Effects of Deep Cumulus Convection on Atmospheric Chemistry

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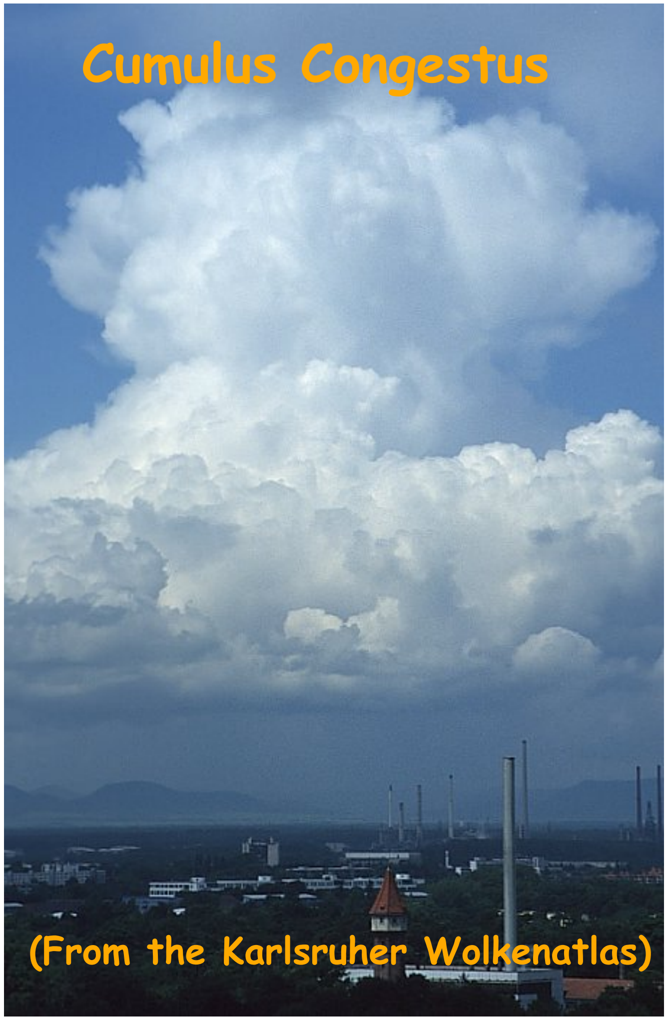
Overview

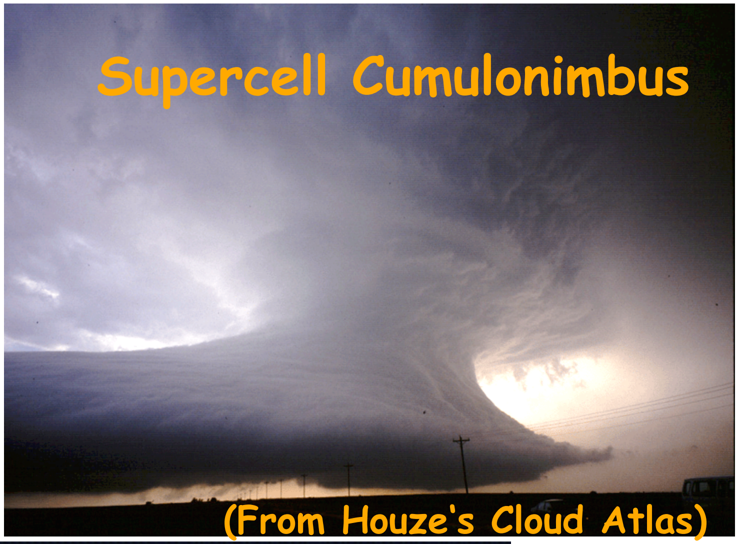
- Deep Cumulus Convection Characteristics and Overview of Effects on Atmospheric Chemistry

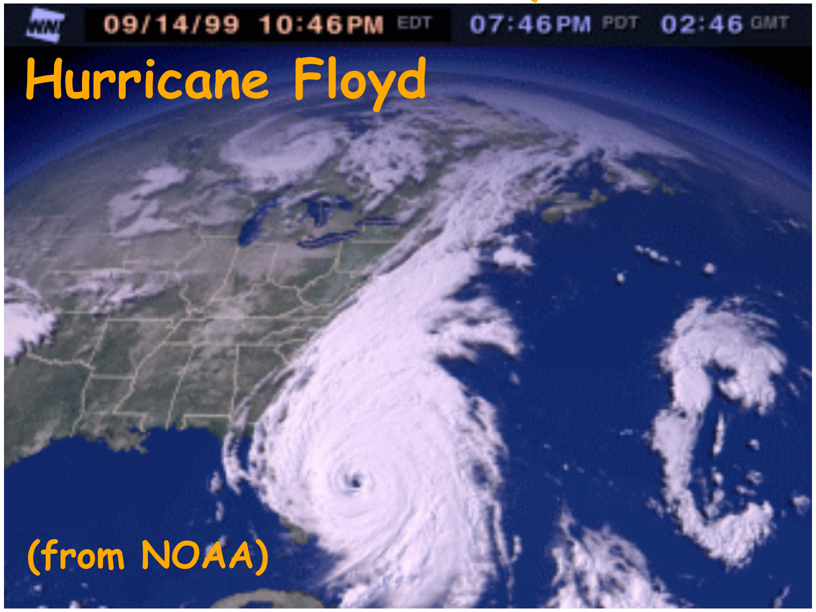
- Modelling Tools

- Examples
  - Vertical transport characteristics and effects
  - Transport into the TTL, effects on airmasses and water vapor
  - Deep convection parameterizations
  - Effects on O_3 and other tracers: reinterpretation of previous studies

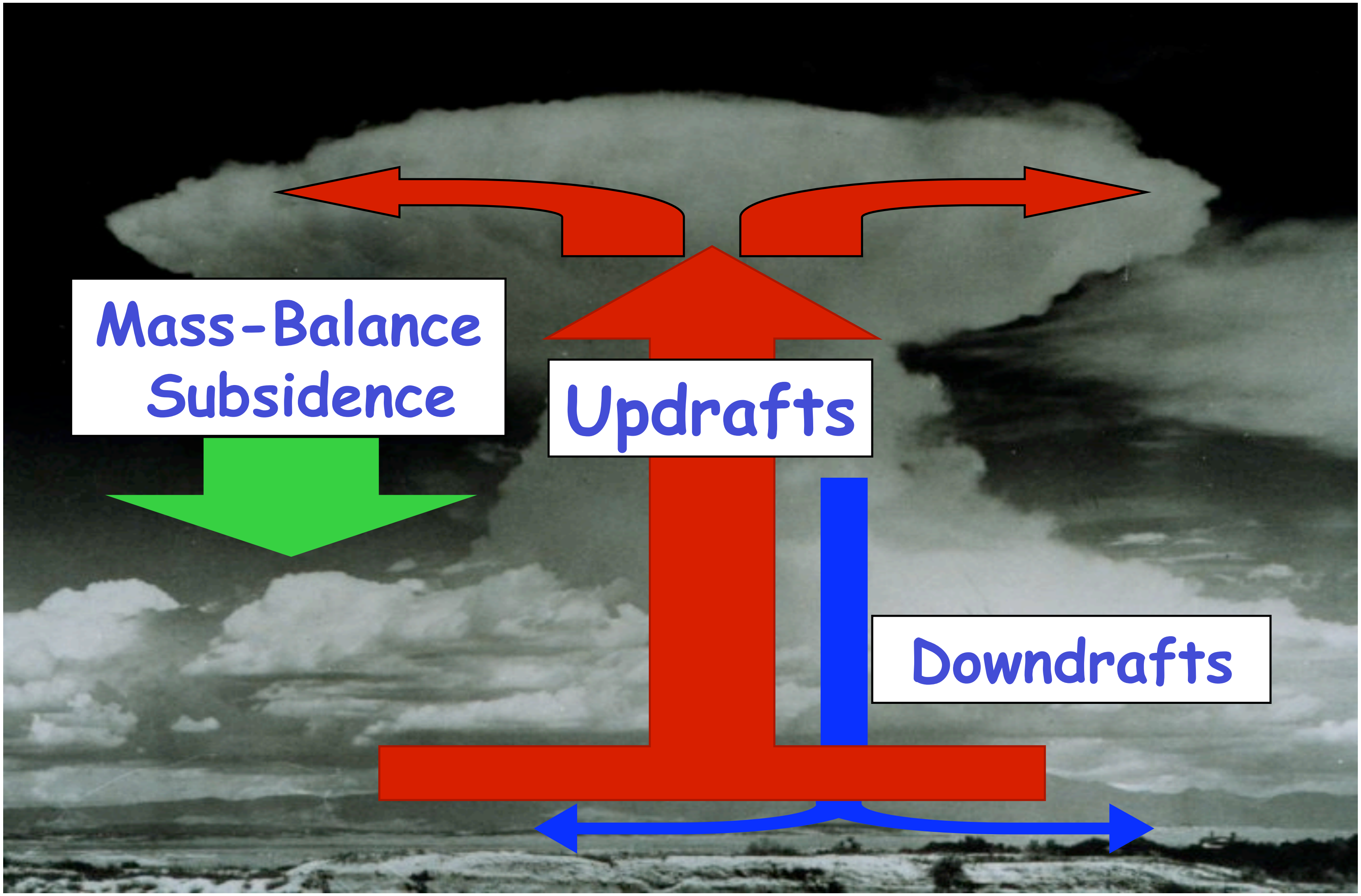
Deep Convective Clouds



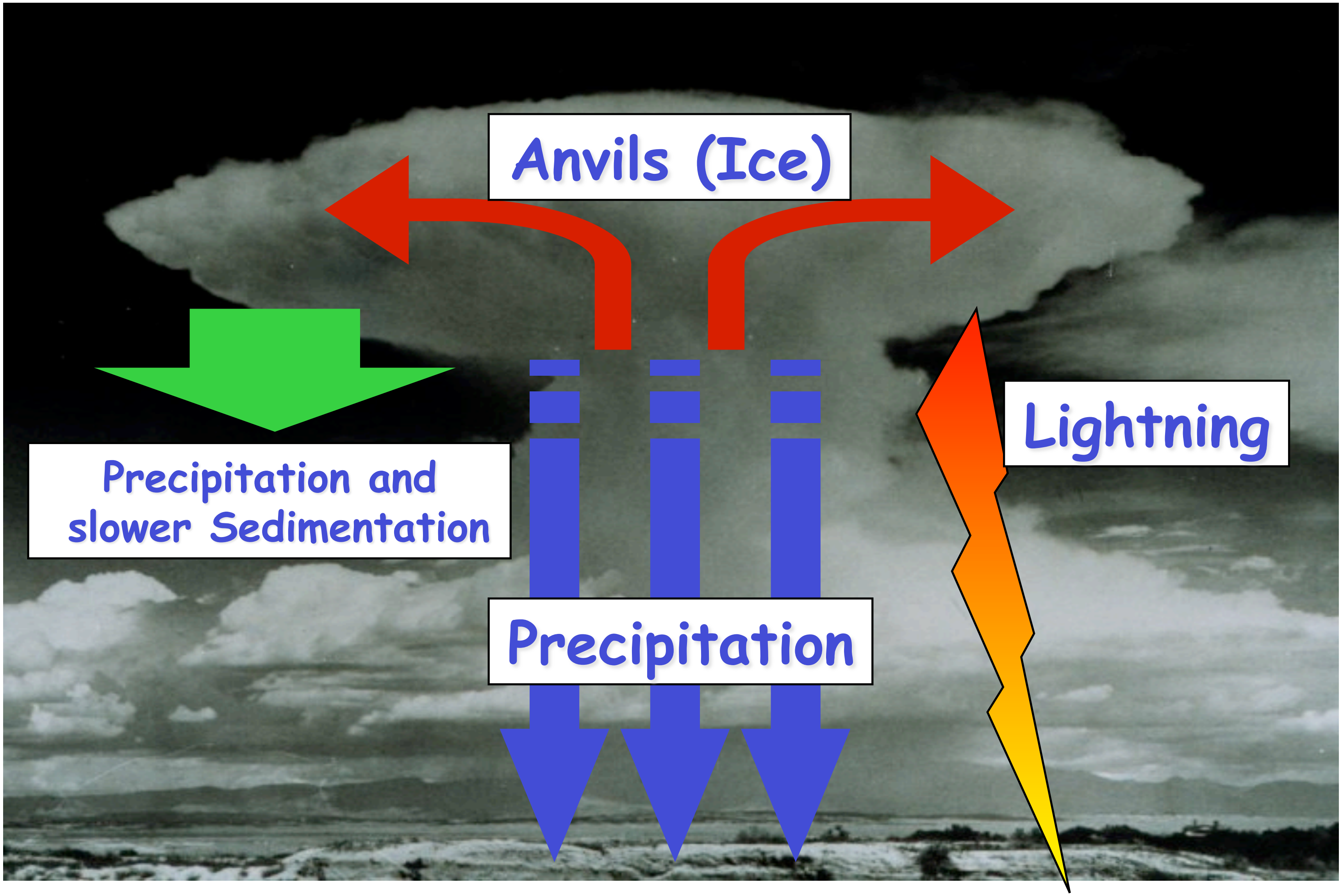




Deep Convection: General Characteristics



Deep Convection: General Characteristics



Effects on Atmospheric Chemistry: Overview

- Transport of Surface Emissions to the UT / TTL / LS
  - O_3 Production
  - OH Production
- Transport of Clean Surface Air (e.g., MBL) to the UT / TTL / LS
- Downward Mixing of UT and Stratospheric Air
- Modification of tropospheric and stratospheric water vapor, impact on ozone via HO_x
- Precipitation Scavenging and Anvil Settling
- Lightning NO_x
- Photolysis Rates
- Other Effects (e.g., reactions in droplets and on ice)

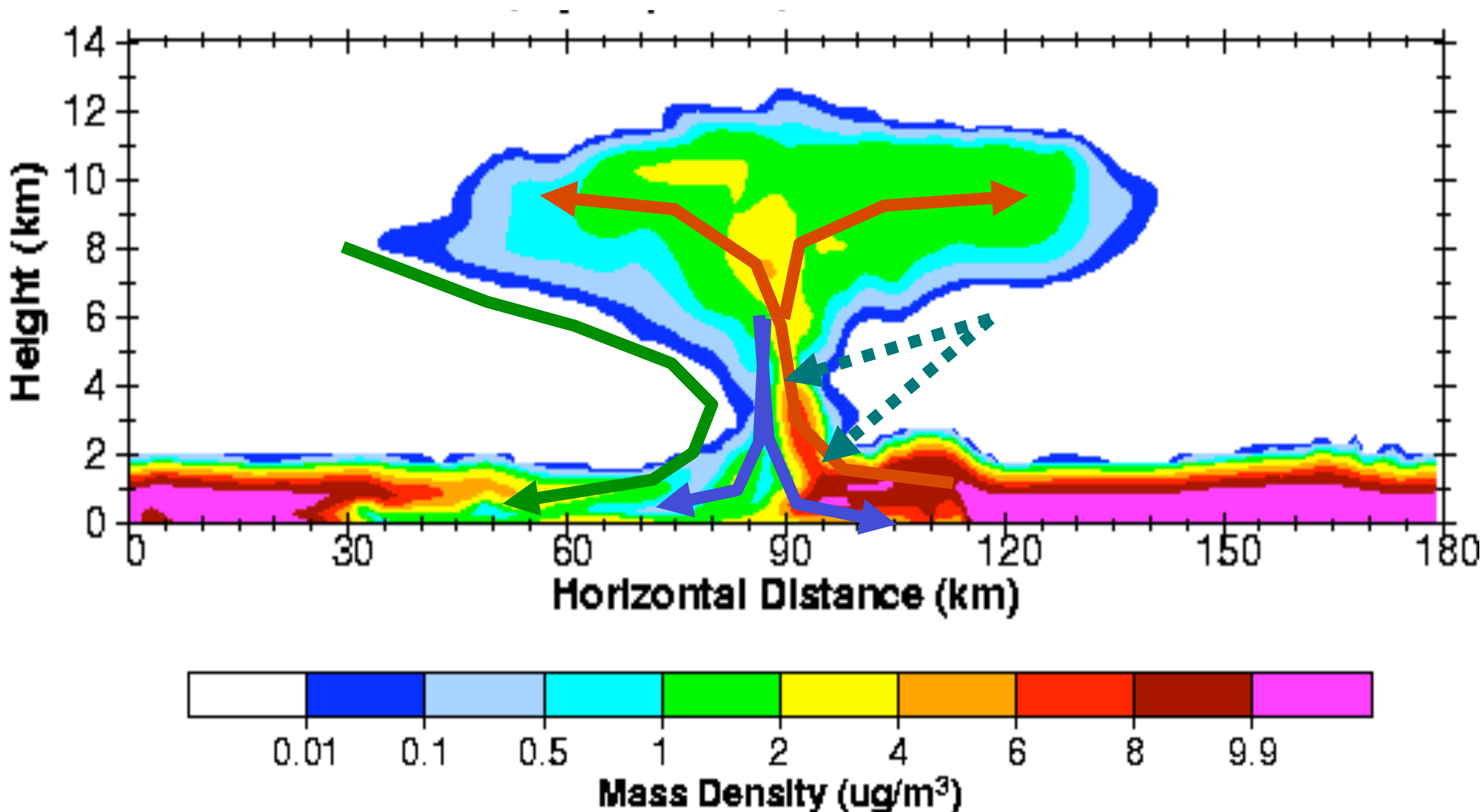
Modelling Tools

- EMAC - ECHAM5/MESSy Atmospheric Chemistry Model
  - EC-Hamburg v5 / Modular Earth Submodel System (currently v1.6)
  - Global coupled atmospheric chemistry-climate model
  - First major evaluation (gas phase) published in Jöckel et al. (ACP, 2006), aerosols under evaluation
  - Extensive chemistry, gas and aerosol, troposphere and stratosphere, many new parameterizations

- MATCH-MPIC - *Model of Atmospheric Transport and Chemistry*
  - Global „Offline" Model (simulations driven by NCEP reanalysis and GFS analysis)
  - Chemical weather forecasting (tropospheric O_3 chemistry, Lawrence et al., 2003), plus regional CO tracers

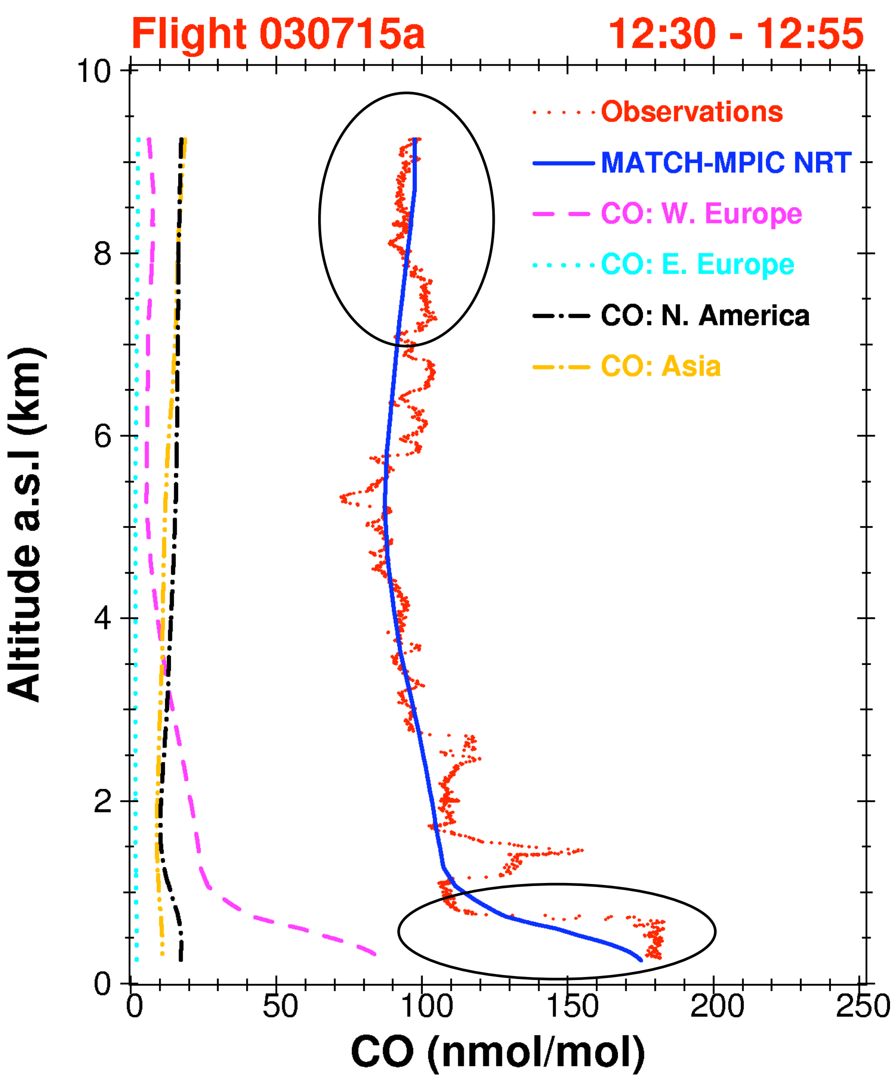
- WRF CSRMC - *Weather Research and Forecast Cloud System Resolving Model w/ Chemistry*
  - Cloud system resolving or regional model (successor to MM5)
  - Tropospheric chemistry module (KPP, based on MATCH-MPIC) now in WRF CHEM
  - Semi-explicit scavenging, gases transported diagnostically in hydrometeors
  - Multi-day simulations of tracers and chemistry (Salzmann et al., 2004, 2007, 2008)

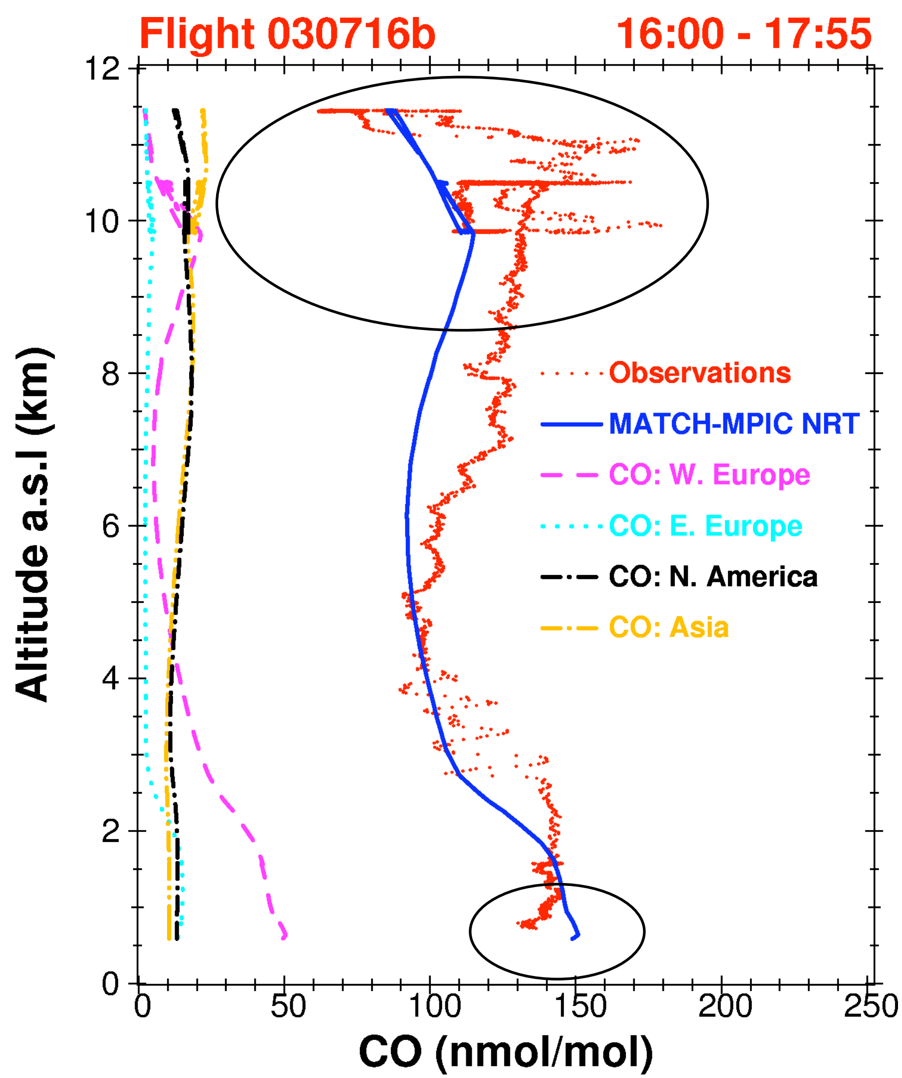
Deep convective transport components: Idealized squall line simulation



- Simulated with WRF
- Initialization:
  - Warm bubble
  - Conditionally instable profile
  - Tracer: 10 $\mu g/m^3$ below 2 km

Effect of Convective Mixing on CO

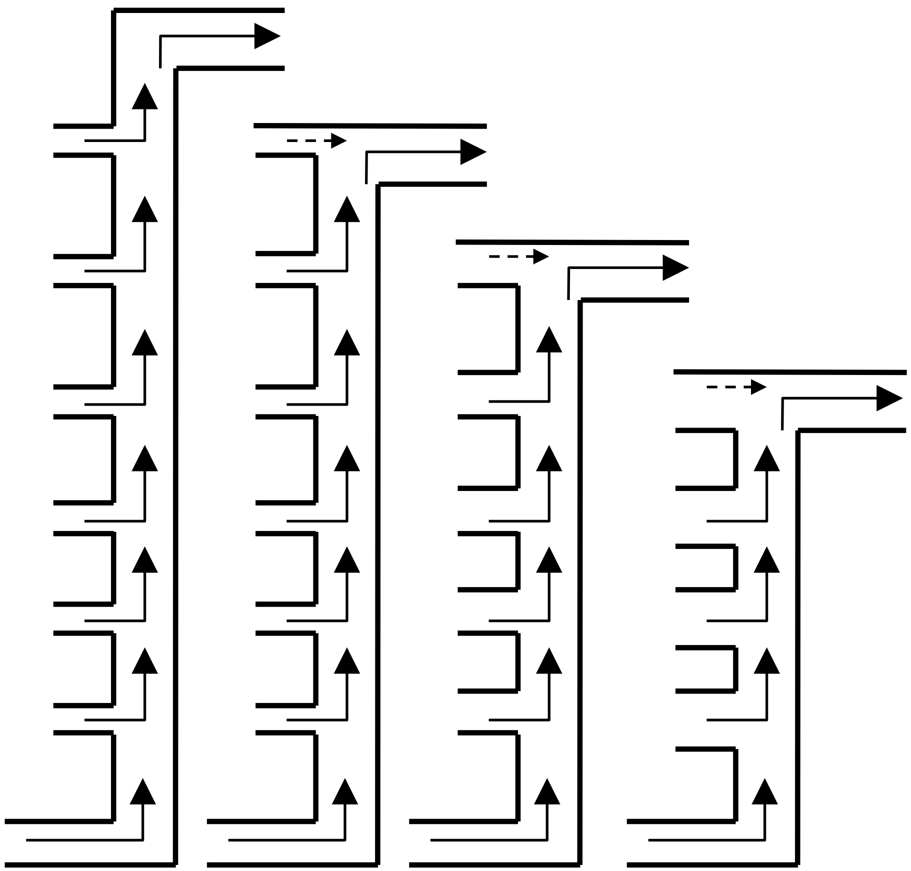




Data from the CONTRACE campaign, Germany, July 2003

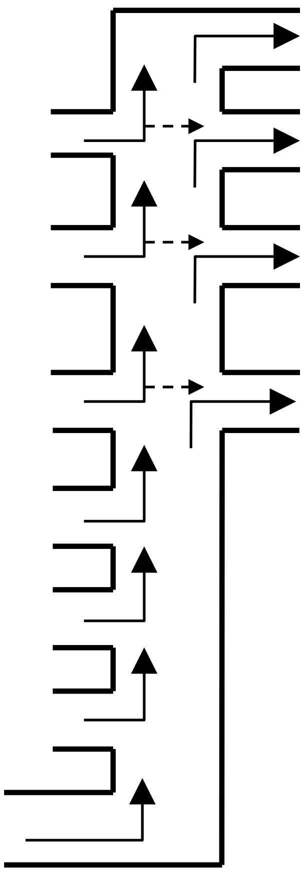
Convective Transport Formulations

Plume Ensemble



Arakawa and Schubert, 1974; Lord et al., 1982; Hack et al., 1984; Grell, 1993

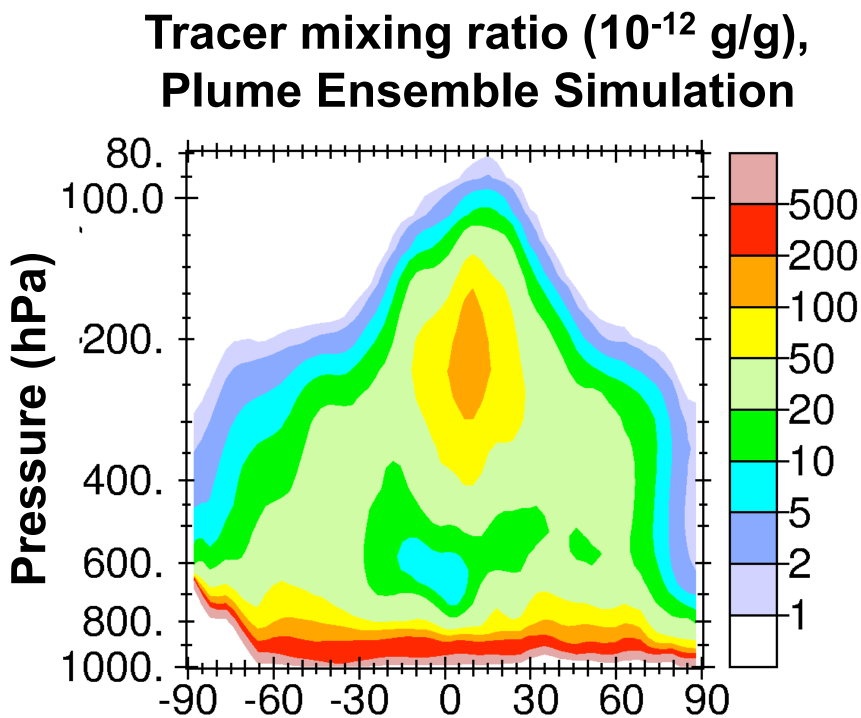
Bulk

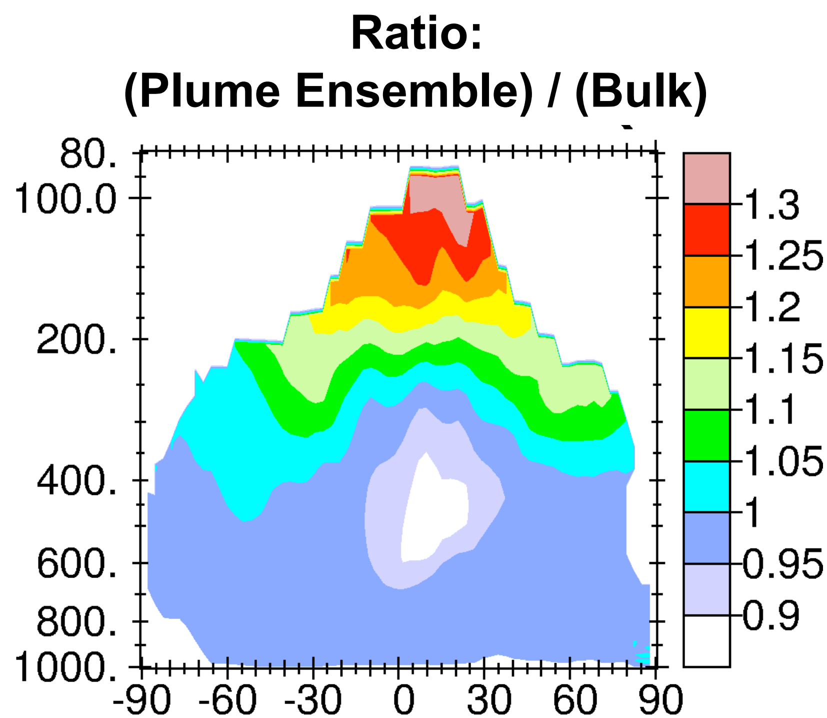


Yanai et al., 1973; Tiedtke, 1989; Grell, 1993; Pan and Wu, 1995; Zhang and McFarlane, 1995

(Lawrence and Rasch, JAS, 2005)

Deep Convective Transport: Effects on Artificial Tracers



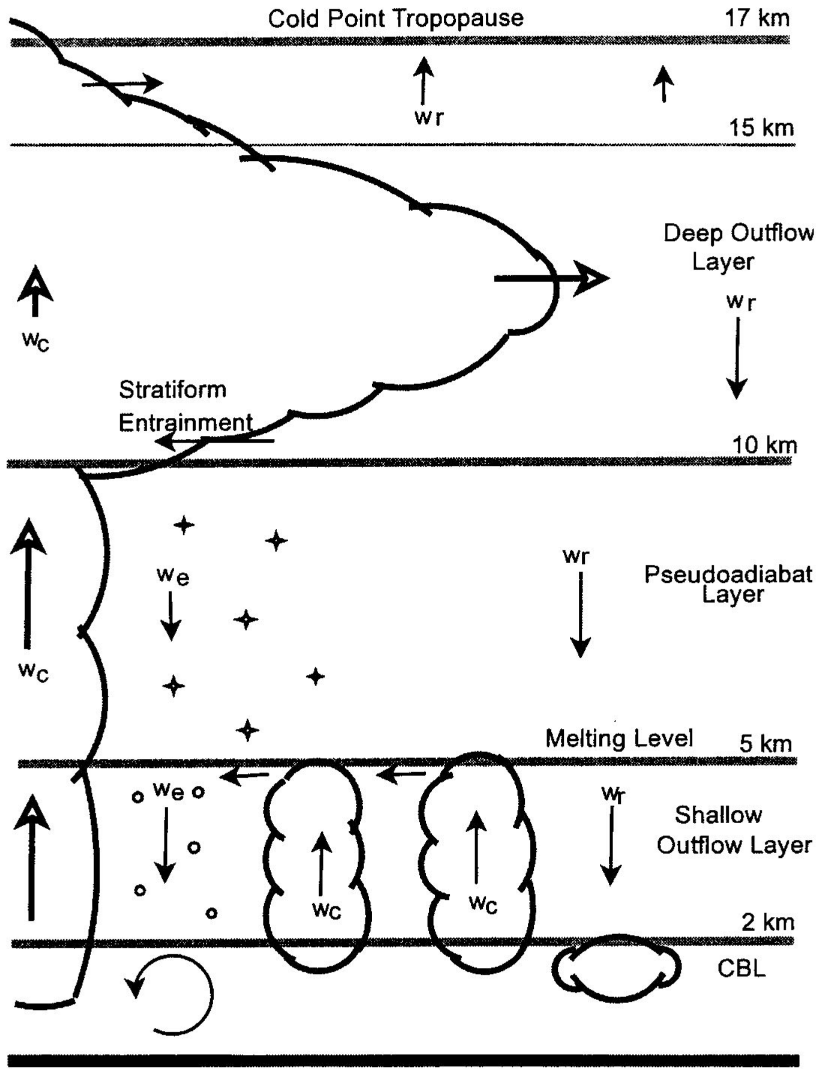


- Simulated with MATCH-MPIC
- Zonal mean, July 2001
- Lifetime: τ = 1 d
- Surface source

- Detrainment especially stronger above ~15 km in the TTL
- Differences small for longer-lived tracers (τ > 10 d)

(Lawrence and Rasch, JAS, 2005)

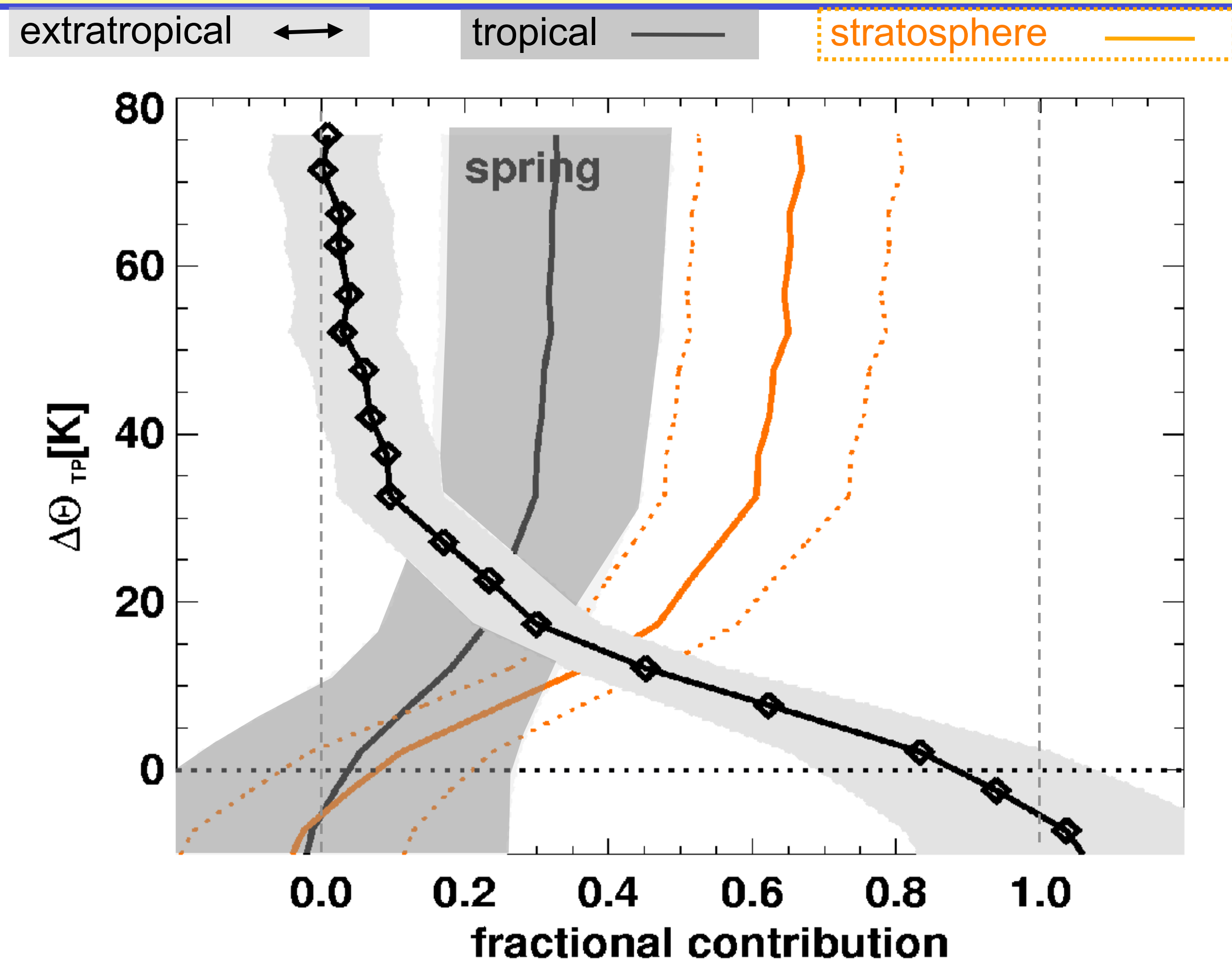
Deep Convection – Outflow in the TTL



Airmasses from convection detraining above the transition from radiative cooling to radiative warming (~15 km) have a much greater chance of being transported into the stratosphere

(Folkins and Martin, JAS, 2005)

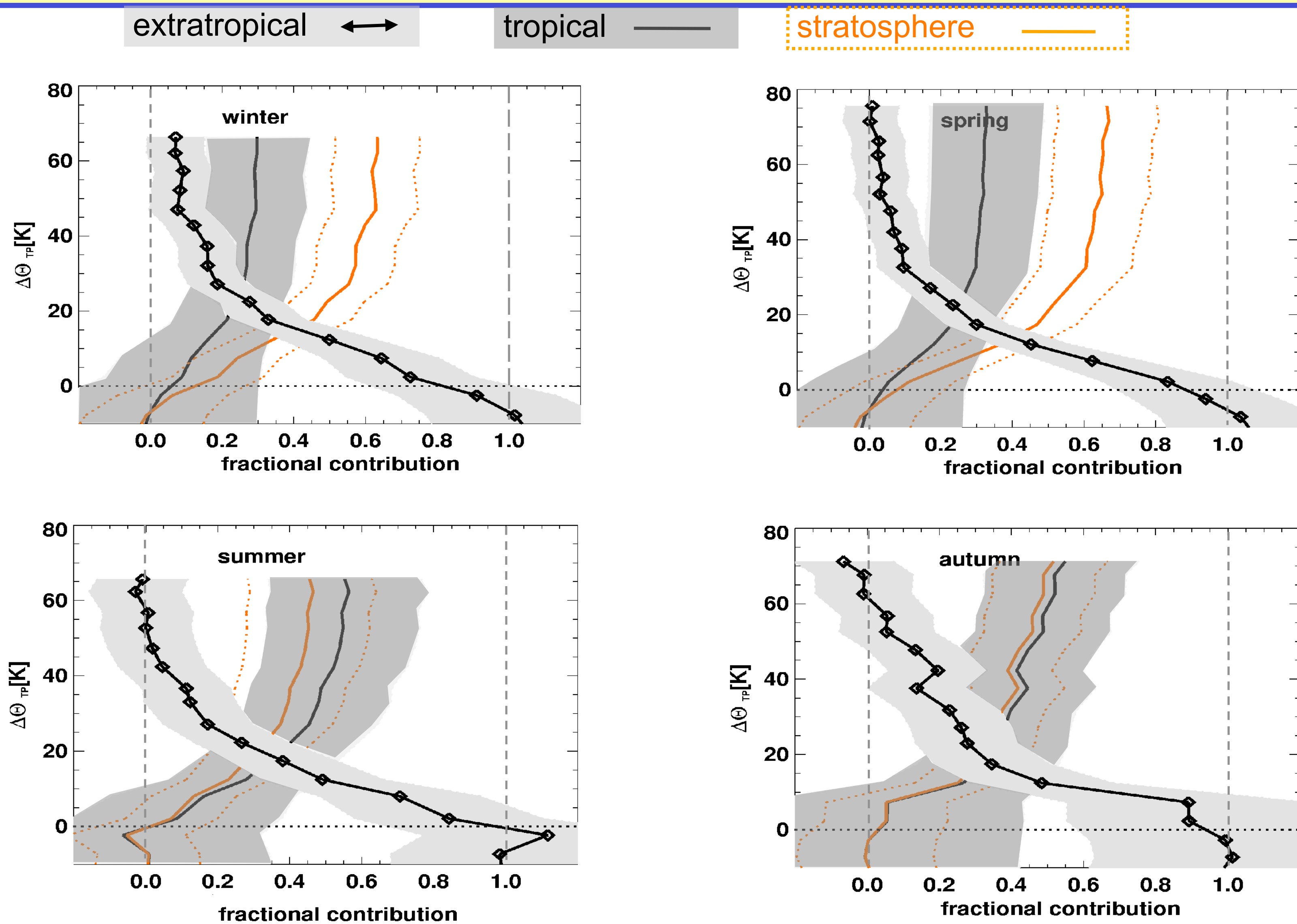
CO-Based Airmass Budgets



fractional contribution of air of different origins to the extratropical lowermost stratosphere

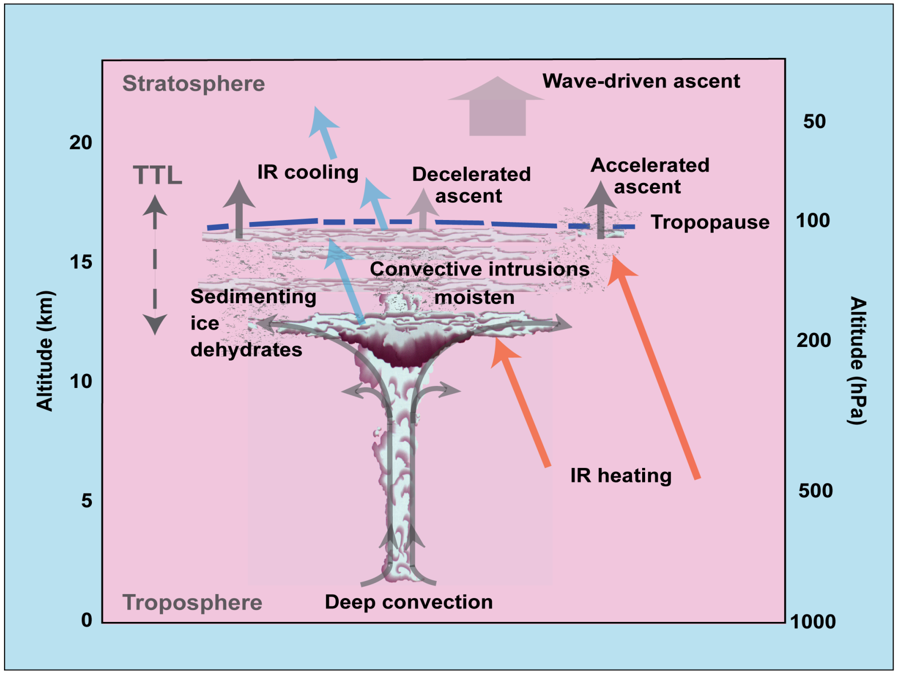
(Hoor et al., GRL, 2005)

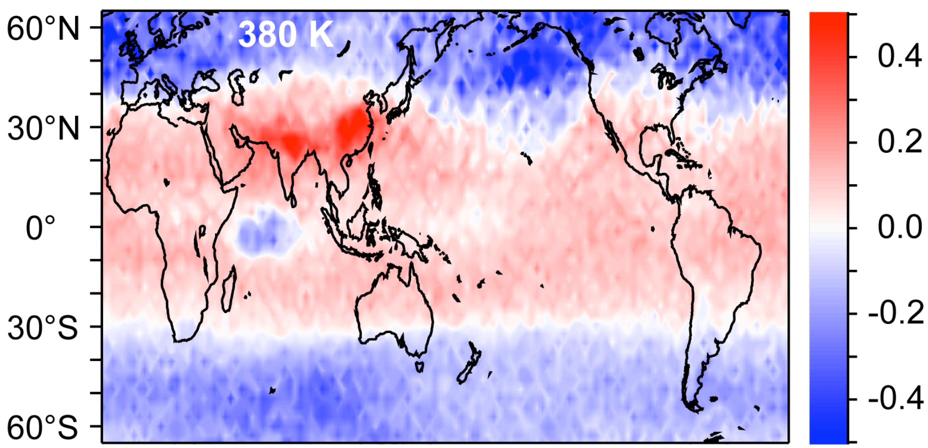
CO-Based Airmass Budgets



(Hoor et al., GRL, 2005)

Stratospheric Water Vapor





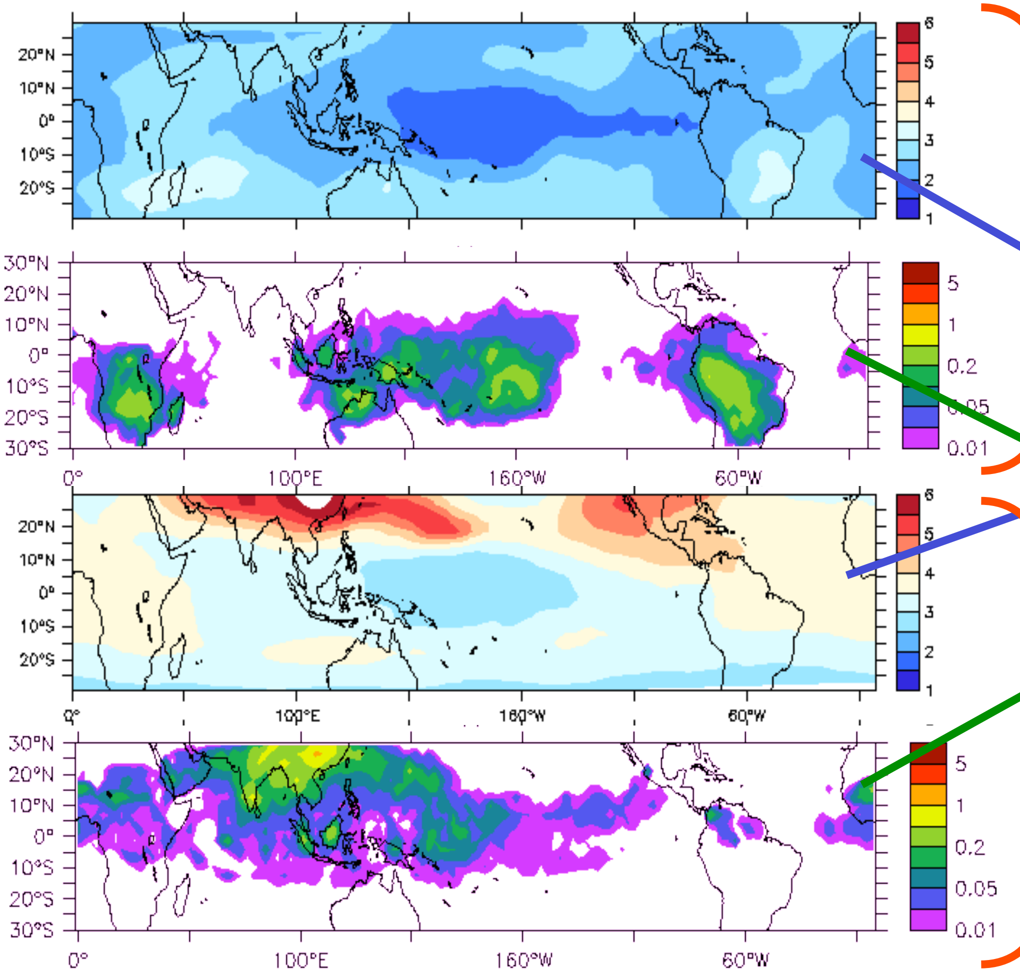
- EMAC simulations consistent with observations (tape recorder, etc.)
- Deep convection moistens the TTL, especially in Asian summer monsoon
- Slow ascent through the tropopause
- Ascent decelerated above Cbs (radiative cooling), accelerated in outflow where anvils have dissipated
- Cirrus desiccate air during ascent by nearly 100x (relative to air mass flux)

Vertical water mass flux (10^{-9} kg m^{-2} s^{-1}), JJA

(Lelieveld et al., ACP, 2007)

Stratospheric Water Vapor

- New 40-year simulation with EMAC, effects of ENSO, Volcanoes, etc.



Dehydration over Pacific in winter (DJF, 1992)

H_2O, ppmv, 97 hPa

Cloud ice, ppmv, 97 hPa

Moistening over S. Asia in summer monsoon (JJA, 1992)

For more, see posters by:
- **Andreas Baumgärtner**
- **Christoph Brühl**

CONVECT Submodel (in EMAC)

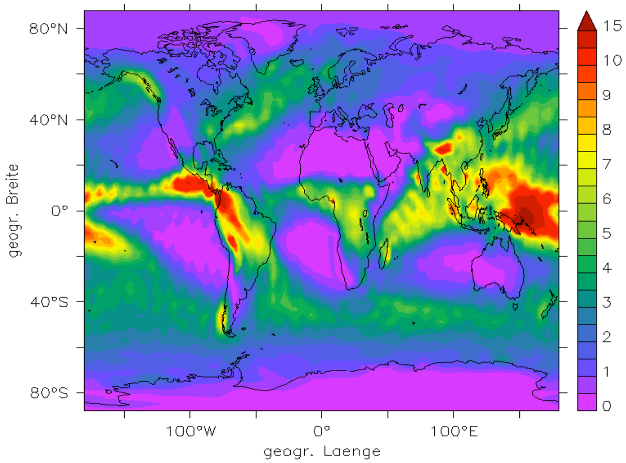
- Tost et al. (ACP, 2006) – different convection parameterisations:
  - Modified Tiedtke (1989) (Nordeng, 1994)
  - ECMWF Tiedkte-scheme (IFS cycle 29r1b, Tompkins et al., 2004)
  - Zhang-McFarlane (1995) + Hack (1994), including precipitation evaporation extension (Wilcox, 2003; Lang and Lawrence, 2005)
  - Bechtold-scheme (2001)
  - Emanuel and Zivkovic-Rothman (1999)
  - Others in progress

- Mostly based on the mass flux approach (Arakawa and Schubert, 1974)

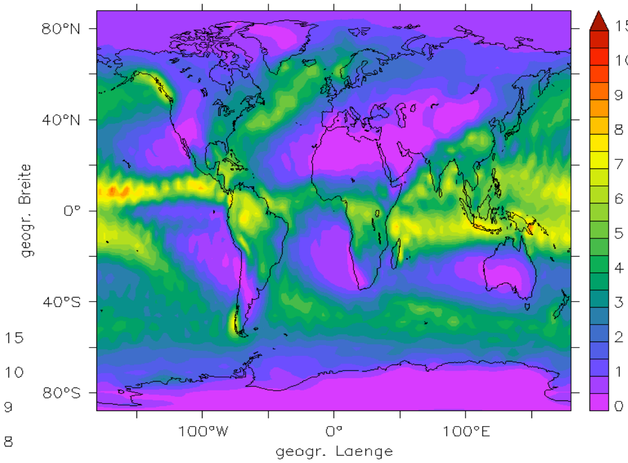
- Differences:
  - trigger criterion, closure, entrainment formulation, microphysics, programming style and efficiency......

(Tost et al., ACP, 2006)

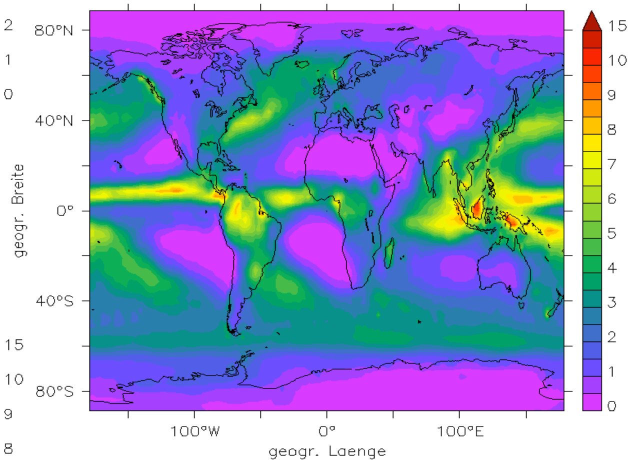
Precipitation Distribution



Tiedtke - Nordeng

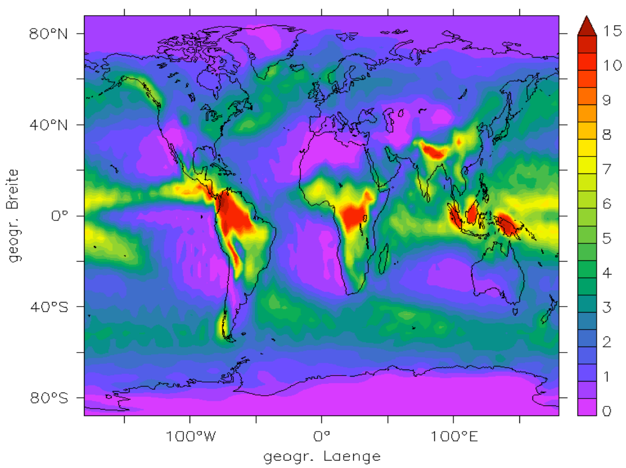


ECMWF

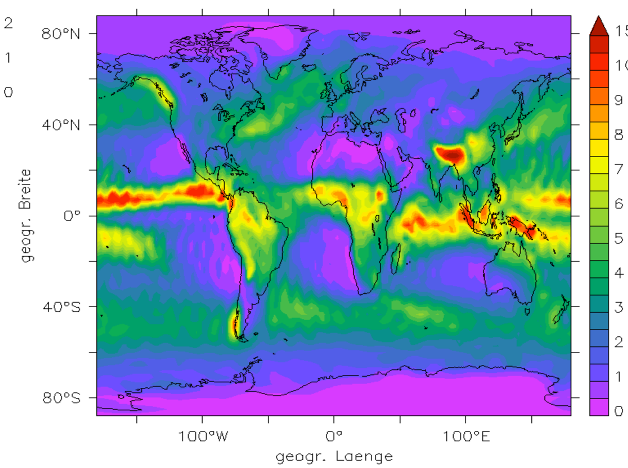


GPCP (Observations)

Zhang – McFarlane – Hack



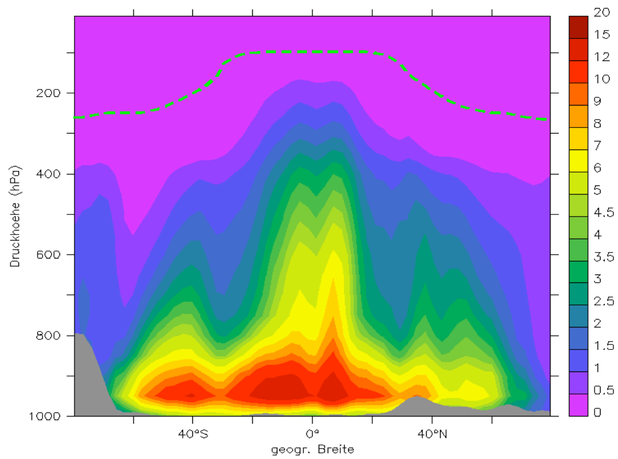
Bechtold



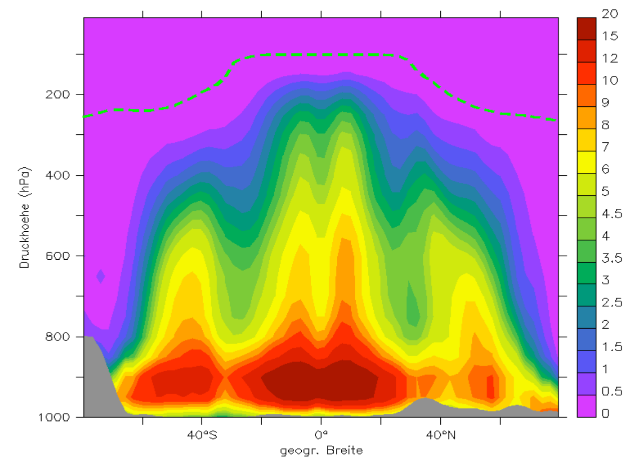
(Tost et al., ACP, 2006)

Convective Massfluxes

MAX-PLANCK-GESELLSCHAFT



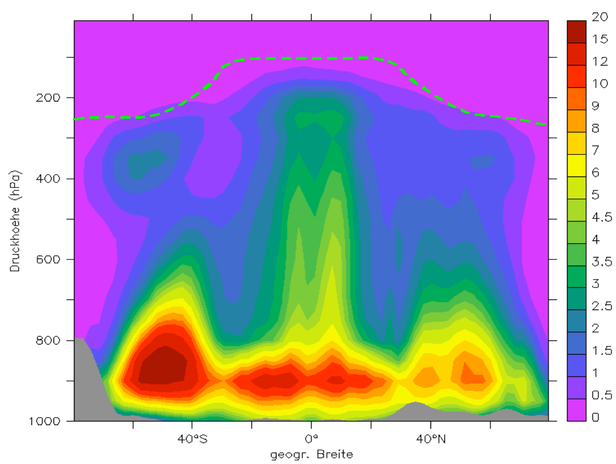
Tiedtke – Nordeng



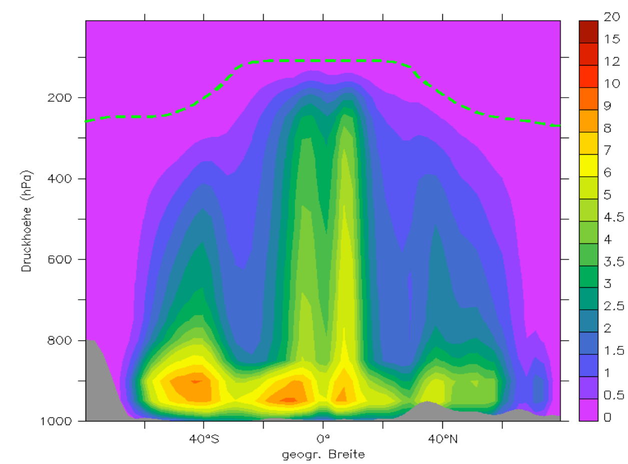
ECMWF

See talk by Holger Tost at IGAC in Annecy for the newest results!

Zhang – McFarlane – Hack

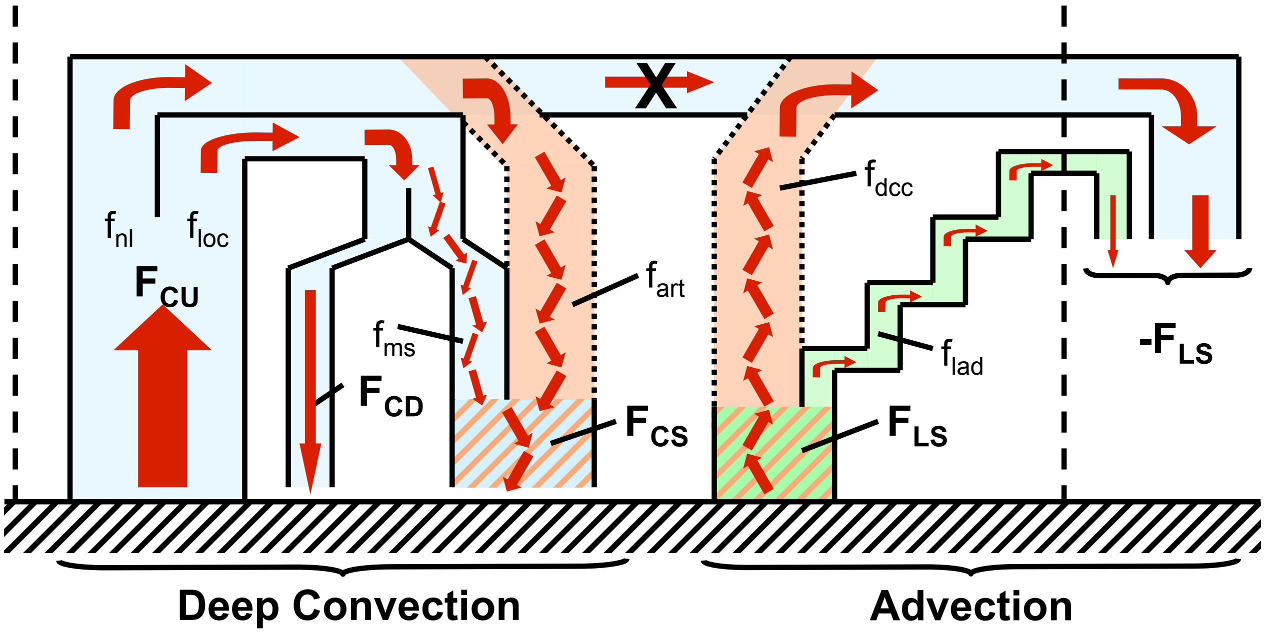


Bechtold



(based on Tost et al., ACP, 2006)

Reinterpreting Studies of Deep Convective Transport Effects on Tropospheric O_3 and Other Tracers



- Simulations with convective transport turned off for various tracers used in several previous studies (e.g., Lelieveld and Crutzen, 1994; Mahowald et al., 1997; Collins et al., 1999; Lawrence et al., 2003; Lintner, 2003; Doherty et al., 2005; Erukhimova and Bowman, 2006)
- Interpretation frequently neglected contribution by "equivalent deep convective mass fluxes" present in vertical velocities used in advection schemes
- Potentially significant underestimates or misrepresentations of effects of convective transport
- Particularly important to consider in designing and interpreting simulations for *AC&C Activity 2*
- Several other implications (e.g., numerical diffusion)

(Lawrence and Salzmann, ACPD, 2008)

Summary/Outlook

- Many different aspects of deep cumulus convection, including effects on chemistry via:
  - Transport
  - Water Vapor
  - Scavenging
  - Multiphase reactions
  - Photolysis
  - Lightning NOx
  - etc.

- Continued use of a combination of tools: global and cloud resolving models

- Synergetic application of models and measurements (*in situ* and satellite)