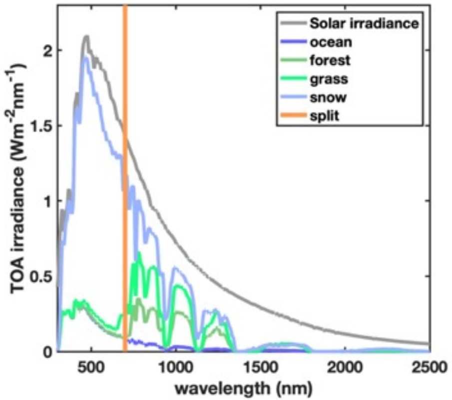
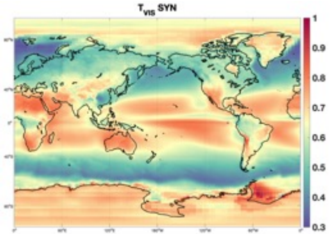
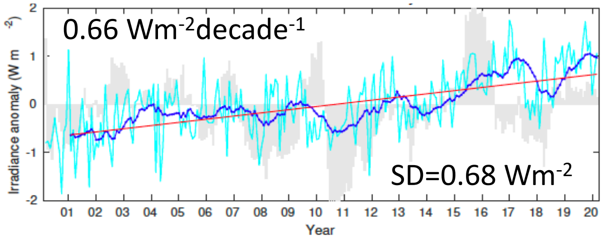
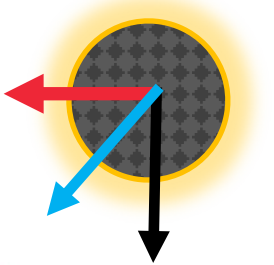








Libera and EEI Science

Maria Hakuba, Peter Pilewskie, Graeme Stephens, and the Libera Science Team

CERES STM, Spring 2023

Jet Propulsion Laboratory
California Institute of Technology

Content

- Libera goals
- ERBE-like SW irradiance (SSF)
- ASR time evolution in NIR & VIS (SYN)
- JPL EEI workshop

Libera goals and objectives

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 (0.5-50 μm) radiance over 24km nadir footprint
- On JPSS-3 with VIIRS imager, launch 2027, 5-year mission
- Electrical Substitution Radiometer using VACNT detectors

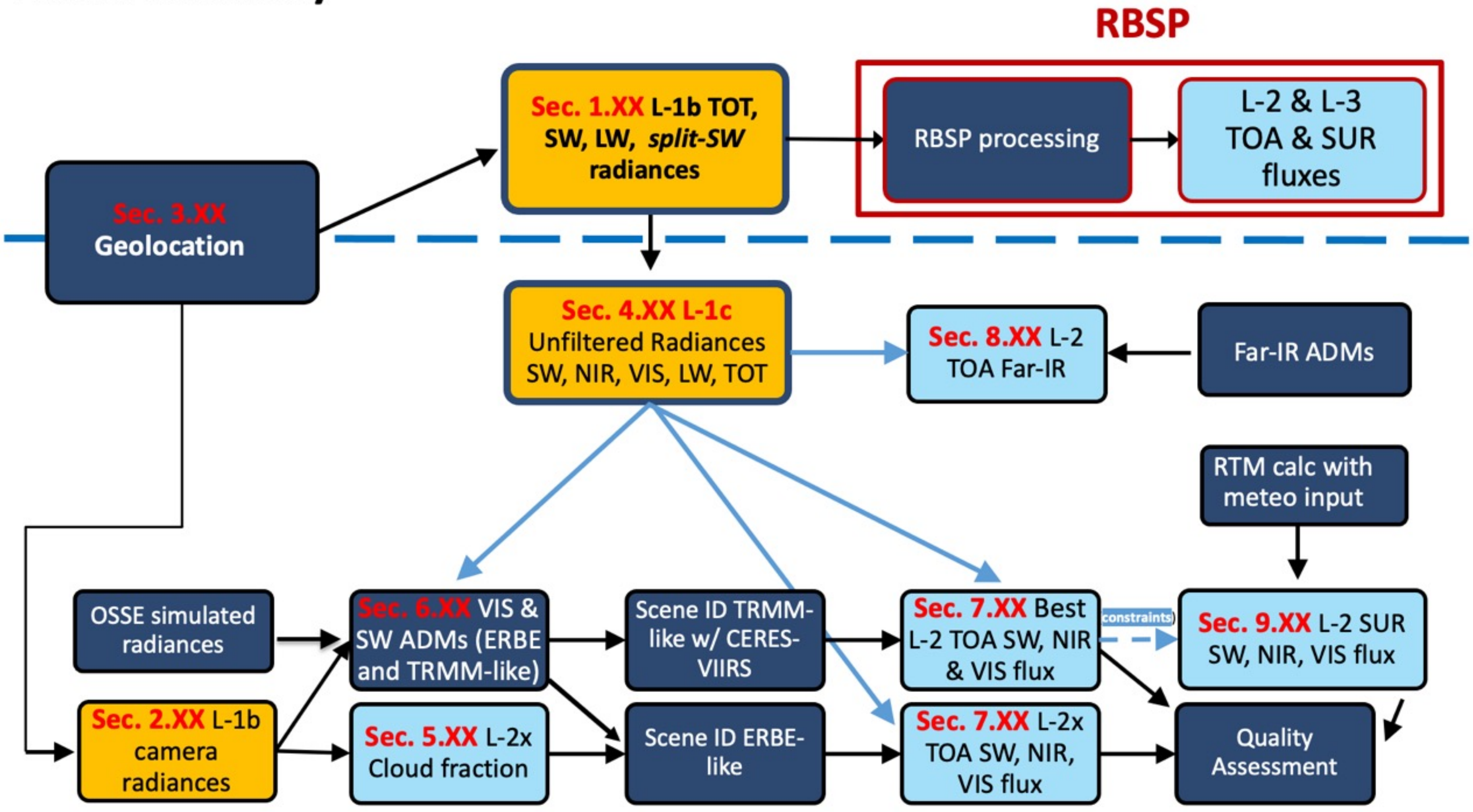
OG2: Advance the development of a self-contained, innovative & affordable observing system.

- Wide field-of-view camera to accelerate split-SW ADM development and aid in scene identification (cloud fraction)

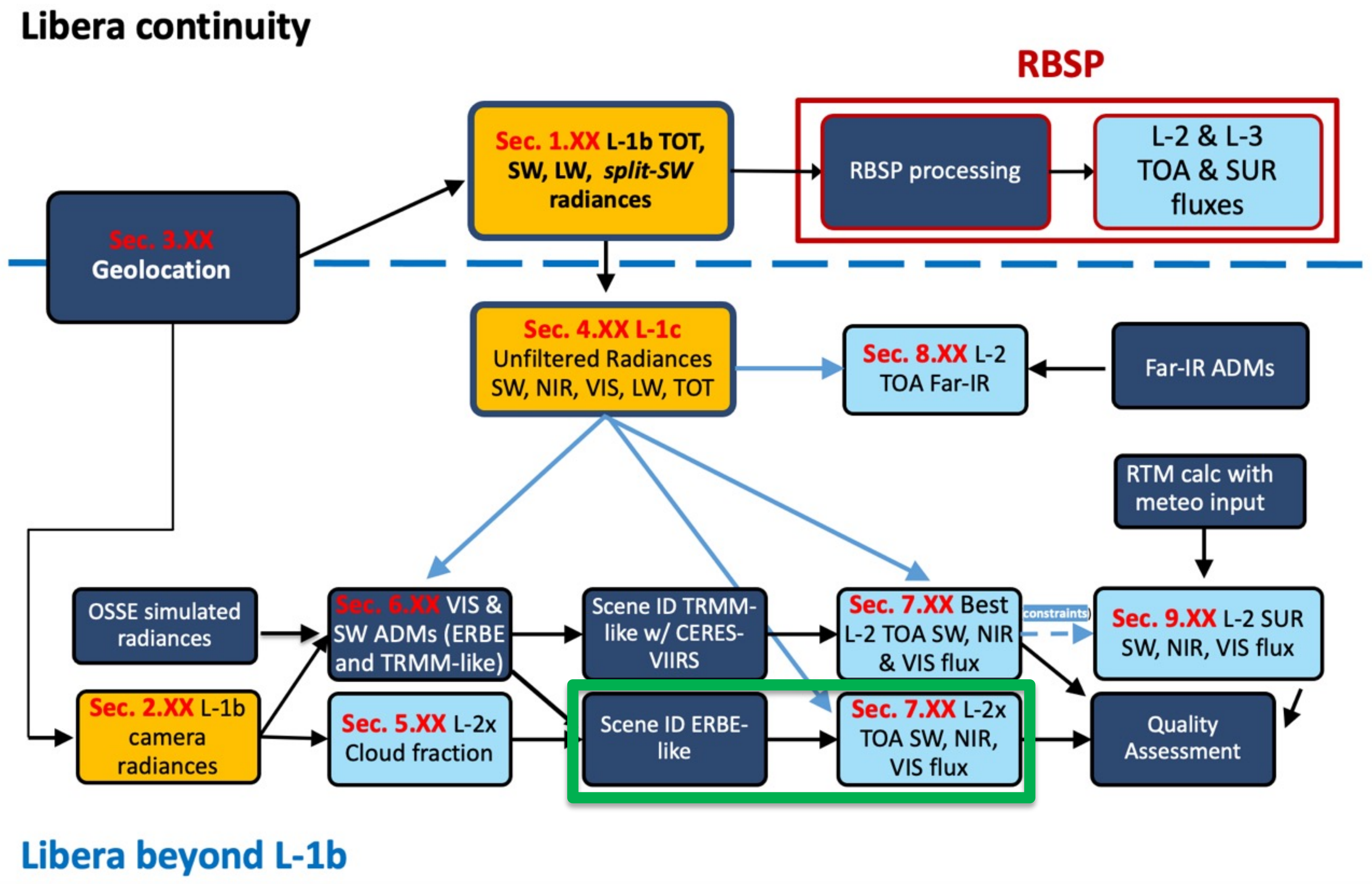
OG3: Provide new and enhanced capabilities that support extending ERB science goals.

- Additional 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 continuity



Libera beyond L-1b



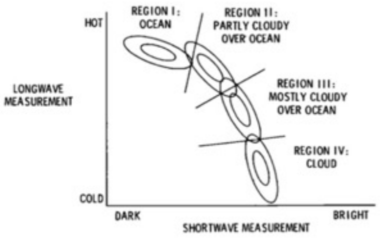
Libera continuity
RBSP
Sec. 1.XX L-1b TOT, SW, LW, split-SW radiances
RBSP processing
L-2 & L-3 TOA & SUR fluxes
Sec. 3.XX Geolocation
Sec. 4.XX L-1c Unfiltered Radiances SW, NIR, VIS, LW, TOT
Sec. 8.XX L-2 TOA Far-IR
Far-IR ADMs
RTM calc with meteo input
OSSE simulated radiances
Sec. 6.XX VIS & SW ADMs (ERBE and TRMM-like)
Scene ID TRMM-like w/ CERES-VIIRS
Sec. 7.XX Best L-2 TOA SW, NIR & VIS flux
constraints
Sec. 9.XX L-2 SUR SW, NIR, VIS flux
Sec. 2.XX L-1b camera radiances
Sec. 5.XX L-2x Cloud fraction
Scene ID ERBE-like
Sec. 7.XX L-2x TOA SW, NIR, VIS flux
Quality Assessment
Libera beyond L-1b

"ERBE-like" SW irradiances – testing inversion draft code with SSF data

One day of SSF footprint radiances, fluxes, and CERES inputs/outputs including angular geometry:

CERES_SSF_Aqua-XTRK_Edition4A_Subset_2021032100-2021032123.nc

- 12 ERBE-scene types + conversion table from IGBP
- 12 SZA, 8 RAA, 7 VZA bins
- ERBE ADMs were generated from Nimbus VII ERB scanner observations (90x90km at nadir): coarse scene types; cloud fraction derived from TOMS and THIR
- CF from SSF clear-sky fraction while ERBE-Like approach derive cloudy scene from SW and LW radiances



- Libera SW and VIS ADMs for ERBE scenes do not exist yet – apply Suttles' ERBE ADMs as is…
- Compare "ERBE-like" results to SSF irradiance

Scene ID number	Cloud fraction	Surface type
1	Cloud-free (0–5%)	Ocean
2	Cloud-free (0–5%)	Land
3	Cloud-free (0–5%)	Snow
4	Cloud-free (0–5%)	Desert
5	Cloud-free (0–5%)	Land-ocean mix
6	Partly cloudy (5–50%)	Ocean
7	Partly cloudy (5–50%)	Land or desert
8	Partly cloudy (5–50%)	Land-ocean mix
9	Mostly cloudy (50–95%)	Ocean
10	Mostly cloudy (50–95%)	Land or desert
11	Mostly cloudy (50–95%)	Land-ocean mix
12	Overcast	All

IGBP index	IGBP surface type	ERBE surface type
1	Evergreen needle-leaf forest	Land
2	Evergreen broad-leaf forest	Land
3	Deciduous needle-leaf forest	Land
4	Deciduous broad-leaf forest	Land
5	Mixed forest	Land
6	Closed shrubland	Land
7	Open shrubland (desert)	Desert
8	Woody savanna	Land
9	Savanna	Land
10	Grassland	Land
11	Permanent wetland	Land
12	Cropland	Land
13	Urban and built-up	Land
14	Cropland/natural vegetation mosaics	Land
15	Permanent snow and ice	Snow
16	Barren (desert)	Desert
17	Water	Ocean
N/A (NSIDC)	Tundra	Land
N/A (NSIDC)	Fresh snow	Snow
N/A (NSIDC)	Sea ice	Snow

ERBE-like vs CERES-TRMM – known differences

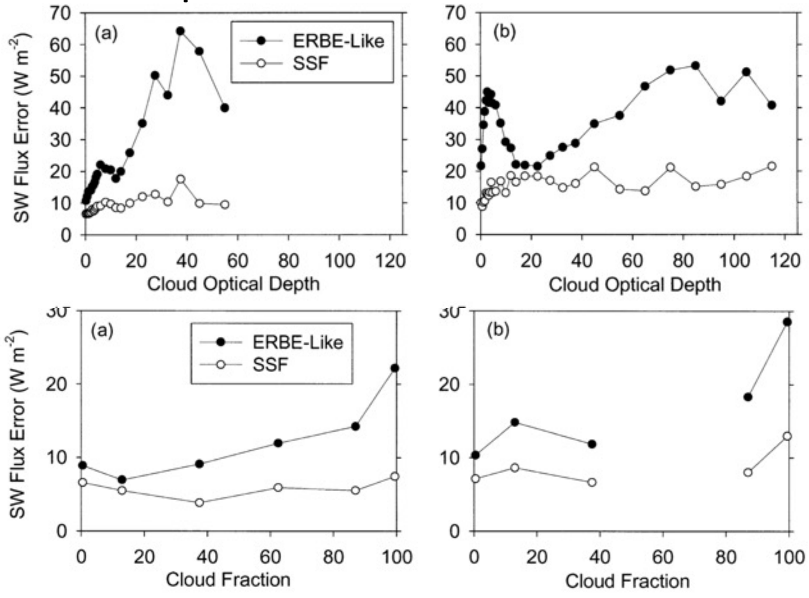
1748 JOURNAL OF APPLIED METEOROLOGY VOLUME 42

Angular Distribution Models for Top-of-Atmosphere Radiative Flux Estimation from the Clouds and the Earth's Radiant Energy System Instrument on the Tropical Rainfall Measuring Mission Satellite. Part II: Validation

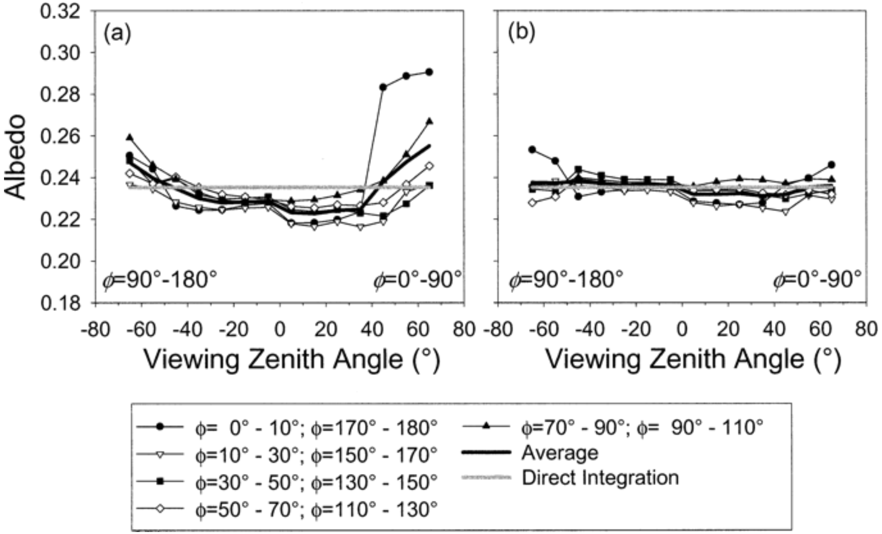
NORMAN G. LOEB

Center for Atmospheric Sciences, Hampton University, Hampton, Virginia

Liquid water **Ice cloud**



ERBE **CERES-TRMM**

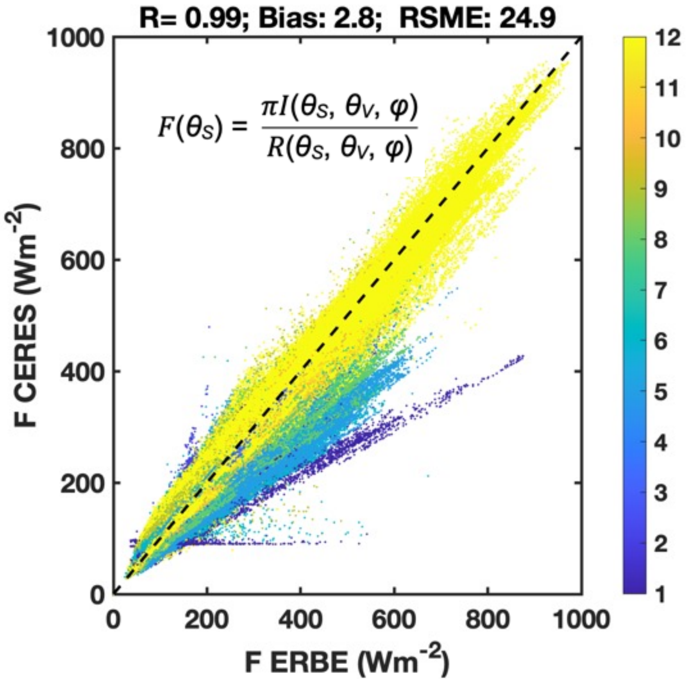


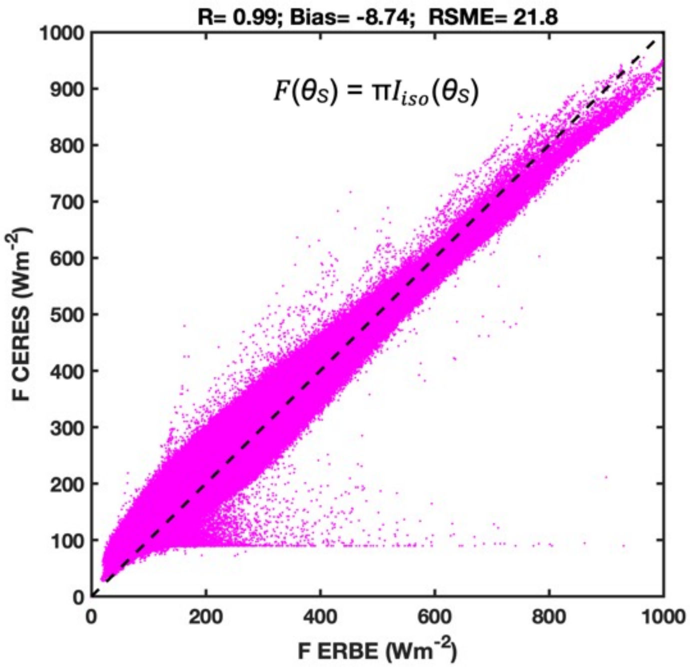
Spurious VZA dependence in albedo

TOA albedos are underestimated close to nadir and overestimated at large viewing zenith angles.

“ERBE-like” SW irradiances comparison to SSF

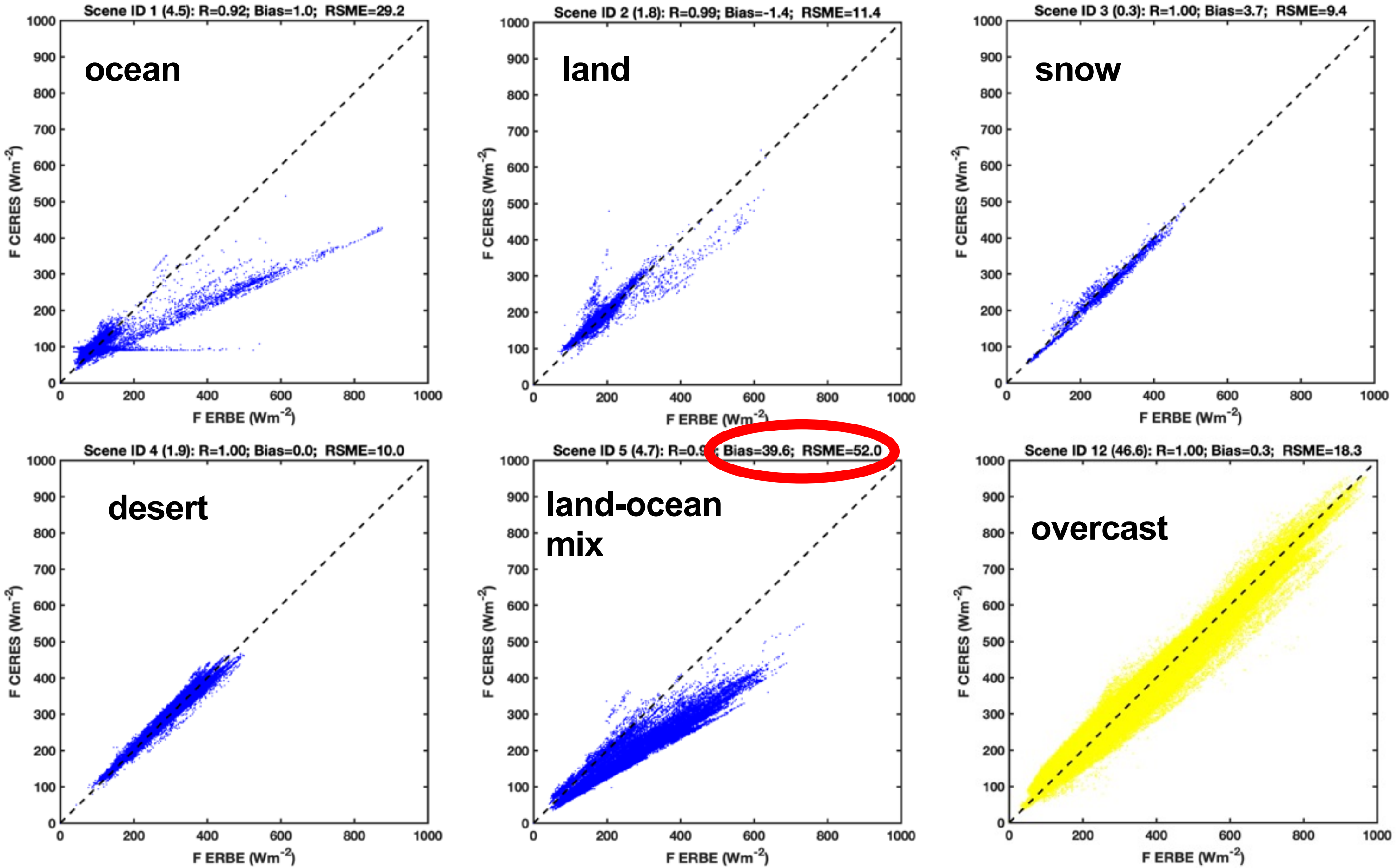
All scenes irradiances compared to SSF: “ERBE-like” is slightly brighter than SSF





ERBE-like conversion reduces bias, but enhances RMSE slightly compared to isotropic radiance assumption.

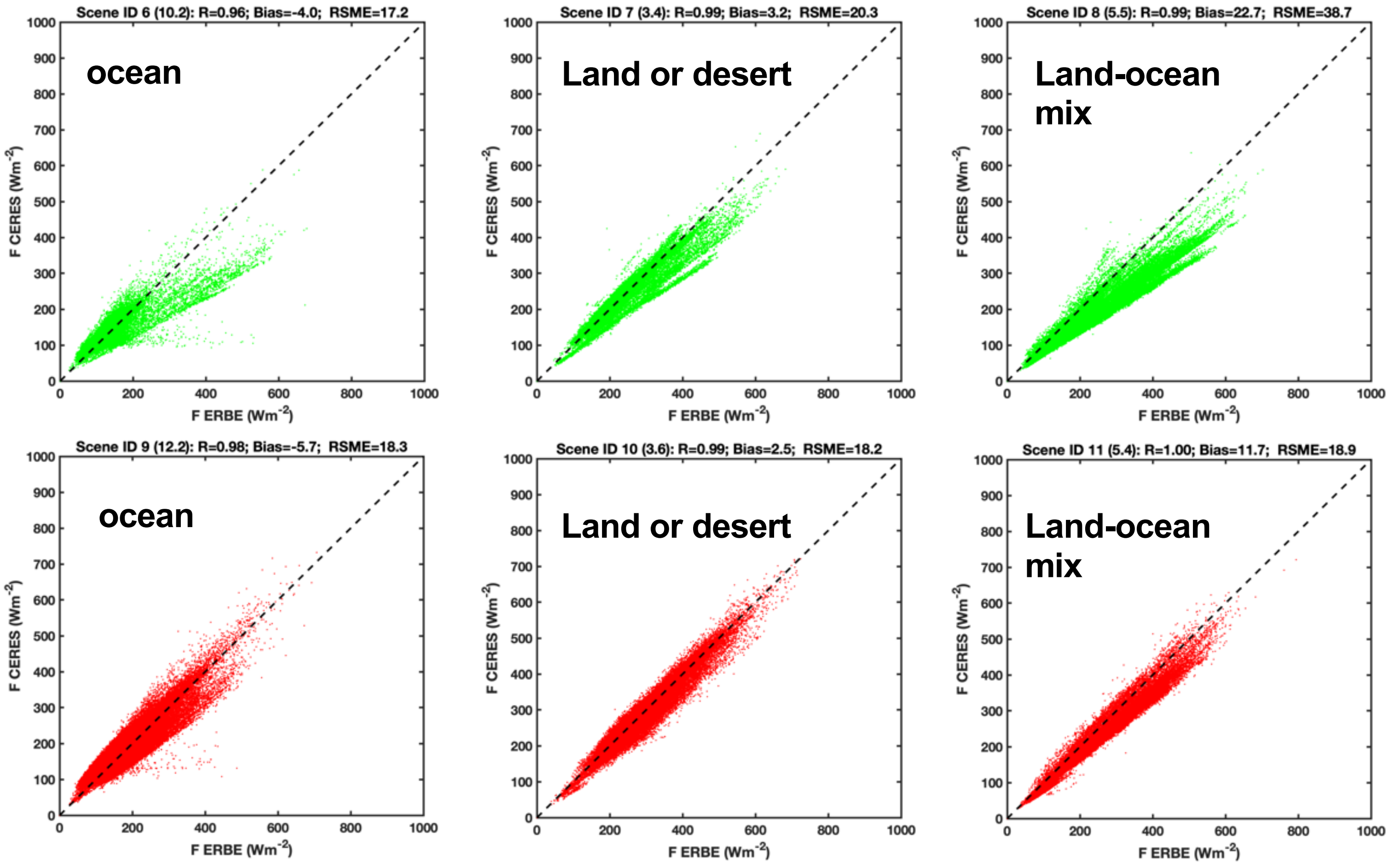
Conversion by scene type: clear sky



- Overcast dominates the sample at almost 50%
- Errors dominated by land-ocean mix
- Misclassification, angular errors, ignoring stratification by cloud properties…

Conversion by scene type: cloudy

Partly cloudy

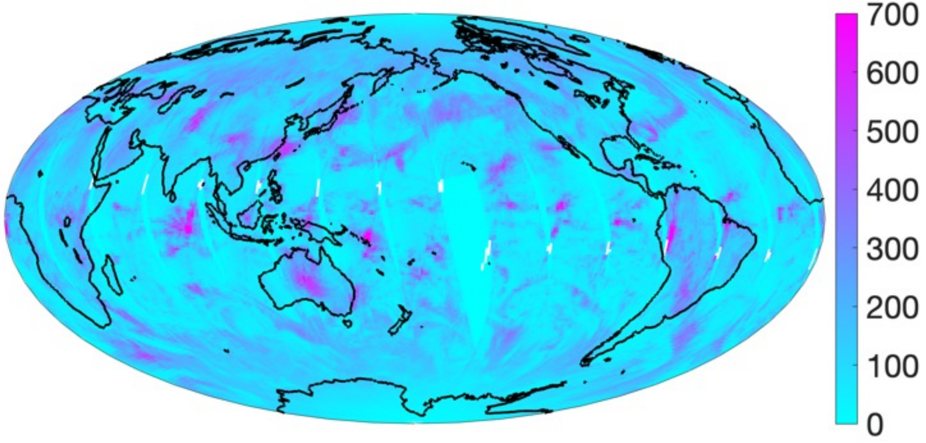


- Over ocean, "ERBE-like" is darker, otherwise brighter
- Errors dominated by land-ocean mix

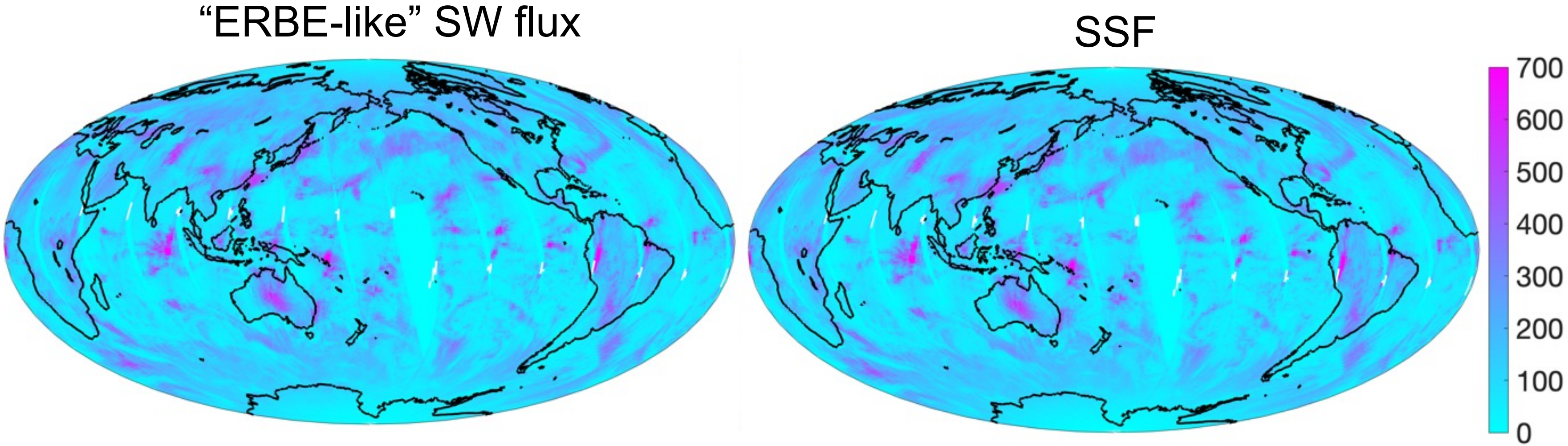
Mostly cloudy

Regional differences (1deg averaging)

"ERBE-like" SW flux



Regional differences (1deg averaging)

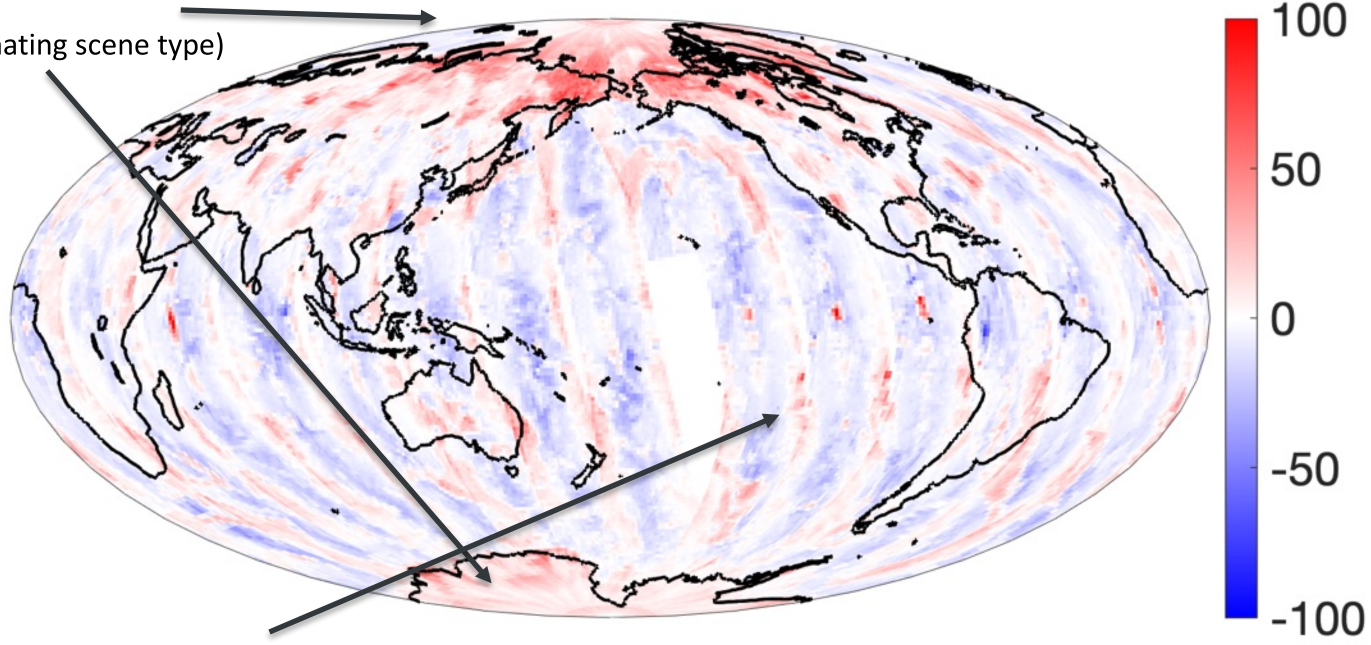


Qualitatively look the same!

Regional differences (1deg averaging)

"ERBE-like" – SSF SW flux

"snow" scene comparison seemed fine?
Misclassification?
(need map of dominating scene type)



Systematic striping: Spurious VZA dependence in albedo?

“ERBE-like” SW irradiances – testing inversion draft code with SSF data

One day of SSF footprint radiances, fluxes, and CERES inputs/outputs including angular geometry:

CERES_SSF_Aqua-XTRK_Edition4A_Subset_2021032100-2021032123.nc

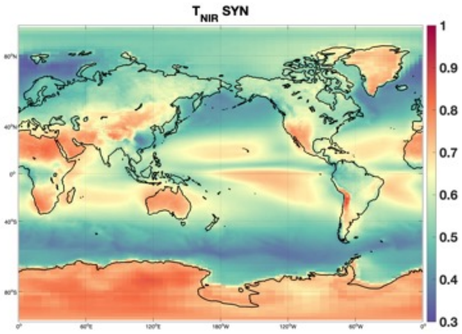
Next steps:

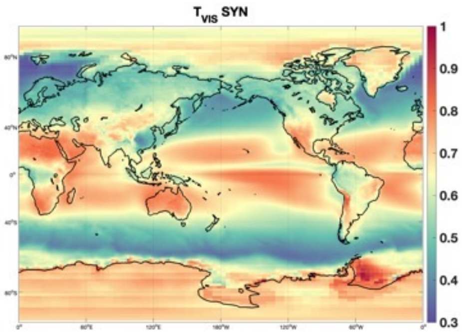
- Work on weighted land-ocean mix
- Understand regional differences better (by scene type)
- Derive SW ADMs for ERBE-like scenes using SSF (or do they exist?)
- Derive SW ADMs for ERBE-like scenes using OSSE output (consistent with VIS ADM)
- Implement TRMM-like conversion (refined ADMs by cloud properties)
- Implement conversion for VIS ADMs from OSSE output
- …

Climate from Libera’s “spectral” lens

Libera’s fourth channel measures NIR (**0.7**-5 µm) and total SW (0.3-5 µm) radiances:

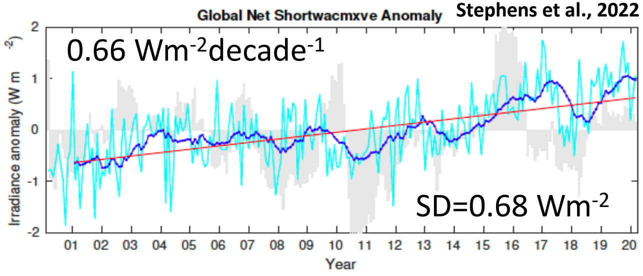
- **NIR & VIS signatures of processes that control the absorption of solar radiation & SW climate response.**
- Better understand the hemispheric symmetry of planetary albedo and model biases.
- Explore Nimbus-7, ESM, RTM, SCIAMACHY



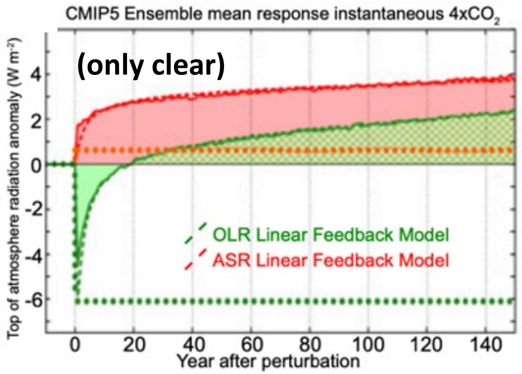


Stephens et al., 2022

ASR

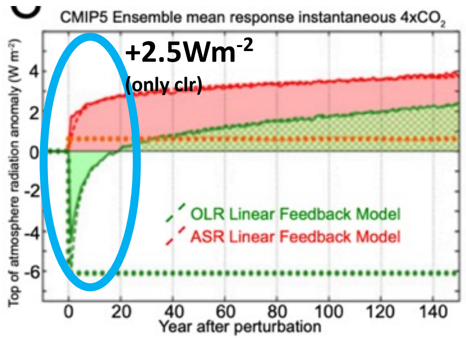


Climate model simulations and observations suggest global warming is sustained by shortwave absorption (positive climate feedbacks).

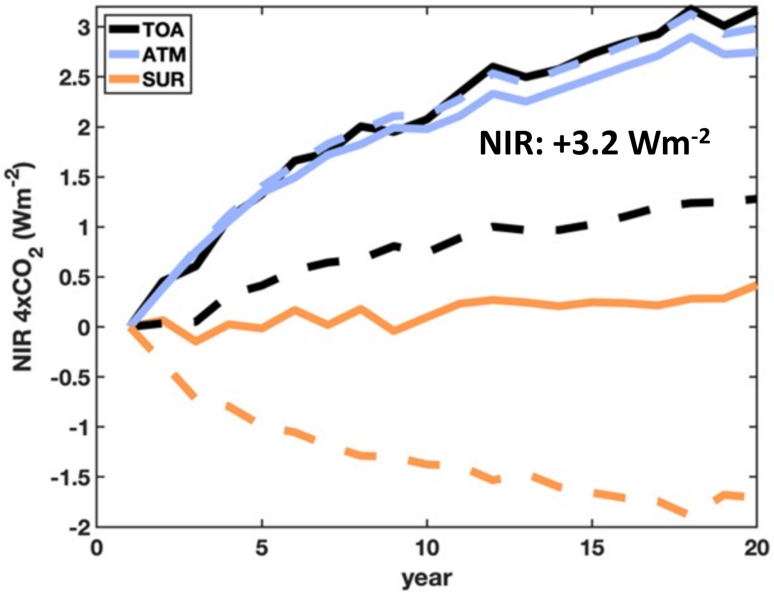


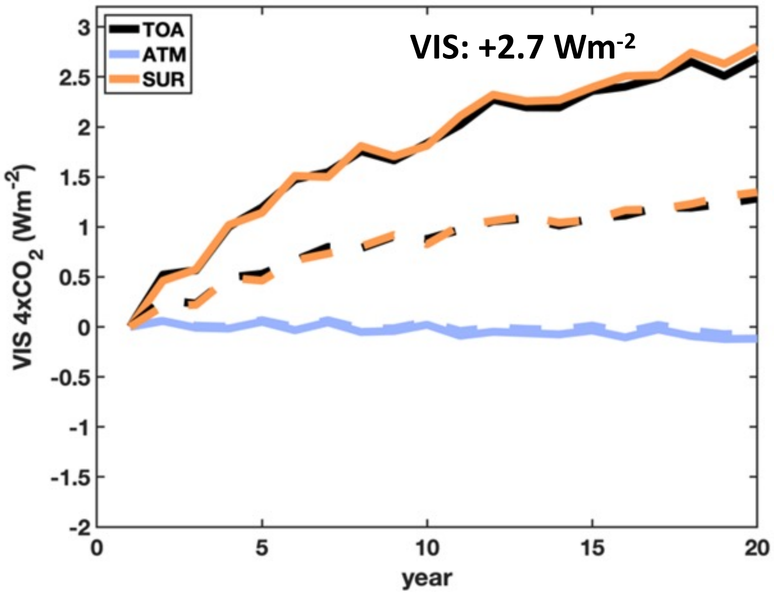
(Donohoe et al., 2014)

SW absorption change in UKESM1 (4xCO_2)



- Clear-sky absorption: ~ 2.5 Wm^{-2} (in line with Donohoe et al., 2014)
- (All-sky: ~ 6 Wm^{-2})
- SUR/ATM & NIR/ VIS ~ 50% (3 Wm^{-2})





Present-day temporal evolution in ASR:
CERES SYN1deg adjusted all-sky spectral SW fluxes integrated over 4 bands

TABLE A1.

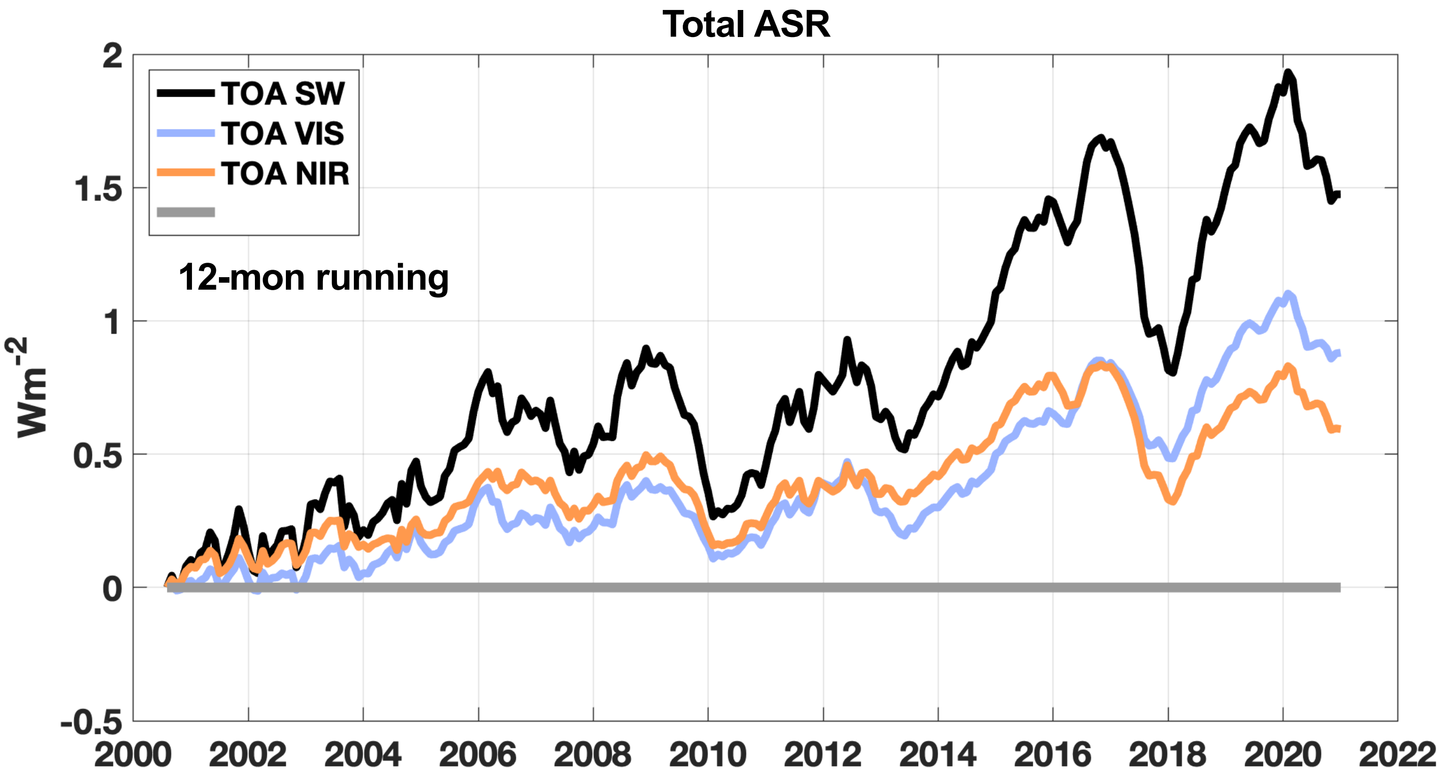
Shortwave spectral bands for Langley Fu and Liou model used in this work.

Band	No. of subbands	Wavelength (μm)		Wavelength (cm^{-1})		Gases treated
1	1	0.1754	0.2247	57 000	44 500	O_3
2	1	0.2247	0.2439	44 500	41 000	O_3
3	1	0.2439	0.2857	41 000	35 000	O_3
4	1	0.2857	0.2985	35 000	33 500	O_3
5	1	0.2985	0.3225	33 500	31 008	O_3
6	1	0.3225	0.3575	31 008	27 972	O_3
7	1	0.3575	0.4375	27 972	22 857	O_3
8	1	0.4375	0.4975	22 857	20 101	O_3, H_20
9	1	0.4975	0.5950	20 101	16 807	O_3, H_20
10	1	0.5950	0.6900	16 807	14 500	O_3, H_20
11	8	0.6900	0.7940	14 500	12 600	O_3, H_20, O_2
12	6	0.7940	0.8890	12 600	11 250	H_20
13	8	0.8890	1.0420	11 250	9600	H_20
14	7	1.0420	1.4100	9600	7090	H_20
15	8	1.4100	1.9048	7090	5250	H_20, CO_2
16	7	1.9048	2.5000	5250	4000	H_20, CO_2, CH_4
17	8	2.5000	3.5000	4000	2850	H_20, CO_2, CH_4, O_3
18	7	3.5000	4.0000	2850	2500	H_20, CO_2, CH_4

Visible Band 1-10: 0.18-0.689 microns (Libera: 0.3-0.7)

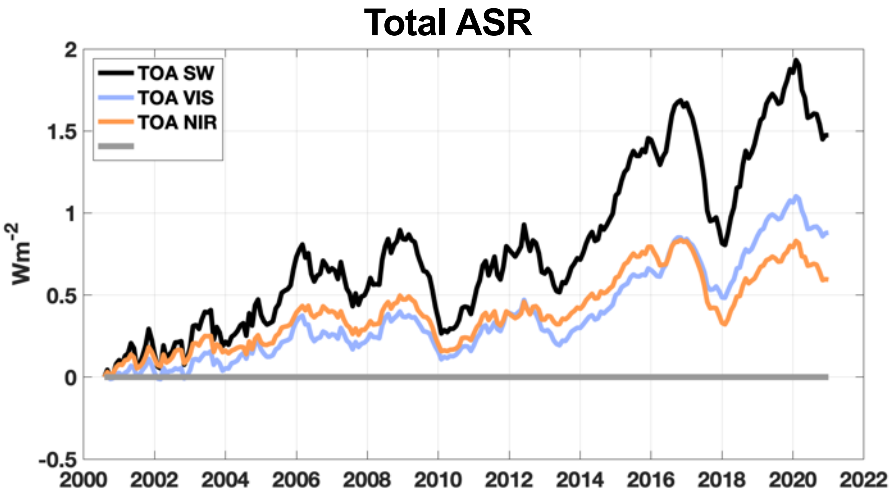
Near-IR: Band 11-18 (0.690-4 microns)
(Libera: 0.7-5)

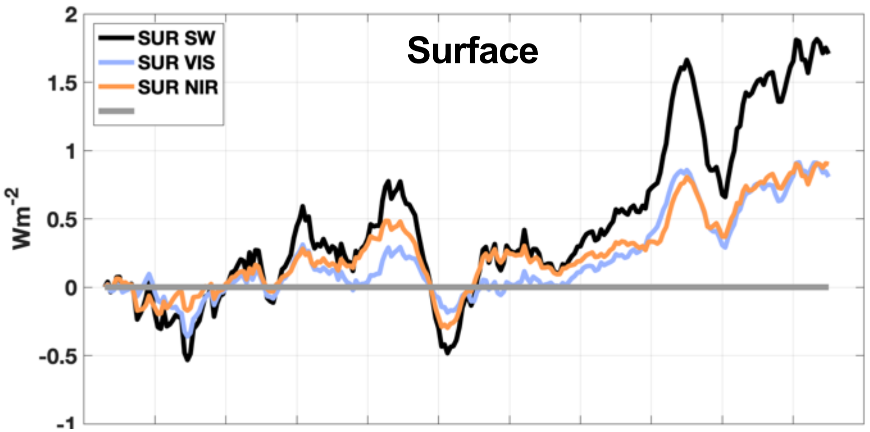
CERES SYN – NIR, VIS, SW time evolution in absorption

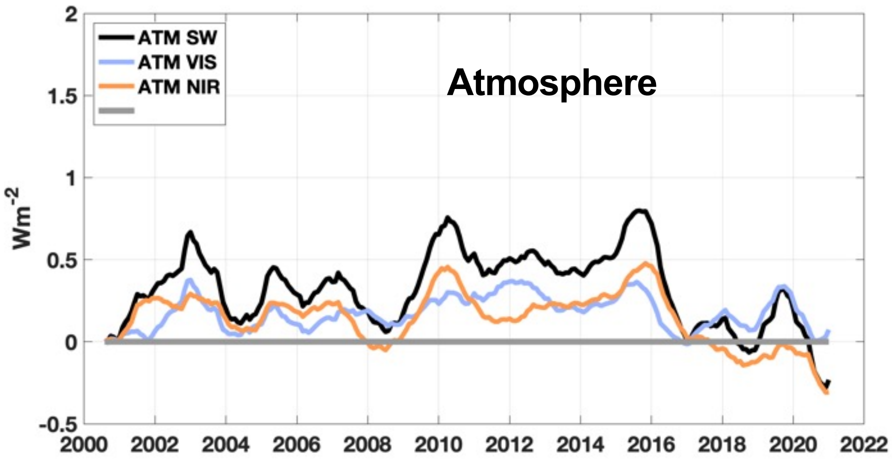


- VIS and NIR contribute to SW change at similar magnitude
- NIR dominates until 2016, then drops while VIS increases
- NIS & VIS exhibit similar interannual variability

CERES SYN – NIR, VIS, SW time evolution in absorption

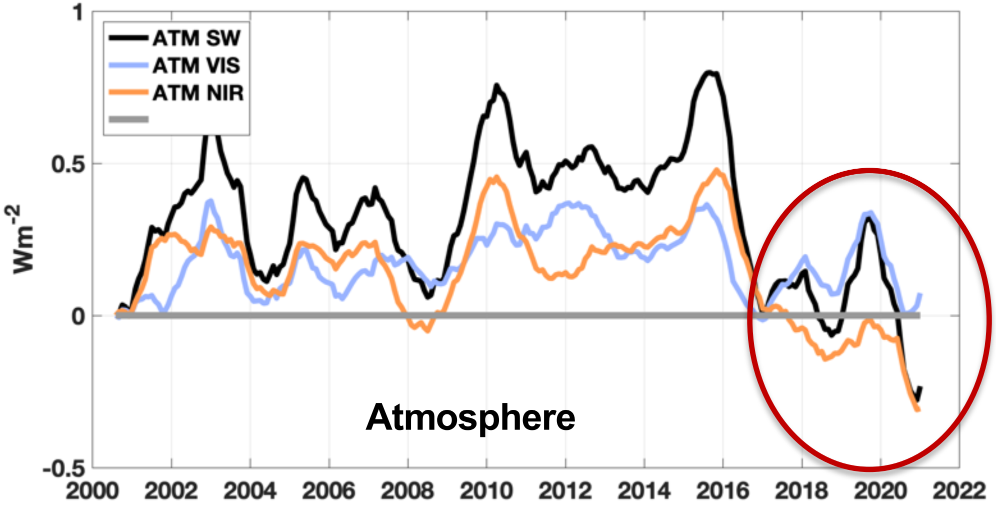


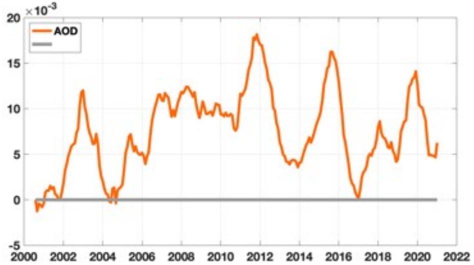




- Change and var in Surface absorption dominates; NIR more dominant
- Atmospheric absorption:
  - contributes significantly to TOA (2010-2016); NIR dominates var in ATM
  - Drop below 2000 levels after 2017 explains drop in total ASR

CERES SYN – NIR, VIS, SW time evolution in absorption





- NIR tracks water vapor changes (R=0.6) – until 2017
- VIS tracks AOD (R=0.8)
- CF increase since 2017 inhibits WV absorption in NIR?

CCS workshop on *Earth's Energy Imbalance*

- Motivated by insight gained during and since

WCRP workshop
"The Earth's Energy Imbalance and its implications"
13 – 16 November 2018, Toulouse, France

- Since then: "EEI form the ocean perspective", accelerometry concept for direct measurement – "Space Balls", participation in Libera.
- Why a workshop at JPL?
  - Planned to occur 2 years ago
  - Inform JPL on the various aspects of EEI research and identify existing and future EEI related research across disciplines.
  - Vast ocean community at JPL (ECCO, altimetry, gravimetry).
  - **Raise awareness that EEI research ought to be an area of focus for JPL/NASA.**

CCS workshop on *Earth's Energy Imbalance & Planetary Heat Uptake*

Organizers: Maria Hakuba & Felix Landerer

JPL 180-101, February 14 - 15, 2023

Motivation

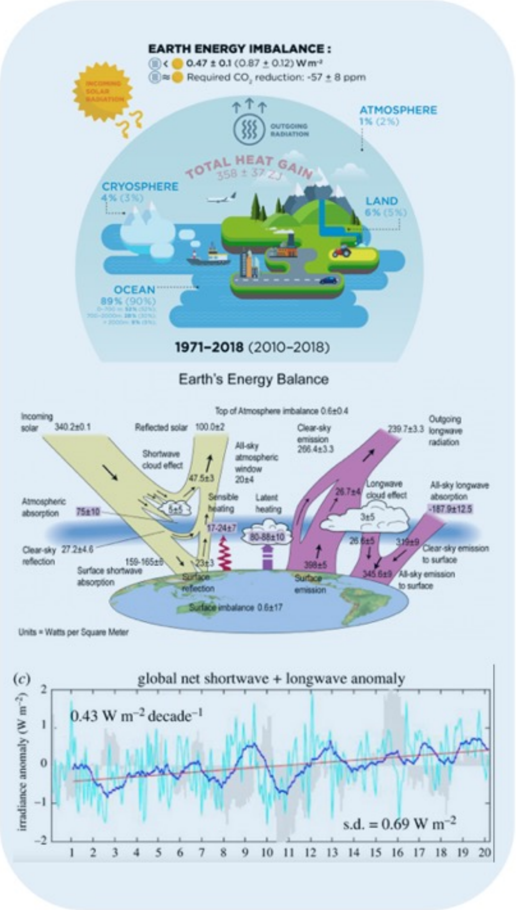
1) EEI is robust and comprehensive measure of global heating rate; indispensable for **informing public and decision-makers.**
2) EEI research and observation not a **core competence** of JPL.
3) Critical scientific & observational **gaps** can be addressed **from space**.

Objectives

1) **Convey** urgent need for Earth Energy imbalance (EEI) monitoring, assessment and understanding.
2) **Strengthen** JPL's **contribution to** EEI assessments.
3) **Identify** assets to advance the quantification, monitoring, and understanding of EEI.
4) Foster discussions on **research and mission opportunities**, including DS ESAS.
5) Contribute toward comprehensive NASA **climate communication.**
6) Foster **collaboration** across JPL and the national and international communities.

Participants

External: G. Schmidt (NASA GISS), P. Pilewskie (LASP), K. von Schuckmann (Meractor Ocean), T. Mauritsen (Univ. Stockholm), S. P. Raghuraman (NCAR), M. Rugenstein (CSU), M. Mayer (ECMWF), F. J. Cuesta-Valero (UFZ), F. Straneo (SIO), T. Boyer (NOAA), G. Johnson (PMEL)
NASA HQ: David Considine & Nadya Vinogradova Shiffer
Internal: 32, 33, 34, 38, 8x



Topics covered

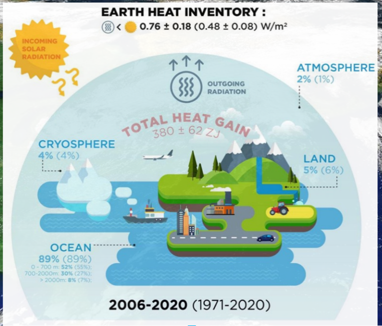
- Importance of **EEI in model** prediction
- Space **radiometric challenge** of measuring EEI
- **Future** EEI mission concepts
- Variability and forced **change** in EEI
- **Spectral** radiation budget missions
- EEI estimates via **heat inventory** method across Earth system components:
  - Land and sea ice melt
  - Ocean heat from in-situ, satellite & models
  - Continental heat storage
  - Atmospheric heat content & divergence
- Carbon and water cycle overviews to spur discussion on **cycle interaction** investigations.

Preliminary Recommendations

- **Integrated EEI & energy flux assessments** across climate system components and **across scales** to quantify EEI globally and understand processes regionally/temporally.
- **Direct EEI measurement from space** is radiometrically impossible at required accuracy? Future concepts (e.g., accelerometry) needed to fill this critical gap.
- **Interpreting change** in EEI requires integration of observation, modeling and spectral fingerprinting.
- **Emerging misfits** across systems (e.g., sea level budget closure; radiation in models vs. observations) & **emerging accelerations** in change (e.g., ocean heat, sea ice melt, water storage) need to be addressed.
- JPL's (indirect) **contributions** (as predominantly data provider) to heat inventory assessments are various, but need to be **streamlined & strengthened**.

Earth's Energy Imbalance (EEI)

Earth's current heating rate= + 0.6 – 1 Wm^{-2}



Implications: EEI manifests as heat content change in ocean (89%), land (5%), ice melt (4%) and atmospheric heating (2%).

Causes: forcings + feedbacks

aerosol clouds
GHG water vapor …
land use albedo

CCS workshop

February 14+15, 2023

Motivation:

1. Urgency for EEI monitoring to inform the public and decision-makers.

2. Critical gaps exist & fillable from space.

3. EEI is not (yet) a **core competence** of JPL

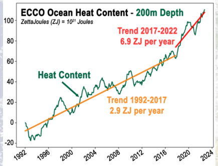
Objectives:

1) **Strengthen** JPL's **contribution** to EEI assessments.
2) **Identify** assets to advance the monitoring and understanding of EEI.
3) Foster discussions on **research and mission opportunities** (DS ESAS).
4) Contribute toward comprehensive NASA **climate communication.**
5) Foster **collaboration** across the international community.

EEI assessments at JPL

JASON-3 – GRACE FOLLOW-ON

Ocean heat content change ≈ Total sea level – ocean mass change



Radiation Budget missions

Will seamlessly continue the CERES record & contribute to understanding change in Earth's radiation budget.

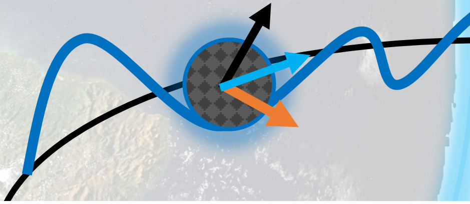
Improve understanding of the role of mineral dust in radiative forcing.

Will document, for the first time, variability in Far-infrared radiation on multiple timescales.

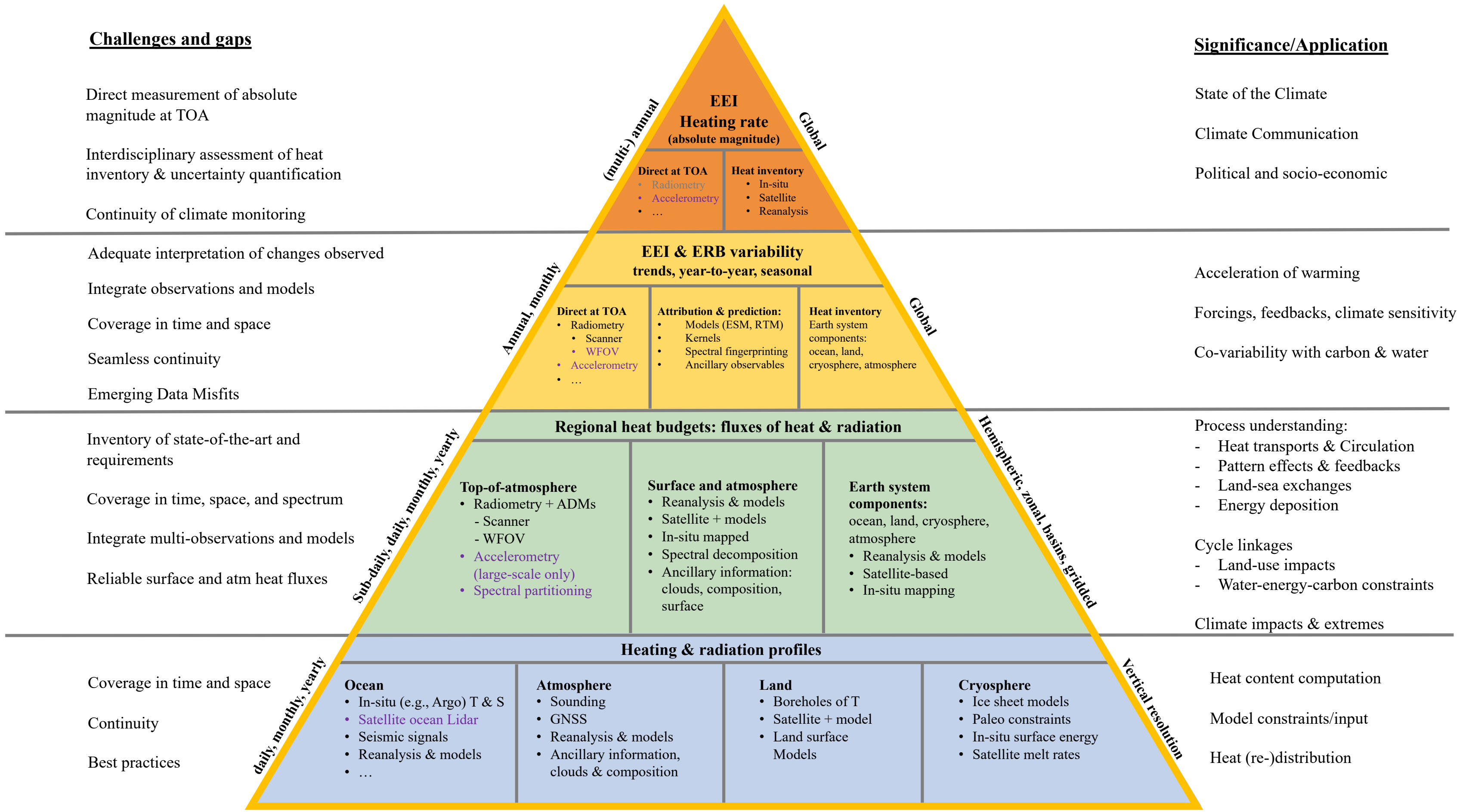
Novel mission concept

Filling a critical observation gap: *Ancient-novel* mission concept to measure EEI directly from space via radiation pressure accelerations.

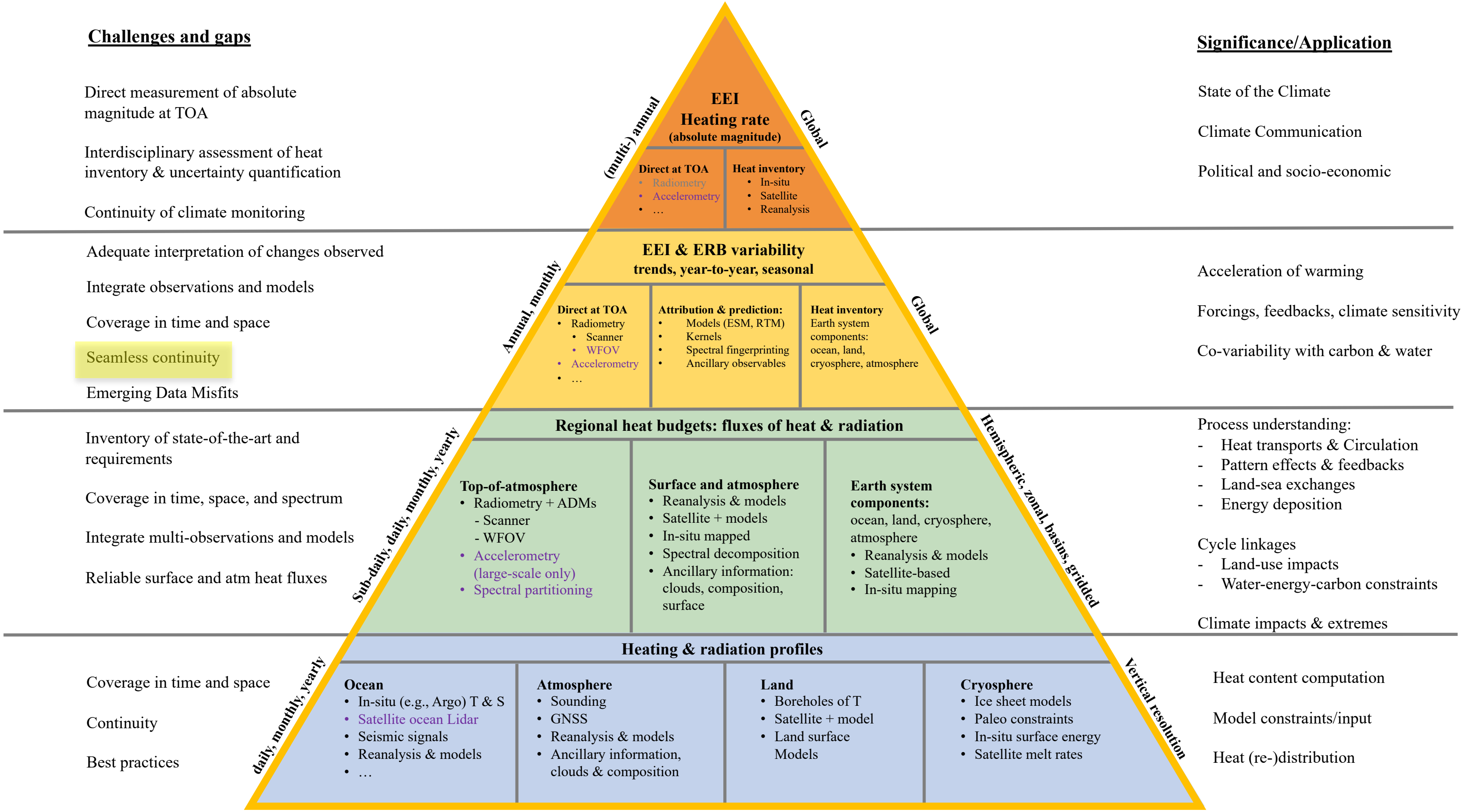
- A near-spherical low-drag S/C that is highly sensitive to radiation pressure from both Sun and Earth (*Space Balls*).



Hitchhiker's pyramid to Earth's Energy System



Hitchhiker’s pyramid to Earth’s Energy System

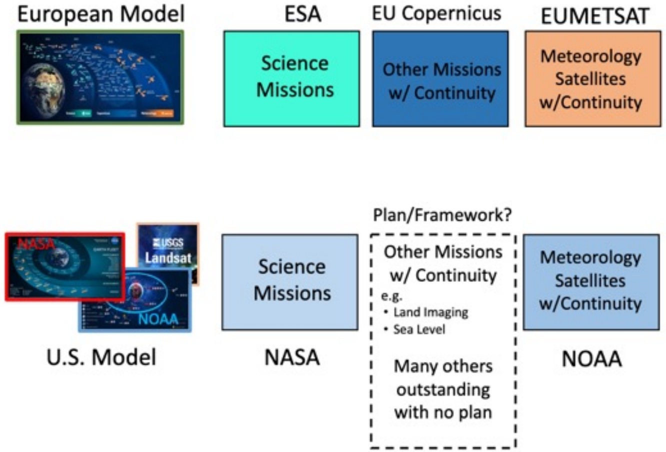


Climate obs. Continuity in the U.S.

Ensure continuity of ERB observations through sustained commitment

KISS Continuity Study Team, <u>Towards a U.S. Framework for Continuity of Satellite Observations of Earth's Climate and for Supporting Societal Resilience</u>, ***Earth's Future***, American Geophysical Union, **Submitted on 4/25/2023**

Considerations & Approaches for Sustained Satellite Observing Systems to Support Climate Science & Societal Resilience

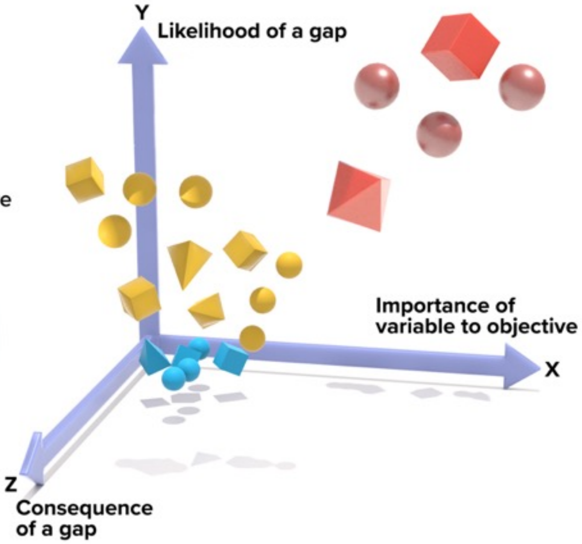


Finding 1.4: The U.S. does not have a systematic, overarching plan or framework for identifying, prioritizing, funding, and implementing additional sustained Earth observations that are critical to supporting our nation's science, policy, and societal resilience goals.

Thank you

Prioritizing Earth observations

Ensure continuity of climate observations through sustained commitment



European Geosciences Union

Atmospheric Measurement Techniques

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Status: this preprint is currently under review for the journal AMT.

Angular Sampling of a Monochromatic, Wide-Field-of-View Camera to Augment Next-Generation Earth Radiation Budget Satellite Observations

Jake J. Gristey, K. Sebastian Schmidt, Hong Chen, Daniel R. Feldman, Bruce C. Kindel, Joshua Mauss, Mathew van den Heever, Maria Z. Hakuba, and Peter Pilewskie

Abstract. Earth radiation budget (ERB) satellite observations require conversion of the measured radiance, which is a remotely-

Short summary

The concept of a satellite-based camera is demonstrated for sampling the angular distribution of...

- Read more

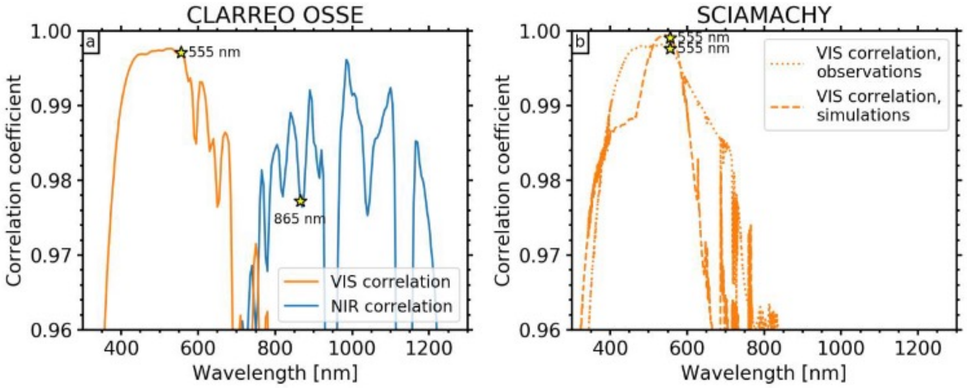
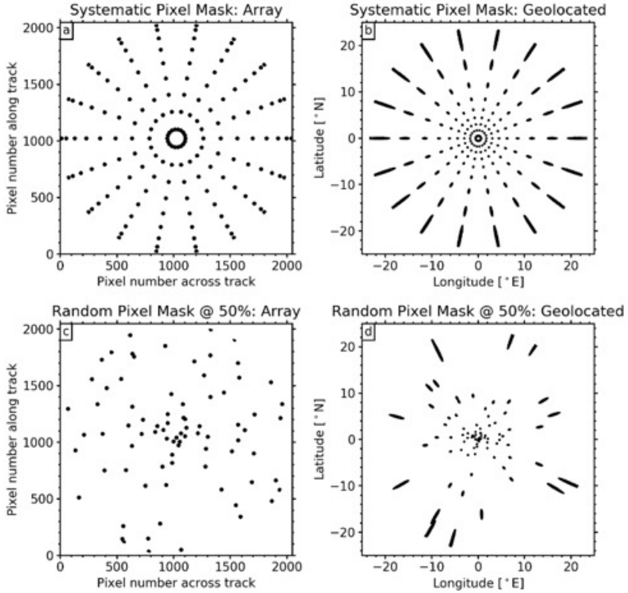


Figure 5. Pearson correlation coefficient between TOA spectral radiances and the VIS (orange) and NIR (blue) sub-band radiances for (a) all scenes in the CLARREO OSSE and (b) SCIAMACHY observations and SCIAMACHY-like simulations. Star symbols highlight the wavelengths of focus: 555 nm and 865 nm. Correlations extend beyond the given vertical axis range, but only the highest correlations are shown. Note that the NIR sub-band correlation is not shown for SCIAMACHY because of spectrally-incomplete data in the NIR.



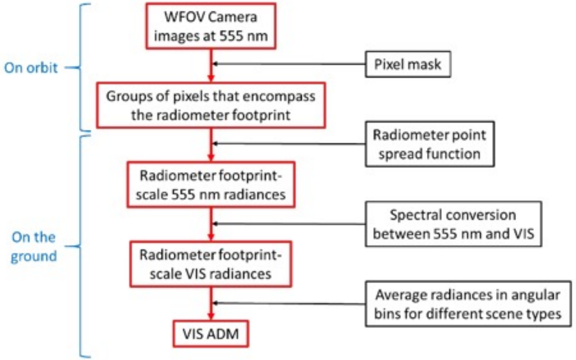


Figure 1. Flow diagram providing a broad overview of the processing steps required to go from WFOV camera images at a single mid-visible wavelength to a VIS sub-band ADM.

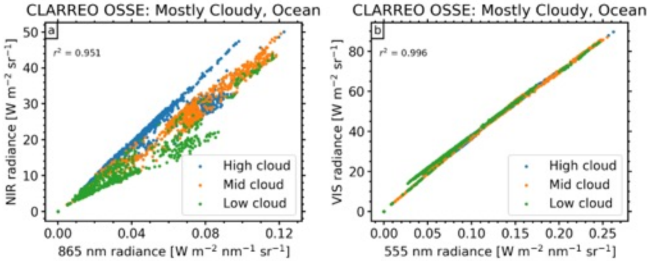


Figure 7. Relationship between nadir radiance at (a) 865 nm and the NIR sub-band, and (b) 555 nm and the VIS sub-band for mostly cloudy over ocean scenes in the CLARREO OSSE. Data points are colored as high cloud (blue), mid-level cloud (orange), or low cloud (green), defined using the International Satellite Cloud Climatology Project (ISCCP) cloud top pressure boundaries.