Towards a U.S. Framework for Continuity of Satellite Observations of Earth's Climate and for Supporting Societal Resilience

Keck INSTITUTE FOR SPACE STUDIES

Study Co-Chairs

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NASA Jet Propulsion Laboratory
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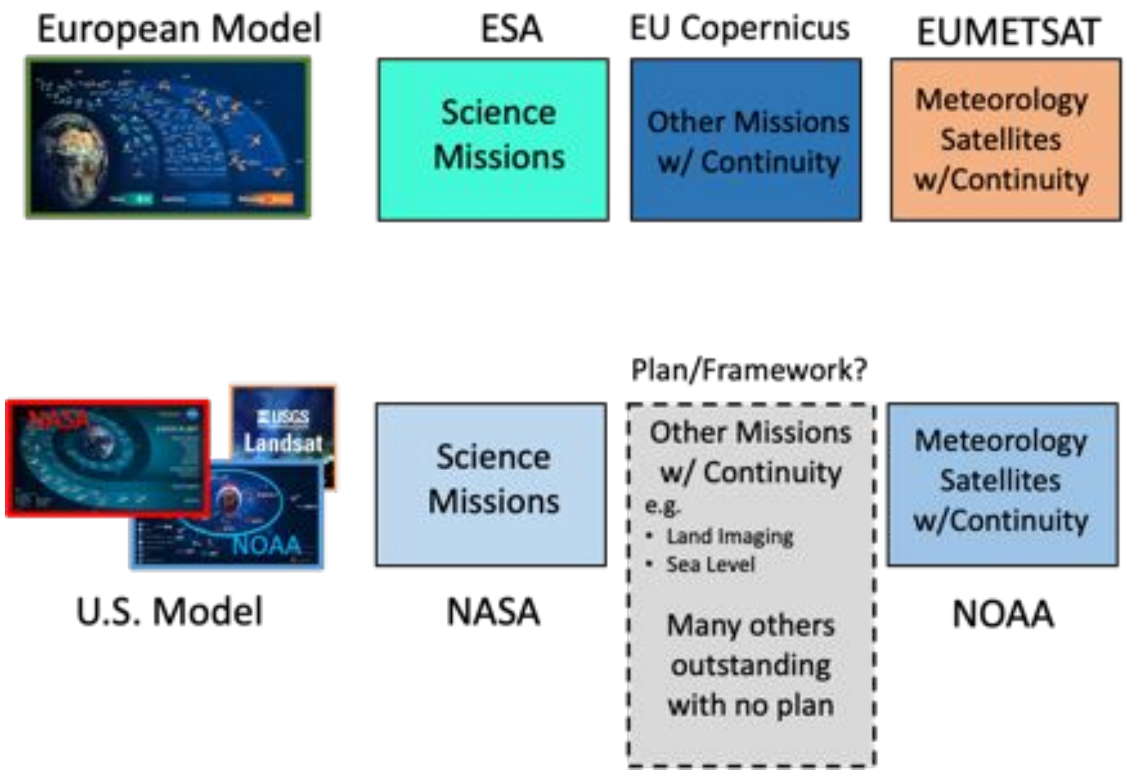
Presentation to NOAA-NASA-USGS
October 25, 2023

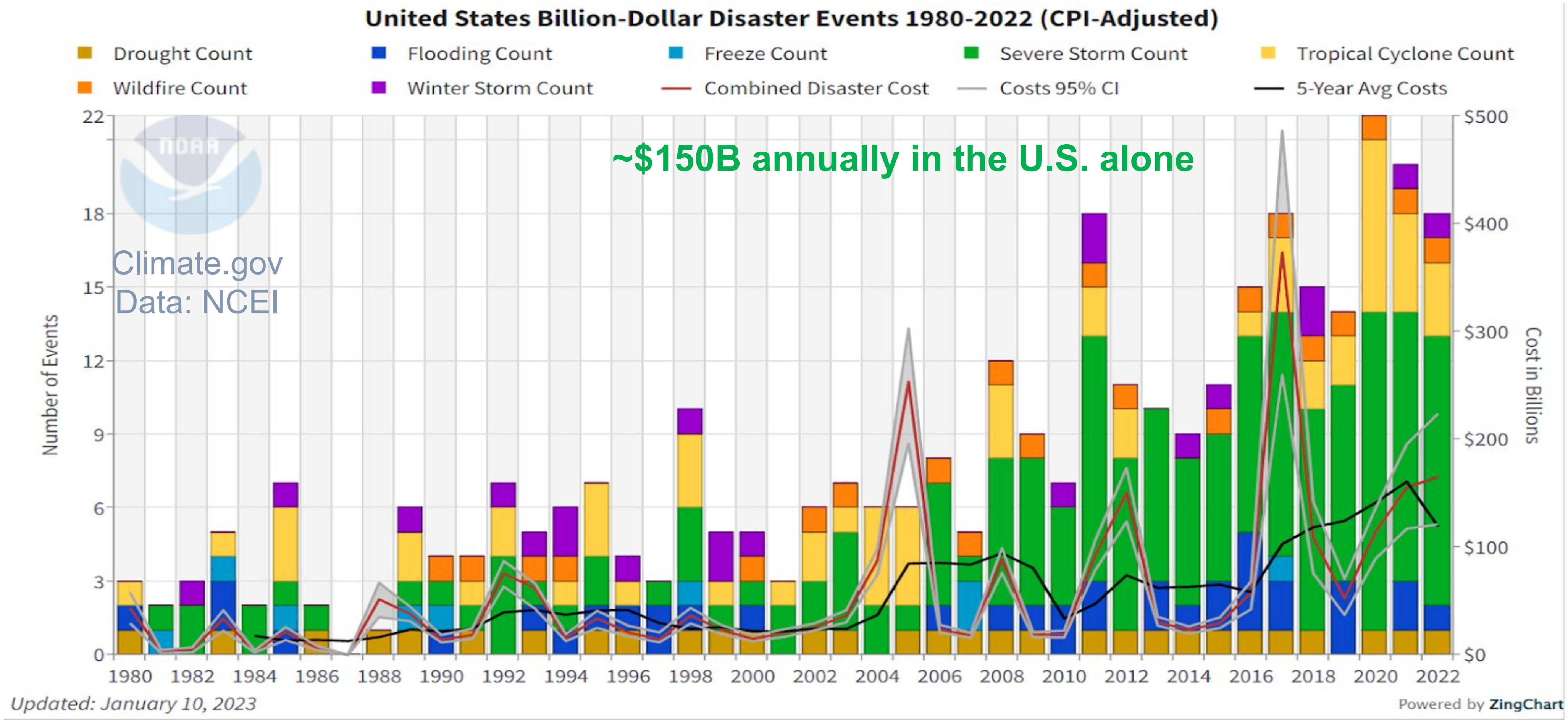
Presented on behalf of the **KISS Study Team**

Questions for the U.S. Concerning Sustained Observations



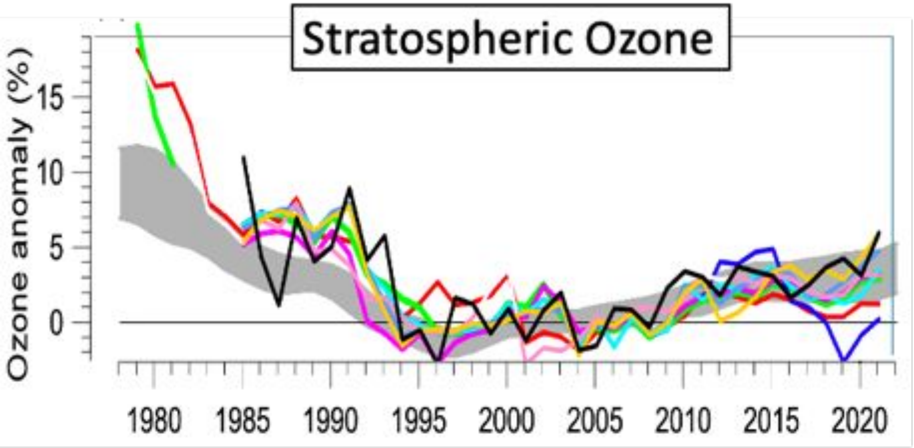
- Apart from weather, what are our national priorities for sustained Earth observations?
- What paradigm will the U.S. use as the basis for setting these national priorities?
- What organization or body will be chartered to develop these priorities for the U.S.?
- What is our national approach to implementing sustained Earth observations that meet these priorities, including the information production and delivery services?

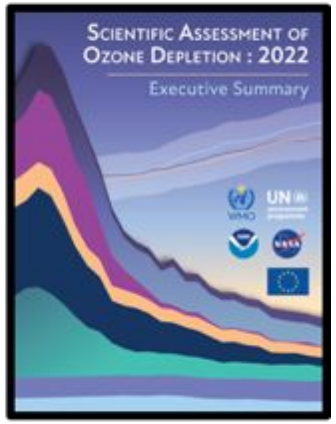
Damages From Climate-related Disasters Have Quadrupled Between 1980's And 2010's

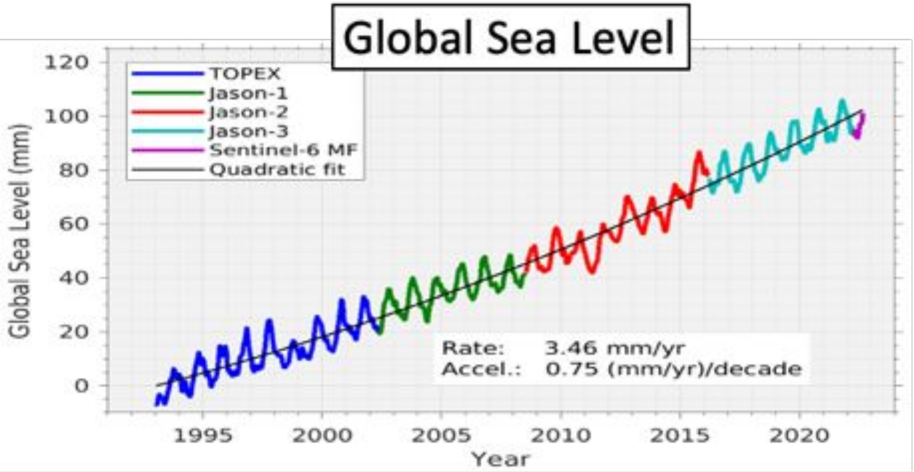


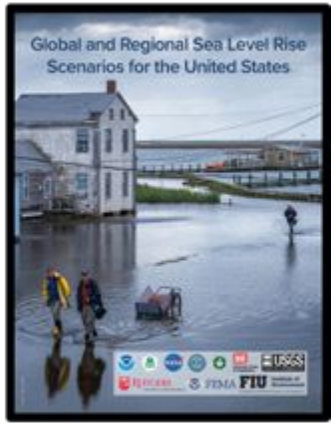
There is growing urgency for improved public and commercial services to support a resilient, secure, and thriving U.S. population and economy, particularly in the face of mounting decision-support needs for environmental stewardship and hazard response, and for climate change adaptation and mitigation actions.

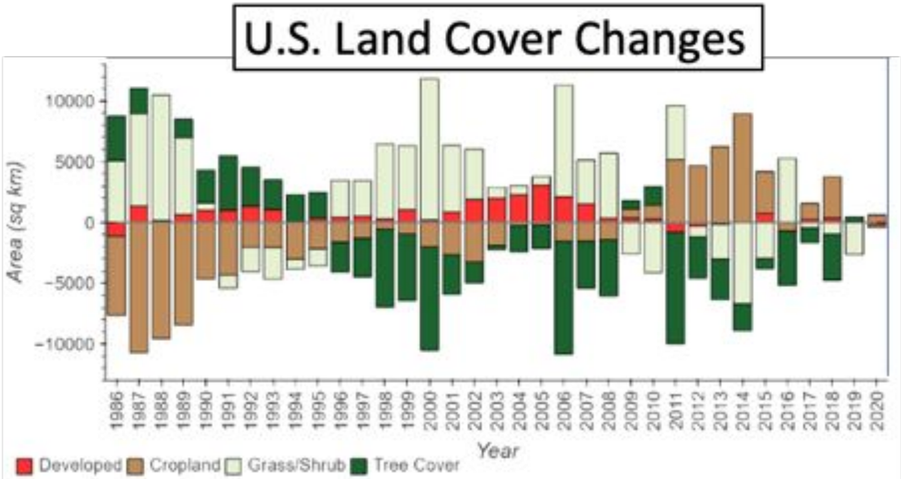
As with weather, significant science and societal benefits have been demonstrated from other long-record, satellite observations of the Earth





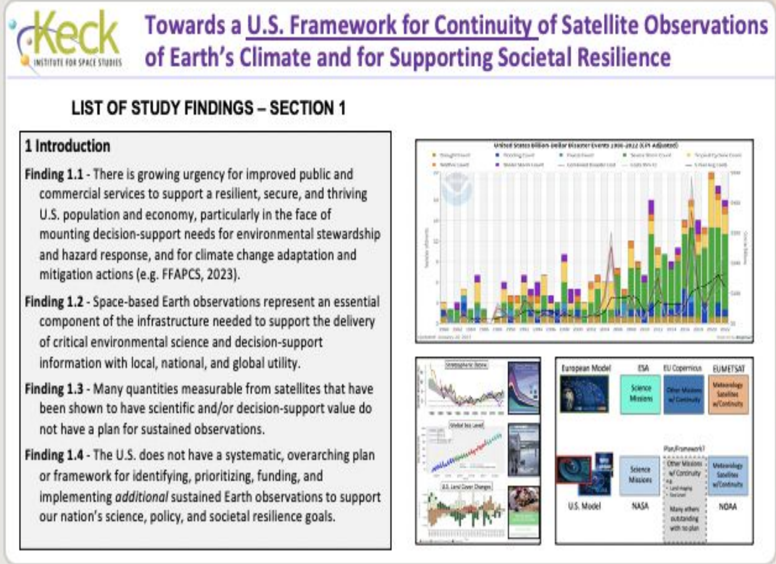






Many quantities measurable from satellites that have been shown to have scientific and/or decision-support value do not have a plan for sustained observations.*

*Examples include: precipitation, soil moisture, streamflow, snowpack, greenhouse gas concentrations and emissions, stratospheric ozone, radiation budget, aerosol/cloud profiles, ocean salinity and surface winds.



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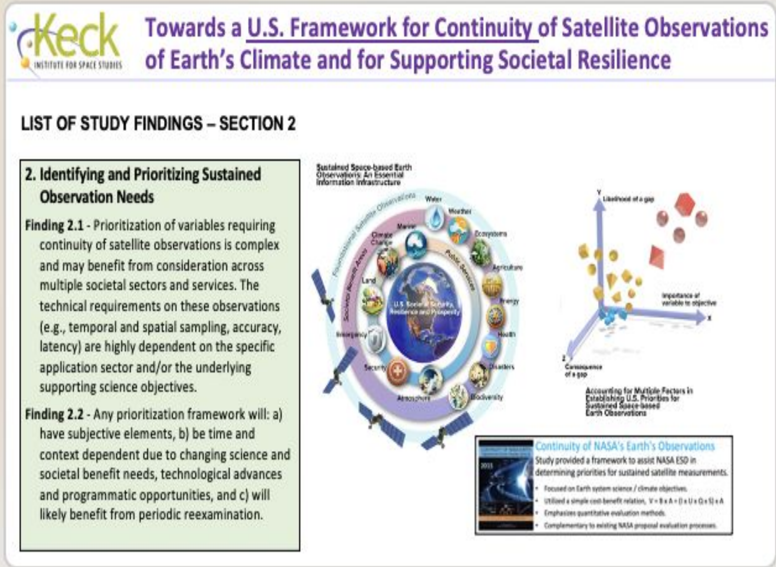

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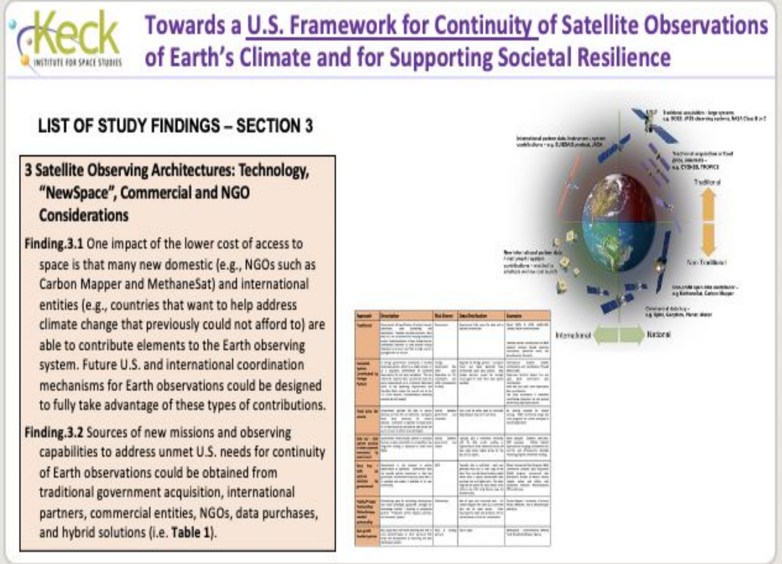

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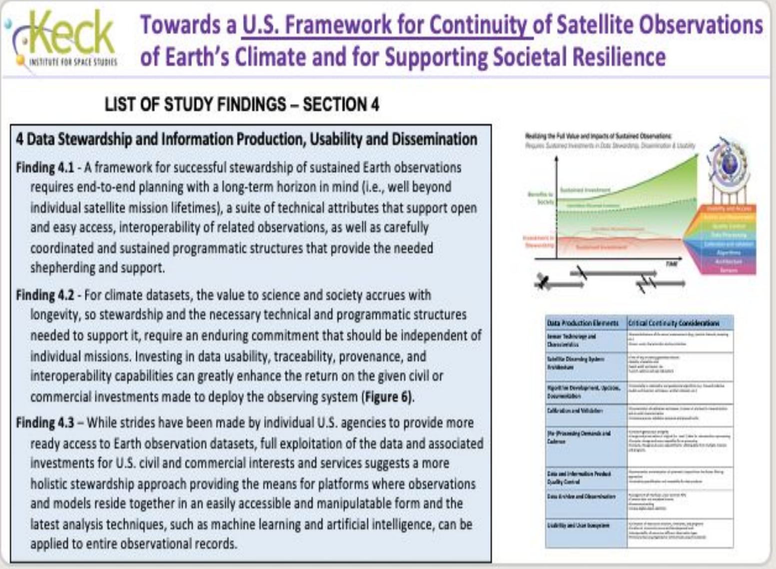

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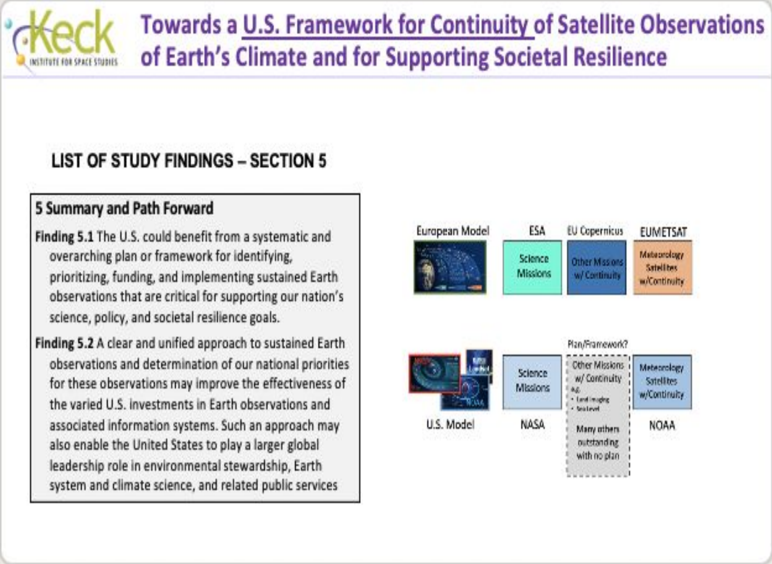

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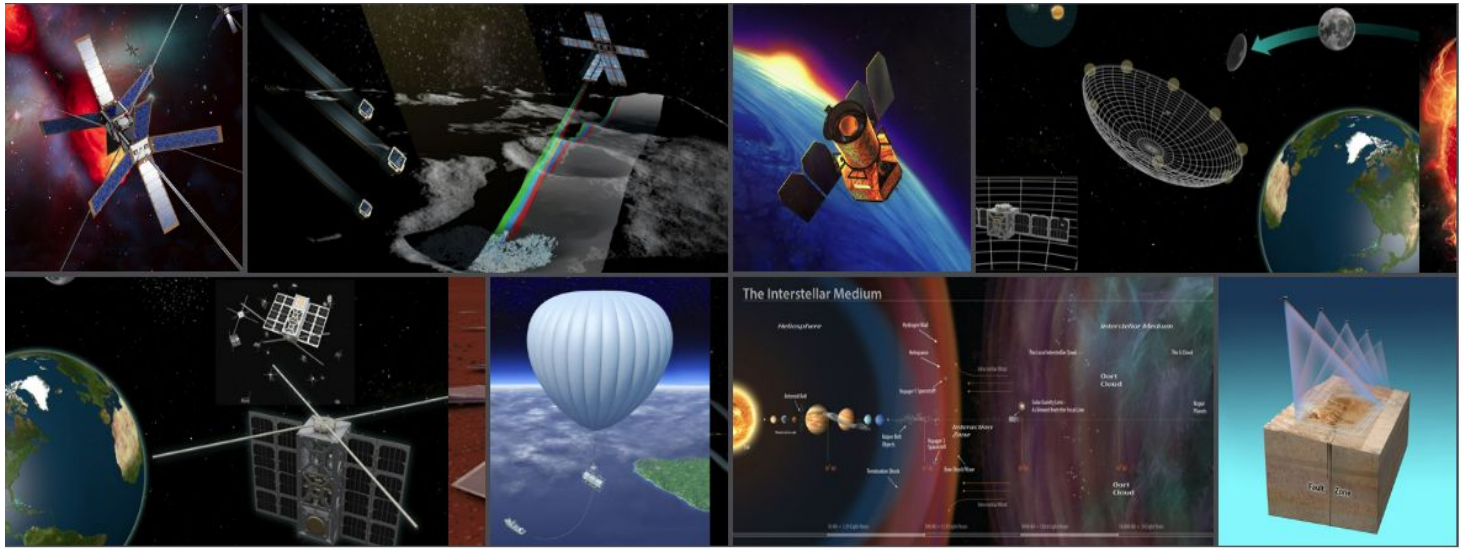
KISS Study 13 Findings Across 5 Sections

KISS Continuity Study Team, *Towards a U.S. Framework for Continuity of Satellite Observations of Earth's Climate and for Supporting Societal Resilience*, ***Earth's Future***, *American Geophysical Union, (To be) Submitted with minor revisions 10/25/2023*



The Keck Institute for Space Studies (KISS) was established at the Caltech in January 2008 with a $24 million grant over 8 years from the W. M. Keck Foundation.

The Institute is a "think and do tank," whose primary purpose is to bring together a broad spectrum of scientists and engineers for sustained technical interaction aimed at developing new space mission concepts and technology.

The Institute is centered on the intellectual, instrumentation, and research strengths of the Caltech Campus and JPL — and augments those strengths by inviting external experts from academia, government, and industry to engage in its programs.

Study Participants

Keck
INSTITUTE FOR SPACE STUDIES

1. **Waleed Abdalati** - University of Colorado Boulder
2. **Nancy Baker** - Naval Research Laboratory
3. **Stacey Boland** – Jet Propulsion Laboratory/Caltech/NASA
4. **Michael Bonadonna** - National Environmental Satellite, Data, and Information Service, NOAA
5. **Carol Anne Clayson** - Woods Hole Oceanographic Institution
6. **Belay Demoz** - University of Maryland, Baltimore County
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8. **Christian Frankenberg** - Caltech
9. **Maria Hakuba** – Jet Propulsion Laboratory/Caltech/NASA
10. **Therese Jorgensen** - NASA Ames Research Center
11. **Ryan Kramer** - University of Maryland, Baltimore County/NASA Goddard Space Flight Center
12. **Daniel Limonadi** – Jet Propulsion Laboratory/Caltech/NASA
13. **Anna Michalak** - Carnegie Institution for Science/Stanford University
14. **Asal Naseri** - Space Dynamics Laboratory
15. **Pat Patterson** - Space Dynamics Laboratory
16. **Peter Pilewskie** - University of Colorado Boulder
17. **Steven Platnick** - NASA Goddard Space Flight Center
18. **Charlie Powell** – University of Michigan / NOAA
19. **Jeff Privette** - NOAA's National Centers for Environmental Information
20. **Chris Ruf** - University of Michigan
21. **Tapio Schneider** - Caltech
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23. **Paul Selmants** - U.S. Geological Survey
24. **Rashmi Shah** – Jet Propulsion Laboratory/Caltech/NASA
25. **Qianqian Song** – University of Maryland, Baltimore County
26. **Graeme Stephens** – Jet Propulsion Laboratory/Caltech/NASA
27. **Timothy Stryker** - USGS National Land Imaging Program
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29. **Mathew Van Den Heever** – University of Colorado
30. **Anna Veldman** – UCLA
31. **Duane Waliser** – Jet Propulsion Laboratory/Caltech/NASA
32. **Elizabeth Weatherhead** - Jupiter Intelligence and University of Colorado Boulder

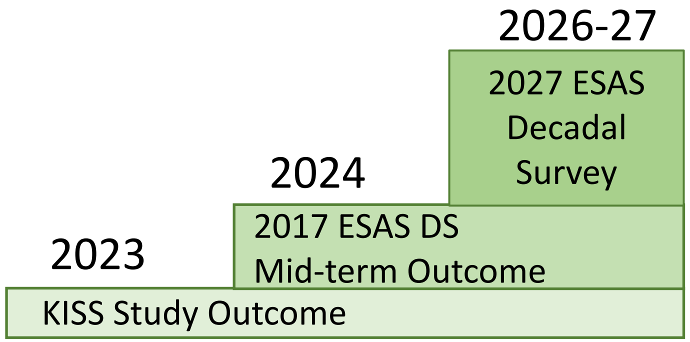
9 on or previously on CESAS and/or 2017 ESAS Decadal Survey
7 Early Career members
4 NASA Centers, 3 NOAA, 2 USGS, Navy, Universities, EUMETSAT, GCOS/CEOS, small sats, etc.

Selected for the 2022 KISS Study Program

Towards a U.S. Framework for Continuity of Satellite Observations of Earth's Climate and for Supporting Societal Resilience

KISS Study Proposal

The goal of this study program is help accelerate discussions and plans for a greater and more impactful U.S. contribution to the global climate observing system. *In this context, "climate" includes observations that support climate science and process understanding, as well as monitoring for situational awareness, climate services, impact response, adaptation, and mitigation assessments.*



Aspiration: *Aid/support the anticipated upcoming NASEM discussions regarding satellite-based climate observing system*

KISS Proposal : Figure 2

Study Website
https://kiss.caltech.edu/programs.html#satellite_observations

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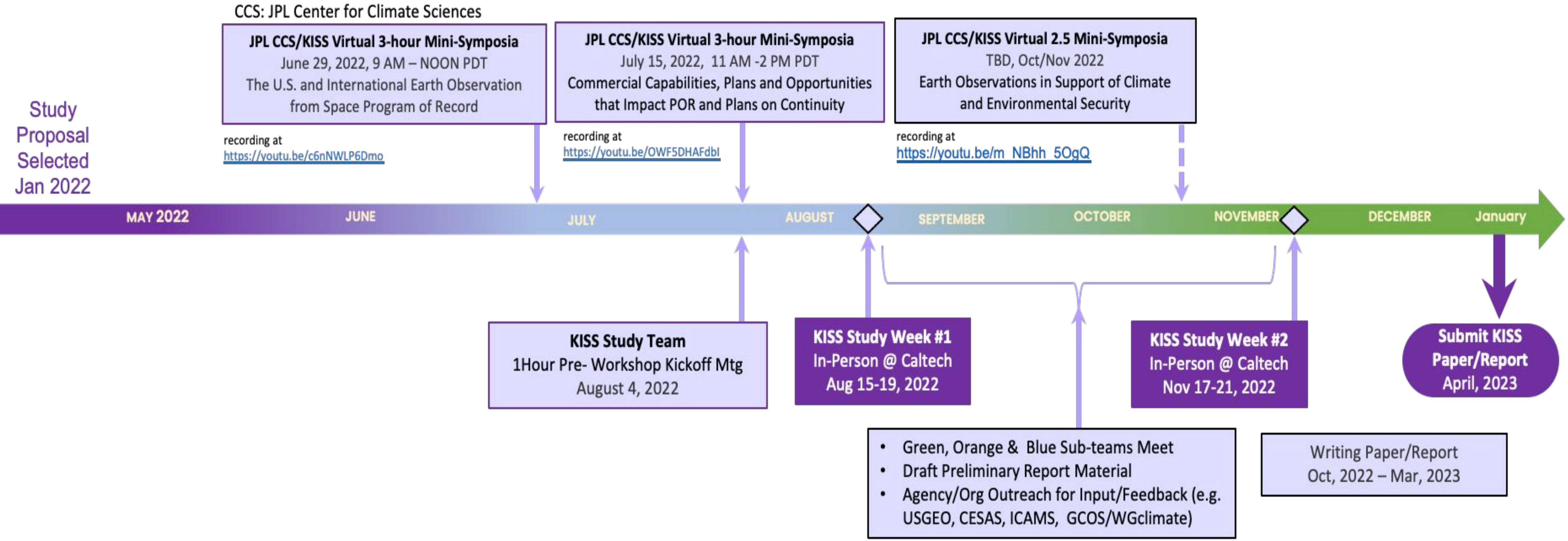
Study Timeline



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Center for Climate Sciences

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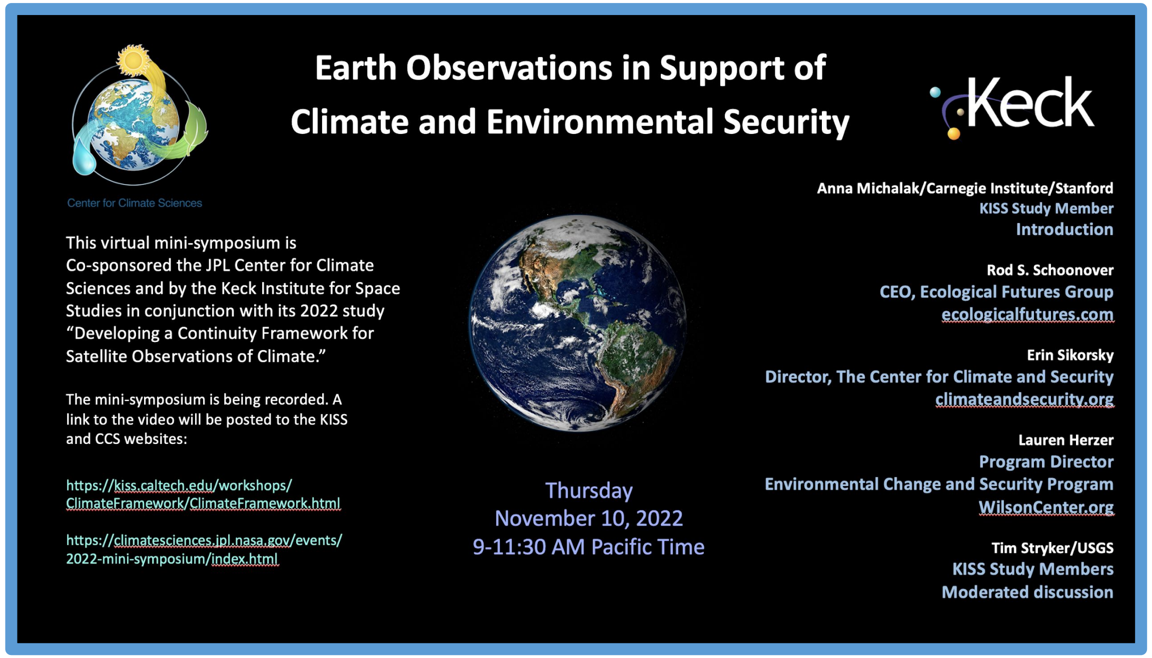
Three Supporting Mini-Symposia: POR, NGO, Climate Security

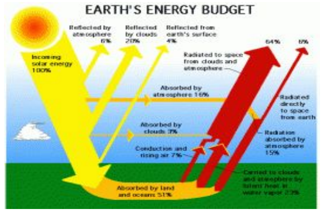
(recorded, links available)



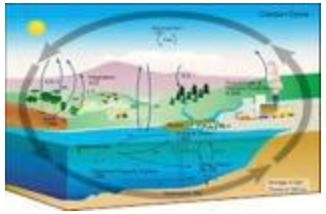

AED

KISS Study 3 Pillar – Left to Right - Approach

Energy Cycle & Resources



Carbon Cycle & Resources



Water Cycle & Resources

? + ? + ?

t | t+10 yrs | t+20 yrs

1What to include?

Observation Priorities Consider approaches to identify and prioritize satellite observables that should be sustained to support Science and Decision Support

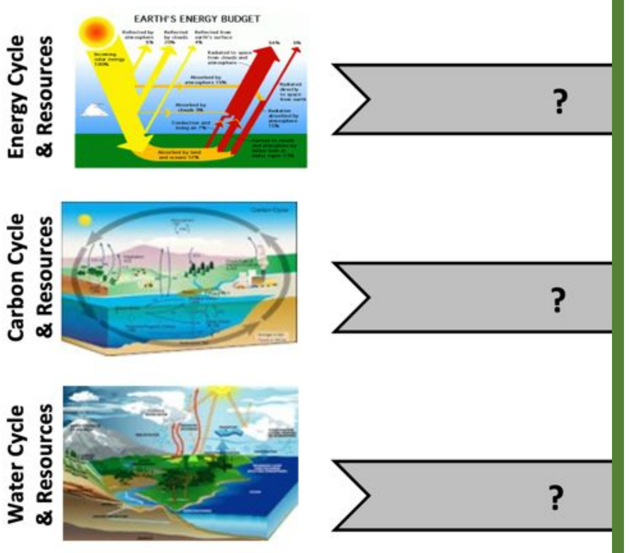
2) How to include?

Architecture Approaches/Configurations: Consider approaches to architecture design and development, including "new space" and technology advances, commercial data, and international considerations.

3) How to sustain & impact?

Stewardship and Implementation: Consider data flow infrastructure and operations, calibration & validation, uncertainty quantification and traceability, data stewardship best practices, dissemination.

Green Team – What to Include? How to Identify/Prioritize?



1What to include?

Observation Priorities Consider approaches to identify and prioritize satellite observables that should be sustained to support Science and Decision Support

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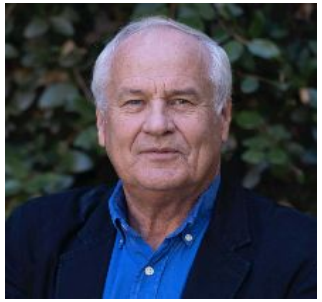

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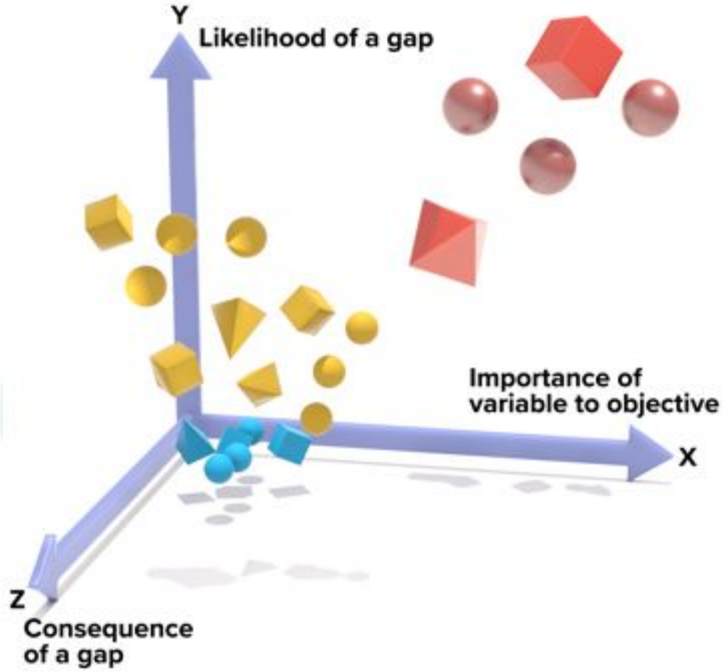
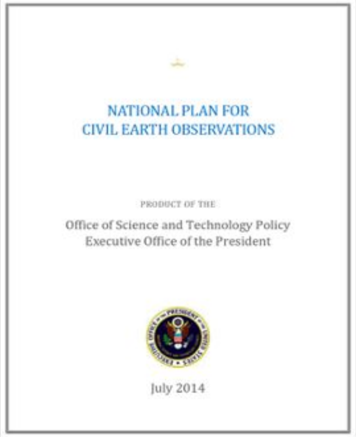
Start with Identifying and Prioritizing Sustained Observation Needs for the U.S.

Example Framework To Highlight Multi-Dimensional Considerations for Sustained Observation Priorities



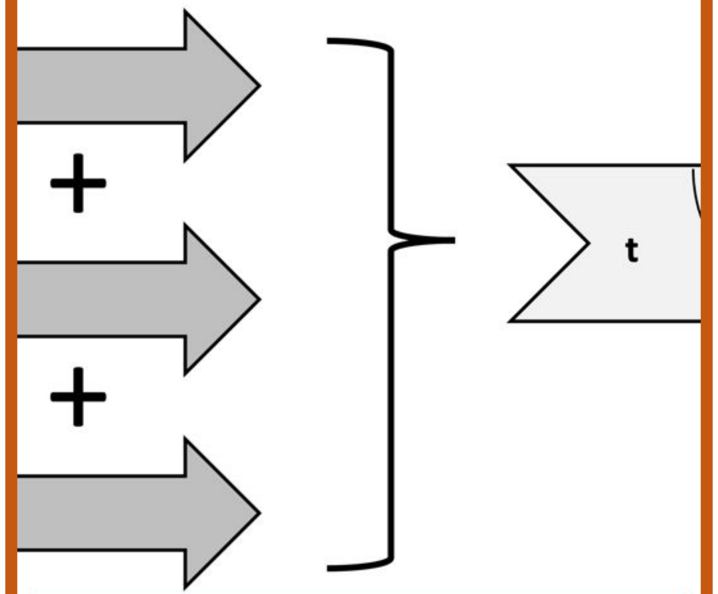


12 Societal Benefit Areas (SBAs)

Agriculture and Forestry
Biodiversity
Climate
Disasters
Ocean and Coastal Resources
Energy and Mineral Resources
Ecosystems
Human Health
Space Weather
Transportation
Water Resources
Weather

c.f. 2015 NASEM Study on Continuity – Value Framework for Science and "QESOs"

Orange Team – How to include? Architecture options?



2) How to include?

Architecture Approaches/Configurations: Consider approaches to architecture design and development, including "new space" and technology advances, commercial data, and international considerations.

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Pat Patterson –
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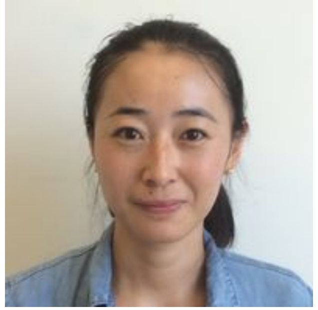
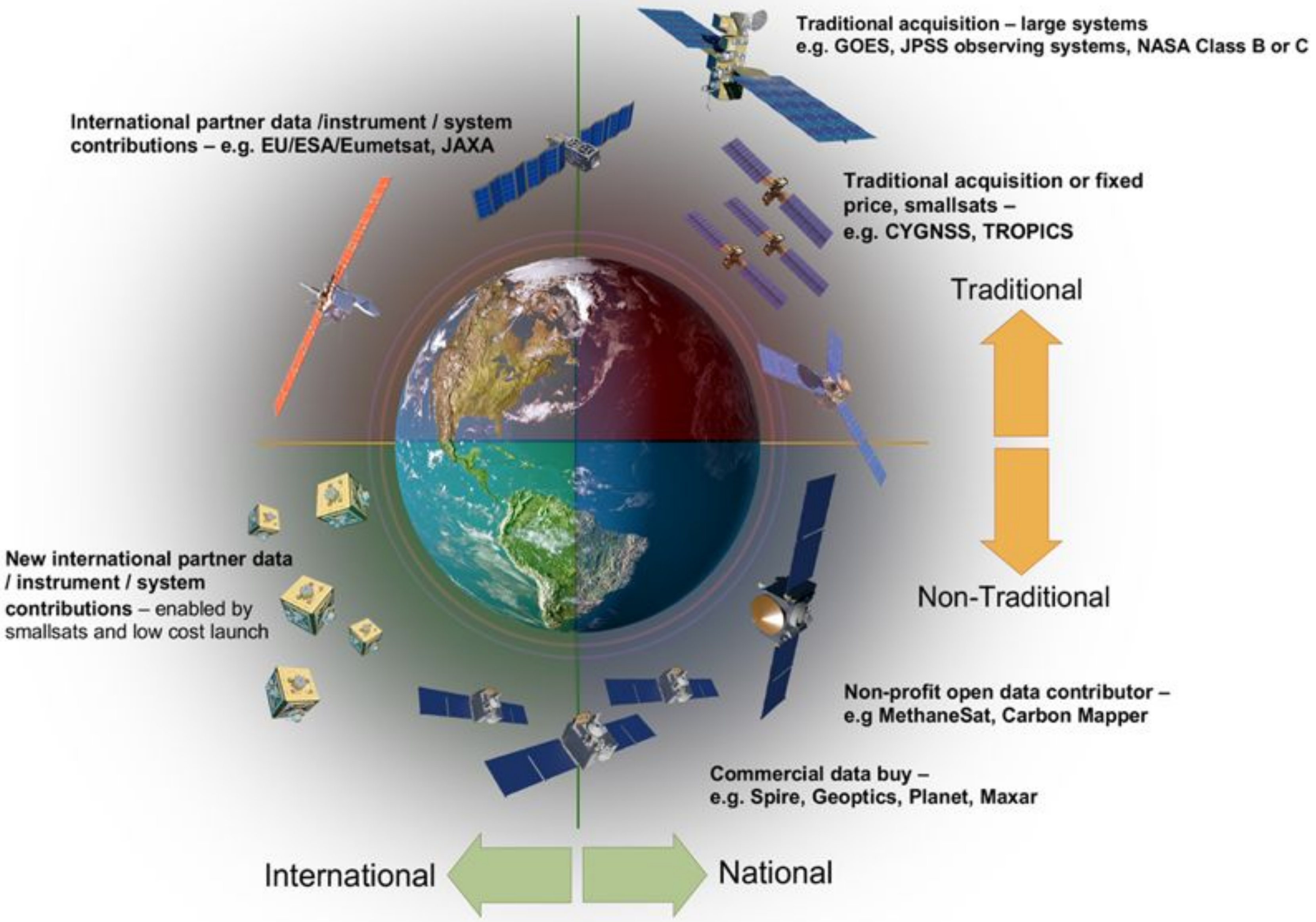


Qianqian Song
U Maryland/BC

Expanding Opportunities for Contributing to and Sustaining Earth Observations



Lower cost of access to space is increasing the sources able to contribute elements to the Earth observing system.

- traditional government agencies
- international partners
- commercial entities with data buys
- NGOs and non-profit
- hybrid solutions

Leveraging "NewSpace", the Latest Technologies, Commercial and NGO Opportunities

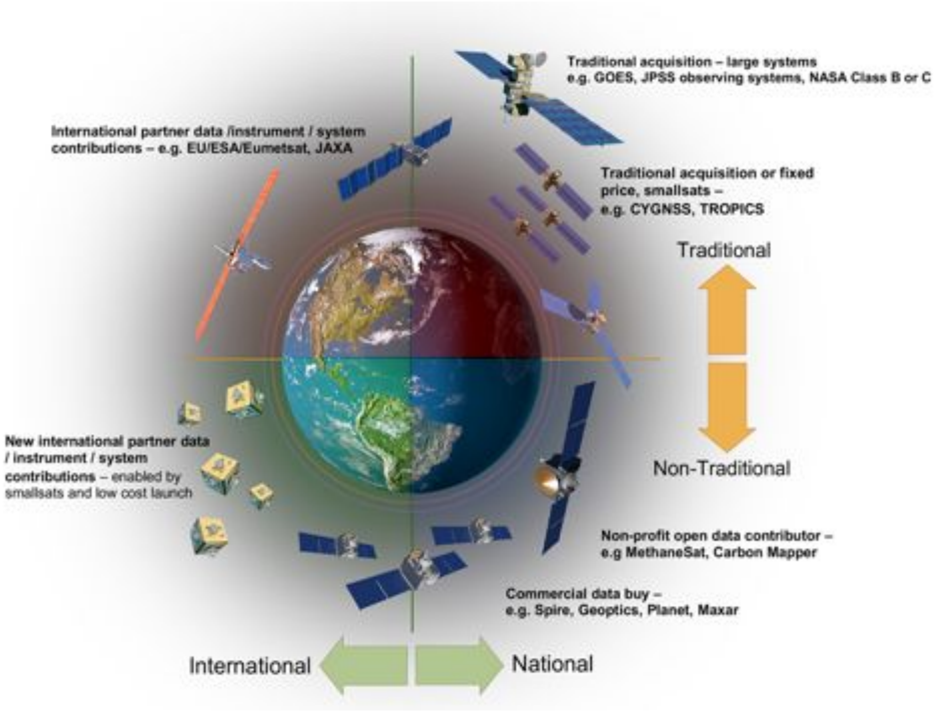
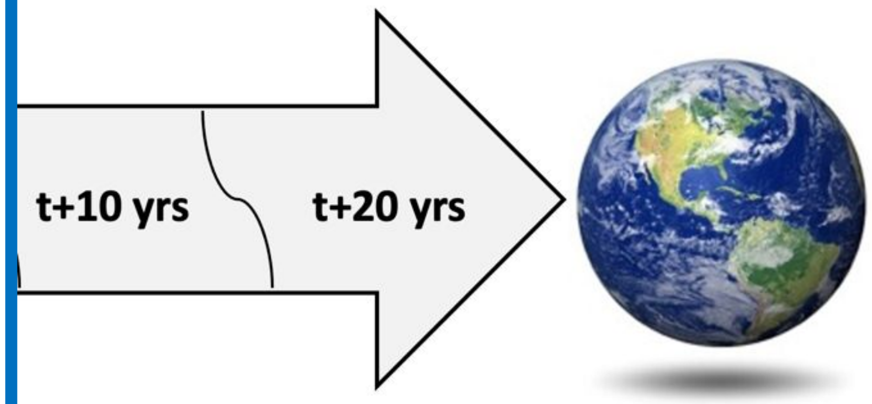


Table 1. Summary of current and potential future acquisition & support models

Approach	Description	Risk Owner	Data Distribution	Examples
Traditional	Government full specification of system, launch, operations, data processing and distribution. Typically, cost-plus contracts. Note that it is not uncommon for existing traditional project implementations to have foreign partner contributed elements to help achieve mutual objectives at a lower cost than a single country paying for the full mission.	Government	Government fully owns the data and is typically unrestricted	NOAA GOES, & NPSS; NASA-USGS Landsat; NASA science missions Example partner contributions for NASA research missions include launches, instruments, spacecraft buses, and ground system elements.
Complete System Contributed by Foreign Partner	A foreign government contributes a needed observing system, either as a single system, or as a long-term commitment of sustained observations for the given variable(s). This can relieve the need for other countries to make the same measurement, or at a minimum help meet some of the observing requirements and therefore likely reduce the overall cost to the U.S. if any residual / complementary observing systems are still needed.	Foreign Government (but other users depending on this contribution also suffer consequences if it fails)	Depends on foreign partner – European Union and Japan generally have unrestricted open data policies. New foreign partners would be strongly encouraged to make their data openly available.	International weather satellite contributions and coordination through WMO-CGMS. Copernicus Sentinel System free and open Earth observation data contributions. JAXA free and open Earth observation data contributions. The Qatar Foundation is interested contributing important ice and ground penetrating radar observations.
Fixed price for service	Government specifies the data or service desired, not how they are delivered. Competes fixed price contracts for service delivery. Contractor is expected to invest some of its own resources and may be able to sell the same services to others once developed.	Shared between government and contractor	Data could be either open or restricted, depending on long term cost share.	No existing example for remote sensing. NASA commercial cargo and crew programs are similar examples in human exploration.
Data buy - with upfront promise or down payment investment by government	Government invests money upfront in company business model, potentially via competition, but long-term funding is expected to come from NGOs.	Shared between government and vendor	Typically, data is somewhat restricted, with the data vendor needing an opportunity to make additional money off data sales unless higher prices for the data are an option.	NASA example - SeaWiFS 1997-2007; DOD examples - Orbital Sidekick hyperspectral imaging constellation has In-Q-Tel and AFVentures's Strategic Financing program investment funding.
Data buy – with no upfront promise by government	Government is not involved in system specification or operation. Government does not provide upfront investment or data buy guarantees. Government only buys data after it is available and makes it available to its user community.	NGO	Typically, data is restricted - each user generally must buy its own copy of the data; There may be future funding models where data is openly distributable after purchase, but at a higher price. The latter might be an option for data whose profit utility is low after long latency (e.g., old weather data).	NOAA Commercial Data Program; NASA Commercial Smallsat Data Acquisition (CSDA) program commercial data distribution models of Maxar, Planet, Capella, IceEye, and others, with substantial National Reconnaissance Office data buys.
Public/Private Partnership: Philanthropy-seeded partnership	Philanthropy pays for technology development and initial prototype spacecraft, arranges for technology transfer / licensing to production partner. Production partner deploys, operates, and maintains systems.	Philanthropy	Mix of open and restricted data. For Carbon Mapper the GHG (Co2 and CH4) data will be open access. Other hyperspectral data and products will be sold by Planet to fund the constellation.	Carbon Mapper - University of Arizona, Planet, NASA/JPL, mix of philanthropies and NGOs.
Non-profit funded system	NGO (typically a non-profit working with one or more philanthropies or other partners) fully funds the development of observing and data distribution system.	NGO & funding partners	Data is open.	MethaneSat - Environmental Defense Fund, New Zealand Space Agency.

Blue Team – How to sustain and make needed impacts?



3) How to sustain & impact?

Stewardship and Implementation: Consider data flow infrastructure and operations, calibration & validation, uncertainty quantification and traceability, data stewardship best practices, dissemination.

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Tapio Schneider
Caltech

Jörg Schulz
EUMETSAT

Timothy Stryker
USGS

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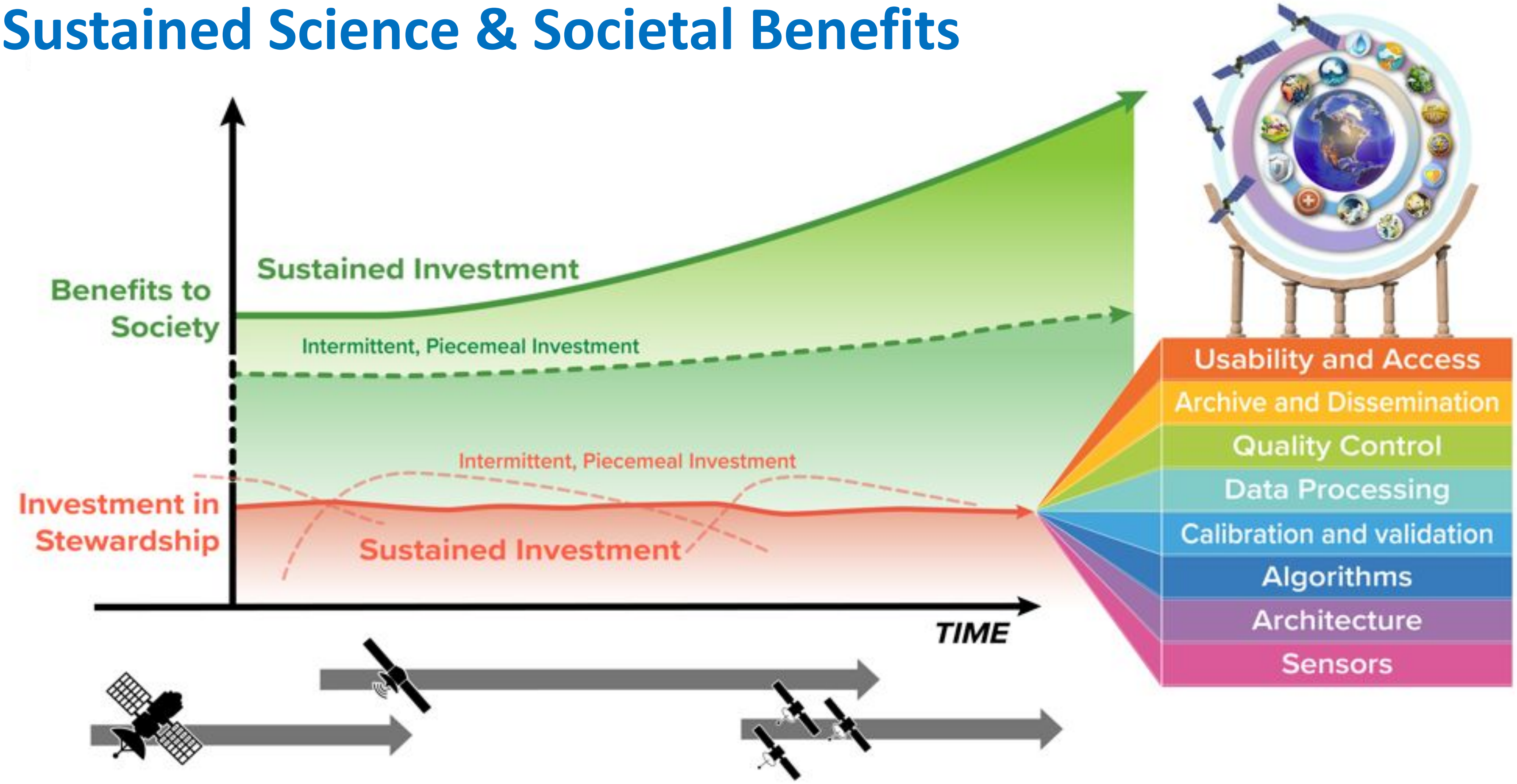
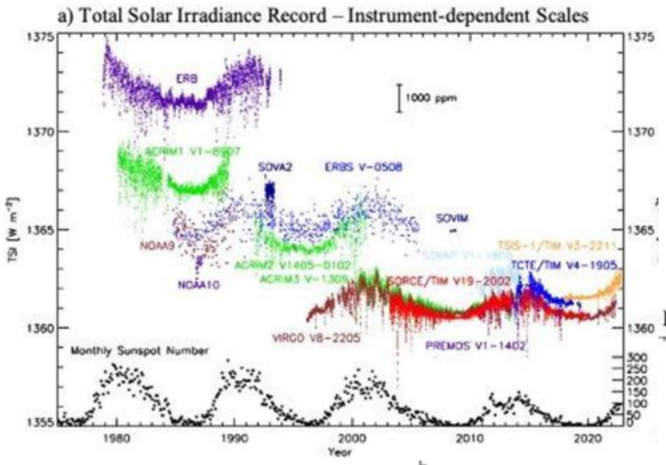
- Jupiter Intelligence

Sustained Observing Systems Yield Sustained Science & Societal Benefits



A framework for successful stewardship of sustained Earth observations requires: **a)** end-to-end planning with a long-term horizon in mind, **b)** a suite of technical attributes and platforms that support open and easy access, **c)** interoperability of related observations, **d)** carefully coordinated and sustained programmatic structures that provide the needed shepherding and support, etc.

Data Stewardship, Information Production, Dissemination & Use



Example highlighting Importance of Data Production Elements of Stewardship

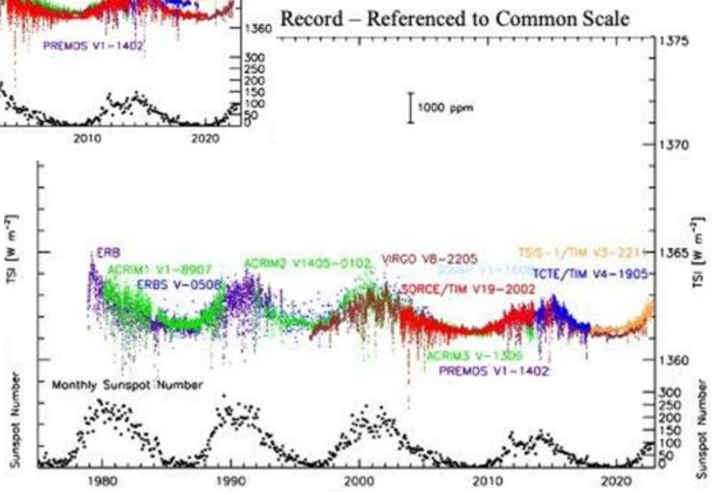
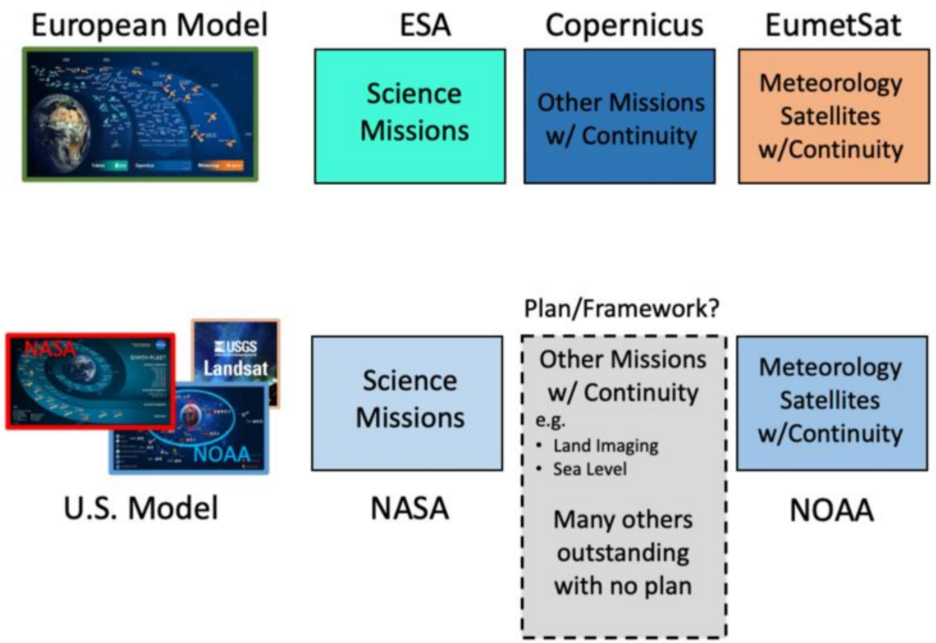


Figure 4.2. *An example of the importance of climate observation continuity. The figure on the left shows incoming radiative energy from the Sun, a fundamental climate data record, from the set of space-based measurements since 1978. The measurements are shown at each instrument's native calibration scale. Because the individual observation records overlap, it enables the construction of the composite record on the right where all measurements are on a common scale. This helps reveal trends in the long-term data record that may have impacts on climate. Figure from G. Kopp (https://spot.colorado.edu/~koppg/TSI/),*

Table 4.1*. Key elements of the data production value chain of satellite-based Earth observations.*

Data Production Elements	Critical Continuity Considerations
Sensor Technology and Characteristics	•Representativeness of the sensor measurements (e.g., spectral channels, sampling, etc.) •Known sensor characteristics and uncertainties
Satellite Observing System Architecture	•Time-of-day or viewing geometry impacts •Stability of satellite orbit •Swath width and revisit rate •Launch cadence and gap risk posture
Algorithm Development, Updates, Documentation	•Commonality in radiometric and geophysical algorithms (e.g., forward radiative models and inversion techniques, ancillary datasets, etc.)
Calibration and Validation	•Documentation of calibration techniques, inclusive of pre-launch characterization and on-orbit characterization •Consistency across validation protocols and ground truths
(Re-)Processing Demands and Cadence	•Consistent geolocation and grids •Lineage and preservation of original (i.e. Level 1) data for retrospective reprocessing •Compute, storage and access capability for re-processing •Compute, storage and access capabilities for utilizing data from multiple missions and programs.
Data and Information Product Quality Control	•Documentation and evaluation of systematic impacts from the chosen filtering approaches •Uncertainty quantification and traceability for data products
Data Archive and Dissemination	•Management of interfaces under common APIs •Common data and metadata formats •Provenance tracking •Unique digital object identifier
Usability and User Ecosystem	•Co-location of data across missions, timeseries, and programs •Curation of community access and development tools •Interoperability of use across different observation types •Permissive licensing regimes for commercially acquired datasets

Path Forward and Next Steps

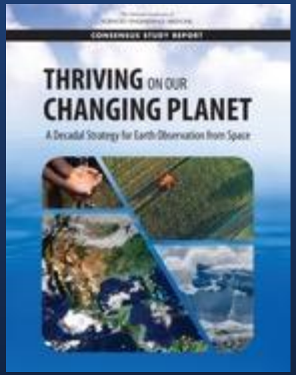


The U.S. could benefit from a systematic and overarching plan or framework for identifying, prioritizing, funding, and implementing sustained Earth observations that are critical for supporting our nation's science, policy, and societal resilience goals.

A clear and unified approach to sustained Earth observations and determination of our national priorities for these observations may improve the effectiveness of the varied U.S. investments in Earth observations and associated information systems. Such an approach may also enable the United States to play a larger global leadership role in environmental stewardship, Earth system and climate science, and related public services

- Formal KISS Study Completed in the Summer of 2023
- ***KISS Continuity Study Team***, Towards a U.S. Framework for Continuity of Satellite Observations of Earth's Climate and for Supporting Societal Resilience, ***Earth's Future***, *American Geophysical Union, (To be) Submitted with minor revisions 10/25/2023*
- *The team is organizing 'Continuity' sessions at AGU'22 and AMS'23.*

Earth Science and Applications from Space Decadal Surveys



2017 Recommendation 2.2: NASA—with NOAA and USGS participation—should engage in a formal planning effort with international partners (including, but not limited to ESA, EUMETSAT, and the European Union via its Copernicus Program) to agree on a set of measurements requiring long-term continuity and to develop collaborative plans for implementing the missions needed to satisfy those needs. This effort to institutionalize the sustained measurement record of required parameters should involve the scientific community, and build on and complement the existing domestic and international Program of Record.

2017 Recommendation 4.6: NASA ESD should employ the following guidelines for maintaining programmatic balance:

- New Measurements versus Data Continuity. Lead development of a more formal continuity decision process (as in NASEM, 2015) to determine which satellite measurements have the highest priority for continuation, then work with U.S. and international partners to develop an international strategy for obtaining and sharing those measurements.

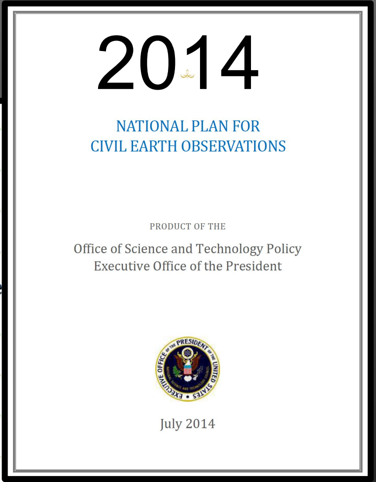
2017 Recommendation 4.7: NASA should make the following scope changes to its program elements:

- Technology Program. Establish a mechanism for maturation of key technologies that reduce the cost of continuity measurements.

2007 Recommendation: The Office of Science and Technology Policy, in collaboration with the relevant agencies and in consultation with the scientific community, should develop and implement a plan for achieving and sustaining global Earth observations.

National Plan for Civil Earth Observations

The purpose of the National Plan for Civil Earth Observation is to help coordinate Federally-supported Earth observations and investments, identify opportunities to advance Earth observations, and achieve national Earth observation policy objectives. This plan serves as a resource to assist Federal departments and agencies (hereafter, "agencies") in their planning, coordination, identifying high-leverage research and development opportunities, and avoiding unnecessary duplication and redundancy. This plan should help inform the normal budget process through which resources are allocated. Under the NSTC which has the responsibility to ensure R&D is coordinated across Federal departments and agencies, the USGEO Subcommittee will use this plan to coordinate implementation of the recommended actions.

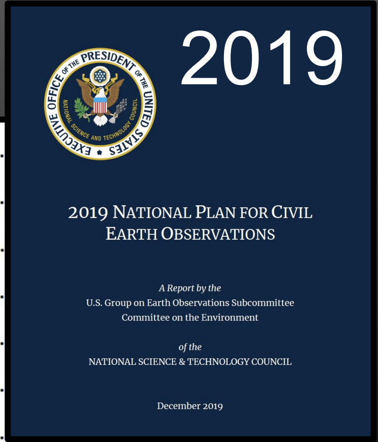

2014

NATIONAL PLAN FOR
CIVIL EARTH OBSERVATIONS

PRODUCT OF THE

Office of Science and Technology Policy
Executive Office of the President

July 2014


2019

2019 NATIONAL PLAN FOR CIVIL EARTH OBSERVATIONS

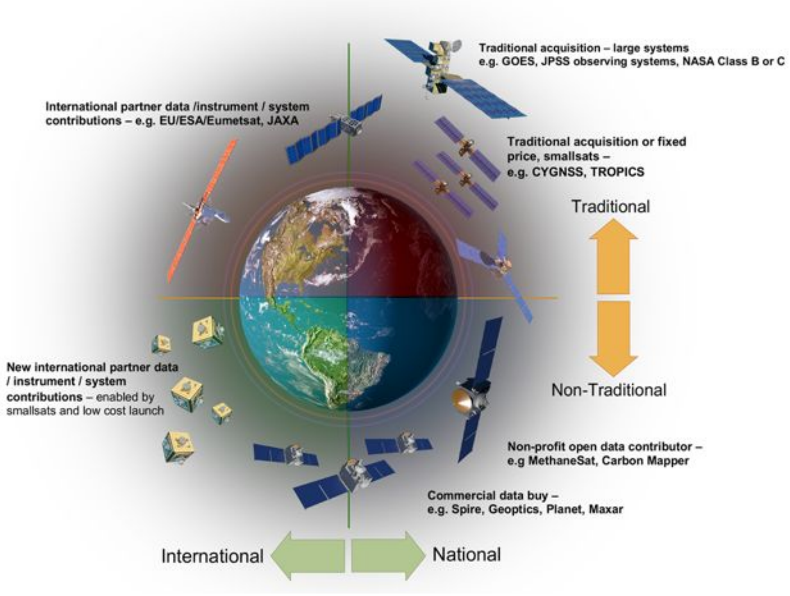
A Report by the
U.S. Group on Earth Observations Subcommittee
Committee on the Environment

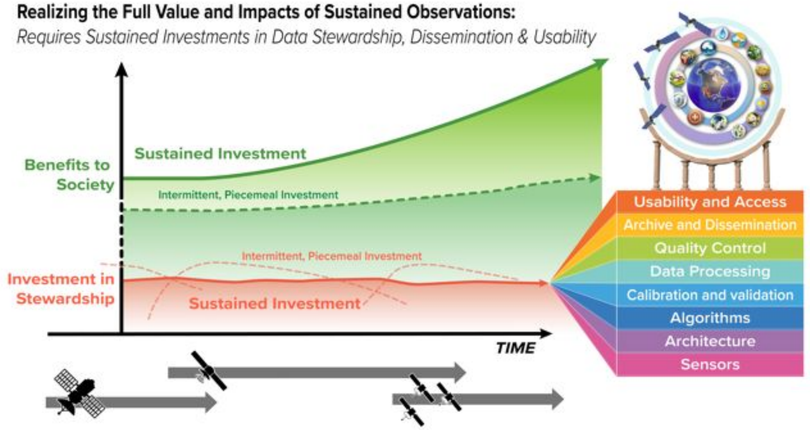
of the
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

December 2019

RFI FOR REVIEW OF 2023 PLAN
FORTHCOMING ~NOV, 2023

Towards a U.S. Framework for Continuity of Satellite Observations of Earth's Climate and for Supporting Societal Resilience

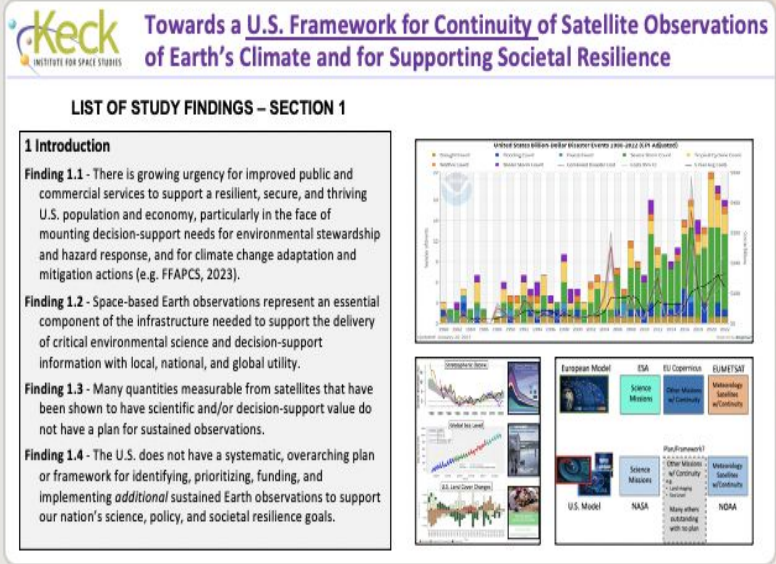




Accounting for Long-term Programmatic and Technical Support

Developing Architecture Options & Opportunities

Identifying Science and Application Priorities



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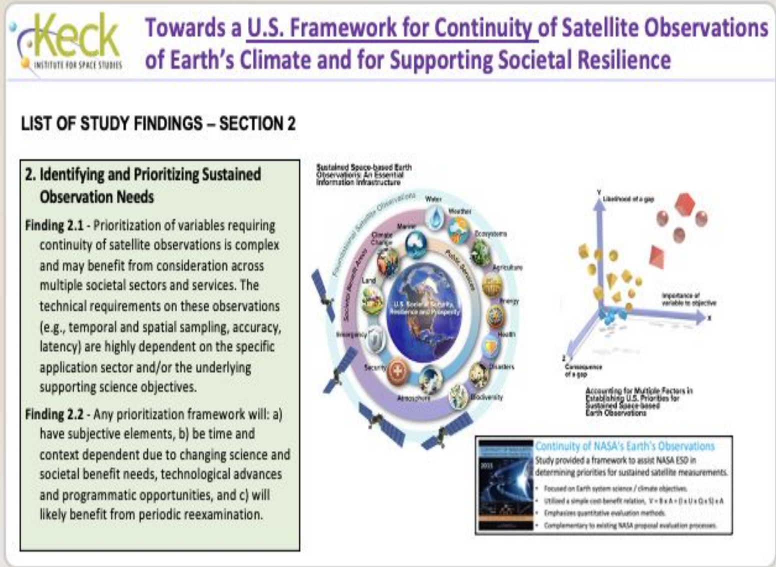

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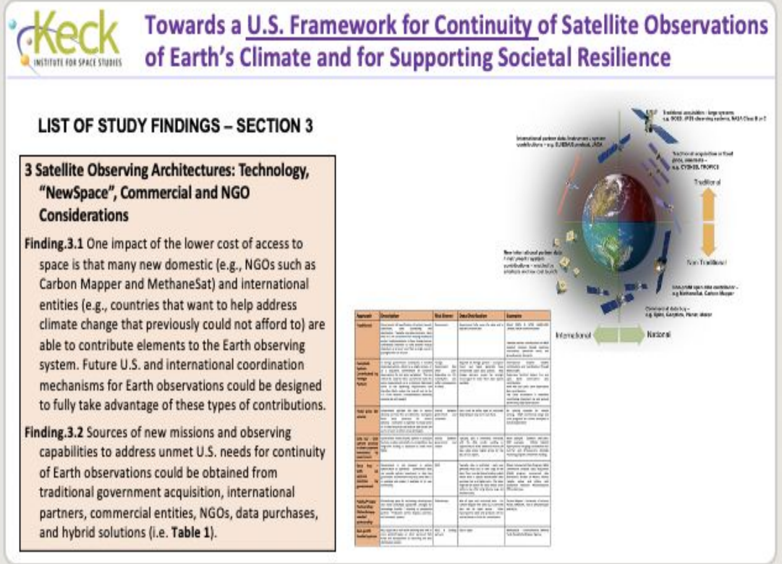

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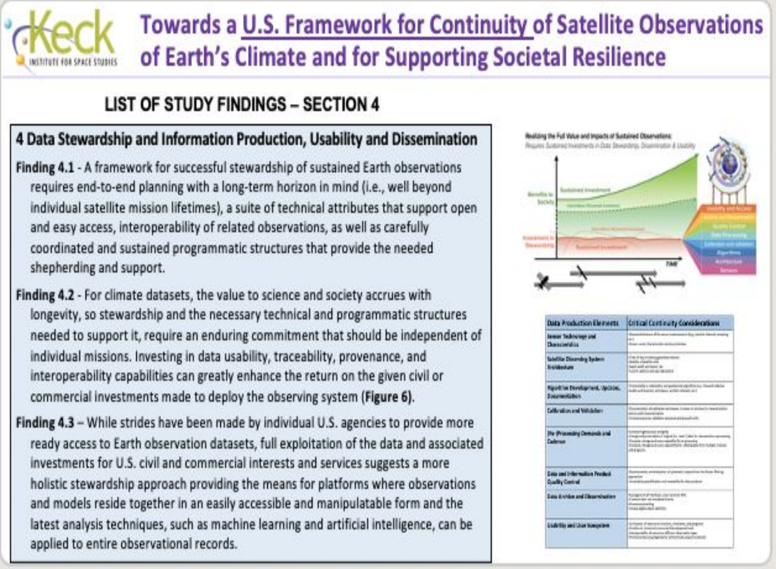

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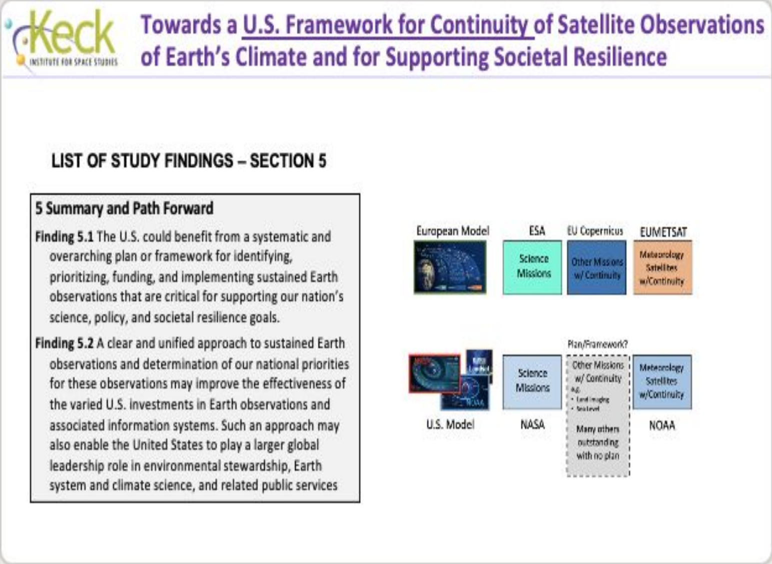

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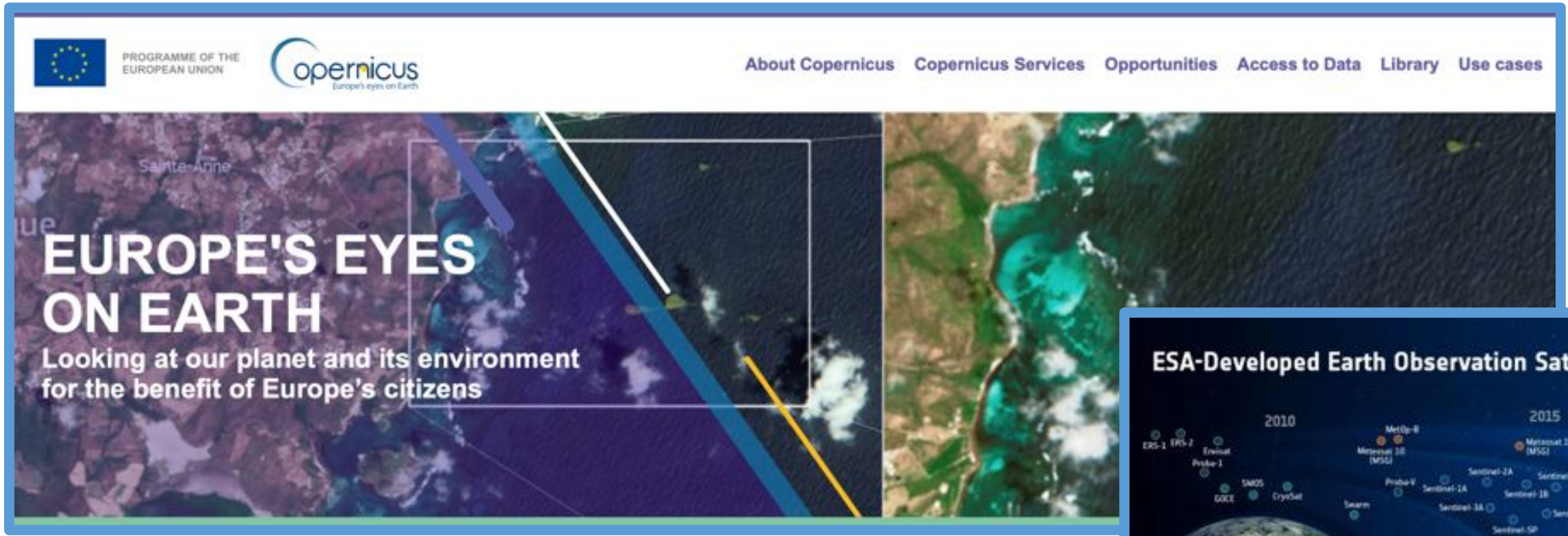
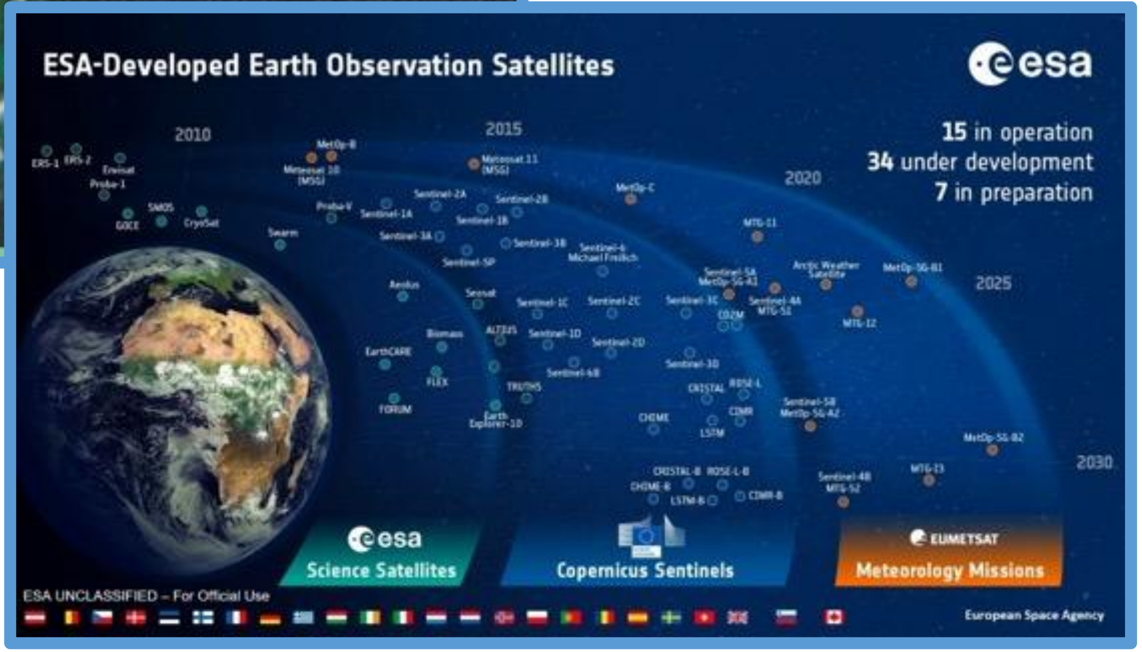
KISS Study 13 Findings Across 5 Sections

KISS Continuity Study Team, *Towards a U.S. Framework for Continuity of Satellite Observations of Earth's Climate and for Supporting Societal Resilience*, ***Earth's Future***, *American Geophysical Union, (To be) Submitted with minor revisions 10/25/2023*

European Union’s Answer





Copernicus is the EU’s Earth observation program that looks *“at our planet and its environment to benefit all European citizens. It offers information services that draw from satellite Earth Observation and in-situ data…to help service providers, public authorities, and other international organizations improve European citizens' quality of life and beyond*.

The satellite component of Copernicus is based on a series of “Sentinel” missions which are developed to provide the observations needed to deliver the public benefits of the Copernicus Programme – which are provided in the form of Atmosphere, Marine, Land, Emergency, Climate, and Security Services.

Towards a U.S. Framework for Continuity of Satellite Observations of Earth's Climate and for Supporting Societal Resilience

LIST OF STUDY FINDINGS – SECTION 1

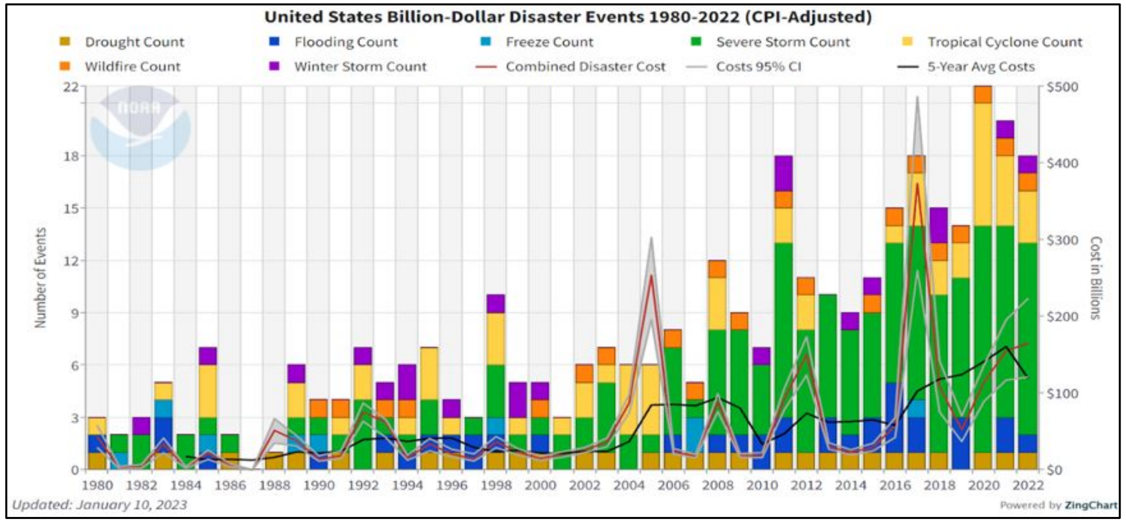
1 Introduction

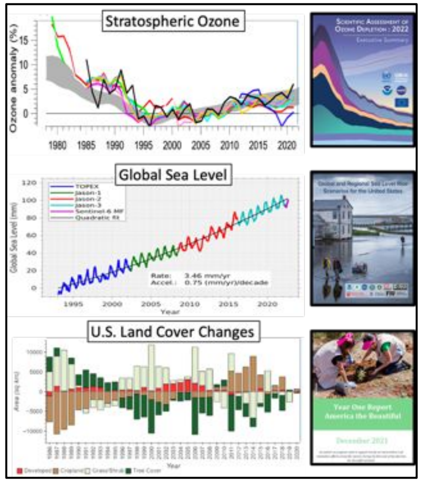
Finding 1.1 - There is growing urgency for improved public and commercial services to support a resilient, secure, and thriving U.S. population and economy, particularly in the face of mounting decision-support needs for environmental stewardship and hazard response, and for climate change adaptation and mitigation actions (e.g. FFAPCS, 2023).

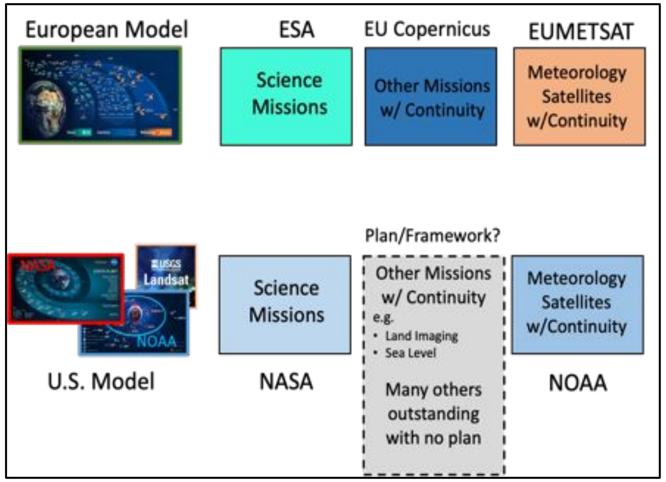
Finding 1.2 - Space-based Earth observations represent an essential component of the infrastructure needed to support the delivery of critical environmental science and decision-support information with local, national, and global utility.

Finding 1.3 - Many quantities measurable from satellites that have been shown to have scientific and/or decision-support value do not have a plan for sustained observations.

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 to support our nation's science, policy, and societal resilience goals.







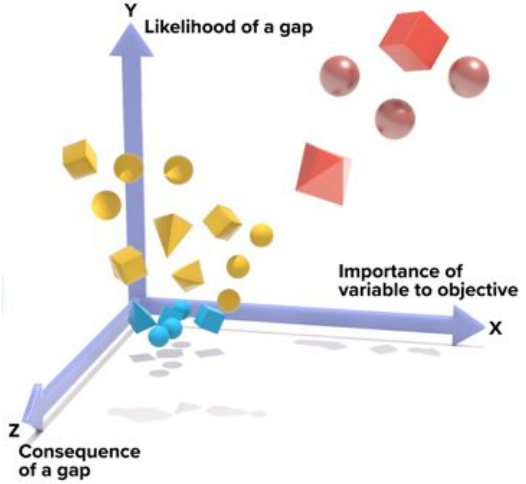
LIST OF STUDY FINDINGS – SECTION 2

2. Identifying and Prioritizing Sustained Observation Needs

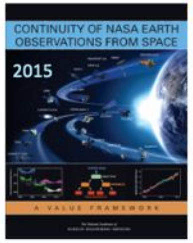
Finding 2.1 - Prioritization of variables requiring continuity of satellite observations is complex and may benefit from consideration across multiple societal sectors and services. The technical requirements on these observations (e.g., temporal and spatial sampling, accuracy, latency) are highly dependent on the specific application sector and/or the underlying supporting science objectives.

Finding 2.2 - Any prioritization framework will: a) have subjective elements, b) be time and context dependent due to changing science and societal benefit needs, technological advances and programmatic opportunities, and c) will likely benefit from periodic reexamination.

Sustained Space-based Earth Observations: An Essential Information Infrastructure



Accounting for Multiple Factors in Establishing U.S. Priorities for Sustained Space-based Earth Observations



Continuity of NASA's Earth's Observations

Study provided a framework to assist NASA ESD in determining priorities for sustained satellite measurements.

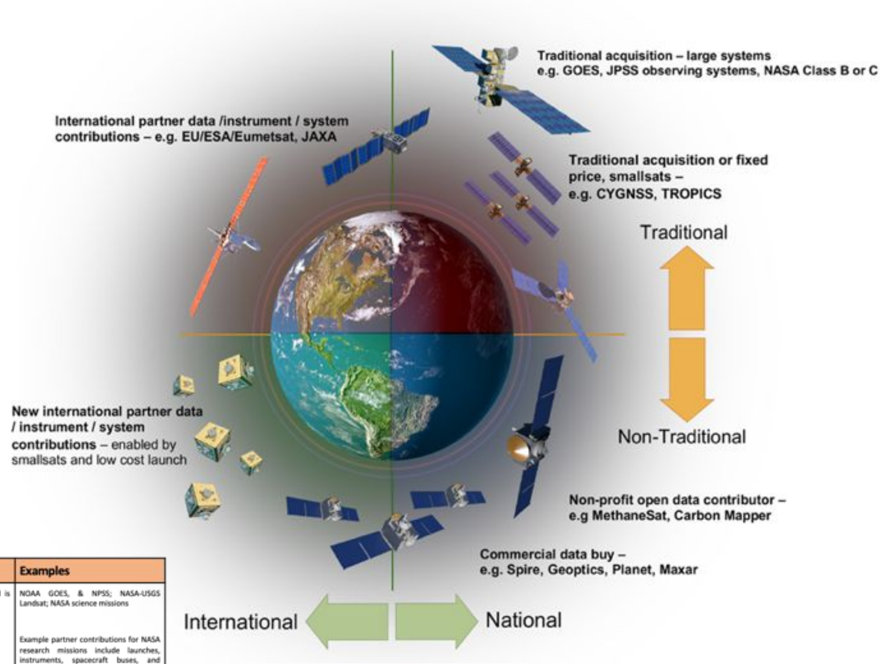
- Focused on Earth system science / climate objectives.
- Utilized a simple cost-benefit relation, $V = B \times A = (I \times U \times Q \times S) \times A$
- Emphasizes quantitative evaluation methods.
- Complementary to existing NASA proposal evaluation processes.

LIST OF STUDY FINDINGS – SECTION 3

3 Satellite Observing Architectures: Technology, "NewSpace", Commercial and NGO Considerations

Finding.3.1 One impact of the lower cost of access to space is that many new domestic (e.g., NGOs such as Carbon Mapper and MethaneSat) and international entities (e.g., countries that want to help address climate change that previously could not afford to) are able to contribute elements to the Earth observing system. Future U.S. and international coordination mechanisms for Earth observations could be designed to fully take advantage of these types of contributions.

Finding.3.2 Sources of new missions and observing capabilities to address unmet U.S. needs for continuity of Earth observations could be obtained from traditional government acquisition, international partners, commercial entities, NGOs, data purchases, and hybrid solutions (i.e. **Table 1**).



Approach	Description	Risk Owner	Data Distribution	Examples
Traditional	Government full specification of system, launch, operations, data processing and distribution. Typically, cost-plus contracts. Note that it is not uncommon for existing traditional project implementations to have foreign partner contributed elements to help achieve mutual objectives at a lower cost than a single country paying for the full mission.	Government	Government fully owns the data and is typically unrestricted	NOAA GOES, & NPSS; NASA-USGS Landsat; NASA science missions Example partner contributions for NASA research missions include launches, instruments, spacecraft buses, and ground system elements.
Complete System Contributed by Foreign Partner	A foreign government contributes a needed observing system, either as a single system, or as a long-term commitment of sustained observations for the given variable(s). This can relieve the need for other countries to make the same measurement, or at a minimum help meet some of the observing requirements and therefore likely reduce the overall cost to the U.S. if any residual / complementary observing systems are still needed.	Foreign Government (but other users depending on this contribution also suffer consequences if it fails)	Depends on foreign partner – European Union and Japan generally have unrestricted open data policies. New foreign partners would be strongly encouraged to make their data openly available.	International weather satellite contributions and coordination through WMO-CGMS. Copernicus Sentinel System free and open Earth observation data contributions. JAXA free and open Earth observation data contributions. The Qatar Foundation is interested contributing important ice and ground penetrating radar observations.
Fixed price for service	Government specifies the data or service desired, not how they are delivered. Competes fixed price contracts for service delivery. Contractor is expected to invest some of its own resources and may be able to sell the same services to others once developed.	Shared between government and contractor	Data could be either open or restricted, depending on long term cost share.	No existing example for remote sensing. NASA commercial cargo and crew programs are similar examples in human exploration.
Data buy - with upfront promise or down payment investment by government	Government invests money upfront in company business model, potentially via competition, but long-term funding is expected to come from NGOs.	Shared between government and vendor	Typically, data is somewhat restricted, with the data vendor needing an opportunity to make additional money off data sales unless higher prices for the data are an option.	NASA example - SeaWiFS 1997-2007; DOD examples - Orbital Sidekick hyperspectral imaging constellation has In-Q-Tel and AFVentures's Strategic Financing program investment funding.
Data buy – with no upfront promise by government	Government is not involved in system specification or operation. Government does not provide upfront investment or data buy guarantees. Government only buys data after it is available and makes it available to its user community.	NGO	Typically, data is restricted - each user generally must buy its own copy of the data; There may be future funding models where data is openly distributable after purchase, but at a higher price. The latter might be an option for data whose profit utility is low after long latency (e.g., old weather data).	NOAA Commercial Data Program; NASA Commercial Smallsat Data Acquisition (CSDA) program commercial data distribution models of Maxar, Planet, Capella, IceEye, and others, with substantial National Reconnaissance Office data buys.
Public/Private Partnership: Philanthropy-seeded partnership	Philanthropy pays for technology development and initial prototype spacecraft, arranges for technology transfer / licensing to production partner. Production partner deploys, operates, and maintains systems.	Philanthropy	Mix of open and restricted data. For Carbon Mapper the GHG (Co2 and CH4) data will be open access. Other hyperspectral data and products will be sold by Planet to fund the constellation.	Carbon Mapper - University of Arizona, Planet, NASA/JPL, mix of philanthropies and NGOs.
Non-profit funded system	NGO (typically a non-profit working with one or more philanthropies or other partners) fully funds the development of observing and data distribution system.	NGO & funding partners	Data is open.	MethaneSat - Environmental Defense Fund, New Zealand Space Agency.

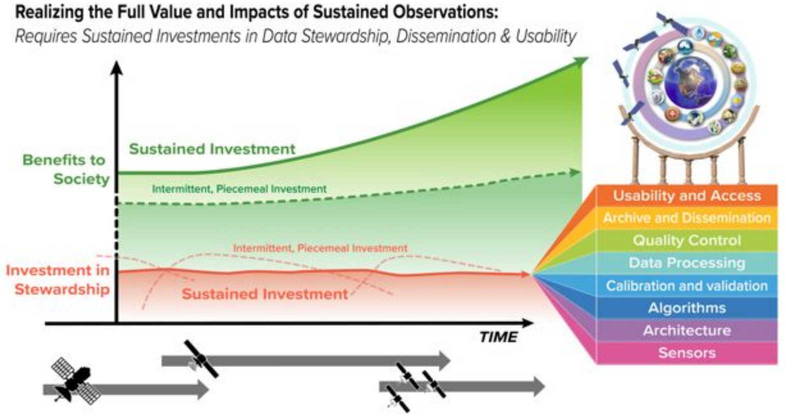
LIST OF STUDY FINDINGS – SECTION 4

4 Data Stewardship and Information Production, Usability and Dissemination

Finding 4.1 - A framework for successful stewardship of sustained Earth observations requires end-to-end planning with a long-term horizon in mind (i.e., well beyond individual satellite mission lifetimes), a suite of technical attributes that support open and easy access, interoperability of related observations, as well as carefully coordinated and sustained programmatic structures that provide the needed shepherding and support.

Finding 4.2 - For climate datasets, the value to science and society accrues with longevity, so stewardship and the necessary technical and programmatic structures needed to support it, require an enduring commitment that should be independent of individual missions. Investing in data usability, traceability, provenance, and interoperability capabilities can greatly enhance the return on the given civil or commercial investments made to deploy the observing system (**Figure 6**).

Finding 4.3 – While strides have been made by individual U.S. agencies to provide more ready access to Earth observation datasets, full exploitation of the data and associated investments for U.S. civil and commercial interests and services suggests a more holistic stewardship approach providing the means for platforms where observations and models reside together in an easily accessible and manipulatable form and the latest analysis techniques, such as machine learning and artificial intelligence, can be applied to entire observational records.



Data Production Elements	Critical Continuity Considerations
Sensor Technology and Characteristics	•Representativeness of the sensor measurements (e.g., spectral channels, sampling, etc.) •Known sensor characteristics and uncertainties
Satellite Observing System Architecture	•Time-of-day or viewing geometry impacts •Stability of satellite orbit •Swath width and revisit rate •Launch cadence and gap risk posture
Algorithm Development, Updates, Documentation	•Commonality in radiometric and geophysical algorithms (e.g., forward radiative models and inversion techniques, ancillary datasets, etc.)
Calibration and Validation	•Documentation of calibration techniques, inclusive of pre-launch characterization and on-orbit characterization •Consistency across validation protocols and ground truths
(Re-)Processing Demands and Cadence	•Consistent geolocation and grids •Lineage and preservation of original (i.e. Level 1) data for retrospective reprocessing •Compute, storage and access capability for re-processing •Compute, storage and access capabilities for utilizing data from multiple missions and programs.
Data and Information Product Quality Control	•Documentation and evaluation of systematic impacts from the chosen filtering approaches •Uncertainty quantification and traceability for data products
Data Archive and Dissemination	•Management of interfaces under common APIs •Common data and metadata formats •Provenance tracking •Unique digital object identifier
Usability and User Ecosystem	•Co-location of data across missions, timeseries, and programs •Curation of community access and development tools •Interoperability of use across different observation types •Permissive licensing regimes for commercially acquired datasets

LIST OF STUDY FINDINGS – SECTION 5

5 Summary and Path Forward

Finding 5.1 The U.S. could benefit from a systematic and overarching plan or framework for identifying, prioritizing, funding, and implementing sustained Earth observations that are critical for supporting our nation's science, policy, and societal resilience goals.

Finding 5.2 A clear and unified approach to sustained Earth observations and determination of our national priorities for these observations may improve the effectiveness of the varied U.S. investments in Earth observations and associated information systems. Such an approach may also enable the United States to play a larger global leadership role in environmental stewardship, Earth system and climate science, and related public services