The Antarctic Atmospheric Energy Budget: Observation and Model Simulation

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Outline

Part 1: Climatology and Intraseasonal-to-Interannual Variability[1]

Part 2: Multidecadal Trends[2]

1 Previdi, M., K. L. Smith, and L. M. Polvani, 2013: The Antarctic atmospheric energy budget. Part I: climatology and intraseasonal-to-interannual variability. *J. Clim.*, **26**, 6406-6418.

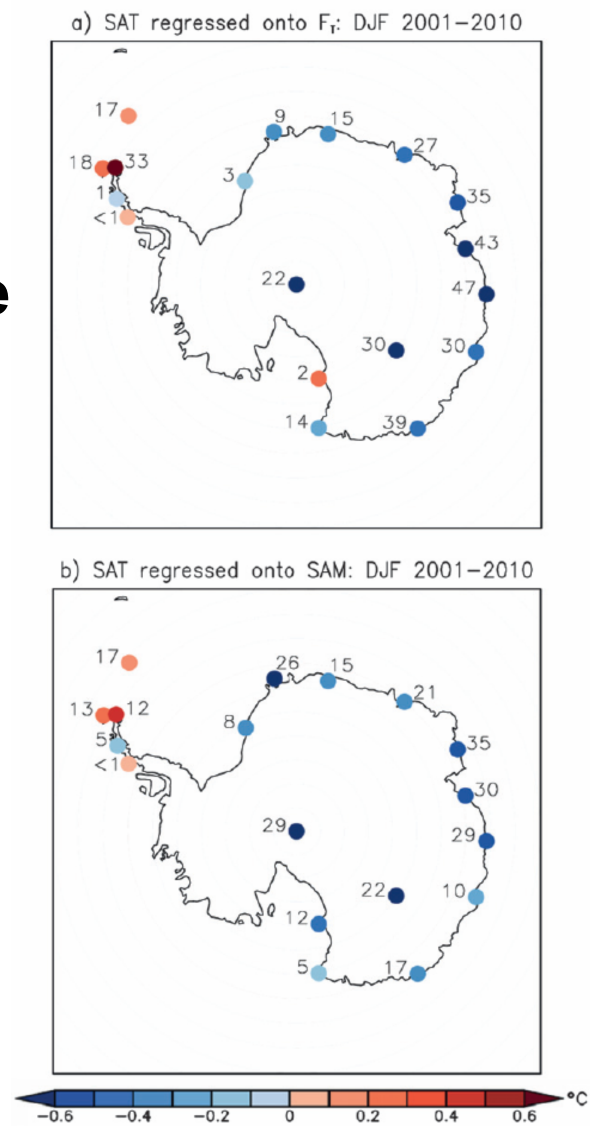
2 Smith, K. L., M. Previdi, and L. M. Polvani, 2013: The Antarctic atmospheric energy budget. Part II: the effect of ozone depletion and its projected recovery. *J. Clim.*, **26**, 9729-9744.

The atmospheric energy budget…

…is tightly coupled with the surface energy budget, and, therefore, with the surface climate.

…can be used as a test of climate model performance.

…responds to anthropogenic forcing.



Previdi et al., 2013

Mathematical expression

Energy budget of an atmospheric column:

$$\frac{\partial E}{\partial t} = F_{\mathrm{TOA:NET}} + F_{\mathrm{SFC:NET}} + F_{\mathrm{WALL}}$$

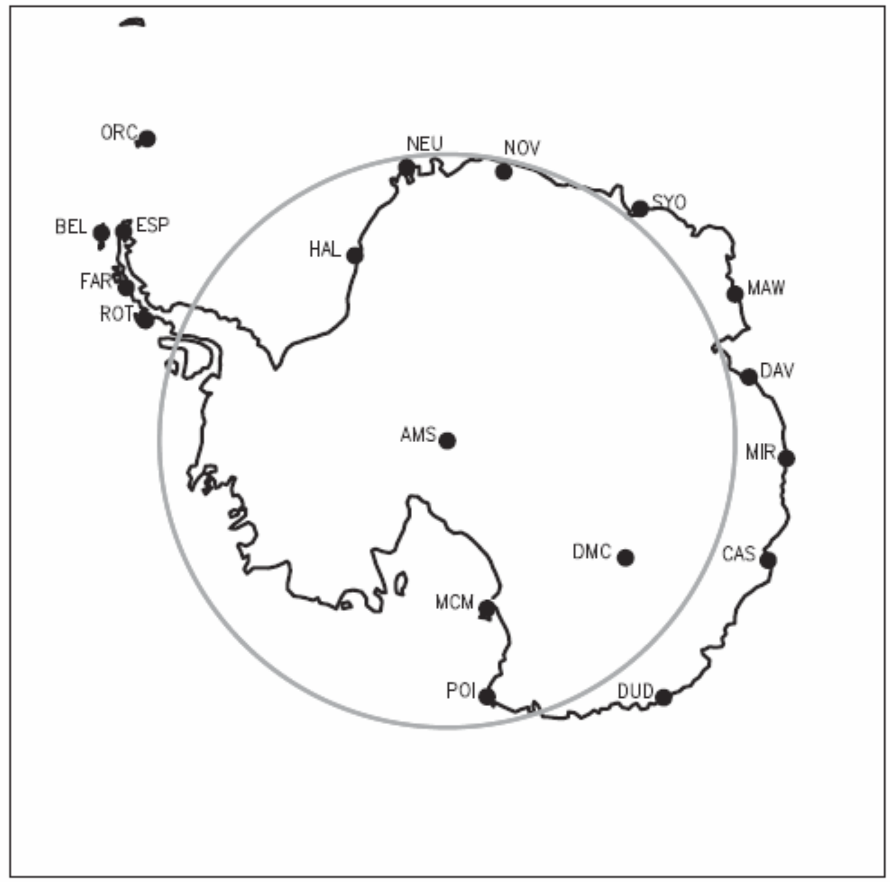
where:

$$\frac{\partial E}{\partial t} = \frac{\partial}{\partial t}\frac{1}{g}\int_0^{p_{SFC}} (c_p T + k + Lq + \Phi_{\mathrm{SFC}})\, dp$$

$$F_{\mathrm{TOA:NET}} = F_{\mathrm{TOA:SW}} + F_{\mathrm{TOA:LW}}$$

$$F_{\mathrm{SFC:NET}} = F_{\mathrm{SFC:SW}} + F_{\mathrm{SFC:LW}} + F_{\mathrm{SFC:LH+SH}}$$

$$F_{\mathrm{WALL}} = -\nabla \cdot \frac{1}{g}\int_0^{p_{\mathrm{SFC}}} (c_p T + k + Lq + \Phi)\mathbf{v}\, dp$$
$$= F_T + F_k + F_q + F_\Phi .$$



Previdi et al., 2013

Part 1: Climatology and Intraseasonal-to-Interannual Variability

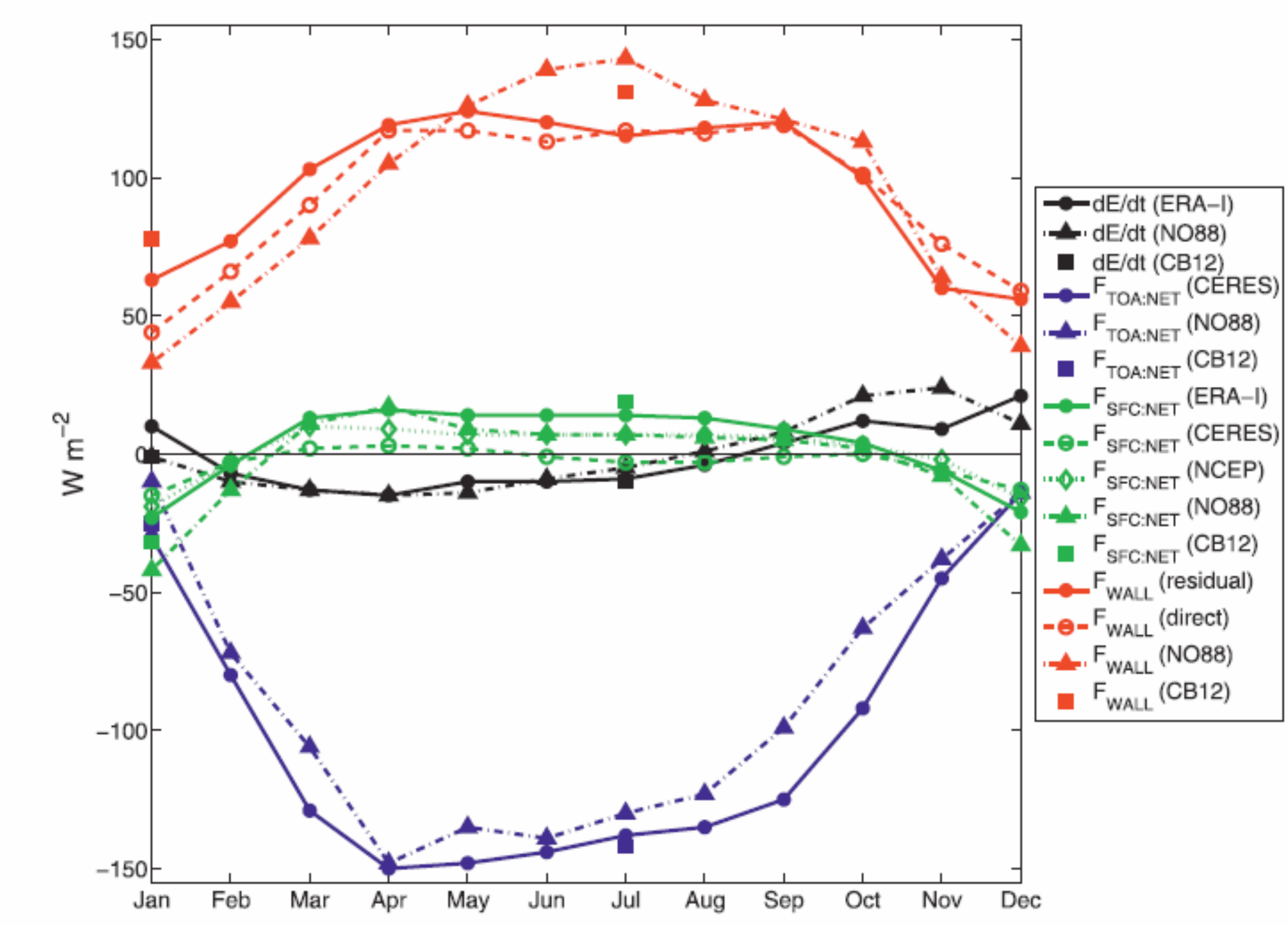
Datasets

- Focus on the period 2001-10 (first full 10 years of CERES satellite measurements)

- Primary observational datasets: CERES EBAF ($F_{TOA:SW}$, $F_{TOA:LW}$) and ERA-Interim reanalysis ($\partial E/\partial t$, $F_{SFC:SW}$, $F_{SFC:LW}$, $F_{SFC:LH+SH}$, F_{WALL})

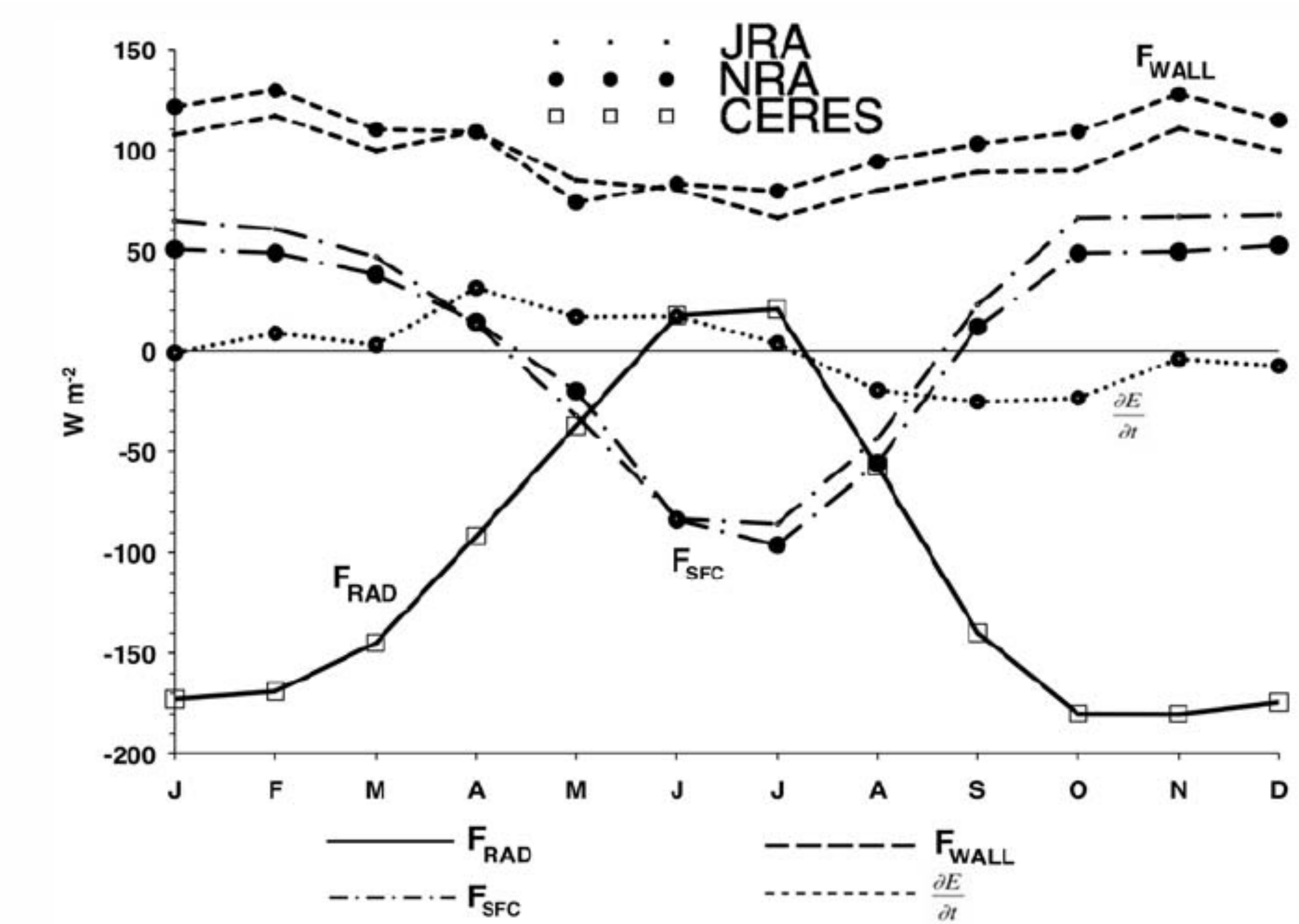
- CMIP5 model data: 11 models so far; 1 realization from each model of the Historical +RCP4.5 scenario

Observed climatological mean energy budget



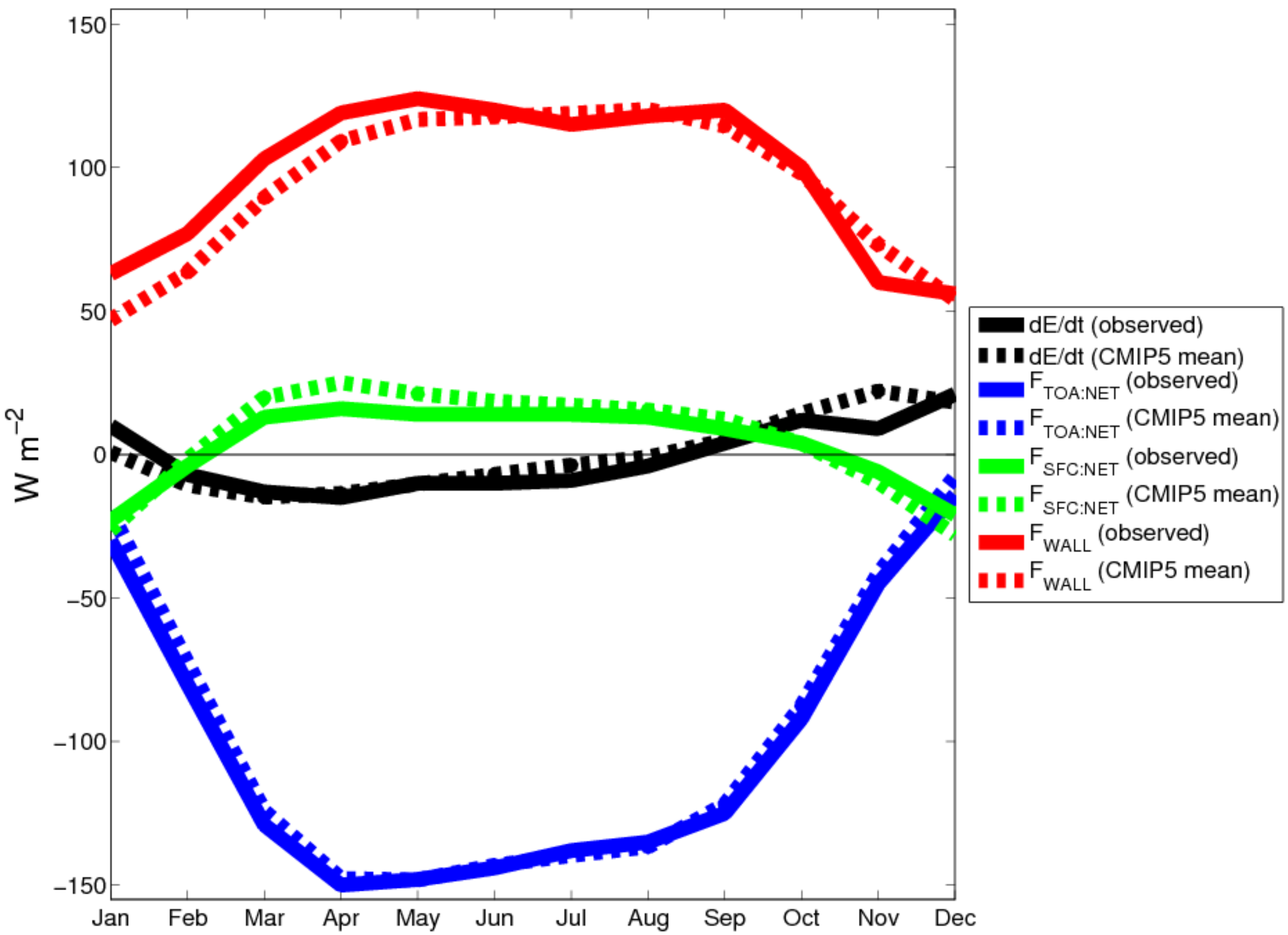
Previdi et al., 2013

Comparison with the Arctic

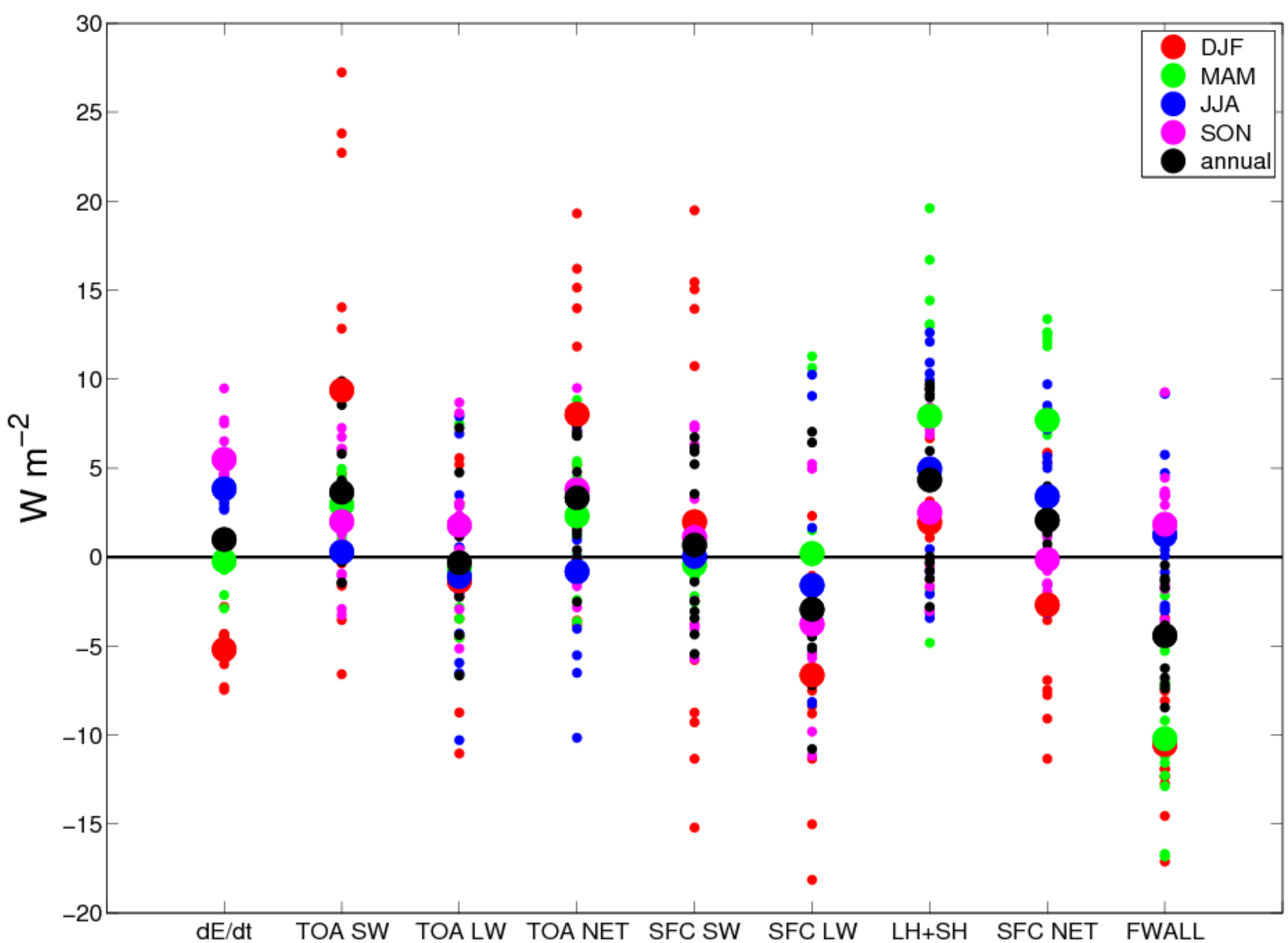


Porter et al., 2010

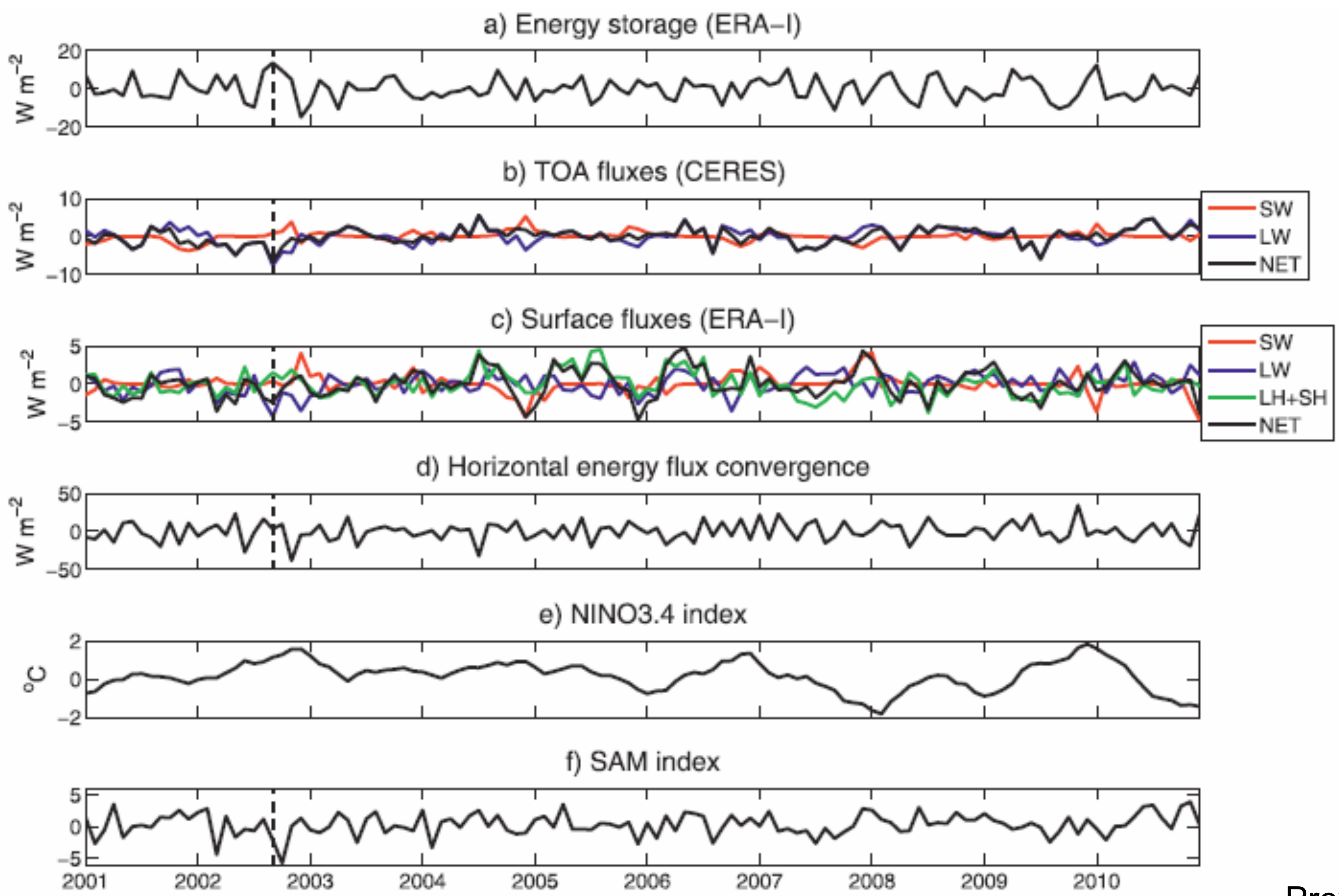
Comparison with CMIP5



CMIP5 biases



Observed intraseasonal-to-interannual variability



Previdi et al., 2013

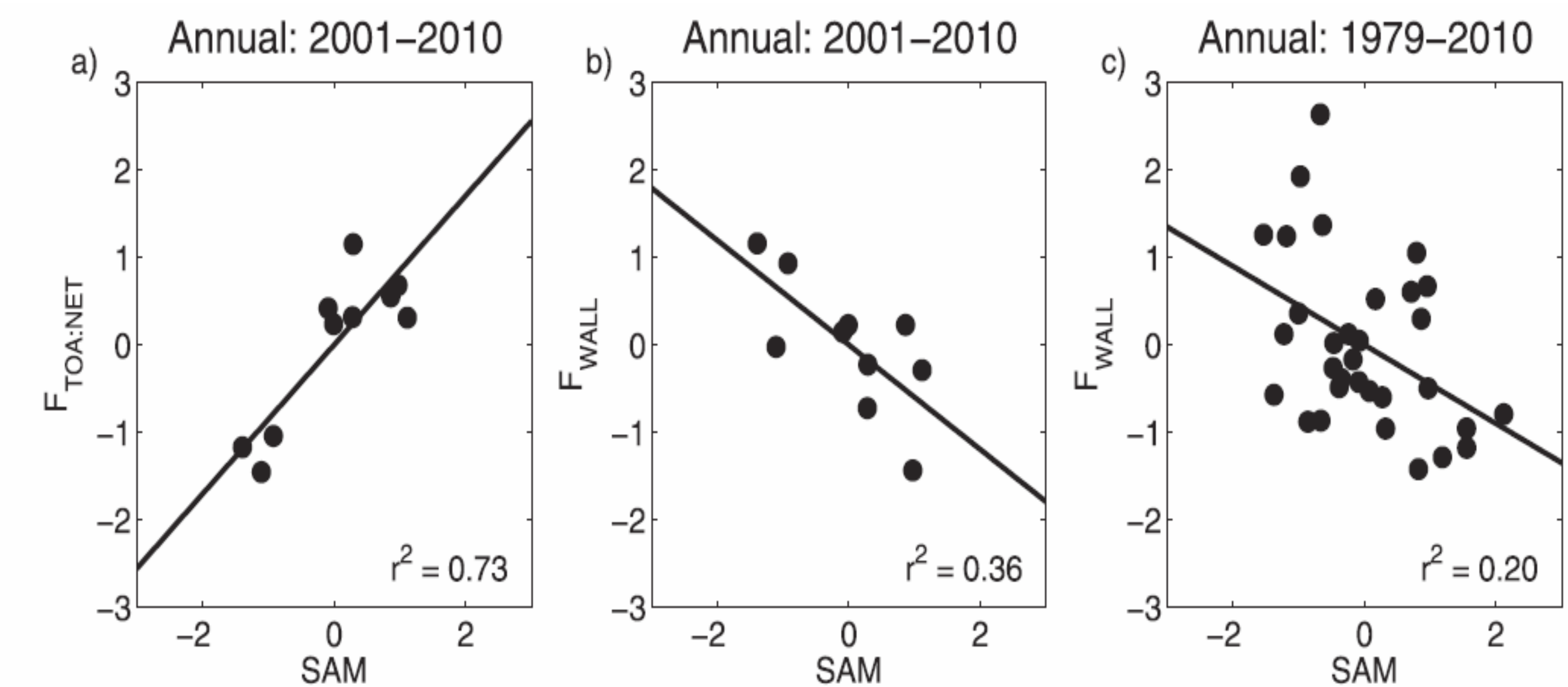
Correlations with ENSO/SAM

TABLE 2. Linear correlations between energy budget components and ENSO/SAM during 2001–10 based on monthly mean data for DJF and JJA. The mean seasonal cycle was removed from the data prior to computing the correlations. Boldface values are statistically significant at the 95% confidence level.

	$\partial E/\partial t$	$F_{\mathrm{TOA:SW}}$	$F_{\mathrm{TOA:LW}}$	$F_{\mathrm{TOA:NET}}$	$F_{\mathrm{SFC:SW}}$	$F_{\mathrm{SFC:LW}}$	$F_{\mathrm{SFC:LH+SH}}$	$F_{\mathrm{SFC:NET}}$	F_{WALL}
ENSO									
DJF	−0.03	0.35	**−0.54**	−0.28	−0.05	−0.06	−0.09	−0.12	−0.28
JJA	−0.04	0.18	−0.36	−0.35	−0.13	−0.18	0.07	−0.03	0.07
SAM									
DJF	−0.19	**−0.51**	**0.67**	0.22	0.21	0.19	**0.54**	**0.55**	−0.09
JJA	0.02	−0.03	**0.60**	**0.60**	0.17	−0.20	0.29	0.21	0.02

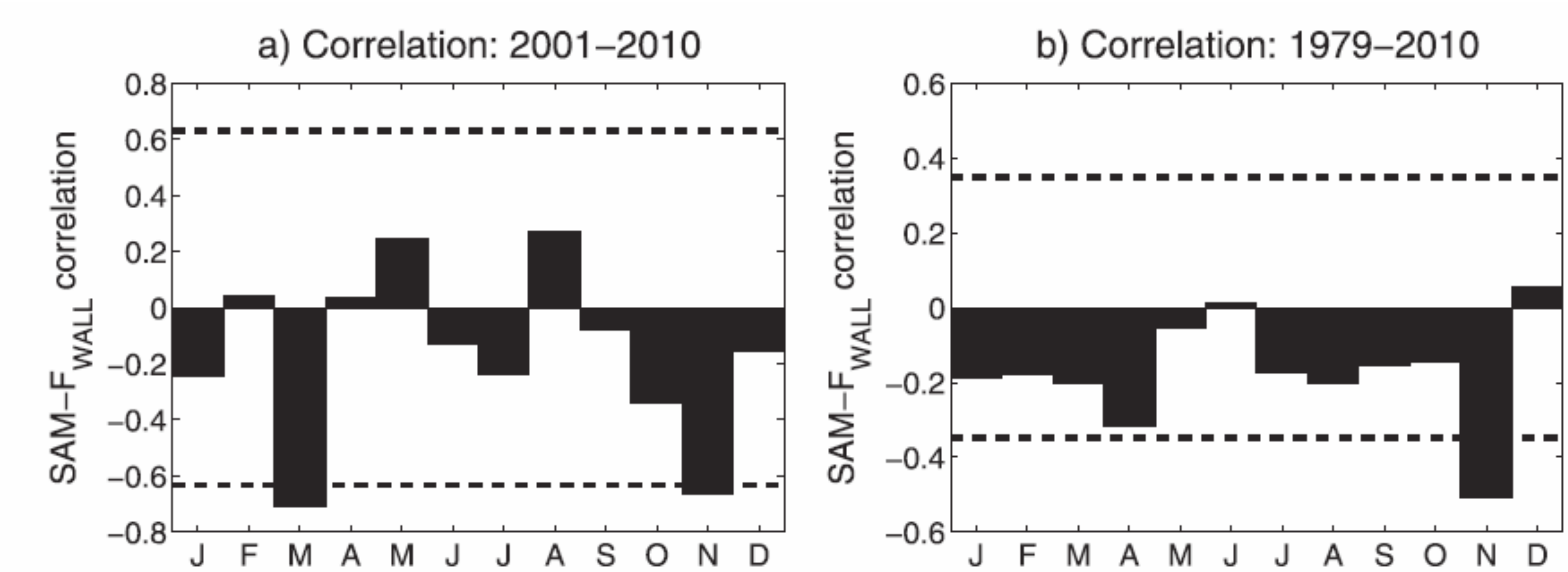
Previdi et al., 2013

Annual-mean relationships



Previdi et al., 2013

The SAM & horizontal energy transport



Previdi et al., 2013

The SAM & horizontal energy transport

Previdi et al., 2013

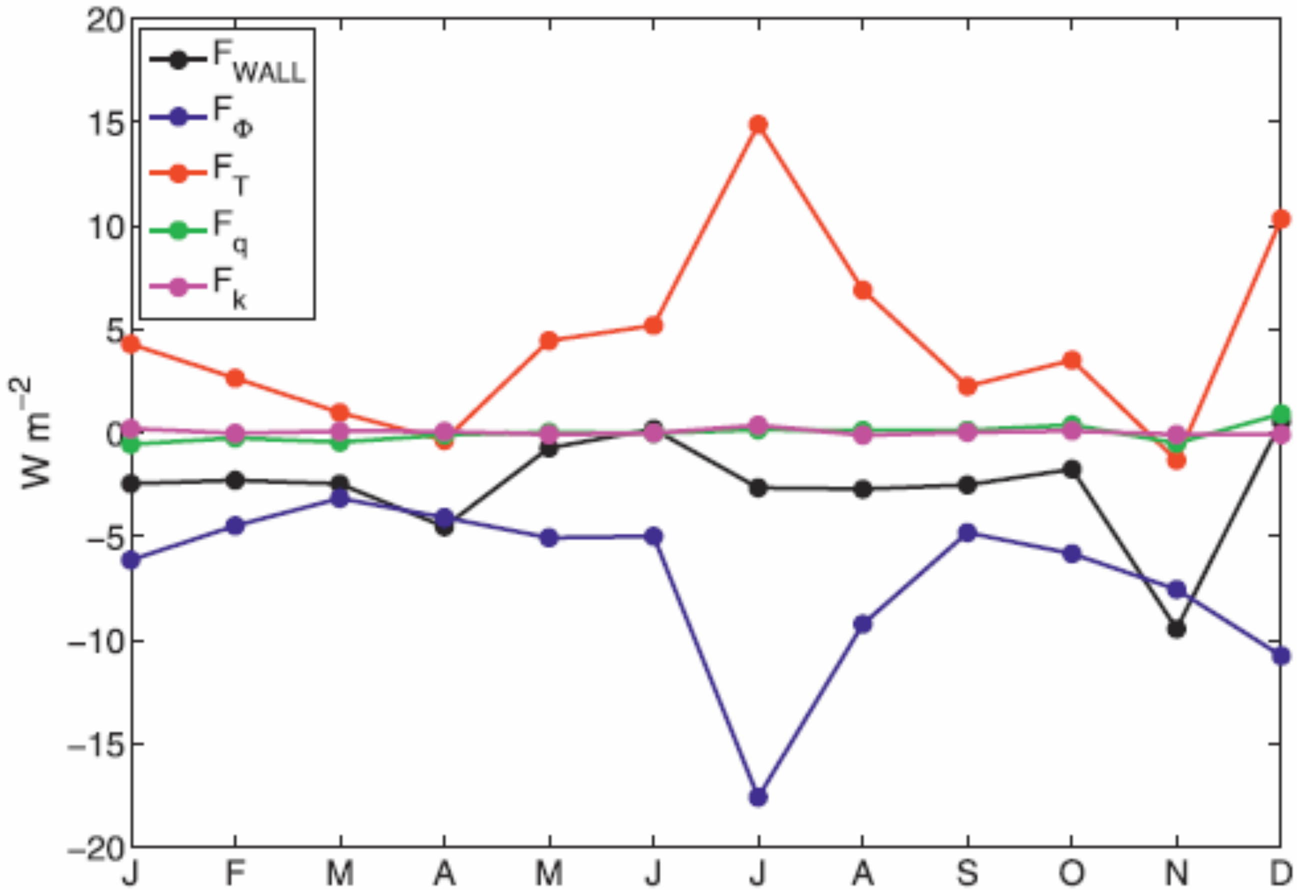


FIG. 7. Regression of F_{WALL} and its components onto the SAM index.

Part 2: Multidecadal Trends

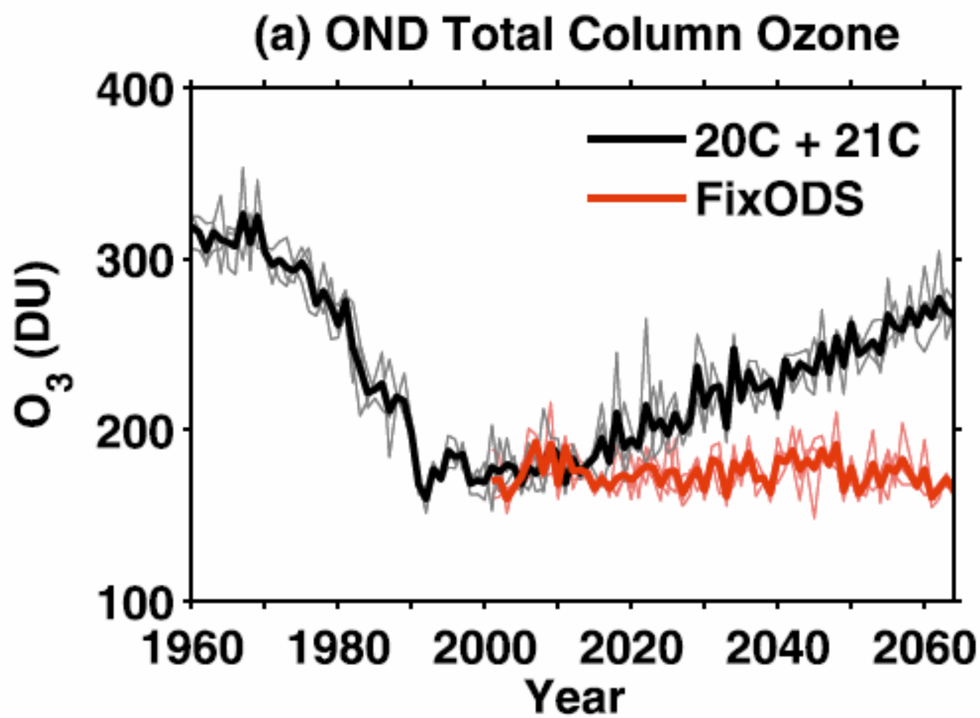
WACCM simulations

3-member ensembles of CESM1-WACCM integrations:

1) 20C: 1960-2000 period; CMIP5 Historical scenario for surface concentrations of GHGs and ODSs

2) 21C: 2001-2065 period; GHG/ODS forcing for 2001-2005 (2006-2065) based on CMIP5 Historical (RCP4.5) scenario

3) FixODS: 2001-2065 period; identical to 21C, except that surface concentrations of ODSs are held fixed at year 2000 levels



Smith et al., 2013

Interannual $F_{TOA:NET}$ / F_{WALL} relationship

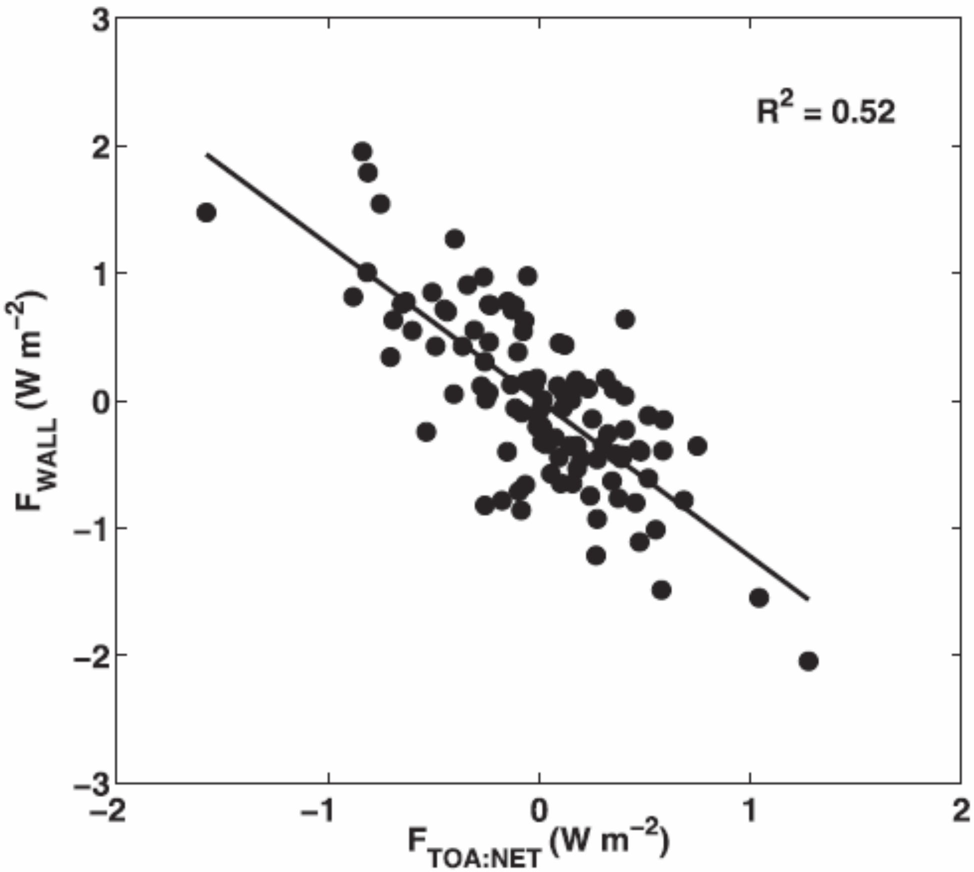
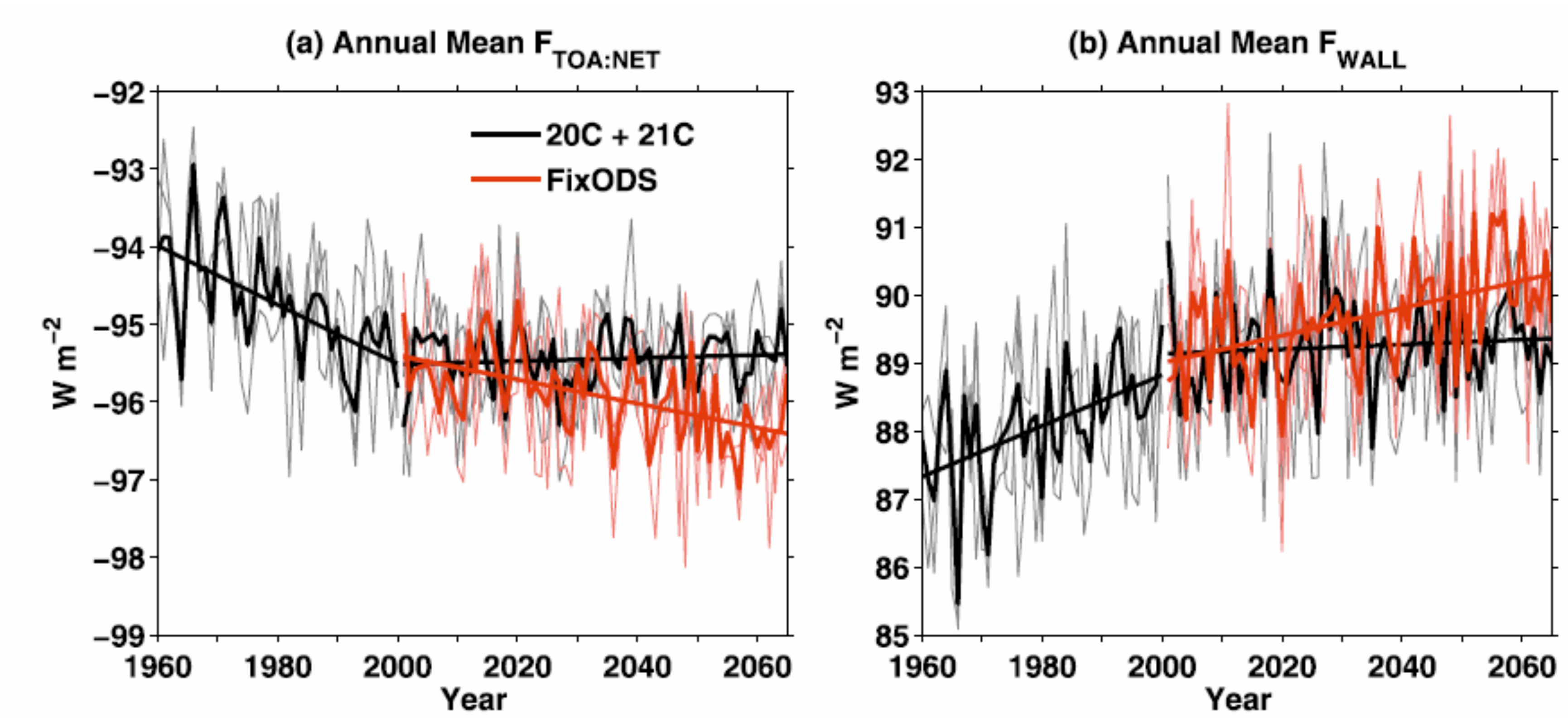


FIG. 4. Scatterplot of WACCM annual mean, piecewise, linearly detrended polar cap averaged (70°–90°S) $F_{\mathrm{TOA:NET}}$ and F_{WALL} anomalies for 1960–2065 (20C and 21C). Solid black line indicates the least squares linear fit to the data.

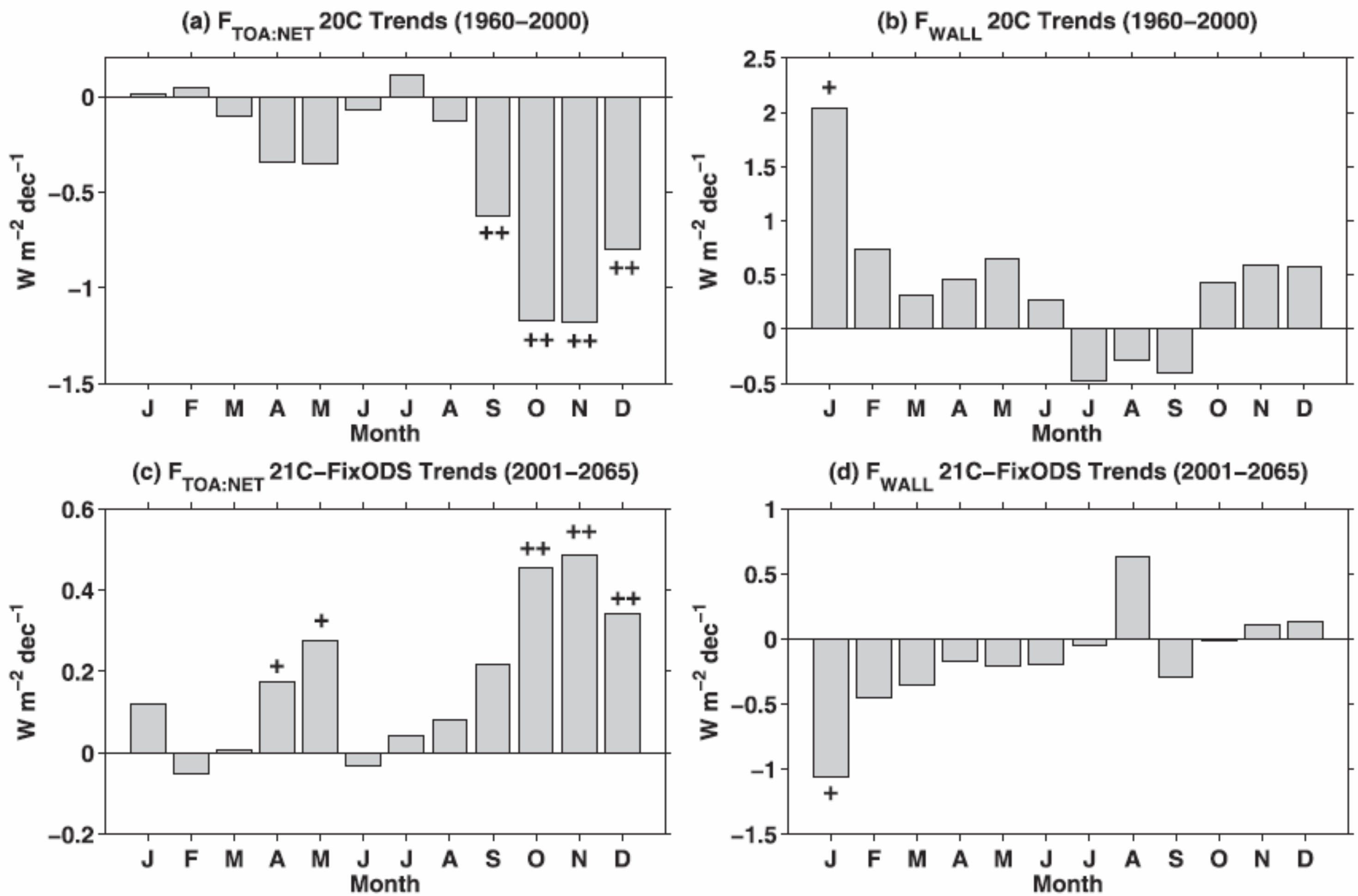
Smith et al., 2013

Multidecadal trends



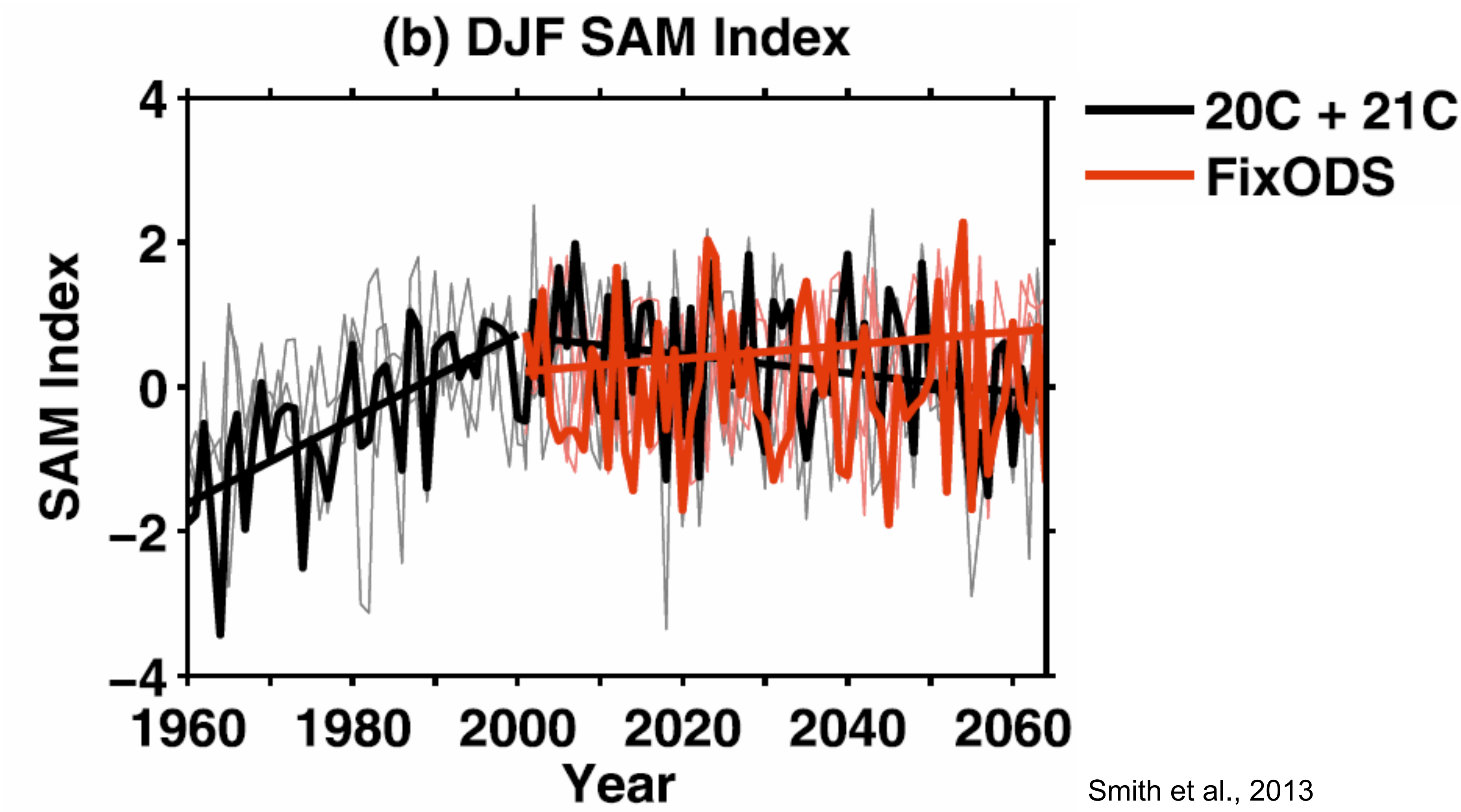
Smith et al., 2013

Multidecadal trends



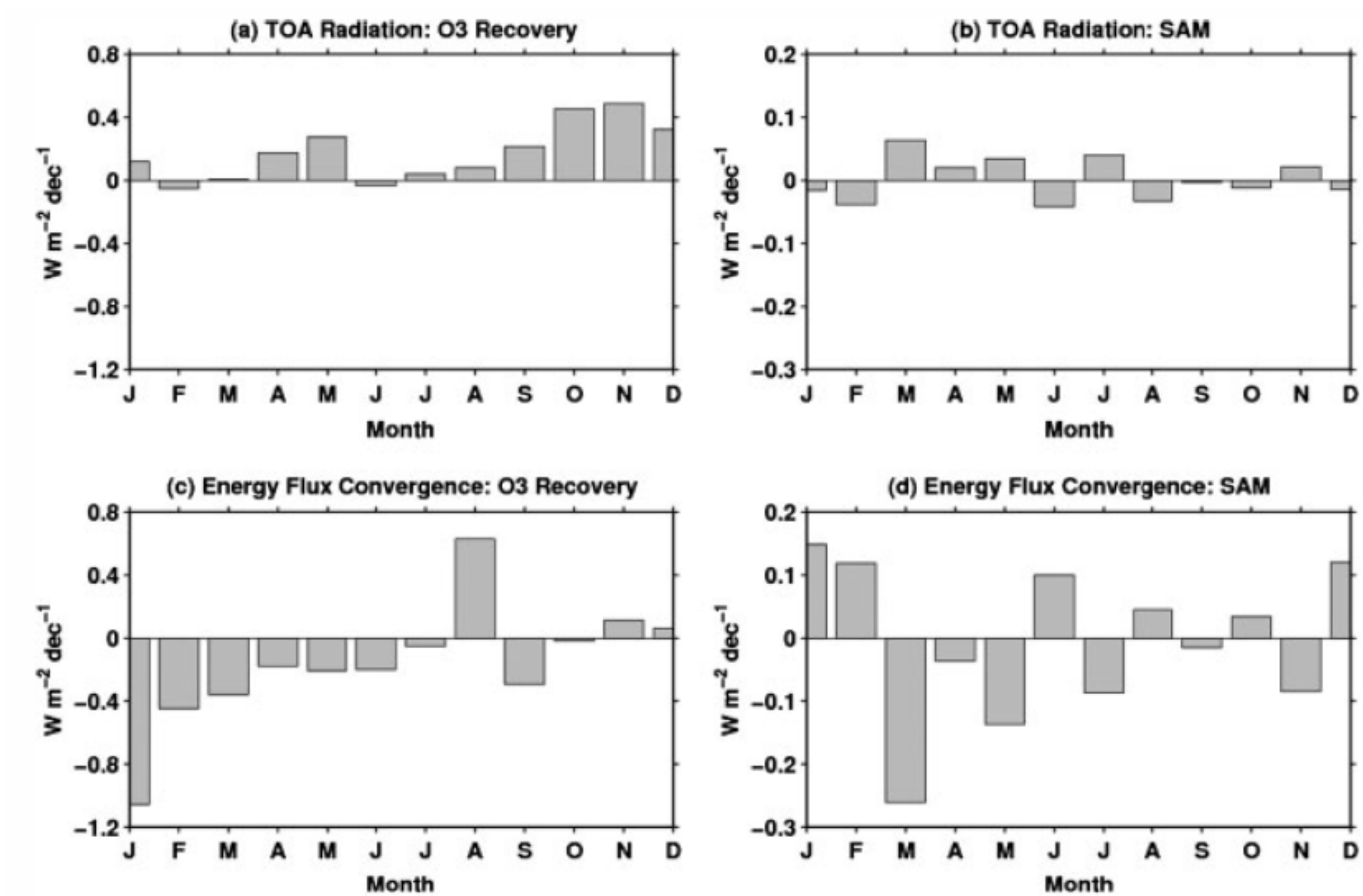
Smith et al., 2013

Role for the SAM?



Smith et al., 2013

Role for the SAM?



Previdi and Polvani, 2014

Conclusions

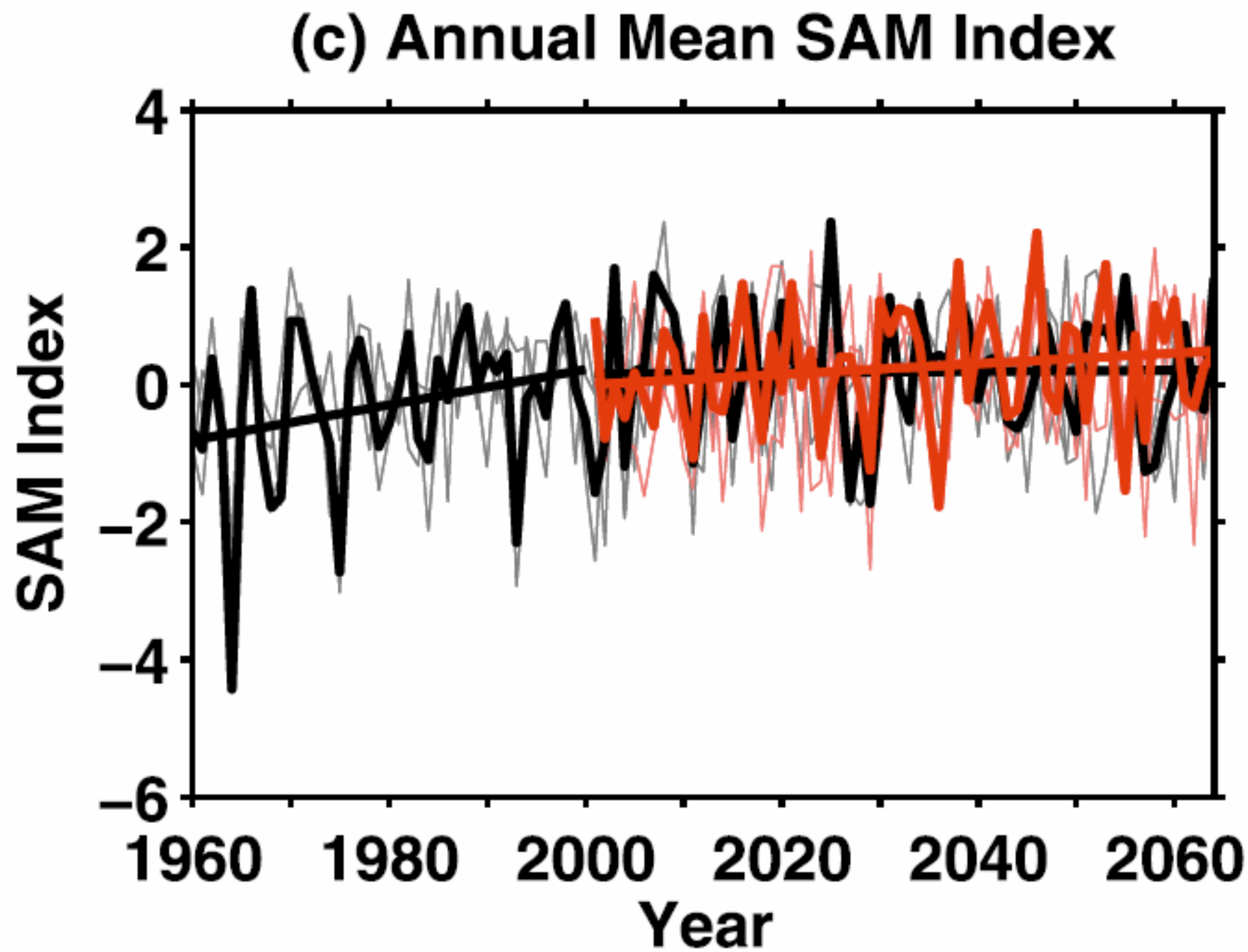
- The observed Antarctic atmospheric energy budget is characterized by an approximate balance between the TOA net radiation and the horizontal convergence of the atmospheric energy transport. This balance is maintained both in the climatological mean, and in association with interannual (largely SAM-related) variability.

- CMIP5 models, on average, do well in simulating the observed climatological mean Antarctic energy budget. However, large biases exist in individual models during certain seasons (e.g., TOA SW radiation during summer).

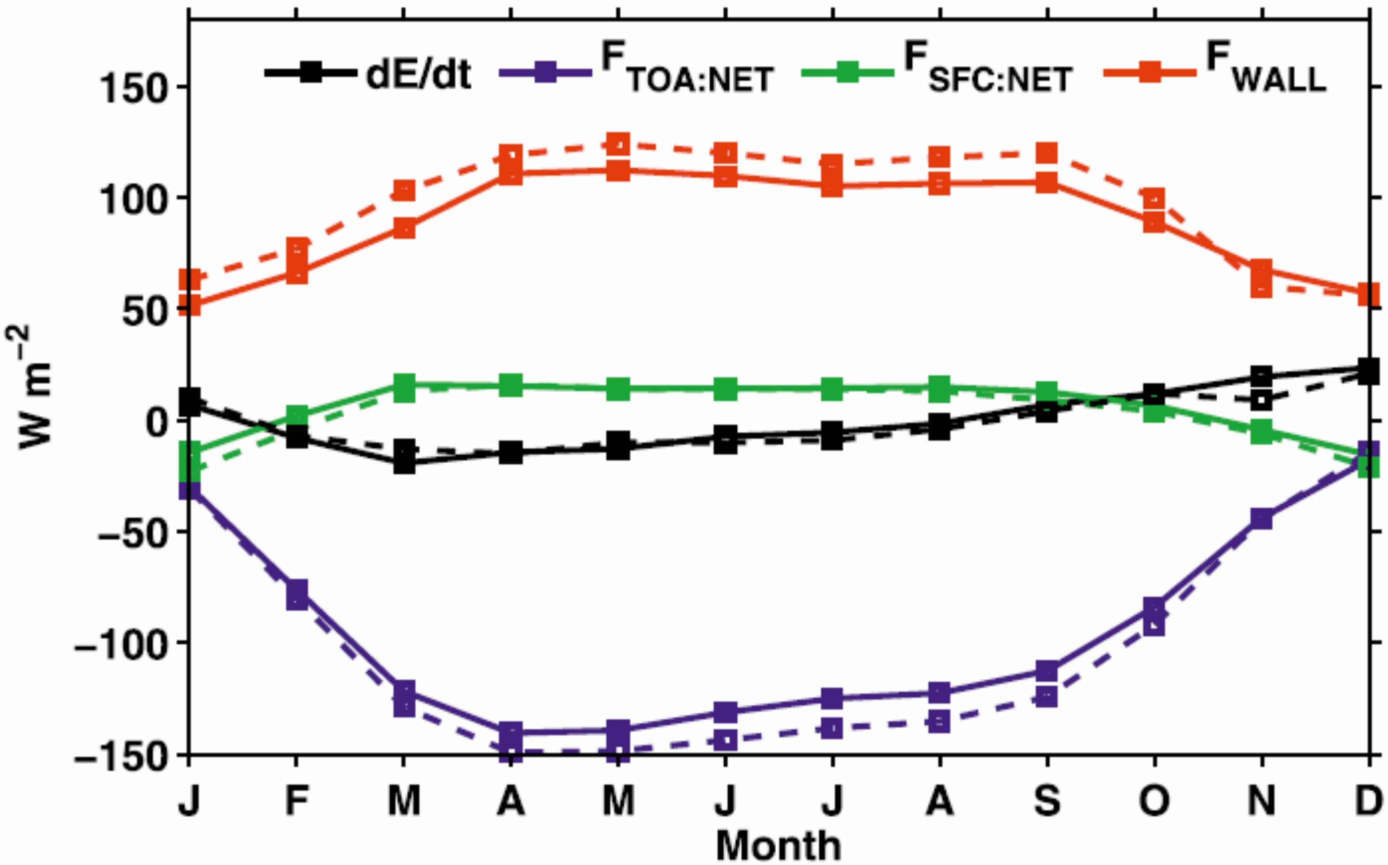
- Multidecadal trends in the Antarctic mean TOA net radiation are simulated by CESM1-WACCM during 1960-2065, primarily in response to stratospheric ozone depletion and recovery. As was the case for the climatological mean and interannual variability, these multidecadal trends are balanced by opposing trends in the horizontal energy transport into the polar region.

TABLE 1. The climatological mean Antarctic atmospheric energy budget (W m^{-2}) for 2001–10. TOA radiative fluxes are based on CERES satellite measurements, surface energy fluxes and $\partial E/\partial t$ are from ERA-Interim, and F_{WALL} is estimated as a residual. Positive values signify a gain of energy for the atmospheric column.

	$\partial E/\partial t$	$F_{\mathrm{TOA:SW}}$	$F_{\mathrm{TOA:LW}}$	$F_{\mathrm{TOA:NET}}$	$F_{\mathrm{SFC:SW}}$	$F_{\mathrm{SFC:LW}}$	$F_{\mathrm{SFC:LH+SH}}$	$F_{\mathrm{SFC:NET}}$	F_{WALL}
Jan	10	169	−199	−30	−98	69	6	−23	63
Feb	−7	105	−185	−80	−62	58	0	−4	77
Mar	−13	40	−169	−129	−21	44	−10	13	103
Apr	−15	6	−156	−150	−3	38	−19	16	119
May	−10	0	−148	−148	0	38	−24	14	124
Jun	−10	0	−144	−144	0	39	−25	14	120
Jul	−9	0	−138	−138	0	40	−26	14	115
Aug	−4	2	−137	−135	−1	40	−26	13	118
Sep	4	20	−145	−125	−10	42	−23	9	120
Oct	12	68	−160	−92	−36	53	−13	4	100
Nov	9	136	−181	−45	−72	66	0	−6	60
Dec	21	184	−198	−14	−105	75	9	−21	56
Annual	−1	61	−163	−102	−34	50	−13	3	98



(c) Annual Mean SAM Index
SAM Index
Year
4
2
0
−2
−4
−6
1960
1980
2000
2020
2040
2060



dE/dt
$F_{TOA:NET}$
$F_{SFC:NET}$
F_{WALL}
150
100
50
0
−50
−100
−150
W m^{-2}
J
F
M
A
M
J
J
A
S
O
N
D
Month

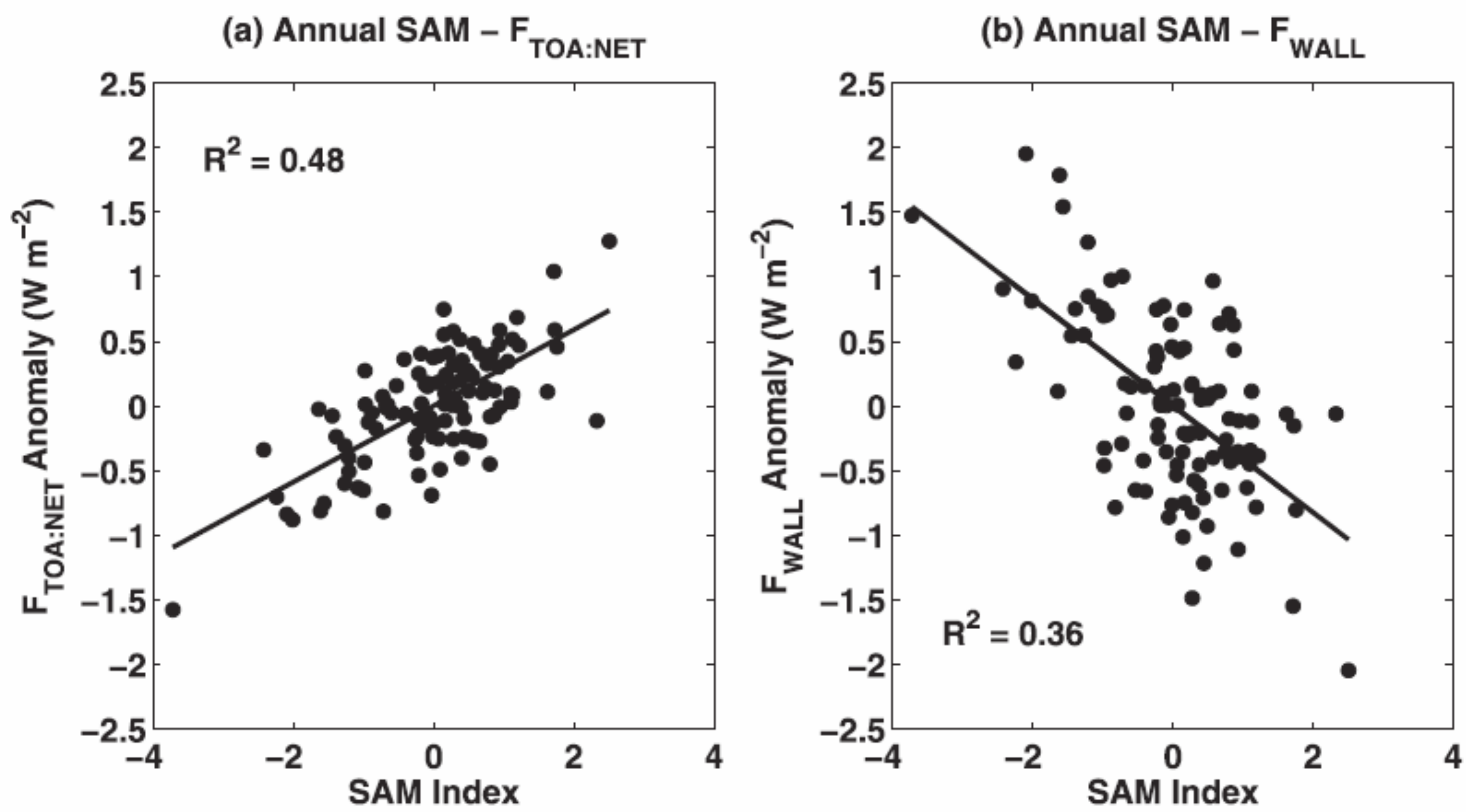

(a) Annual SAM – $F_{TOA:NET}$
$R^2 = 0.48$
$F_{TOA:NET}$ Anomaly (W m^{-2})
SAM Index
(b) Annual SAM – F_{WALL}
$R^2 = 0.36$
F_{WALL} Anomaly (W m^{-2})
SAM Index

TABLE 2. DJF and JJA correlations between piecewise, linearly detrended Antarctic energy budget components and the SAM for 1960–2065 (20C and 21C). Bold font indicates correlations that are statistically significant at the 95% level.

	$\frac{\partial E}{\partial t}$	$F_{\mathrm{TOA:SW}}$	$F_{\mathrm{TOA:LW}}$	$F_{\mathrm{TOA:NET}}$	$F_{\mathrm{SFC:SW}}$	$F_{\mathrm{SFC:LW}}$	$F_{\mathrm{SFC:LH+SH}}$	$F_{\mathrm{SFC:NET}}$	F_{WALL}
DJF	−0.006	**−0.34**	**0.55**	**0.20**	0.14	0.11	**0.24**	**0.56**	**−0.26**
JJA	−0.10	0.12	**0.59**	**0.59**	−0.15	**0.39**	**0.28**	**0.46**	**−0.49**