Drew Slater


STELVIO
2760

Overview of the Community Land Model (and the Community Earth System Model)

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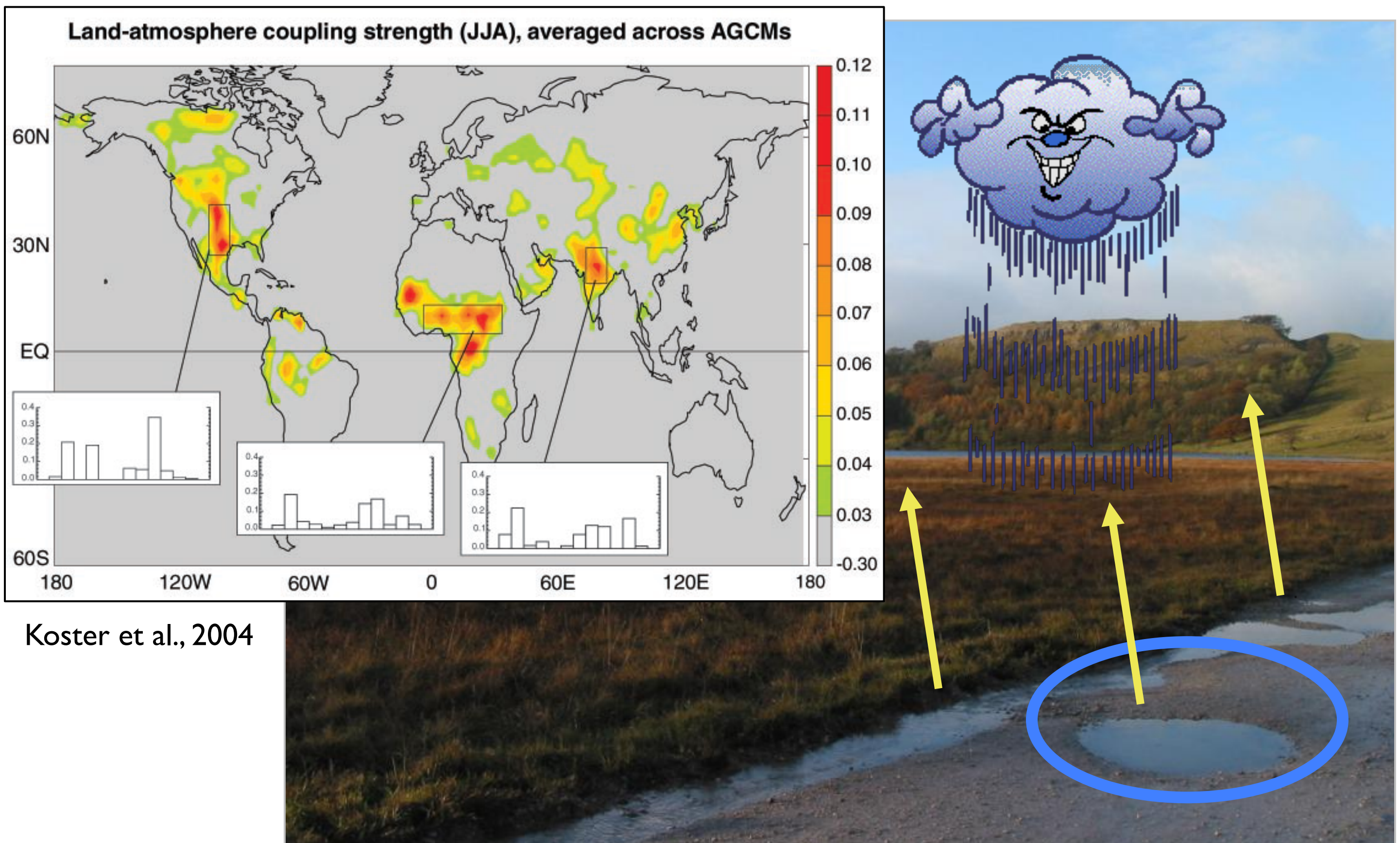
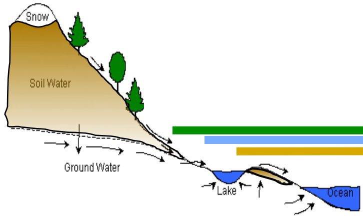
NCAR is sponsored by the National Science Foundation

Land in Earth System: Land-atmosphere interactions

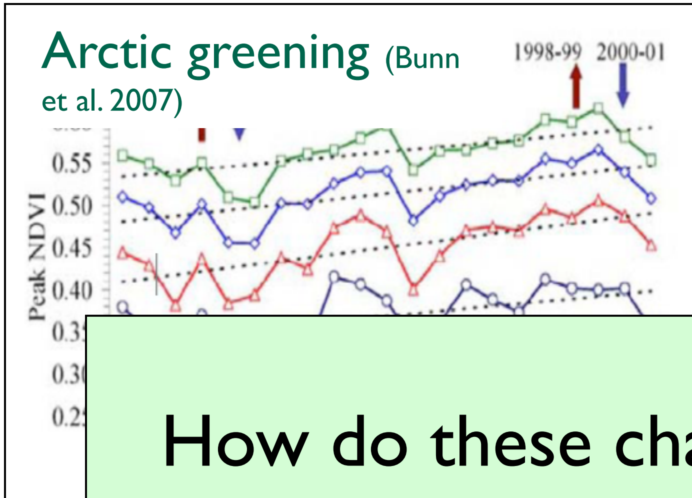
How much does a precipitation-induced soil moisture anomaly influence the overlying atmosphere and thereby the evolution of weather and the generation of precipitation?

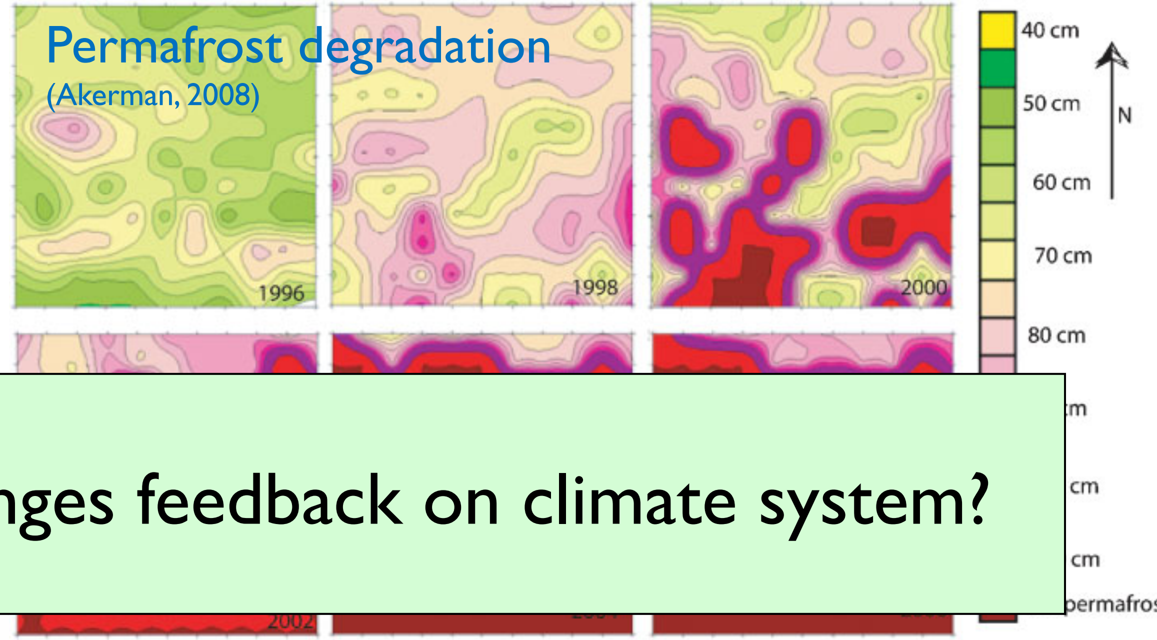


Koster et al., 2004

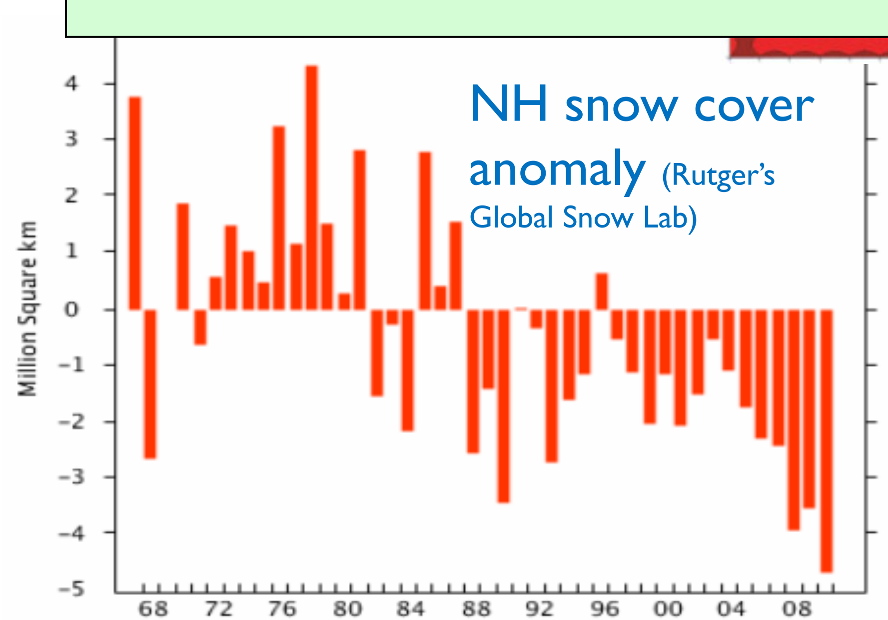


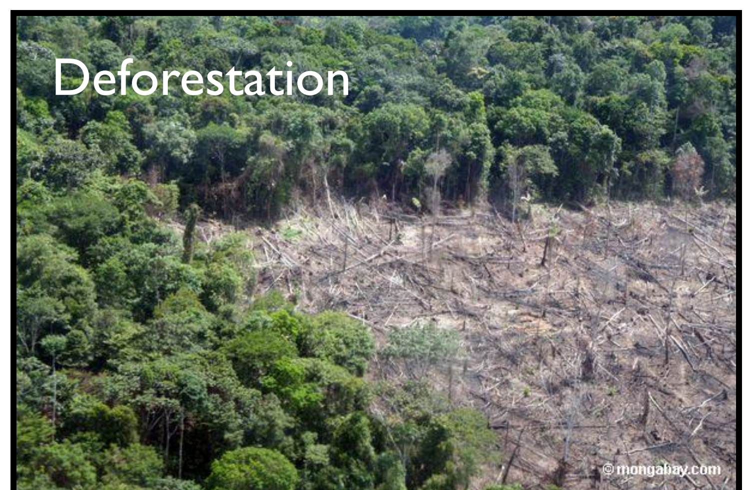
Land in Earth System: Terrestrial system is showing change

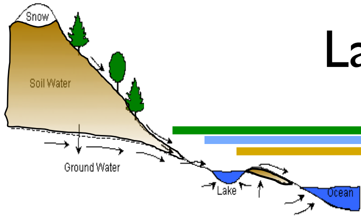




How do these changes feedback on climate system?







Land in Earth System: Land is critical sink of CO_2 emissions

8.3±0.4 PgC/yr 90%

1.0±0.5 PgC/yr 10%

+

4.3±0.1 PgC/yr

46%

2.6±0.8 PgC/yr

28%

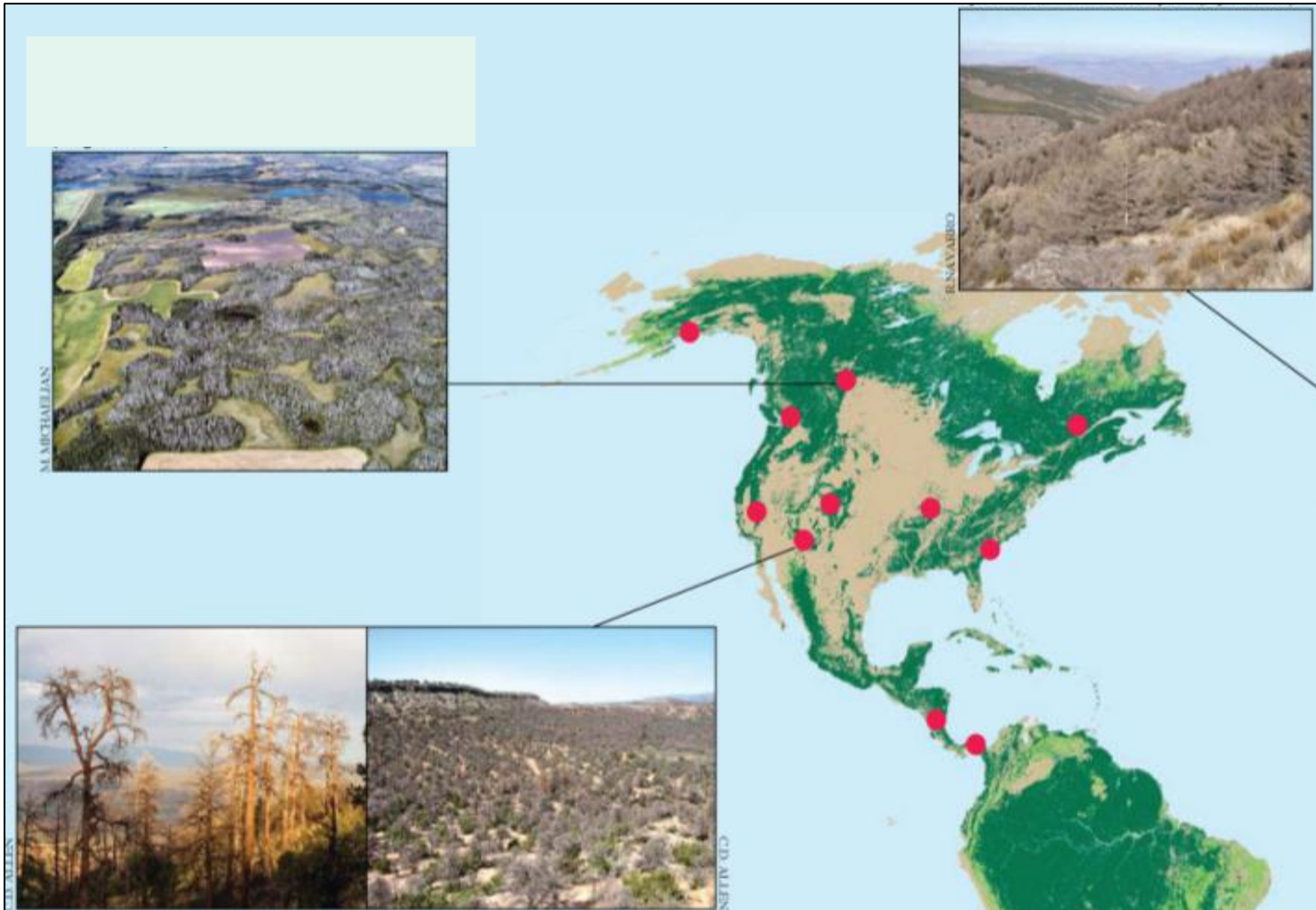
Calculated as the residual
of all other flux components

26%

2.5±0.5 PgC/yr

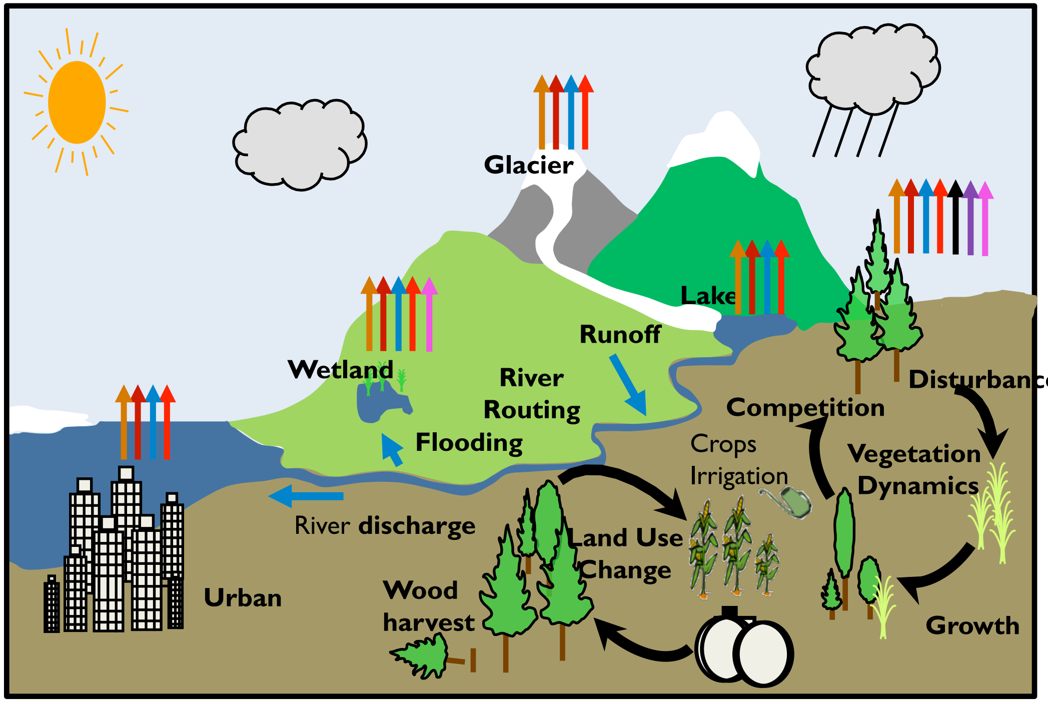
Source: Le Quéré et al. 2012; Global Carbon Project 2012

Land in Earth System: But, trees (carbon sinks) are dying due to fire, insects, drought, and deforestation

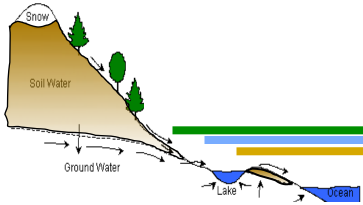


Community Land Model (CLM)

Motivation:
Land is the critical interface through which humanity affects, adapts to, and mitigates global environmental change



Comprehensive representations of land biogeophysics, hydrology, plant physiology, biogeochemistry, anthropogenic land use, and ecosystem dynamics



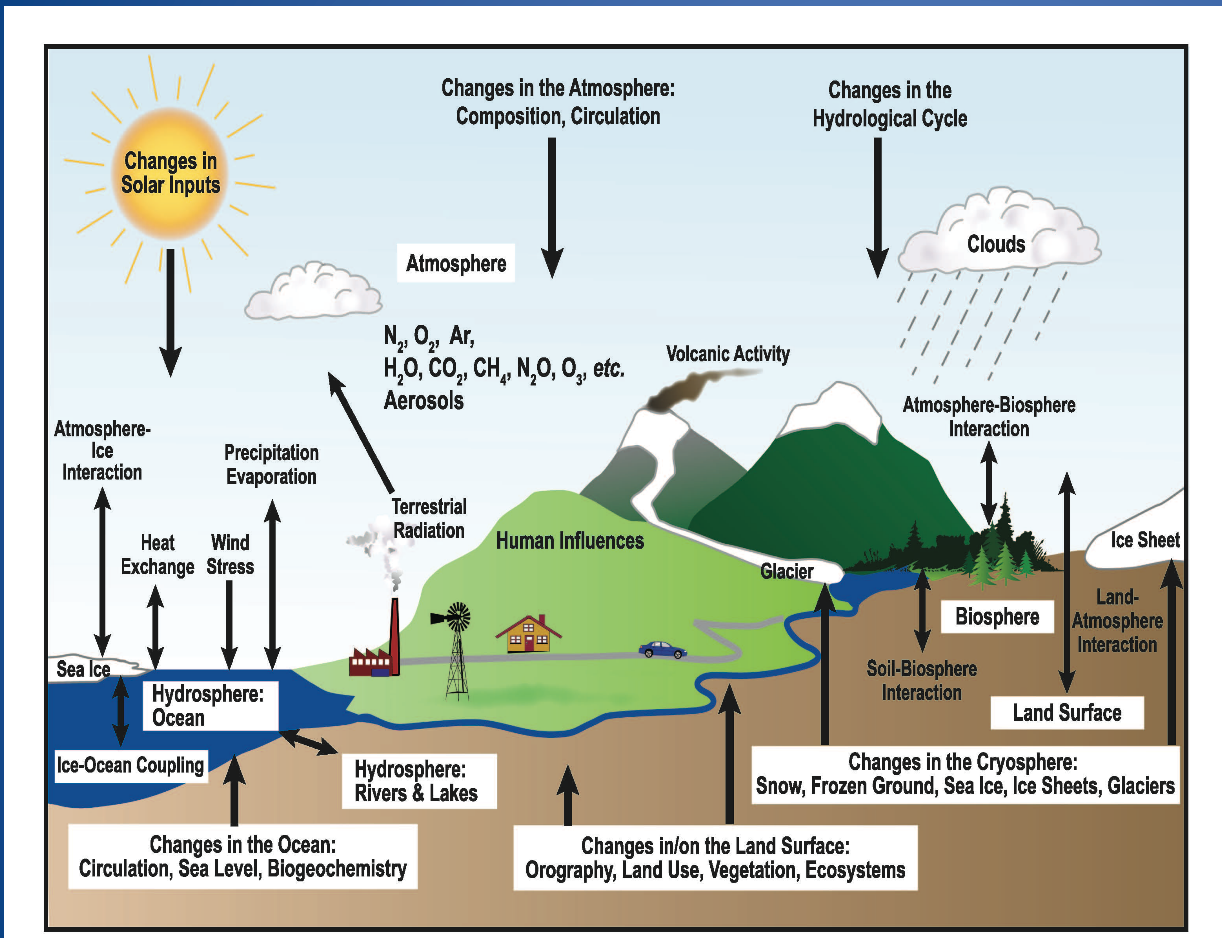
Some scientific goals driving CLM development and use

- Improve understanding of carbon and nitrogen cycle interactions and their impact on long term trajectory of terrestrial carbon sink
- Assess response and vulnerability of ecosystems to climate change and disturbances (human and natural)
- Evaluate utility of ecosystem management as mechanism to mitigate climate change
- Ascertain vulnerability of water resources under climate change; establish role of land in drought and flood
- Quantify land feedbacks to climate change: e.g. permafrost-carbon, snow- and vegetation-albedo, soil moisture-ET feedbacks

Earth System Models

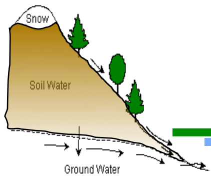
Community Earth System Model (CESM)

Earth System Models

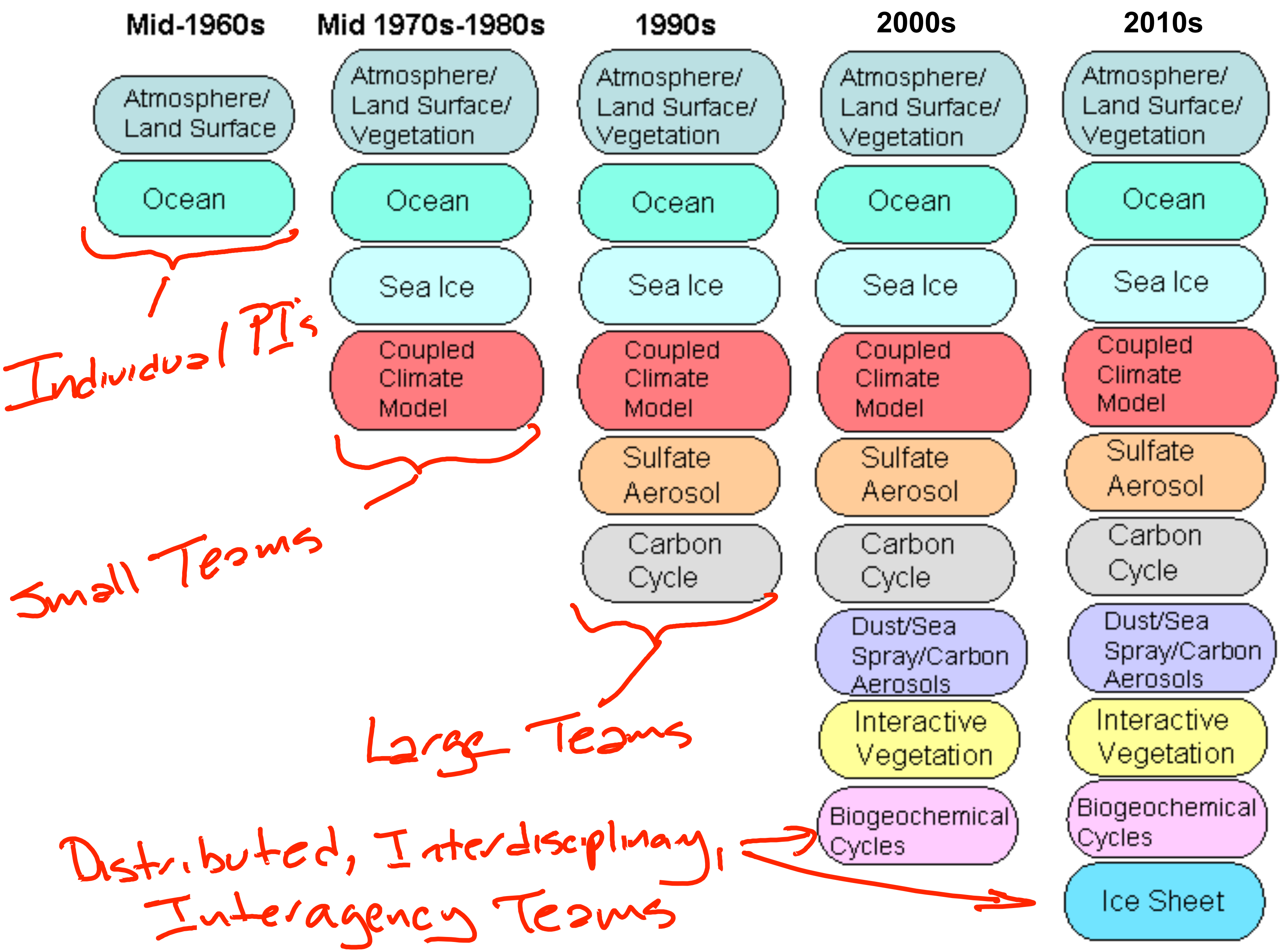


Earth System Models are utilized to support a vast and expanding array of scientific research into the climate system

- climate change feedbacks and attribution
- climate variability
- roles of clouds, aerosols, sea ice, ocean, land use, ozone, etc on climate
- climate change impacts on humans and ecosystems



History of Climate Model to Earth System Model Development
http://www.aip.org/history/climate/GCM.htm



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.

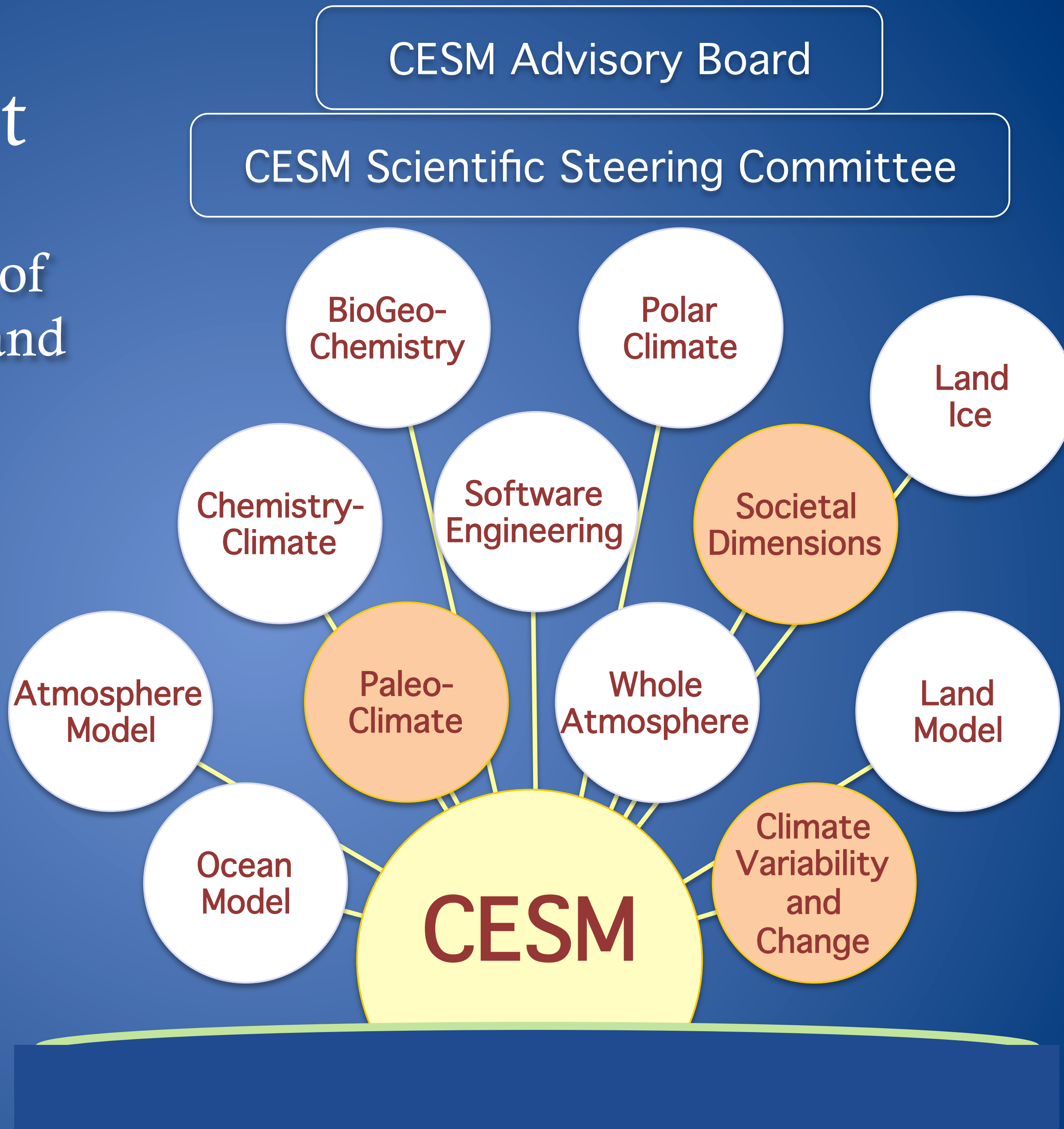
Graphic courtesy of Steve Ghan and DOE Graphics team

CESM Project

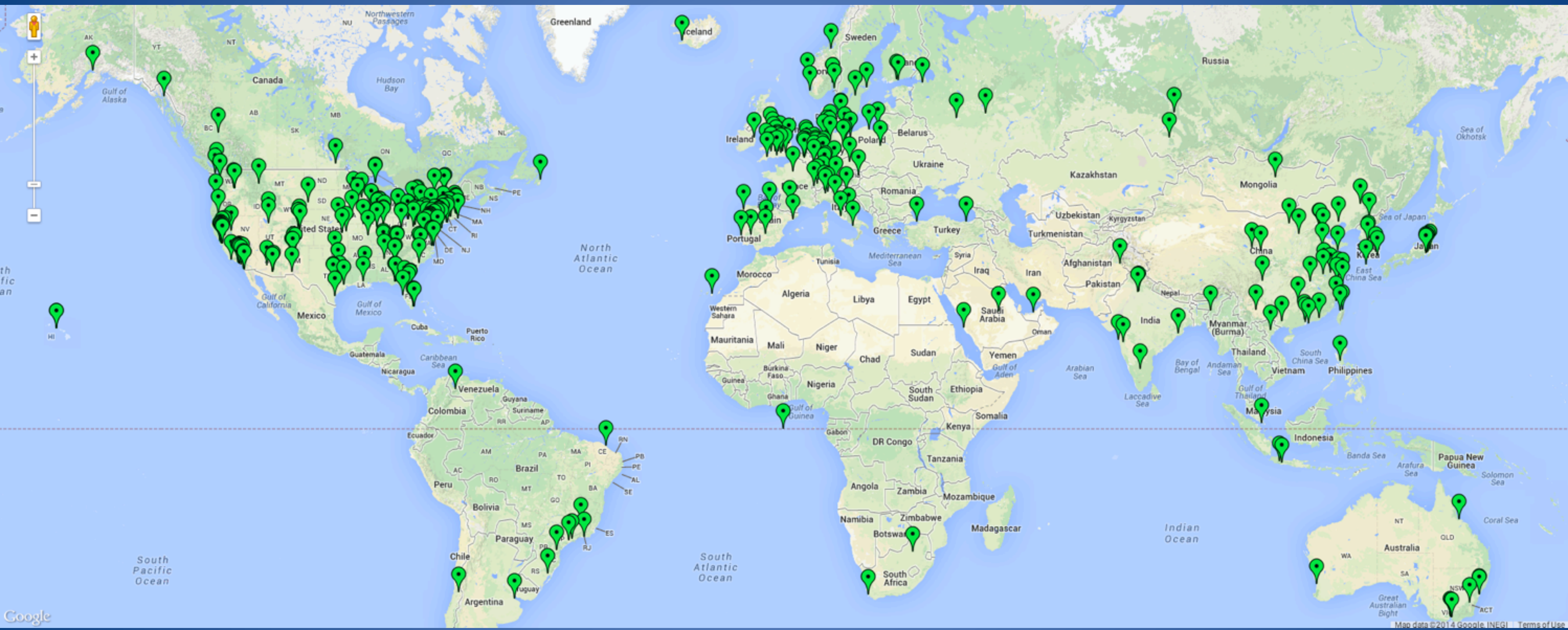
Based on 20+ Years of Model development and application

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).

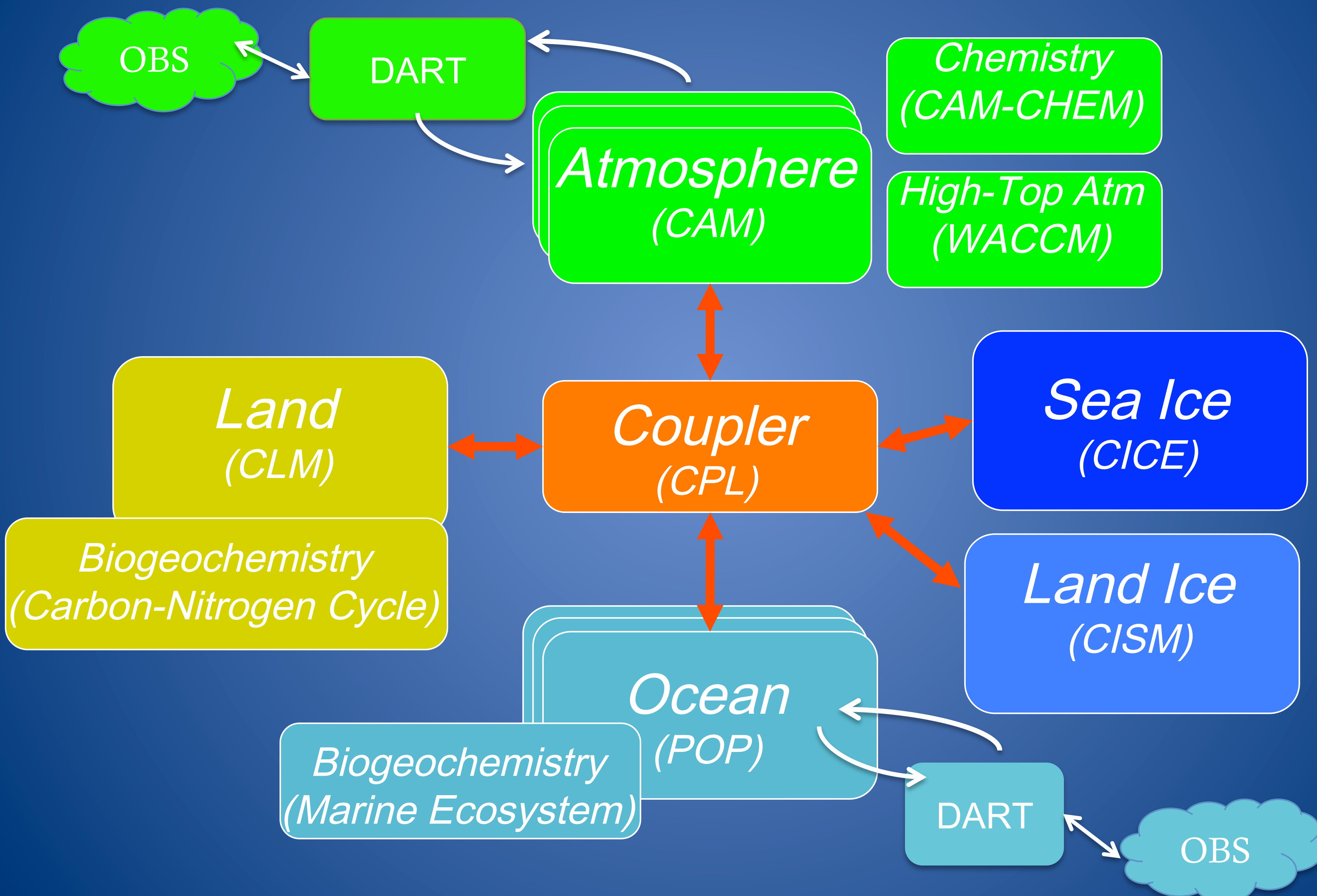


A truly global community



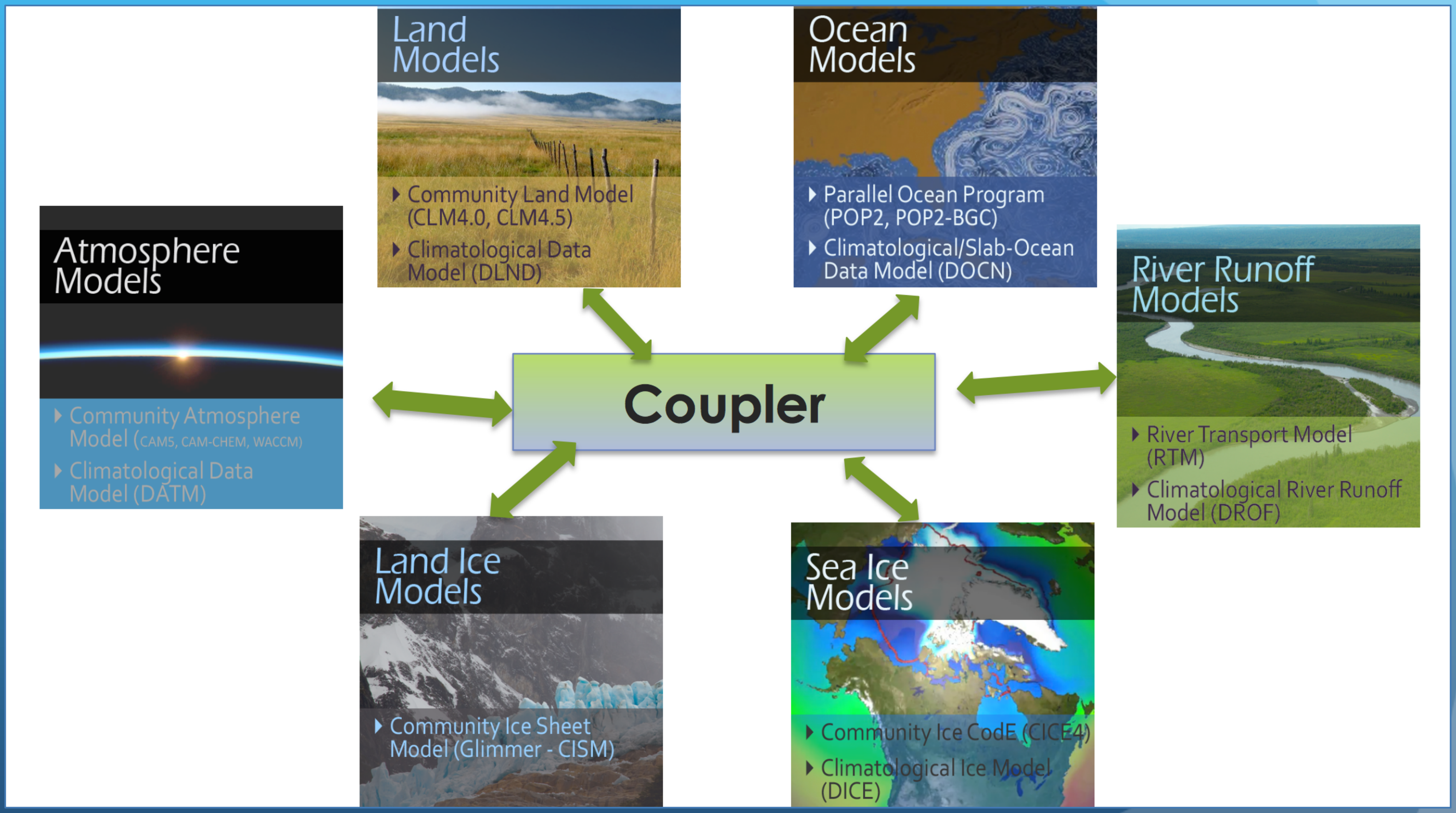
Download of released version since 2010

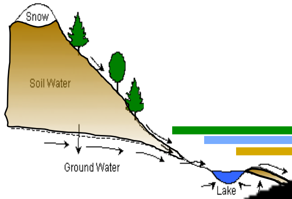
CESM Prediction System



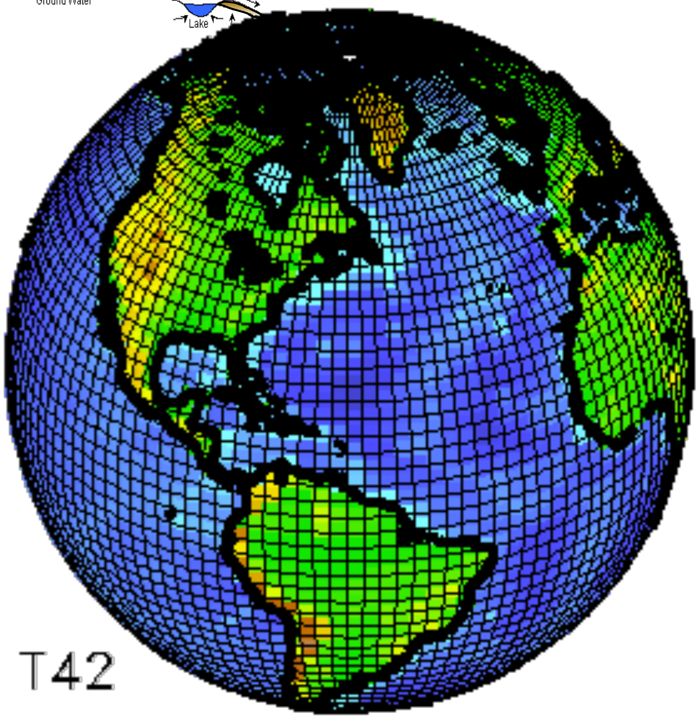
CESM coupling infrastructure

Permits selective inter-component feedbacks



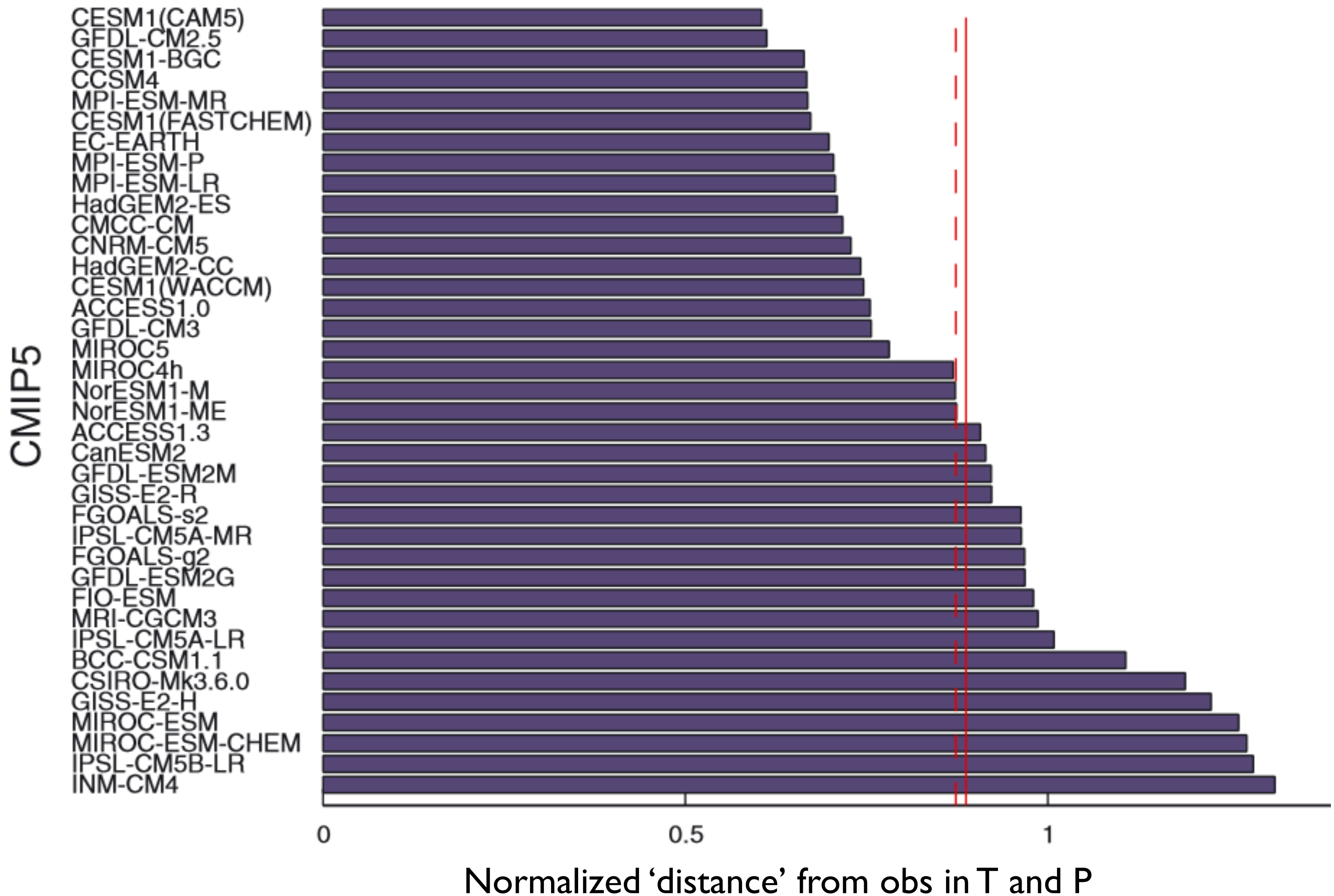


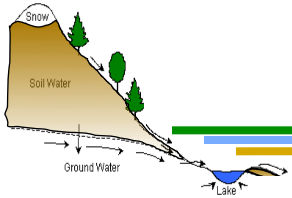
Community Earth System Model (CESM2)



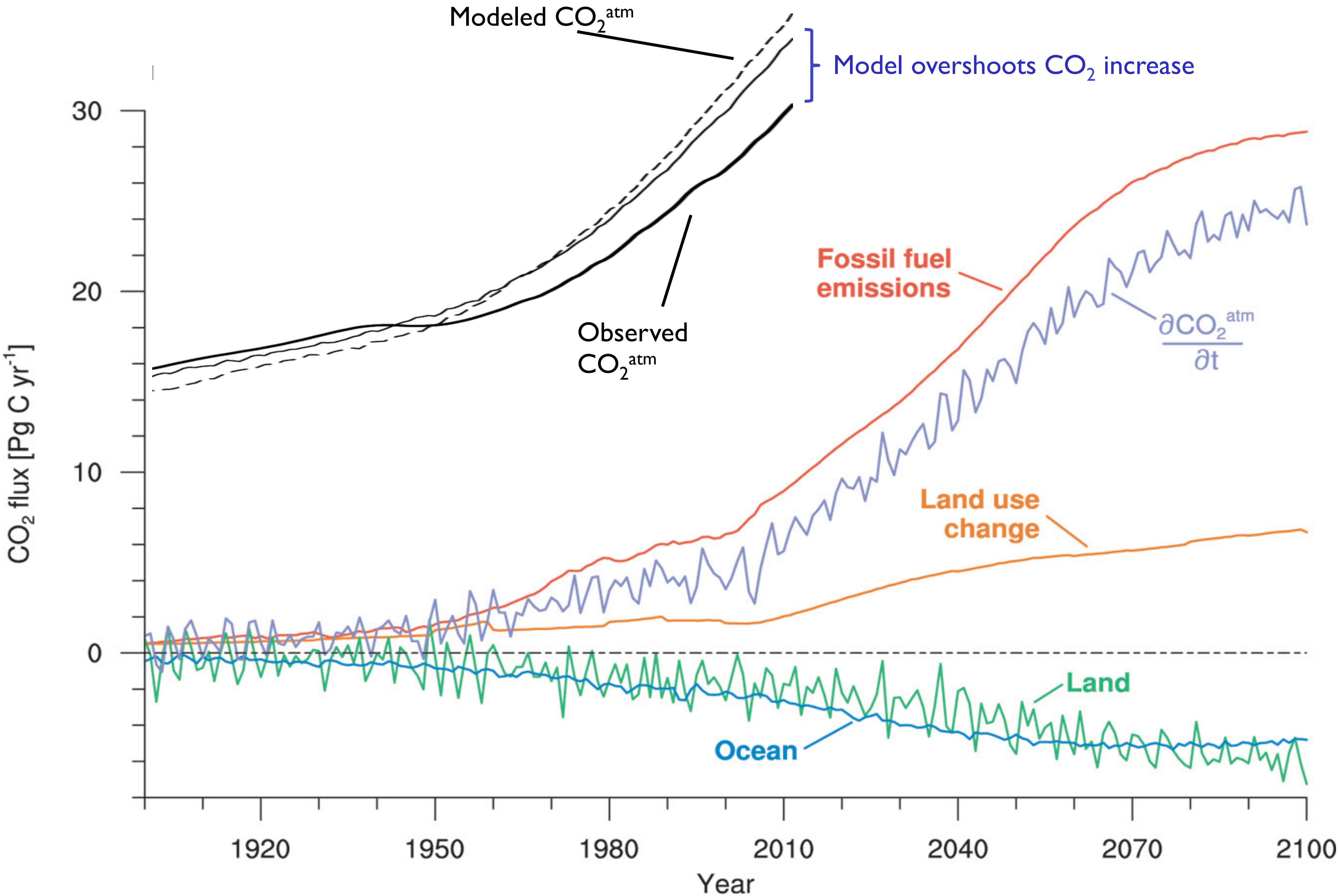
- 0.25°, 1° , 2°, and regionally-refined grids
- 30 minute time step
- 31 atmosphere levels
- 60 ocean levels
- 25 ground layers
- ~5 million grid boxes at 1° resolution
- ~2 million lines of computer code
- Data archived (monthly, daily, hourly) for hundreds of geophysical fields (over 450 in land model alone)
- Utilized by hundreds of scientists all around the world

CESM in Coupled Model Intercomparison Project (CMIP5)

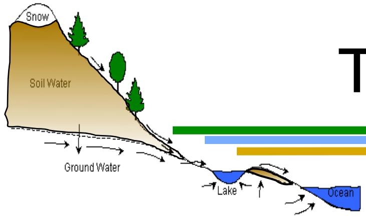




Carbon cycle in CESM1



Terrestrial Processes within the Earth System



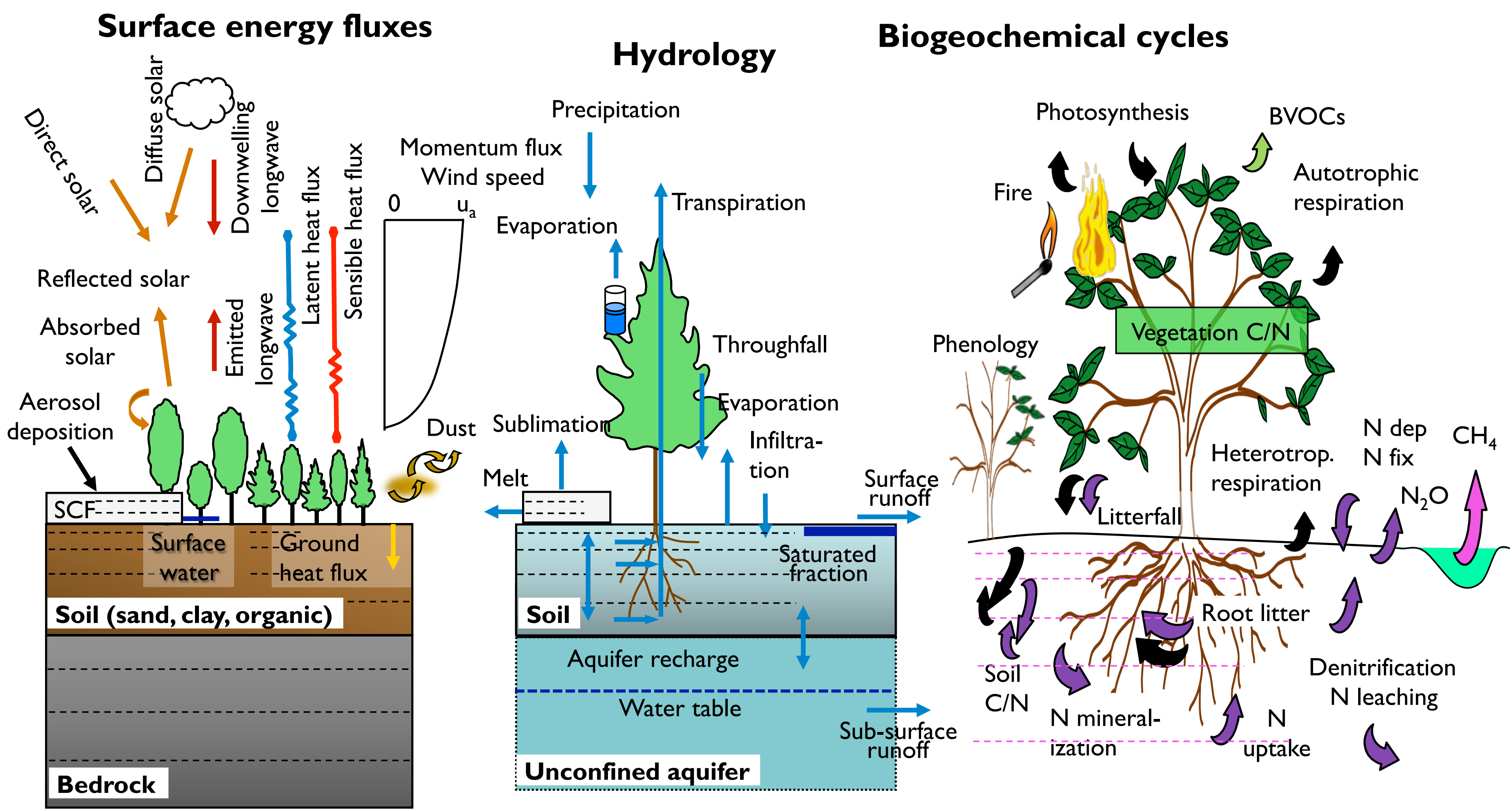
The role of a land model in an Earth System Model

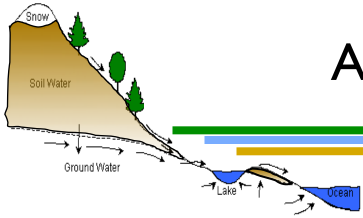
- exchanges of momentum, energy, water vapor, CO_2, dust, and other trace gases/materials between land surface and the overlying atmosphere (and routing of runoff to the ocean)
- states of land surface (e.g., soil moisture, soil temperature, canopy temperature, snow water equivalent, C and N stocks in vegetation and soil)
- characteristics of land surface (e.g., soil texture, surface roughness, albedo, emissivity, vegetation type, cover extent, leaf area index, and seasonality)

Community Land Model

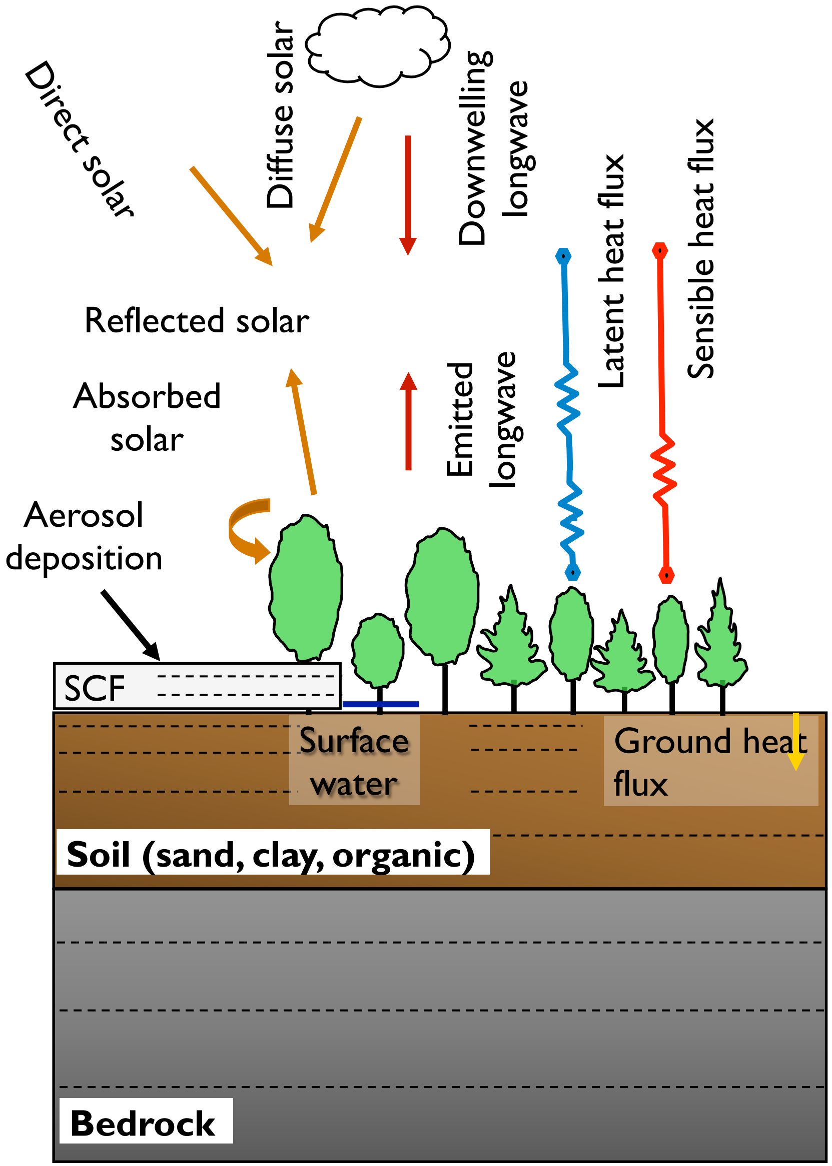
www.cesm.ucar.edu/models/lnd

Community Land Model (CLM4.5) Key Processes





At each time step the land model solves Surface Energy Balance



$$S^{\uparrow} - S^{\downarrow} + L^{\uparrow} - L^{\downarrow} = \lambda E + H + G$$

$S^{\uparrow}$, $S^{\downarrow}$ are down(up)welling solar radiation,

$L^{\uparrow}$, $L^{\downarrow}$ are up(down)welling longwave rad,

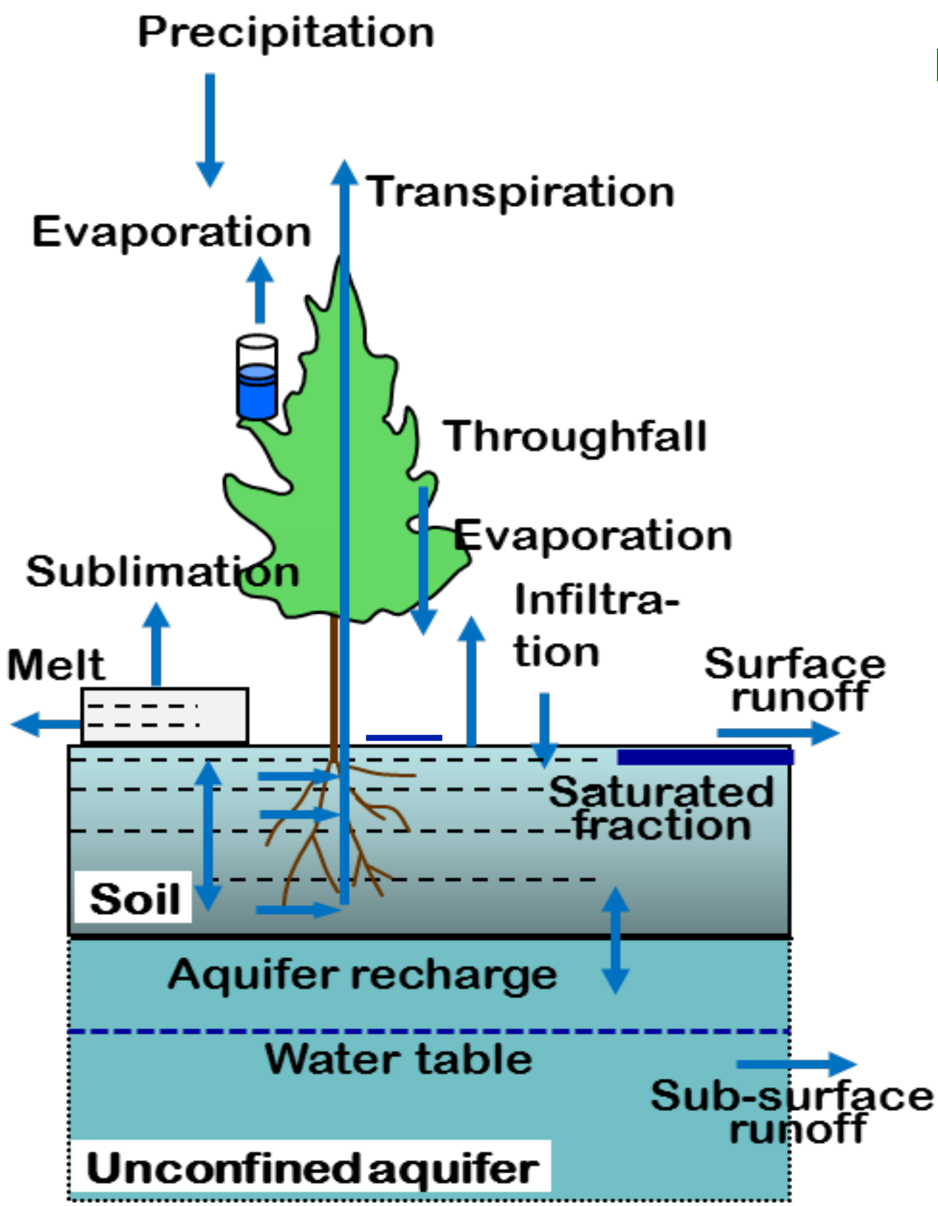
λ is latent heat of vaporization,

E is evaporation,

H is sensible heat flux

G is ground heat flux

… and the Surface Water Balance



$$P = E_S + E_T + E_C + R + (\Delta W_{soi} + \Delta W_{snw} + \Delta W_{sfcw} + \Delta W_{can}) / \Delta t$$

P is rainfall/snowfall,

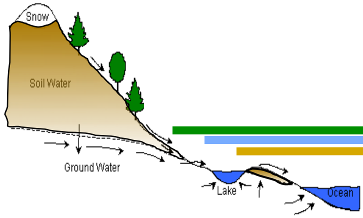
E_S is soil evaporation,

E_T is transpiration,

E_C is canopy evaporation,

R is runoff (surf + sub-surface),

$\Delta W_{soi} / \Delta t$, $\Delta W_{snw} / \Delta t$, $\Delta W_{sfcw} / \Delta t$, $\Delta W_{can} / \Delta t$, are the changes in soil moisture, surface water, snow, and canopy water over a timestep

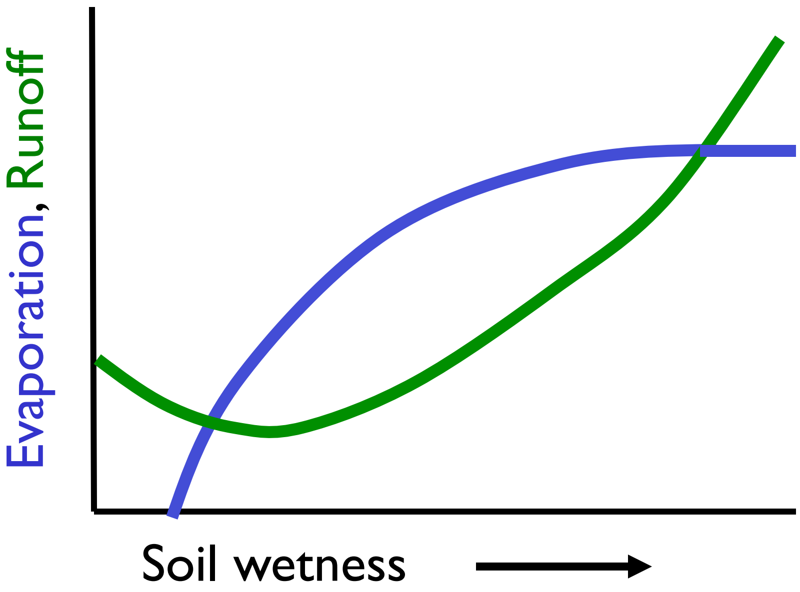


Land water and energy cycles intricately linked

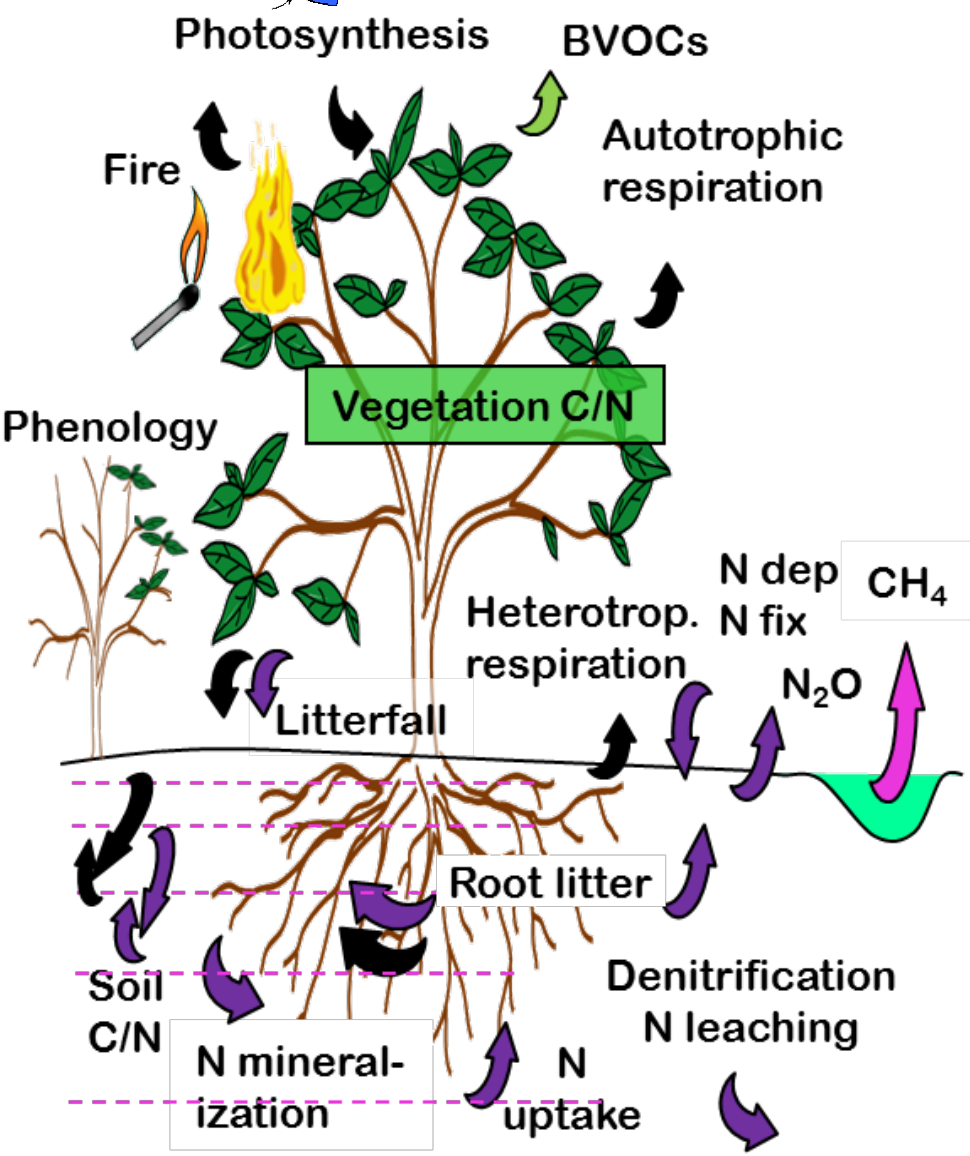
"The ability of a land-surface scheme to model evaporation correctly depends crucially on its ability to model runoff correctly. The two fluxes are intricately related through soil moisture."

(Koster and Milly, 1997).

Runoff and evaporation vary non-linearly with soil moisture



… and Surface Carbon Exchange



$$\mathbf{NEE = GPP - HR - AR - Fire - LUC}$$

NEE is net ecosystem exchange

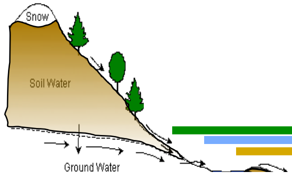
GPP is gross primary productivity

HR is heterotrophic respiration

AR is autotrophic respiration

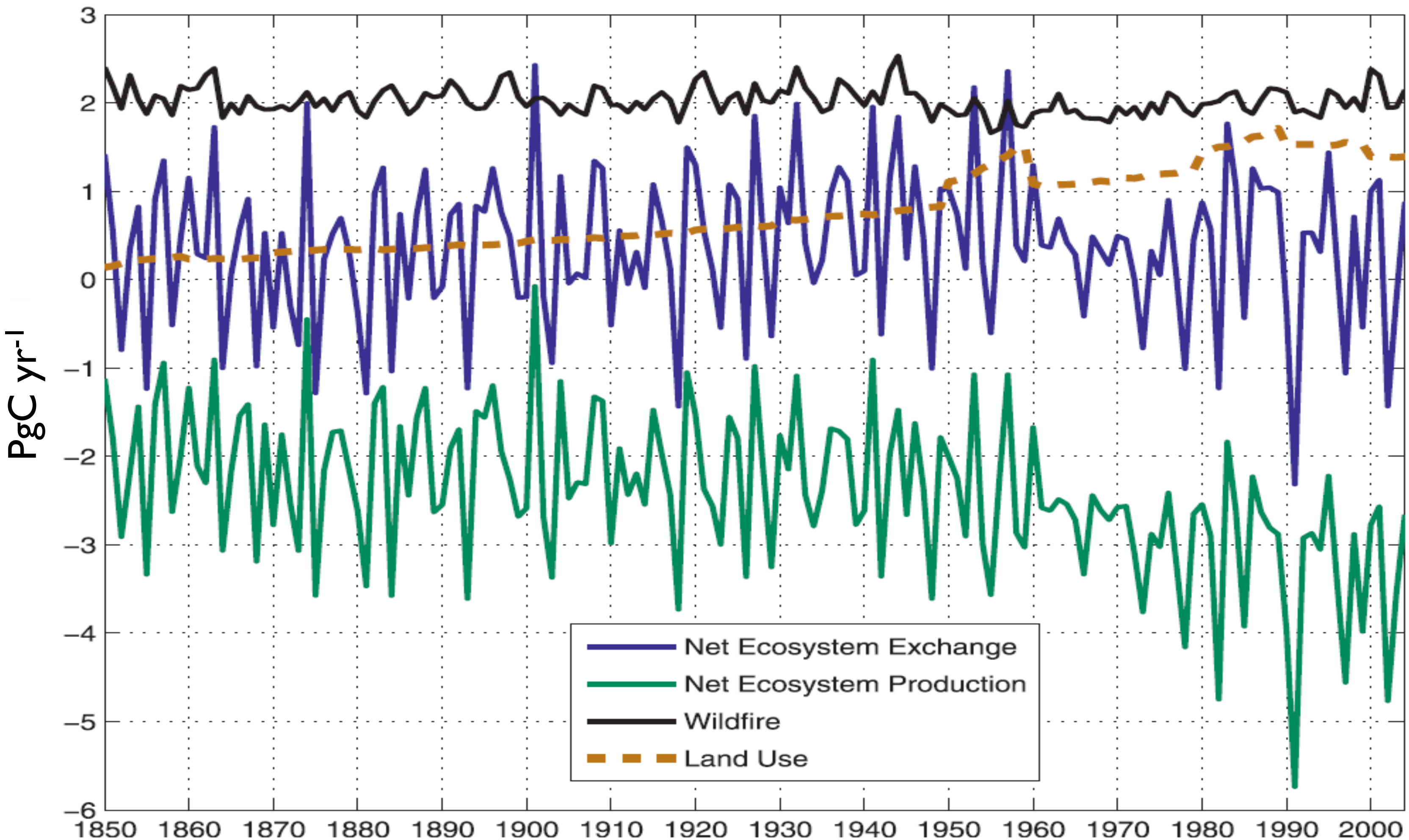
Fire is carbon flux due to fire

LUC is C flux due to land use change



Carbon exchange

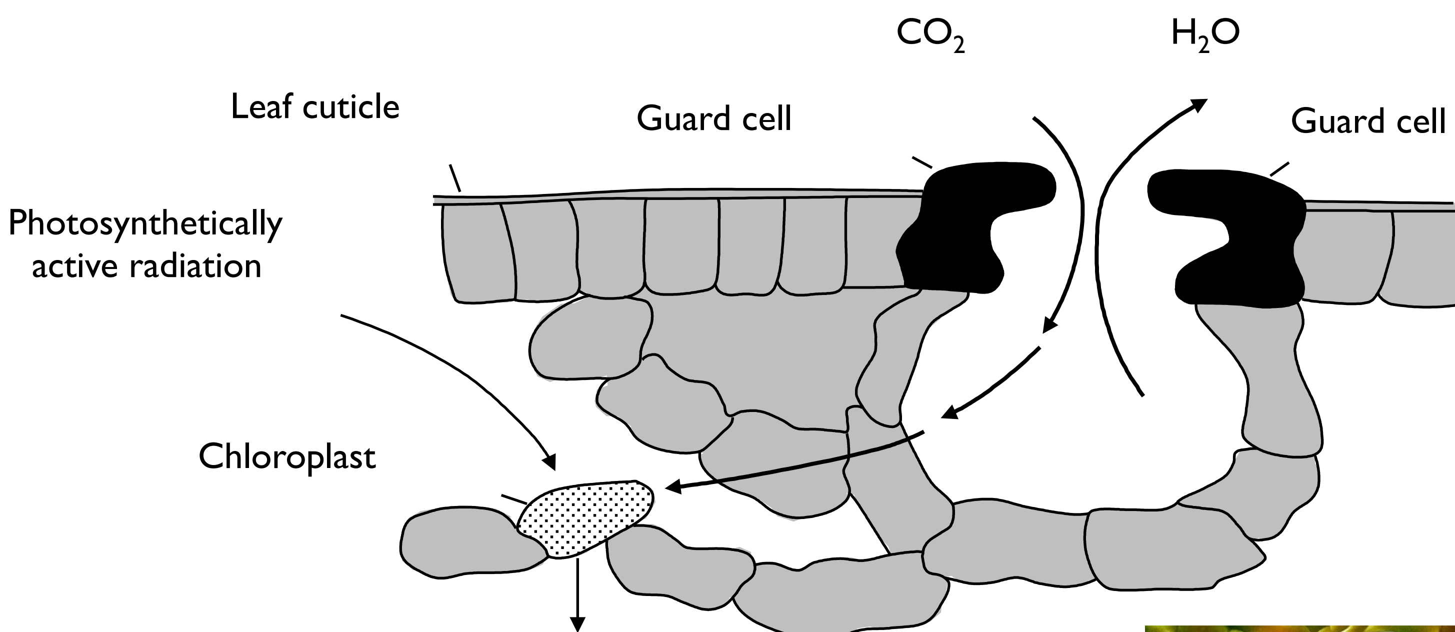
NEE = GPP – HR – AR – Fire – LUC



Photosynthesis model

Plant physiological controls on CO_2 exchange and transpiration

Function of solar radiation, humidity deficit, soil moisture, [CO2], temperature, leaf N content



$$CO_2 + 2\ H_2O \xrightarrow{\text{light}} CH_2O + O_2 + H_2O$$

Figure courtesy G. Bonan

Bonan (1995) JGR 100:2817-2831
Denning et al. (1995) Nature 376:240-242
Denning et al. (1996) Tellus 48B:521-542, 543-567
Cox (1999)

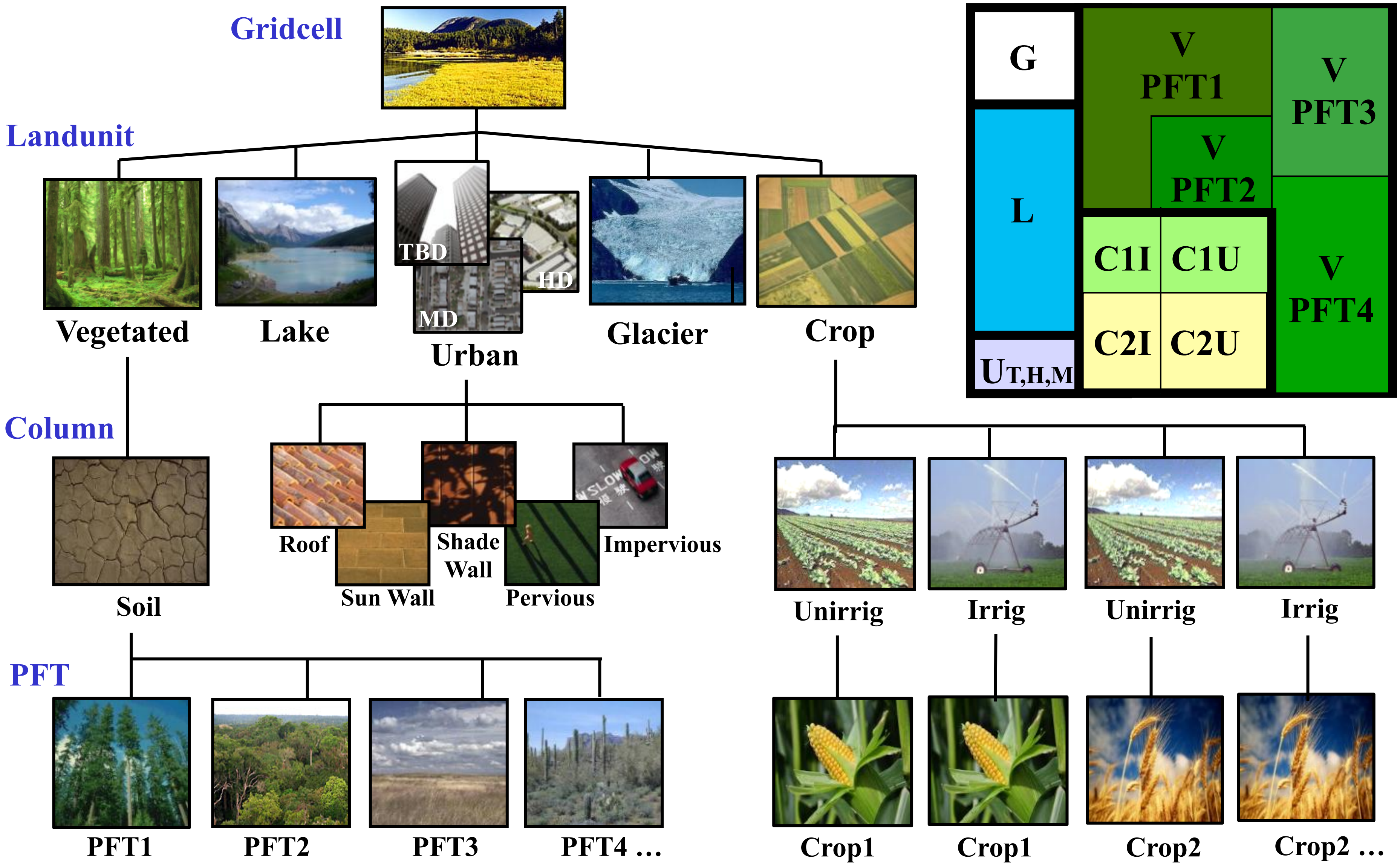
Land complexity: Submodels of CLM

- Biogeophysics
  - Photosynthesis and stomatal resistance
  - Hydrology
  - Snow
  - Soil thermodynamics
  - Surface albedo and radiative fluxes
- Biogeochemistry
  - Carbon / nitrogen pools, allocation, respiration
  - Vegetation phenology
  - Decomposition
  - Plant Mortality
  - External nitrogen cycle
  - Methane production and emission

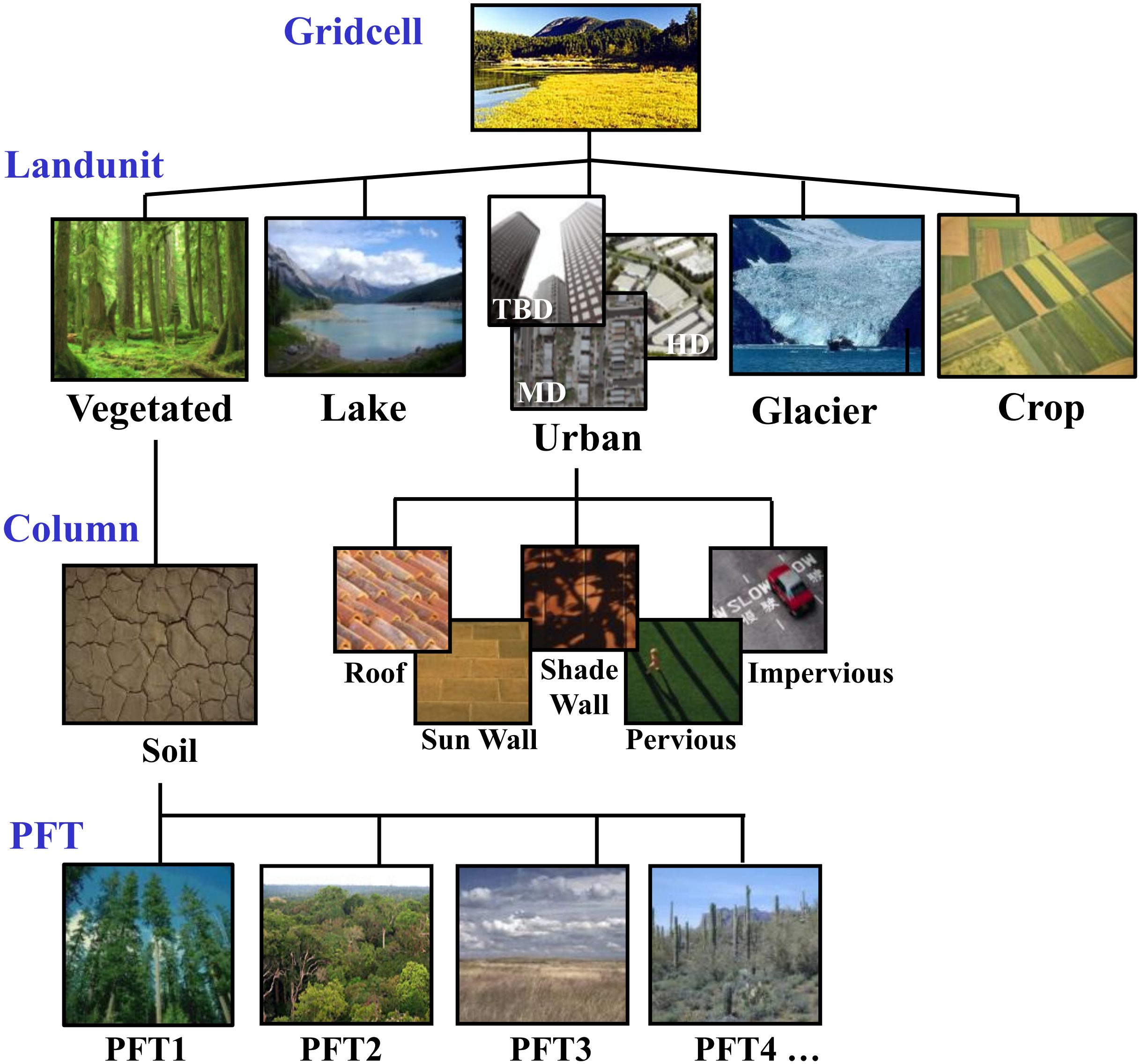
- Vegetation dynamics
- Urban
- Crop and irrigation
- Lakes
- Glaciers and ice sheets
- Fire and fire emissions
- Dust emissions
- River flow
- Biogenic Volatile Organic Compound emissions

Land surface heterogeneity

Land surface heterogeneity
CLM subgrid tiling structure



Land surface heterogeneity
CLM subgrid tiling structure



Plant Functional Types:

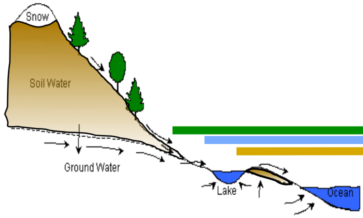
0. Bare

Tree:

1. Needleleaf Evergreen, Temperate
2. Needleleaf Evergreen, Boreal
3. Needleleaf Deciduous, Boreal
4. Broadleaf Evergreen, Tropical
5. Broadleaf Evergreen, Temperate
6. Broadleaf Deciduous, Tropical
7. Broadleaf Deciduous, Temperate
8. Broadleaf Deciduous, Boreal

Herbaceous / Understorey:

9. Broadleaf Evergreen Shrub, Temperate
10. Broadleaf Deciduous Shrub, Temperate
11. Broadleaf Deciduous Shrub, Boreal
12. C3 Arctic Grass
13. C3 non-Arctic Grass
14. C4 Grass
15. Crop

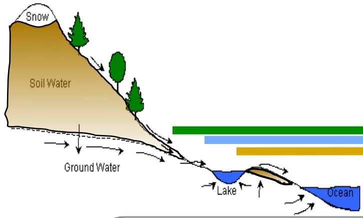


Plant Functional Type Parameters

- Optical properties (visible and near-infrared):
  - Leaf angle
  - Leaf reflectance
  - Stem reflectance
  - Leaf transmittance
  - Stem transmittance
- Fire:
  - Combustion completeness
  - Fire mortality
- Land surface models are parameter heavy!!!
- Morphological properties:
  - Leaf area index (annual cycle)
  - Stem area index (annual cycle)
  - Leaf dimension
  - Roughness length/displacement height
  - Canopy top and bottom height
  - Root distribution
- Photosynthetic parameters:
  - Specific leaf area
  - m (slope of conductance-photosynthesis relationship)
  - Vcmax (maximum rate of carboxylation)
  - Leaf carbon to nitrogen ratio
  - Fraction of leaf nitrogen in Rubisco
  - Soil water potential at stomatal open/closure

CLM Development

http://www2.cesm.ucar.edu/working-groups/lmwg/developer-guidelines



Model Development Process

Model release (CESM1/CLM4)

Use model for scientific studies

Detailed model assessment (identify strengths and weaknesses)

LMWG members develop parameterizations or add features

Present ideas/ results at LMWG meetings

Publish papers

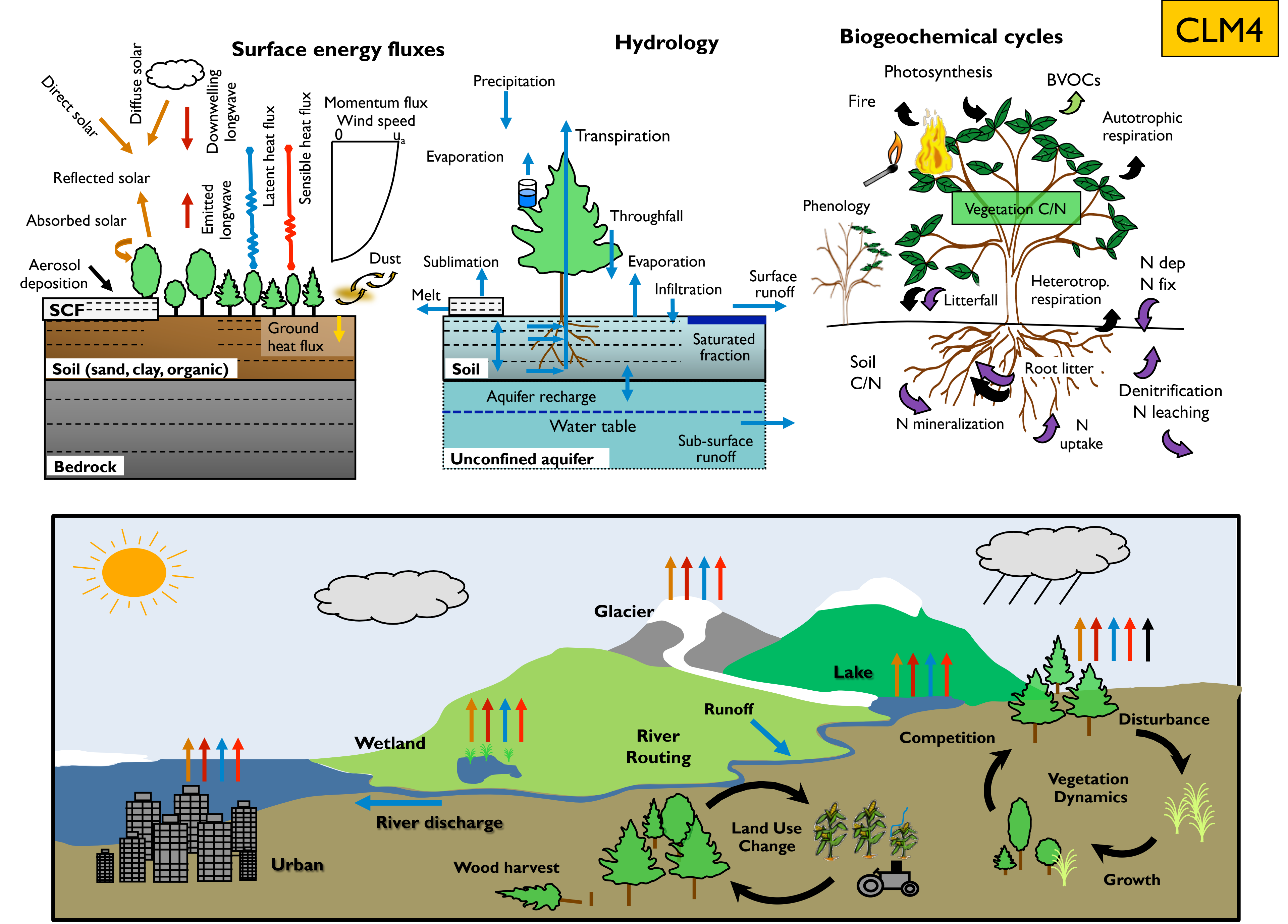
Evaluate competing parameterizations

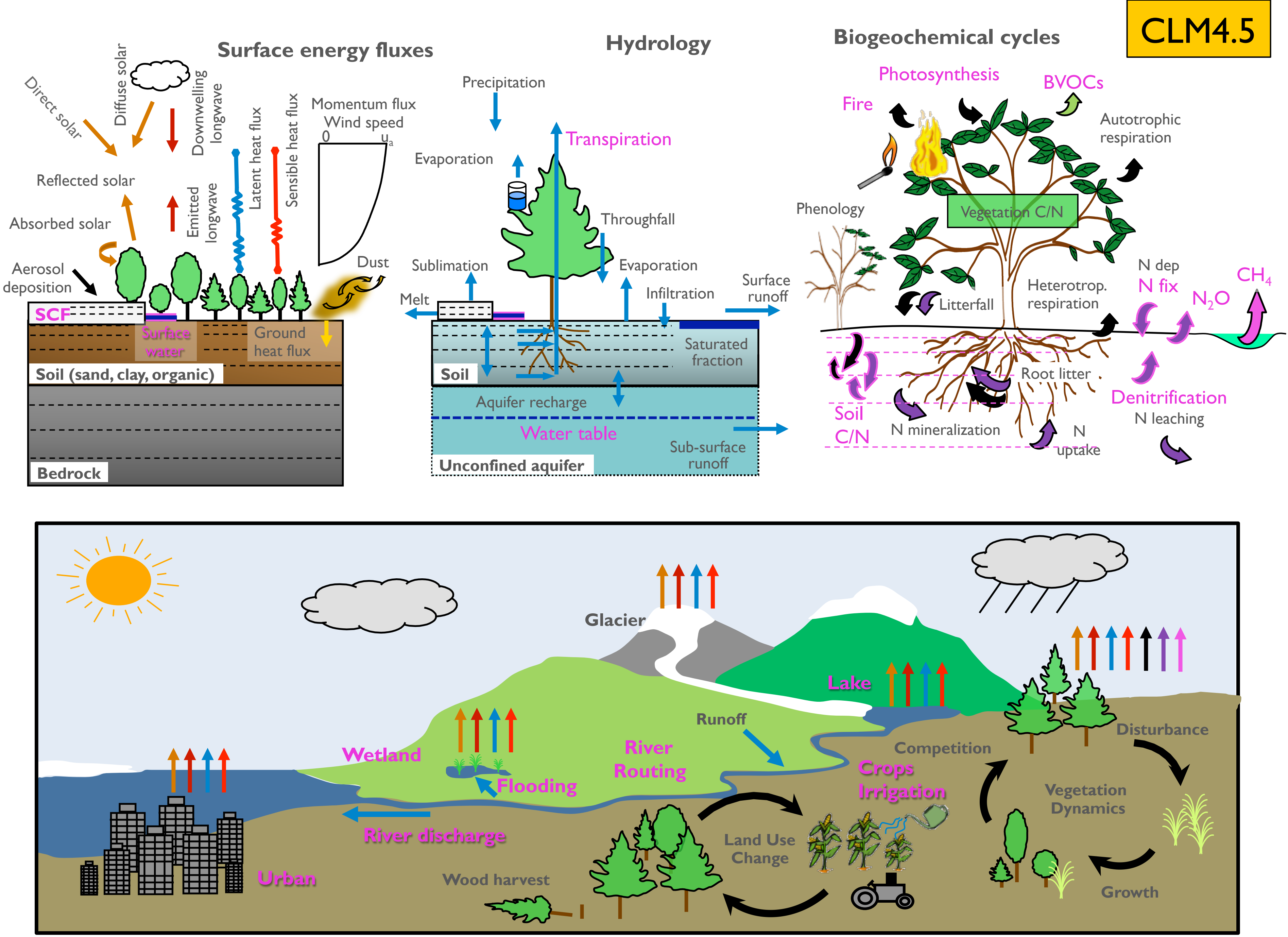
Plans for next (and next next) model version discussed at LMWG meetings

Build and test beta version of offline model

Finalize and test within CESM

Document; Control integrations


CLM4
Surface energy fluxes
Direct solar
Diffuse solar
Downwelling longwave
Reflected solar
Absorbed solar
Emitted longwave
Latent heat flux
Sensible heat flux
Momentum flux
Wind speed
0
u_a
Aerosol deposition
Dust
SCF
Ground heat flux
Soil (sand, clay, organic)
Bedrock
Hydrology
Precipitation
Transpiration
Evaporation
Throughfall
Evaporation
Sublimation
Infiltration
Surface runoff
Melt
Saturated fraction
Soil
Aquifer recharge
Water table
Sub-surface runoff
Unconfined aquifer
Biogeochemical cycles
Photosynthesis
BVOCs
Fire
Autotrophic respiration
Phenology
Vegetation C/N
Litterfall
Heterotrop. respiration
N dep
N fix
Soil C/N
Root litter
N mineralization
N uptake
Denitrification
N leaching
Glacier
Lake
Wetland
Runoff
River Routing
Competition
Disturbance
Vegetation Dynamics
Growth
River discharge
Land Use Change
Urban
Wood harvest



CLM4.5
Surface energy fluxes
Hydrology
Biogeochemical cycles
Direct solar
Diffuse solar
Downwelling longwave
Reflected solar
Absorbed solar
Emitted longwave
Latent heat flux
Sensible heat flux
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N dep
N fix
N_2O
CH_4
Root litter
Soil C/N
N mineralization
N uptake
Denitrification
N leaching
Glacier
Lake
Runoff
Wetland
River Routing
Flooding
River discharge
Urban
Wood harvest
Land Use Change
Competition
Crops Irrigation
Disturbance
Vegetation Dynamics
Growth

What's New for CLM5

A LOT!

More than 50 scientists and software engineers from 15 different institutions involved in development of CLM5

What's New for CLM5

Hydrology: dry surf. layer, var. soil depth w/ deeper (8.5m) max soil, revised GW and canopy interc

Snow: canopy snow updates, wind effects, firn model (12 layers), glacier MEC, fresh snow dens.

Rivers: MOSART(hillslope → tributary → main channel)

Nitrogen: flexible leaf C:N ratio, leaf N optimization, C cost for N (FUN)

Carbon: revisions to carbon allocation and decomposition

Fire: updates, trace gas and aerosol emissions

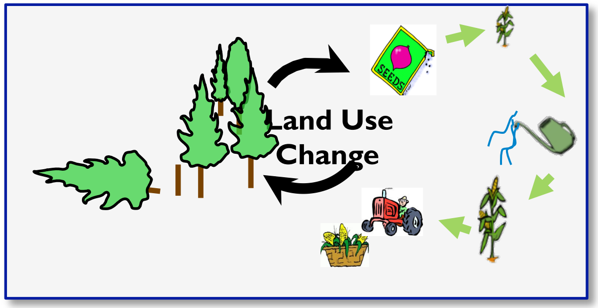
Vegetation: plant hydraulics and hydraulic redistribution, deep rooted tropical trees, Ecosystem Demography (FATES), prognostic roots, ozone damage

Crops: global crop model with transient irrig. and fertilization (8 crop types), grain prod. pool

Land cover/use: dynamic landunits, revised PFT-distribution, wood harvest by mass, shifting cultivation

Isotopes: carbon and water isotope enabled

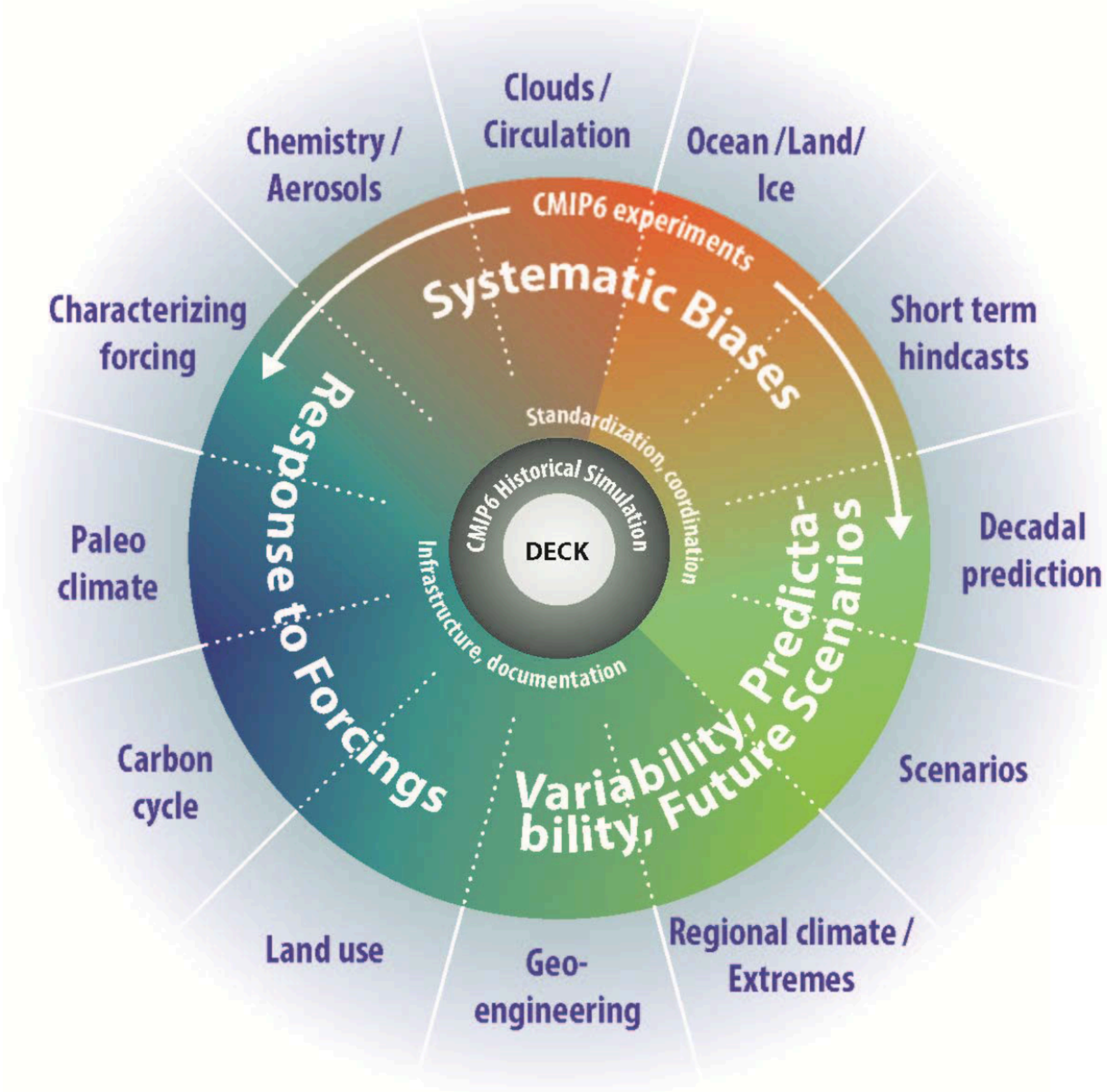
CLM5 default configuration
CLM5 optional feature



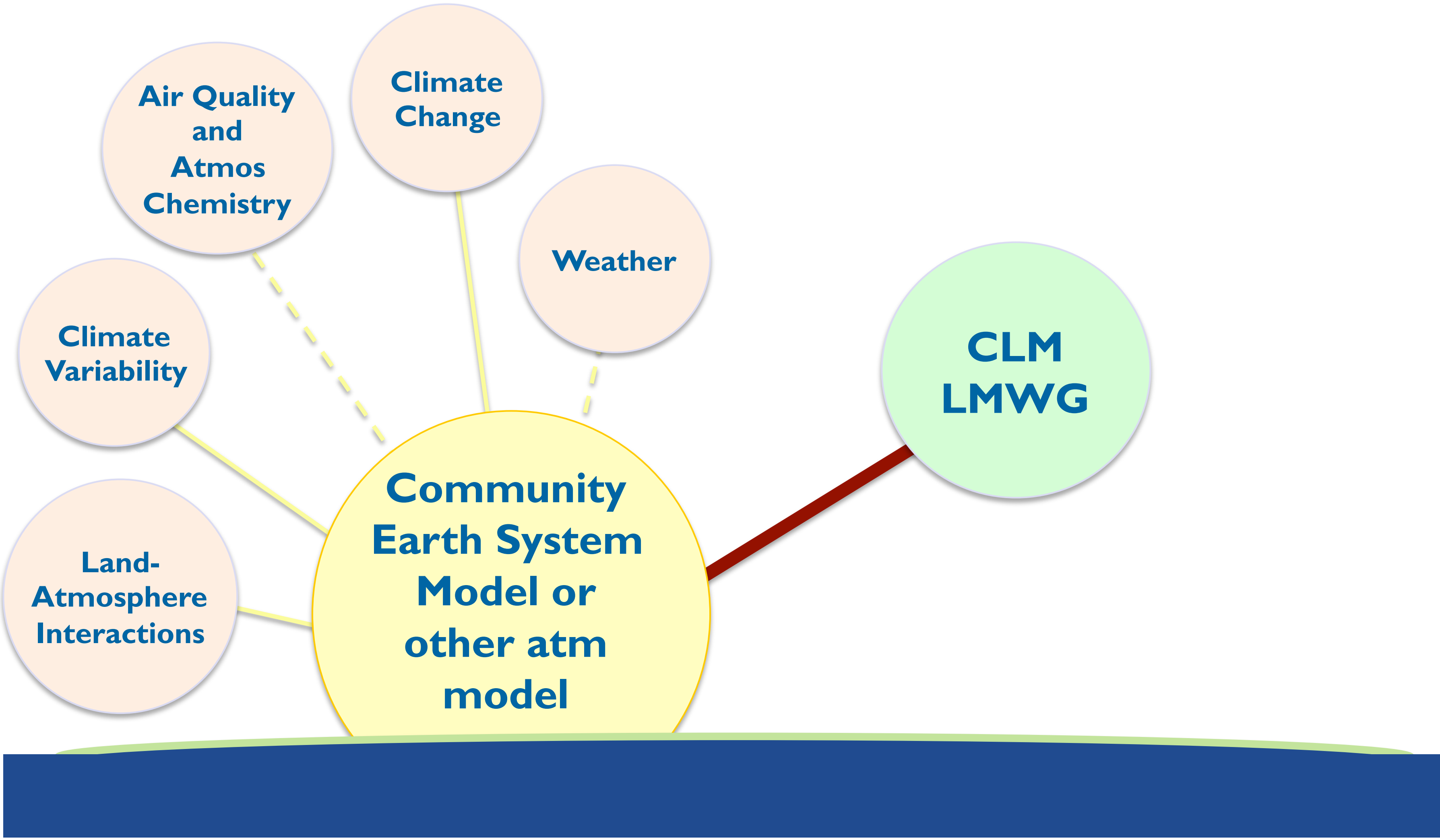
Increased focus on terrestrial processes in CMIP6

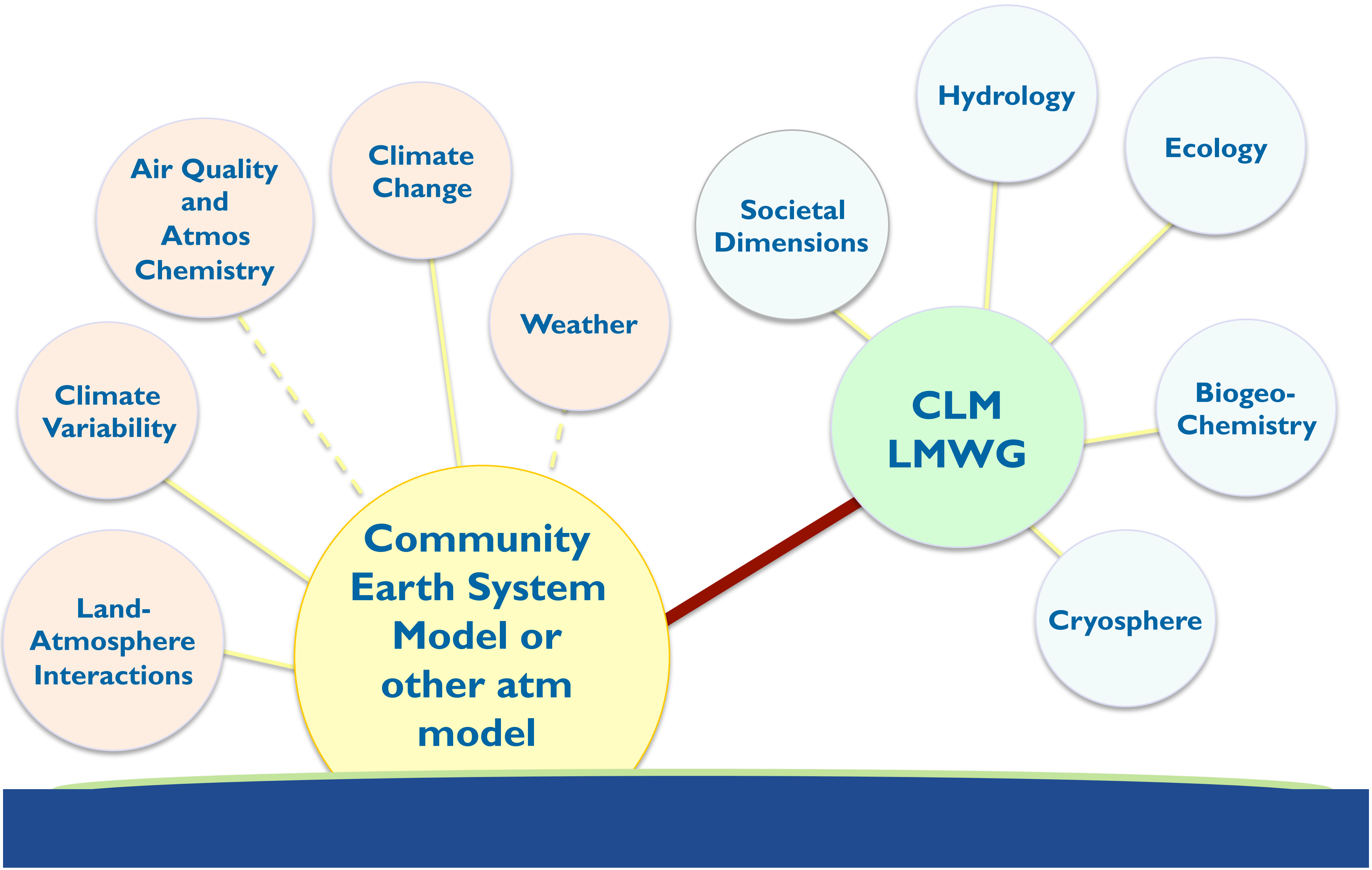
Coordinated activities to assess land role in climate and climate change

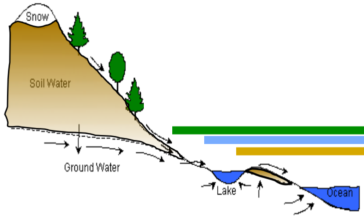
- **Land-only** simulations forced with obs historical climate, land-systematic biases
- **Land Use = LUMIP**
  land use forcing on climate, biogeophysics and biogeochemistry with policy relevance
- **Land = LS3MIP**
  biogeophys feedbacks including soil moisture and snow feedbacks
- **Carbon Cycle = C4MIP**
  land biogeochemical feedbacks on climate



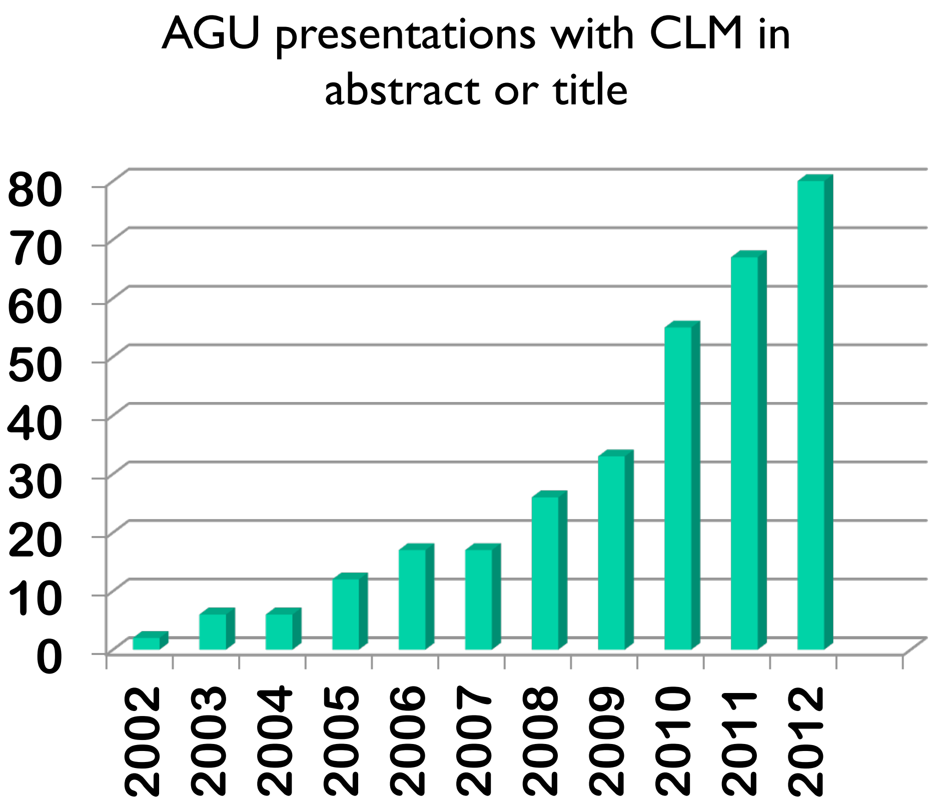
Updated from Meehl et al., EOS, 2014

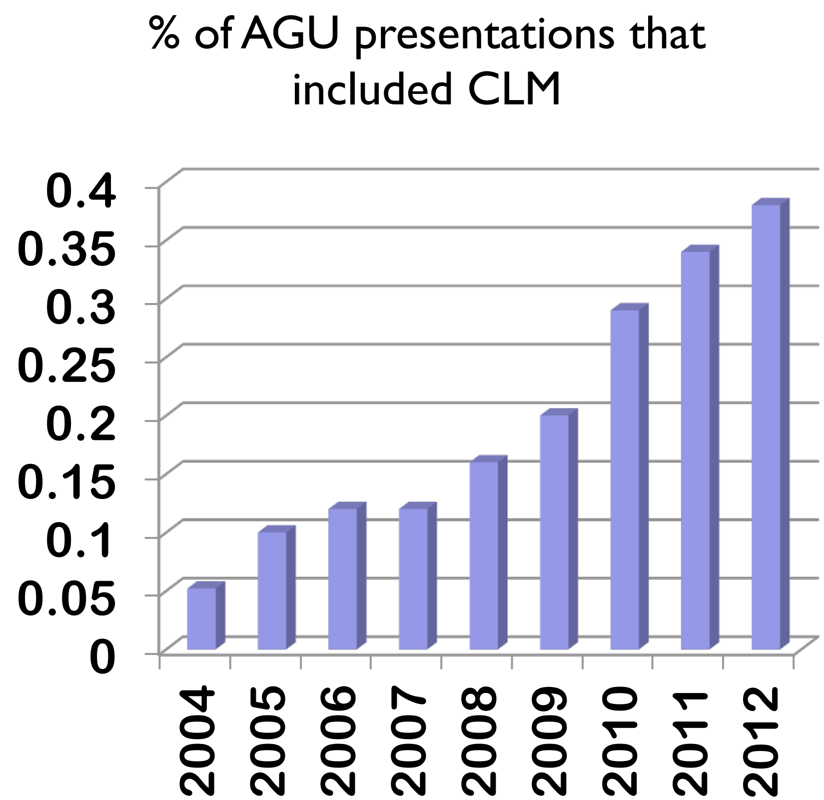

Air Quality and Atmos Chemistry
Climate Change
Weather
Climate Variability
Land-Atmosphere Interactions
Community Earth System Model or other atm model
CLM LMWG


Air Quality and Atmos Chemistry
Climate Change
Weather
Climate Variability
Land-Atmosphere Interactions
Community Earth System Model or other atm model
Societal Dimensions
Hydrology
Ecology
CLM LMWG
Biogeo-Chemistry
Cryosphere



CLM as a community modeling tool



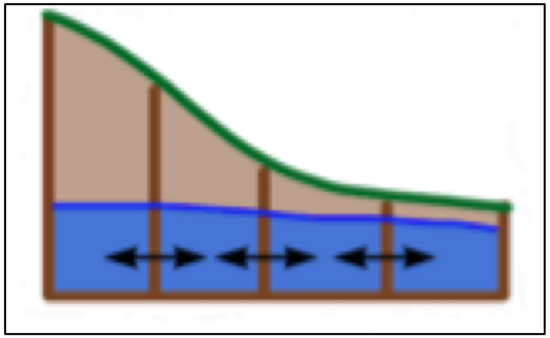


CLM3.5 [Oleson et al., 2008] (236 citations)

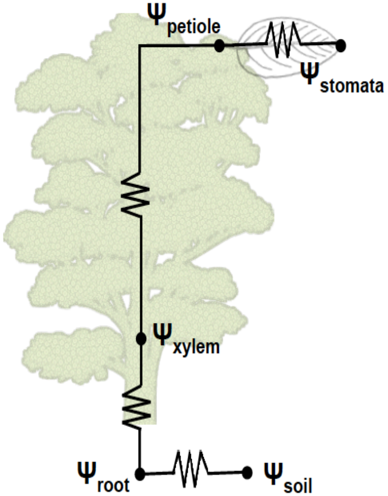
CLM4.0 [Lawrence et al., 2011] (164 citations)

The future of CLM

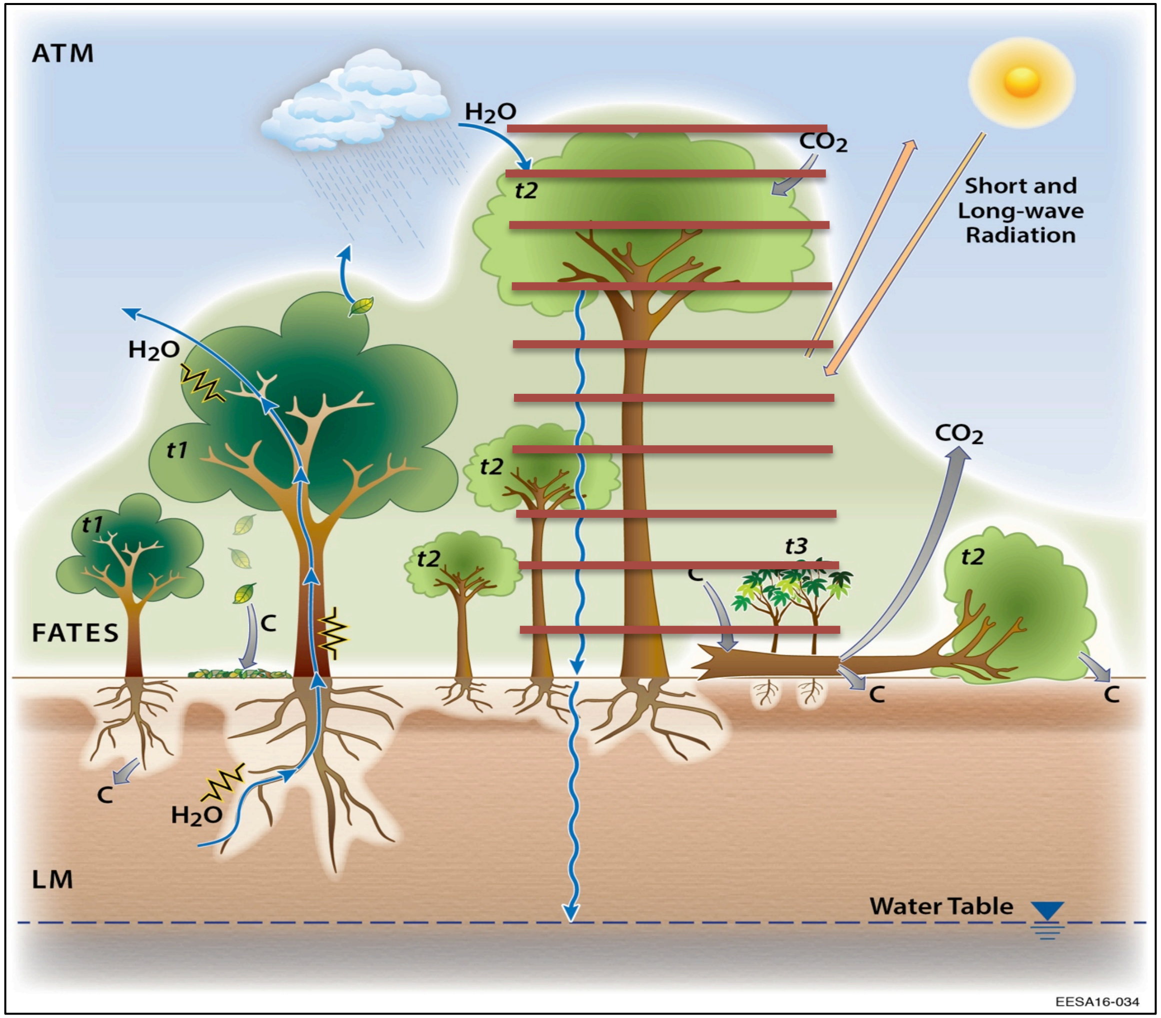
Hillslope hydrology



Plant hydrodynamics



Ecosystem Demography / multi-layer canopy



Where to find information about CLM and CESM

NCAR
UCAR
CESM
COMMUNITY EARTH SYSTEM MODEL

earth • modeling • climate

Google™ Custom Search | Search

CESM Models

CESM1.2: CLM DOCUMENTATION

INTRODUCTION

The Community Land Model versions 4.0 and 4.5 in CESM1.2.0 are the latest in a series of land models developed through the CESM project. More information on the CLM project and access to previous CLM model versions and documentation can be found via the CLM Web Page.

www.cesm.ucar.edu/models/cesm1.2/clm

DOCUMENTATION

- User's Guide for CLM4.5 and CLM4.0 in CESM1.2.0 [html] [pdf] (Last update: [an error occurred while processing this directive])
- Technical Description for CLM4.5 (Last update: Aug/ 1/2013)
- Technical Description for CLM4.0, CLM4.0 Urban Model, CLM4.0 Crop and Irrigation Model
- Explanation of supported configurations in CLM4.5 and CLM4 in CESM1.2
- What's new in CLM in CESM1.2 (CLM4.5 release) Science, CESM1.2 (CLM4.5 release) Software, CESM1.1.1, CESM1.1.0, CESM1.0.5, CESM1.0.4, CESM1.0.3, CESM1.0.2, CESM1.0.1, CESM1.0, CCSM4.0 (CLM4.0 release).
- Known bugs in CLM in CESM1.2.0, CESM1.1.0, CESM1.0.4, CESM1.0.3, CESM1.0.2, CESM1.0.1, CESM1.0.
- Known limitations in CLM in CESM1.2.0, CESM1.1.0.

MODEL OUTPUT AND OFFLINE FORCING DATA AND DIAGNOSTIC PLOTS

- CLM4.0 and CLM4.5 offline control simulations: Diagnostic plots
- CLM4.0 and CLM4.5 offline control simulations (links need to be updated and data posted to ESG)): Model output data
- CLM4.0 and CLM4.5 offline control simulations (links need to be updated and data posted to ESG): Model forcing data
- CLM4.0 and CLM4.5 offline historical and RCP simulations: CCSM4 coupler history forcing data

CLM configurations in CESM2

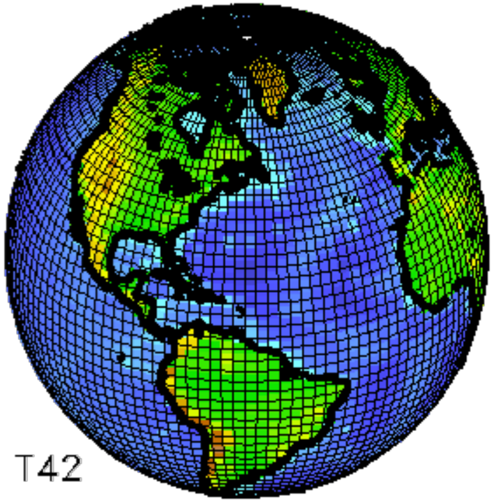
CLM5(SP) Prescribed vegetation states

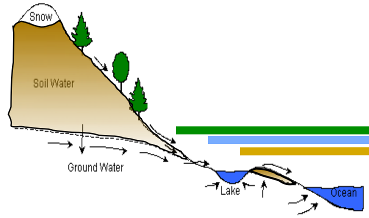
CLM5(BGC) Prognostic vegetation state / biogeochemistry

CLM5(FATES) Prognostic BGC with ecosystem demography

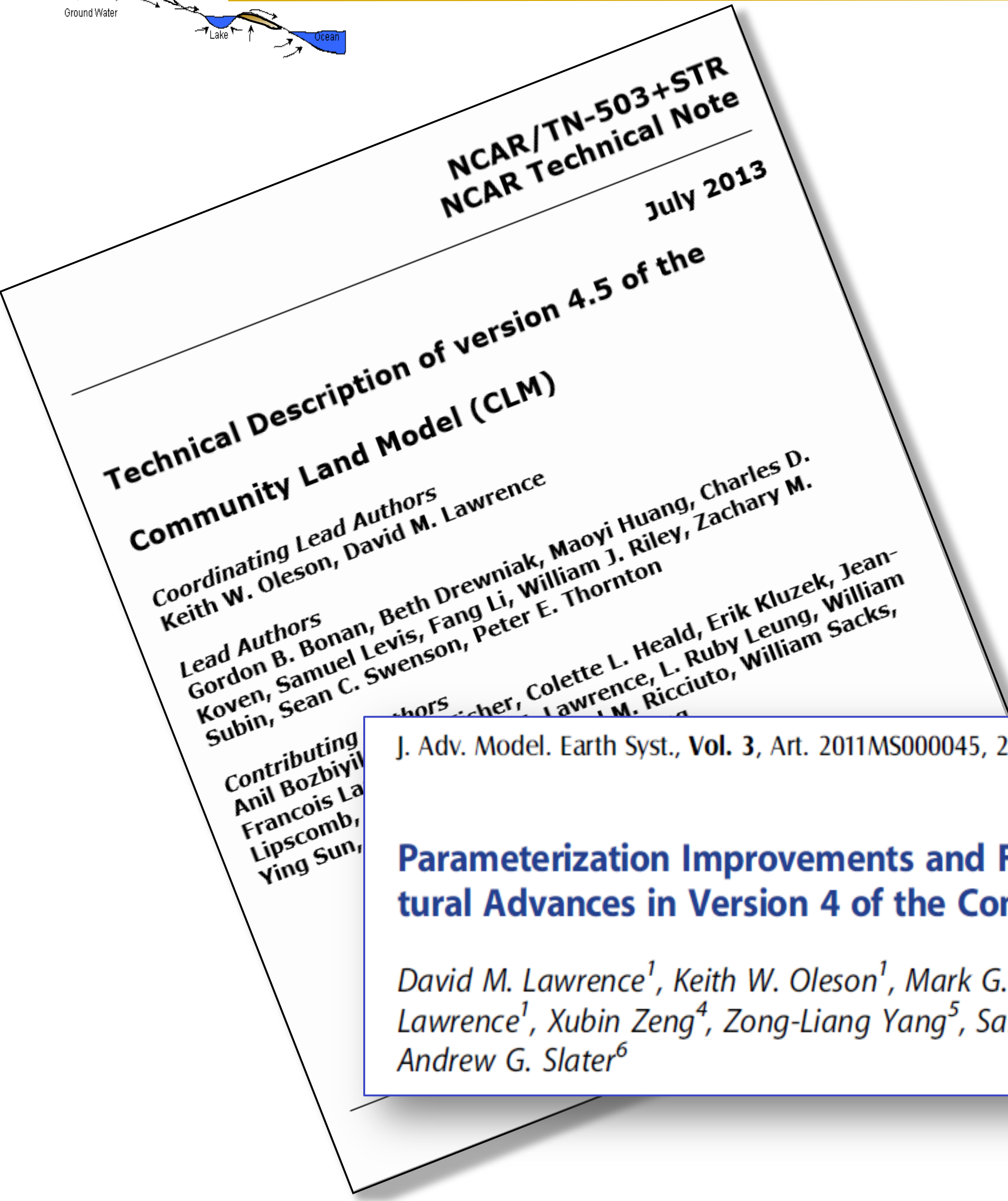
Options: Prescribed land use change
Crops and irrigation, ozone damage

Global (low and high resolution), regional, single point





Documentation
http://www.cesm.ucar.edu/models/cesm1.2/clm


NCAR/TN-503+STR
NCAR Technical Note
July 2013

Technical Description of version 4.5 of the Community Land Model (CLM)

Coordinating Lead Authors
Keith W. Oleson, David M. Lawrence

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Gordon B. Bonan, Beth Drewniak, Maoyi Huang, Charles D. Koven, Samuel Levis, Fang Li, William J. Riley, Zachary M. Subin, Sean C. Swenson, Peter E. Thornton

Contributing
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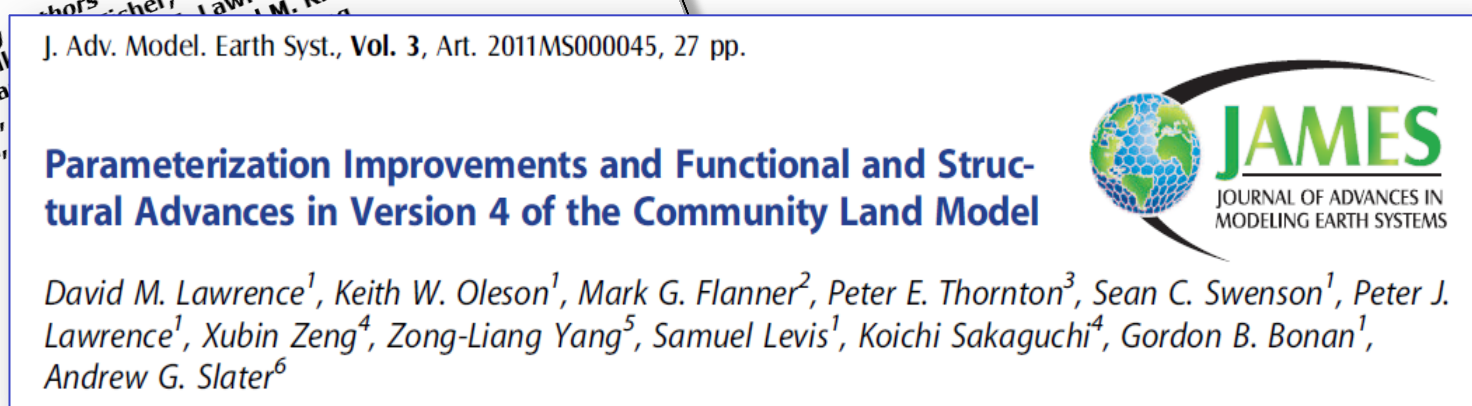
Francois La
Lipscomb,
Ying Sun,
Colette L. Heald, Erik Kluzek, Jean-
L. Ruby Leung, William
Ricciuto, William Sacks,

CLM4.5 Technical Description

- ~420 pages
- 27 chapters

Papers – Over 350 papers in CLM Bibliography


J. Adv. Model. Earth Syst., **Vol. 3**, Art. 2011MS000045, 27 pp.

JAMES
JOURNAL OF ADVANCES IN MODELING EARTH SYSTEMS

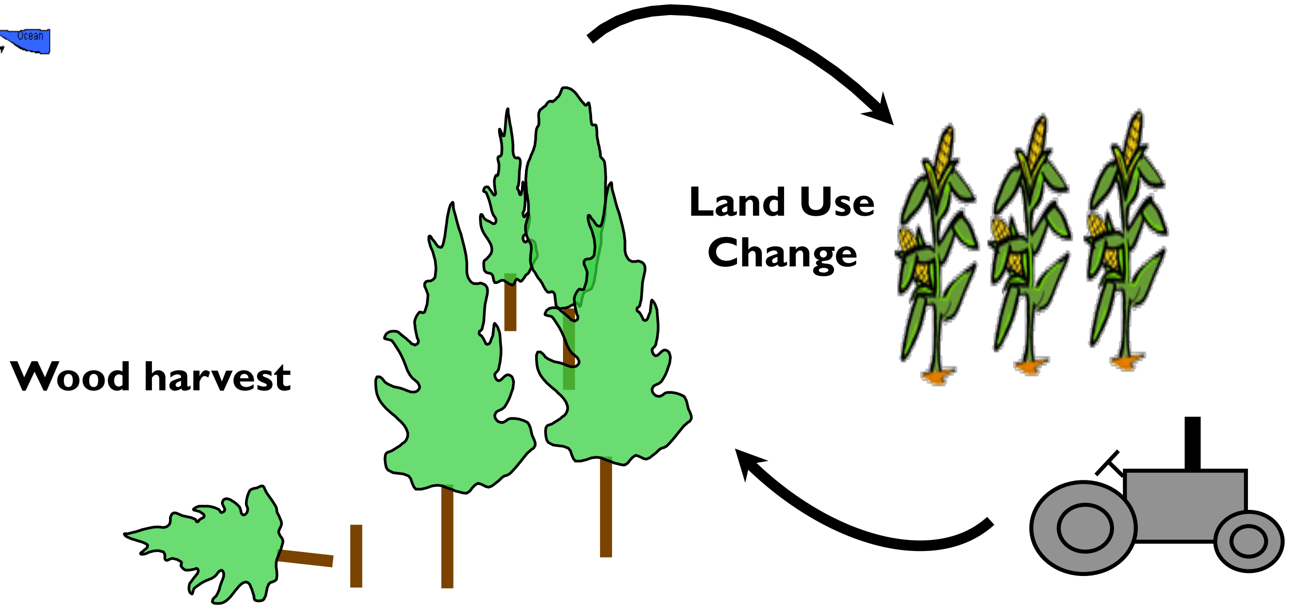
Parameterization Improvements and Functional and Structural Advances in Version 4 of the Community Land Model

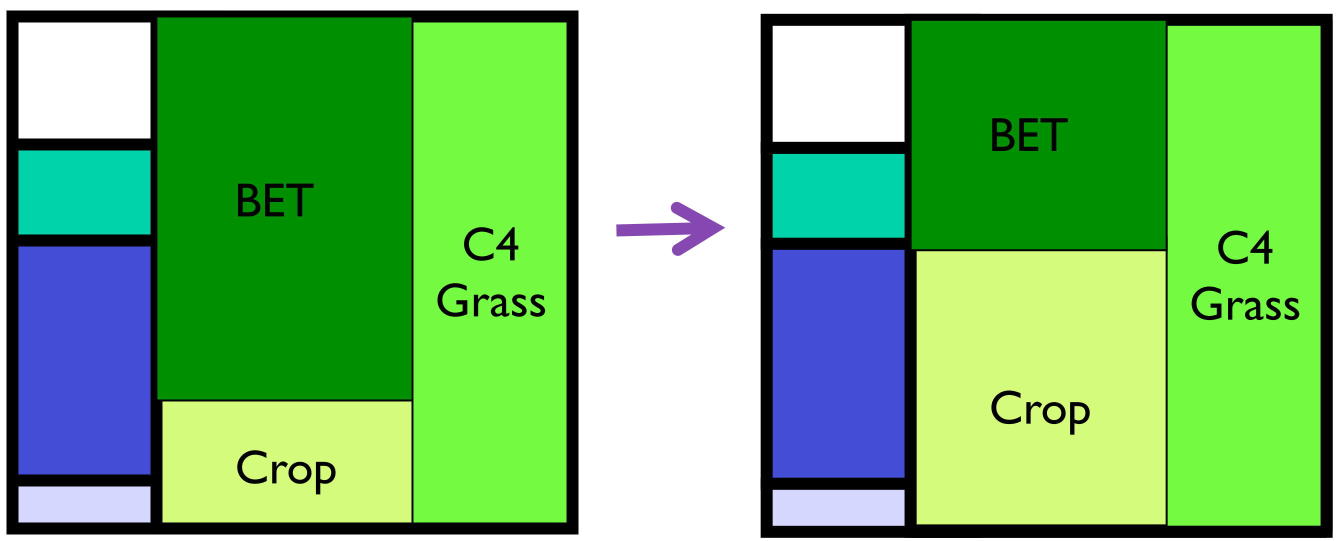
David M. Lawrence[1], Keith W. Oleson[1], Mark G. Flanner[2], Peter E. Thornton[3], Sean C. Swenson[1], Peter J. Lawrence[1], Xubin Zeng[4], Zong-Liang Yang[5], Samuel Levis[1], Koichi Sakaguchi[4], Gordon B. Bonan[1], Andrew G. Slater[6]

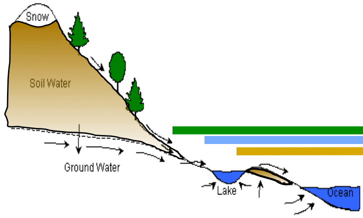
Thanks and welcome to the CESM/CLM research community!

Questions?

Land cover / land use change (prescribed)





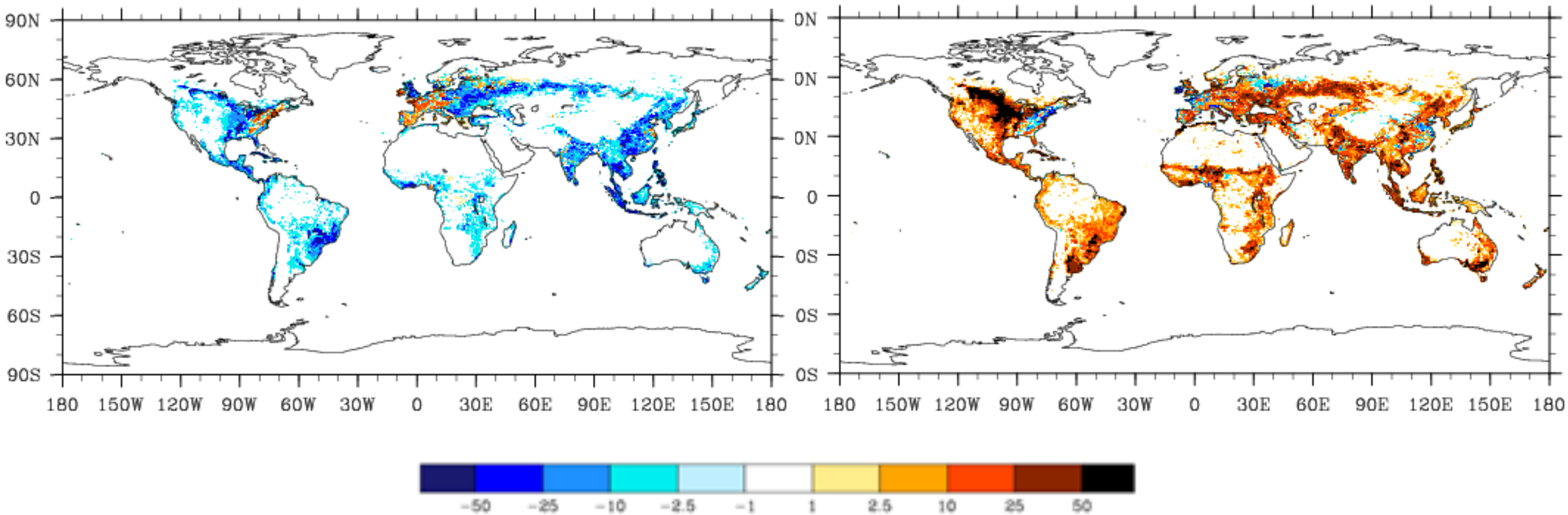


Land cover change (prescribed)

2005 – 1850

Trees

Crops



Deforestation across Eastern North America, Eastern Europe, India, China, Indonesia, SE South America for Crops

Lawrence, P et al. J. Climate, 2012