Development of the CCPP-Based GEFS-Aerosols Component in the Unified Forecast System for Subseasonal Prediction (UFS-Chem v1.0)

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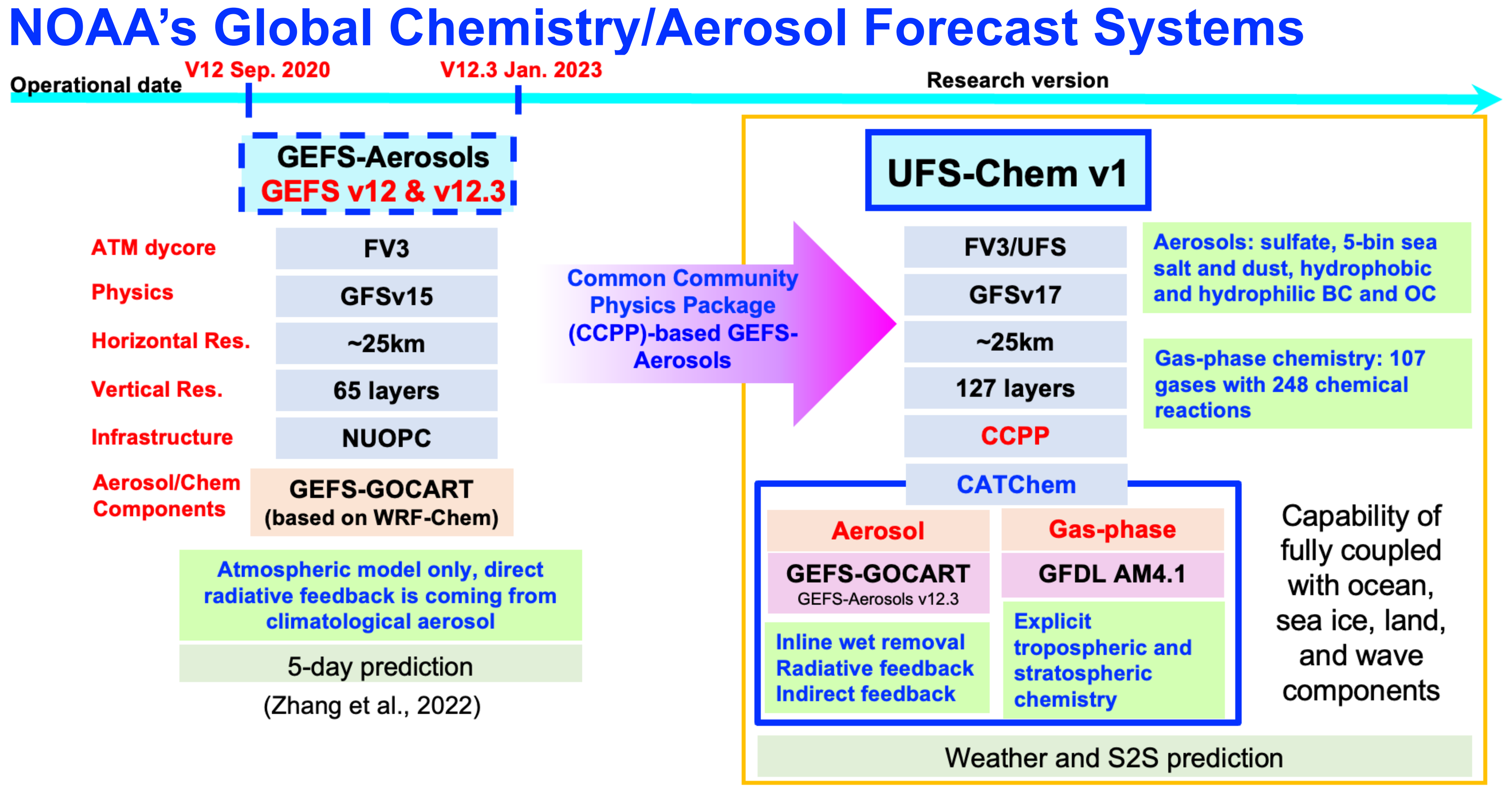
Introduction

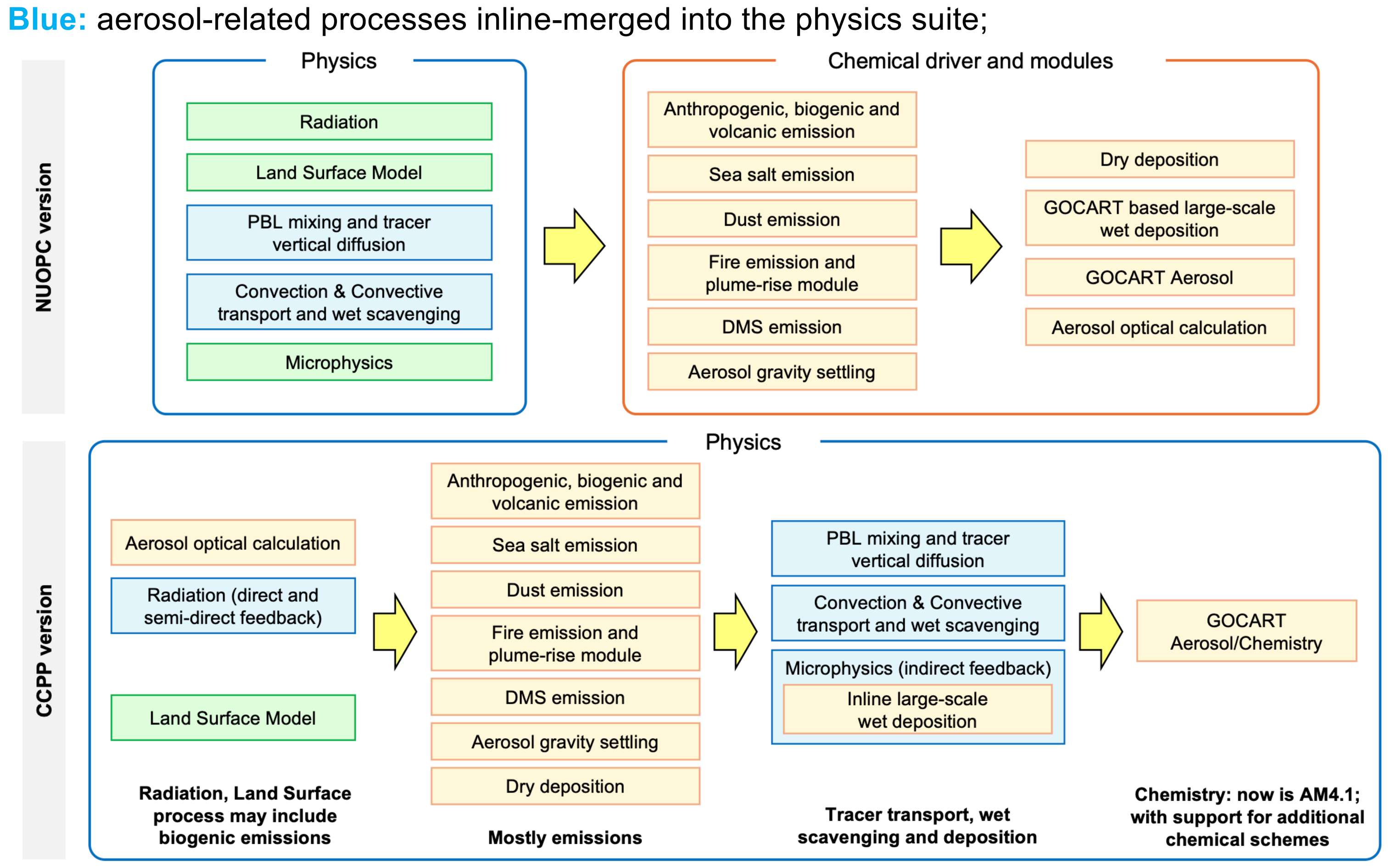
- GEFS-Aerosols v12.3 has been operational at NOAA/NCEP since 2023, providing global aerosol forecasts with improved wet deposition, emissions, aerosol optical depth, and dust emission schemes. However, its one-way coupling limits interactive aerosol–atmosphere feedbacks, reducing its capability for extended-range prediction.
- To address this limitation, we developed UFS-Chem, a fully coupled atmospheric chemistry model within the Unified Forecast System (UFS). Built upon the operational GEFS-Aerosols v12.3 and the Configurable Atmospheric Chemistry (CATChem) framework, UFS-Chem includes inline aerosol radiative feedback, inline large-scale wet deposition, updated dust emissions, and aerosol indirect effects through the Thompson aerosol-aware microphysics scheme. These developments improve aerosol–cloud interactions and support weather and subseasonal-to-seasonal (S2S) prediction. Model performance is evaluated against reanalysis, ground-based, and satellite observations to quantify the impacts of aerosol radiative and indirect feedbacks on forecast skill.

NOAA's Global Chemistry/Aerosol Forecast Systems



Aerosol–Physics Tight Coupling in CCPP-based UFS-Chem

Orange: original GOCART aerosol processes; **Green:** original physics processes.
Blue: aerosol-related processes inline-merged into the physics suite;



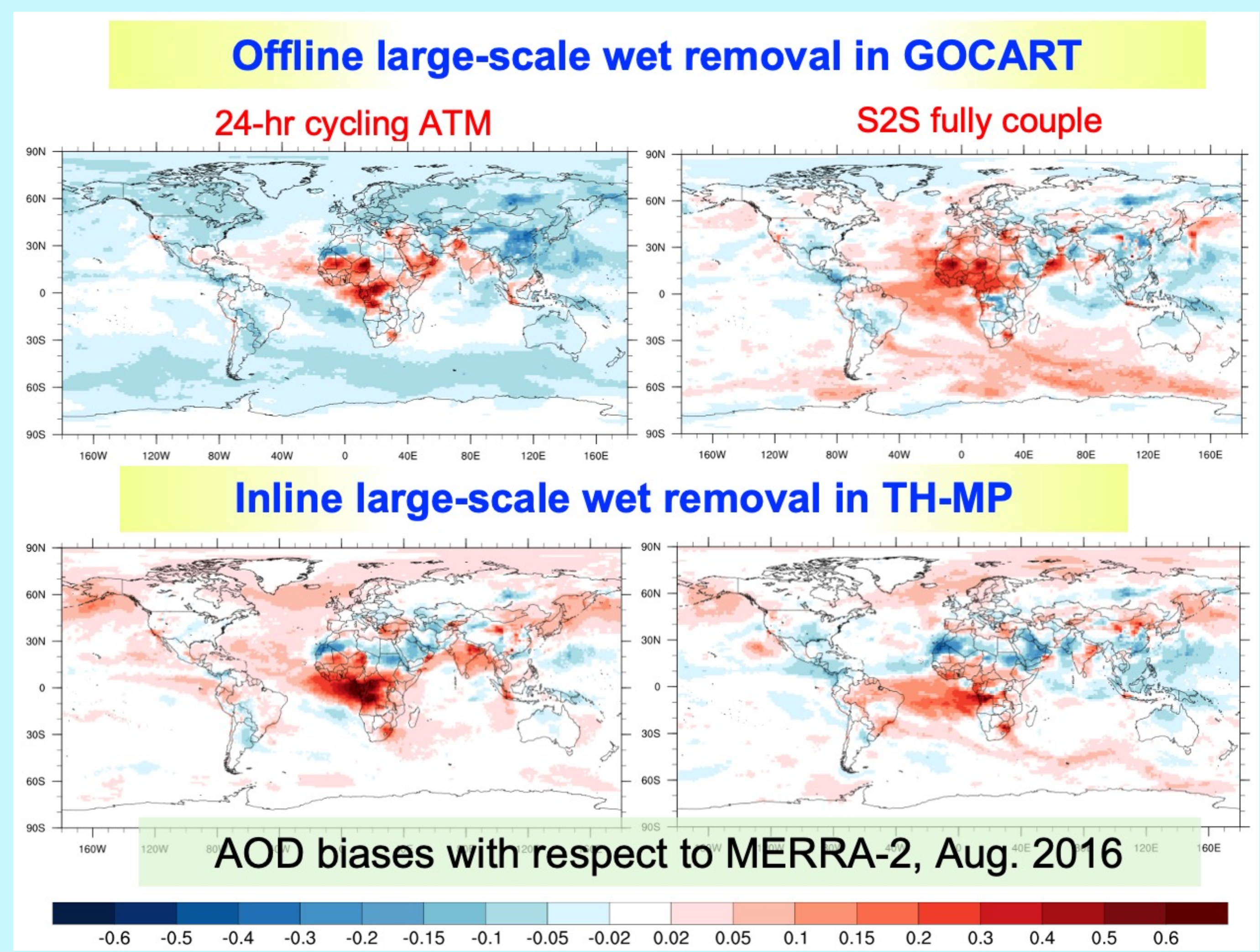
NUOPC: Atmospheric physics and chemistry are separate components: physics parameterizations run in the physics component, while aerosol and chemistry processes run in dedicated chemistry/aerosol drivers.

CCPP: Chemistry and aerosol processes are modularized and integrated directly into the GFS physics suite, enabling transport, mixing, scavenging, and aerosol–radiation-cloud interactions within the host physics time step.

- Aerosol and chemistry processes are embedded directly within the FV3 physics time step, eliminating inter-component hand-offs.
- Shared physics parameterizations provide consistent tracer transport, mixing and wet scavenging, avoiding inconsistencies from external aerosol/chemistry models.
- Inline aerosol–radiation and aerosol-cloud interactions reduce inconsistencies and redundant diagnostics, improving efficiency.

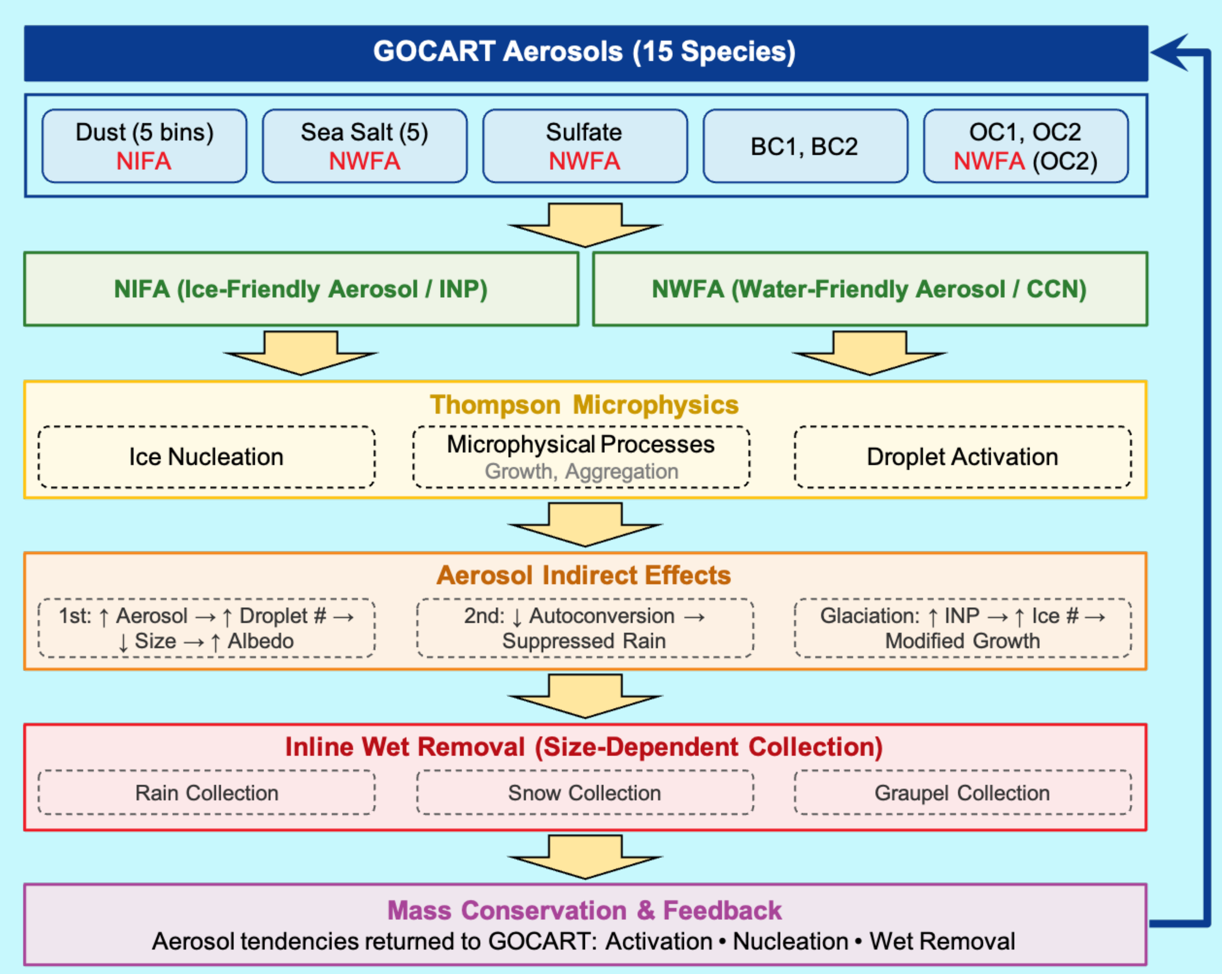
Aerosol-Physics Interactions

Implementation of inline large-scale wet removal into Thompson MP for GOCART aerosol



Inline large-scale wet-removal significantly improves S2S aerosol predictions in UFS-Chem while reducing discrepancies in AOD biases between cycling and fully coupled **S2S run** relative to the offline approach.

GOCART–Thompson coupling framework for prognostic aerosol–cloud interactions in UFS-Chem

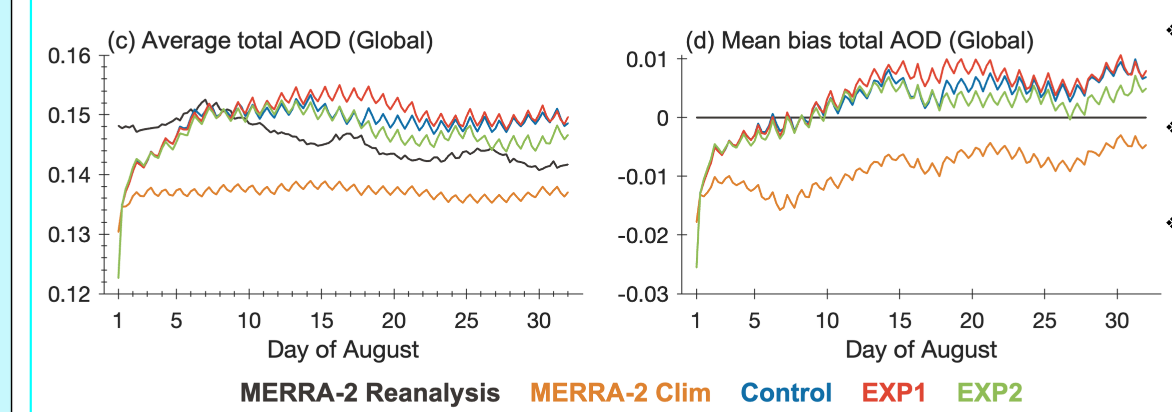


Experiments of aerosol-physics interactions in UFS-Chem subseasonal prediction (August 2012–2017)

Table 3. UFS-Chem subseasonal experiments for radiative and indirect feedback.

Experiment	Control	EXP1	EXP2
Aerosol source for radiative feedback	MERRA-2 climatology	Inline updated GEFS-GOCART	Inline updated GEFS-GOCART
Indirect feedback from inline aerosol prediction	Off	Off	On

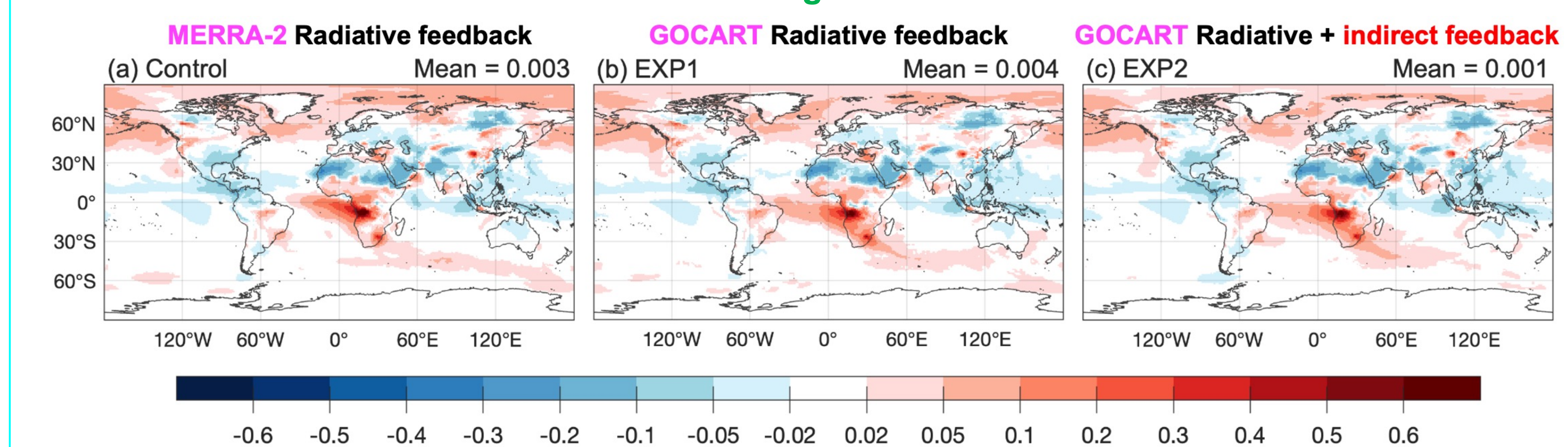
Six-year averaged AOD mean bias against MERRA-2 August 2012–2017



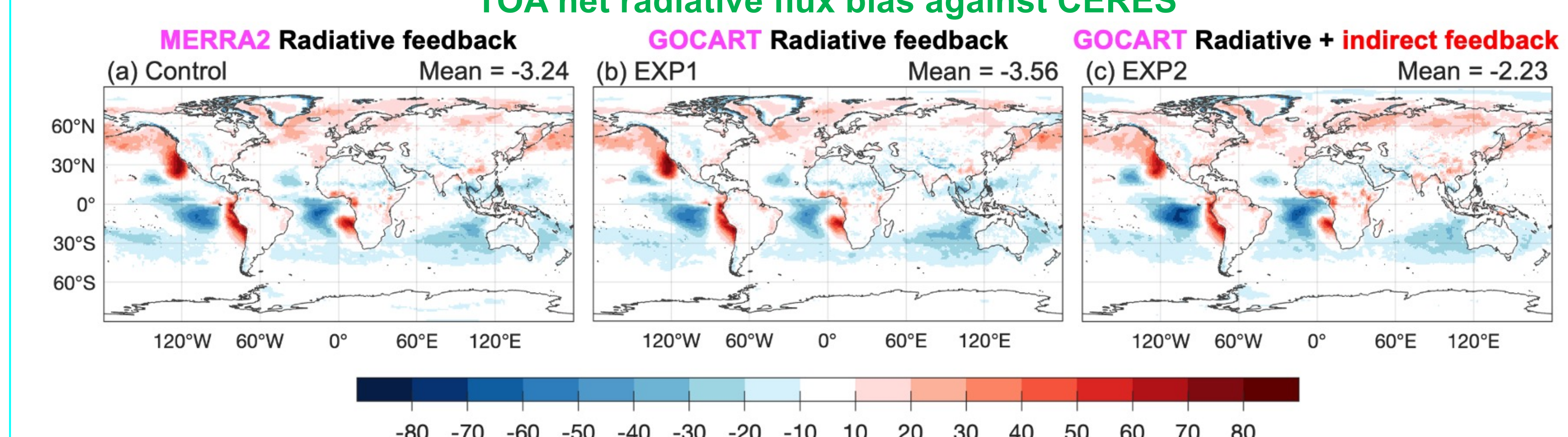
- MERRA-2 climatological aerosols exhibit persistent negative AOD biases.
- Inline-predicted GOCART aerosols produce substantially smaller AOD biases.
- The green line, which includes both radiative and indirect aerosol feedback, shows the smallest AOD bias throughout the forecast period.

Impact of aerosol feedbacks August 2012-2017

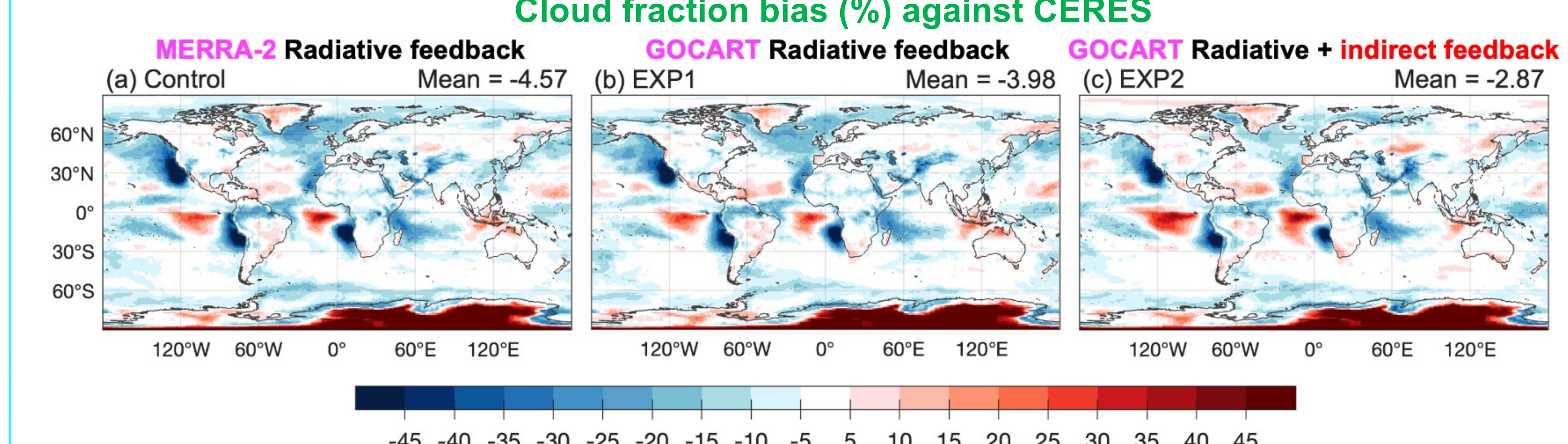
AOD biases against MERRA-2



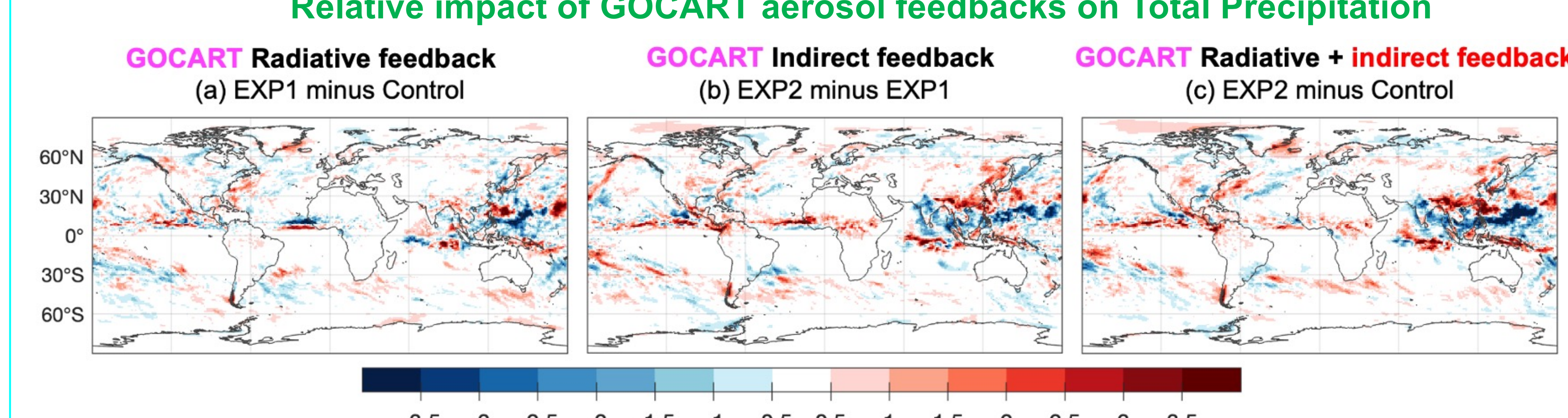
TOA net radiative flux bias against CERES



Cloud fraction bias (%) against CERES



Relative impact of GOCART aerosol feedbacks on Total Precipitation



The spatial coherence between the precipitation response and the improvements in AOD, TOA net radiative flux, and cloud fraction highlights the importance of aerosol–radiation–cloud coupling, with indirect aerosol effects playing the dominant role in subseasonal precipitation changes.