Continuous observation of high latitudes from space: a review of medium earth orbit (MEO) and highly elliptical orbit (HEO) options

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Motivation

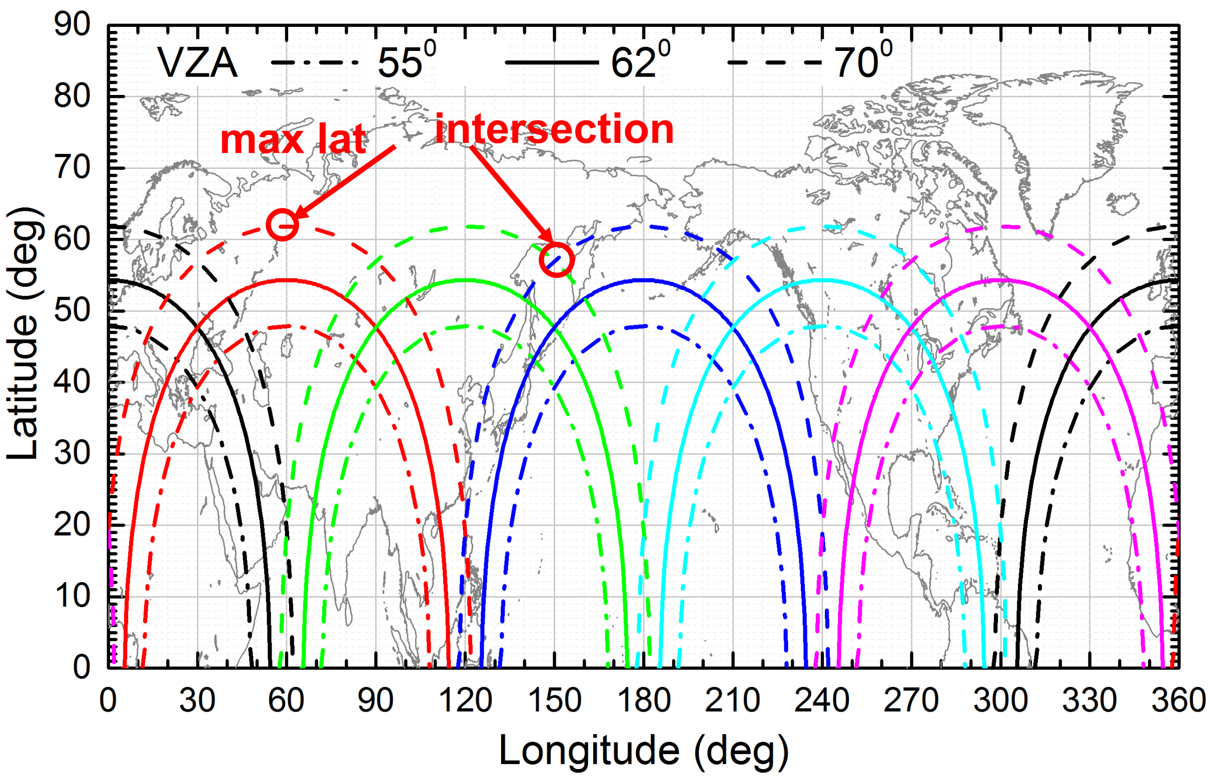
- To achieve high temporal meteorological imaging (~10 min or less) at high latitudes, similar to what is obtained from GEO at lower latitudes, this with a minimum of satellites. Good overlap with GEO down to 45º N/S is desirable, considering limit of ~60º N/S from GEO (VZA < 70º).

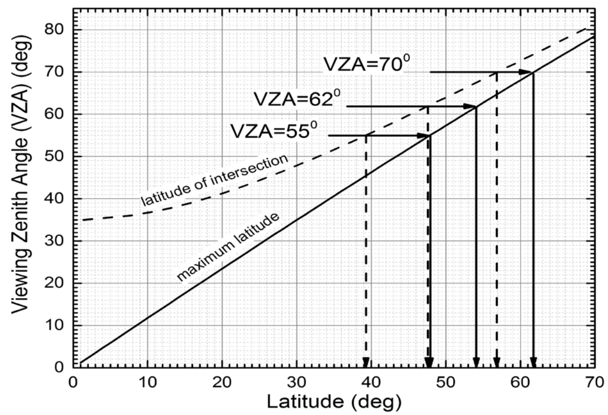
- Several studies have shown that continuous coverage of latitude band 60º-90º can be achieved from a constellation of, at a minimum, 2 satellites for each pole in a highly elliptical orbit (HEO) and max VZA=70º.

- Many key applications, such as AMVs and quantitative cloud retrievals require smaller limit of VZA (55º-65º), therefore overlap with GEO should occur around the latitude range 45º-50º. Can 3 HEO satellites per pole achieve this?

- Sometime ago NOAA has considered an alternative solution using circular orbits with heights between LEO and GEO, so-called Medium Earth Orbit (MEO), requiring many satellites with height of order 10 K km. Here we consider the value of heights closer to GEO (~36 K km) in order to minimize the number of satellites.

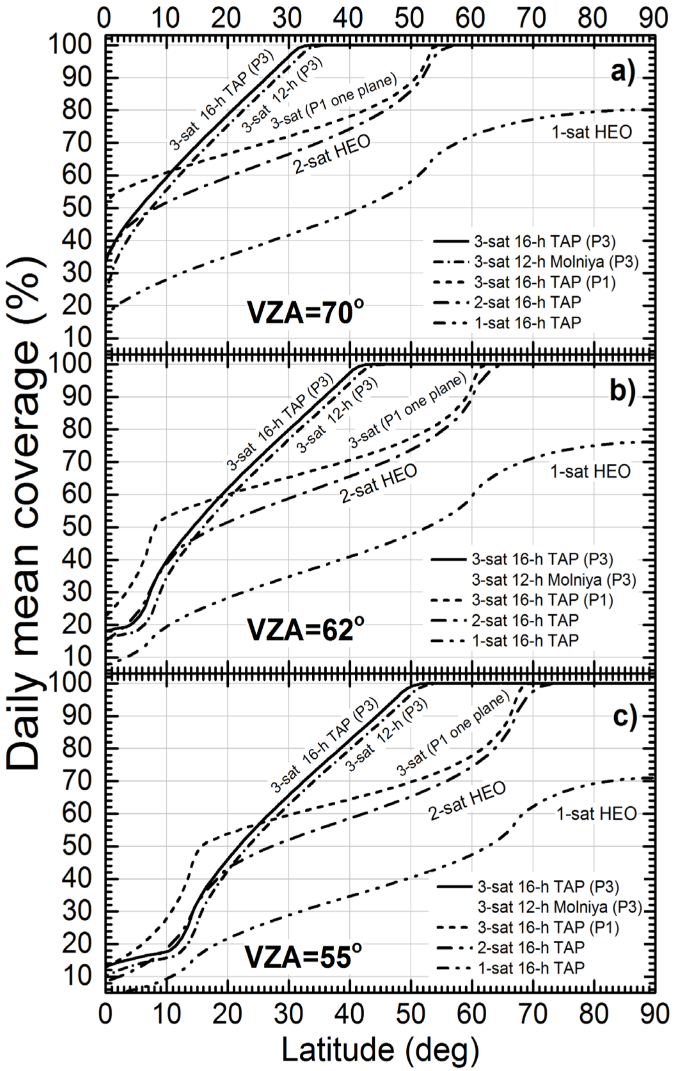
GEO coverage vs VZA





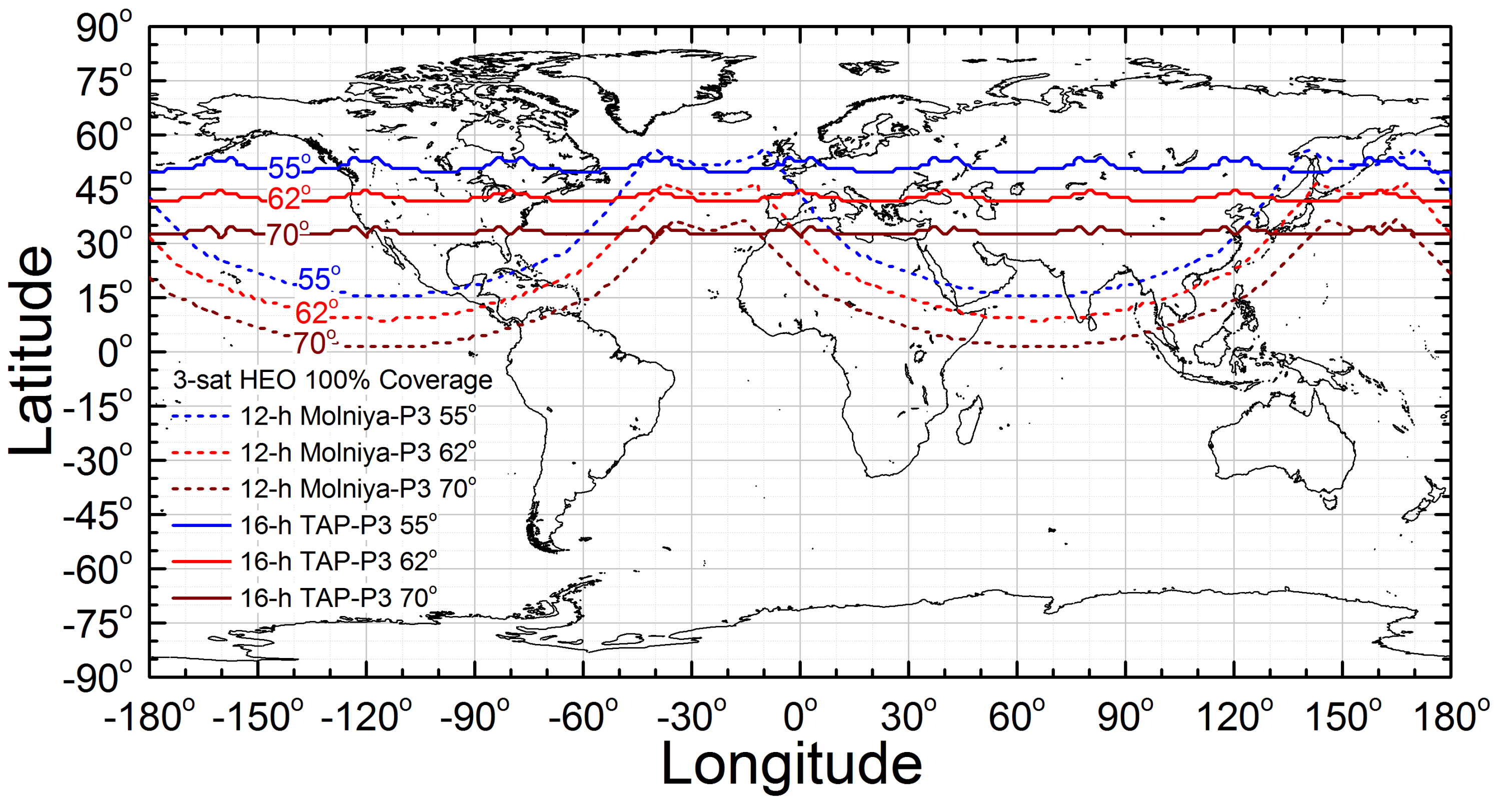
Continuous GEO coverage with VZA limit 62º can occur only up to ~ 48º latitude

HEO coverage vs VZA: the advantage of 3 satellites

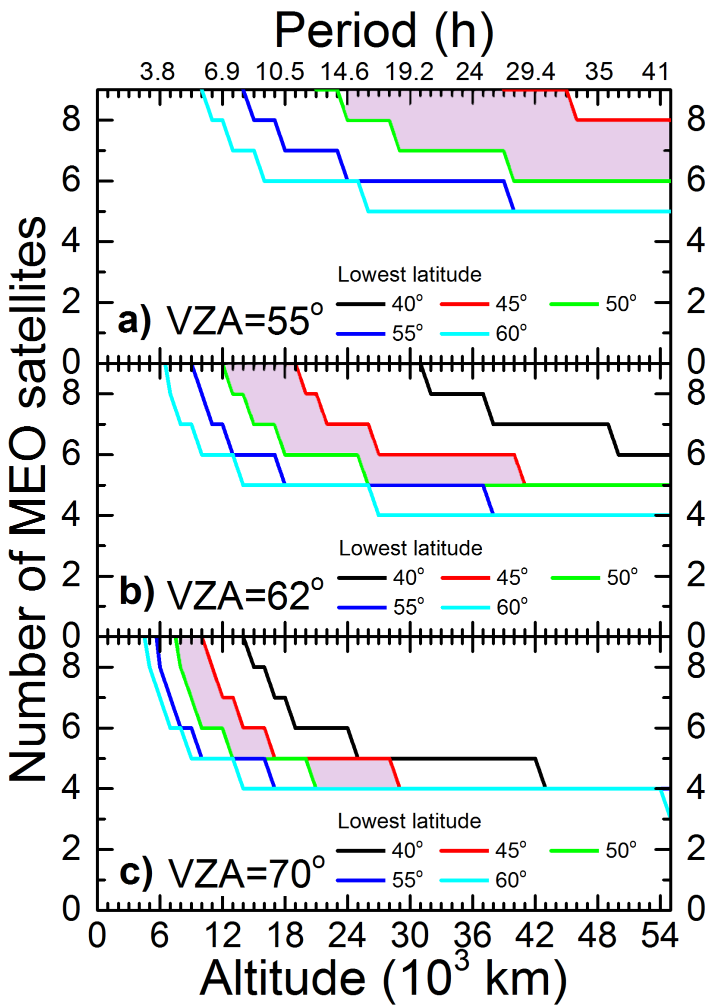


- 2-sat HEO gets full coverage from pole to down to ~65° with VZA limit of 62°
- Need of 3 satellites to get coverage down to ~42° N for VZA of 62°. With VZA of 55° coverage down to 50°N is still achieved (reasonable overlap with GEO)
- Configuration in 3 orbital planes (P3) clearly better than one orbital plane (P1)
- HEO periods 12-h to 16-h can be considered

HEO 3-sat 100% latitude coverage limit for maximum VZA of 55°, 62°, 70°

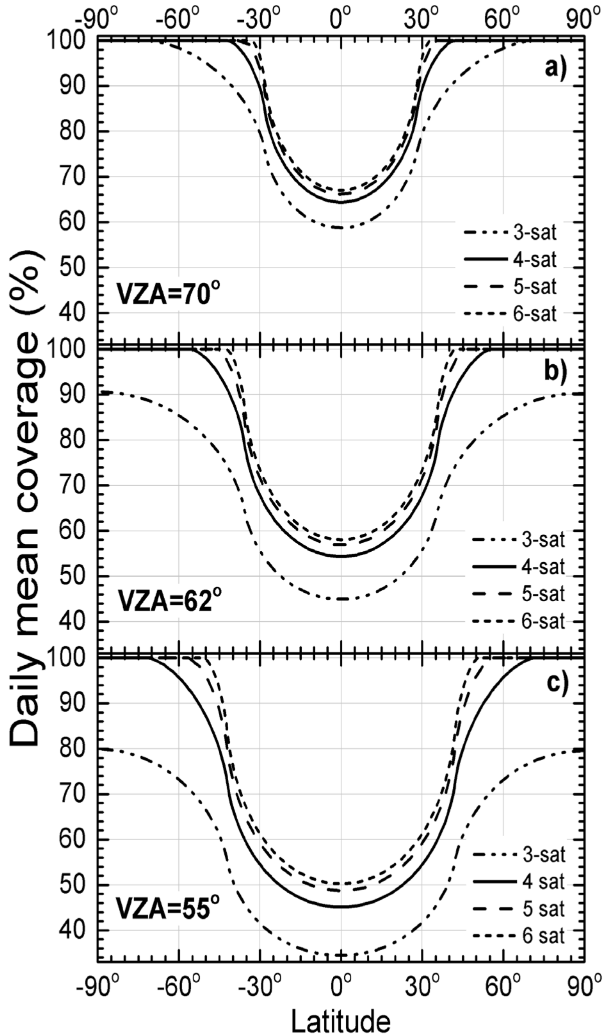


Orbit selection for MEO

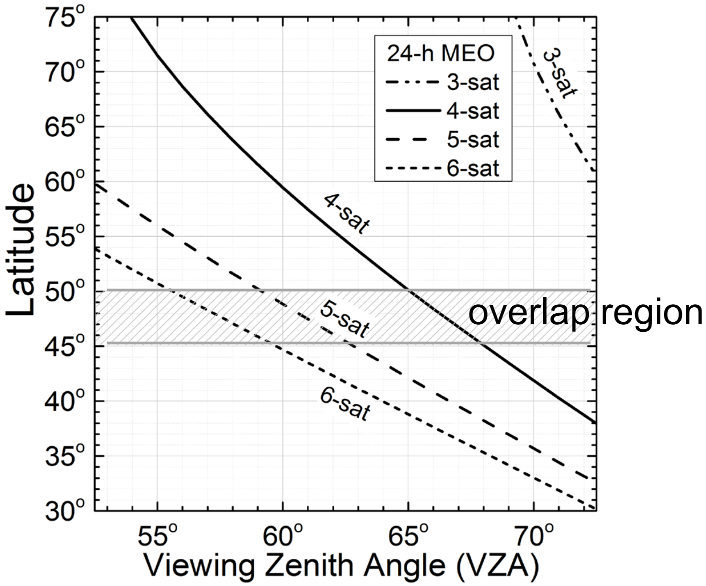


- Goal is full coverage down to 45-50°N (pink region)
- 36,000 km (24-h period) seems good compromise to limit the number of satellites to 5 or 6 (VZA of 62° or higher)

MEO 24-h coverage vs VZA limit and number of satellites



- For VZA of 62° need of at least 5 satellites to get coverage down to 45-50° N area
- Need 6 satellites if VZA limit is 55°
- Need 4 satellites if VZA limit is 70°

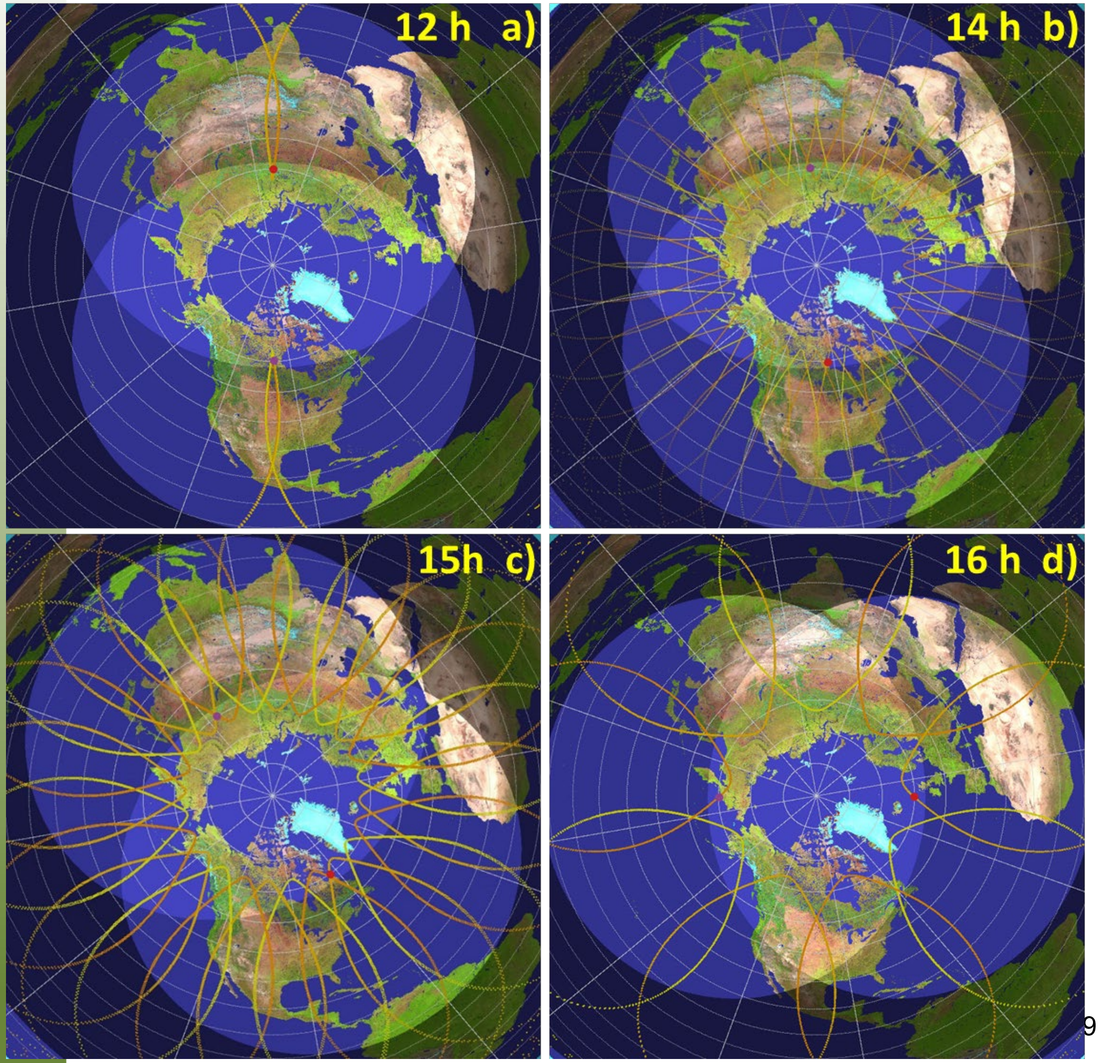


Comparing GEO, MEO-24 h and LEO

Parameter	GEO	MEO 24 h	LEO	HEO 12 h (e=0.74)				HEO 16 h (e=0.74)			
				Apogee	Mid point (±2 h)	Average	Start/End imaging period (±4 h)	Apogee	Mid point (±2 h40’)	Average	Start/End imaging period (±5 h20’)
Altitude [km]	35,800	35,800	830	39,850	36,200	34,800	24,050	49,600	45,200	43,500	30,450
Ground speed [km/s]	0	0.46-0.66	6.60	0.00	0.10	0.13	0.35	0.05	0.10	0.12	0.28
Altitude scale factor relative to GEO	1.00	1.00	1.00*	1.11	1.01	0.97	0.67	1.39	1.26	1.22	0.85
VZA (deg)	Pixel Growth Factor (PGF) relative to VZA=0°										
55°	1.86	1.86	2.75	1.85	1.86	1.86	1.91	1.83	1.84	1.84	1.88
60°	2.16	2.16	3.47	2.14	2.16	2.16	2.22	2.12	2.13	2.13	2.18
65°	2.58	2.58	4.59	2.56	2.58	2.59	2.67	2.53	2.54	2.55	2.62
70°	3.23	3.23	6.42	3.20	3.23	3.24	3.36	3.15	3.17	3.18	3.28

GEO and MEO-24-h altitude are the same
MEO ground speed about twice that of HEO at start of imaging

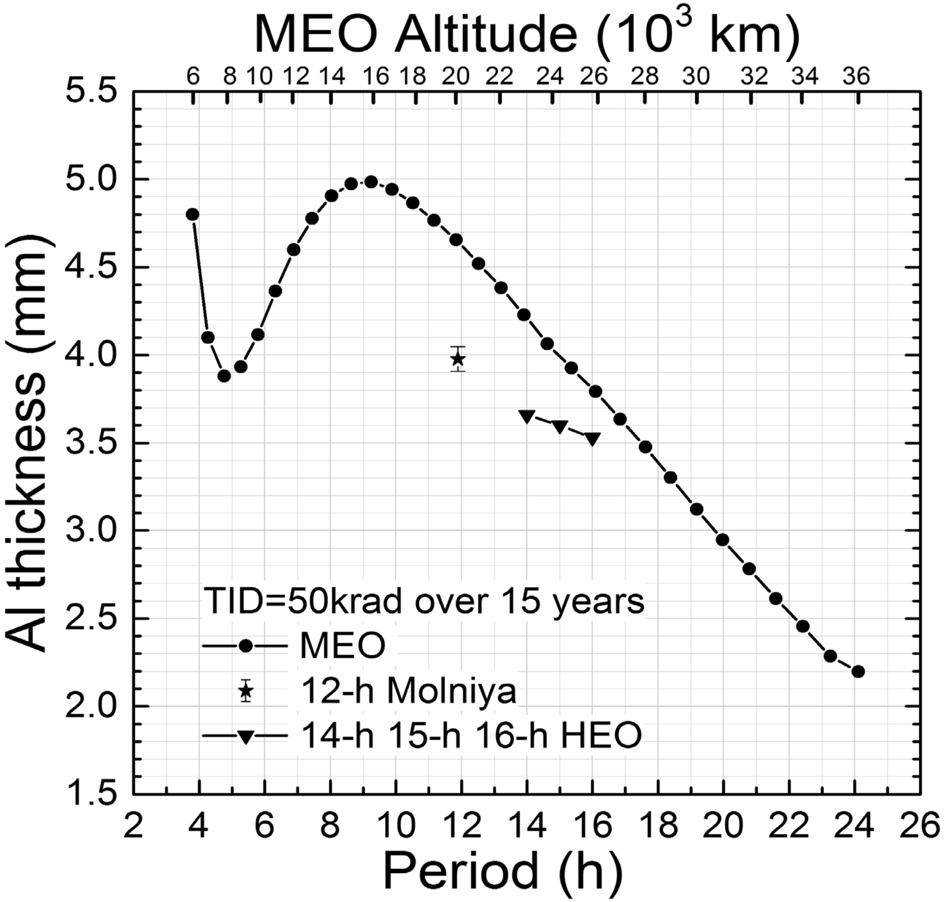
Comparing 12h, 14-h, 15-h, 16-h HEO



P3 configuration: 3 orbital Planes

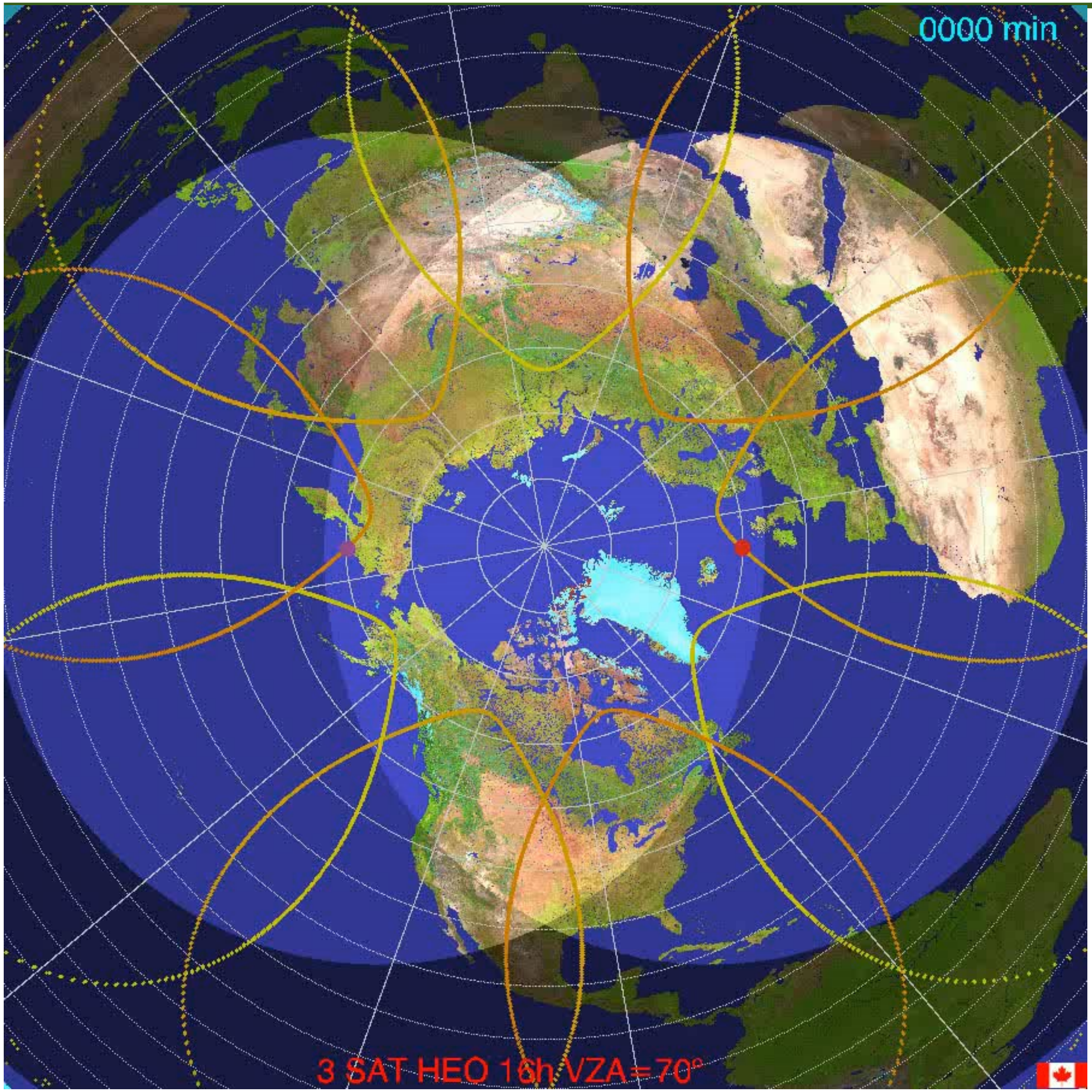
- 2 apogee locations over 1 day for 12-h orbit
- 36 (12 X 3) over 7 days for 14-h orbit
- 24 over (8 X 3) over 5 days for 15-h orbit
- 9 (3 X 3) over 2 days for 16-h orbit

Radiation shielding required for a 15-year mission duration



- MEO 24-h least affected by ionizing radiation
- HEO 12-h most affected
- Computed using ESA SPENVIS tool with AP-8/AE-8 trapped radiation models

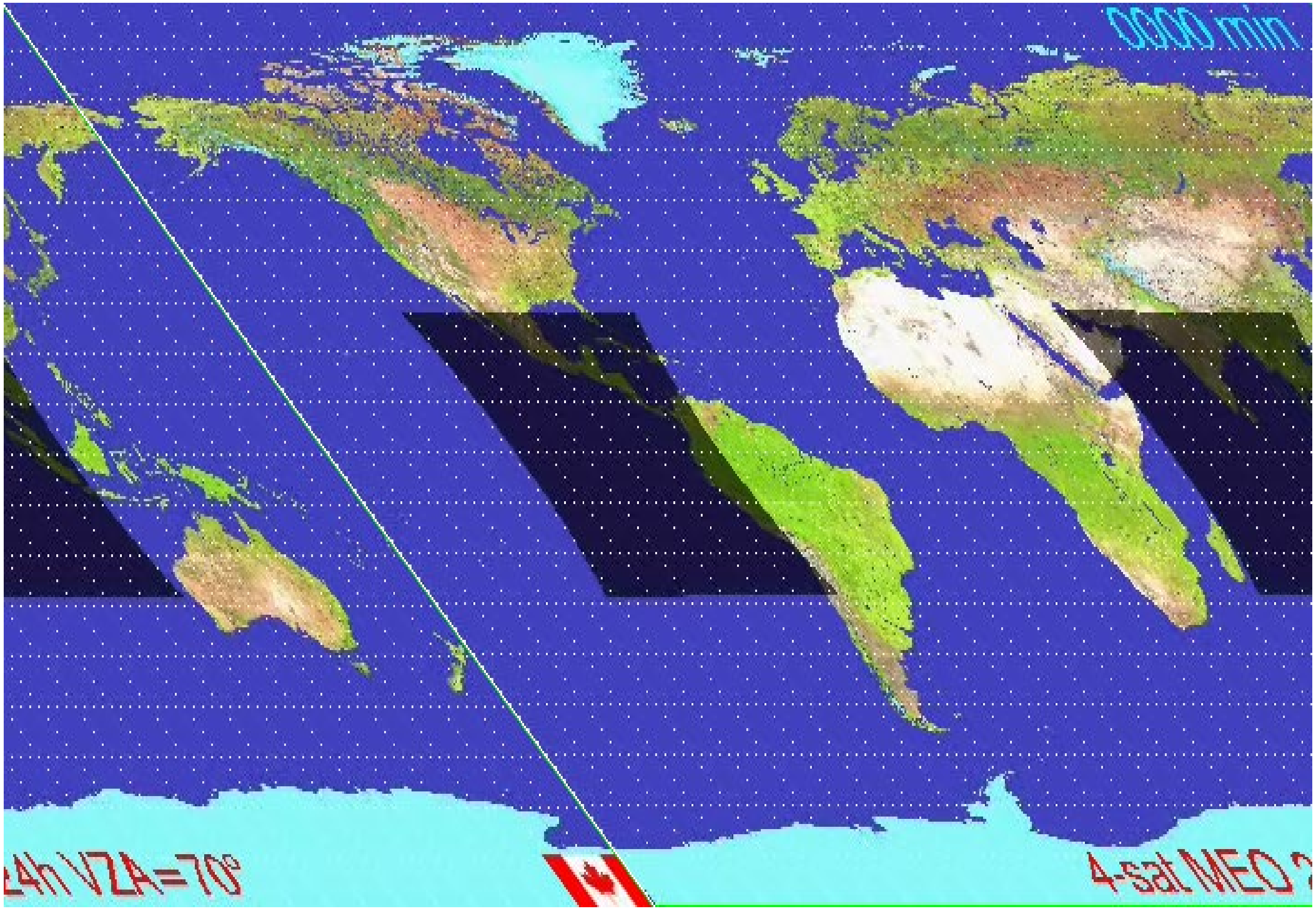
3-sat HEO with max VZA 70 deg



16-h HEO
9 apogees:
3 for each satellite
in 48-h period

Canada

4-sat MEO with max VZA 70 deg



Conclusion

- Both HEO and MEO can provide continuous imaging capacity over polar areas using 4-6 satellites
- Both provide full coverage down to ~58 N/S from 4 satellites (VZA=70º) and down to 45-50 N/S region from 6 satellites with VZA limit 62º. MEO global coverage is superior to HEO with same number of sats.
- MEO is most advantageous from a viewpoint of ionizing radiation.
- HEO has the advantage of slightly slower ground speed, but added complexity linked to variable pixel size.
- Possibility of other payloads should be investigated

→ No significant technical barrier; international cooperation likely required

Reference: Trishchenko, Garand, Trichtchenko, 2019: JTECH, 36(8), 1605-1621
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