

MOTECUSOMA: MOnitoring The Energy Cycle for a better UnderStanding Of cliMate chAnge

Gilles Larnicol^{1*}, Benoit Meyssignac², Chris Merchant³, Robin Fraudeau¹, Michael Ablain¹, Ramiro Ferrari¹, Elisabeth Armaut¹, Sébastien Fourest², Darren Ghent⁴, Abigail Waring⁴, Karen Veal⁴, Colin Morice⁵, Jonathan Winn⁵, Jacob Hoeyer⁶, Pia Englyst⁶, Maxime Beaucamp⁶, Michael Mayer⁷, Susanna Winkelbauer⁷, William Llovel⁸, Damien Desbruyeres⁸, Yingjie Liu⁸, Richard Cornes⁹, Archie Cable⁹, Sarah Connors¹⁰

¹Magellium (France), ²LEGOS (France), ³University of Reading (UK), ⁴University of Leicester (UK), ⁵Met Office (UK), ⁶DMI (Denmark),
⁷University of Vienna (Austria), ⁸CNRS/LOPS (France), ⁹NOC (UK), ¹⁰ESA/ECSAT

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For more information, visit https://climate.esa.int/en/Cross_ECV_Projects/motecusoma/.



Objectives of the project

1. The global climate feedback (Planck feedback, water vapor feedback, lapse rate feedback, surface albedo feedback) and the climate sensitivity play a central role in the response of climate to anthropogenic GHG emissions. This makes their quantification arguably the key problem of climate change science.
1. The objective of the MOTECUSOMA X-ECV project is to utilise existing ESA Climate Change Initiative (CCI) Essential Climate Variable datasets (ECV) to estimate simultaneously the Earth Energy Imbalance (EEI) and Surface Air Temperature (TAS) mean trend and variability over the last three decades, and to offer insights into the fundamental questions regarding the global energy cycle.

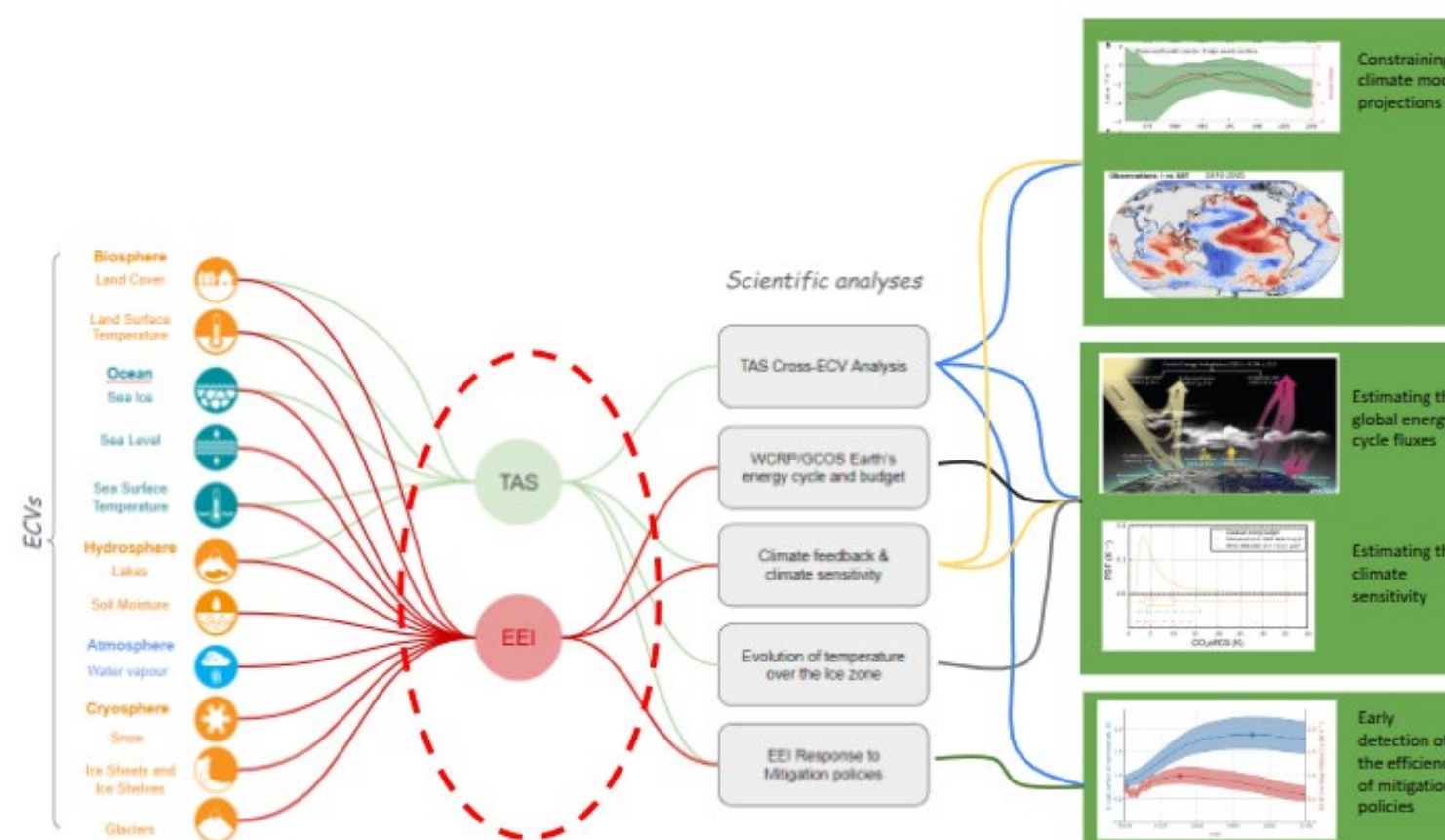


Figure 1: Overview of MOTECUSOMA project approach: Generating EEI and TAS records from the ECVs to investigate scientific questions.

Latest results - Estimate the TAS

The most critical climate variable for parameterising climate changes and feedbacks is the TAS, because it is tightly coupled on monthly timescales to (1) surface radiation and turbulent heat fluxes, and (2), via convection, to the tropospheric temperature, atmospheric humidity and water vapour feedbacks.

But no satellite measures TAS. The skin temperature observations available from satellite are, however, useful in constraining the values of TAS anomalies via skin-TAS relationships that can be learned in a domain-specific sense (informed by the different physics of land, ocean water and ice to atmosphere interactions).

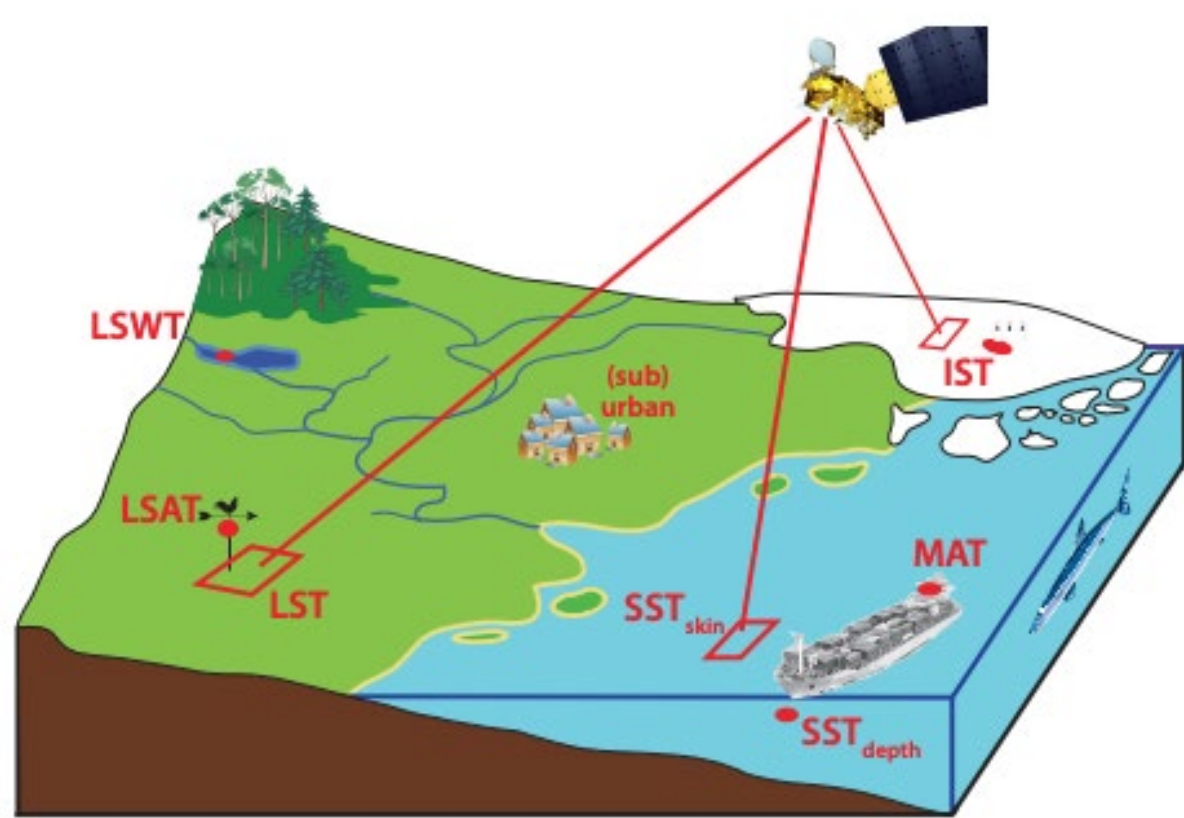


Figure 2a: The concept of inter-relating the various surface temperatures of the Earth. From Merchant et. al 2017.

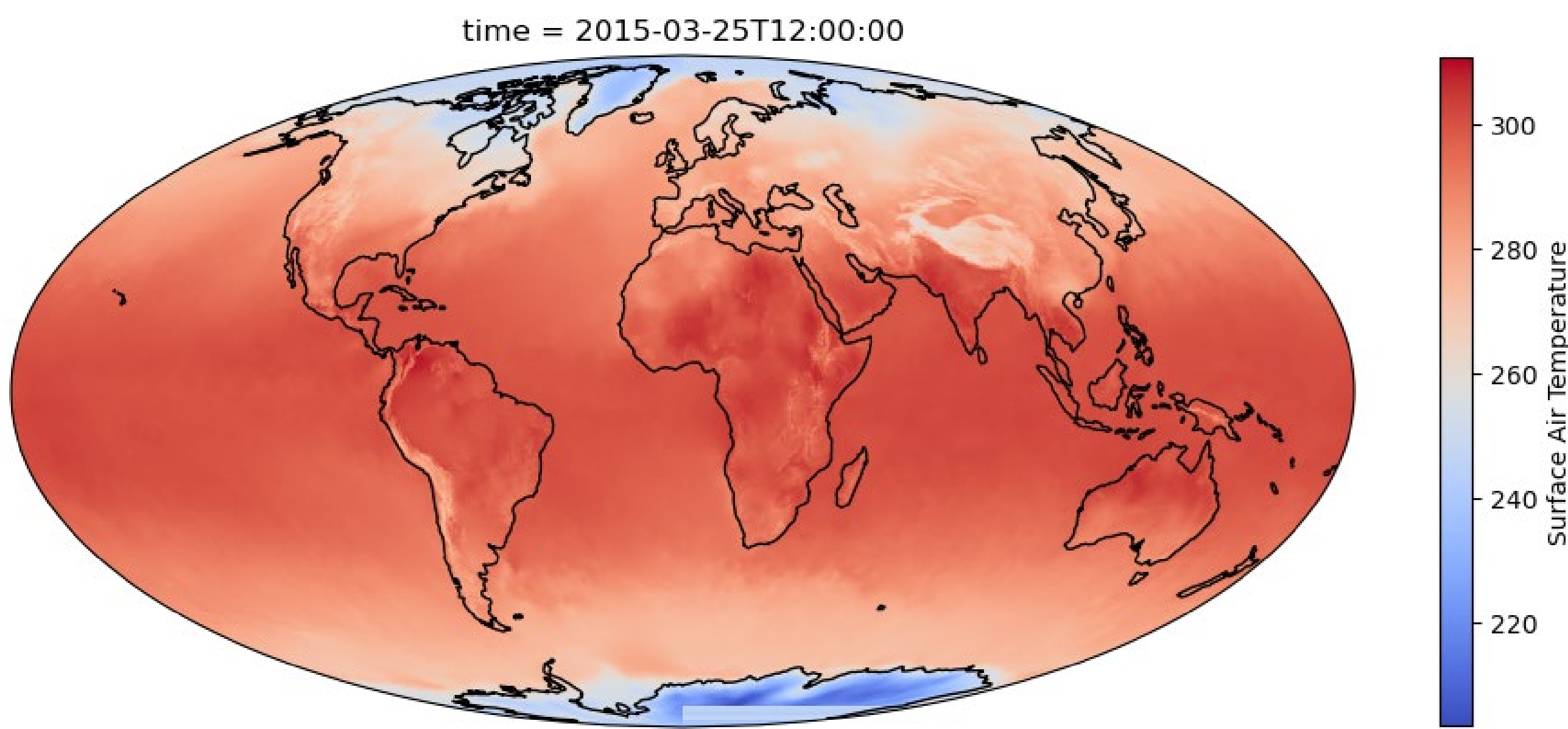


Figure 2b: One day of a trial analysis of TAS covering 2015 and 2016.

TAS will therefore be globally estimated by combining:

- direct land (station) and marine (shipping etc) air temperature measurements
- “satellite-TAS” temperatures derived from skin temperatures passed through skin-TAS relationships

The underlying analysis will be at 0.25 deg daily resolution, to ensure even spatio-temporal sampling when creating the 1 deg monthly TAS product that will be primarily exploited in the climate study of EEI and feedbacks.

Key to a successful analysis is realistic estimation of uncertainty in all inputs, as the analysis system combines data by weighting with respect to uncertainty across length scales that also need to be estimated.

Latest results - Estimate the EEI

- New estimate of the Ocean Heat Content (OHC), called MOHeaCAN product, has been developed (V6) based on an inverse method developed by Fourest et al. (2026, submitted), which combines Argo T/S profiles with space geodetic measurements (altimetry and gravimetry)
- Allows to provide estimates for first 1000m depth. An estimation of deep ocean OHC (below 1000m) is also estimated from inverse method coefficients (as a linear trend)

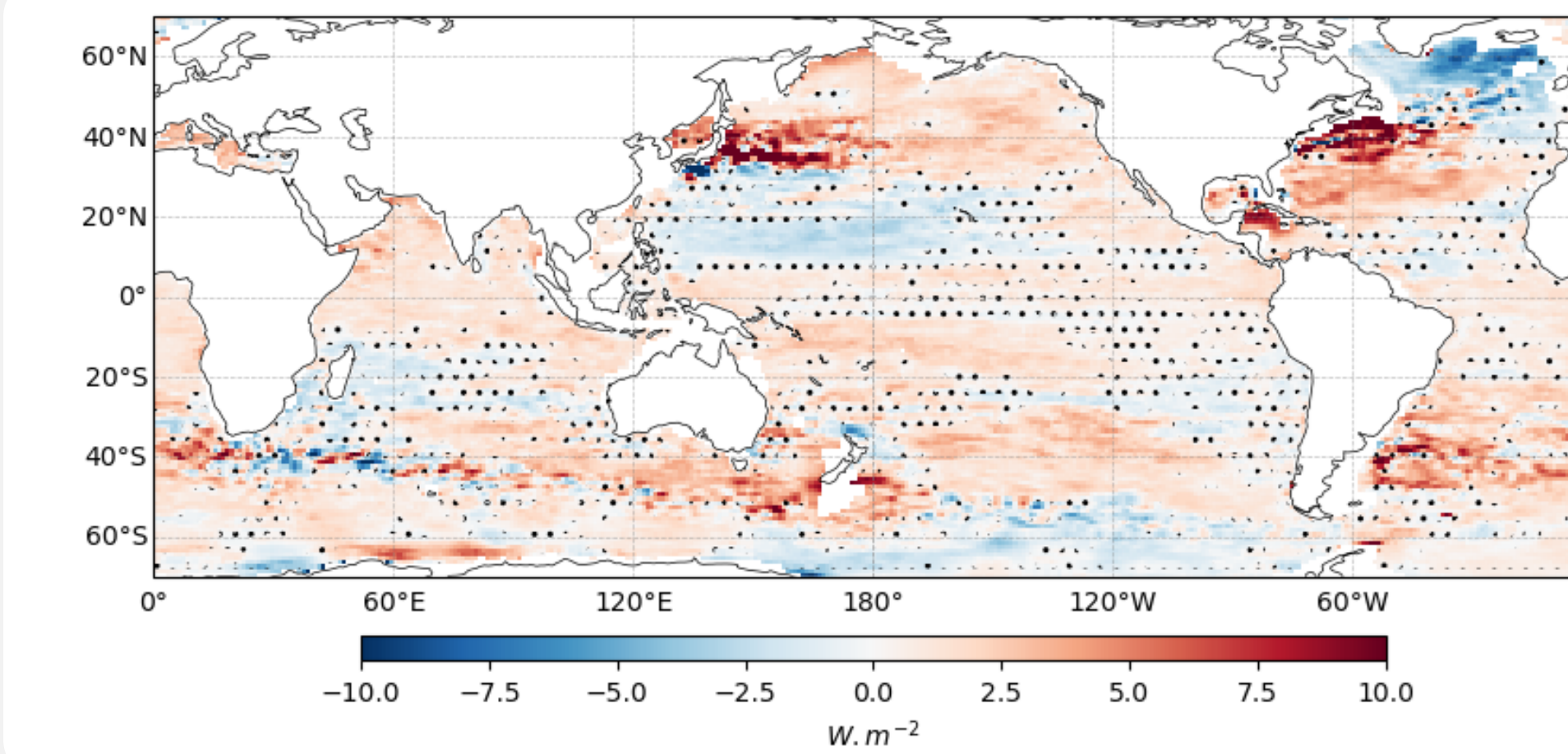


Figure 3: Regional trend of OHC over the 2004–2024 period. Black-dotted areas indicate regions where the trend is not significant relative to the uncertainties. Fourest et al., 2026

- At regional scale, OHC trends are significant across most parts of the globe, exhibiting pronounced dipoles particularly in the North Atlantic and the northwestern Pacific.
- At high latitude we can see the signature of the Antarctic Circumpolar Current and the Atlantic overturning circulation signature
- Spatial patterns agree very well with Lyman and Johnson (2023, Fig. 7c).

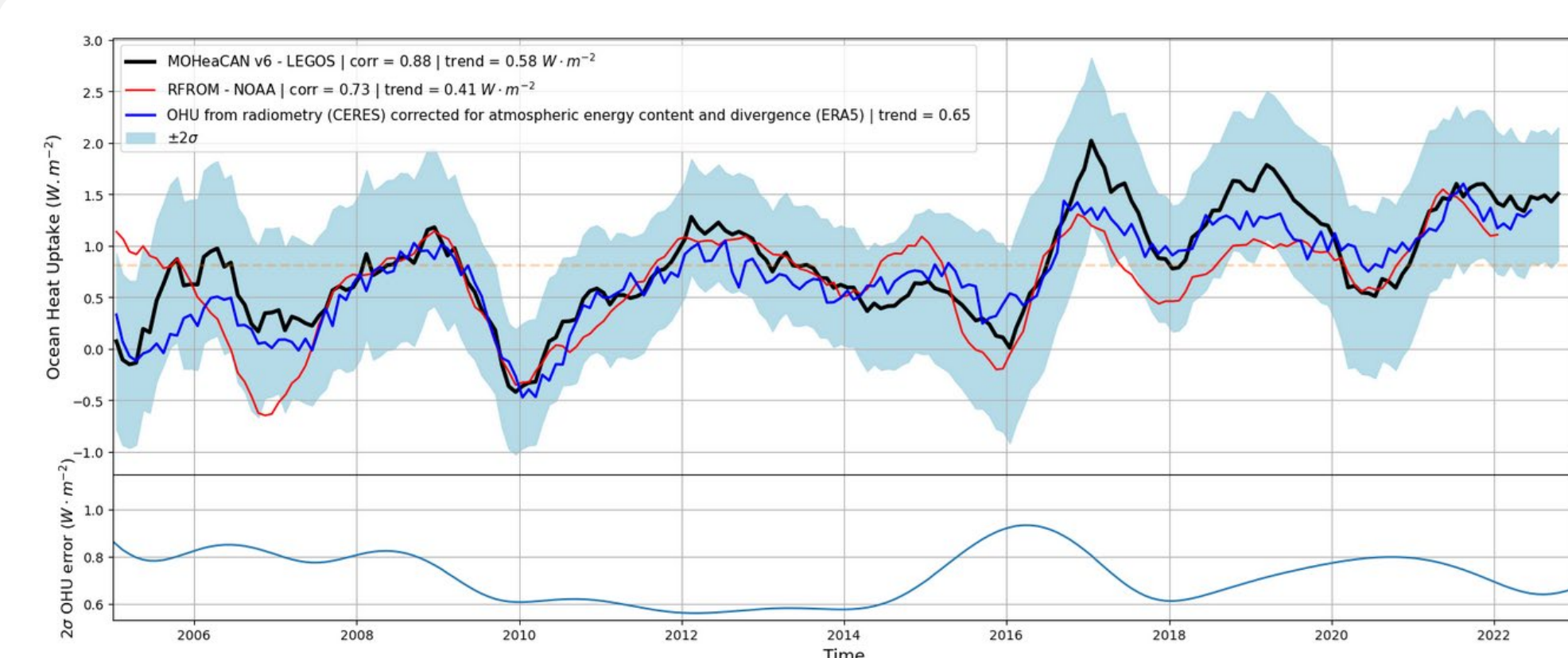


Figure 4: Upper panel: In black, OHU derived from MOHeaCAN; in red, OHU derived from the RFROM product; and in blue, the CERES-TEDIV-DAE flux integrated over the oceans and filtered with a 12 month running mean. Lower panel: OHU error at the 2 level which do not exceed 0.8 except in 2016. Fourest et al., 2026

- Global ocean heat uptake (OHU, i.e. the temporal derivative of global OHC) agrees closely with an independent estimate based on CERES top-of-atmosphere radiation combined with ERA5 atmospheric energy divergence and storage.
- The two OHU time series correlate at 0.88 (correlation was 0.54 with V5) on annual timescales over 2004–2024, and the global energy budget is closed within $\pm 0.5 \text{ W m}^{-2}$ (1σ level) from Top of the Atmosphere to ocean bottom.
- Both approaches also yield a comparable positive trend of approximately 0.6 W m^{-2} per decade over 2005–2023

Future work and conclusion

- Work to refine the EEI estimate will continue through improvements to the OHU using the new inverse method. More specifically, the estimate of deep ocean layers (below 1,000 m) will be improved by incorporating information on interannual variations derived from least-squares residuals. Improvements will also be made to uncertainty estimates, such as the propagation of uncertainties associated with altimetry and gravimetry data to the OHU at regional and global scales.
- The TAS analysis will be refined and then applied to the project target periods, and will be comprehensively compared to alternative realisations of global surface air temperature (from reanalyses, interpolated in-situ only products). A key area where improvement is expected is the quantification of Arctic changes, where satellite ice surface temperatures will provide a far more realistic constraint than NWP (ERA5 has been shown to have significant biases in TAS in this region) or interpolation of sparse station data. This will enable a requantification of Arctic amplification.

During the last year of the project, efforts will be made on fresh perspectives on the four science inquiries listed below through dedicated scientific analysis:

- i) Quantifying the EEI mean, trend and variability to constrain the top of the atmosphere radiation budget on interannual to decadal time scales. This activity shall contribute to the WCRP/GCOS initiative on the Earth's energy, water and carbon budgets and further to the UNFCCC's global stocktake initiative.
- ii) Estimating simultaneously the EEI and TAS with their uncertainty, to constrain the range of the global climate feedback parameter and the effective climate sensitivity with observations.
- iii) Quantifying the time-response of the energy cycle to GHG mitigation policies to determine the expected time needed to detect the first physical effect of Paris agreement GHG mitigation policies
- iv) Quantifying the unfolding impacts of the energy cycle changes induced by anthropogenic emissions through the analysis of the temporal changes in TAS in the Arctic