Medium Earth Orbit as an Observational Venue for NOAA's Environmental Satellites (Post GOES-R)

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Polar Orbiting Environmental Satellites
POES & DMSP Merge Into NPOESS

Today

- 4-Orbit System
  - 2 US Military
  - 2 US Civilian

Tomorrow (2005)

- 4-Orbit System
  - 2 US Military
  - 1 US Civilian
  - 1 EUMETSAT/METOP

Future (2008-2018)

- 3-Orbit System
  - 3 US Converged
  - 1 EUMETSAT/METOP
  - Specialized Satellites

Geostationary Orbiting Environmental Satellites (GOES)

GOES – Geostationary (GEO) Orbit at 35,800 km Equatorial Orbit

- 2 US
  - GOES East @ 75W,
  - GOES West @ 135W

- 7 Foreign
  - 3 European, METEOSAT Second Generation (MSG)
  - 1 Japanese, GMS
  - 1 Russian, GOMS
  - 1 Indian, Insat

Can GOES & NPOESS Merge Into MEOES?

GOES

GOES

GEO – 35,800km

LEO – < 1000km

1000km < MEO < 35,800km

High Temporal Resolution
High Spatial Resolution

Low Temporal Resolution
High Spatial Resolution

High Temporal Resolution
Low Spatial Resolution

+

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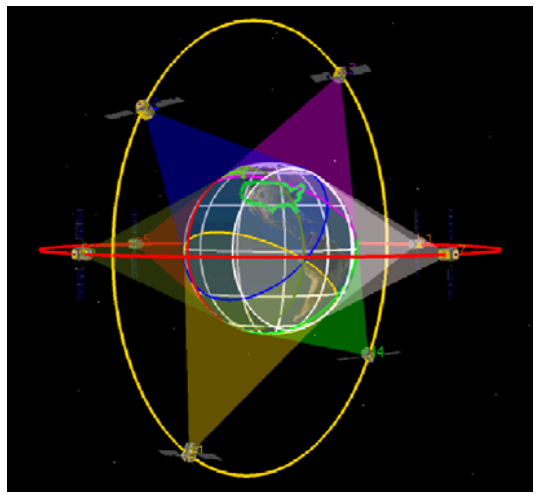


MSG

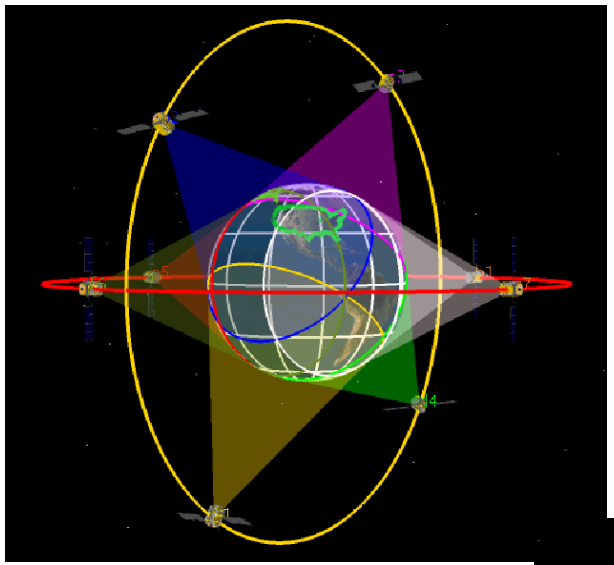
GMS

GOMS

2008 - 2018

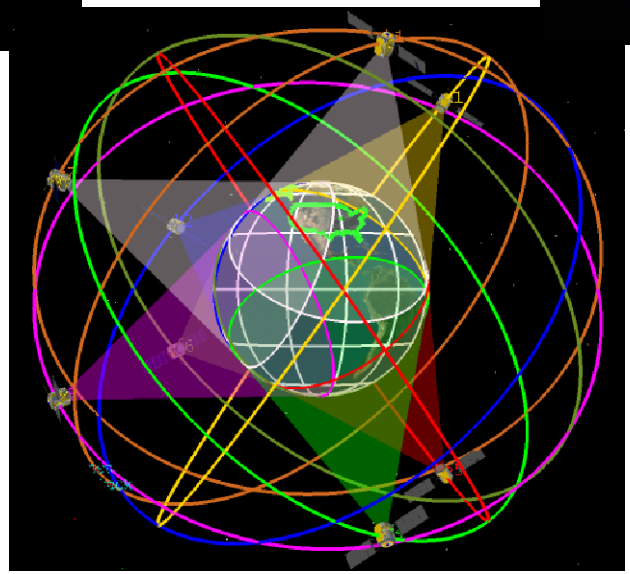
>2018

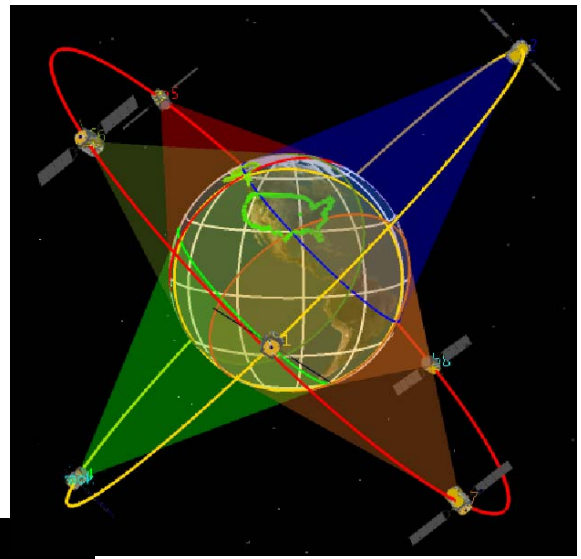
MEO Constellations Studied



Equatorial-Polar
(EP)
0^0 & 90^0 Inclinations

Walker
57^0 Inclination



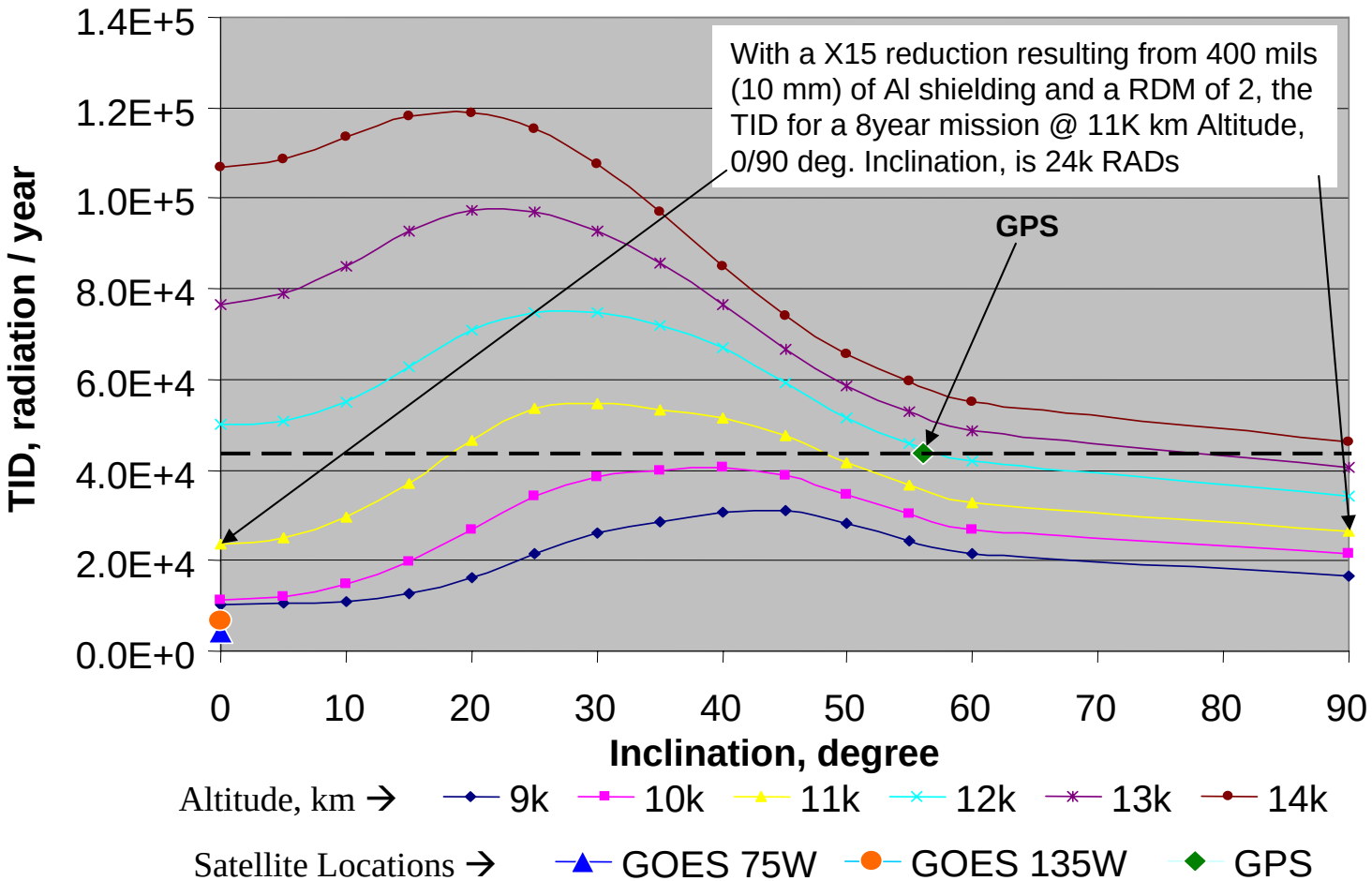


Intermediate
Circular
Orbit
(EP)
57^0 Inclination

What is the Optimal Altitude For The Constellation?

Annual Total Integrated Dose (TID) Received By Silicon Chip With 5mm Al Shielding

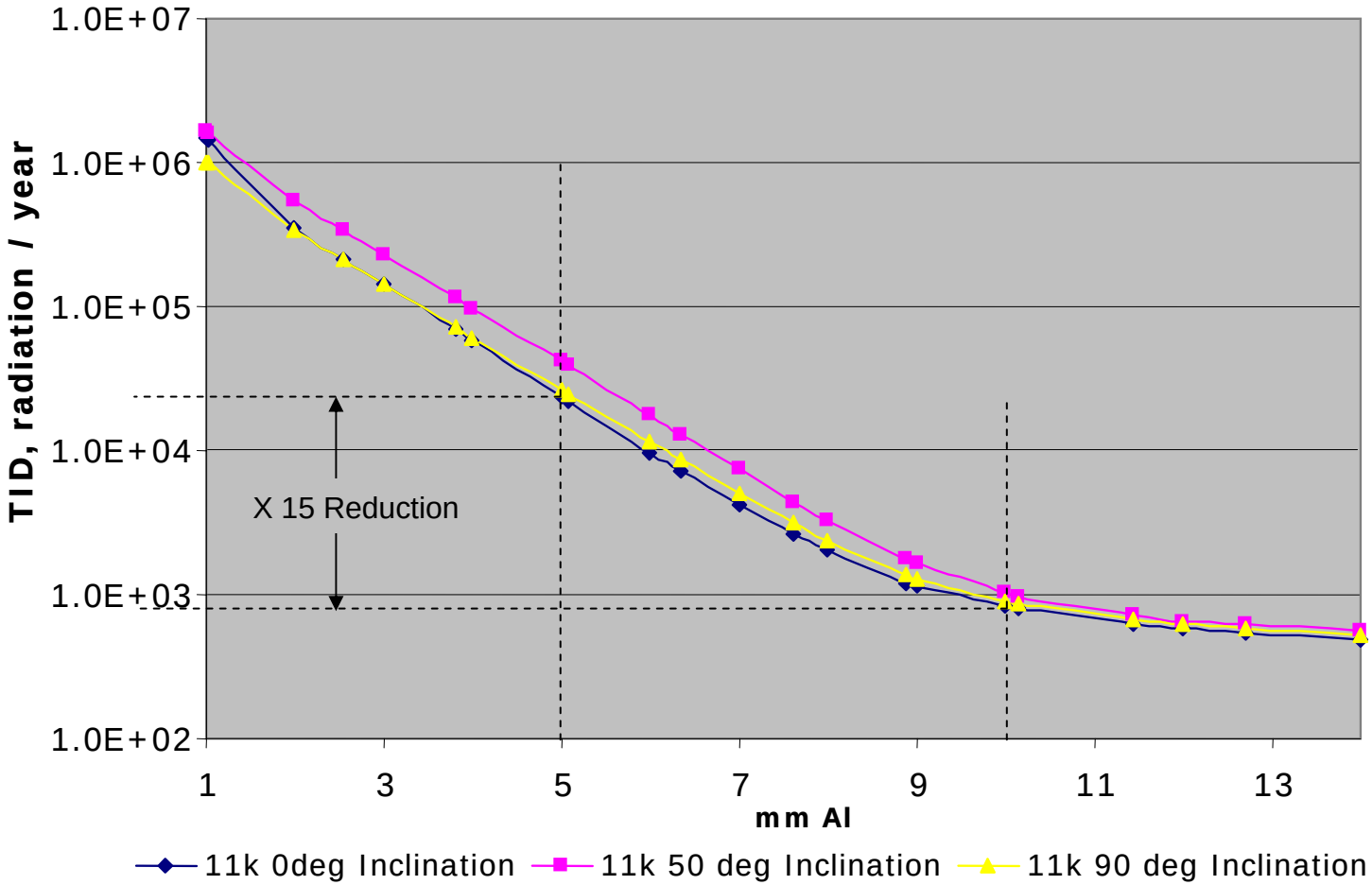
(Calculations Based on Solar Max Conditions)



An altitude of less than 11k km and inclinations less than 20^0 and/or greater than 50^0 are best from a TID radiation perspective.

What is the Optimal Altitude For The Constellation?

Total Integrated Dose (TID) Attenuation Versus Aluminum (Al) Shielding Thickness

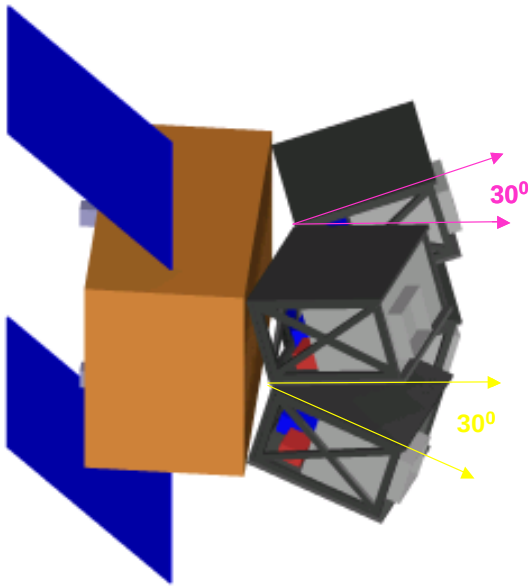


A total of 10mm of Al shielding between the IC chip and the external radiation environment makes the TID radiation manageable. Most spacecraft ray trace analysis predicts 7.5mm without doing anything.

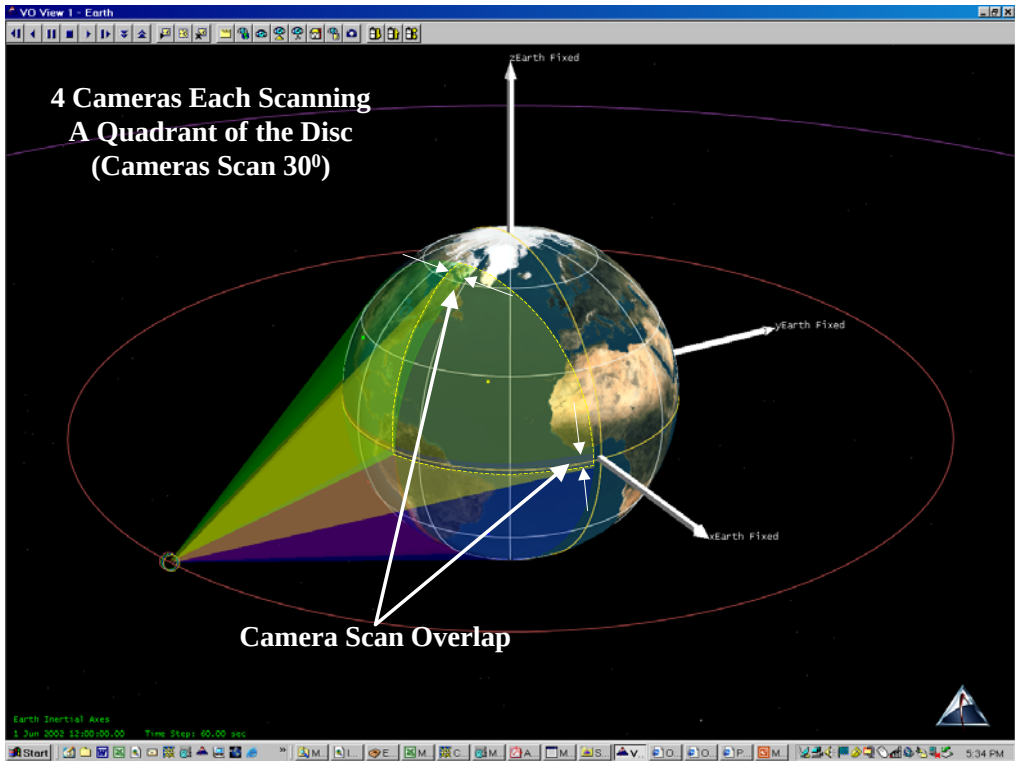
What is the Optimal Altitude For The Constellation?

- < 11k km Altitude Optimal From TID Radiation Considerations
- Largest Observable Earth Disc Image Is Desirable Indicating Higher Altitude Is Better
- Long Target Observation Period, Temporal Resolution, Is Desirable Indicating Higher Altitude Is Better
- High Target Spatial Resolution Is Desirable Indicating Lower Altitude Is Better
- 10.4k Km Selected As Optimal Altitude for Both Temporal and Spatial Resolutions

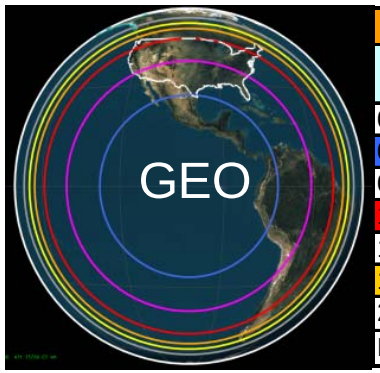
MEO Constellation Instrument Simulation for Study Purposes



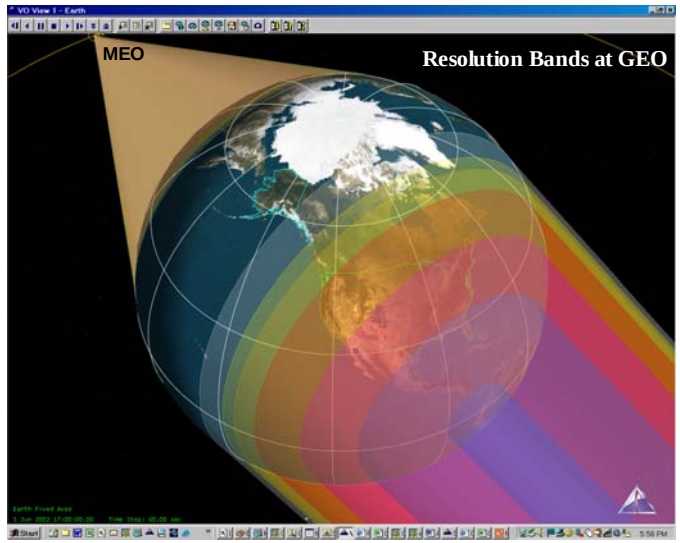
4 ABI Instruments to simulate MEO instrument with full disc scanning capability

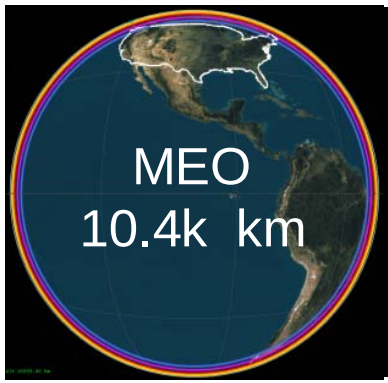


Moving the Advanced Baseline Instrument (ABI) From GEO To MEO Improves Resolution.

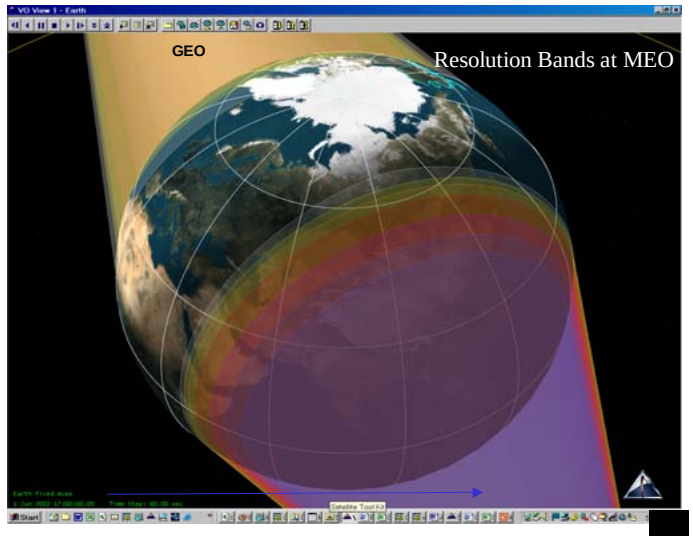


RESOLUTION BANDS: ABI at GEO			
Resol (km)	Lat (deg)	Cone half Angle (deg)	Color
0.5	0	0.000783	None
0.6	27.09	4.453	Blue
0.75	39.67	6.106	Magenta
1	50.38	7.197	Red
1.25	56.52	7.679	Orange
1.5	60.57	7.938	Yellow
2	65.64	8.195	Grey
Horizon	81.43	8.534	White

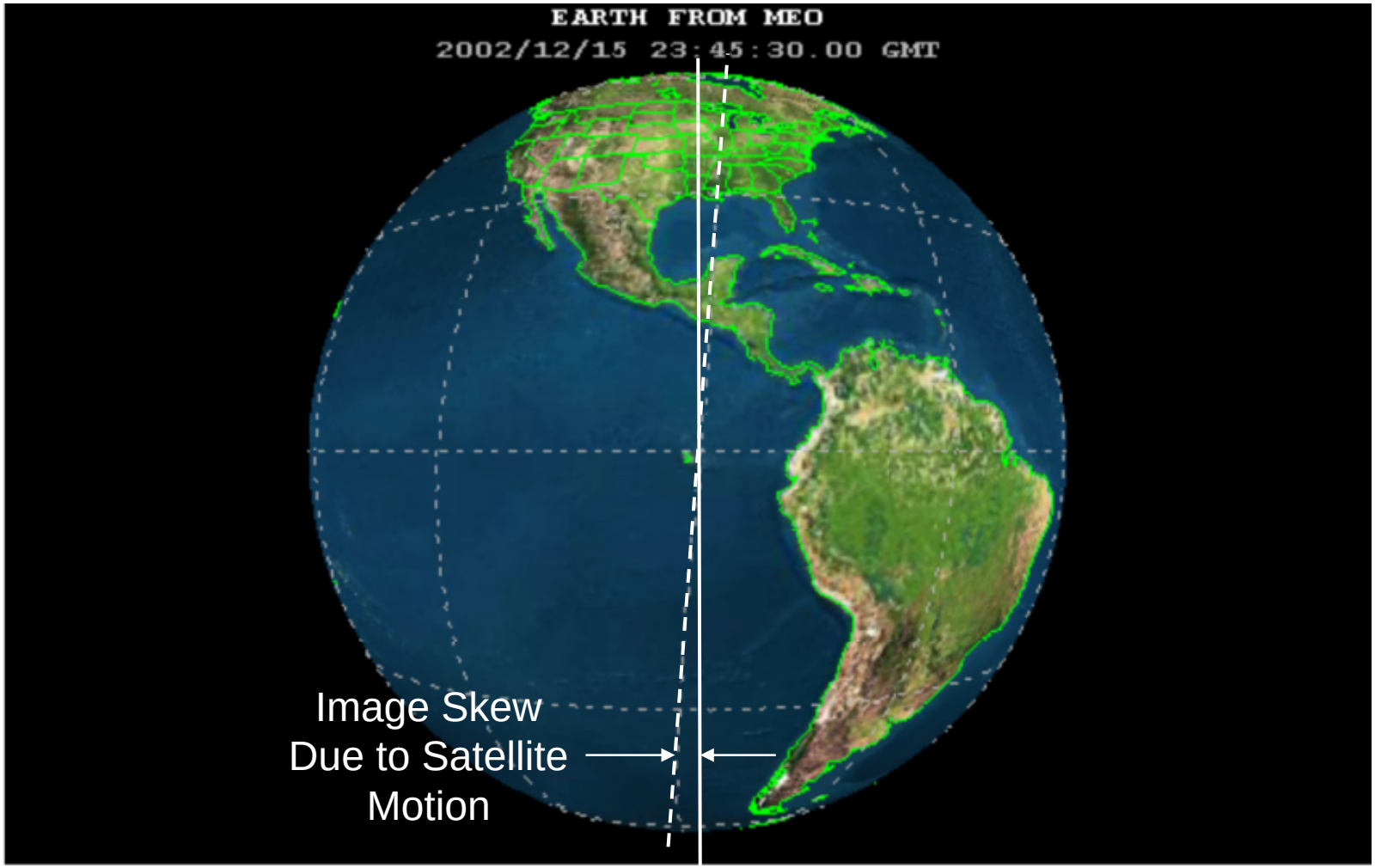




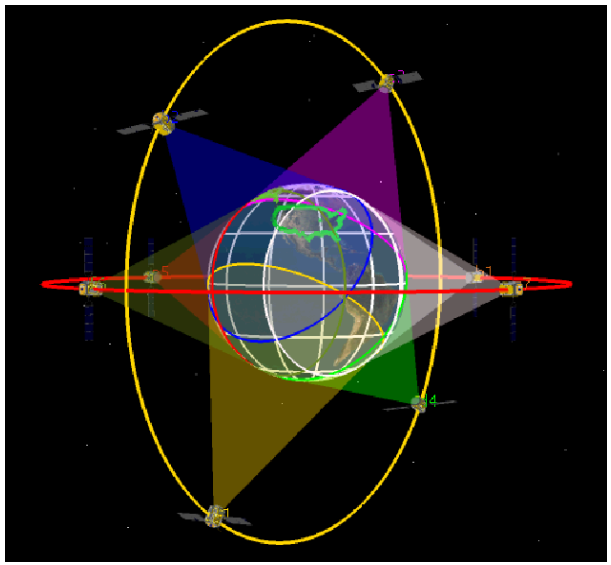
RESOLUTION BANDS: ABI at 10.4K km			
Resol (km)	Lat (deg)	Cone half Angle (deg)	Color
0.15	0	0.000783	None
0.6	50.77	20.317	Blue
0.75	53.89	20.725	Magenta
1	57.18	21.059	Red
1.25	59.25	21.221	Orange
1.5	60.68	21.332	Yellow
2	62.516	21.406	Grey
Horizon	68.455	21.533	White



Composite Picture 10 Minute Scan Time
Equatorial Satellite



Which Constellation Gives Best Observation Coverage, and The Most Robust To Failure?



MEO Imager 24hr Average Coverage Percent

Altitude: 10.4k km, Maximum Elevation Angle: 5 deg

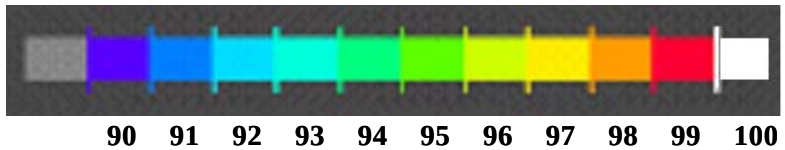


Figure 11. MEO Imager 24 hour average coverage percent, 5^0 maximum elevation angle

Figure 12. 8 EP spacecraft, 4 in the equatorial plane, 4 in polar

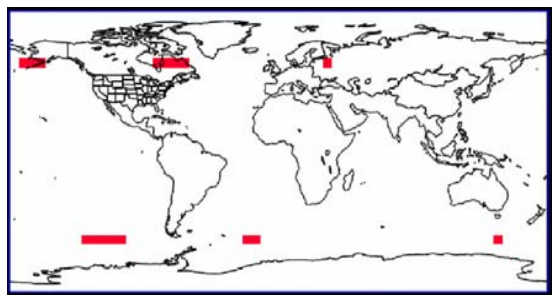


Figure 13. 8 EP spacecraft, 4 in the equatorial plane, only 3 of 4 in polar is operational

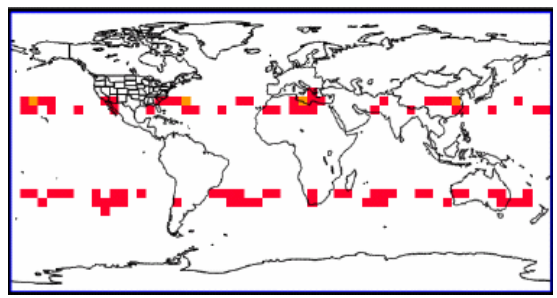


Figure 14. 8 EP spacecraft, 3 in the equatorial plane, only 3 of 4 in equatorial is operational

Which Constellation Gives Best Observation Coverage, and Is The Most Robust?

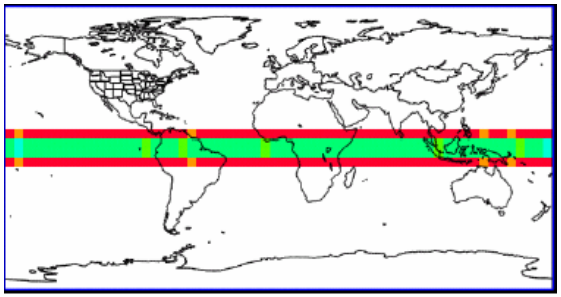


Figure 15. 8 Walker spacecraft at 57^0 inclination phased 45^0 apart

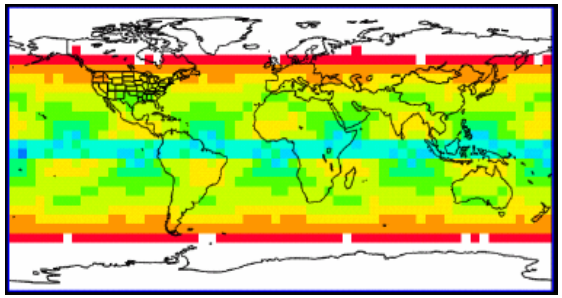


Figure 16. 7 of 8 Walker spacecraft at 57^0 inclination phased 45^0 apart is operational

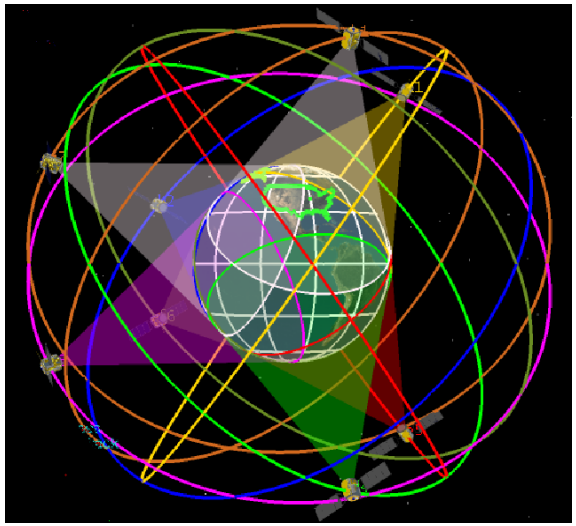


Figure 17. 8 ICO spacecraft at 57^0 inclination in 2 planes, 4 spaced 90^0 apart in 1 plane, 4 in another plane 180^0 out of phase with the first also separated by 90^0

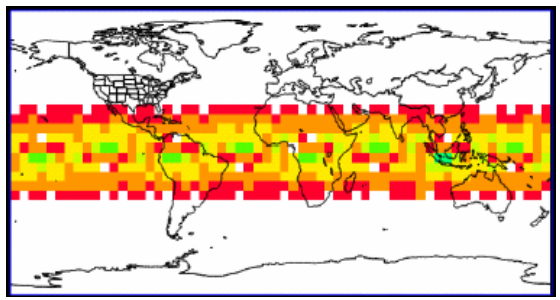
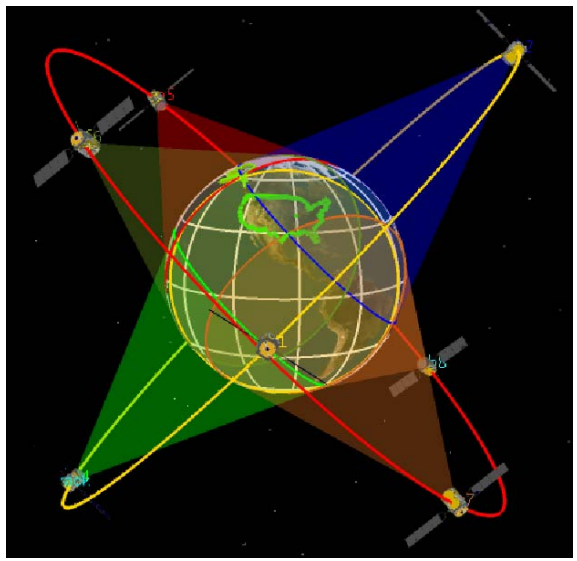


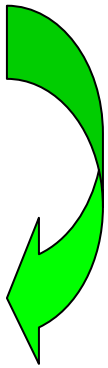
Figure 18. 7 of 8 ICO spacecraft at 57^0 inclination in 2 planes, 4 spaced 90^0 apart in 1 plane, 4 in another plane 180^0 out of phase with the first, also separated by 90^0 is operational



Which Constellation Gives Best Observation Coverage, and Is The Most Robust?

MEO Implementation of GOES Auxiliary Comms/Imaging, Sounding, & Robustness Analysis Summary/Ranking

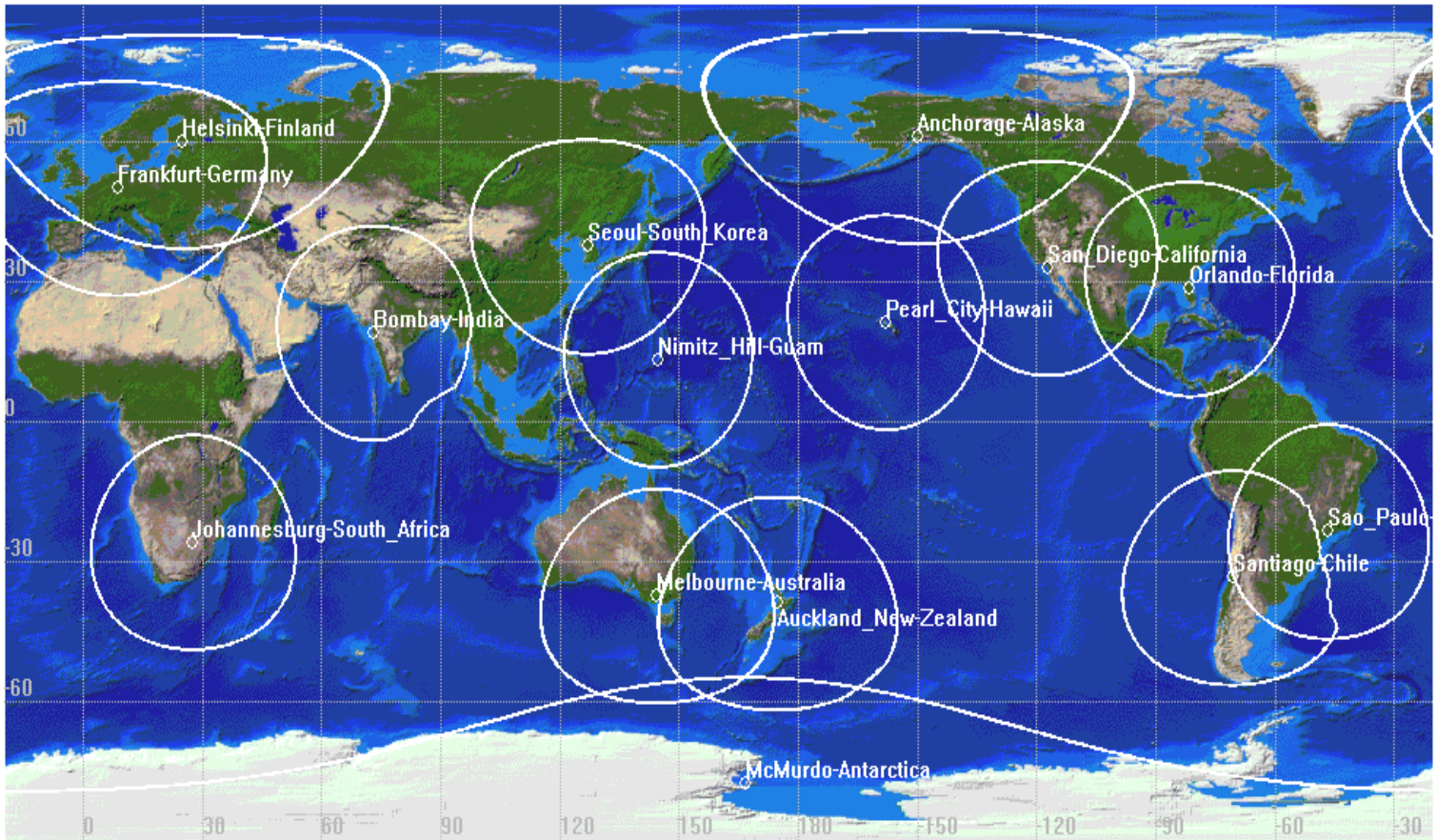
Constellation Configuration	Coverage Imaging/Comms	Coverage Sounder	Robustness (CONUS)	Inter-Sat & D/L Comms Complexity	Ease of Migrating From GEO-LEO Configurations
EP - 8	Excellent	Fair	Very Good	Moderate	Excellent
Walker - 8	Good	Very Good	Good	Difficult	Poor
ICO - 8	Excellent	Very Good	Very Good	Moderate	Poor



Communications Architectures

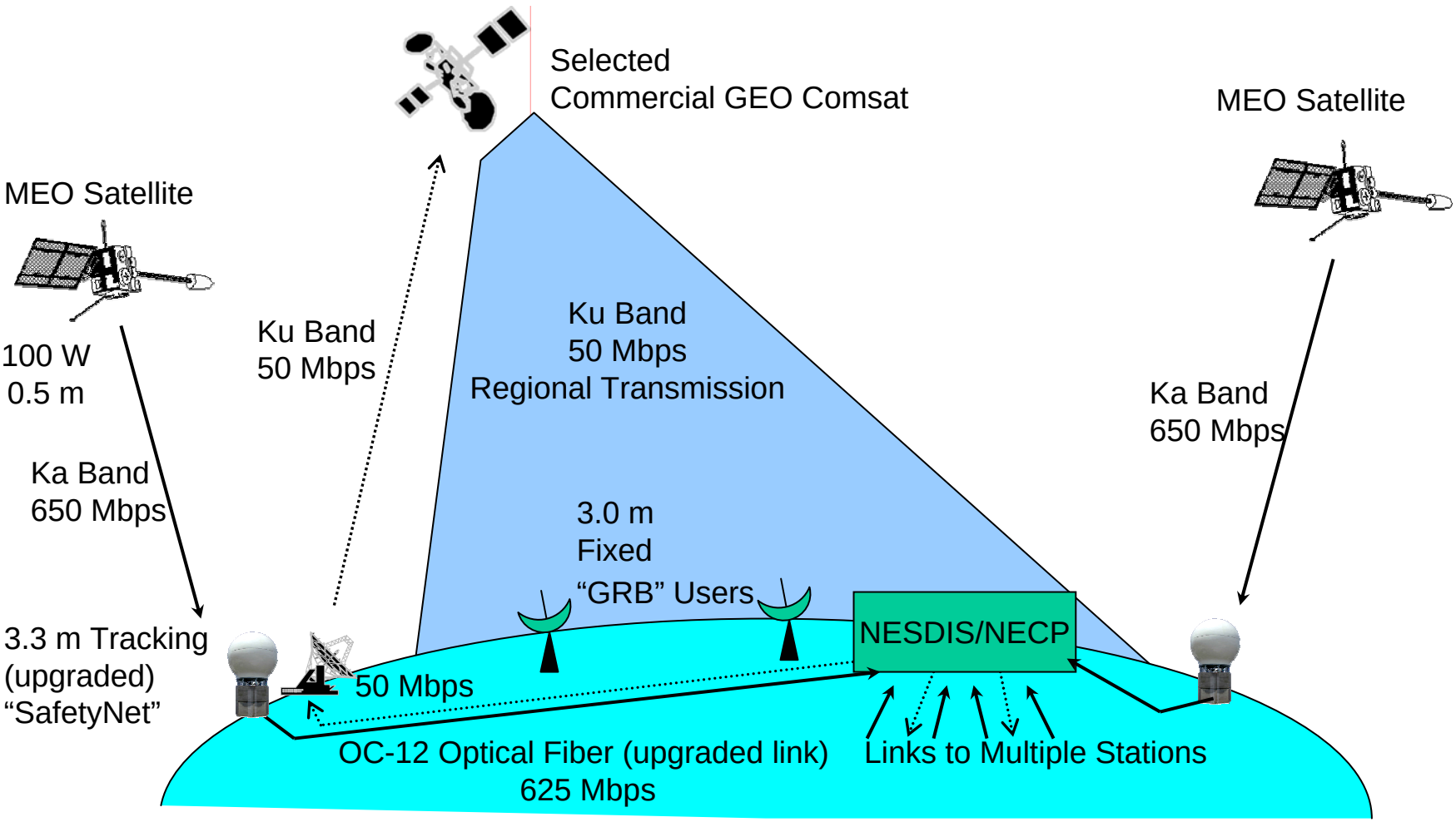
- Options for MEO Communications Architectures
  - Option 1: Distributed High Speed Ground Network With Commercial Rebroadcast
    - Upgraded SafetyNet Sites and Ground Network
    - Medium Data Rate Rebroadcast
  - Option 2: Optical Satellite Crosslinks With Client-server Network
    - Data Downlink to Single Ground Node
    - Client-server Data Redistribution Network
  - Option 3: Optical Satellite Crosslinks With Hybrid Data Redistribution
    - Medium Data Rate Rebroadcast + Client-server Network
- Link Budgets Generated for All Downlinks
  - Transmit Power and Antennas Sized to Existing Hardware
  - At Least 3 Db Positive Link Margin
  - Requires High Speed Error Correction Coding
- Uplinks/Crosslinks Are Notional

NPOESS Ground Network Map



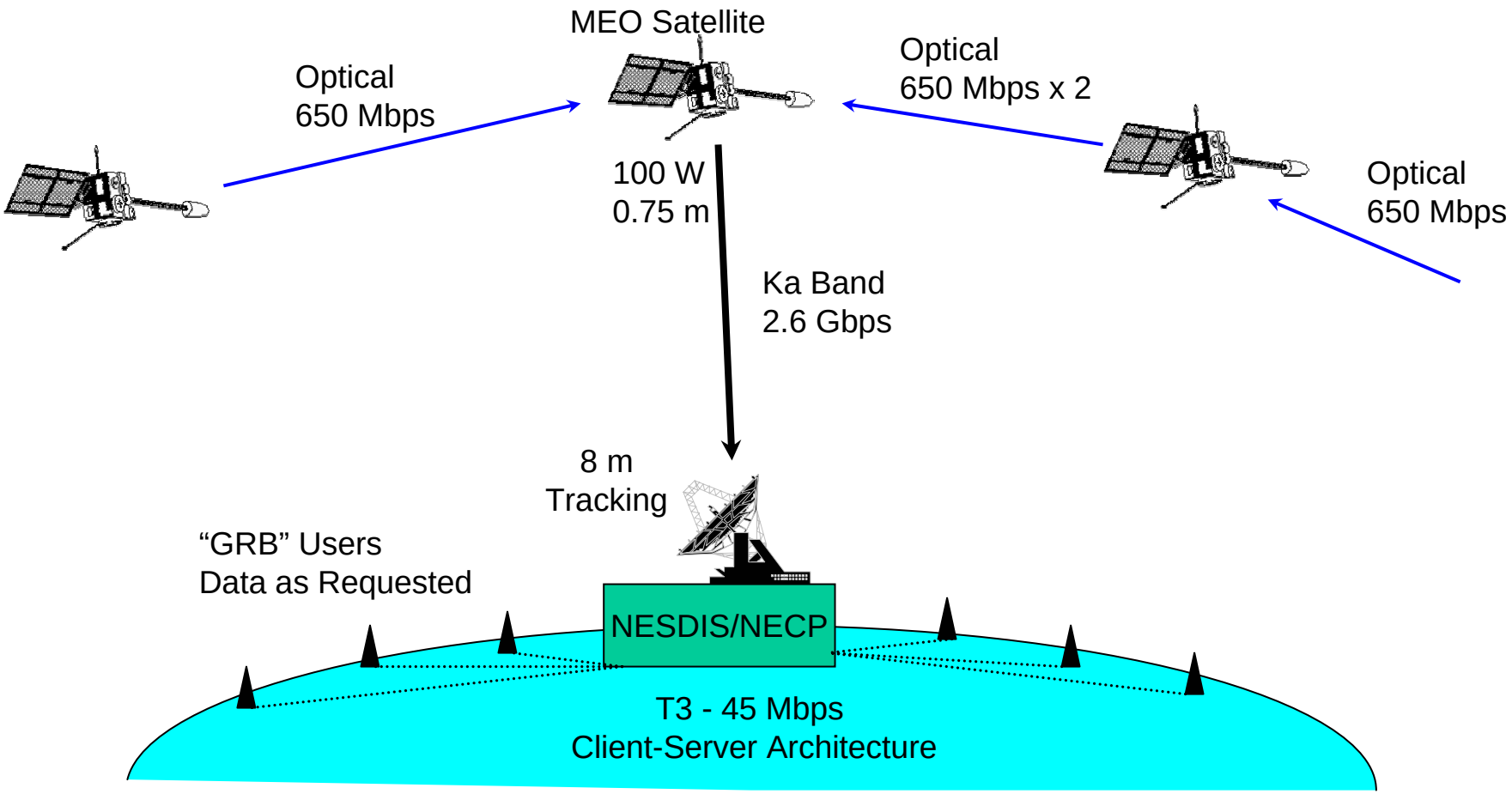
Source: NPOESS ground station - "National Polar-orbiting Operational Environmental Satellite System (NPOESS)" 0252_006_maxi presentation NP-EMD.02.520.006, October 31, 2002.

Option 1: Modified "SafetyNet" with Commercial Rebroadcast



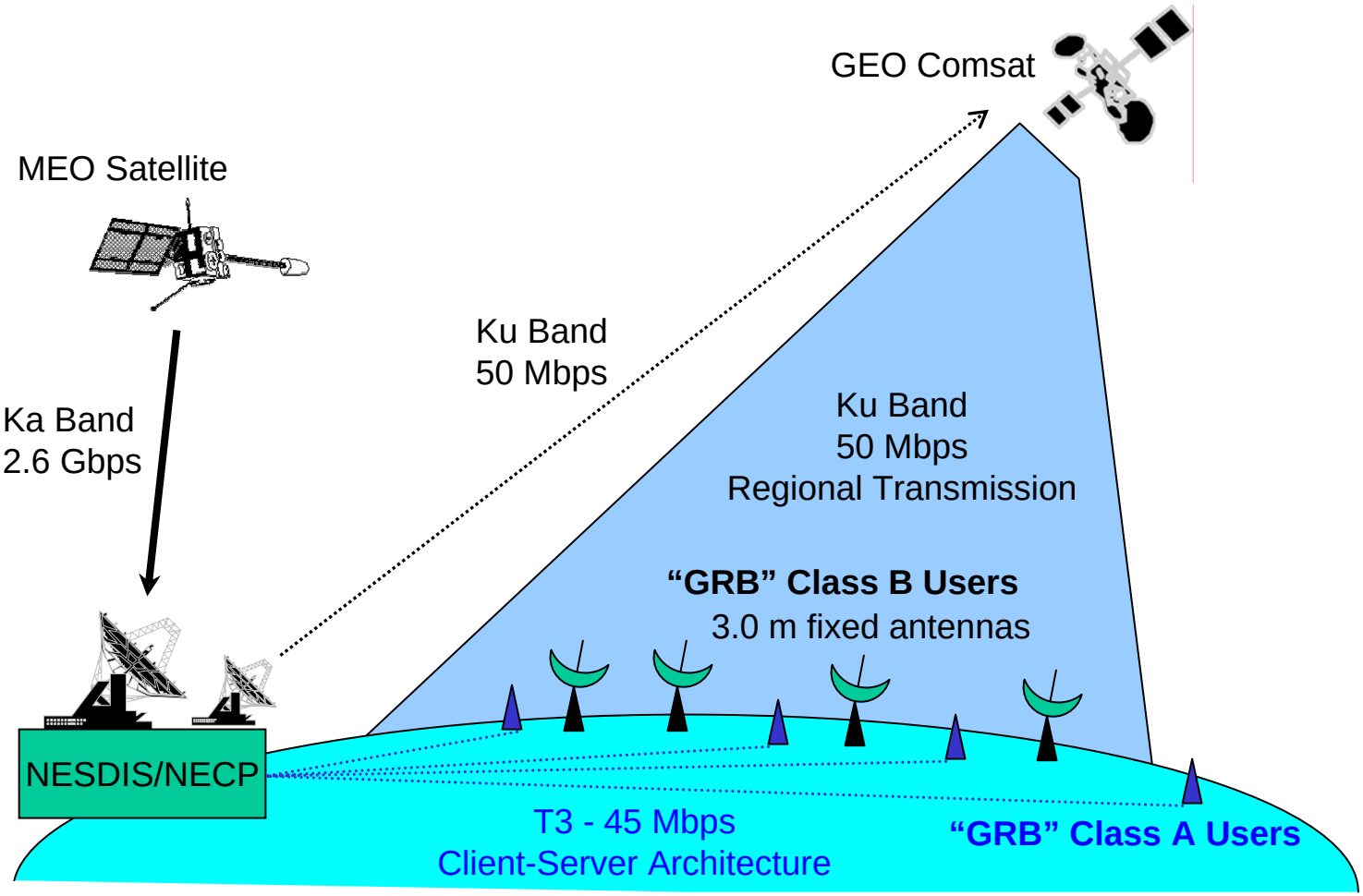
650 Mbps Main Downlinks - 50 Mbps Rebroadcast

Option 2: Optical Satellite Crosslinks with Client-Server Network



2.6 Gbps Main Downlinks - 45 Mbps On-Demand Redistribution

Option 3: Optical Satellite Crosslinks with Hybrid Data Redistribution



Class A - 45 Mbps On-Demand Redistribution
Class B - 50 Mbps Rebroadcast

MEO Study Results To Date

- **MEO Architecture Affords NOAA the Potential to Provide High Spatial, Temporal and Spectral Resolution Environmental Data Comparable to or Exceeding That of NPOESS and GOES-R.**
- **MEO Opens up a Vista to the Future for Global Earth Observations. Data Can Be Captured Anywhere, Everywhere, All the Time and Transmitted to the User in Near Real-time.**
- **The Equatorial-Polar Constellation Configuration Provides the Best 24 Hour % Coverage and Robustness to Failure.**
- **The Optimal MEO Altitude Is 10.4k Km.**
- **The Optimal Range of Inclinations for MEO Satellites Is 0^0 to 20^0 and 50^0 to 90^0 at Orbital Altitudes of < 11k km.**
- **The MEO Total Integrated Dose (TID) Radiation Can Be Managed With an Additional 2.5 Mm (~100 Mils) of Al Between the IC Chip and the Natural Environment**