LOW-COST MULTI-MODE SAR-AIS CONSTELLATION FOR SHORT-REPEAT ARCTIC MARITIME SURVEILLANCE

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OVERVIEW

- **Introduction**
  - Arctic Background
  - Mission Objectives
  - Simulated Mission Environment
- **Payload Design**
  - Methodology
  - SAR Performance Analysis
  - AIS Selection
  - SAR-AIS Summary
- **SAR-AIS Constellation Design**
  - Methodology
  - Constellation Performance
  - Coverage Capabilities
- **Conclusions**

BACKGROUND

ARCTIC SITUATION:

- Rapid regression of Arctic Ice giving place to new ice-free corridors. Beneficial for commercial, industrial, and military stake-holders in the region.
- Studies report an increase of 128% in marine traffic in 2008, and an increment of 30% of international presence (determined by number of flag states) in the time-span of 2 years (2015-2017).
- By continuously monitoring the individual assets guarantees safe, secure, and reliable operations, while providing long-term reporting and aiding the decision-making process at any given scenarios.

OBJECTIVES

1. To develop a design space and performance analysis for a remote sensing payload capable of providing imagery for maritime surveillance.
2. To define a suitable payload configuration adopting requirements and limitations based on OneWeb's Arrow space platform.
3. To propose a satellite constellation configuration capable of achieving revisit times in the range of 1-3 hours in the arctic zone.

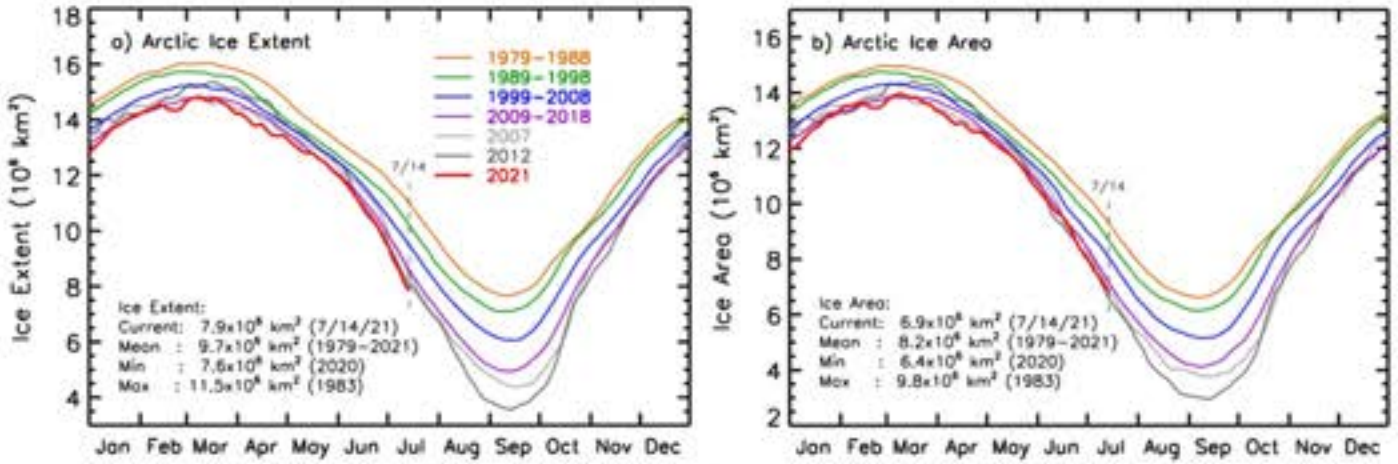

Figure 1. Progressive Arctic Ice Extent / Area (NASA, 2021)

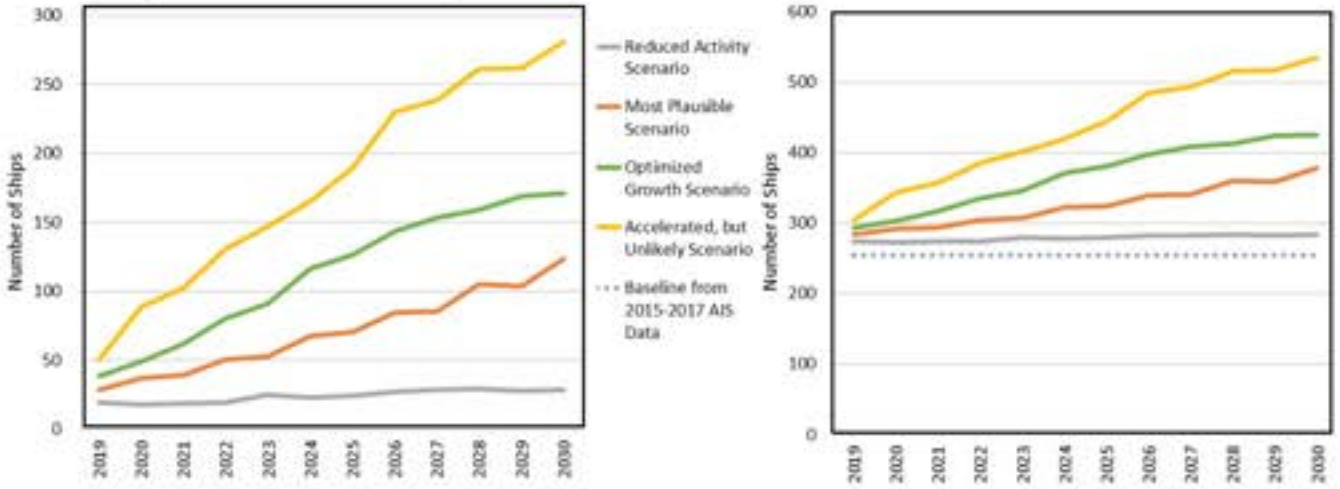

Figure 2. Projected Increase of Vessels in Arctic Region (US. CMTS, 2019)

SIMULATED MISSION ENVIRONMENT

OPERATIONAL PARAMETERS & CONSTRAINTS:

- Satellite Operational Altitude range : h = 500 – 1500 km
- Ground Resolution, Azimuth : ρ_{az} = 2.5 – 10 m
- Ground Resolution, Range : ρ_{rg} = 2.5 – 10 m
- Carrier Frequency : λ = Ka/Ku/X (35/13.8/10 GHz)
- Max allowed Antenna Dimensions: $L_{az}\ x\ L_{rg}$ = 5m x 1m

- **Surface Target: Medium-Large Vessels in Ocean Surface**
- **Specific Application: Ship Detection**

Figure 3. Airbus – Arrow Platform (Airbus, 2021).

COVERAGE LIMITS

- The desired area for coverage in this system's study is limited to the arctic circle (lat. ≥ 66°) with exclusion to the permafrost region (lat. ≥ 80°). The following initial computation validates the user requirements set for revisit times between 1 and 3 hours

Figure 4. Arctic Region Definition and Relevant Areas (NASA, 2021).

Item	Target Area	Latitude (deg)	Longitude (deg)
1	Chukchi Sea	65.7 N	168.9 W
2	Davis Strait	68.9 N	62.6 W
3	Barents Sea	74.8 N	40.1 E
4	Kara Sea	74.9 N	73.4 E
5	Greenland Sea	77.7 N	5.5 W
6	Svalbard	78.9 N	20.5 E
7	Arctic Region	68 - 80 N	-

Table 1. Identified areas of interest for coverage analysis

SAR PAYLOAD DESIGN

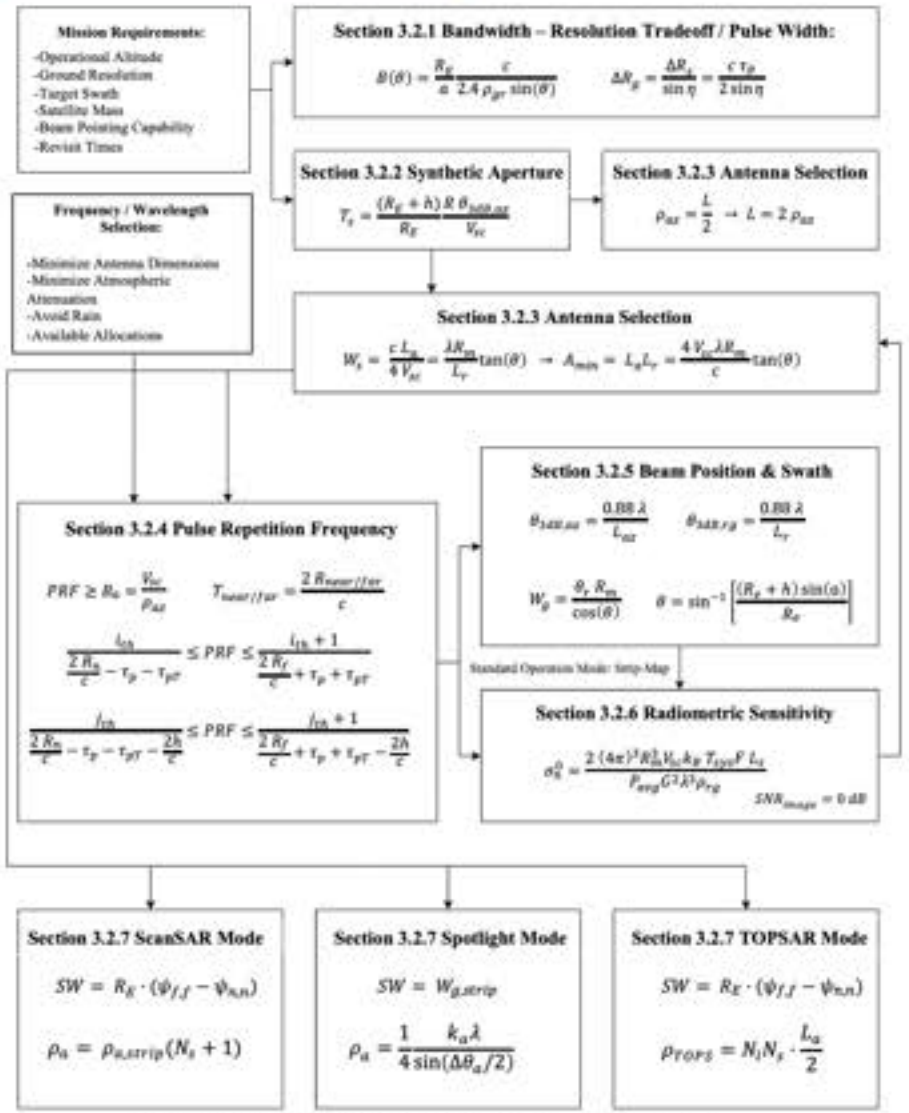

Figure 4. SAR Payload Design Methodology

REMARKS:

- Validated through system performance comparison with *M. D'Enrico, et. al. (1996). Space Constellation of High-Resolution SARs for Fast Global Access, 1996.* (95-97% match to analytical results).
- Standard modes of operation include: Strip-Map, Spotlight, ScanSAR, TOPSAR.
- SIMO ScanSAR mode as an alternative to ultra-wide swath coverage.

Parameter	Variable	Strip-Map	Spotlight	ScanSAR	TOPSAR	Units
Altitude	h	600	600	600	600	km
Min. Ap. Area	A_e	2.426	2.426	2.426	2.426	m^2
Antenna Length	L_a	5	5	5	5	m
Antenna Width	L_r	0.485	0.485	0.485	0.485	m
Beam Width, Az	$\theta_{3dB,\,a}$	0.304	0.304	0.304	0.304	deg
Beam Width, Rg	$\theta_{3dB,\,r}$	3.138	3.138	3.138	3.138	deg
Min. Look Angle	θ	15	15	15	15	deg
Max. Look Angle	θ	40	40	40	40	deg
No. of Beams	N_s	1	1	3	3	-
Pulse Width	τ_p	10	10	10	10	μs
Ground Res. Az	ρ_a	2.5	1	10	10	m
Ground Res. Rg	ρ_r	2.5	1	10	10	m
Carrier Frequency	f	10	10	10	10	GHz
Range Bandwidth	B	71 - 176	72 - 176	13 - 44	14 - 44	MHz
PRF Range	PRF	3.0 - 4.3	-	2.7 - 4.5	-	kHz
Max. Swath Width	W_g	51	20-30	152	152	km
DC Power Input	P_{elec}	200	200	200	200	W
TWT, Eff.	η	60	60	60	60	%
RF Power, Pavg	P_{avg}	120	120	120	120	W
Sensitivity, NESZ	σ_n^0	≤-13.4	-	-	-	dB

Table 2. SAR Payload Performance Summary

SAR PAYLOAD DESIGN

Parameter	Variable	Strip-Map	Spotlight	ScanSAR	TOPSAR	Units
Altitude	h	600	600	600	600	km
Min. Ap. Area	A_e	2.426	2.426	2.426	2.426	m^2
Antenna Length	L_a	5	5	5	5	m
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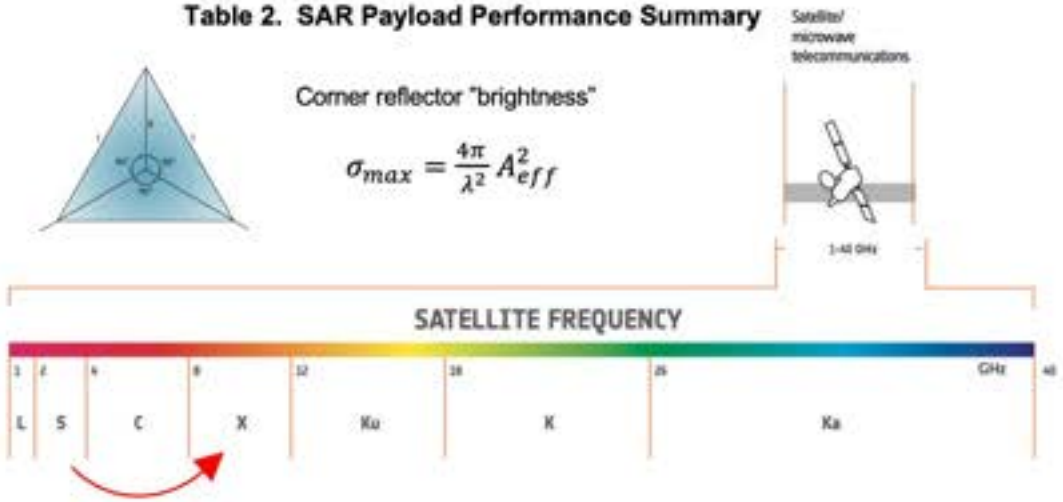


Figure 6. NESZ requirement reduction due to wavelength drop (Ulaby, F., 2019)

SIMO ScanSAR Mode Features:

- No. Azimuth Channels: 2
- Number of bursts: 6
- Achievable Swath: 280 km
- Achievable Resolution: 10m

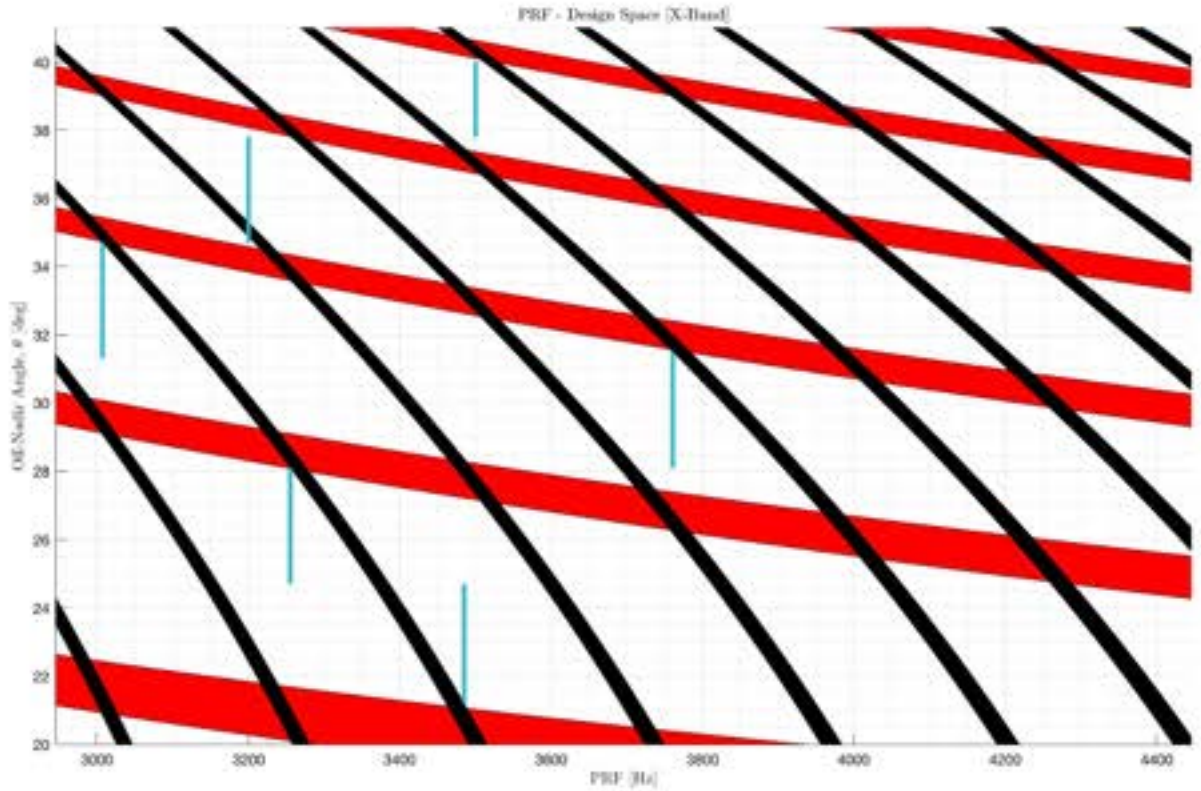


Figure 8. SIMO ScanSAR Capabilities

AIS PAYLOAD SELECTION

- Automated Identification System (AIS) defined as secondary payload
- NorSat-1 and NorSat-2 missions demonstrated that a single AIS payload receiver provided low cost, effective monitoring of maritime vessels in the high north regions of the planet.

Item	System Mass	Power Gen	Orbit	AIS Mass	AIS Power
NorSat-1	15.6 kg	45 W	600 km (SSO)	1.3 kg	4.5 W
NorSat-2	16.7 kg	56 W	600 km (SSO)	1.3 kg	4.5 W

Table 3. NorSat-1/2 Spacecraft and AIS payload features

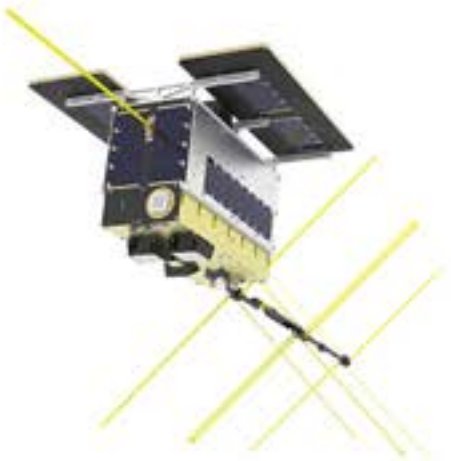


Figure 9. NorSat-1/2 (eoPortal, 2021)

Selected payload: Honeywell Satellite-AIS Receiver AIS-MS03

GENERAL	
MASS	1400g
DIMENSIONS	228 x 180 x 41 mm
DC POWER CONSUMPTION	6 W maximum, with two channels powered
SUPPLY VOLTAGE	28V ± 6V
OPERATING TEMPERATURE RANGE	-10°C to +50°C
NON-OPERATING TEMPERATURE RANGE	-35°C to +80°C
RADIATION TOLERANCE	10 KRad
RECEIVER	
POLARIZATIONS	2, coherent
AIS CHANNELS PER POLARIZATION	4
DEFAULT CHANNEL FREQUENCIES	161.975 MHz, 162.025 MHz, 156.775 MHz, 156.825 MHz
SUPPORT FOR FUTURE FREQUENCIES	161.950 MHz, 162.000 MHz
CHANNEL BANDWIDTH	25 kHz
SENSITIVITY	< -118 dBm (10% AIS Packet Error Rate)
SIMULTANEOUS DYNAMIC RANGE	55 dB
RF INPUT BANDWIDTH	156.0 MHz to 163.0 MHz
FREQUENCY STABILITY	±0.5 ppm
PHASE COHERENCY	± 5°
PASSBAND RIPPLE	< 1dB
DIGITAL PROCESSOR	
RAW SAMPLE RATE	> 28.8 Ksps
SAMPLE BIT DEPTH	12 bits
OPTIONAL BUILT-IN STORAGE CAPACITY	8 GB Flash (4 x 2GB banks)
INTERFACES	
RF	2 x SMA-F, 50 Ohm
TM/TC	Dual redundant CAN bus
HIGH SPEED DATA	Dual redundant Synchronous Serial LVDS Interface up to 50 Mbps

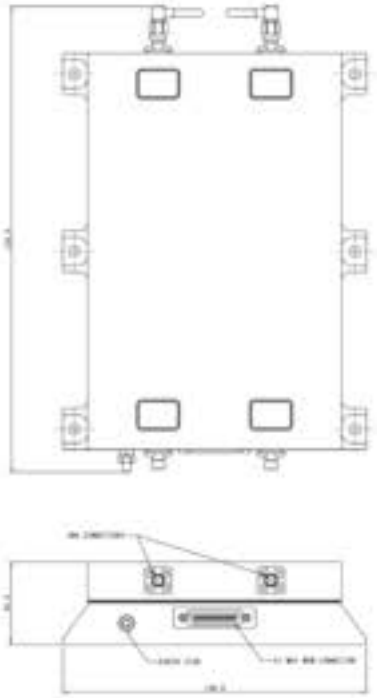


Figure 10. Honeywell AIS-MS03 datasheet (Honeywell Aerospace, 2018)

SAR-AIS CONSTELLATION DESIGN

- The desired area for coverage in this system's study is limited to the arctic circle (lat. ≥ 66°) with exclusion to the permafrost region (lat. ≥ 80°).
- Coverage is evaluated via ***Age of Data*** and ***Revisit Times***.
- Satellite constellation configuration based on streets-of-coverage approach.
- The simulated environment accounts for 2 case studies as follows:

Parameter	Variable	S/C #1	S/C #2	S/C #3	S/C #4
Semimajor Axis	a	6978 km	6978 km	6978 km	6978 km
Eccentricity	e	0	0	0	0
Inclination	i	77.3°	75.0°	77.3°	75.0°
Arg. of Periapsis	ω	0°	0°	0°	0°
RAAN	Ω	0°	0°	180°	180°
True Anomaly	θ	0°	0°	0°	0°

Orbit Epoch	JDT	2459400.9	Julian Days
Propagation Time	T-Span	72	Hours

Table 3. Satellite Constellation - Classical Orbital Parameters

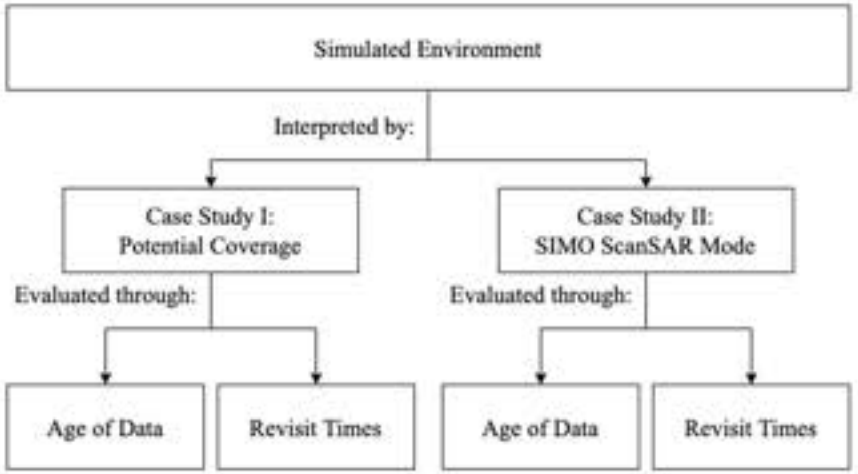
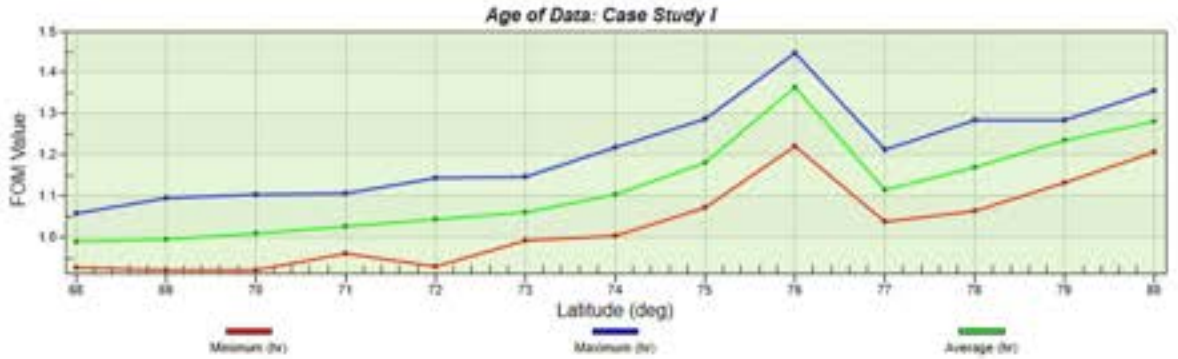


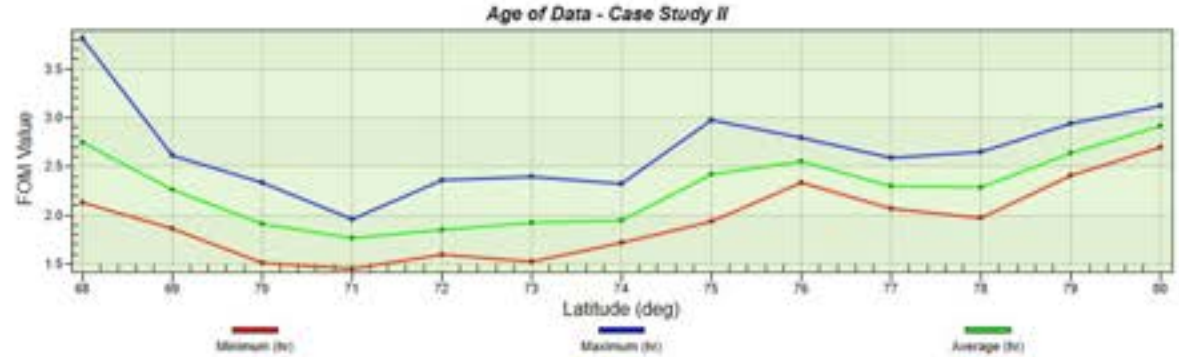
Figure 11. Methodology for coverage evaluation

Figure 12. Area coverage definition

SAR-AIS CONSTELLATION PERFORMANCE ANALYSIS

Within permitted range Outside permitted range





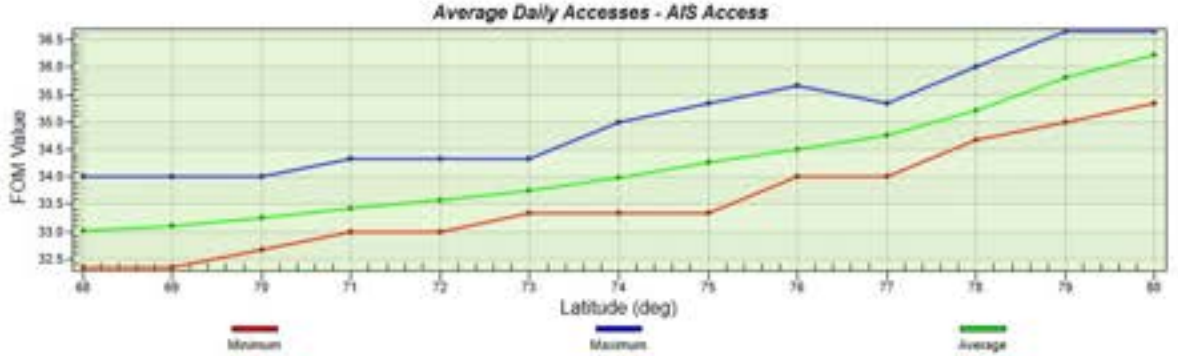
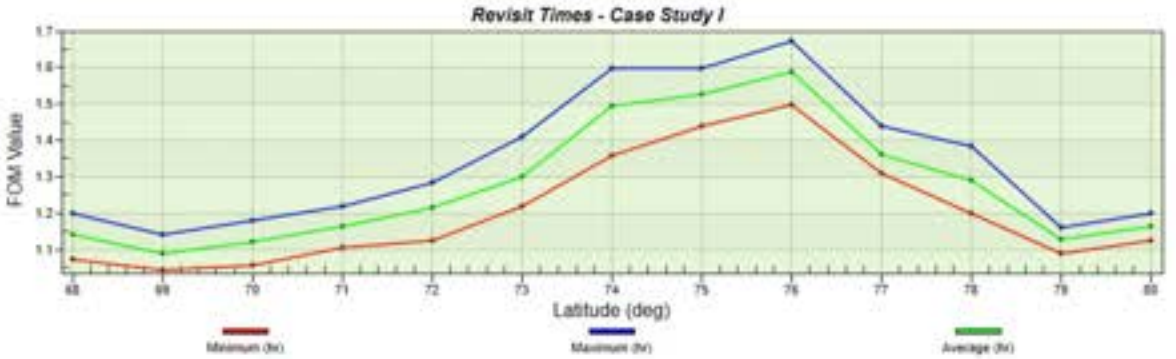
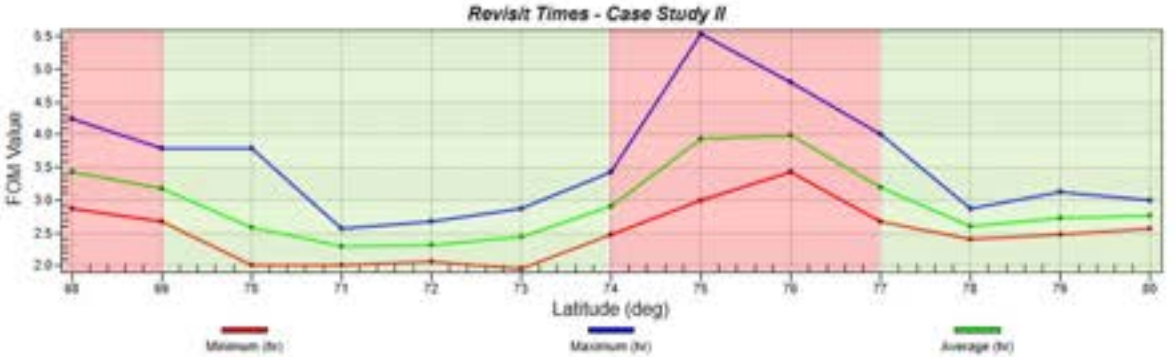


Figure 13. Age of Data Results – Case Study I, II & AIS Access (STK, 2021)





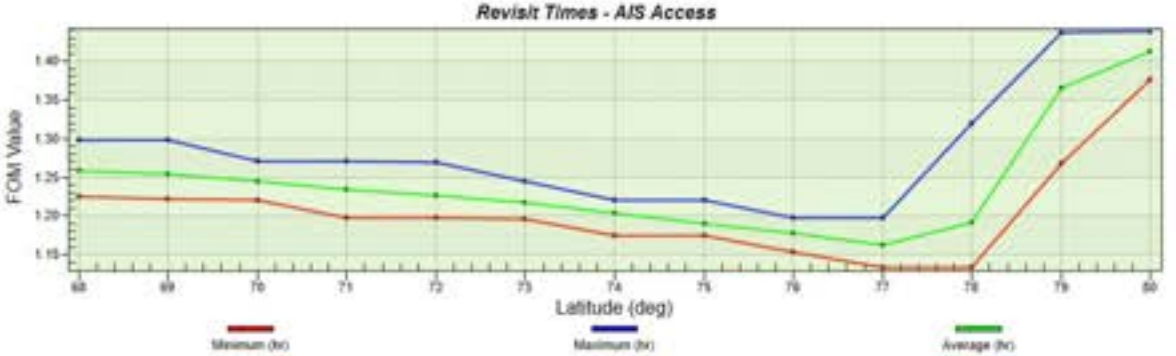


Figure 14. Revisit Times Results – Case Study I, II, & AIS (STK, 2021)

CONCLUSIONS AND IMPORTANT REMARKS

Coverage Analysis Results:

Item	Target Area	Latitude (deg)	Coverage (%)	Case Study I		Case Study II		AIS Access	
				Age of Data (AVG)	Revisit Time (AVG)	Age of Data (AVG)	Revisit Time (AVG)	# Daily Accesses (AVG)	Revisit Time (AVG)
1	Chukchi Sea	65.7	100	1.14 Hrs	1.36 Hrs	3.84 Hrs	4.13 Hrs	32	1.29 Hrs
2	Davis Strait	68.91	100	0.99 Hrs	1.12 Hrs	2.19 Hrs	2.96 Hrs	32	1.24 Hrs
3	Barents Sea	74.8	100	1.2 Hrs	1.54 Hrs	2.23 Hrs	3.59 Hrs	34	1.18 Hrs
4	Kara Sea	74.9	100	1.19 Hrs	1.52 Hrs	2.28 Hrs	3.58 Hrs	34	1.19 Hrs
5	Greenland Sea	77.7	100	1.13 Hrs	1.29 Hrs	2.23 Hrs	2.77 Hrs	35	1.19 Hrs
6	Svalbard	78.9	100	1.18 Hrs	1.22 Hrs	2.37 Hrs	2.72 Hrs	35	1.27 Hrs

Table 4. Coverage results for identified areas of interest

Concluding Remarks:

- Average Arctic region age of data: 1.13 hrs (CS I), 2.52 hrs (CS II).
- Average Arctic region Revisit Times: 1.30 hrs (CS I), 3.29 hrs (CS II).
- Extent of results outside the permitted limits does not rise above the 150% mark (average).
- SIMO ScanSAR subject to data-processing and signal-processing requirements.

Future Work:

Potential improvements to the above remarks may be found within:

- Extended Ambiguous Swath (e.g., NovaSAR-1).
- SAR payload improvements through NESZ reduction.
- Satellite constellation design approach: Discontinuous Polar Coverage.
- Increased spacecraft count.

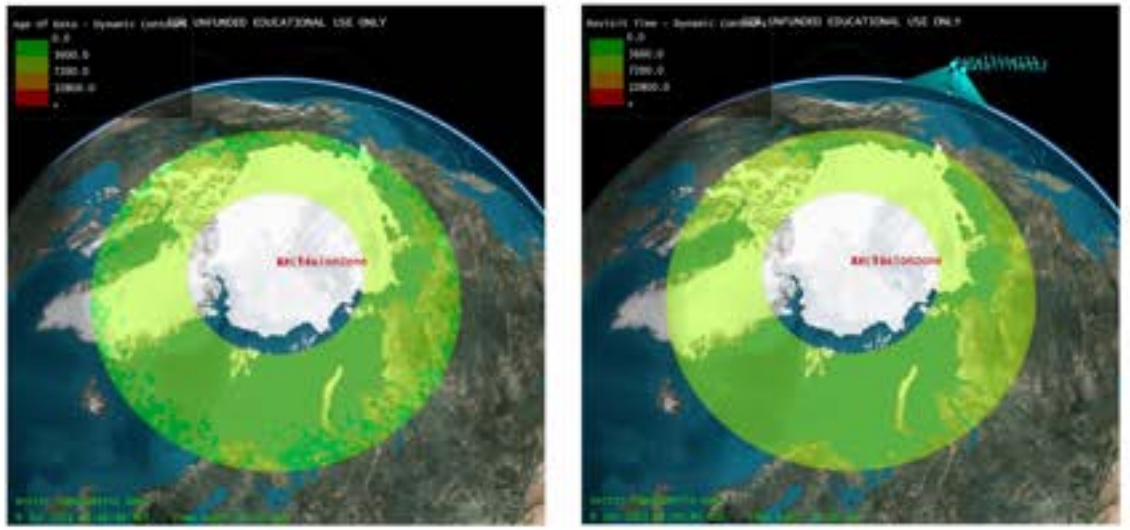


Figure 15. Age of Data & Revisit Times Simulation – Case Study I (STK, 2021)

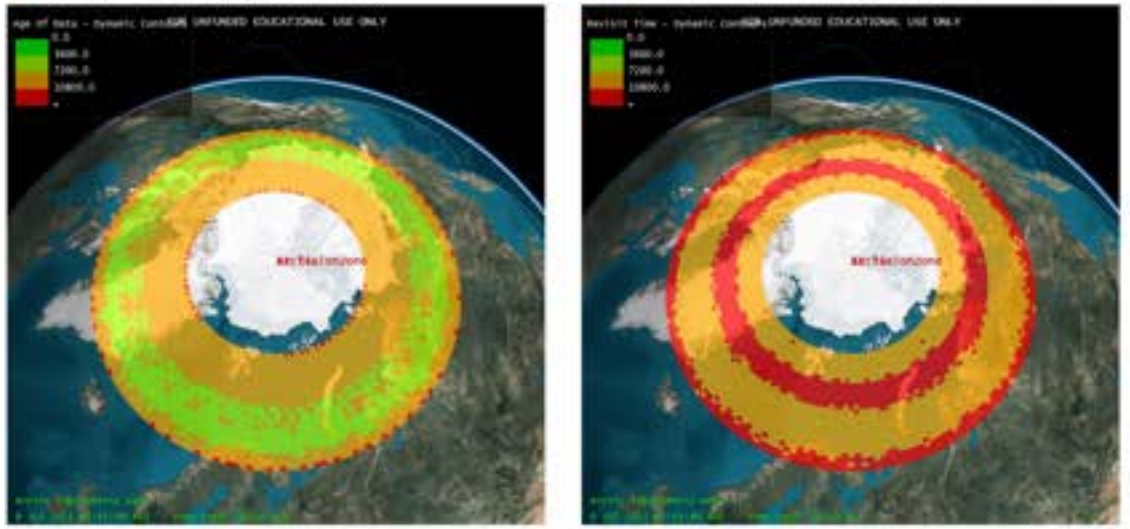


Figure 16. Age of Data & Revisit Times Simulation – Case Study II (STK, 2021)

Q & A: MINIMALIST MULTI-MODE SAR-AIS CONSTELLATION

LOW-COST MULTI-MODE SAR-AIS CONSTELLATION FOR SHORT-REPEAT ARCTIC MARITIME SURVEILLANCE

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THANK YOU!