ALAPATY.KIRAN@EPA.GOV

# Precipitation Partitioning Across Grey Zone Scales using Scale-Aware Cloud Formulations: Impacts of Aerosols

Timothy Glotfelty[1], Kiran Alapaty[1], Jian He[1], Patrick Hawbecker[2], Xiaoliang Song[3], and Guang Zhang[3]

[1]*National Exposure Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC, USA*

[2]*Department of Marine, Earth, and Atmospheric Sciences North Carolina State University, University Park, PA, USA*

[3]*Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, USA*

# Introduction

- Aerosol-Cloud interactions (ACI) remain one of the most uncertain aspects in climate science
- Many climate models do not include complex ACI processes such as aerosol interactions within cumulus clouds and ice nucleation of aerosols
- Even if these complex processes are included in climate models, the treatments are typically not consistent across various spatial scales
- Understanding these processes and their relationship to spatial scales is necessary to accurately quantify anthropogenic influences on Earth's energy balance
- Previous modeling studies have explored the scale dependency of ACI, finding either a limited impact of spatial resolution on aerosol indirect effects (Archer-Nicholls et al., 2016) or reductions in the cloud life time effect at finer spatial resolutions (Ma et al., 2015)
- However, these studies do not simulate both solid and liquid phase ACI in both grid scale and subgrid scale clouds
- This study expands upon past research by employing the new WRF-ACI configuration to explore the scale dependency of ACI across the "grey zone" scales over the continental United States

# Objectives

1) Determine if ACI are scale dependent in the WRF-ACI framework
2) Identify the factors that contribute to the scale dependency of ACI

# WRF-ACI Configurations

| Meteorological Process | Parameterization |
|---|---|
| Land Surface Model | NOAH LSM |
| Surface Layer | Monin-Obukhov |
| Planetary Boundary Layer | Yonsei University (YSU) |
| Cumulus/Subgrid Scale Microphysics | Multi-scale Kain-Fritsch (MSKF)/ Song and Zhang, 2011 |
| Grid Scale Microphysics | Morrison Double Moment (MDM) |
| Radiation | Rapid Radiative Transfer Model for GCMs (RRTMG) |
| Data Assimilation | FDDA (Free Troposphere) and FASDAS (Surface) |
| **Configuration** | **Values** |
| Horizontal Grid Spacing | 36km, 12km, 4km, 1km |
| Simulation Period (Domains) | 1) June $17^{th}$ -$24^{th}$ 2006 (U.S., Eastern U.S., Southeast, Northern MS)<br>2) July $23^{rd}$-$28^{th}$ 2006 (U.S., Western U.S., Four Corners, Northern CO) |

# Numerical Experiments

- **WACI**: Default WRF-ACI configuration using bias corrected aerosols from CESM-NCSU
- **LAERO**: Same configuration as **WACI**, but with aerosol concentrations lowered by 90%
- **WACI-LAERO**: The difference between WACI and LAERO illustrates the impact of current aerosol levels on cloud properties, precipitation, and radiation

# WRF-ACI System

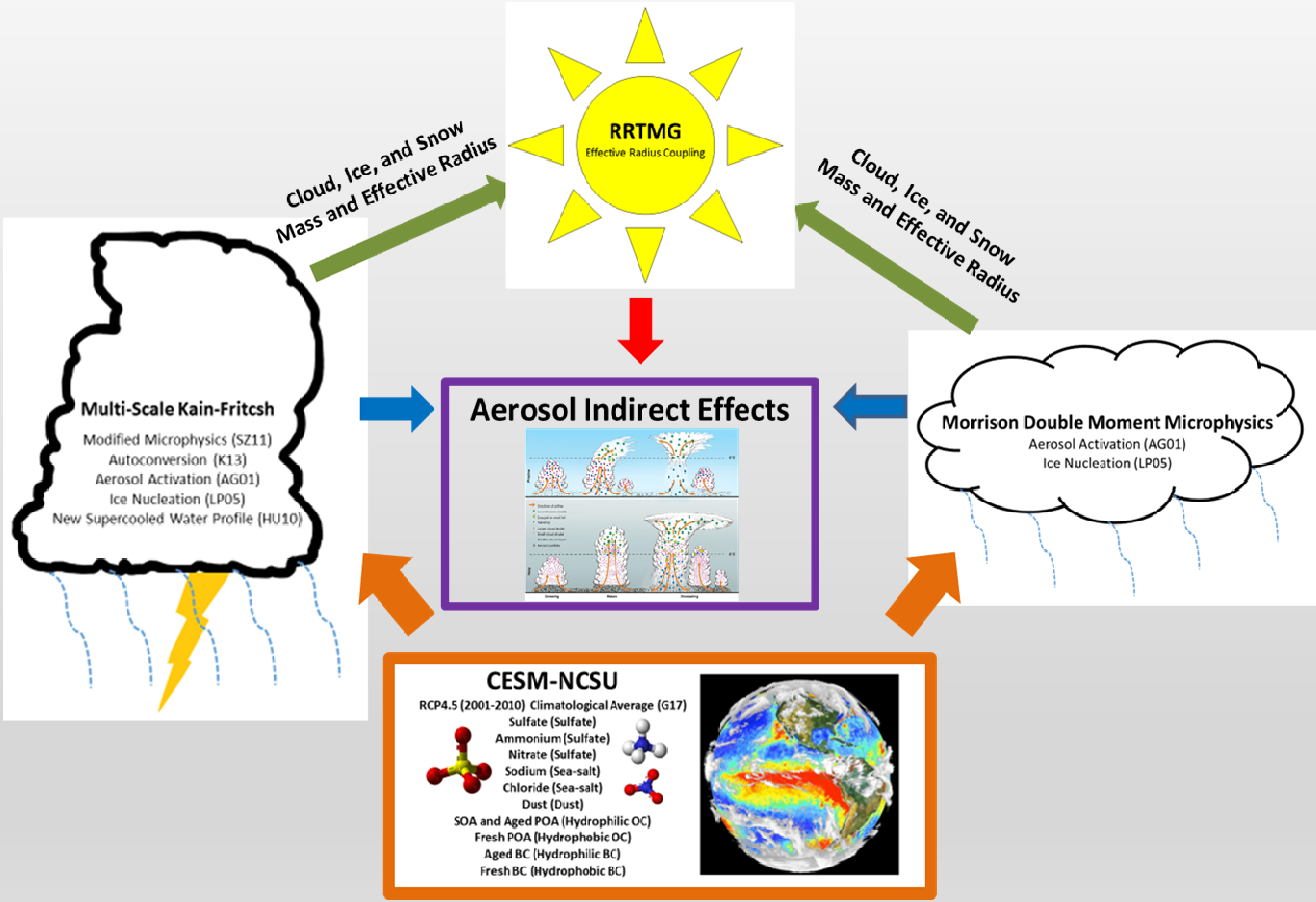
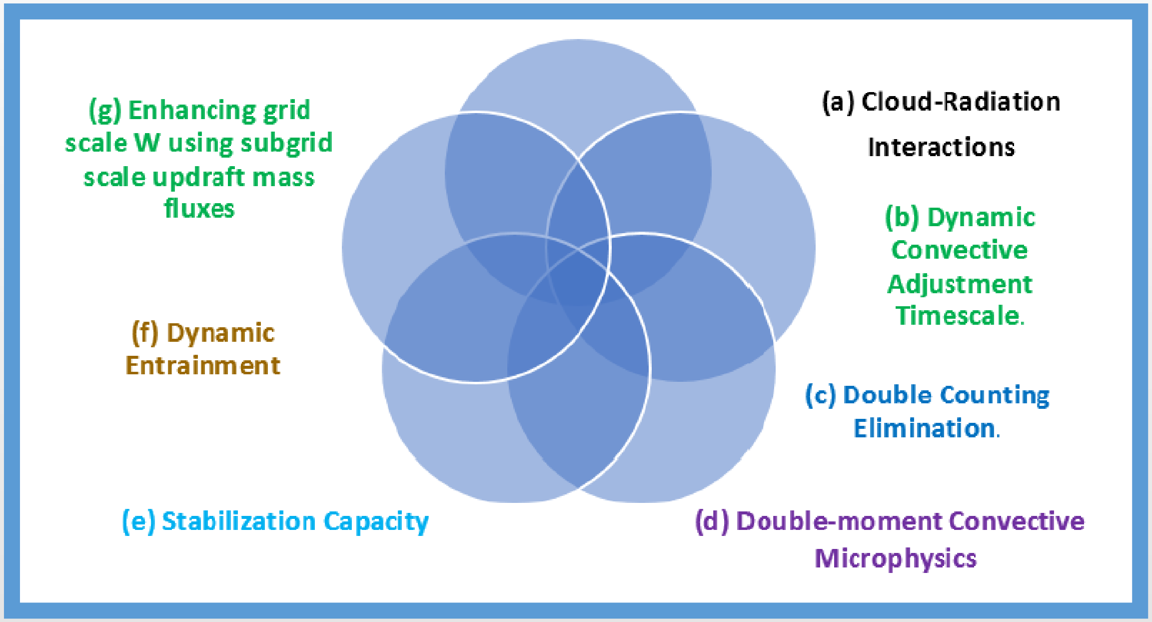



**Figure 1**. WRF-ACI Diagram




Multi-Scale Kain-Fritsch Scheme

Subgrid Scale Microphysics

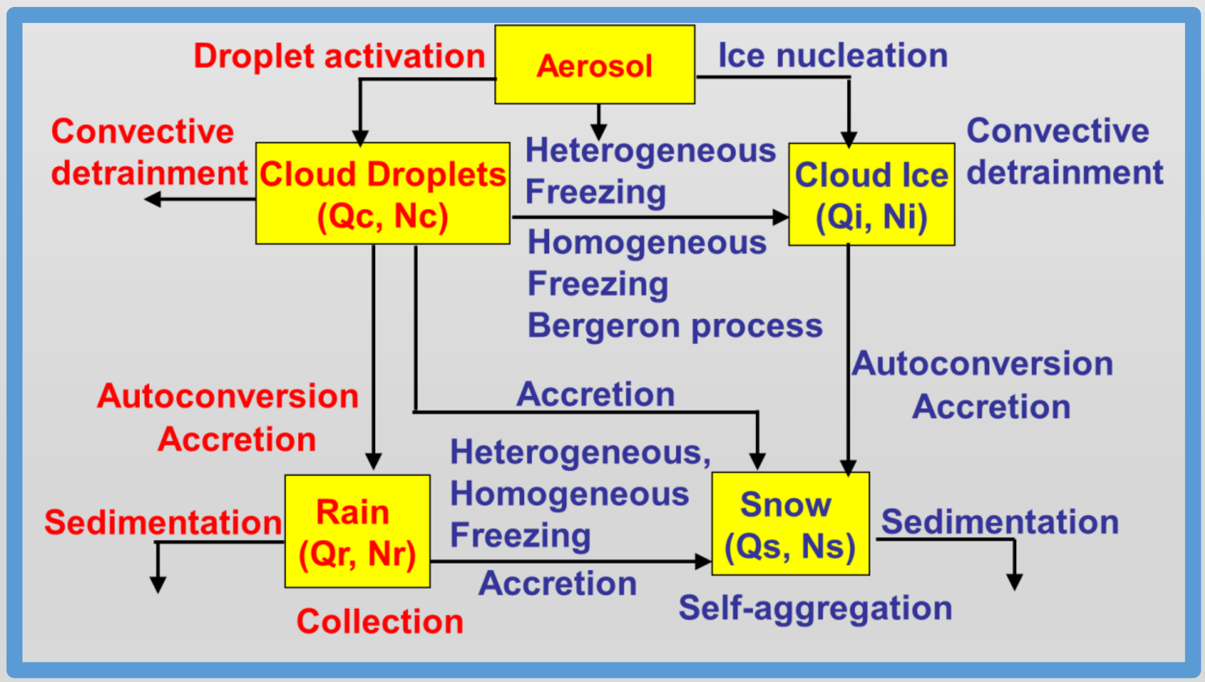



**Figure 2.** Process Diagrams for MSKF and associated Subgrid Scale Microphysics

# CONFIGURATION DETAILS

**WRF-ACI Experiment Configurations**

| Time Period | Domain Coverage/Name | Horizontal Resolution |
|---|---|---|
| June 17th-24th 2006 | Continental United States (CONUS) | 36 km |
| | Eastern United States (EUS) | 12 km |
| | Northeast/Mid Atlantic United States (NE) | 4 km |
| | Southeast United States (SE) | 4 km |
| | Northern Mississippi (NMS) | 1 km |
| July 23rd-28th 2006 | Continental United States (CONUS) | 36 km |
| | Western United States (WUS) | 12 km |
| | Four Corners Region (FC) | 4 km |
| | Northern Colorado (NCO) | 1 km |

**Mapping of Aerosol Species from CESM-NCSU to WRF-ACI**

| SZ11 Bulk Aerosol Name | CESM-NCSU Aerosol Mode | CESM-NCSU Species |
|---|---|---|
| Sulfate | Aiken and Accumulation | Sulfate, Nitrate, and Ammonium |
| Sea-salt | Fine Sea-salt and Coarse Sea-Salt | Sulfate, Nitrate, Ammonium, Sodium, and Chloride |
| Dust 1 | 50% of Fine Dust | Sulfate, Nitrate, Ammonium, and Mineral Dust |
| Dust 2 | 50% of Fine Dust | Sulfate, Nitrate, Ammonium, and Mineral Dust |
| Dust 3 | 50% of Coarse Dust | Sulfate, Nitrate, Ammonium, and Mineral Dust |
| Dust 4 | 50% of Coarse Dust | Sulfate, Nitrate, Ammonium, and Mineral Dust |
| Hydrophilic Black Carbon | 40% of Accumulation | Black Carbon |
| Hydrophobic Black Carbon | Primary Carbon and 60% of Accumulation | Black Carbon |
| Hydrophilic Organic Carbon | Aiken and Accumulation | Secondary and Semi-Volatile Organic Aerosol |
| Hydrophobic Organic Carbon | Primary Carbon and Accumulation Mode | Primary Organic Aerosol |

**Table 1.** Process Diagrams for MSKF and associated Subgrid Scale Microphysics

# Western U.S. Precip. (WACI-LAERO)

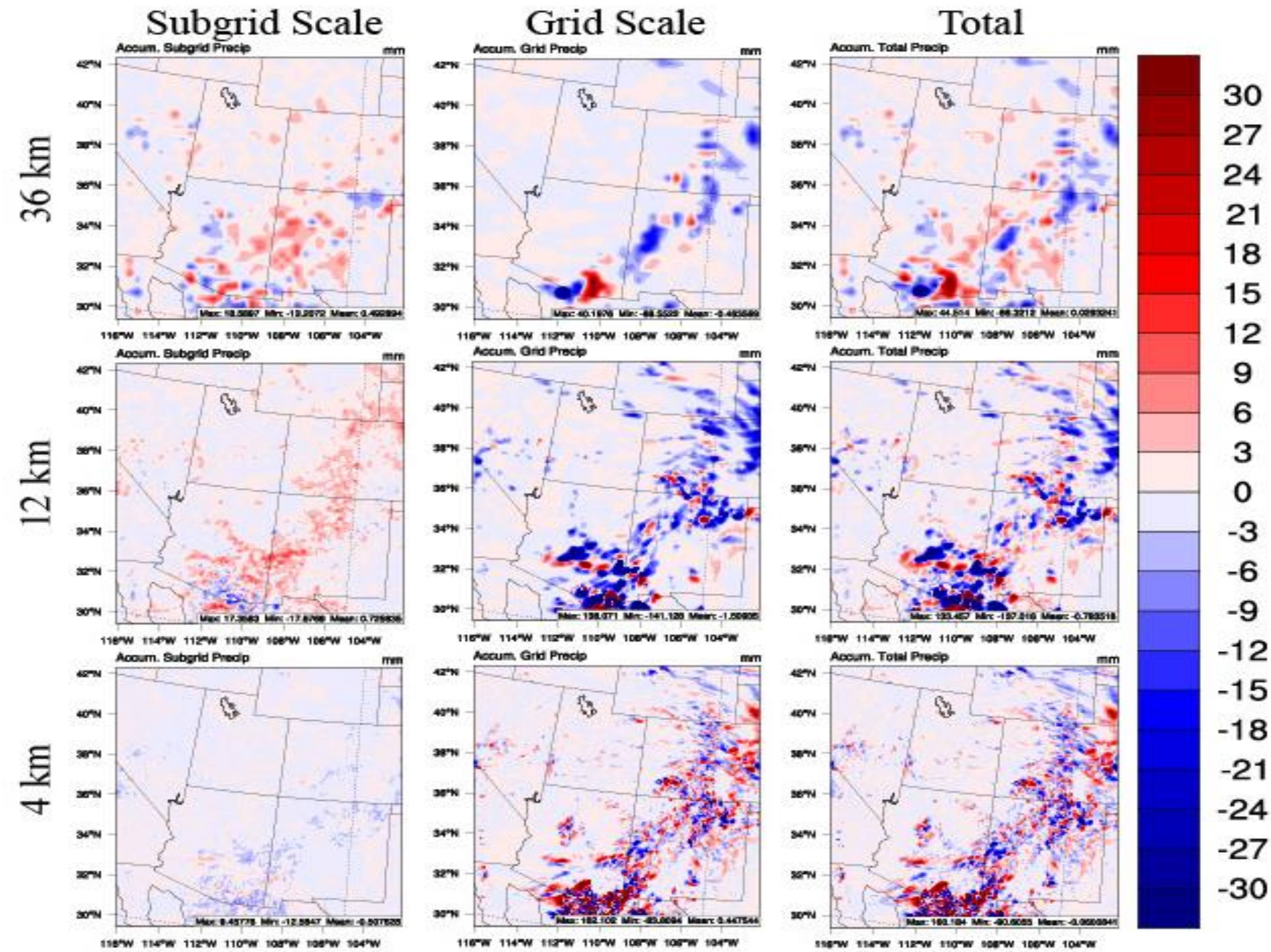



**Figure 3**. The difference in subgrid scale, grid scale, and total precipitation between the WACI and LAERO simulations over the Four Corners region at 36 km, 12 km, and 4 km.

# Eastern U.S. Precip. (WACI-LAERO)

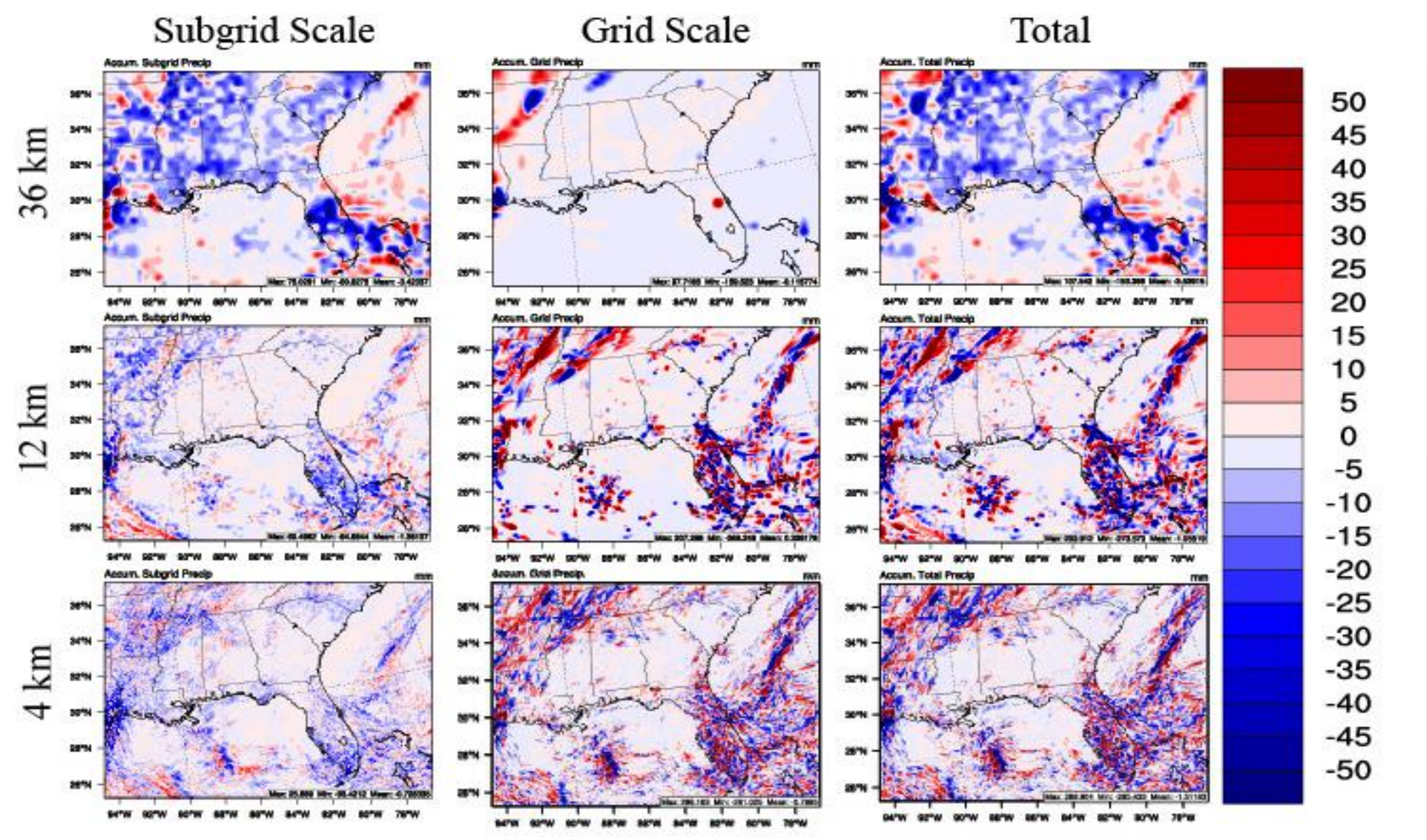
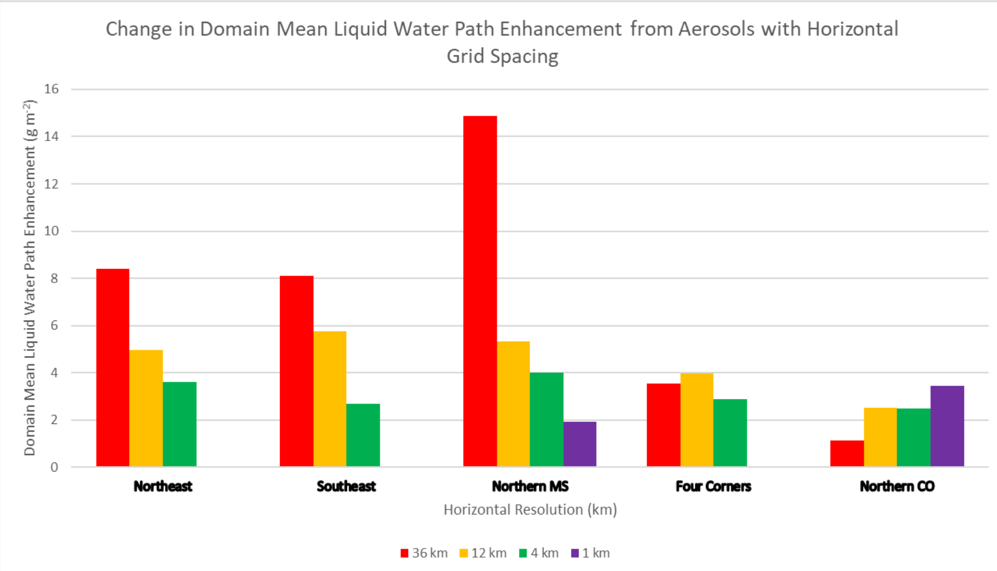


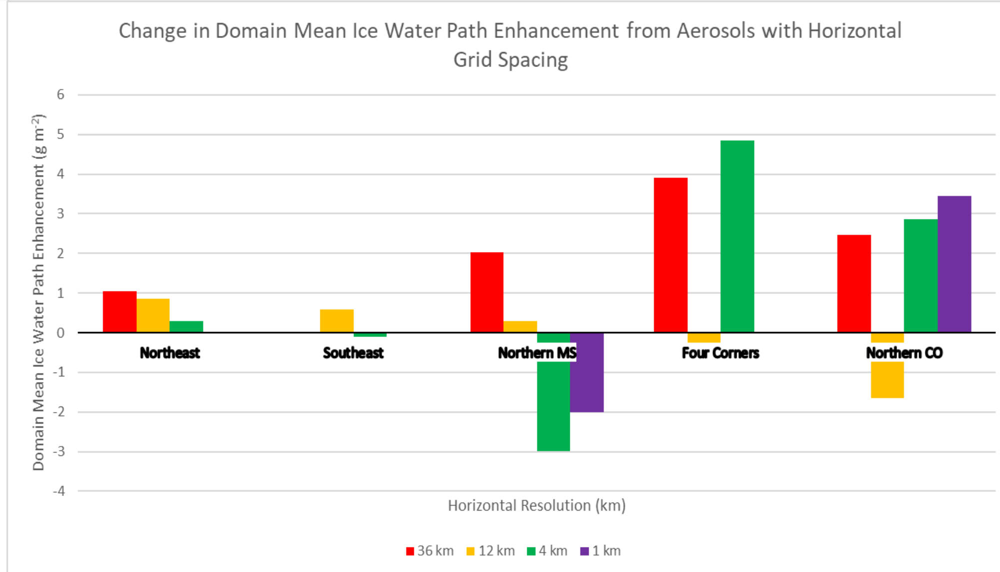

**Figure 4**. The difference in subgrid scale, grid scale, and total precipitation between the WACI and LAERO simulations over the Southeast region at 36 km, 12 km, and 4 km

# Domain Average Impacts

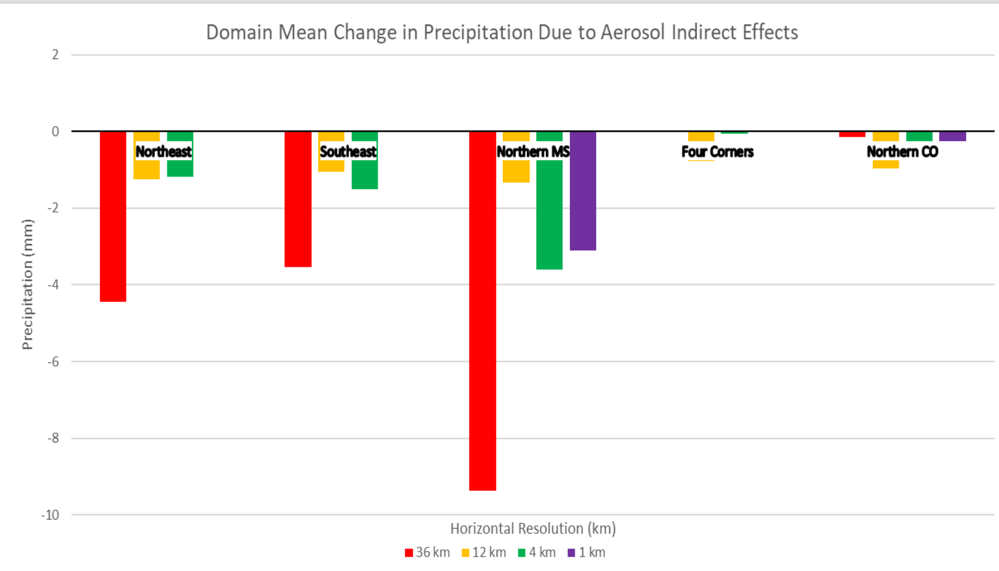
## Liquid Water Path




## Ice Water Path




## Precipitation




## Shortwave Cloud Forcing

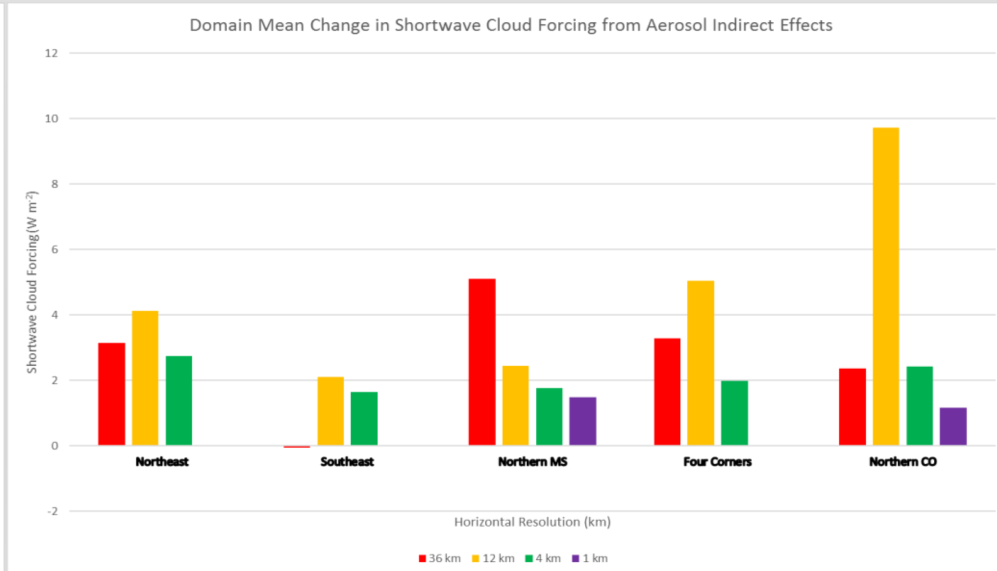



**Figure 5**. The domain-wide mean change in LWP, IWP, precipitation, and SWCF between the WACI and LAERO simulations for the Northeast, Southeast, Northern Mississippi, Four Corners, and Northern Colorado domains at 36 km (red), 12 km (gold), 4 km (green), and 1 km (purple) grid spacing.

# Domain Average Cloud Lifetimes (hr)

| | | Subgrid Scale | | | Grid Scale | | |
|---|---|---|---|---|---|---|---|
| **Region** | Resolution | WACI | LAERO | WACI-LAERO | WACI | LAERO | WACI-LAERO |
| **Northeast** | 36 km | 2.07 | 1.25 | 0.82 | 27.85 | 24.75 | 3.10 |
| | 12 km | 0.28 | 0.24 | 0.04 | 2.23 | 2.20 | 0.03 |
| | 4 km | 0.31 | 0.23 | 0.08 | 2.42 | 2.48 | -0.06 |
| **Southeast** | 36 km | 1.37 | 1.09 | 0.28 | 33.89 | 23.35 | 10.54 |
| | 12 km | 1.44 | 1.05 | 0.39 | 20.21 | 17.43 | 2.78 |
| | 4 km | 0.09 | 0.05 | 0.04 | 1.92 | 1.70 | 0.23 |
| **Northern MS** | 36 km | 2.09 | 1.76 | 0.33 | 39.09 | 37.21 | 1.88 |
| | 12 km | 3.05 | 2.60 | 0.45 | 30.95 | 29.09 | 1.86 |
| | 4 km | 3.14 | 2.61 | 0.53 | 5.15 | 4.58 | 0.57 |
| | 1 km | 0.59 | 0.51 | 0.08 | 3.15 | 3.02 | 0.13 |
| **Four Corners** | 36 km | 3.51 | 3.13 | 0.38 | 27.52 | 24.11 | 3.41 |
| | 12 km | 2.66 | 2.33 | 0.33 | 15.66 | 14.53 | 1.13 |
| | 4 km | 0.52 | 0.43 | 0.09 | 4.91 | 4.18 | 0.73 |
| **Northern CO** | 36 km | 3.44 | 4.44 | -1.00 | 20.96 | 17.52 | 3.44 |
| | 12 km | 0.80 | 0.84 | -0.04 | 3.55 | 3.55 | 0.0 |
| | 4 km | 0.02 | 0.02 | 0.00 | 0.09 | 0.08 | 0.01 |
| | 1 km | 0.68 | 0.48 | 0.20 | 3.87 | 3.34 | 0.53 |

Table 2. The cloud time scale parameters and difference in cloud time scale parameters between the WACI and LAERO simulations for the Northeast, Southeast, Northern MS, Four Corners, and Northern CO domains at each resolution.

# Findings

- Domain average LWP is enhanced at all resolutions in all domains indicating dominance of the cloud lifetime effect
- The cloud lifetime effect decrease with increasing grid spacing due to an increase in the importance of rain drop accretion compared to autoconversion
- The cloud lifetime effect dominates in the eastern U.S. leading to precipitation suppression from aerosols
- In the western U.S. complicated interactions within mixed phase clouds (possibly from the thermodynamic invigoration effect) lead to offsetting minimal impacts of aerosols on precipitation
- The reduced cloud lifetime effect at finer resolutions results in reduced SWCF
- At 12 km grid spacing, equal activity from grid scale and sub-grid scale clouds results in moisture competition that complicates the understanding of ACI at this spatial resolution

# Conclusions

- The WRF-ACI experiments indicate that subgrid scale ACI impacts and solid phase ACI are important at coarse resolutions and in mixed phase cloud environments, respectively
- These processes are lacking in coupled regional coupled meteorology-chemistry models and this likely introduces a level of uncertainty/inaccuracy
- The decline in the importance of ACI impacts at finer resolutions likely indicate that aerosol indirect effect estimates from global climate models are overestimated