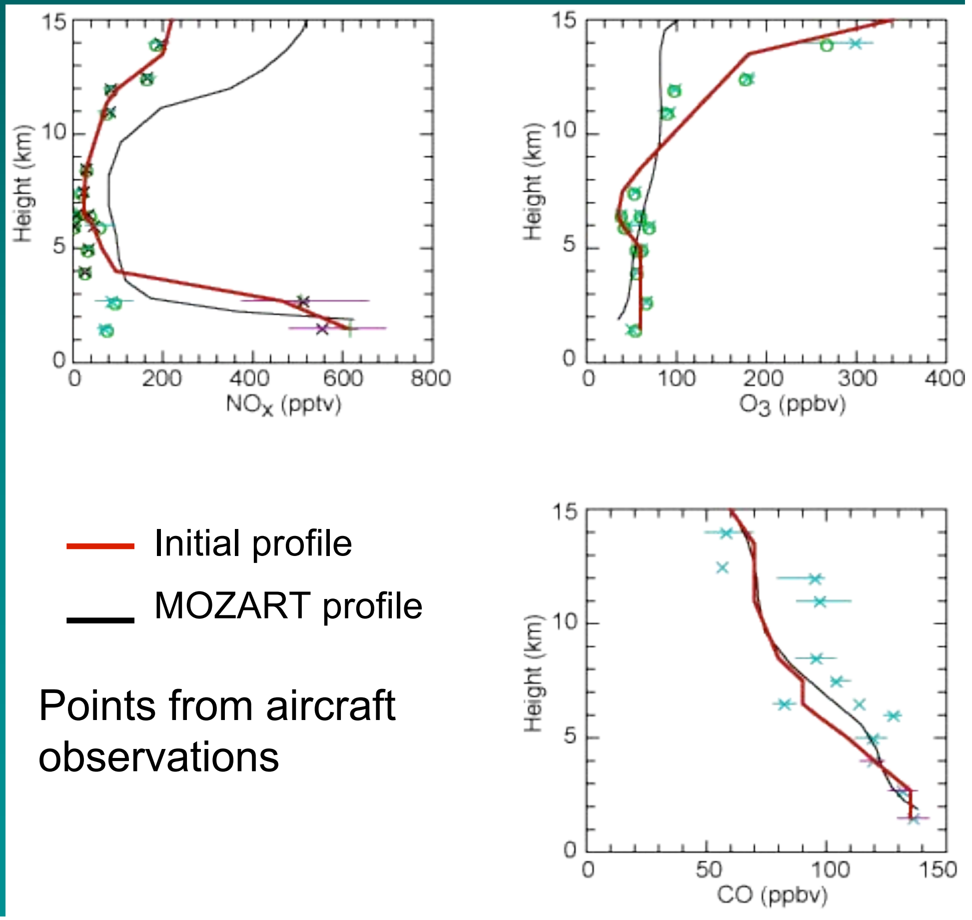
Hydrogen peroxide (H_2O_2)

Formaldehyde (CH_2O)

affected by microphysics parameterization

Initialization

- Soundings for T, qv, u, and v
- Initiation via 3 warm bubbles
- Aircraft vertical profiles for chemical species



Participants and their Models

Mary Barth and *Si-Wan Kim* (NCAR) – **WRF–AqChem** sensitivity sim.

Chien Wang (MIT) – **C.Wang** sensitivity sim.

Ken Pickering and *Lesley Ott* (U. Maryland), and *Georgiy Stenchikov* (Rutgers Univ.) – **UMd/GCE**

Ann Fridlind and *Andy Ackerman* (NASA/Ames) – **DHARMA**

Jean-Pierre Pinty and *Celine Mari* (CNRS--Toulouse) – **Meso-NH**

Maud Leriche and *Sylvie Cautenet*, (LaMP, U. B-P, Clermont-Ferrand) –**Leriche or RAMS**

Vlado Spiridonov, (Hydrometeor. Inst., Macedonia) – **Spiridonov**

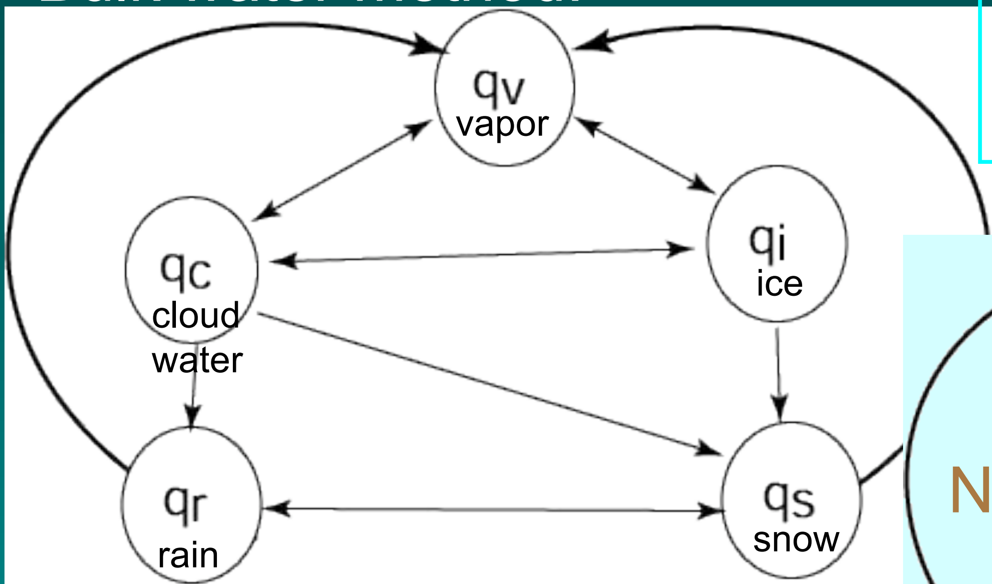
John Helsdon, Richard Farley (South Dakota School M&T) – **SDMST**

Formulation of Models for the Convective-Scale Simulations

- 3-d, fully compressible, non-hydrostatic
  - WRF-AqChem – WRF dynamics (flux form)
  - C.Wang – pseudo-elastic
  - UMd/GCE – GCE dynamics (anelastic)
  - DHARMA –Large Eddy Simulation
  - Meso-NH – anelastic, MPDATA advection
  - Leriche/RAMS – RAMS dynamics (anelastic)
  - Spiridonov – based on Klemp and Wilhelmson
  - SDMST – modified Clark-Hall model, MPDATA

Microphysics and Chemistry

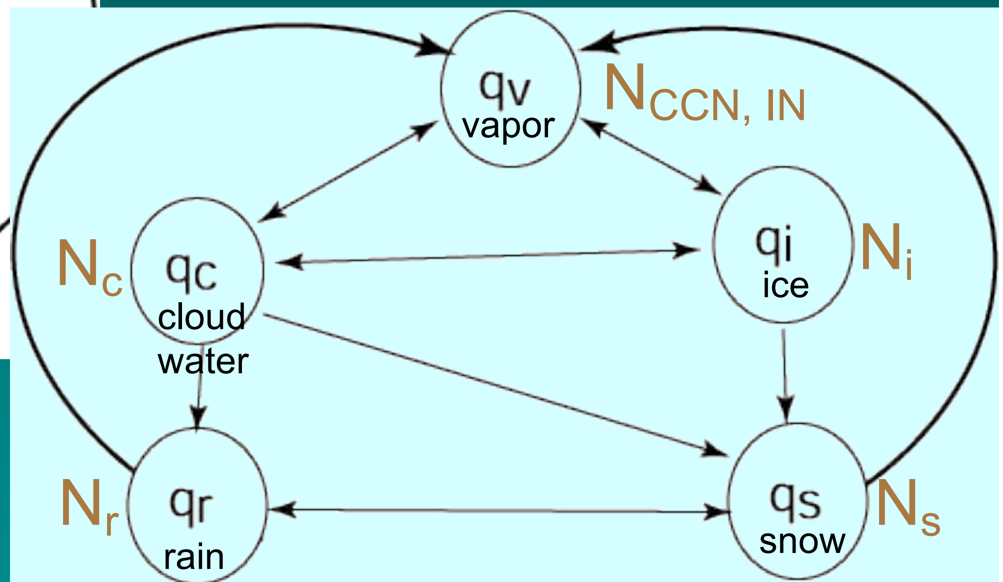
Bulk water method:



WRF-aqchem, Meso-NH, RAMS, Spiridonov, UMd/GCE, SDSMT

C. Wang

Two Moment method:



Sectional method:

q_v, q_{aer}, N_{aer}, size of aerosols (16 bins)

q_{liq}, N_{liq}, size of drops (16 bins)

q_{ice}, N_{ice}, size of ice (16 bins)

DHARMA

Models Configured for an Idealized Convective Case

- 160 km x 160 km x 20 km Domain: WRF-AqChem
- 120 km x 120 km x 20 km Domain: C.Wang, DHARMA, Meso-NH, RAMS/Leriche, Spiridonov, SDSMT
- 360 km x 328 km x 25 km Domain: UMd/GCE

- Resolution: $\Delta x = \Delta y = 1$ km

stretched vertical grid (50 grid points): WRF-AqChem, Meso-NH, RAMS/Leriche

$\Delta z = 500$ m: Spiridonov, UMd/GCE

$\Delta z = 400$ m: C. Wang

$\Delta z = 250$ m: DHARMA, SDSMT

Sample of the Results Analyzed for the Intercomparison

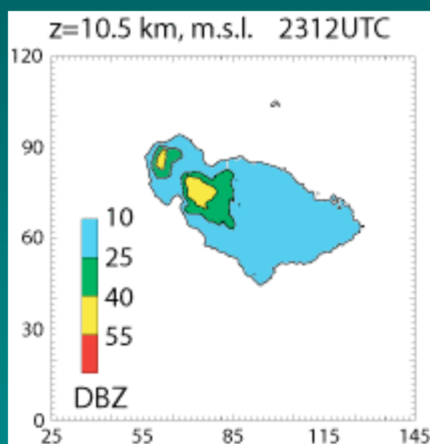
STERAO-1996
From Dye et al. (2000)

Radar Reflectivity

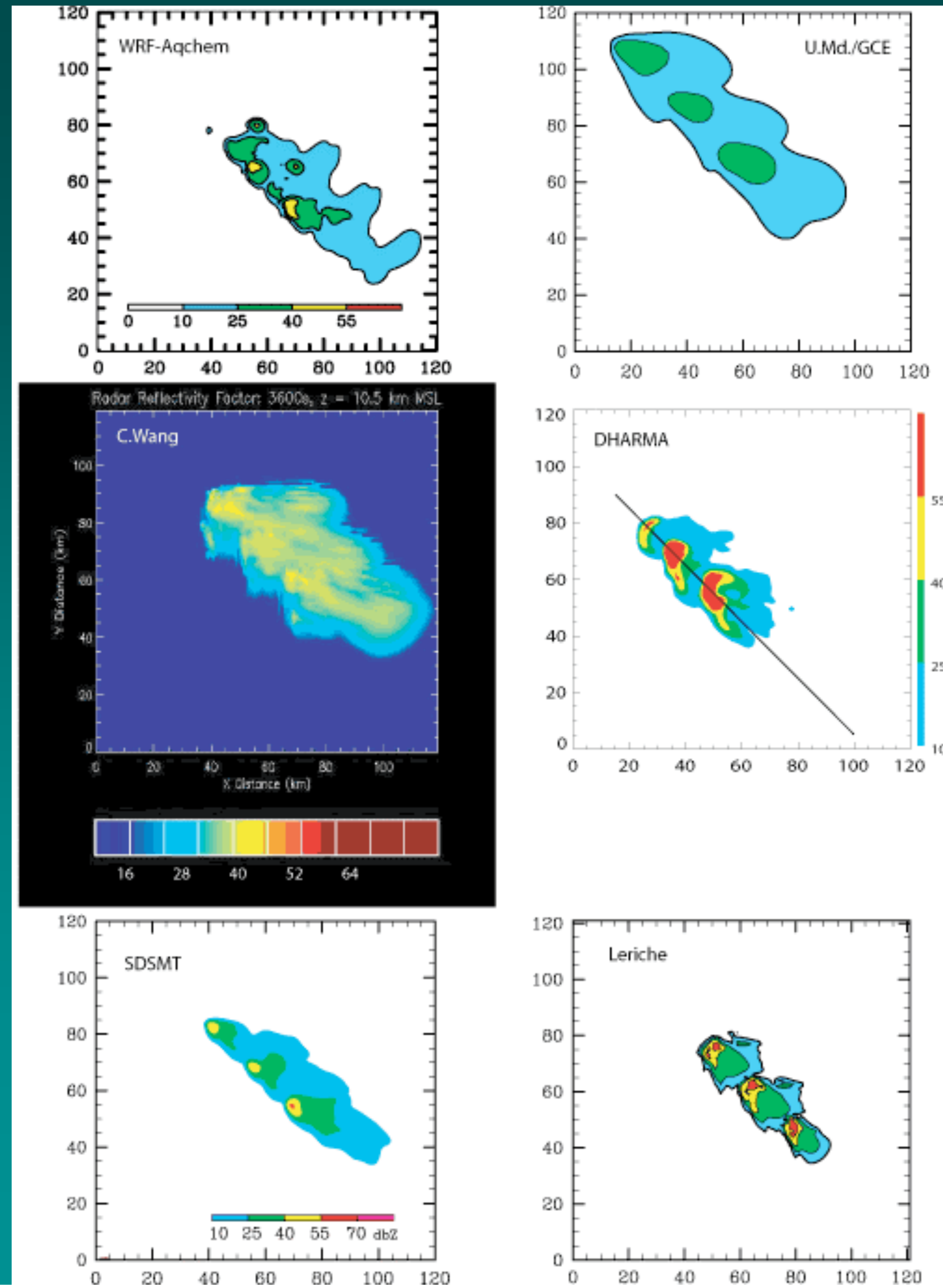
z = 10.5 km m.s.l.

t = 1 hr

observations



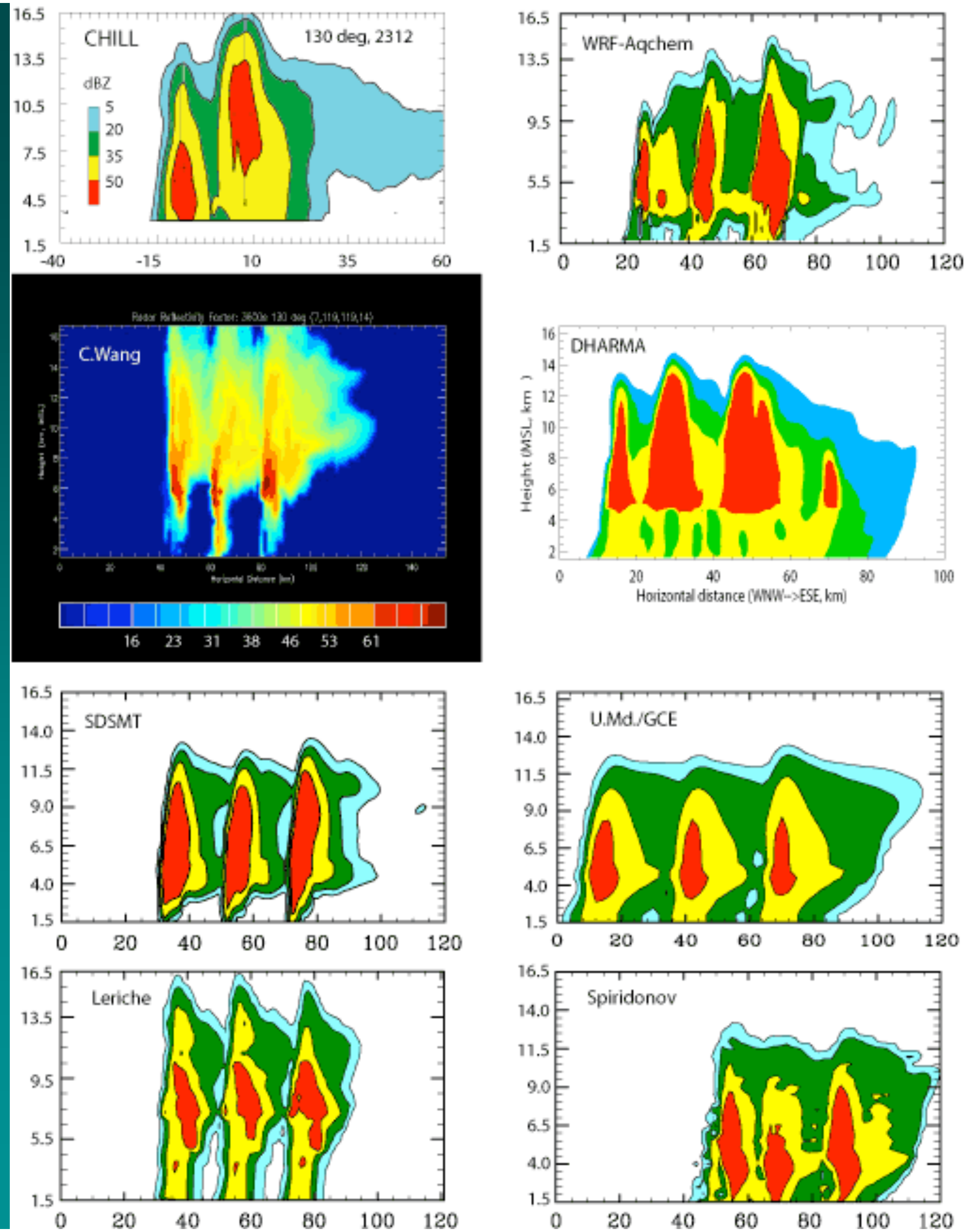
Model results



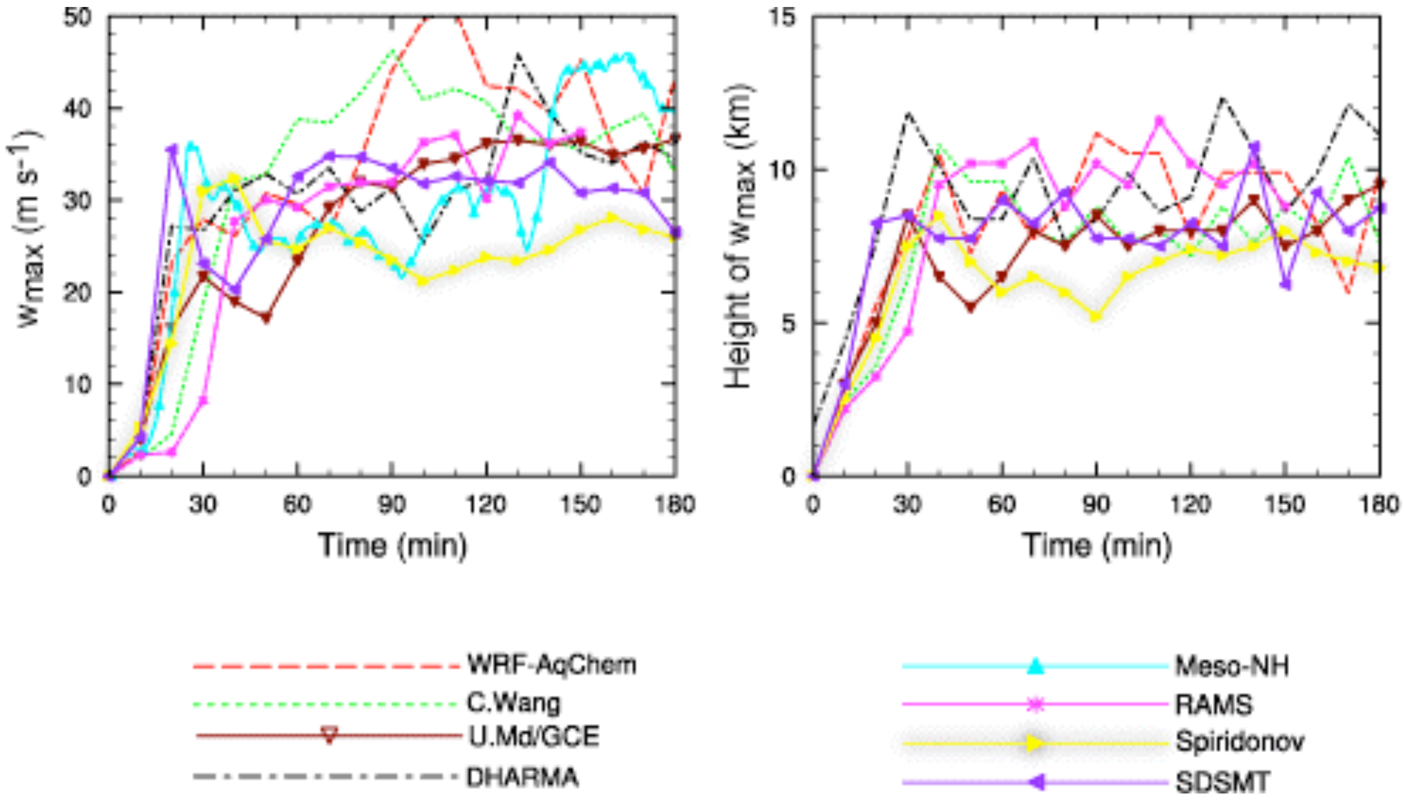
Radar Reflectivity

along-axis cross section

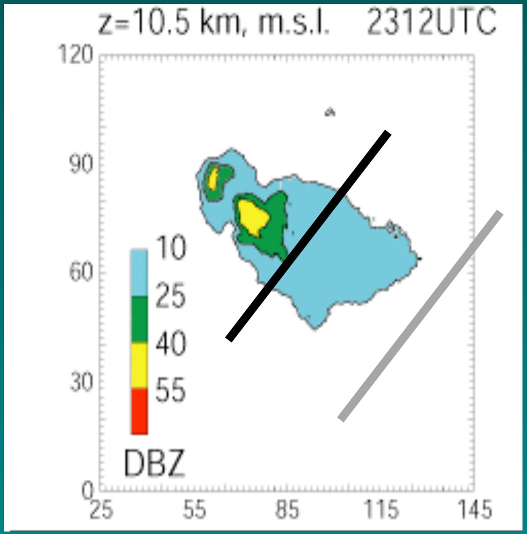
t = 1 hr

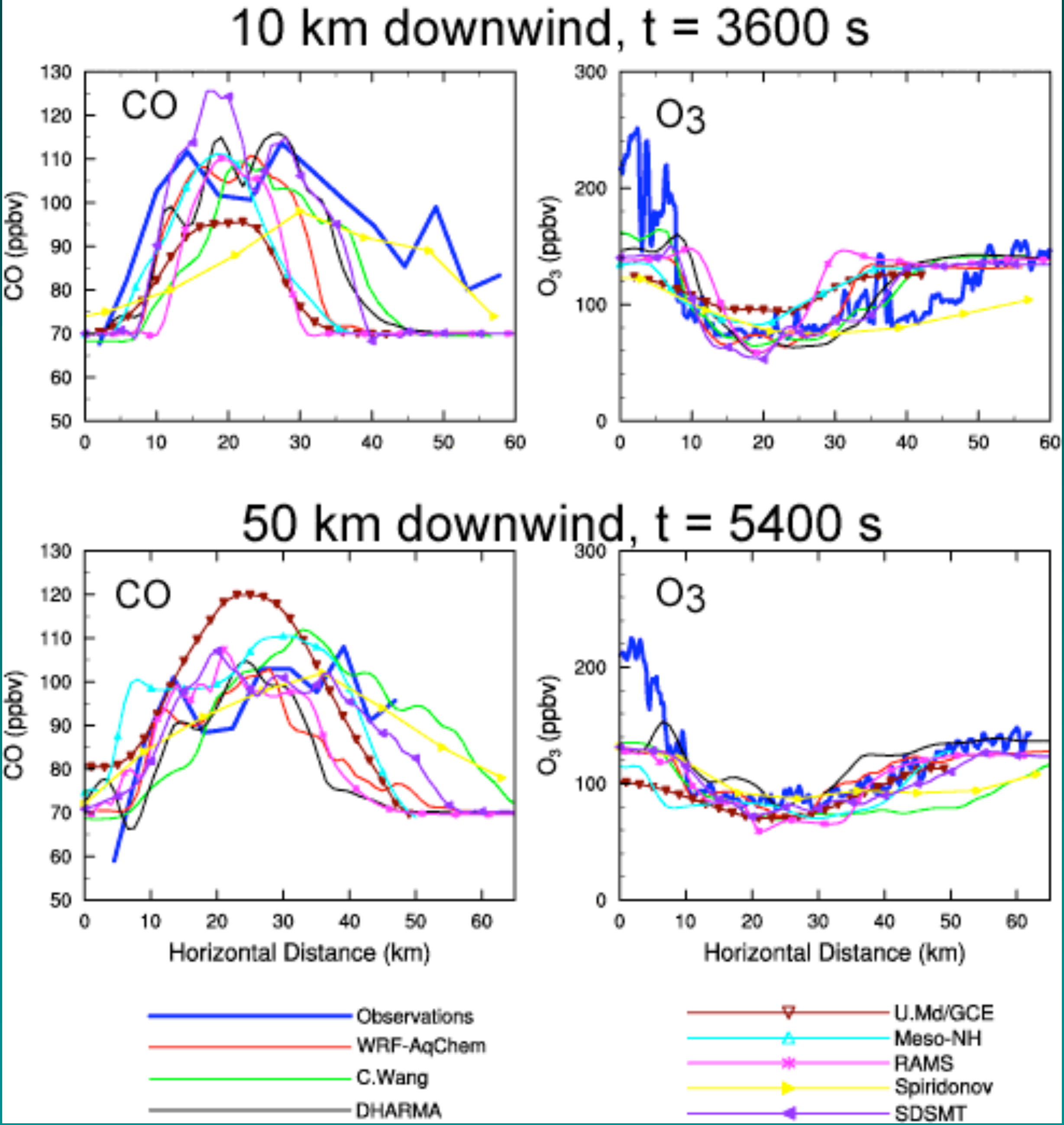


Maximum Updraft

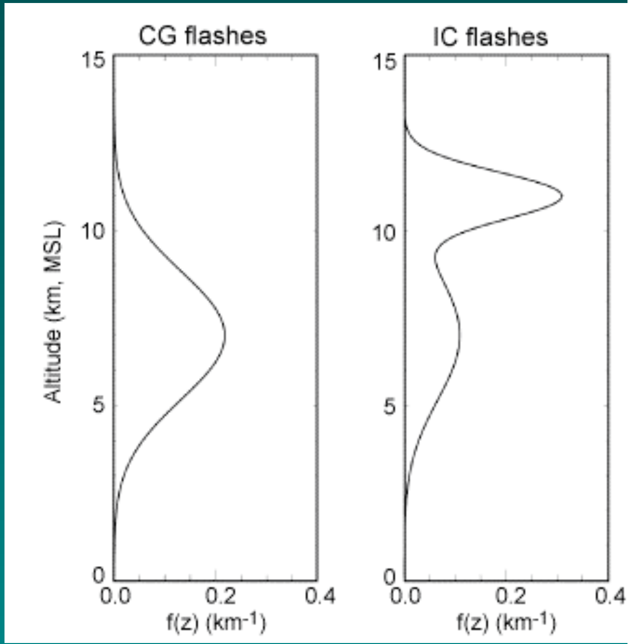


Transects across Anvil





NOx production from Lightning



DeCaria et al. (2005)

- Lightning interferometer data as input
- Finds region of reflectivity > 20 dBZ
- Distributes NO vertically

WRF-AqChem, UMd/GCE

Parameterized flash rate based on max updrafts

RAMS/Leriche

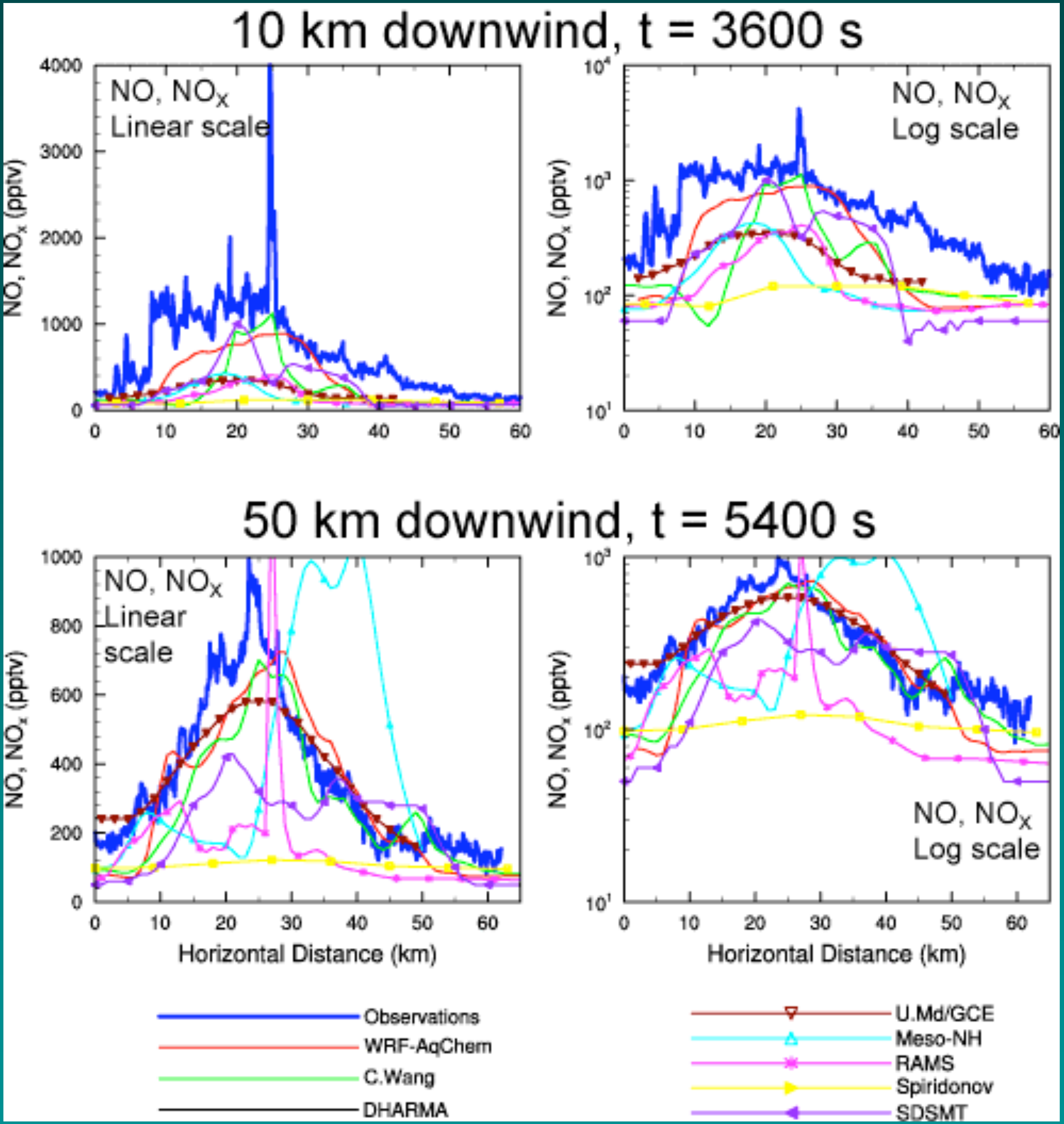
Parameterized electric field based on microphysics

C. Wang

Predicts charge density in model

Meso-NH, SDSMT

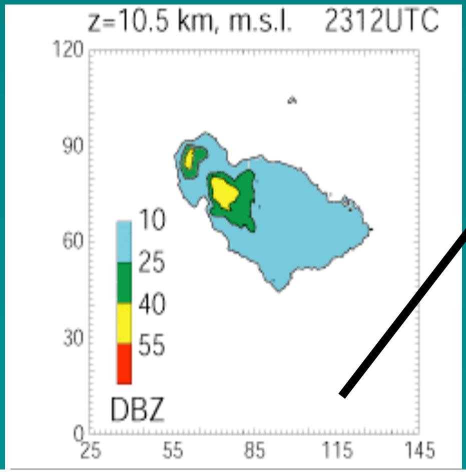
Transects across Anvil

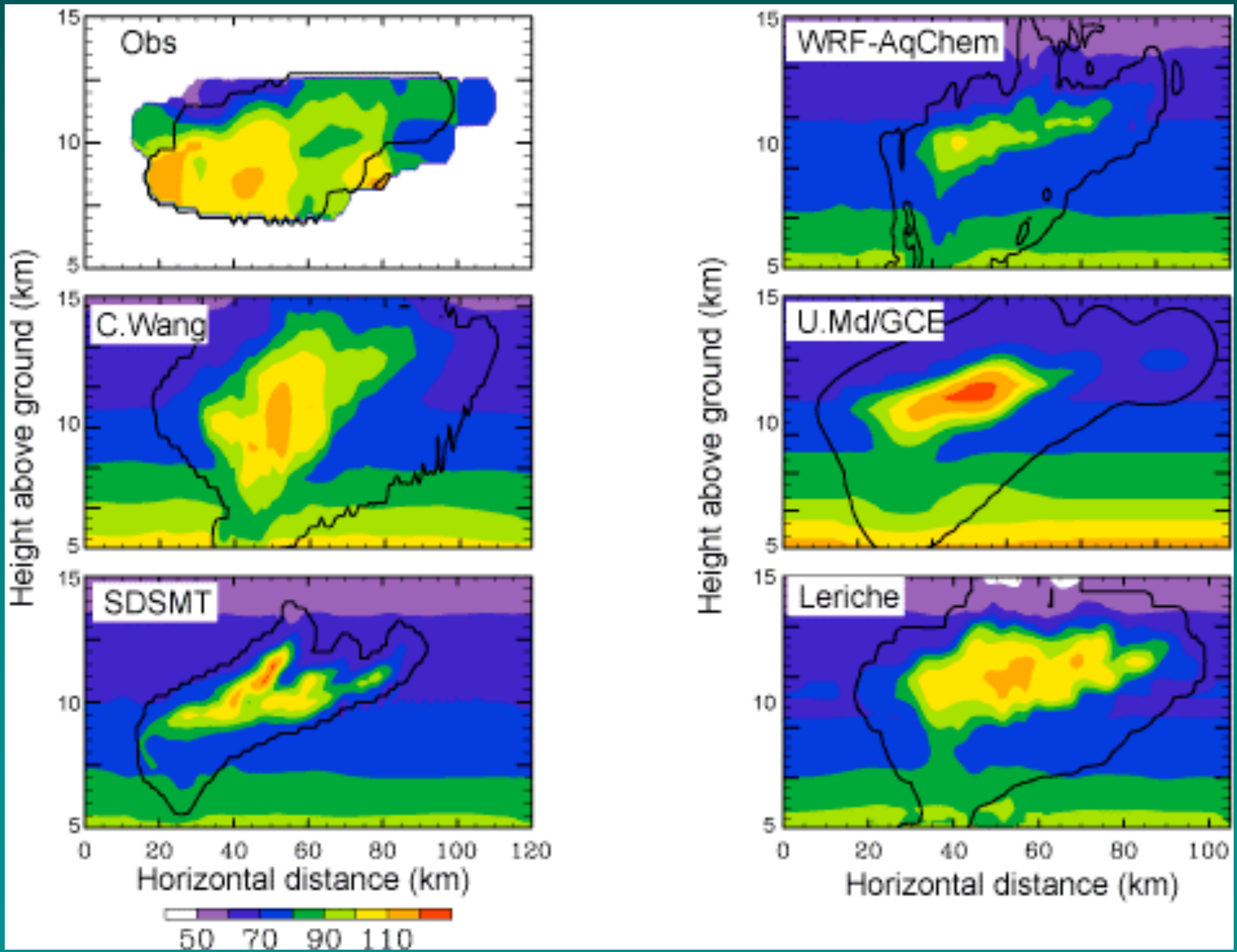


Left side has linear plots, Right side has log plots

Cross sections
CO

50 km from core
t = 6000 s



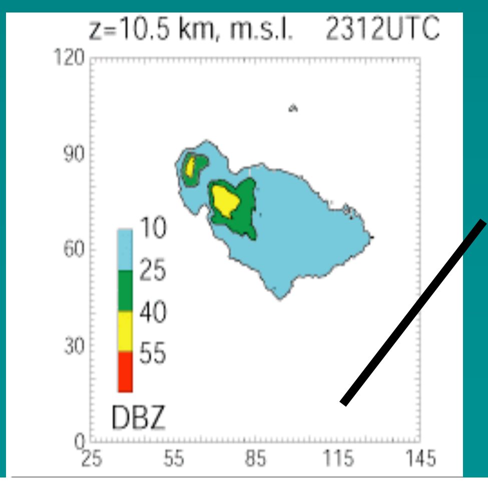


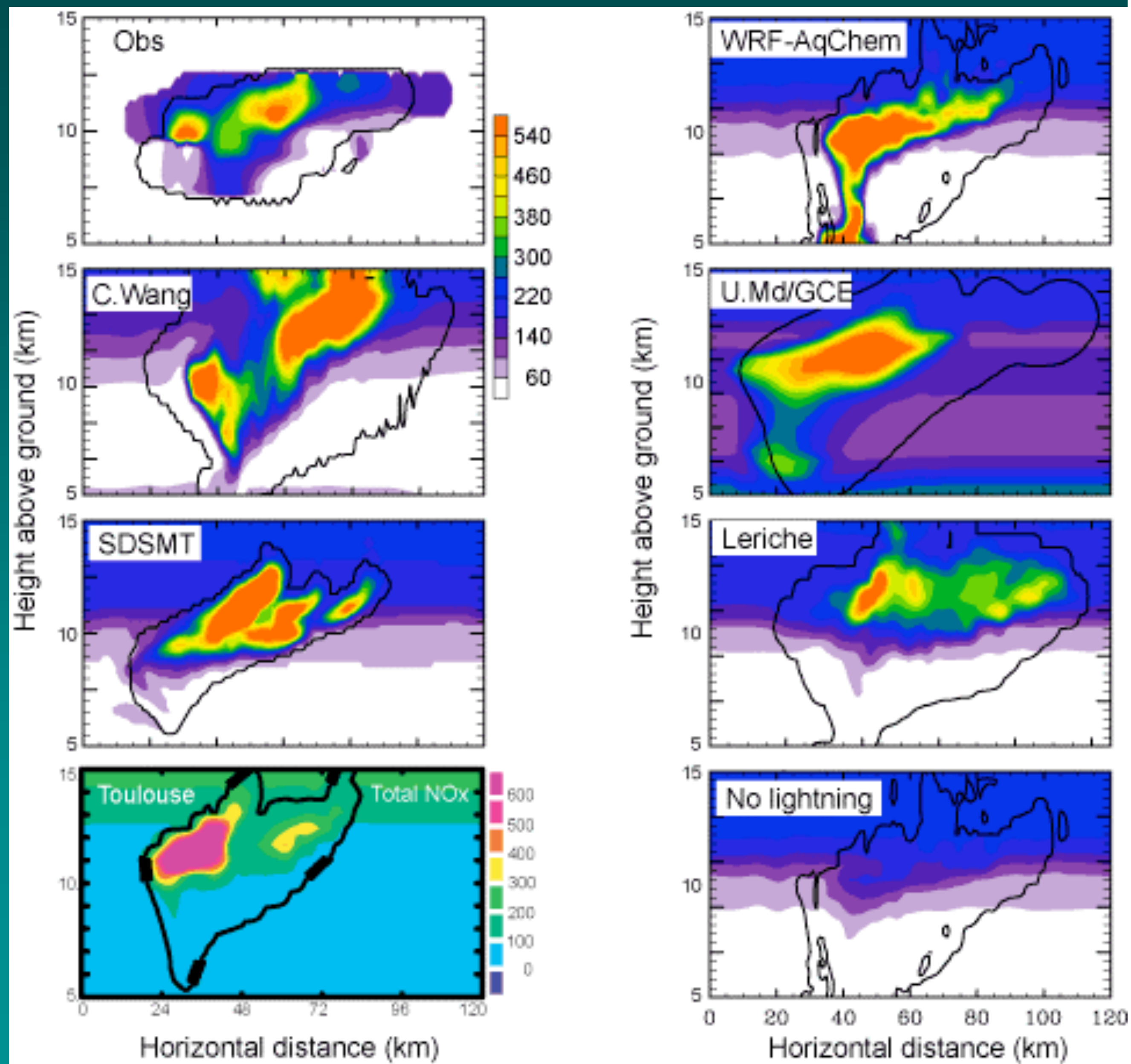
Cross sections

NO_x

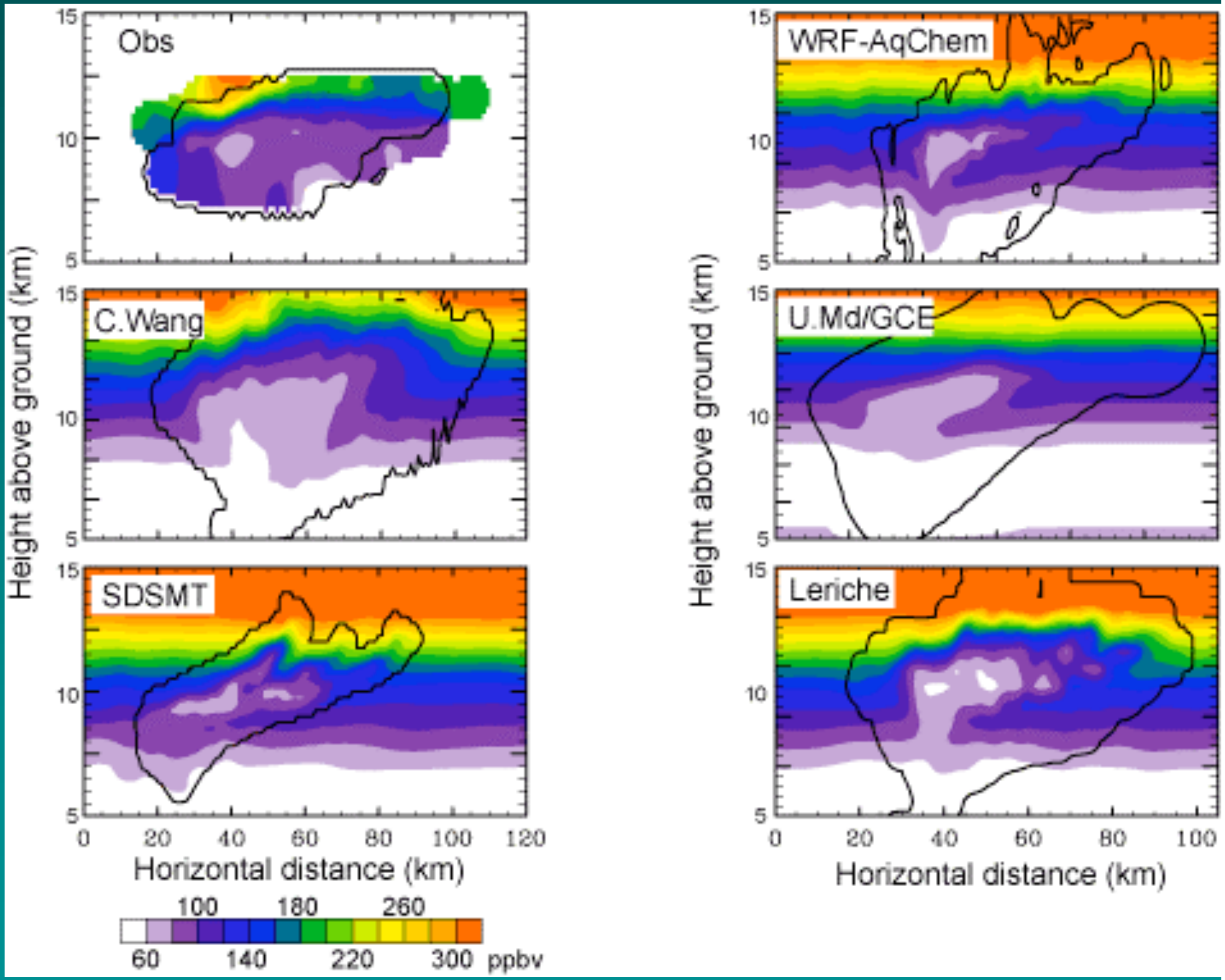
50 km from core

t = 6000 s

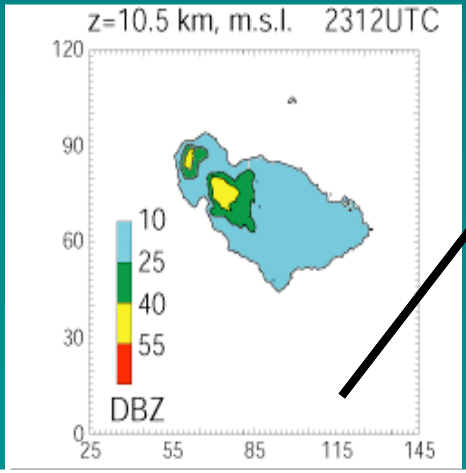




Cross sections
O_3



50 km from core
t = 6000 s



Flux Through Anvil

Average values through vertical cross-sections from t = 1 h to t = 2 h

Model	Anvil Area (10^6 m2)	Mass Flux (kg m^{-2} s^{-1})	CO Flux (10^{-5} mol m^{-2} s^{-1})	NO_x Flux (10^{-8} mol m^{-2} s)
Observations*	315	5.9	1.90	5.8
WRF-AqChem (Barth, Kim)	187.7	6.75	1.94	7.23
C. Wang	442.7	6.72	1.94	5.97
DHARMA (Fridlind et al.)	531.9	7.69	2.39	n/a
Meso-NH (Pinty, Mari)	n/a	5.41	1.59	2.84
RAMS (Leriche et al.)	332.7	7.68	2.29	5.30
V. Spiridonov	444.0	5.00	3.3	3.2
U. Md / GCE (Pickering et al.)	274.0	9.06	2.54	8.45
SDSMT (Helsdon et al.)	196.9	6.59	1.93	13.04
avg +/- std dev	344.3 +/- 133.0	6.86 +/- 1.30	2.24 +/- 0.53	6.58 +/- 3.49

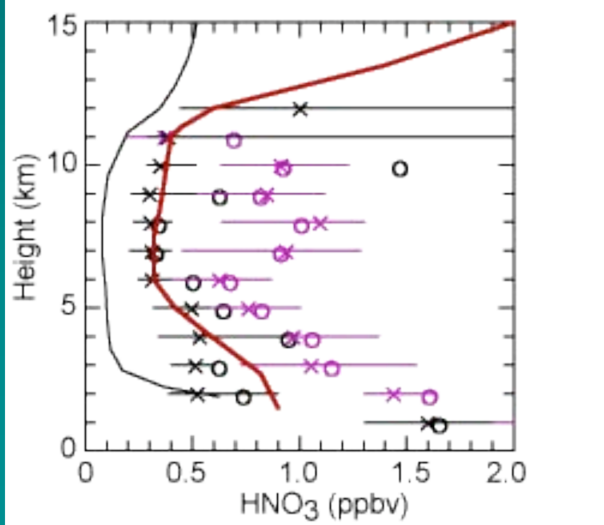
*Skamarock et al. (2003) JGR

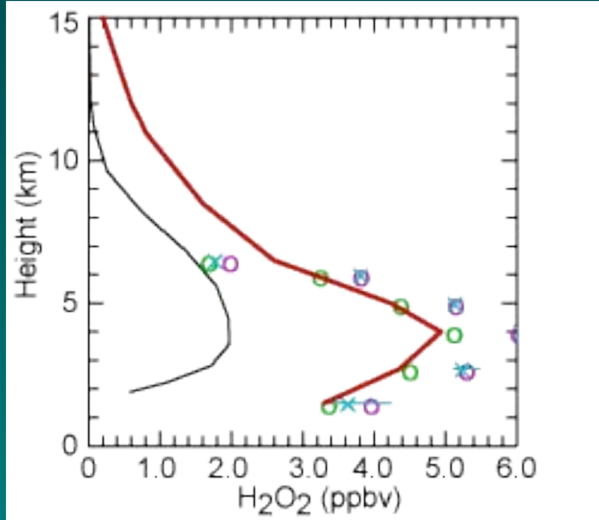
Simulations of HNO_3, H_2O_2, and CH_2O

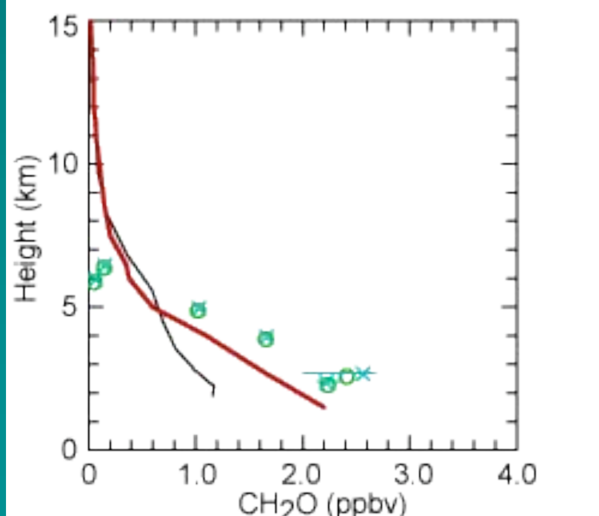
Initial profile

MOZART profile

Points from aircraft observations







Chemistry and Aerosols

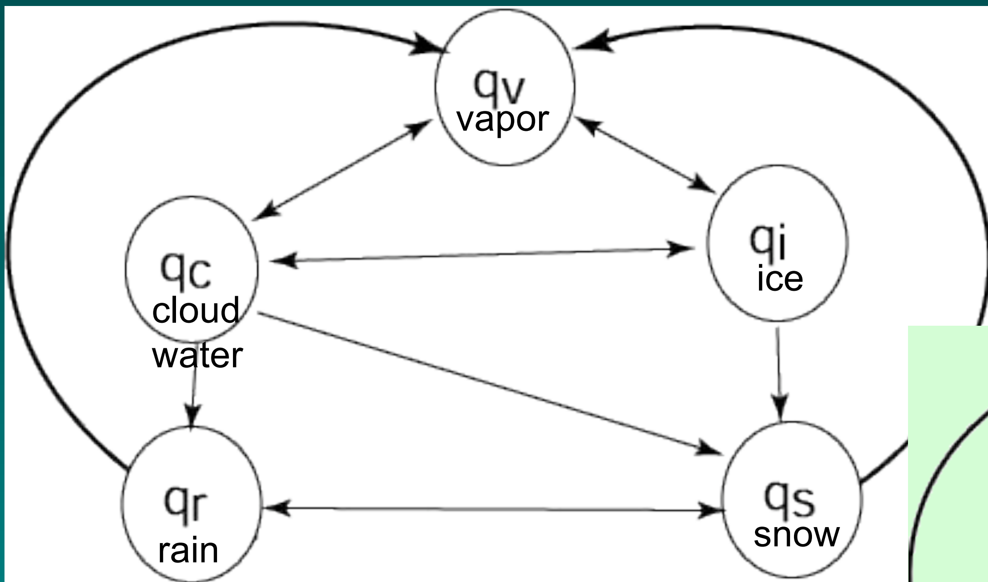
- CO, O_3, NO_x, H_2O_2, CH_2O, HNO_3

  Chemistry simulated: WRF-AqChem, C. Wang, RAMS/Leriche, UMd/GCE

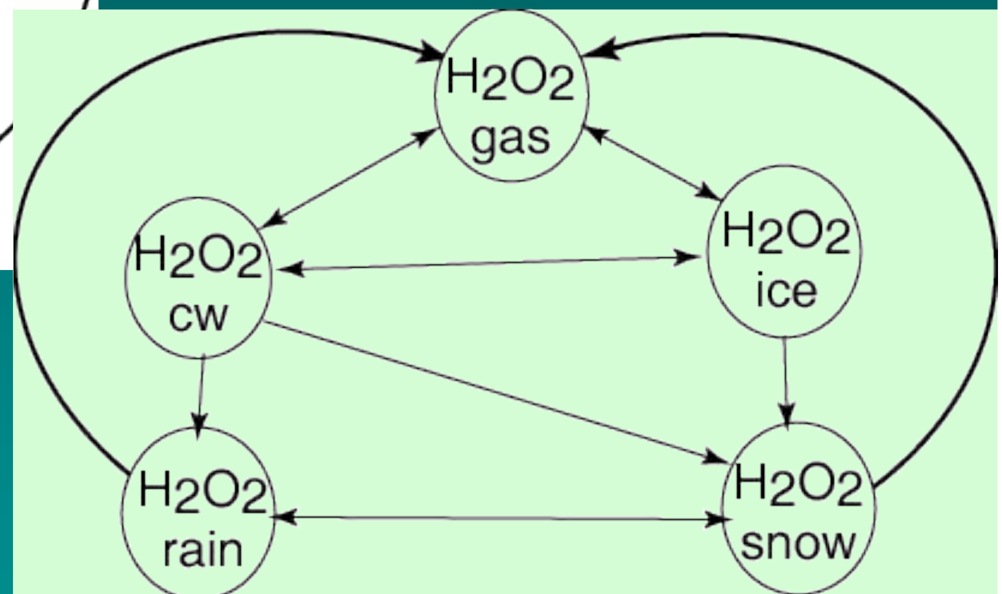
- Aerosols simulated:

  C. Wang

Microphysics and Chemistry



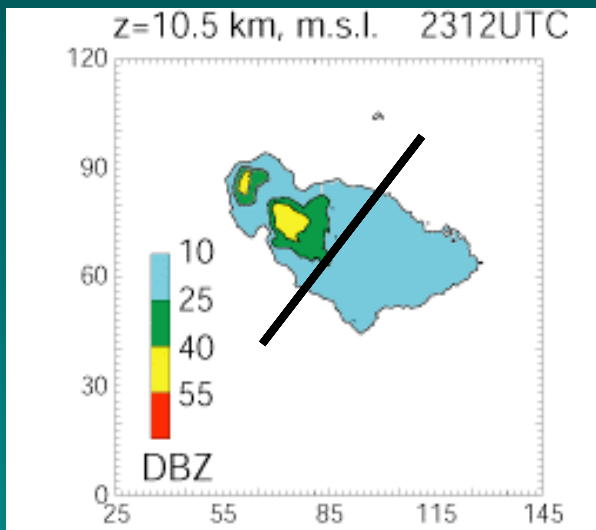
Species are transferred among hydrometeors according to the microphysics

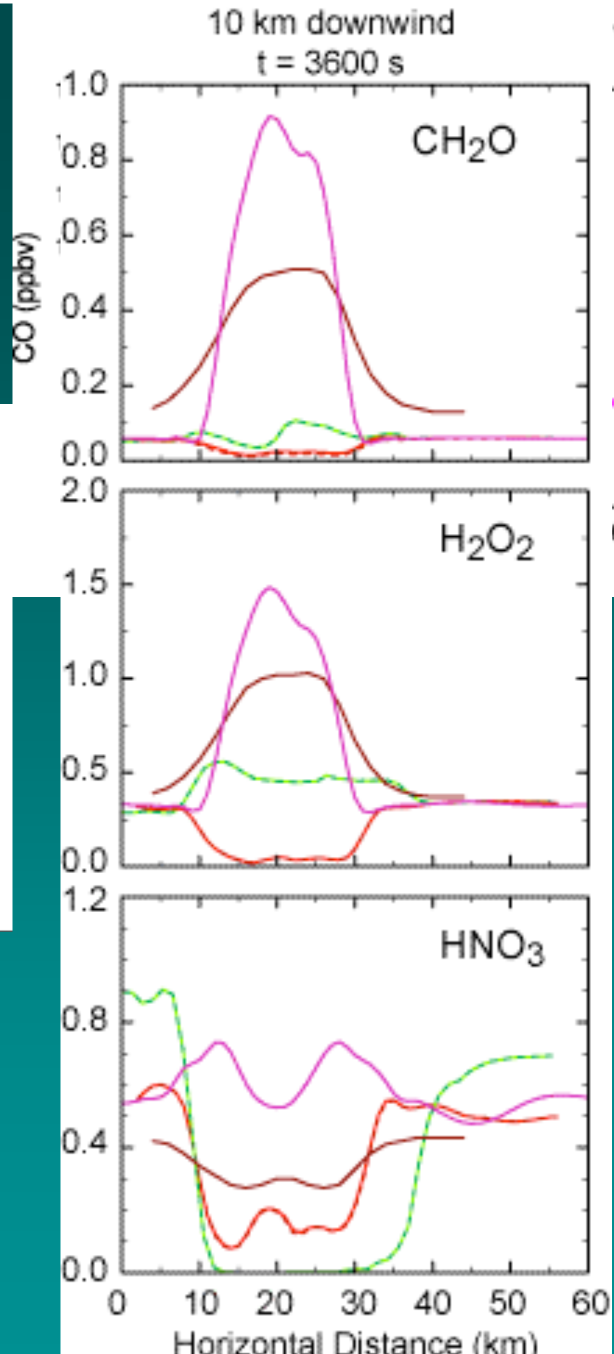


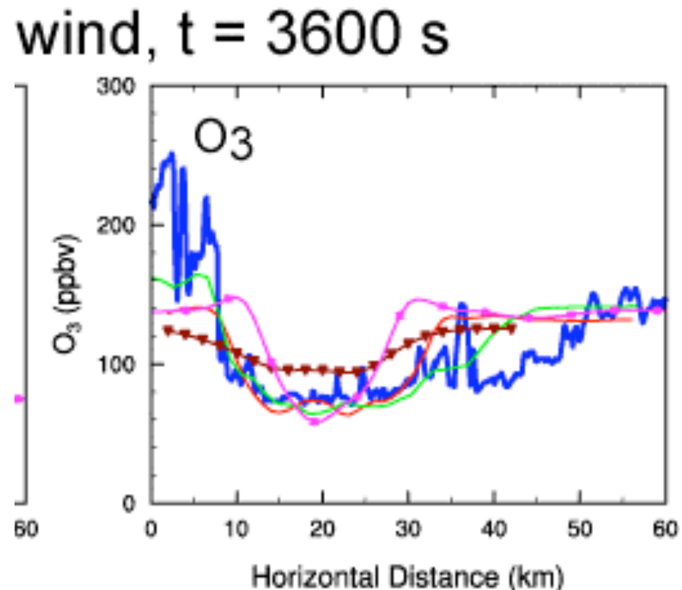
Liquid to ice, snow, or hail: WRF-AqChem, C. Wang

Liquid to gas: UMd/GCE*, RAMS

Transects across Anvil







Observations

WRF-AqChem (NCAR)

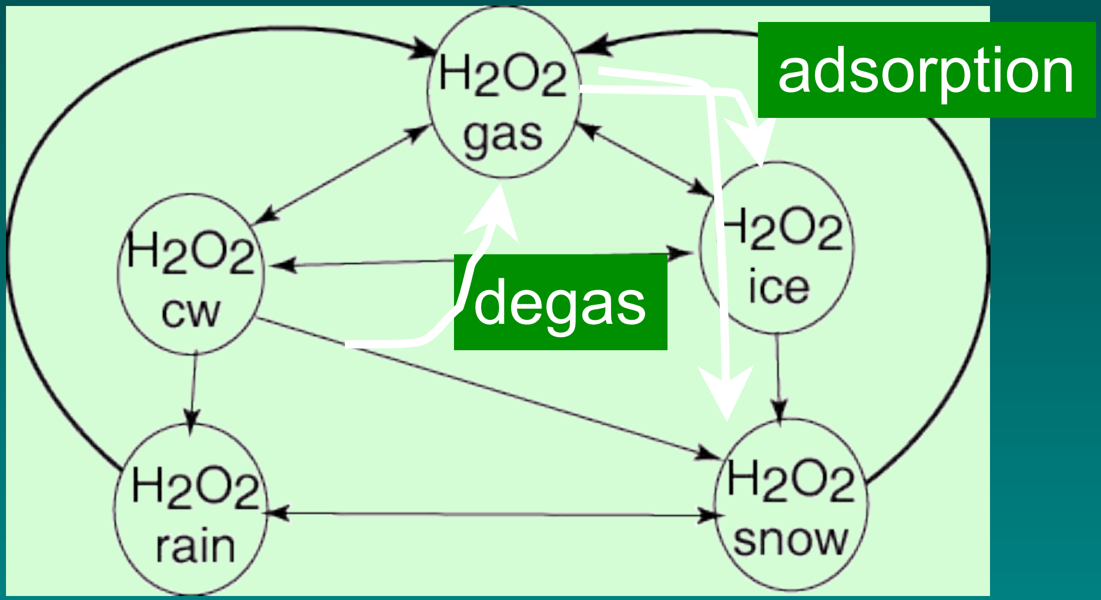
Chien Wang

U.Md/GCE

RAMS/Leriche

No lightning – dotted lines

Gas-phase mixing ratios



Liquid to ice, snow, or hail: WRF-AqChem, C. Wang

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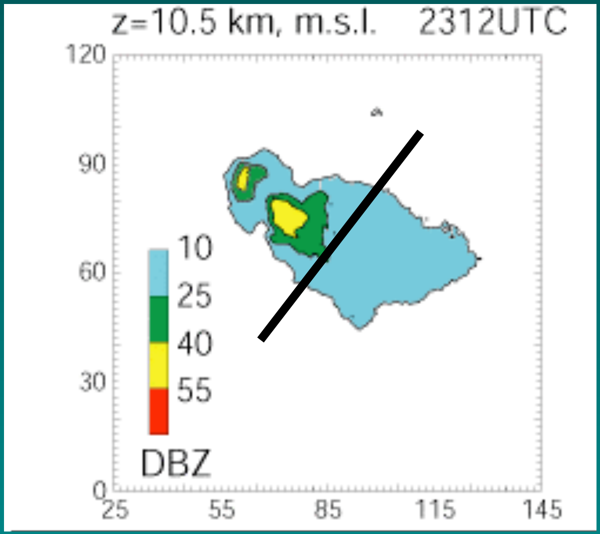
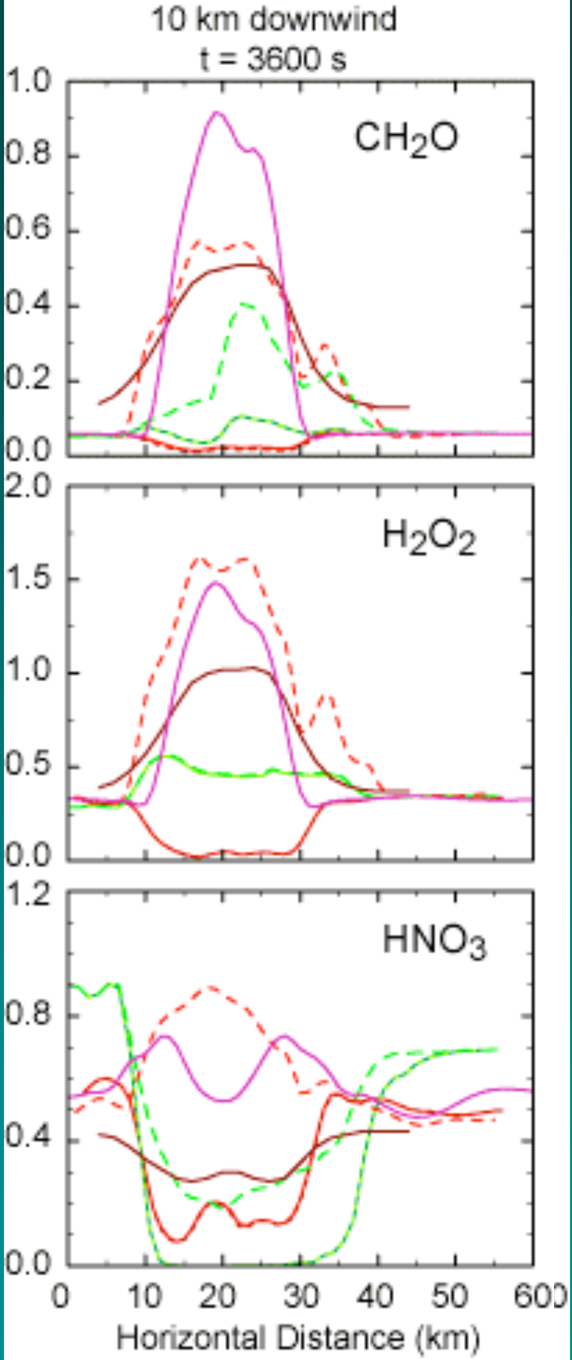


Microphysical effects

Degassing during drop freezing

No adsorption of gases onto ice



Observations

WRF-AqChem (NCAR)

Chien Wang

U.Md/GCE

RAMS/Leriche

Gas-phase mixing ratios

Conclusions

- Tracer transport (CO and O_3) are similar among models and similar to observations.
- NOx is consistently underestimated when no lightning is included.
- Lightning-NOx parameterizations perform reasonably well.
- Comparison of soluble species HNO_3, H_2O_2, and CH_2O shows we have much more to evaluate.

What's next?

Observations

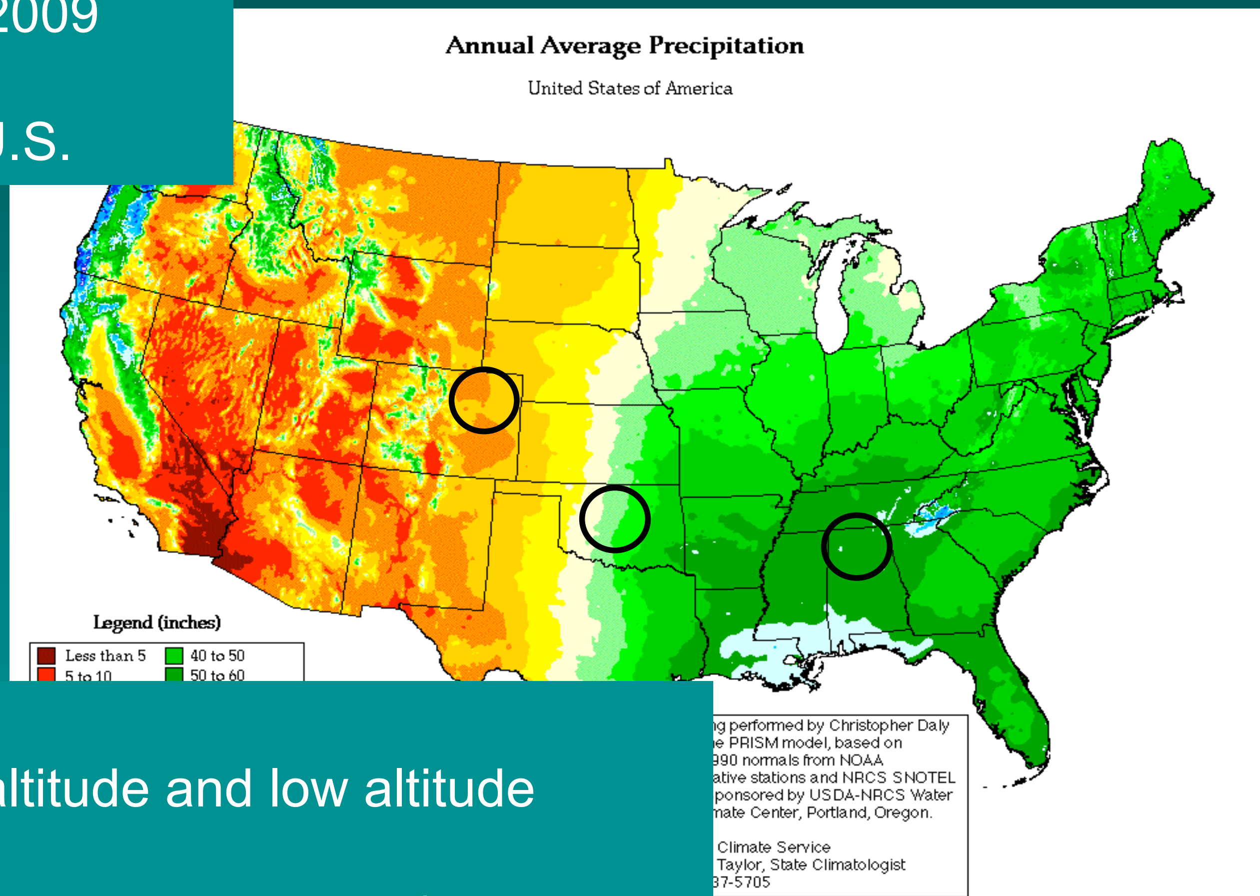
- ◊ Measurements of HOx precursors in both the inflow air and the convective outflow are lacking.

Intercomparison of tropical convection and chemistry? Impact of aerosols?

Planning: Deep Convective Clouds and Chemistry (DC3) Field Experiment

When: Summer 2009

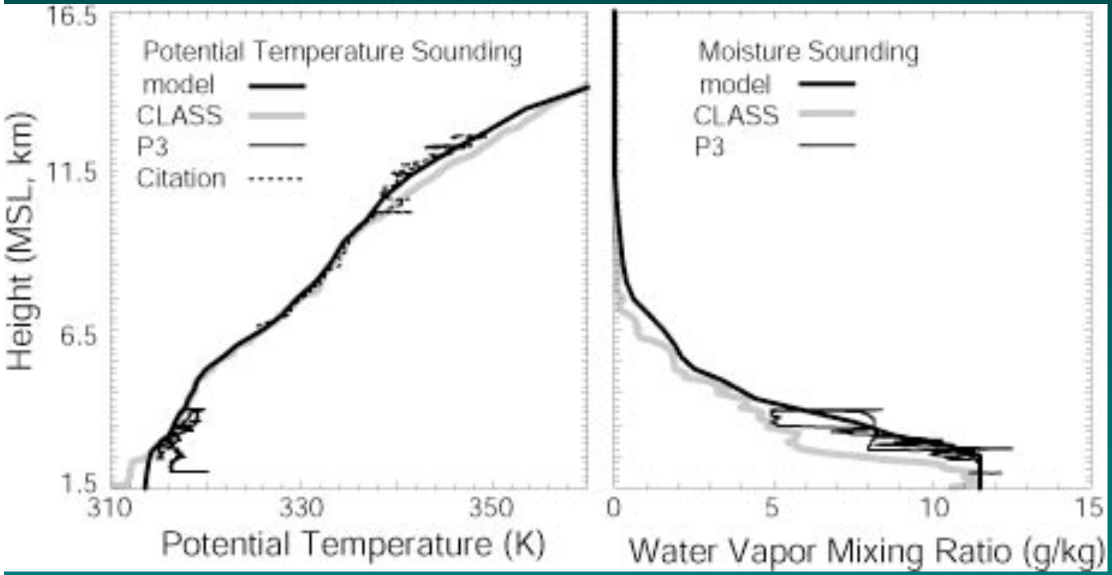
Where: Central U.S.



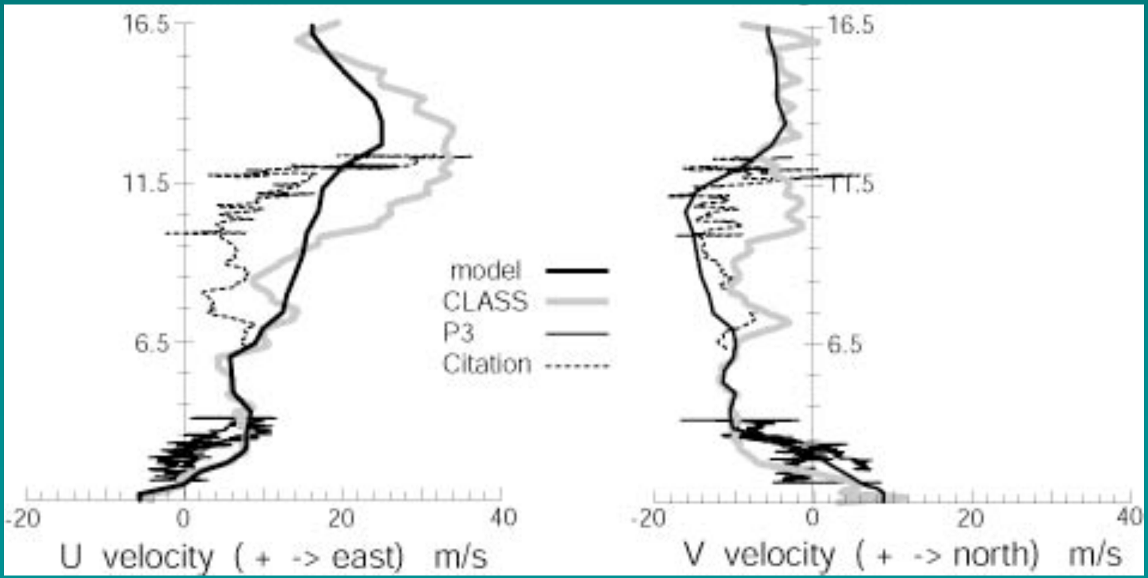
Major Facilities:

- Aircraft (high altitude and low altitude planes),
- Radar (Doppler and polarimetric)
- Lightning Mapping Array

Initialization

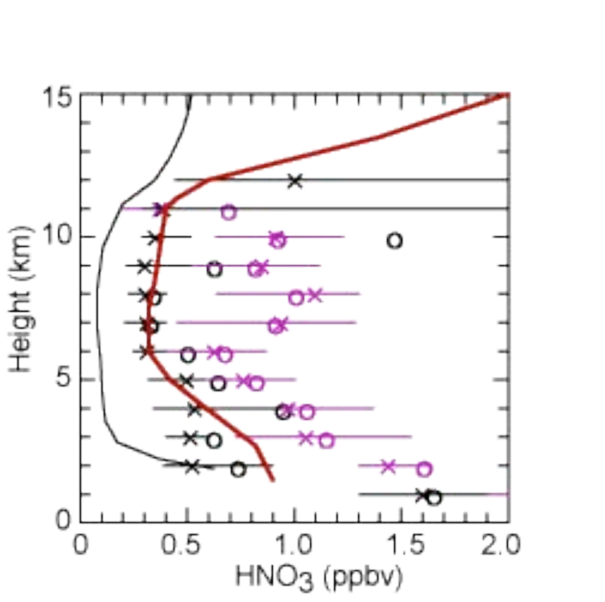


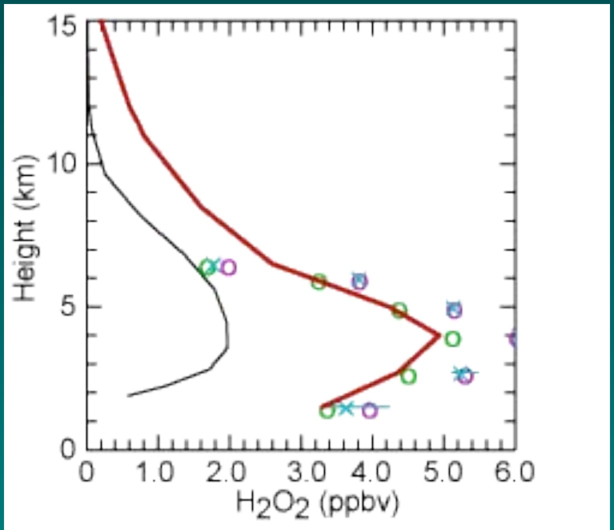
Sounding data came from Skamarock et al. (2000)

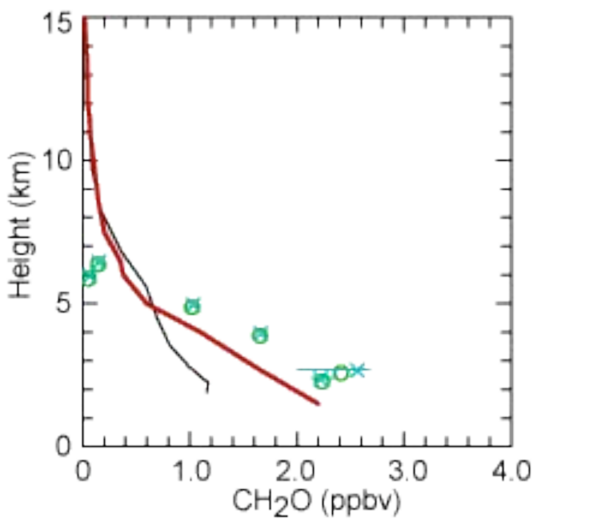


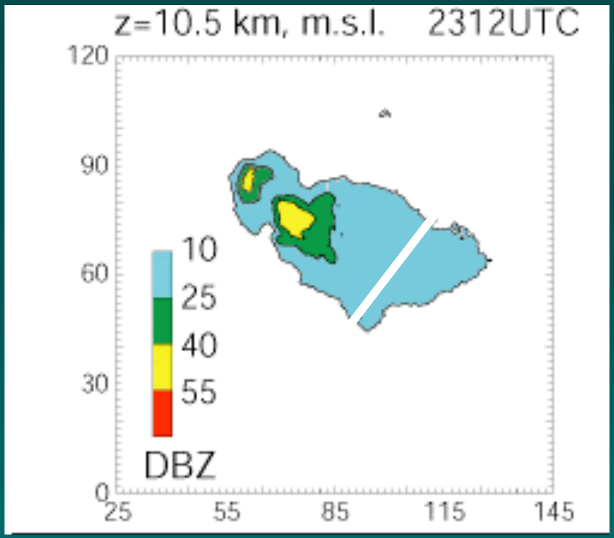
Convection initiated with 3 warm bubbles

Initialization of Chemical Species

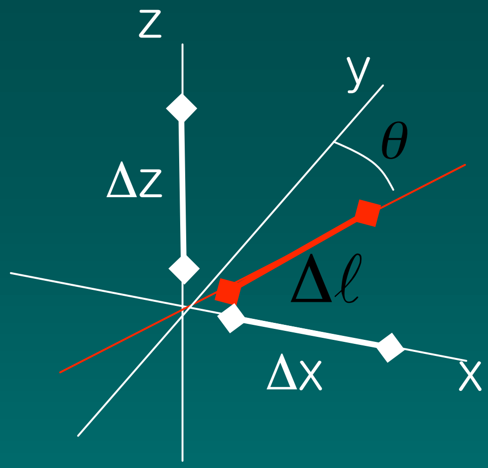








Flux Calculation

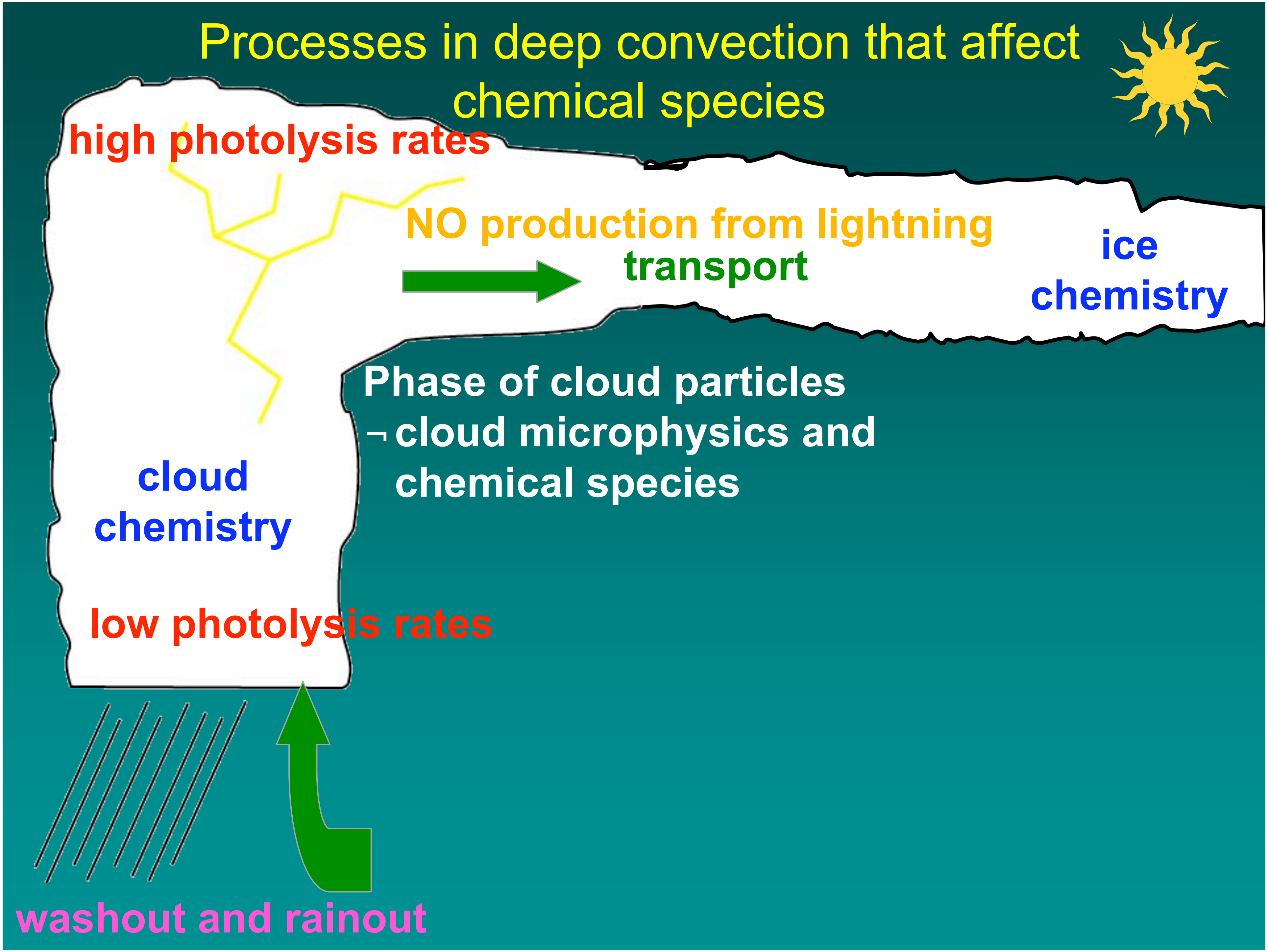


$$flux = \frac{\sum_{anvil\,cells} \rho\, U_{\perp}\, C\, \Delta\ell\, \Delta z}{\sum_{anvil\,cells} \Delta\ell\, \Delta z}$$

where $\Delta\ell$ = horizontal length of grid cell in cross−section

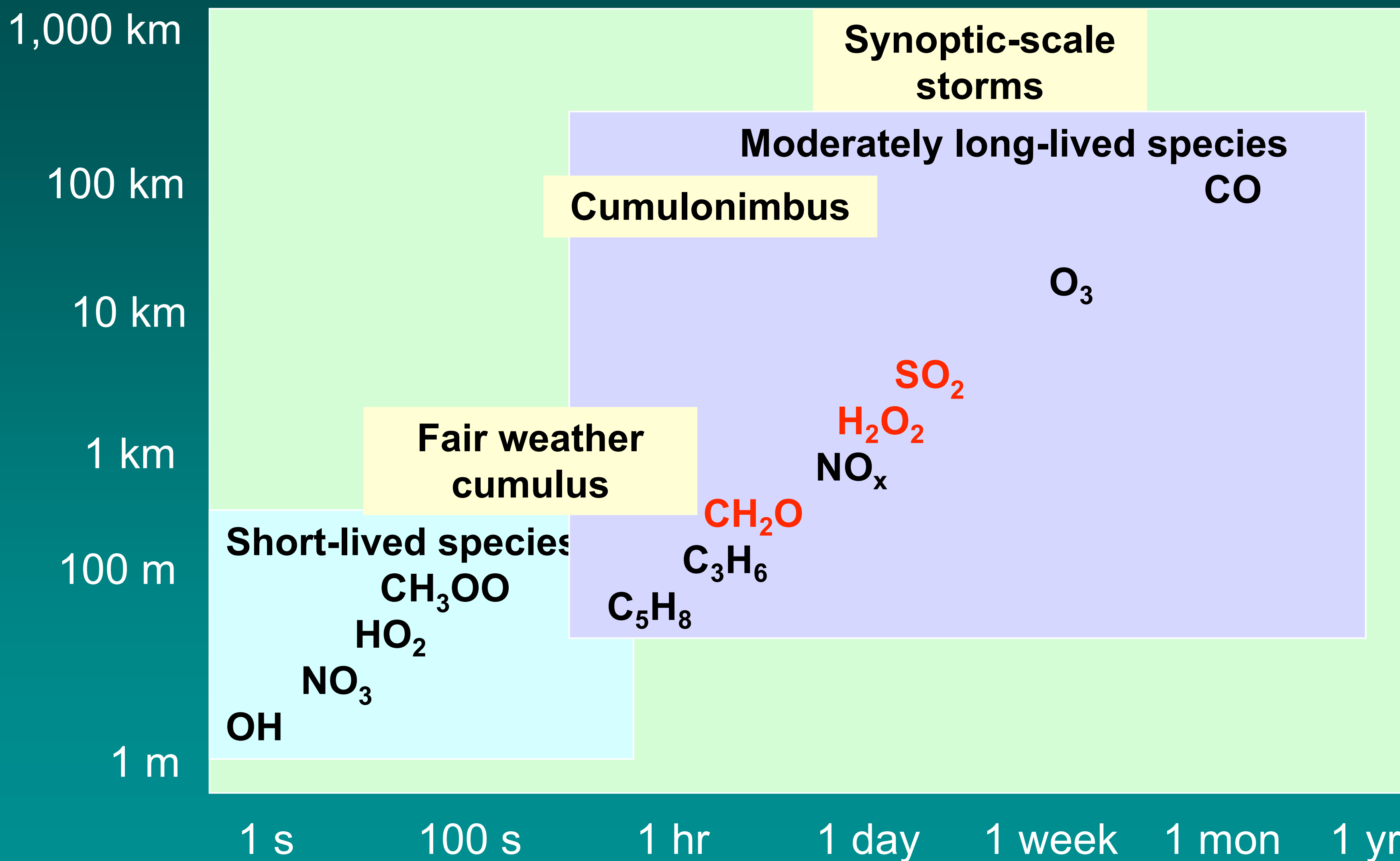
C = mixing ratio of species (= 1 for air mass flux)

Calculation is done on grid cells that contain cloud particles.
The area of the anvil is the denominator.



Processes in deep convection that affect chemical species
high photolysis rates
NO production from lightning
transport
ice chemistry
Phase of cloud particles
¬ cloud microphysics and chemical species
cloud chemistry
low photolysis rates
washout and rainout

Spatial Scales and Time Scales



Adapted from Brasseur *et al.* (1999)