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Automated Policy-based Scheduling for the ECOSTRESS Mission

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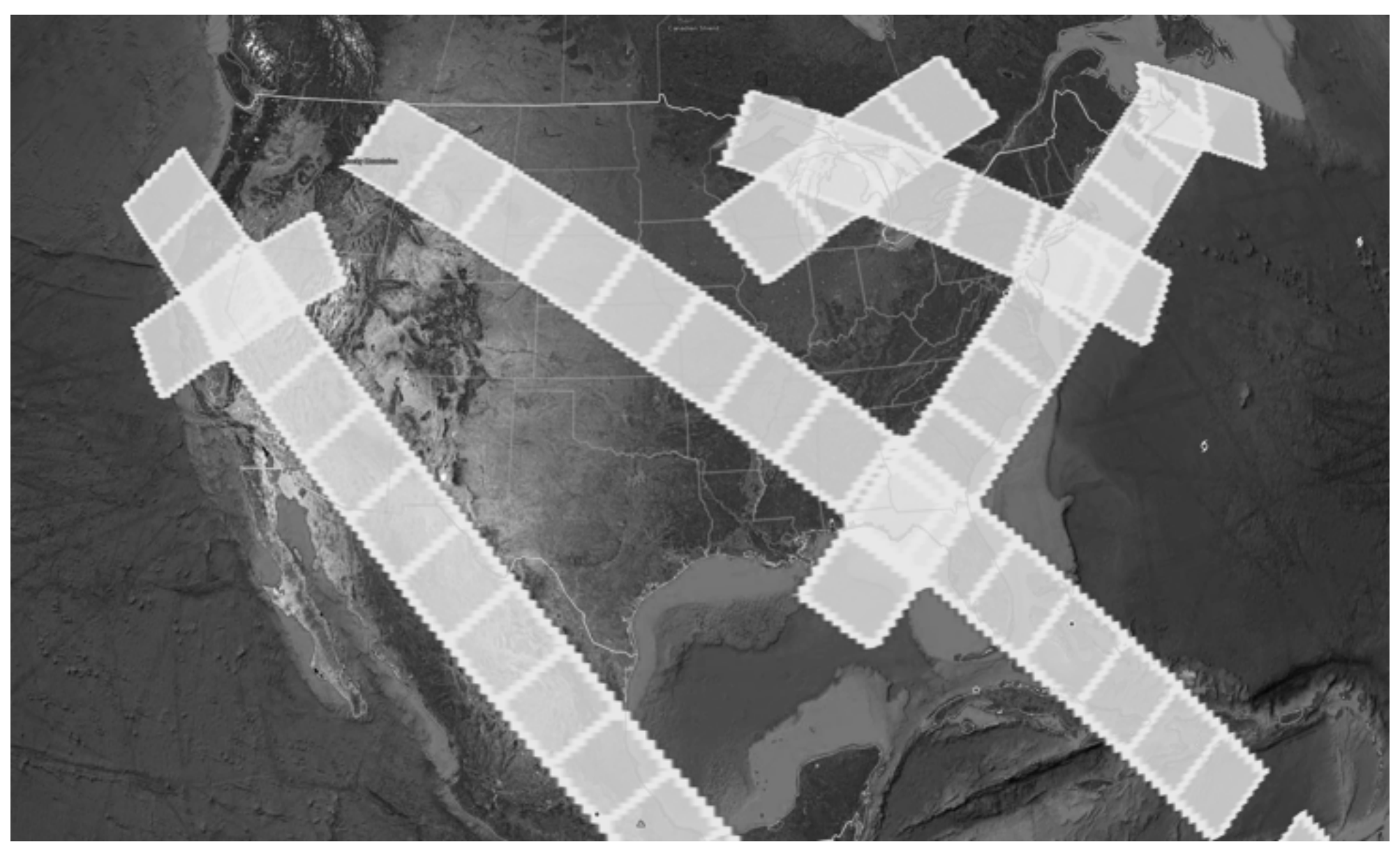
ECOSTRESS

The ECOSystem Thermal Radiometer Experiment on Space Station (ECOSTRESS) mission seeks to better understand how much water plants need and how they respond to stress. ECOSTRESS measures the temperature of plants to understand combined evaporation and transpiration, known as evapotranspiration.

ECOSTRESS launched on June 29, 2018 to the ISS (International Space Station) on a Space-X Falcon 9 rocket as part of a resupply mission. The instrument is attached to the Japanese Experiment Module – Exposed Facility (JEM-EF) on the ISS and targets key biomes on the Earth's surface, as well as calibration/validation sites. Other science targets include cities and volcanoes. From the orbit of the Space Station the instrument can see target regions at varying times throughout the day, rather than at a fixed time of day, allowing scientists to understand plant water use throughout the day. ECOSTRESS is scheduled to operate through summer 2021.

ECOSTRESS Science Targets



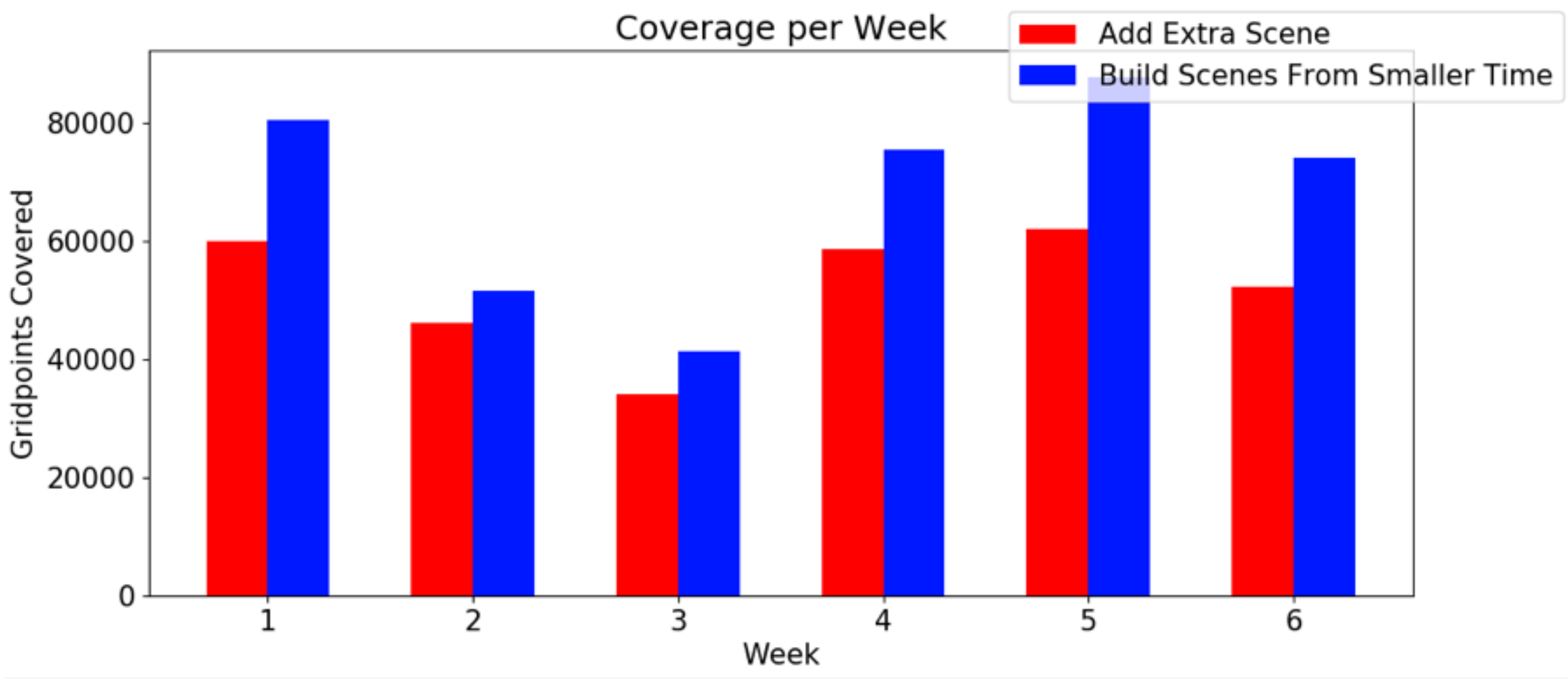
Observations scheduled over North America on February 28, 2019

Orbit Uncertainty

Command sequences are uploaded weekly to ECOSTRESS. Being in Low Earth Orbit (LEO), the ISS experiences some drag from the atmosphere, causing it to drift over time from its predicted location at the beginning of the week. This can cause a planned observation to miss its intended target.

Two strategies were developed to deal with the uncertainty. They needed to account for the fixed size of observations that ECOSTRESS takes and at least a few seconds of extra time to ensure a target is not missed.

1) Static Padding - Add ½ of an observation to the start and end of each contiguous observation
2) Targeted Padding - analyzes the target regions and calculates padding around the targets



When working with the same fixed data volume constraints, Targeted Padding uses less data volume on padding, therefore enabling it to cover more science targets as seen above.

Mass Storage-less Operations

After further operations, both Mass Storage Units on ECOSTRESS became non-functioning. Updates to the instrument firmware were developed to allow data to be acquired and downlinked avoiding the MSU. CLASP was adapted again to be able to schedule with a new set of constraints.

New constraints included:

- Reduced onboard storage capability
- Greater downlink capability with removal of certain spectral bands
- All data onboard must be downlinked at once to regain use of storage

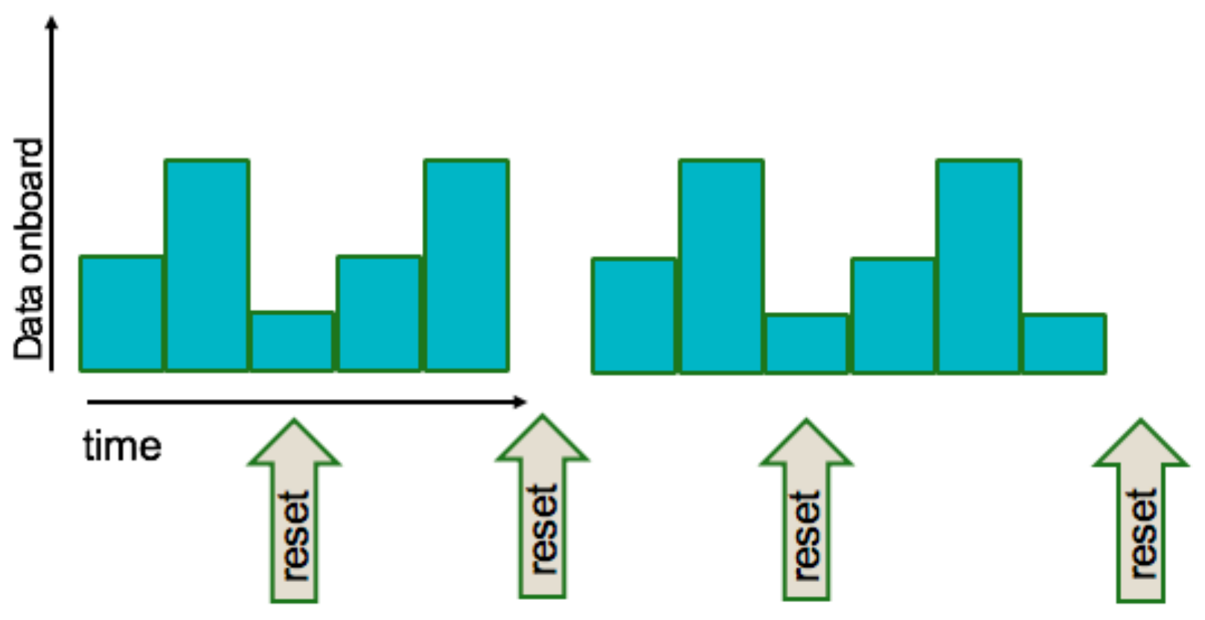
CLASP

The Compressed Large-scale Activity Scheduler and Planner (CLASP) has been in use in various ways for ECOSTRESS. Coverage planning technology in the CLASP scheduler has been used in the aid of:

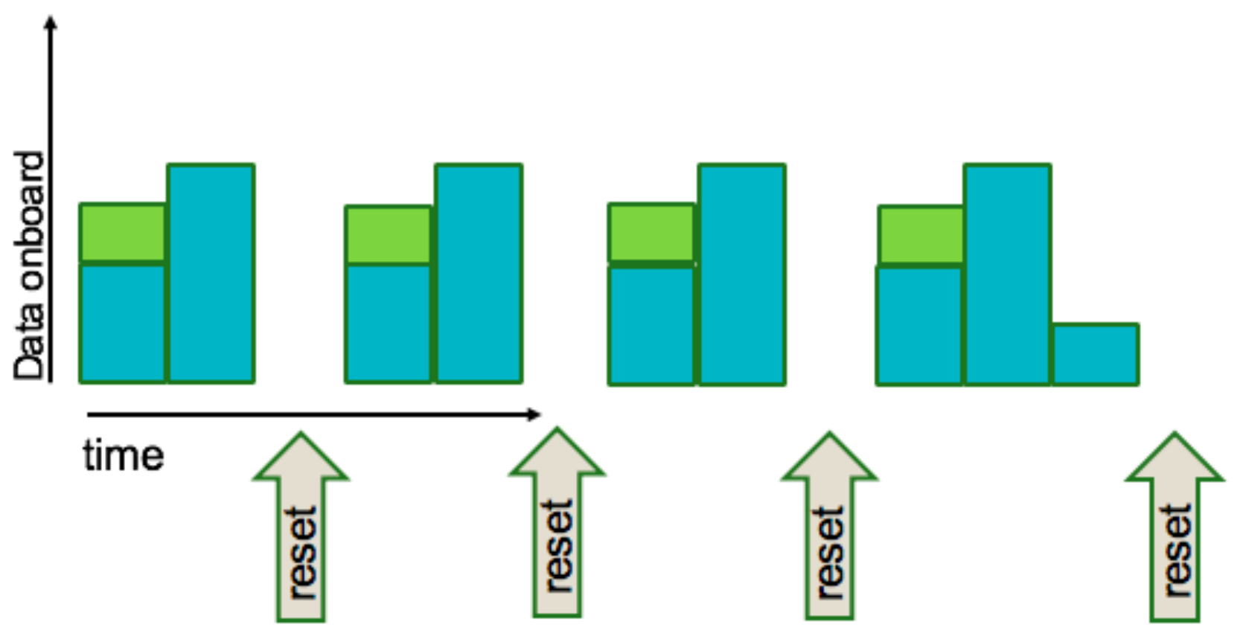
- evaluating designs of the overall science campaign implementation prior to launch
- Generating command sequences for operations
- designing new science coverage strategies
- updated scheduling approaches to address hardware challenges on orbit

Ring Buffer Issue

The Mass Storage Unit firmware onboard ECOSTRESS implemented a ring buffer. However, the read and write pointers did not correctly handle the buffer boundary, causing lost data. Rather than perform a firmware update to the instrument, CLASP was updated to automatically schedule resets of the ring buffer to avoid the issue.



High priority targets are initially scheduled to determine natural places where resets of the ring buffer should occur – when the amount of data onboard will be low and the end of the buffer has not been reached.



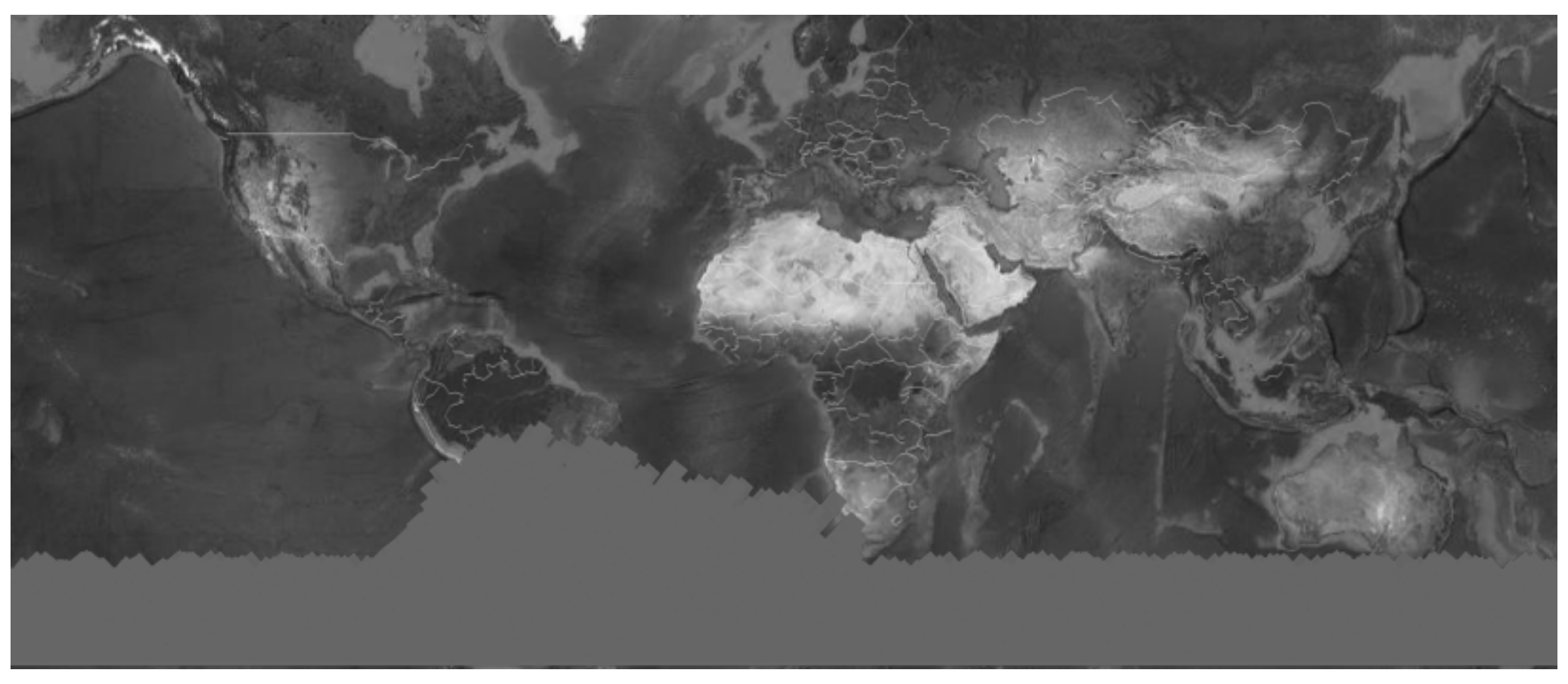
High and low priority targets are then scheduled, accounting for the times the ring buffer resets occur.

Radiation Sensitivity

One of the possible reasons for stalls of the Mass Storage Unit on ECOSTRESS was radiation sensitivity. It was found that most of the stalls were occurring in areas that had higher levels of radiation, like over the South Atlantic Anomaly and Low Latitudes. Many strategies for mitigating this were analyzed, and CLASP assessed the impact of the strategies on coverage.

Strategies included:

- Taking data and downlinking only on orbits overflying Australia
- Turning off the MSU over the South Atlantic Anomaly and Southern High Latitudes
- Not downlinking data over High Latitudes



Regions where the MSU needed to be powered down due to radiation

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Automated Scheduling for the OCO-3 Mission

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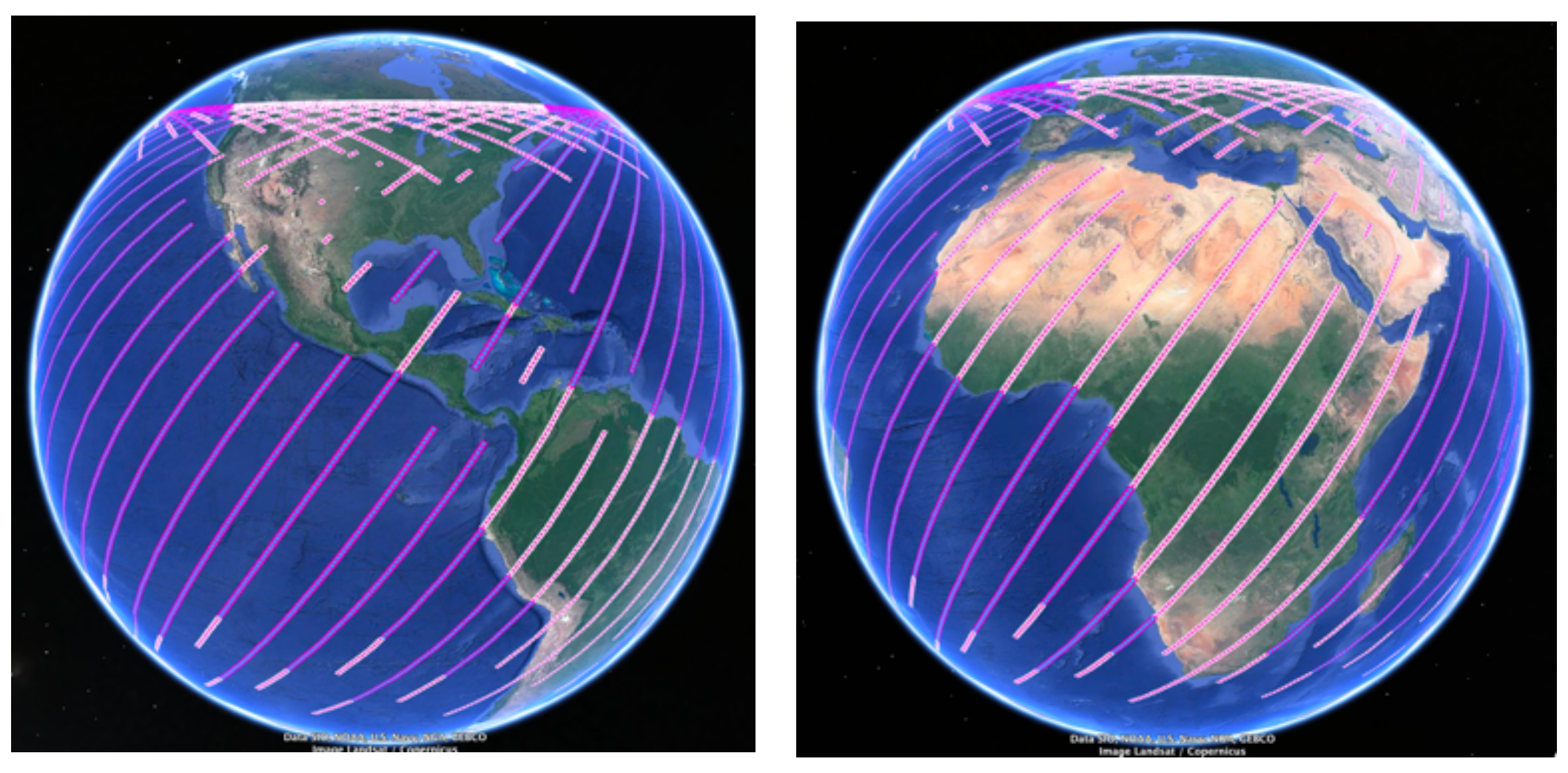
Summary

The Orbiting Carbon Observatory-3 (OCO-3) is a NASA instrument for measuring atmospheric CO_2. OCO-3 launched to on May 4, 2019 to the ISS (International Space Station) on a SpaceX Falcon 9 rocket as part of a resupply mission. It is mounted on the International Space Station on the Japanese Experiment Module – Exposed Facility (JEM-EF). It is expected to begin nominal science operations in August 2019 and its planned mission duration is three years. OCO-3 will enable identification of CO_2 sources and sinks and study changes in CO_2 levels over time.

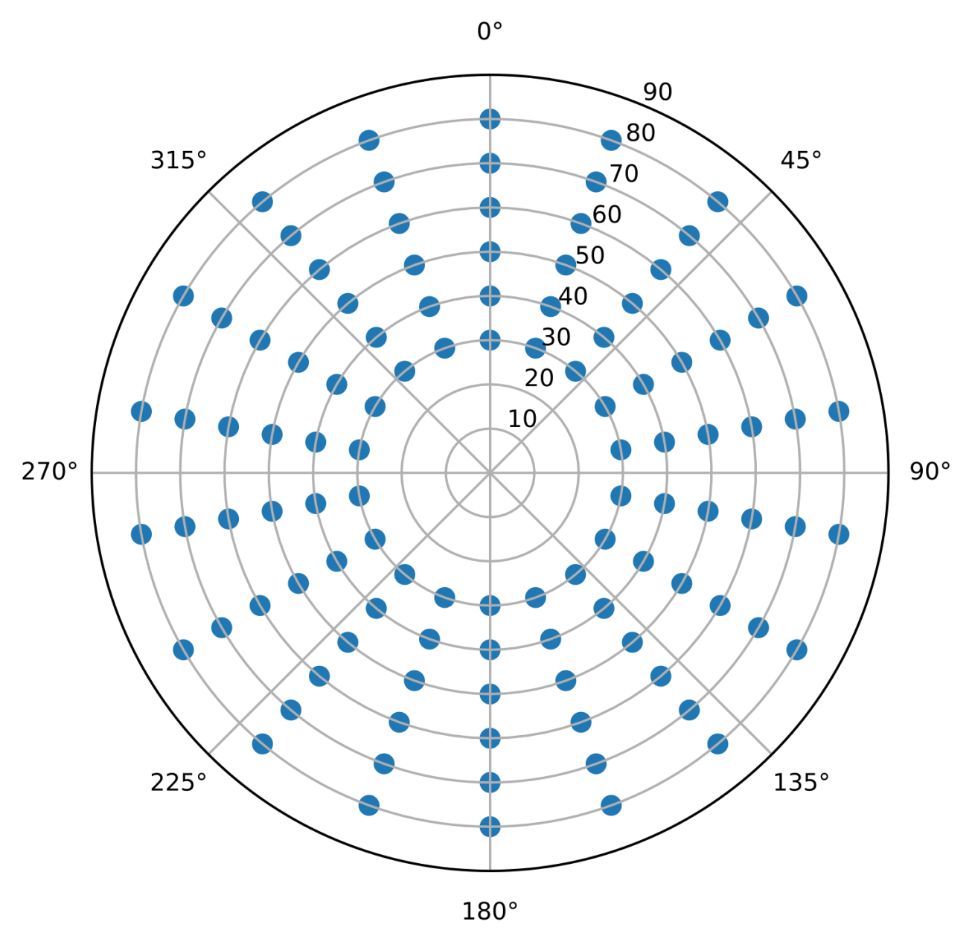
Automated scheduling is being deployed for operations of OCO-3. The OCO-3 scheduling process begins with a mostly-automated dynamic science priority assignment that is input to an automated scheduling of area targets, calibration targets, nadir, and glint mode. It is also being used to schedule observations for the calibration of the pointing mirror.



A visualization of part of a generated schedule

Pointing Mirror Assembly Calibration

To calibrate the Pointing Mirror Assembly (PMA), observations are taken from a set of pointings relative to the instrument body. The observations must be taken over land in daytime to be compared to reference images to determine the error in the pointing based on the ISS location. Corrections are then applied to minimize the pointing error for future observations.



Azimuth, elevation target points that are observed to calibrate the PMA

Agile pointing

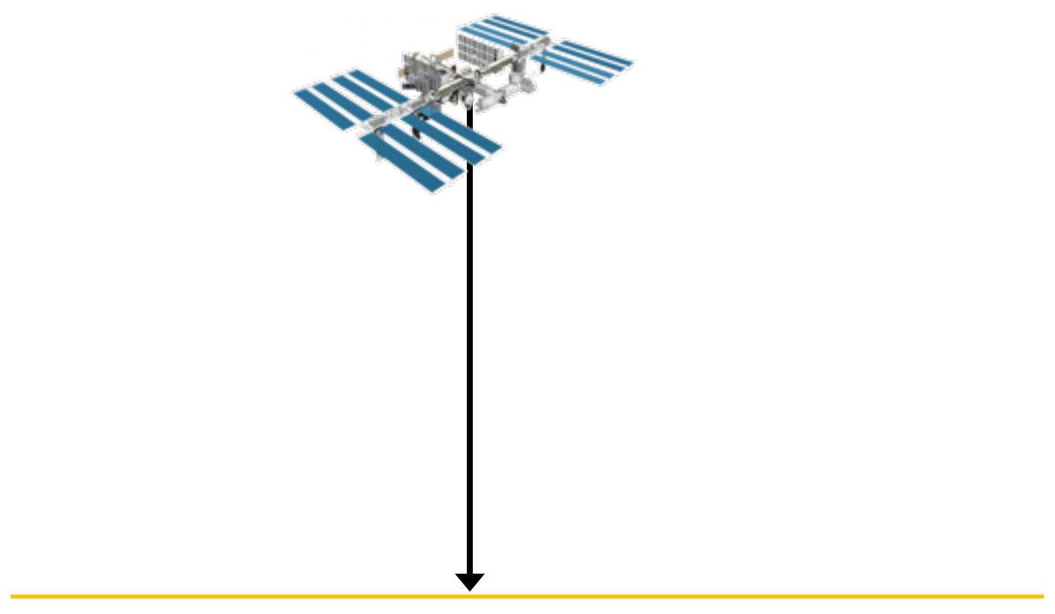
While the current OCO-3 scheduler does not schedule fine instrument pointing (this is controlled in flight software), technology exists in the Eagle Eye system[12] to construct detailed pointing plans to cover arbitrary polygons.

Agile pointing of 2d sensor to cover area[12]

Operational Modes

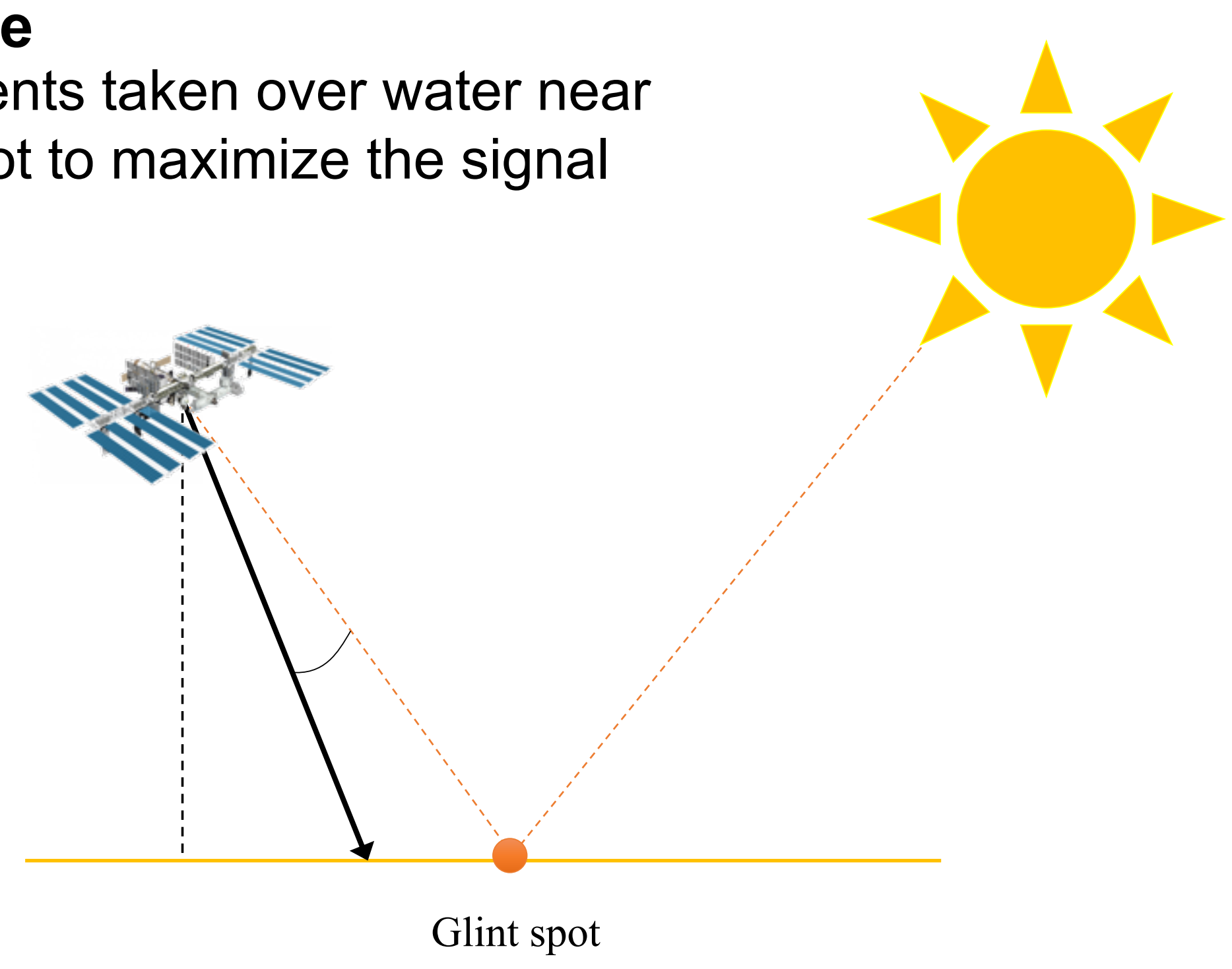
Nadir mode

Default mode over land in the daytime



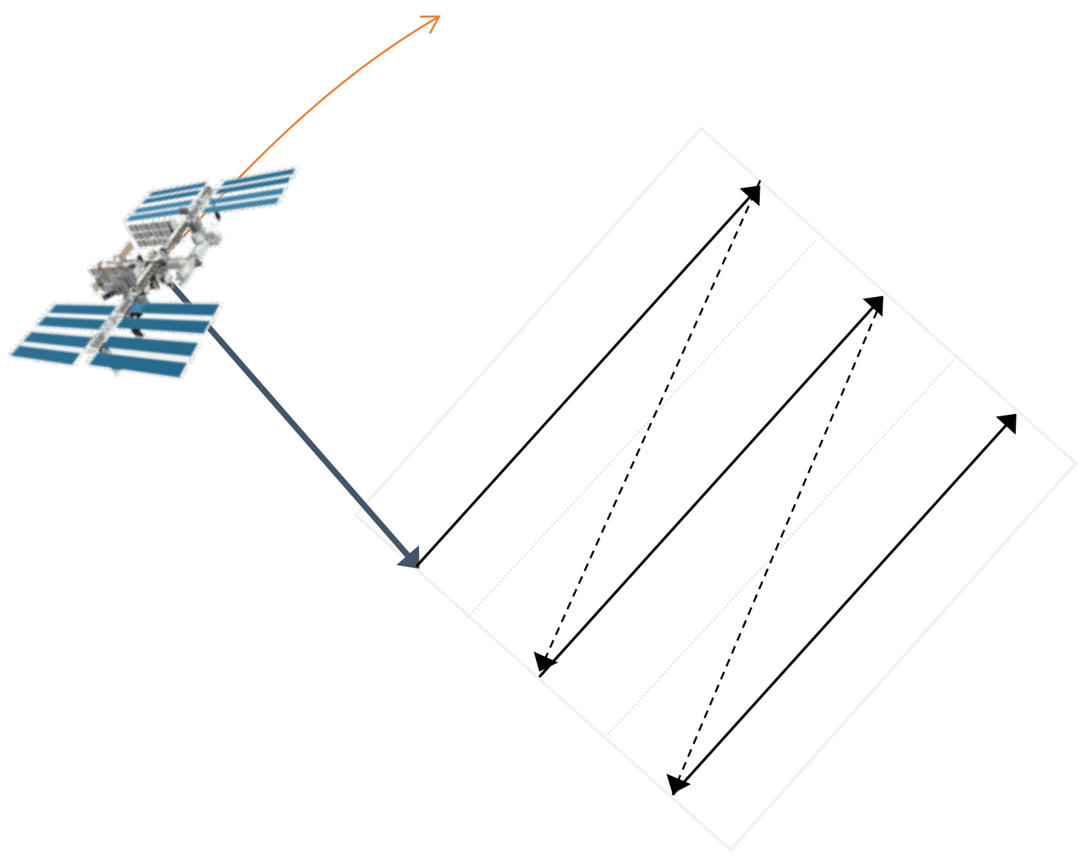
Glint mode

Measurements taken over water near the glint spot to maximize the signal



Area Mapping mode

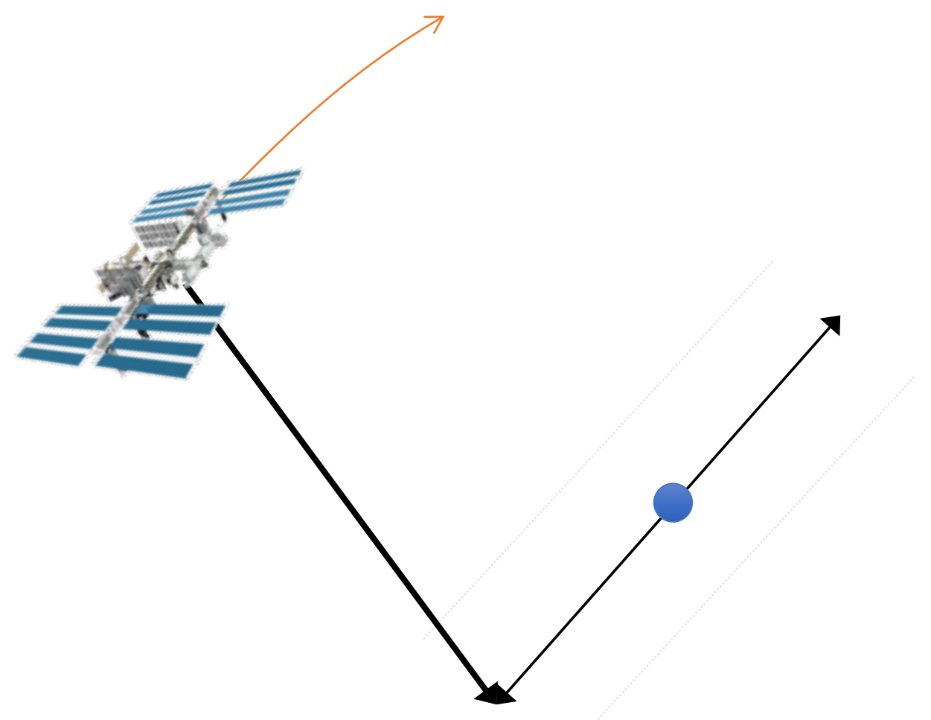
Measurements taken over regions of interest, such as a city



Observe several non-overlapping stripes over the target area

Target Mapping mode

Measurements taken over a specific point, such as a validation site



Observe a single stripe over the target point repeatedly

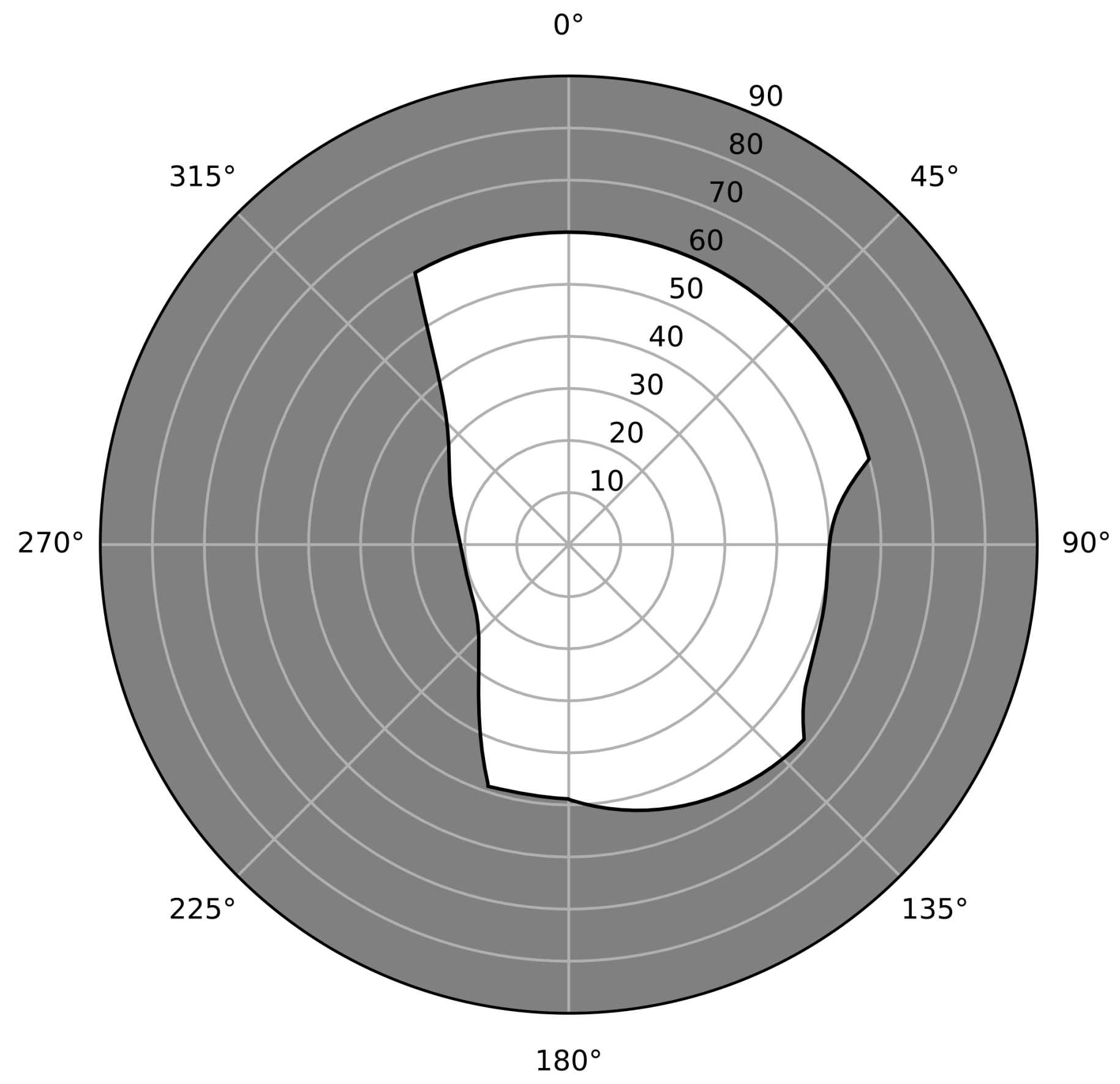
Checking Visibility

OCO-3's field of view is limited due to obstructions by other components of the ISS. The scheduling software must account for the limitation without sacrificing too much runtime or precision. The occlusion mask is defined as a set of polynomials for several longitude segments. We currently check visibility for area map mode, target mode, and glint mode.

To check if a target is visible at a particular point in time, we project the target onto the unit sphere around the satellite. This gives us an azimuth/elevation point that can be checked for inclusion in the visibility set.

For glint mode, this approach is satisfactory. But for area map and target mode, we do not know exactly where the PMA is pointed at any time. We consider three approaches to addressing this complication:

- **Centroid:** Project the centroid of the target and check visibility set
- **Corners:** Project the corners of the target and check visibility set
- **Configuration space:** Define a configuration space that characterizes all points on the unit sphere that represent the centroid of a visible target. Project only the centroid of the target on the unit sphere and check if that the point falls within the configuration space.



A visualization of the "keepout zone" (in grey) that the scheduling software must avoid pointing the PMA at

References:

[1] Moy, A.; Yelamanchili, A.; Chien, S.; Eldering, A.; and Pavlick, R. 2019. Automated scheduling for the orbiting carbon observatory 3 mission. International Workshop on Planning and Scheduling for Space (IWPSS 2019) in preparation.

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Automated Scheduling for the EMIT Mission

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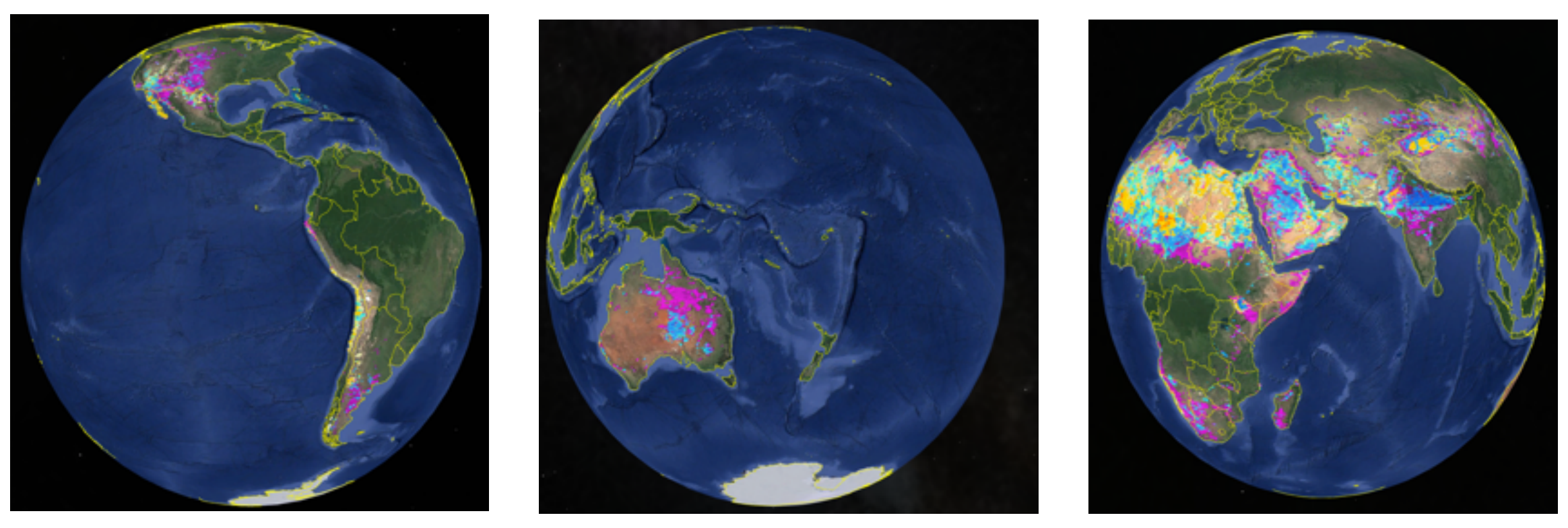
Summary:

The **E**arth Surface **M**ineral Dust Source **I**nves**T**igation (**EMIT**) is an Earth Ventures-Instrument (EVI-4) Mission to map the surface mineralogy of arid dust source regions via imaging spectroscopy in the visible and short-wave infrared (VSWIR). The maps of the source regions will be used to improve forecasts of the role of mineral dust in the radiative forcing (warming or cooling) of the atmosphere. EMIT is scheduled for launch to the International Space Station (ISS) in the early 2020's.

Automated scheduling technology was used to to construct schedules which were then automatically analyzed with respect to science acquired. These analyses can be performed for a range of spacecraft hardware configurations, observation strategies, and science requirements. by studying the effects of changes on the above inputs, better hardware configurations, observation strategies, and science requirements can be formulated.



The initial target regions are taken from Paul Ginoux's global attribution of dust sources[2].

CLASP for Automated Coverage Scheduling:

The **C**ompressed **L**arge-scale **A**ctivity **S**cheduling and **P**lanning (**CLASP**) project is a long-range scheduler which addresses the problem of choosing the orientation and on/off times of a space-based pushbroom instrument such that the schedule covers as many target points as possible, but without oversubscribing memory and violating any other spacecraft constraints[3,4]. Orientation and time of observation is derived from geometric computations that CLASP performs using the SPICE ephemeris toolkit. CLASP allows mission planning teams to start with a baseline mission concept and simulate the mission's science return using models of science observations, spacecraft operations, downlink, and spacecraft trajectory. This analysis can then be folded back into many aspects of mission design -- including trajectory, spacecraft design, operations concept, and downlink concept. The long planning horizons allow this analysis to span an entire mission.

Scheduling Parameters

- Instrument data rate
- Downlink rate
- Across-track swath size
- Push broom imager
- Off-track look limits
- Slew rate
- Minimum along-track imaging duration
- Solar zenith angle limits & preferences
- Observation angle preference

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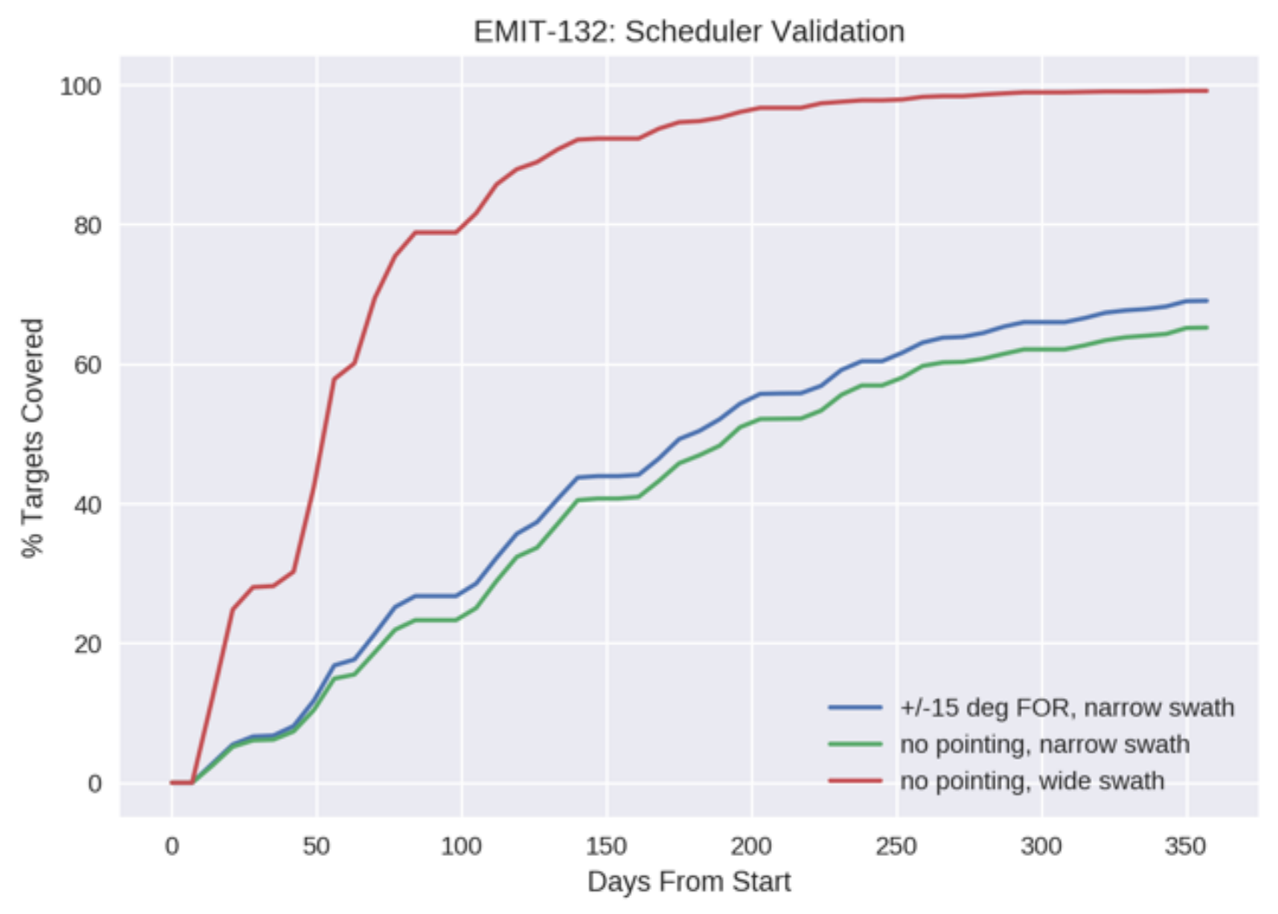
Hardware Configurations

Analysis of hardware's effects on coverage can be achieved through automated scheduling. Some hardware components involved in the analysis were the pointing mirror and the resolution of the instrument. The effects on the level of coverage achievable and the time necessary to achieve certain levels of coverage can be impacted by how far off-nadir the instrument is able to look and the swath size of the instrument.



Graph comparing

1) large swath size with no pointing capability
2) small swath size with pointing capability
3) small swath size with no pointing capability

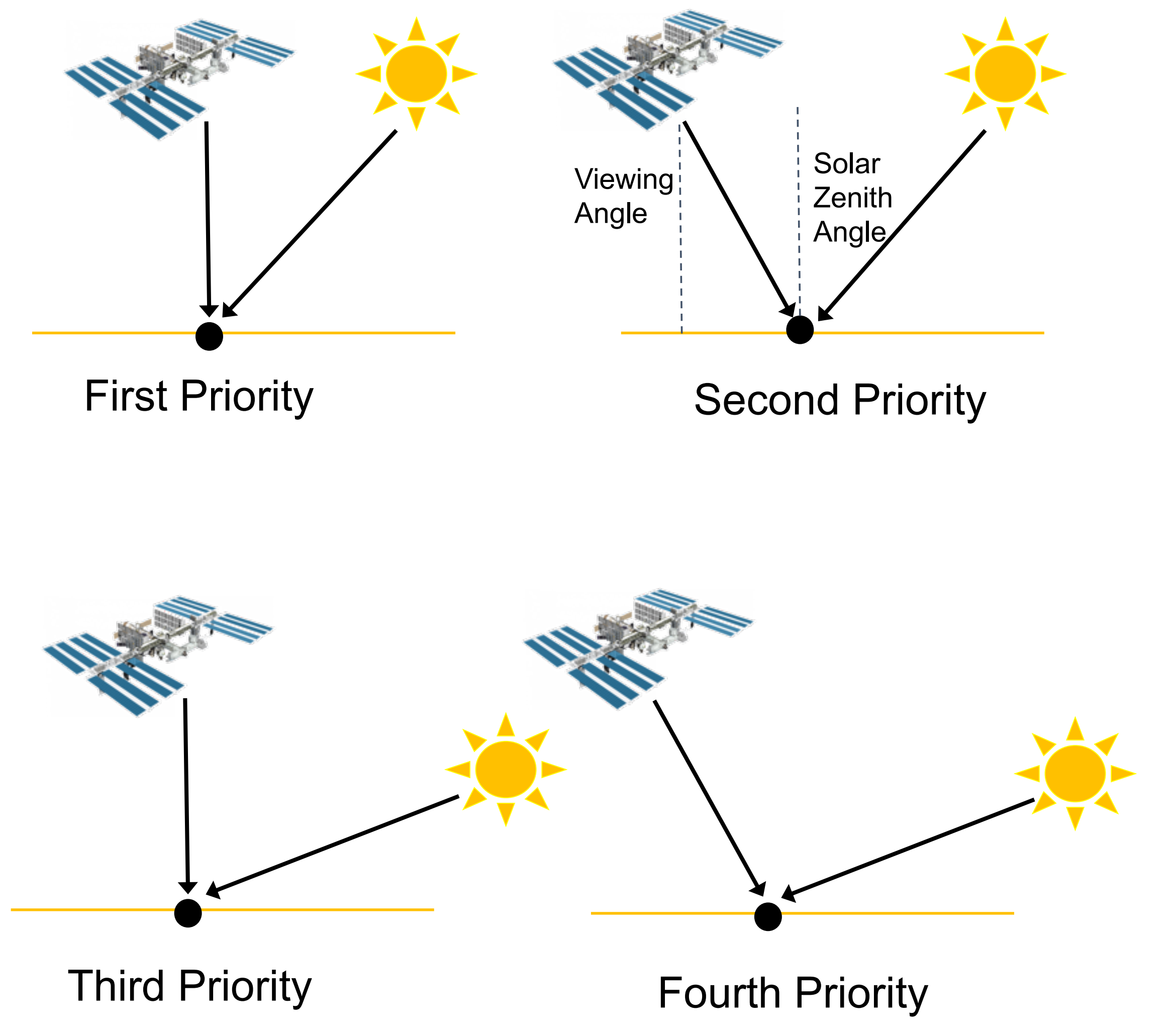
This analysis helped to quantify the effect of pointing on the overall science return, a major factor in the pointing/no pointing design trade.

Observation Design and Coverage Strategy

The quality of an observation can be impacted by multiple factors including

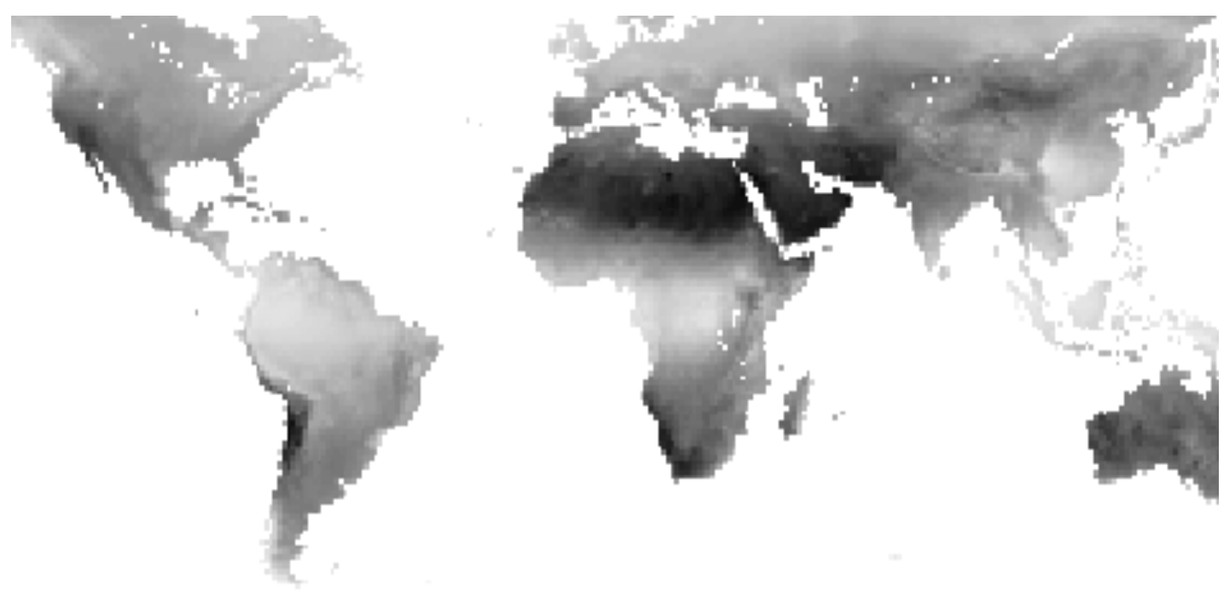
1) The illumination of the observation
2) The viewing geometry

In the case of EMIT, it is preferable for observations to have higher solar zenith angles and be viewed closer to nadir. The priorities of scheduling observations can take these preferences into account.



Cloud Statistics

Onboard cloud screening software[5] will detect clouds in observations and excise that data. Clouds will thus have a large impact on data volume and coverage.



A mask of the likelihood of clouds based on location over a year[1] was used in determining the probability of an observation being successful.

If a (Lat, Lon) point is cloudy with probability *C*, and has *N* observations the probability there is at least one non-cloudy observation is $1 - C^N$.

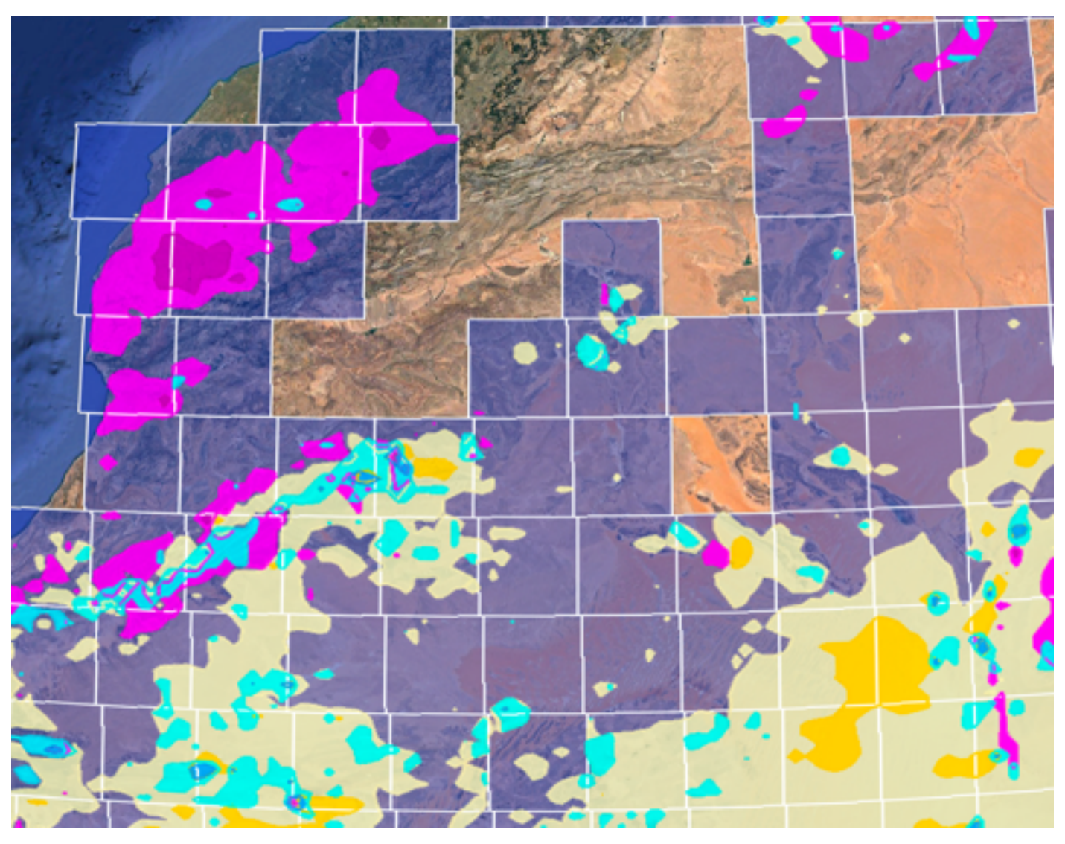
4 observations

0.30 cloud probability

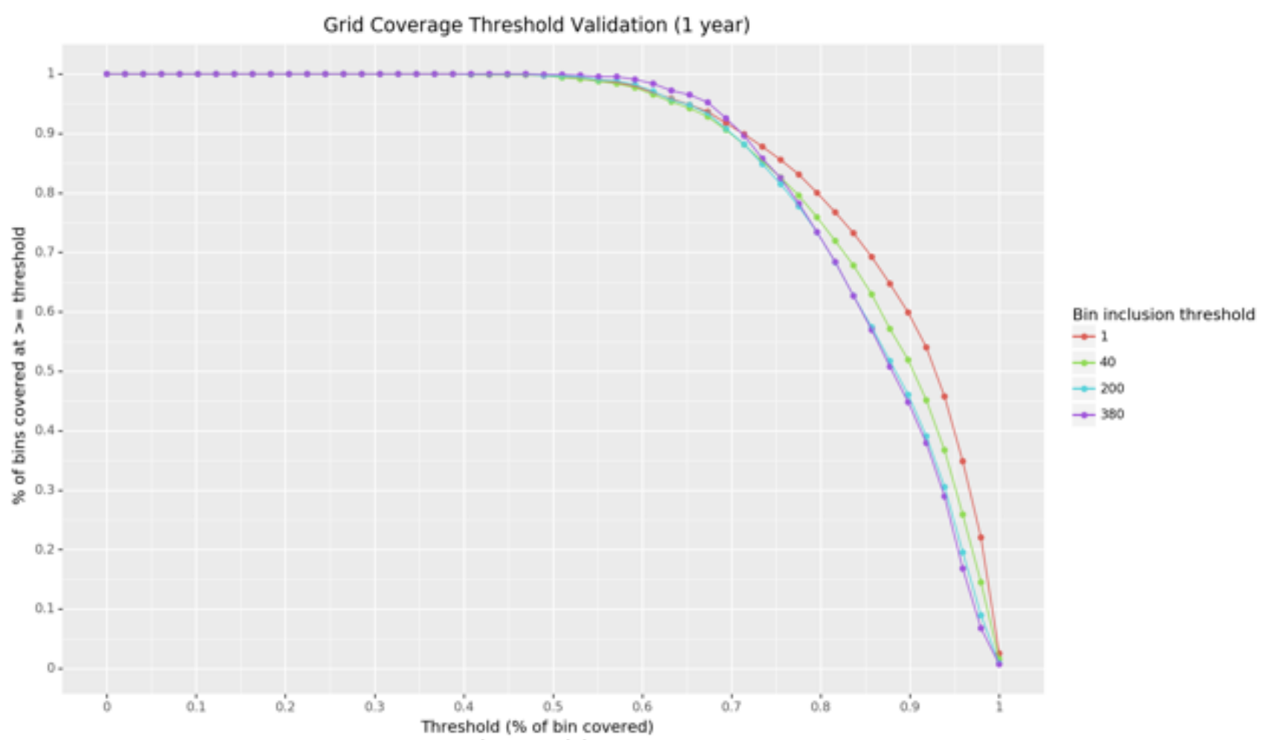
→ 0.9919 probability of having at least one non-cloudy observation

Coverage Criteria

The automated scheduling technology was used in defining coverage criteria such as percentage coverage and grid resolution. The original target region was abstracted to 100 km x 100 km bins. Analysis determined which bins would be considered in the final target region, and how much of each bin needed to be covered to be considered satisfied.



Abstraction of Target Region



Achievable coverage of different bin inclusion levels

References:

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Automated Scheduling for the NISAR Mission

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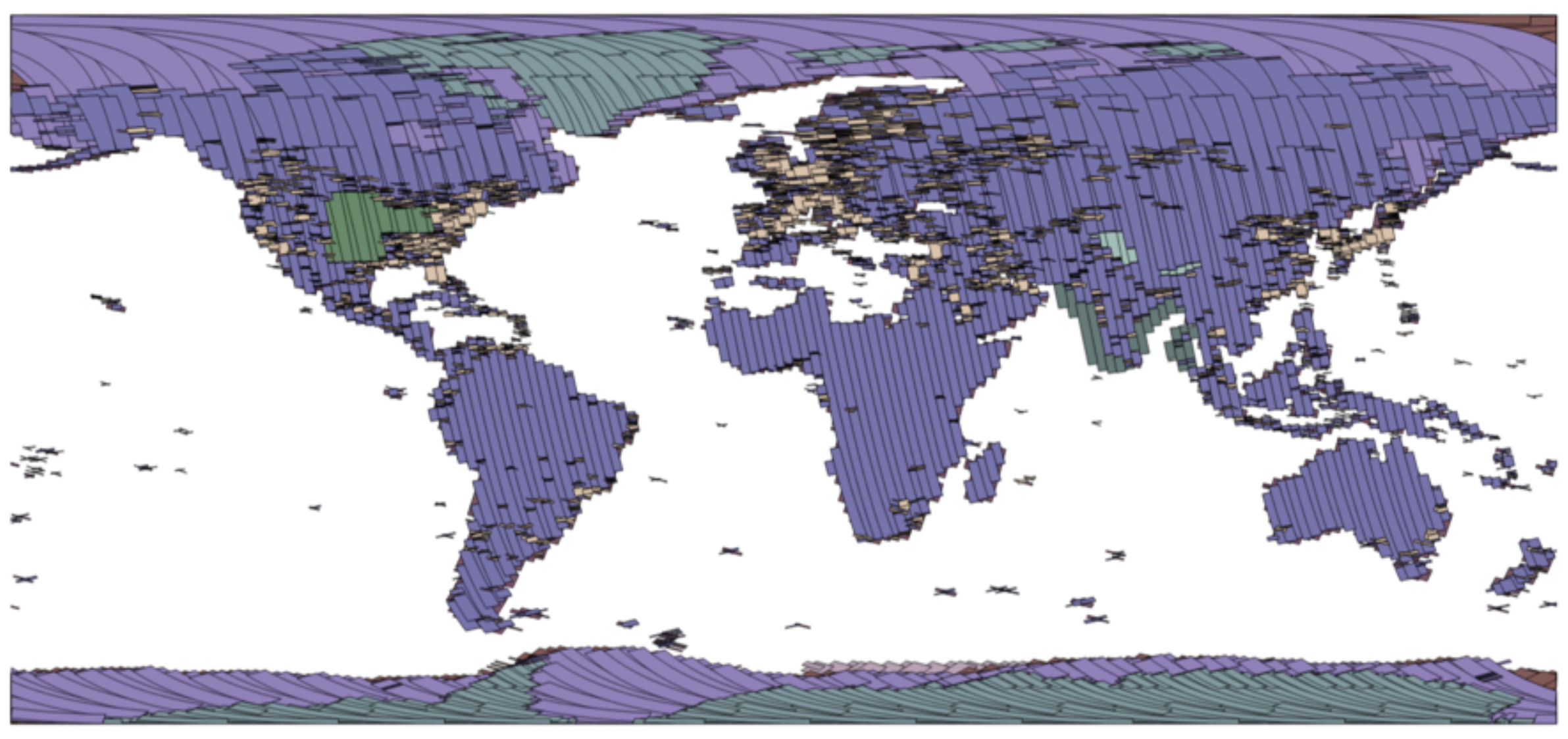
Summary

The **N**ASA-**I**SRO **S**ynthetic **A**perture **R**adar (**NISAR**) Mission is the first dual-frequency microwave radar mission[1]. The mission will observe many processes on the Earth and how they change the landscape of the land and oceans. These processes include volcanic activity, earthquakes, flooding, and flow of glaciers and ice sheets.

NISAR is scheduled to launch in 2022 and will be using automated coverage planning technology to plan its operations. The mission will use the **C**ompressed **L**arge-scale **A**ctivity **S**cheduling and **P**lanning (**CLASP**) System in long-term planning for operations. Parts of the system will also be used in short-term tactical replanning for the instrument.

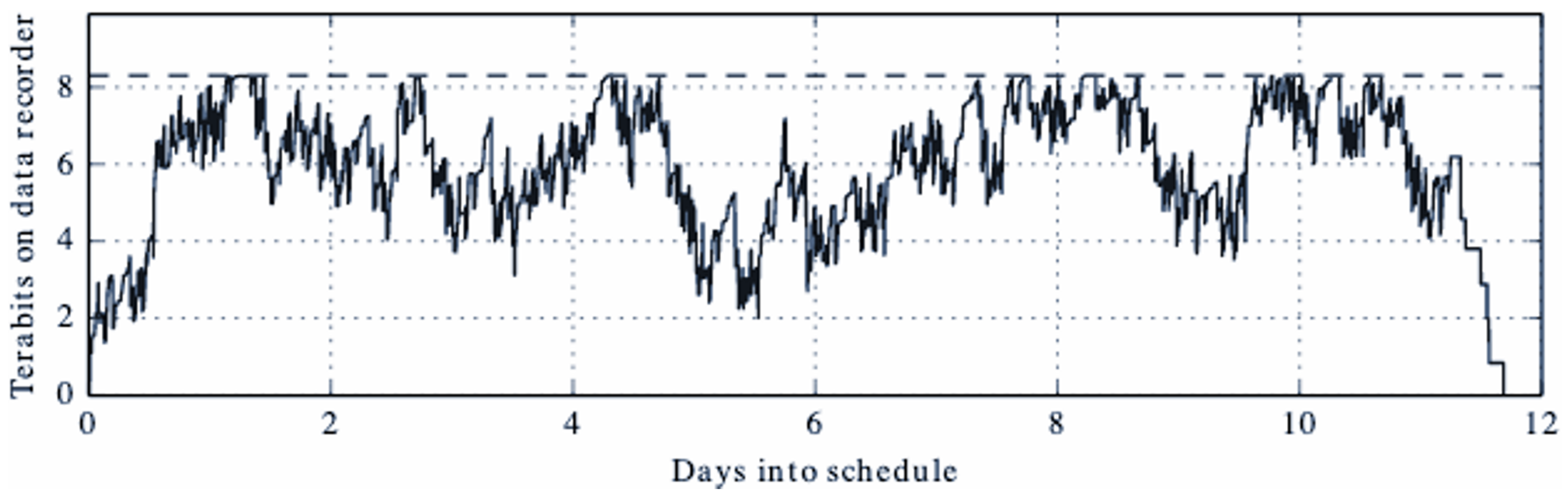
Observations may be taken in one of multiple modes, and observations may compete for data availability.



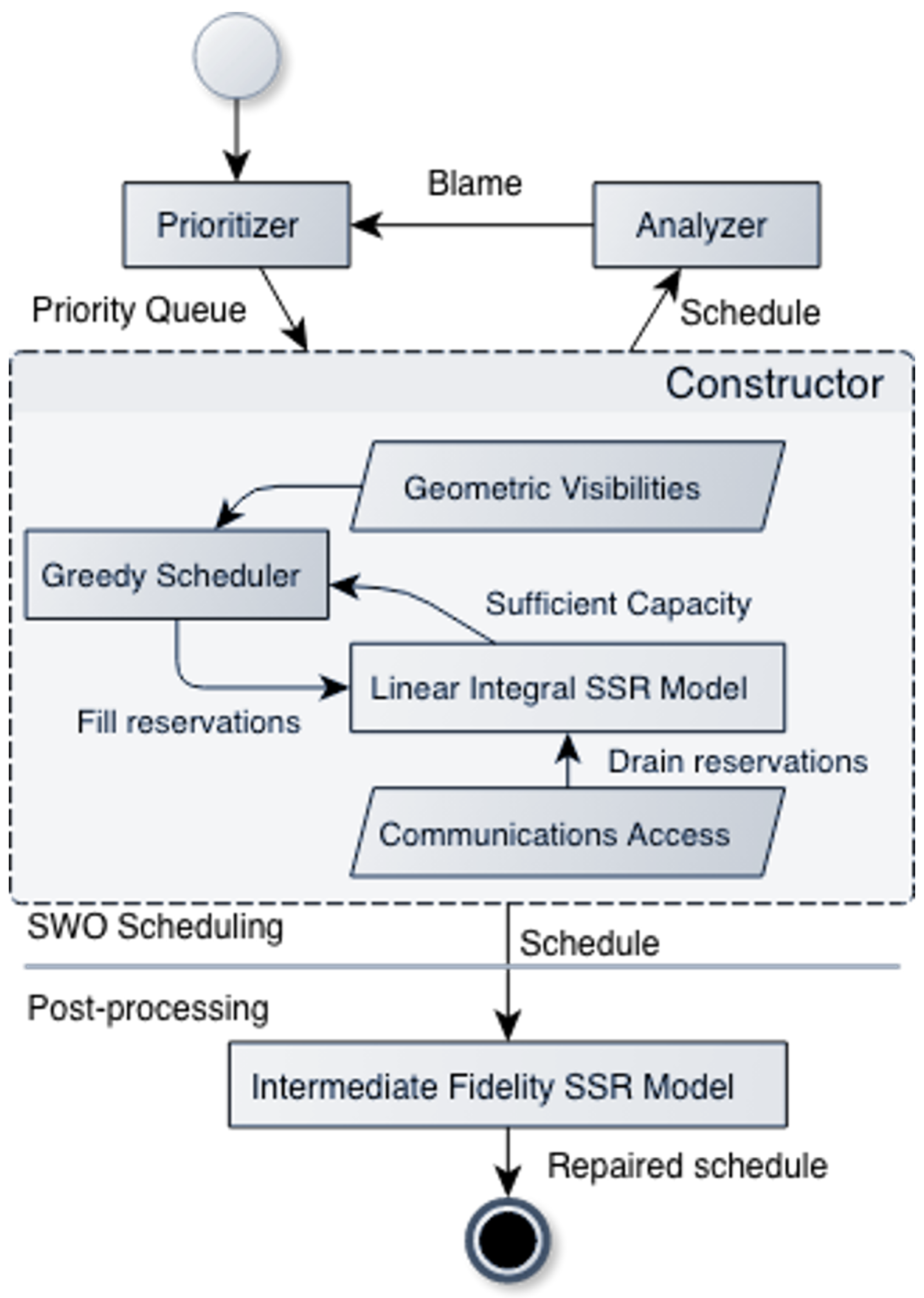
The descending observations for one 12-day repeat cycle of the NISAR mission[2]

Custom Data Model

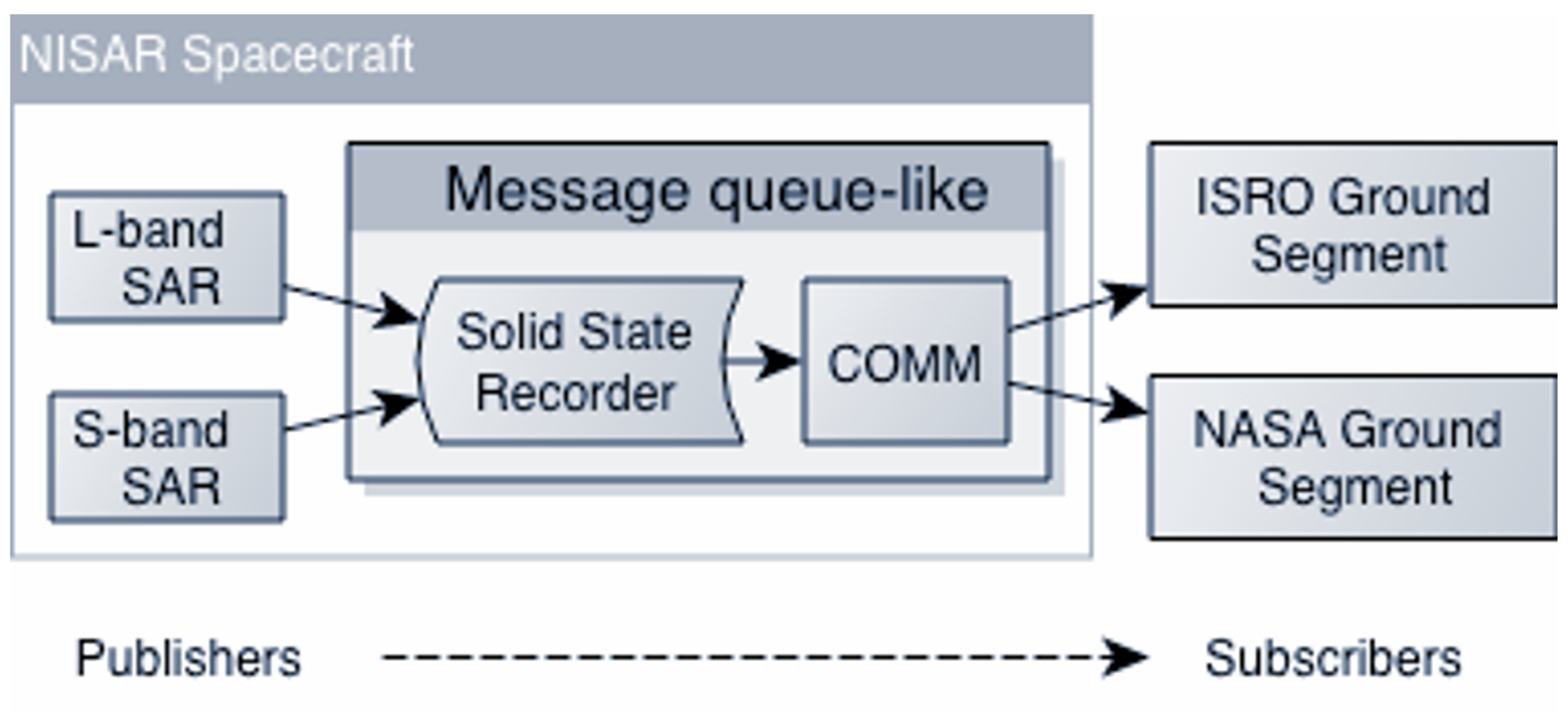
There is a common Solid State Recorder (SSR) onboard the spacecraft that holds data from both of the separate radar instruments. Science data from each instrument may be downlinked by one or both of the involved space agencies. The mission uses a custom data model to simulate NISAR's actual flight SSR in attempting to produce a conflict-free schedule.



SSR fill level over 12-day simulation[3]



Two data models of varying fidelity are involved in the scheduling[3]



Data comes from two sources and may be played back to one or two destinations[3]

References:

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