The relative importance of forced and unforced temperature patterns in driving the time variation of low-cloud feedback

Yuan-Jen Lin (Columbia University & NASA GISS)

Gregory Cesana (Columbia University & NASA GISS)
Cristian Proistosescu (University of Illinois at Urbana-Champaign)
Mark Zelinka (Lawrence Livermore National Laboratory)
Kyle Armour (University of Washington)

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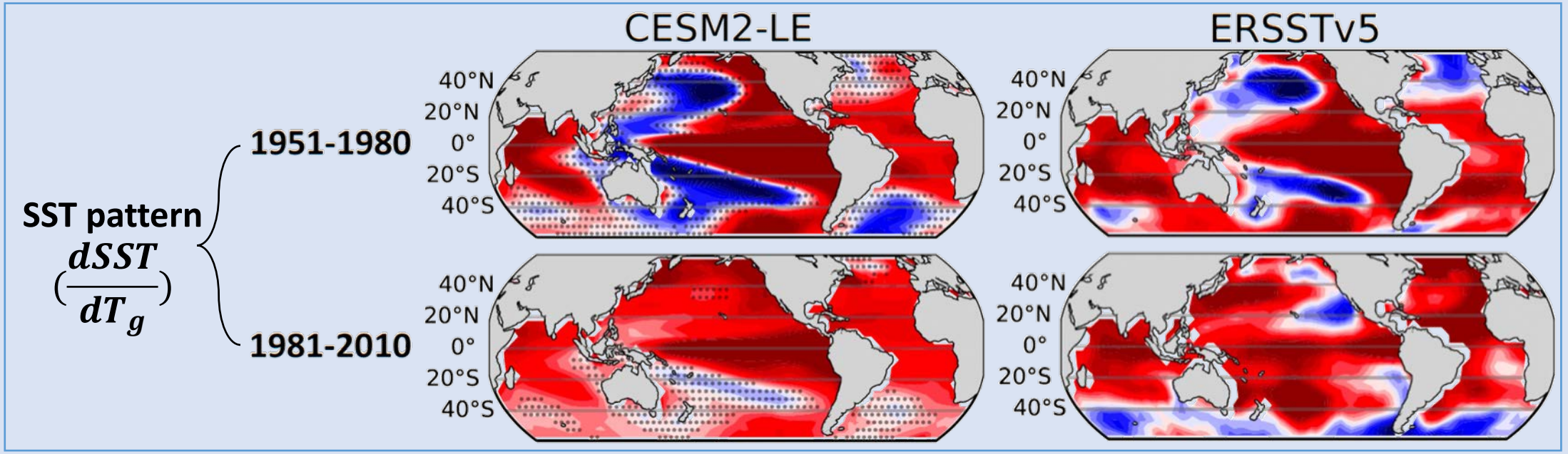
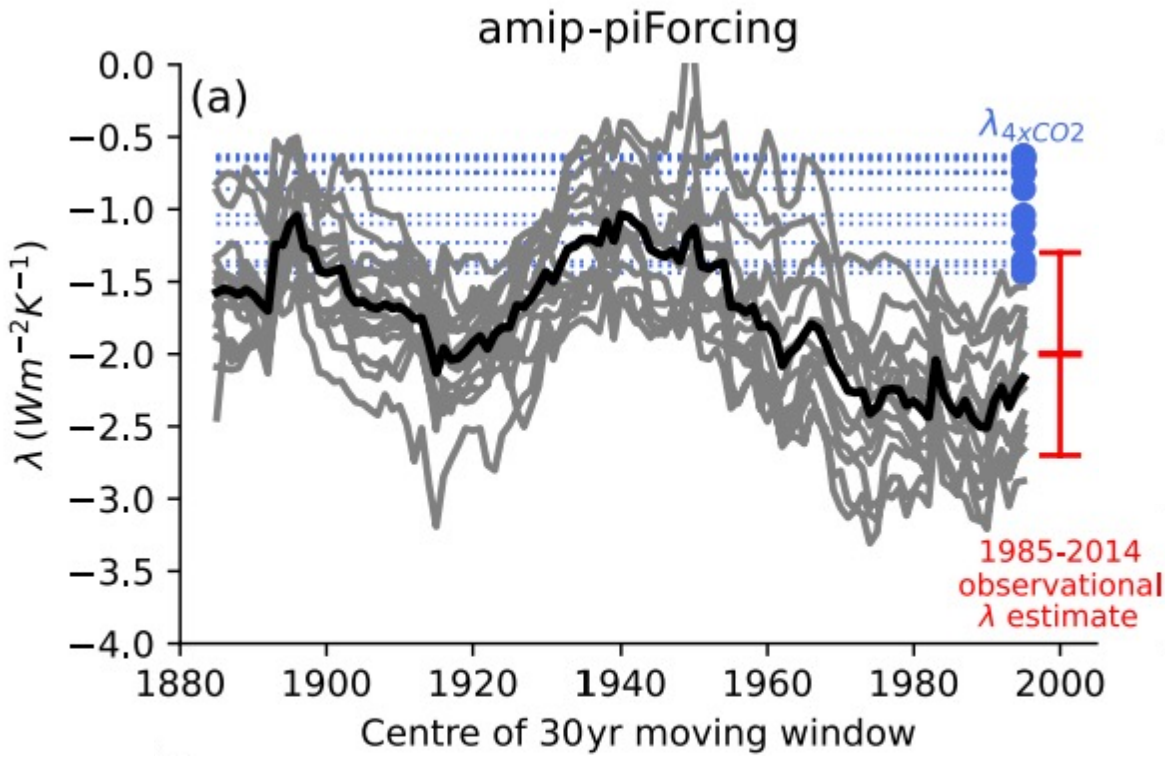
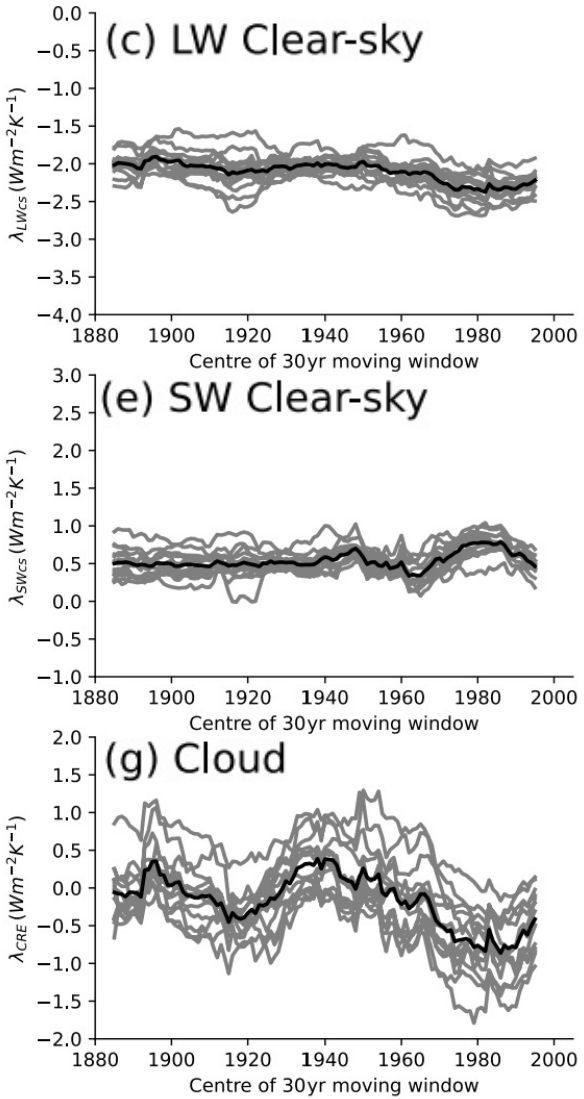


The ugly: time-varying climate feedback



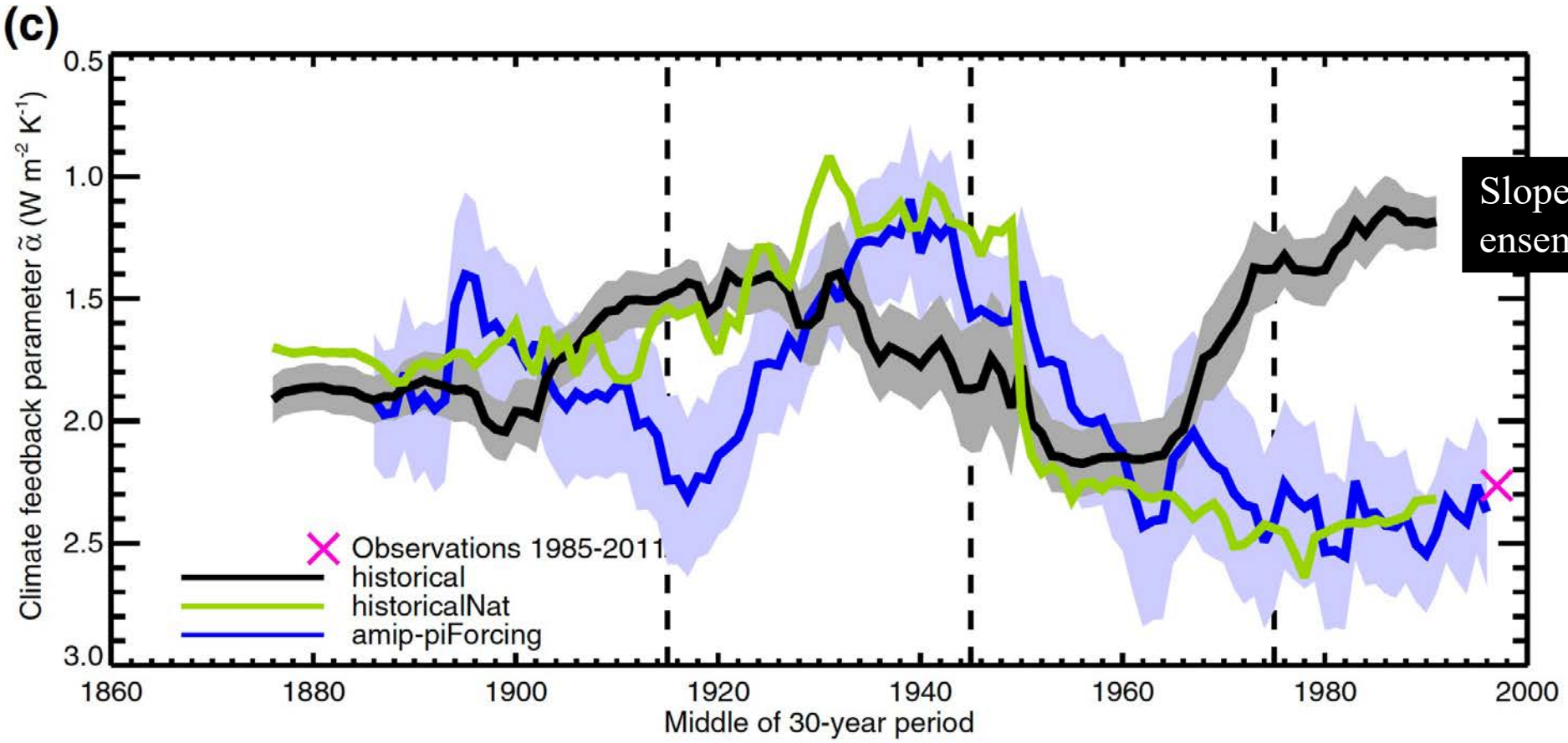


Andrews et al. 2022

See also: Zhou et al (2016); Gregory and Andrews (2016)

The ugly: time-varying climate feedback

- amip-piForcing simulations and historical simulations in coupled models yield different (opposite!) time evolution of climate feedback

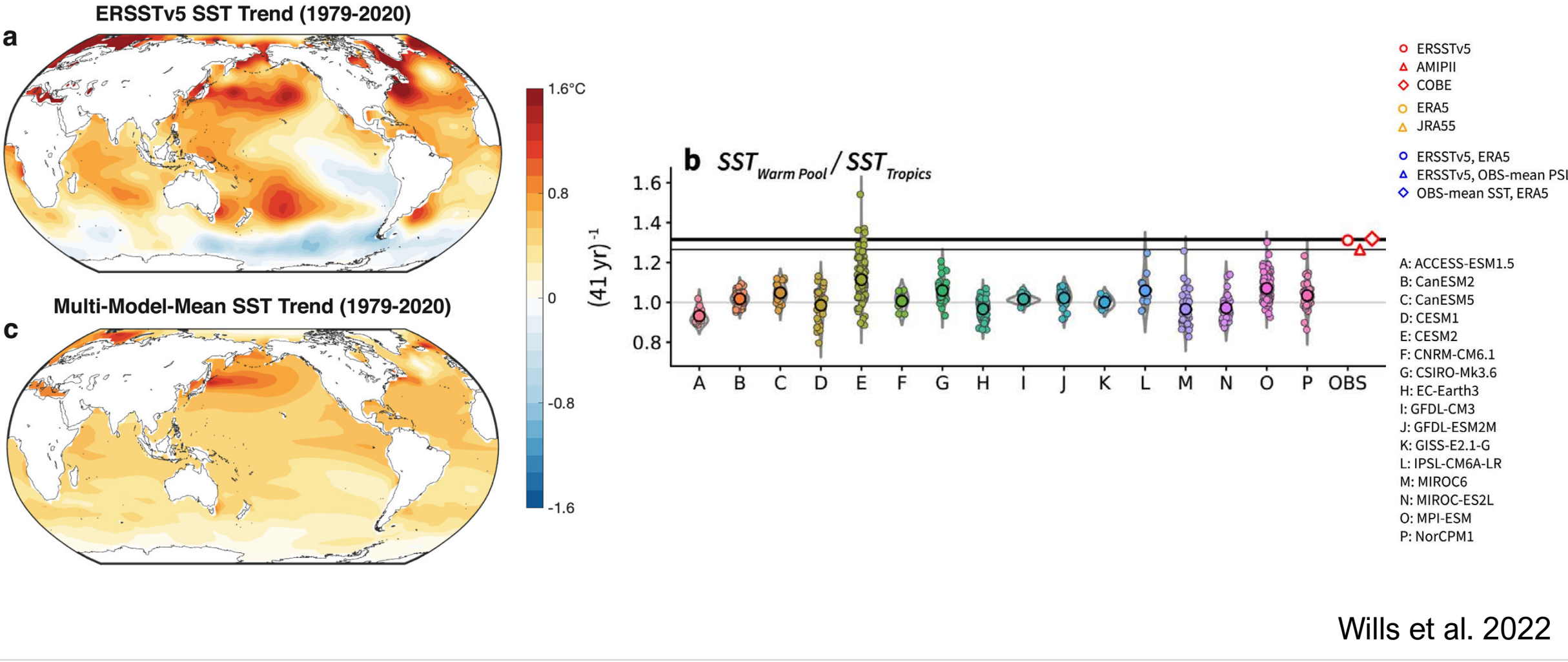


Slope of multimodel-mean ensemble-mean R against T

Gregory et al. 2020

See also: Dong et al. (2021)

The bad: SST trends



Wills et al. 2022

The ugly: time-varying climate feedback

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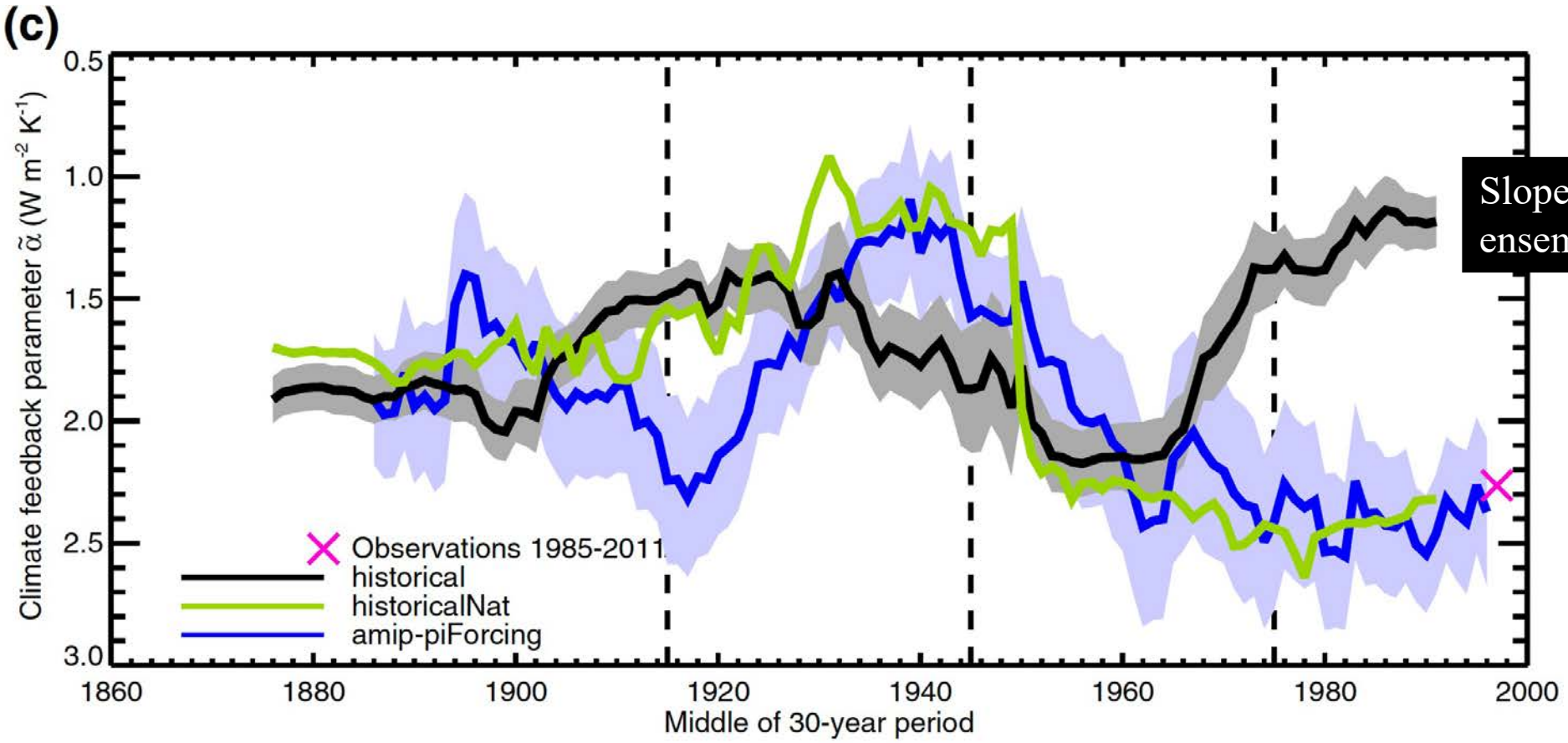

Slope of multimodel-mean ensemble-mean R against T

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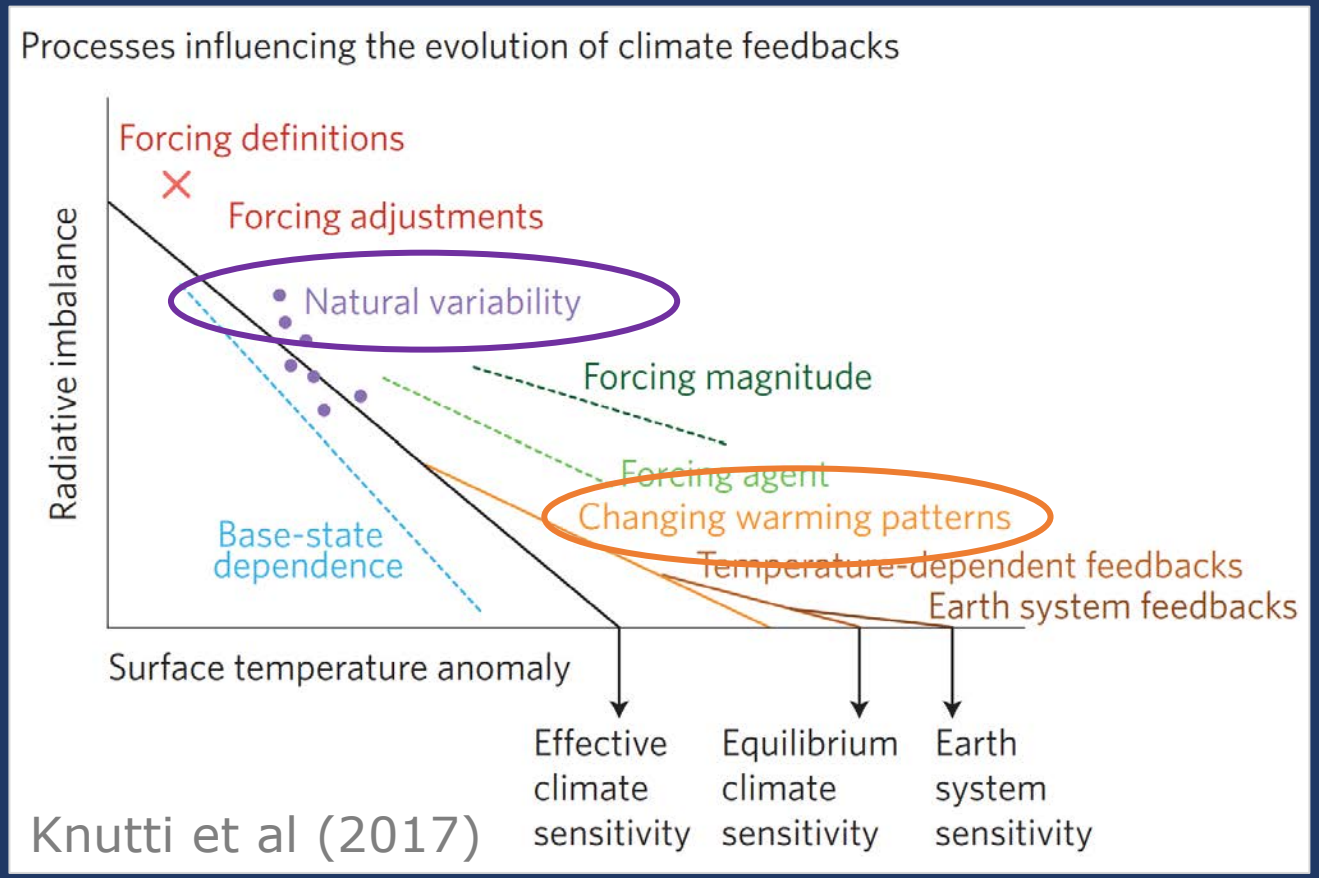
See also: Dong et al. (2021)

Question

Considering both "natural variability" and "pattern effect":
How would forcing (forced responses) and natural variability (unforced responses) jointly shape the time-evolving SST patterns and cloud feedback?



Forced and unforced contributions to OLS regressions

For each 30-year window, the OLS regression of X against T_g:

$$\frac{dX}{dT_g} \equiv \frac{cov(X, T_g)}{var(T_g)}$$

$$= \frac{cov(X_f + X_u, T_{g,f} + T_{g,u})}{var(T_{g,f} + T_{g,u})}$$

$$X = X_f + X_u,$$
$$T_g = T_{g,f} + T_{g,u}.$$

$$= \frac{cov(X_f, T_{g,f}) + cov(X_f, T_{g,u}) + cov(X_u, T_{g,f}) + cov(X_u, T_{g,u})}{var(T_{g,f}) + 2cov(T_{g,f}, T_{g,u}) + var(T_{g,u})}$$

Assume the covariance between the forced and unforced response is small

$$= \frac{cov(X_f, T_{g,f}) + cov(X_u, T_{g,u})}{var(T_{g,f}) + var(T_{g,u})} + \sigma$$

Re-arrange

$$= \frac{cov(X_f, T_{g,f})}{var(T_{g,f})} \frac{var(T_{g,f})}{var(T_{g,f}) + var(T_{g,u})} + \frac{cov(X_u, T_{g,u})}{var(T_{g,u})} \frac{var(T_{g,u})}{var(T_{g,f}) + var(T_{g,u})} + \sigma$$

$(\equiv r)$ $(1 - r)$

Final form:

$$\frac{dX}{dT_g} = \frac{dX_f}{dT_{g,f}} r + \frac{dX_u}{dT_{g,u}} (1 - r) + \sigma,$$

$$r = \frac{var(T_{g,f})}{var(T_{g,f}) + var(T_{g,u})}.$$

Forced & unforced Tg: variance and the relative importance

T_g

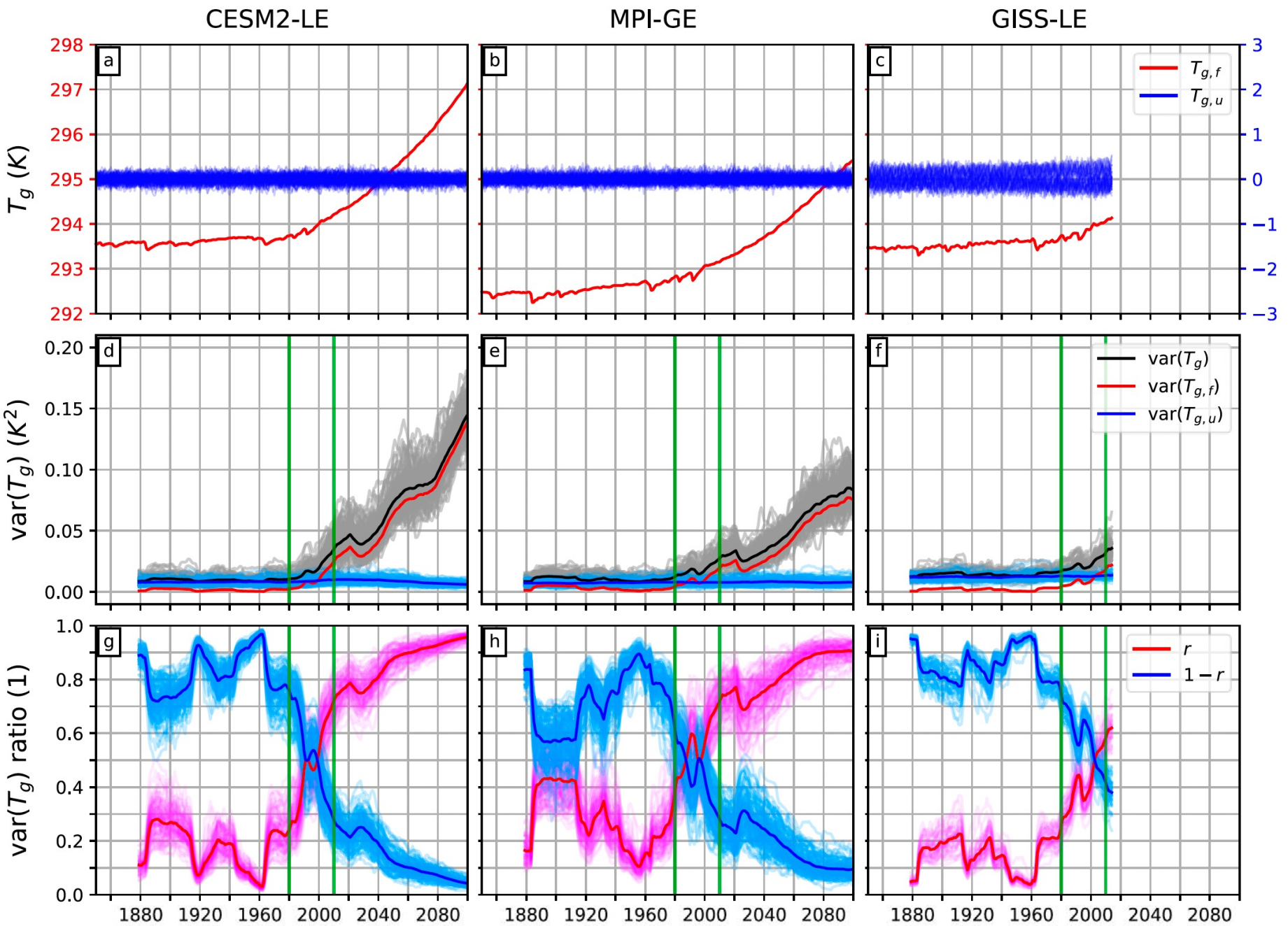
- The warming rate of $T_{g,f}$ becomes stronger since the 1980s.
- The standard deviation of $T_{g,u}$ remains similar.

$var(T_g)$

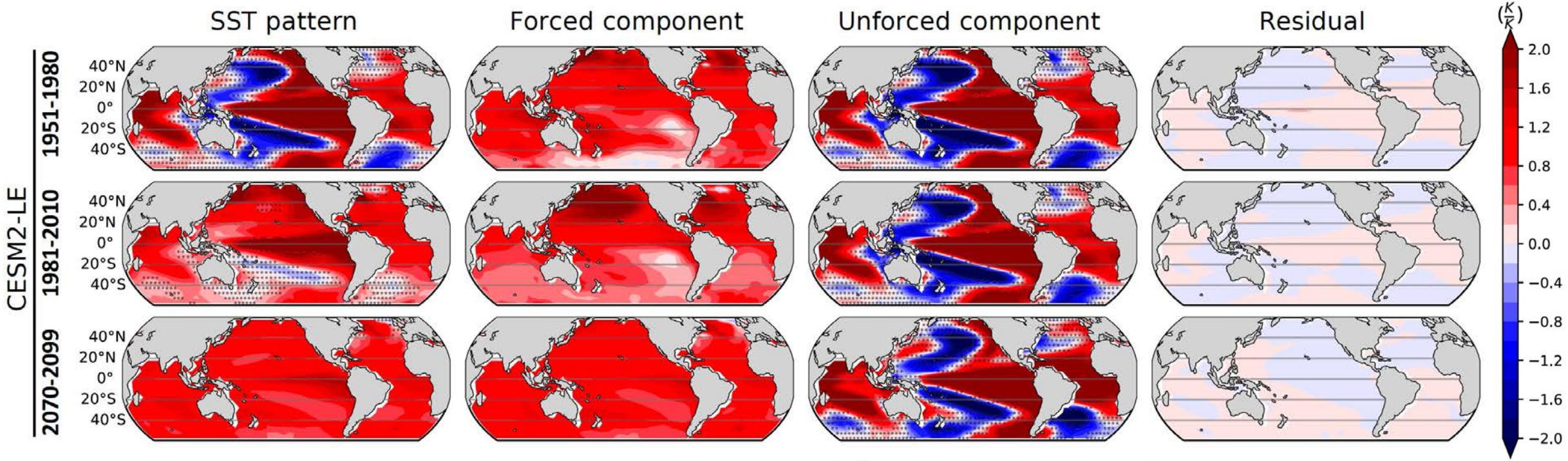
- For 30-year windows ending before the 1980s, $var(T_{g,f}) < var(T_{g,u})$.
- For 30-year windows ending after the 2010s, $var(T_{g,f}) > var(T_{g,u})$.

$$r = \frac{var(T_{g,f})}{var(T_{g,f}) + var(T_{g,u})}$$

- **Regressions are shifted from** "being dominated by internal variability" **to** "being dominated by forced responses".



The role of pattern effect (take CESM2 for example)



Final form:

$$\frac{dX}{dT_g} = \frac{dX_f}{dT_{g,f}} r + \frac{dX_u}{dT_{g,u}} (1 - r) + \sigma,$$

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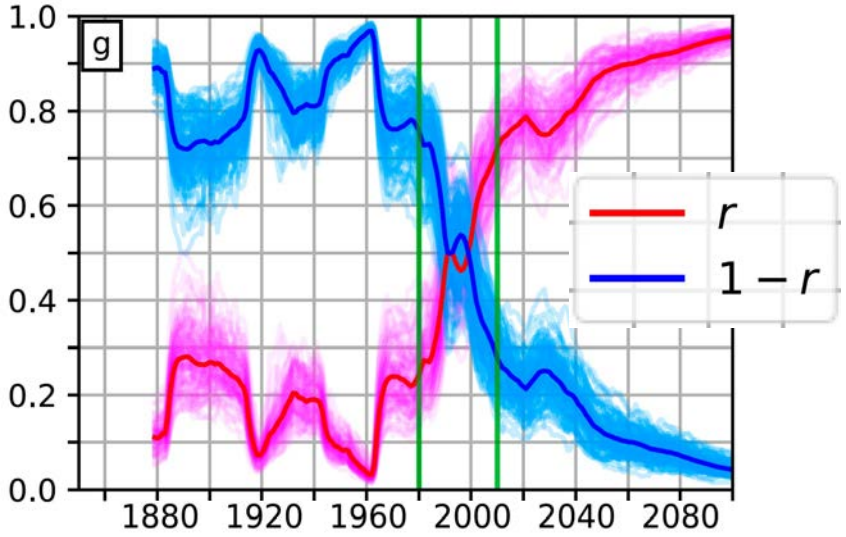


Low-cloud feedback estimation

- For large ensemble simulations, $X = X_f + X_u$

  ensemble mean

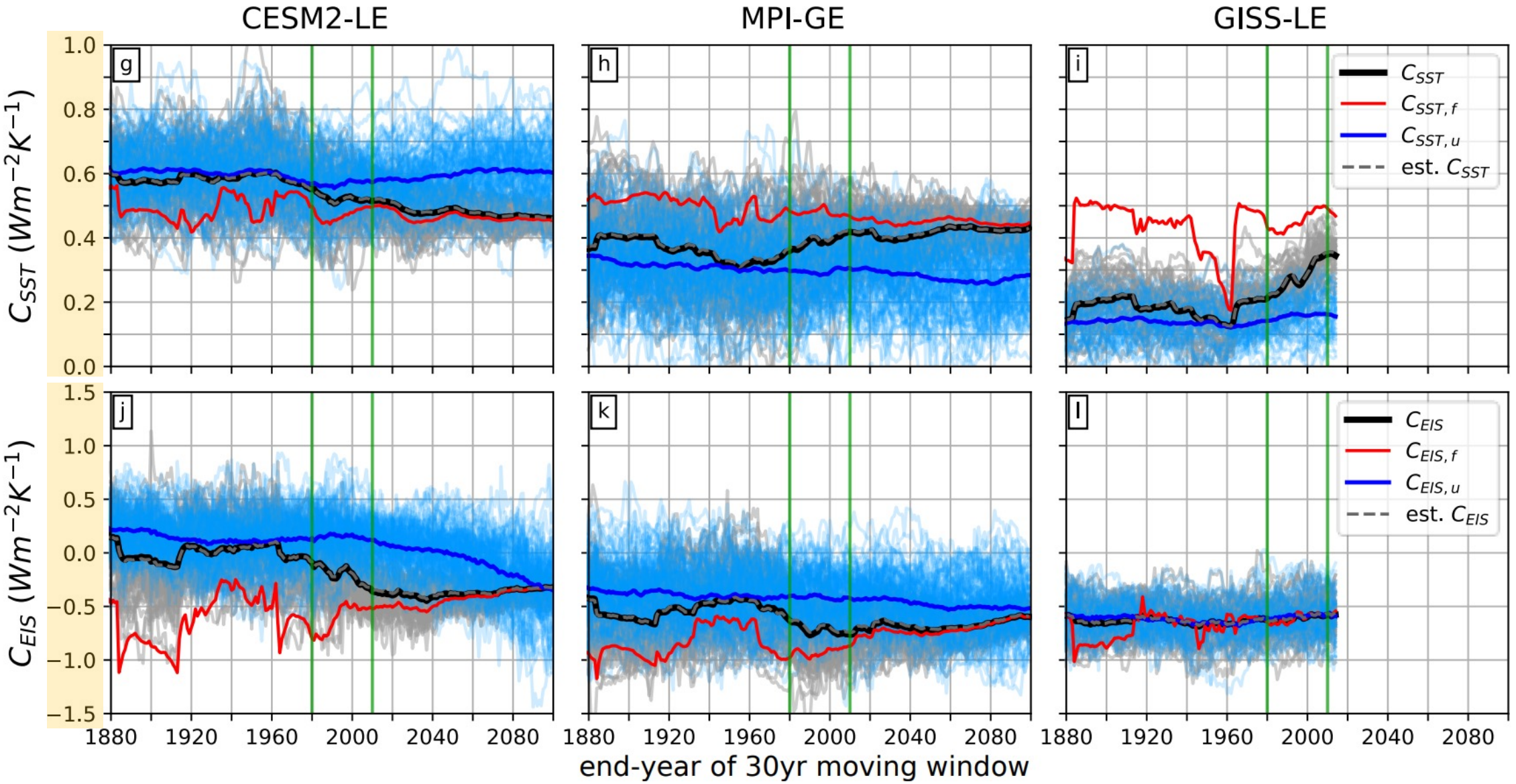
  anomalies rel. to ensemble mean

$$\left\{\begin{array}{l} Total \\ Forced \\ Unforced \end{array}\right\} low\ cloud\ feedback\ (SST\ contribution) \left\{\begin{array}{l} C_{SST} = \frac{dR}{dSST}\frac{dSST}{dT_g} \\ C_{SST,f} = \frac{dR}{dSST}\frac{dSST_f}{dT_{g,f}} \\ C_{SST,u} = \frac{dR}{dSST}\frac{dSST_u}{dT_{g,u}} \end{array}\right\}$$

$$\left\{\begin{array}{l} Total \\ Forced \\ Unforced \end{array}\right\} low\ cloud\ feedback\ (EIS\ contribution) \left\{\begin{array}{l} C_{EIS} = \frac{dR}{dEIS}\frac{dEIS}{dT_g} \\ C_{EIS,f} = \frac{dR}{dEIS}\frac{dEIS_f}{dT_{g,f}} \\ C_{EIS,u} = \frac{dR}{dEIS}\frac{dEIS_u}{dT_{g,u}} \end{array}\right\}$$

$\frac{dR}{dSST}, \frac{dR}{dEIS}$: *meteorological radiative kernels (Scott et al 2020)*

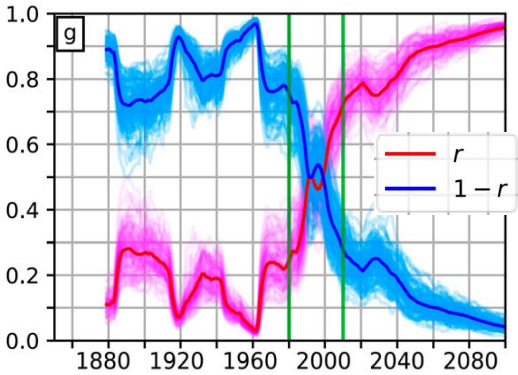
Time variation of low-cloud feedback (C_{SST} & C_{EIS})

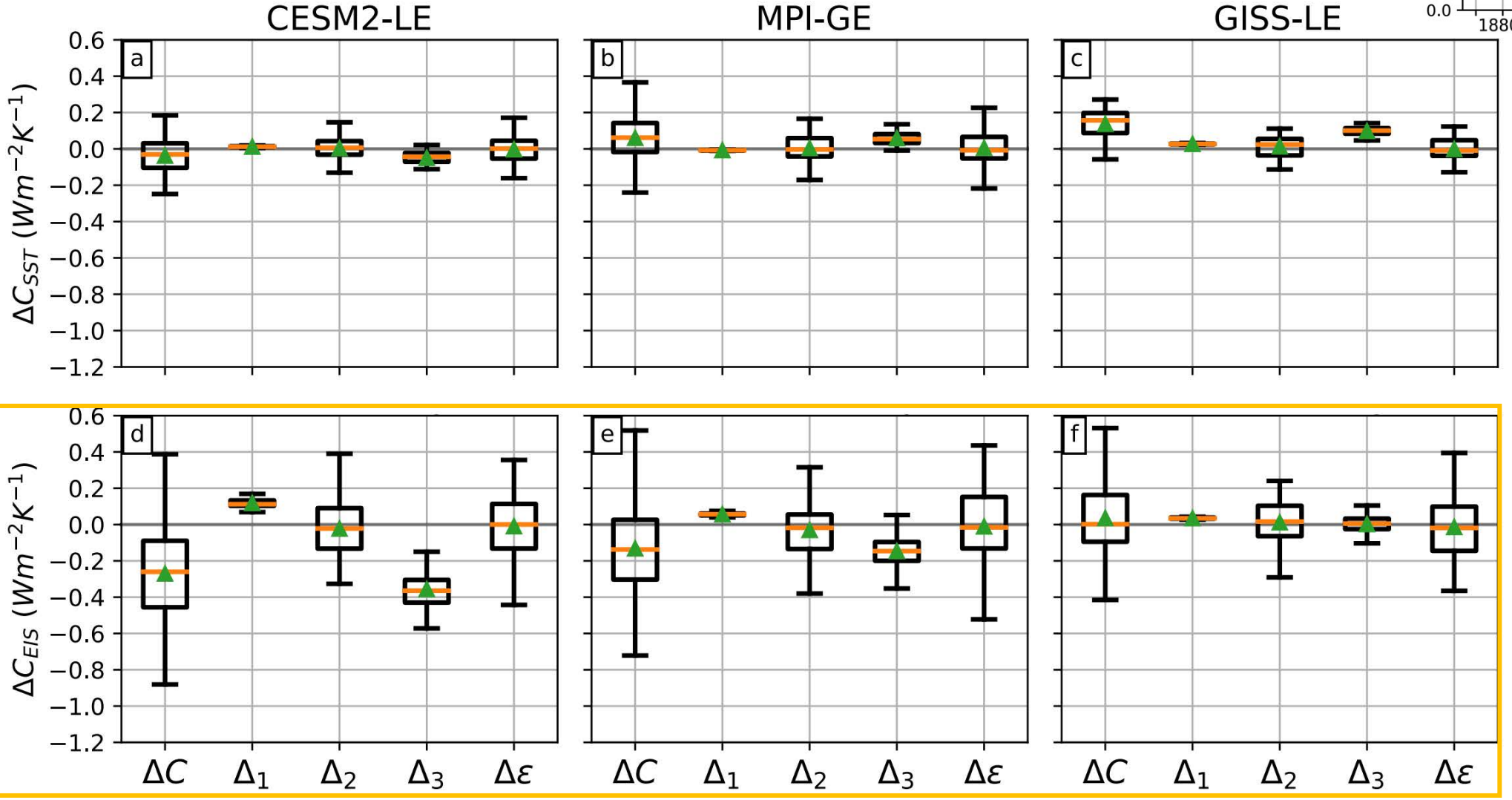


ΔC attribution between 1951-1980 & 1981-2010

$$\Delta C = \sum \delta C_f \bar{r} + \sum \delta C_u (1-\bar{r}) + \sum \delta r (\overline{C_f} - \overline{C_u}) + \Delta\epsilon$$

Δ_1 Δ_2 Δ_3





Conclusion

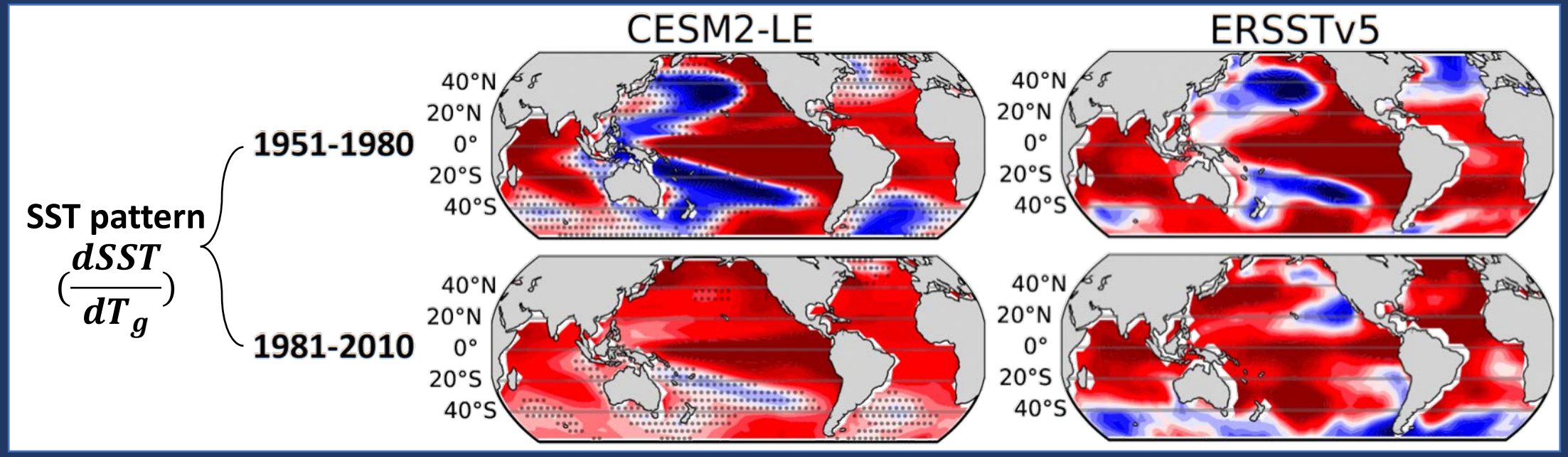
- OLS regressions (SST pattern, feedback, etc.) are shaped by forced and unforced responses, weighted by r and (1-r).

$$\frac{dX}{dT_g} = \frac{dX_f}{dT_{g,f}} r + \frac{dX_u}{dT_{g,u}} (1-r) + \epsilon \qquad r = \frac{var(T_{g,f})}{var(T_{g,f}) + var(T_{g,u})}$$

- Before 1980, low cloud feedback (C) is largely influenced by unforced responses (small r). After 1980, forced signals strengthen and overtake unforced signals.

- In CESM2-LE and MPI-GE, unforced C is more positive than the forced C, thus the increasing ”r” gives rise to a negative trend of total C. In GISS-LE, unforced and forced C have similar magnitudes, thus the total λ trend is insignificant.

More to think …

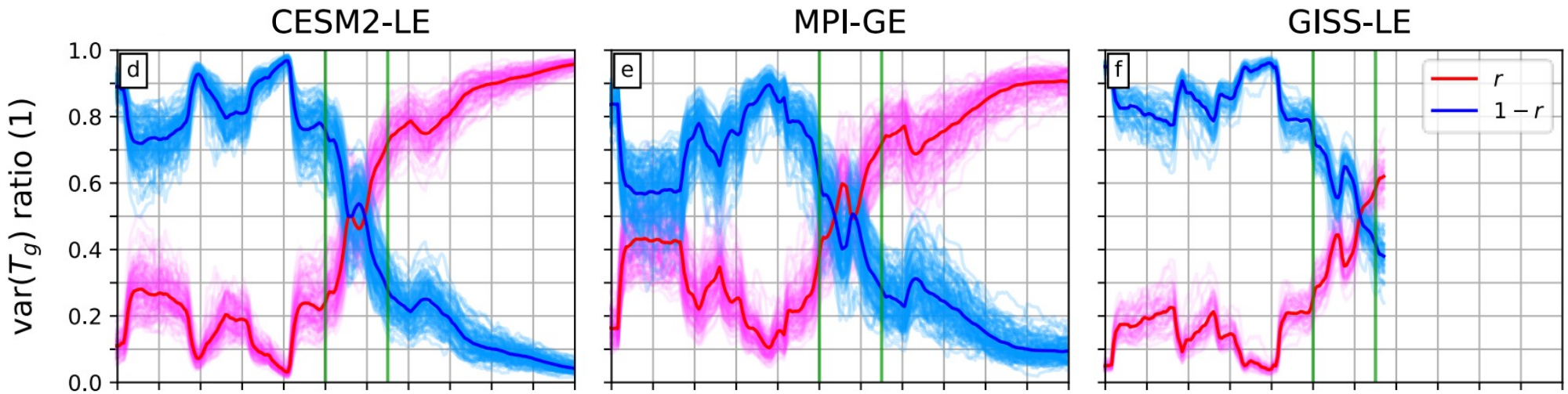


What if we do not have large ensemble simulations?

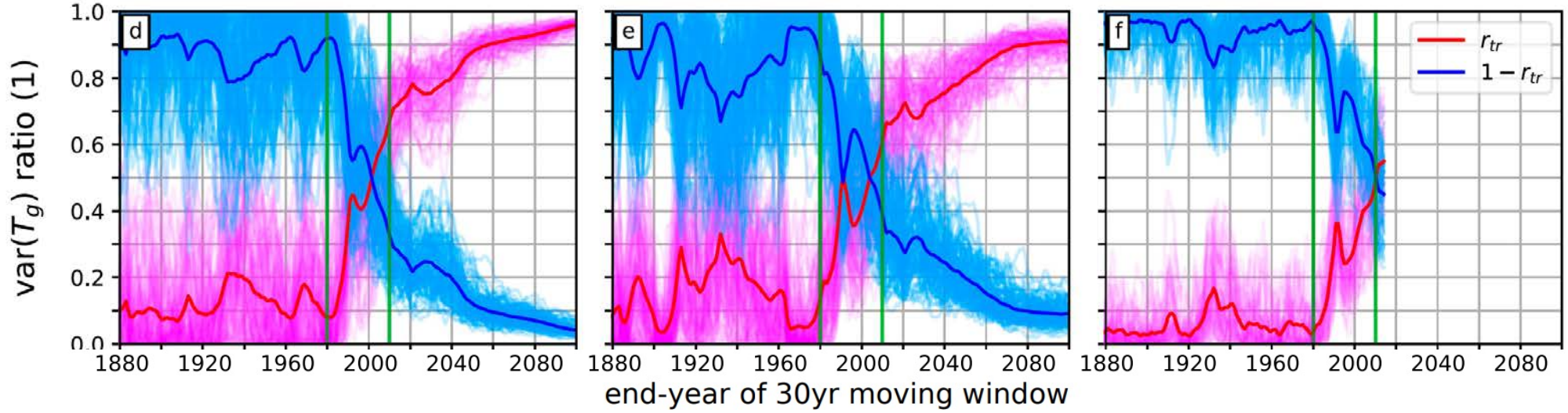
Try:
linear trend part as “proxy” of forced responses
and detrended part as “proxy” of internal variability

How good (bad) is it?

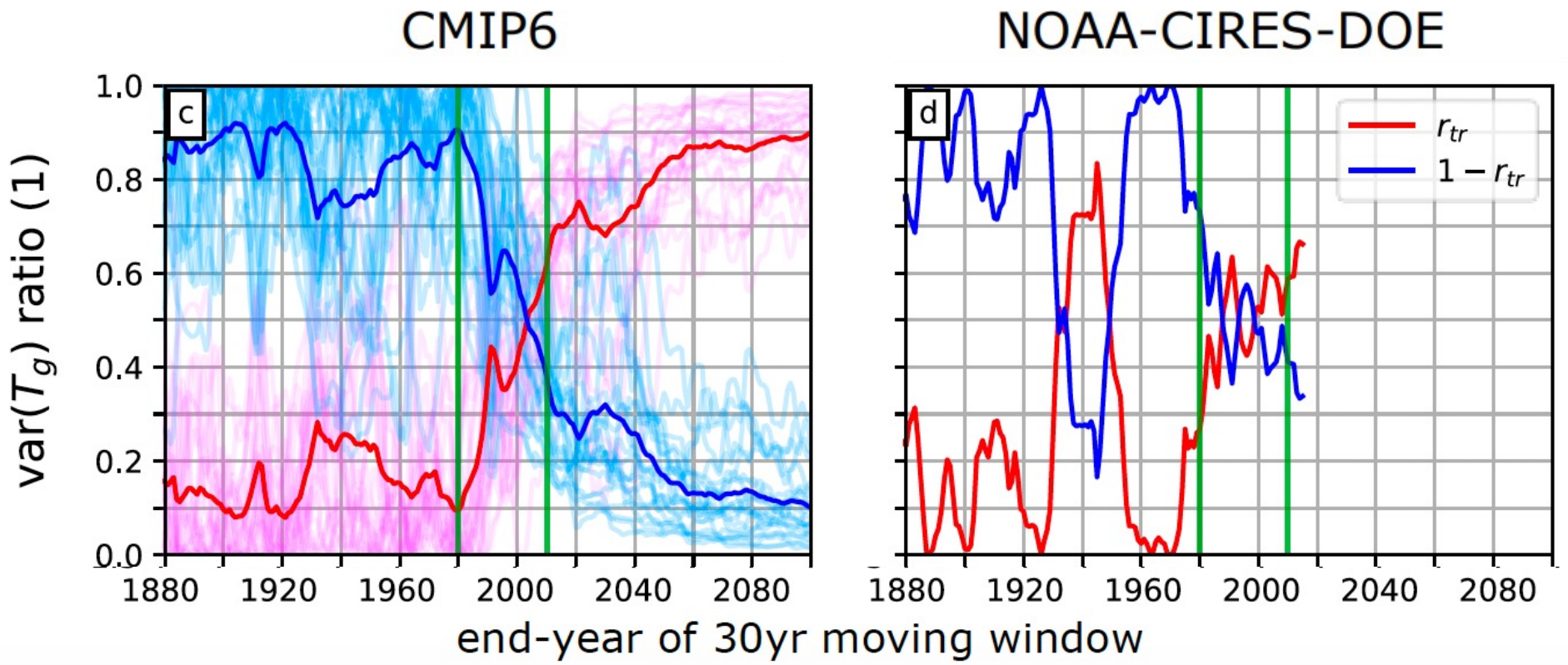
*1) **Ensemble averages and anomalies** as forced and unforced responses:*



*2) **Linear trends and anomalies** as forced and unforced responses:*



Time evolution of "r" (relative importance between trend and detrend comp.) in Obs & CMIP6 models



Observation: SST pattern time evolution