Impacts of CO_2 concentration and climate change on NPP and NEP by six coupled models

Focusing on:

- What does climate change influence net primary production(NPP), net ecosystem production (NEP)?
- What does NPP and NEP respond to rising CO_2 ?
- Which determines the terrestrial carbon sink or source? (increasing CO_2 or climate change)

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Introduction

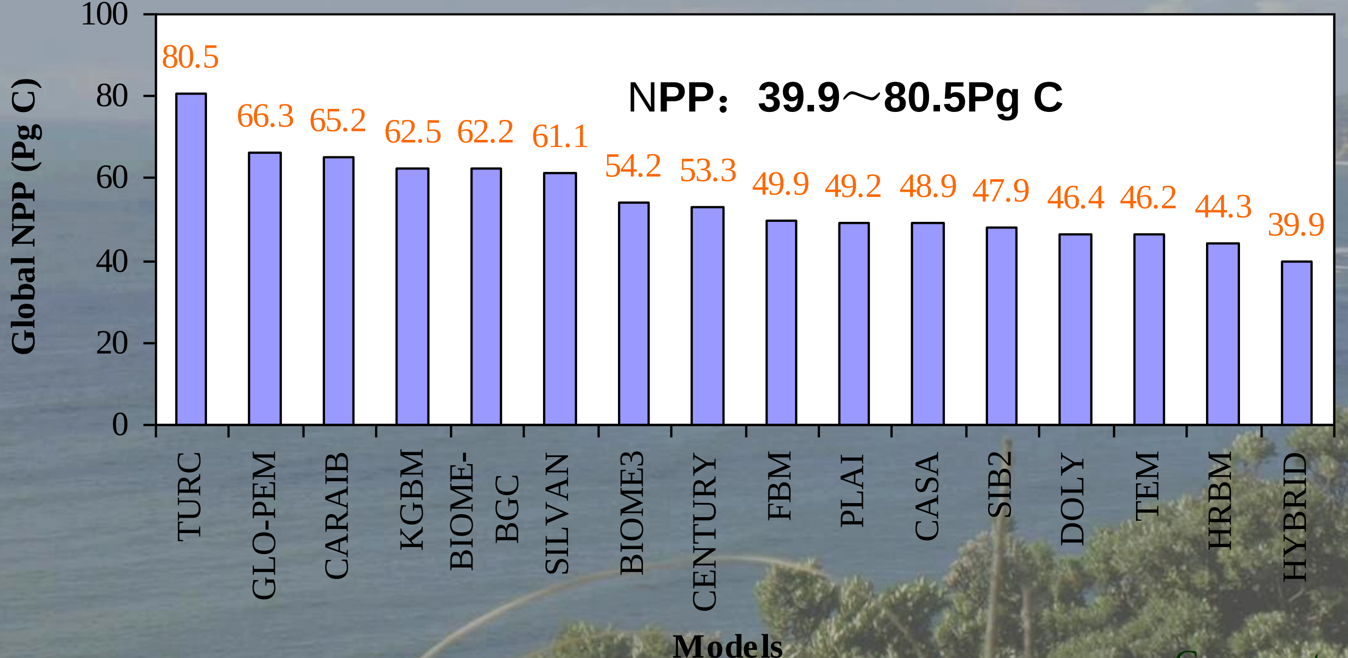
- Increasing atmospheric CO_2 concentration is a primary factor in climate system. It can cause significant land–atmosphere carbon exchanges and enhanced the land carbon uptake, in addition to long-term impacts on the terrestrial carbon balance at both regional and global scales by affecting vegetation photosynthesis and water use efficiency (Brodribb et al., 2009; Beer et al., 2010; Cox et al., 2013).
- Climate change can play direct role on the carbon exchange between land and atmosphere through influencing the photosynthesis, respiration, land cover, and fire disturbances (Flannigan et al., 2009; Lawrence and Chase, 2010; Scheller et al., 2012).

Introduction

- Friedlingstein et al. (2006) compared 11 fully coupled climate–carbon cycle models and suggested that none was in agreement on the changes in NPP versus respiration.
- It is difficult to accurately estimate the strength of response of NPP to climate change in northern versus tropical forests and drought effect on NPP in tropics using models (Cramer et al., 2001; Zhao and Running, 2010).

Introduction

The magnitude of the global NPP varies markedly among models



Cramer et al., 1999

MODELS

1. HadGEM2-ES
2. IPSL-CM5A-LR
3. CESM1-BGC
4. MPI-ESM-LR
5. CanESM2
6. BCC-CSM1-1

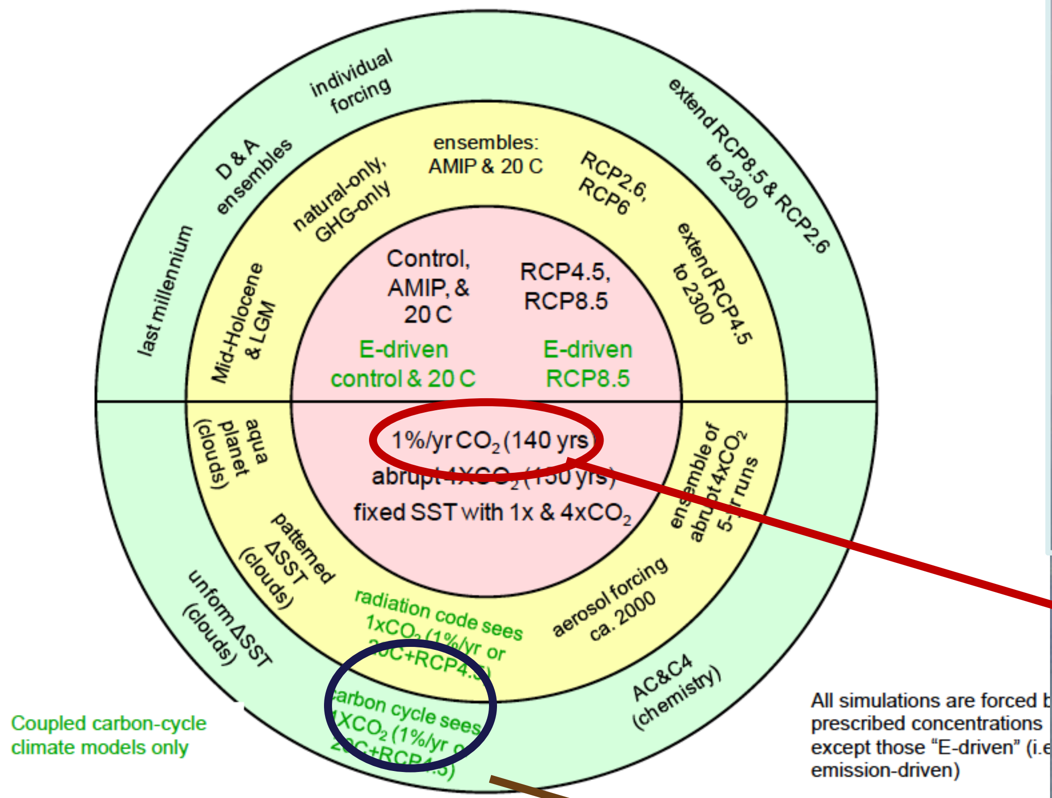


Figure 3: Schematic summary of CMIP5 long-term experiments.

- ❑ CO_2+Climate
- ❑ CO_2 or Climate

CMIP5 long-term experiment
(Taylor, et al. 2012)

Experiments

Including three experiments:

A “CO_2” experiment is conducted in which biogeochemistry responds to the increasing CO_2, while the CO_2 radiation is calculated by the pre-industrial CO_2 concentration.

A “Climate” experiment was implemented in which CO_2 radiation is calculated by increasing atmospheric CO_2 concentration with an increased rate of 1% per year, while biogeochemistry is fixed at the pre-industrial CO_2 level.

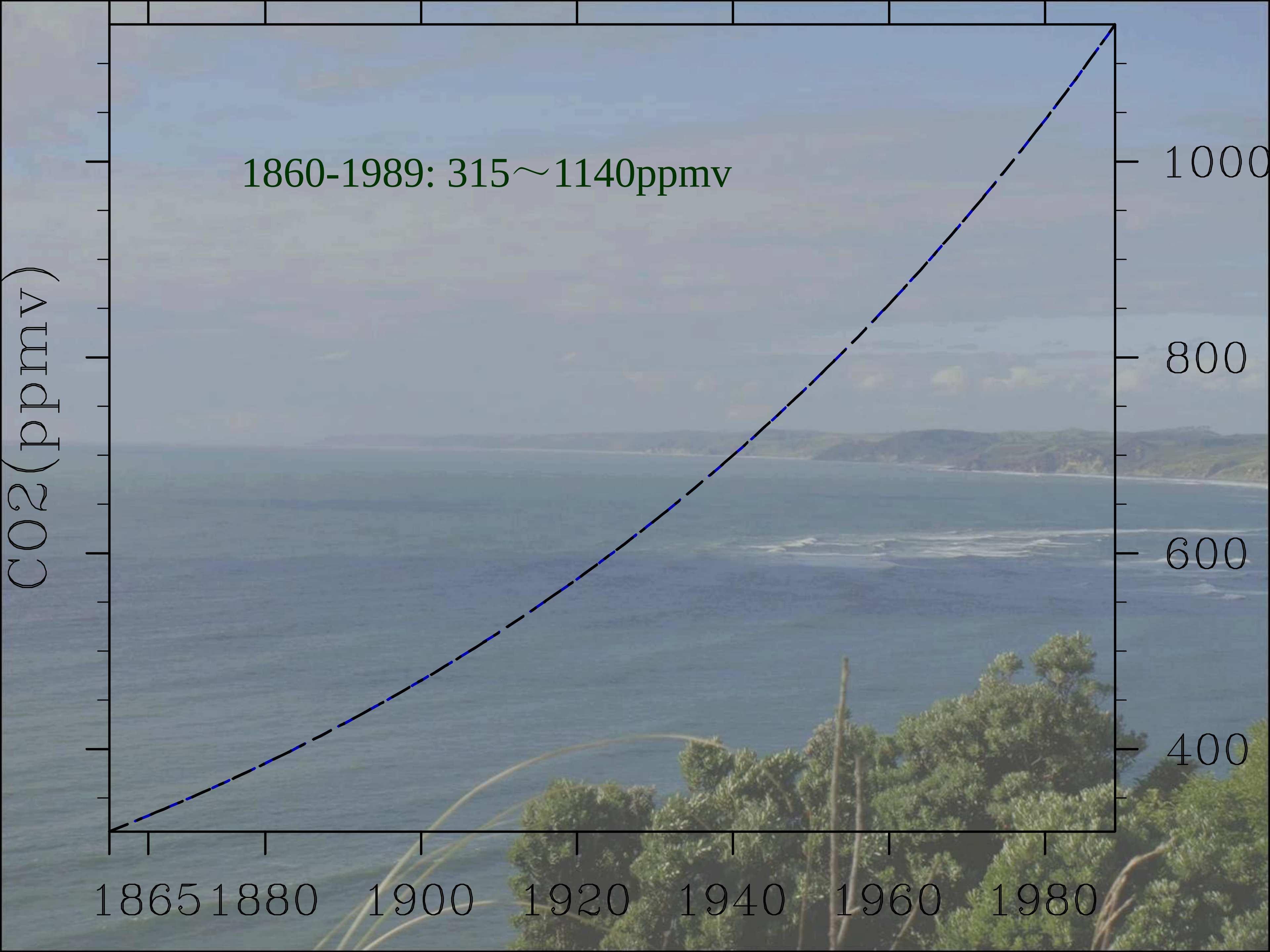
The effects of both CO_2 and climate change are included in the results of the “Total” experiment, in which both CO_2 biogeochemistry and radiation respond to the increasing CO_2 concentration.

Methods

$$NPP = GPP - Ra \quad (1)$$

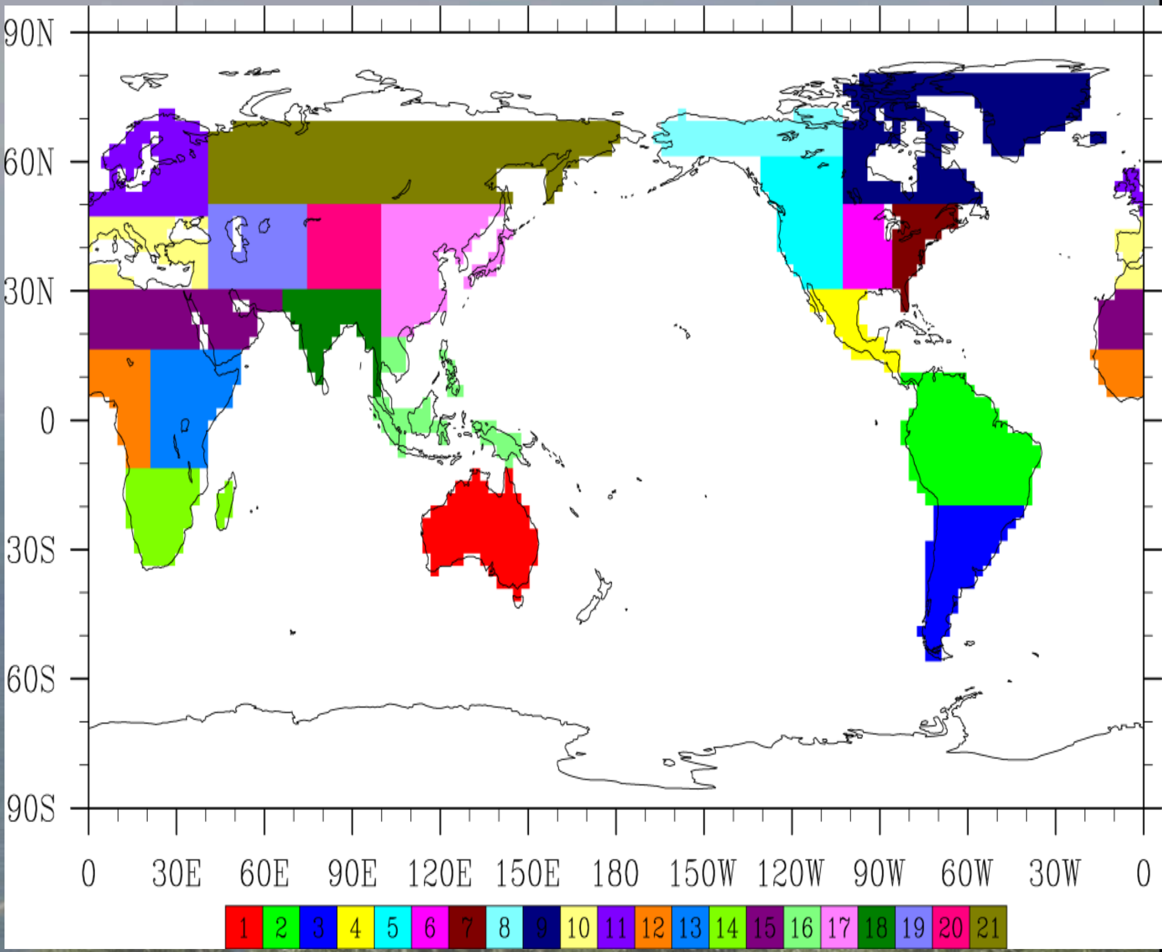
$$NEP = NPP - RH \quad (2)$$

NPP: net primary production;
NEP: net ecosystem production;
GPP: gross primary production;
RH: heterotrophic respiration
Ra: growth and maintenance respiration


1860-1989: 315～1140ppmv
CO2(ppmv)
1000
800
600
400
18651880
1900
1920
1940
1960
1980

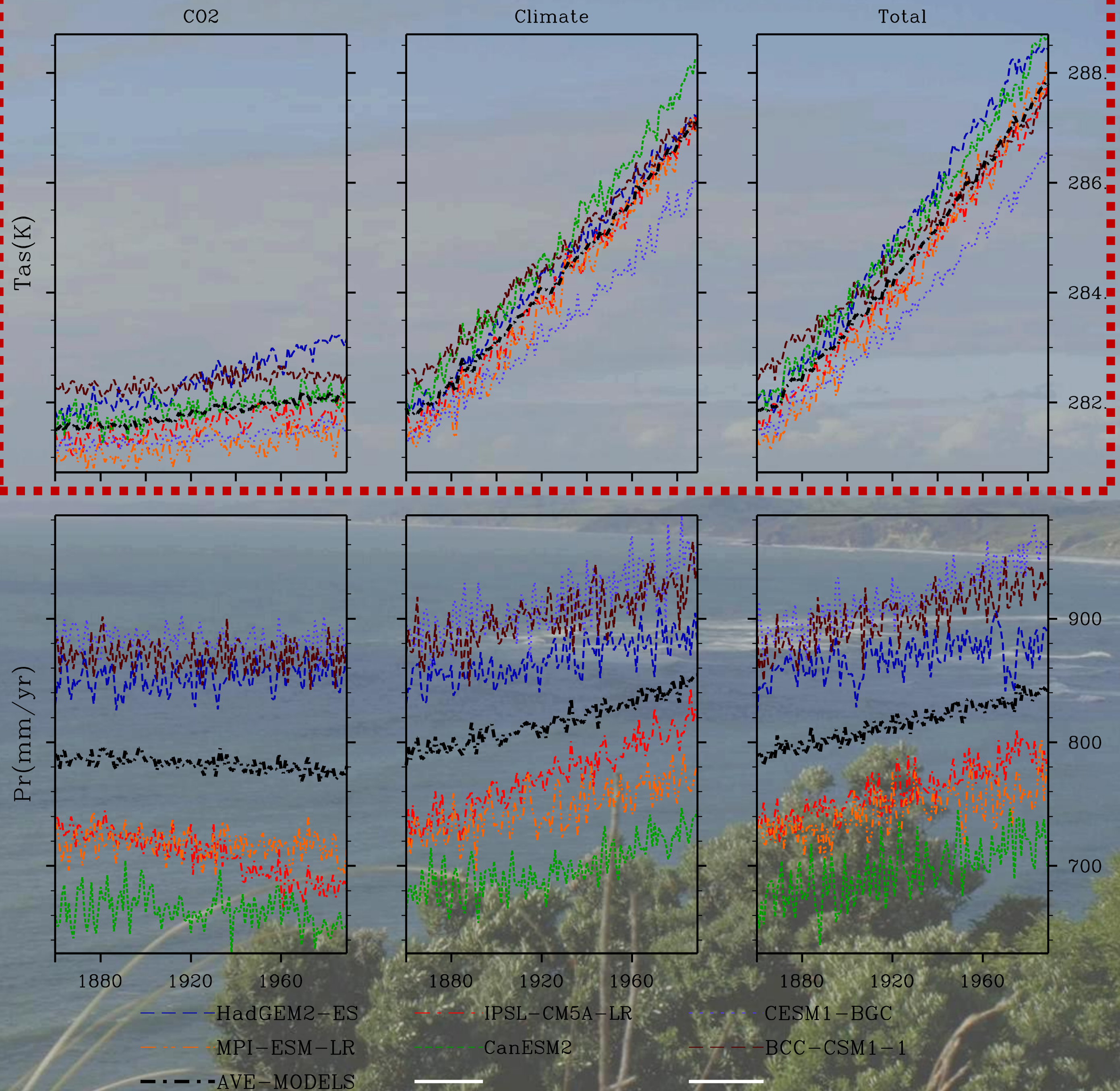
List of 21 regions

Region	Abbreviation
Australia	AUS
Amazon basin	AMZ
southern South America	SSA
Central America	CAM
western North America	WNA
central North America	CNA
eastern North America	ENA
Alaska	ALA
Greenland	GRL
Mediterranean basin	MED
northern Europe	NEU
western Africa	WAF
eastern Africa	EAF
southern Africa	SAF
Sahara	SAH
southeastern Asia	SEA
eastern Asia	EAS
southern Asia	SAS
central Asia	CAS
Tibet	TIB
northern Asia	NAS



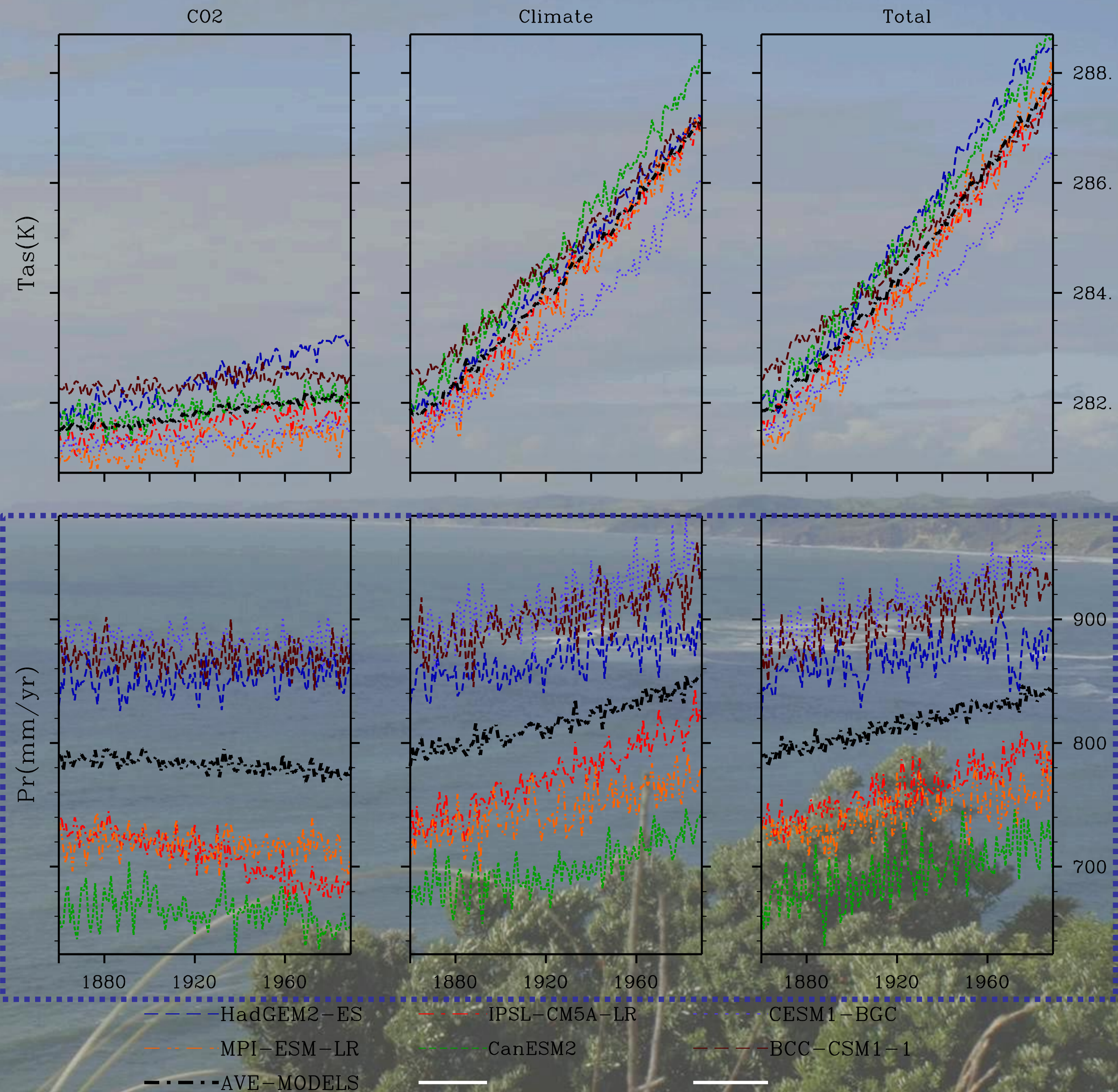
Changes in temperature :

- Increasing temperature is determined primarily by climate change but not increasing CO_2.
- The averaged temperature is presented from 283K of CESM1-BGC to 285K of CanESM2

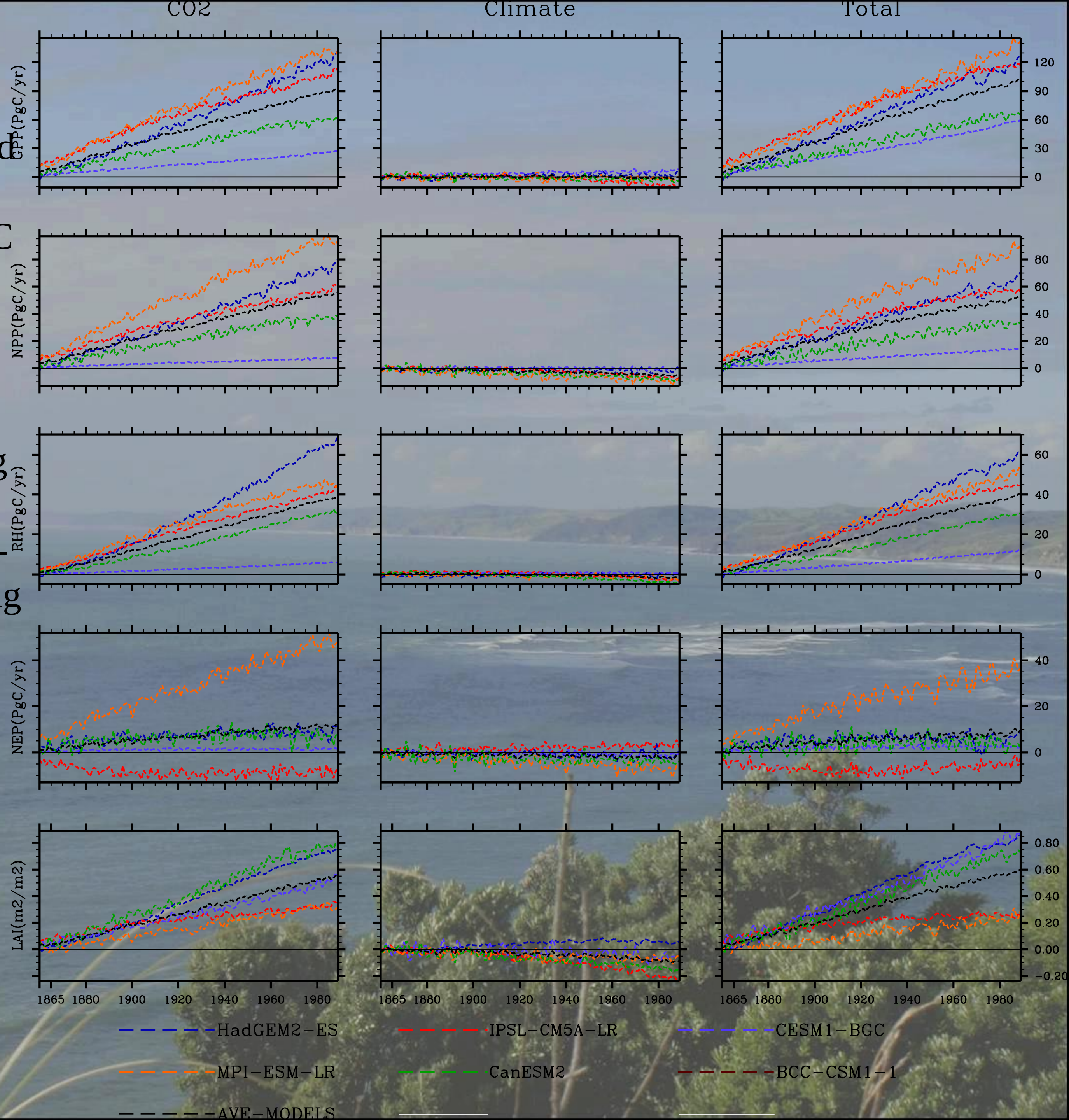


Changes in precipitation:

- Increasing precipitation is determined primarily by climate change.
- There is a large difference in precipitation among models



A large difference in the changes of GPP, NPP and RH ranging from 27PgC/yr in CESM-BGC to 133PgC/yr in MPI-ESM-LR, between 7PgC/yr in CESM-BGC and 94PgC/yr in MPI-ESM-LR, between 6.1Pg C/yr in CESM-BGC and 70Pg C/yr in HadGEM2-ES, respectively, resulting from rising atmospheric CO_2 concentration.



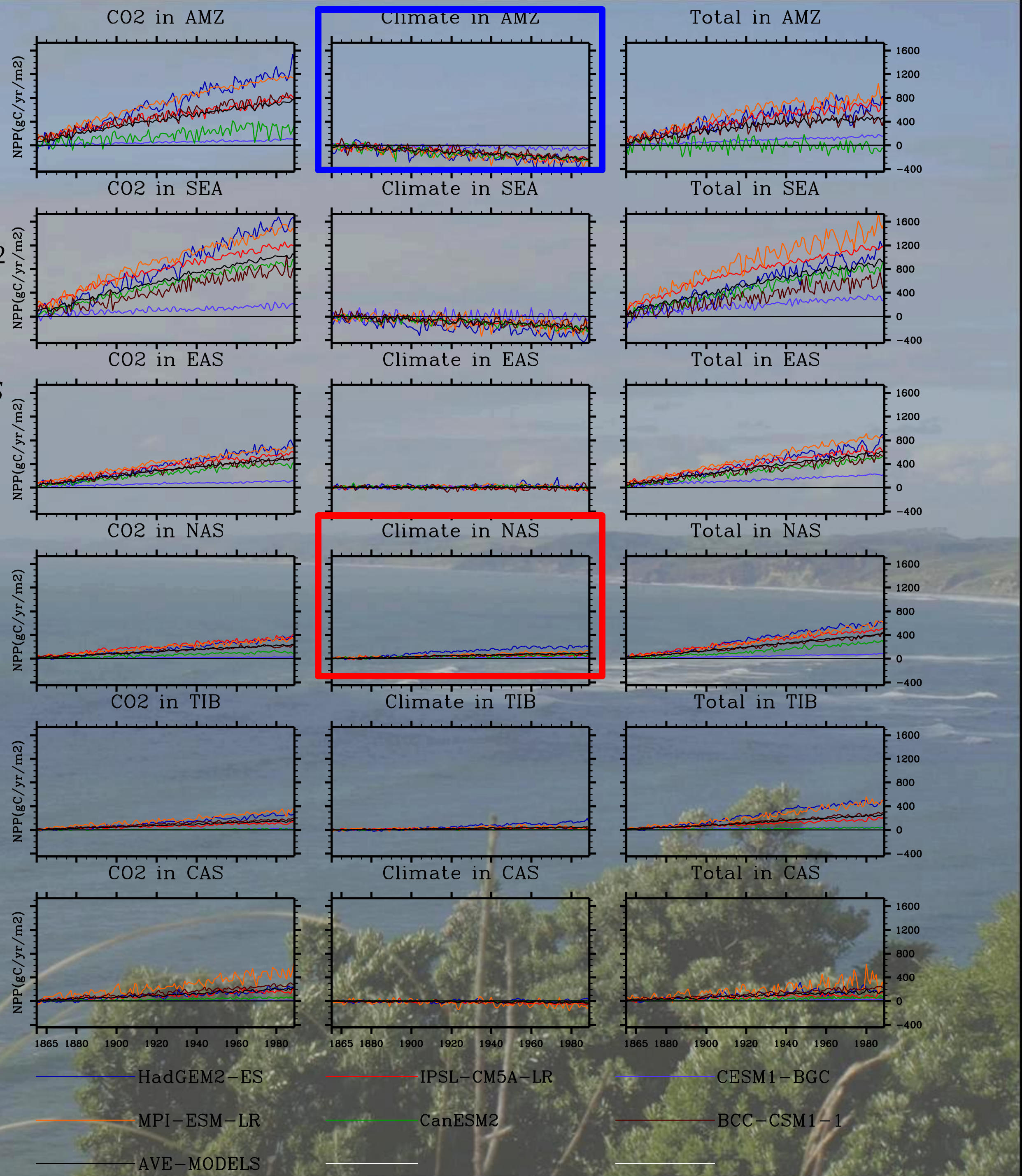
RH(heterotrophic respiration)

Changes in regional NPP

Messages from regions…

- Increase of NPP everywhere is observed under rising CO_2 concentration
- *The coupled models exhibit large difference in the trends of NPP among regions only considering the effect of climate change.*
- *Changes in NPP among the six regions due to the combined effect of increasing CO_2 and climate change is similar to the changes due to the single effect by increasing CO_2 concentrations.*

Regions: Amazon Basin (AMZ), Southeast Asia (SAS), East Asia (EAS), North Asia (NAS) ,Tibet (TIB) and Central Asia (CAS)

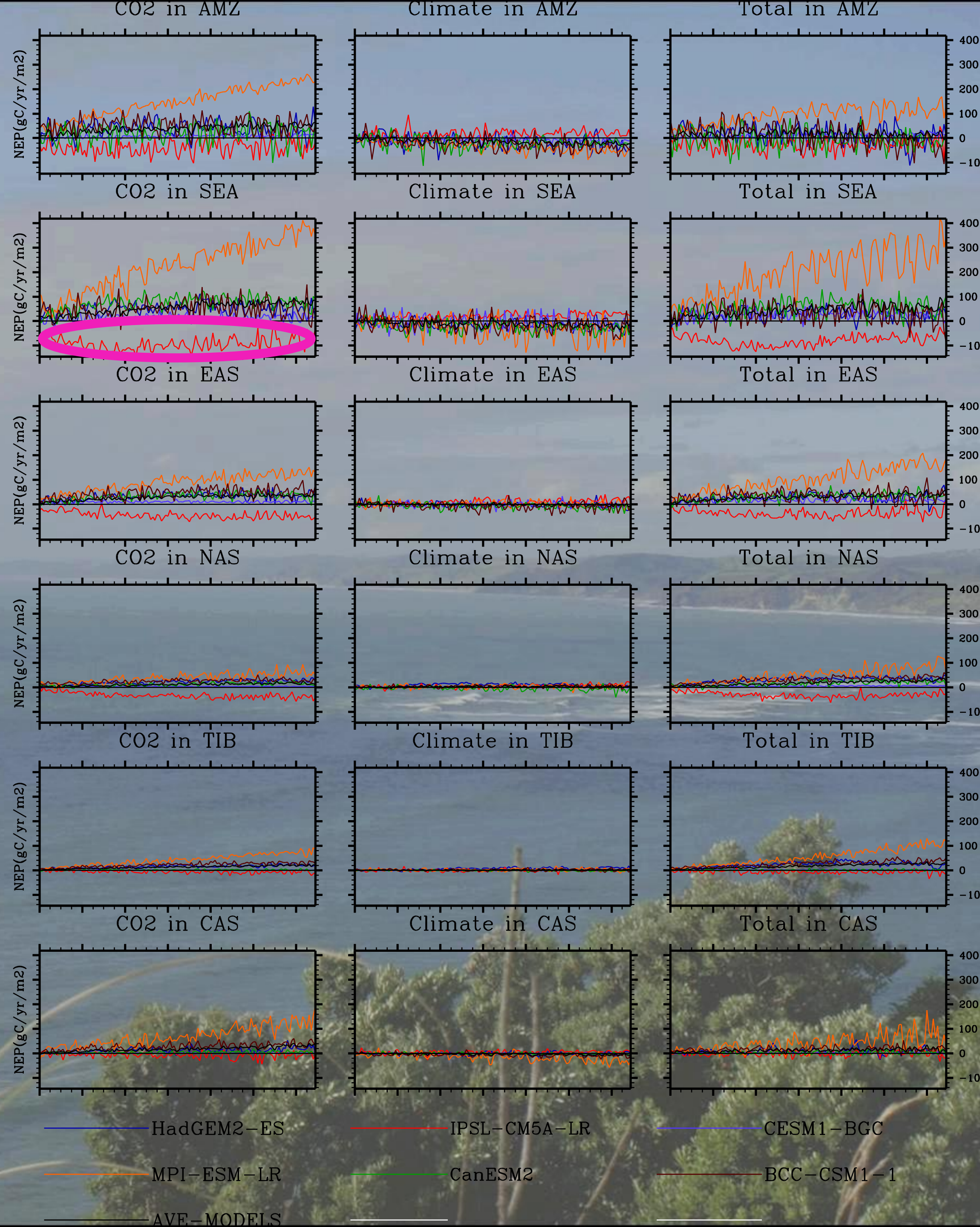


Changes in regional NEP

Enhanced carbon sink(elevated NEP) is shown among regions by models except for IPSL-CM5A-LR responding to the single effect of increasing CO_2.

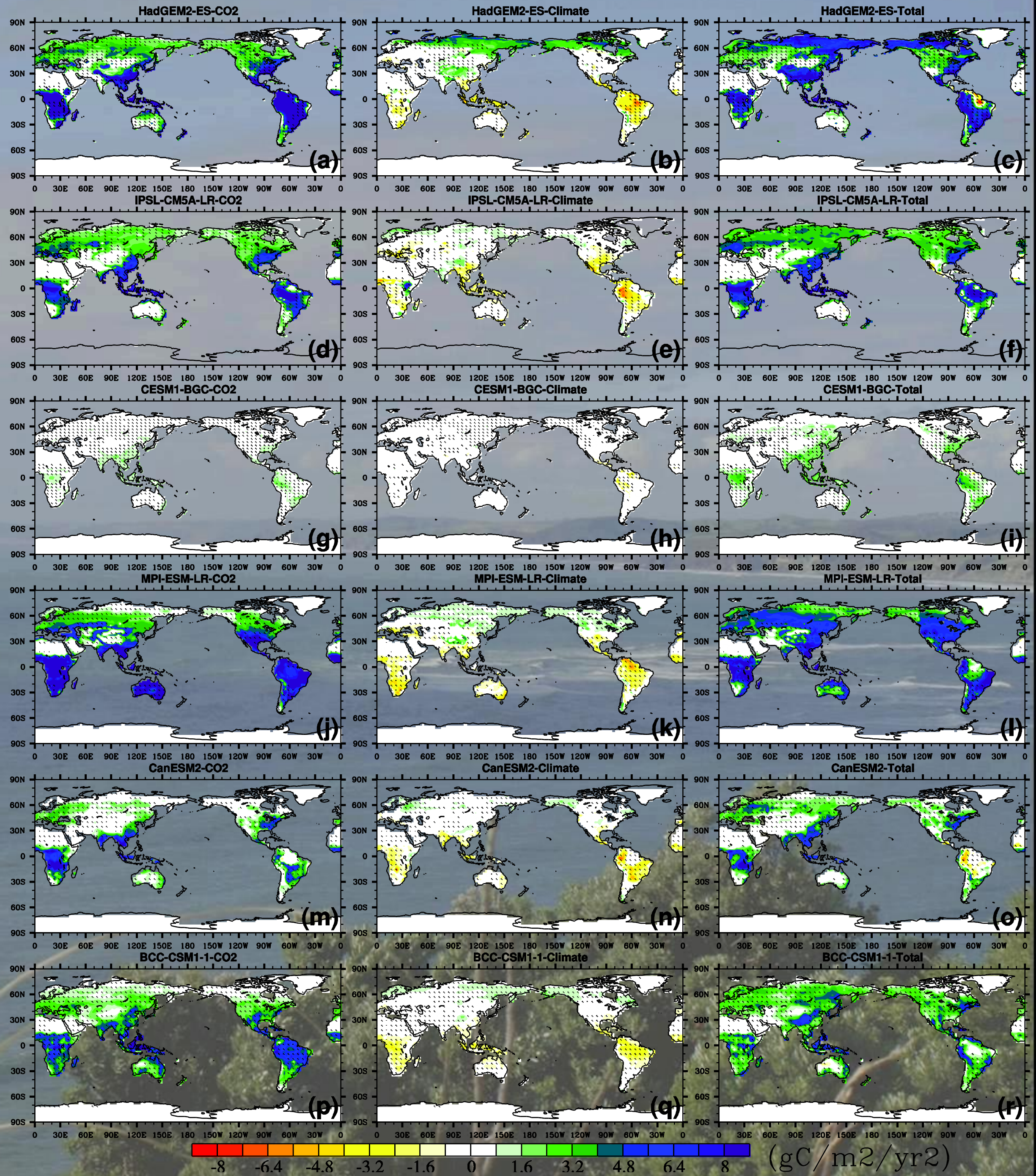
When only climate change was considered, the models showed marked differences with region-to-region variability.

For example, increased carbon loss is shown in Amazon basin, while carbon sink is enhanced in northern Asia.



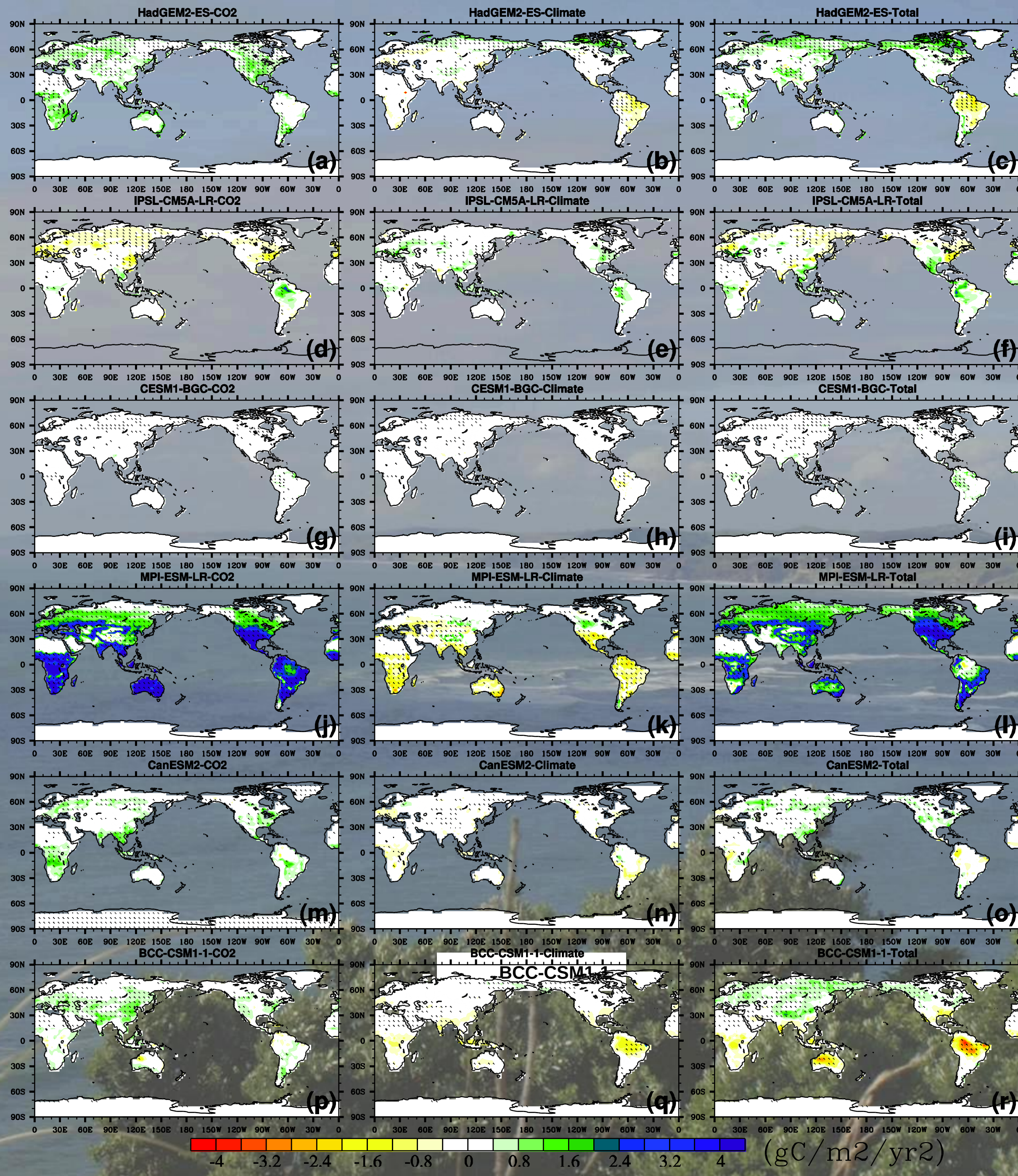
- Due to the rising CO_2 MPI-ES-LR has the largest increase of NPP ($0.16 gC/m^2/yr^2$) and CESM-BGC shows the smallest increase by $0.01 gC/m^2/yr^2$.
- Climate change attributes a decreased trend in NPP for six models.

Spatial distribution of the NPP trend simulated by HadGEM2-ES, IPSL-CM5A-LR, CESM1-BGC, MPI-ESM-LR, CanESM2 and BCC-CSM1-1 accounting for the effect of atmospheric rising CO2 concentration ((a,d,g, j, m, p), the effect of climate change (b, e, k, n, q) and the effect of both rising CO2 concentration and climate change (c, f, l, o,r) , units: gC/m2/yr2 .



Messages from right figure…

- MPI-ESM-LR has a significant increase in NEP by 340.7TgC/yr^2 ($P<0.05$). Its increase is 47 times larger than that of CESM-BGC
- Only considering climate change effect, the models show marked difference with regional variability.
- Spacial pattern due to the combined impact is similar to the spacial pattern caused by the single effect of increasing CO_2.



Response to CO2

(0.1TgC/yr2)

Region	HadGEM	IPSL	CESM	MPI	CanESM	bcc	AVE
AUS	183	91	20	728	132	249	234
AMZ	1247	678	92	1053	294	685	675
SSA	402	161	35	361	148	186	216
CAM	175	91	13	215	70	118	114
WNA	154	143	10	285	45	116	126
CNA	186	161	18	200	86	107	126
ENA	148	93	16	93	120	85	93
ALA	77	53	1	44	-4	14	31
GRL	83	91	4	66	14	34	49
MED	105	137	13	240	91	106	115
NEU	143	163	10	129	85	91	104
WAF	491	312	46	578	334	335	349
EAF	427	247	35	626	305	378	336
SAF	396	213	24	592	237	249	285
SAH	0	0	0	19	3	17	7
SEA	461	330	45	359	322	245	294
EAS	386	302	53	360	251	276	271
SAS	202	156	46	325	234	204	195
CAS	100	70	5	223	27	112	90
TIB	109	44	5	122	4	61	58
NAS	439	392	28	348	130	217	259
WORLD	5969	3993	533	6986	2950	3932	4060

Legend: 550 - 7000; 350 - 550; 150 - 350; 90 - 120; 60 - 90; 30 - 60; 0 - 30; -50 - 0; -100 - -50; -2000 - -100

Response to Climate

(0.1TgC/yr2)

Region	HadGEM	IPSL	CESM	MPI	CanESM	bcc	AVE
AUS	-27	-25	3	-107	-50	-52	-43
AMZ	-315	-251	-52	-260	-227	-224	-221
SSA	-48	-32	1	-28	-62	-19	-31
CAM	-35	-53	-13	-34	-41	-30	-35
WNA	-7	-13	2	19	-3	7	0
CNA	1	-54	0	-7	-9	-13	-13
ENA	4	-9	3	15	-2	-3	1
ALA	100	12	3	34	22	25	32
GRL	90	21	4	36	15	25	32
MED	-18	-49	-9	-66	-26	-21	-31
NEU	4	10	1	14	23	11	10
WAF	-34	-103	-1	-122	-109	-112	-80
EAF	-37	47	10	-42	-35	-78	-22
SAF	-59	-39	-8	-150	-67	-73	-66
SAH	0	0	0	-1	-1	-4	-1
SEA	-88	-74	-3	-44	-70	-62	-57
EAS	17	-29	11	10	-4	-6	0
SAS	18	0	-4	-38	-74	-23	-20
CAS	10	-19	0	-33	-2	-11	-9
TIB	65	11	4	22	1	12	19
NAS	257	50	20	127	68	86	101
WORLD	-40	-591	-25	-642	-656	-554	-418

Legend: 550 - 7000; 350 - 550; 150 - 350; 90 - 120; 60 - 90; 30 - 60; 0 - 30; -50 - 0; -100 - -50; -2000 - -100

- Each model trend has a fair agreement on sign of increased NPP trend at global scale, considering the effect of rising CO_2 concentration
- The increased trend in NPP simulated by **CESM1-BGC** is much smaller than values simulated by other models due to considering the limited nitrogen effect.
- Climate change attributes a decreased trend in NPP for six models due to climate change

Response to CO2

(0.1TgC/yr2)

	HadGEM	IPSL	CESM	MPI	CanESM	bcc	AVE
AUS	30	-5	3	433	17	2	80
AMZ	7	50	18	453	34	7	95
SSA	20	-10	4	212	19	18	44
CAM	16	-6	2	125	12	0	25
WNA	32	-12	1	186	9	23	40
CNA	26	-17	2	133	14	5	27
ENA	12	-15	1	41	22	13	12
ALA	12	-6	0	17	-3	2	3
GRL	11	-14	0	24	3	4	5
MED	12	-24	1	125	11	21	24
NEU	21	-24	0	52	11	17	13
WAF	43	4	6	280	38	3	62
EAF	33	8	4	262	37	10	59
SAF	49	2	2	245	36	12	58
SAH	0	0	0	5	0	3	1
SEA	10	8	3	192	34	7	42
EAS	27	-35	2	142	39	54	38
SAS	14	-3	7	130	31	27	34
CAS	15	-5	0	133	5	30	29
TIB	14	-5	0	63	1	20	15
NAS	67	-69	4	139	35	41	36
WORLD	488	-192	71	3407	412	329	752

475 - 3500
275 - 475
75 - 275
45 - 60
30 - 45
15 - 30
0 - 15
-50 - 0
-100 - -50
-600 - -100

Response to Climate

(0.1TgC/yr2)

	HadGEM	IPSL	CESM	MPI	CanESM	bcc	AVE
AUS	-1	2	-1	-67	-16	-18	-17
AMZ	-63	34	-21	-113	-16	-91	-45
SSA	-18	6	-2	-27	-20	-6	-11
CAM	-8	5	-2	-21	-4	-9	-6
WNA	-6	4	0	-4	-8	-6	-3
CNA	-5	13	-2	-16	-2	-8	-3
ENA	-3	6	-1	0	-8	-6	-2
ALA	11	1	0	1	1	4	3
GRL	14	6	0	5	-1	0	4
MED	-6	17	-1	-29	-13	-9	-7
NEU	-10	8	0	-4	-11	-5	-3
WAF	-7	15	-4	-59	-26	-25	-18
EAF	-3	5	-1	-45	-22	-29	-16
SAF	-12	7	-2	-73	-15	-13	-18
SAH	0	0	0	0	0	-2	0
SEA	-10	18	-4	-25	-20	-20	-10
EAS	-11	19	-4	-1	-22	-14	-5
SAS	0	0	-2	-30	-11	-23	-11
CAS	0	4	0	-30	-1	-8	-6
TIB	8	2	0	1	-2	0	1
NAS	11	29	-3	9	-17	0	5
WORLD	-114	211	-60	-527	-243	-290	-170

475 - 3500
275 - 475
75 - 275
45 - 60
30 - 45
15 - 30
0 - 15
-50 - 0
-100 - -50
-600 - -100

Due to climate change:

- Simulations from models except for IPSL-CM5A-LR reproduce: enhanced land loss at global scale
- The CESM–BGC shows a more modest negative values of -8.0TgC/yr^2 in NEP than those simulated by other models.
- Regions except for northern Asia, Tibet, Alaska and Greenland show enhanced land loss (decreased NEP).

Comparison of simulated NPP with previous studies

Time	Region	Factors	NPP ($PgCyr^{-1}$)	Trends of NPP($PgCyr^{-2}$)	Res.
1830-2100	Global	CO_2	50～100		Cramer et al.,2001
		Climate	50～60		
		Total	50～85		
1980-2002		CO_2		0.24	Piao et al., 2009
		Climate		**0.05**	
		Total		0.30	
1860-1989		CO_2	20.76～58.28	0.05～0.3	This study
		Climate	18.92～31.55	**-0.003～-0.07**	
		Total	22.37～56.36	0.05～0.28	

Estimation of simulated NEP

Time	Region	Factors	NEP	NEP trends	Res.
			$PgCy^{-1}$	$PgCy^{-2}$	
1830-2100	Global	CO_2	1.4～8.6		Cramer et al.,2001
		Climate	-0.3～-3.8		
		Total	0.3～6.6		
		CO_2		0.091	Piao et al.,2009
		Climate		-0.065	
		Total	1.9	0.065	
		Total	-0.3～3.8		Prentice et al., 2001
		Total	1.32～1.8		Sitch et al.,2008
2006-2100		Total	-0.97～2.27		Ahlström et al.,2013
2008		Total	3.5～5.9		
1860-1989		CO_2	0.59～12.9	0.006～0.13	This study
		Climate	-1.94～-0.21	-0.002～-0.02	
		Total	0.58～12.7	0.006～0.12	

Conclusions

From results…

- **Global terrestrial ecosystems act as enhanced carbon sinks (increased NEP), among models except for IPSL-CM5A-LR accompanied with increasing CO_2.**
- **Our results also show that climate change has already accelerated carbon losses at low and middle latitudes.**
- ***However, northern high-latitudes show signs of strongly accelerated NPP and NEP in response to the single effect of rising CO_2 or climate change, although large differences in magnitudes of the two variables are clear among models.***
- **To reduce such discrepancies in magnitude at global and regional scales, it is important to accurately quantify the effects of nitrogen limitation on the changes in the terrestrial carbon fluxes.**


THANKS