National Aeronautics and Space Administration

Maximizing Simultaneous Multi-Angle Cloud Tomography Observations using Cubesats and On-board Scheduling

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Objectives:

Develop a cubesat constellation mission concept that maximizes the number of simultaneous multi-angle measurements of clouds in order to enable low-cost space-based cloud tomography. Cubesats are assumed to carry cameras with agile pointing capability.

Background:

Cumuliform clouds scatter outgoing longwave radiation which interacts with aerosols generating new clouds (primarily trade-cumuli) which scatter radiation causing a feedback loop. Inter-model differences in cloud feedback constitute by far the primary source of spread of both equilibrium and transient climate responses (IPCC 2013, Bony 2008). Current satellite observations are inadequate to detect sharp vertical gradients of water vapor (Bony 2017). Computed cloud tomography, like a CT scan for sky, recreates volumetric cloud properties using multiple images from multiple angles and fit images to a 3D radiative transfer model. Successful cloud tomography requires High Resolution Cloud Imagery, multiple images with wide angular variety, and an illumination source, Sun.

Approach and Results:

We used a simple model for cloud generation and preprocessing. Using models for SoA cubesat camera we calculated swam FoV. Could data pruning was performed to reduce data for parts of the orbit that cloud targets are not suitable. A MILP problem was formulated to optimize observations assuming fixed orbits and pointing capability only. LoS comm link was used to share cloud info among swarm members. A baseline push broom style swarm (similar to Landsat9) was also simulated to compare results. Simulations were ran for 7 consecutive flyovers of the region of interest. The MILP successfully targeted at least one cloud per time step with a total count of 161 clouds being imaged with 148 deg avg. angular rate of observation.

Significance/Benefits to JPL and NASA:

This work showed that a 9 cubesat string of pearls configuration in low Earth orbit, each carrying cameras with agile pointing capability, and scheduled autonomously with mixed integer linear programing to maximize the number of simultaneous observations of clouds significantly outperformed a push broom camera configuration. Our method was able to observe 59% more cloud targets than the push broom configuration. This is a promising result that demonstrates the utility of autonomous observation scheduling to future on-orbit Earth science missions, such as computed cloud tomography.

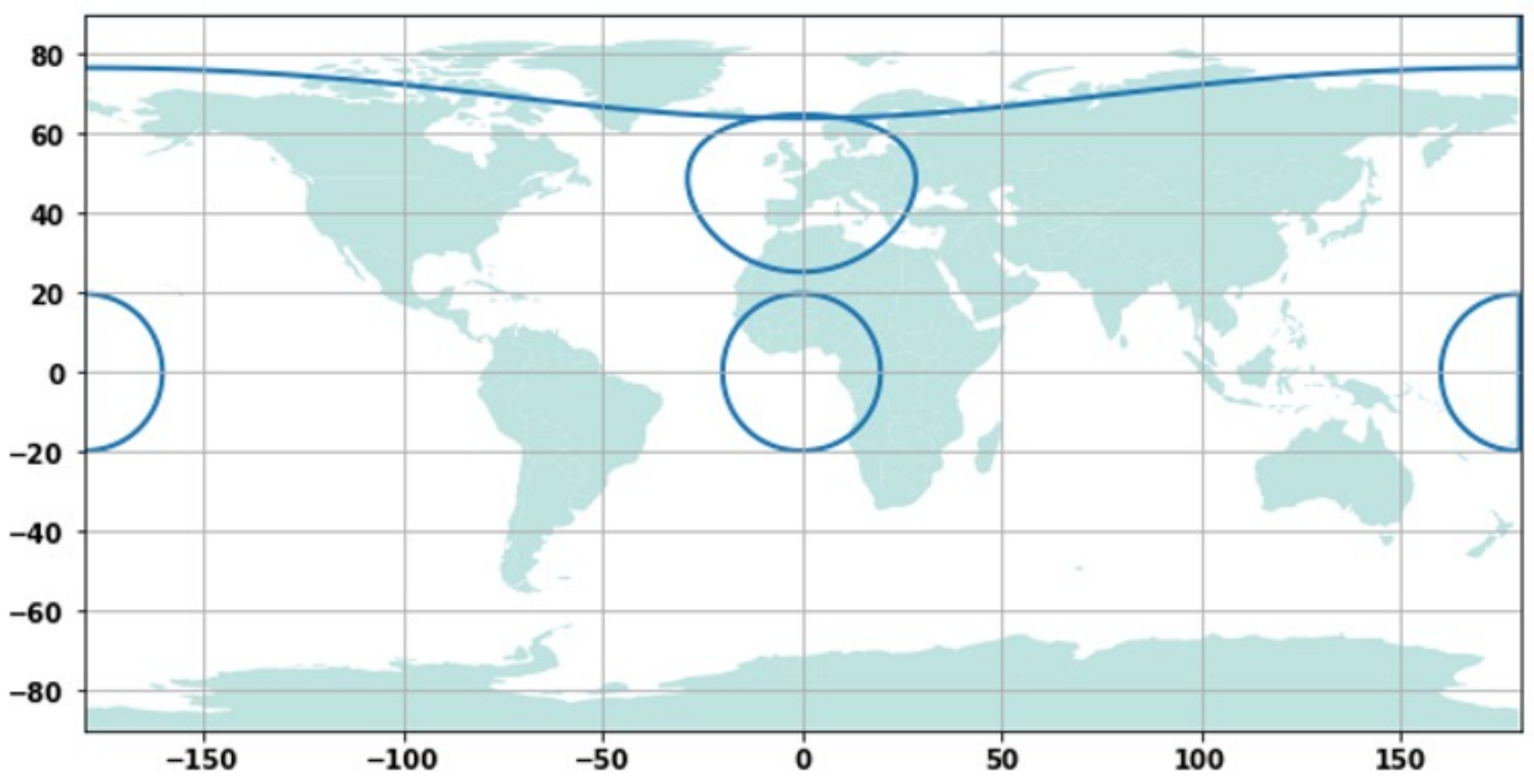

Figure 1. Horizon-to-horizon slewing range for a satellite at an altitude of 400 km. Showing range at equator over the meridian and antemeridian, at 45 degrees N and over the North Pole.

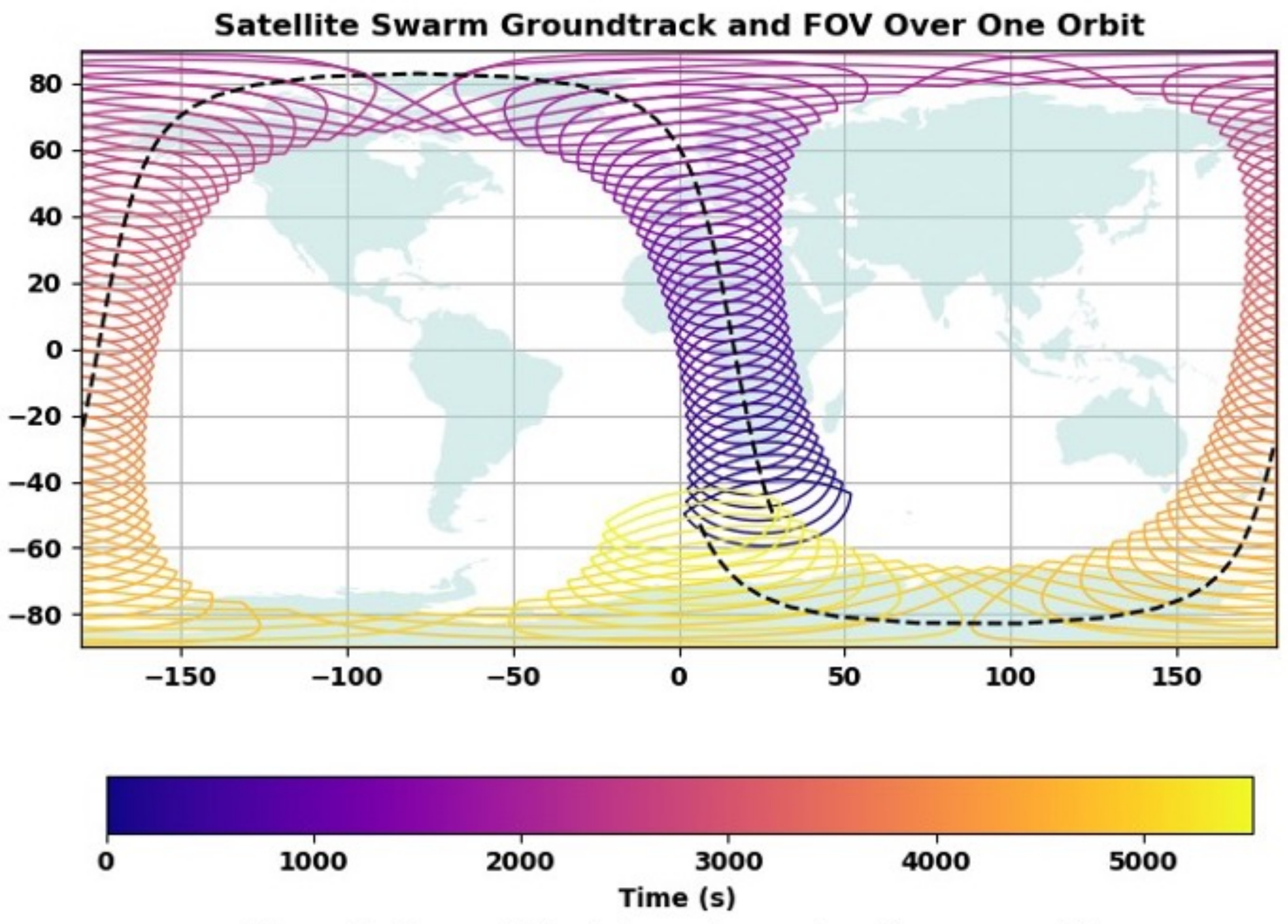

Figure 2. Swarm field of view and ground track over one orbit.

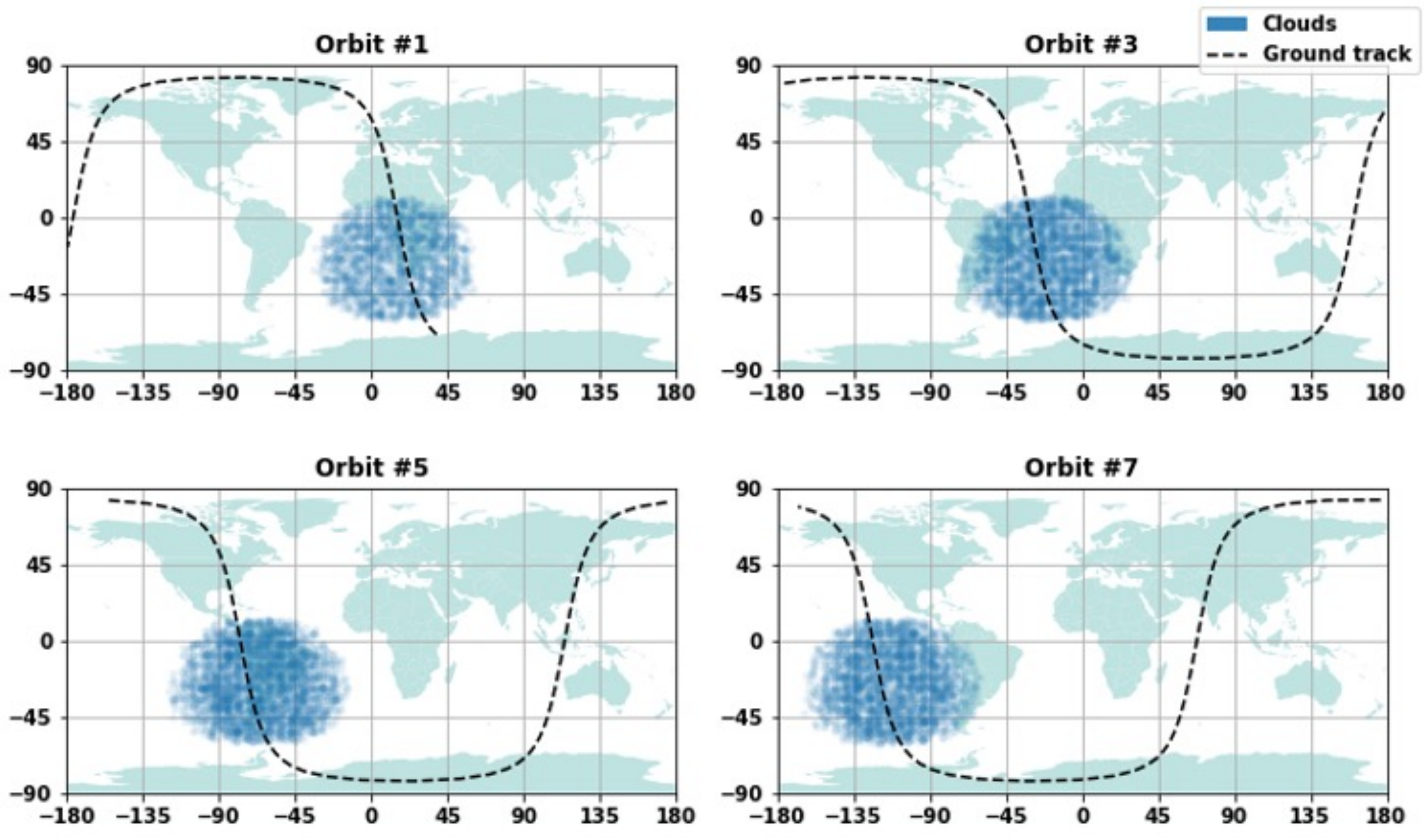

Figure 3. Flyovers for multiple orbits.

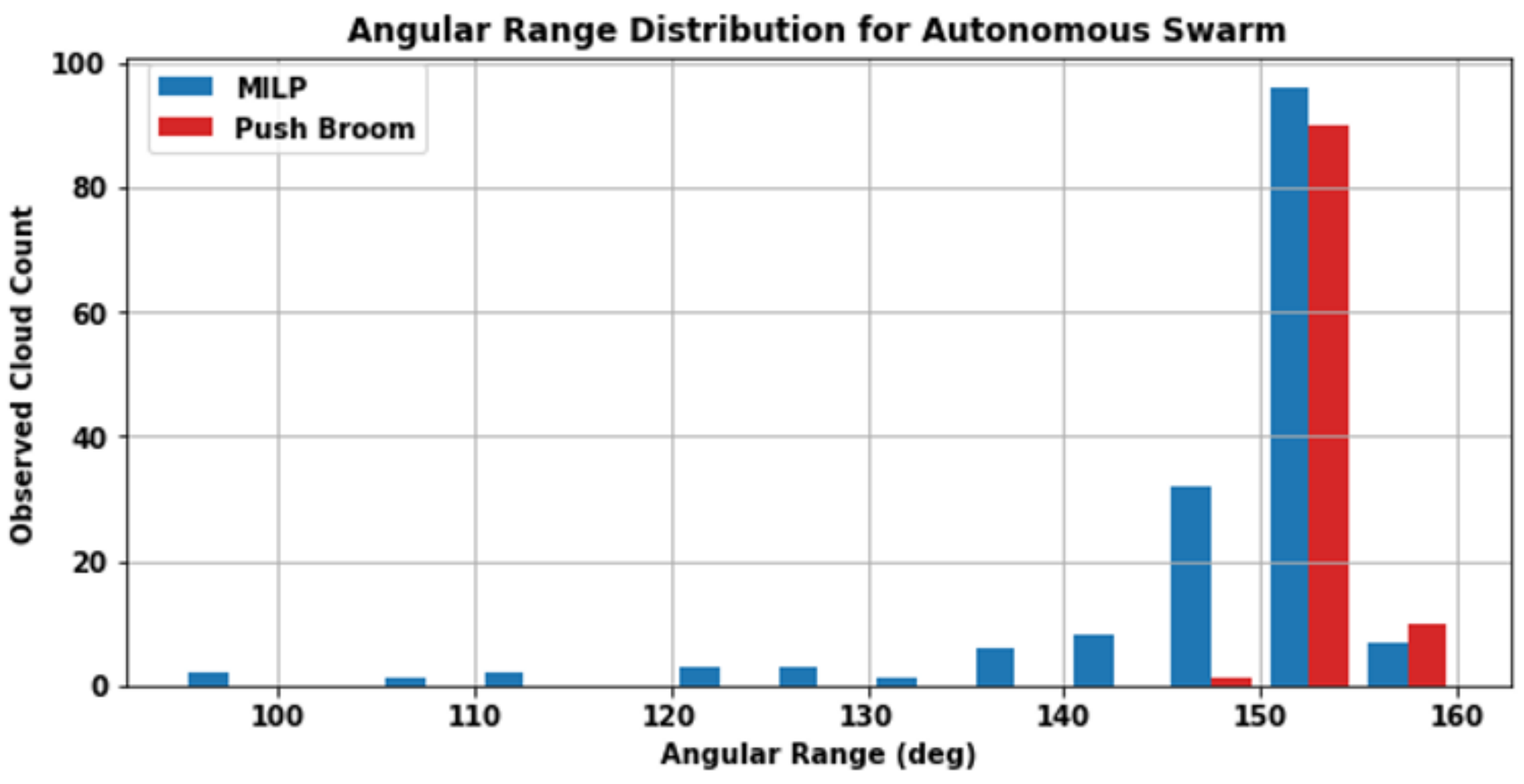

Figure 5. Observation angular range distribution in 5-degree intervals. Note that the push broom configuration is limited to larger angular range.

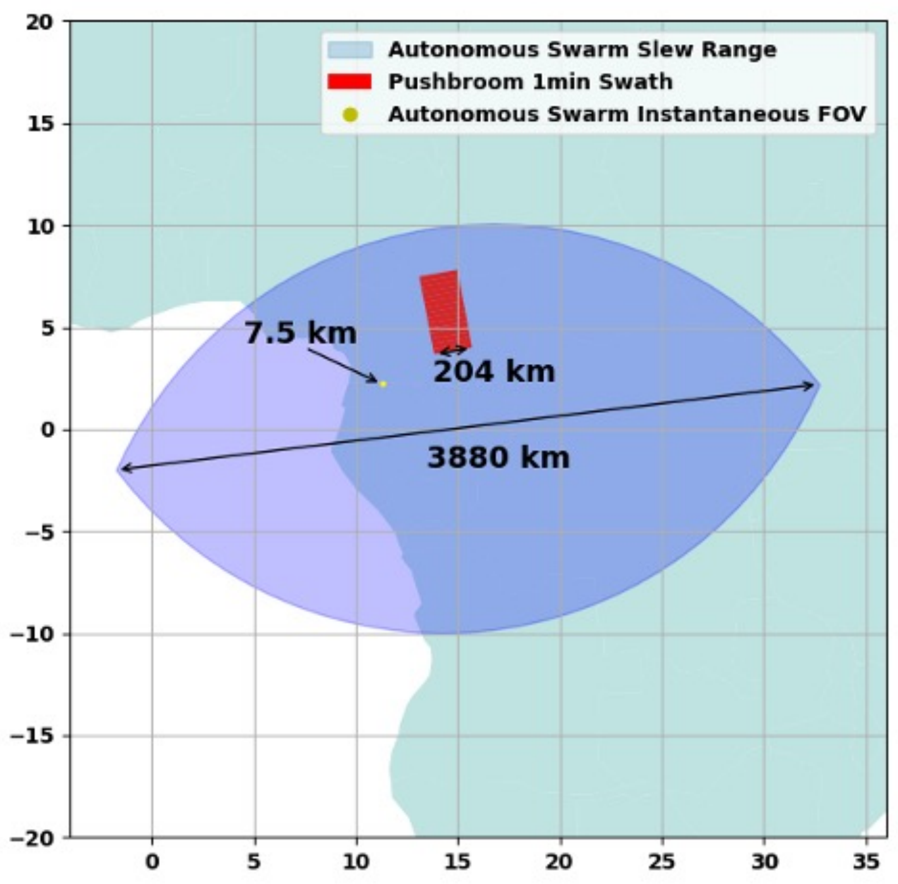

Figure 4. Pushbroom scanning swath over 1 minute (red) compared to swarm slewing range for 1 time step (blue), as well as the instantaneous field of field for a camera in the string of pearls (yellow).

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