Automating Mission Planning for a Targetable Earth Observing Mission

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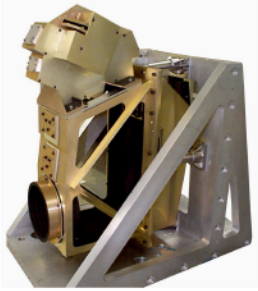
Collaborative work: JPL & GSFC.

Outline

- Background & Context – EO-1
- 2003: Phase 1: Automating existing processes
- 2008: Phase 2: Optimizing Spacecraft Performance
- Lessons Learned and Summary

Earth Observing One (EO-1)

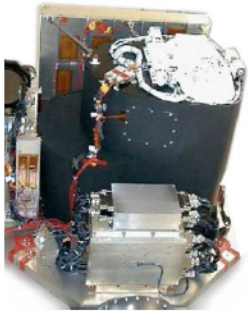
- EO-1: Operated by NASA GSFC
  - Launched in 2000
  - Demonstrated new imaging instruments
    - Hyperion Hyperspectral >200 Bands, Very Near to Shortwave IR
    - Advanced Land Imager – Landsat (ETM) replacement
    - Atmospheric Corrector
    - Boresighted – s/c must slew to image
  - Currently in extended mission to support science



Hyperion

- CDH'S: Two Mongoose V CPU's
  - Mongoose V @ 8 MIPS and 256 MB RAM
  - Conventional Flight software on CDH CPU
  - Autonomy software on data recorder CPU

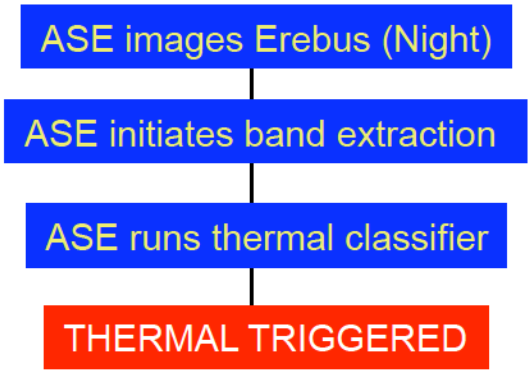
Advanced Land Imager



Phase 1 (2003):

Automating Existing Manual Processes

7 May 2004 ASE monitors Mount Erebus



13:40 GMT

} +10 min

} +28 min

} +29 min

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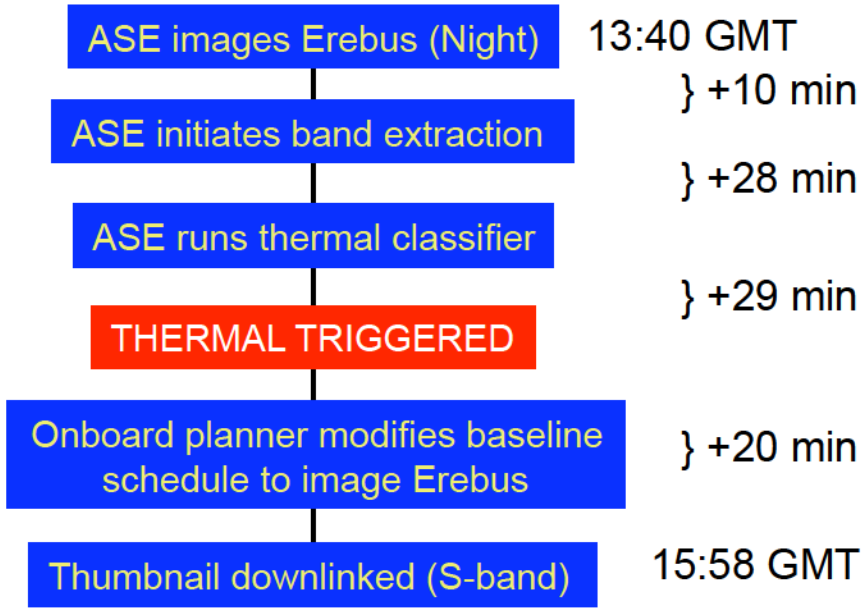
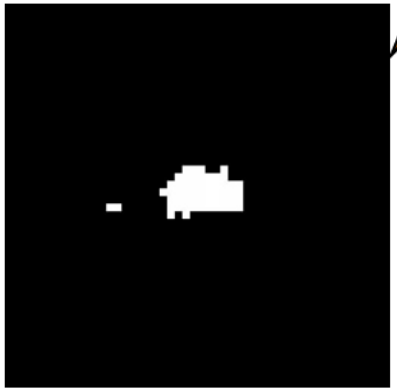


ASE Onboard Thermal Classifier Thumbnail (Erebus Night)



+ 2 hours 18 minutes

7 May 2004 ASE monitors Mount Erebus

ASE images Erebus Night — 13:40 GMT

} +10 min

ASE initiates band extraction

} +28 min

ASE runs thermal classifier

} +29 min

THERMAL TRIGGERED

Onboard planner modifies baseline schedule to image Erebus

} +20 min

Thumbnail downlinked (S-band) — 15:58 GMT

ASE images Erebus again — 20:10 GMT

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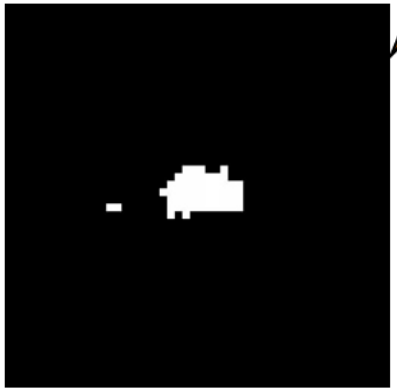
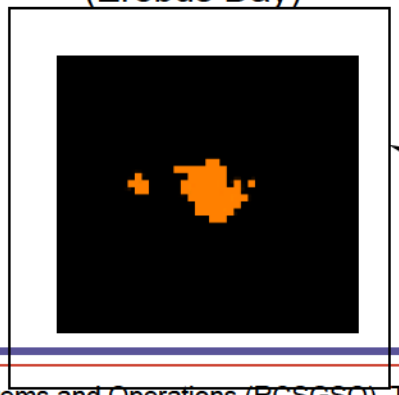


+ 2 hours 18 minutes

ASE Onboard Thermal Classifier (Erebus Day)



+ 6 hours 30 minutes

7 May 2004 ASE monitors Mount Erebus

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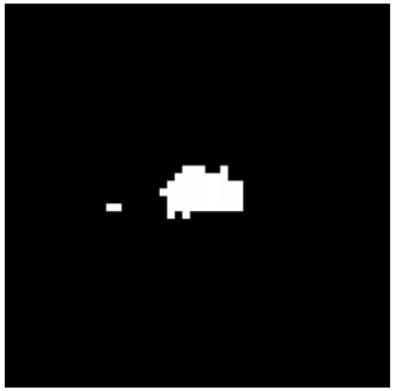

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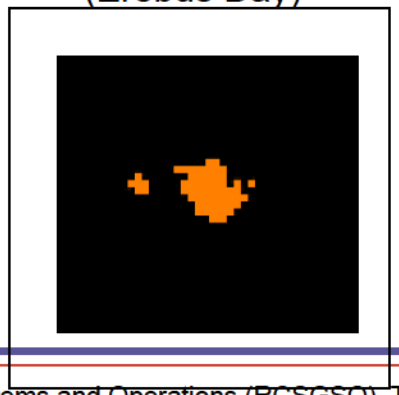
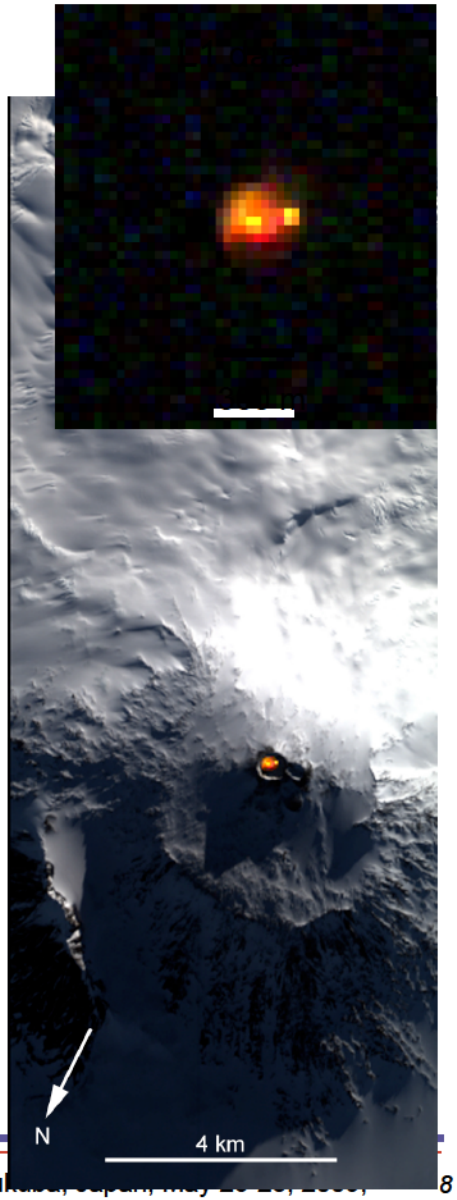




- **ASE enabled rapid notification of volcanic event**
- **ASE enabled rapid re-imaging of this event**
- **Autonomous response as normal operations!**
  - **Highest leverage for deep space missions**

Past

USGS

GSFC

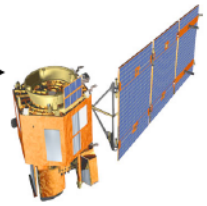
Engineer

Mission Planner

MOPSS

CMS

ASIST



Present

JPL

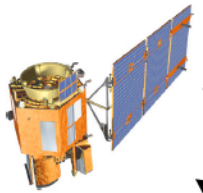
USGS

GSFC

WWW

ASPEN

ASIST



Science

CASPER

SCL

Limitations of Past Operations

- Priority observation requests require 1-2 days of lead time
- Modifications to the baseline plan are difficult as spacecraft command sequences are static
- Manual scheduling of observations and station contacts tedious
- Turnaround time for science data days or weeks after requests
  - Short-lived science opportunities may be missed

Key Differences post upgrade

- Scenes and ground contacts are selected automatically based on scene priorities
- World Wide Web interface for requesting and acquiring observations
- High-level scene and contact “goals” are uploaded to the spacecraft instead of detailed command sequences
- Execution sequence can be automatically changed on-board
- Priority observations can be requested and acquired within hours
- Science data is immediately available for analysis on-board compared to days or weeks

Impact

- Current count > 20000+ autonomous data collects
  - 1st flights in Fall 2003
- **ASE Software so successful it is now in use as baseline operations for the remainder of the mission (Nov 2004-)**
  - **Enabled > 100x increase in science return**
    - **Measured as: # events captured / MB downlink**
  - **Enabled a reduction in net operations costs $3.6M/year → $1.6M/yr ; >$1M directly from ASE (source EO-1 FOT)**
    - **Ops cost reduction enabled extended mission from 2005-2007, 2007-2009**
  - **Reduce re-planning time to respond to anomalies from: days → hours**
  - **ASE co-winner NASA Software of the Year 2005**

Phase 2 (2008):

Optimizing Spacecraft Operations

EO-1 Operations Constraints

- Priority – higher priority scenes pre-empt lower priorities
- Scene and Downlink Overlap – scenes cannot overlap other scenes (instrument) onboard recorder cannot playback and record simultaneously (recorder)
- Maneuver – spacecraft must be able to slew and settle from one scene to the next
- Onboard Storage – spacecraft has limites on # of files and total blocks (bytes) storage
- Thermal – instrument heats while taking scenes, must be allowed to cool before too many consecutive scenes

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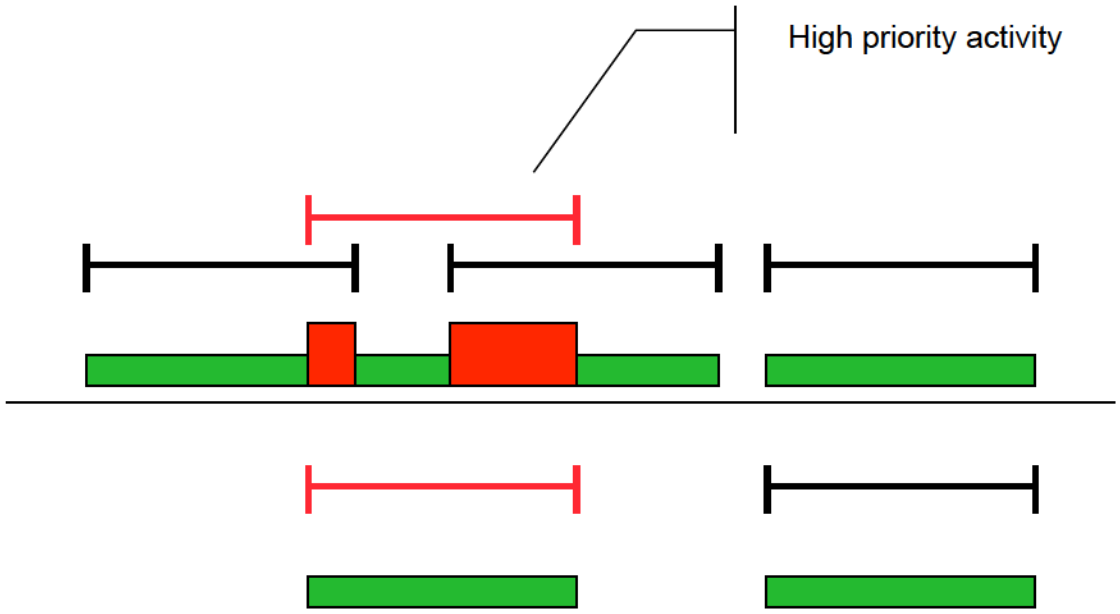

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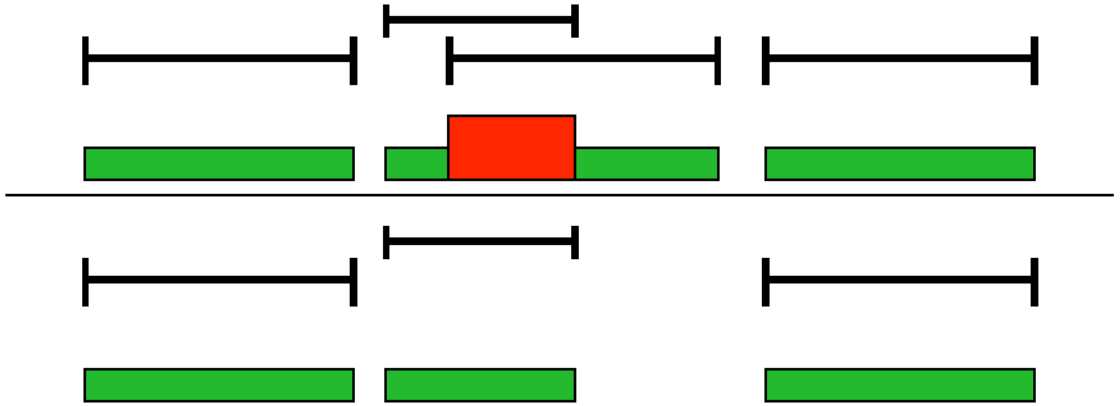

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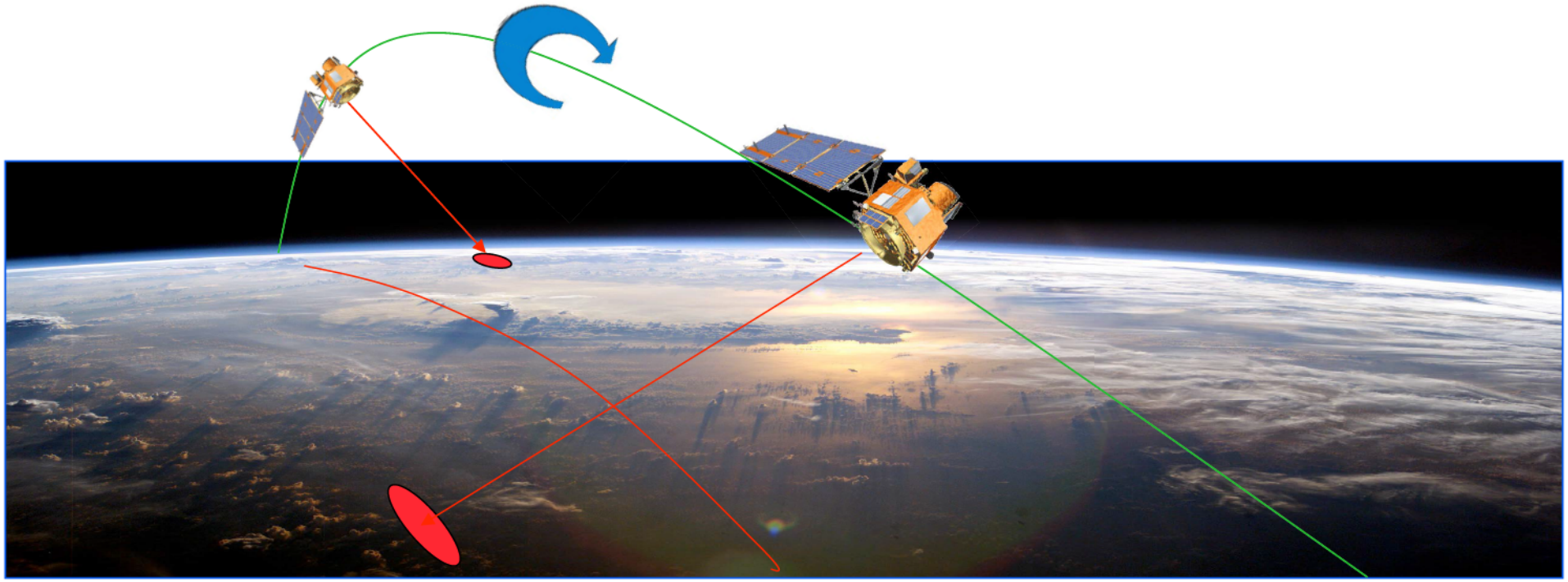
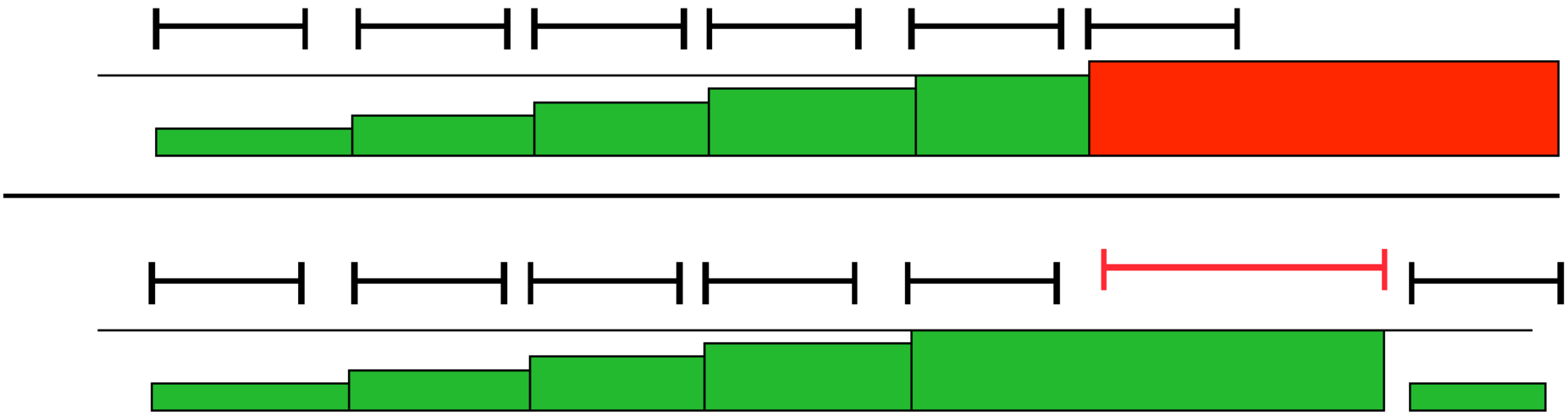


EO-1 Operations Constraints

- Onboard Storage – spacecraft can only store 5 scenes before needing to downlink
  - Actual constraint on number of files and total bytes storage



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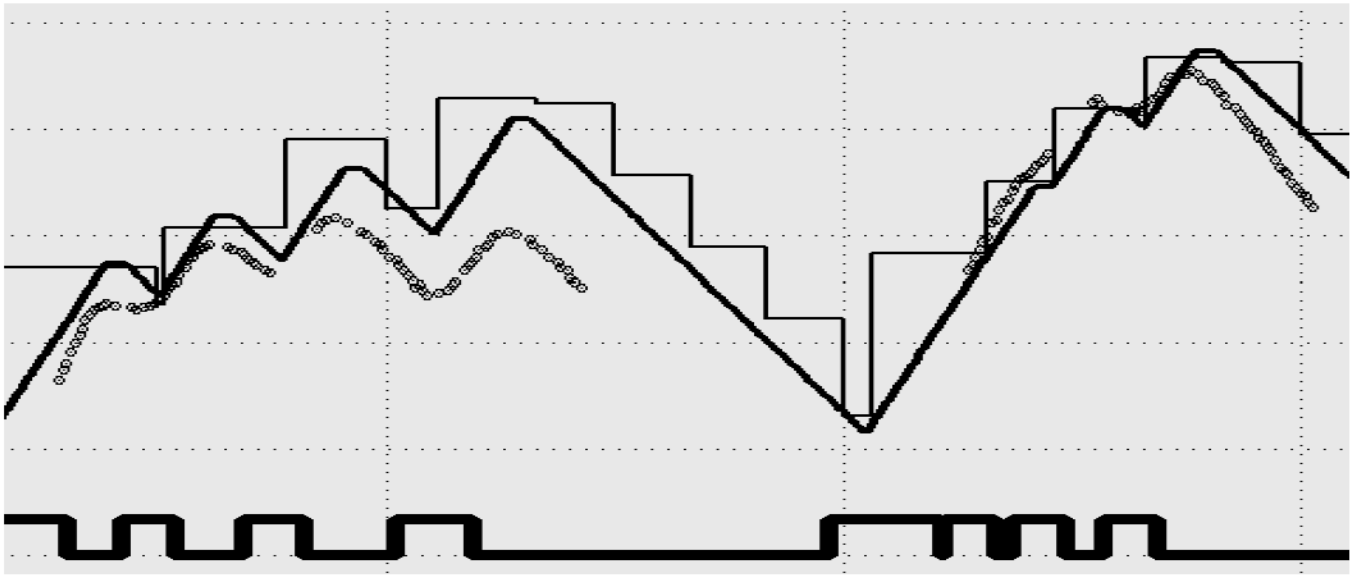

EO-1 R5 Scheduling algorithm

- Generate tuples by searching space of adjacent requests (maneuver)
  - 100s scenes → 1000s tuples
- Sort tuples by decreasing lowest priority scene
- Insert, allowing only bumping with scene subsumption
- Effectively starts with highest priority scenes, then grows by adding more of lower priority

Evaluation

Algorithm	X-bands	Scenes scheduled	Priority Score
R4	32	130	1233
R5	51	217	1243
O1: Optimal no thermal, no maneuver, R5 X-bands	51	243	1286
O1A: O1 removing onboard storage	51	419	1286
O1B: O1 ignoring scene overlap	51	252	1422
O2: O1 but choose all X-bands not in conflict with high priority	48	229	1246

R5 is within 11% of the optimal upper bound by scene count and within 3.4% of the optimal upper bound by priority score.

Summary

- Technology exists to automate significant portions of uplink operations, with benefits:
  - Increased responsiveness
  - Reduction in operations staffing
  - Increased science return
- Numerous missions have reaped these benefits (EO-1, Orbital Express, …)