International Land Model Benchmarking (ILAMB) Project

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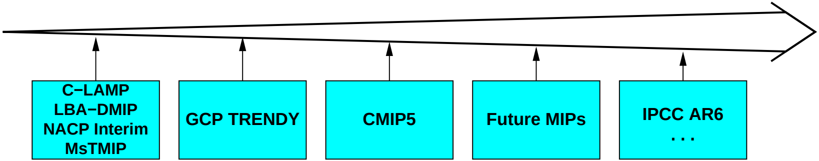
ILAMB Goals

- 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.
- 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.

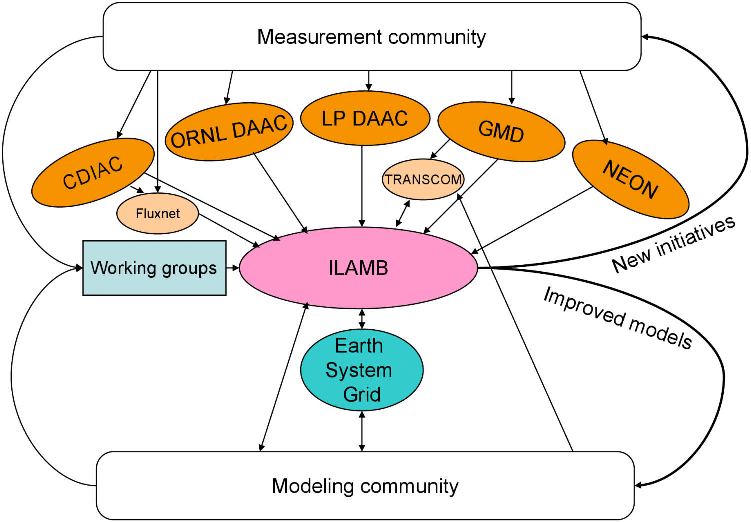
Why Benchmark?

- to show the broader science community and the public that the representation of the carbon cycle in climate models is improving;
- to provide a means, in Earth System models, to quantitatively diagnose impacts of model development in related fields on carbon cycle and land surface processes;
- to guide synthesis efforts, such as the Intergovernmental Panel on Climate Change (IPCC), in the review of mechanisms of global change in models that are broadly consistent with available contemporary observations;
- to increase scrutiny of key datasets used for model evaluation;
- to identify gaps in existing observations needed for model validation;
- to provide a quantitative, application-specific set of minimum criteria for participation in model intercomparison projects (MIPs);
- to provide an optional weighting system for multi-model mean estimates of future changes in the carbon cycle.

An Open Source Benchmarking Software System



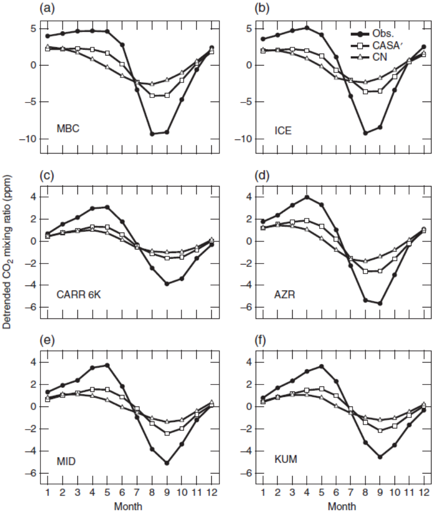
- Human capital costs of making rigorous model-data comparisons is considerable and constrains the scope of individual MIPs.
- Many MIPs spend resources "reinventing the wheel" in terms of variable naming conventions, model simulation protocols, and analysis software.
- **Need for ILAMB:** Each new MIP has access to the model-data comparison modules from past MIPs through ILAMB (*e.g.*, MIPs use one common modular software system). Standardized international naming conventions also increase MIP efficiency.



International Land Model Benchmarking project and diagnostic system

What is a Benchmark?

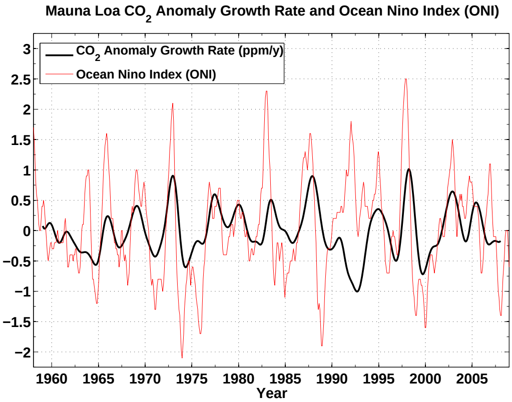
- A benchmark is a quantitative test of model function, for which the uncertainties associated with the observations can be quantified.
- Acceptable performance on benchmarks **is a necessary but not sufficient condition** for a fully functioning model.
- Since all datasets have strengths and weaknesses, an effective benchmark is one that draws upon a broad set of independent observations to evaluate model performance on multiple temporal and spatial scales.



From Randerson et al. (2009)

Example Benchmark – *Interannual to Decadal Time Scale*

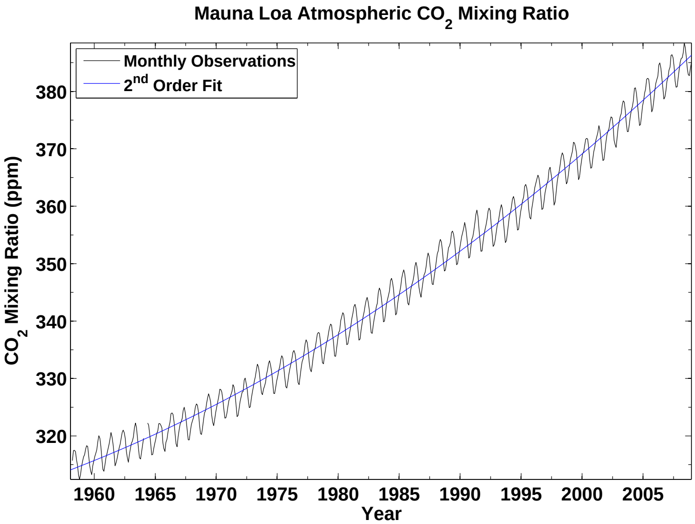
The relationship between El Niño-Southern Oscillation (ENSO) and observed CO_2 anomalies at Mauna Loa may be exploited to evaluate ocean and terrestrial model responses.



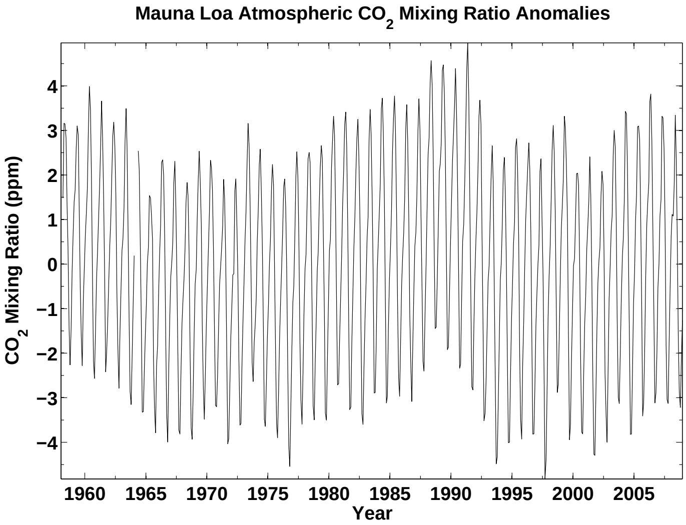
CO_2 Dependence on El Niño-Southern Oscillation (ENSO)

- Keeling and Revelle (1985) described a shutdown in upwelling and biological activity during El Niño years, resulting in a shutdown of CO_2 out-gassing.
- Many others have confirmed this response, including Rayner et al., Feeley et al., Baker et al., and others.
- They suggested the deficiency in CO_2 flux is more than compensated for by widespread forest fires and plant deaths due to drought.
- While the net effect of *natural* processes may once have been a sink, the opposite effect is observed today.
- Opportunistic burning for forest clearing is likely to strengthen the sensitivity of CO_2 to El Niño.

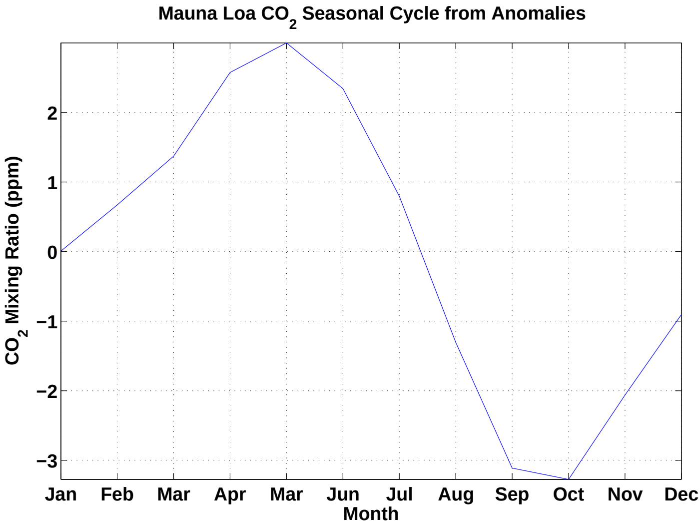
Mauna Loa CO_2 (1957–2008) and Polynomial Curve Fit



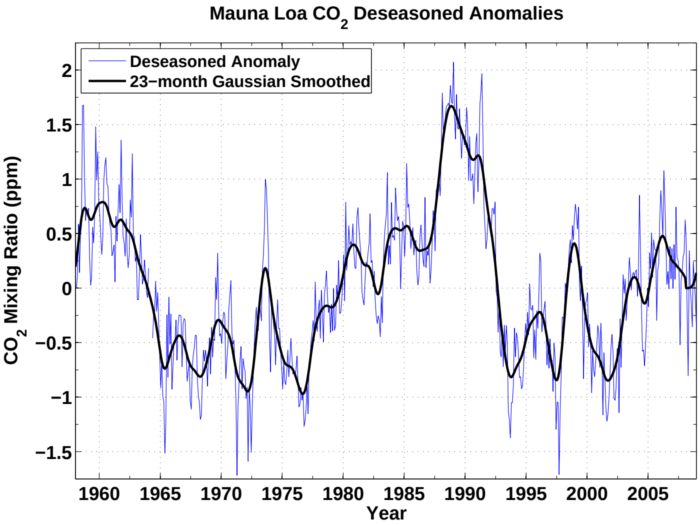
Mauna Loa CO_2 (1957–2008) Minus the Trend



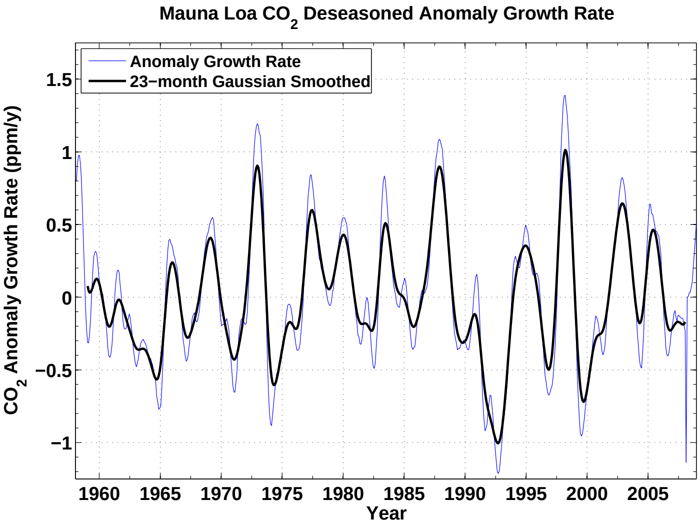
Mauna Loa CO_2 (1957–2008) Mean Seasonal Cycle



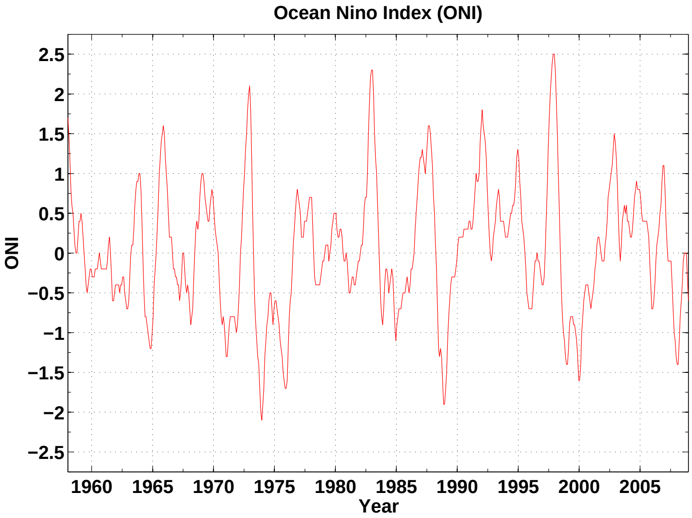
Mauna Loa CO_2 (1957–2008) Deseasoned Anomalies



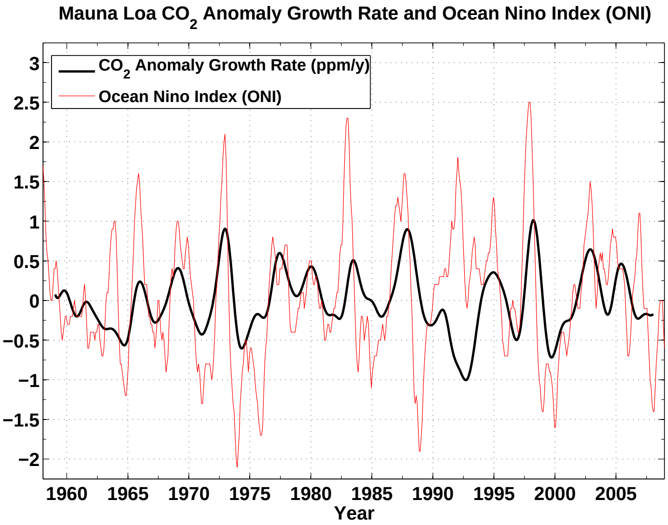
Mauna Loa CO_2 (1957–2008) Anomaly Growth Rate



Ocean Niño Index (ONI)



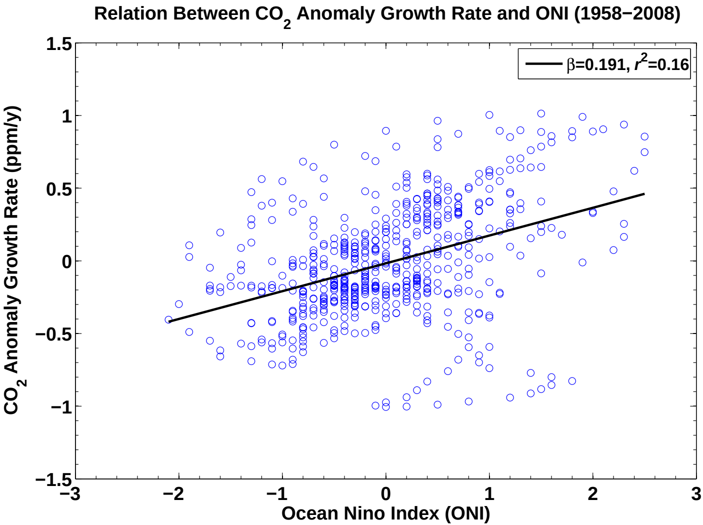
CO_2 Anomaly Growth Rate and Ocean Niño Index



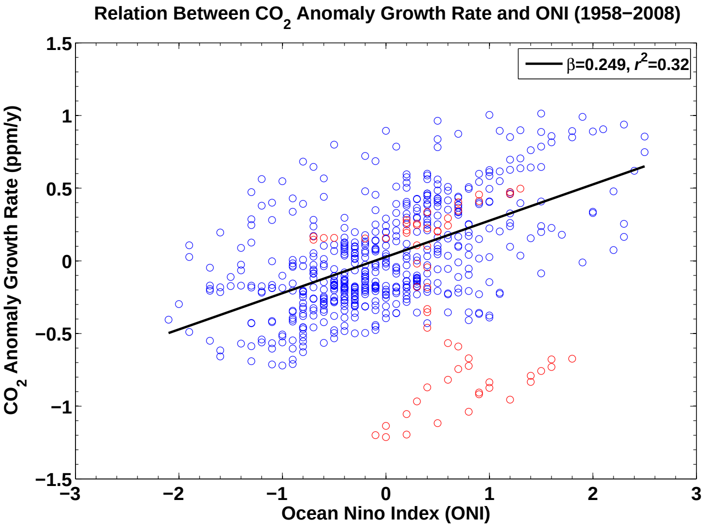
Mount Pinatubo Eruption

- June 1991 on island of Luzon in the Philippines
- Second largest volcanic eruption of 20th century
- Millions of tons of sulfur dioxide discharged into atmosphere
- Gases and ash reached 34 km high and over 400 km wide
- Largest disturbance of stratosphere since Krakatau in 1883

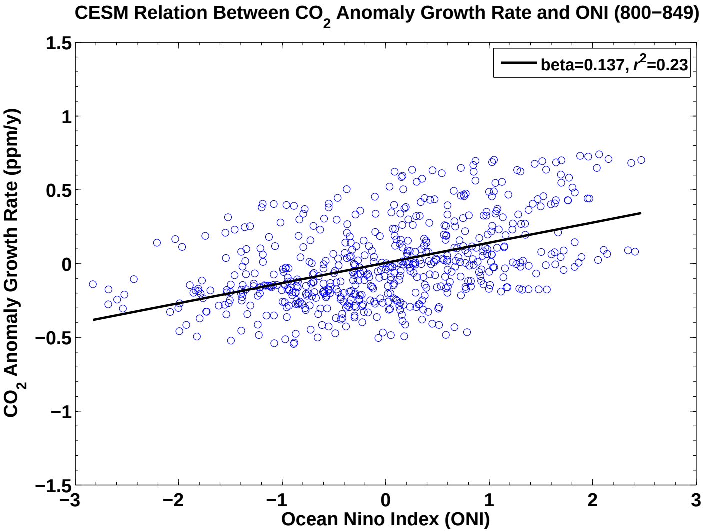
Relation Between CO_2 Anomaly Growth Rate and ONI



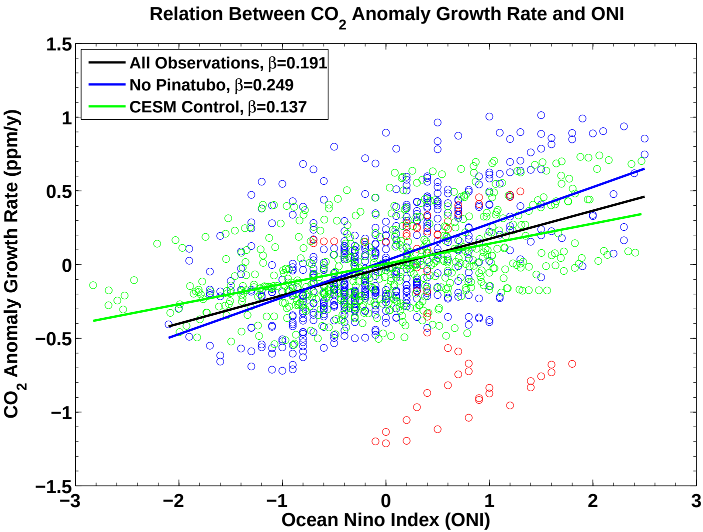
Relation Without 1991–1995 (Pinatubo Period)



Community Earth System Model (CESM) Control Run

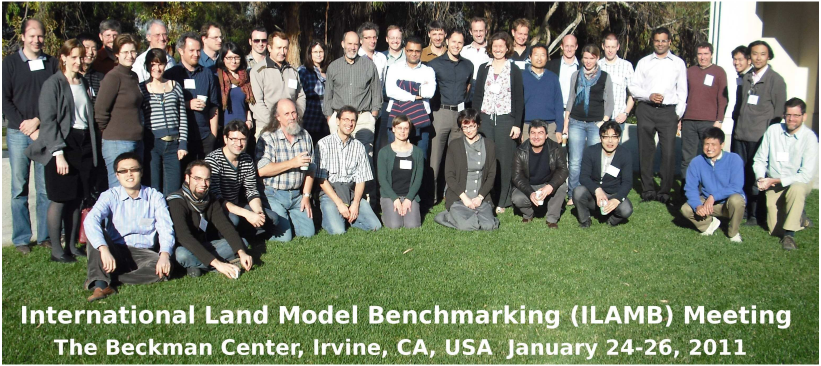


CESM vs. Observations



Benchmark Conclusions

- Relationship between Mauna Loa CO_2 anomalies and El Niño are strongly related, except during intervening events.
- Models should capture this relationship *for the right reasons*, so this may be a useful metric for model evaluation.
- More broadly, atmospheric CO_2 is an integrator of terrestrial and ocean fluxes with valuable information for constraining model behavior over a wide range of time scales (see also Cadule et al., 2010).
- For this analysis, time-lag correlation may improve the fit and yield a more accurate slope.
- This slope may change over time as humans exploit El Niño-induced drought for tropical forest clearing.
- The CESM control run does a reasonable job of capturing this relationship.



- Meeting Co-organized by Forrest Hoffman (UC-Irvine and ORNL), Chris Jones (UK Met Office), Pierre Friedlingstein (U. Exeter and IPSL-LSCE), and Jim Randerson (UC-Irvine).
- About 45 researchers participated from the United States, Canada, the United Kingdom, the Netherlands, France, Germany, Switzerland, China, Japan, and Australia.

ILAMB Meeting Goals

- Design the first set of ILAMB benchmarks for global models.
  - How many flavors (carbon cycle, LUC, hydrology, . . .)?
  - What datasets do we include?
  - What graphics and cost functions?
- Coordinate carbon cycle and land model evaluation analyses for TRENDY and CMIP5 results.
- Develop an implementation plan for application of the ILAMB 1.0 benchmarks to TRENDY and CMIP5 output over next year.
- Decide upon the approach for developing ILAMB code.
  - netCDF for datasets? Language for evaluation code?
  - Need to extend variable naming conventions beyond CMIP5.
- Decide upon a future schedule and means to secure funding.
  - Key deadline is July 2012 for submission of manuscripts for IPCC AR5 Working Group 1.
  - Should ILAMB meet once a year until AR6?

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**	

From Randerson et al. (2009)

	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					
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

Meeting Summary

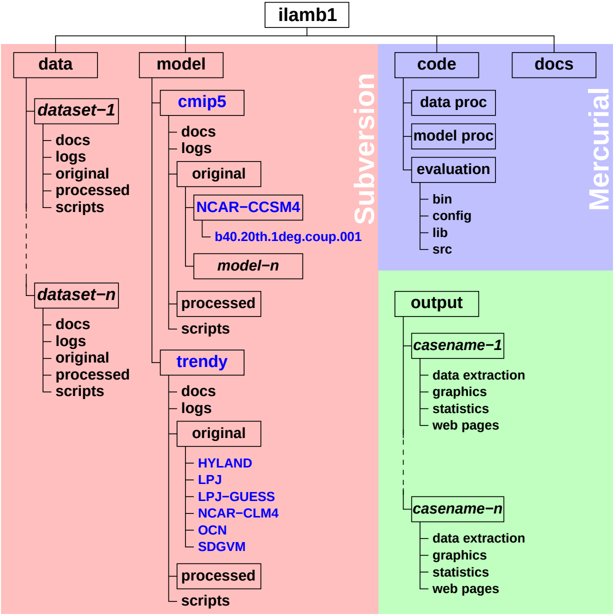
- Five break-out groups met, one for each benchmark category, to identify cost function metrics and graphics.
- Measurement and model uncertainty must be characterized and spatial scaling mismatch considered for evaluation.

- Key objectives are to use publicly available data and freely available software.
- The R package will be used for generating statistical results and diagnostics.
- Five initial benchmarks will be implemented to evaluate existing TRENDY and CMIP5 model results.

A team was identified to begin software architecture design.

A developmental hierarchy for data, model results, code, and docs is established.

Server-based and distributed version control systems will be used for handling data and code, respectively.



Next Steps

- Common model output
  - A draft document proposing additional new netCDF Climate and Forecast (CF) conventions, beyond those created for CMIP5, is available for comment.
  - To assist the modeling community, a translator between ALMA and CF standards may be created.
- Future: New protocols and forcing data comparisons.
- C-LAMP2 will produce new metrics and diagnostics for CESM1-CLM4 using the ILAMB software architecture.
- Certain C-LAMP2 diagnostics will be contributed to ILAMB.

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

References

P. Cadule, P. Friedlingstein, L. Bopp, S. Sitch, C. D. Jones, P. Ciais, S. L. Piao, and P. Peylin. Benchmarking coupled climate-carbon models against long-term atmospheric CO_2 measurements. *Global Biogeochem. Cycles*, 24(2):GB2016, Oct. 2010. doi:10.1029/2009GB003556.

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