CMIP6 Global Carbon Cycle Model Evaluation Needs

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obs4MIPs–CMIP6 Planning Meeting

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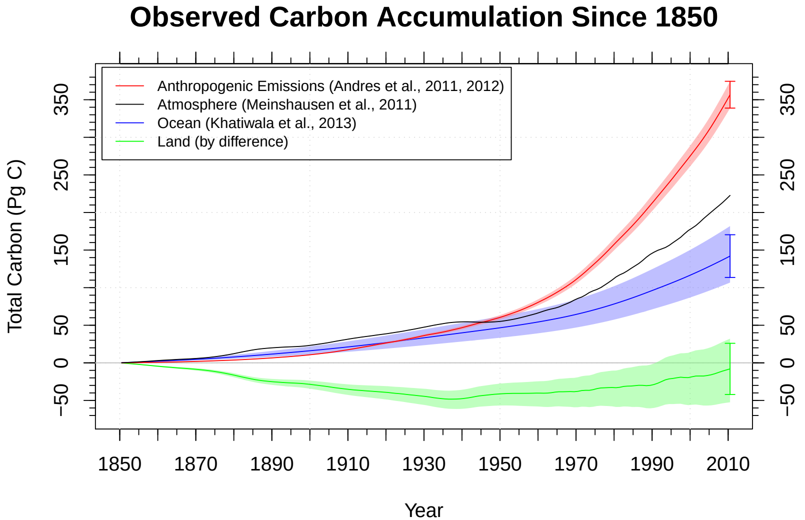
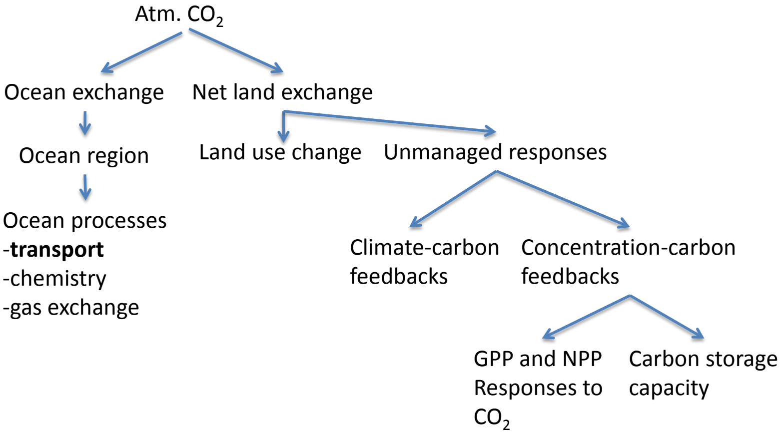


Observational estimates of anthropogenic carbon inventories in atmosphere, ocean, and land reservoirs for 1850–2010. Atmosphere carbon is a fusion of Law Dome ice core CO_2 observations, the Keeling Mauna Loa record, and more recently the NOAA GMD global surface average, integrated for the purpose of forcing IPCC models. Total land flux is computed by mass balance as follows:

$$\Delta C_L = \sum_i F_i - \Delta C_A - \Delta C_O.$$

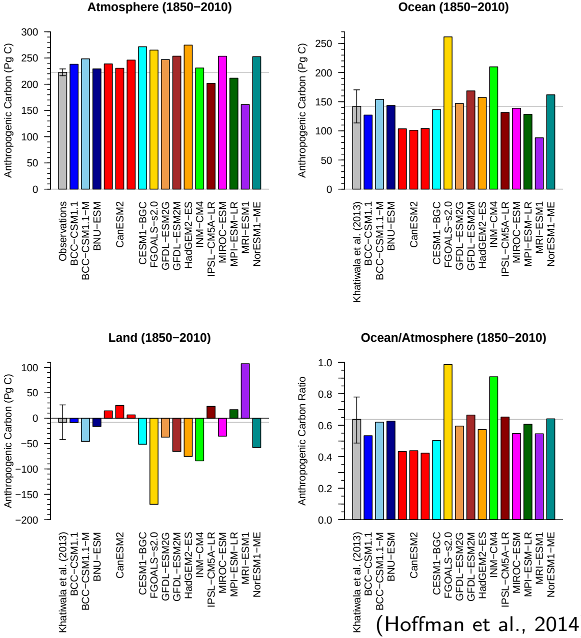
Bias Attribution Process



Model inventory comparison with Khatiwala et al. (2013)

Once normalized by their atmospheric carbon inventories, most ESMs exhibit a low bias in anthropogenic ocean carbon accumulation through 2010.

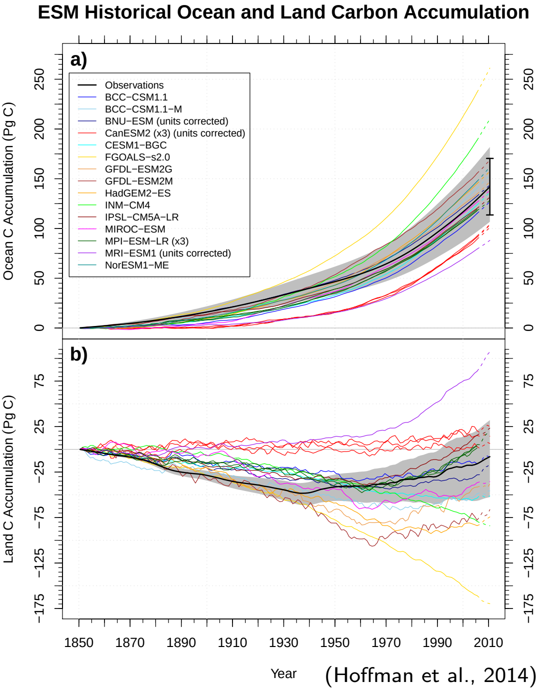
The same pattern holds for the Sabine et al. (2004) inventory derived using the ΔC^* separation technique.



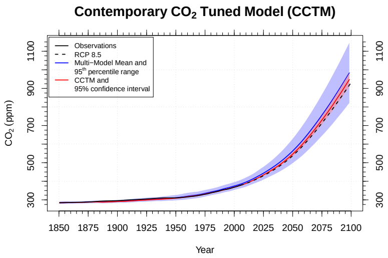
(Hoffman et al., 2014)

(a) Ocean inventory estimates have a fairly persistent ordering during the second half of the 20th century.

(b) ESMs have a wide range of land carbon accumulation responses to increasing CO_2 and land use change, ranging from a net source of 170 Pg C to a sink of 107 Pg C in 2010.

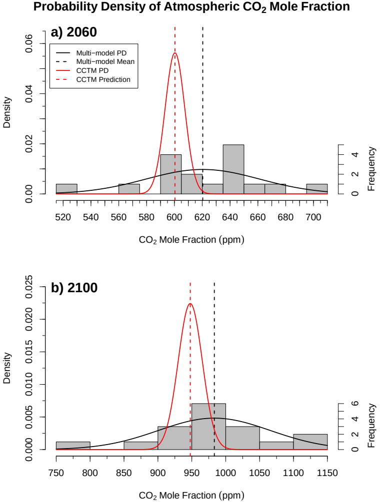


(Hoffman et al., 2014)



We used this regression to create a contemporary CO_2 tuned model (CCTM) estimate of the atmospheric CO_2 trajectory for the 21st century.

The width of the probability density is much smaller for the CCTM, by almost a factor of 6 at 2060 and almost a factor of 5 at 2100, indicating a significant reduction in the range of uncertainty for the CCTM prediction.



Best estimate tuned using Mauna Loa CO_2 data:

At 2060: 600 ± 14 ppm, 21 ppm below the multi-model mean

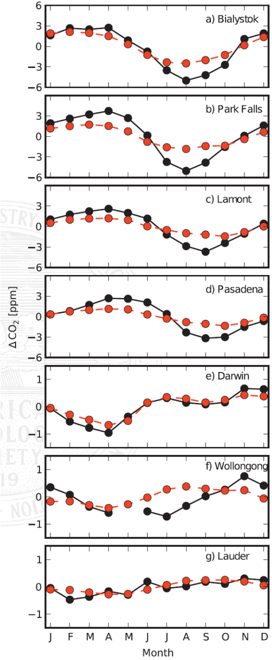
At 2100: 947 ± 35 ppm, 32 ppm below the multi-model mean

(Hoffman et al., 2014)

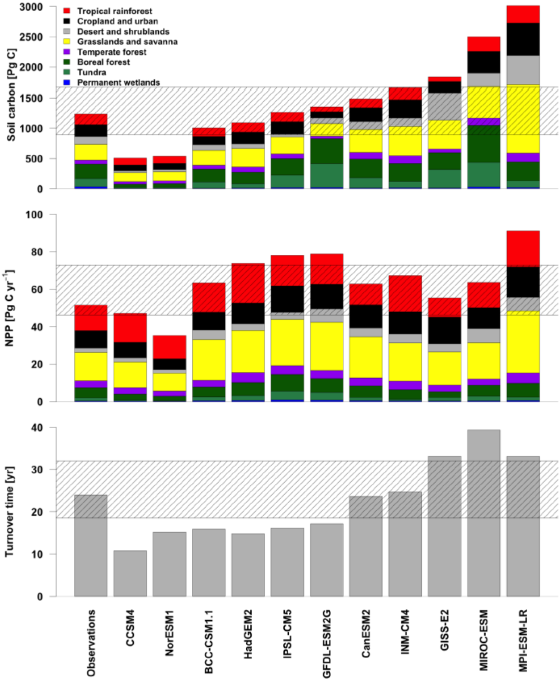
Total Carbon Column Observing Network

- Not all ESMs carry a 3-D atmospheric CO_2 tracer
- Transport of land and ocean fluxes using an offline atmospheric model may be needed for some comparisons

- **TCCON**
- **CESM 1**

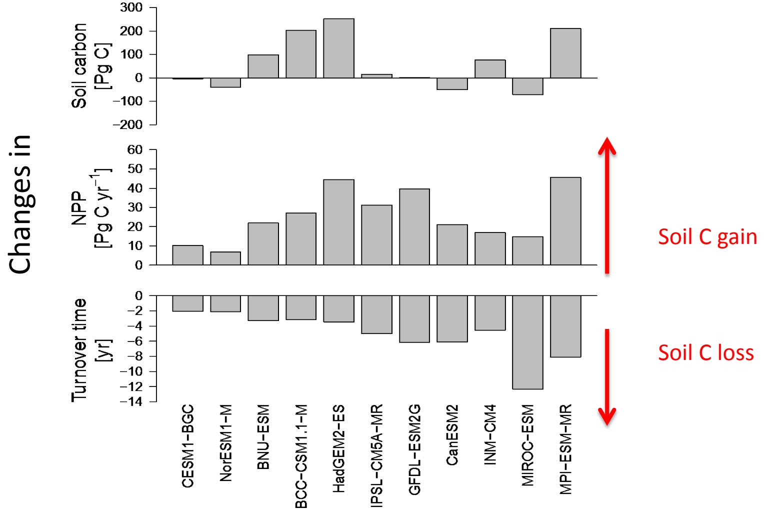


Keppel-Aleks et al. (J. of Climate, 2013)

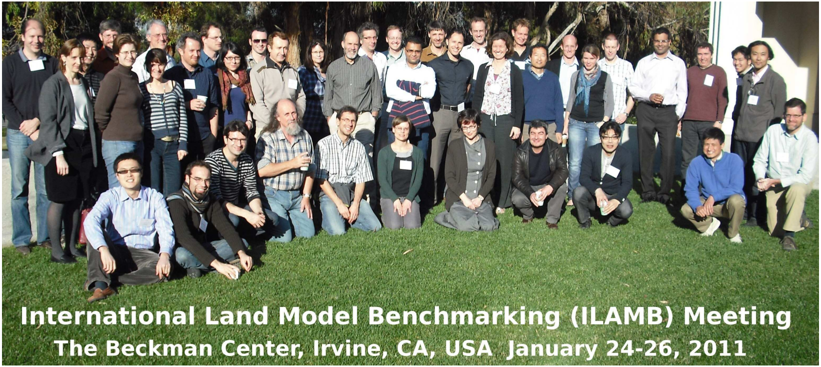


Todd-Brown et al. (2014)

21^{st} century gains and losses: $\overline{(2090\text{-}2099)}$-$\overline{(1997\text{-}2006)}$



Todd-Brown et al. (2014)



- We co-organized inaugural meeting and ∼45 researchers participated from the United States, Canada, the United Kingdom, the Netherlands, France, Germany, Switzerland, China, Japan, and Australia.
- **ILAMB Goals:** Develop internationally accepted benchmarks for model performance, advocate for design of open-source software system, and strengthen linkages between experimental, monitoring, remote sensing, and climate modeling communities. *Initial focus on CMIP5 models.*
- Provides methodology for model–data comparison and baseline standard for performance of land model process representations (Luo et al., 2012).

ILAMB 1.0 Benchmarks Now Under Development

	Annual Mean	Seasonal Cycle	Interannual Variability	Trend	Data Source
Atmospheric CO_2					
Flask/conc. + transport		✓	✓	✓	NOAA, SIO, CSIRO
TCCON + transport		✓	✓	✓	Caltech
Fluxnet					
GPP, NEE, TER, LE, H, RN	✓	✓	✓		Fluxnet, MAST-DC
Gridded: GPP	✓	✓	?		MPI-BGC
Hydrology/Energy					
runoff ratio (R/P) ~~river flow~~	✓		✓		GRDC, Dai, GFDL
global runoff/ocean balance	✓				Syed/Famiglietti
albedo (multi-band)		✓	✓		MODIS, CERES
soil moisture		✓	✓		de Jeur, SMAP
column water		✓	✓		GRACE
snow cover	✓	✓	✓	✓	AVHRR, GlobSnow
snow depth/SWE	✓	✓	✓	✓	CMC (N. America)
T_{air} & P	✓	✓	✓	✓	CRU, GPCP and TRMM
Gridded: LE, H	✓	✓			MPI-BGC, dedicated ET
Ecosystem Processes & State					
soil C, N	✓				HWSD, MPI-BGC
litter C, N	✓				LIDET
soil respiration	✓	✓	✓	✓	Bond-Lamberty
FAPAR	✓	✓			MODIS, SeaWIFS
biomass & change	✓			✓	Saatchi, Pan, Blackard
canopy height	✓				Lefsky, Fisher
NPP	✓				EMDI, Luyssaert
Vegetation Dynamics					
fire — burned area	✓	✓	✓		GFED3
wood harvest	✓			✓	Hurtt
land cover	✓				MODIS PFT fraction

Example Benchmark Score Sheet from C-LAMP

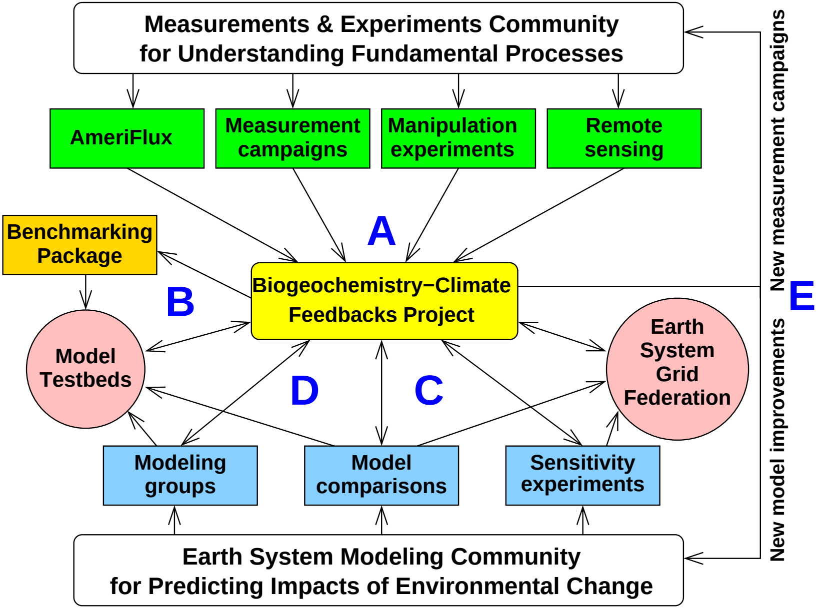
Models →

BGC Datasets ↓

Metric	Metric components	Uncertainty of obs.	Scaling mismatch	Total score	Sub-score	CASA′		CN	
LAI	Matching MODIS observations			15.0		13.5		12.0	
	• Phase (assessed using the month of maximum LAI)	Low	Low		6.0		5.1		4.2
	• Maximum (derived separately for major biome classes)	Moderate	Low		5.0		4.6		4.3
	• Mean (derived separately for major biome classes)	Moderate	Low		4.0		3.8		3.5
NPP	Comparisons with field observations and satellite products			10.0		8.0		8.2	
	• Matching EMDI Net Primary Production observations	High	High		2.0		1.5		1.6
	• EMDI comparison, normalized by precipitation	Moderate	Moderate		4.0		3.0		3.4
	• Correlation with MODIS (r^2)	High	Low		2.0		1.6		1.4
	• Latitudinal profile comparison with MODIS (r^2)	High	Low		2.0		1.9		1.8
CO_2 annual cycle	Matching phase and amplitude at Globalview flash sites			15.0		10.4		7.7	
	• 60°–90°N	Low	Low		6.0		4.1		2.8
	• 30°–60°N	Low	Low		6.0		4.2		3.2
	• 0°–30°N	Moderate	Low		3.0		2.1		1.7
Energy & CO_2 fluxes	Matching eddy covariance monthly mean observations			30.0		17.2		16.6	
	• Net ecosystem exchange	Low	High		6.0		2.5		2.1
	• Gross primary production	Moderate	Moderate		6.0		3.4		3.5
	• Latent heat	Low	Moderate		9.0		6.4		6.4
	• Sensible heat	Low	Moderate		9.0		4.9		4.6
Transient dynamics	Evaluating model processes that regulate carbon exchange on decadal to century timescales			30.0		16.8		13.8	
	• Aboveground live biomass within the Amazon Basin	Moderate	Moderate		10.0		5.3		5.0
	• Sensitivity of NPP to elevated levels of CO_2: comparison to temperate forest FACE sites	Low	Moderate		10.0		7.9		4.1
	• Interannual variability of global carbon fluxes: comparison with TRANSCOM	High	Low		5.0		3.6		3.0
	• Regional and global fire emissions: comparison to GFEDv2	High	Low		5.0		0.0		1.7
			Total:	**100.0**		**65.9**		**58.3**	

(Randerson et al., 2009)

Biogeochemistry–Climate System Feedbacks



Prototype System

- Current variables:
  - Above Ground Live Biomass (North America FIA, pan tropical from Saatchi et al.), Soil carbon (HWSD, NCPSCD), Burned area (GFED3), Albedo (MODIS, CERES), LAI (LAI3g), Gross Primary Production (Max Plank MTE), Net Ecosystem Exchange (Ameriflux)
- Near term targeted variables:
  - Terrestrial water storage (GRACE), Atmospheric CO2 (TCCON, NOAA GMD, HIPPO, CARVE, GCP), and runoff (GRDC).
- Graphics and scoring systems
  - Bias, RMS, seasonal phase, interannual variability, long-term trend scores
  - Global maps, variable-variable comparisons
- Software
  - Open source, designed to be user friendly and to enable easy entrainment of new variables

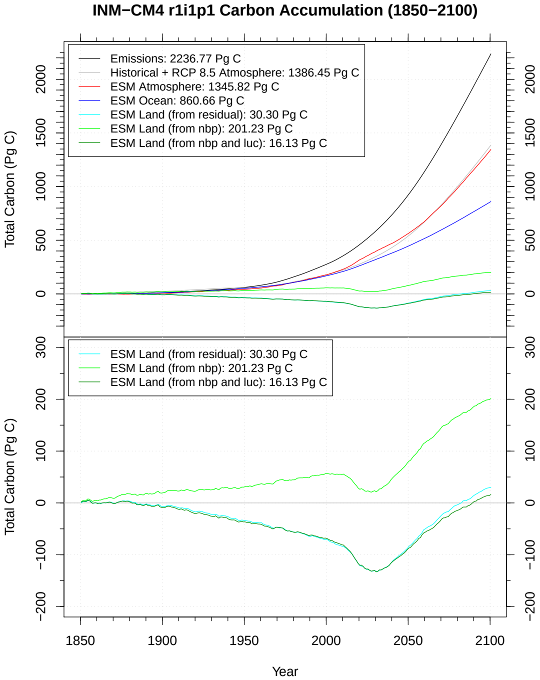
Mu, Hoffman, Riley, Koven, Lawrence, Randerson

Model Evaluation Needs

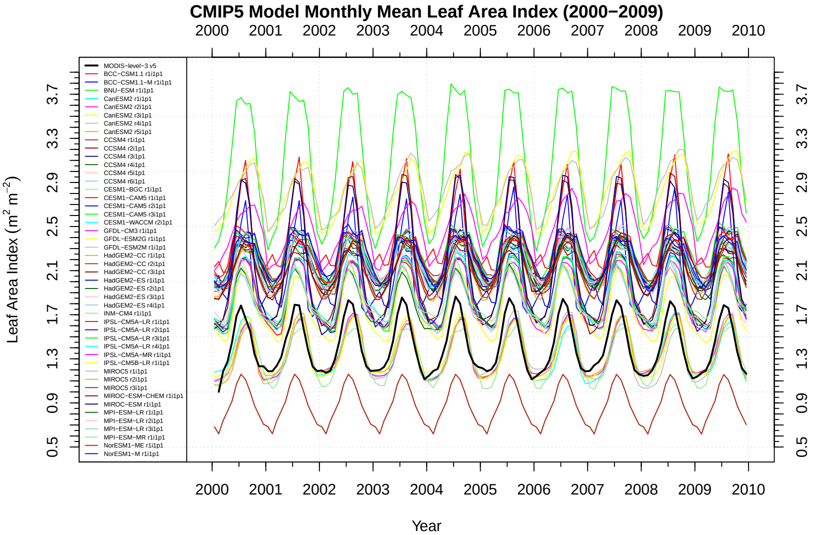
- Clear definitions of model variables and units (e.g., land use change, net biosphere productivity)
- Additional model variables needed to diagnose process-level behavior, e.g.,
  - FAPAR or NDVI (models simulating observations)
  - canopy height
  - above- and below-ground litter
  - wood harvest and other land-use-related fluxes
- Process-response benchmarks
- Model simulators (e.g., run the land model in MODIS or A-Train mode)
- Realistic and usable uncertainty estimates on all observations

In CMIP5, land carbon uptake computed as the residual did not always match the reported net biosphere productivity (nbp).

Some fluxes were reported in units of $\mathrm{g\,C\,m^{-2}\,s^{-1}}$ and some in units of $\mathrm{g\,CO_2\,m^{-2}\,s^{-1}}$.



Global LAI for 47 CMIP5 Simulations Compared to MODIS



We need “observations” and uncertainties useful for comparison with model results.

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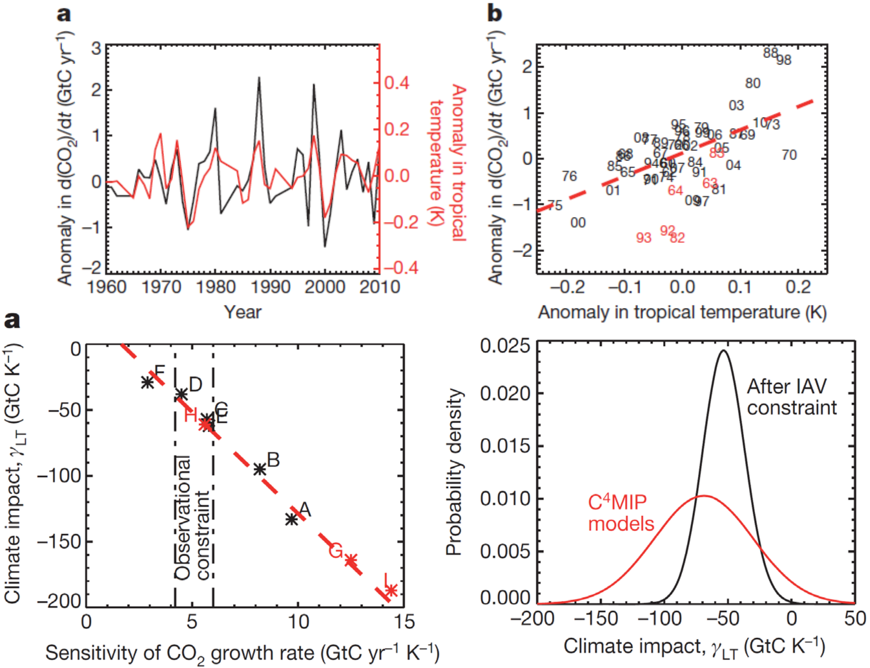
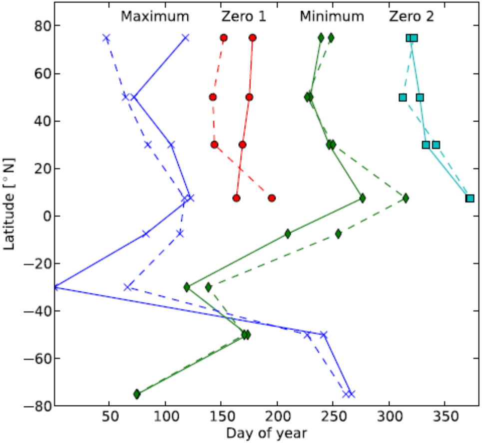
Extra Slides



Cox et al. 2013

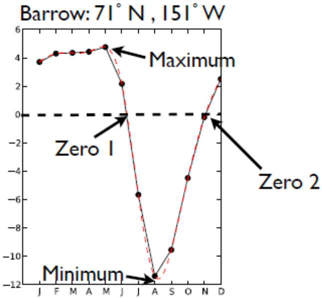
Diagnostics of the phase of the annual cycle of atm. CO_2



NOAA GMD Observations

CESM 1

The onset of the growing season occurs too early in CESM.



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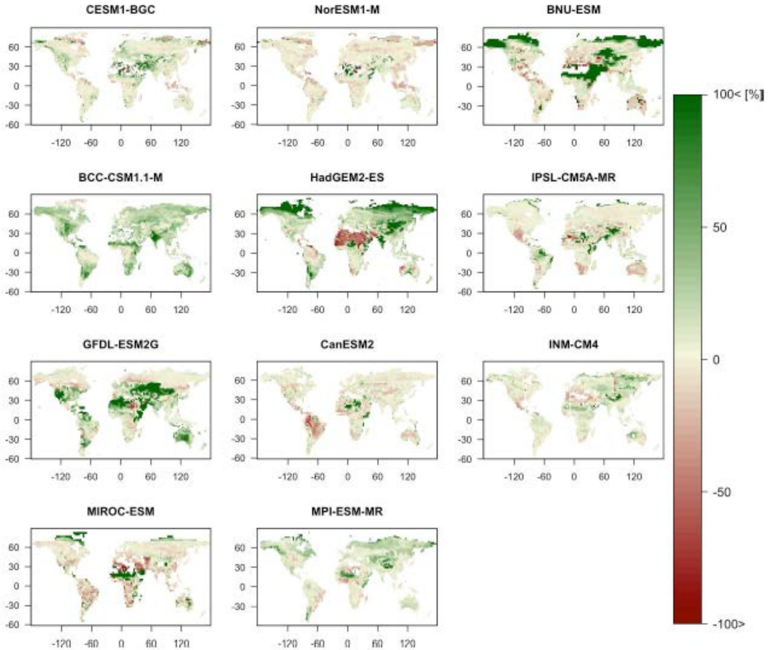

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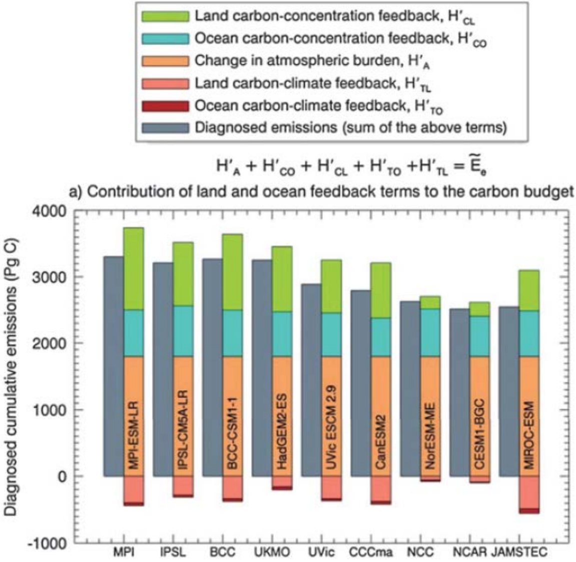

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