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Automated Science Scheduling for the ECOSTRESS Mission

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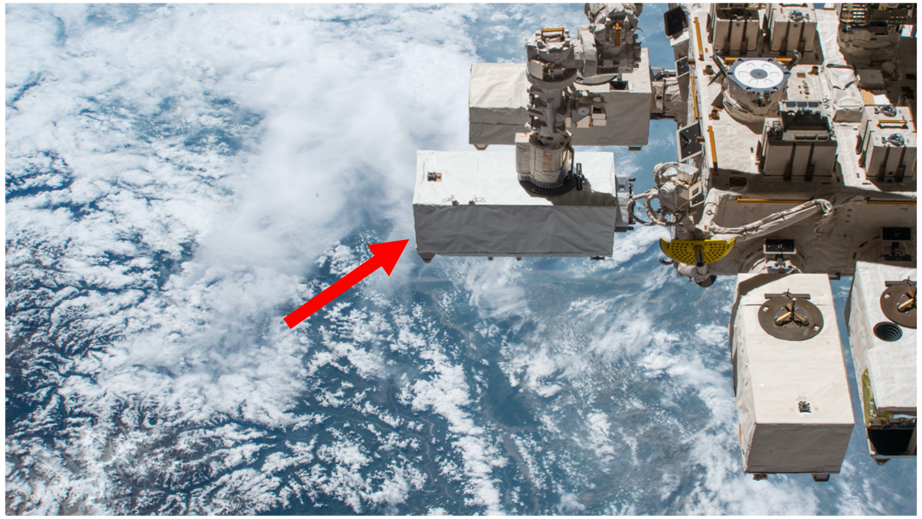
Overview

- ECOSTRESS Mission
- CLASP Scheduling System
- Scheduling Challenges
  1. Scheduling ring buffer resets added additional complexity to scheduling
  2. Robustness to uncertainty in along track orbit prediction
  3. Scheduling campaigns with extent beyond a single planning cycle

ECOSTRESS

- **ECOS**ystem **T**hermal **R**adiometer **E**xperiment on **S**pace **S**tation
- Studies the temperature of plants to determine how they use water
- Launched to the ISS in July 2018
  - Installed on the Japanese Experiment Module – Exposed Facility
- Planned mission end Summer 2019

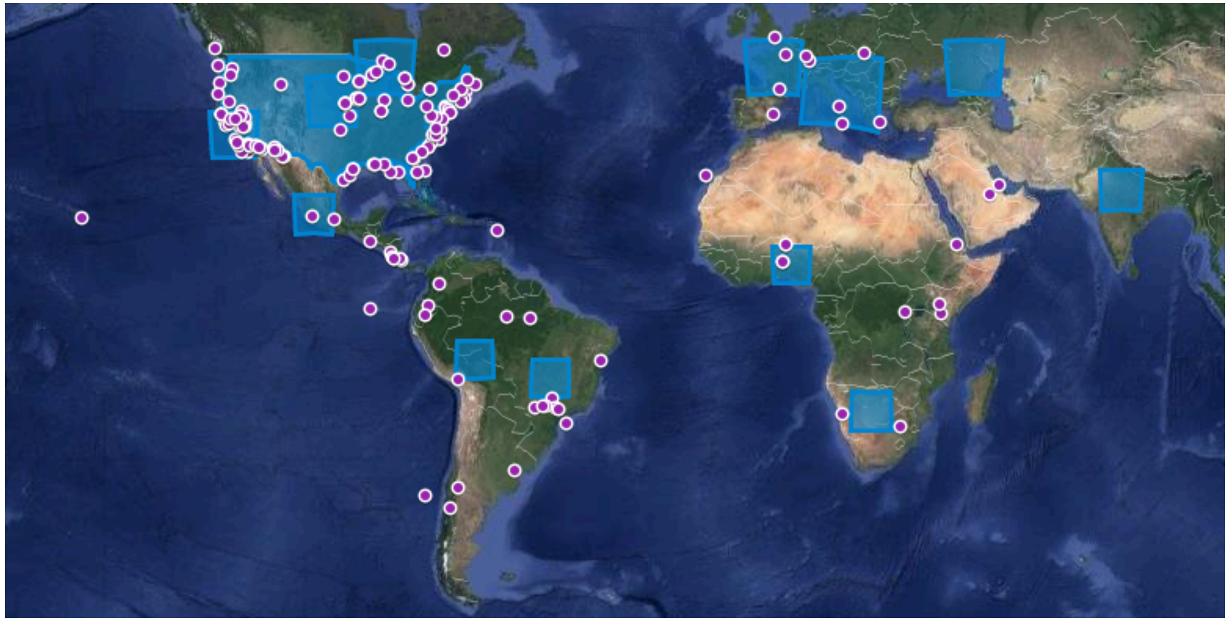


ECOSTRESS mounted on the JEM-EF

SpaceX CRS-15 launch on June 29, 2018

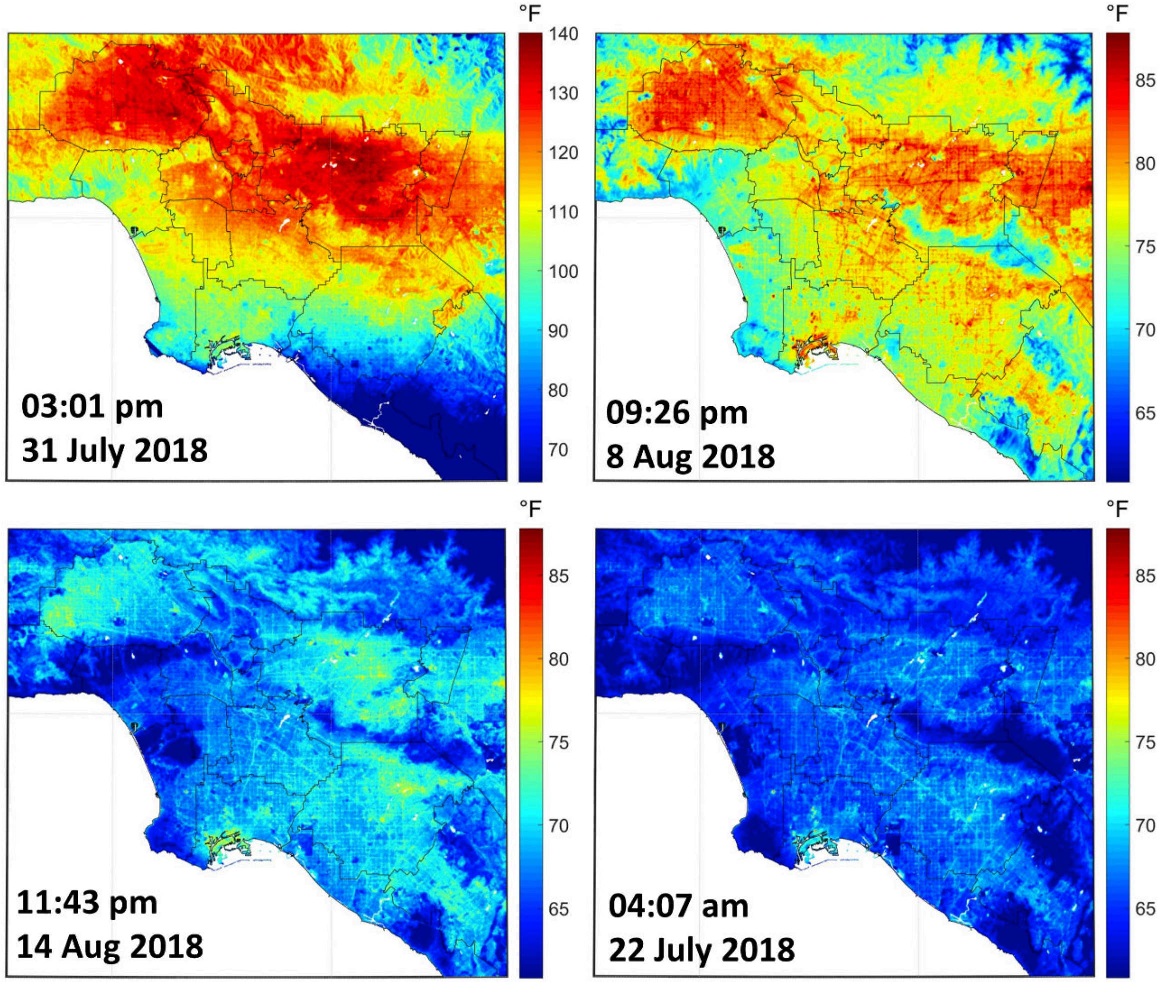
ECOSTRESS

- Nadir pointed instrument
- Campaigns have different illumination constraints – dependent on angle of sun at target location



Targets include key biomes (polygons), calibration/validation sites, cities, and volcanoes (points)

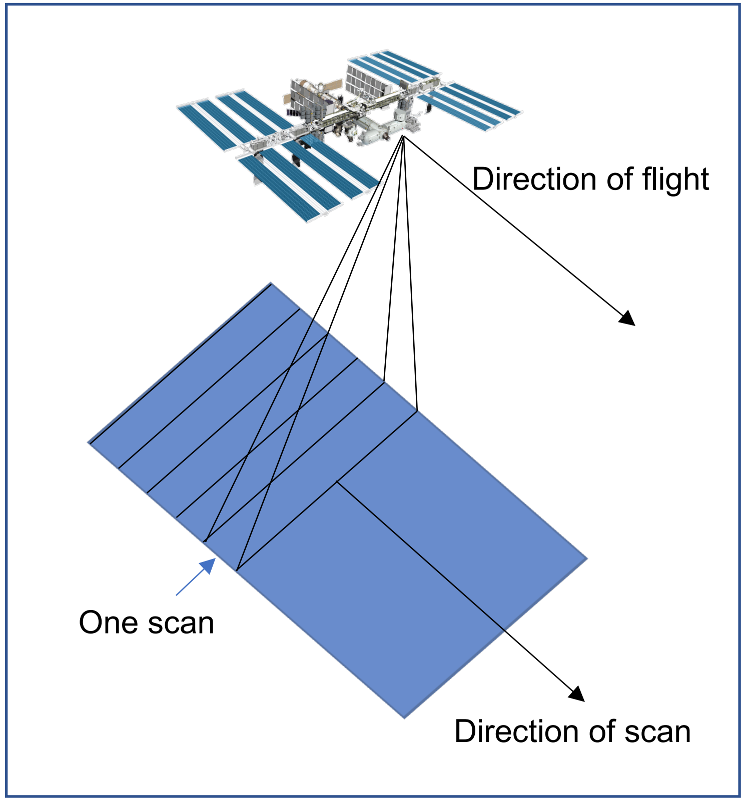
ECOSTRESS



ECOSTRESS data showing temperatures throughout Los Angeles at different times of day

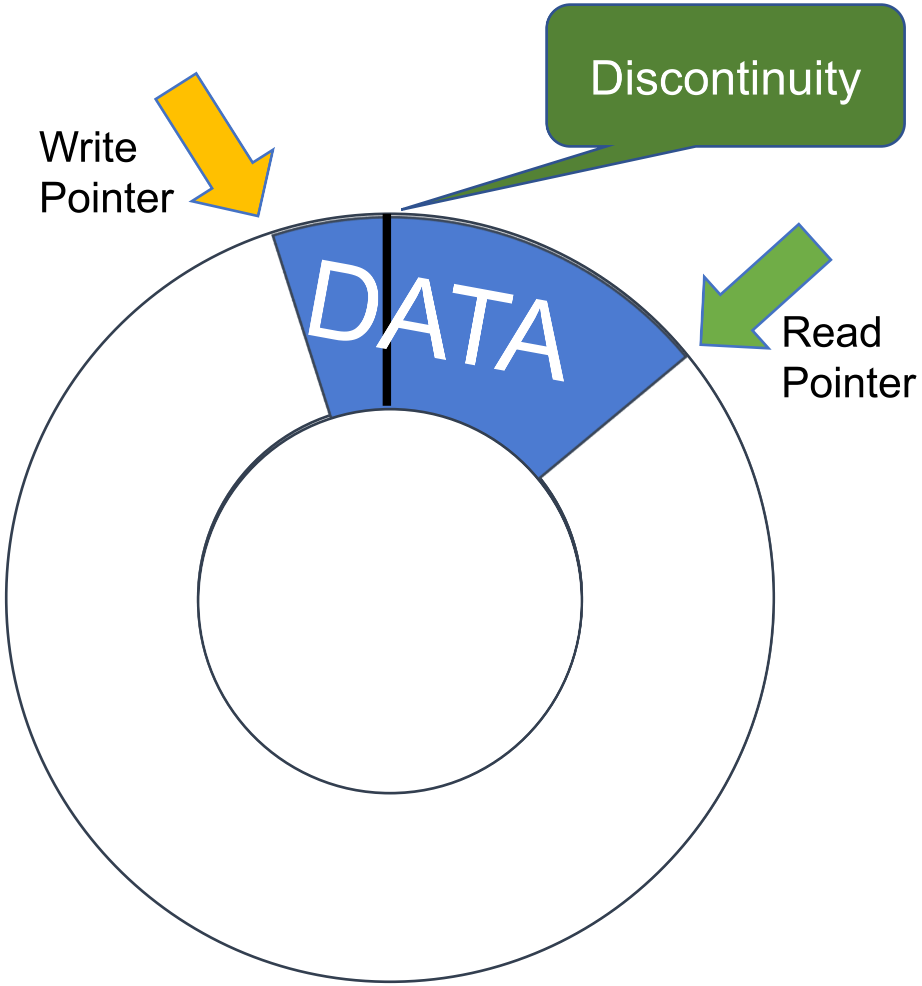
CLASP

- **C**ompressed **L**arge-scale **A**ctivity **S**cheduler and **P**lanner (Knight and Chien 2006)
  - Scheduler for space-based instruments that can be modelled as pushbrooms
- Uses by ECOSTRESS
  - Evaluating designs of the overall science campaign implementation prior to launch
  - Generating schedules (and therefore command sequences) for operations



Pushbroom Imager

Ring Buffer Issue

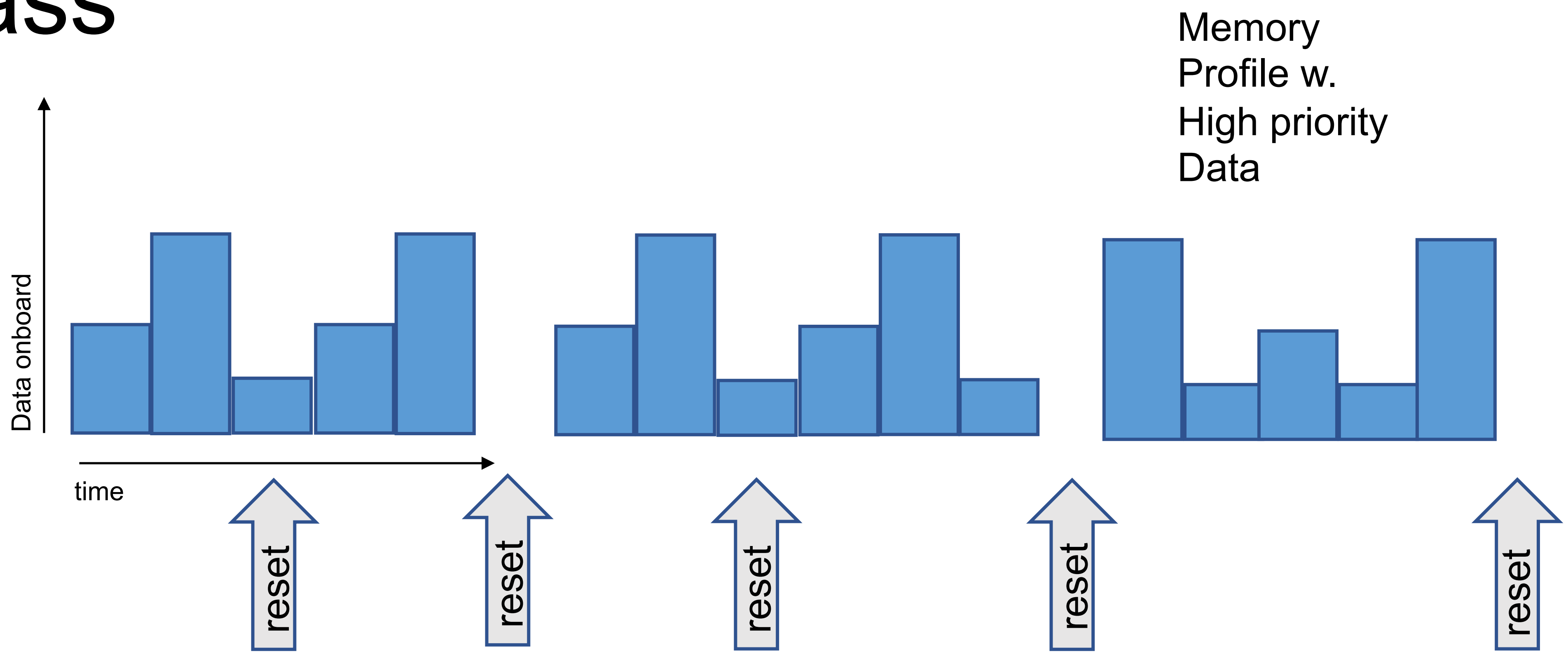


- MSU (Mass Storage Unit) is a Ring Buffer
- Read pointer does not properly advance over discontinuity – continually reads from last memory address
- Time that read pointer reaches discontinuity is probabilistic due to data-dependent compression rates
- Pointers need to be commanded to a reset
  - Sets both read and write pointers to start, but also loses all data stored

Ring Buffer Solution

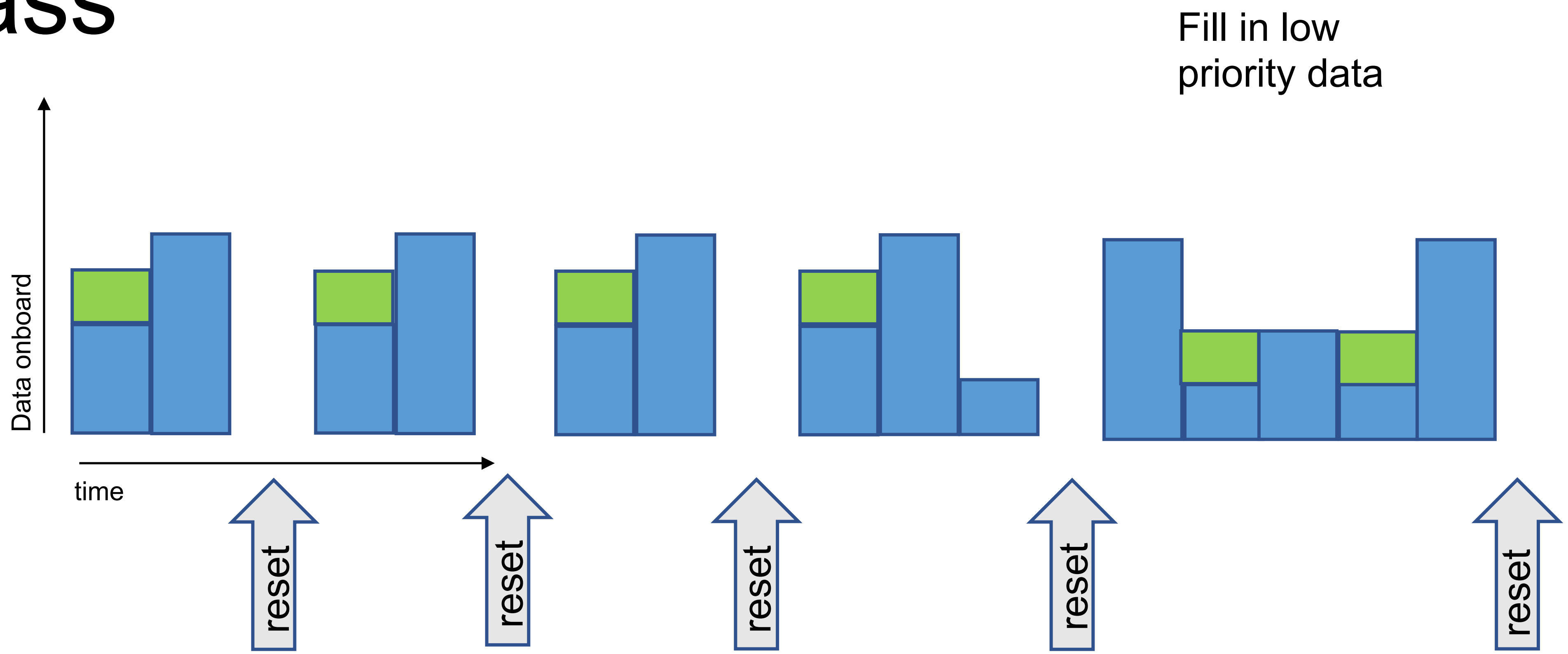
- Instrument firmware update to fix ring buffer more risky than ground-based scheduling solution
- Schedule pointer reset commands in command sequences at appropriate times to avoid the previous issue
  - Need to command a reset before write pointer wraps around
  - Need all data to be downlinked by the time of a reset command

Scheduling Ring Buffer Resets – First Pass



- Run once with high priority targets
- Choose reset points when amount of data onboard is low
- Trade-off: (a) fewer resets to avoid disrupting operations (constraining schedule) with (b) making sure a reset occurs before the end of the buffer

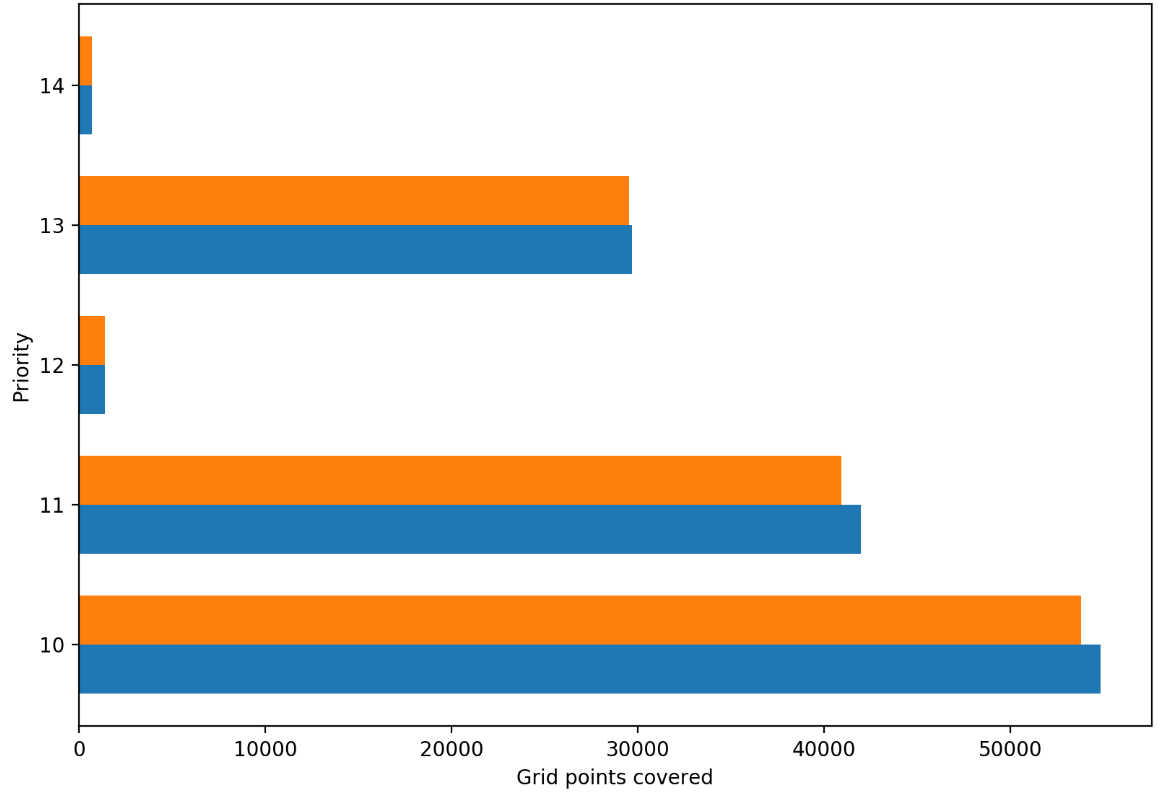
Scheduling Ring Buffer Resets – Second Pass



- Scheduler runs again with high and low priority targets, enforcing the buffer must be empty at previously determined reset points
- Algorithm tries to minimally affect the amount of high priority observations that are scheduled

Ring Buffer Resets – Results

- Blue: Resets only at week boundaries
- Orange: Additional resets to correct ring buffer issue
- ~2% difference in covered area

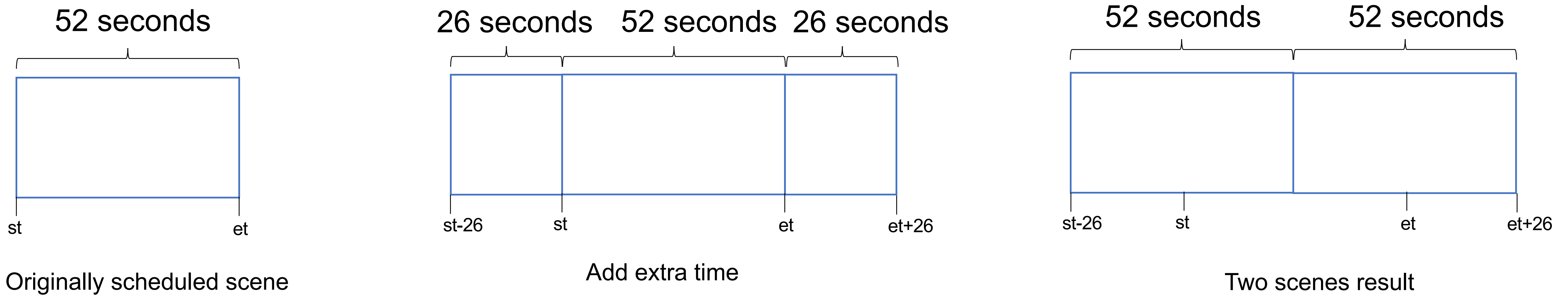


Uncertain Ephemeris

- Have access to predictions about spacecraft location, but spacecraft can drift from this due to drag from Low Earth Orbit
- If a target is viewable near the start or end of an observation, it is possible this drift could cause the target to not be observed
- ECOSTRESS has fixed observation length (52 seconds) to make data processing simpler
  - Planning horizon broken up into to 52 second periods
    - Observations were chosen from these times

Uncertain Ephemeris – Initial Solution

- Because observations had to be 52 seconds long, 26 seconds of time were added before/after every contiguous set of observations
- This caused the minimum acquisition length to be 104 seconds

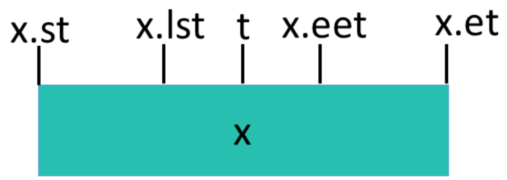


Uncertain Ephemeris – Updated Solution

- Needed a solution that still added extra time to make sure scheduled targets are observed, but did not waste data volume
- Break planning horizon into periods of time (one second), and build the observations from there accounting for some amount of uncertainty in the position and the fixed observation size

Uncertain Ephemeris – Creating an Observation

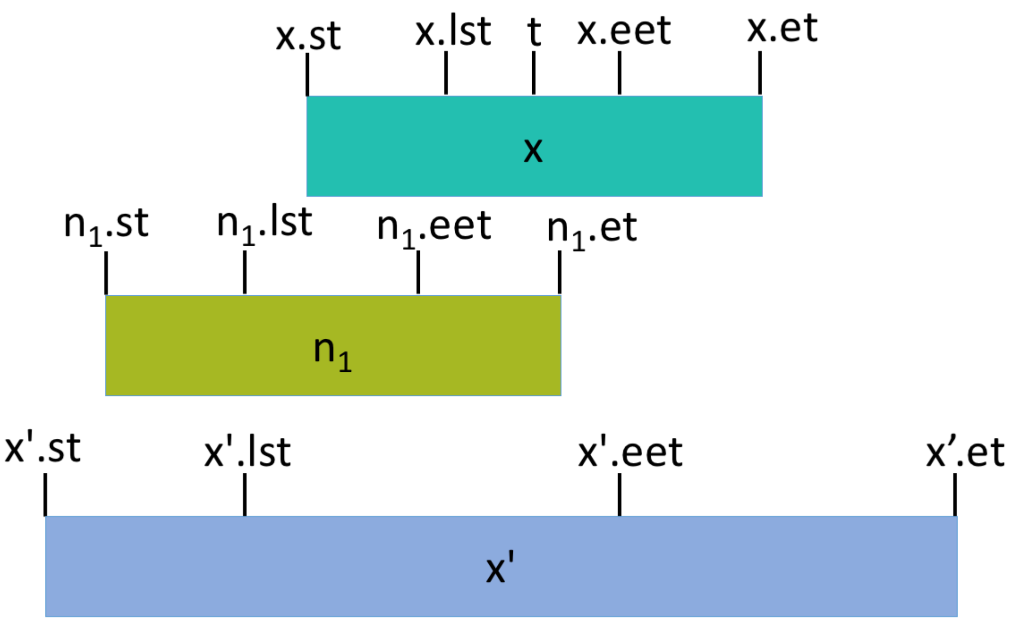
- Have two padding functions p_a and p_b that return the necessary amount of padding time that should be added after/before a target is visible to ensure the observation will cover the target
- The observation for a target visible in the time (t, t+1) will have
  - lst (latest start time) = $t - p_b$
  - eet (earliest end time) = $t + p_a$
  - st (start time)
  - et (end time)



- st and et have three possible values by making the observation have the latest possible start, the earliest start, or be centered

Uncertain Ephemeris – Merging Observations

- Newly created observations may directly overlap with previous observations or violate the minimum time between observations, so they need to be merged

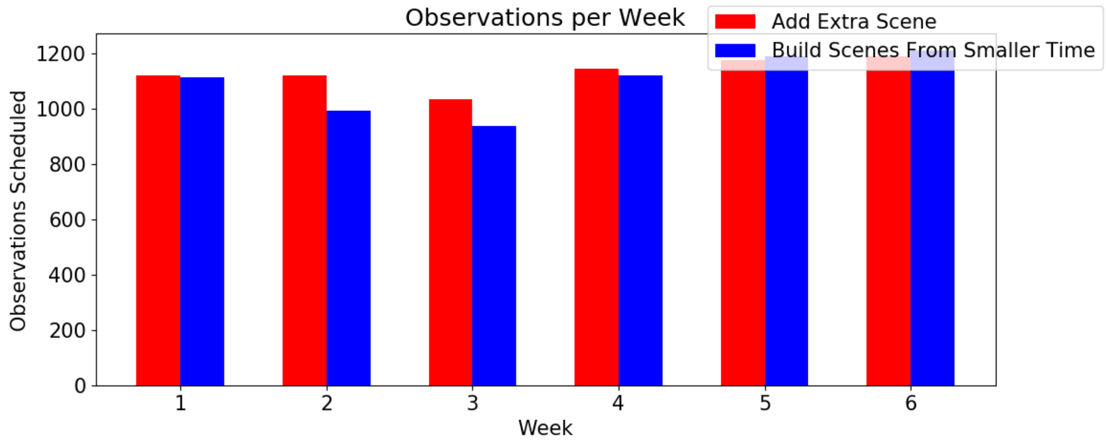


Merging observation x with neighbor observation n_1 results in merged observation x', which has

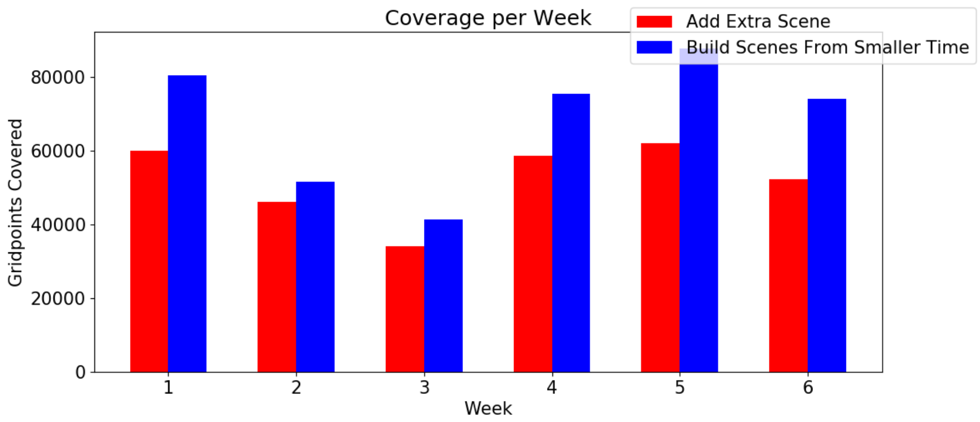
- $x'.eet = \max(x.eet, n_1.eet)$
- $x'.lst = \min(x.lst, n_1.lst)$

x'.st and x'.et are given values that results in x' having a length of the smallest possible multiple of 52 second

Uncertain Ephemeris – Results



Schedule similar numbers of 52 second observations



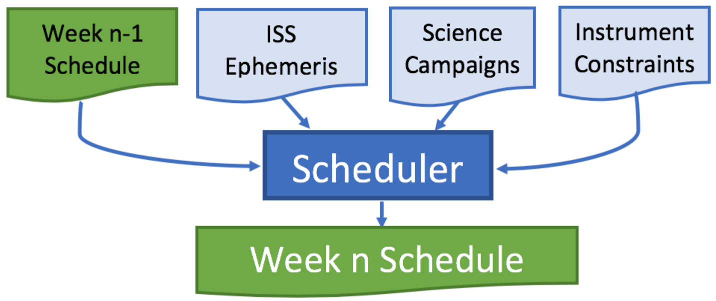
The number of gridpoints covered increases by 30% between the two methods

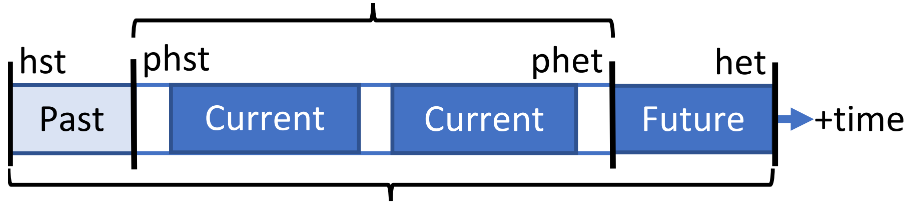
Fulfilling Long-Term Campaigns with Changing Information

- A background ”global map” was added as the lowest priority campaign
- Updated ephemeris (prediction of spacecraft location) is provided weekly, and the instrument is commanded weekly
  - Two weeks worth of commands are uploaded in case a new schedule cannot be uploaded the next week
  - Global map takes four weeks to acquire – longer than a single planning horizon
    - Takes this long due to the ISS orbit, illumination constraints, and data volume constraints
- Need to know what regions of the global map have already been observed in current cycle when determining which regions to schedule observations of

Receiving Prior Schedule as Input

- CLASP was adapted to be able to receive a previous schedule as input, and account for previous observations when scheduling future observations
- Horizon is entire period over which is considered to have activities satisfying campaigns (hst, het)
- Planning horizon is period over which new activities can be schedule (phst, phet)





Future Work

- Currently require buffer to be empty at schedule hand-off times
  - Could account for predictions of buffer state when creating new schedule
- Planned observations may not be considered successful due to cloud cover or downlink malfunctions
  - Could take out these unsuccessful observations from input schedule so these targets are re-scheduled
- Padding function just returns a constant based on the upperbound of the ephemeris error, but it could be time-dependent. The farther out the time the prediction was supplied, the more error there could be.

Related Work

- Uses of CLASP in other missions:
  - On-orbit scheduling of the IPEX CubeSat (Chien et al. 2015)
  - Long-term mission studies for Europa Clipper, JUICE (Troesch, Chien, and Ferguson 2017), and NISAR (Doubleday and Knight 2014)
  - Scheduling for OCO-3 (Moy et al. 2019)
  - Prototype for early stage mission planning for the THEMIS instrument on Mars Odyssey (Rabideau et al. 2010)
- Long-term ARIEL mission study (Roussel et al. 2017)
- Sliding window scheduling approach for scheduling Earth observations (Lemaître et al. 2002; Aldinger et al. 2013; Lewellen et al. 2017)

Conclusion

- Issue with the instrument ring buffer required additional scheduling constraints, and scheduling a new type of activity
- Issue with error in ephemeris required new approach to scheduling observations
- Fulfilling long-term campaigns with changing information required adapting CLASP to consider past observations

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