Iterative Use of Observations and Machine Learning to Design ESM Perturbed Parameter Ensembles (PPEs)

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obs4MIPs
Observations for Model Intercomparisons Project

NSF

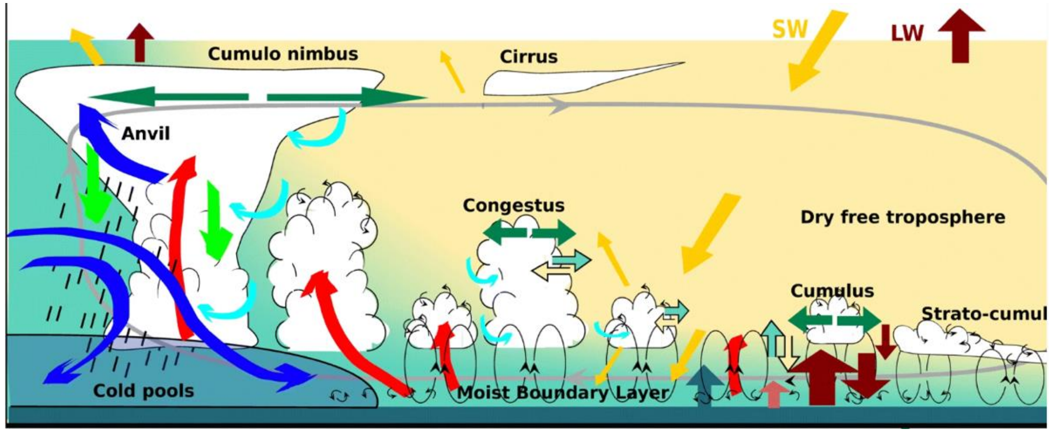
LEAP

Micro2Macro, 29 Oct 2024

A Typical Climate Model (Atmosphere) PPE

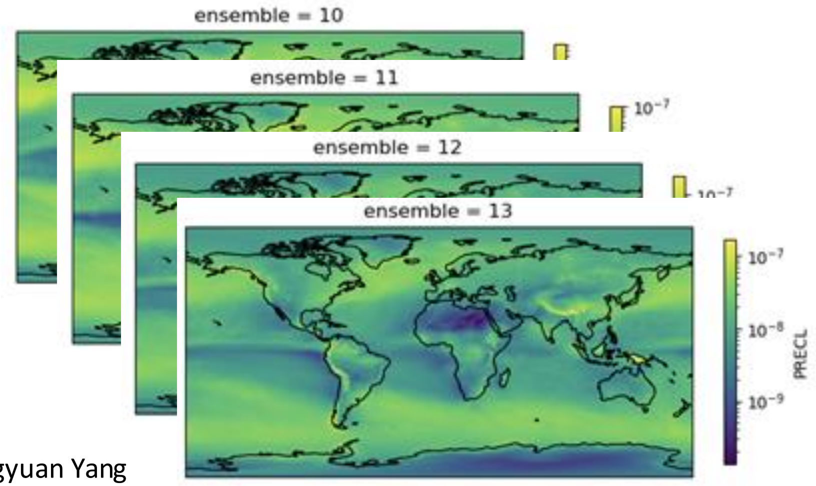
- Survey the parameterizations representing the various atmospheric processes/structures.

- Select the equations used to describe the processes, and perturb their parameters (coefficients/constants) simultaneously.



Rio et al. 2019

- Which parameters? Perhaps parameter(s) in equations representing conversion of cloud drops to rain drops. (what not to perturb: Coriolis parameter, acceleration due to gravity).



From Qingyuan Yang

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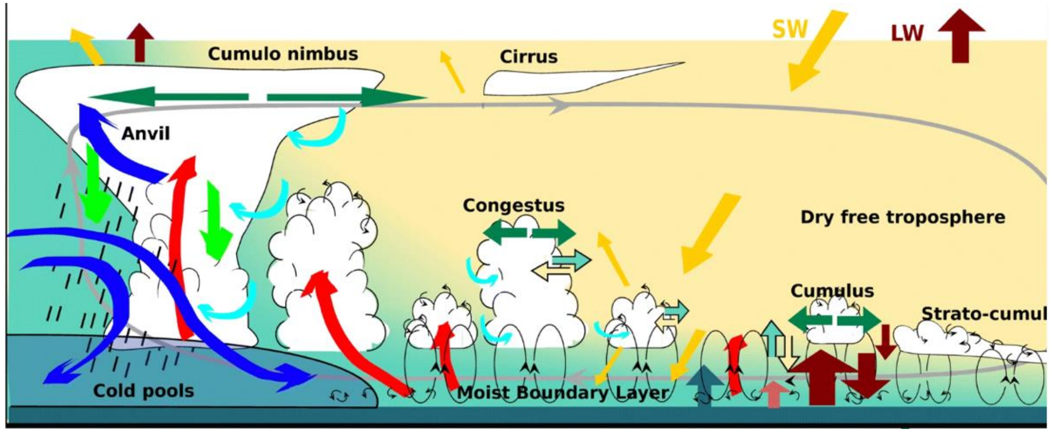

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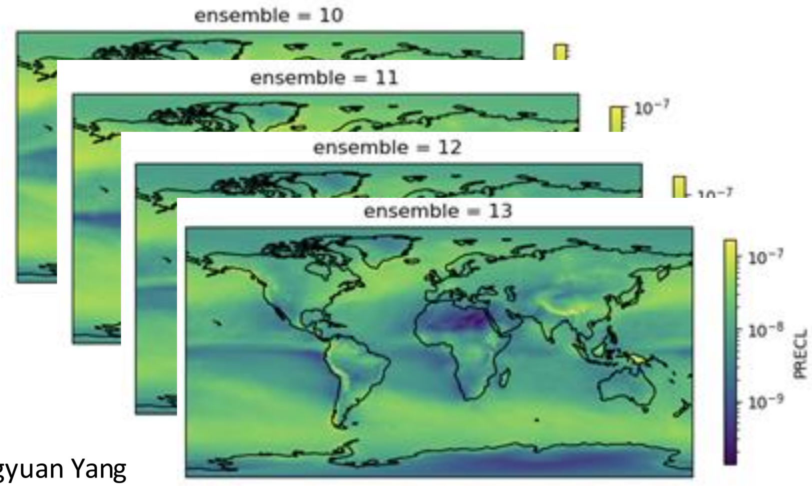
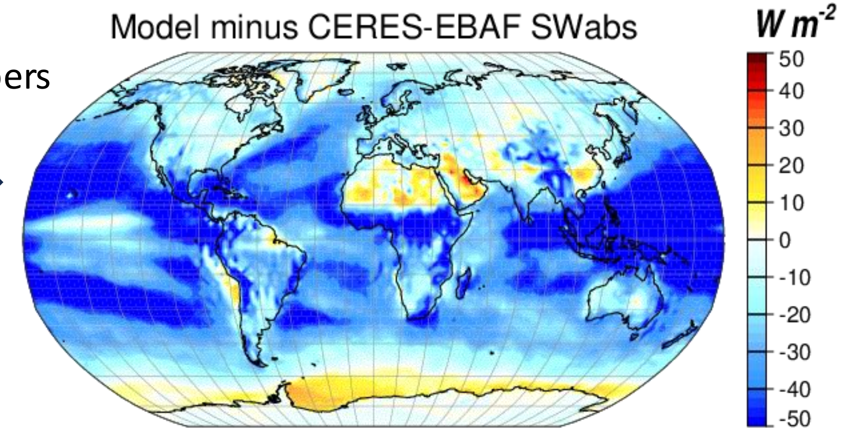


From Qingyuan Yang

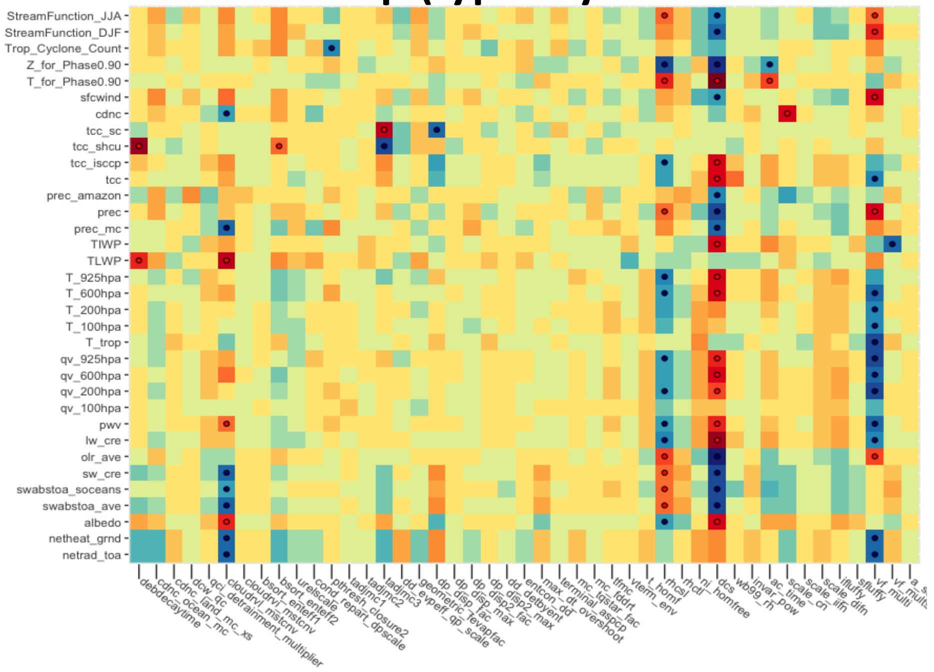
Many PPE members not Earth-like!

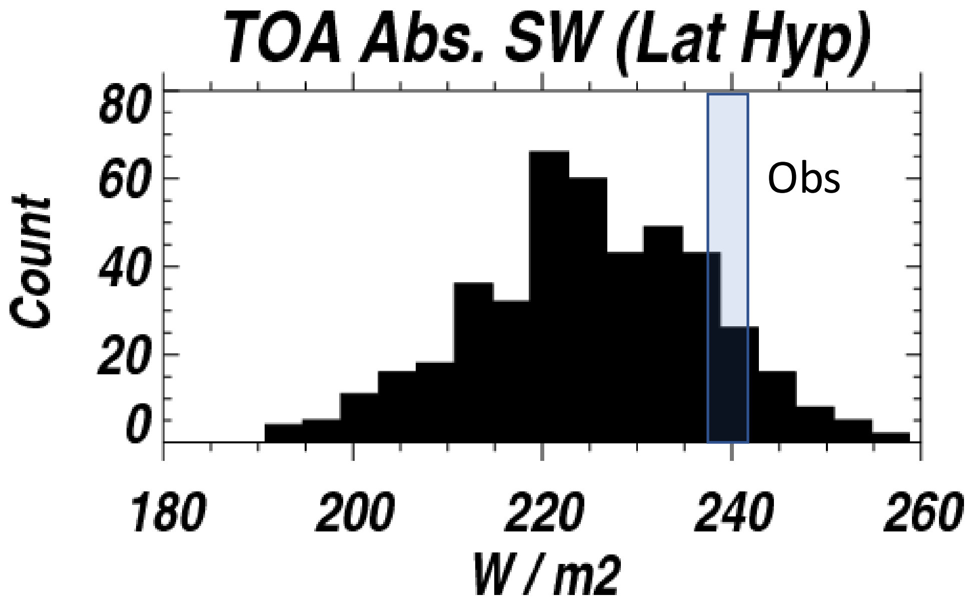


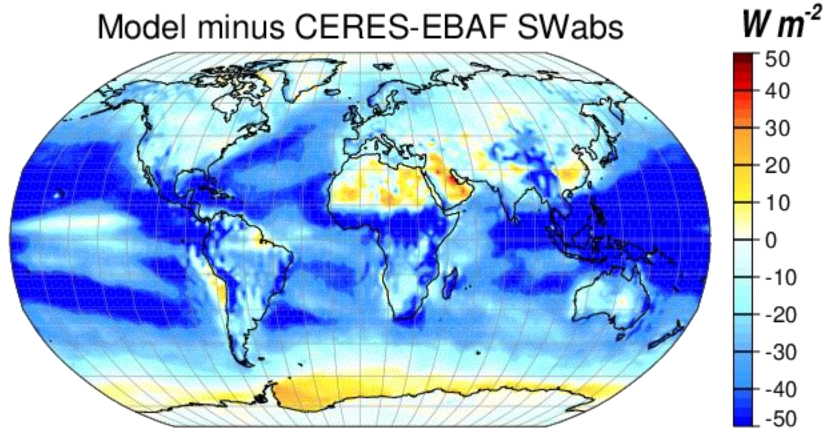
A Typical Climate Model (Atmosphere) PPE

A mapping of parameters-outputs constructed independent of what model mean states look like.

PPE Heat Map (typically linear correlations)







Constructing a different type of (Atmosphere) PPE

- Minimum requirement: find ***all*** combinations of parameters that yield model output in agreement with the base-state climate.

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  **Requires closer, two-way OBS-MODELer interaction.

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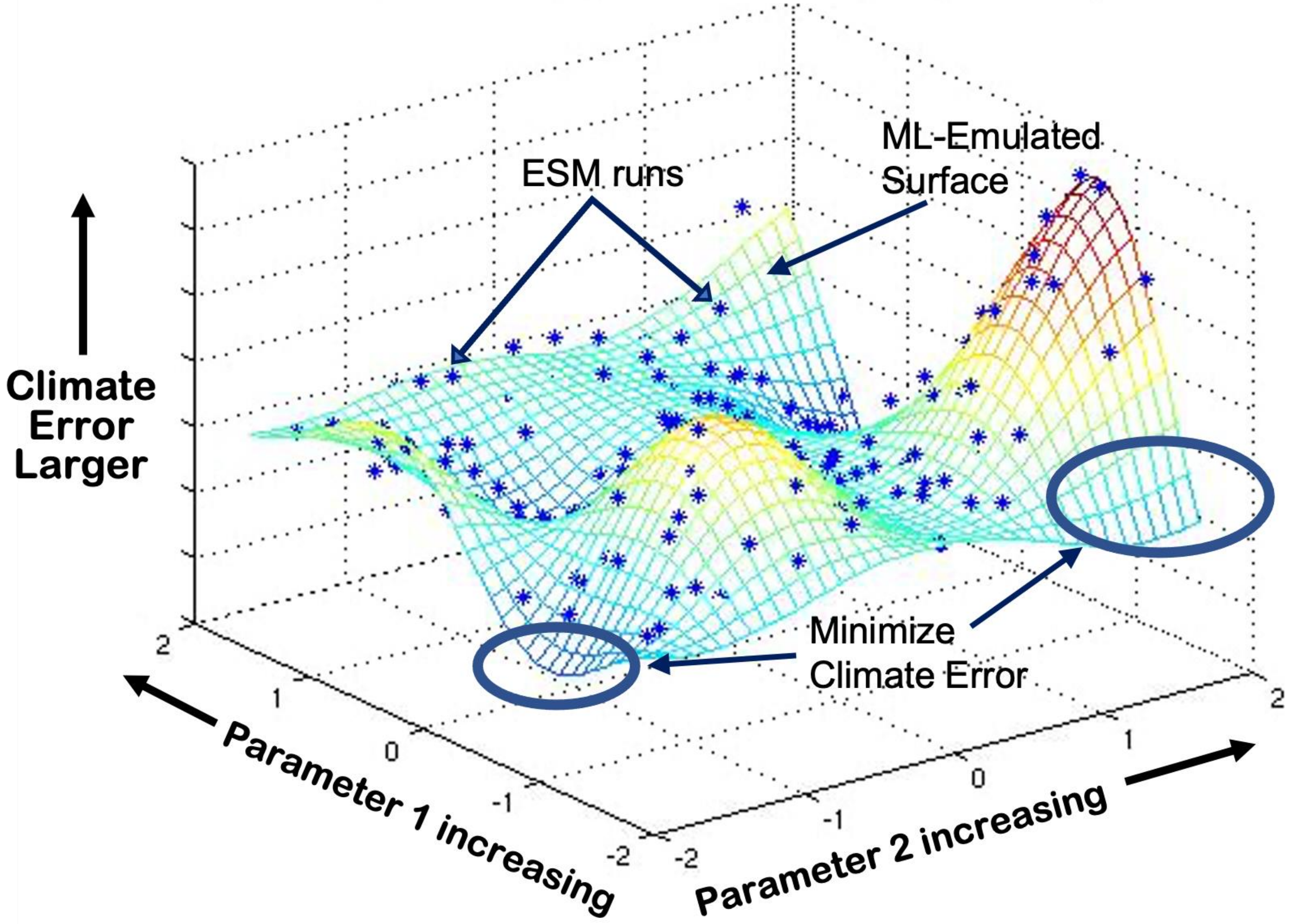
Define this PPE: "**Calibrated Physics Ensemble**", or **CPE**

Definition of "calibration" can evolve; "physics" represents the hope that we can span structure too

Elsaesser et al. (2024)

Generation of Calibrated Physics Ensemble (CPE)

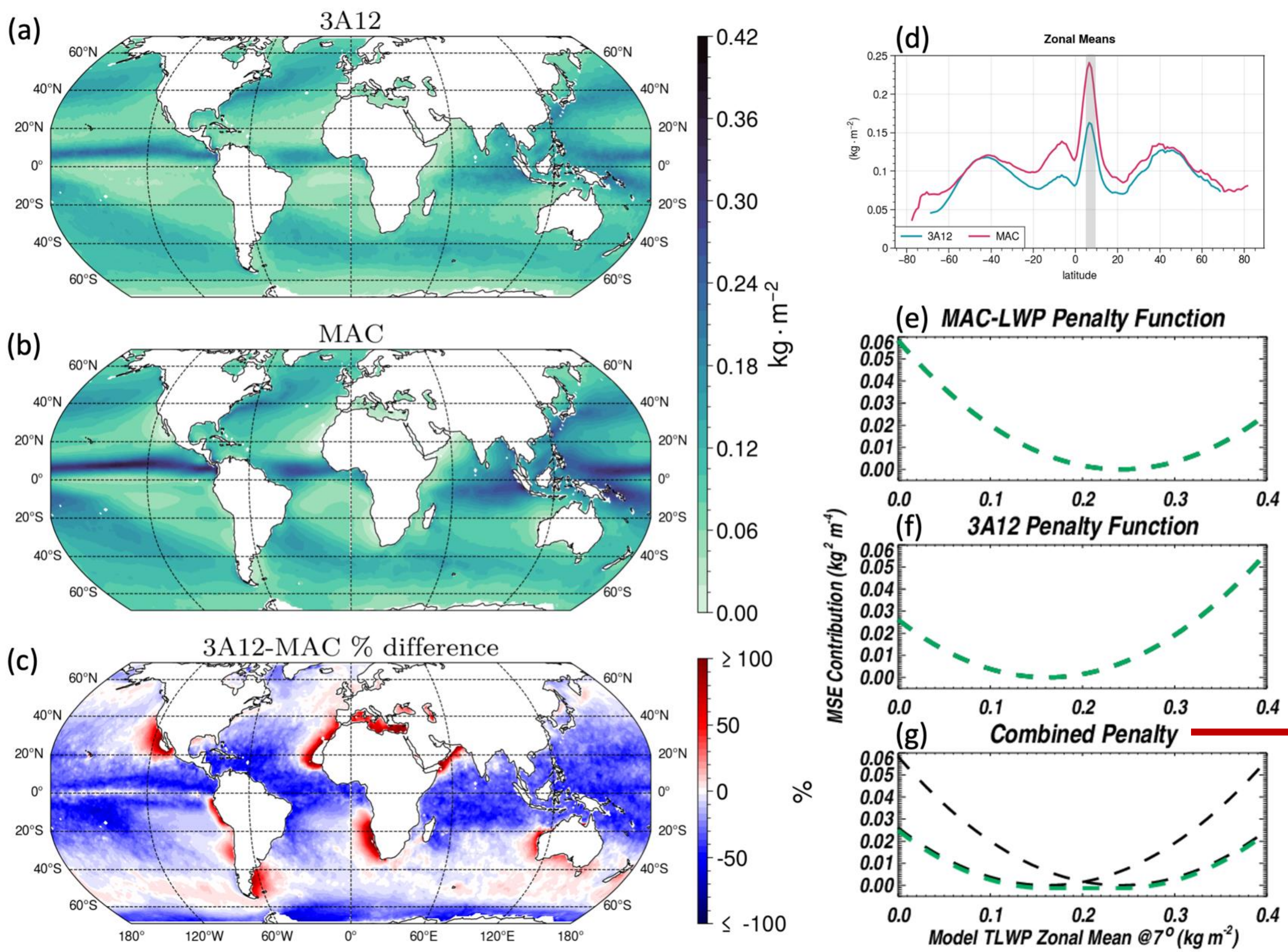
CPE: members similar in mean-state *fidelity*, but with possibly different emergent properties and projections (that are likely different from that of a PPE).

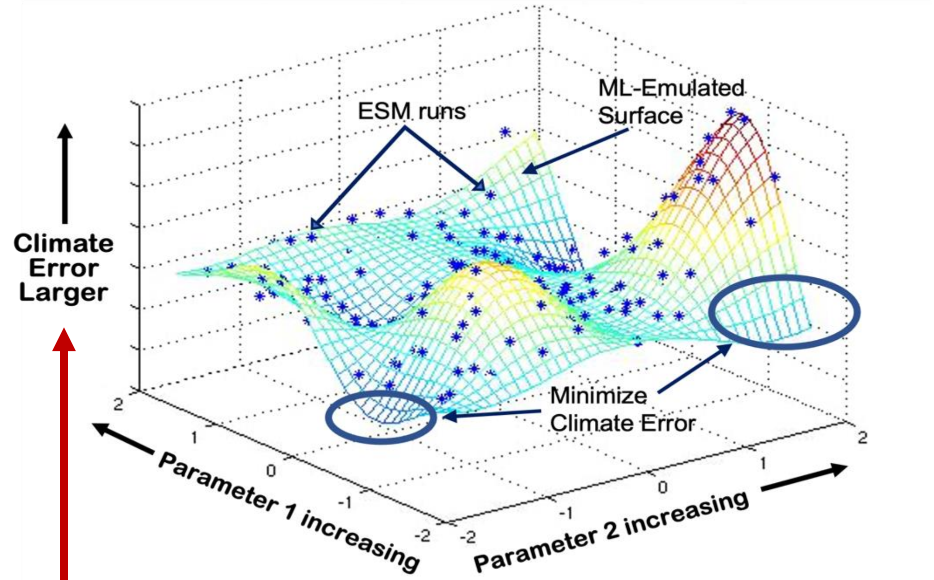


- ❖ Workflow: PPE → emulator → parameter estimation → CPE.
- ❖ Key: many parameters, many obs (& uncertainty [bias?])

Metrics (36 in total)	Data Source
Radiation (Longwave [LW], Shortwave [SW])	CERES-EBAF
Cloud Radiative Forcing (LWcrf, SWcrf)	CERES-EBAF
Column Water Vapor (CWV)	*Obs4MIPS RSS, G-VAP
Specific Humidity profiles (qv)	*Obs4MIPS AIRS, MLS
Temperature profiles (T)	*Obs4MIPS AIRS, MLS, GNSS-RO
Total Liquid Water Path (TLWP)	*MAC-LWP, GPM/TRMM
Total Ice Water Path (TIWP)	*CloudSat, MODIS
Total Precipitation (Pr)	*GPCP, GPM/TRMM
Convective Precipitation (Prc)	GPM/TRMM
Total Cloud Cover (TCC)	CloudSat/CALIPSO, ISCCP
Low (Shallow Cu, StratoCu) Cloud Cover	CloudSat/CALIPSO
Cloudtop Droplet Number Concentration (CDNC)	*MODIS (Bennartz, Grosvenor)
Surface Wind (W)	*WindSat, QuikSCAT
Liquid-to-ice transition Temperature/Height	CALIPSO

Climate Error Computation is Aware of Obs. Discrepancies

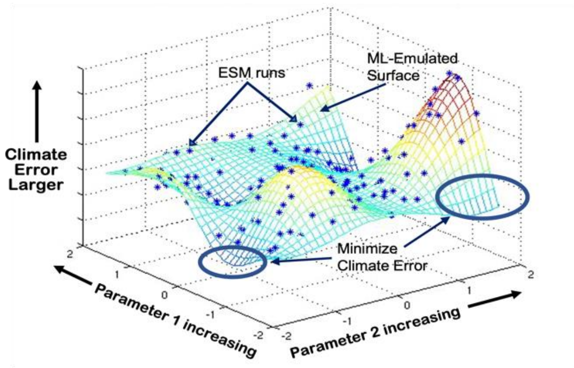




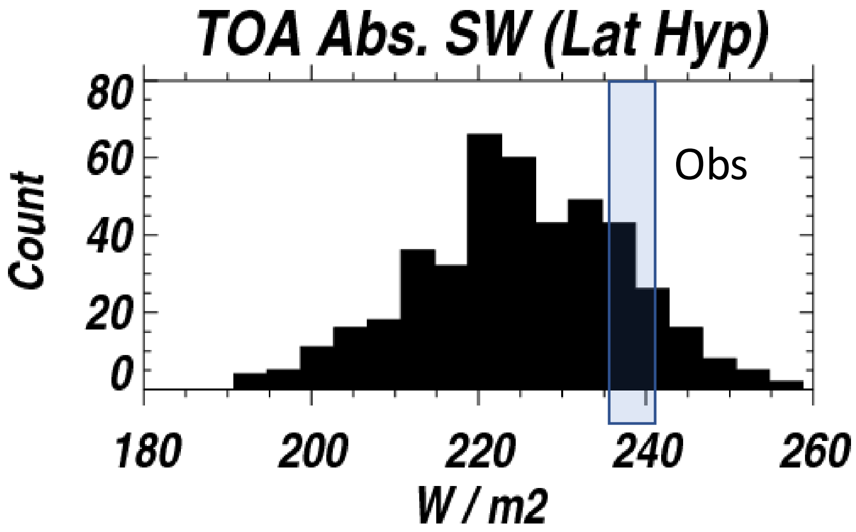
Example to LEFT of larger obs. uncertainties: liquid water path from satellites. Discrepancies are quantitatively accounted for in the model penalty (i.e., climate error) functions.

In this way, we account for systematic obs error in the emulation stage, not estimation stage.

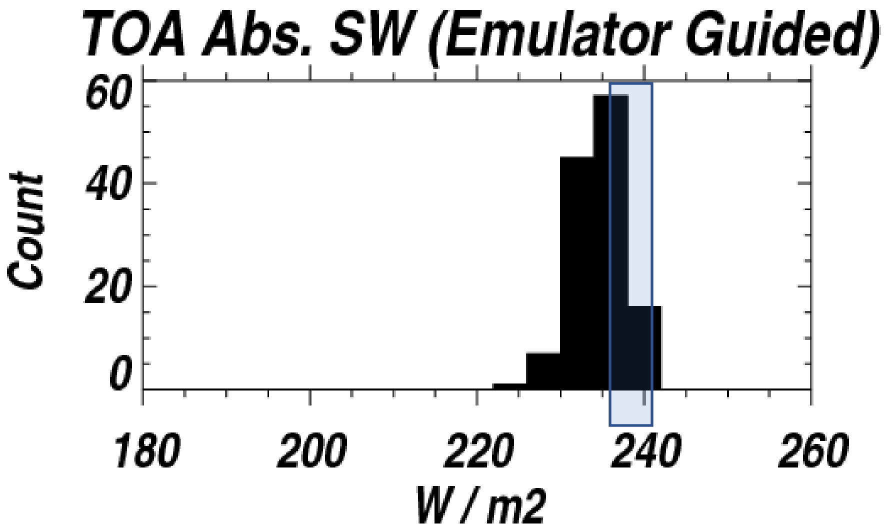
PPE vs CPE



Traditional PPE



Calibrated Physics Ensemble (CPE)



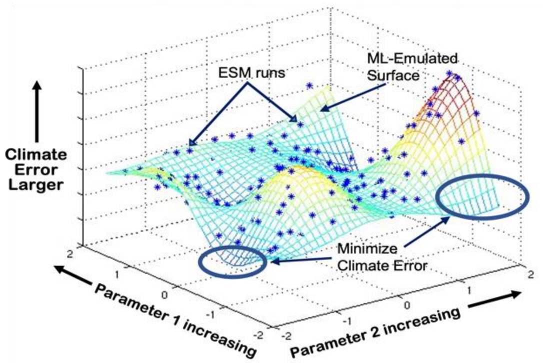
…But, really, in multiple dimensions…

Equifinality (i.e., equally plausible parameter combinations) favored not just because we have more parameters (more DOFs), but also because obs. uncertainty is accounted for.

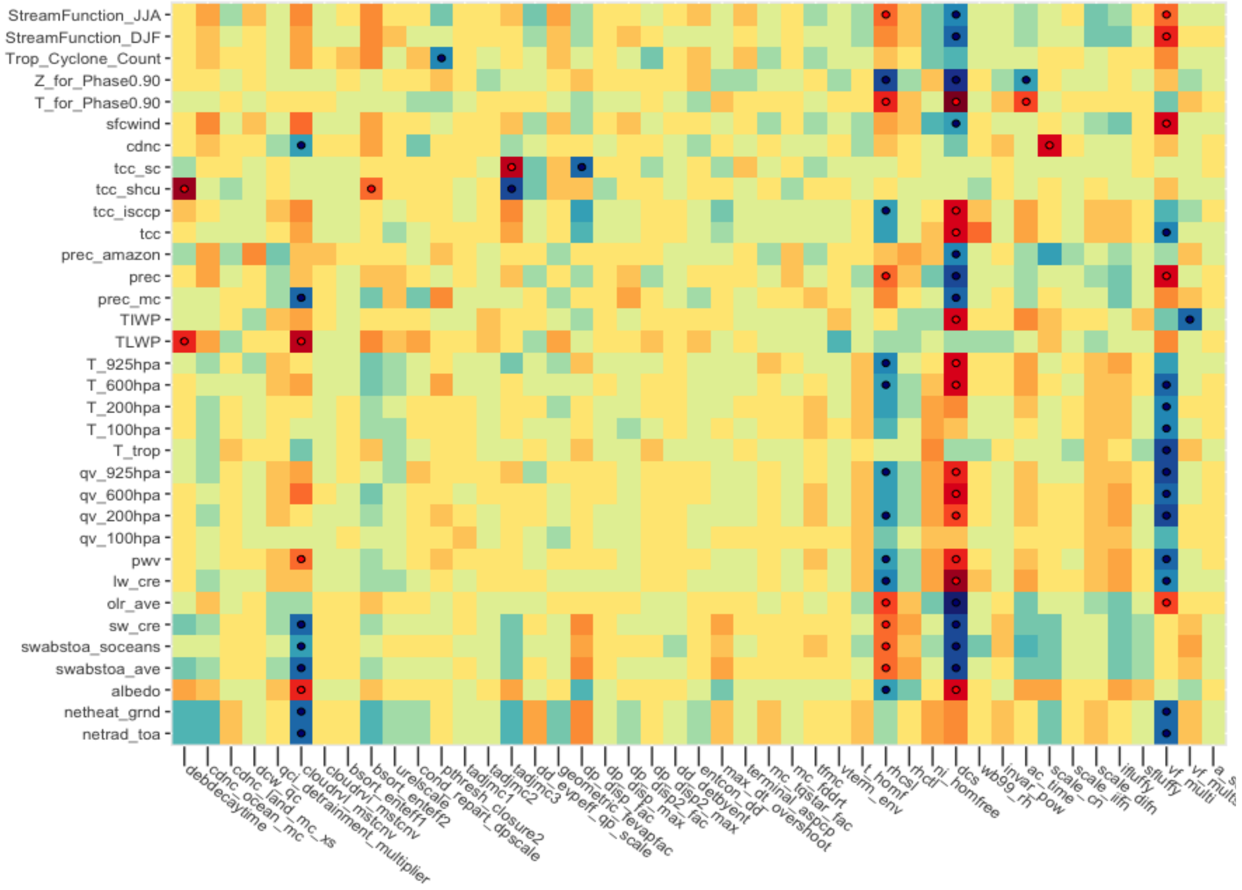
An advantage to equifinality: auto-calibration efforts in climate models.
It is very likely that many CPE members will not play well when coupled to ocean.
One can stack-the-deck toward ensuring coupling success with more members.

Heat Maps in a PPE vs CPE

Sensitivities (doutput/dparameter) under the constraint that the mean states are Earth-Like – and, your perspective of "importance" might change.



Perturbed Physics Ensemble (PPE)



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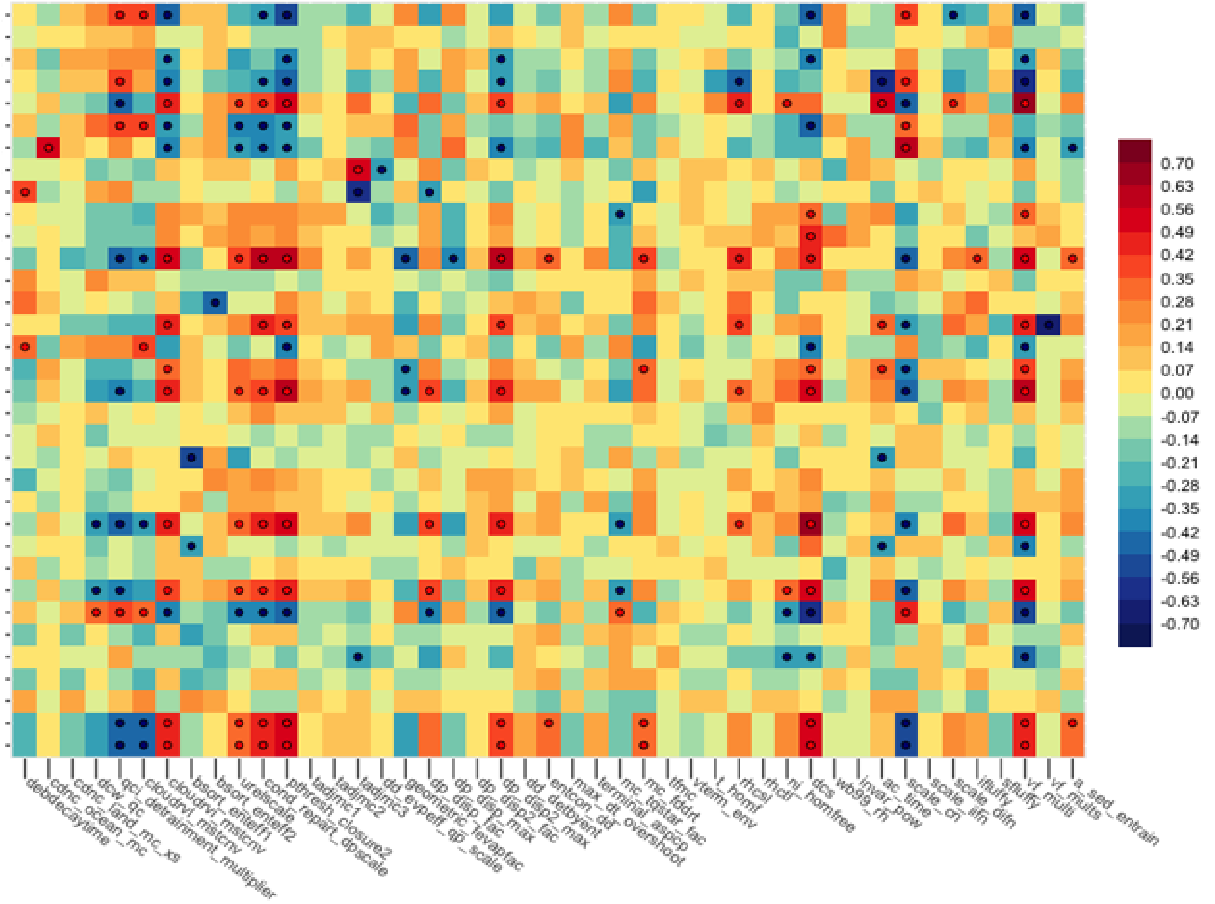
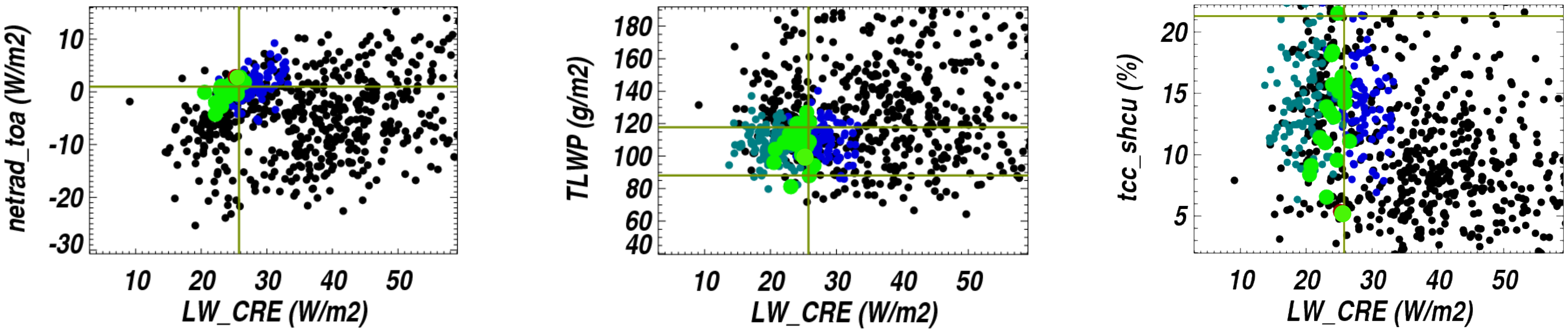
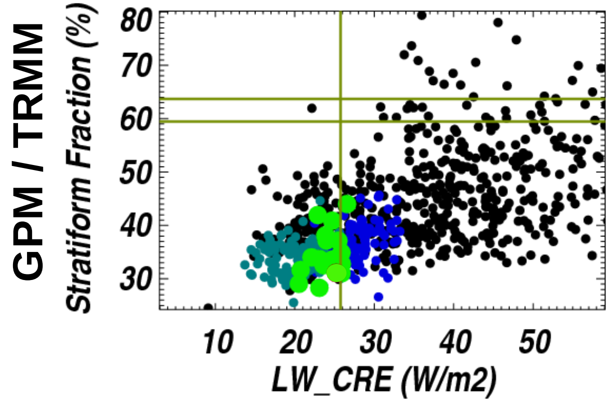


Assessing model-observation mismatches.

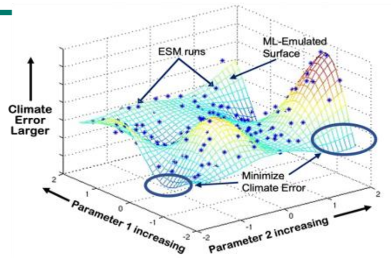
-ML-MCMC does its job at finding physics parameter combinations that yield GCM configurations matching satellite data *where possible.*



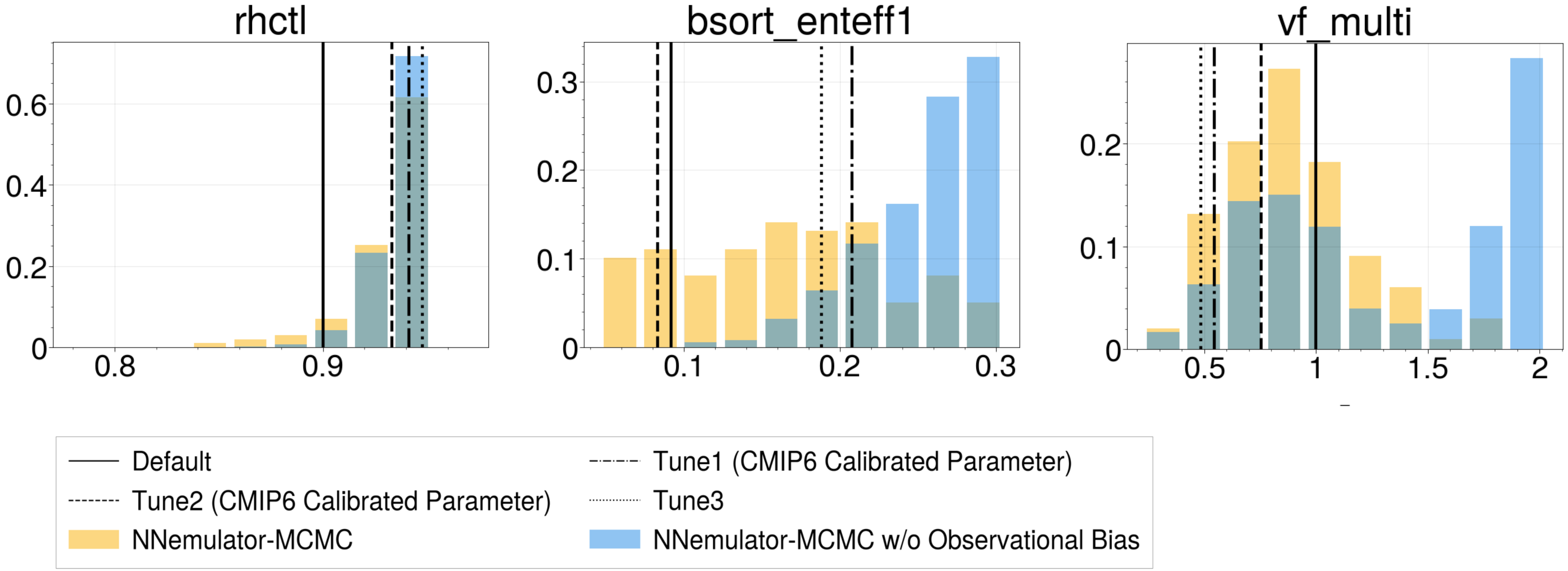
-Suitable parameter combinations possibly **non-existent**. Why?
Structural deficiencies?



Was accounting for obs. product discrepancy important?



PDFs of critical RH (-), entrainment const. (1/km), & ice fall speed multiplier (-)



Sensitivity to obs. product discrepancy is important…

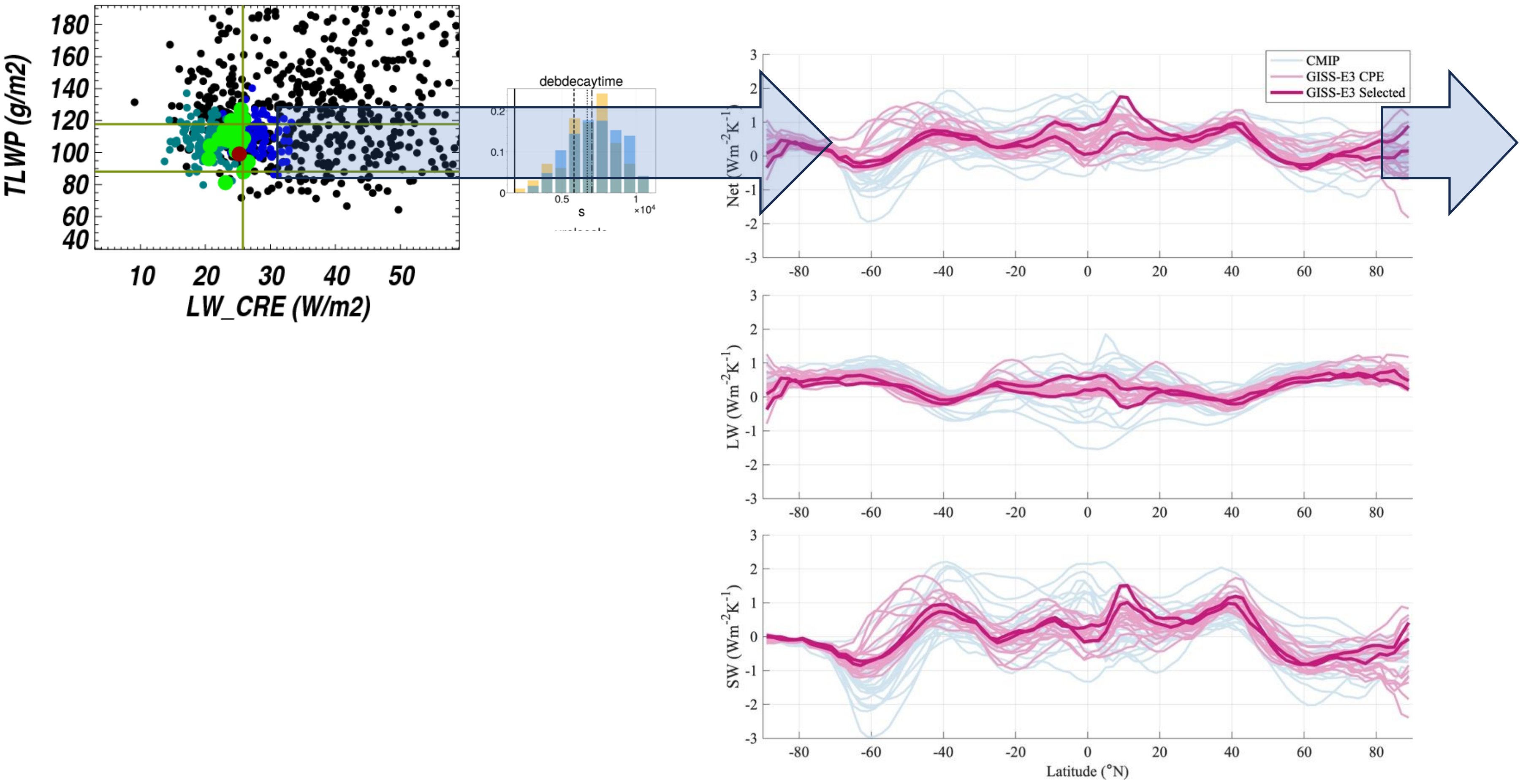
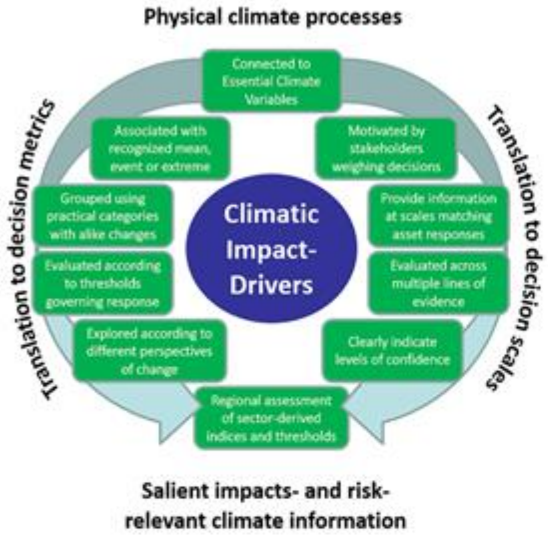


Figure From Greg Cesana

Uncertainty envelope of
- -Projections
- -Extremes
- -Climate Impact Drivers.



Ruane et al. 2022, *Earth's Future*

Sensitivity to obs. product discrepancy is important…

…and with the surrogate model (or emulator) being able to simulate a diverse selection of model outputs (spanning water and energy cycle diagnostics), we can add new hypothetical observations (and their uncertainties), run the CPE process, and see impact on parameters & outputs.

We might call this a Climate Observing System Simulation Experiment, or Climate OSSE.

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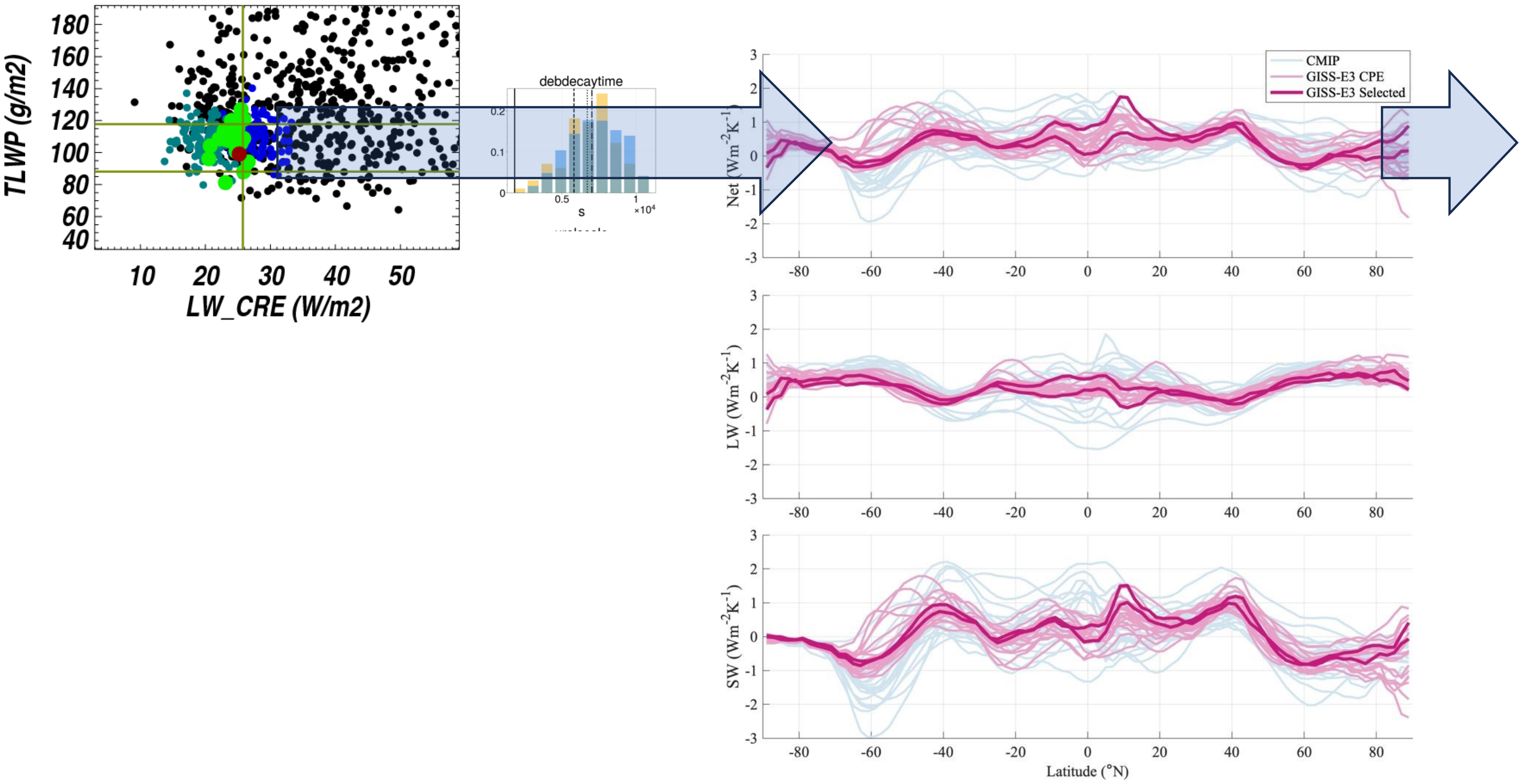

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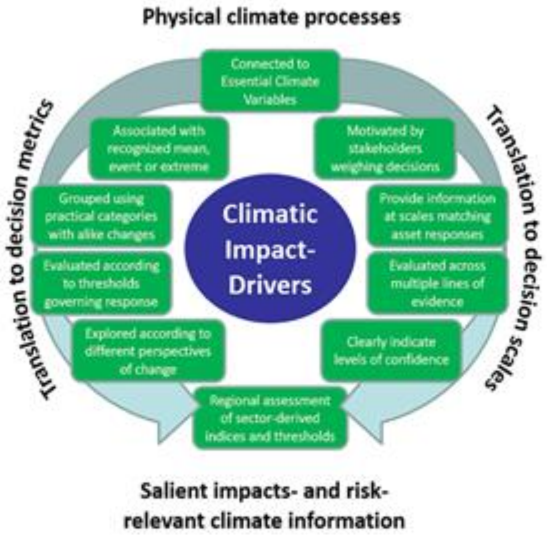

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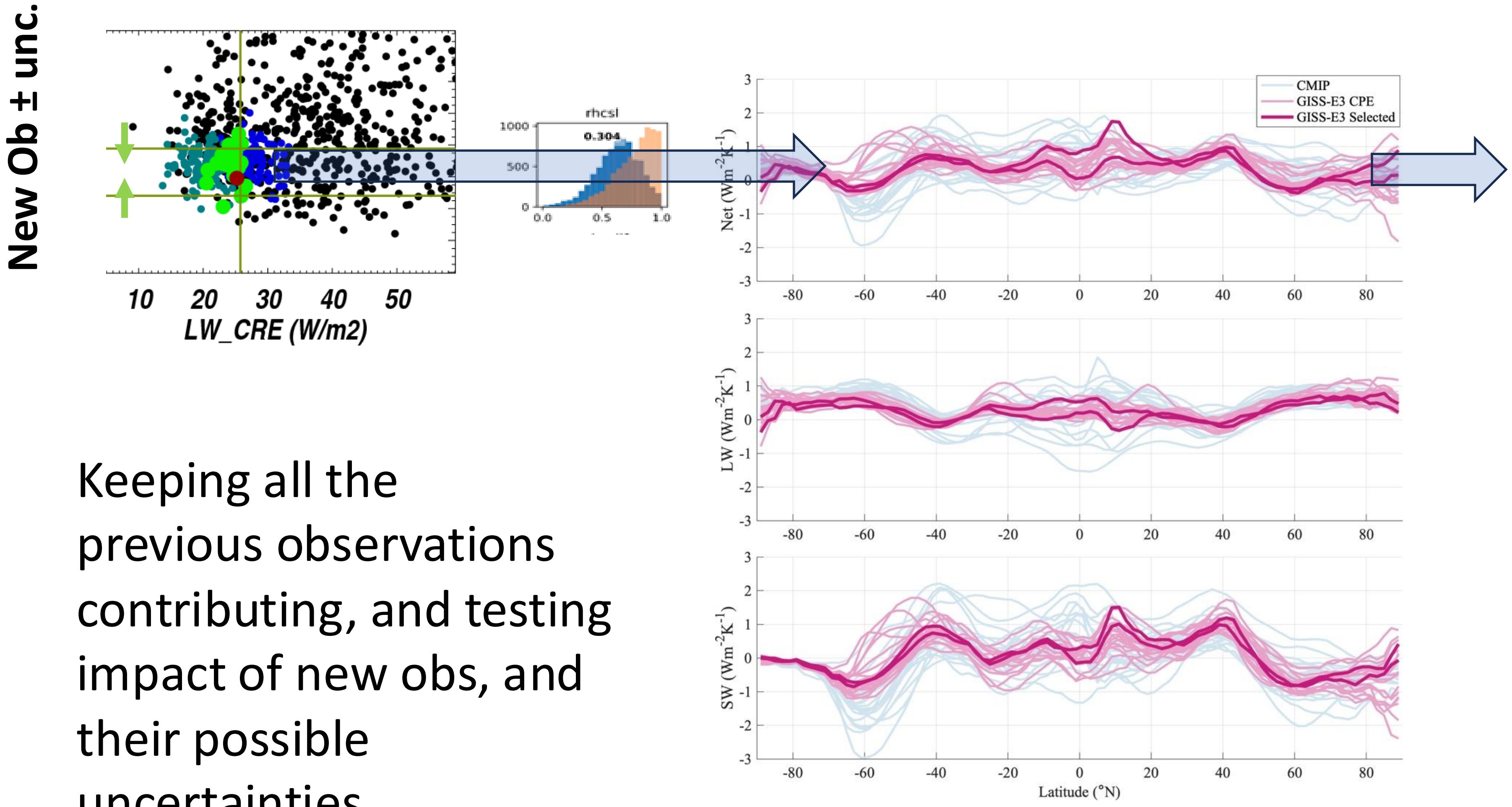

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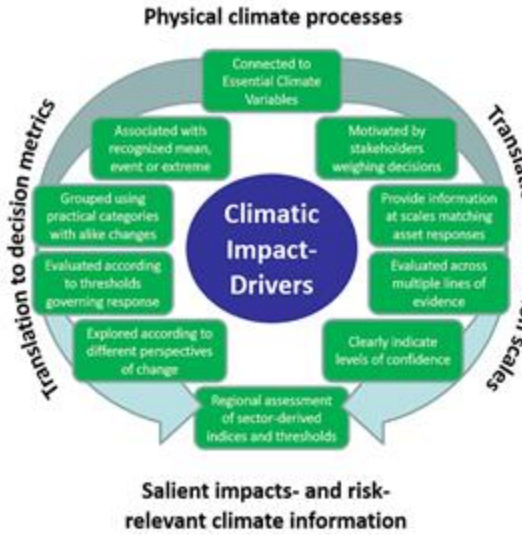

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Keeping all the previous observations contributing, and testing impact of new obs, and their possible uncertainties.

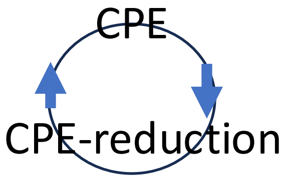
Conclusions

Elsaesser et al. (2024)

- A calibrated physics ensemble (or CPE) is useful for assessing sensitivities under the constraint that mean states look more like Earth (different from most PPE designs). *Observational uncertainty favors lots of members*. *We need to convey this message*.

- “Physics”: plans for accommodating both parameters and spans across structure.

- In between GISS’ (or any modeling center’s) construction of a CPE, their many members can be explored using process level metrics to reduce membership and feedback onto next CPE.



- Even with expanded mean state definition, should design calibration metrics related to variabilities (spatial/temporal) and sensitivities.

- CPE framework nice for serving as a bridge to understand different model projections (do their projection envelopes overlap? What causes them to simultaneously reduce?), and nice for stacking-the-deck in finding members that work in coupled mode.