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THIRD WORKSHOP AND EARLY-CAREER SCHOOL

APRIL 7-10, 2026
MONTEREY, CALIFORNIA

Overview of the International Ocean Model Benchmarking (IOMB) Package

Georgina Gibson, Forrest Hoffman, Nathan Collier

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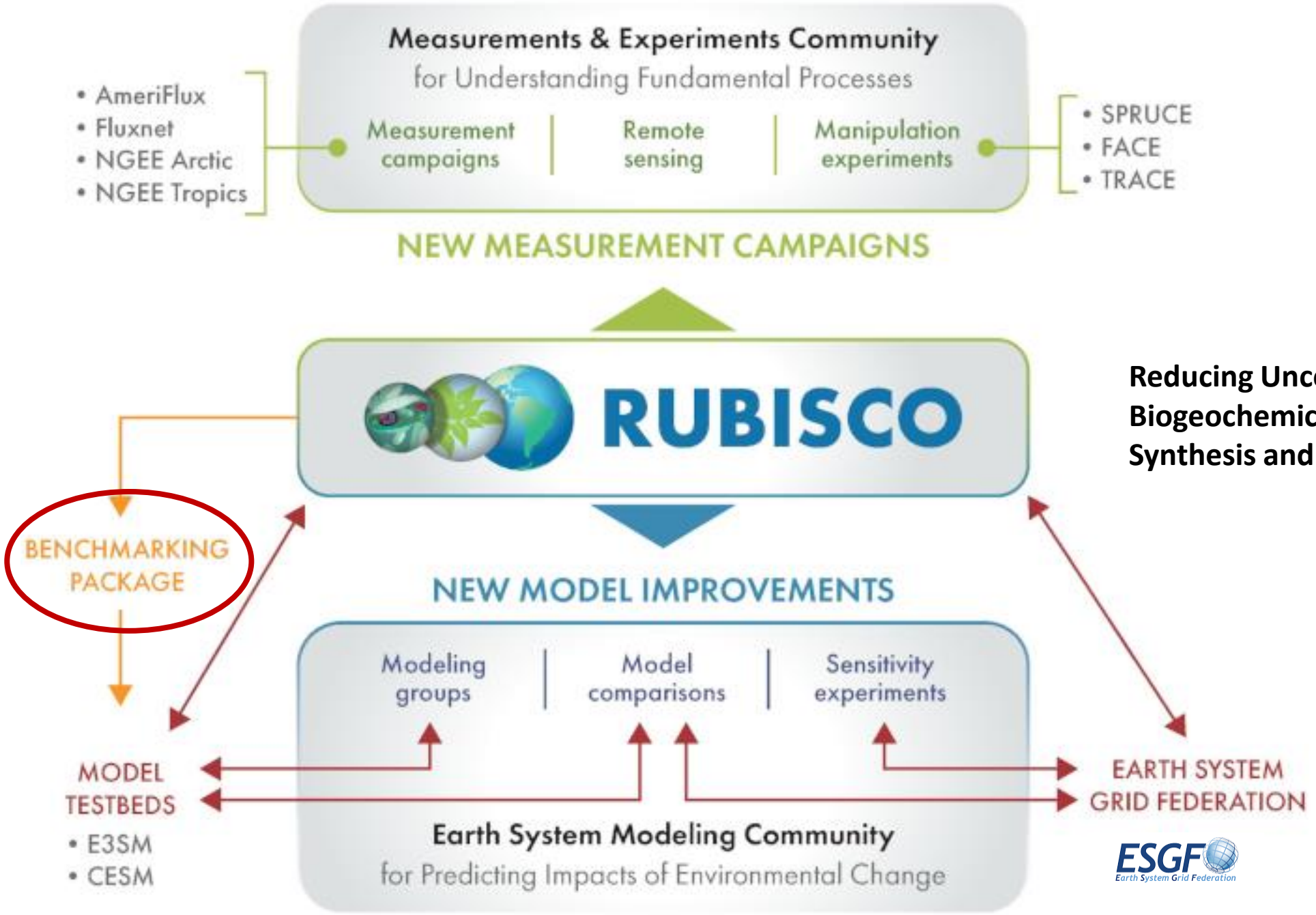
Background

- Better representation of biogeochemistry–climate feedbacks and ecosystem processes in ESMs is essential for reducing uncertainties associated with projections of climate change during the remainder of the 21st century.
- Earth system models (ESMs) becoming increasingly complex ->
  Growing need for comprehensive and multi-faceted evaluation of predictions.
- Need to develop new ways to use observations to constrain model results and inform model development.

- **RUBISCO SFA- Reducing Uncertainties in Biogeochemical Interactions through Synthesis and Computation**

Tasked with reducing uncertainties in biogeochemical Interactions through Synthesis and Computation

Berkeley Lab · NCAR National Center for Atmospheric Research · Oak Ridge National Laboratory · Sandia National Laboratories · The University of California Irvine · Michigan



Reducing Uncertainties in Biogeochemical Interactions through Synthesis and Computation

open source effort providing a robust, distributed data and computation platform, enabling world wide access to Peta/Exa-scale data

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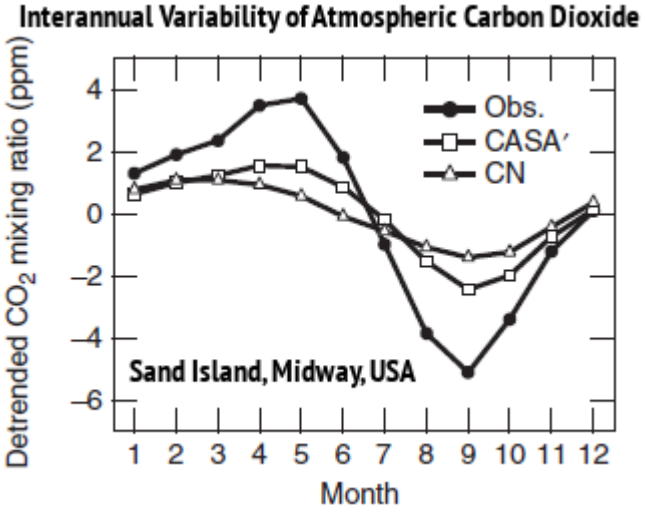
What is a Benchmark?

- A **benchmark** is a quantitative test of model function achieved through comparison of model results with observational data
- Acceptable performance on a benchmark **is a necessary but not sufficient condition** for a fully functioning model
- Effective benchmarks must draw upon **a broad set of independent observations** to evaluate model performance at multiple scales



Models often fail to capture the amplitude of the seasonal cycle of atmospheric CO_2

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Why Benchmark Models ?

- To **quantify and reduce uncertainties** – originally focusing on carbon cycle feedbacks to improve projections of future climate change (Eyring et al., 2019; Collier et al., 2018)
- To **diagnose impacts of process-based or machine learning model development** on process representations and their interactions
- To **guide synthesis efforts**, such as the Intergovernmental Panel on Climate Change (IPCC), by determining which models are broadly consistent with observations (Eyring et al., 2019)
- To **increase scrutiny of key datasets** used for model evaluation
- To **identify gaps in existing observations** needed to inform model development
- To **accelerate delivery of new measurement datasets** for rapid and widespread use in model assessment

International Land Model Benchmarking (ILAMB) Project

A community coordination activity created to:

- **Develop internationally accepted benchmarks** for land model performance by drawing upon collaborative expertise
- **Promote the use of these benchmarks** for model intercomparison
- **Strengthen linkages between experimental, remote sensing, and Earth system modeling communities** in the design of new model tests and new measurement programs
- **Support the design and development of open source benchmarking tools**

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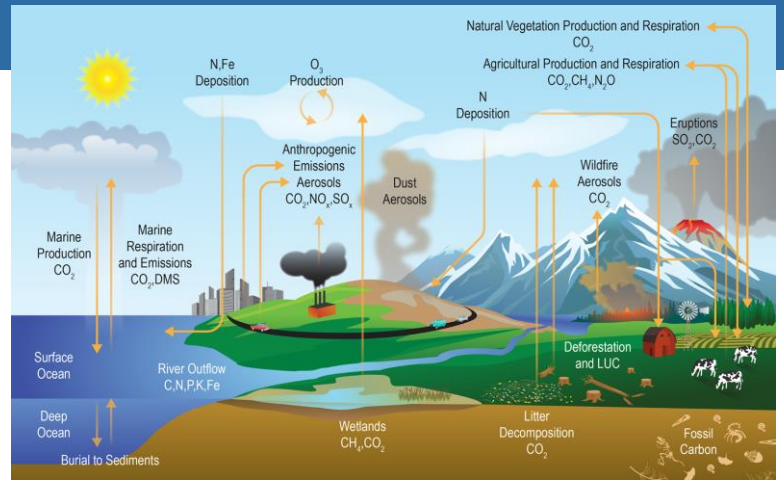
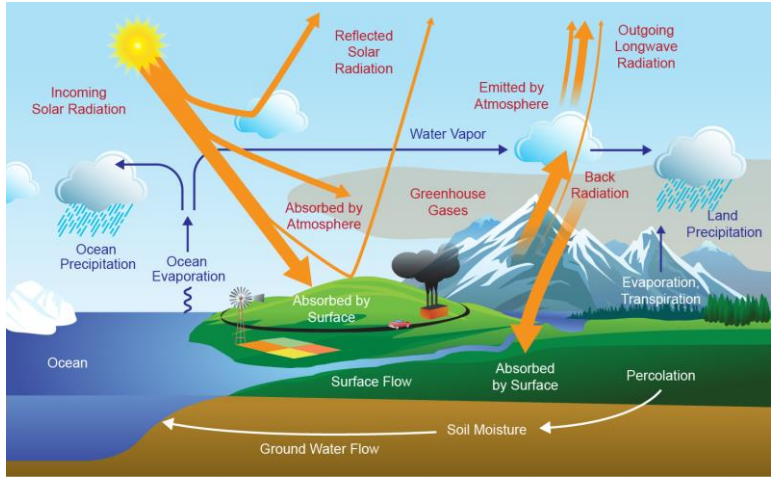
International Land Model Benchmarking (ILAMB) Project

- **First ILAMB Workshop** was held in Exeter, UK, on June 22–24, 2009
- Methodology for model-data comparison and baseline standard for performance of land model process representations
- **ILAMBv1** released at 2015 AGU Fall Meeting Town Hall.
- Originally developed for LAND
- **ILAMBv2** released at 2016 ILAMB Workshop,
- Ocean benchmarking capabilities (**IOMB**) became available ~2022 (introduced within the ILAMB v2 framework).



Carbon and Biogeochemical Cycles



Energy and Water Cycles

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International Land Model Benchmarking (ILAMB) Project

- Open source benchmarking system that leverages a growing collection of laboratory, field, and remote sensing data.
- Written in Python 3.
- Runs in parallel on laptops, clusters, and supercomputers
- The ILAMB/IOMB package was developed to provide quick and easy model-data comparison capabilities for multiple earth system models (ESMs).
- Routinely used for land model evaluation during development of ESMs, including the **E3SM Land Model** (Zhu et al., 2019) and the **CESM Community Land Model** (Lawrence et al., 2019)
- ILAMB (and now IOMB) were designed for use by:
  - Individual modelers or model developers for verification and rapid model development cycles,
  - Modeling centers to track the evolution of model performance,
  - Model intercomparison projects for multi-model analysis.

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Diagnostics and Model Scores

- ILAMB generates a top-level **portrait plot** of models scores
- For every variable and dataset, ILAMB can produce:
  - **Tables** containing individual metrics and metric scores (when relevant to the data), including
    - Benchmark and model **period mean**
    - **Bias** and **bias score** (S_{bias})
    - **Root-mean-square error (RMSE)** and **RMSE score** (S_{rmse})
    - **Phase shift** and **seasonal cycle score** (S_{phase})
    - **Interannual coefficient of variation** and **IAV score** (S_{iav})
    - **Spatial distribution score** (S_{dist})
    - **Overall score** ($S_{overall}$)
  - **Graphical diagnostics**
    - Spatial contour maps
    - Time series line plots
    - Spatial Taylor diagrams (Taylor, 2001)

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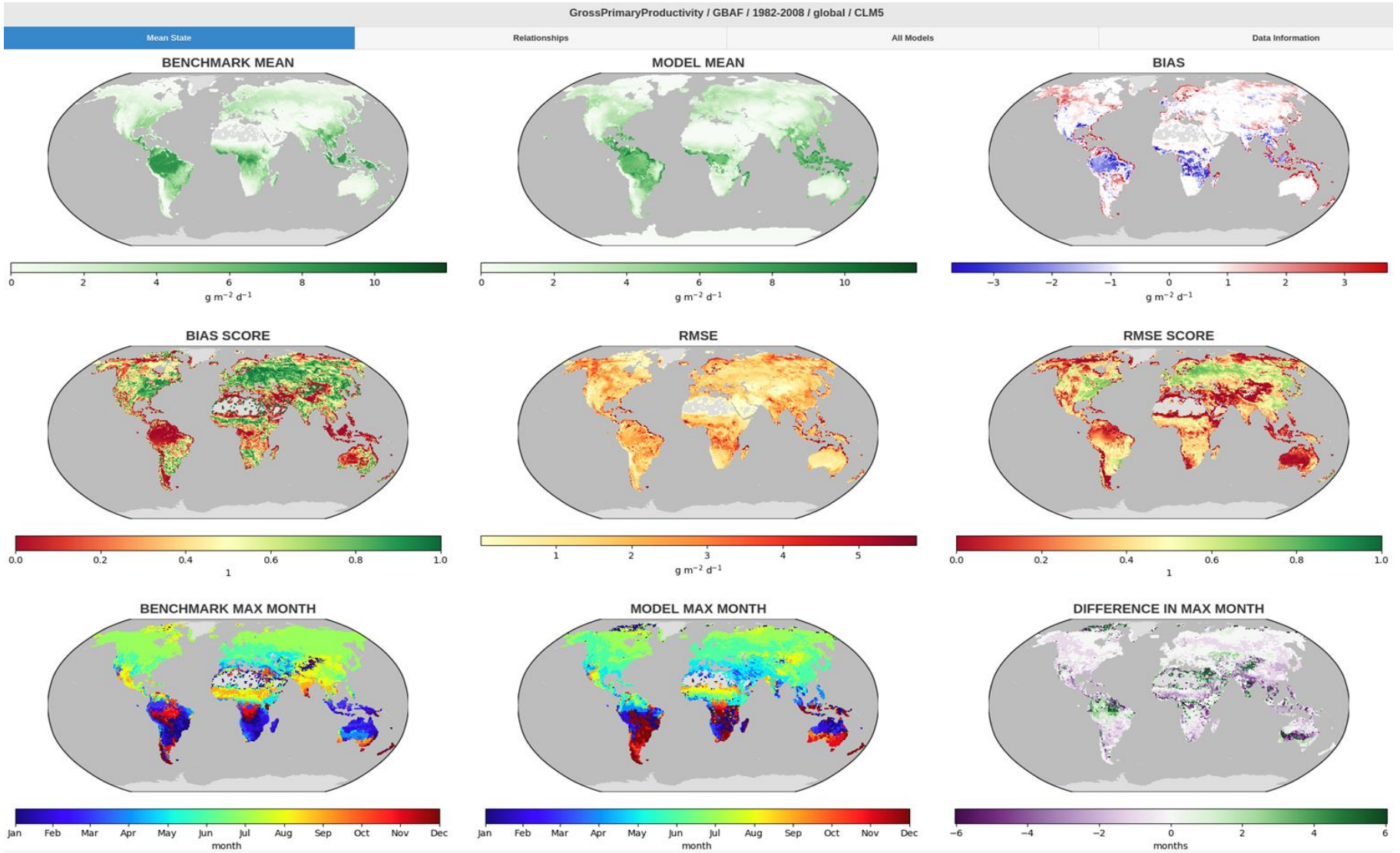
Graphical Diagnostics



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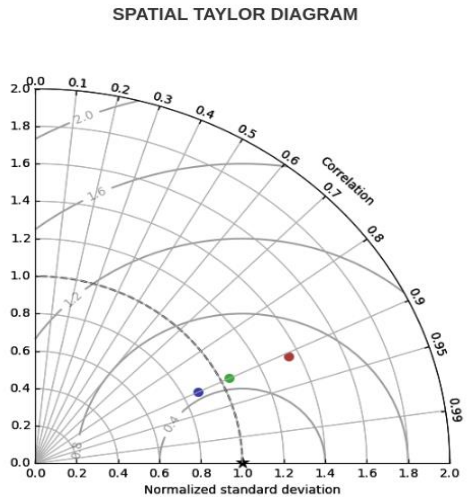
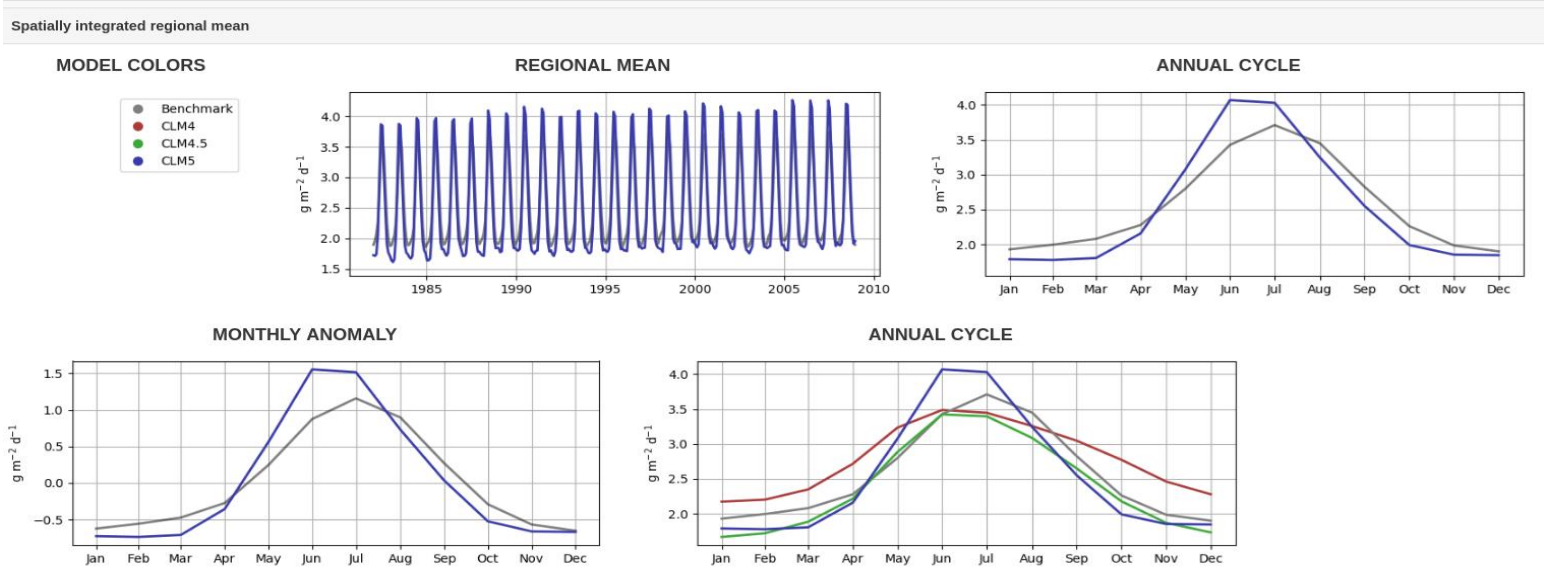
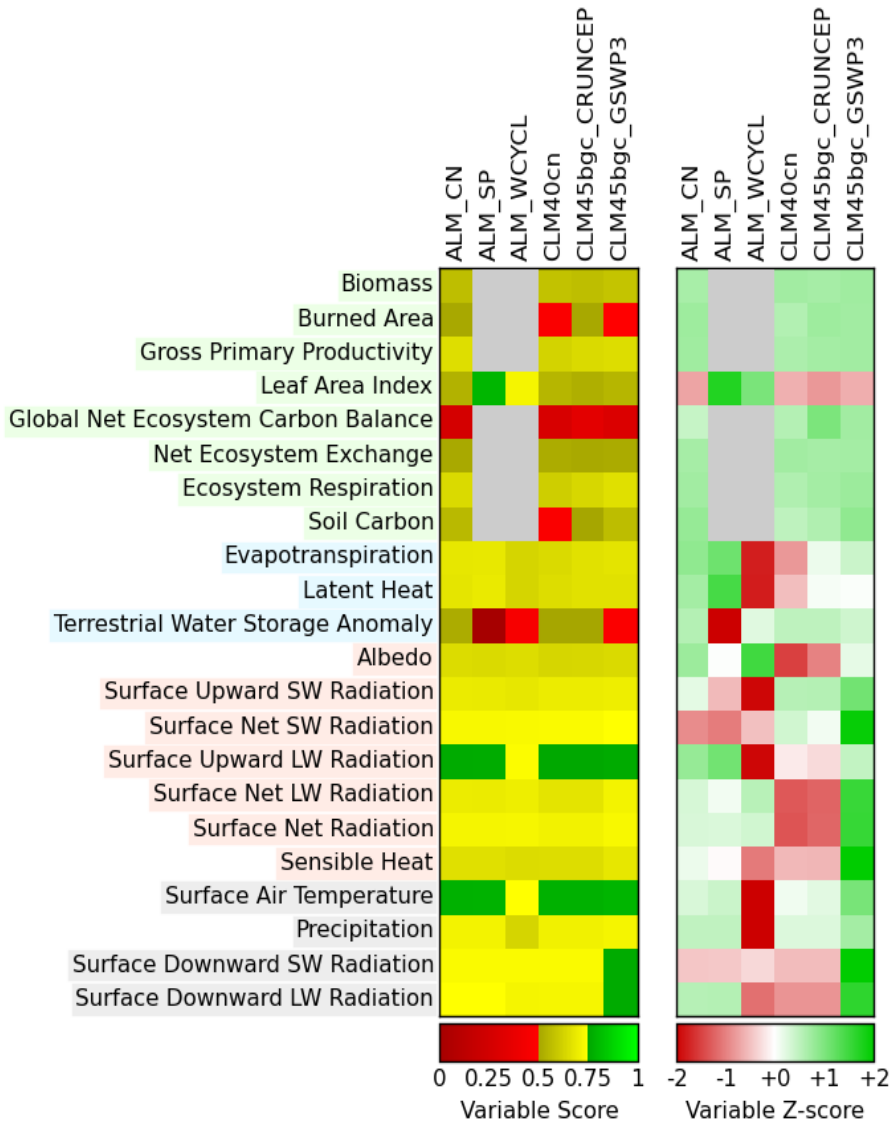
Graphical Diagnostics



Models are scored based on statistical comparisons and functional response metrics





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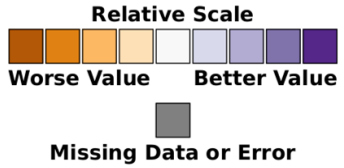
CMIP Evaluation

- ILAMB/IOMB benchmarking was used to evaluate models in the Coupled Model Intercomparison Project (CMIP) - global climate science initiative to improve climate models.
- Model fidelity is assessed through comparison of historical simulations with a wide variety of contemporary observational datasets.
- Evaluated how land and ocean model performance have changed from CMIP5 to CMIP6.
- ILAMB/IOMB evaluation was inluded in the UN's Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) from Working Group 1 (WG1).



	CMIP5 ESMs									CMIP6 ESMs									
(a) Land Benchmarking Results	bcc-csm1-1	CanESM2	CESM1-BGC	GFDL-ESM2G	IPSL-CM5A-LR	MIROC-ESM	MPI-ESM-LR	NorESM1-ME	HadGEM2-ES	BCC-CSM2-MR	CanESM5	CESM2	GFDL-ESM4	IPSL-CM6A-LR	MIROC-ES2L	MPI-ESM1.2-LR	NorESM2-LM	UKESM1-0-LL	Mean CMIP5	Mean CMIP6
Land Ecosystem & Carbon Cycle	-0.72	-0.93	-1.55	-1.51	-0.13	0.60	-0.43	-1.31	0.19	-0.43	0.66	0.48	-1.09	0.22	0.60	-0.07	1.00	0.49	1.63	2.30
Biomass	0.20	-0.45	-1.52	-0.40	-1.26	-0.26	-1.07	-1.77	0.92	1.39	0.74	-0.20	-0.54	0.16	0.93	-0.96	-0.01	1.04	1.23	1.82
Burned Area			-0.87				0.10	-0.83				1.60								
Leaf Area Index	-0.20	-0.64	-1.30	-2.53	-0.01	0.30	0.01	1.85	-0.16	0.27	0.08	0.34	-0.70	1.19	0.82	0.46	0.37	0.69	1.04	1.81
Soil Carbon	0.27	1.26	-1.46	0.07	0.75	0.47	-0.03	-1.14	0.07	0.23	1.35	-0.99	-2.04	-1.55	0.90	-0.75	-0.17	0.24	1.01	1.48
Gross Primary Productivity	0.59	-1.23	0.01	-1.81	-1.40	0.29	-0.53	-0.24	-1.04	0.77	0.04	0.59	-0.38	1.17	-1.02	-0.37	0.73	0.09	1.51	2.22
Net Ecosystem Exchange	-0.42	-1.81	-0.21	-0.65	1.10	-0.24	0.80	0.02	-1.03	-1.02	-1.19	0.59	1.69	-0.42	0.63	-0.21	1.08	-1.43	1.28	1.43
Ecosystem Respiration	0.90	-0.56	-0.86	-0.24	-1.35	0.99	-0.01	-0.94	-1.54	0.81	0.59	0.51	-0.79	0.90	-0.21	-1.24	0.43	-0.94	1.34	2.21
Carbon Dioxide		-1.54	-0.36	-2.92	-0.74	1.53	-0.00	0.37	0.85		0.42	0.26	0.39	0.59	1.10	-0.87	0.21	0.69	0.09	-0.07
Global Net Carbon Balance		-1.64	-0.88	-1.13	0.17	-0.31	-0.38	-0.50	0.24		-0.23	1.34	-1.70	0.17	-0.74	1.45	1.56	0.26	0.92	1.40
Land Hydrology Cycle	-2.65	-0.42	0.44	-0.18	-0.49	-0.52	-0.57	0.17	0.70	0.15	-0.47	1.51	-1.24	0.58	-0.72	-0.83	0.97	0.87	1.00	1.70
Evapotranspiration	-0.82	-0.99	-0.27	-1.02	0.64	-1.14	-0.62	-0.60	0.28	0.39	-1.08	1.09	0.65	0.43	-1.40	-1.01	0.82	1.05	1.41	2.20
Evaporative Fraction	-0.34	0.74	0.74	-0.14	-0.85	0.21	-1.98	0.22	-0.34	0.10	0.11	1.25	-0.88	1.29	-1.65	-1.81	1.11	-0.06	0.98	1.29
Sensible Heat																				
Terrestrial Water Storage Anomaly	-2.79	-0.45	0.47	0.50	-0.38	0.34	0.35	0.43	0.58	0.15	-0.08	0.95	-2.91	0.43	0.37	0.15	0.39	0.51	0.49	0.50
Permafrost	-0.88	-2.26	0.01	0.13	0.83	0.69	0.56	0.69	-0.56	-0.11	-3.02	0.83	0.74	-0.18	0.49	0.42	0.89	0.43	0.06	0.23
(b) Ocean Benchmarking Results																				
Ocean Ecosystems			2.18	0.20	-0.20		0.04		0.22		-0.37	0.83	-0.37	-0.26	-0.91	-0.67	-1.93	0.27	0.30	0.67
Chlorophyll		-1.50	2.15	0.44	1.02		0.49		0.56		-0.67	0.88	-0.21	0.10	-1.02	-0.41	-2.19	0.18	0.13	0.04
Oxygen, surface			0.73	-0.13	-1.98		-0.53	-1.53	-0.29		0.73	0.34	-0.09	-0.41	0.35	-0.30	0.40	0.49	0.64	1.57
Ocean Nutrients			-0.84	-0.10	0.91		-0.80	-1.25				-0.02	1.00	1.88		-0.90	-1.14	-0.17	-0.16	1.60
Nitrate, surface		0.21	-1.63	0.67	1.22		-0.18	-1.70	0.82		1.21	-0.90	0.29	1.21	1.02	0.39	-1.78	-0.56	-0.47	0.18
Phosphate, surface			-0.69	-0.04	0.04		-0.45	-0.43				0.39	-0.14	0.17	-0.41	-0.98	0.00	0.02	0.88	1.63
Silicate, surface			0.44	-0.71	0.24		-0.81	-0.20	-2.16			0.50	1.24	1.60		-1.21	-0.19	0.18	-0.29	1.37
Ocean Carbon											1.24	-0.23	-0.62	-0.69	-1.08	-1.12	1.31			1.19
TAlk, surface		-0.27	1.01	0.12	0.19		0.32	2.31	-0.22		0.06	-0.36	0.85	-0.42	0.29	-2.40	1.27	0.06	1.27	0.54
Salinity, 200m	-0.62	-0.29	-0.07	-0.57	0.54	-0.57	-0.26	-0.75	-0.76	-0.25	0.49	-0.47	0.15	0.65	0.58	0.01	-0.98	-0.22	1.41	1.99
Salinity, 700m	0.44	-0.35	-1.06	-0.54	0.70	0.46	-0.46	-0.80	0.32	0.36	0.25	-1.16	-0.47	0.54	0.33	-0.39	-0.87	-0.54	1.58	1.64
Ocean Relationships			-1.86	-0.36	-0.29		1.50	-0.43	0.68		-0.02	0.72	1.20	0.17	1.86	0.02		-1.12	0.39	1.25
Oxygen, surface/WOA2018			0.27	0.23	-0.63		-0.26	-0.12	-0.38		0.29	-0.21	0.19	0.18	0.14	-0.07		0.03	-0.23	0.53
Nitrate, surface/WOA2018		-2.41	-1.38	-0.18	0.06		1.41	-0.16	0.78		0.09	0.79	1.07	0.26	-1.35	0.20		-0.74	0.52	1.04

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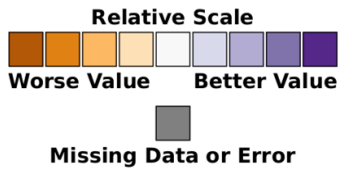
CMIP Evaluation

- The CMIP6 suite of land models (right) has improved over the CMIP5 suite of land models (left).
- The multi-model mean outperforms any single model for each suite of models.
- The multi-model mean CMIP6 land model is the "best model" overall



	CMIP5 ESMs									CMIP6 ESMs										
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(a) Land Benchmarking Results																				
Land Ecosystem & Carbon Cycle	-0.72	-0.93	-1.55	-1.51	-0.13	0.60	-0.43	-1.31	0.19	-0.43	0.66	0.48	-1.09	0.22	0.60	-0.07	1.00	0.49	1.63	2.30
Biomass	0.20	-0.45	-1.52	-0.40	-1.26	-0.26	-1.07	-1.77	0.92	1.39	0.74	-0.20	-0.54	0.16	0.93	-0.96	-0.01	1.04	1.23	1.82
Burned Area			-0.87				0.10	-0.83				1.60								
Leaf Area Index	-0.20	-0.64	-1.30	-2.53	-0.01	0.30	0.01	1.85	-0.16	0.27	0.08	0.34	-0.70	1.19	0.82	0.46	0.37	0.69	1.04	1.81
Soil Carbon	0.27	1.26	-1.46	0.07	0.75	0.47	-0.03	-1.14	0.07	0.23	1.35	-0.99	-2.04	-1.55	0.90	-0.75	-0.17	0.24	1.01	1.48
Gross Primary Productivity	0.59	-1.23	0.01	-1.81	-1.40	0.29	-0.53	-0.24	-1.04	0.77	0.04	0.59	-0.38	1.17	-1.02	-0.37	0.73	0.09	1.51	2.22
Net Ecosystem Exchange	-0.42	-1.81	-0.21	-0.65	1.10	-0.24	0.80	0.02	-1.03	-1.02	-1.19	0.59	1.69	-0.42	0.63	-0.21	1.08	-1.43	1.28	1.43
Ecosystem Respiration	0.90	-0.56	-0.86	-0.24	-1.35	0.99	-0.01	-0.94	-1.54	0.81	0.59	0.51	-0.79	0.90	-0.21	-1.24	0.43	-0.94	1.34	2.21
Carbon Dioxide		-1.54	-0.36	-2.92	-0.74	1.53	-0.00	0.37	0.85		0.42	0.26	0.39	0.59	1.10	-0.87	0.21	0.69	0.09	-0.07
Global Net Carbon Balance		-1.64	-0.88	-1.13	0.17	-0.31	-0.38	-0.50	0.24		-0.23	1.34	-1.70	0.17	-0.74	1.45	1.56	0.26	0.92	1.40
Land Hydrology Cycle	-2.65	-0.42	0.44	-0.18	-0.49	-0.52	-0.57	0.17	0.70	0.15	-0.47	1.51	-1.24	0.58	-0.72	-0.83	0.97	0.87	1.00	1.70
Evapotranspiration	-0.82	-0.99	-0.27	-1.02	0.64	-1.14	-0.62	-0.60	0.28	0.39	-1.08	1.09	0.65	0.43	-1.40	-1.01	0.82	1.05	1.41	2.20
Evaporative Fraction	-0.34	0.74	0.74	-0.14	-0.85	0.21	-1.98	0.22	-0.34	0.10	0.11	1.25	-0.88	1.29	-1.65	-1.81	1.11	-0.06	0.98	1.29
Sensible Heat																				
Terrestrial Water Storage Anomaly	-2.79	-0.45	0.47	0.50	-0.38	0.34	0.35	0.43	0.58	0.15	-0.08	0.95	-2.91	0.43	0.37	0.15	0.39	0.51	0.49	0.50
Permafrost	-0.88	-2.26	0.01	0.13	0.83	0.69	0.56	0.69	-0.56	-0.11	-3.02	0.83	0.74	-0.18	0.49	0.42	0.89	0.43	0.06	0.23
(b) Ocean Benchmarking Results																				
Ocean Ecosystems			2.18	0.20	-0.20		0.04		0.22		-0.37	0.83	-0.37	-0.26	-0.91	-0.67	-1.93	0.27	0.30	0.67
Chlorophyll		-1.50	2.15	0.44	1.02		0.49		0.56		-0.67	0.88	-0.21	0.10	-1.02	-0.41	-2.19	0.18	0.13	0.04
Oxygen, surface			0.73	-0.13	-1.98		-0.53	-1.53	-0.29		0.73	0.34	-0.09	-0.41	0.35	-0.30	0.40	0.49	0.64	1.57
Ocean Nutrients			-0.84	-0.10	0.91		-0.80	-1.25				-0.02	1.00	1.88		-0.90	-1.14	-0.17	-0.16	1.60
Nitrate, surface		0.21	-1.63	0.67	1.22		-0.18	-1.70	0.82		1.21	-0.90	0.29	1.21	1.02	0.39	-1.78	-0.56	-0.47	0.18
Phosphate, surface			-0.69	-0.04	0.04		-0.45	-0.43				0.39	-0.14	0.17	-0.41	-0.98	0.00	0.02	0.88	1.63
Silicate, surface			0.44	-0.71	0.24		-0.81	-0.20	-2.16			0.50	1.24	1.60		-1.21	-0.19	0.18	-0.29	1.37
Ocean Carbon											1.24	-0.23	-0.62	-0.69	-1.08	-1.12	1.31			1.19
TAlk, surface		-0.27	1.01	0.12	0.19		0.32	2.31	-0.22		0.06	-0.36	0.85	-0.42	0.29	-2.40	1.27	0.06	1.27	0.54
Salinity, 200m																				
Salinity, 700m	0.44	-0.35	-1.06	-0.54	0.70	0.46	-0.46	-0.80	0.32	0.36	0.25	-1.16	-0.47	0.54	0.33	-0.39	-0.87	-0.54	1.58	1.64
Ocean Relationships			-1.86	-0.36	-0.29		1.50	-0.43	0.68		-0.02	0.72	1.20	0.17	1.86	0.02		-1.12	0.39	1.25
Oxygen, surface/WOA2018			0.27	0.23	-0.63		-0.26	-0.12	-0.38		0.29	-0.21	0.19	0.18	0.14	-0.07		0.03	-0.23	0.53
Nitrate, surface/WOA2018		-2.41	-1.38	-0.18	0.06		1.41	-0.16	0.78		0.09	0.79	1.07	0.26	-1.35	0.20		-0.74	0.52	1.04

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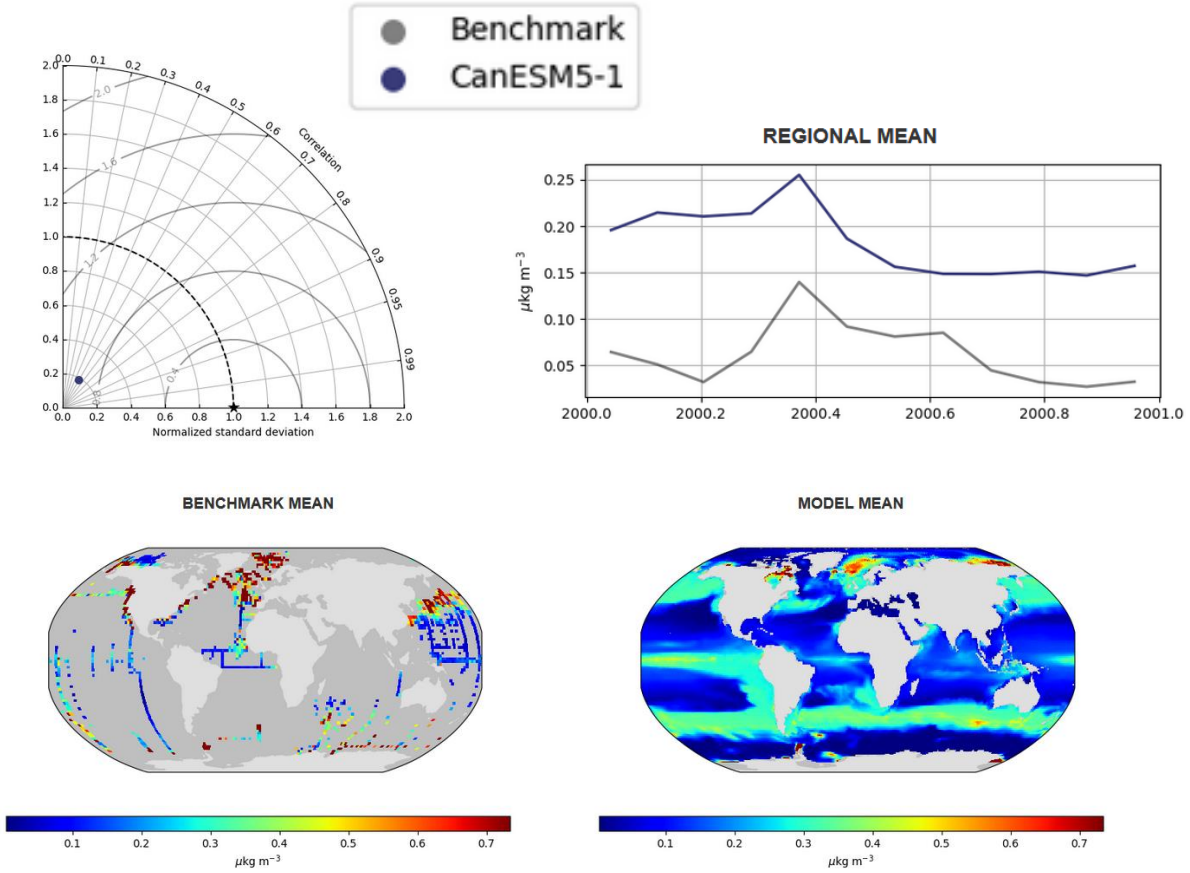
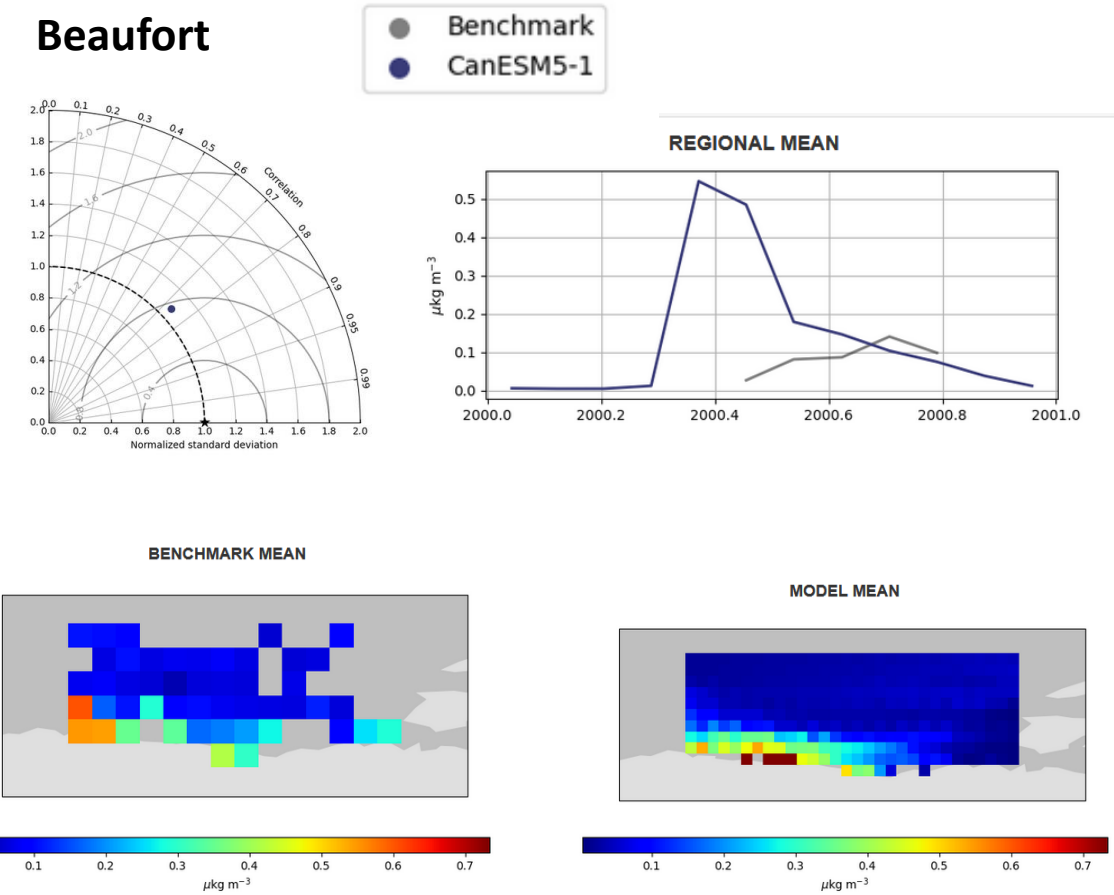
Regional Arctic Metrics



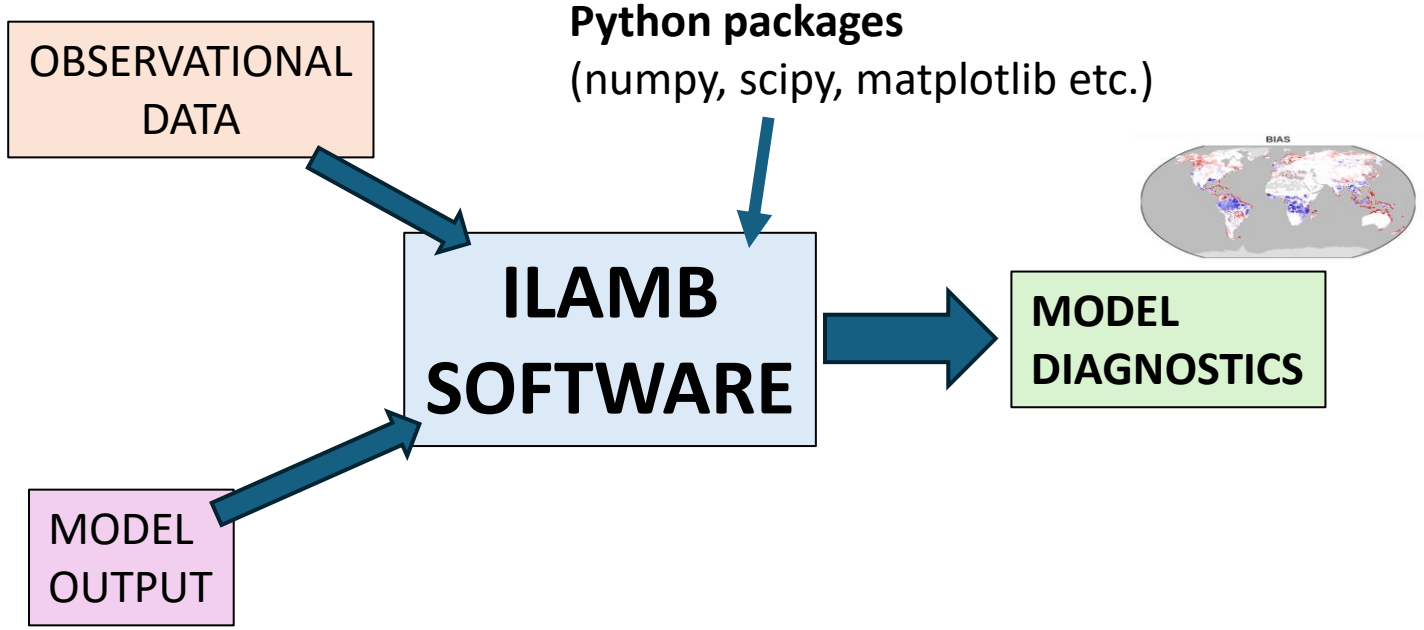


- *Usefulness* of ILAMB depends on the quality of incorporated observational data and selection of relevant metrics.
- IOMB provides the ability to incorporate your own data, define regions of interest… and ideas for metrics.

Working with IOMB

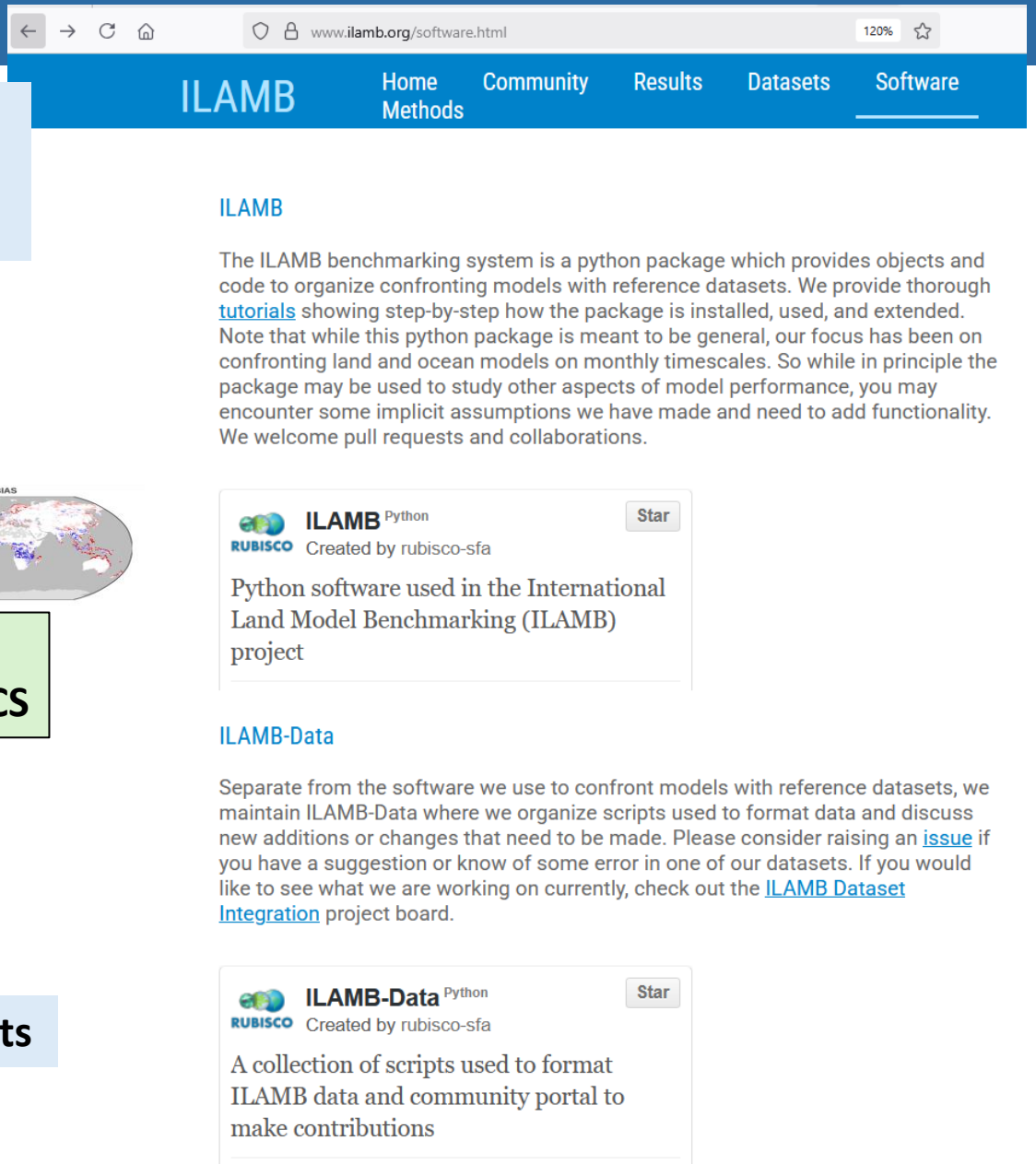
The software comes with no data. It is a generic software which facilitates the automatic confrontation of model results with benchmark observational datasets.

IOMB-Data



ESGF-Data

IOMB added new configs and datasets



Setting up a Benchmark

Iomb.cfg

```
#######################################################

[h1: Ecosystems]
bgcolor = "#ECFFE6"

#~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

[h2: Chlorophyll]
variable       = "chla"
alternate_vars = "chl"
depths = 0
skip_rmse = True
skip_cycle = True

[GLODAP2.2022]
source = "DATA/GLODAP2.2022/chla.nc"
skip_rmse = True
skip_cycle = True
table_unit = "1e-6 kg m-3"
plot_unit = "1e-6 kg m-3"

[SeaWIFS]
source = "DATA/SeaWIFS/SeaWIFS.nc"
skip_rmse = True
skip_cycle = True
table_unit = "1e-6 kg m-3"
plot_unit = "1e-6 kg m-3"
```

The configure file describes the variable of interest and which data sets you are interested in.

models.yaml

```
CanESM5:
  modelname: CanESM5-1
  color: "#393b79"
  path: ~/esgf_cache/CMIP6/CMIP/CCCma/CanESM5-1/historical/r1i1p1f1/Omon/chl/gn/v20190429
```

The yaml file describes the model you with to benchmark.

ilamb-run --config **iomb.cfg** --model_setup **models.yaml**

ILAMB 3

https://github.com/rubisco-sfa/ilamb3

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github.com/rubisco-sfa/ilamb3?tab=readme-ov-file#readme 110%

README | BSD-3-Clause license

RUBISCO

Experimental version under development

CI passing | docs passing | coverage 69%

ILAMB - International Land Model Benchmarking

The python package designed to help confront earth system models with reference data products, and then present the results in a hierarchical set of webpages. Please see ilamb.org where we have details about the datasets we use, the results we catalog, and the methods we employ.

This package is being developed and not currently listed in PyPI or conda-forge. You may install it directly from this repository:

```
pip install git+https://github.com/rubisco-sfa/ilamb3
```

The above command will install the latest code from the repository. We will make *releases* as new methods and functionality are ready, updating the documentation as we develop. To install a specific version of the code, append it to the URL. The following will install the released version v2025.5.20:

```
pip install git+https://github.com/rubisco-sfa/ilamb3@v2025.5.20
```

Eventually this package will replace the current ILAMB package. Consult the documentation for more information on current status and to see what is functional.

Packages

No packages published

Contributors 7

Languages

Python 94.7% HTML 5.3%

- More robust code
- A pure python package
- Improved user interface
- Ability to transform data for comparison
- Already being used in the community (since 2024)
- Encouraged to check it out but a lot of documentation is still missing.

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Prepping Data/Model Output

1. File Format
Must be NetCDF (.nc). , CF-like NetCDF with usable coordinates. (full CMOR not required)

2. Target Variable
Variable exists in file
Name matches ILAMB expectation OR use alternate_vars
Units defined and physically meaningful
Can define a derived variable in the config file (e.g., derived = var1 + var2)
Examples: total chlorophyll

3. Time Coordinate
'time' variable present
Includes units (e.g., days since YYYY-MM-DD)
Includes calendar (e.g., noleap, gregorian)
Consistent timestep (monthly typical)
Optional: time_bnds

4. Spatial Coordinates
Latitude (lat) and longitude (lon) present
Associated with data dimensions
Units: degrees_north / degrees_east

5. Dimensions / Grid compatibility
Must be interpretable by ILAMB. Regular lat/lon grid preferred
(time, lev, lat, lon) acceptable
(time, nCells) often problematic (require regridding in practice)

6. Missing Values
_FillValue or missing_value defined
Consistent masking

7. Cell Area (Recommended)
Provide area, cell_area, or areaCell
Units: m^2
Needed for spatial averaging

8. Depth Handling (if applicable)
Provide depth coordinate (lev/depth) OR
Pre-process (e.g., 0–30 m average)

9. Physical Consistency
Units match expectation

Depending on native ESM model output format several pre-processing steps may be required

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Tutorial Plan

- Log in to NERSC Perlmutter
- Run tutorial using Jupyter notebook
- Use pre-installed ILAMB
- Download IOMB data
- Download model data using ESGF
- Setup and run an IOMB benchmark
- View the output

https://ggibson-lanl.github.io/lomb-tutorial/

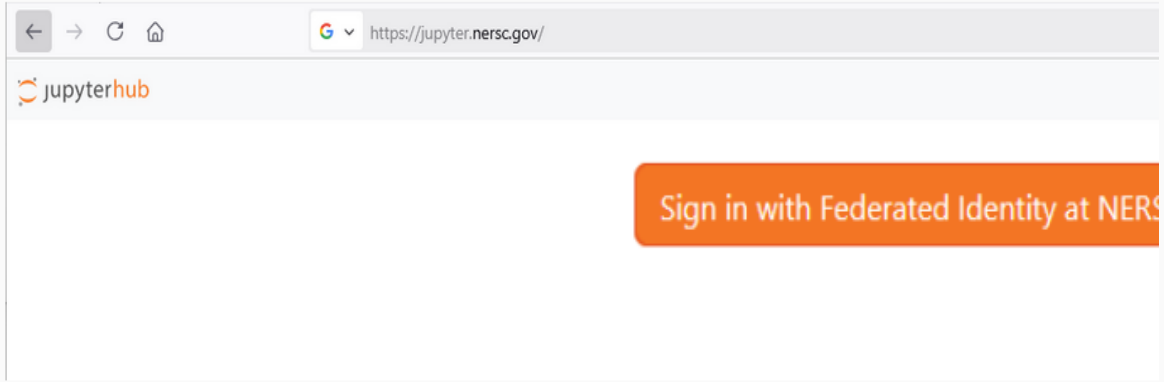
CAMAS Early Career IOMB Tutorial

This page provides the **quick-start instructions** for accessing the tutorial on NERSC Perlmutter.

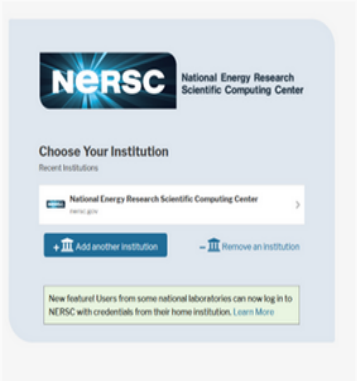
These instructions assume you already have a regular or a training account at NERSC.

Step 1 — Sign in to NERSC JupyterHub

Go to:
https://jupyter.nersc.gov/hub/login



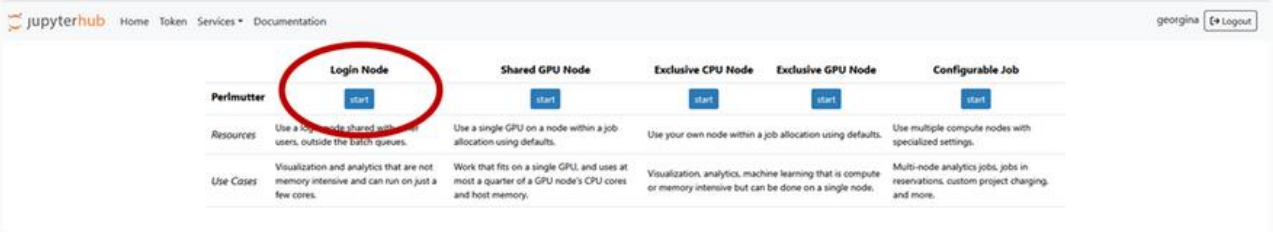
This will take you to the NERSC log in page



This will then prompt you for your Multi-Factor-Authentication (MFA). You will likely be getting this from an authenticator app on your phone

Step 2 — Start a session

Click the **START** button to launch a login node.



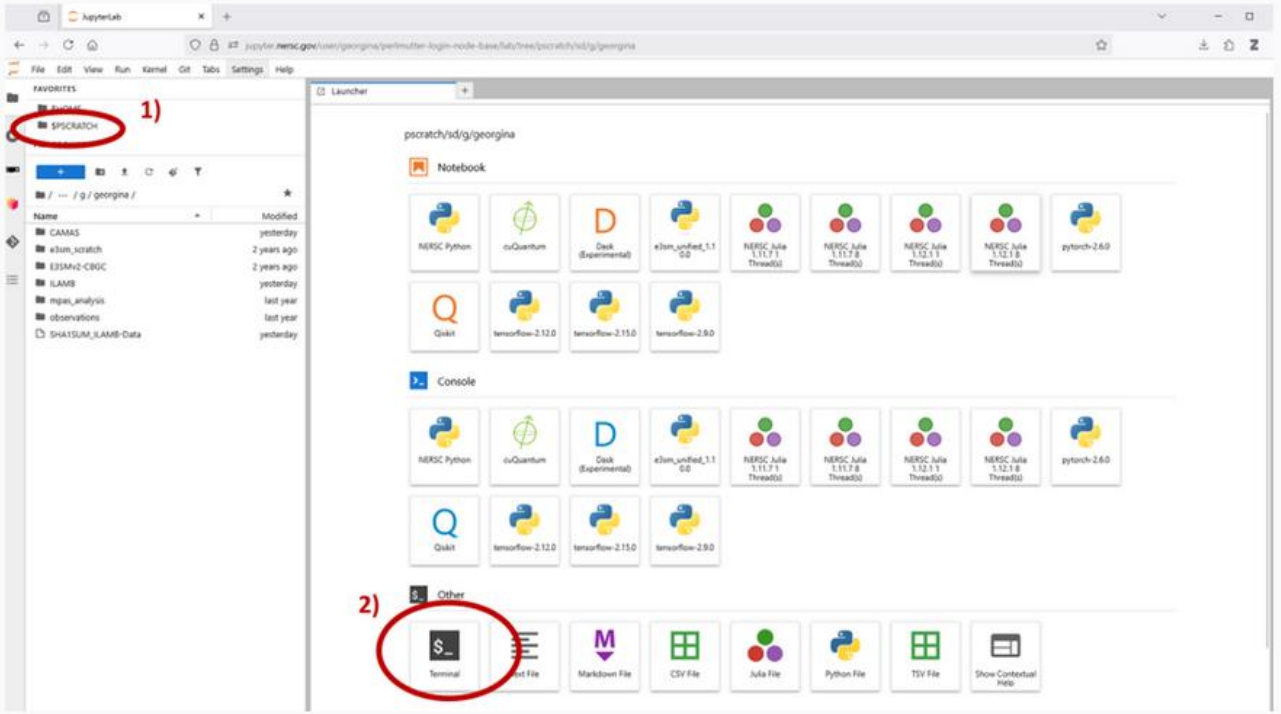
Step 3 — Open your scratch space

Click $PSCRATCH in the left file browser.

Open **Launcher → Terminal**.

Example path:

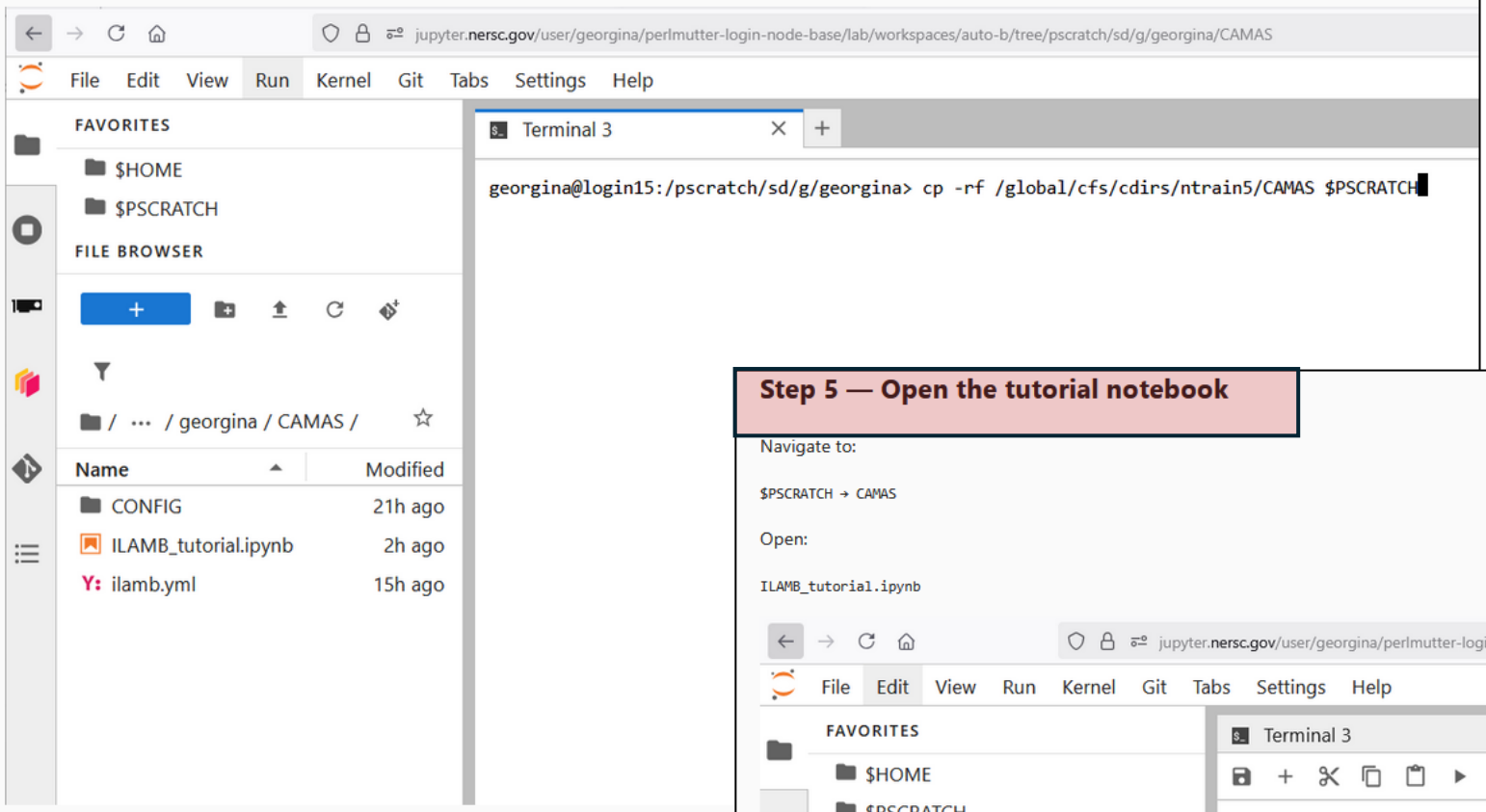
```
/pscratch/sd/g/your_username
```



Step 4 — Copy the CAMAS tutorial files

Run this command in the terminal:

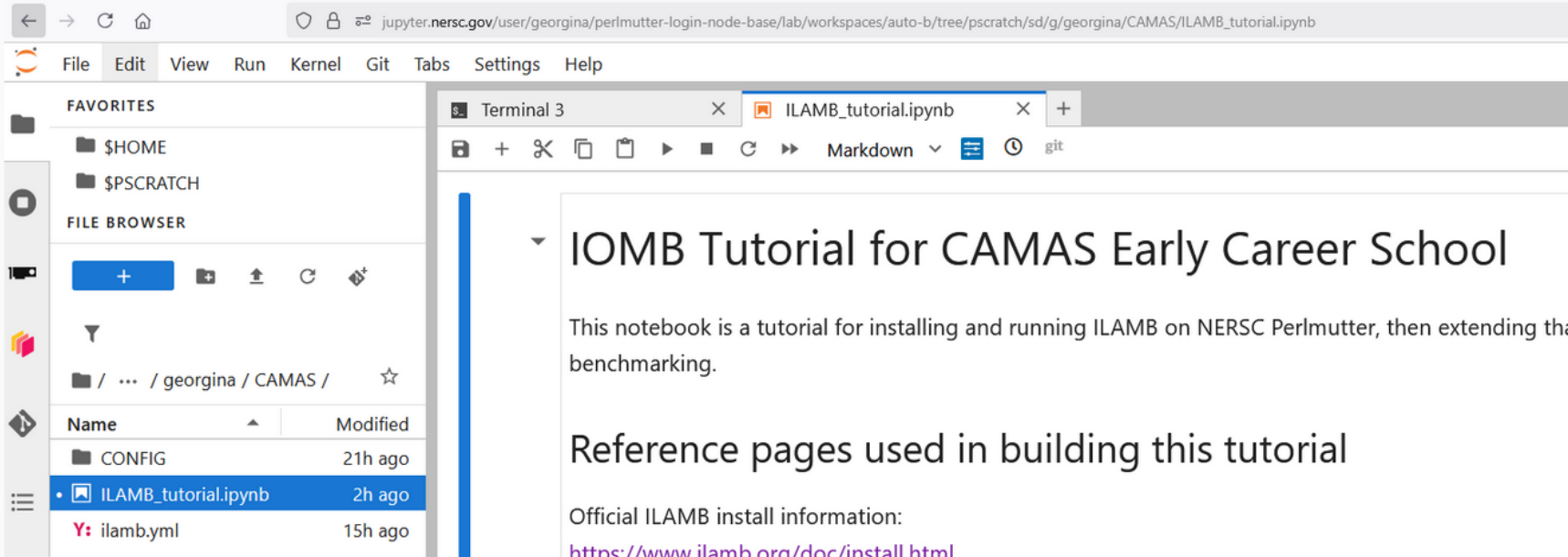
```
cp -rf /global/cfs/cdirs/ntrain5/CAMAS $PSCRATCH
```



Step 5 — Open the tutorial notebook

Navigate to:

```
$PSCRATCH → CAMAS
```

Open:

```
ILAMB_tutorial.ipynb
```