5th Nano-Satellite Symposium

"Missions and Enabling Technologies towards Future"

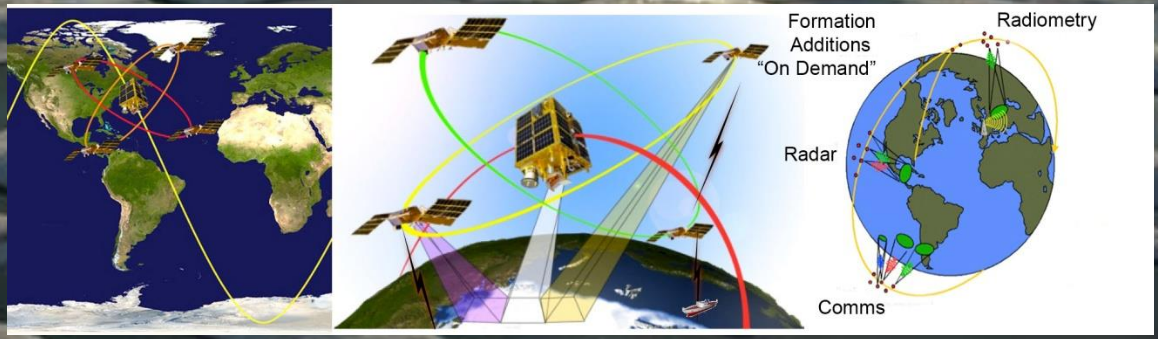
The Arctic Regional Communications small SATellite (ARCSAT)

Joseph Casas[1], Martin Kress[2], William Sims[1], Stephen Spehn[3], Talbot Jaeger[4] and Devon Sanders[1]

[1]NASA Marshall Space Flight Center, USA; [2]The Von Braun Center for Science & Innovation, USA; [3]HQ USEUCOM,ECJ8-Q; [4]Novawurks Inc., USA

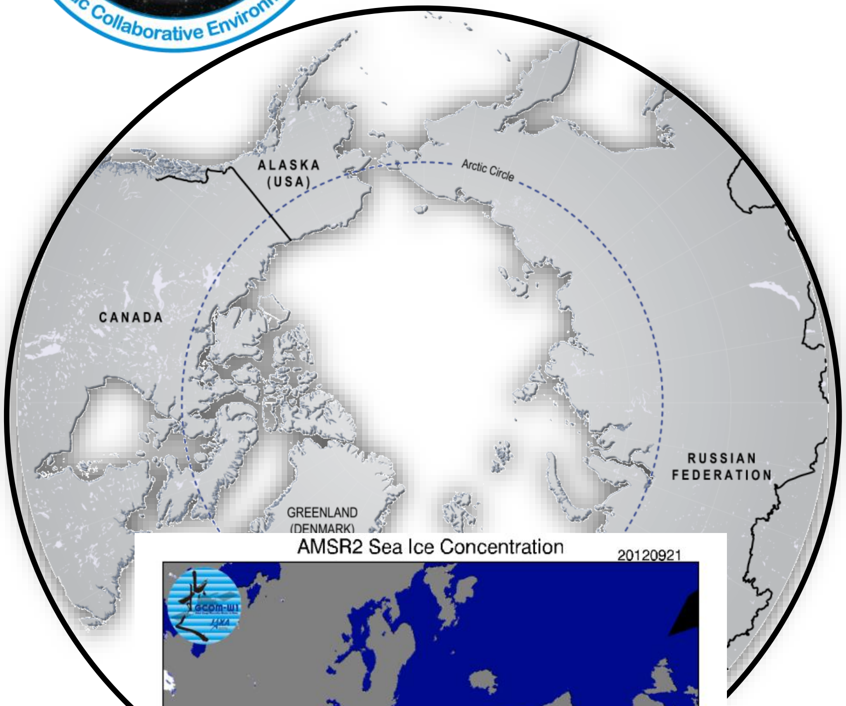
Joseph.c.casas@nasa.gov

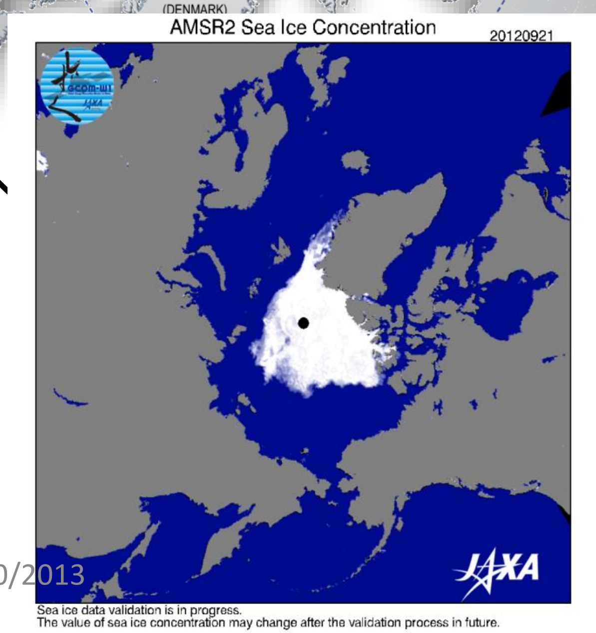
November 20 - 22, 2013
Takeda Hall, University of Tokyo
Tokyo, Japan



Outline for Discussion

- Background for Concept of Small Satellite Arctic Mission
- Status of Communications Gap
- Desired Capabilities
- Integration of Proven Technologies
- Concept of Operations
- Summary of Conclusions





The Arctic is increasingly important to regional economic and national security

Our challenge is to frame a systems solution for very complex technical , societal and political issues – to think differently about the region and our options – capitalize on the full portfolio of regional capabilities and assets – provide a suite of traditional and new innovative approaches for needed services and capabilities - a well balanced invested portfolio approach of solutions

This all starts with the basics – sharing, working together, prioritizing, adapting, innovating ,comprising…….

Arctic Collaborative Environment (ACE) Operational Problem

There exists no Arctic awareness, decision-support system to enable long-term environmental planning, near-term cooperative actions, and real-time responses to humanitarian, environmental, and security issues in the Arctic

- No overarching operational architecture or universal core system for data & tool integration
- No common integrator of varied data sources
- Inadequate environmental visualization to support development of cooperative Arctic policies
- Inadequate access to models to support planning
- Insufficient integration of environmental data to support ongoing and future research and operations (e.g., exploration, SAR, Humanitarian Response, Economic Activities, Environmental Response, Recovery Operations, Strategic Movement, Training)

The ACE JCTD will provide immediate capabilities and jump-start new solutions to common problems shared across the Arctic Community

Mini-Overview of Arctic Collaboration Environment (ACE) Project

- The ACE Joint Capabilities Technology Demonstration will provide a **web-based, open-access, Arctic-focused, environmental research and decision-support system** that integrates data from existing remote sensing assets and in situ observations to provide monitoring, analysis, and visualization based on earth observation data and modeling. The ACE JCTD will enable local, regional, and international cooperation and coordination on long-term environmental planning and near-term actions in response to climatic and environmental changes occurring in the Arctic Region.
- The ACE software tool capitalizes on prior earth science applications work done at NASA MSFC: RTMM, SPoRT, SERVIR, AMSR-E, etc.
- ACE was designed to capitalize on the IPY, foster and promote the exchange of data and models for use in the Arctic Region – create a common area of interest for the Arctic Nations.
- The ACE tool is directly applicable to other regions and applications.
- The ACE Team is committed to “give” its tool to any Arctic Nation or organization – in return the ACE Team would hope it facilitates the exchange of data and models through the use of this tool , other related tools, unique capability studies and new enabling mission formulations
- **Sustaining Arctic Observing Network (SAON) needs each activity and project it endorses as part of an integrated set of capabilities that meet the needs of multiple Arctic nations**

Seven Key Dimensions of ACE

- Create an open access tool to integrate disparate data sets in response to key user requirements in the Arctic Region
- Facilitate data and model sharing and the creation of new and/or enhanced products for end users
- Transition the System to the National Ice Center to sustain its viability and value to regional operators & researchers
- Open source the tool to other regions and potential applications
- Get the next generation of researchers working together
- Serve as the first step to additional collaborative projects and activities
- **Identify and define new data sets, instruments and infrastructure for situational awareness and <u>missions that will be provide enhanced societal benefits within the arctic</u>**

A Gap: Communications Operational Problem

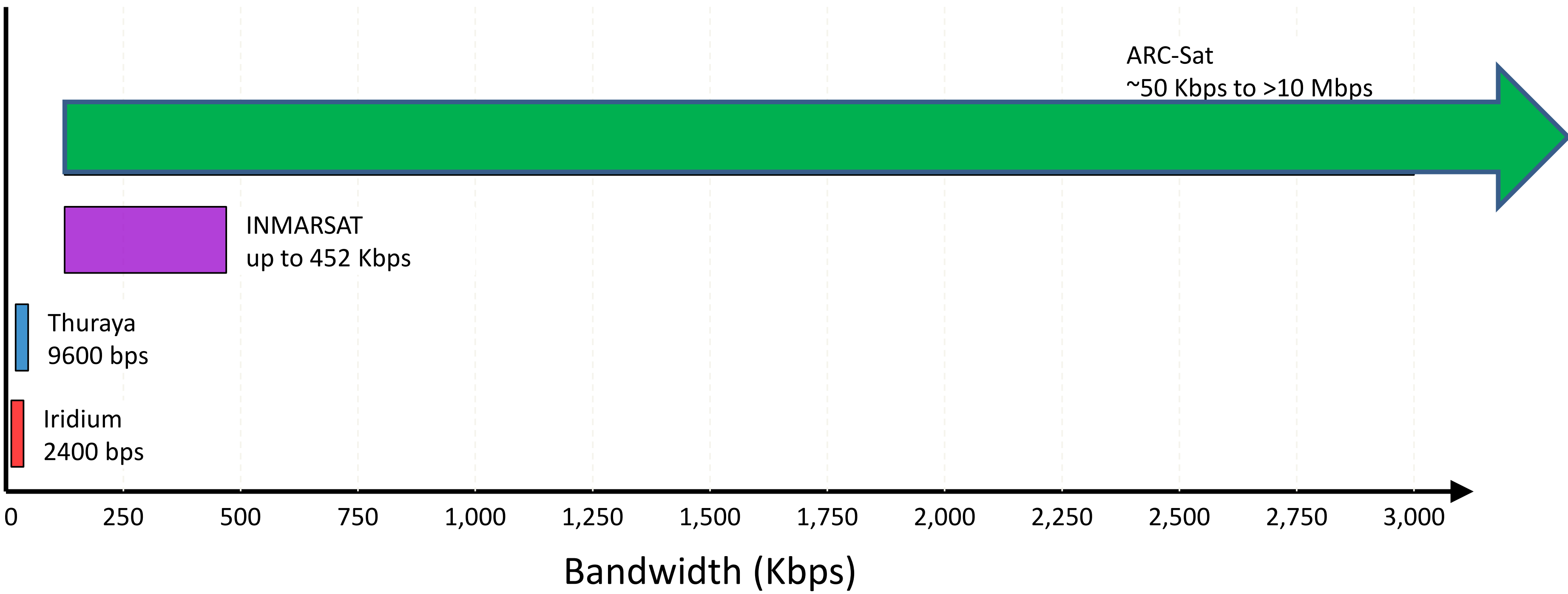
Organizations with operational responsibility in the Arctic lack the capabilities necessary to meet emerging challenges and operational requirements in the Region

- Organizations are unable to support near- and mid-term Arctic operations and research to include: Humanitarian Response, Environmental Response, International Search & Rescue (SAR), Climate Change and Counter-Trafficking
- Shortfalls to these missions include:
  - Inadequate coverage and throughput of communications relay to support Arctic operations and research
  - Inadequate Maritime Domain Awareness (MDA) in the Arctic Region to coordinate responses to regional security issues
  - No capability for near-real time data-extraction of unattended sensors in the Arctic Region
- Existing and planned capabilities cannot satisfy these shortfalls
  - Iridium, Thuraya, and INMARSAT do not meet growing requirements for tactical communications and cannot interrogate unattended sensors
  - Existing AIS collection has gaps and restrictions to data dissemination and sharing that inhibit collaborative Maritime Domain Awareness

ARC-Sat will provide near term capabilities through responsive small satellite orbital assets to support emergent operational and research requirements in the Arctic Region

Example of Technology Push

ARC-Sat provides greater bandwidth by capitalizing on low-cost, advanced CubeSat technology



- Current commercial systems are simultaneous multi-user but have max data rate limitations
- ARC-Sat integrates a MiniSat and two or four CubeSats to provide robust, adaptable communications relay
- DARPA algorithms enable formation flying and precision spotlighting of directional beams
- ARC-Sat can tailor the link margin to the mission and environment through SDR band selection beam-forming, precision spotlighting, waveform shaping, and channel bundling

Some Desired Capabilities

U.S. and its Arctic partners contribute to the peaceful opening of the Arctic in a manner that strengthens international cooperation

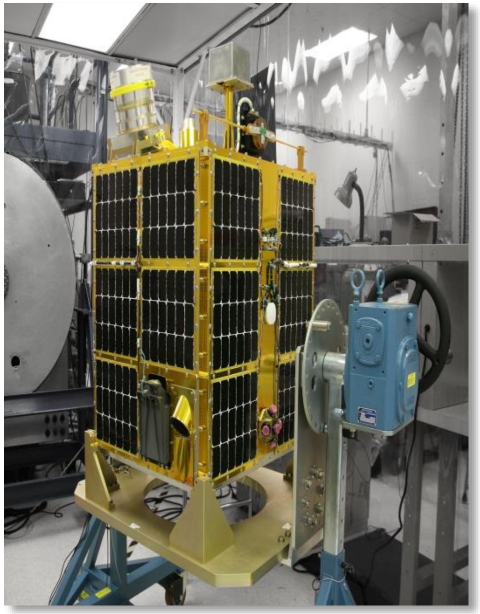
- Technical
  - Communications relay to support Arctic operations
    - Periodic coverage to support voice relay and high rate data communications
    - Communications relay with waveform and frequency agility to support existing and developing systems
  - Enhanced Maritime Domain Awareness (MDA) in the Arctic
  - Remote data extraction from unattended sensors
  - Reception and relay of emergency position-indicating radio beacon (EPIRB) transmissions
  - Satellite fractionation for LEO long-baseline interferometry
- Operational: CONOPS and TTP
  - Arctic Environmental Awareness to plan and execute collaborative international response
  - Communications to coordinate international response to Arctic environmental and humanitarian issues

ARC-Sat will enable collaboration and cooperation through enhanced communications and data sharing in the Arctic Region

Activities of Interest : Integration of Innovative Proven Technologies

- "Mothership" spacecraft capability for formation flying mission to support lower vehicle integration, launch and orbital deployment cost while still reducing total mission development schedule. Mothership also provides additional capabilities to support imagery , AIS , data extraction, SAR and other potential instruments
- Highly capable nanosatellites(each 10 X 10 X 30 cm and less than 10 kg) with advanced capabilities in power generation, autonomous tasking flight control, high energetic green fuel propulsion and multi-functional spacecraft arrays. Small satellites in formation flying that can perform elements of fractionalization to enhance overall mission capabilities.
- Incorporation of RF communications capabilities reconfigurable for UHF, S , C , X and future Ka band that focus on a reprogrammable software defined radio(SDR) which includes a cost effective SAR radio capability with a total low power, mass and size requirements that can then be used as an infusion path for subsequent developments and missions
- Maintaining compatibility with most current heritage communication systems while infusing the enhanced capabilities of new light weight portable ground antenna systems compatible with the Arctic
- ARC-Sat and its associated systems are transferrable to the Antarctic Region communications

Mini satellite FASTSAT – Proven on STP-S26 Mission
Scheduled for 12 month mission
(Actual November, 2010 through May 2013)



Designed and Built in Huntsville, AL

Kodiak – Nov 19, 2010 Minotaur IV

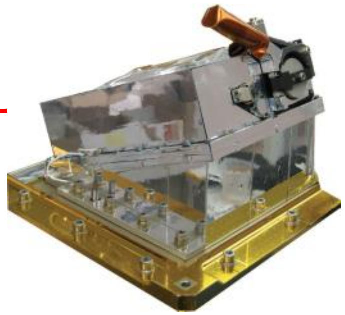
Supported 6 Separate Experiments

Met all NASA cost, schedule and performance targets

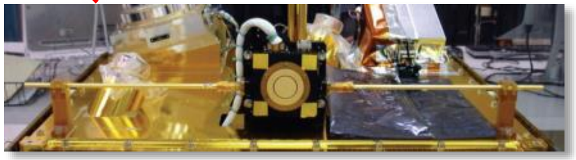
Six Instruments on One Platform

NASA & USNA Miniature Imager for Neutral Ionospheric Atoms and Magnetospheric Electrons (MINI-ME)
(Improve space weather forecasting for operational use)

AFRL Light Detection System
(Evaluate atmospheric propagating characteristics on coherent light generated from known ground stations)



NASA & USNA Thermospheric Temperature Imager (TTI)
(Increase accuracy of orbital predictions for low-earth orbiting assets)



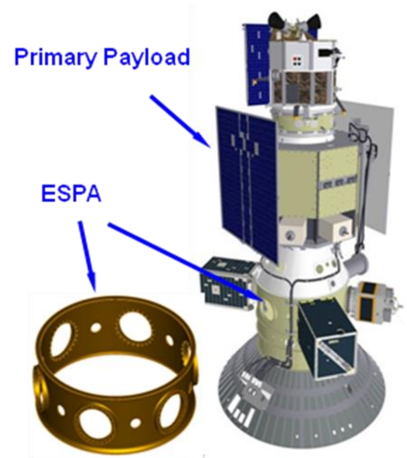
NASA & USNA Plasma Impedance Spectrum Analyzer (PISA)
(Permit better predictive models of space weather effects on communications and GPS signals)

NASA + ARMY + AFRL NanoSail-D
(Demonstrate deployment of a compact 10-m^2 solar sail ejected as CubeSat)

AFRL + NASA + AF Miniature Star Tracker (MST)
(Demonstrate small and low-power star tracker)

Launch Options

- ESPA Class ridesharing

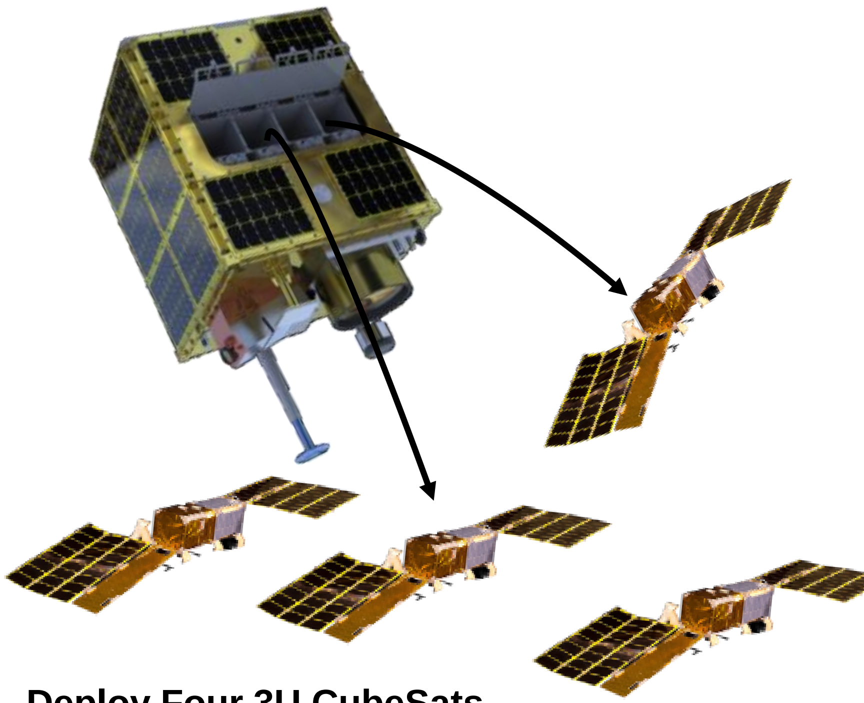


- Current Options

- Future Options

FASTSAT TYPE "Mothership"

Total Mass (kg)	180
Orbit	400 – 850 km 30° - 99°
Stabilization	3-Axis
Attitude Control	0.1°
Attitude Knowledge	0.02°
Downlinks (Mbps)	>5 (S-band) >150 (X-band)
Uplink (kbps)	300 max (S-band)
Ground Networks	STDN, SGLS
Encryption	AES, COMSEC
Mission Life	2 - 4 yr
Number Payloads	4 x 3U CubeSat 4 x Integrated
Payload Mass (kg)	45 - 50
Payload Power (W)	30 – 50 W Avg.
Payload Interface	RS-422 (5) SpaceWire (2) Digital (20 in/40 out)
Payload Data (GB) store & forward	100



- **Deploy Four 3U CubeSats or Two 6U CubeSats**
- **On-Demand, On-orbit Assets,**
- **Constellation Deployment**
- **Communications and imagery "Mothership"**
- **On-Orbit Charging, Status, & SW Upgrades**
- **System Design In Process**

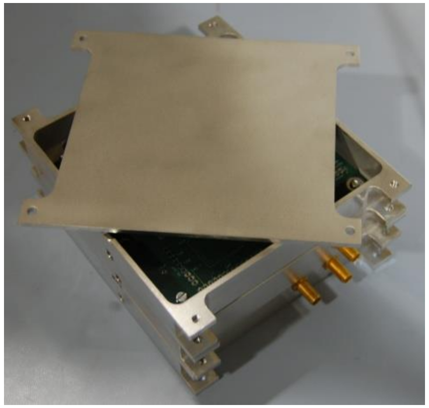
Example Challenge Progress Goals

Challenge	Near-term through 2016	Mid-term 2017 – 2022	Far-term 2023 – 2028
• Remove Comm. as a Constraint		• 200 Mbps from 1 AU • 30 Gbps from LEO	• 20 Gbps from 1 AU • 3 Tbps from LEO
• Minimize Impact of Latency	• Millimeter-level formation control	• Navigation/timekeeping to support: • Micrometer-level formation control	• Navigation/timekeeping to support: • Nanometer-level formation control
• Minimize User Burden		• Reduction of 50% in transponder mass	• Reduction of 75% in transponder mass
• Integrity and Assurance	• Validate unconditional information security techniques to low-Earth orbit (LEO)	• Unconditional information security techniques employed with LEO and some deep space missions	• Global information trust relationships • Internationally-standard unconditional information security with all missions
• Lower Lifecycle	• 20% Reduction from current	• 40% reduction from current	• 80% reduction from current
• Lack of Demo's		• Multi-function SDR demo	• Deep-space relay tech demo
SDR Achievements	• Reduction of 50% in transponder mass Already Completed • 80% reduction from current Already Completed		
SDR Goals	• NASA Near Earth Network (NEN) certification (FY 2013) • Hope Hero Balloon Flight (FY 2014) • TRL 7 or 8 (FY 2013) • Begin Generation 3 – Ka–Band SDR (FY 2014) • Begin SDR Ground Station (FY 2014)	• Lunar missions	

SDR Comparable Comm Systems

- From the OCT “Communication and Navigation Systems Roadmap” - large issues currently impact planned missions that will require slight to moderate improvements in the communication link. The SDR - ***<u>will provide major communication advancements in the communication link TODAY</u>***.
- As depicted in the Roadmap TA05 - ***<u>development of a reprogrammable software defined radio that can then be used as an infusion path for subsequent developments</u>***.
- Software Defined Radio (SDR) technology offers potential to revolutionize satellite transponder technology by increasing ***<u>science data through-put capability by at least an order of magnitude</u>***.
- This project will leverage existing radiation tolerant MSFC SDR TRL-4 hardware and increase it to a TRL-5.

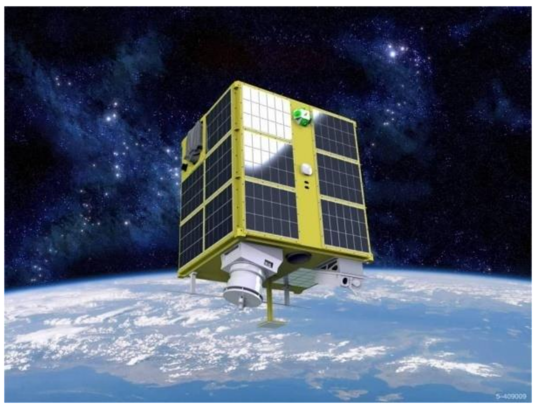
1970’s Cellphone “Transponder”



SDR “Transponder”

Manufacturer	Freq Band	Input DC Power (W)	Uplink Data Rate (kbps)	Downlink Data Rate (Mbps)	Radiation Tolerance (kRads)	Mass (kg)	Cost	Rcvr Bits/Watt (b/W)	Trx Bits/Watt (b/W)
General Dynamics	S	>30	2	10	50	3.3	$1.6M	66 b/W	333 Kb/W
Cubic	S	26	32	1	50	3.2	$2.2M	1.2Kb/W	38.5 Kb/W
L3-Comm	S	35	2	8	100	2.5	$1.5M	55 b/W	227 Kb/W
Thales	S	49	16	40		2.9	$12M	333 b/W	833 Kb/W
MSFC SDR	S-, C-, X-	<15	300	150	100	1.5	$100K	20Kb/W	10 Mb/W
Deltas		Δ2↓	Δ10x↑	Δ4x ↑		Δ2↓	Δ15x ↓	Δ16.7x↑	Δ44x↑

SDR Flight Heritage – Gen 1



- First generation telemetry module made for Micro-satellites.
- Uplink data rate is 50kbps
- Downlink data rate is 1Mbps
- Interfaces to the flight computer via a source synchronous 422 interface. This means , data , and clock are coming from the flight computer.
- Power is ~ 200mW
- Telemetry is CCSDS compatible.
- Reed- Solomon encoding (255,223,1) is done in an ASIC from GSFC.
- FPGA handles all CCSDS encoding , decoding and bit – synchronization as well as interfacing to flight computer.
- On-board processor handles housekeeping and interfaces to flight computer through 422 interface.
- Low Cost < $10K

SDR Current Design – Gen 2

- SDR is a modular design and is comprised of slices or decks.
  - S-Band Command Receiver
  - S-Band Telemetry Transmitter
  - X-Band Telemetry Transmitter
  - Processor
  - Power Supply
- Transponder can be built “al La Cart” as missions requirements dictate.
  - Typical size is 4.25” x 4.25” x 3” (L x W x H) for S-band command, telemetry, power supply and processor slices
  - Add 0.75” in height for each additional slice.

Example Data Rate Throughput with Inflatable Ground System

Sat-Elevation	5 Deg	7.5 Deg	10 Deg	20 Deg	Sat-Sat& (Min distance, Max distance)
S-Band**	2.7Mbps	6Mbps	10Mbps	40Mbps	10Mbps, 700Kbps
C-Band***	10Mbps	22Mbps	40Mbps	150Mbps	21Mbps, 1.4Mbps
X-Band****	24Mbps	55Mbps	95Mbps	350Mbps	20Mbps, 1.3Mbps

GATR 2.4M Dish

Example Data Rate Throughput with Inflatable Ground System

1.8M Dish	5 Deg	7.5 Deg	10 Deg	20 Deg
S-Band**	1.9Mbps	4.3Mbps	7.5Mbps	30Mbps
C-Band***	3.25Mbps	7Mbps	13Mbps	50Mbps
X-Band****	26Mbps	57Mbps	100Mbps	400Mbps

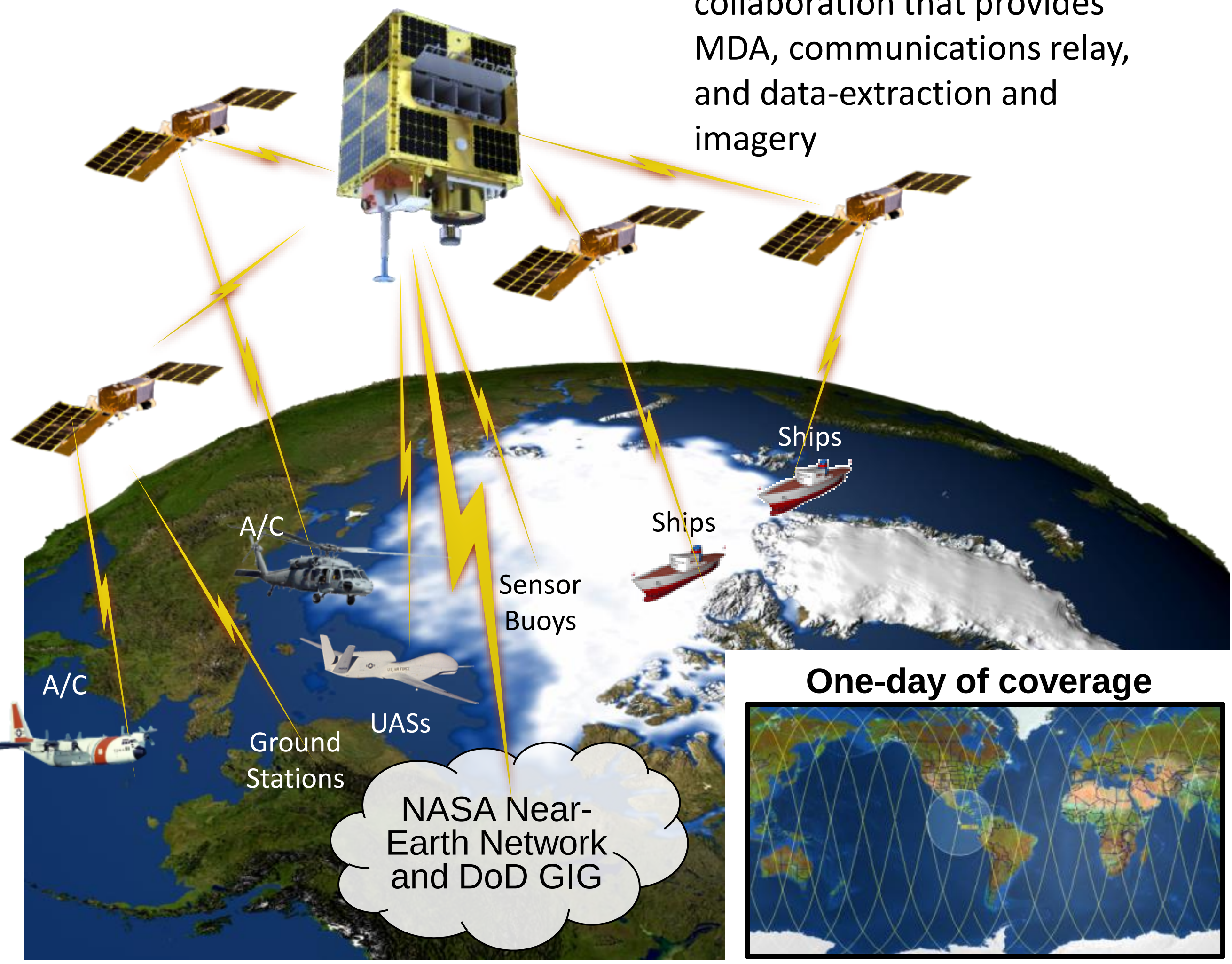
1.2M Dish	5 Deg	7.5 Deg	10 Deg	20 Deg
S-Band**	0.85Mbps	1.9Mbps	3.5Mbps	13Mbps
C-Band***	1.7Mbps	3.8Mbps	6.9Mbps	26Mbps
X-Band****	3.4Mbps	7.6Mbps	13.8Mbps	52Mbps

ARC-Sat Operational View

Mission Concept
- 1 Minisatellite Mothership
  - CubeSat Launcher
  - AIS, Data-X, & EPIRB Receivers
  - Multi-band SDR Communications packages with SAR capabilities
- 4 Communications CubeSats
- 650 km low-earth-orbit (LEO)
- Circular orbit (eccentricity = 0)
- 90-98° Inclination
- Up to Mbps total data throughput
- UHF,C,S and X bend pipe or network hub
- EPIRB relay supports Search & Rescue

Payloads
- Mothership launches CubeSats and has extensive computational, control, and data store-and-forward capacity
- Mothership and 4 CubeSats each with 2 software-defined radios
- Mothership candidate payloads
  - AIS provides global Maritime Domain Awareness (MDA)
  - Data-X provides data collection from unattended sensors
  - Imagery

An innovative, multi-agency collaboration that provides MDA, communications relay, and data-extraction and imagery



One-day of coverage

Mission-Tailored Communications

Powerful

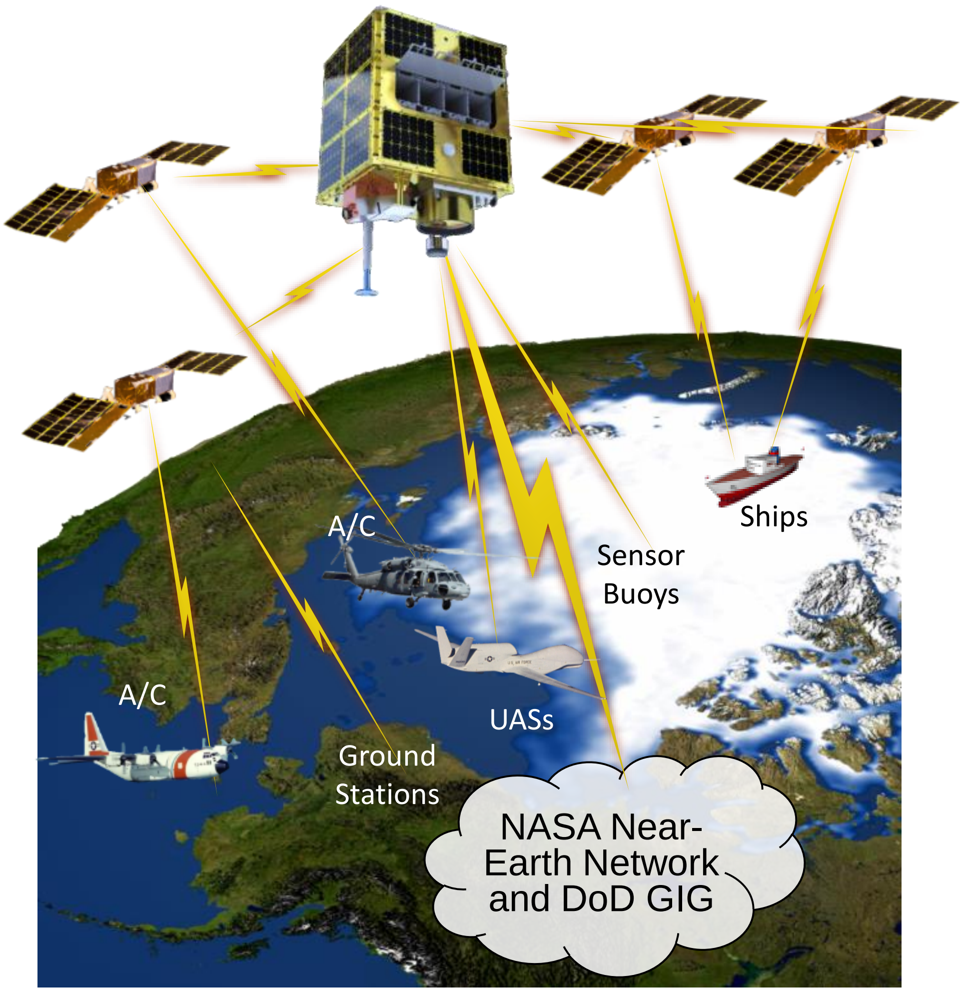
- 6 Software-Defined Radios (SDRs) total
  - 2 SDR payload on each of 4 cube-sats
  - 2 SDR payload on the mothership
  - 2 SDR for primary network communications
- Multiple Voice Channels per CubeSat (bended pipe and network)
- > 10 Mbps per payload SDR for some mission configurations
- Mothership has S-Band and X-Band network downlinks for combined for > 150 Mbps
- Example mission provides 13.48 minutes in satellite foot-print for overhead Arctic pass

Compatible

- Joint Tactical Radio System (JTRS)
  - Airborne & Maritime/Fixed Station (AMF)
  - UHF Satellite Communications
  - Wideband Network Waveform
  - Soldier Radio Waveform (SRW)
- Mobile User Objective System (MUOS)
- Standard Voice protocol channels and data

Flexible

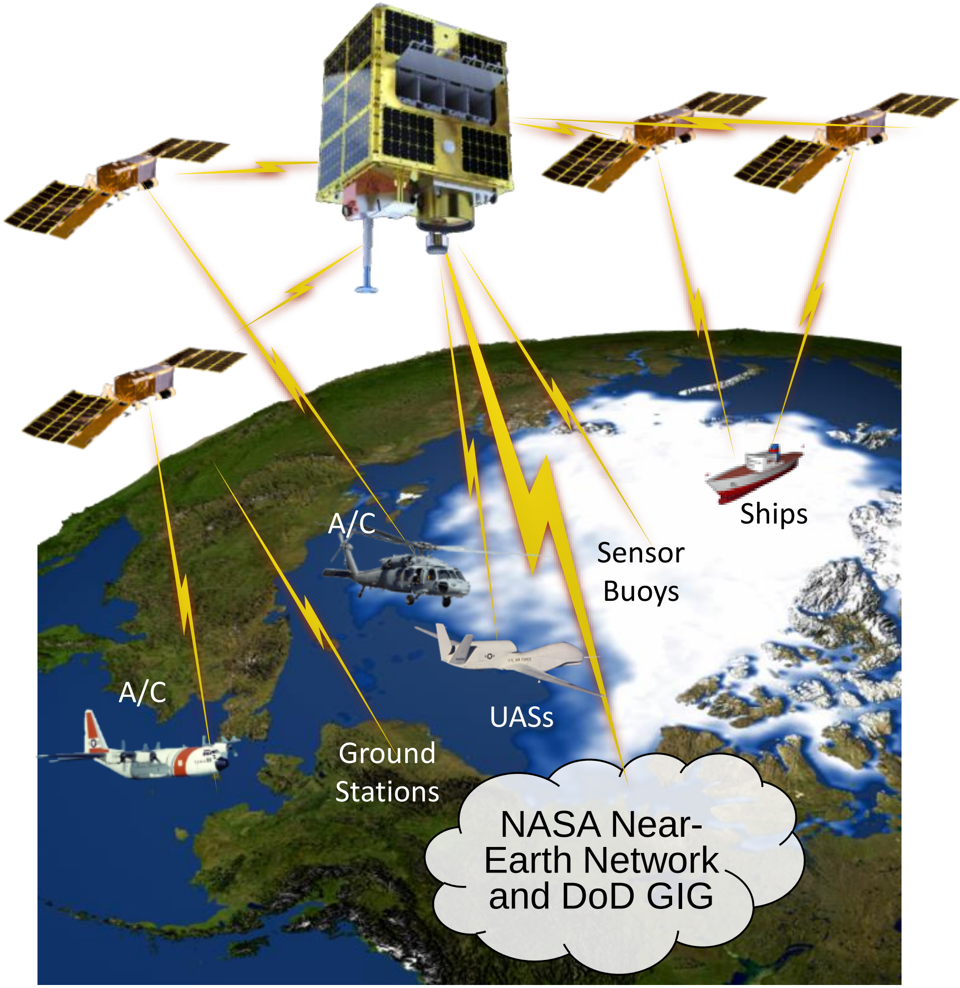
- Controllable Virtual Beam
  - Each SDR has wide-Beam for total-area coverage
  - Steerable Beams for greater link margin and higher throughput
- Reprogrammable in-flight from the ground



Use Scenario: Arctic Search & Rescue

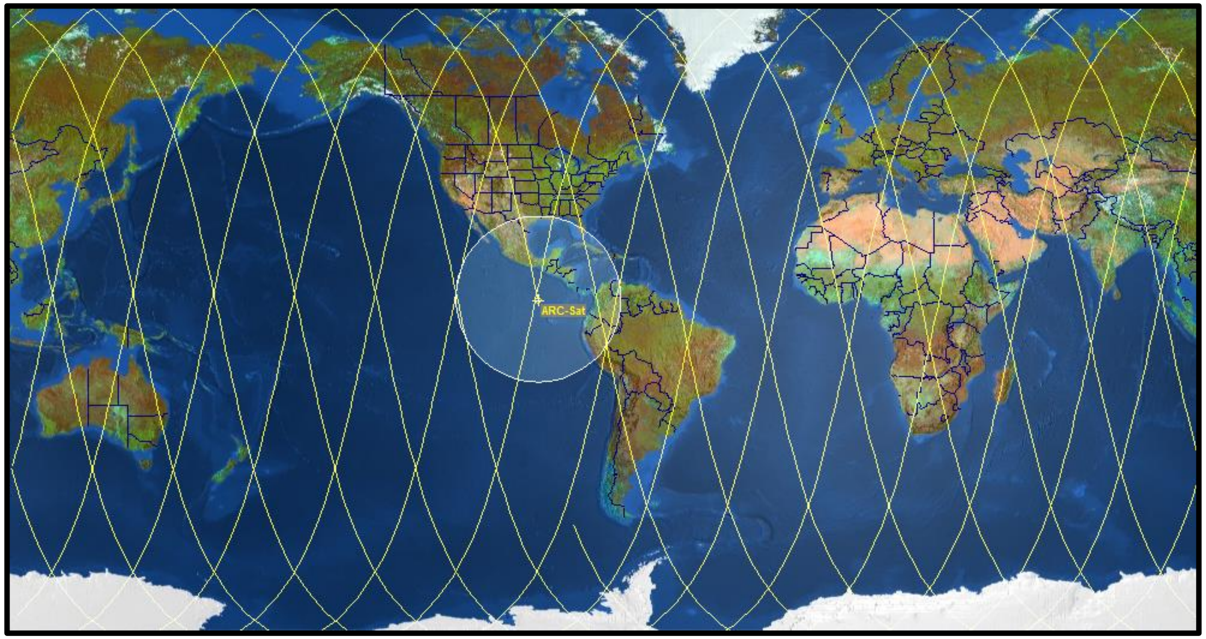
Sequence of Events

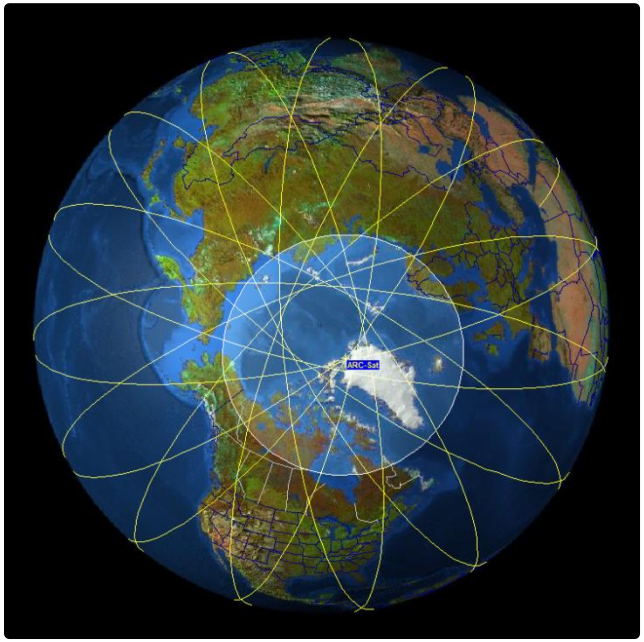
1. Ship suffers an engineering casualty and is dead in the water (DIW)
2. Ship activates 406 MHz digital Emergency Position Indicating Radio Beacon (EPIRB)
3. Ship begins sending Automatic Identification System (AIS) distress message
4. ARC-Sat detects EPIRB beacon and forwards ship's location and information to USCG District 17
5. ARC-Sat feeds the AIS distress message into the Volpe Center's global AIS system
6. ARC-Sat provides communications relay support
   1. Two CubeSats re-orient to provide priority support to distress vessel
   2. Two CubeSats re-orient to provide priority support to response force
   3. Mothership provides general support
7. ARC-Sat provides data link between response force and the National Ice Center (NIC) for updates on sea-ice, sea surface conditions, and surface weather via the Arctic Collaborative Environment (ACE) system



Orbit Parameters and Daily Ground Track

One Day of Coverage





Orbit

- Altitude: 650 km
- Eccentricity: 0 (Circular)
- Inclination: 98°
- Period: 97.7 minutes

Ground Track

- Diameter: 5,529 km
- Area: 24 million km^2
- Speed Over Ground: 6.836 km/s

With a track overlap of 50.8% at the Equator, ARC-Sat will cover the Earth twice per day

ARC-Sat will provide service to each point on the Earth from 4 times per day at the Equator, up to 14 times per day at the Poles

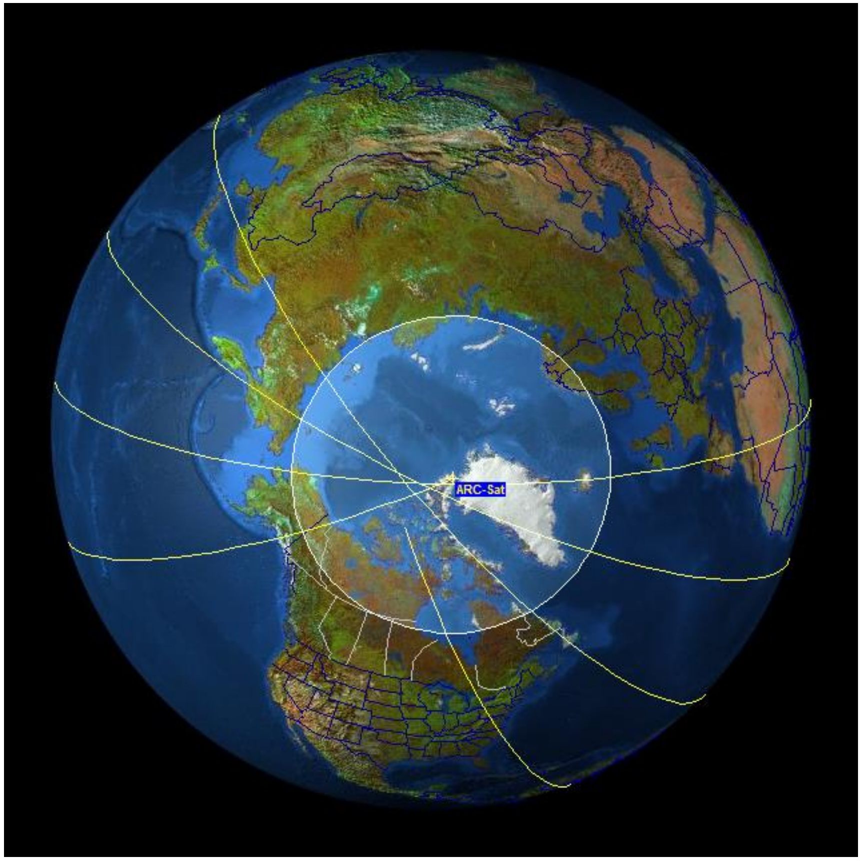
Example ARC-Sat Mission Provides Year-Round Global Capability, with a Polar Focus

Orbit
- Altitude: 650 km (LEO)
- Eccentricity: 0 (Circular)
- Inclination: 98°
- Period: 97.7 minutes

Ground Track
- Diameter: 5,529 km
- Area: 24 million km^2
- Speed Over Ground: 6.836 km/s

- With a track overlap of 50.8% at the Equator, ARC-Sat will cover the Earth twice per day

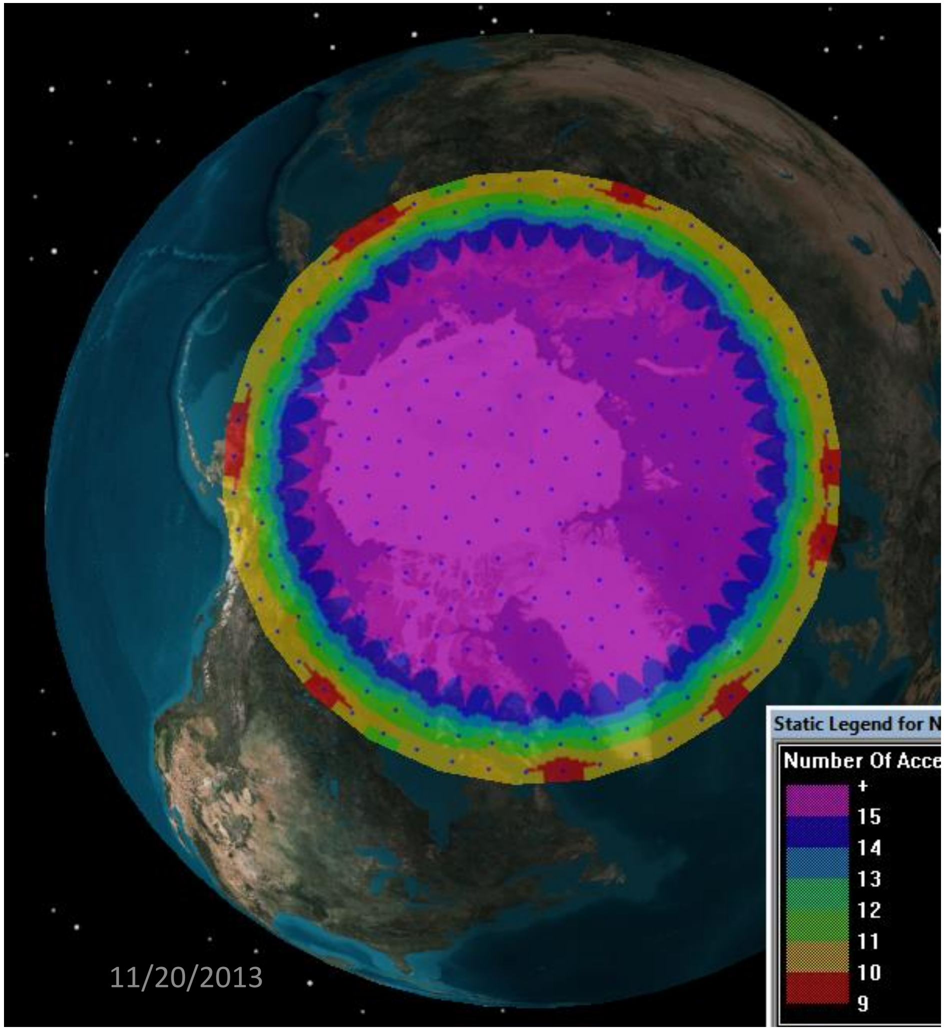
- ARC-Sat will provide service to each point on the Earth
  - Minimum of 4 times per day at the Equator
  - Up to 14 times per day at the Poles



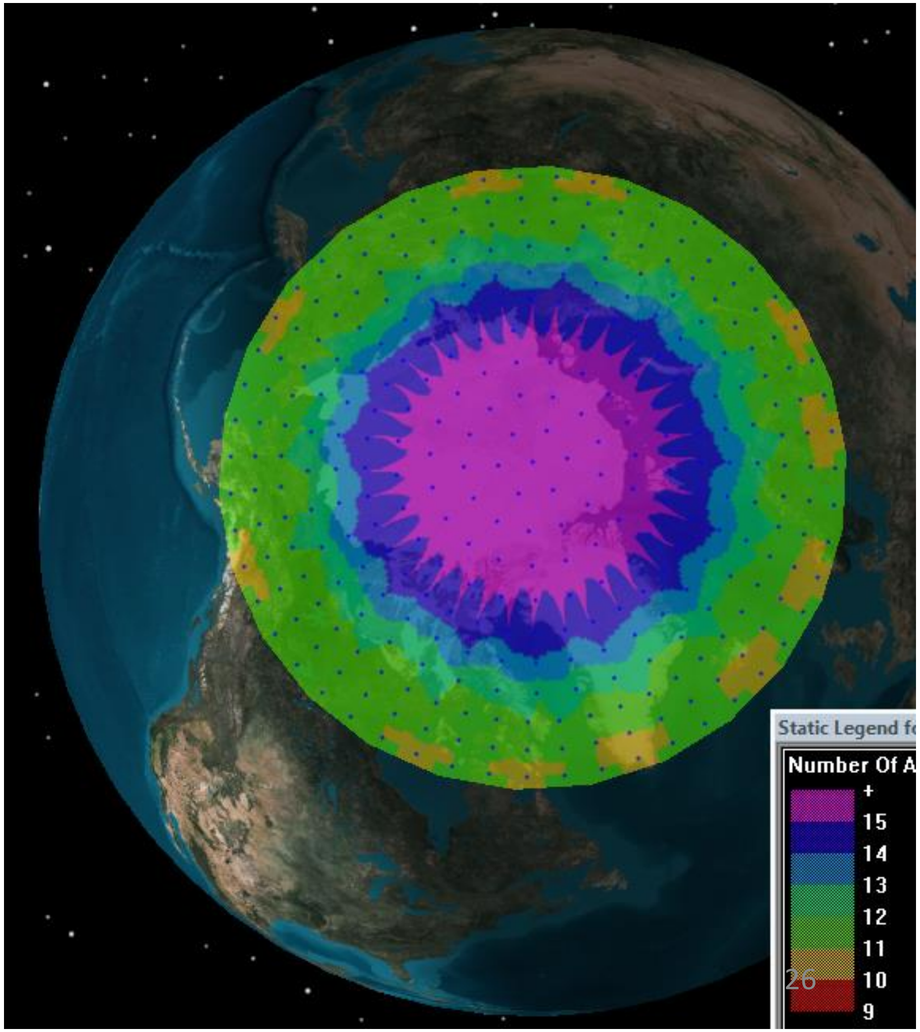
Typical ground coverage and track

Sun Sync vs. Polar
Individual Day of Access

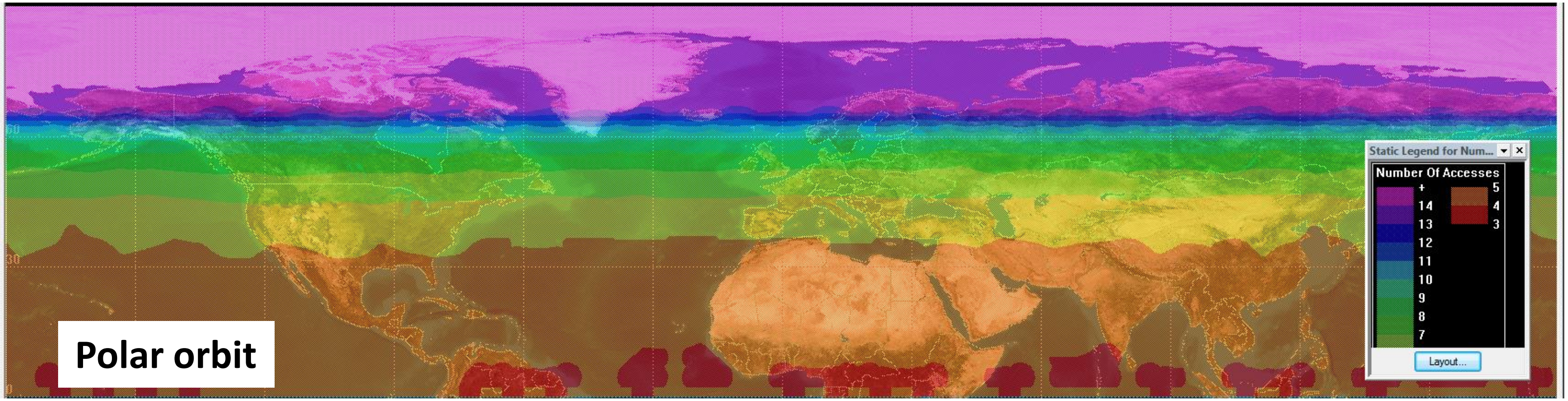
Polar – 600 km

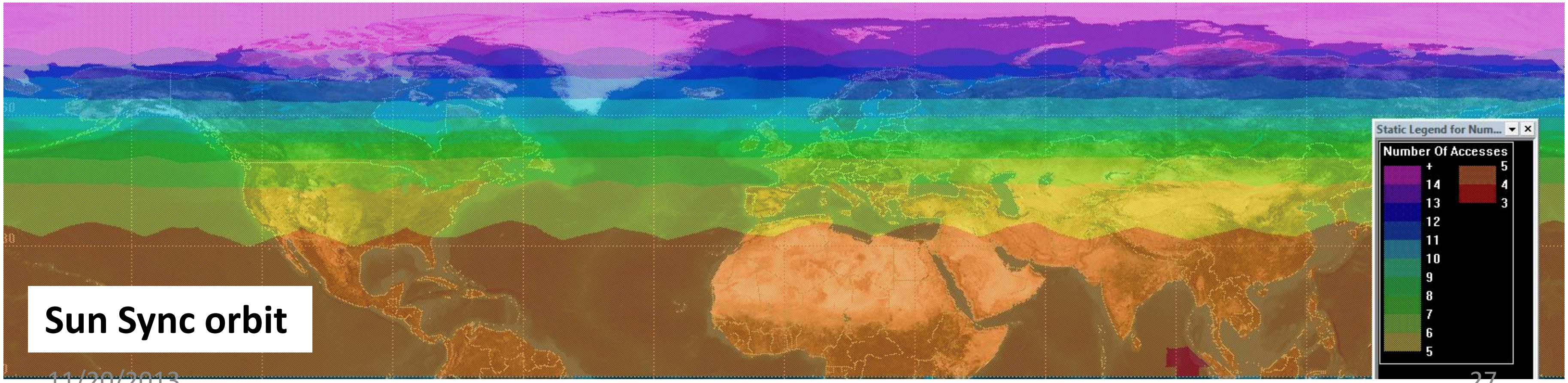


Sun Synch – 600 km



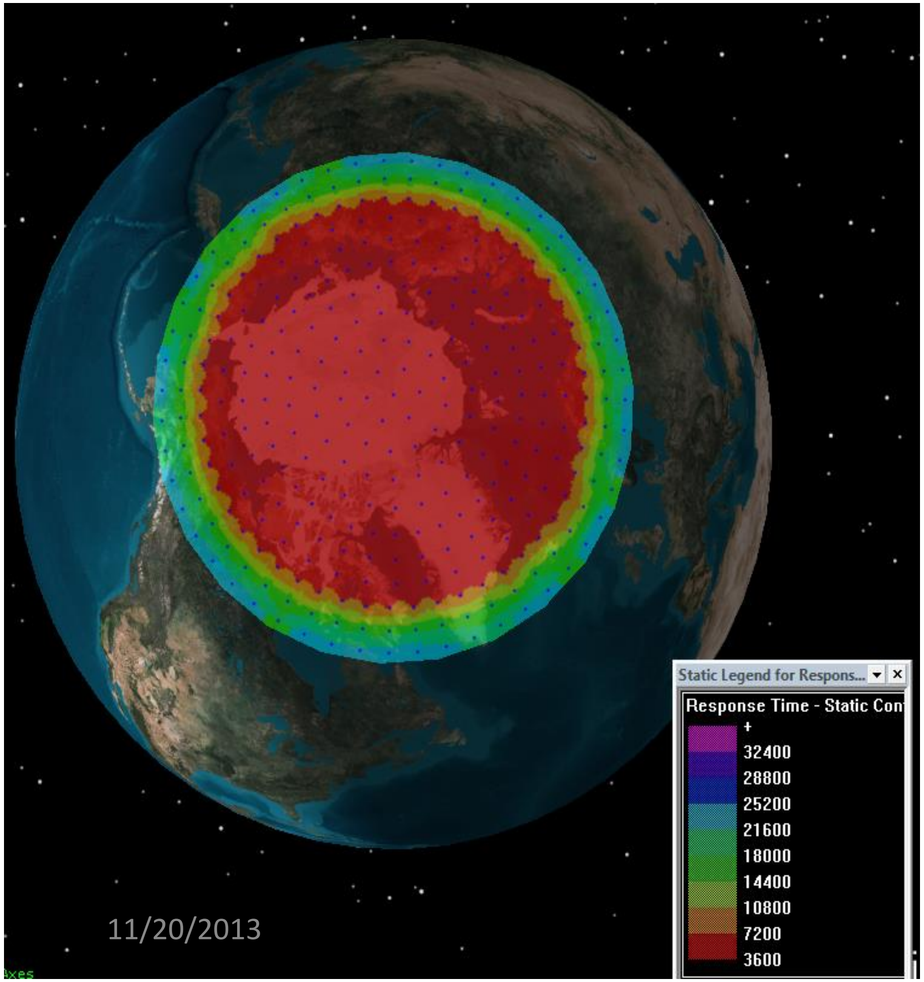
Sun Sync vs. Polar
Average Daily Accesses



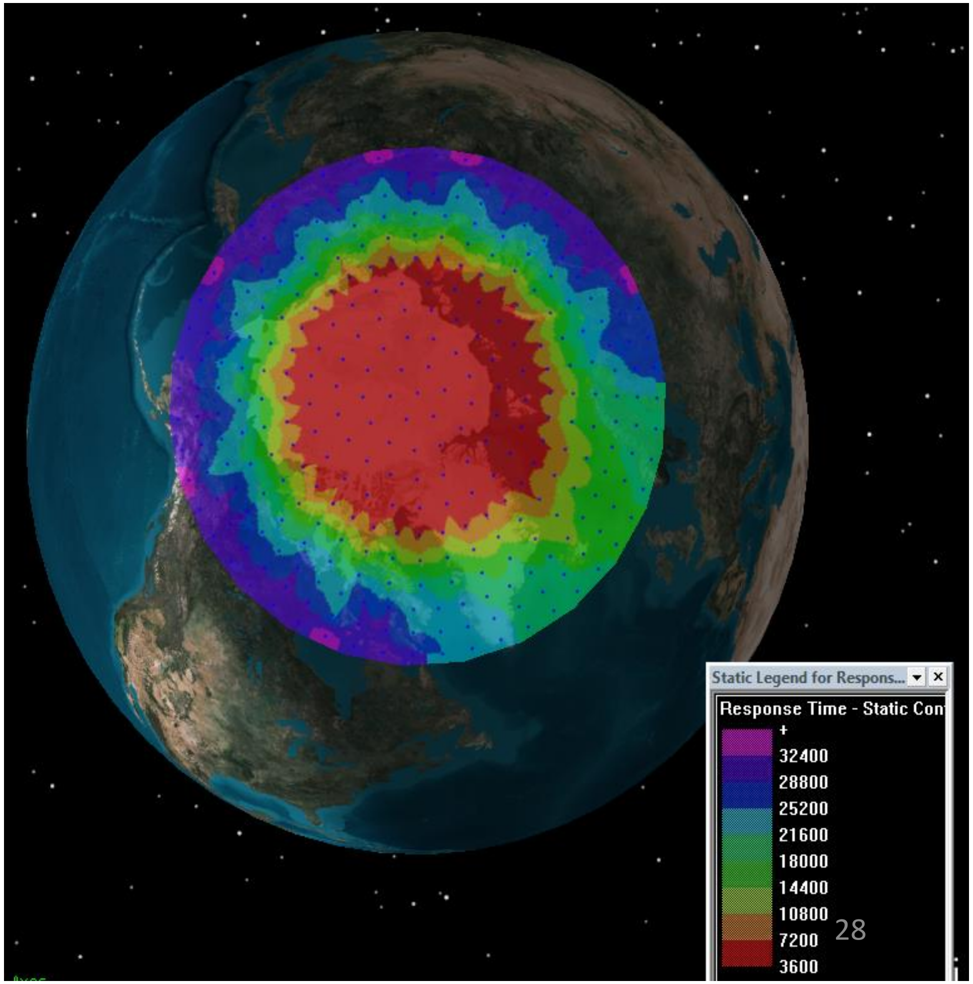


Sun Sync vs. Polar
Maximum Revisit Time (seconds)

Polar – 600 km



Sun Synch – 600 km



Summary of Conclusions

- The Arctic is an important geographical region of the world with respect to the world environment, international economics, and humanitarian interest .
- Low cost and effective communications in the Arctic is critical now and will significantly increase in importance in the near future
- Traditional larger satellite system approaches to addressing gaps in communications and data acquisition requirements in the Arctic are costly and require significant time to become reality in todays economic pressures
- Current small scale satellite system technologies are mature and can be integrated into a mission to potentially address required effective communications and data exchange in the Arctic
- The total initial cost of a small scale satellite communication system would be significantly lower than the traditional large satellite systems
- Uniquely configured formations of small scale satellites used for future Arctic communication missions offer near term, low cost, redundant capabilities for at least 70 percent of the data exchange and communication critical needs

Innovative Formations of Small Scale Satellites Can Be an Important, Cost Effective and Timely Component of the Solution Set Portfolio for Many Missions

ACE

FASTSAT-HSV01

ARCSat

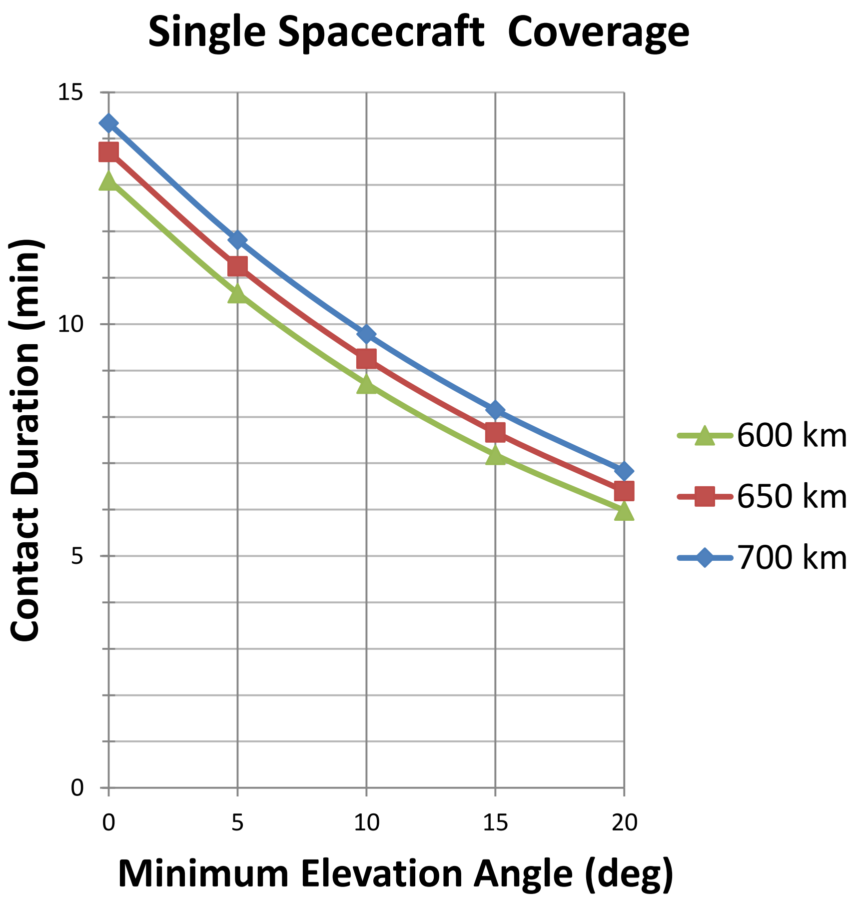
Thank you for your interest, Questions ?

BACKUP

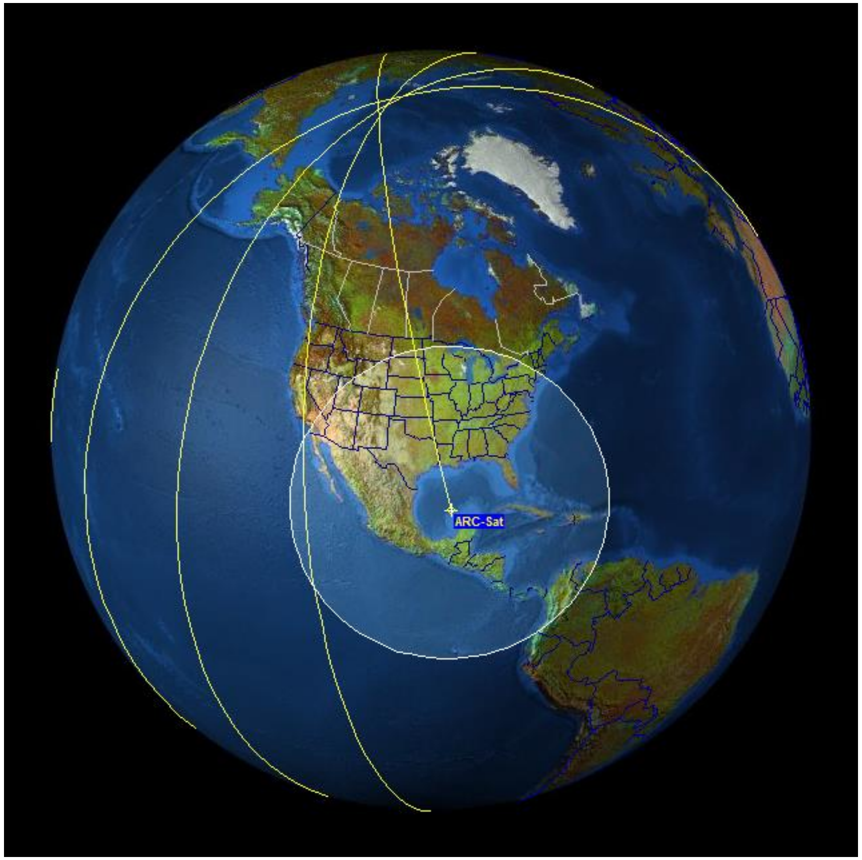
Single Spacecraft Results

- Duration of contact to a ground station with a ground station elevation angle constraint

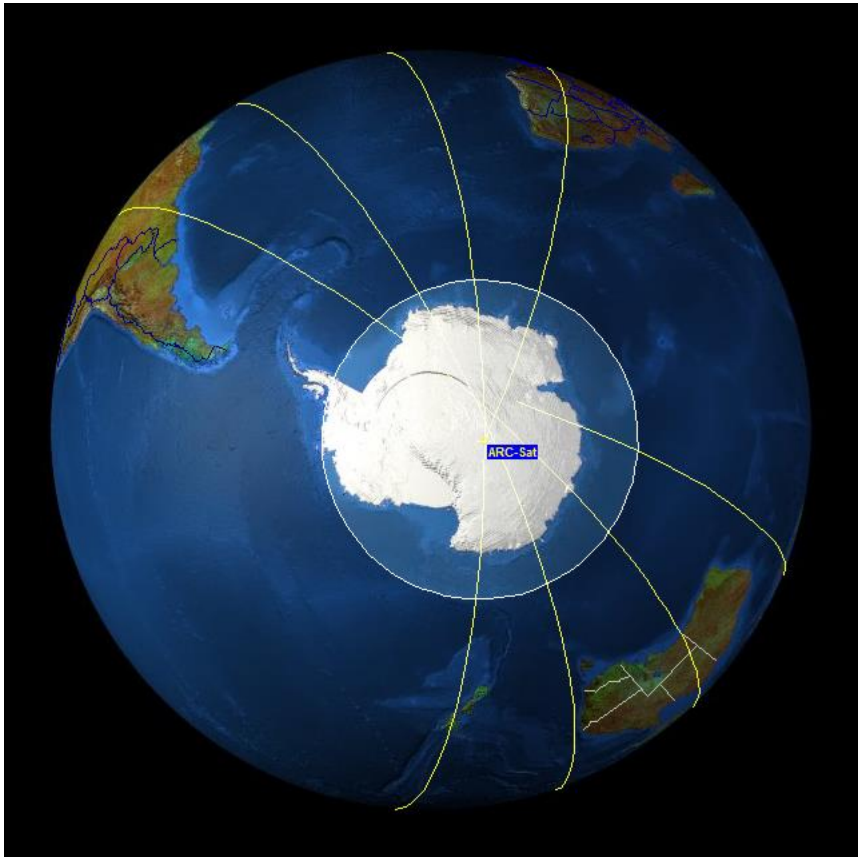
- Contact times increase with altitude
- Contact times decrease with increase in elevation angle constraint



Coverage in Other Critical Regions



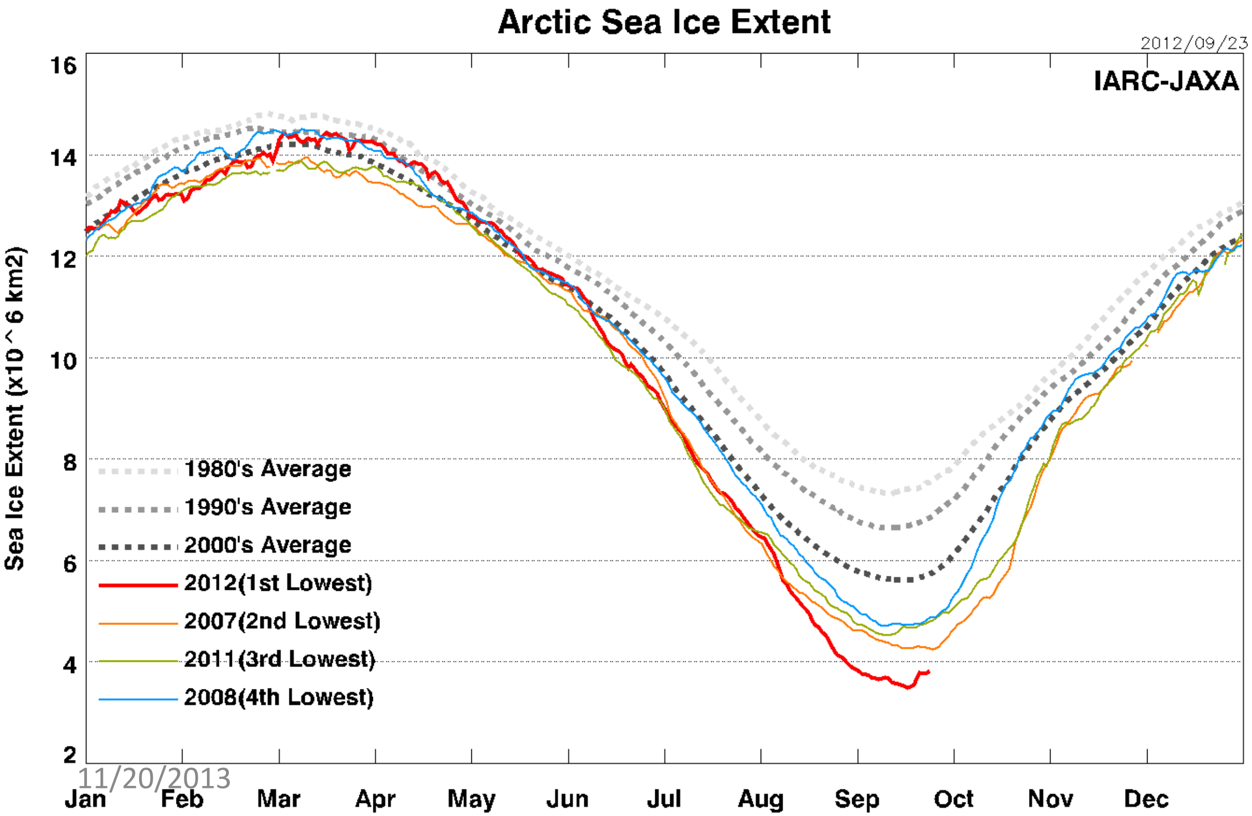
Central America



Antarctic

Acknowledgements

William “Herb” Sims, NASA MSFC
Kosta Varnavas, NASA MSFC
Devon Sanders, NASA MSFC
Marty Kress, VCSI
Stephen Spehn , US EUCOM
Hal Moore, US NORTHCOM



Arctic Collaborative Environment Team International and Growing

- We have an incredible team – been able to integrate some of the best people and organizations in the business
  - Pablo Clemente-Colón, National Ice Center
  - Thorsten Markus, NASA Goddard
  - John Calder, NOAA
  - Corky Clinton, NASA Marshall
  - John Farrell, Arctic Commission
  - John Frim, Canadian Embassy
  - Julie Gourley, State Department, Arctic Council
  - Brendan Kelly, OSTP
  - John Walsh, UAF
  - Julie Payette, Government of Quebec
  - EUCOM, NORTHCOM, NORAD, USCG, Navy Task Force Climate Change, Navy, AMRDEC, DLR, CRREL, ORNL, NOAA, NSF, ONR, OSTP, ERMA, NWS, State Department
  - Norwegian Polar Institute, DLR, German Embassy, Finnish Meteorological Institute, Inuit Circumpolar Council, SAON
  - University of Alabama in Huntsville (NASA MSFC -EUCOM), University of Alaska Fairbanks (AARI & Environment Canada), University of Maryland (NASA GSFC), University of Delaware (NIC), Aurora Research Institute (Inuit Nation), Universities Space Research Association
  - Working to Fully Integrate Canada and Russia into Project