New developments and applications using the scale and aerosol aware Grell-Freitas convective parameterization

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With major acknowledgements to:
RAP/HRRR crew, HWRF folks, FIM crew, GEOS-5 crew
And not to forget the folks that distribute the NGGPS funding

Grell-Freitas Convective Param

- **Scale-aware/Aerosol-aware (Grell and Freitas, 2014, ACP)**
  - Stochastic approach adapted from the Grell-Devenyi (2002) scheme, but changed to include temporal and spatial perturbation patterns
  - Scale awareness through Arakawa approach (2011)
  - Aerosol awareness is implemented with empirical assumptions based on a paper by Jiang and Feingold

2014 version of GF operational at EMC in RAP, also in Brazil (using a version of B-RAMS)

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  - Originally to fit LES modeling for shallow convection
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  - Provides smooth vertical profiles
- Third type of cloud (congestus type convection)
- Changed cloud water detrainment treatment
- Stochastic part now coupled to Stochastic Parameter Perturbation (SPP), and Stochastic Kinetic Energy Backscatter (SKEBS) approach (J. Berner)
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Momentum transport

Effect of cloud scale horizontal pressure gradients (Gregory et al. 1997, Zhang and Wu, 2000) is to adjust the in-cloud winds towards those of the large scale flow. For the ECMWF approach (follows Gregory et al., 1997), the entrainment rate is simply adjusted

$$E(u,v)_{up} = E_{up} + \lambda D_{up}$$
$$D(u,v)_{up} = D_{up} + \lambda D_{up}$$

Where E(u,v) and D(u,v) are simply the entrainment/detrainment rates.

For SAS approach equations follow directly Zhang and Wu, 2003

- The pressure gradient force across the updraft is proportional to the product of mass flux and vertical shear of the mean wind,
- Proportionality constant is -.55 for Zhang and Wu,
- Gregory at al at first assumed the constant to be -.7

$$\mathbf{P}_G^u = -C_u M_u \frac{\partial \overline{\mathbf{v}}}{\partial p}$$

$$\mathbf{P}_G^d = -C_d M_d \frac{\partial \overline{\mathbf{v}}}{\partial p}$$

Both are very simple to implement. Proportionality constant was tested for Stochastic Parameter Perturbation (SPP)

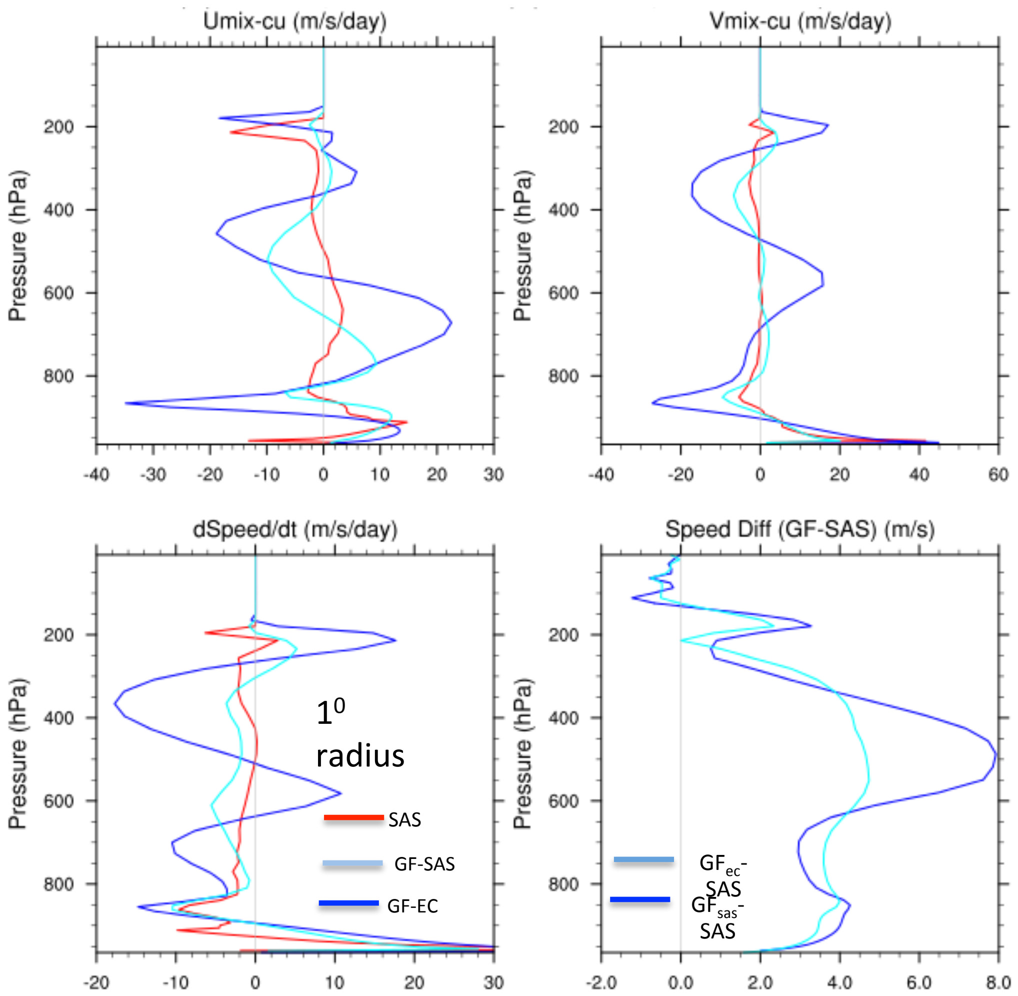
Heat source from momentum transport: dissipation of kinetic energy

As in ECMWF, we also include an additional heat source representing dissipation of kinetic energy (Steinheimer et al 2007)

$$\left(\frac{\partial \bar{T}}{\partial t}\right)_{\mathrm{cu}} = c_p^{-1} D_{\mathrm{st}} g f(p); \qquad f(p) = \frac{\sqrt{\left(\frac{\partial u}{\partial t}\right)_{\mathrm{cu}}^2 + \left(\frac{\partial v}{\partial t}\right)_{\mathrm{cu}}^2}}{-\int_{P_{surf}}^{0} \sqrt{\left(\frac{\partial u}{\partial t}\right)_{\mathrm{cu}}^2 + \left(\frac{\partial v}{\partial t}\right)_{\mathrm{cu}}^2} dp}$$

$$D_{\mathrm{st}} \approx -\left(\frac{\partial K}{\partial t}\right)_{\mathrm{cu}} \approx \int_{P_{surf}}^{0} \left(\bar{u}\left(\frac{\partial u}{\partial t}\right)_{\mathrm{cu}} + \bar{v}\left(\frac{\partial v}{\partial t}\right)_{\mathrm{cu}}\right)\frac{dp}{g}$$

Runs with HWRF, Hurricane Sandy



Sandy: Momentum transport, 10-29-06 GF with EC or SAS method, compared to SAS

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Improving the simulation of the diurnal cycle of convection in GF scheme

- In the attempt to improve the diurnal cycle of convection in the GF scheme, we adopted a closure for non-equilibrium convection developed by Bechtold et al. (2014).
- B2014 proposed the following equation for the convective tendency for deep convection:

$$\left.\frac{\partial A}{\partial t}\right|_{conv} = -\left(\frac{A}{\tau} - \frac{\tau_{BL}}{\tau}\left.\frac{\partial A}{\partial t}\right|_{BL}\right)$$

where ***A*** is called density-weight buoyancy integral, and ? and $?_{BL}$ are appropriated time scales.

- The tendency on the right side of this equation, is the total boundary layer production given by:

$$\left.\frac{\partial A}{\partial t}\right|_{BL} = -\frac{1}{T^{*}}\int_{p_{surf}}^{p_{base}} \left.\frac{\partial T_v}{\partial t}\right|_{BL} dp$$

T^{*} is a scale temperature parameter with a range of about 1 to 4 K.

Diurnal cycle of convection over the Amazon Basin

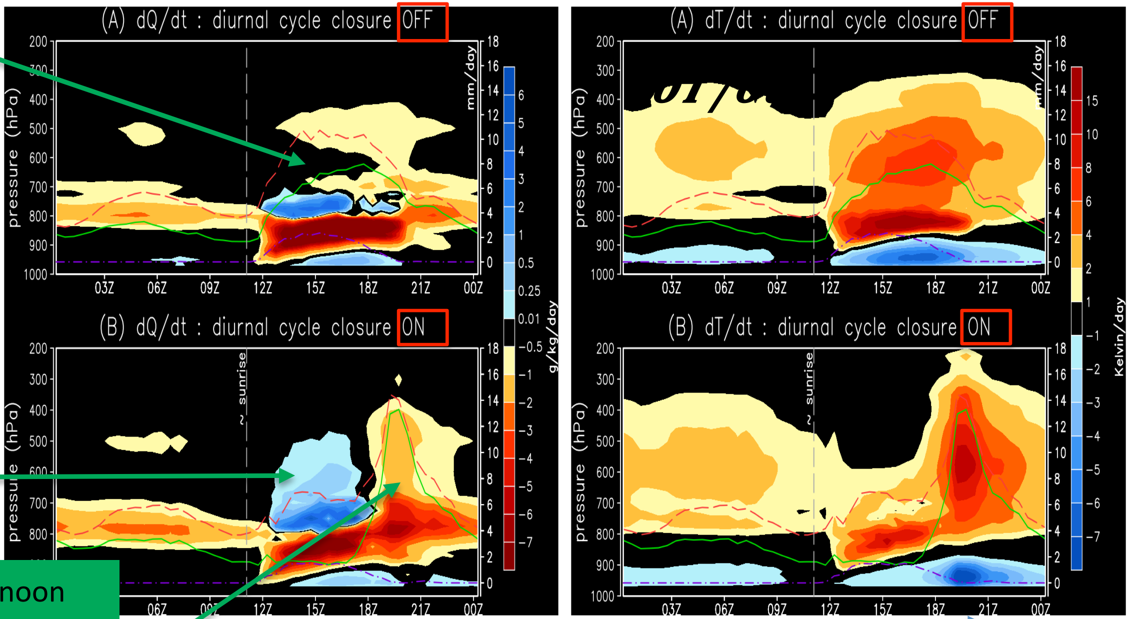
Not applying the diurnal cycle closure, the 3 convective modes occur at the same time, with the deep convection occurring too early.

Late morning and early afternoon low/ mid tropospheric moistening by shallow congestu

Late afternoon and early evening tropospheric drying by the rainfall from the deep cumulus

Drying tendencies

Heating tendencies



UTC time (LT=UTC-4h)

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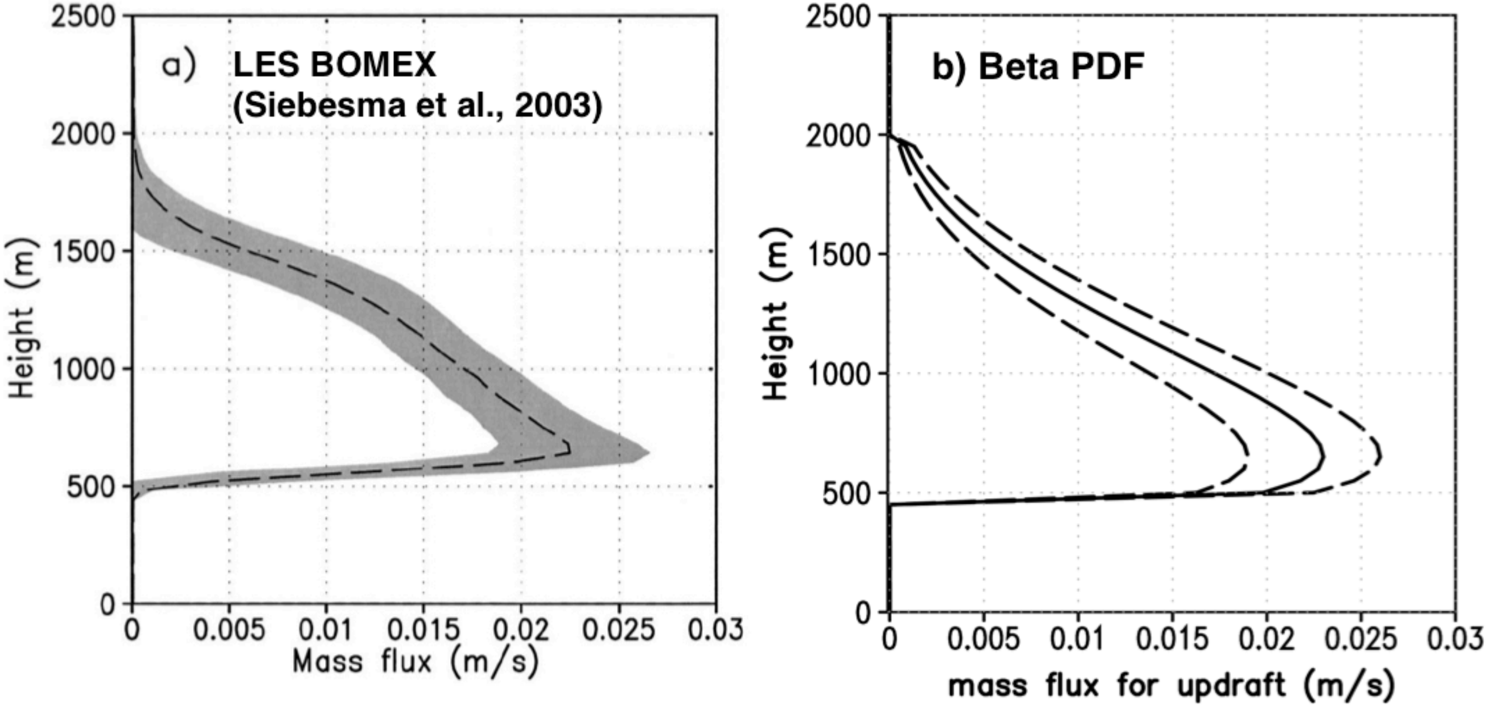
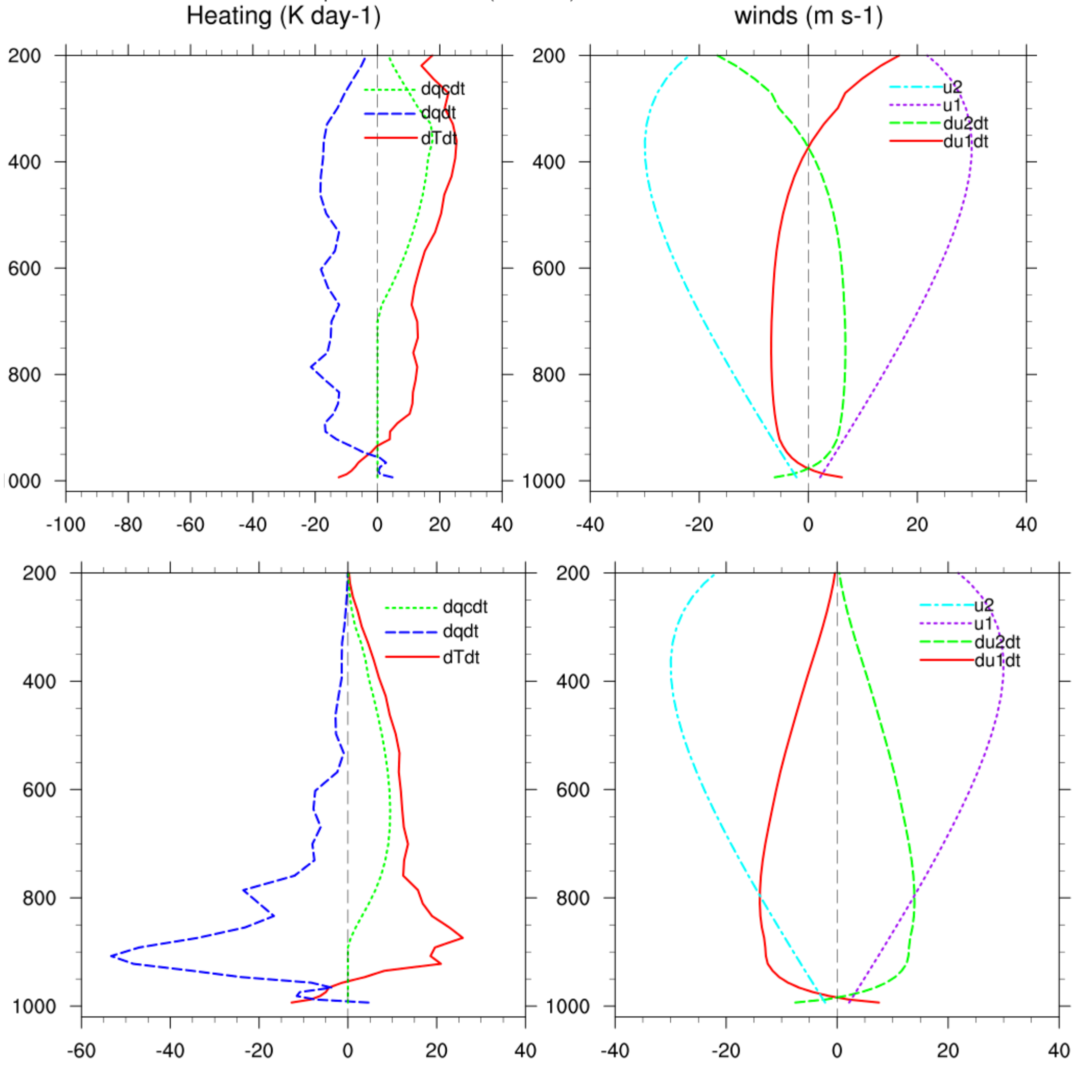
The original reason for implementing PDF's for vertical mass flux: shallow convection



Changing the vertical mass flux PDF's

- Large changes in vertical redistribution of heat and moisture
- Mass conserving for stochastic approaches
- Significant impact on HAC's,
- Increases spread for ensemble data assimilation

1d version of GF only



PDF1

PDF2

Stochastic parameter perturbation in GF scheme

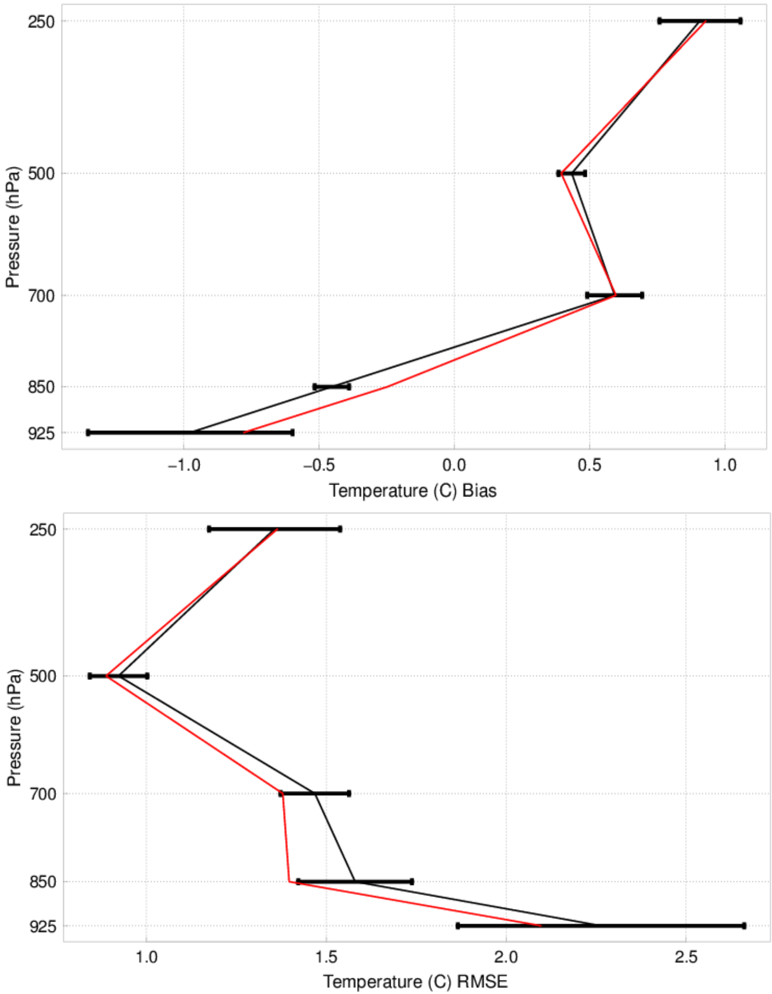
- For stochasticism: significantly different from original approach through bringing in temporal and spatial perturbations, but still possible to perturb the ensembles from GD scheme
  - Apply directly to closure assumptions – for location and strength of convection
  - Apply to skewness and sharpness of vertical mass flux PDF's: an easy way to significantly alter **vertical** heating and drying profiles, but conserving mass
  - Momentum transport

Using SPP to perturb normalized vertical mass flux PDF’s

- Perturbed 8-member RAP ensemble mean is compared against deterministic RAP – initial results are for 4 days only
- July 1, 3, 5, and 8, initial time 00Z

Preliminary results produced by Isidora Jankov

Temperature Bias and RMSE profiles for 24hr lead time



SPP with GF: Opportunities, but much work remains

- Simple initial test for perturbing normalized vertical mass flux PDF's: For most of the variables similar or improved performance from the ensemble mean (including RH, winds and precipitation)
- Coupling with SKEBS (J. Berner)
- Sensitivity: much to learn with "best" stochastic fields, but also limits to perturbation of PDF's
- Can this be tied more to physics?
- Momentum

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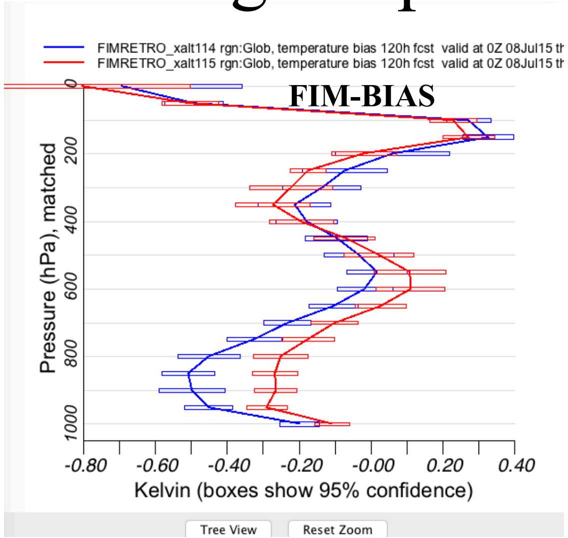
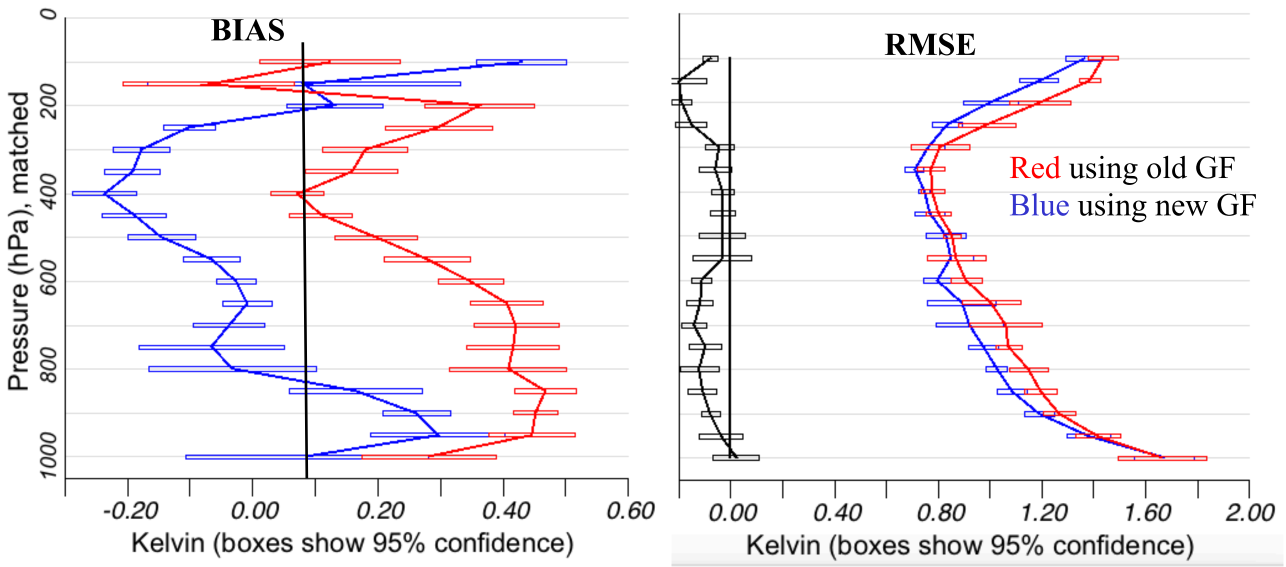
Large impact in physics from **clw detrainment** profiles



FIM, 120hr forecasts, 30 days, only change is a slight modification of clw detrainment



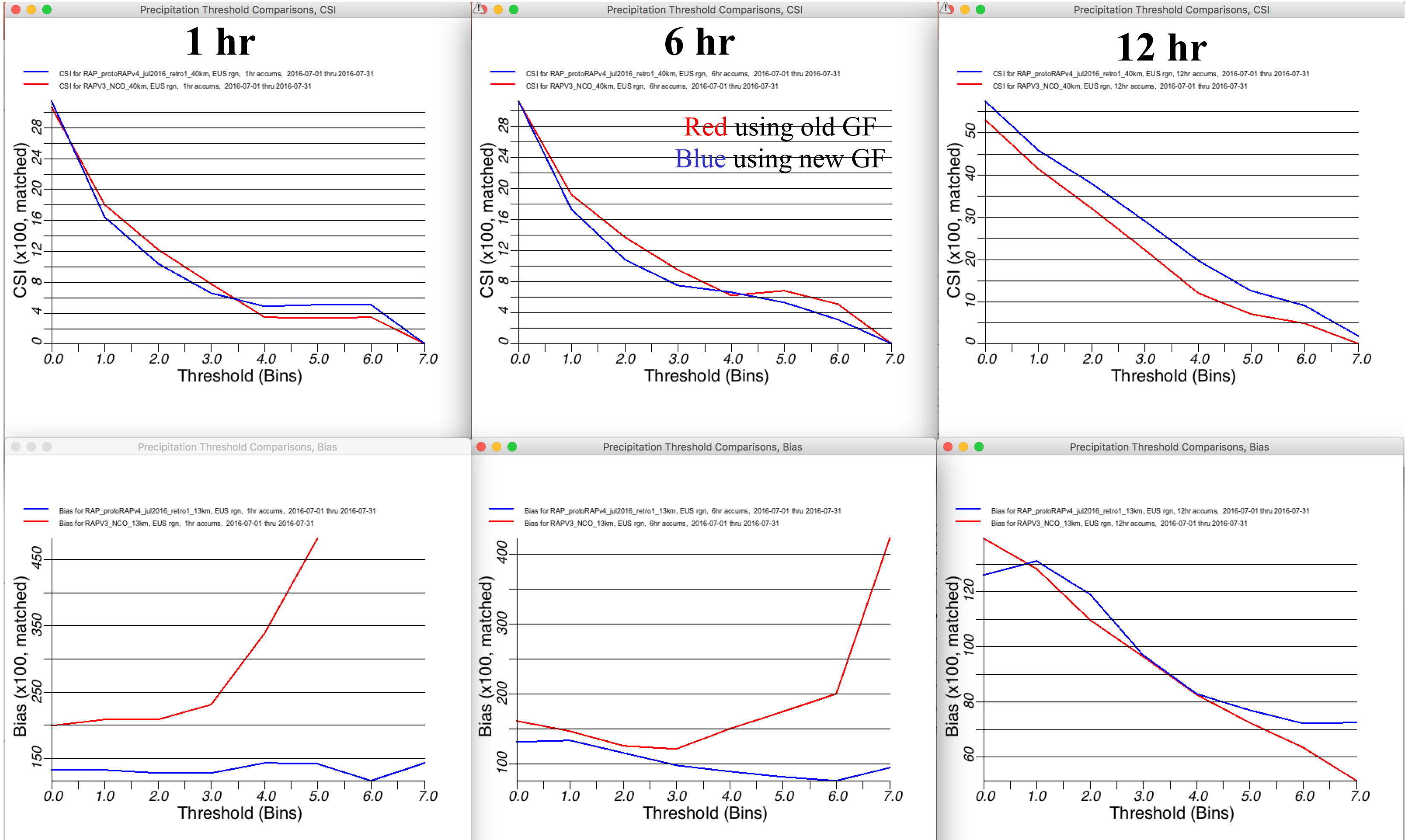
WRF, 12hr forecasts, RAP with cycling for 10 days, many other changes

Small changes in clw/ice detrainment can cause large impact in biases – interaction with microphysics

Tuning: usually done within a physics suite, will determine statistical performance for operational applications!

- WRF version of GF was tuned to meet RAP standards (RAP/HRRR physics suite), focus on CONUS, short range storm scale type verification
- Use in other suites may require significant amount of work
- Example: GEOS-5 (NASA's version of FV3)

RAP CSI/BIAS Precipitation Summer (Three Weeks Jul 2016)



GF in NASA GEOS Model, Summary of scale dependence tests: Saulo Freitas probably spent close to half a year tuning global precipitation (now very close to observed)

GEOS Model Resolution		**Precipitation (mm/day)**	
		PARAMETERIZED (PARAM/TOTAL)	TOTAL
C180	~ 50km	1.75 (55%)	3.20
C360	~ 25km	1.59 (50%)	3.21
C720	~ 12km	1.19 (38%)	3.17
C1000	~ 09km	0.84 (26%)	3.23
C1440	~ 06km	0.54 (16%)	3.28

Technical changes in new GF scheme

Splitting the module into three parts:

- Driver (may be different for various physics suites)
- Module for deep convection (independent of dynamic core or physics suite)
- Module for shallow convection (also independent)

General clean up of unused arrays, and adding comments

Near future experiments with WRF and NGGPS: Memory and organization

- Depending on how long the convective parameterization has been active:
  - Modify entrainment rate
  - Modify vertical mass flux pdf's
  - Modify cloud water detrainment