Improving Simulated Tropical Storm Landfall Precipitation with a Modified Kain-Fritsch Scheme

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Introduction

- The US EPA has been using WRF to downscale GCM data for regional climate analysis on grid spacings down to 12 km.
- Our downscaling products at 36-km scale showed a positive bias in precipitation that got even worse with refinement to 12 km (Otte *et al.*, 2012; Bowden *et al.*, 2012; Bullock *et al.*, 2014).
- Treating the radiative effects of sub-grid convection in the Kain-Fritsch CPS reduced this bias (Alapaty *et al.*, 2012, Herwehe *et al.*, 2014), but more needed to be done for 12-km applications.
- Recently, we tried setting the convective time scale (τ) based on new dynamical considerations. This reduced the precipitation bias further, but also had a surprising beneficial effect on simulated inland precipitation from tropical storms.

Tau in Kain-Fritsch

$$\tau_0 = \frac{\Delta X}{0.5\left(wind_{LCL} + wind_{500}\right)}$$

$$\tau_{KF} = \max\left(1800, \tau_0\right)$$

$$\tau_{KF} = \min\left(3600, \tau_0\right)$$

- So, when the grid spacing is smaller the convective time scale tends to be shorter and the resulting precipitation is more intense.
- With our 12-km grid spacing, Tau was often 1800 seconds.
- As model grid spacing approaches the so-called “grey zone” of 2-10 km where model processes begin to capture convection, we want the CPS to be less vigorous and defer to the resolved physics.

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Our new dynamic Tau

$$\tau = \frac{z_{Eq.Lev.} - z_{LCL}}{w^*} \delta$$

w^* is a convective velocity scale defined by Grant and Lock (2004) based on large eddy simulations of shallow convection. δ is simply a global constant parameter intended to make the formulation suitable for deep convection. We started our experimentation with this parameter set to 1 and this value seems to work well at our current grid spacing of 12 km.

In Grant and Lock (2004), the convective velocity scale is defined as follows.

$$w^* = \left(m_B \times ABE\right)^{1/3}$$

m_B is the "cloud base mass flux" and ABE is the "available buoyant energy".

Convective velocity scale

$$w^* = \left(m_B \times ABE\right)^{1/3}$$

Although m_B is called the cloud base mass flux, it has units of m s^{-1} and really represents the vertical transfer rate of mass at the cloud base.

$$m_B = \frac{UMF_{LCL}}{\left(\Delta x\right)^2 \times \rho_{LCL}}$$

Note that we are diluting the upward mass flux across the entire grid square to obtain a time scale based on convective overturning within the entire grid column where sub-grid convection is occurring.

$$\rho_{LCL} = \frac{p_{LCL}}{R \times T_{LCL}}$$

Blue color denotes variables already available from the Kain-Fritsch CPS

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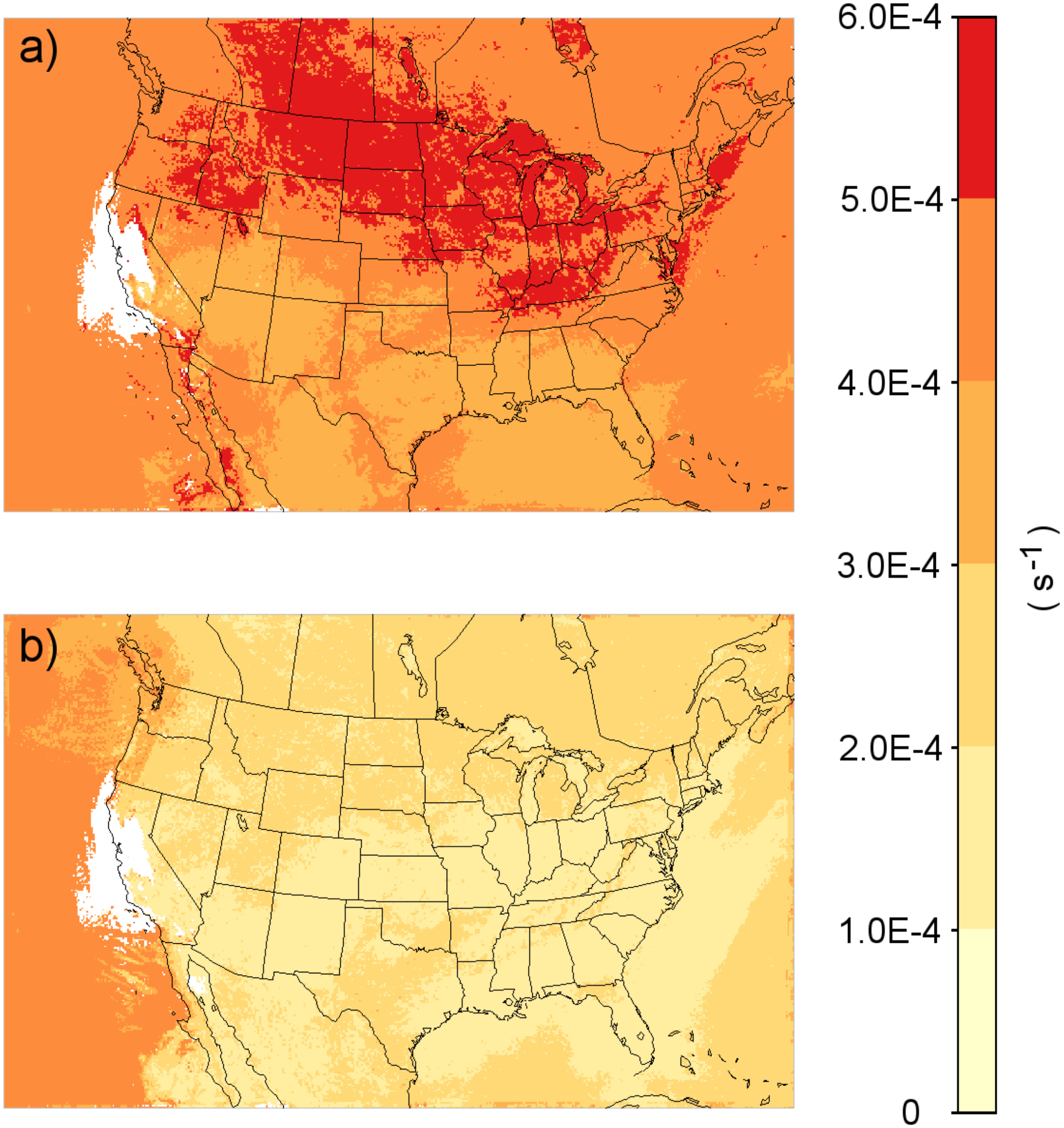
Average Rate of CAPE Dissipation (1/τ)
July 2006



Standard Tau

Dynamic Tau

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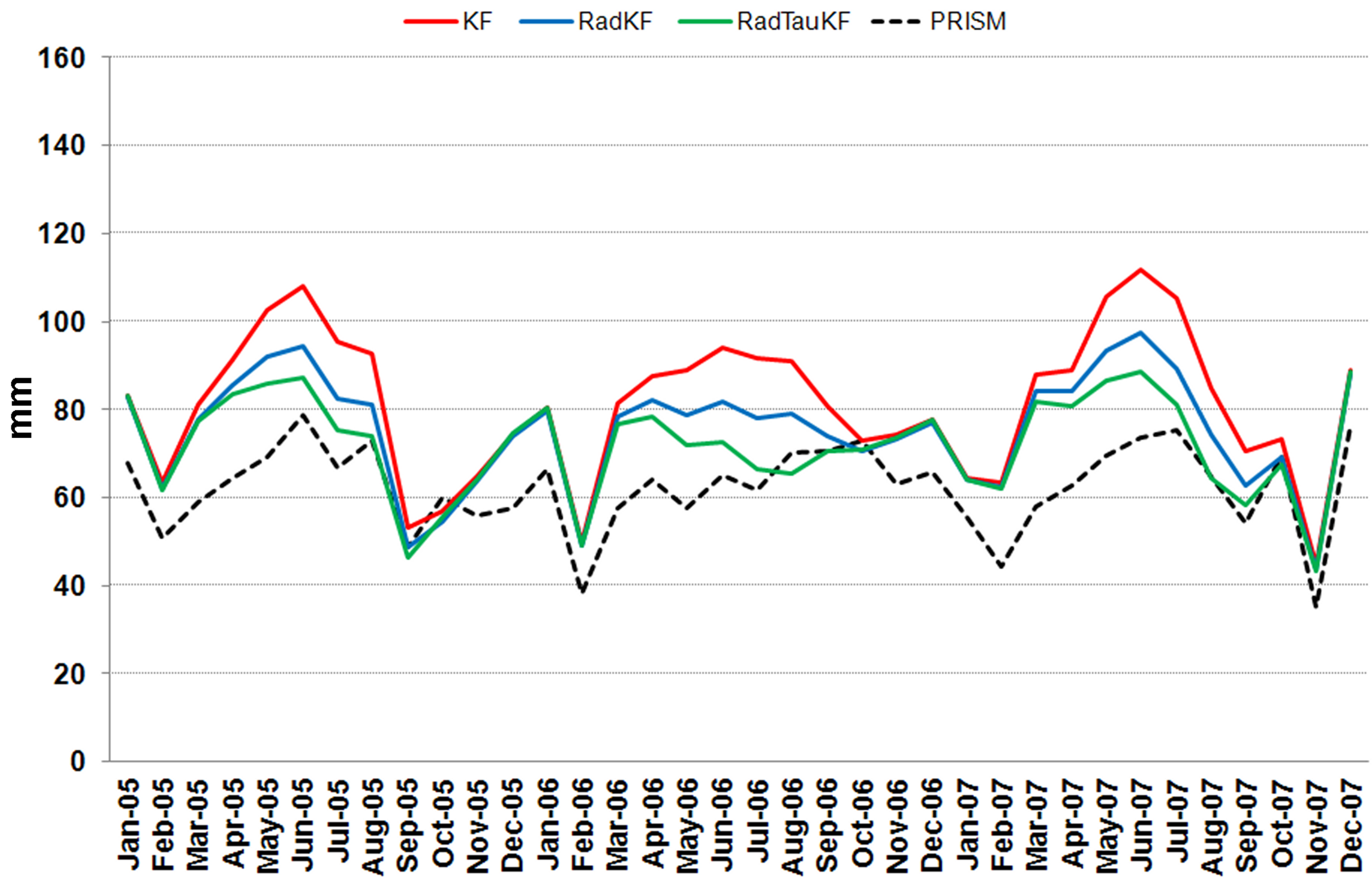
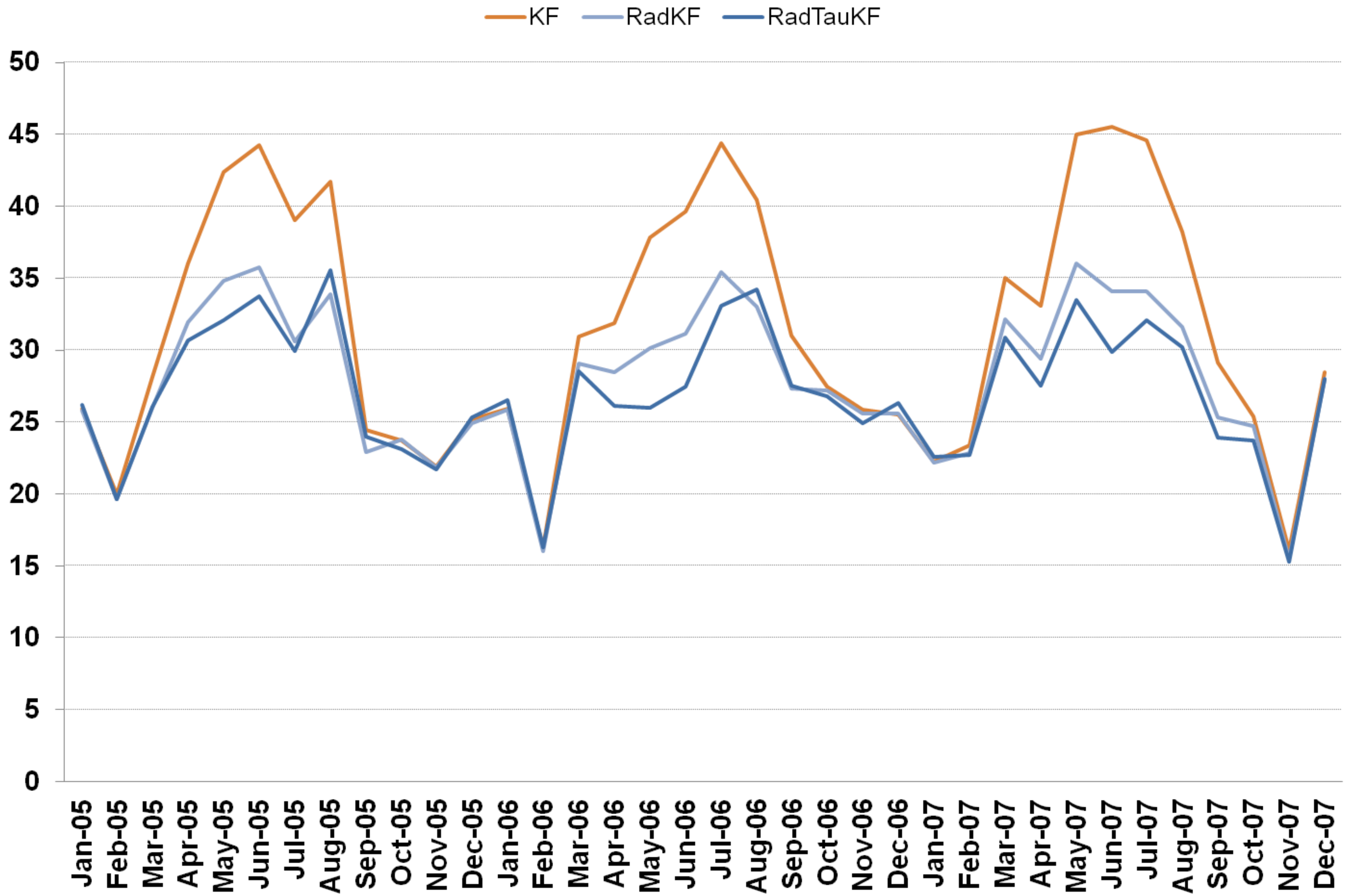
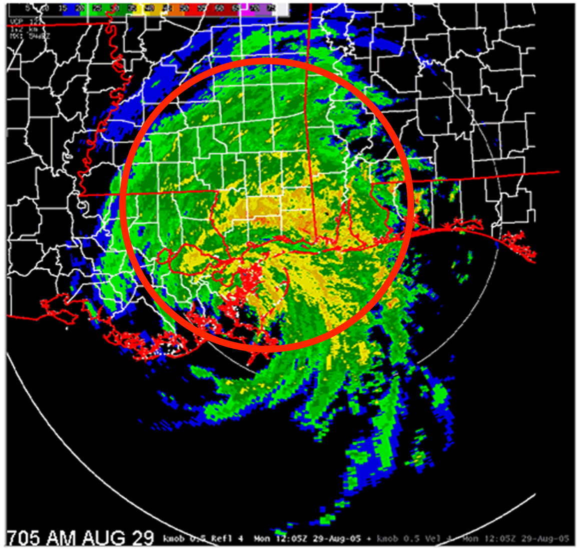
Average monthly precipitation from WRF test cases versus data from the Parameter-elevations Regressions on Independent Slopes Model (PRISM)



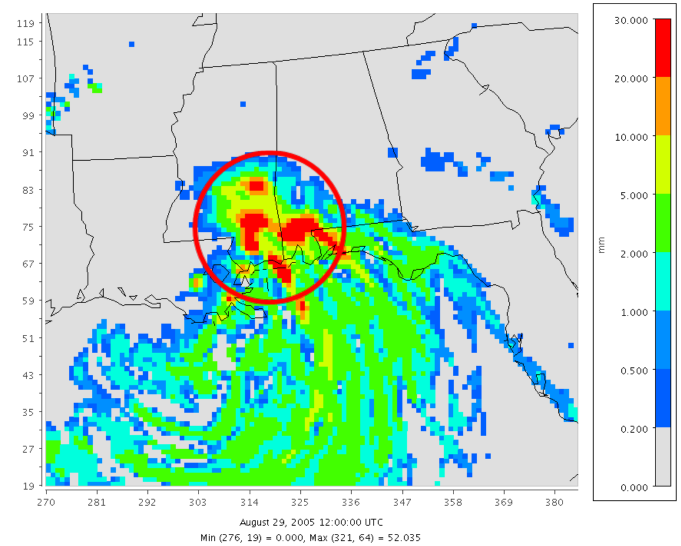
Mean Absolute Error vs. PRISM (mm)



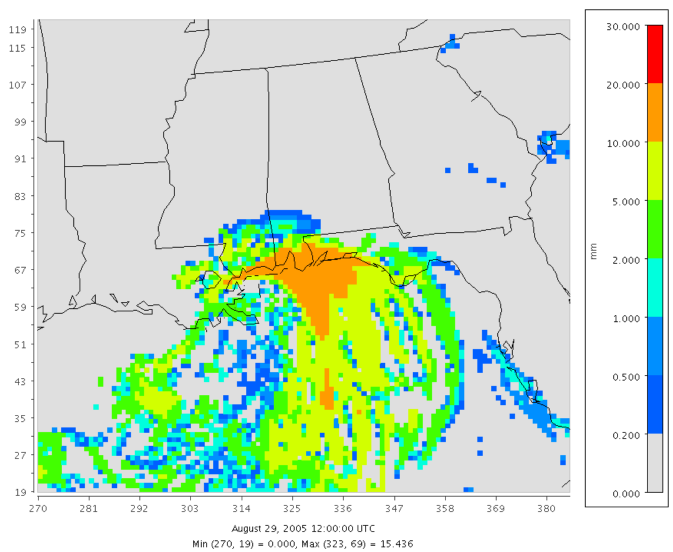
Tropical Storm Rainfall (Katrina)



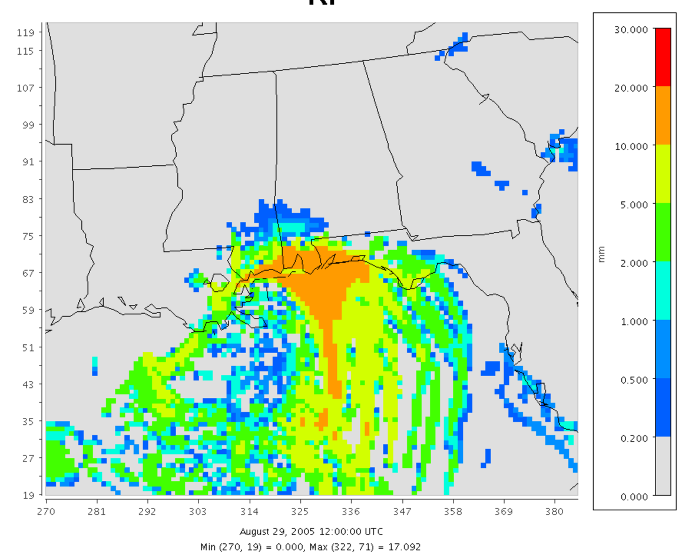
RadTauKF



RadKF



KF



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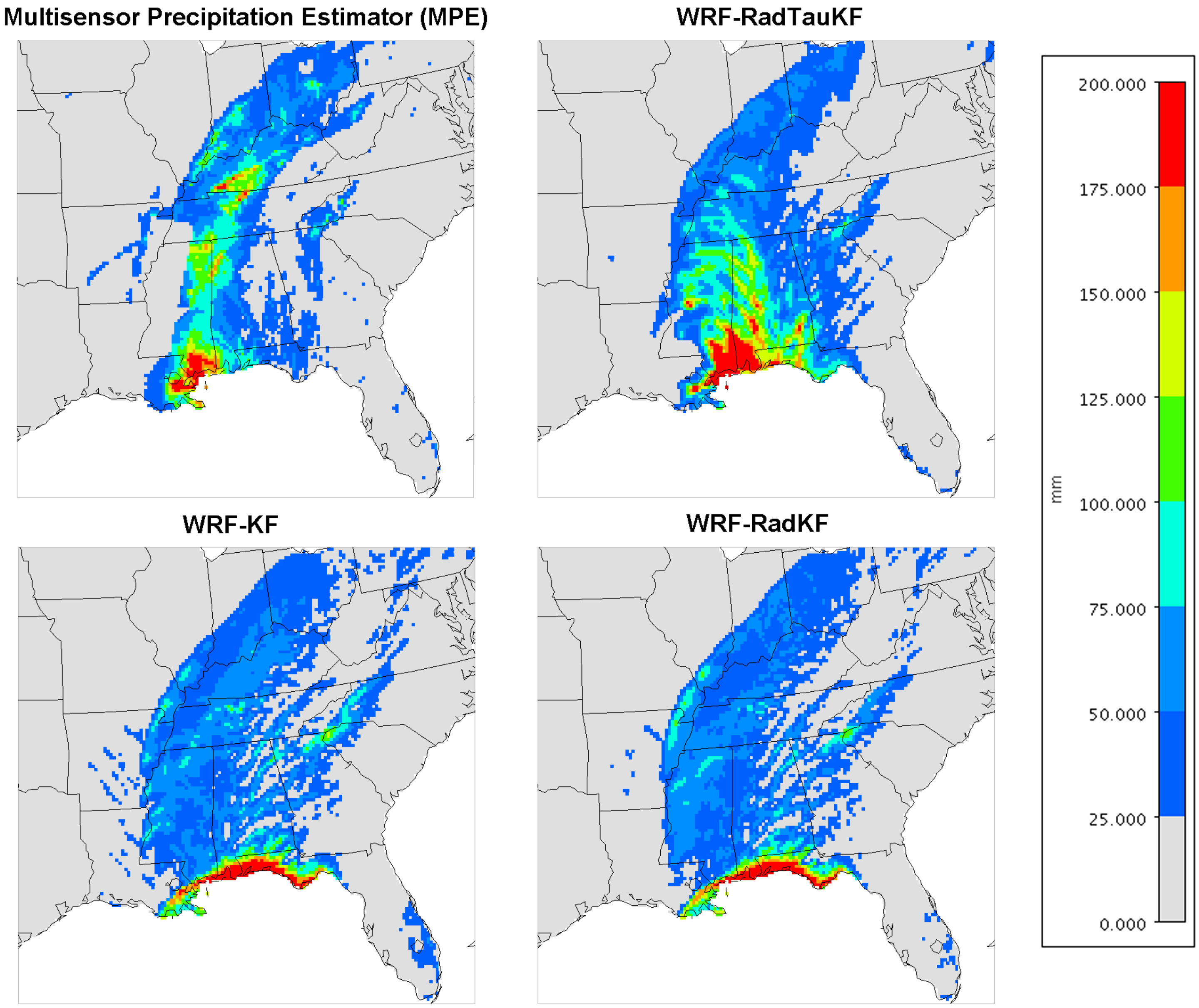
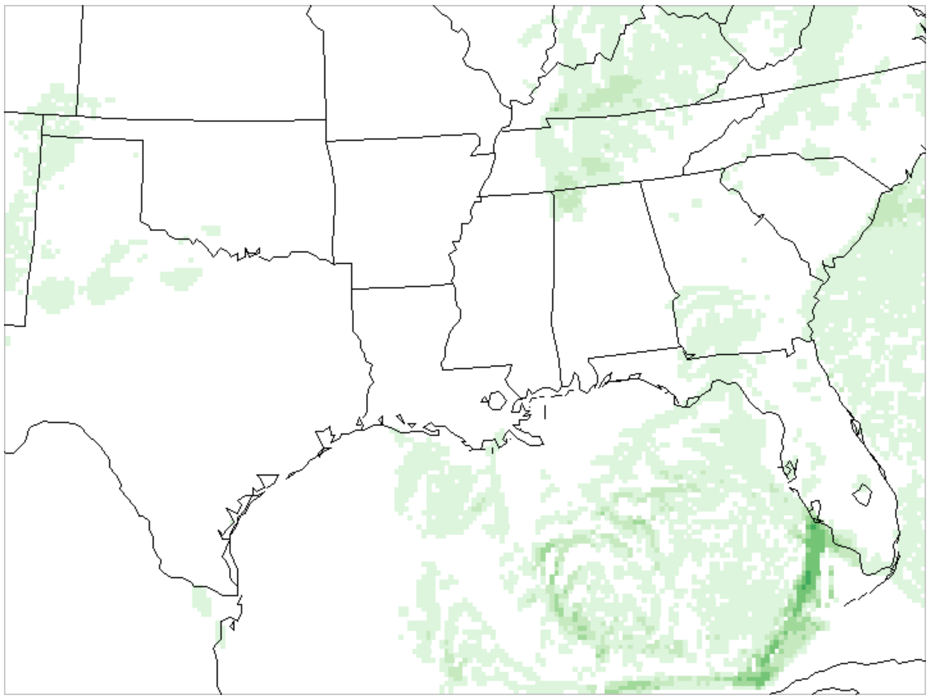
Katrina: August 28-31, 2005



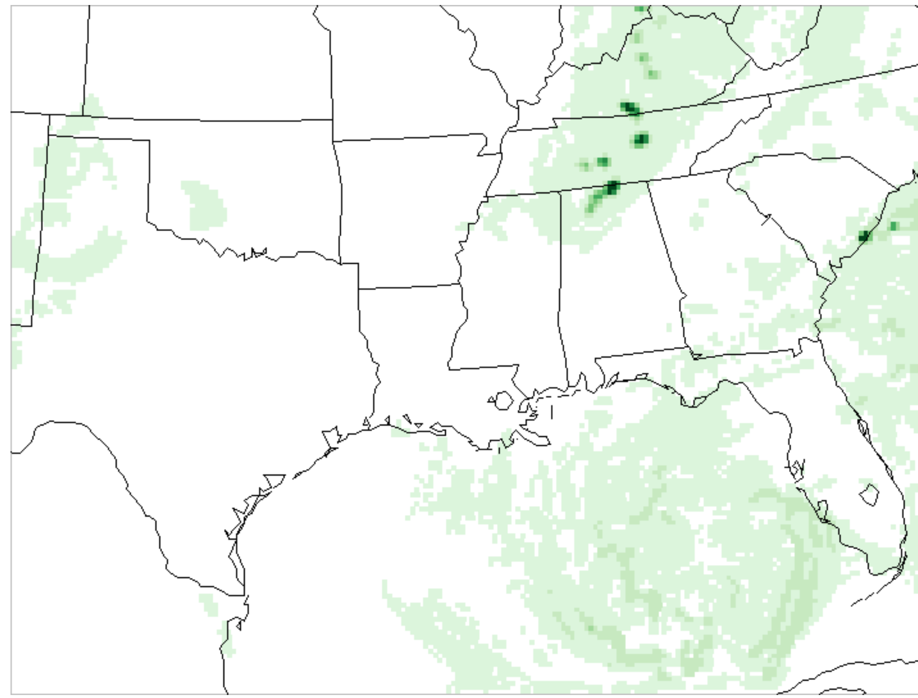
Katrina Landfall

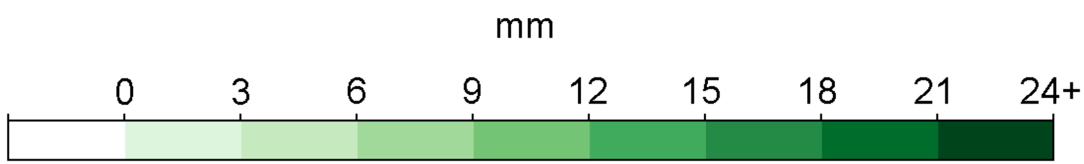
Animation of hourly precipitation (total = resolved + conv.)

Standard KF



RadTauKF



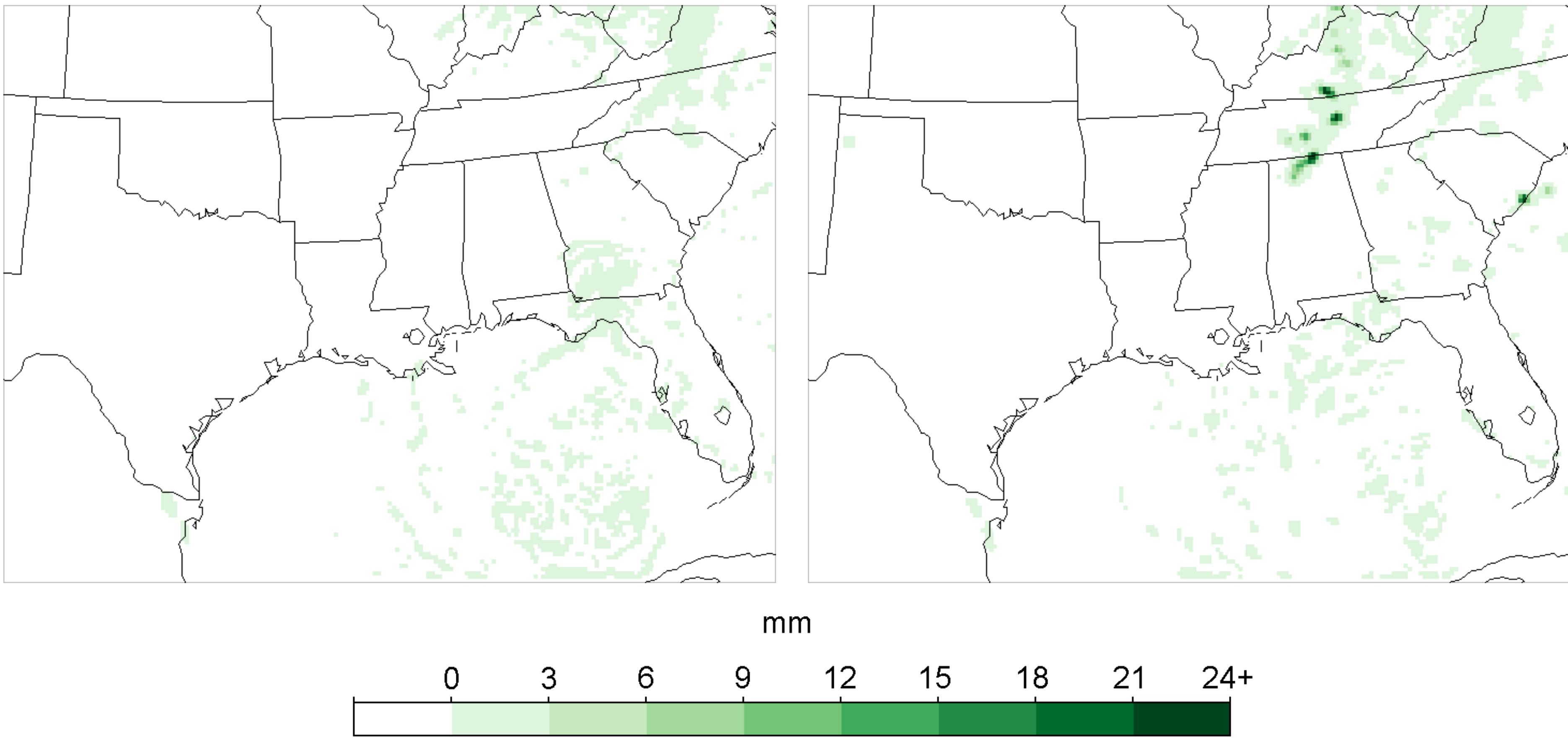


Katrina Landfall

Animation of hourly resolved precipitation

Standard KF

RadTauKF



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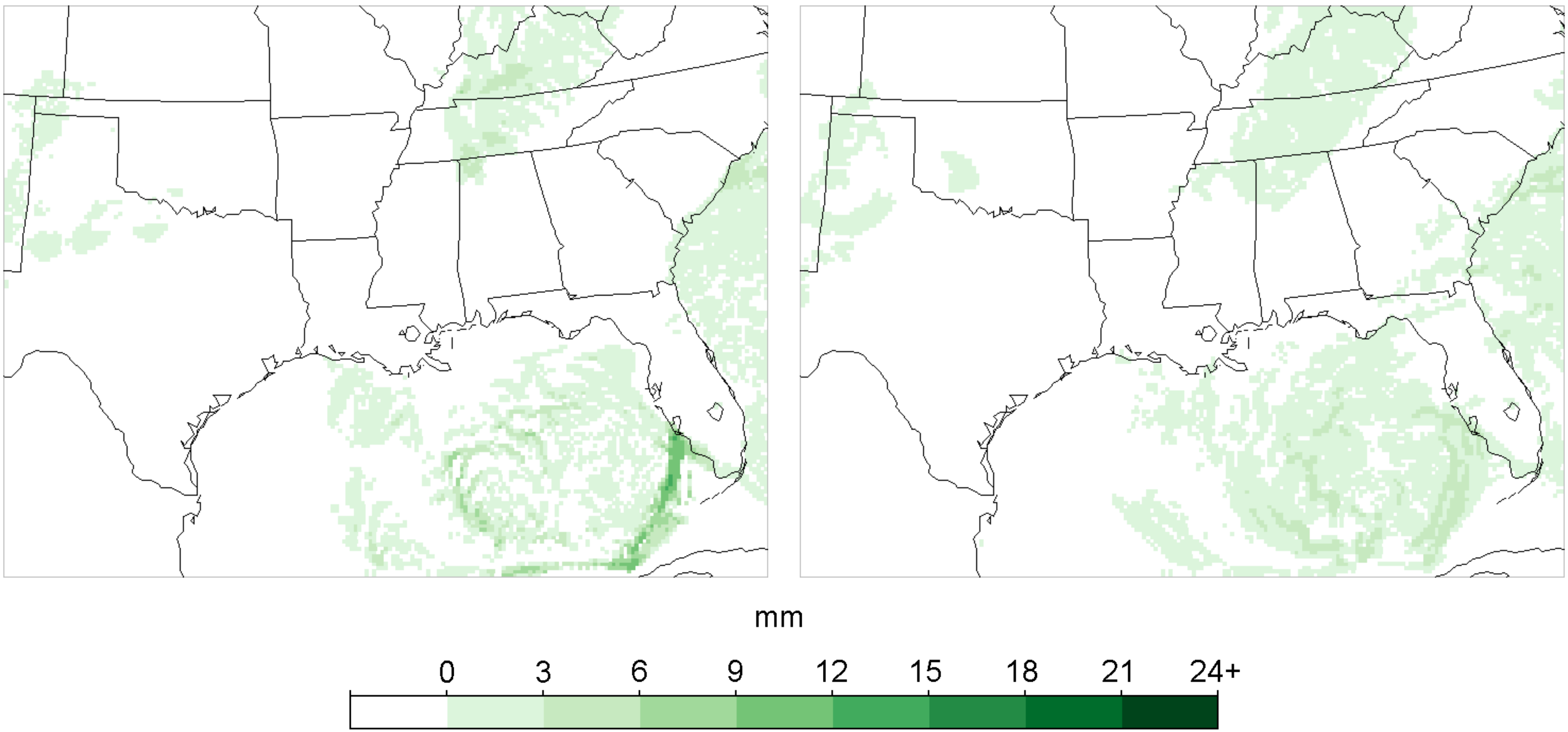
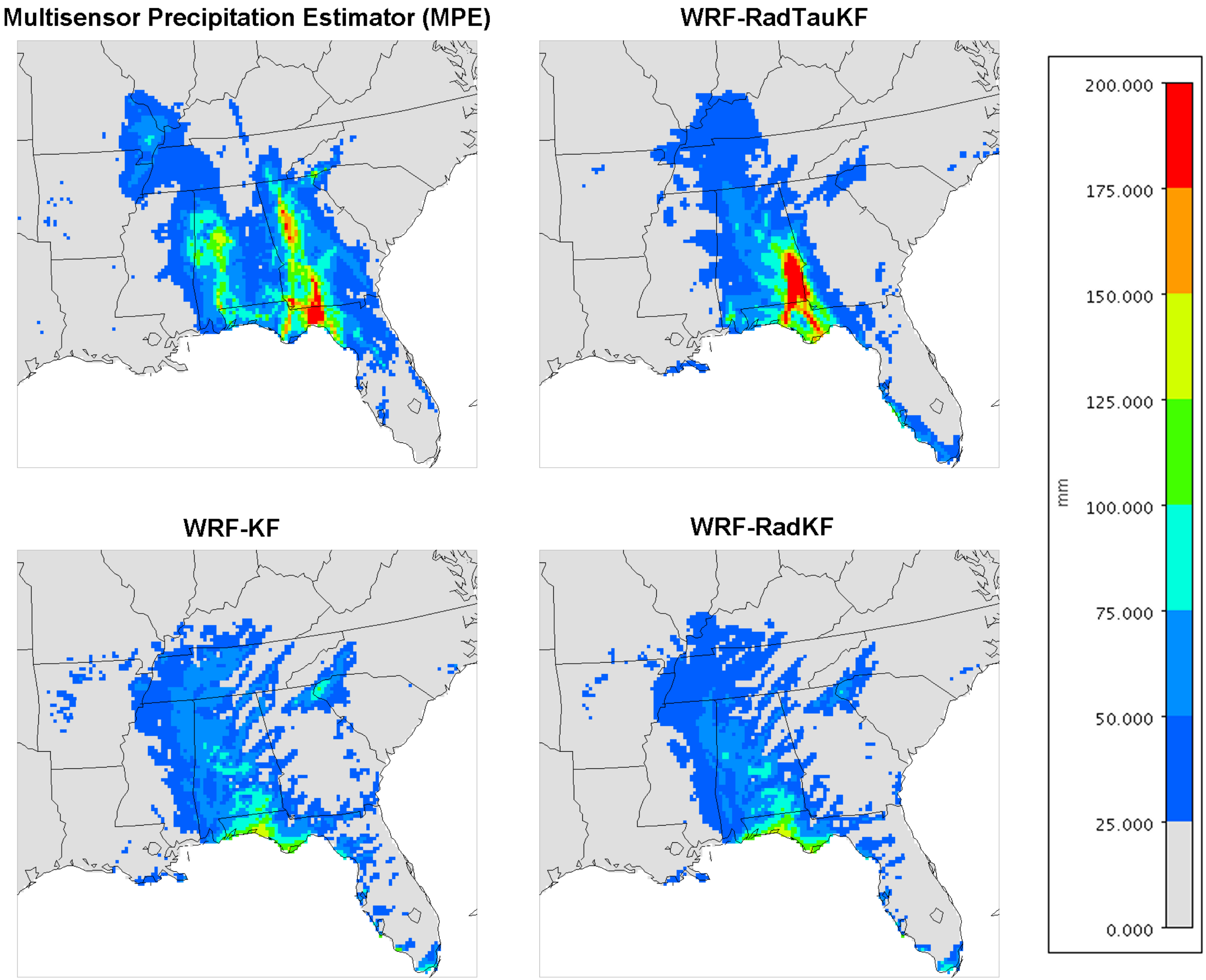
Katrina Landfall

Animation of hourly convective precipitation

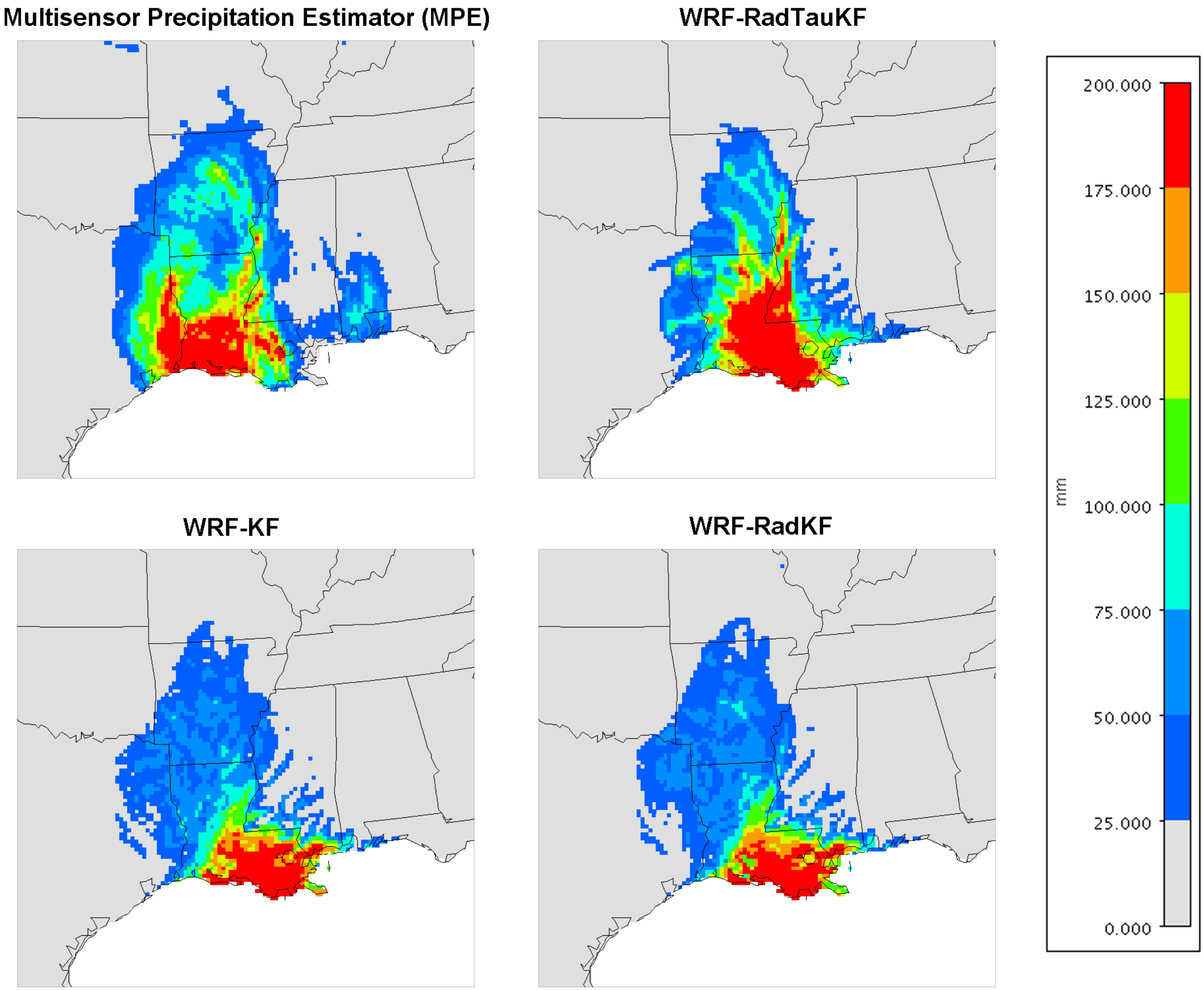
Standard KF | RadTauKF



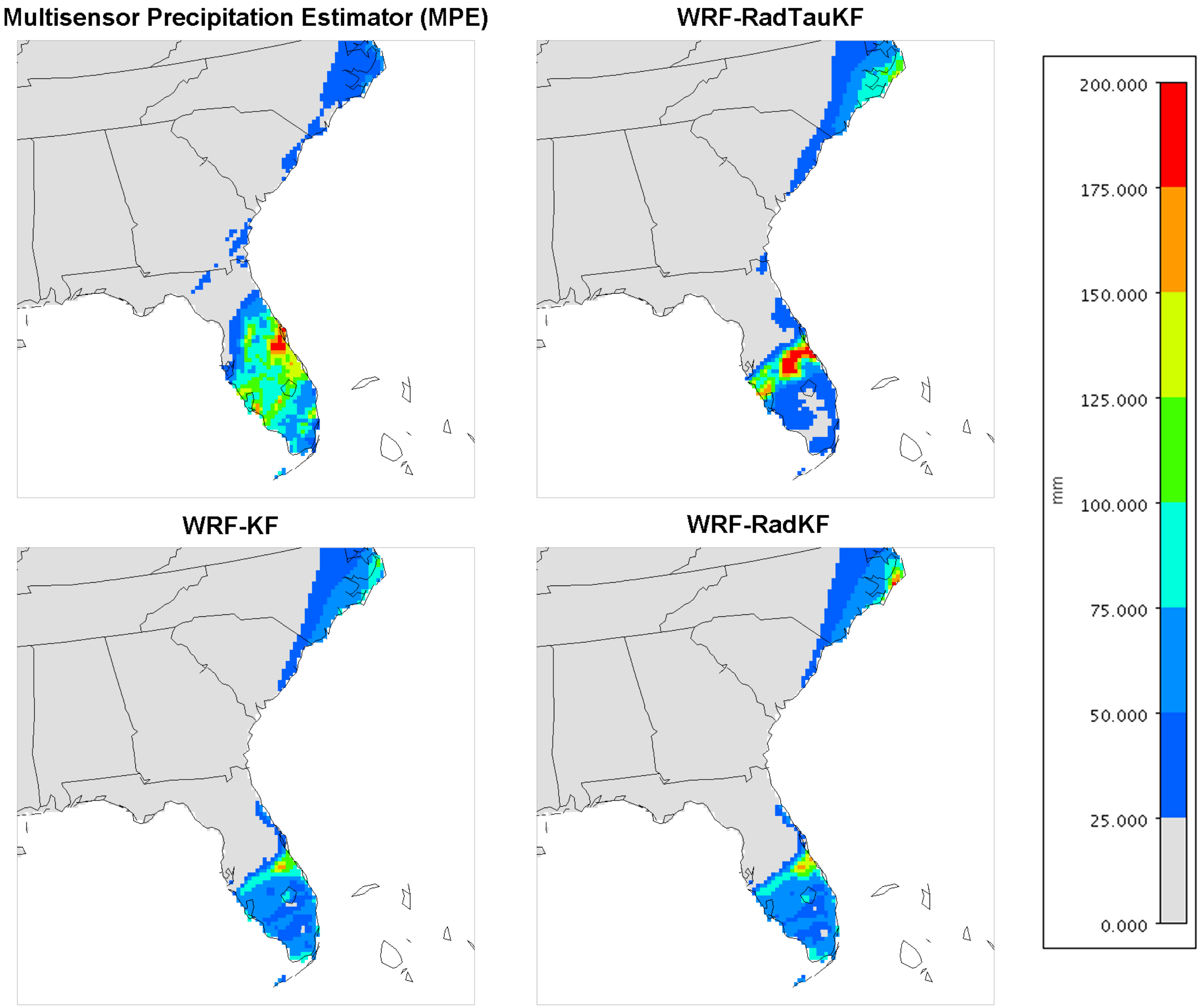
Dennis: July 10-11, 2005



Rita: September 23-25, 2005



Wilma: October 24-25, 2005



Summary and Future Work

- Our dynamic Tau reduces precipitation bias and error at 12-km grid spacing.
- The patterns of inland rainfall from tropical storms is **significantly** improved.
- We continue to study other aspects of the Kain-Fritsch scheme that may not be scale-appropriate for 12-km grid spacing and below.
  - entrainment
  - mixing of vertical velocity
  - coincident resolved and convective precipitation

References

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Questions?