Using cloud resolving WRF-Chem simulations to explore the aerosol impact on numerical weather prediction, and evaluate the aerosol aware Grell-Freitas convective parameterization

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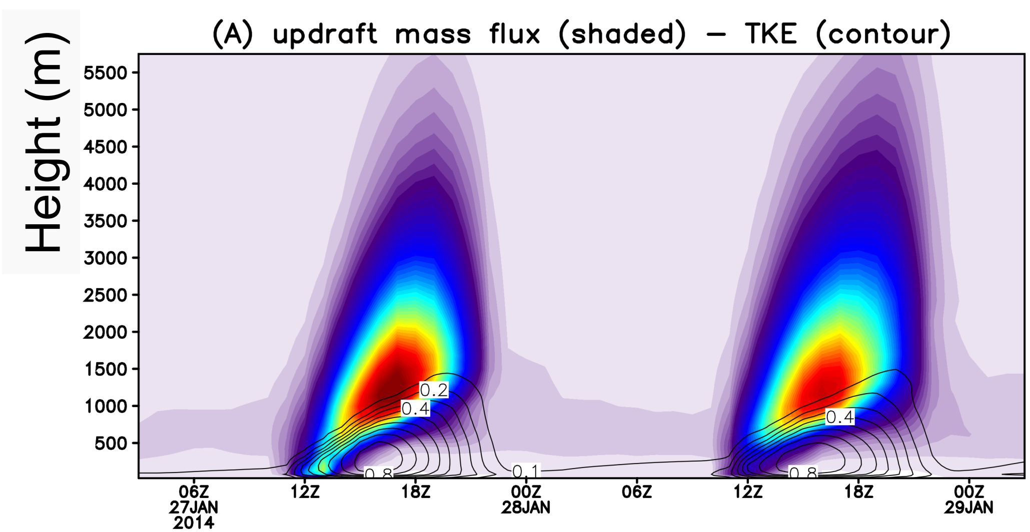
New additions for GF scheme

- PDF's were implemented for vertical mass flux distribution (this allows easy application of stochastic perturbation of vertical heating and moistening profiles
- Completely mass conserving
- Refinement of aerosol interactions
- Bechtold approach for diurnal cycle
- Momentum transport
- Scheme is currently being evaluated in MPAS(scale awareness), FIM (aerosol awareness and capability to produce the dreaded "good" height anomaly correlations), HWRF (scale-awareness), WRF (aerosol awareness), and B-RAMS
- Will be operational in Rapid Refresh (RAP) at NCEP and is operational at CPTEX in Brazil

Grell-Freitas-Olson (GFO) Shallow Convection Scheme

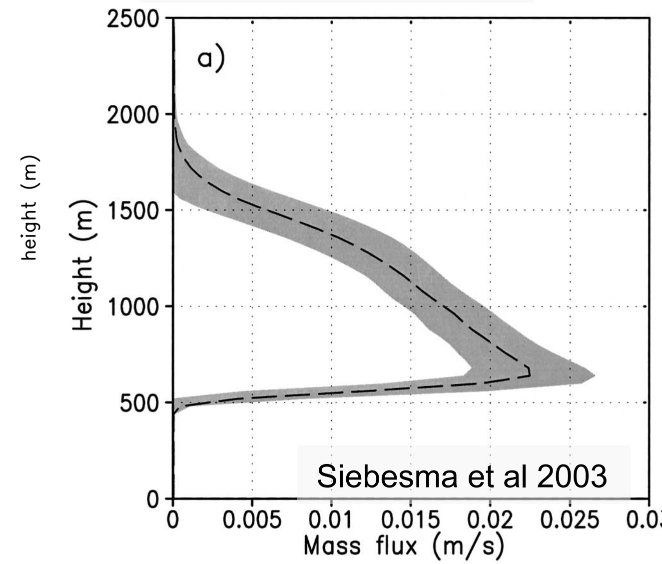
- Non-precipitating
- Transport of moisture, heat and tracers – no aerosol 2-way interaction yet
- Mass flux profile given by a PDF (easy to adjust profile, and/or to apply stochasticism)
- Three closures – BLQE (Raymond, 1995), W^*(Grant, 2001) and convection as natural heat engine (Rennó and Ingersoll, 1996).
- Completely mass conserving
- Scale awareness implemented so far with Honnert approach

Diurnal cycle of shallow convection and diffusion in PBL



updraft mass flux: shaded TKE: contour

Mass flux Profile



- Similar with LES
- Sharp increase, peaking just above boundary layer
- Smooth decrease above

Aerosol awareness

Constant autoconversion rate is changed to aerosol (CCN) dependent Berry conversion

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

Evaporation of raindrops is changed (Jiang and Feingold) based on empirical relationship

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

CCN can be from complex model results (WRF-Chem), or simply from observed AOD (global or regional analysis)

Evaporation effect will have a strong impact on downdrafts, but is limited by other environmental conditions (e.g., If the precipitation efficiency is already very low, it cannot get much lower, and vice versa)

Currently receiving much attention at operational NWP centers: Aerosols

Interaction with radiation (direct and semi-direct effect), clouds (indirect effect), and impact on data assimilation

Working Group for Numerical Experimentation (WGNE) for aerosol impacts on numerical weather prediction

Second and third test case selected to evaluate aerosol impact on NWP (WRF-Chem, but also global modeling systems)

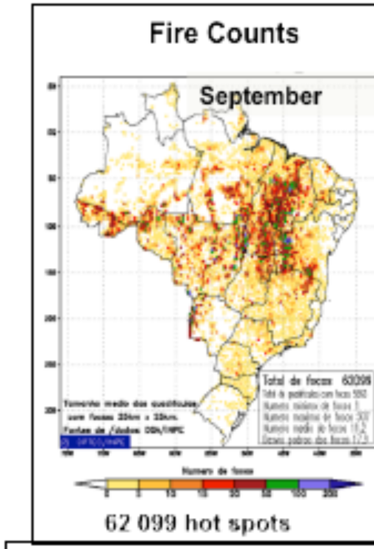
Case 3: Extreme biomass burning smoke in Brazil – the SAMBBA case

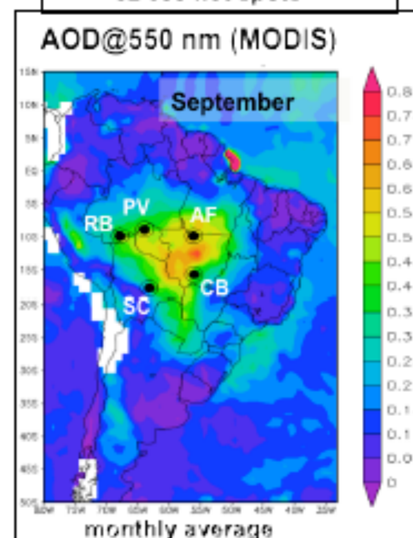
Experiment set-up

- Aerosol effects: forecast with and without interactive aerosols, including direct and indirect effects.
- Ideally four experiments should be performed:

Experiment	Direct effect	Indirect effect	Direct + indirect effects	No aerosol interaction
1	X			
2		X		
3			X	
4				X

- Duration and time period: 10 days, 05-15 September 2012
- Length: minimum of 3 days forecasts from the 00UTC or 1200UTC analysis with and without interactive aerosols.
- Center of the model domain (for limited area models): 60^0 W, 10^0 S
- Model configuration should be compatible with the configuration of the operational system used currently for NWP.
- Initial and boundary conditions for meteo fields can be provided upon by ECMWF (eg MACC) for the limited area models.





Our planned Methodology for WGNE testcases

① Aerosol impacts on NWP: Use more sophisticated cloud resolving simulations, then decrease complexity and resolution to what is used in operational systems

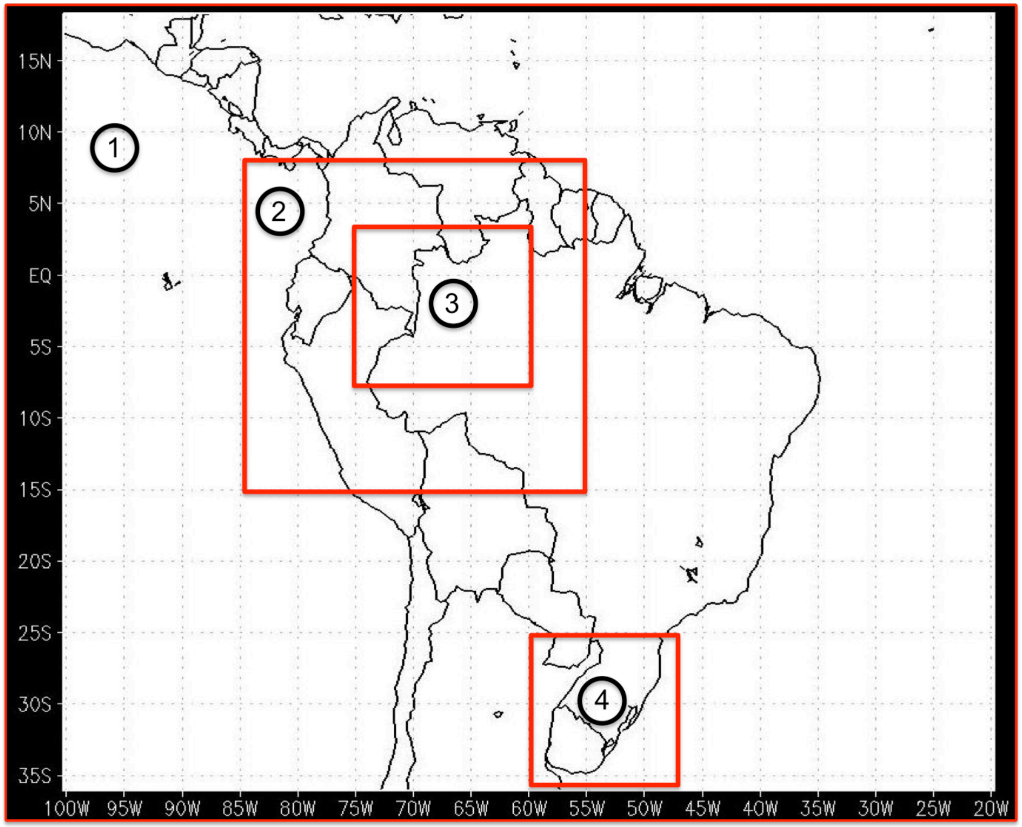
② How different are simple, lower resolution simulations from complex simulations? Observations?

③ Many studies of indirect effect use resolutions that require convective parameterizations. Unless the CP includes aerosol interactions, conclusions are at best suspect.

④ Conclusions are also suspect with a CP that includes aerosol interactions – unless we can show agreement with cloud resolving simulations

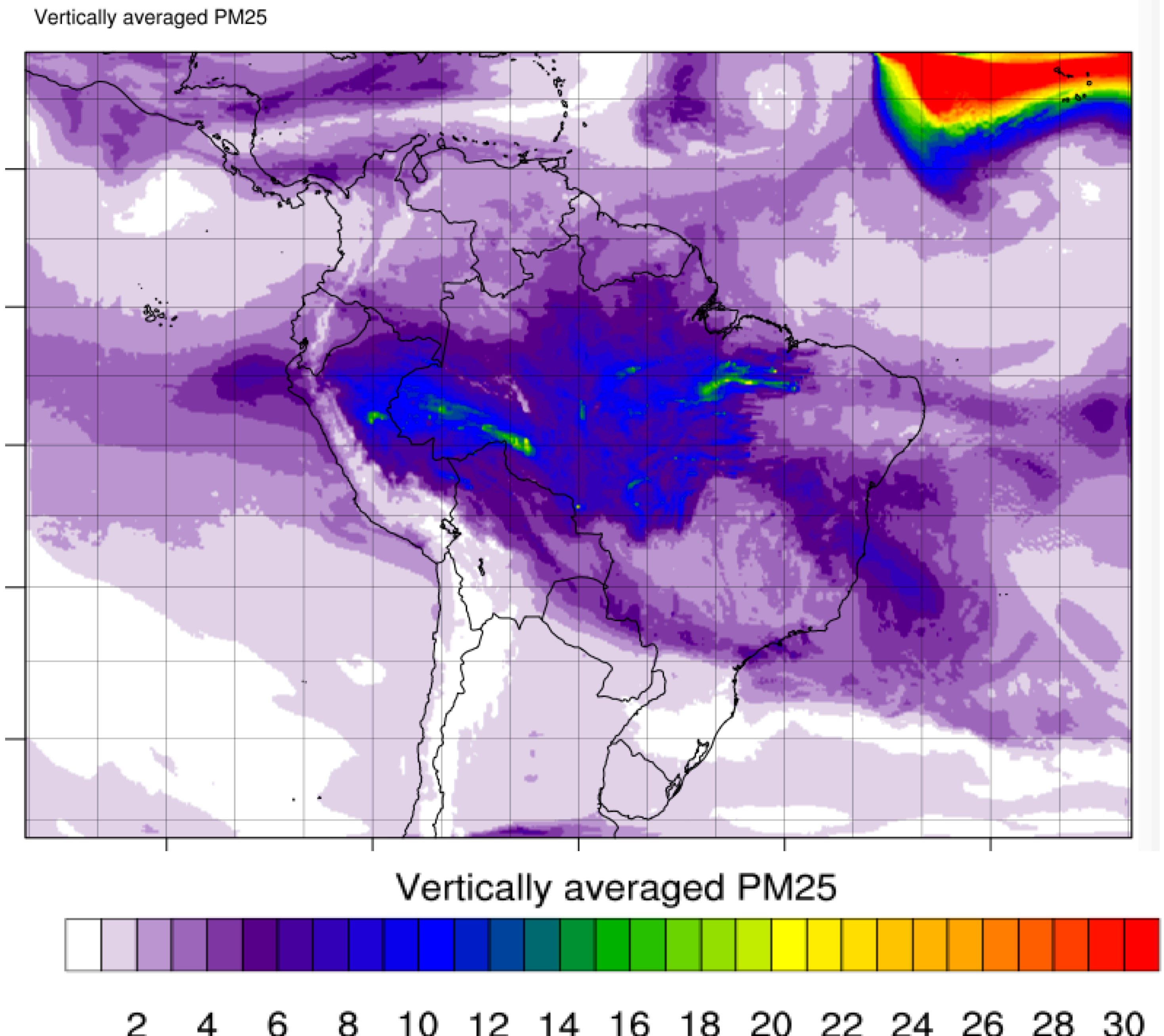
Can we even believe in cloud resolving simulations? – Hopefully strong signals will tell us something..

WRF-Chem domains



Domain	Resolution	Grid Size
1 (South America)	15km	590 * 420
2 (North Brazil)	5km	586 * 439
3 (North Brazil)	1.67km	847 * 595
4 (South Brazil)	5km	276 * 276

Typical vertically averaged PM25 distribution

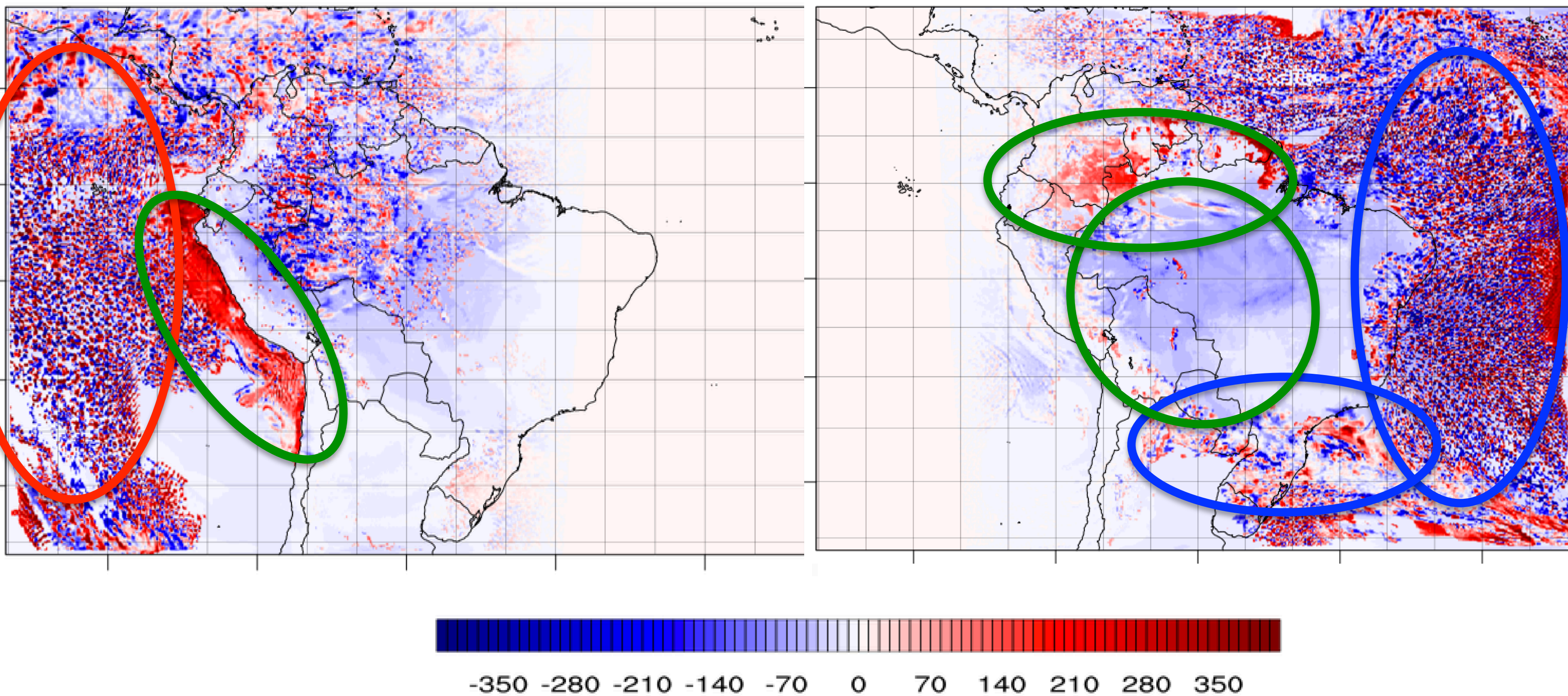


Systematic and random SW differences (Chem – Met) (almost every run, 20 runs, 3-day forecasts)

Apparently random changes, almost every run,
usually less SW radiation reaching the ground

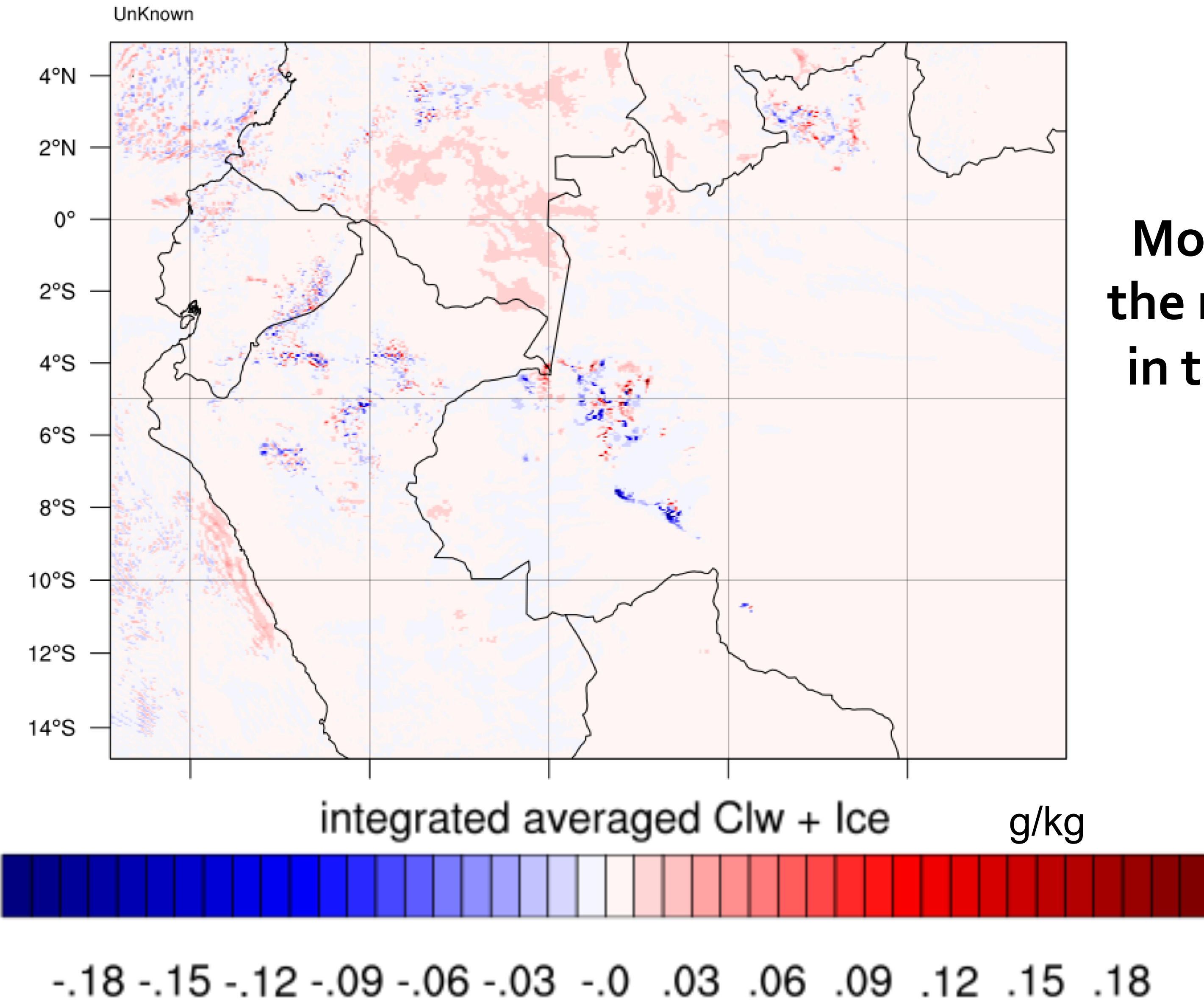
Random changes, caused by different
location of clouds, not consistent with runs

Systematic changes, interesting
point



Differences in integrated cloud water and ice concentrations, 36 hour simulations starting Sep 9, 12Z. DX=5km, displayed is Sep 10, 12Z

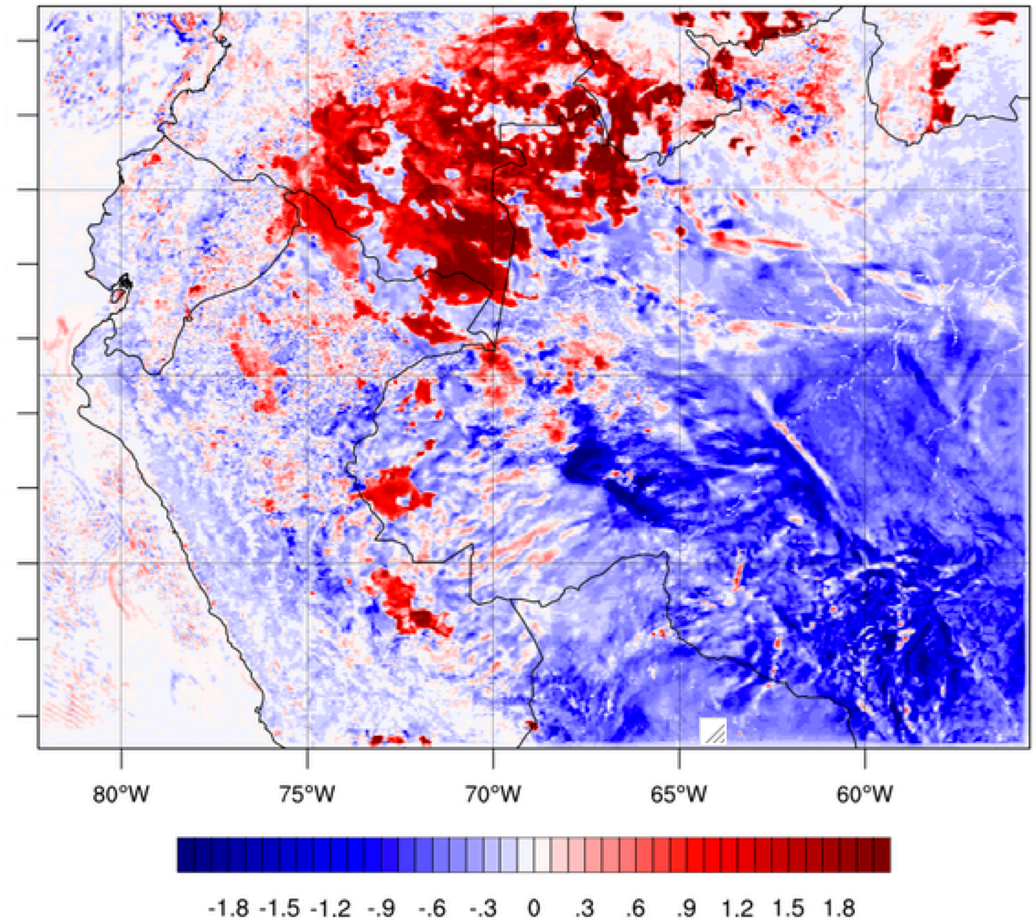
MET - Chem



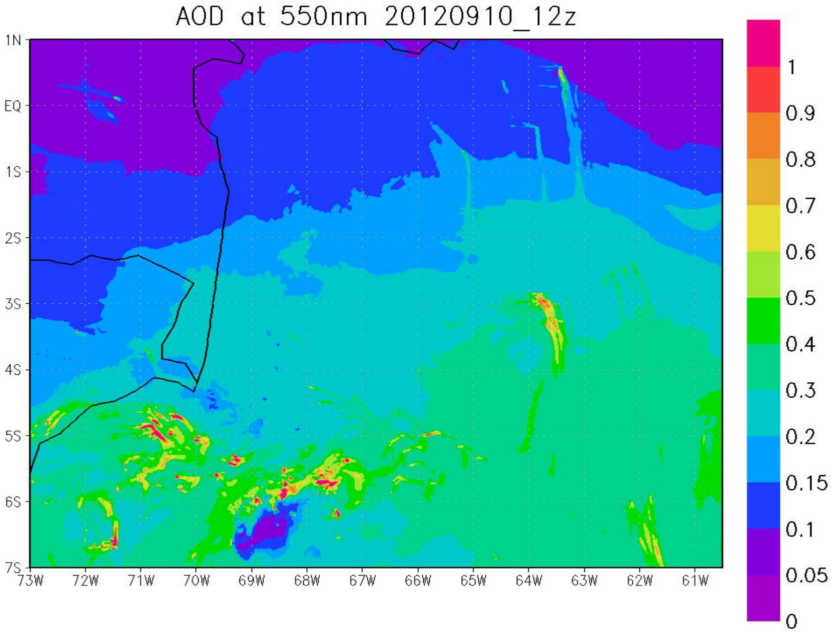
More cloudwater in the met run! But only in the lowest levels!

Results from 5km resolution simulation, T2m differences, CHEM - MET

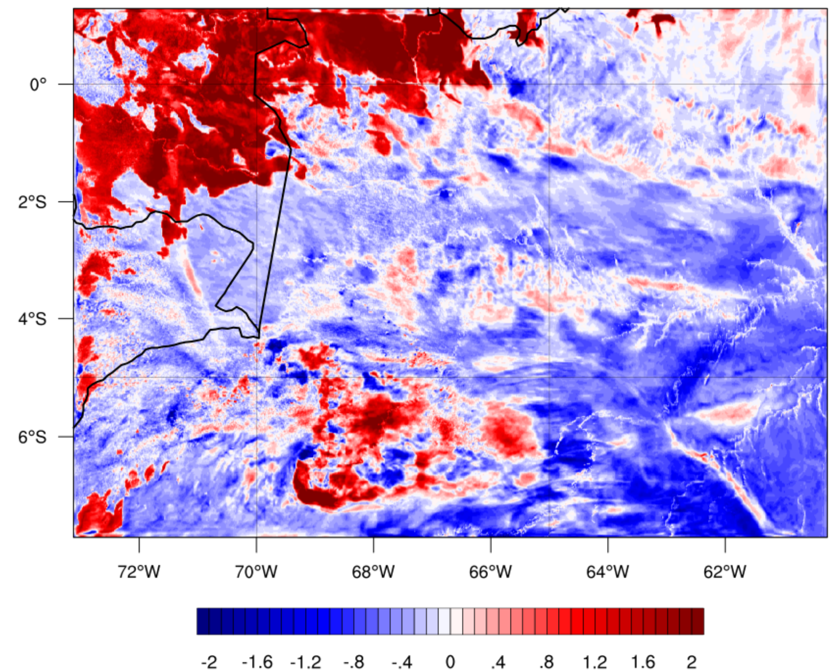
Sep 10, 12Z

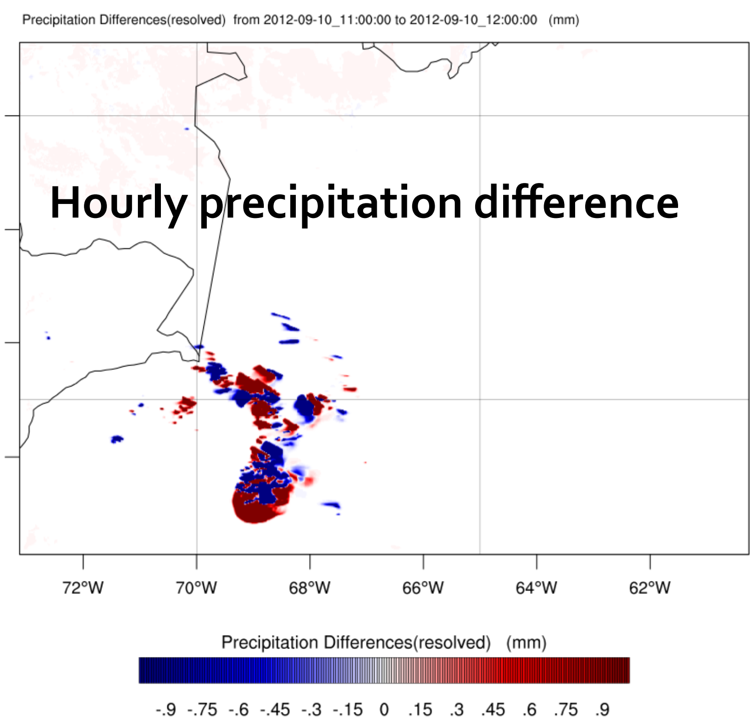


Next: 1.7km resolution, convection: WRF-Chem simulation over 30hr period, initialized at 18Z, Sep 9



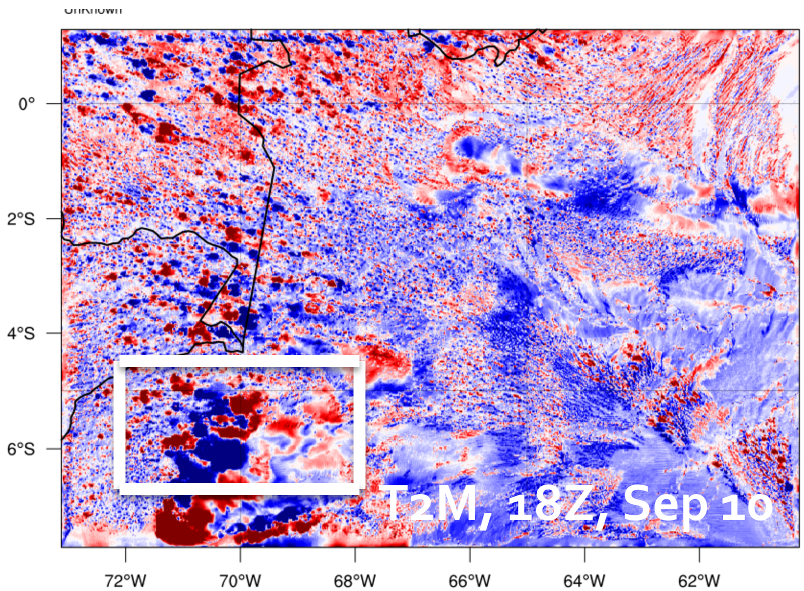
T2M differences, Chem-Met, 12Z, Sep 10

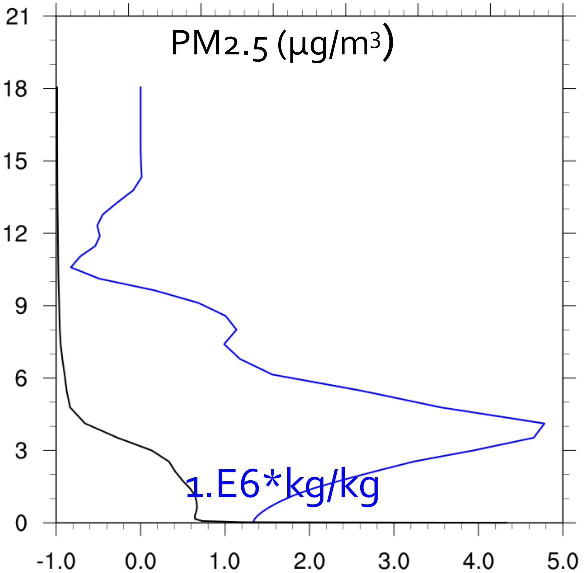




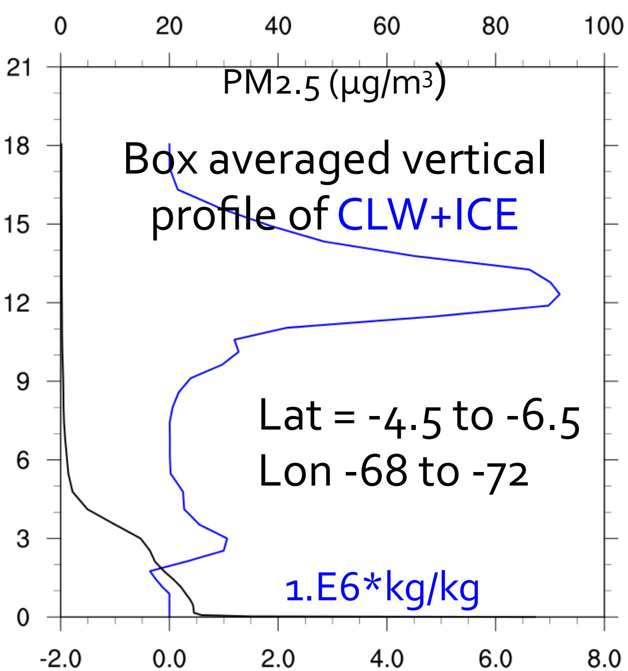
Low level clouds in NE corner do not exist in run with indirect effect included...

Averaging in areas with significant convection



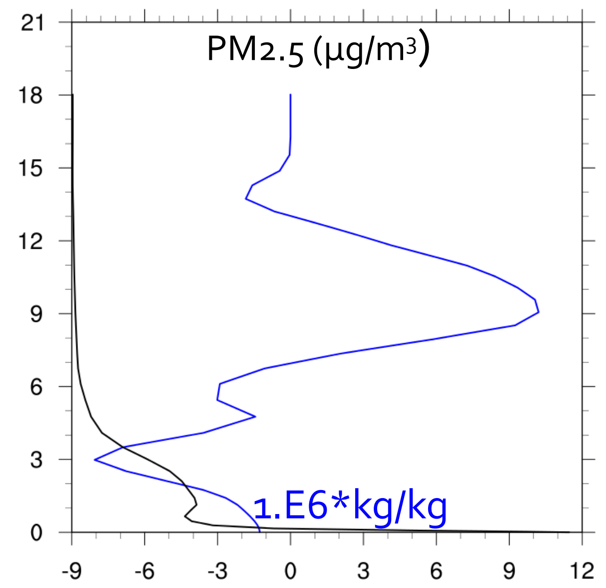


RNW+SNOW at different locations

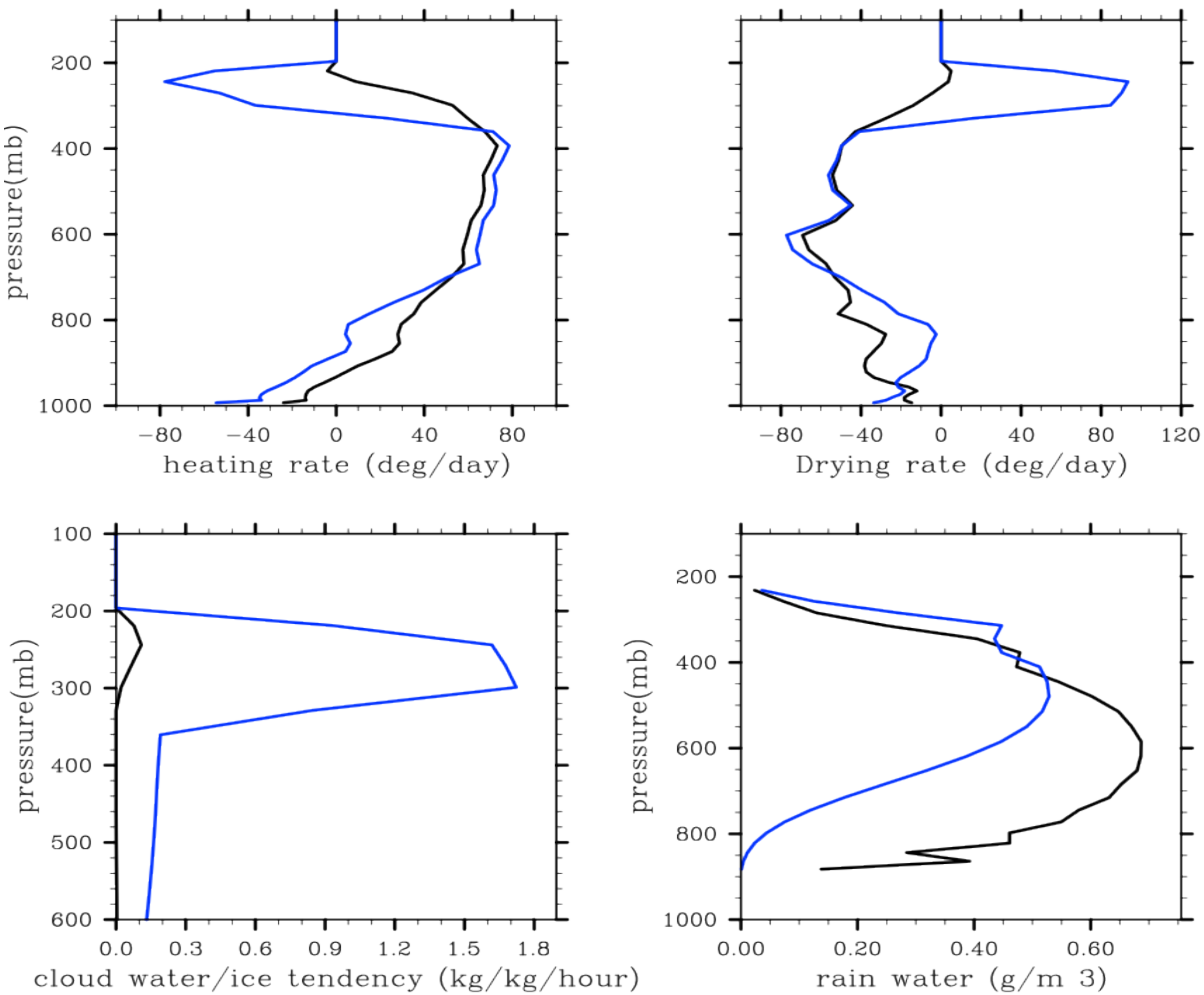


RNW unpredictable: Convection has different strength

CLW and ICE appear to have a signal



So what if you try this with aerosol-awareness turned on in the GF convective parameterization



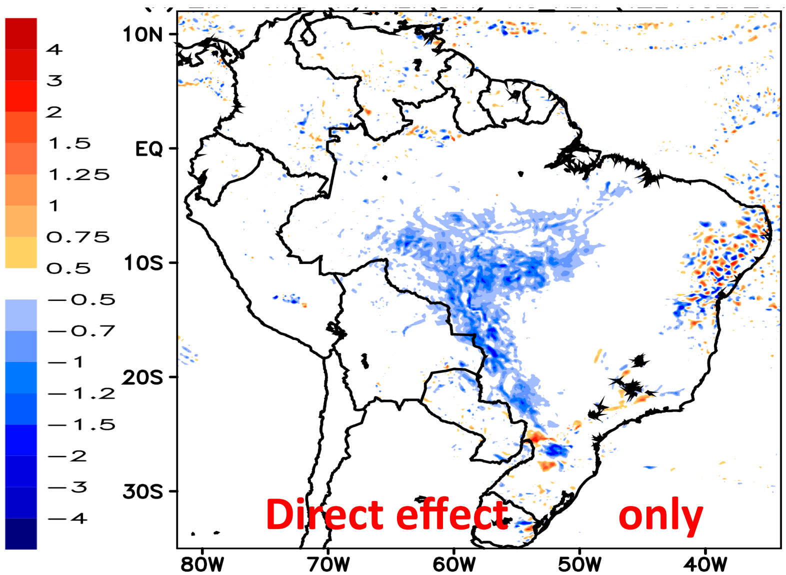
Polluted (AOD=1.)

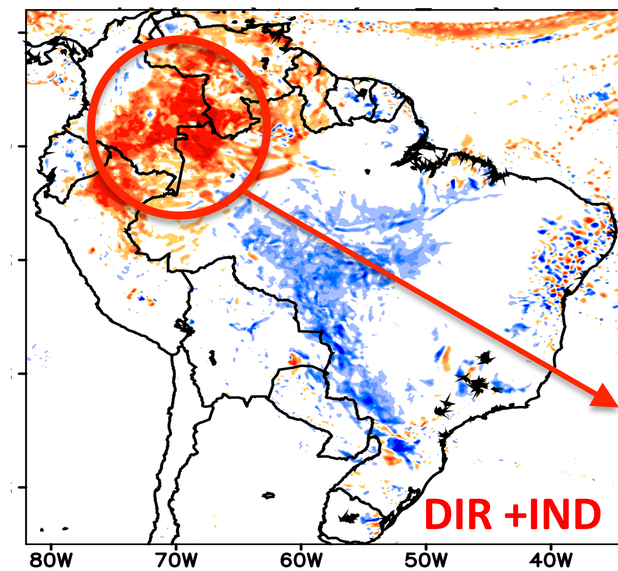
clean (AOD=.01)

Previous 1-d tests

- much more detrainment of cloud water and ice at cloud top
- less suspended hydrometeors, especially in lower part of parameterized clouds
- stronger downdrafts. Leading to less drying in and just above the boundary layer, but stronger cooling in lowest levels

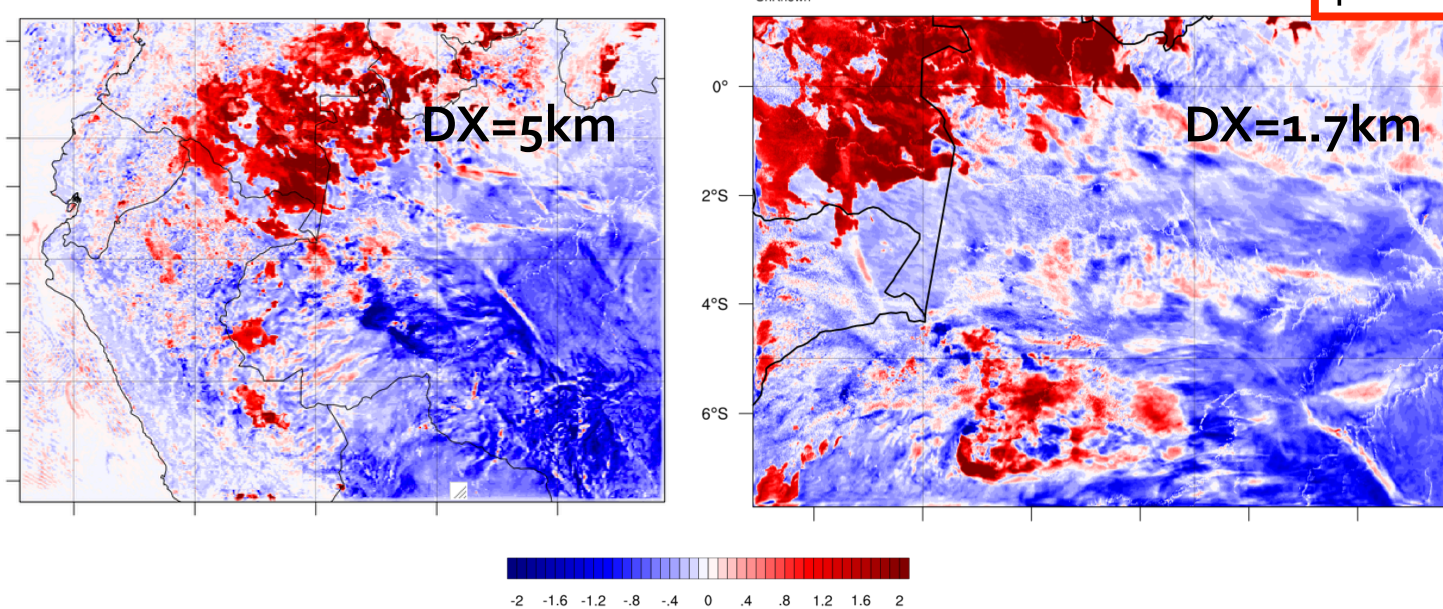
T2M difference fields, September 10, 1200UTC- mid-morning. Positive (red) is warmer compared to MET – simulation with convective parameterization





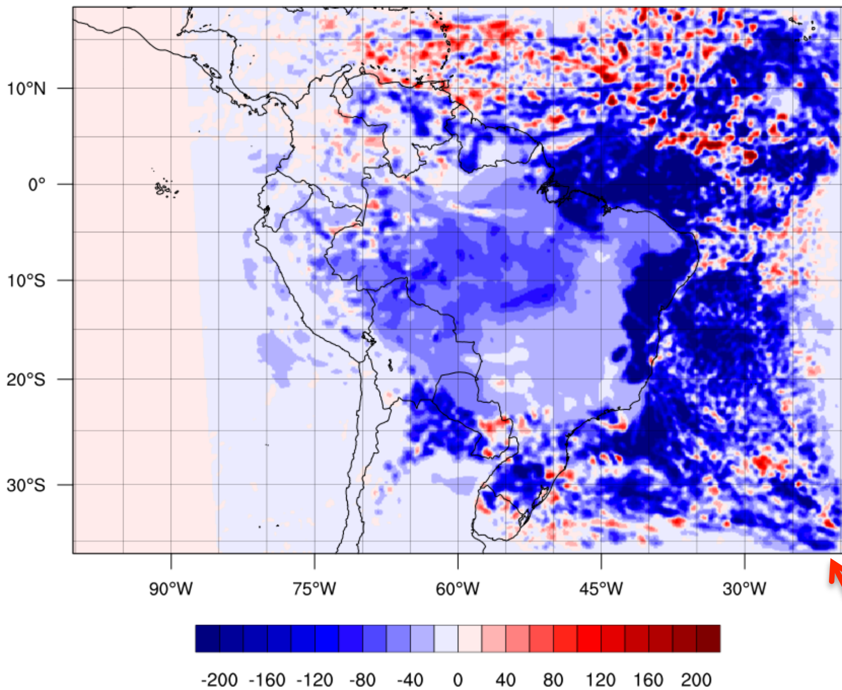
Using convective parameterization with and without aerosol awareness

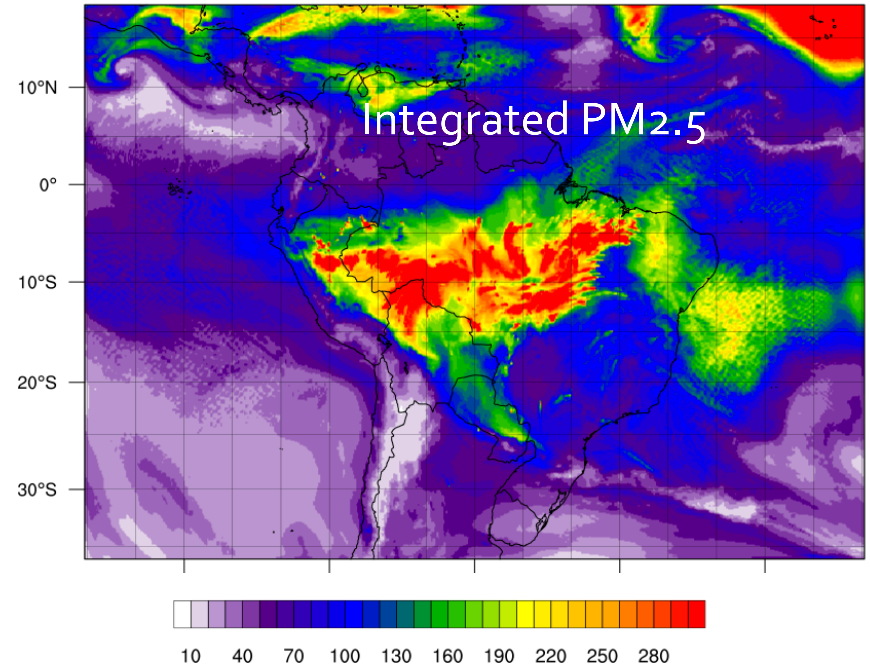
Why should this be related to convective parameterization?

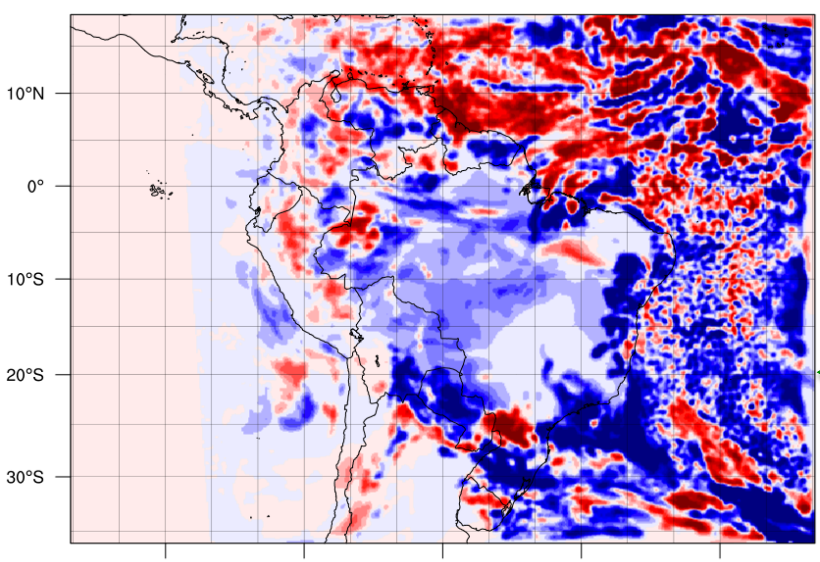


Convection permitting simulations

WRF-Chem – full physics/chemistry: fire – no fires







Direct and indirect effect, but not in convective parameterization

Direct and indirect effect, but indirect only in convective parameterization

Aerosol tests – initial conclusions

- Tropical environments may be the most likely to see an impact
- Strength of convection at this point, and with our model setup, may be difficult to correlate to aerosols
- Initial results for aerosol aware convective parameterization indicate more tests needed
  - Shallow convection
  - Use CCN from model
- 3d impacts will depend on environmental conditions
  - Because of the dependence of precipitation efficiency on wind shear and subcloud humidity in addition to CCN, impacts in middle latitudes may be much more mixed

Aerosol tests – ongoing and future work

- More simulations are currently being done with dx=1.7km, also over the mid latitude domain in southern Brazil
- We will also test simpler chemistry modules and microphysics schemes with a focus on:
  - Thompson aerosol aware microphysics would be much less expensive approach and will be used operationally at NCEP on regional scales
  - GF scheme can run with observed AOD (no chemistry at all necessary)
  - How simple can we go and still compare well to the complex simulations
- We are planning on testing the impact on NWP within a global modeling system (FIM, http://fim.noaa.gov), also for seasonal predictions using FIM-iHYCOM-Chem
- Experiments with stochasticism (J. Berner)