Light-weight Infrastructure for Land Atmosphere Coupling (LILAC)

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Photo: Steven Gnam

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NCAR

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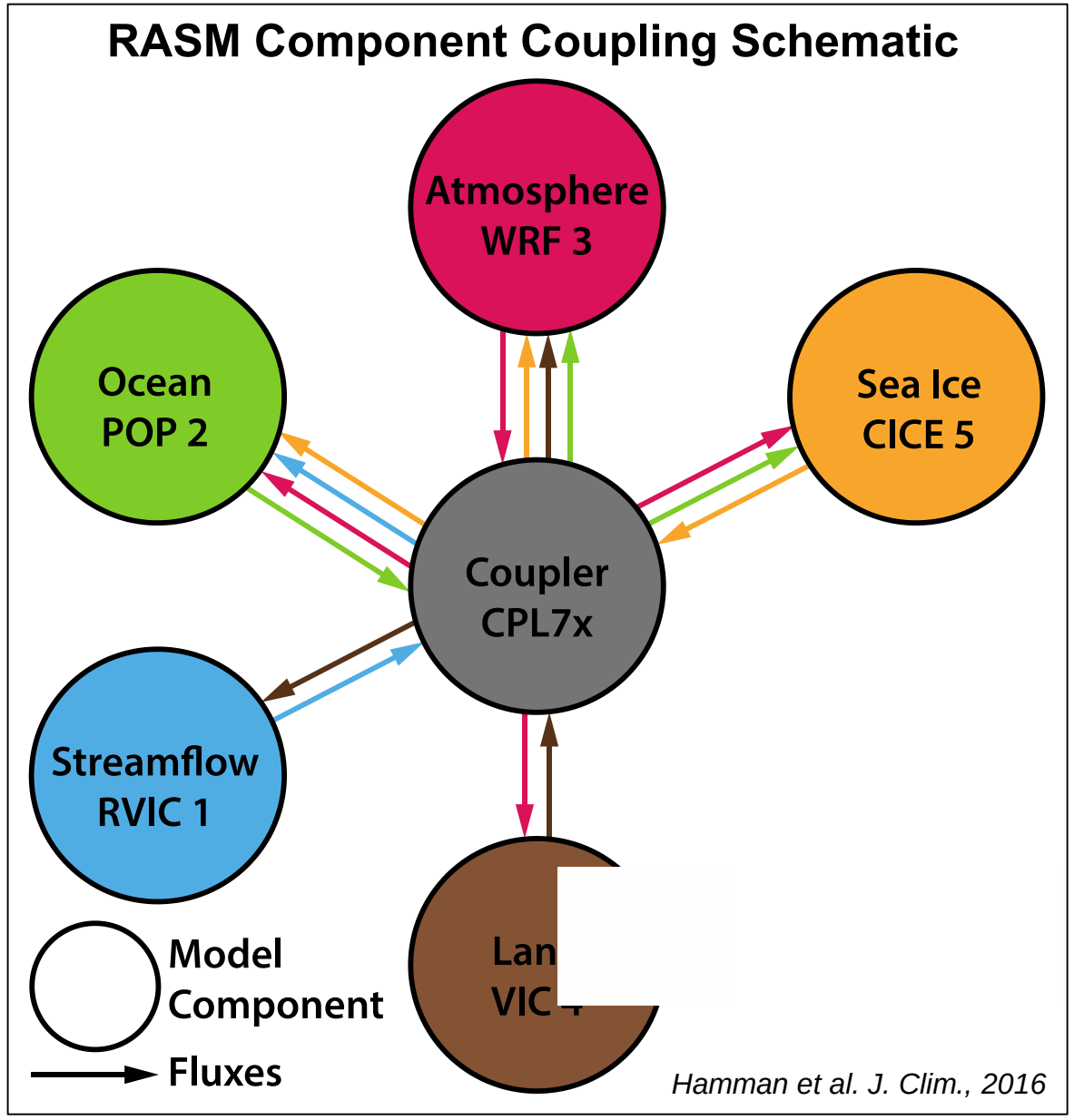
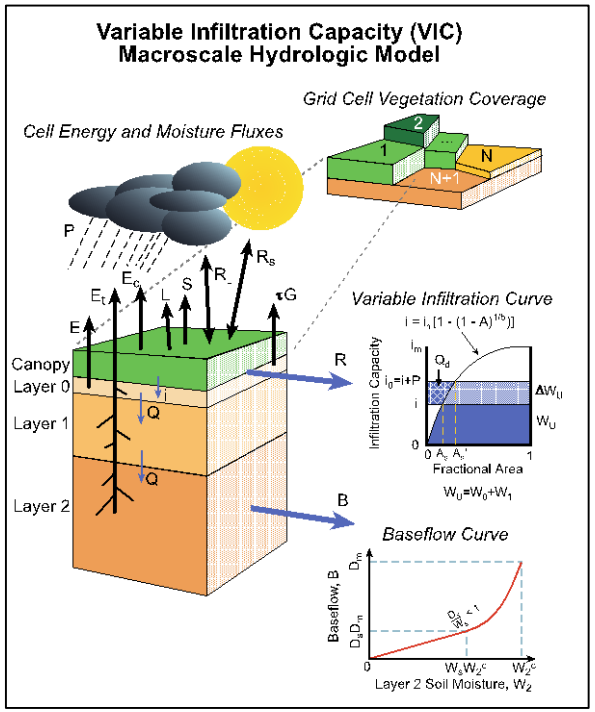
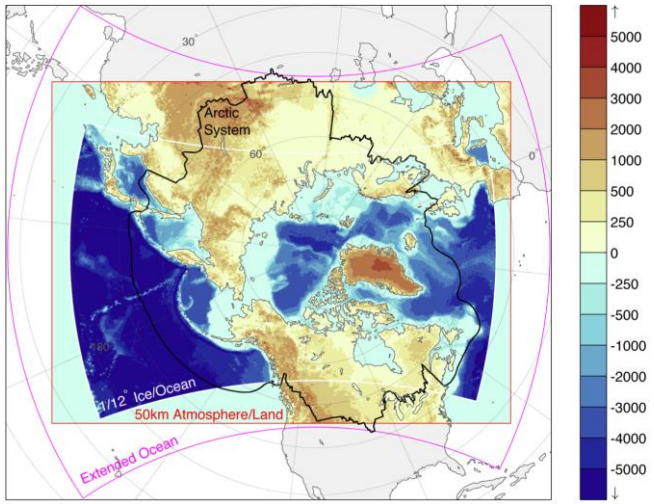
Background: Regional Arctic System Model





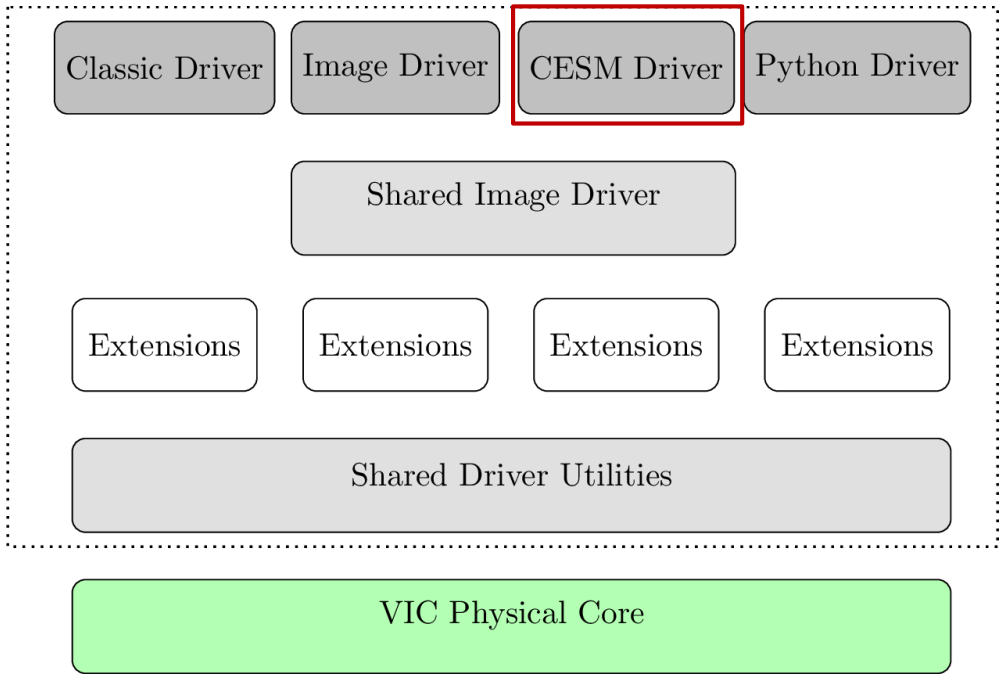


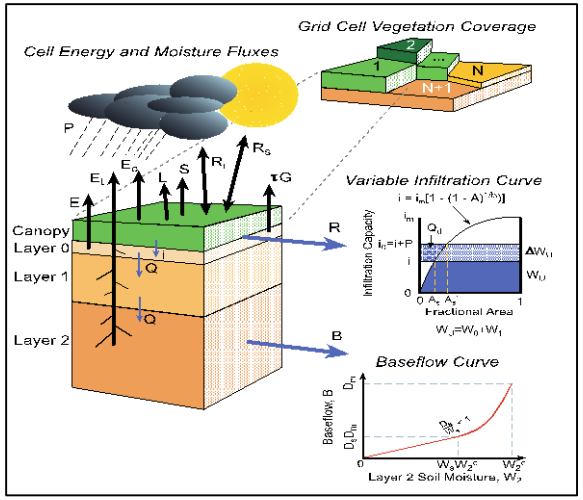
- Regional configuration of CESM 1
  - CPL7/POP/CICE
  - WRF/VIC/RVIC
- Required custom coupling interfaces for 3 of 5 model components
  - These interfaces needed to be rewritten when model versions
- Highlights the need for simple/portable interfaces

Lessons from VIC Version 5

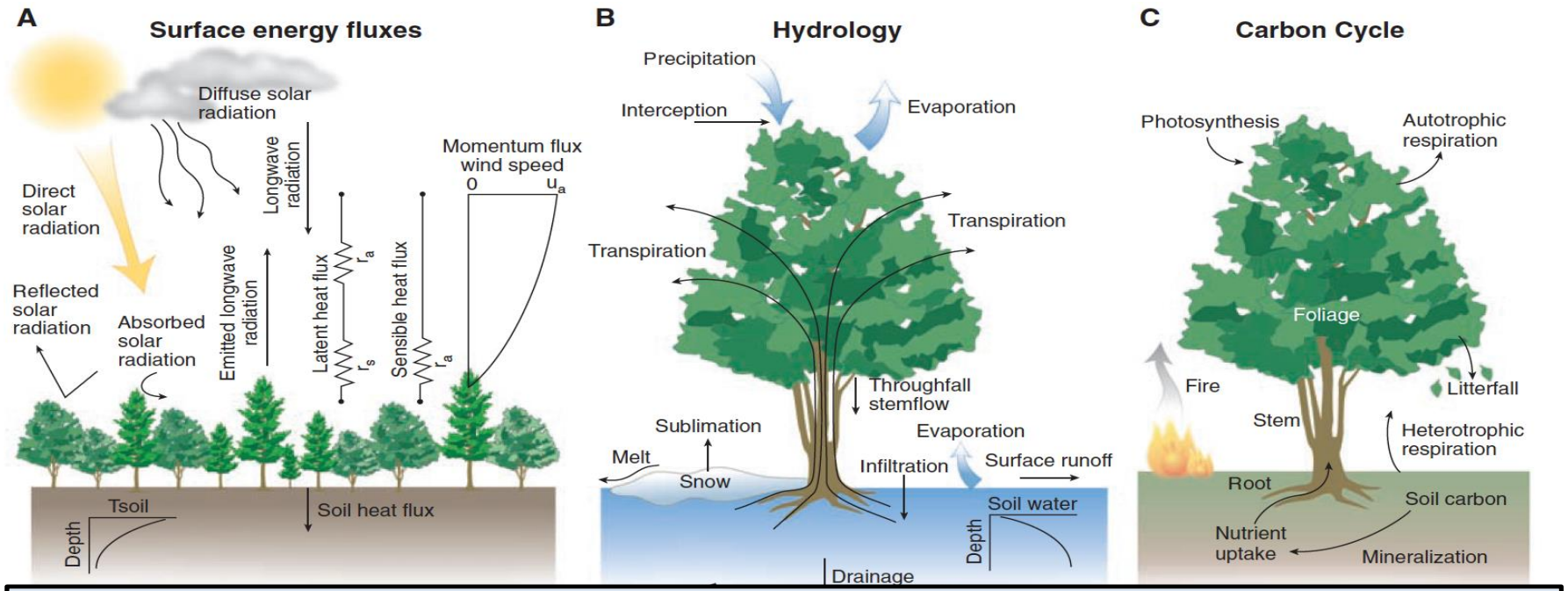
- Why was VIC successful?
  - Open-source
  - Portable and light weight - minimal dependencies
    - C Compiler
    - VIC 5 added NetCDF and MPI
  - Flexible
    - Applications include forecasting, coupled modeling, water resources, and climate change
    - Configurations include single point, regional, and global
- What was new in VIC 5?
  - Clean separation of physics from drivers
  - Improvements to infrastructure to support new applications (like RASM)
  - Made coupling to CESM easy!

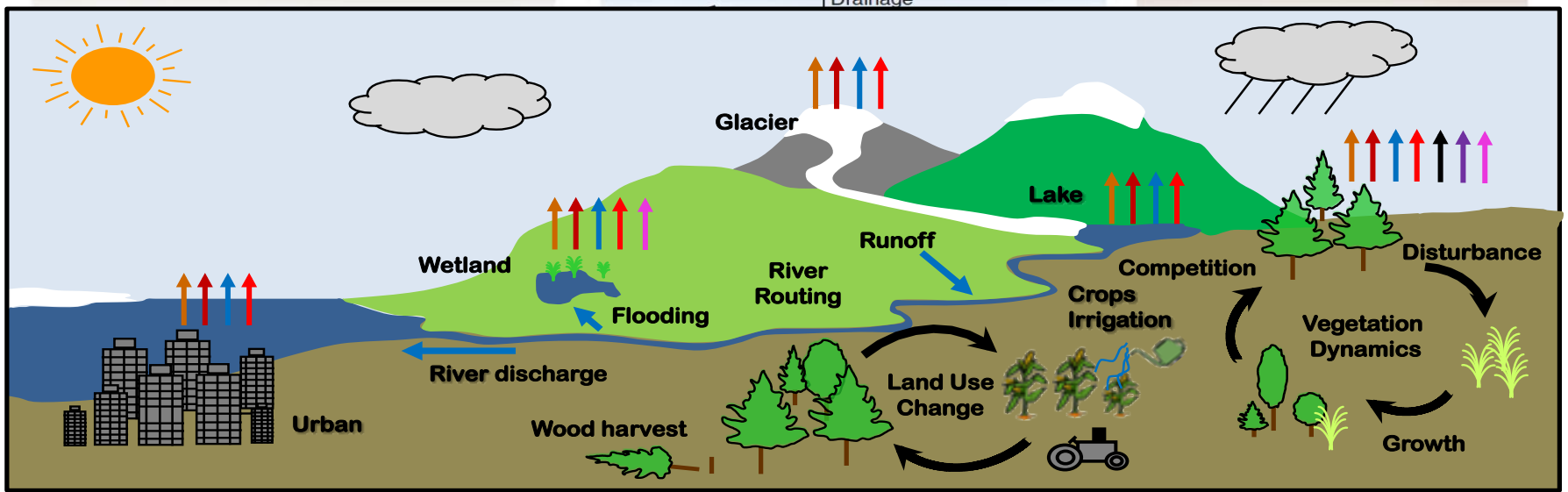
Hamman et al. GMD, 2018



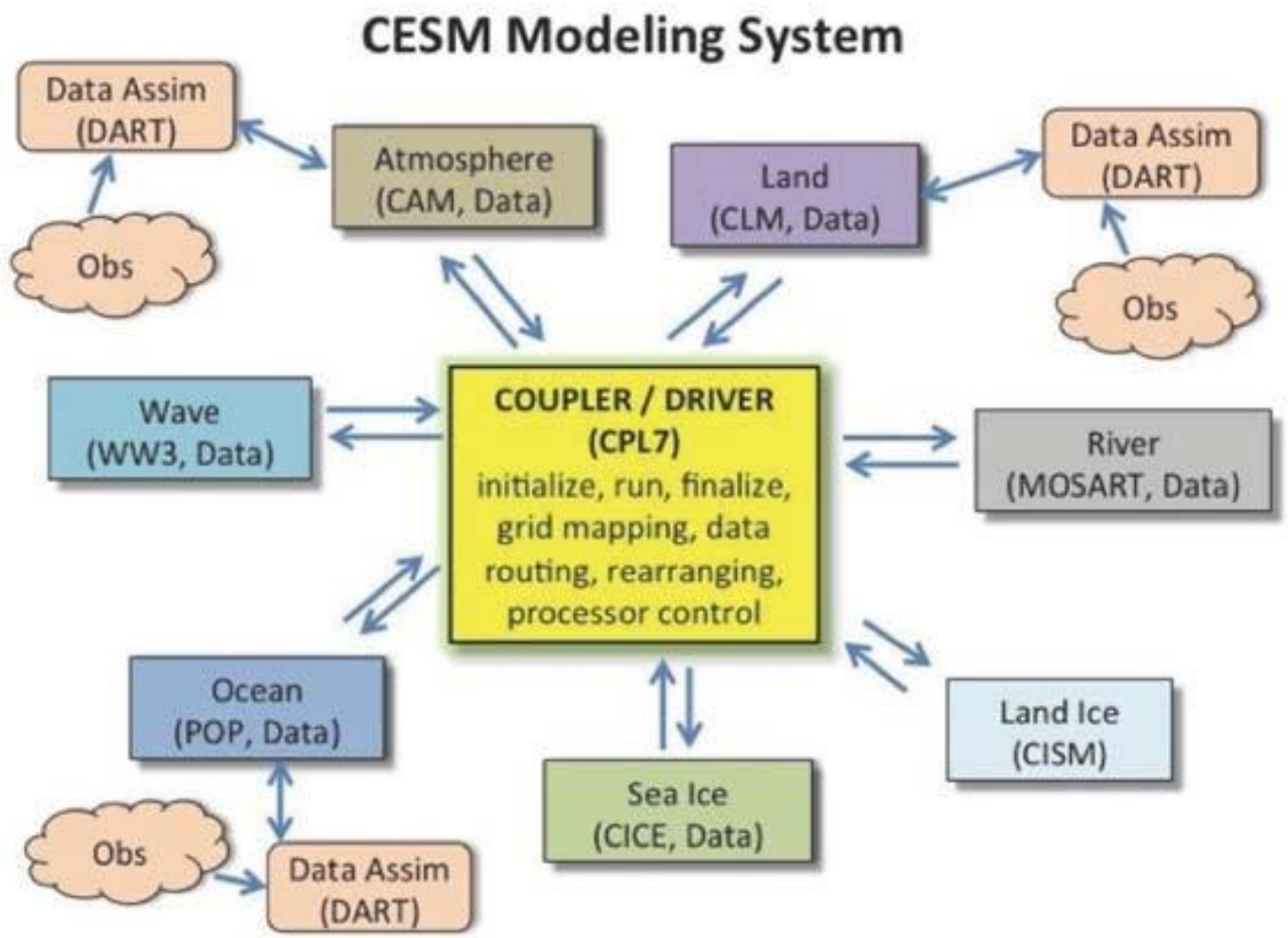


…but LILAC is for CTSM



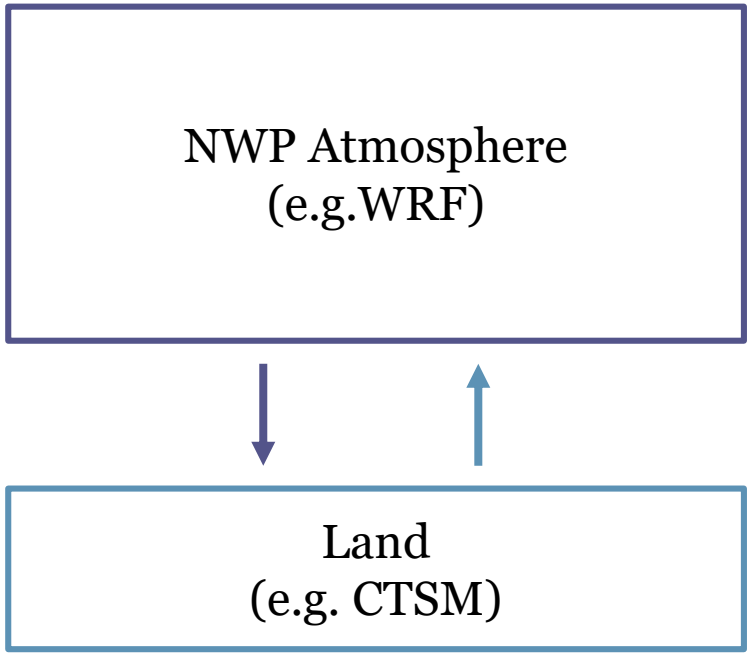


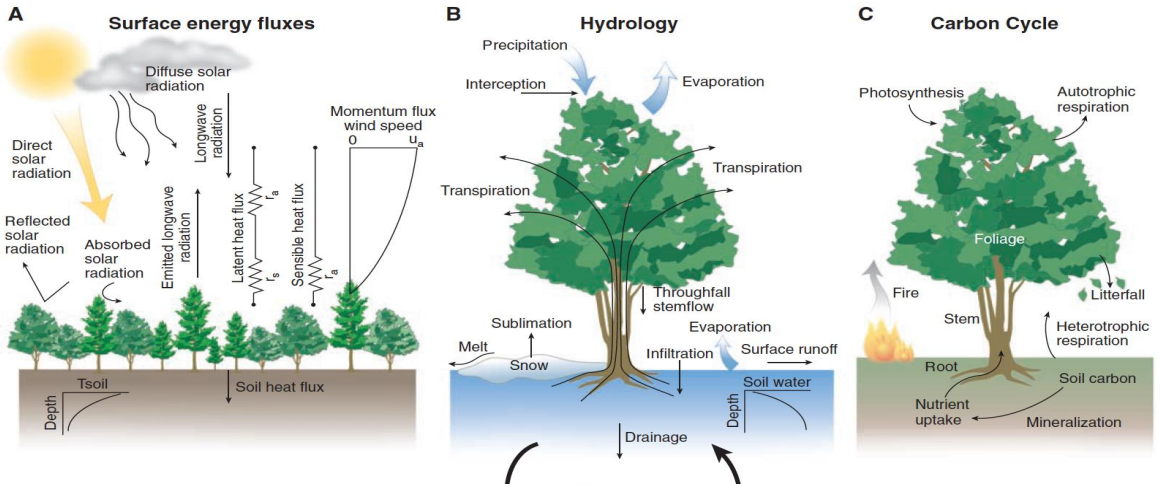
CTSM and CESM



- CTSM is typically run as part of CESM using the Model Coupling Toolkit (MCT)
- All fluxes are routed through CPL7
- CESM/CPL7 is the driver
- Lots of supporting infrastructure
- Fairly strict requirements:
  - Global model domain
  - Time stepping scheme
  - CIME dependency

CTSM in the NWP Context





1. NWP models (e.g. WRF) are the simulation driver

2. The land model is a subroutine call within the atmosphere run sequence.

3. Models like WRF come with their own build/test/run infrastructure

Motivating Challenges

- Community model with applications beyond CESM
  - Regional climate modeling
  - NWP and forecasting
  - Stand-alone model simulations
  - Integration in multi-model systems (e.g. NLDAS)
- CTSM is typically run as part of CESM via CPL7
  - CPL7 is the simulation driver
  - MCT or NUOPC frameworks
- CESM is a heavy dependency
  - CESM/CIME is a very complex dependency
  - Porting is a persistent challenge
- Existing CLM-NWP couplings are growing stale

LILAC Project Goals

Support the flexible coupling of CTSM to arbitrary Target Atmosphere Models (TAM)

- Provide coupling interface for multiple TAMs
- Separate CTSM from CESM/CIME dependency
- Make it easy to implement in new coupling configurations
- Make it easy to port to new computing environments

LILAC Target Atmosphere Models

WRF

- Weather Research Forecast model

SAM

- CSU's System for Atmospheric Modeling

COSMO

- ETH-Zurich's coupled biosphere-atmosphere Regional Climate Model

RegCM

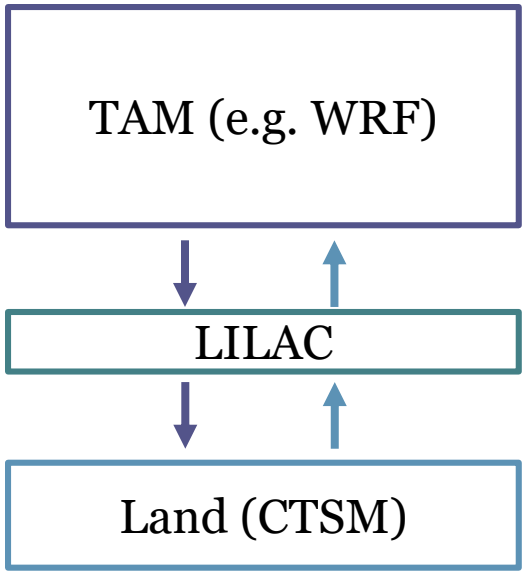
- Regional climate model originally developed at ICTP

CESM DATM

- Data atmosphere for testing and verification

How LILAC will work

- Each TAM will replace its current land surface scheme with calls to LILAC
- The basic interface includes 3 subroutine calls and some core data structures.
- Uses ESMF extensively for communication, regridding, parallelization



- Each TAM will implement an interface including:
  - Initialization

```
call lilac_init(grid, clock, …)
```

  - Run a single timestep

```
call lilac_run(a2l_vars, l2a_vars, clock, …)
```

  - Finalize

```
call lilac_final(…)
```

LILAC Project Status

Development started in summer 2018

ESMF is being used as a central building block

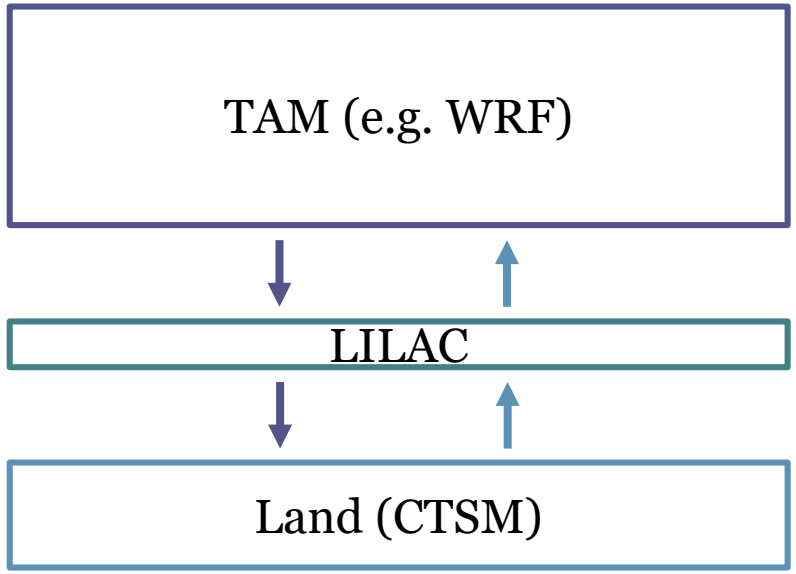
- Regridding
- Data structures
- Model coupling

Build and test infrastructure is in place

- Continuous integration running on TravisCI
- Docker containers for portable testing

Current efforts

- ESMF Cap for CTSM
- Developing test cases for coupling CTSM to data atmosphere



Quick Facts

- LILAC GitHub Repo:
  - https://github.com/NCAR/lilac
- LILAC Documentation
  - https://ctsm-lilac.readthedocs.io
- Dependencies:
  - Fortran
  - ESMF
  - CTSM (with CESM share code)

Thanks!

- Contact Info
  - Joe Hamman: jhamman@ucar.edu, joehamman.com
  - NCAR Computational Hydrology: https://rap.ucar.edu/hap/computational-hydrology
- LILAC
  - https://github.com/NCAR/lilac
  - https://ctsm-lilac.readthedocs.io

Photo: Steven Gnam

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The evolution of land models

Land as a lower boundary to the atmosphere

Focus on land-atmosphere energy fluxes

Limited representation of land processes & feedbacks

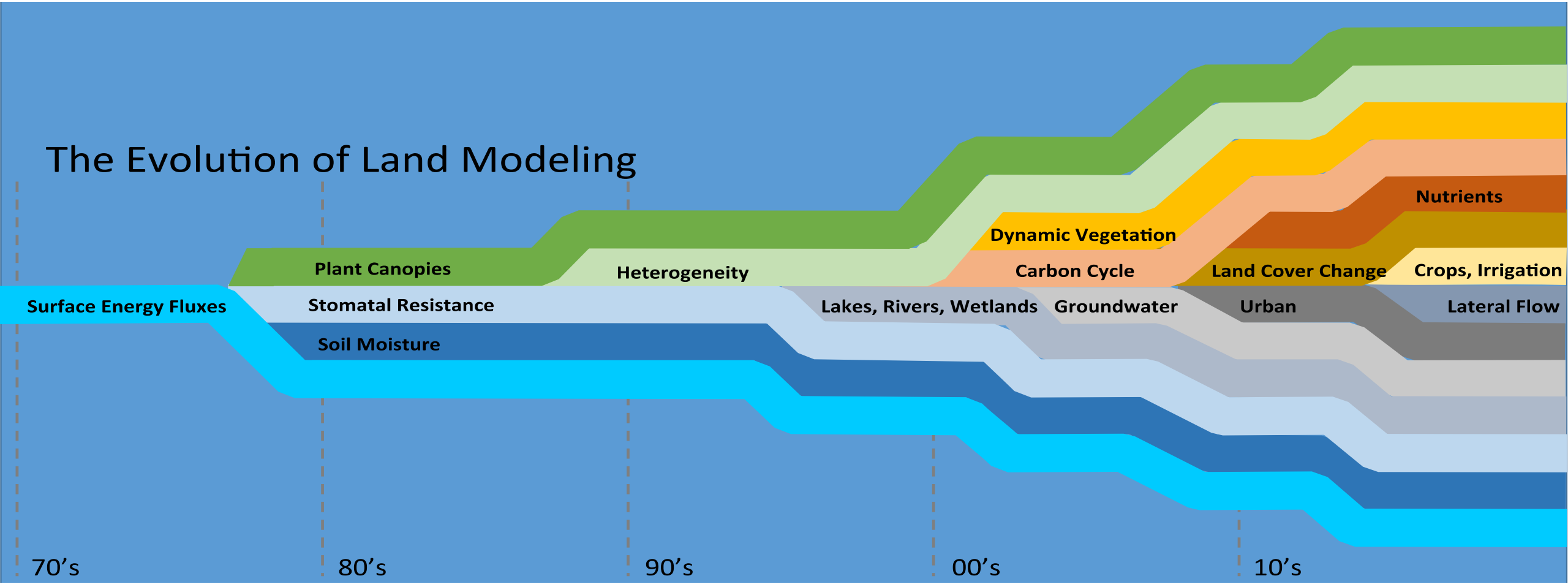
Mechanistic modeling of land processes

Properties define processes (focus on short-term fluxes)

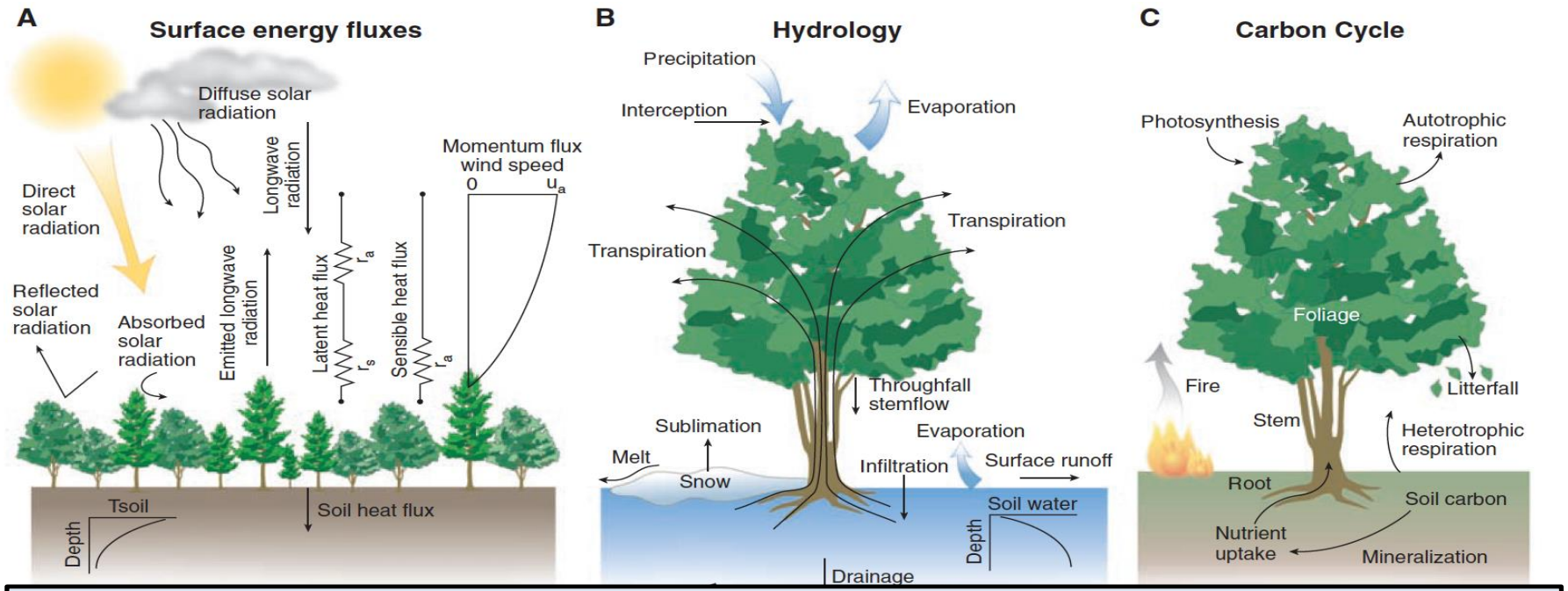
Land as an integral component of the Earth System

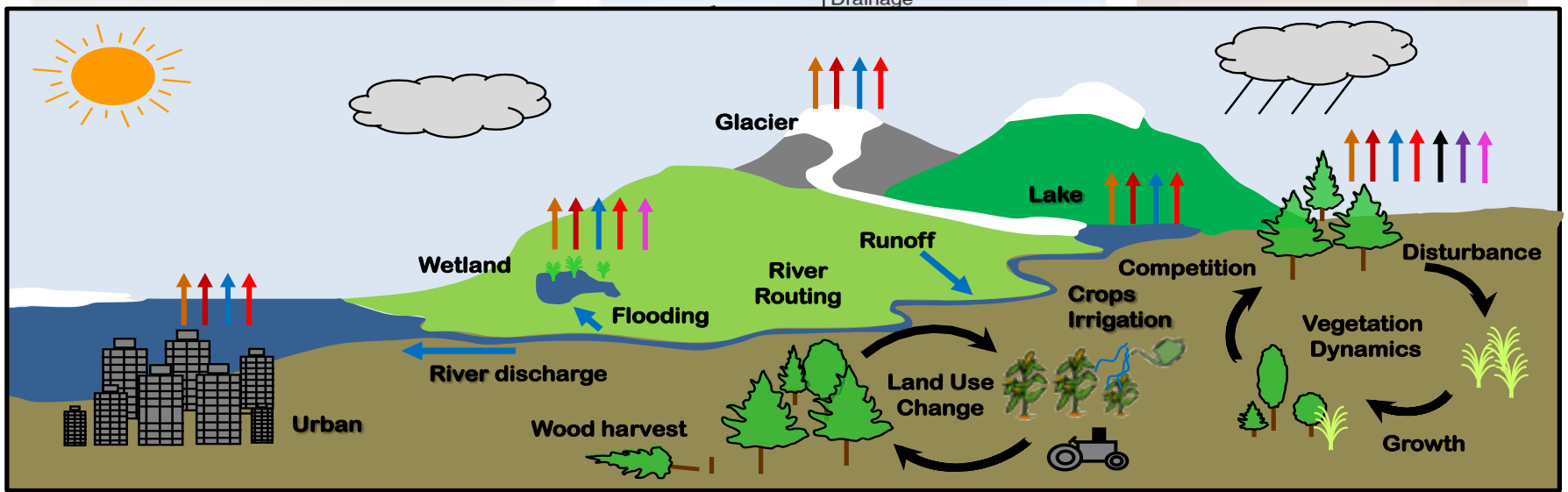
Simulate the dynamics of change (e.g., dynamic vegetation)

Processes define properties (feedbacks and interactions across time scales)



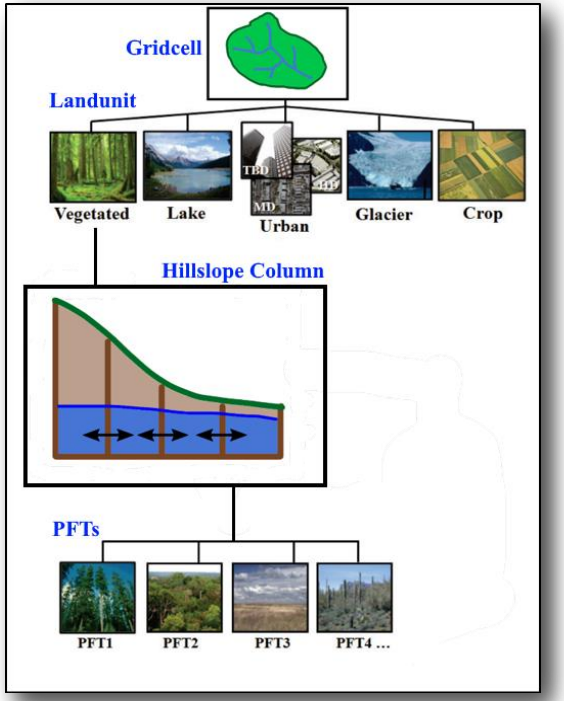
CTSM


A
Surface energy fluxes
Diffuse solar radiation
Direct solar radiation
Longwave radiation
Momentum flux
wind speed
0
u_a
Reflected solar radiation
Absorbed solar radiation
Emitted longwave radiation
Latent heat flux
r_a
r_s
Sensible heat flux
r_a
Tsoil
Depth
Soil heat flux
B
Hydrology
Precipitation
Interception
Evaporation
Transpiration
Transpiration
Throughfall
stemflow
Sublimation
Melt
Snow
Evaporation
Infiltration
Surface runoff
Soil water
Depth
Drainage
C
Carbon Cycle
Photosynthesis
Autotrophic respiration
Foliage
Fire
Litterfall
Stem
Heterotrophic respiration
Root
Soil carbon
Nutrient uptake
Mineralization


Glacier
Lake
Wetland
Runoff
River Routing
Flooding
Competition
Disturbance
Crops Irrigation
Vegetation Dynamics
River discharge
Land Use Change
Urban
Wood harvest
Growth

Evolution of CTSM

- 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
- Water and food security in context of climate change, climate variability, and extreme weather



Lateral fluxes of water

Water and land management

Ecosystem Demography / Multi-layer canopy