# The relative importance of forced and unforced SST patterns in driving the time variations of low cloud feedback

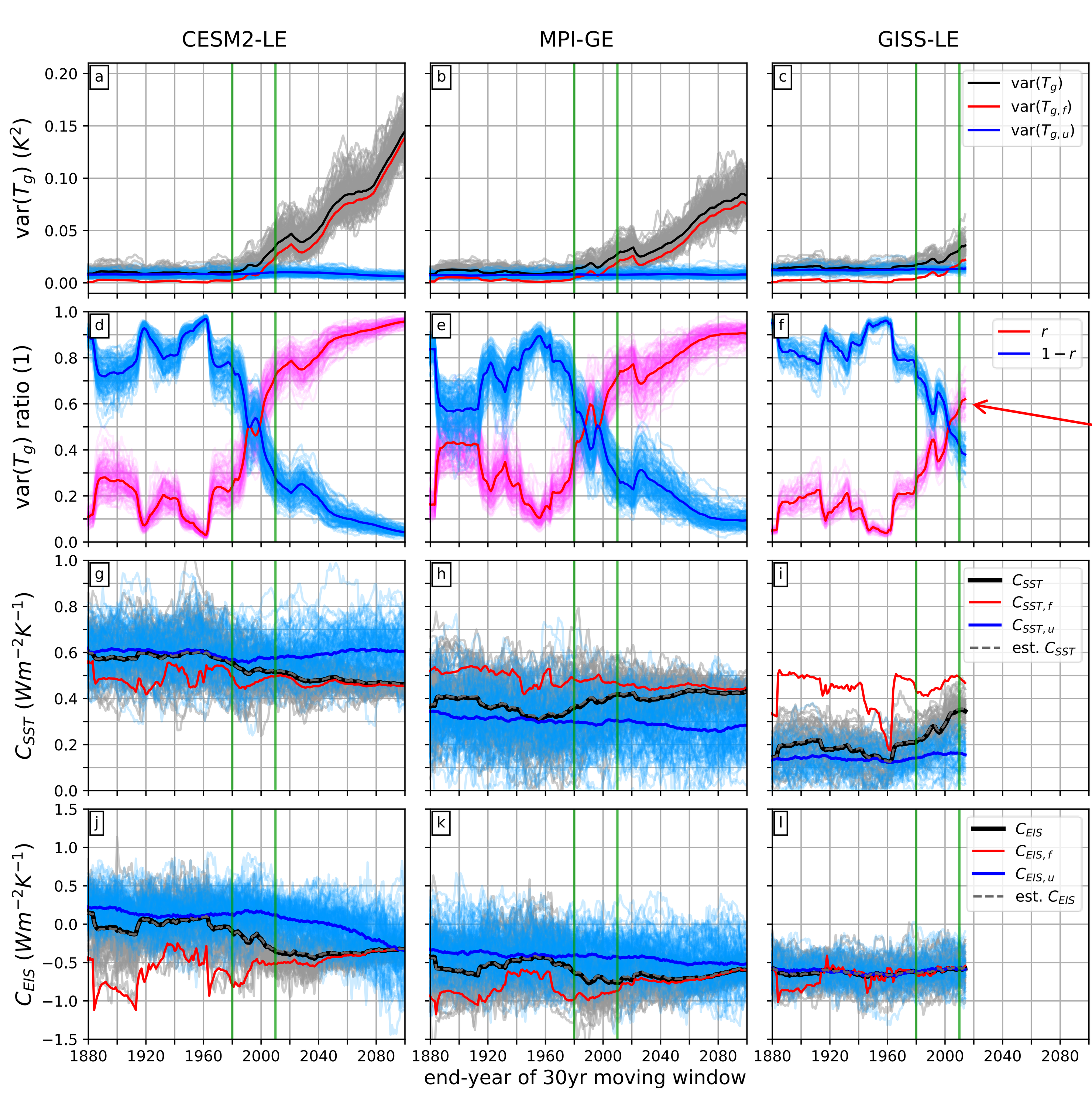
Yuan-Jen Lin [a,b], Gregory V. Cesana [a,b], Cristian Proistosescu [c], Mark D. Zelinka [d], and Kyle C. Armour [e]

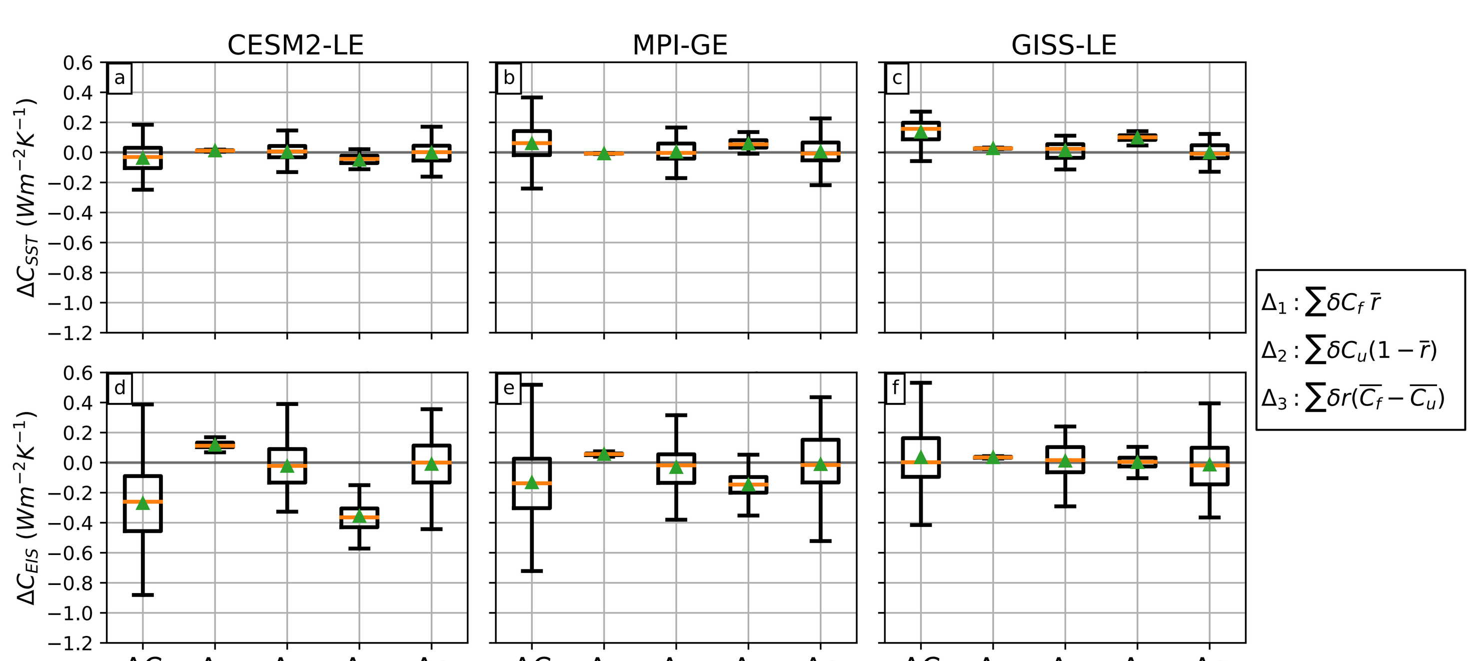
[a] Center for Climate Systems Research, Columbia University, New York, NY, USA | [d] Center for Climate Systems Research, Columbia University, New York, NY, USA
[b] NASA Goddard Institute for Space Studies, New York, NY, USA | [e] School of Oceanography and Department of Atmospheric Sciences, University of Washington, Seattle, WA, USA
[c] Department of Atmospheric Sciences and Department of Geology, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL, USA

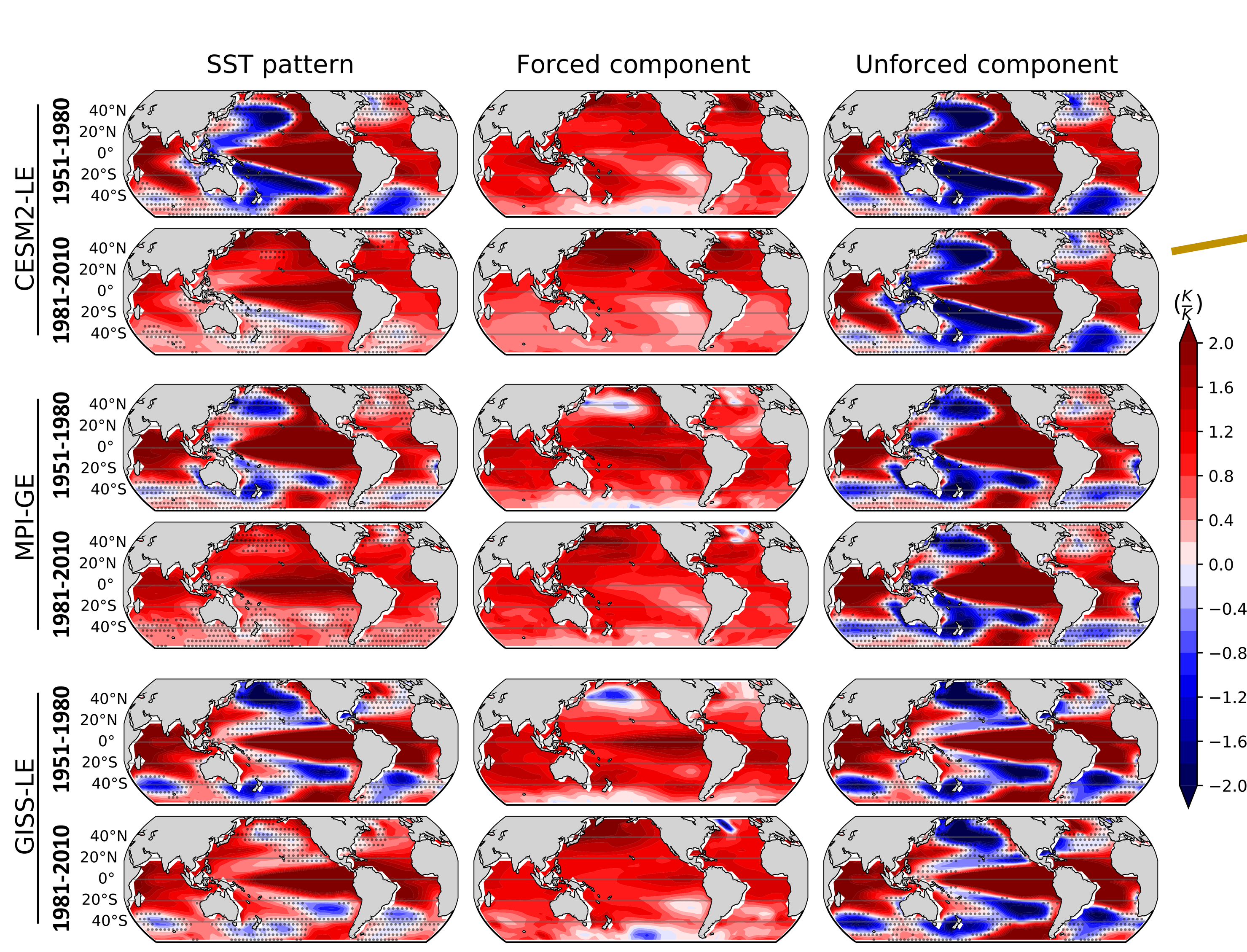
## Summary & Discussion


- Time variations of low cloud feedback depend on the relative importance between the forced and unforced feedback components.
  - For 30-yr windows ending before the 1980s, the SST patterns are dominated by unforced variations, which are representative of an ENSO-like pattern, corresponding to weak low-level stability in the tropics.
  - For 30-yr windows ending after the 1980s, the forced signals have become stronger, outweighing the unforced signals in the 2010s. Forced SST patterns are characterized by relatively uniform warming with an enhancement in the WP, accounting for more stabilizing low cloud feedback.
- <u>The time-evolving SST pattern due to the increasing importance of forced signals is the dominant contributor to the recent stabilizing shift of low cloud feedback in the LEs.</u>
- The observed SST patterns consistently suggest a reduction in the relative role of unforced ENSO-like variability since the 1980s. However, the emergent observed SST patterns highlight the WP warming trend and the EP cooling trend, which actuates a stronger stabilizing shift of low cloud feedback that lies outside the model ensembles, implying the systematic bias of the forced SST patterns obtained from the models.


## Initial-Condition Large Ensembles (LEs)




Forced ($\cdot_f$) and unforced ($\cdot_u$) contribution on OLS regressions

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

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

$$C_{SST} = \frac{dR}{dSST}\left[\frac{dSST_f}{dT_{g,f}} r + \frac{dSST_u}{dT_{g,u}}(1-r) + \sigma\right] = C_{SST,f}\, r + C_{SST,u}(1-r) + \epsilon,$$

$$C_{EIS} = \frac{dR}{dEIS}\left[\frac{dEIS_f}{dT_{g,f}} r + \frac{dEIS_u}{dT_{g,u}}(1-r) + \sigma\right] = C_{EIS,f}\, r + C_{EIS,u}(1-r) + \epsilon,$$

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

- *Change in feedback*
- $\Delta_1$: *Due to change in forced comp.*
- $\Delta_2$: *Due to change in unforced comp.*
- $\Delta_3$: *Due to change in the relative importance between forced and unforced comp.*
- *Residual*

- *Similarity in LEs:* 3 LEs show similar pattern transition (being dominated by unforced comp. to forced comp.)
- *Spread in LEs:* WP warming in unforced SST pattern is weaker in CESM2-LE (more positive unforced $C_{EIS}$), followed by MPI-GE, then GISS-LE (less positive unforced $C_{EIS}$).

- *Compare LEs & OBS:* While the time variations of `r` are similar between LEs and observations, the observations suggest a recent WP warming/EP cooling trend that is not included in the forced SST pattern of LEs.

(When LEs are not available, trend/detrend components can be good proxies for forced/unforced components)

## CMIP6 | OBS