# A scale and aerosol aware stochastic convective parameterization for weather and air quality modeling

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# Objectives

- Parameterizing Convection with applicability on “Almost” Cloud-Resolving Scales (“Gray Scales”),
- including transport of chemical compounds, wet-deposition, aqueous phase chemistry
- aerosol interactions

# Simple derivation of vertical eddy transport

***assuming***

$$\overline{\psi} = \sigma \psi_c + (1-\sigma)\widetilde{\psi}$$

$$\overline{w} = \sigma w_c + (1-\sigma)\widetilde{w}$$

$$\overline{w\psi} = \sigma w_c \psi_c + (1-\sigma)\widetilde{w}\widetilde{\psi}$$

***One gets***

$$\boxed{\overline{w\psi} - \overline{w}\,\overline{\psi} = \frac{\sigma}{1-\sigma}(w_c - \overline{w})\left(\psi_c - \overline{\psi}\right)}$$

***With $\sigma$<<1 and $w_c$>>$\hat{w}$***

$$\rho\left(\overline{w\psi} - \overline{w}\,\overline{\psi}\right) \approx M_c\left(\psi_c - \overline{\psi}\right)$$

# Obvious problems – from theory

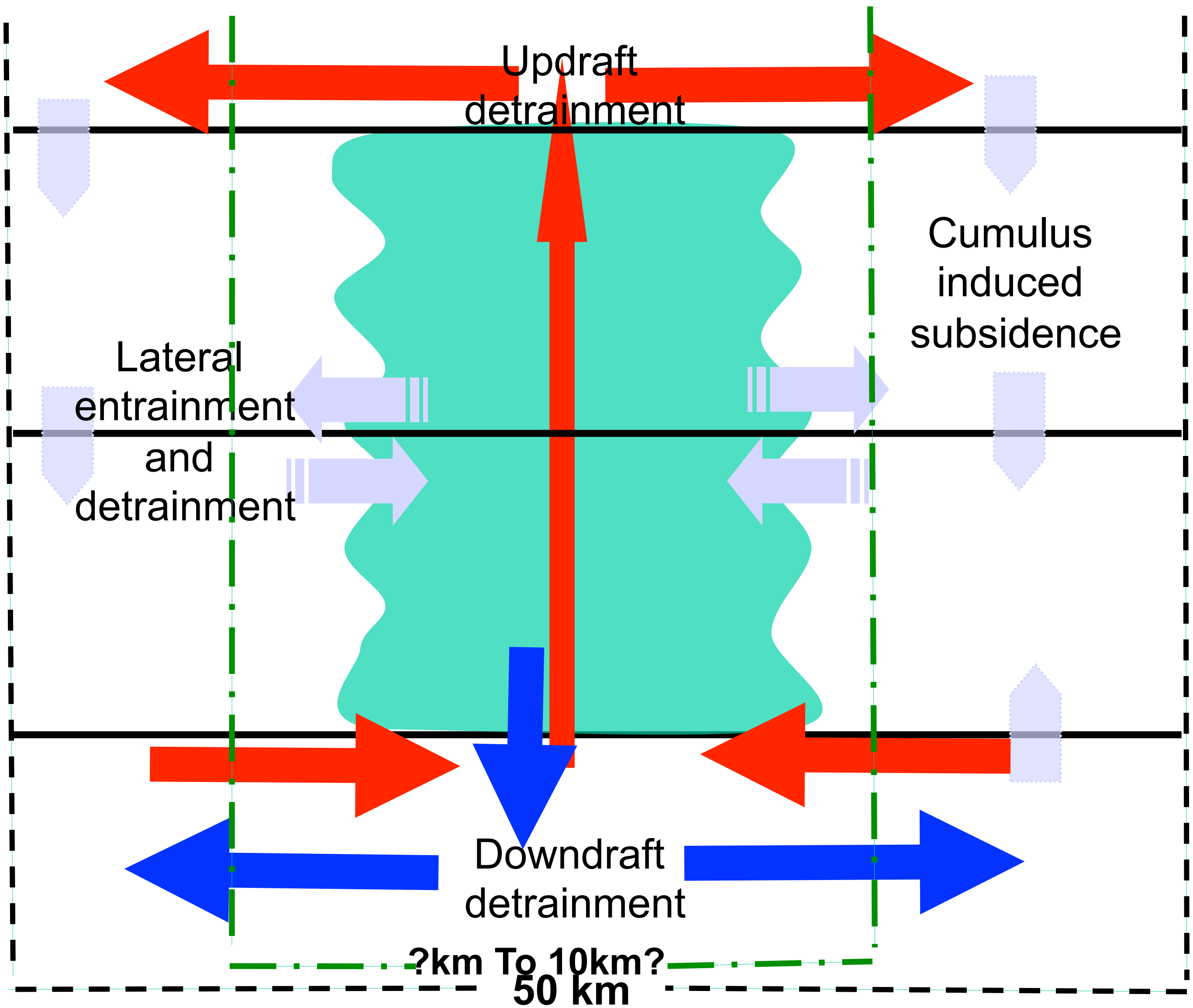
- Vertical eddy flux equations are derived assuming fractional area coverage ($\sigma$) of updraft much smaller than one, and $w_c >> \hat{w}$

# Possible solutions ?

1. Arakawa et al., 2011 simply define a setup that will lead to convergence to an explicit solution and get

$$\overline{w\psi} - \bar{w}\bar{\psi} = (1-\sigma)^2(\overline{w\psi} - \bar{w}\bar{\psi})_{adj}$$

# Take 2 derives from simplified conceptual picture of statistically averaged convective cloud



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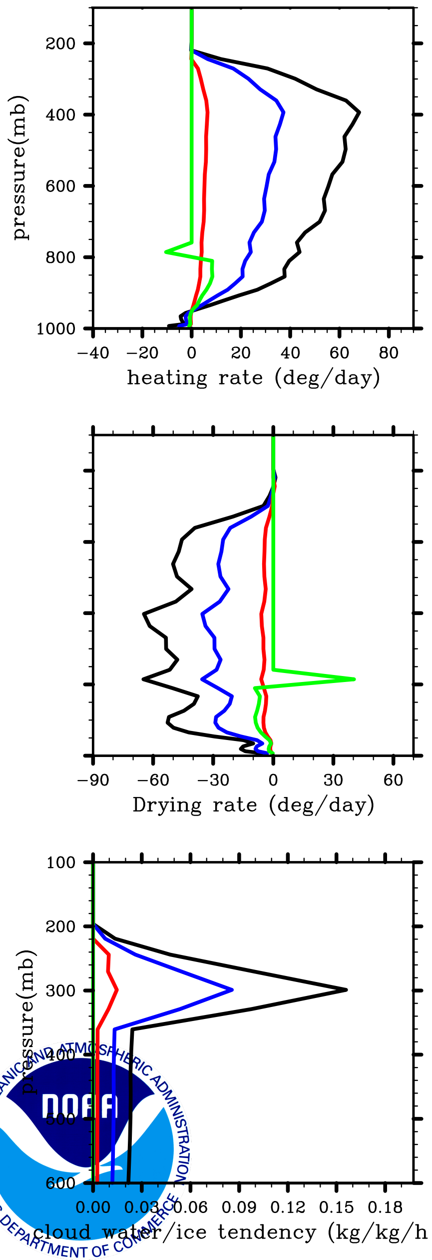
2. Spreading of subsidence? This is equivalent to applying the parameterization over a larger area – G3, cu_phys=5
3. Letting the model do the subsidence? What then is the understanding of "vertical eddy fluxes" ?

# Our adaptation of Arakawa's approach

1. We define $\sigma$ not as the cloudy area, but as the area covered by active updraft and downdraft plume
2. We then define a very simple relation ship between $\sigma$ and entrainment rate (which is related to radius of plume)
3. The initial entrainment rate determines when $\sigma$ is becoming important (when scale awareness kicks in), the maximum allowable fractional coverage determines when the scheme transforms itself to a shallow convection parameterization

# First test: 1-d, single sounding: effect of assumed resolution on vertical profiles of heating, drying, cloud water and ice tendency, and rainwater distribution in cloud




**Scale awareness chosen to start at dx=25km, transforming to shallow convection becomes important at dx < 4km (but dependent on environmental conditions)**

Different approaches to parameterize the cloud fraction may be used, the most simple worked best for us: entrainment relation ship for plumes

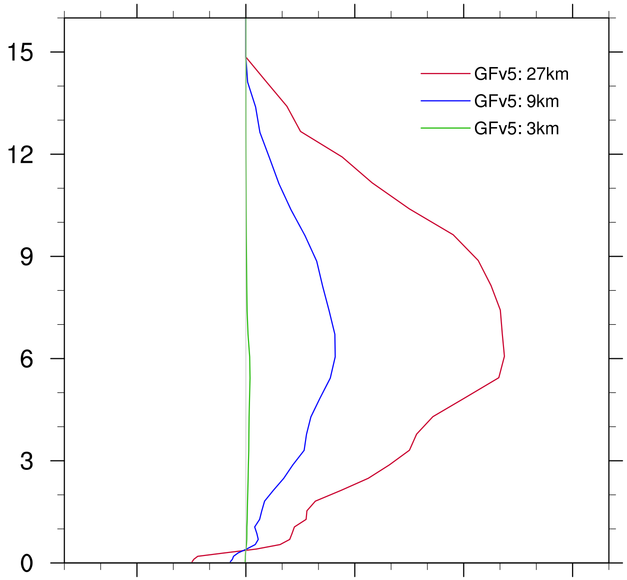
dx = 30 km

dx = 10 km

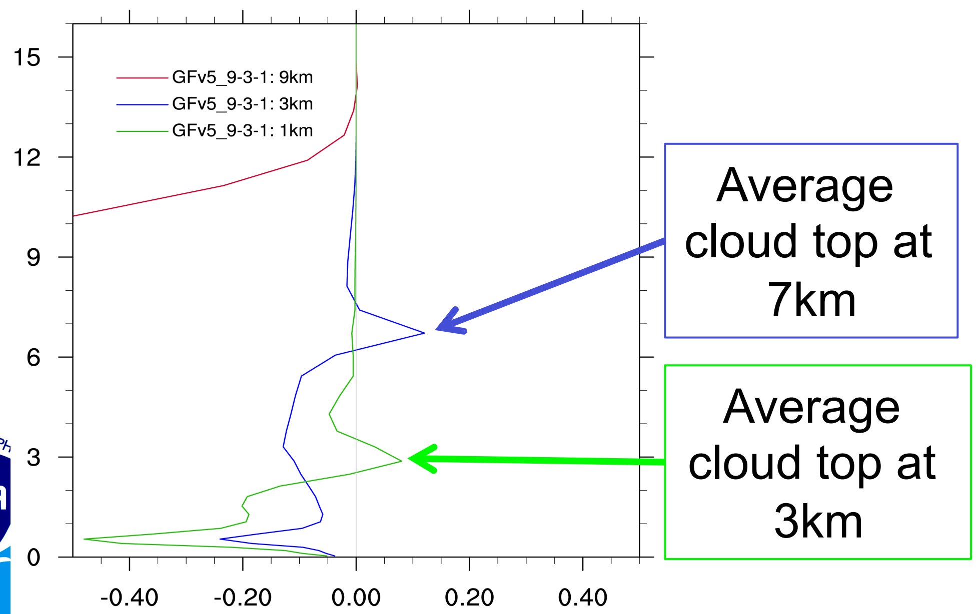
dx = 3 km

dx = 1 km

# From a poster by E. Grell




Heating profiles from convective parameterization for idealized tropical cyclone simulations at 27km, 9km, and 3km




Drying profiles from convective parameterization for idealized tropical cyclone simulations at 3km and 1km (!) resolution

# Scale awareness tests

- Paper by Grell and Freitas to be submitted very soon – application with BRAMS over South America, dx=5km, comparing different approaches
- Paper by E.Grell et al on tropical cyclone simulation using WRF – near future
- Hopefully a detailed WRF evaluation using RAP and/or HRRR will follow in more distant future

# GF versus G3 and GD: Main differences for the meteorological part

- Made GF simpler and faster:
  - G3 is used operational at NCEP (in RAP modeling system) and at CPTEC in Brazil (5km resolution)
  - In GF: only use forcing ensembles (stability equilibrium, stability removal, low level vertical velocity, integrated moisture convergence)
- Can use random number generator to perturb ensembles or stochastic field provided by WRF to perturb ensembles or fields that forcing depends on
- Entrainment rates have been adjusted to give smooth normalized mass flux profiles (parabolic start-up and end, instead of going from zero to one or one to zero.
- Add a depending on surface heat and moisture fluxes, similar to the method described in Jakob and Siebesma (2003)

# Aerosol interactions

# Step 1: Change constant autoconversion rate to aerosol (CCN) dependent Berry conversion

In G3 parameterization autoconversion from cloud water to rain is constant: $c_0$=.002

In GF, the equations for conversion of cloud water to rain water are re-derived using the Berry formulation:

$$\left(\frac{\partial r_{rain}}{\partial t}\right)_{\substack{\text{autoconversion}\\\text{Berry, 1968}}} = \frac{\left(\rho r_c\right)^2}{60\left(5+\dfrac{0.0366\ CCN}{\rho r_c m}\right)}$$

**50 km**

# Step 2: Increase evaporation in dependence of CCN: Smaller droplets evaporate more efficiently

- Including only the Berry auto conversion in G3 is not sufficient: Resulting changes in precipitation predictions are dependent on CCN in a very simple way
- In real life, aerosol effects on convection are very complex and non linear
- Smaller droplets may lead to an increase in evaporation, which in turn may lead to stronger downdrafts
- Stronger downdraft may in fact strengthen convection, increasing precipitation

**Strong dependence of impact on sub-cloud humidity as well as wind shear**

# Aerosol dependent evaporation

- Based on discussions with Graham Feingold and a paper by Jiang et al (2010), making the precipitation efficiency (PE) dependent on CCN

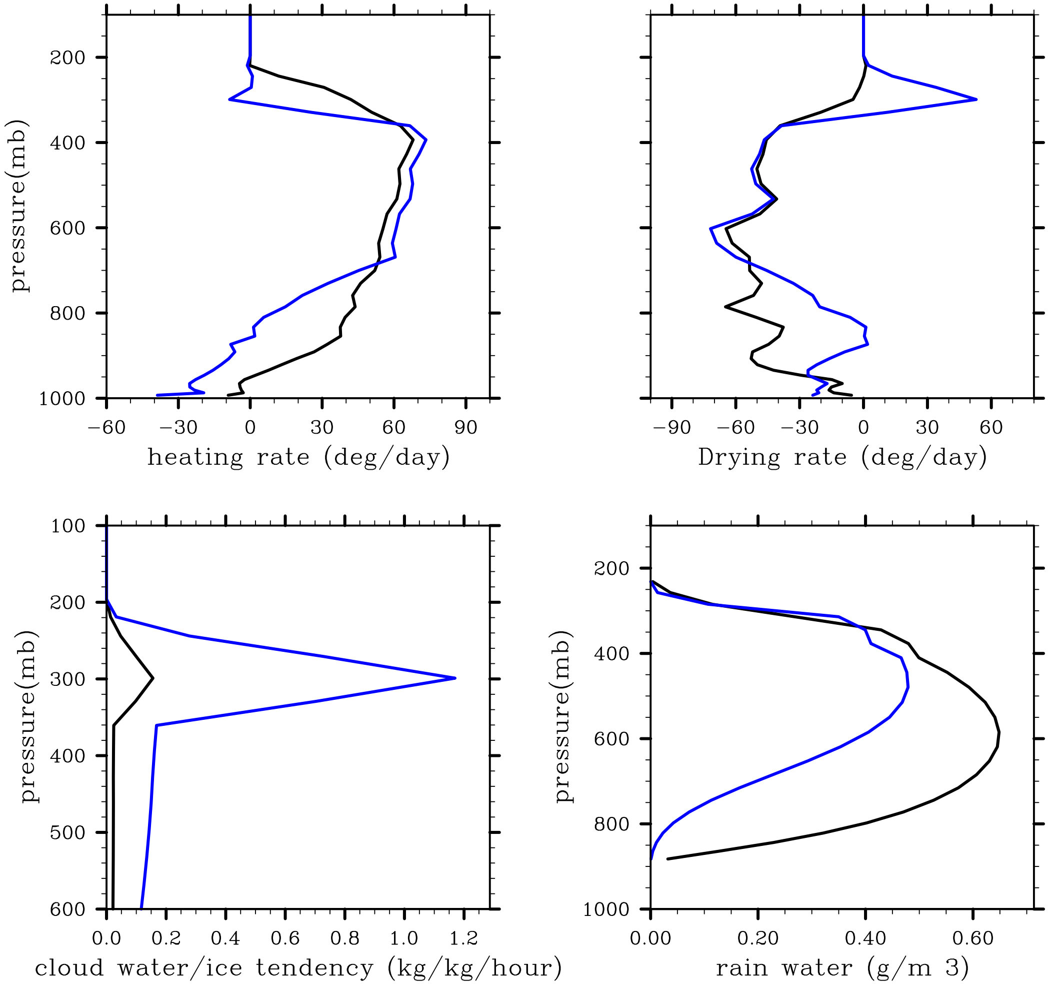
$$PE \sim (I_1)^{\alpha_s - 1}(CCN)^{\zeta} = C_{pr}(I_1)^{\alpha_s - 1}(CCN)^{\zeta},$$

Where for our parameterization $\alpha_s$ and $\zeta$ are empirical constants and $C_{pr}$ is a constant of proportionality

# First a 1-d test for a tropical sounding. Combined effects on vertical profiles of heating, drying, cloud and rainwater

Autoconversion and evaporation**, polluted**

Autoconversion and evaporation, **clean**



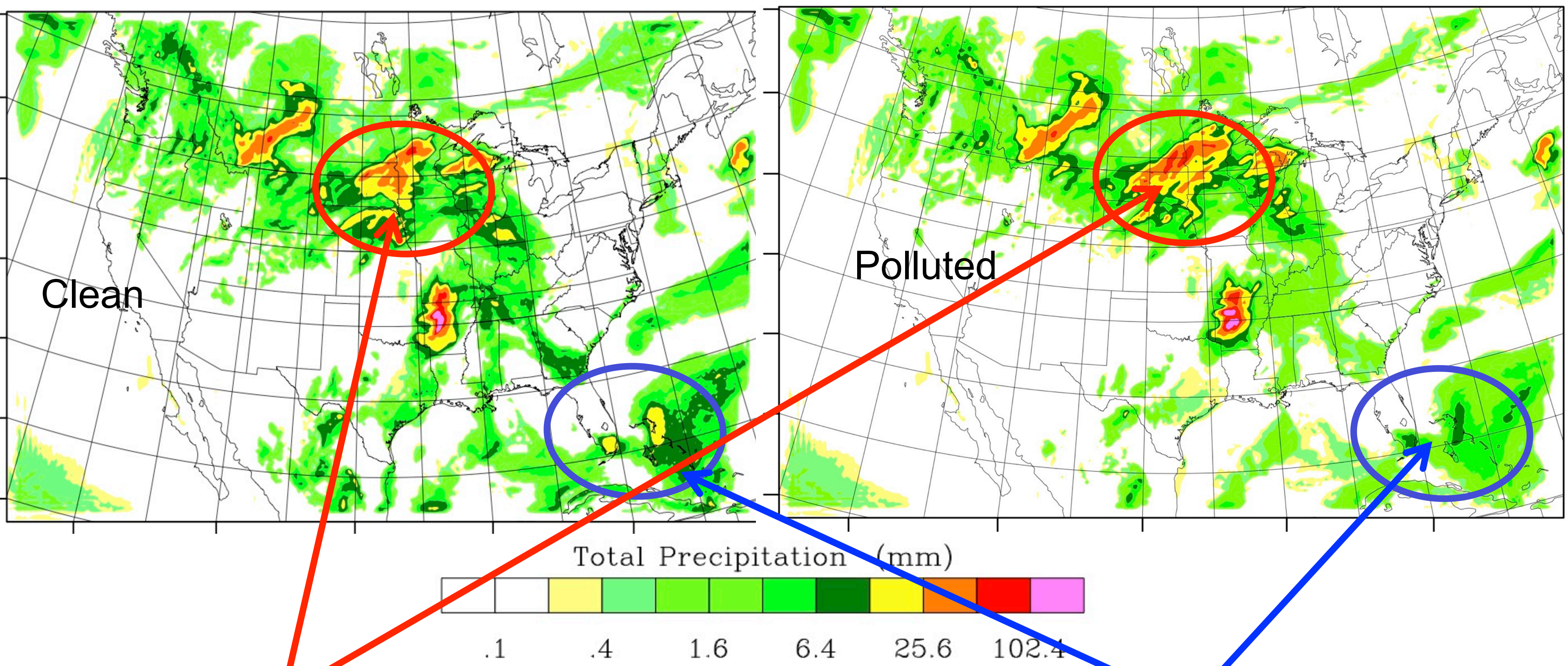
# 1-d test for a tropical sounding

For 1-d tests results are plausible.

- In a polluted environment there is less precipitation (as in Step 1),
- more detrainment of cloudwater/ice at the umbrella,
- but also more evaporation which may lead to stronger downdrafts

**How will stronger downdrafts effect a 3-d simulation? Use WRF-Chem to see what happens**

# WRF simulations, 24hr total precipitation, clean ($CCN = 50\ cm^{-3}$) and polluted ($CCN = 1500 cm^{-3}$)



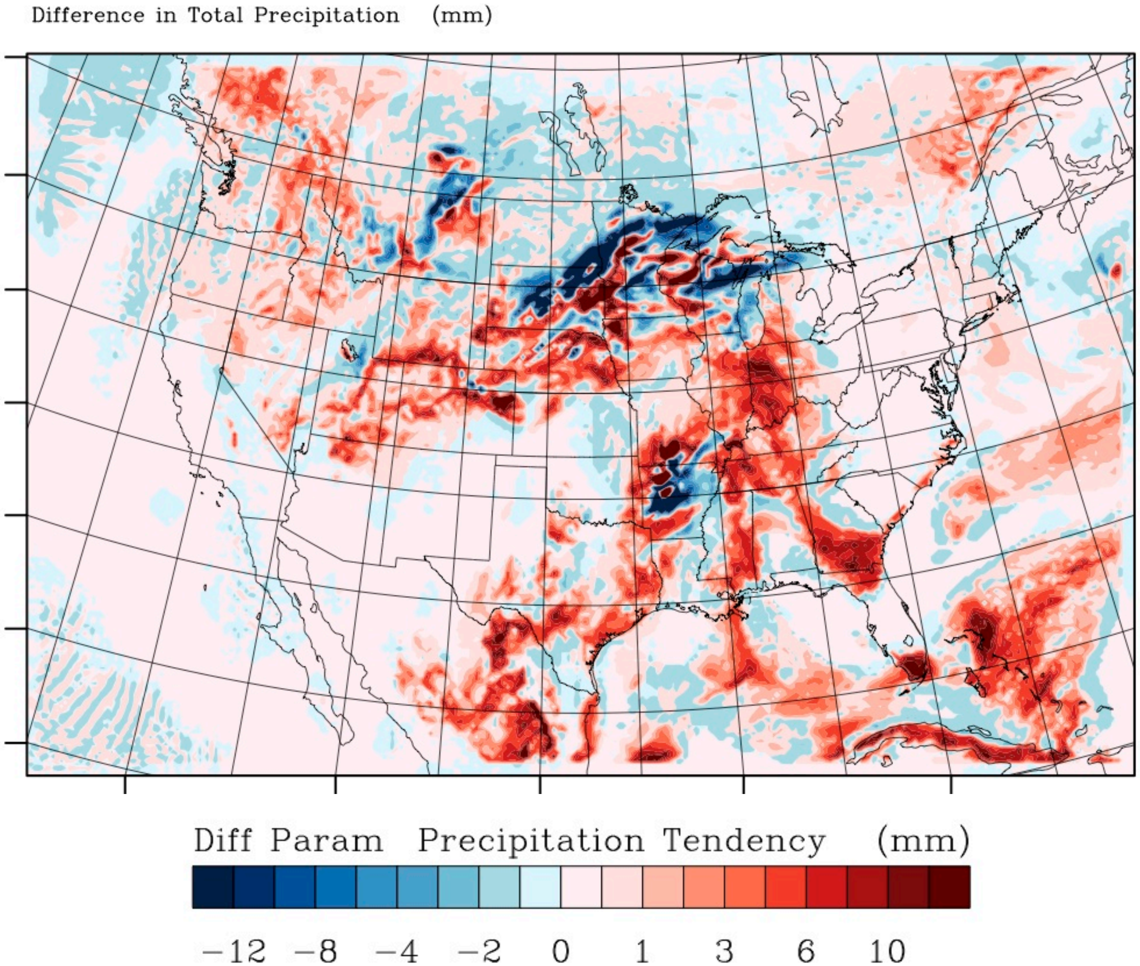

More precipitation when polluted

Dx=20 km

Less precipitation when polluted

# WRF simulations, difference fields of accumulated total and parameterized precipitation (clean – polluted)

Parameterized + resolved




Dx=20 km

# Conclusions

- We are satisfied with the scale awareness results

- As implemented, aerosols have significant but plausible effects on how convection will modify the environment. Heavy pollution leads to
  - Less efficient conversion of cloud water to rainwater, resulting in upward shift of rainwater concentrations, and more detrainment of cloud water and ice in upper levels
  - Stronger downdrafts through more efficient evaporation: This results in less heating and drying in lower troposphere
  - Stronger downdrafts may lead to stronger dynamics and more intense convection and rainfall

**However all of this depends on environmental wind shear and sub-cloud humidity**

Thank you!   Questions?