Quantifying and Reducing Climate-Carbon Cycle Feedback Uncertainties: Analysis of CMIP5 Earth System Model Feedbacks

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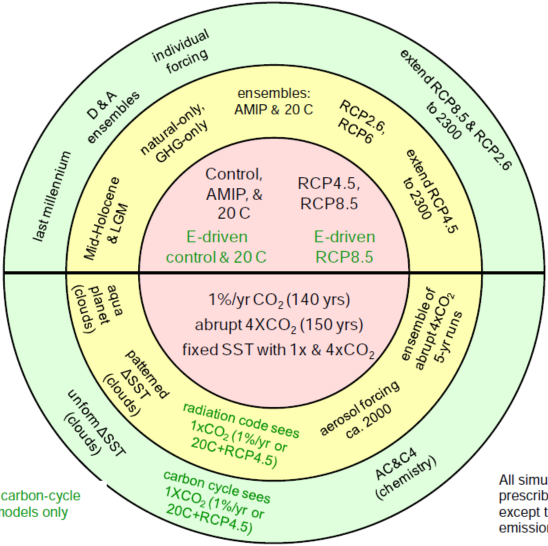
December 9, 2011

Session GC54A. Climate Modeling: Analysis of CMIP5 Simulations II

AGU FALL MEETING 2011
San Francisco, California, USA | 5-9 December

Schematic Summary of CMIP5 Long-Term Experiments



Coupled carbon-cycle climate models only

All simulations are forced by prescribed concentrations except those "E-driven" (i.e., emission-driven)

Model (AM, CSM, ESM)	Country	Preindustrial Control 3.1	Historical 3.2	RCP2.6 4.3	RCP4.5 4.1	RCP6.0 4.4	RCP8.5 4.2
ACCESS1.0†	Australia	✘	1	✘	✘	✘	✘
BCC-CSM1.1	China	1	1	1	1	1	1
CanAM4	Canada	✘	✘	✘	✘	✘	✘
CanCM4	Canada	✘	✘	✘	✘	✘	✘
CanESM2	Canada	1	5	5	5	✘	5
CCSM4	U.S.	✘	6	5	5	5	6
CNRM-CM5	France	1	9	1	1	✘	4
CSIRO-Mk3.6	Australia	1	10	10	10	10	10
GFDL-CM3	U.S.	1	5	1	✘	1	1
GFDL-ESM2G	U.S.	1	✘	✘	✘	✘	✘
GFDL-ESM2M	U.S.	1	1	✘	✘	✘	✘
GFDL-HIRAM-C180	U.S.	✘	✘	✘	✘	✘	✘
GFDL-HIRAM-C360	U.S.	✘	✘	✘	✘	✘	✘
GISS-E2-H	U.S.	1×2p	5×2p	✘	✘	✘	✘
GISS-E2-R	U.S.	1×3p	5×3p	1	5	1	1
HadCM3	U.K.	✘	9	✘	9	✘	✘
HadGEM2-A	U.K.	✘	✘	✘	✘	✘	✘
HadGEM2-CC	U.K.	1	2	✘	1	✘	1
HadGEM2-ES	U.K.	1	4	1	4	4	4
INM-CM4	Russia	1	1	✘	1	✘	1
IPSL-CM5A-LR	France	1	5	1	4	1	4
IPSL-CM5A-MR	France	1	1	✘	1	✘	1
MIROC-ESM	Japan	1	3	1	1	1	1
MIROC-ESM-CHEM	Japan	1	1	1	1	1	1
MIROC4h	Japan	1	3	✘	3	✘	✘
MIROC5	Japan	1	3	2	2	1	2
MPI-ESM-LR	Germany	1	3	3	3	✘	3
MPI-ESM-P	Germany	1	✘	✘	✘	✘	✘
MRI-AGCM3-2H	Japan	✘	✘	✘	✘	✘	✘
MRI-AGCM3-2S	Japan	✘	✘	✘	✘	✘	✘
MRI-CGCM3	Japan	1	5	1	1	✘	1
NorESM1-M	Norway	1	3	1	1	1	1

† Unable to access data due to subscription requirement

As of 3 December 2011

Model (AM, CSM, ESM)	Country	ESM Control 5.1	ESM Historical 5.2	ESM RCP8.5 5.3	ESM FixClim1 5.4-1	ESM FixClim2 5.4-2	ESM Fdbk1 5.5-1	ESM Fdbk2 5.5-2	1% CO_2 6.1
ACCESS1.0†	Australia	✘	✘	✘	✘	✘	✘	✘	✘
BCC-CSM1.1	China	1	1	1	1	1	1	1	1
CanAM4	Canada	✘	✘	✘	✘	✘	✘	✘	✘
CanCM4	Canada	✘	✘	✘	✘	✘	✘	✘	✘
CanESM2	Canada	1	3	3	1	1	1	1	1
CCSM4	U.S.	✘	✘	✘	✘	✘	✘	✘	✘
CNRM-CM5	France	✘	✘	✘	✘	✘	✘	✘	1
CSIRO-Mk3.6	Australia	✘	✘	✘	✘	✘	✘	✘	1
GFDL-CM3	U.S.	✘	✘	✘	✘	✘	✘	✘	1
GFDL-ESM2G	U.S.	✘	✘	✘	✘	✘	✘	✘	✘
GFDL-ESM2M	U.S.	1	1	✘	✘	✘	✘	✘	1
GFDL-HIRAM-C180	U.S.	✘	✘	✘	✘	✘	✘	✘	✘
GFDL-HIRAM-C360	U.S.	✘	✘	✘	✘	✘	✘	✘	✘
GISS-E2-H	U.S.	✘	✘	✘	✘	✘	✘	✘	✘
GISS-E2-R	U.S.	✘	✘	✘	✘	✘	✘	✘	✘
HadCM3	U.K.	✘	✘	✘	✘	✘	✘	✘	✘
HadGEM2-A	U.K.	✘	✘	✘	✘	✘	✘	✘	✘
HadGEM2-CC	U.K.	✘	✘	✘	✘	✘	✘	✘	✘
HadGEM2-ES	U.K.	✘	1	1	1	1	✘	✘	1
INM-CM4	Russia	1	1	1	✘	✘	✘	✘	1
IPSL-CM5A-LR	France	1	✘	✘	1	1	1	1	1
IPSL-CM5A-MR	France	✘	✘	✘	✘	✘	✘	✘	✘
MIROC-ESM	Japan	1	1	1	✘	1	✘	✘	1
MIROC-ESM-CHEM	Japan	✘	✘	✘	✘	✘	✘	✘	✘
MIROC4h	Japan	✘	✘	✘	✘	✘	✘	✘	✘
MIROC5	Japan	✘	✘	✘	✘	✘	✘	✘	1
MPI-ESM-LR	Germany	✘	✘	✘	1	✘	1	✘	1
MPI-ESM-P	Germany	✘	✘	✘	✘	✘	✘	✘	1
MRI-AGCM3-2H	Japan	✘	✘	✘	✘	✘	✘	✘	✘
MRI-AGCM3-2S	Japan	✘	✘	✘	✘	✘	✘	✘	✘
MRI-CGCM3	Japan	✘	✘	✘	✘	✘	✘	✘	1
NorESM1-M	Norway	✘	✘	✘	✘	✘	✘	✘	1

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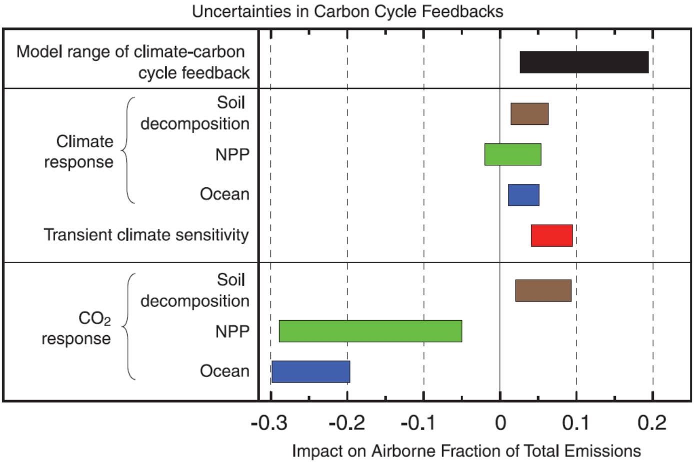
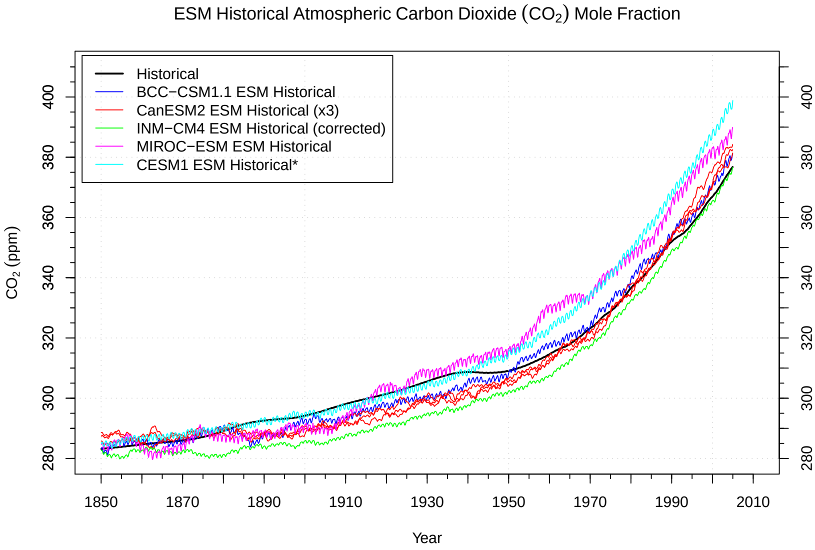
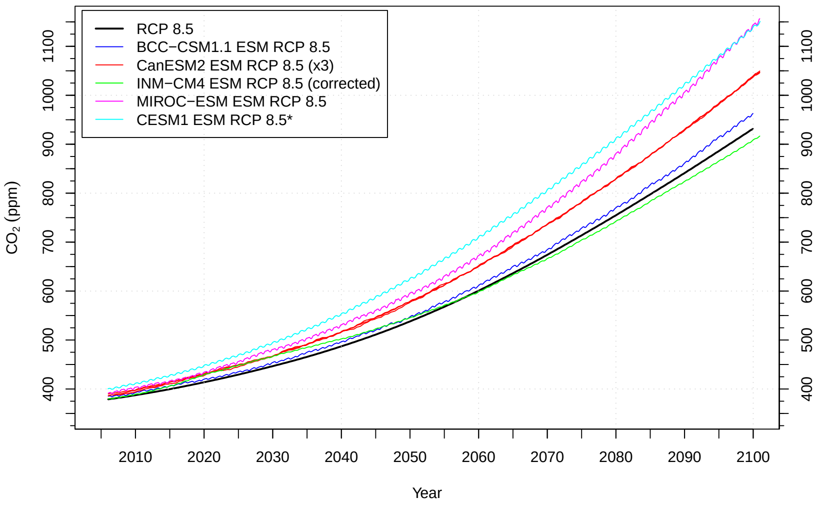
Uncertainties in Carbon Cycle Feedbacks



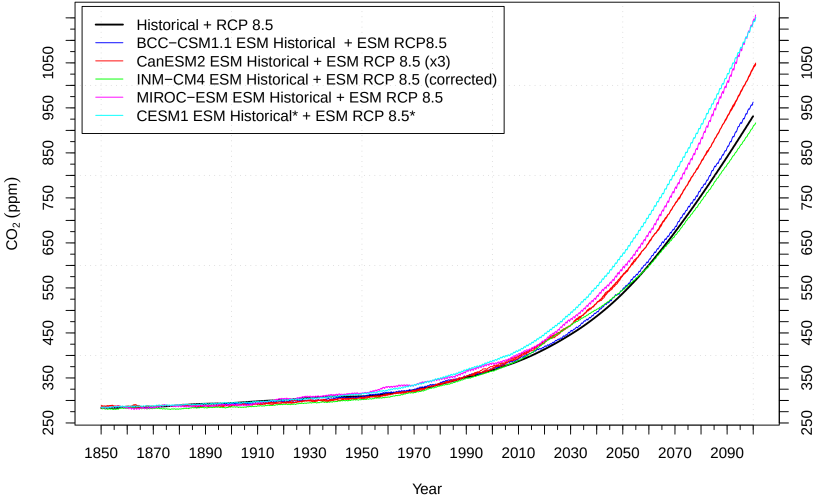
Carbon cycle feedback uncertainties are large, as estimated from analysis of the results from the 11 C^{4}MIP models. From Denman et al. (2007, Figure 7.14).


ESM Historical Atmospheric Carbon Dioxide (CO_2) Mole Fraction
Historical
BCC−CSM1.1 ESM Historical
CanESM2 ESM Historical (x3)
INM−CM4 ESM Historical (corrected)
MIROC−ESM ESM Historical
CESM1 ESM Historical*
CO_2 (ppm)
280
300
320
340
360
380
400
1850
1870
1890
1910
1930
1950
1970
1990
2010
Year

ESM RCP 8.5 Atmospheric Carbon Dioxide (CO_2) Mole Fraction



ESM Historical + ESM RCP 8.5 Atmospheric Carbon Dioxide (CO_2) Mole Fraction



Reducing Uncertainties Using Observations

To reduce feedback uncertainties using contemporary observations,

1. there must be a relationship between contemporary variability and future trends on longer time scales within the model, and

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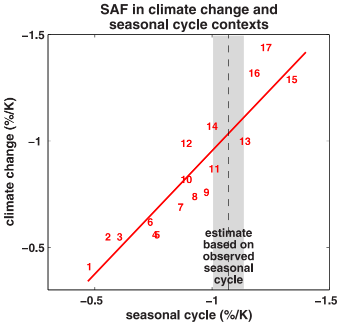
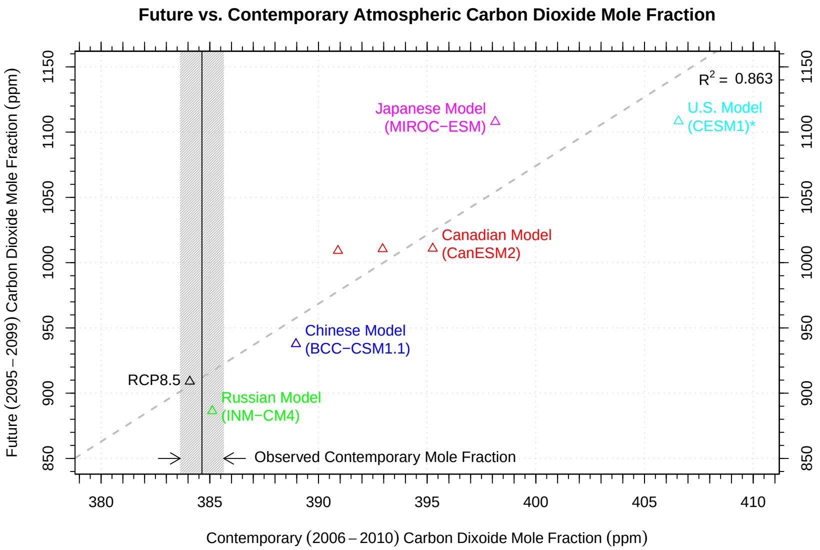
Example

Hall and Qu (2006) evaluated the strength of the springtime snow albedo feedback (SAF; $\Delta\alpha_s/\Delta T_s$) from 17 models used for the IPCC AR4 and compared them with the observed springtime SAF from ISCCP and ERA-40 reanalysis.




Future vs. Contemporary Atmospheric Carbon Dioxide Mole Fraction
Future (2095 – 2099) Carbon Dioxide Mole Fraction (ppm)
Contemporary (2006 – 2010) Carbon Dixoide Mole Fraction (ppm)
R2 = 0.863
Japanese Model (MIROC−ESM)
U.S. Model (CESM1)*
Canadian Model (CanESM2)
Chinese Model (BCC−CSM1.1)
RCP8.5
Russian Model (INM−CM4)
Observed Contemporary Mole Fraction
380 385 390 395 400 405 410
850 900 950 1000 1050 1100 1150

Output Variable Availability for ESM RCP 8.5 Simulations

Model	Country	co2 or co2mass	nbp	fgco2	fco2antt	fco2nat	fco2fos
ACCESS1.0†	Australia	✘	✘	✘	✘	✘	✘
BCC-CSM1.1	China	1	✘	1	1	1	1
CanESM2	Canada	3	3	✘	3	3	✘
GFDL-ESM2G	U.S.	✘	✘	✘	✘	✘	✘
GFDL-ESM2M	U.S.	✘	✘	✘	✘	✘	✘
HadGEM2-ES	U.K.	✘	✘	1	✘	✘	✘
INM-CM4	Russia	1	1	✘	✘	✘	✘
IPSL-CM5A-LR	France	✘	✘	✘	✘	✘	✘
MIROC-ESM	Japan	1	1	✘	1	1	1
MIROC-ESM-CHEM	Japan	✘	✘	✘	✘	✘	✘
MPI-ESM-LR	Germany	✘	✘	✘	✘	✘	✘
MPI-ESM-P	Germany	✘	✘	✘	✘	✘	✘
NorESM1-M	Norway	✘	✘	✘	✘	✘	✘

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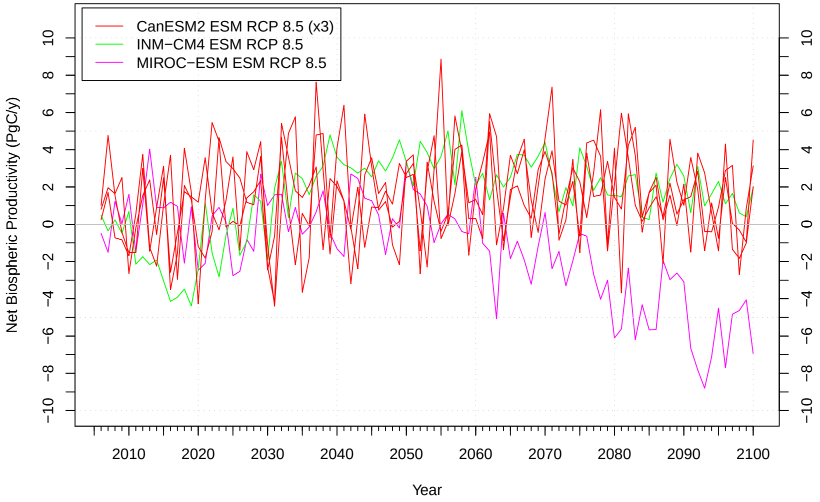
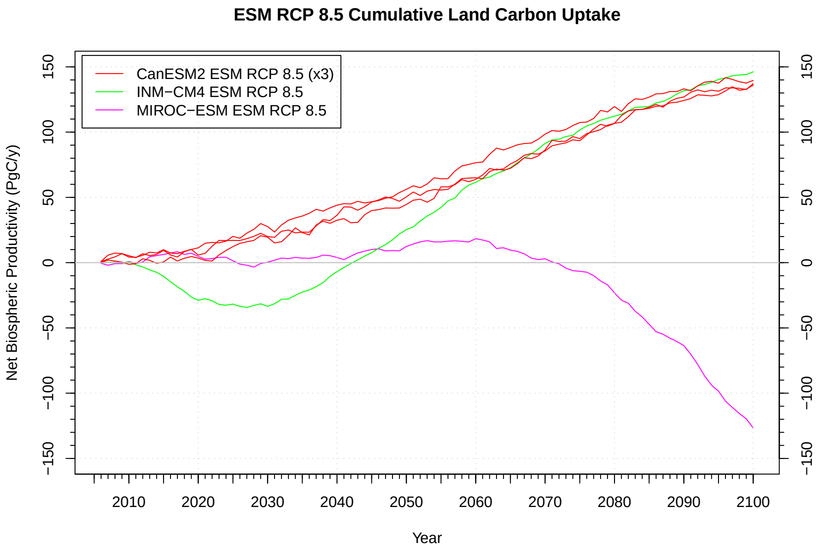
ESM RCP 8.5 Land Carbon Uptake

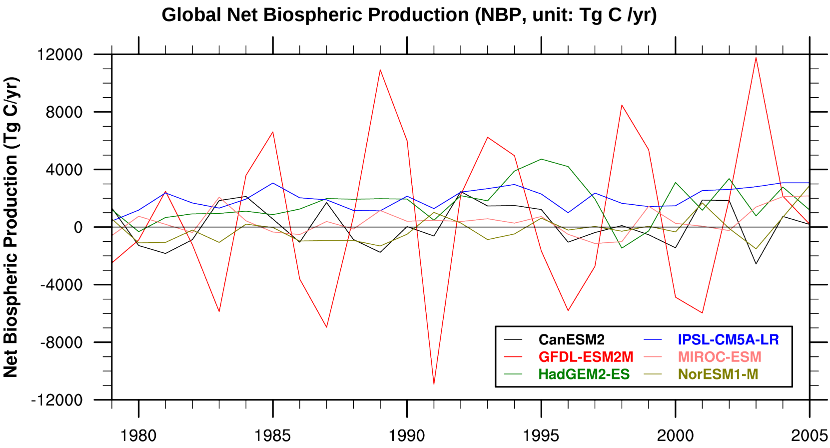



ESM RCP 8.5 Cumulative Land Carbon Uptake
CanESM2 ESM RCP 8.5 (x3)
INM−CM4 ESM RCP 8.5
MIROC−ESM ESM RCP 8.5
Net Biospheric Productivity (PgC/y)
Year
150
100
50
0
−50
−100
−150
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

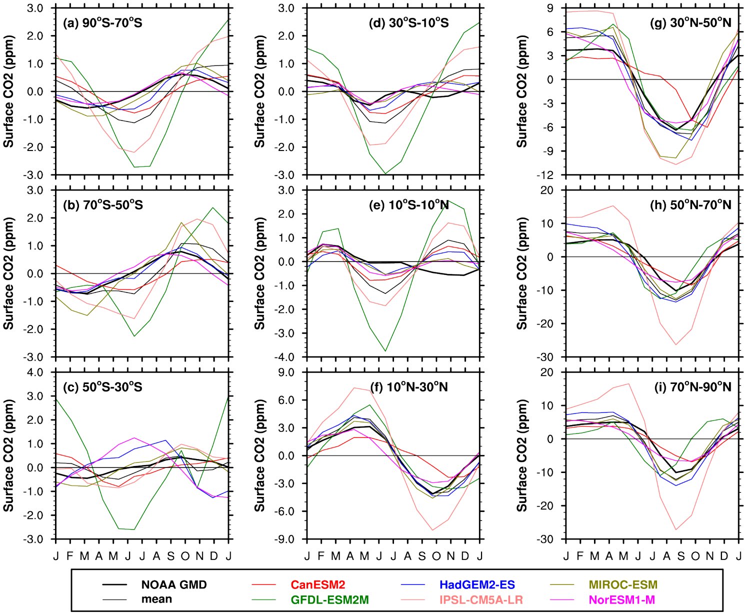
Concentration-Forced Historical Simulations

Global Net Biospheric Production (NBP, unit: Tg C /yr)

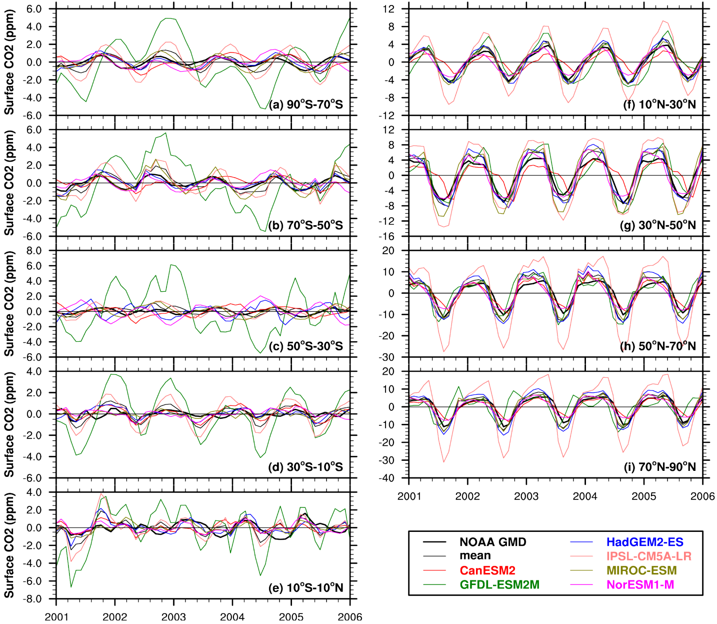
Year	CanESM2	GFDL-ESM2M	HadGEM2-ES	IPSL-CM5A	MIROC-ESM	NorESM1-M
1979	1324	-2488	1212	419	-586	563
1980	-1281	-897	-316	1182	747	-1096
1981	-1835	2491	665	2372	191	-1065
1982	-875	-1220	917	1672	-380	-206
1983	1843	-5875	950	1317	2078	-1063
1984	2127	3595	1104	1946	432	202
1985	557	6614	866	3060	-347	-28
1986	-1051	-3607	1252	2035	-520	-971
1987	1703	-6958	1985	1891	389	-931
1988	-862	711	1933	1156	-134	-930
1989	-1753	10926	1970	1131	1154	-1313
1990	39	5994	1946	2143	403	-496
1991	-620	-10919	480	1281	476	1020
1992	2466	2252	2182	2430	384	280
1993	1463	6236	1825	2667	578	-868
1994	1502	4961	3891	2958	274	-479
1995	1219	-1658	4724	2295	735	620
1996	-1045	-5801	4200	999	-500	-208
1997	-381	-2726	1955	2360	-1140	48
1998	106	8477	-1458	1653	-1012	-287
1999	-532	5377	-268	1424	1448	62
2000	-1438	-4867	3106	1483	261	-336
2001	1879	-5968	1170	2541	63	1677
2002	1849	1911	3367	2609	-243	-93
2003	-2560	11782	776	2801	1394	-1511
2004	739	2144	2780	3077	2112	682
2005	187	196	1181	3084	2161	2897
Mean	177	766	1644	2000	386	-142
σ	1425	5704	1403	738	895	974


Global Net Biospheric Production (NBP, unit: Tg C /yr)
Net Biospheric Production (Tg C/yr)
12000
8000
4000
0
-4000
-8000
-12000
1980
1985
1990
1995
2000
2005
CanESM2
IPSL-CM5A-LR
GFDL-ESM2M
MIROC-ESM
HadGEM2-ES
NorESM1-M

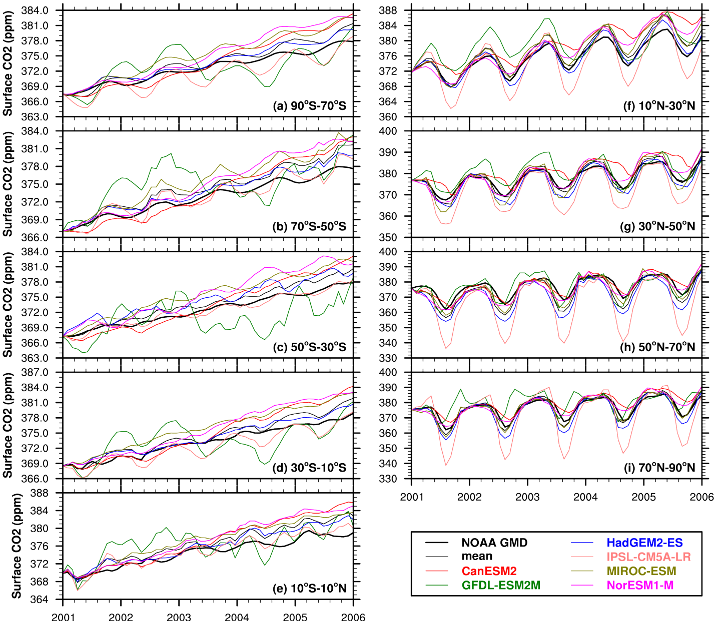
CO_2 Concentration (FF+OC+BAL+SHIP+AIRCRAFT) in 2001–2005, Trend Removed



CO_2 Concentration (FF+OC+BAL+SHIP+AIRCRAFT) in 2001–2005, Trend Removed



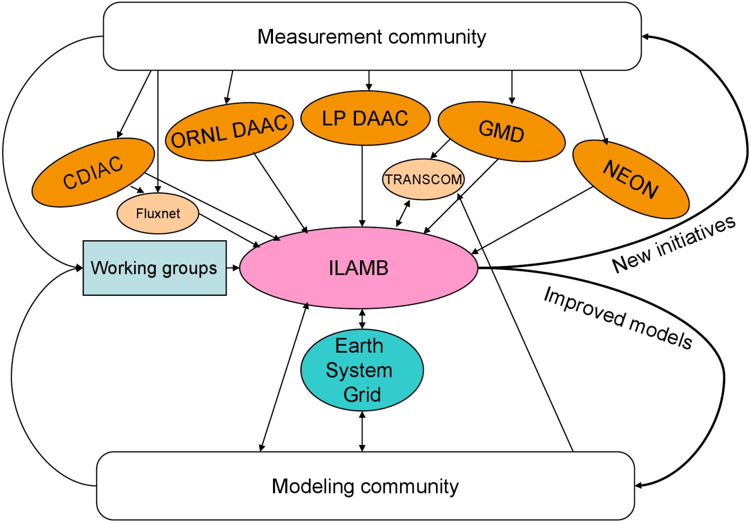
CO_2 Concentration (FF+OC+BAL+SHIP+AIRCRAFT)



International Land Model Benchmraking (ILAMB) Project

- Develop benchmarks for land model performance, with a focus on carbon cycle, ecosystem, surface energy, and hydrological processes. The benchmarks should be designed and accepted by the community.
- Apply the benchmarks to global models, beginning with CMIP5 model results.
- Support the design and development of a new, open-source, benchmarking software system for either diagnostic or model intercomparison purposes.
- Strengthen linkages between experimental, monitoring, remote sensing, and climate modeling communities in the design of new model tests and new measurement programs.

ILAMB Project Organization



International Land Model Benchmarking project and diagnostic system

Summary

- Uncertainties in climate-carbon cycle feedbacks were large in C^4MIP model results.
- Early CMIP5 emissions-forced model results suggest a continuing large range of uncertainty.
- Reducing the range of uncertainty in model representation of feedbacks requires comparisons with contemporary observations.
- Model benchmarking using internationally agreed-upon observational data can help guide synthesis efforts.

International Land Model Benchmarking (ILAMB) Project
http://www.ilamb.org/

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