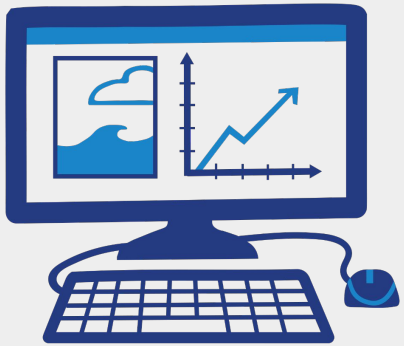
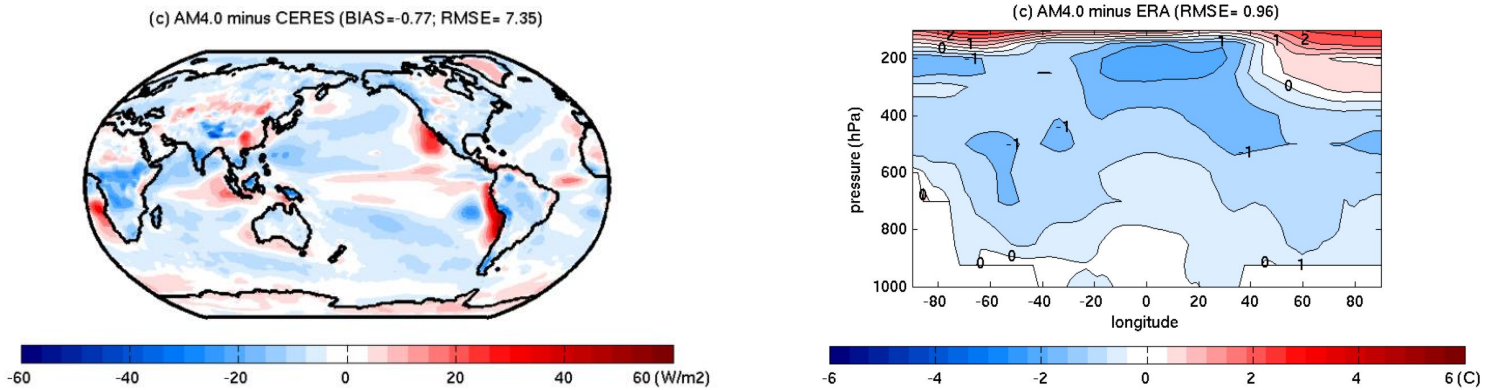


Improving the Subgrid-Scale (SGS) Turbulence Scheme and its Coupling with Cloud Microphysics

Zhihong Tan

Q1: Concerning GFDL's core strength of building and improving models of the weather, oceans, and climate for societal benefits, how can GFDL leverage advances in science and computational capabilities to improve its key models? What are the strengths, gaps, and new frontiers?

AM4's biases are partially linked to SGS turbulence scheme

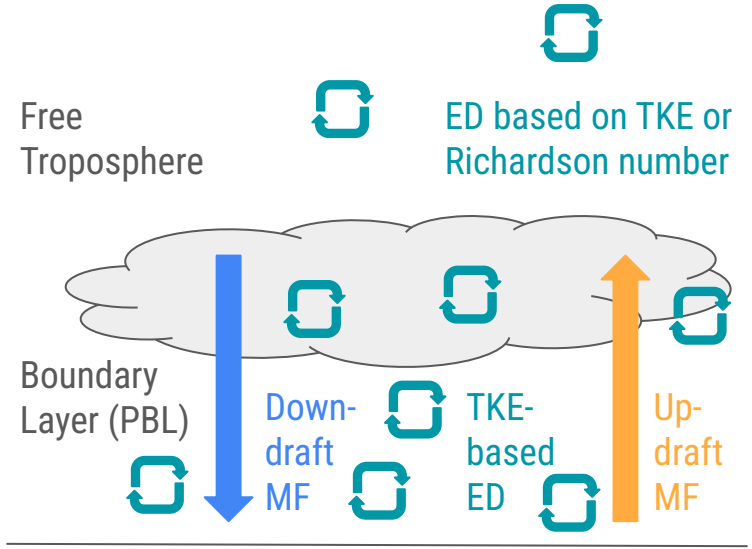


Long-term annual-mean AM4 model biases in: (Left) top-of-atmospheric (TOA) net downward shortwave flux; (Right) zonal-mean temperature in pressure coordinate. Adapted from Zhao et al. (2018).

- AM4's biases in TOA shortwave radiation, cloudiness, and tropospheric temperature and humidity are linked to its physical parameterizations, including the SGS turbulence scheme.

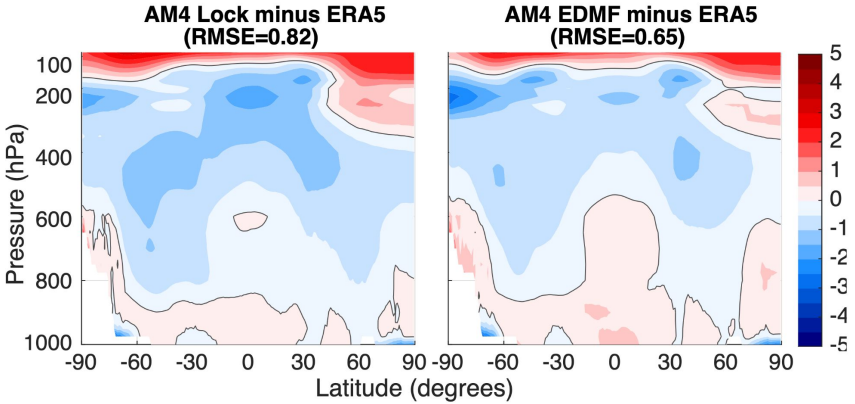
Updated AM4 with Eddy-Diffusivity Mass-Flux (EDMF) scheme

- We implemented the NCEP turbulent kinetic energy (TKE)-based EDMF scheme (Han et al. 2019) to parameterize SGS turbulence in the boundary layer (PBL) and free-troposphere.
- The MF component represents coherent updrafts (driven by surface buoyancy flux) and downdrafts (driven by cloud-top cooling) within PBL.
- It replaces the Lock k-profile ED-only scheme used from AM2 to AM4, which does not represent these coherent drafts.

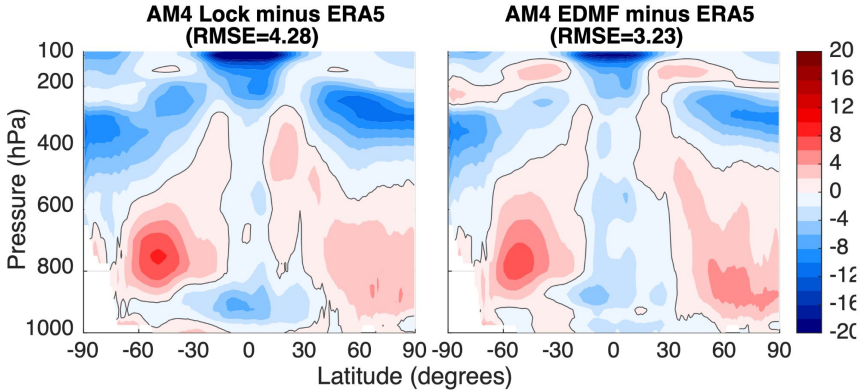


Schematic: SGS turbulence parameterizations in the updated AM4 with NCEP EDMF scheme.

EDMF improves AM4's temperature and humidity biases



Zonal mean temperature (T) bias (K).
Left: Original AM4; Right: AM4 with EDMF.



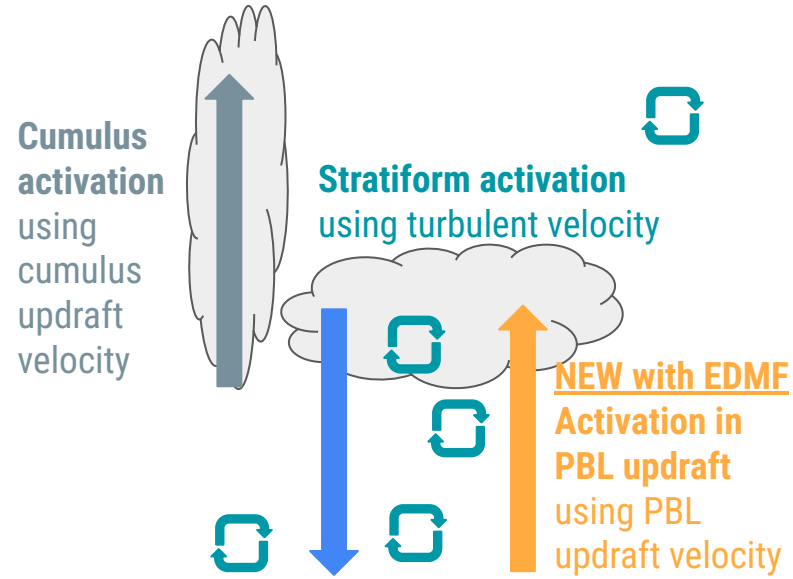
Zonal mean relative humidity (RH) bias (%).
Left: Original AM4; Right: AM4 with EDMF.

Tan & Zhao (in prep)

- The zonal-mean biases are improved by EDMF, as indicated by the reduced RMSE.
- Other model fields such as net top-of-atmospheric radiation are overall unchanged.

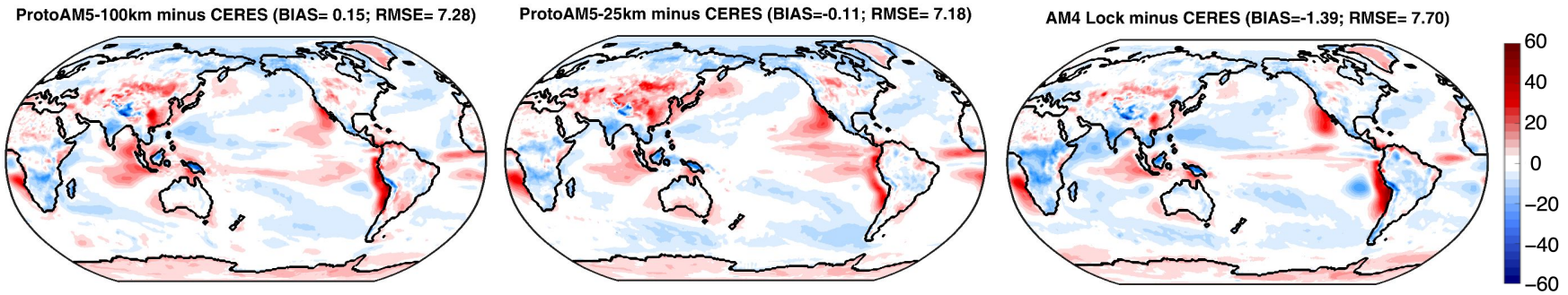
Coupling EDMF to the MG2 cloud microphysics scheme

- In addition to AM4's aerosol activation in cumulus and stratiform clouds, we added aerosol activation in the PBL updraft as simulated by NCEP EDMF.
- PBL updraft has stronger vertical velocity and is thus more efficient in activation than stratiform activation.
- Smaller droplets are detrained from PBL updrafts into stratocumulus, which favors its maintenance.



Schematic: Three aerosol activation processes in the updated AM4 with MG2 and NCEP EDMF schemes.

EDMF-MG2 improves coastal stratocumulus in prototype AM5



Annual-mean TOA net downward shortwave flux bias in prototype-AM5 at 100km and 25km resolutions compared to AM4. Note that AM4 bias is slightly larger than Zhao et al. (2018) due to the CERES-EBAF dataset update.

- Shortwave bias is reduced, especially over Eastern Pacific coastal stratocumulus regions.
- The EDMF scheme, MG2 microphysics, and refined horizontal resolution are all beneficial.
- AM5 development is ongoing; more results to come this year.