Diurnal Variation of Precipitation during MC3E: NASA Unified - WRF (NU-WRF) Simulations

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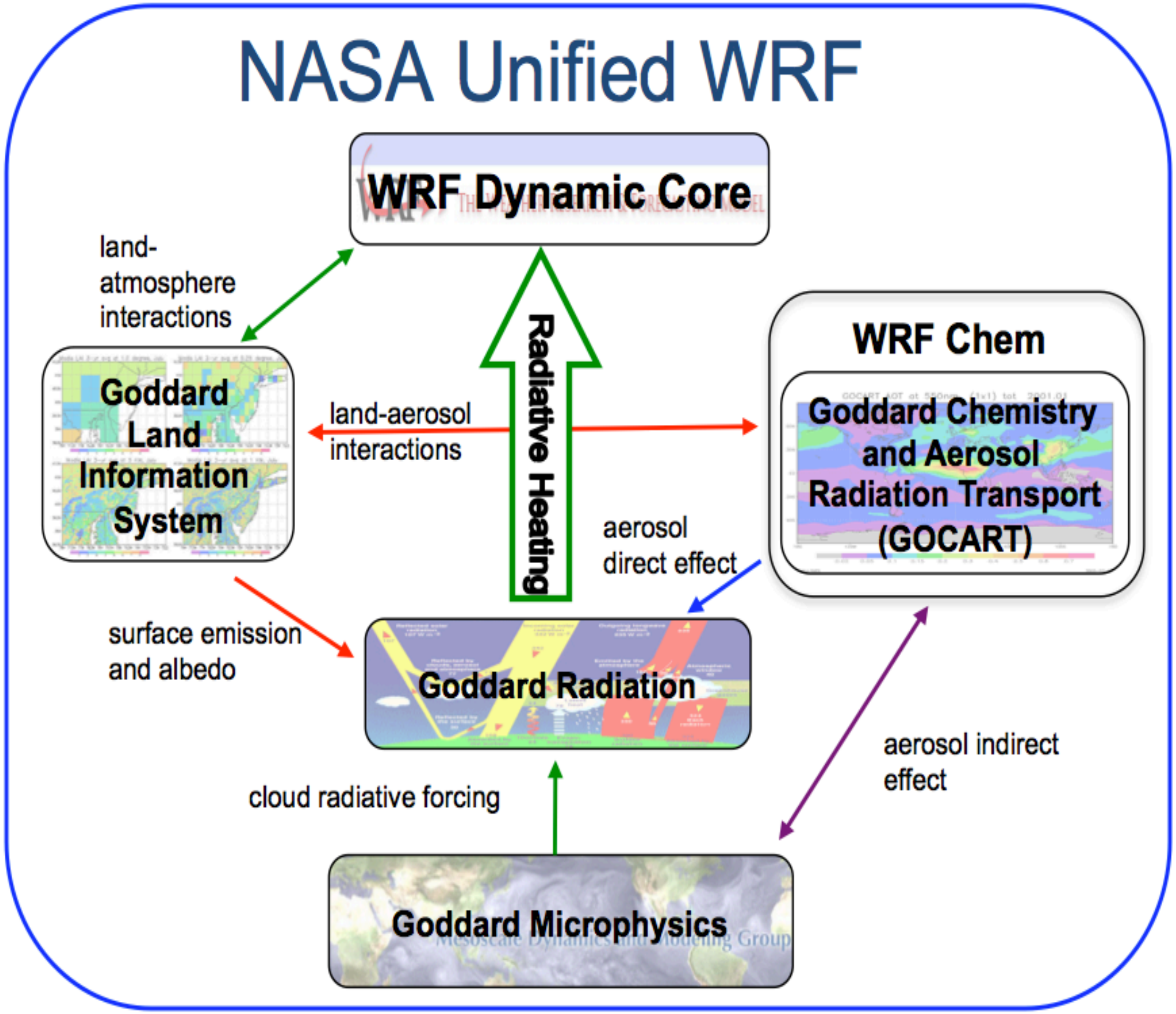
J. Geophys. Rev. (in press

NASA Unified WRF: NU-WRF (1)
Goddard Radiation (2)
Goddard Microphysics (2)

Physical Processes for Diurnal Variation of a MCS during MC3E

MC3E: Midlatitude Continental Convective Clouds Experiment
NASA / DOE Joint Field Campaign

1/13 + 1 (other WRF cases)



PI: C. Peters-Lidard

Land DA: J. Santaneilo
Rainfall DA: A. Hou
Aerosol: M. Chin
Microphy+Rad: Tao

Goddard Microphysics, Radiation, LIS and GoCART are coupled with **Goddard Cumulus Ensemble (GCE) model** and **Goddard MMF (Tao et al. 2009)**

Coupled with Goddard Satellite Data Simulator Unit (SDSU)
Microphysics and Radiation are being coded in GPU

Goddard Radiation Packages

Goddard radiation package (original name CLIRAD) has been developed for two decades at NASA Goddard by Drs. Ming-Dah Chou and Max J. Suarez for use in general circulation models (**GEOS GCM**), regional model (**MM5, WRF**) and cloud-resolving models (**GCE**).

Chou M.-D., and M. J. Suarez, 1999: A solar radiation parameterization for atmospheric studies. NASA Tech. Rep. NASA/TM-1999-10460, vol. 15, 38 pp

Chou M.-D., and M. J. Suarez, 2001: A thermal infrared radiation parameterization for atmospheric studies. NASA/TM-2001-104606, vol. 19, 55pp

Wavelength	SW (Solar)	LW (thermal)
Flux solution	Two-stream adding method	Schwarzchild equation
# of bands	UV&PAR(8 bands) Solar-IR(3 bands)	10 bands
Optical approximation	Delta-Eddington approximation (for scattering and transmission)	Henyen-Greenstein function (for scattering), One/two-parameter scaling, modified k-distribution (for absorption)
Optical parameters	H_2O, O_2, O_3, CO_2, condensates (cloud water, cloud ice, snow, rain, and graupel), aerosols (sulfate and precursors, dust, black carbon, organic carbon, sea salt)	H_2O, O_3, CO_2, trace gases (N_2O, CH_4 , CFC11, CFC12, CFC22), condensates (cloud water, cloud ice, snow, rain, and graupel), aerosols (sulfate and precursors, dust, black carbon, organic carbon, sea salt),
Accuracy	Heating rate error within 5% accuracy in comparison with a LBL model.	Cooling rate error within 0.4K/day in comparison with a LBL model.

Differences between GEOS and CRM's radiation

- **Overlap assumption**: CRMs assume cloud fraction is zero or unity, while GEOS assumes cloud fraction varies from 0~1 (random or maximum overlap assumption).

  Thus, cloud overlapping routine and clear-sky radiative transfer are completely skipped in a CRM radiation (x2 faster).

- **Optical depths for condensates** (definition of cloud)

  cloud optical depth (**0.0001 in CRM** – thin cloud) vs (0.05 in GEOS)

- **Effective Radius**

  Ice cloud effective radius (25~125micron) depends on ambient temperature vs fixed value (80micron – GEOS)

  Effective radius for precipitation particles (rain, aggregate, graupel) is considered in CRM

- **Optimization**

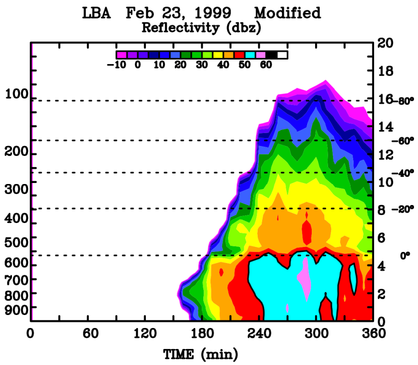
  Used 1-dimensionalized radiative transfer to skip nighttime computation

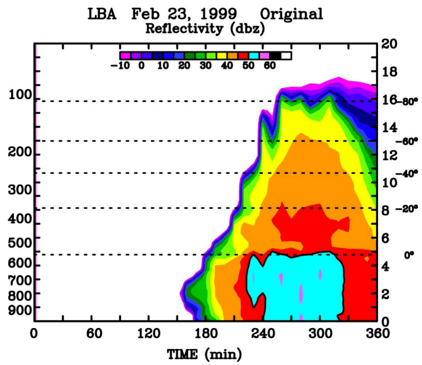
  Removed redundant routines

  Added option (fast_overcast) that used a pre-computed look-up table for F_{cloud}/F_{clear} as a function of cloud albedo.

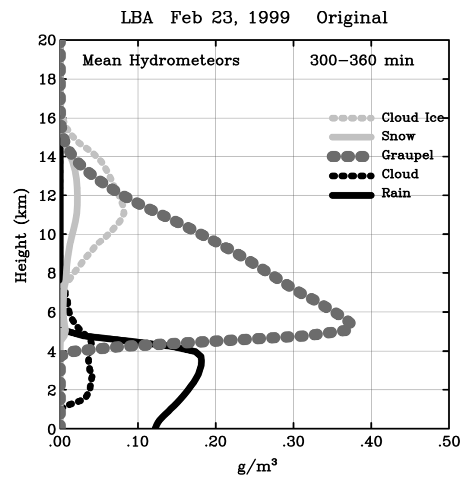
More than 25% computational cost even call it every 10 time steps

- Lang et al. (2007, JAS) – WRF V3
- Lang et al. (2011, JAS): Reduced un-realistic 40 dBZ aloft and reduced graupel amount – Next WRF

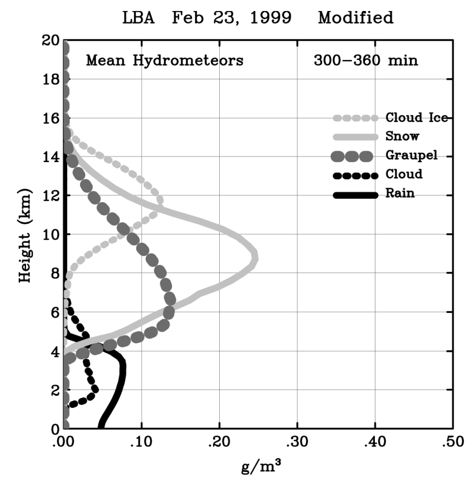


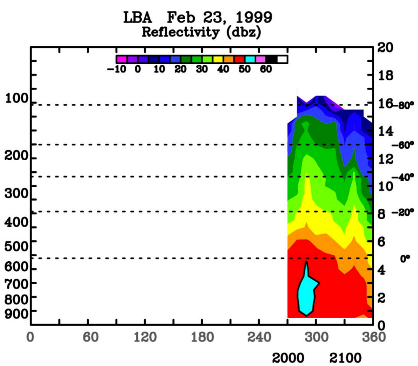


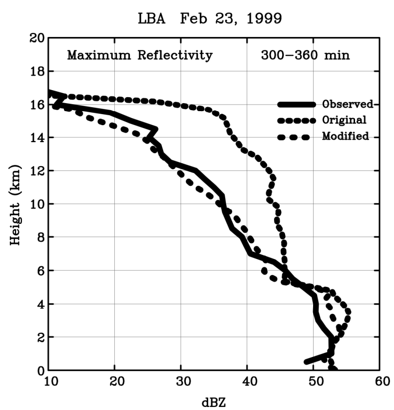
Lang et al. (2007)



Lang et al. (2011)



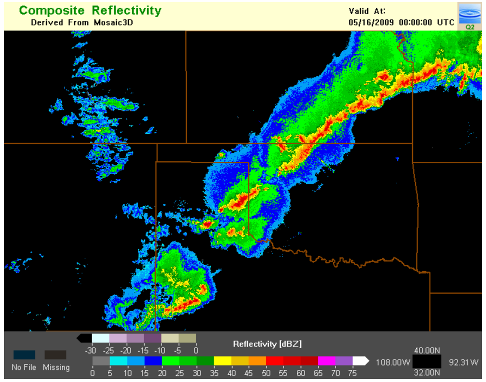


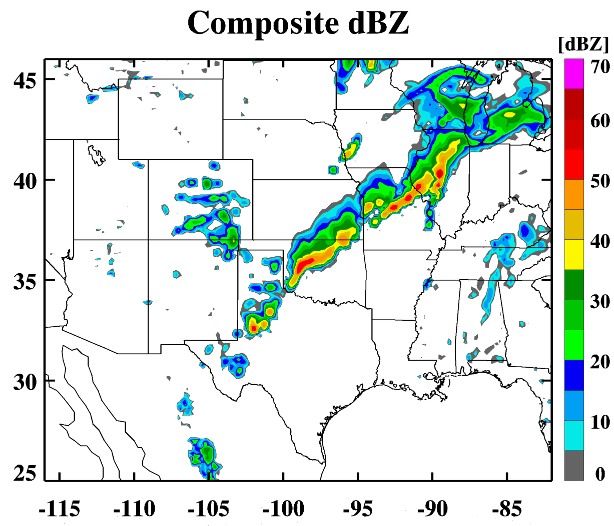


Reduce the graupel, but increase both cloud ice and snow mass

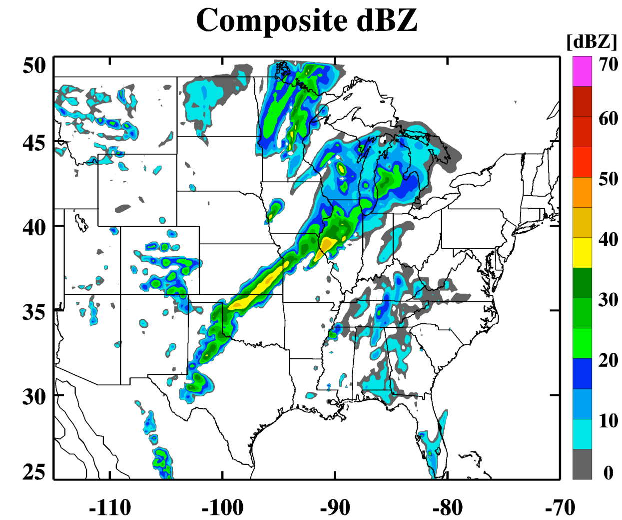
Reduce the rainfall due to less melting by less graupel (not always true for CRM simulation with prescribed large-scale advective forcing)

Observation





3ICE-Hail



3ICE-Graupel

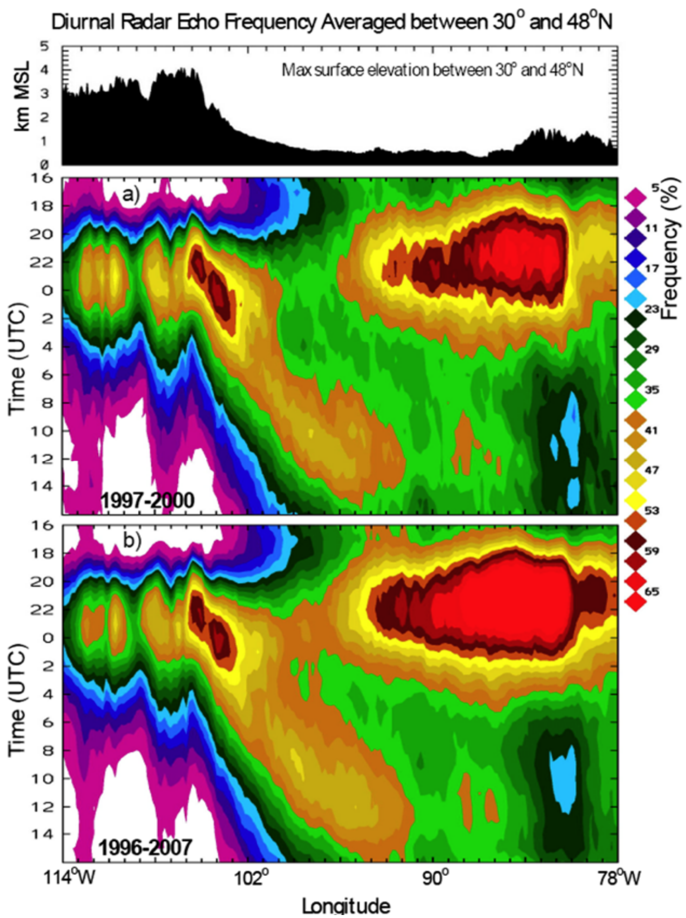
Latent Heating Profiles aloft are quite different between these two schemes

Lang et al. (2013, JAS – 4ICE scheme) + reduction of rain evaporation (derived from spectral bin Microphysics)

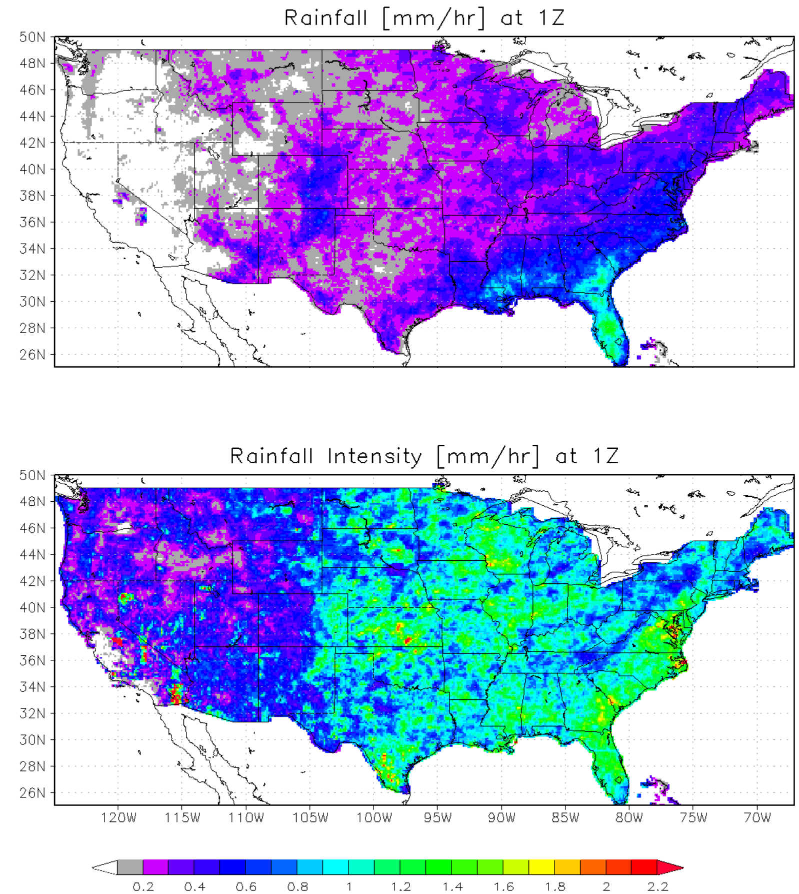
Two Moments 4-ICE (2014)

IR

R. Carbone



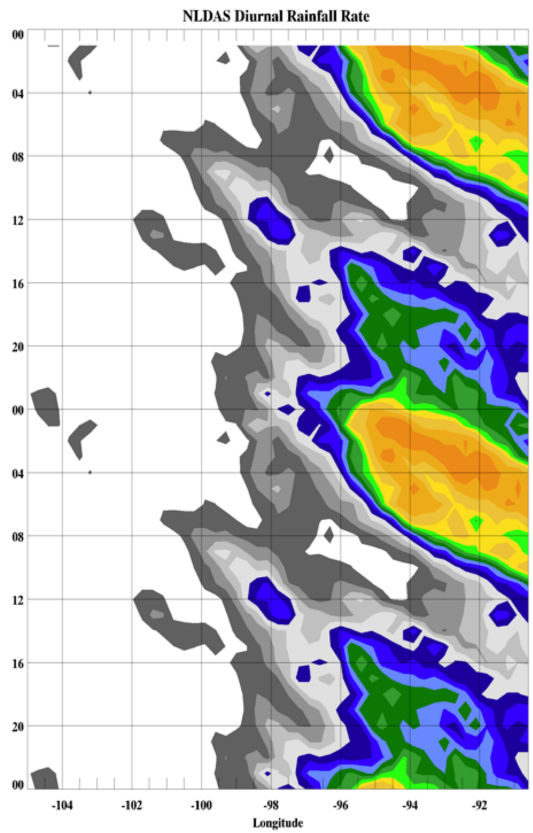
Rainfall and Rainfall Intensity

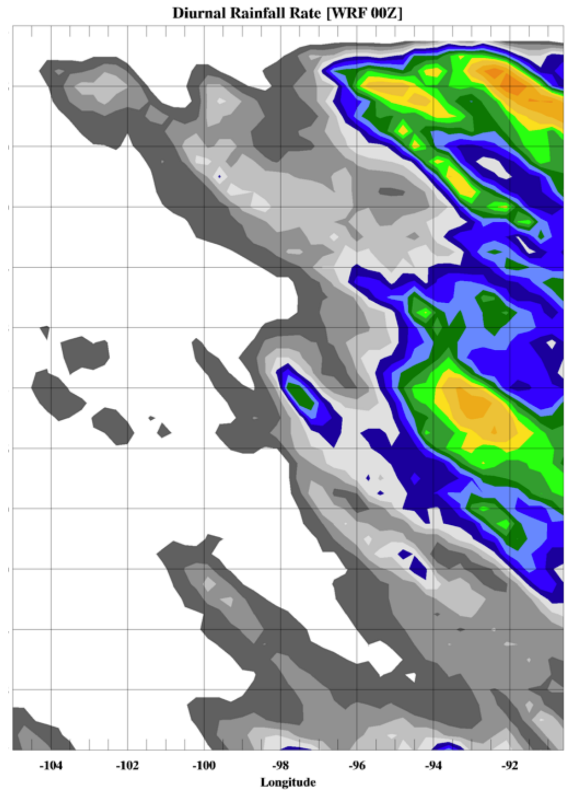


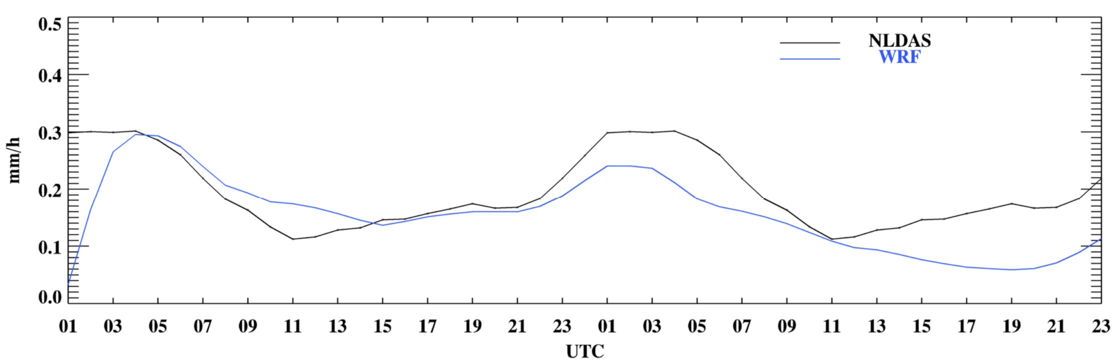
The diurnal variation of precipitation over central US can also be generally categorized into two different types:

1) afternoon rainfall maxima due to mesoscale and local circulations over the south and east of the Mississippi and Ohio valleys, and
2) nocturnal rainfall maxima from eastward-propagating mesoscale convective systems (MCSs) over the Lee side of Rocky Mountain regions

Diurnal Variation (April 20-June 3, 2011)







Time series of WRF model-estimated domain mean surface rainfall rate (mm h^{-1}). The observation is also shown for comparison.

The model simulated diurnal variation of rainfall captures observed well. For example, two peaks at 05 UTC and 03 UTC are simulated.

Key high resolution modeling papers to study the diurnal variation of the precipitation. Model types (MM5, WRF, GCE), microphysical schemes, cumulus parameterization, domain size (km), resolution (km), initial conditions, cases and integration time (hours) are listed.

	Model	Forcing data	Physics	Domain Size	Resolution	Period
Moncrieff and Liu (2006)	MM5	Eta operational model analyses	Microphysics and Cumulus parameterization	2400 x 1800 km	3 and 10 km 40 layers	7 day simulation 3- 9 July 2003
Liu and Moncrieff (2007)	MM5	Eta operational model analyses	Different Microphysics Schemes	2400 x 1800 km	3 and 10 km 40 layers	7 day simulation 3- 9 July 2003
Surcel *et al.* (2010)	GEM	3DVAR regional Data Assimilation System	Kuo Kain and Fritsch	North America	15km 58 layers	30 h forecast Spring and Summer 2008
Clark *et al.* (2007)	WRF-NMM WRF-ARW	NAM 12km	Kain and Fritsch Ferrier	North Central US	5 km and 22km 38 layers	48 h forecast 1 April-25 July, 200[illegible]
Davis *et al.* (2003)	Eta (NCEP) WRF	Eta forecast	Kain and Fritsch Simple ice scheme	Continental United States (CONUS)	22 km	1-3 day forecast 2001 (July–August) and 2002 (June–July)
Trier *et al.* (2006)	WRF	Eta operational model analyses	Purdue - Lin	2500 x 1780 km	4 km	7 day simulation 3 - 10 July 2003
Lee *et al.* (2007)	GCE Model	DOE ARM SGP	Goddard 3-Ice scheme	128 km	1 km 41 layers	55 days Summer 1995, 1997 and 1999

The **physical processes for the diurnal variation of rainfall** over land during summer time in US, generally, are

(1) large-scale flow including **Eastward upper wind** (Moncrieff and Liu, 2006; and others),

(2) Land surface (continental thermal) forcing including thermodynamic instability within **PBL** (Carbone *et al.* 2002; Warner *et al.* 2002; Lee *et al.* 2007; Trier *et al.* 2006);

(3) Successive propagating organized convection caused by convective gravity wave (Carbone *et al.* 2002; Moncrieff *et al.* 2006);

(4) LLJ (Trier *et al.* 2006);

(5) Diabatic heating effect (Moncrieff *et al.* 2066); and

(6) Terrain effect (Carbone *et al.* 2002).

Model Setup (NASA Unified WRF – NU-WRF)

- Three nested domains: 18, 6, and 2 km, and 40 vertical layers.
- Physics:

  Goddard Improved Microphysics Scheme (reduce un-realistic 40 dBZ aloft)

  Morrison, 4ICE, 3ICE-Hail, Spectral Bin

  Goddard Radiation scheme

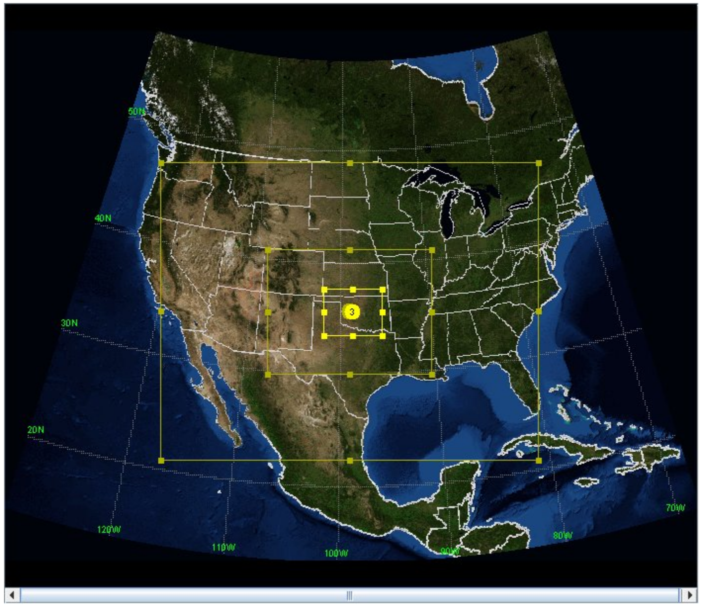
  Grell-Devenyi ensemble cumulus scheme

  MYJ planetary boundary layer scheme

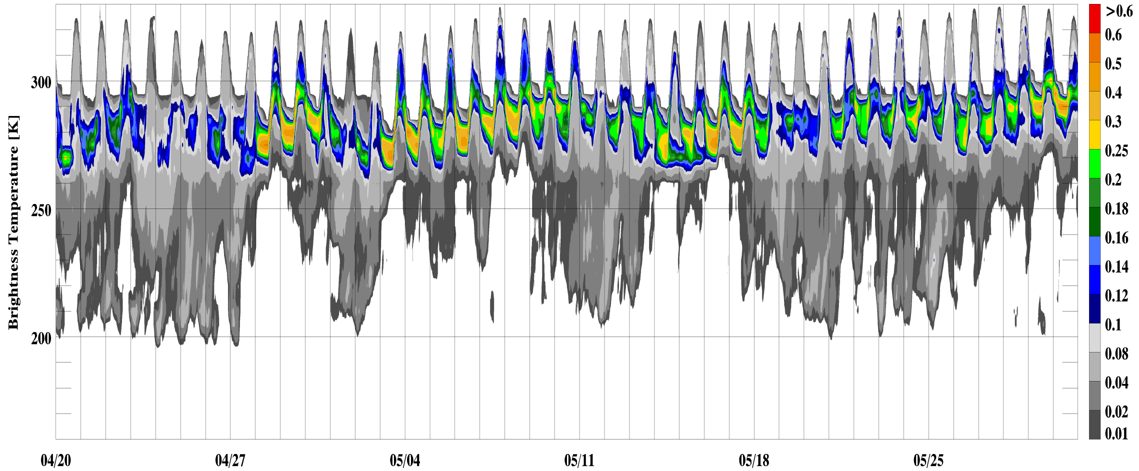
  Noah surface scheme

  Goddard LIS or without LIS

  Eta surface layer scheme
- Initial condition: NAM, ECMWF



MC3E Observed IR Bright Temperature : April 20 – June 3 2011



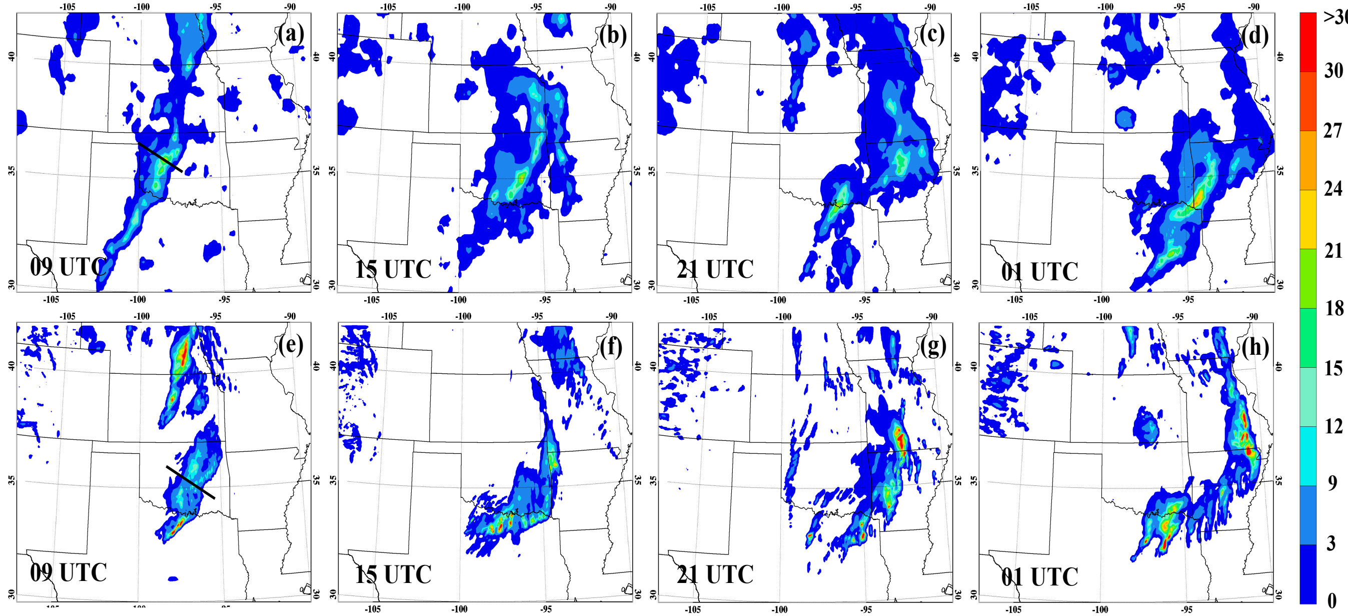
RED: have done the simulations

Strong Diurnal Variation in IR

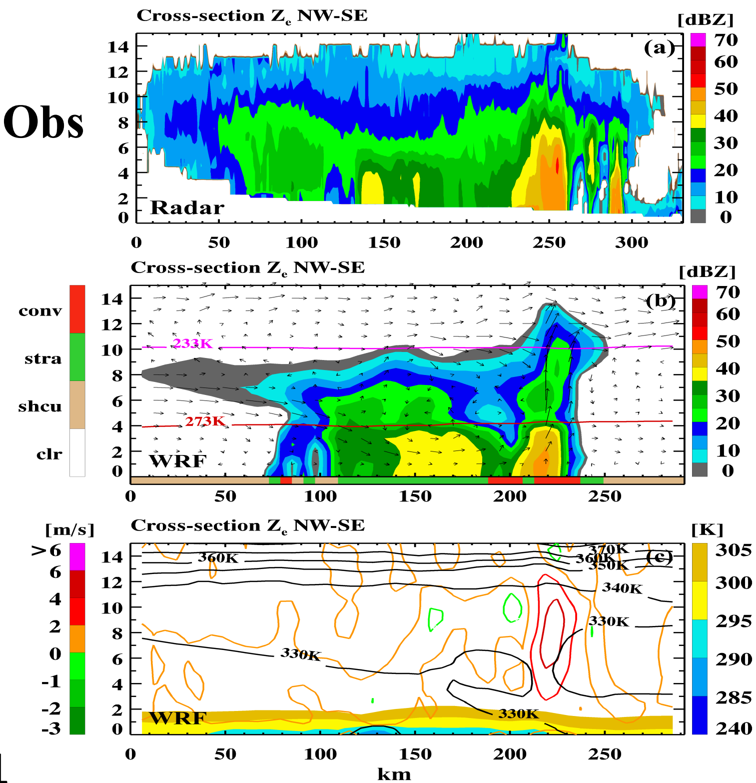
May 20 Case

Surface Rainfall

WRF →

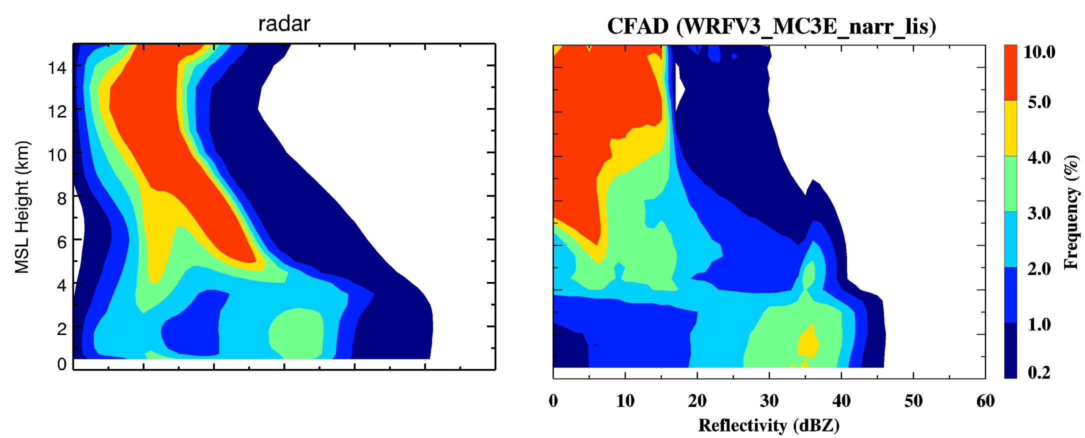


Obs

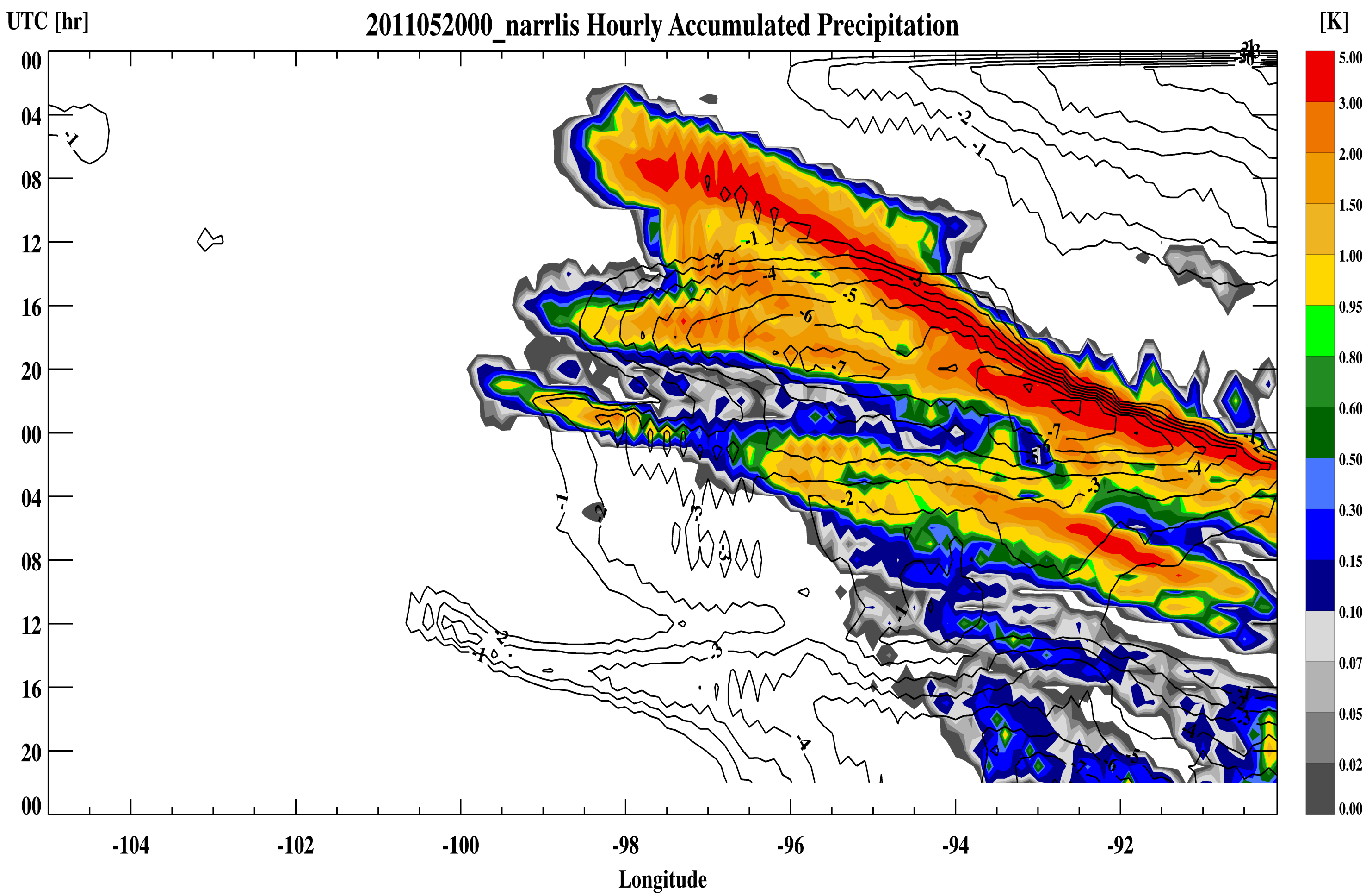


← Vertical cross section (dBZ)

CFADs (Radar Refelectivity)

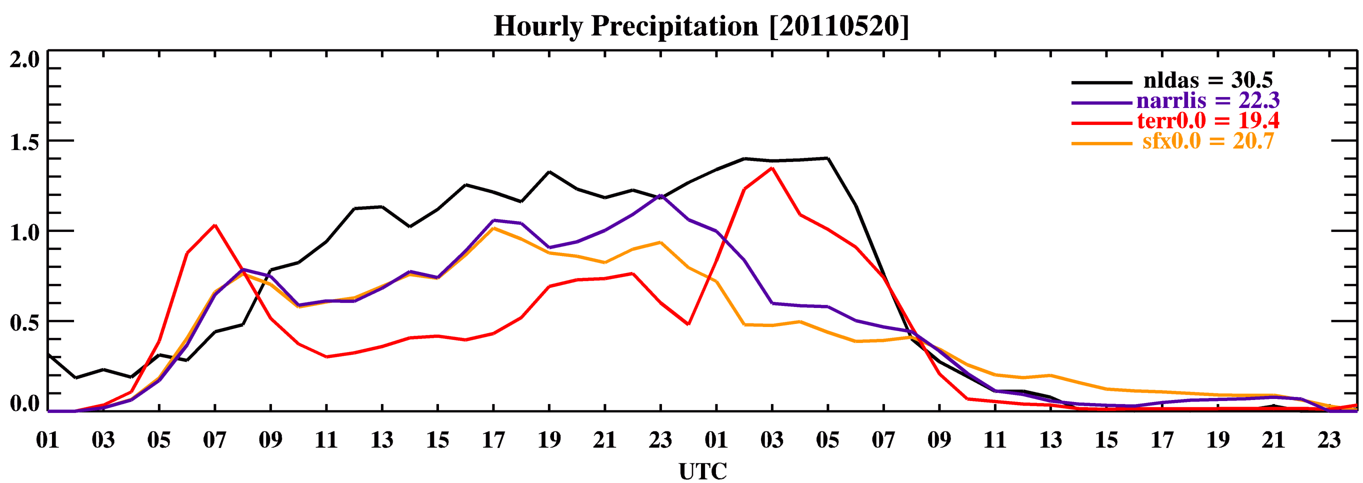


Time-longitude diagram for **deviation of virtual potential temperature from the domain average (filled contour)**, and **hourly precipitation (over laid in black)**.
From 00Z May 20th to 00Z May 22nd.



Close relationship between cool pool and rainfall
Cool pool boundary is ahead of intense rainfall

	mm/hour
Nldas	30.5
Control	**22.3**
Surface Effect	**5 -10% change, no impact on phase**
No surface flux	20.7
50% surface flux	21.6
Radiation Effect	**15% change, negative (positive) impact by solar heating (longwave cooling)**
No radiation	19.9
Terrain effect	**Increase terrain height has better agreement with observation, terrain is important in the initial stage of diurnal variation**
No terrain	19.4
50% terrain	19.2
110% terrain	22.9



References	Field Campaigns/Weather Events	Regions
Iguchi *et al*. (2012a) Shi *et al*. (2011)	C3VP/Snow events	Canada
Santanello *et al*. (2010)	IHOP/Squall line	Central USA
Shi *et al*. (2013)	NAMMA/MCS	Africa
Tao *et al*. (2011a, 2011b)	Hurricanes/Typhoon	South USA, Taiwan
Iguchi *et al*. (2012b) Tao *et al*. (2013)	MC3E/MCS	Central USA
Han *et al*. (2012)	HMT/Frontal	California
Nicholls *et al*. (2013)	Cyclones	N. E. USA
Ma *et al*. (2012)	African Easterly Waves/TCs	Africa/Eastern Atlantic Ocean

Two real time forecasts (MC3E 20111 and IFLOOD 2013) to support NASA PMM Field campaigns

Hurricane Sandy (1 and 10 km grid, 3 and 10 day simulations)

MJO (DYNAMO)

West Coast Storms