Emergent Constraints for Cloud Feedbacks and Climate Sensitivity

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A review paper conditionally accepted to *Current Climate Change Reports*

CFMIP Meeting on Cloud Processes and Cloud Feedbacks

June 8, 2015

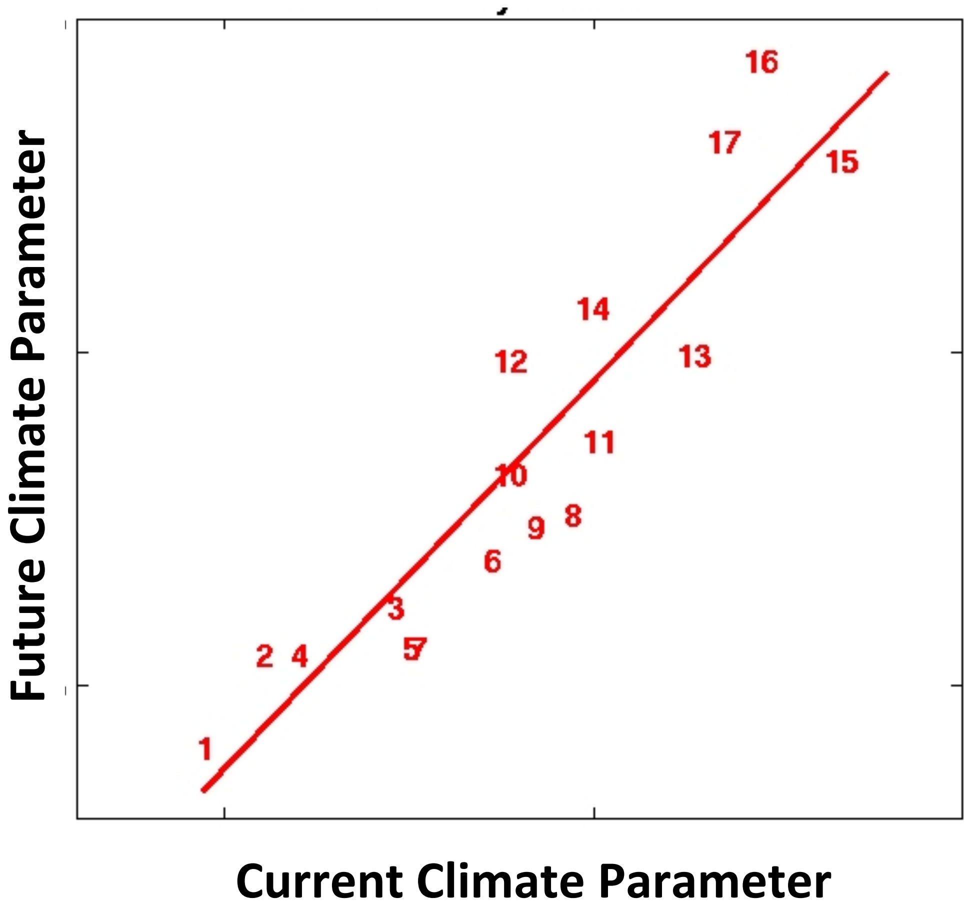
What is an emergent constraint?

- Suppose we find some parameter of a GCM's current climate (current climate parameter) that is ***physically linked*** to some important aspect of the GCM's response to anthropogenic forcing (future climate parameter).
- Suppose further that the current climate parameter is observable.
- Then to the degree the GCM simulation of the current climate parameter is in error, we have reason to believe its simulation of the future climate parameter is also in error.
- This is the basic idea behind emergent constraints: GCMs should be constrained by parameters that matter most for future climate change.

What is an emergent constraint?

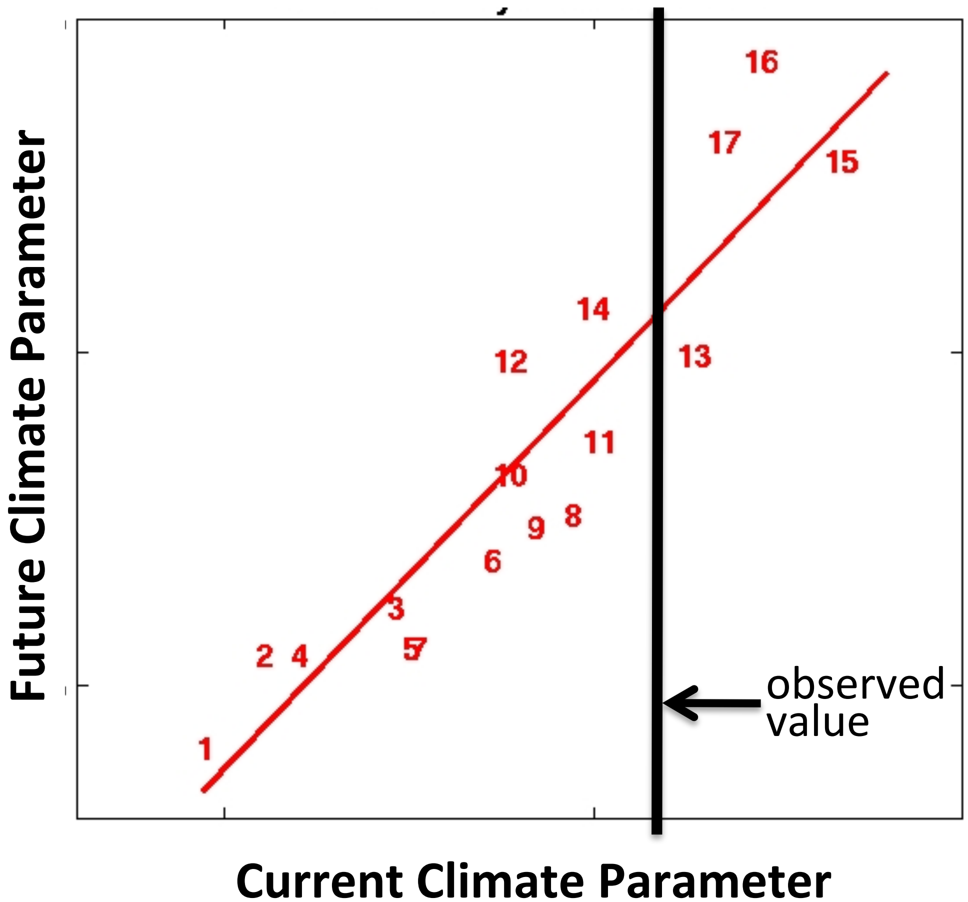
- In practice, a candidate emergent constraint is discovered through analysis of a GCM ensemble.
- In other words, it “emerges” from the collective behavior of multiple GCMs.
- A candidate emergent constraint might be diagnosed through a correlation between current and future climate parameters.

What is an emergent constraint?



- This is an example of what such a correlation might look like.
- **If such a correlation is found, it can only be an emergent constraint if the relationship between current and future climate parameters can be substantiated with physical argumentation and/or analysis** (i.e. the correlation is also causal).

What is an emergent constraint?



- If these conditions are satisfied, then observations of the current climate parameter can be used for GCM evaluation.
- In this hypothetical case, many GCMs are clearly biased in their simulations of the current climate parameter.
- If these biases were eliminated, the physical links between current and future climate parameters guarantee that spread in the future climate parameter would be reduced.

More about reliability criteria

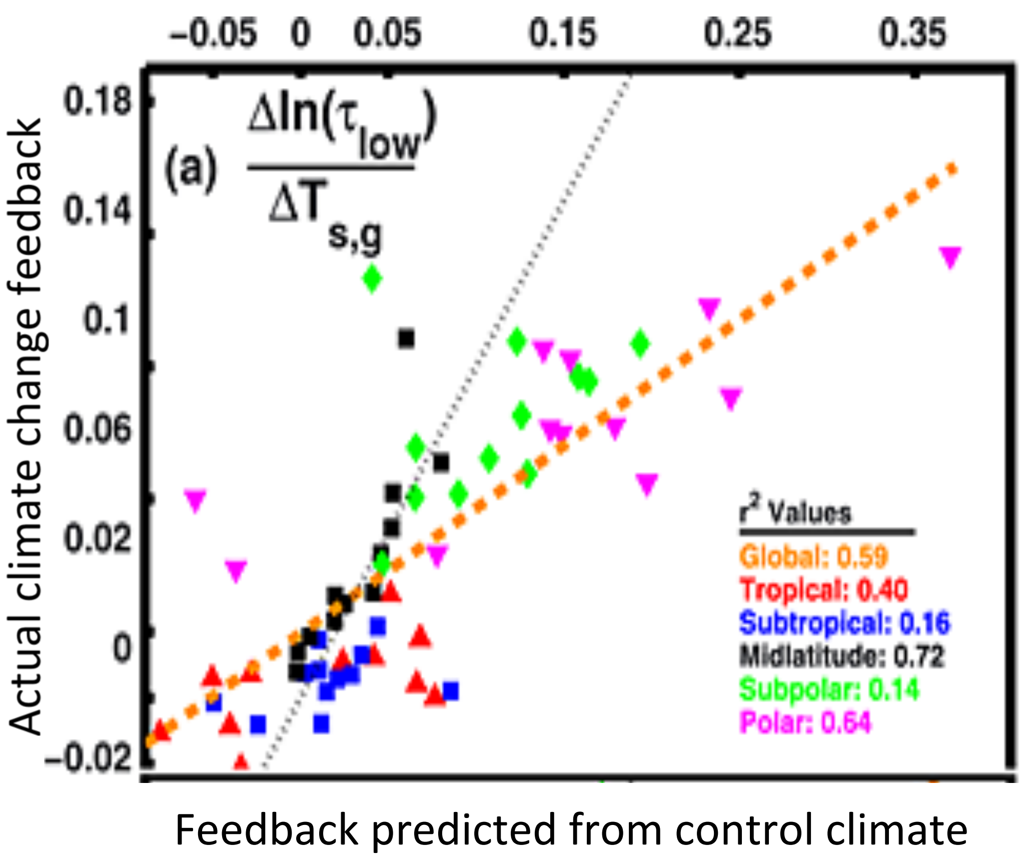
We've already noted that a physical mechanism linking the current and future climate parameters is a necessary condition for an emergent constraint to work. Here are two indicators this requirement may not be completely satisfied.

Model ensembles behave differently. The presence of a correlation between current and future climate parameters in one ensemble but not another suggests the relationship may not be physical.

Possible multiple influences. If the climate parameters could be subject to the influence of multiple physical processes, a model could agree with observations due to compensating errors in the underlying processes. Or models might be deemed unrealistic even if they get all the processes right and are biased in only one.

In light of this background we now turn to three recent examples of potential emergent constraints related to cloud feedback.

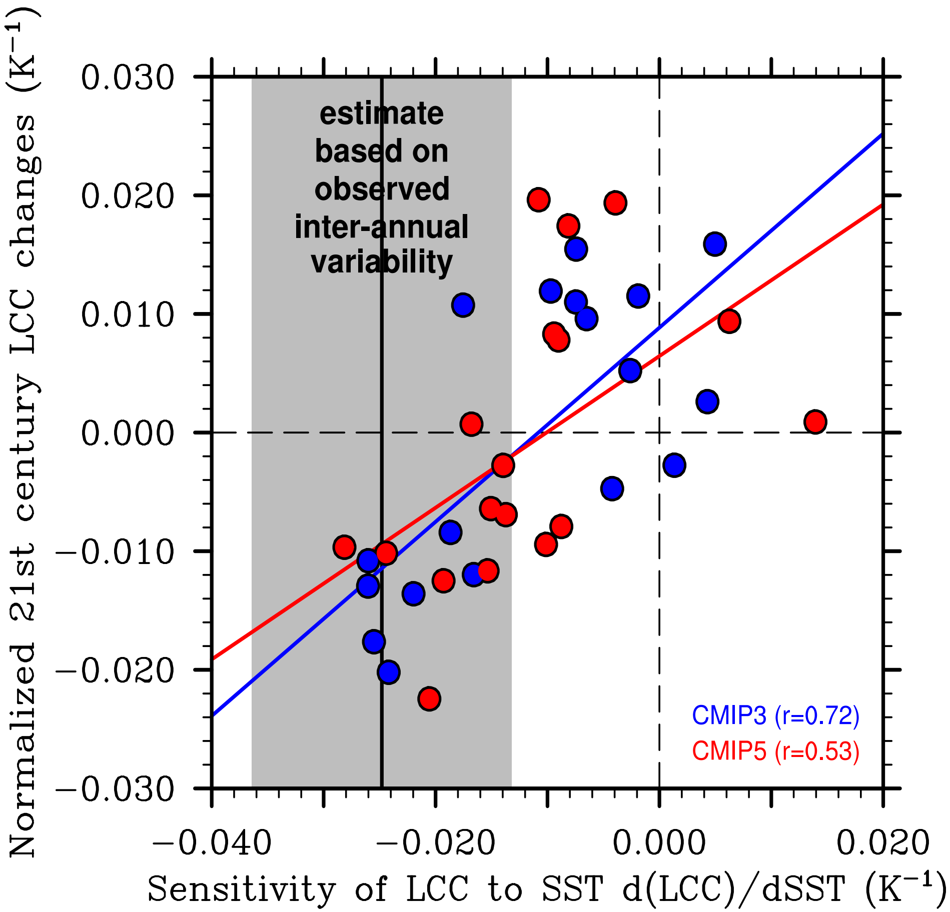
Example 1: Cloud optical depth feedback



Gordon and Klein (2014)

- A model's sensitivity of optical depth to local surface temperature can be derived from daily to inter-annual variability.
- When appropriately scaled to correspond to a global feedback, this sensitivity is highly correlated with the models' cloud optical depth feedback in climate change.
- This work is promising as there is a plausible physical mechanism associated with it involving the adiabiatic relationship between cloud liquid water content and temperature.
- But more remains to be done to diagnose this mechanism, and there may be other mechanisms shaping simulated sensitivities.
- Chris Terai has a talk shortly on this topic.

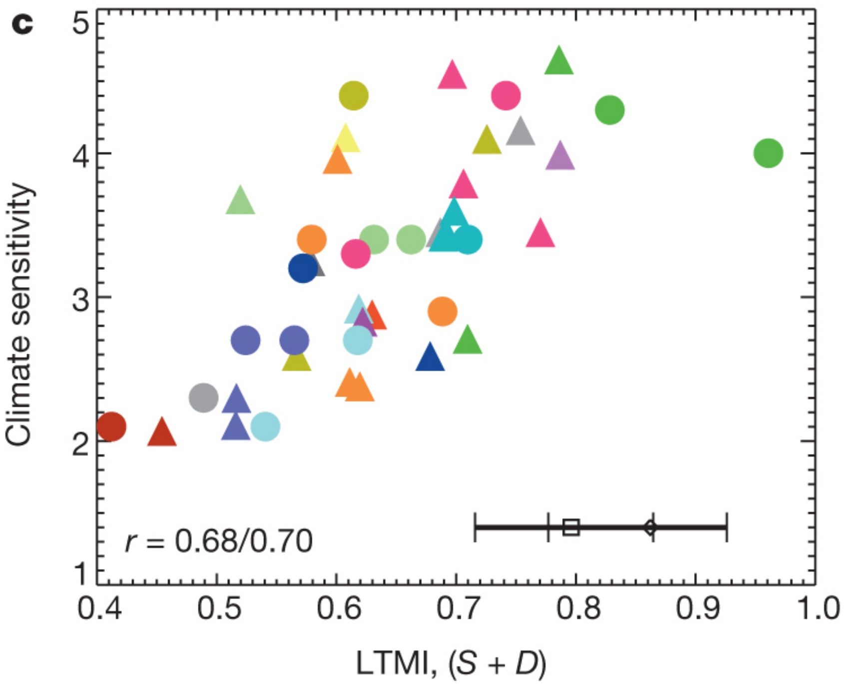
Example 2: Subtropical low cloud cover feedback



Qu et al. (2014)

- A model's sensitivity of low subtropical cloud cover to SST can be diagnosed from inter-annual variability.
- In both CMIP3 and CMIP5 ensembles, this sensitivity is correlated with anthropogenic low cloud cover changes.
- In this case, the SST sensitivity may encapsulate effects of multiple physical processes, so that it isn't quite an emergent constraint yet.
- Qu et al. (2015) makes an attempt to untangle these. Xin Qu will speak about this shortly.

Example 3: Lower tropospheric mixing and climate sensitivity



Sherwood et al. (2014)

- A metric can be constructed that combines mixing resulting from parameterized circulations and that resulting from resolved shallow-depth, large-scale circulations
- In the CMIP3 and CMIP5 ensembles, this metric is correlated with climate sensitivity.
- Because mixing between the boundary layer and free troposphere plays a central role in low cloud variations, and because low cloud feedback is so important for climate sensitivity, this correlation may have a physical origin.
- Due to multiple processes shaping both the current and future climate parameters, more research is required to discover the potential emergent constraint here.

Conclusion

- We review three potential emergent constraints related to long-term cloud feedbacks and climate sensitivity, and discuss criteria to assess how close they are to being true emergent constraints.
- The examples we review may eventually become emergent constraints, as they each have candidate physical explanations associated with them that are credible.
- A barrier common to all of them is the presence of multiple physical mechanisms, leading to concerns about error cancellation.
- It seems noteworthy that two of the potential emergent constraints are related to low cloud, and independently suggest more positive cloud feedbacks and larger climate sensitivity.
- For the emergent constraint technique to yield reductions in GCM spread, a further step of determining how GCM parameterizations lead to variation in the current climate parameters is required. So far very little work has been done along these lines.

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