AEROSPACE REPORT NO.
TOR-2012(2228)-1

National Science Foundation (NSF) United States Antarctica Program (USAP) Science Workshop

27 February 2012

NASA Program Division (NPD)
Civil and Commercial Operations (CCO)

Prepared for:

The National Science Foundation
Office of Polar Programs (OPP)
4201 Wilson Boulevard
Arlington, Virginia 22230, USA

Contract No. FA8802-09-C-0001

Authorized by: Civil and Commercial Operations

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Approved by:

Matthew Hart Principal Director Advanced Studies and Analysis Civil and Commercial Operations	Debra Emmons Asst. Principal Director Program Development Civil and Commercial Operations

Acknowledgement

We would like to acknowledge the NSF team and support staff, science team members and other subject matter experts who helped to make this study possible. Below is an extensive but not exhaustive list of individuals that we would like to express our appreciation.

User Requirement Workshop Science Team
- Dr. Sridhar Anandakrishnan, Pennsylvania State University
- Dr. Peter Doran, University of Illinois
- Dr. Ian Evans, Smithsonian Astrophysical Observatory
- Steve Foley, Scripps/University of California
- Dr. John Helly, University of California
- Bjorn Johns, UNAVCO
- Dr. John Kovac, Harvard University
- Dr. Albrecht Karle, University of Wisconsin – Madison
- Dr. Matthew Lazzara, University of Wisconsin – Madison
- Timothy Parker, IRIS/PASSCAL
- Dr. Theodore Scambos, CIRES/University of Colorado
- Dr. Allan Weatherwax, Siena College

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1. Executive Summary

The National Science Foundation (NSF) Office of Polar Programs (OPP) commissioned the Aerospace Corporation (Aerospace) to conduct an Analysis of Alternatives (AoA) study addressing future communication needs for the US Antarctica Program (USAP). The results of this study will inform decisions on USAP communication architectures and mission support capabilities for a planning horizon of 2015-2030. Part of this charter led to sponsoring a science workshop to help define the requirements baseline for future USAP communications needs. The two-day workshop was held on 24-24 May 2011 at the National Center for Supercomputing Applications (NCSA) ACCESS facility in Arlington, VA. This document summarizes the material from this venue.

Three focus areas emerged from the workshop, 1) South Pole users, 2) distributed users, and 3) maritime users. South Pole users have the largest bulk data requirements. Distributed users include low power users, which are serviced by low Earth orbit (LEO) narrowband servicing systems like Iridium. Maritime users can have stressing requirements if the unconstrained future requirements are included as part of the baseline.

Many of the requirements can be accommodated within realizable communication offerings. Some of the demanding maritime requirements may drive the required architectures. Tables 33 through 37 represent the combined summary of requirements from the workshop inputs that were utilized in an Analysis of Alternative (AoA) analysis of the potential methods of meeting future United States Antarctica Program communication needs.

2. Background and Introduction

NSF held two previous workshops that have looked at the future of communication infrastructure to support NSF USAP, one in 1987 and one in 1999. With the changing landscape of communications systems that are available and the increasing science data needs another workshop was deemed necessary. In order to effectively plan for future communication needs it is important to canvas existing science users to ascertain how much communication resources they are using now and to project what the future utilization will be. The workshop helps to define requirements that can be used when making decisions on what system or systems to use in the future.

A data call went out before the workshop asking for the scientists to prepare summary information of their communication needs. This was briefed on Day 1 of the workshop. NSF and Aerospace also presented orientation material. On Day 2 break out sessions were held where South Pole Users, Distributed Users and Maritime Users separately derived a comprehensive set of requirements they would need in the near future and in the 2020 timeframe.

3. Goals of the Workshop

The goals of the workshop were defined for Aerospace in their statement of work to be the following:

1. Assist the National Science Foundation's Office of Polar Programs with the formulation of early concept definition for long range strategic planning of broadband communications servicing the United States Antarctic Program research station, Amundsen-Scott South Pole Station. Concept definition includes science mission requirements definition and forecasting, an analysis of alternative solutions, and formulation of recommendations.
2. The results of this science requirements workshop feed the analysis of alternatives, whose results will be brief to the NSF director for inclusion in the NSF Blue-Ribbon Panel to be convened in early FY12.

This report will provide a summary of the material that was presented along with initial findings that were used in an analysis of alternative (AoA) study that explored ways to meet the science and operational users communication needs.

The main objective of the workshop was to determine the science communications required to enable the missions hosted by USAP. The science workshop brought together experts in the major fields that perform science with USAP. With these representatives, the goal was to ascertain how much communication infrastructure is necessary to support their current mission and their (unconstrained) projection in 2020.

4. Agenda, Workshop Attendees and Break Out Groups

The two-day workshop was held on 24-24 May 2011 at the National Center for Supercomputing Applications (NCSA) ACCESS facility. The address is 901 North Stuart Street, Suite 800, Arlington, Virginia 22203. Their website is www.accesscenterdc.org. The first day focused on giving the science workshop experts an orientation to the study and the opportunity for each of the science experts to provide summary briefings on their science missions. The second day consisted primarily of breaking the science teams into groups where they could provide detailed recommendations on what data communications are required to support their science mission. After agreements were established these were tabulated into summary charts that were briefed at the workshop conclusion. The two-day workshop agenda is shown in Table 1.

Table 1. Workshop Agenda

Day 1	
8:00 AM	Introduction – NSF/Aerospace Study Process Summary, Workshop Objectives, Understand how operators user communication resources, Quantify needs in terms of goals and thresholds, Ascertain timeliness requirements, Determine geographical requirements, and Derive prioritization within community
8:15 AM	Science Needs and Ops - Science Representatives
8:15 AM	**Astronomy/Photon Astrophysics** - John Kovac, Harvard University
8:30 AM	**Astronomy/Particle Astrophysics** - Albrecht Karle, University of Wisconsin
8:45 AM	**Antarctic Organism and Ecosystem** - Peter Doran, University of Illinois
9:00 AM	**Atmospheric (lower) Sciences** - John Helly, San Diego Supercomputer Center & Scripps Institution of Oceanography and Matthew Lazzara, University of Wisconsin
9:15 AM	**Meteorology** - Matthew Lazzara, University of Wisconsin
9:30 AM	**Glaciology** - Theodore Scambos, CIRES/University of Colorado
9:45 AM Break	
10:00 AM	**Antarctic System Science** - Sridhar Anandakrishnan, Pennsylvania State University
10:15 AM	**Antarctic Earth Sciences** - Bjorn Johns, UNAVCO
10:30 AM	**Antarctic Earth Sciences (Seismometers)** - Timothy Parker, IRIS/PASSCAL
10:45 AM	**Antarctic Ocean Sciences** - Steve Foley, Scripps Institute of Oceanography
	Atmospheric (upper) and Geospace Sciences - Allan Weatherwax, Siena College (unable to attend but submitted charts)
11:15 AM	Panel Discussion - Summarize Communication Needs - NSF/Aerospace moderated
12:15 PM Lunch	
1:15 PM	Introduction - Mark Cowdin, Aerospace
1:30 PM	Current USAP Communication Architecture and Data Trends - Jim Johansen, Aerospace
2:00 PM	Survey of Alternative Concept Categories & Mix of Media - Mark Cowdin, Aerospace
2:30 PM	Orbit Visualizations - Jim Johansen, Aerospace
3:00 PM Break	
3:15 PM	Data Processing Trends in Astronomy - Dr. Ian Evans, Smithsonian Astrophysical Observatory and Dr. Bryan Jacoby, Aerospace
4:30 PM	Communication System Requirements - Jim Johansen, Aerospace
5:00 PM End of Day 1	
Day 2	
8:00 AM	Orientation for Break Out Groups - NSF and Jim Johansen, Aerospace
8:20 AM	Move to Break Out Group Rooms
8:30 AM	Break Out Groups: Group 1 – South Pole Science Users, Group 2 – Distributed Science Users, Group 3 – Maritime

12:00 PM Lunch	
1:00 PM	Briefing Results from Break Out Groups - break-out representatives
3:00 PM	Summary and Action Items - NSF/Aerospace
3:30 PM End of Workshop	

Below is the list of workshop attendees.

Table 2. Workshop Attendees

Name	Organization	Discipline/Relationship to Study	Contact Information
John Kovac	Harvard University	Astronomy/Photon Astrophysics	jmkovac@cfa.harvard.edu
Albrecht Karle	University of Wisconsin	Astronomy/Particle Astrophysics	karle@icecube.wisc.edu
John Helly	San Diego Supercomputer Center	Atmospheric (lower) Sciences and Meteorology	hellyj@ucsd.edu
Matthew Lazzara	University of Wisconsin	Atmospheric (lower) Sciences and Meteorology	mattl@ssec.wisc.edu
Theodore Scambos	CIRES/University of Colorado	Glaciology and Antarctic System Science	teds@kryos.colorado.edu
Srihdar Anandakrishnan	Pennsylvania State University	Glaciology and Antarctic System Science	sak@essc.psu.edu
Bjorn Johns	UNAVCO	Antarctic Earth Sciences	johns@unavco.org
Timothy Parker	IRIS/PASSCAL	Antarctic Earth Sciences	tparker@passcal.nmt.edu
Steve Foley	Scripps Institute of Oceanography	Antarctic Ocean Sciences	sfoley@ucsd.edu
Peter Doran	University of Illinois	Antarctic Organism and Ecosystem	pdoran@uic.edu
Ian Evans	Smithsonian Astrophysical Observatory	Astronomical Data Analysis Software & Systems (ADASS)	ievans@head-cfa.harvard.edu
Allan Weatherwax	Siena College	Atmospheric (upper) and Geospace Sciences	aweatherwax@siena.edu
Peter Milne	NSF	OD/OPP	pmilne@nsf.gov
Jesse Crain	NSF	OD/OPP	jlcrain@nsf.gov
Scott Borg	NSF	OD/OPP	sborg@nsf.gov
Vladimir Papitashvili	NSF	OD/OPP, OPP/ANT	vpapitashvili@nsf.gov
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Dr. Bryan Jacoby	Aerospace Corporation	Workshop Co-Chair	Bryan.Jacoby@aero.org
James Johansen	Aerospace Corporation	Workshop Lead	James.D.Johansen@aero.org
Mark Cowdin	Aerospace Corporation	Project Lead	Mark.A.Cowdin@aero.org
Matthew Hart	Aerospace Corporation	Project Steering Committee	Matthew.J.Hart@aero.org
Debra Emmons	Aerospace Corporation	Project Steering Committee	Debra.L.Emmons@aero.org

Three breakout groups were composed with the goal of having similar science missions from a communication support point of view grouped together. The three groups were, 1) South Pole users, 2) Distributed Science users, and 3) Maritime users. Below is a listing of the individuals that participated in each group, along with the facilitator that helped to track the results of the discussion.

Table 3. Workshop Break Out Groups

Group 1 – South Pole Astronomy
Astronomy/Photon Astrophysics - John Kovac, Harvard University **Astronomy/Particle Astrophysics** - Albrecht Karle, University of Wisconsin Dr. Bryan Jacoby – Aerospace facilitator Dr. Ian Evans - Smithsonian Astrophysical Observatory, co-facilitator
Group 2 – Distributed Sensing
Meteorology - Matthew Lazzara, University of Wisconsin **Glaciology** - Theodore Scambos, CIRES/University of Colorado **Antarctic System Science** - Sridhar Anandakrishnan, Pennsylvania State University **Antarctic Earth Sciences (Seismometers)** - Timothy Parker, IRIS/PASSCAL **Antarctic Earth Sciences** - Bjorn Johns, UNAVCO **Antarctic Organism and Ecosystem** - Peter Doran, University of Illinois Dr. Phil Schwartz – Aerospace facilitator Mark Cowdin – Aerospace co-facilitator
Group 3 – Maritime
Atmospheric (lower) Sciences - John Helly, San Diego Supercomputer Center & Scripps Institution of Oceanography and Matthew Lazzara, University of Wisconsin **Antarctic Ocean Sciences** - Steve Foley, Scripps Institute of Oceanography Jim Johansen – Aerospace facilitator

5. Overview of Science Missions

The yellow highlights in Figure 1 show the focus of the science workshop. The focus was on science communication needs, both the specific requirements for each area of scientific research and the necessary science operations required to make these scientific endeavors possible. Site and non-science operational mission needs were not addressed in this venue.

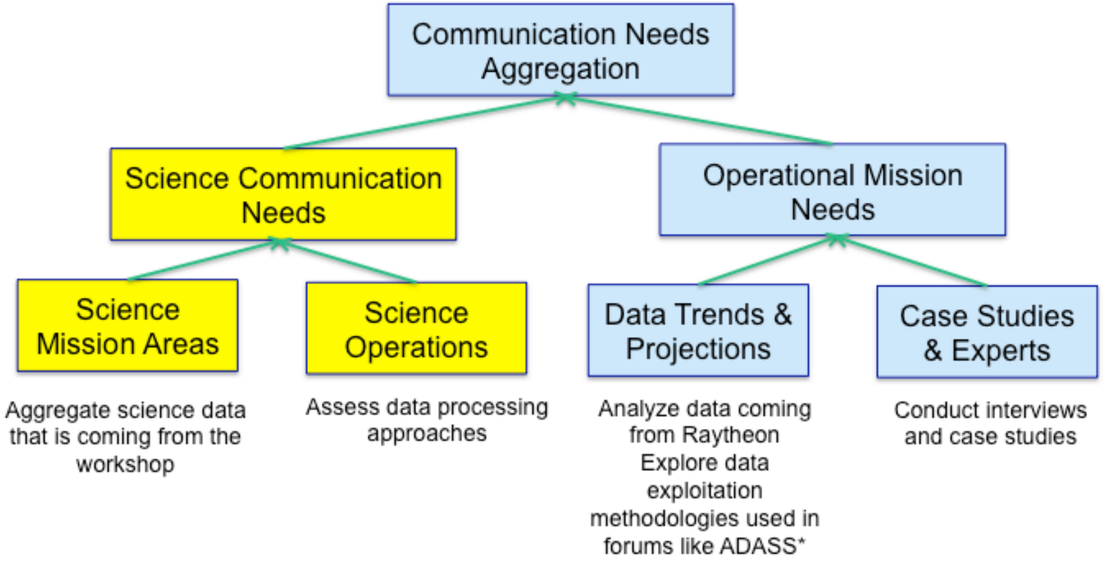

Figure 1. Focus of Science Workshop

The main mission of USAP is scientific research and the operational support of this research. Its focus is to expand fundamental knowledge in the region, to promote research on global and regional problems of current scientific importance and to use Antarctica as a portal to support research. USAP provides field support and analytical research support when it deems it is necessary.[1] The Polar Regions are unique windows to outer space from Earth. There are interesting phenomena to be explored where the solar wind (ionized plasma that is blown from the sun) interacts with the Earth's magnetosphere. Because of the favorable atmospheric conditions on the high Antarctic plateau astronomers and astrophysicists can use this region to understand better the structure of the Sun, the Milky Way, other galaxies, and probe the early Universe. Antarctic's deep clear ice sheet also provides a window to detect neutrinos.[2]

The following science summaries are provided to show the nature of experimentation that provides context for the communication requirements.

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[1] Antarctic Research http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5519&org=ANT&from=home (last

[2] Antarctica Astrophysics and Geospace Sciences, http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13420&org=ANT&from=home (last accessed 12 Dec 2011).

5.1 Astronomy - Photon Astrophysics

The visibility attained at the South Pole provides valuable observations for the astronomy community. The 10m South Pole Telescope (SPT) is a good example of photon astronomy at the South Pole. The telescope can detect millimeter and sub-millimeter waves that exist within the cosmic microwave background (CMB).[3] Cosmic Background Radiation observation and characterization is a key area of research. It is designed to study phenomena such as the formation and evolution of the early universe and the formation and evolution of solar systems similar to our won. There are other instruments like the Background Imaging of Cosmic Extragalactic Polarization (BICEP), which is specifically designed to measure the polarization of the Cosmic Microwave Background radiation with high precision. This allows for further understanding and characterization of the beginning of the universe.

SPT achieved first light in February 2007. This instrument is demonstrating its value in the search for Dark Matter and Dark Energy and testing cosmological models for the origin of the universe. So far it has had three productive seasons of observations. The first galaxy clusters were discovered using only the Sunyaev–Zel'dovich (S-Z) effect, which deals with the result of high-energy electrons distorting the CMB radiation. New populations of high red shifted star formation galaxies were discovered. Future work will include B-mode polarization of the CMB radiation.

5.2 Astronomy - Particle Astrophysics

IceCube is a good example of South Pole Particle Astrophysics. Occupying a volume of about one cubic kilometer, it records the signatures of neutrinos originating from space as messengers from violent events such as the collision of galaxies or black holes. Neutrinos have no charge and very little mass, making them difficult to detect. As a sensitive neutrino detector, IceCube has the capability to monitor the particle quantity and source direction. This opens up new bands for astronomy, including the PeV (1015 eV) energy region. IceCube is sensitive to supernova within our galaxy.[4]

The IceCube observatory detector array contains 80 regular strings and 6 deep core strings. Each of the 80 strings contain 60 sensors each resulting in 5,160 optical sensors. The 6 deep core strings are optimized for low energies. The detector is functioning better than anticipated and science exploitation is underway. IceCube supports broad international collaboration.

5.3 Lower Atmospheric Sciences and Meteorology

NSF lower atmosphere research looks at atmosphere chemistry, climate dynamics, large-scale dynamic meteorology, meso-scale dynamic meteorology, paleoclimate and physical meteorology. Lower atmosphere sciences and meteorology investigates the surface climate on Antarctica and cloud mass transport. The impact and characteristics of iceberg melt water are also analyzed.

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[3] South Pole Telescope, http://pole.uchicago.edu/spt/index.php (last accessed 12 Dec 2011).

[4] IceCube South Pole Neutrino Detector, http://icecube.wisc.edu/science/depth (lasted visited 12 Dec 2011).

5.4 Upper Atmospheric and Geospace Sciences

The polar upper atmosphere provides the means to observe the interactions of the solar wind and the earth's magnetosphere. Current research is exploring the atmospheric temperature changes and dynamics of neutral winds at altitudes from 30 to a few hundred kilometers. The polar upper atmosphere extending all the way up to near earth space (geospace) is a field of continued interest and growth.[5]

The Antarctic plateau provides a unique window to observe the dynamic processes that lead to the transfer of mass, energy, and momentum from the Sun and solar wind into and throughout the geospace system. Over the course of one day, geomagnetic field lines emanating from the southern high latitude region extend to the outer dayside magnetosphere, boundary layers and cusp across the polar cap to the mantle, lobe and portions of the plasma sheet. High quality, coordinated geophysical measurements from this region are critical to solving outstanding scientific questions involving a wide range of physical processes that occur in the coupled geospace system.[6]

5.5 Glaciology and Antarctic System Science

Snow and ice of the high latitude regions have an active role in the global environment. Glaciology explores the history and dynamics of all naturally occurring forms of snow and ice, including floating ice shelves, glaciers and continental and marine sheets. Program focus areas are ice core paleoenvironments, ice dynamics, numerical modeling, glacial geology, and remote sensing of ice sheets.[7]

5.6 Antarctic Earth Sciences

Antarctic Earth science explores ice dynamics, responses to climate change, how the Earth rebounds after being engulfed in glaciers. Earth science missions deploy distributed remote autonomous systems for multi-year unattended operation.

5.7 Antarctic Ocean Sciences

Antarctica oceanic and tropospheric studies focus on the structure and processes of the ocean-atmosphere environment and their relationships with the global oceans, the atmosphere and the marine biosphere. Major program areas include physical oceanography, chemical oceanography, sea ice dynamics and meteorology.[8]

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[5] Antarctica Astrophysics and Geospace Sciences, http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13420&org=ANT&from=home (last accessed 12 Dec 2011).

[6] Allan Weatherwax information provided for the science workshop

[7] Antarctica Glaciology, http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=12798&org=ANT (last accessed 12 Oct 2011).

[8] Antarctica Ocean and Atmospheric Sciences, http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13422&org=ANT&from=home (last accessed 12 Dec 2011).

5.8 Antarctic Organism and Ecosystem

The goal of the Antarctica Organisms and Ecosystems Program is to improve our understanding of organisms and their interactions within the biosphere and geosphere. This biological research explores the gamut of molecular, cellular, organism, communities and ecosystems. Particular areas of interest are 1) marine ecosystems, 2) terrestrial and freshwater ecosystems, 3) population dynamics, 4) physiological ecology and adaptation, and 5) genomics.[9] In the dry valleys, Antarctica organism and ecosystem research investigates 1) spatial and temporal distribution of populations, 2) pattern and control of organic matter accumulating in surface layers and sediments, 3) patterns of inorganic inputs and movements of nutrients through soils, and 4) patterns and frequencies of site disturbances.

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[9] Antarctic Organisms and Ecosystems, http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13421&org=ANT (last accessed 15 Dec 2011).

6. Day 1 - Science Briefings Highlighting Communication Utilization

The science workshop representatives were asked to present an assessment of the communication needs they see are necessary for their mission. This section summarizes what was presented on the first day of the workshop.

6.1 Astronomy - Photon Astrophysics

John Kovac, Harvard University, characterized his cosmic background radiation research as "relentless observing". Highly efficient, high duty cycle scientific measurement equipment can map through 9 months of harsh winter-like weather. Prompt deployment of cutting edge technology keeps the South Pole assets ahead of space missions. The science operations involve a mixture of remotely scheduled observing and on-site caretaking. Real-time voice and Internet is essential. Having continuous, 24/7 coverage would improve efficiency.

The cosmic microwave radiation data represents scanning time streams. Bulk data rate requirements can be calculated from the number of detectors, samples per beam, number of beams per second, bytes in each samples and the number of seconds per day. Projections based on BICEP2, SPUD and SPT instruments were developed. The table below represents how the data requirement was developed.

Table 1. Photon Astrophysics Current Data Need Calculation

Current System	No. of Detectors	Samples per beam	G_{dyn} beams/sec	K_{dyn} bytes/sample	Sec/day	Result
BICEP2 & SPUD	2048	5	4	5	86,000	18 GB/day
SPT	960	5	30	2.5	86,000	30 GB/day

Table 2 provides a complete list of historical systems used at the South Pole. Based on historical trends there is projected continued growth in the communication data needs to service photon astrophysics. Figure 2 shows the historical trend. Table 3 shows the summary of data needs.

Table 2. Historical Trends of South Pole Instrument Characteristics[10]

	Observation Years	Where	Number of Detectors	Power (kW)	LHe (L/day)	Data GB/day	TCP/IP Hours/day
“Heroic Age”	1986-1992	Snow	0-4	Generators	5-10	< .01	0
Python	1992-1997	Snow	2 or 4	< 5	7	< .1	Few
Viper	1998-2000	MAPO[11]	16?	5	-	< .1	Few
DASI	2000-2003	MAPO	13	25	-	.1	12
ACBAR[12]	2001-2005	MAPO	16	5	20	.3	12
QUAD[13]	2005-2007	MAPO	62	10	25	1	12
BICEP	2006-2008	DSL[14]	98	5	25	2	12
SPT-SZ	2007-2011	DSL	960	40	-	30	12
BICEP2	2010-2012	DSL	512	5	20	5	9
SPUD	2011-	MAPO	1536+	30	-	15+	9
SPT-pol	2012-	DSL	1500	40	-	60	?
POLAR-1[15]	2013-	DSL	4000	12	-	120	
Future		?	10000’s		-	1000	

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[10] Table from John Kovac presented at the science workshop.

[11] Martin A. Pomerantz (MAPO) building

[12] Arcminute Cosmology Bolometer Array Receiver

[13] QUEST and DASI. QUEST is “Q & U Extragalactic Survey Telescope”.

[14] Dark Sector Laboratory

[15] Polarization Observations of Large Angular Regions

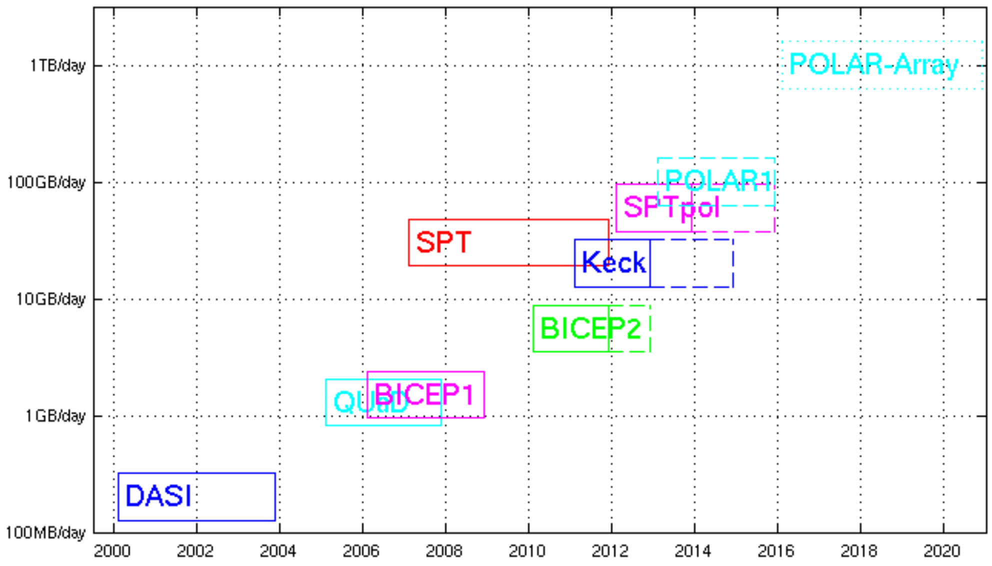

Figure 2. Historical Trend for Photon Astrophysics Data Collection per Day[16]

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[16] Figure from John Kovac presented at the science workshop.

Table 3. Data Needs Summary for Astronomy - Photon Astrophysics

Required Data Rates	• 2011: 50 GB/day • 2012: 80 GB/day (from adding SPTpol) • 2013: 200 GB/day (from adding POLAR-1) • 2016-2030: 1-2 TB/day (adding POLAR Array, unfunded, Note for comparison, LSST has 20 TB/night)
Timeliness Requirements	• Daily bulk transfer needed for raw data quality assessment
Geographic Locations	• CMB data needs are all at the South Pole – Other photon astrophysics applications at Pole involve smaller datasets
Block Data Requirements	• If science bulk data transfer fails to maintain 1-2 day latency, or if real-time connections drop significantly below 30%, this would be extremely disruptive for the current program o At >1 week bulk data latency, or 10% real-time availability, operations under the current model would not be feasible
Real-time Data Requirements	• T1 (1.5Mb/s, dedicated to science) is fine o Need more (and more continuous) coverage o 24/7 would be great • Real-time instrument connection provides telescope control uplink and operational status downlink o ~5GB per day data volume with LEO-mobile compatible bandwidth requirements o Requires low latency and moderately high availability o Currently ~40% availability (9hrs/day) for this data stream: continuous trade-off of operational efficiency between 40% and 90% availability • Science operations includes high availability voice and email links, and ability to uplink ~20MB data files once per day o Would prefer to have video link (e.g. Skype) instead of voice link
Seasonal Variation Impacts	• 9 month winter observing (except UV, < 6 month)

6.2 Astronomy - Particle Astrophysics

Albrecht Karle, University of Wisconsin-Madison, presented the data needs of the neutrino and astro-particle experiments at the South Pole. The major component in the USAP particle astrophysics research capabilities is the IceCube instrument.

Science data is generated in regular operational cycles. Collection runs typically last around eight hours with only a few minutes between runs. A small fraction of time is used for calibration and test runs. It is possible that a portion of the IceCube array will be kept operational through given hardware failures or testing configurations. IceCube uses a complex system for data acquisition, processing and forwarding. Each system has internal buffers and they communicate via Ethernet network. There is a need for high data rate transfer on a daily basis to minimize the data exfiltration backlog.

Table 4. Data Needs Summary for Astronomy - Particle Astrophysics

Type of Data Generated	• Science data is generated in regular operational cycles. Collection runs typically last around eight hours with only a few minutes between runs.
Required Data Rates	• ~100GB/day
Timeliness Requirements	• Required latency on the order of 1 day for routine operations based on need to monitor the data stream and perform timely processing • Maximum 1 week data buffer permits (but does not encourage) lower availability requirements
Block Data Requirements	• Existing bulk data stream already make use of compression techniques based on analysis of data properties o Unlikely to achieve further significant improvements in reduction of data volume • Data processing is compute- and labor- intensive o Processing at pole would require significantly increased computing capability, power, and winter-over staffing on site
Real-time Data Requirements	• Real-time science link sends transient source alerts for distribution over the internet o Examples include supernovae, gamma-ray bursts, etc. o Alerts can trigger target-of-opportunity responses by other observatories on minutes to hours timescales o Low latency, high availability critical to this function • Real-time interactive TCP/IP sessions for instrument control and monitoring o Several hundred MB per day, requires low latency and moderately high availability • Real-time instrument monitoring stream provides operational status o ~5MB per day data volume steady data stream with low latency and high availability requirements
Requirements Unique to the Science	• The alert systems need low bandwidth low latency connectivity to the north. Current RPSC systems don't provide this functionality • Unique astrophysical events may profit from the ability to transmit very high data amounts for a very short time period • Unexpected failures may need a usable bandwidth from the north to allow assistance to onside winter over. • A high bandwidth channel from the north to the south would be very helpful to transfer software updates and needed data to the south in a timely fashion (timescale of a day)
Seasonal Variation Impacts	• IceCube data are collected 365 days/year without interruption. • During austral summer data rates are higher due to temperature effects and special treatment of data from the direction of the Sun. (20-25%) • During phases where the moon is above the horizon (5-10%)
Data Communication Periodicity	• Event data are queued for transmission to RPSC, need to transmit in less then 1 week to not exceed available buffering capacity. • Alerts are sent at a rate of 1/min.
How do the requirements vary over time?	• Variations of up to 30% may occur due to seasonal/celestial effects • Test data may add a significant short time burst of data

6.3 Lower Atmospheric Sciences and Meteorology

John Helly and Matt Lazzara were the chosen representatives for this science area. John Helly discussed lower atmospheric sciences and Matt Lazzara spoke about meteorology.

John Helly was asked to discuss the current approaches and capabilities used in lower atmospheric sciences. He also provided useful information on shipboard operations on vessels like the Nathaniel Palmer and the Laurence Gould. His research has included the spatial characterization of melt water fields from icebergs in the Weddell Sea. This characterization requires the correlation of multisource measurements accurately and precisely across spatial and temporal scales, necessitating careful management of the geo-referencing and geo-registration of the data and error sources.[17]

Ship based field programs have long ocean survey scans utilizing sweeping observations gradually characterizing large areas over the ocean. These programs require near real time radar satellite imagery, real-time ship navigation information and near real time iceberg track data. As a result communication is necessary to ingress and egress information. Satellite communication is important to off load the data produced by a number of sensors. The figure below shows the compliment of a sensor basing option Helly would envision in a future robust architecture.

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[17] John Helly, et al, "Spatial characterization of the meltwater field from icebergs in the Weddell Sea," www.pnas.org/cgi/doi/10.1073/pnas.0909306108 (last accessed 15 Oct 2011.

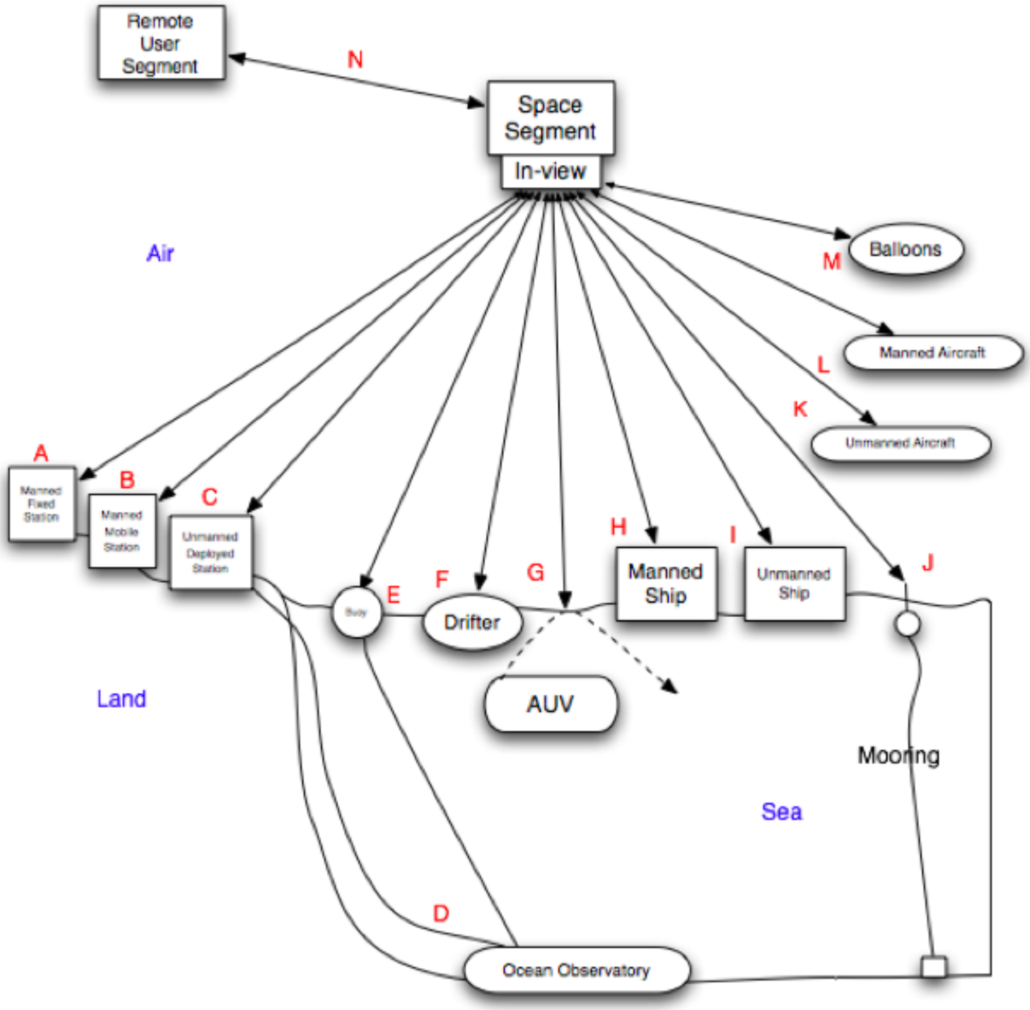

Figure 3. Exemplar Maritime Future System Architecture and Interfaces[18]

Matt Lazzara illustrated meteorology by discussing two examples, the Antarctica Automated Weather Station (AWS) Program and the Antarctica satellite meteorology derived from composites. AWSs take weather measurements every 10 minutes. Antarctic weather composites are created every hour (some views are created every three hours). Data from a variety of sources are collected off the ice via the Argos system or from remote sensing and used to generate timely views that are then disseminated.

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[18] John Helly figure from the science workshop.

Table 5. Data Needs Summary for Lower Atmospheric Sciences and Meteorology

	Antarctica Weather Station (AWS)	Antarctica Satellite Meteorology Composites
Type of Data Generated	• Meteorological observations	• Satellite observations
Required Data Rates	• As fast as Argos I to III: 0.4 to 4.8kbps • SBD 1.9kbps • As fast as Iridium (2.4 to 10kbps), or faster in the future (100 kbps)	• As fast as available from satellite providers direct broadcast: (up to 15 Mbps) •
Timeliness Requirements	• Real-time: AMPS (forecasting), • Archival/science: non-real-time	• Real-time (Most affordable option) •
Geographic Locations	• Continent-wide	• Continent-wide/Southern Ocean +
Block Data Requirements	• Possible with Iridium (e.g. BAS) • Newer AWS record data onboard via compact flash	• Only applicable for GAC, FRAC and MODIS data •
Real-time Data Requirements	• ~200 sec transmissions o 32 bytes per AWS • ~75% of the network require Argos DCS – historic inherent “real-time” • Data Volume per Day: • 420 Mb/month - 10 to 14 Mb/day	• Direct broadcast data: o Up to 15 Mbps o 14 to 16 passes per satellite per day o Up to 1.4 Gb per pass (raw) • Data Volume per Day: 505 Mb/day (could increasing up to 2.9 Gb) for the final product…input amounts vary based on data availability o ~500 Mb/day to as much as 2 to 4 Gb/day o 420 Mb/month - 10 to 14 Mb/day
Seasonal Variation Impacts	• None	
How do the requirements vary over time?	• However, the future might see variable observing for meeting future specific science objectives or operational forecast needs with adaptive observing (aka the LEAD (Linked Environments for Atmospheric Discovery) project) • Future of Argos DCS is a concern for AWS real-time usage	

6.4 Upper Atmospheric and Geospace Sciences

Allan Weatherwax submitted information on upper atmospheric and geospace sciences. The science consists of magnetic, electric field, particle, GPS scintillation, optical (all sky imagers and photometers), radar measurements (SuperDARN, Meteor, etc.), and radio measurements (e.g., ULF-HF). Real time data retrieval of data from remote Antarctica observatories uses Iridium.

Table 6. Data Needs Summary for Upper Atmosphere and Geospace Sciences

Type of Data Generated	• At most remote space science facilities, there is 24/7 data collection when power is available. • What is the concept of operation of the system? o Continuous: Selected instruments such as magnetometers, radio receivers etc. o Seasonal (dark): Optical auroral observations o Campaign modes: Increased data rates for solar storm events (space weather) • What types of communication are required between components? o Accurate timing required (0.1 second minimum) o GPS is currently employed at all remote stations • What type of connectivity is required among local and remote players? o Real time connectivity is need for space weather monitoring
Required Data Rates	• 1 to 50 Hz o Magnetometers (1 Hz) o GPS scintillation receivers (50 Hz) o
Timeliness Requirements	• A mix of "timeliness" is required depending on the science needs and goals. • Selected real-time data and/or parameters are needed for space weather monitoring.
Geographic Locations	• Antarctic Plateau
Block Data Requirements	• Each station might collect 500-1000 GB/year (multiple flash drives) o e.g. 32GB Compact Flash drives
Real-time Data Requirements	• At present, a single Automatic Geophysical Observatory (AGO) site transmits 20 MB/day via Iridium
Requirements Unique to the Science	• Space weather and solar storm monitoring • During solar storms, increased data rates would be desirable
Seasonal Variation Impacts	• During darkness, optical instruments operate • All-sky images (e.g., 1-5 GB/day per station)
Data Communication Periodicity	• Near real-time connectivity is desired
How do the requirements vary over time?	• The data volume varies depending on night/day conditions.

6.5 Glaciology and Antarctic System Science

Theodore Scambos, CIRES University of Colorado, described the requirements for glaciology and Antarctica system science. Glaciology studies ice flow, ice and snow accumulation, paleoclimate, and the balance of ice mass verses sea level. Research includes detecting and mapping changes by measuring elevation, temperature, speed, melt and ice fracture. In the field there are three types of mission operations with each having different communication needs, 1) ice core samples and drilling in large camps, Figure 4, 2) traverse or survey measurements, Figure 5, and 3) automated measurement stations, Figure 6.

Figure 4. Aerogeophysics Ice Core Camps[19]

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[19] Base Camp pictures from Theodore Scambos

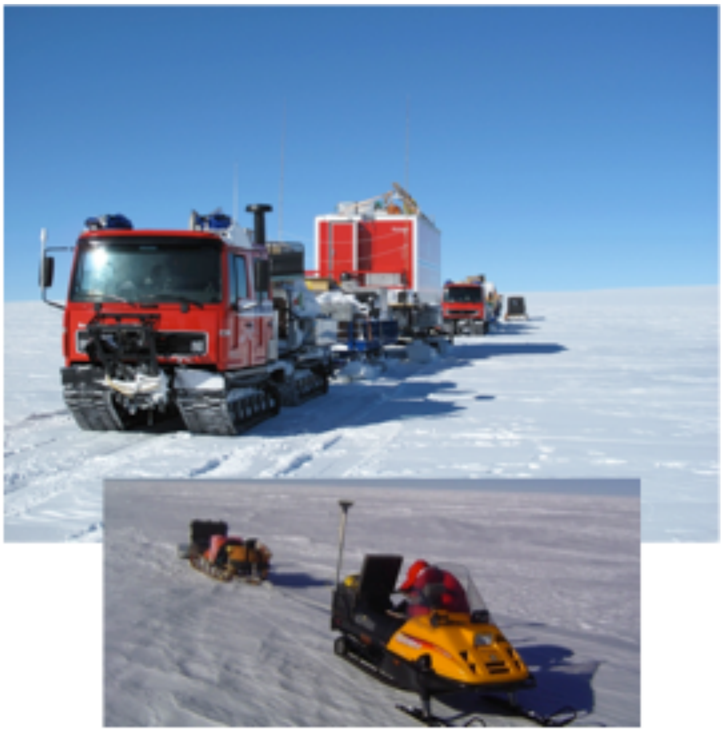

Figure 5. Research Traverse[20]

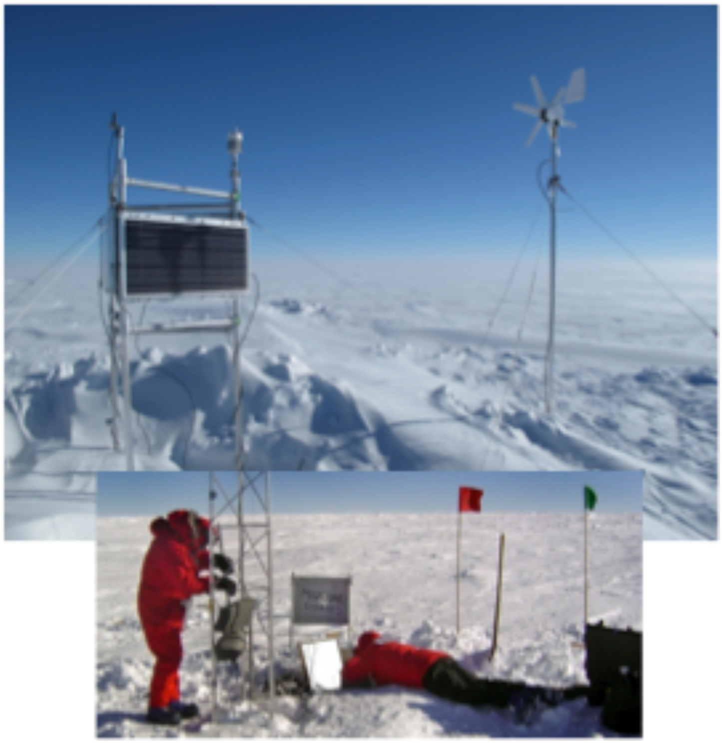

Figure 6. Automated Stations[21]

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[20] Research traverse pictures from Theodore Scambos

Table 7. Data Needs Summary for Glaciology and Antarctic System Science

	Aerogeophysics Ice Core Camps	Traverse or Survey Measurements	Automated Measurement Stations
Type of Data Generated	• Daily flights, multiple high-data-rate sensors: radar, images, GPS, laser altimeter • Ice core drilling – monitoring, drill core system engineering	• Daily data collection from radar, GPS, images	• Daily data collection from GPS, images, weather, seismic
Required Data Rates	• ~1 Tb/day	• ~10 Gb/day	• ~100 Mb/day • Asymmetric two-way coms needed
Geographic Locations	• Large, fixed camps	• Small, mobile camp; time, power, weight issues. Quick camp set-up.	• Quick set-up, small camps
Scenarios Requiring Significant Data Transmissions or Downloads	• Re-planning flights with stateside or in-the-field partners (e.g. AGAP, AGASEA) • Troubleshooting sensors or systems – send data samples for examination • Responding to in-the-field discoveries – literature and data downlinking, telecoms, re-designing data collection to adapt • High-resolution (to <1 meter) satellite images; weather images and data daily • Health – safety - flight ops	• Troubleshooting sensors, data processing – send data samples for examination by colleagues • Responding to in-the-field discoveries – literature and data downlinking, telecoms, re-designing data collection plan to adapt • Health – safety - flight ops	• AUV, ROV, UAV need fast, high data rate, two-way coms at 128 kbps

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[21] Automated station pictures from Theodore Scambos

6.6 Antarctic Earth Sciences

Bjorn Johns, UNAVCO, provided the science overview and communication needs for Antarctica earth science. The science instruments consist of a network of distributed remote autonomous systems that are intended for multi-year unattended operation.

Table 8. Data Needs Summary for Antarctic Earth Sciences

Type of Data Generated	• Currently dual-frequency GPS. Additional GNSS signals are anticipated.
Required Data Rates	• 30 second sample rate minimum. Higher rate data desired for shorter timescale signals. 1Hz data collection is common elsewhere when communications allow. Applications exist for 50Hz (1Gb/site/day).
Timeliness Requirements	• Real-time is required for command and control, near real time (hours) is good for state of health, operational met data, keeping up with data collection, and providing base station data to other projects.
Geographic Locations	• Continent wide, and Greenland.
Block Data Requirements	• ~1Mb/day/site minimum in near-real-time mode (<24hrs latency). This is partly determined by necessity using serial Iridium modem-modem data retrieval, additional bandwidth could enable better science.
Real-time Data Requirements	• On demand for command and control, real-time data could enable more applications such as real-time positioning and navigation.
Requirements Unique to the Science	• Bedrock observations require several years' continuous data to determine secular trends. Remote GPS sites are also used as survey base stations for other projects. Potential for precise real-time navigation.
Seasonal Variation Impacts	• Higher rate data (1-5Hz) may be requested during summer season as geodetic control for airborne missions or other projects. Operational met data, precise real-time navigation could be desirable in summer with low latency.
Data Communication Periodicity	• ~4 times/day
How do the requirements vary over time?	• Currently steady at about 1Mb/site/day. This limits some science, but is adequate for Post-Glacial Rebound measurements. Expanded communication capacity will be met with demand for higher rate and lower latency data.

6.7 Antarctic Ocean Sciences

Steve Foley, Scripps Institute of Oceanography, presented the Antarctica ocean sciences overview and communication needs. This science takes the form of either ship-based or on-ice science operations above 60° latitude. The science missions vary and include all aspects of ocean science. The data needs vary widely based type on type of science, number of science groups supported, and data intensity. Certain assets are mobile (i.e. Argo, gliders, tags, etc.), while others are continuous observatories (i.e. OOI at 60°N).

The science techniques of coring, moorings, sampling, and towed/submerged equipment are used. The equipment used includes hull mounted sonars (multi-beam, sub-bottom profilers, Acoustic Doppler Current Profilers), towed instruments, atmospheric instruments, sampling gear (CTDs, nets, etc.), and AUVs and gliders.

Communications needs for science collaboration include shared data in both directions, remote access to shore-based experts (video, image, email), communications between ships, and equipment support, such as access to documentation and software updates. For outreach, videoconferences, blogs, and movies are needed, and ship operations require weather/ice reports, as well as support for maintenance and planning.

Table 9. Data Needs Summary for Antarctic Ocean Sciences

Type of Data Generated	• Observatory data (streamed or batched data, images) • Collaboration data with live scientists (email, video conference, VoIP, images, maps, etc.) • Outreach data (web/blog updates, HD video, video conference, etc.) • Operations data consumed (weather, ice conditions, software updates, etc.)
Required Data Rates	• Each set of observatory data (MET, current, hydro, occasional image, etc.) is ~50kbps continuous stream. Video feeds are extra (100kbps up to 20Mbit for HD), Ship sonars add another ~3.5+GB/day (highly compressible) • A 5 Mega Pixel camera sending 1 compressed JPEG per min is ~2GB/day • Deep water full multi-beam with full backscatter is 250MB/day (90%+ is backscatter) • Collaboration and outreach data varies with the mission. Up to 1Mbit in bursts of large files or good videoconference.
Timeliness Requirements	• Real-time is required for some collaboration, hourly works for others
Geographic Locations	• Potentially anywhere in the water/ice above 60 degrees latitude
Block Data Requirements	• ~500MB/day/site for observatory raw stream
Real-time Data Requirements	• 100MB/day/site during videoconferences
Requirements Unique to the Science	• Data can be bursty with concurrent science • How many stations are operating at one time? o A few ships, some science sites
Seasonal Variation Impacts	• Most ships/stations work during the summer season, but data needs do not necessarily vary by season
Data Communication Periodicity	• Preferably continuous, but can usually be batched hourly or daily
How do the requirements vary over time?	• Data transmit needs seem to be growing steadily as instruments record more data

6.8 Antarctic Organism and Ecosystem

Peter Doran, University of Illinois, presented the long-term ecological research of the McMurdo Dry Valleys. There are a variety of remote sensors that have automated data loggers that generate data on sub-hourly time scales. The current approach is to fly by helicopter to each station once or twice a year to service the station and collect data. This approach prevents real-time or near real-time acquisition of data collection or assessment of the viability of a station at any given time. Their goal is to establish year round collection of telemetry data in the US and two-way communication with all stations from within the dry valleys or at McMurdo. Three types of data loggers are required, meteorological stations, lake stations and stream gages.

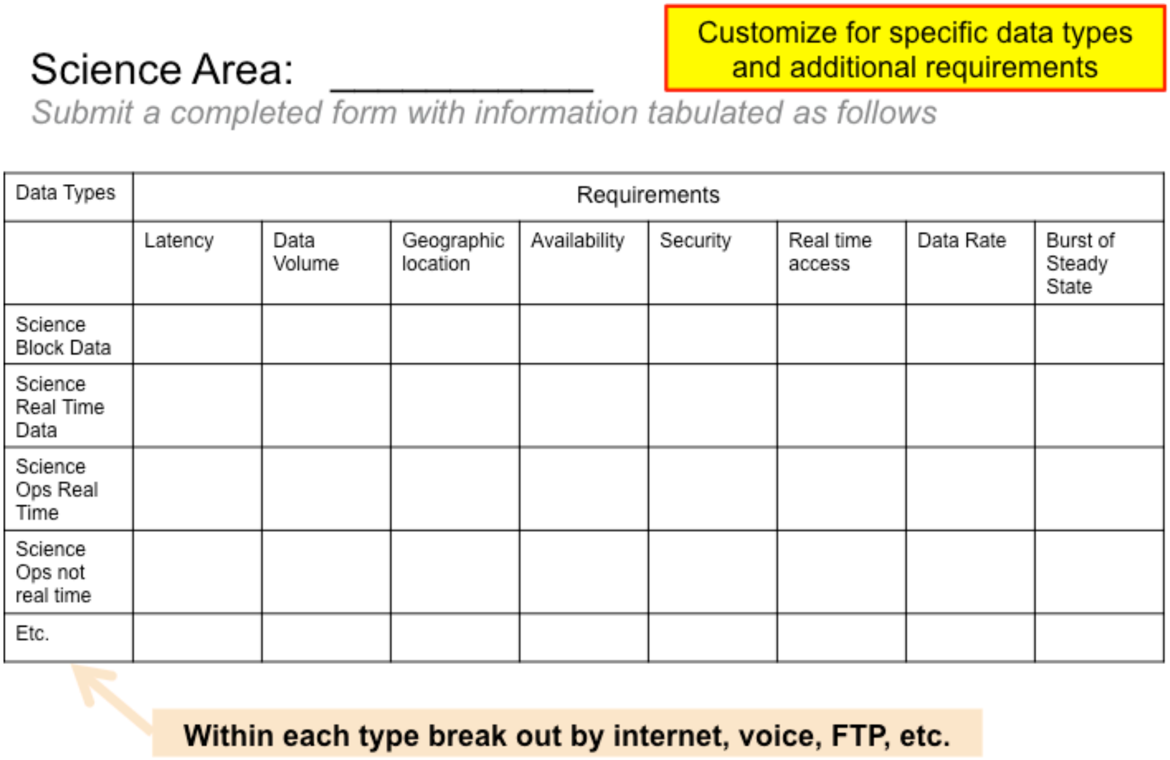
Table 10. Data Needs Summary for Antarctic Organism and Ecosystem

Required Data Rates	• All 3 types of data, meteorological stations, lake stations and stream gages, operate in the kbit/day range
Requirements Unique to the Science	• Winter-over telemetry from the dry valleys. Many line of site and power issues.
Seasonal Variation Impacts	• Meteorological and lake stations generate data year-round. Streams only flow Nov-Mar
Data Communication Periodicity	• At a minimum desire daily data communications in winter, more frequent in summer
How do the requirements vary over time?	• Summer is 110 kB/day but more frequent, winter is 54 kB/day and less frequent

7. Day 2 - Science User Breakout Group Results

The tables below summarize the inputs from the science users collected on Day 2 during breakout groups. During the break out groups the science users were asked to write out what they thought their current, 2012 time frame, and future, 2020 time frame, communication requirements would be to support their science missions. The table below was given to each of the team members as a template to capture these requirements.

Table 11. Science Communication Input Template



Customize for specific data types and additional requirements

Science Area: ____________

Submit a completed form with information tabulated as follows

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data								
Science Real Time Data								
Science Ops Real Time								
Science Ops not real time								
Etc.								

Within each type break out by internet, voice, FTP, etc.

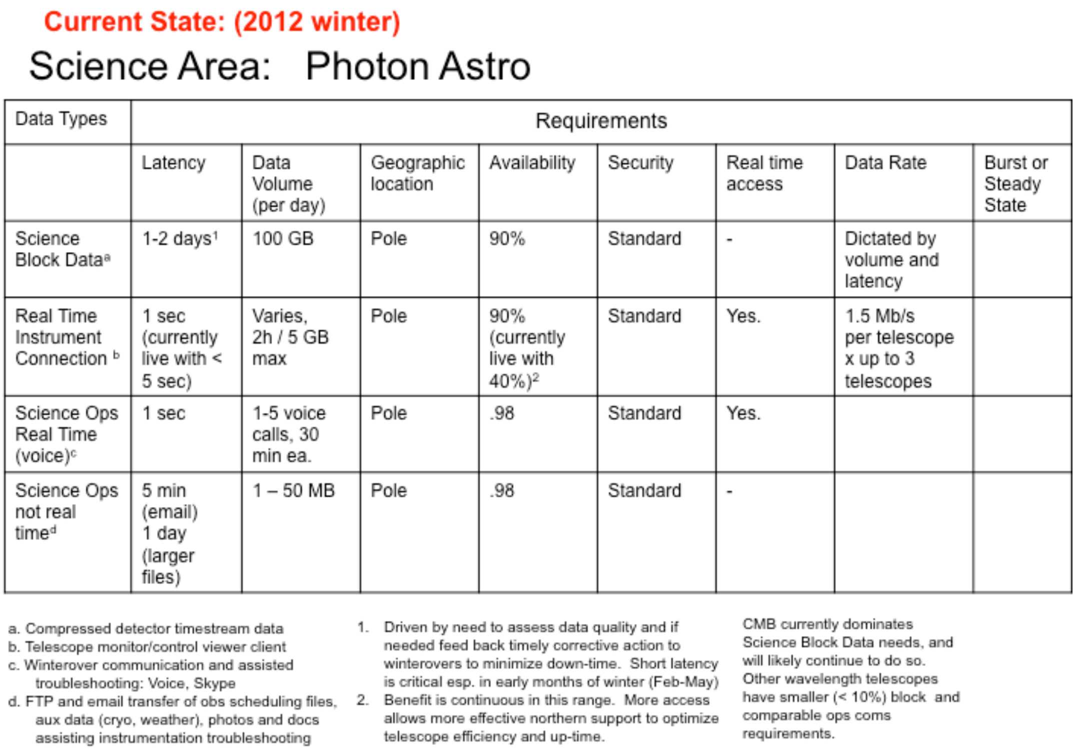
Each group provided these tables and summary briefing material that conveyed any additional information that would be useful in the requirement development process.

7.1 South Pole Users

The South Pole users have the largest data needs in a single location. With the continued growth of instruments fielded around the South Pole location this will only grow. There are two major groupings of astronomy science being serviced but the goal is to use the same communication infrastructure to support both of them.

7.1.1 Photon Astronomy

Table 12. Photon Astronomy – Current State



Current State: (2012 winter)

Science Area: Photon Astro

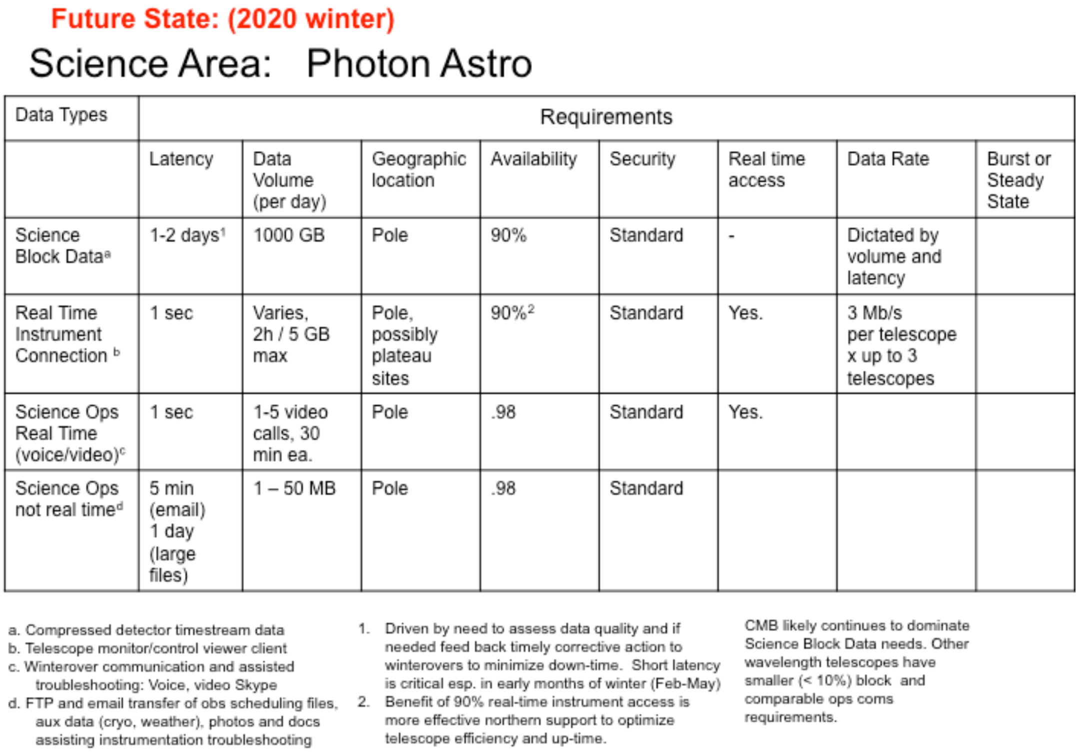
Data Types	Requirements							
	Latency	Data Volume (per day)	Geographic location	Availability	Security	Real time access	Data Rate	Burst or Steady State
Science Block Data[a]	1-2 days[1]	100 GB	Pole	90%	Standard	-	Dictated by volume and latency	
Real Time Instrument Connection [b]	1 sec (currently live with < 5 sec)	Varies, 2h / 5 GB max	Pole	90% (currently live with 40%)[2]	Standard	Yes.	1.5 Mb/s per telescope x up to 3 telescopes	
Science Ops Real Time (voice)[c]	1 sec	1-5 voice calls, 30 min ea.	Pole	.98	Standard	Yes.		
Science Ops not real time[d]	5 min (email) 1 day (larger files)	1 – 50 MB	Pole	.98	Standard	-		

a. Compressed detector timestream data
b. Telescope monitor/control viewer client
c. Winterover communication and assisted troubleshooting: Voice, Skype
d. FTP and email transfer of obs scheduling files, aux data (cryo, weather), photos and docs assisting instrumentation troubleshooting

1. Driven by need to assess data quality and if needed feed back timely corrective action to winterovers to minimize down-time. Short latency is critical esp. in early months of winter (Feb-May)
2. Benefit is continuous in this range. More access allows more effective northern support to optimize telescope efficiency and up-time.

CMB currently dominates Science Block Data needs, and will likely continue to do so. Other wavelength telescopes have smaller (< 10%) block and comparable ops coms requirements.

Table 13. Photon Astronomy – Future State



Future State: (2020 winter)

Science Area: Photon Astro

Data Types	Requirements							
	Latency	Data Volume (per day)	Geographic location	Availability	Security	Real time access	Data Rate	Burst or Steady State
Science Block Data[a]	1-2 days[1]	1000 GB	Pole	90%	Standard	-	Dictated by volume and latency	
Real Time Instrument Connection [b]	1 sec	Varies, 2h / 5 GB max	Pole, possibly plateau sites	90%[2]	Standard	Yes.	3 Mb/s per telescope x up to 3 telescopes	
Science Ops Real Time (voice/video)[c]	1 sec	1-5 video calls, 30 min ea.	Pole	.98	Standard	Yes.		
Science Ops not real time[d]	5 min (email) 1 day (large files)	1 – 50 MB	Pole	.98	Standard			

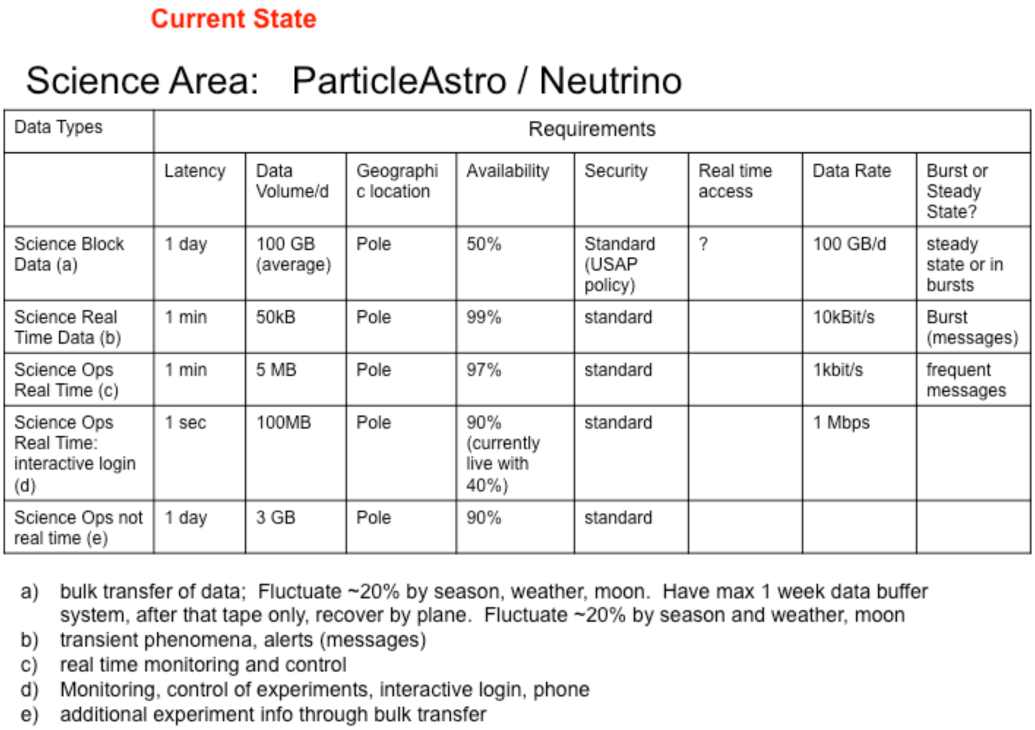
a. Compressed detector timestream data
b. Telescope monitor/control viewer client
c. Winterover communication and assisted troubleshooting: Voice, video Skype
d. FTP and email transfer of obs scheduling files, aux data (cryo, weather), photos and docs assisting instrumentation troubleshooting

1. Driven by need to assess data quality and if needed feed back timely corrective action to winterovers to minimize down-time. Short latency is critical esp. in early months of winter (Feb-May)
2. Benefit of 90% real-time instrument access is more effective northern support to optimize telescope efficiency and up-time.

CMB likely continues to dominate Science Block Data needs. Other wavelength telescopes have smaller (< 10%) block and comparable ops coms requirements.

7.1.2 Particle Astronomy

Table 14. Particle Astronomy – Current State



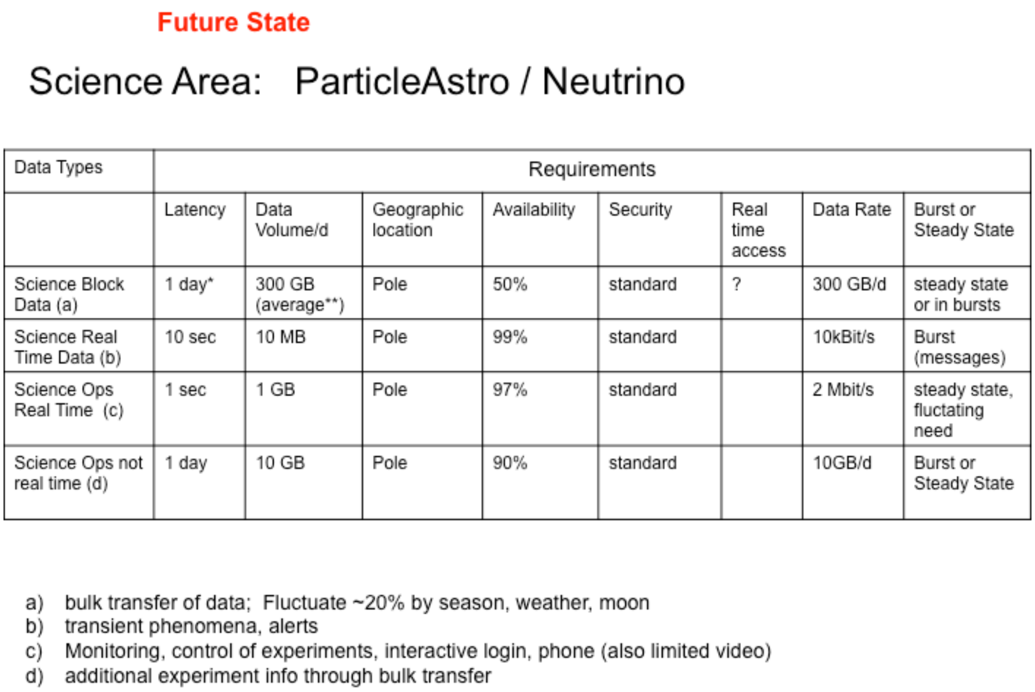
Current State

Science Area: ParticleAstro / Neutrino

Data Types	Requirements							
	Latency	Data Volume/d	Geographic location	Availability	Security	Real time access	Data Rate	Burst or Steady State?
Science Block Data (a)	1 day	100 GB (average)	Pole	50%	Standard (USAP policy)	?	100 GB/d	steady state or in bursts
Science Real Time Data (b)	1 min	50kB	Pole	99%	standard		10kBit/s	Burst (messages)
Science Ops Real Time (c)	1 min	5 MB	Pole	97%	standard		1kbit/s	frequent messages
Science Ops Real Time: interactive login (d)	1 sec	100MB	Pole	90% (currently live with 40%)	standard		1 Mbps	
Science Ops not real time (e)	1 day	3 GB	Pole	90%	standard			

a) bulk transfer of data; Fluctuate ~20% by season, weather, moon. Have max 1 week data buffer system, after that tape only, recover by plane. Fluctuate ~20% by season and weather, moon
b) transient phenomena, alerts (messages)
c) real time monitoring and control
d) Monitoring, control of experiments, interactive login, phone
e) additional experiment info through bulk transfer

Table 15. Particle Astronomy – Future State



Future State

Science Area: ParticleAstro / Neutrino

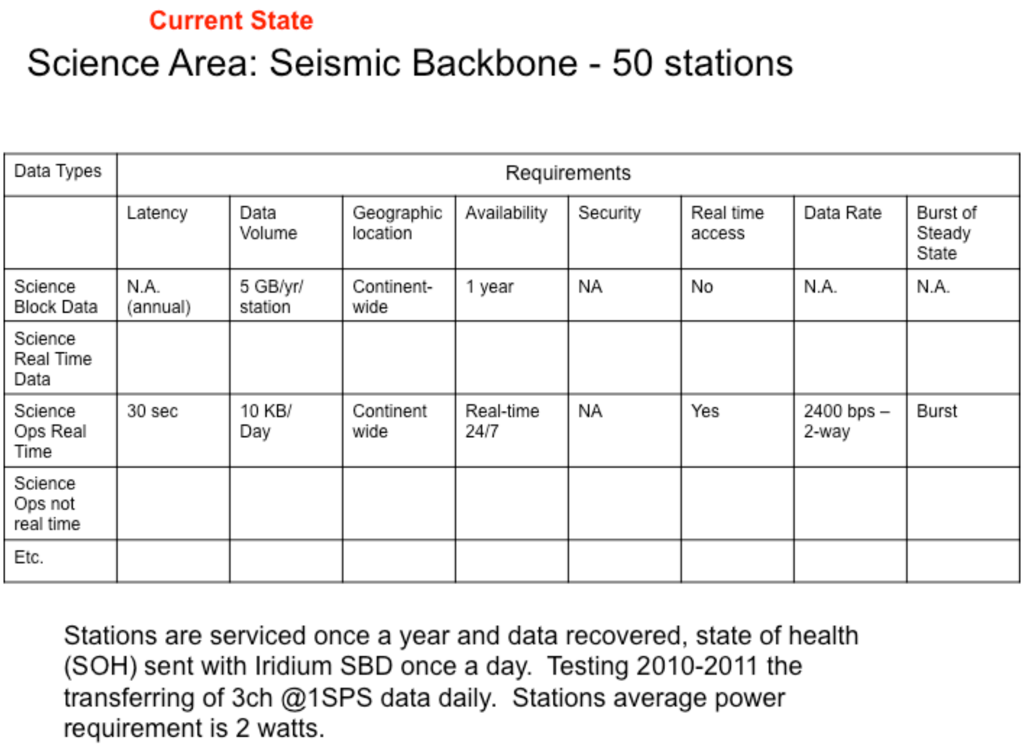
Data Types	Requirements							
	Latency	Data Volume/d	Geographic location	Availability	Security	Real time access	Data Rate	Burst or Steady State
Science Block Data (a)	1 day*	300 GB (average**)	Pole	50%	standard	?	300 GB/d	steady state or in bursts
Science Real Time Data (b)	10 sec	10 MB	Pole	99%	standard		10kBit/s	Burst (messages)
Science Ops Real Time (c)	1 sec	1 GB	Pole	97%	standard		2 Mbit/s	steady state, fluctating need
Science Ops not real time (d)	1 day	10 GB	Pole	90%	standard		10GB/d	Burst or Steady State

a) bulk transfer of data; Fluctuate ~20% by season, weather, moon
b) transient phenomena, alerts
c) Monitoring, control of experiments, interactive login, phone (also limited video)
d) additional experiment info through bulk transfer

7.2 Distributed Users

7.2.1 Seismic Backbone

Table 16. Seismic Backbone – Current State



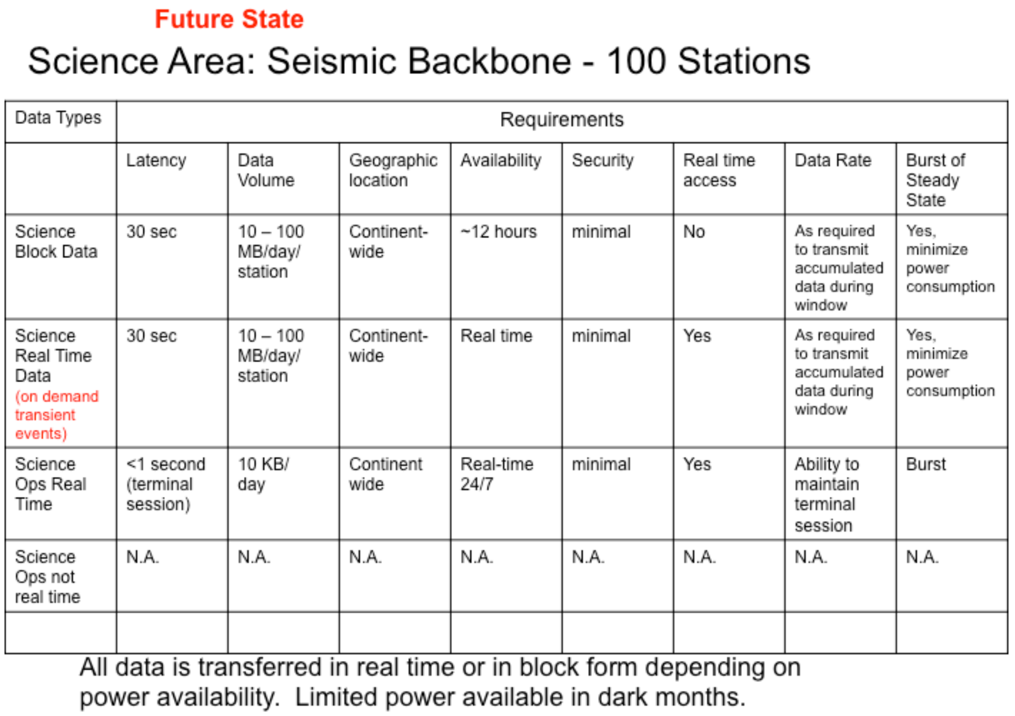
Current State

Science Area: Seismic Backbone - 50 stations

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	N.A. (annual)	5 GB/yr/ station	Continent-wide	1 year	NA	No	N.A.	N.A.
Science Real Time Data								
Science Ops Real Time	30 sec	10 KB/ Day	Continent wide	Real-time 24/7	NA	Yes	2400 bps – 2-way	Burst
Science Ops not real time								
Etc.								

Stations are serviced once a year and data recovered, state of health (SOH) sent with Iridium SBD once a day. Testing 2010-2011 the transferring of 3ch @1SPS data daily. Stations average power requirement is 2 watts.

Table 17. Seismic Backbone – Future State



Future State

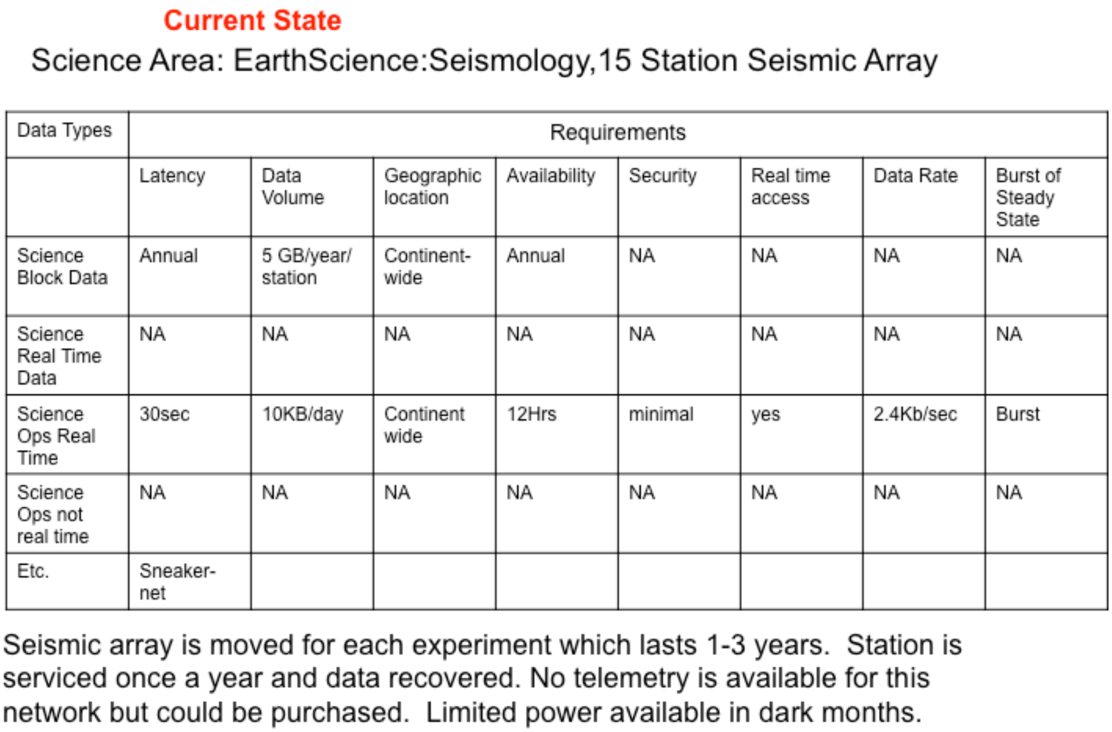
Science Area: Seismic Backbone - 100 Stations

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	30 sec	10 – 100 MB/day/ station	Continent-wide	~12 hours	minimal	No	As required to transmit accumulated data during window	Yes, minimize power consumption
Science Real Time Data (on demand transient events)	30 sec	10 – 100 MB/day/ station	Continent-wide	Real time	minimal	Yes	As required to transmit accumulated data during window	Yes, minimize power consumption
Science Ops Real Time	<1 second (terminal session)	10 KB/ day	Continent wide	Real-time 24/7	minimal	Yes	Ability to maintain terminal session	Burst
Science Ops not real time	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

All data is transferred in real time or in block form depending on power availability. Limited power available in dark months.

7.2.2 Seismology

Table 18. Seismology – Current State



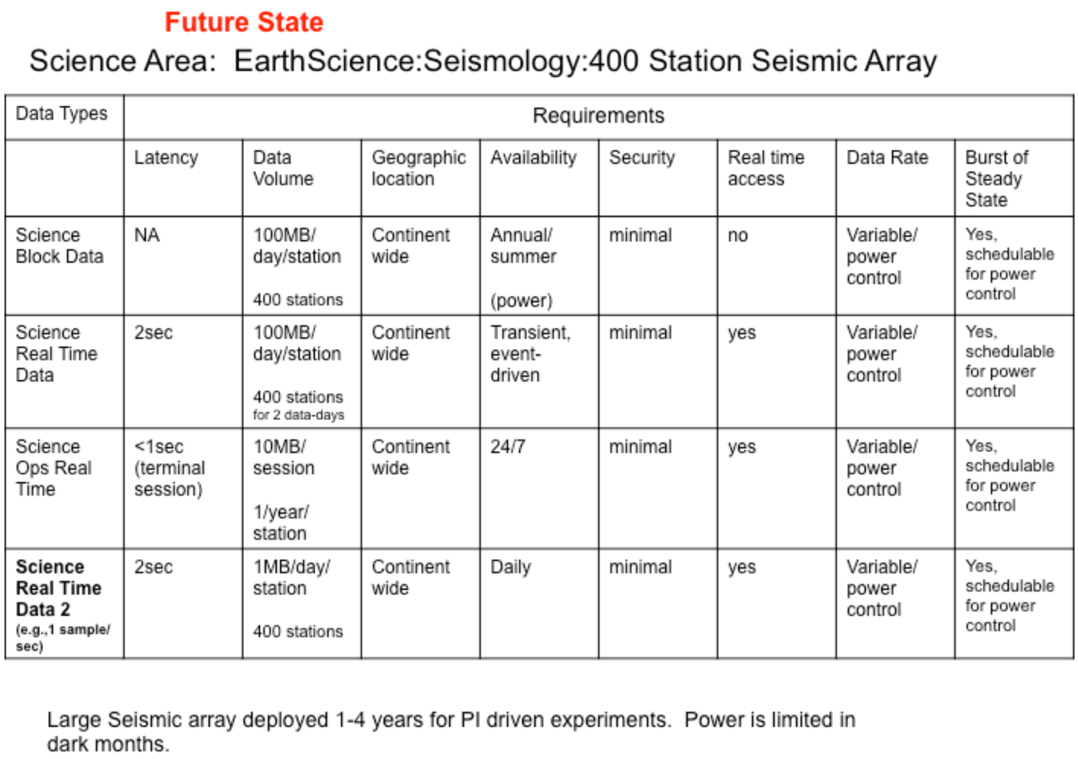
Current State

Science Area: EarthScience:Seismology,15 Station Seismic Array

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	Annual	5 GB/year/ station	Continent-wide	Annual	NA	NA	NA	NA
Science Real Time Data	NA	NA	NA	NA	NA	NA	NA	NA
Science Ops Real Time	30sec	10KB/day	Continent wide	12Hrs	minimal	yes	2.4Kb/sec	Burst
Science Ops not real time	NA	NA	NA	NA	NA	NA	NA	NA
Etc.	Sneaker-net							

Seismic array is moved for each experiment which lasts 1-3 years. Station is serviced once a year and data recovered. No telemetry is available for this network but could be purchased. Limited power available in dark months.

Table 19. Seismology – Future State



Future State

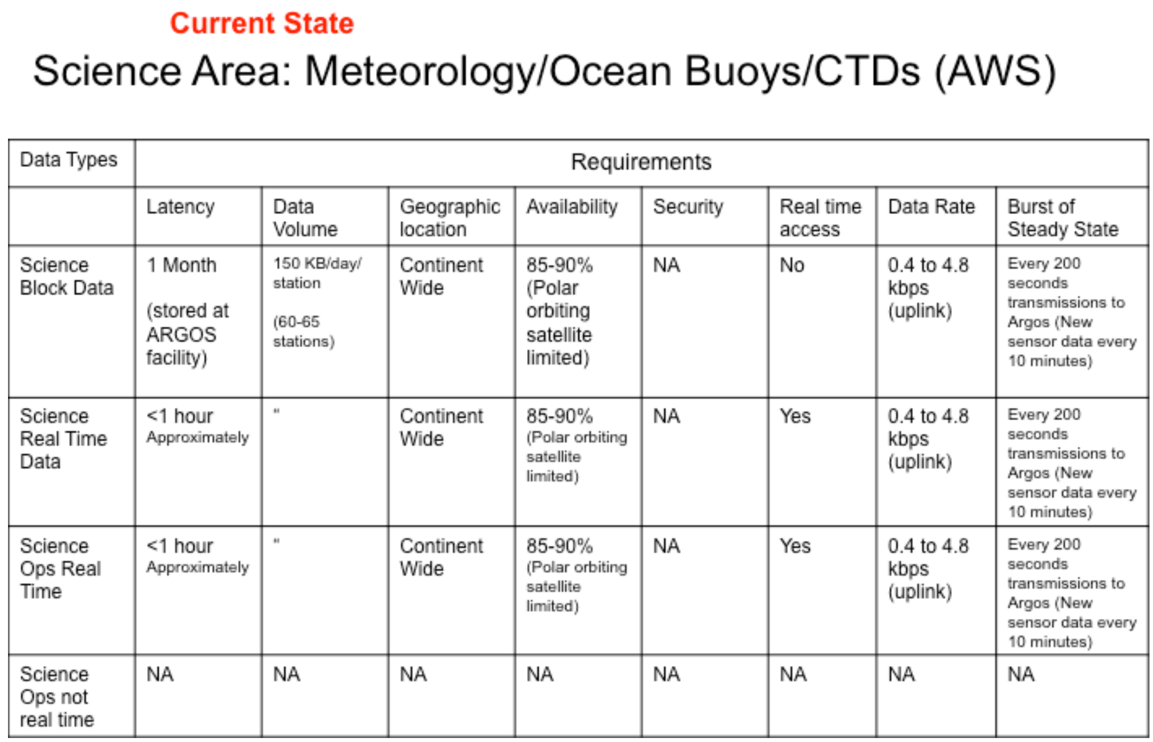
Science Area: EarthScience:Seismology:400 Station Seismic Array

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	NA	100MB/ day/station 400 stations	Continent wide	Annual/ summer (power)	minimal	no	Variable/ power control	Yes, schedulable for power control
Science Real Time Data	2sec	100MB/ day/station 400 stations for 2 data-days	Continent wide	Transient, event-driven	minimal	yes	Variable/ power control	Yes, schedulable for power control
Science Ops Real Time	<1sec (terminal session)	10MB/ session 1/year/ station	Continent wide	24/7	minimal	yes	Variable/ power control	Yes, schedulable for power control
Science Real Time Data 2 (e.g.,1 sample/ sec)	2sec	1MB/day/ station 400 stations	Continent wide	Daily	minimal	yes	Variable/ power control	Yes, schedulable for power control

Large Seismic array deployed 1-4 years for PI driven experiments. Power is limited in dark months.

7.2.3 Meteorology, Ocean Buoys and CTDs

Table 20. Meteorology, Ocean Buoys and CTDs – Current State

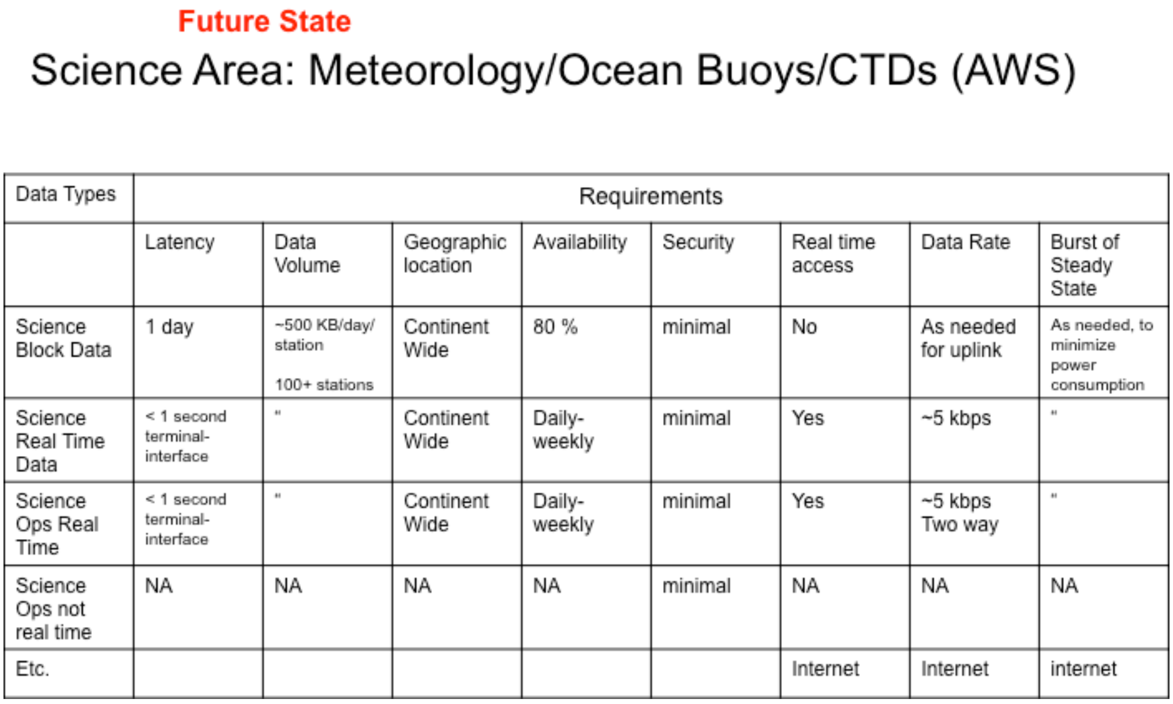


Current State

Science Area: Meteorology/Ocean Buoys/CTDs (AWS)

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	1 Month (stored at ARGOS facility)	150 KB/day/ station (60-65 stations)	Continent Wide	85-90% (Polar orbiting satellite limited)	NA	No	0.4 to 4.8 kbps (uplink)	Every 200 seconds transmissions to Argos (New sensor data every 10 minutes)
Science Real Time Data	<1 hour Approximately	"	Continent Wide	85-90% (Polar orbiting satellite limited)	NA	Yes	0.4 to 4.8 kbps (uplink)	Every 200 seconds transmissions to Argos (New sensor data every 10 minutes)
Science Ops Real Time	<1 hour Approximately	"	Continent Wide	85-90% (Polar orbiting satellite limited)	NA	Yes	0.4 to 4.8 kbps (uplink)	Every 200 seconds transmissions to Argos (New sensor data every 10 minutes)
Science Ops not real time	NA	NA	NA	NA	NA	NA	NA	NA

Table 21. Meteorology, Ocean Buoys and CTDs – Future State

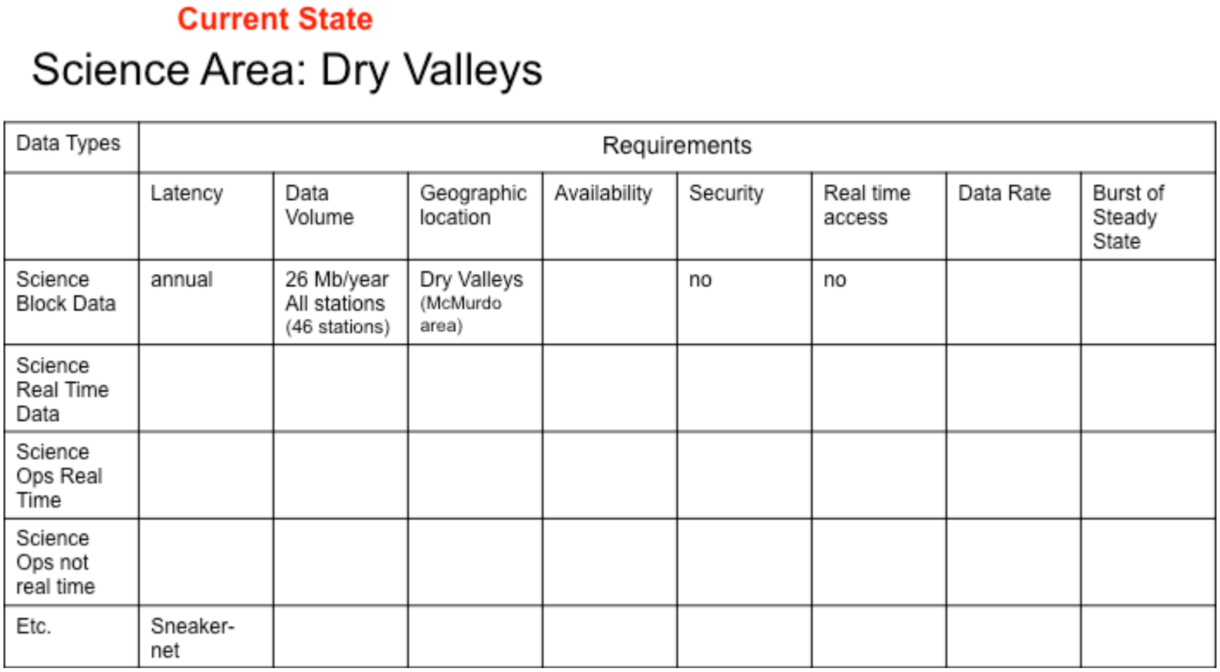


Future State

Science Area: Meteorology/Ocean Buoys/CTDs (AWS)

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	1 day	~500 KB/day/ station 100+ stations	Continent Wide	80 %	minimal	No	As needed for uplink	As needed, to minimize power consumption
Science Real Time Data	< 1 second terminal-interface	"	Continent Wide	Daily-weekly	minimal	Yes	~5 kbps	"
Science Ops Real Time	< 1 second terminal-interface	"	Continent Wide	Daily-weekly	minimal	Yes	~5 kbps Two way	"
Science Ops not real time	NA	NA	NA	NA	minimal	NA	NA	NA
Etc.						Internet	Internet	internet

Table 22. Dry Valleys – Current State

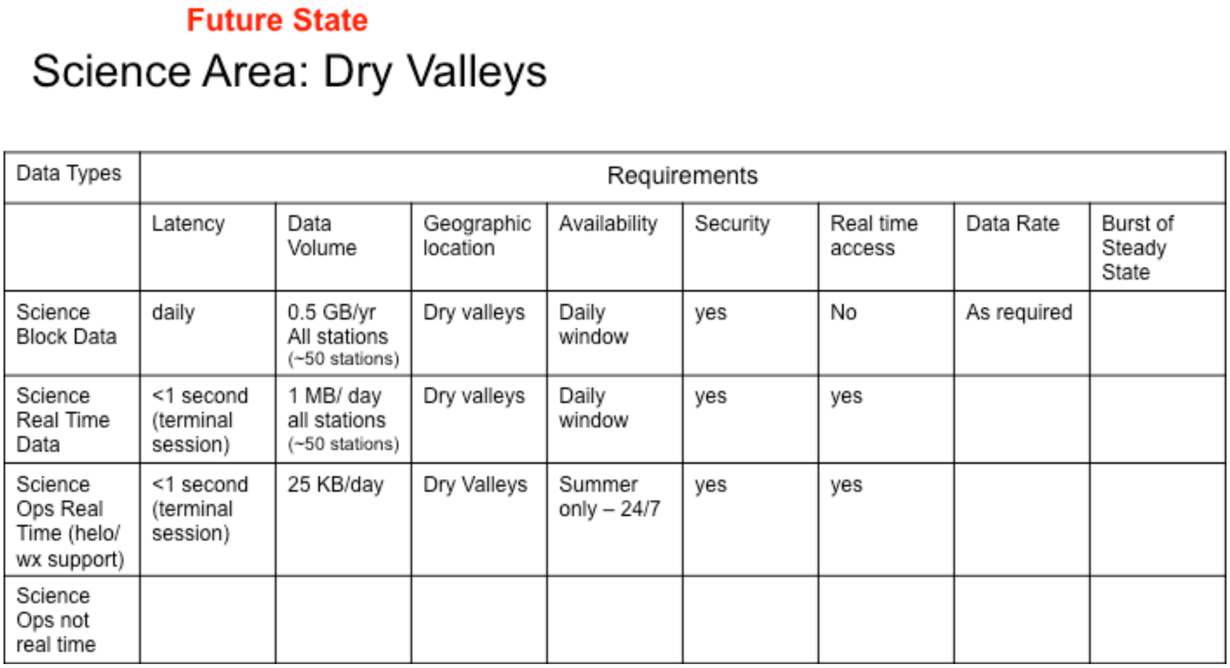


Current State

Science Area: Dry Valleys

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	annual	26 Mb/year All stations (46 stations)	Dry Valleys (McMurdo area)		no	no		
Science Real Time Data								
Science Ops Real Time								
Science Ops not real time								
Etc.	Sneaker-net							

Table 23. Dry Valley – Future State



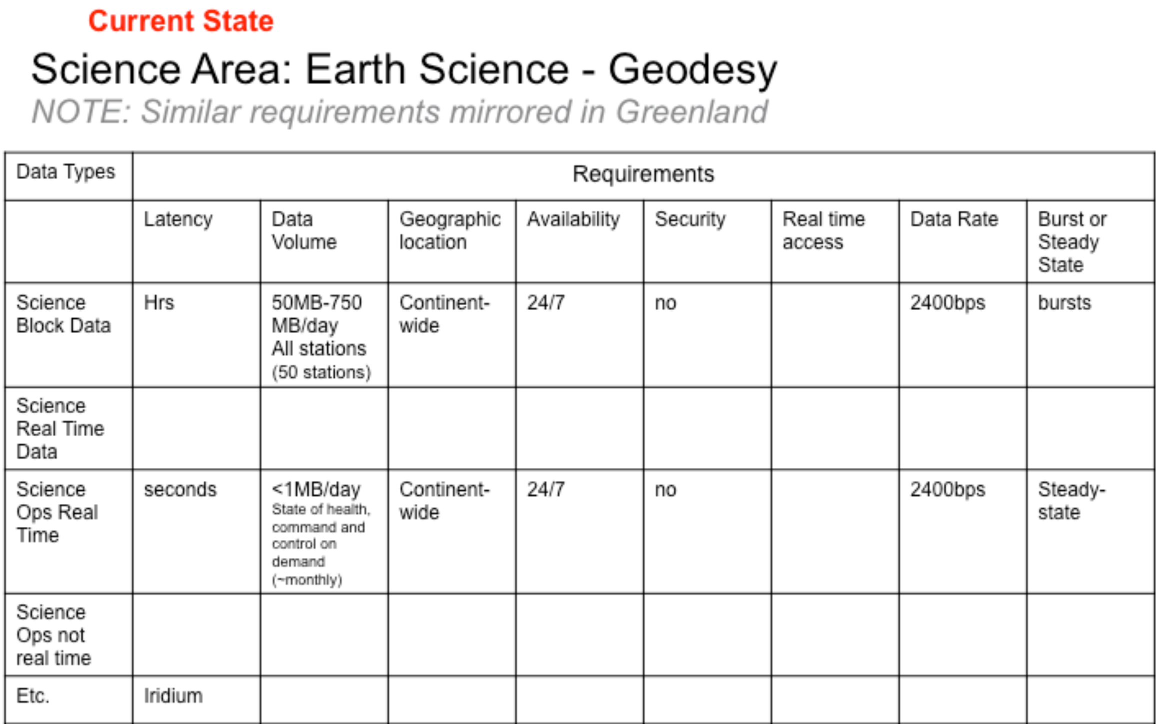
Future State

Science Area: Dry Valleys

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	daily	0.5 GB/yr All stations (~50 stations)	Dry valleys	Daily window	yes	No	As required	
Science Real Time Data	<1 second (terminal session)	1 MB/ day all stations (~50 stations)	Dry valleys	Daily window	yes	yes		
Science Ops Real Time (helo/ wx support)	<1 second (terminal session)	25 KB/day	Dry Valleys	Summer only – 24/7	yes	yes		
Science Ops not real time								

7.2.4 Earth Science - Geodesy

Table 24. Earth Science Geodesy – Current State



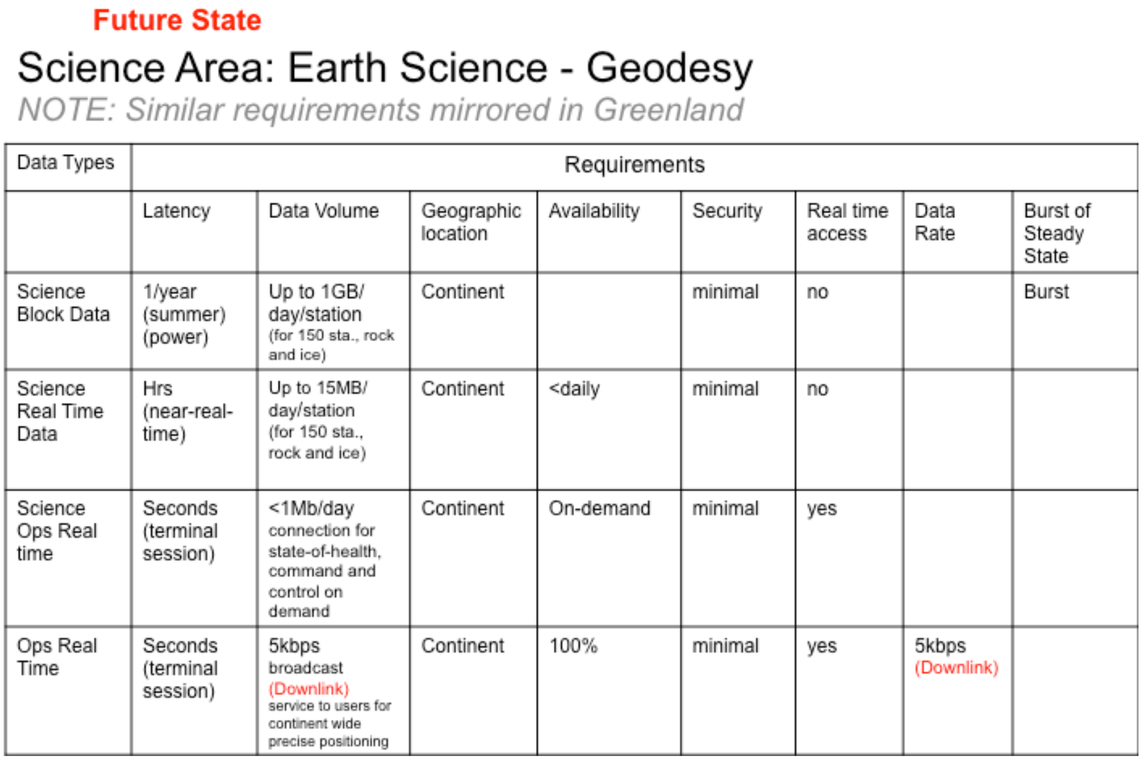
Current State

Science Area: Earth Science - Geodesy

NOTE: Similar requirements mirrored in Greenland

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst or Steady State
Science Block Data	Hrs	50MB-750 MB/day All stations (50 stations)	Continent-wide	24/7	no		2400bps	bursts
Science Real Time Data								
Science Ops Real Time	seconds	<1MB/day State of health, command and control on demand (~monthly)	Continent-wide	24/7	no		2400bps	Steady-state
Science Ops not real time								
Etc.	Iridium							

Table 25. Earth Science Geodesy – Future State



Future State

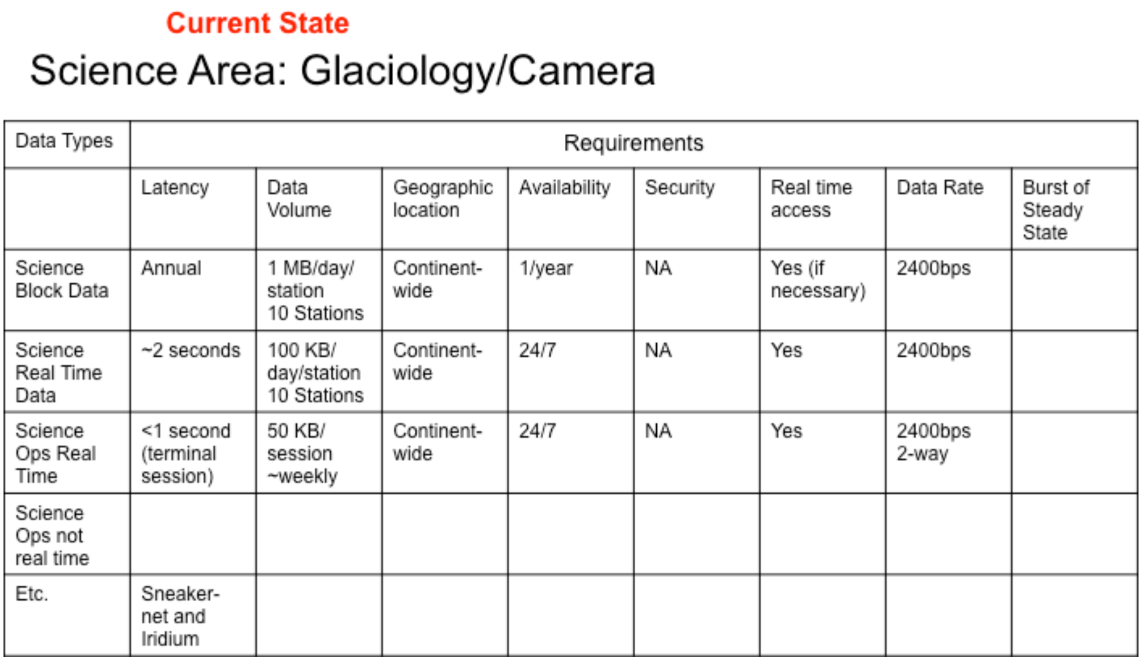
Science Area: Earth Science - Geodesy

NOTE: Similar requirements mirrored in Greenland

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	1/year (summer) (power)	Up to 1GB/ day/station (for 150 sta., rock and ice)	Continent		minimal	no		Burst
Science Real Time Data	Hrs (near-real-time)	Up to 15MB/ day/station (for 150 sta., rock and ice)	Continent	<daily	minimal	no		
Science Ops Real time	Seconds (terminal session)	<1Mb/day connection for state-of-health, command and control on demand	Continent	On-demand	minimal	yes		
Ops Real Time	Seconds (terminal session)	5kbps broadcast (Downlink) service to users for continent wide precise positioning	Continent	100%	minimal	yes	5kbps (Downlink)	

7.2.5 Glaciology

Table 26. Glaciology – Current State

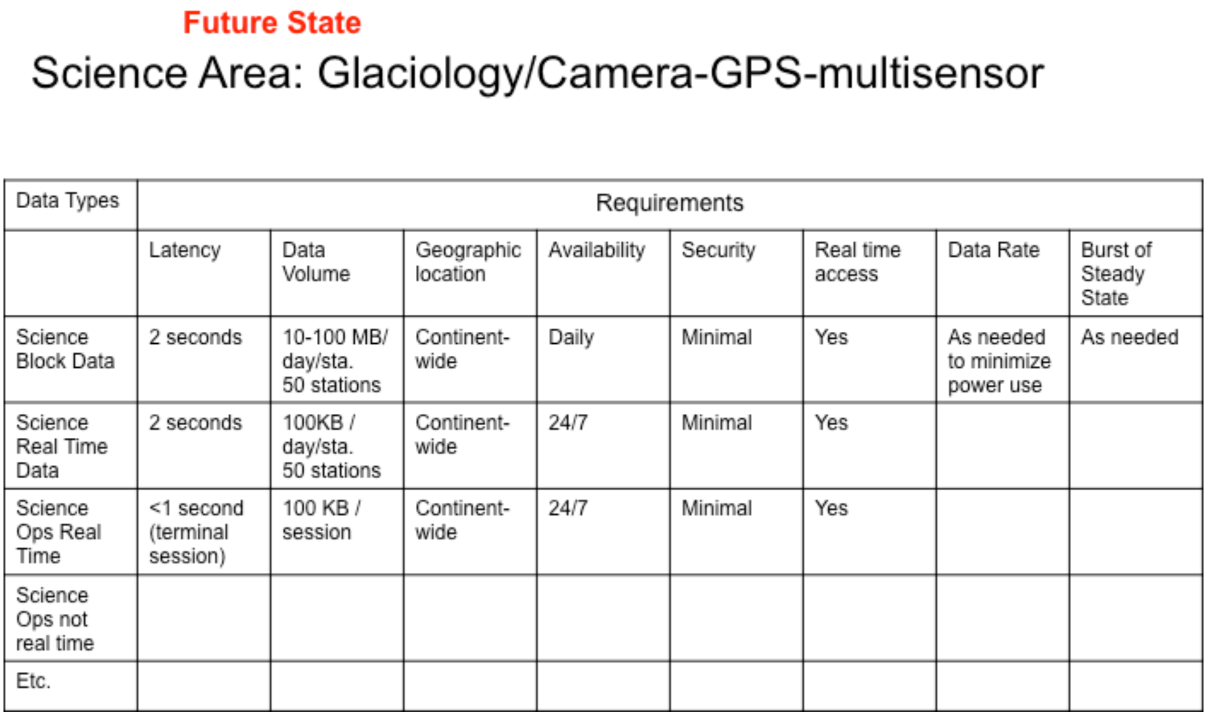


Current State

Science Area: Glaciology/Camera

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	Annual	1 MB/day/ station 10 Stations	Continent-wide	1/year	NA	Yes (if necessary)	2400bps	
Science Real Time Data	~2 seconds	100 KB/ day/station 10 Stations	Continent-wide	24/7	NA	Yes	2400bps	
Science Ops Real Time	<1 second (terminal session)	50 KB/ session ~weekly	Continent-wide	24/7	NA	Yes	2400bps 2-way	
Science Ops not real time								
Etc.	Sneaker-net and Iridium							

Table 27. Glaciology – Future State



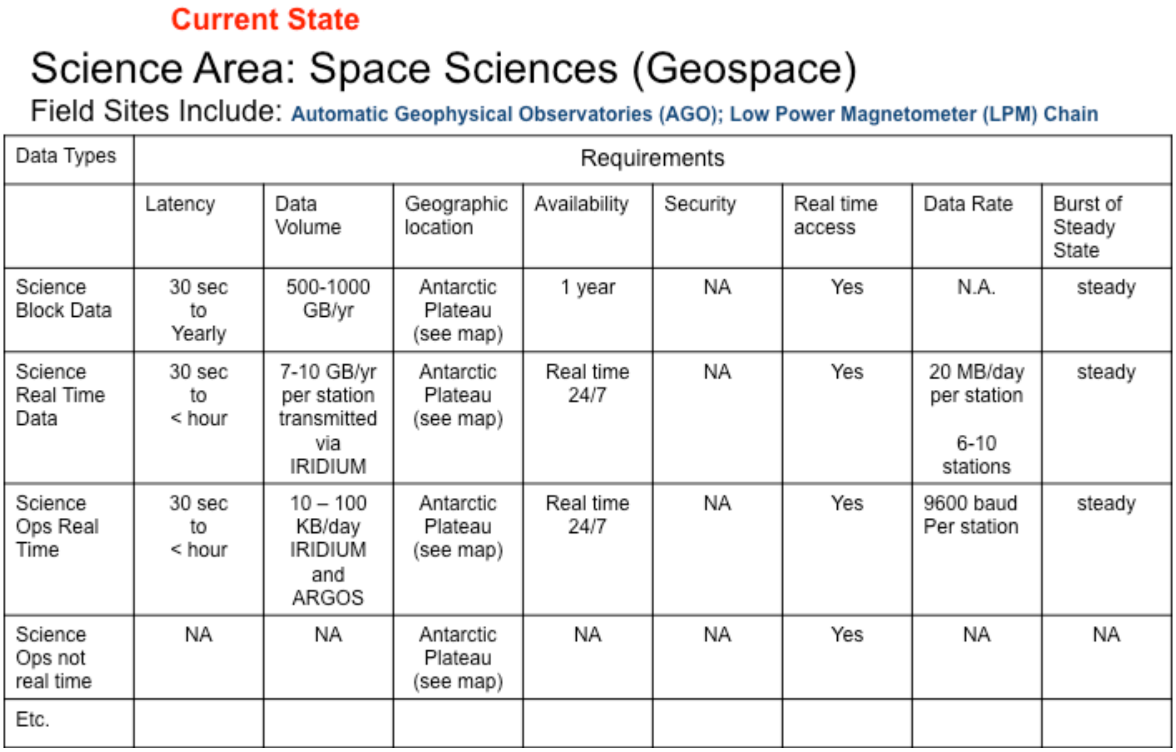
Future State

Science Area: Glaciology/Camera-GPS-multisensor

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	2 seconds	10-100 MB/ day/sta. 50 stations	Continent-wide	Daily	Minimal	Yes	As needed to minimize power use	As needed
Science Real Time Data	2 seconds	100KB / day/sta. 50 stations	Continent-wide	24/7	Minimal	Yes		
Science Ops Real Time	<1 second (terminal session)	100 KB / session	Continent-wide	24/7	Minimal	Yes		
Science Ops not real time								
Etc.								

7.2.6 Geospace Space Science

Table 28. Geospace Space Science – Current State



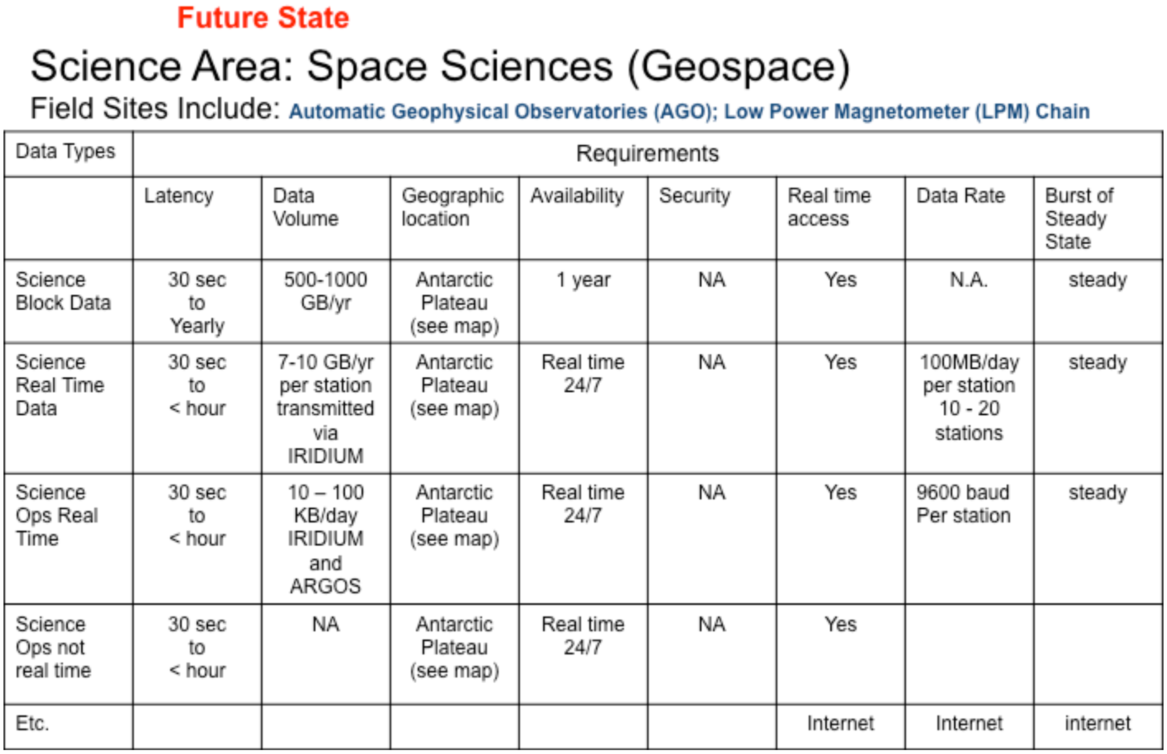
Current State

Science Area: Space Sciences (Geospace)

Field Sites Include: **Automatic Geophysical Observatories (AGO); Low Power Magnetometer (LPM) Chain**

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	30 sec to Yearly	500-1000 GB/yr	Antarctic Plateau (see map)	1 year	NA	Yes	N.A.	steady
Science Real Time Data	30 sec to < hour	7-10 GB/yr per station transmitted via IRIDIUM	Antarctic Plateau (see map)	Real time 24/7	NA	Yes	20 MB/day per station 6-10 stations	steady
Science Ops Real Time	30 sec to < hour	10 – 100 KB/day IRIDIUM and ARGOS	Antarctic Plateau (see map)	Real time 24/7	NA	Yes	9600 baud Per station	steady
Science Ops not real time	NA	NA	Antarctic Plateau (see map)	NA	NA	Yes	NA	NA
Etc.								

Table 29. Geospace Space Science – Future State



Future State

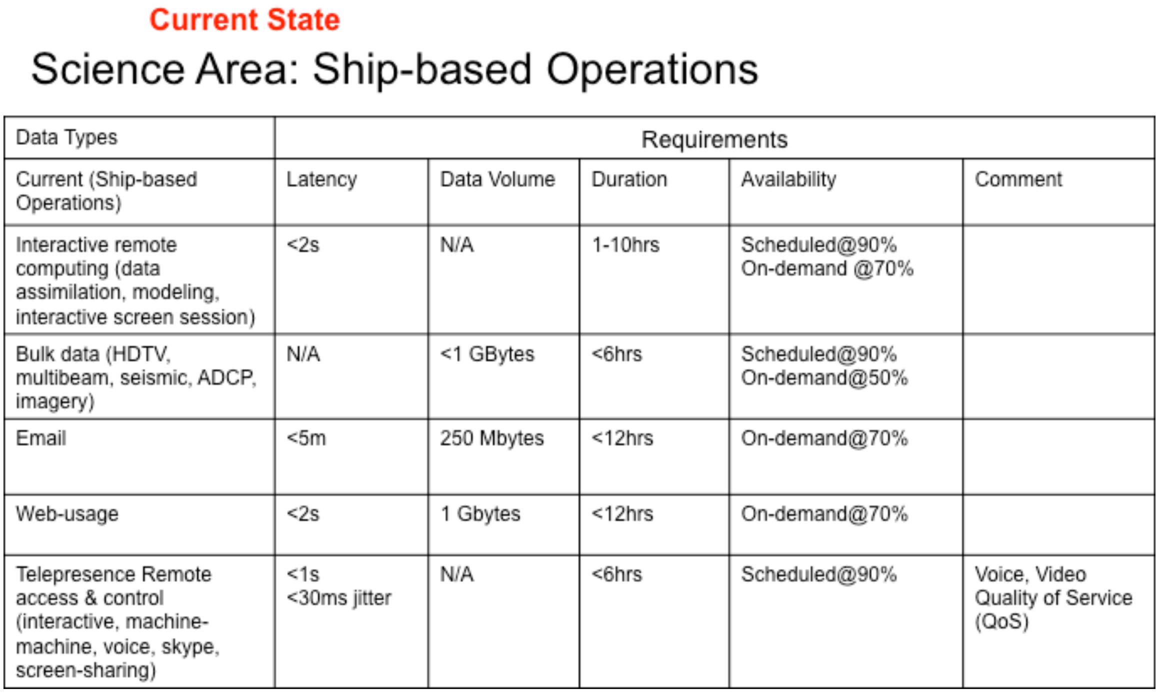
Science Area: Space Sciences (Geospace)

Field Sites Include: **Automatic Geophysical Observatories (AGO); Low Power Magnetometer (LPM) Chain**

Data Types	Requirements							
	Latency	Data Volume	Geographic location	Availability	Security	Real time access	Data Rate	Burst of Steady State
Science Block Data	30 sec to Yearly	500-1000 GB/yr	Antarctic Plateau (see map)	1 year	NA	Yes	N.A.	steady
Science Real Time Data	30 sec to < hour	7-10 GB/yr per station transmitted via IRIDIUM	Antarctic Plateau (see map)	Real time 24/7	NA	Yes	100MB/day per station 10 - 20 stations	steady
Science Ops Real Time	30 sec to < hour	10 – 100 KB/day IRIDIUM and ARGOS	Antarctic Plateau (see map)	Real time 24/7	NA	Yes	9600 baud Per station	steady
Science Ops not real time	30 sec to < hour	NA	Antarctic Plateau (see map)	Real time 24/7	NA	Yes		
Etc.						Internet	Internet	internet

7.3 Maritime

Table 30. Maritime – Current State

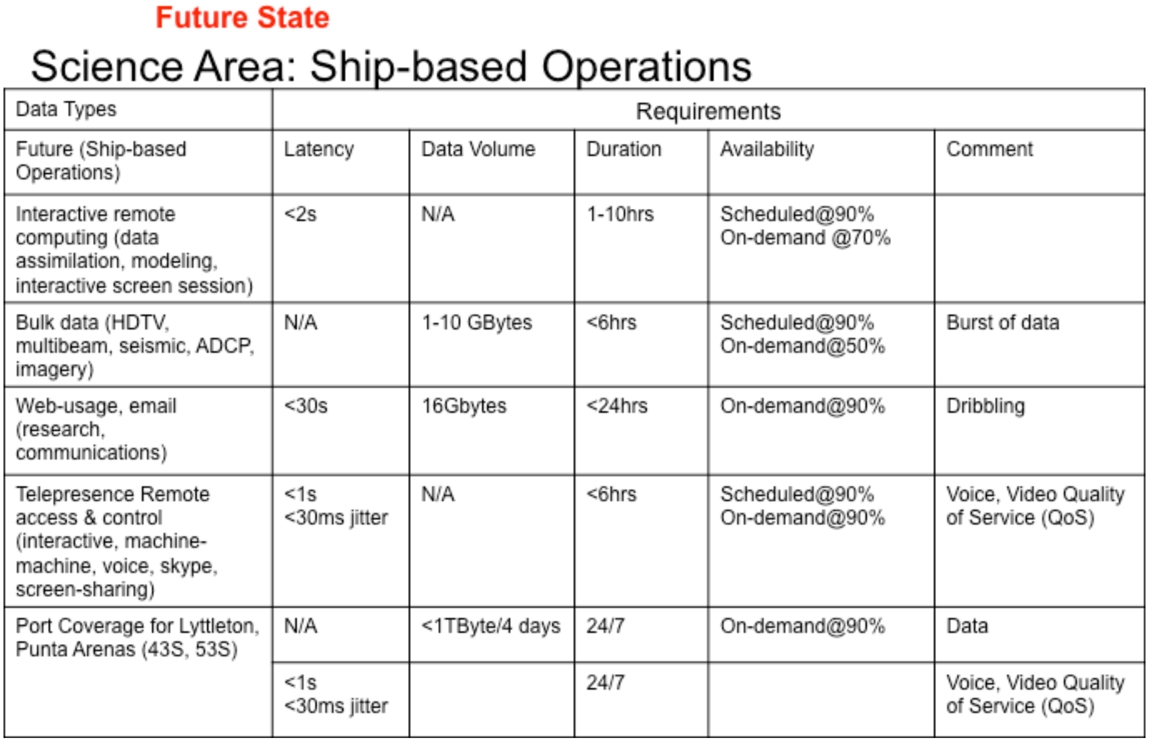


Current State

Science Area: Ship-based Operations

Data Types	Requirements				
Current (Ship-based Operations)	Latency	Data Volume	Duration	Availability	Comment
Interactive remote computing (data assimilation, modeling, interactive screen session)	<2s	N/A	1-10hrs	Scheduled@90% On-demand @70%	
Bulk data (HDTV, multibeam, seismic, ADCP, imagery)	N/A	<1 GBytes	<6hrs	Scheduled@90% On-demand@50%	
Email	<5m	250 Mbytes	<12hrs	On-demand@70%	
Web-usage	<2s	1 Gbytes	<12hrs	On-demand@70%	
Telepresence Remote access & control (interactive, machine-machine, voice, skype, screen-sharing)	<1s <30ms jitter	N/A	<6hrs	Scheduled@90%	Voice, Video Quality of Service (QoS)

Table 31. Maritime – Future State



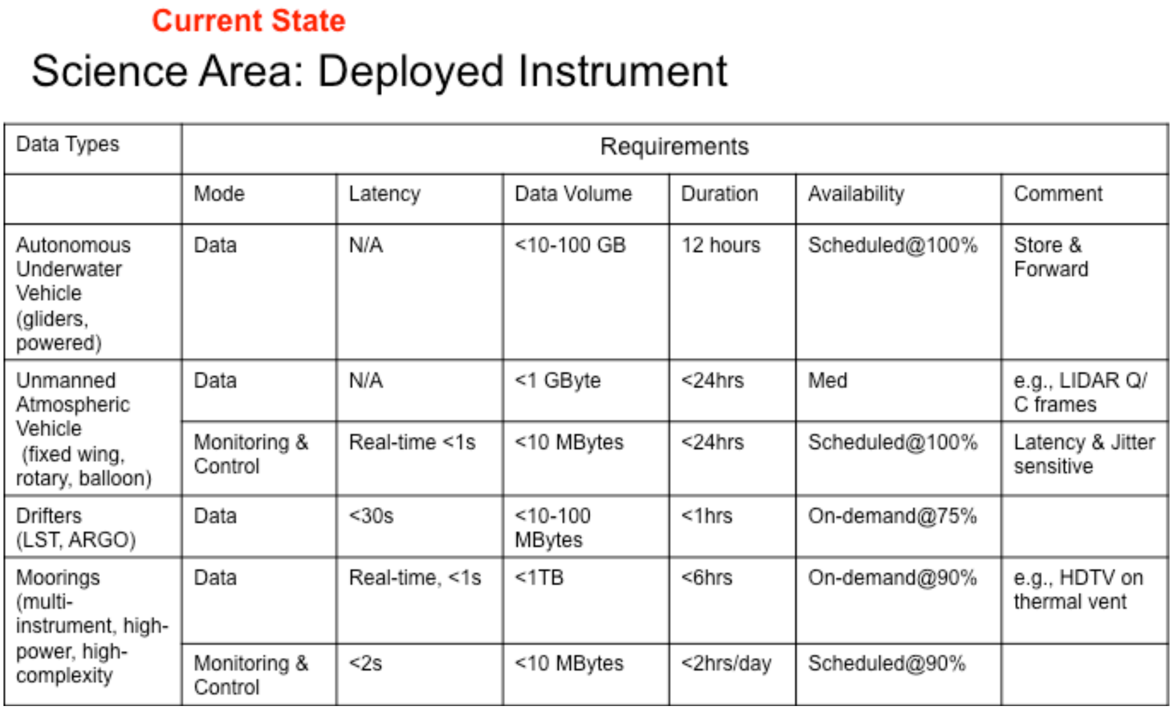
Future State

Science Area: Ship-based Operations

Data Types	Requirements				
Future (Ship-based Operations)	Latency	Data Volume	Duration	Availability	Comment
Interactive remote computing (data assimilation, modeling, interactive screen session)	<2s	N/A	1-10hrs	Scheduled@90% On-demand @70%	
Bulk data (HDTV, multibeam, seismic, ADCP, imagery)	N/A	1-10 GBytes	<6hrs	Scheduled@90% On-demand@50%	Burst of data
Web-usage, email (research, communications)	<30s	16Gbytes	<24hrs	On-demand@90%	Dribbling
Telepresence Remote access & control (interactive, machine-machine, voice, skype, screen-sharing)	<1s <30ms jitter	N/A	<6hrs	Scheduled@90% On-demand@90%	Voice, Video Quality of Service (QoS)
Port Coverage for Lyttleton, Punta Arenas (43S, 53S)	N/A	<1TByte/4 days	24/7	On-demand@90%	Data
	<1s <30ms jitter		24/7		Voice, Video Quality of Service (QoS)

Table 32. Maritime Deployed Instruments – Current State

During the workshop the maritime science community representatives also summarized what the current compliment of deployed instruments are. Below is the current state chart they developed. There was no companion future state chart offered up along with this one.



Current State

Science Area: Deployed Instrument

Data Types	Requirements					
	Mode	Latency	Data Volume	Duration	Availability	Comment
Autonomous Underwater Vehicle (gliders, powered)	Data	N/A	<10-100 GB	12 hours	Scheduled@100%	Store & Forward
Unmanned Atmospheric Vehicle (fixed wing, rotary, balloon)	Data	N/A	<1 GByte	<24hrs	Med	e.g., LIDAR Q/C frames
	Monitoring & Control	Real-time <1s	<10 MBytes	<24hrs	Scheduled@100%	Latency & Jitter sensitive
Drifters (LST, ARGO)	Data	<30s	<10-100 MBytes	<1hrs	On-demand@75%	
Moorings (multi-instrument, high-power, high-complexity	Data	Real-time, <1s	<1TB	<6hrs	On-demand@90%	e.g., HDTV on thermal vent
	Monitoring & Control	<2s	<10 MBytes	<2hrs/day	Scheduled@90%	

8. Requirements Derived from Day 2 Breakout Group Summaries

This section summarizes the initial results that were provided from the break out groups. There was a natural alignment of the high data rate users at the South Pole, the various distributed users deployed over the continent, and the maritime users. These formed the focus of the three breakout groups.

8.1 South Pole Users

The largest data users are resident at the South Pole. Based on current trends it is doubtful that any other location will have more significant science data requirements. This represents the major element that has to be satisfied in terms of data rates, bulk data transfer and overall stressing requirements.

8.2 Distributed Users

There is a tremendous amount of science from the various locations around the continent. In terms of distinct sensor quantities, the distributed user community has a large and varied array. However, there are rough similarities in the instrument footprints. These researchers seek to obtain measurements in remote regions without the infrastructure to support traditional instrumentation programs.

Based on the recently released Autonomous Polar Observing System (APOS) Workshop Report, current autonomous sensors mostly use Iridium to offload data. Wisconsin Automatic Weather Station (AWS) uses the Argos system, and several store data locally until data archives are picked up off the ice.[22]

Below is a summary of the common distributed user science communication characteristics that exist for the unattended sensors on the continent.

- Highly inhomogeneous scientific landscape
- Installation by small aircraft/helicopter by 2-3 people
    - *Total weights of 1000 pounds*
- Wintertime power limitation
- Use cases:
    - *GPS*
    - *Seismology*
    - *Meteorology*
    - *Dry Valleys*
    - *Cameras*
    - *UAV*
- Power limited in winter (few Watt-hours).
- Antenna/infrastructure limited: fixed antenna only
- Well-defined and common standard for connecting to the radio.
    - *Interest in a turnkey solution with battery and antenna integrated*
- Possibility of aircraft over-flight to download data for some sensors

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[22] Autonomous Polar Observing Systems (APOS) Workshop Report, page 14.

8.3 Maritime Users

NSF has several vessels in its fleet that support research and logistics in the oceans around Antarctica. The ARSV Laurence M. Gould[23] and RVIB Nathaniel B. Palmer[24] are two good examples. Both accept science research proposals as part of their seasonal scheduling in various locations and ports of call. Maritime users hope to find an effective solution that meets their needs out at sea as well when in port in lower latitudes like Lyttleton at 43 degrees south latitude and Punta Arena at 53 degrees south latitude.

8.4 Requirements Summary

Each of the science missions were analyzed to see what mix of media services could satisfy their current and future communication needs. The aggregated set of requirements are fully assessed and laid out in Aerospace's National Science Foundation (NSF) United States Antarctica Programs (USAP) Analysis of Alternatives (AoA) report.[25] In the Appendix a listing of the raw inputs that were received from each of the science mission areas is provided.

The tables below represent a summary of the inputs that were received from the workshop. They are divided along the lines of the break out groups, the South Pole users, distributed users and maritime users. The NSF USAP AOA Final Report takes this data further and aligns it with other sources of requirements.

Table 33. South Pole Users

South Pole Station Users					
Application	Service Type	Capacity	Connectivity	Quantity	Requirement Type
Science Block Data	Bulk data transfer, uni-directional outbound to CONUS	200 GBytes/day	90%	1	Current
Science Block Data	Bulk data transfer, uni-directional outbound to CONUS	1300 GBytes/day	90%	1	Future
Real Time Instrument	Bi-directional IP wide area network	4.5 Mbits/s	99%	1	Current
Real Time Instrument	Bi-directional IP wide area network	9 Mbits/s	99%	1	Future
Science Ops Real Time	Bi-directional IP wide area network	1 Mbits/s	98%	1	Current
Science Ops Real Time	Bi-directional IP wide area network	2 Mbits/s	98%	1	Future
Science Ops not real time	Bulk data transfer, uni-directional outbound to CONUS	1 Mbits/s	98%	1	Current
Science Ops not real time	Bulk data transfer, uni-directional outbound to CONUS	10 GBytes/day	98%	1	Future

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[23] R/V Laurence M. Gould, http://www.nsf.gov/od/opp/support/gould.jsp (last accessed 15 Dec 2011).

[24] R/V Nathaniel B. Palmer, http://www.nsf.gov/od/opp/support/nathpalm.jsp (last accessed 15 Dec. 2011).

[25] National Science Foundation (NSF) United States Antarctica Programs (USAP) Analysis of Alternatives (AoA) Report, Section 3.

Table 34. Aggregated Distributed Users

Distributed Users Preliminary Aggregation of Operations					
Application	Service Type	Capacity	Connectivity	Quantity	Requirement Type
Autonomous instrumentation	Bulk data transfer	Less than 150 MBytes/day	Annual data transfer - manual collect	135	Current
Autonomous instrumentation	Bulk data transfer	0.15 MBytes/day	Monthly data transfer - manual collect	65	Current
Autonomous instrumentation	Bulk data transfer	15 MBytes/day	Daily	50	Current
Autonomous instrumentation	Bi-directional IP wide area network (terminal access)	2.4 kbits/sec	24 hours/day (continuous)	125	Current
Autonomous instrumentation	Bi-directional IP wide area network	4.8 kbits/sec	24 hours/day (continuous)	65	Current
Autonomous instrumentation	Bi-directional IP wide area network	9.6 kbits/sec	24 hours/day (continuous)	10	Current
Autonomous instrumentation	Bulk data transfer	100 MBytes/day	Connection every 12 hours	100	Future
Autonomous instrumentation	Bulk data transfer	15 MBytes/day	Daily	300	Future
Autonomous instrumentation	Bulk data transfer	100 MBytes/day	Daily	50	Future
Autonomous instrumentation	Bulk data transfer	150 MBytes/day	Yearly - manual collect	420	Future
Autonomous instrumentation	Bi-directional IP wide area network (terminal access)	4.8 kbits/sec	24 hours/day (continuous)	100	Future
Autonomous instrumentation	Bi-directional IP wide area network	2.4 kbits/sec	24 hours/day (continuous)	650	Future
Autonomous instrumentation	Bi-directional IP wide area network	9.6 kbits/sec	24 hours/day (continuous)	120	Future

Table 35. Distributed Users - Current Usage

Distributed Users - Current				
Application	Service Type	Capacity	Connectivity	Quantity
Seismic Backbone	Bulk data transfer	15 MB/day	Annual data transfer	50
	Bi-directional IP wide area network (terminal access)	2.4 kbps	24 hours/day (continuous)	50
Seismology: Seismic Array	Bulk data transfer	15 MB/day	Annual data transfer	15
	Bi-directional IP wide area network (real-time ops)	2.4 kbps	24 hours/day (continuous)	15
Dry Valleys	Bulk data transfer	10 MB/day	Annual data transfer	50
Meterology/Ocean Buoys/CTDS	Bulk data transfer	0.15 MB/day	Monthly data transfer	65
	Bi-directional IP wide area network	4.8 kbps	24 hours/day (continuous)	65
Space Sciences (Geospace)	Bulk data transfer	150 MB/day	Annual data transfer	10
	Bi-directional IP wide area network	9.6 kbps	24 hours/day (continuous)	10
Geodesy	Bulk data transfer	15 MB/day	Daily	50
	Bi-directional IP wide area network (real time science ops)	2.4 kbps	24 hours/day (continuous)	50
Glaciology/Camera-GPS-multisensor	Bulk data transfer	1 MB/day	Annual data transfer	10
	Bi-directional IP wide area network (science data and ops)	2.4 kbps	24 hours/day (continuous)	10

Table 36. Distributed Users - Future Usage

Distributed Users - Future				
Application	Service Type	Capacity	Connectivity	Quantity
Seismic Backbone	Bulk data transfer	100 MB/day	Connection every 12 hours	100
	Bi-directional IP wide area network (terminal access)	4.8 kbps	24 hours/day (continuous)	100
Seismology: Seismic Array	Bulk data transfer	100 MB/day	Annual data transfer	400
	Bi-directional IP wide area network (real-time ops)	2.4 kbps	24 hours/day (continuous)	400
Dry Valleys	Bulk data transfer	10 MB/day	Daily	50
	Bi-directional IP wide area network (real time instrument)	2.4 kbps	24 hours/day (continuous)	50
	Bi-directional IP wide area network (real time ops)	2.4 kbps	24 hours/day (summer only)	50
Meterology/Ocean Buoys/CTDS	Bulk data transfer	0.5 MB/day	Daily	100
	Bi-directional IP wide area network	4.8 kbps	24 hours/day (continuous)	100
Space Sciences (Geospace)	Bulk data transfer	50 GB/year	Yearly	20
	Bi-directional IP wide area network	9.6 kbps	24 hours/day (continuous)	20
Geodesy	Bulk data transfer	15 MB/day	Daily	150
	Bi-directional IP wide area network (real time science ops)	2.4 kbps	24 hours/day (continuous)	150

Table 37. Maritime Users

Maritime Users					
Application	Service Type	Capacity	Connectivity	Quantity	Requirement Type
Imagery, HDTV, seismic, ADCP, multibeam	Bulk data	1 GBytes/day	Every six hours or less	2	Current
Web usage, email	Bi-directional IP wide area network	128 kbits/s	24 hours/day (continuous)	2	Current
Interactive computing, telepresence	Bi-directional IP wide area network	1 Mbits/s	24 hours/day (scheduled)	2	Current
Bulk Maritime Data	Bulk data	10 GBytes/day	Connection every six hours	2	Future
Telepresence, remote access and control	Bi-directional IP wide area network	1 Mbits/s	24 hours/day (continuous)	2	Future
Web usage, email	Bi-directional IP wide area network	2 Mbits/s	24 hours/day (continuous)	2	Future
Unmanned aerial and underwater vehicles	Bulk data	100 GBytes/day	Twice a day		Future
Drifers (LST, ARGO)	Bulk data	100 MBytes/day	Once per hour or less		Future
Moorings (multi-instrument)	Bi-directional IP wide area network	1 TBytes/day	24 hours/day (on-demand)		Future
Outside Coverage Area					
Port coverage: Lyttleton, Punta Arenas	Bi-directional IP wide area network	10 Mbits/s	24 hours/day (once every four days)	2	Future

9. Conclusions and Recommendation

South Pole and distributed user requirements can be met via several communication systems or services. There is a desire to move towards real time data retrieval rather than store and forward or store and recovery once a season.

Maritime requirements include some challenging bulk data transfers and data rates. To meet these requirements will stress the system and may be cost drivers.

No single communication system can provide for all the communication needs. A mixed architecture between low rate distributed coverage and high data rate at specific locations can effectively meet most of the requirements.

10. Aerospace Biographical Sketches

Dr. Bryan Jacoby

- Dr. Bryan Jacoby has a background in observational astrophysics, including remote observations and very large data sets. He works on a variety of data exploitation and image science projects at Aerospace. He received his PhD in astrophysics from Caltech. Dr. Jacoby is a senior member of the technical staff at Aerospace.

Dr. Phil Schwartz

- Dr. Philip R. Schwartz is a Distinguished Scientist for the Advanced Technology Division at Aerospace. Dr. Schwartz has had an extensive career in astrophysics and atmospheric sciences with broad applications and contributions in the areas of radio astronomy, atmospheric science, and ocean remote sensing.
- Dr. Schwartz works across the Division's Intelligence Community technology efforts to assist with division and customer strategic goals. He will provide direct support to the NRO, especially the Chief Scientist in Advanced Systems and Technology and those in other Directorates. He will provide advice, guidance and independent assessments on advanced concepts and technologies under consideration for NRO and IC developments.
- Dr. Schwartz joined The Aerospace Corporation in 2003 as a Senior Scientist in the Advanced Technology Group of ATD/NSG. In his time at Aerospace he has performed many technical reviews for ATD where he was fully engaged in all aspects of technology and system developments within AS&T and Aerospace. Also during this time, Dr. Schwartz has focused his efforts in driving innovation into advanced sensor systems for both military and IC applications. He has a proven record of positively impacting programs from the device level to systems. Dr. Schwartz has lead or performed IPA reviews on several critical DOD and Civil programs (SBIRS High, NPOEES) during his Aerospace tenure and continues to stay involved in relevant efforts at AFRL, DARPA, DIA, NSF, NASA, NOAA and the Embry-Riddell University Industrial Advisory Board.
- Prior to joining Aerospace, Dr. Schwartz retired from the Naval Research Laboratory, as superintendant for the Remote Sensing Division as an SES ES4. He joined the Naval Research Laboratory in 1971 in the Radio Astronomy Branch.
- Dr. Schwartz has authored / co-authored over 200 combined scientific publications, refereed journals, and edited and reviewed books. He was the principle investigator or project leader for seven NASA and DoD space sensor or satellite programs including, CORIOLIS/WINDSAT.
- Dr. Schwartz holds a Ph.D. in Physics from the Massachusetts Institute of Technology.

Jim Johansen

- Mr. Johansen has a BSEE and MSEE from USC and work experience at USC, LANL, Boeing, Lockheed Martin, MITRE and Aerospace, proficiency in technology maturation, and numerous aerospace domain areas. He joined The Aerospace

Corporation in 2008. He currently serves as a Senior Project Leader in the Advanced Studies and Analysis Directorate within Civil & Commercial Operations. He has led or held key roles numerous studies like the James Webb Space Telescope (JWST) AoA, NSF US Antarctica Program Future Communications AoA, and demonstration satellite system development of a common GEO bus system to host special payloads.

- Mr. Johansen served as Director of Science and Technology (S&T), where he directed Space and Missile Center (SMC) S&T Integration efforts, and managed Concept Design Center (CDC) Studies for Distributed Common Ground System (DCGS), Space Situational Awareness (SSA) and Satellite Operations Air Force Satellite Control Network (SATOPS AFSCN) architectures.
- Mr. Johansen worked 10 years at MITRE where he was Director of S&T. He managed Space Control Technology (SCT), SSA technology, multi-mission systems, and GPS User Equipment technology development. He also worked on National Security Space Programs including MILSTAR and classified programs at Lockheed Martin as Deputy System Engineering Department Manager and Boeing as a Senior Project Engineer. While at the USC Physics Department he served as a visiting scientist at LANL working on free electron laser technology.
- Mr. Johansen has received numerous awards at Aerospace, MITRE, and Lockheed for excellent customer support and effective team building. He has briefed at numerous conferences and gave the Keynote Speech at the AOC Protection Conference 2008.

Mark Cowdin

- Mark Cowdin serves as a Senior Project Leader in the Advanced Studies & Analysis Directorate within Civil & Commercial Operations, where he provides mission assurance support to numerous NASA and civil programs. Mark has over 15 years of experience in programmatic assessments, space system architecture design and evaluation, algorithm/analysis, computing, and communication architectures. Mark holds a B.S. in Aerospace Engineering from Iowa State University.

Matt Hart

- Mr. Matthew J. Hart is Principal Director of Advanced Studies and Analyses (AS&A) Subdivision in Civil & Commercial Operations, which is responsible for independent technical and programmatic assessment of programs under development, and strategic studies to inform programmatic decision-making for NASA.
- Mr. Hart has over 20 years of experience in program management, systems engineering and mission assurance, system architecting, mission design, mission operations, and modeling and simulation. He led several high profile architecture-level studies for NASA Headquarters, including studies on Human Rating the Air Force's Evolved Expendable Launch Vehicle as a replacement for NASA's Ares I crew launch vehicle, in support of President Obama's Blue Ribbon Panel on Human Space Flight.
- Mr. Hart has extensive experience in programmatic analysis and has provided technical analysis and source selection support to a number of critical national security programs and launch systems during his tenure at Aerospace.

- Mr. Hart received numerous awards and citations throughout his career, including the President's Distinguished Achievement Award in 2006 and 2010 for providing senior decision support and programmatic guidance to programs of national importance.
- Mr. Hart has B.S. and M.S. degrees in Aerospace Engineering from Purdue University and Stanford University, respectively.

Debra Emmons

- Ms. Emmons is Assistant Principal Director of Program Development in Aerospace's Civil & Commercial Operations, which is responsible for early program formulation and strategy for NASA and other civil programs.
- Ms. Emmons has over 18 years of experience in project and system engineering, technical analysis, program management, and business development. Ms. Emmons previously served as Systems Director for Independent Assessment in the NASA/JPL Advanced Programs Office, providing technical direction to staff supporting independent assessments of NASA interplanetary and earth science programs in Science Mission Directorate.
- Ms. Emmons was a member of teams awarded Aerospace's highest honor, The President's Award in 2006, "for providing crucial analysis of alternatives for the Hubble Space Telescope Servicing and Repair Mission," and again in 2010 "for providing technical studies critical to the Augustine Commission's recommendations for future U.S. human spaceflight."
- Prior to joining Aerospace, Ms. Emmons spent seven years at Hughes Space and Communications Company where she gained commercial experience working as a systems engineering Program Manager for telecommunications satellites.
- Ms. Emmons has an MBA from Imperial College Management School, London, UK. She earned an M.S. and a B.S in Electrical Engineering from Cornell University.

11. References

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