Jet Propulsion Laboratory
California Institute of Technology

Automated Policy-based Scheduling for the OCO-3 Mission

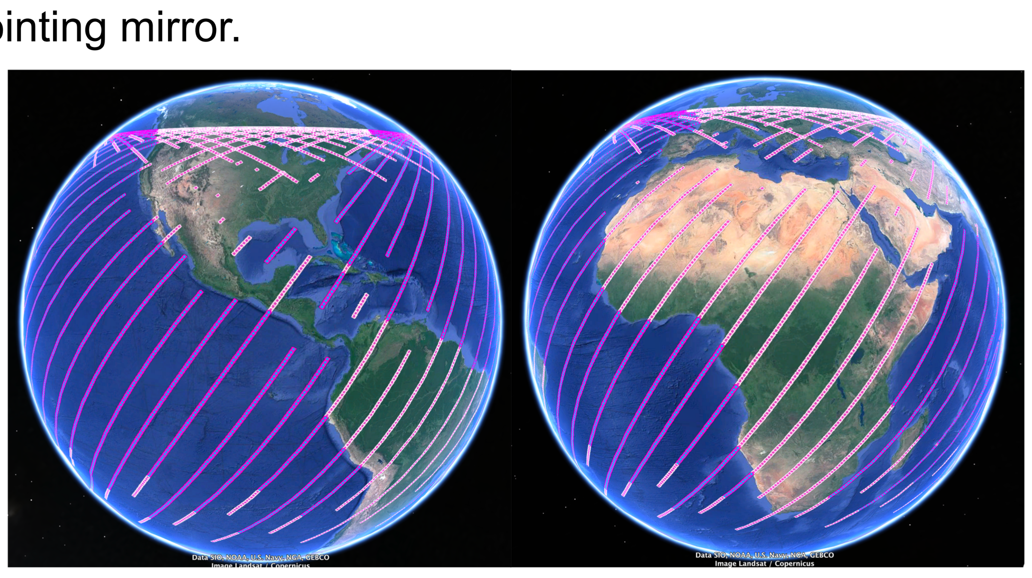
Amruta Yelamanchili, Alan Moy, Steve Chien, Annmarie Eldering, Ryan Pavlick, Christopher Wells

Jet Propulsion Laboratory
California Institute of Technology

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.

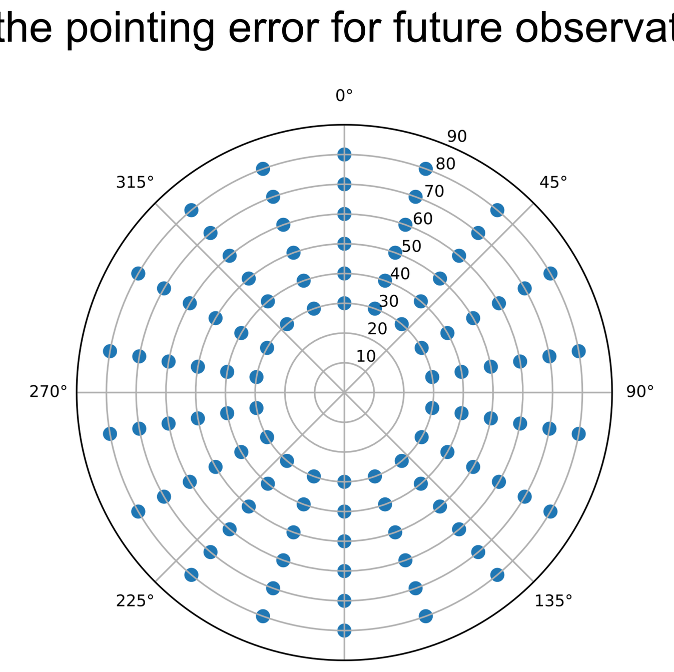
Automated scheduling is being deployed for operations of OCO-3. The OCO-3 scheduling process begins with a mostly-automated dynamic science priority assignment that is input to an automated scheduling of area targets, calibration targets, nadir, and glint mode. It is also being used to schedule observations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

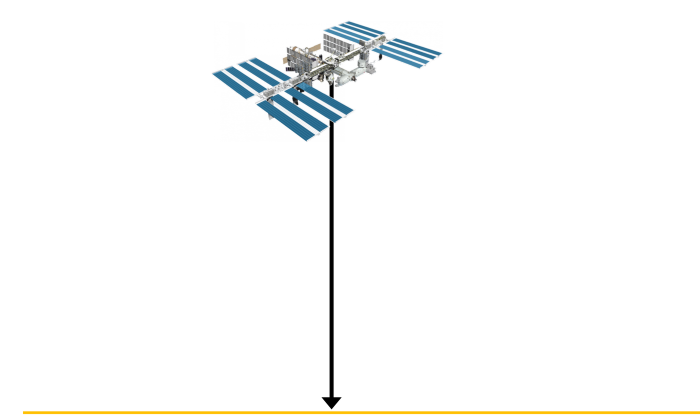
While the current OCO-3 scheduler does not schedule fine instrument pointing (this is controlled in flight software), technology exists in the Eagle Eye system[12] to construct detailed pointing plans to cover arbitrary polygons.

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

Operational Modes

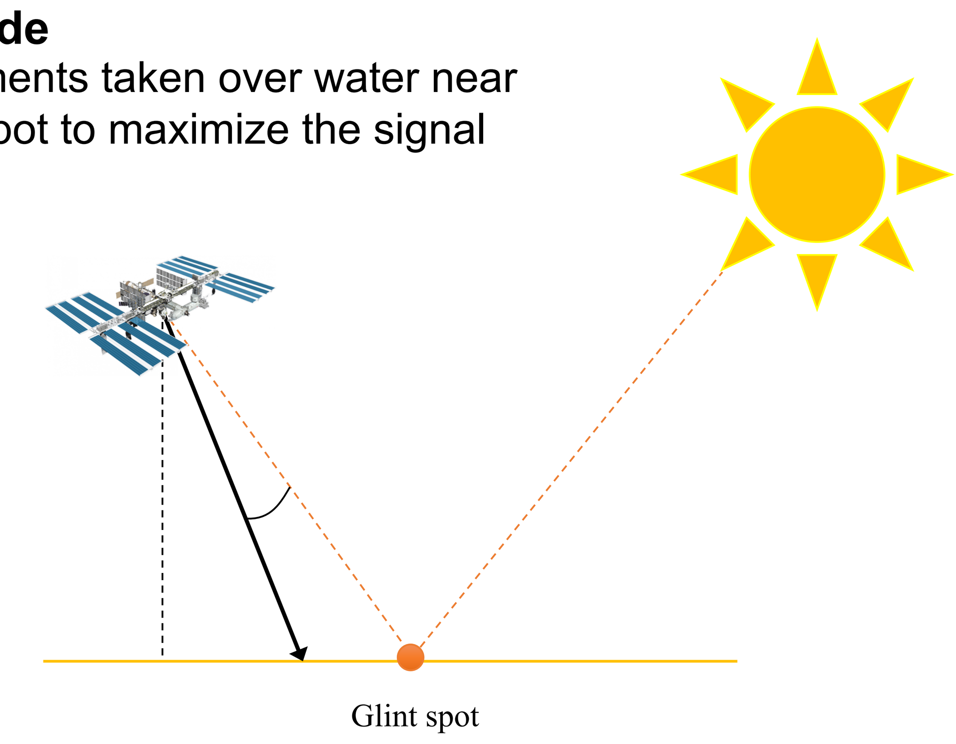
Nadir mode

Default mode over land in the daytime



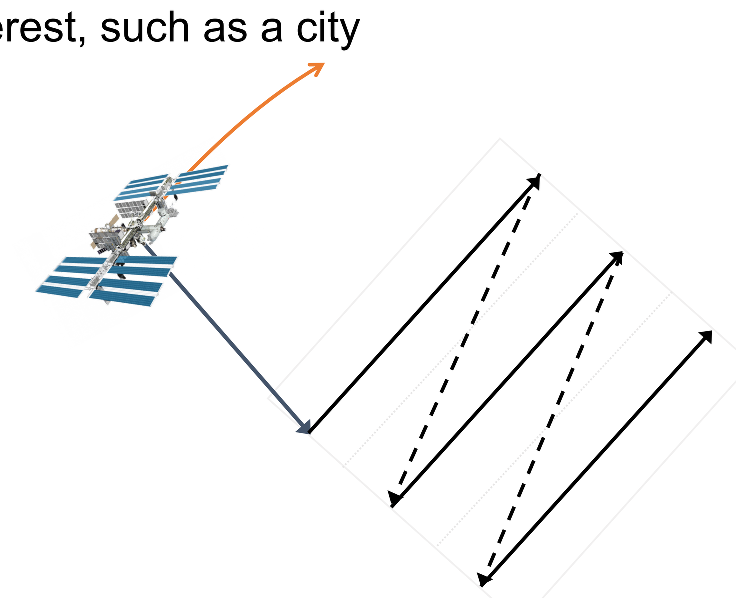
Glint mode

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



Area Mapping mode

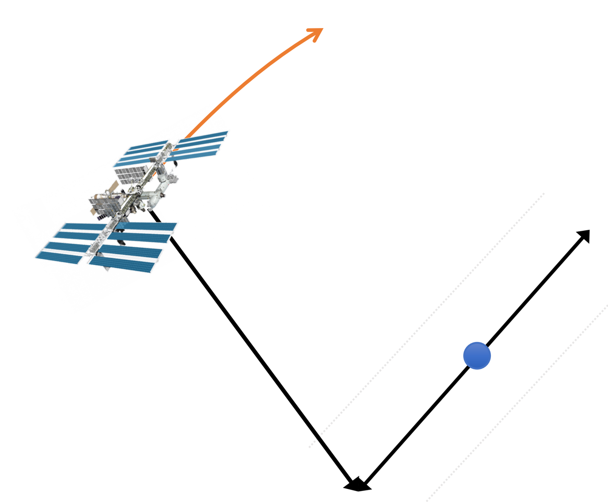
Measurements taken over regions of interest, such as a city



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

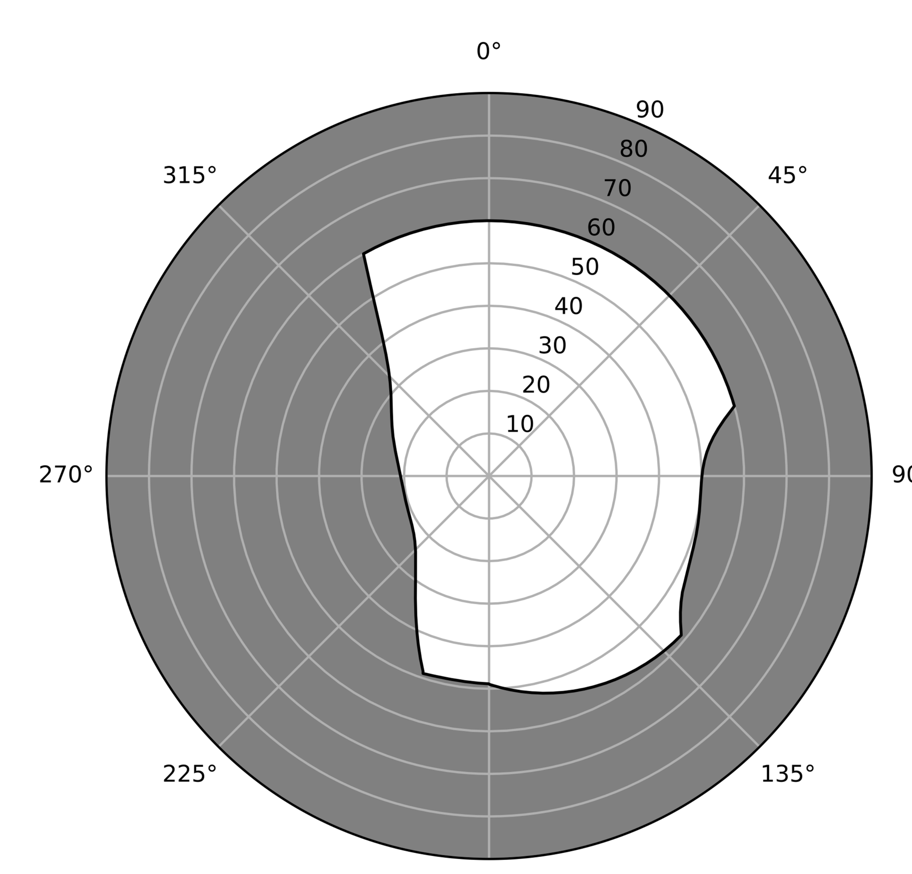
Checking Visibility

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.

[2] Acton, C. 2019. Naif https://naif.jpl.nasa.gov/naif.

[3] Chien, S.; Doubleday, J.; Thompson, D. R.; Wagstaff, K.; Bellardo, J.; Francis, C.; Baumgarten, E.; Williams, A.; Yee, E.; Stanton, E.; and Piug-Suari, J. 2016. Onboard autonomy on the intelligent payload experiment (ipex) cubesat mission. *Journal of Aerospace Information Systems (JAIS).*

[4] Doubleday, J., and Knight, R. 2014. Science mission planning for nisar (formerly desdyni) with clasp. In *SpaceOps 2014.*

[5] Doubleday, J. R. 2016. Three petabytes or bust: Planning science observations for nisar. In *SPIE 9881.*

[6] Hurkala, J. 2015. Time-dependent traveling salesman problem with multiple time windows. In *Position Papers of the 2015 Federated Conference on Computer Science and Information Systems, volume 6 of Annals of Computer Science and Information Systems,* 71–78.

[7] Knight, R., and Chien, S. 2006. Producing large observation campaigns using compressed problem representations. In *International Workshop on Planning and Scheduling for Space (IWPSS-2006).*

[8] Rabideau, G.; Chien, S.; Mclaren, D.; Knight, R.; Anwar, S.; Mehall, G.; and Christensen, P. 2010. A tool for scheduling themis observations. In *International Symposium on Space Artificial Intelligence, Robotics, and Automation for Space (ISAIRAS 2010).*

[9] Roussel, S.; Pralet, C.; Jaubert, J.; Queyrel, J.; and Duong, B. 2017. Planning the observation of exoplanets: the ariel mission. In *International Workshop on Planning and Scheduling for Space (IWPSS 2017).*

[10] Schubert, E.; Zimek, A.; and Kriegel, H.-P. 2013. Geodetic distance queries on r-trees for indexing geographic data. In *Advances in Spatial and Temporal Databases,* 146–164.

[11] Troesch, M.; Chien, S.; and Ferguson, E. 2017. Using automated scheduling to assess coverage for europa clipper and jupiter icy moons explorer. In *International Workshop on Planning and Scheduling for Space (IWPSS 2017).*

[12] Shao, E.; Byon, A.; Davies, C.; Davis, E.; Knight, R.; Lewellen, G.; Trowbridge, M.; and Chien, S. 2018. Area coverage planning with 3-axis steerable, 2D framing sensors. In *Scheduling and Planning Applications Workshop , International Conference on Automated Planning and Scheduling (ICAPS SPARK 2018).*

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov