Small Satellites, Large Numbers

Sreeja Nag

Bay Area Environmental Research Institute

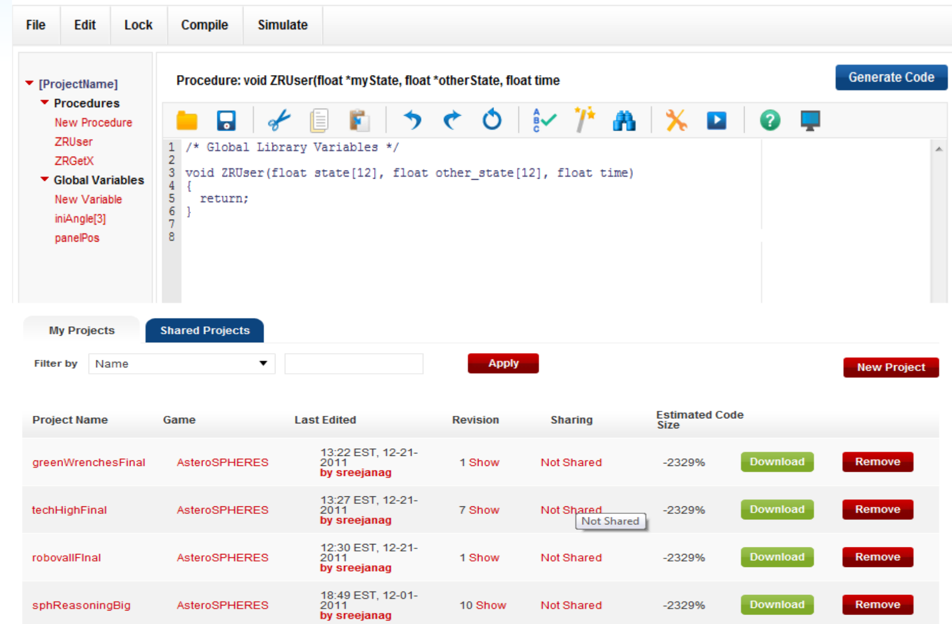
NASA Ames Research Center, CA and NASA Goddard Space Flight Center, MD

U.S.A.

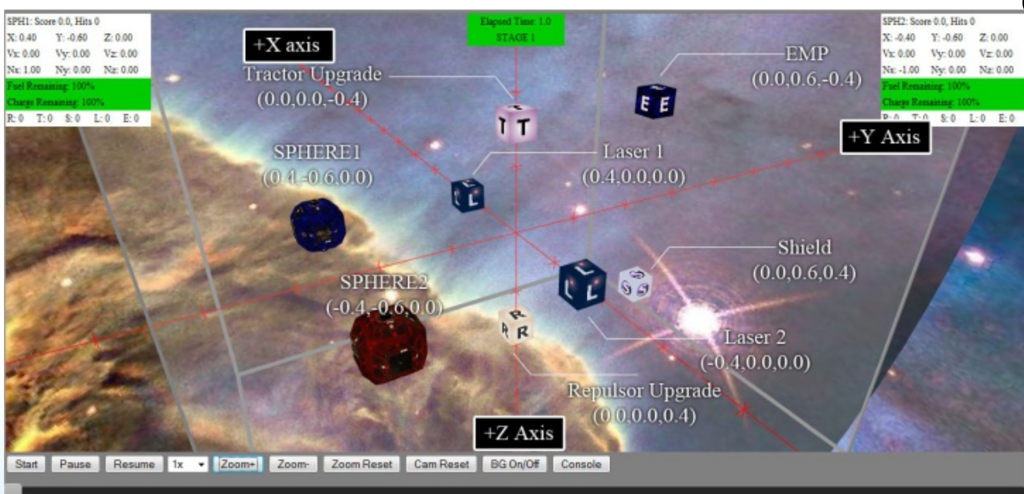
January 13, 2017

My Past Life of Space Robotics

SPHERES onboard the International Space Station



Online gaming system for coding the SPHERES



Example animation of an online SPHERES game

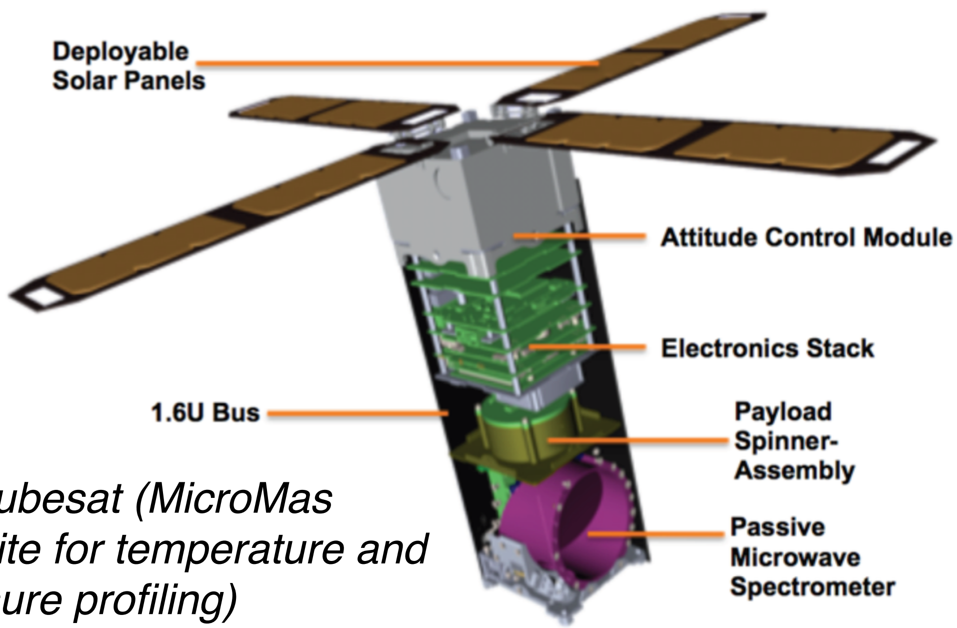
Finals broadcast from the ISS

Bay Area Environmental Research Institute

A Decade of EO CubeSats

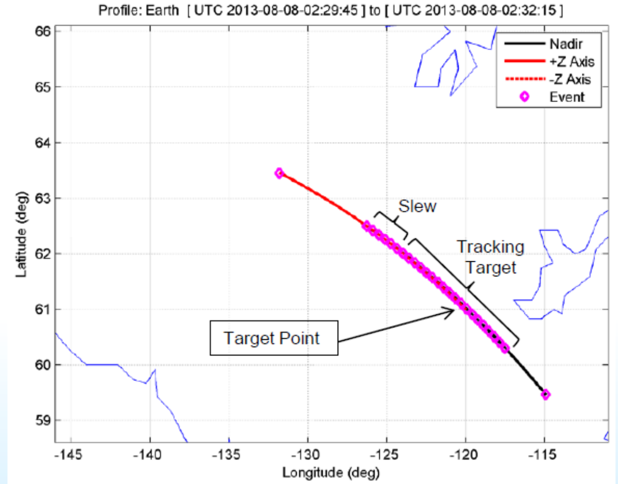
- 1 U Cubesat: 1.33 kg and 10 x 10 x ~11 cc
- In 1999, Cal Poly and Stanford University developed the CubeSat specifications to promote and develop the skills necessary for the design, manufacture, and testing of small satellites intended for low Earth orbit (LEO)
- Since 2007, science based satellites

1U Cubesat (Wikipedia)



3U Cubesat (MicroMas satellite for temperature and pressure profiling)

AeroCube Fire Detection (CubeSat Developers' Workshop, April 2014)



Why did Small Sats get popular?

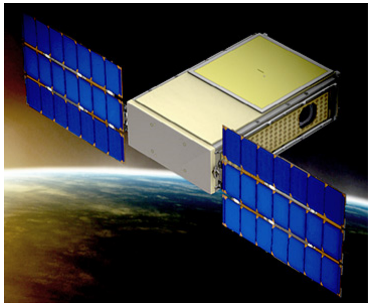
- The advent of the CubeSat standard
- Miniaturization of propulsion, power systems or electronics
- Frequent and cheaper launch opportunities by emerging companies such as SpaceX and RocketDyne
- Hosted payload opportunities on traditional rockets using the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA)
- Deployment mechanisms for CubeSat payloads using the PPOD launcher or NanoRacks
- Increasing availability of ground stations

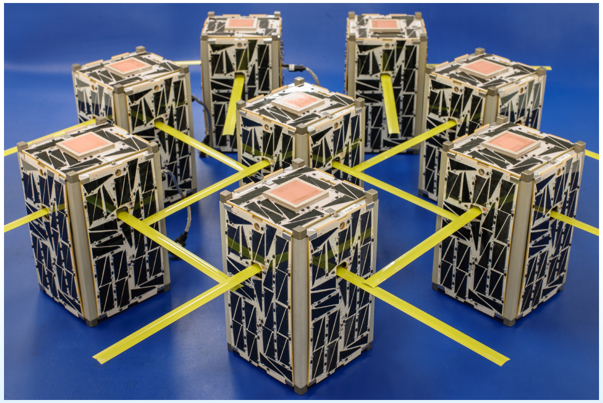
Deployment and operation of large numbers of small satellites more feasible than it ever used to be

CubeSats/NanoSats at NASA Ames

SPHERES

Proposed and funded BioSentinel

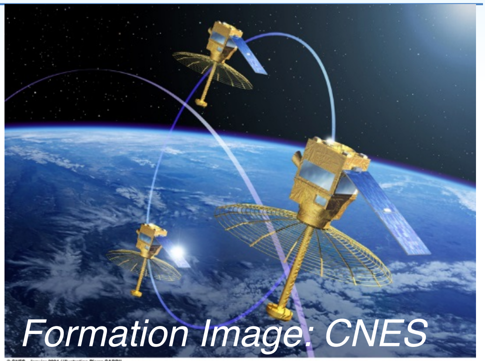




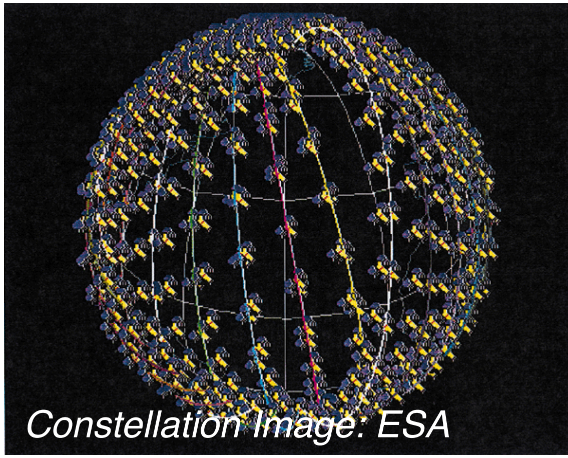
Edison 1.5U satellites

Why Multiple Satellites?

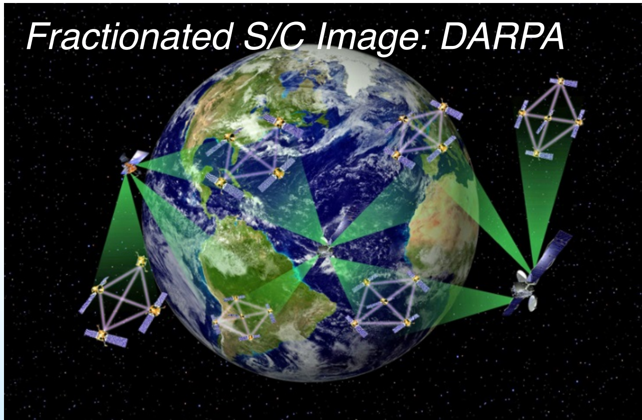
- **Distributed Space Missions (DSMs):** Constellations, formations, ad-hoc constellation - home or hetero, cellularized systems, federated satellites
- **Performance**: Improve sampling and range in spatial (synthetic apertures), temporal (constellations), spectral (fractionated S/C), angular (formations) dimensions
- **Cost**: Need more inter-operability planning, autonomy, scheduling commands + data, ground station networks
- **Ilities in Operations**: Flexibility, Reconfigurability, Scalability, etc.
- **Better Design**: Many conflicting variables and objectives thus better methods needed in Phase A+ - coupled models, machine learning, planning/scheduling methods, etc.



Formation Image: CNES



Constellation Image: ESA

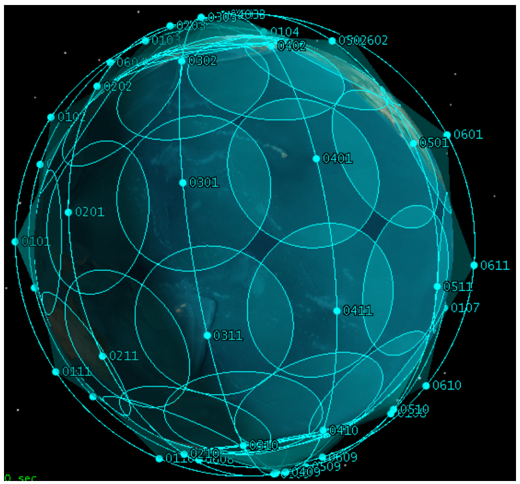


Fractionated S/C Image: DARPA

Constellation Design Applications

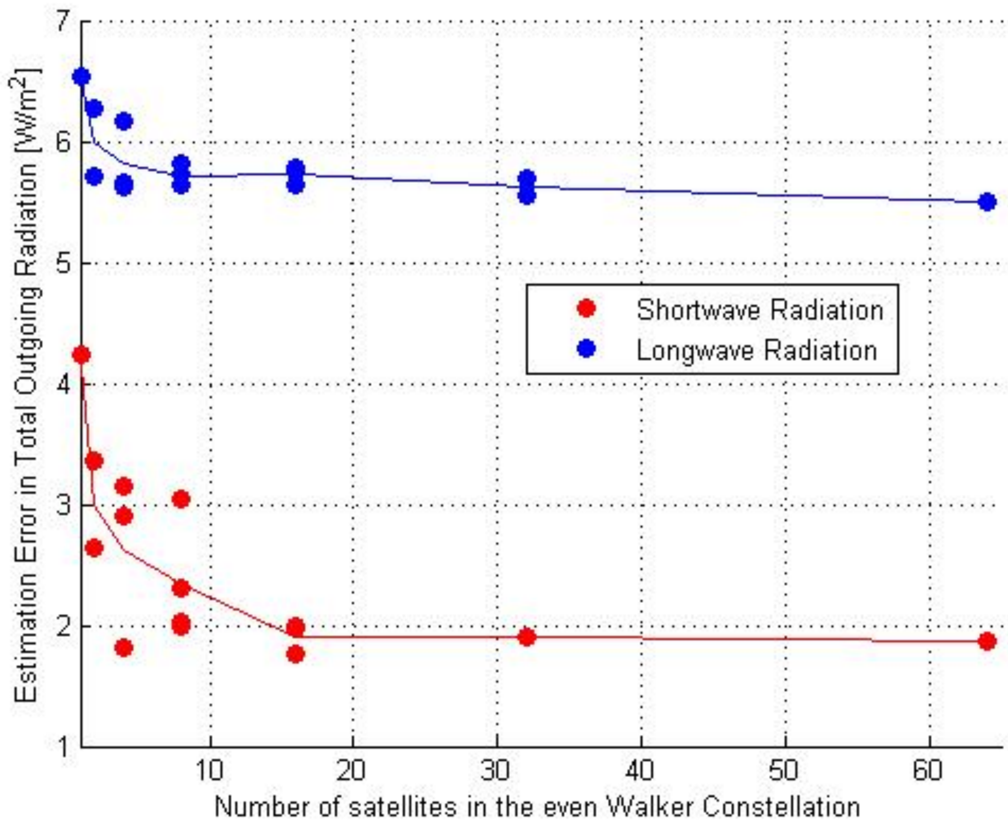
All products in Time-Critical Remote Sensing are improved by Constellations

Total Global Outgoing Radiation: There is an imbalance between the amount of energy entering the Earth vs. leaving/absorbed by the Earth. Need dense spatio-temporal measurements to quantify.



Orbit at 710 km, 130° FOV, 98.18° inc

CERES on TRMM errors: *15.37 W/m² for shortwave radiation and 34.31 W/m² for longwave radiation.*

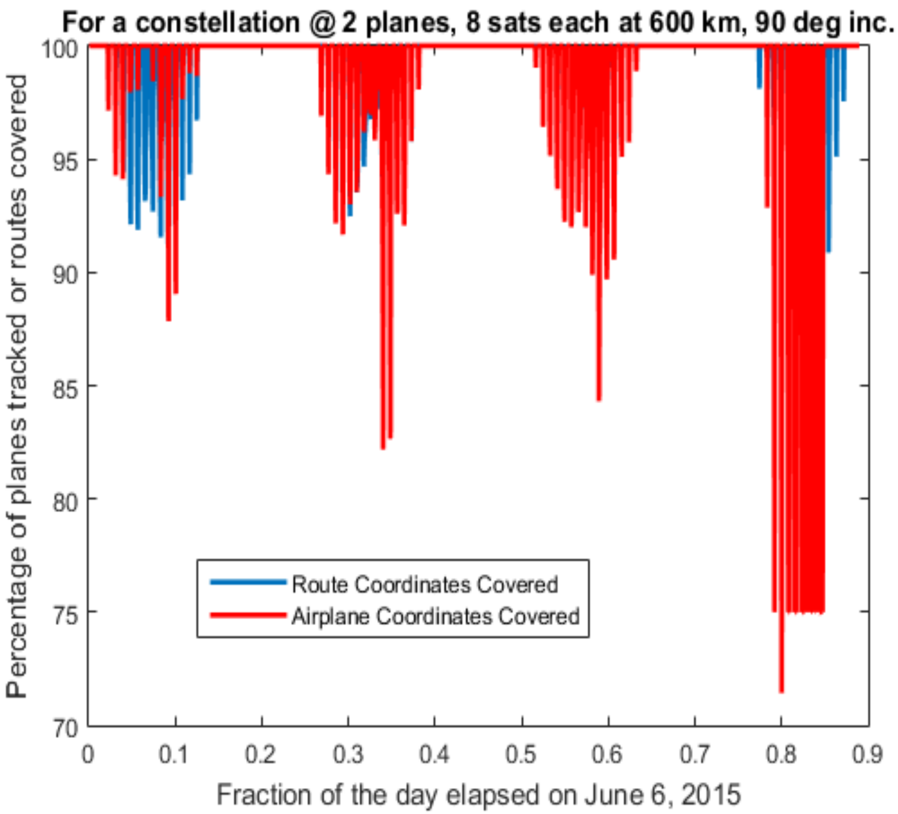


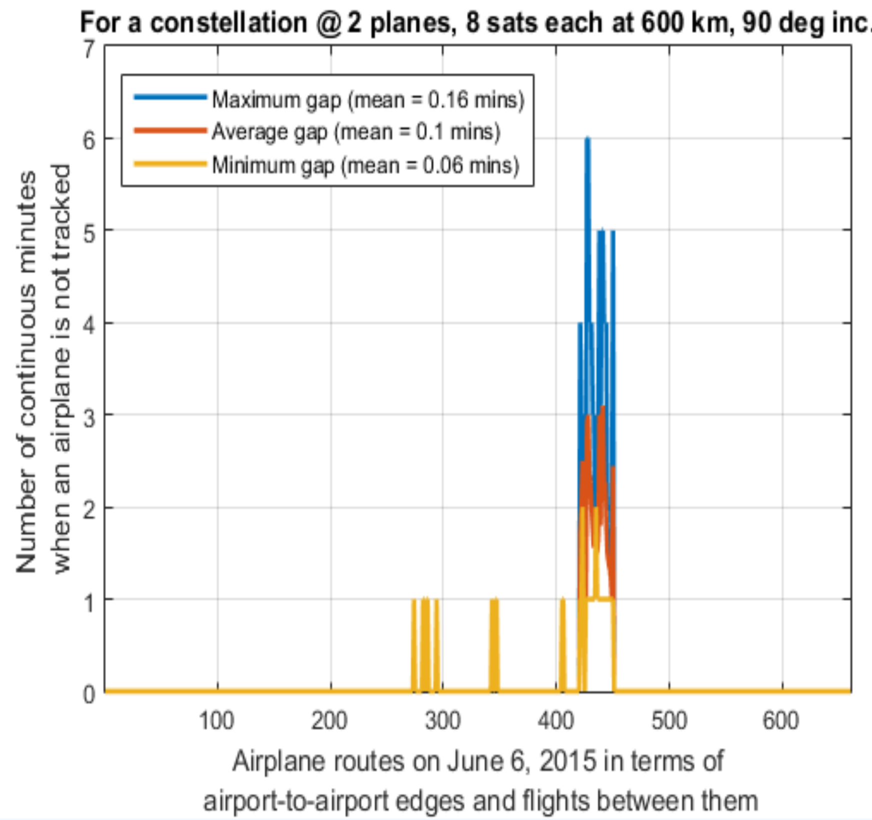
References: S. Nag, *"Satellite Constellation Mission Design using Model-Based Systems Engineering and Observing System Simulation Experiments"*, AIAA/USU Small Satellite Conference, August 2014

Constellation Design Applications

All products in Time-Critical Remote Sensing are improved by Constellations

Air Traffic Monitoring: Airplanes have ADS-B transponders that broadcast state information but remote areas rarely have receivers to intercept and relay.



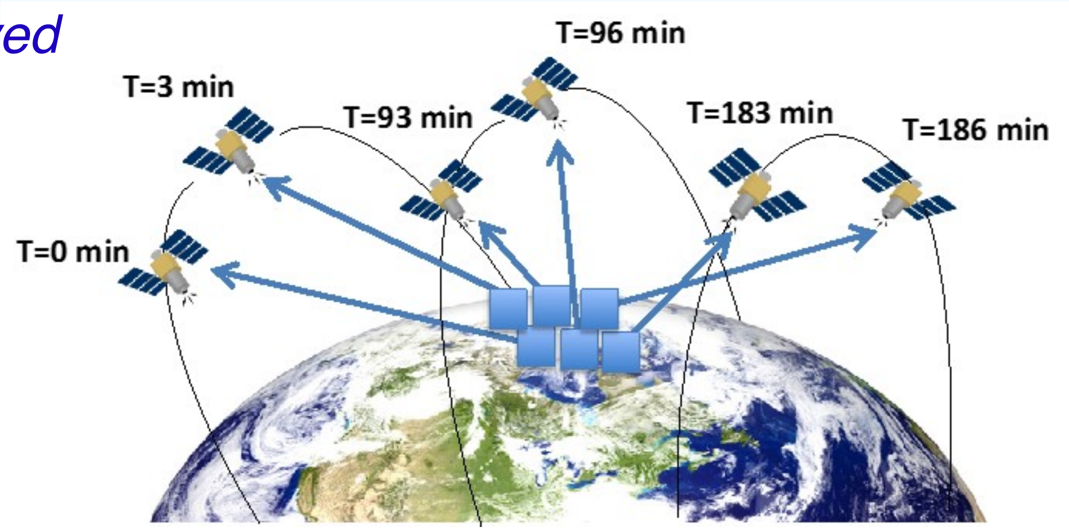


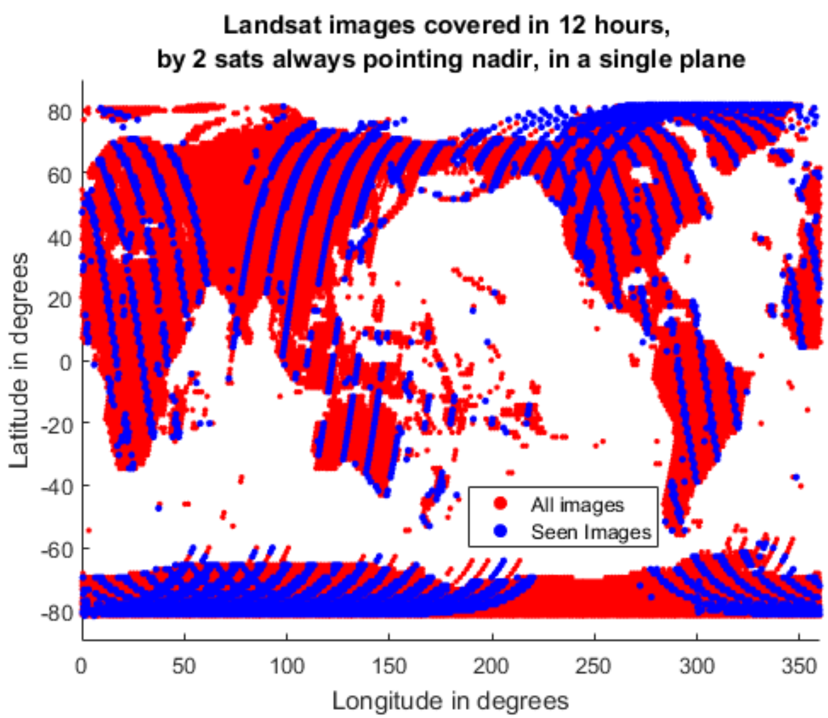
Reference: S. Nag, J. L. Rios, D. Gerhardt, C. Pham, *"CubeSat Constellation Design for Air Traffic Monitoring"*, Acta Astronautica, June 2016

Constellation Design w/ Pointing

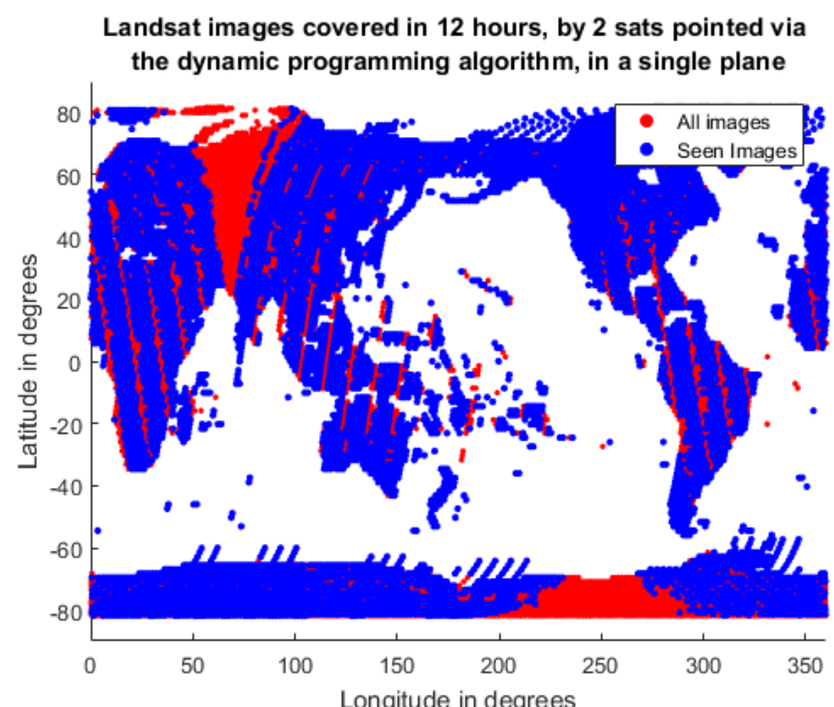
All Coverage products are improved by Constellations

Scheduling pointing ops for narrow sensors on LEO sats to maximize global coverage + minimize image distortion under attitude control, cloud cover, etc. constraints.





vs.

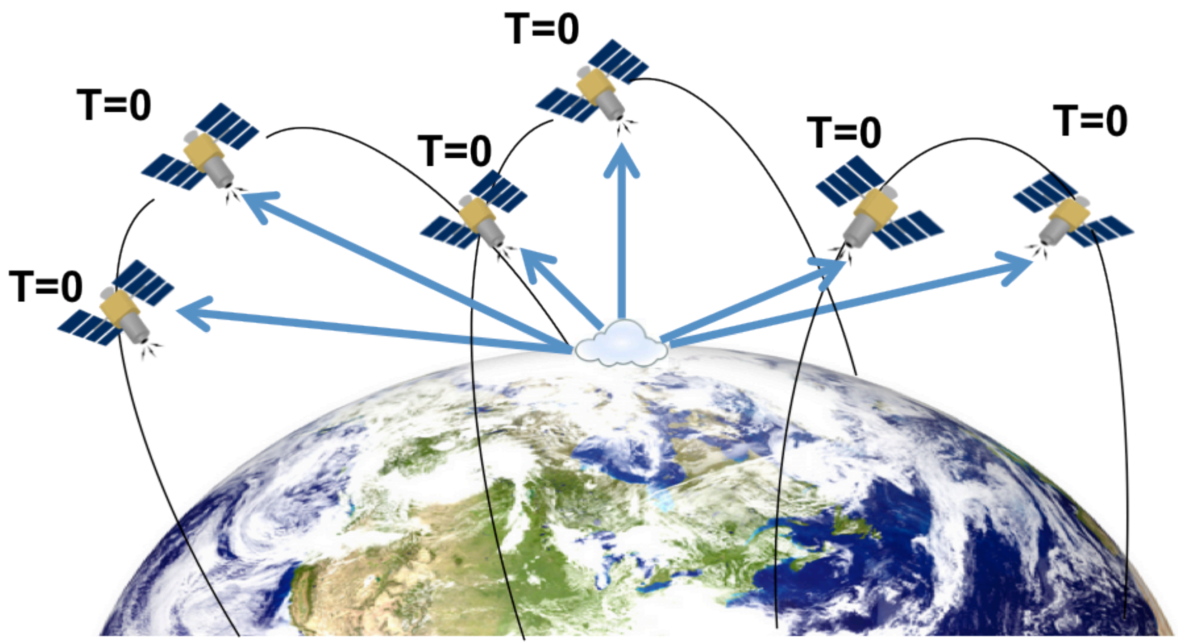


Formation Flight Applications

All products in Multi-Angular Remote Sensing are improved by co-pointing formations

Bi-Directional Reflectance Distribution Function Measurements:
A major limitation is the angular under-sampling of the Earth locally. The impact of this uncertainty is large uncertainty in albedo, carbon budget, Earth Radiation Budget.

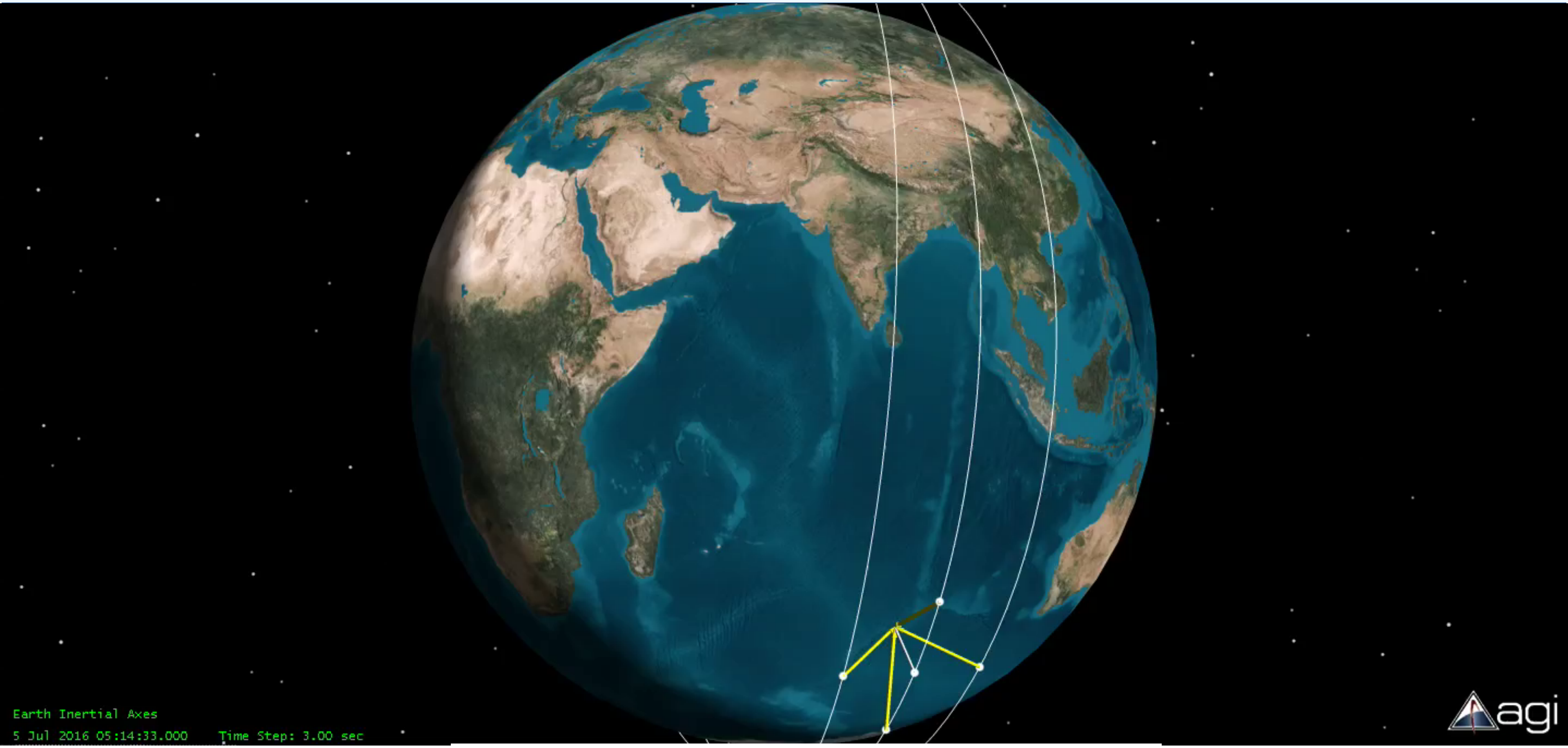
A potential solution is formation flight using narrow field of view sensors.

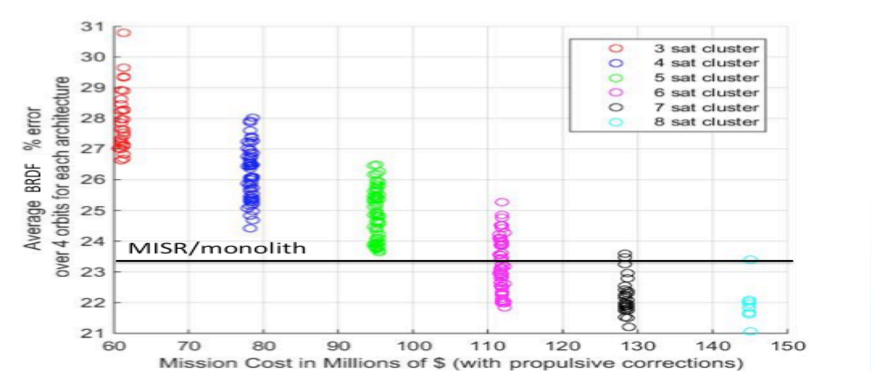


References: S. Nag, C.K. Gatebe, T.Hilker, *"Simulation of Bidirectional Reflectance-Distribution Function Measurements using Small Satellite Formations"*, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, June 2016

S. Nag, C.K. Gatebe, D.W. Miller, O.L. de Weck, *"Effect of Satellite Formation Architectures and Imaging Modes on Global Albedo Estimation"*, Acta Astronautica 126 (2016), 77-97, DOI:10.1016/j.actaastro.2016.04.00

Formation Flight Applications





Constellation Design for UAV tracking

Unmanned Aircraft System (UAS) Traffic Management (UTM)
Enabling Civilian Low-Altitude Airspace and Unmanned Aircraft System Operations

Reference: S. Nag, K.S. Inamdar, J. Jung, “Communication Simulations for Unmanned Aerial Vehicles equipped with Automatic Dependent Surveillance”, AIAA Aviation Conference, June 2017

- Coordinated communication of state info between UAV to ground stations using Automatic Dependent Surveillance Broadcast (ADS-B)
- Detailed model of range and signal fidelity of every UAV with respect to operator, other UAVs *and manned aircraft*
- Adding satellites to the model, especially those with intelligent and dynamic pointing abilities, will create a Sensor Web of remote sensing capability.

Summary

- Small sats in large numbers allow scalability therefore collaborations and market flexibility, resilience therefore graceful degradation, low cost therefore risk appetite.
- Small sats and constellations are new technologies for Earth Observation and better science measurements, aside of being great tech demos and opportunities for education
- The performance to cost feasibility of such an approach is yet to be determined. How many satellites arranged how? Pointing schedules? Downlink schedules? Time to coverage and revisit? Spatial overlap?
- There are several candidate applications for large numbers of small satellites – Earth radiation measurements, air traffic monitoring, unmanned air traffic tracking, rapid response coverage, multi-angular measurements …
- There are several technologies being developed to support such applications – constellation mission design software, scatter maneuvering and collision avoidance, attitude control of pointing ops, command and control…

Questions?

sreeja.nag@nasa.gov