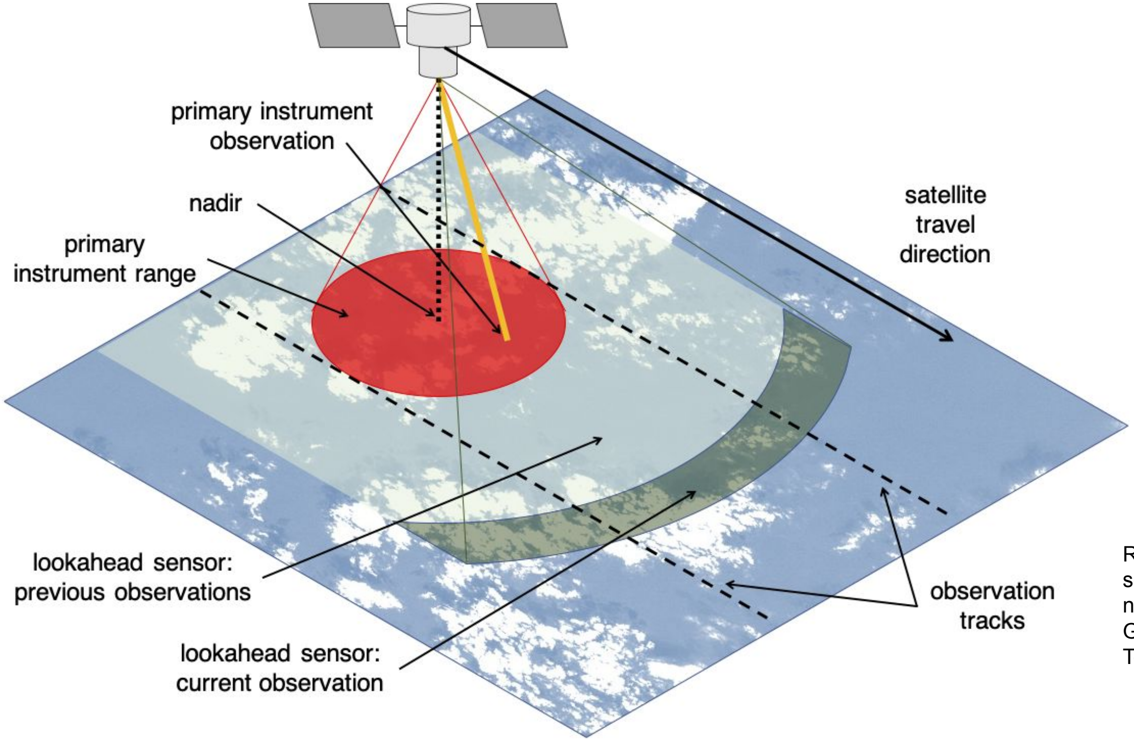

Dynamic Targeting to Improve Earth Science Missions

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California Institute of Technology

2023 Earth Science Technology Forum

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Jet Propulsion Laboratory
California Institute of Technology

Overview

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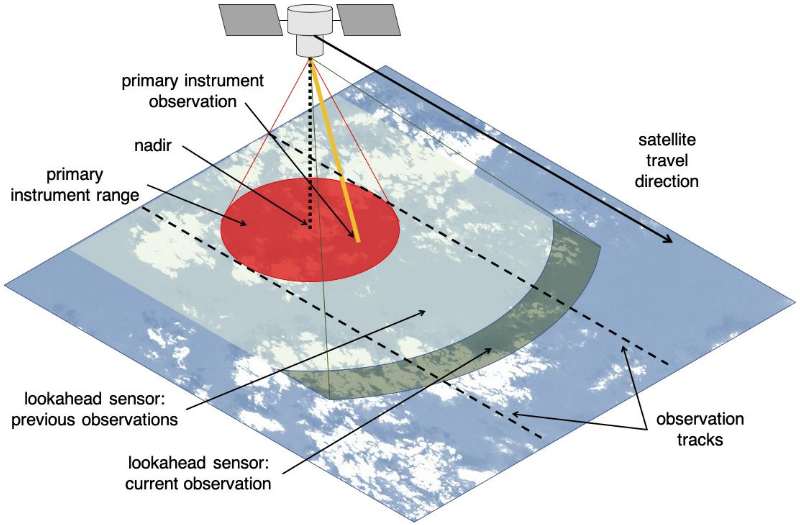
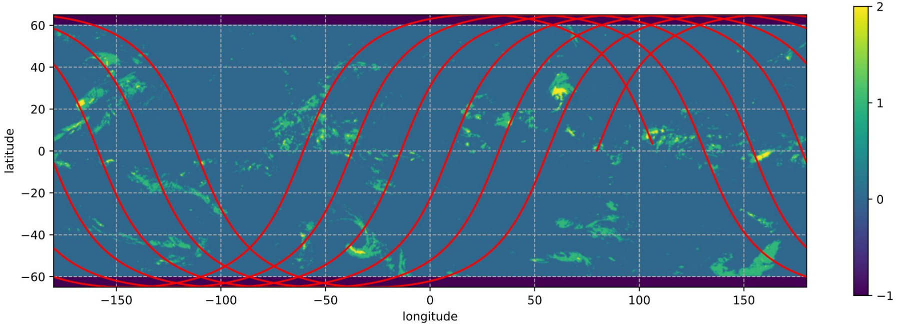




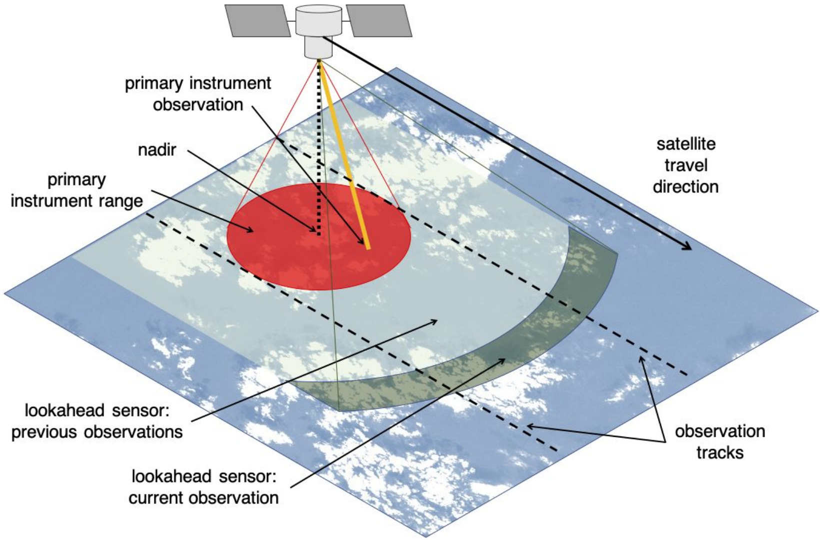
Introduction

- Remote sensing: high spatial resolution can be expensive and physics dictates trades of footprint versus spatial resolution. Often instrument configuration can be optimized to target.

- DT uses information from a lookahead sensor to identify targets for the primary, pointable sensor to improve science yield

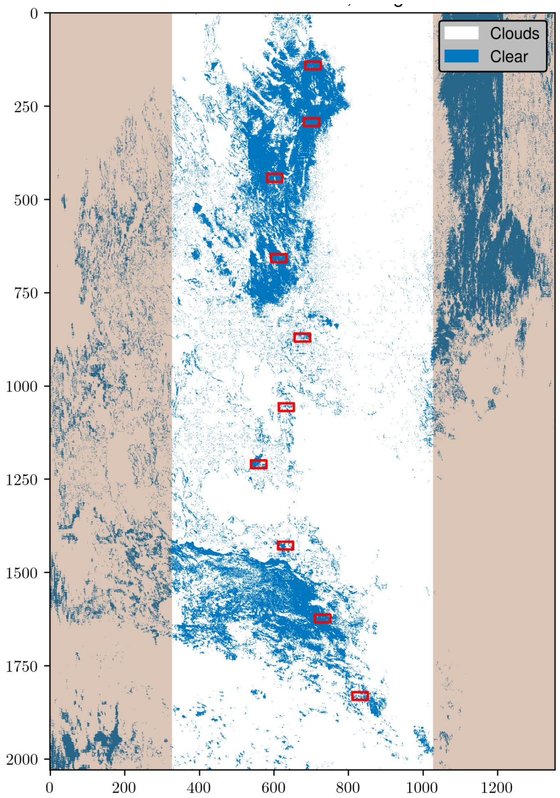
- Dynamic targeting (DT) can improve the science return of swath/mode limited instruments

- We advocate DT to become commonplace across many future Earth Science missions



Related Work: Cloud Avoidance

- JPL Mission (Thompson et al., 2014): Rapid spectral cloud screening (compression) for AVIRIS airborne instrument
- JAXA - L3Harris Mission (Suto et al., 2021): cloud avoidance for TANSO-FTS-2 thermal and near infrared carbon observations
- JPL Study (Hasnain et al., 2021): Greedy, graph-search, DP algorithms for agile spacecraft imaging of clear vs. cloudy skies (binary)

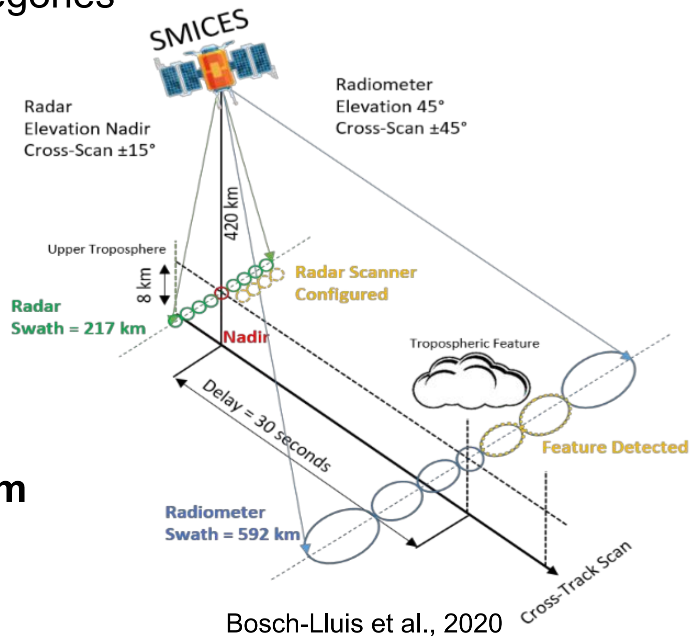


Hasnain et al., 2021

Concept: SMICES

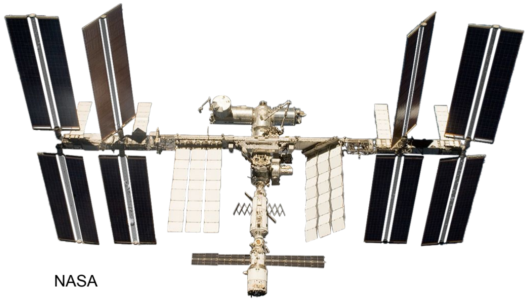
- NASA ESTO MIssion Concept: Smart Ice Cloud Sensing (SMICES)
  - Dynamic measurements of different storm clouds categories
  - Swope et al. 2021: greedy heuristics
- Reconfigurable, smart instrument combining:
  - *Radiometers (lookahead): up to 45°
  - **Radar (primary): up to ±15°
- SMICES would use AI for:
  - instrument calibration
  - **primary instrument on/off and targeting:**
    - **radiometer → likely deep convective ice storm**
    - **radar → on/off and targeting**

❖ Our work continues and generalizes the SMICES concept



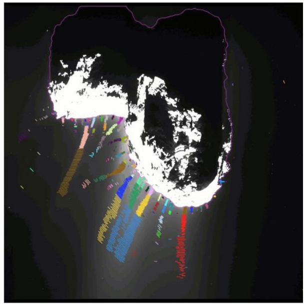
Bosch-Lluis et al., 2020

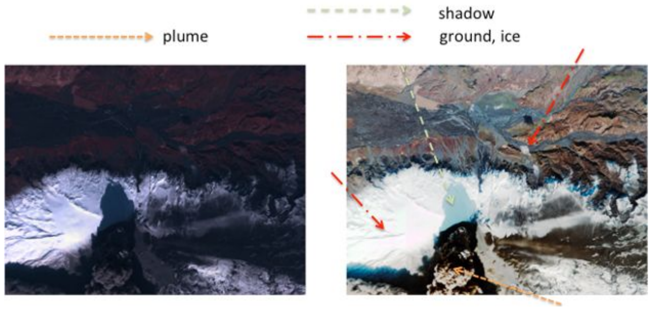
Mission Concepts

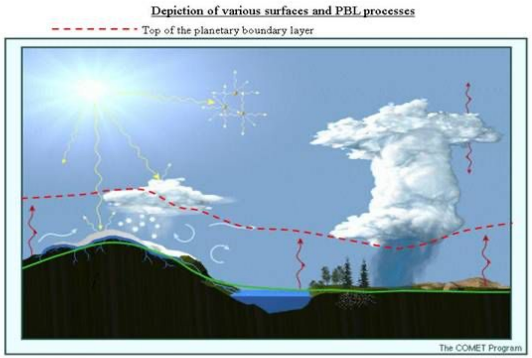


NASA

- Cloud avoidance: eg. interference for OCO-3, VSWIR spectrometers, etc.
- Planetary Boundary Layer: rare and short-lived
- Non-terrestrial and terrestrial plumes

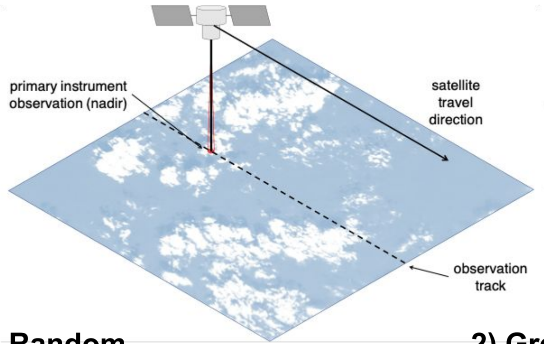




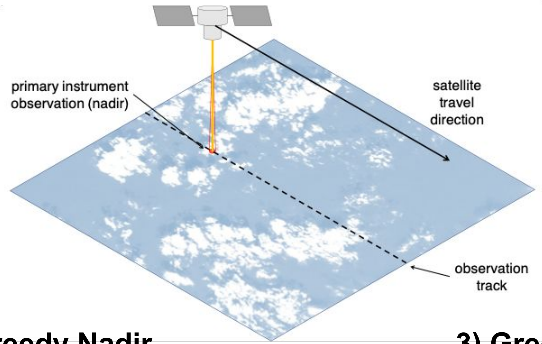


ESRL NOAA

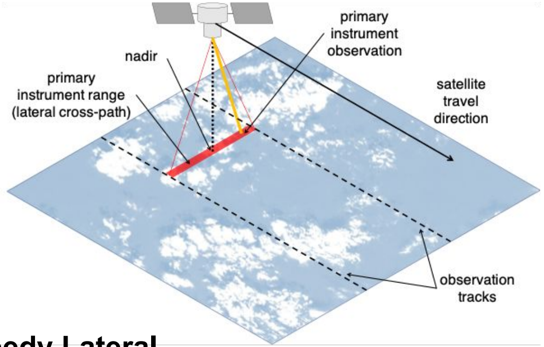
Dynamic Targeting: Algorithms



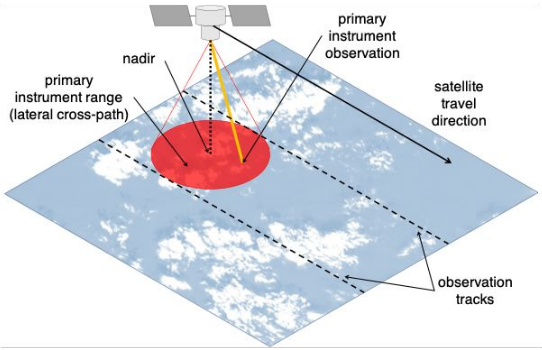
1) Random



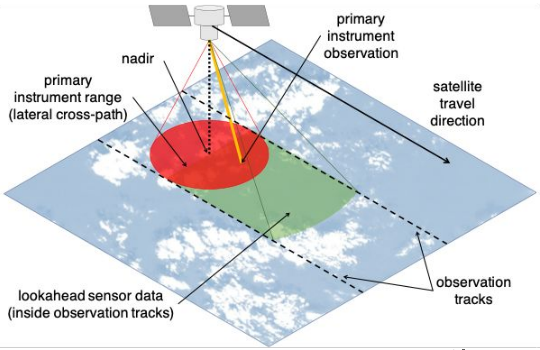
2) Greedy Nadir



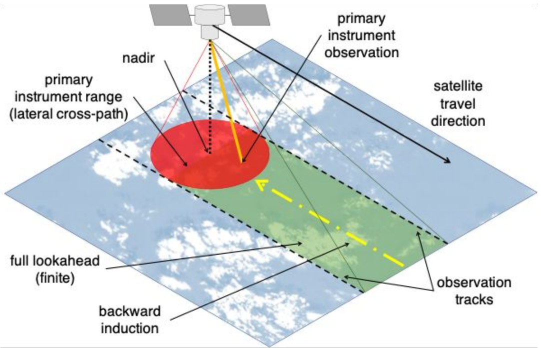
3) Greedy Lateral



4) Greedy Radar

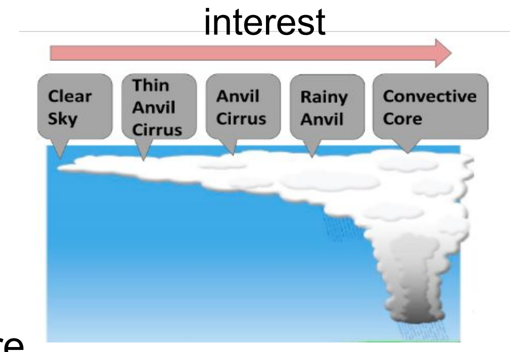


5) Greedy Window

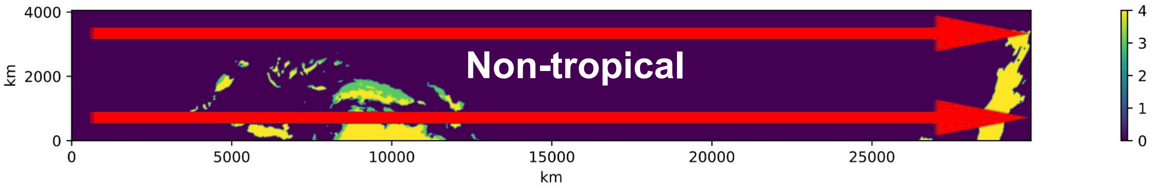


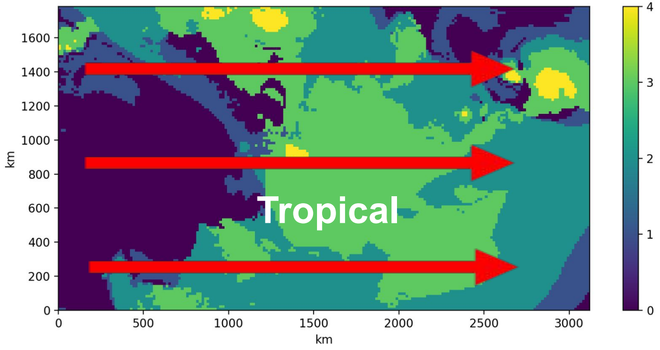
6) Dynamic Programming

Simulation Studies: SMICES

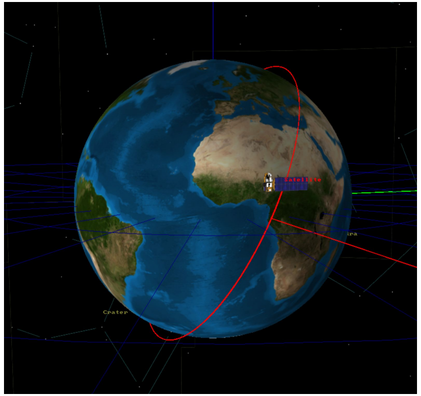


- Continuation of previous SMICES work (Swope et al. 2021)
- Storm hunting: collect data of storm clouds
- 5 cloud classes: most interesting/scarce rainy anvil and convective core
- Data comes from Global Weather Research and Forecasting (GWRF) (Skamarock et al. 2019)
- 2 datasets of high-storm regions, resolution 15 km/pixel:
  - Non-tropical (U.S. Eastern Coast): 4,050 km x 29,970 km
  - Tropical (Caribbean): 3,120 km x 1,785 km



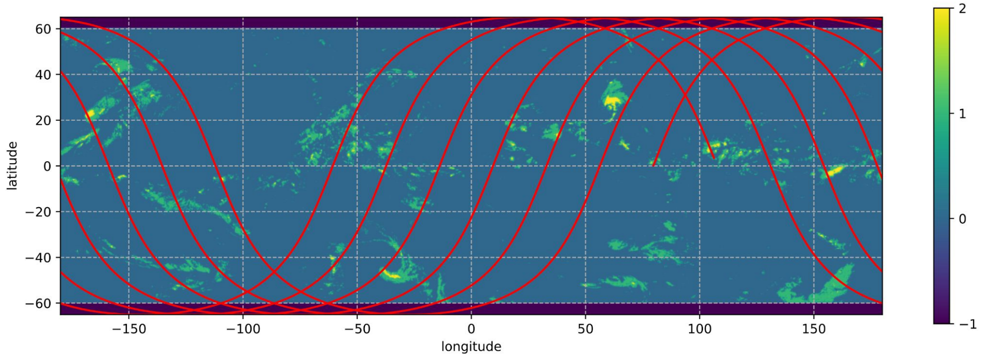


Simulation Studies: Global

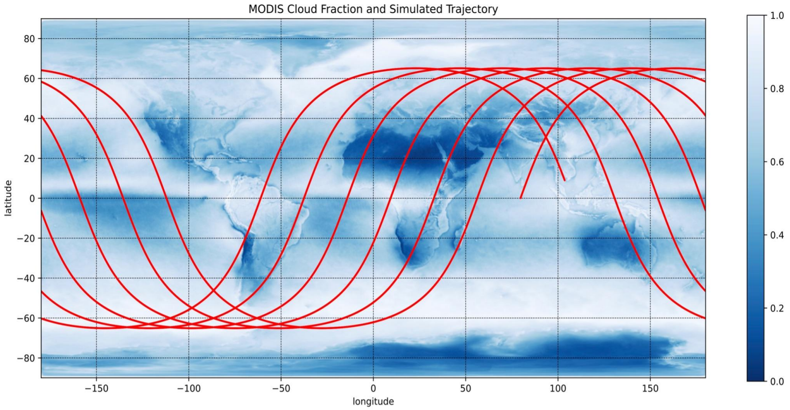


- Global datasets that extend and complement the SMICES study
- Simulate more realistic satellite trajectories of Earth science missions
- 2 studies: storm hunting and cloud avoidance

Storm Hunting: GPM/IMERG



Cloud Avoidance: MODIS

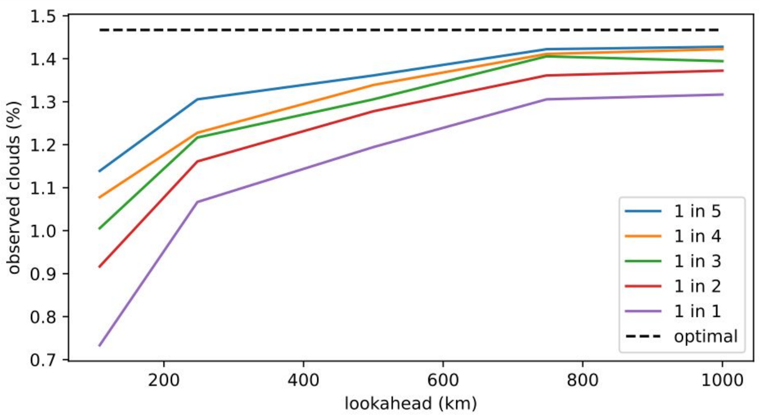


Experiments and Results

1. Science return (observed clouds)

Scenario/Dataset	Baseline	Optimal
SMICES Tropical (storms)	22.65	0.74
SMICES Non Tropical (storms)	3.19	0.84
GPM / IMERG (global storms)	88.45	0.69
MODIS (global clear skies)	2.63	0.79

2. Lookahead sensitivity analysis



3. Runtimes on flight processors

Average Runtime	***MacBook Pro 16***	**HPE Spaceborne Computer-2**	**Qualcomm Snapdragon 855**	**GR740/ Sabertooth**	**RAD750**
ms/timestep	*~0.1*	~0.4	~20	~1,500	~2,800

Ongoing and Future Work

- Customized policies for regions, seasons
- Explore deep reinforcement learning for DT policies
- Study of pointing with costs use cases (current cases assume electronic steering)
- Additional studies/ data sets for further evaluation; Planetary Boundary Layer
- Investigate ESA OPS SAT and Planet Pelican 2 flight opportunities

ESA

Planet Inc.

Closing Remarks

- Dynamic targeting algorithms use lookahead sensor information to improve primary sensor science yield including global (energy, thermal) constraints
- Presented DT heuristic and new optimal DP approach (useful for evaluation purposes)
- Evaluated on 4 different datasets/scenarios: storm hunting and cloud avoidance
- DT methods' performance is much better than baseline (random), close to optimal
- Greater lookahead improves performance
- DT algorithms are extremely fast and produce results approaching optimal

Publications

- Candela, A.; Swope, J.; and Chien, S. Dynamic Targeting for Cloud Avoidance to Improve Science of Space Missions. In 16th Symposium on Advanced Space Technologies in Robotics and Automation, June 2022.

- Candela, A.; Swope, J.; Chien, S.; Su, H.; and Tavallali, P. Dynamic Targeting for Improved Tracking of Storm Features. In International Geoscience and Remote Sensing Symposium (IGARSS 2022), Kuala Lumpur, Malaysia, July 2022.

- Delfa, J.; Candela, A.; Chien, S. Enhanced Dynamic Targeting for the OPS-SAT Cubesat. In International Workshop on Planning and Scheduling in Space, July 2023.

- Candela, A.; Swope, J.; and Chien, S. Dynamic Targeting to Improve Earth Science Missions. AIAA Journal of Aerospace Information Systems. *In review,* 2023.

- 2 more papers after this summer!

Acknowledgements

- Jason Swope, Juan Delfa
- SMICES Team
- Global storm study: Hui Su, Peyman Tavallali
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