Flight of Dynamic Targeting on CogniSAT-6

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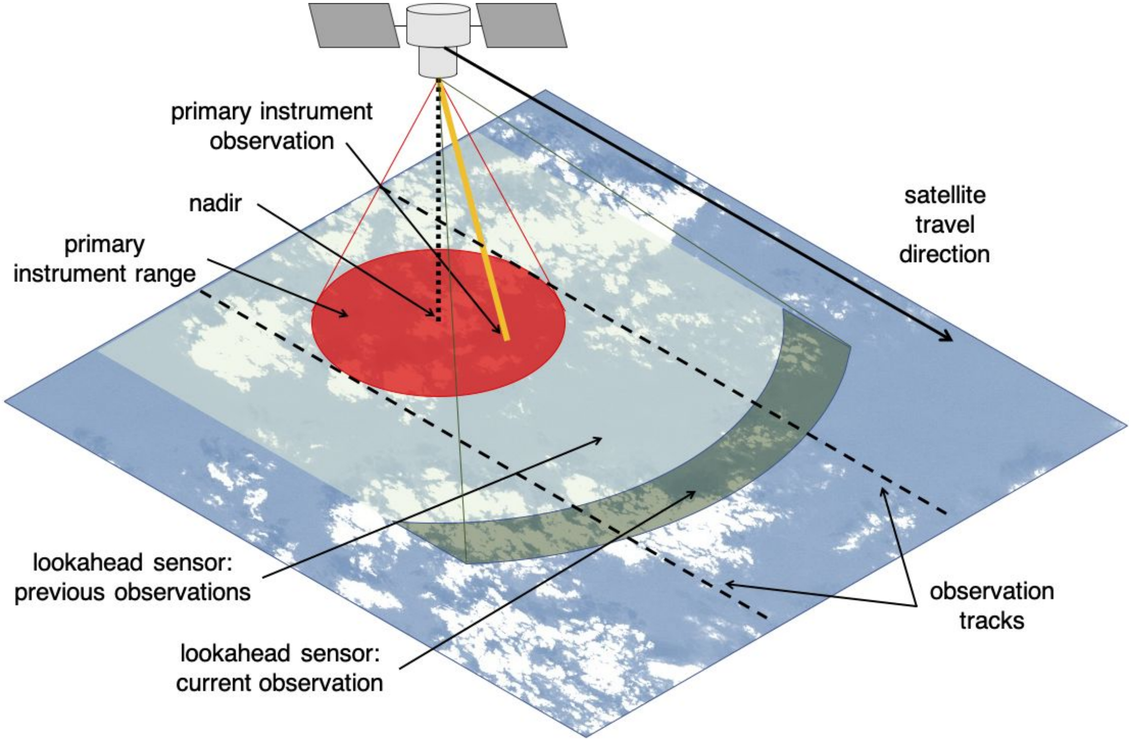
What is Dynamic Targeting?

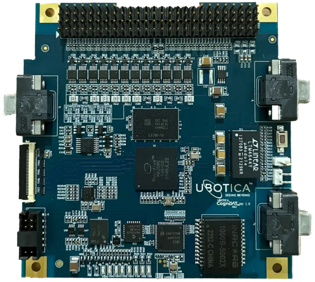


- Use lookahead or wide FOV sensor to acquire data
- Rapidly process data for insights
- Use gleaned knowledge to retarget primary sensor
(in the same overflight)

For further details see [Candela et al. 2023 JAIS].

Rapidly Changing Earth Observation Market

- Edge Computing - many such satellites have significant edge computing, at least by conventional flight computing standards
  - Multiple GHz+ ARM cores commonplace
  - Edge AI computing via Intel Myriad, Nvidia, etc.
- Proliferated LEO - many more Earth Observation satellites spurred by new entrants and decreased launch costs
- Intersatellite Link - use of commercial constellations as communications pathway leads to 24/7 connectivity for KB/s notifications (e.g. knowledge not data)



Intel Myriad Edge Processor
Image courtesy Ubotica

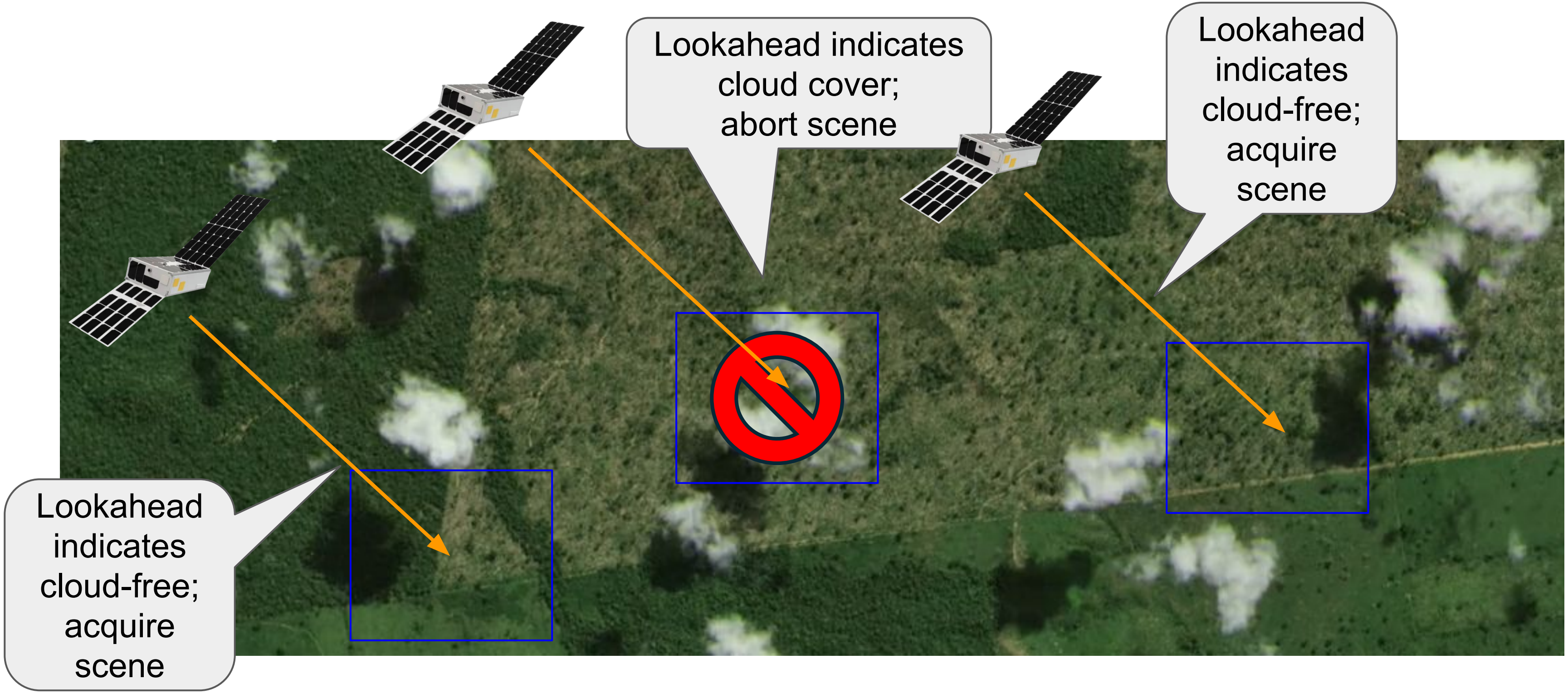
Proliferated LEO and
Intersatellite links

NASA's NOS and ESA's ϕ-Lab

- NASA New Observing Systems (see [Lemoigne 2020])
  - Multiple collaborative sensor nodes producing measurements integrated from multiple vantage points and in multiple dimensions (spatial, spectral, temporal, radiometric)
  - Provide a dynamic and more complete picture of physical processes or natural phenomena

- ESA's ϕ-Lab (See [ESA ϕ-Lab])
  - "accelerating the future of Earth observation exploiting transformational innovation" including artificial intelligence

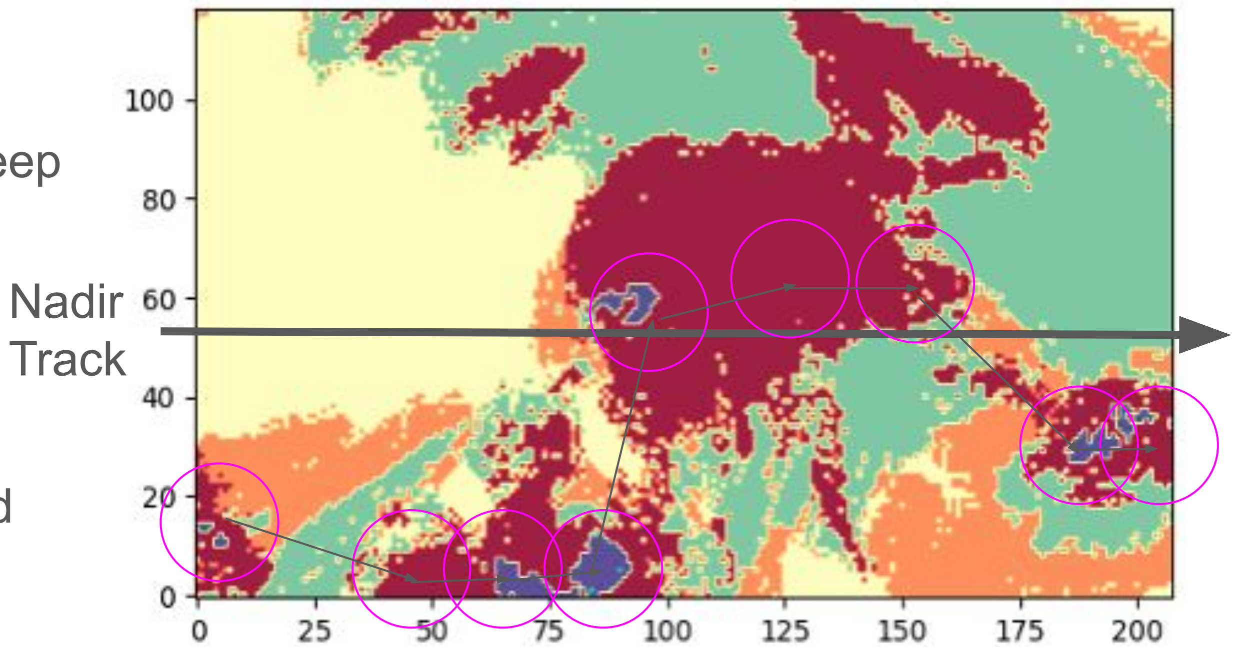
DT Use Case - Active Cloud Avoidance



e.g. see [Suto et al, 2021 AMT]

DT Use Case - SMICES Storm Hunting

- Lookahead radiometer used to identify likely deep convective ice storms ahead of spacecraft
- Radar then directed to collect data on identified storms



For further details see [Swope et al. 2024 JAIS]

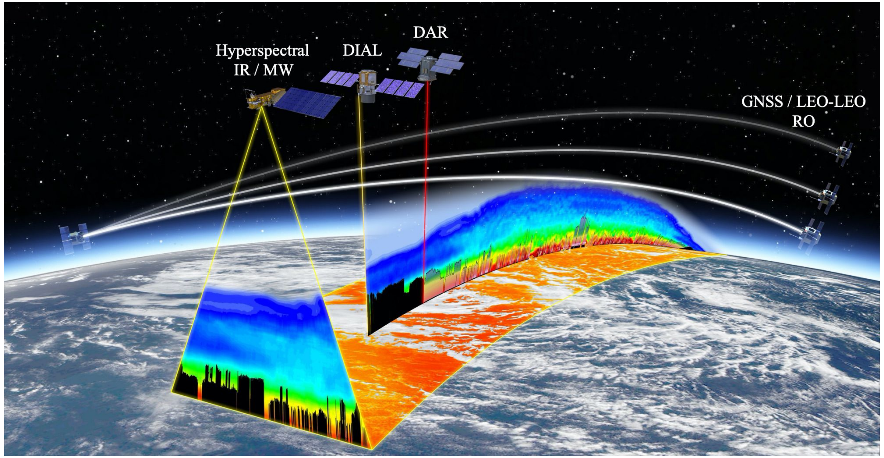
DT Mission Scenario - Planetary Boundary Layer

- Based on mission concept to study the PBL by [Teixeira et al. 2021]

- Train of 3 satellites

- 1 Lookahead satellite: pushbroom
  - Hyperspectral IR/MW sounders
  - Estimate water vapor, cloud properties, temperature, etc.

- 2 primary satellites: whiskbroom
  - Differential Absorption Lidar (DIAL)
    - Can't see through clouds
    - Less energy intensive to use (100% duty cycle)
  - Differential Absorption Radar (DAR)
    - Can see through clouds
    - More energy intensive to use (25% duty cycle)



Source: Teixeira et al. 2021

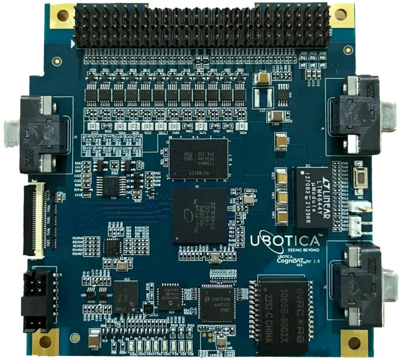
For further details see [Candela et al. 2024 IGARSS]

Overview of CogniSAT-6

- 6U Cubesat
- Launched March 2024
- Sun-synchronous orbit at 500 km
- Myriad X Vision Processing Unit (VPU)
  - Rapid computer vision
  - Image signal processing
  - Neural network execution
- Hyperscape 100 Instrument
  - 440nm−884nm
  - Can select 32 out of 442 spectral bands
  - GSD of 5 meters per pixel

CogniSAT-6 launch on 4 March 2024 on Transporter-10
from Vandenberg Space Force Base, CA, USA.
Image courtesy of SpaceX

CogniSAT-6 Spacecraft
Image courtesy of Open Cosmos



Intel Myriad X VPU
Image courtesy of Ubotica Technologies

For further details see
[Rijlaarsdam et al. 2025 JSTARS].

Dynamic Targeting on CogniSAT-6

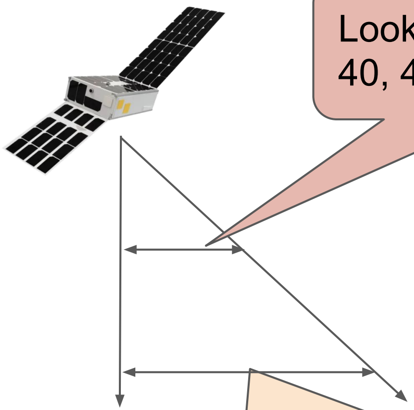
- Onboard Deep Learning Algorithms
  - *U-Net CNN for image classification/segmentation*
  - Cloud detection
  - Storm hunting (SMICES)
  - Thermal Emission
- Onboard Spectral Algorithms
  - *Signature and anomaly/outlier detection*
  - Cloud detection
  - Storm hunting (SMICES)
  - Thermal Emission

Image courtesy of Ubotica Technologies

For further details see [Chien et al. 2024 IGARSS, Zilberstein et al. 2024 i-SAIRAS]

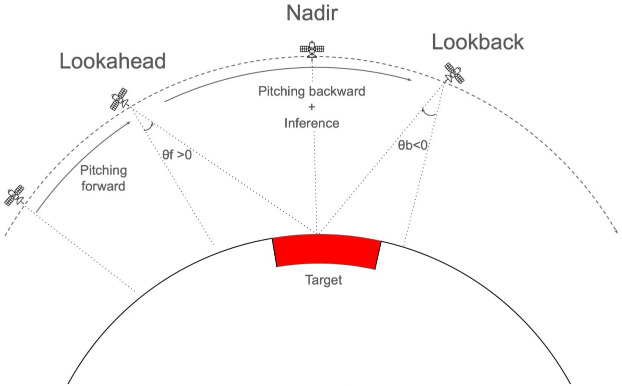
Challenges to flight

- CogniSAT-6 does not carry a dedicated lookahead sensor; therefore slewing from lookahead to nadir must be accounted for in response time.
- Sensor readout on CogniSAT-6 was not designed with DT scenario in mind.
  - To speed readout, reducing data volume that is readout.
  - Readout subsampling of the pan-band for lookahead interpretation.



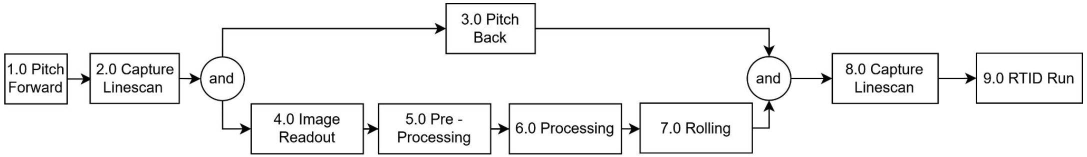
Lookahead of 40, 45, or 50 degrees

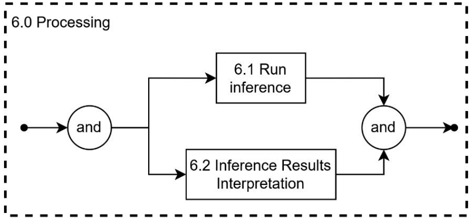
corresponds to lookahead time of 60s, 74s, 90s for a 500 km orbital altitude

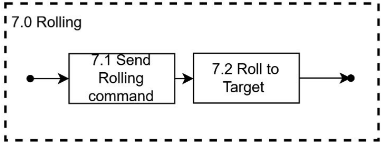


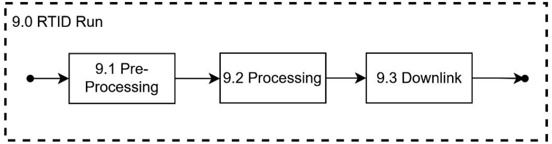
Functional Flow for DT on CogniSAT-6

- After a look-ahead image is acquired the image is processed in parallel as the spacecraft pitches back towards nadir





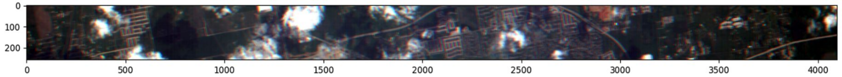




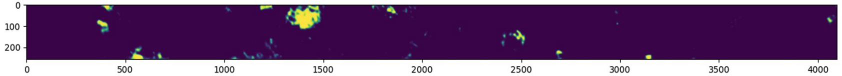
DT Algorithm on CogniSAT-6

- Input: panchromatic look-ahead imagery
- Output: roll angle to view

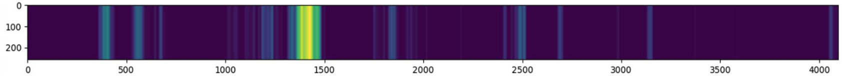
1. Classify look-ahead imagery using CNN
2. Compute across track cloud presence
3. Compute fixed window summarization
4. Select lowest value window and retrieve roll angle from ground computed table



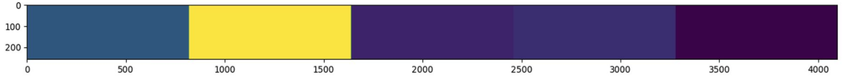
(a) Illustrative "notional" Lookahead image. *Includes imagery from CogniSAT-6/HAMMER, 2025, Ubotica. All rights reserved.*



(b) cloud classifier run on (a) - yellow indicates identified clouds



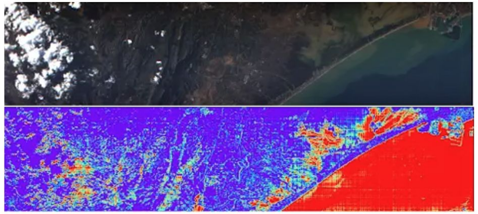
(c) summarised across track cloud pixels from (b) - yellow indicates cloudiest across track locations



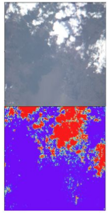
(d) fixed window summarization across track from (c) (brightest = most clouds, darkest = least clouds)

Flight Preparation Status

- Flights of JPL onboard data analysis on CogniSAT-6
    - 36+ executions of data analysis models
    - Deep CNN: (thermal, cloud, surface water extent) x 2 models
    - 48+ executions of spectral Algorithms: (cloud, surface water extent, vegetation, minerals) x 3 models + anomaly detector
- Working engineering challenges in meeting rapid 40 second timeline for image analysis and slewing.
- Anticipated flights in May 2025.



(a) Valencia, Spain, 11/02/2024. At top is a color mapping of the scene acquired by the spacecraft. At bottom is the segmentation obtained onboard for surface water extent with red indicating water and purple indicating non-water. *Image at top is from CogniSAT-6/HAMMER, 2024, Ubotica. All rights reserved.*



(b). Ulsan, South Korea, 10/27/2024. At top is a color mapping of the scene acquired by the spacecraft. At bottom is the segmentation obtained onboard for cloud detection with red indicating clouds and purple indicating non-clouds. *Image at top is from CogniSAT-6/HAMMER, 2024, Ubotica. All rights reserved.*

Related Work

- Near-real-time onboard spectral Cloud screening for AVIRIS and EMIT [Thompson et al. TGARS 2014]
- Cloud avoidance using lookahead visible sensor TANSO-FTS2 GOSAT2 [Suto et al. AMT 2021]
- Lookahead radiometer to target radar at deep convective ice storms (proposed) SMICES [Swope et al. JAIS, 2024]
- Simulated lookahead for cloud detection and storm measurement [Candela et al. JAIS 2023]
- Simulated Cloud Avoidance [Hasnain et al. IWPSS 2021]

Next Steps

- Flight of Dynamic Targeting for cloud avoidance on CogniSAT-6 in May 2025
- Deployment of Dynamic Targeting to spacecraft with dedicated lookahead sensor
- Deployment of Dynamic Targeting for Science Missions
- Widespread deployment of onboard image analysis and cross-cue-ing using inter-satellite link – FAME demonstration [Chien et al. 2025 SpaceOps]

Conclusions

- Dynamic Targeting
  - Uses a lookahead sensor to acquire data
  - Rapidly analyzes such data using edge computing
  - Uses this analysis to target a primary sensor; increasing science return
- Several science use cases for dynamic targeting exist including cloud avoidance, hunting for deep convective ice storms, and capturing planetary boundary layer events
- Demonstration of dynamic targeting technology on the CogniSAT-6 spacecraft in May 2025

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