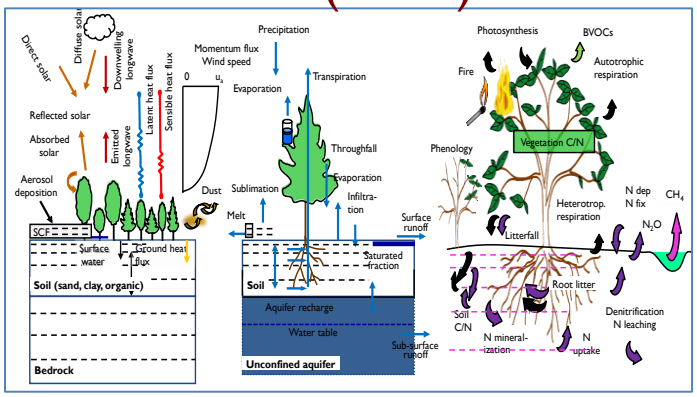
# Unifying land modeling across NCAR:
## The Community Terrestrial System Model (CTSM)

Dave Lawrence, Mike Barlage, Martyn Clark, Bill Sacks, Mariana Vertenstein, Sean Swenson, Naoki Mizukami, Gordon Bonan, Rosie Fisher, Fei Chen, Andy Wood, David Gochis, Ned Patton, Roy Rasmussen, Joe Hamman, Erik Kluzek, and others

# The Community Terrestrial System Model

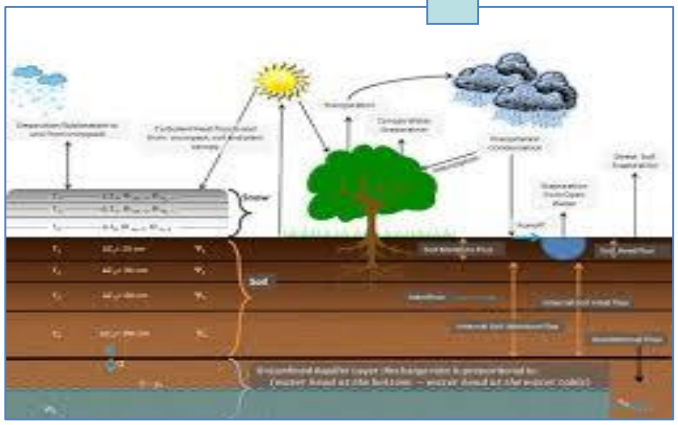
a unified model for research and prediction in climate, weather, water, and ecosystems

## CLM (CGD)



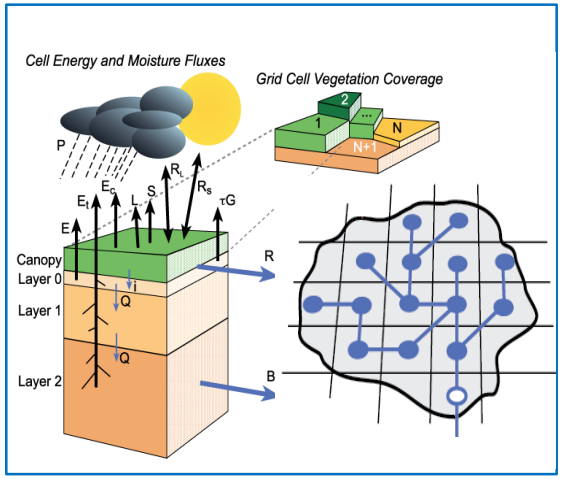

SUMMA concepts

# CTSM



## Noah-MP, WRF-Hydro (RAL)

## Other model contributions



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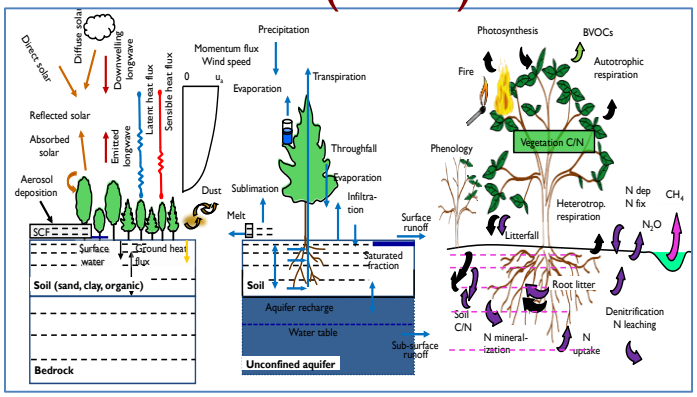
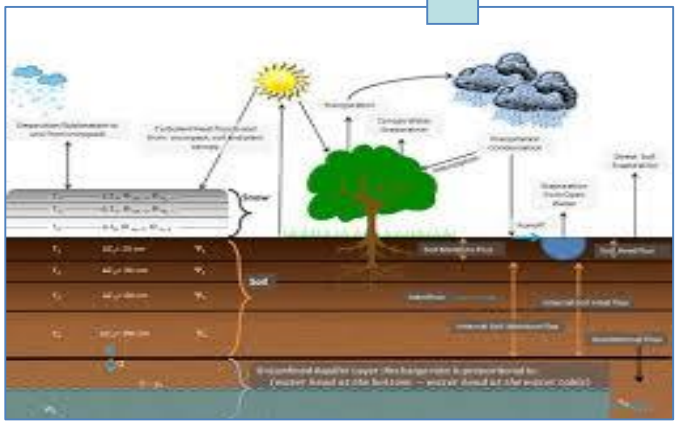
CLM (CGD)




SUMMA concepts → CTSM



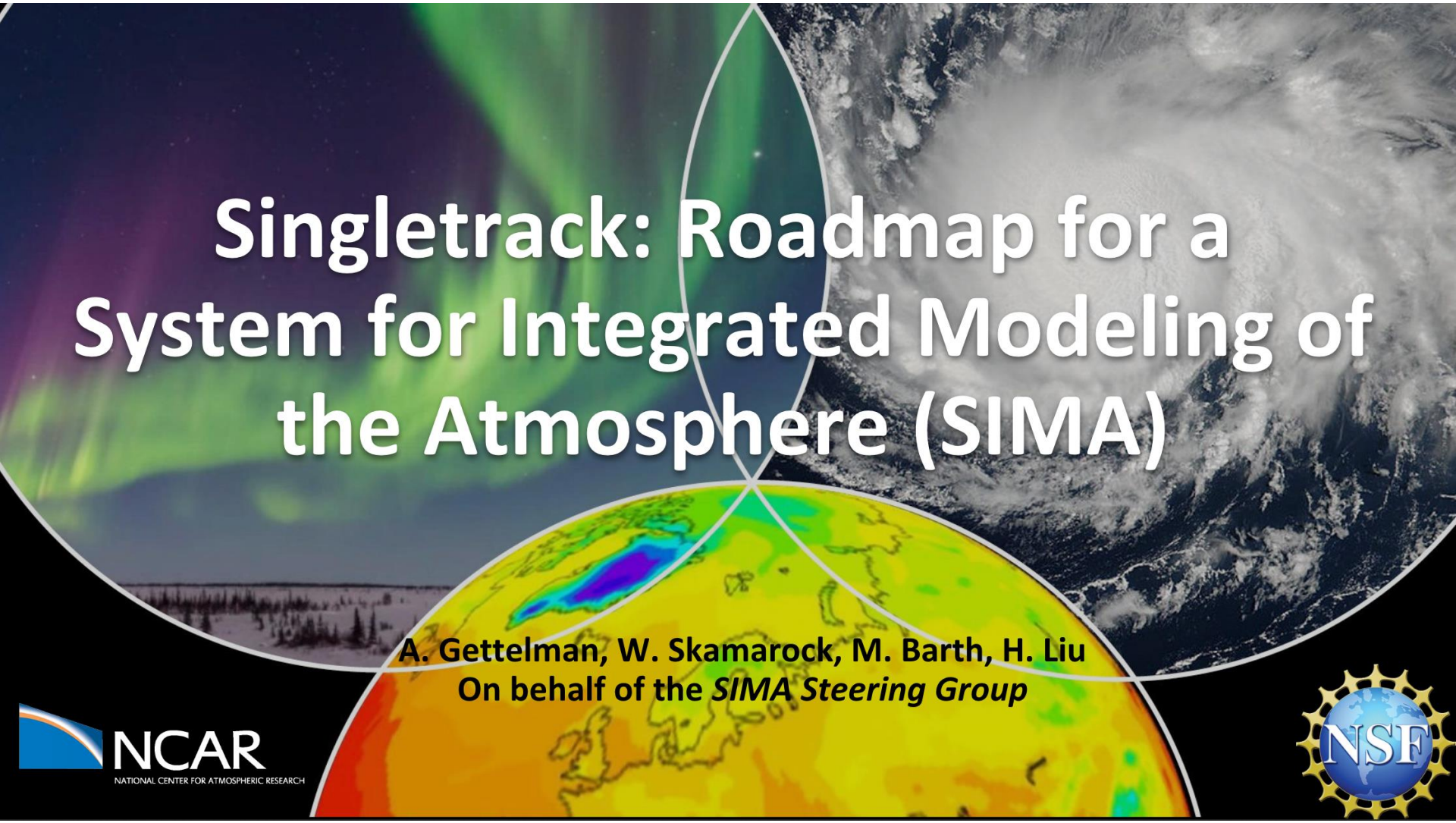
Noah-MP, WRF-Hydro (RAL)

- **CTSM (unification) benefits:**
  - extend leadership in community modeling
  - reverse trends of model proliferation and shantytown syndrome
  - more efficient use of NCAR and community model development resources
  - integrate and expand land modeling research
  - accelerate advances, improve science through multiple hypothesis testing
- **CTSM software improvement goals:**
  - reduce accumulated technical debt
  - clean separation of flux parameterizations and numerical solution
  - modularity; alternative hypotheses
  - hierarchy of complexity (climate, NWP, water, and ecology applications)
  - flexibility of spatial disaggregation

# CTSM development plan

NCAR UCAR

- Model development
  - Use SUMMA concepts to refactor CLM, and integrate capabilities from Noah-MP
  - Major focus on supporting datasets, documentation, user support, etc., to make the model easier to use/modify
  - Model will necessarily be more complex than individual models since it must meet a broader range of objectives
- Model transition
  - Existing land models (e.g., CLM, Noah-MP) will be instantiations of CTSM (CTSM-Climate and CTSM-NWP)
  - Near-term parallel development efforts: Existing models (Noah-MP, SUMMA, WRF-Hydro, etc.) will continue to evolve, shift to CTSM once capabilities exist for specific applications
- Progress
  - CTSM public git repository (github.com/ESCOMP/ctsm)
  - CTSM-NWP configuration
  - CTSM coupling to Target Atmosphere Models (including WRF) – LILAC
  - CTSM biogeophysics code refactor (using need for water tracers as guide for implementation)
  - CTSM reinvestment: crop model development and unification; multiple irrigation methods; Coupling network-based mizuRoute river model to CTSM; adding reservoirs/lakes to mizuRoute



# Singletrack: Roadmap for a System for Integrated Modeling of the Atmosphere (SIMA)

A. Gettelman, W. Skamarock, M. Barth, H. Liu
On behalf of the *SIMA Steering Group*

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NSF

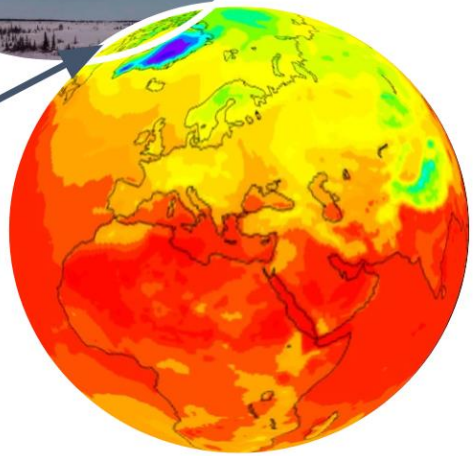
# Current Community Atmosphere Models

## Existing Applications

Weather (WRF & MPAS)

Geospace (TIE-GCM)

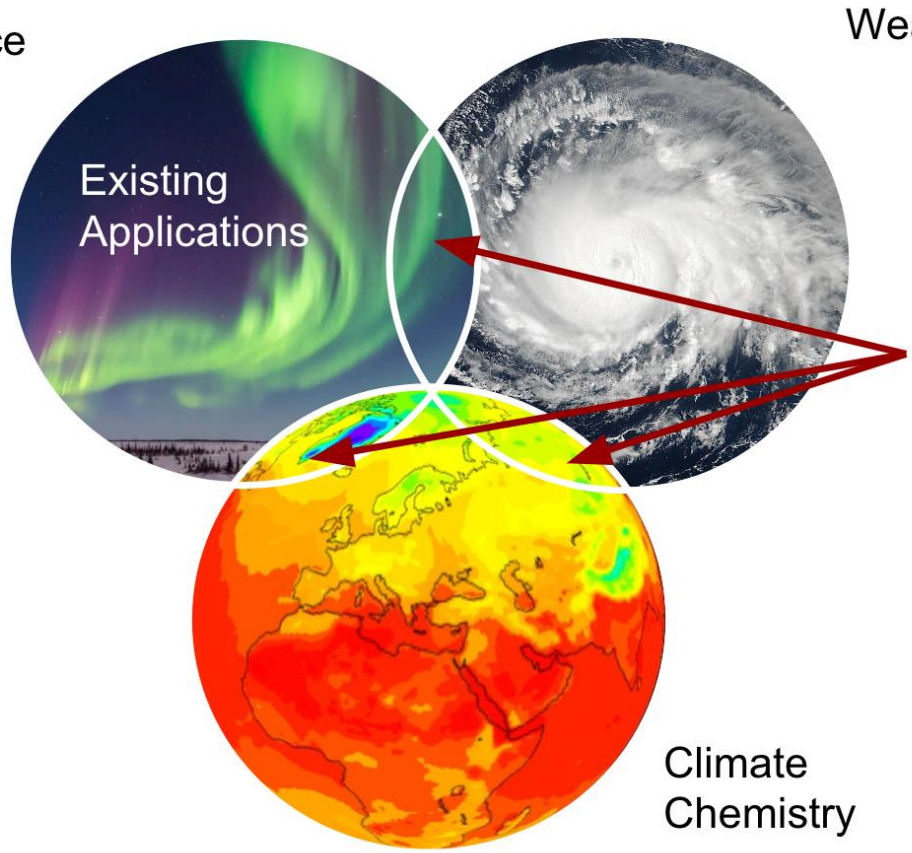
WACCM-X



Climate (CAM)
Chemistry (WACCM/CAM-CHEM)

# SIMA Vision

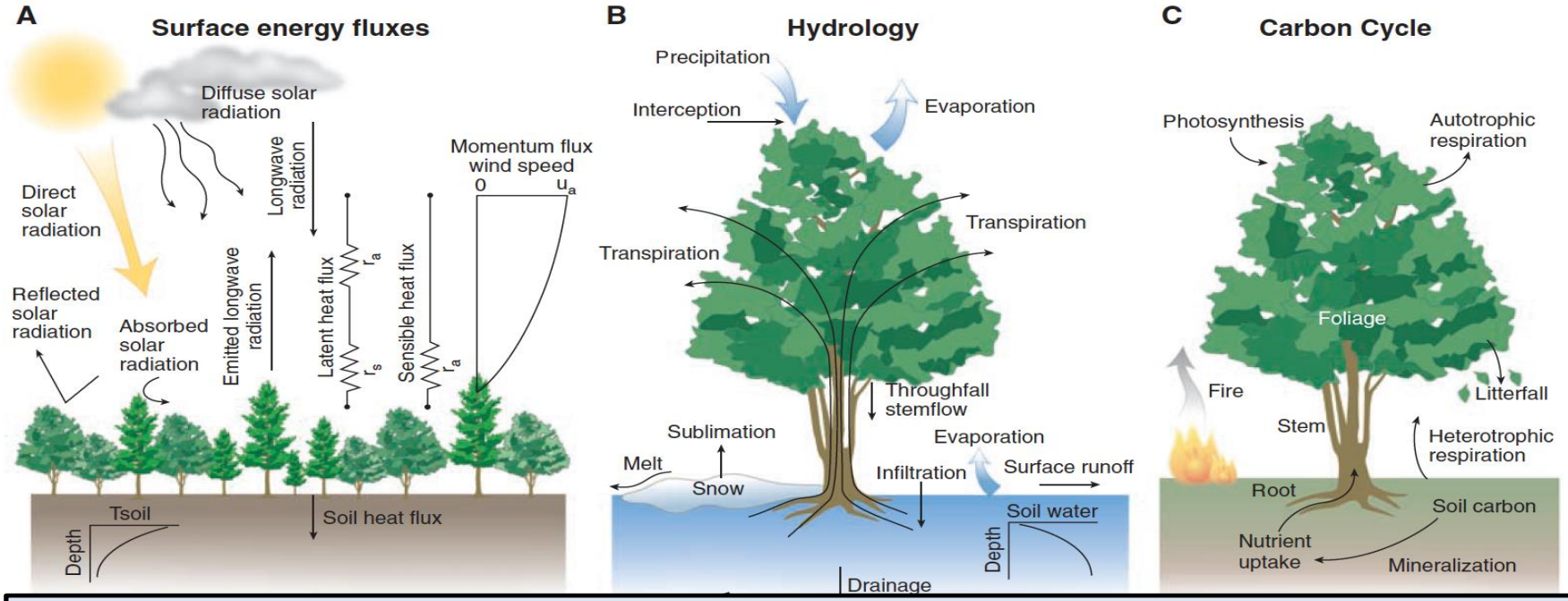
## Support Existing and Frontier Applications

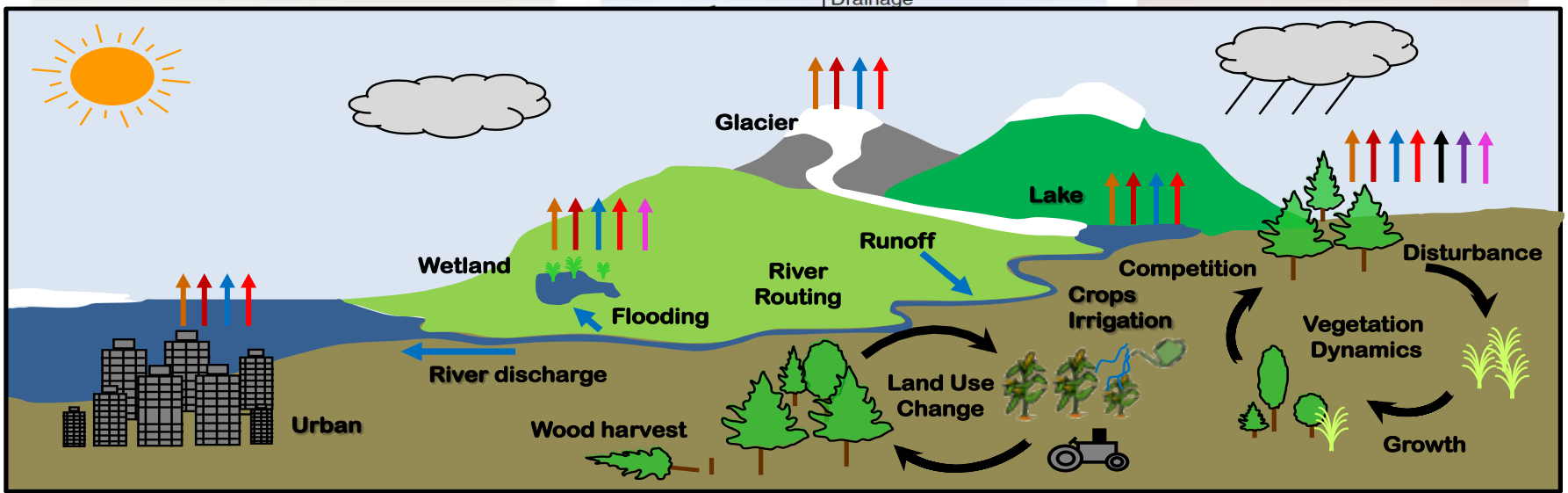



Frontier Applications

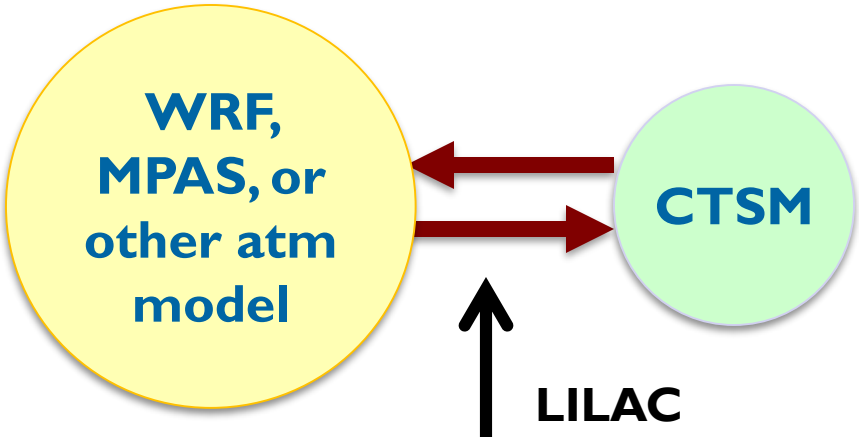
- Coupled Weather
- Climate Extremes
- Space Weather
- Air Pollution

# CTSM code infrastructure start with CLM codebase



# LILAC - Lightweight Infrastructure for Land-Atmosphere Coupling




## Coupling with LILAC

- From the Target Atmosphere Model (TAM) perspective, CTSM will exist as a library
- LILAC acts as an interface between the TAM and CTSM
- Called from within TAM, e.g., WRF surface_driver
- Only fields provided or needed by the TAM are passed through LILAC
- Output fields, CTSM I/O handled within CTSM
- LILAC is evolving; if you have suggestions, we would like to hear them

LILAC project also focusing on ease-of-use, initialization, input data flexibility

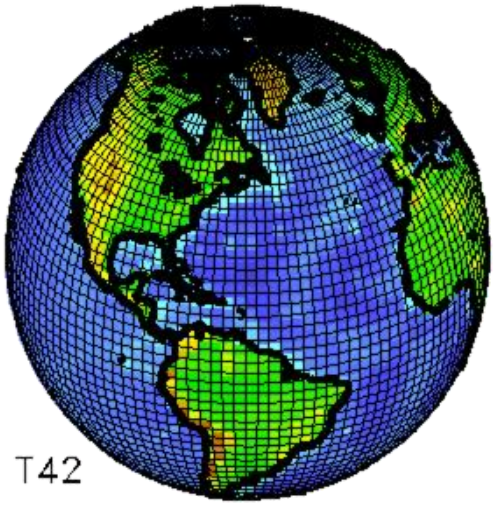
# CTSM configurations

**Model configurations**

- SP (satellite phenology, prescribed vegetation)
- BGC (prognostic carbon, vegetation)
- BGC-crop (default in CESM2, same as BGC with crops)
- BGC no-anthro
- + many options for individual parameterizations (i.e., can revert to CLM4.5

**Spatial configurations**

- Global (low and high resolution)
- Regional
- Single point (tower site)
- Irregular grids (cubed sphere, *basin*)



# CTSM options

**Options to reduce complexity (i.e., can be turned off or switched)**

- $CH_4$ emissions
- Carbon isotopes
- Land-use change
- VOC emissions
- Plant Hydraulics
- Soil structure (15-level vs 25-level)

**Options to increase complexity**

- Representative hillslopes
- FATES (Ecosystem dynamics)
- Fire trace gas emissions
- Additional land management
- Flooding
- Ozone damage to plants
- *Water tracers (available soon)*

# CTSM Advisory Committee

External committee that can provide advice and external support for project. Members selected for ability to provide constructive criticism and also to help ensure that CTSM is a success (e.g., people who may use CTSM in their research and/or in their operational systems).

First meeting TBD (May 2019?)

1. Paul Dirmeyer (GMU): land-atmosphere interactions
2. Martyn Clark (U. Saskatchewan): hydrology
3. Christa Peters-Lidard (NASA): Land Information System, drought
4. Charlie Koven (LBNL): carbon and ecology
5. Ashley Matheny (U. Texas): ecology
6. Reed Maxwell (Colorado School of Mines): groundwater hydrology
7. Stan Benjamin (NOAA): numerical weather prediction
8. Gonzalo Miguez-Macho (U. Santiago): hydrology
9. Xubin Zeng (U. Arizona): general
10. Abby Swann (U. Washington): land-atmosphere interactions, vegetation
11. Stefan Kollet (FZ Julich): software infrastructure, hydrology
12. Lisa Ainsworth (U. Illinois): agriculture

**Agency reps:**

USGS (Don Cline),
USACE (Jeff Arnold)
DOE (David Lesmes)
NOAA (Jin Huang)
NSF (???)

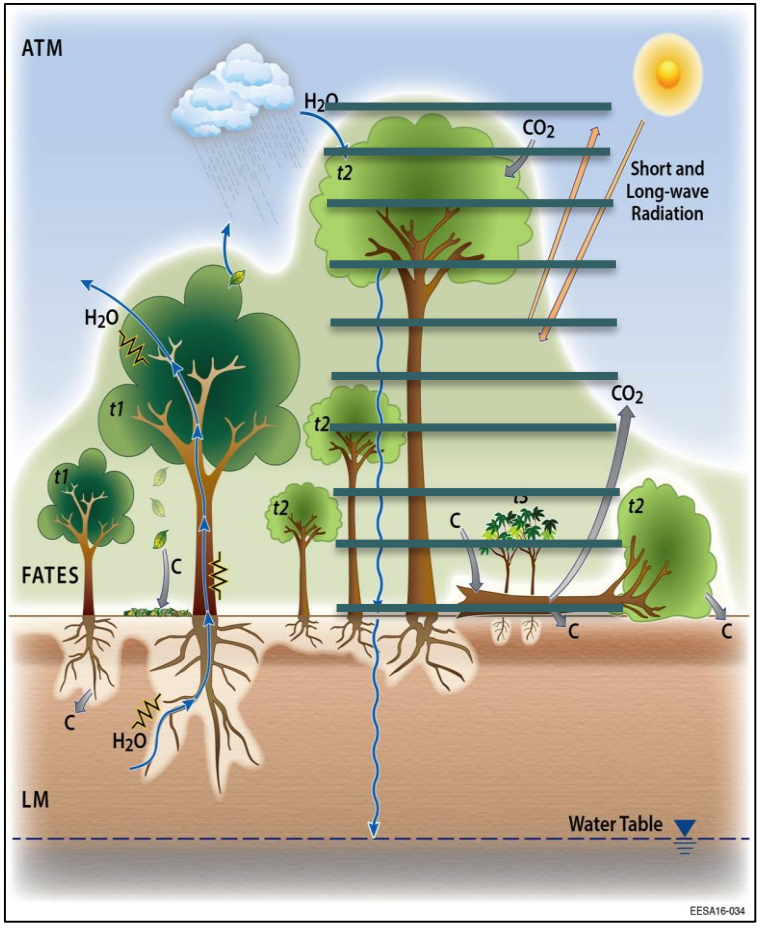
**Ex-Officio**

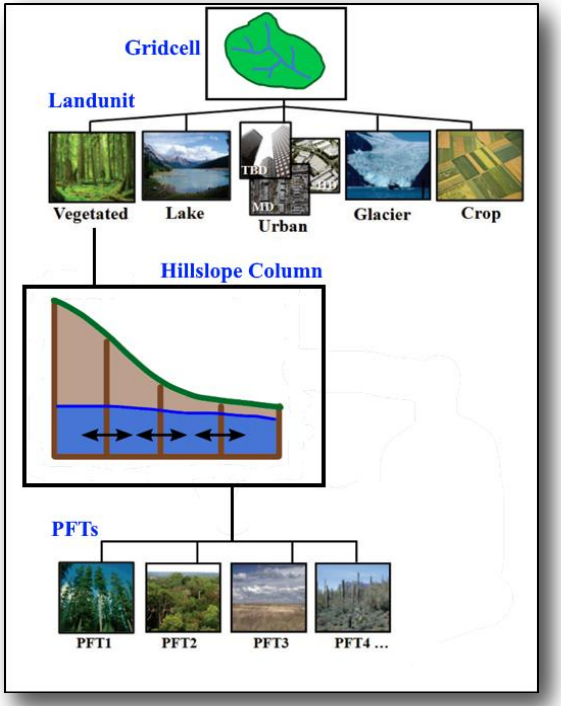
Jean-Francois Lamarque
Bill Mahoney

# CTSM can help pave wave way for next-generation land model

- Water and food security in context of climate change, climate variability, and extreme weather
- Ecosystem vulnerability and impacts on carbon cycle and ecosystem services
- Sources of predictability from land processes
- Impacts of land use and land-use change on climate, carbon, water, and extremes

Ecosystem Demography / Multi-layer canopy

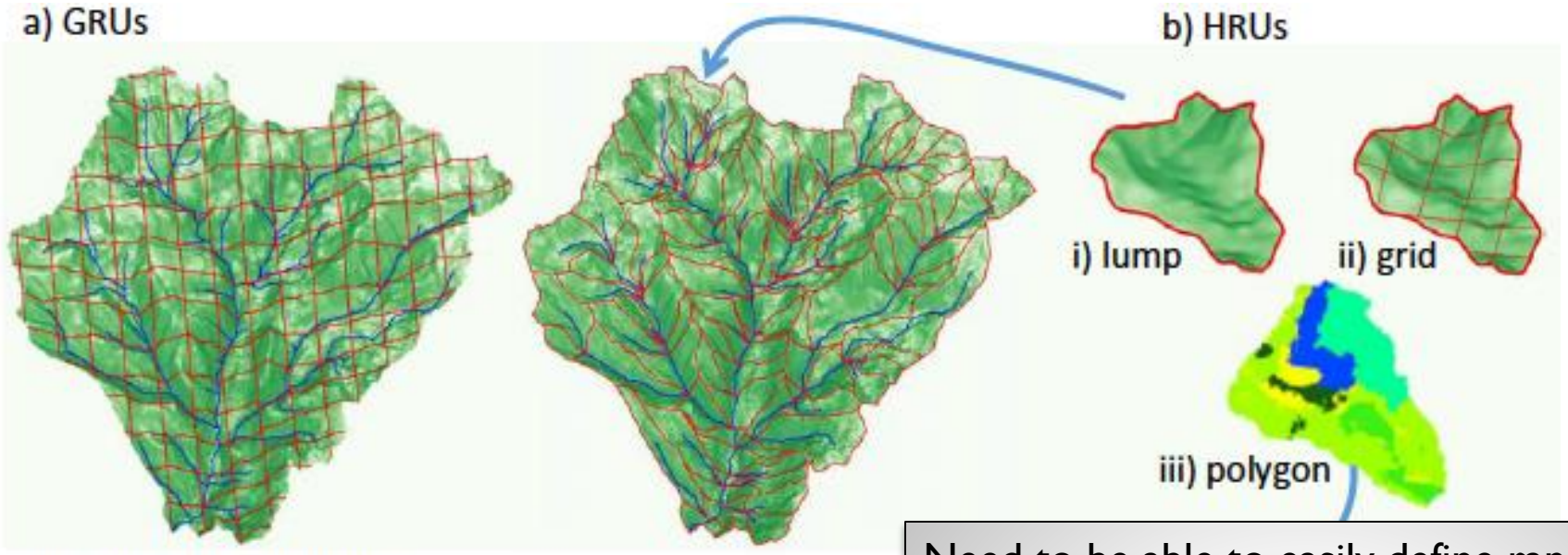


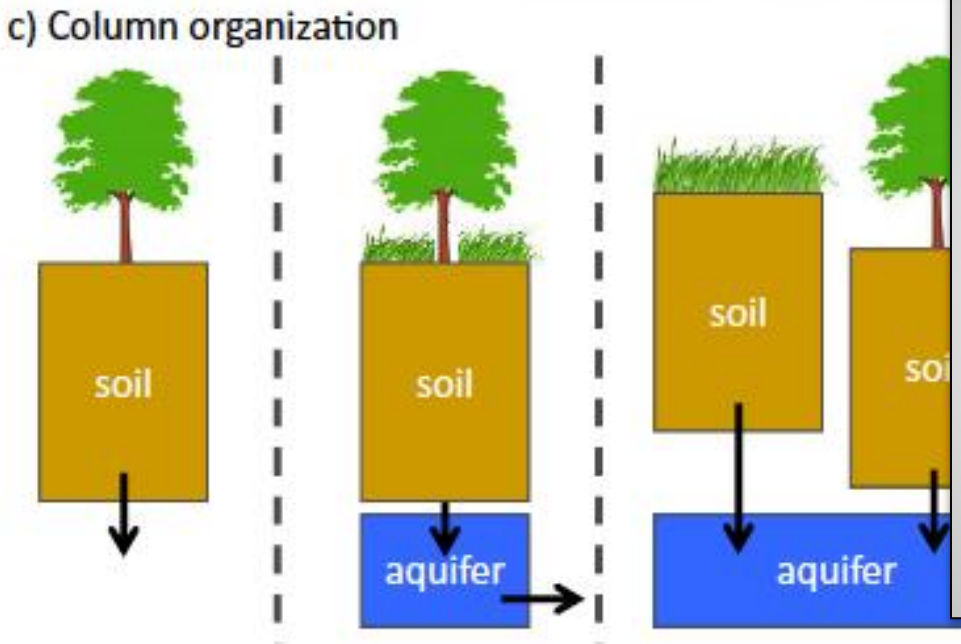




Lateral fluxes of water

Water and land management

# Spatial flexibility

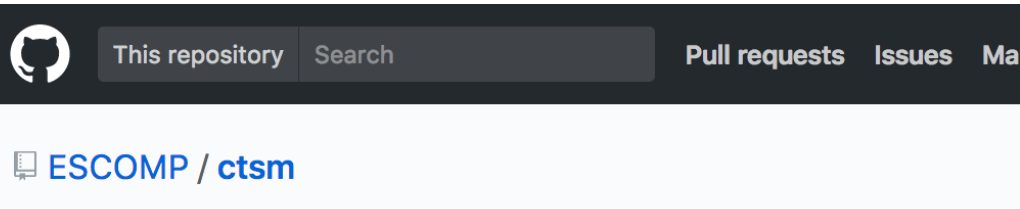



Need to be able to easily define range of spatial structures

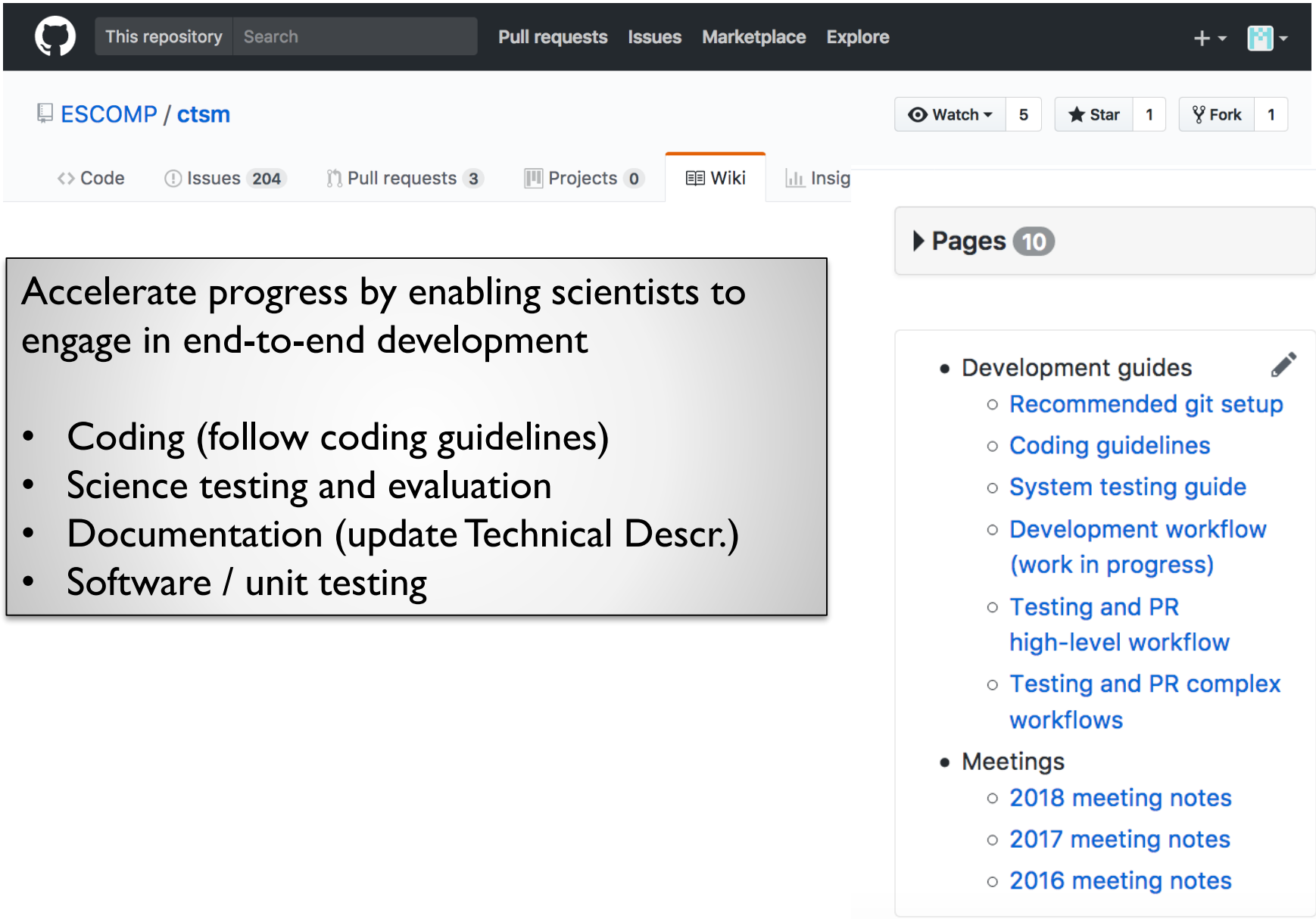
1. CLM – lower resolution, high representation of spatial heterogeneity within grid cell, slow
2. Noah-MP – higher resolution, less spatial heterogeneity within grid cell, faster
3. New research-driven spatial structures, e.g., hydrologic response units or representative hillslopes

# Collaborative software development




- CTSM public git repository in place
  - Branched off of CLM development code
  - Initial development focusing on modularization, parameterizations and numerical solution for hydrology
  - Merging of Noah-MP parameterization options that are not already included in CLM
  - Preliminary assessments of model efficiency (e.g., CLM vs Noah-MP)
- CLM transitioning(ed) to public git repository
  - After CLM5 release branch created, merge CTSM-dev/CLM5 and CLM will cease to exist as separate code base

# Collaborative software development

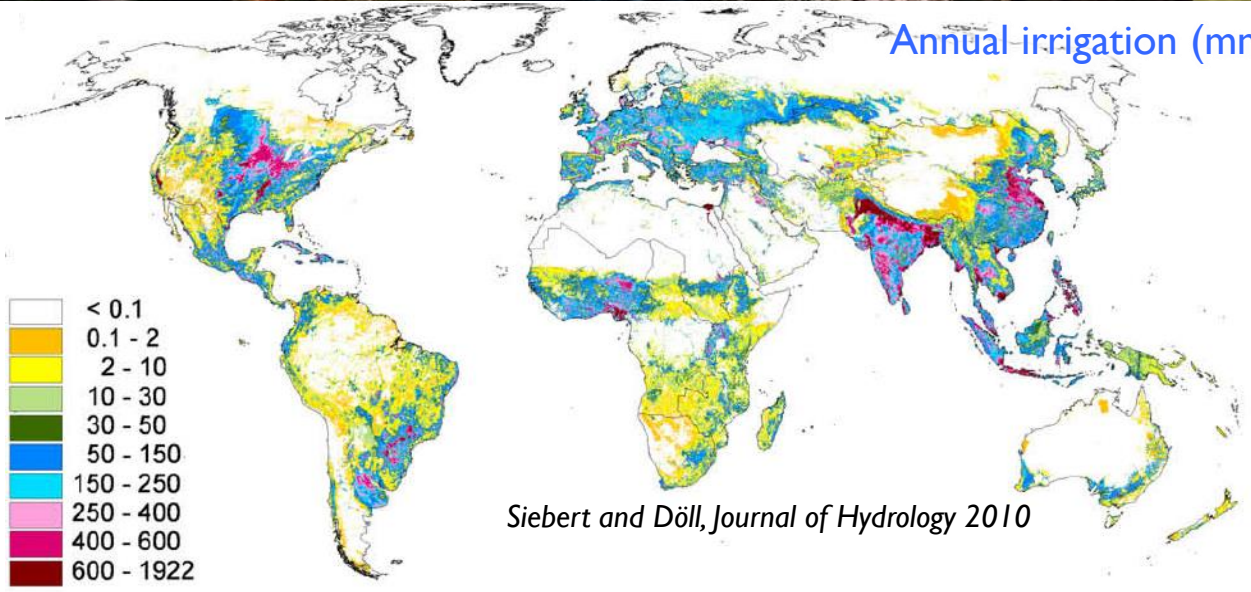



Accelerate progress by enabling scientists to engage in end-to-end development

- Coding (follow coding guidelines)
- Science testing and evaluation
- Documentation (update Technical Descr.)
- Software / unit testing

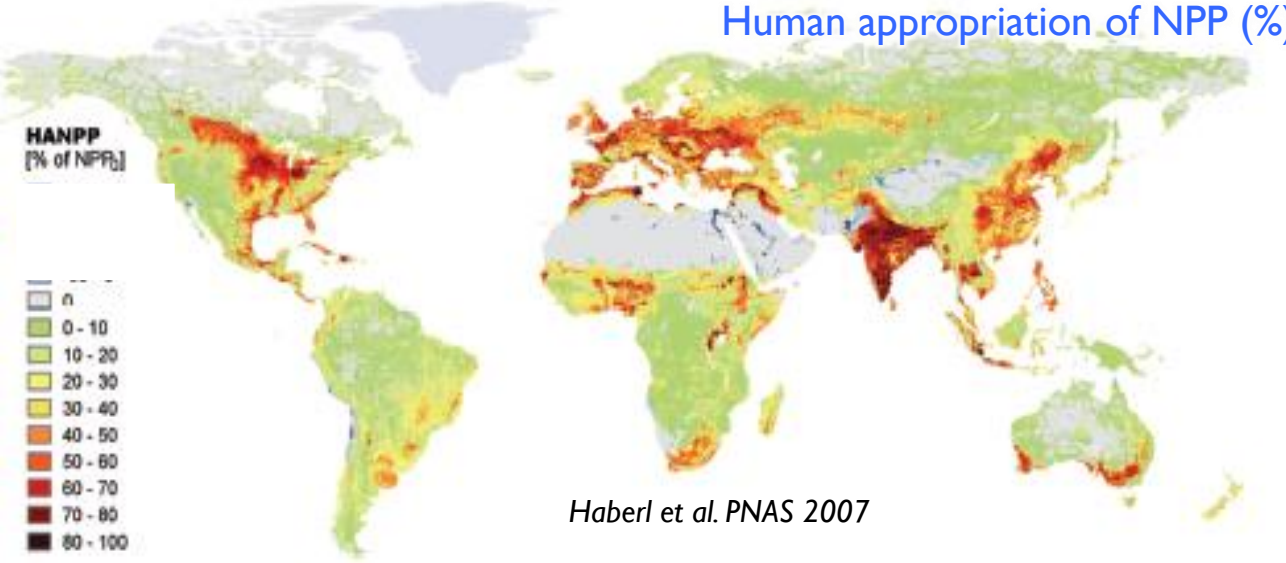
# CTSM development: Human modification of water and biogeochemical cycles

Annual irrigation (mm)




*Siebert and Döll, Journal of Hydrology 2010*

Human appropriation of NPP (%)




*Haberl et al. PNAS 2007*

Climate/carbon/water impacts due to land management can be as large as due to land-cover change

~25% non-ice land area undergone anthropogenic land-cover change

~80% non-ice land area under some form of land management

NCAR Reinvestment proposal on water management and agriculture in CTSM

# Outline

- The interdisciplinary evolution of land models
- CTSM Motivation
  - Land modeling challenges
  - Ad-hoc approaches to model development
- CTSM development
  - Underpinnings and structure
  - Development process
- Summary and challenges