Yale 耶鲁大学-南京信息工程大学大气环境中心

Yale-NUIST Center on Atmospheric Environment

Comparison of Bowen ratio of the world's oceans and its temperature sensitivity among GCMs and air-sea flux products

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Outlines

1. Introduction
2. Results

- Air-sea flux products

—Bowen ratio spatial distribution; time series; zonal average; temperature sensitivity

- GCMs with RCP4.5 experiment

—Bowen ratio spatial distribution; time series; zonal average; temperature sensitivity

3. Next steps

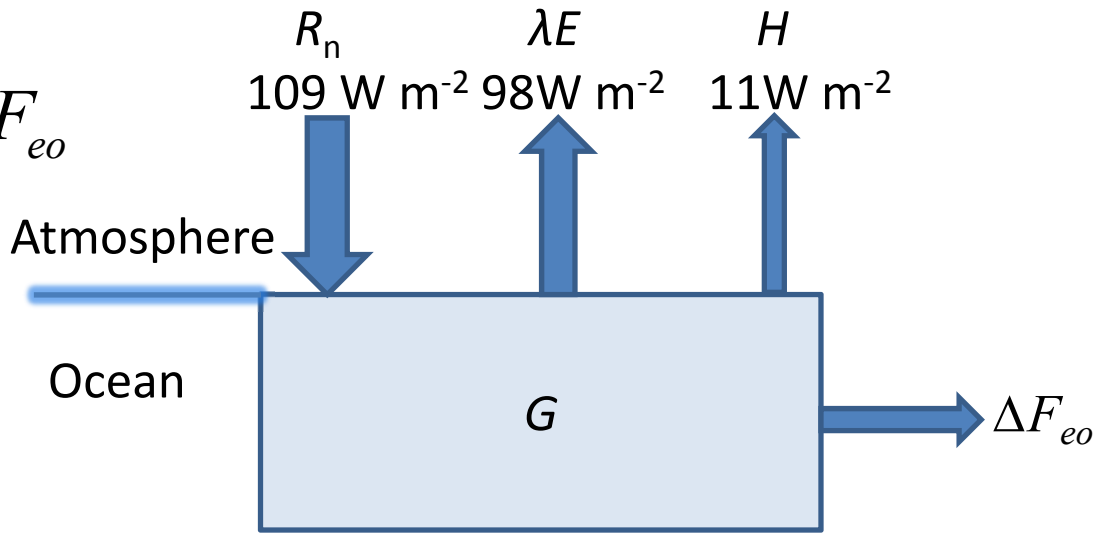
Introduction

- The oceans, where 78% of global precipitation occurs, hold 97% of the planet water and contribute 80% of the global evaporation (*NASA, 2013*).
- Bowen ratio variability of oceans is crucial for evaluating hydrological cycle (*Perez et al., 2008*).
- Bowen ratio varies (*IPCC, 2007*), negative relationship between Bowen ratio and air temperature *(Brutsaert 1982).*
- Motivated by the scarcity research on energy partitioning response of oceans to global warming (*Wilson et al., 2002; Cho, J., T. Oki, et al., 2012*).

Basic knowledge

- Ocean surface energy balance

$$G = R_n - H - \lambda E - \Delta F_{eo}$$



- Bulk transfer approach

(Hartmann, 1994)

$$H = \rho_a c_p C_H U(\theta_s - \theta_a)$$

$$\lambda E = \rho_a L_v C_E U(q_s - q_a)$$

$$\beta = \frac{\overline{H}}{\overline{\lambda E}}$$

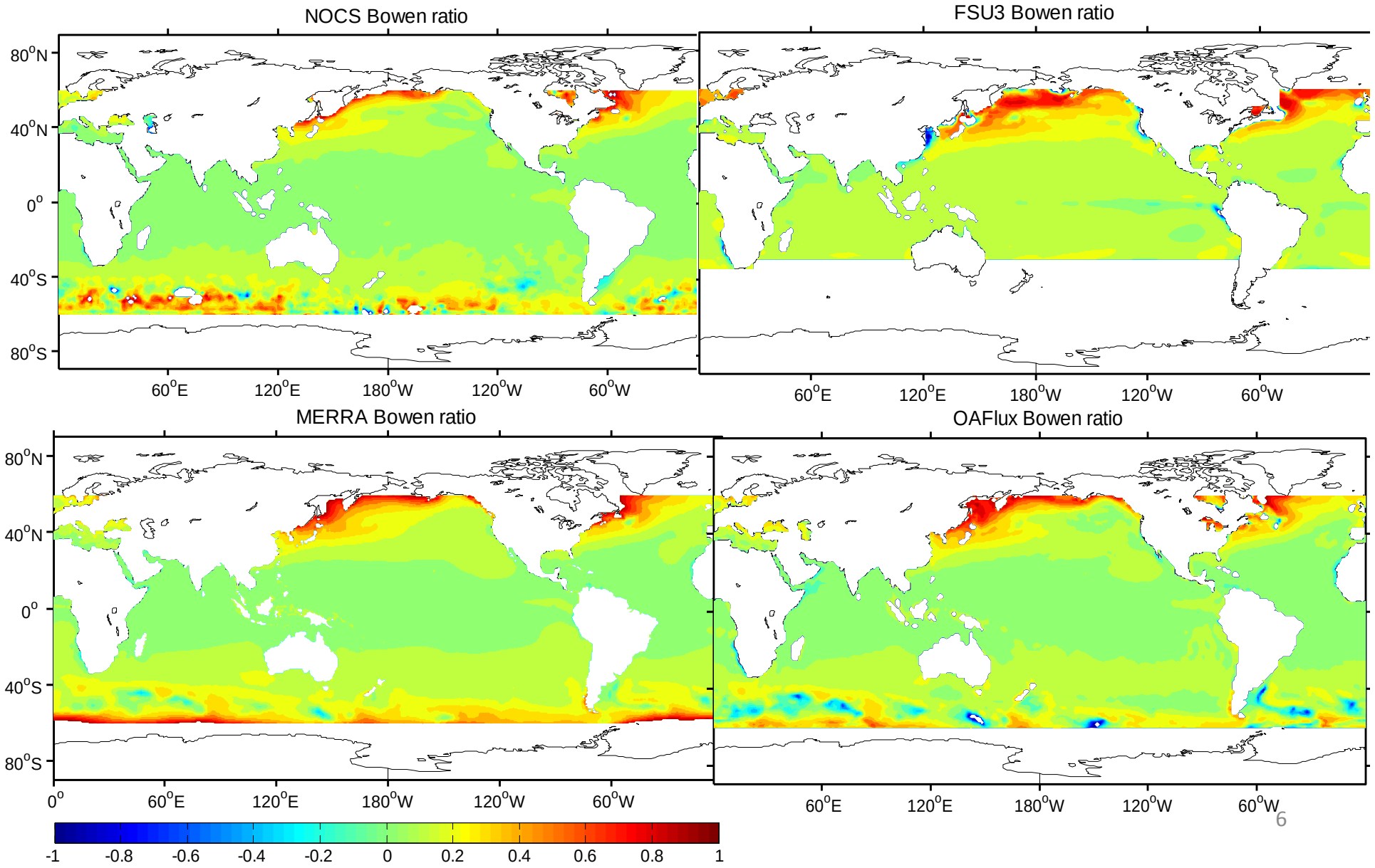
(Liu et al., 1979; Garratt, 1994)

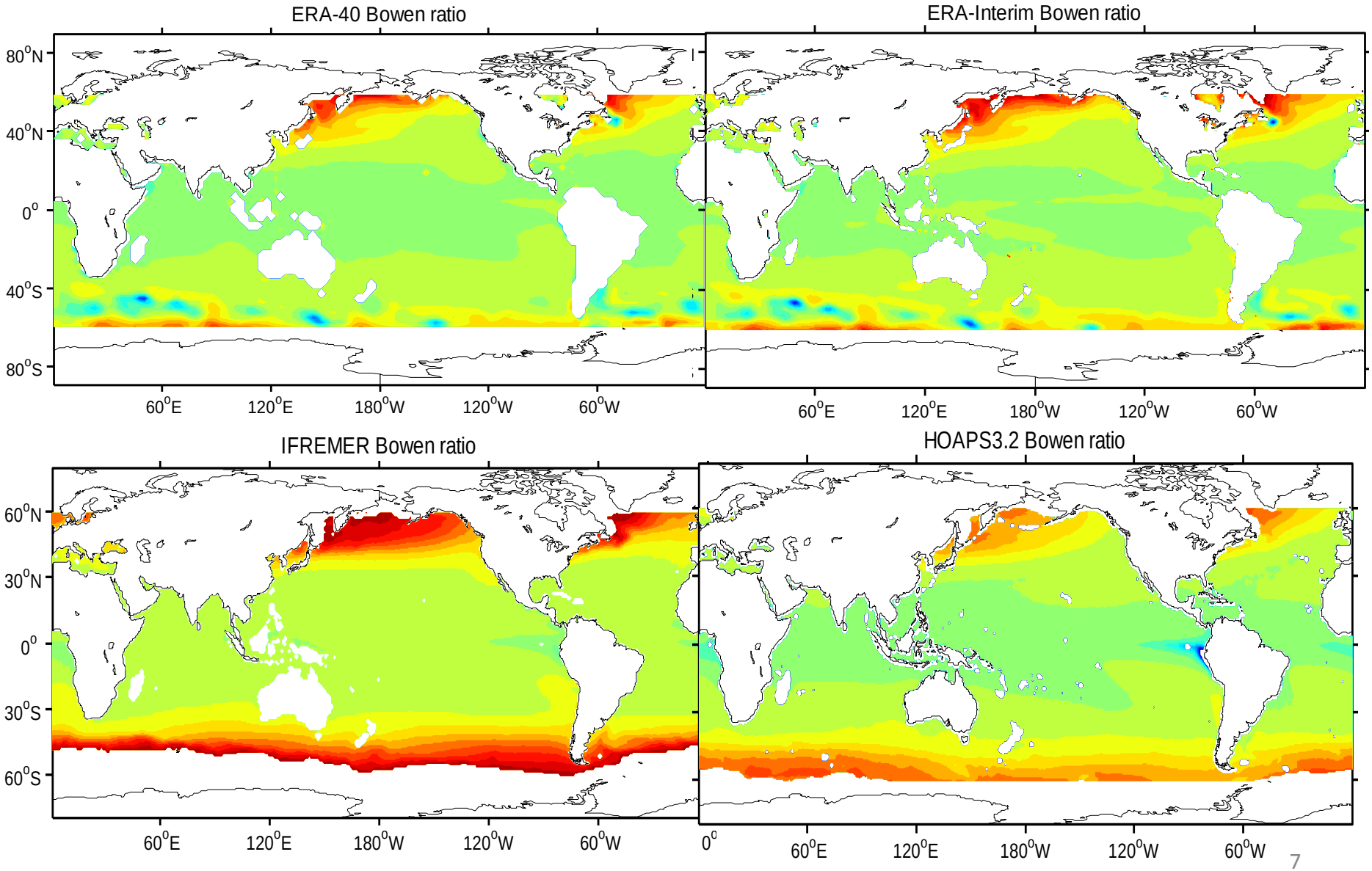
15 air-sea flux products

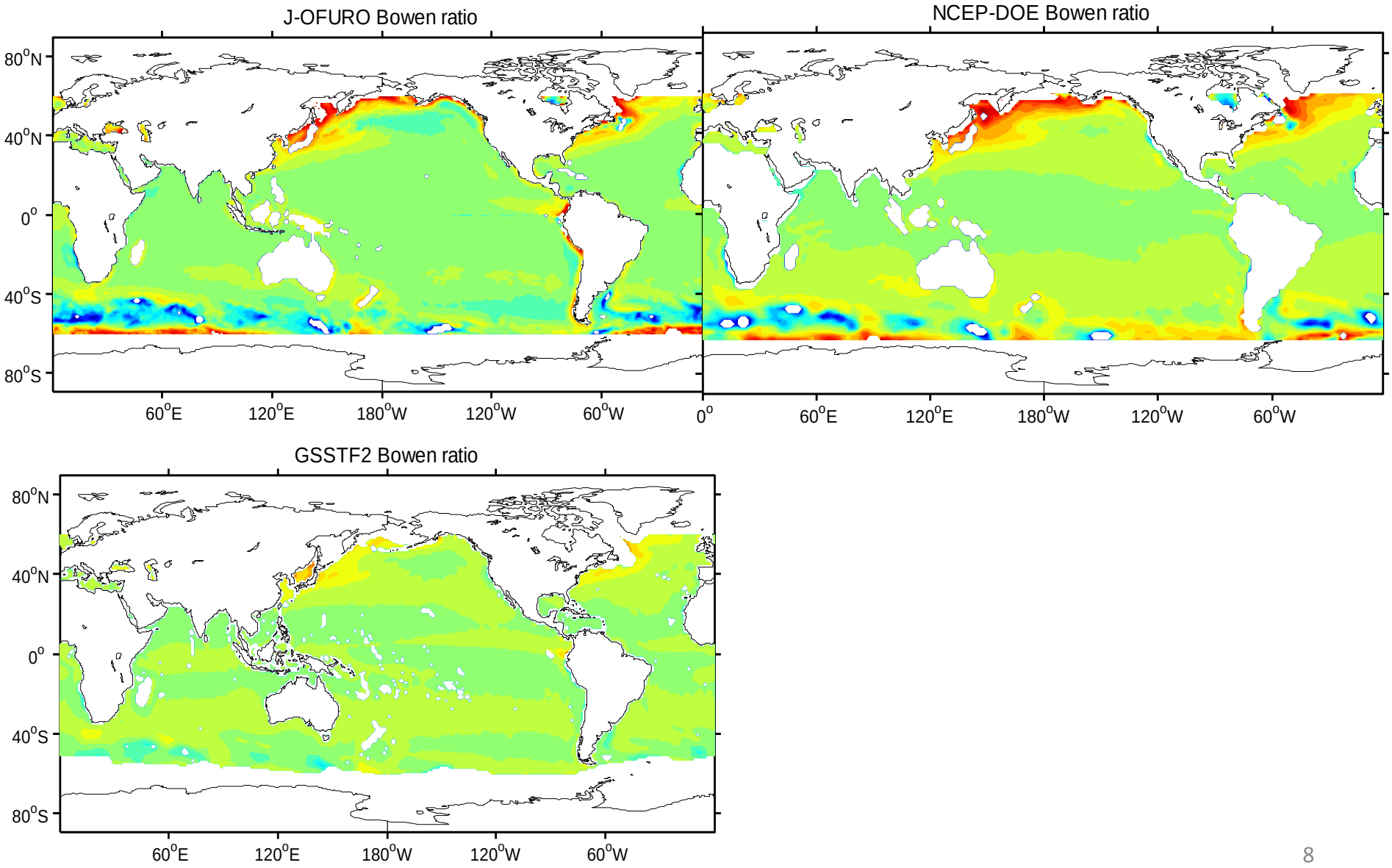
Type	Product	Period	Temporal resolution	Spatial resolution
In-situ	NOCS	1980-2005	monthly	1°lat×1°lon
	FSU3	1978-2004	monthly	1°lat×1°lon
Reanalysis	MERRA	1979-2011	monthly	1/2°lat×2/3°lon
	ERA-40	1957-2002	monthly	2.5°lat×2.5°lon
	ERA-Interim	1957-2012	monthly	T255
	NCEP-NCAR	1979-2012	monthly	T62, 192lon×94lat
	NCEP-DOE	1979-2012	monthly	T62, 192lon×94lat
	CFSR	1979-2012	monthly	1/4-1/2°lat×1/2°lon
	JRA	1979-2005	monthly	T106
Satellite	IFREMER	1992-2006	monthly	1°lat×1°lon
	HOAPS2	1987-2002	monthly	0.5°lat×0.5°lon
	J-OFURO2	1988-2006	monthly	1°lat×1°lon
Hybrid	OAFlux	1985-2011	monthly	1°lat×1°lon
	GSSTF2	1987-2000	monthly	1°lat×1°lon
	GSSTF3	1987-2008	monthly	0.25°lat×0.25°lon

- Common period: Jan. 1993 to Dec. 2000

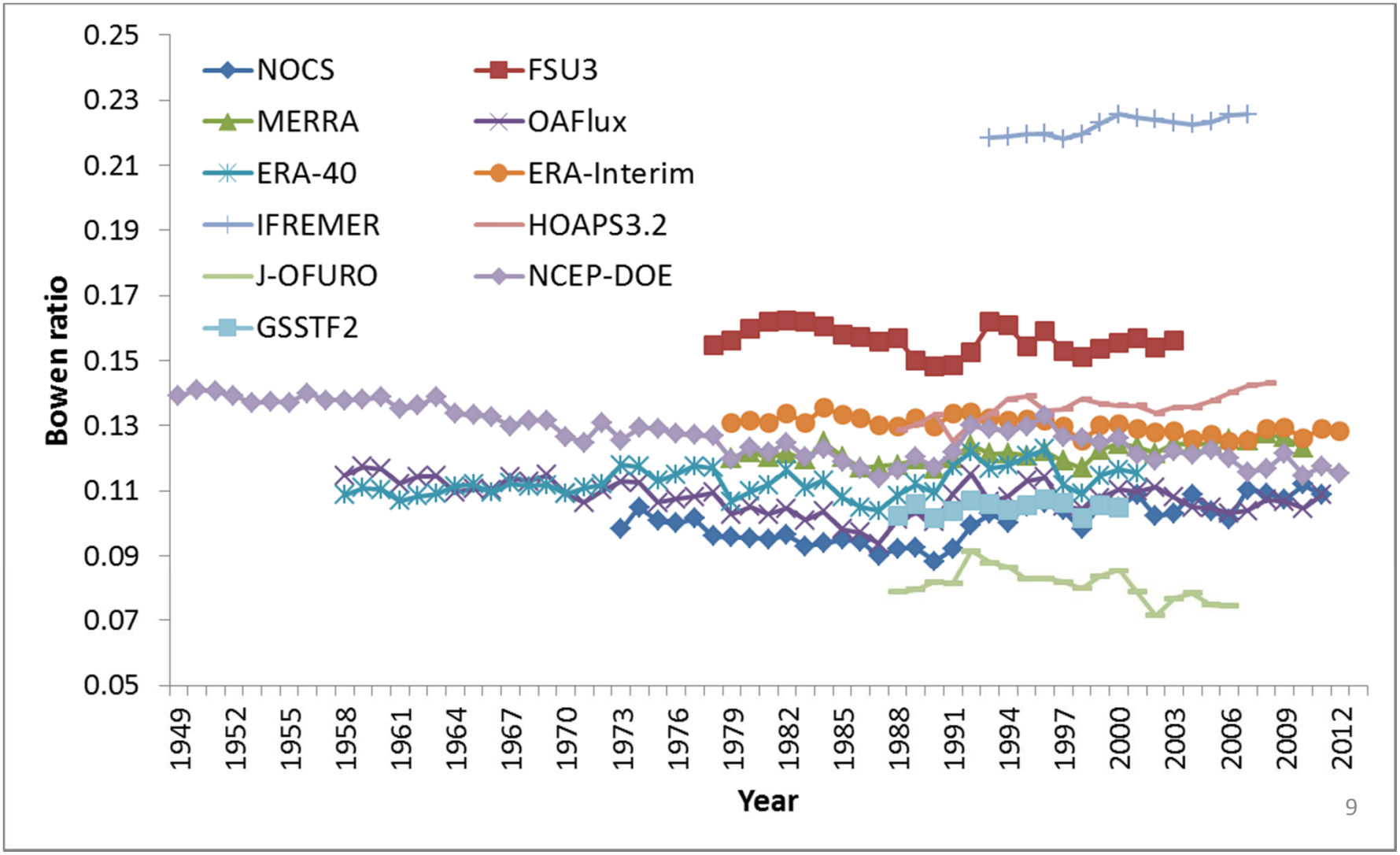
Annual mean Bowen ratio (1993-2000)



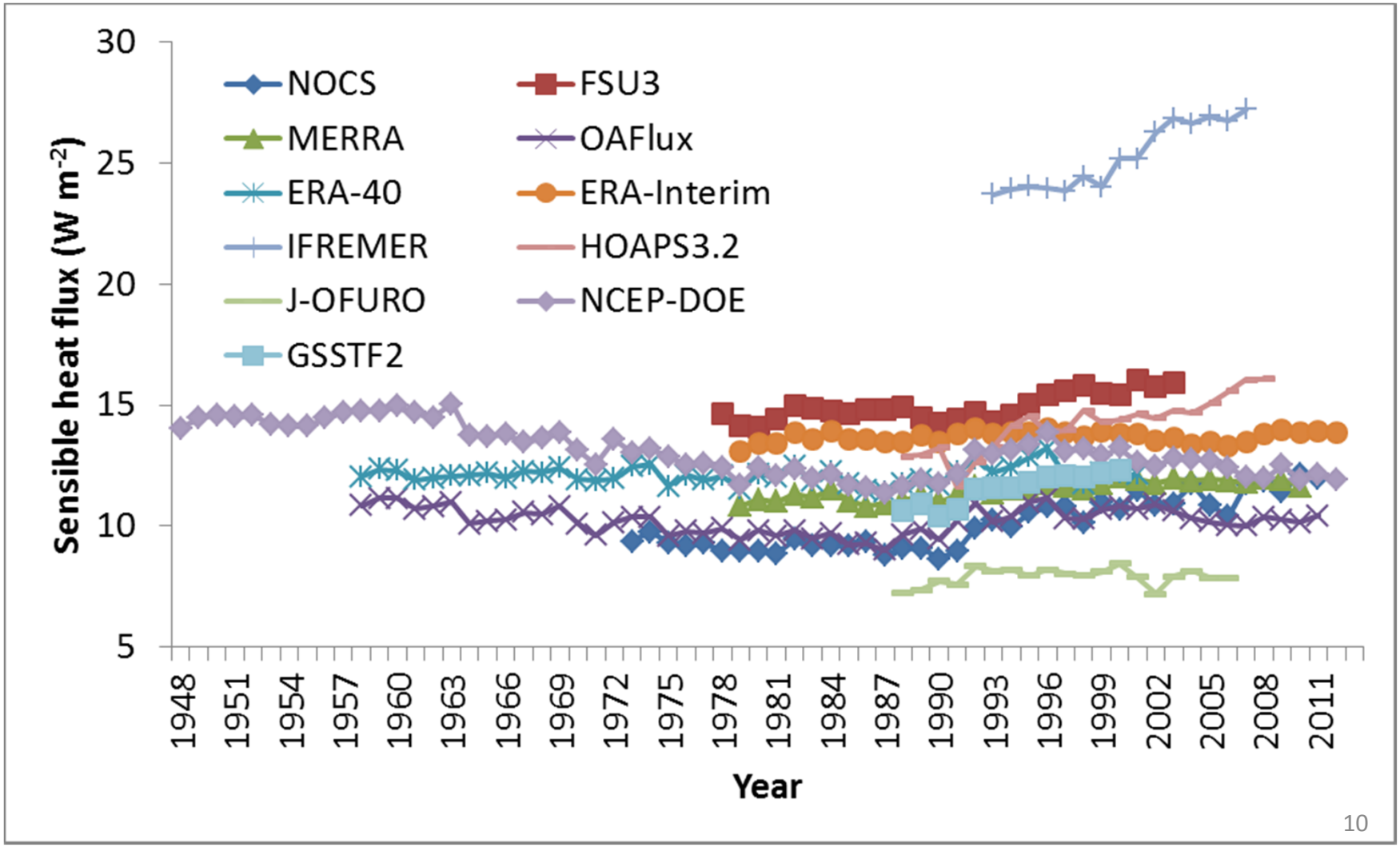

ERA-40 Bowen ratio
ERA-Interim Bowen ratio
IFREMER Bowen ratio
HOAPS3.2 Bowen ratio
80°N
40°N
0°
40°S
80°S
60°N
30°N
30°S
60°S
60°E
120°E
180°W
120°W
60°W


J-OFURO Bowen ratio
NCEP-DOE Bowen ratio
GSSTF2 Bowen ratio
80°N
40°N
0°
40°S
80°S
60°E
120°E
180°W
120°W
60°W
0°

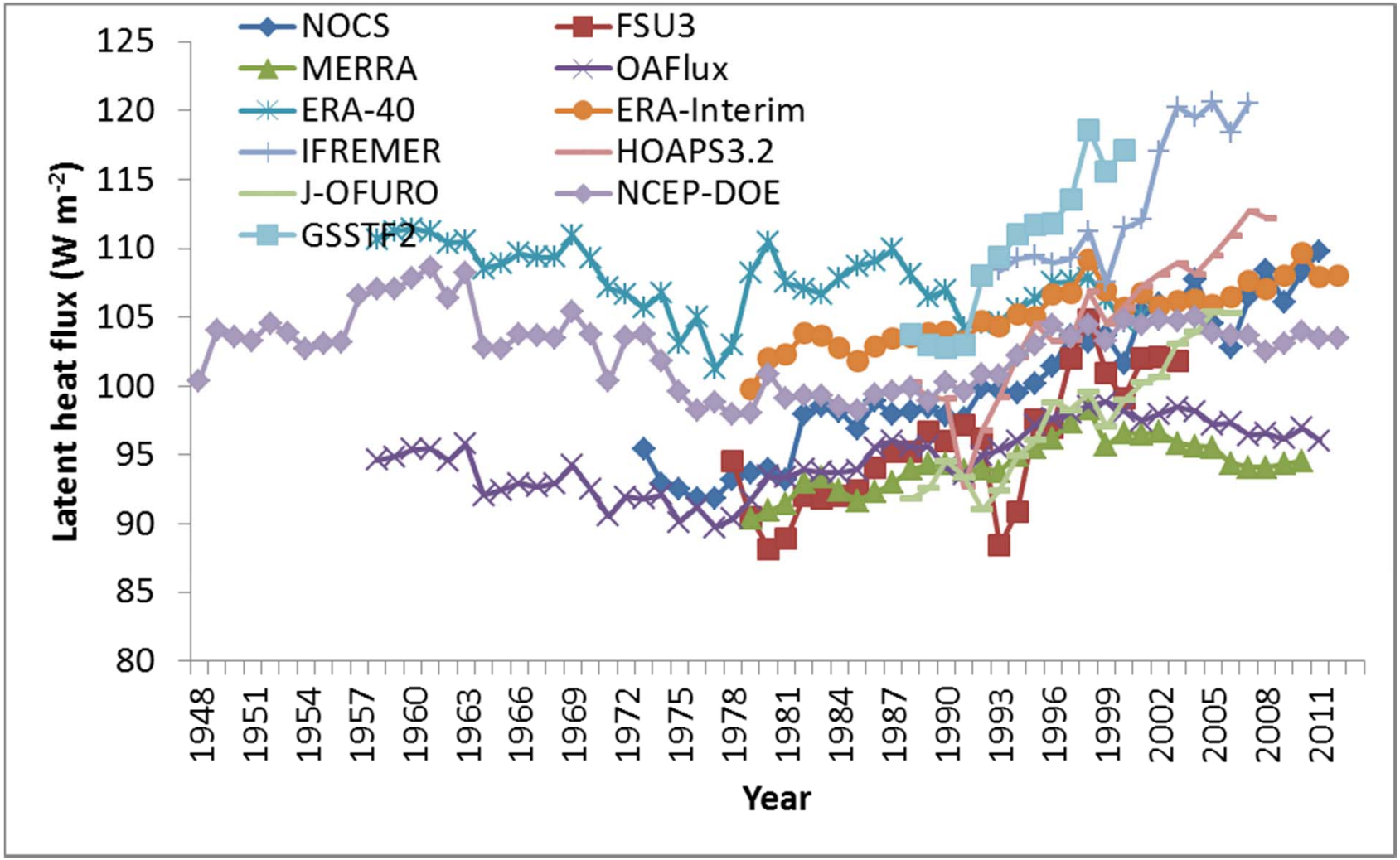
Bowen ratio time series



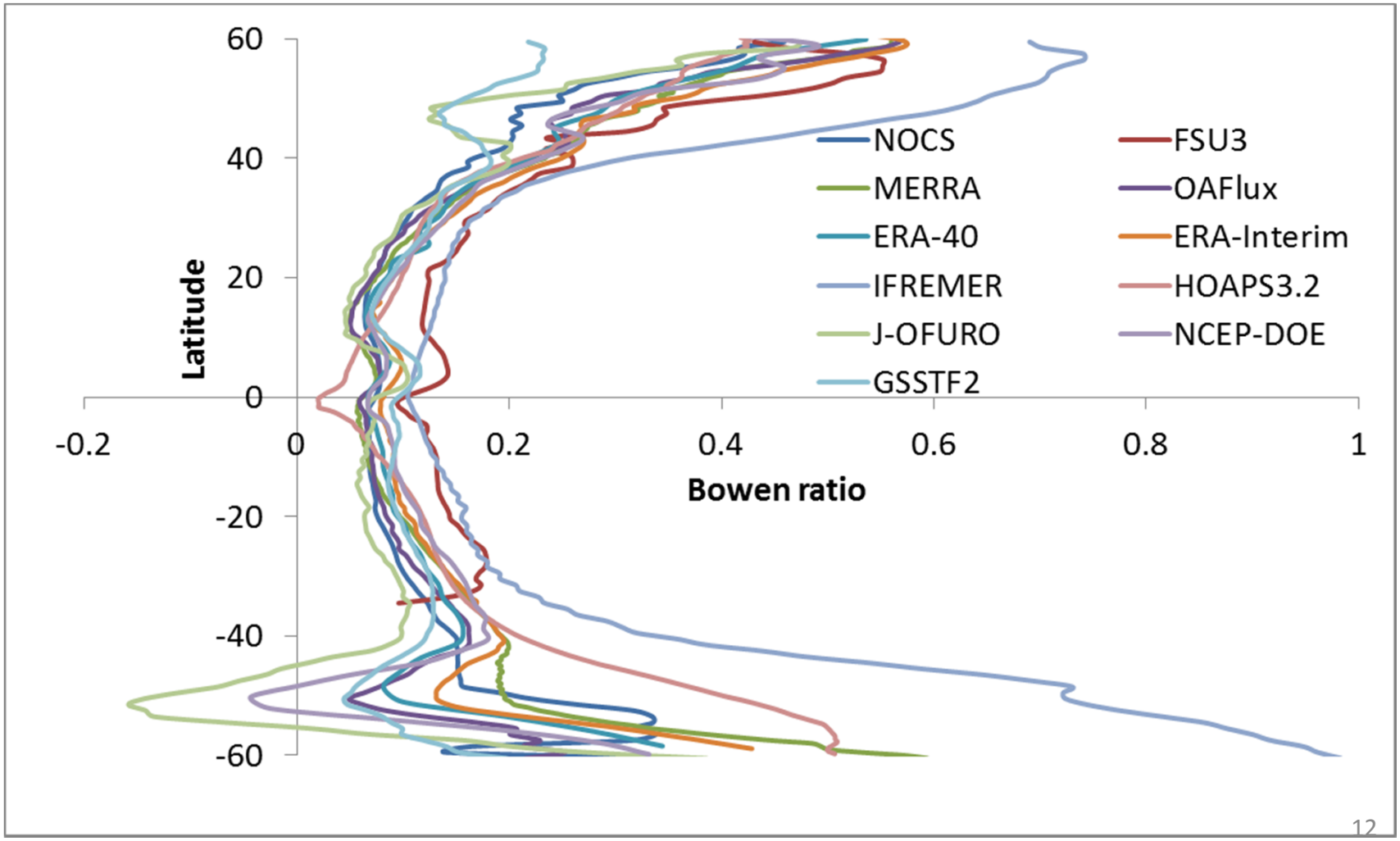
Sensible heat flux series



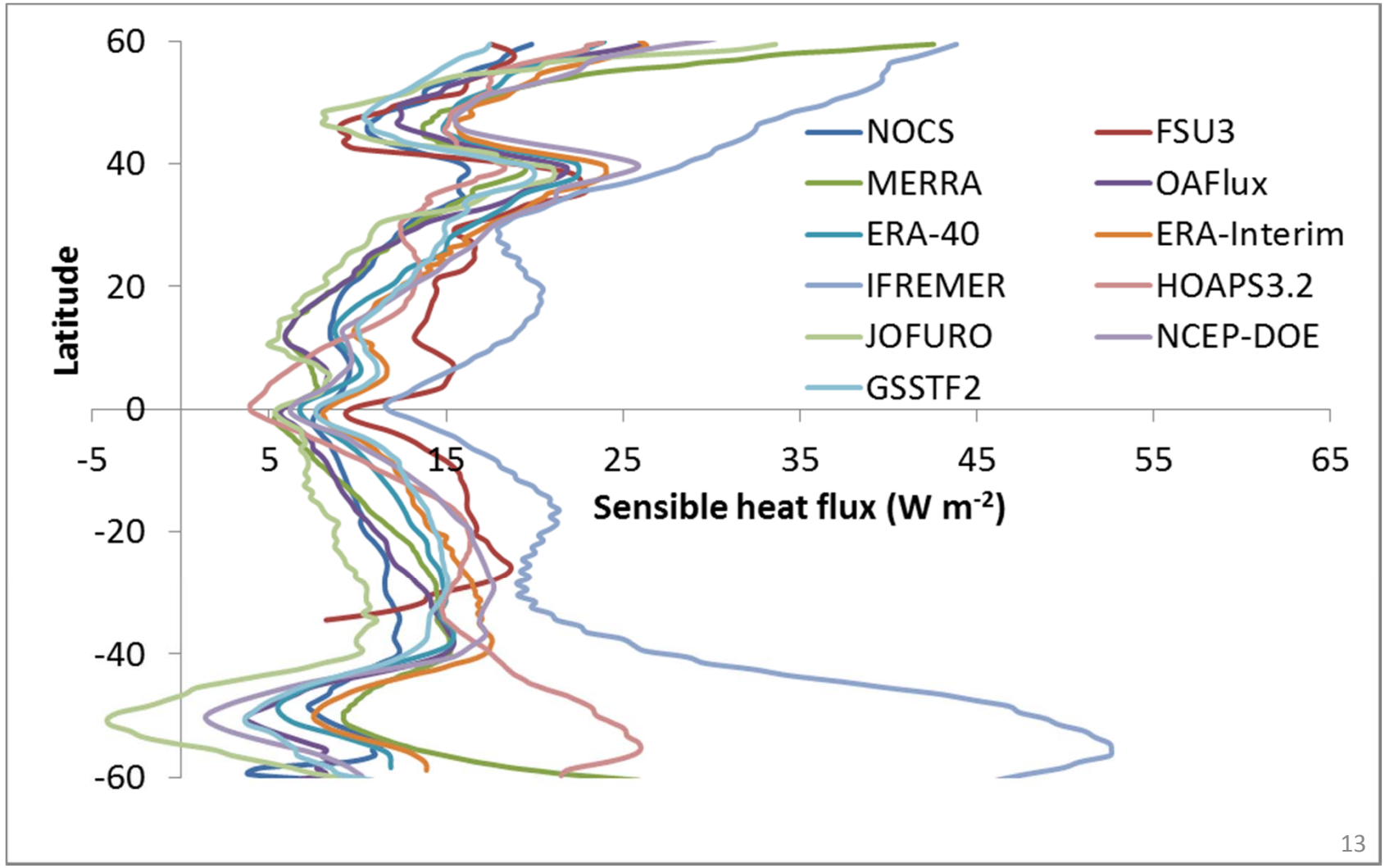
Latent heat flux series



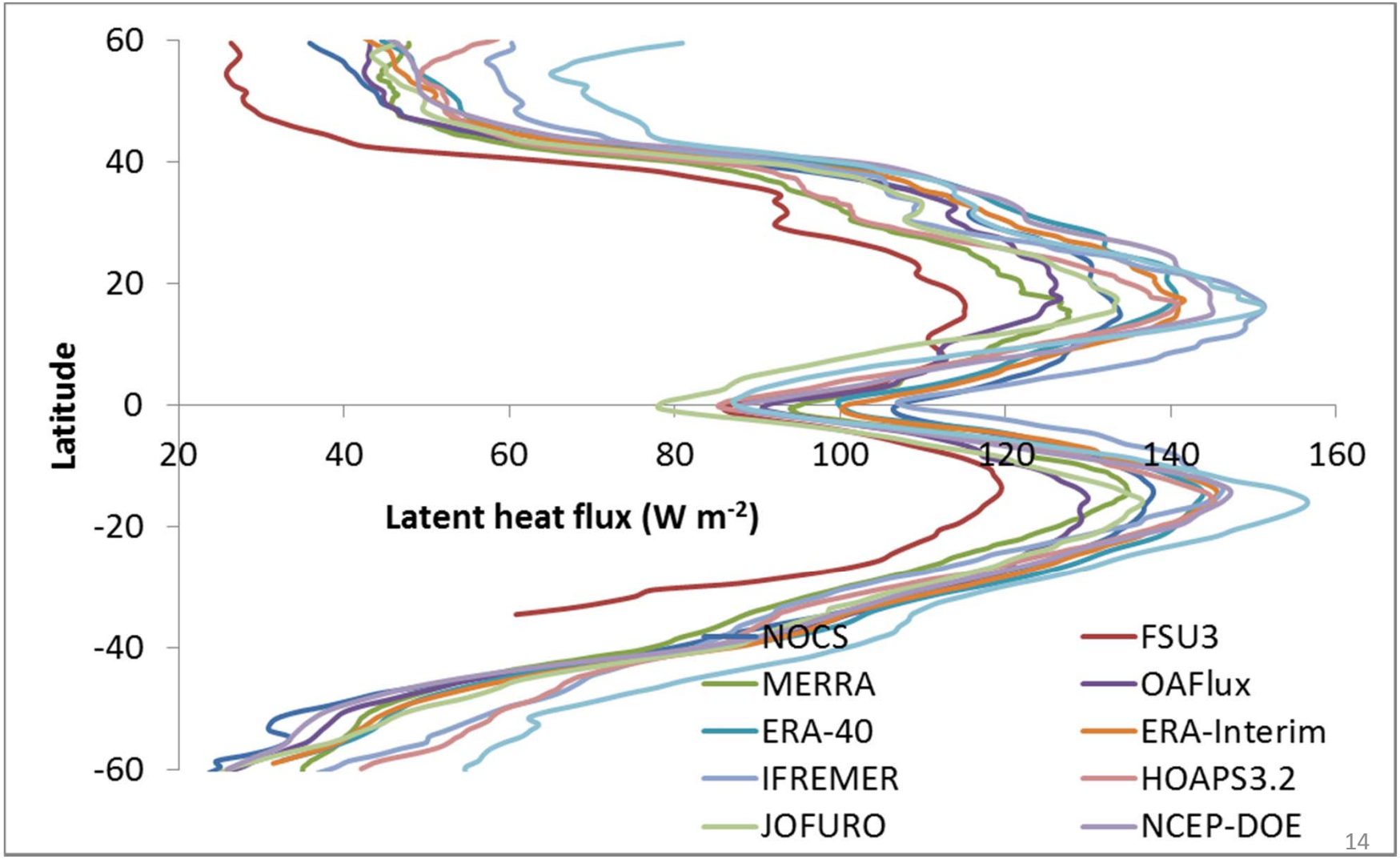
Zonal average Bowen ratio



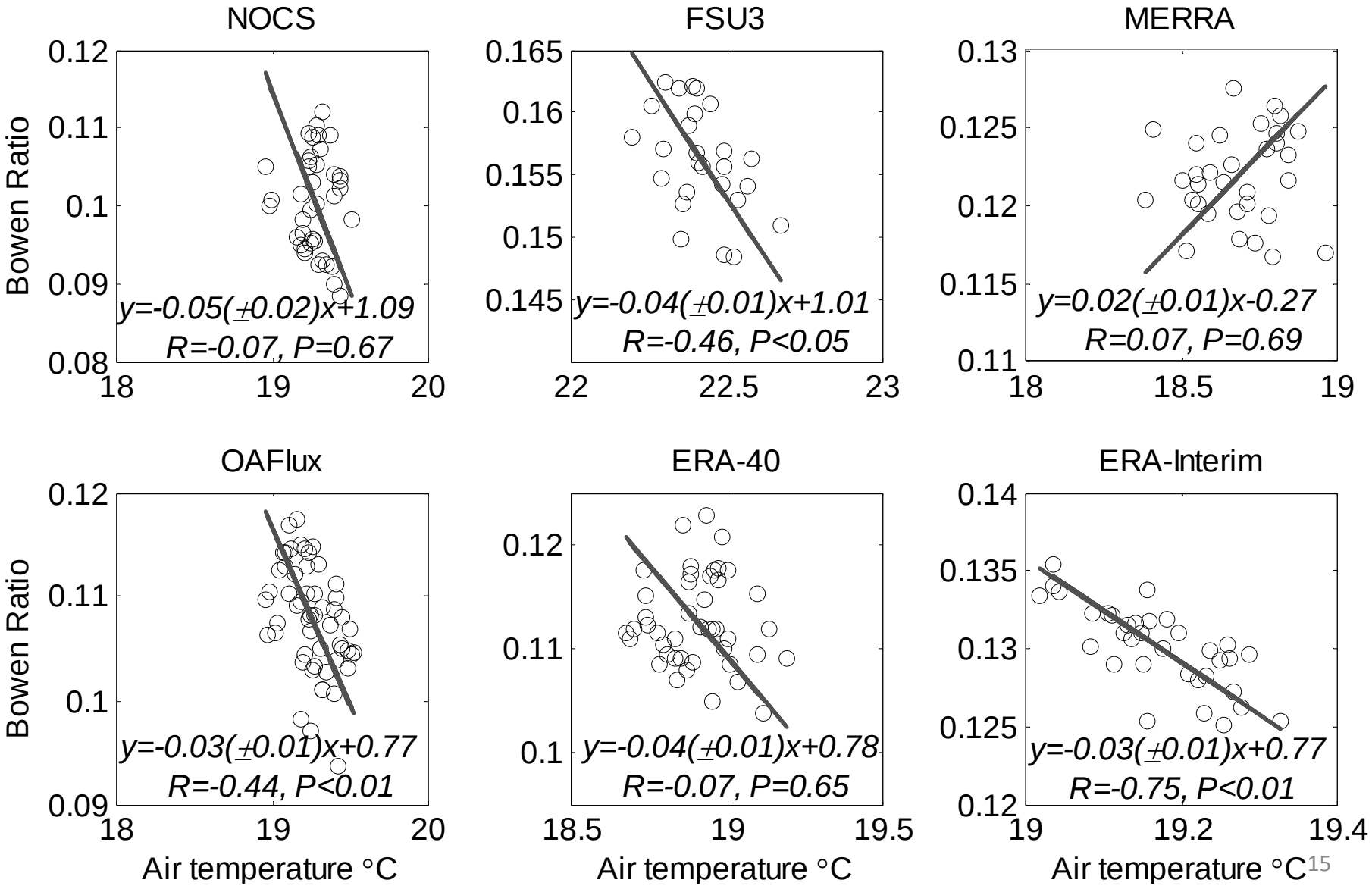
Zonal average sensible heat flux

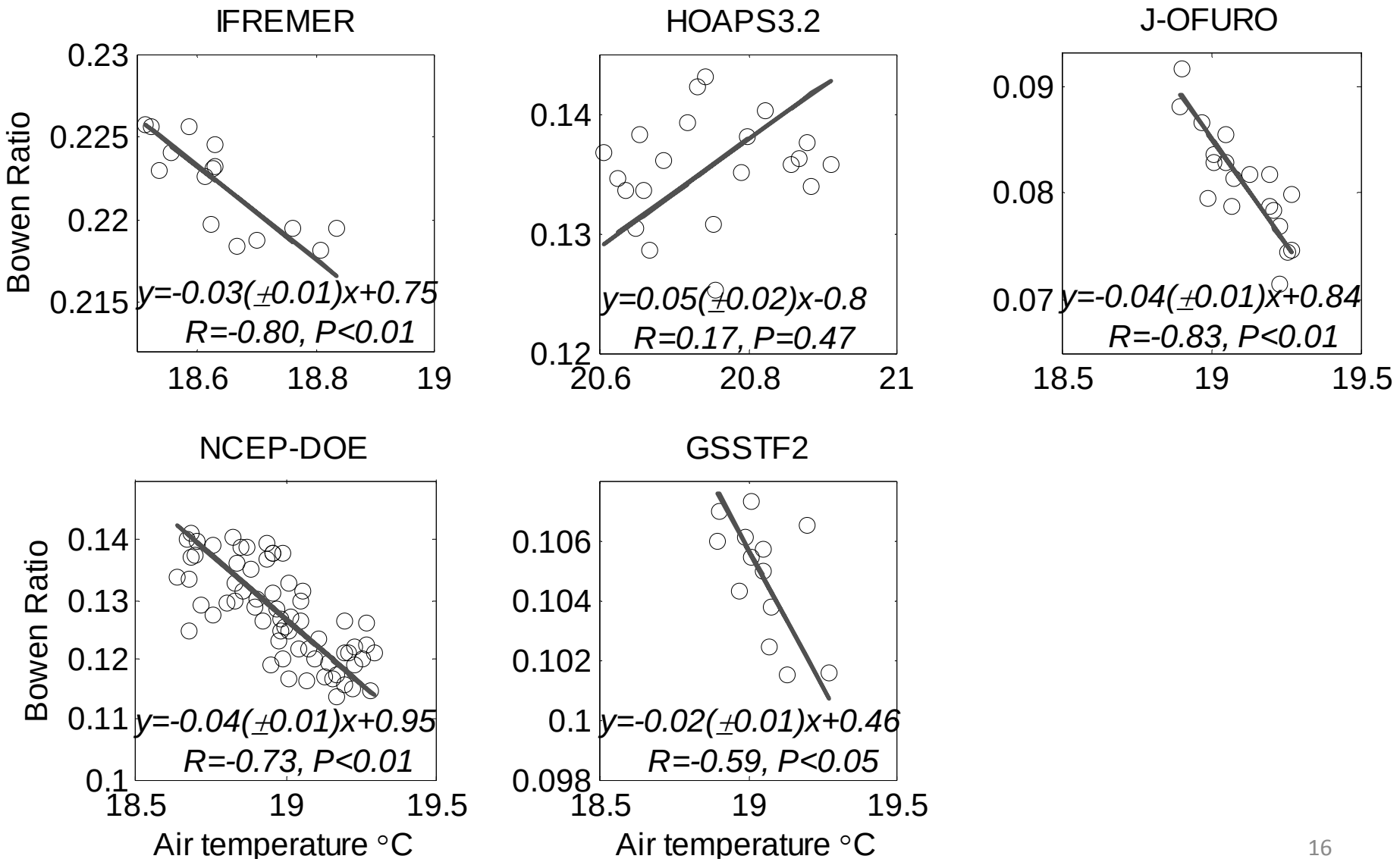


Zonal average latent heat flux



Temperature sensitivity of Bowen ratio




IFREMER
HOAPS3.2
J-OFURO
NCEP-DOE
GSSTF2
Bowen Ratio
Air temperature °C
y=-0.03(±0.01)x+0.75
R=-0.80, P<0.01
y=0.05(±0.02)x-0.8
R=0.17, P=0.47
y=-0.04(±0.01)x+0.84
R=-0.83, P<0.01
y=-0.04(±0.01)x+0.95
R=-0.73, P<0.01
y=-0.02(±0.01)x+0.46
R=-0.59, P<0.05

Summary

Products	H	λE	β	T_a	$\Delta\beta/\Delta T_a$
	W m^{-2}	**W m^{-2}**		**℃**	**per ℃**
NOCS	10.5	101.6	0.10	19.3	-0.052
FSU3	15.2	97.6	0.16	22.5	-0.038
MERRA	11.6	96.1	0.12	18.7	**0.021**
OAFlux	10.6	97.5	0.11	19.3	-0.034
ERA-40	12.4	106.3	0.12	19.0	-0.035
ERA-Interim	13.8	106.2	0.13	19.2	-0.033
IFREMER	24.1	109.4	**0.22**	18.7	-0.028
HOAPS3.2	14.2	103.7	0.14	20.7	**0.045**
J-OFURO	8.1	97.0	**0.08**	19.1	-0.040
NCEP-DOE	13.2	103.3	0.13	19.1	-0.043
GSSTF2	12.0	113.6	0.11	19.1	-0.019

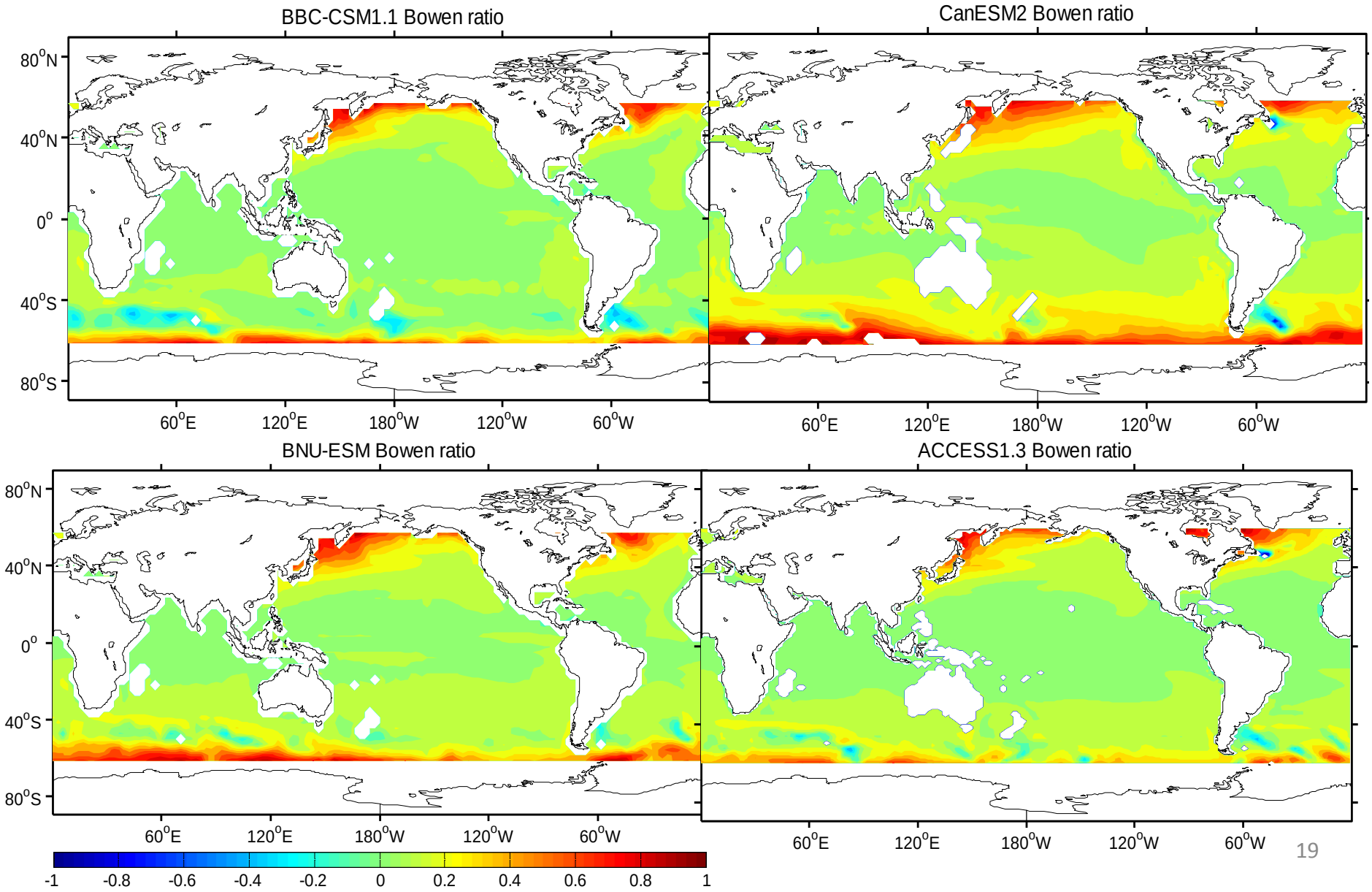
10 GCMs from CMIP5

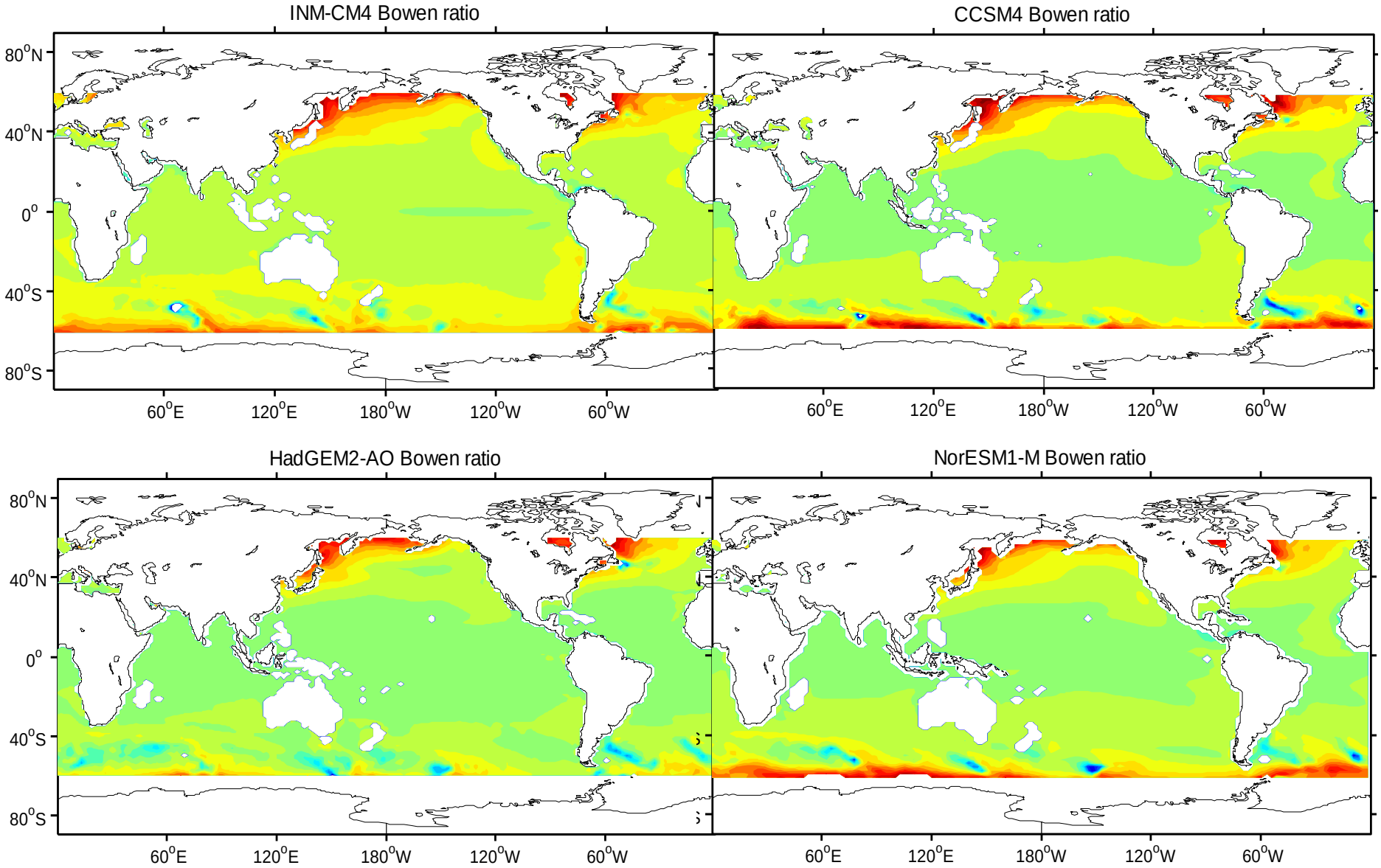
(Coupled Model Intercomparison Project Phase 5)

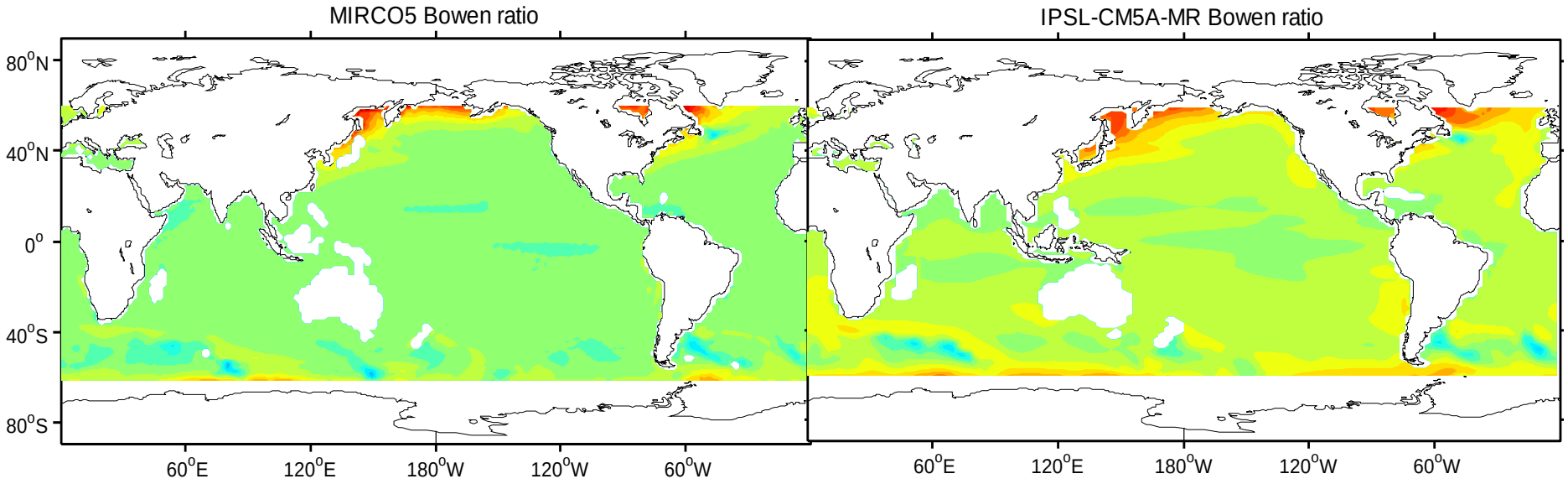
Institute ID	Model	Period	Temporal resolution	lon×lat
BCC	BCC-CSM1.1	2006-2099	monthly	128×64
CCCMA	CanESM2	2006-2099	monthly	128×64
GCESS	BNU-ESM	2006-2099	monthly	128×64
CSIRO-BOM	ACCESS1.3	2006-2099	monthly	192×145
INM	INM-CM4	2006-2099	monthly	180×120
NCAR	CCSM4	2006-2099	monthly	288×192
NIMR/KMA	HadGEM2-AO	2006-2099	monthly	192×145
NCC	NorESM1-M	2006-2099	monthly	144×96
MIROC	MIROC5	2006-2099	monthly	256×128
IPSL	IPSL-CM5A-MR	2006-2099	monthly	144×143

(http://cmip-pcmdi.llnl.gov/cmip5/)

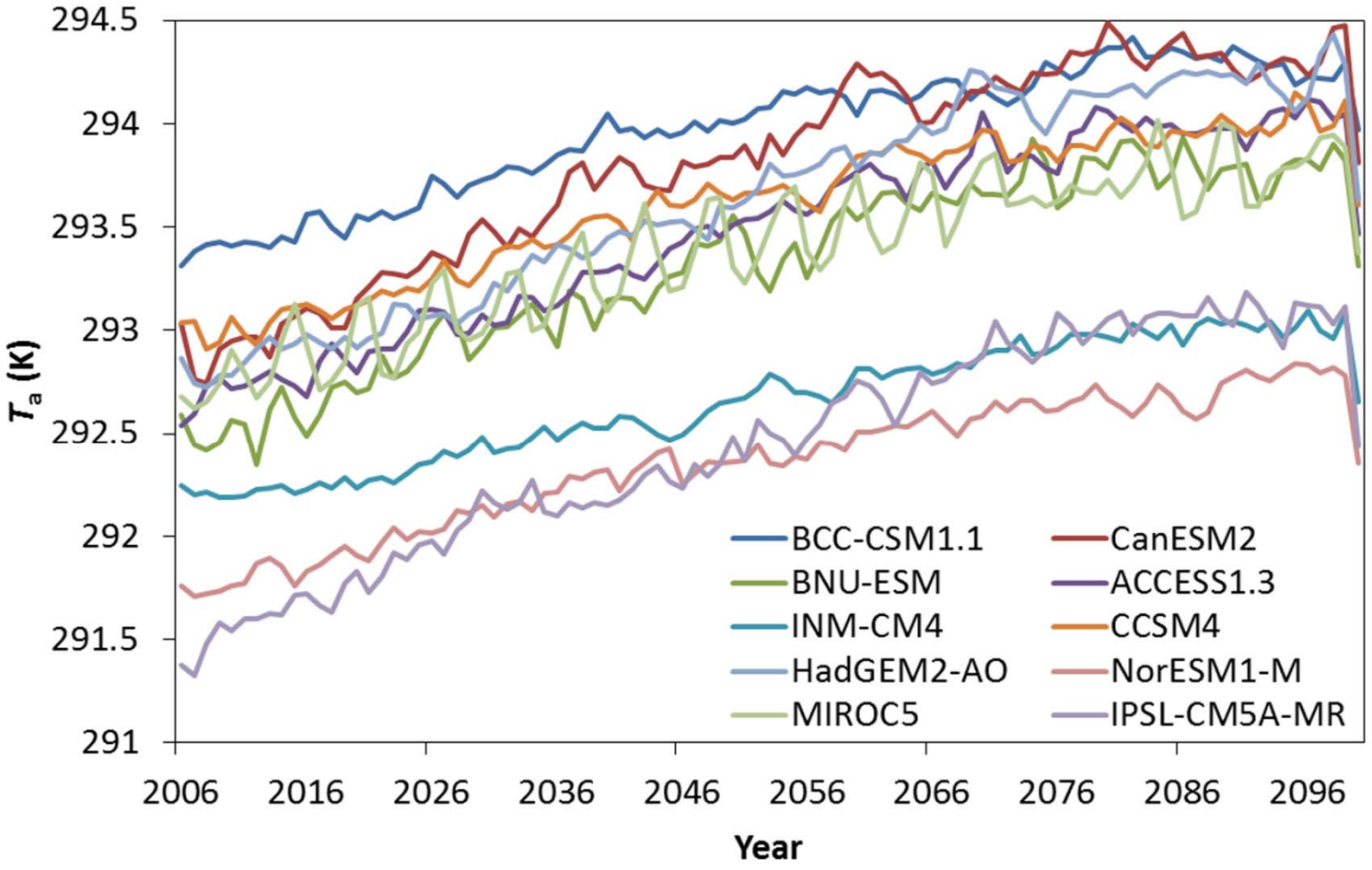
Annual mean Bowen ratio (2006-2099)



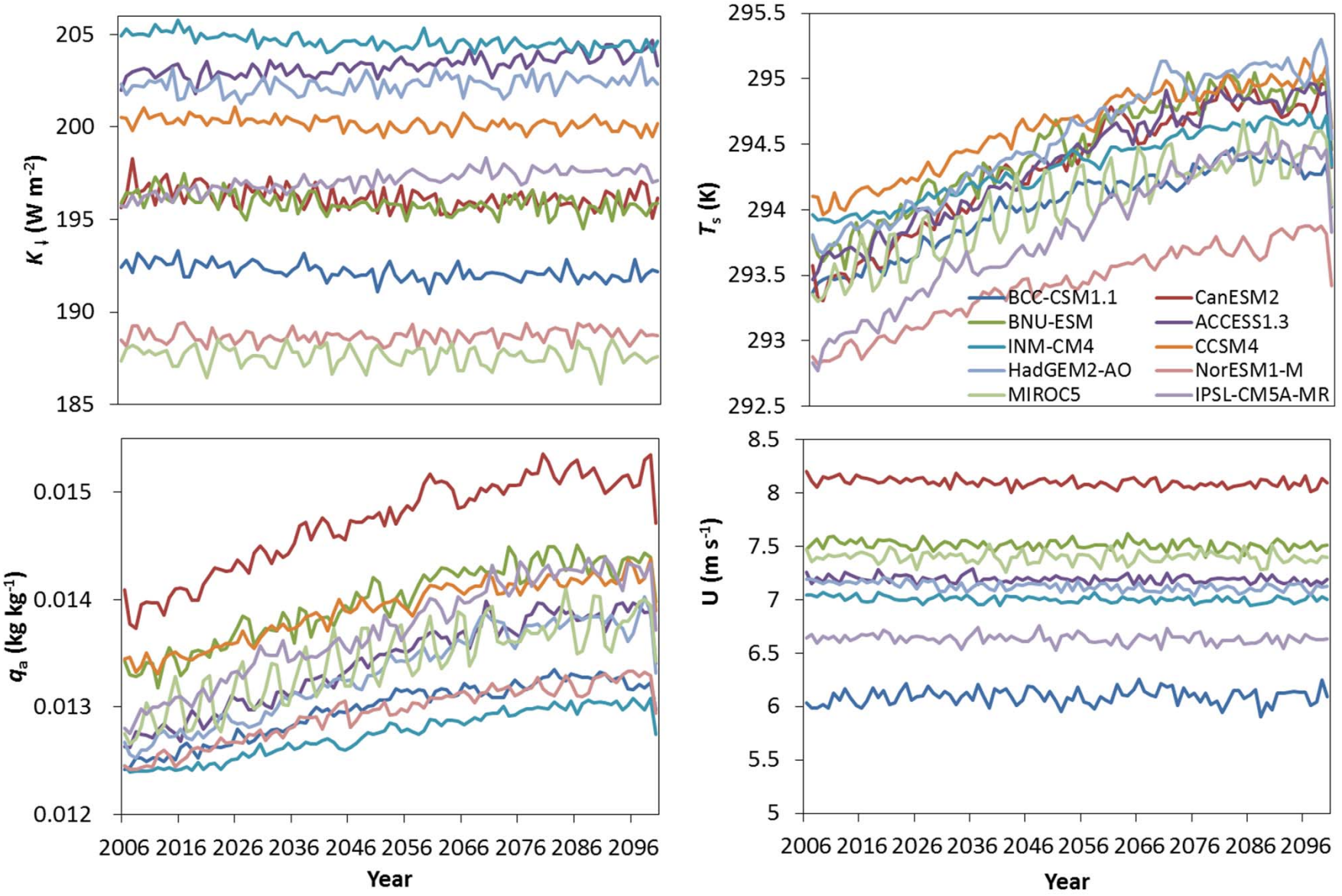

INM-CM4 Bowen ratio
CCSM4 Bowen ratio
HadGEM2-AO Bowen ratio
NorESM1-M Bowen ratio
80°N
40°N
0°
40°S
80°S
60°E
120°E
180°W
120°W
60°W


MIRCO5 Bowen ratio
IPSL-CM5A-MR Bowen ratio
80°N
40°N
0°
40°S
80°S
60°E
120°E
180°W
120°W
60°W
60°E
120°E
180°W
120°W
60°W

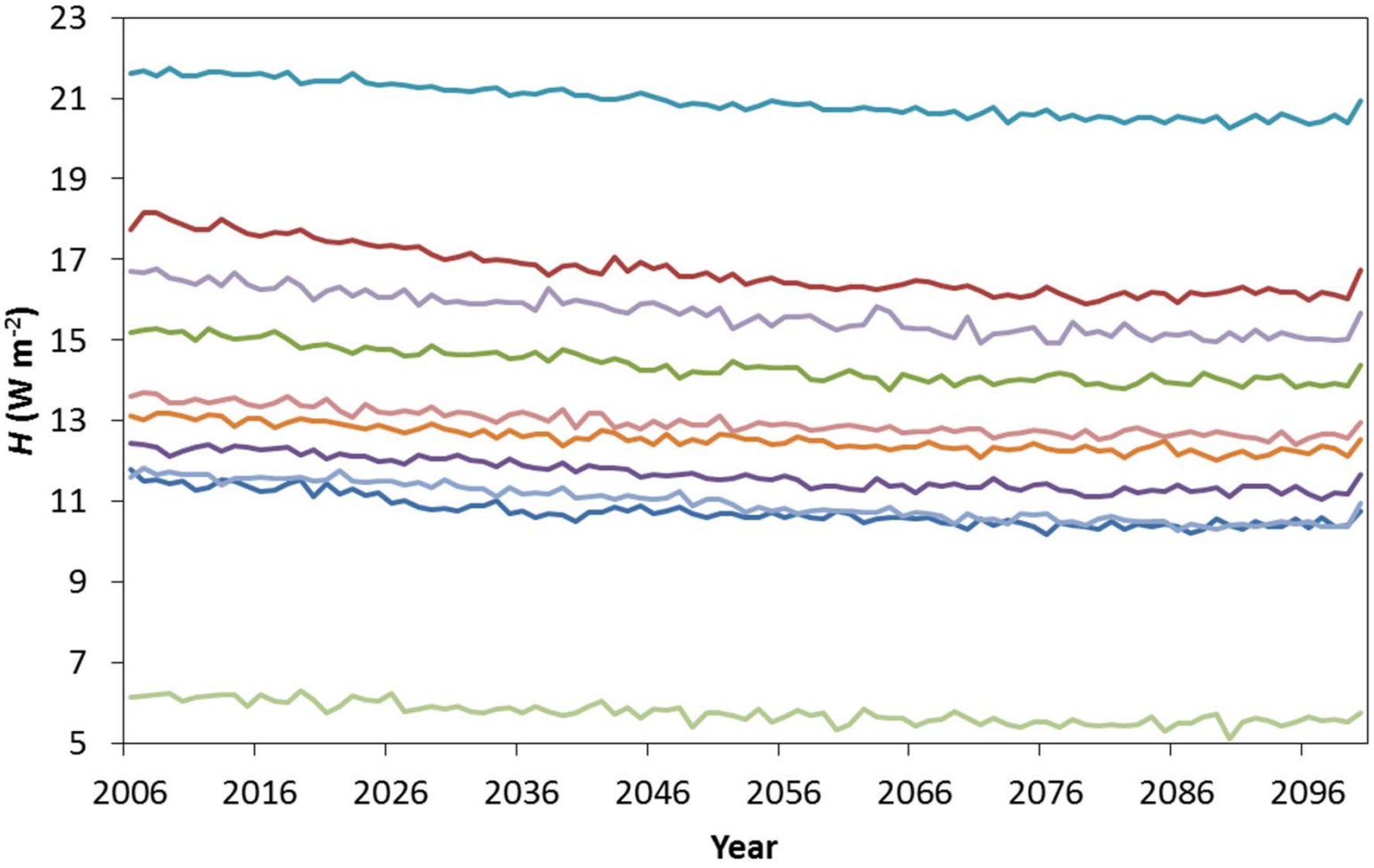
Air temperature series



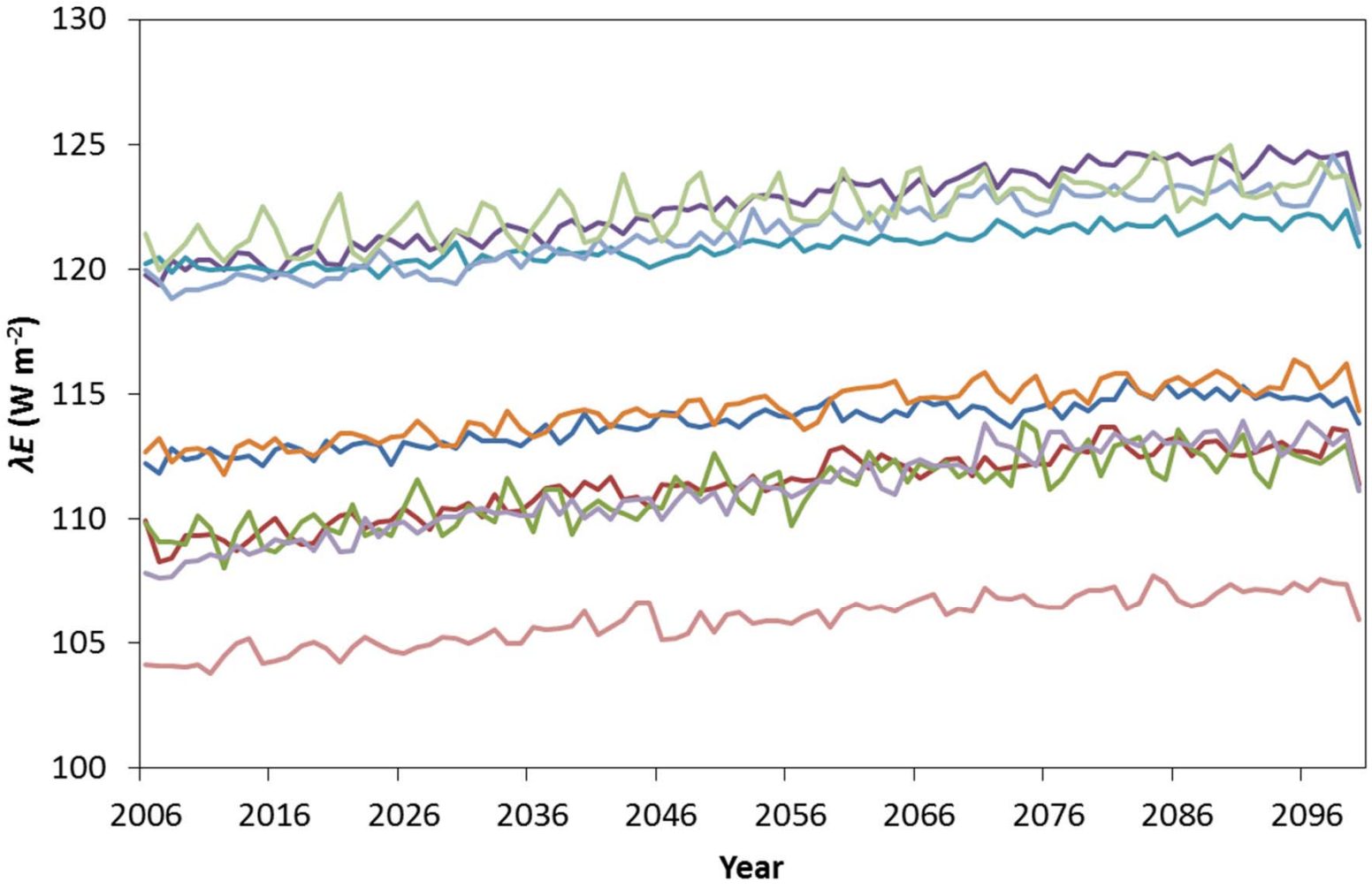
Bulk variables series



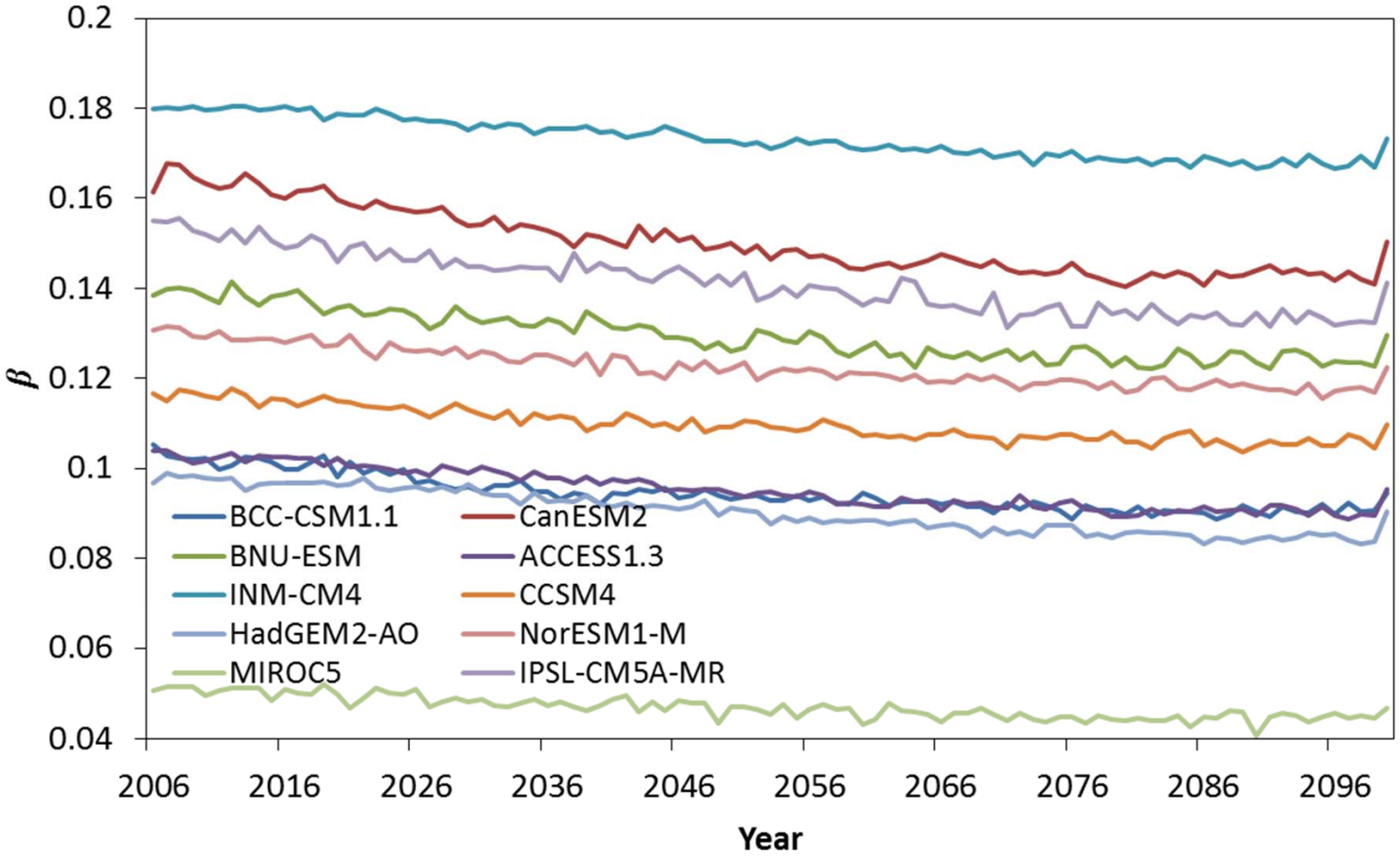
Sensible heat flux series



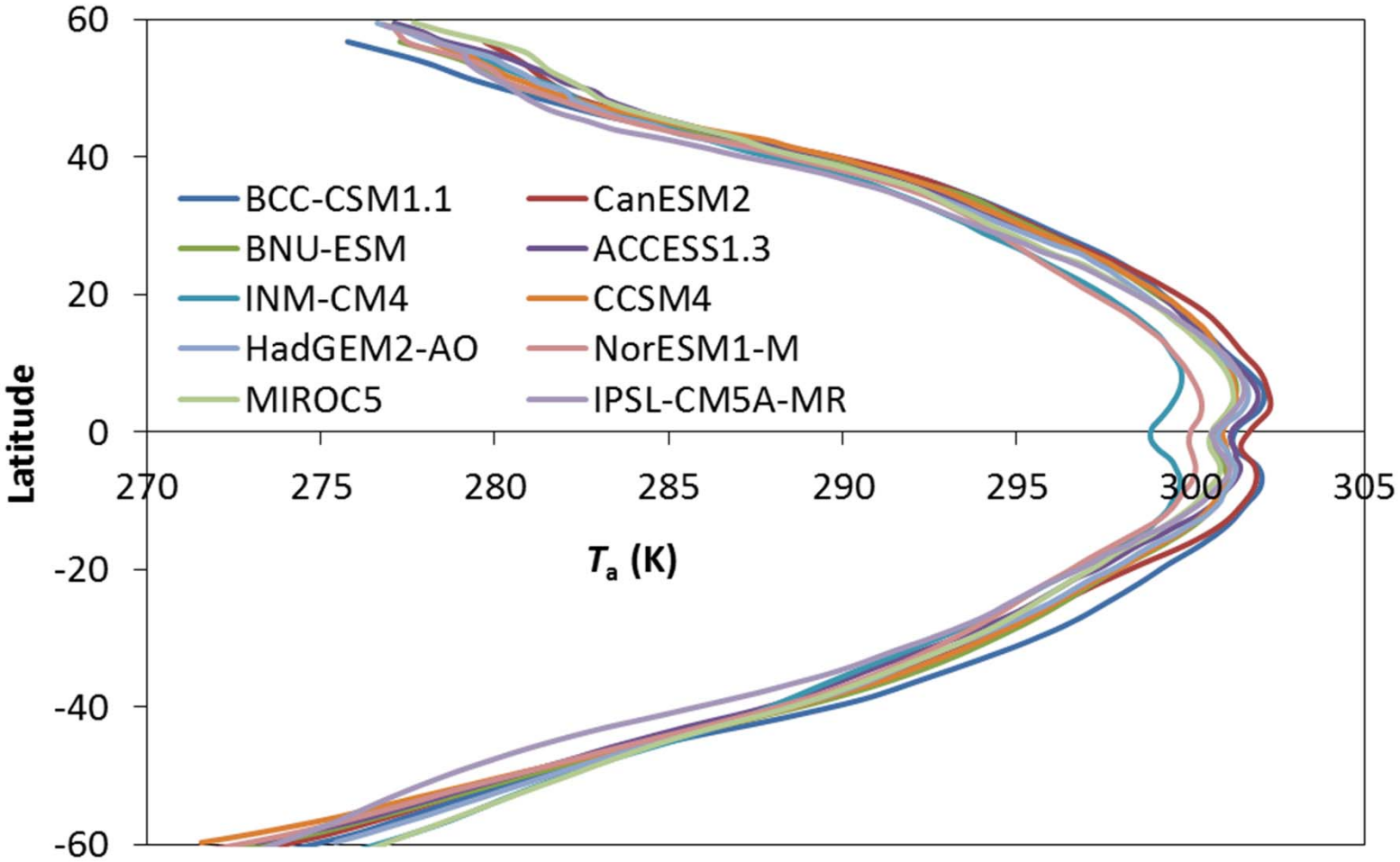
Latent heat flux series



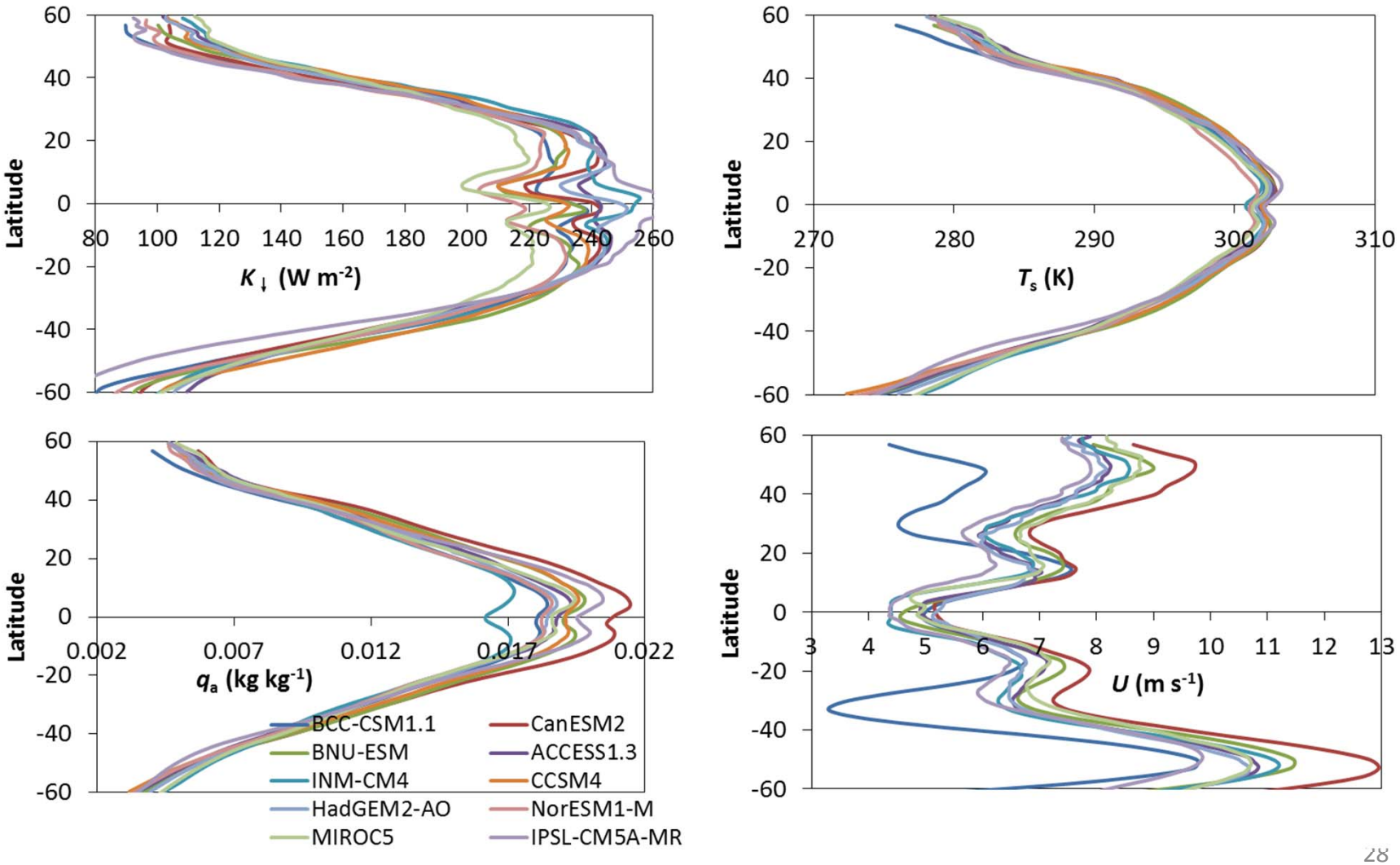
Bowen ratio series



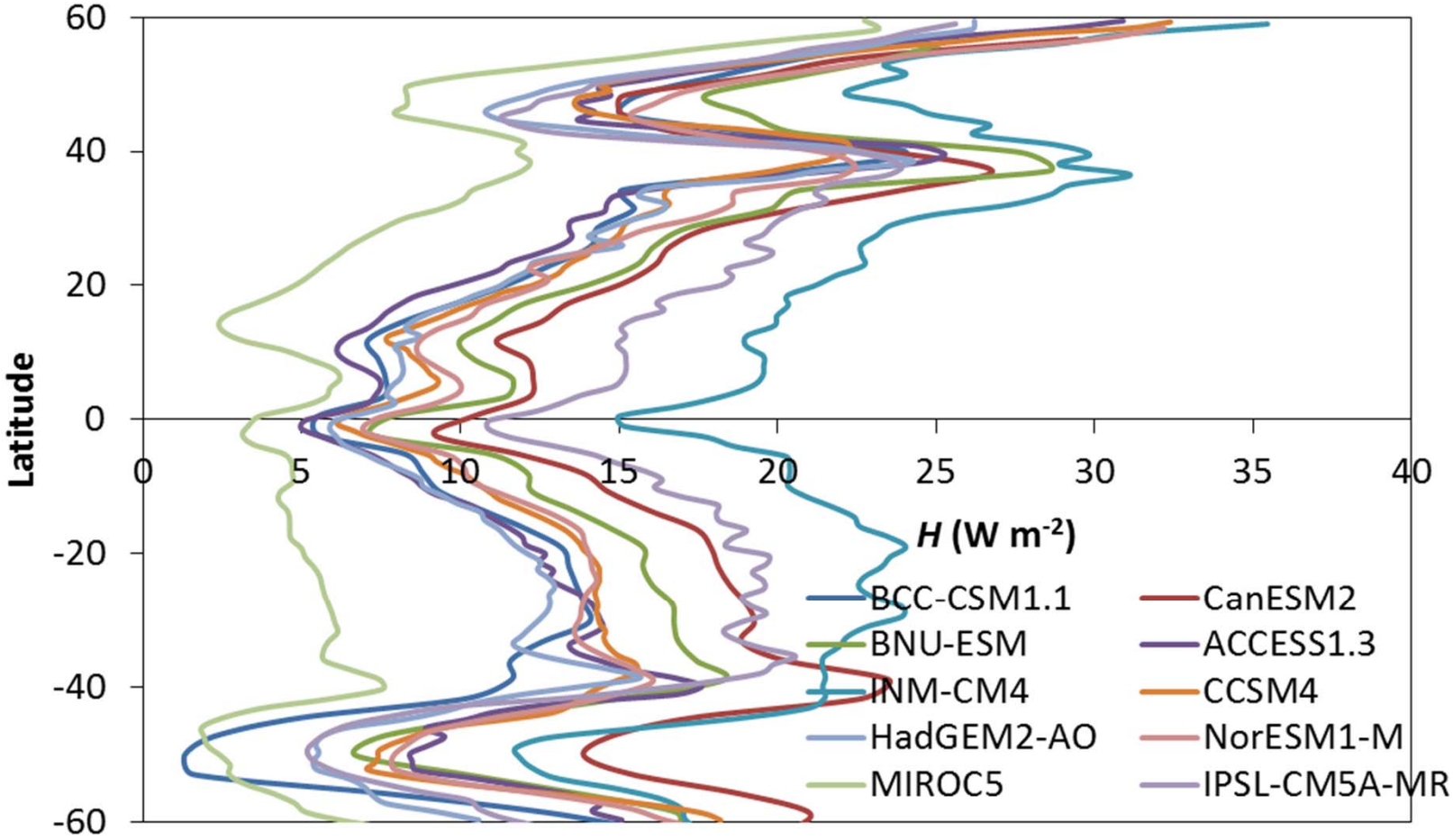
Zonal average air temperature



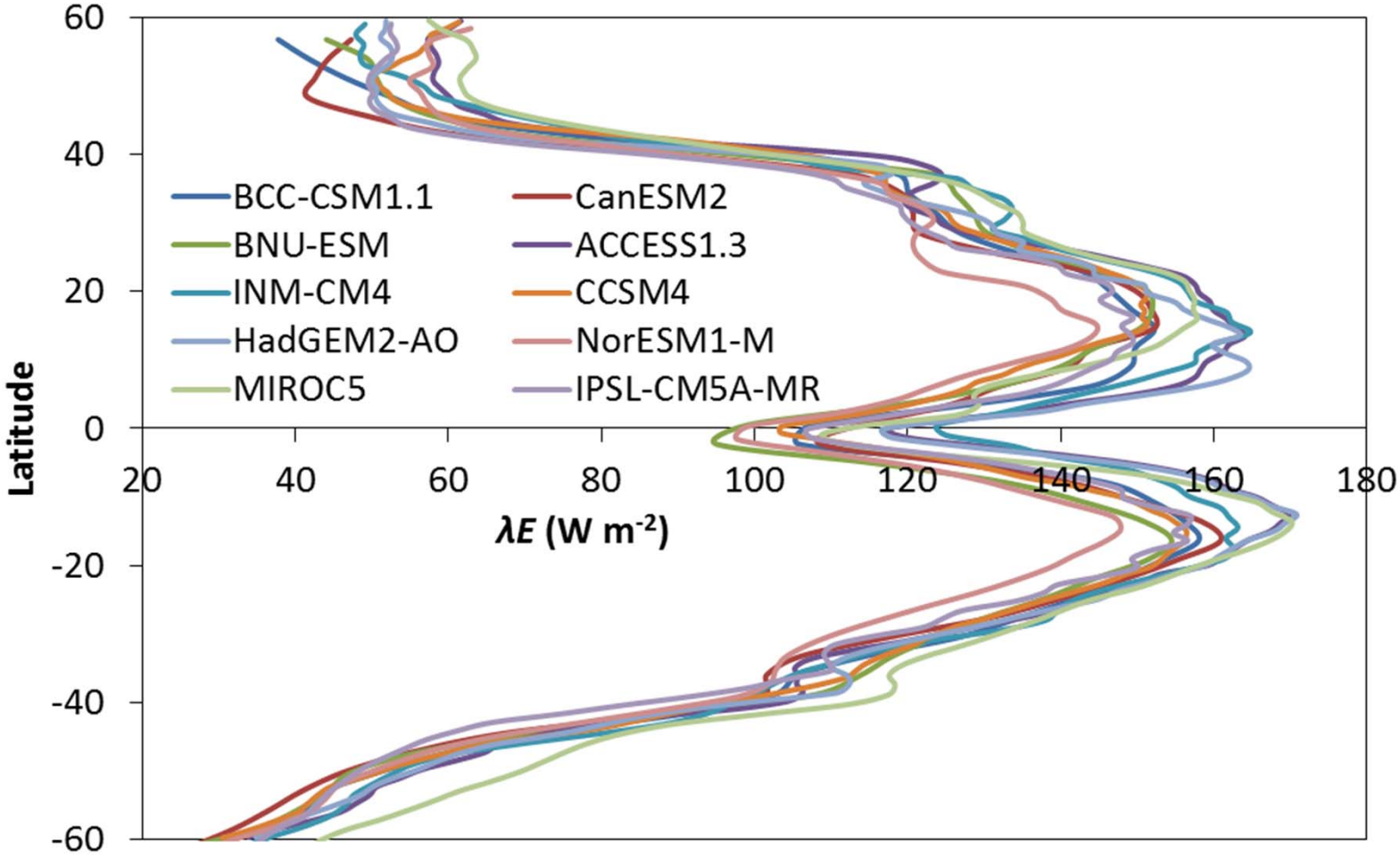
Zonal average of other bulk variables



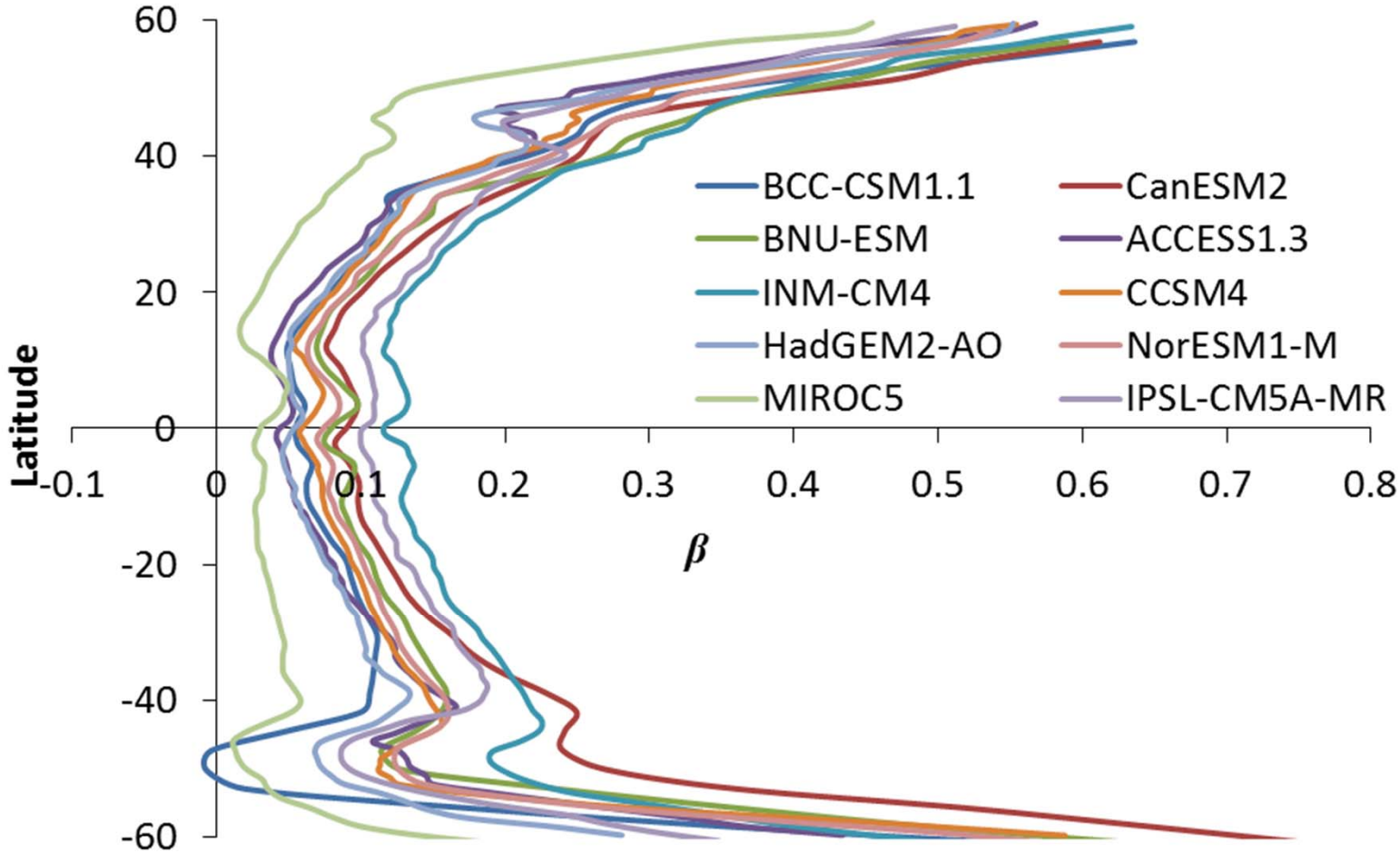
Zonal average sensible heat flux



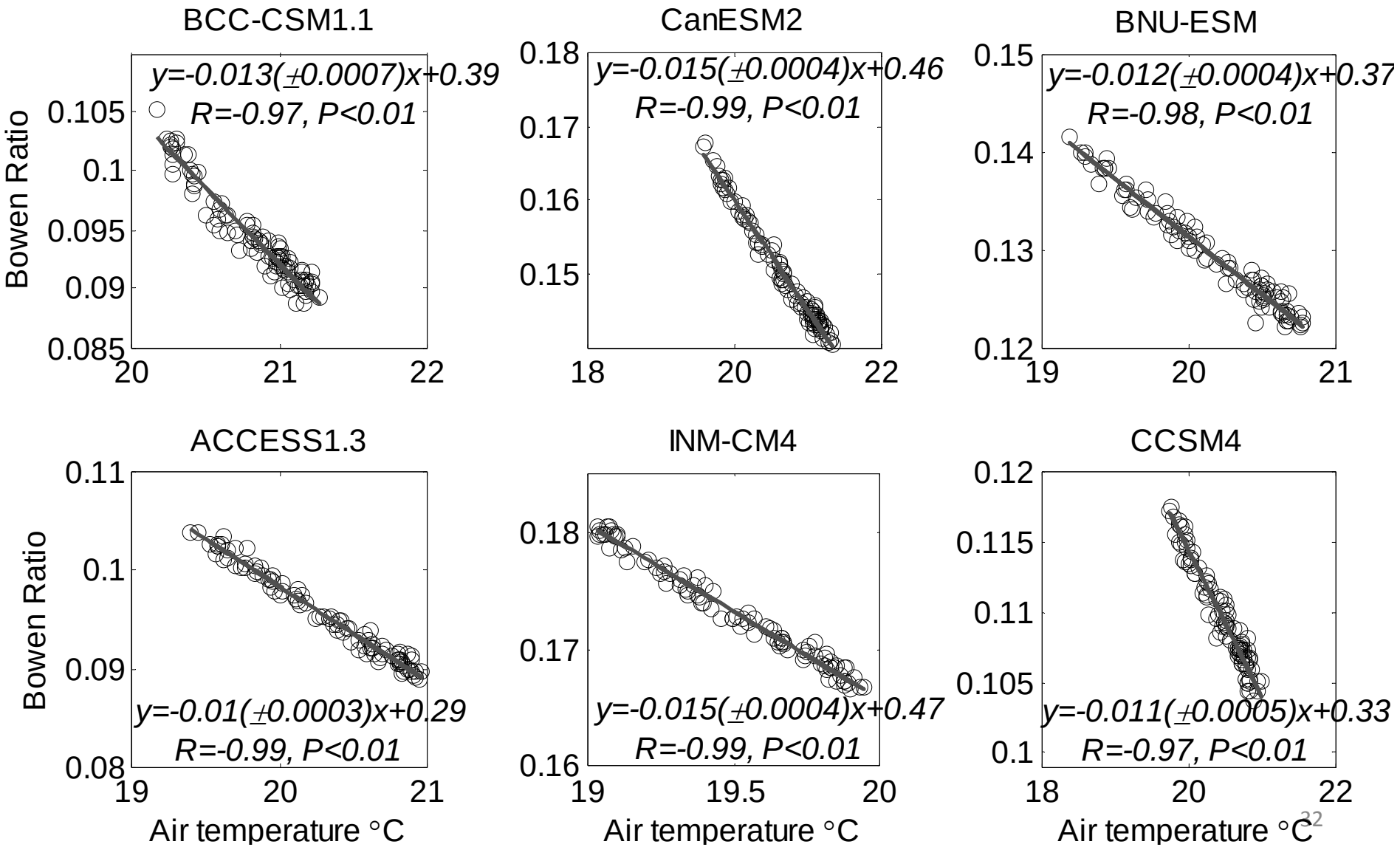
Zonal average latent heat flux

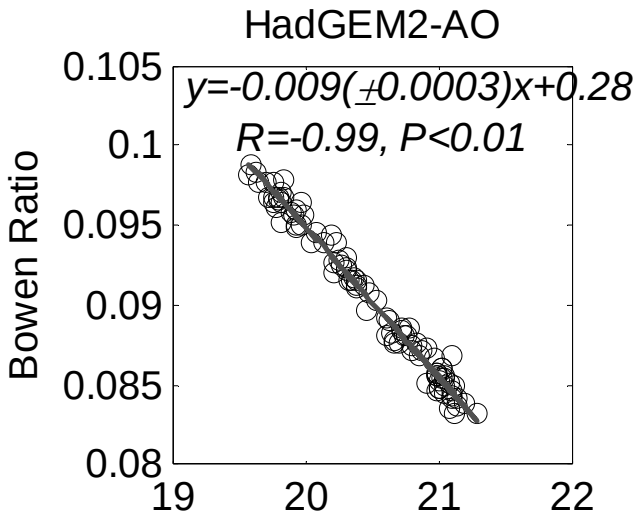


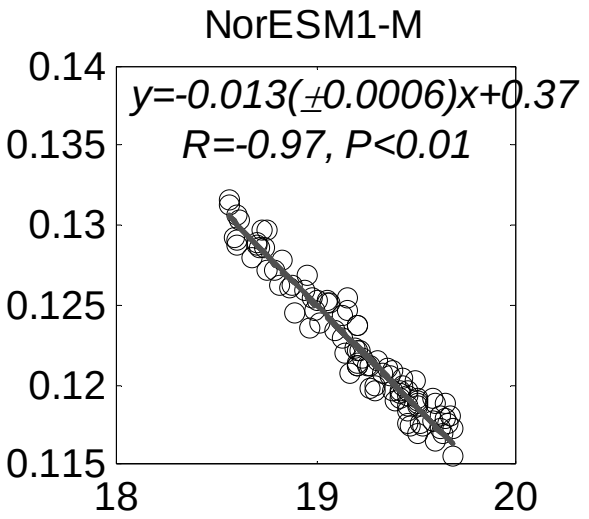
Zonal average Bowen ratio

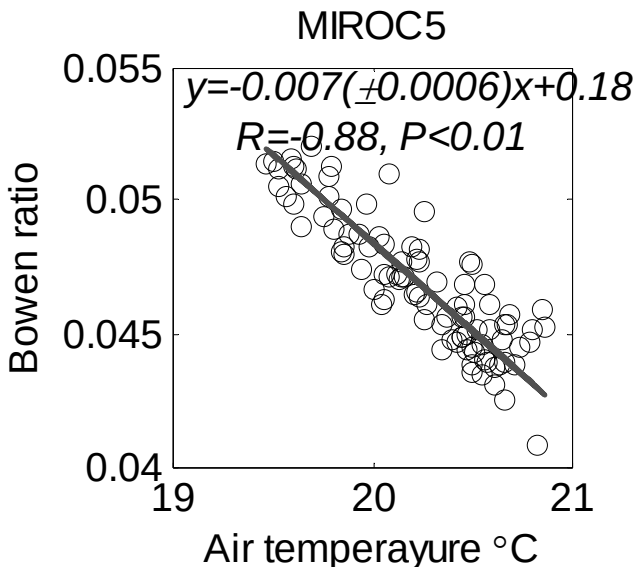


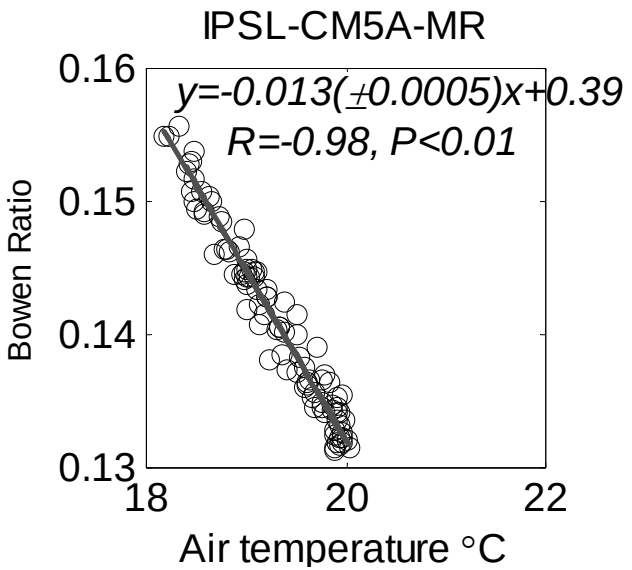
Temperature sensitivity of Bowen ratio




HadGEM2-AO
y=-0.009(±0.0003)x+0.28
R=-0.99, P<0.01
Bowen Ratio
0.105
0.1
0.095
0.09
0.085
0.08
19
20
21
22


NorESM1-M
y=-0.013(±0.0006)x+0.37
R=-0.97, P<0.01
0.14
0.135
0.13
0.125
0.12
0.115
18
19
20


MIROC5
y=-0.007(±0.0006)x+0.18
R=-0.88, P<0.01
Bowen ratio
0.055
0.05
0.045
0.04
19
20
21
Air temperayure °C


IPSL-CM5A-MR
y=-0.013(±0.0005)x+0.39
R=-0.98, P<0.01
Bowen Ratio
0.16
0.15
0.14
0.13
18
20
22
Air temperature °C

Summary

GCM models	T_a	T_s	q_a	U	K	H	λE	β	$\Delta\beta/\Delta T_a$
	K	K	kg kg^{-1}	m s^{-1}	W m^{-2}	W m^{-2}	W m^{-2}		per℃
BCC-CSM1.1	294.0	294.0	0.012	6.1	192.2	10.7	113.8	0.09	-0.013
CanESM2	293.8	294.3	0.014	8.1	196.2	16.7	111.4	0.15	-0.015
BNU-ESM	293.3	294.5	0.013	7.5	195.9	14.4	111.1	0.13	-0.012
ACCESS1.3	293.5	294.4	0.013	7.2	203.3	11.7	122.5	0.10	-0.010
INM-CM4	292.7	294.3	0.012	7.0	204.6	20.9	120.9	0.17	-0.015
CCSM4	293.6	294.6	0.013	/	200.2	12.5	114.3	0.11	-0.011
HadGEM2-AO	293.6	294.5	0.013	7.1	202.3	11.0	121.5	0.09	-0.009
NorESM1-M	292.4	293.4	0.012	/	188.7	13.0	105.9	0.12	-0.013
MIROC5	293.4	294.0	0.013	7.4	187.6	5.7	122.4	**0.05**	-0.007
IPSL-CM5A-MR	292.4	293.8	0.013	6.6	197.1	15.7	111.1	0.14	-0.013

Next steps

- Point-wise correlation between ocean Bowen ratio and air temperature.
- Reasons for biases or uncertainty of Bowen ratio among products.
- Diversities in GCMs performance of modeling Bowen ratio and its temperature sensitivity.