Housekeeping

This seminar series is an activity of the Climate-Rapid Evaluation Framework Panel which is supported by the CMIP International Project Office. Please note the following housekeeping principles:

- **Abide by the WCRP code of conduct** - www.wcrp-climate.org/wcrp-code-of-conduct
- **Recording** - This meeting is being recorded and AI-transcribed*. The recording will be uploaded within two weeks. Turn off your camera if you do not wish to appear in the recording. See: www.wcrp-cmip.org/privacy-policy
- **Minimise data usage** - during presentation, only the presenter should have their video on.
- **Raise hand to ask question or place in the chat**
- **Be mindful of non-native English speakers** - use plain English (short and direct), avoid unnecessary jargon and acronyms.

***AI notetaker tools not listed in Annexure A of the *AI Usage Policy for Community Members and Participants Attending CMIP IPO Hosted Activities* will be ejected from the event**

Climate-REF
Seminar-Series

Land & land ice

Net ecosystem carbon balance

05 November 2026, online

Diagnostic authors: Forrest Hoffman (ORNL)

Package: ILAMB

Chair’s welcome



Moet Ashfaq

ORNL, USA

Climate – Rapid Evaluation Framework

- Vision: A community owned evaluation framework, built upon, and compatible with, existing community evaluation packages that incorporates an application programming interface (API) for executing metrics generation from those community evaluation packages, across the globe.
- Goal: The Climate - Rapid Evaluation Framework (REF) is a complete end to end system, designed to provide a systematic and rapid performance assessment of the expected models participating in the CMIP Assessment Fast Track, supporting the next IPCC Assessment Report 7 (AR7) cycle.
- Outcome: The REF provides ability to fully integrate evaluation tools into the CMIP publication workflow, and their diagnostic outputs published alongside the model output on the Earth System Grid Federation (ESGF) through an easily accessible website. The REF serves as a starting point for deeper exploration of CMIP model data.
- Wider community use beyond CMIP: The REF is designed to be a starting point for the community to develop and build upon, with applications across the WCRP Modelling Multiverse and beyond.

Diagnostics for the CMIP Assessment Fast Track

The Assessment Fast Track is a subset of CMIP7 experiments drawn from the community MIPs intended to support upcoming policy assessments and downstream climate services applications

The REF has Assessment Fast Track diagnostic collections are organised into realms to align with the CMIP data request

A diagnostic collection is a grouping of one or more diagnostics for a given model variable, phenomena, or theme being evaluated.

CMIP7 Assessment Fast Track Diagnostics list for the Rapid Evaluation Framework
doi.org/10.5281/zenodo.14284375



Find out more about the realms in the GMD paper: doi.org/10.5194/gmd-19-7415-2026

New for CMIP 7

Branded variables:

- A new naming system termed **"branded variables"** has been created to address some of the issues with the earlier naming system.

Amon.tas (Monthly-mean near-surface air temperature for the whole globe) **becomes** **tas_tavg-h2m-hxy-u** (temporal label, vertical label, horizontal label, area label) + frequency = monthly + region = global ← **branded variable name** (Taylor et al. in prep)

- Variables differing only by **frequency** or **region** have same **branded name**
- Data Request "compound name": **atmos.tas.tavg-h2m-hxy-u.mon.GLB**
  - To ease the transition, DR also includes CMIP6 style names, such as Amon.tas

https://guidance.wcrp-cmip.org/CMIP7/Branded_Variables/

Diagnostic Collection

ID 2.5 Net ecosystem carbon balance



Forrest Hoffman

ORNL, USA

ILAMB RUBISCO

Diagnostic collection overview

ID 2.5 Net ecosystem carbon balance

- Function: nbp-Hoffman
- Package: ILAMB
- Breakdown of diagnostics within collection per variable:

Emon.netAtmosLandCO2Flux is used if present; otherwise,
Lmon.nbp is used for the annual flux and the accumulated flux


Rapid Evaluation Framework for the CMIP7 Assessment Fast Track

Hoffman et al. (2026)
https://doi.org/10.5194/gmd-19-7415-2026

Diagnostic	Package	CMIP6 Variable Table	Physical CMIP7 Variable	Branded Variable Name	Reference Dataset
Net ecosystem carbon balance	ILAMB	Lmon	Lmon.nbp	nbp_tavg-u-hxy-lnd	HOFFMAN
	ILAMB	Emon	Emon.netAtmosLandCO2Flux	netAtmosLandCO2Flux.tavg-u-hxy-lnd	HOFFMAN

Diagnostic collection overview

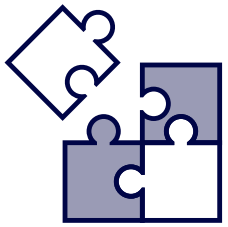
ID 2.5 Net Ecosystem Carbon Balance

The diagnostic collection is based on the ILAMB Package for the NBP Confrontation (ConfNBP.py)

Reference data from 1850–2010 are used for REF, and an updated version to include data until 2024 is planned.

- In these calculations, model nbp fluxes are integrated globally and yearly for comparison with annual flux estimates
- Monthly time series is accumulated over time to compare the overall trajectory of the land carbon sink
- Uncertainty estimates provide an envelope for assessing model deviation from the accumulated land carbon uptake

Diagnostic collection 2.5: Useful resources



Code

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



Papers

Hoffman et al. (2026) DOI: https://doi.org/10.5194/gmd-19-7415-2026

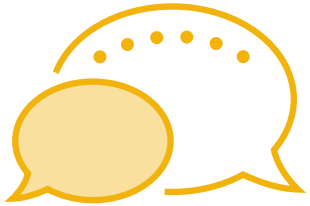
Collier et al. (2018) DOI: https://doi.org/10.1029/2018MS001354

Hoffman et al. (2014) DOI: https://doi.org/10.1002/2013JG002381



Documentation

Collier et al. (2018) DOI: https://doi.org/10.1029/2018MS001354



Support

Reference the diagnostic collection ID when logging a question https://github.com/orgs/Climate-REF/discussions/categories/q-a

Reference datasets

ID 2.5 Net Ecosystem Carbon Balance



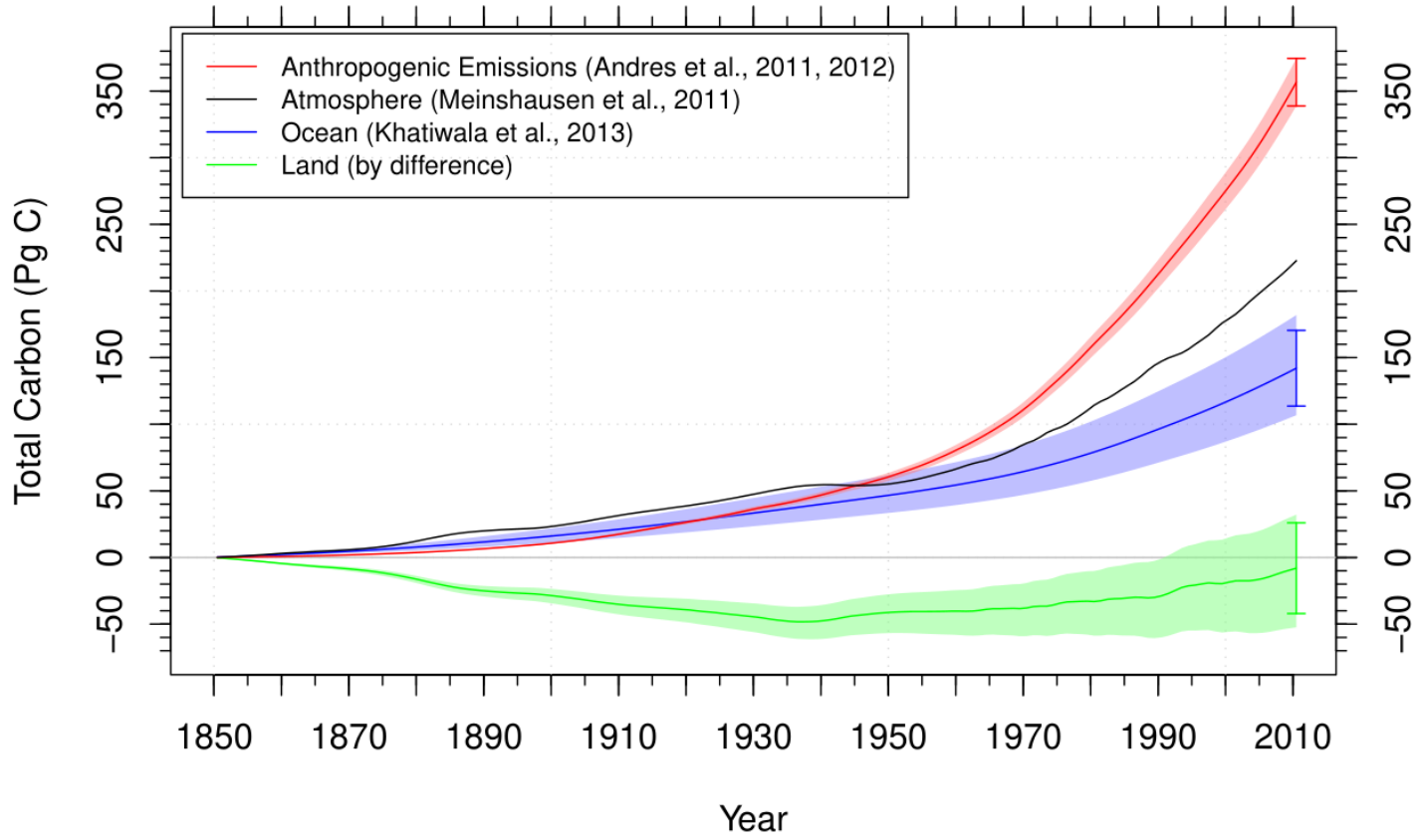
Diagnostic collection reference datasets

ID 2.5 Net Ecosystem Carbon Balance

A reference dataset is a collection of observationally constrained or model data used as a standard within a model evaluation diagnostic.

DIAGNOSTIC	PHYSICAL CMIP7 VARIABLE NAME	BRANDED VARIABLE NAME	REFERENCE DATASET	VERSION NO.	TIMESPAN
Net ecosystem carbon balance	Lmon.nbp	nbp_tavg-u-hxy-lnd	HOFFMAN	1.0	08/01/1850 - 31/12/2010
	Emon.netAtmosLandCO2Flux	netAtmosLandCO2Flux.tavg-u-hxy-lnd	HOFFMAN	1.0	0/01/1850 – 31/12/2010

Observed Carbon Accumulation Since 1850

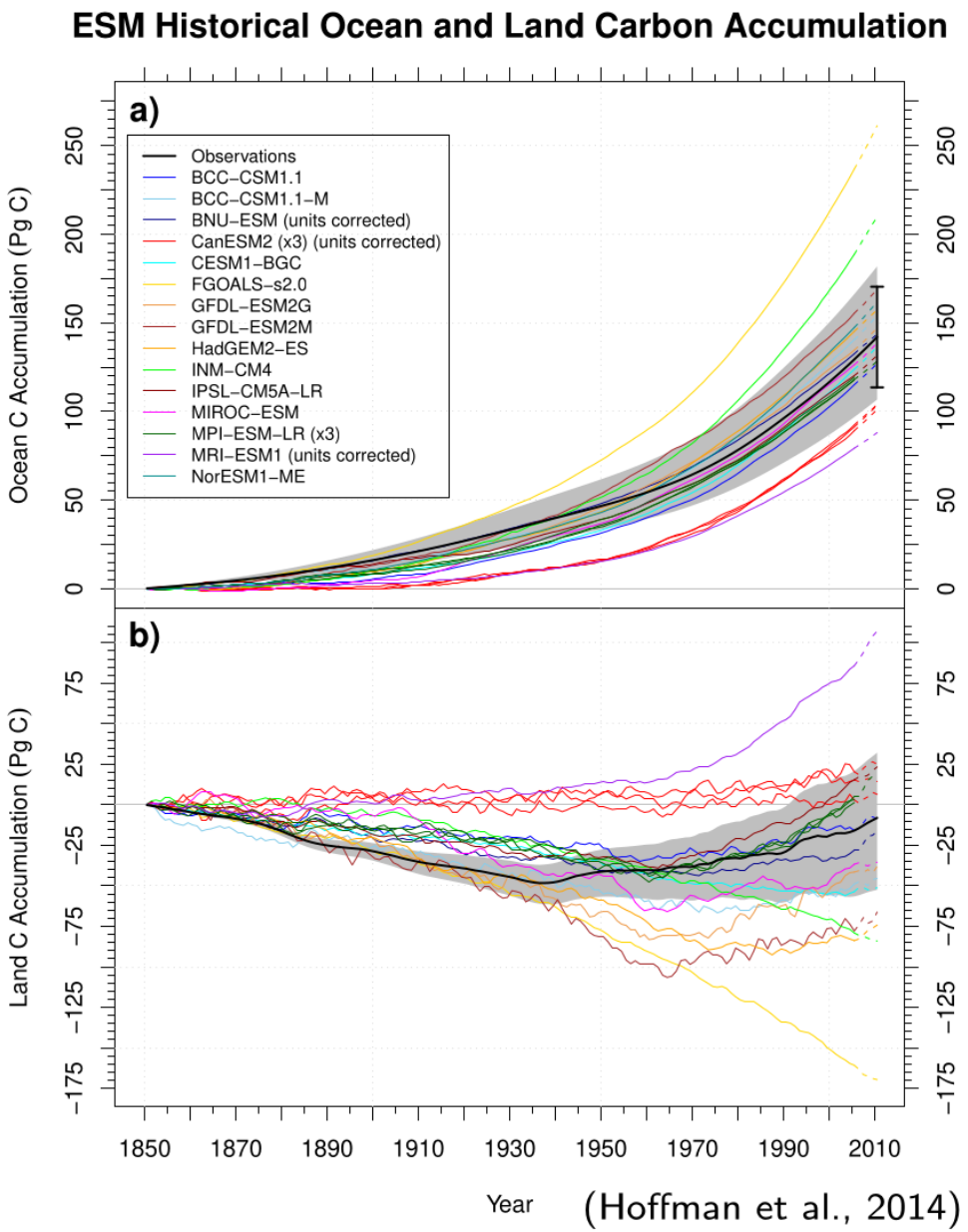


Observational estimates of anthropogenic carbon inventories in atmosphere, ocean, and land reservoirs for 1850–2010. Atmosphere carbon is a fusion of Law Dome ice core CO_2 observations, the Keeling Mauna Loa record, and more recently the NOAA GMD global surface average, integrated for the purpose of forcing IPCC models. Total land flux is computed by mass balance as follows:

$$\Delta C_L = \sum_i F_i - \Delta C_A - \Delta C_O.$$

(a) Ocean inventory estimates have a fairly persistent ordering during the second half of the 20th century.

(b) ESMs have a wide range of land carbon accumulation responses to increasing CO_2 and land use change, ranging from a net source of 170 Pg C to a sink of 107 Pg C in 2010.



Diagnostic collection reference datasets

ID 2.5 Net Ecosystem Carbon Balance

Khatiwala et al. [2013] produced a newly updated global ocean anthropogenic carbon sink trajectory through 2010 using the Green's function model. A cumulative sum of this ocean uptake provided an ocean anthropogenic carbon inventory estimate for 2010 of 150 ± 26 Pg C. Adding a partial estimate for accumulation in marginal seas and coastal areas from Lee et al. [2011] of 8.6 ± 0.6 Pg C yielded a more spatially comprehensive estimate of 160 ± 26 Pg C. Since the Lee et al. [2011] estimate was a lower bound, the upper bound was constrained using multiple Community Climate System Model-based simulations, resulting in a range for the inventory outside the GLODAP region of 9–14 Pg C. However, Khatiwala et al. [2013] ultimately computed a "best estimate" inventory for the GLODAP region in 2010 of 143 Pg C by averaging results from three different inversion methods, including the Green's function model. Using the above range for marginal seas and coastal areas, they provide a 2010 global best estimate inventory of 152–157 Pg C. Selecting the midpoint value yields a final estimate of 155 Pg C with an uncertainty of ±20%. Here we scaled the Green's function time series to obtain the 155 Pg C best estimate for 2010 and to account for marginal seas and coastal areas.

The Sabine et al. [2004] and Khatiwala et al. [2013] data-based estimates with uncertainties provide valuable global constraints on model carbon cycle processes and feedbacks. However, these inventory estimates must be further adjusted to the 1850 equilibrium starting date of model simulations. The Sabine et al. [2004] ocean inventory estimate for 1994 was adjusted by subtracting the difference between the 1850 and 1800 ocean inventory estimates from the scaled Khatiwala et al. [2013] 1765–2010 time series, yielding 109 ± 19 Pg C. Similarly, the scaled Khatiwala et al. [2013] ocean inventory best estimate for 2010 was adjusted by subtracting the 1850 value, yielding 141 ± 38 Pg C. Using the adjusted trajectory of ocean uptake and applying equation (1) on the time series through 2010, we calculated total carbon accumulation in the ocean and on land from 1850 to 2010 with their uncertainties based on Khatiwala et al. [2013] uncertainty estimates (Figure S1). Land and ocean carbon sinks computed using this approach were consistent with combined estimates reported by Ballantyne et al. [2012]; however, here the net land flux included land use emissions.

From Hoffman et al. (2014) DOI: https://doi.org/10.1002/2013JG002381

Diagnostic collection reference datasets

ID 2.5 Net ecosystem carbon balance HOFFMAN

Data Provider: UCI & ORNL

- Documentation: See Hoffman et al. (2014) DOI: https://doi.org/10.1002/2013JG002381
- ESGF DOI: (Temporary CEDA archive)

Dataset duration: 1850/01–2010/12

Source dataset frequency: Annually

Update frequency on ESGF: NA, no update needed for CMIP AFT REF



Source data

- See: (Temporary CEDA archive)
- Annual integration, 1850 to 2010



Processing

- No additional processing



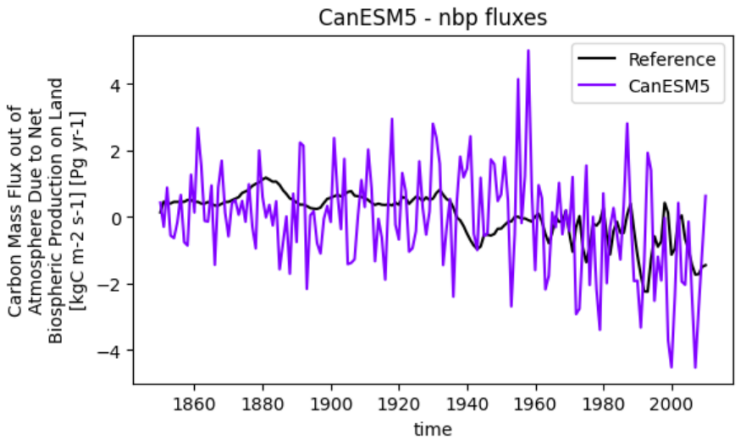
Caveats

- See Hoffman et al. (2014) DOI: https://doi.org/10.1002/2013JG002381

Diagnostic demo

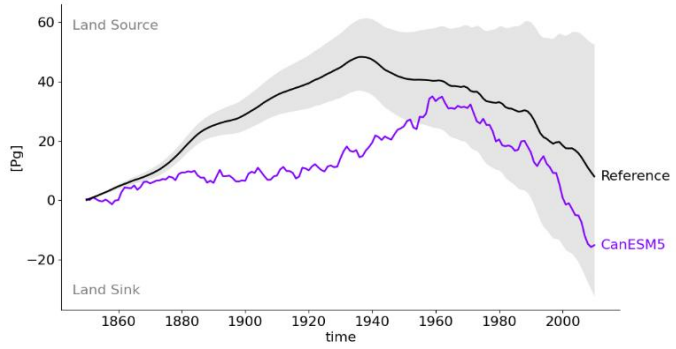
ID 2.5 Net ecosystem carbon balance

Demo using the REF dashboard



Group: cmip6_esm-hist_gn_r2i1p2f1_CanESM5__obs4mips_gm_Hoffman-1-0_nbp_v20251117

Filename: CanESM5_None_nbp.png



Group: cmip6_esm-hist_gn_r2i1p2f1_CanESM5__obs4mips_gm_Hoffman-1-0_nbp_v20251117

Filename: None_None_accumulation.png

Try it out!

Responsible use

ID 2.5 Net ecosystem carbon balance

Uncertainty

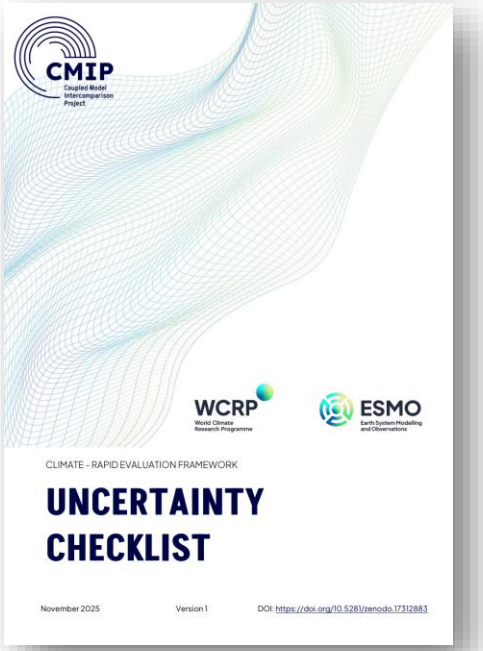


Table 1: Variable_id suffixes for including uncertainty information in REF and obs4MIPs

Suffix	Long name
nobs	Number of observations
ustd	Standard uncertainty
stderr	Standard error
uind	Uncertainty due to independent effects
ustr	Uncertainty due to structured effects
ucom	Uncertainty due to common effects
lbnd	Lower bound of asymmetrical uncertainty information
ubnd	Upper bound of asymmetrical uncertainty information

Table 2: Global attributes describing any observational uncertainty provided in obs4MIPs and REF

obs4MIPs global attributes	Description
has_aux_unc	Flag for existence of uncertainty data
aux_uncertainty_id	Suffix added to variable_id to indicate statistical uncertainty quantity

- Observations community has co-produced augmented set of uncertainty variables. These align with obs4MIPs ODS 2.6.1
- Pathways include uncertainties in separate files using CMOR or in a single CMOR-like file following CF standards for ancillary variables, with the help of global attributes
- Providers of reference datasets selected for inclusion in this version of the REF have been contacted for this information.
- The current version of the REF does not have uncertainty incorporated but goal is to have this in subsequent versions.

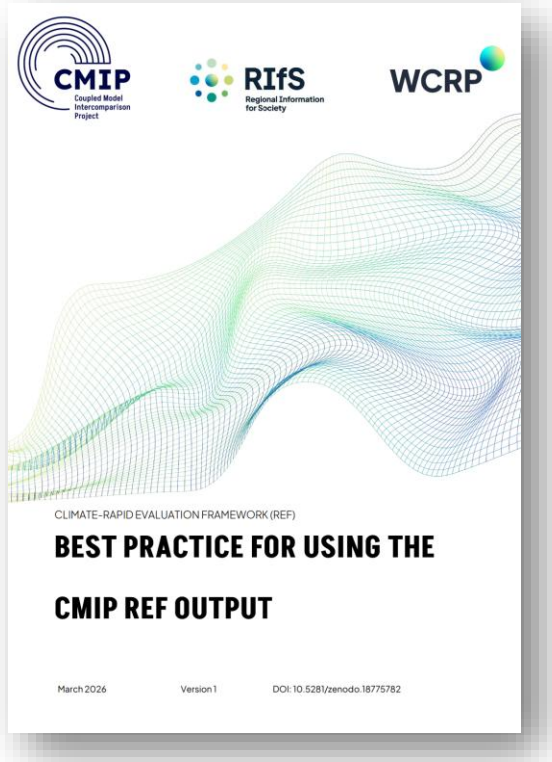
Hegedus, D. et al (2025). Climate - Rapid Evaluation Framework Uncertainty Checklist https://doi.org/10.5281/zenodo.17312882

Responsible use: conditions & caveats

ID 2.5 Net ecosystem carbon balance

- Net land carbon flux estimates are derived from a Green's function model for the global ocean by difference
- Net land carbon flux includes the land use change flux implicitly; however, models may separate these fluxes
- Land carbon flux uncertainties are estimated from the ensemble of Green's function model simulations and propagated with assumed uncertainties for fossil fuel emissions
- Uncertainties expand forward in time because the 1850 equilibrium is assumed to be known exactly
- Fossil fuel emissions come from country reporting that is increasingly believed to be biased
- Contemporary carbon balance is not fully understood and is the subject of annual re-estimation by the Global Carbon Project

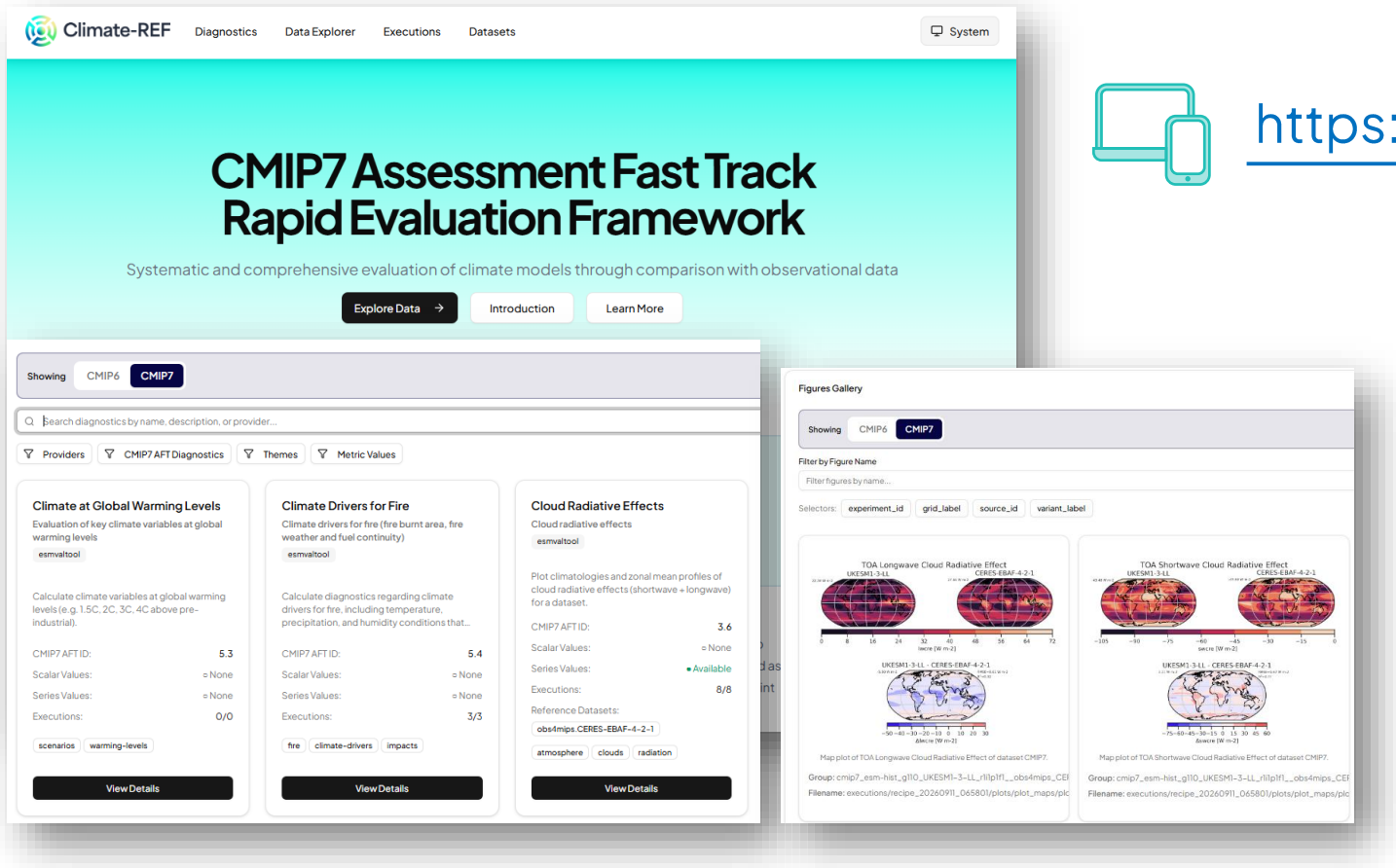
Using the REF



Morrison, M. et al. (2026). Best Practice for Using the CMIP Rapid Evaluation Framework Output. https://doi.org/10.5281/zenodo.18775782

- This best practice note was prepared by members of the CMIP and RIfS joint task team on Responsible Data Use and members of the CMIP Model Benchmarking Task Team.
- This document provides non-binding community guidance on how to interpret REF outputs in a rigorous and informed manner.

Try out the REF dashboard



https://dashboard.climate-ref.org

Try it out!

Citing the REF



If you are writing a paper, a proposal and/or any presentations making use of or planning to make use of the REF, you must cite the REF as follows:

Get the citation for the software version you are using

And for CMIP7 AFT diagnostics cite Hoffman et al 2026

Lewis, J., Andela, B., Collier, N., Lee, J., Hegedūs, D., Pflüger, M., Xu, M., Hoffman, F., Swaminathan, R., Hassler, B., & Price, Z. (2026). Rapid Evaluation Framework (Version v0.20.3) [Computer software]. Zenodo. https://doi.org/10.5281/zenodo.23753722

Hoffman, F. M., Hassler, B., Swaminathan, R., Lewis, J., Andela, B., Collier, N., Hegedűs, D., Lee, J., Pascoe, C., Pflüger, M., Stockhause, M., Ullrich, P., Xu, M., Bock, L., Chun, F., Gier, B. K., Kelley, D. I., Lauer, A., Lenhardt, J., Schlund, M., Sreeush, M. G., Weigel, K., Blockley, E., Beadling, R., Beucher, R., Dugassa, D. D., Lembo, V., Lu, J., Brands, S., Tjiputra, J., Malinina, E., Medeiros, B., Scoccimarro, E., Walton, J., Kershaw, P., Lanfer Marquez, A., Roberts, M. J., O'Rourke, E., Dingley, B., Turner, B., Hewitt, H., and Dunne, J. P.: Rapid Evaluation Framework for the CMIP7 Assessment Fast Track, Geosci. Model Dev., 19, 7415–7455, https://doi.org/10.5194/gmd-19-7415-2026, 2026

How to propose a new diagnostic

Step 1: Look at the existing packages, is there a diagnostic within them that would cover what you need? Reach out to the package PIs/diagnostic developer. If not, you need to find a package that meets inclusion criteria for the Climate-REF set by its governing panel.

Step 2: Put your idea on the Climate-REF diagnostic proposal board: https://bit.ly/REF-discussions

Step 3: Working with the package diagnostic development process, identify at least one appropriate reference dataset. First check the REF and obs4MIPs for existing REF-ready datasets

Step 4: Follow any procedural direction and process provided by the ESMO REF Panel which is the governing body of the REF (up and running soon!)

The REF would not have been possible without…

CMIP Coupled Model Intercomparison Project
Model Benchmarking

esa

U.S. DEPARTMENT of ENERGY

REF delivery team & packages

Oak Ridge National Laboratory

ESGF Earth System Grid Federation

DLR

Climate Resource

UKRI Science and Technology Facilities Council
RAL Space

netherlands eScience center

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Centre for Environmental Data Analysis
SCIENCE AND TECHNOLOGY FACILITIES COUNCIL
NATURAL ENVIRONMENT RESEARCH COUNCIL

Lawrence Livermore National Laboratory

ILAMB RUBISCO

IOMB RUBISCO

CMEC

PMP

ESMValTool
Earth System Model Evaluation Tool

Community contributions

THANK YOU ALL!
This would not have been possible without the direction, testing, feedback and input from modelling centres, modellers, reference dataset providers and IPCC authors through surveys, drop-ins, the REF hackathon, GitHub and your ideas shared at this conference, in addition to the steer, input and support from the CMIP governing panels, CMIP task teams and the ESMO SSG.

Climate-REF Seminar-Series

Atmosphere



Forrest Hoffman
Chair
Climate-REF Panel, ORNL



Jiwoo Lee
Diagnostic Author
ORNL

Join us 19 November

3.3 Climate variability modes

19 November 2026

16:00 UTC

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