# CESM Reveals Shortcomings in Current Forced Regional Sea Level Rise Estimates

## Using CESM Large Ensembles and CESM-HR to Assess Estimates of Forced Regional Sea Level Rise

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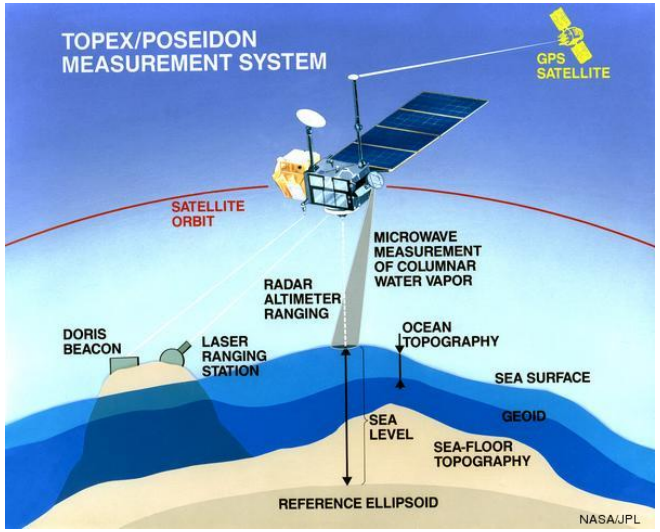
# The Altimeter Record: 1993 - present

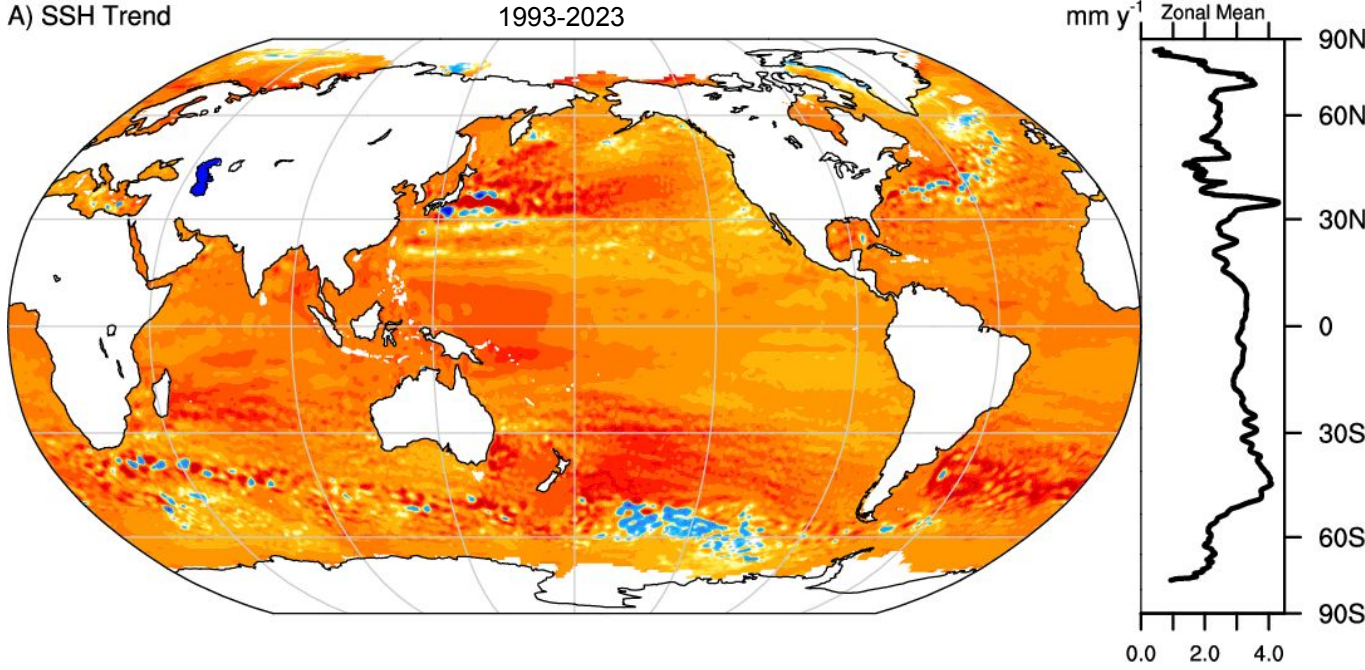


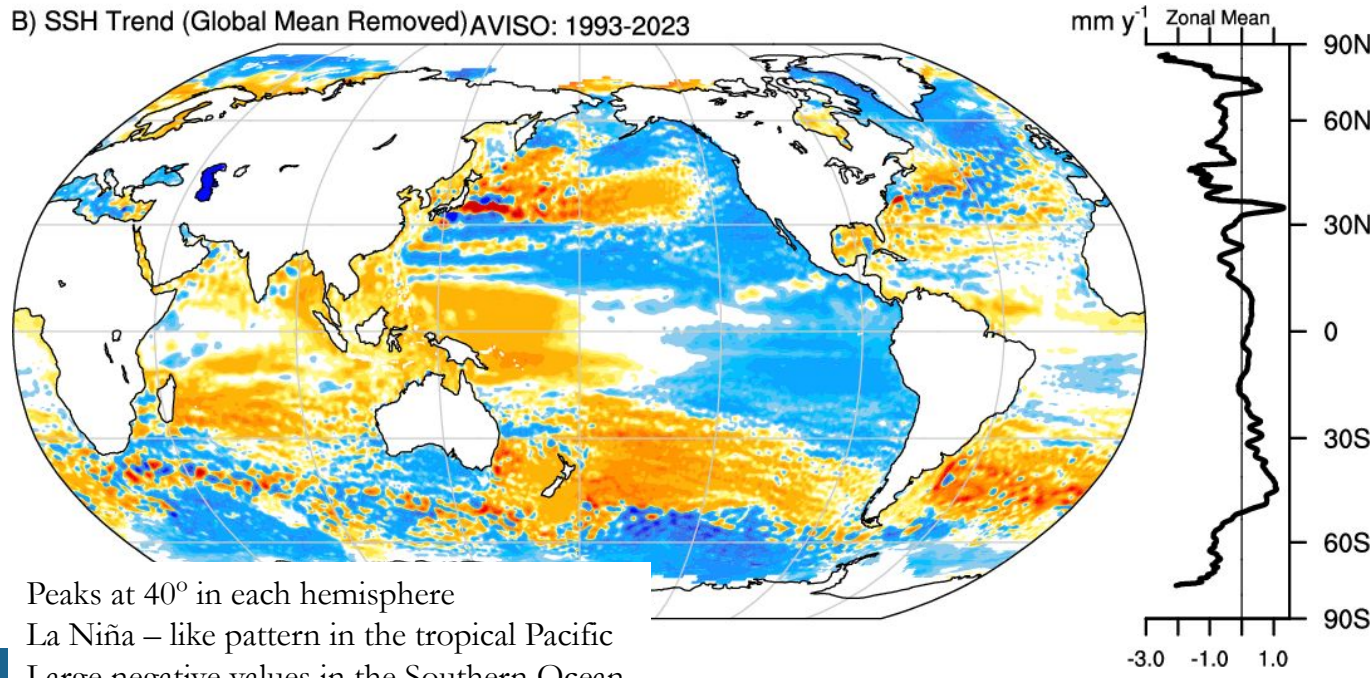

Global rate: ~3.6 mm yr$^{-1}$; regional rates 0⇨10 mm yr$^{-1}$

**Is the pattern forced? Is it predictable?**
**⇨ A need for attribution/models/large ensembles.**

Trends exhibit features on small and large scales; evidence for a role for fronts (e.g. Kuroshio) and eddies (e.g. Agulhas).

**How well do 1 deg models capture these features?**




Peaks at 40° in each hemisphere
La Niña – like pattern in the tropical Pacific
Large negative values in the Southern Ocean

# Key Points

CESM1/2 suggest the forced regional sea level rise (RSLR) pattern is emerging.
*Can we estimate the forced response?* ***Yes but CMIP6 MMM likely underestimates its magnitude, misses pattern.***

- **Issue #1**: Model Structural Uncertainty - diverse range of simulated RSLR responses.
  *Multi-model averages lead to signal cancelation, dampening of response pattern.*

- **Issue #2**: Most standard resolution models fail to generate sufficient spatial variability, miss the pattern.
  *Systematic underestimation ~1 degree models, perhaps due to poorly resolved processes (fronts/eddies).*

# The Framework for Assessing Changes To Sea-level (FACTS) v1.0

- Used in AR6 for RLSR (aka dynamic) projections.
- Scales CMIP6 multi-model RSLR pattern by global thermosteric sea-level change.
- **Assumes that both the forced response and internal variability are consistently represented across models.**

# The Framework for Assessing Changes To Sea-level (FACTS) v1.0

**RATIO of spatial variance AVISO/MMM= 2.2**

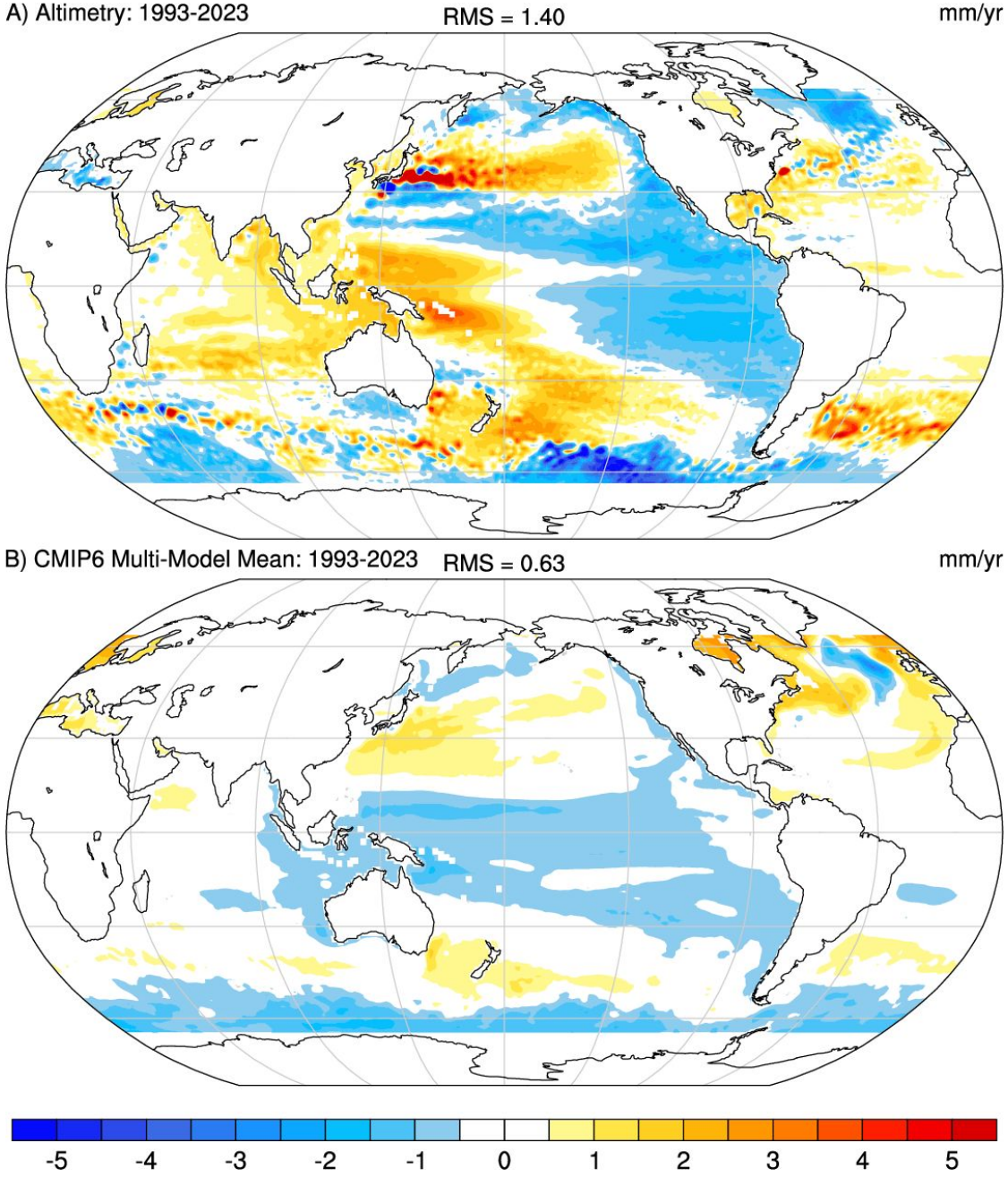
**Pattern Correlation (R, AVISO/MMM)= 0.18**

The MMM suggests that only a small fraction of the observed pattern is forced. Also suggests the forced pattern is very different in form than altimetry.

These aspects are at odds with previous efforts to remove variability from altimetry (Hamlington et al. 2019, GRL).

**Is the vast majority of spatial variance driven by internal variability?**

**Is the CMIP6 MMM suitable for estimating the forced response?**

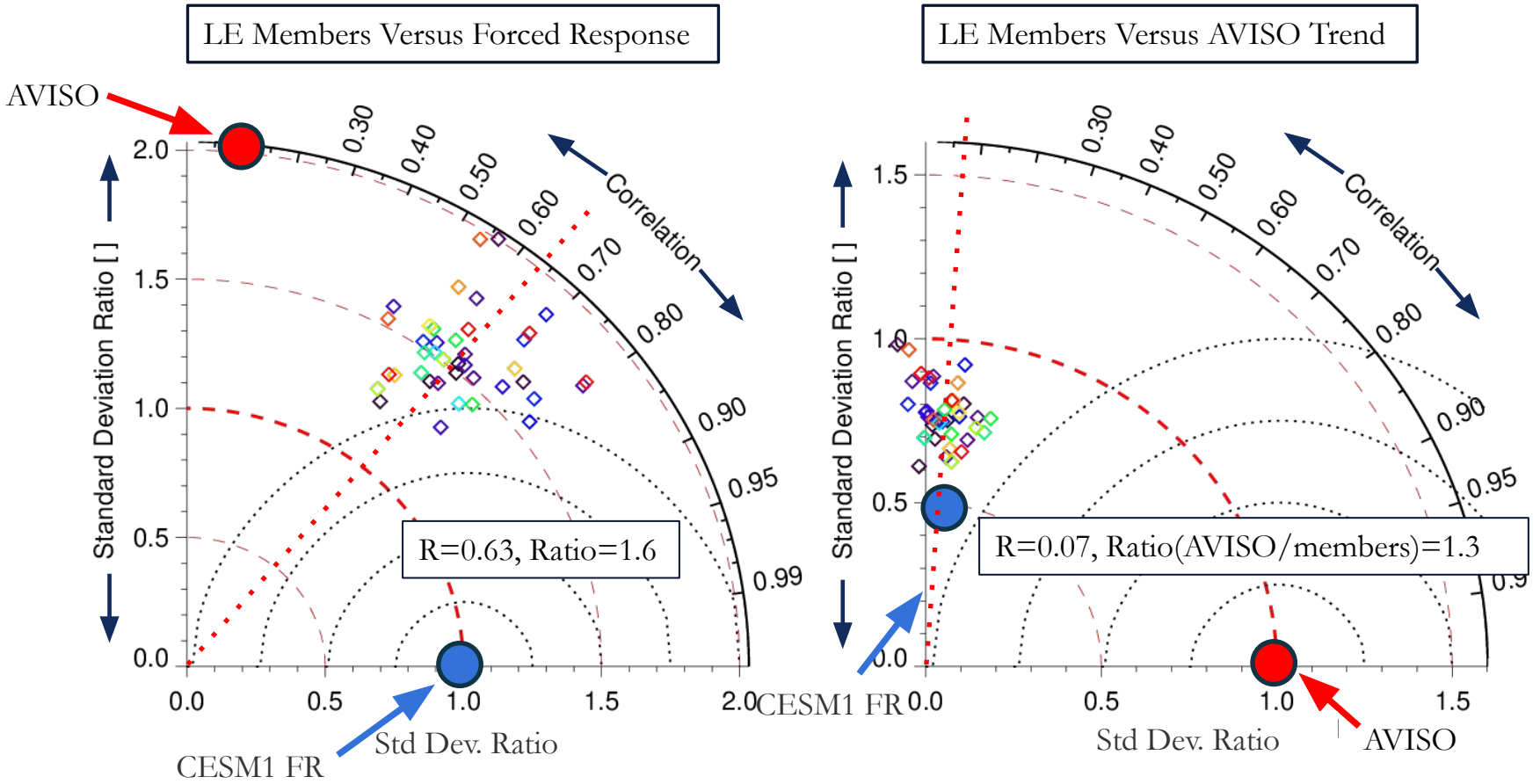


# Taylor Diagrams: CESM1 SSH Trend Pattern: 1993-2023 (RCP85)

**40 members**

**(left) Spatial variance in altimetry is greater than any CESM1 member; Also correlates poorly with FR (0.07),** differences that cannot be explained by internal variability.

**(right) The altimeter pattern is not well-captured by any member of the CESM1-LE** (r=0.07±0.08).




Standard deviation = radial distance from origin
Correlation = radial angle
For more on Taylor diagrams, see Taylor 2001 JGR-Atm

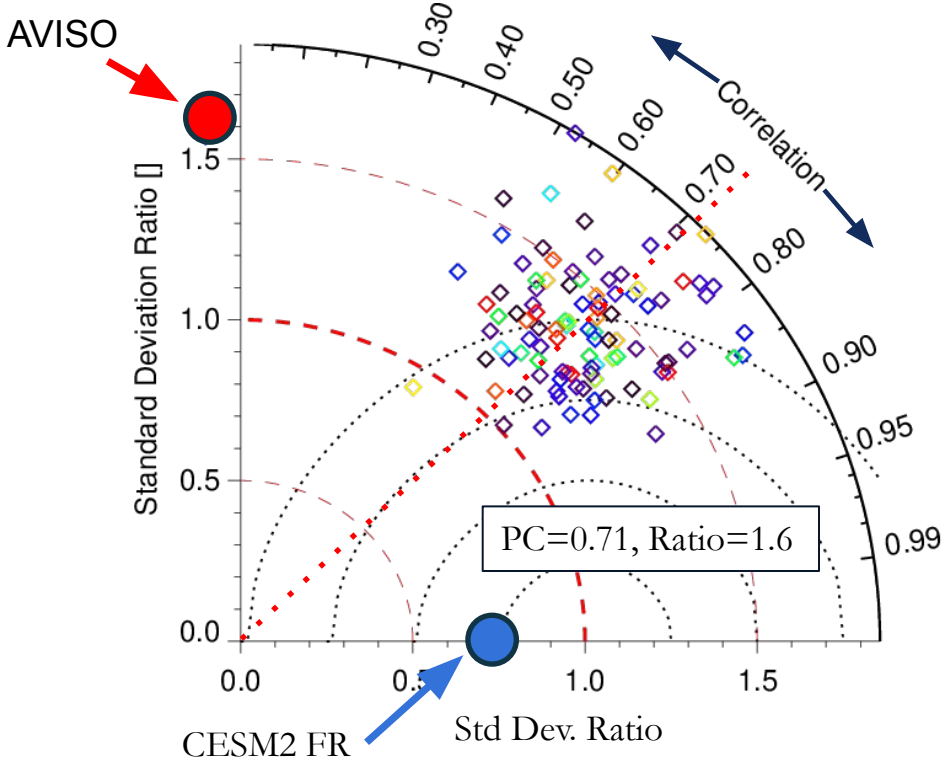
# Taylor Diagrams: CESM2 SSH Trend Pattern: 1993-2023 (SSP370)

**100 members**

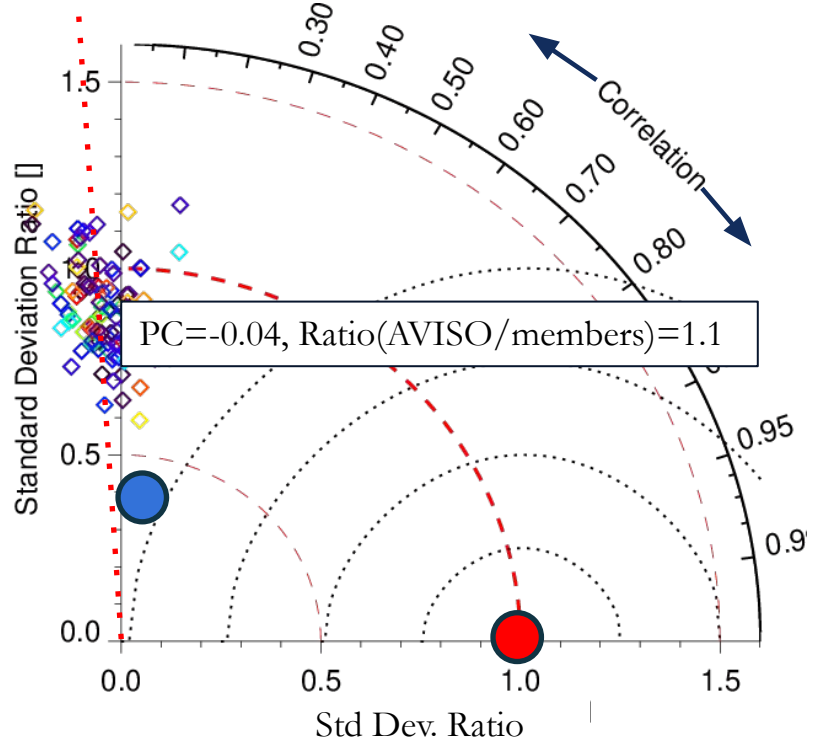
**(left) Spatial variance in altimetry is much greater than any CESM2 member, also correlates poorly with FR,** differences that cannot be explained by internal variability.

**(right) The altimeter pattern is not well-captured by any member of the CESM2-LE** (r=-0.04±0.12).

LE Members Versus Forced Response




LE Members Versus AVISO Trend



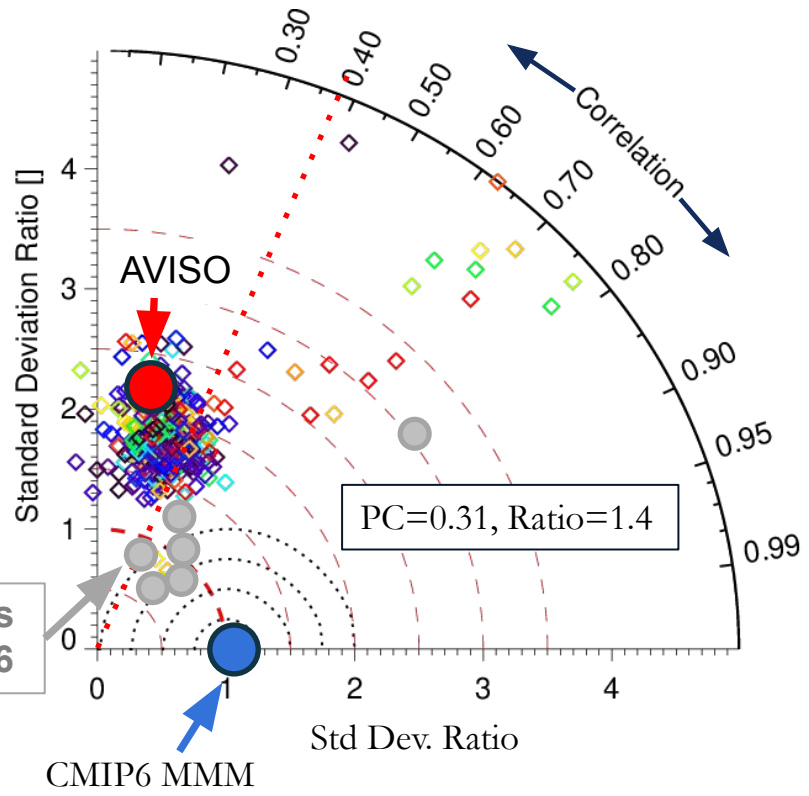
# Taylor Diagrams: CMIP6 SSH Trend Pattern: 1993-2023 (SSP370)

**>300 CMIP6 members**

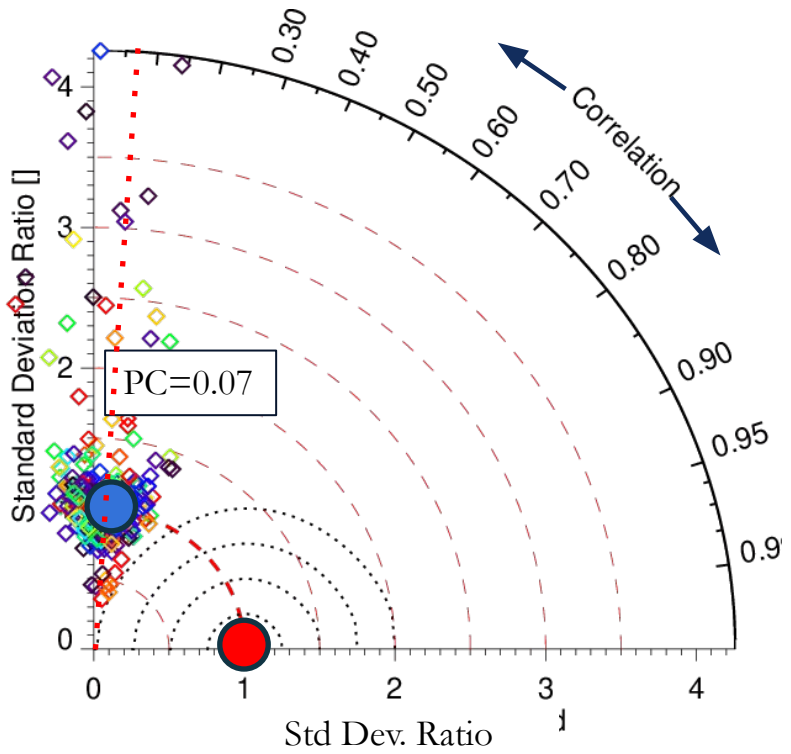
**(left) Spatial variance in altimetry is > than 90% individual members >FR of single models but 1 (gray) >>MMM. FRs don't mutually agree.**

**(right) The altimeter pattern is not well-captured by any CMIP6 member** (r=0.08±0.13).

CMIP6 Members Versus Forced Response

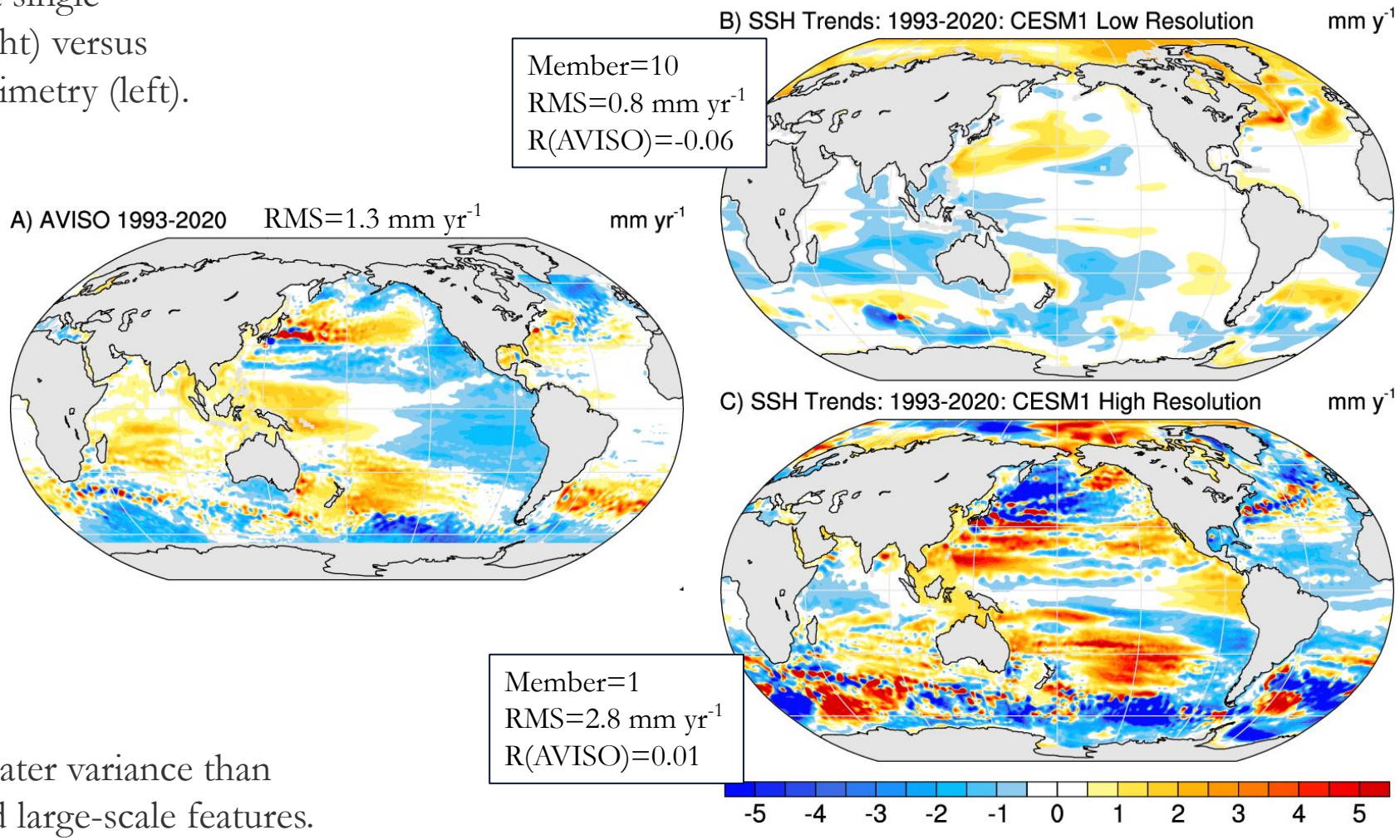



CMIP6 Members Versus AVISO Trend



# Issue #2: High Spatial Variance in CESM1-HR

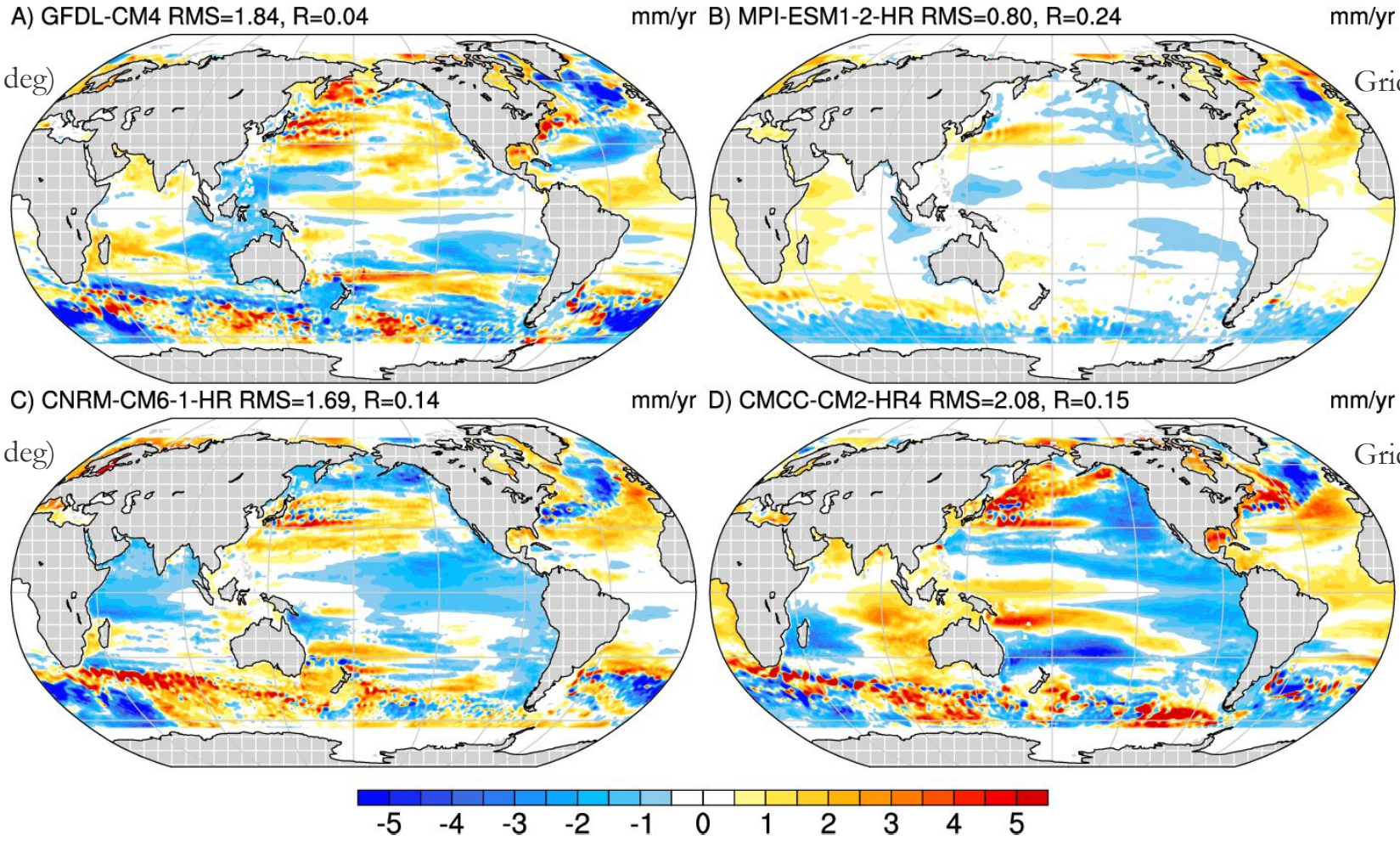
Comparison of SSH trends from a single member from CESM1-LE (top right) versus CESM1-HR (bottom right) and altimetry (left).




CESM1-HR simulates >3x greater variance than CESM1 due to both small- and large-scale features. But R=Will some members capture the pattern?

# High Spatial Variance in Other CMIP6 Models

Grid: 1440x1080 (~1/4 deg)




Grid: 802x404 **(~1/2 deg)**

Grid: 1442x1050 (~1/4 deg)

Grid: 1442x1051 (~1/4 deg)

High resolution models at ~1/4 degree produce greater spatial variance than 1 deg/observed (1.4). Weak correlations with obs..

# Conclusions

CESM1/2 suggest the forced regional sea level rise (RSLR) pattern is emerging.
*Can we estimate the forced response?* ***Yes but CMIP6 MMM underestimates magnitude; misses pattern.***

- **Issue #1**: Model Structural Uncertainty - diverse range of RSLR responses.
  *Multi-model averages lead to mutual cancelation, dampening of response.*

- **Issue #2**: Standard resolution models fail to generate sufficient spatial variability.
  *Systematic underestimation ~1 degree models, perhaps due to poorly resolved processes (fronts/eddies).*

**CESM1/2 LEs suggest the altimetry/MMM variance ratio is too large – underestimating FR.**

**Standard resolution models are likely not fit for purpose** (deficient variance, unresolved features).

# Paths Forward

**Open question, the promise of high-resolution**:
1) High resolution ensembles produce systematically stronger patterns of RSLR. Too much? Systematically biased?
2) Will high resolution lead to a improved RSLR agreement with altimetry? Member 10?

**Alternatively**, can statistical methods be used to estimate the FR directly from altimetry?

e.g. Forced Component Estimation Statistical Method Intercomparison Project (**ForceSMIP**)

Methods in the following talk by Dr. Ashley Bellas-Manley.

END