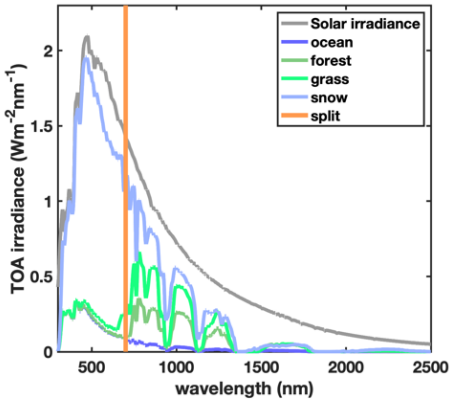
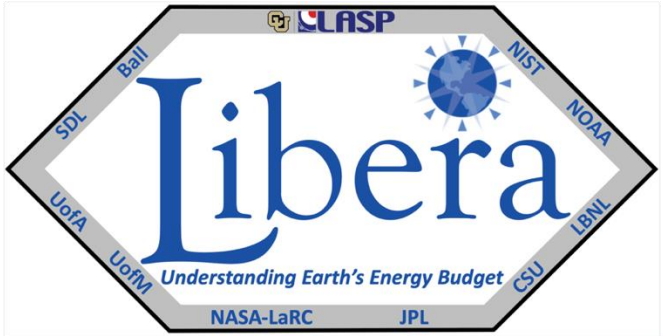
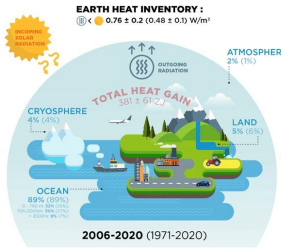
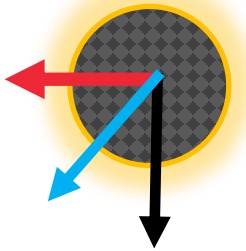
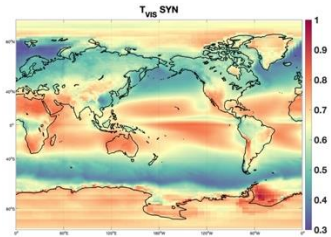
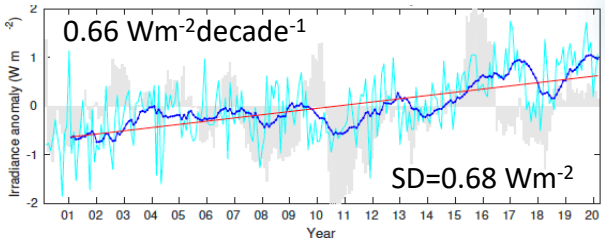


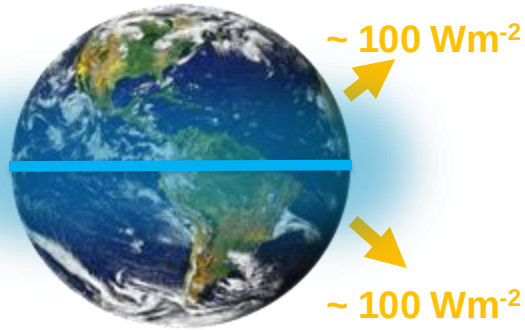












Libera Science Update and Split-SW research

Maria Hakuba

CERES STM – LLNL, Livermore, CA, October 2, 2024

Jet Propulsion Laboratory
California Institute of Technology

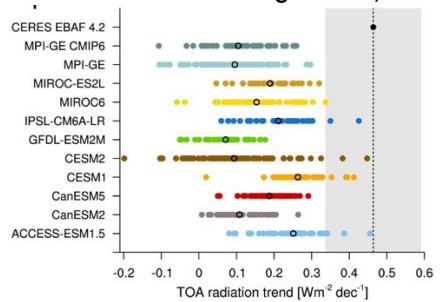
Content

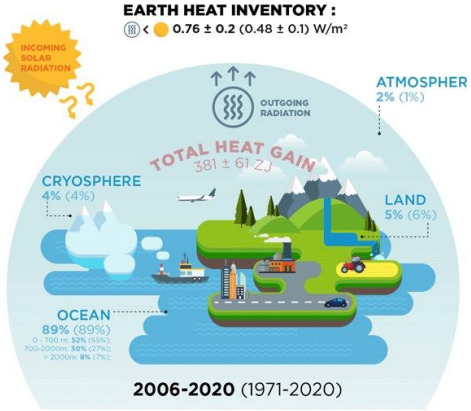
- GEWEX-EEI assessment
- Libera Science overview and products
- NIR/VIS studies
- ERB observing system of the future?

Why we research ERB and EEI variability

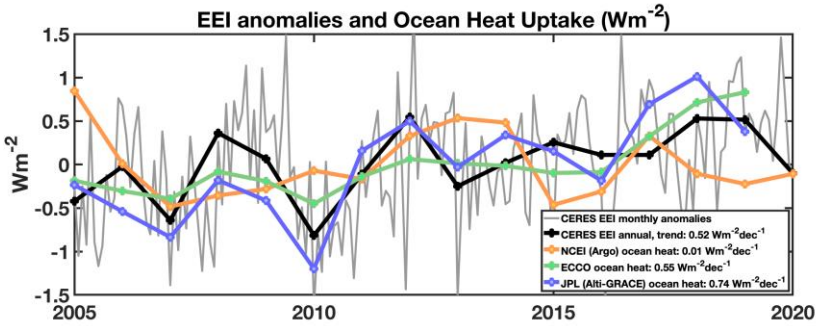
- EEI is a fundamental metric of Earth System Change.
- Increase implies an acceleration of global warming.
- Satellite-based estimates suggest larger EEI trends than in-situ observations of ocean heat content; climate model trends systematically low.
- Any large-scale climate intervention (geoengineering, mitigation) requires knowledge of Earth's radiative energy imbalance.

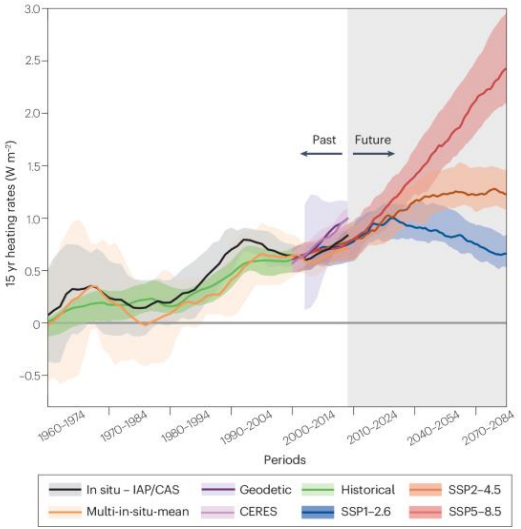
Olonschek & Rugenstein, 2024





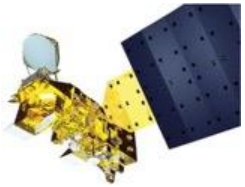
Von Schuckmann et al., 2023





Cheng et al., 2024

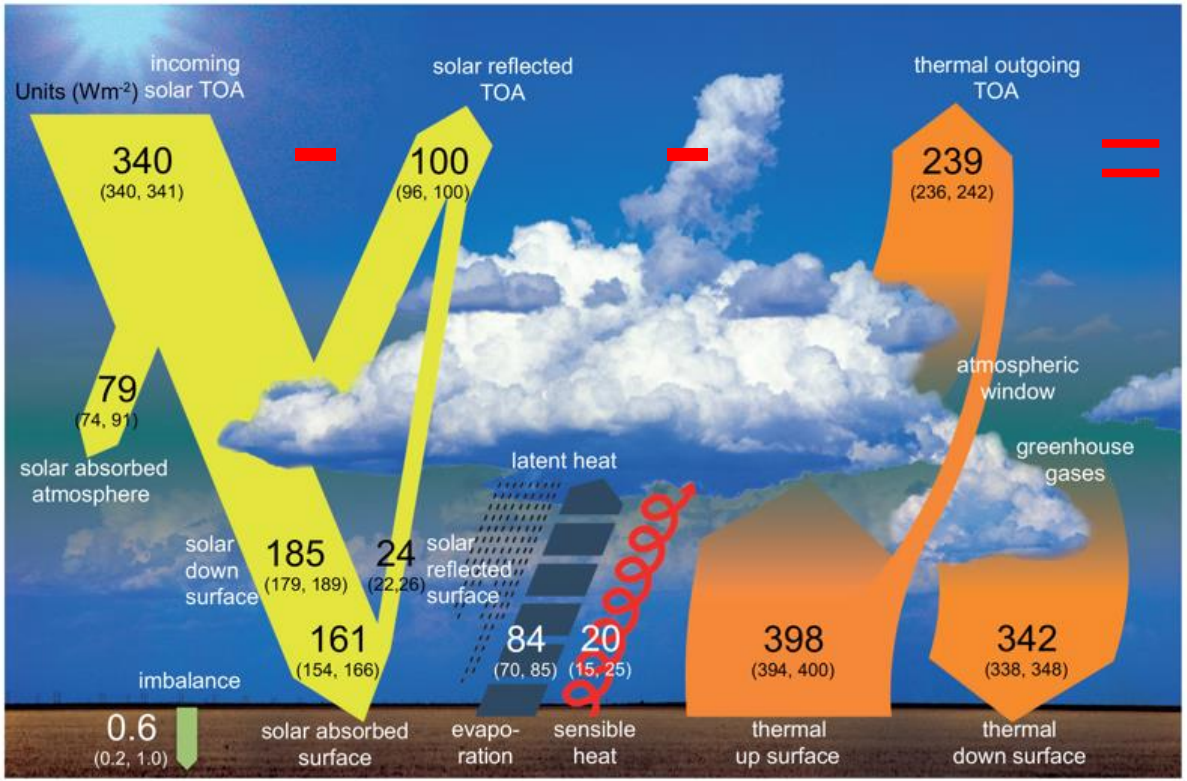
Top-of-the-atmosphere Radiation and Earth's (Radiative) Energy Imbalance (EEI)



CERES & future Libera
Clouds and Earth's Radiant Energy System

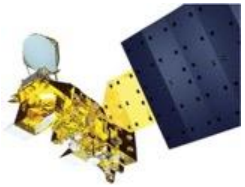
SORCE & TSIS
Solar Radiation and Climate Experiment
Total and Spectral *Solar* Irradiance Sensor

Processing heavily involves Imager (VIIRS) and Geo data



Updated from IPCC AR5 / Wild et al. 2013, 2015 Climate Dynamics

Top-of-the-atmosphere Radiation and Earth's (Radiative) Energy Imbalance (EEI)



CERES & future Libera
Clouds and Earth's Radiant Energy System

SORCE & TSIS
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Total and Spectral *Solar* Irradiance Sensor

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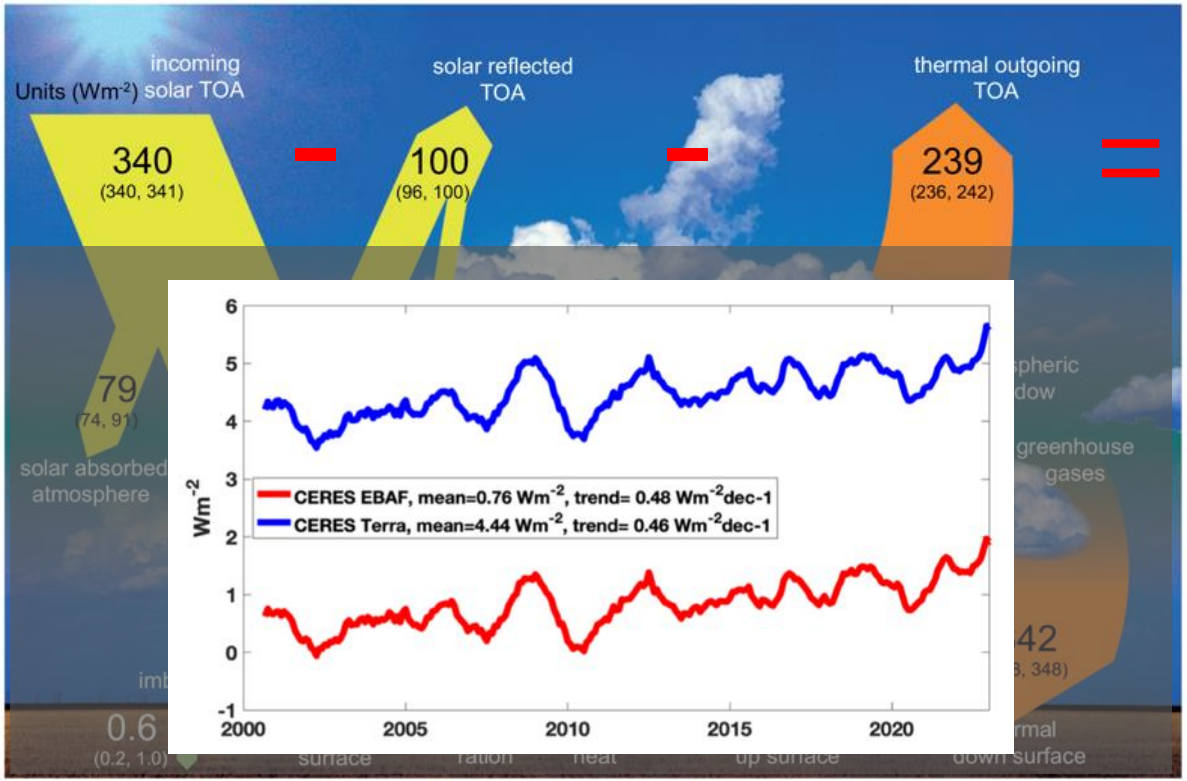
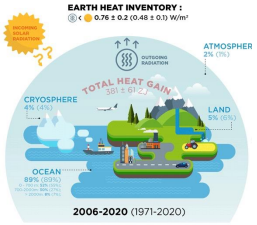


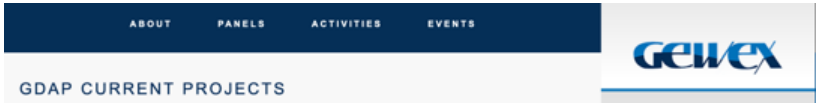
Updated from IPCC AR5 / Wild et al. 2013, 2015 Climate Dynamics

~1 Wm^{-2}

EBAF: ERB record is adjusted to match long-term EEI from heat inventory aka **planetary heat uptake.**



The GEWEX-EEI assessment



Summary & Motivation:

- A wide range of EEI estimates exist, often with error bars that are difficult to trace to measurement principles.
- Since the ocean stores more than 90% of the total planetary heat uptake, the EEI assessment focuses on intercomparing estimates of the time rate of change of ocean heat content (ocean heat uptake). This first EEI assessment will focus on:

  (a) Documenting and understanding the spread of global (and regional) ocean heat content and ocean heating rate among products.

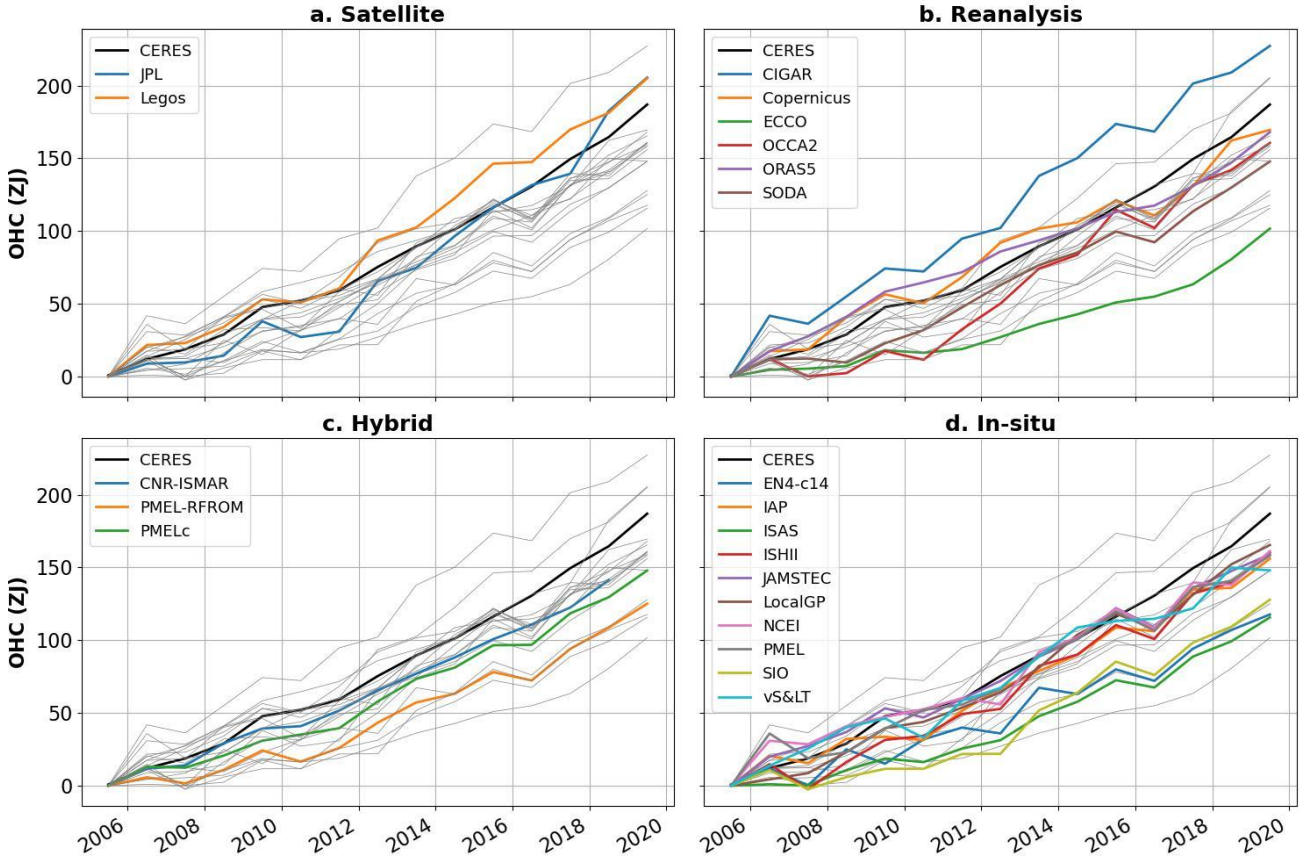
  (b) Determining systematic errors that depend on assumptions, models, and combined observations.

  (c) Understanding the spread of uncertainties depending on the method and formulae used.

https://www.gewex.org/panels/gewex-data-and-analysis-panel/gdap-projects/

Global mean Ocean Heat Content intercomparison

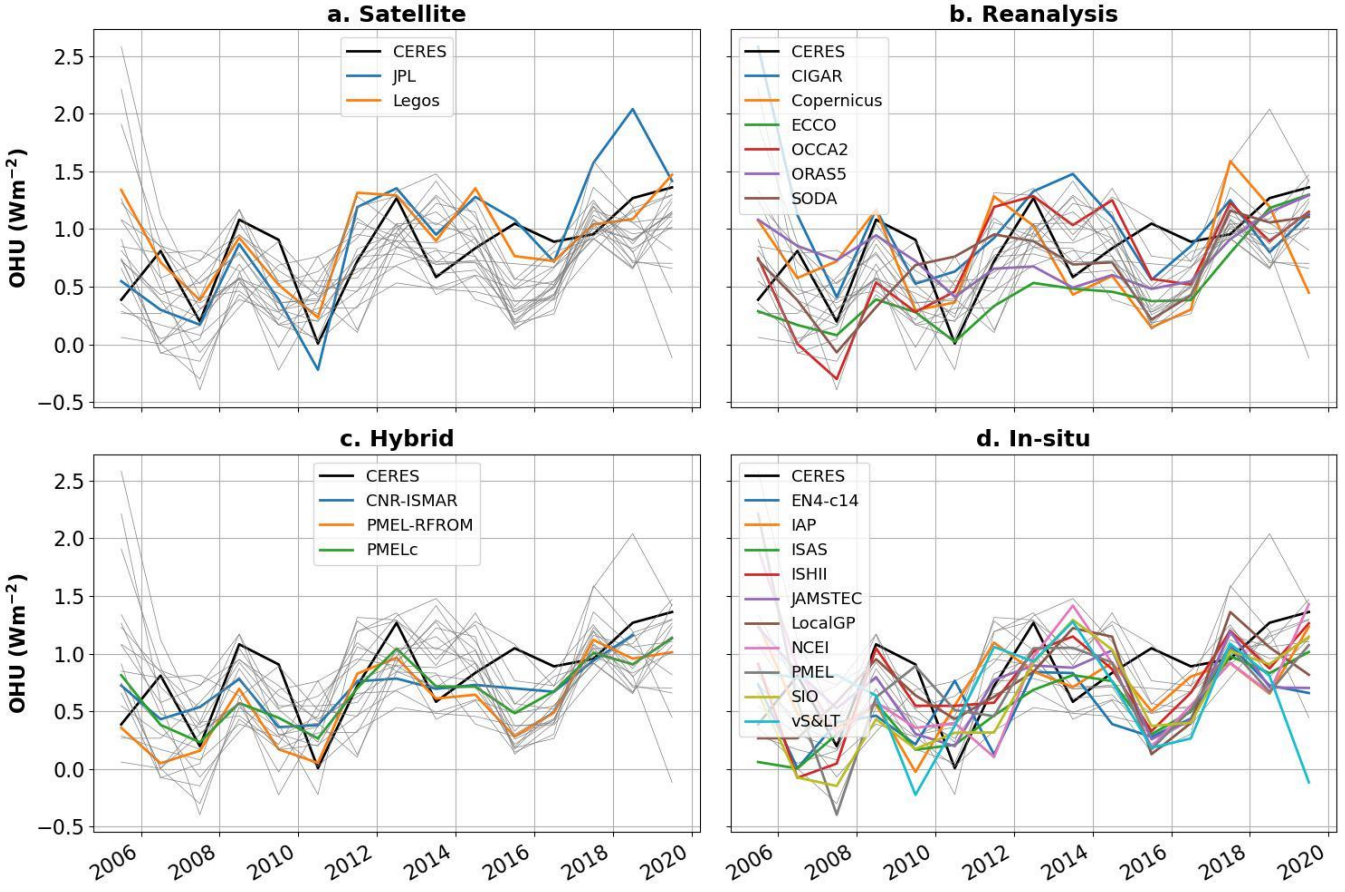
- Satellite-based estimates mark upper end. Suggest OHU: 0.9 Wm^{-2} (2005-2020)
- Reanalysis represent largest spread and mark upper and lower bound: 0.4 - 1 Wm^{-2}
- In-situ spread substantial, suggests OHU: 0.4 -0.8 Wm^{-2}



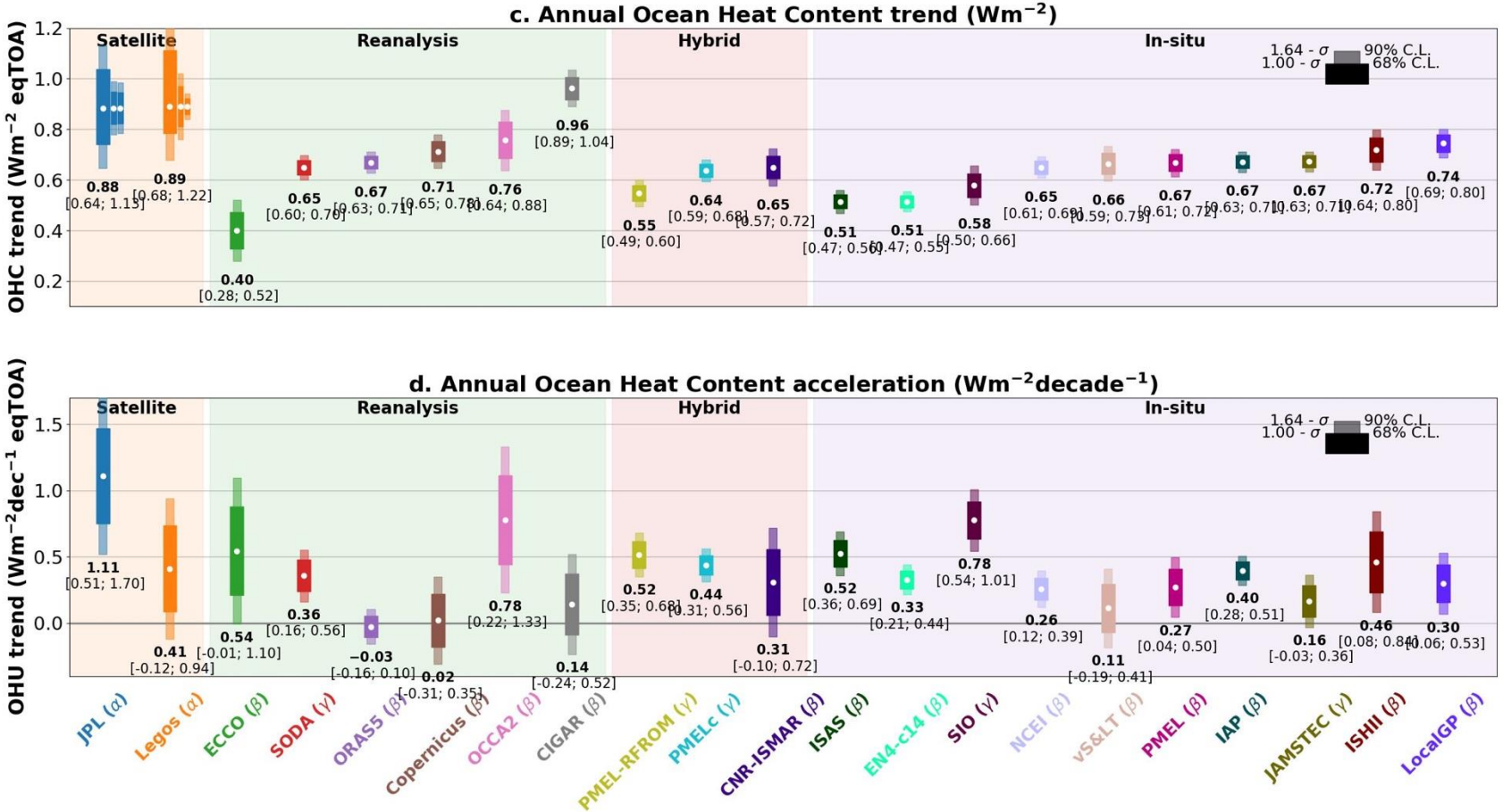
Hakuba et al., 2024

Global mean Ocean Heat Uptake intercomparison

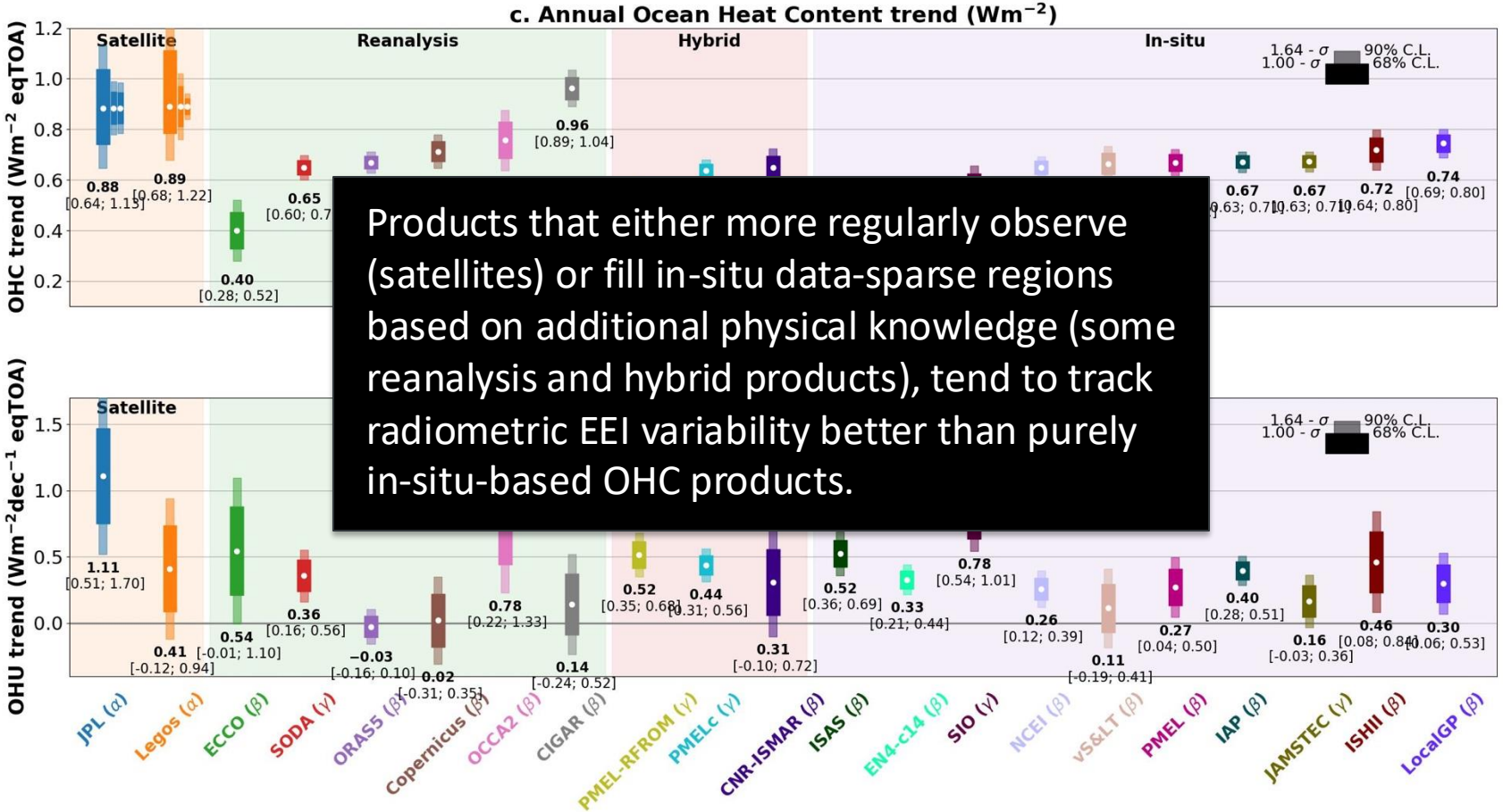
- Satellite-based: similar trends as CERES and high correlation in year-to-year variability (R=0.7)
- Reanalysis: some compare well (e.g., ECCO).
- In-situ spread substantial in correlations with CERES and trends.
- Trend spread: -0.3 to 1 $Wm^{-2}dec^{-1}$



Global mean Ocean Heat Uptake intercomparison



Global mean Ocean Heat Uptake intercomparison

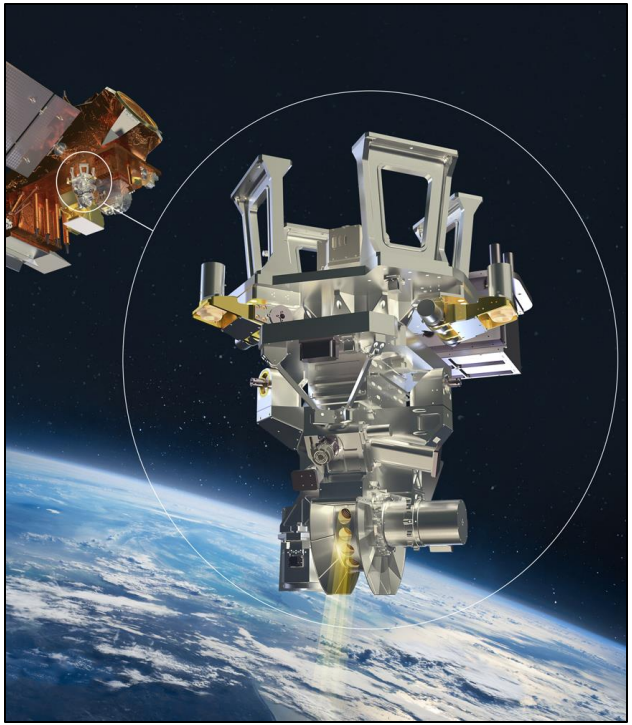


Products that either more regularly observe (satellites) or fill in-situ data-sparse regions based on additional physical knowledge (some reanalysis and hybrid products), tend to track radiometric EEI variability better than purely in-situ-based OHC products.

Libera science overview

Libera, NASA's first *Earth Venture* ***Continuity*** Mission

Overarching Science Goals



OG1: Provide **radiances for seamless continuity** of the Clouds and the Earth's Radiant Energy System (CERES) ERB Climate data record

- TOTAL (0.3->100 μm), SW (0.3-5 μm) and LW (5-50 μm) radiance over 24km nadir footprint, **uncertainty ~ 0.3%**
- On **JPSS-4** with VIIRS imager, launch 2027, 5-year mission
- **Electrical Substitution Radiometer using VACNT detectors**

OG2: Advance the development of a self-contained, innovative & affordable observing system.

- **Wide field-of-view camera** for split-SW ADM development and scene context (cloud fraction) paves way for future free-flyer ERB observing system

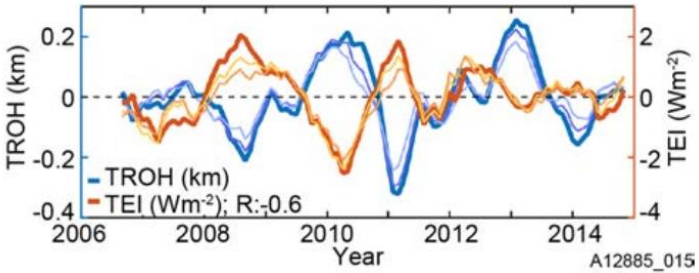
OG3: Provide new and enhanced capabilities that support extending ERB science goals.

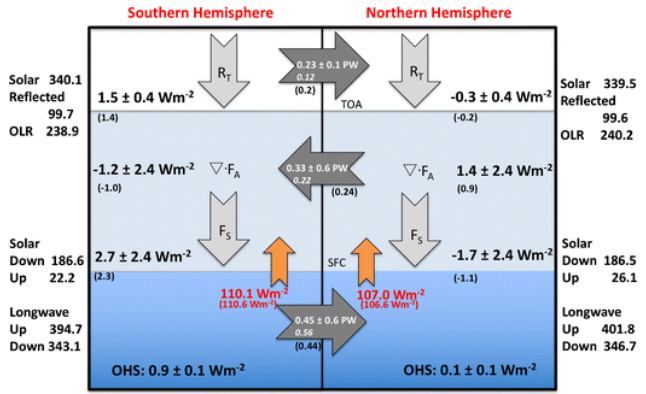
- Novel **split-SW channel** (near-IR: 0.7-5 μm) to derive shortwave near-IR and visible irradiance.
- Improved understanding of solar energy deposition in climate system

Libera Science Objective 1

OG1: Provide radiances for seamless continuity of the ERB Climate data record.

Science objective 1: Use extended CDR to identify and quantify processes responsible for ERB variability on various times scales.





a) Explore patterns of variability in ERB & cloud radiative effects (CRE).

b) Study processes responsible for ERB variability across time scales.

c) Estimate meridional energy transports, their variability, and the controls they pose on the dynamics of the ocean and atmosphere.

Libera Science Objective 2

OG2: Development of a self-contained, innovative & affordable observing system

Demonstrate feasibility of separating Libera from complex imagers.

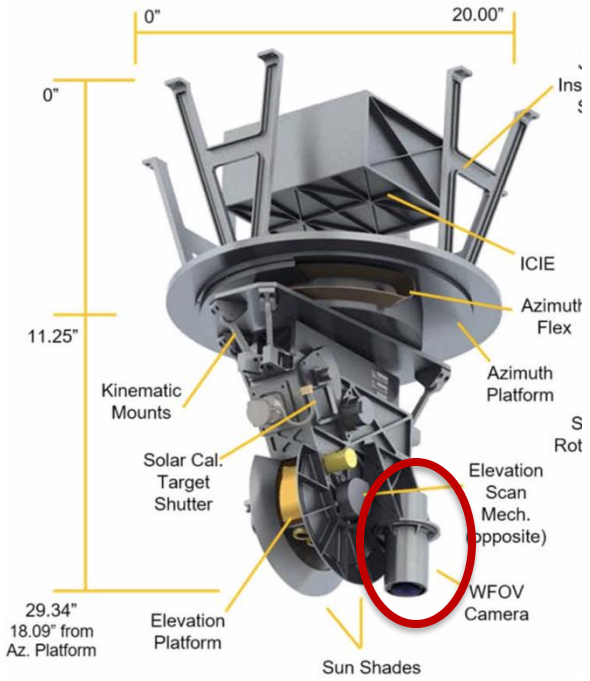
Science objective 2:

- Explore utility of scene identification from a small and cost-effective camera.
- Develop angular distribution models (ADM) to facilitate shortwave visible radiance-to-flux conversion.

$\frac{\pi L}{F}$ **= Anisotropy factor for a certain scene type & viewing geometry**

Measured Radiance L

Estimated Flux F



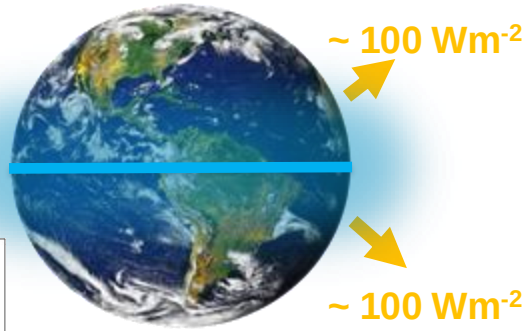
Monochromatic (555 nm) wide field of view (WFOV, 123º) camera provides images at 1 km pixel resolution.

Libera Science Objective 3

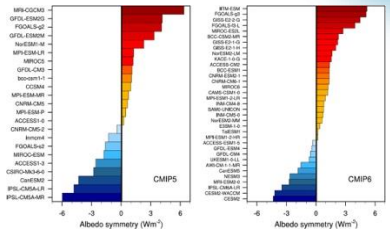
OG3: Provide new and enhanced capabilities that support extending ERB science goals.

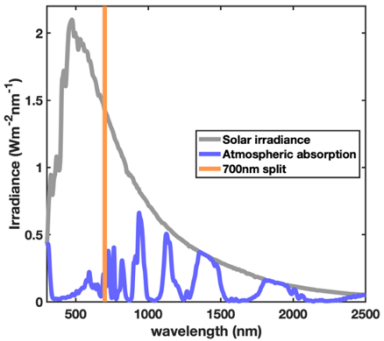
Science objective 3:

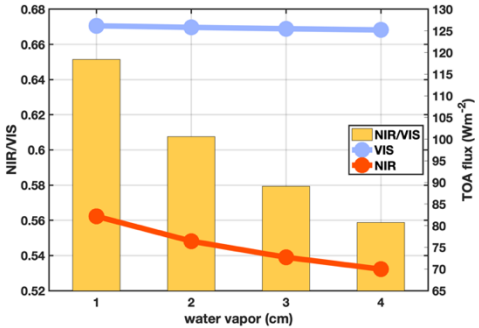
- Improve understanding of SW energy deposition (split at 700 nm)
- NIR and VIS fluxes at TOA and surface (L2 instantaneous footprint)
- Characterize NIR & VIS signatures of processes that control the
  - **Changes in absorption of solar radiation**
  - **SW climate feedbacks**
  - **Hemispheric symmetry of planetary albedo**



Rugenstein & Hakuba, 2023

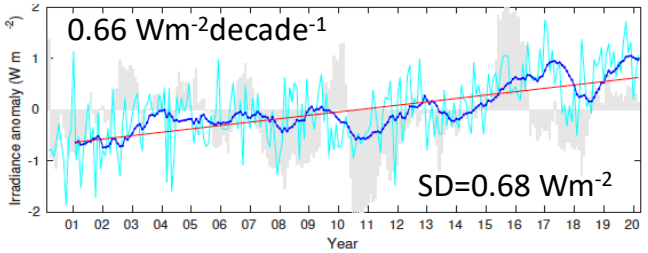


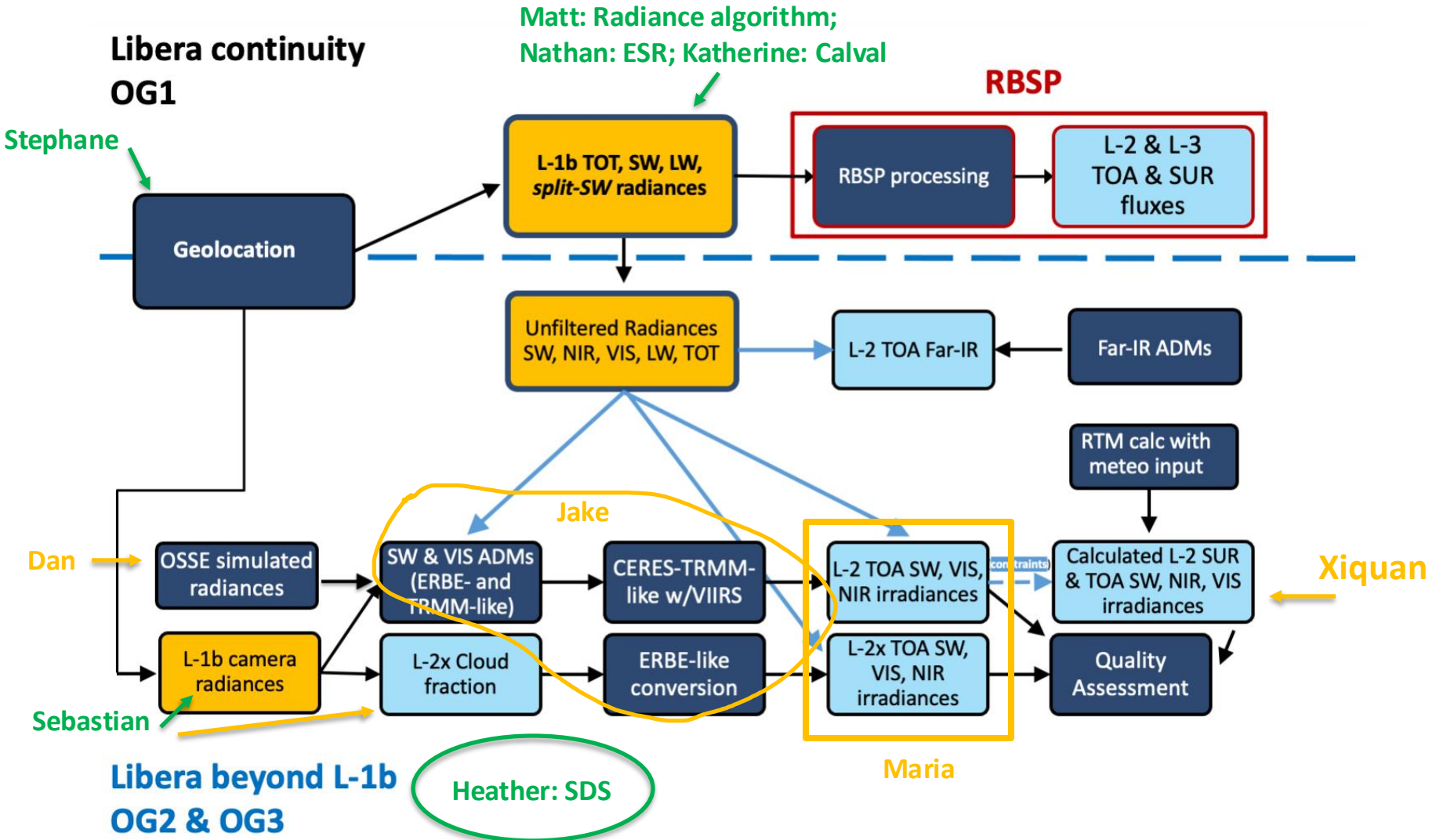


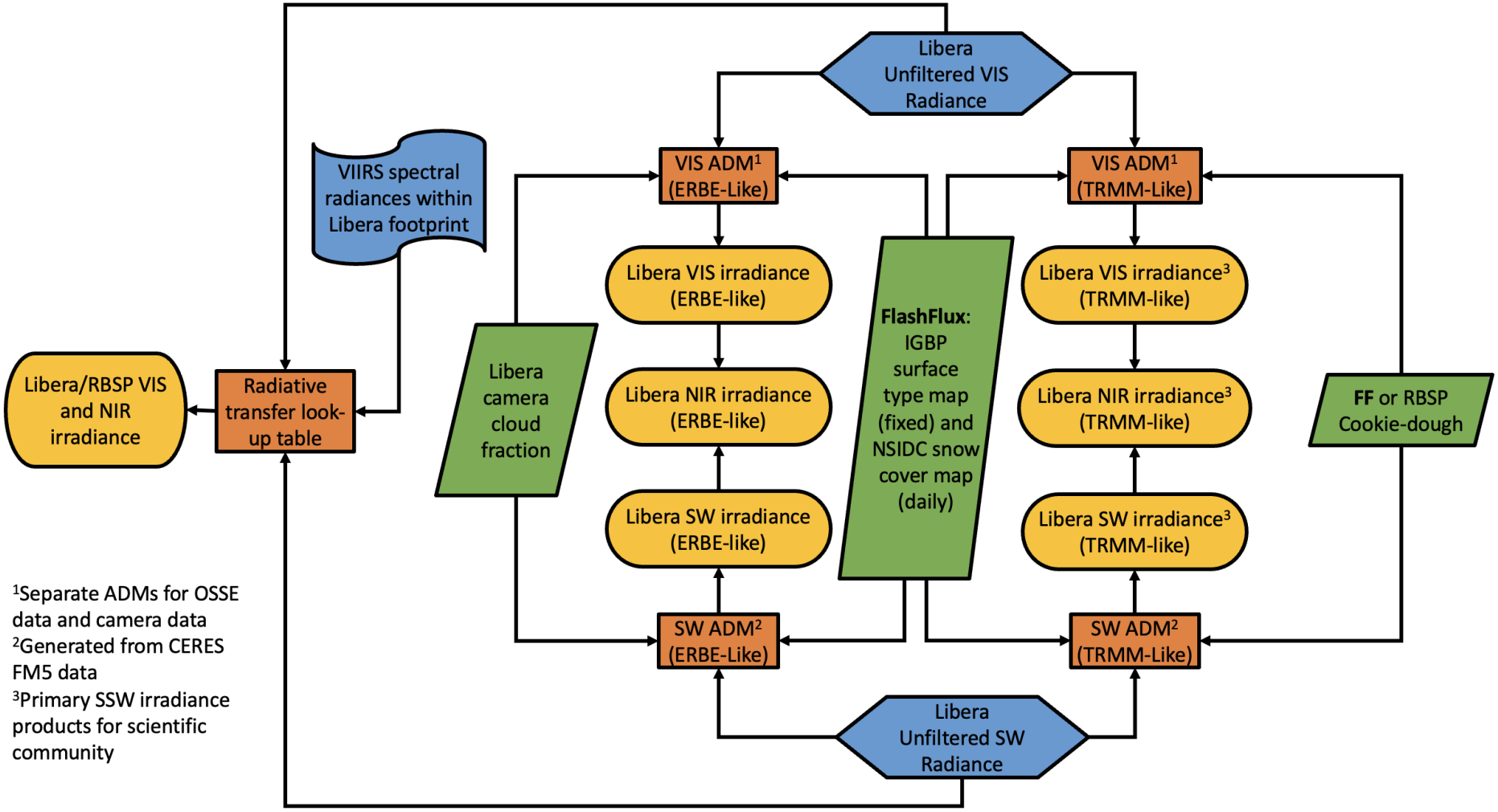


Stephens et al., 2022

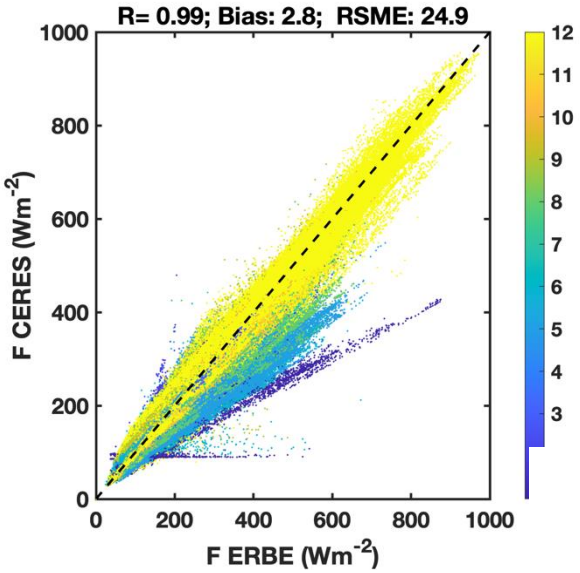
ASR

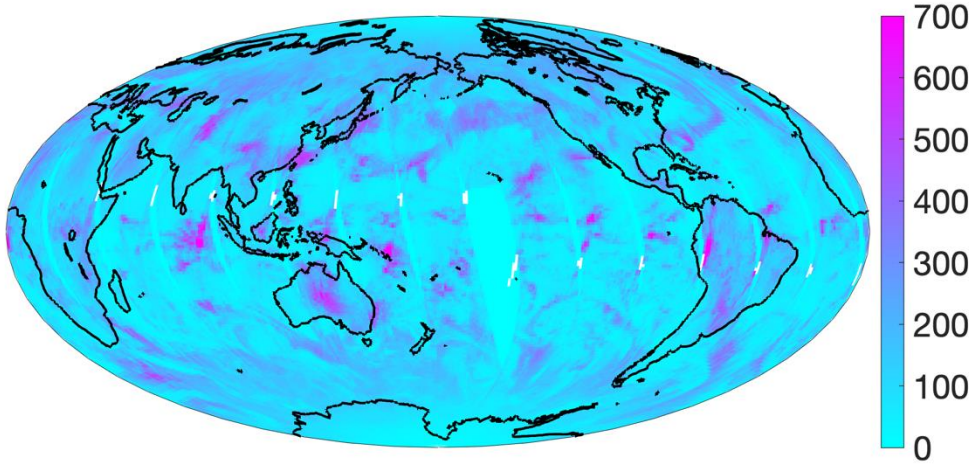


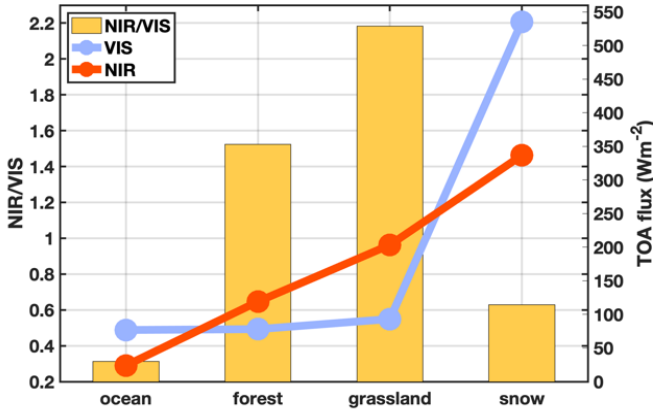

Libera continuity
OG1
Matt: Radiance algorithm;
Nathan: ESR; Katherine: Calval
RBSP
Stephane
L-1b TOT, SW, LW, split-SW radiances
RBSP processing
L-2 & L-3 TOA & SUR fluxes
Geolocation
Unfiltered Radiances SW, NIR, VIS, LW, TOT
L-2 TOA Far-IR
Far-IR ADMs
RTM calc with meteo input
Jake
Dan
OSSE simulated radiances
SW & VIS ADMs (ERBE- and TRMM-like)
CERES-TRMM-like w/VIIRS
L-2 TOA SW, VIS, NIR irradiances
Calculated L-2 SUR & TOA SW, NIR, VIS irradiances
Xiquan
L-1b camera radiances
L-2x Cloud fraction
ERBE-like conversion
L-2x TOA SW, VIS, NIR irradiances
Quality Assessment
Sebastian
Maria
Libera beyond L-1b
OG2 & OG3
Heather: SDS

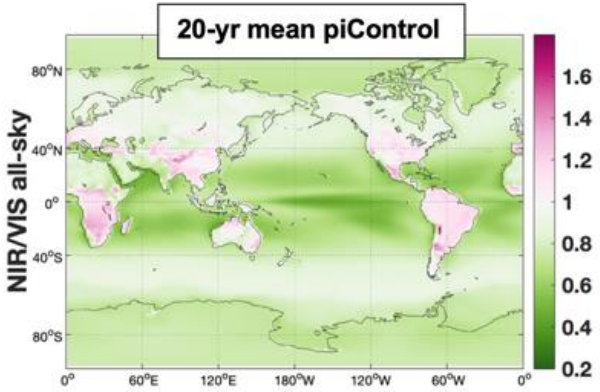

Libera Unfiltered VIS Radiance
VIIRS spectral radiances within Libera footprint
VIS ADM[1] (ERBE-Like)
VIS ADM[1] (TRMM-Like)
Libera VIS irradiance (ERBE-like)
Libera NIR irradiance (ERBE-like)
Libera SW irradiance (ERBE-like)
FlashFlux: IGBP surface type map (fixed) and NSIDC snow cover map (daily)
Libera VIS irradiance[3] (TRMM-like)
Libera NIR irradiance[3] (TRMM-like)
Libera SW irradiance[3] (TRMM-like)
Libera/RBSP VIS and NIR irradiance
Radiative transfer look-up table
Libera camera cloud fraction
FF or RBSP Cookie-dough
SW ADM[2] (ERBE-Like)
SW ADM[2] (TRMM-Like)
Libera Unfiltered SW Radiance
[1]Separate ADMs for OSSE data and camera data
[2]Generated from CERES FM5 data
[3]Primary SSW irradiance products for scientific community

Expected results



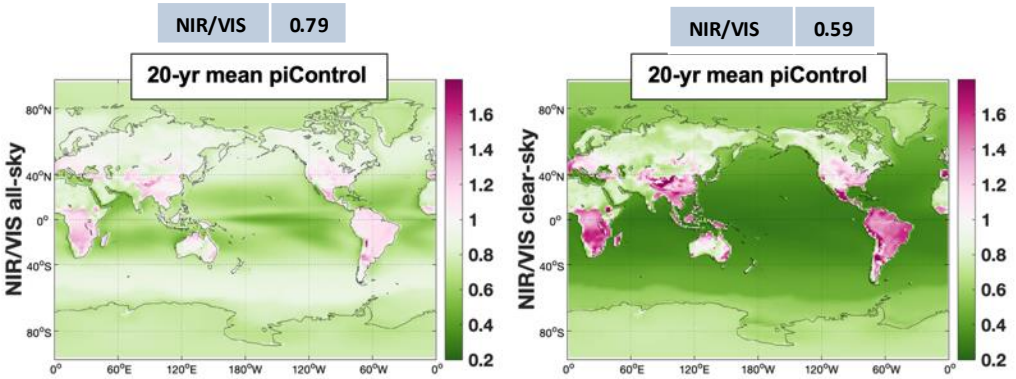






Split-SW Science

NIR and VIS radiation in an Earth system model UKESM1: albedo symmetry



All-sky	Glo	NH	SH
TOT SW	99.3	**99.1**	**99.6**
NIR	44.0	44.2	43.7
VIS	55.0	54.8	55.4
NIR/VIS	0.79	**0.80**	**0.78**

Clear-sky	Glo	NH	SH
TOT SW	54.4	57.4	51.4
NIR	20.2	22.3	18.2
VIS	34.2	35.1	33.2
NIR/VIS	0.59	**0.63**	**0.55**

UKESM1 pre-industrial simulation:

- Vegetated land surfaces particularly bright in NIR
- Cloud free ocean particularly dark in NIR
- Clouds increase NIR/VIS globally and decrease land-sea contrasts

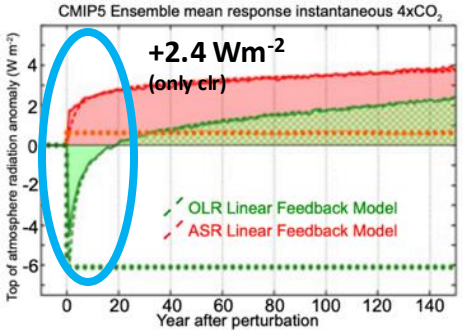
According to model:

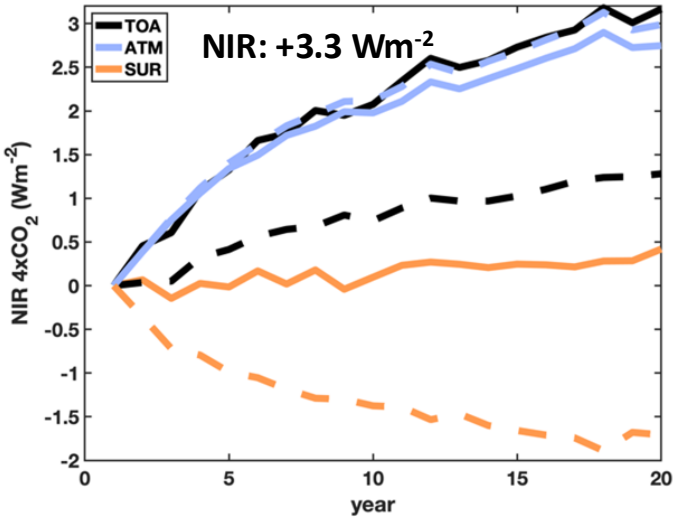
Clouds not only balance mean albedo and trend across hemispheres but also NIR/VIS ratio.

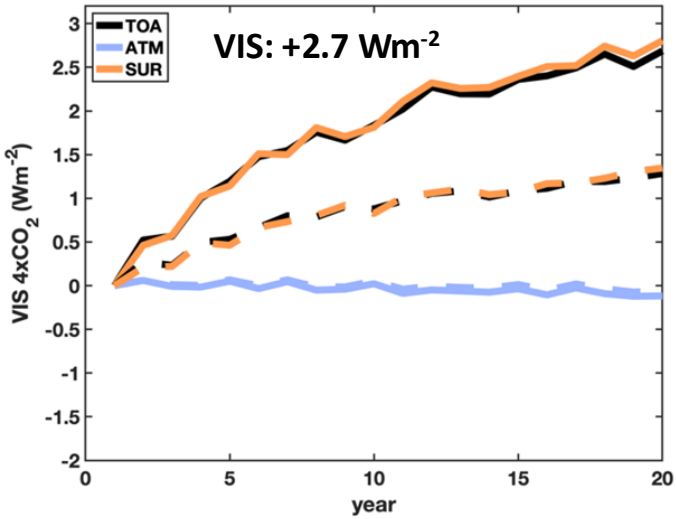
Hakuba et al., in prep.

Change in SW absorption in 4xCO_2 simulation

- Clear-sky absorption after 20 years: ~ 2.5 Wm^{-2}
- All-sky: ~ 6 Wm^{-2} (positive cloud effect)
- Surface (VIS) & atmosphere (NIR) absorption contribute each ~ 50%

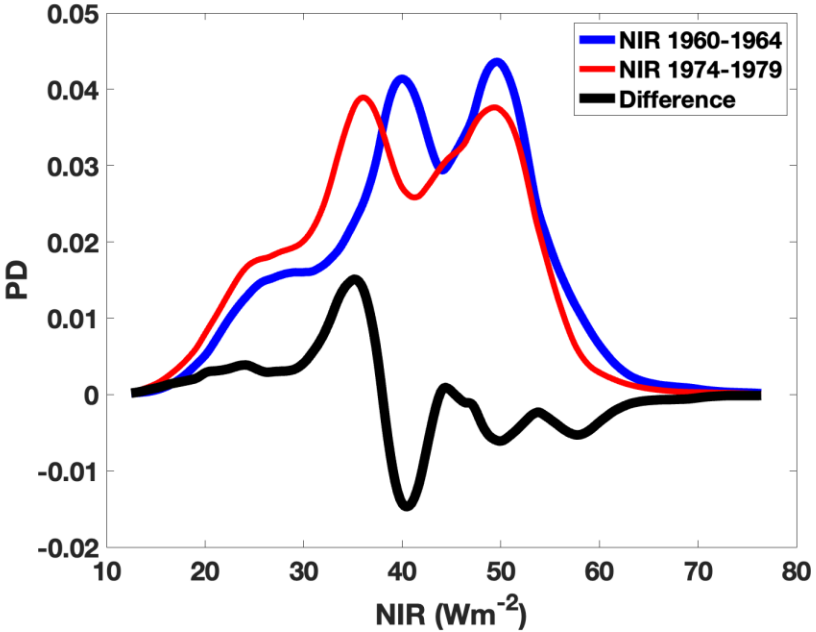


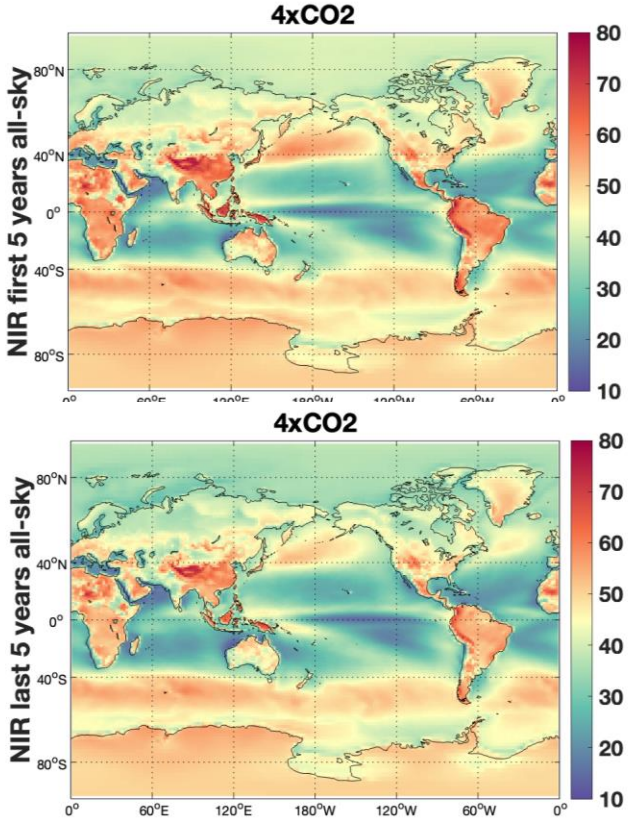




Spatial-Spectral (SPACTAL) signatures of change - NIR

Probability distribution fit to data (kernel smoothing, nonparametric)

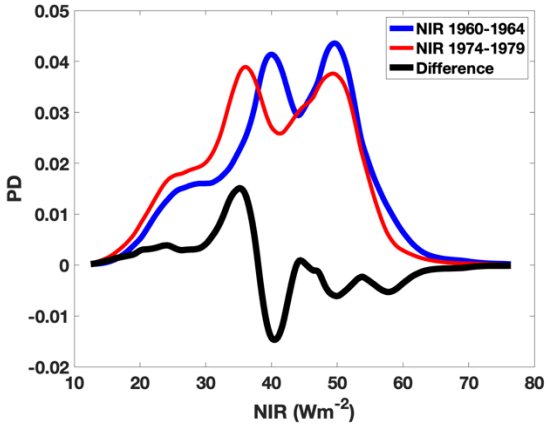




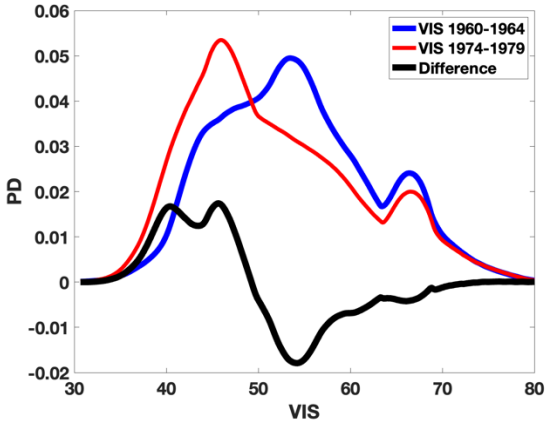
TOA all-sky

Spatial-Spectral (SPACTAL) signatures of change

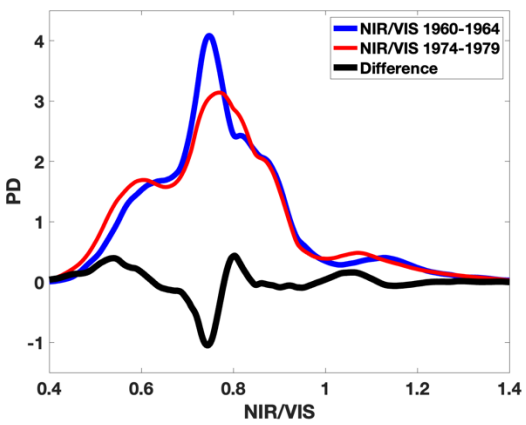
TOA all-sky



-2.5 Wm^{-2}



-2 Wm^{-2}



0.77 to 0.76

Next: Identify key processes and hotspots

Vision of a future ERB & EEI observing system

BOSS-E - A Better Observing System Strategy for EEI: Multi-sensor Composite constellation

SUNCUBEs TSI & SSI

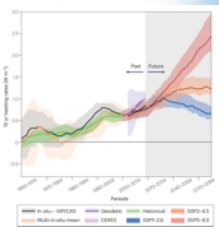
Total **solar irradiance**
Spectral solar irradiance

- Key component of ERB – Earth's energy input
- Tracks stability of Space Ball
- Complements HYPER

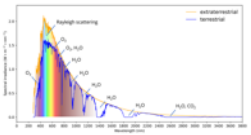
HOT-EARTH

(Ocean) **heat inventory**

- Altimetry - gravimetry
- Independent indirect EEI estimate
- Links to EEI impacts:
  - Sea level
  - Ice melt
  - TWS change



*** Don't forget Argo and other in-situ!**



HYPER-SATs

Earth radiation and change in EEI
(Spectral) UV-FIR radiances

- Scanner: Daily coverage, <20km
- To address:
  - ERB Continuity
  - Process understanding
  - Scene context
  - Composition
- 6 SSO to sample diurnal cycle
- High-res changes in SW, LW, EEI and their causes

Space Balls (or ECO)

Direct net irradiance - EEI

- **Uniform sensitivity to** UV-FIR
- Global annual EEI
- "WFOV" in 3 precessing LEO orbits
- EEI constraint for HYPER
- Serves fundamental climate science and public information on state of climate.

Summary

- ERB & EEI research is fundamentally important for society
- ERB & EEI research is interdisciplinary
  - Requires best-possible radiation, composition AND heat content observations
- In the future, we hope to ensure **continuity**, enhance **spatial, temporal, spectral** resolution, and measure EEI directly
- **Libera** ensures **continuity** (for now), paves way for a **high-accuracy free-flyer system**, and extension of science goals.

Thank you