

Evaluation of Climate Model Top-of-Atmosphere Earth Radiation Budget Changes During and After the Global Warming Hiatus

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IUGG, July 12, 2019, Montreal, QC, Canada

Background/Motivation

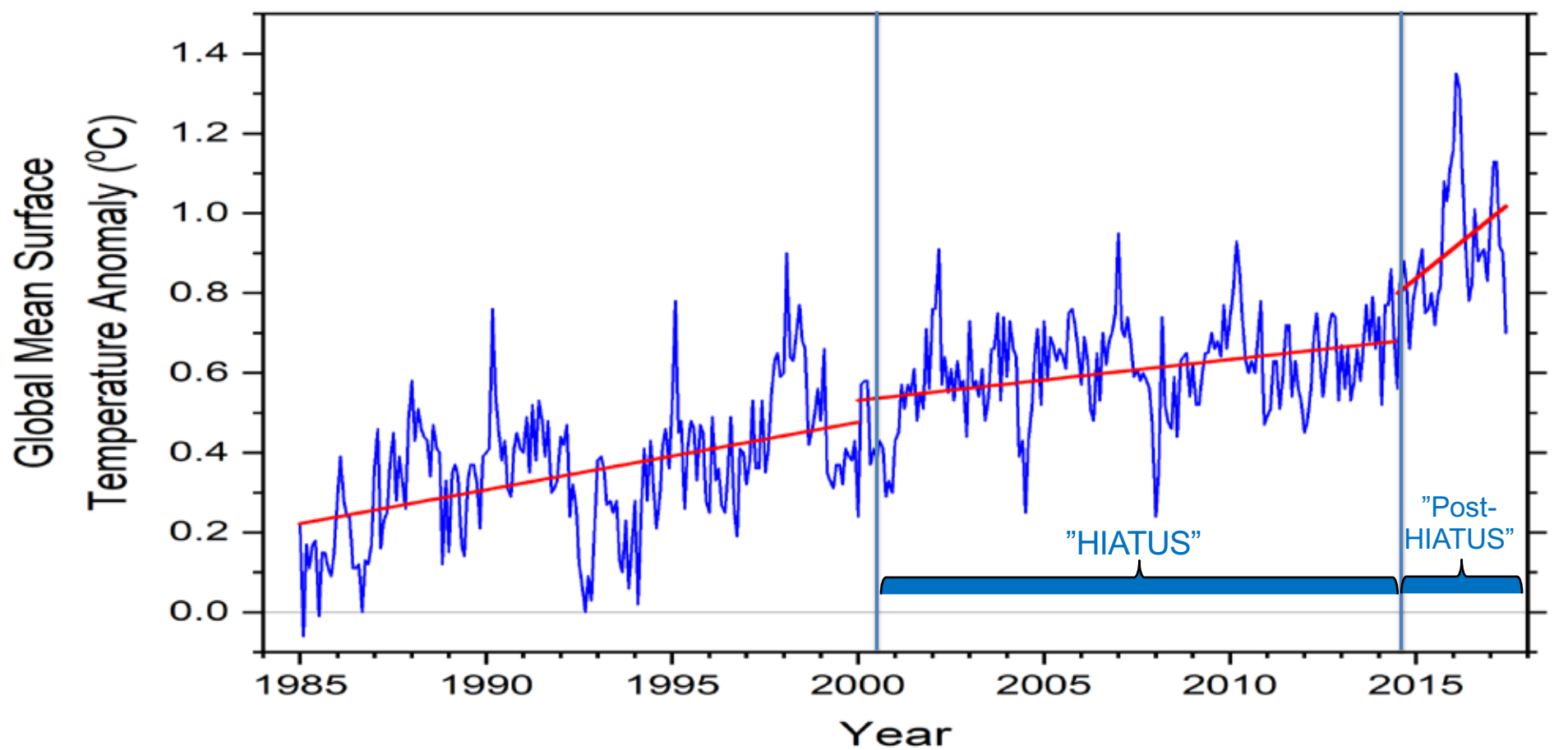
- Global radiative feedback under transient warming is time dependent.
 - Changes in surface warming patterns induce changes in global TOA radiation that are distinct from those associated with global mean surface warming (“Pattern Effect”).
- Recent decades have seen cooling over the eastern tropical Pacific and Southern Oceans while temperatures have risen globally.
- GCMs driven with historical patterns of SST and sea-ice concentrations produce radiative feedbacks that trend toward more stabilizing, implying low climate sensitivity.
- The pattern of future warming is expected to produce radiative feedbacks that are less stabilizing, implying increasing climate sensitivity in the future.

Can we use ERB observations to test model response to SST pattern changes?

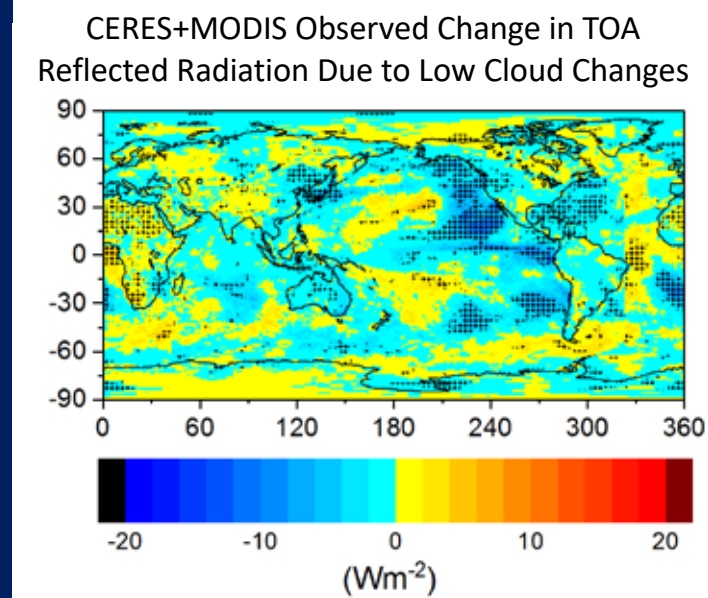
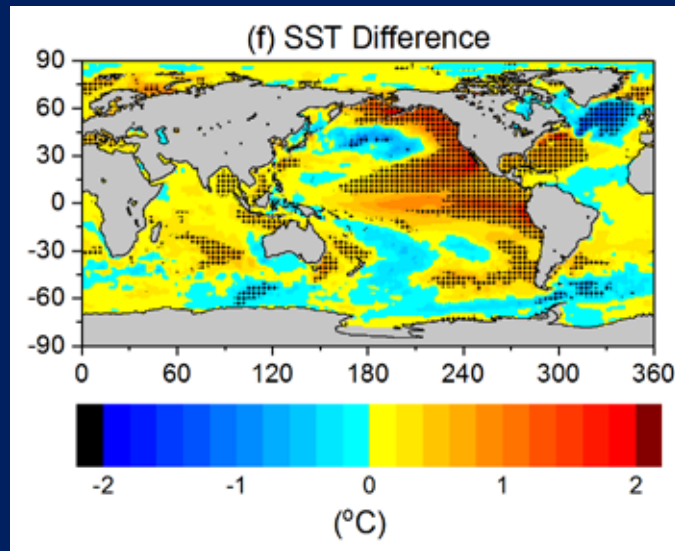
Definition of “Hiatus” and “Post-Hiatus” Periods

Hiatus: 07/2000 – 06/2014

Post-Hiatus: 07/2014 – 06/2017



Post-Hiatus Minus Hiatus SST and Radiative Flux Differences



- Large increase in SST over Eastern Pacific after hiatus produced a pronounced decrease in low cloud cover.
- CERES data quantify the corresponding increase in radiative heating.
- Increased radiative heating further warms the surface – a positive cloud feedback.

Do climate models forced with observed SSTs reproduce these cloud-radiation changes?

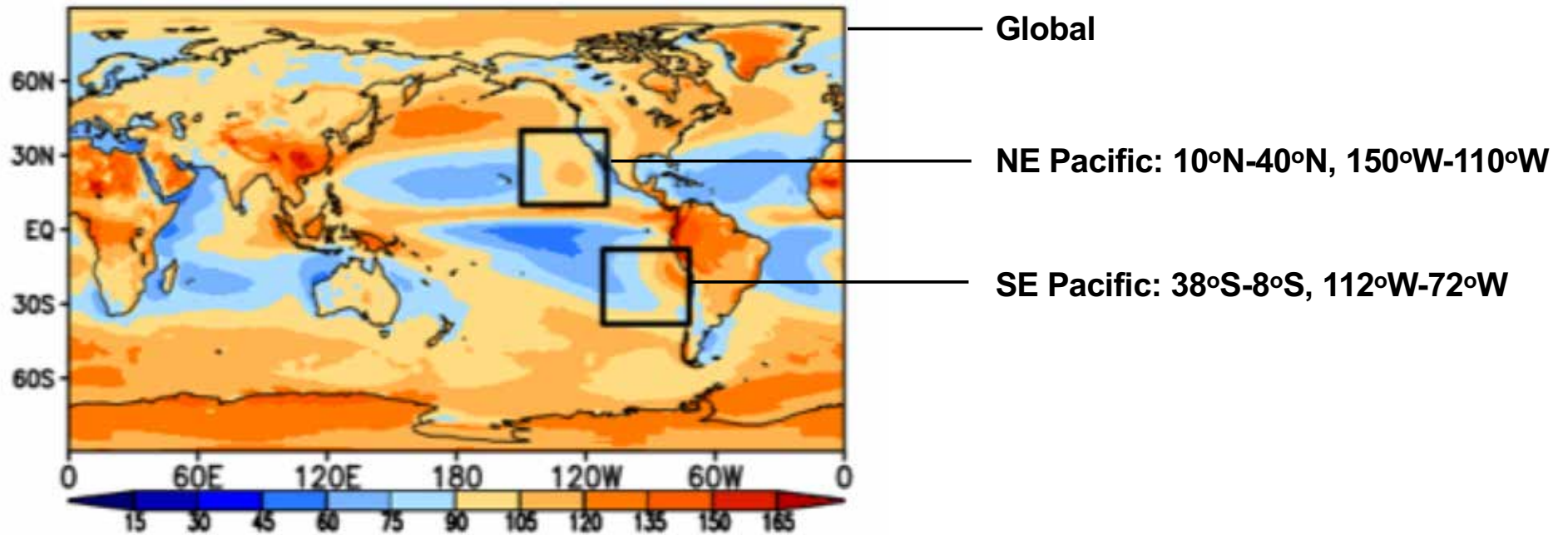
(Loeb et al., 2018)

CERES Observations & CMIP6 AMIP Simulations

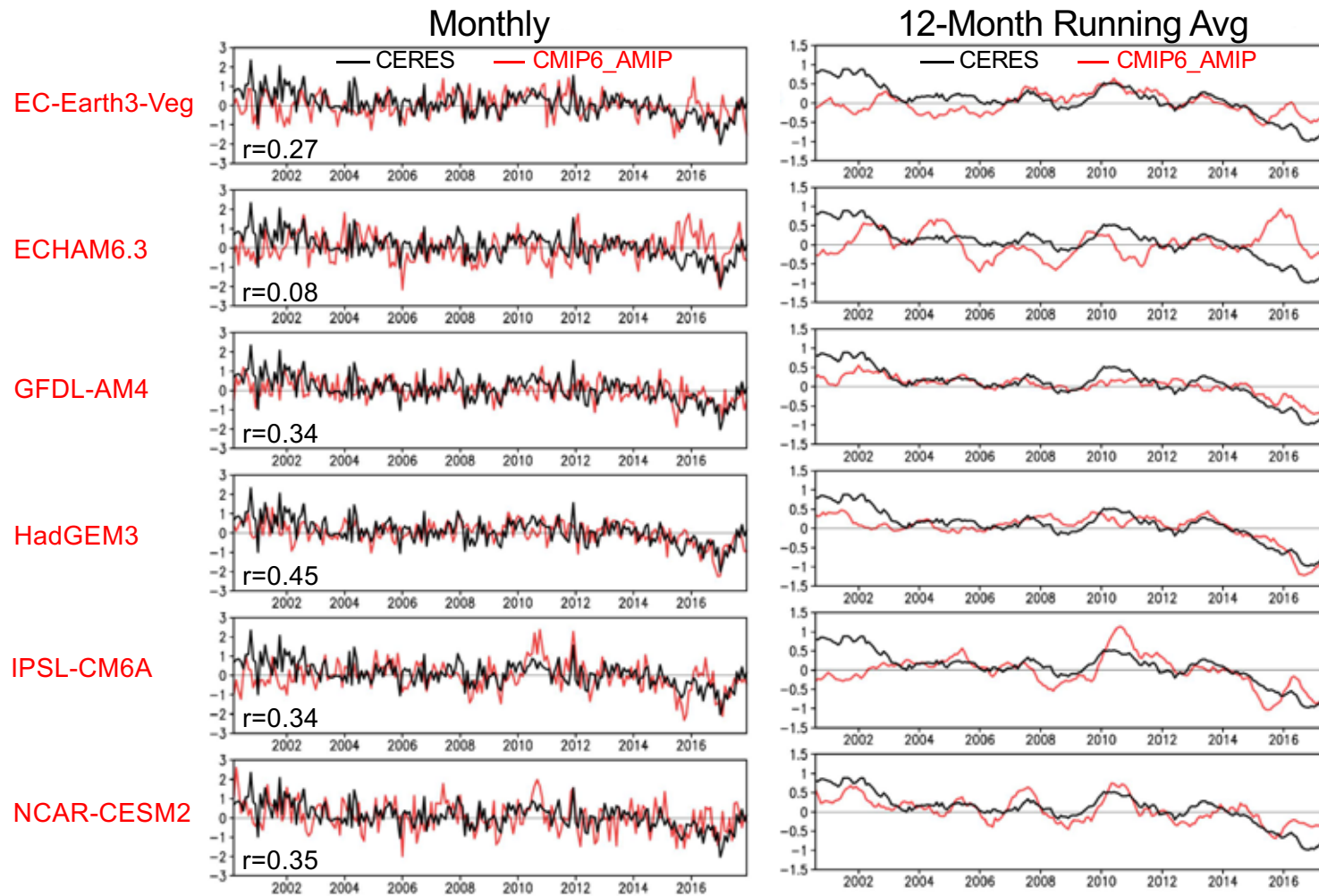
Data	Data_FullName	Country	Resolution (lonxlat)	Variables
CERES	CERES EBAF4.0	USA	1x1	TOA radiative fluxes
	CERES SSF1deg_Ed4 Terra		1x1	Cloud fraction, EIS
ERA5	ERA5	Europe/EC	0.25x0.25	Ts
EC-Earth3-Veg	EC-Earth3-Veg AMIP	Europe/EC	0.7x0.7	All variables
ECHAM6.3	echam6.3.05-LR AMIP	Germany	1.875x1.86	All variables
GFDL-AM4	GFDL-AM4 AMIP	USA	1.25x1.0	All variables
HadGEM3	HadGEM3-GC31-LL AMIP	UK	1.875x1.25	All variables
IPSL-CM6A	IPSL-CM6A-LR AMIP	France	2.5x1.27	All variables
NCAR-CESM2	NCAR-CESM2 AMIP	USA	1.25x0.94	All variables

- Official CMIP6 AMIP simulations end in 2014.
- We extended the simulations through 2017. Radiative forcings were time varying through 2014 and held fixed at 2014 levels between 2014-2017.
- All AMIP simulation output are spatially interpolated onto CERES 1°x1° grid for the comparison.

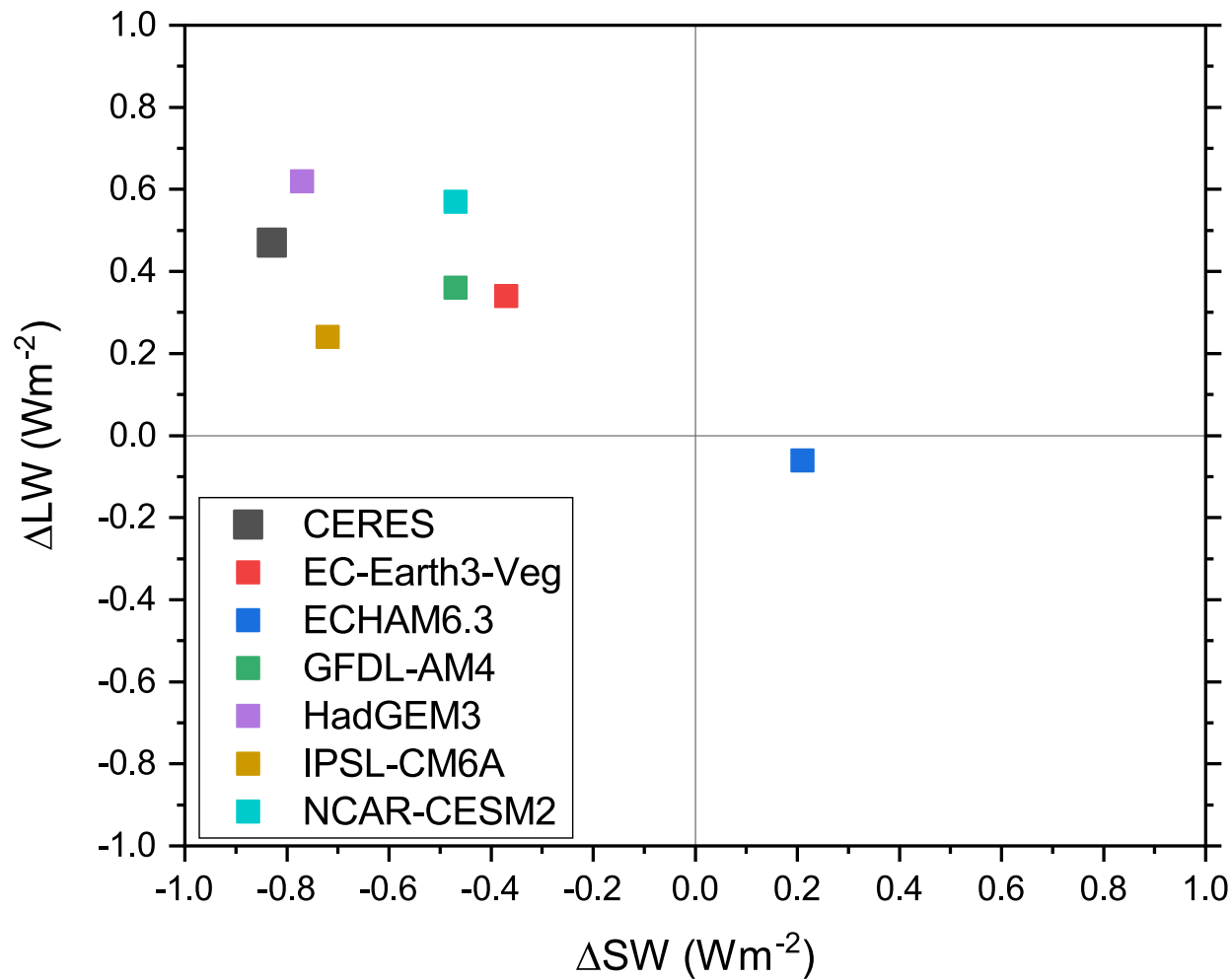
Analysis Domains



Deseasonalized Anomalies in SW TOA Flux: Global

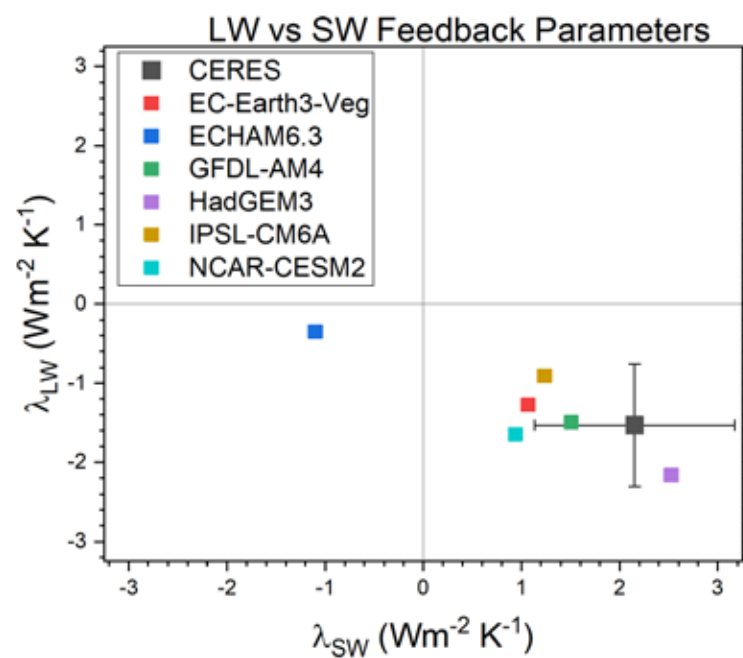
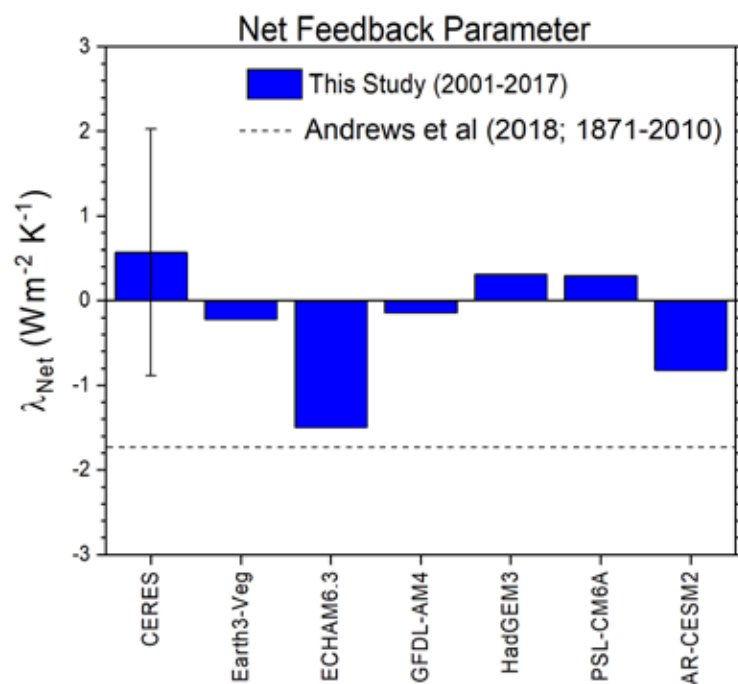


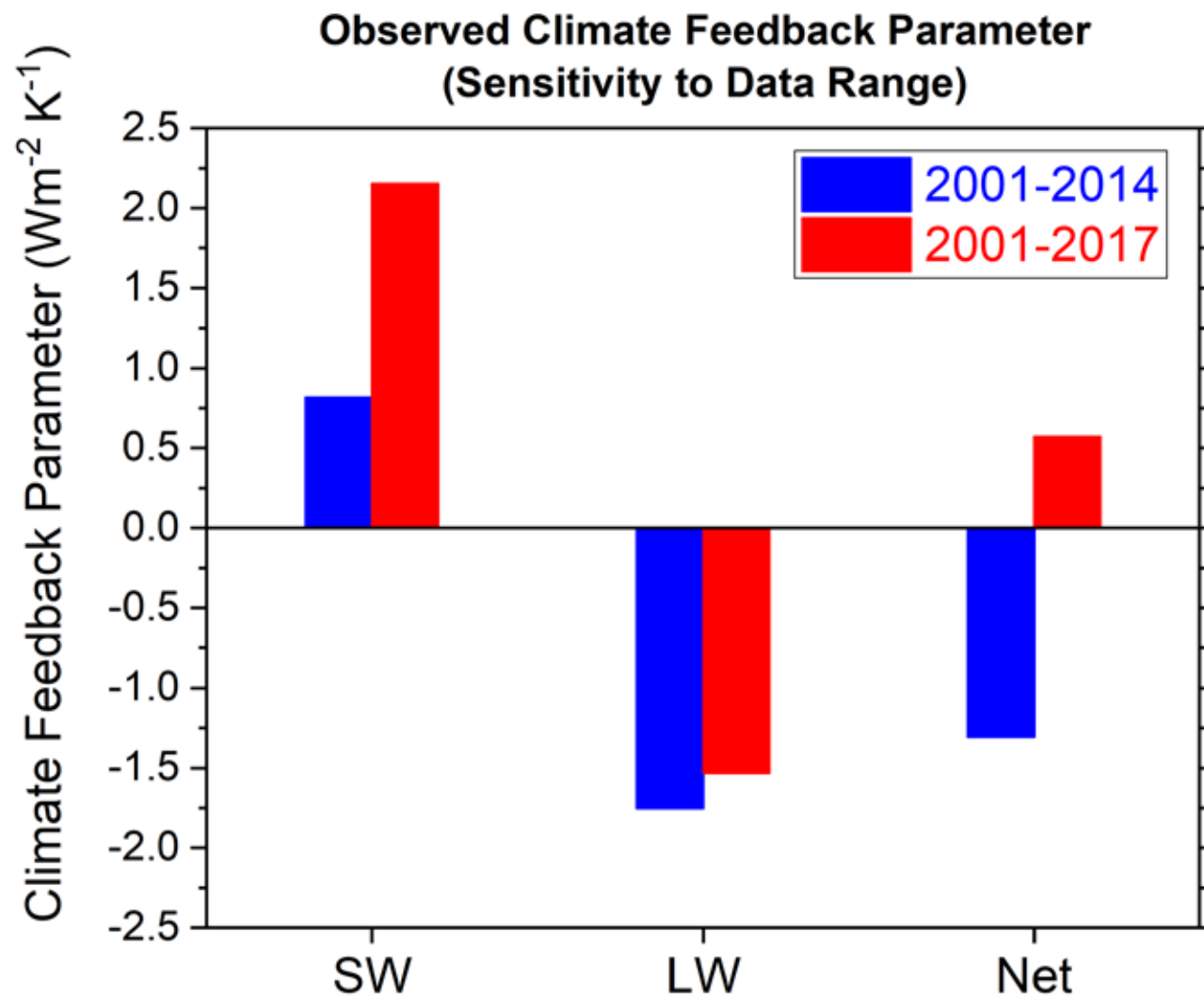
LW vs SW Post-Hiatus –Hiatus Difference (Global)



- Observations: Magnitude of SW diff. is 75% larger than LW diff.
- All models but one show SW decrease & LW increase, consistent with obs.
- Model spread in difference is 45% larger in SW than LW.
- All models underestimate the SW diff.

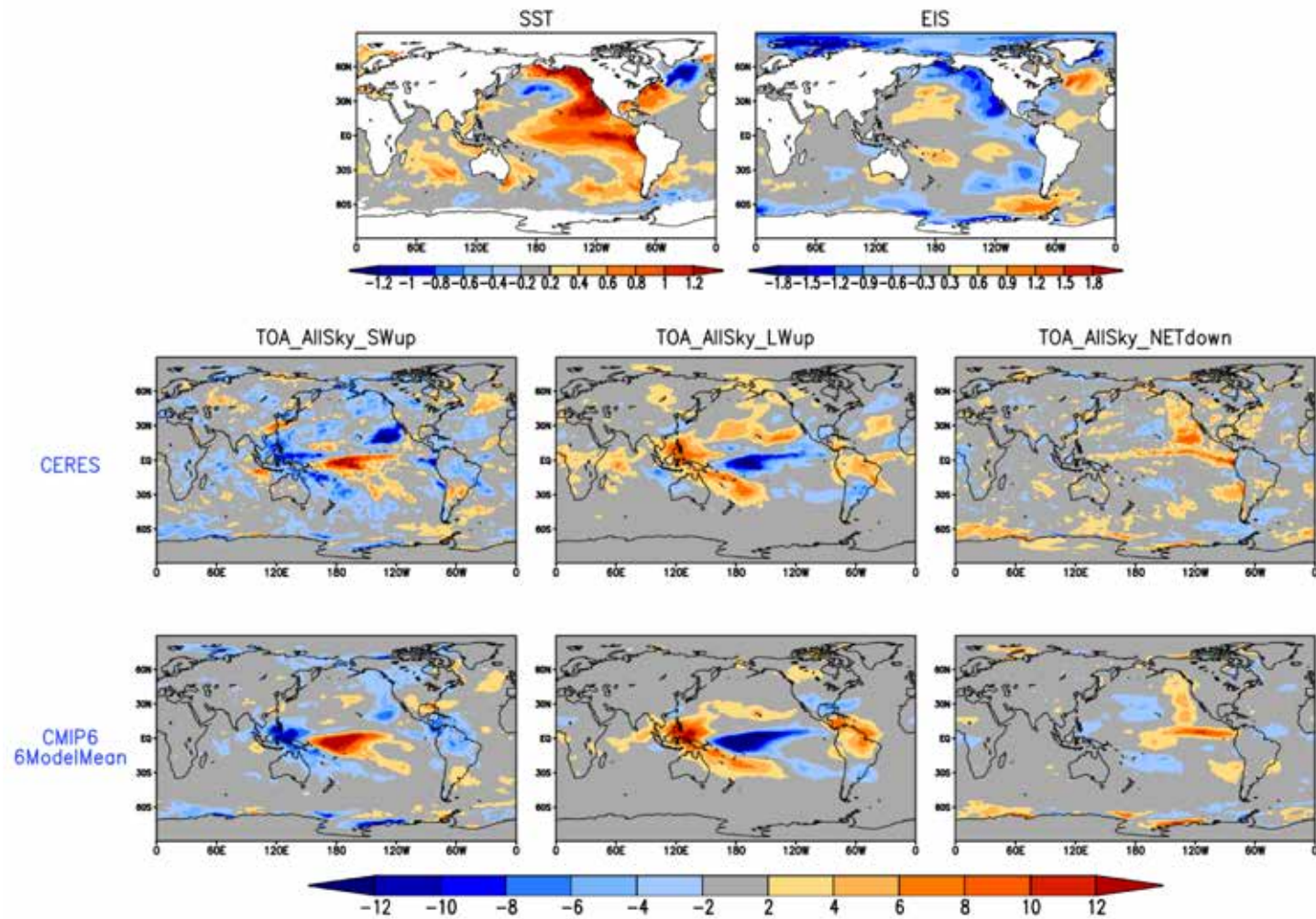
Observed & Model Feedback Parameters





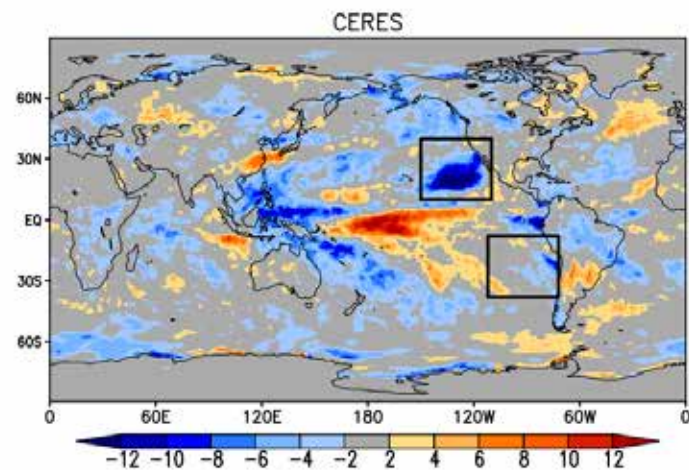
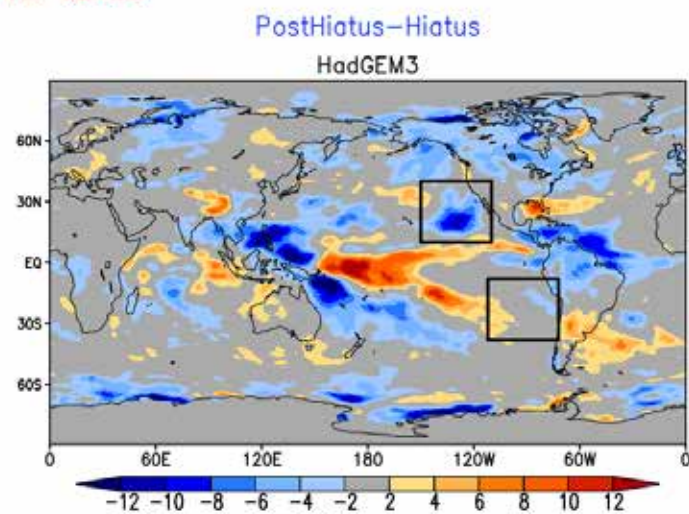
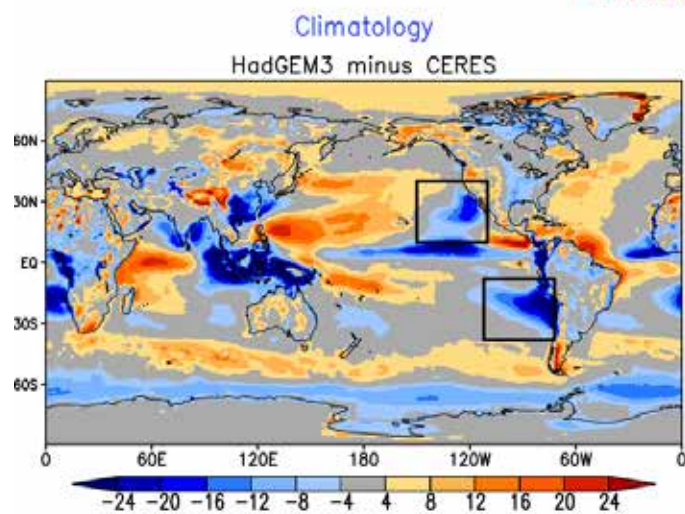
- SW response during post-hiatus period cause net climate feedback parameter to become positive.

Post-Hiatus minus Hiatus Differences



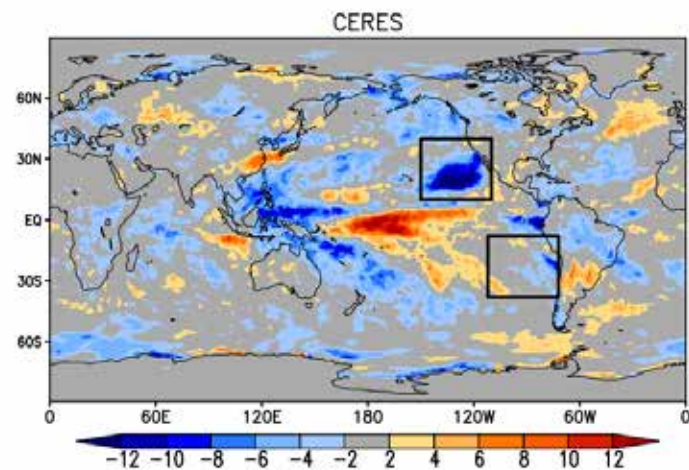
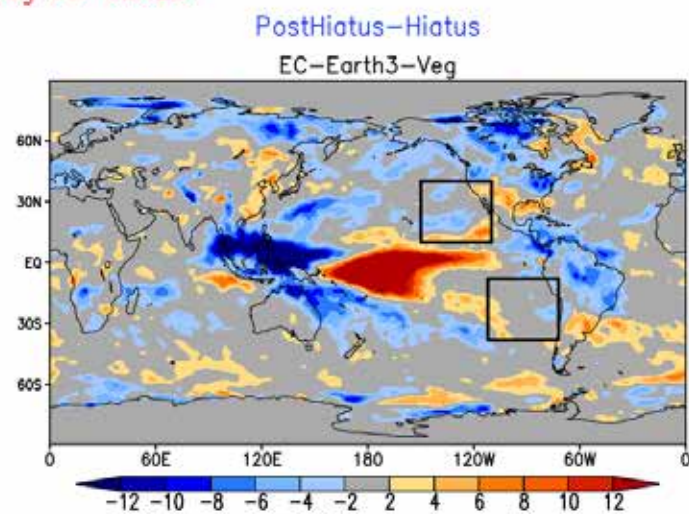
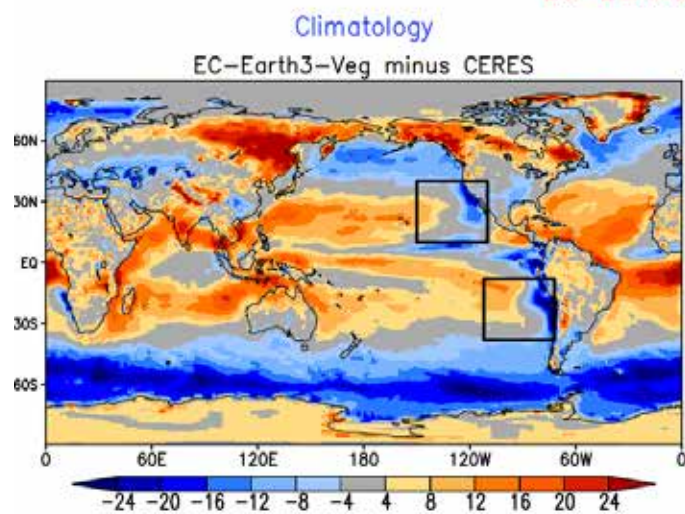
TOA SW Up Flux Comparisons

HadGEM3 vs. CERES

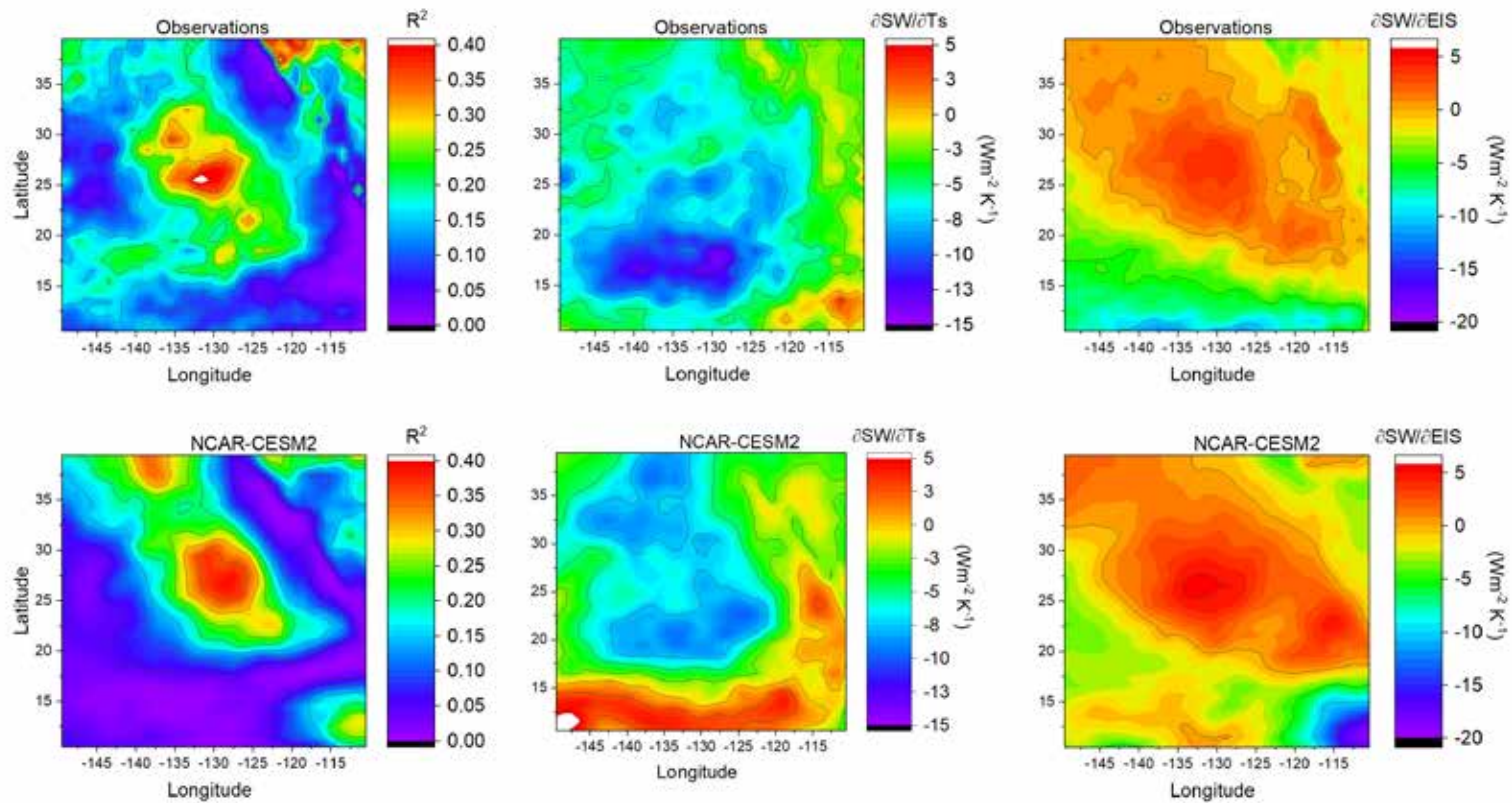


TOA SW Up Flux Comparisons

EC-Earth3-Veg vs. CERES

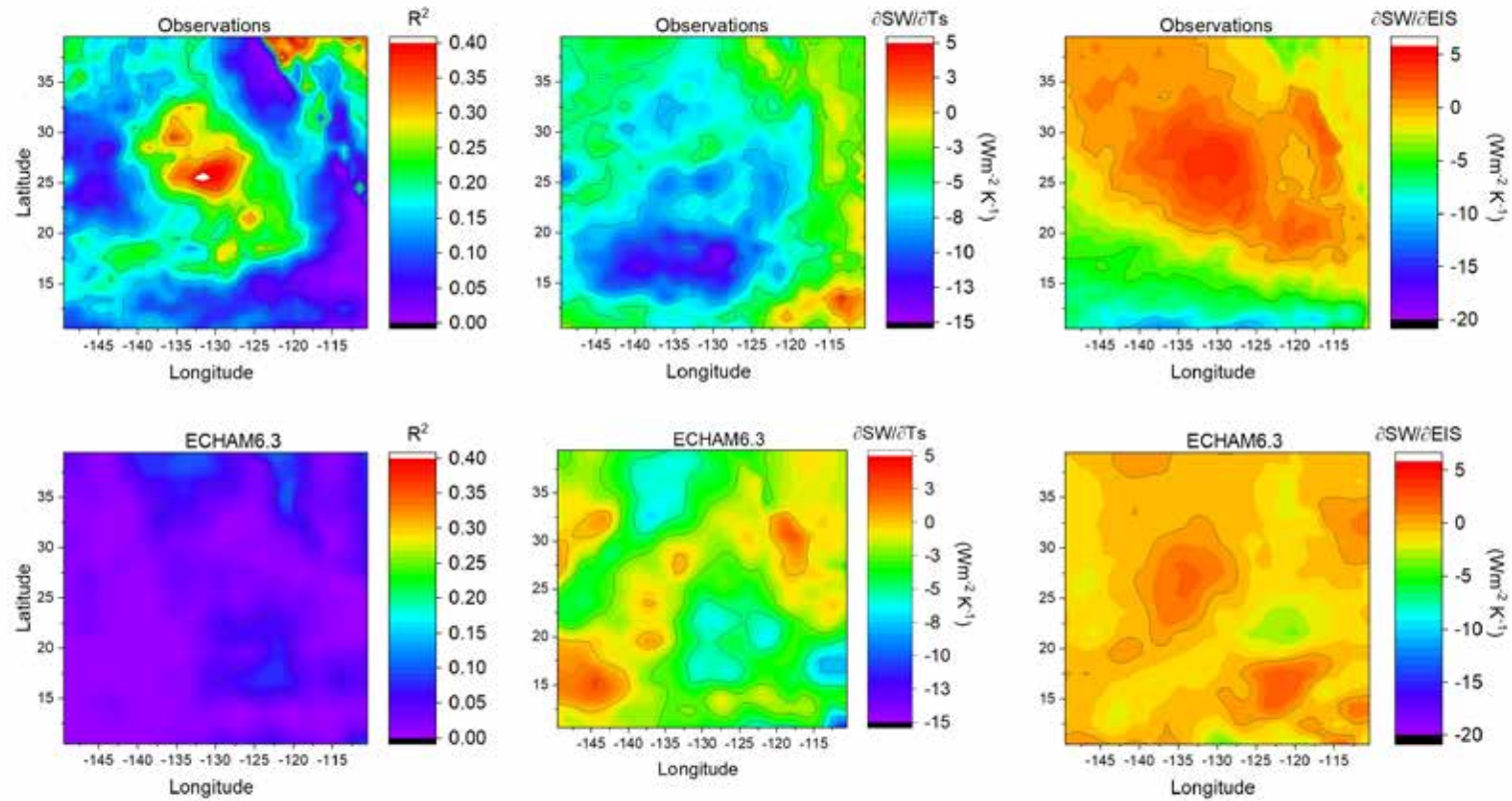


Multi-Linear Regression Analysis: Observations & NCAR-CESM2 (NE Pacific Region; $\delta SW = (\partial SW/\partial T_s)\delta T_s + (\partial SW/\partial EIS)\delta EIS$)



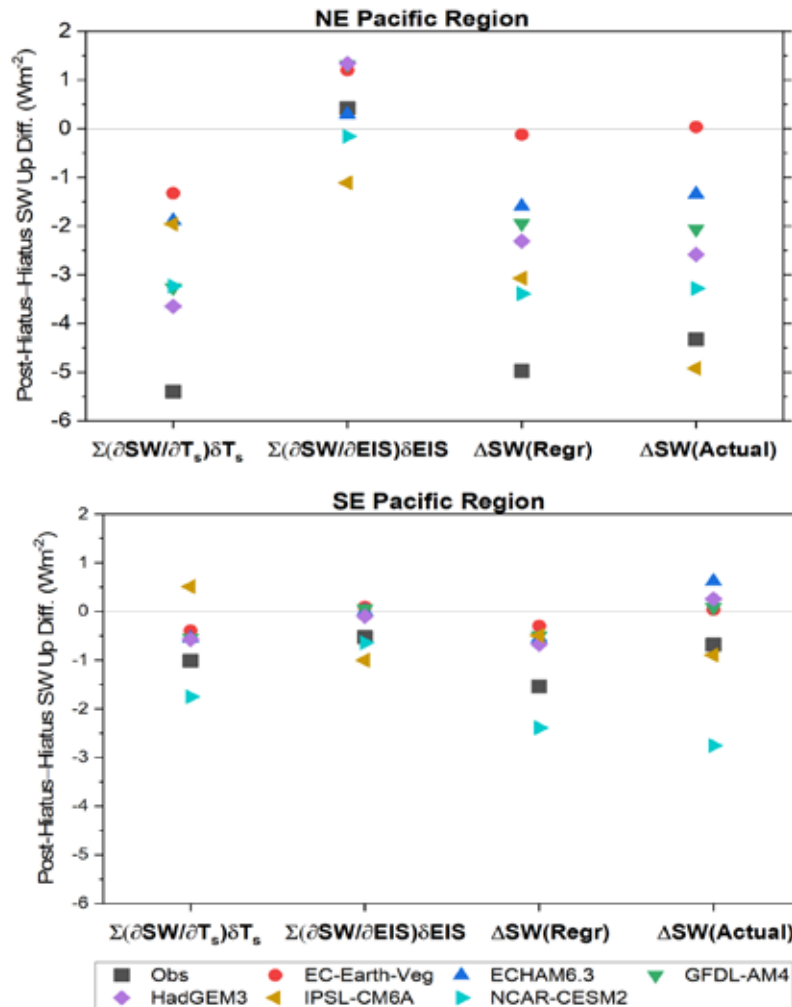
Multi-Linear Regression Analysis: Observations & ECHAM6.3

(NE Pacific Region; $\delta SW = (\partial SW / \partial T_s) \delta T_s + (\partial SW / \partial EIS) \delta EIS$)



Multi-Linear Regression Analysis: Post-Hiatus–Hiatus SW Domain Avg Diff

$$[\Delta SW(\text{regr}) = \Sigma(\partial SW/\partial T_s)\delta T_s + \Sigma(\partial SW/\partial EIS)\delta EIS]$$



- $\partial SW/\partial T_s$ and $\partial SW/\partial EIS$ derived from MLRA using monthly anomalies in each 1° gridbox.
- δT_s & δEIS are gridbox post-hiatus–hiatus diffs.

NE Pacific:

- MLRA is good approximation to ΔSW in obs and most models (except IPSL).
- Most of the ΔSW response is associated with ΔT_s contribution.
- All models underestimate the ΔT_s contribution.

SE Pacific:

- Much weaker ΔT_s contrib.

Conclusions

- ERB observations provide key data for testing model representation of both mean climatology and climate system response to SST pattern changes (e.g., hiatus vs post-hiatus periods).
- There is not an obvious correlation between model bias in climatology and model bias in response to SST pattern changes.
- In response to dramatic SST changes following the “hiatus”, GCM-AMIP simulations are generally consistent with observations:
 - Show decrease in reflected SW TOA flux in marine Sc regions, but underestimate the magnitude compared to observations.
 - Both models and observations show a less stabilizing climate feedback parameter compared to published values for 1871-2010 (Andrews et al, 2018), especially when post-hiatus period is included.
- Multilinear regression analysis of SW response in terms of T_s and EIS is a good approximation in marine Sc regions, with the T_s contribution dominating.
 - All models significantly underestimate the T_s contribution.