Trait-Based Vegetation Optical Properties Impact Future Climate Projections

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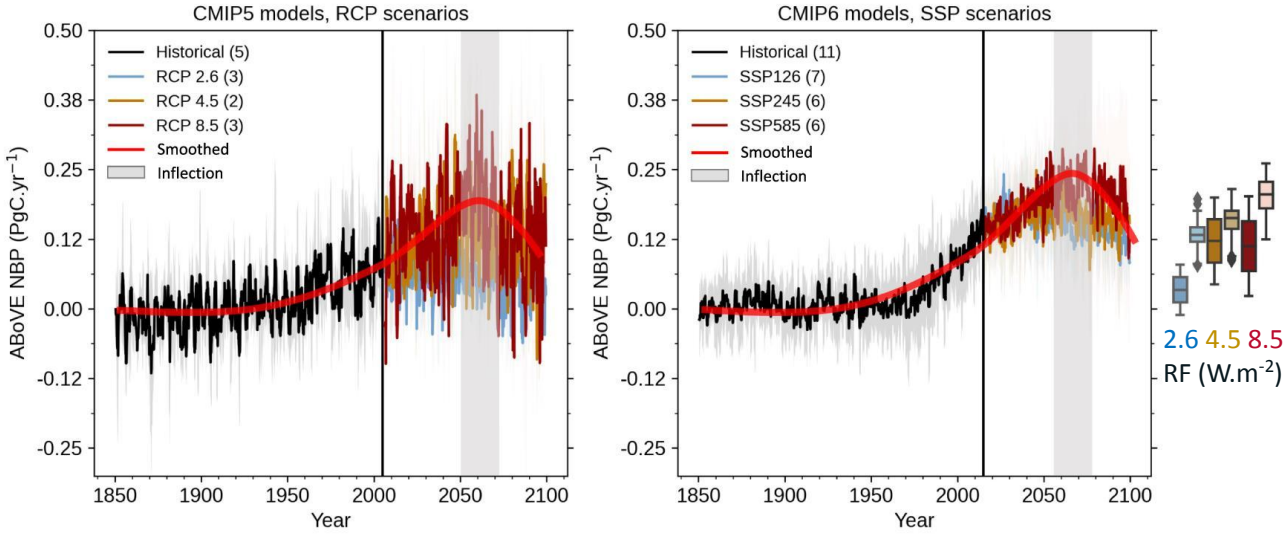
Caltech

Jet Propulsion Laboratory
California Institute of Technology

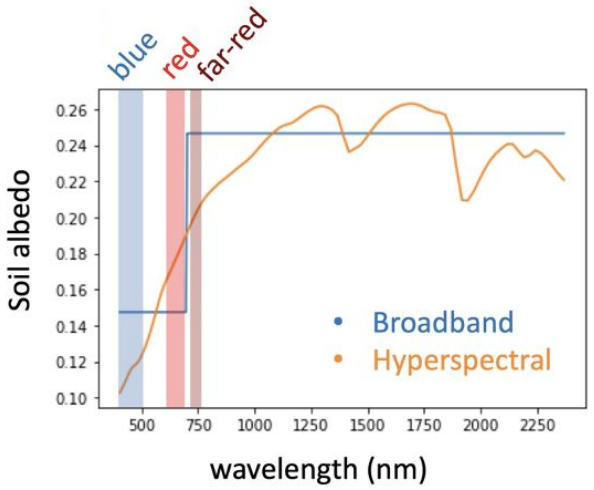
WHAT'S NEXT FOR SCIENCE

Earth System Modeling

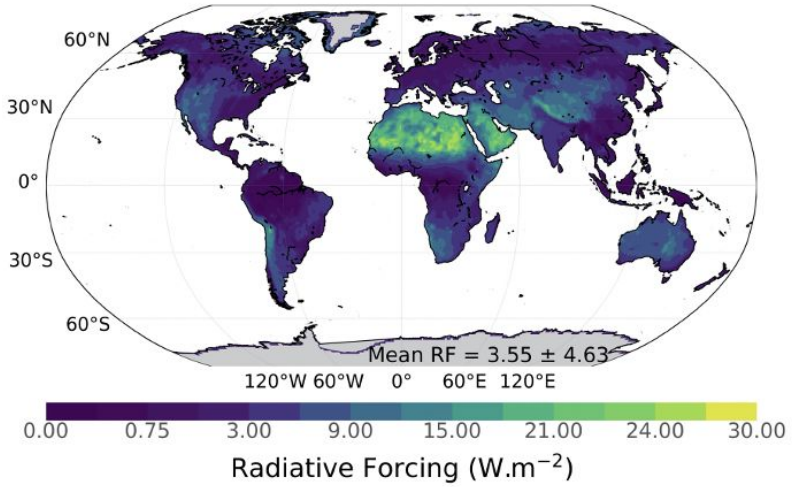
By modeling **physical processes**, ESMs help **understand** and **predict** how the Earth system **interacts** and **responds** to **natural changes** and **human activities**



Braghiere et al. 2023a



Braghiere et al. 2023b



"[…] **transfer of radiation**, water and heat in the vegetation-soil-atmosphere continuum are **treated very simply** in the **global ecosystem models** […]"

IPCC 2013

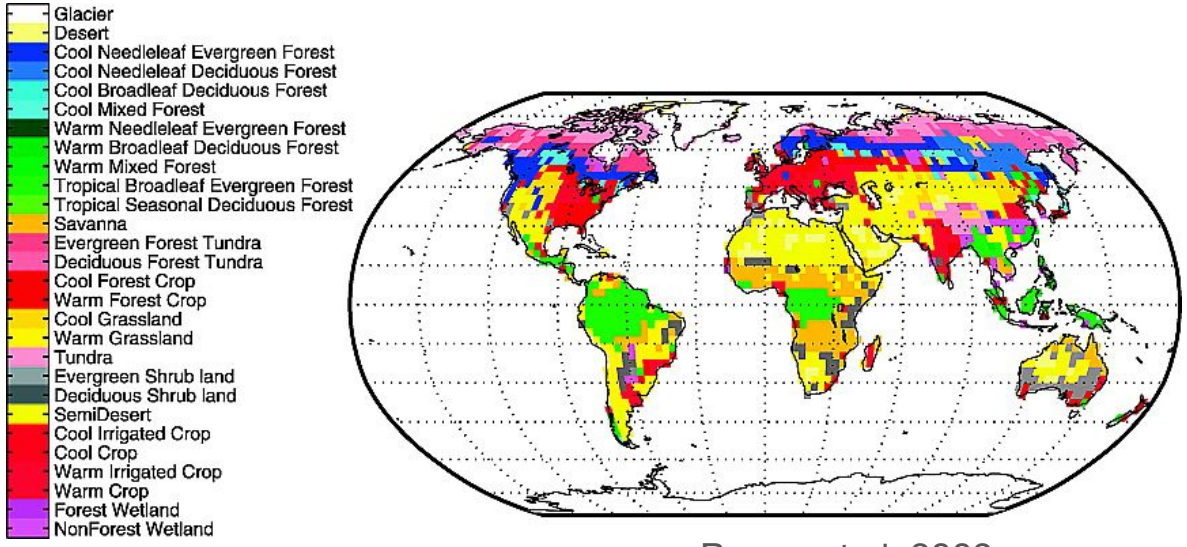
Biodiversity in Earth System Models

Plant functional types (**PFTs**) represent **broad groupings** of **plant species** that share **similar** characteristics in **ecosystem function**.

Why **PFTs**?

- **Lack of observations**;
- **Simpler Look-up** tables;
- Time **invariant properties**;

But are **PFTs** a **sufficient** representation of **biodiversity** in **ESMs**?



Bonan et al. 2002

Radiative transfer scheme: Two-stream

Why the **two-stream scheme**?

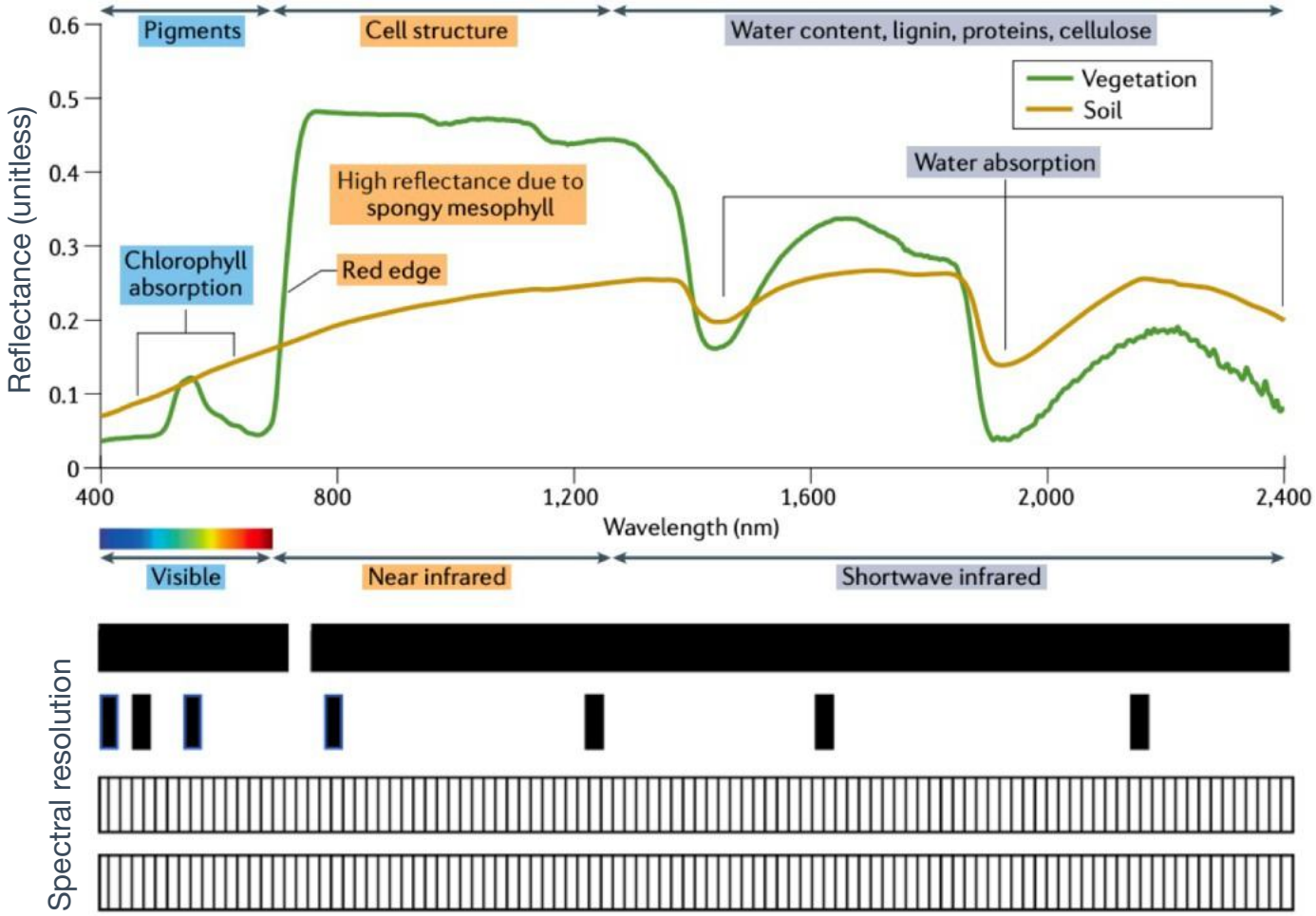
- **Fewer** parameters;
- Computationally **efficient**;
- **Lack of observations**;
- **Broadband:**

PAR: 400 - 700 nm,

NIR: 700 - 2500 nm;

ESMs	2 bands
MODIS	7 bands
EMIT/PACE/SBG…	100s bands
New ESMs?	100s bands

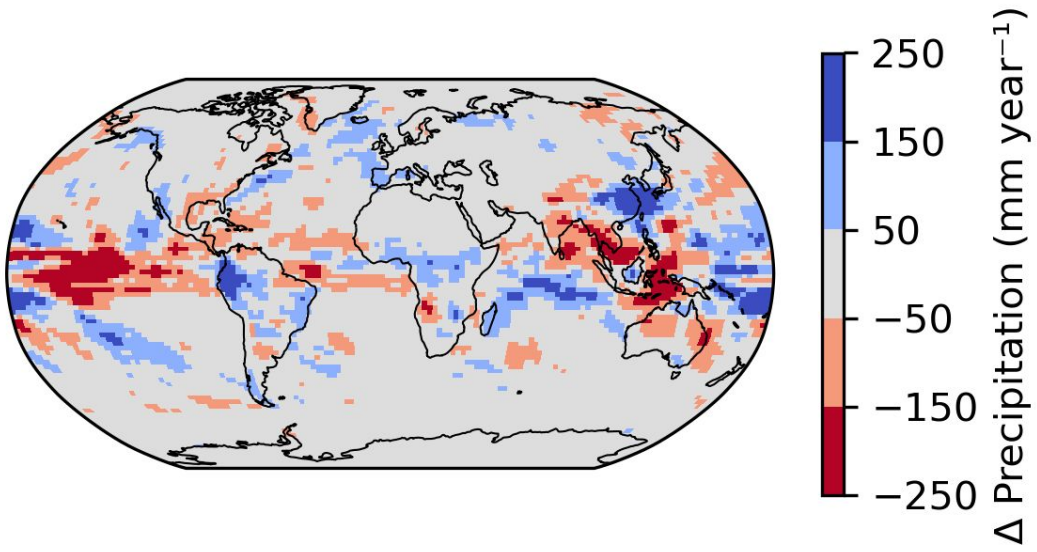
Sir Isaac Newton color wheel, 1672

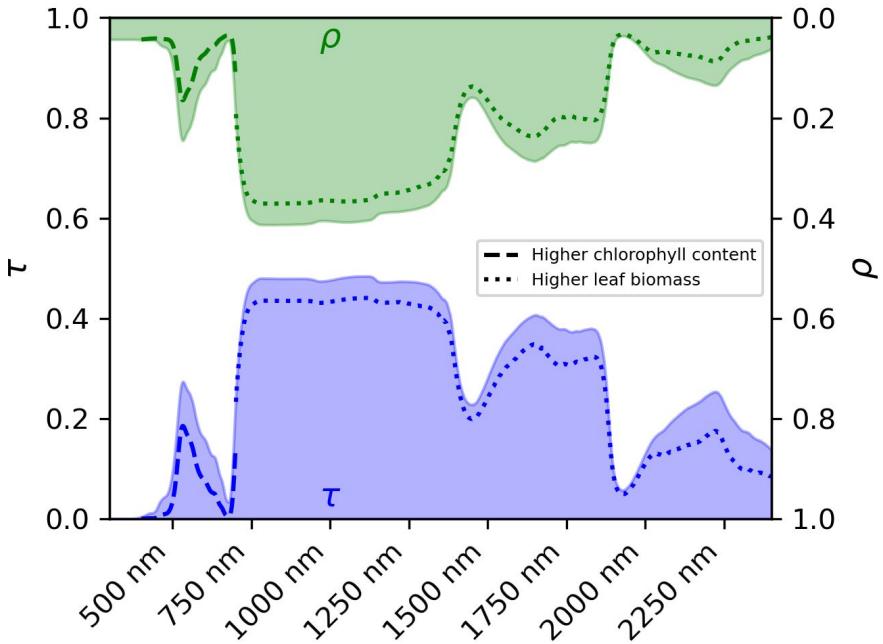


Does it matter?

1. What is the **bias** in **canopy spectral properties** between **PFT vs. Trait**?

- Global **canopy albedo maps**;
- Calculate **bias**.





2. What is the **impact** of the **canopy albedo bias** on **climate and carbon simulations**?

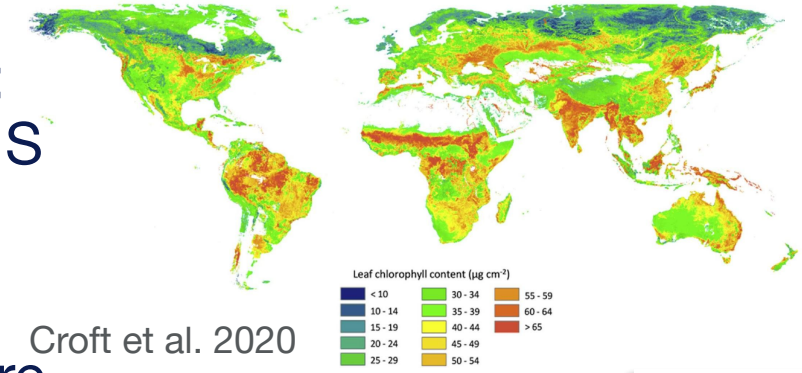
- Run a **climate model**;
- Compare **performance**.

PFT vs. Trait: methodology

We developed a **global map of canopy spectral properties**:

- Using **a leaf chlorophyll content map** derived from ENVISAT MERIS (Croft et al. 2020);
- Using the **CliMA land model** (Wang et al., 2021, 2023; Braghiere et al. 2021) to calculate **optical properties** (ρ and τ) from **leaf traits**;
- Replacing the **optical properties** from a **PFT look-up table** with the **trait-based** one in the Community Earth System model (**CESM**) 2 (Danabasoglu et al., 2020).

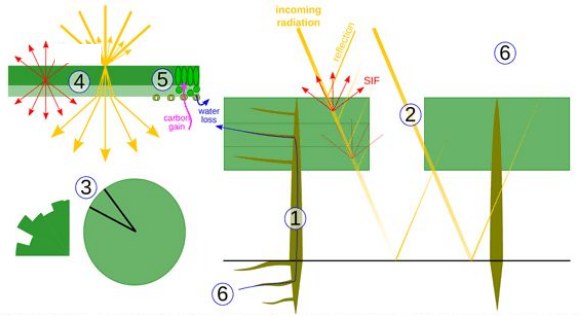
A



Croft et al. 2020

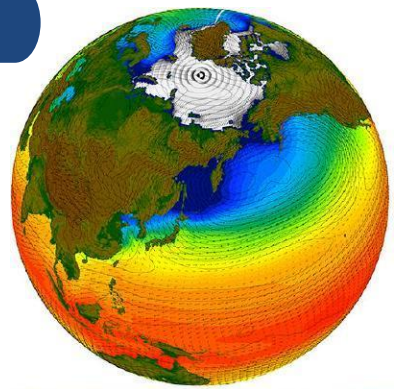
B

CliMA
CLIMATE MODELING ALLIANCE



Wang et al. 2021

C



NCAR

Table 3.1: Plant functional type optical properties

Plant Functional Type	χ_L	α_{vis}^{leaf}	α_{nir}^{leaf}	α_{vis}^{stem}	α_{nir}^{stem}	τ_{vis}^{leaf}	τ_{nir}^{leaf}	τ_{vis}^{stem}	τ_{nir}^{stem}
NET Temperate	0.01	0.07	0.35	0.16	0.39	0.05	0.10	0.001	0.001
NET Boreal	0.01	0.07	0.35	0.16	0.39	0.05	0.10	0.001	0.001
NDT Boreal	0.01	0.07	0.35	0.16	0.39	0.05	0.10	0.001	0.001
BET Tropical	0.10	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BET temperate	0.10	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BDT tropical	0.01	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BDT temperate	0.25	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BDT boreal	0.25	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BES temperate	0.01	0.07	0.35	0.16	0.39	0.05	0.10	0.001	0.001
BDS temperate	0.25	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BDS boreal	0.25	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
C_3 arctic grass	-0.30	0.11	0.35	0.31	0.53	0.05	0.34	0.120	0.250
C_3 grass	-0.30	0.11	0.35	0.31	0.53	0.05	0.34	0.120	0.250
C_4 grass	-0.30	0.11	0.35	0.31	0.53	0.05	0.34	0.120	0.250

reflectance transmittance

PFT vs. Trait: climate bias

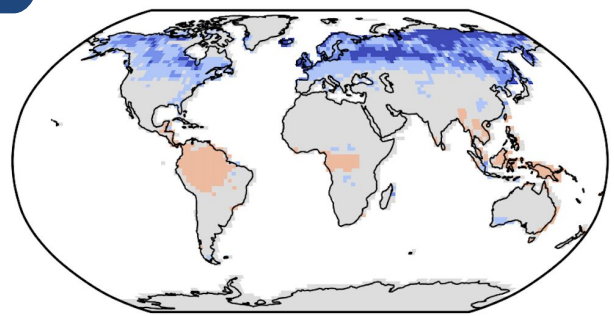
Hyperspectral trait modeling not only enables us to better exploit **satellite data** but also impacts the **surface energy balance**

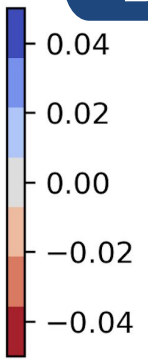
PFT vs. Trait

Canopy albedo differences can reach up to ± 10%

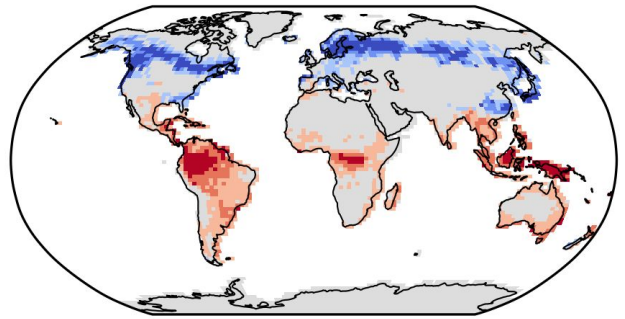
Differences in radiative fluxes exceed 5 W.m^{-2} and 0.4°C

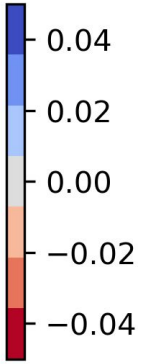
A Trait – PFT PAR albedo



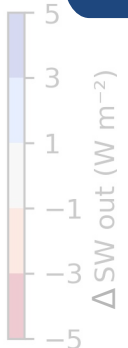


B Trait – PFT NIR albedo





C Trait – PFT Sw_{out} (W.m^{-2})



D Trait – PFT T_{air} (K)

Wang & Braghiere et al, Nature Comm. *under review*

PFT vs. Trait: climate bias

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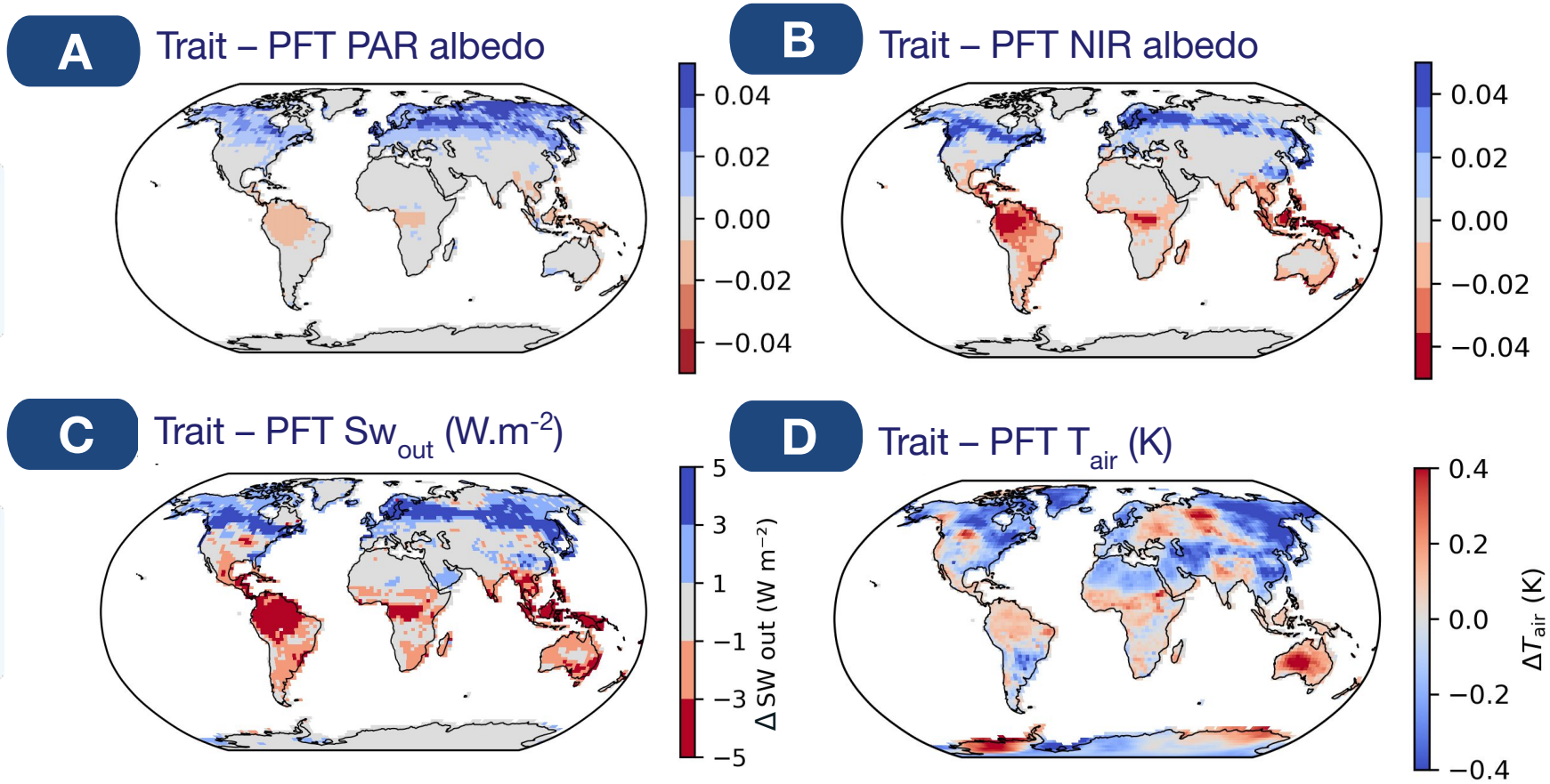


Wang & Braghiere et al, Nature Comm. *under review*

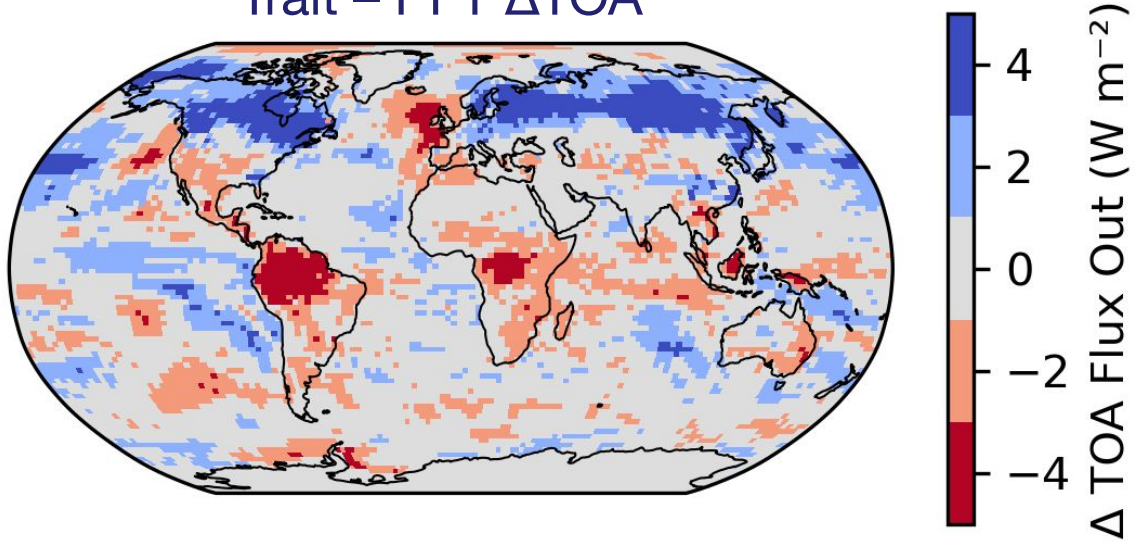
PFT vs. Trait: validation

Changes are observed throughout the **climate system** including **energy**, **water** and **carbon** variables;

	Bias		
Variable	**PFT**	**Trait**	**Reference data**
Tropical PAR albedo	-50.1%	-16.2%	MODIS
Tropical NIR albedo	-78.5%	-62.8%	MODIS

Worse ← Relative agreement with satellite observations → Better

Trait – PFT ΔTOA



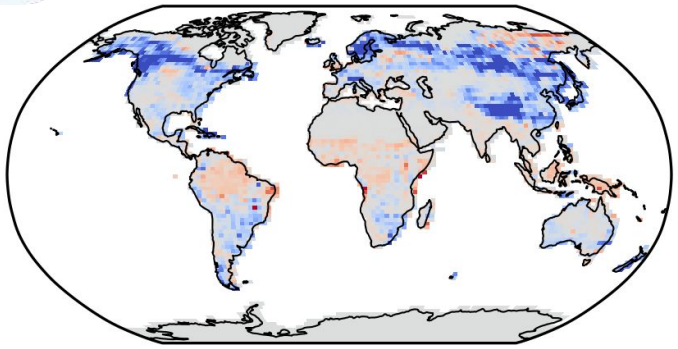
Improvements are observed in the evaluated variables in the **land surface** when compared with **satellite observations.**

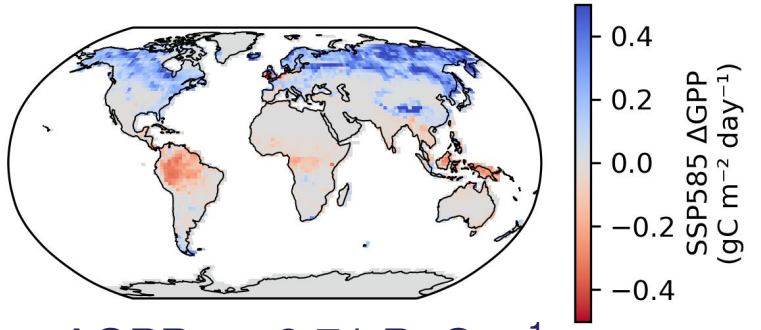
PFT vs. Trait: carbon bias

Boreal regions exhibit **higher GPP** due to improved **light penetration** and **lower vapor pressure deficit**

SSP585

Trait – PFT
ΔGPP = +0.38 PgCyr^{-1}





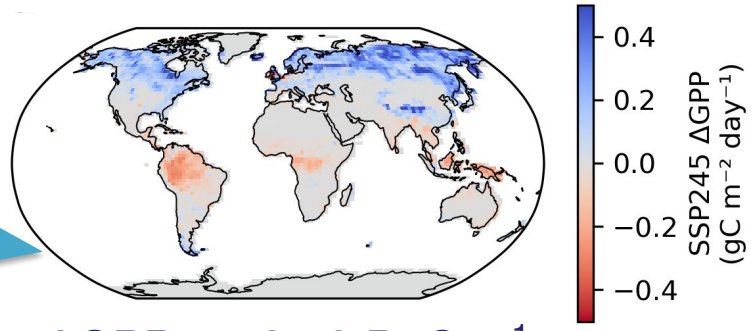
ΔGPP = +0.71 PgCyr^{-1}

*the **SSP585 scenario** exhibits nearly a **2-fold increase** in ΔGPP

Wang & Braghiere et al, Nature Comm. *under review*

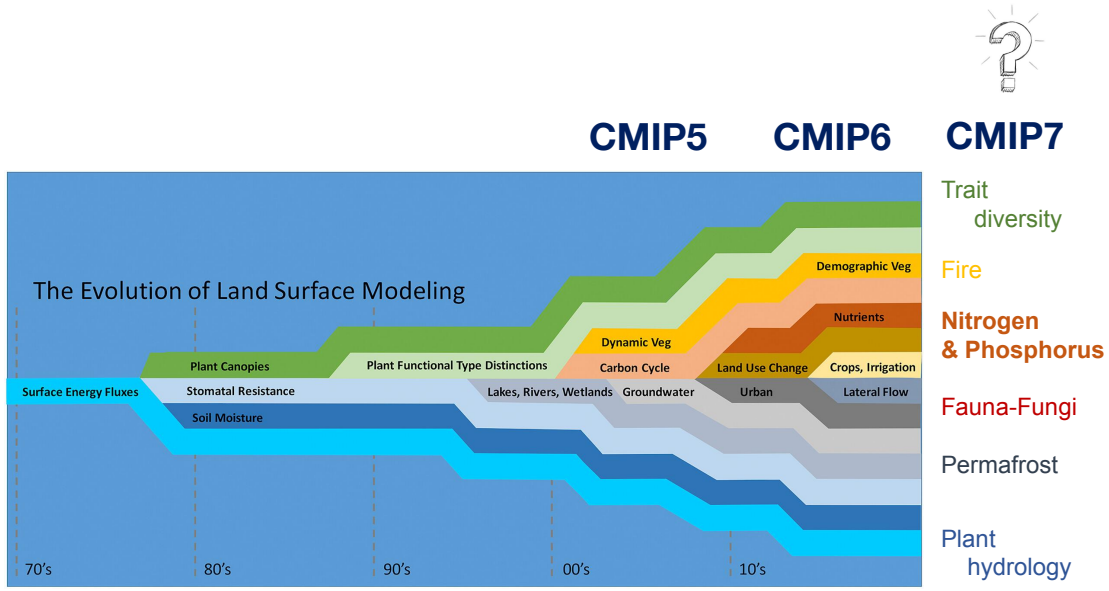
Tropics show **reduced GPP** despite **higher absorbed radiation** due to **increased stress conditions**

SSP245



ΔGPP = +0.50 PgCyr^{-1}

Indirect impact of Nutrients on Climate

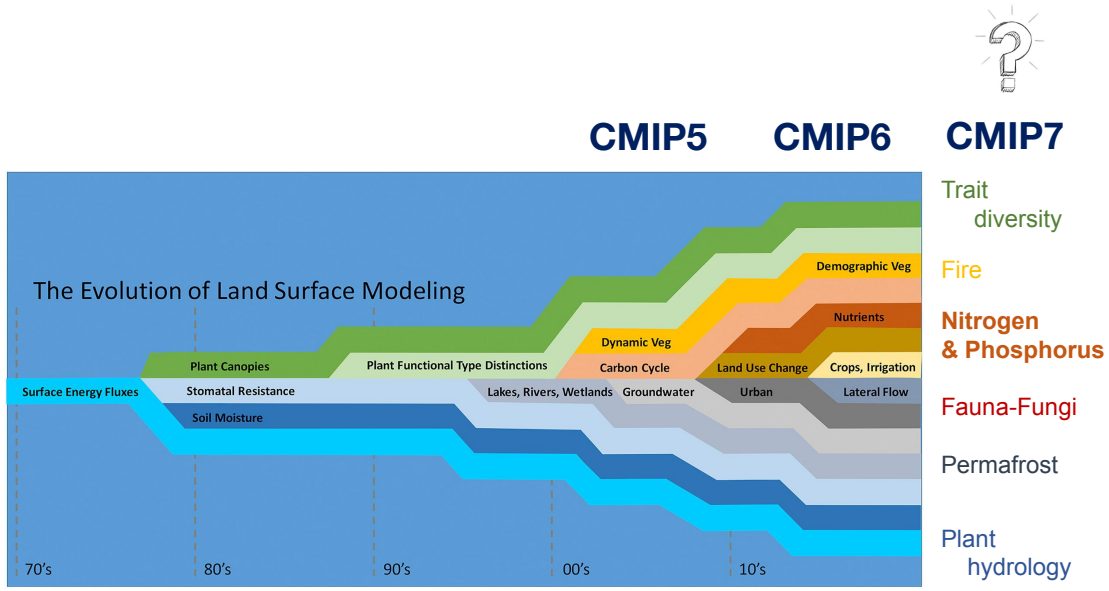


Fisher and Koven, 2020

Nutrient Dynamics

Another example where **trait variability** representation can **impact** the **climate**…

Indirect impact of Nutrients on Climate



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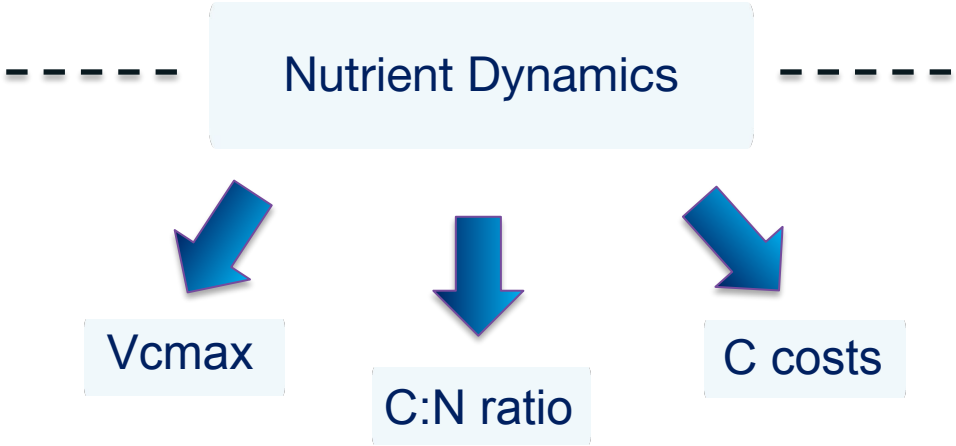
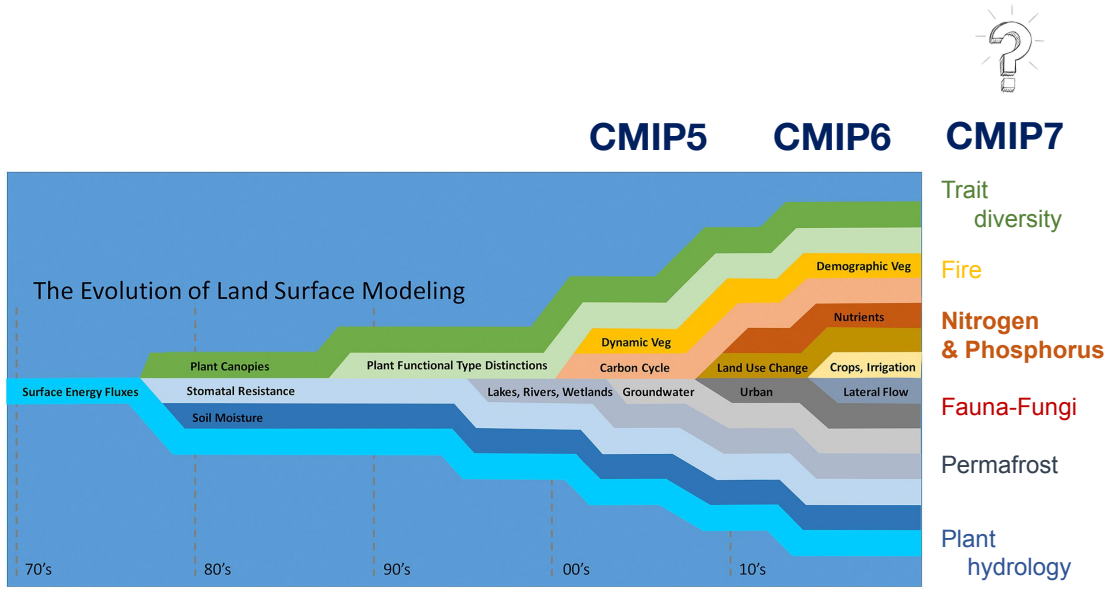


Indirect impact of Nutrients on Climate



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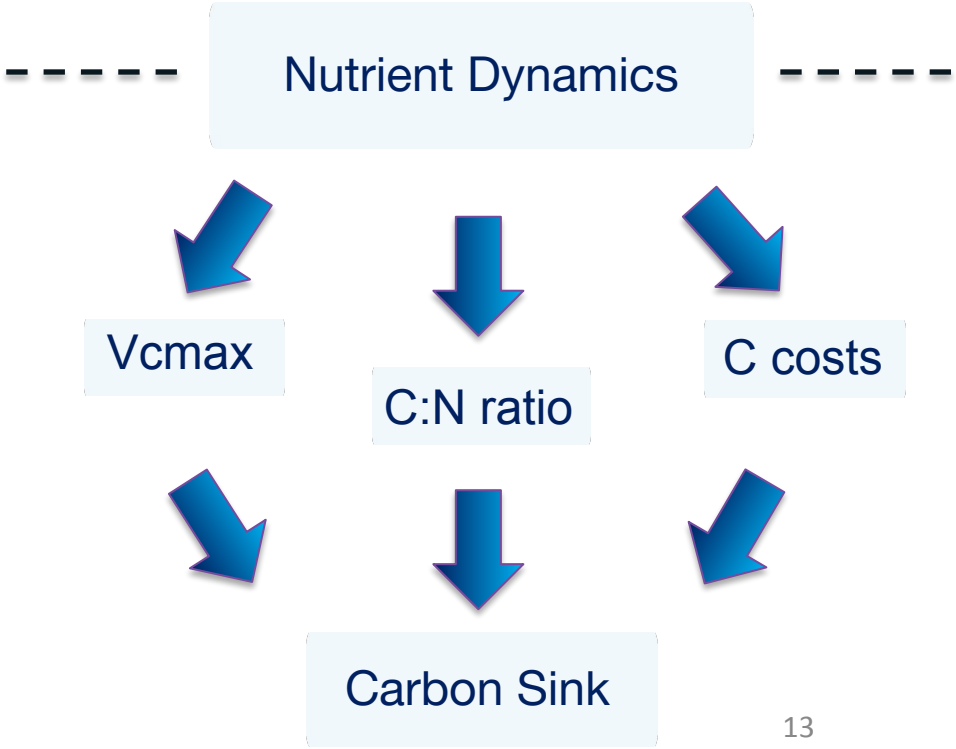

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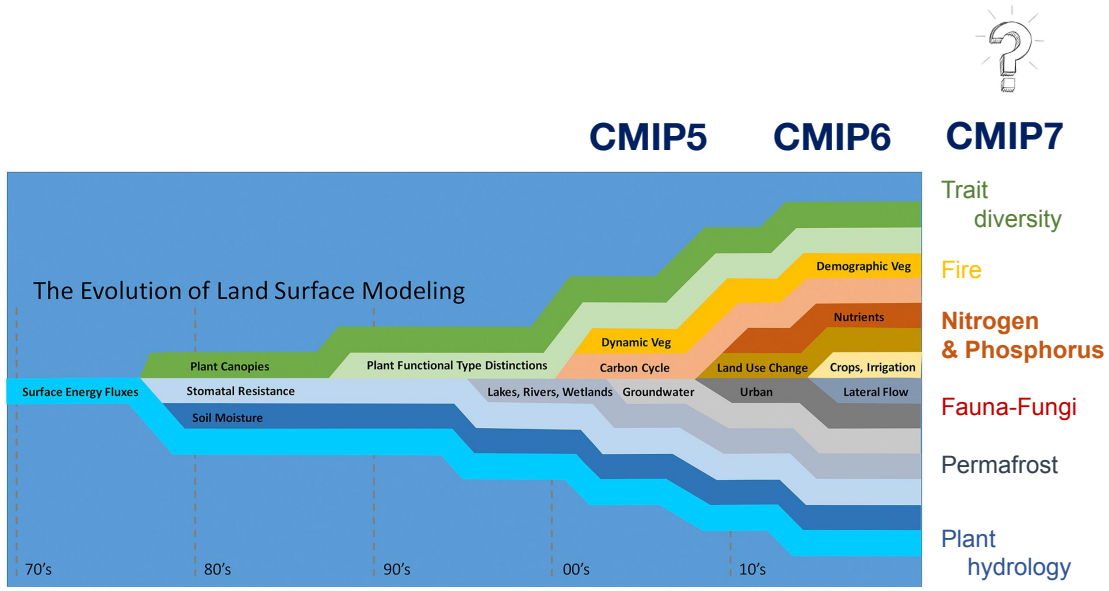
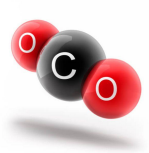
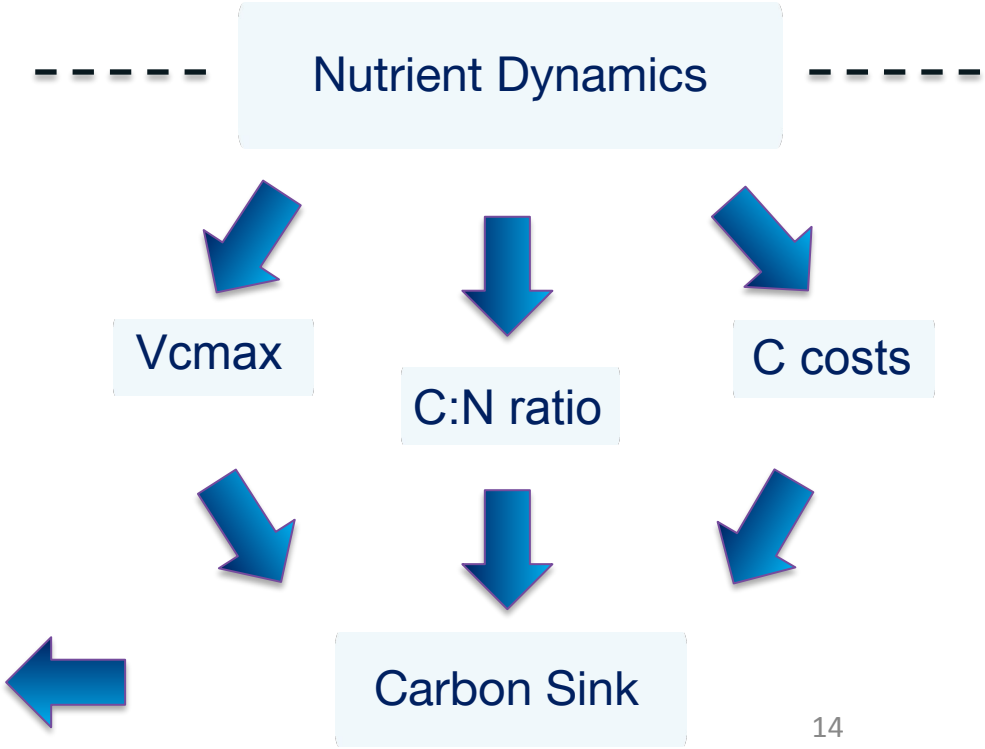


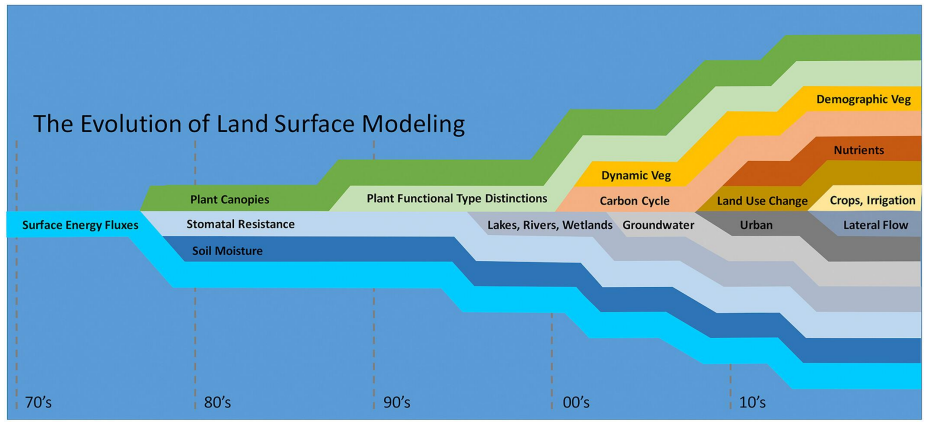
Fisher and Koven, 2020



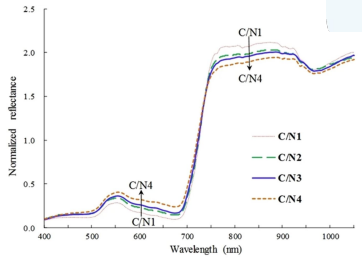
Indirect impacts on climate via CO_2



Indirect & Direct impact of Nutrients on Climate



Fisher and Koven, 2020



Xu et al, 2018

Leaf optical properties

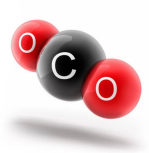
Nutrient Dynamics

Vcmax

C:N ratio

C costs

Carbon Sink



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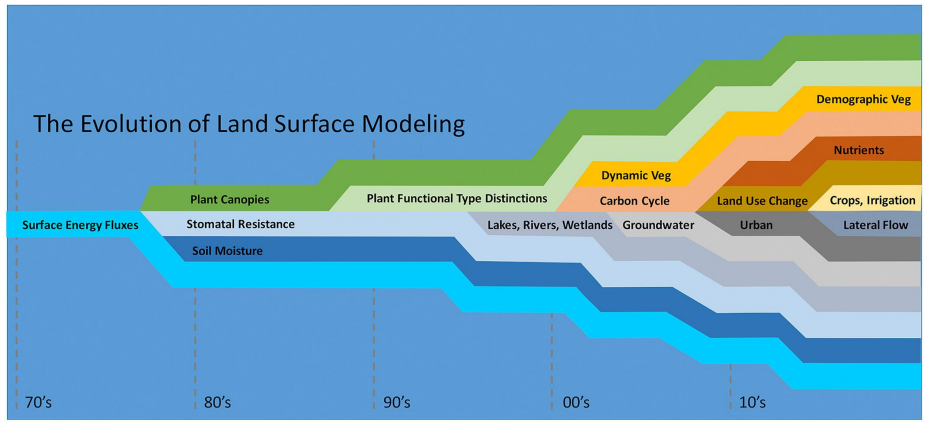
Indirect & Direct impact of Nutrients on Climate



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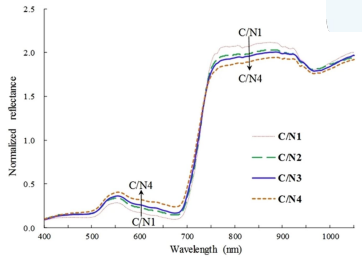

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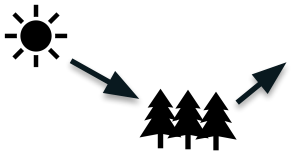

Direct impacts on climate via **albedo**

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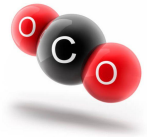
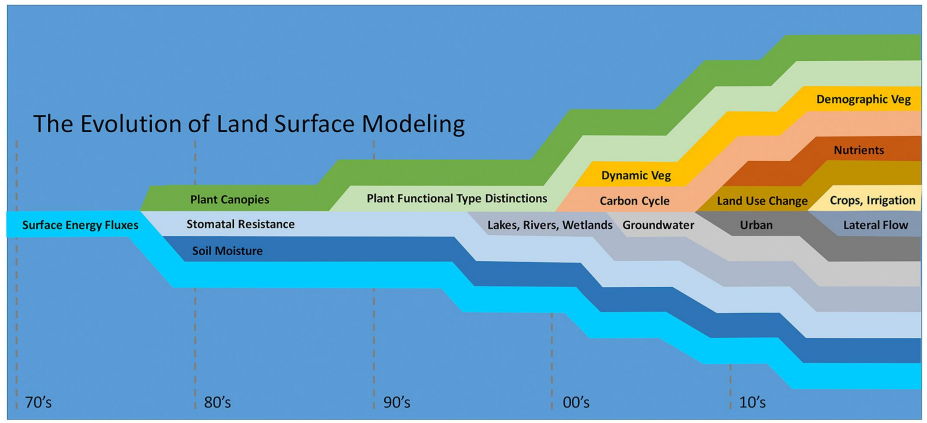


Indirect impacts on climate via **CO_2**

Indirect & Direct impact of Nutrients on Climate



Fisher and Koven, 2020

Trait diversity

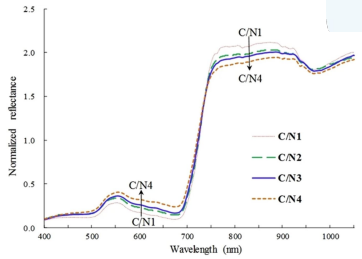
Fire

Nitrogen & Phosphorus

Fauna-Fungi

Permafrost

Plant hydrology



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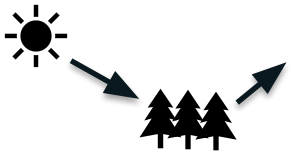

Direct impacts on climate via **albedo**

Nutrient Dynamics

Vcmax

C:N ratio

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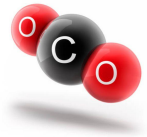


Indirect impacts on climate via CO_2

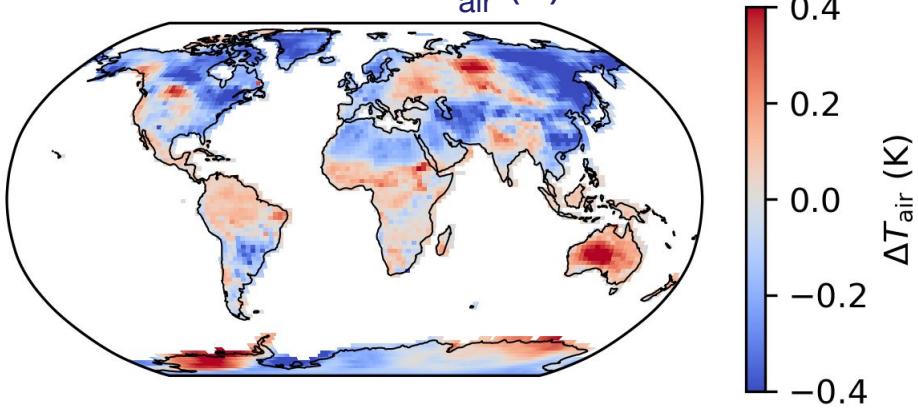
Trait variability can also represent the ***Direct impact*** of **Nutrients** on **Climate**

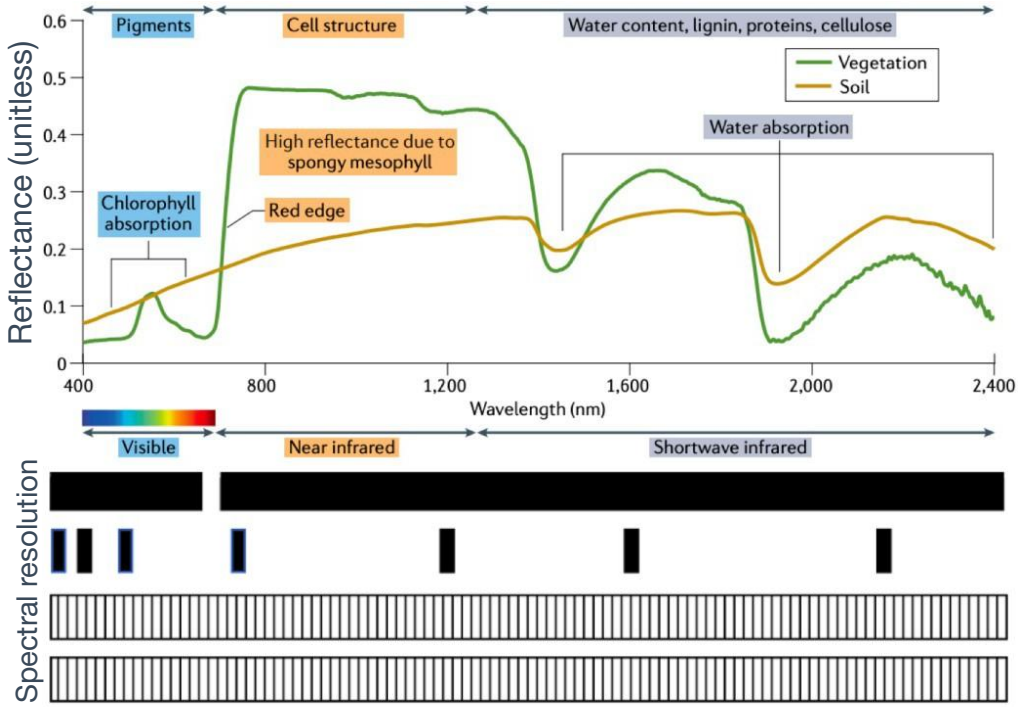
Conclusions

Canopy albedo biases between the **PFT** and **trait** cases:

- Can **impact climate** and **carbon cycle** simulations**;**

Trait – PFT ΔT_{air} (K)





ESMs	2 bands
MODIS	7 bands
EMIT/SBG…	100s bands
New ESMs?	100s bands

- **Trait-based** configurations **improved agreement** with **MODIS albedo** data in the **tropics**;

New generation ESMs should include **trait-based parametric variability** to **reduce uncertainty** in **climate projections**

Thank you

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