Land surface modeling in NorESM

NorESM tutorial, 2026

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CICERO Center for International Climate Research
15th January 2026

Who are we?

Rosie Fisher:.

Co-chair, CESM Land Model Working Group.

Plant demography, plant hydraulics, fire, nutrient cycling,

Kjetil Aas:

Land lead, NorESM consortium.

Land atmosphere exchange, cryosphere, hydrology, land use.

Jessica Needham:

Senior Researcher, CICERO

Tropical forest ecology, ecosystem demography, land use change

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Content

- **Introduction and context**
- Land surface models
- Land in NorESM: the Community Land Model
  - Biogeophysics
  - Biogeochemistry
- CLM configurations
- Future plans: NorESM3-CLM-FATES. +
- Benchmarking
- Online Resources

Land phenomena are integral to how humans **experience** the climate system


food
water
snow
cities
fires
droughts
heatwaves
flooding

Land surface models are repositories for our **understanding** of how **living system**s are integral to the **climate** of the Earth

CMIP
Coupled Model Intercomparison Project

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

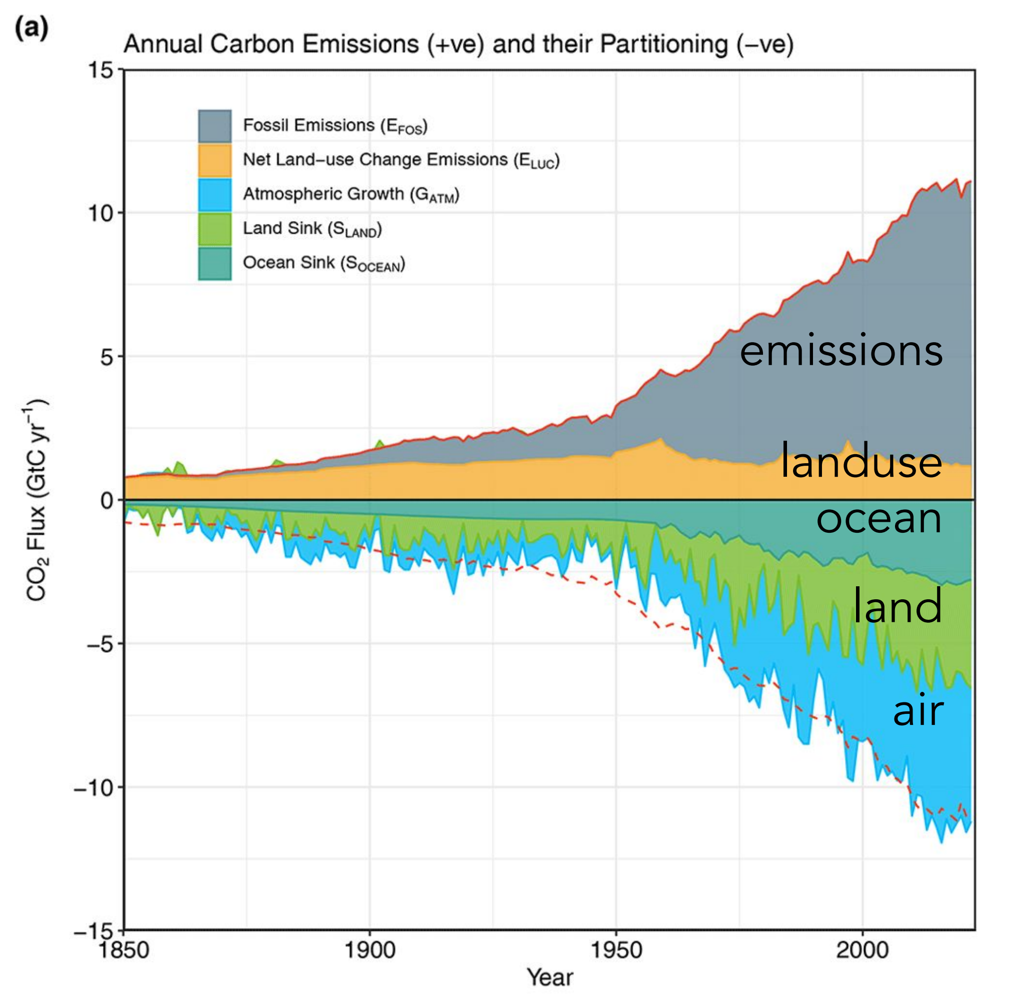
GLOBAL CARBON project

land surface models

are used operationally to provide answers to big questions

Working Group I	Working Group II	Working Group III
The Physical Science Basis	Impacts, Adaptation, and Vulnerability	Mitigation of Climate Change

CLIMATE SYSTEM: How much carbon do terrestrial ecosystems absorb?



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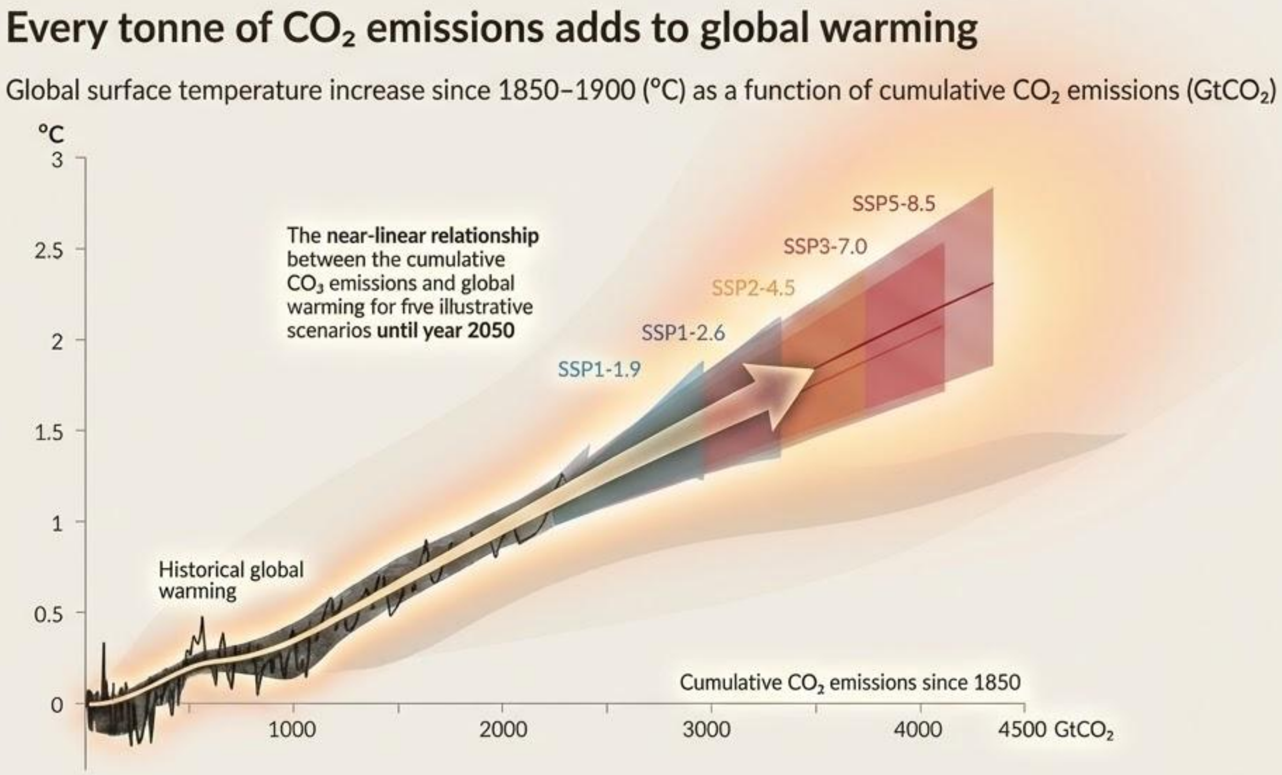
CLIMATE SYSTEM: What is the **T**ransient **C**limate **R**esponse to Cumulative CO2 **E**missions (**TCRE**)?



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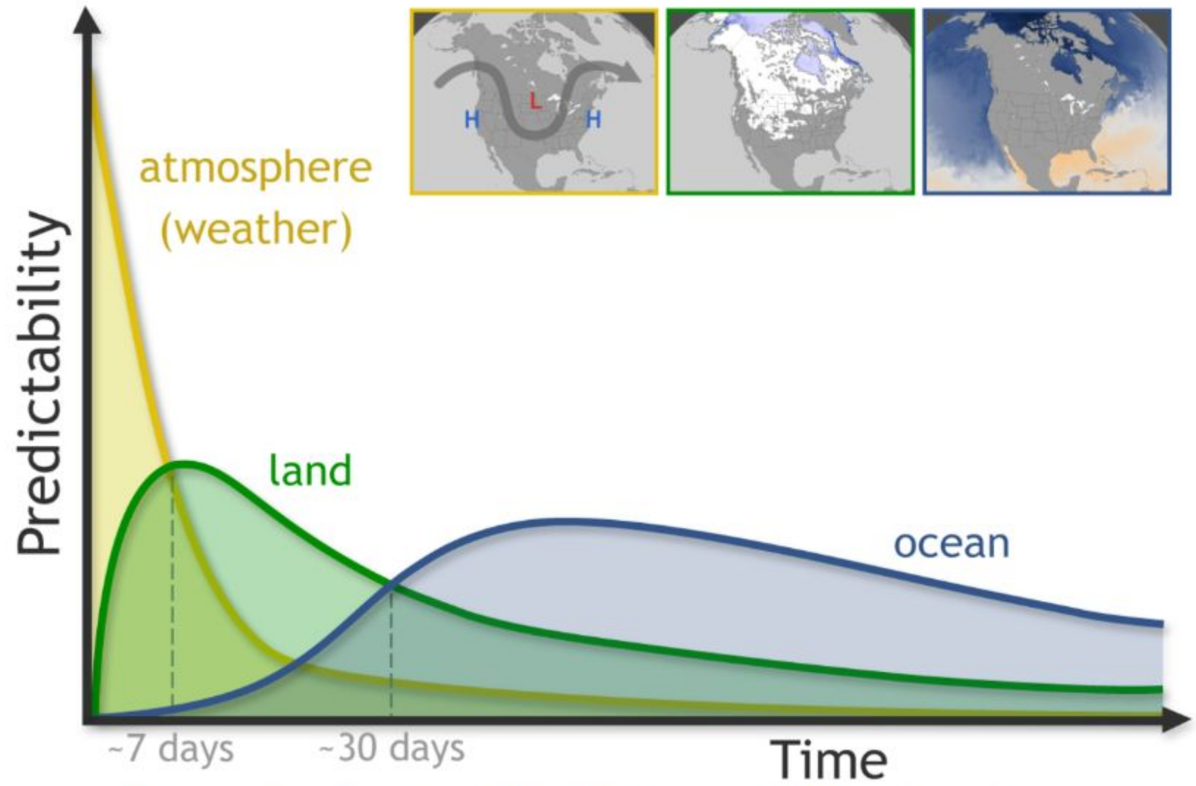
CLIMATE SYSTEM: What is the role of the land surface in the coupled Earth System?



Relative contribution to predictability as a function of forecast lead time of the initial states of the atmosphere, land and ocean in numerical model forecasts at a typical mid-latitude continental location.

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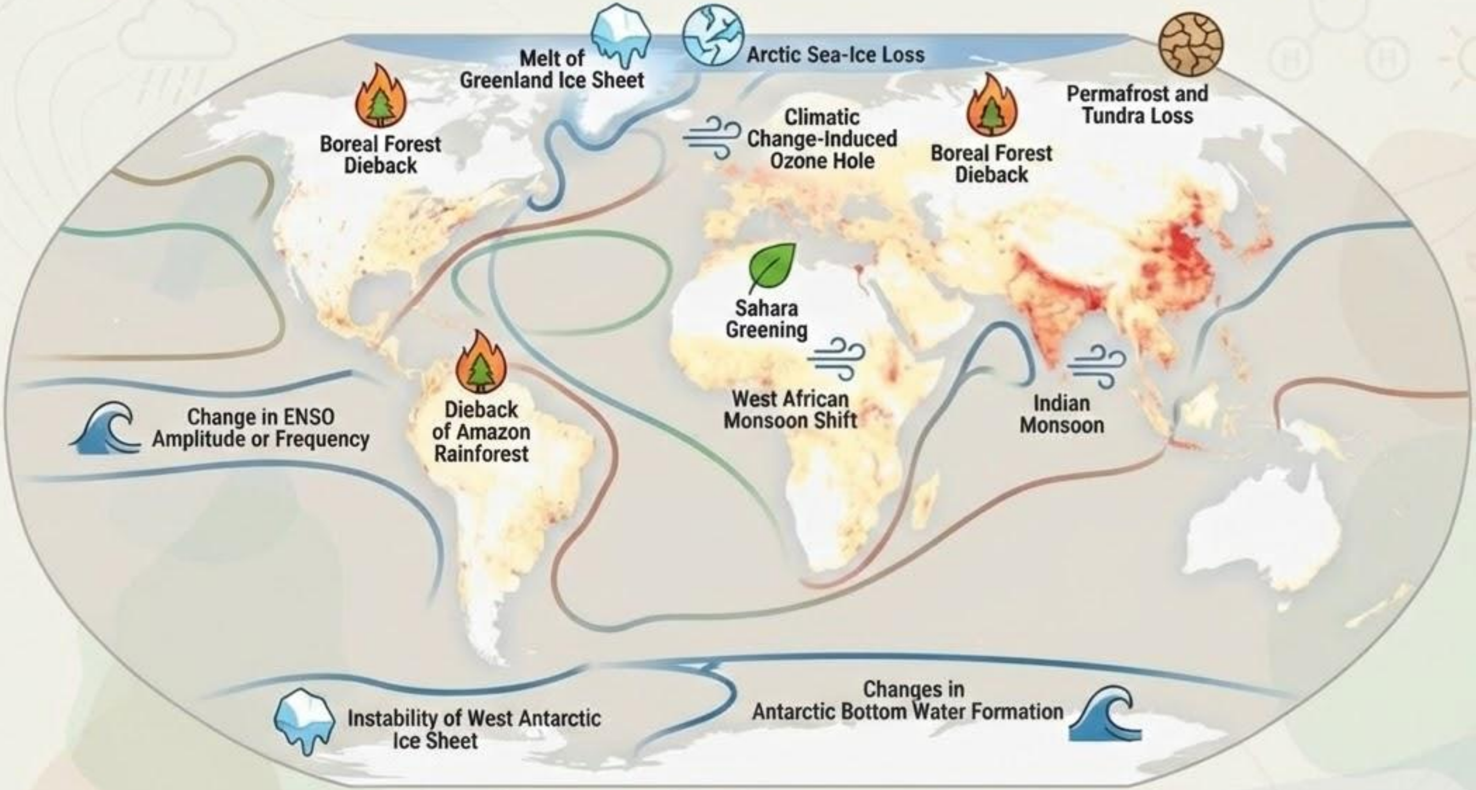
science.gmu.edu

CLIMATE SYSTEM: Are there land-mediated **'tipping points'?**



Lenton et al. 2008

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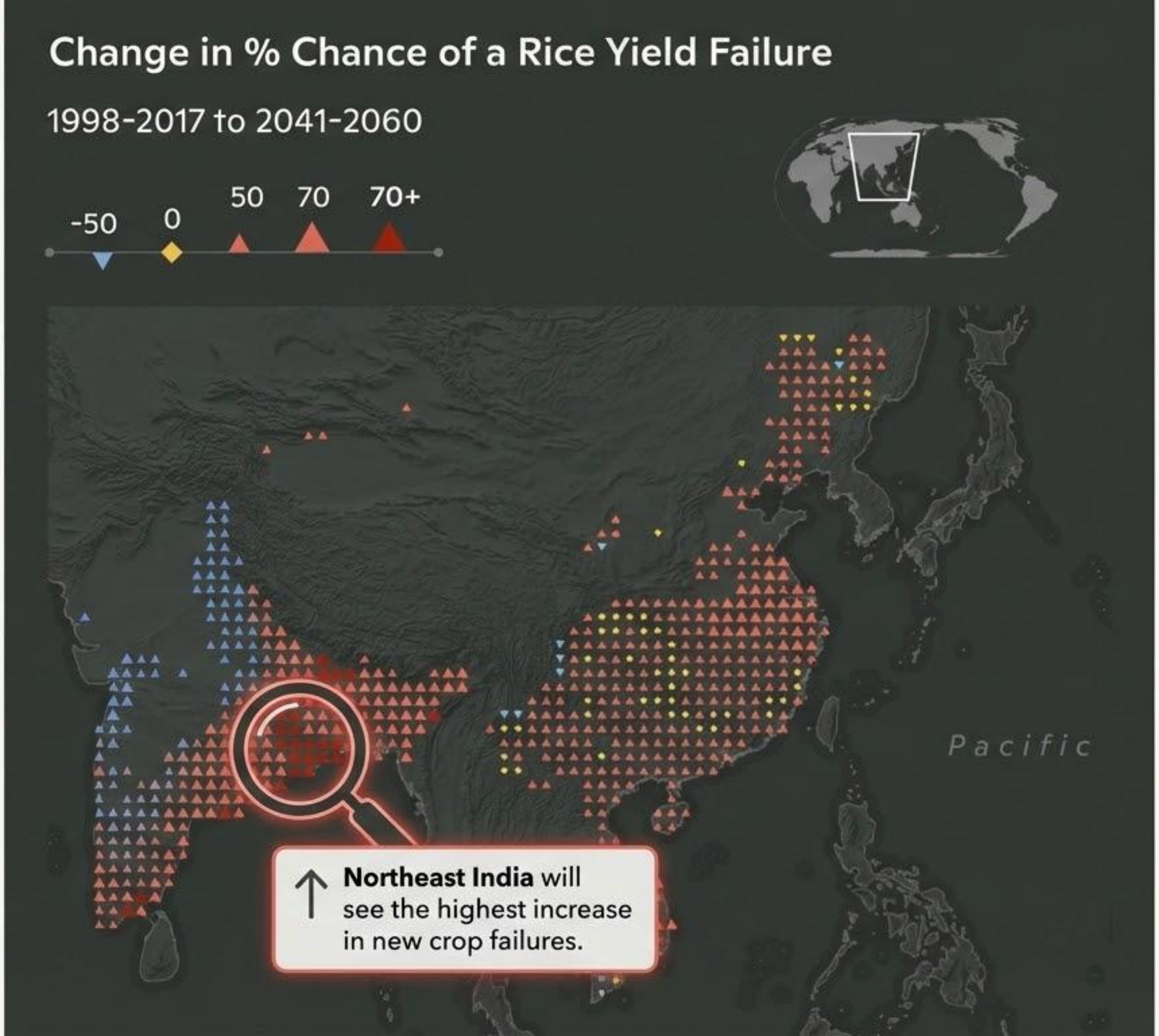
CLIMATE IMPACTS:

Will **crops** fail under future climate change?

Caparas et al. 2021



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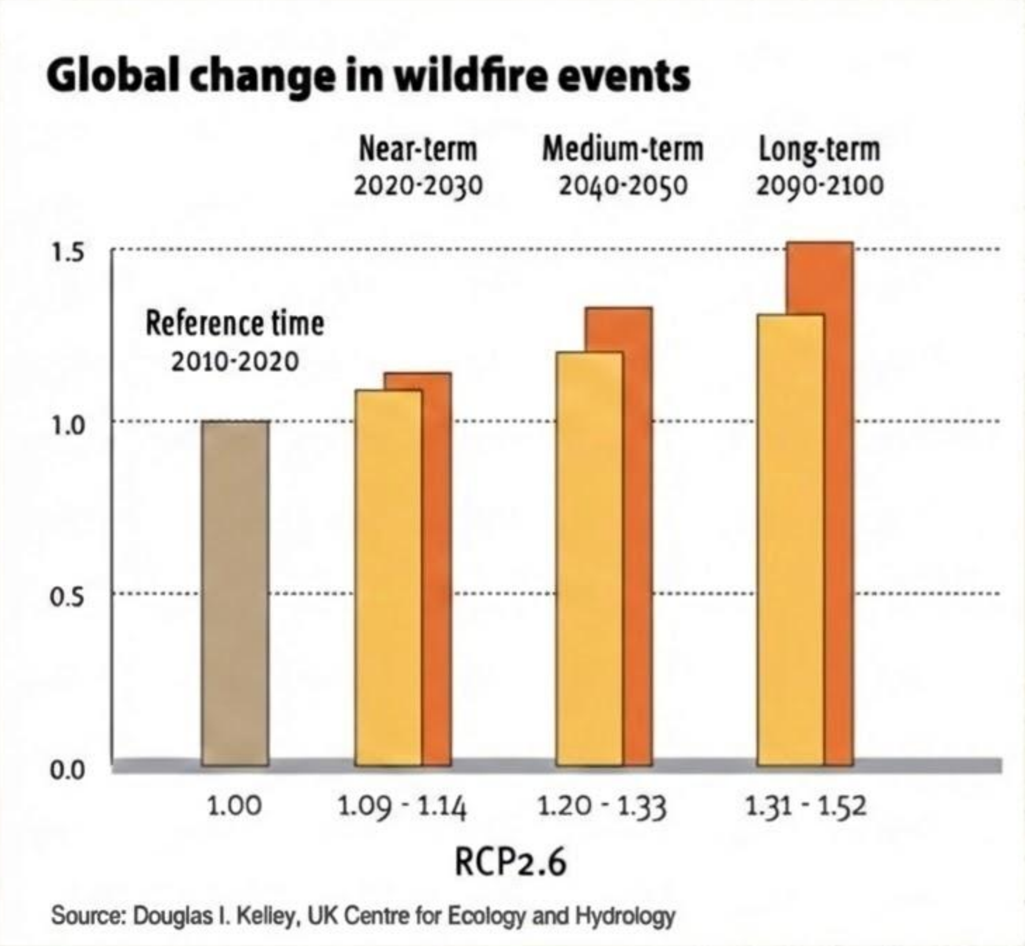
CLIMATE IMPACTS:

How will **wildfires** change?

UNEP 2022



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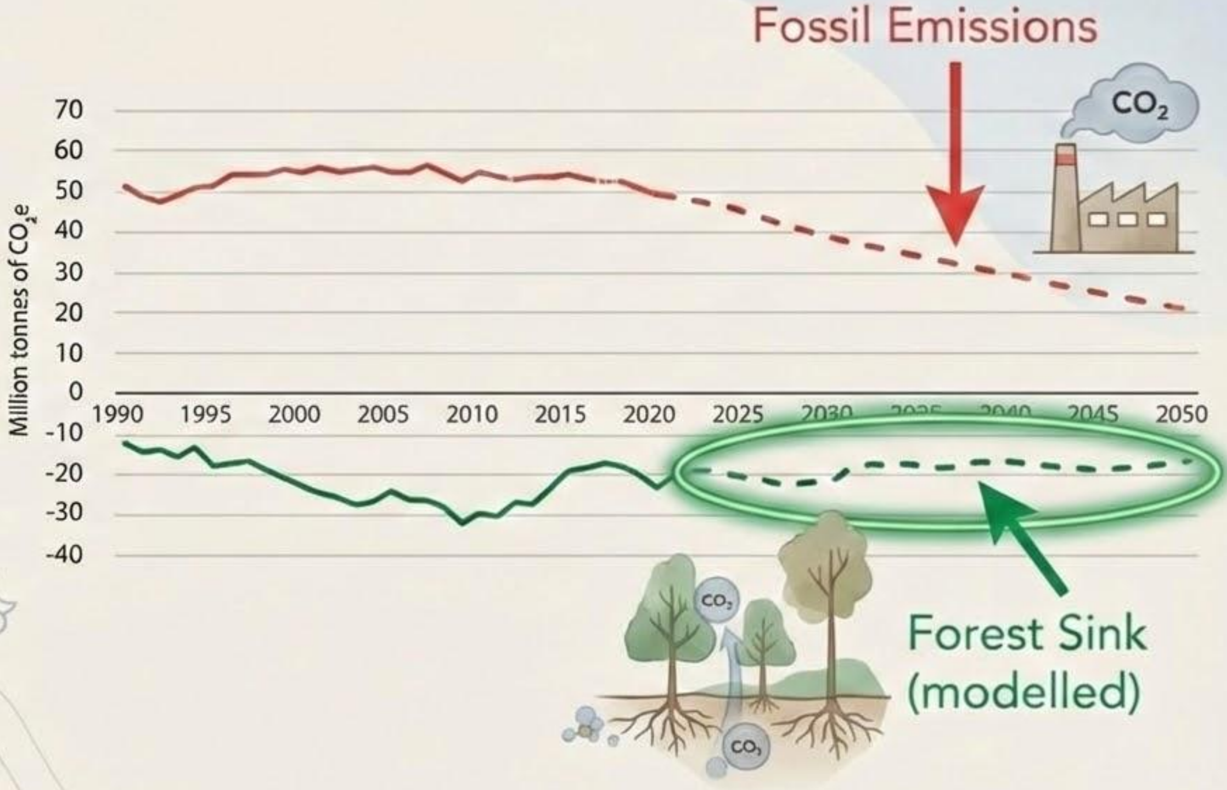
CLIMATE MITIGATION:

Can the land keep **absorbing** our CO_2 emissions?

Net Zero Emissions scenario for Norway



Source: Klimautvalget2050

NIBIO

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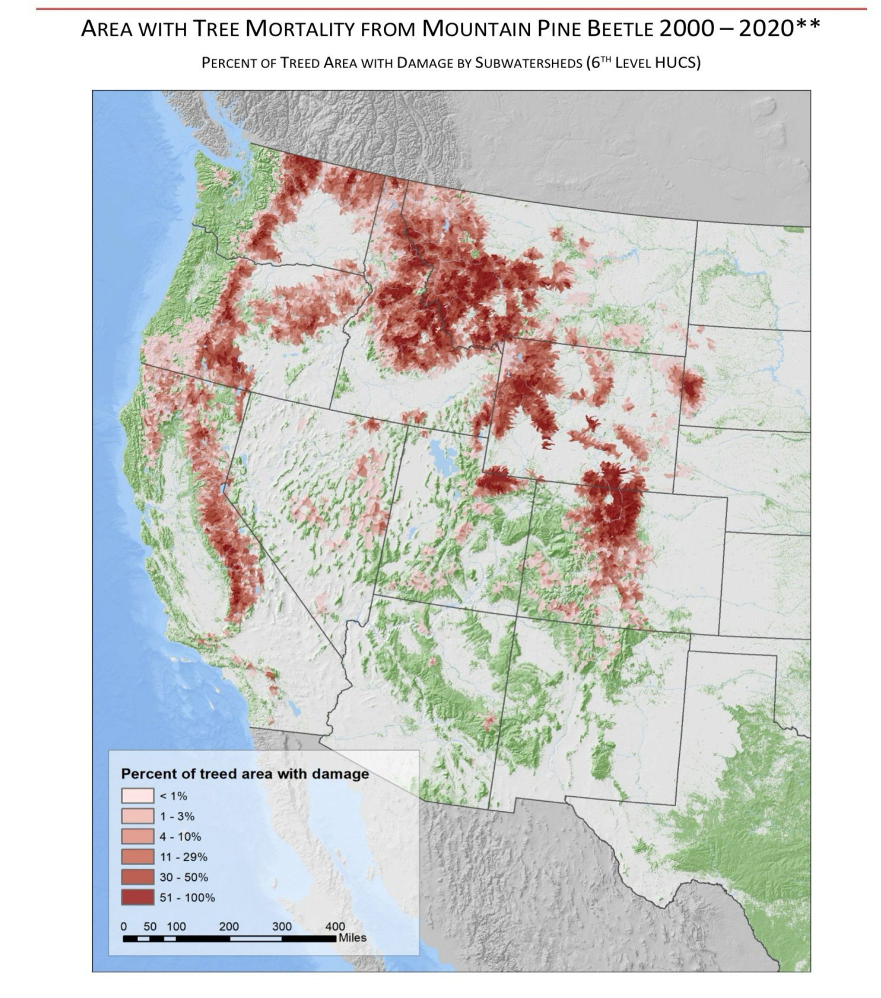
CLIMATE SYSTEM & IMPACTS & MITIGATION:

Will climate-mediated **feedbacks decrease** land **carbon storage?**



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All these phenomena are governed by the **physics** and **biology** of the terrestrial biosphere

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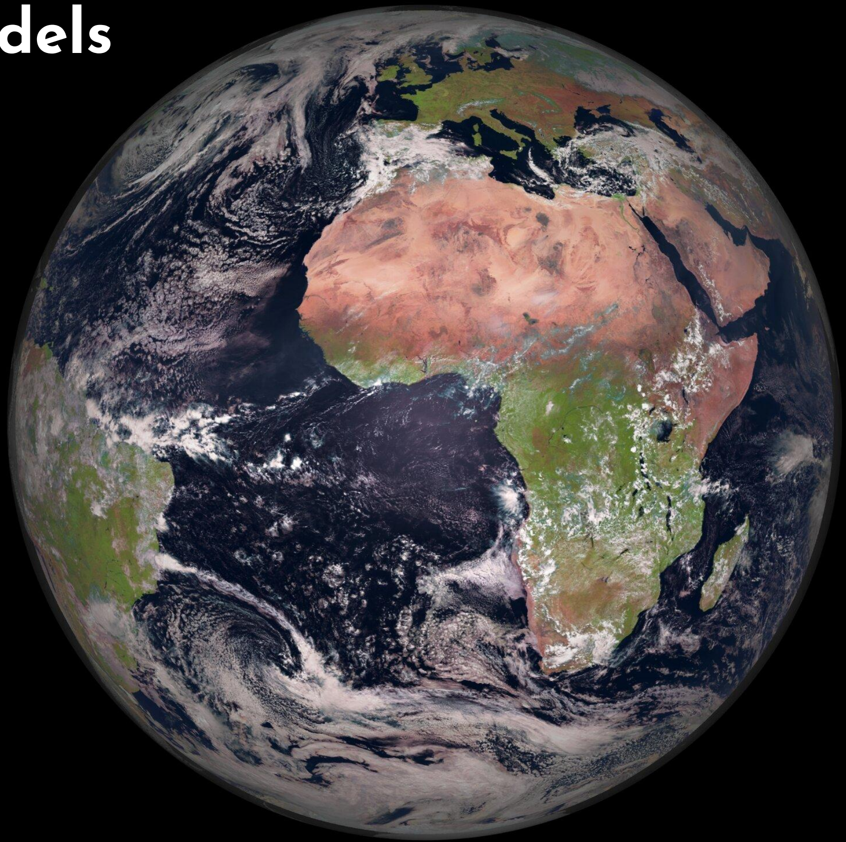
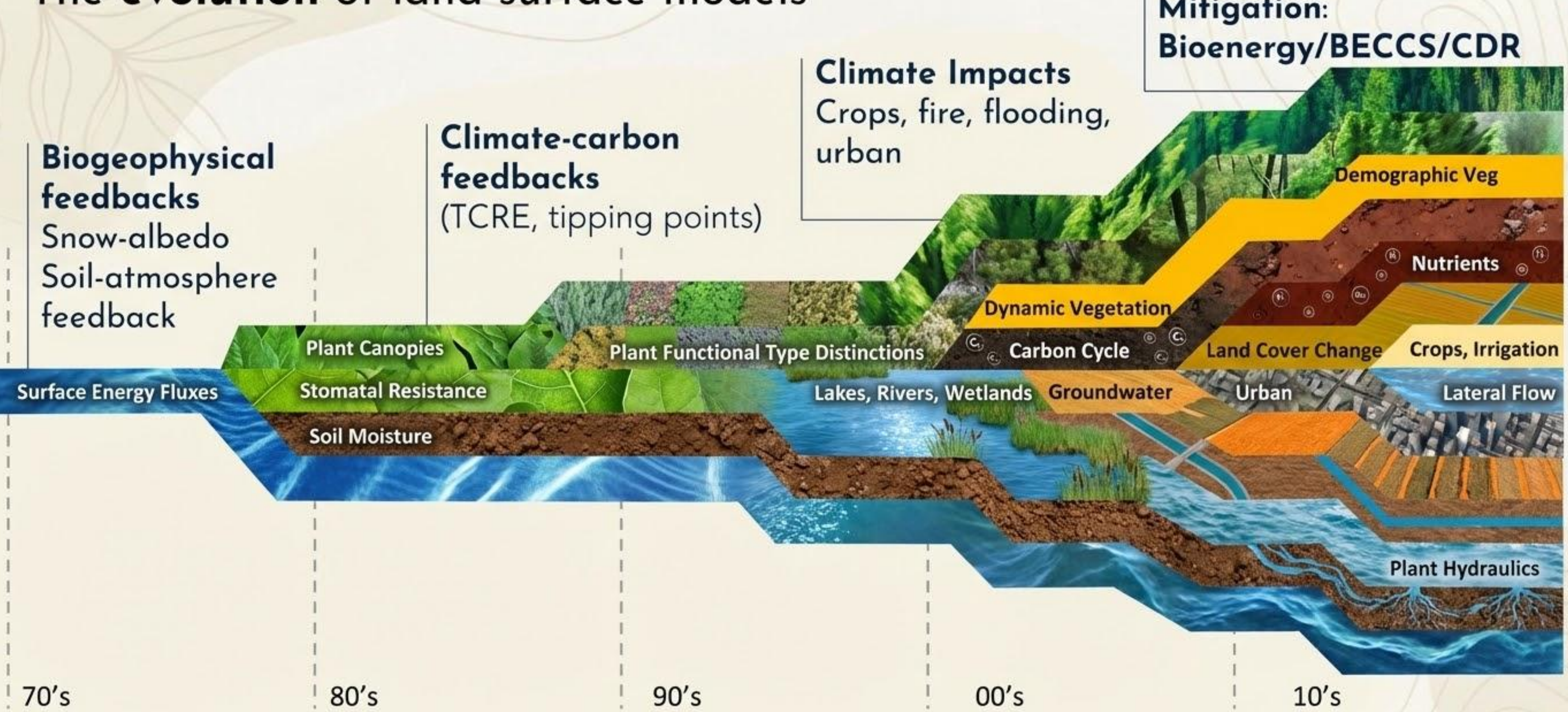
Land Surface Models

:

Mathematical representations of the **carbon**, **energy**, **water** and **nutrient** cycling of the terrestrial biosphere.



The **evolution** of land surface models



BIOGEOPHYSICS: land-atmosphere exchange

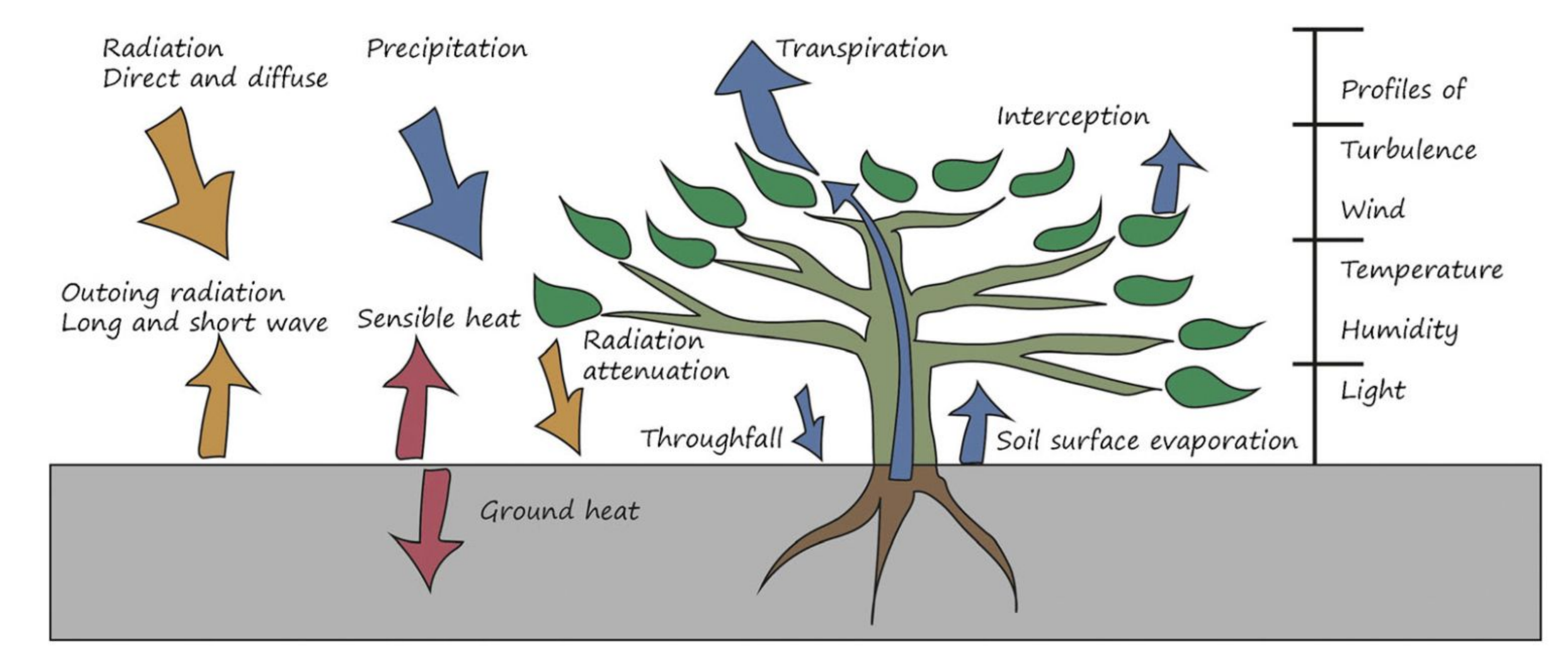


Fig from Blyth et al. 2022

BIOGEO*PHYSICS*: cryosphere, rivers

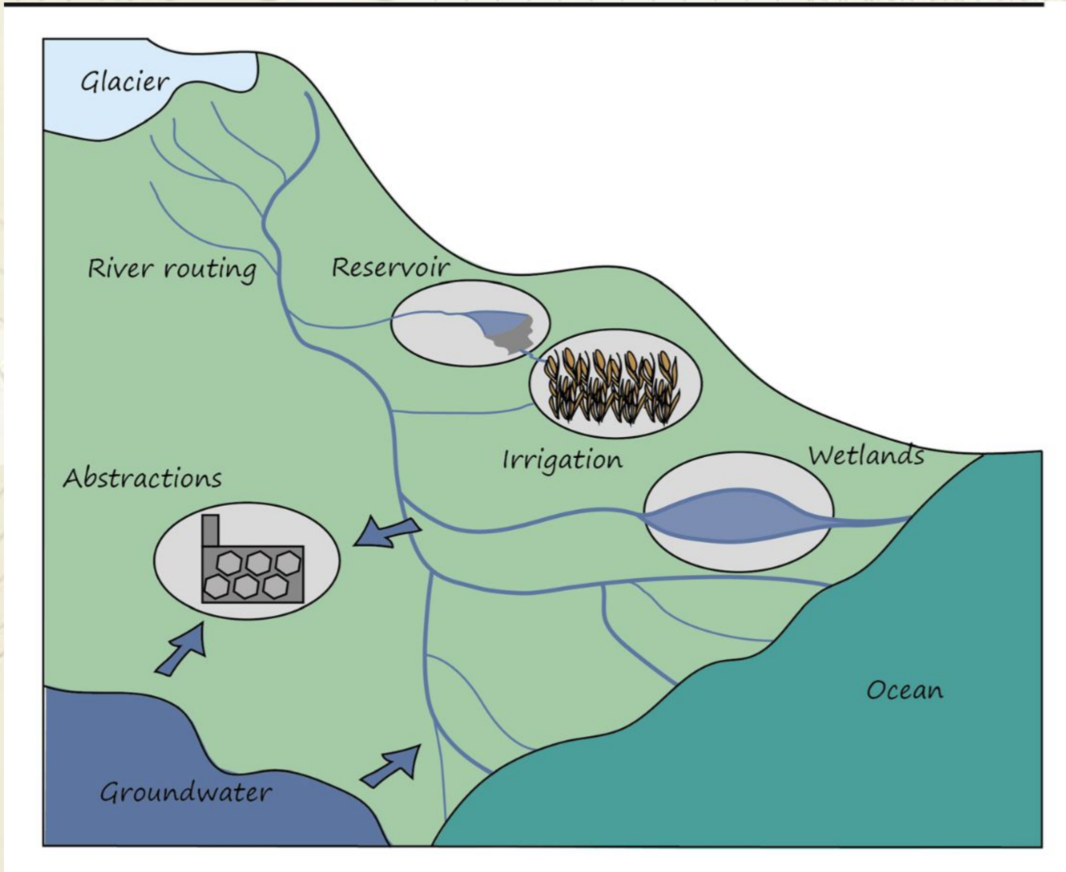


Fig from Blyth et al. 2022

BIOGEOCHEMISTRY: carbon, nitrogen (& phosphorus) cycles

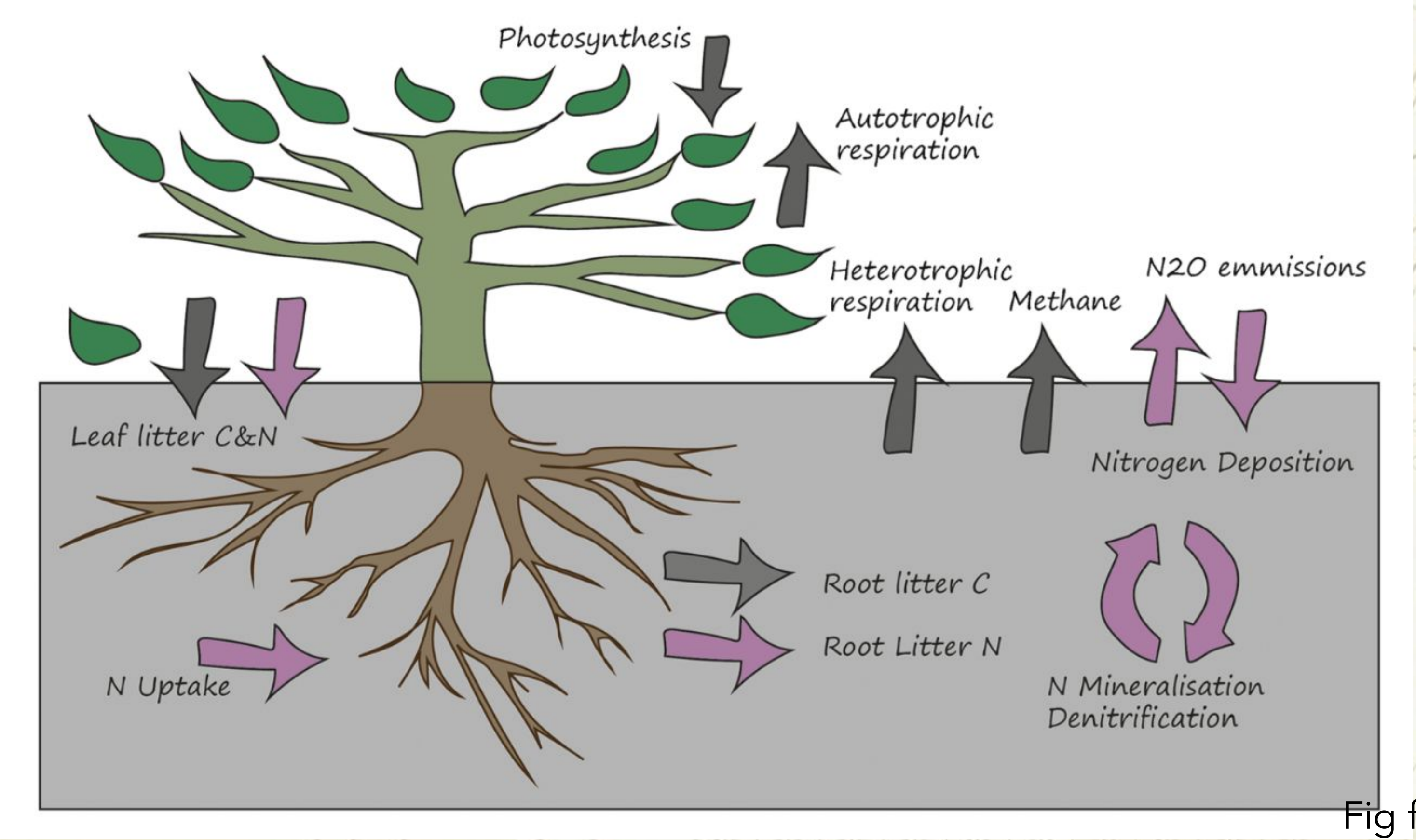


Fig from Blyth et al. 2022

ECOLOGY: vegetation dynamics & disturbance

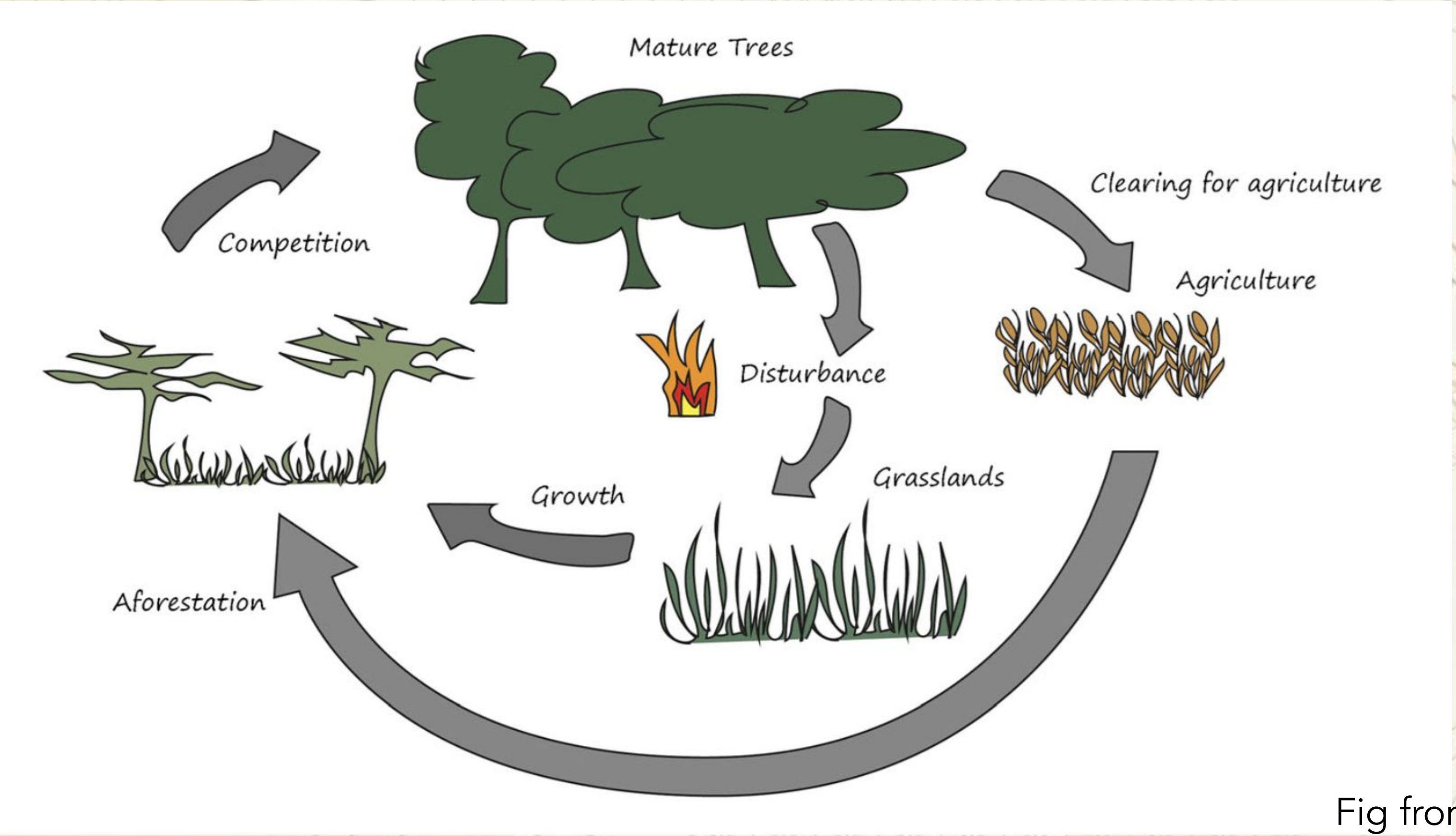
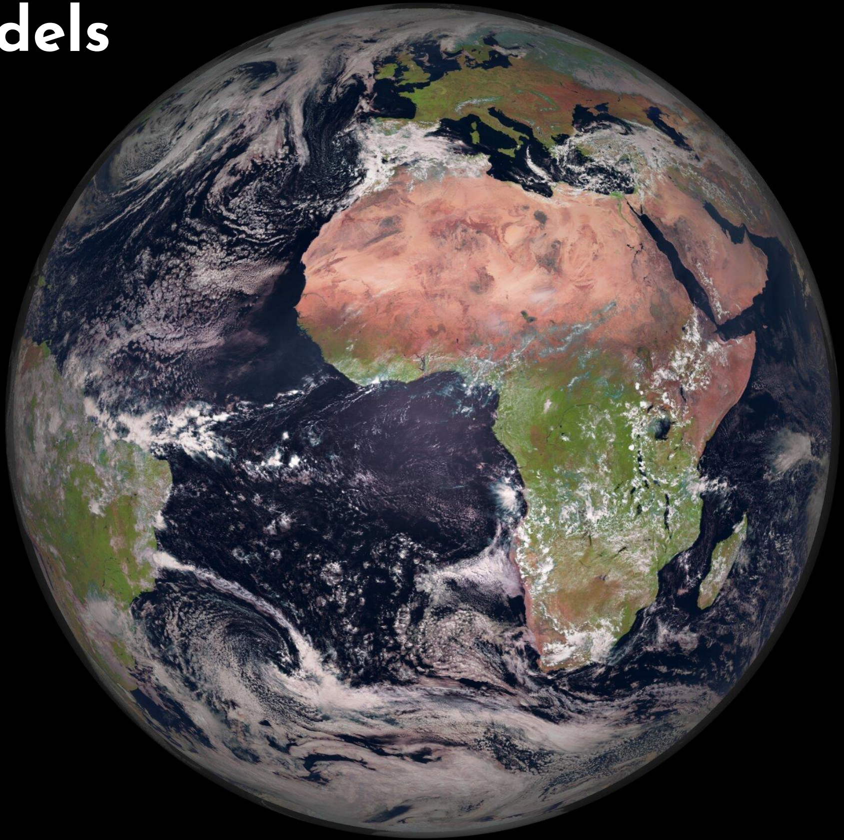


Fig from Blyth et al. 2022

Land Surface Models

Arguably the **most complete** tools available to tackle **big questions** about future **land/climate** processes



Land Surface Schemes in Earth System Models

CABLE: ACCESS

CLASSIC: CanESM

JULES: UKESM

ISBA: CNRM-ESM

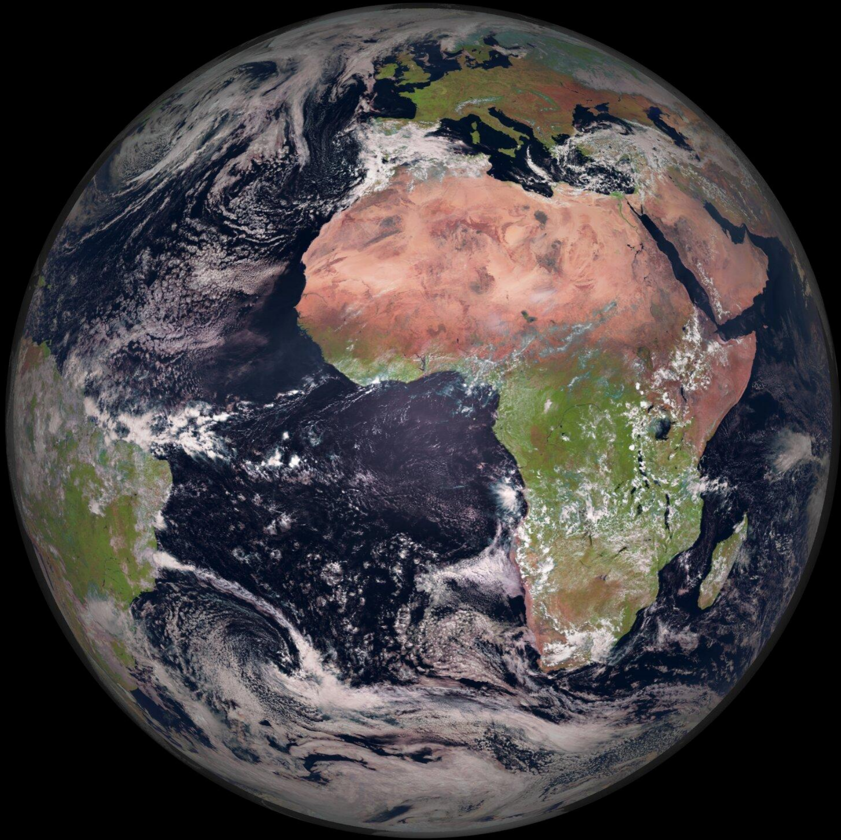
ORCHIDEE: IPSL

JSBACH: ICON

HTESSEL: EC_Earth

G/LM; GFDL

Matsiro: MIROC



CLM: The Community Land Model

CESM 🇺🇸

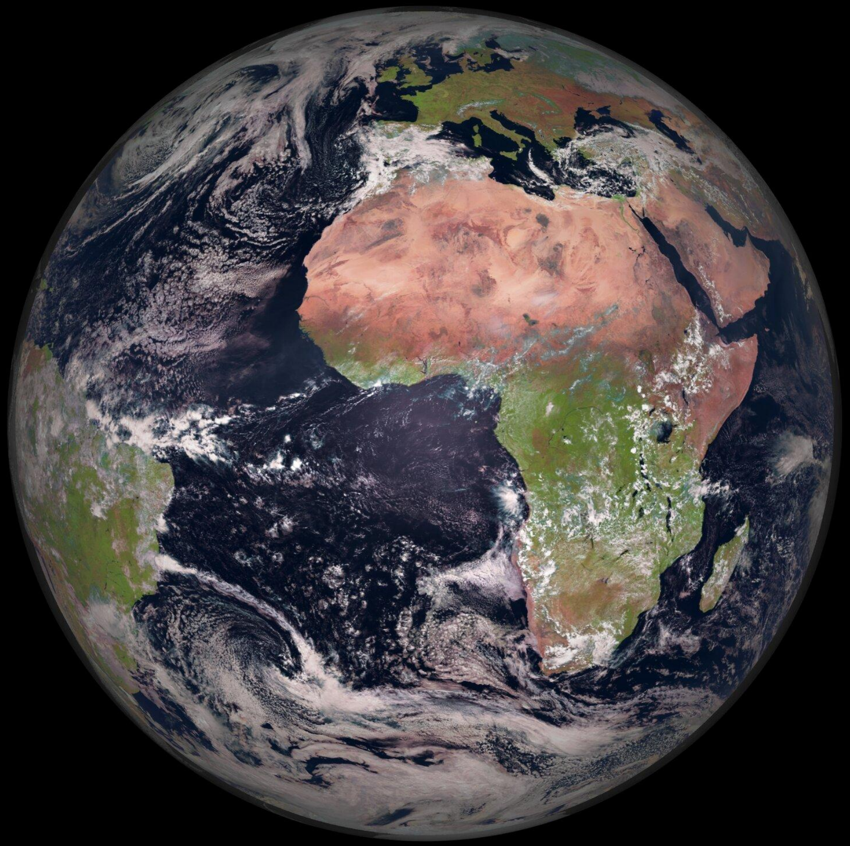
CMCC 🇮🇹

NorESM 🇳🇴

CLM relatives

ELM: E3SM 🇺🇸 (sibling)

CoLM: BCC-ESM 🇨🇳 (second cousin)



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The **Community** Land Model: **CLM**

https://www.cesm.ucar.edu/models/clm

JAMES | Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2018MS001583

Special Section:
Community Earth System Model version 2 (CESM2) Special Collection

Key Points:
- Updated Community Land Model has more hydrological and ecological process fidelity and more comprehensive representation of land management.
- The model is systematically evaluated using International Land Model Benchmarking system and shows marked improvement over prior versions.

Supporting Information:
- Supporting Information S1

The Community Land Model Version 5: Description of New Features, Benchmarking, and Impact of Forcing Uncertainty

David M. Lawrence[1], Rosie A. Fisher[1], Charles D. Koven[2], Keith W. Oleson[1], Sean C. Swenson[1], Gordon Bonan[1], Nathan Collier[3], Bardan Ghimire[2], Leo van Kampenhout[4], Daniel Kennedy[5], Erik Kluzek[1], Peter J. Lawrence[1], Fang Li[6], Hongyi Li[7], Danica Lombardozzi[1], William J. Riley[2], William J. Sacks[1], Mingjie Shi[8,9], Mariana Vertenstein[1], William R. Wieder[1,18], Chonggang Xu[10], Ashehad A. Ali[11], Andrew M. Badger[12], Gautam Bisht[2], Michiel van den Broeke[4], Michael A. Brunke[13], Sean P. Burns[14,35], Jonathan Buzan[15], Martyn Clark[1], Anthony Craig[1], Kyla Dahlin[16], Beth Drewniak[17], Joshua B. Fisher[8,9], Mark Flanner[19], Andrew M. Fox[20], Pierre Gentine[5], Forrest Hoffman[3], Gretchen Keppel-Aleks[21], Ryan Knox[2], Sanjiv Kumar[22], Jan Lenaerts[23], L. Ruby Leung[24], William H. Lipscomb[1], Yaqiong Lu[25], Ashutosh Pandey[22], Jon D. Pelletier[26], Justin Perket[1,27], James T. Randerson[28], Daniel M. Ricciuto[29], Benjamin M. Sanderson[30], Andrew Slater[31], Zachary M. Subin[32], Jinyun Tang[2], R. Quinn Thomas[33], Maria Val Martin[34], and Xubin Zeng[13]

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The history of **CLM**

https://www.cesm.ucar.edu/models/clm

- **1996: LSM - CCSM1**
- **2002: CLM2 - CCSM2**
- **2004: CLM3.0 - CCSM3**
- **2008: CLM3.5 - CCSM4**
- **2010: CLM4.0 - CESM1, NorESM1**
- **2013: CLM4.5**
- **2018: CLM5.0 - CESM2, NorESM2**
- **2026: CLM6 - CESM3 &**
- **CLM-FATES- NORESM3**

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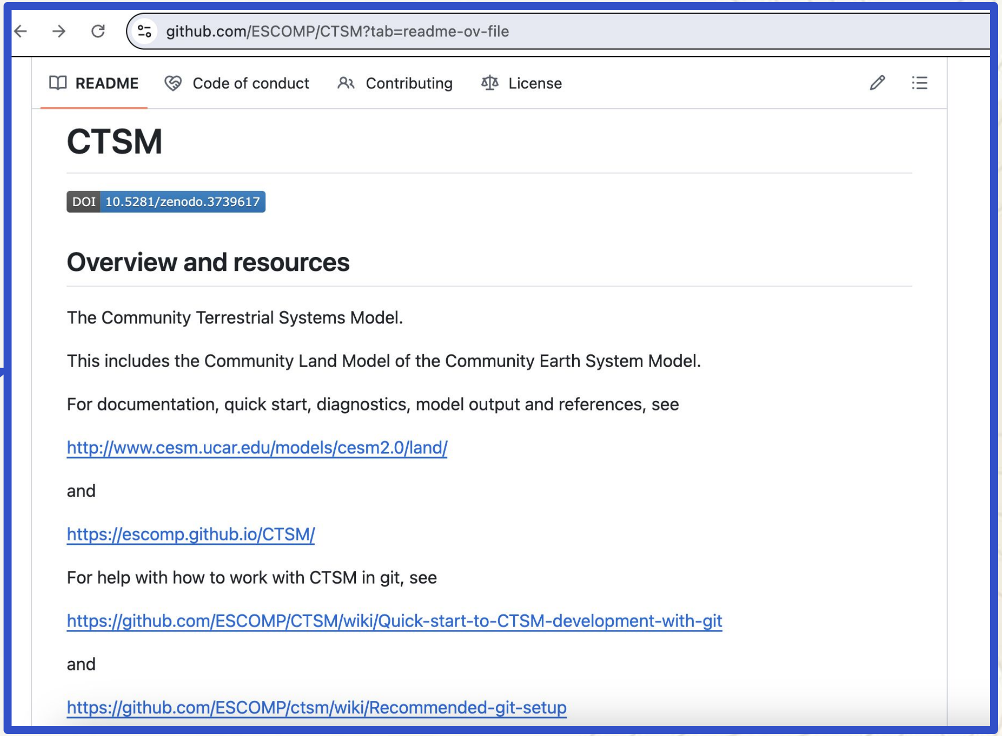
CLM GitHub repository

https://www.cesm.ucar.edu/models/clm



https://github.com/escomp/ctsm

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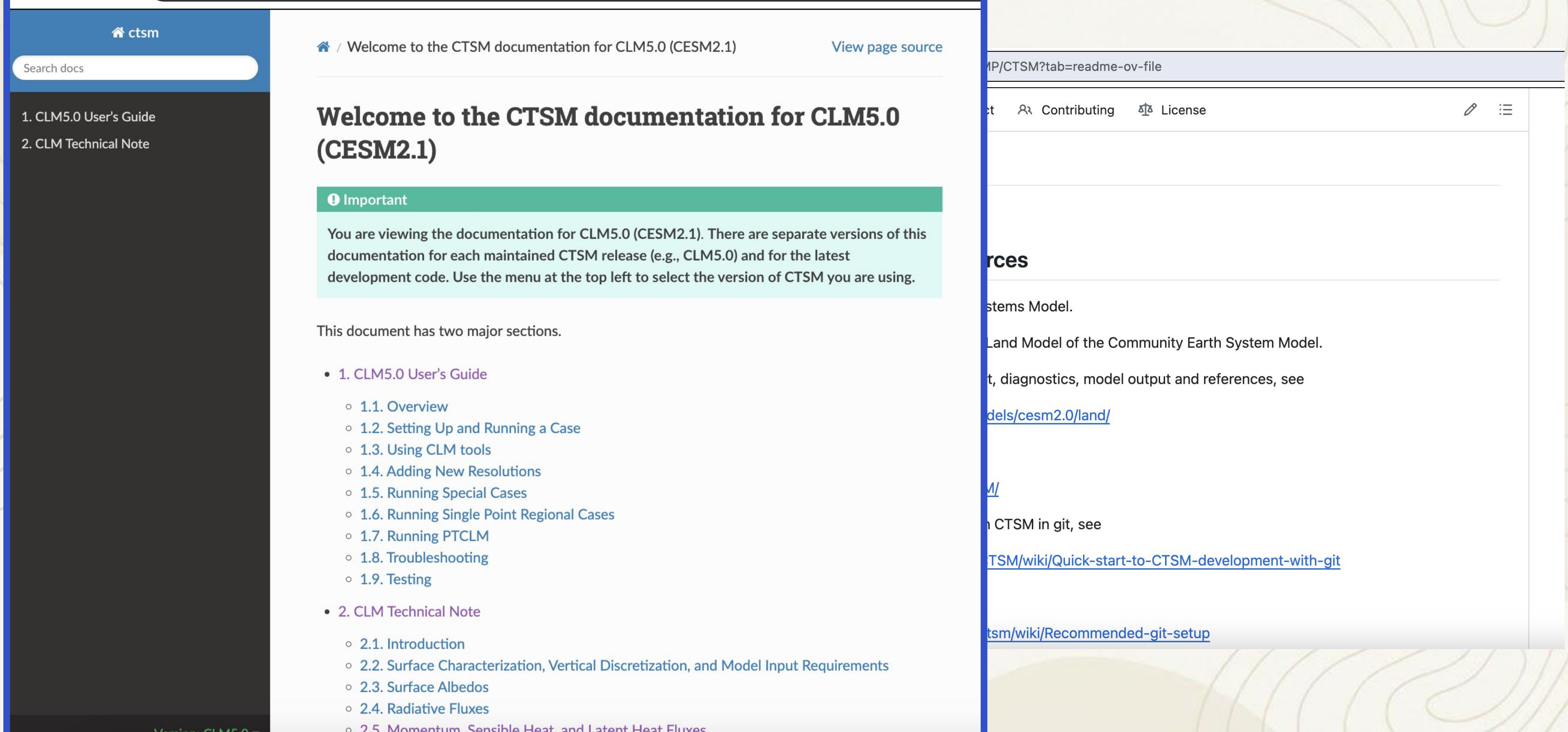
CLM GitHub repository

https://www.cesm.ucar.edu/models/clm



2.3. Surface Albedos

2.3.1. Canopy Radiative Transfer

Radiative transfer within vegetative canopies is calculated from the two-stream approximation of Dickinson (1983) and Sellers (1985) as described by Bonan (1996)

$$-\bar{\mu}\frac{dI\uparrow}{d\left(L+S\right)} + \left[1-\left(1-\beta\right)\omega\right]I\uparrow - \omega\beta I\downarrow = \omega\bar{\mu}K\beta_0 e^{-K(L+S)} \tag{2.3.1}$$

$$\bar{\mu}\frac{dI\downarrow}{d\left(L+S\right)} + \left[1-\left(1-\beta\right)\omega\right]I\downarrow - \omega\beta I\uparrow = \omega\bar{\mu}K\left(1-\beta_0\right) e^{-K(L+S)} \tag{2.3.2}$$

where $I\uparrow$ and $I\downarrow$ are the upward and downward diffuse radiative fluxes per unit incident flux, $K = G\left(\mu\right)/\mu$ is the optical depth of direct beam per unit leaf and stem area, μ is the cosine of the zenith angle of the incident beam, $G\left(\mu\right)$ is the relative projected area of leaf and stem elements in the direction $\cos^{-1}\mu$, $\bar{\mu}$ is the average inverse diffuse optical depth per unit leaf and stem area, ω is a scattering coefficient, β and β_0 are upscatter parameters for diffuse and direct beam radiation, respectively, L is the exposed leaf area index , and S is the exposed stem area index (section 2.2.1.4). Given the direct beam albedo $\alpha_{g,\Lambda}^{\mu}$ and diffuse albedo $\alpha_{g,\Lambda}$ of the ground (section 2.3.2), these equations are solved to calculate the fluxes, per unit incident flux, absorbed by the vegetation, reflected by the vegetation, and transmitted through the vegetation for direct and diffuse radiation and for visible ($< 0.7\mu\text{m}$) and near-infrared ($\geq 0.7\mu\text{m}$) wavebands. The absorbed radiation is partitioned to sunlit and shaded fractions of the canopy. The optical parameters $G\left(\mu\right)$, $\bar{\mu}$, ω, β, and β_0 are calculated based on work in Sellers (1985) as follows.

The relative projected area of leaves and stems in the direction $\cos^{-1}\mu$ is

$$G\left(\mu\right) = \phi_1 + \phi_2\mu \tag{2.3.3}$$

CESM, NorESM and CLM are built on the **idea** that:

- We **need** to model the **future of the Earth**
- It is better if we do that **collectively**
- This is hard, and needs **long term collaboration** & investment.

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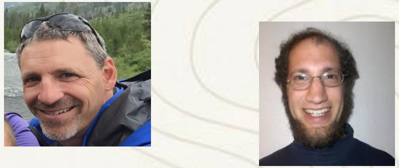
The **Community** Land Model: CLM



Trump Administration Plans to Break Up Premier Weather and Climate Research Center

Russell Vought, the White House budget director, called the laboratory a source of "climate alarmism."

Threatening NCAR, Trump administration seeks to extinguish a beacon of climate science

By Benjamin Santer | December 19, 2025

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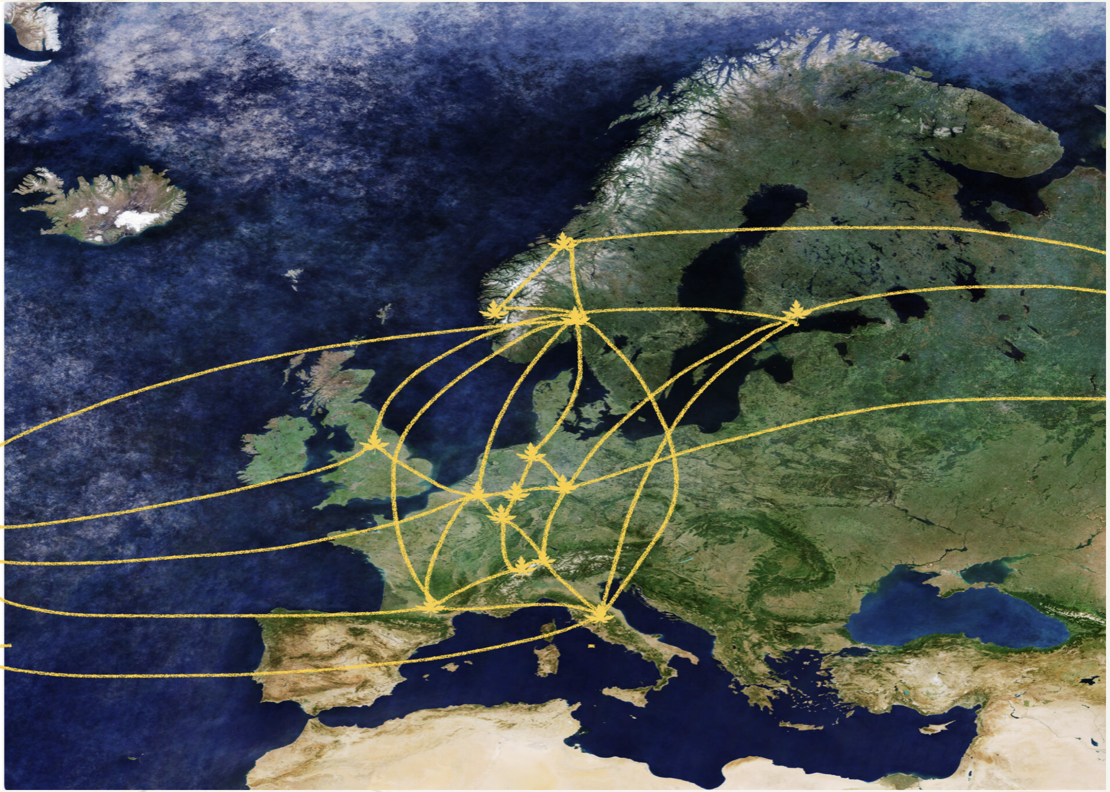
The **Norwegian** land surface modeling community

European CLM **network**



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CLM is an **international intellectual resource**

It is **more important than ever** that people are trained in the theory and use of the CLM

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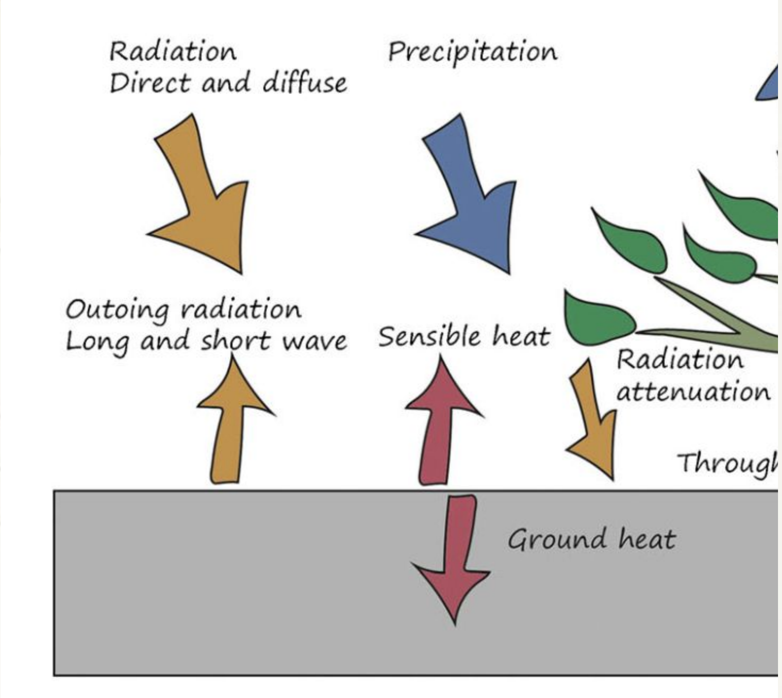
Energy



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

$S^{\downarrow}$, $S^{\uparrow}$ are down / upwelling solar radiation,

$L^{\downarrow}$, $L^{\uparrow}$ are down / upwelling longwave radiation,

λ is latent heat of vaporization,

E is evaporation,

H is sensible heat flux

G is ground heat flux

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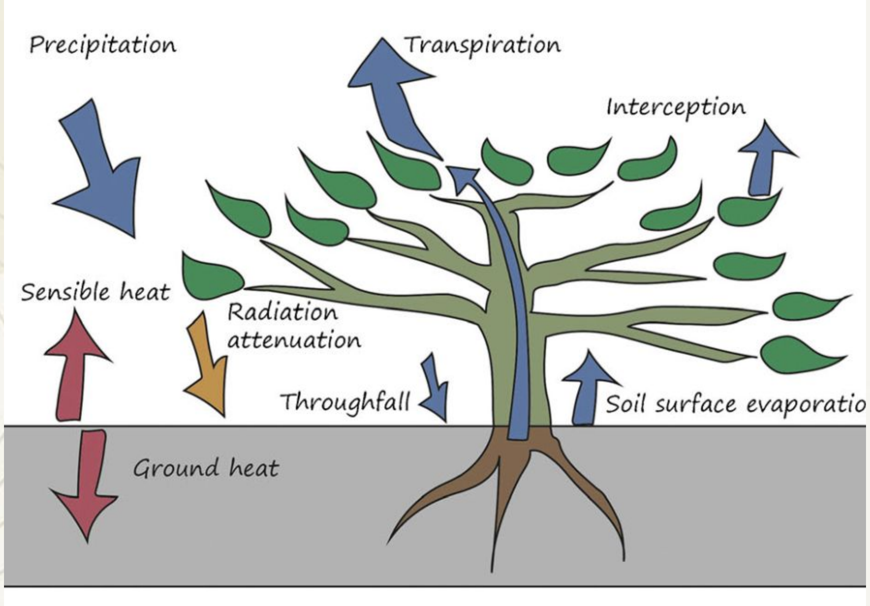
Water



$$P = ES + ET + EC + R + (\Delta W_{soil} + \Delta W_{snow} + \Delta W_{sfcw} + \Delta W_{can}) / \Delta t$$

P is rainfall/snowfall,

ES is soil evaporation,

ET is transpiration,

EC is canopy evaporation,

R is runoff (surf + sub-surface),

ΔW_{soil}, ΔW_{snow}, ΔW_{sfcw}, & ΔW_{can} - changes in soil moisture, snow, surface water, and canopy water over a timestep

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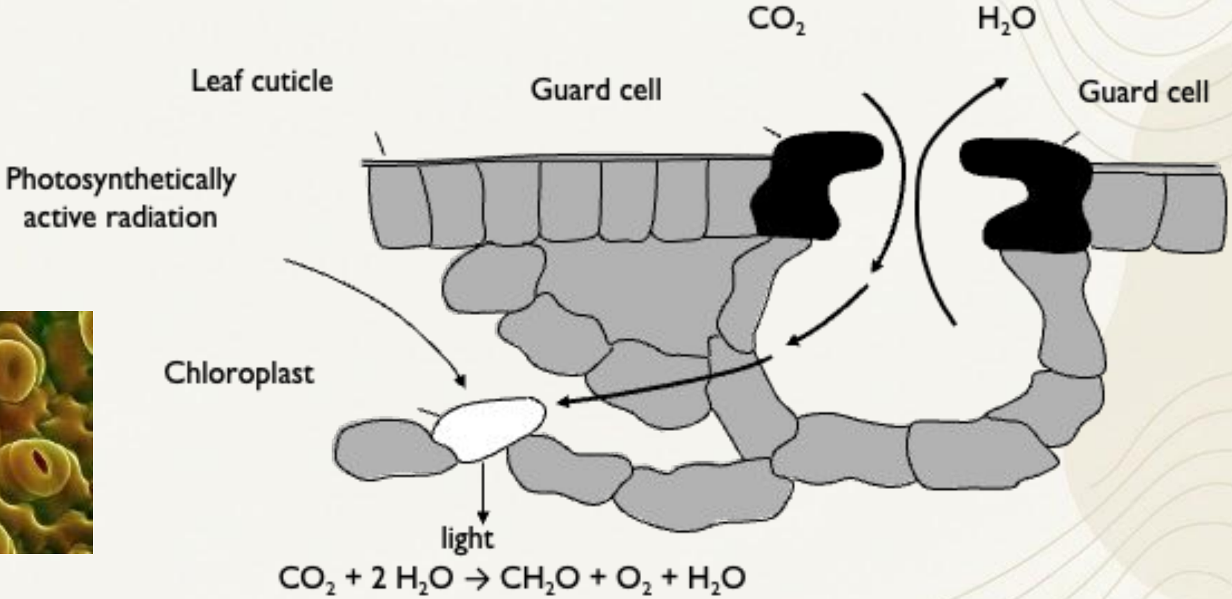
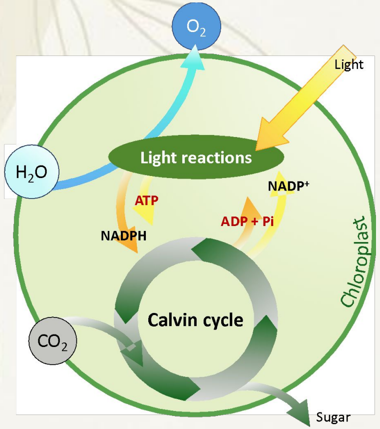
Water and stomata



Carbon



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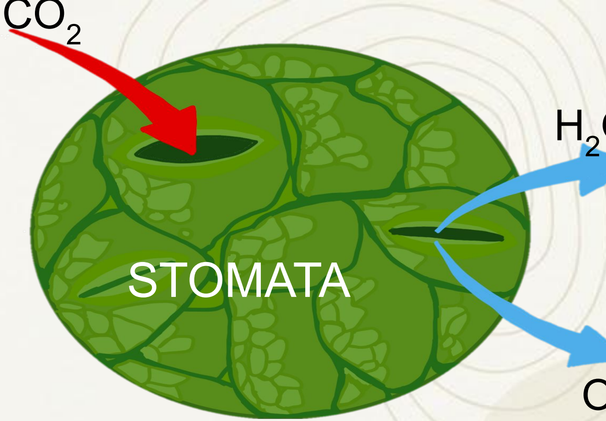

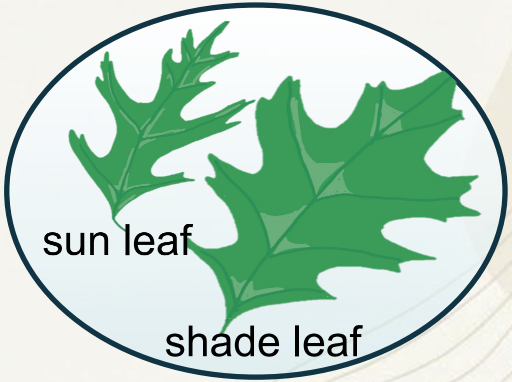

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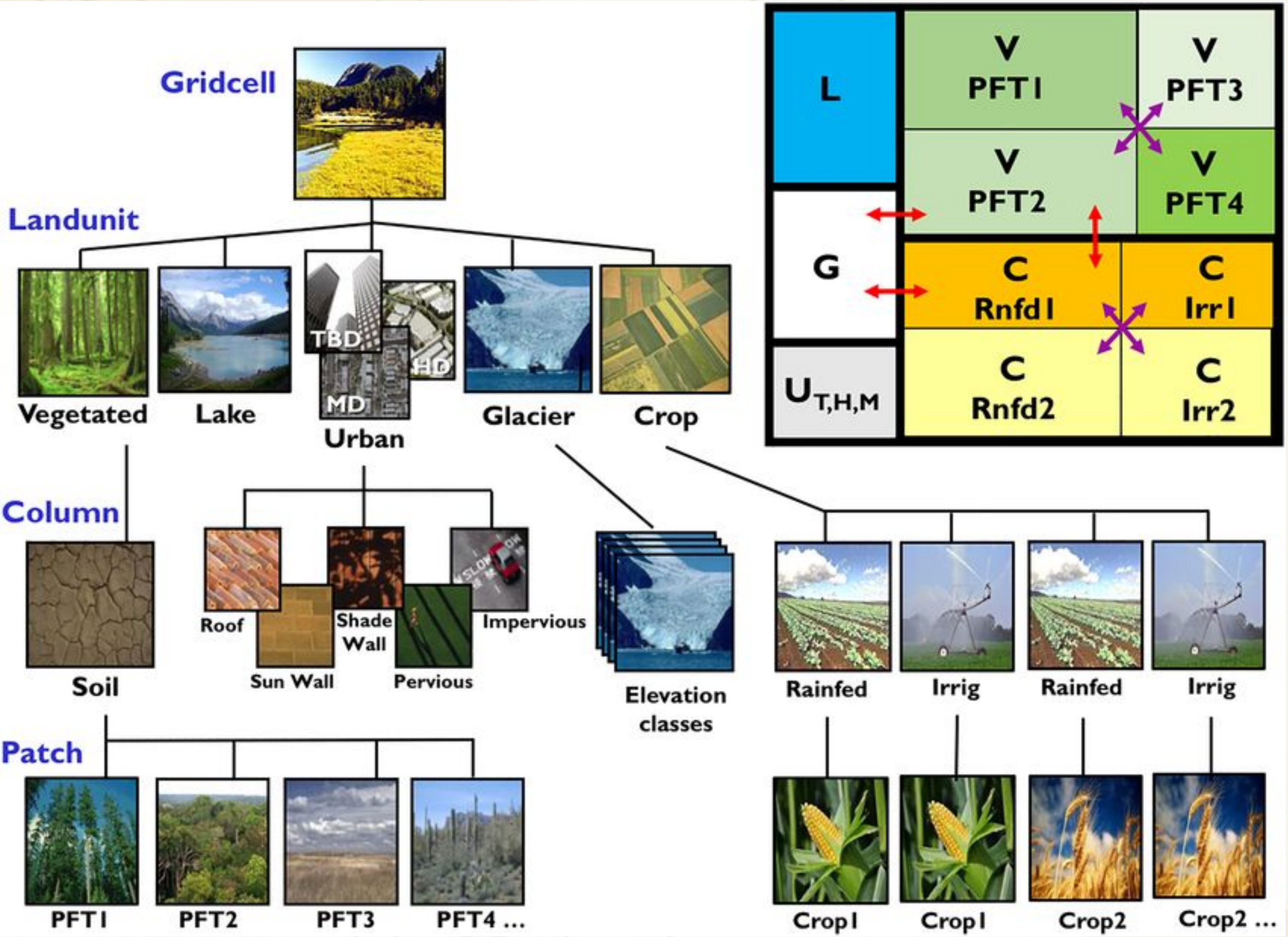
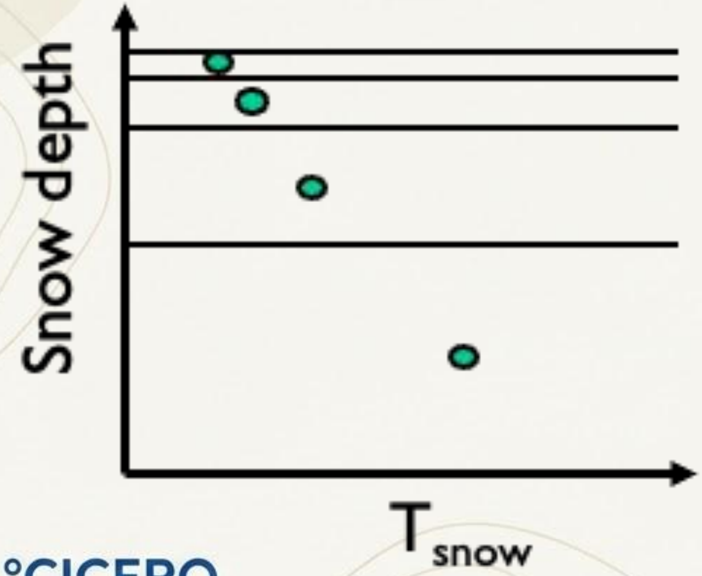
Land Surface Heterogeneity in CLM5



Snow



State Variables

$N, w_{liq,i}, w_{ice,i}, \Delta z_i, T_i$

- **<=10-layers** of varying thickness
- **Melt, refreezing, aging**
- **Compaction**
  - metamorphism: *f*(T, wind)
  - melt-freeze cycles
- **Sublimation**
- H2) & energy **transfer** btwn layers
- Black carbon & dust **deposition**
- Canopy snow **storage**
- Snow **burial** of vegetation

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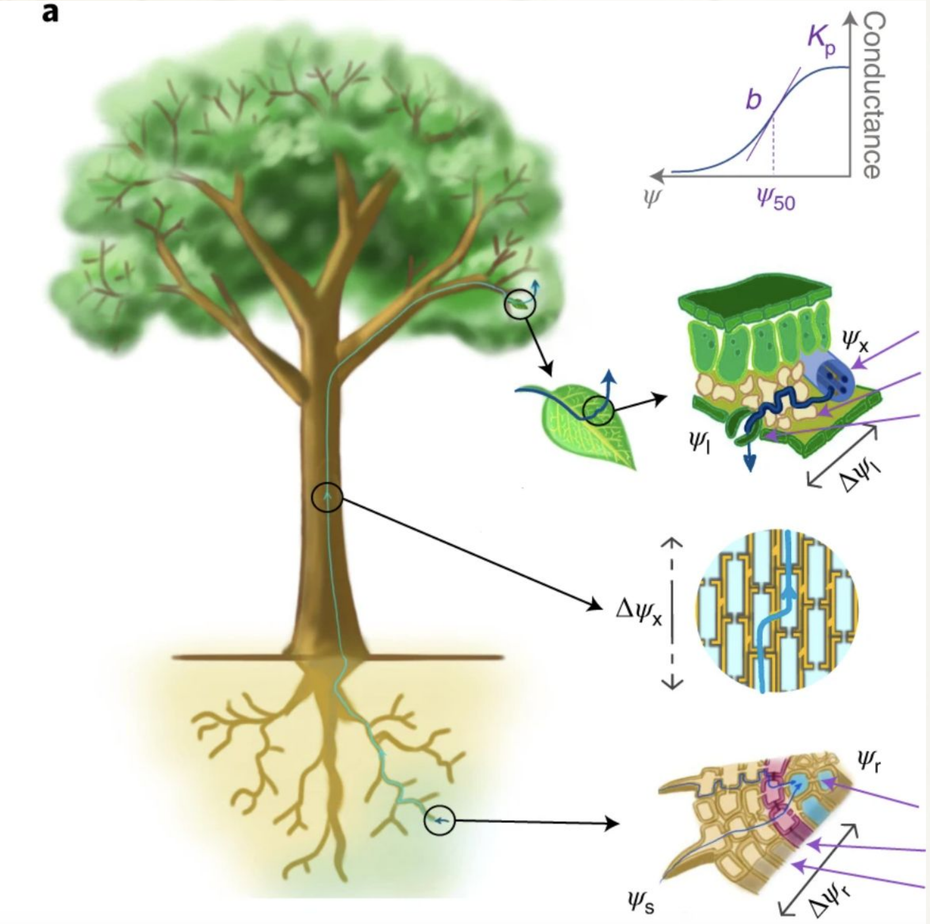
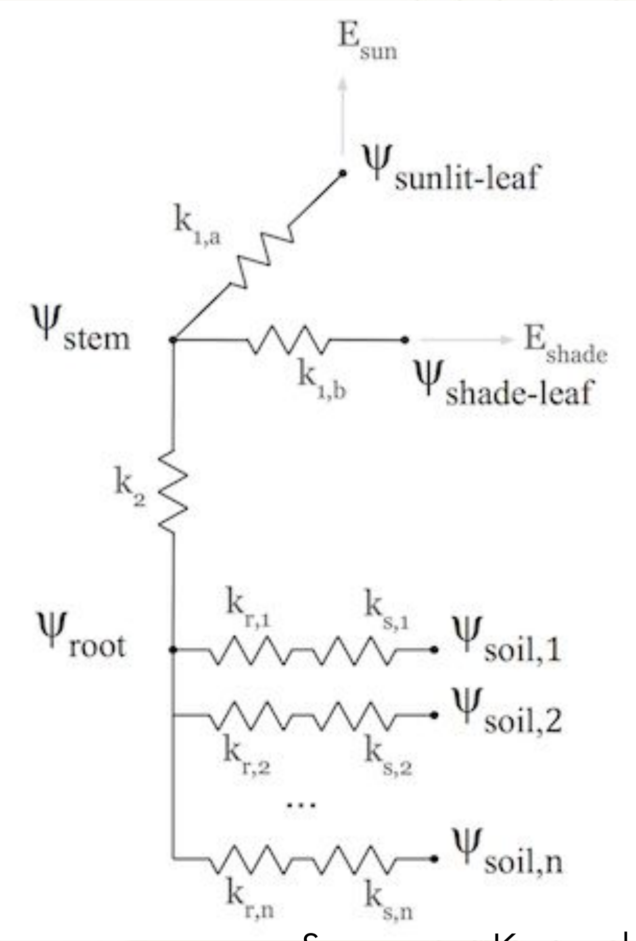
Plant hydraulics: water movement as an electrical analog





oshi et al. 2022

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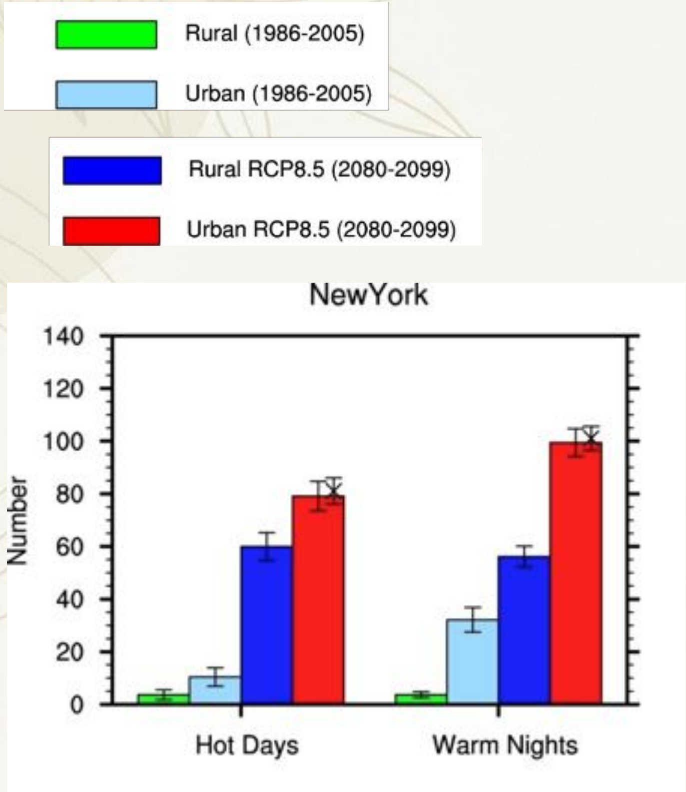
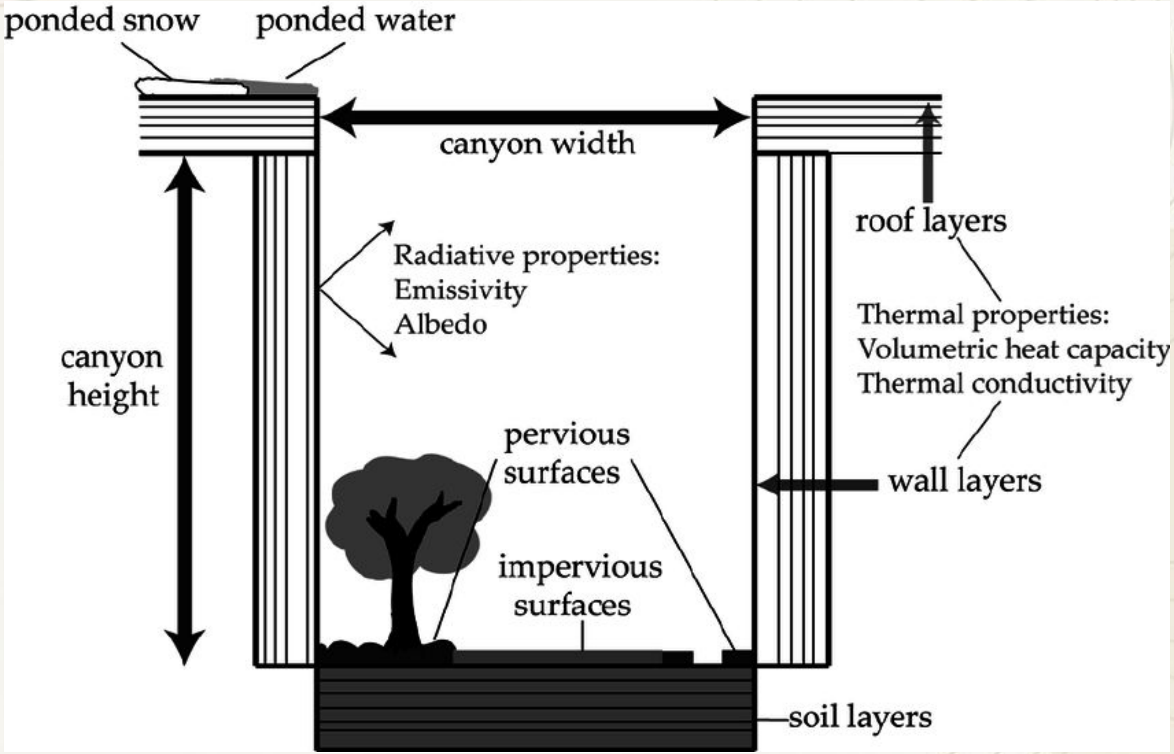
Kennedy et al 2019

Urban Model

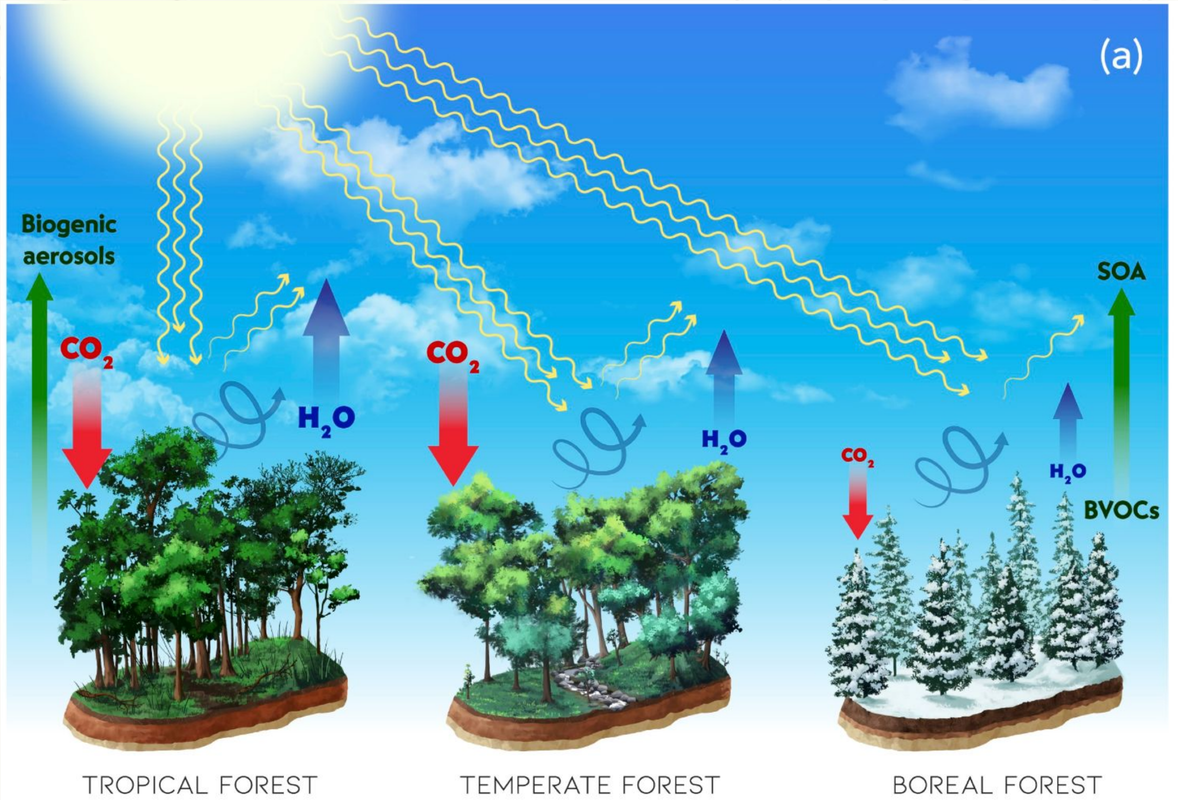




Oleson, K. W., & Feddema, J. (2020).JAMES 12, e2018MS001586.
https://doi.org/10.1029/2018MS001586

Biogenic Volatile Organic Compounds (MEGAN2.1)

f(leaf area, plant type, Temp, humidity, irradiance, CO_2)



Guenther et al. GMD 2012, DOI:[10.5194/gmdd-5-1503-2012](https://doi.org/10.5194/gmdd-5-1503-2012)

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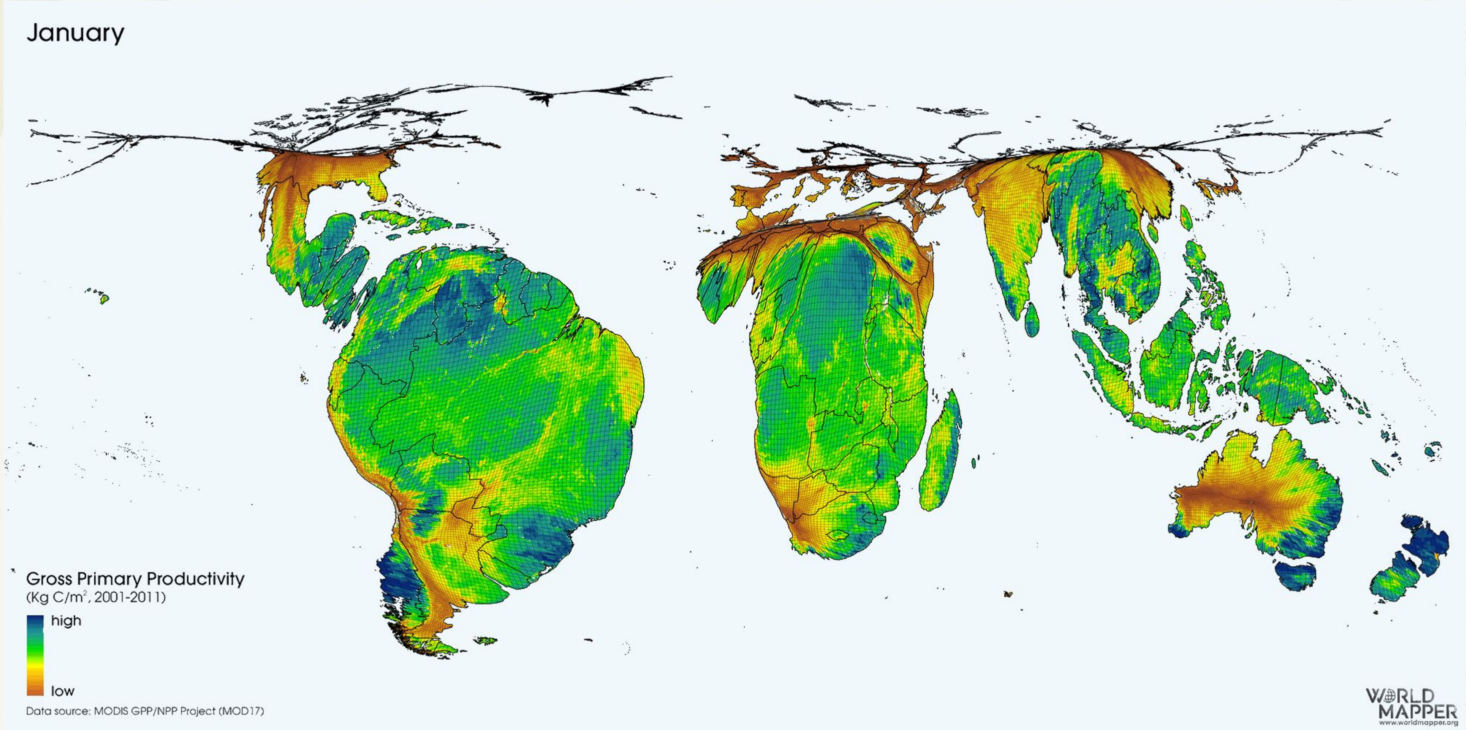
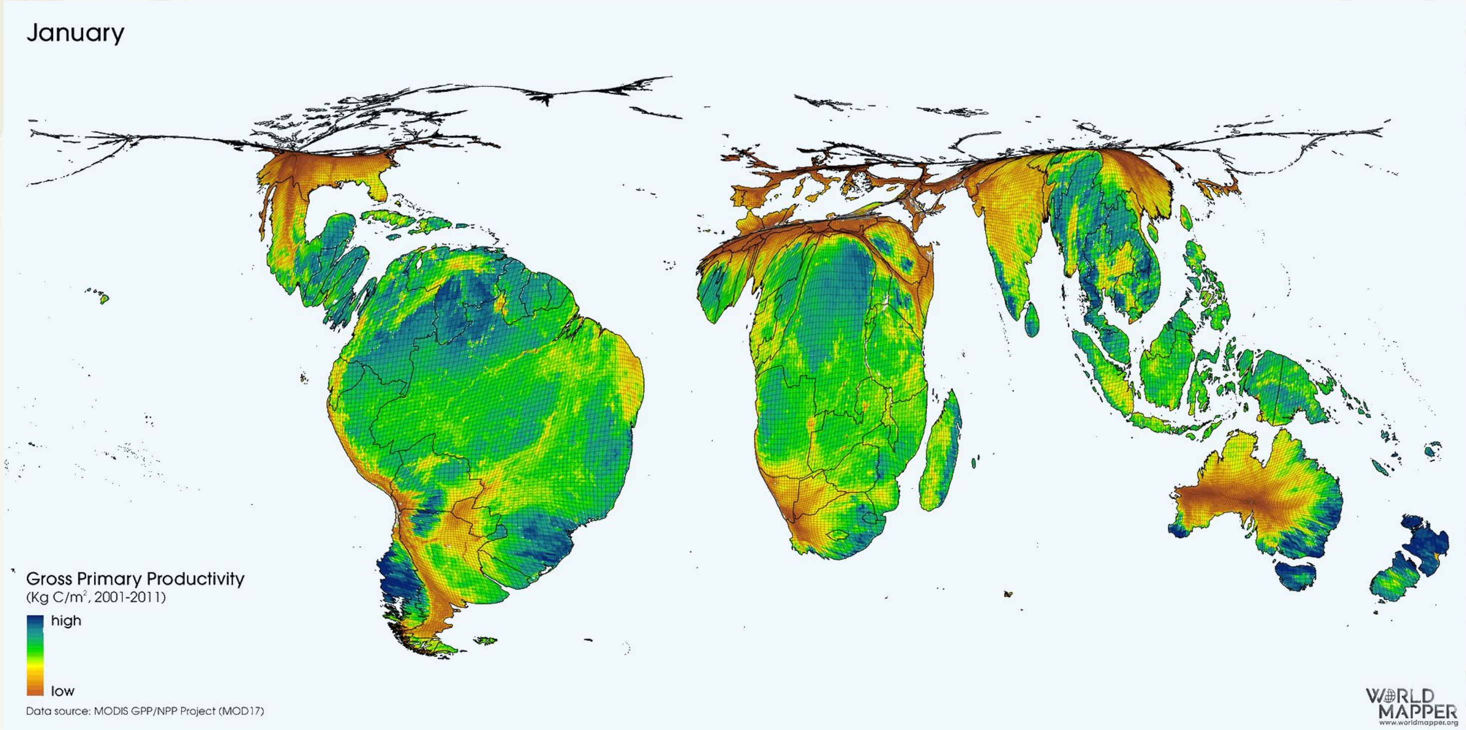
Assimilation of **Carbon** into **sugar** is the energetic basis for **life on Earth.**



'Nature's heartbeat'.

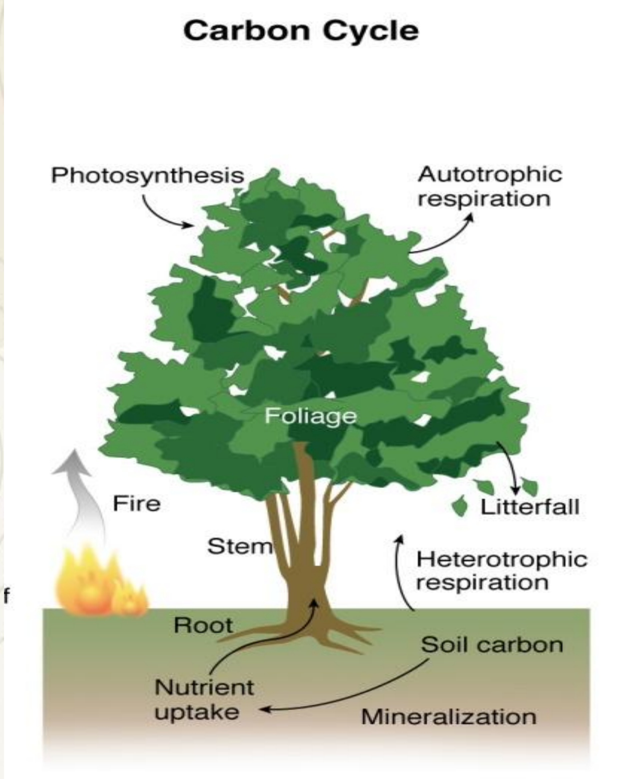
Yadvinder Malhi, University of Oxford

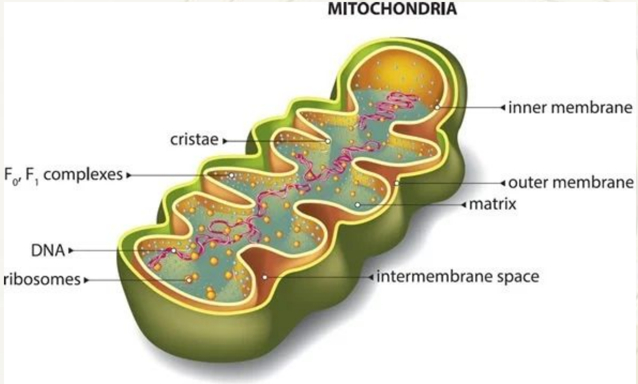
Assimilation of **Carbon** into **sugar** is the energetic basis for **life on Earth.**



'Gross Photosynthesis Productivity' - GPP

(upscaled from tower observations)





Plants use ~**50%** of their photosynthetic carbon (GPP) for **doing plant things…**

Autotrophic (plant) **Respiration**
AR=f(N, temperature, moisture, growth)

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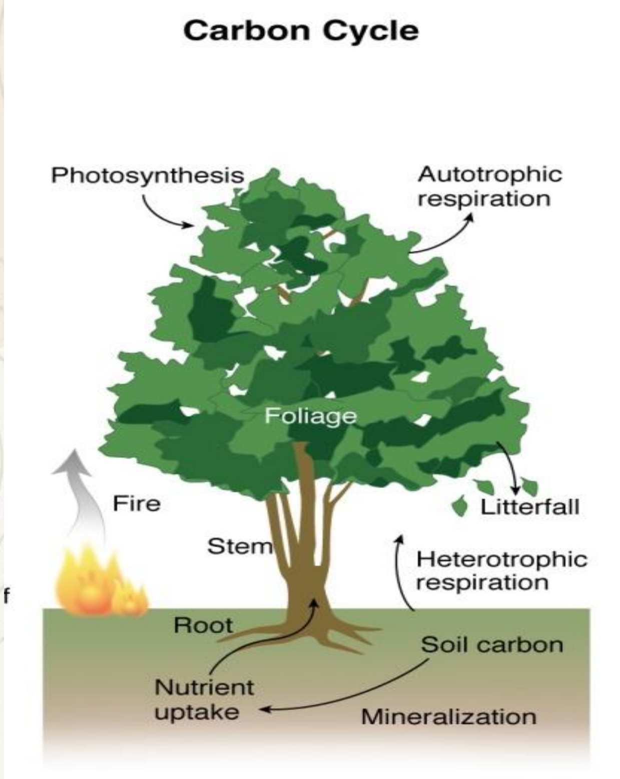

The rest (Net Primary Productivity 'NPP') is left over for growing...

NPP = GPP - AR

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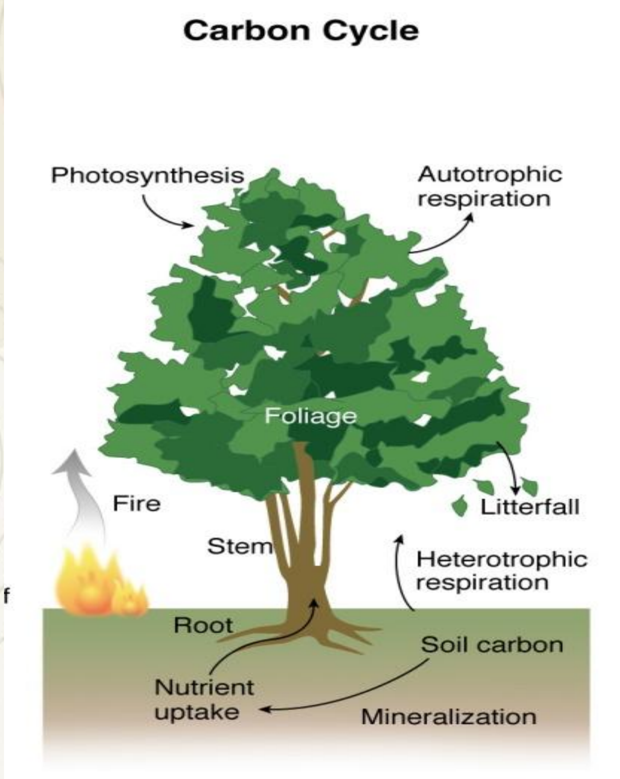
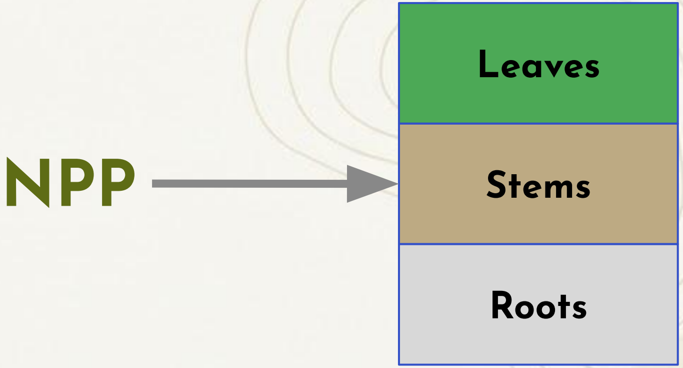




NPP => **leaves, roots, wood**

‘**Allocation**’= **fixed fractions** in CLM5.

These are ‘**boxes**’ of carbon - not plants

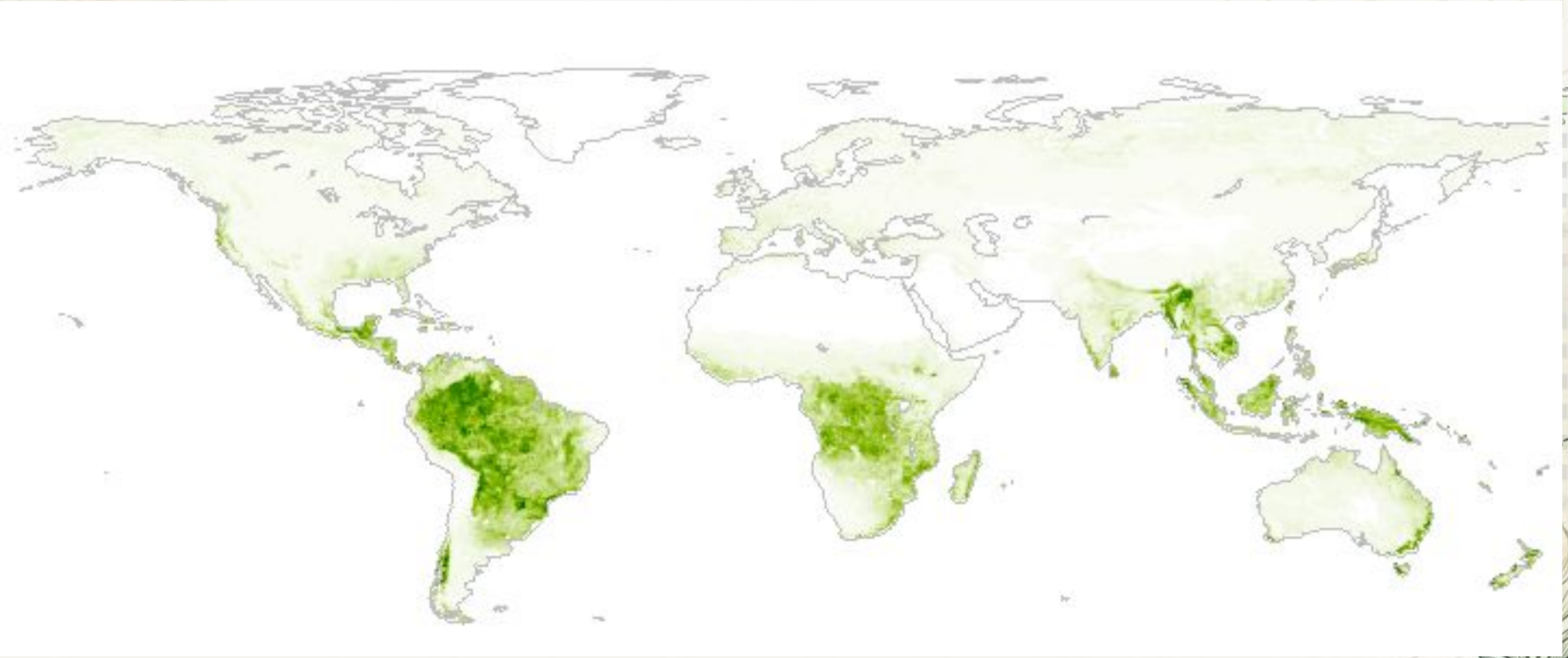
Functions of vegetation tissues

Leaves - make the canopy

Roots - take up water and N

Wood - inert C store in CLM5

Carbon **uptake** comes from and is used to make leaves!



Leaf Area Index (m2 leaf per m2 ground)

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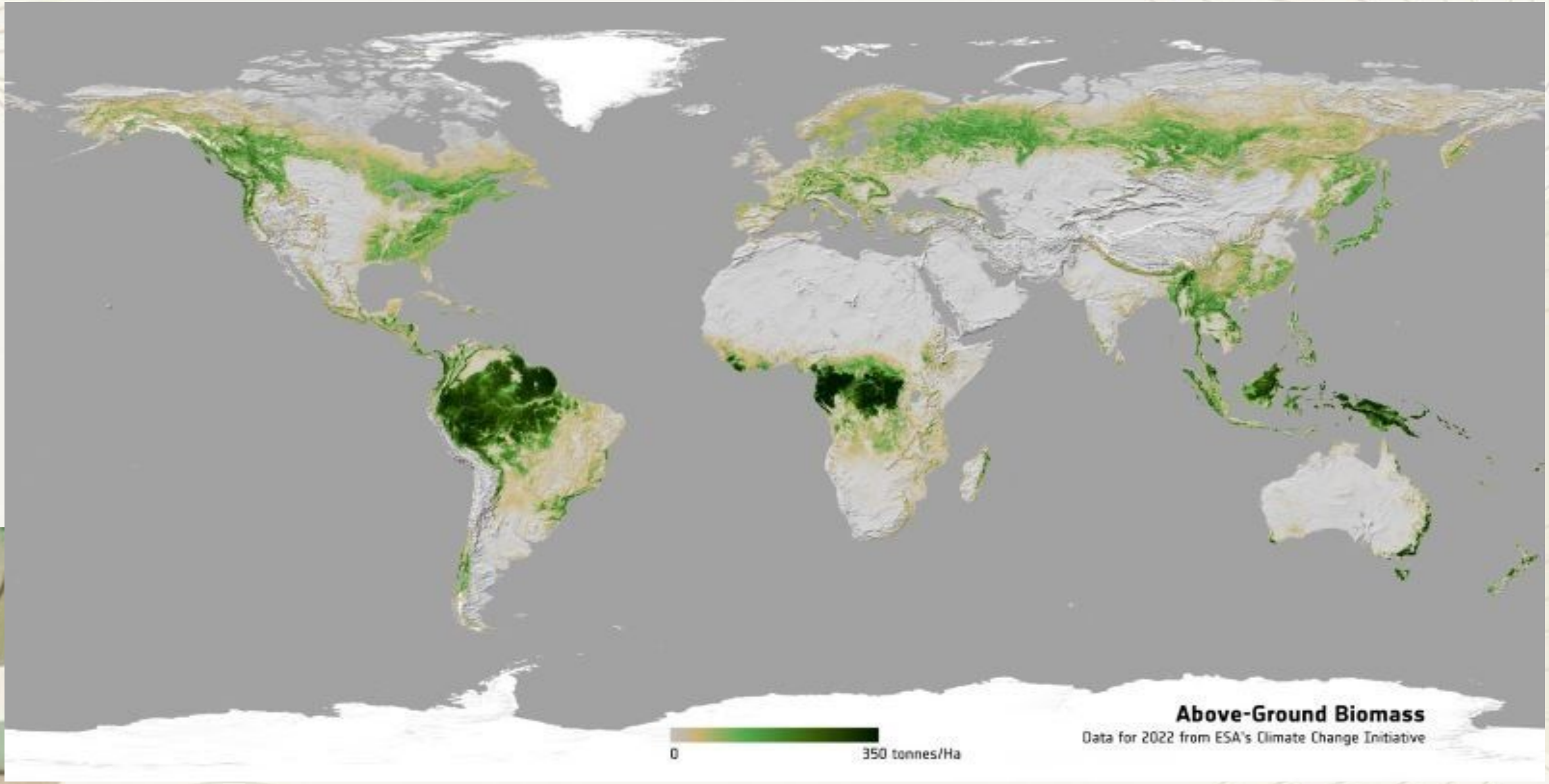
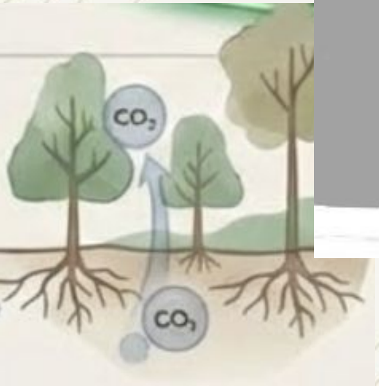
Carbon accumulates in vegetation biomass





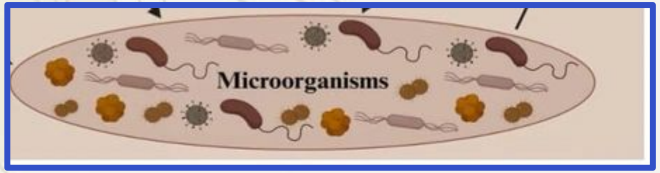
Vegetation C fluxes & stocks

Turnover: plant tissues don't last forever...

% loss per day mostly fixed per plant type.

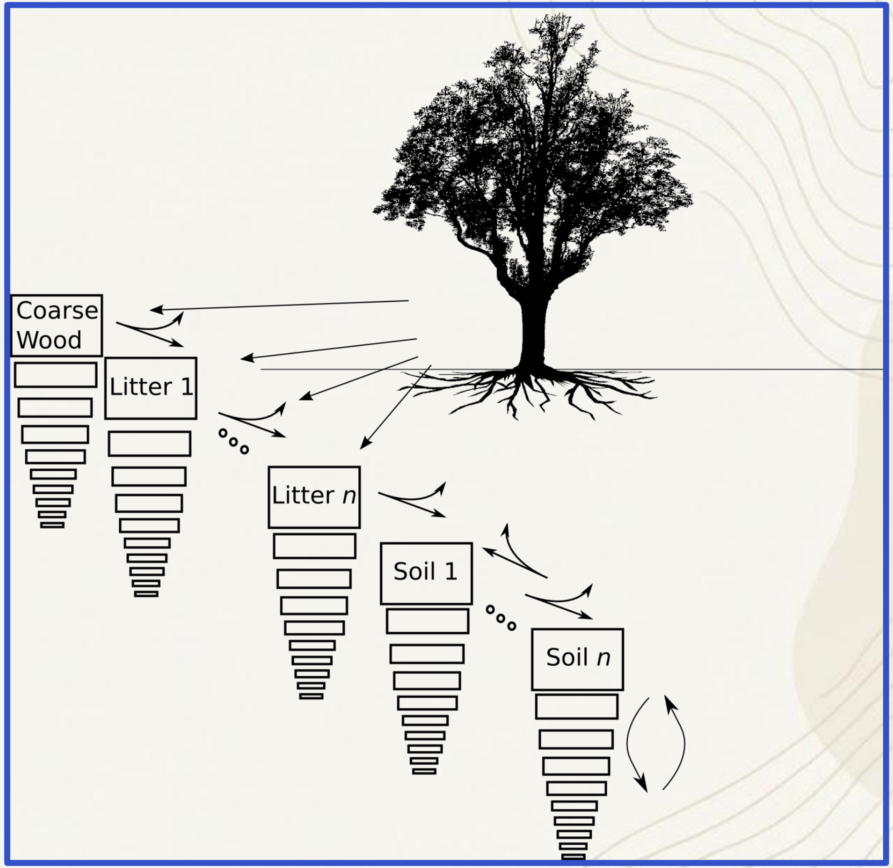
Empirical models of plant phenology for deciduous trees. f(temperature)

Soil respiration & decomposition



Decomposition Cascade':

3 pools: fast, med, slow
Turnover factors
f(T,H20)



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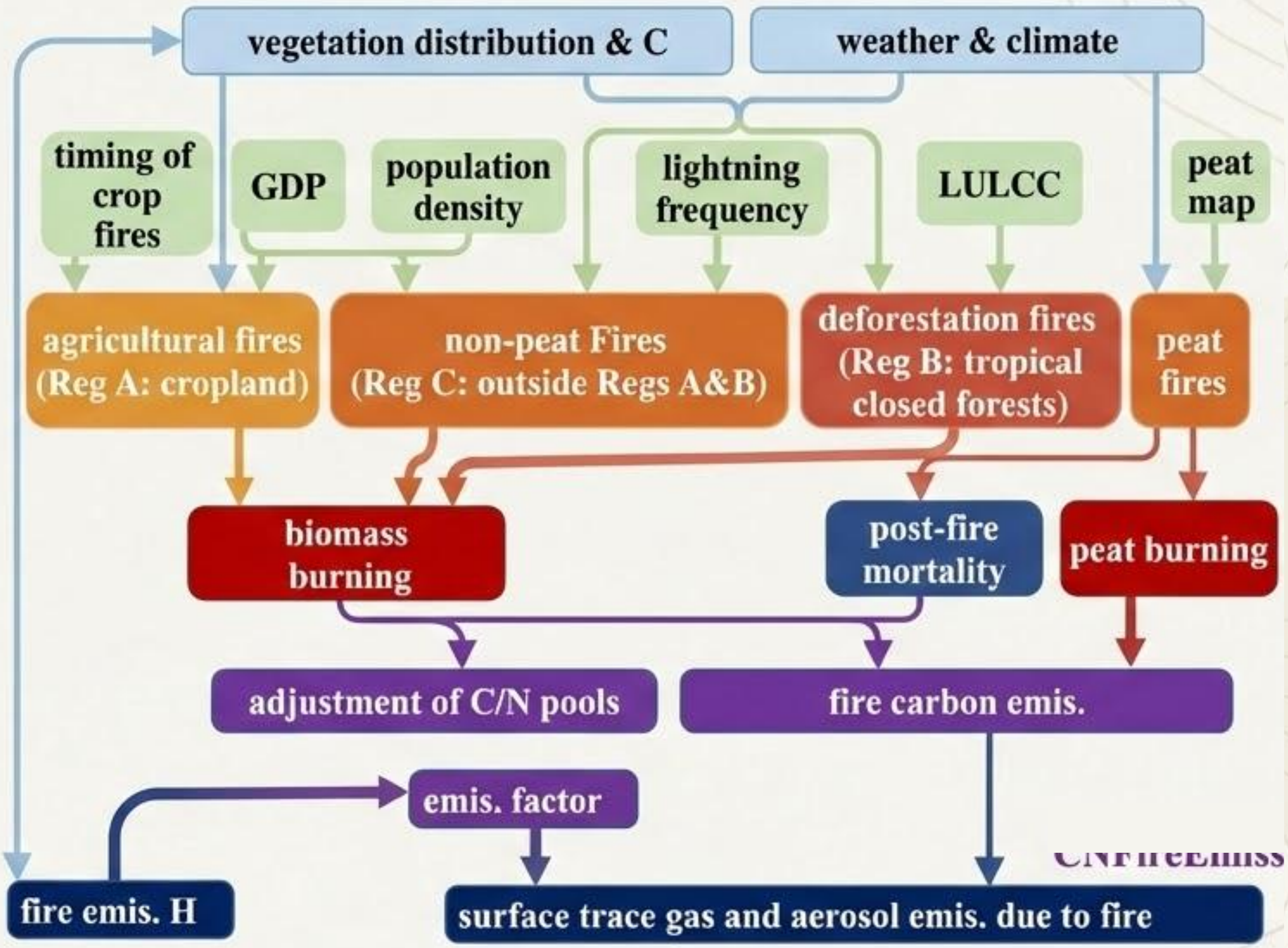
Fire in CLM5



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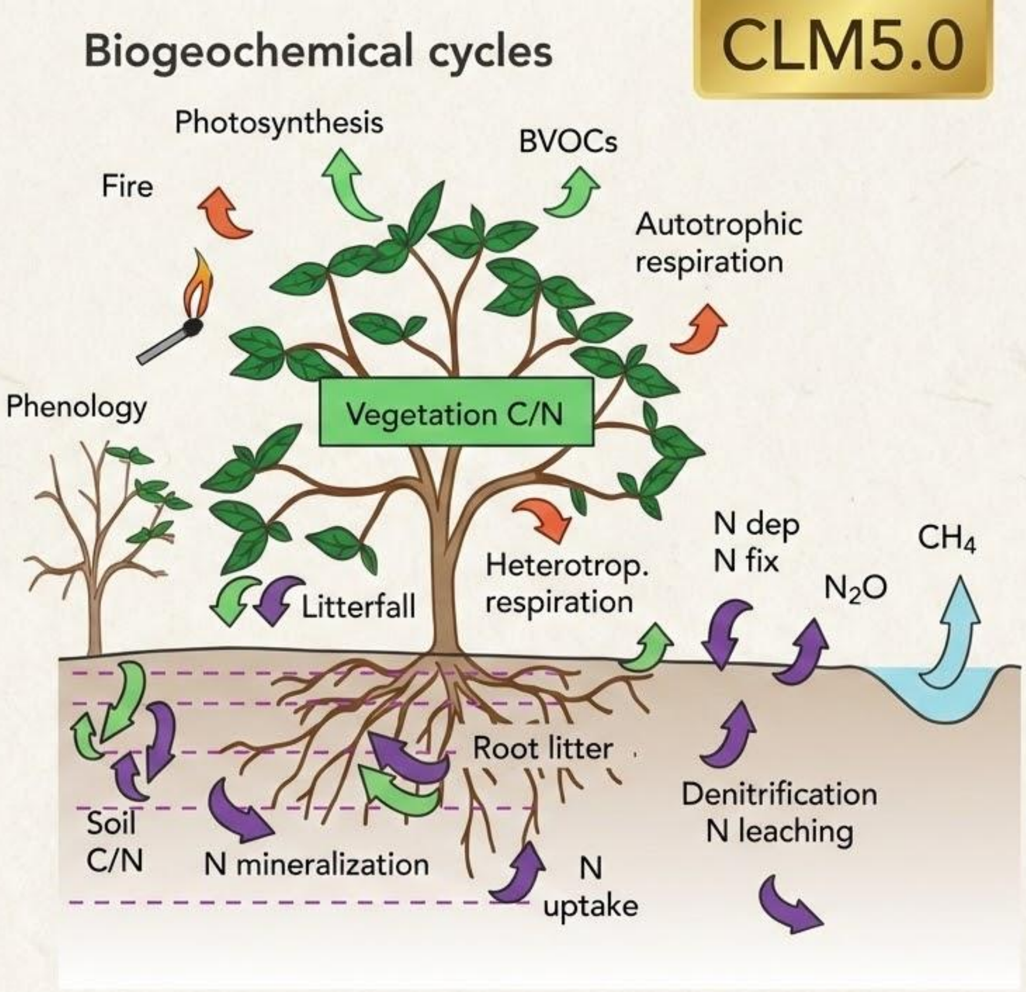
Nitrogen cycling

N is needed for growth

It comes from fixation and mineralization

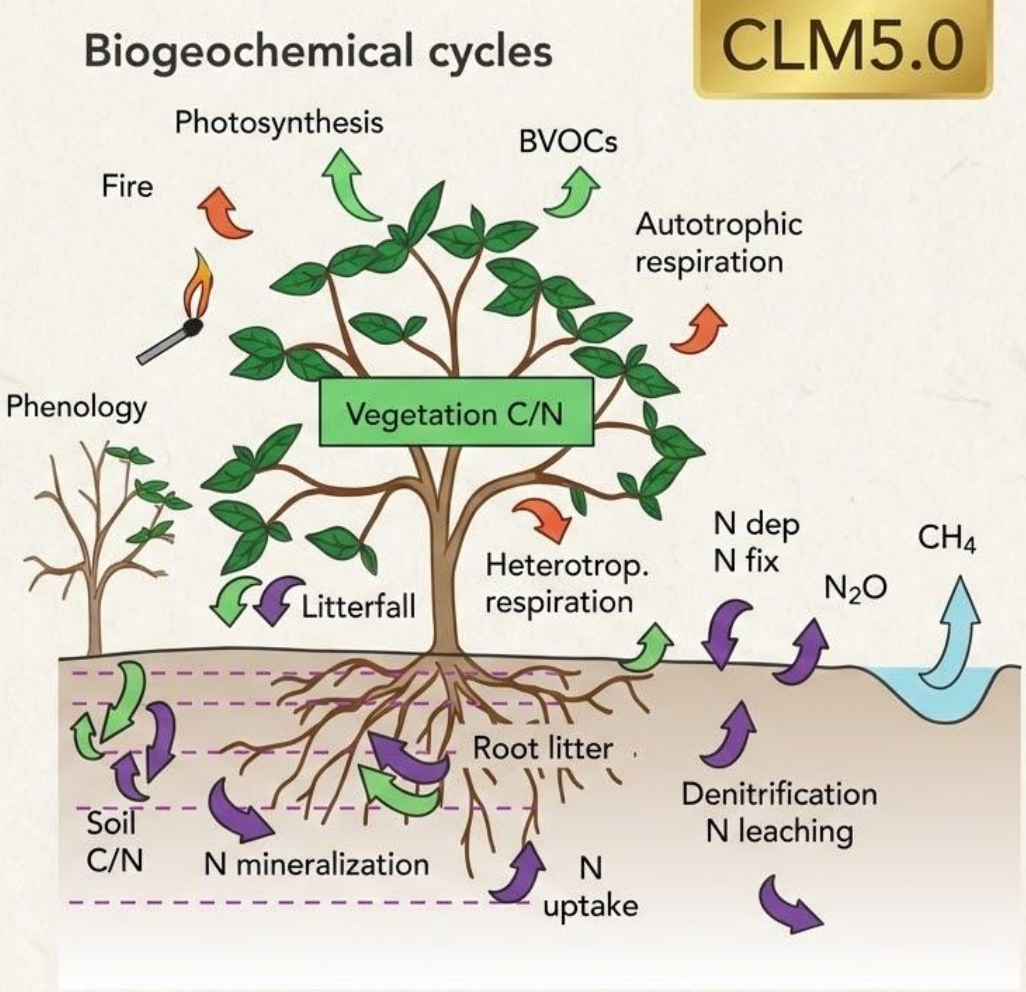
It leaves via denitrification and leaching.



Nitrogen cycling

Some plants can get their own N from symbionts

CLM5 simulates the economics of this with the FUN model (Fixation and Uptake of Nitrogen)
(Fisher et al. 2010, 2019)



Agriculture in CLM5:
planting/harvest dates & crop allocation phenology

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Agriculture in CLM5:
planting/harvest dates **& crop allocation phenology**

Transient fertilizer and irrigation (1850 – 2100)

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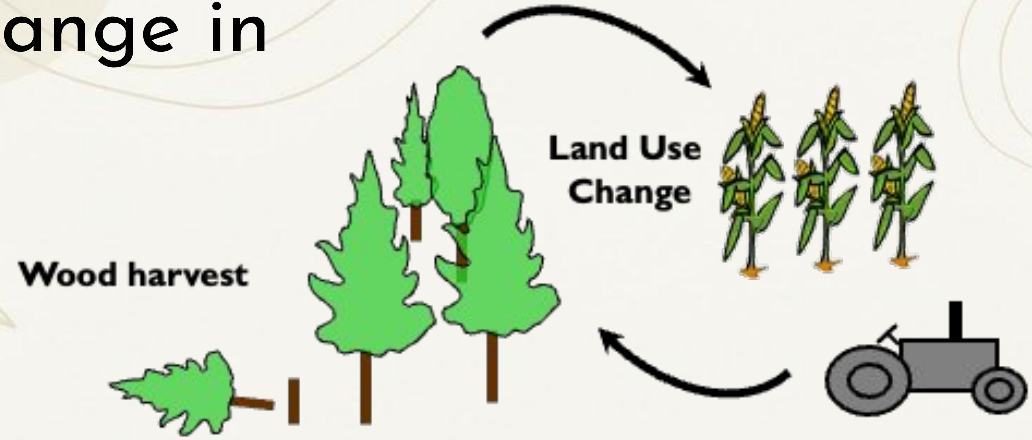
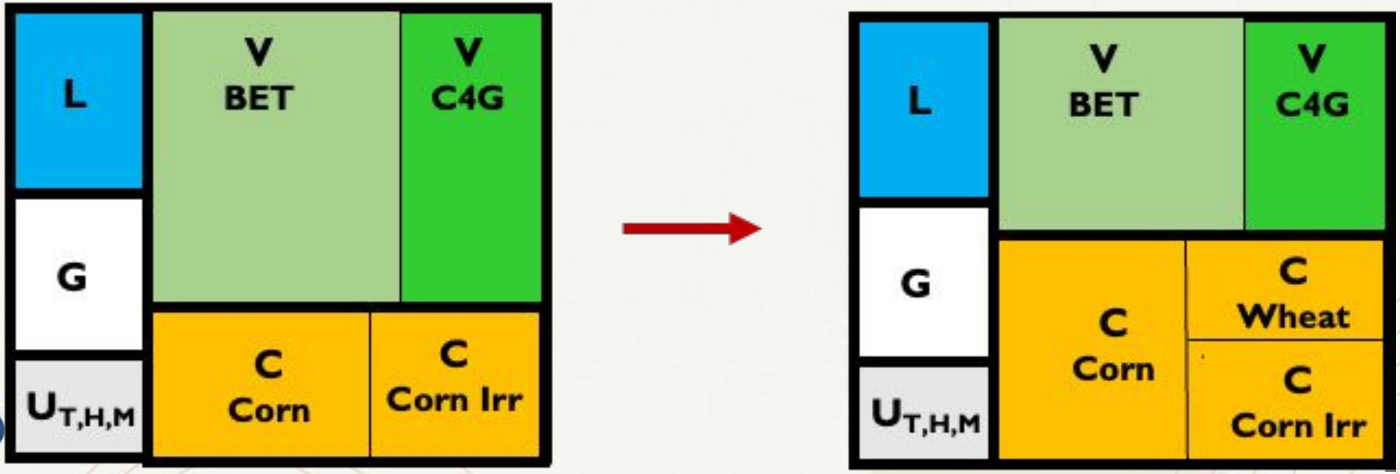
Land Use Change in CLM5



Deforestation example



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- Online Resources

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CLM configurations

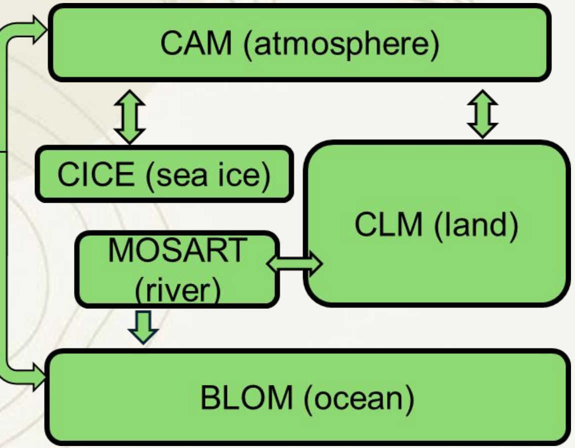
- N-, NF- and I-cases
- BGC(-Crop) vs SP
- Namelist options

Color code:

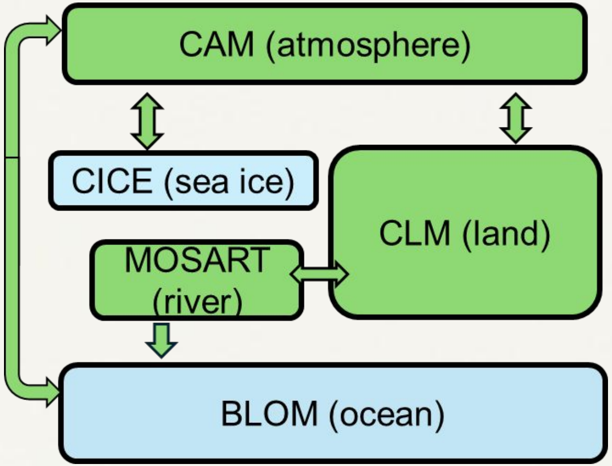
Stub Active Data

N, NF and I cases

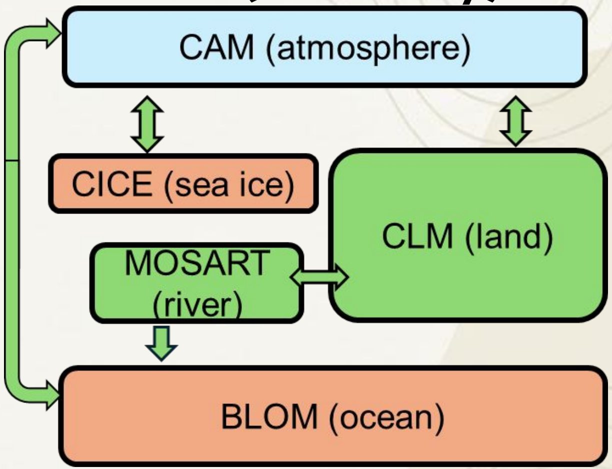
N-cases (all active)



NF-cases (land-atm)



I-cases (land only)



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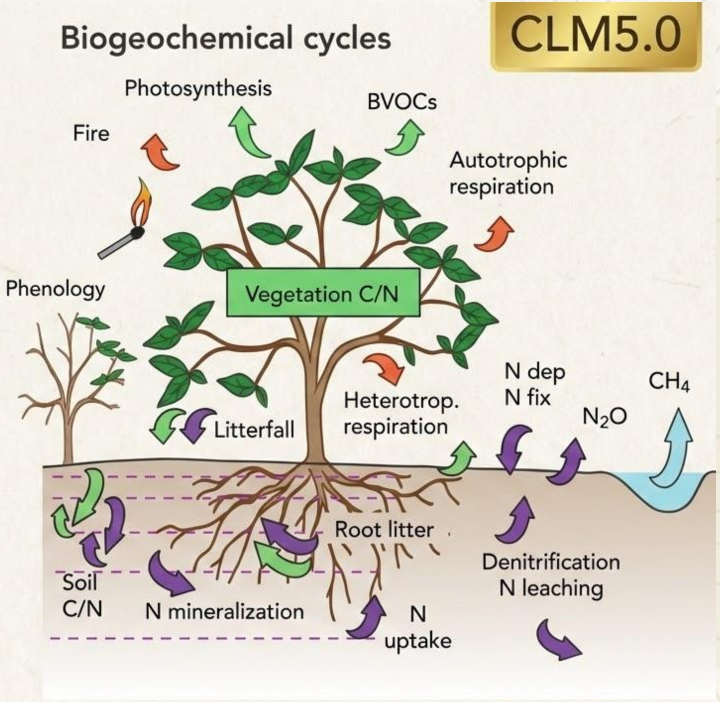
Two modes (levels of complexity)

- SP (satellite phenology): fixed leaf area and no carbon cycle.
- BGC(-Crop): full biogeochemical cycle, and possibility to run with crop model



Namelist options (example: snow)

CaseDocs/lnd_in:

```
nlevsno = 12
nsegspc = 35
o3_veg_stress_method = 'unset'
paramfile = '/cluster/shared/noresm/inputdata/lnd/clm2
run_zero_weight_urban = .false.
snicar_dust_optics = 'sahara'
snicar_numrad_snw = 5
snicar_snobc_intmix = .true.
snicar_snodst_intmix = .false.
snicar_snw_shape = 'hexagonal_plate'
snicar_solarspec = 'mid_latitude_winter'
snicar_use_aerosol = .true.
snow_cover_fraction_method = 'SwensonLawrence2012'
snow_thermal_cond_glc_method = 'Jordan1991'
snow_thermal_cond_lake_method = 'Jordan1991'
snow_thermal_cond_method = 'Sturm1997'
```

paramfile:

```
snw_rds_refrz = 1500 ;
snw_rds_min = 54.526 ;
fresh_snw_rds_max = 400 ;
snow_canopy_storage_scalar = 6 ;
snowcan_unload_temp_fact = 187000 ;
snowcan_unload_wind_fact = 0.5 ;
snow5d_thresh_for_onset = 0.2 ;
wind_snowcompact_fact = 5 ;
```

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FATES: the Functionally Assembled Terrestrial Ecosystem SImulator

https://github.com/NGEET/fates

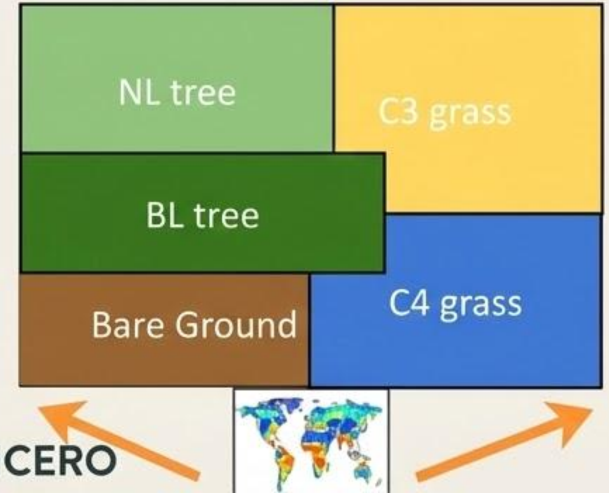
FATES is an advanced **vegetation** model, integrated into the Community Land Model* (**CLM**)

Open source, decentralized **community** development.

Flexible structural assumptions, parameters and complexity

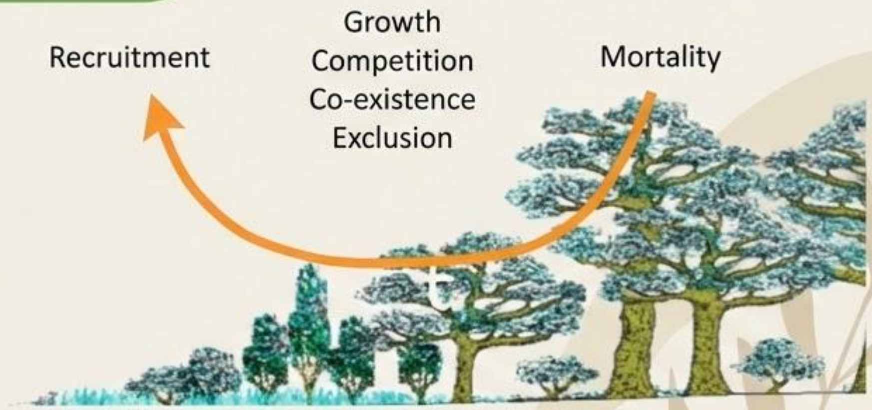
Ecological processes in land surface models

Big Leaf Model



Cohort model

Stochastic Individual Model



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Stand Age - 350
Biomass - 390 kg C
Stems - 32
Mean DBH - 18 cm
CO2
H2O
ALBEDO

Status of FATES

- FATES is the default vegetation model in NorESM3
- It will be the default vegetation of the CESM post CLM6 (i.e. as of now)
- No new developments in the old vegetation scheme will be supported.

Resources - CTSM

CTSM Resources

NorESMhub / CTSM GitHub

https://github.com/NorESMhub/CTSM

CTSM

https://www.cesm.ucar.edu/models/cesm2/land

CTSM documentation

(latest development version)

https://escomp.github.io/CTSM/index.html

FATES Resources 1

FATES GitHub

https://github.com/NGEET/fates

NorESM-FATES GitHub

https://github.com/NorESMhub/fates/tree/noresm

FATES Tech note

https://fates-users-guide.readthedocs.io/projects/tech-doc/en/stable/

FATES Resources 2

FATES User Guide

https://fates-users-guide.readthedocs.io/en/latest/

FATES Namelist Options

https://fates-users-guide.readthedocs.io/en/latest/user/namelist-options.html

NorESM-FATES Diagnostics Package

https://github.com/NorESMhub/xesmf_clm_fates_diagnostic

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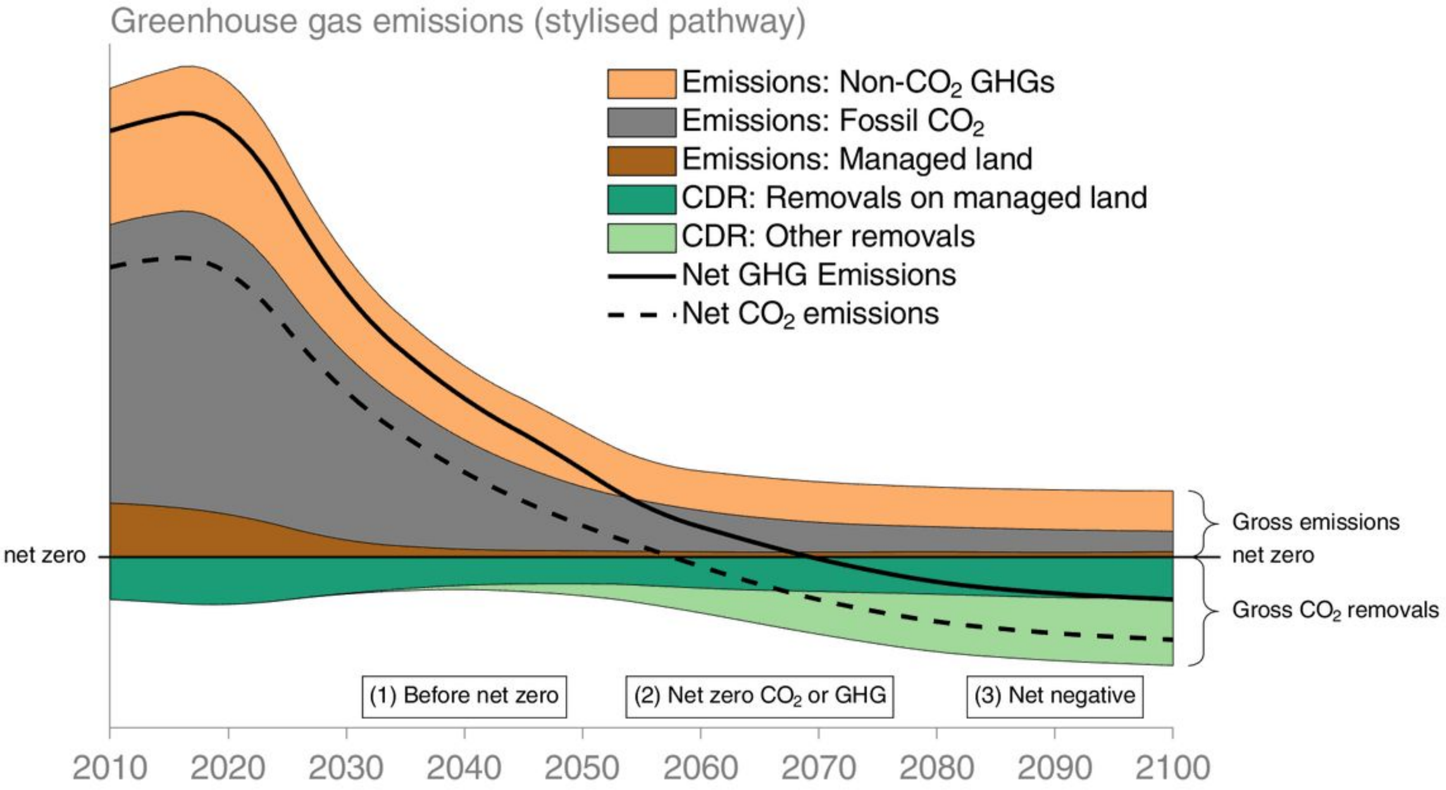
- SPARE SLIDES

CLIMATE MITIGATION:

Can the land keep **absorbing** our CO2 emissions?

Paris compatible future scenarios



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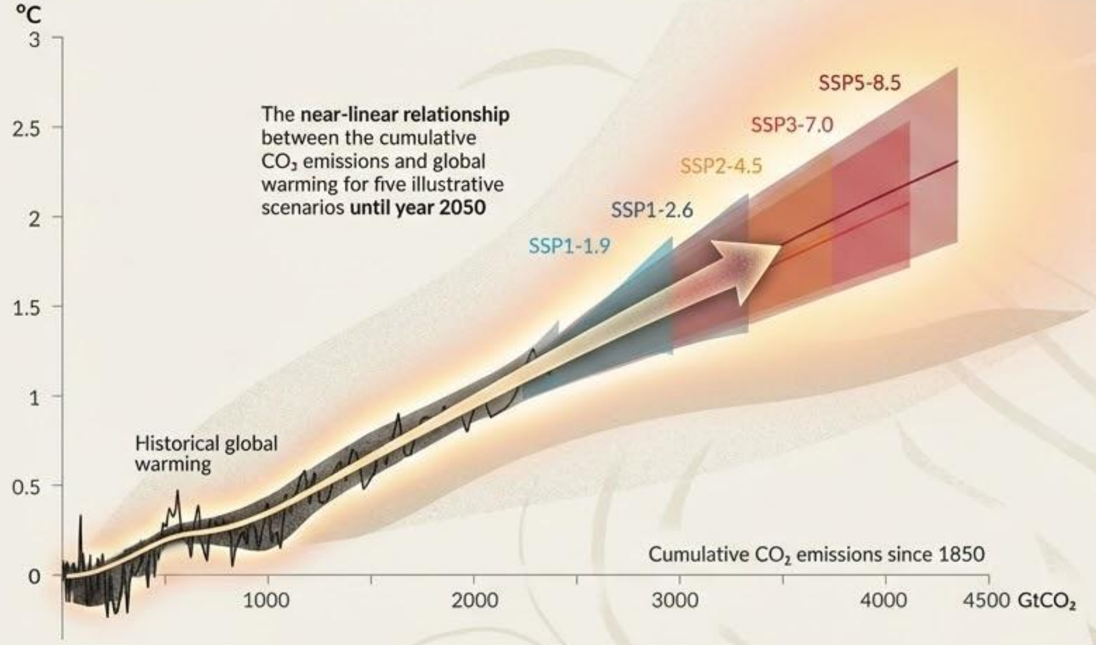
Glen Peters, based on IPCC AR6

CLIMATE SYSTEM: What is the Transient Climate Response to Cumulative CO2 Emissions (TCRE)?

Every tonne of CO_2 emissions adds to global warming

Global surface temperature increase since 1850–1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$)



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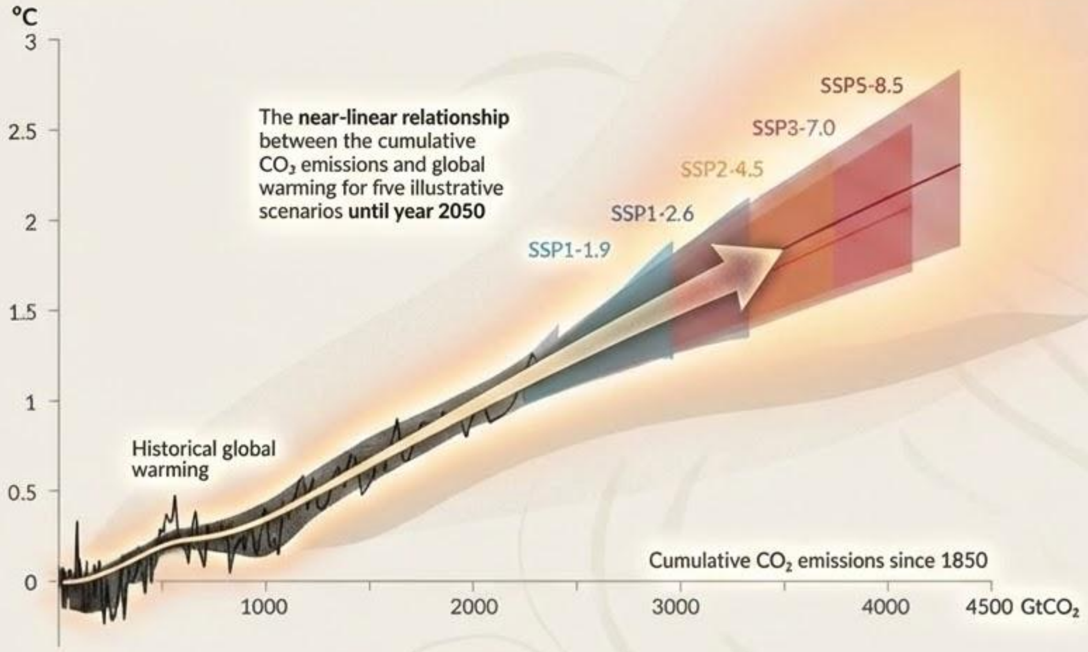

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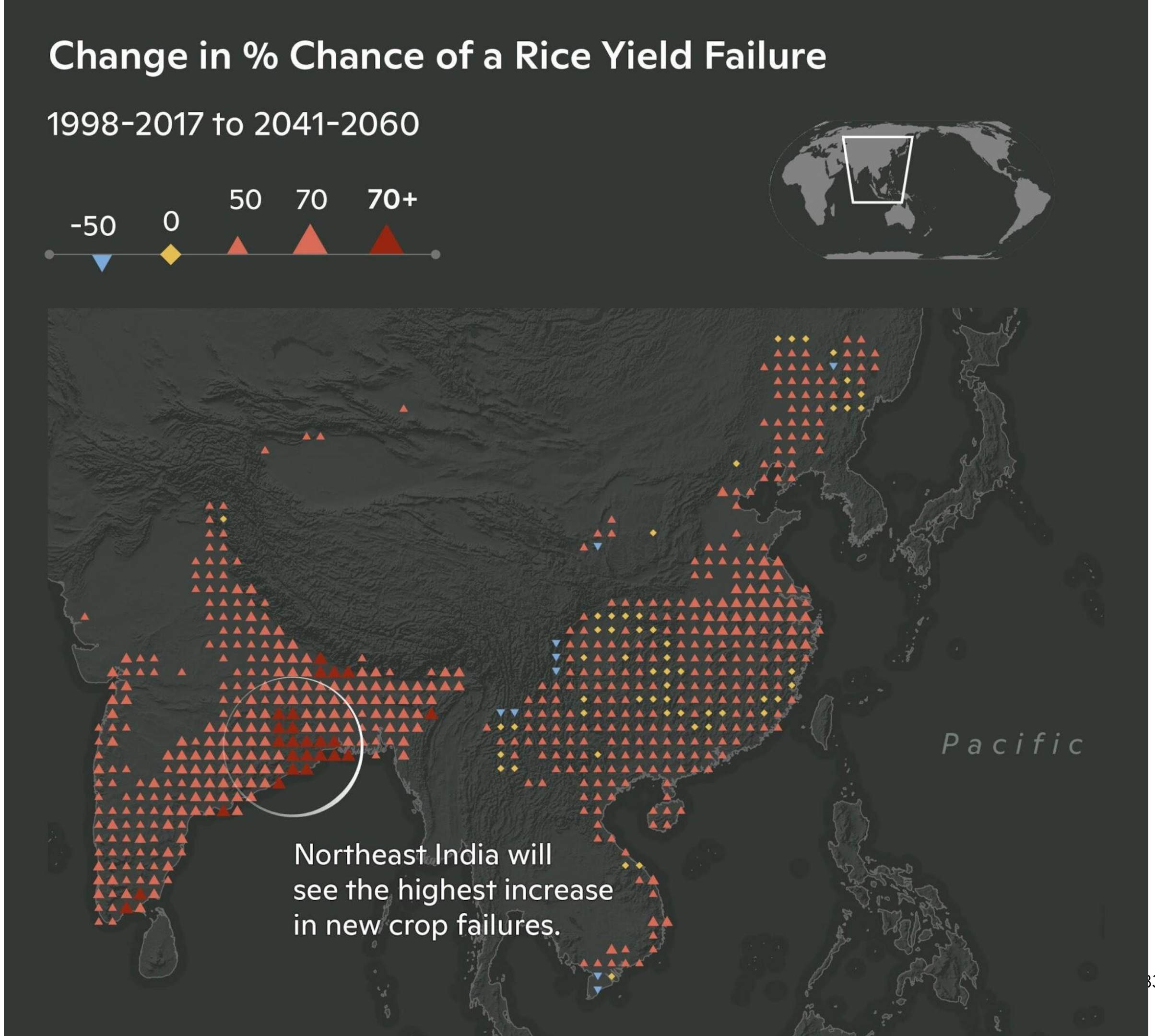
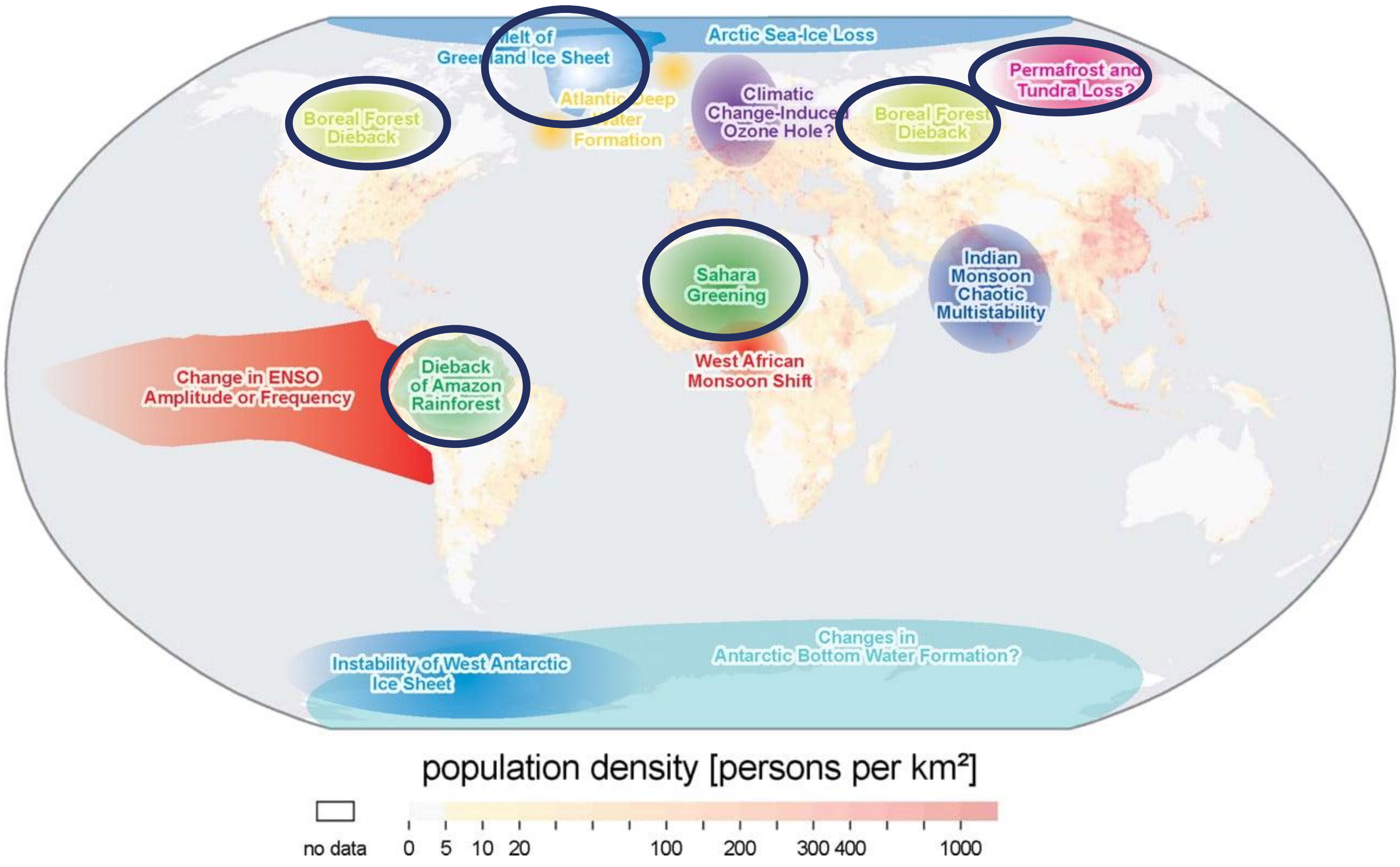
CLIMATE IMPACTS: Will **crops** fail under future climate change?

Caparas et al. 2021



CLIMATE SYSTEM:
Are there land-mediated '**tipping points**'?

Lenton et al. 2008



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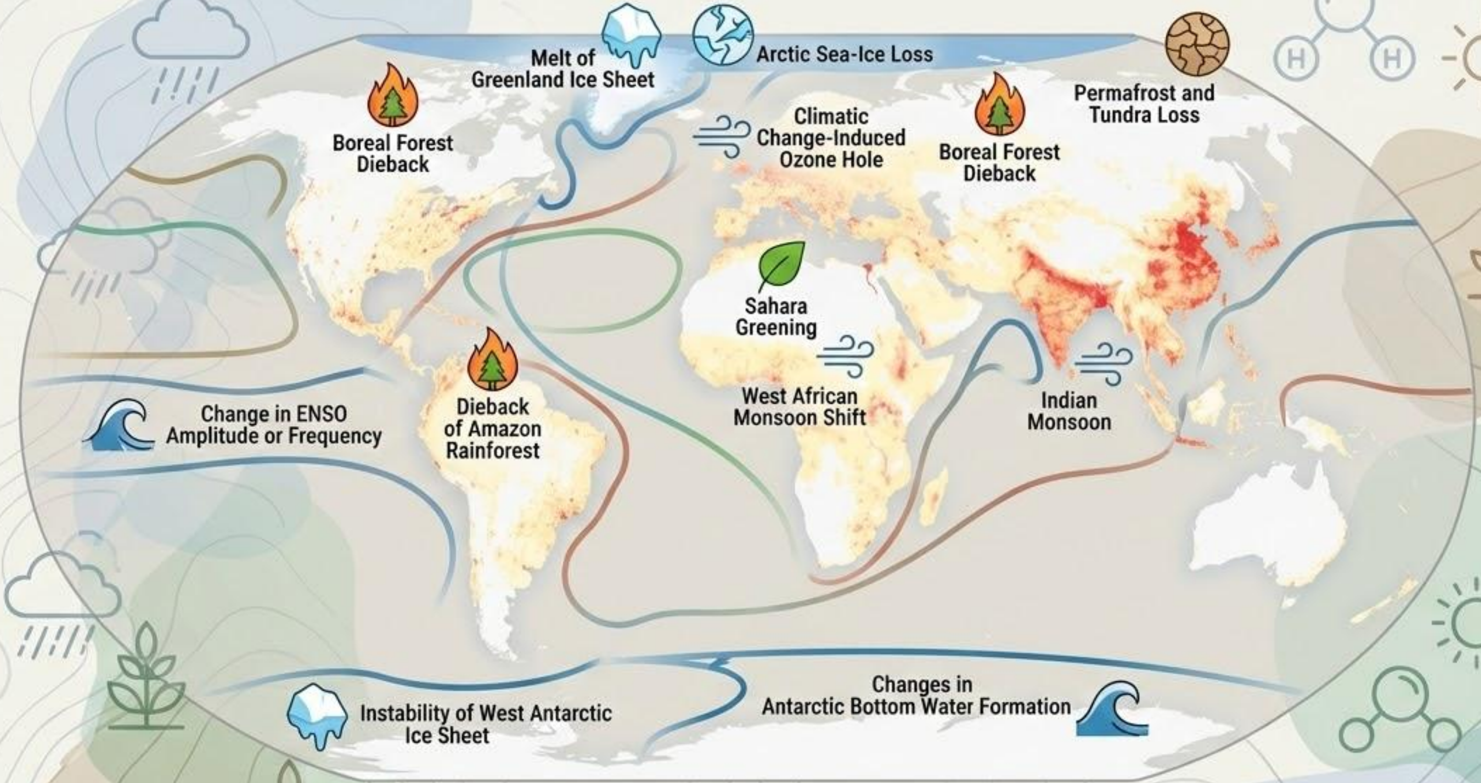
Are there land-mediated **'tipping points'?**

Lenton et al. 2008



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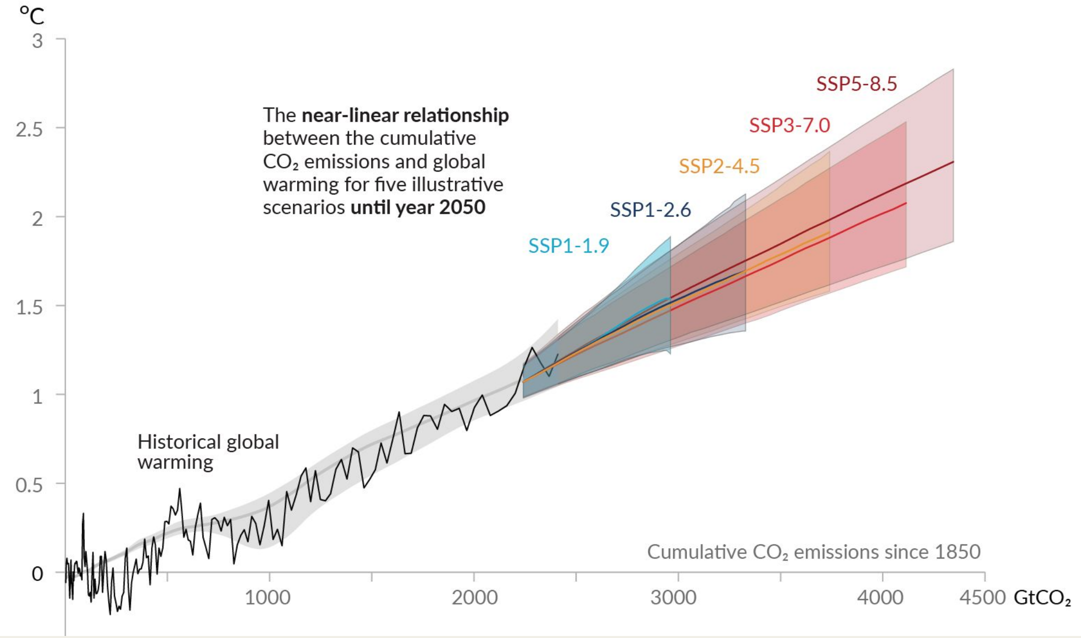

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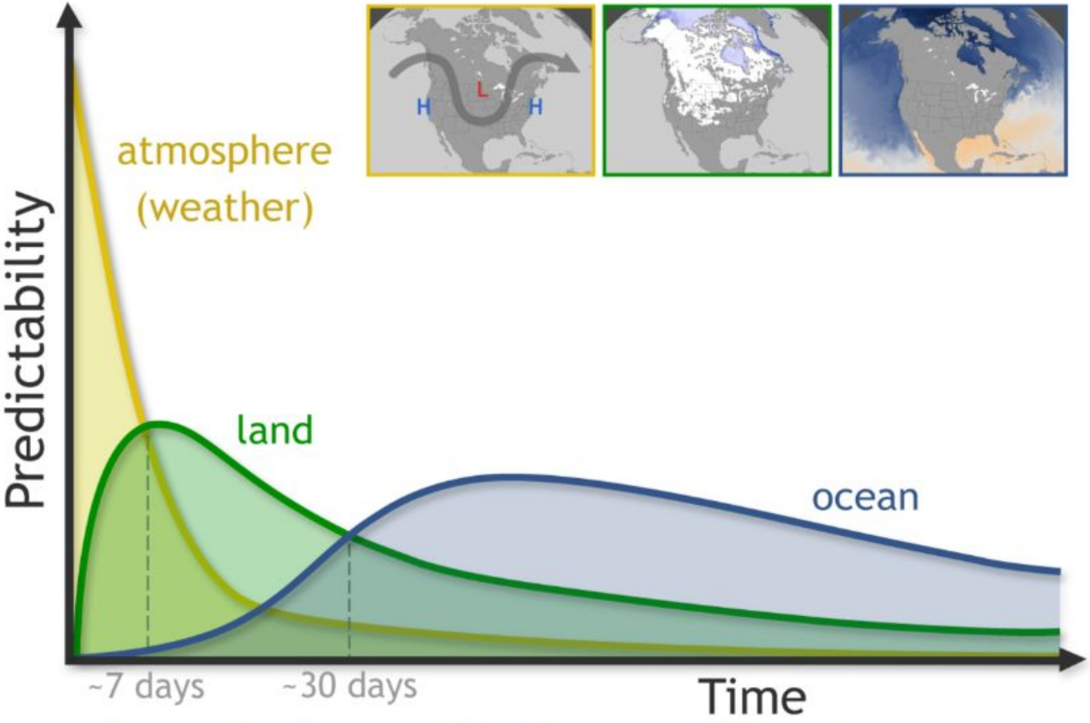
CLIMATE SYSTEM: What is the role of the land surface in the coupled Earth System?



Relative contribution to predictability as a function of forecast lead time of the initial states of the atmosphere, land and ocean in numerical model forecasts at a typical mid-latitude continental location.

science.gmu.edu

Who are we?

Rosie Fisher:. Co-chair, CESM Land Model Working Group,.
plant demography, plant hydraulics, fire, nutrient cycling,

Kjetil Aas: Land lead, NorESM consortium.

Land atmosphere exchange, cryosphere, hydrology, land use.

Jessica Needham: Senior Researcher.

Tropical forest ecology, ecosystem demography, land use change.

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Some model configurations: N1850 (all active)

1850_CAM60%NORESM_CLM50%BGC-CROP_CICE%NORESM-CMIP6_BLOM%ECO_MOSART_SGLC_SWAV_BGC%BDRDDMS

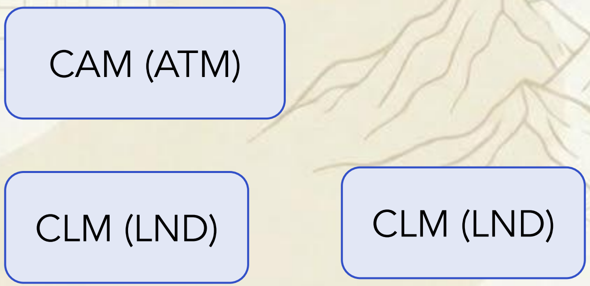
CAM (ATM)

CLM (LND)

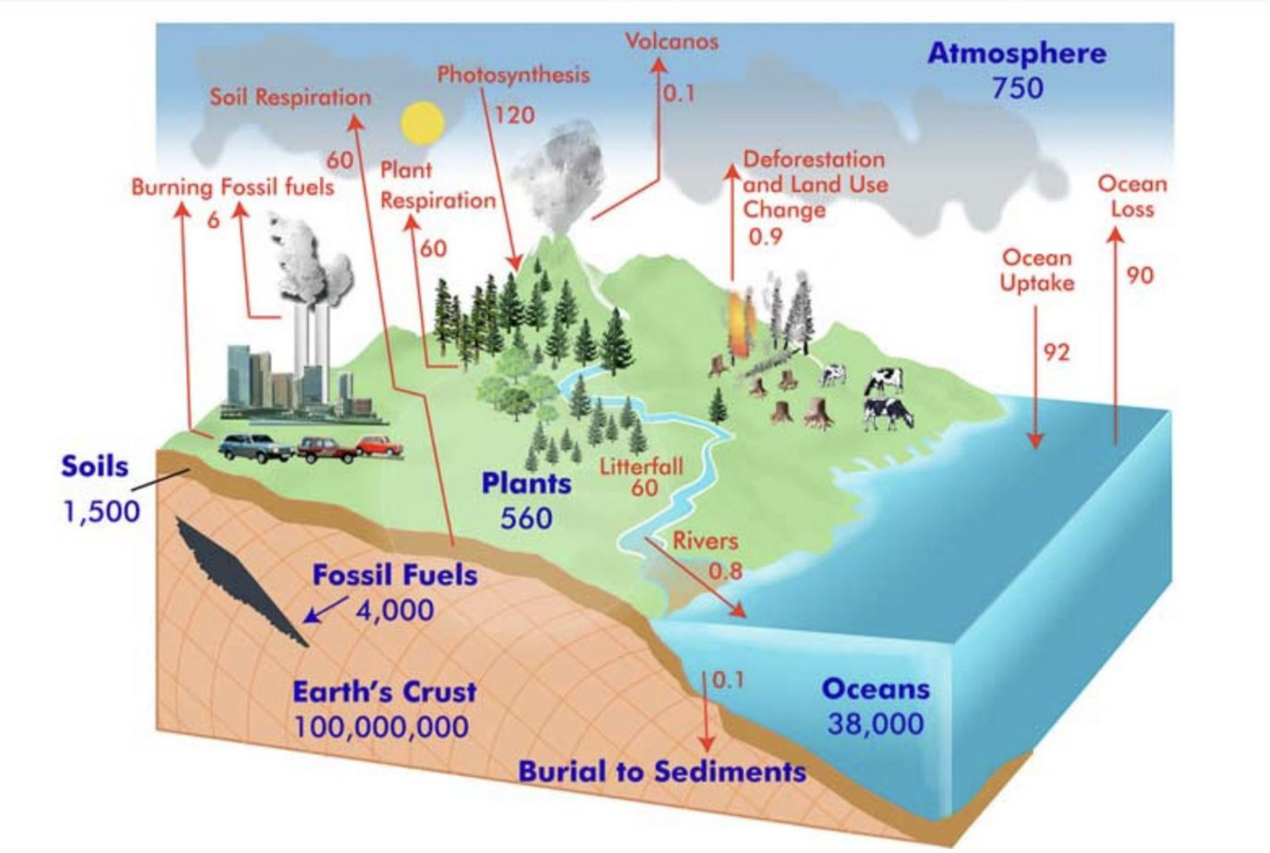
CLM (LND)

Some model configurations: N1850 (all active)

1850_CAM60%NORESM_CLM50%BGC-CROP_CICE%NORESM-CMIP6_BLOM%ECO_MOSART_SGLC_SWAV_BGC%BDRDDMS



Global Carbon fluxes & stocks



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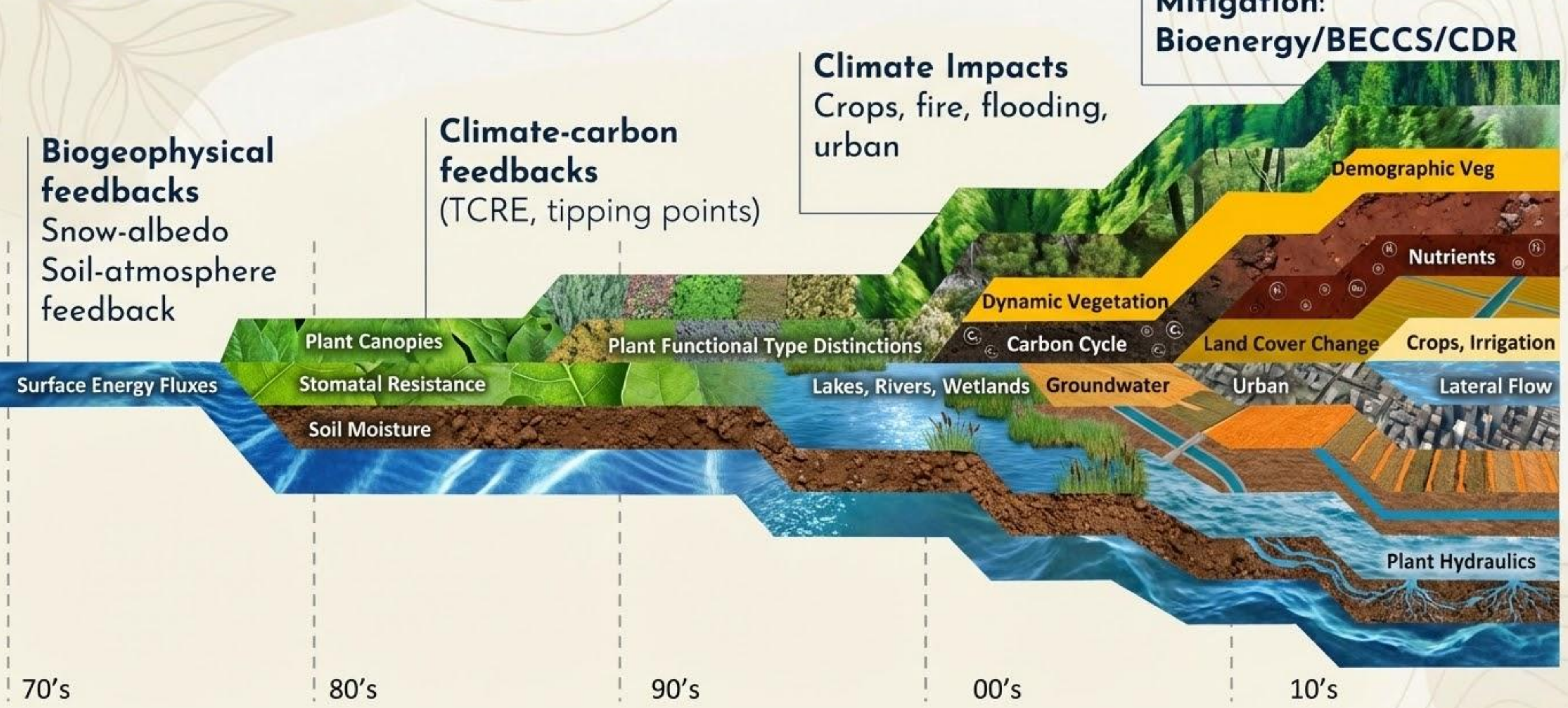
Some model configurations: N1850 (all active)

1850_CAM60%NORESM_CLM50%BGC-CROP_CICE%NORESM-CMIP6_BLOM%ECO_MOSART_SGLC_SWAV_BGC%BDRDDMS

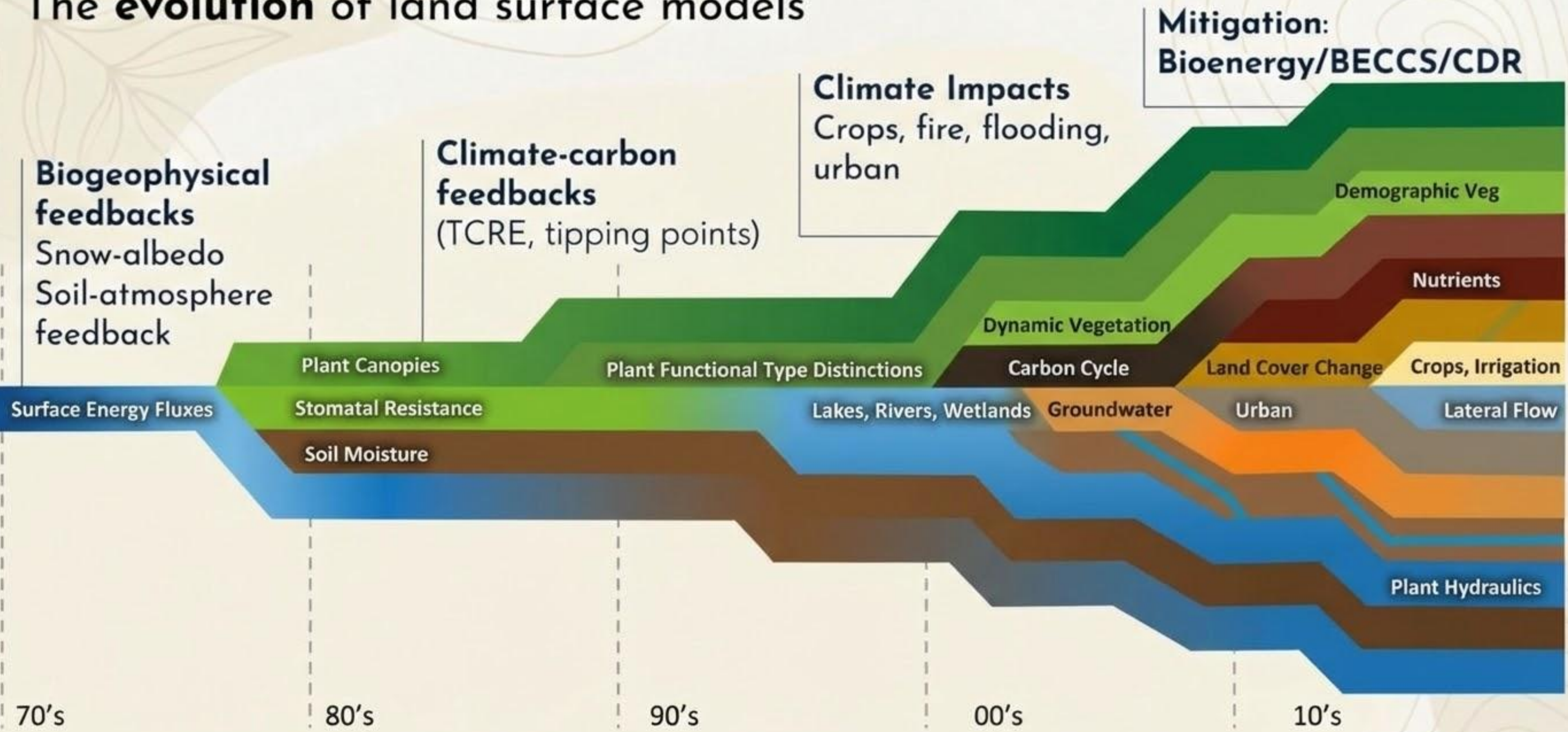
Some model configurations: NF1850 (land-atm)

1850_CAM60%NORESM_CLM50%SP_CICE%PRES_DOCN%DOM_MOSART_SGLC_SWAV

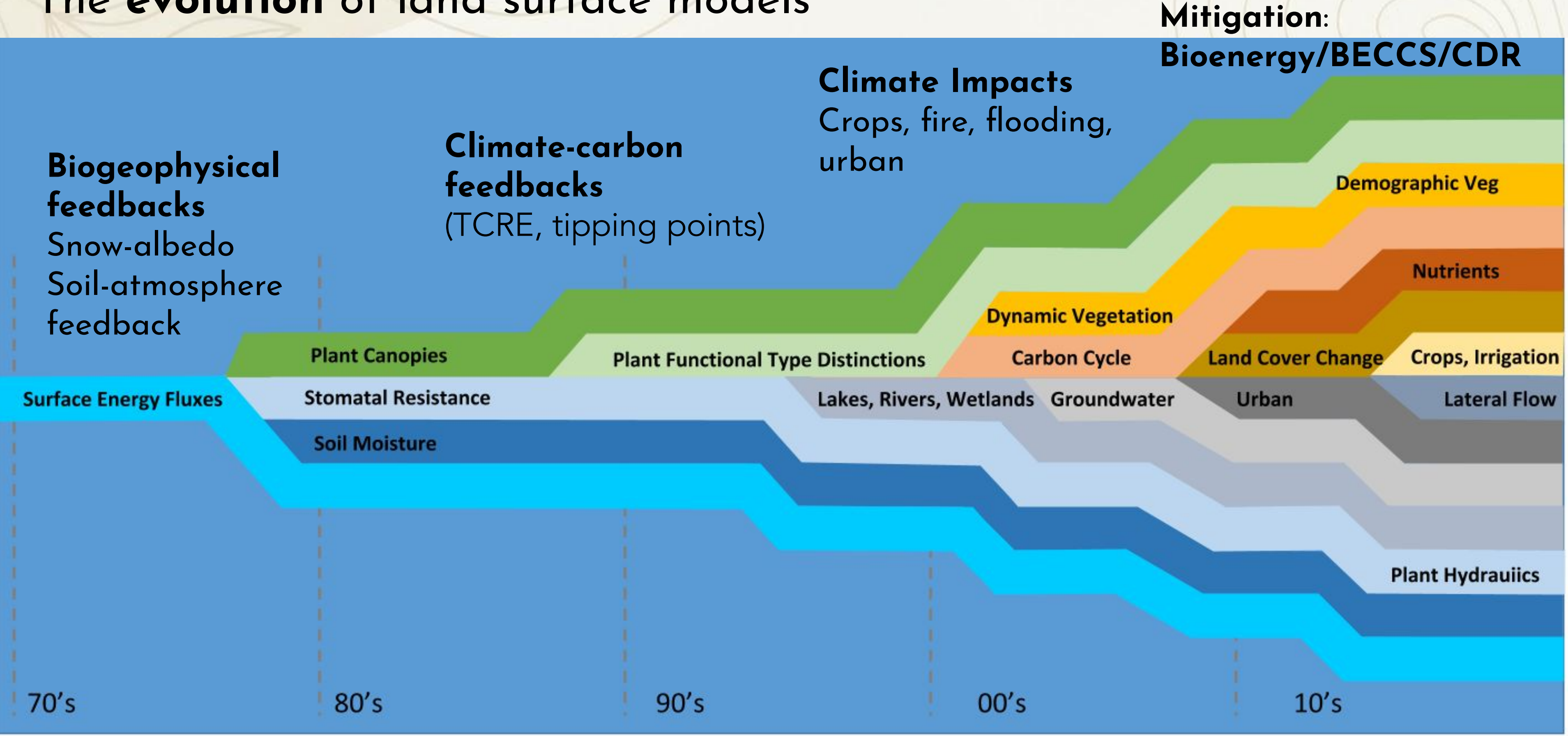
The **evolution** of land surface models



The **evolution** of land surface models

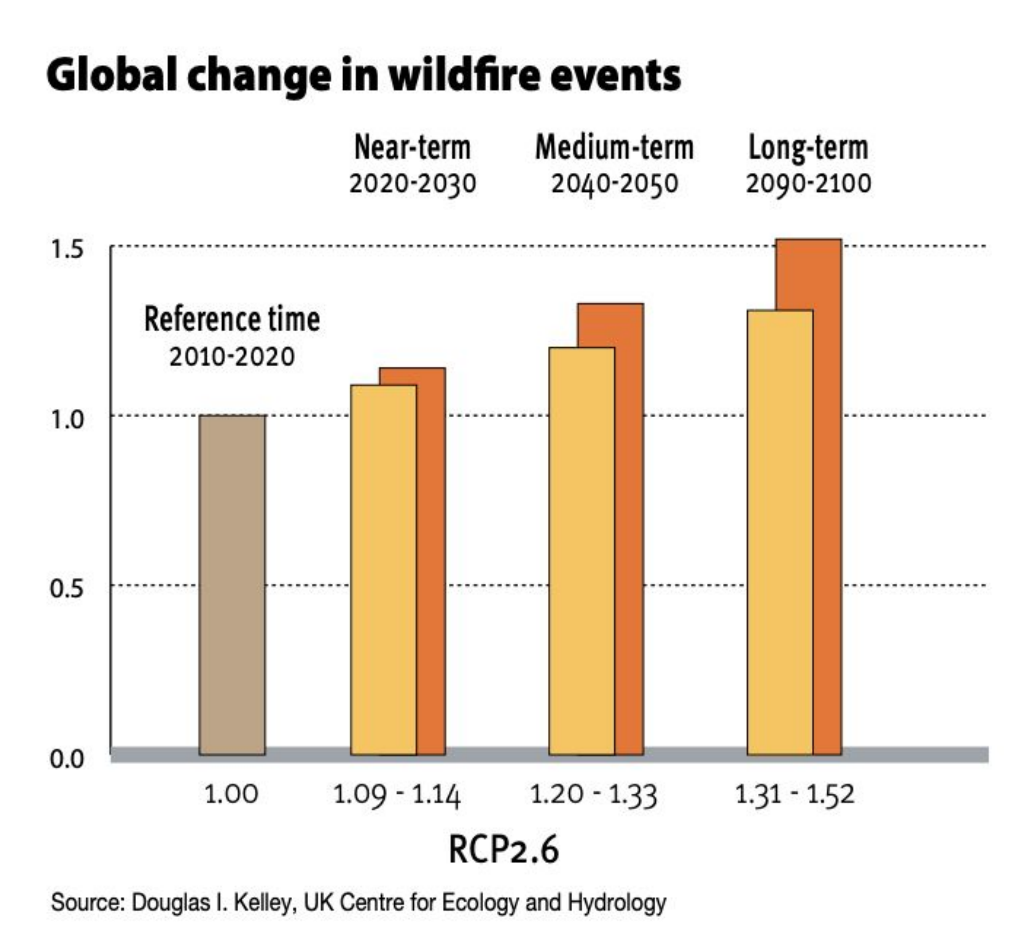


The **evolution** of land surface models



CLIMATE IMPACTS: How will **wildfires** change?

UNEP 2022



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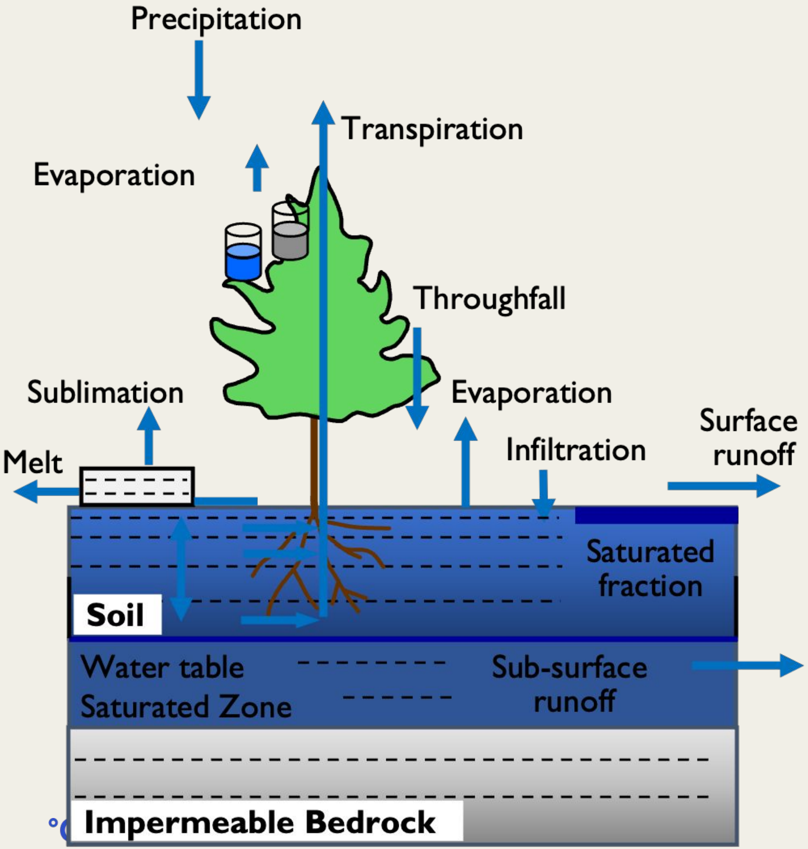
Water



$$P = ES + ET + EC + R + (\Delta W_{soil} + \Delta W_{snow} + \Delta W_{sfcw} + \Delta W_{can}) / \Delta t$$

P is rainfall/snowfall,

ES is soil evaporation,

ET is transpiration,

EC is canopy evaporation,

R is runoff (surf + sub-surface),

ΔW_{soil}, ΔW_{snow}, ΔW_{sfcw}, & ΔW_{can} are changes in soil moistu snow, surface water, and canopy water over a timestep

Model configurations: I1850… (land only)

I1850Clm50Sp : 1850_DATM%GSWP3v1_CLM50%SP_SICE_SOCN_MOSART_CISM2%NOEVOLVE_SWAV
I1850Clm50Bgc : 1850_DATM%GSWP3v1_CLM50%BGC_SICE_SOCN_MOSART_CISM2%NOEVOLVE_SWAV
I1850Clm50BgcCrop : 1850_DATM%GSWP3v1_CLM50%BGC-CROP_SICE_SOCN_MOSART_CISM2%NOEVOLVE_SWAV

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Land Modeling in ESMs: How

- **Exchanges** of momentum, energy, water vapor, CO_2, dust, and other trace gases/materials between land and atmosphere + routing of runoff to the ocean
- **States** of land surface (e.g., soil moisture, soil temperature, canopy temperature, snow, carbon and nitrogen stocks in vegetation and soil)
- **Characteristics** of land surface (e.g., soil texture, surface roughness, albedo, emissivity, vegetation type, and leaf area index)