

Parameterizing Convection on “Almost” Cloud-Resolving Scales (“Gray Scales”)

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Structure of talk

1. Part I: Background on gray-scale issues, why is there a problem?
2. Some examples of what might be done
3. Part II: The GD/G3 group of convection parameterizations in WRF

Simple derivation of vertical eddy transport

assuming

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

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

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

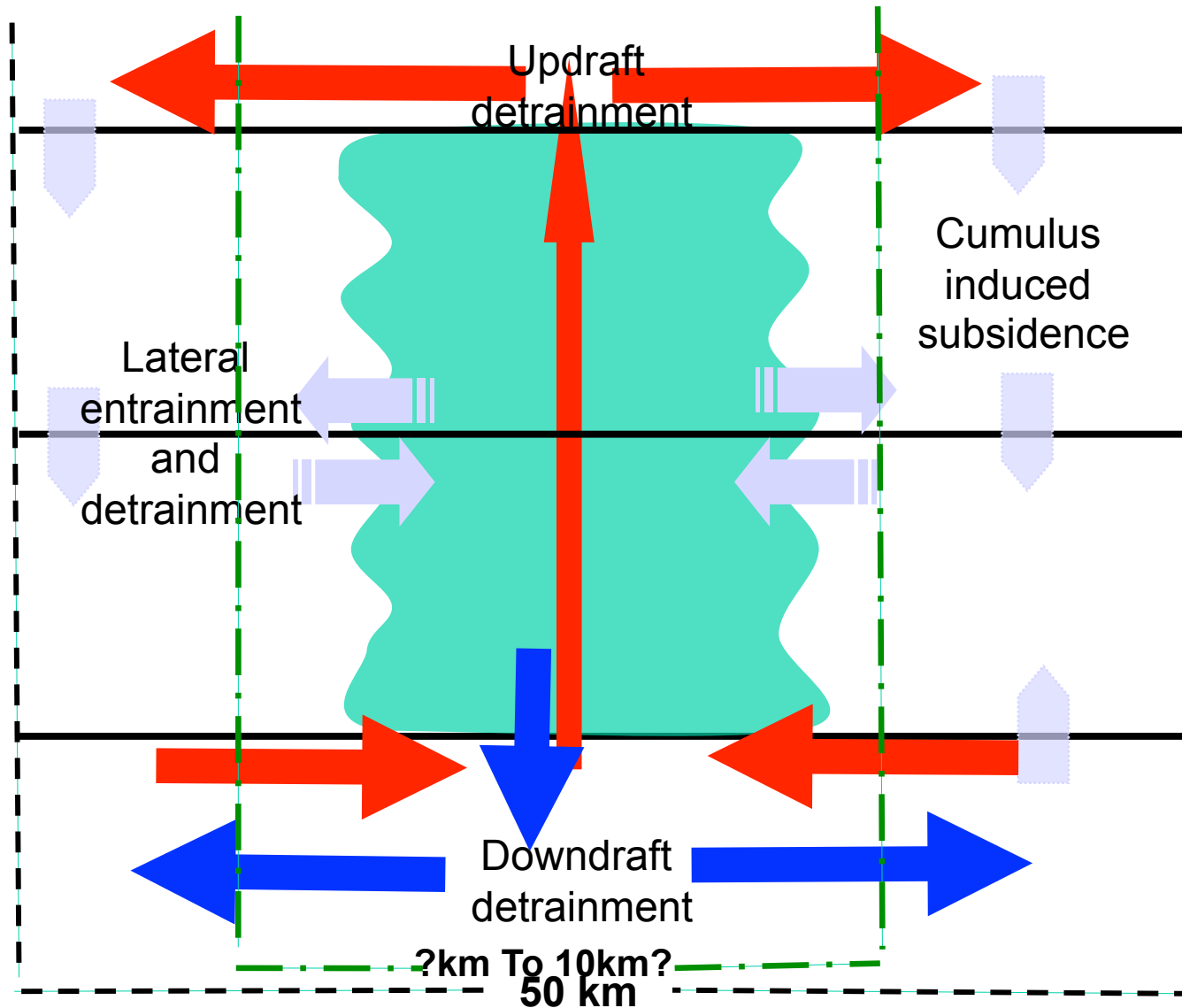
One gets

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

With $\sigma \ll 1$ and $w_c \gg \hat{w}$

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

Figure 1: simplified conceptual picture of statistically averaged convective cloud



Obvious problems – from theory

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

Arakawa et al., 2011: From theory, compensating subsidence is a component of the sub-grid scale eddy, not necessarily the subsidence that we may envision in Figure 1!

Arakawa et al. define σ as the fractional area covered by all convective clouds in the grid cell, Figure 1 defines it as the statistical average of updraft or downdraft core of a cloud of just one particular type

Obvious problems – with respect to the commonly used conceptual picture (Figure 1)

- Mass detrainment at top of cloud and surface (from downdrafts) and compensating subsidence
 - Have by far the strongest effect on the resolved scales
 - Could well be mostly out of the grid box with $dx < 10\text{km}$
- The better the resolution, the worse the assumption that every feedback is within the same grid box

Obvious problems, so what!

**Who cares where the subsidence hits? As long as
we conserve mass....and it rains...
parameterizations are inherently inaccurate
anyway**

Convective parameterizations are being
used without any modifications on gray
scales, because of “better” results (see also
Hong and Dudhia, 2012, BMS)

Obvious problems: What happens physically in the model simulations

- Subsidence has strong heating and drying effect
- May keep the explicit scheme from becoming active
- Strong diffusive effect, flow will become too viscous for model to simulate the dynamics of explicit convection that may be resolvable (this “viscous” effect has also been found by other scientists in PBL/LES applications)
 - Squall-lines or MCC’s may be an example
 - Another problem – probably caused by the oversimplified conceptual picture - that is sometimes observed:
Parameterized convection may be stuck over area of forcing (such as mountains), may not move with flow as dynamically simulated convection would

So why not just forget about convective parameterization on gray scales all together?

Common problems if no convective parameterization is used

Convection spans many scales, a Δx of 4km for example would give an effective resolution of $> 20\text{km}$, not good enough for explicit simulation

- With no convective parameterization, convection may take too long to develop
- Once it develops it may be too strong
- For operational forecasting, results are quite often worse if no convective parameterization is used (see also Hong and Dudhia, 2012)

What should we do when running WRF for applications that reach to cloud resolving scales?

- To understand physical processes with very strong relation to convection, we should stay away from convective parameterizations, and adjust resolution so the simulated process is fully resolved ($dx \leq 1\text{km}$)
 - Example: MCC's, squall-lines, hurricanes

Bryan et al. 2003, MWR, $O(100\text{m})$ for some systems?

What should we do when running WRF for applications that reach to cloud resolving scales?

- For long term regional climate runs and/or for operational forecasting
 - Although it would also be the best choice to fully resolve convection, it is usually not feasible (operational forecasts much beyond 6hr may require an ensemble of CR runs)
 - Using gray scales, results may be better with convective parameterization (do “better” results justify everything?)
 - Try using schemes that are available in WRF, but keep the limitations (gray scales and figure 1) in mind
 - You could use your knowledge to modify or tune some of the ensembles from G3

If nothing helps you could develop and/or implement a new approach

Some attempts to address these problems with modifications in parameterizations

1. UKMET office in 80's attempt to let the convective parameterization only do transport of mass – so no compensating subsidence – no known publication
2. Kuell and Bott (2007, QJRM) – as in (1) but claim success.
 - (1) and (2) can only be done in non-hydrostatic models, (2) exists in a version of the operational model that is used by the German weather service
3. Super parameterization approach (Grabowski and Smolarkiewicz 1999 and/or Randall et al 2003,...) – using a 2d CRM inside the non cloud resolving model
4. Gerard et al (2009, MWR) –prognostic equations for σ and w_c (maybe a very simplified version of (3))
5. Arakawa et al 2011 by relaxing the σ requirement and defining a relaxed adjustment
6. In WRF: G3D scheme: towards (1) or (2)
*(1), (2), and now and future (6) may be in contrast to (5) – may not be consistent with the derived eddy flux equations, but purely based on the conceptual ideas from Figure 1 – so far (5) is the only one offering a smooth transition.
(2) ?, (4), and (6) are used operationally, maybe in the future we can combine (5) with (2) and (6)*

Part II: The GD and G3 ensemble schemes

(ensemble not in the sense of Arakawa-Schubert scheme, but more in the sense of stochasticism)

- This stochasticism in GD and G3 is introduced through varying closure assumptions, feedback assumptions, or trigger functions used by various convective parameterizations
 - These ensembles of assumptions can also be weighted
 - The weighting can also be used to make the transition to CR scales smooth
- In G3 the meteorological input to the parameterization may also be stochastically varied

“Closures” within GD (assumptions that regulate the amount and location of parameterized convection)

- Integrated vertical advection of moisture (Krishnamurthi)
- Low level vertical velocity (Brown or Frank and Cohen)
- Removal of instantaneous stability (like KF)
- Dependence on destabilization (old MM5 Grell)
- Dependence on destabilization (as in SAS or NSAS of GFS)

Possible perturbations of feedback assumptions

1. Radius (size) of clouds, entrainment
2. Detrainment from updraft (stability dependent)
3. Wind shear dependent precipitation efficiency (dependence of downdraft strength on updraft strength)

Because of expense not turned on in WRF release version of scheme

(1) And (2) may be much more important than we originally thought, especially on gray scales – may find their way back into G3

Improvements of capabilities in G3 versus GD

- Remove AS closure (SAS GFS)
- Add an ensemble to look at the min/max/average values of the other ensembles within the nearest neighbor grid points (could be nine or 25 grid points)
- Add a random number generator to arbitrarily pick some ensemble values out of the “pack”
 - Currently not turned on in release version
 - Random number generators that come with compilers
 - Other modeling system that are using G3 (global FIM as well as Brazilian RAMS model) also use arbitrary random modifications

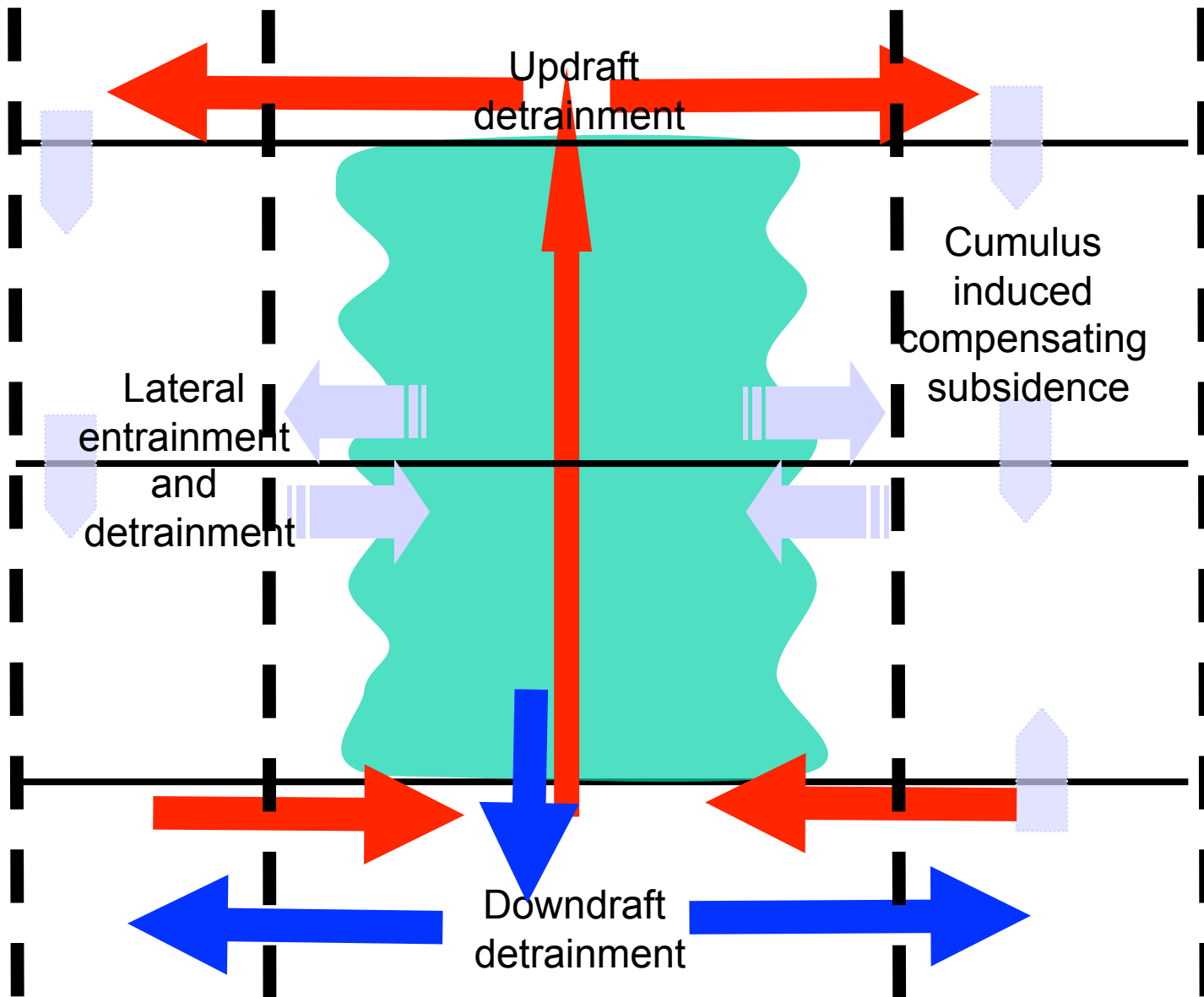
Current development work focuses on G3, no further development on GD!

More changes G3 versus GD

The G3 scheme has additional features that may be turned on or off:

- Horizontal and vertical smoothing of tendencies
- A stochastic approach to shallow convection
- Option for tracer transport and some aqueous phase chemistry and scavenging (currently only in WRF-Chem)
- Direct coupling with atmospheric radiation (and photolysis) through outputting clw/ice mix ratios and cloud fraction (**experimental**, cu_rad_feedback and cu_diag, where cu_diag also provides time-averaged values of clw/ice)
- Aerosol dependence is currently being tested, will be in WRFV3.5

G3d modification for gray scales: nine grid boxes



Subsidence spreading, cugd_avedx=3

- Mass detrainment at top and bottom are also spread over neighboring grid cells
- No preferred directional choice in spreading, all grid points are treated equally
- No other direct dependence of one grid point on another (e.g., subsidence or other terms will not impact unresolved convection through additional forcing/suppression)

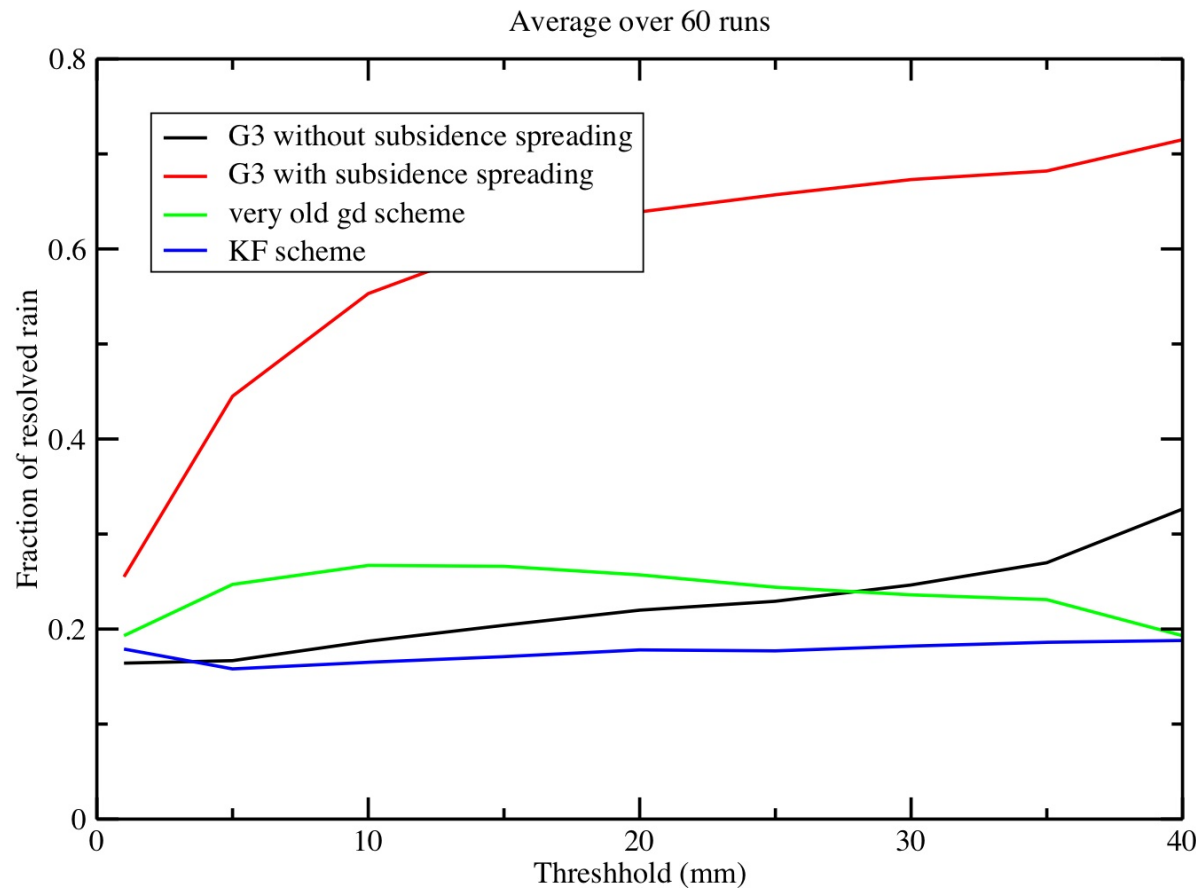
We consider this a somewhat clumsy initial step towards examples (1) and (2) from slide 11. It is, however, decreasing the subsidence heating and leads to a shift of unresolved versus resolved precipitation, increasing the resolved part

First, use “core comparison” test bed
data set (July 2005) and test with
ARW WRF

- Data set (1-month worth of 60 runs) was used to compute statistics
- CONUS grid with 12km resolution
- 24hr accumulated precipitation data based on rain gauge and radar analysis
- Currently working on a paper describing the scheme in it's latest version (a bit beyond the current WRF release version), applying it to resolutions of 12km, 5km, and 3km.

Fraction of modeled precipitation that is resolved over all runs!

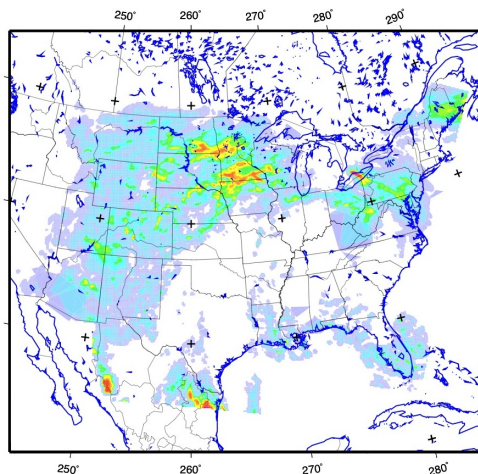
Effects of subsidence spreading on resolved versus non resolved preip



**As was intended:
precipitation shifts
from convective to
explicit!**

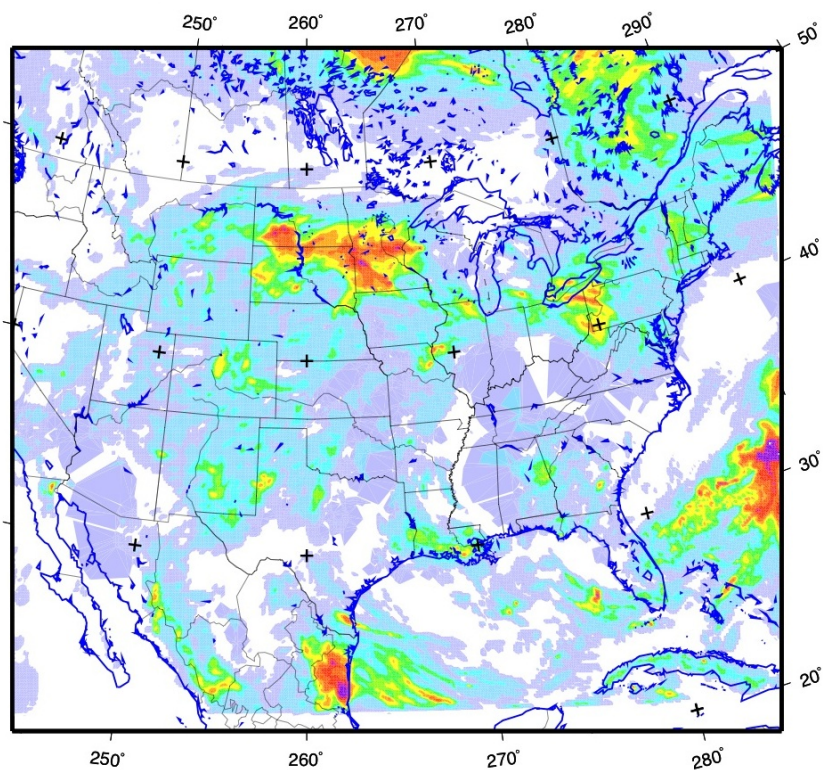
24hr accumulation at 07-26-00

**Overall pattern not
changed too much,
less coverage, heavier
precip at large
thresholds**

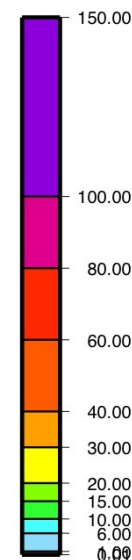
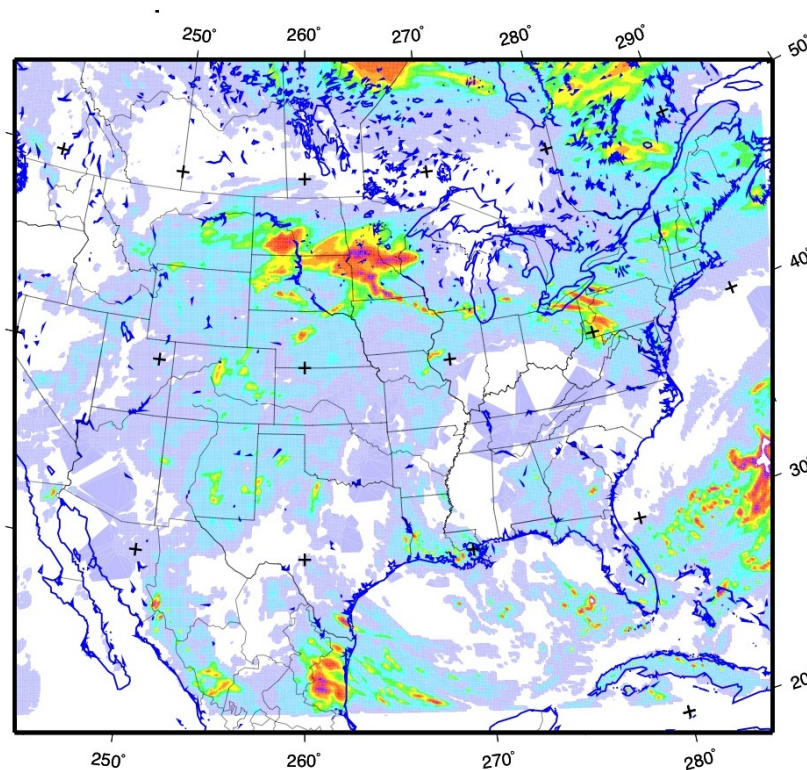


OBS

G3, no spreading

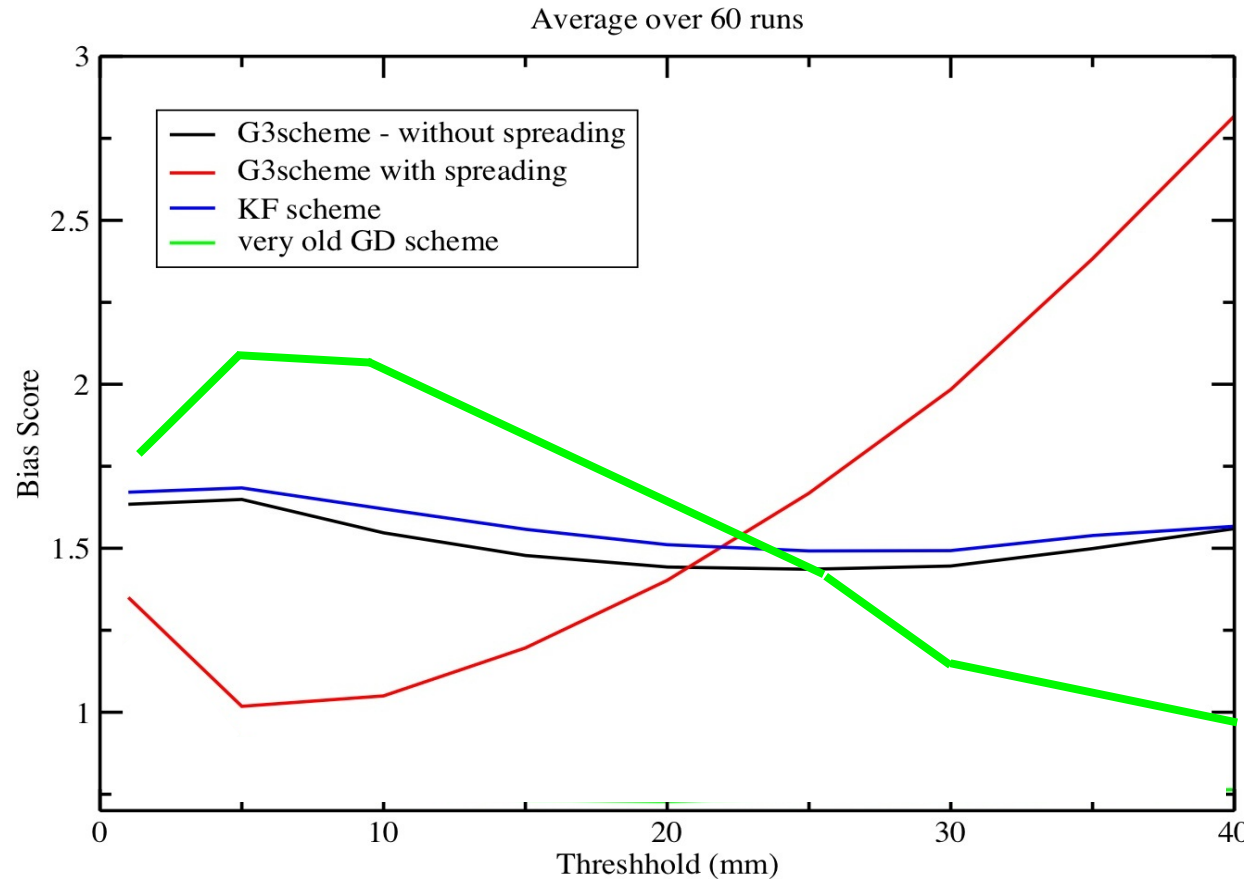


G3, with spreading



Bias scores over all runs!

Effects of subsidence spreading on resolved versus non resolved]



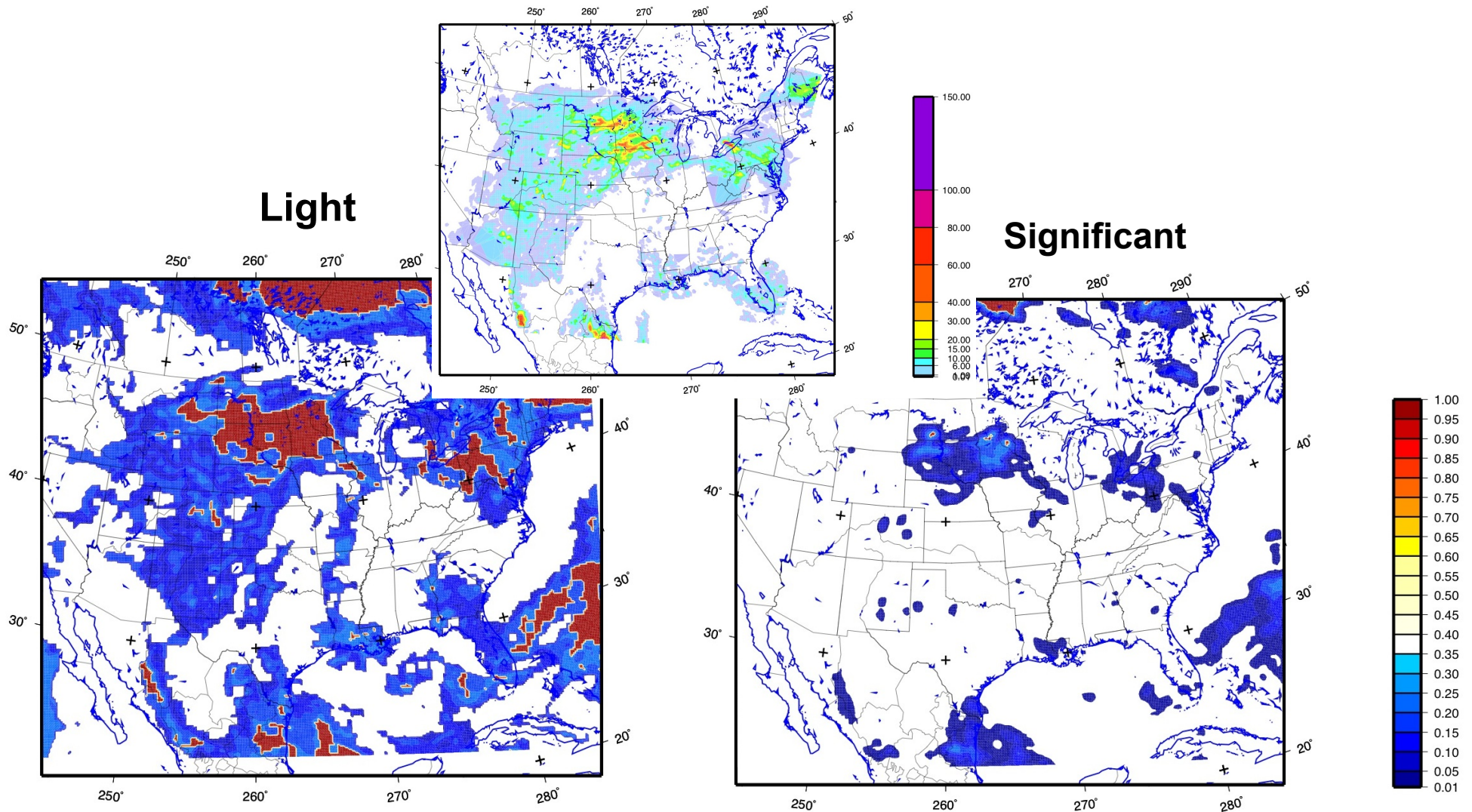
ETS scores were almost identical, with spreading slightly but insignificantly higher for low thresholds

An example using PDF's

- PDF's are calculated on output, using all ensembles as well as ensembles of neighboring grid points)

Probability density functions

Forecast probabilities for light ($>1\text{mm}$) and significant ($>25\text{mm}$) precipitation, 26-July 2005



An example of using weights (calculated using singular value decomposition, comparing output from each closure to 24hr rainfall observations)

- Constant everywhere (w_1),
- threshold dependent (w_2),
- threshold dependent only applied to output (w_3), not influencing the run)

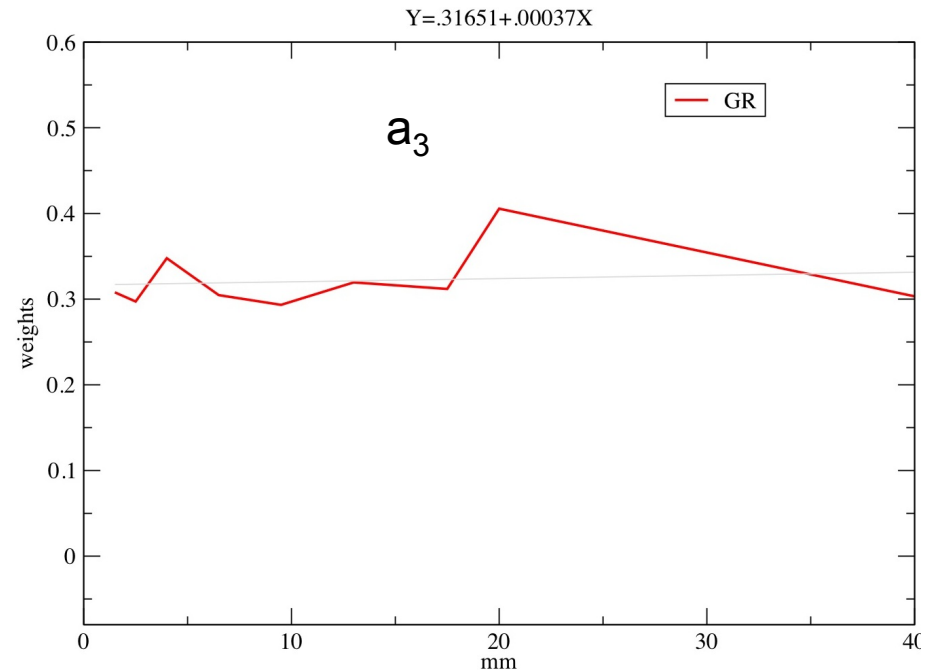
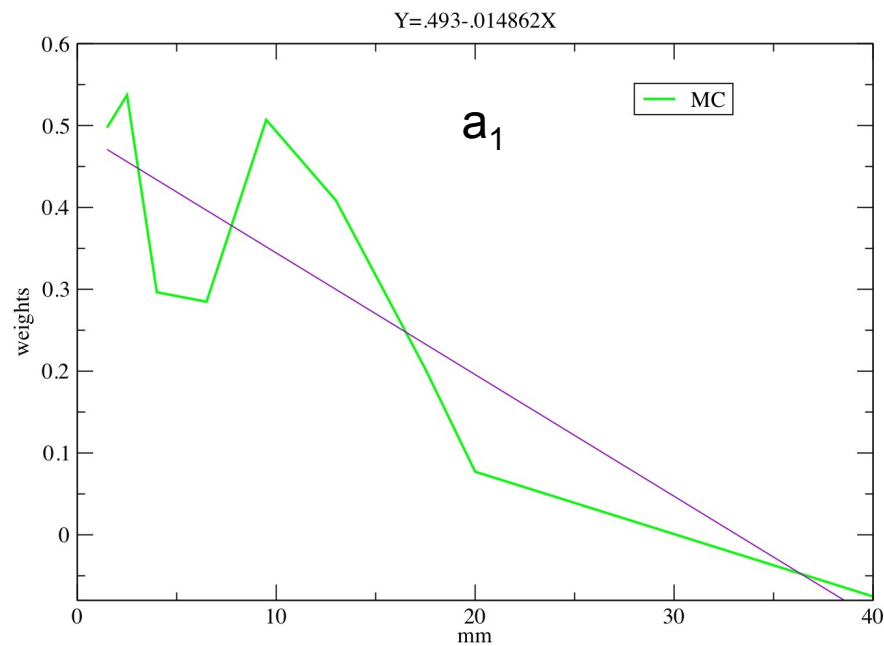
Example:

$$M_b = a_1 m_b(mc) + a_2 m_b(w) + a_3 m_b(gr) + a_4 m_b(kf) + a_5 m_b(random)$$

In WRF: $a_1 = a_2 = a_3 = a_4 = a_5$

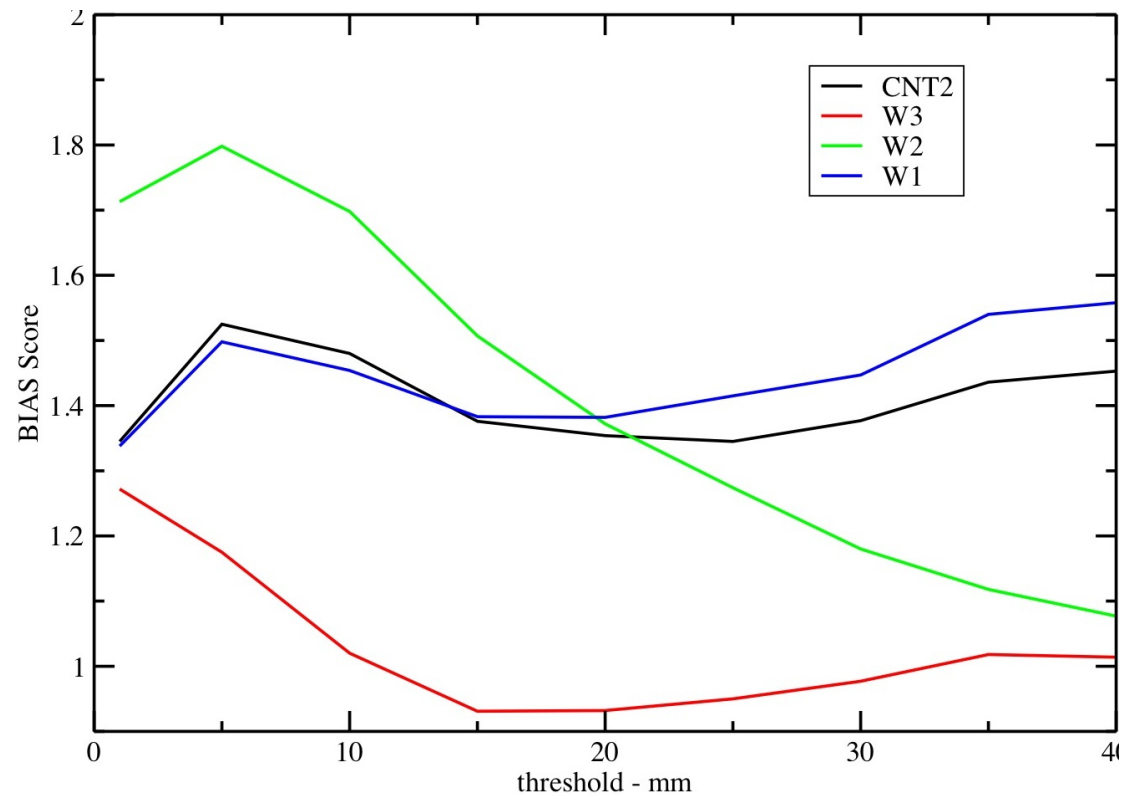
Here weights are only applied to different closures, only calculated when skill exists

Threshold dependent weight calculation for 2 closures



30 runs – WRF (first two weeks)

Different Weight calculations and their verification scores



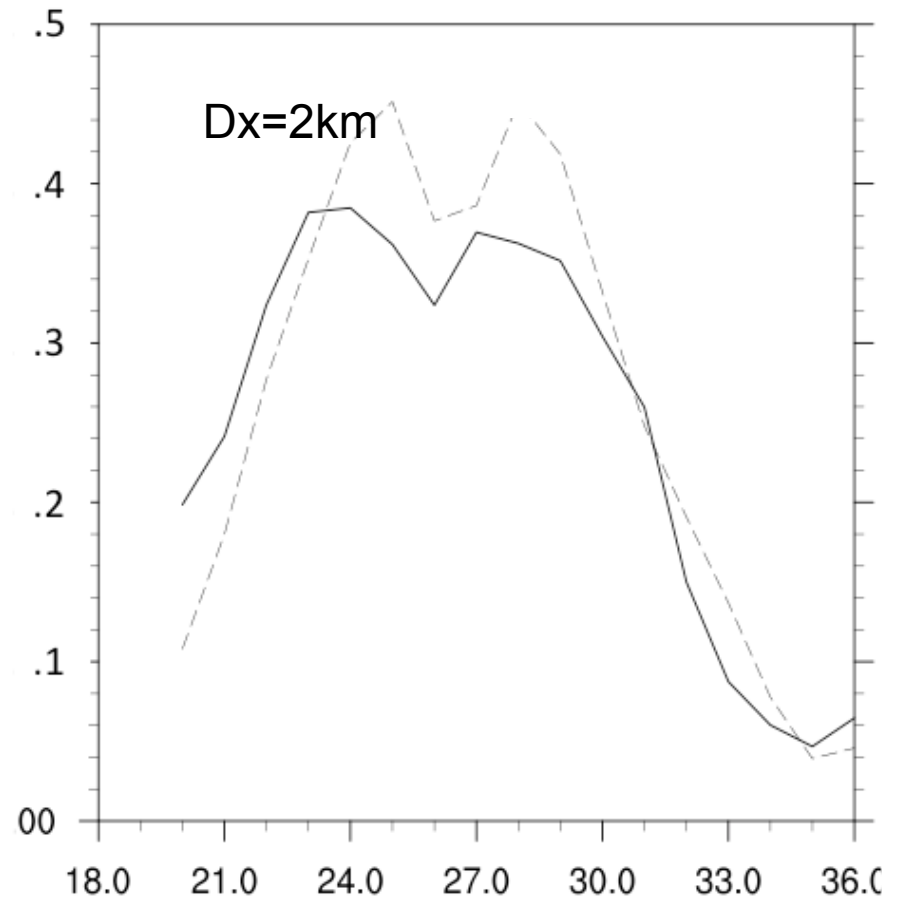
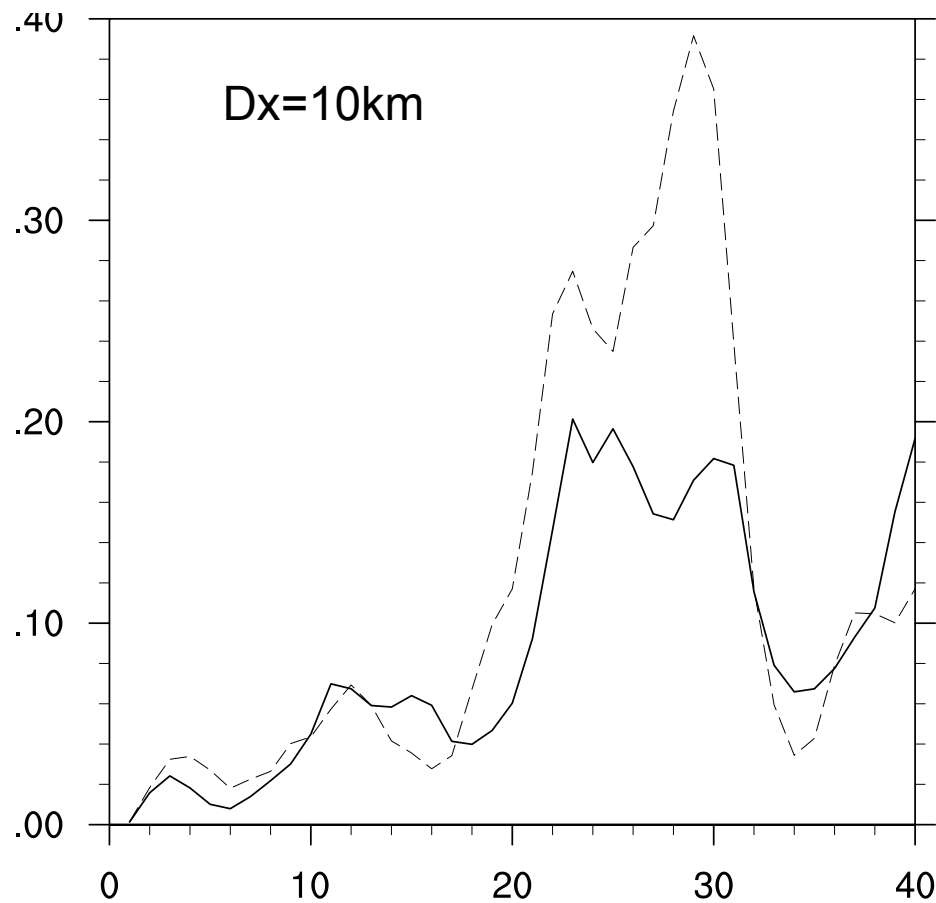
Bias Scores (last two weeks)

Including the effect of aerosols – Why?

- Aerosol interactions are an important link for climate, weather, and air quality. Considering their interactions by using coupled approaches maybe an important next step in future modeling systems (Grell and Baklanov, 2011)
- From a case study on cloud-resolving scales (Grell et. al, ACP2011), using WRF-Chem

In strongly polluted areas: convective parameterization only feels radiation effects, which lead to an overestimation of the aerosol effects

Direct and indirect effect with WRF-Chem



Domain averaged precipitation (mm/hr)



Change constant autoconversion rate to aerosol (CCN) dependent Berry conversion

In parameterization: $c_0=.002$

change to:

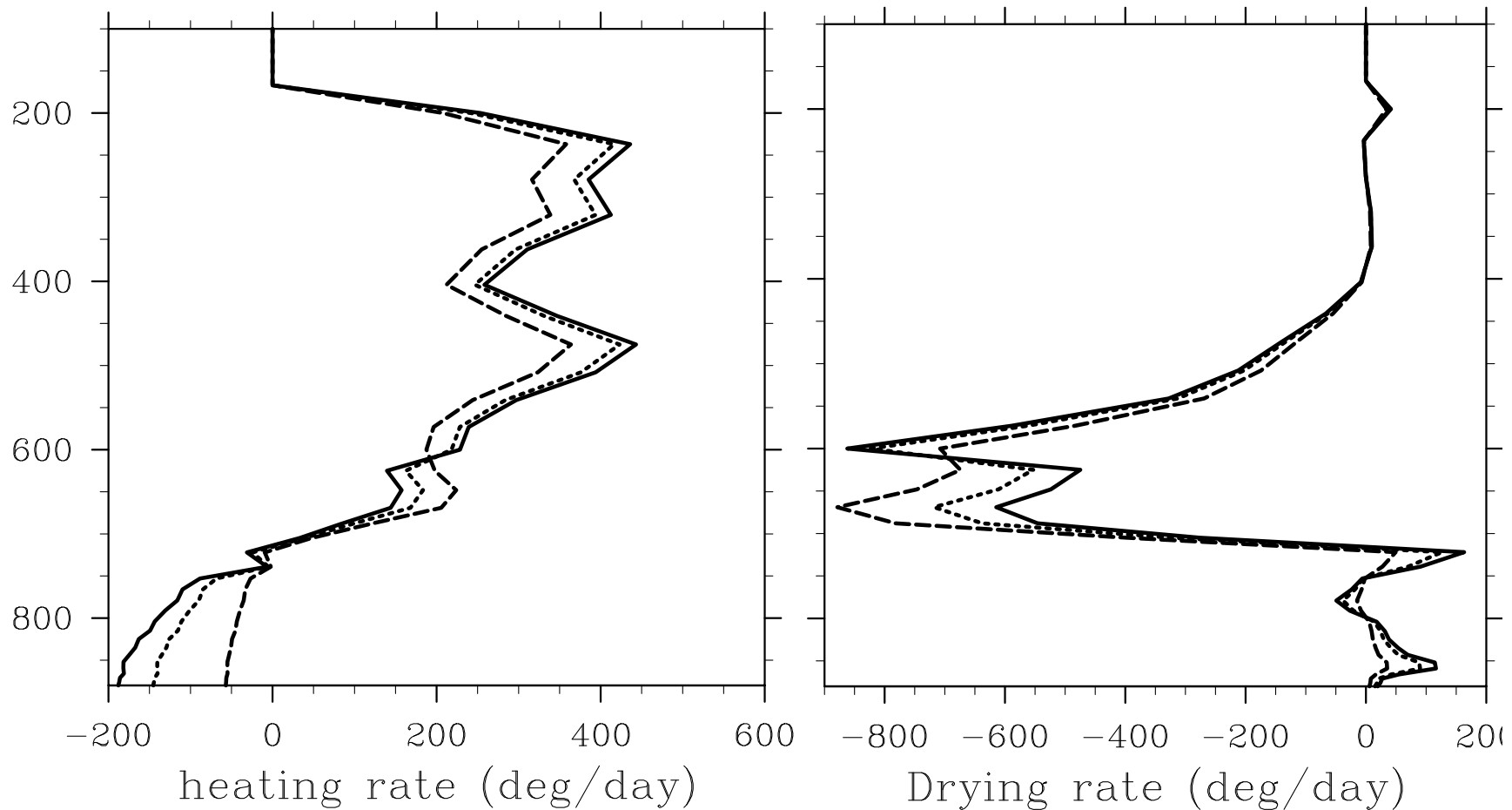
$$\left(\frac{\partial r_{rain}}{\partial t} \right)_{\text{autoconversion Berry, 1968}} = \frac{(\rho r_c)^2}{60 \left(5 + \frac{0.0366 \text{ CCN}}{\rho r_c m} \right)}$$

Additionally: Change precipitation efficiency
calculation to include aerosol (CCN) dependence

—— C0 = constant

----- Berry conversion + evaporation

- - - Berry, CCN=300



**In heavily polluted areas: Decreases
precipitation by up to 50%, detrains
much more cloud water and ice**

Future plans with G3 (V3.5)

- All new additions described here will be in next release (aerosols, new entrainment formulations) – after submission of paper describing all aspects in greater detail
- Let model do the subsidence, only transport mass
- Try approach from Arakawa et al 2011 paper
- Will continue to work with Brazilian scientists on evaluation of G3 in B-RAMS at 5km resolution, covering South America

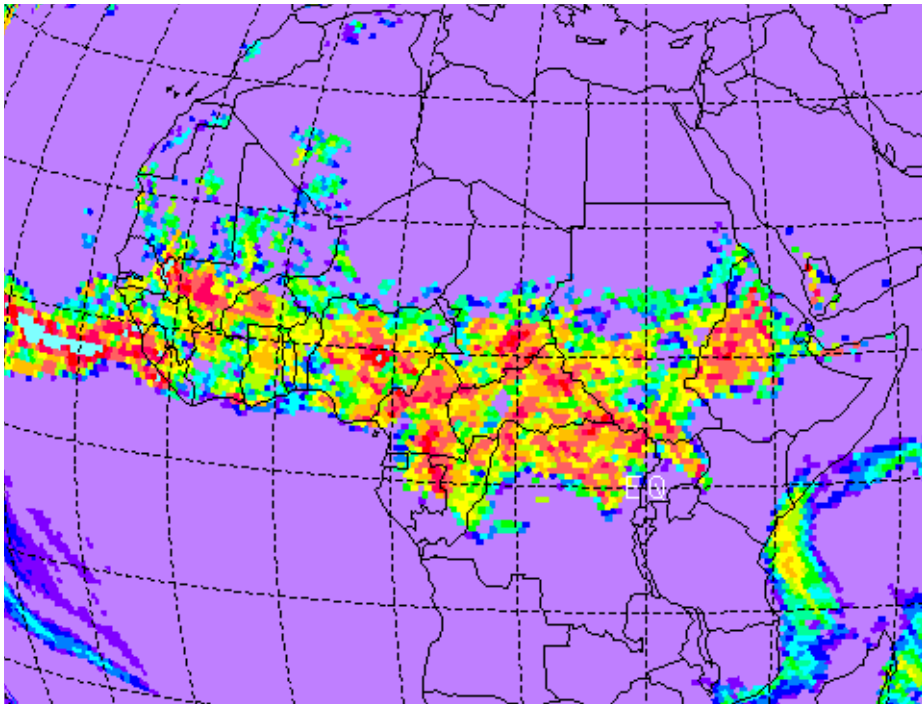
Some publications that were used in the talk

- Arakawa, A., J.-H. Jung, and C.-M. Wu, 2011: Toward unification of the multiscale modeling of the atmosphere. *Atmos.Chem. Phys.*, **11**, 3731-3742.
- Bryan, G. H., J. C. Wyngaard, and J. M. Fritsch, 2003: Resolution Requirements for the Simulation of Deep Moist Convection, *Mon. Wea. Rev.*, **131**, 2394 – 2416.
- Randall, D., M. Khairoutdinov, A. Arakawa, and W. Grabowski, 2003: Breaking the cloud parameterization deadlock. *Bull.Amer. Meteor. Soc.*, **84**, 1547-1564.
- Gerard, L., J-M. Piriou, R. Brozkova, J.-F. Geleyn, and D. Banciu, 2009: Cloud and Precipitation Parameterization in a Meso-Gamma_scale Operational Weather Prediction Model. *Mon. Wea. Rev.*, **137**, 3960 -3977.
- Hong, S.-Y. and J. Dudhia, 2012: Next-generation Numerical Weather Prediction. *Bull. Amer. Meteor. Soc.*.
- Kuell, V. , A. Gassmann, and A. Bott, 2007: Towards a new hybrid cumulus parameterization scheme for use in nonhydrostatic weather prediction models. *Q.J.R. Meteorol. Soc.*, **133**, 479-490.
- Grabowski, W. W., and P. K. Smolarkiewicz, 1999: CRCP: A Cloud Resolving Convective Parameterization for Modeling the Tropical Convective Atmosphere. *Phicica D*, **133**, 171-178.
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- Grell, G.A., S. R. Freitas, M. Stuefer, and J. D. Fast, 2011: Inclusion of Biomass burning in WRF-Chem: Impact of Wildfires on Weather Forecasts. *Atmos. Chem. Phys.*, **11**, 1-16. 2011, doi:10.5194/acp-11-1-2011.

Thank you! Questions?

Example of convective precipitation in heavily polluted area (smoke from fires and dust) – using global FIM model

$C_0 = .002$



$C_0 = \text{berry conversion}$

