National Aeronautics and Space Administration

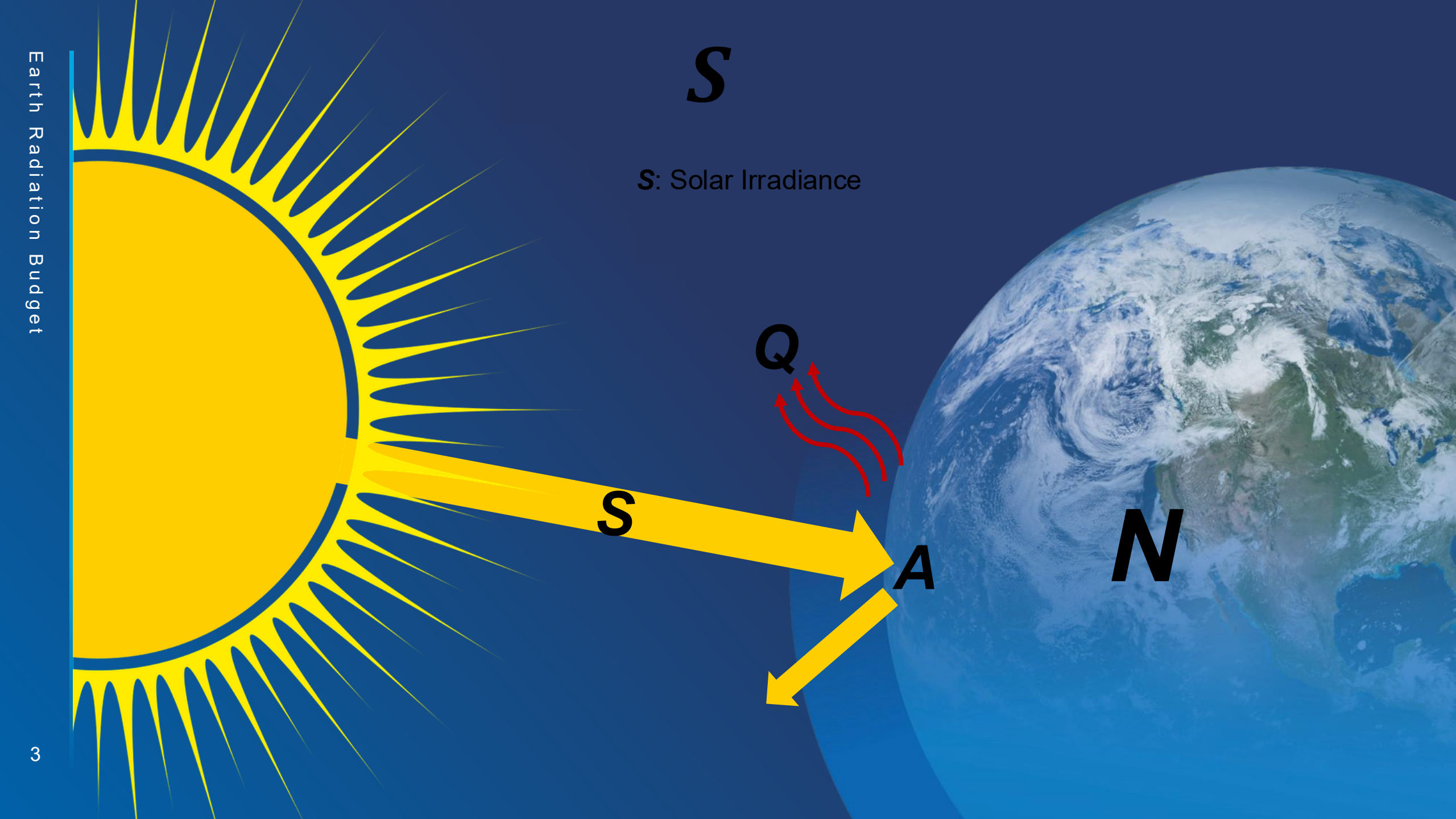
CERES Science Team Meeting
Spring 2026

From Langley's Bolometer to DEMETER

A Brief History and Look to the Future of Earth Radiation Budget Measurements

Alexander Jarnot, PhD
NASA Langley Research Center, Hampton, VA

History of the **Earth’s Radiation Budget**


S
S: Solar Irradiance
Q
S
A
N

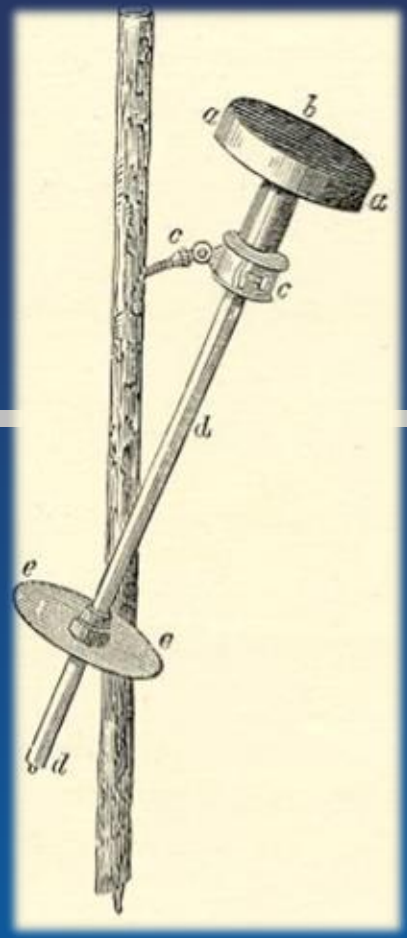
Pre-Satellite Era

$$N = S(1 - A) - Q$$

1211 W/m²

1837

Pouillet reports first measurements of solar constant using the first pyrheliometer



Pre-Satellite Era

$$N = S(1 - A) - Q$$

1211 W/m²

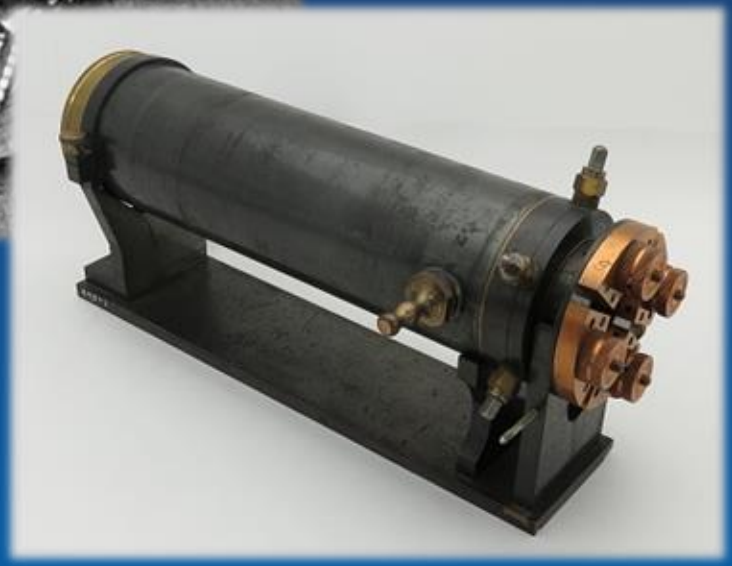
1837

Pouillet reports first measurements of solar constant using the first pyrheliometer

1825 – 2432 W/m²

1881

Samuel P. Langley develops the bolometer, measures solar constant



Current Measurement **Capabilities & Unknowns**

To Date

Solar Irradiance Measurements

Developments are made into the measurement of solar irradiance, but there is no push to understand how this piece fits into the wider ERB system yet.

Current Measurement **Capabilities & Unknowns**

To Date

Solar Irradiance Measurements

Developments are made into the measurement of solar irradiance, but there is no push to understand how this piece fits into the wider ERB system yet.

The components of the ERB system on a larger spatial and temporal scale are not understood.

Average planetary albedo is difficult to determine, solar irradiance estimates are generally too high.

Solar Constant

???

???

Pre-Satellite Era

$$N = S(1 - A) - Q$$

1211 W/m²

1837

Pouillet reports first measurements of solar constant using the first pyrheliometer

1825 – 2432 W/m²

1881

Samuel P. Langley develops the bolometer, measures solar constant

1485.16 W/m²

1903

Abbott and Fowle separate ERB components, make first “global” measurements using Smithsonian Table Mountain data

Pre-Satellite Era

$$N = S(1 - A) - Q$$

1211 W/m²

1837

Pouillet reports first measurements of solar constant using the first pyrheliometer

1825 – 2432 W/m²

1881

Samuel P. Langley develops the bolometer, measures solar constant

1485.16 W/m²

1903

Abbott and Fowle separate ERB components, make first “global” measurements using Smithsonian Table Mountain data

1485.16 W/m²

1928

Using Abbott and Fowle’s solar constant, Simpson makes first ERB estimate that considers water vapor spectral signature

Pre-Satellite Era

$$N = S(1 - A) - Q$$

1211 W/m²

1837

Pouillet reports first measurements of solar constant using the first pyrheliometer

1825 – 2432 W/m²

1881

Samuel P. Langley develops the bolometer, measures solar constant

1485.16 W/m²

1903

Abbott and Fowle separate ERB components, make first "global" measurements using Smithsonian Table Mountain data

1485.16 W/m²

1928

Using Abbott and Fowle's solar constant, Simpson makes first ERB estimate that considers water vapor spectral signature

1350 W/m²

1954

Further Smithsonian Observatory measurements refine solar constant estimate, but stability is uncertain

Current Measurement **Capabilities & Unknowns**

To Date

Large-Scale Climate Modeling

Attempts to model climatological parameters on a wide area scale are met with some success.

It's possible to capture variations in climate across short time periods and estimate albedo.

Solar Constant

???

???

Current Measurement **Capabilities & Unknowns**

To Date

Large-Scale Climate Modeling

Attempts to model climatological parameters on a wide area scale are met with some success.

It's possible to capture variations in climate across short time periods and estimate albedo.

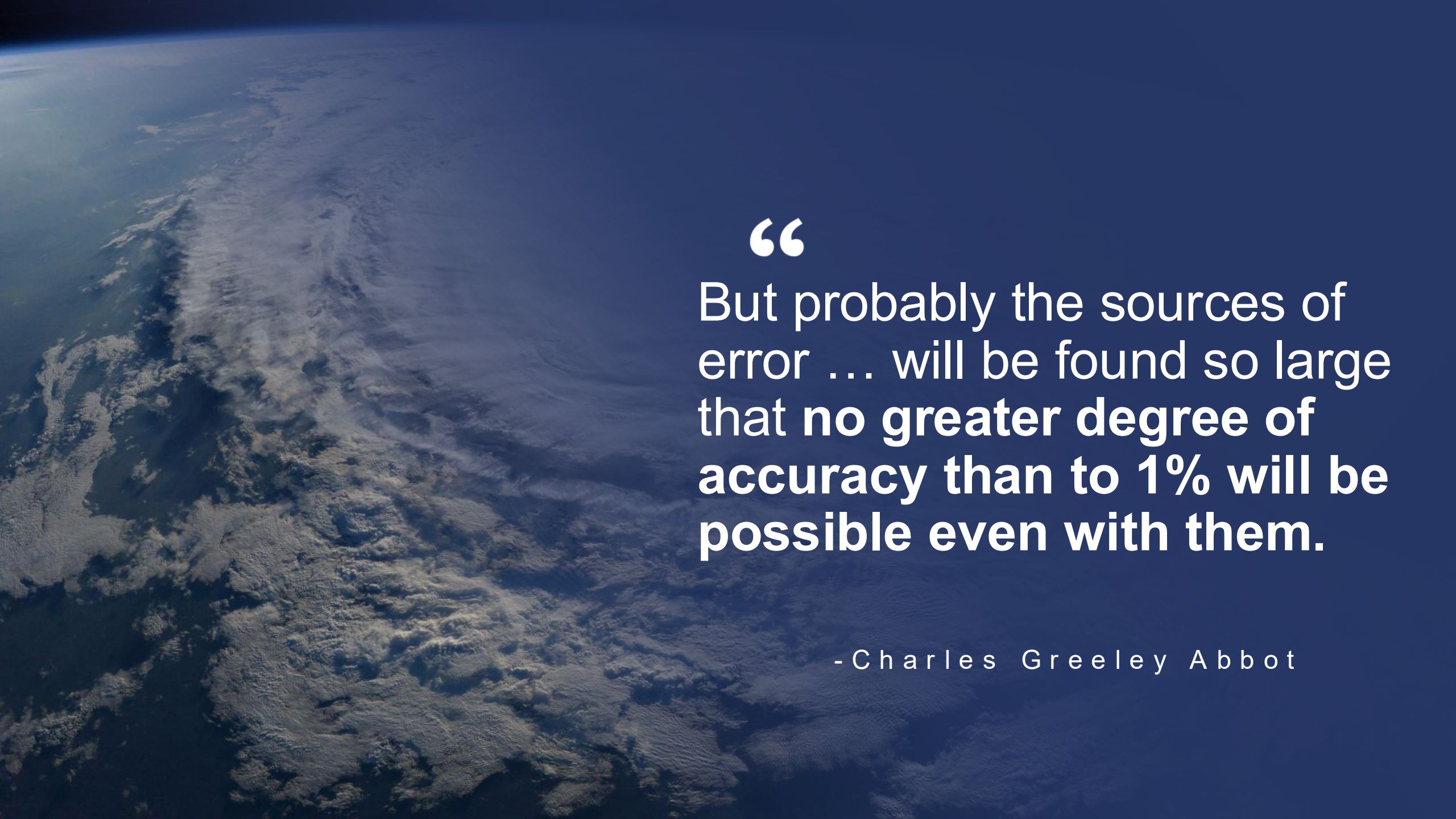
The average surface albedo, distribution of clouds, and the role of water vapor remain primary unknowns.

“

It is plainly our duty to transmit to posterity accurate measure of the intensity of the Sun’s radiation as it is now, so that they will be in a better position in this branch of science than we find ourselves…

-Charles Greeley Abbot


“
It may be in the future apparatus can be shot up by means of rocket devices to go outside of the atmosphere altogether…
-Charles Greeley Abbot


“
But probably the sources of error … will be found so large that **no greater degree of accuracy than to 1% will be possible even with them.**
-Charles Greeley Abbot

Pre-Satellite Era

$$N = S(1 - A) - Q$$

1211 W/m²

1837

Claude Pouillet reports first measurements of solar constant using water tube apparatus

1825 – 2432 W/m²

1881

Samuel P. Langley develops the bolometer, measures solar constant

1485.16 W/m²

1903

Abbott and Fowle separate ERB components, make first "global" measurements using Smithsonian and Mt Wilson data

1485.16 W/m²

1928

Using Abbott and Fowle's solar constant, Simpson makes first ERB estimate that considers water vapor spectral signature

1350 W/m²

1954

Further Smithsonian Observatory measurements refine solar constant estimate, but stability is uncertain

1957 Sputnik

Satellite Era

$$N = S(1 - A) - Q$$

October 13

1959

Explorer 7 carries first satellite-based ERB instrument developed by Vernier Suomi

Satellite Era

$$N = S(1 - A) - Q$$

October 13

1959

Explorer 7 carries first satellite-based ERB instrument developed by Vernier Suomi

November 23

1960

TIROS-3, 4 and 7 satellites carry Suomi's radiometer to orbit

Spin-stabilization limits scanning and instrument acquisition time is slow (~30s)

Satellite Era

$$N = S(1 - A) - Q$$

October 13

1959

Explorer 7 carries first satellite-based ERB instrument developed by Vernier Suomi

November 23

1960

TIROS-3, 4 and 7 satellites carry Suomi's radiometer to orbit

Spin-stabilization limits scanning and instrument acquisition time is slow (~30s)

June 12

1975

Nimbus 7 satellite carries the ERB instrument to orbit

First scanning and non-scanning radiometers

First space-borne measurements of TSI

Satellite Era

$$N = S(1 - A) - Q$$

October 13
1959
Explorer 7 carries first satellite-based ERB instrument developed by Vernier Suomi

November 23
1960
TIROS-3, 4 and 7 satellites carry Suomi's radiometer to orbit

Spin-stabilization limits scanning and instrument acquisition time is slow (~30s)

June 12
1975
Nimbus 7 satellite carries the ERB instrument to orbit

First scanning and non-scanning radiometers

First space-borne measurements of TSI

August 28
2002
First geostationary ERB satellites in orbit (GERB)

Satellite Era

$$N = S(1 - A) - Q$$

October 13

1959

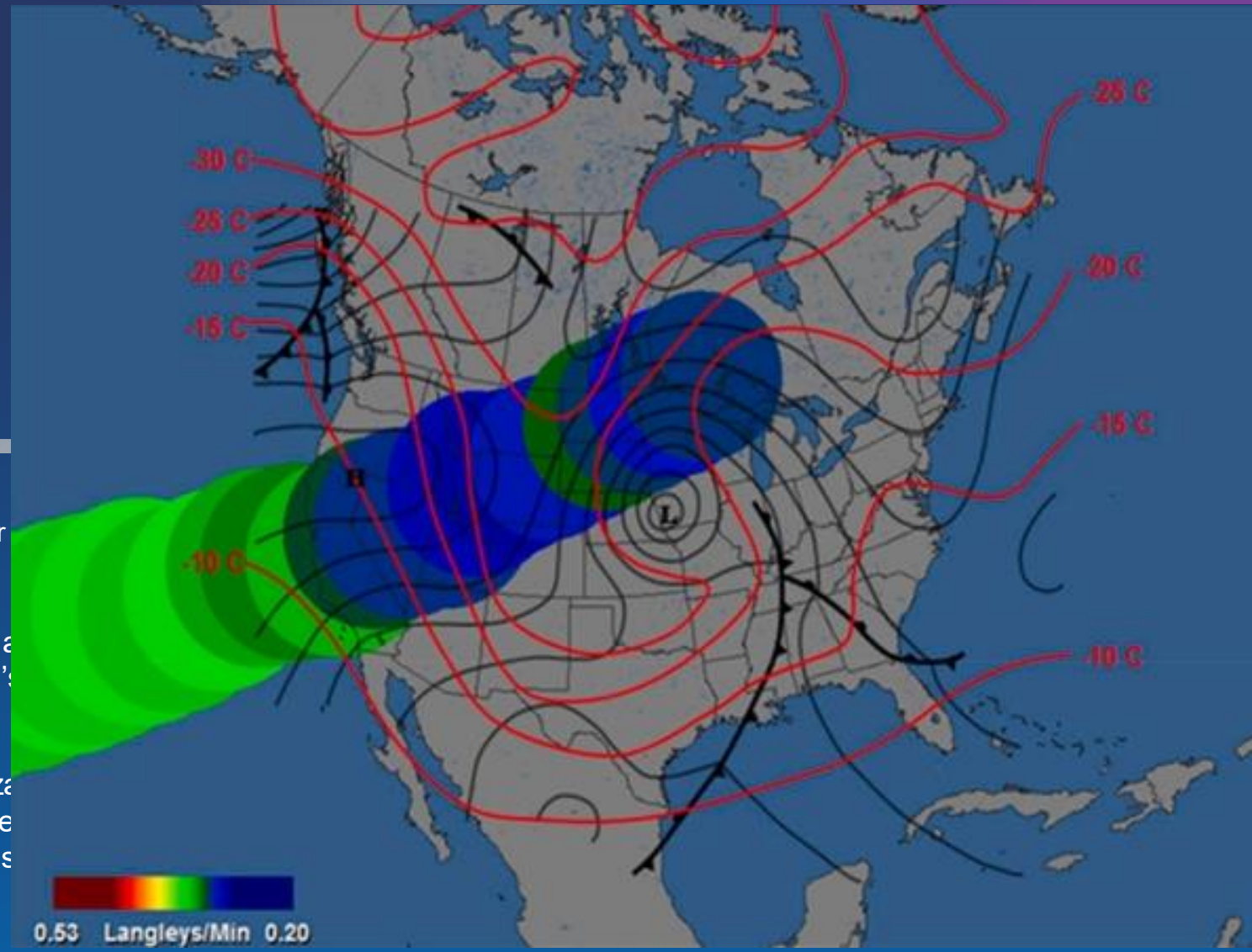
Explorer 7 carries first satellite-based ERB instrument developed by Vernier Suomi

November

1960

TIROS-3, 4 a
carry Suomi'
orbit

Spin-stabiliza
and instrume
is slow (~30s



T.V. Haar et al. 2026; Kohrs & Menzel U. of Wisconsin

Satellite Era

$$N = S(1 - A) - Q$$

October 13
1959
Explorer 7 carries first satellite-based ERB instrument developed by Vernier Suomi

November 23
1960
TIROS-3, 4 and 7 satellitses carry Suomi's radiometer to orbit

Spin-stabilization limits scanning and instrument acquisition time is slow (~30s)

June 12
1975
Nimbus 7 satellite carries the ERB instrument to orbit

First scanning and non-scanning radiometers

First space-borne measurements of TSI

August 28
2002
First geostationary ERB satellites in orbit (GERB)

ERBS & ERBE
October 5, 1984

Astronaut Sally Ride removes ERBS from the Shuttle cargo bay

ERBS & ERBE
October 5, 1984

And after a small hangup with the solar panels…

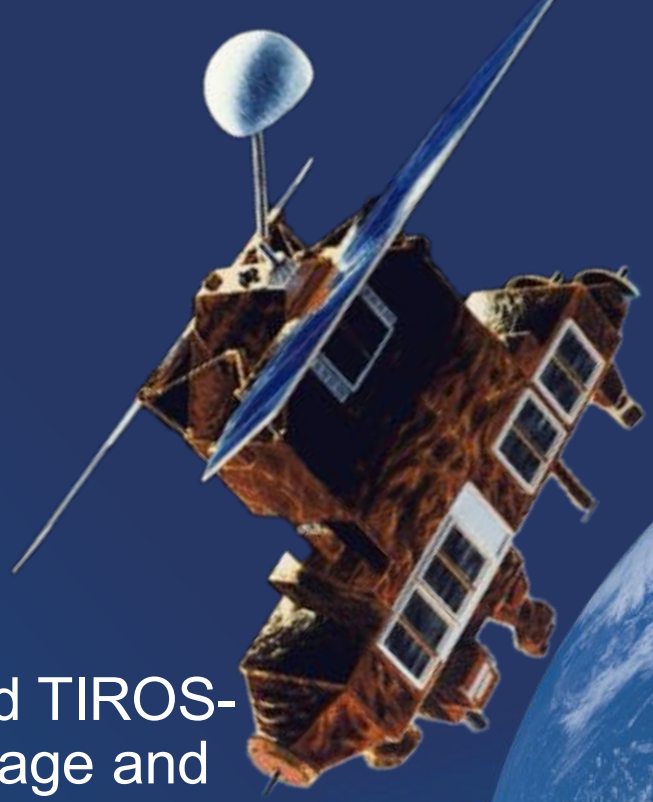
ERBS & ERBE
October 5, 1984

ERBS is pushed out into a prograde, precessing orbit

ERBS & ERBE
October 5, 1984

ERBS is pushed out into a prograde, precessing orbit

ERBS & ERBE
October 5, 1984



In conjunction with TIROS-N(1) and TIROS-N(2), ERBS provided diurnal coverage and overlapped with Nimbus to continue the CDR.

Carried scanning and non-scanning, highly calibrated radiometers to capture climate data record, overlapping with Nimbus-7.

ERBS measured the cloud radiative effect for the first time.

ERBS & ERBE
October 5, 1984

You can watch the ERBS deployment in IMAX

Current Measurement **Capabilities & Unknowns**

To Date

Satellite-Based Observations

Humanity is now able to directly measure solar irradiance unimpeded by the atmosphere, and measure average global albedo from top of the atmosphere.

Global observations of ERB components are now possible.

Solar Constant

Synoptic Coverage

???

Current Measurement **Capabilities & Unknowns**

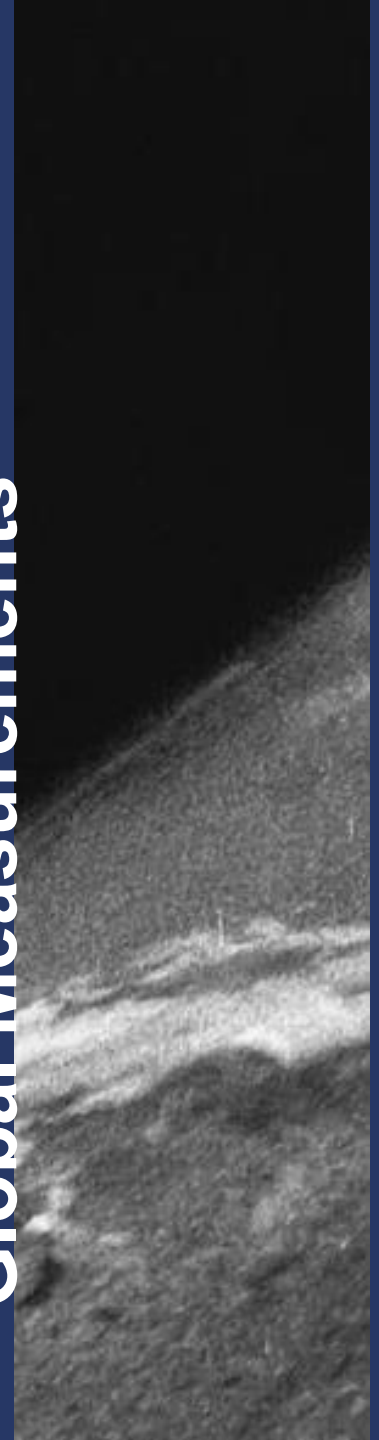
To Date

Satellite-Based Observations

Humanity is now able to directly measure solar irradiance unimpeded by the atmosphere, and measure average global albedo from top of the atmosphere.

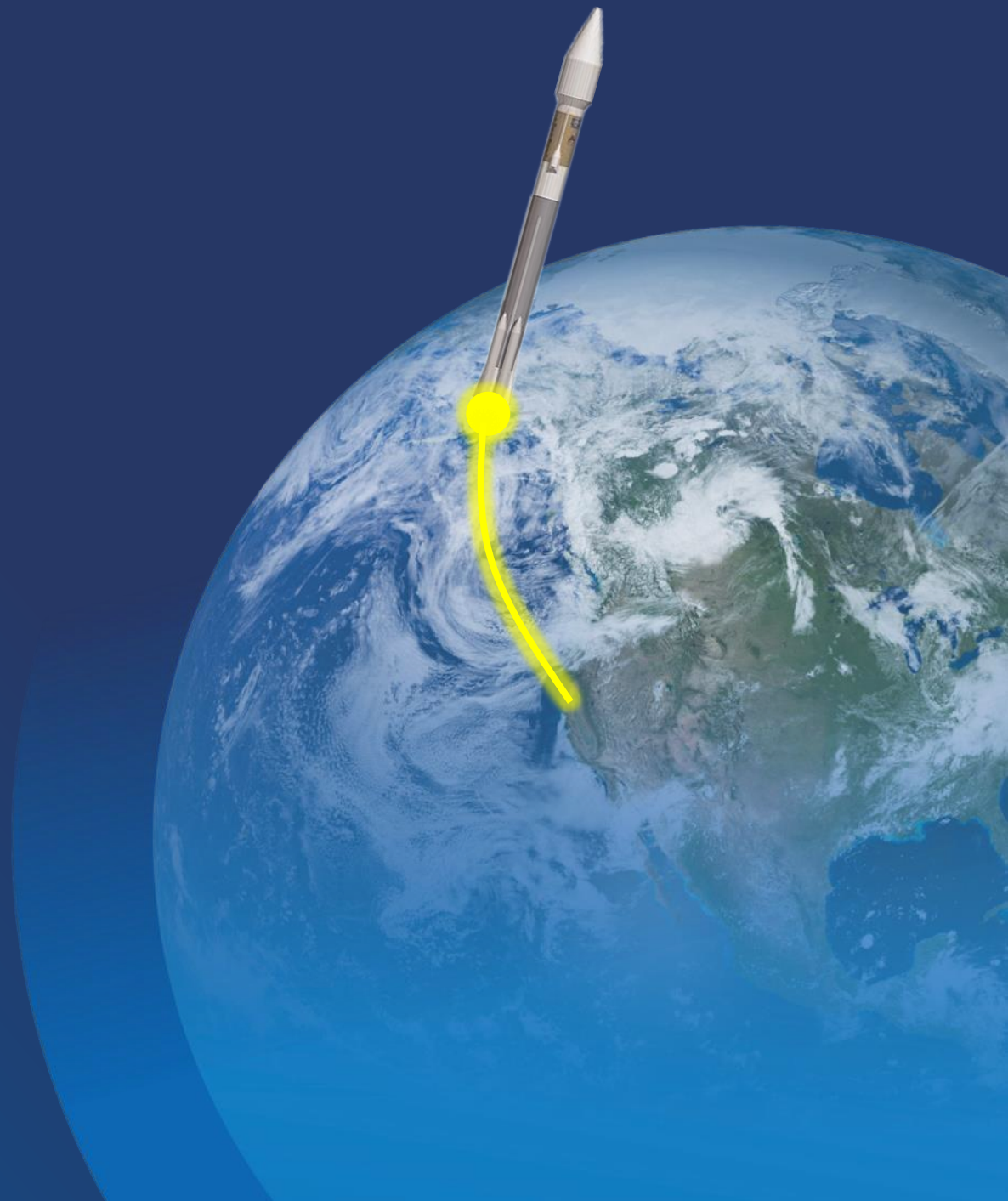
Global observations of ERB components are now possible.

Questions around the value of reflected shortwave, outgoing longwave, and average energy remain. The role of clouds and aerosols on the ERB is a key measurement.



CERES FM 1 & 2
December 18, 1999

At 11:57 AM Pacific Time, an Atlas IIAS rocket carrying the Terra satellite, leaves the pad at Vandenberg AFB.

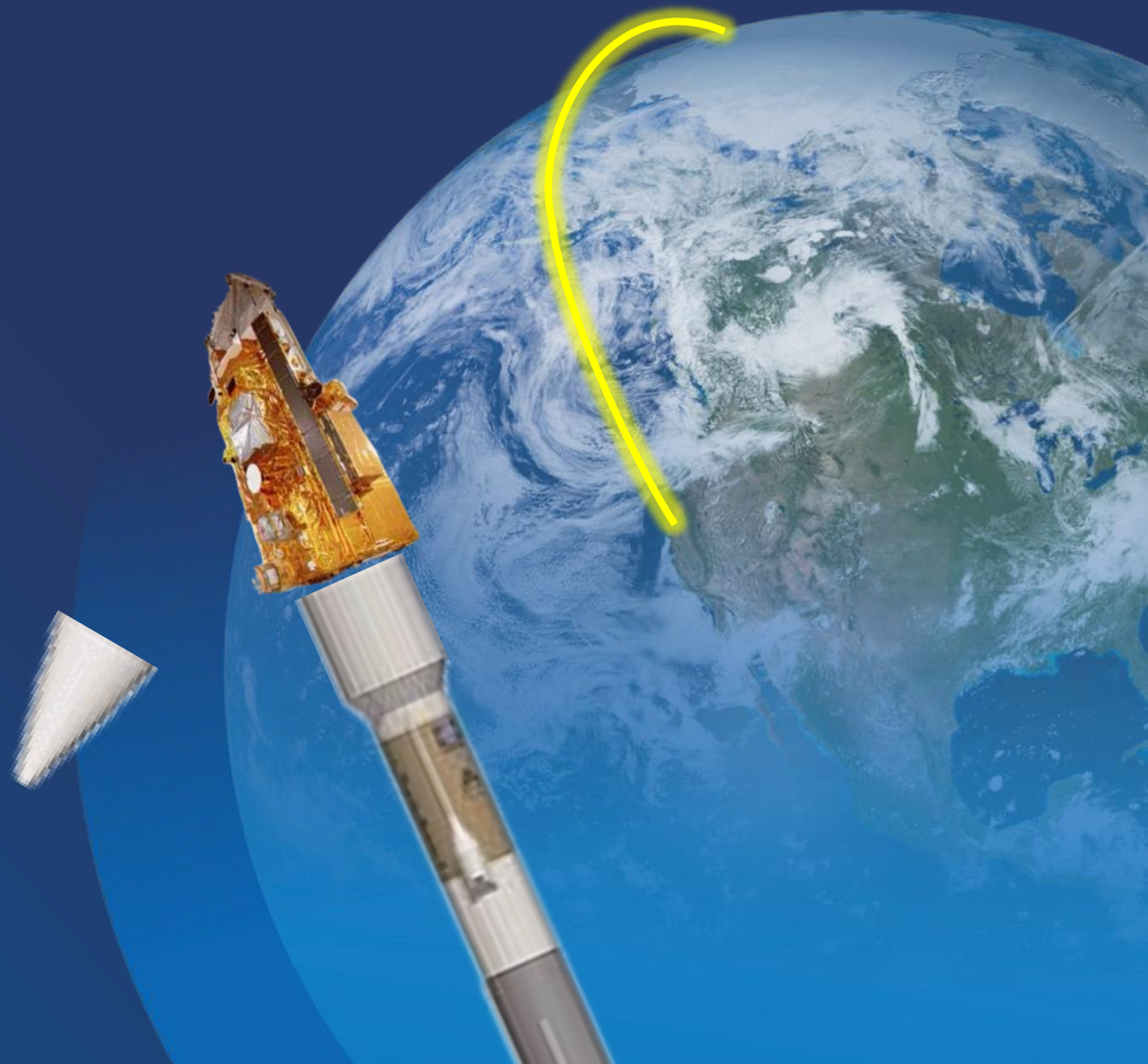


CERES FM1 & 2
December 18, 1999

Terra, carrying CERES FM1 & FM2, is dropped off in a polar, sun-synchronous orbit

CERES FM1 & 2
December 18, 1999

Terra, carrying CERES FM1 & FM2, is dropped off in a polar, sun-synchronous orbit



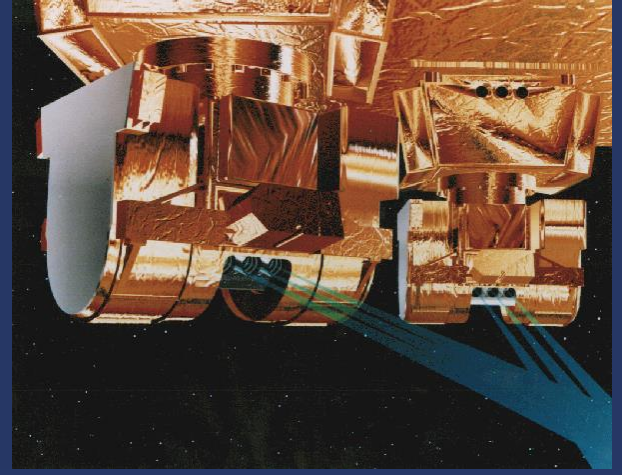
CERES FM1 & 2
December 18, 1999

CERES FM1 & 2 provide global, diurnal coverage of ERB, improving upon ERBE's measurements.

Ability to scan in Crosstrack and RAPS modes allows for the generation of ADMs while collecting science data.

Onboard multispectral imagers provide imaging for cloud coverage, ground processing team generates data products.

CERES Satellites



December 18
1999
FM1 & 2 launch on board Terra

May 4
2002
FM3 & 4 launch on board Aqua

October 28
2011
FM5 launches on board Suomi/NPP

November 18
2017
FM6 launches on board NOAA-20

Current **Measurement Design**

Sum of Knowledge

Climate Data Record is based on

Global, diurnal coverage

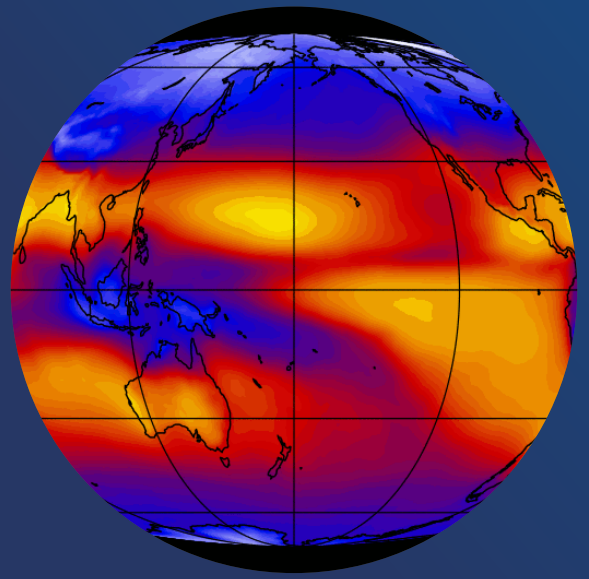
Limb-to-limb coverage

Three channels

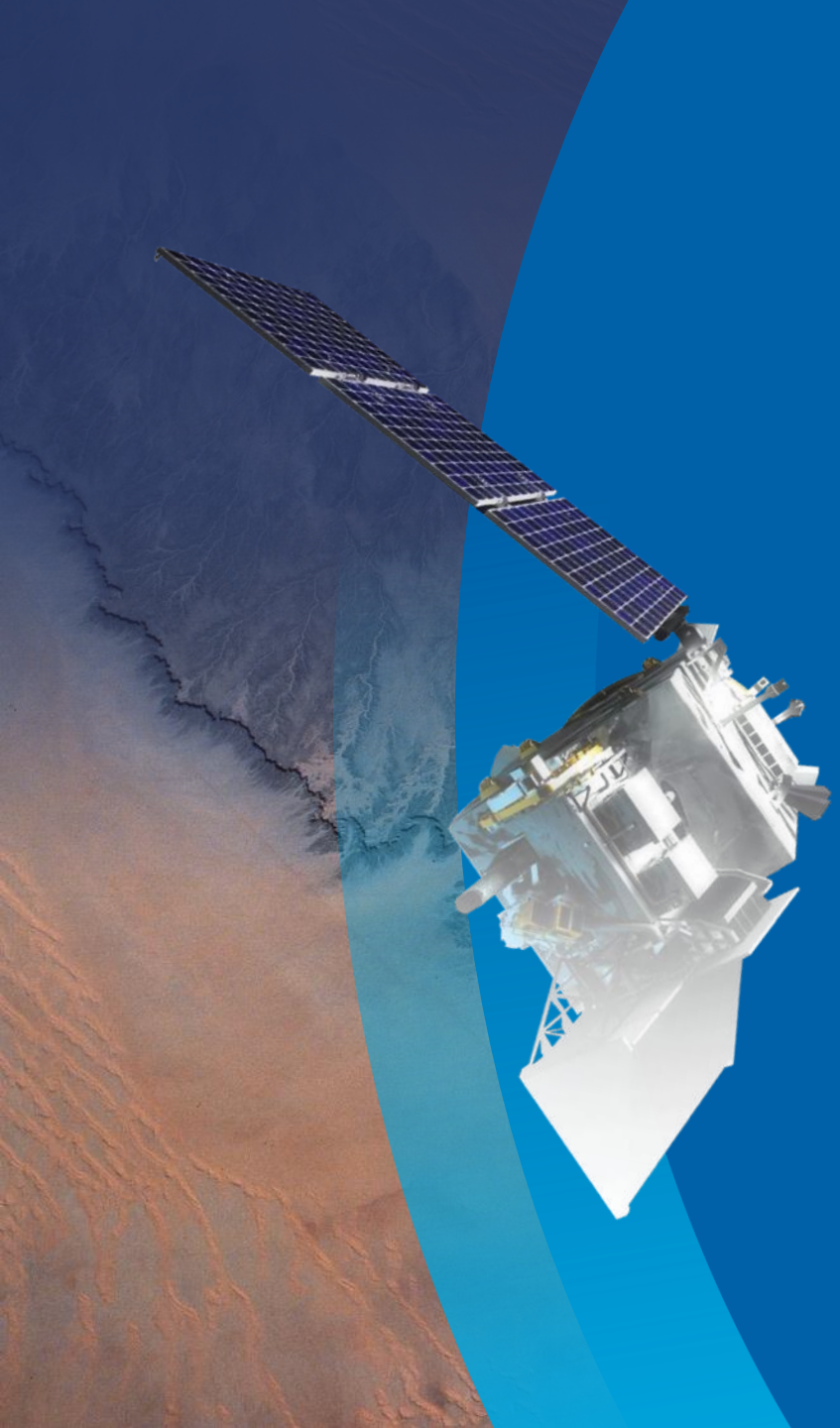
Biaxial measurement capability

Angular Distribution Model Development

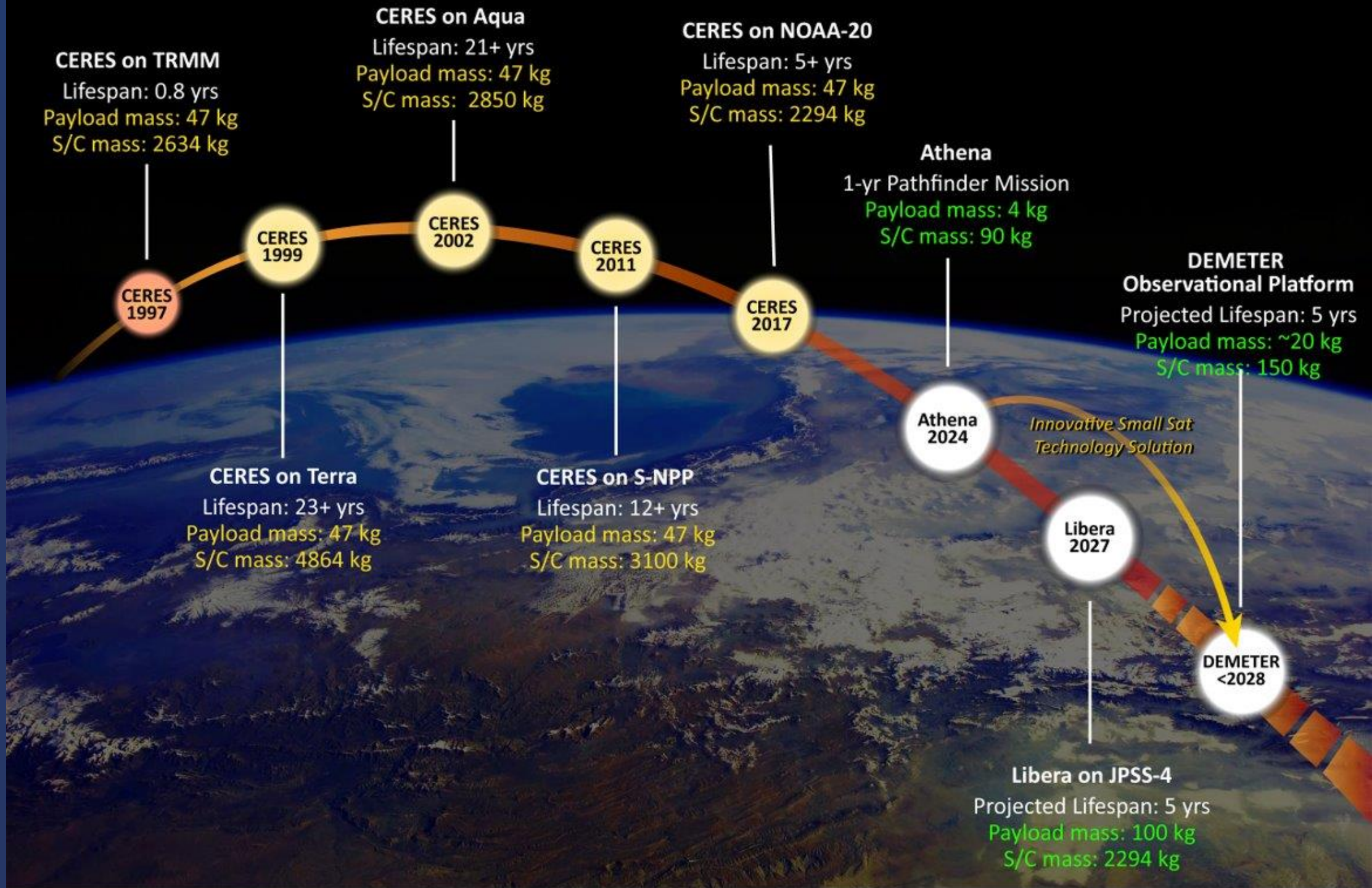
Data Fusion with Vicarious Measurements



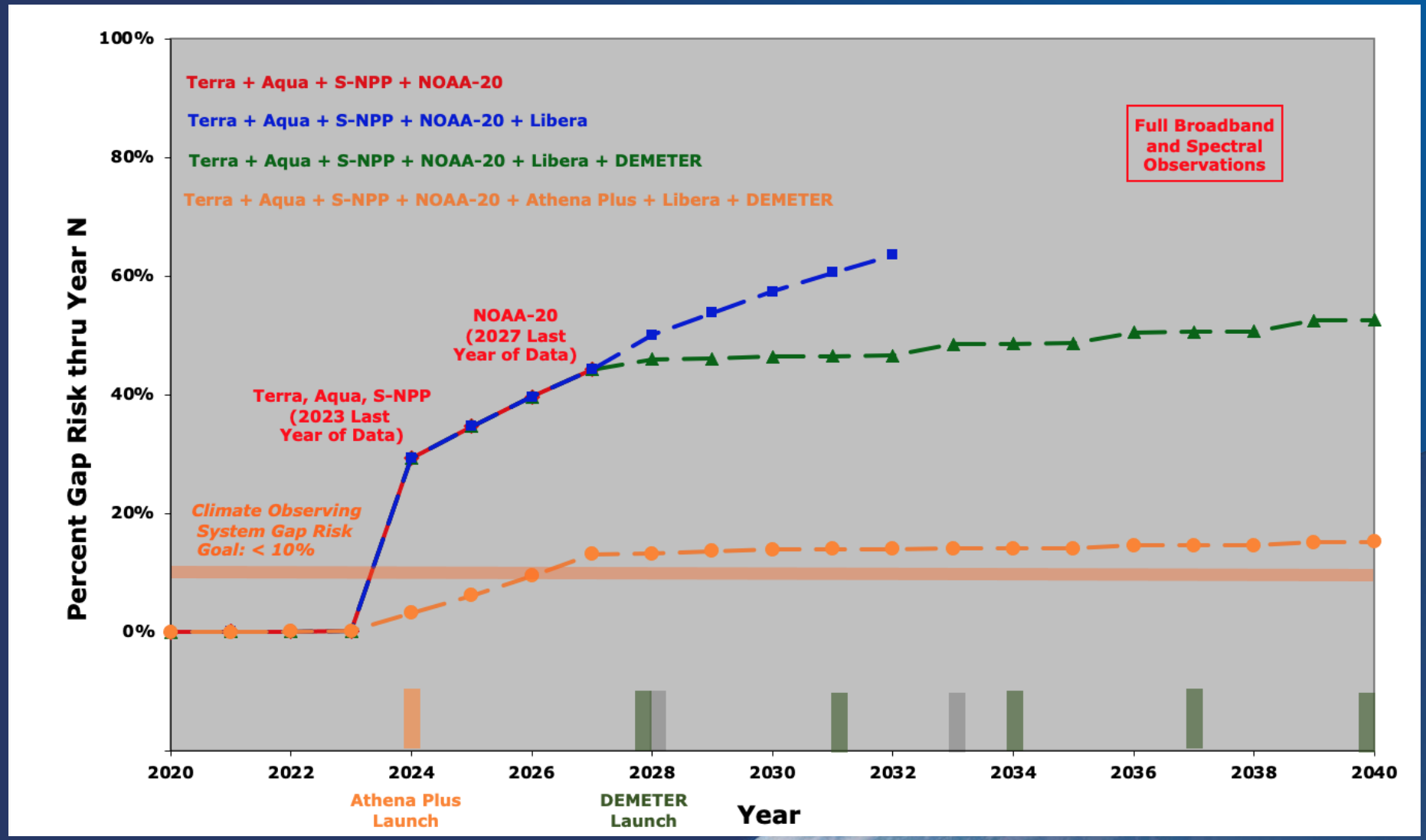
Focus has shifted to maintaining the Climate Data Record



Continuing the **Climate Data Record**


CERES on TRMM
Lifespan: 0.8 yrs
Payload mass: 47 kg
S/C mass: 2634 kg
CERES on Aqua
Lifespan: 21+ yrs
Payload mass: 47 kg
S/C mass: 2850 kg
CERES on NOAA-20
Lifespan: 5+ yrs
Payload mass: 47 kg
S/C mass: 2294 kg
Athena
1-yr Pathfinder Mission
Payload mass: 4 kg
S/C mass: 90 kg
DEMETER
Observational Platform
Projected Lifespan: 5 yrs
Payload mass: ~20 kg
S/C mass: 150 kg
CERES 1997
CERES 1999
CERES 2002
CERES 2011
CERES 2017
Athena 2024
Libera 2027
DEMETER <2028
Innovative Small Sat Technology Solution
CERES on Terra
Lifespan: 23+ yrs
Payload mass: 47 kg
S/C mass: 4864 kg
CERES on S-NPP
Lifespan: 12+ yrs
Payload mass: 47 kg
S/C mass: 3100 kg
Libera on JPSS-4
Projected Lifespan: 5 yrs
Payload mass: 100 kg
S/C mass: 2294 kg

Addressing the **Gap Risk**



DEMonstrating the Emerging Technology for measuring the Earth's Radiation

DEMETER

New Technology for

Continuing the Climate Data Record

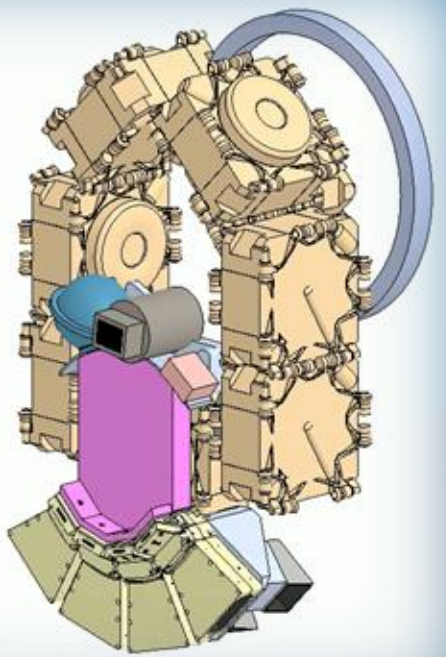
Next-generation ERB sensor hosted as its own sensorcraft.

Nominally: NovaWurks, a cellular, configurable, conformable architecture (SLEGOs).

Continue the long-term, sustained, and accurate climate observations currently provided by the suite of CERES instruments.

The current approach relies on flying as hosted payloads on large and expensive flagship missions.

NASA and NOAA are moving toward small, standalone satellite instruments.



DEMETER Calibration

DEMETER is a free-flying sensorcraft that will provide broadband observations for data continuity

Comparison to **CERES**

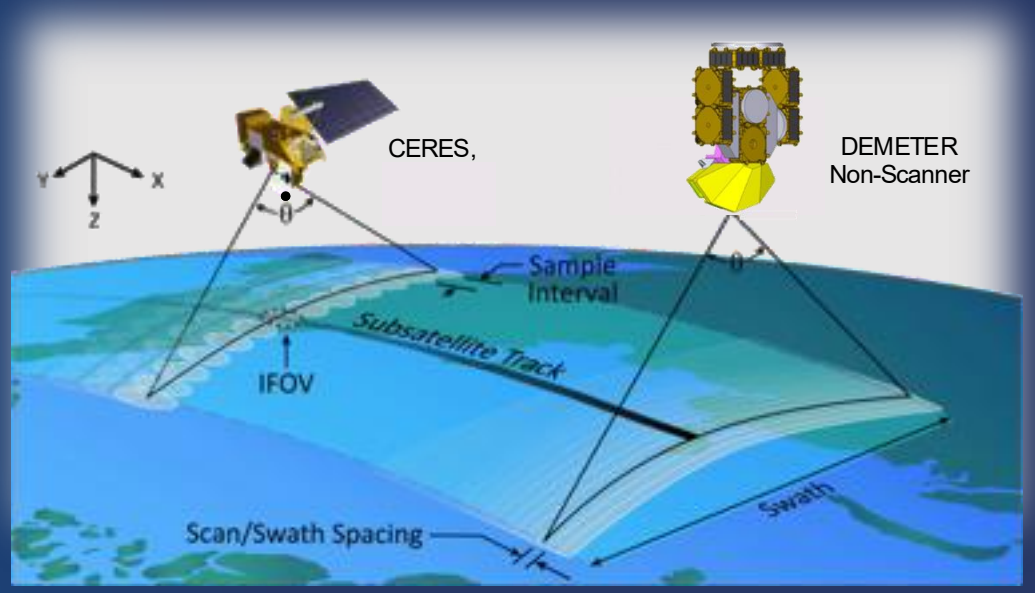
DEMETER

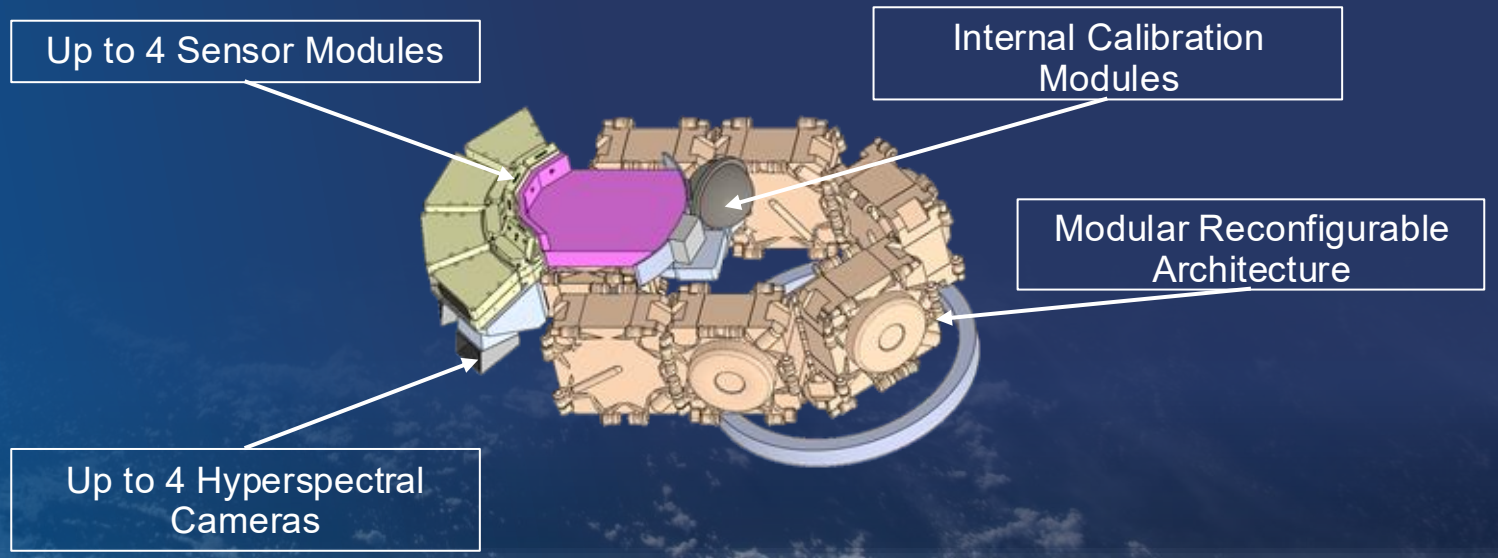
Non-Scanner

Non-scanning, Pushbroom, wide field of view radiometer to measure limb-to-limb TOA radiances, while integrated with a NovaWurks Hyper Integrated Satlet (HISat) sensorcraft.

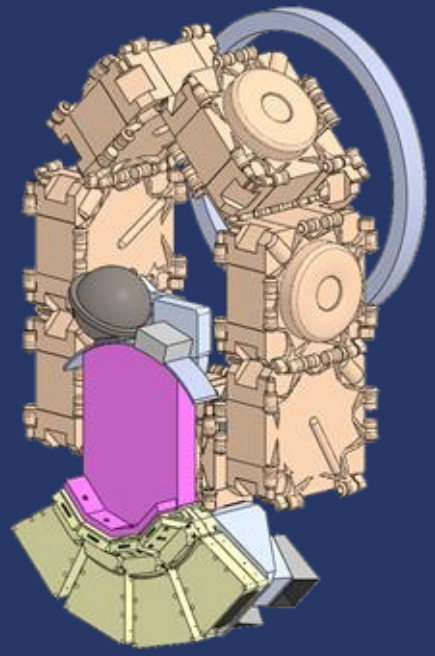
Detector array oriented perpendicular to the satellite ground track to simultaneously collect a single limb-to-limb swath.

Successive readouts of the array represent consecutive swaths providing the necessary spatial coverage of the TOA radiation fields for nominal observations.

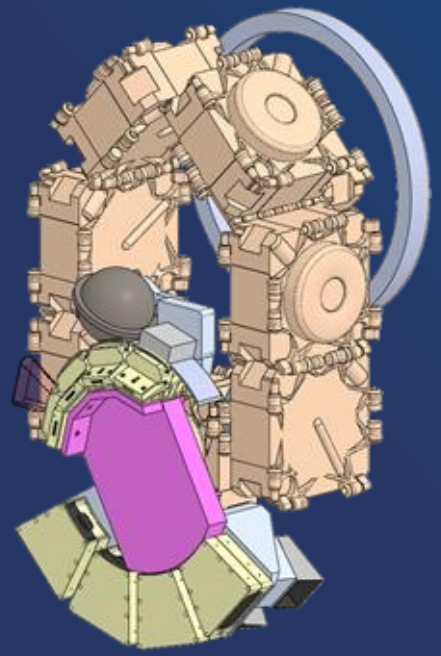




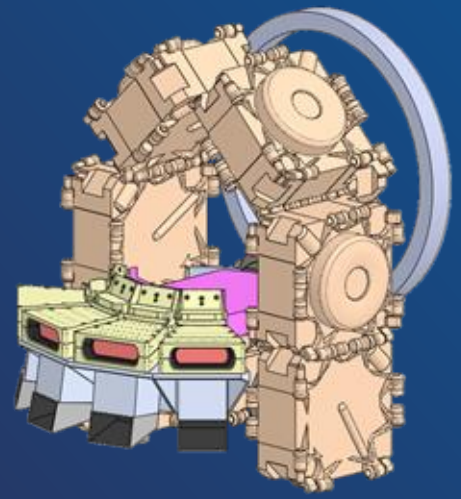
DEMETER
Concept of Operations



Earth Viewing

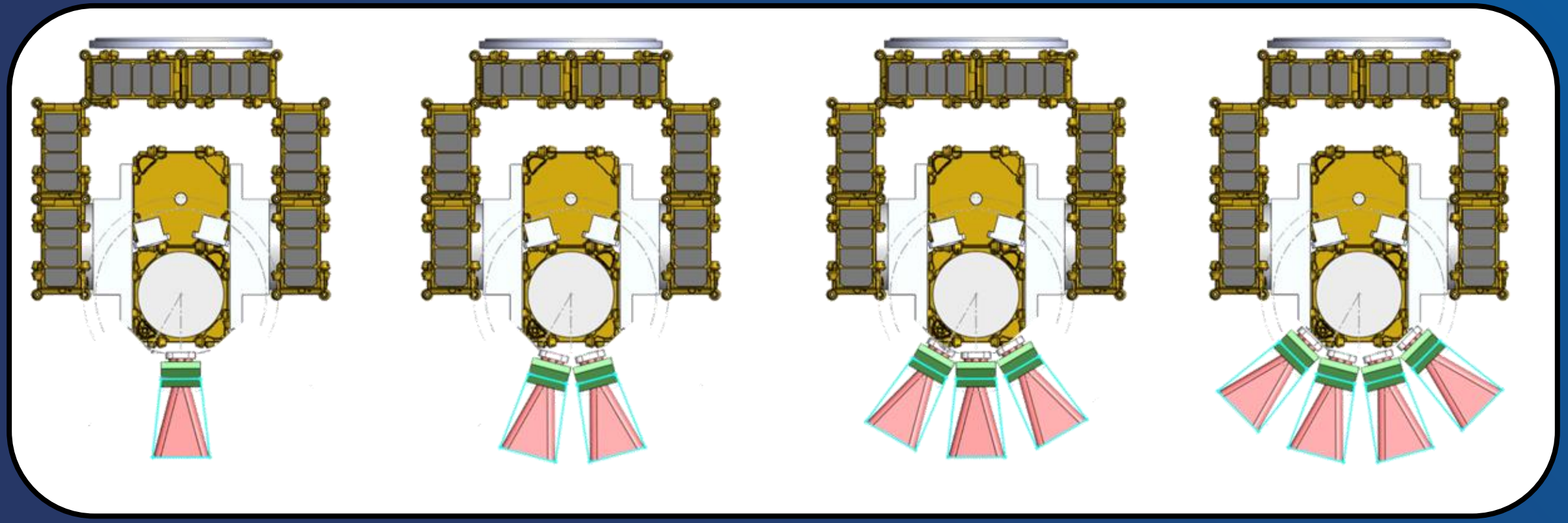


On-Board Calibration
(rotate about Azimuth Axis (AZ))



Space Viewing
(rotate about Elevation (EL) Axis)

Rapidly Reconfigurable **Architecture**



$FOR_{system} = N_{telescope} * FOV_{telescope}$

$FOV_{telescope}$ = 30 Deg (w/overlap)

For global coverage in <u>24 hours</u>
from ~600 Km Altitude Constellation

- 1 orbital plane
- 1 sensorcraft per orbit

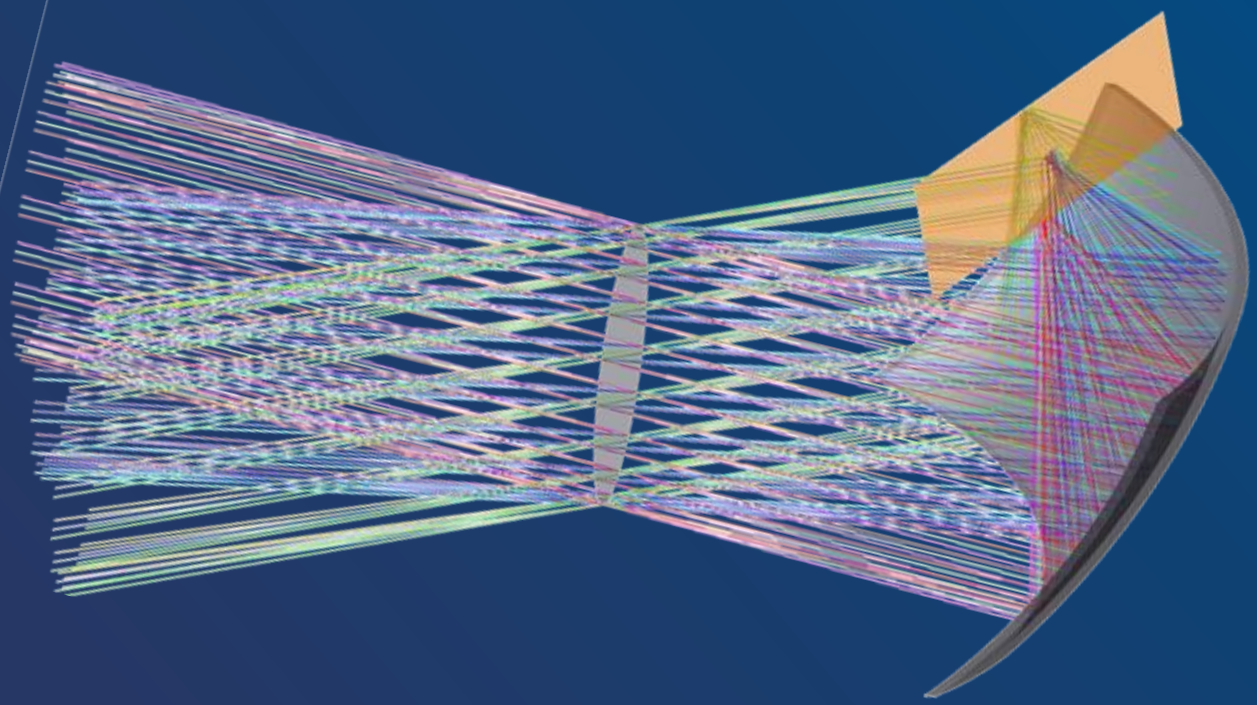
2018 IRAD

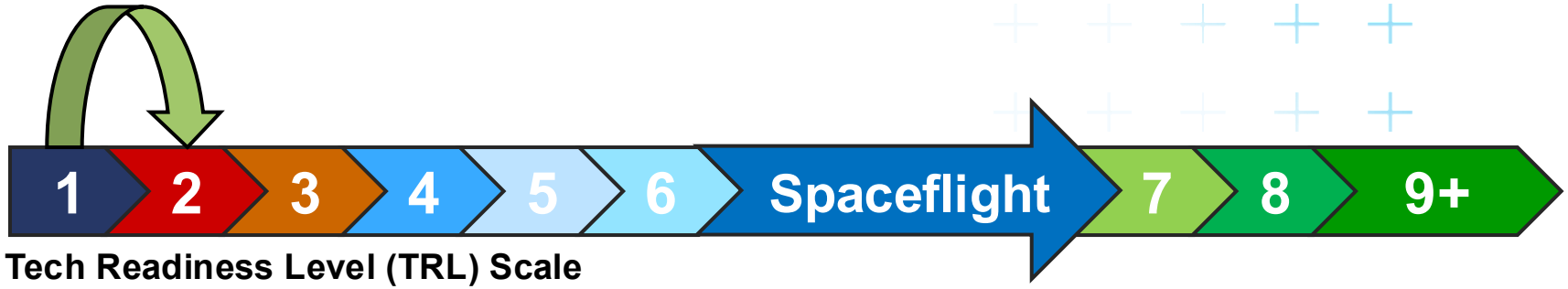
Internal Research and Development

Competitively selected initial proof of concept study to flesh out the DEMETER design and specifications at NASA Center level.

Met with Systems Engineers and industry partners to generate a system-level mission concept.

Basic BUS trades between hosted payloads on JPSS vs on a free-flyer.





Tech Readiness Level (TRL) Scale

2019
IIP-19

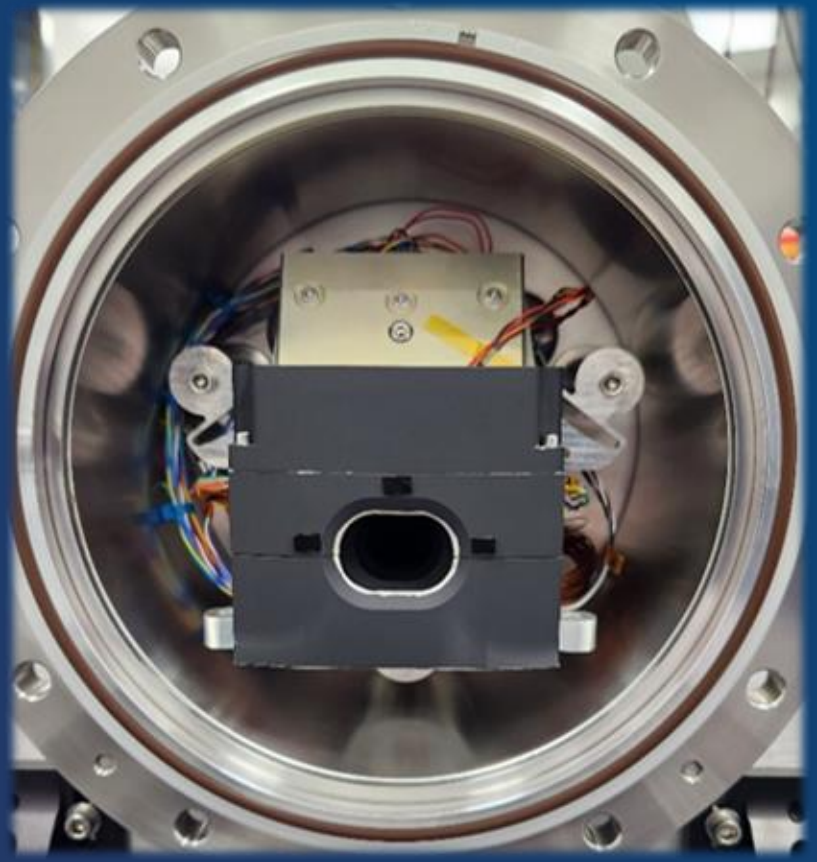
Instrument Incubator Program

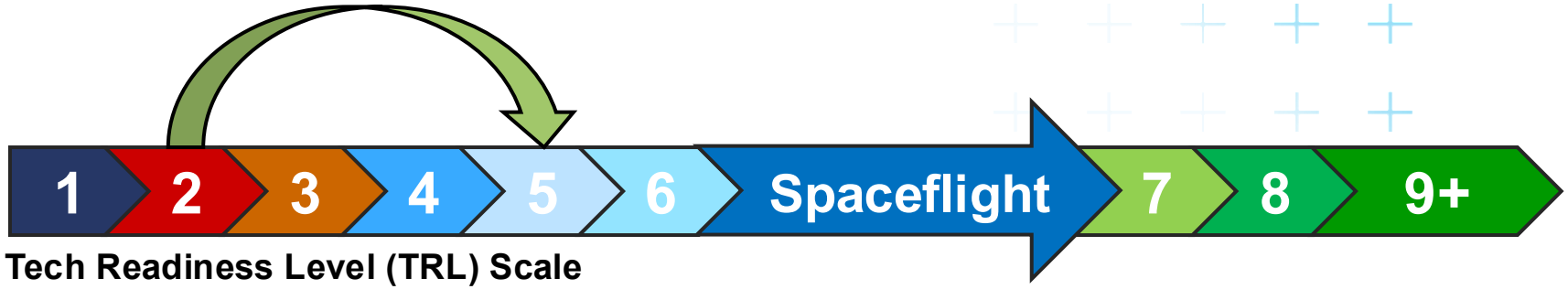
Competitively selected, peer-reviewed activity at NASA HQ level.

Selected industry partners and pulled together NASA Langley team.

Began hardware development and initial testing to advance TRL.

Ended with sensor module and shortwave calibration source at TRL 5.





Tech Readiness Level (TRL) Scale

2023 IIP-23

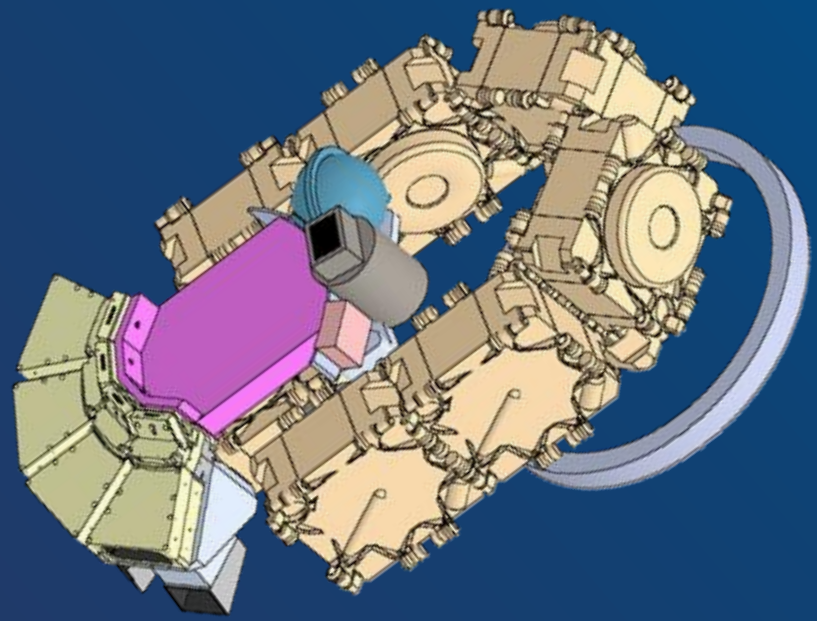
Late-stage technology development to bring hardware up to TRL 6.

Key Activities:

- Update and full-scale testing of optical sensor module
- Design and build longwave calibration source
- Update and test shortwave calibration source

Mission study team is concurrently developing the goals, requirements, risks, and concept of operations details for a flight opportunity.

Next TRL advancement would require spaceflight or a flight-like activity.



Tech Readiness Level (TRL) Scale

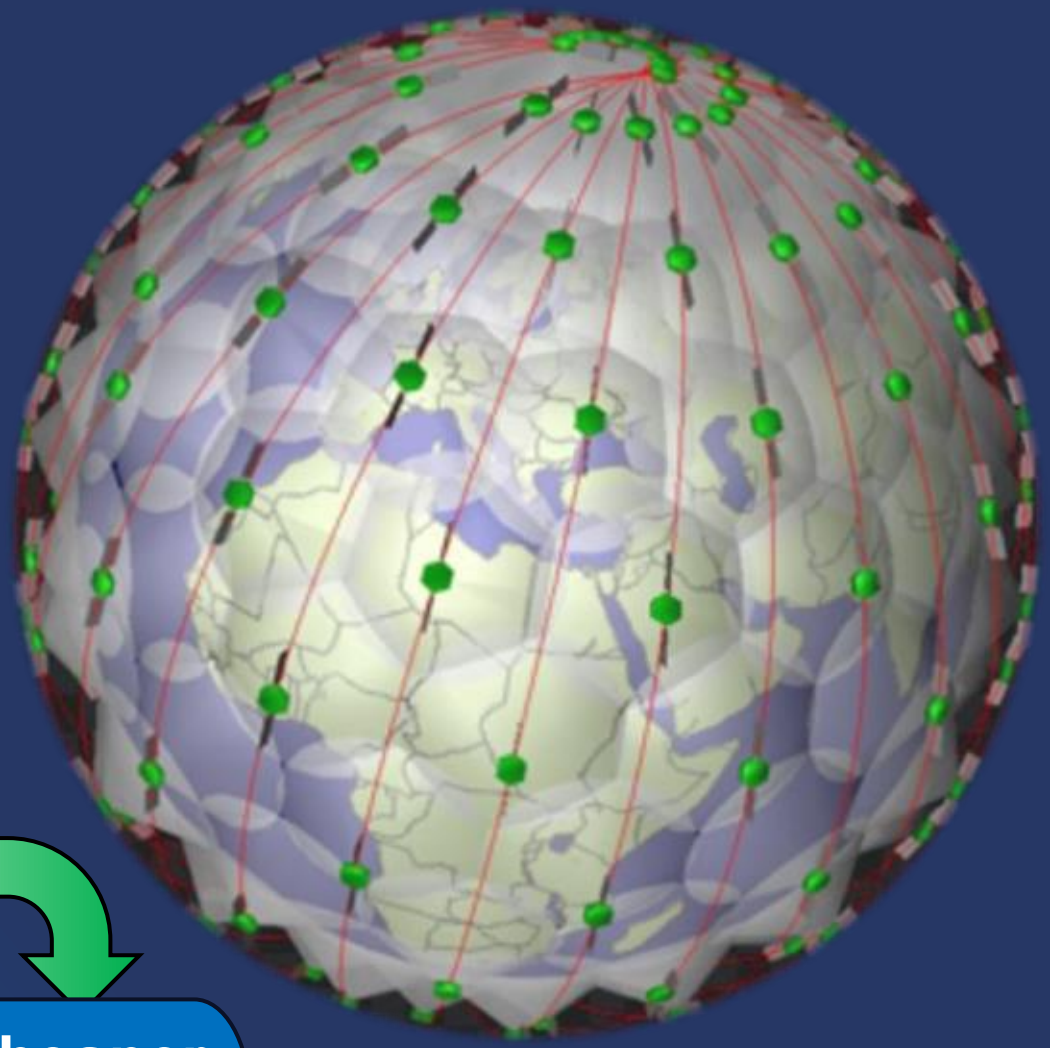
DEMETER
Vision for the Future

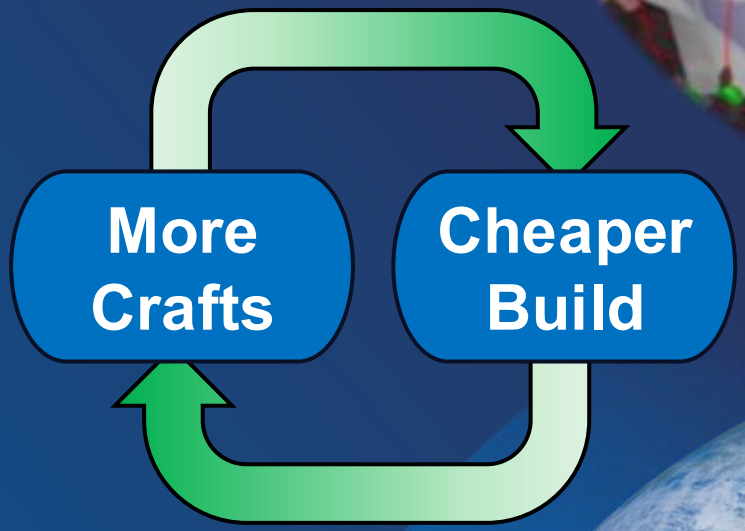
The Future of DEMETER is a
Constellation

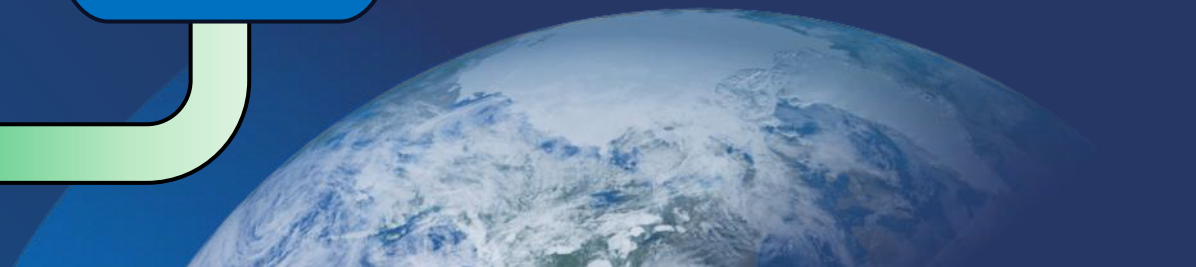
Because the DEMETER is based on a modular, free-flyer architecture, it will be able to be rapidly reconfigured for any orbit.

Producing more HISats reduces costs, which allows for more HISats to be built.

A constellation such as the one pictured would allow for ***instantaneous*** global coverage.







NASA Earth

Your Home.

Our Mission.

science.nasa.gov/earth