FY23 Topic Areas Research and Technology Development (TRTD)

Measuring Earth's Energy Imbalance via radiation pressure acting on spherical LEO satellites (Space Balls): Simulating feasibility, confounding effects, and sampling requirements

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Strategic Focus Area: Climate Science

Objectives

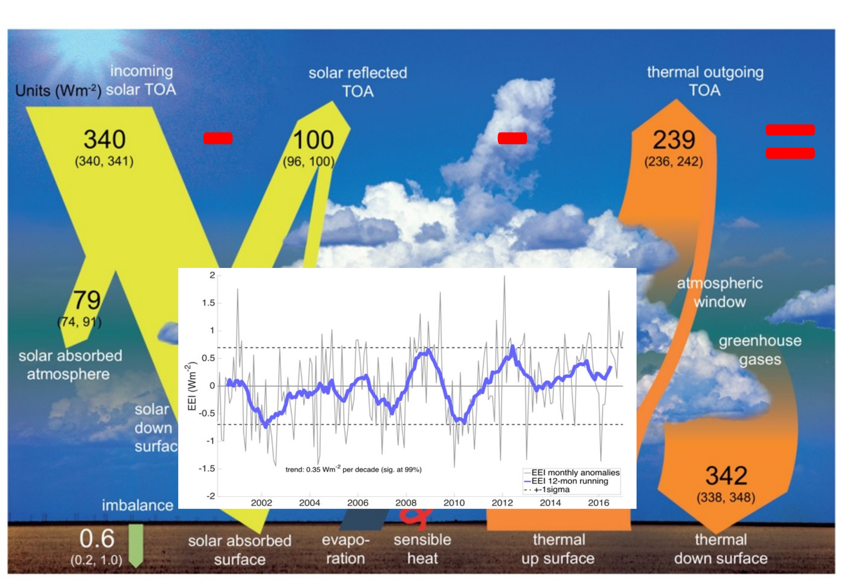
The goal of this research task is to develop a simulation environment for "*Space Ball(s)*", a near-spherical LEO spacecraft equipped with an accelerometer at its center of mass which measures radiation pressure-induced radial accelerations to quantify Earth's Energy Imbalance (EEI) and its variability in time.

1. Improve upon the representation of Earth radiation pressure in Monte and integrated force models.
2. Evaluate the impact of spacecraft characteristics (absorptivity, shape, spin) on simulated accelerations.
3. Study the significance of confounding effects such as related to aerodynamic drag and thermal variations across the spacecraft skin.

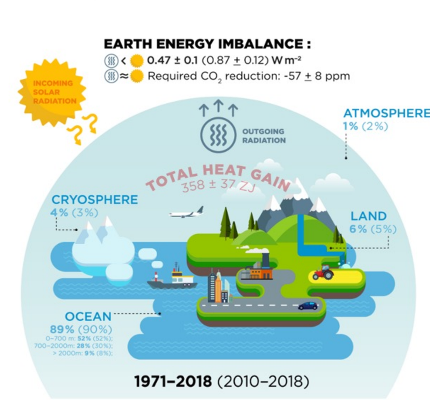
These sensitivity analyses are to inform requirements for a spacecraft and mission that enables a high-accuracy measurement of net radiative flux at the top-of-the-atmosphere (TOA). This work could inform ESTO InVEST or EVM proposals.

Background

Earth's (radiative) Energy Imbalance (EEI) quantifies the rate of global energy accumulation in response to radiative forcings & feedbacks and drives climatic changes and impacts. EEI is considered a reliable metric for quantifying global warming and does not "miss" any heat sinks in the climate system, while other metrics such as surface temperature change do.



~0.9 Wm^{-2}



A direct high-accuracy EEI measurement does not exist. Indirectly, EEI is estimated through tracking global heat content change.

Measuring EEI directly from space would allow us to:

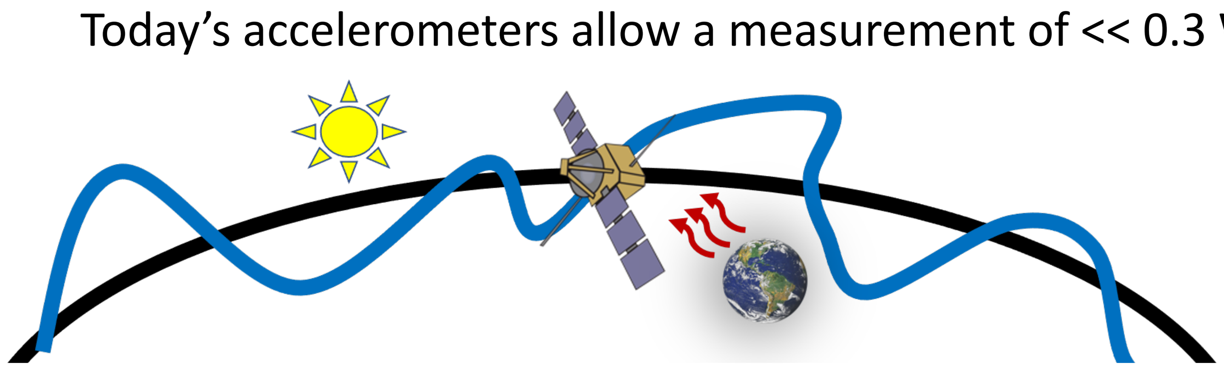
1. Quantify the global long-term (~ 1yr) accumulation of heat in the Earth system
2. Constrain radiative forcings, feedbacks & climate sensitivity with observations
3. Anchor data products (i.e., CERES EBAF) and 'tune' global climate models that lack energy balance closure
4. Track climate change mitigation efforts through their direct impact on EEI

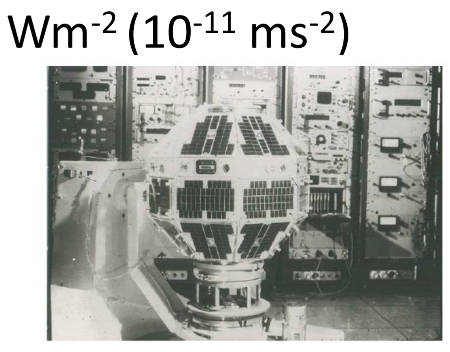
Current (CERES) and radiation budget (ERB) observations lack the absolute accuracy (± 4 Wm^{-2}) to resolve EEI as the ERB components' residual.

A potential solution based on accelerometry: "Space Balls"

Direct measurement of the net radiative flux (EEI) at TOA through sensing radiation pressure accelerations acting on a near-spherical LEO spacecraft

- Not a residual of radiative components (radiometry)
- More complete coverage (as opposed to in-situ heat content)
- Today's accelerometers allow a measurement of << 0.3 Wm^{-2} (10^{-11} ms^{-2})



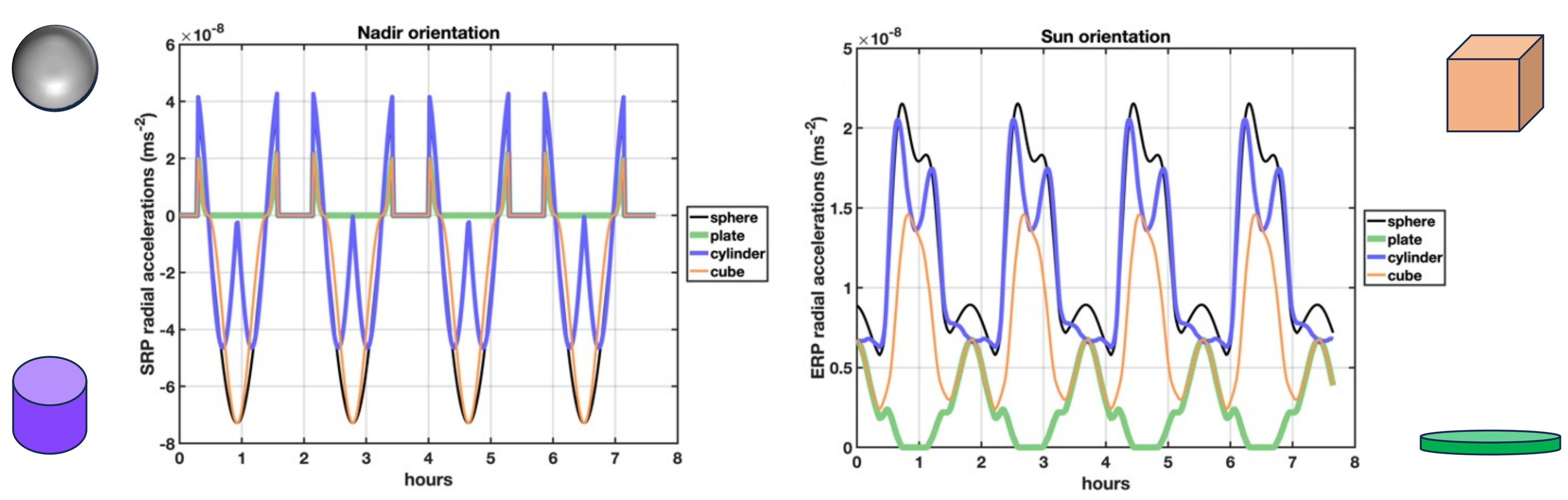


CASTOR D5B Satellite

Approach and Results

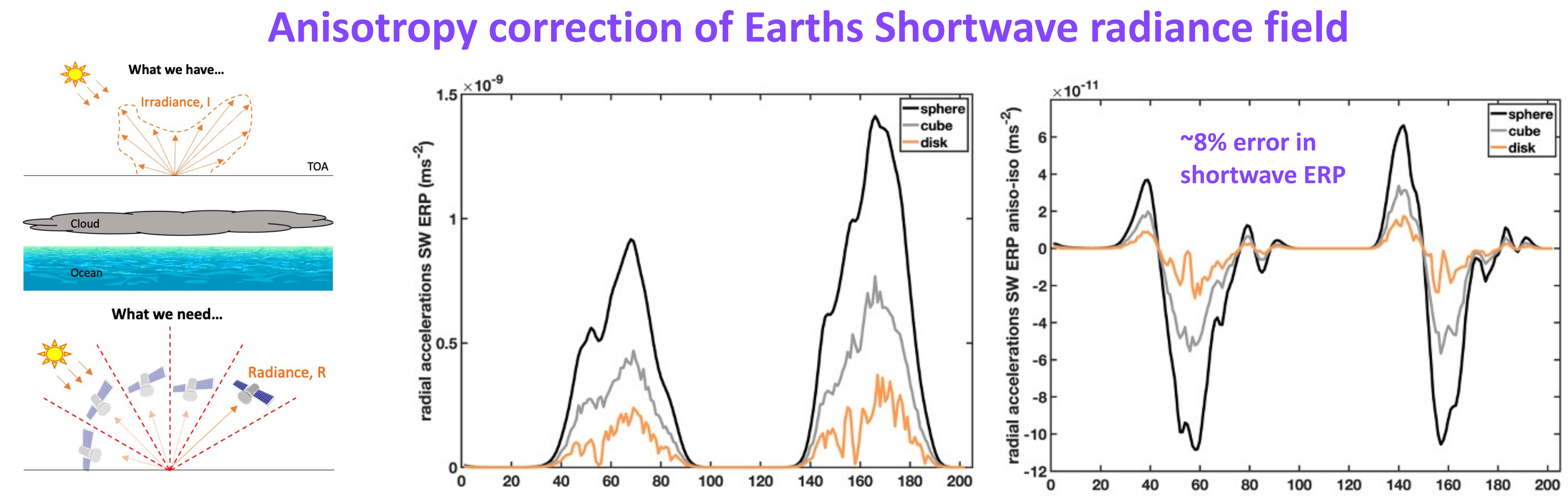
Space Balls simulation environments: Monte, Integrated force model, Orbital sampling

Impact of different shapes on Earth Radiation Pressure radial accelerations

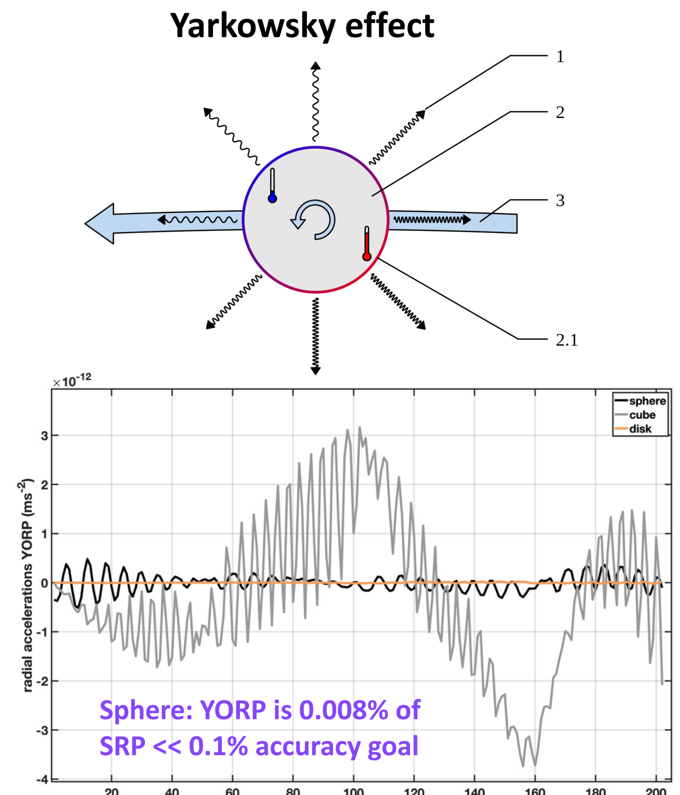


Orientation modulates the incident angle and surface area exposed to sun beam and Earth radiation; accelerations significantly deviate from the sphere's.

Anisotropy correction of Earths Shortwave radiance field

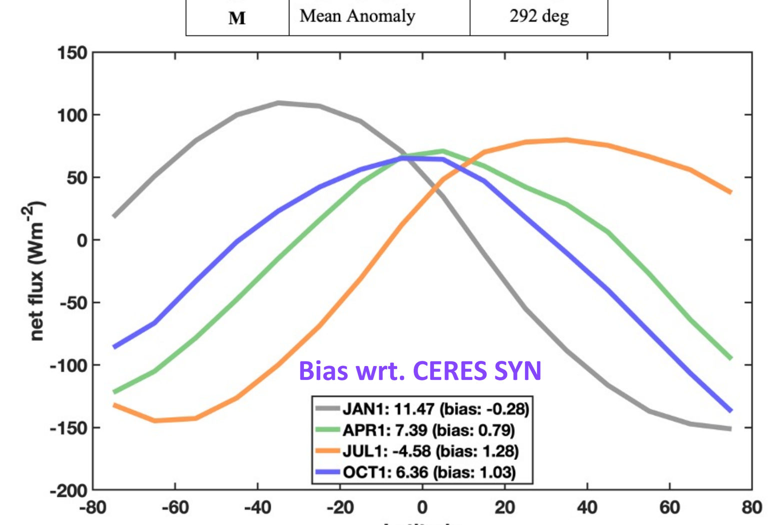


Are YORP effects confounding the radiation pressure signal?



How close we get to "true" daily global mean with one S/C in sun-synchronous orbit (MLTAN 12 pm)

Parameter	Description	Value
h	Altitude	1300km
e	Eccentricity	0.004
i	Inclination	100.66 deg
Ω	Long. of Asc. Node	180 deg
ω	Arg. of perigee	68 deg
M	Mean Anomaly	292 deg



Significance/Benefits to JPL and NASA

- EEI represents the integrated Earth system radiative response to changes in surface & atmospheric properties observed by NASA missions (e.g., future AOS).
- A dedicated EEI measurement complements NASA's vision of a space-based Earth System Observatory.
- *Space Balls* would serve as a companion to future and current NASA projects that provide the individual shortwave and longwave fluxes (CERES, *Libera)*.
- Concept represents a concerted effort toward energy cycle closure and heat uptake estimation and addresses several science questions posed by the ESAS-2017 *Decadal Survey* (C-1b, C-2f, H-1a, H-2b).
- Novel radiation pressure and coverage algorithms for use in *Monte* may support other projects such as GRACE-FO non-gravitational force modeling.

Publications:

1. M. Hakuba, C. Reynerson, B. Quadrelli, D. Wiese, C. Mccullough, G. Stephens, F. Landerer, "Measuring Earth's Energy Imbalance with "Space Balls"," International Radiation Symposium 2022, Thessaloniki, Greece, 2022.
2. M. Hakuba, C. Reynerson, B. Quadrelli, D. Wiese, C. Mccullough, G. Stephens, F. Landerer, "Measuring Earth's Energy Imbalance via Radiation Pressure Accelerations Experienced in Orbit," IEEE Aerospace conference, Big Sky, Montana, 2023.
3. C. Reynerson, M. Hakuba, B. Quadrelli, D. Wiese, C. Mccullough, G. Stephens, F. Landerer, "Real-Time Modeling of Albedo Pressure on Spacecraft and Applications for Improving Trajectory Estimation and Earth's Energy Imbalance Measurements," AIAA SciTech Forum, 2023.
4. C. Reynerson, M. Hakuba, B. Quadrelli, D. Wiese, C. Mccullough, "Modeling Spacecraft Earth Radiation Pressure to Improve Spacecraft Trajectory Estimation and Design", AAS/AIAA Astrodynamics Specialist Conference, Big Sky, MT, 2023.

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