GFDL's Fourth Generation CM4.0 and ESM4.1

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Geophysical Fluid Dynamics Laboratory Review

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GFDL's 4th Generation is a Major Advance

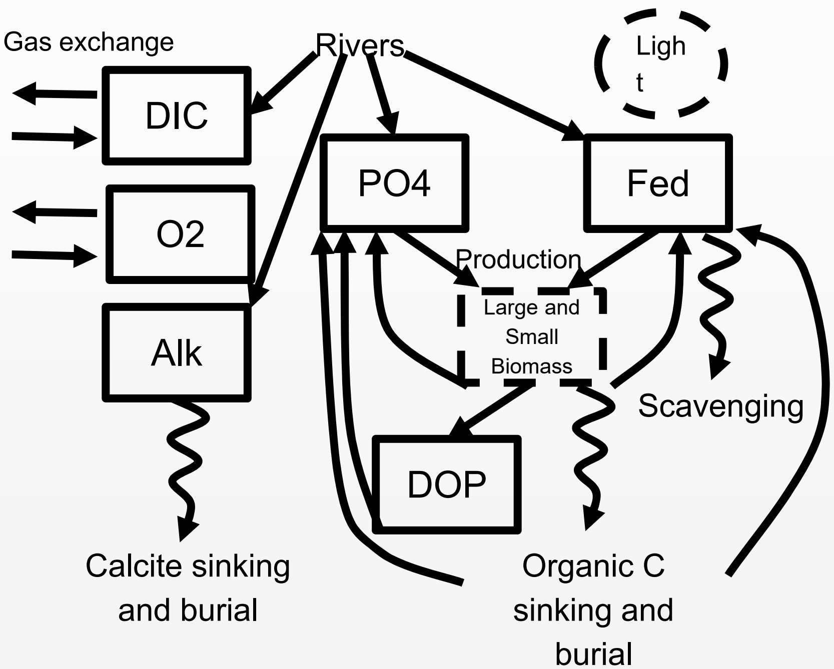
- AM4/OM4 substantively improved dynamics , physics, clouds, and radiation along with doubled resolution.
- CM4.0 vastly improves SST, Southern Hemisphere sea ice, variability modes and teleconnections.
- Overall, CM4.0 surface climate provides strong analysis framework.
- ESM4.1 improves carbon, chemistry, dust and nitrogen interactions and captures most CM4.0 baseline simulations characteristics.
- ESM4.1 provides for understanding forced response, feedbacks and impacts across climate, carbon, ecosystems, and air quality.

Development Activity On Many Fronts

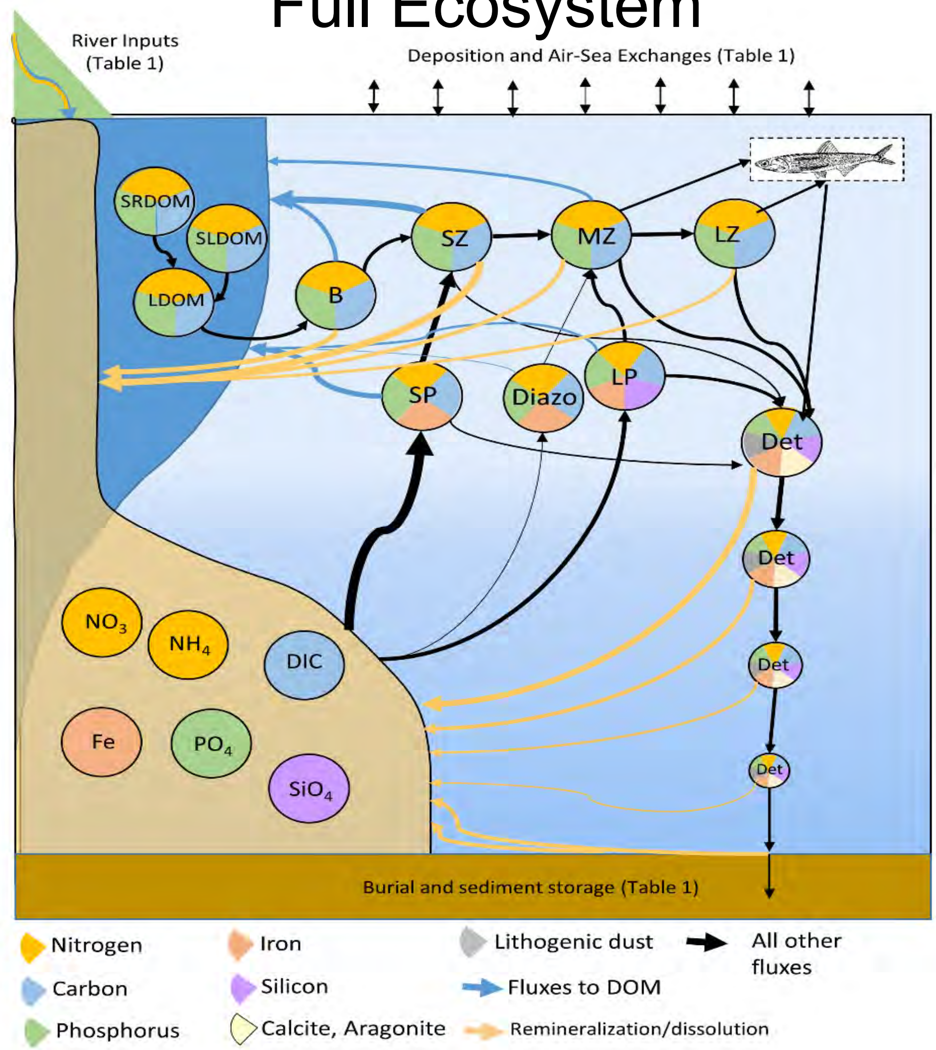
- CM4.0 development foci included
  - Ocean cold bias and heat uptake without mesoscale formulation
  - Convergence of mean atmospheric fidelity at 1°
  - Boreal forests and snow masking for albedo seasonality
  - Understanding high climate sensitivity given moderate AM4 CESS Sensitivity
  - Sensitivity to parameterization of orographic drag
  - Southern Ocean Polynya/sudden warming
- ESM4.1 development foci included
  - Coupled carbon-chemistry
  - Atmospheric aerosol emission and deposition
  - Comprehensive earth system dust/iron representation
  - Vegetation and canopy competition, daily fire, and nitrogen cycling
  - Ocean eddy parameterization for midlatitude SSTs and water masses
  - Southern Ocean Polynya/sudden warming

CM4.0 (BLINGv2) and ESM4.1 (COBALTv2)

6 Tracer Biogeochemistry and Steady State Ecosystem

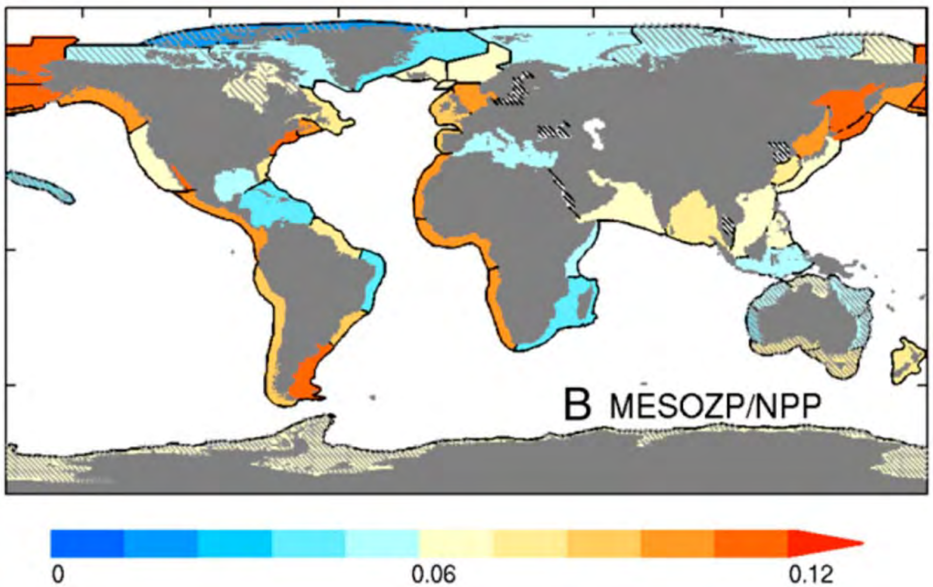


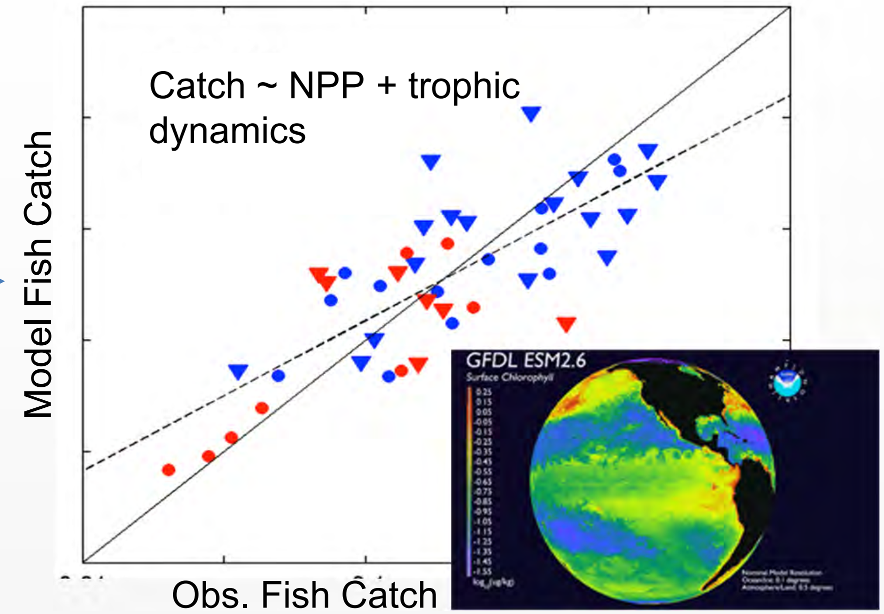
33 Tracer Biogeochemistry and Full Ecosystem



COBALT Builds upon ESM2 Generation Success in Resolving Energy Flows from Primary Production to Fish

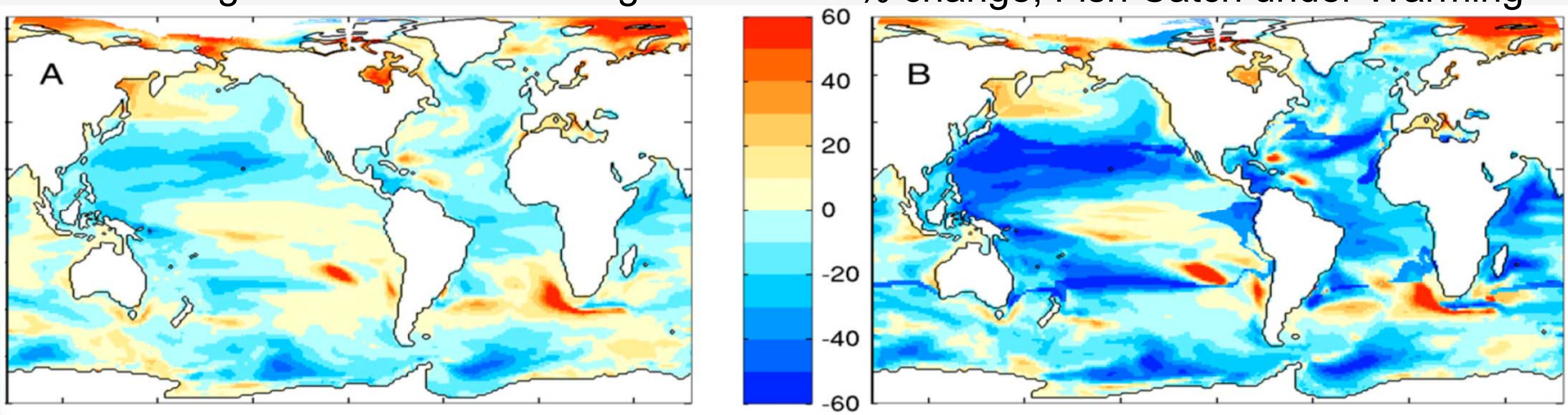
Stock, C. A. et. al., **Reconciling fisheries catch and ocean productivity**, PNAS, 114 (8) E1441-E1449.





% change in PP under warming

% change, Fish Catch under Warming



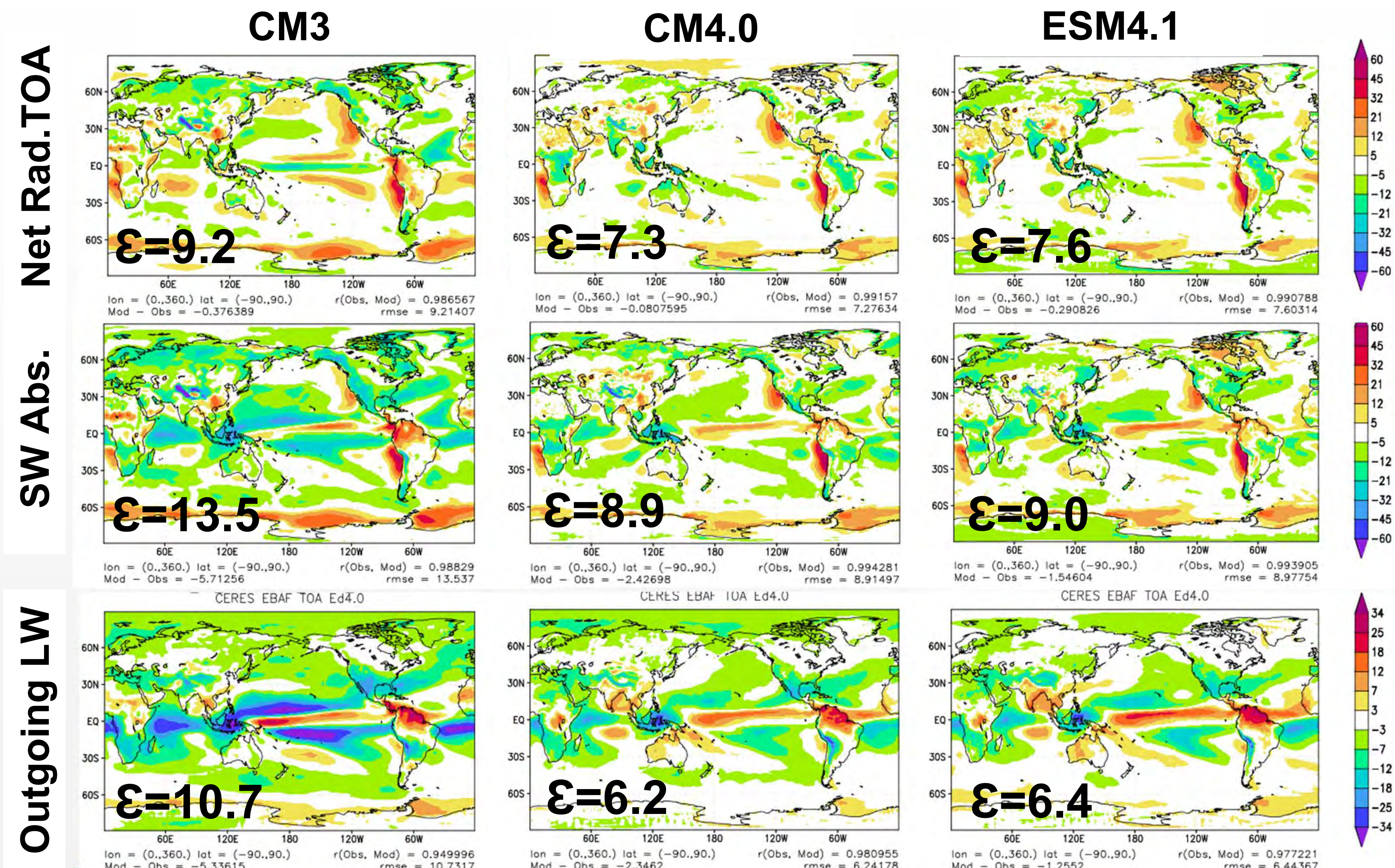
- Fidelity Highlights of GFDL 4th Generation Models

- For further information, see:

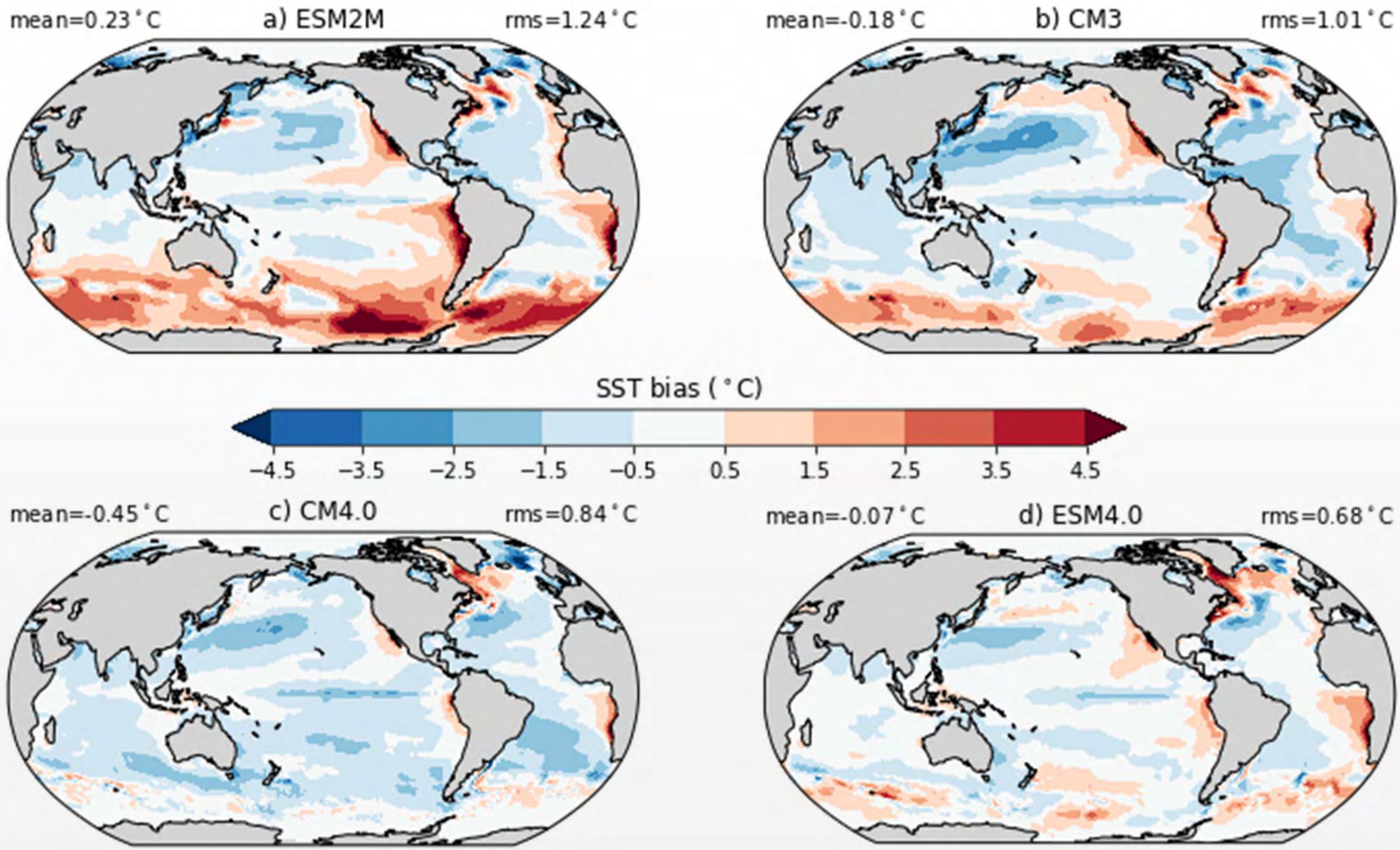
Held et al. in press: **Structure and Performance of GFDL's CM4.0 Climate Model.** *Journal of Advances in Modeling Earth System.*

Dunne et al., in prep.: **The GFDL Earth System Model version 4.1 (GFDL-ESM4.1): Model description and simulation characteristics.** *Journal of Advances in Modeling Earth System.*

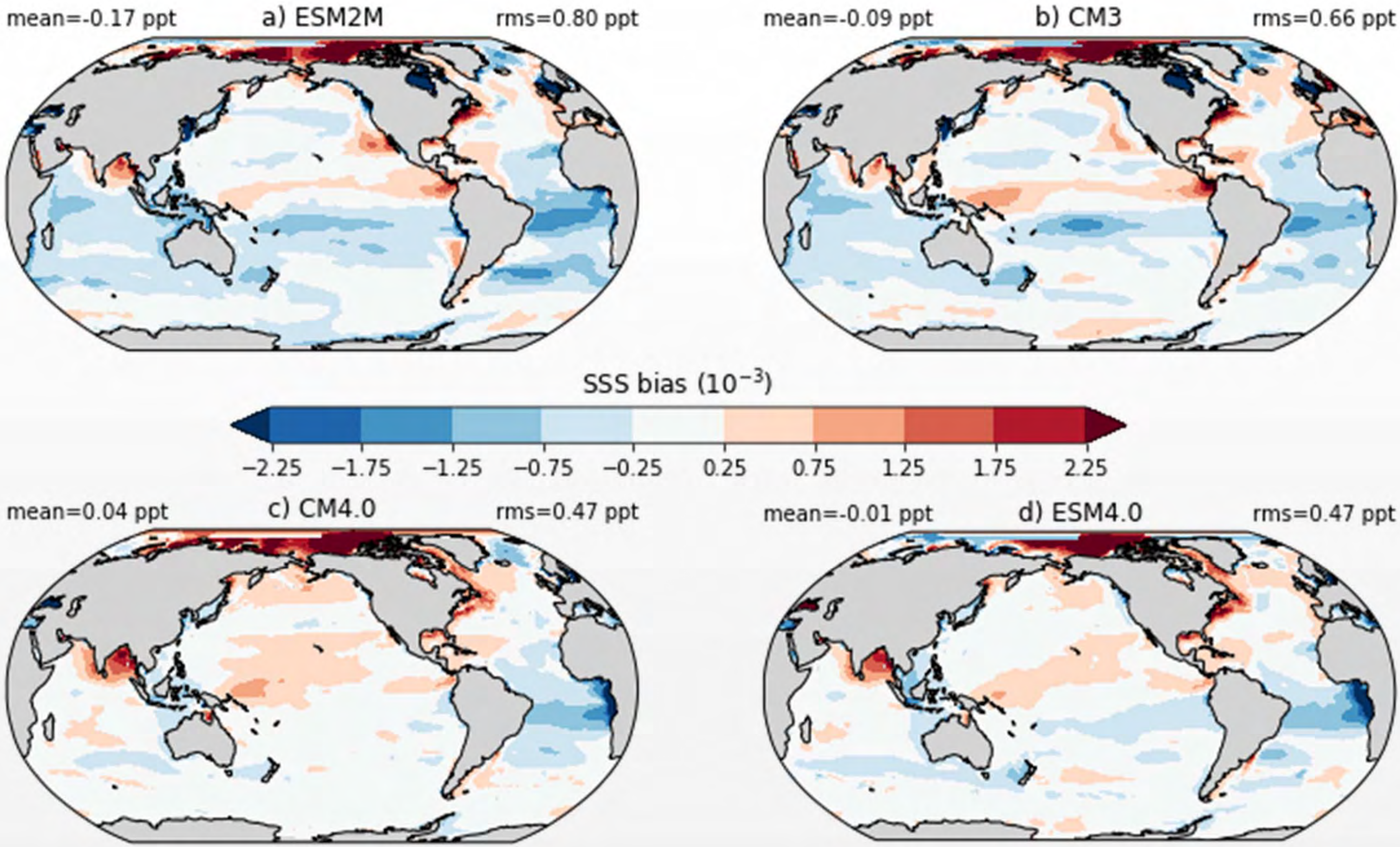
Cloud and Radiation Improvement on Bias



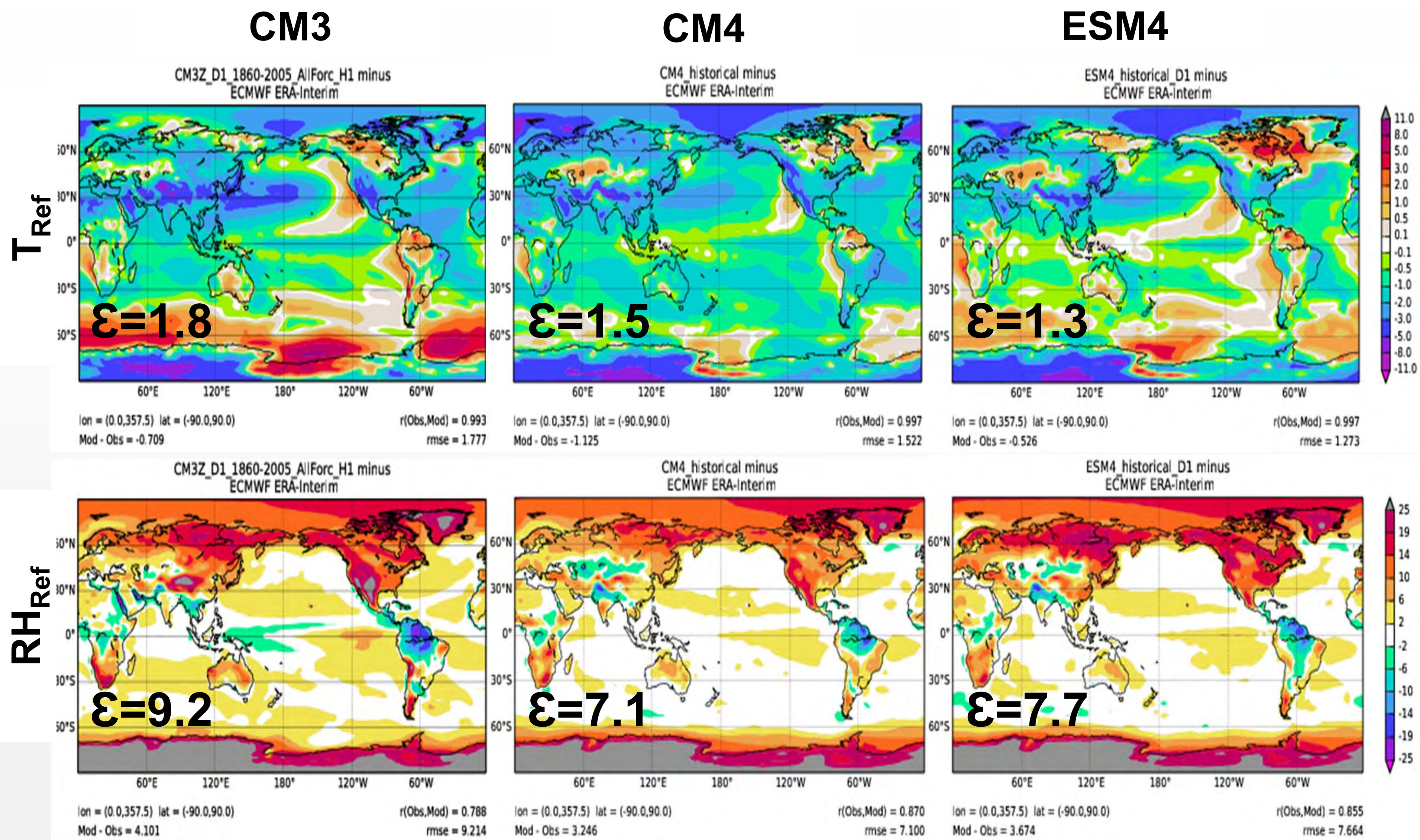
Vast Improvement in Sea Surface Temperature



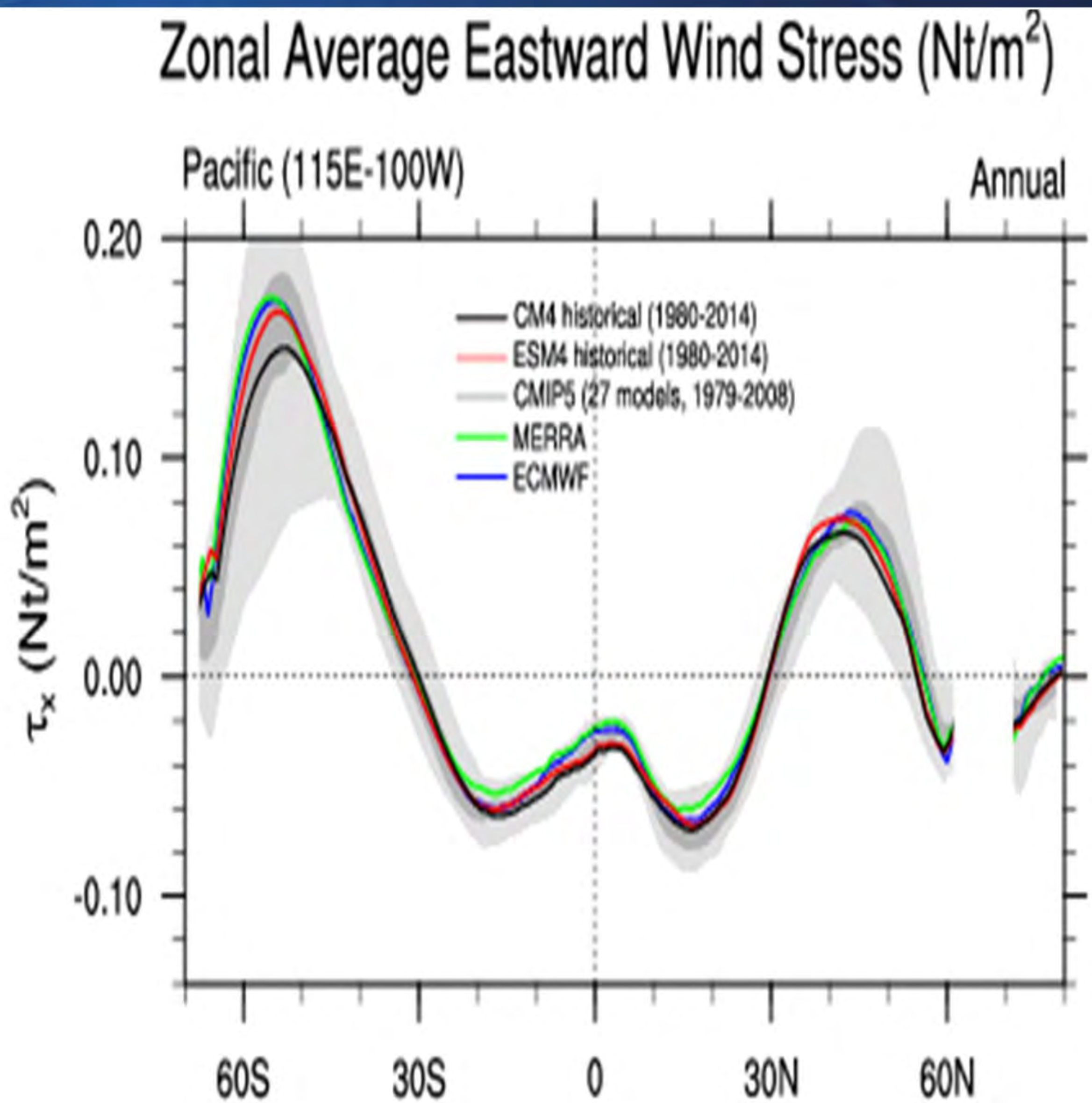
Strong Improvement in Sea Surface Salinity



Strong Improvement in Surface Climate Bias

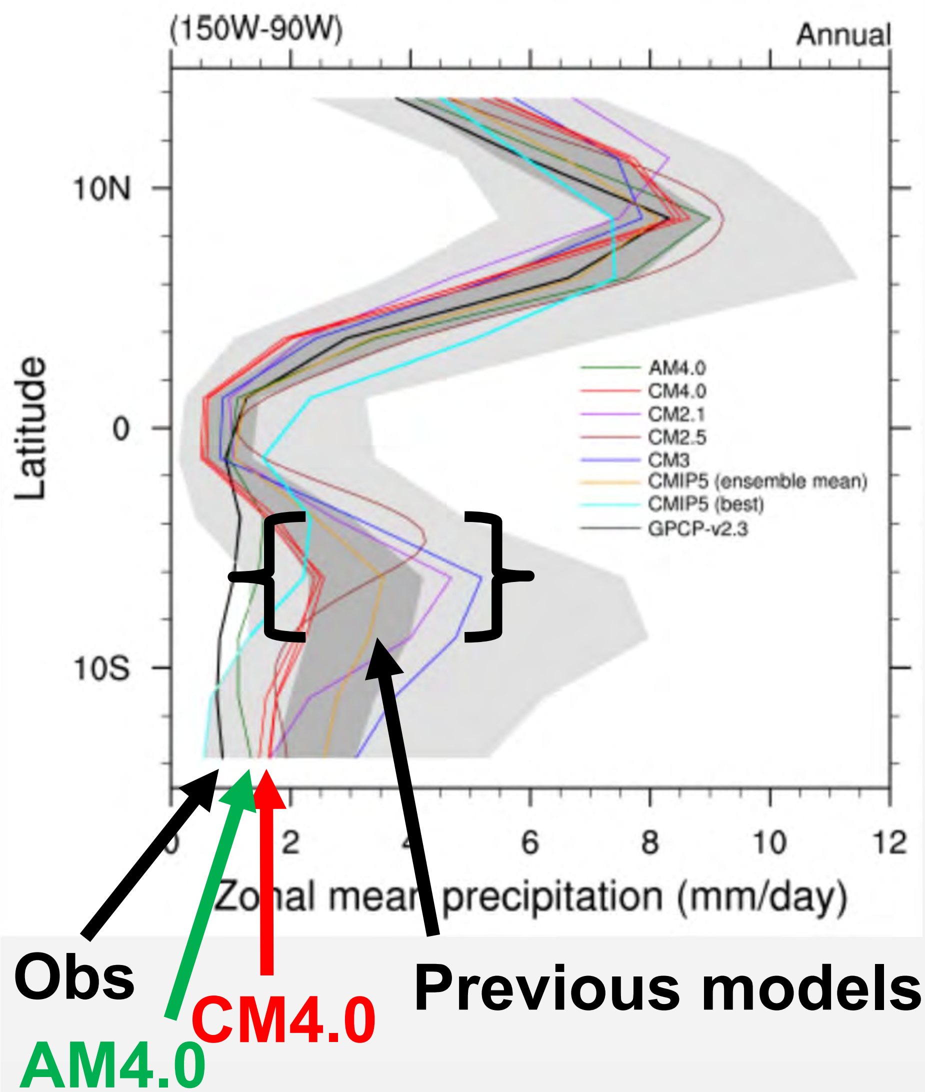


ESM4 eliminates Southern Ocean Wind Bias

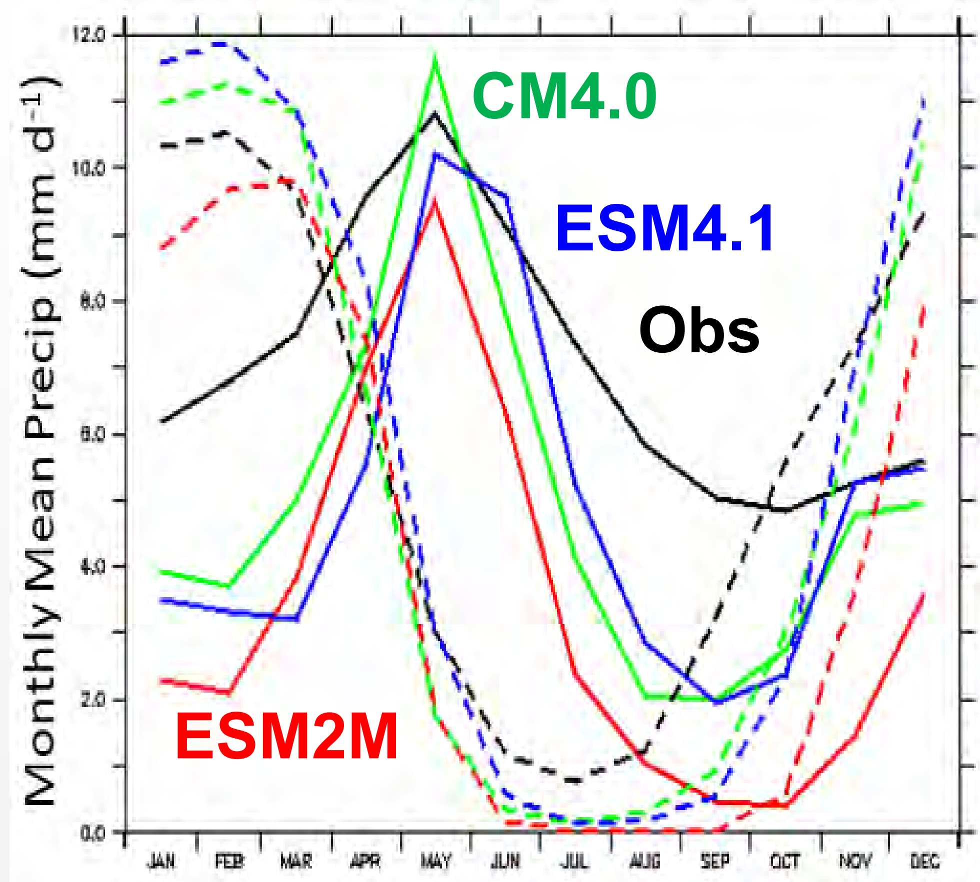


Strongly Improved Regional Precipitation

Pacific Double ITCZ Challenge

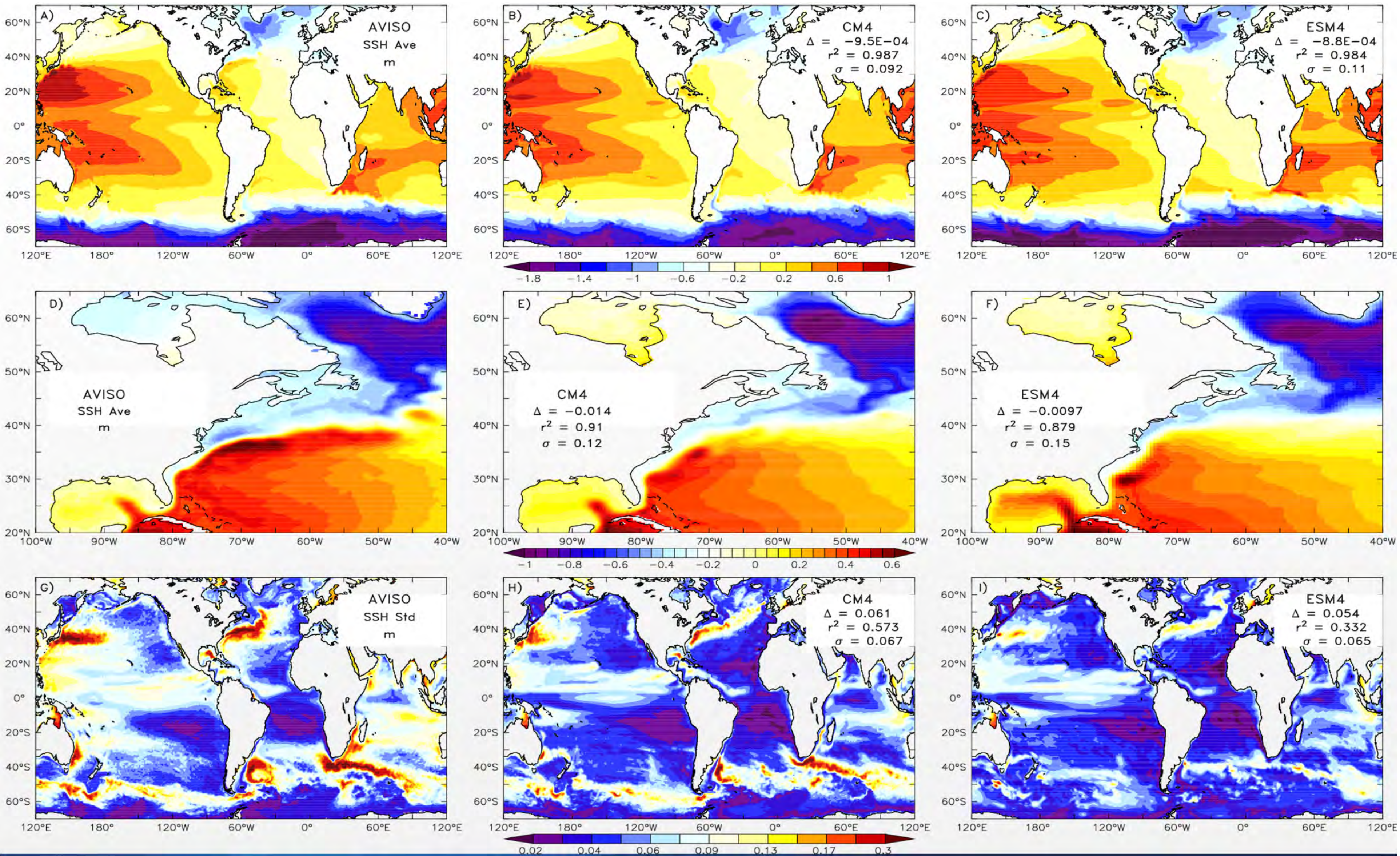


Amazon Dry Bias

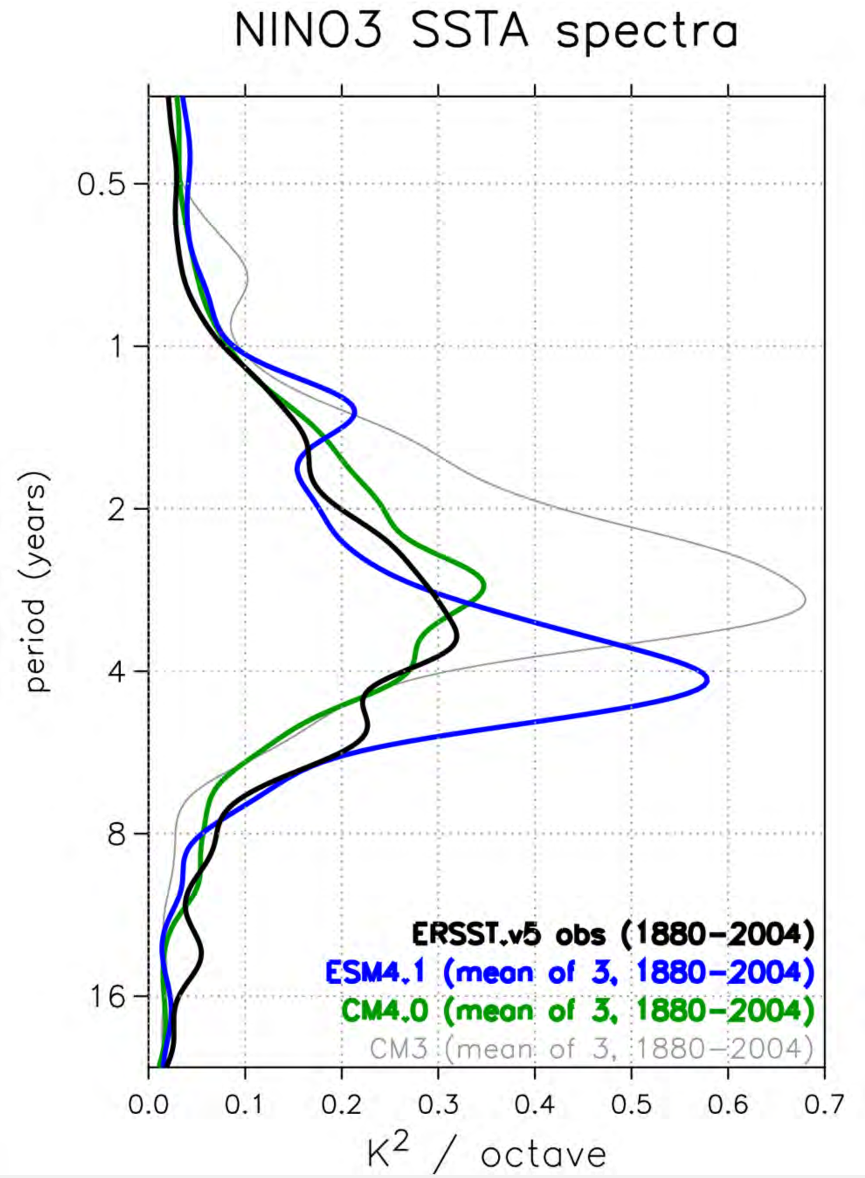


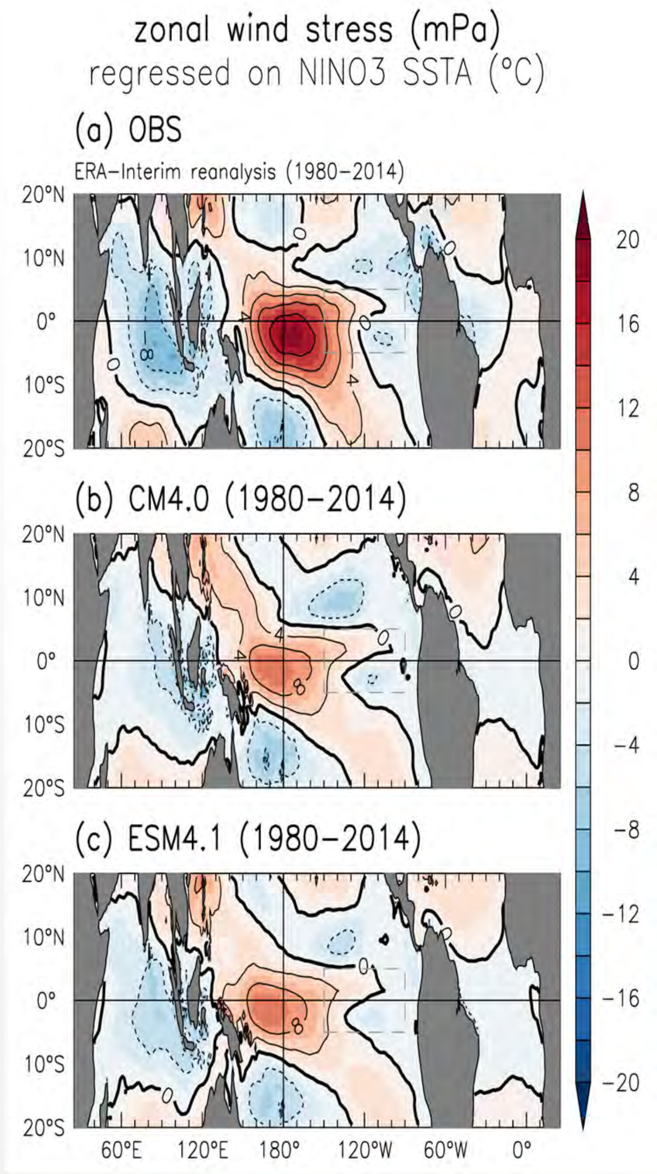
Solid – North Amazon
Dash – South Amazon

Good Boundary Currents and Eddies at ¼°

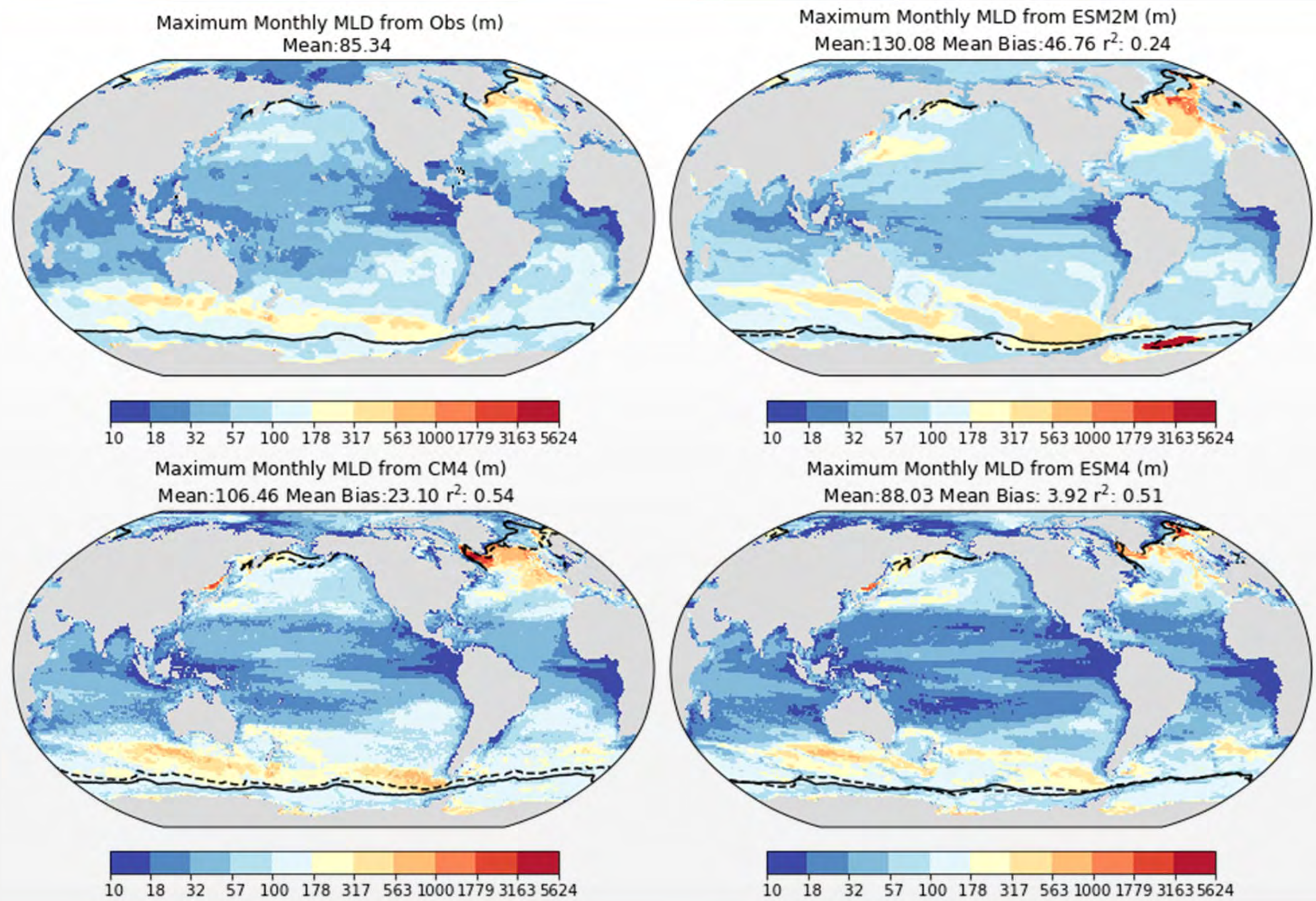


ENSO Terrific in CM4.0, less so in ESM4.1





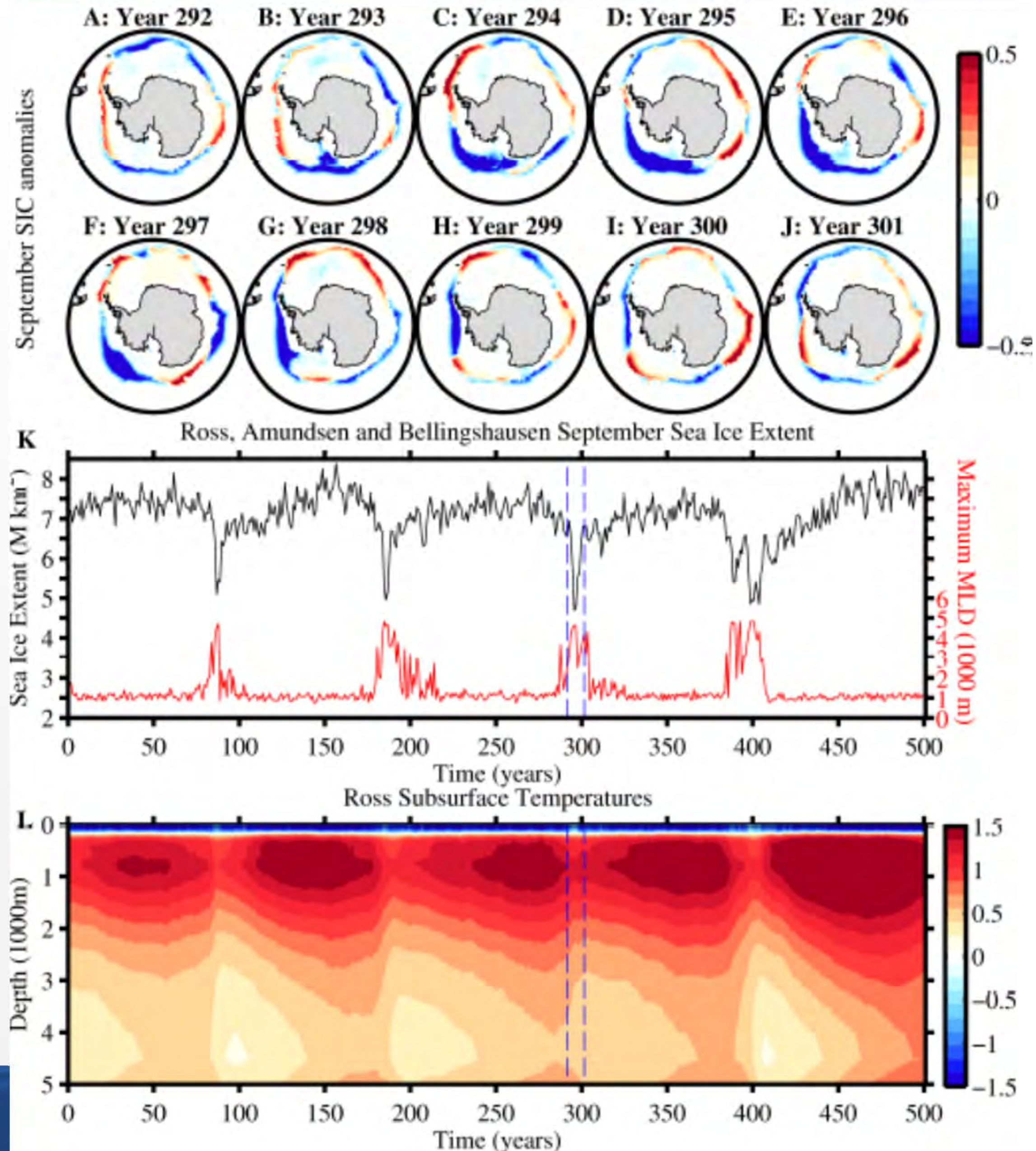
Improved SO Sea Ice Brings Complex Dynamics



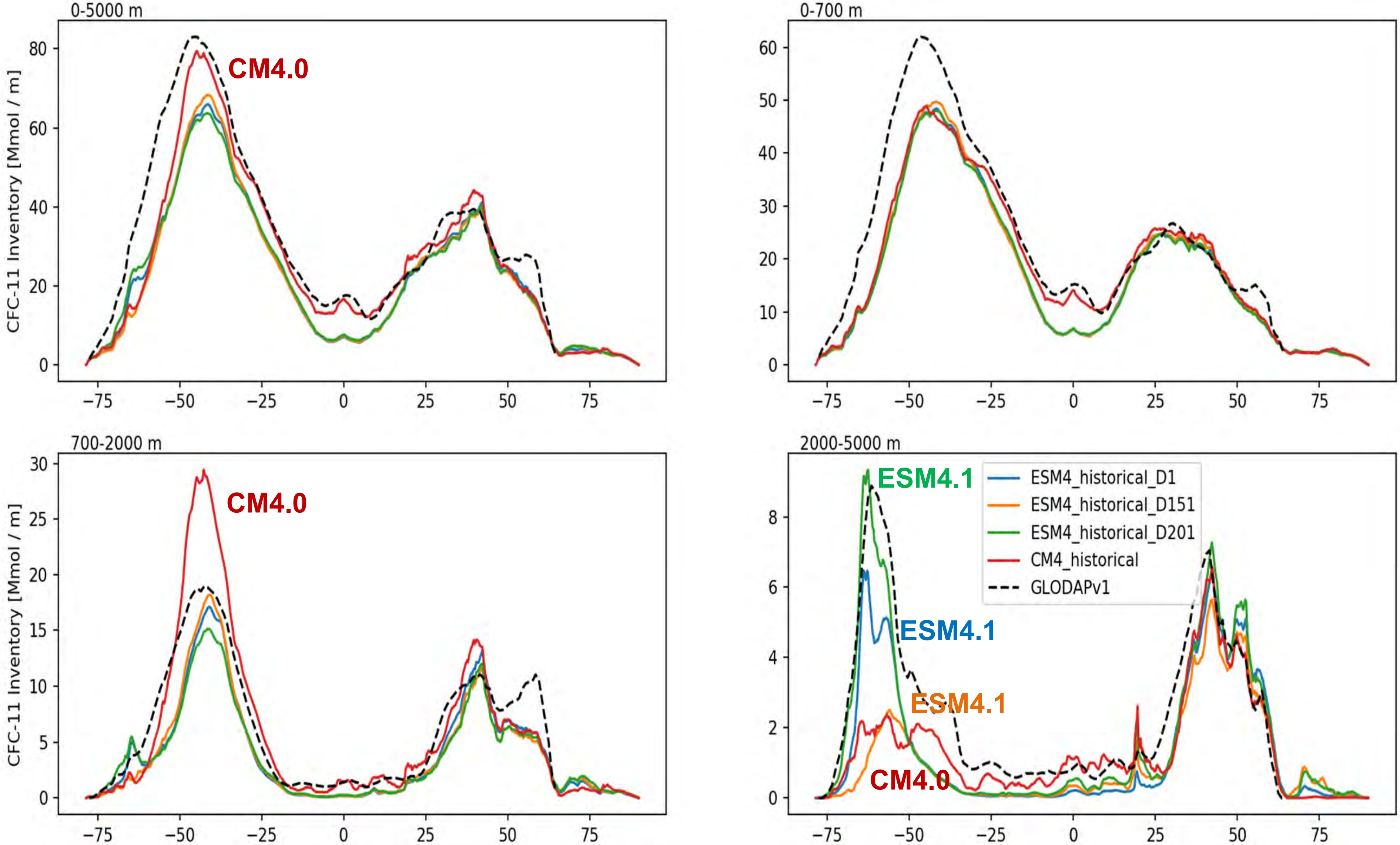
Centennial Polyna/Overturning Key Mode

Southern Ocean Sea Ice anomaly patterns reflect recharge and discharge of interior ocean heat.

See Liping Zhang's Presentation for mechanisms!

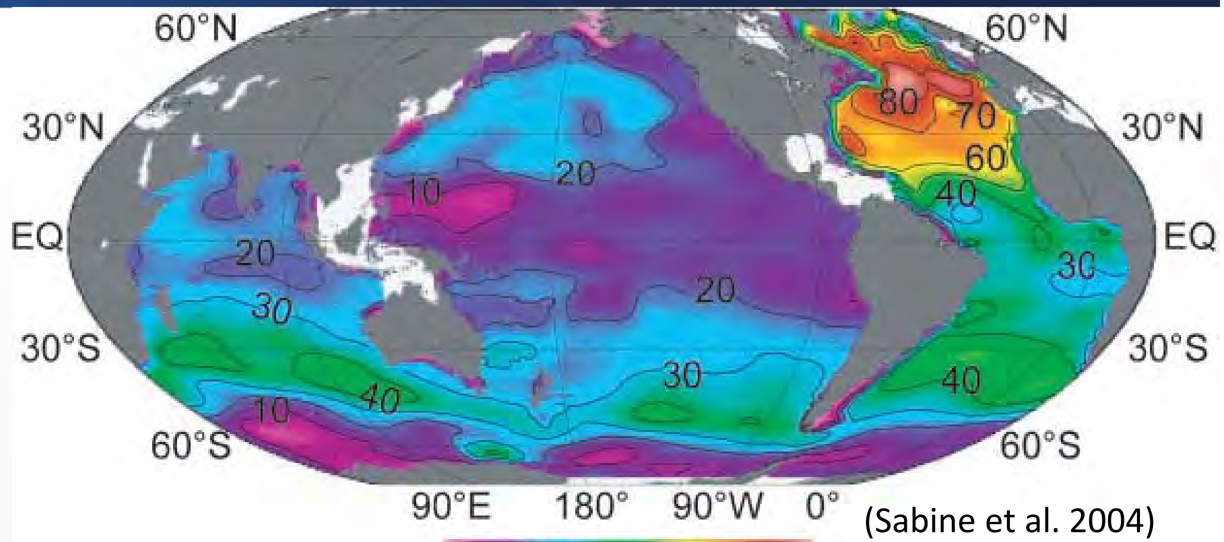


CFCs Show CM4 Deep Mixing & ESM4 Polynya



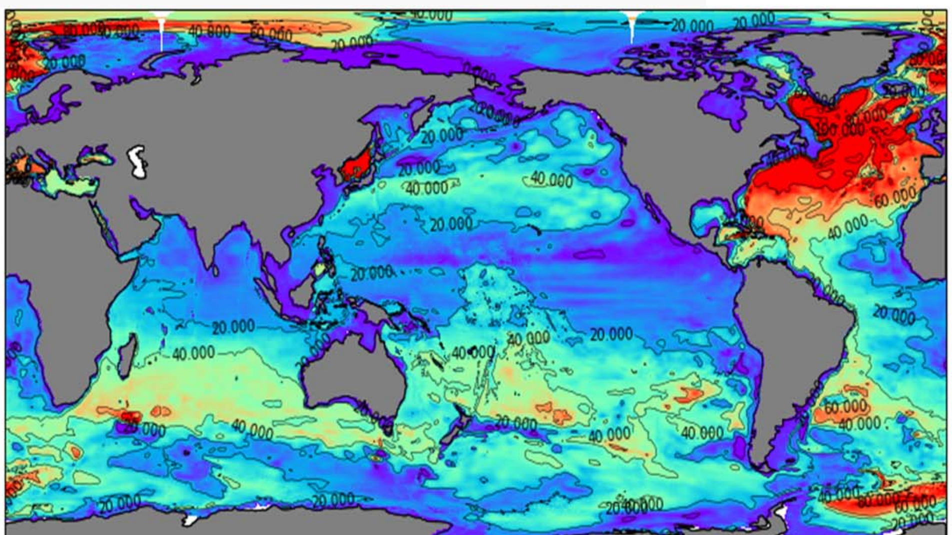
Anthropogenic CO_2

Similar total uptake, more in North Atlantic in ESM4.1, more Southern Ocean in CM4.0

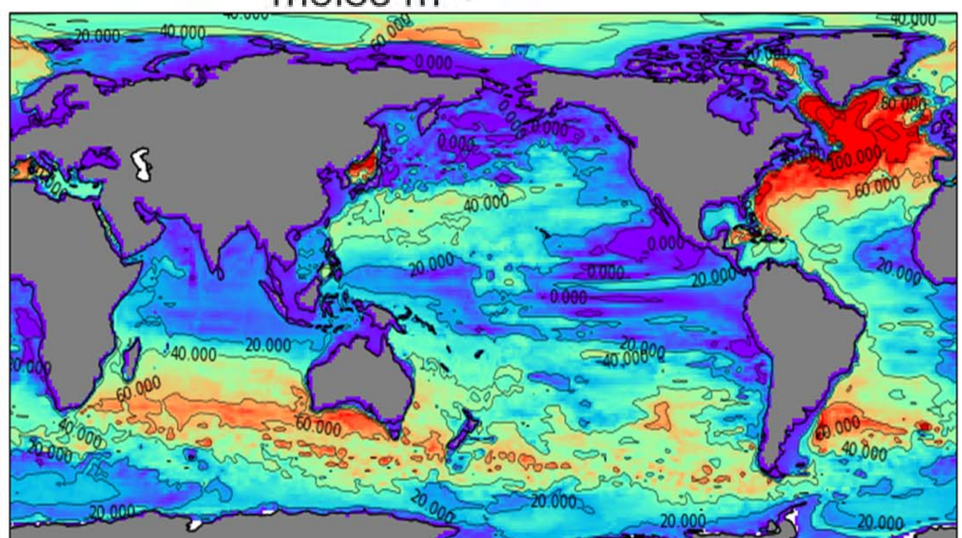


(Sabine et al. 2004)

ESM4.1



CM4.0

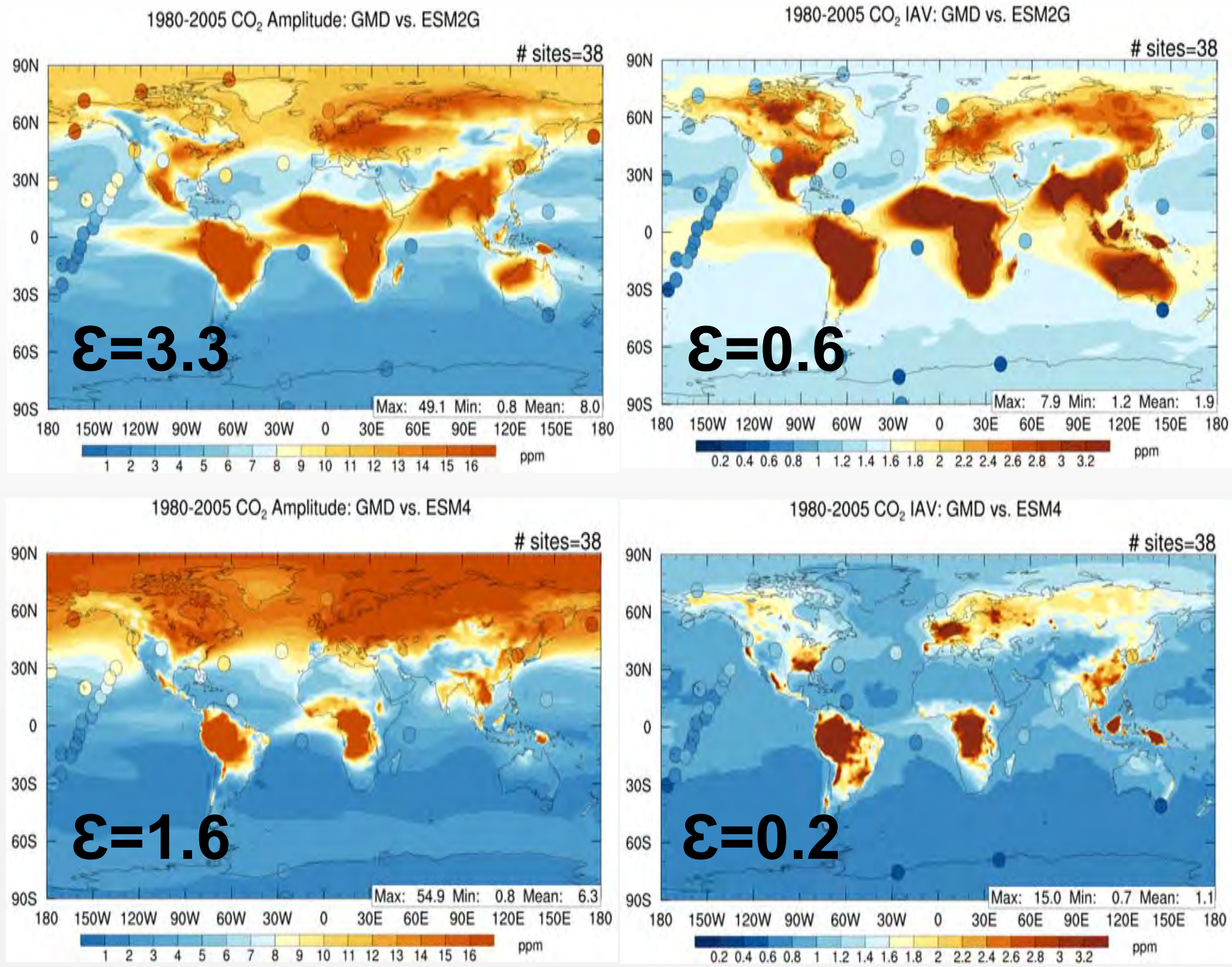


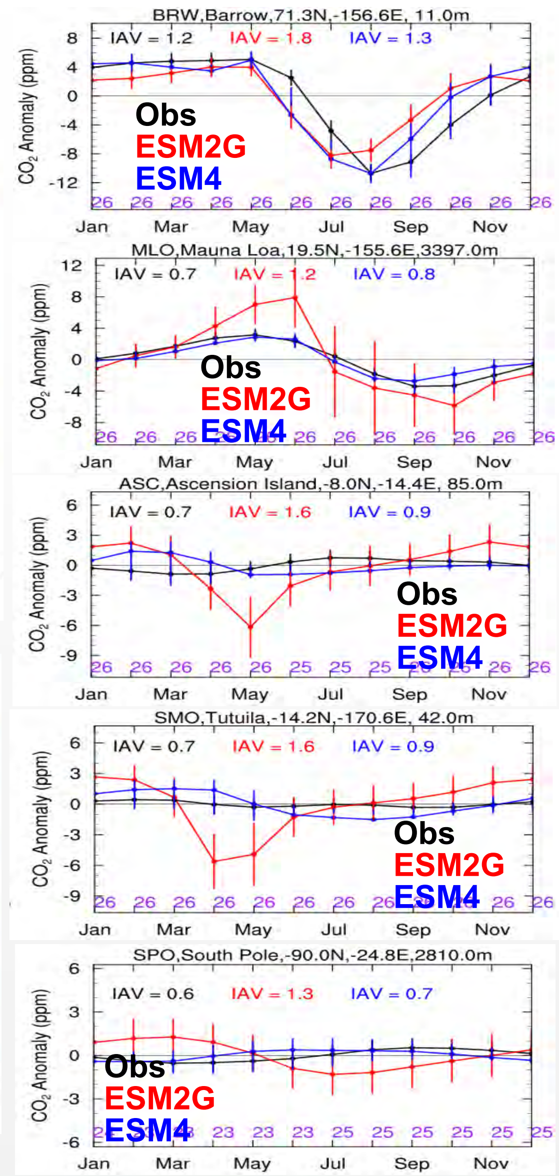
Vastly Improved CO_2 Variability Over ESM2

Seasonal CO_2 Amplitude | Interannual CO_2 Variability

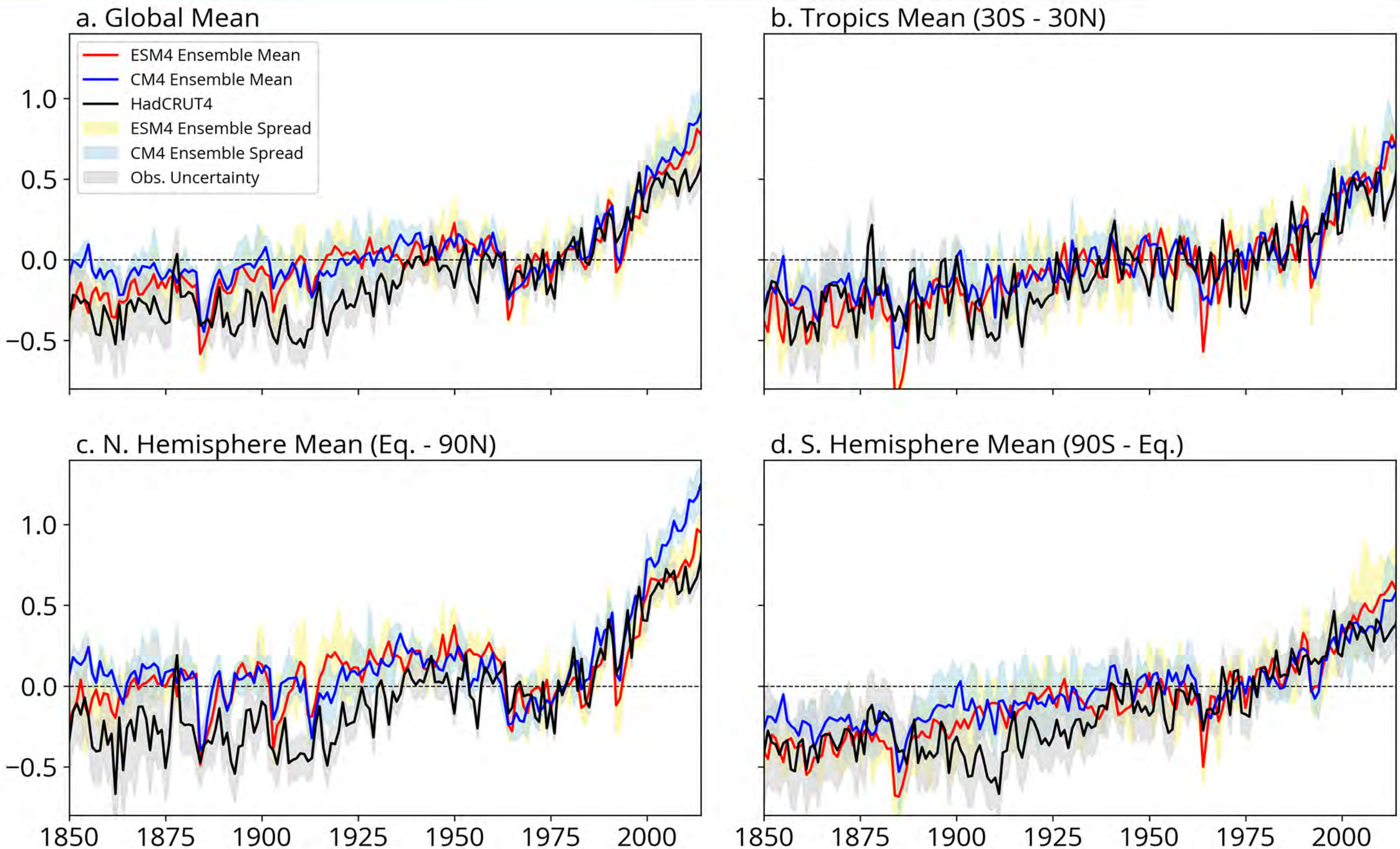
ESM2G

ESM4



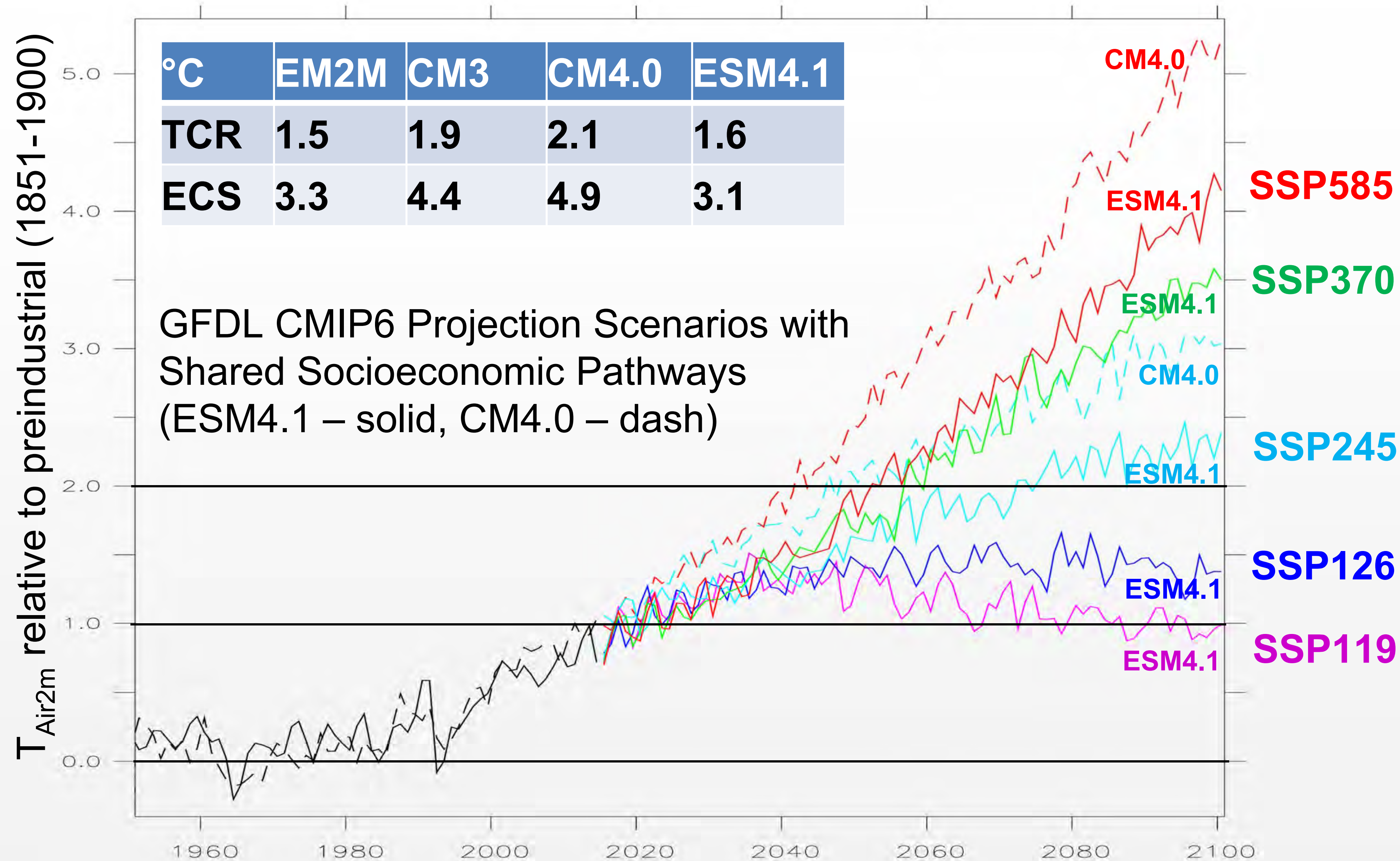


CM4.0 more recent NH warming than ESM4.1



anomalies relative to the 1961-1990 base period

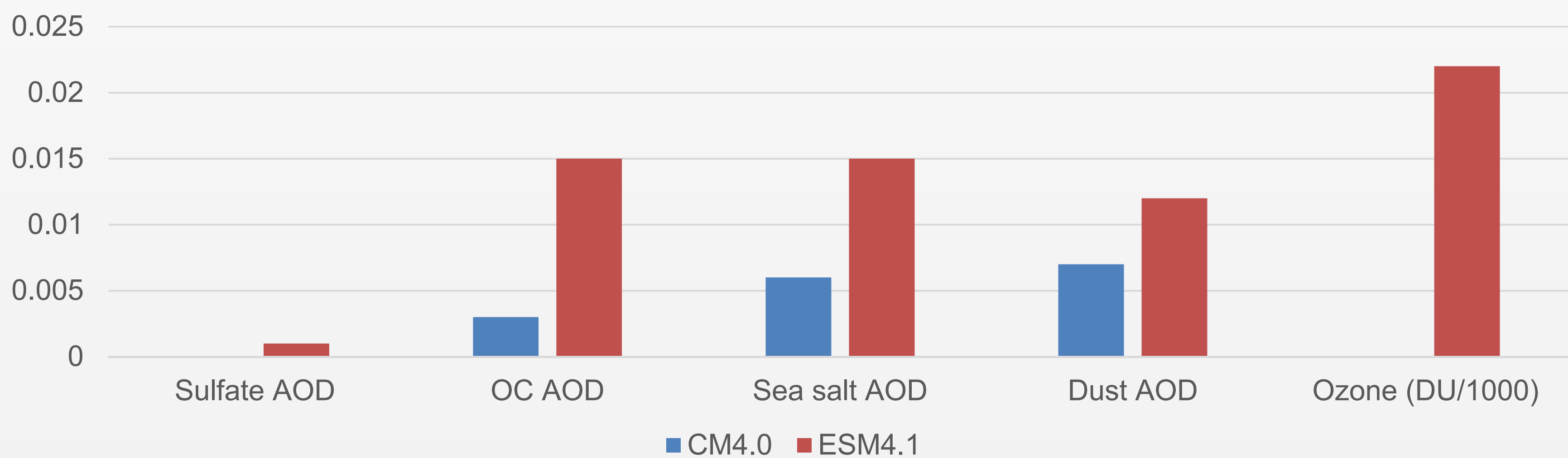
ESM4.1 Lower Climate Sensitivity than CM4.0



°C	EM2M	CM3	CM4.0	ESM4.1
TCR	1.5	1.9	2.1	1.6
ECS	3.3	4.4	4.9	3.1

Lower sensitivity under $4xCO_2$ in ESM4.1 than CM4.0

- Differences in pre-industrial control (ESM4.1 0.7°C warmer than CM4.0)
- Earth System feedbacks included in ESM4.1, but neglected in CM4.0
    - Greater temperature-dependence of sea salt emissions
    - Sea ice masking of marine aerosols (DMS, sea salt, organic carbon)
    - Temperature dependence of biogenic VOC emissions (source of secondary organic aerosols)
    - Interactive stratospheric ozone
    - Dust emissions from semiarid regions modulated through dynamic vegetation and hydrology



GFDL's 4th Generation is a Major Advance

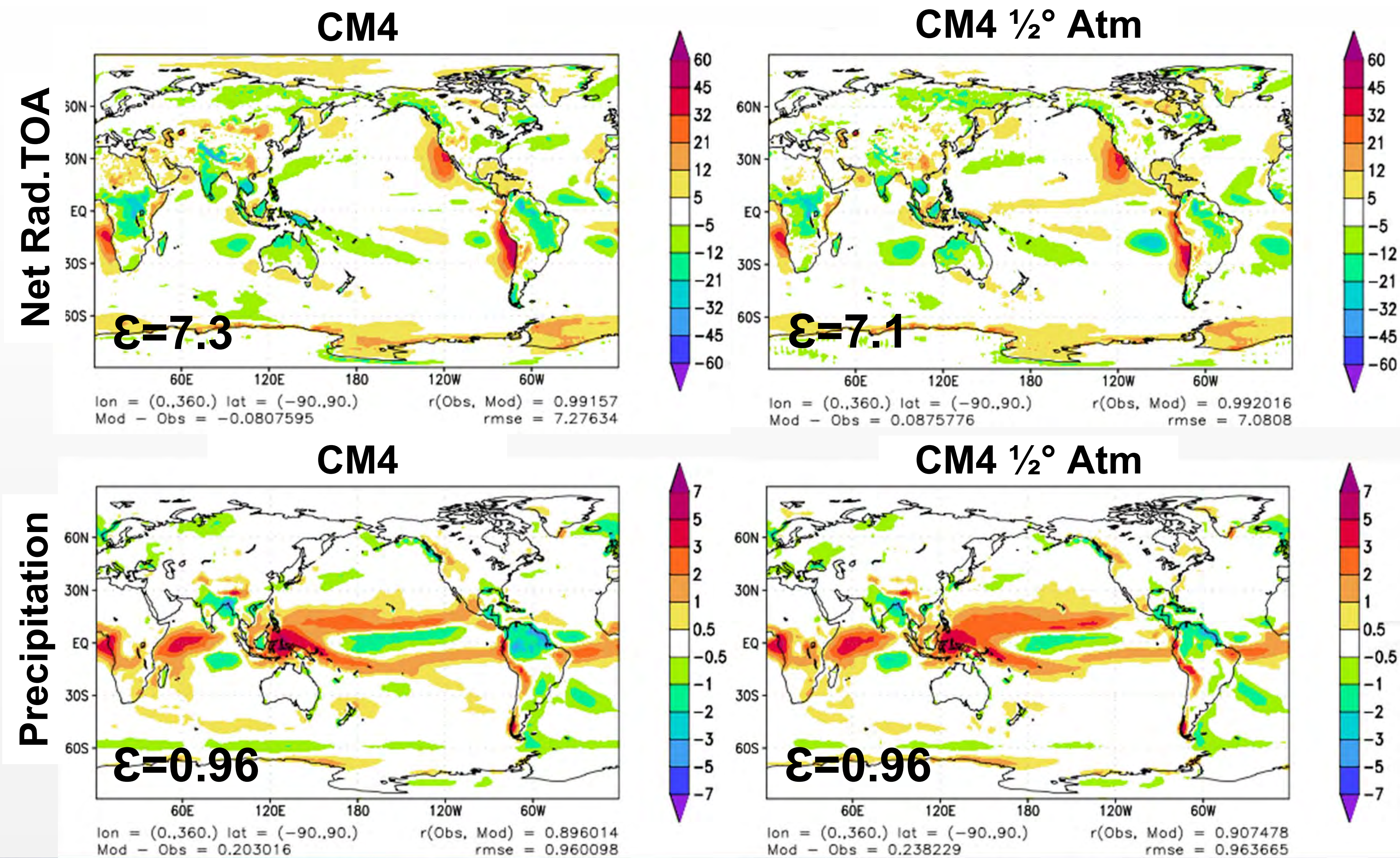
- AM4/OM4 substantively improved dynamics, physics, clouds, and radiation along with doubled resolution.
- CM4.0 vastly improves SST and Southern Hemisphere sea ice variability modes and teleconnections providing good surface climate as an analysis framework
- ESM4 combines improved interactive carbon, chemistry, dust and other cycles:
  - Much improved representation of chemistry and aerosols than CM3
  - Much improved representation of Carbon cycle relative to EMS2
- ESM4.1 captures much of the baseline simulations characteristics of CM4.0 with different advantages for each.
- ESM4.1 provides for understanding of forced response, feedbacks, and impacts across climate, carbon, ecosystems, and air quality.
- Overall, these models have many novel emergent behaviors worth exploration.

- Extra Slides

Ocean Resolution versus Comprehensiveness

Component	CM4.0	ESM4.1
Atmospheric Dynamics	100 km, 33 levels	100 km, 49 levels
Atmospheric Chemistry	aerosol (21 tracers)	aerosol+ozone (103 tracers)
MOM6 Ocean	$1/4^{o}$, 75 hybrid levels, no mesoscale parameterization	$1/2^{o}$, 75 hybrid levels with mesoscale eddy kinetic energy parameterization
Ocean BGC	BLINGv2 (6 tracers)	COBALTv2 (33 tracers)
Land physics	LM4.0???	LM4.1???
Land Ecosystem	Leaf canopy dynamics with annual fire model	Perfect Plasticity Approximation canopy dynamics with daily fire model
Dust	Emission areas prescribed from external map based on wind and soil moisture	Emissions fully interactive with vegetation dynamics (Evans et al)
Atmospheric CO2	Externally prescribed	Either interactive or restored to externally prescribed value

CM4 Mean State Plateau at 1° Atm



Evolution of Southern Ocean Polynya