Using CERES Observations to Assess CMIP6 Climate Model Simulations of Changes in Earth's Radiation Budget During and After the Global Warming "Hiatus"

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CERES Science Team Meeting, October 31, 2019, Berkeley, CA

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”).

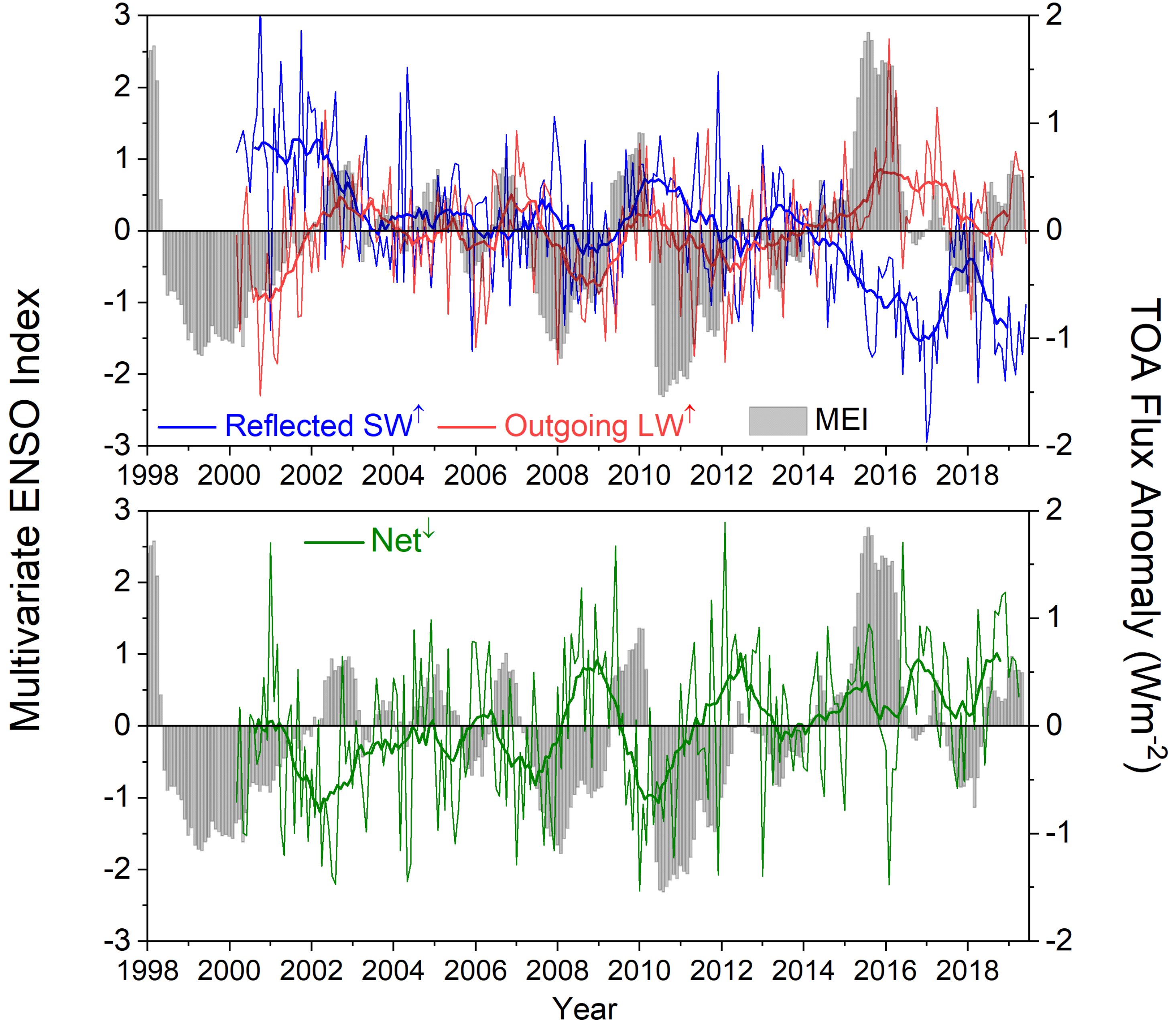
- Recent decades have seen cooling over the eastern tropical Pacific and Southern Oceans while temperatures have risen globally.

- 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.

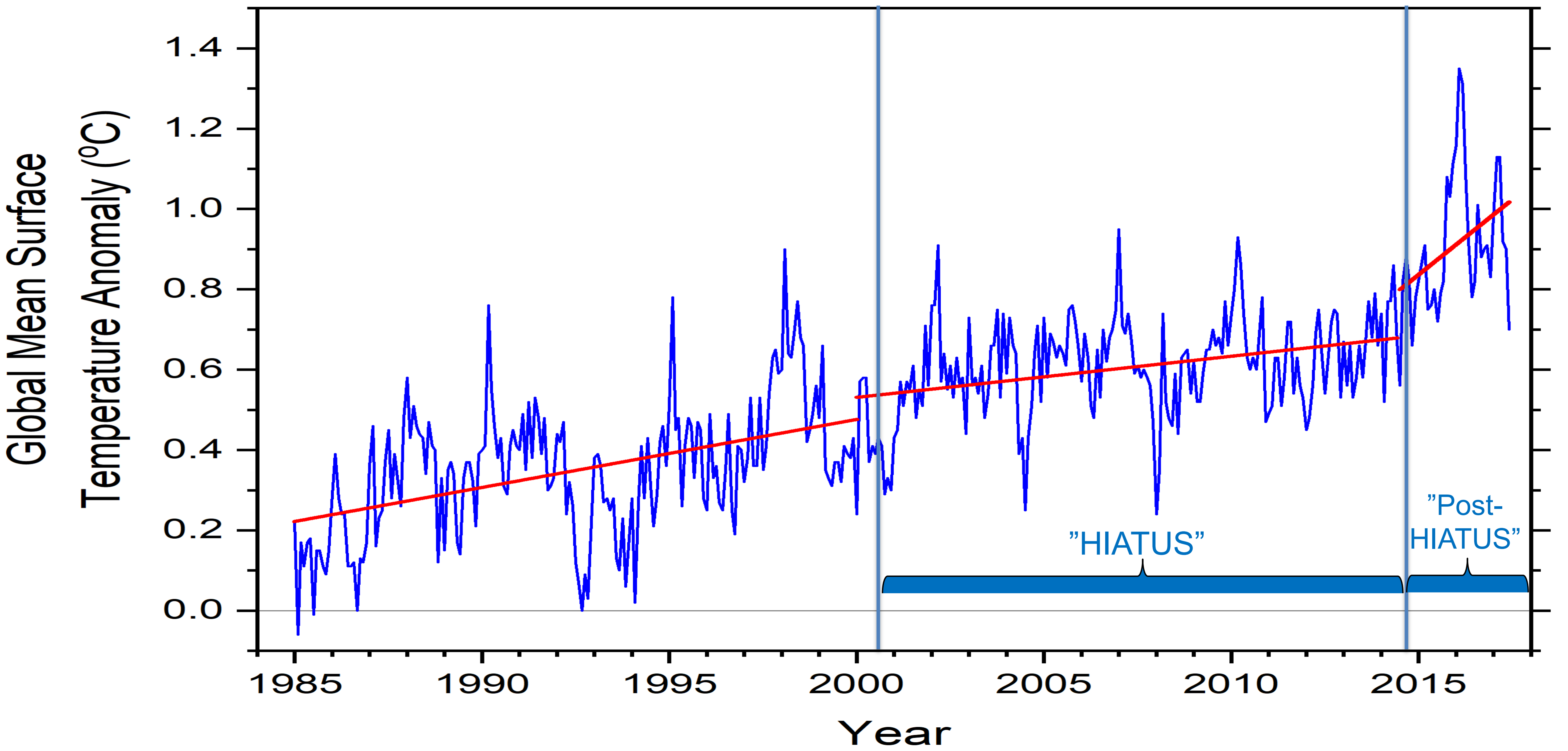
Can we use ERB observations to test model response to SST pattern changes?

Global Mean All-Sky TOA Flux Anomalies & Multivariate ENSO Index
(CERES EBAF Ed4.1; 03/2000 – 06/2019)

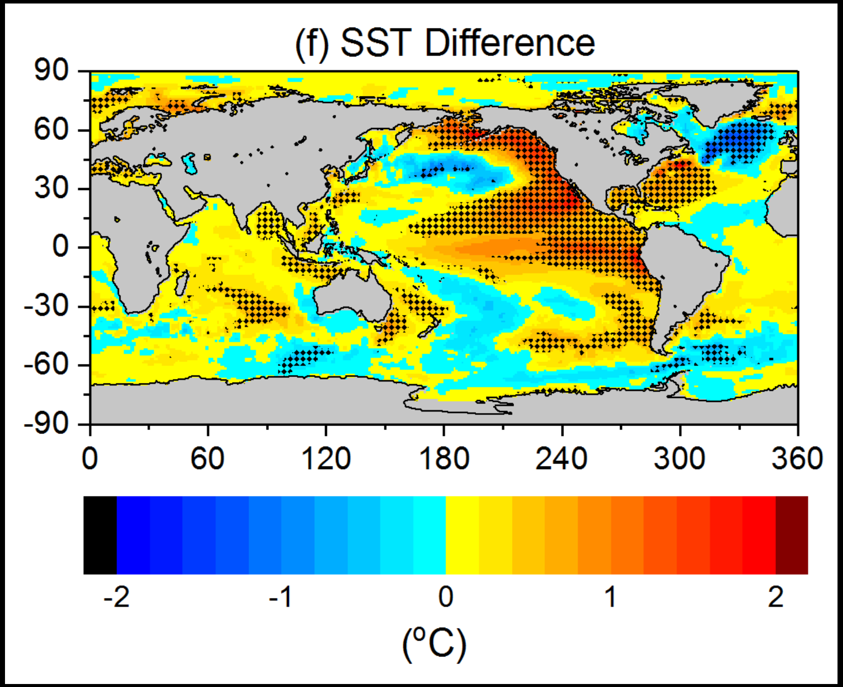


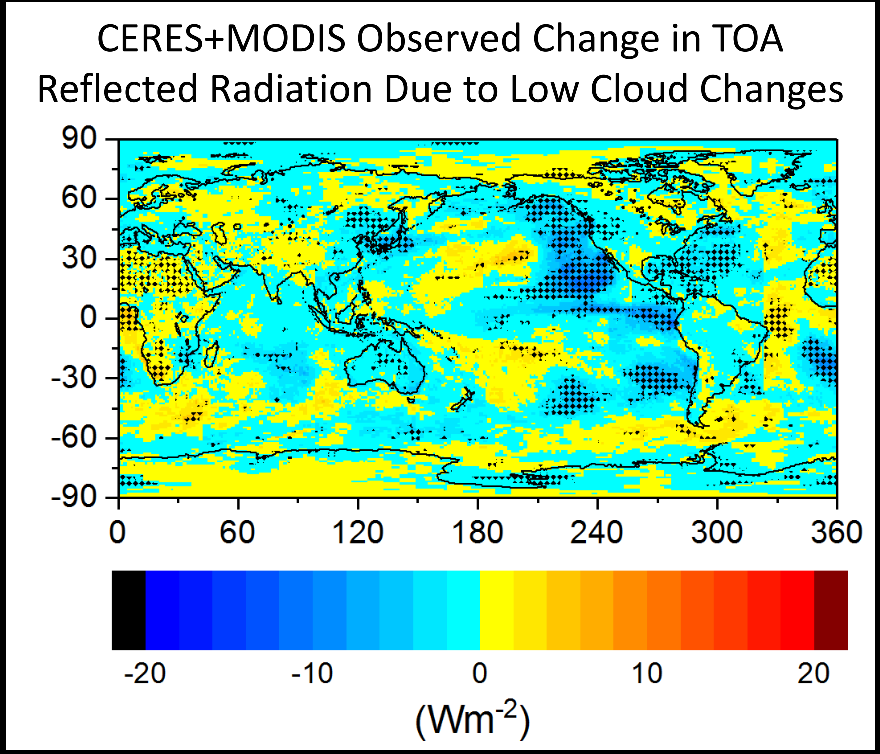
Definition of “Hiatus” and “Post-Hiatus” Periods

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?

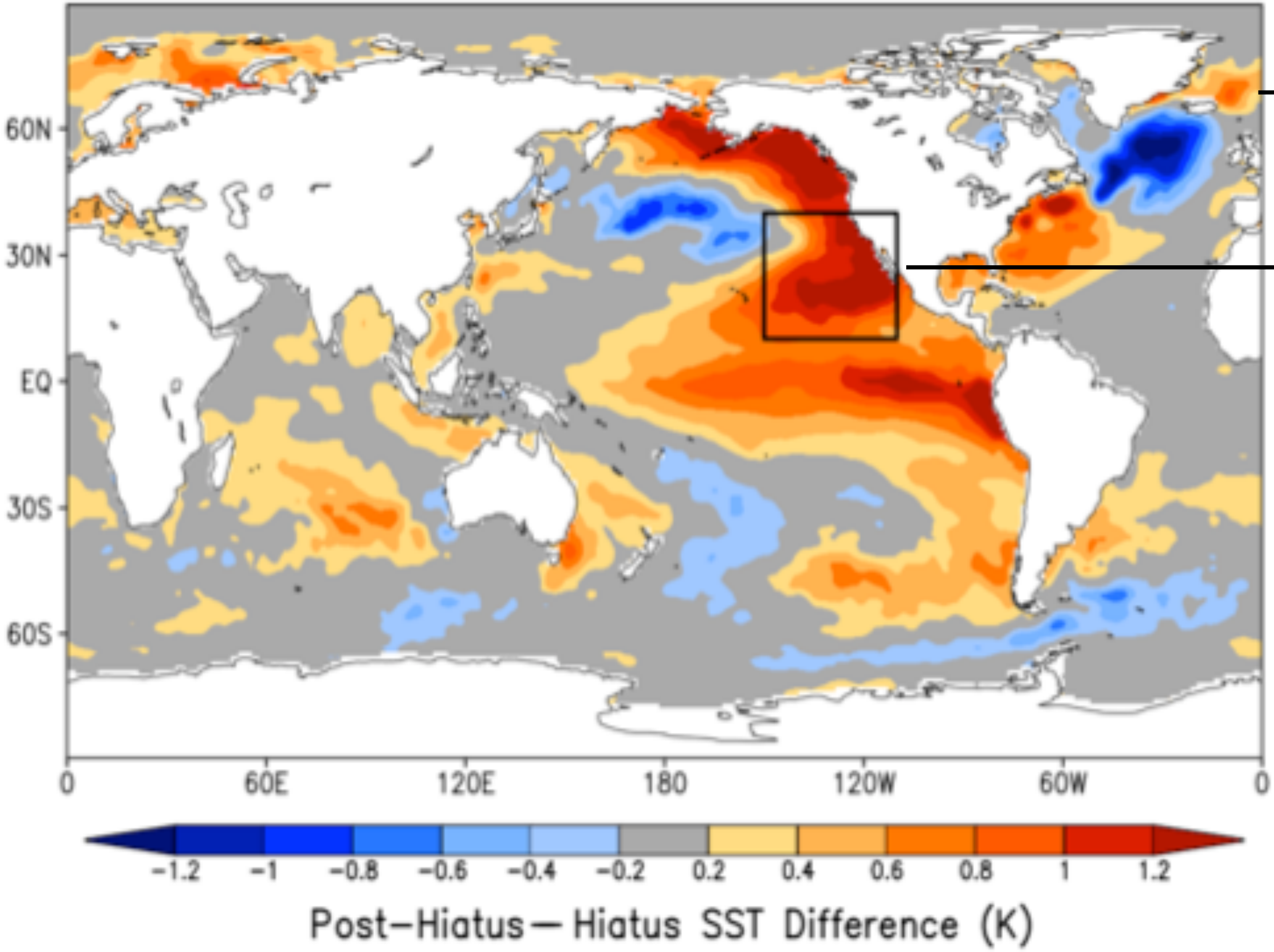
(Loeb et al., 2018)

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
CESM2	CESM2 AMIP	USA	1.25x0.94	All variables
CanESM5	CanESM5 AMIP	Canada	2.8x2.8	All variables
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

- 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.

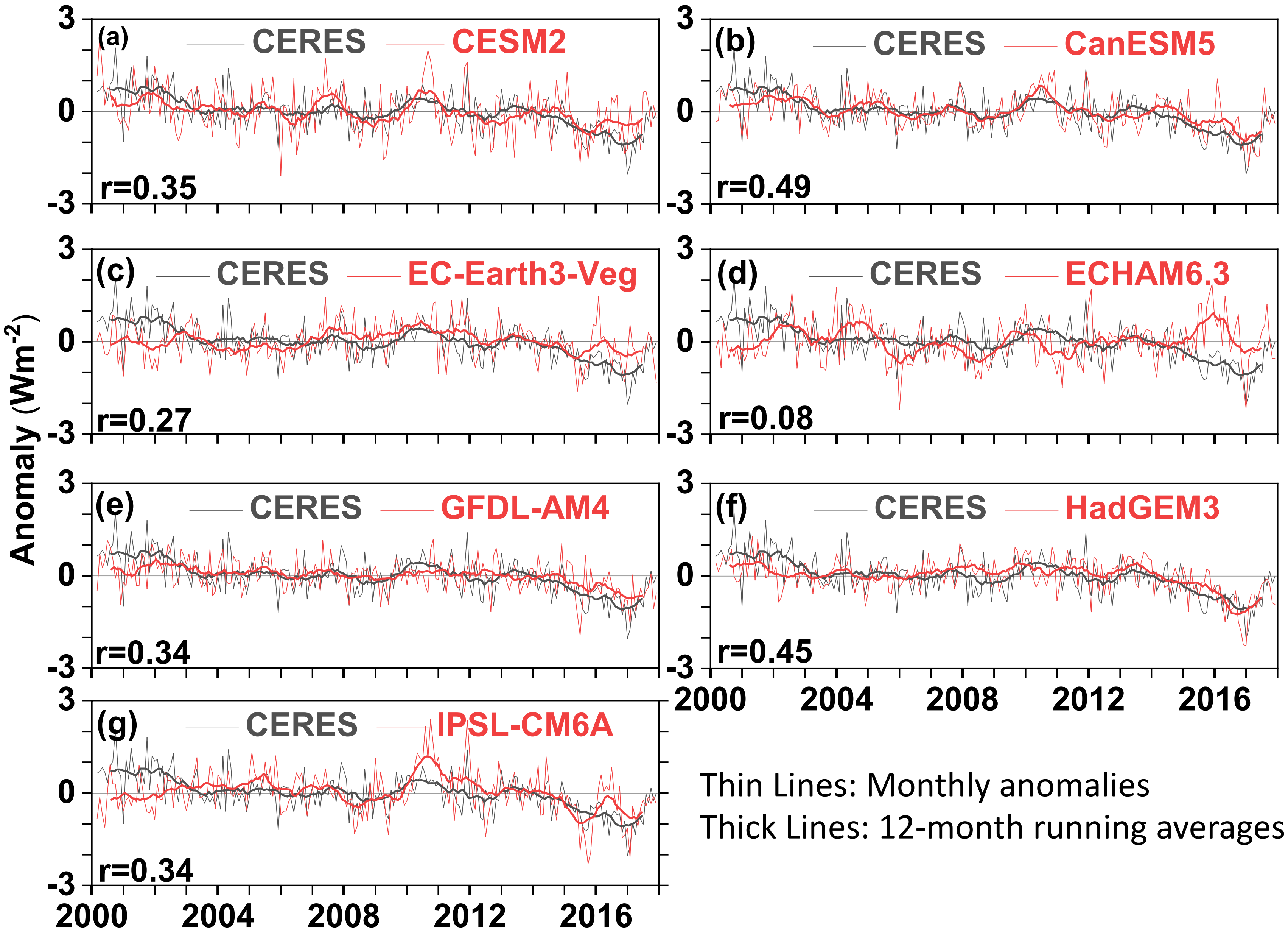
Analysis Domains



Global

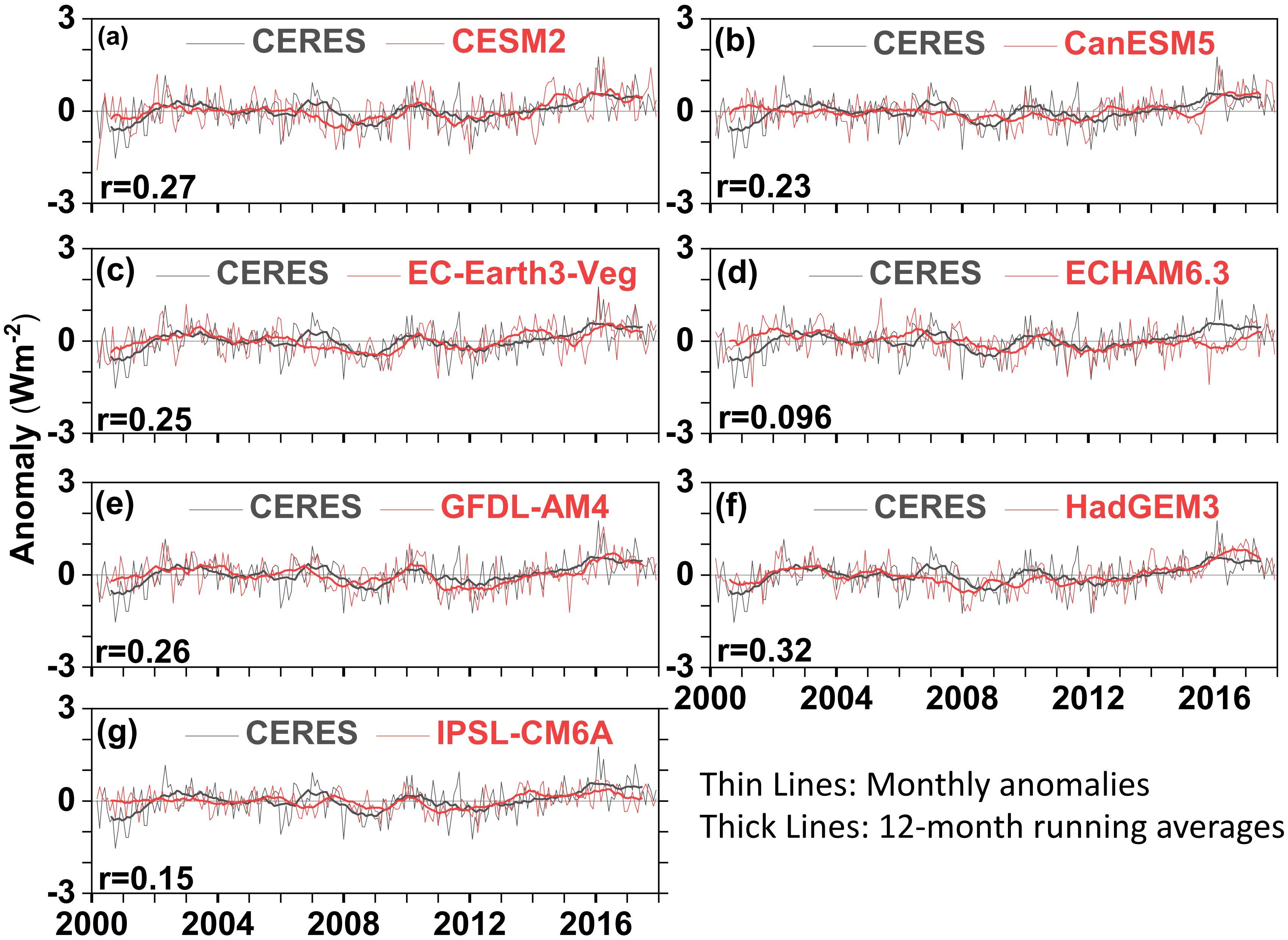
E Pacific: 10°N-40°N, 150°W-110°W

Deseasonalized Anomalies in TOA SW Upwards Flux: Global



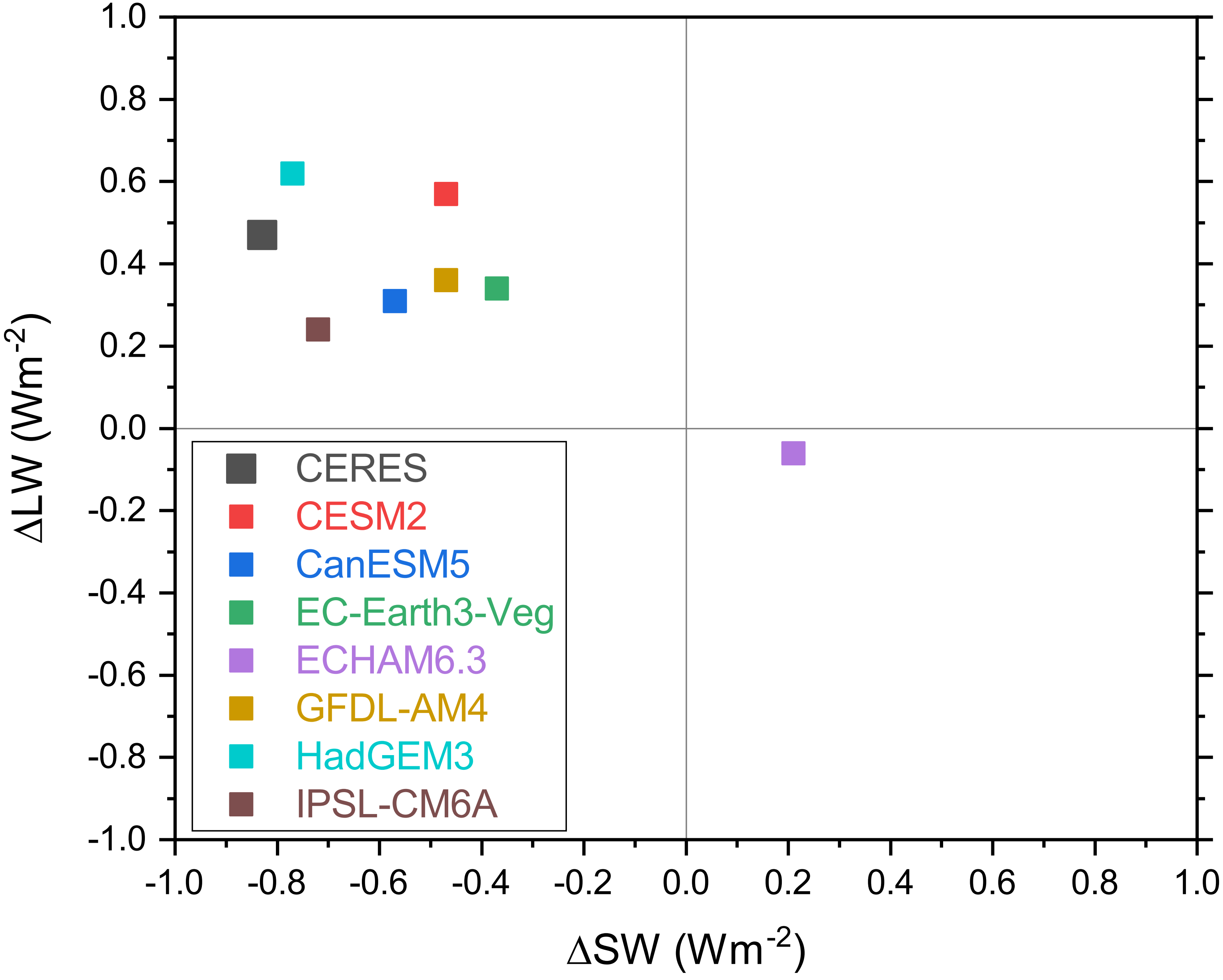
Thin Lines: Monthly anomalies
Thick Lines: 12-month running averages

Deseasonalized Anomalies in TOA LW Upwards Flux: Global

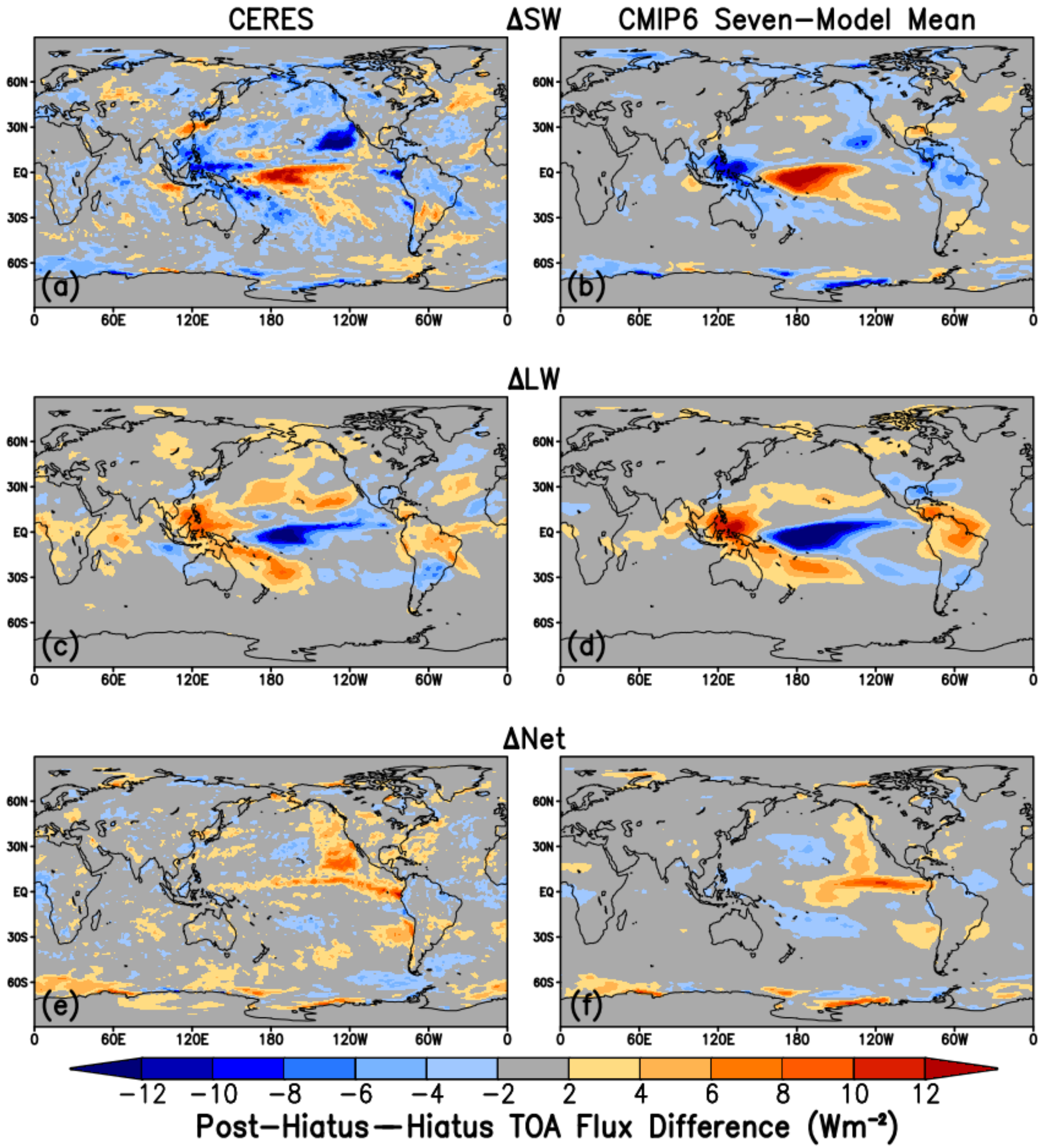


Thin Lines: Monthly anomalies
Thick Lines: 12-month running averages

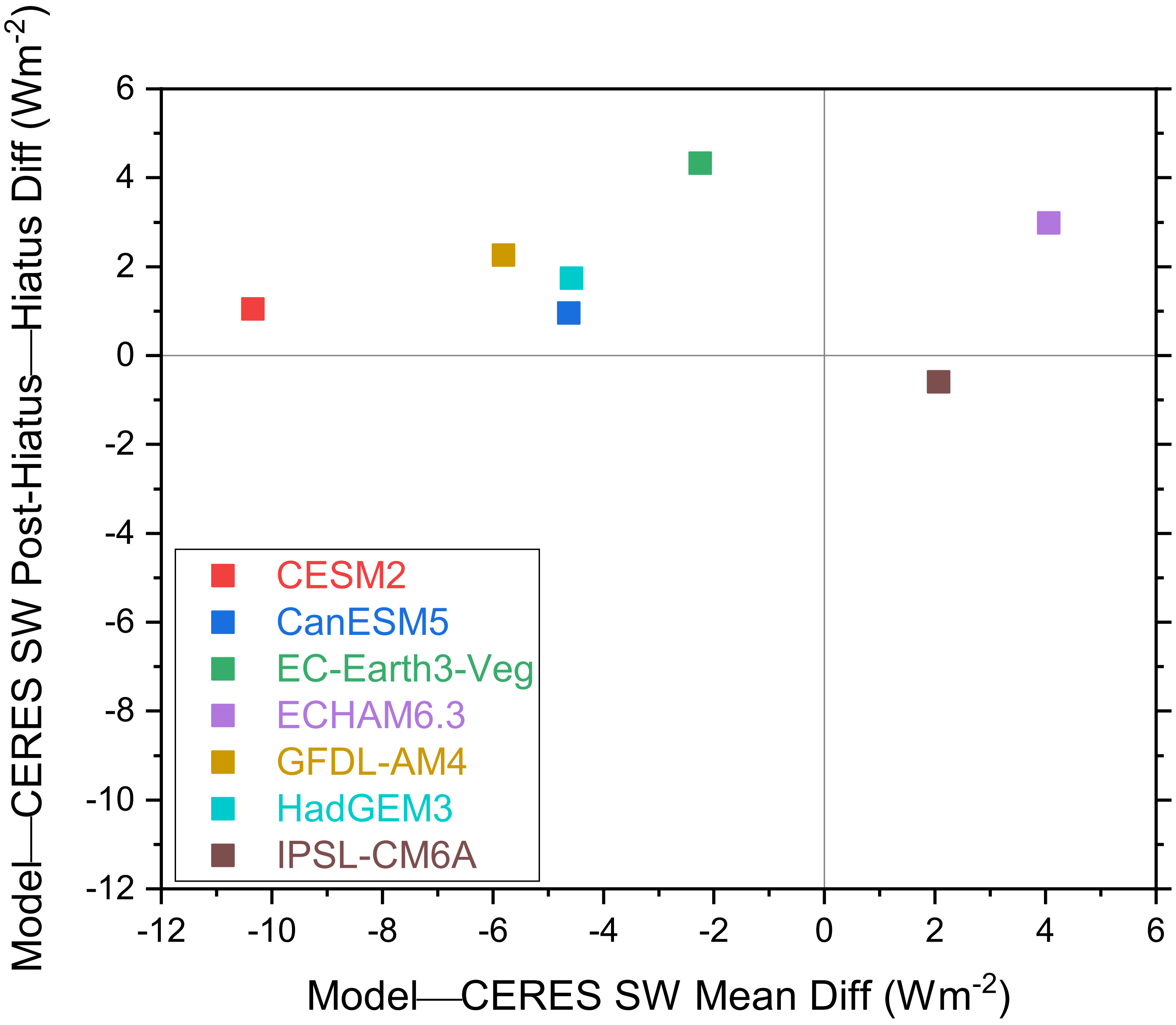
LW vs SW Post-Hiatus –Hiatus Difference (Global)



- 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.


CERES
ΔSW
CMIP6 Seven-Model Mean
ΔLW
ΔNet
(a)
(b)
(c)
(d)
(e)
(f)
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
−12
−10
−8
−6
−4
−2
2
4
6
8
10
12
Post-Hiatus—Hiatus TOA Flux Difference (Wm⁻²)

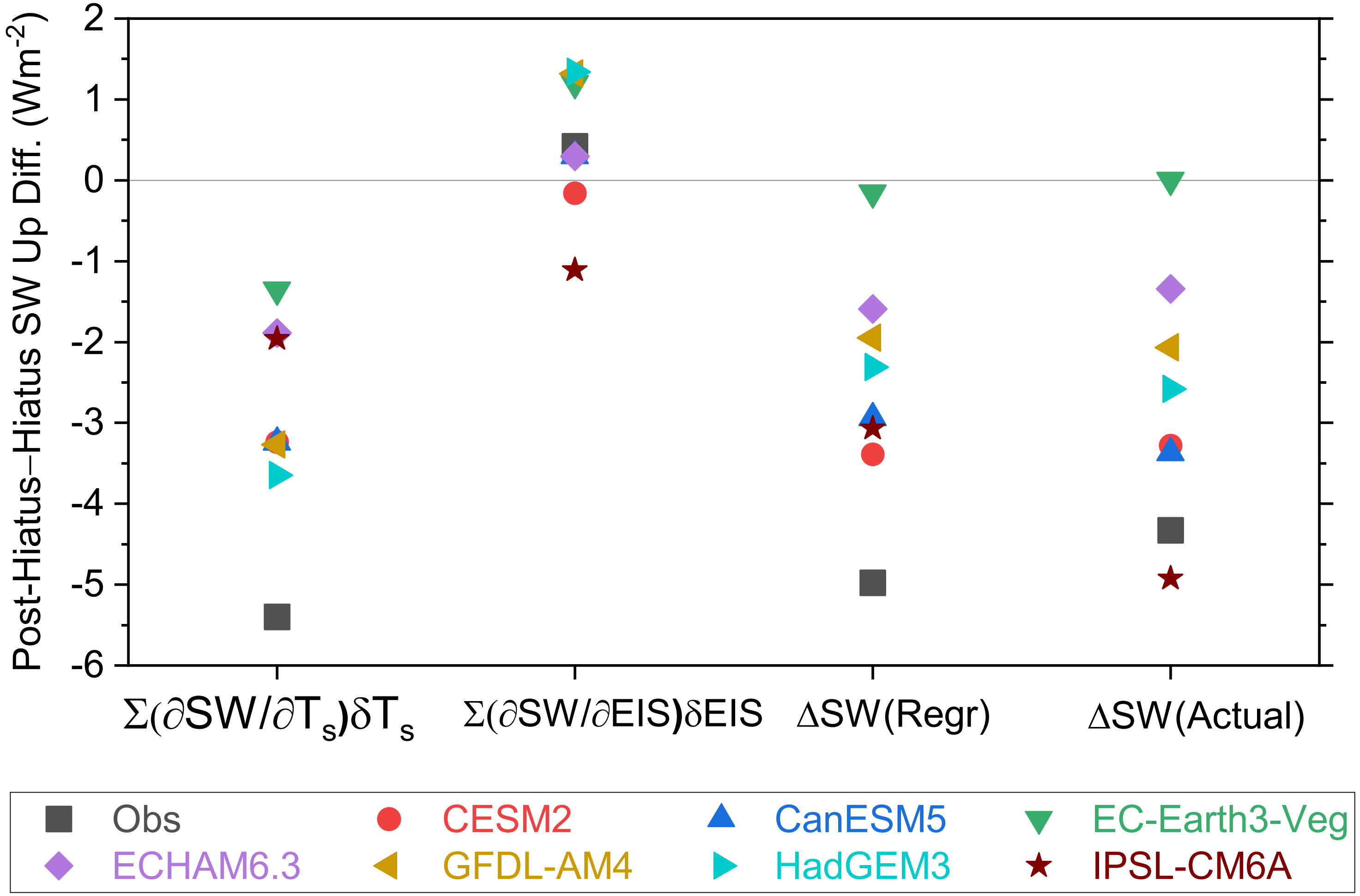
Bias in SW TOA Flux Post-Hiatus—Hiatus Difference vs Bias in SW TOA Flux Climatological Mean (E Pacific Region for July 2000-June 2017)



- No correlation!

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

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



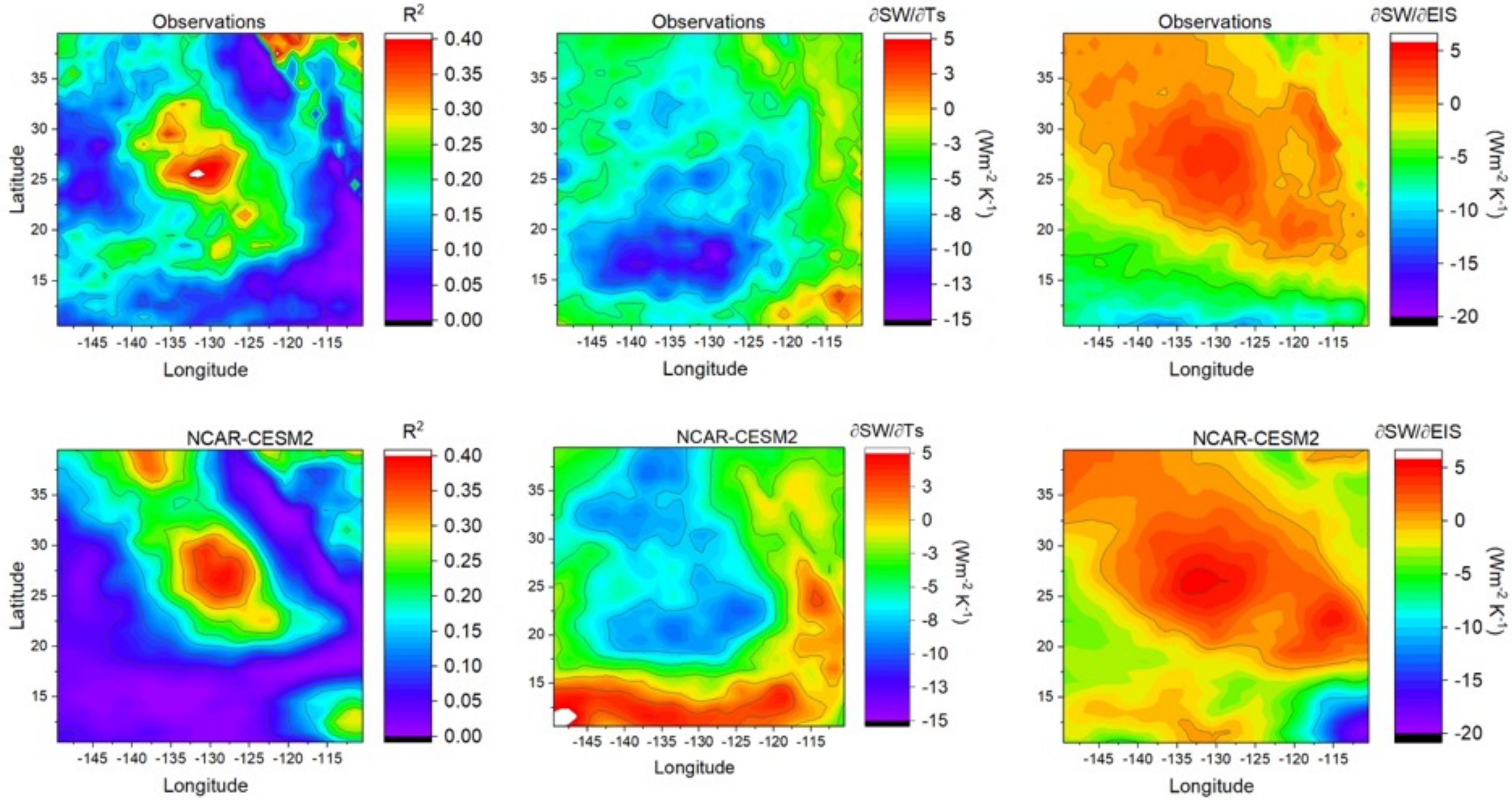
- $\partial SW/\partial T_s$ and $\partial SW/\partial EIS$ derived from MLRA using monthly anomalies in each 1° gridbox.
- δT_s & δEIS are gridbox post-hiatus–hiatus diffs.

E 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.

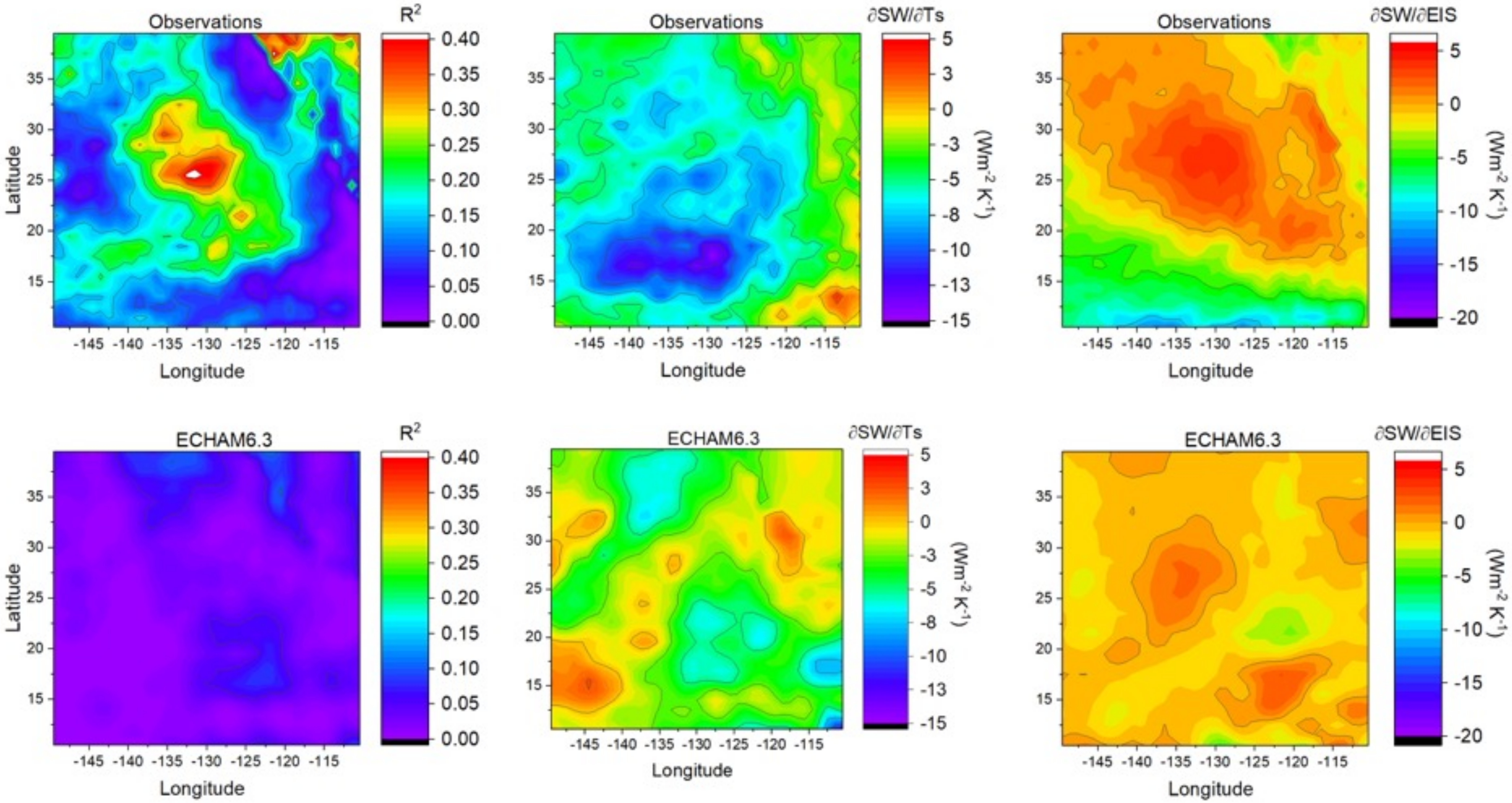
Multi-Linear Regression Analysis: Observations & NCAR-CESM2

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

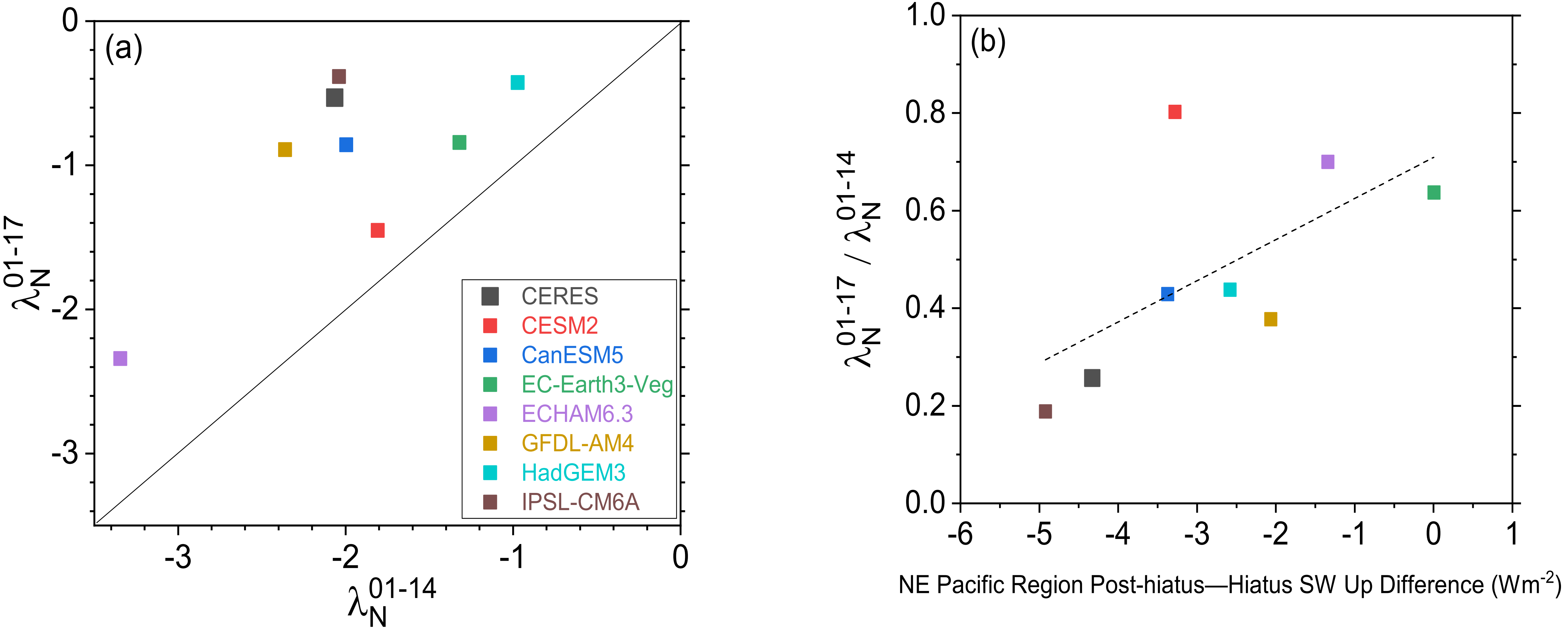


Multi-Linear Regression Analysis: Observations & ECHAM6.3

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



“Net Climate Feedback Parameter”



$$\lambda = (N–F)/\Delta T$$

N = CERES net flux
F = Effective radiative forcing (from AR5)
ΔT = Surface temperature response

Conclusions

- ERB observations provide key data for testing model representation of both mean climatology and climate system response to SST pattern changes.

- Model biases in climatology and biases in response to SST pattern changes are not correlated in Sc region over eastern Pacific.

- GCM-AMIP simulations show decrease in reflected SW TOA flux in marine Sc regions following hiatus, but underestimate the magnitude compared to observations.

  - ➢ Some models do excellent job of reproducing observed patterns in ERB response to SST pattern changes (e.g., HadGEM3).

- T_s and EIS variations in marine Sc regions explain most of the variability in SW TOA flux, with the T_s contribution dominating.