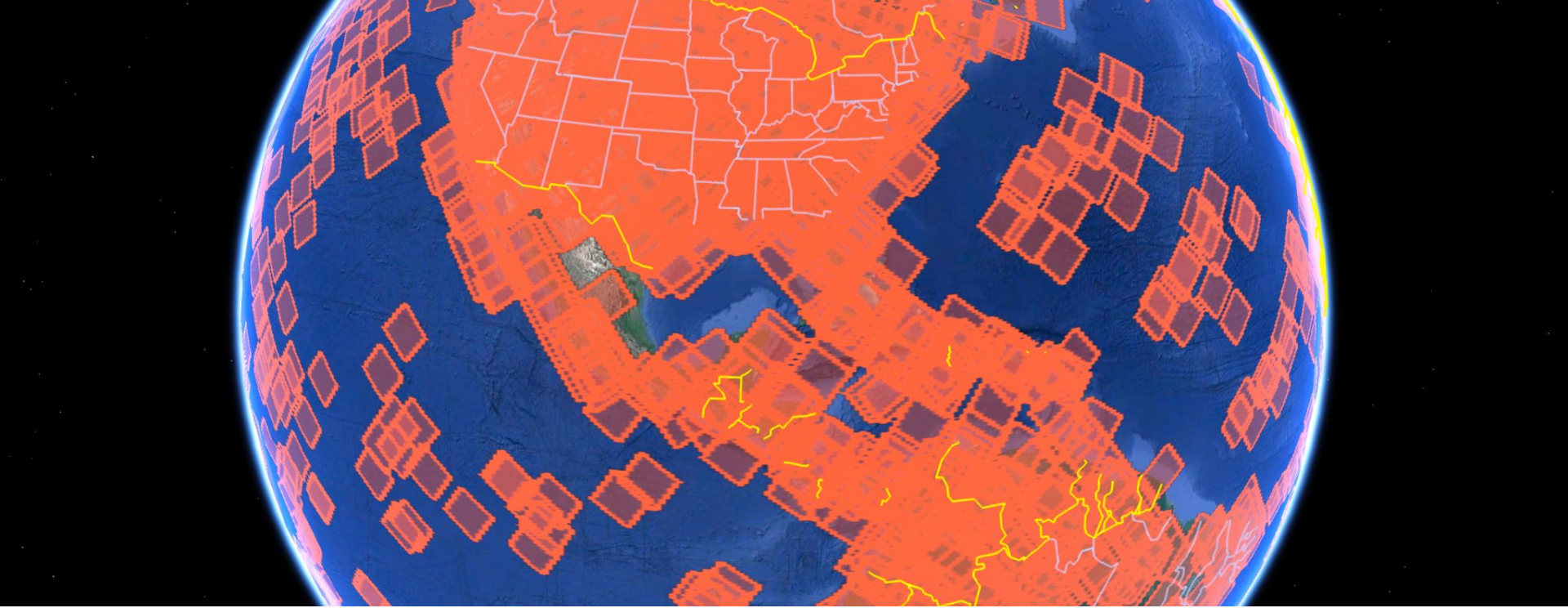

Automated Observation Scheduling with CLASP for Mission Analysis and Operations

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https://ai.jpl.nasa.gov/public/projects/clasp/

Jet Propulsion Laboratory
California Institute of Technology

JPL Clearance CL#26-0984 URS338134

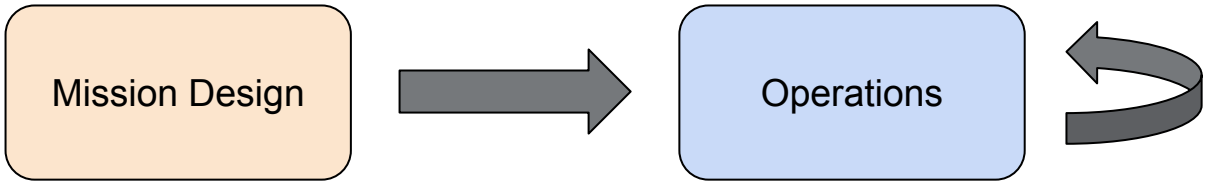
Outline

- What is CLASP?
- How CLASP works
- Why use CLASP?
- Customer quotes

What is CLASP?

- **C**overage-aware **L**arge-scale **A**ctivity **S**cheduler/**P**lanner
- Automated science observation scheduler for remote sensing
  - Given areas scientists want to observe on the target body, operational constraints, etc. create a schedule of on/off timings for onboard instrument(s)
  - Primarily for pushbroom instruments (not mosaics)
- Originally developed by Russell Knight
- Implemented in C++, uses SPICE for geometric calculations
- Used in for scheduling in operations by multiple missions
  - ECOSTRESS, OCO-3, EMIT, NISAR
- Used to inform mission design for many studies
  - SDC, SBG, HyspIRI, IPEX, and many more… (about 100 mission studies in total)

Mission Design ➡ Operations



- Data storage sizing
- Battery capacity sizing
- Coverage requirements
- Science campaigns
- Downlink strategy

Using observation schedules and constraints

- Science observation scheduling
- Enforcing constraints

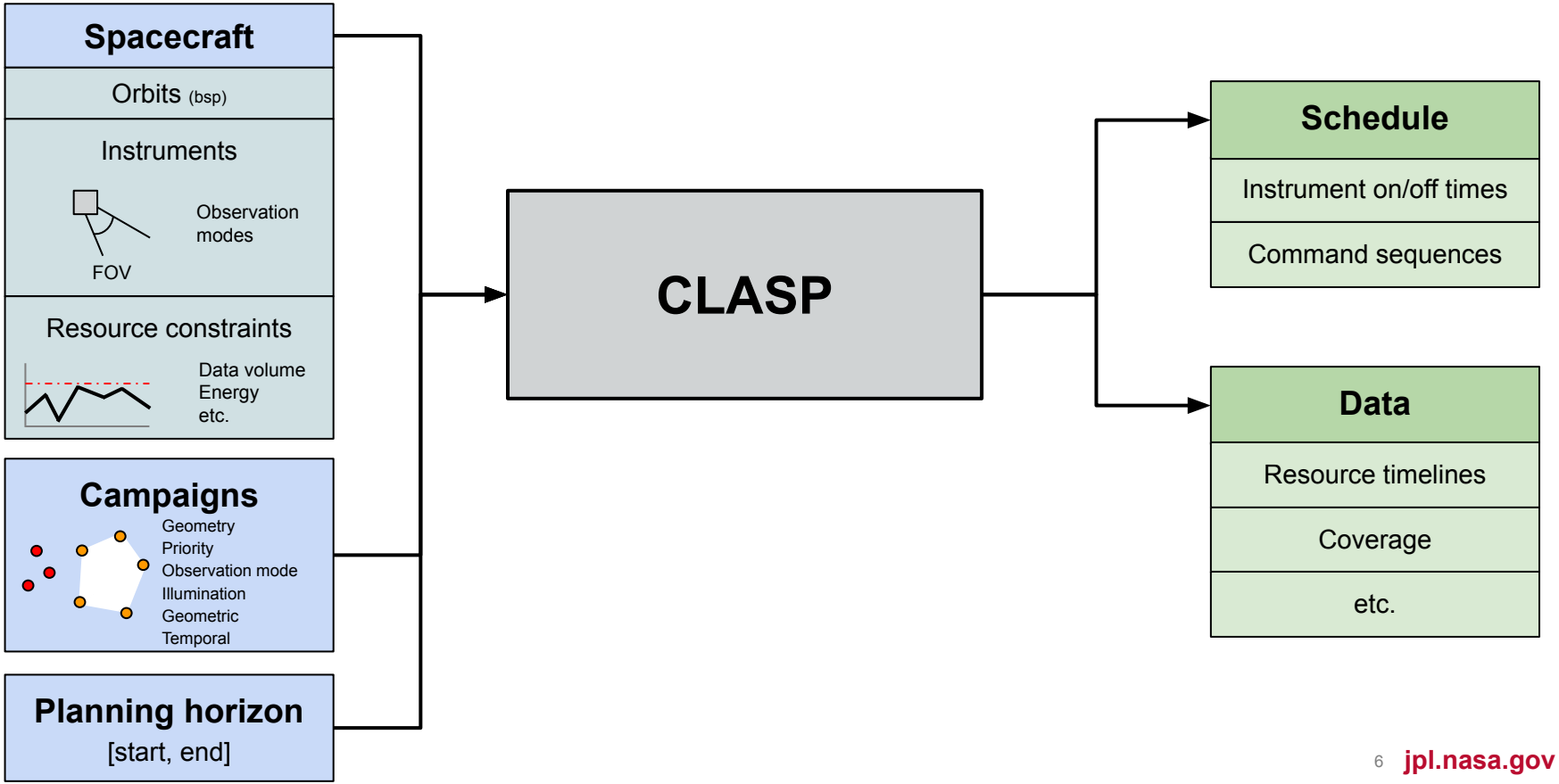
Using the same tooling from mission design (ex. DESDynI / NISAR)

- Changes to science goals
- Changes to constraints

Missions and Studies using CLASP

Name	Mission Design	Operations	Time in Ops	# of observations
ECOSTRESS	✅	✅	**7** years	**610,000** scenes
OCO-3	-	✅	**6** years	
EMIT	✅	✅	**3** years	**26,000** observations
NISAR	✅	✅	**100** days	**120,000** observations
SDC	✅	-	-	-
SBG	✅	-	-	-

How CLASP works



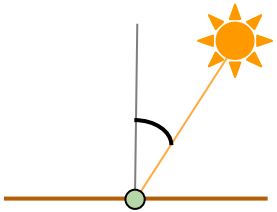
How CLASP works

(1) Select a candidate observation

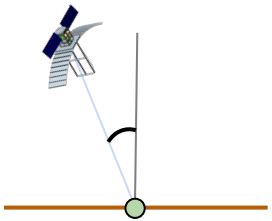
(2) Check observation geometry

(3) Check impacts on resource timelines

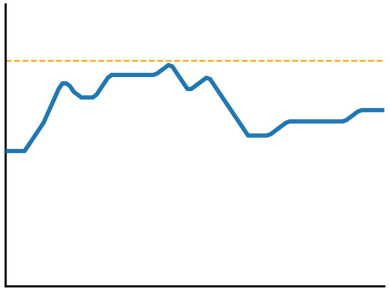
(4) Schedule and apply impacts

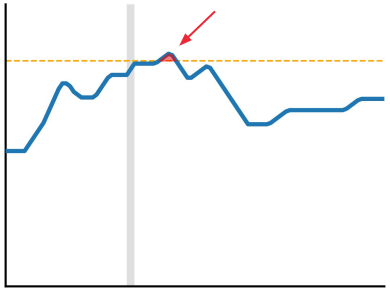


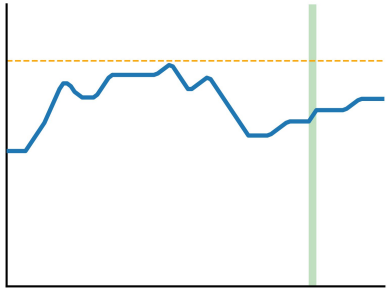
Solar Zenith Angle



Emission Angle

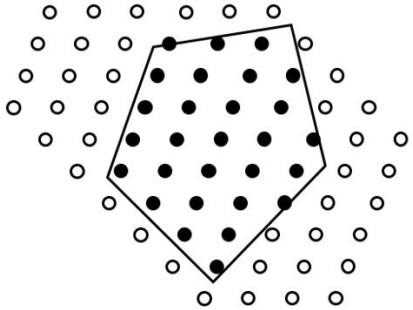




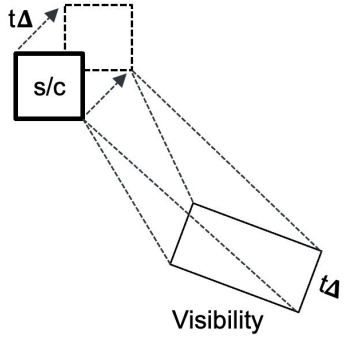


How CLASP works - Coverage driven

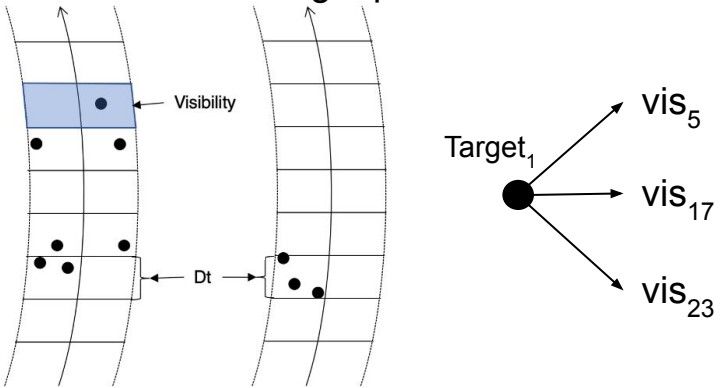
(1) Discretize campaigns



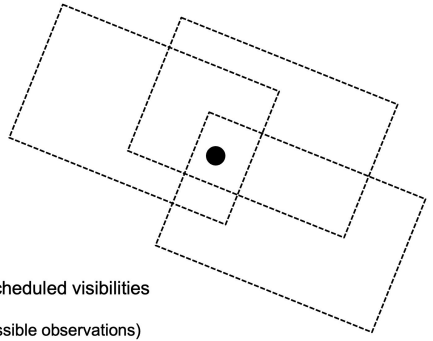
(2) Calculate visibilities



(3) Find visibilities that cover target points



(4) Schedule observations of target points in priority order



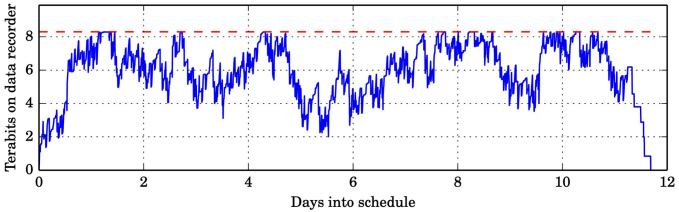
Unscheduled visibilities

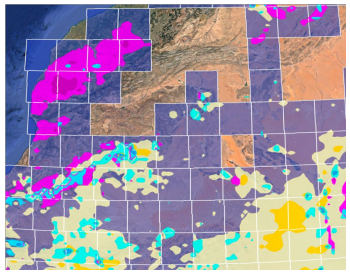
(Possible observations)

Why use CLASP?

- **Uses constraints and campaigns to inform mission design decisions**
- Enables balancing of tradeoffs between competing science goals
- Enforces resource constraints during scheduling (ex. data volume)
- Allows implementing mission-specific constraints and scheduling algorithms
- Flexible to constraint changes as a mission evolves
- Flexible to science goal / campaign design changes

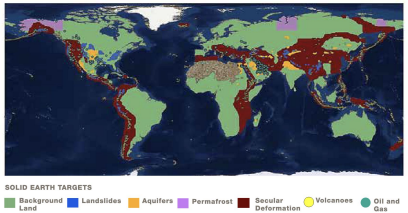
Using Constraints and Campaigns to Inform Design

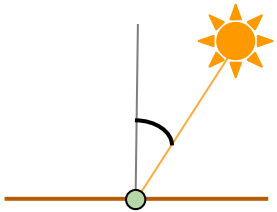


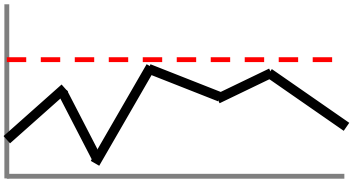


Estimates

Inform using



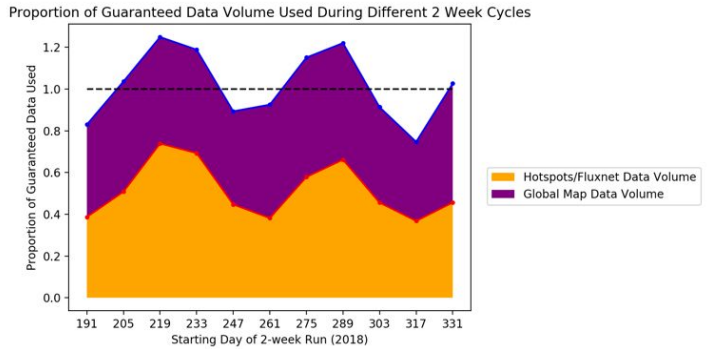


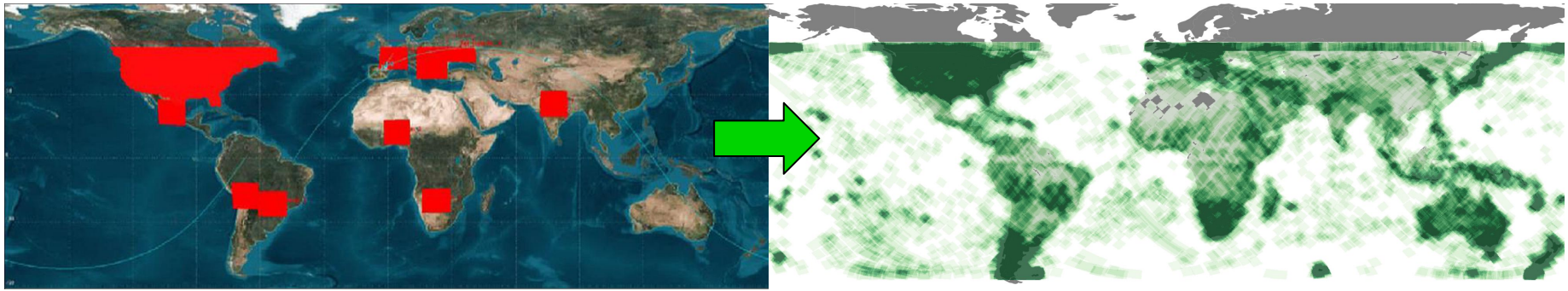


- Examples
  - **NISAR, EMIT, ECOSTRESS, SDC, SBG**
  - *HyspIRI coverage*
  - *etc.*

ECOSTRESS - Mission Design

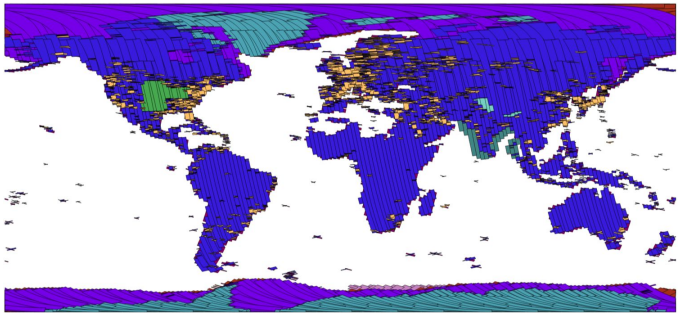
- ECOSTRESS is primarily data volume limited
  - Campaign design
  - Data volume usage per campaign
- Time to cover areas of interest
  - Tested different SZA constraint thresholds

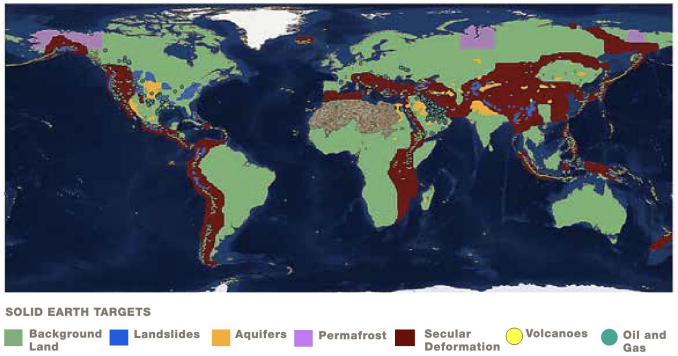


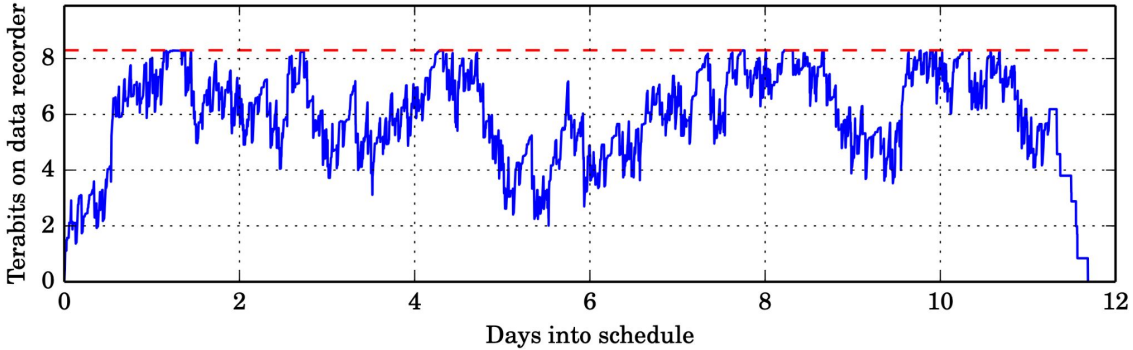


NISAR - Mission Design

- NISAR is primarily data volume limited
  - Increasing levels of fidelity for data recorder
- Complex set of competing campaigns
  - Many different observation modes
  - Tradespace of coverage

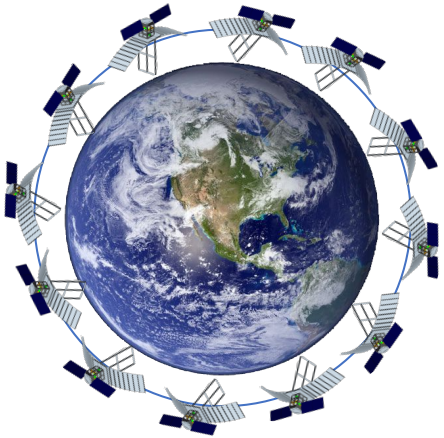


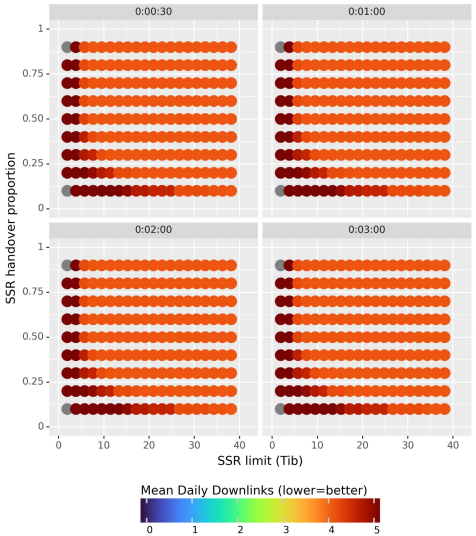


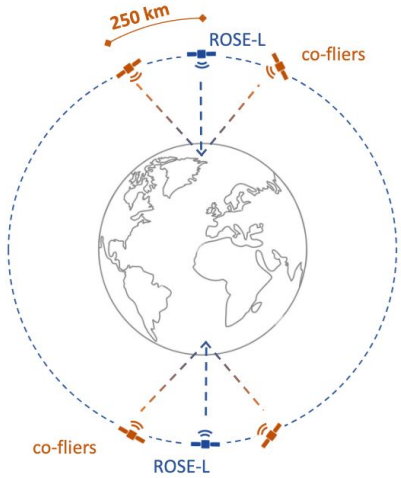


SDC - Mission Design

- Modelled **12+** candidate architectures
  - Varying number of spacecraft
  - Varying orbits
  - Varying coordination strategies
- Analyses
  - Battery capacity
  - Data volume tradespace
  - Urgent response coverage impacts

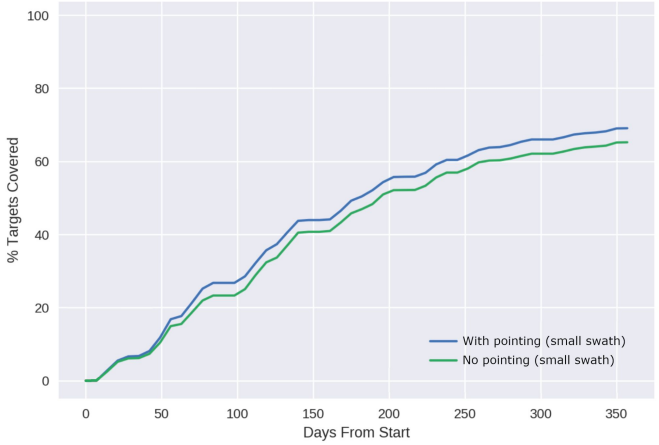


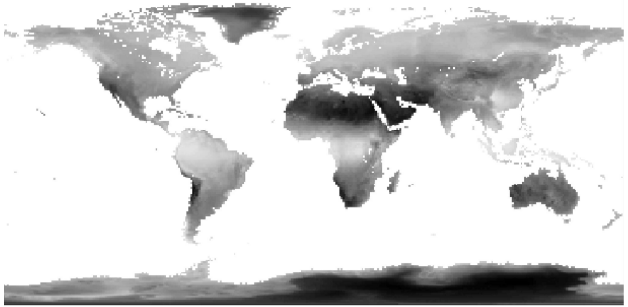


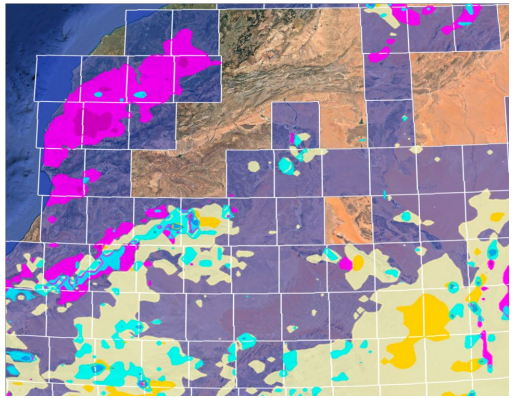


EMIT - Mission Design

- Across-track pointing mirror
- Coverage requirements
  - Discretization of target regions
  - Cloud cover impacts on coverage
- Onboard storage sizing
  - Data volume and processing time impacts of onboard cloud screening

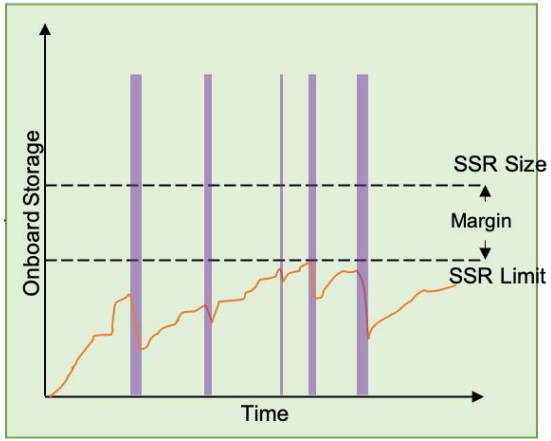


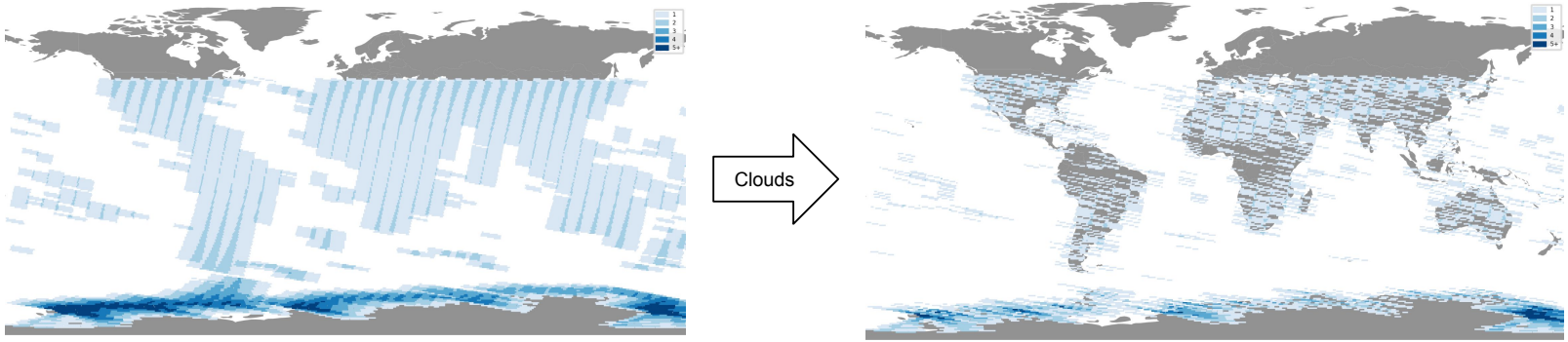




SBG - Mission Design

- Data volume
  - Impacts of onboard cloud screening
  - Onboard processing latency
  - Downlink scheduling
- Coverage impacts of clouds





Why use CLASP?

- Uses constraints and campaigns to inform mission design decisions
- **Enables balancing of tradeoffs between competing science goals**
- Enforces resource constraints during scheduling (ex. data volume)
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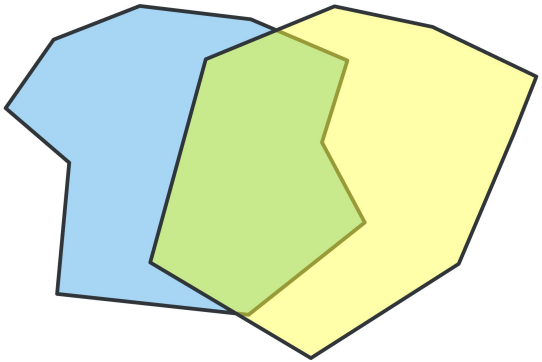
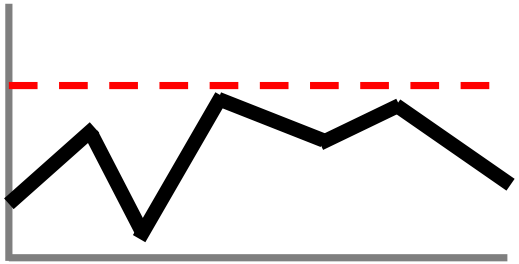
Balancing of tradeoffs between competing science goals

Different instrument modes



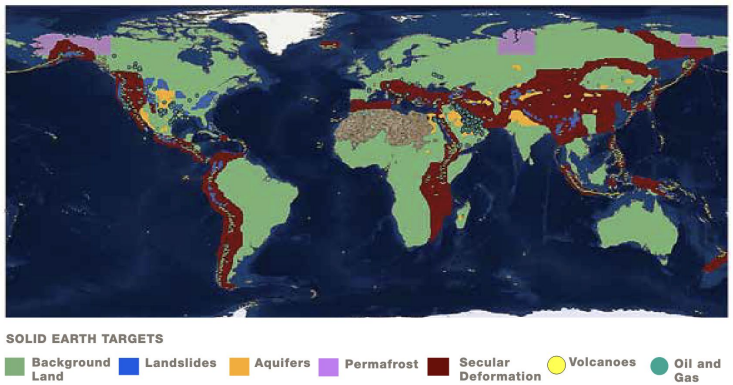
Shared resource constraints

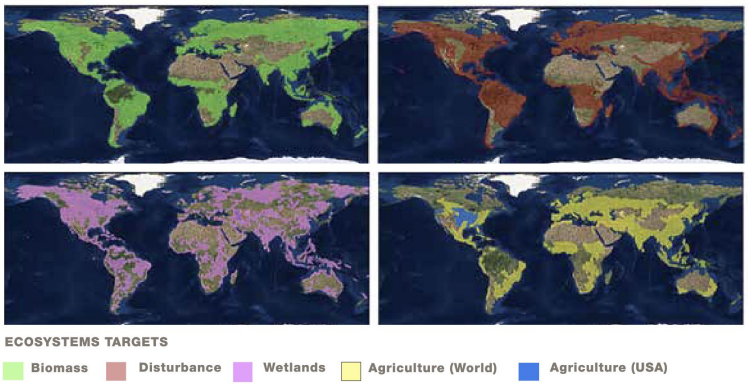


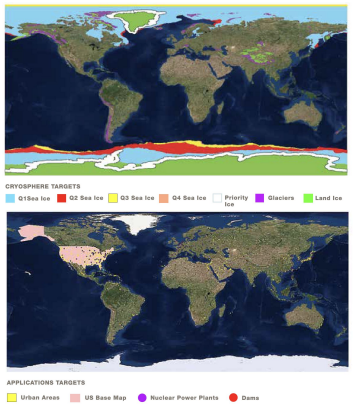
- Examples
  - **NISAR campaign design**
  - *ECOSTRESS campaign design*

NISAR - Campaign Design

- NISAR is primarily data volume limited, high resolution SAR imagery
- Many science goals, many radar modes
- Created a set of **50+ campaigns** that trade off between competing science goals







Why use CLASP?

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- **Enforces resource constraints during scheduling (ex. data volume)**
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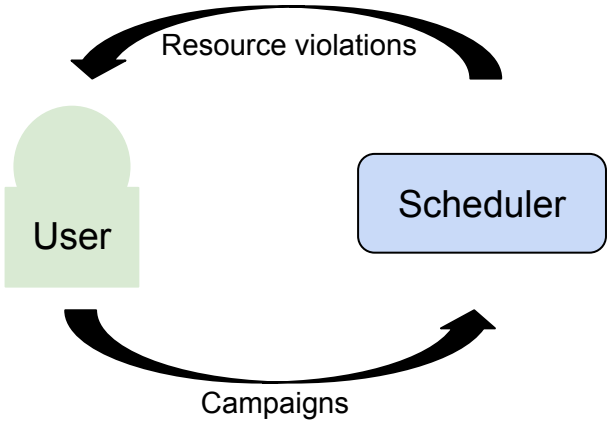
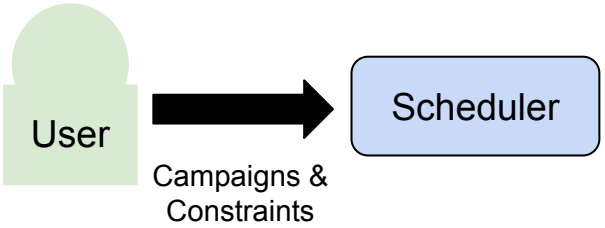
Enforcing resource constraints during scheduling

User feedback loop



Enforce during scheduling

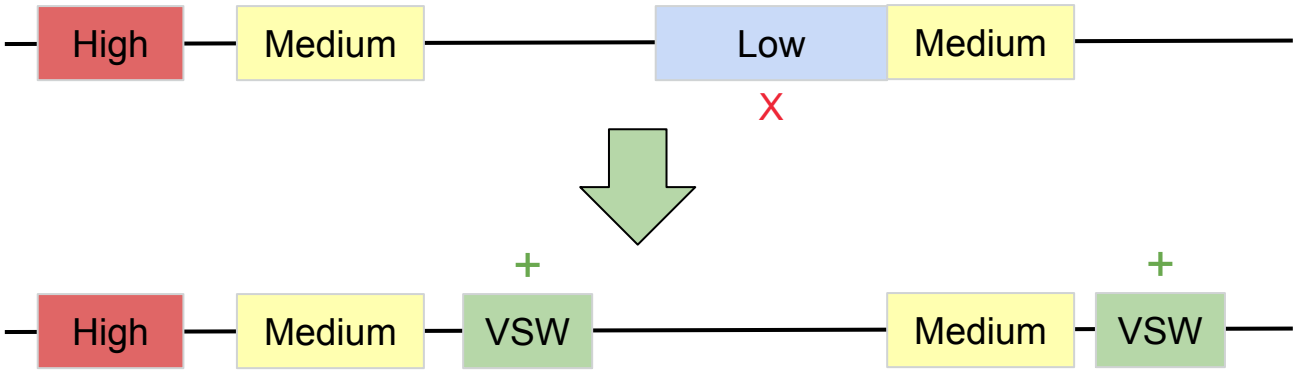


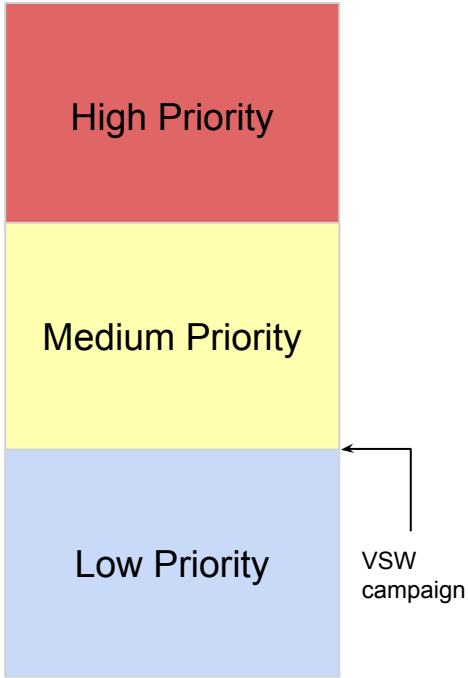
More flexible to changing conditions
(ex. transient campaigns)

- Examples
  - **ECOSTRESS VSW integration**
  - *EMIT data volume constraint*

ECOSTRESS - Volcano SensorWeb Integration

- Volcano SensorWeb (VSW)
- ECOSTRESS is primarily limited by data volume
- Campaign priorities and data volume constraint
  - Ensure only low priority observations will be dropped





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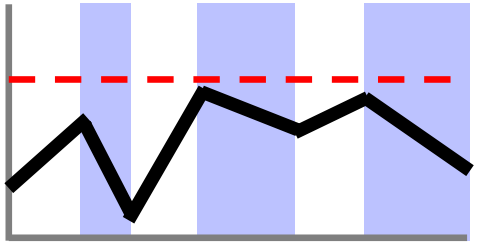
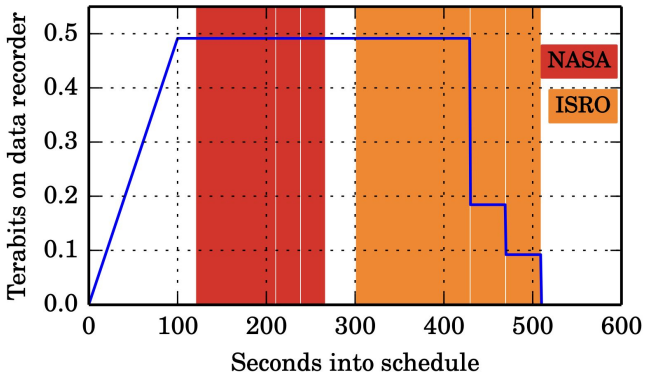
Mission-specific Constraints & Scheduling

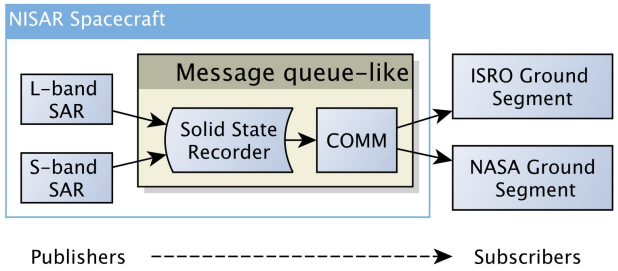


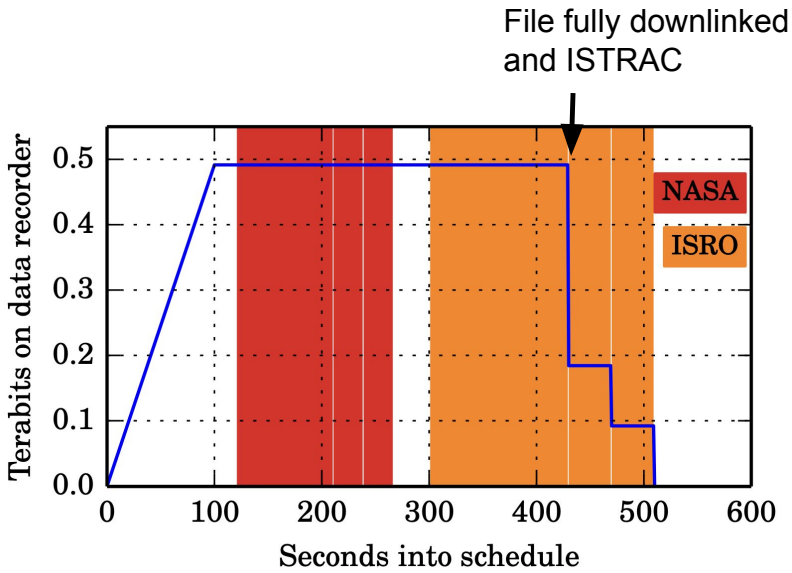


- Examples
  - **NISAR solid state recorder model**
  - **OCO-3 KOZ constraint**
  - *NISAR supporting activity scheduling*
  - *ECOSTRESS scene scheduling*
  - *EMIT dark calibration activity scheduling*
  - *OCO-3 calibration activity scheduling*
  - *SDC coordination between spacecraft in constellation*

NISAR - Solid State Recorder Model

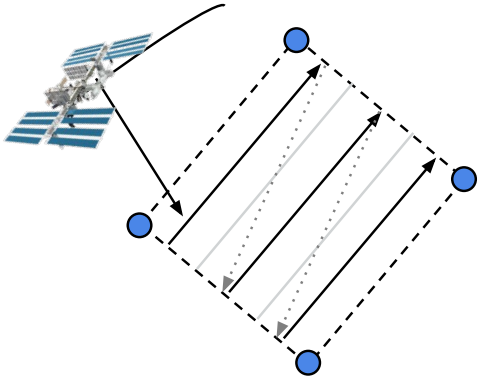
- High-fidelity solid state recorder model
  - Downlinking to multiple ground station networks (NSN & ISTRAC)
  - Discrete file deletion
  - File prioritization

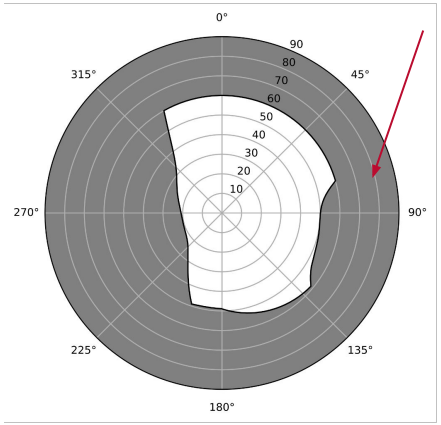




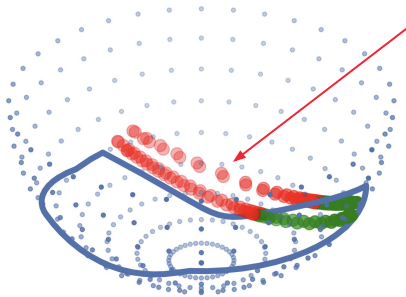
OCO-3 - KOZ constraint

- Pointing Mirror Assembly (az/el pointing)
  - Area mapping mode

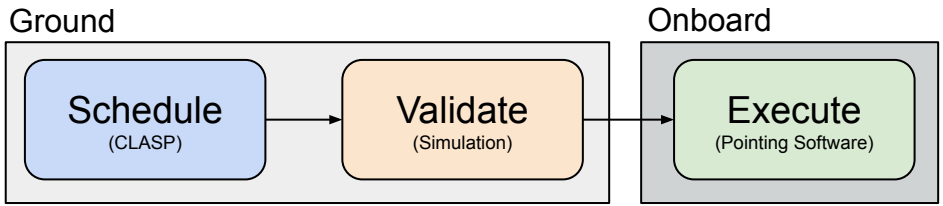




Keepout zone



Would point within keepout zone for some timesteps



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- Uses constraints and campaigns to inform mission design decisions
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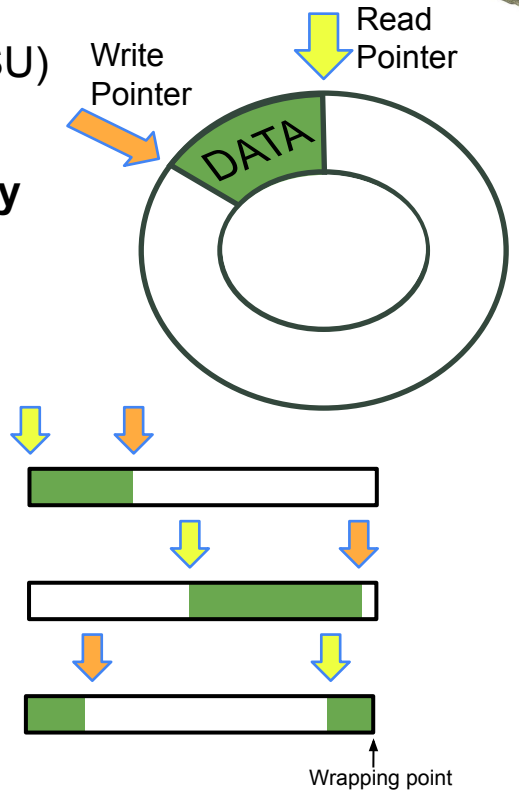
- **Flexible to constraint changes as a mission evolves**
- Flexible to science goal / campaign design changes

Flexibility to constraint changes

- As a mission is in operations, there can be new constraints that manifest
  - ex. due to hardware & onboard firmware issues
- Examples
  - **ECOSTRESS MSU**

ECOSTRESS - Mass Storage Unit

- Issue with onboard firmware for Mass Storage Unit (MSU)
  - Ring buffer **did not correctly increment its read and write pointers across the physical boundary address restart**
  - Caused significant data loss
- Schedule resets of the MSU read and write pointers
  - Mitigated data loss without requiring an onboard firmware update



Why use CLASP?

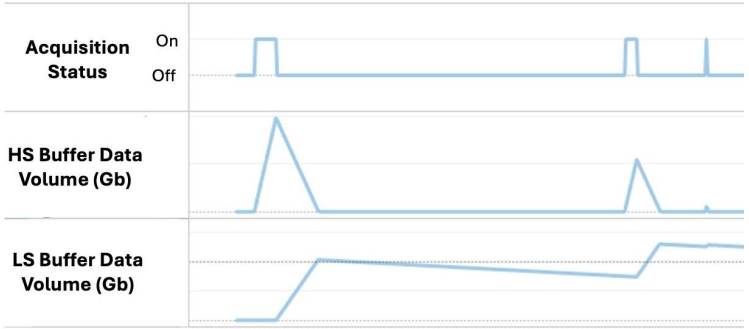
- Uses constraints and campaigns to inform mission design decisions
- Enables balancing of tradeoffs between competing science goals
- Enforces resource constraints during scheduling (ex. data volume)
- Allows implementing mission-specific constraints and scheduling algorithms
- Flexible to constraint changes as a mission evolves
- **Flexible to science goal / campaign design changes**

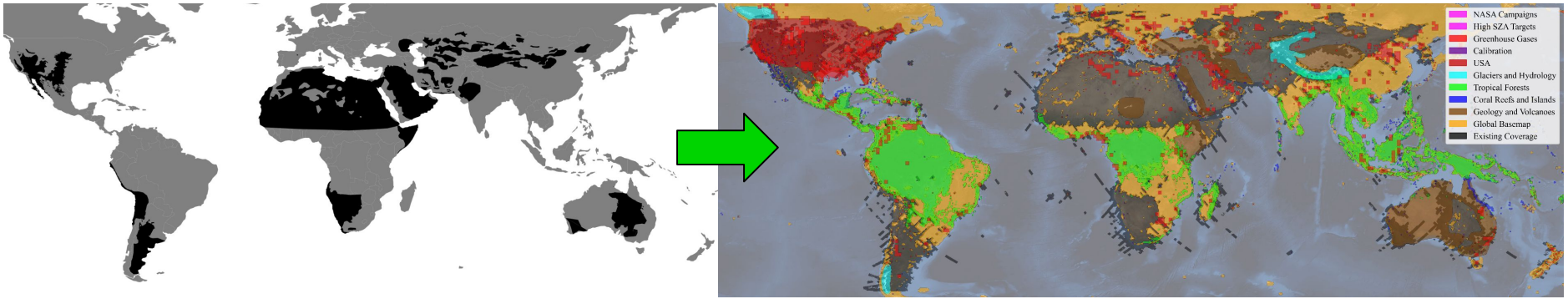
Flexibility to science goal changes

- As a mission continues operations, science goals and priorities can change
  - Extended missions
  - Improvements in onboard firmware that enable new opportunities
- Examples
  - **EMIT extended mission**
  - *ECOSTRESS 5-band observations*

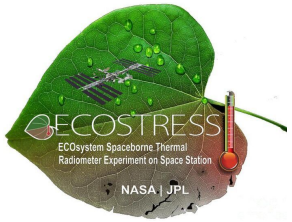
EMIT - Extended Mission

- EMIT began extended mission phase in 2024
- Many new science campaigns + increase in data
- Implemented data volume model
  - Processing time of onboard cloud screening
  - High and low-speed buffers





ECOSTRESS - Customer Quotes



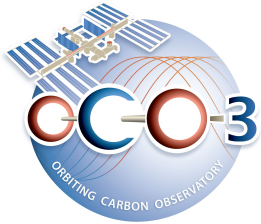
"When we submitted the ECOSTRESS proposal we were told JPL already had the necessary capabilities, we quickly realized that was not the case. Fortunately, the building blocks of CLASP were available, and these were put together to create what is now CLASP. CLASP has worked well for ECOSTRESS, and subsequent missions have also been able to use CLASP, providing **a win for science and a competitive advantage**."

- Simon Hook (ECOSTRESS Principal Investigator)

"ECOSTRESS was originally designed to acquire data over specific priority areas only, but **CLASP has enabled the mission to acquire data near-globally** (within ISS latitude limits) while keeping within data volume constraints."

- Kerry Cawse-Nicholson (ECOSTRESS Deputy Principal Investigator)

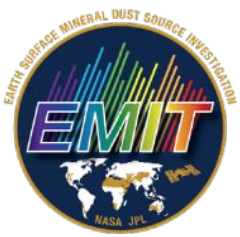
OCO-3 - Customer Quotes



"CLASP is an invaluable resource in OCO3 operations, **allowing for flexible weekly sequence planning** and a quick, customizable turnaround for replacement sequence generation."

- Dula Walker (OCO-3 Ops Team Lead)

EMIT - Customer Quotes



"CLASP is essential for EMIT mission success. **CLASP was used to write the proposal, develop the mission, assess our coverage performance, and today for all key elements of measurement acquisition planning.** CLASP was also important to enable onboard cloud screening, a first-of-its-kind capability that has improved EMIT mission science yield by approximately 35%."

- Robert Green (EMIT Principal Investigator) and David Thompson (EMIT Deputy Principal Investigator)

NISAR & SDC - Customer Quotes

“CLASP is a powerful, adaptable and extendable mission planning tool that has been essential to the NASA-ISRO SAR (NISAR) mission and the Surface Deformation and Change (SDC) Architecture Study.

For NISAR, we were able to schedule a very complex set of observations, including those from two multi-mode radars where often different science team disciplines would select different modes for the same site of interest. NISAR acquires data with blanket coverage of land and ice, with seasonal variability. The science team is also constantly optimizing the plan which requires iterations. **CLASP was essential for efficiently adding observing requirements and determining a new plan and its implications.**

For SDC, we needed to push even further than NISAR, often attempting the same or augmented observation campaigns with multiple smaller satellites. The CLASP team was able to adapt and extend CLASP to over a dozen new constellation architectures to support trade among them. **CLASP's ability to deal with architectural complexity was essential to our success.**”

- Paul Rosen (NISAR Project Scientist, SDC Study Coordinator)

Conclusions

- CLASP has been used by many missions and studies
  - To inform mission design
  - To enable mission operations

- CLASP
  - Uses constraints and campaigns to inform design decisions
  - Enables balancing of tradeoffs between competing science goals
  - Enforces resource constraints during scheduling (ex. data volume)
  - Allows implementing mission-specific constraints and scheduling algorithms
  - Is flexible to constraint changes as a mission evolves
  - Is flexible to science goal / campaign design changes

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SBG	https://ai.jpl.nasa.gov/public/projects/sbg/