Introducing Scale-Aware Microphysics and Aerosol Cloud Interactions to the Weather Research and Forecasting Model (WRF-ACI)

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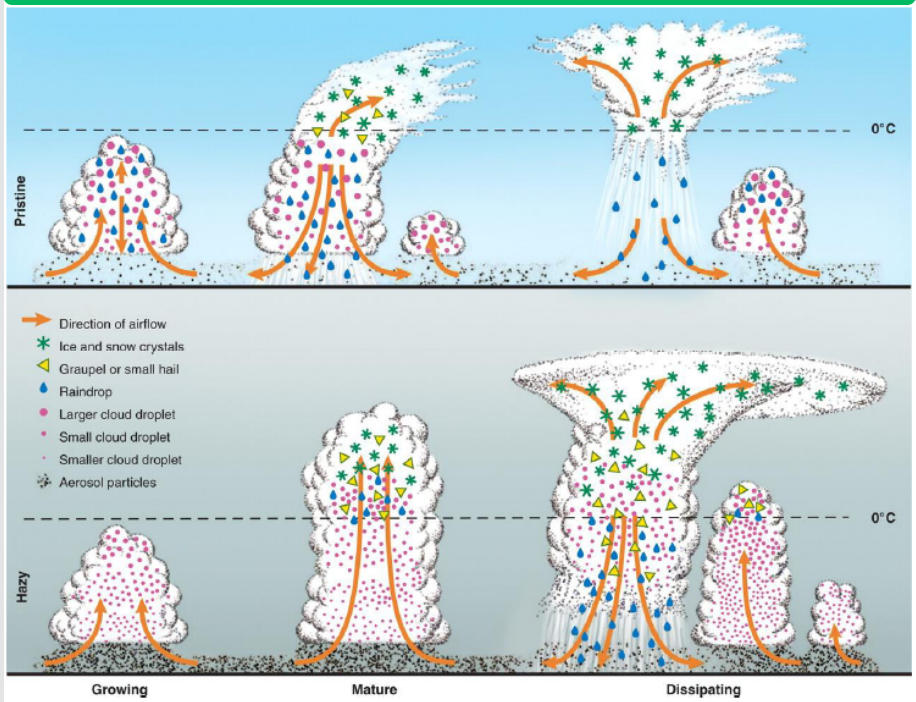
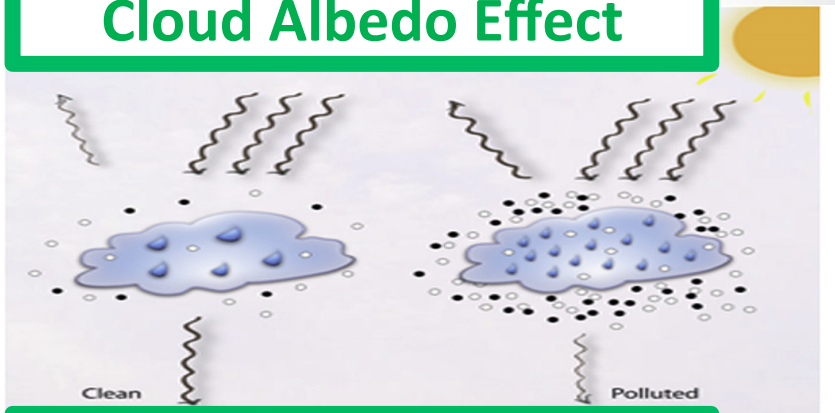
Aerosol Indirect Effects

Thermodynamic Invigoration

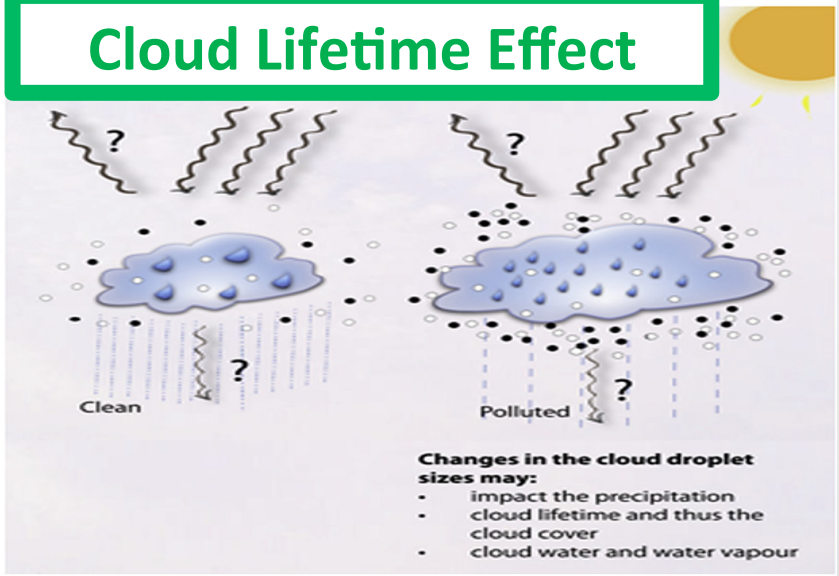


Some of the possible effects of anthropogenic aerosols on cloud structure and precipitation are illustrated in this conceptual cartoon. Cloud droplets coalesce into raindrops that rain out from pristine clouds. Anthropogenic aerosol perturbation causes formation of a larger number of smaller droplets which do not precipitate before reaching the freezing level, giving rise to deep and vigorous clouds that create thunderstorms and, possibly, hail. Secondary convection is promoted. (Rosenfeld et al., *Science*, 2008)

Cloud Albedo Effect



Cloud Lifetime Effect



Major Objective

Develop a scale-aware modeling system to represent the impacts of aerosols on both grid-scale and subgrid-scale clouds for use in high resolution regional numerical weather prediction simulations supporting ecosystem and human health research studies at the US Environmental Protection Agency

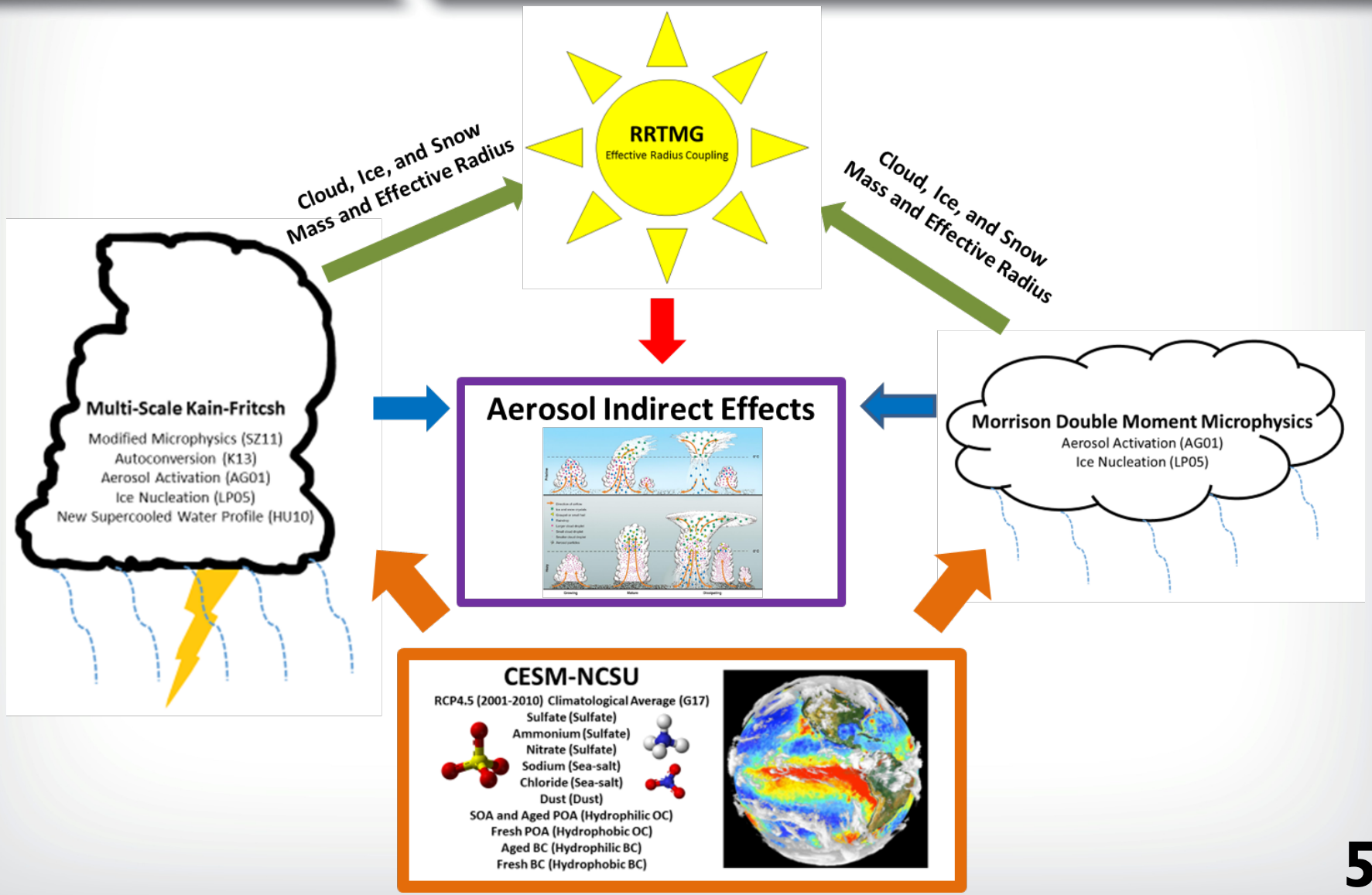
WRF-ACI:

Weather Research and Forecasting Model with Aerosol Cloud Interactions

WRF-ACI has four components:

- **Temporally and spatially varying bias corrected prescribed aerosol concentrations climatology with global coverage for current and future conditions**
- **Modified Song and Zhang (2011) subgrid-scale microphysics**
- **Consistent aerosol activation and ice nucleation parameterizations in both the grid-scale and subgrid-scale and microphysics packages**
- **Coupling of subgrid- and grid-scale microphysics to the radiation scheme**

WRF-ACI System



WRF-ACI Physics Configurations

- WRF Version: WRFv3.8.1
- Boundary Layer: YSU
- Land Surface Model: NOAH
- Cumulus Scheme: MSKF
- Microphysics: Morrison DMS
- Radiation: RRTMG
- Nudging: FDDA and FASDAS
- Two Part Study: JJA 2006 (Summer) and NWP (7 day)
- INPUTS: 12 km NAM, CESM-NCSU RCP4.5 (2001-2010)
- Evaluation Data: QCLCD, CERES-EBAF, MODIS, and PRISM

Part I (Model Evaluation)

Configuration of Simulations

Time Period: 3 months (June, July, and August 2006)

Type: Seasonal /Long term Simulation

Resolution: 12km

Region: Eastern United States

Simulations

Default WRFv3.8.1 = **WRF-BASE**

WRF-ACI Updates = **WRF-ACI**

Objectives

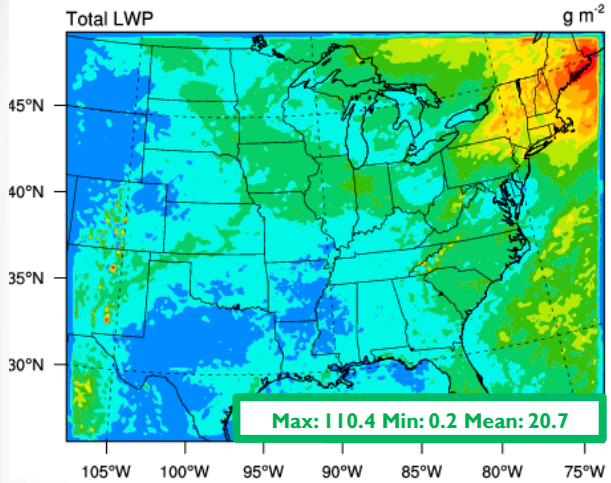
1) Quantify the differences between WRF-ACI and WRF-BASE
2) Evaluate model performance of WRF-BASE and WRF-ACI

Performance Evaluation of JJA Liquid and Ice Water Path

WRF-BASE

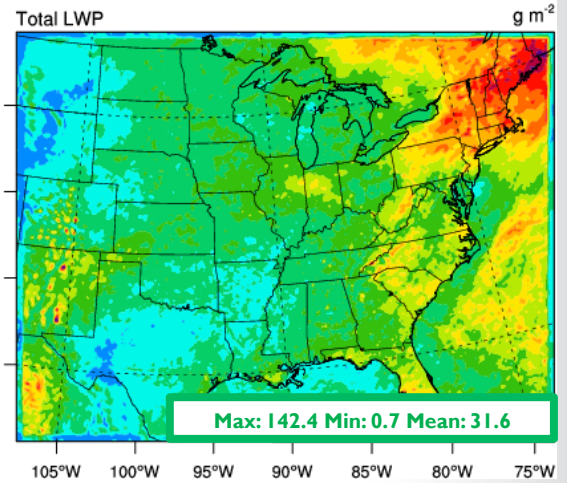
WRF-ACI

LWP ($g\ m^{-2}$)

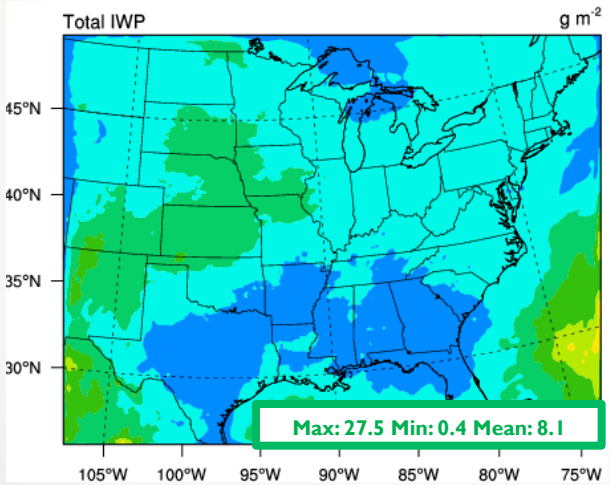


Compared to MODIS

Stat	WRF-BASE	WRF-ACI
Corr.	0.34	0.27
MB	-56.92	-26.40
RMSE	72.70	57.66

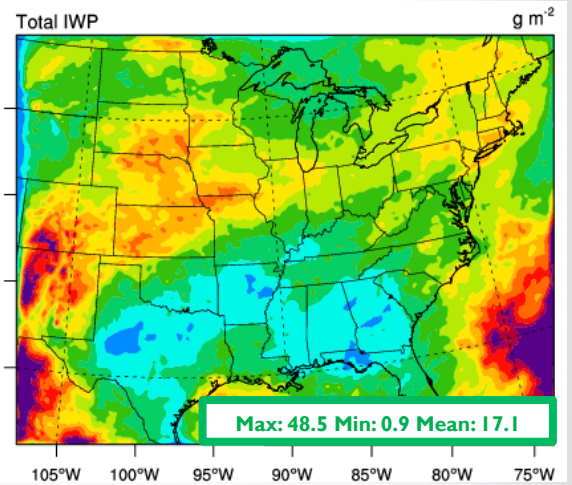


IWP ($g\ m^{-2}$)

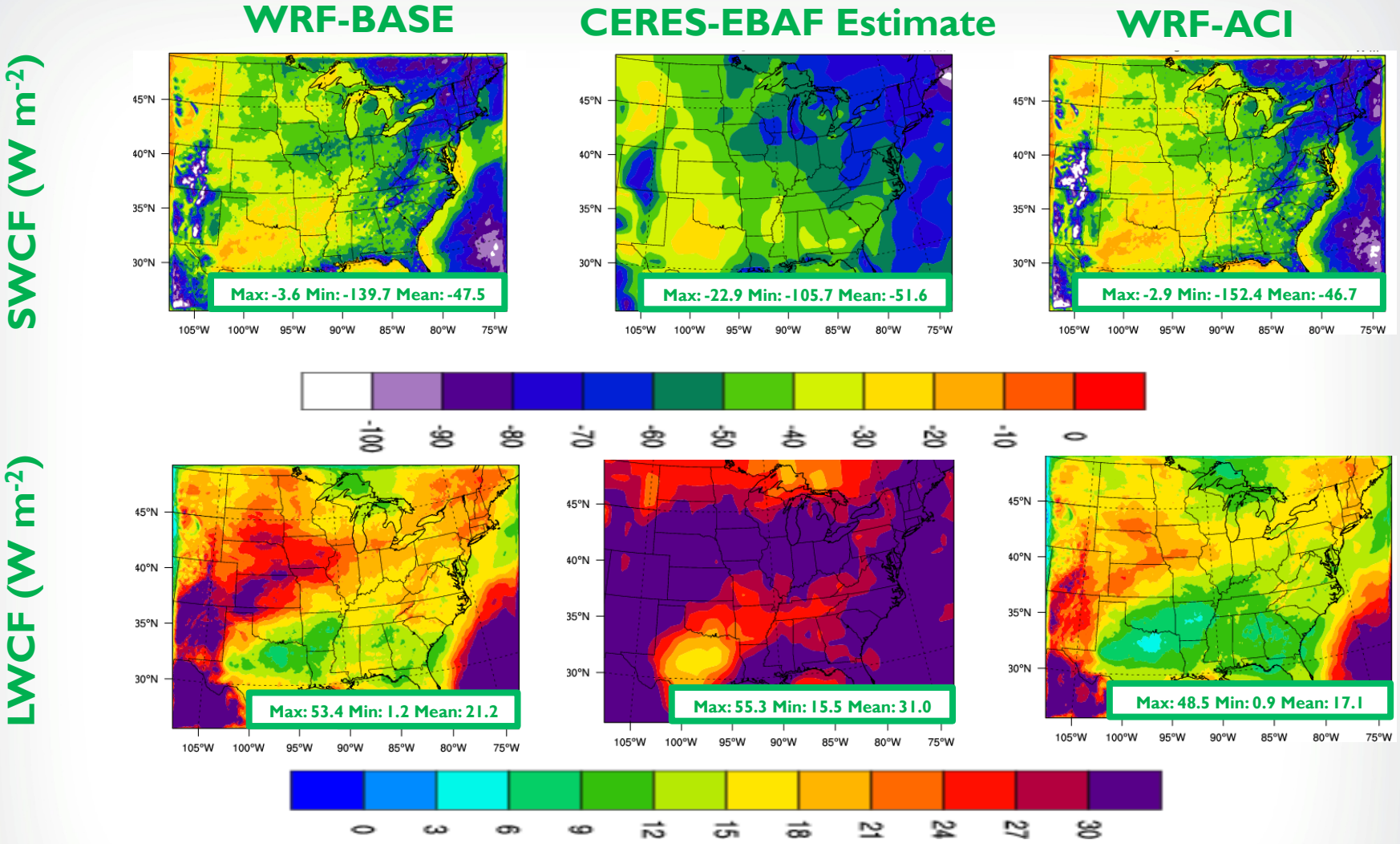


Compared to NOAA

Stat	WRF-BASE	WRF-ACI
Corr.	0.005	0.03
MB	-130.47	-92.28
RMSE	151.06	123.68



Performance Evaluation of JJA Radiation



Stat (LWCF)	WRF-BASE	WRF-ACI
Corr.	0.52	0.53
MB	-9.86	-13.90
RMSE	12.03	15.25

Stat (SWCF)	WRF-BASE	WRF-ACI
Corr.	0.64	0.67
MB	-4.07	-4.88
RMSE	14.11	14.85

Performance Evaluation of JJA Precipitation

WRF-BASE

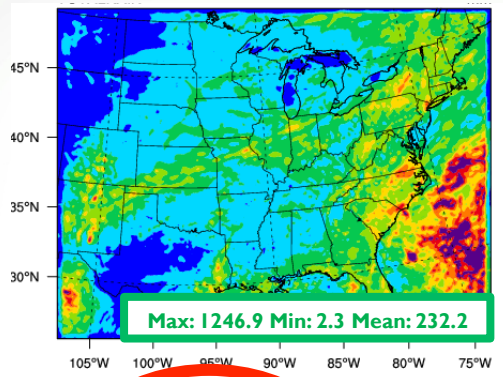
PRISM Estimate

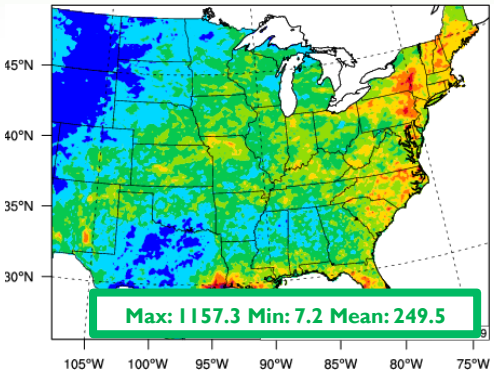
WRF-ACI

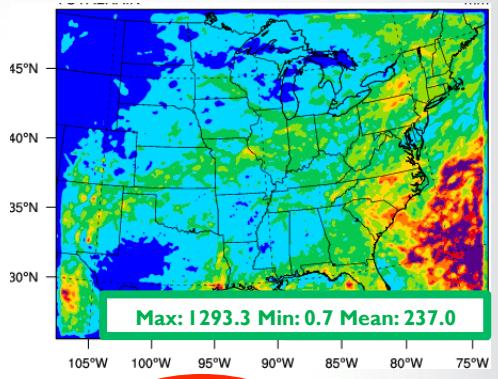
Total (mm)

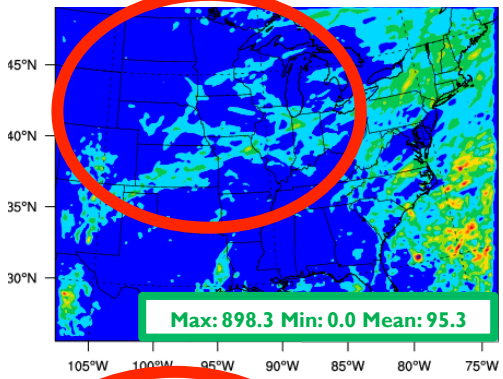
Grid-Scale (mm)

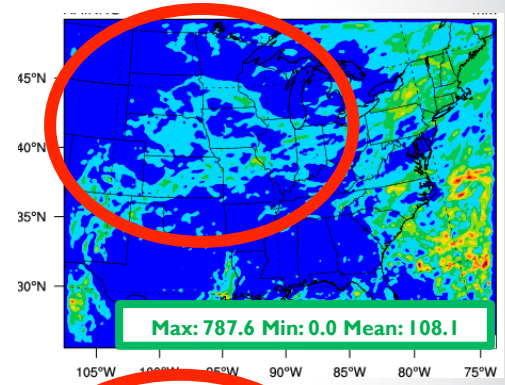
Subgrid-Scale (mm)

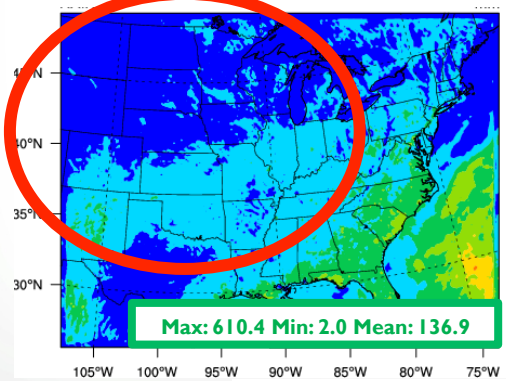


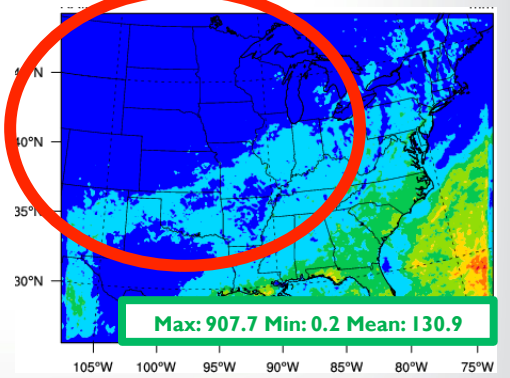








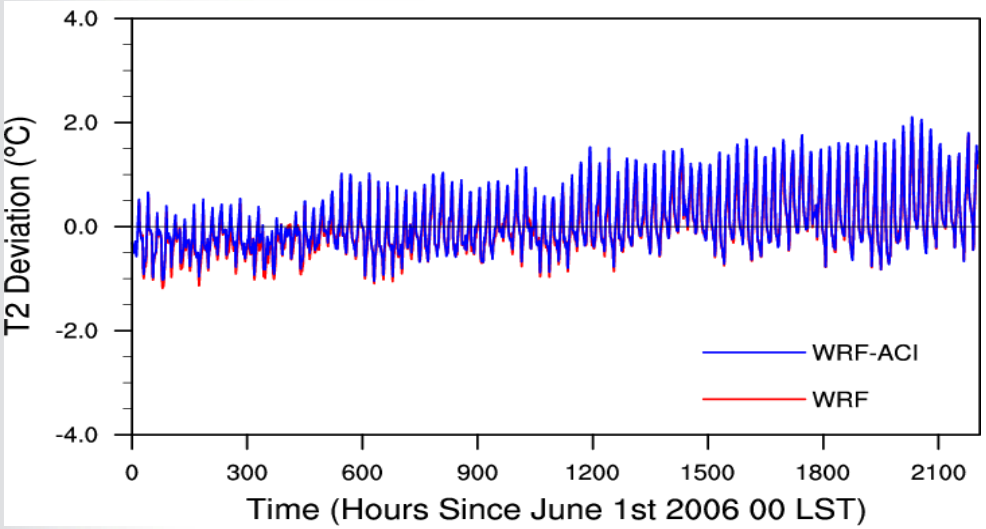




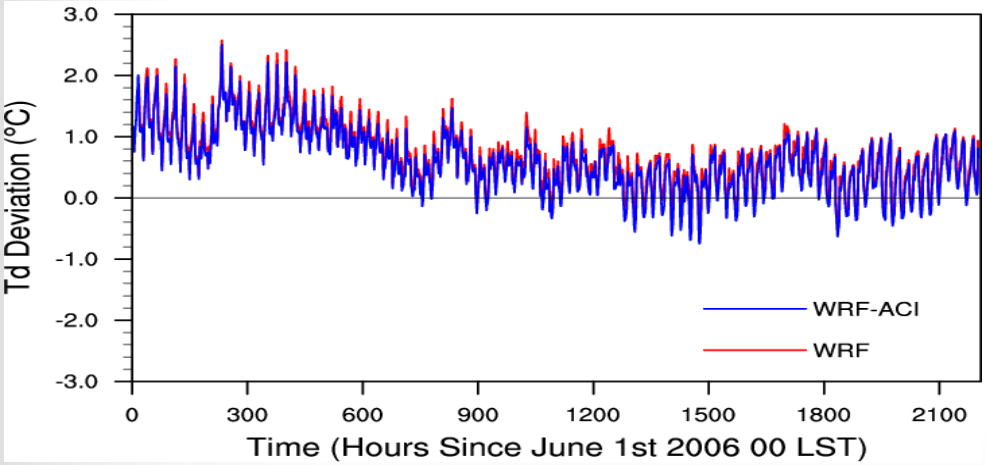
Stat	WRF-BASE	WRF-ACI
Corr.	0.76	0.78
MB	-48.42	-58.31
RMSE	96.74	101.22

Performance Evaluation of JJA 2-m Temperature and Dew Point Temperature

Deviations from QCLCD Observations



Stat (T2)	WRF-BASE (Series)	WRF-ACI (Series)	WRF-BASE (Spatial)	WRF-ACI (Spatial)
Corr.	0.99	0.99	0.95	0.95
MB	0.02	0.11	0.02	0.11
RMSE	0.54	0.60	1.12	1.14



Stat (T_d)	WRF-BASE (Series)	WRF-ACI (Series)	WRF-BASE (Spatial)	WRF-ACI (Spatial)
Corr.	0.98	0.98	0.96	0.96
MB	0.71	0.60	0.49	0.40
RMSE	0.87	0.79	1.25	1.21

Part II (Scale Dependency)

Configuration of Simulations

Time Period: 7-day (Jun 17th 00Z –Jun 24th 00Z 2006)

Type: Numerical Weather Prediction Simulation

Multiple Resolutions: 36km, 12km, and 4km

Region: Southeast United States

Simulations

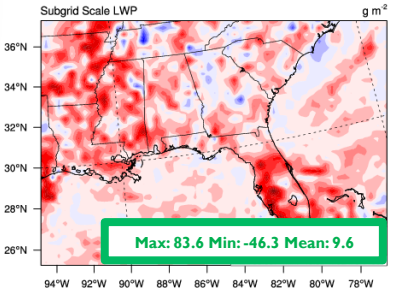
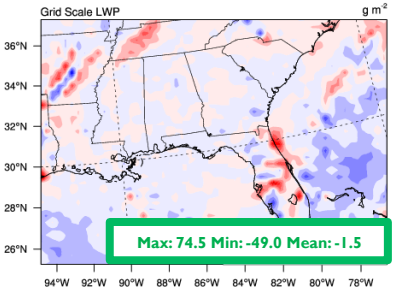
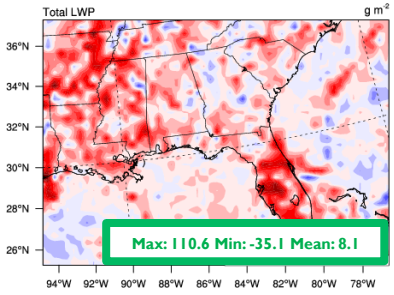
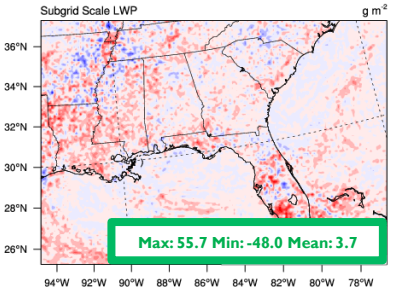
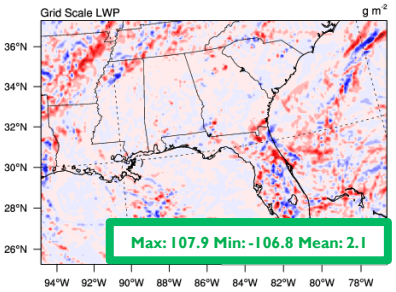
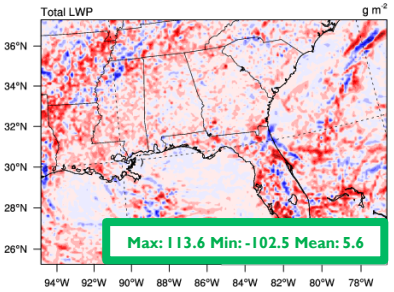
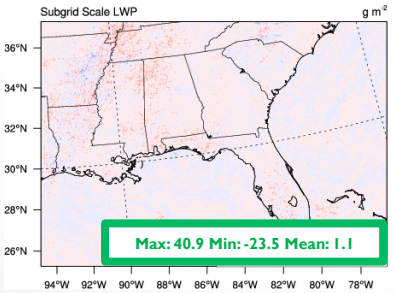
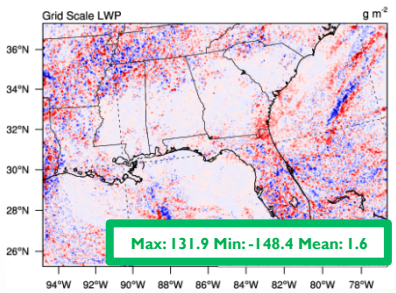
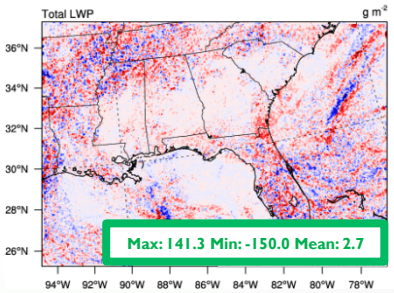
WRF-ACI Updates = **WRF-ACI**

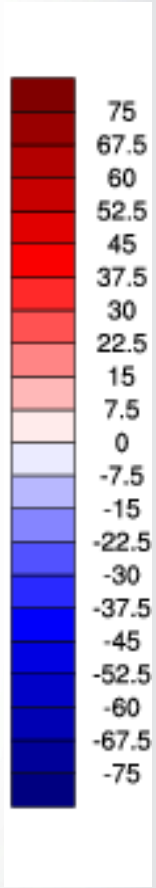
WRF-ACI with Aerosols Reduced by 90% = **LAERO**

Objectives

1) Quantify aerosol indirect effects on cloud properties, precipitation, and radiation
2) Determine the scale dependency of these aerosol effects

LWP Impact (Cloud Lifetime Effect) (WRF-ACI minus LAERO)

	Subgrid Scale LWP ($g\ m^{-2}$)	Grid Scale LWP ($g\ m^{-2}$)	Total LWP ($g\ m^{-2}$)
36 km			
12 km			
4 km			



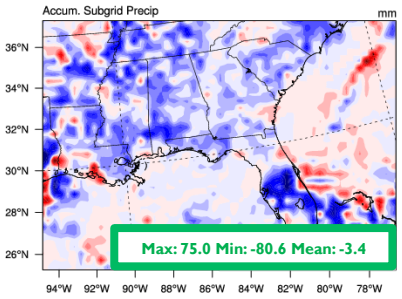
Precip. Impact (Cloud Lifetime/ Invigoration Effect (WRF-ACI minus LAERO)

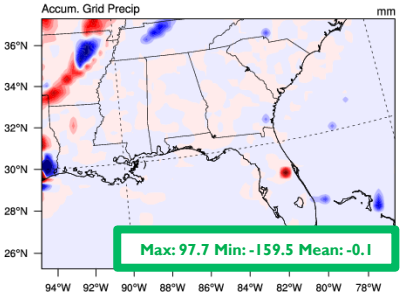
Subgrid Scale Precip. (mm)

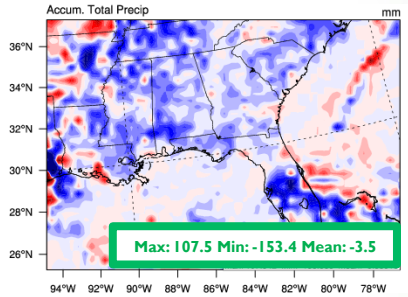
Grid Scale Precip. (mm)

Total Precip. (mm)

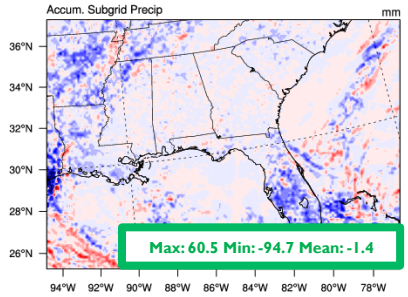
36 km

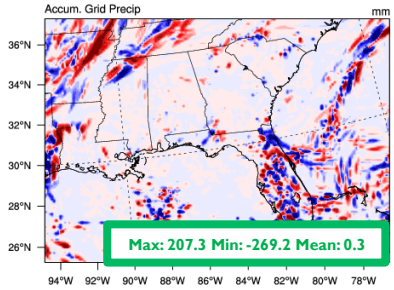


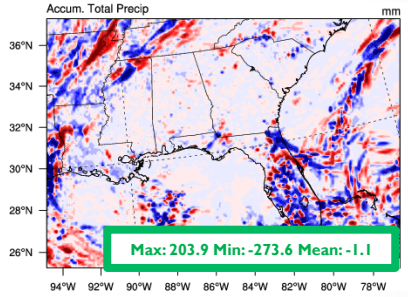




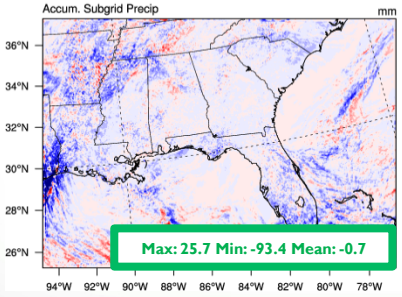
12 km

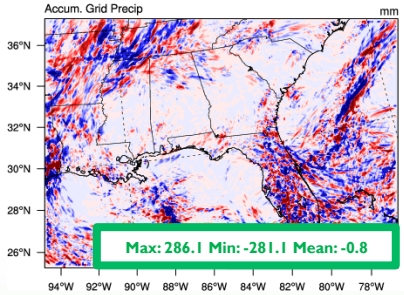


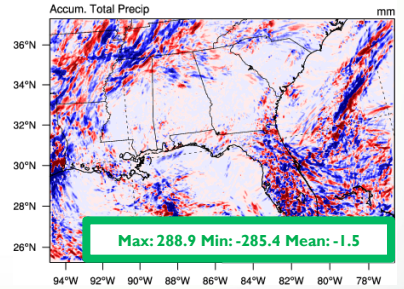


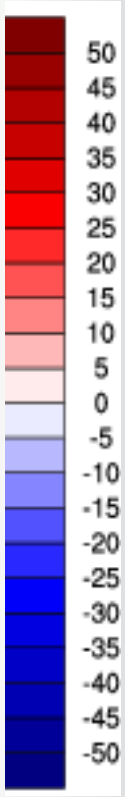


4 km









Radiation Impact (Cloud Lifetime Effect/ Cloud Albedo Effect) (WRF-ACI minus LAERO)

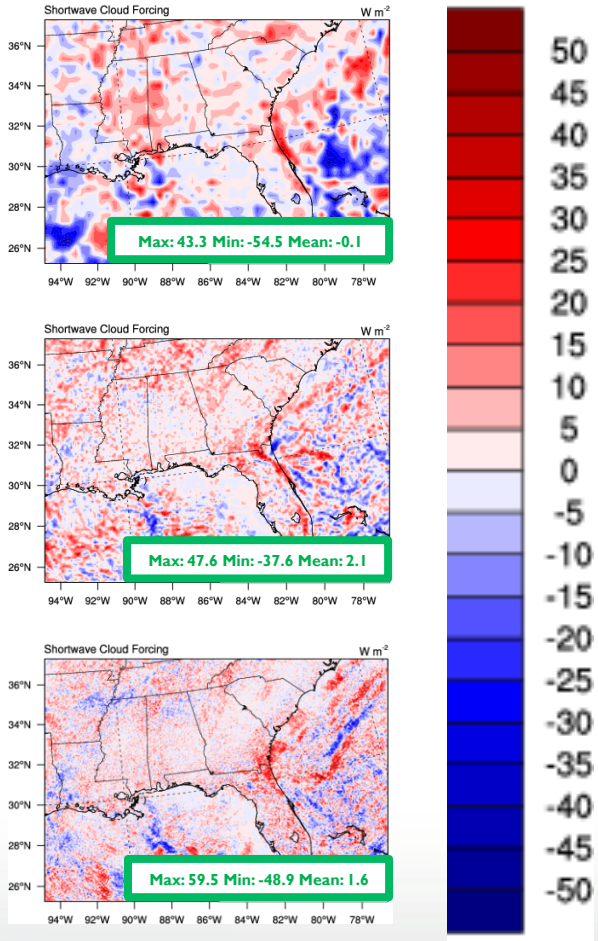
Shortwave Cloud Forcing (W m^{-2})

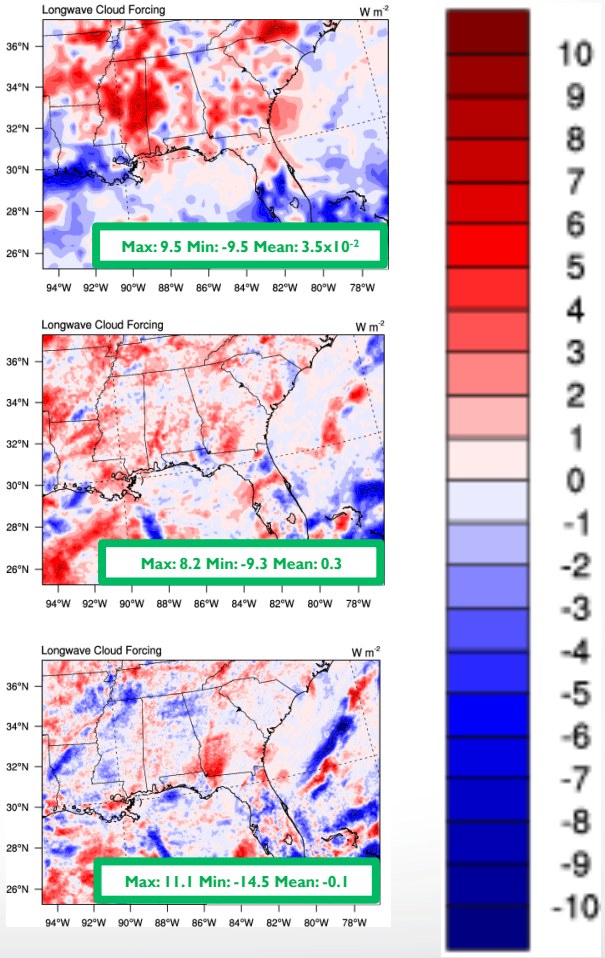
Longwave Cloud Forcing (W m^{-2})

36 km

12 km

4 km





Summary

1) The WRF-ACI system leads to improved LWP, IWP, and 2-m T_d but slightly worse LWCF, SWCF, Precipitation, and T2
2) The WRF-ACI system performs similarly to the default WRF model
3) A detectible cloud lifetime effect is present at all resolutions but it weakens with increasing resolution
4) Precipitation is generally suppressed in the Southeast U.S. due to aerosols
5) Changes in grid scale precipitation and cloud parameters from aerosols are not as straightforward as subgrid scale aerosol effects
6) The impact of aerosols on SWCF is fairly consistent across resolutions but the impact on LWCF varies significantly across resolutions
7) Overall, WRF-ACI provides the WRF community with a computationally efficient method for studying aerosol indirect effects on weather phenomena.

Thanks You

Questions?

Additional Material

Limitations and Future Work

1) The subgrid scale microphysics scheme over represents aerosol effects
2) Uncertainties are introduced by solving the grid scale microphysics after all other model physics processes
3) The scale dependency of aerosol formation is not considered in this study
4) Future work should focus linking the WRF-ACI and WRF-Chem frameworks
5) The subgrid scale microphysics scheme relies heavily on parameterizations designed for large scale clouds
6) Future work should focus on the development of more detailed subgrid scale microphysics based on deep convection
7) More case studies needed to be carried out to determine if the scale dependency of the aerosol effects vary by region or time period