Modeling the Couplings Across the Earth Surface in CESM

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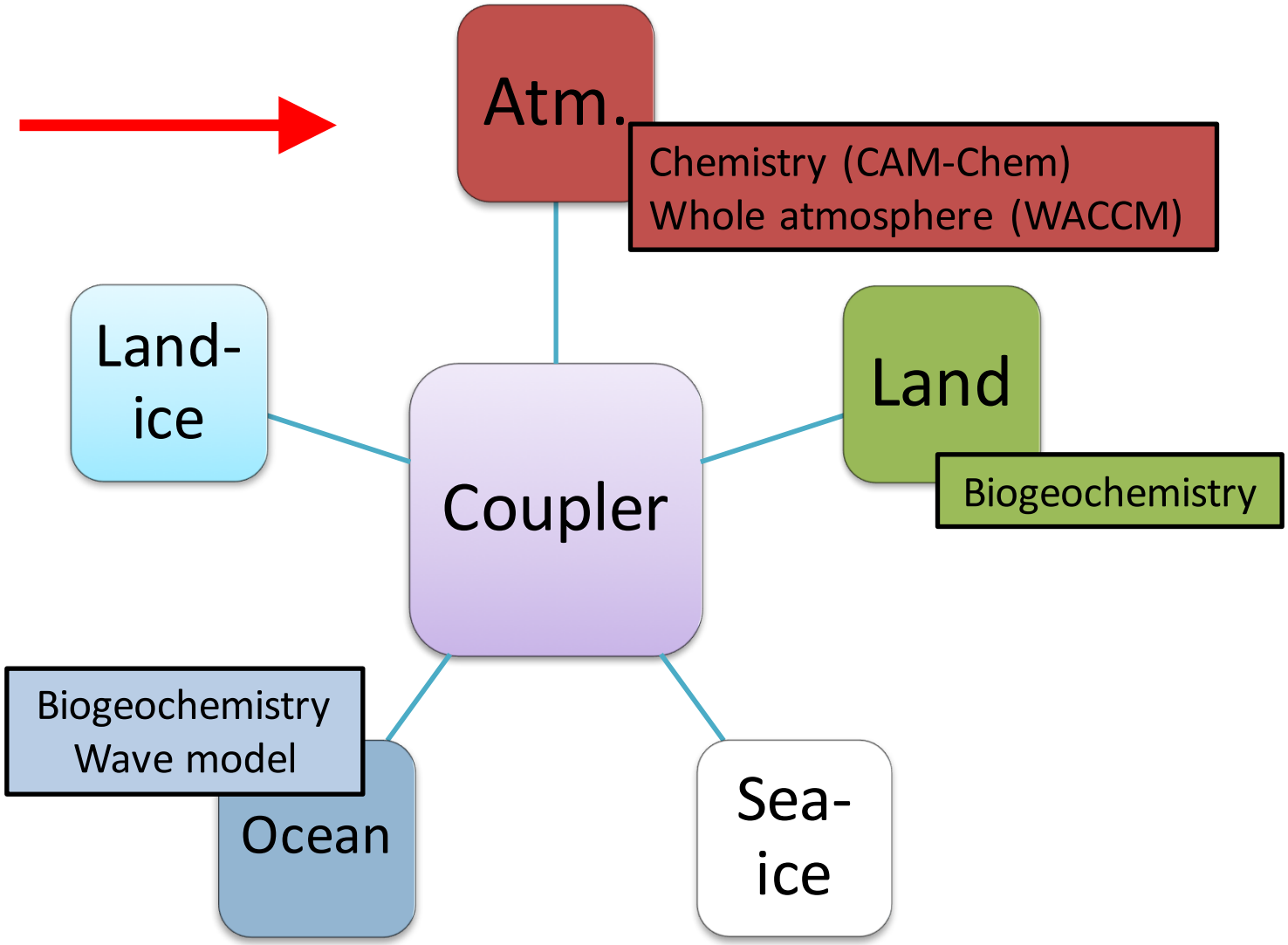
Components of CESM (Community Earth System Model)

Forcings:
- Greenhouse gases
- Manmade aerosols
- Volcanic eruptions
- Solar variability
- Land-use change



CESM Project

Based on 20+ Years of Model development and application

CESM is primarily sponsored by the National Science Foundation and the Department of Energy

Most working groups have winter/spring meetings. Annual meeting in June (≈400 participants).

Commun

www2.cesm.ucar.edu

The Community Earth System Model: A Framework for Collaborative Research

J.W. Hurrell, M.M. Holland, P.R. Gent, S. Ghan, J.E. Kay, P.J. Kushner, J.-F. Lamarque, W.G. Large, D. Lawrence, K. Lindsay, W.H. Lipscomb, M.C. Long, N. Mahowald, D.R. Marsh, R.B. Neale, P. Rasch, S. Vavrus, M. Vertenstein, D. Bader, W.D. Collins, J.J. Hack, J. Kiehl, S. Marshall, **Bulletin American Meteorological Society**, 2013.

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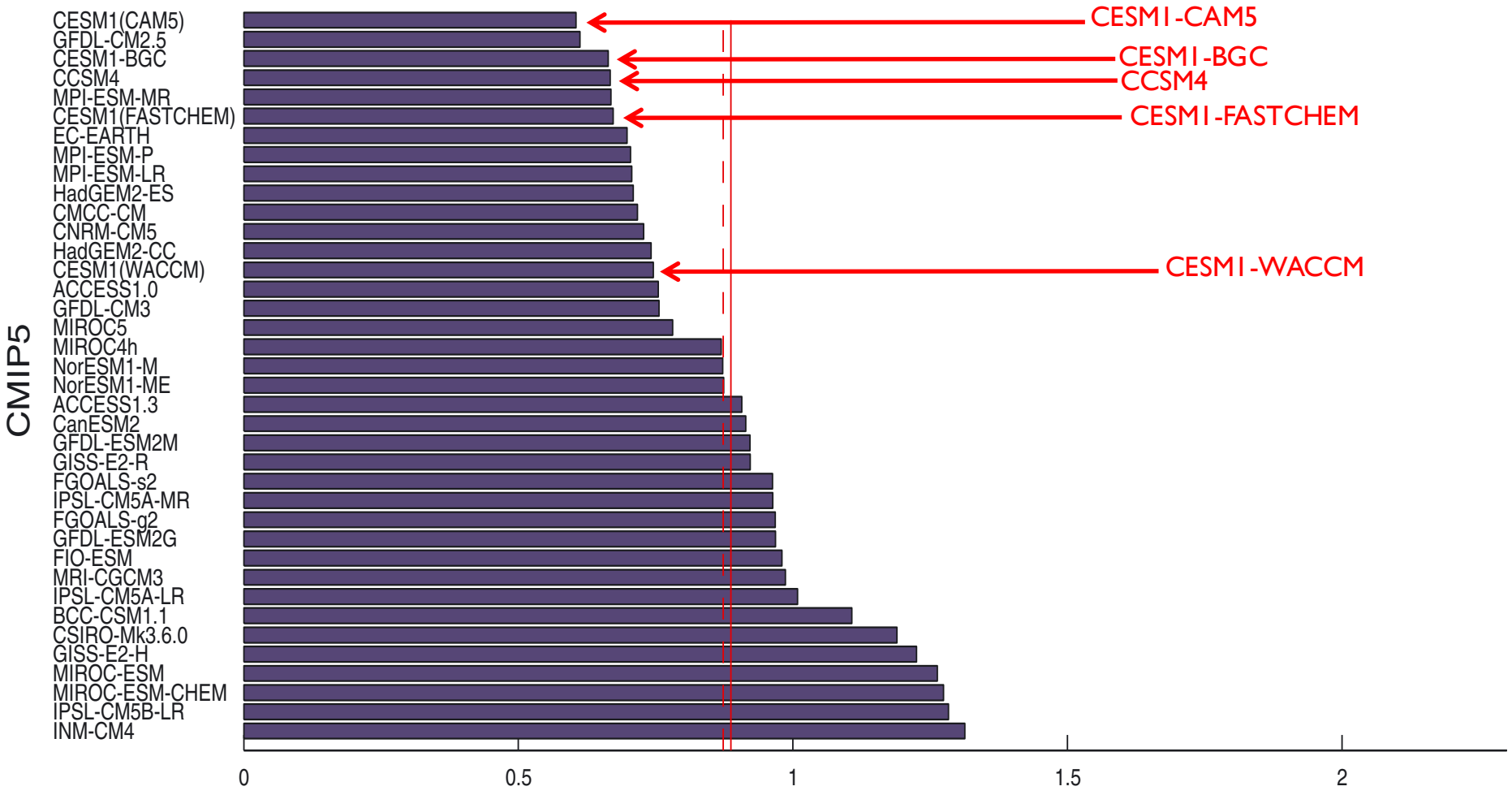
Graphic courtesy of Steve Ghan and DOE Graphics team

CMIP5 Model Intercomparison



(Knutti, Masson, Gettelman, GRL, 2013)

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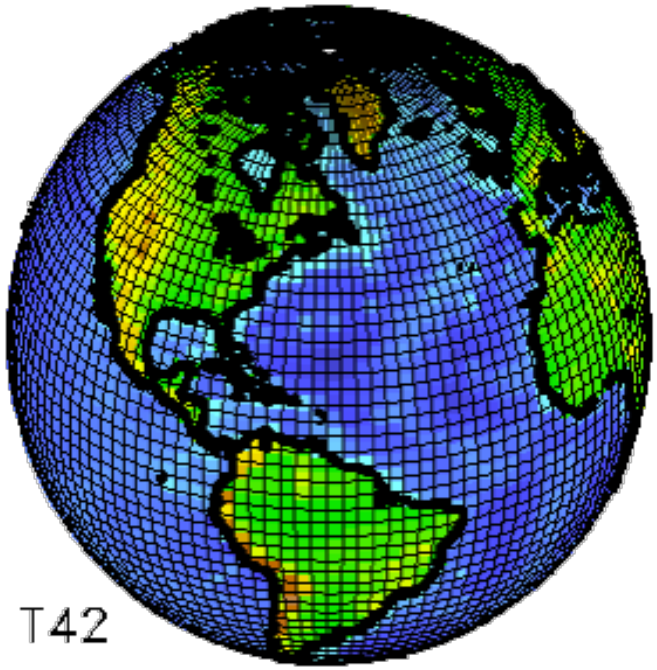
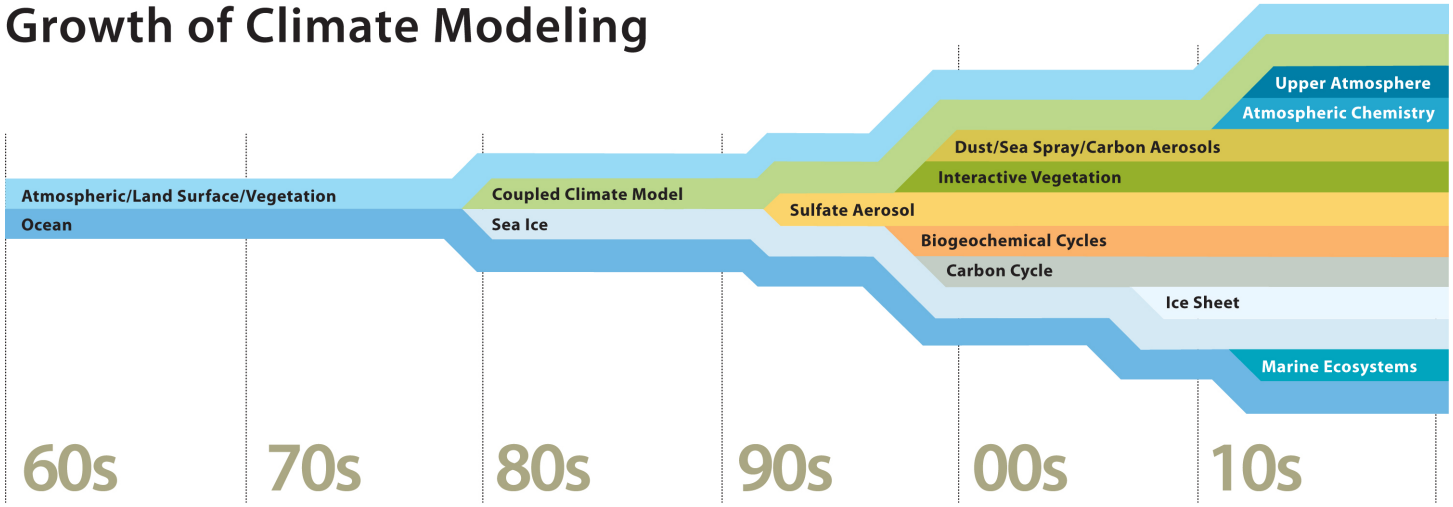
Community Earth System Model (CESM1)

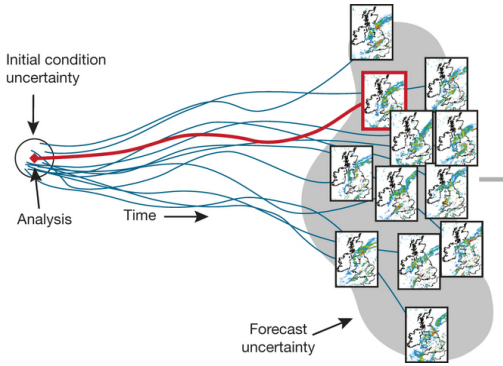


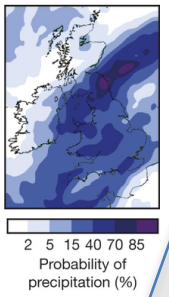
- 0.25°, 1° , 2° resolutions, +regional-refinement
- 30 minute time step (for 1° and 2°)
- 32 atmosphere levels (72 for WACCM)
- 60 ocean levels (0.1° or 1°)
- 25 ground layers
- ~5 million grid boxes at 1° resolution
- >1.5 million lines of computer code
- Data archived (monthly, daily, hourly) for hundreds of geophysical fields
- Utilized by hundreds of scientists all around the world

CESM2 will be released in December 2016

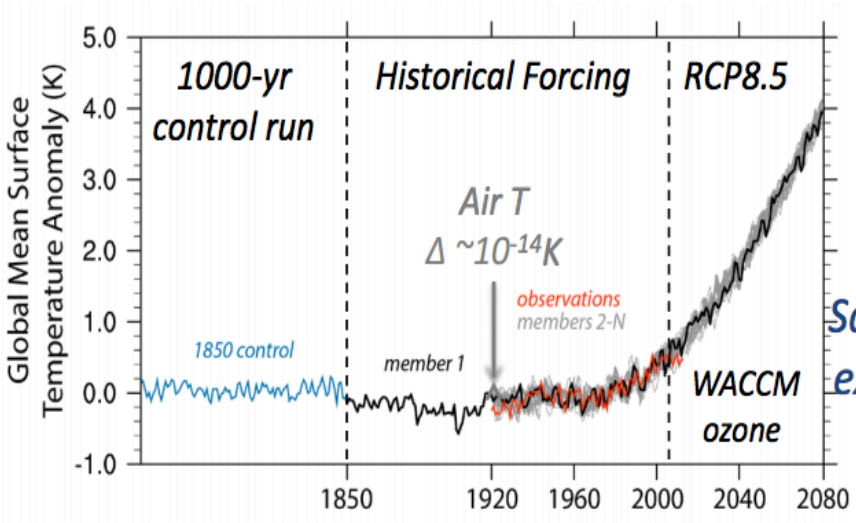
Growth of Climate Modeling







Internal variability and ensemble

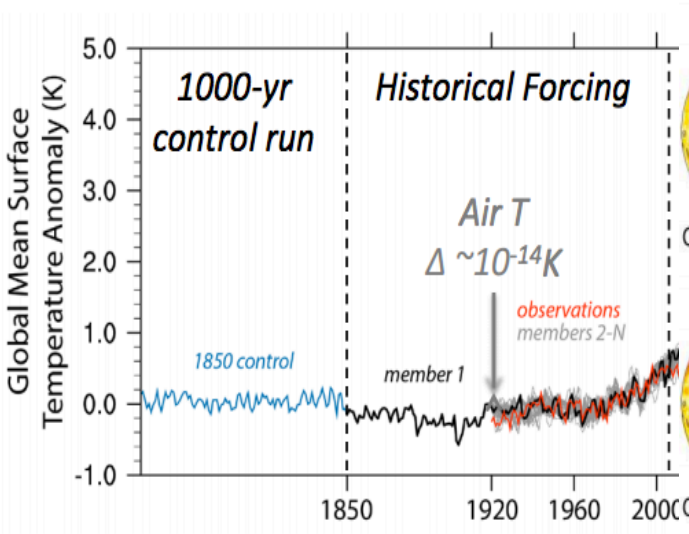


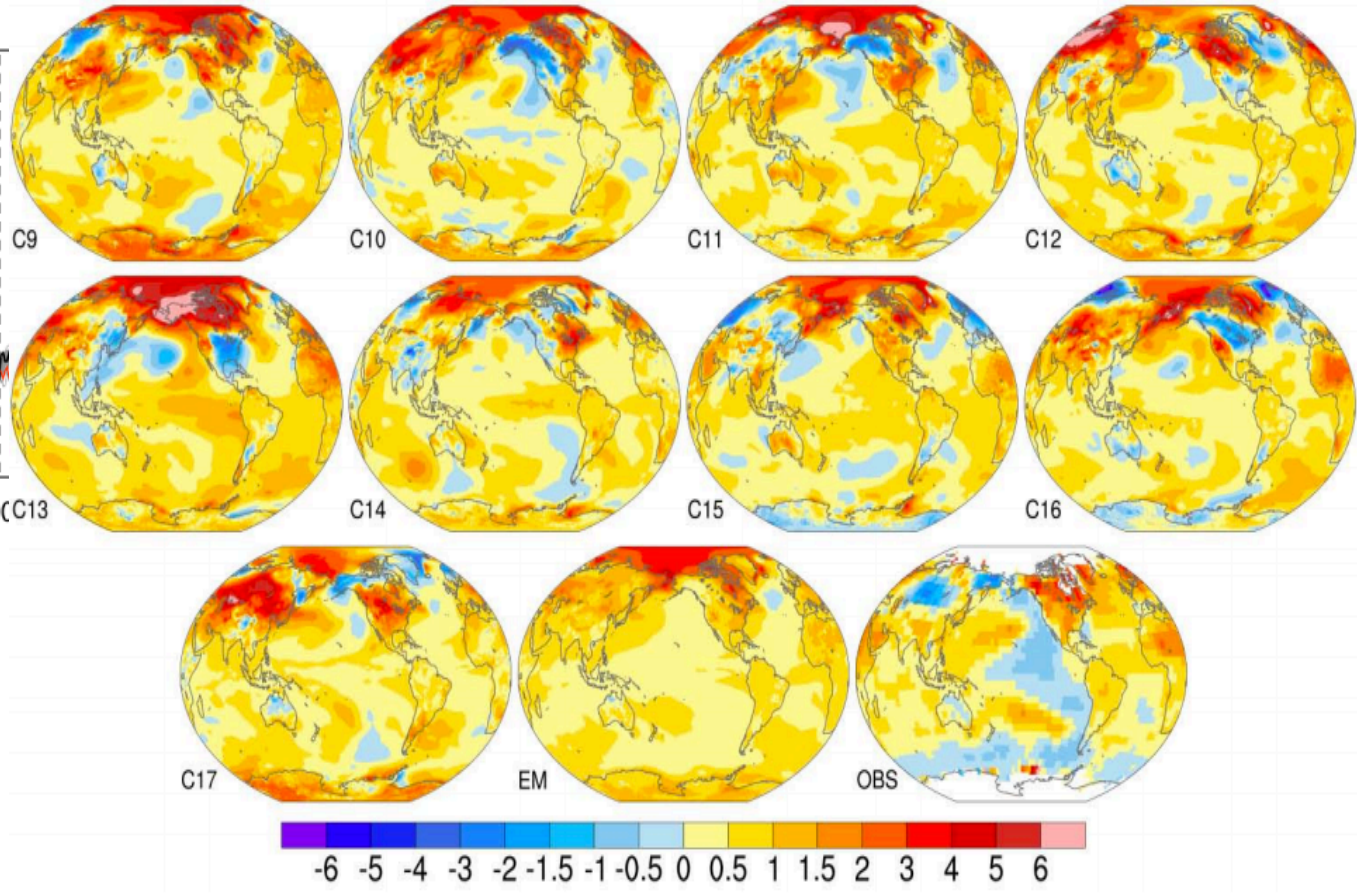
30 Runs
1920-2080

Same forcing
Same initial conditions
except round-off error
to initial air temps

Slide from C. Deser

Internal variability and ensemble

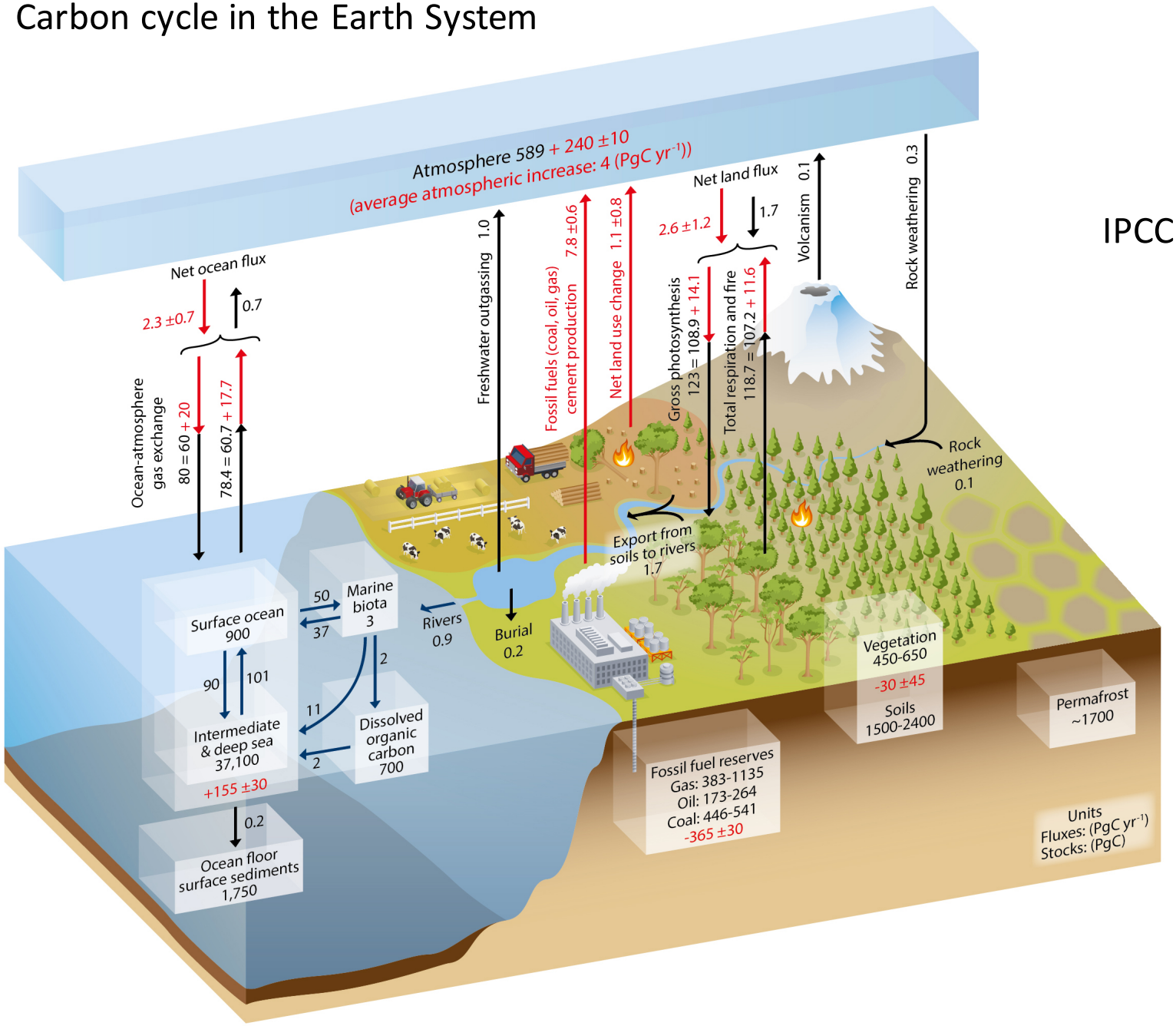




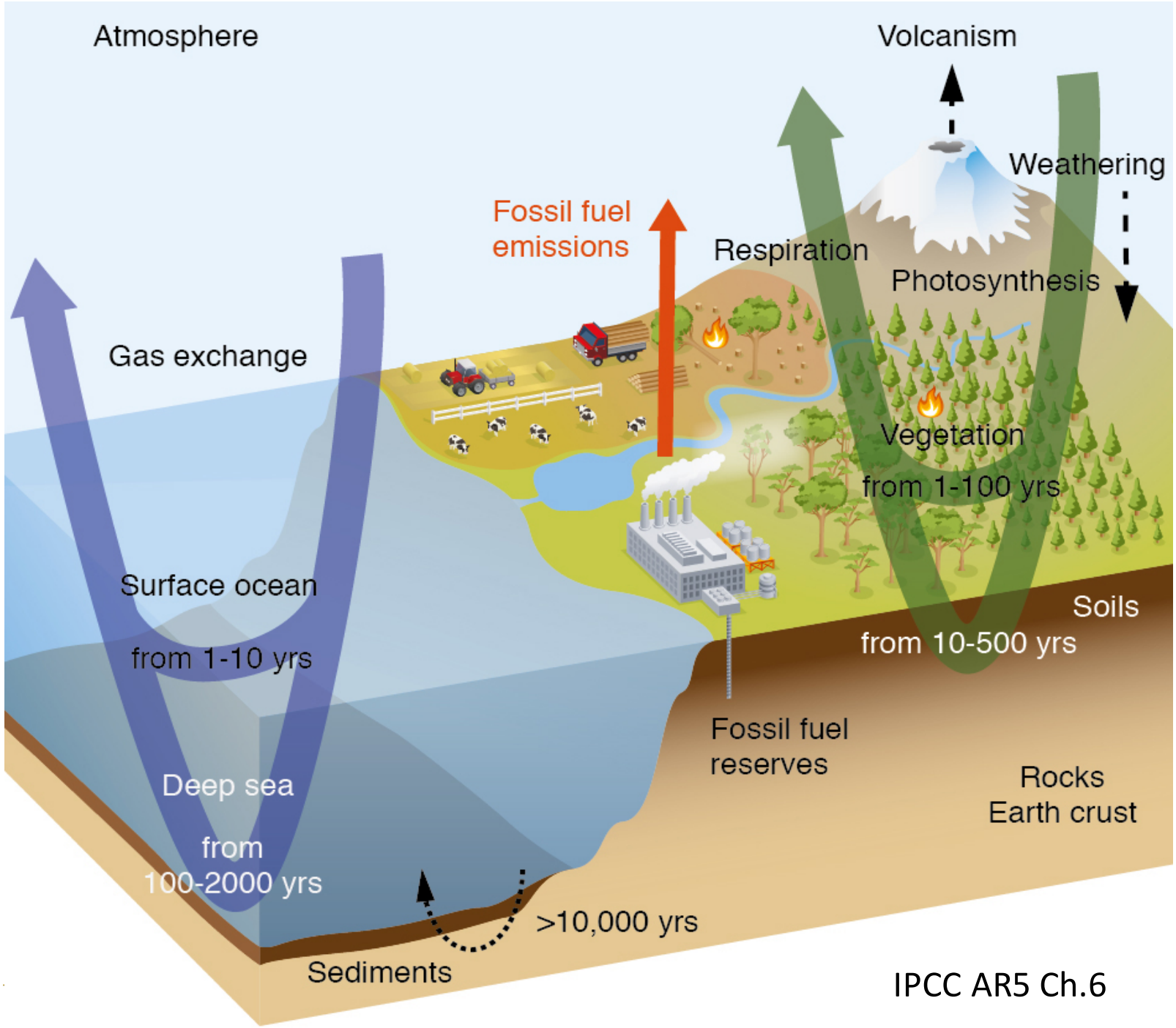
Slide from C. Deser

Panels show 1979-2012 DJF surface temperature trends for 9 ensemble members, the ensemble mean, and observations.

Carbon cycle in the Earth System

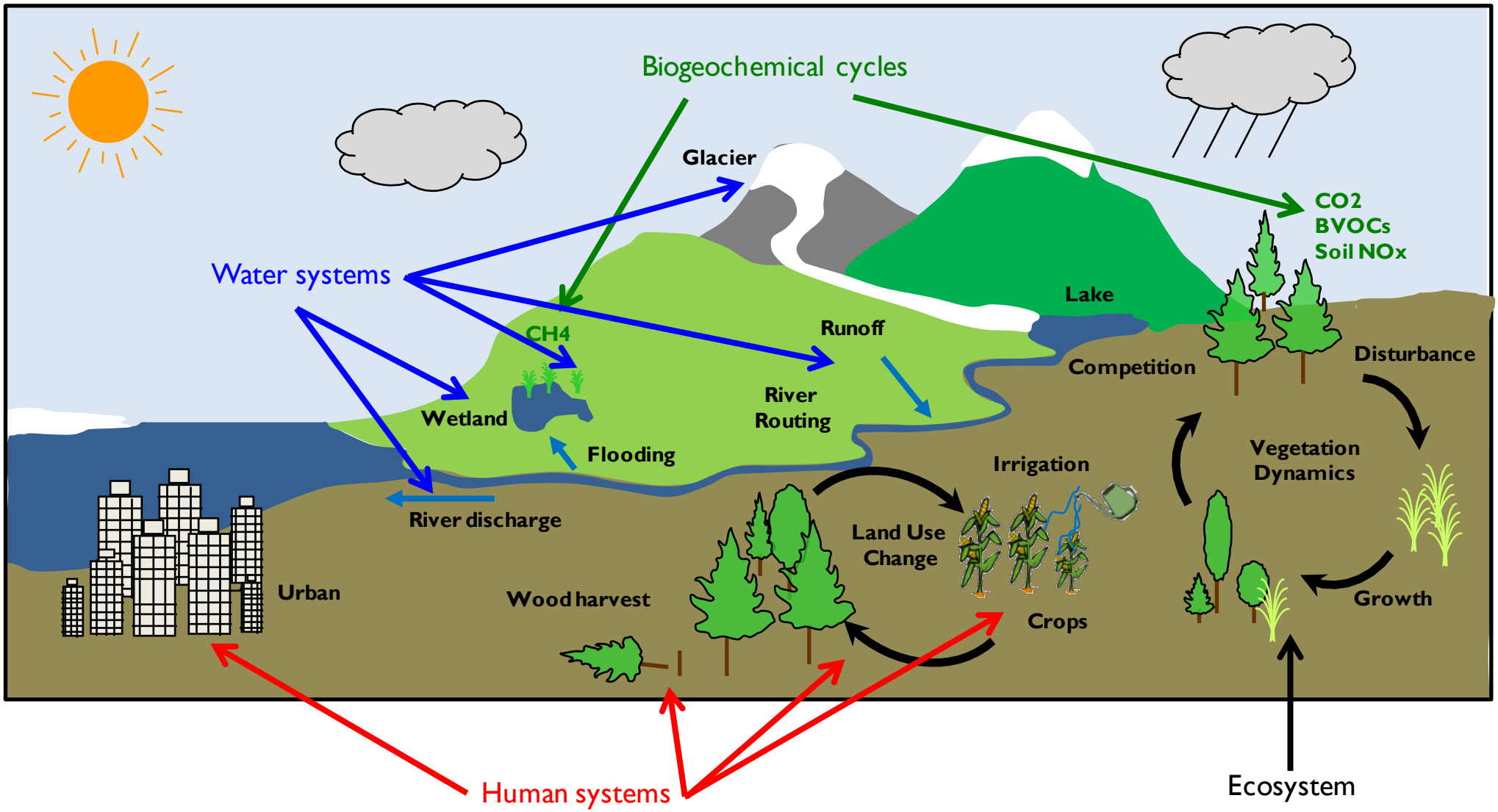


IPCC AR5 Ch.6

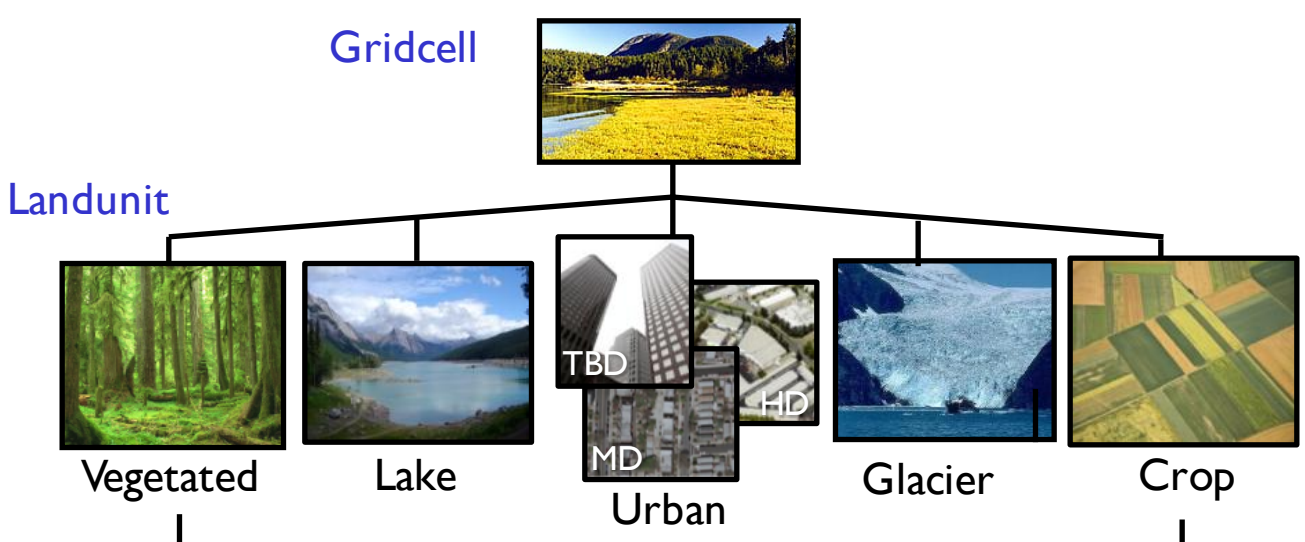

Atmosphere
Volcanism
Weathering
Fossil fuel emissions
Respiration
Photosynthesis
Gas exchange
Vegetation
from 1-100 yrs
Surface ocean
from 1-10 yrs
Soils
from 10-500 yrs
Fossil fuel reserves
Rocks
Earth crust
Deep sea
from 100-2000 yrs
>10,000 yrs
Sediments

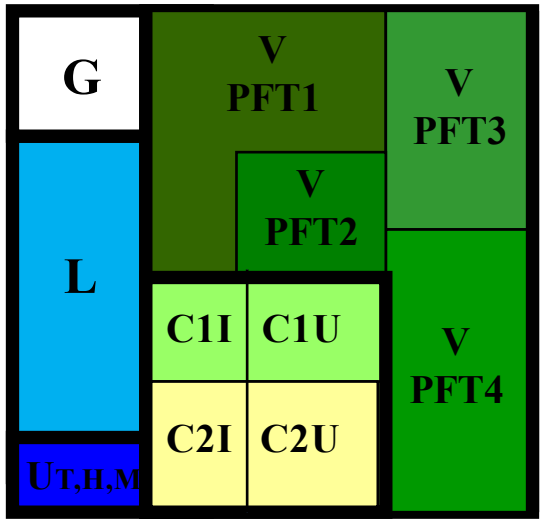
IPCC AR5 Ch.6

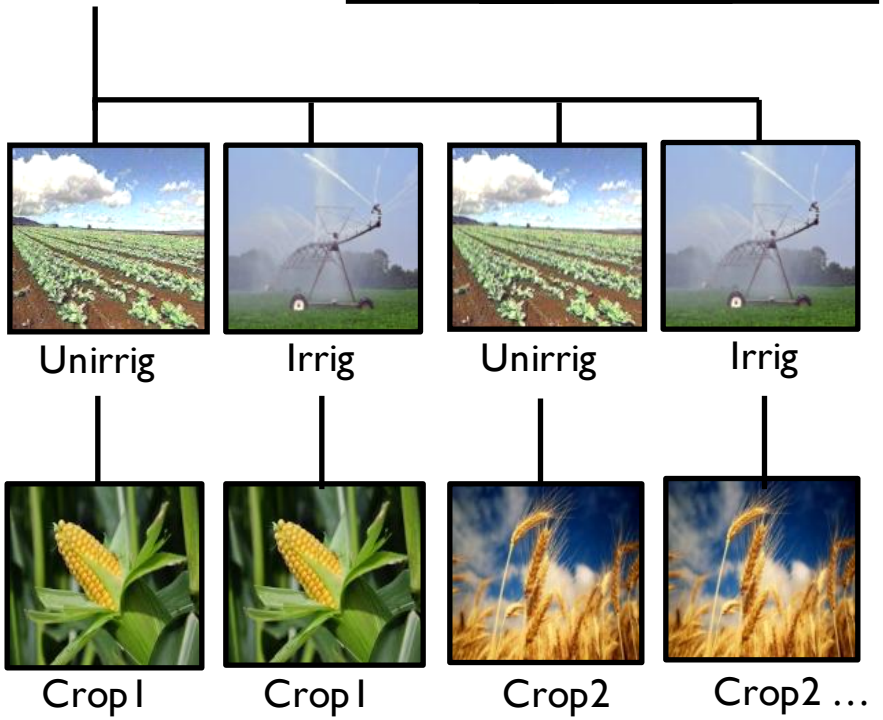
Processes in the CESM land model



Land surface heterogeneity
CLM subgrid tiling structure

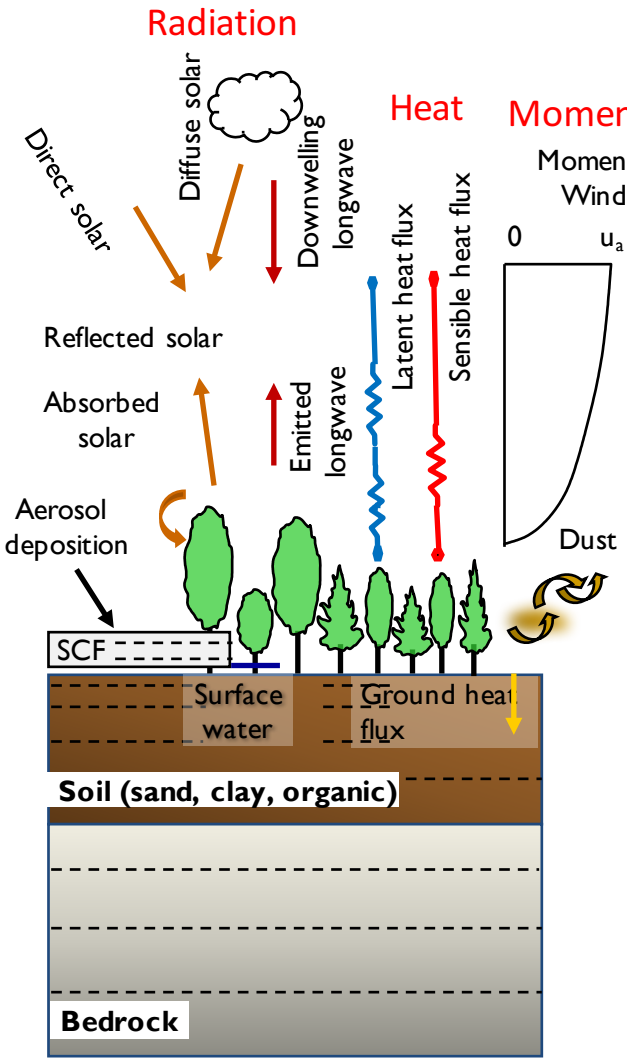




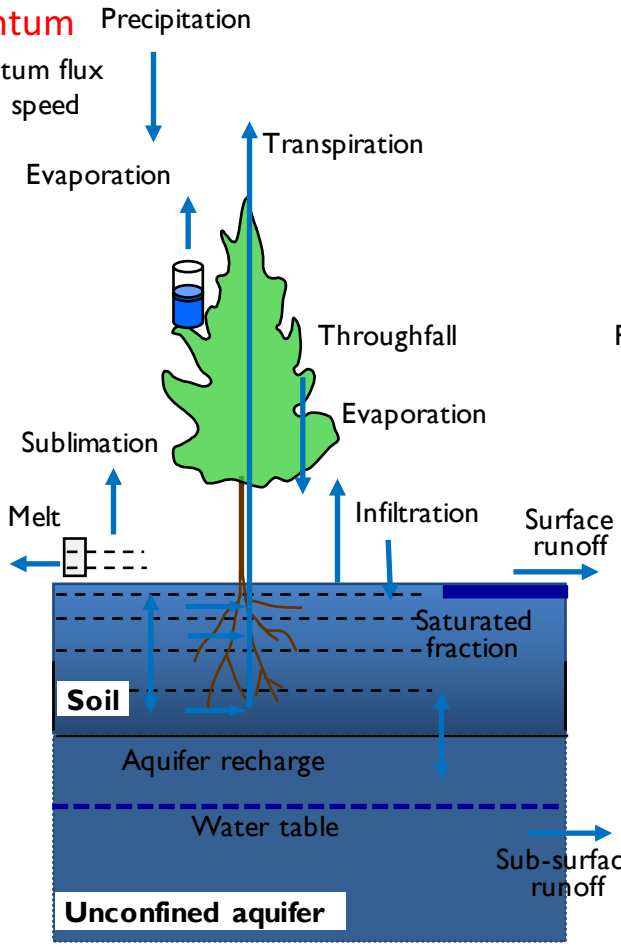


Current processes in CLM

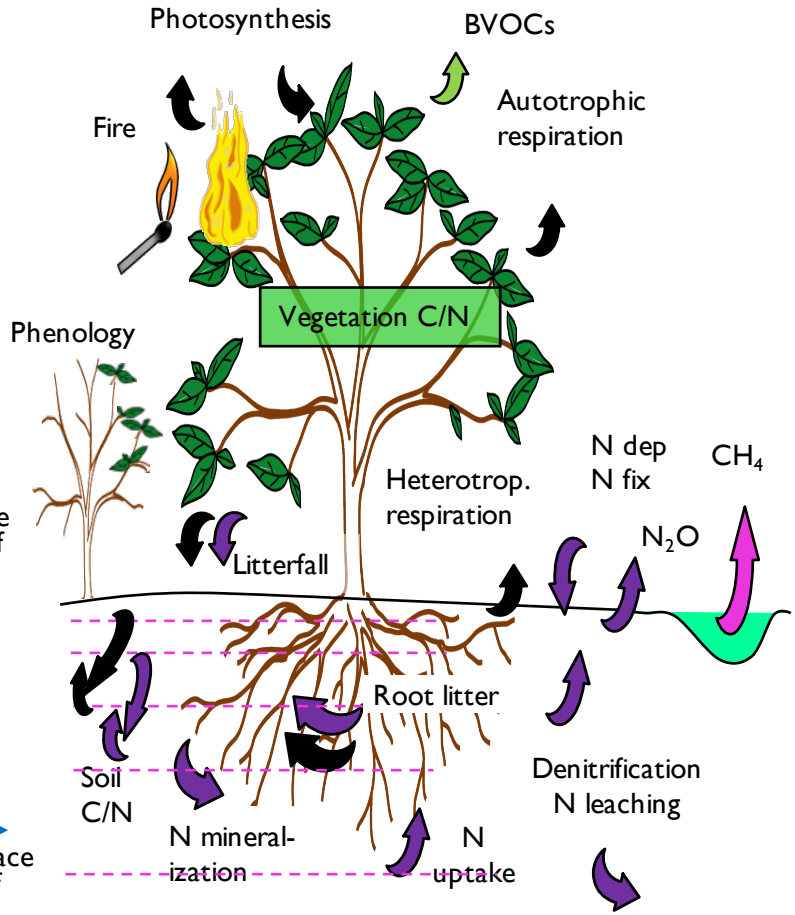
Surface energy fluxes



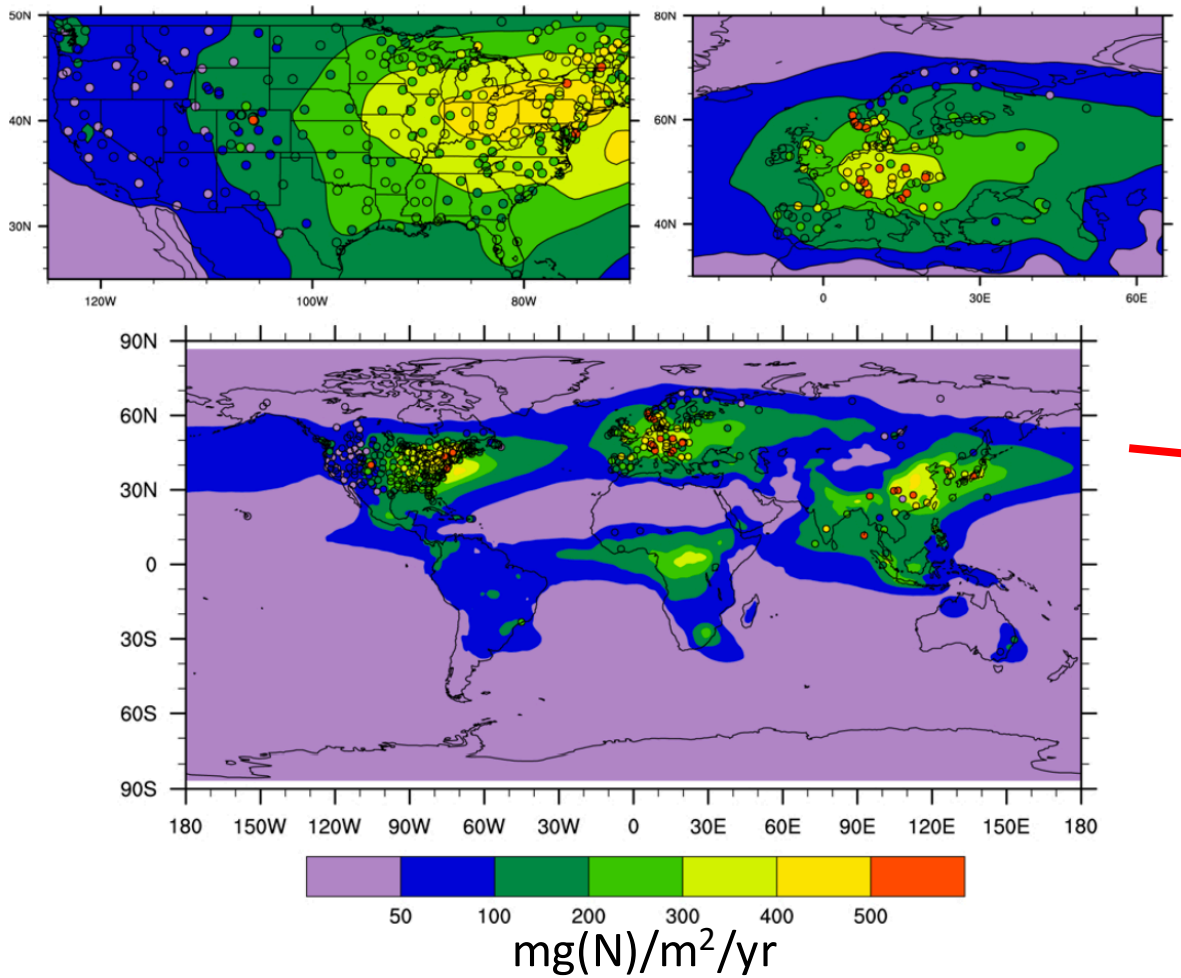
Hydrology



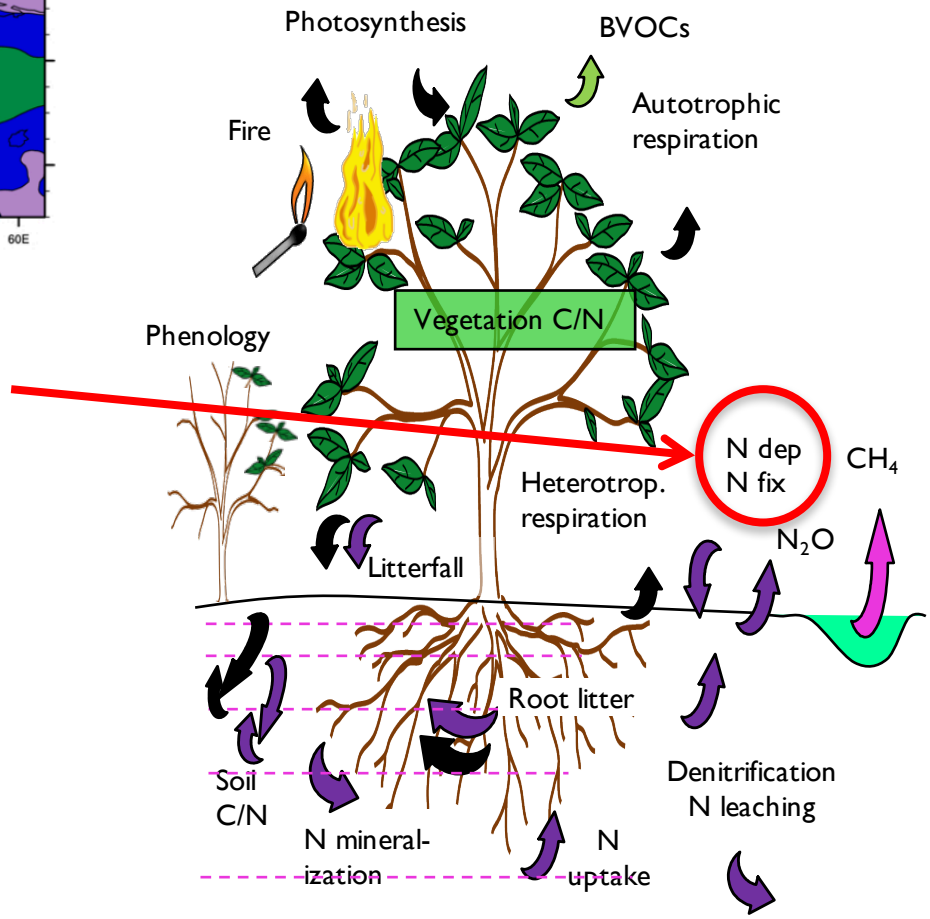
Biogeochemical cycles



Current processes in CLM



Biogeochemical cycles



Lamarque et al., 2013

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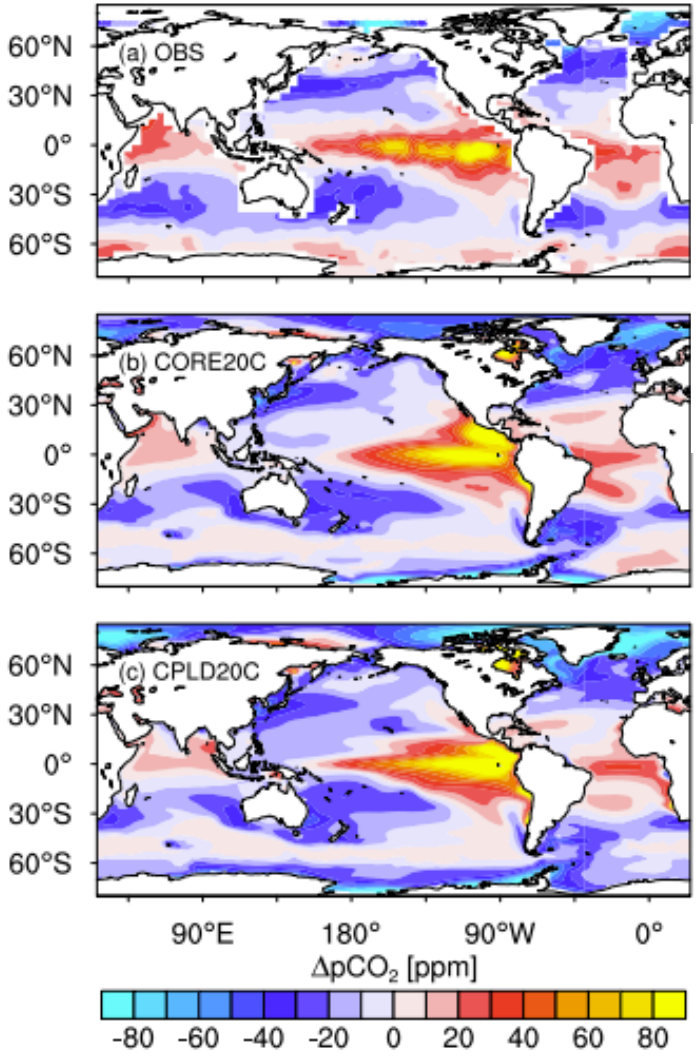
Air-sea exchange of CO_2



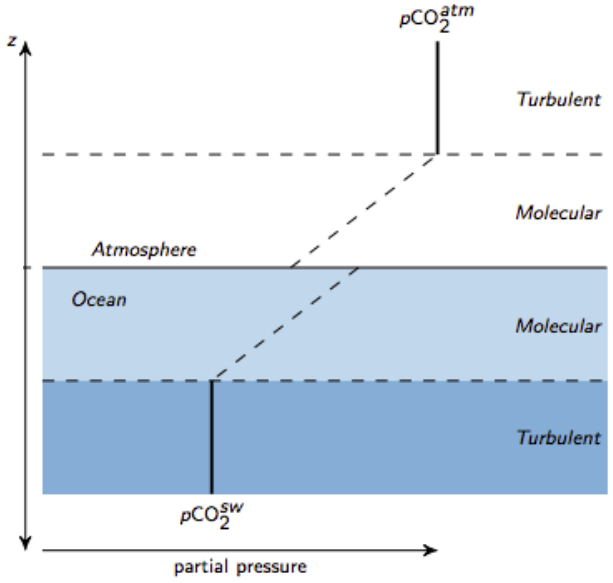
Obs: Takahashi et al. 2009

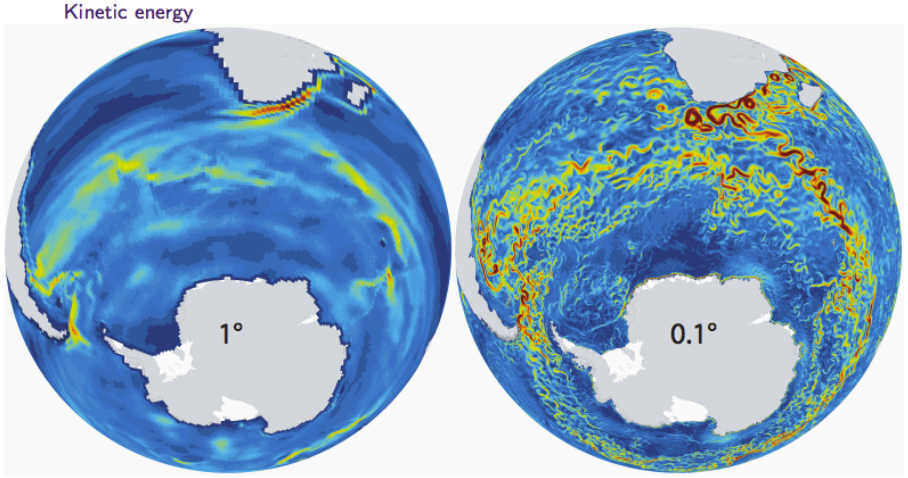
negative := ocean uptake

Air-sea exchange:

$$J_{co_2} = (1 - A_{ice}) k\alpha \left(pCO_2^{sw} - pCO_2^{atm}\right)$$
$$= (1 - A_{ice}) k\alpha \Delta pCO_2$$

where
k = piston velocity (empirical), and
α = solubility, $f(T, S)$

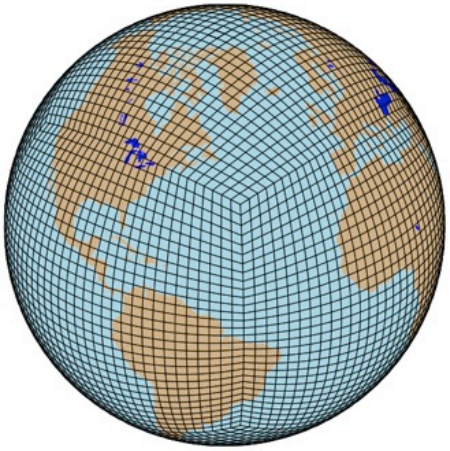




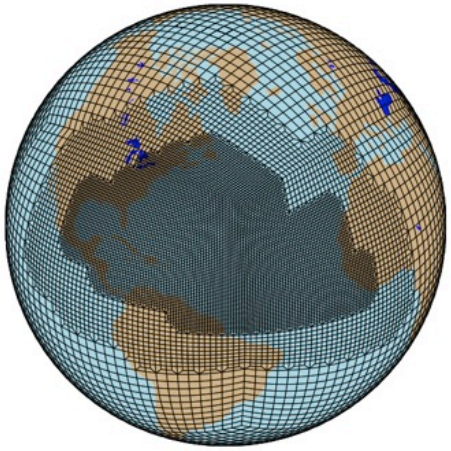
Slide courtesy of M. Long

High res: Regionally refined grids

Uniform 1°

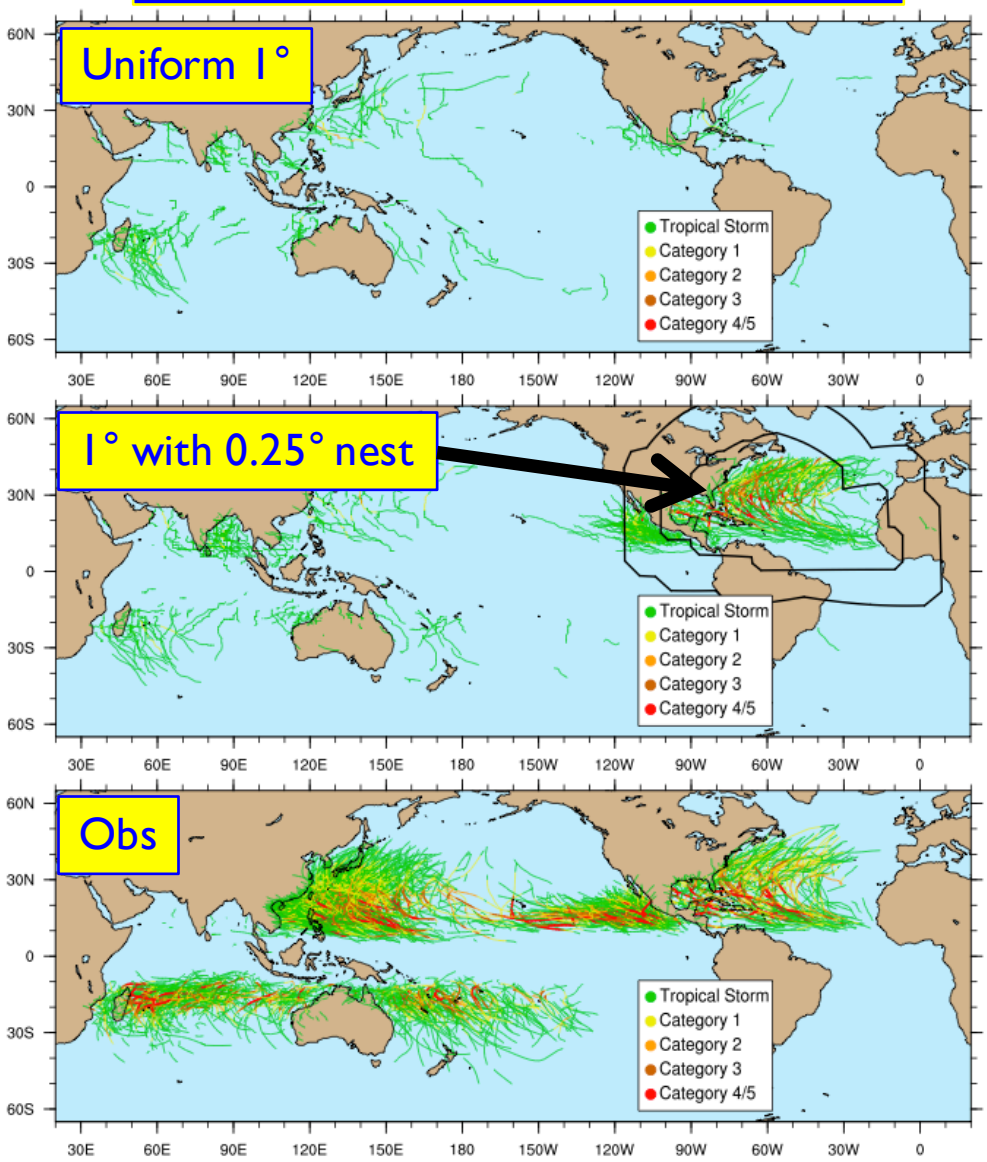


1° with 0.25° nest



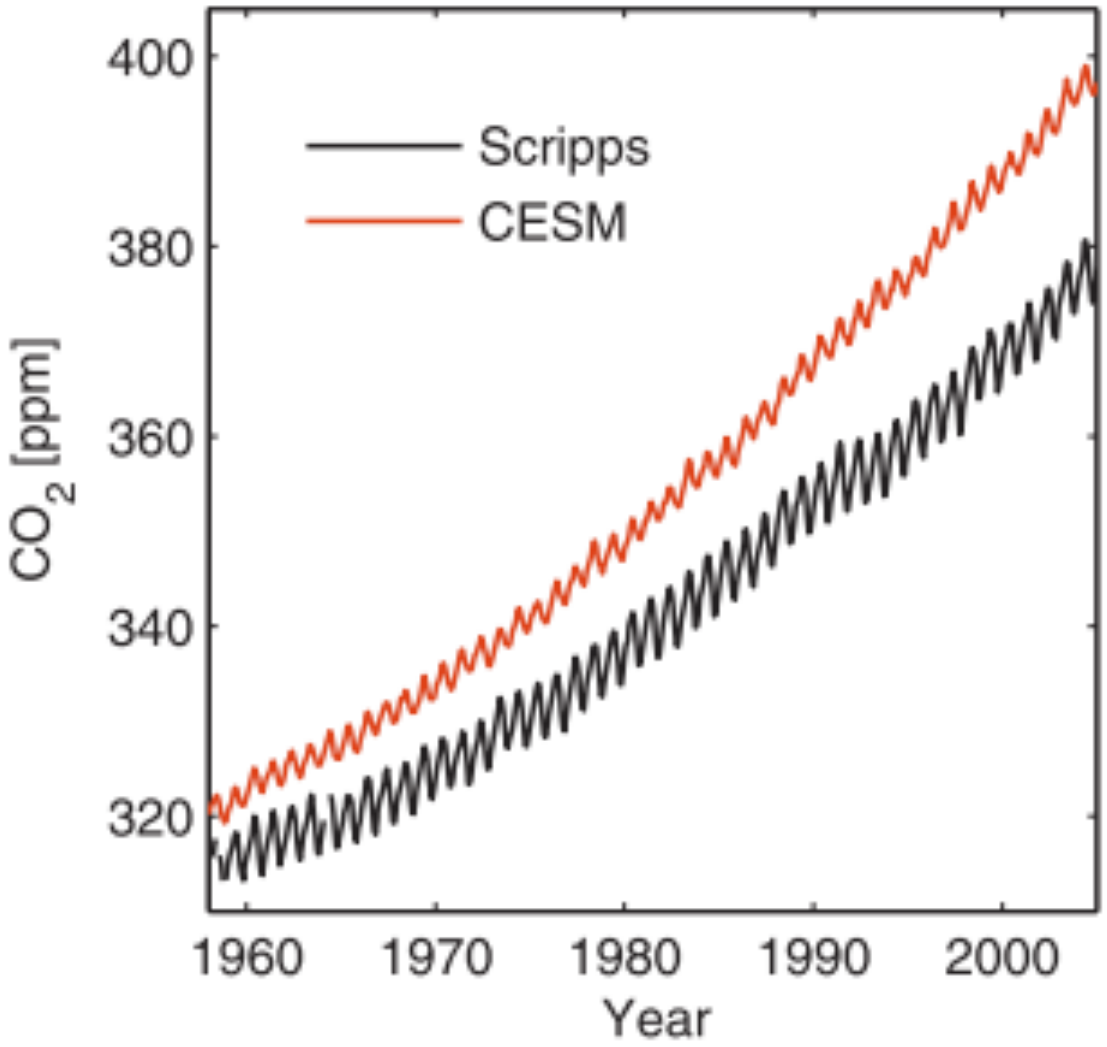
- Variable-resolution CAM-SE (CAM5) simulations -> dramatically improved tropical cyclone representation at regional scale
- 0.25° nest produces realistic storm counts/intensities in North Atlantic at 1/6th compute cost of globally-uniform 0.25° mesh
- Challenges: Streamlining generation of new grids; Ensuring that physics parameterizations work across resolutions

Tropical cyclone tracks, 1980-2002



Courtesy: Colin Zarzycki, U. Mich.

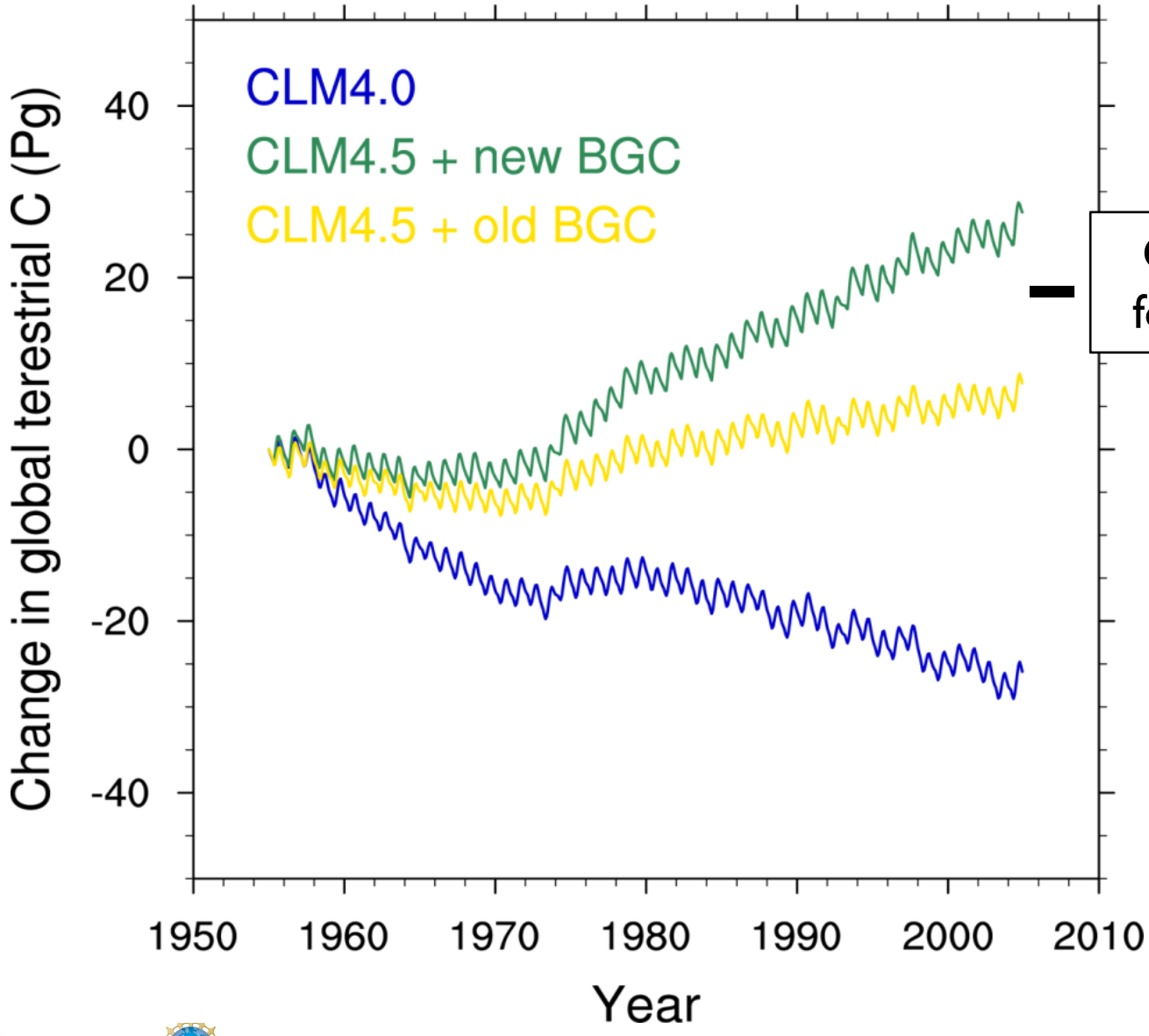
CO_2 over historical period in CESM1



Mauna Loa

Keppel-Aleks et al., 2013

Impact of CLM4.5 model changes on historical global terrestrial carbon trajectory

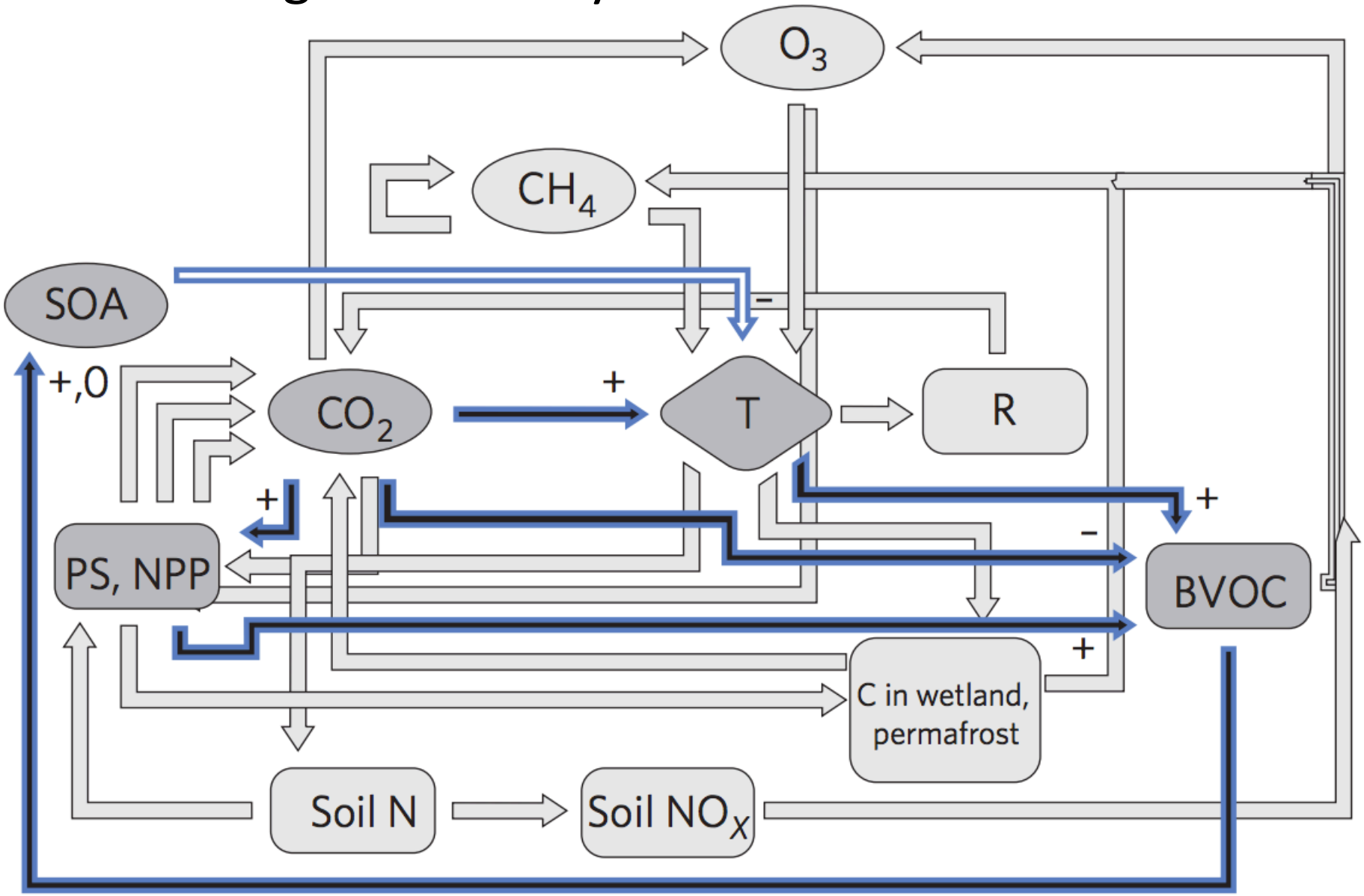


GCP estimate for land C sink

In CLM4.5, land is a C sink over latter half of 20thC, as observed

Koven et al., 2013

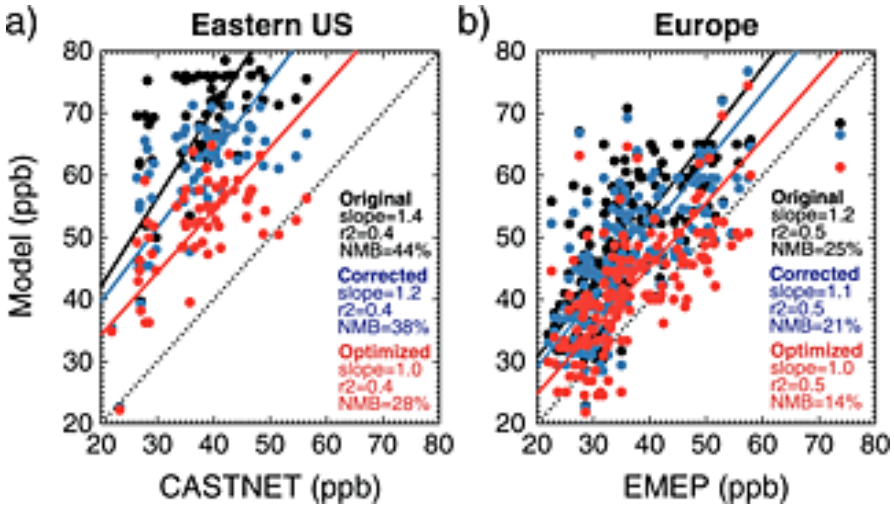
Land biogeochemistry feedbacks: CESM1 to CESM2



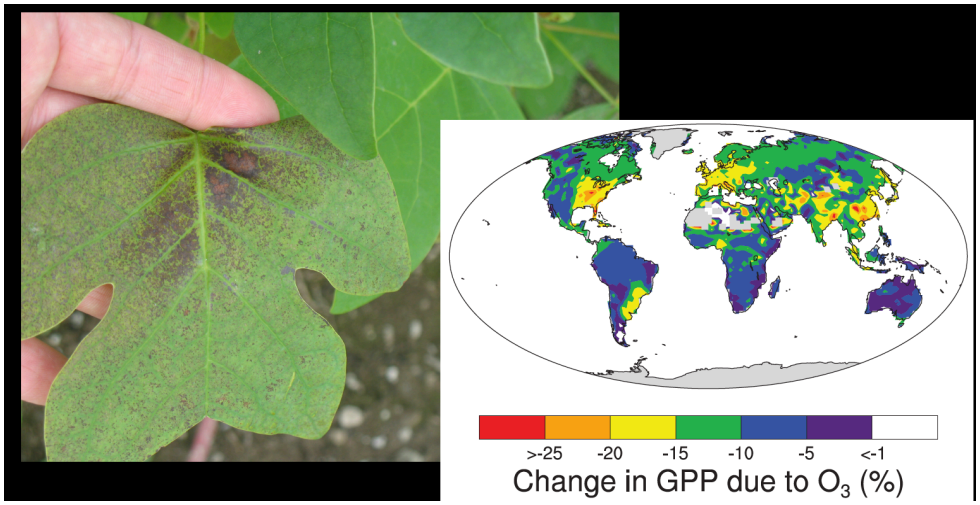
Arneth et al., 2010

Improvement in ozone deposition and stomatal resistance

Original Scheme	Corrected Scheme
Stomatal Resistance (R_s)	
$R_s = r_s \left\{1 + \frac{1}{[200(G+0.1)]^2}\right\} \left\{\frac{400}{T_s(40-T_s)}\right\} \frac{D_{H_2O}}{D_x}$	$\frac{1}{r_s} = m\frac{A}{c_s}\frac{e_s}{e_i}P_{atm} + b$
[*Wesely* , 1989]	[*Collatz et al.* , 1991 ; *Sellers et al.* , 1996]
	$R_s = \frac{f_{sun} \times r_s^{sun}}{LAI} + \frac{(1 - f_{sun}) \times r_s^{sha}}{LAI}$
Leaf Cuticular Resistance (R_{lu})	
$R_{lu} = \frac{r_{lu}}{10^{-5}H + f_o}$	$R_{lu} = \frac{r_{lu}}{LAI \times (10^{-5}H + f_o)}$
[*Wesely* , 1989]	[*Gao and Wesely* , 1995]



Val Martin et al., 2015



Lombardozzi et al., 2015

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Summary

- CESM is a versatile tool to explore complex interactions and feedbacks within and across elements of the Earth system
- Strong emphasis is placed on continual improvement in process representation
- This can only be achieved through numerous collaborations across disciplines and scales