Future Observations of Earth's Radiation budget and the science they enable

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2022 Sun Climate Symposium, May 19, 2022

LASP

Jet Propulsion Laboratory
California Institute of Technology

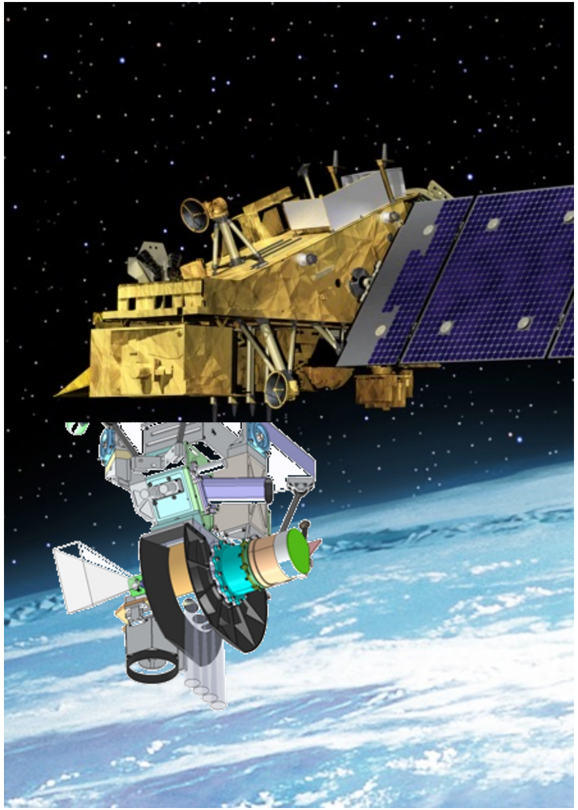
Outline

- Libera science overview
- Libera's sub-band shortwave measurement
- *Space Ball* concept overview
- *Space Ball* feasibility simulations

Like mother (CERES), like daughter (Libera)

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

Overarching Science Goals



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

- Measurement of TOT, SW and LW with same characteristics as CERES to prevent gap in ERB Climate data record.

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

- Wide field-of-view camera for Scene ID and split-SW ADM development.

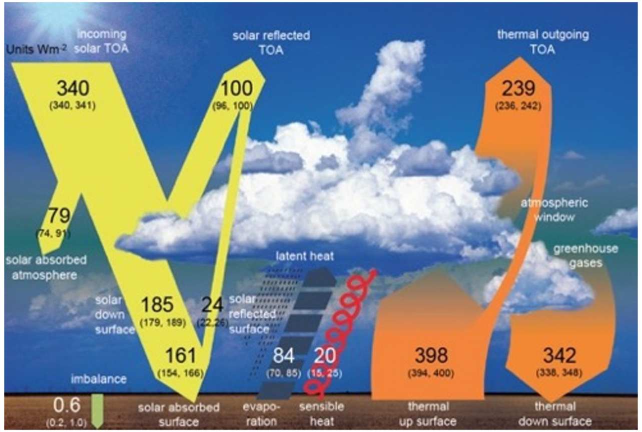
OG3: Provide new and enhanced capabilities that support extending ERB science goals.

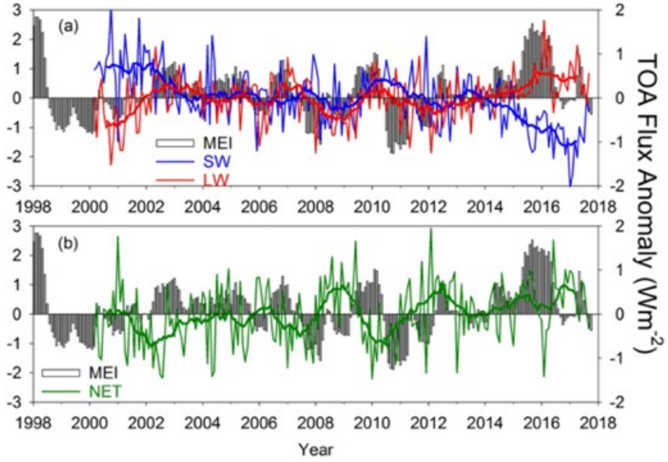
- **Additional split-SW channel to derive shortwave near-IR and visible irradiance.**

Benefits of continuity

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

- What will the *unprecedented* >1.5°C future bring?
- Trend vs. internal variability
- Time-evolving temperature patterns impact global mean ERB
- Constraining climate models, forcing and feedback





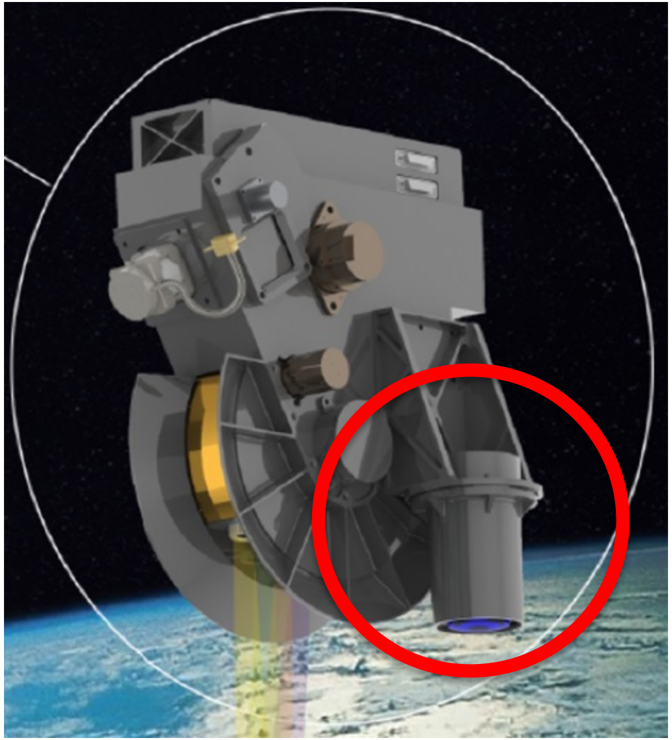
ADMs & camera application

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

Demonstrate feasibility of separating Libera from complex imagers so to fly on SmallSats

Science objective 2:

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

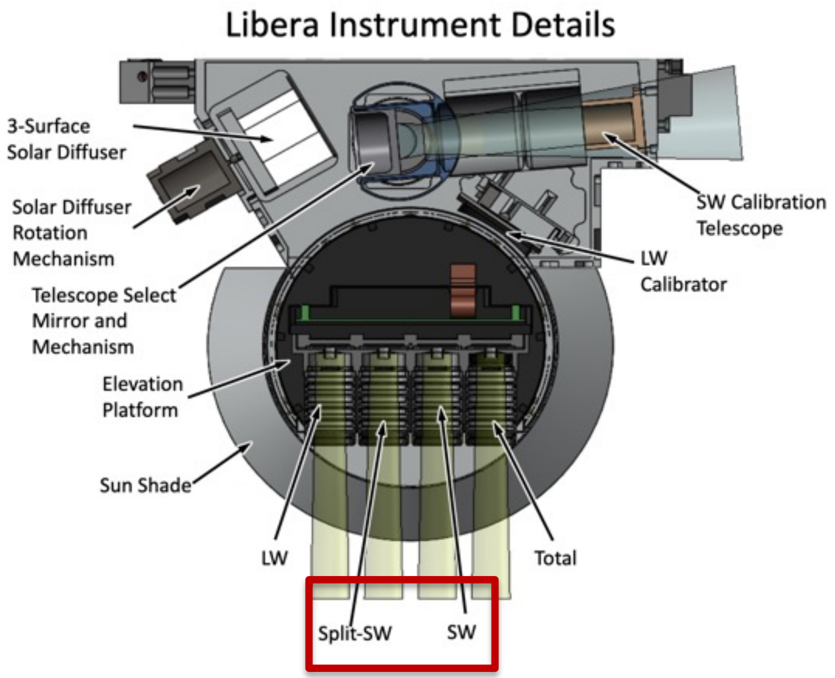


Monochromatic (555 nm) wide field of view (WFOV) camera provides images at ~1 km pixel resolution.

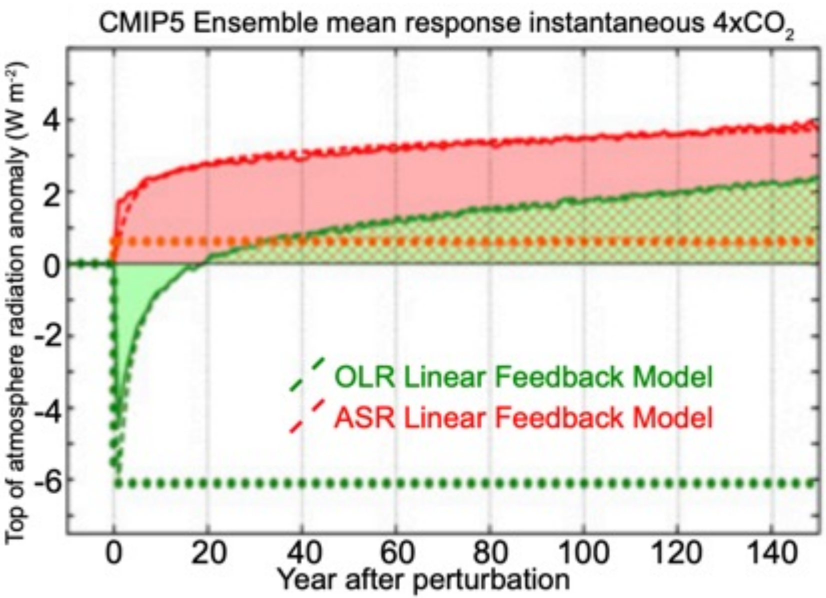
Libera's shortwave sub-band measurement

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

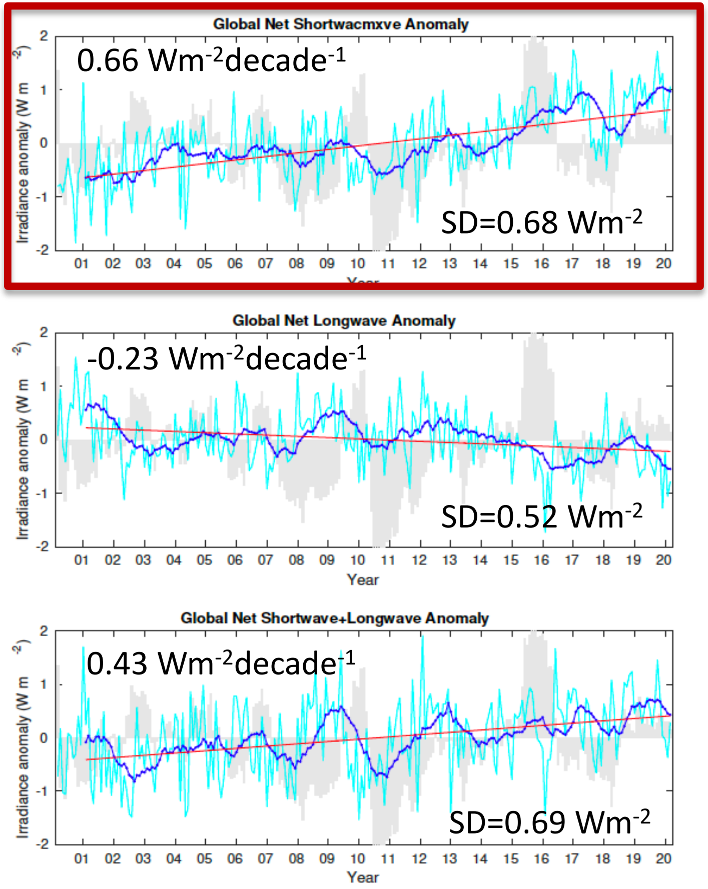
- Libera's fourth channel measures VIS at the same accuracy as the total SW radiance (0.17%)
- Retrieval of VIS, NIR, SW irradiance at TOA and surface:
  - VIS at 0.3-0.7 µm
  - SW at 0.3-5 µm
  - Conversion to VIS irradiance using WFOV camera radiances at 555nm **(J. Gristey, S. Schmidt)**
  - NIR = SW - VIS
- **Goals:**
  - **NIR & VIS signatures of processes that control the absorption of solar radiation & SW climate feedbacks.**
  - **Better understand the hemispheric symmetry of planetary albedo.**
  - **Quasi-spectral model evaluation to reveal process-related biases**



Motivation: Absorption of solar radiation warms our planet



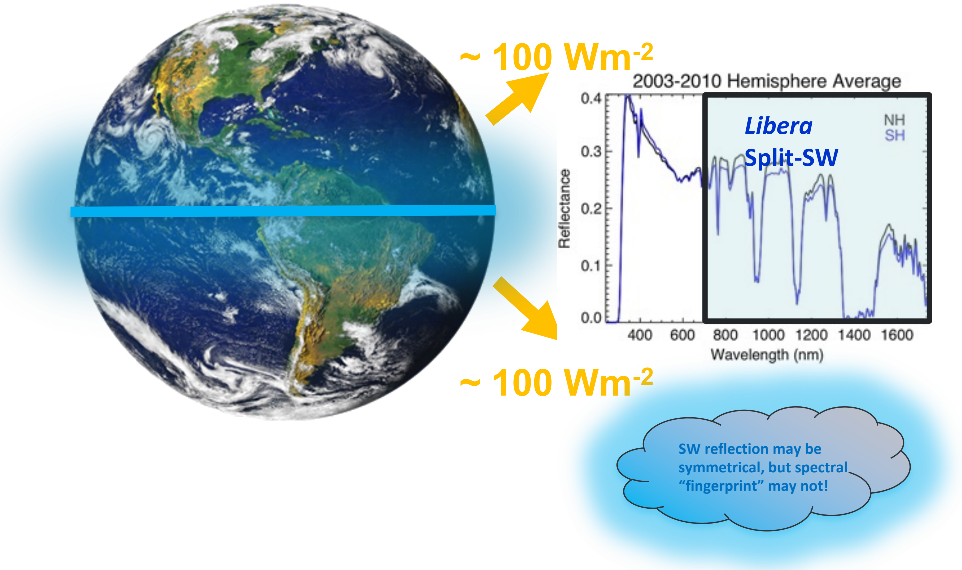
(Donohoe et al., 2014).



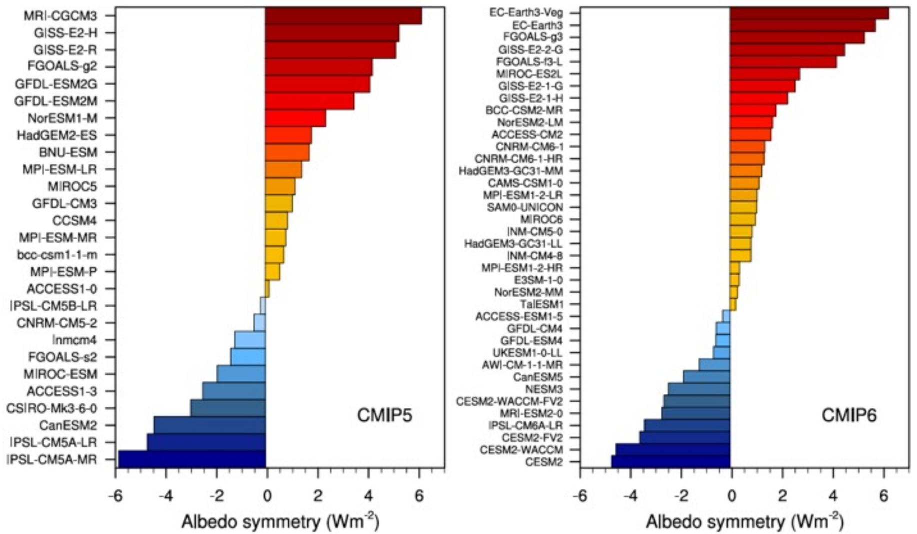
Stephens et al., accepted

Climate model simulations under different future scenarios suggest global warming on decadal to centennial time scales is largely sustained by shortwave absorption (positive climate feedbacks).

Motivation: Hemispheric albedo symmetry



Rugenstein & Hakuba, in prep

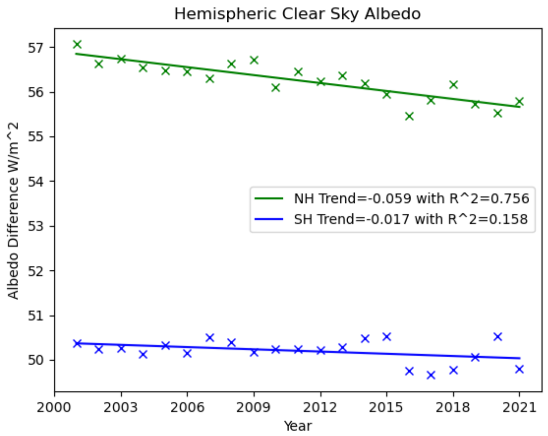


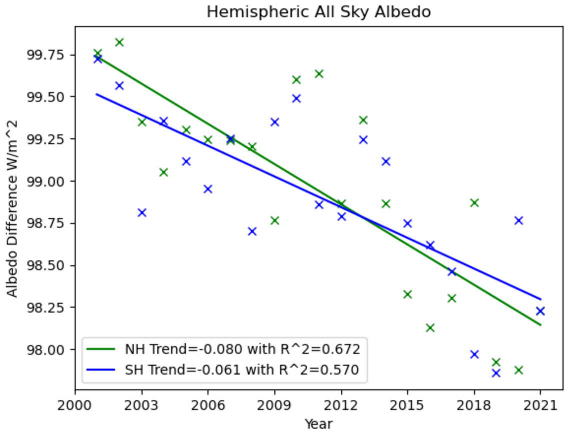
- Average and decreasing trends in albedo are symmetric across hemispheres
- Surface albedo asymmetry compensated by cloud asymmetry over extra-tropics, SH storm-tracks are 10% cloudier

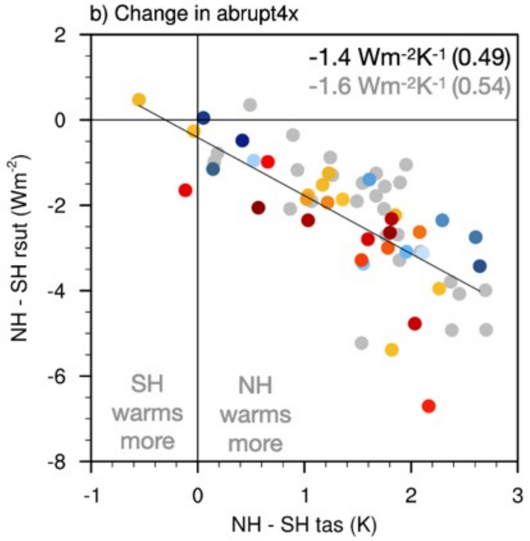
- 30% of models are symmetric within ± 1 Wm^{-2}
- 70 (80)% of models are symmetric within ± 4 Wm^{-2}. (An asymmetry of 4 Wm^{-2} in the hemispheric energy budget would imply 3 times more heat transport across equator!)

Evolution of hemispheric albedo symmetry

- CMIP models suggest hemispheric albedo is evolving to a-symmetry in response to asymmetric surface warming
- Observations indicate a positive trend in NH-SH clear-sky albedo of -0.4 Wm^{-2} /decade







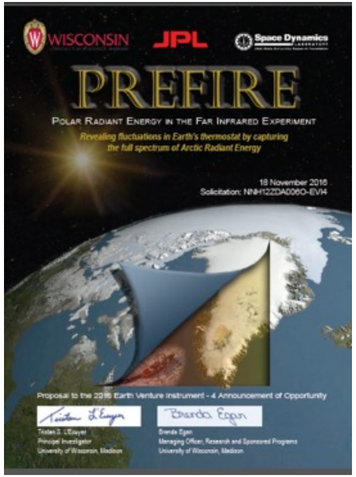
Matt Watwood

Rugenstein & Hakuba, in prep

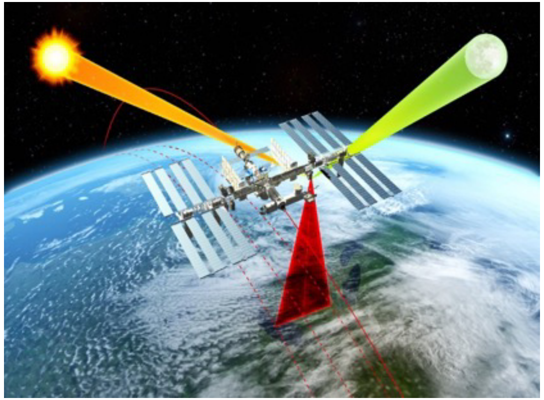
Motivation: The future is spectral

- Spectral signatures of the TOA fluxes reveal insights into processes that shape the ERB and changes to it
- Measurements are on the way:

Spectral OLR – 2022 (L'Ecuyer)



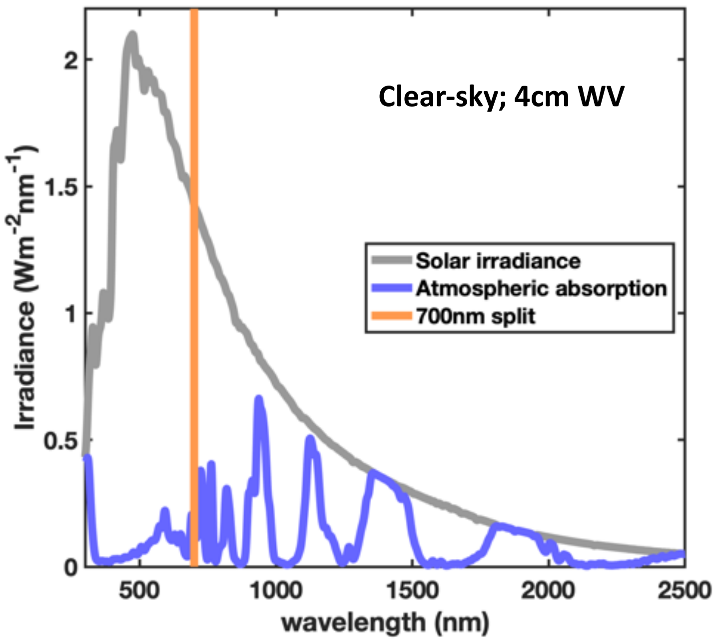
CLARREO-PF - 2022 spectral SW (Shea)

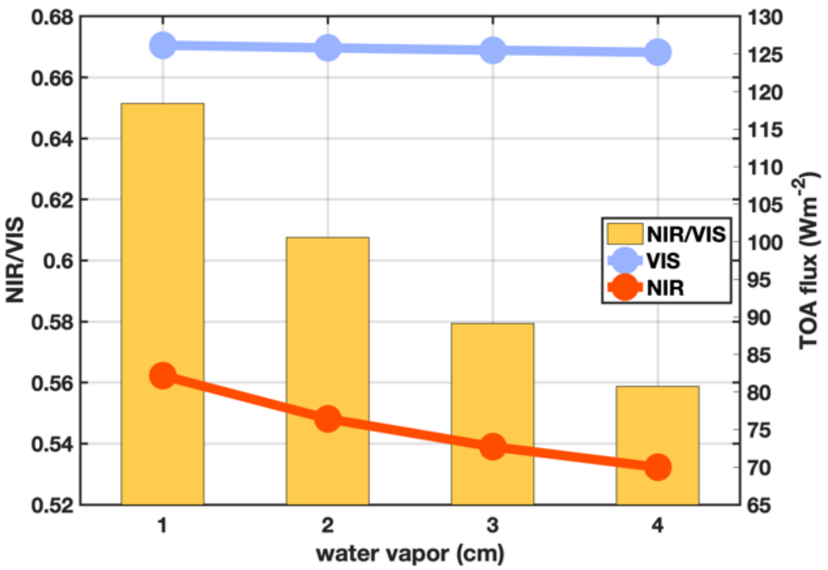


X-element linear array of absolute radiometers to enhance spatial & spectral resolution (Coddington)

Libera-FO?

Spectral nature of shortwave radiation (MODTRAN calc. by Bruce Kindel)

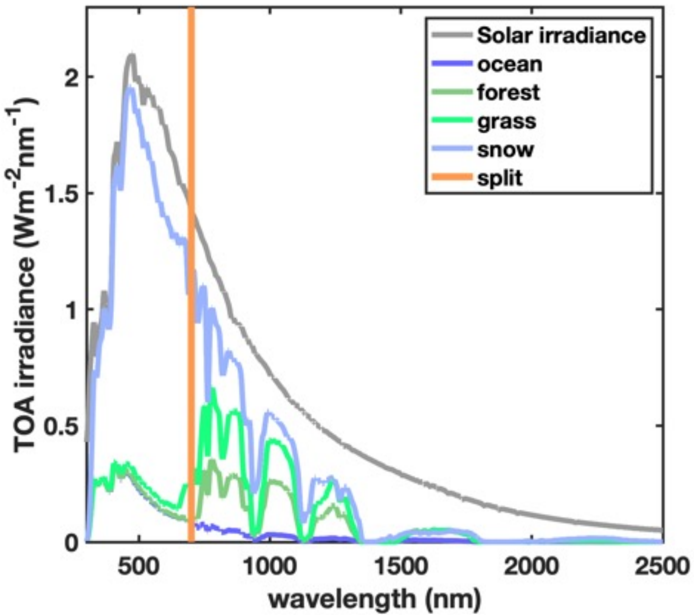


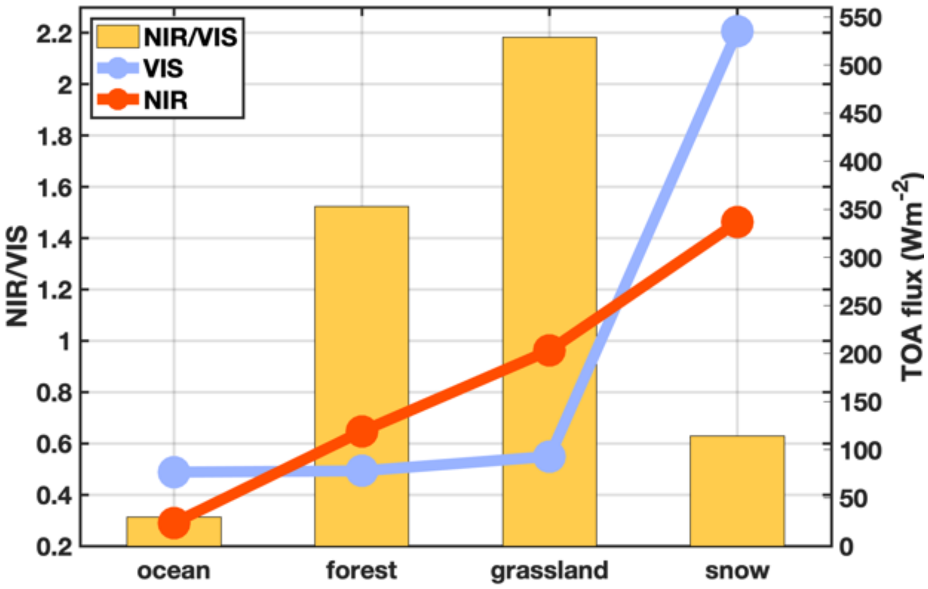


Water vapor absorption acts mostly in the NIR; ~6 Wm^{-2}/cm NIR absorption

C-C 7%/K ~ 0.2cm/K $\longrightarrow$ ~ 1 Wm^{-2} NIR absorption

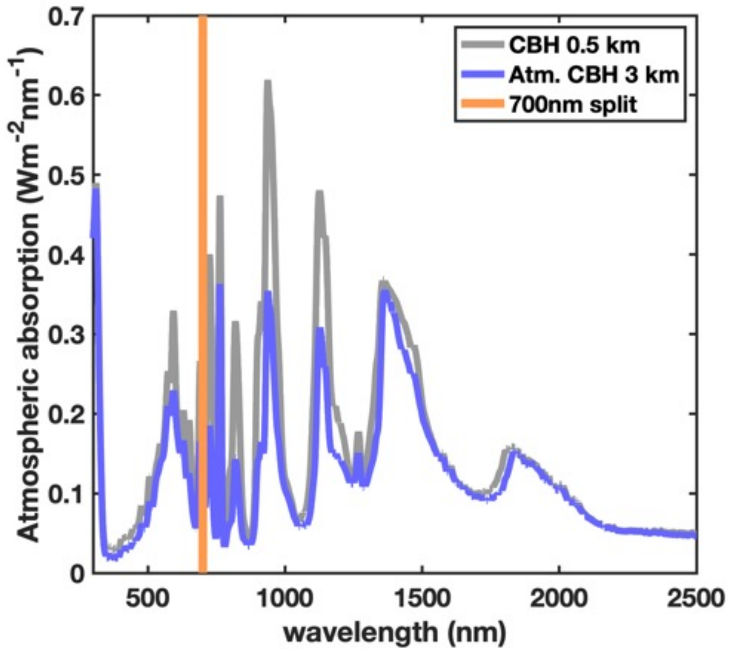
Spectral nature of shortwave radiation

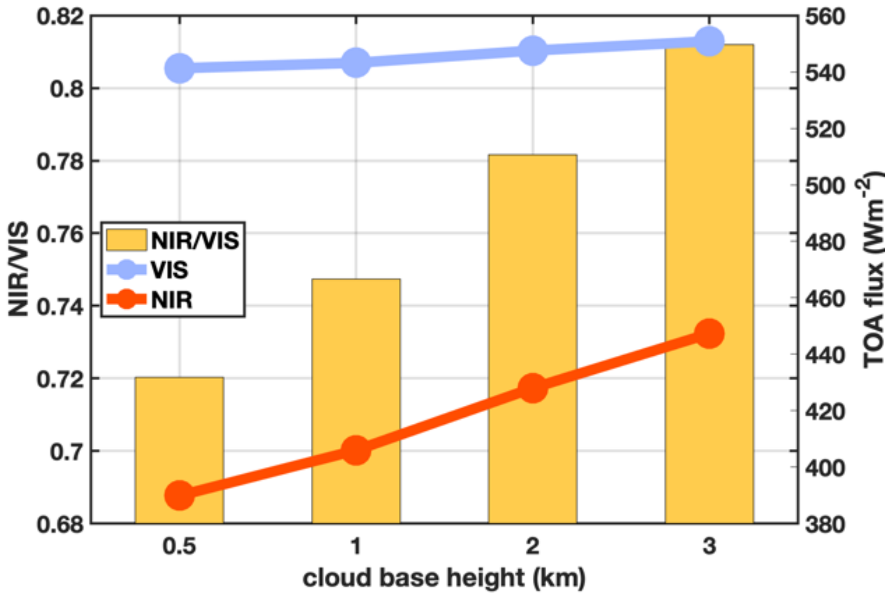




Different surface types associated with very different NIR/VIS ratios (~NDVI); Libera's NIR/VIS may help track land cover change and impact on ERB

Spectral nature of shortwave radiation





Cloud SW absorption is ~15 % of SW CRE (~47 Wm^{-2}) and subject to change; example shows impact of cloud base height, shifting the ratio in favor of NIR

Change in cloud height alone does impact albedo!?

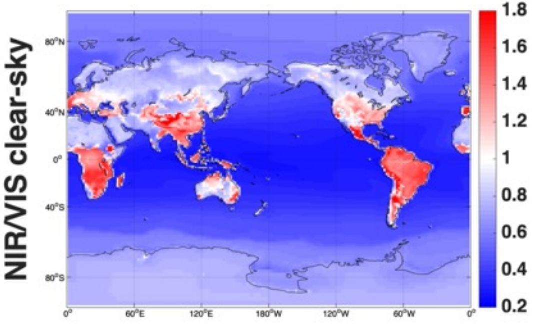
Outlook: Libera SW sub-band measurement

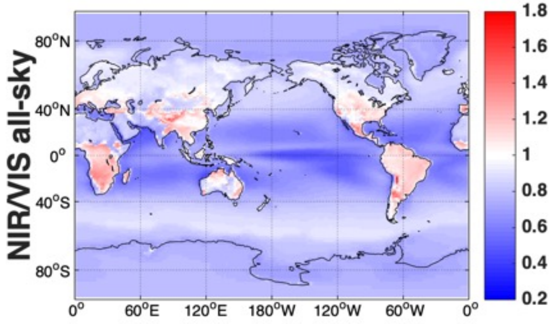
- Three idealized process examples indicate NIR is particularly sensitive to changes in climate relevant properties
- Set expectations for NIR/VIS of different processes and scene types
  - Calculations and ML
  - Set of ancillary information
- Improved knowledge of SW absorption processes and change therein can help understand bigger picture mysteries… or unveil more mystery…

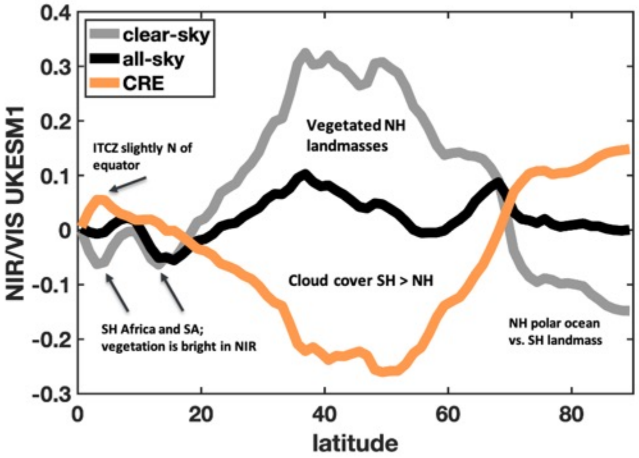
UKESM1 is symmetric in albedo and NIR/VIS (20y pi control)

All-sky	Glo	NH	SH
TOT SW	99.3	**99.1**	**99.6**
NIR	44.0	44.2	43.7
VIS	55.0	55.8	55.4
NIR/VIS	0.79	**0.80**	**0.78**

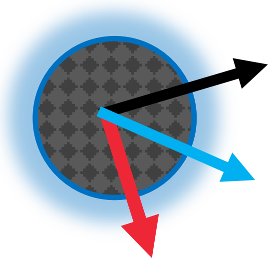
Clear-sky	Glo	NH	SH
TOT SW	54.4	57.4	51.4
NIR	20.2	22.3	18.2
VIS	34.2	35.1	33.2
NIR/VIS	0.59	**0.63**	**0.55**







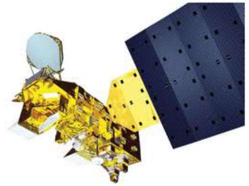
- Clear-sky hemispheric "land-sea contrast", NIR/VIS high over land
- CRE increase NIR/VIS especially over SH ocean
- CRE diffuse spatial gradients in NIR/VIS
- **Clouds not only balance mean albedo and trend across hemispheres but also NIR/VIS ratio**



Space Balls

Direct measurement of the net radiative flux (EEI) at TOA

EEI = Global mean Net radiative flux at TOA



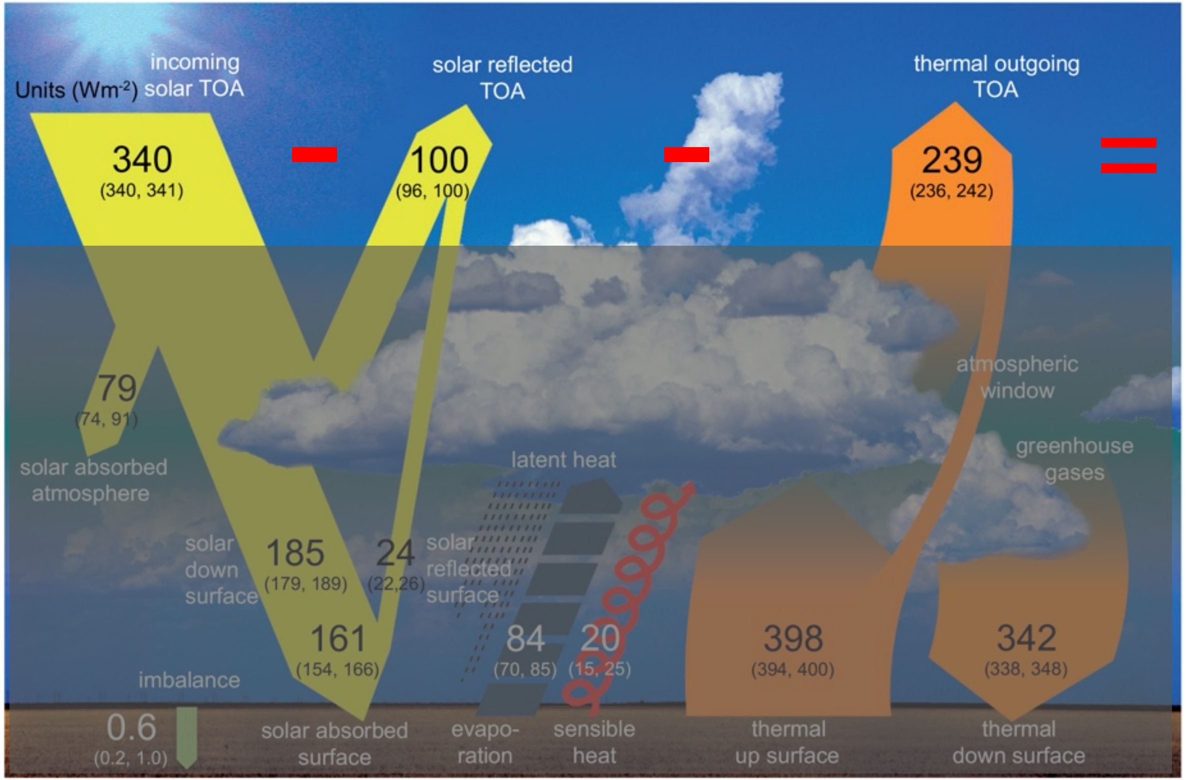
CERES EBAF & Libera

Clouds and Earth's Radiant Energy System

SORCE & TSIS

Solar Radiation and Climate Experiment

Total and Spectral *Solar* Irradiance Sensor



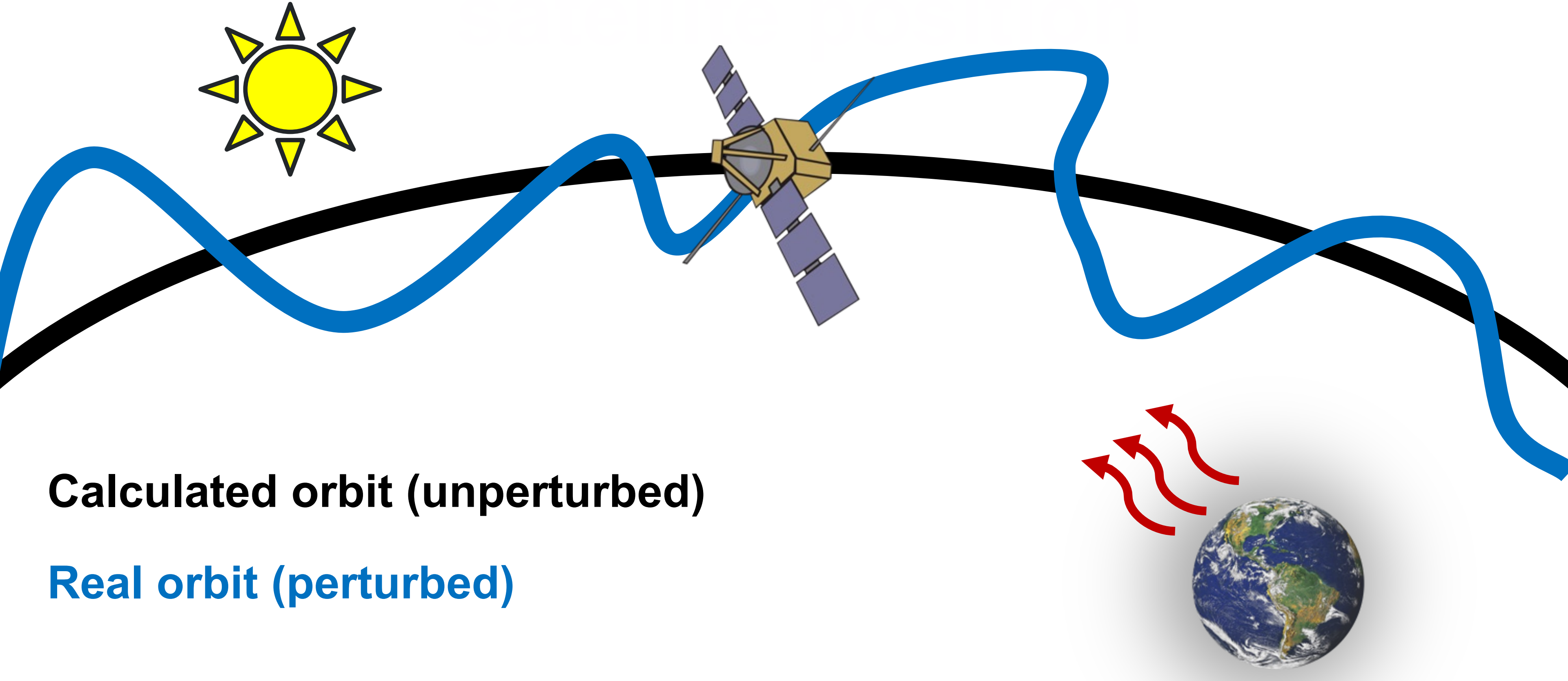
Updated from IPCC AR5 / Wild et al. 2013, 2015 Climate Dynamics

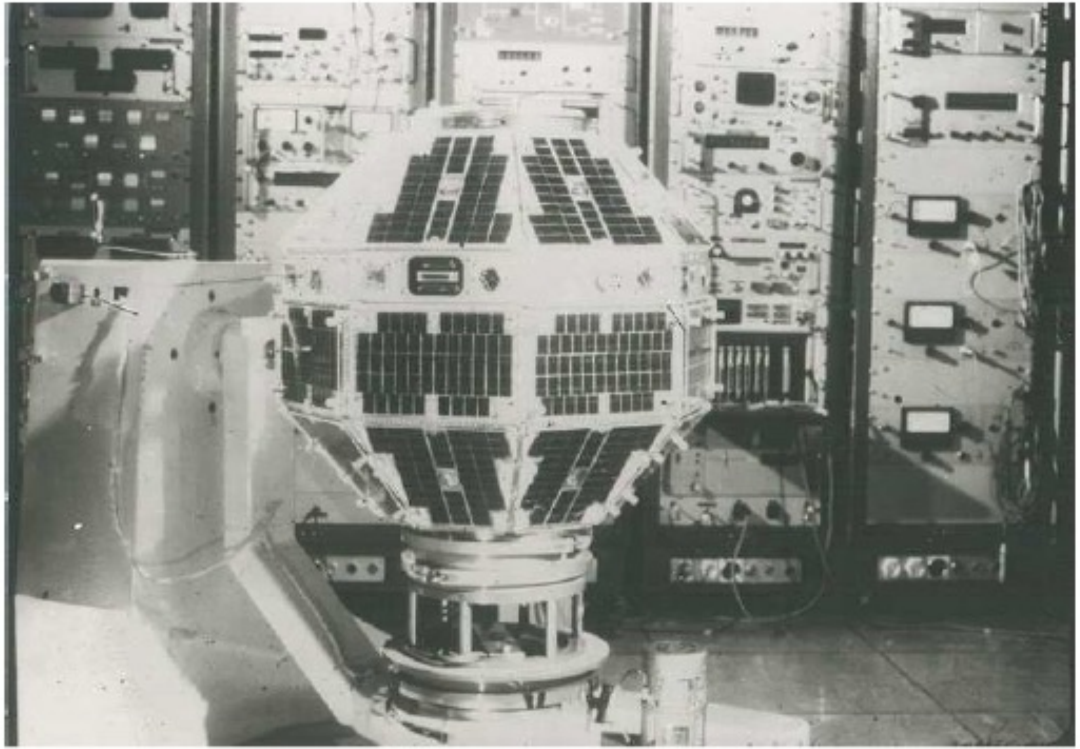
~0.7 Wm^{-2}

(Johnson et al., 2016)

Spoiler: this number does not come from TOA radiation data, but from heat uptake assessments!

Radiation pressure affects satellite position

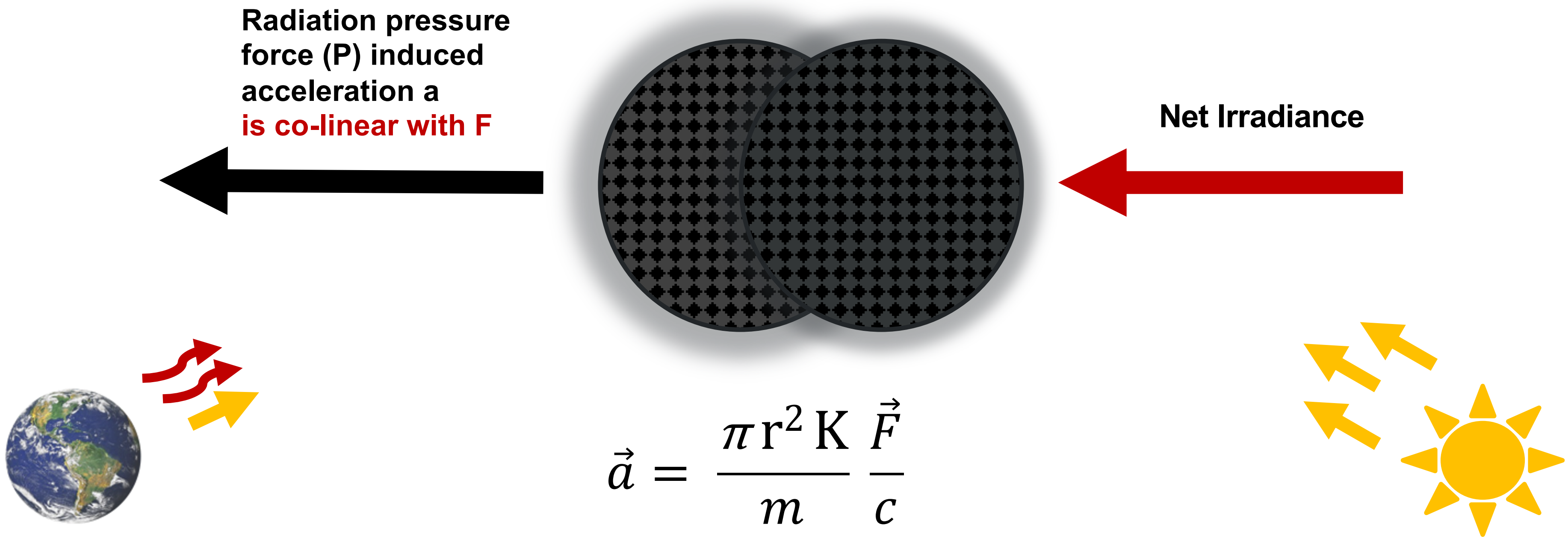




CASTOR D5B Satellite **CNES, 1975**

radius: 0.8 m, mass: 76 kg

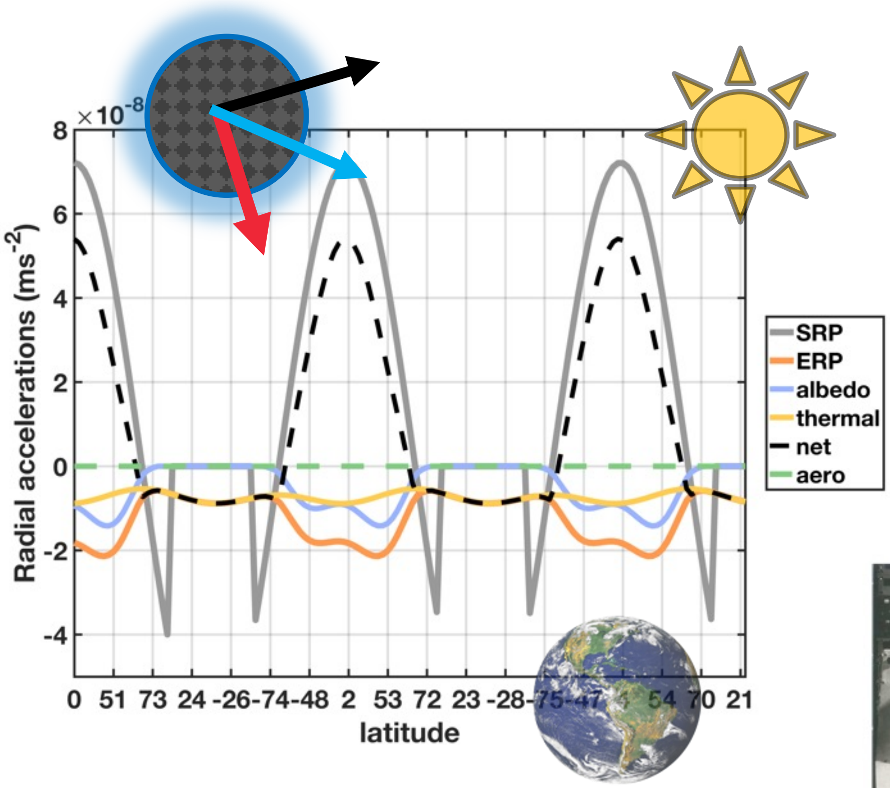
Simple relationship between net irradiance and induced acceleration if space craft is spherical and perfectly absorbing across Earth and Solar radiation



$$\vec{a} = \frac{\pi \mathrm{r}^2 \mathrm{K}}{m} \frac{\vec{F}}{c}$$

***Space Balls* Update** (~2-yr JPL R&TD project)

Earth's Energy Imbalance via radiation pressure accelerations



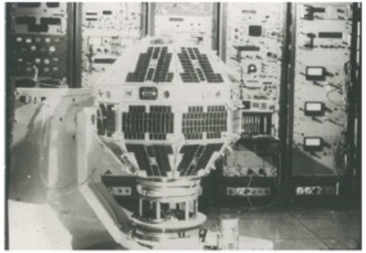
Is a high-accuracy measurement of Earth's Energy Imbalance (EEI) feasible via radiation pressure accelerations experienced in orbit?

Objectives:

1. Build SB simulation environment using mission design software Monte
2. Enhance fidelity of force and shape models
3. Study measurement errors due to S/C and orbit characteristics, and confounding forces
4. Explore different sampling strategies

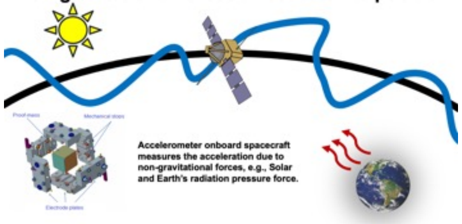
Theoretical Comparison Between Radiometric and Radiation Pressure Measurements for Determination of the Earth's Radiation Budget

T.H. Vonder Haar and E.A. Smith



CASTOR D5B Satellite

Non-gravitational forces affect satellite position

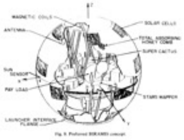


Potential European climatological satellite missions: SEOCS and BIRAMIS

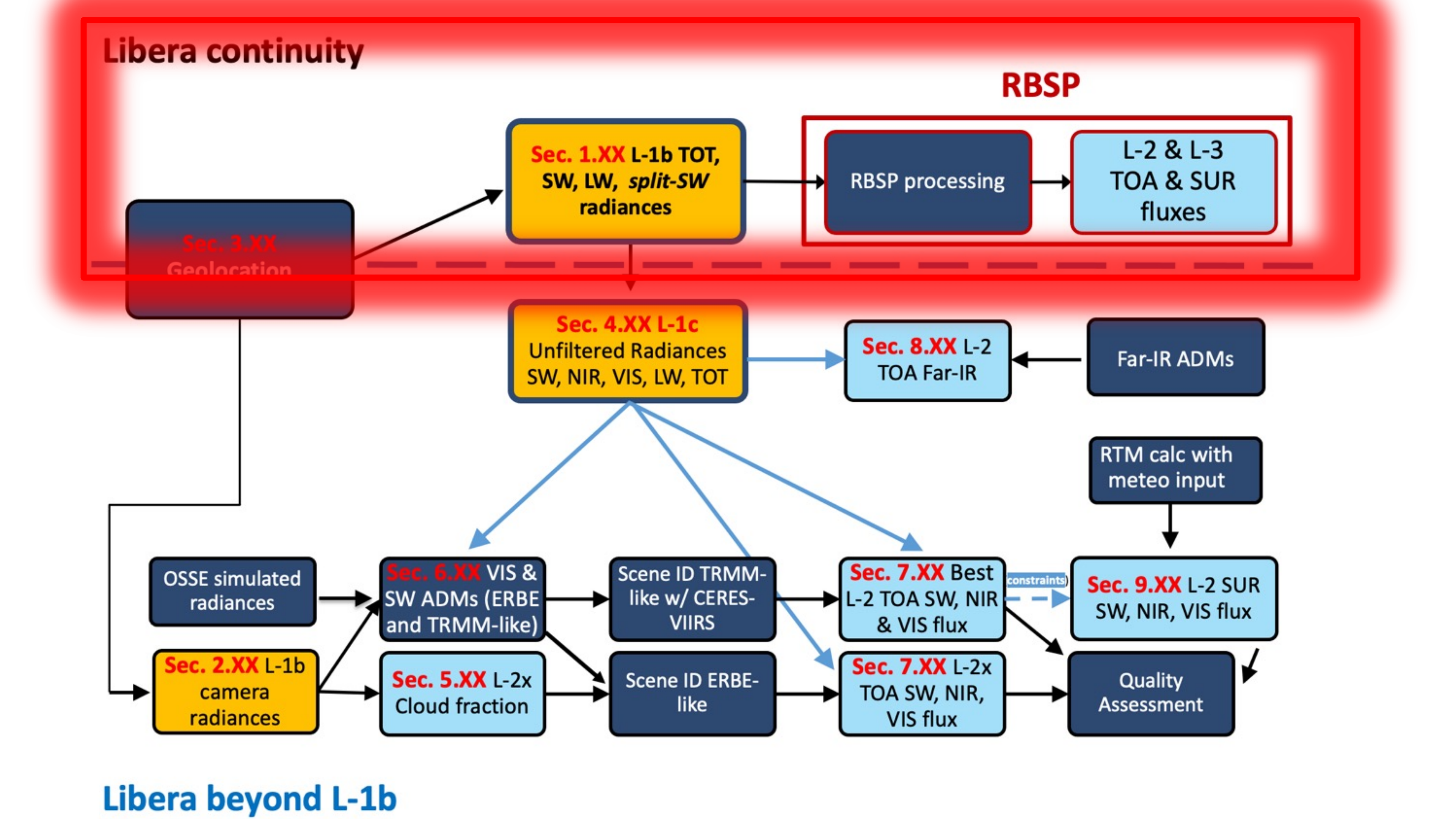
G. DUCHOSSOIS

Department of Application Programmes, Directorate of Planning and Future Programmes, Eu... Space Agency, 8 rue Mario Nikis, 75738, Paris Cedex 15, France

(Received 19 December 1979)

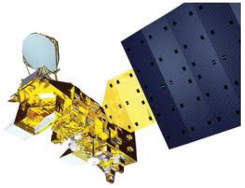


Thank you!



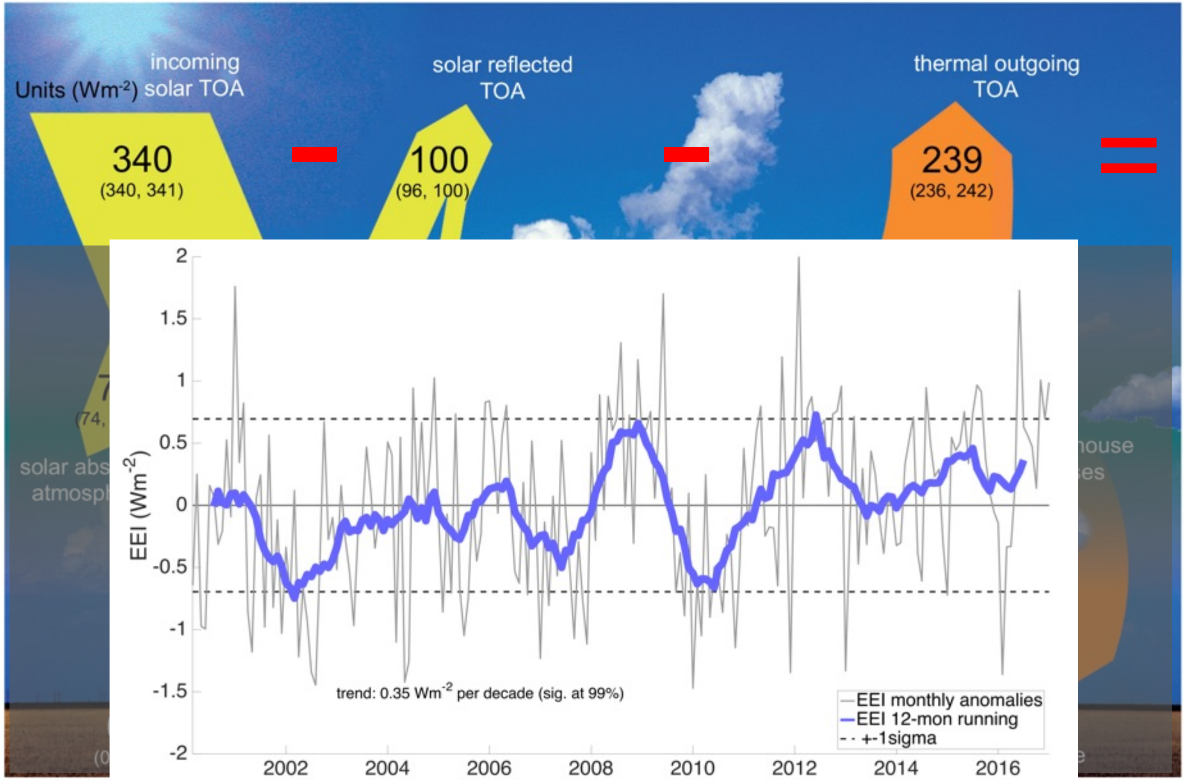
Libera continuity
RBSP
Sec. 1.XX L-1b TOT, SW, LW, split-SW radiances
RBSP processing
L-2 & L-3 TOA & SUR fluxes
Sec. 3.XX Geolocation
Sec. 4.XX L-1c Unfiltered Radiances SW, NIR, VIS, LW, TOT
Sec. 8.XX L-2 TOA Far-IR
Far-IR ADMs
RTM calc with meteo input
OSSE simulated radiances
Sec. 6.XX VIS & SW ADMs (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

EEI = radiative forcings – radiative feedbacks



CERES EBAF

SORCE & TSIS

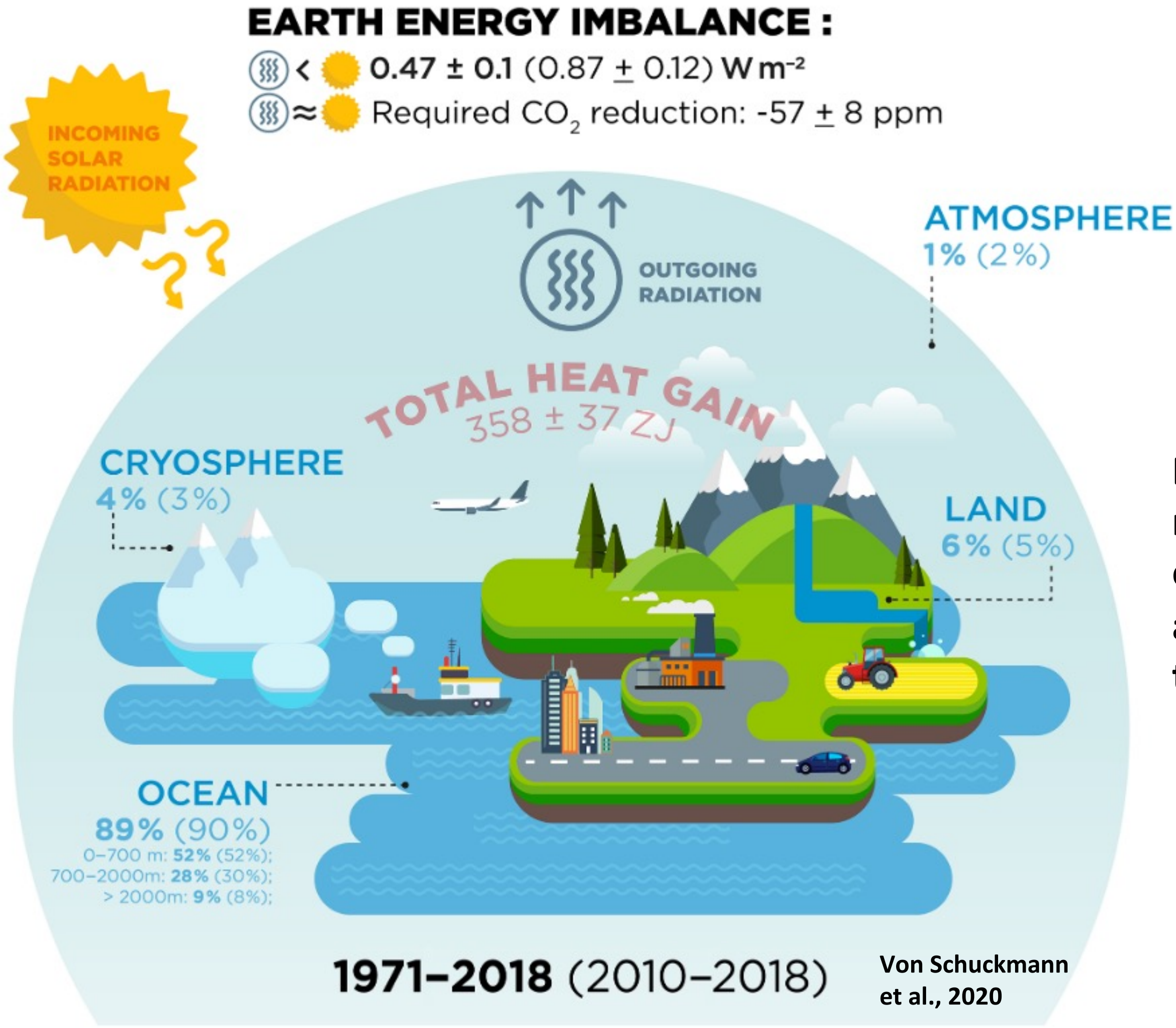


~0.7 Wm-2

global long-term mean 2005-2015

EEI variability reflects natural and anthropogenic radiative effects on multiple time scales

EEI = rate of global warming



Von Schuckmann et al., 2020

EEI = heat that melts ice, expands ocean, warms the atmosphere and the land

EARTH ENERGY IMBALANCE :

Geophysical Research Letters

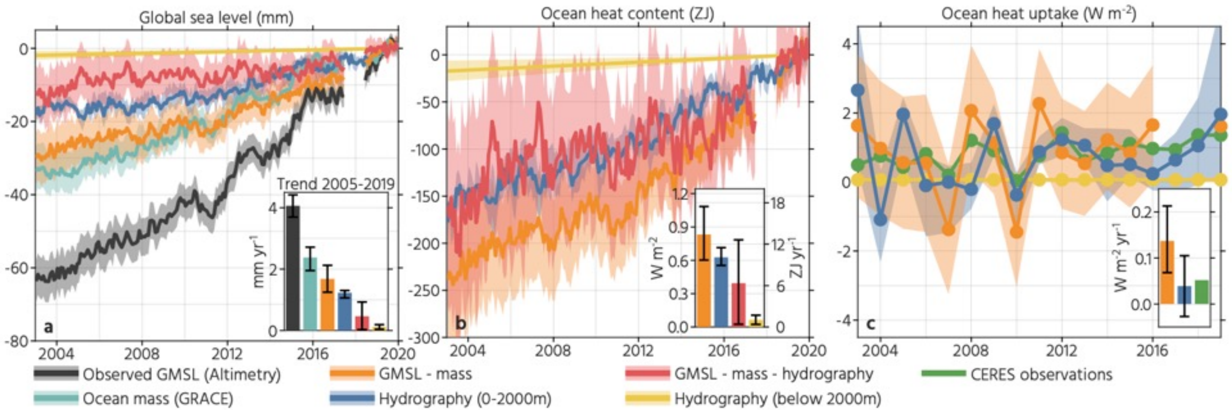
Research Letter

RE

Earth's Energy Imbalance From the Ocean Perspective (2005–2019)

M. Z. Hakuba, T. Frederikse, F. W. Landerer

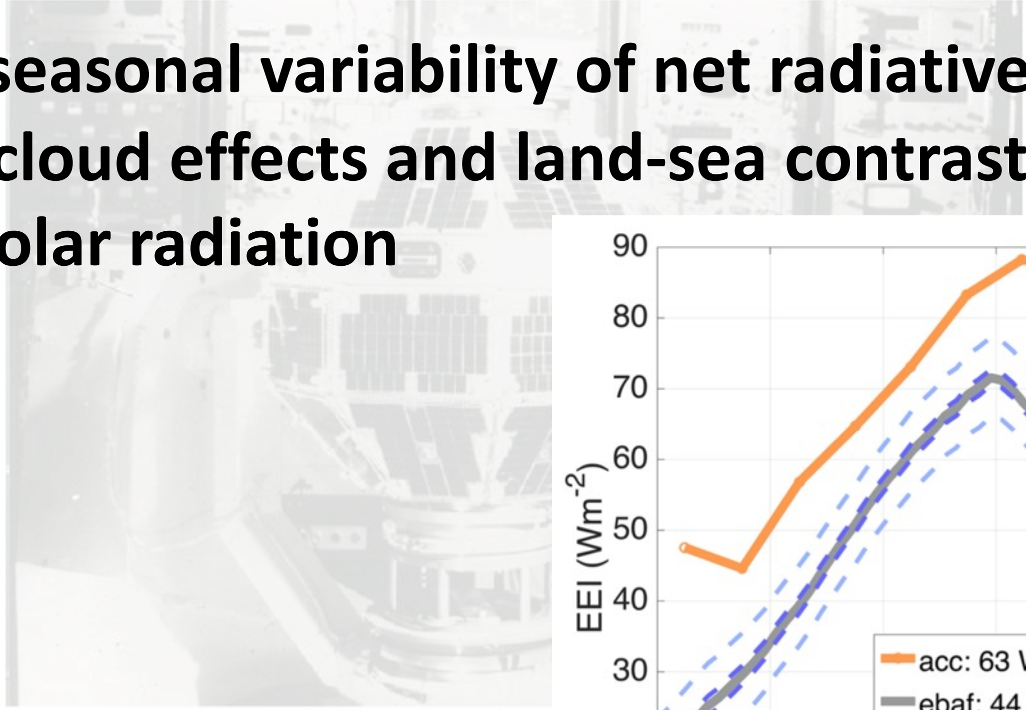
First published: 12 August 2021 | https://doi.org/10.1029/2021GL093624 | Citations: 1



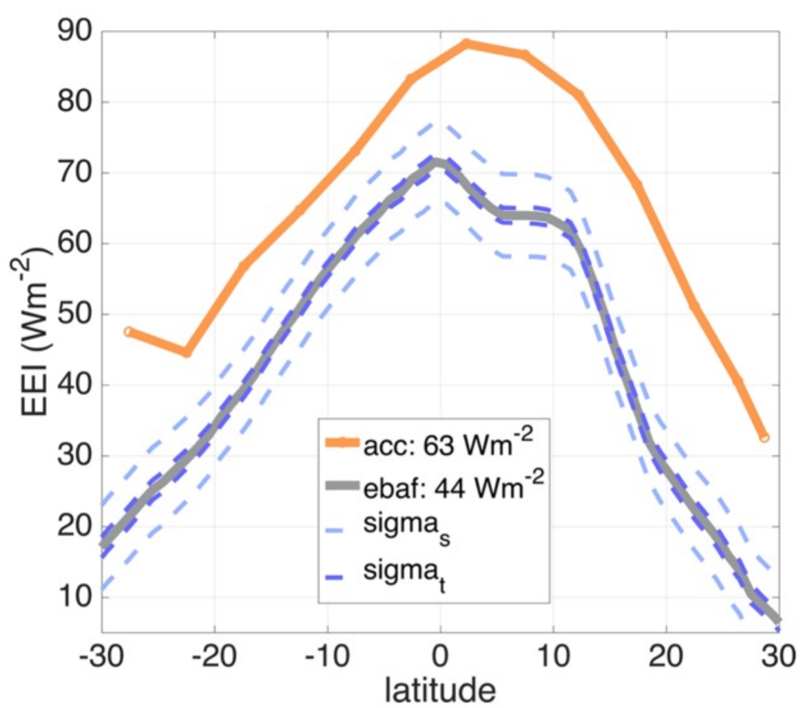
1971–2018 (2010–2018)

CACTUS analysis delivered

- Zonal and seasonal variability of net radiative flux
- Longwave cloud effects and land-sea contrasts
- Incoming solar radiation



CASTOR D5B Satellite



UKESM1 SW, NIR, and VIS fluxes

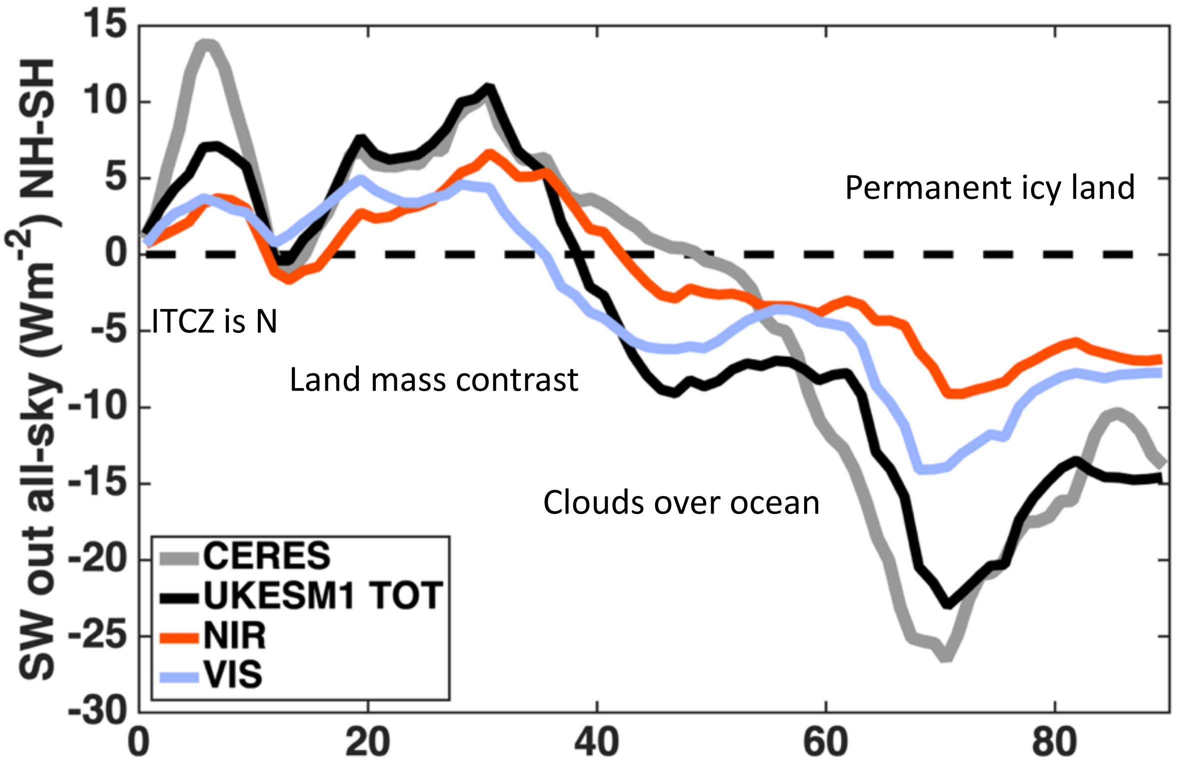
- UK Earth system modeling project
- Successor to HadGEM2-ES
- "The complexity of coupling between the ocean, land, and atmosphere physical climate and biogeochemical cycles in UKESM1 is unprecedented for an Earth system model." (Sellar et al., 2019)
- Limits of spectral intervals (wavelengths in m.)

Band	Lower limit	Upper limit
1	2.000000000E-07	3.200000000E-07
2	3.200000000E-07	5.050000000E-07
3	5.050000000E-07	6.900000000E-07
4	6.900000000E-07	1.190000000E-06
5	1.190000000E-06	2.380000000E-06
6	2.380000000E-06	1.000000000E-05

- Integrate bands 2-3 for visible, and bands 4-5 for near-IR

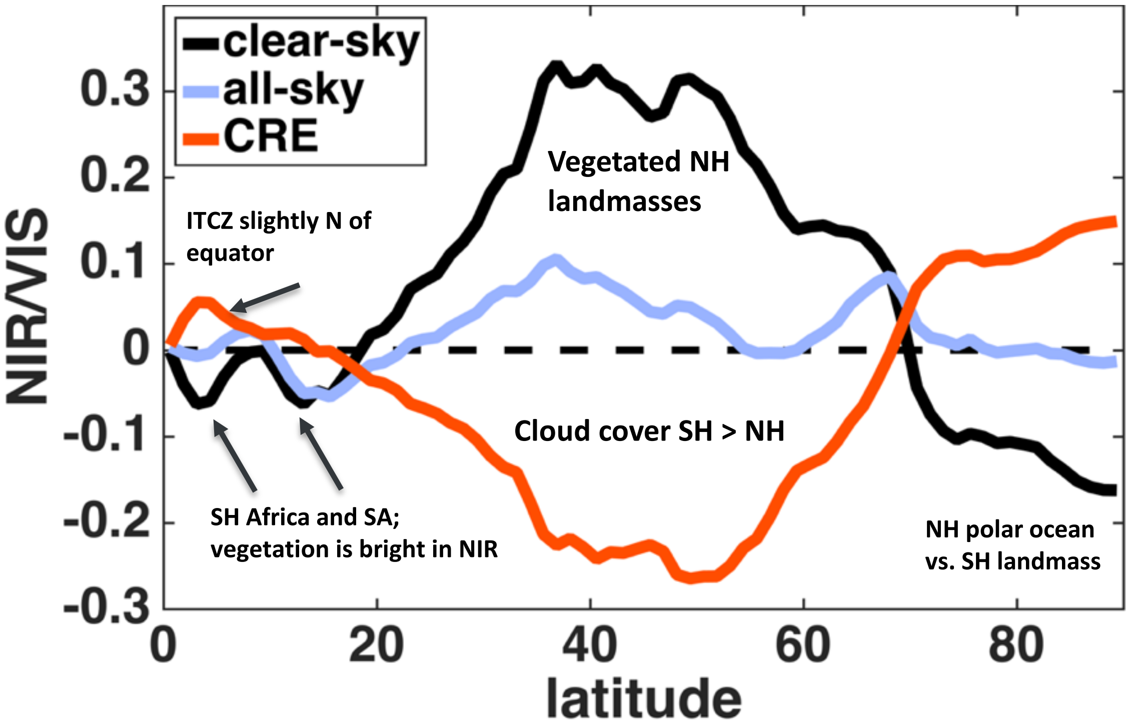
Model simulation:
Alejandro Bodas-Salcedo

NH-SH differences per latitude



- NH is mostly brighter over 0-40 degree, but darker poleward
- Model agrees OK with CERES
- NIR & VIS zonal variability looks similar to total SW

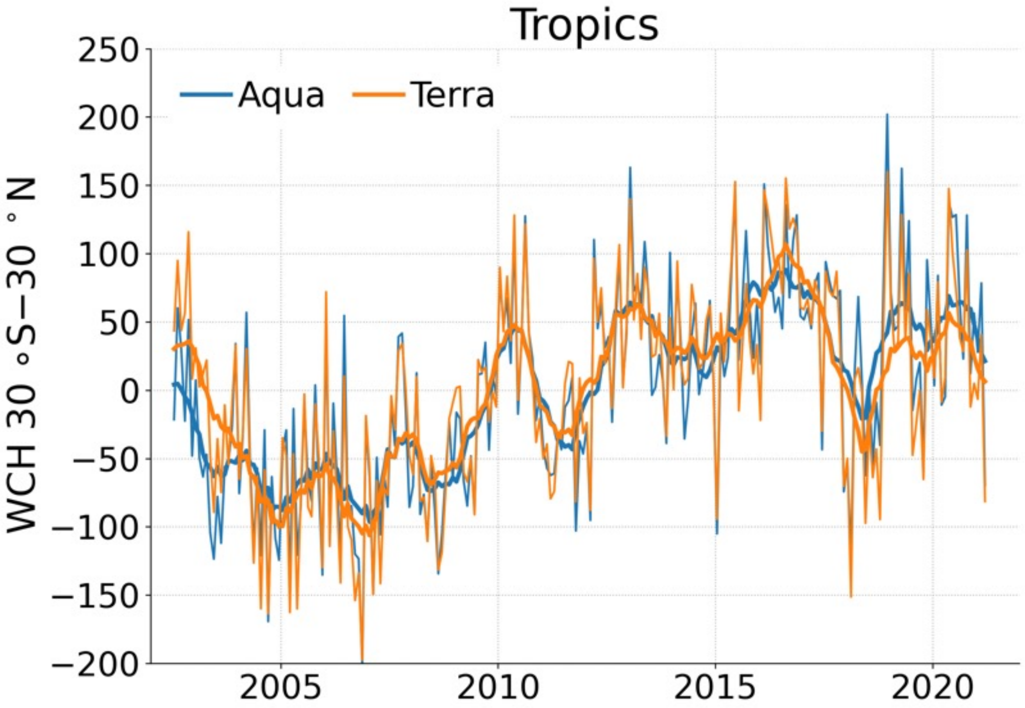
NH-SH differences NIR/VIS ratio per latitude



- Positive values: NIR/VIS ratio is larger on NH than on SH; especially true under clear-sky between 20-70 deg. (note: locally, SH Africa and SA have largest NIR/VIS)
- CRE balance the hemispheric NIR/VIS ratio zonally & mirror the Clear-sky effects.
- But NIR/VIS ratio remains slightly larger on NH under all-sky conditions.

Tropical clouds are getting higher

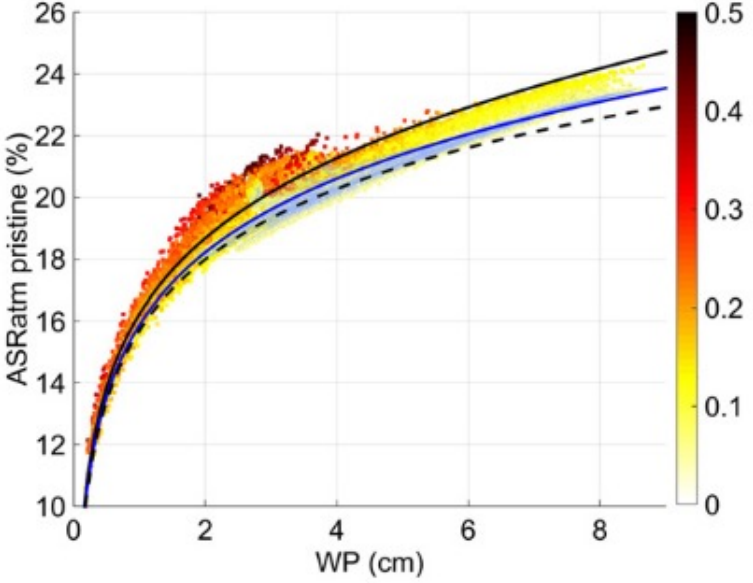
Richardson et al., 2022

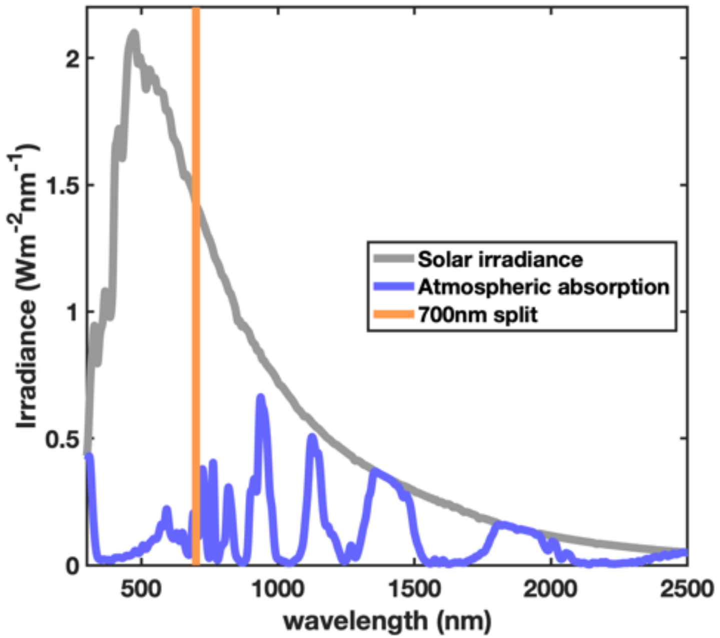


Cloud height trend sensitivity: 330±60 m K^{-1}

This would imply doubling of NIR above-cloud absorption per K warming.

Spectral nature of shortwave radiation





- **Water vapor saturation yields non-linear increase**
- **Underlying surface impacts relationship by several Wm^{-2}**