United States Antarctic Program Meteorological Cyberinfrastructure Task Force Report

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This report is dedicated to Dr. Charles R. Stearns, who has been a role model for all of us in the United States Antarctic Program, with his vision of a freely and supported meteorological data archive to benefit all.

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Executive Summary

Antarctica presents a unique opportunity embedded with unprecedented challenges. Antarctica has been called the world's largest laboratory. An uninhabited continent surrounded by a vast ocean is attractive for science but comes at a cost to conduct even the most straightforward experiment. Getting to any location and back home safe presents its own level of triumph as every year each team of researchers succeeds at this endeavor and feels as though they have lived to tell the tales of the lost continent. Polar meteorology is a discipline where science and operations go hand-in-hand to achieve these positive outcomes.

An essential element to understanding this vast land and the earth as a whole is basic meteorological measure and record. Without this the field programs become more arduous and costly. It is in our global best interest that these measures occur and expand for even greater achievement and understanding. We are in an age when new exploration and measurement technologies foster unprecedented fresh discoveries and where rapidly expanding cyberinfrastructure garners new results from old but consistently archived data sets. Understanding the history of the Antarctic and its meaning for the planet will only occur with our dedication toward preserving the meteorological and climatological record and continuing best practices to collect and distribute these data, as the Antarctic Meteorological Research Center has done for the past quarter century.

This Task Force recommends the following priorities going forward:

(1) Satellite composites providing hourly views of the polar atmosphere,
(2) Real-time automatic weather station (AWS) data from Antarctica,
(3) Detailed surface and upper air observations from the three permanent US Antarctic research stations,
(4) Maintaining a database of observations from temporary field camps and runways,
(5) Archiving broadcast satellite data streams received at Palmer and McMurdo Stations,
(6) Centrally archiving campaign atmospheric science data sets,
(7) Issuance of digital observation identifiers (doi) for all AMRC data holdings,
(8) Establishing a center for authoritative evaluation of atmospheric and climate variations in Antarctica, analogous to what the National Snow and Ice Data Center (NSIDC) does for the cryosphere, and
(9) Establishing a shared Antarctic Internet Data Distribution System (Antarctic-IDD).

A. Introduction

For the past 25 years the Antarctic Meteorological Research Center (AMRC) has played an important role in Antarctic meteorological data collection, curation, and dissemination, for the United States Antarctic Program (USAP), which is overseen by the National Science Foundation (NSF). The effort toward maintaining these data has historically been funded as a part of science research programs. The acquisition of the meteorological observations and data sets, the ongoing care of the data holdings, and the expert assistance provided with the data holdings are all essential to maximize the data's value. Now that these activities are no longer funded as science activities, a more sustainable arrangement must be established to ensure the preservation of current and future US Antarctic meteorological data. A task force was therefore established comprising Antarctic meteorological researchers, engineers, and forecasters to create a set of sustainable recommendations for the future of the AMRC. This report will detail the history, current status, and future recommendations for the AMRC.

B. History

1. The US Antarctic Automatic Weather Station (AWS) Program

The University of Wisconsin-Madison became involved with Antarctic meteorology in the 1960s with Professor Werner Schwerdtfeger's Antarctic meteorological research. In 1980 Professor Schwerdtfeger was approached by the NSF regarding long-term management of the newly developed AWS in Antarctica created by Stanford University. Schwerdtfeger's recommendation to the NSF was to engage Professor Charles Stearns, who was already building AWS units in support of projects in Wisconsin. Since then the University of Wisconsin has maintained a long-lasting relationship with USAP and collaborations with other countries by continuing to build, install and service AWS in remote locations throughout Antarctica (Figure 1, Lazzara et al., 2012). Starting in the mid-1980's, the University of Wisconsin developed a second generation AWS2B hardware electronics. Communications utilized the Argos satellite system. Once transmitted, the AWS data were provided to UW-Madison, decoded, quality controlled, and archived at University of Wisconsin for public use.

For the past 37 years, the AWS processing and hardware has seen only minimal changes. By the late 1990s to early 2000s there was no longer laboratory capability to fabricate the AWS2B electronics. The electronics were therefore changed to a commercial off the shelf (COTS) option, based on Campbell Scientific's CR1000. Then a new suite of instruments followed with a few needed changes in the software. Otherwise, communications, quality control, and archiving continued in the same fashion as before. Within the past five to ten years, there have been changes in transmission by using the Iridium satellite suite and Ultra High Frequency (UHF) radio transmissions for AWS near McMurdo Station, Antarctica.

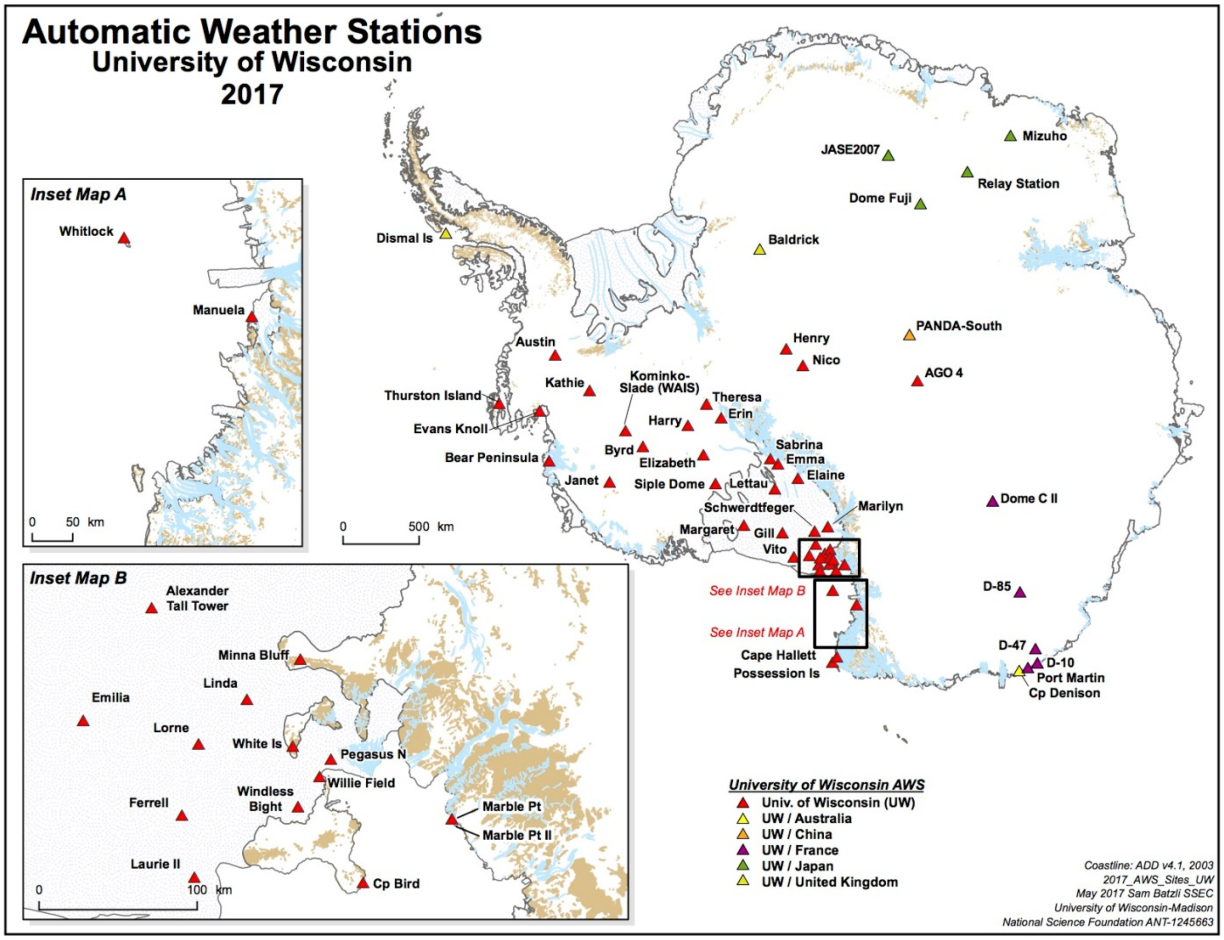

Figure 1. University of Wisconsin AWS as of the end of the 2016-2017 Antarctic Field Season

AWS have become a standard tool used by many national programs across the Antarctic. They have become the standard for acquiring weather information applied to operational activities such as weather forecasting as well as research activities. In several critical research applications, including the role of Antarctic Peninsula warming in Larsen-B ice shelf loss, and detection of multi-decadal temperature trends in West Antarctica, AWS have provided the only reliable direct observations. While several other in-situ and remote sensing instruments will emerge in the coming years, a base AWS network will be an indispensible tool moving into the future. With limited funding in many national Antarctic programs, AWS offer the most affordable means of collecting critical weather observations to support a variety of objectives. AWS may be part of a backbone network of an autonomous polar observing system (APOS, 2012).

2. US Antarctic Program Satellite Meteorology

McMurdo flight operations during the 1960s were supported by a state-of-the-art Polar Orbiting ground station that collected automatic picture transmission (APT) satellite imagery. McMurdo was one of the first 50 stations purchased to provide situational awareness of pending cloud formations for synoptic weather pattern recognition. At a cost of $30,000 it was considered a major investment of its day. The pictures were sent using a slow delivery TV scan process to ground station facsimile recorders (See Figure 2). The images were somewhat crude by today's standards; they were often not useful for distinguishing clouds over ice and snow, but they were helpful at detecting cloud patterns over the open waters. Since then the United States has historically maintained the National Oceanic and Atmospheric Administration (NOAA) series of polar orbiting meteorological satellites. Additionally the Department of Defense Meteorological Satellite Program (DMSP) satellite system provided even higher-resolution images for McMurdo starting in the late 1970s and for Palmer Station staring in the late 1980s. These high-quality images now printed on high gloss photographic paper, allowed greater distinction of clouds from ice. The advent of these two low earth orbit (LEO) constellations (NOAA and DMSP) was a major improvement.

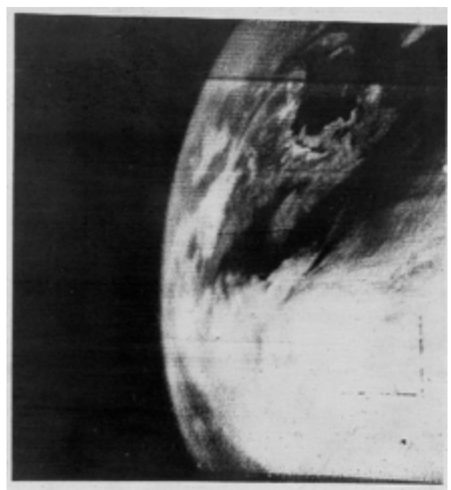

Figure 2. The first television image of Earth from space from the TIROS-1 weather satellite in 1960.

In 1987 the Scripps Institution of Oceanography (SIO) in cooperation with the SeaSpace Corporation, provided the first computer displayed imagery for the weather satellite systems. The major operational advantage of this system was the capability overlay each image to a standard map projection. This provided a capability for still animation, which allowed an accurate depiction of weather system movements. Prior to this invention, each image was a stand-alone tool due to differing curvature from each different satellite overpass geometry. This was an improvement in forecasting that provided an historical boost to short term forecast accuracy of 7% averaged over time. Today we maintain the same system from SeaSpace with modern advances of greater visual displays and faster processing time.

In the early 1990s the original AMRC proposal envisioned: (1) creating an archive for a wide variety of Antarctic meteorological data, (2) ingesting satellite observations on site, and (3) developing Antarctic satellite composites. The AMRC proposal was motivated by the need for improved weather forecasting in Antarctica and the need for a central Antarctic meteorological data collection center, as envisioned by then NSF Director Peter Wilkniss. The AMRC used the Man computer Interactive Data Access System (McIDAS) program to develop Antarctic composites in near-real-time every three hours. The Antarctic satellite composites were eventually developed to be made hourly in five different channels (infrared, longwave, shortwave, water vapor, and visible) and were even used to support other science investigations and research applications (Figure 3, Lazzara et al., 2003; Kohrs et al., 2013). One example of a science application is the detection of atmospheric motion vectors over Antarctica (Lazzara et al., 2014). Over the years, the AMRC was funded not only to create, archive, and provide assistance with Antarctic meteorological data (Table 1), but also to conduct science using these data. The AMRC's role in satellite data has been subordinate to other meteorological services, and primarily in support of satellite compositing efforts.

Table 1. Sample list of AMRC's data holdings and collections accumulated over the past 25 years.

Real-Time and Archive	Non-Real-Time/Archive
• **Automatic Weather Stations** (Meteorograms, Weather Maps, Raw Data) • **Staffed Stations** (Meteorograms, Weather Maps, Raw Data) • **Ship and Buoy Data** • **Flight** (Aireps and TAFs) • **Antarctic Composites** (Infrared, Psuedo-Color, Longwave, Shortwave, Visible, Water Vapor, Google Earth KMZ) • **METOP A** (Centered over McMurdo) • **Suomi-NPP** (CrIS, ATM and VIIRS (coming soon)) • **NOAA** (LAC, GAC, HRPT) • **Satellite Navigation** • **Atmospheric Motion Vectors** • **Models** (AMPS (real-time only), GFS, ECMWF, UKMET) • **Analysis** (ICE, SST) • **Upper-Air** (Hodographs and Skew-T) • **Forecast HySPLIT AMPS Back Trajectories** (at AWS in McMurdo area)	• **Automatic Weather Stations** (Quality Controlled 10 minute, hourly, 3-hourly, CLIMAT Messages, Monthly Summaries) • **Field Camps** • **McMurdo** (Barocharts, Surface and Upper Air CLIMAT Messages, Climatology Sheets, Pegasus Runway, Radiosonde, Arrival Heights, Building 189, Building 69, Building 71, SPAWAR AWS, BIF, White Island, Black Island, MWS) • **Neumayer** (Radiosonde) • **Palmer** (Surface CLIMAT Messages, Climatology Sheets, Station Observations) • **South Pole** (Surface and Upper Air CLIMAT Messages, Local Climatology Data, Climatology Sheets, South Pole Runway, One Minute Observations, Radiosonde, Synoptic Observations)

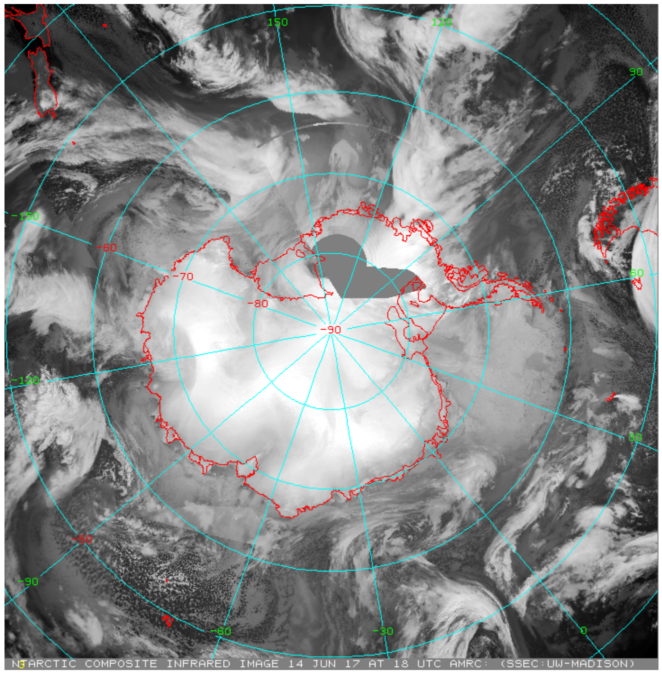

Figure 3. Antarctic Infrared Satellite Composite valid 18 UTC on June 14th, 2017

3. Outreach

Community outreach has always been a strong priority and a multi-faceted effort for AMRC. One community activity spearheaded by the AMRC after a community discussion at an Antarctic Meteorological Observation, Modeling and Forecasting Workshop (AMOMFW), was the formation of the Antarctic-Internet Data Distribution or Antarctic-IDD (Seefeldt et al., 2009). The community of Antarctic meteorological scientists, forecasters, and engineers formed a group to make data sharing easier among each other and beyond. The AMRC has overseen the Antarctic-IDD and is the point of contact for questions or concerns about Antarctic meteorological data. Another way that the AMRC focuses on community is strong student involvement. Within the past ten years, the AMRC has hired ten undergraduate students and two of these students continue to work full-time at the AMRC. These students have had the opportunity to learn a variety of computing skills, more general meteorology, and other career skills. Students have left the group to move on to graduate studies at a host of institutions (e.g. SUNY-Albany, U. Washington, etc.) and industry (e.g. SRC, Understory, etc.). Finally, the AMRC was motivated to do grassroots outreach. This outreach effort has latest for decades and involves presentations at public libraries, service organizations (e.g. Rotary,) elementary, middle, and high schools across Wisconsin, other parts of the US, as well as tours for students at the Space Science and Engineering building in Madison, WI.

C. Current Status

1. Data Archives

In the last 10 to 15 years the AMRC has been funded less and has had to adjust its goals and expectations to match funding levels. The decrease in funding occurred because NSF's view of the AMRC changed over time. The up-keep of data was originally funded as part of a science research program, and now these activities are no longer funded in this manner. Presently, the AMRC's historical meteorological data activities are funded between a one-time polar cyberinfrastructure grant and annual SPAWAR contributions to continue making AWS data available in real-time and generating Antarctic satellite composites. Aside from these limited tasks, the AMRC is no longer supported to provide services with any other Antarctic meteorological data. There is currently no budget for new infrastructure, new data acquisition, new data requests, or new hardware.

We expect that several if not all of these functions will end in 2018 if no other arrangements are made. While some activities have potential for transformation (e.g. Antarctic composite imagery is under consideration for transition to NOAA/NESDIS operation), there may be lost capabilities in the future with no future planning (e.g. no archival planned for the Antarctic composites at NOAA). Several unique observational datasets are threatened without any planning and action (e.g. USAP Field Camp observations). There is no other archive or distribution point for observations such as these, and their value will increase into the future as more efforts are being made to use as much observational data as possible to improve weather forecasting and logistical planning (Pauley, US Navy/Naval Research Laboratory, personal communication).

2. AMRC Real-time AWS Relay System

The availability of real-time AWS observations using the Argos communications is dependent on a serial network of working systems. After the observations are transmitted from the AWS to the satellites, the starting point is with a direct broadcast reception system acquiring the relay of data, which are then passed to SSEC Satellite Data Ingestors (SDI). These SDI systems are located in McMurdo Station and Palmer Station. The SDIs at McMurdo and Palmer Stations have been running for several years more than planned and could fail at any time. In fact these are the last operational systems of this generation anywhere in the world. A backup SDI at Palmer and a backup SDI at McMurdo have already failed within the last three years. If the remaining Antarctic SDIs stop working, AWS observations are still acquired from the Wallops Command and Data Acquisition Station in Wallops, VA and the Gilmore Creek Geophysical Observatory near Fairbanks, AK where the AWS data are then relayed to the SSEC Data Center and the AMRC at UW-Madison. One limitation with this specific system is the delay in relay of the observations (at times up to 11 hours). However, while the SDI system in use at the SSEC Data Center is a more recent model, the software will no longer work beyond the NOAA-18 satellite, which is the same situation for the older first generation hardware. It is now only a matter of time before the real-time AWS relay system will completely fail.

Other communication methods for relaying AWS observations in real-time are possible, with two specifically in use: Iridium satellite and UHF modem relay. Currently only three AWS sites are using the Iridium communications system, which does not require any of the above data relay infrastructure. Observations are received in Wisconsin within minutes of transmission via the Department of Defense Iridium Gateway; however there are considerations with decoding software maintenance and relay of the observations to end users (including those in Antarctica requiring the data). Switching the entire AWS network to Iridium communications will take some years to accomplish with the current level of funding and logistical support. Also, Iridium modem hardware is known to not work well at very cold temperatures; below -40 °C. Workaround systems are available at an additional cost and larger power requirements. Another method is the use of UHF modems to transmit AWS observations. However, this novel method only works within the range of a main hub such as McMurdo Station. Here the data can be relayed on to users via the Internet. Hence, with this distance dependence, this solution cannot be used continent wide and is limited by any issues that impact McMurdo Internet communications (e.g. data can be lost due to loss of network connectivity requiring extra attention, retransmitting data, etc.).

3. Infrastructure Investment Needs

Regardless of means to relay observations and other Antarctic meteorological data, there are needs to serve this data via modern software and hardware systems with support. The current system the AMRC is using employs nearly 20-year-old software to decode AWS observations from hexadecimal raw transmissions and translate them to text data. The data are then served via the AMRC website, FTP site, and Local Data Manager (LDM) in the form of text listings, meteorograms, and other file formats. If any of this necessary software or hardware were to fail, there is no budget for replacement.

The Antarctic satellite composites are being generated on machine that is over five years old. As expected, if this machine fails there is no replacement machine capable of generating the hourly composites in five spectral channels, and the current funding for the composites by SPAWAR does not ensure hardware replacement. At the same time, funding for the SIO Antarctic satellite data activities expired in 2006 and these activities ceased as the SIO oceanographic satellite applications were supplanted by dedicated NASA remote sensing missions (e.g., SeaWIFS, Terra, Aqua) whose data are archived at the NASA Distributed Active Archive Centers (DAACs). Research applications for oceanography and cryospheric science are a high priority for NASA, whereas satellite meteorology in near-real-time for polar forecasting applications is not. Therefore AMRC is the only group currently capable of making the satellite composites.

4. Missed Opportunities

Over the years, many opportunities have been available to the US Antarctic meteorological community. For example, the Antarctic-IDD has been a successful research and development project, linking the research and forecasting communities, and sharing meteorological data and observations via Unidata's Local Data Manager (LDM). However, without a champion, the Antarctic-IDD has not been a priority for the AMRC or the rest of the Antarctic meteorological community (e.g. reduced participation, limited use, etc.). The ideas of the Antarctic-IDD were innovative but full operational embracement of them has not been fully endorsed by the NSF (and at times has been challenged by the NSF), thus hindered its proper growth to benefit more of the Antarctic community.

AMRC in the last five years has steadily evolved into more of a limited center for Antarctic meteorological data. With eroding support for the datasets, archive and distribution, focus has turned inward toward science activities while striving to not damage the enterprise. This has impacted the original desire to have the AMRC be the one-stop resource for Antarctic meteorological data resources (whether as holder of the data or as a resource/pointer to where the data can be found – a clearinghouse). The Antarctic meteorological datasets aren't centrally located, and without a plan and future action, they are at risk of being more dispersed than ever.

The AMRC is overseen by PI Dr. Matthew Lazzara, whose involvement has been reduced over the past 20 years. He has switched his employment from full time at the AMRC and adjunct faculty at Madison College, to now full time faculty at Madison College and part time scientist at AMRC. Staff and students focused on the AMRC have been reduced as well. Carol Costanza, a young scientist, devotes about 25% of her time on AMRC related activities. These activities include completing a monthly data transfer, monitoring the flow of real-time AWS data, and monitoring the generating of the Antarctic satellite composites. Over the last 12 months, there was only one student employed for about 3 months. Historically several students were employed at the AMRC. The USAP is at risk of losing skilled staff and students – in essence critical "corporate" knowledge.

Nevertheless, there is a need for something that can take on the role of an AMRC in the Antarctic meteorological community. For the last two years, the AMRC's focus has been providing real-time AWS data, generating Antarctic composites hourly in five spectral channels, and completing a bare bones monthly data transfer/distribution of mostly USAP meteorological data. Both the needs for a steward and new hardware/software are becoming critical as current systems are at risk of failing without support. Now is the time to decide what to continue archiving/generating, and what to do with the 29 TB archive that been collected for the last 25 years. This is a significant taxpayer asset with benefits still to be realized by the Antarctic community well into the future.

D. Recommendations

Given the current state of affairs with the Antarctic meteorological community, there are clearly some requirements that need to be defined in order to move forward. Some of these requirements include (1) designate a data archive location; (2) determine a plan for data distribution (3) decide if science will or will not be a focus in the future, and (4) determine technology/hardware/software needs. Once these requirements are addressed, NSF will be able to decide how to move forward given the Task Force's recommendations.

We must keep a historical perspective on meteorology's accomplishments in Antarctica over the past 60 years to set a course for the future. As presented by James Balog, Frank Hurley's photograph of 1914 compared to Phil Stone's of 1972 now provides science with an unprecedented capture of the glacier's retreat. A pair of photographs that could have easily been disregarded as just explorer voyage memorabilia has now, thanks to the Extreme Ice Survey (EIS), played an important role in illustrating high latitude climate change. The Antarctic AWS systems and satellite composites also provide such a record and should be safeguarded and continued for even greater comparative value.

Maintaining present data sets is also not enough. While one can argue that expansion of urban sprawl can affect historical meteorological documentation in some mid-latitude regions, in the Antarctic we have much more confidence that local human impact is negligible. Moreover, this record cannot rest with an instance, a day, a year or even a decade. The true science is in the whole, both spatial and temporal. Current scientific issues require identifying natural cycles from longer-term trends possibly attributable to human influence on the global climate system. Multi-decadal data collection and curation are essential, always keeping up with the latest technology.

It is clear from this Task Force's point of view that the AMRC needs to continue to operate and be a part of the community. No other group is as capable of meeting this community need. Below are very specific recommendations that outline a focused effort that the AMRC should concentrate and embark upon with the proper sustained support.

1.) An Authorative Antarctic Meteorological Data Archive

Recommendations for the Antarctic Meteorological Research Center (AMRC): Unique Antarctic atmospheric data sets that are not archived anywhere else and can advance weather and climate science by their preservation should be the archival goal for the AMRC. The 24x7 global online availability of data without restriction or cost is a precedent that should be continued. The following is a listing of important and unique data sets that should be preserved at AMRC (1-7) along with a suggested new role for AMRC (8) that advances and raises the profile of Antarctic weather and climate science.

1. **Satellite composites for both the Antarctic and Arctic.** These hourly satellite views of the atmosphere of the Polar Regions are a unique resource available nowhere else about the constantly varying atmospheric circulation. Yet they are not widely known or appreciated. They need publicity and demonstration of their value. Development of an automatic feature tracking capability would yield a systematic extraction of their valuable depiction of cyclones and fronts, akin to cyclone tracking for atmospheric analyses/reanalyses. AMRC's unique satellite composite data record collection must be preserved and added to for as long as the production of this product exists. It is a unique record that cannot be duplicated but may be possible in the future to replace.
2. **Real-time automatic weather station observations from Antarctica.** These can inform the scientific community and the general public about the characteristics and the climate change underway in the Great White South that fascinates the populace. This is an educational resource that could be greatly developed by some creative thinking.
3. **Detailed surface and upper air observations from the US stations at South Pole, McMurdo, and Palmer**. There is no other source for this vital information about climate variations and change both at the surface and in the free atmosphere; the GTS transmitted data streams are incomplete and not nearly as detailed. Yet these data sets need rigorous quality control and development of metadata.
4. **Observations from temporary field camps, and runway observations (e.g. METARs) from the airfields around McMurdo and South Pole** are not archived anywhere else. They need quality control, reformatting, and development of metadata where this is possible. User guidance is needed as to the usefulness and reliability of these observations.
5. **Broadcast satellite data streams received at McMurdo and Palmer** are a highly valuable resource for science that complements those available from NASA, NOAA, and other satellites to provide detailed temporal coverage from space. AHVRR and DMSP are notable examples. A catalog and compressed thumbnails would make the data easily accessible to users. Easily used data formats are needed.
6. **Campaign atmospheric science data sets** need to be archived before they are lost. The recent PIPERS campaign in the Ross Sea with its extensive radiosonde profiles is one example. The extensive array of POLENET GPS sites in West Antarctica collects basic weather information that should be captured and quality controlled. Their value is enhanced by the sparseness of observations from this rapidly changing part of Antarctica.
7. **Issuance of digital observation identifiers** (doi) for all data sets would bring credit to the data collectors and preserve the data sets for posterity.
8. There is no single location for **authoritative evaluation of climate variations and change in Antarctica.** NSIDC does this for the polar cryosphere. AMRC could follow their example but targeted at Antarctic climate variability and change by engaging with the community.

2.) A Shared Antarctic Meteorological Data Distribution System

Recommendation for an Antarctic Internet Data Distribution System (Antarctic-IDD): It is recommended the Antarctic Internet Data Distribution (Antarctic-IDD) is the medium between this long term archive science project at the AMRC and operational/real-time observing systems as well as other projects, programs, or agencies. This is a community effort, and an integral one as the Antarctic-IDD is a pathway for meteorological datasets to be both available for operational use and be included in the AMRC data archive. Outside agencies, other national Antarctic meteorological programs (e.g. BAS, IPEV, etc.) and other science projects will be encouraged and welcomed to participate. If a project is part of an NSF OPP grant, it will be utilize the AMRC for the formal collection and archive of data.

- Outside agencies will be encouraged to participate in the collection of data through the provision of making available the means to establish an account with AMRC through Antarctic-IDD or other cooperative means to provide their data.
- NSF funded science projects will either use the established AMRC datasets or be provided an account with AMRC through Antarctic-IDD or other cooperative means to provide their data. If the project requires additional, measures beyond what the current AWS sensor suite supports, they will work with AMRC to either expand the AWS sensor suite if possible, replace the AMRC system with an agreed upon upgrade, or provide an independent system and establish collected data through an independent account into the data archive.
- NSF funded Operational AWS and other weather sensor data not included in WMO/ICAO assigned data will be mandated to share data sets through an establish account with AMRC A/IDD. WMO/ICAO data is available via official established means and is not intended to be duplicated by this project. Current Operational data sets will include fixed AWS systems in and around McMurdo operational area and all NSF camp operational systems (METKITs) and manual weather observation records.

The objective will be to work toward a single data system where weather data can be sent from each sensor suite to its parent server collection system then shared by that agency with the AMRC repository/archive. This will allow all other agencies and the science community/projects the ability to obtain data in either near real-time or from historical records.

3.) A Sustained Effort

Recommendation for the AMRC to be funded as a cooperative agreement. The commitment behind the AMRC requires a sustainable effort. As such, it is recommended that this effort be considered as a cooperative agreement between the NSF OPP and the AMRC. While other support efforts are encouraged, this effort is on par with other NSF funded efforts such as the

Polar Geospatial Center (PGC) at the University of Minnesota-Twin Cities, the United States Rock Repository at the Byrd Polar Climate and Research Center at the The Ohio State University and a focused subset of the Interdisciplinary Earth Data Alliance (IEDA)/USAP Data Center at Lamont-Doherty Earth Observatory at Columbia University. All are funded as cooperative agreements, and all are members (along with the AMRC) as a part of the Antarctic and Arctic Data Consortium. This funding method may be best means to ensure sustainability and meteorological datasets will continually be an active part of the consortium.

E. Acknowledgements

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Appendix A: Supplemental Antarctic Operational Satellite Meteorology

1. Overview:

SPAWAR METOC Operations, as part of a Joint team, deliver accurate, consistent, relevant, and timely environmental products and services within the designated Area of Operational Responsibility (AOR), tailored to the operational requirements of supported USAP operations. In the data sparse environment of the Southern Ocean and Antarctic continent, weather satellites become more important than at lower latitudes in the development of weather forecasts. Specifically, LEO weather satellites are required due to the location of operations being at too great of an angle for geostationary satellites to provide a view to the “bottom of the earth”.

Historical usage of weather satellite derived images has been from a host of agencies providing access to spacecraft that can be tracked line-of-sight over the McMurdo celestial dome. This includes currently satellites from NOAA (POES), Air Force (DMSP), and NASA (EOS and NPP). Since 1987, USAP has used a version of the current SeaSpace (Inc.) receiver and display system known as TeraScan. Images are downloaded as the spacecraft passes over the McMurdo Ground Station providing a view of the area and assisting forecasters in monitoring weather elements over the horizon.

McMurdo is part of the current “store and forward” process for DMSP, NOAA, and NASA systems. The process stores data on the satellite and delivers a download at specified locations as JPSS concept in Figure 1. The information is compressed and decoded at the delivery site of the agency via Internet connection from the download site. This information is intended to provide users around the globe with weather satellite imagery but has not yet been realized in near-real-time delivery with quality images.

USAP ground stations receive decoded direct broadcast that the satellites are transmitting as they fly overhead. The system currently in use is the SeaSpace TeraScan. All “store and forward” systems are not under USAP authority, and although they will play a part of USAP future, they are not mature to the level of replacing the McMurdo ground station at this time. It behooves USAP to maintain a relationship with all Satellite agencies and work toward future goals of merging into this “store and forward” process. The McMurdo and Palmer ground stations are the USAP funded parts that could be considered for modification and eventual elimination, if the “store and forward” systems could be adapted to local near-real-time use.

1. Current end user requirements

SOPP as the end user requires at minimum area coverage of imagery for all aviation forecast supported locations three times per 12-hour period at 1 km resolution with geo-referenced mapping including looping, text overlay, and zoom capabilities. We emphasize this is a bare

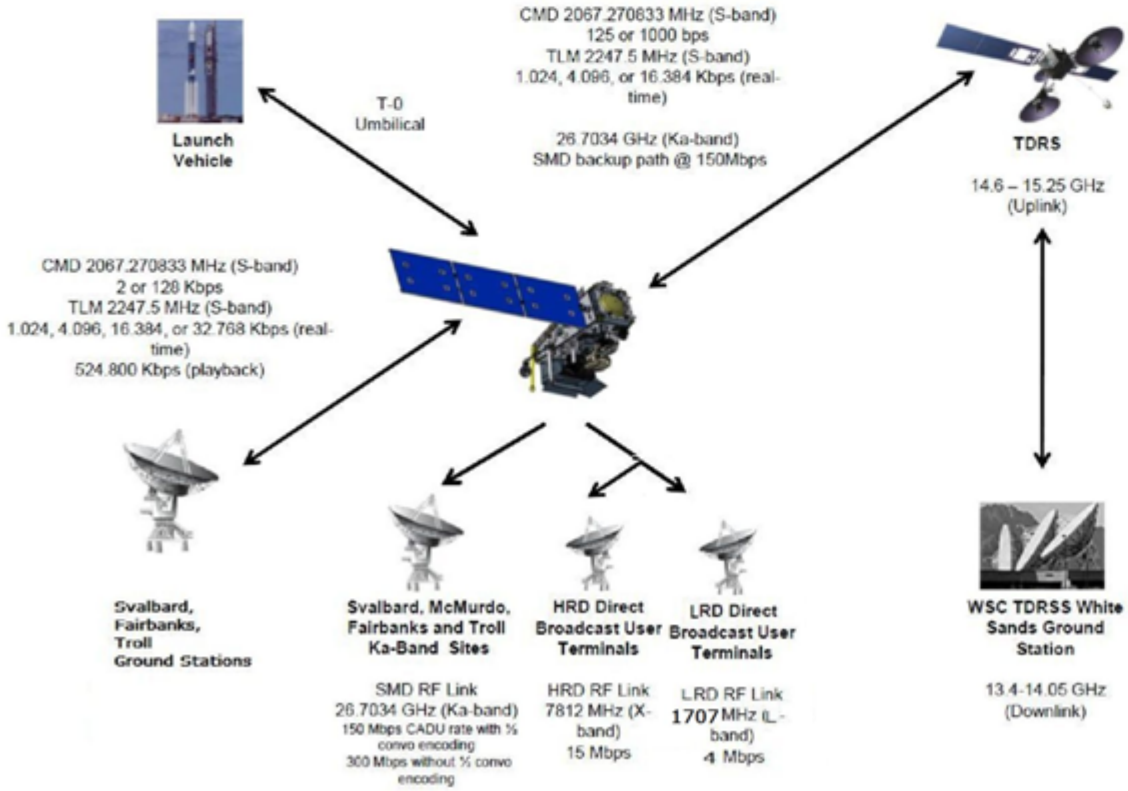

Figure 1: JPSS-2+ Conceptual Direct Readout Configuration.

minimum for looping purposes and SOPP floor forecasters would protest such minimal availability. Increased resolution and periodicity would result in improved forecasting capabilities and accuracy. Conversely, any decrease in periodicity or resolution would result in limited forecasting capabilities and a large decrease in accuracy. This is based on comparative experience with the pre- verses post-TeraScan installation period (1987) and the positive change in forecasting accuracy at McMurdo, and also improvement in Palmer area forecast accuracy when imagery with better than 1 km resolution became available from the local ground station at Palmer. In areas without these capabilities, costly mission aborts would be more commonplace and safety issues of below minimum or whiteout landings would increase.

Without the availability of high resolution imagery, high tempo and/or aviation forecasts such as those conducted with "Lamanna", in and around James Ross Island in 2016, would not be advisable. The Lamanna project required detailed forecasting for multiple locations using ship, small craft boat operations and helicopter aviation support. Events as these with large terrain features and rapid moving weather systems require near-real-time and high-resolution imagery for detailed analysis.

2. Issue

SeaSpace has not been able to repair the USAP visualization software (TeraVision1) currently used. New visualization software (TeraVision2) from the vendor is far less capable in the provision of products and requires more training for personnel to operate this less intuitive system.

3. Immediate Plan

Continue using current TeraVision 1 software and work with the frequent computer lockup by limiting the number of loaded images and refreshing the system periodically with a full shutdown and restart.

4. Long Range Plan

The ultimate goal is to eliminate the McMurdo direct readout ground station and its image production suite, and to tap into a futuristic design where the network of earth orbiting satellites are processed into images at large repositories including NOAA, EUMETSAT (METOP), and the Air Force Weather Agency. These services have both current and futuristic designs to distribute imagery to customers via the Internet. Processes and services such as these are accomplished today at EUMETSAT, NASA, NOAA, and AFWA with their respected satellite systems but these currently lack either in the quality of the resolution and/or in timeliness. Many of the images are processed and made available via Internet many hours or even days after the satellite passed over Antarctica.

5. Staged Implementation

To accomplish the long-range plan with the JPSS and METOP near-real time retrieval systems not being in place at this time, a staged change in how weather satellites are being managed and processed could be established. This would be consistent with the USAP model of moving more elements of operations off the Antarctica continent.

The first stage should be one of working into networked model as presented by the Air Force in the Mark-IV B satellite network. The concept would be one of a micro "store and forward" service using USAP ground stations, mining any available low resolution taped data, and a production center to build and distribute required products. Over time the low resolution taped data can be replaced by large centers' high resolution imagery as they become available over the next decade.

Initially a hybrid would have to be formulated due to bandwidth limitations. USAP Ground stations including McMurdo and Palmer would be required to process imagery for local use, and selected imagery could be moved to the processing center.

The imagery processing center could be naturally supported at Denver where they could collect and build required data imagery and provide a repository for users at local and remote locations.

This model in its most economical mode would maximize use of existing hardware and modify only those components required. A complete software modification would be required in this model to produce images that could be managed through display software that uses a common format. Using a common format would allow link capability to outside collection centers, as AFWA and NOAA contributing satellite data not captured by one of the USAP ground stations could be incorporated and available to operational forecaster.

i. Initial Stage

- Establish a server in McMurdo and possibly Palmer for processing locally in a common format.
- Establish a server in Denver to collect:
  - McMurdo and possibly Palmer imagery, and
  - Retrieve other negotiated and when available AFWA, NOAA, NASA, and/or METOP imagery.
- Configure the Denver Center to serve images to end users.
  - Establish a file transfer program or storage with capability to retrieve or distribute imagery to required agencies as SOPP Charleston, McMurdo, USAP Web page updates, etc.
- User locations
  - Installation of viewer software available at customer locations including SOPP Charleston, Denver, and McMurdo.

The primary means of receiving satellite data is through the system, which requires additional display software and Internet connectivity to access geostationary and polar orbiter data from other agencies.

Unification of center-retrieved imagery and post processing of direct readout data from the McMurdo ground stations to imagery level would be conducted in Denver and monitored/maintained by the USAP Denver IT Center. This bolsters the move off-continent and establishes the foundation for our future design.

ii. Second Stage

Move the server off continent when a larger pipe is available to move ~25 GB of data per day or reduced amount if compression can be done. Increase post processing in Denver. Produce an image that indicates raw data moved off and all post processing has been done in Denver, including unification of outside imagery. This configuration allows USAP to be ready for the final stage to eliminate local ground stations as more imagery becomes available from outside sources in near real time. During the final stage, the networked imagery from McMurdo direct ready out will be eliminated by the production of satellite imagery from these central repositories. This process should be considered when real time delivery from these agencies is reduced to near 3 hours from satellite flyover time.

6. Summary

It may take a decade or longer to realize the primary goal of moving to the primary agencies store and forward system and eliminating the need for direct readout ground stations in McMurdo and Palmer Station. Establishing as much of the foundation as practical should allow USAP to maximize usage for all sources as they become available. If practical in cost and bandwidth, it is recommended USAP develop and move forward in centralized processing in Denver and develop relationships with outside agencies to provide imagery to the Denver site for operational product development and customer distribution.