Climate Forcing, Feedbacks and Projections

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Q2: Concerning NOAA's key mission element of understanding, predicting, and projecting changes in the Earth System, how can GFDL drive further advances in these areas, including extremes and environmental hazards, through scientific innovation based on observations, theory, and modeling? Where are the strengths, gaps, and new frontiers?

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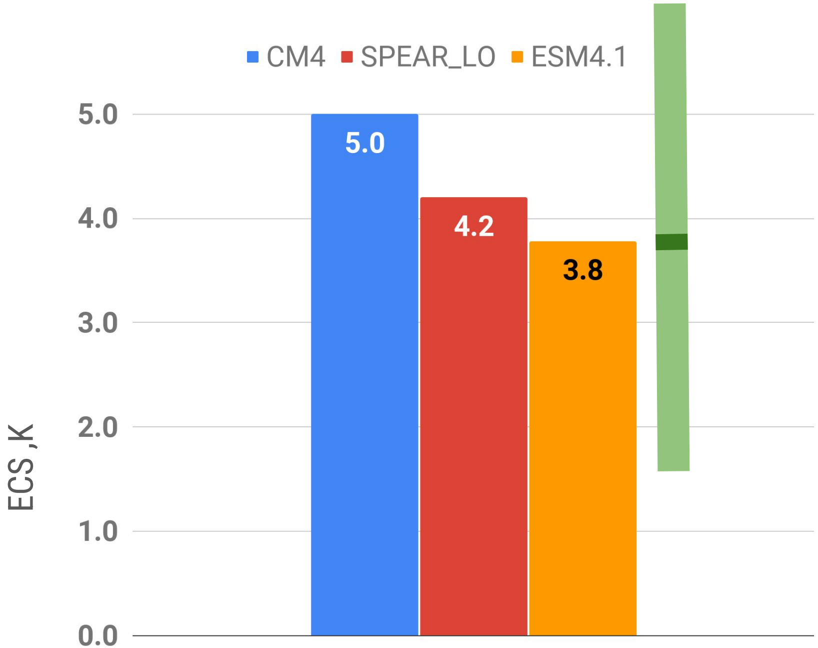
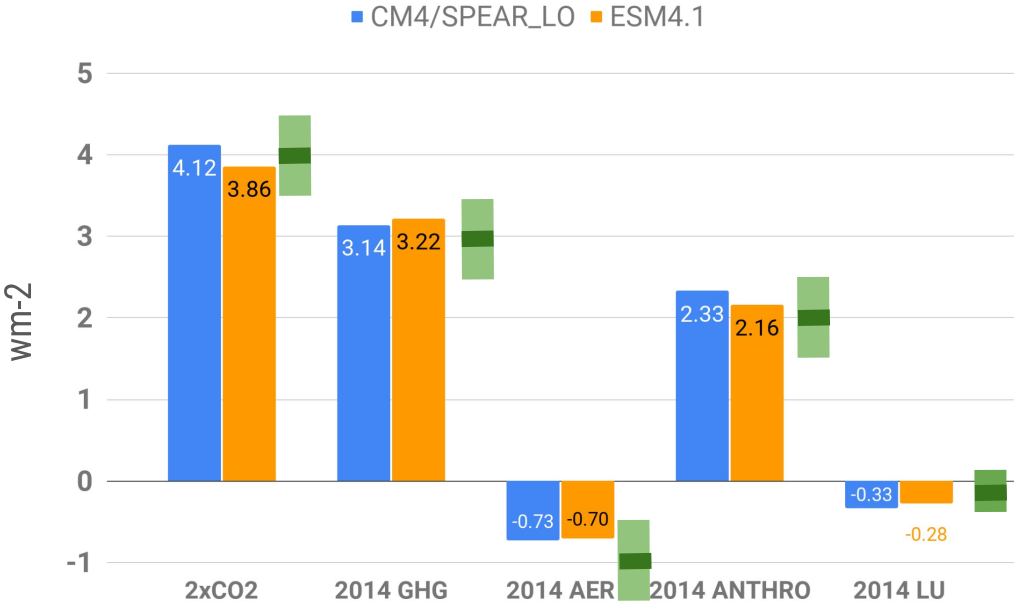
GEOPHYSICAL FLUID DYNAMICS LABORATORY

5-Year Review
January 28-30, 2025

ECS and Radiative Forcing Strength in 4th Generation GFDL Models



Equilibrium Climate Sensitivity(ECS) across the 4th generation of GFDL models. **Green bar** is 5-95% range for CMIP6 models, dark green is the mean.



RFMIP contribution: Effective Radiative Forcing (ERF) across the 4th generation of GFDL models. **Green bar** is the 5-95% range across RFMIP models. dark green is the mean.

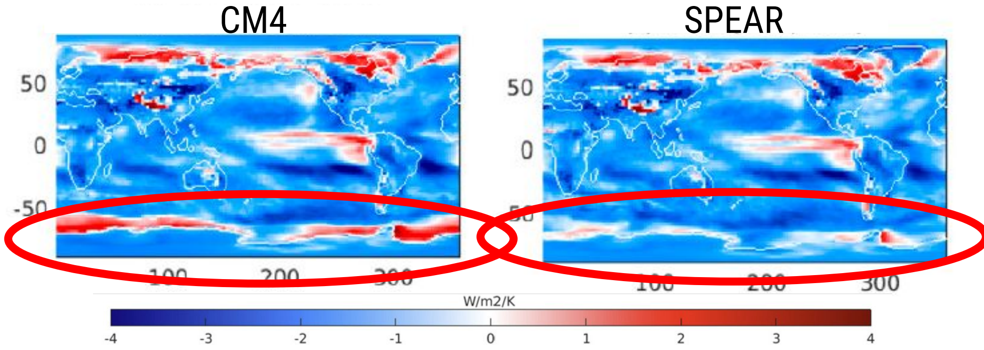
Understanding Differences in ECS Between GFDL Models

CM4.0 (5.0 K) vs SPEAR_LO (4.2 K) (Zhao 2022)

Key points:

-Difference in sea-ice response tied to change in ocean configuration (25 km vs 100 km).

-Cloud feedbacks change over time, leading to increased estimate of ECS in both models (also see Dunne et al. 2020 and Winton et al.2020).



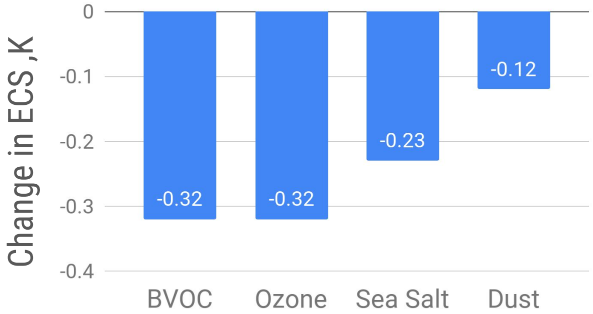
Feedback (Wm-2/K) differences between CM4 and SPEAR

CM4.0 (5.0 K) vs ESM4.1(3.8 K) (Sentman et al. sub.)

Key points:

-More comprehensive representation of aerosol and chemisity processes leads to lower ECS in ESM4.1

-Slab ocean runs found that no single component change is responsible, but that they all sum up to cause the large difference (See also Paulot et al. 2020)

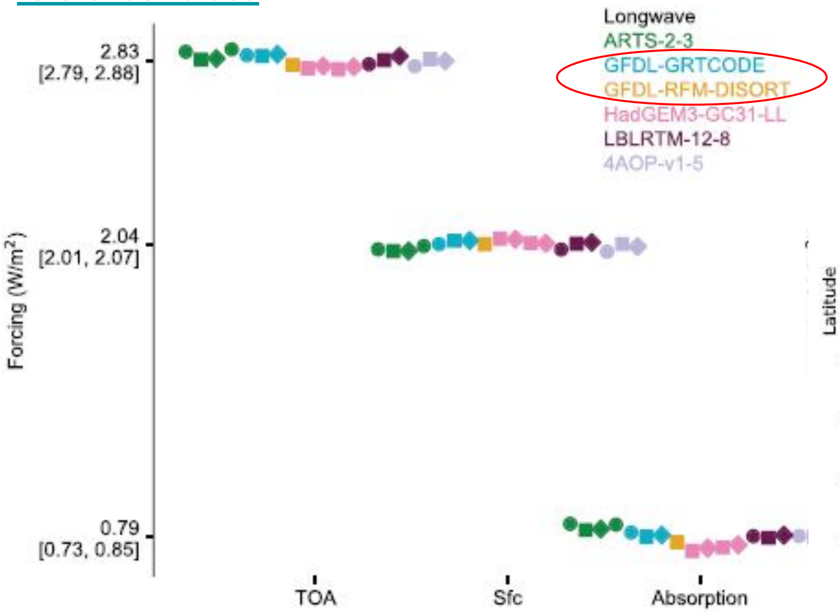


Reduction in ECS in CM4 caused by switching to ESM4.1 schemes

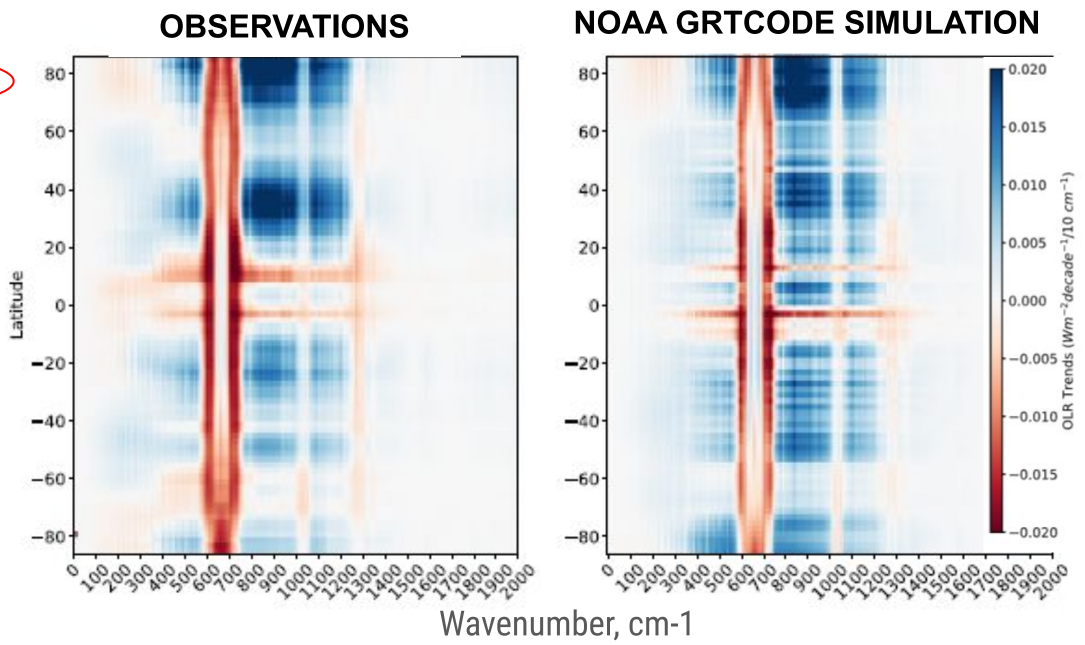
Forcing and Feedbacks from GFDL Benchmark Hyperspectral Codes

GFDL has one of the few benchmark hyperspectral radiation codes (GRTcode). Used for CMIP6 reference values

GFDL is the also the only modelling center that can perform benchmark calculations at the global scale including clouds.



Benchmark GHG Forcing values from 1850 to 2014

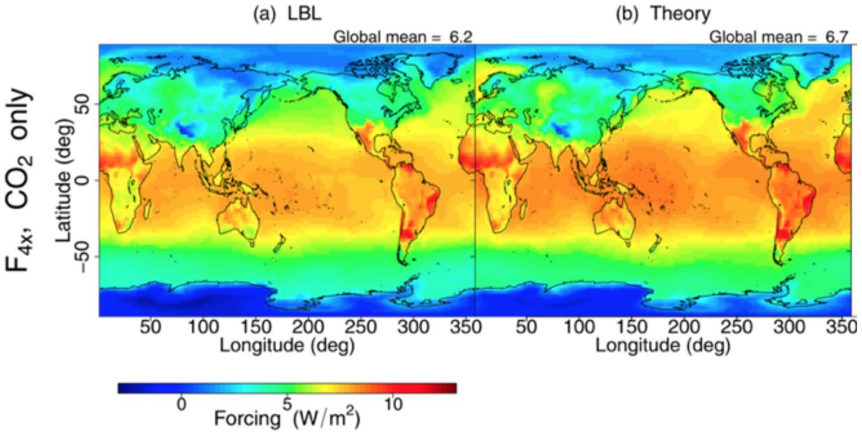


Zonal Mean Trends in the Thermal Spectra 2003-2021

An Improved Theoretical Underpinning of Forcing and Feedbacks

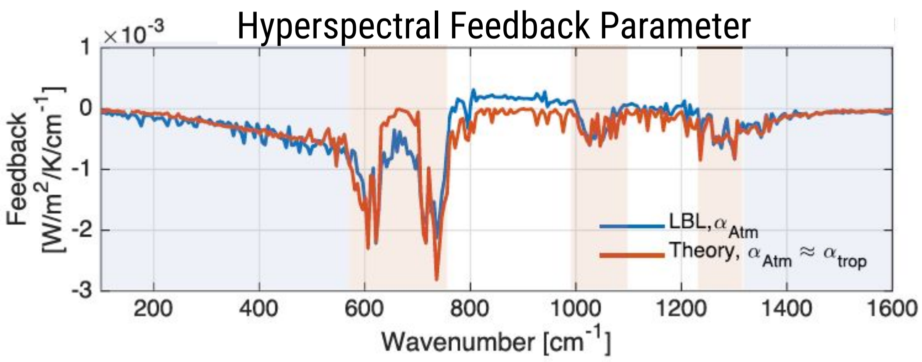
At GFDL we have conducted numerous studies on factors controlling the magnitude of forcing and feedbacks. Here we highlight two that have used hyperspectral calculations

Jeevanjee et al. (2021) Developed a model to constrain the factors controlling CO2 forcing.



$$\mathcal{F} = 2\ln\left(\frac{q_f}{q_i}\right)\left[\pi B(\nu_0, T_s) - \pi B(\nu_0, T_{strat})\right]$$

Feng et al. (2023) showed how a stable greenhouse effect is maintained under global warming, by creating a simplified hyperspectral model of how Earth loses thermal energy as it warms.



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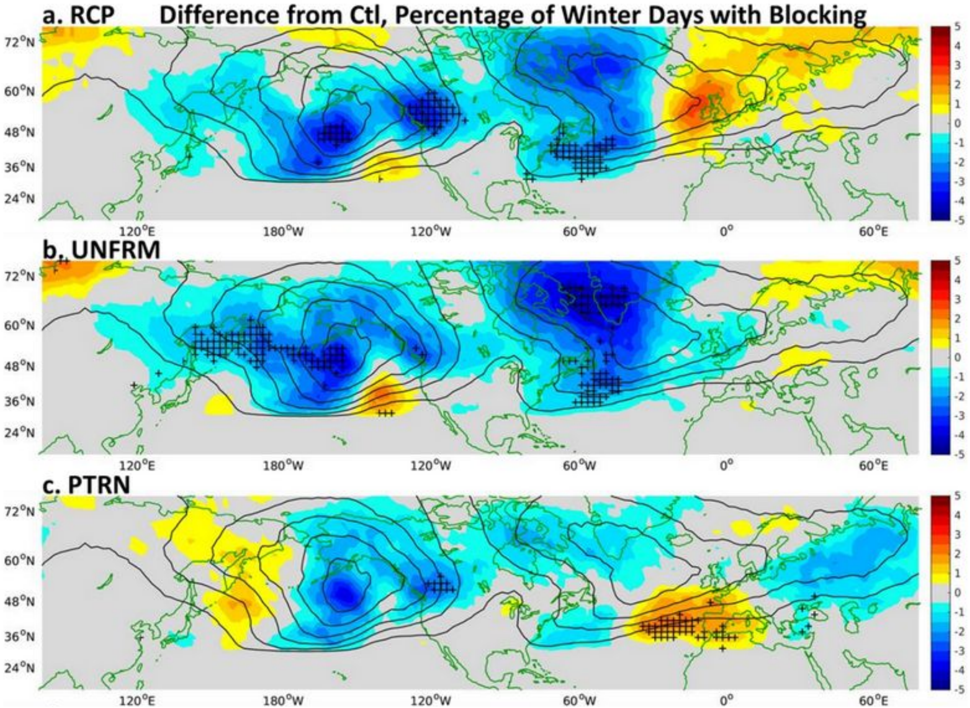
Atmospheric Blocking in Future Climate Projections

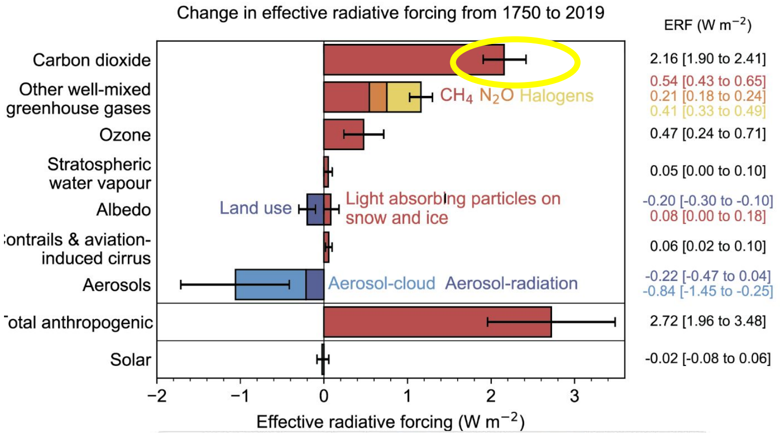
- [Narinesingh et al. (2024)](#) looked at the impact of uniform warming vs SST pattern on the number of blocking days by 2100 following SSP5-8.5
- CM4 model projects less blocking in the warmer world.
- Most of the change comes from the uniform warming rather than the spatial pattern of surface temperature.
- Relationship between heat extremes and blocking is also investigated.

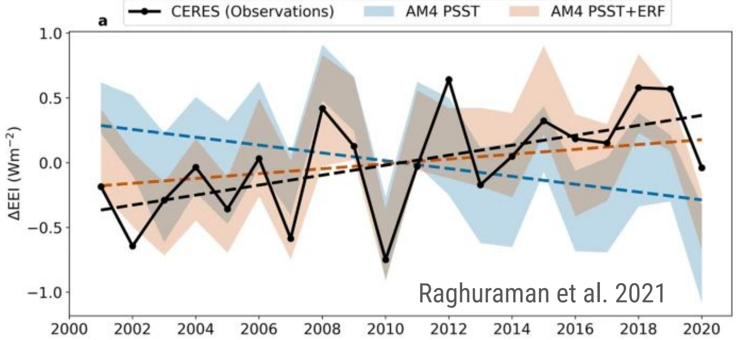


Future Work

1) Produce global scale benchmark hyperspectral greenhouse gas forcing calculations.
2) Will provide leadership of RFMIP for CMIP7.
3) Continue to use GFDL models to inform us of factors controlling the magnitude of ECS.
4) Relate forcing and feedback strengths to high societal impact events.
5) Use GFDL models and hyperspectral codes to continue to evaluate trends and changes in Earth's’ Energy Budget

IPCC AR6 Chapter 7 Forcing estimates





CERES observed energy imbalance timeseries (black) and GFDL AM4 simulations with (orange) and without (blue) anthropogenic forcing