The Grell-Freitas Cumulus Parameterization: Recent Advancements and Future Development

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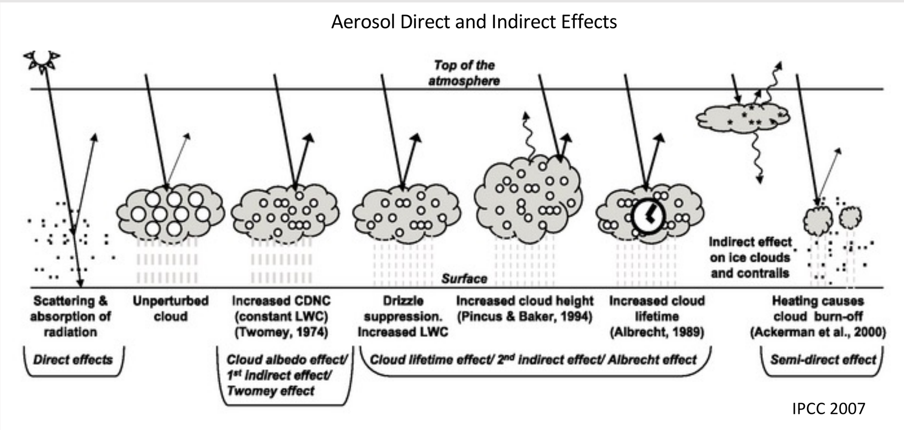
Introduction

- It is well established that aerosols significantly impact weather and climate.



- Within models, aerosol interactions are most often represented in:
  - Low resolution climate models with low complexity
  - High resolution chemistry models with high complexity
  - Within radiation or microphysical parameterizations, but not convective parameterizations
- Relatively little work has been done to add aerosol impacts in convective parameterizations in operational weather prediction models

Objective

Develop methods to represent aerosol – convection interactions within the Grell-Freitas Convective Parameterization that:

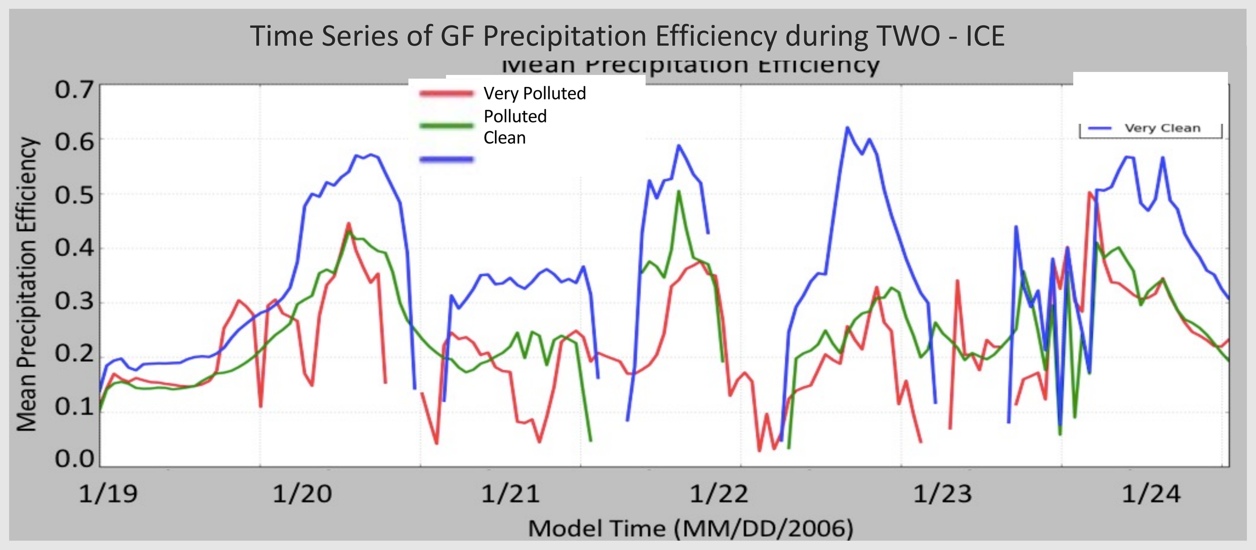
1. Capture impacts of aerosols on convection
2. Remains computationally efficient enough for operational weather forecast models

The Grell-Freitas Convective Parameterization (GF)

- First published in Grell and Freitas (2014, ACP)
  - Subsequently updated in: Freitas et al. (2018, JAMES) and Freitas et al. (2021, GMD)
- Versions of the code are available for use in WRF, RAP, FIM, FV3, GEOS-5, BRAMS
- Used in both global and regional applications
- Basic features:
  - Ensemble mass-flux approach
  - Shallow, congestus, and deep convective represented
  - Includes updrafts and downdrafts
  - Scale – aware
  - Aerosol – aware (Added in 2014, but not extensively tested until recently)
- Aerosol – aware features:
  - In the most simple application Aerosol Optical Depth (AOD) used as a measure of aerosol pollution
    - Can be obtained from a climatology, an analysis, or an aerosol model (ex: GEFS-Aerosols, WRF-Chem)
  - Aerosol impact based on how far the AOD at a given point is from an assumed background AOD p resent when the cloud to rain conversion constants were originally derived
    - Makes aerosol impacts most notable in very clean or very polluted environments
  - Processes influenced by aerosols
    - Auto-conversion - cloud water to rain *(Berry 1968)*
    - Evaporation of rain *(Jiang et al. 2010)*
    - Aerosol wet scavenging *(Lee and Feingold 2010, Wang 2013)*
  - Active in congestus and deep convection

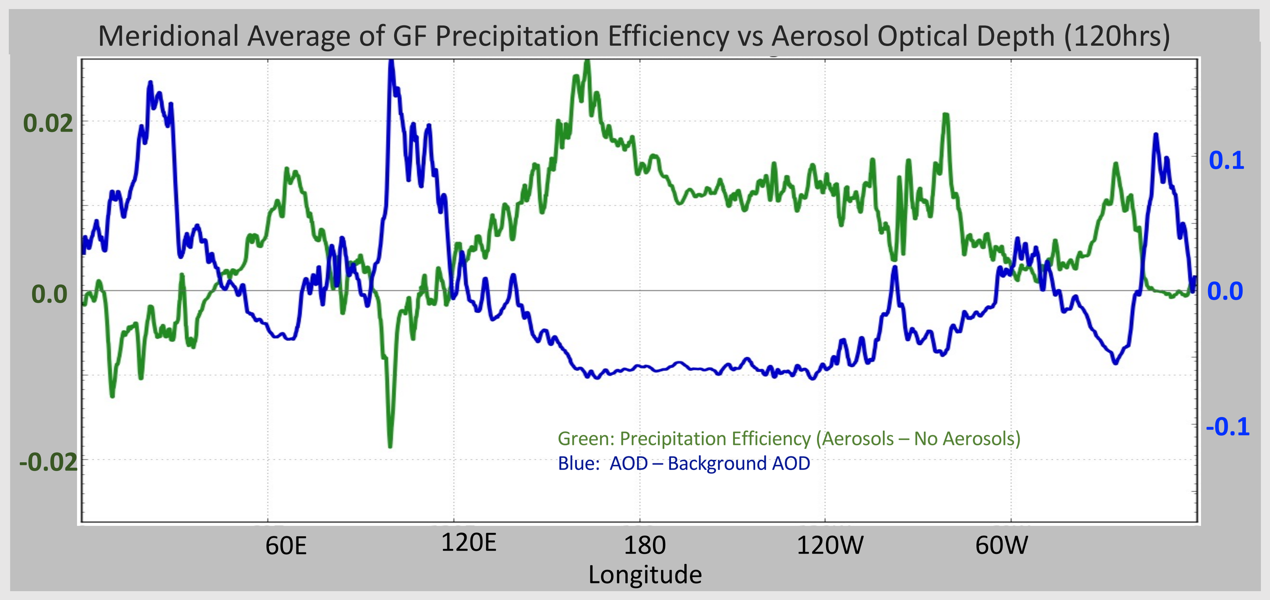
Aerosol – Aware GF: Single-Column Model (SCM) Results

- Three FV3 Single-Column Model simulations assuming different pollution levels in GF
  - 1) Very clean, 2) Polluted, 3) Very polluted
  - Uses the GFSv16 physics suite except with GF and 127 vert. levs
- Precipitation efficiency is greater in Very Clean than Polluted and Very Polluted
  - Physically reasonable: Increased pollution -> Smaller particles -> less precipitation fall out

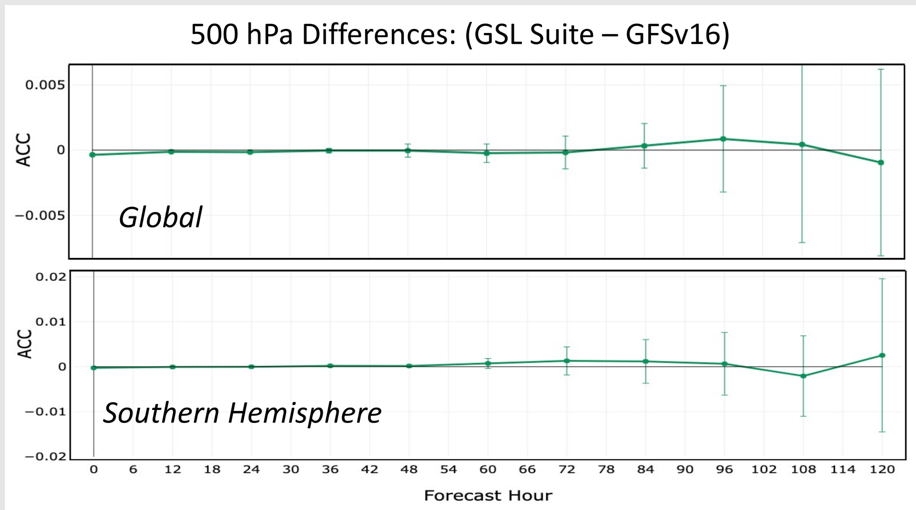


Aerosol – Aware: 3D FV3 Results

- Two global FV3 C786 Simulations
  - 1) GF aerosol - aware, 2) GF No aerosols
  - GFSv16 physics suite with GF for SAS and 127 vertical levels
  - Initialized from GFS analysis and MERRA2 AOD climatology
- Precipitation efficiency inversely related to AOD deviation from background (i.e. greater efficiency where relatively less polluted)
  - Consistent with single – column model results



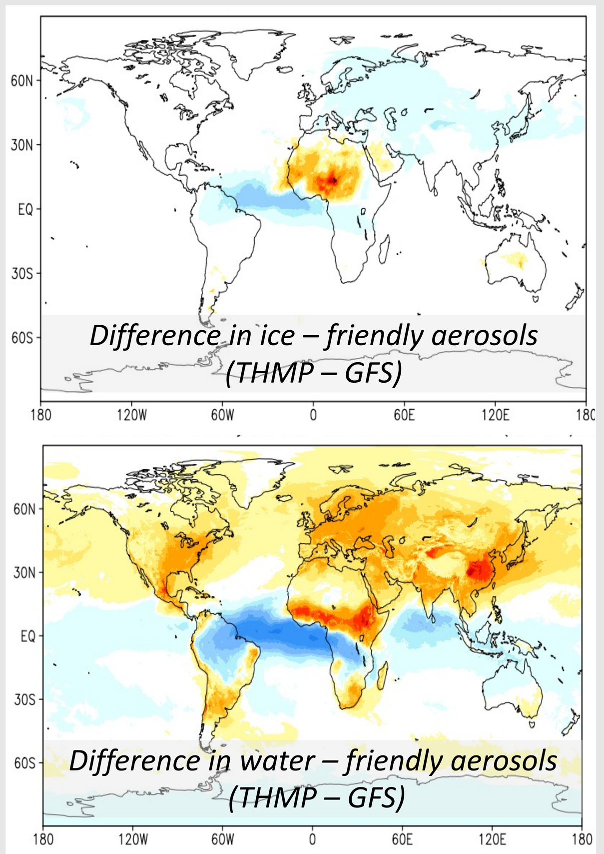
- ACC Comparison of 5 – Day Global FV3 Simulations:
  1. GFSv16
  2. GSL physics suite
     - Differences: MYNN PBL, GF deep Convection, No Shall Conv, THMP, Unified GWD
- C768 and 128 levels, 14 cases

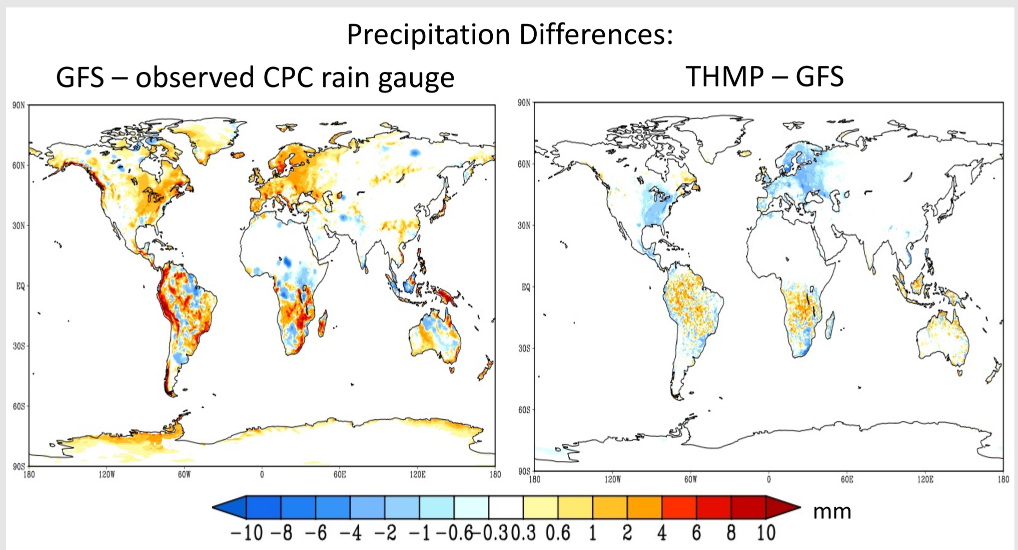


- GSL 500 hPa ACC scores comparable and slightly exceeds GFS
- This version of the GSL suite used GF with aerosol – awareness, but prior to some of our latest tuning and most recent aerosol updates.
- We expect results to continue to improve.

Thompson (THMP) Aerosol – Aware Microphysics Parameterization

- THMP also has aerosol – aware capabilities
  - Currently, THMP aerosol emissions create too many aerosols over tropical oceans
- We have a new, more realistic prognostic method for THMP emissions
  - Uses emissions modules from GEFS – Aerosols, no extra variables, and adds minimal extra computing time
- Two sets of of 10 simulations out 120 hr:
  - 1) GFS, 2) THMP with prognostic aerosol emissions

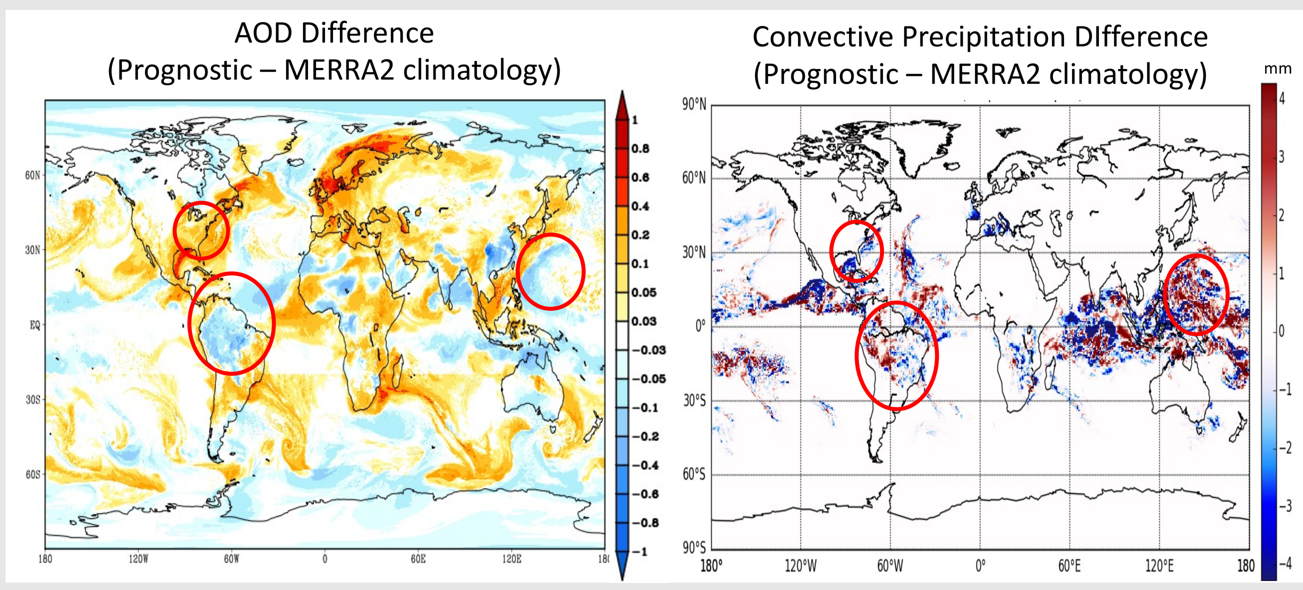




Using THMP with prognostic variables addresses some of the precipitation biases, especially in the Northern Hemisphere

Aerosol – Aware GF + Thompson Aerosol – Aware Microphysics Parameterization

- Traditionally, aerosols in GF and THMP are completely independent
  - We have coupled our prognostic THMP aerosols with GF's aerosols
- Two simulations:
  - 1) GF aerosols based of MERRA2, 2) GF from prognostic THMP
  - GSL physics suite, C786, 128 levels, 1 case
- Changes in convective precipitation demonstrates that GF can now respond in a physically reasonable manner to aerosols in THMP



Conclusions

- The Grell-Freitas Convective Parameterization (GF) is a scale – aware, aerosol – aware convective parameterization
- This research continues to develop and extensively evaluate the aerosol – awareness aspects of GF
  - GF strives to represent aerosol-convection interactions as simply and computational efficient as possible, while remaining physically reasonable
  - Relatively few convective parameterizations include aerosol – convection interactions, especially in medium range weather models
- Testing and evaluation indicate that the aerosol– aware aspects of GF are responding in physically reasonable manners
  - Increased pollution -> smaller & more numerous particles -> less precipitation fall out
  - Results also suggest that aerosol – awareness impacts both updraft and downdraft mass – flux
- A new, efficient, prognostic method was developed to represent aerosol emissions in resolved and unresolved precipitation physics
  - Prognostic emissions (wildfires, sea salt, dust, anthropogenic) are lumped into just 2 variables
  - Can also be used to couple with GF and radiation

Future Work

- Run using observation or modeled AOD initial conditions and a realistic background AOD
  - Evaluate model performance in regions with high and low AOD
- Develop code so that GF can respond to the full 3D structure pollution
- Add aerosol-awareness to the shallow component to GF
  - Compare to high-resolution WRF Chem or LES simulations
- Test the impact of aerosol-awareness at subseasonal – to – seasonal time scales with GEFS or GEFS-Aerosols data
  - Evaluation for WGNE 19-year S2S comparisons

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