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

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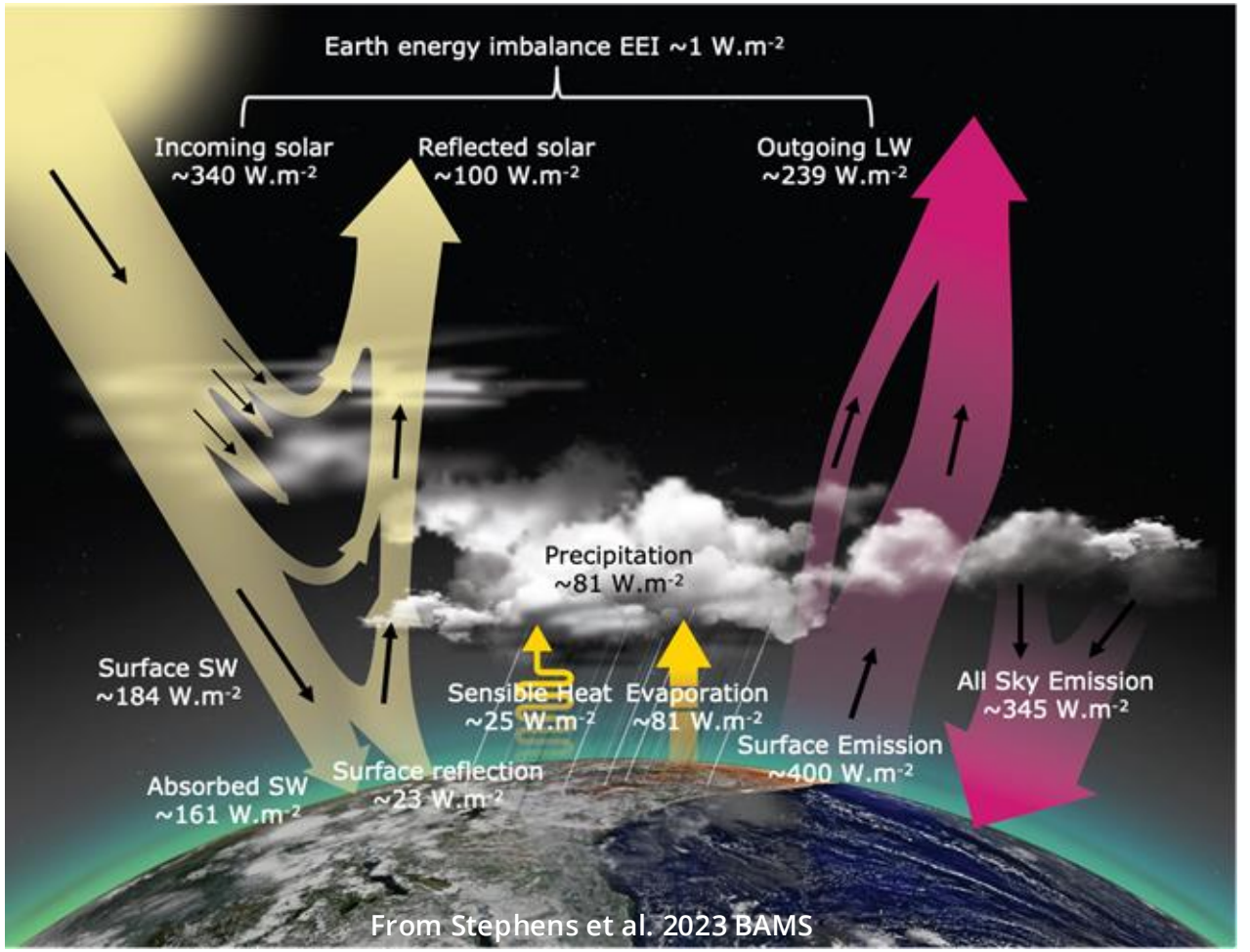
Context: Energy Cycle & Earth Energy Imbalance

General objective: Understanding the global energy cycle to better understand climate change

- Understand how changes in the atmospheric GHG impact climate variables (Earth Energy Imbalance (EEI) and Air Surface Temperature (TAS))
- Need to estimate the fluxes in the energy cycle and their changes (TAS and EEI trend, global warming Hiatus, etc…)
- Evaluation of the physical efficiency of mitigation policies



Project Objectives & Approach

- Projected started in September 2024
- 3 years duration

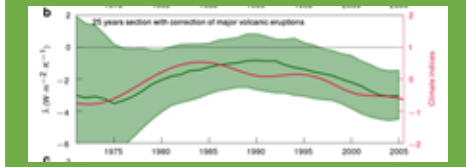
ECVs

Biosphere
Land Cover
Land Surface Temperature
Ocean
Sea Ice
Sea Level
Sea Surface Temperature
Hydrosphere
Lakes
Soil Moisture
Atmosphere
Water vapour
Cryosphere
Snow
Ice Sheets and Ice Shelves
Glaciers

TAS
EEI

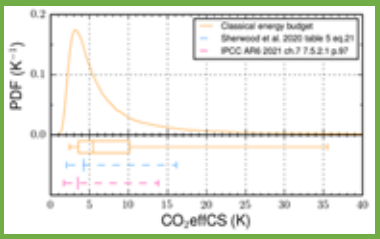
Scientific analyses

TAS Cross-ECV Analysis
WCRP/GCOS Earth's energy cycle and budget
Climate feedback & climate sensitivity
Evolution of temperature over the Ice zone
EEI Response to Mitigation policies

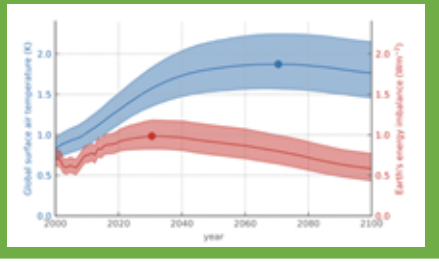


Constraining climate model projections

Estimating the global energy cycle fluxes



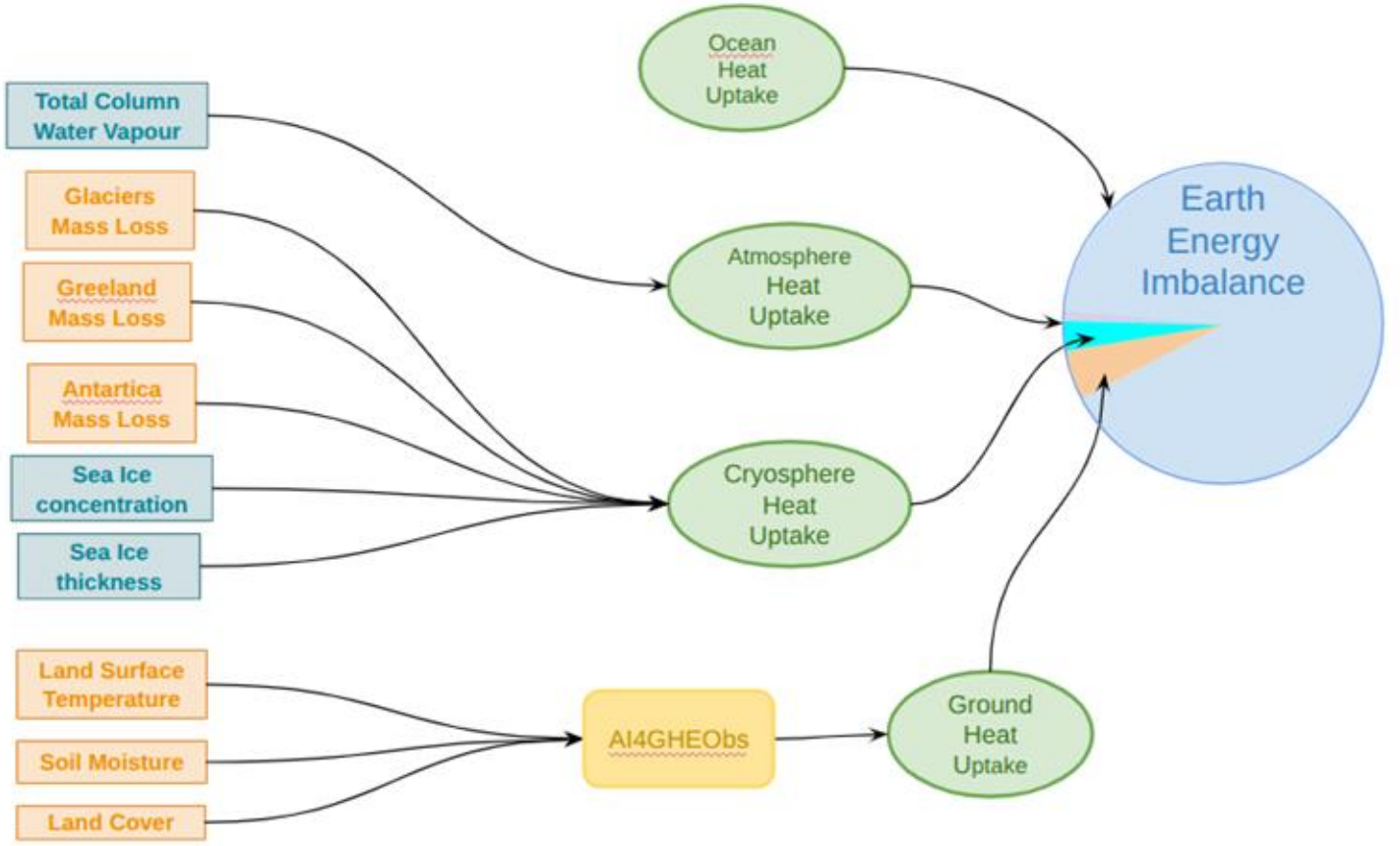
Estimating the climate sensitivity



Early detection of the efficiency of mitigation policies

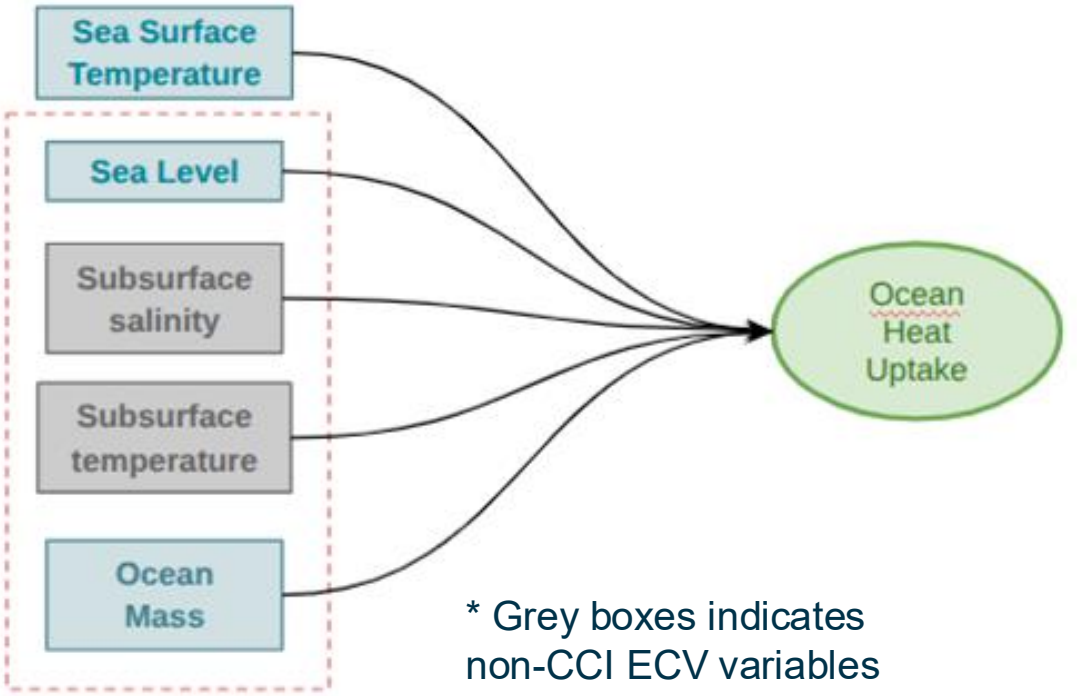
ECVs being used for EEI

- EEI is estimated based on the different reservoirs contribution (ocean, atmosphere, land and cryosphere)
- Depending on the needs, CCI ECVs are used in purpose of estimation, validation or uncertainty assessment
- ~ 91% of the EEI is coming from the oceans contribution



ECVs being used for EEI

- Ocean Heat Uptake (OHU) is estimated from the ocean heat content time tendency
- OHU is derived from different CCI-ECV and non-CCI products
- MOTECUSOMA and SLBC_cci+ are **strongly connected** since the consistency of the sea level components is assessed in the SLBC_cci+ project (red box)



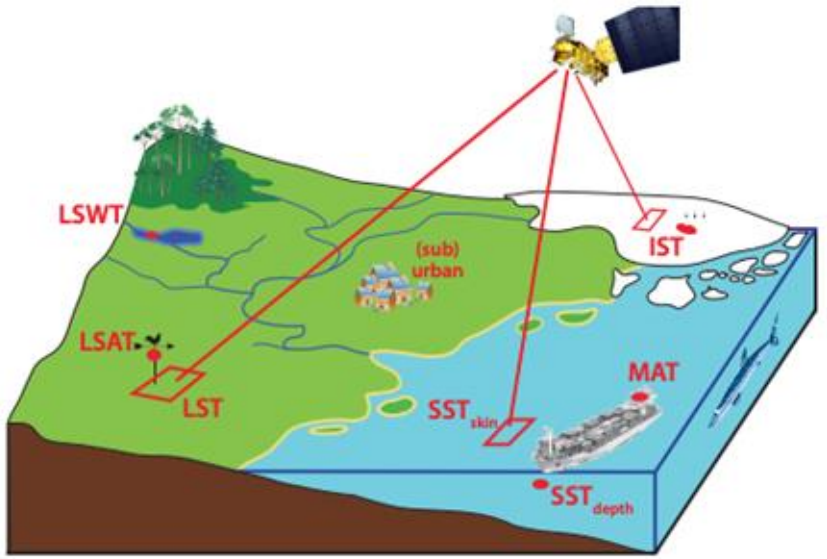
* Grey boxes indicates non-CCI ECV variables

ECVs being used for EEI

- Summary of the ECV datasets used for the EEI generation or validation, with their limitations :

	ECV	CCI Dataset usage (product/validation)	CCI dataset limitation	Dataset used
Ocean Heat Uptake	**Sea surface temperature**	EEI product		
	Sea level, ocean mass, etc…	Presented in SLBC_cci+ presentation		
Atmosphere Heat Uptake	**Total Column Water Vapour**	EEI validation	time coverage (≥ 2002) no ocean coverage	ERA5
Cryosphere heat Uptake	**Sea ice (concentration/ Thickness)**	EEI validation	time coverage (≥ 2002)	GIOMAS
	Glaciers	No	Mass Balance not provided, only provide glacier area	Zemp et al. Dussaillant et al.
	Ice sheet	EEI validation	time coverage (≥ 2002)	IMBIE
Ground Heat Uptake	**Land surface temperature**	EEI product		
	Soil moisture	EEI validation		ERA5
	Land cover	EEI product		

ECVs being used for TAS



Merchant et al, 2013
LSAT = land surface air temperature
MAT = marine air temperature
TAS = the global combination of LSAT and MAT

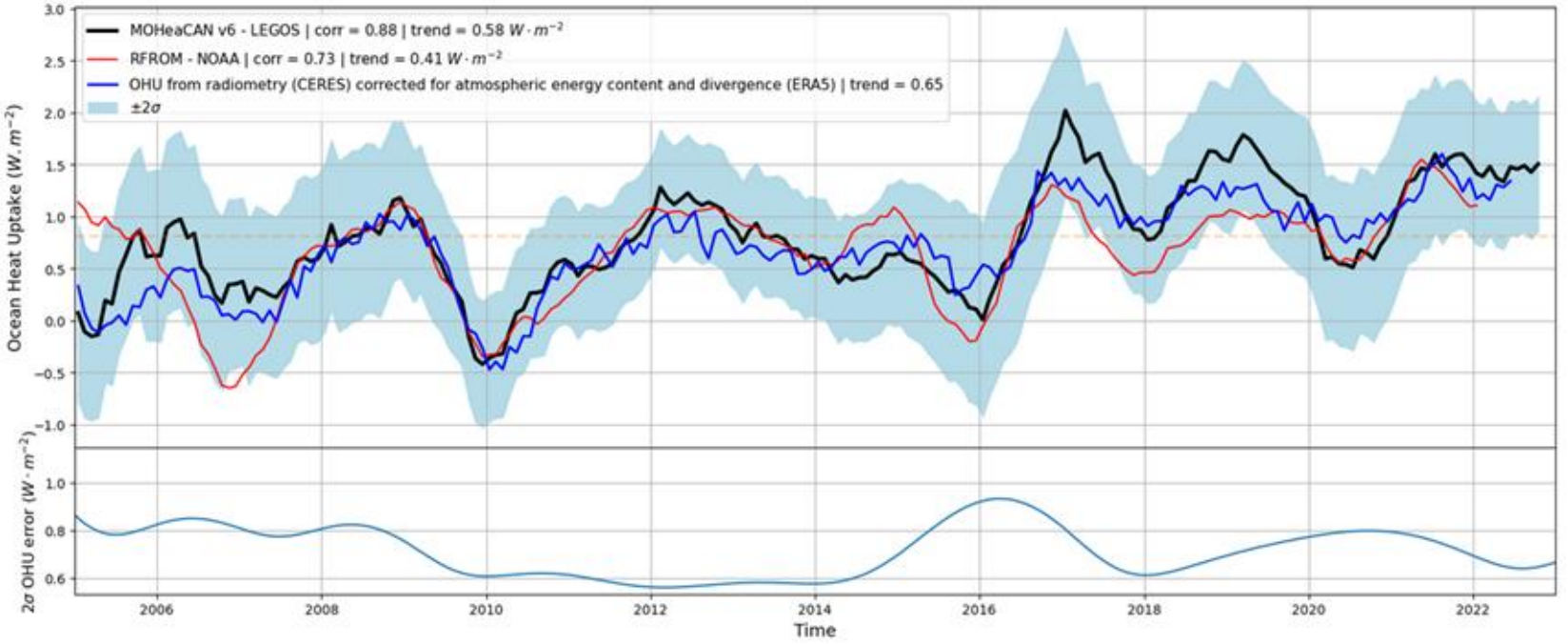
TAS is a GCOS “surface temperature” ECV but not directly retrievable from satellite.

But satellite surface temperature measurements can constrain the values of TAS using skin-TAS relationships developed per domain

CCI CDR	Use for satT-to-TAS	Limitations
Sea surface temperature (ESA SST CCI)	Training: L4 with in situ MAT and NWP winds (ERA5) TAS (MAT): L3 SST	Daily cycle not resolved fully
Land surface temperature (ESA LST CCI)	L3 LST with station TAS and various auxiliary inc. ERA5 winds, training and data	Daily cycle not resolved fully prior to SEVIRI or for central Asia
Sea ice surface temperature (C3S/AASTI)	In situ, L4 IST, L3 IST locations, Sea ice concentration	Daily cycle not fully resolved
(Land) Ice surface temperature (C3S/AASTI + LST CCI)	In situ, L4 IST, L3 IST locations	Daily cycle not fully resolved

Results & relevance to the CCI community

- MOHeaCAN product provides an estimate of the Ocean Heat Uptake (OHU) from combination of Altimetry, gravimetry and in-situ Argo profiles
- A new version (V6) developed within MOTECUSOMA is based for the first time on an inverse method with an objective mapping
- OHU is estimated from 2004 to 2025 over the first 1000m depth. An estimation of deep ocean OHU (below 1000m) is also estimated from inverse method coefficients (as two linear trends)



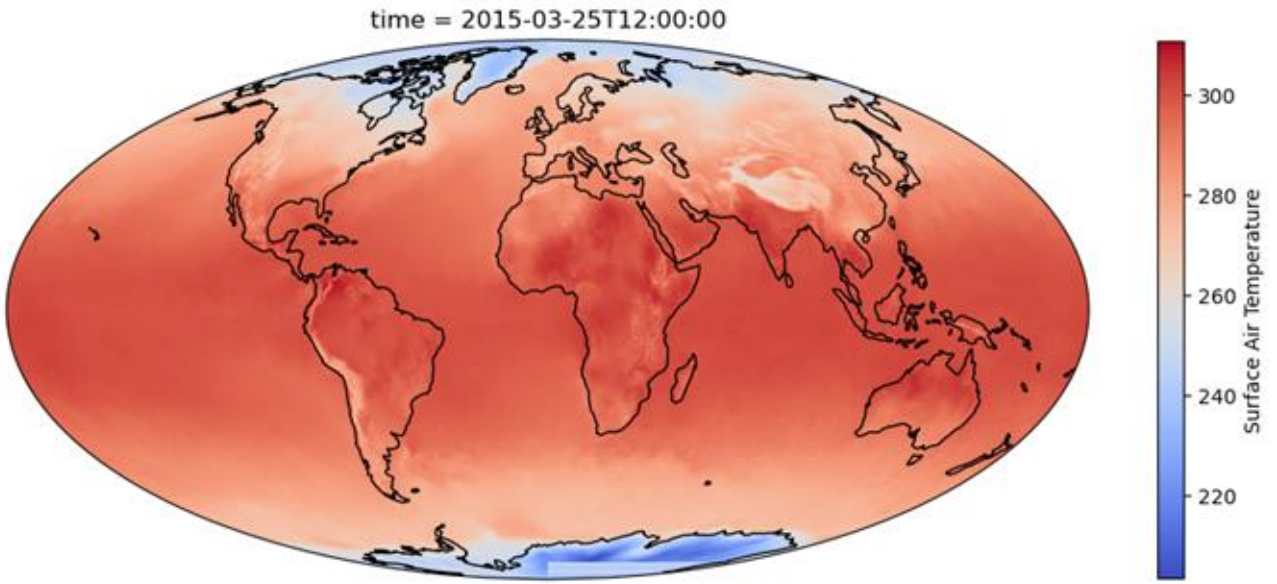
From Fourest et al. 2026, submitted

- Correlation of MOHeaCAN product with CERES corrected from atmospheric divergence and tendency has been significantly improved from 0.54 (V5) to 0.88 (V6)
- On annual timescales, the global oceanic energy budget is closed within approximately ±0.7 W m⁻² (2σ) from TOA to ocean bottom

Results & relevance to the CCI community

A trial analysis of TAS has been generated using satellite and in situ TAS inputs, for 2015 and 2016

The analysis system seeks to balance optimally the observational constraints from all the different sources of data, and using spatial structures of correlation.



MOTECUSOMA trial analysis, 25 March 2015

Realistic models of uncertainty and error correlation are crucial to creating the best possible TAS estimate:

CCI CDR & auxiliary variable uncertainty → propagation to TAS uncertainty and error cov. estimates

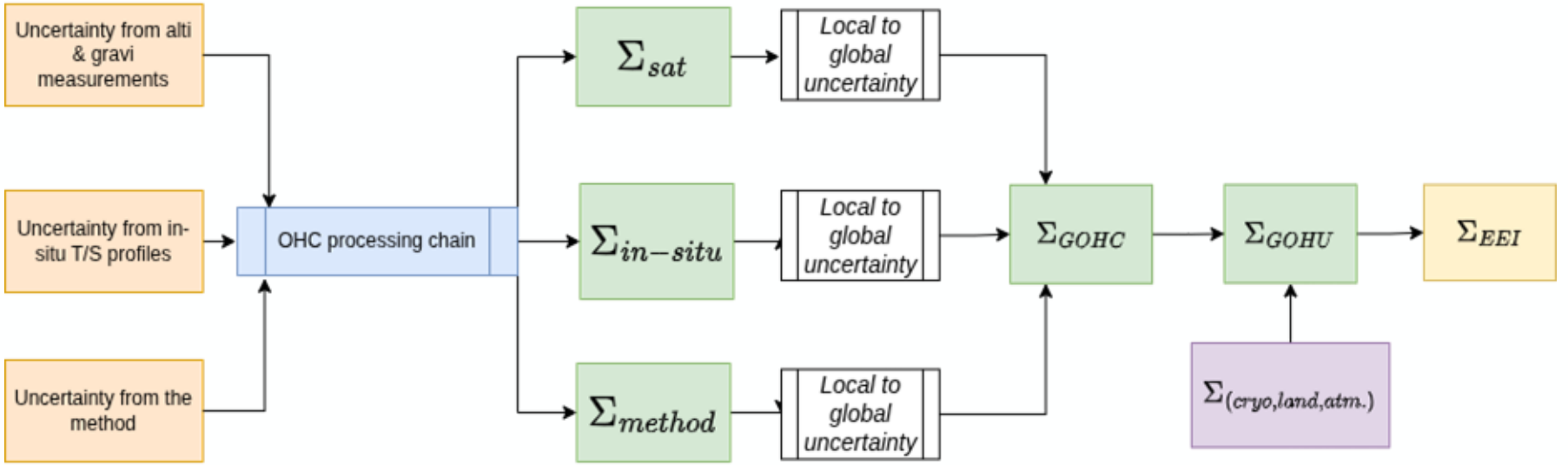
TAS **uncertainty and error cov. structure** → **determine analysis best estimate combination** of inputs

Further trial analyses and then final analysis coming during 2026

Results & relevance to the CCI community

Uncertainties:

- Spatial and/or temporal structures of the errors in the EO data provided in the error covariance matrix.
- Error covariance matrix propagated from the EO data to the TAS and EEI, taking into account the effects due to the methods, formulations and approximations.
- Realistic uncertainties in the trend and acceleration, calculated using a formal mathematical approach (e.g. extended OLS or GLS).



Example of uncertainty propagation for EEI product

Results & relevance to the CCI community

Paper produced within the MOTECUSOMA project:

- Review on knowledge on the EEI: Hakuba, M.Z., Fourest, S., Boyer, T., B. Meyssignac et al. Trends and Variability in Earth's Energy Imbalance and Ocean Heat Uptake Since 2005. Surv Geophys 45, 1721–1756 (2024).

- Data paper describing the strengths and weaknesses of the TAS product
- "Estimating Ocean Heat Content from Satellite Altimetry, Space Gravimetry, and In Situ Observations closes the Earth's Energy Budget on Interannual to Decadal Timescales" Fourest et al. 2026, submitted

- Scientific paper on Climate feedback & Climate sensitivity
- Scientific paper on the evolution of temperature over the Arctic Zone
- Scientific paper on the use of EEI index to assess the impact of mitigation policies