Modeling canopy fluxes and optical properties using CliMA Land

Yujie WANG, 2022-Sep-01

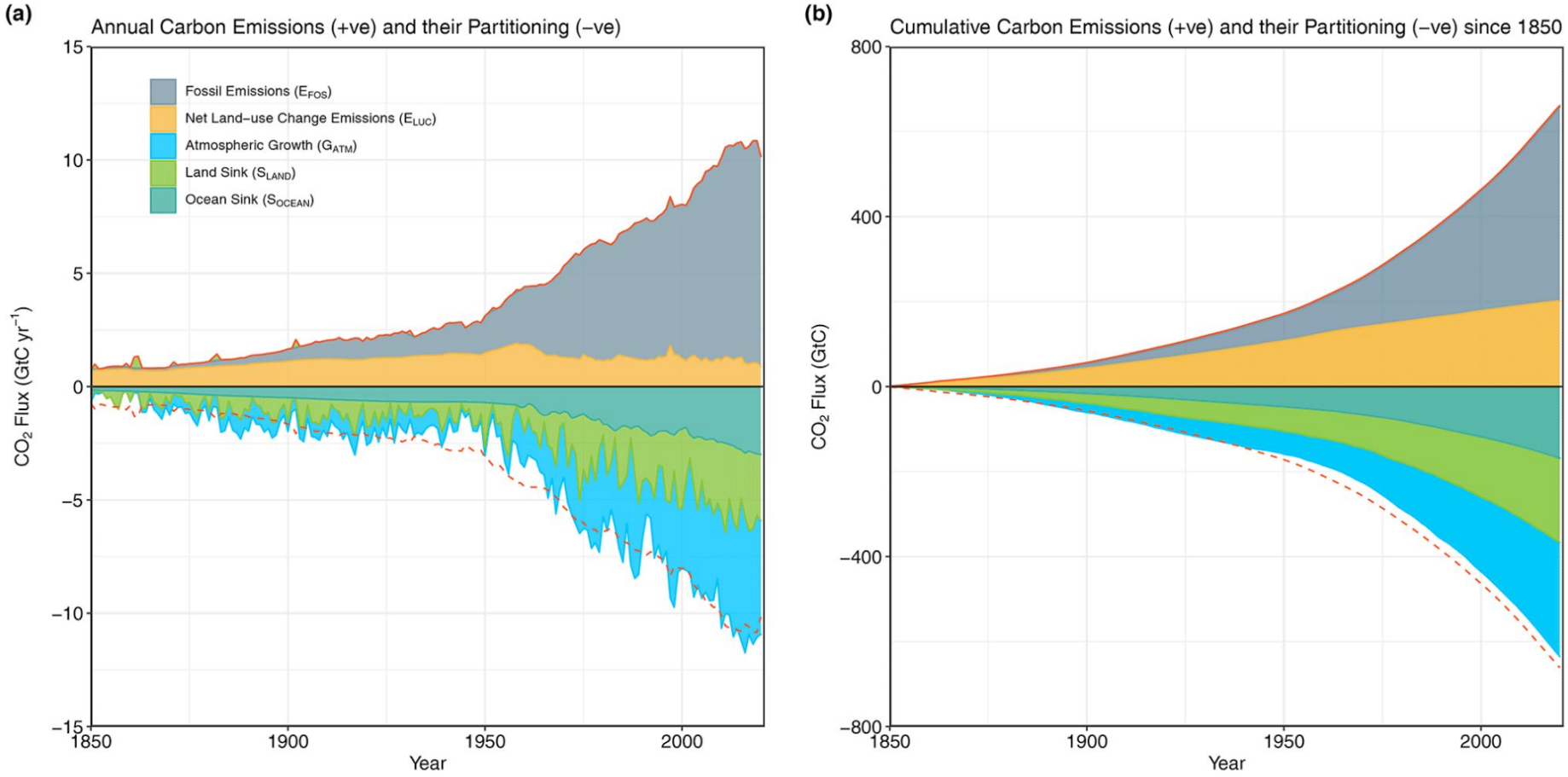


Figure from Friedlingstein et al (2022) ESSD

Direct “observation”

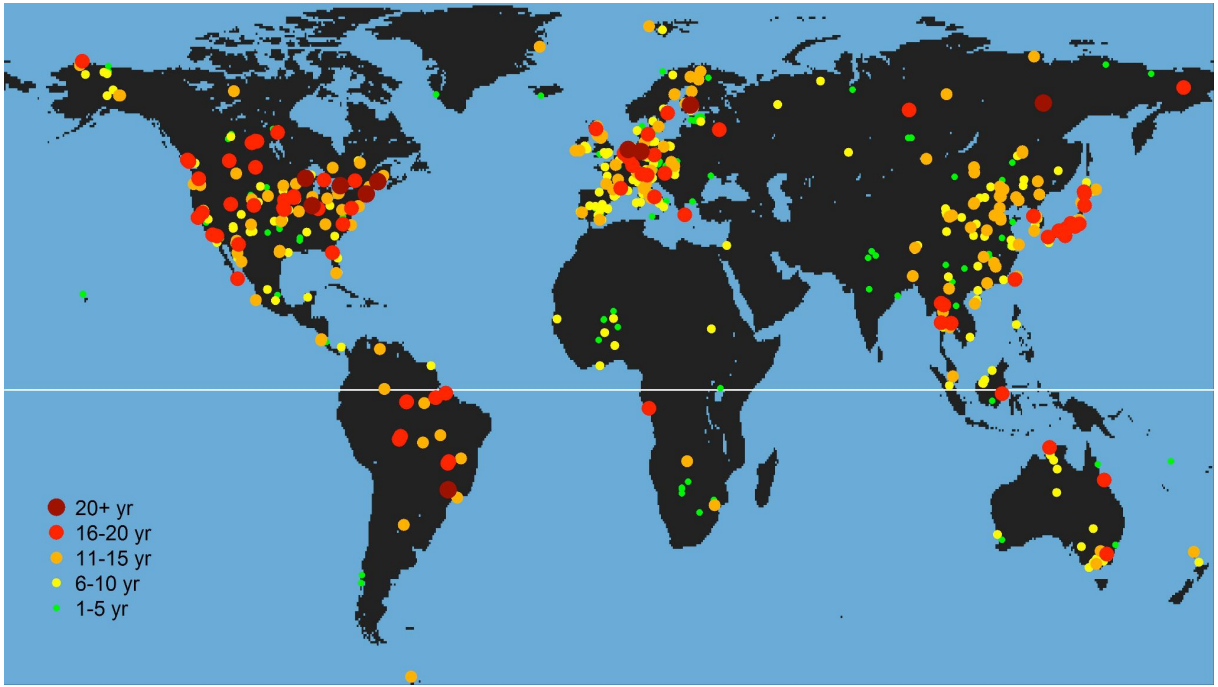


Figure from FLUXNET

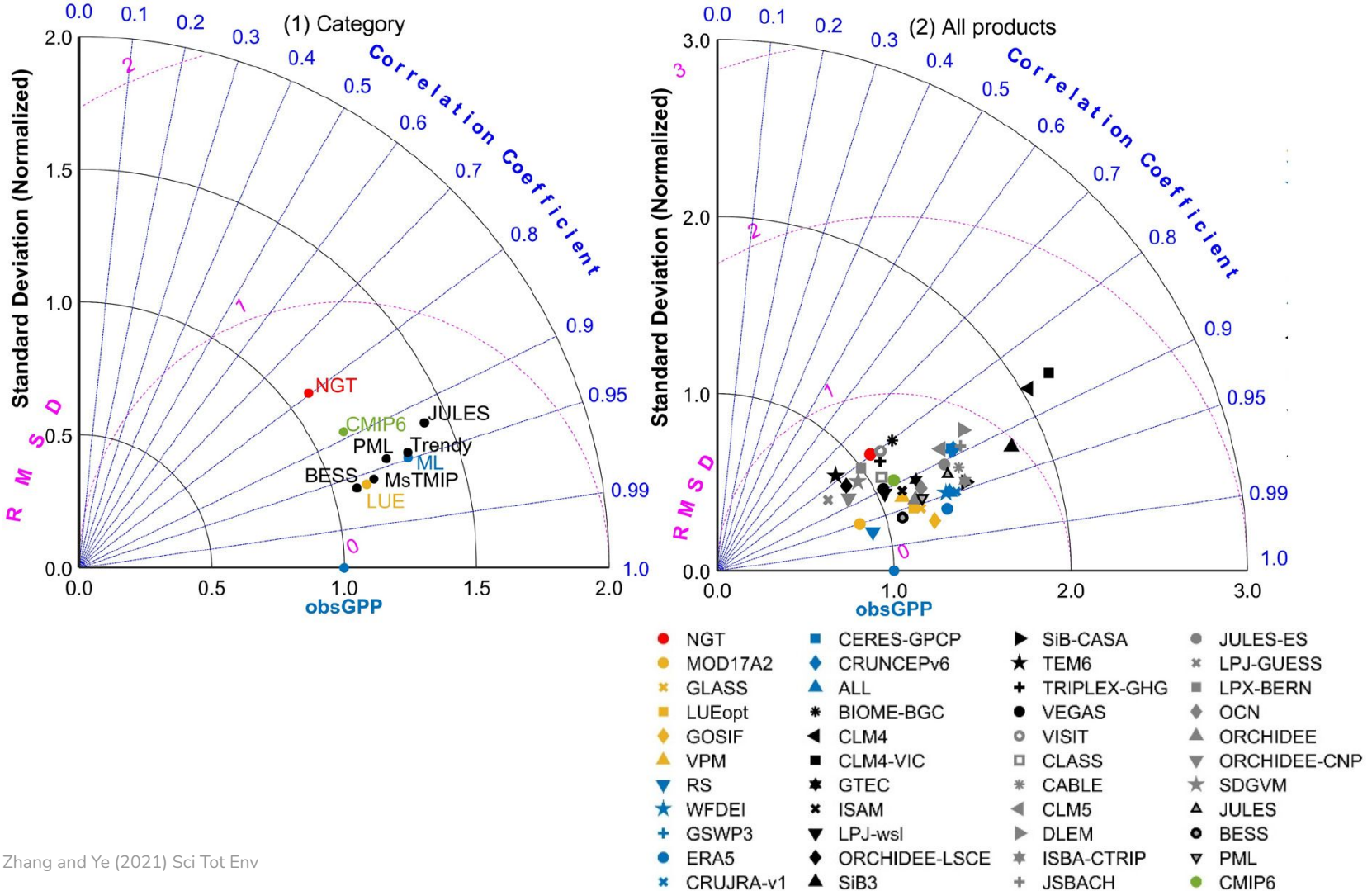


Figure from Zhang and Ye (2021) Sci Tot Env

More constraints from observations

- Spatial coverage
- Temporal resolution

MODIS

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110

TROPOMI

Band	Wavelength (µm)	Bandwidth (µm)	Resolution (m)
Band 1 UV (UV)	0.27 to 0.3		28000 (68000)
Band 2 UV (UV)	0.3 to 0.32		7000 (17000)
Band 3 UV-VIS (VIS)	0.32 to 0.405		7000 (17000)
Band 4 UV-VIS (VIS)	0.405 to 0.495		7000 (17000)
Band 5 NIR (NIR)	0.675 to 0.725		7000 (17000)
Band 6 NIR (NIR)	0.725 to 0.775		3500 (8500)
Band 7 SWIR (SWIR)	2.305 to 2.345		7000 (34000)
Band 8 SWIR (SWIR)	2.345 to 2.385		7000 (34000)

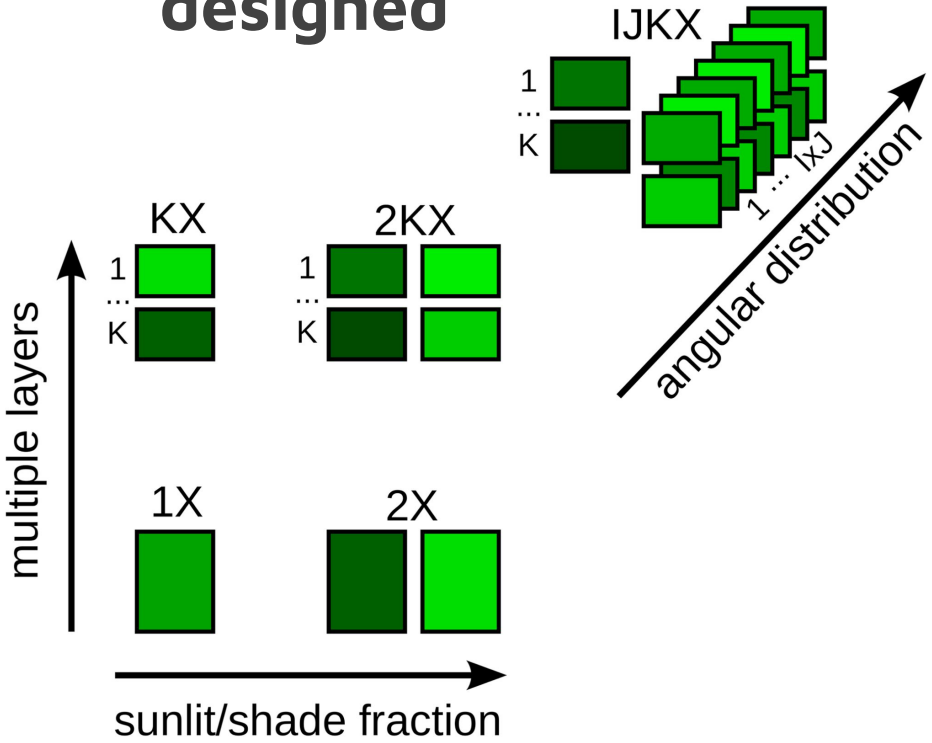
OCO-2

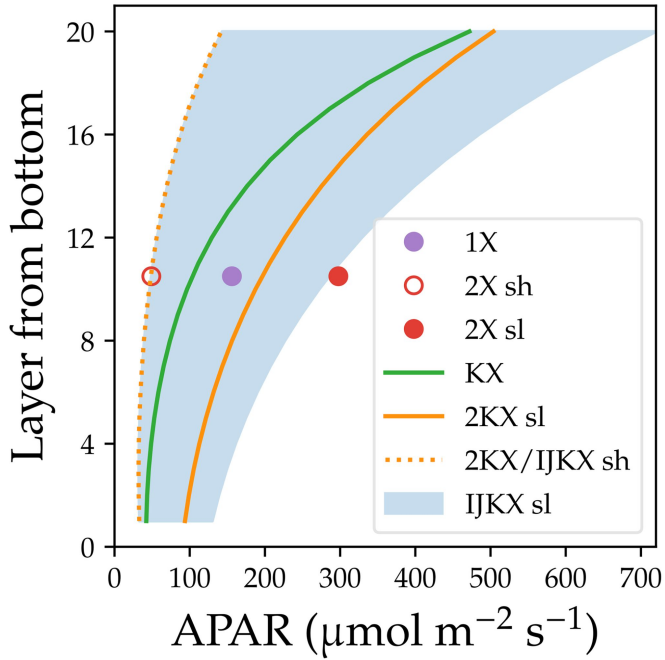
Band	Wavelength (µm)
Band 1 O2 A-band (NIR)	0.758 to 0.772
Band 2 weak CO2 (SWIR)	1.594 to 1.619
Band 3 strong CO2 (SWIR)	2.042 to 2.082

Tools designed to use these spectra

as well as ground-based measurements

Existing Land surface models are not designed





Figures from Wang and Frankenberg (2022) Biogeosciences

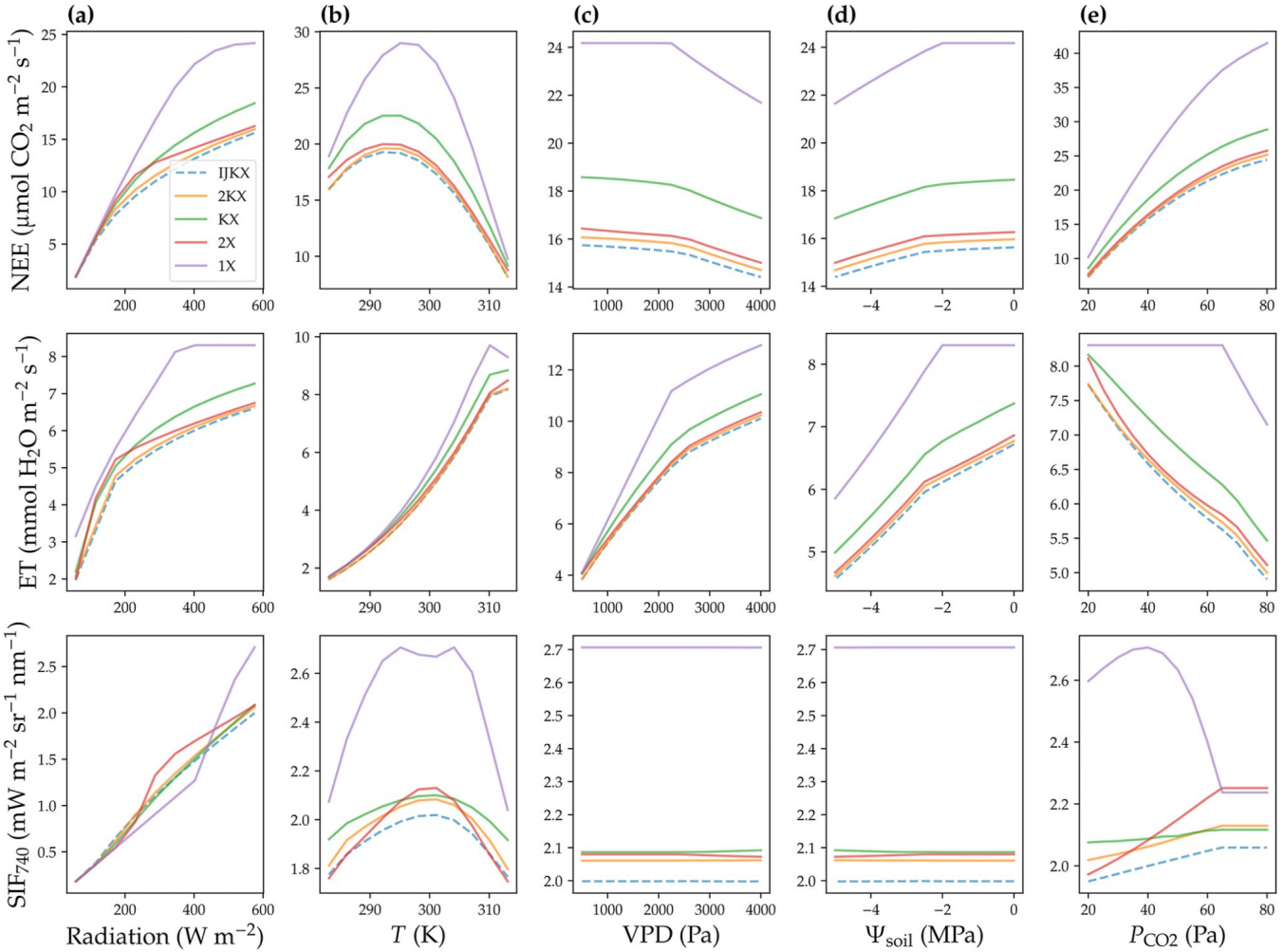
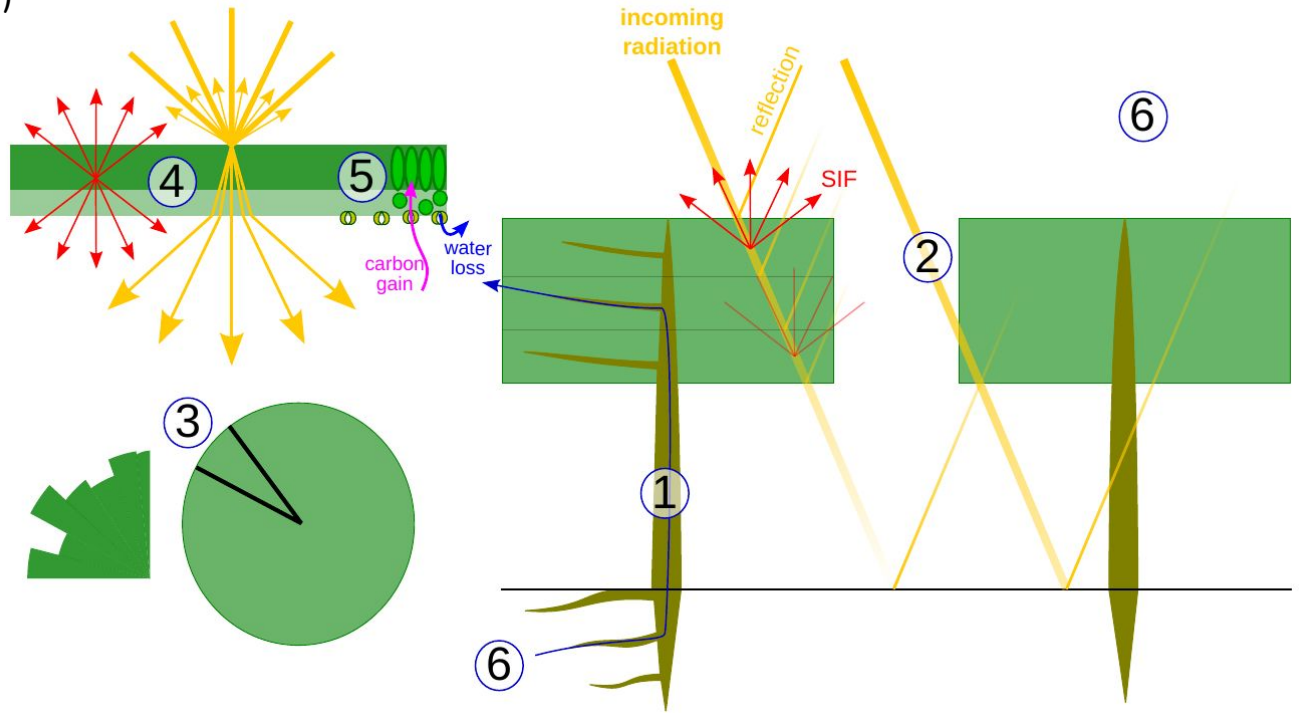


Figure from Wang and Frankenberg (2022) Biogeosciences

The CliMA Land Model

a highly modular solution

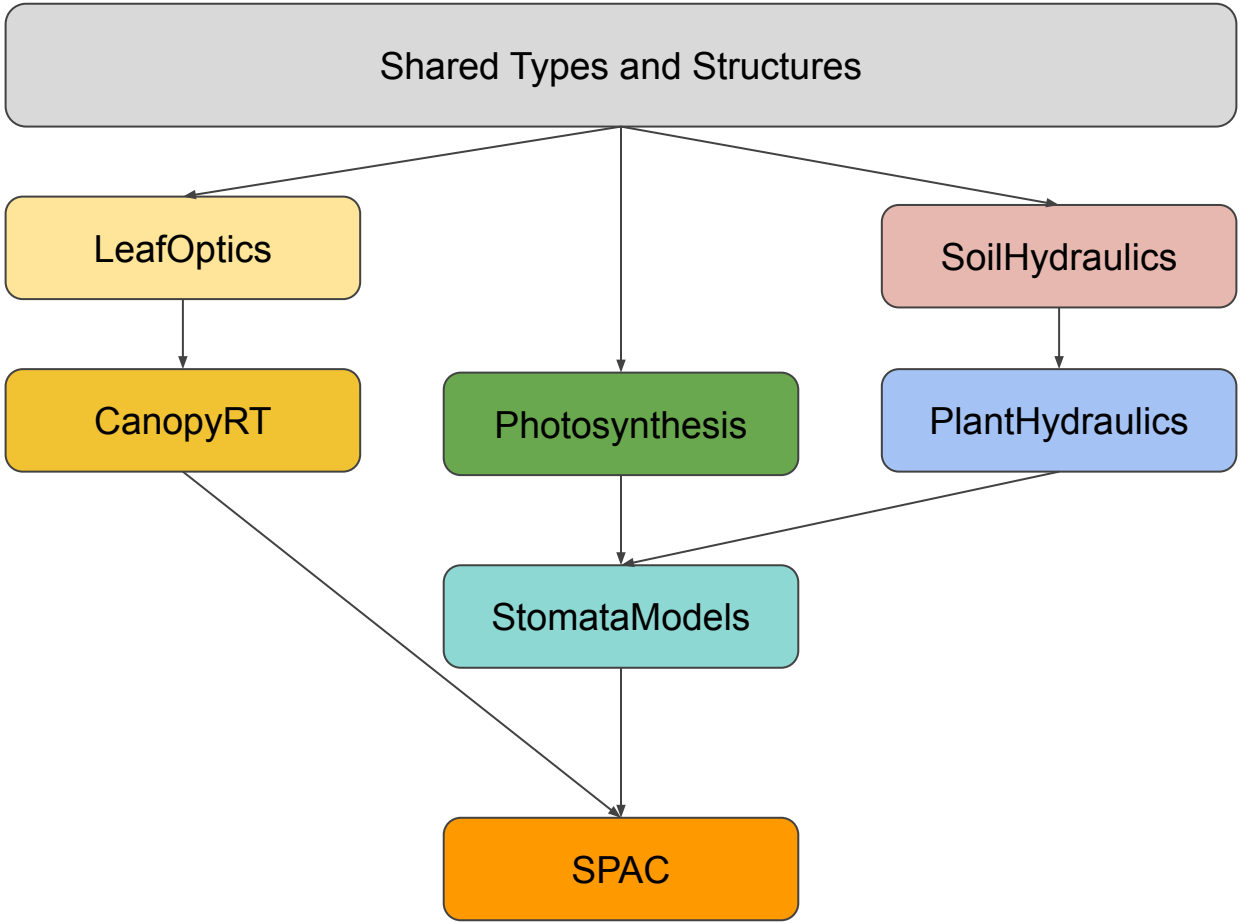
CliMA Land (v0.1)



1. **Hydraulic traits** such as vulnerability curve and maximum conductance impact water transport, and thus stomatal behavior.
2. **Canopy traits** such as leaf area index and clumping index impact light penetration to lower canopy, and reflected light and solar-induced chlorophyll fluorescence (SIF) escaping from lower canopy.
3. **Leaf angular distributions** impact light scattering within the canopy.
4. **Leaf biophysical traits** such as chlorophyll and carotenoid contents impact leaf level reflectance, transmittance, and SIF spectra.
5. **Leaf physiological traits** such as maximum carboxylation rate impact leaf gas exchange.
6. **Environmental conditions** such as soil moisture and atmospheric humidity impact plant's physiological responses.

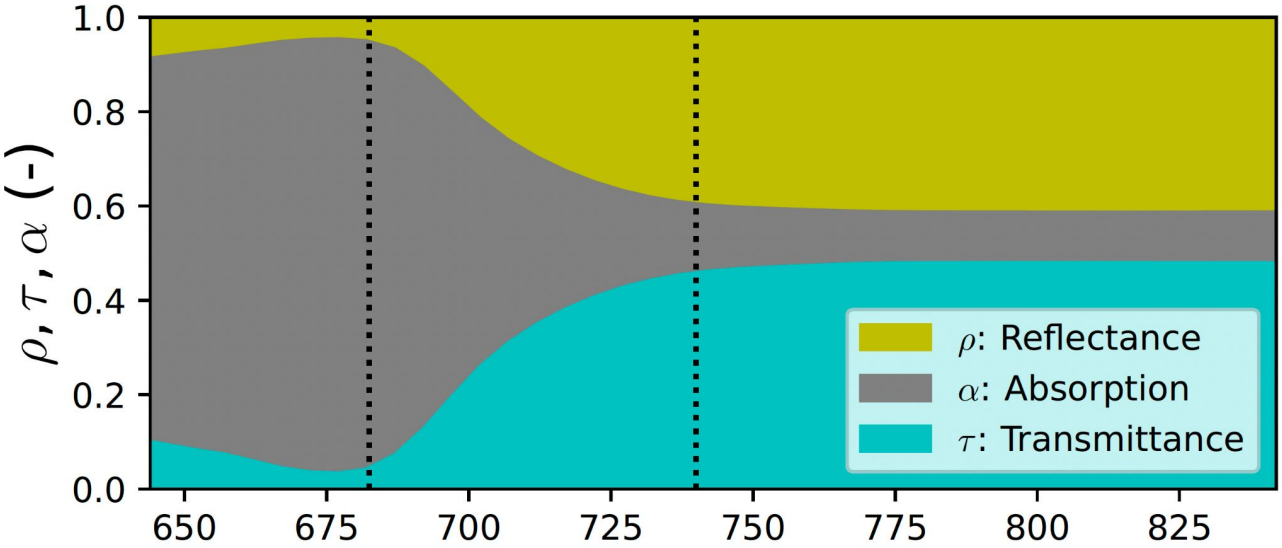
Figure from Wang et al. (2021)

Refactored CliMA Land (v0.2)

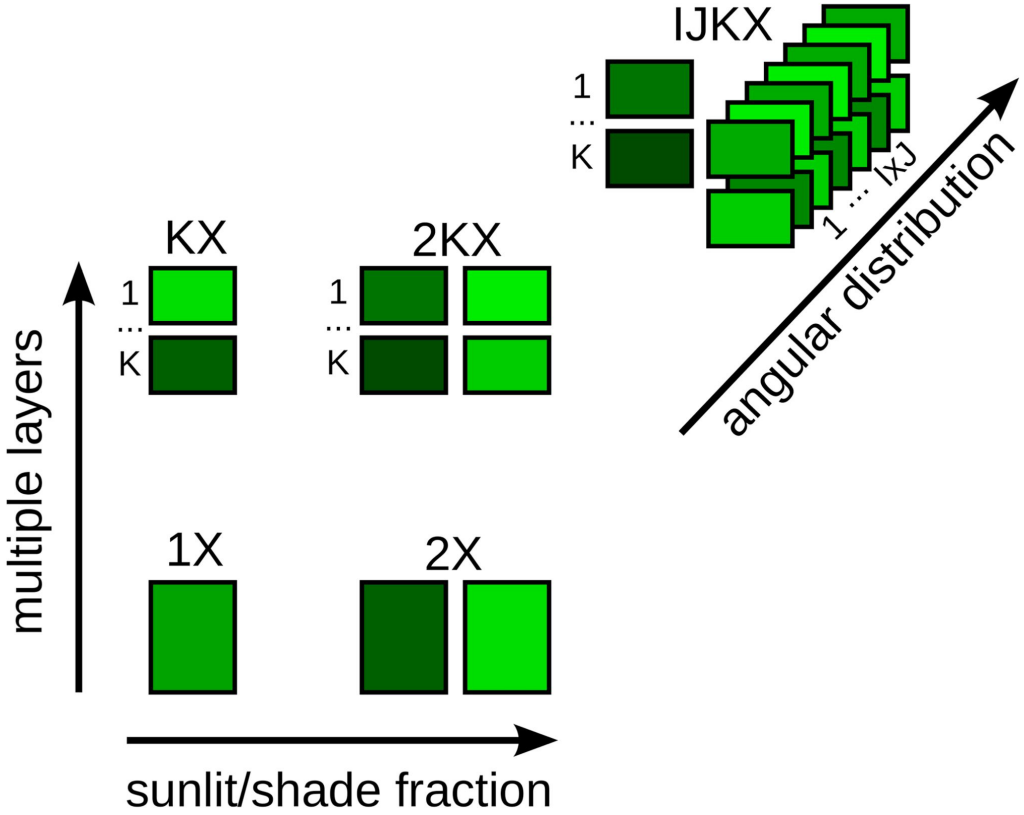


LeafOptics.jl

- Hyperspectral mode
- Broadband mode



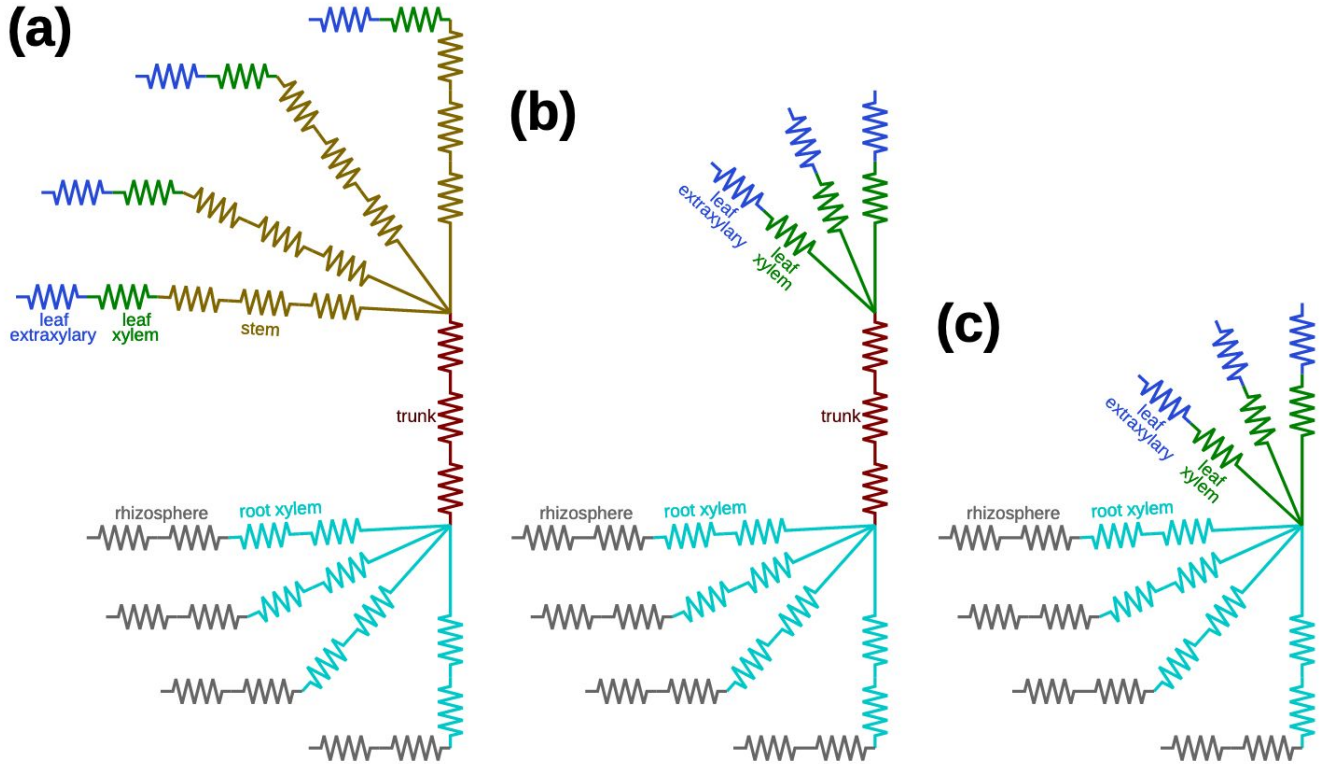
CanopyRadiativeTransfer.jl



SoilHydraulics.jl

- Soil types
- Soil layers
- Soil albedo
  - Broadband
  - Hyperspectral

PlantHydraulics.jl



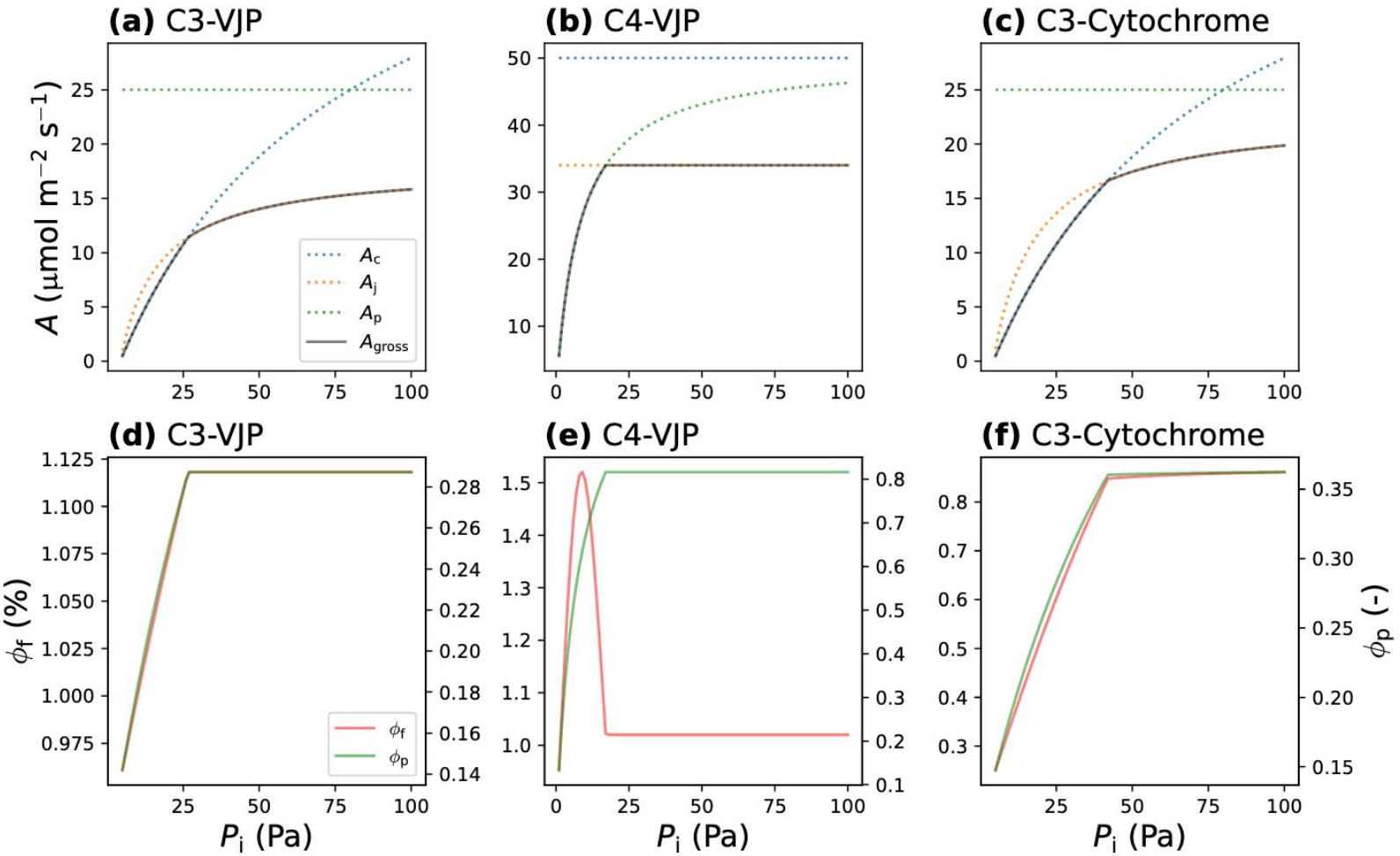
Photosynthesis.jl

Photosynthesis

- Classic C3 model
- Classic C4 model

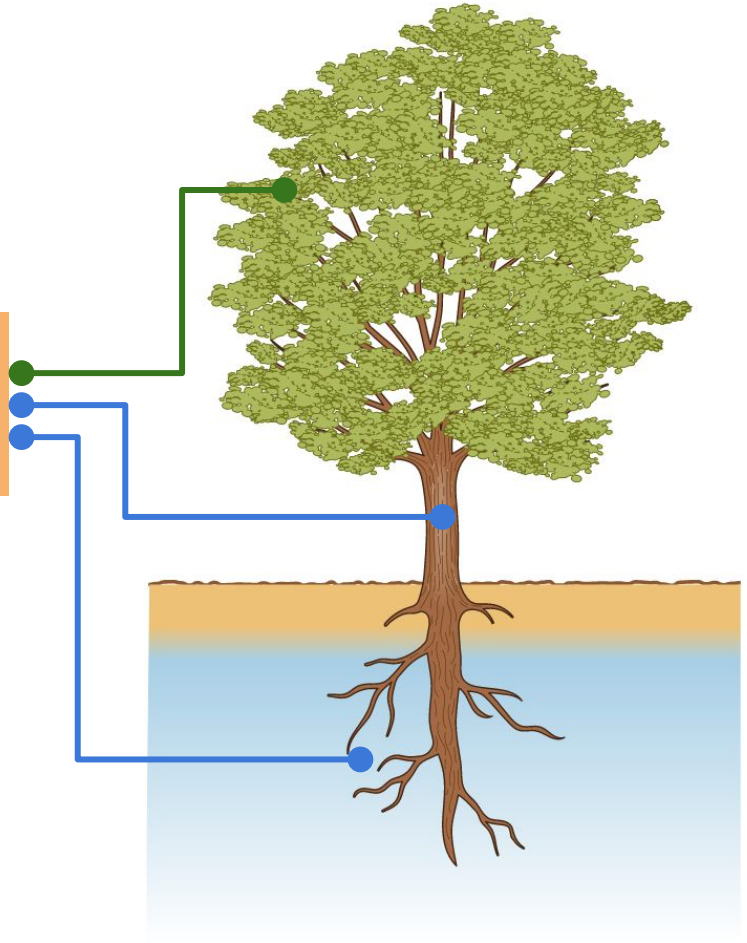
Use with an empirical fluorescence model

- New C3 model (fluorescence model included)


(a) C3-VJP
(b) C4-VJP
(c) C3-Cytochrome
A (μmol m⁻² s⁻¹)
Ac
Aj
Ap
Agross
(d) C3-VJP
(e) C4-VJP
(f) C3-Cytochrome
ϕf (%)
ϕp (-)
ϕf
ϕp
Pi (Pa)
Pi (Pa)
Pi (Pa)

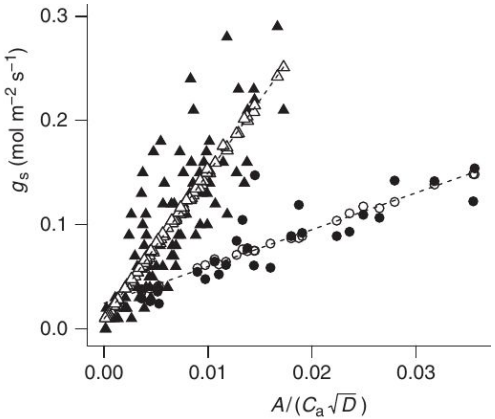
StomataModels.jl

Stomatal Models
(decision making)

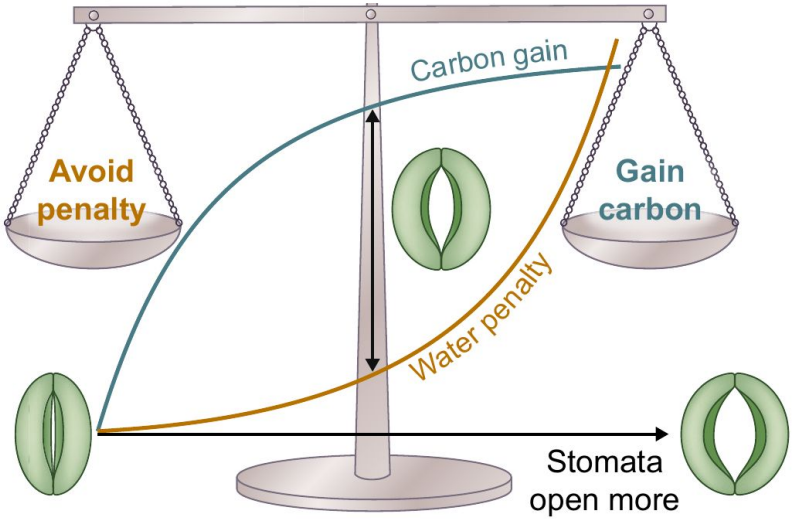


Figures from Wang et al. (2020)

Statistical models



Optimization models



Empirical Models

- Ball-Berry
- Leuning
- Medlyn
- Gentine

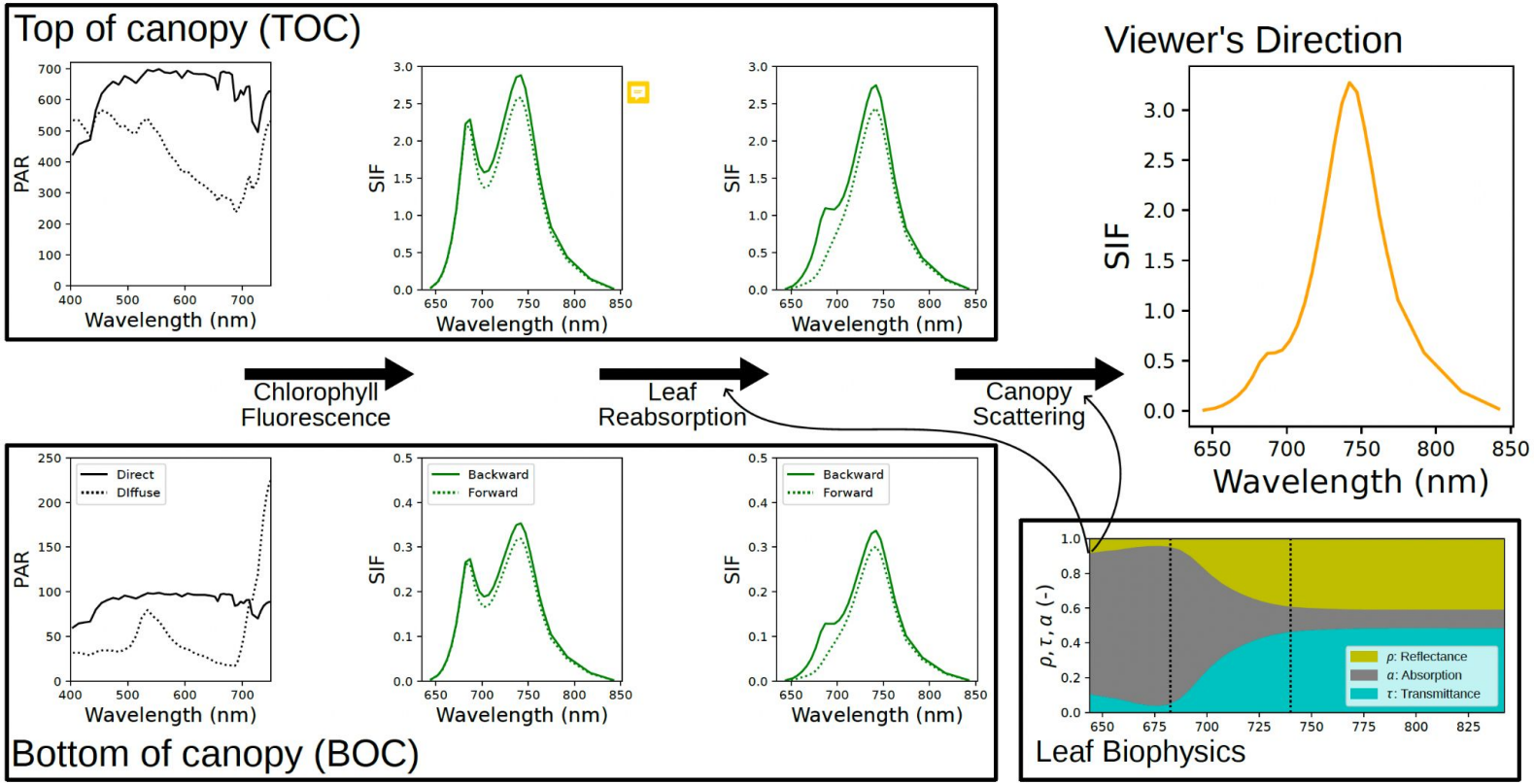
Optimization Models

- Wolf-Anderegg-Pacala
- WAP MOD
- Sperry
- Eller
- Wang

More pending…

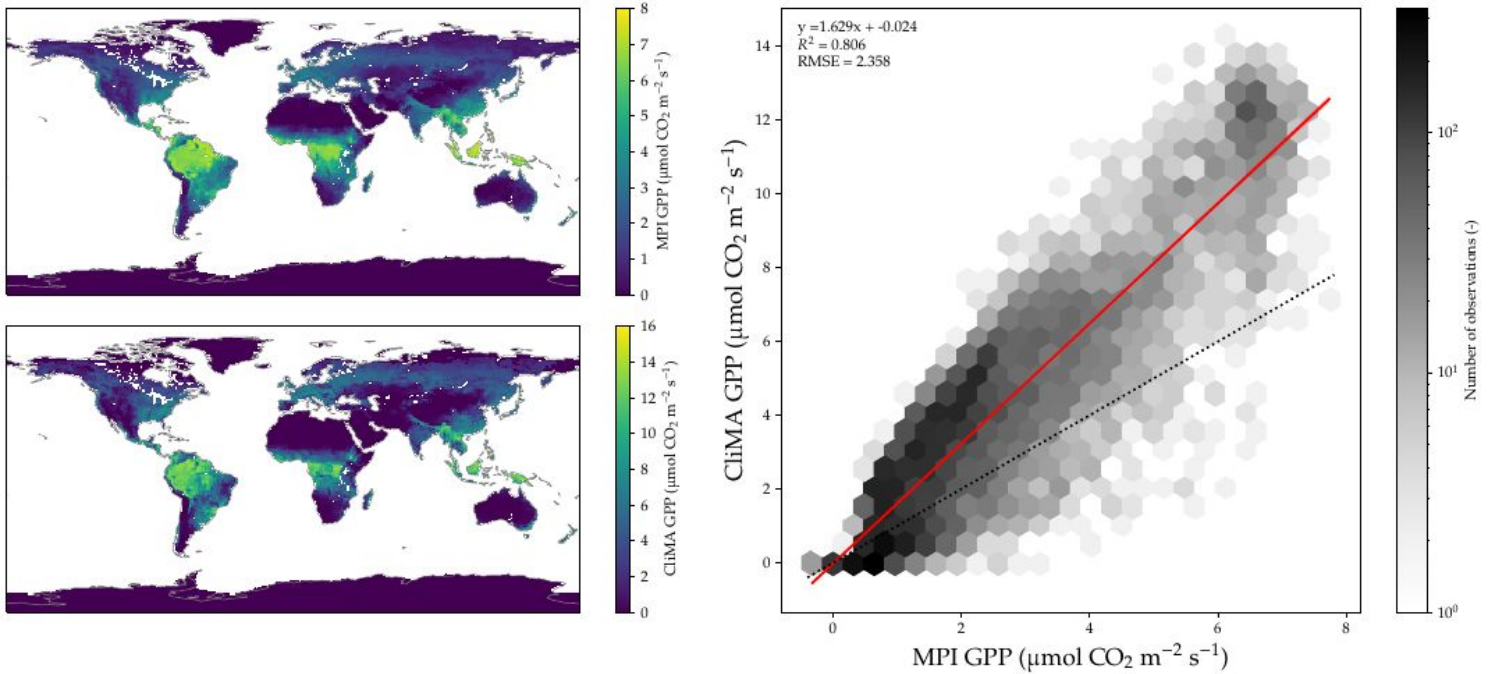
Figures from Medlyn et al. (2011) and Wang et al. (2020)

SoilPlantAirContinuum.jl

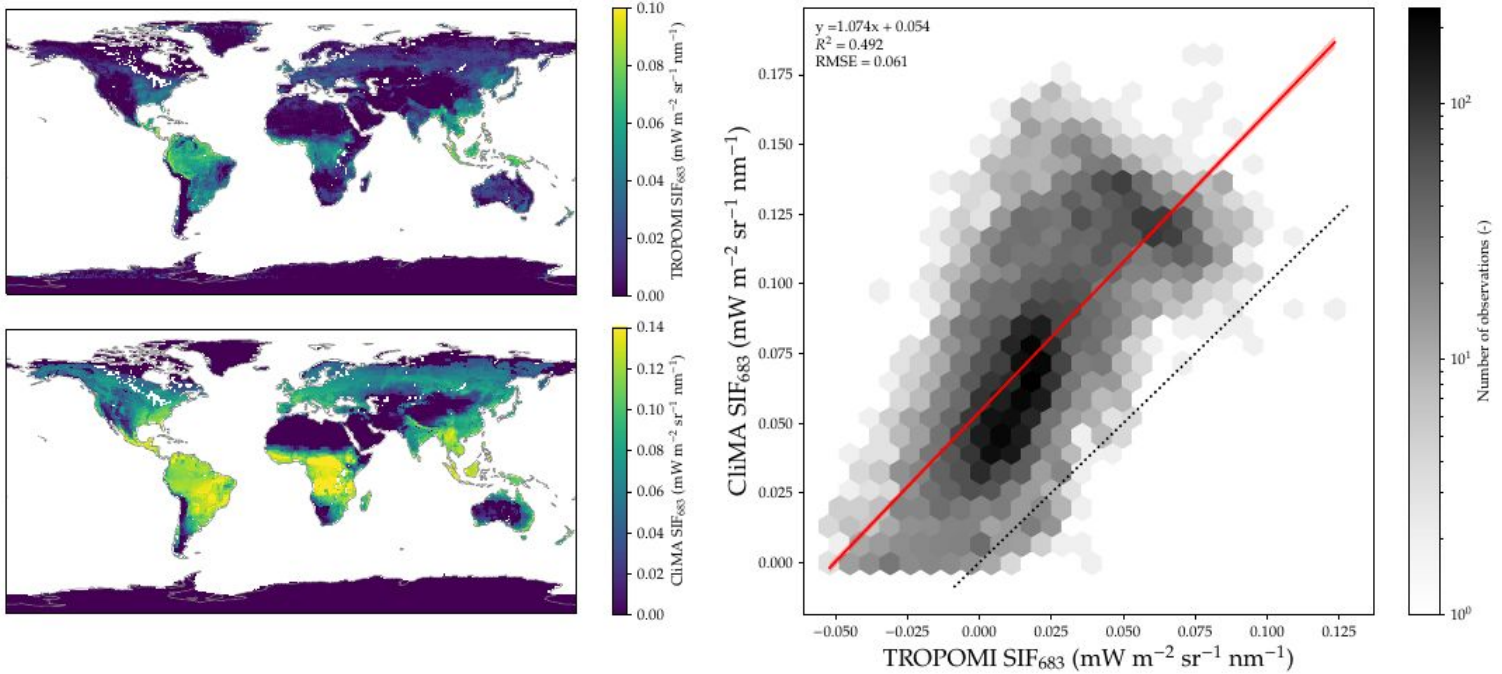


Scaling for global simulation

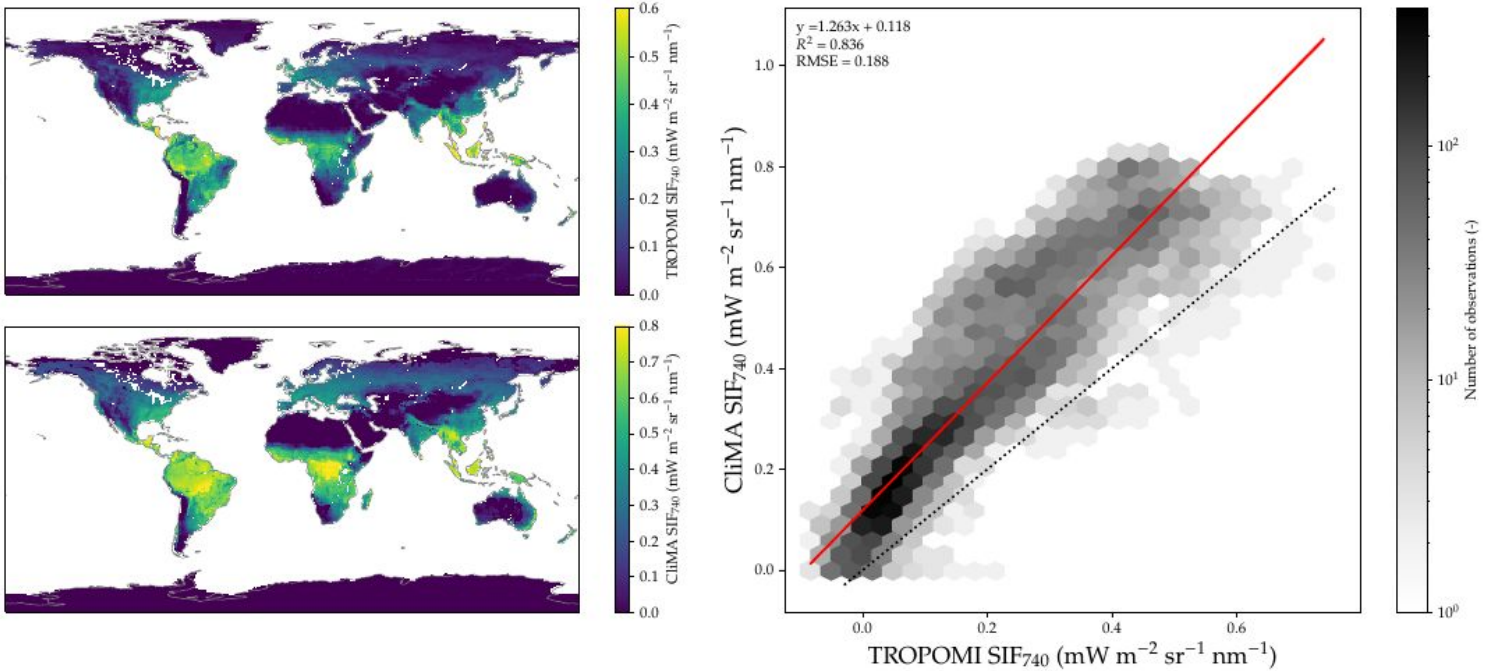
Global scale pattern of GPP



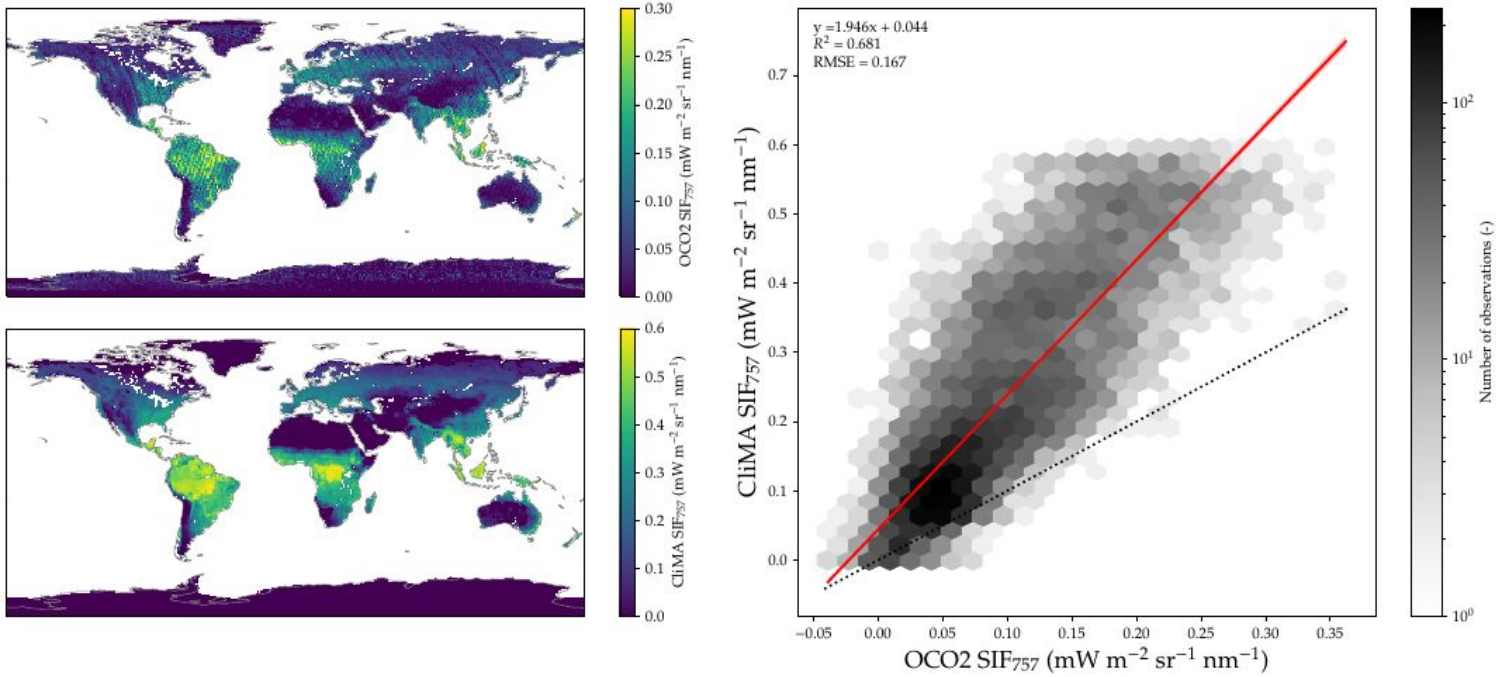
Global scale pattern of SIF_{683}



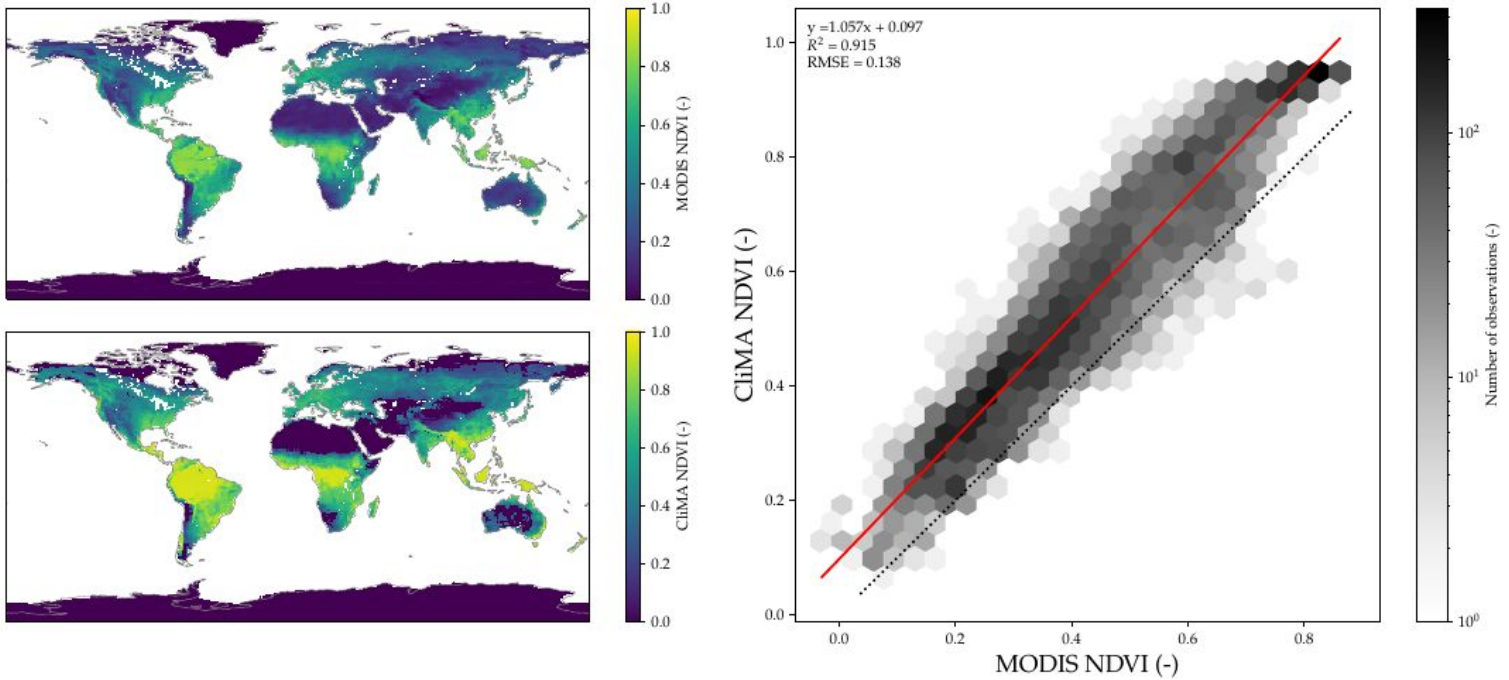
Global scale pattern of SIF_{740}



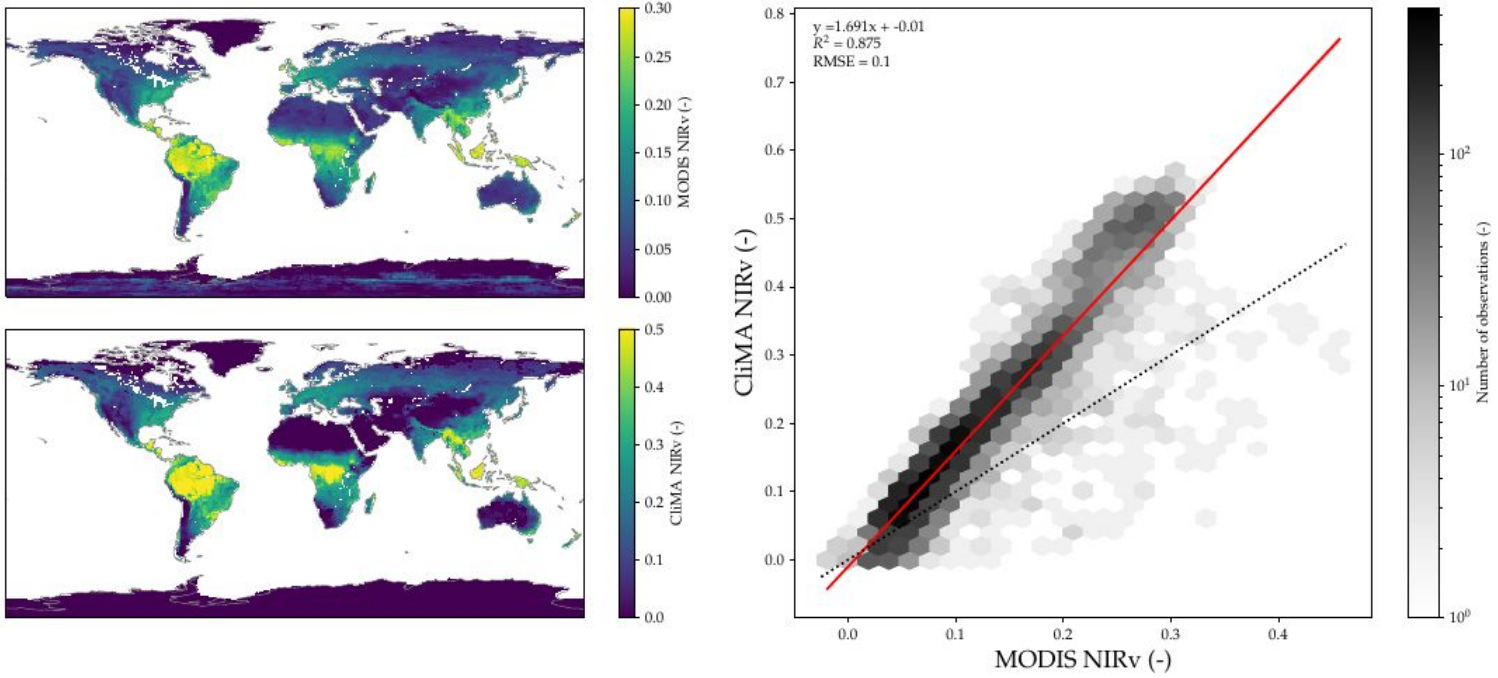
Global scale pattern of SIF_{757}



Global scale pattern of NDVI



Global scale pattern of NIRv



> 3000 Options

- LeafOptics.jl x2
- Photosynthesis.jl x3
- SoilHydraulics.jl x2 x2
- PlantHydraulics.jl x3
- StomataModels.jl x9
- CanopyRatiativeTransfer.jl x5

Thanks

A “byproduct”

GriddingMachine.jl

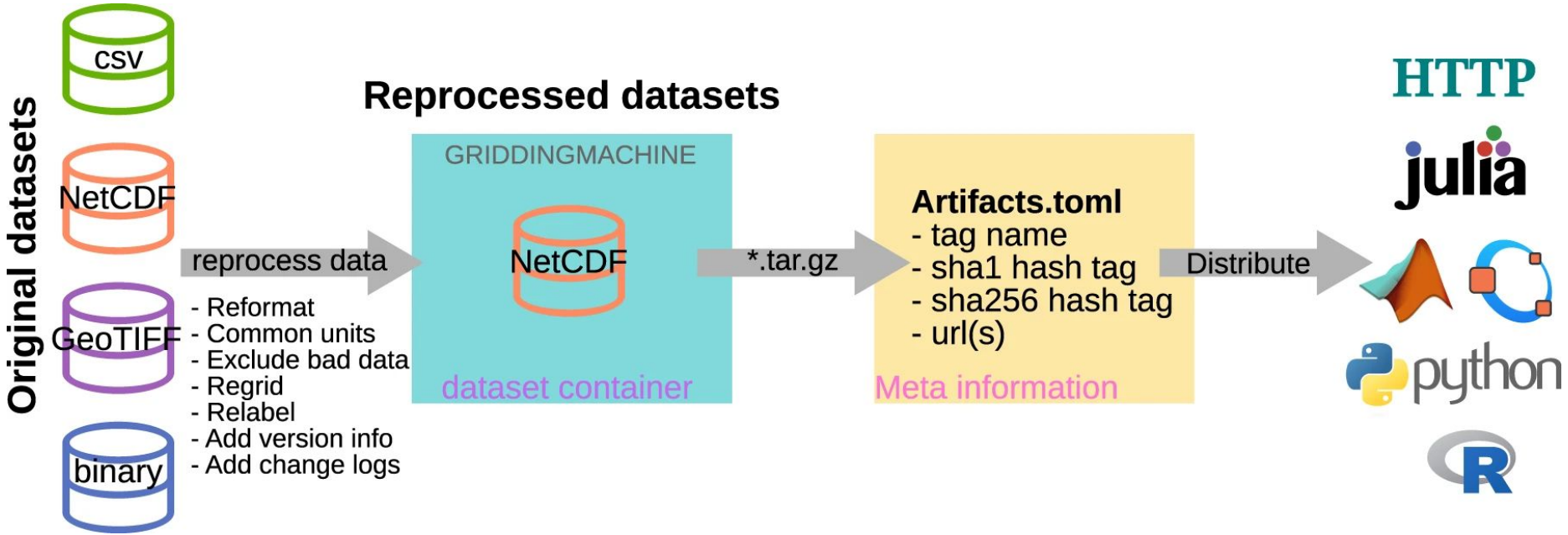


Figure from Wang et al. (2021) Scientific Data

https://github.com/CliMA/GriddingMachine.jl/issues/62

These datasets are supposed to be updated on annually basis:

Dataset type	LABEL	EXTRALABEL	IX	JT	YEAR	VK	Reference	Change logs
Gross primary productivity	GPP	MPI_RS	2X	1M, 8D	2001-2019	V1	Tramontana et al. (2016)	4,9
	GPP	VPM	5X, 12X	8D	2000-2019	V2	Zhang et al. (2017)	1,4
Leaf area index	LAI	MODIS	2X, 10X, 20X	1M, 8D	2000-2020	V1	Yuan et al. (2011)	1,4,9
Latent heat flux	LE	MPI_RS	2X	1M, 8D	2001-2015	V1	Jung et al. (2019)	4,9
Solar induced chlorophyll fluorescence	SIF	TROPOMI_683, TROPOMI_683DC	1X, 2X, 4X, 5X, 12X	1M, 8D	2018-2020	V2	Köhler et al. (2020)	1,8
	SIF	TROPOMI_740, TROPOMI_740DC	1X, 2X, 4X, 5X, 12X	1M, 8D	2018-2021	V1	Köhler et al. (2018)	1,8
	SIF	OCO2_757, OCO2_757DC, OCO2_771, OCO2_771DC	5X	1M	2014-2020	V3	Sun et al. (2017)	1,8

Dataset type	LABEL	EXTRALABEL	IX	JT	YEAR	VK	Reference	Change logs
Biomass	BIOMASS	ROOT	120X	1Y	-	V1	Huang et al. (2021)	1,2
	BIOMASS	SHOOT	120X	1Y	-	V2	Santoro et al. (2021)	1,2
Canopy height	CH	-	20X	1Y	-	V1	Simrad et al. (2021)	1
	CH	-	2X	2Y	-	V2	Boonman et al. (2020)	1,3,4,5
Clumping Index	CI	-	240X	1Y	-	V1	He et al. (2012)	1,3,4
	CI	-	2X	1Y	-	V1	He et al. (2012)	1,3,4,6
	CI	-	2X	1Y	-	V2	Braghiere et al. (2019)	1
Elevation	ELEV	-	4X	1Y	-	V1	Yamazaki et al. (2017)	1,4
Land mask	LM	-	4X	1Y	-	V1	ERA5	1
Leaf nitrogen content	LNC	-	2X	1Y	-	V1	Butler et al. (2017)	
	LNC	-	2X	1Y	-	V2	Boonman et al. (2020)	1,3,4,5
Leaf phosphorus content	LPC	-	2X	1Y	-	V1	Butler et al. (2017)	
Plant functional type	PFT	-	2X	1Y	-	V1	Lawrence and Chase (2007)	1,4,7
Solar induced luminescence	SIL	-	20X	1Y	-	V1	Köhler et al. (2021)	1,3,4
Specific leaf area	SLA	-	2X	1Y	-	V1	Butler et al. (2017)	
	SLA	-	2X	1Y	-	V2	Boonman et al. (2020)	1,3,4,5
Soil color	SC	-	2X	1Y	-	V1	Lawrence and Chase (2007)	1,4,6
Soil hydraulic parameters	SOIL	SWCR	12X	1Y	-	V1	Dai et al. (2019)	1,3,6
	SOIL	SWCR	120X	1Y	-	V1	Dai et al. (2019)	1,3
	SOIL	SWCS	12X	1Y	-	V1	Dai et al. (2019)	1,3,6
	SOIL	SWCS	120X	1Y	-	V1	Dai et al. (2019)	1,3
	SOIL	VGA	12X	1Y	-	V1	Dai et al. (2019)	1,3,6
	SOIL	VGA	120X	1Y	-	V1	Dai et al. (2019)	1,3
	SOIL	VGN	12X	1Y	-	V1	Dai et al. (2019)	1,3,5,6
	SOIL	VGN	120X	1Y	-	V1	Dai et al. (2019)	1,3,5
	SOIL	KSAT	100X	1Y	-	V2	Gupta et al. (2021)	1,2,3,4,5
Surface area	SA	-	1X	1Y	-	V1	Lawrence and Chase (2007)	1,4,6
	SA	-	2X	1Y	-	V1	Lawrence and Chase (2007)	1,4
Tree density	TD	-	2X	1Y	-	V1	Crowther et al. (2017)	1,3,4,6
	TD	-	120X	1Y	-	V1	Crowther et al. (2017)	1,3,4
Maximum carboxylation rate	VCMAX	-	2X	1Y	-	V1	Smith et al. (2019)	1,2,4
	VCMAX	-	2X	1Y	-	V2	Luo et al. (2019)	1,8
Wood density	WD	-	2X	1Y	-	V1	Boonman et al. (2020)	1,3,4,7

Julia: GriddingMachine.jl

https://github.com/CliMA/GriddingMachine.jl

```
# To install
using Pkg; Pkg.add("GriddingMachine");
# To use
using GriddingMachine.Collections;
file_path = query_collection("VCMAX_2X_1Y_V1");
```

```
% Matlab script
% Install the toolbox
url = 'https://github.com/Yujie-W/octave-griddingmachine/raw/main/GriddingMachine.mltbx';
urlwrite(url, 'GriddingMachine.mltbx');
matlab.addons.toolbox.installToolbox('GriddingMachine.mltbx');
delete('GriddingMachine.mltbx');
% Use the toolbox
update_GM();
art_name = 'VCMAX_2X_1Y_V1';
file_path = query_collection(art_name);
[vcmax,error] = request_LUT(art_name, 35.1, 115.2);
[vcmax,error] = request_LUT(art_name, 35.1, 115.2, 'interpolation', true);
```

```
% Octave script
% Install the package
pkg install "https://github.com/gnu-octave/pkg-json/archive/v1.5.0.tar.gz";
pkg install "https://github.com/Yujie-W/octave-griddingmachine/archive/v0.1.1.tar.gz";
% Use the package
pkg load griddingmachine;
update_GM();
art_name = 'VCMAX_2X_1Y_V1';
file_path = query_collection(art_name);
[vcmax,error] = request_LUT(art_name, 35.1, 115.2);
[vcmax,error] = request_LUT(art_name, 35.1, 115.2, 'interpolation', true);
```

```
# Python script
from griddingmachine import update_GM, query_collection, request_LUT;
update_GM();
art_name = "VCMAX_2X_1Y_V1";
file_path = query_collection(art_name);
vcmax,error = request_LUT(art_name, 35.1, 115.2);
vcmax,error = request_LUT(art_name, 35.1, 115.2, interpolation = True);
```

```
# R script
# Install the package
library(devtools);
install_github("Yujie-W/r-griddingmachine");
# Use the Package
library("griddingmachine");
update_GM();
art_name <- "VCMAX_2X_1Y_V1";
file_path <- query_collection(art_name);
results <- request_LUT(art_name, 35.1, 115.2);
results <- request_LUT(art_name, 35.1, 115.2, interpolation = TRUE);
```