Effect of Satellite Formation Architectures and Imaging Modes on Albedo Estimation of major Biomes

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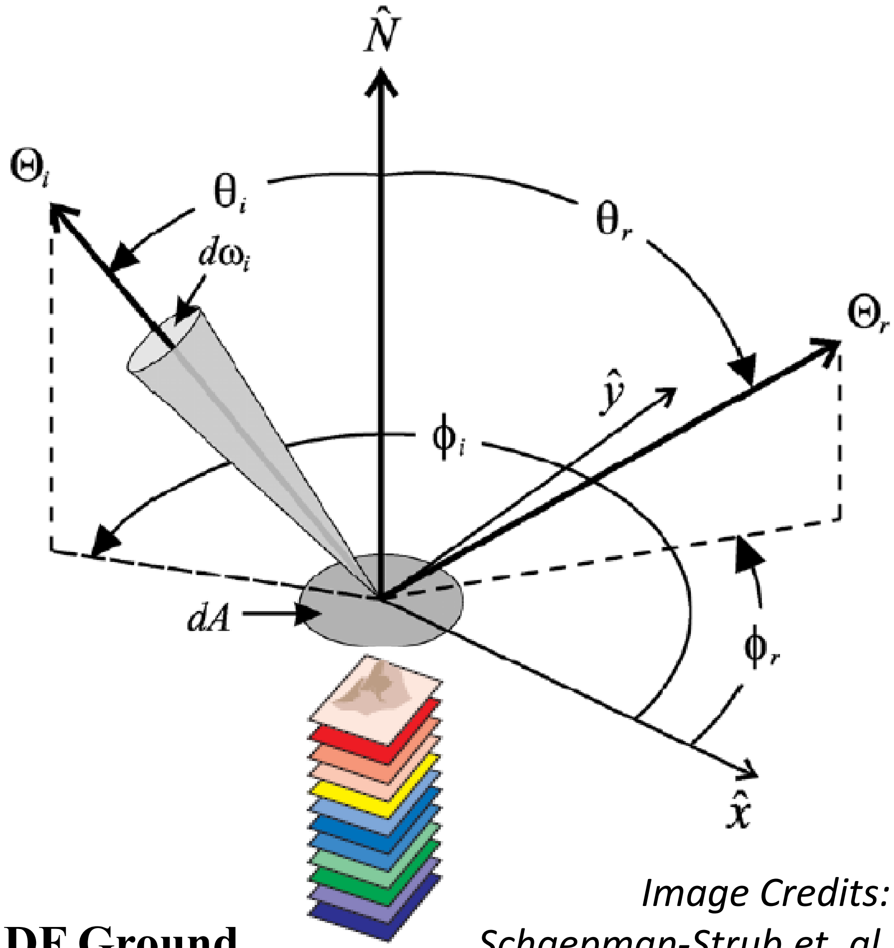
Outline

- The Angular Acquisition problem
- Example Application dependent on Angular Sampling
- Proposed Solution and Design Methodology
- Baseline Case Study using a few Formation Configurations
- Value of Imaging Modes
- Summary and Future Work

Introduction: Why Angular?

- Because reflectance values depend on the direction of solar illumination and direction of measured reflection
- Angular performance metric: Bi-directional reflectance distribution function (BRDF)
- Anisotropic (angle-dependent) and multispectral (near-solar spectrum) reflectance of clouds and ground surface
- Angular sampling is inadequate using monolithic spacecrafts presenting an angular challenge

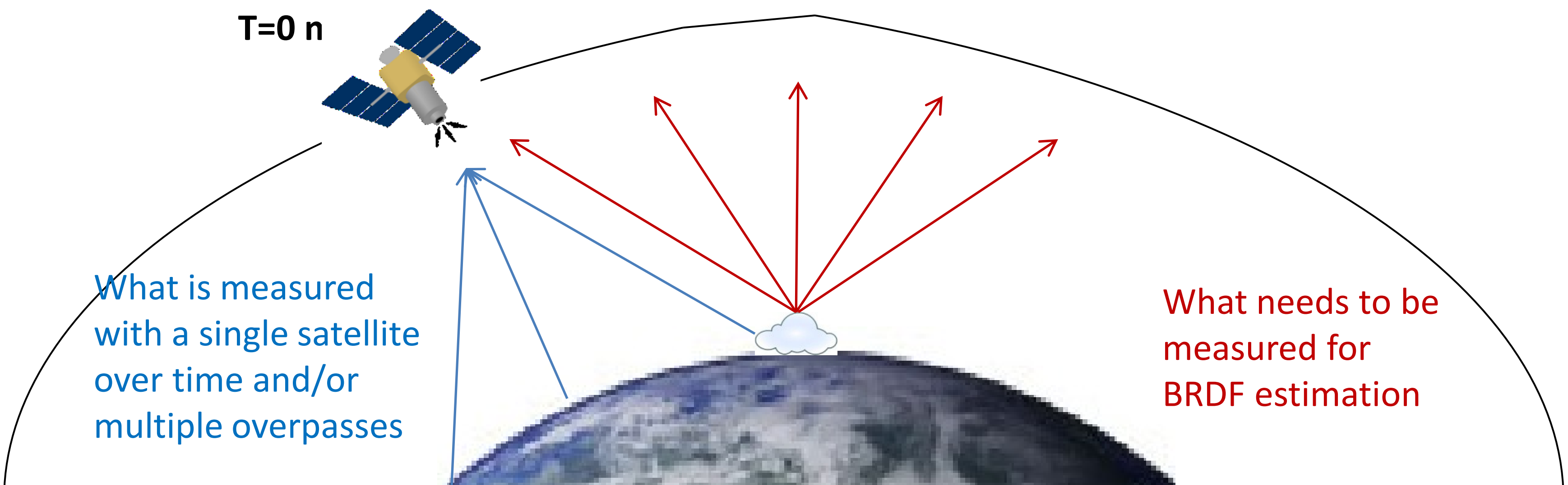


BRDF Ground Spot spectrum

Image Credits: Schaepman-Strub et. al, 2006

Angular Acquisition Problem

Measurements for BRDF Estimation using a single satellite with **forward aft sensors** – one angle at a time



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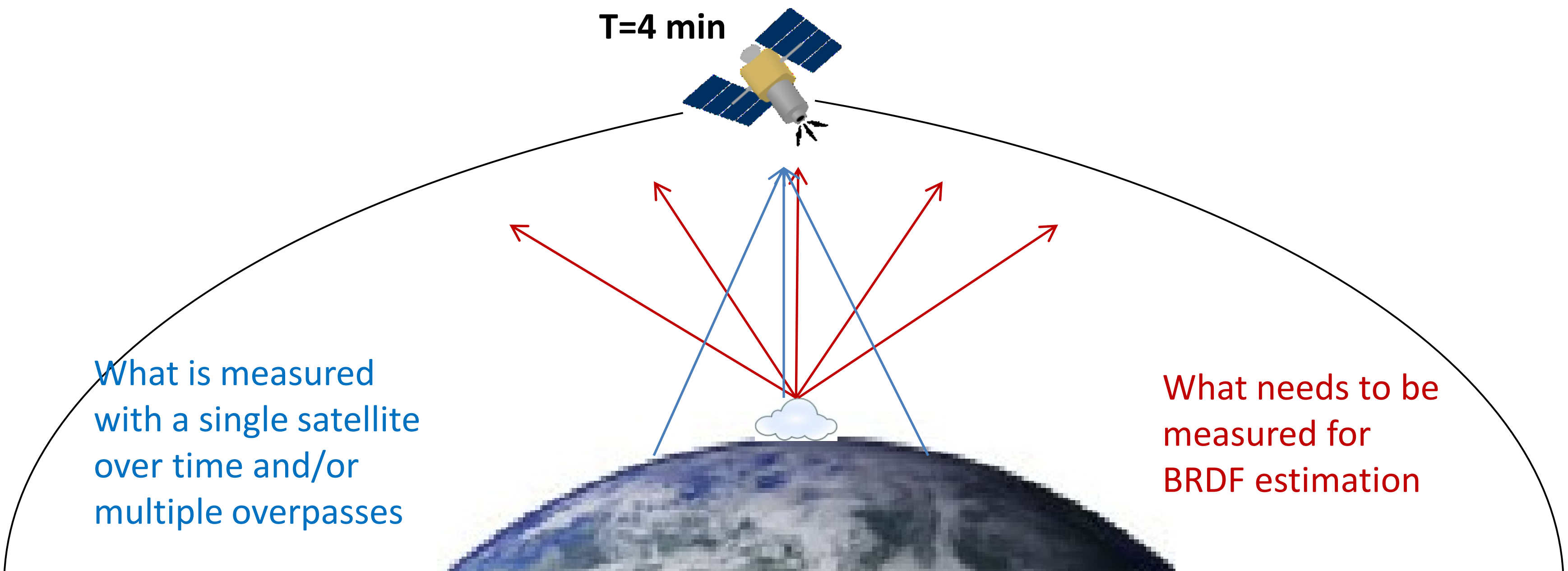

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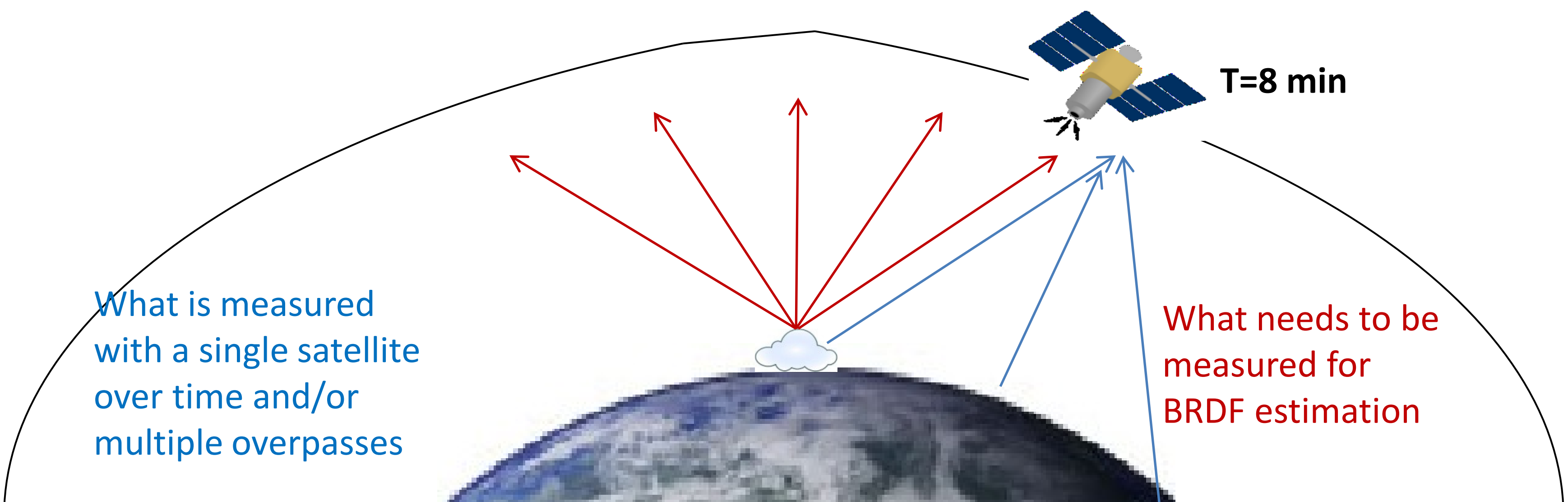
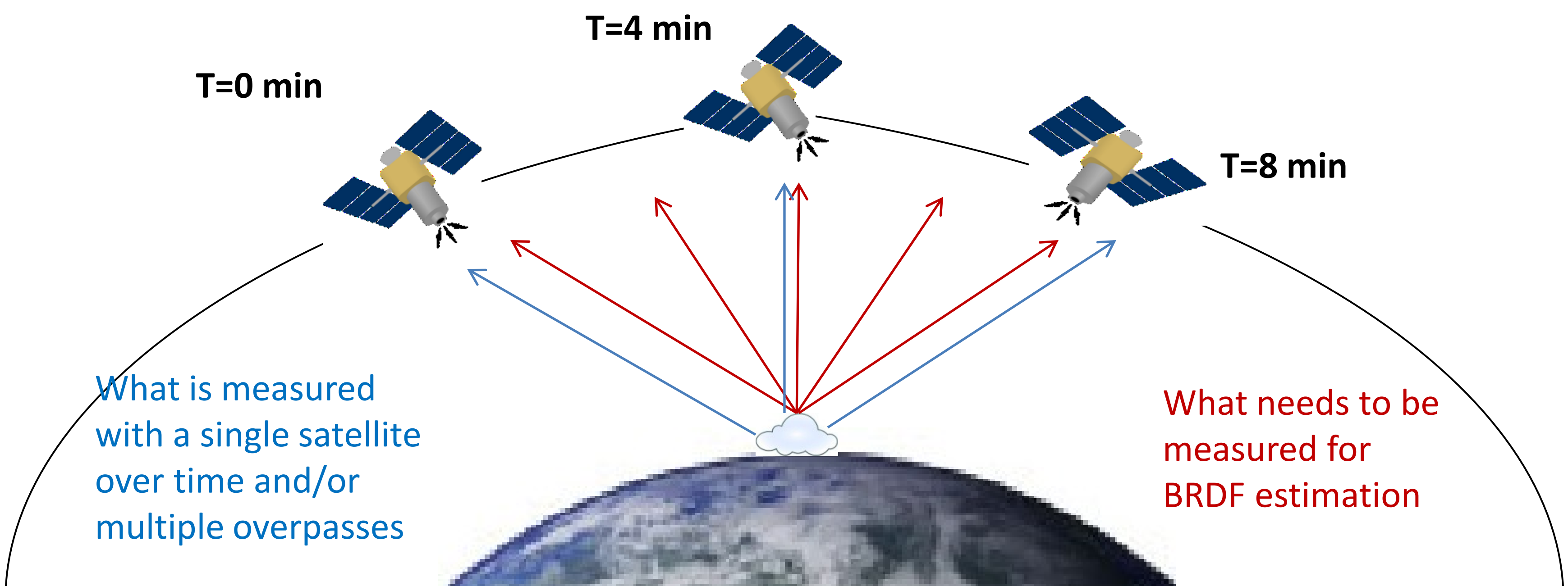


Angular Acquisition Problem

BRDF Estimation by combining the consecutive measurements

Problem: 1. Restrictive plane with respect to the sun
2. Up to 10 minutes between measurements



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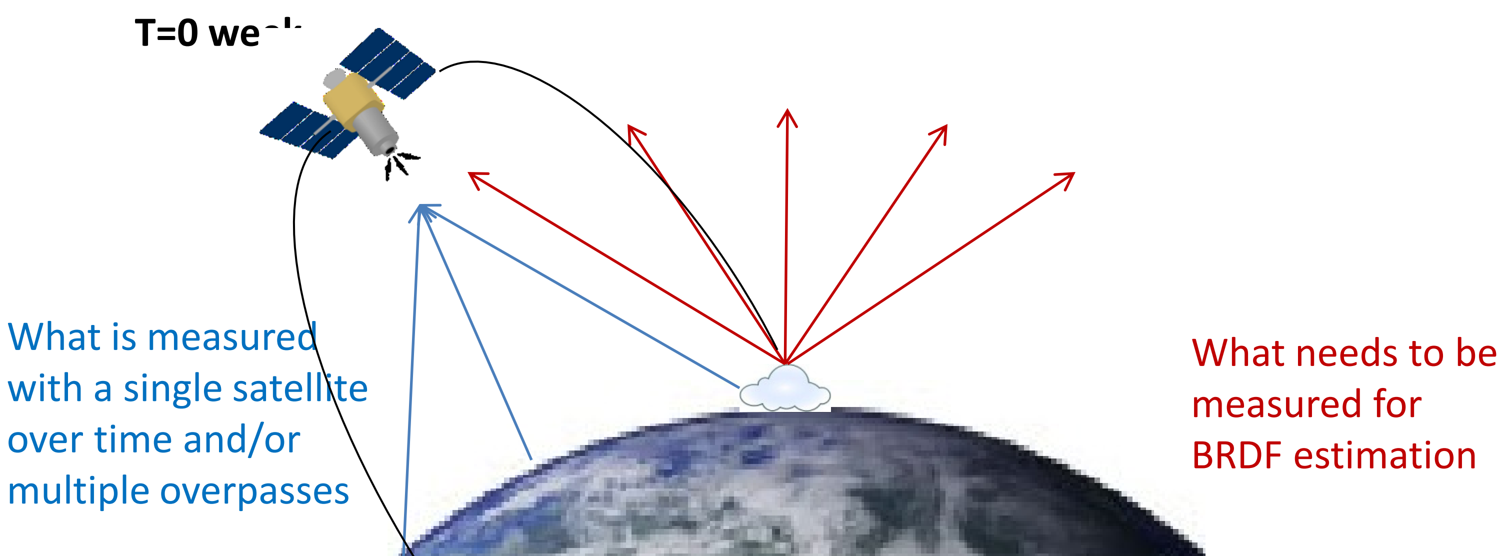
Measurements for BRDF Estimation using a single satellite with **large cross-track swath** – one angle at a time



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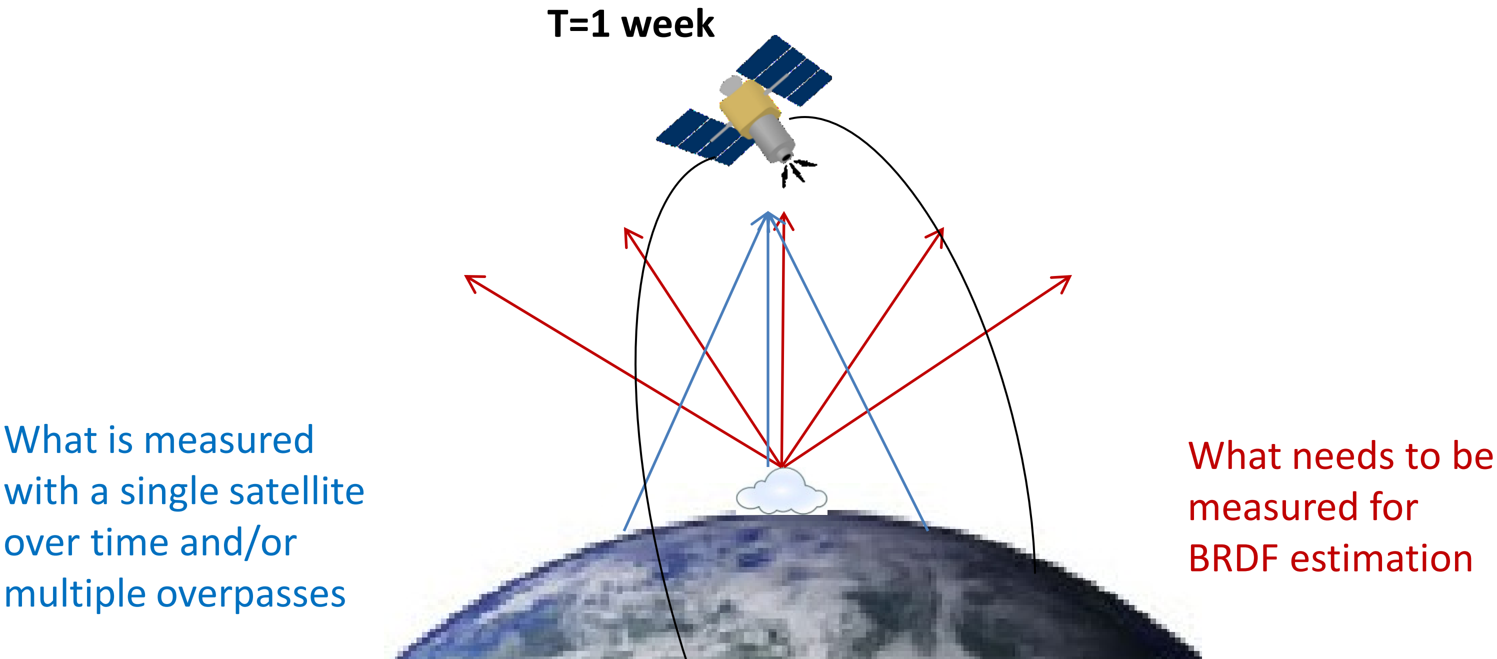

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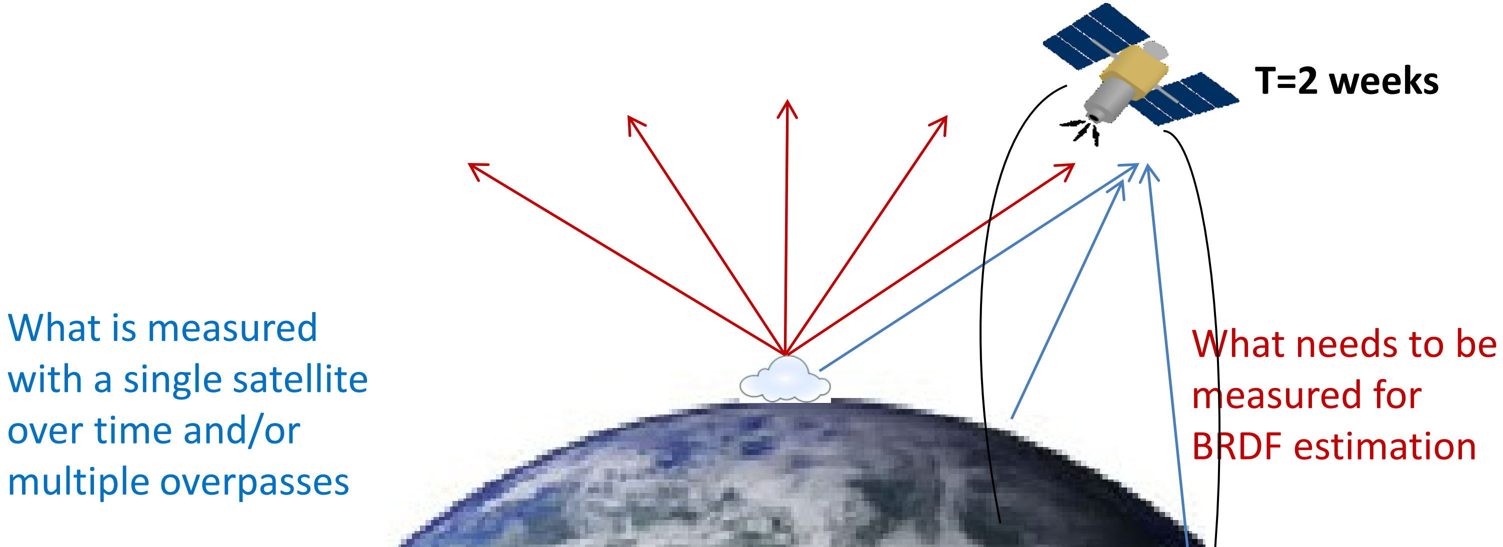
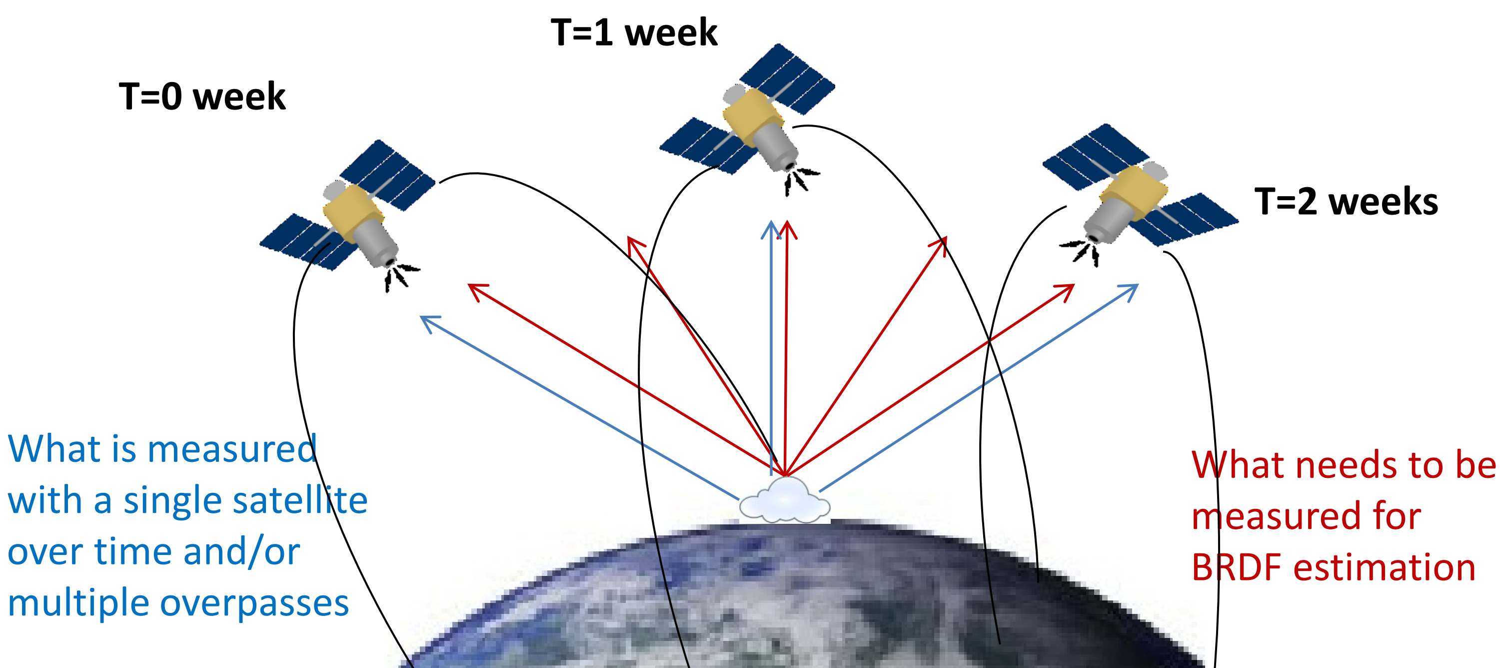


Angular Acquisition Problem

BRDF Estimation by combining measurements over consecutive overpasses

Problem: 1. Restrictive plane with respect to the sun
2. Up 2 weeks between measurements



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Albedo Estimation

Albedo is the hemispheric integration of BRDF over all view zenith and azimuth angles. Can be estimated from nadir measurements BUT big errors in the Arctic…

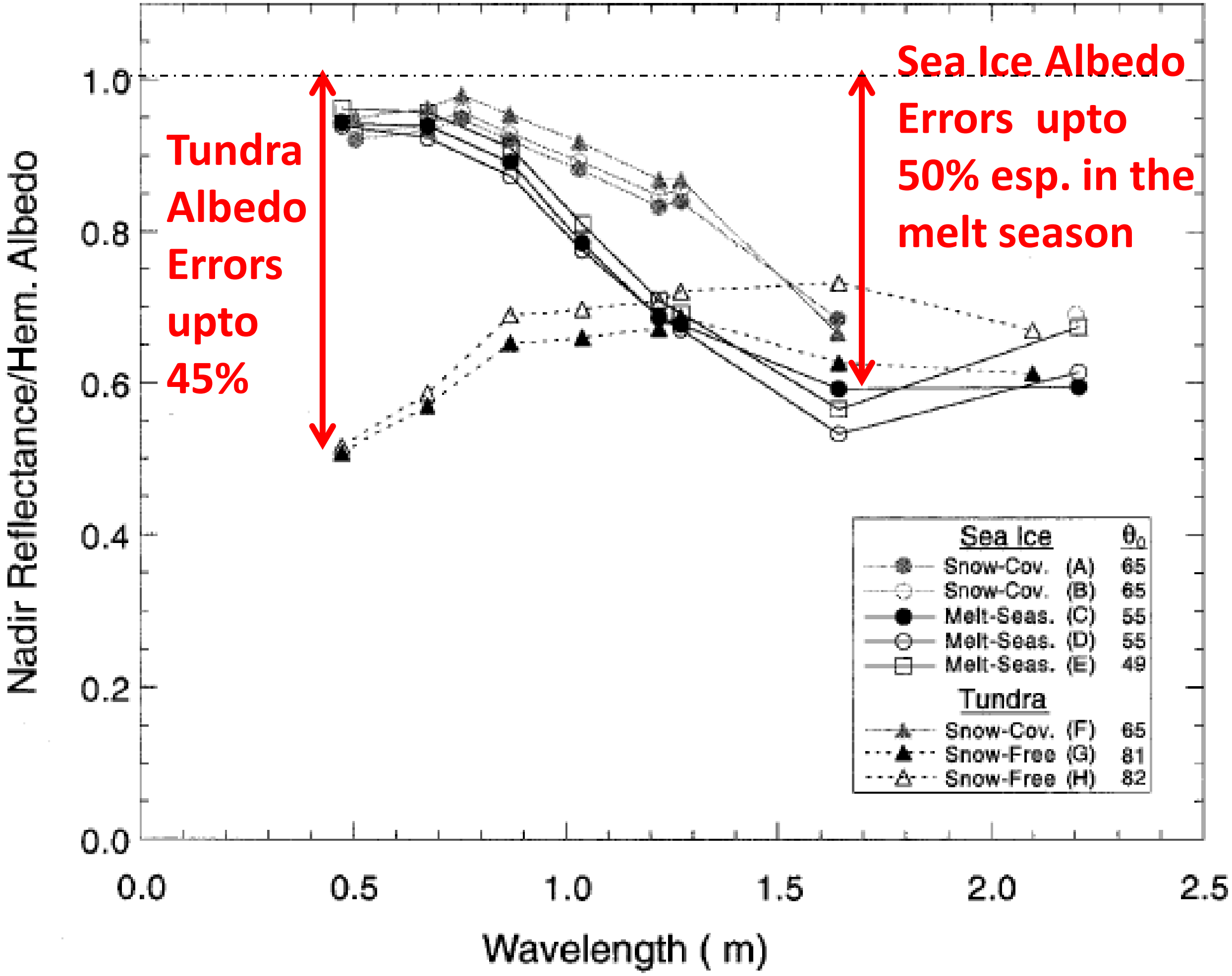

Image Credits: Arnold et. al, 2002

Figure uses thousands of angular measurement data from the airborne Cloud Absorption Radiometer taken during the ARMCAS campaign in 1998.

Albedo Estimation

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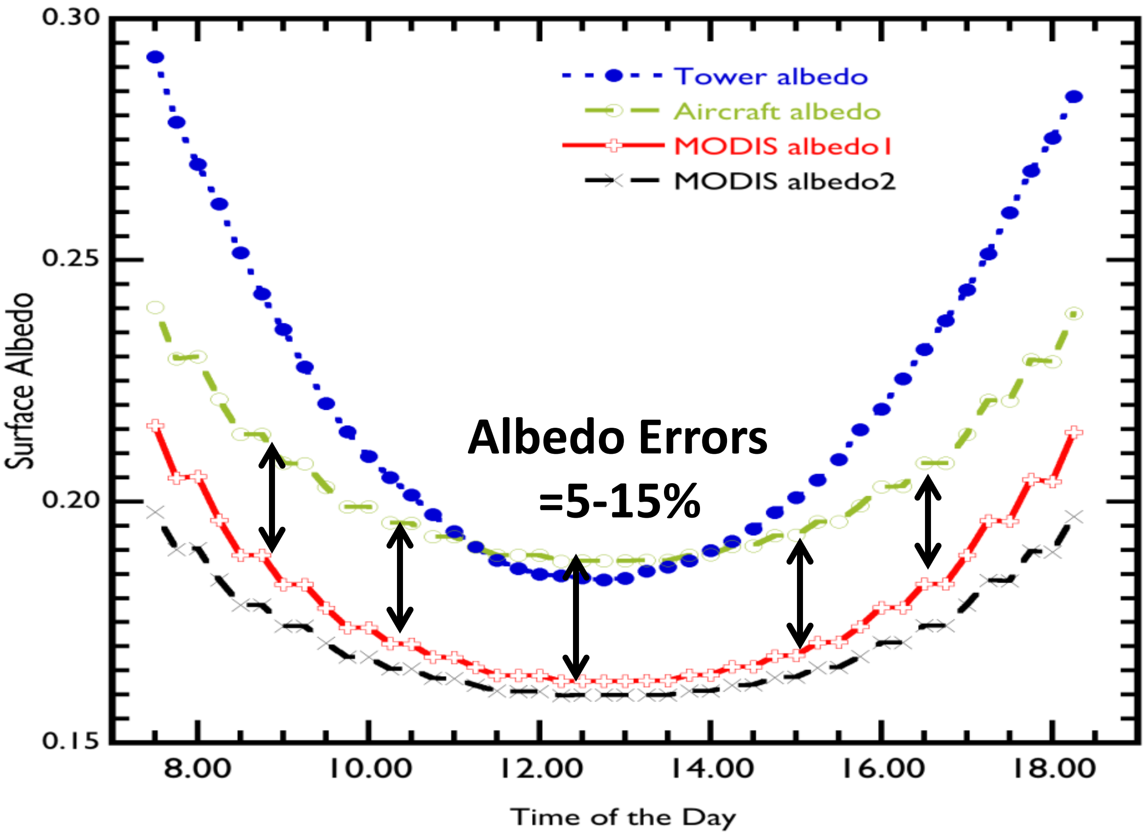

BRDF Data (Image Credits: Gatebe et. al, 2012) from the

airborne
Cloud Absorption Radiometer

vs.

spaceborne ***MODIS***

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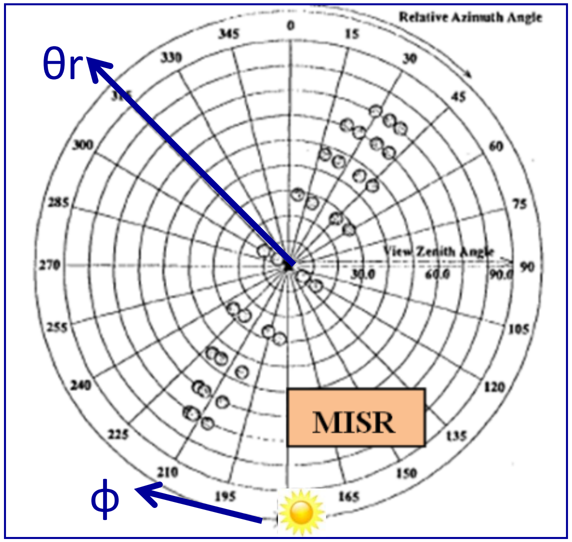
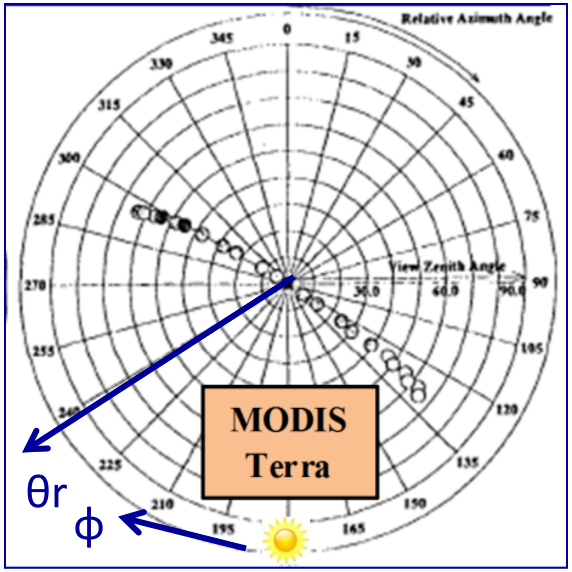
Proposed Solution to Angular Acq.

Major Limitation: Angular undersampling

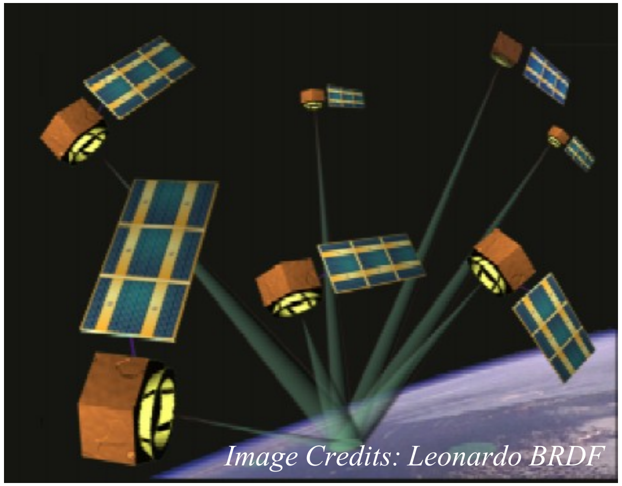


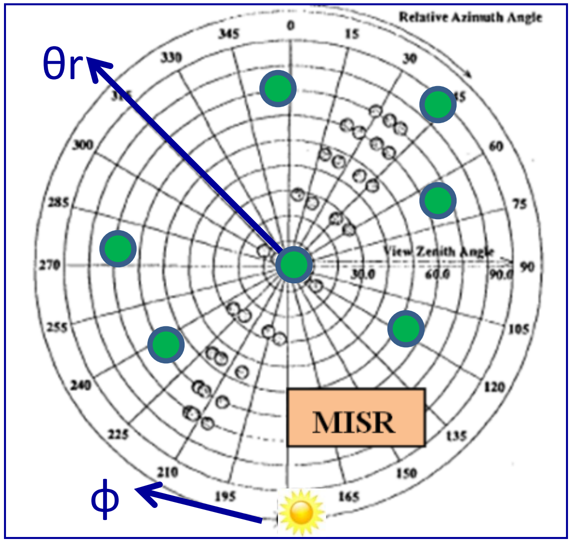


Proposed Solution to Angular Acq.

Major Limitation: Angular undersampling

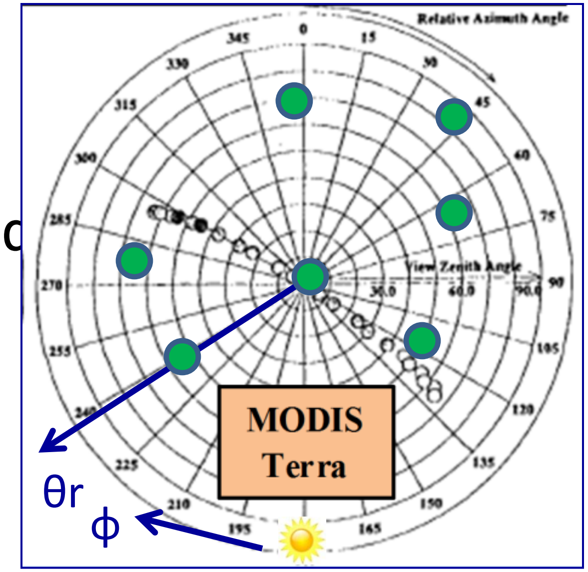
Potential Solution: Clusters (NFOV) of nano-satellites in formation flight.





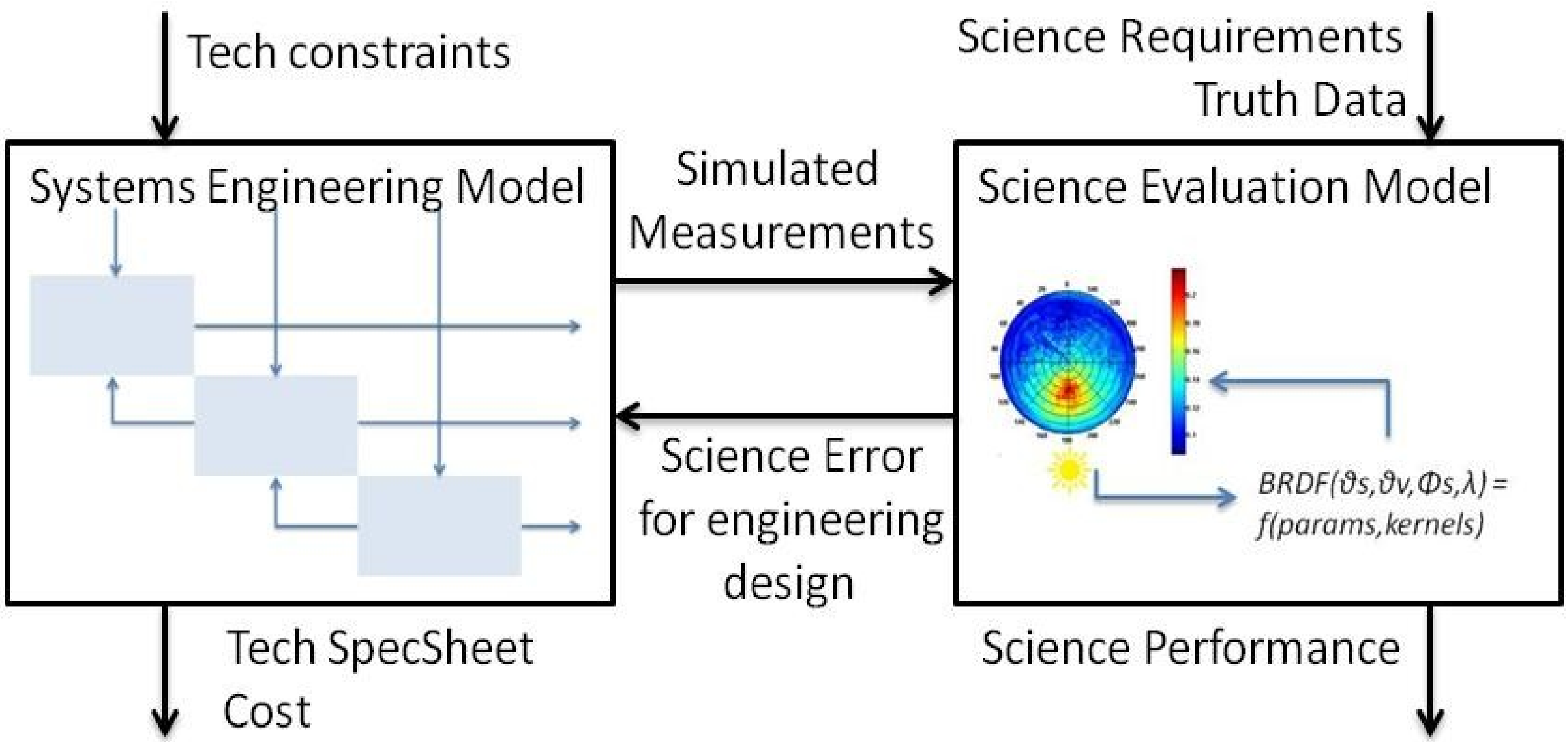
Additional advantages:- Small satellite design and development, Standard bus like 6U, Secondary payload launches, Cubesat GS network

Disadvantages:- Restrictive orbits, mass/volume constraints, limited propulsion and ADCS



Cluster Design Approach

Build a Systems engineering (SE) model integrated with traditional BRDF Estimation models



*as a function of tech requirements, biomes of interest, science applications

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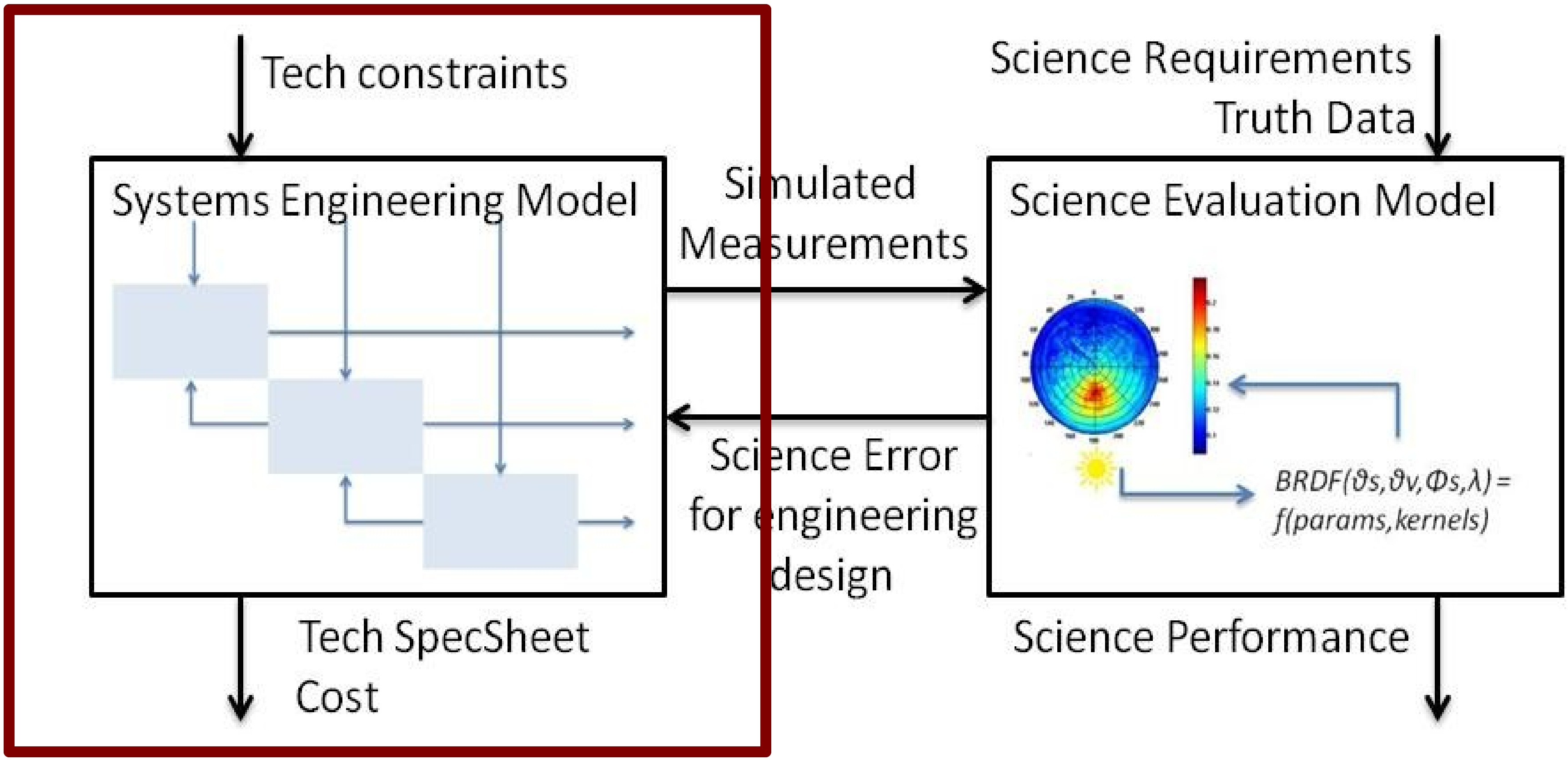

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Constellation vs. Formation Flight

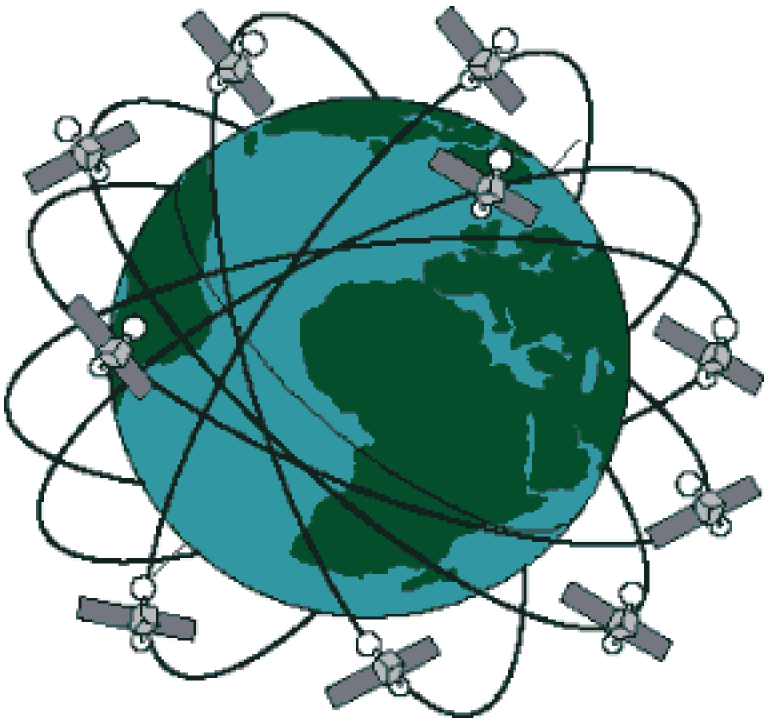

Image Credits: www.cienciaviva.pt

vs.

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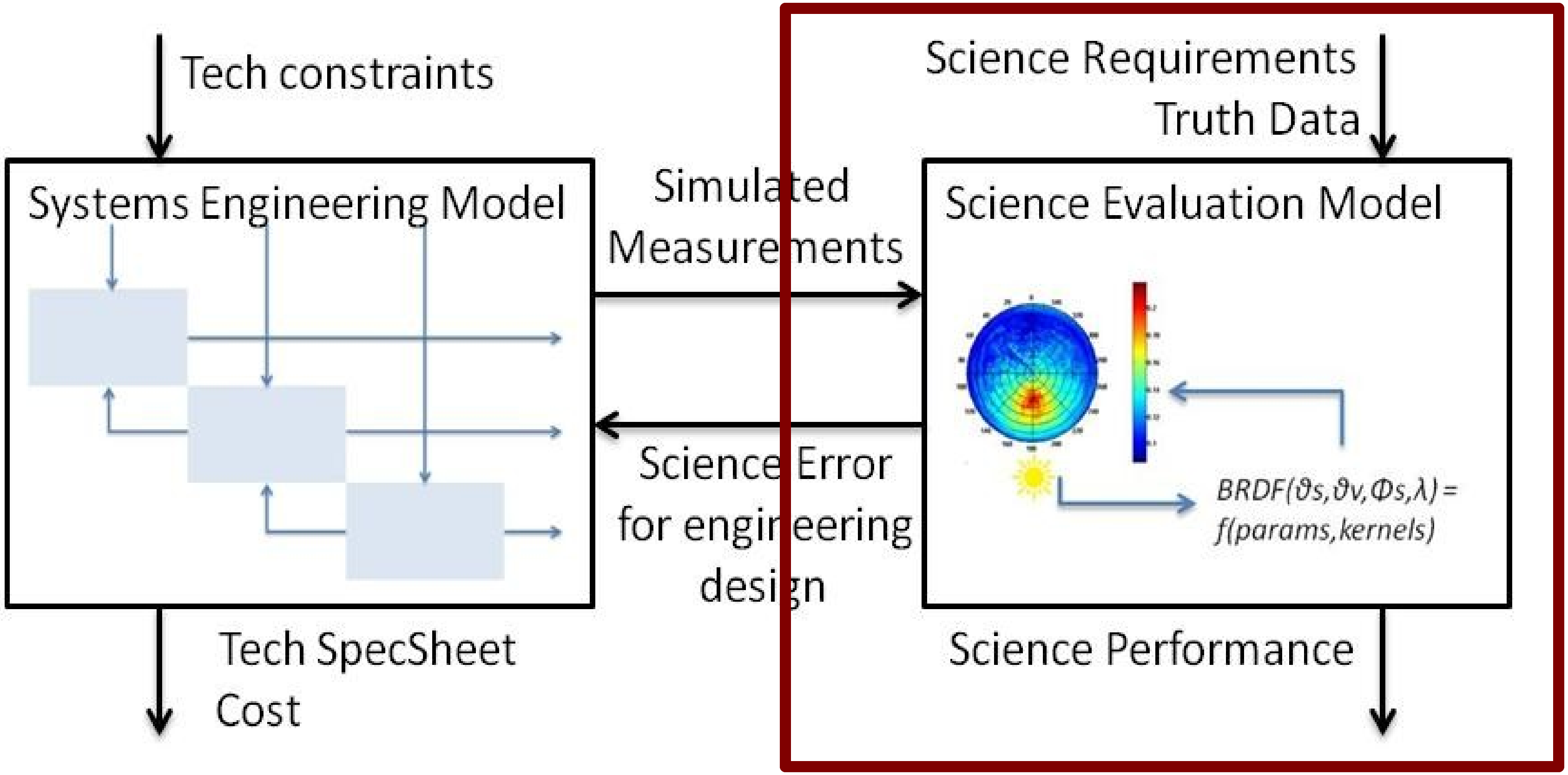

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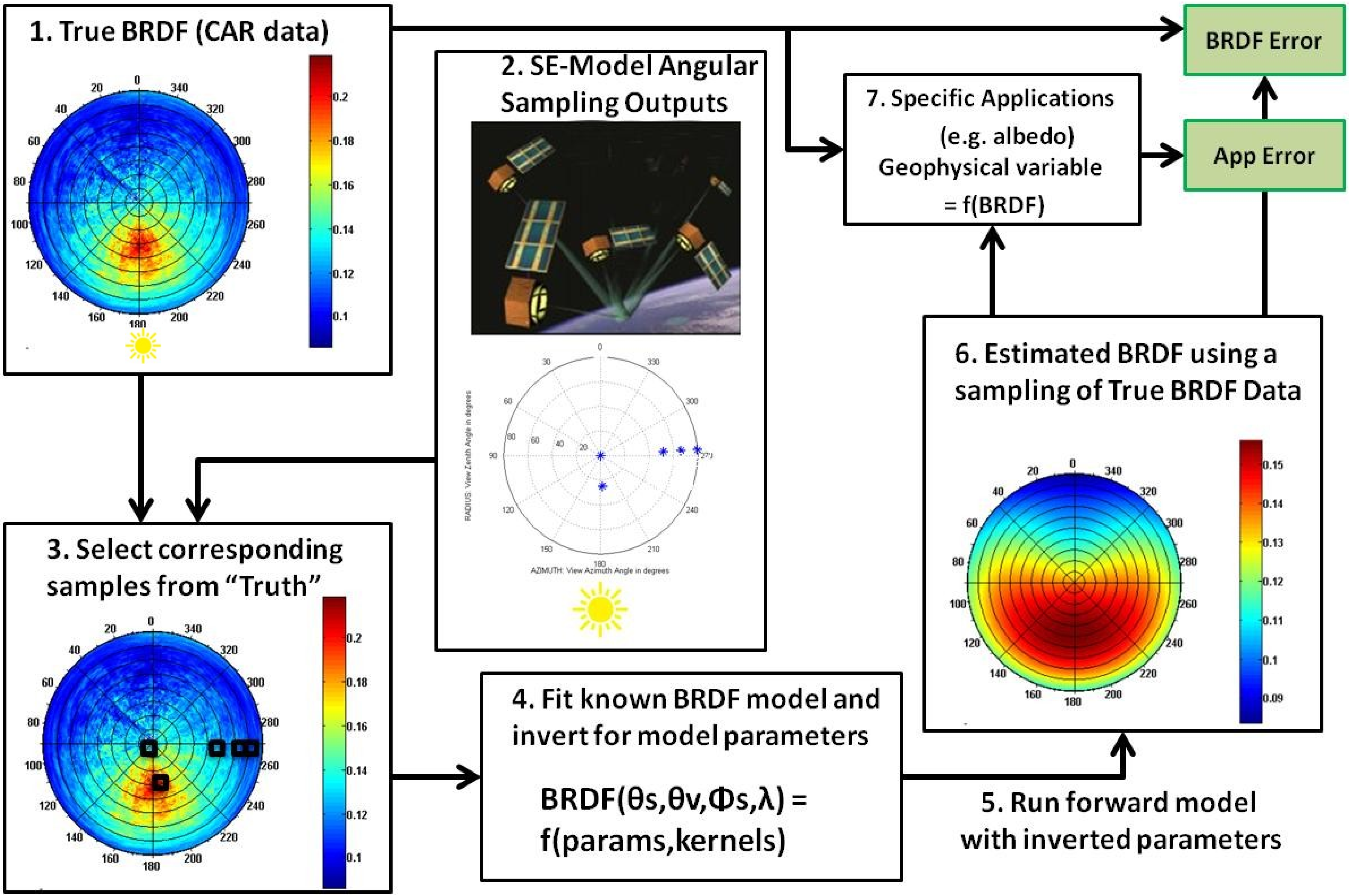
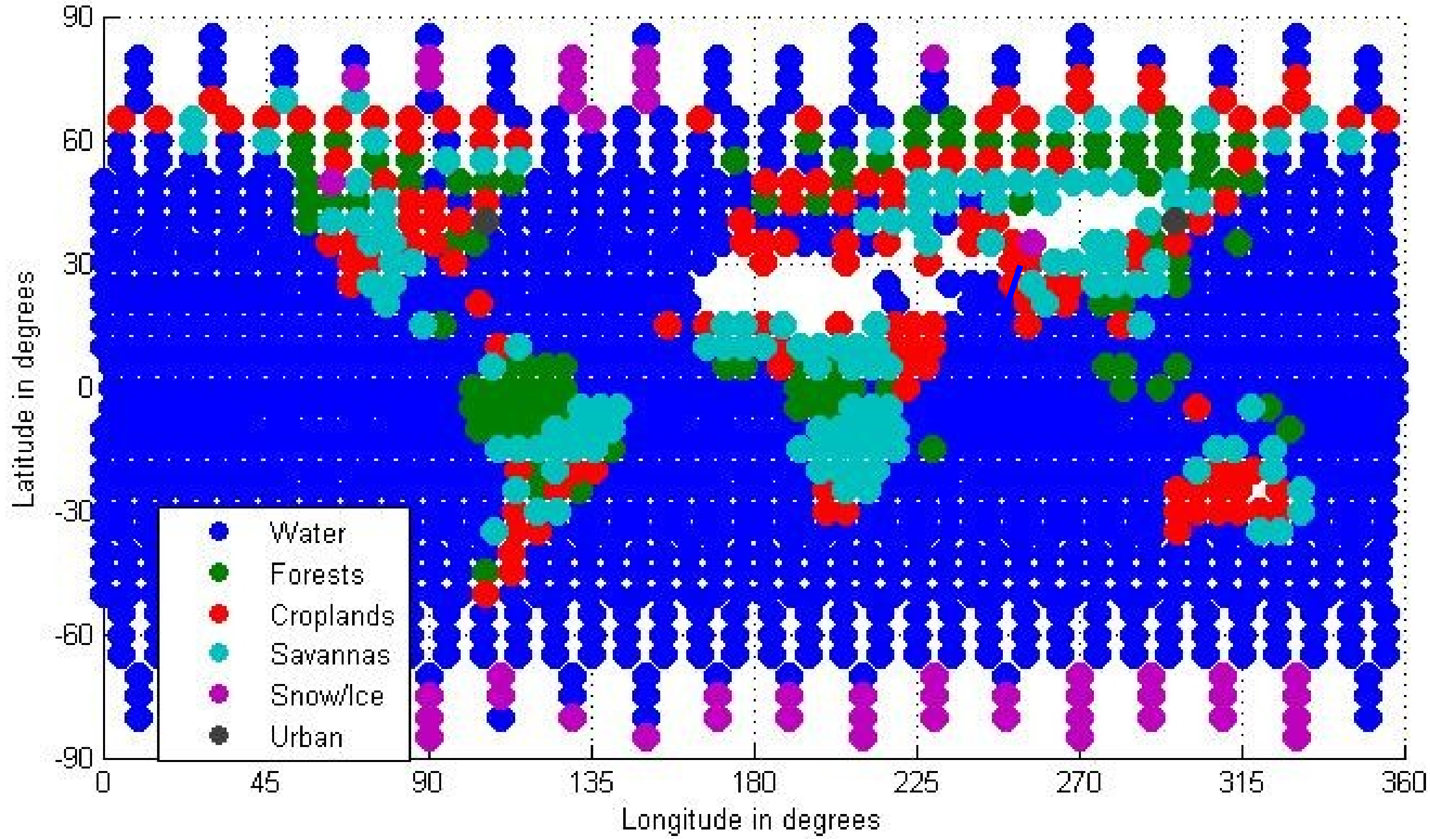
Science Evaluation



Setting up the “Truth”

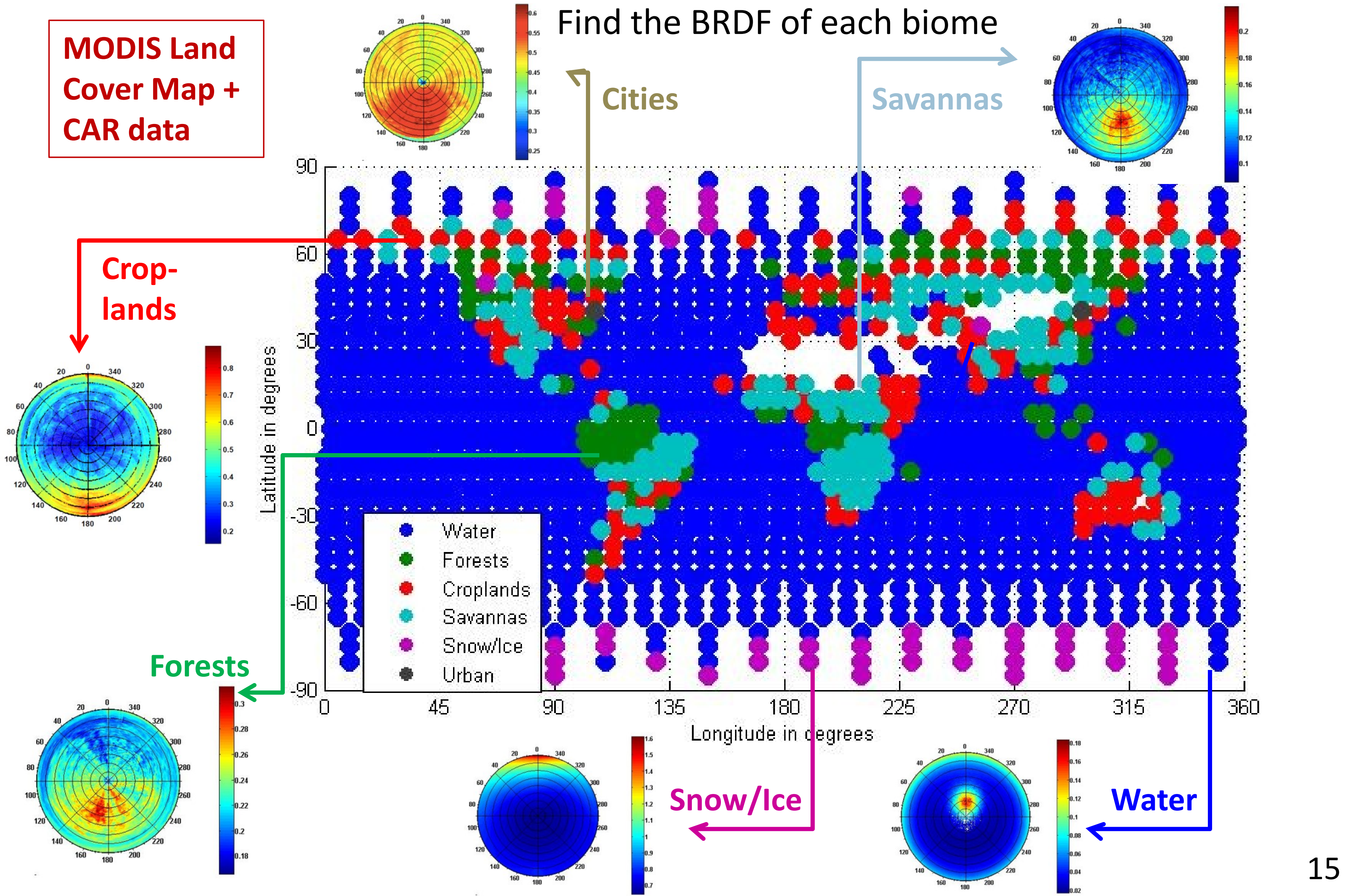
MODIS Land Cover Map:

Find the global biome distribution
Because local & static BRDF data is available per biome



Setting up the “Truth”

MODIS Land Cover Map + CAR data



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Formation Flight – Orbit Config

Simplest case considered – 4 satellites, no propulsion but +/- 50deg of sensor slew, ISS inclination of 51.6 deg, 650 km.

Biome considered – Savanna vegetation considered for the baseline. Will be expanded to snow and others.

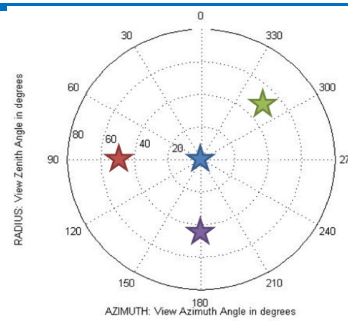
Differential Keplerian variables	
Semi Major Axis	No
Inclination	No
Arg. Of Perigee	No
Eccentricity	No
RAAN	Yes
True Anomaly	Yes

Effect of configurations (few architectures) and modes will be shown. Mode #1 is the baseline mode.

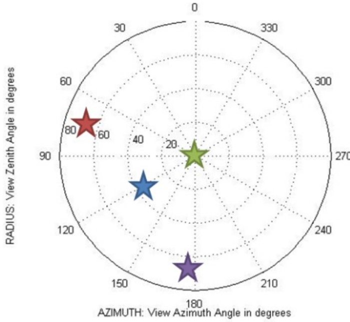
RAAN::TA of the following satellites in degrees				
	Sat #1	**Sat #2**	**Sat #3**	**Sat #4**
Config #1	0::0	0::-5	-5::-1	-5::-6
Config #2	0::0	0::-5	-5::-1	5::-4
Config #3	0::0	0::-5	-5::-6	5::-4
Config #4	0::0	0::-5	-5::-3	5::-4
Config #5	0::0	0::-5	-5::-3	3::-3
Config #6	0::0	0::-3	-3::0	-3::-3

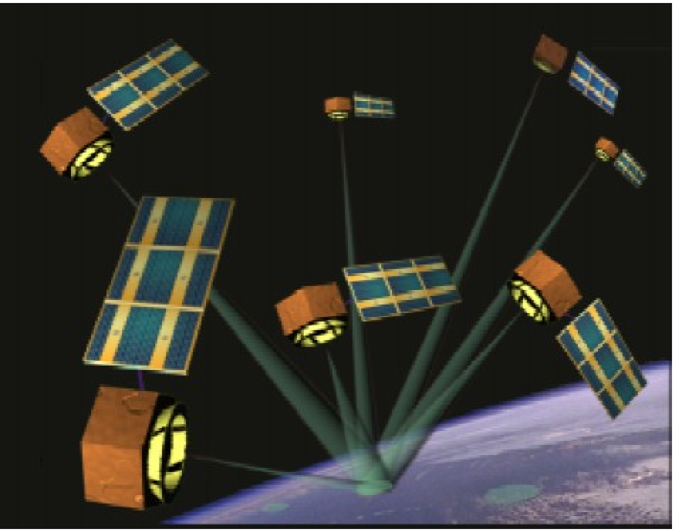
Formation Flight – Imaging Modes

MODE #1 – Same reference satellite
One satellite in the cluster is the designated leader and always points nadir. Other sats point to the ground spot directly nadir to the leader satellite.

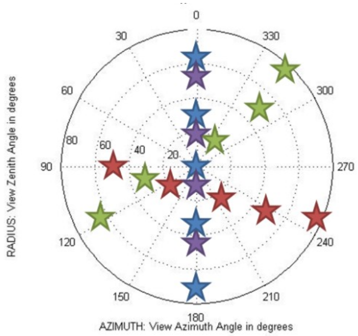


MODE #2 – Change the reference satellite over the orbit
Like Mode #1 but the leader satellite changes over the course of the orbit so as to optimize the angular coverage of the BRDF plane.





MODE #3 – Tracking/Staring at a Spot
All satellites such that they point to the same ground target/s as they approach over the horizon and recede into the horizon.



MODE #4 – Multiple Payloads
Each follows a different mode among the above or fractionate functionality.

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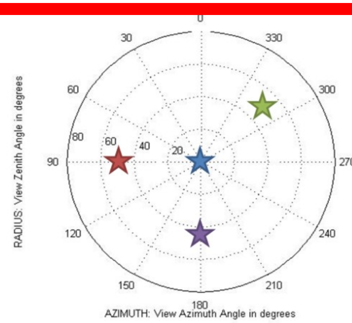

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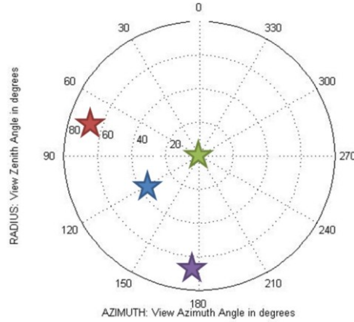

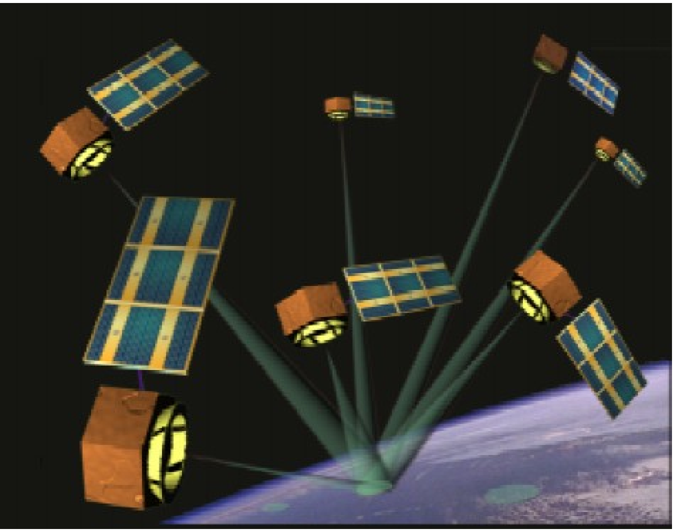

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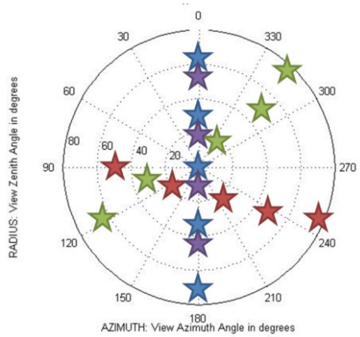

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Albedo Errors by Configuration

Compared 6 diff. TA+RAAN orbits wrt CAR data (682 nm) from South Africa assuming same biome over a 20 minute pass over African Peninsula.

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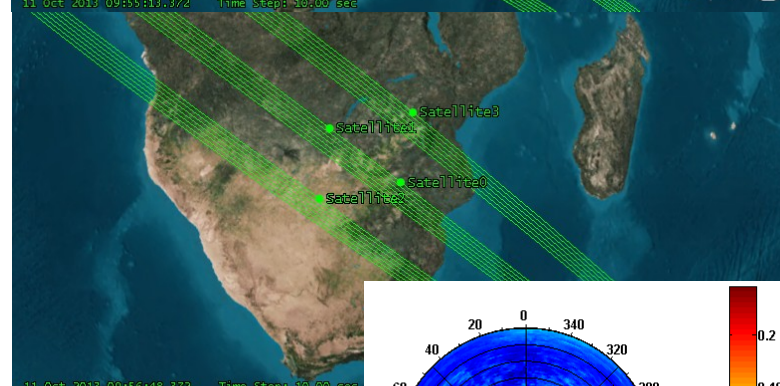

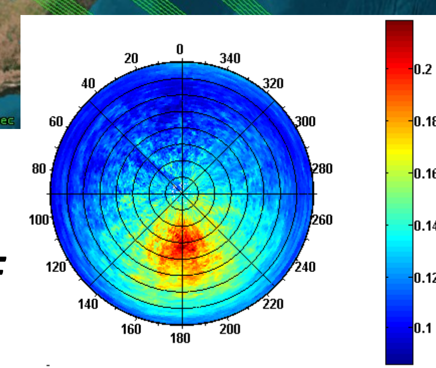

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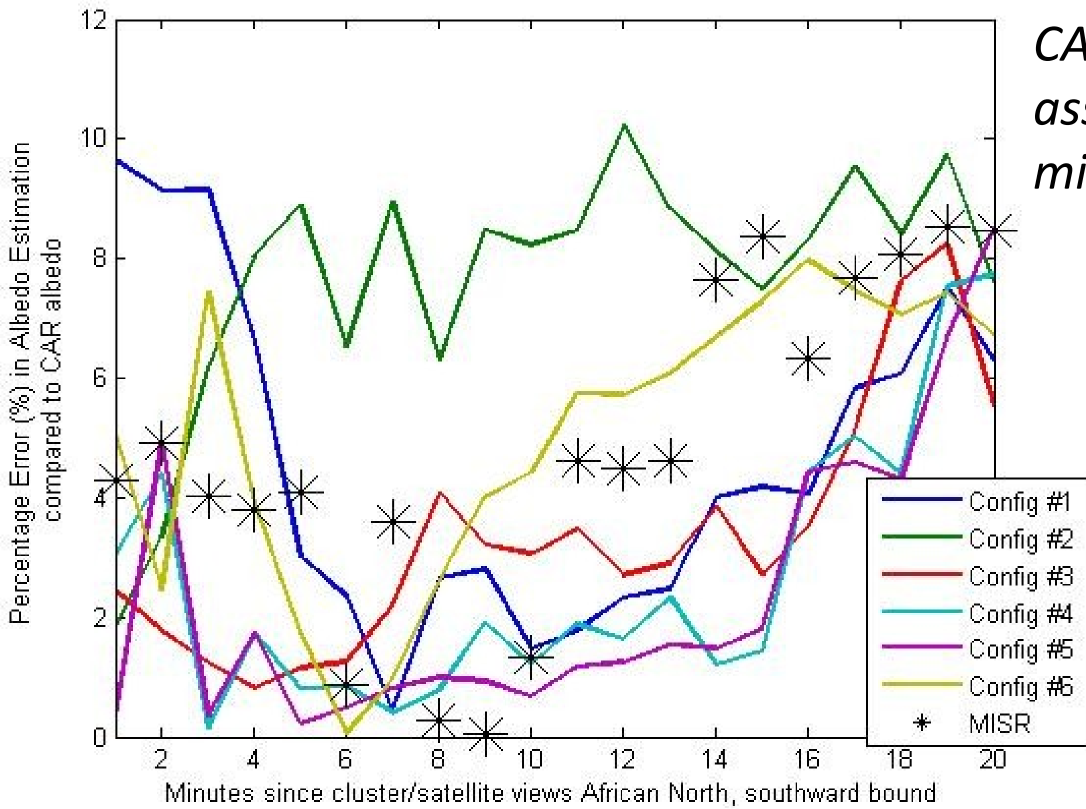

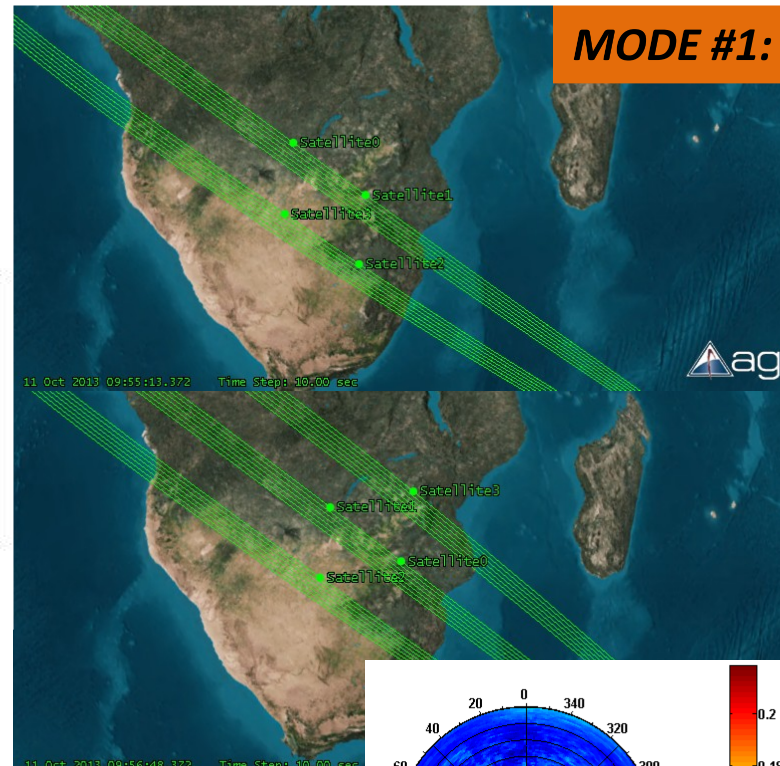

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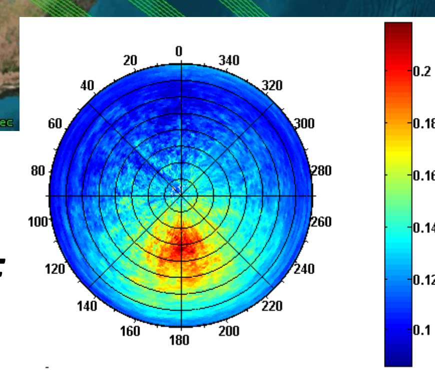

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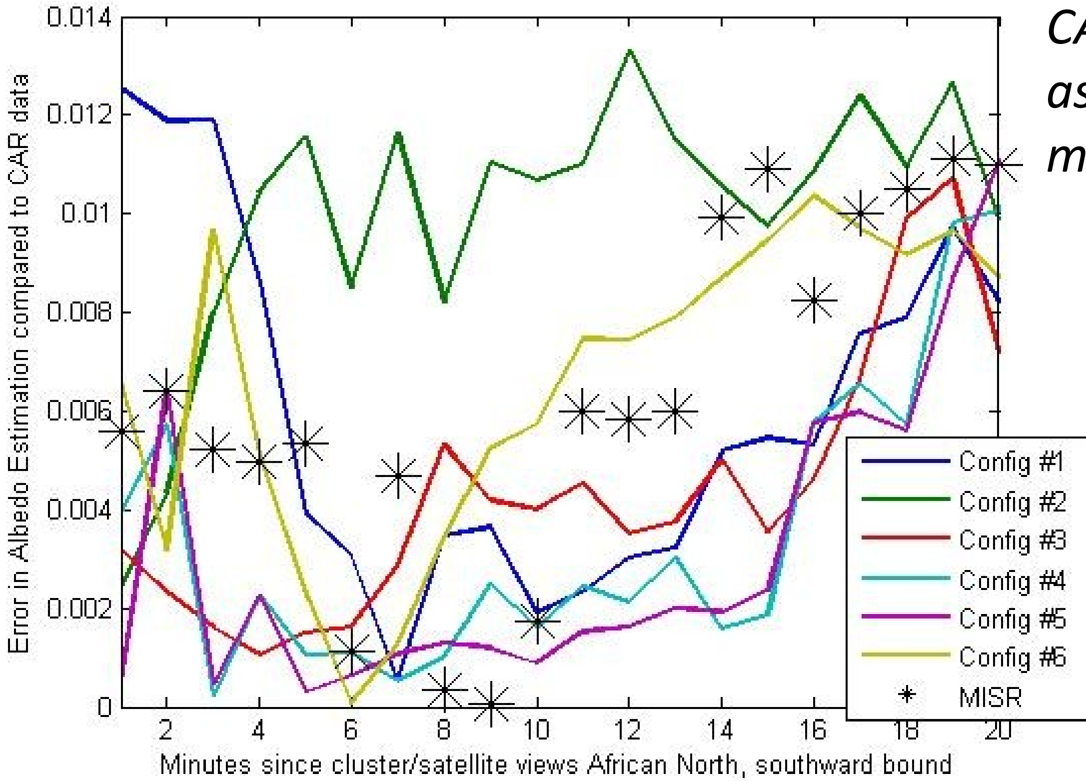

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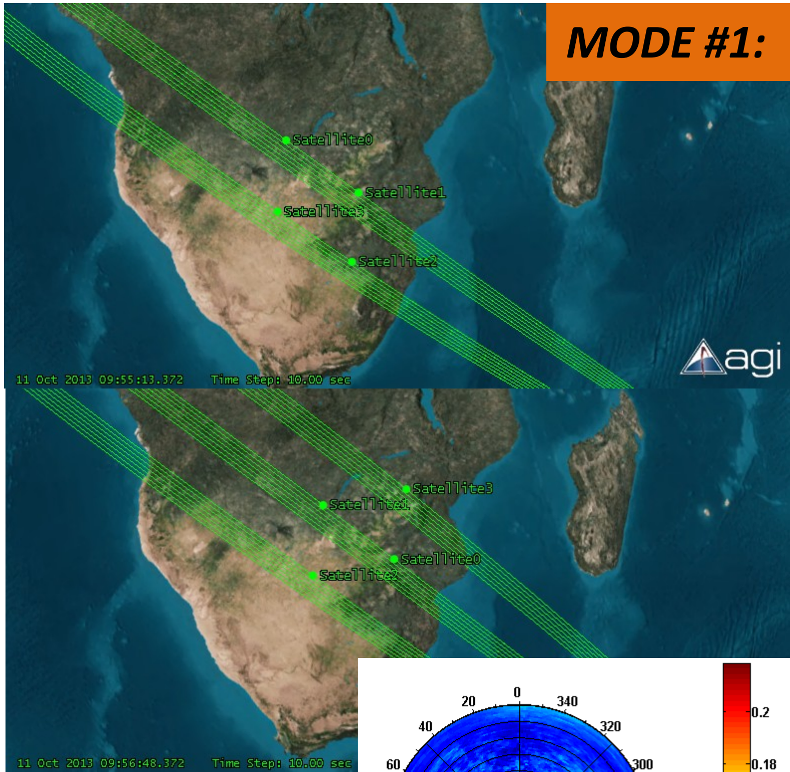

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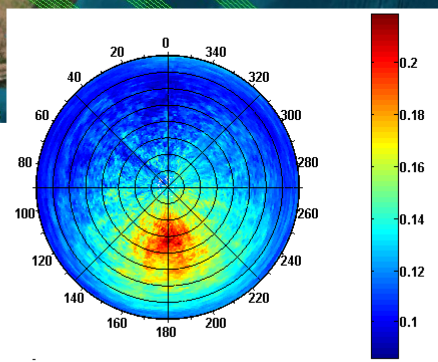

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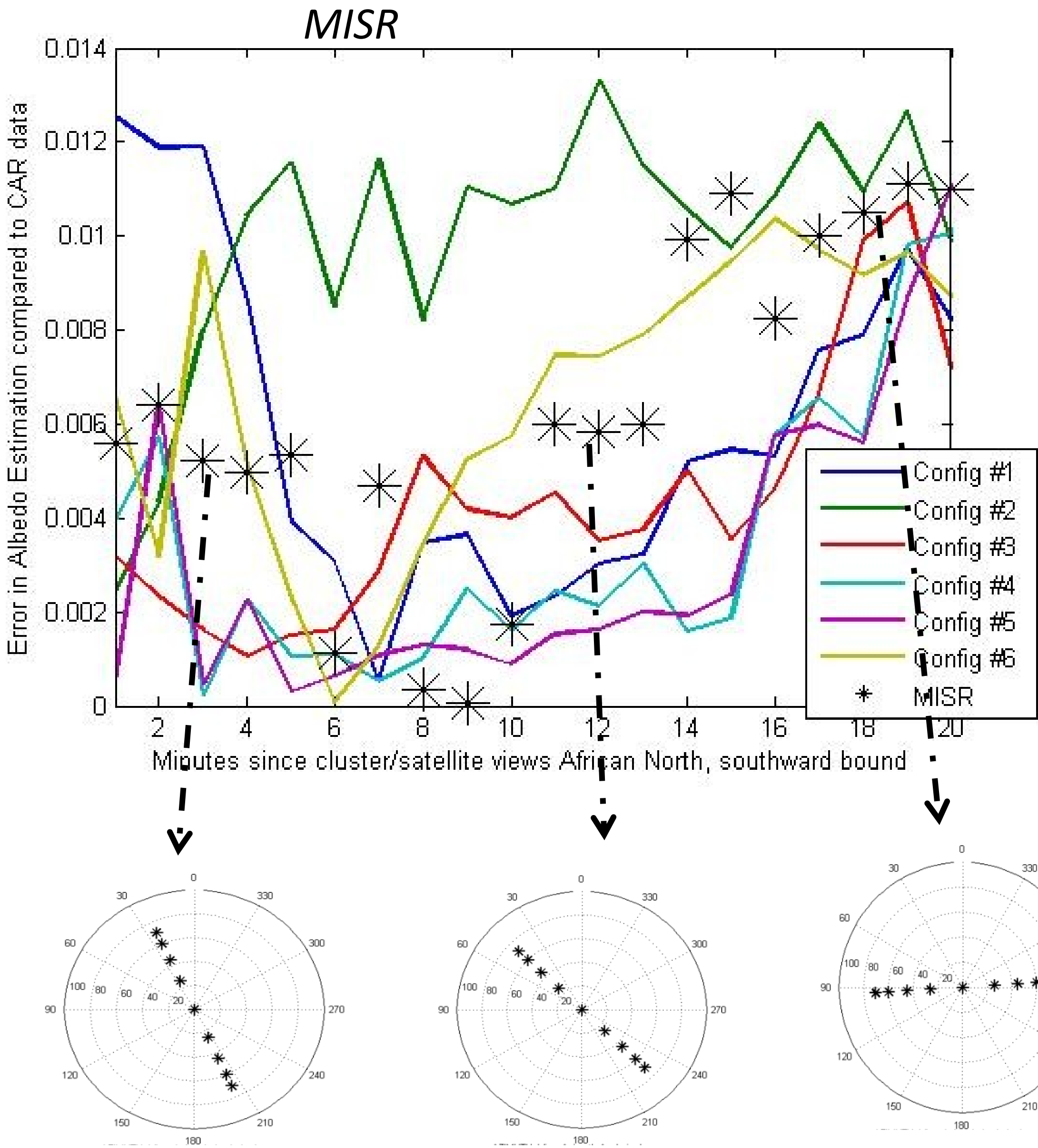

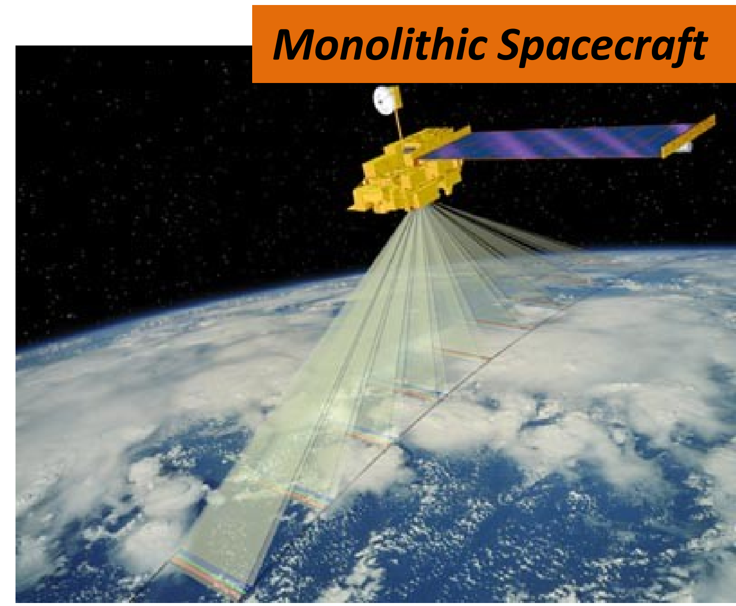

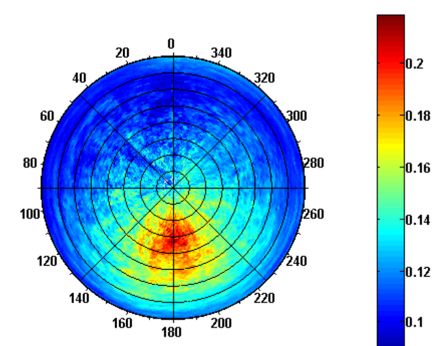

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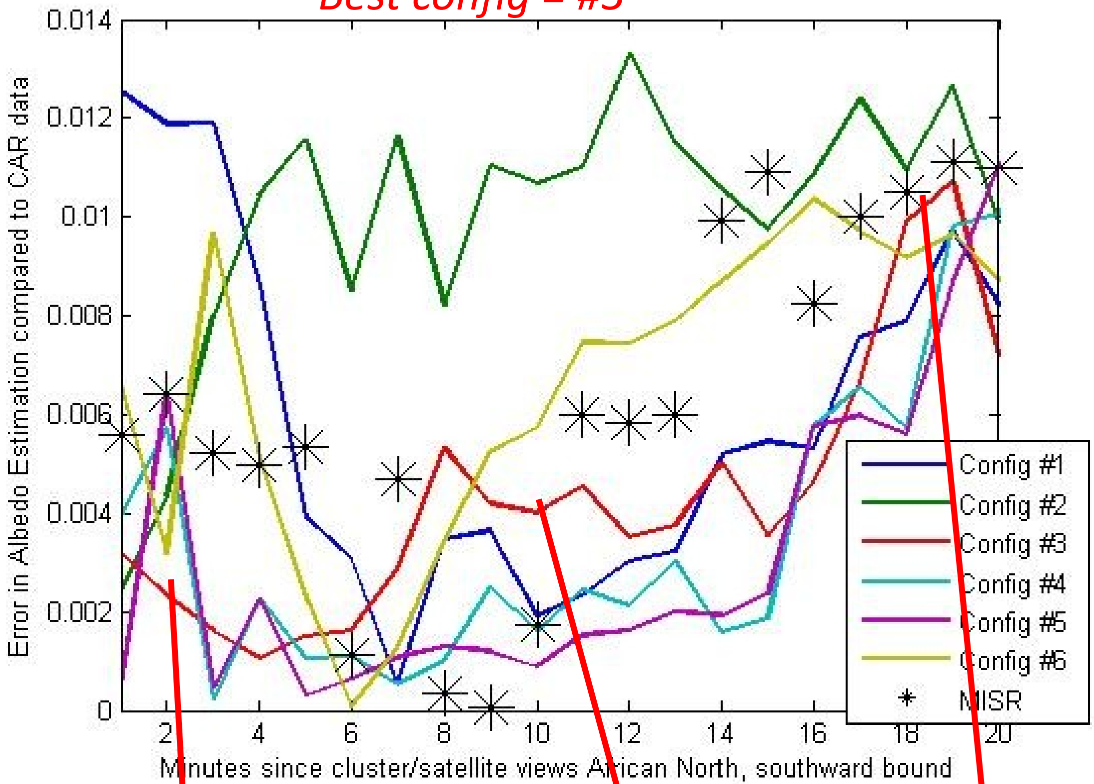
Best config = #3



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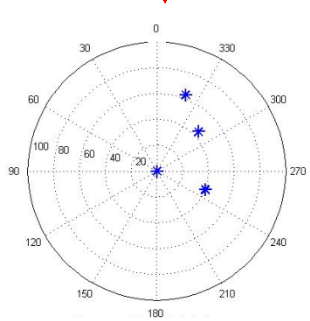

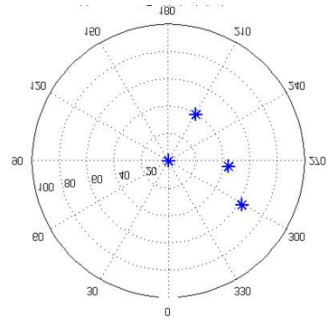

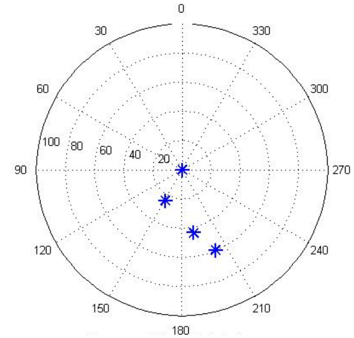

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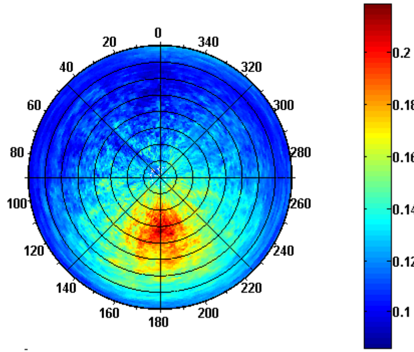

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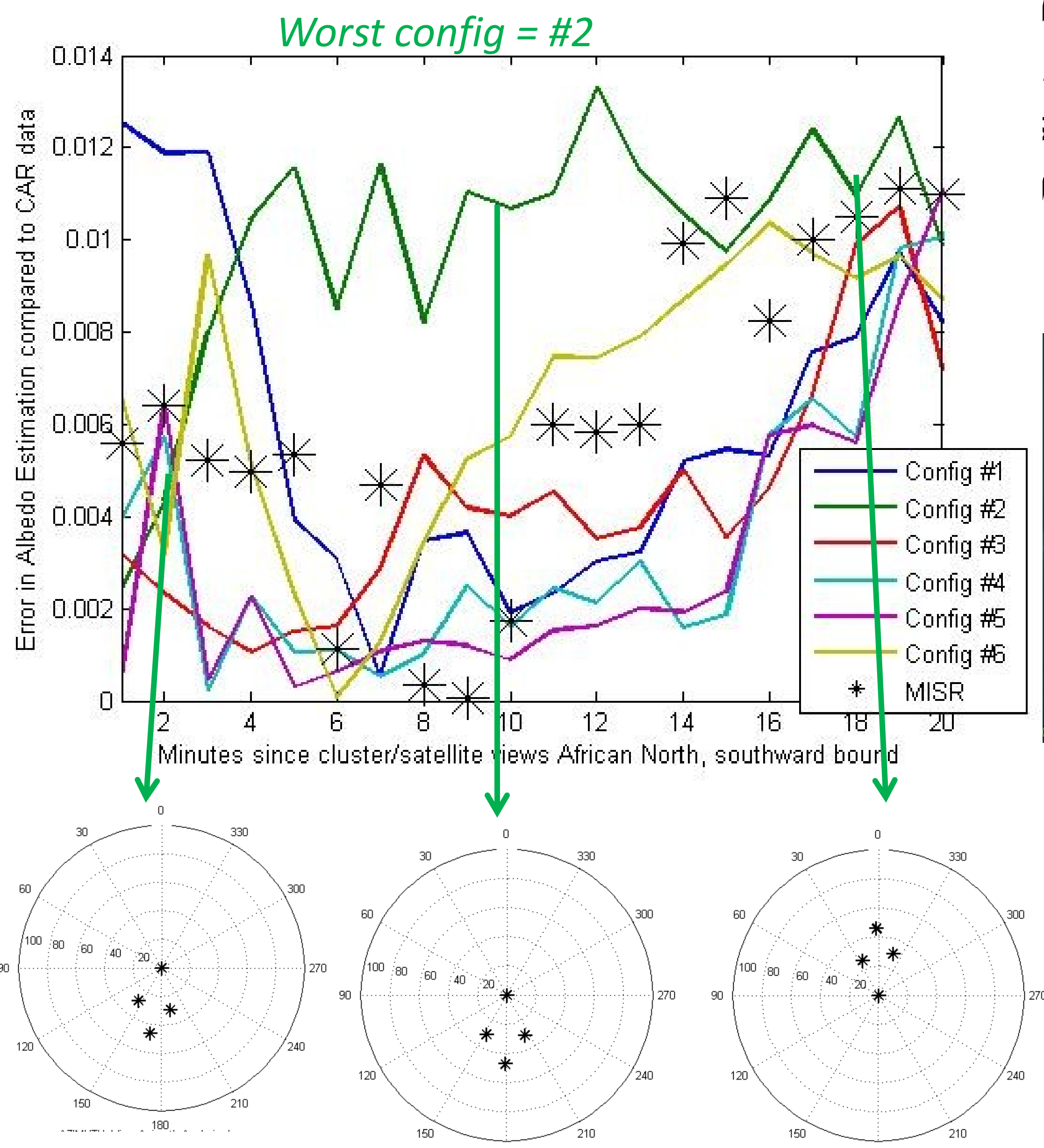

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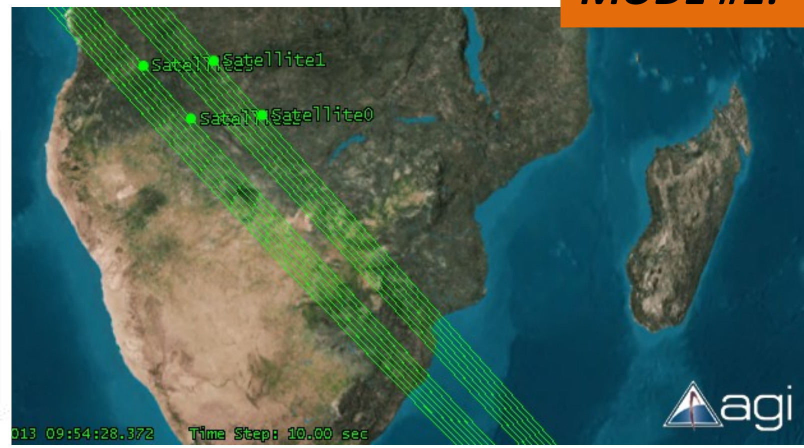

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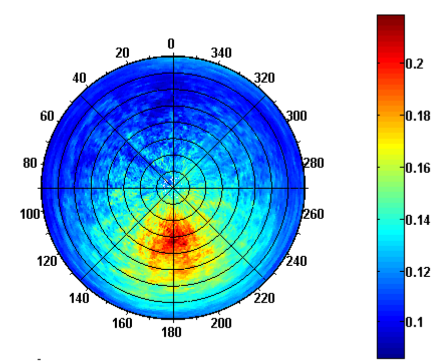

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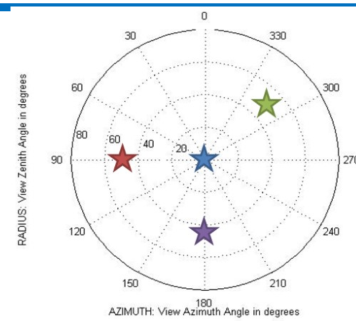
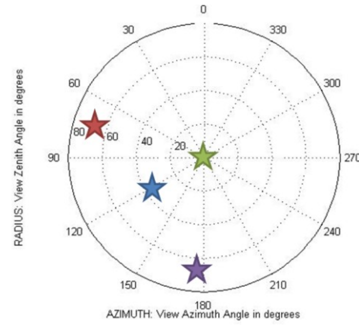
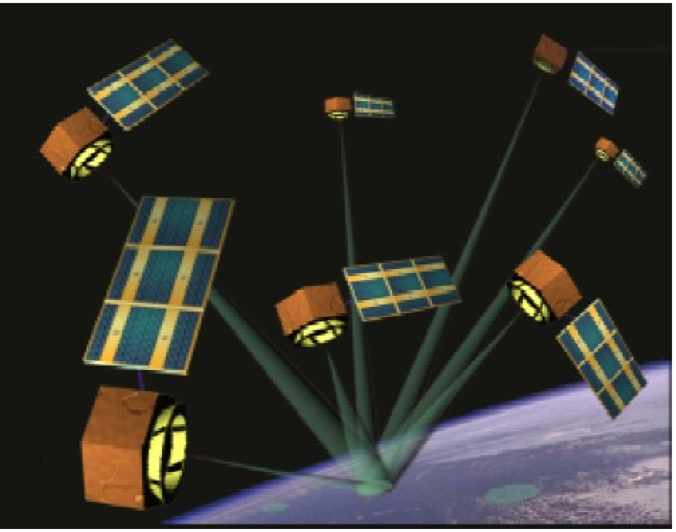
MODE #1 – Same reference satellite
Needs differential elements that are impossible to maintain with smallsat technologies to cover both hemispheres at all times (e.g. diff. inclination, diff. eccentricity)

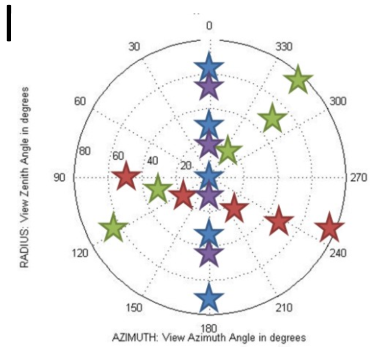


MODE #2 – Change the reference satellite over the orbit
An appropriately selected ref. satellite *allows both angular hemispheres to be covered using maintainable diff. elements*. Satellites drift apart over a year even in true anomaly.. This mode helps upto ~6 months.





MODE #3 – Tracking/Staring at a Spot
More angular coverage and lesser local errors at the cost of spatial coverage.
Polar + high latitude coverage only possible with this mode.
Allows *mission continuity* beyond 6 months in spite of drifting satellites.



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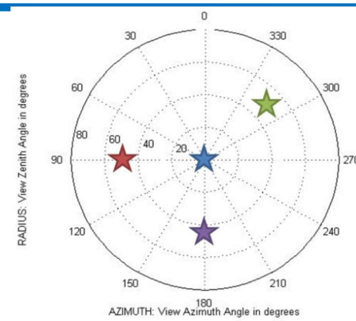

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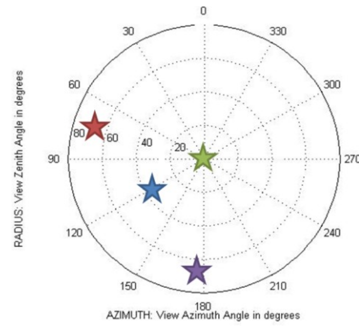

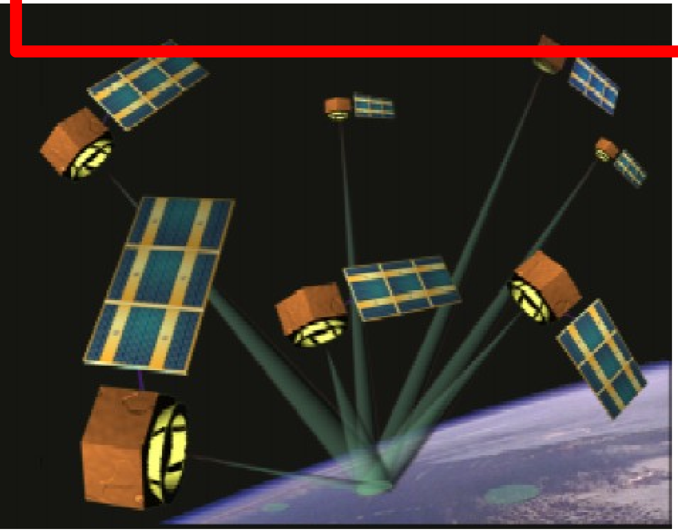

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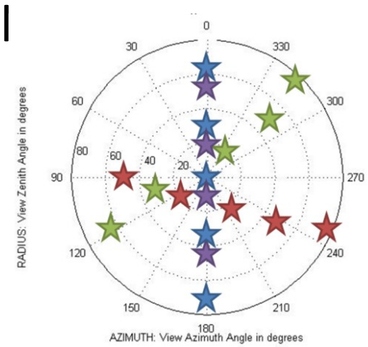
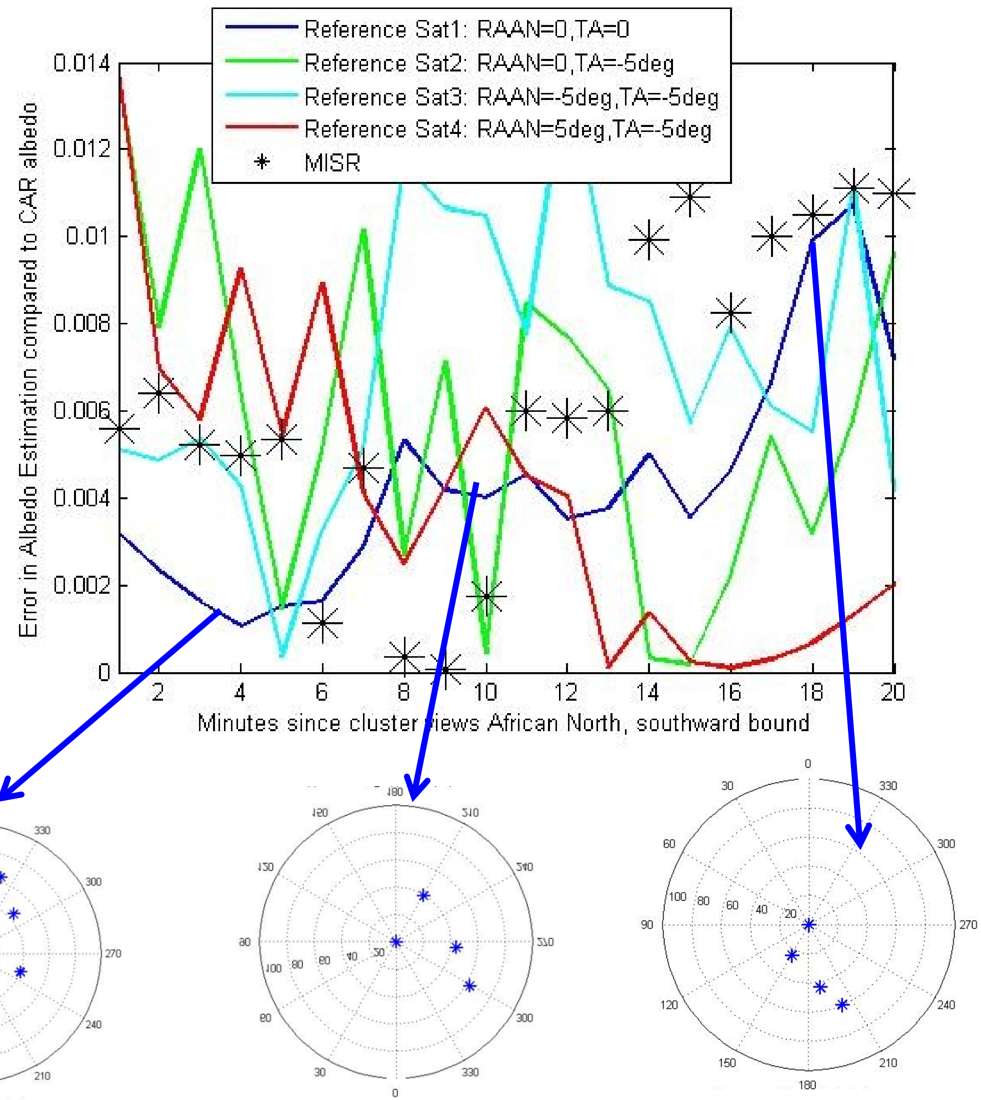


Albedo Errors by Reference Sat

For the best configuration (#3), analyzed errors using different sats as reference.

By changing the ref sat once in 20 mins, we can outdo monoliths.



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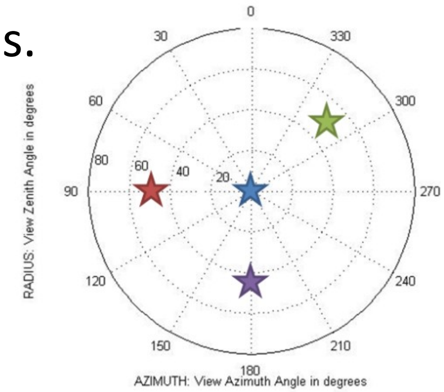

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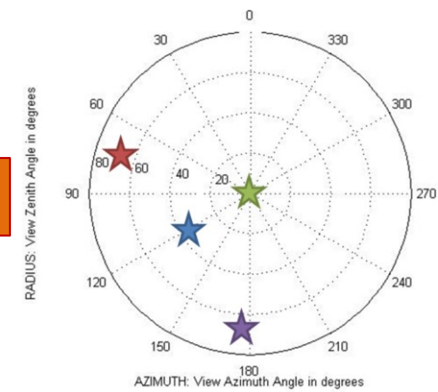
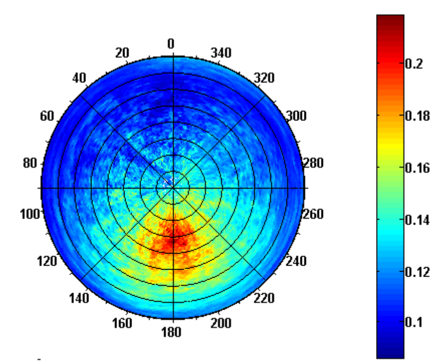


True BRDF from CAR:



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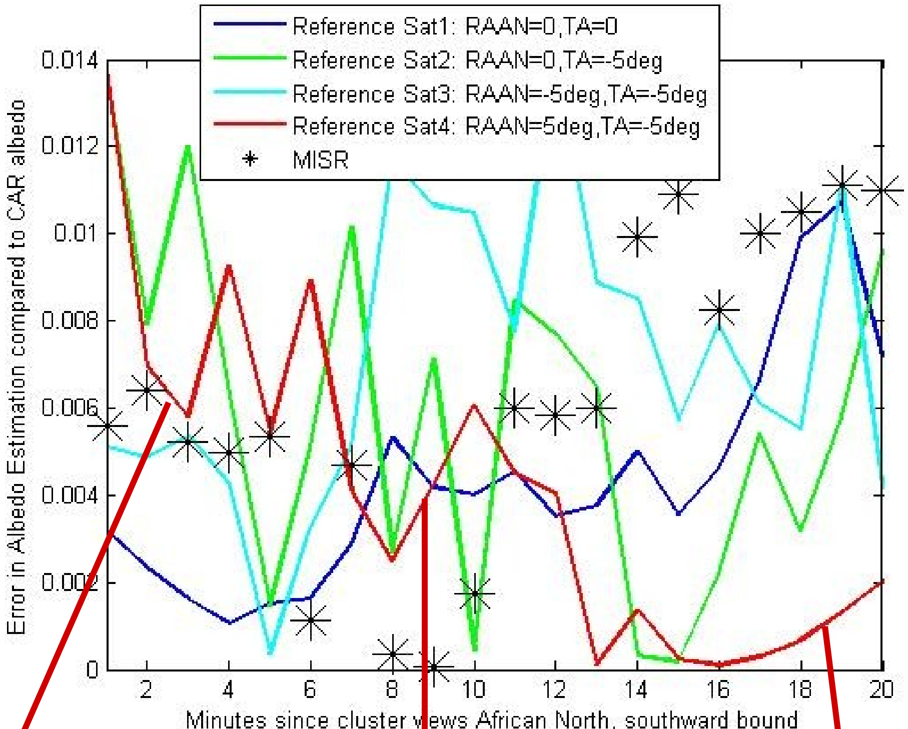

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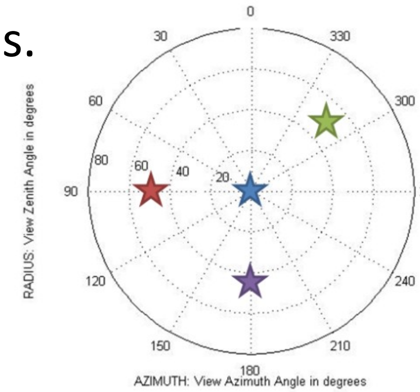

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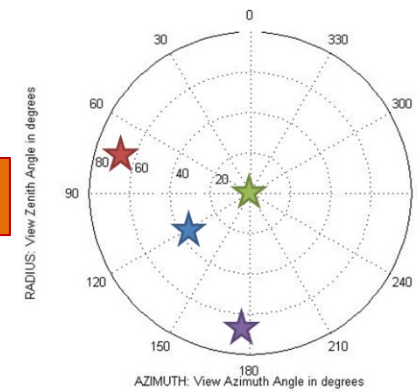

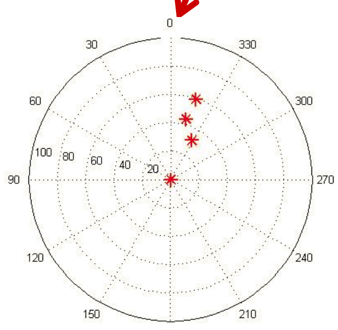

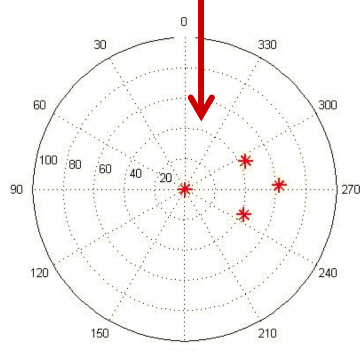

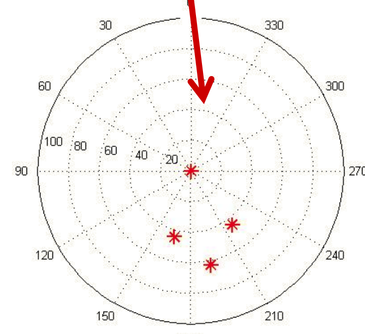

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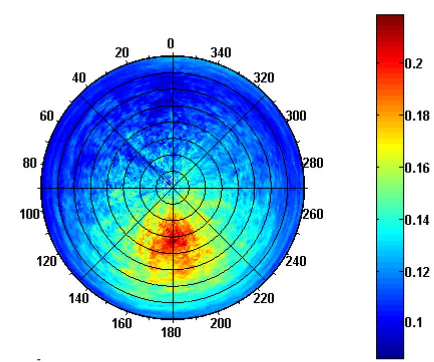

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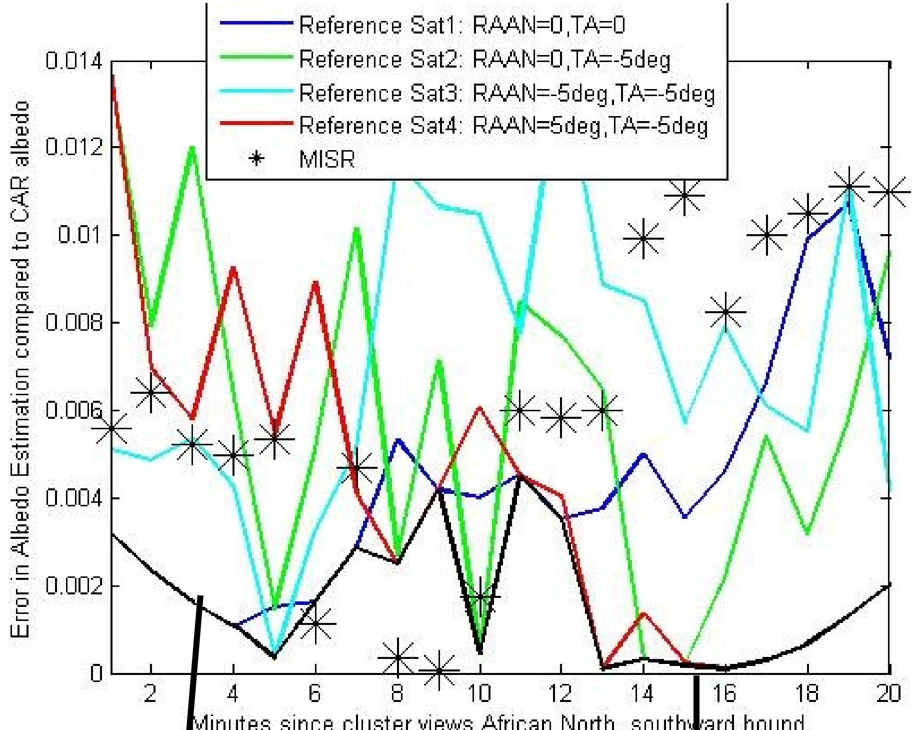

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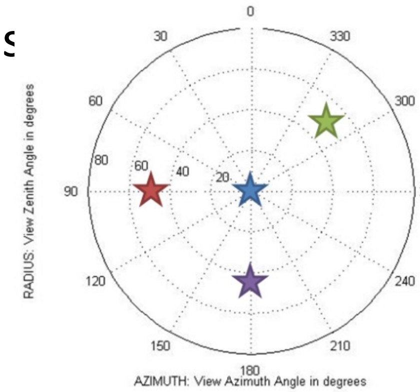

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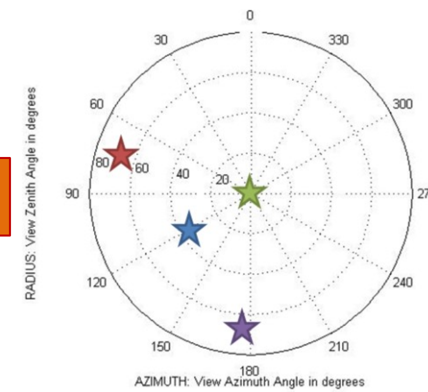
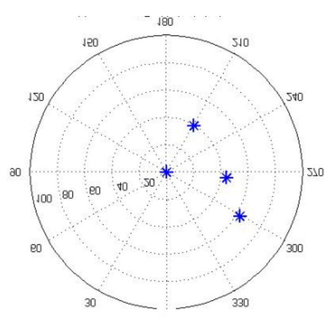
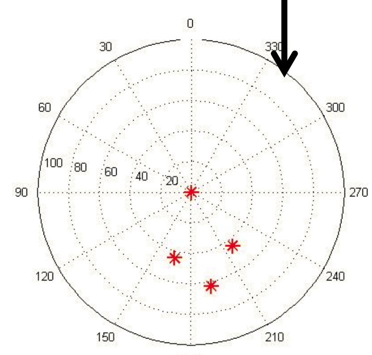


Minimum Estimation Error:





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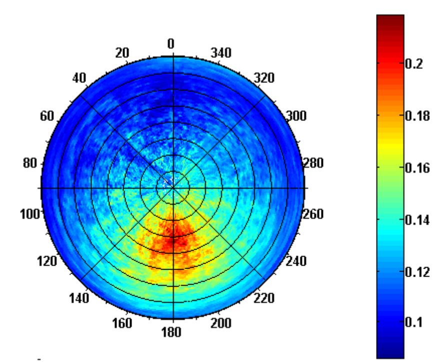

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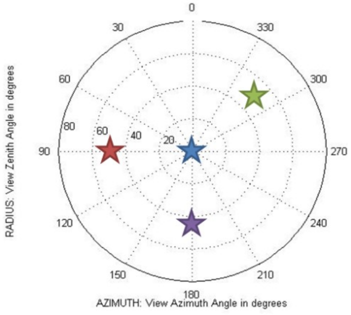

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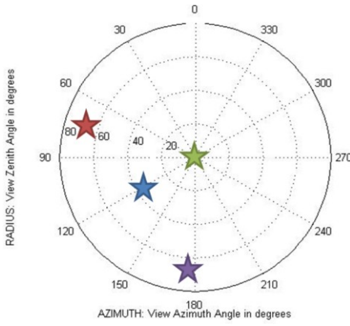

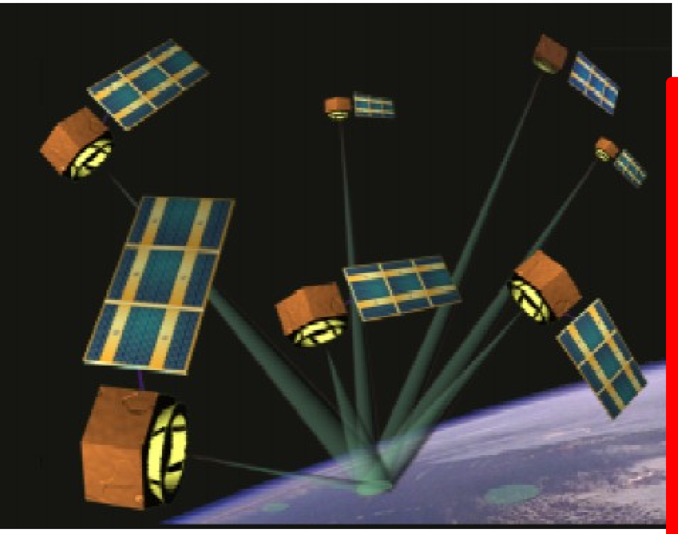

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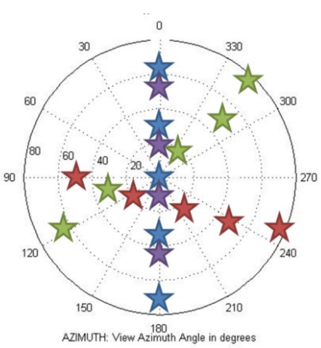

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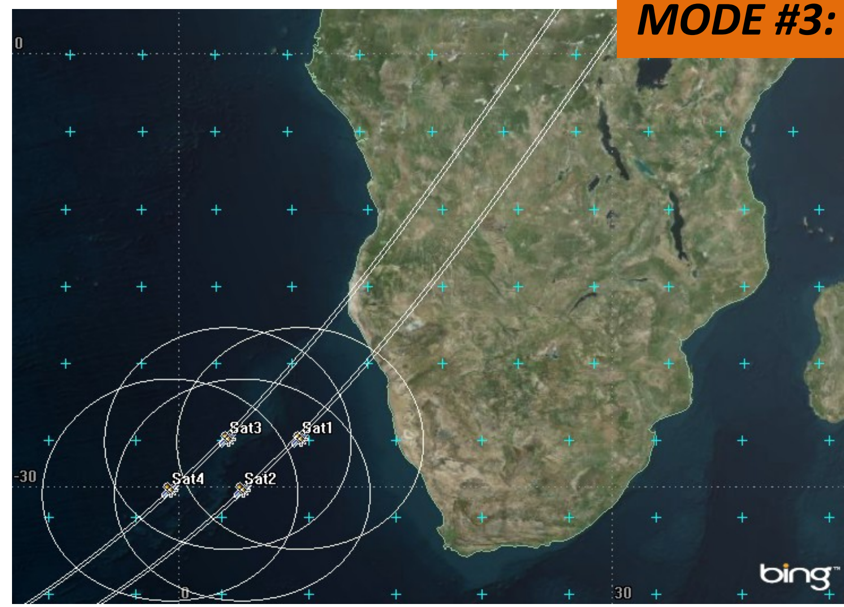

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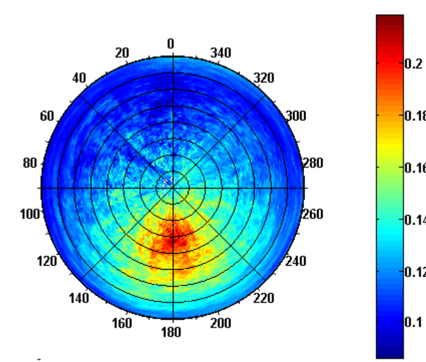

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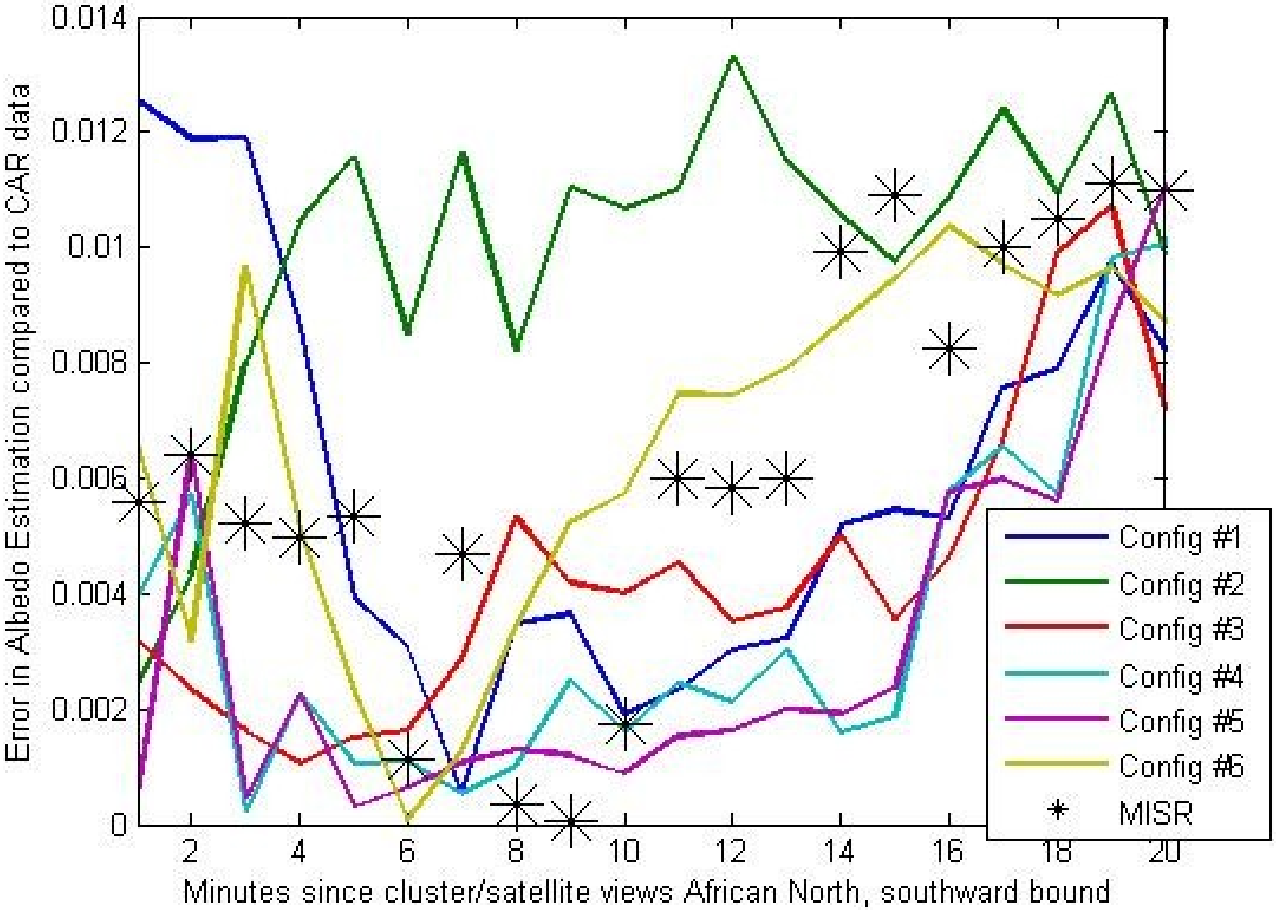
RECAP -

Config #1 : Mode #1 Worst but Improved by Mode#2

Config #2 : Mode #1 Worse, NOT improved by Mode #2

Config #3 : Best for Mode#1 and Mode#2



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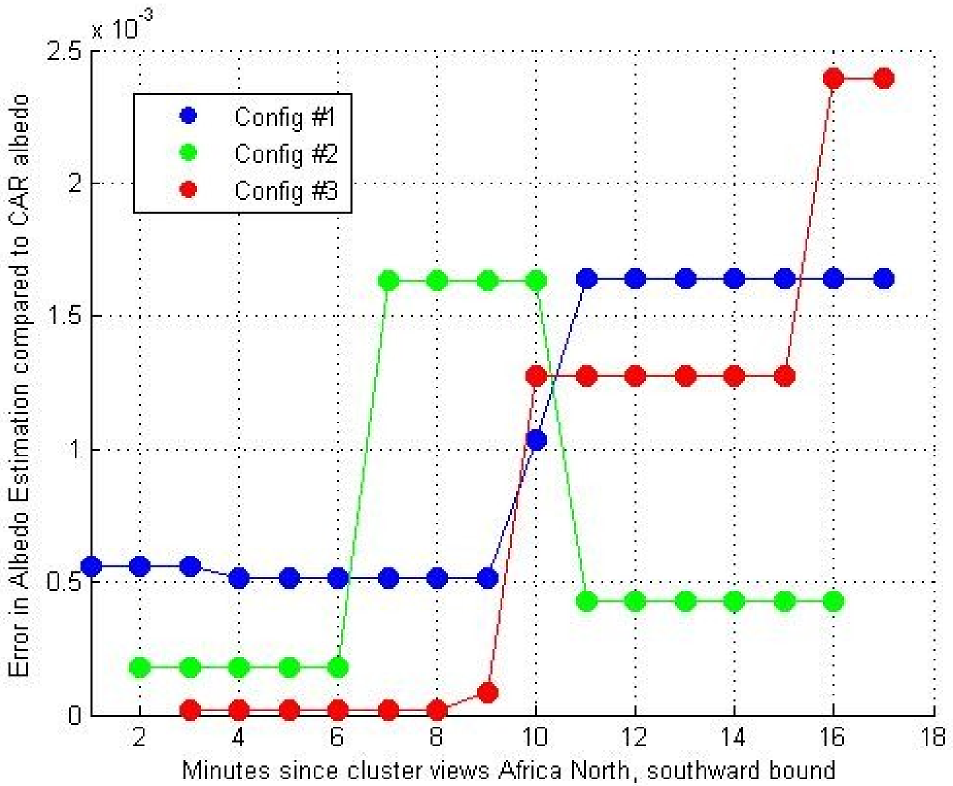

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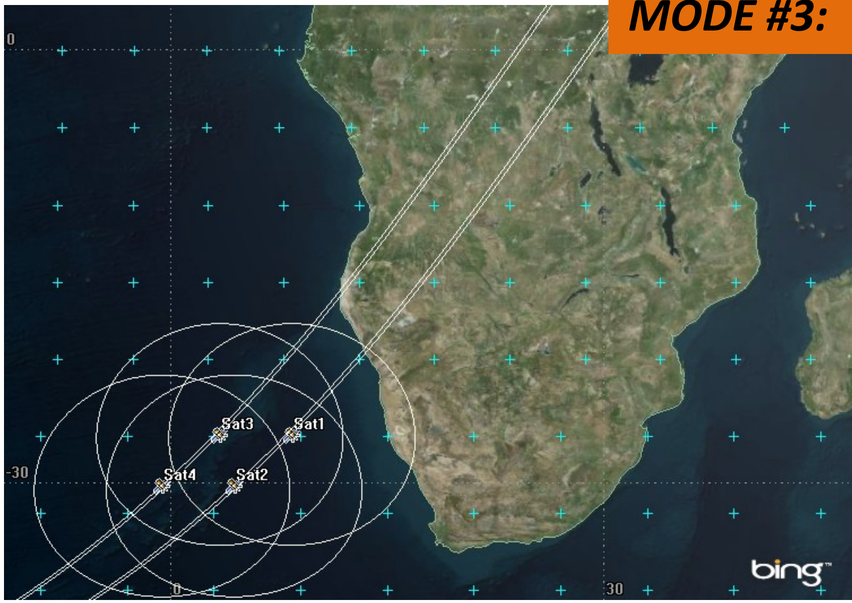

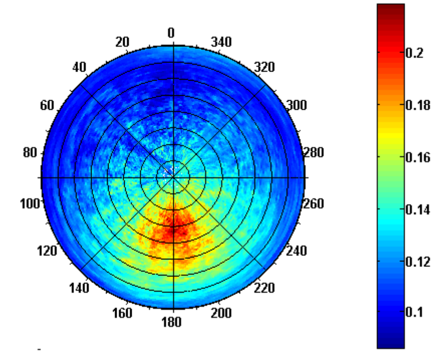

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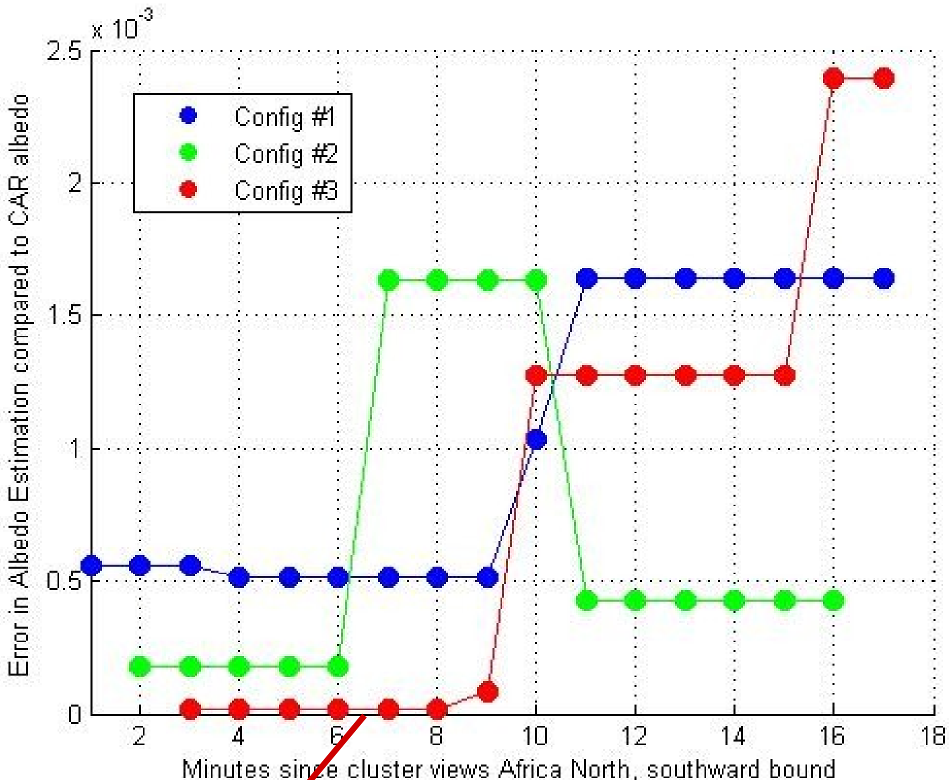

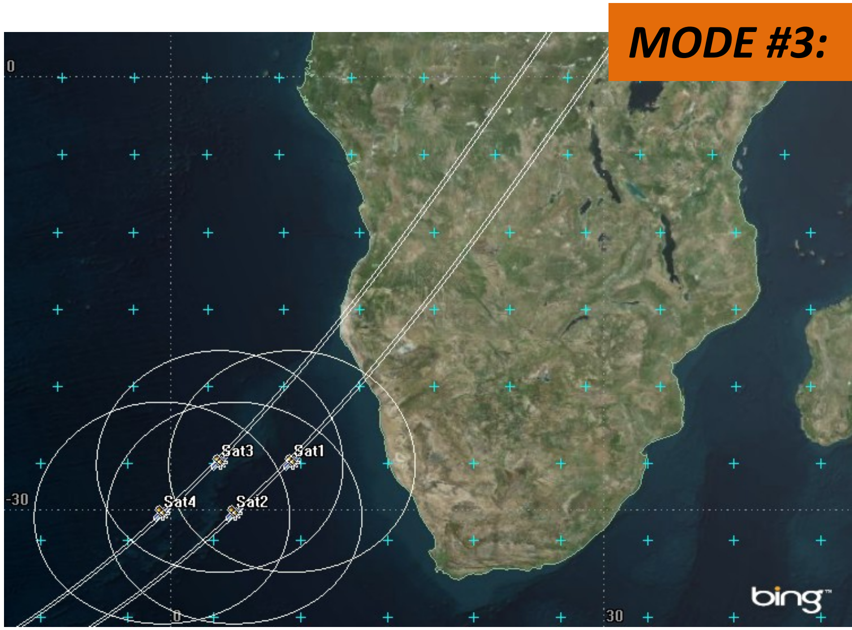

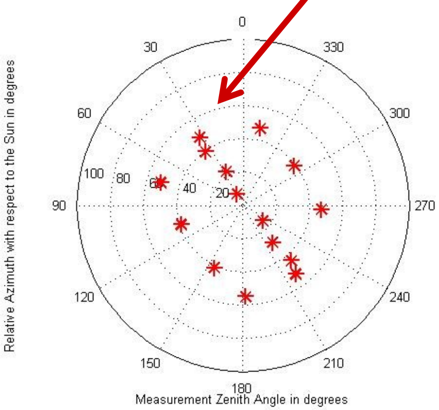

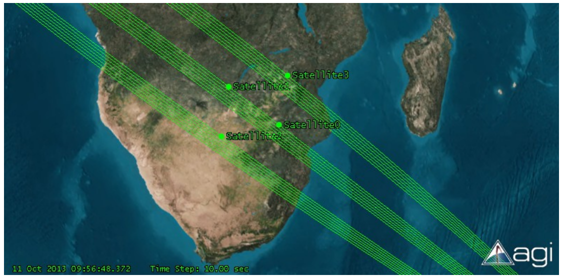

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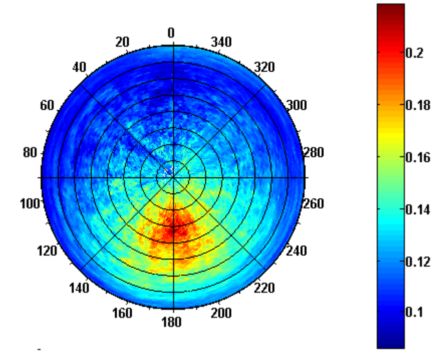

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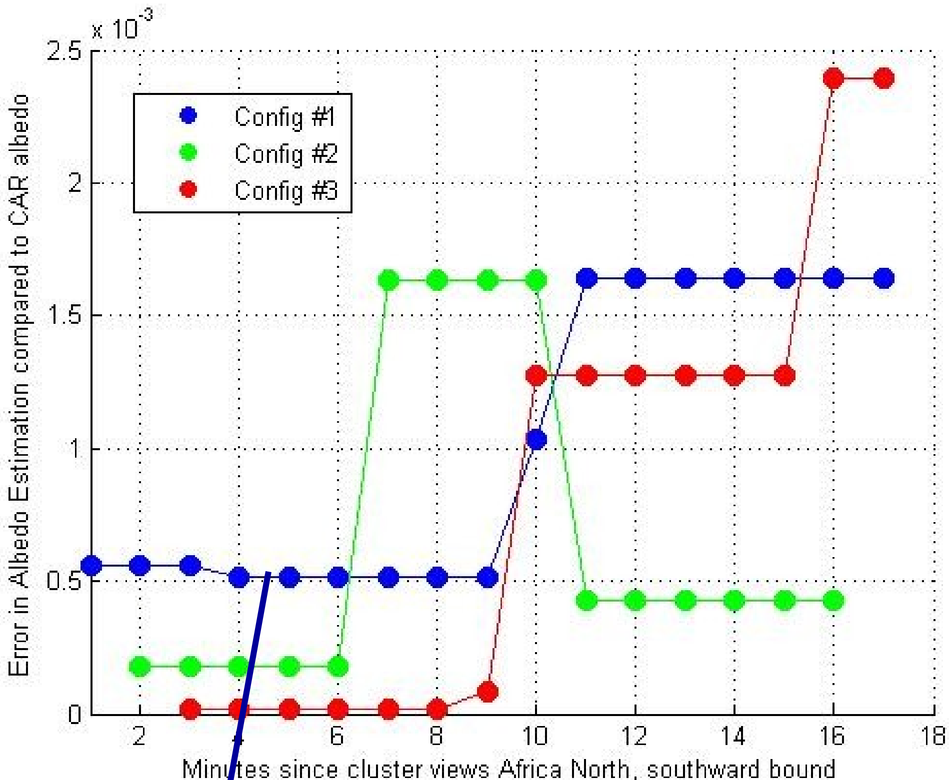

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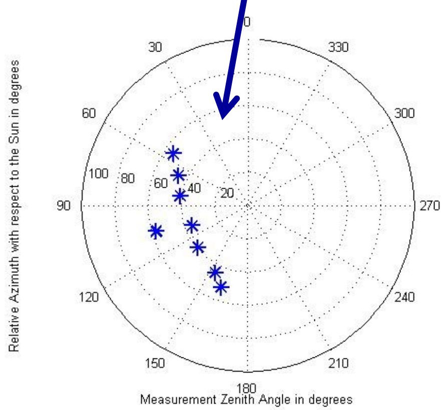

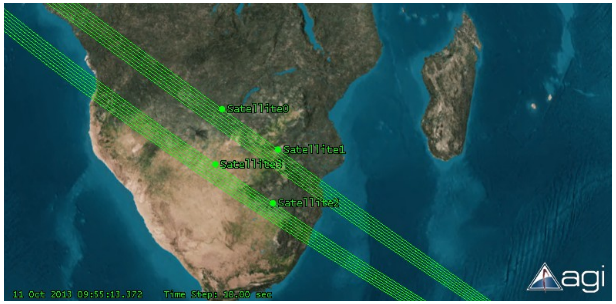

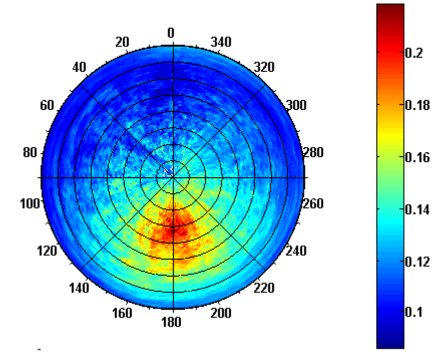

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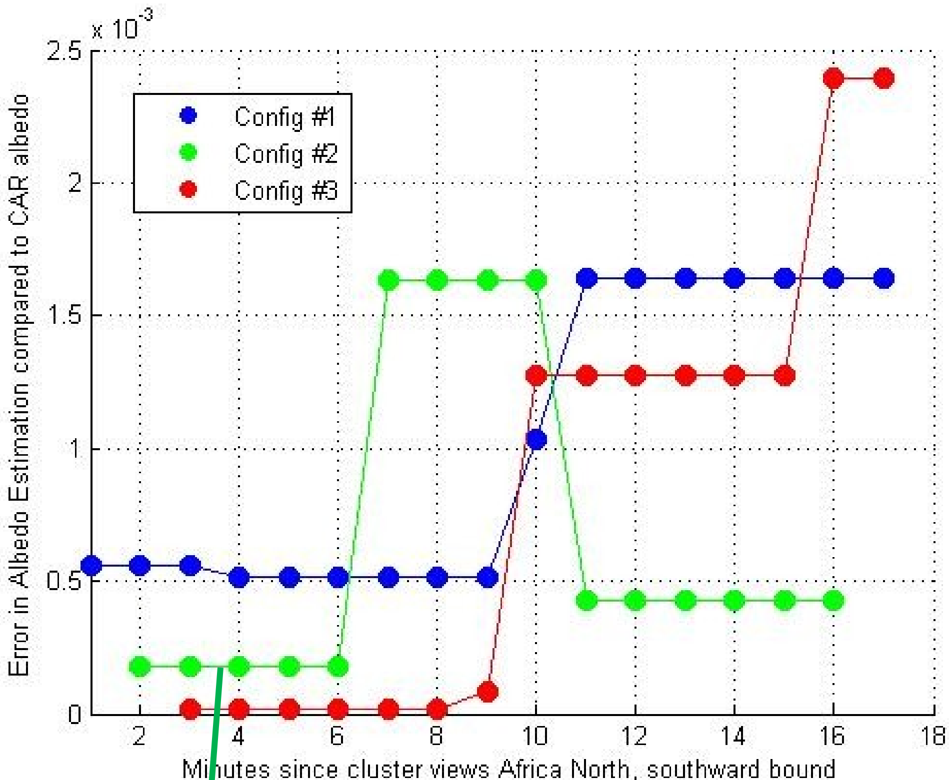

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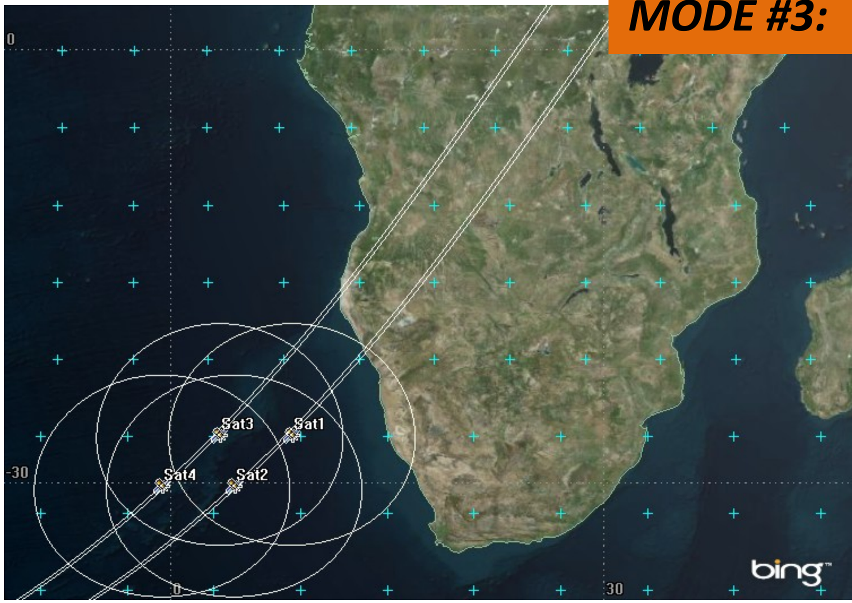

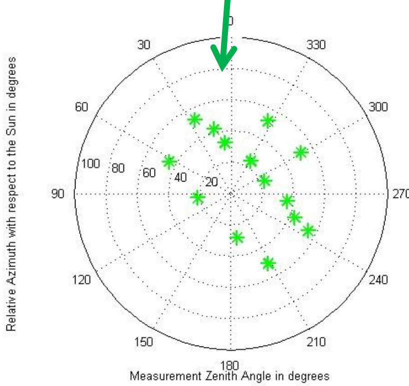

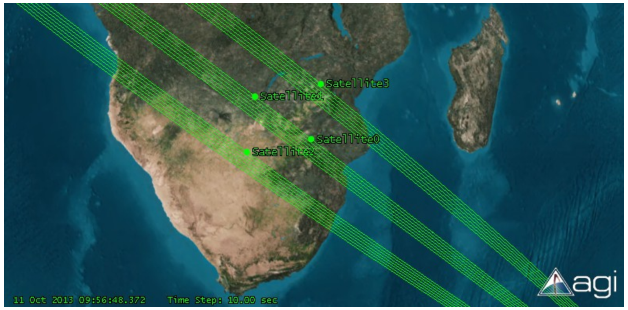

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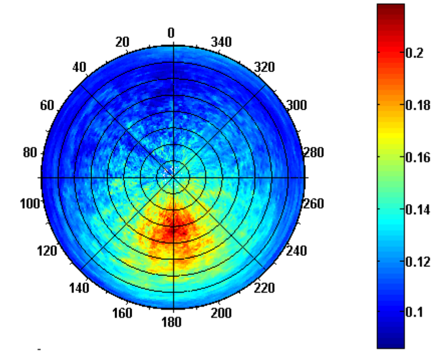

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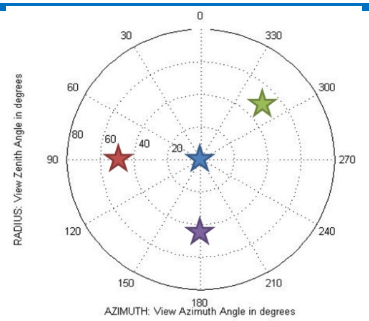

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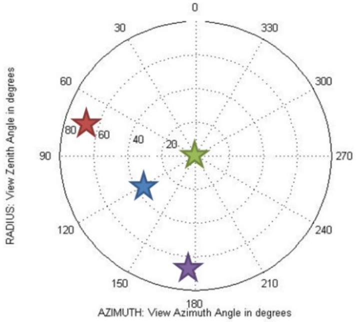

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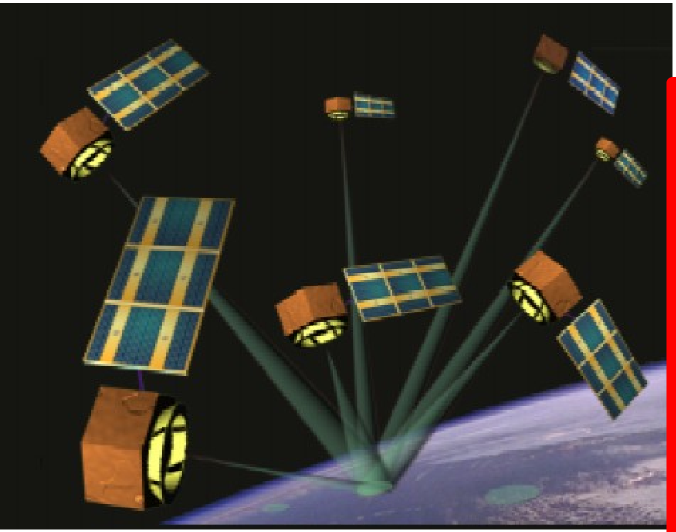

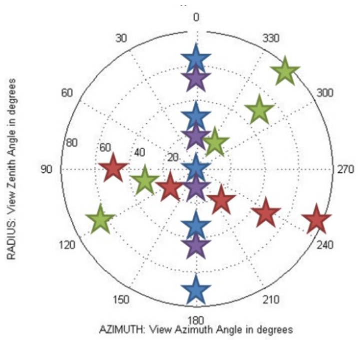

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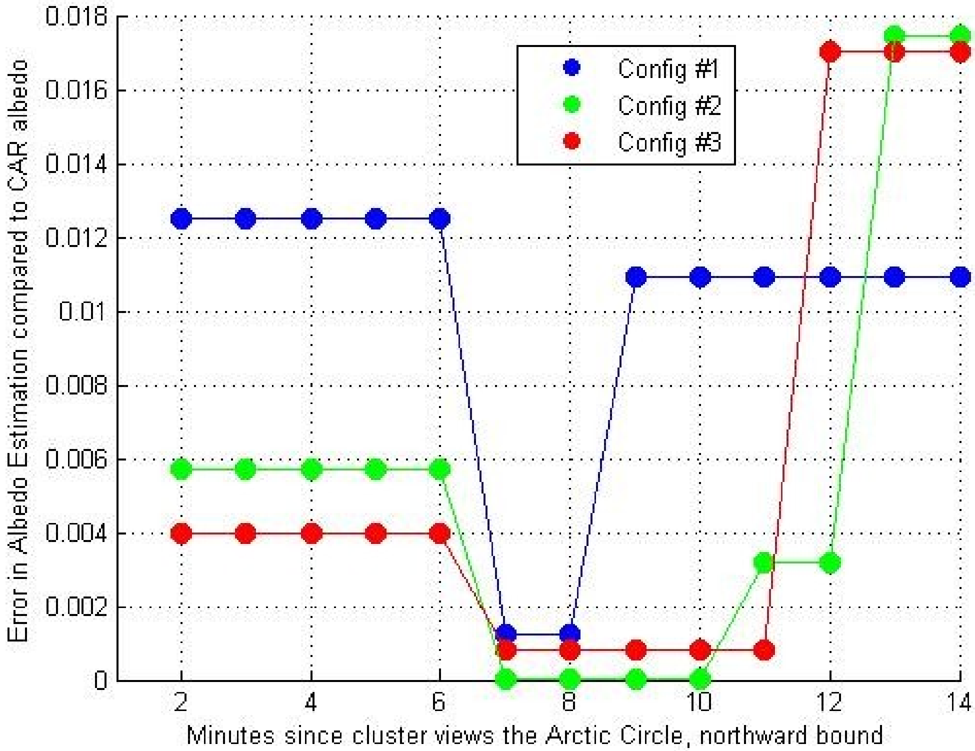

Compared 3 of the previous TA+RAAN orbits wrt CAR data (1031 nm) from Alaska assuming same biome over a 12 minute pass over the Arctic Circle.

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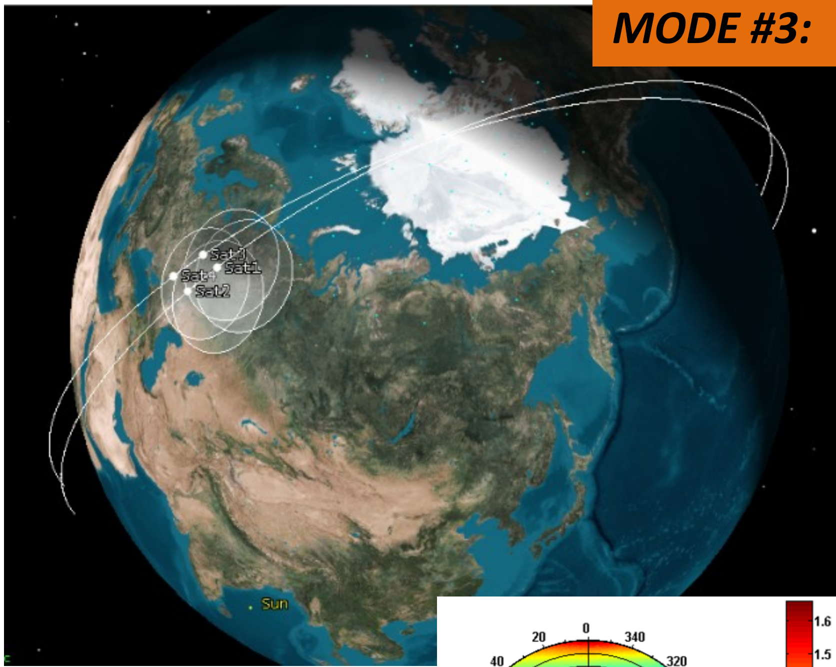

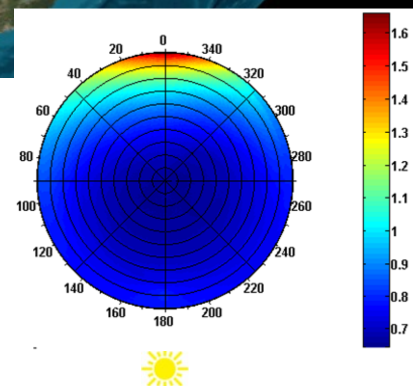

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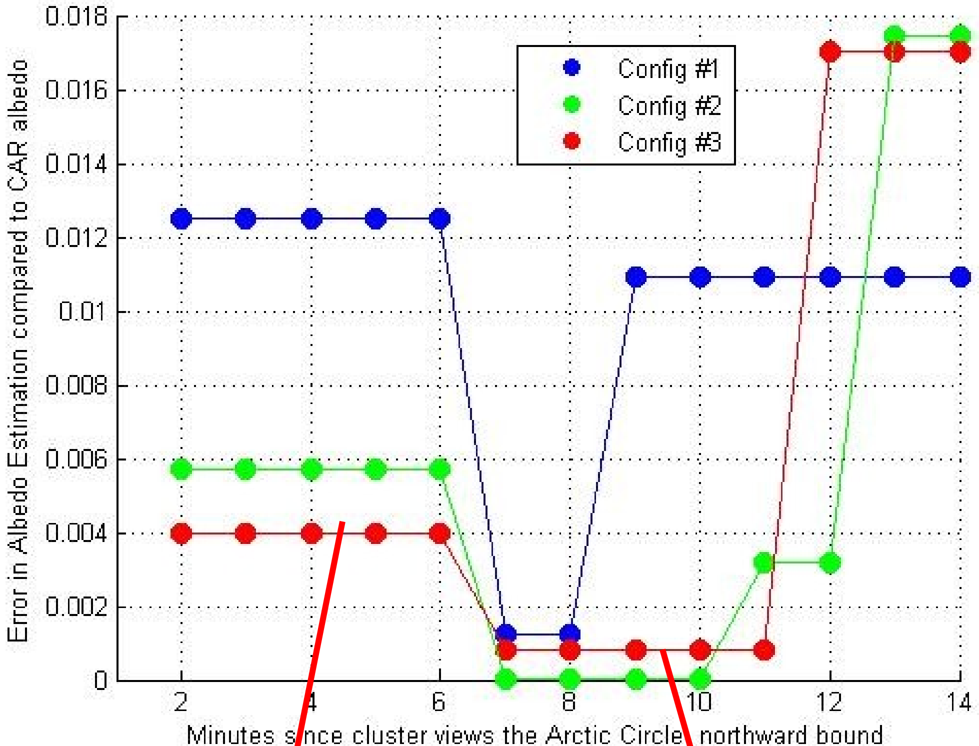

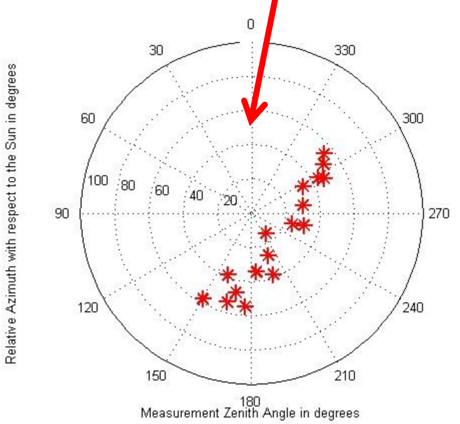

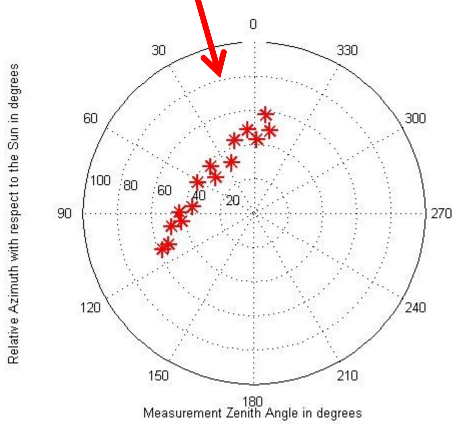

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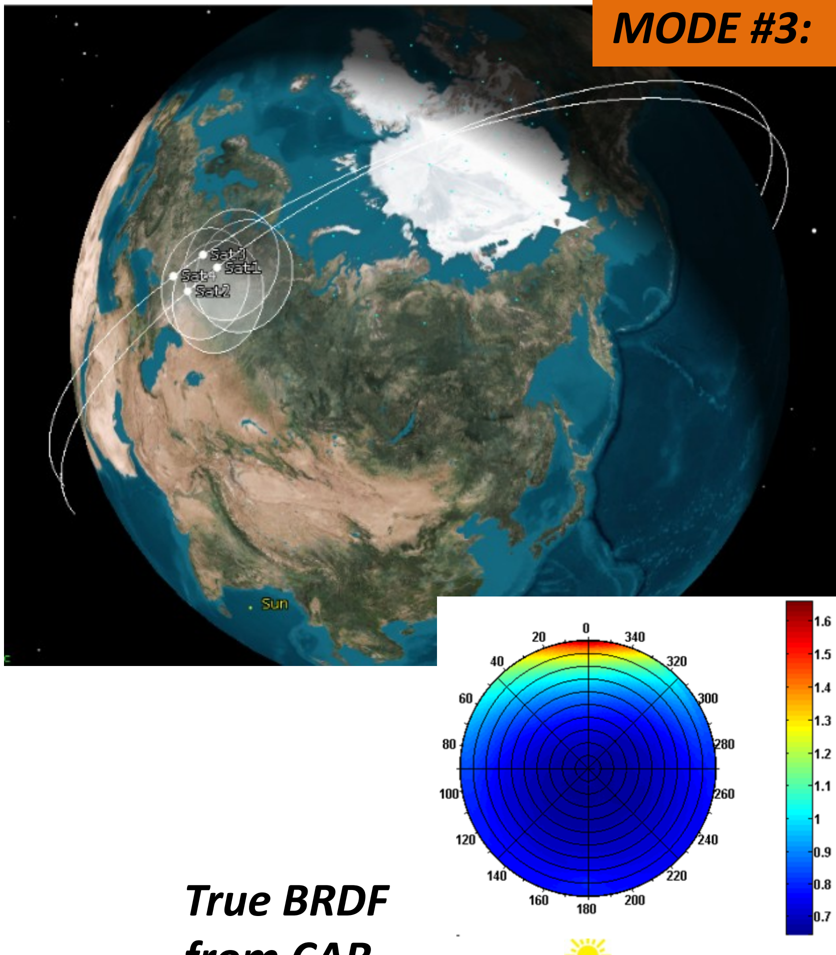

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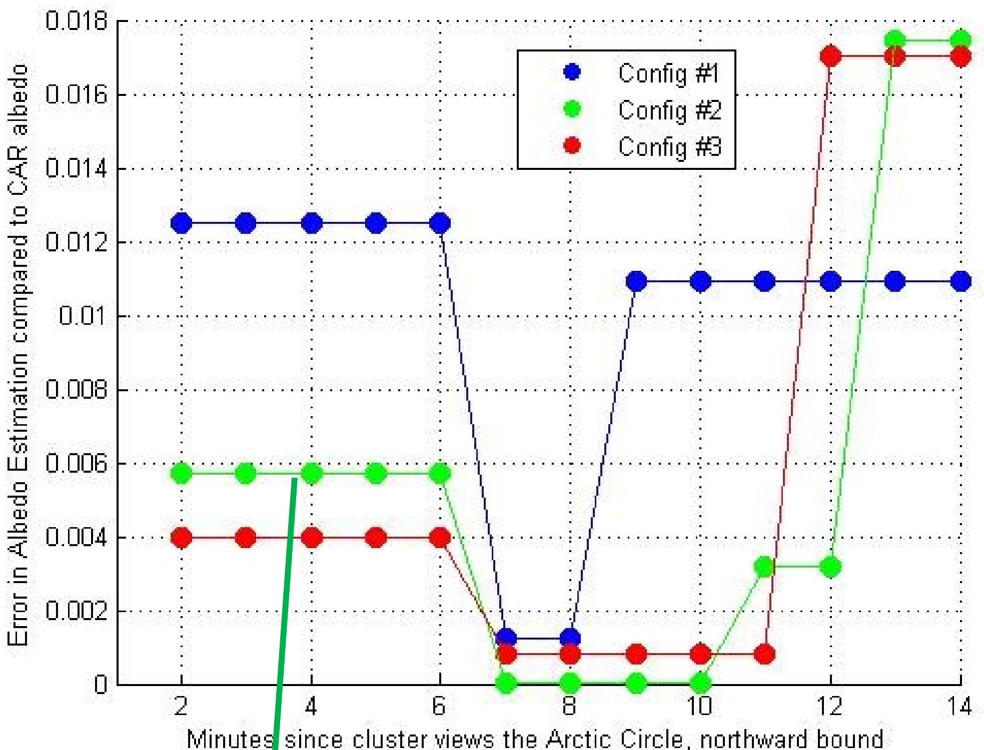

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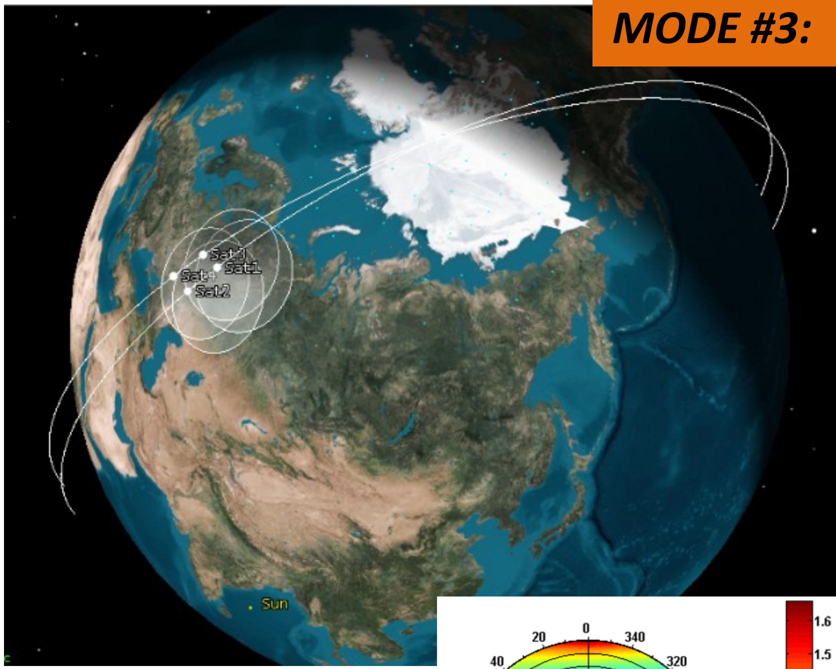

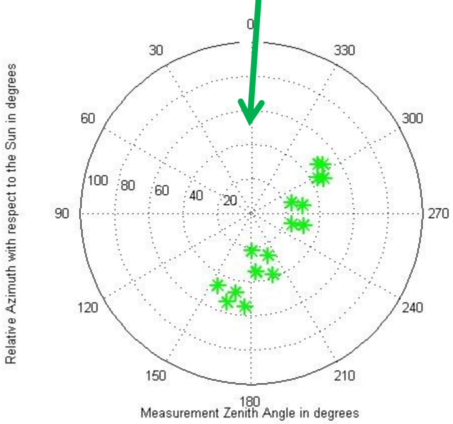

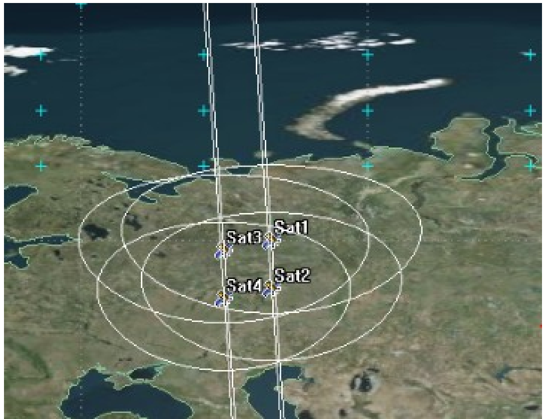

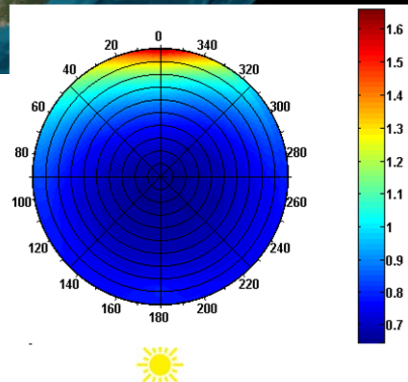

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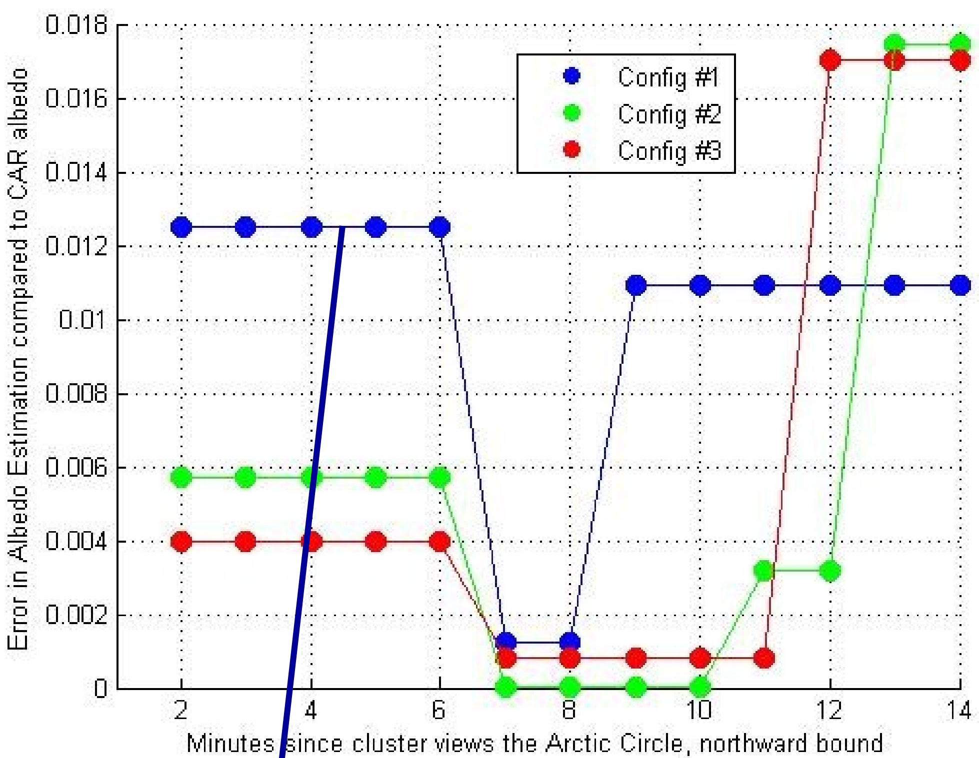

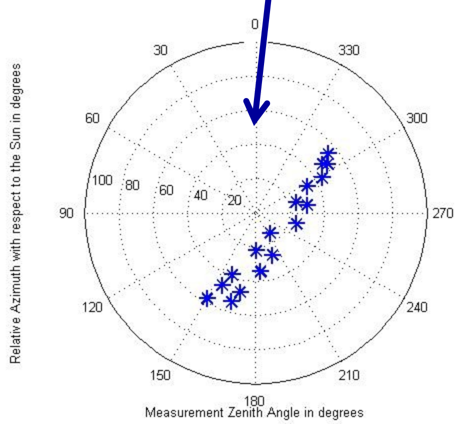

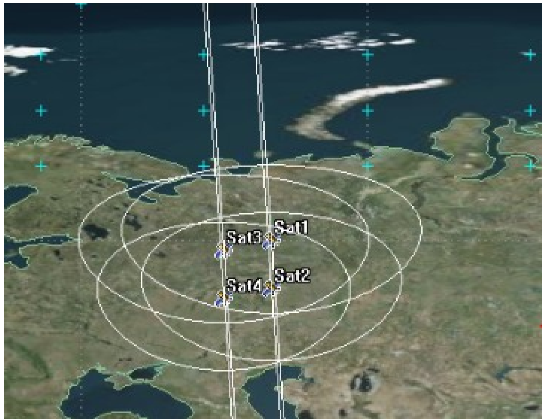

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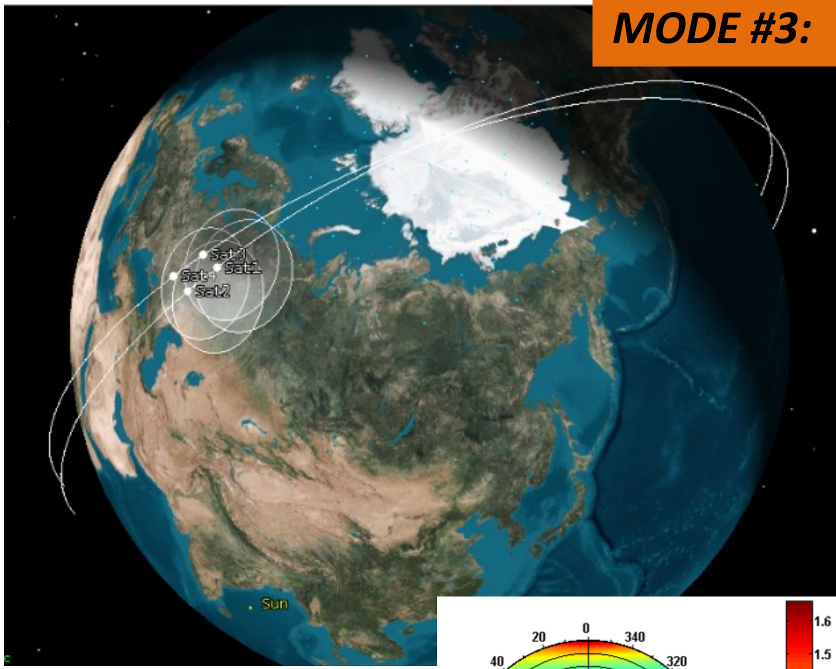

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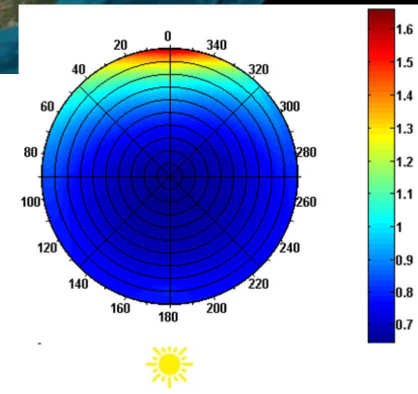
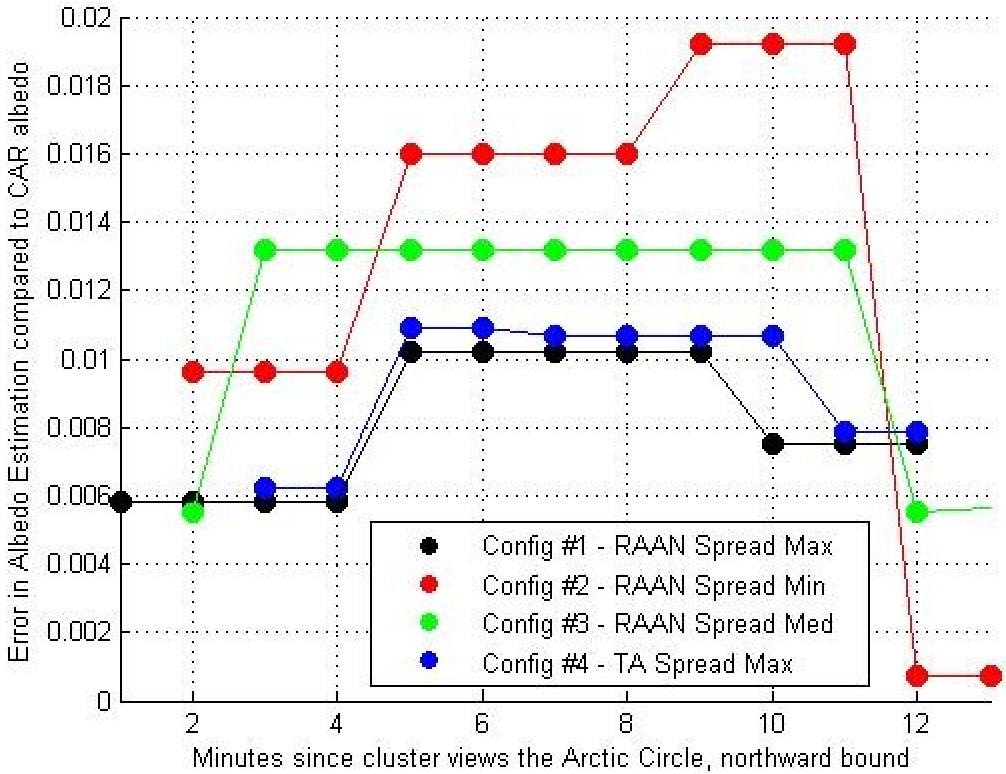
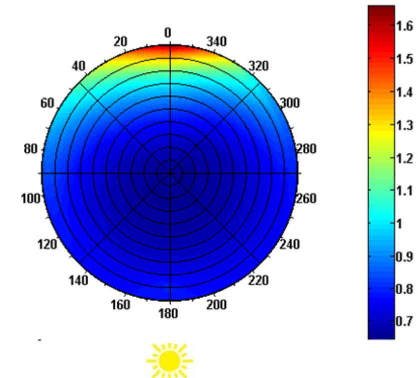


Polar Albedo Estimation



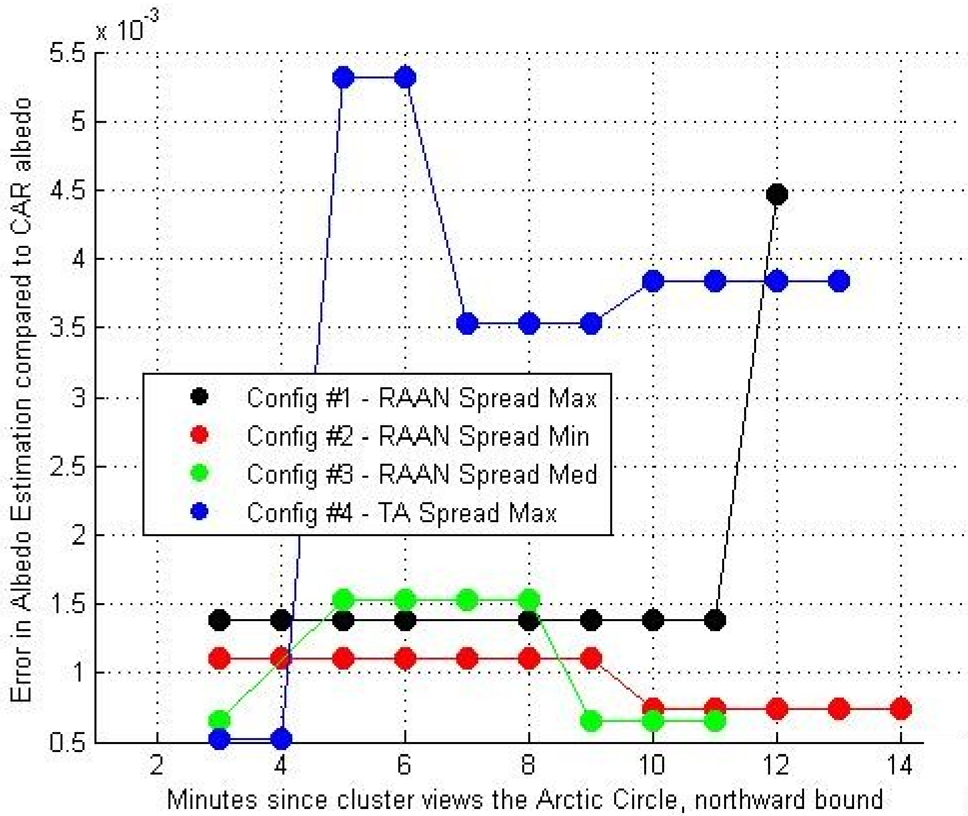
Instead, by spreading out the RAAN and TA, we may get lower errors. However, BRDF near the equator would need a clustellation (more spatio temporal coverage)

MODE #3:



True BRDF from CAR

Polar Albedo Estimation



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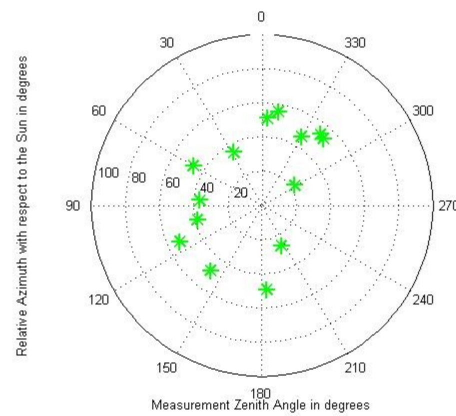

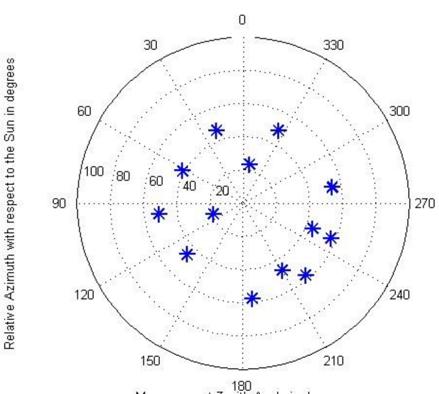

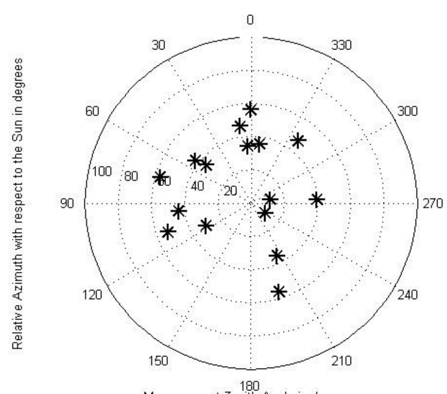

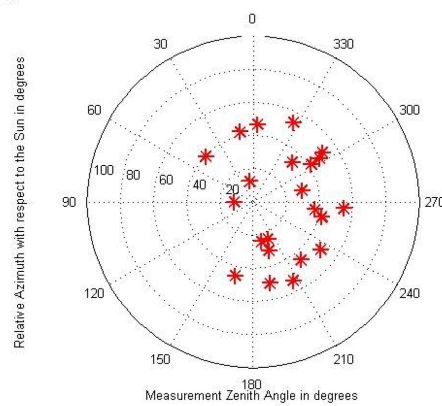

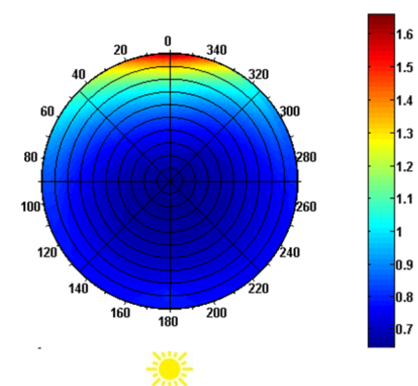

True BRDF from CAR

Outline

- Distributed Space Missions for the Angular Acquisition problem
- Example Application dependent on Angular Sampling
- Proposed Solution and Design Methodology
- Baseline Case Study using a few Formation Configurations
- Value of Imaging Modes
- Summary and Future Work

Conclusions and Future Work

- The angular acquisition problem for more accurate albedo estimation can be solved using small satellite formation flight
- Coupled science (BRDF estimation) and engineering (differential Keplerian) models proposed to validate the performance of a baseline formation design
- Simple formations with 4 satellites and no propulsion (only RAAN, TA variation) can achieve better performance than monoliths over few months, especially when different imaging modes are used
- Imaging modes are indispensible for albedo retrievals at the poles and for when the TA spread becomes too large because of unpredictable J2 effects
- Future work – Assess effect on major variables like chief orbit altitude/inclination+satellites and minor variables like their differential variation in RAAN, TA, eccentricity
- The same cluster designs are applicable for 3D mapping and biomass estimation from space

Thank you!

Questions?

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