Impact of Turbulence on the Relationship between Cloud Feedback and Aerosol-Cloud Interaction in an E3SMv2 PPE

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1. Introduction

- Importance of the Relationship:

The relationship between **cloud feedback (CF)** and **effective radiative forcing due to aerosol-cloud interaction (ERFaci)** is crucial for historical predictions in climate models.

- Observed Anti-Correlation:

An **anti-correlation** between equilibrium climate sensitivity (ECS) and total historical anthropogenic forcing has been observed in CMIP models, especially those capturing historical global warming (e.g., Kiehl, 2007; Forster et al., 2013; Wang et al., 2021).

- Uncertainties in Processes:

The **physical processes** driving the relationship between ERFaci and CF remain uncertain.

Recent studies using single-model **perturbed parameter ensembles (PPEs)** indicate that **mixed-phase cloud physics and moist processes** significantly influence this relationship (Gettelman et al., 2024; Zhao et al., 2024).

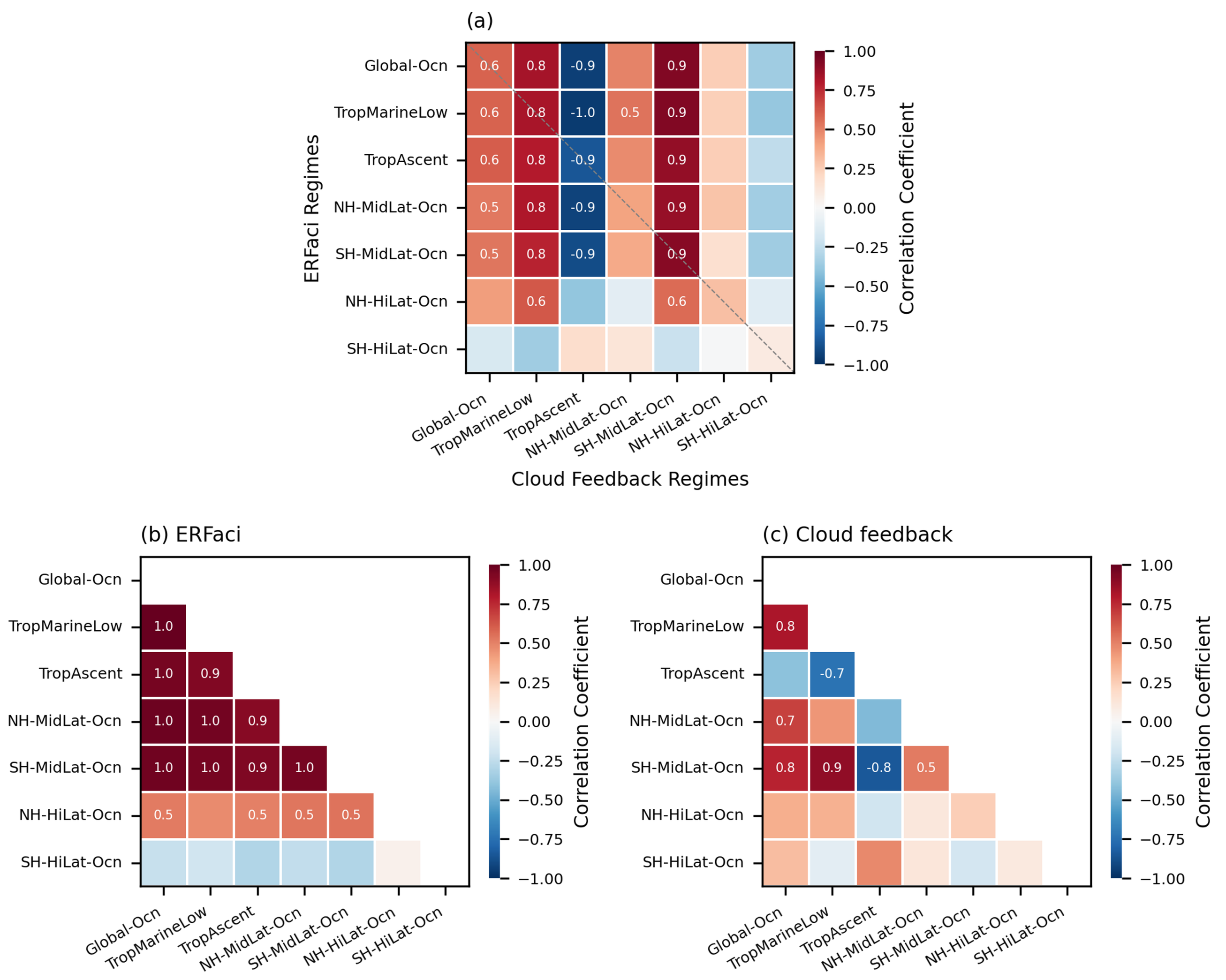
- Focus of Current Study:

This study complements previous research by investigating the impact of **turbulent processes** on the relationship.

2. Methods

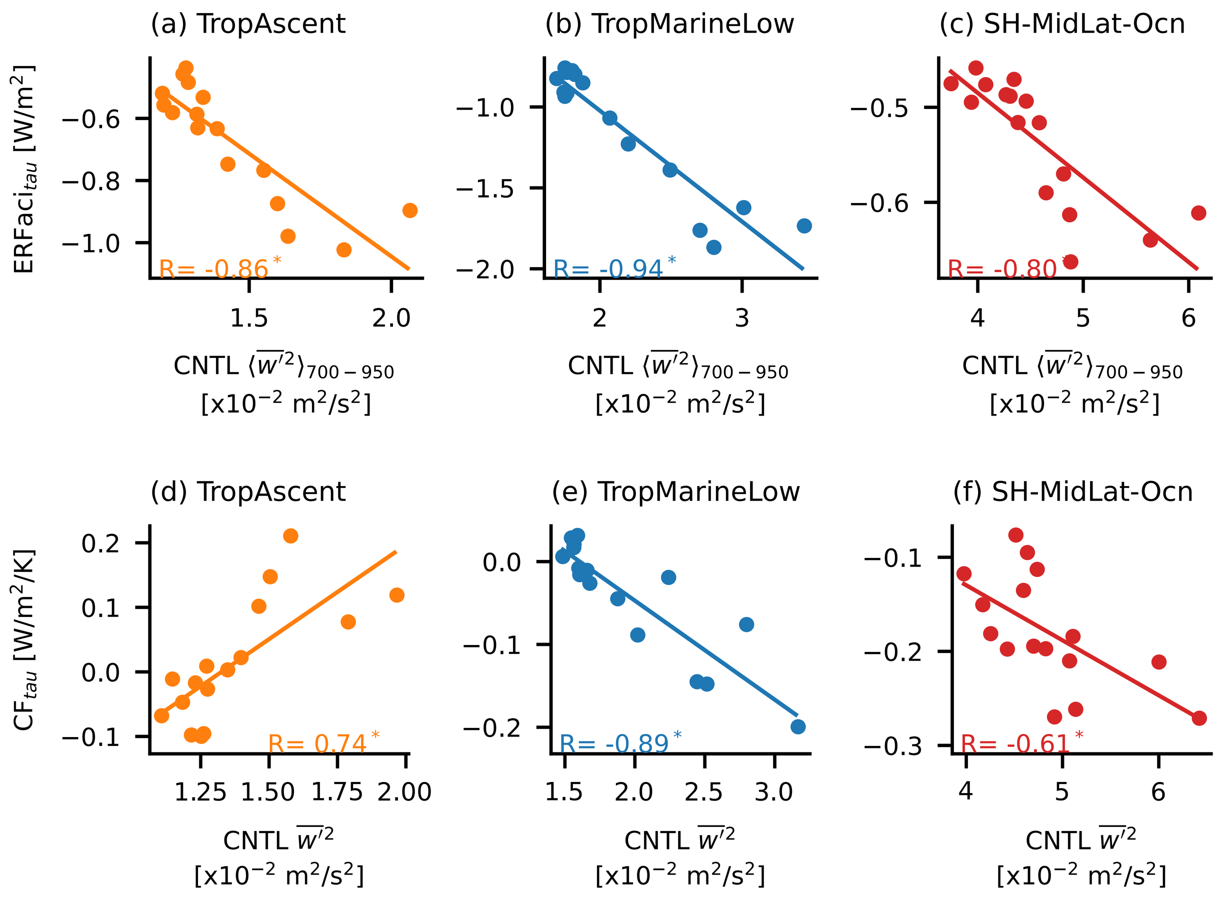
Model	E3SM version 2 (Golaz et al., 2022)
Parameter perturbation strategy	one-at-a-time (OAT)
PPE members	16 (turbulent-related)
Exp. for CF	6-year present-day (PD) and PD + uniform 4K warming
Exp. for ERFaci	2-year nudged PD and pre-industrial (PI)

3. Results



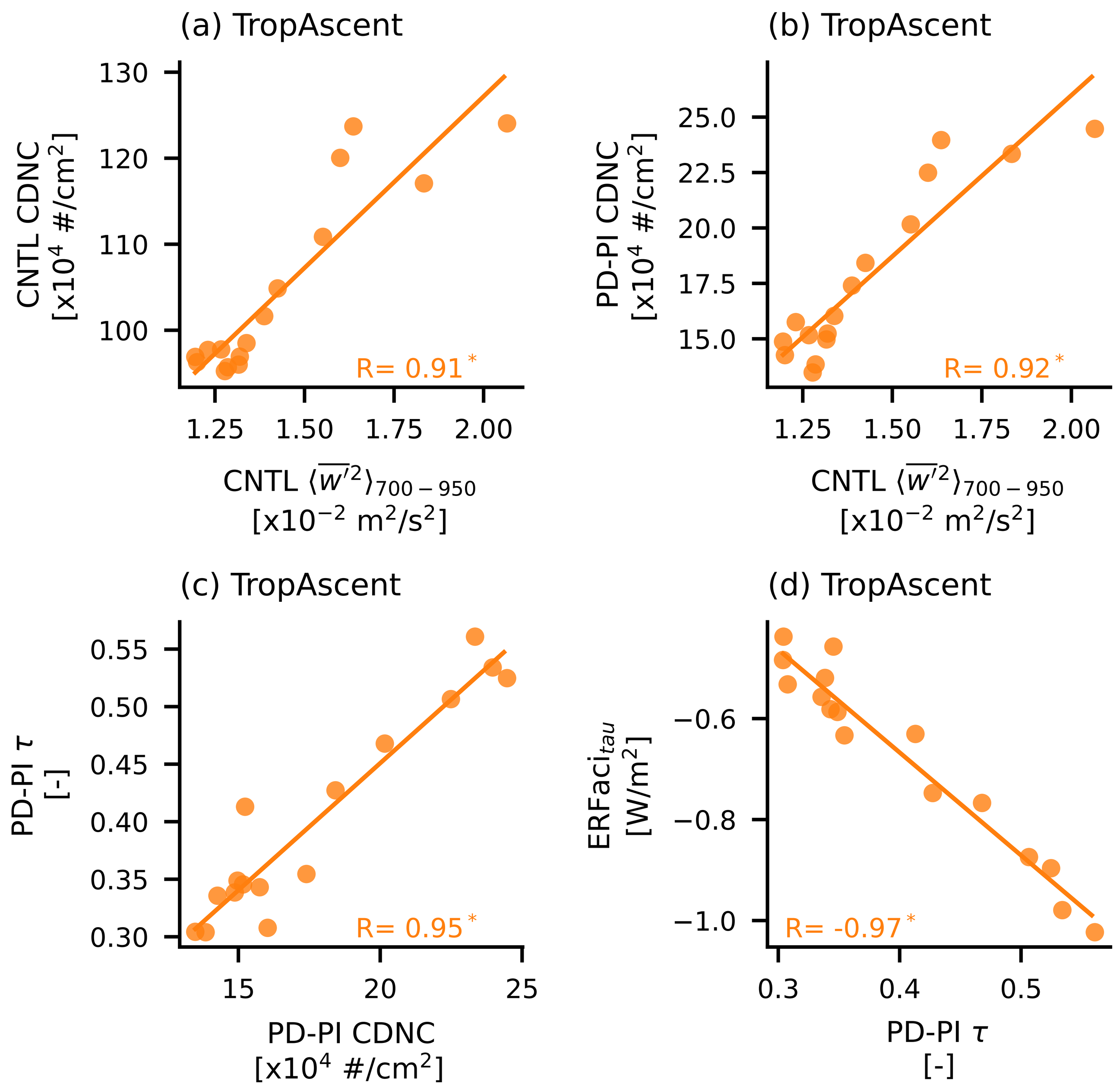
- **Significant negative correlation** observed in **TropAscent**, while **positive correlations** are noted in **TropMarineLow** and **SH-MidLat-Ocn** regimes.
- These diverse correlations are related to **varying cloud feedbacks** across cloud regimes (see panel c).

3.1 Dependency on turbulent mixing strength



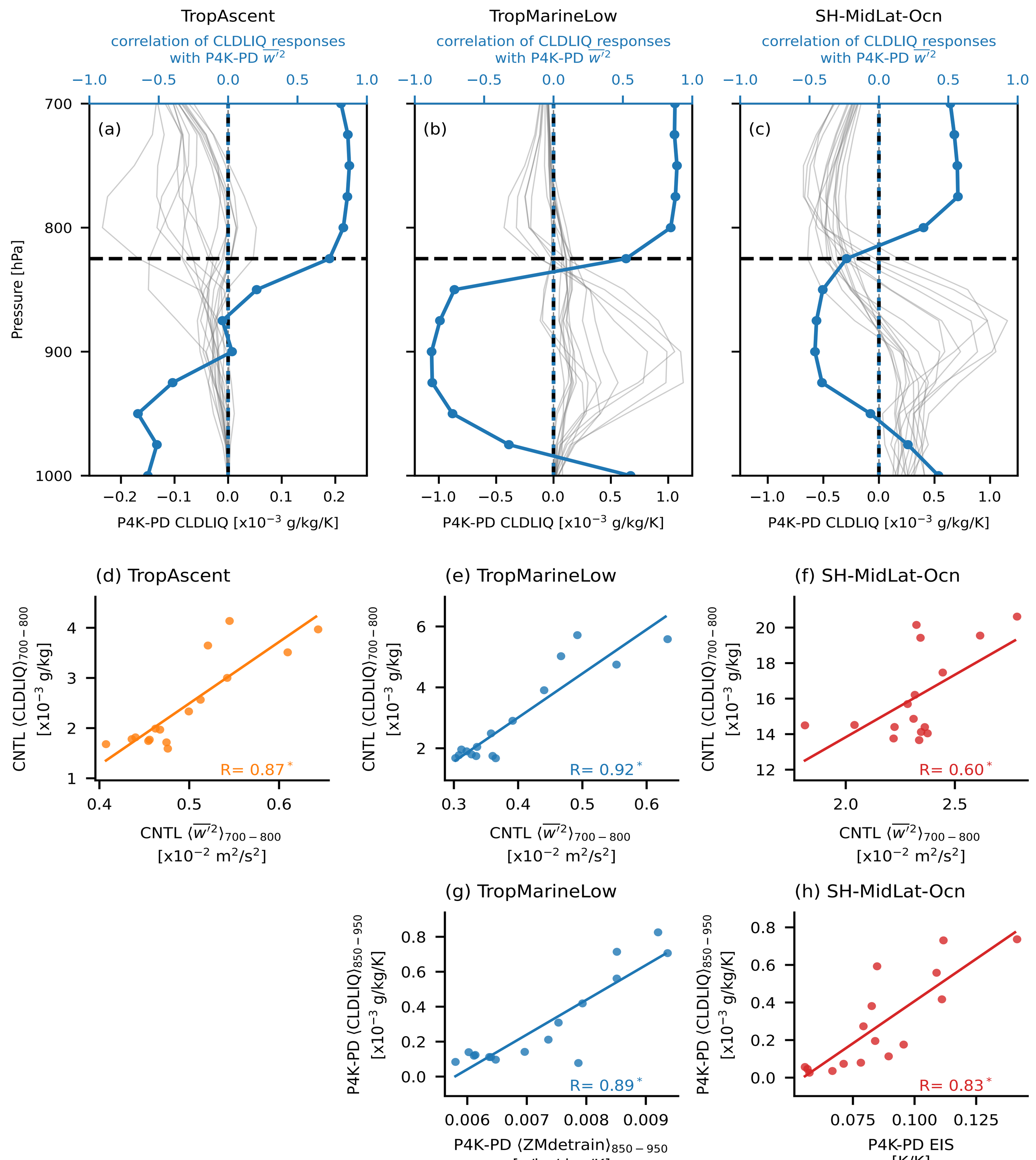
- Increased **mean-state turbulent mixing strength ($\overline{w'^2}$)** is associated with more **negative ERFaci** across the three regimes.
- Stronger $\overline{w'^2}$ is associated with more **positive cloud feedback** in **TropAscent** but more **negative cloud feedback** in **TropMarineLow** and **SH-MidLat-Ocn** regimes.

3.2 Physical processes driving the ERFaci



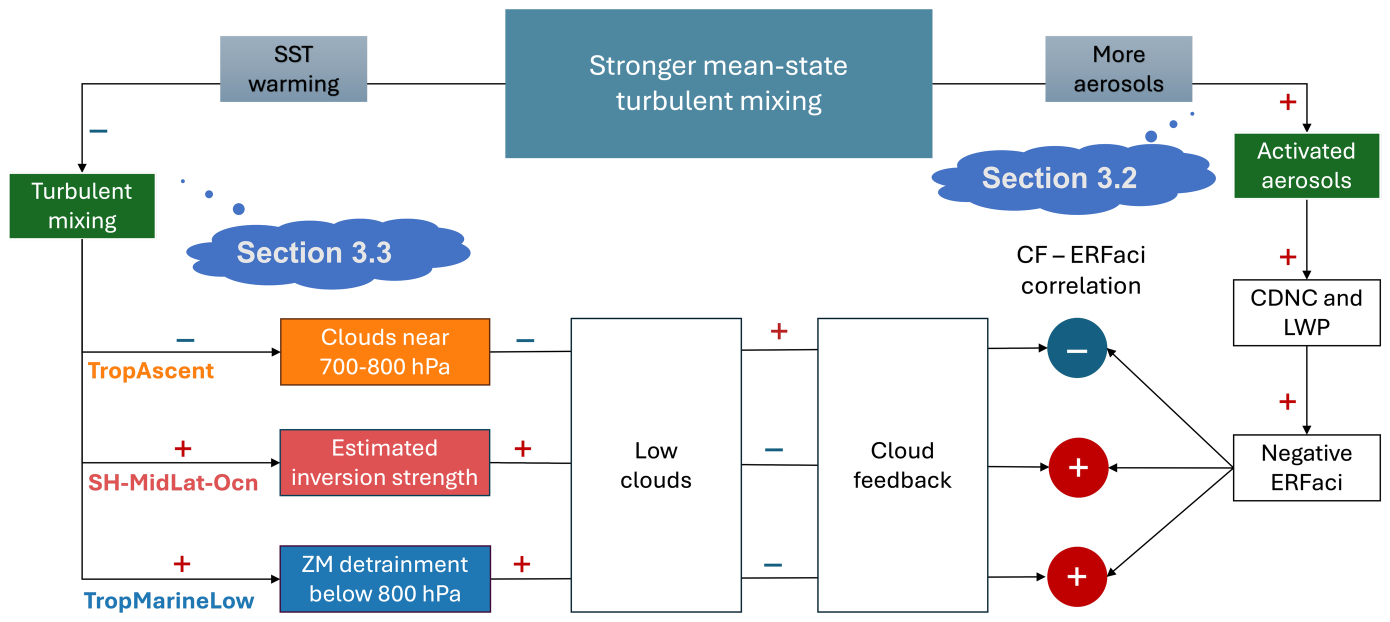
- The mechanism is consistent across the three cloud regimes (only the TropAscent regime is shown above).
- Increased $\overline{w'^2}$ is associated with enhanced **cloud droplet nucleation** and higher **nucleation efficiency**, resulting in greater **PD-PI changes** in cloud optical depth and, consequently, more **negative ERFaci**.

3.3 Physical processes driving the cloud feedback



- **Warming-induced changes in cloud water (CLDLIQ)** vary across the three cloud regimes: there is a consistent **reduction above 825 hPa**, while below 825 hPa, an **increase** occurs only in the **TropMarineLow** and **SH-MidLat-Ocn** regimes (panels a-c).
- The decrease in CLDLIQ above 825 hPa is associated with a **positive feedback loop** between cloud water, buoyancy flux and turbulence.
- The increase in CLDLIQ below 825 hPa is attributed to enhanced **ZM cloud water detrainment** in the **TropMarineLow** regime and increased **EIS** in the **SH-MidLat-Ocn regime** (panels g-h).

4. Conclusions



Turbulent mixing strength influences both cloud feedback and aerosol-cloud interaction, enabling the CF-ERFaci correlation in certain regimes.

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