

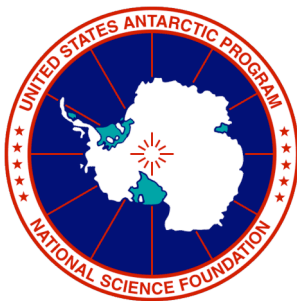
Antarctic Meteorological Satellite Report 2006

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This report is dedicated to Elena Teresa Susi Fountain for her endless encouragement and bringing clarity to these reports.

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Introduction

Meteorological satellites are perhaps the most critically important observing tools available to operational Antarctic weather forecasters and decision-makers. Having this information affords improved weather forecasts and ultimately increased safety for those working and traveling in and around the Antarctic. This report reviews the current and future launch status of both operational and research meteorological satellites, with a focus on those impacting the Antarctic. It is an update to reports from 2002 entitled *Meteorological Satellite Status Report* (Lazzara, 2002) and from 2004 entitled *Antarctic Meteorological Satellite Status Report* (Lazzara, 2004). The current uses, limitations, and potential applications of meteorological satellites acquired by the United States Antarctic Program (USAP) are outlined. Meteorological satellites that are currently not available to the USAP are reviewed, including their applications, benefits, limiting factors and other miscellaneous considerations. Some important issues facing satellite meteorology are also discussed, especially with regard to data encryption and availability of frequencies for remote sensing.

Geostationary Satellites

Although geostationary satellites may not seem to be of great importance since the Antarctic region is on the limb of the field of view, they are indeed important. Most geostationary satellites do image the Southern Ocean and up to the coast of the Antarctic. Observations from geostationary platforms are a critical basis for satellite composites such as those generated by the Antarctic Meteorological Research Center (Lazzara et al. 2003a, and Lazzara et al. 2003b) because they show systems that will impact Antarctic weather. See Figure 1.

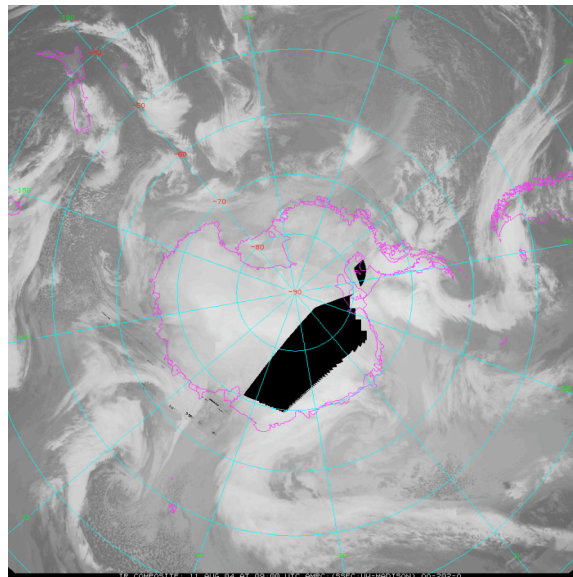
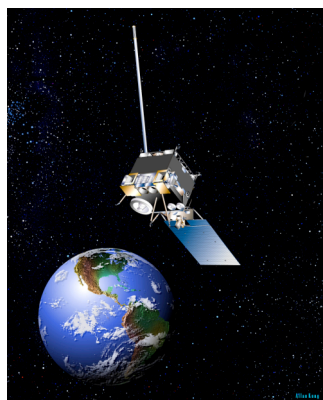
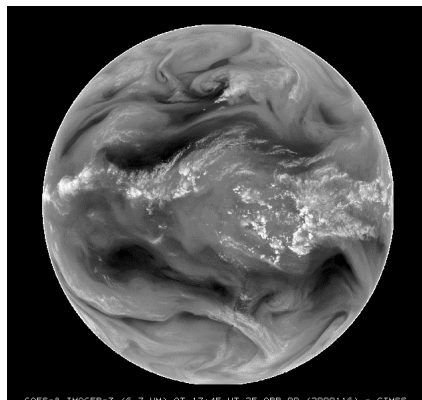


Figure 1. An infrared Antarctic composite satellite image combined from both geostationary and polar orbiting satellite platform observations. (Courtesy of AMRC)

Geostationary Operational Environmental Satellite (GOES)

Boeing



UW-Madison/SSEC/CIMSS

The Geostationary Operational Environmental Satellite (GOES) program operated by the National Oceanic and Atmospheric Administration (NOAA), United States, currently has four satellites in orbit. GOES-10 (West – 135 degrees West) and GOES-12 (East – 75.1 degrees West) are the current operational satellites, with GOES-11 (105 degrees West) currently in on-orbit storage. GOES-11 is a fully functional satellite ready for use as a backup within 48 hours. In mid-June, 2006, GOES-11 is due to be reactivated for testing and will replace GOES-10 as the operational GOES West satellite on July 20, 2006. GOES-9 (formerly Pacific – 155 degrees East) satellite was on loan to the Japanese Meteorological Agency (JMA) from NOAA to assist with coverage over the Far East due to the end of the useful life of the GMS satellite and failure of the MTSAT-1 satellite launch (see MTSAT). NOAA terminated GOES-9 operations on November 15, 2005 with the successful launch and operations of MTSAT-1R. In a recent development, there are plans to have GOES-10 be used for the benefit of Central and South America, when it is expect to be replaced with GOES-11 as the GOES West satellite. This special GOES-10 mission may indeed benefit the USAP, depending on the scanning schedule and field of view selected. (See Appendix for letter of support and details). As of this writing, the plans for this mission and scheduling are under review.

All GOES satellites in this generation are 3-axis stabilized satellites offering visible, short & long wave and window infrared, as well as water vapor data. The GOES satellites also offer a 19 channel sounder; however, they do not cover below 60 degrees South or the Antarctic at all. This may be changed with the GOES-10 special mission. The instruments on board include:

<u>Sensors</u>	<u>Description</u>
Imager	5 Channel imager
Sounder	19 Channel sounder
DCP	Data Collection Platform
SEM	Space Environment Monitor
SXI	Solar X-Ray Imager (GOES-12 and beyond)

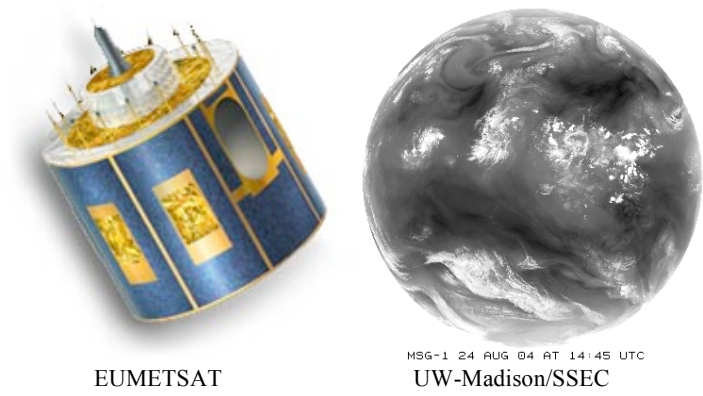
Built by Boeing, the next series of GOES satellites begins with launches in the middle of the first decade of 2000. This next series of satellites will be very much like the current series (similar instruments with a magnetometer added and still a 3-axis stabilized satellite), with some

modifications for which channels and resolutions are available (including a 13.3 micron band replacing the pre-GOES-12 era of 12.7 microns). The GOES-N/O/P do have improvements for navigation accuracy as well as have capability to operate through eclipse times. It is expected that GOES-N after on-orbit checkout, will be placed in storage. Otherwise, this is the best-known launch schedule:

Platform	Launch Date
-----	-----
GOES-N	Not before May 3, 2006
GOES-O	April 2008
GOES-P	October 2009
GOES-Q	<i>Cancelled</i>
GOES-R	September 2012
GOES-S	April 2014

It is important to note that the GOES-R satellite will mark a significant change in this satellite series. GOES-R will be the platform for the Advanced Baseline Imager (ABI) and Hyperspectral Environmental Sounder (HES, formally called the Advanced Baseline Sounder or ABS). These instruments are currently under development by NOAA, with additional instrumentation planned, including a lightning mapper. The launch of GOES-R offers the first operational sounder with Southern Hemisphere support (not the Antarctic continent itself), as well as having routine imaging to cover the Southern Hemisphere on a half-hourly or hourly basis since the pre-GOES-NEXT era (pre-GOES-8). As a minor note, the GOES low rate data transmission and distribution method, to comply with international agreement, has been moving away from the historical analog method (WEFAX) in favor of the new LRIT digital method (at 1691 MHz). GOES high rate data transmission and distribution or GVAR (GOES Variable) continues as before (at 1685.7 MHz)

Meteosat



The Meteosat geostationary satellite program is overseen by EUMETSAT (Europe) with assistance from the European Space Agency. Currently, EUMETSAT is operating its older satellite series, Meteosat Operational Program (MOP), and its new Meteosat Second Generation

(MSG). The oldest satellite, Meteosat-5 (INDOEX - 63 degrees East) continues an extended Indian Ocean Data Coverage (IODC). This satellite is beyond its life span and is starting to acquire an almost one-degree inclination or more. EUMETSAT plans to continue to operate this satellite at this location into 2006. Meteosat-6 is the in-orbit stand-by spacecraft and is located around 10 degrees East. It is noteworthy that the stand-by satellite is used for rapid scanning operations over Europe. Meteosat-7 is the operational spacecraft at a position of 0 degrees (since 3 June 1998) and is due to be terminated for primary use as of 14 June 2006. Meteosat-8 (3 degrees West - formally MSG-1) became operational on 29 January 2004. EUMETSAT plans to have a two satellite configuration with a primary operational satellite and a backup spare satellite located near 0 degrees. IODC will likely continue, with the likely movement of the Meteosat-7 satellite to 63 degrees East, to have it take over for the aging Metosat-5 satellite. This satellite might also support a rapid scanning service, although it is unlikely this will impact the Antarctic region. On December 21, 2005 MSG-2 (6.5 degrees West) was launched, and as of the writing of this report, it is undergoing commissioning and will soon be renamed Meteosat-9. Last known future launches, including the estimated start of Meteosat Third Generation (MTG) are:

Platform	Launch Date
-----	-----
MSG-3	2009
MSG-4	2012
MTG	2015

All MOP satellites are spinner satellites offering visible, infrared and water vapor data. The MSG satellites are also a spinner satellite system that carries the Spinning Enhanced Visible and Infrared Imager (SEVIRI) 10-channel imager system. EUMETSAT also offers a rebroadcast service to its user community via commercial telecommunications satellites named EUMETCAST. The broadcast contains Meteosat data, products and more, which are retransmitted to the European community for a fee. The Hotbird satellite at 13 degrees East hosts the EUMETCAST service (much like USA's DOMSAT service), among others. IODC data will be provided via direct broadcast as well as via EUMETCAST.

<u>Sensors</u>	<u>Description</u>
SEVIRI	Spinning Enhanced Visible and Infrared Imager (MSG satellites only)
MVIRI	Meteosat Visible and InfraRed Imager (MOP satellites only)

As with the GOES satellite series, the Meteosat satellites also offer a WEFAX service, with the older satellites (Meteosat-5, -6, and -7) offering analog transmissions (1691 and 1694.Z Mhz), and the new satellite (Meteosat-8) offering LRIT along with the full data service HRIT – however not directly from the satellite, but from EUMETCAST. The older satellites full data service is HRI (1691 and/or 1694.5 Mhz).

Multifunctional Transport Satellite (MTSAT)



ABoM/JMA

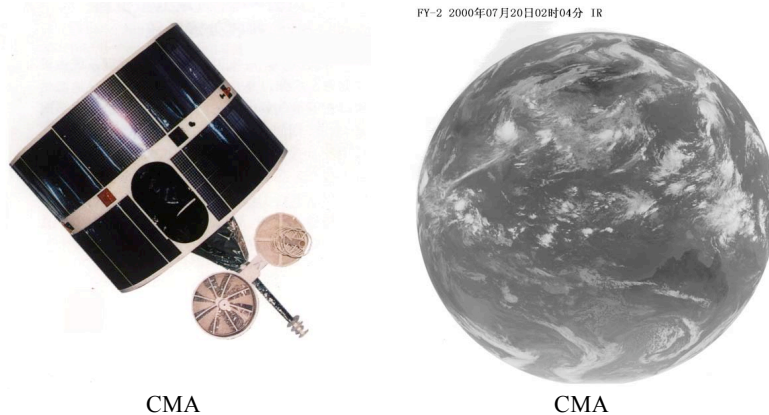
The replacement satellite series for the Japanese GMS series is the Multifunctional Transport Satellite (MTSAT). This satellite system is built for both meteorological and communication applications. The first MTSAT-1 satellite unfortunately failed on launch. The replacement is MTSAT-1R, which was launched on February 26, 2005 and declared operational by JMA on June 28, 2005. MTSAT-1R (140 degrees East) is also known as Himawari-6. The second satellite in the series, MTSAT-2, recently launched on 18 February 2006, will be placed in a standby mode until it is needed to replace MTSAT-1R. These satellites are a 3-axis stabilized system carrying a 5-channel imager. This imager has visible, infrared (short wave, window and long wave), and water vapor bands.

As of this writing, plans for MTSAT-3 and beyond are just getting underway. It is expected at this time that any launches will take place next decade close to the time frame that GOES-R and MTG would be launched.

The MTSAT supports the LRIT transmission service, common to many current and all planned geostationary satellites, and may share the service with a WEFAX analog transmission service as well. It also offers a full resolution service, HiRID (enhanced SVISSR)/HRIT (1691 Mhz).

<u>Sensors</u>	<u>Description</u>
S-VISSR	Stretched Visible Infrared Spin Scan Radiometer

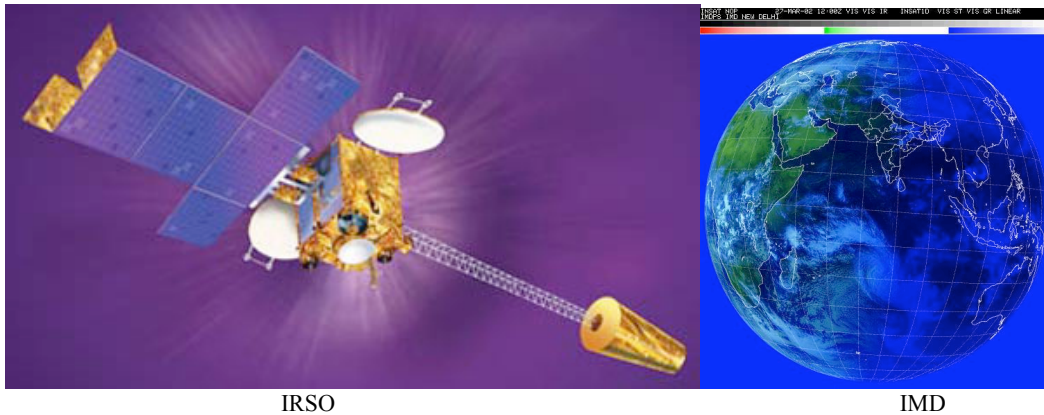
Feng Yun (FY)



The Chinese geostationary satellite series, operated by the Chinese Meteorological Agency (CMA), is Feng Yun 2 (FY-2, Feng Yun means Wind and Cloud). The first satellite, FY-2A (FY-2 1R) launched on June 10, 1997, is of limited use due to de-spin subsystem problems and S-Band antenna problems and has been operated as only an experimental satellite. The next operational satellite, FY-2B launched June 25, 2000, had to be turned off for eclipse seasons (mainly in autumn and spring for roughly 90 days). For technical reasons there were no image transmissions covering the Southern Hemisphere. FY-2B has been moved to 123.5 degrees East and, like its experimental sister, is a three-channel (visible, infrared, and water vapor) spinner satellite, and suffers spin stabilization problems. The current active operational satellite, FY-2C, located at 105 degrees East, was launched on 19 October 2004. Full resolution data is transmitted at 1687.5 Mhz (last known frequency) (S-VISSR) with future satellites to offer LRIT data. The Chinese geostationary satellite program expects to launch four more satellites in its current series and begin a new series in the future (FY-4). It is expected that the rest of the FY-2 series will be a five-channel spinner satellite system, taking data in the visible, infrared and perhaps water vapor bands. The FY-4 series will be divided into two series of satellites: A-series for visible and infrared observations and B-series for microwave. The FY-4 series will be a 3-axis stabilized satellite series.

<u>Sensors</u>	<u>Description</u>
S-VISSR	Stretched Visible and Infrared Spin Scanning Radiometer
<u>Platform</u>	<u>Launch Date</u>
-----	-----
FY-2D	2007
FY-2E	2009
FY-2F	2011
FY-2G	2013
FY-4	Not before 2012 for A-series Not before 2015 for B-series

INSAT



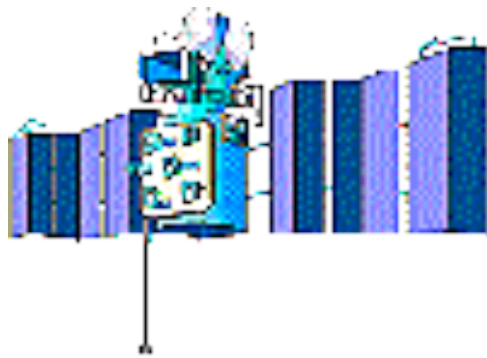
The India Meteorological Department (IMD) operates the INSAT series of geostationary satellites. These satellites are shared for meteorological and communications use. The INSAT constellation includes both spinner (older series) and 3-axis stabilized satellites, most with the 5 channel Very High Resolution Radiometer (VHRR) sensors including visible, infrared, and water vapor channels. The historical satellites include INSAT-1A, -1B, -1C, -1D, -2A, -2B, and -2E located typically at 74, 83, and 93.5 degrees East. There are two currently operational satellites: Kalpana-1 and INSAT-3A. Originally known as METSAT-1, Kalpana-1 was launched 12 September 2002 (74 degrees East). It was re-named in Feb 2003 after Kalpana Chawla, one of the seven-crew members of the Space Shuttle Columbia STS-107, first Indian-born woman in space. INSAT-3A was launched 10 April 2003. Both INSAT-3A and Kalpana-1 host the VHRR instrument, which is transmitted and encrypted at 2599 Mhz. In addition to the VHRR, Kalpana-1 also has a Charge Coupled Device (CCD) camera/payload with three channels in the visible and near infrared. All of the meteorological data from the INSAT satellites is encrypted. However, NOAA and IMD have made arrangements to share data.

<u>Sensors</u>	<u>Description</u>
VHRR	Very High Resolution Radiometer
CCD	Charged Coupled Device

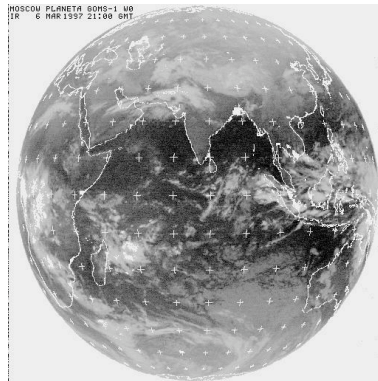
The next Indian INSAT series satellite to be launched is the INSAT-3D. This new satellite will carry a 6-channel imager and a 19-channel sounder very much like the GOES satellite system. At this time, it appears the data will remain encrypted. It is unclear if the US will work to navigate and calibrate the data retransmitted to NOAA, although there are some efforts on-going. It is noteworthy that INSAT-3D may possibly be renamed Kalpana-2 after it is launched and operating. There may be possible plans for a Kalpana-3, but little is known at this time. The launch information is:

Platform	Launch Date
-----	-----
INSAT-3D/Kalpana-2	2007 or 2008

Global Operational Meteorological System (GOMS)



Planeta-C

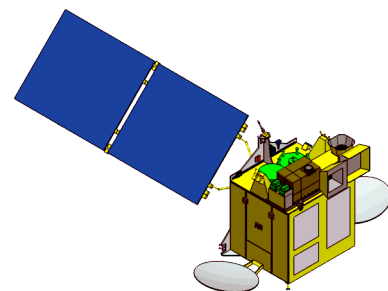


Planeta-C

The Russian Planeta-C Meteorological Space System includes Elektro or the Global Operational Meteorological System (GOMS or GOMS-N1) that was launched 31 October 1994. GOMS went operational 1 June 1996 and broadcasts on 1691 MHz (WEFAX). It has provided very little imagery since it was launched and placed on orbit due to some operational issues. This three-axis stabilized satellite offers two channels - visible and infrared. It appears to have come to the end of its life in September 1998. It was expected that the Russian Federation would launch the GOMS-N2, also known as Elektro 2 satellite sometime in 2005 or 2006, and that this may have been canceled at this time (this information is not confirmed at this time). The three-axis stabilized satellite was due to carry the Scanning Television Radiometer (STR) which will offer three-channels of visible, infrared and water vapor data, and may carry other sensors as well. Updated information notes that GOMS-N2 was to have a new satellite sensor system, the Multi-Channel Scanning Unit (MSU-GS), which would be much like the SEVIRI 10 channel sensor system with one exception, a 0.85-micron water vapor sensitive channel. The new satellite will likely have HRIT and LRIT data formats.

<u>Sensors</u>	<u>Description</u>
STR	Scanning Television Radiometer

<u>Platform</u>	<u>Launch Date</u>
-----	-----
GOMS/Elektro-L (N1) 2	2006/2007
GOMS/Elektro-L (N2) 3	2009



Communications, Ocean and Meteorological Satellite (COMS)

KMA

The Korea Meteorological Administration (KMA) in a joint effort with other governmental agencies of the Republic of Korea has started to plan a geostationary satellite of its own, named COMS (communication, ocean and meteorological satellite), with a planned launch date in 2008 and a second satellite in 2014. It is due to carry a 5-channel instrument, very much like the GOES imager. This 3-axis stabilized satellite will also carry a geostationary ocean color imager

(GOCI), as well as a communications payload. This satellite will offer HRIT and LRIT transmission data format, and will likely be placed at either 128.2 degrees East or 116.2 degrees East.

Platform	Launch Date
COMS-1	2008
COMS-2	2014

Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS)



NASA

The Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) is an instrument set to go on the New Millennium Program (NMP) Earth Observing 3 (EO-3) geostationary satellite. GIFTS has 32,600 sensors to collect data, scanning an area of 512 kilometers square every ten seconds resulting in over 3000 spectral channels. The data rate is roughly 60 Megabytes per second, in the X-band for data transmission. This project is a joint partnership of NASA, NOAA and the US Navy. The instrument development is a joint effort by SSEC/UW-Madison and Space Dynamic Laboratory/Utah State University. The original plans called for the NASA EO-3 platform, after finishing the NMP mission for NASA, to be moved to the Eastern hemisphere for US Navy use. At such time, the satellite/sensor would have been subsequently renamed Indian Ocean Meteorology and Oceanography (METOC) Imager (IOMI).

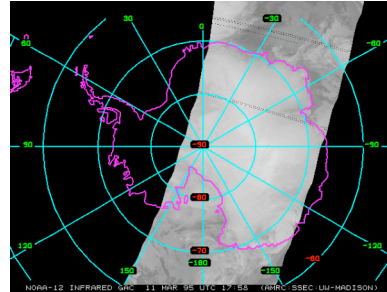
As of the summer of 2004, NASA had in essence canceled the NMP EO-3. The US Navy continues to be a partner in the project despite the lack of spacecraft funding. NOAA is still funding the research and development effort, because it is a risk reduction effort for the GOES-R satellite. It does appear the instrument will still be built and tested regardless of the lack of a spacecraft to place it on in the immediate future. Other satellite systems, especially foreign, are being actively pursued as possible platforms to launch the GIFTS instrument. Overall, GIFTS represents the future of remote sensing from space platform. As of the writing of this report, the US National Research Council (NRC) has started to draft a report on the future of satellite systems and missions for the US entitled a Decadal Survey. The GIFTS instrument is one of the key topics in the initial testimony from the NRC to the U.S. Congress (See: <http://www.spaceref.com/news/viewsr.html?pid=16381>).

Polar Orbiting Satellites

Polar Operational Environmental Satellite (POES)



NOAA



UW-Madison/SSEC/AMRC

The US Polar Operational Environmental Satellite (POES) system operated by NOAA currently has five satellites in primary, backup, or standby mode. Currently, NOAA-18 and NOAA-17 are operational, with NOAA-16 and NOAA-15 in backup mode, and NOAA-12 and NOAA-14 in stand-by or limited use mode. NOAA-11 has been decommissioned as of 16 June 2004. NOAA-9, which was permanently deactivated some years ago and is tumbling freely, has a sporadic carrier on 137.5 Mhz (varies quickly according to orientation) and can cause interference to NOAA-12 and NOAA-15. This problem has not been reported recently as it has been compared to the past several years. Additionally, there are reports from the amateur community of TIROS-N and NOAA-6 satellites putting out carrier signal on the same 137.5 Mhz frequency, also interfering with NOAA-12 and NOAA-15 when they are within the same footprint.

NOAA-18 was launched on May 20, 2005 into an afternoon approximately 2 pm equatorial cross-time. The satellite is transmitting well with Automatic Picture Transmission (APT - analog) on 137.1 Mhz, and with high-resolution picture transmission (HRPT - digital) on 1689 Mhz. NOAA-17 has a mid-morning orbit with an approximate 10:30 am equatorial cross time. There have been some problems with the HRPT, causing the STX-3 to reduce power from 8 watts to 2.4 watts, resulting in reduced signal strength. NOAA-17 is transmitting on APT 137.62 Mhz and HRPT on 1707 Mhz. NOAA-16 has an afternoon orbit with an approximate 2 pm equatorial cross time. This satellite is fully functional, with the exception of the APT system, which failed a few months after launch. It is transmitting HRPT on 1702.5 Mhz. NOAA-15 has a morning orbit with an approximate 7:30 am equatorial cross time. This satellite is also functional. NOAA-15 also is transmitting direct broadcast data from its backup antenna system after a failure occurred with its primary system (APT on 137.5 Mhz and HRPT on 1702.5 Mhz). Recently NOAA-16, like NOAA-15 has had in the past, had problems with its imager, the Advanced Very High Resolution Radiometer (AVHRR), scan motor and the High resolution Infrared Radiation Sounder (HIRS).

NOAA-14, which has an older suite of satellite instrumentation, is in an afternoon orbit with an approximate 2 pm equatorial cross-time. It is functional, but its AVHRR unit scan motor has had problems much like NOAA-16 and NOAA-15, making the data unusable at times. NOAA engineers will no longer be making attempts to restart the scan motor on NOAA-14. Reports

from the amateur satellite community note that NOAA-14 has been doing much better in recent months and does have some fairly good imagery. NOAA-14 does not have APT transmitting on however it does have its HRPT transmissions on 1707 Mhz. NOAA-12 is in a morning orbit with a 6:40 am cross-time that is currently functioning well, with the exception of the sounding instruments. It did have a recent problem that forced the satellite into a safe-mode with the instruments turned off. NOAA operators have since turned back on the instrumentation, and the satellite continues to operate at this time. NOAA-12 operates APT on 137.5 Mhz and HRPT on 1698 Mhz.

The POES series plans one more satellite in the series. This satellite will carry the AVHRR imager, and an advanced sounding system (both infrared and microwave). The NOAA-N' satellite will also carry the next generation of Argos-III 2-way messaging capability for remote data collection systems, including Automatic Weather Stations (AWS). After the launch of NOAA-N', the POES series of satellites will combine with the DMSP series to form a new national polar orbiting satellite series (NPOESS).

NOAA-KLM series:

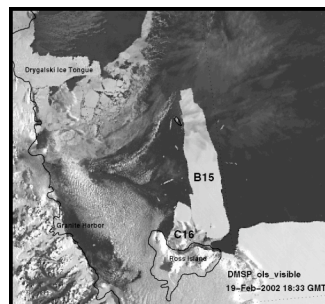
<u>Sensors</u>	<u>Description</u>
AVHRR	Advance Very High Resolution Radiometer
HIRS	High Resolution Infrared Radiation Sounder
AMSU-A	Advanced Microwave Scanning Unit-A (1 and 2)
AMSU-B	Advanced Microwave Scanning Unit-B
DCS	Data Collection System (Service Argos)
SEM	Space Environment Monitor
SARP/SARR	Search and Rescue Processor/Repeater

<u>Platform</u>	<u>Launch Date</u>
-----	-----
NOAA-N'	2008 (Afternoon equatorial cross-time: Launch date is pending on repairs)

Defense Meteorological Satellite Program (DMSP)



NGDC



RPSC

The Defense Meteorological Satellite Program (DMSP) satellite system is a polar orbiting satellite series, operated by the United States (NOAA) for both military and civilian (in non-real-time) use. Over the Antarctic (south of 60 degrees South), the DMSP send clear transmissions in

what would otherwise be an encrypted satellite data signal. Current operational satellites are the DMSP F-16, F-15, F-14, F-13, and F-12. All DMSP satellites have a morning equatorial crossing time orbit. These satellites offer a high-resolution imager of infrared and visible data (OLS instrument) and microwave imager and sounder data (SSM/I, SSM/T, & SSM/T2). Starting with the DMSP F-16 satellite, the new special sensor microwave imager/sounder (SSMIS) replaces the SSM/I, SSM/T, and SSM/T2 sensors, and will also be on future DMSP satellites.

<u>Sensors</u>	<u>Description</u>
OLS	Operational Linescan System
SSM/I	Special Sensor Microwave Imager (F-15 and before)
SSM/T	Special Sensor Atmospheric Temperature Profiler (F-15 and before)
SSM/T2	Special Sensor Atmospheric Water Vapor Profiler (F-15 and before)
SSMIS	Special Sensor Microwave Imager/Sounder (F-16 and after)

There are other sensors on the DMSP satellites for space weather applications including: X-ray detectors, Ion spectrometers, precipitating electron detectors, etc.

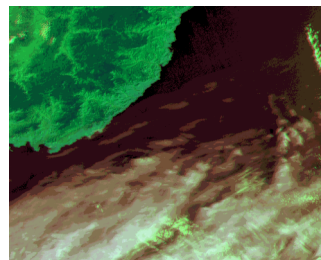
The DMSP program plans four more launches over the next several years. These series of satellites will offer the same or similar instruments and sensors, visible and infrared data as well as microwave data. It may be that the F17, F19, and F20 satellites will break from the current morning satellites, and be launched as afternoon satellites. After the launch of DMSP F-20, the DMSP series of satellites will combine with the POES series to form a new national polar orbiting satellite series (NPOESS).

<u>Platform</u>	<u>Launch Date</u>
DMSP F-17	TBD
DMSP F-18	October 2007
DMSP F-19	April 2009
DMSP F-20	October 2011

Feng Yun (FY)



CMA



UW-Madison/SSEC/CIMSS

The Feng Yun (FY-1) is the operational polar orbiting satellite series operated by the Chinese Meteorological Agency for China. Currently, FY-1C and FY-1D are the operational satellites. The main instrument on the FY-1 series of satellite, a color HRPT (CHRPT), has 10 channels in the visible and infrared spectrum. Both FY-1 satellites transmit on 1700.4 Mhz, with the FY-1C

satellite no longer transmitting data. It is important to note that the FY-1 series of satellites are not encrypted and transmit in the free and clear for users worldwide to use, including the Antarctic.

<u>Sensors</u>	<u>Description</u>
MVISR	Multichannel Visible and Infrared Scan Radiometer

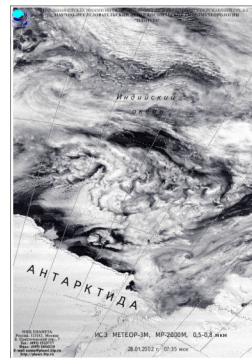
The next generation polar orbiting satellite system from China is the FY-3 series. It is expected that this series of satellites will have improved imaging abilities, and that all of these satellites will be in morning equatorial cross-times. In the meantime, one more of the existing generation of satellites will be launched.

Platform	Launch Date
-----	-----
FY-1E	Unknown
FY-3A	2007
FY-3B	2010

Meteor



Planeta-C



Planeta-C

The Russian Federation operates the Meteor polar orbiting satellite system. Currently, there are no Meteor satellites operating. At this time, the Russian Federation has plans to launch an additional Meteor satellite Meteor-3M N2. It is likely that this satellite will be launched in a sun-synchronous orbit with a morning equatorial cross time. Meteor-3M N1 failed by December 2003 after all of its data transmitters failed.

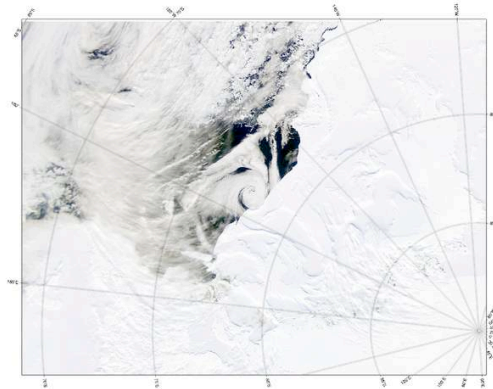
<u>Sensors</u>	<u>Description</u>
SAGE III	Stratospheric Aerosol and Gas Experiment (NASA Instrument)
Other instruments for infrared and visible scanning	

Platform	Launch Date
-----	-----
Meteor-3M N2	2006

SeaStar



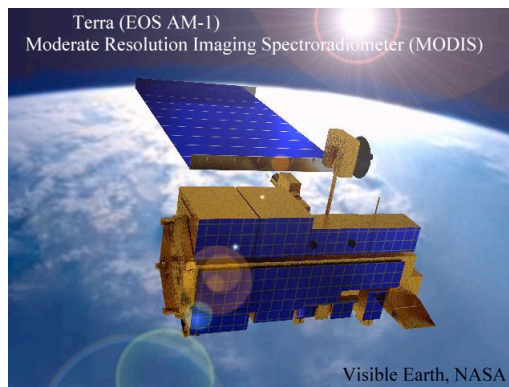
NASA



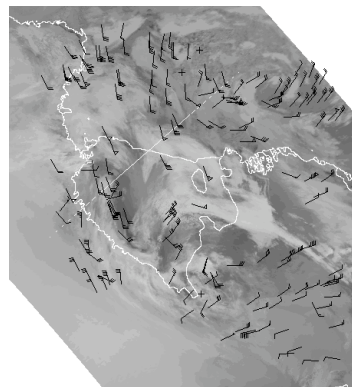
NASA

Orbital Science Corporation in conjunction with NASA operates the Orbview-2/SeaStar polar orbiting satellite, which has the SeaWiFS (Sea-viewing Wide Field-of-view Sensor) instrument (a Coastal Zone Color Scanner or CZCS) onboard. This satellite system is a joint NASA/private corporation effort. These observations have been made available in real-time to the weather forecasters at McMurdo Station, Antarctica and are used for science projects in the Antarctic by the USAP. However, the data is encrypted, thus requiring a decryption unit. They are also available for science use, with permission from NASA. However, within the last year or two, this offer has come to an end with the availability of MODIS ocean color channels. The observations from SeaWiFS offer a variety of visible channel data for ocean color applications as well as infrared data. Data is transmitted in an HRPT styled format at 1702.5 Mhz. No future satellites with the SeaWiFS/CZCS are planned.

Earth Observing System (EOS)



NASA



UW-Madison/SSEC/CIMSS

NASA's Mission to Planet Earth (MTPE) includes an Earth Observing System (EOS). This system offers a series of research polar orbiting satellites with the aim of studying the Earth system. The flag satellites of EOS are Terra, launched in 1999; Aqua, launched on 4 April 2002; and Aura, launched on 15 July 2004. Terra and Aqua offer direct broadcast data, while Aura

does not. There are a host of other satellites considered a part of the EOS program, and they are reviewed in the “Other Polar Orbiting Satellites” section.

These flagship satellites offer a suite of instruments and sensor systems. This new generation of polar orbiting observing systems offers dramatic increases in geographic and spectral resolution. The MODIS instrument, which has been derived from AVHRR and is on the Terra and Aqua satellite, offers 36 channels of one-kilometer resolution data, of which seven offer half-kilometer resolution data, and two offer quarter-kilometer resolution data. The AIRS instrument, which has heritage from the HIRS instrument and is on the Aqua satellite, offers thousands of spectral channels of data that allow high-resolution profiles of temperature and moisture to be generated. The AIRS sensor, combined with the AMSU and HSB, gives a complete atmospheric profiling system. The AMSU is much like the AMSU-A on the NOAA satellites while the HSB is much like the AMSU-B on the NOAA satellites. The AMSR-E instrument is also on the Aqua satellite, and is a next generation microwave sensor.

Aqua:

<u>Sensors</u>	<u>Description</u>
MODIS	Moderate-resolution Imaging Spectroradiometer
AMSR-E	Advanced Microwave Scanning Radiometer for EOS
AIRS	Atmospheric Infrared Sounder
AMSU	Advanced Microwave Sounding Unit
HSB	Humidity Sensor for Brazil
CERES	Clouds and the Earth’s Radiant Energy System

Aura:

<u>Sensors</u>	<u>Description</u>
HiRDLS	High Resolution Dynamics Limb Sounder
MLS	Microwave Limb Sounder
OMI	Ozone Monitoring Instrument
TES	Tropospheric Emission Spectrometer

Terra:

<u>Sensors</u>	<u>Description</u>
MODIS	Moderate-resolution Imaging Spectroradiometer
MISR	Multi-angle Imaging SpectroRadiometer
MOPITT	Measurements of Pollution in the Troposphere
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CERES	Clouds and the Earth’s Radiant Energy System

Terra is operational and has had a few problems over its five years of operation, but is currently operating nominally. It is nearing its end of life expectancy. Aqua is operational as well, and is also operating nominally, with only a few problems with some channels (known before launch). Only the MODIS sensor is offered from the Terra satellite, while all sensors on Aqua are a part of the direct broadcast.

The plans to install a dual X-band and L-band satellite system at McMurdo Station became a reality during the 2004-2005 field-season (Lazzara and Stearns, 2004). This has made Terra and Aqua observations for the first time available to the weather forecasters for real-time use. Products and observations are being produced in a joint effort between the AMRC and the Cooperative Institute for Meteorological Satellite Studies at UW-Madison on site at McMurdo Weather Office (Straka et al 2006).

EUMETSAT Polar System (EPS)



EUMETSAT

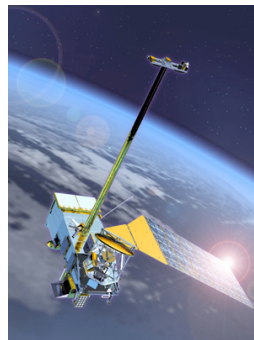
In a joint venture between EUMETSAT and the European Space Agency (ESA) and in collaboration with the new US national polar orbiting satellite program (named the International Joint Polar-orbiting Satellite (IJPS) system) , the European community plans to launch its first series of polar orbiting meteorological satellites, called MetOp. The MetOp satellite series will host many common instruments already on board POES, including AVHRR, HIRS, etc. In addition, a suite of European sensors will be onboard as well:

<u>Sensors</u>	<u>Description</u>
A/DCS	Advanced Data Collection System (also known as ARGOS)
AMSU-A1	Advanced Microwave Sounding Unit (USA)
AMSU-A2	Advanced Microwave Sounding Unit (USA)
ASCAT	Advanced SCATterometer (Europe)
AVHRR/3	Advance Very High Resolution Radiometer (USA)
GOME-2	Global Ozone Monitoring Experiment 2 (Europe)
GRAS	GNSS Receiver for Atmospheric Sounding (Europe)
HIRS/4	High Resolution Infra-Red Sounder (USA)
IASI	Infra-Red Atmospheric Sounder Interferometer (Europe)
MHS	Microwave Humidity Sounder (Europe)
SARP-3	Search And Rescue Processor (SARP-3)
SARR	Search And Rescue Repeater
SEM	Space Environment Monitor (USA)

One concern with regard to accessing this platform over the Antarctic is data transmission encryption and data denial (See section on Data Encryption). MetOp-2 will indeed be launched first in the series, followed by MetOp-1. MetOp-2 will be renamed METOP-A after launch.

Platform	Launch Date
METOP-1	2010
METOP-2	June 2006
METOP-3	2015

National Polar-orbiting Operational Environmental Satellite System (NPOESS)



IPO

The US next generation polar orbiting meteorological observing platform is the National Polar-orbiting Operational Environmental Satellite System (NPOESS). By combining prior US civilian and military programs, NPOESS aims to take polar orbiting observing into the next decade, with lessons learned from the DMSP, POES and EOS satellite systems as well as be a part of the International Joint Polar-orbiting System (IJPS) (See Figure 2). NPOESS will offer an advanced imaging system Visible/Infrared Imager/Radiometer Suite (VIIRS), a sounding system Crosstrack Infrared Sounder—atmospheric moisture (CrIS), and a microwave sounding system Advanced Technology Microwave Sounder (ATMS), among other instruments. One major concern for the Antarctic is that the imaging instrument currently planned for NPOESS does not have any partly absorptive channels, especially the water vapor channel. Water vapor channel data, at high resolution, had not been available on polar orbiting platforms until the launch of the Terra satellite in the EOS satellite program. It is expected that by the third NPOESS satellite a water vapor channel will be available. NPOESS system will offer an L-band (low rate data or LRD) direct broadcast service as well as an X-band (high rate data or HRD) direct broadcast service.

<u>Sensors</u>	<u>Description</u>
VIIRS	Visible/Infrared Imager/Radiometer Suite
CMIS	Conical Microwave Imager/Sounder
CrIS	Crosstrack Infrared Sounder
GPSOS	Global Positioning System Occultation Sensor
OMPS	Ozone Mapping and Profiler Suite

SESS	Space Environment Sensor Suite
APS	Aerosol Polarimeter Sensor
ATMS	Advanced Technology Microwave Sounder (NASA)
ADCS	Data Collection System (Service Argos)
ERBS	Earth Radiation Budget Sensor
SARSAT	Search and Rescue Satellite Aided Tracking
TSIS	Total Solar Irradiance Sensor
RADAR	Radar Altimeter

As an important aspect of this program, there are plans to launch an NPOESS Preparatory Project satellite, allowing all who are involved in polar orbiting meteorological satellites - users to developers - the chance to test out and learn about this new system.

As of this writing, the NPOESS program is suffering from budget overruns, and is currently under review by the Nunn-McCurdy commission. The launch of the satellite series has been delayed for roughly two years or more, pending.

Platform	Launch Date
-----	-----
NPP	2008 or later
NPOESS-1	2012

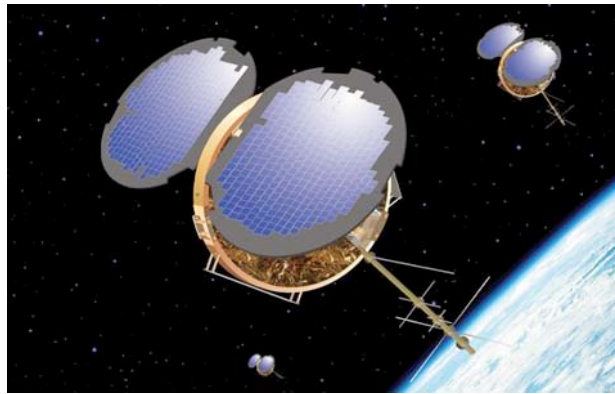
Other Polar Orbiting Satellites



NASA

Many other satellites are due to be launched over the next several years, others have already been launched as well. Many of these listed below have some impacts on Antarctic meteorology, with regard to forecasting, observing, and research. Here is the list of some of these satellites in the categories of GPS/MET, Environmental and other noteworthy satellite systems.

Global Positioning System/Meteorology Satellites (GPS/MET)



COSMIC

Currently, there are three satellites, SAC-C, CHAMP, and GRACE that are already in orbit that could offer the ability to profile temperature and moisture using the global positioning system instrumentation. A future and much more definitive satellite system to offer this ability is the COSMIC satellite series. These satellites will offer the ability to provide tens, if not hundreds of profiles of temperature and moisture around and over the Antarctic.

- Gravity Recovery and Climate (GRACE)- in orbit (USA/Germany/Russian Federation)
- Satellite de Aplicaciones Cientificas-C (SAC-C) - in orbit (Argentina/USA/Italy/France/Brazil)
- CHALLENGING Minisatellite Payload (CHAMP) - in orbit (Germany)
- Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) – Planned launch April 2006/TBD (USA/Taiwan)

Platform	Launch Date
----- FORMOSAT-3/COSMIC	----- April 2006/TBD

Other Environmental Satellite Systems



Colorado State University

There are a host of other polar orbiting satellites that may offer some information that could be of value to weather forecasting operations in the Antarctic. However, often the data are not available, costly to process, or unable to be received as a direct broadcast. Some of those satellites with the country sponsoring them are:

- Envisat: Launched 1 March 2002 with Advanced Synthetic Aperture Radar (ASAR), Medium Resolution Imaging Spectrometer (MERIS), Advanced Along-Track Scanning Radiometer (AATSR), Microwave Radiometer (MWR), etc. among other instruments (Europe/ESA)
- QuikScat: Launched 19 June 1999 Scatterometer sensor satellite offering ocean surface derived winds (NASA/USA)
- ERS-1 and ERS-2: Launched 17 July 1991 (ERS-1) and 21 April 1995 (ERS-2) Synthetic Aperture Radar (SAR) and Along-Track Scanning Radiometer (ATSR), Wind scatterometer, microwave sounder, GOME, etc. (Europe/ESA)
- Coriolis/WindSat: Polarimetric microwave radiometer Launched 6 January 2003 (IPO/USA)
- ICESAT: Launched 12 January 2003 with Geoscience Laser Altimeter System (GLAS) (NASA/USA)
- ADEOS-II: Launched 16 December 2002; Failed October 24, 2003 (Japan/USA/NASA – Carried new Argos/2 system in addition to a microwave radiometer (AMSR), a scatterometer (SeaWinds), an imager (GLI), a limb sounder (IILAS-II) and a polarimetric visible and infrared radiometer (POLDER))
- OceanSat-1 (IRS P4): Launched 26 May 1999 (India – Carrying Ocean Color Monitor (OCM) and a Multifrequency Scanning Microwave Radiometer (MSMR)).
- Sich 1-M: Unsuccessfully launched 24 December 2004. Satellite may be tumbling (unconfirmed). There may be plans for a Sich 2 & Sich 3 satellite series. (Ukraine)
- PARASOL: Launched successfully December 18, 2004 (France)

This is not an exhaustive list, but offers reference to some other satellites that are in operation, or were attempted. Earth resource satellites such as Radarsat, Landsat, Spot, Cryosat, Resurs, etc. are left off of these lists due to the limited meteorological applications. Below is a selective list of satellites to be launched in the future. It is interesting to note that several of these polar orbiting satellites are planned to fly in formation, specifically Aqua, Aura, Cloudsat, Calipso, OCO, and PARASOL (See Figure 3). This planned formation has been dubbed the “A-Train.” Also CLOUDSAT and CALIPSO will be launched on the same rocket.

Platform	Launch Date
-----	-----
OceanSat-2 (India)	2006/2007
Cloudsat (USA)	NET 10 April 2006 (shared launch vehicle w/ CALIPSO)
CALIPSO (USA/France)	NET 10 April 2006 (shared launch vehicle w/ Cloudsat)
OCO (USA)	September 2008
Megha-Tropique (France/India)	December 2009

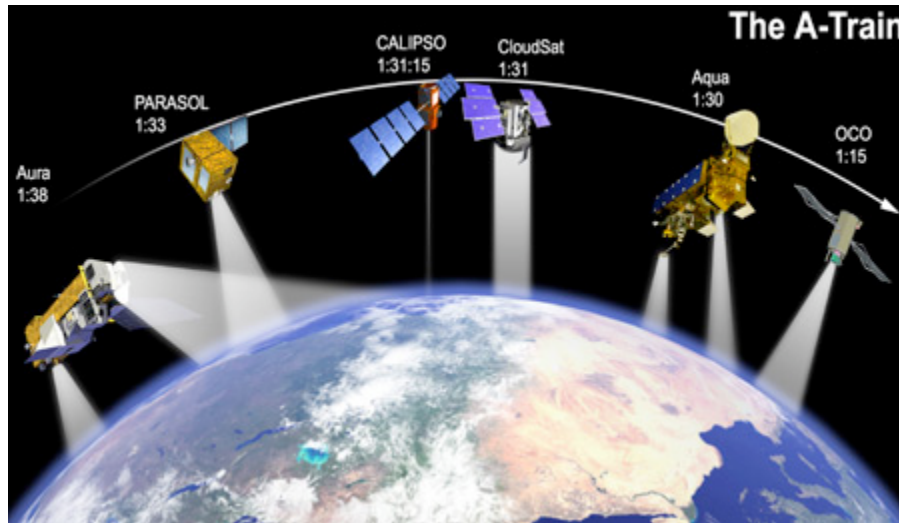
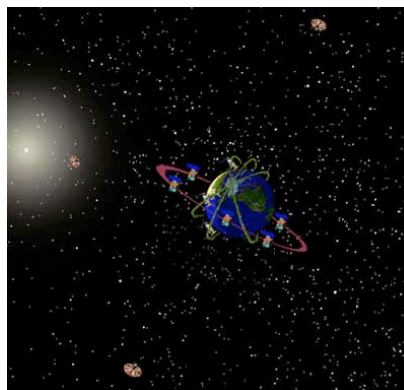


Figure 2. The near future will showcase a series of satellites flying in formation, also known as the A-Train (Courtesy of NASA).

Below is a listing of the key sensors that will be a part of the CloudSat, CALIPSO and PARASOL portion of the “A-train”:

<u>Sensors</u>	<u>Description</u>
CPR	Cloud Profiling Radar (CloudSat)
CALIOP	Cloud Aerosol Lidar with Orthogonal Polarization (CALIPSO)
IIR	Imaging Infrared Radiometer (CALIPSO)
WFC	Wide-Field Camera (CALIPSO)
POLDER	Polarization and Directionality of the Earth’s Reflectance (PARASOL)

Polar Sitter/Solar Sail



NOAA

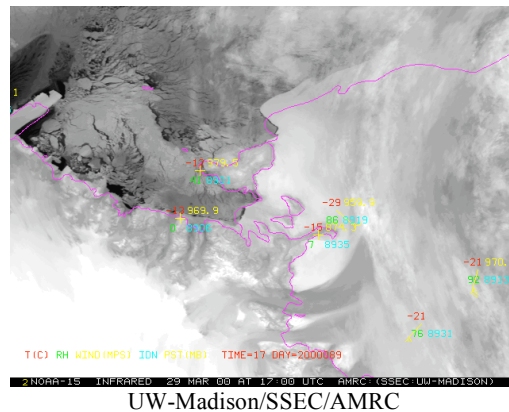
Meteorological satellites in other orbits are being considered and planned. One such satellite was to be Triana, which was proposed to orbit between the Sun and Earth at the LaGrange 1

point. Triana and its major sensor, EPIC, currently is in storage pending identification of launch flight/vehicle. Geostorm is another project (joint NOAA and United States Air Force) that had proposed to place a solar sail into an orbit that would have a mission of monitoring space weather.

Recently, NOAA has begun the investigation of placing a solar sail satellite into a polar stationary orbit (artificial LaGrange orbit or ALO), primarily for inter-satellite communications (McInnis and Mulligan, 2003). Of course, this orbit offers the exciting chance to image the Antarctic directly and often as well as give the opportunity to have improved communications (both inter-satellite and with the ground). Currently, the most active solar sail activities are private efforts, although there are efforts underway in the government sector as well. Other solar sail efforts are underway, including efforts in Germany and work in Japan. Unfortunately efforts by the Planetary Society, which would have been the first to launch a demonstration satellite, named COSMOS, launched from a Russian submarine platform, failed after launch in 2005. Another casting of the Triana, the DSCOVER or Deep Space Climate Observing mission, which would have placed the Triana sensors at L1 has been canceled by NASA.

Meteorological Satellite Usage in the USAP

Current Uses and Applications



The USAP has used POES and DMSP satellite data for over 25 years. These satellites have been the staples for weather forecasting and research applications during this period. It is worthwhile to emphasize the high importance and value that these two satellite platforms have to weather forecasting activities for the USAP. Beginning in 1992, the Antarctic composites generated at the University of Wisconsin offered a critical supplement. Additionally during the 1990s, the GMS satellite observations had been used for some years as yet another supplement to the mainstay polar orbiting satellites. The major use of the data from each of these sources has been limited to just viewing the imagery for weather forecasting applications (Lazzara et al. 2003a). Some derived products have been utilized (i.e. sea ice depiction). This is beginning to change, however, as the USAP is embarking on the beginning of a new era in Antarctic meteorology. The

Antarctic Mesoscale Prediction System (AMPS) is making significant progress in Antarctic numerical weather prediction and is beginning to utilize satellite-derived observations (Jordan et al. pers. comms. 2004). The Antarctic Regional Interaction Meteorology Experiment (A-RIME – formerly the Ross Island Meteorology Experiment) has plans to begin its program. It will investigate a variety of Antarctic meteorological phenomena leading toward improved applications of satellite observations (Parish and Bromwich, 2002). Finally, the installation of a dual X-and L-band satellite receiving system at McMurdo for joint operational and research use will be the means to acquire and apply advanced satellite observations for the benefit of both forecasters and researchers at the same time (Lazzara and Stearns, 2004).

Current Limitations

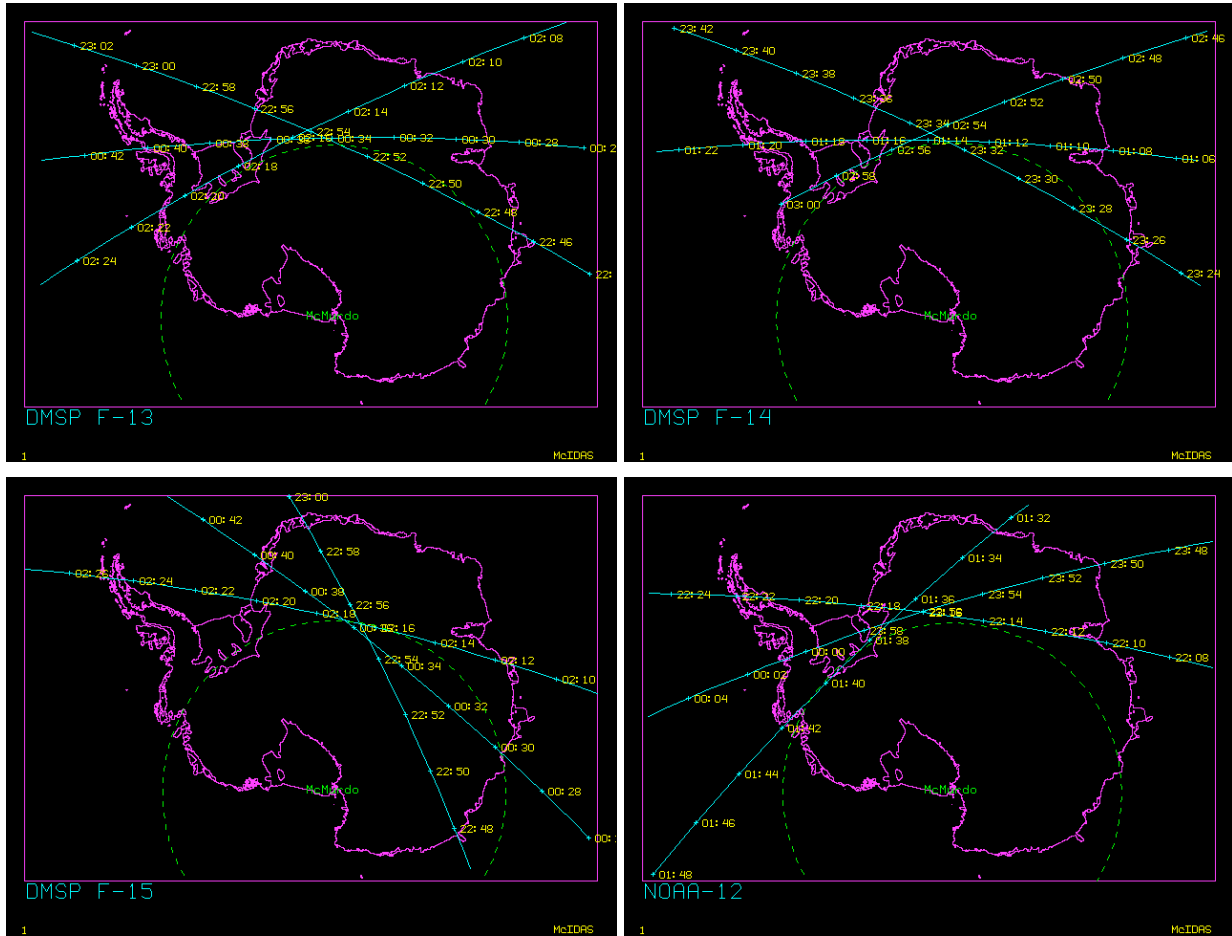
The “Data Gap”

The biggest issue that affects the use of polar orbiting data for forecasting operations is the coverage limitations during the operational day at McMurdo Station, Antarctica, and the headquarters for USAP forecasting activities. Before the launch of NOAA-16 and NOAA-17, the orbital drift of older NOAA satellites and the limits of DMSP satellites to morning orbits only resulted in a significant gap in coverage over the McMurdo Station region, impacting weather forecasting operations at the nearby airfields for aircraft landing forecasts. Since the launch of the NOAA-16 and NOAA-17 satellites this gap has been reduced – as much as can be practically accomplished given the limitations placed on sun-synchronous polar orbiting slots for satellites as imposed by operators’ climatological, operational and operating/maintenance requirements. Use of other satellites (e.g. Aqua and Terra) by the USAP with new X-band capabilities will allow the USAP to have more access to other satellites that could keep this gap at a minimum for the forecasting efforts.

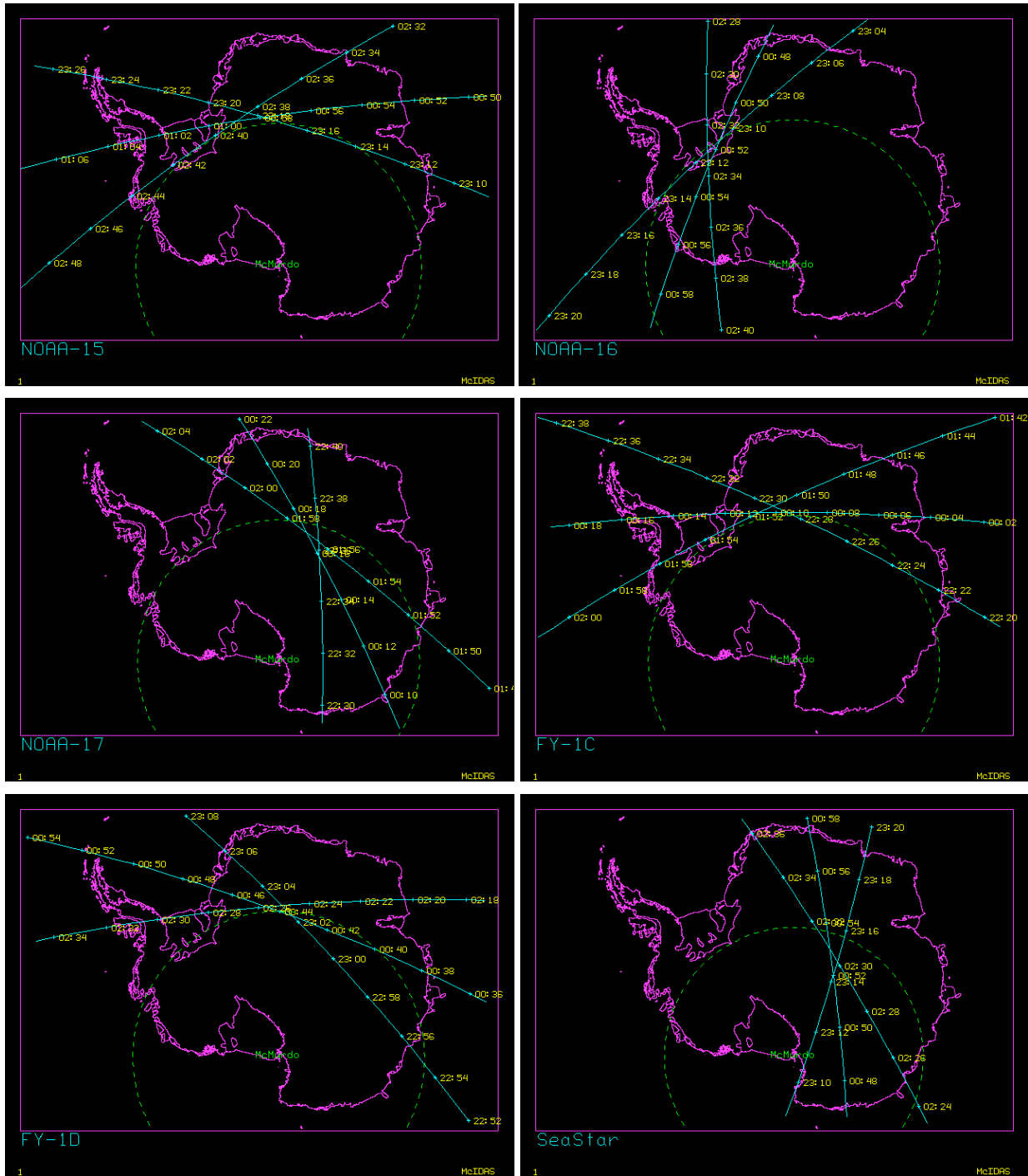
Satellite Orbital Analysis: Over-flight Tracks

Below are depictions of several meteorological satellites and their over-flight tracks during the peak of the data gap period from 22 UTC to 3 UTC from an example day during WINFLY (25-26 August 2004). As can be seen visually, several satellites offer no coverage for McMurdo Station and the Ross Island/Ross Ice Shelf/Ross Sea region, including but not limited to DMSP F-13, DMSP F-14, NOAA-12, NOAA-15, FY-1C and FY-1D. There are some satellites that offer some help of varying degrees, such as DMSP F-15, NOAA-16, NOAA-17, OceanSat-1, Aqua, Terra, Envisat and Aura. Other satellites such as Quikscat offer the best help, but this platform does not offer the right sensors to benefit weather forecast operations (as well as the inability of McMurdo Station to receive this data and process it for science use in real-time on station). Thus the SeaStar (SeaWiFS) satellite is the only platform that assists with this problem. It would appear that due to the preference for current and future polar orbiting satellites to be in fixed equatorial cross-times, there will be no polar orbiting solution available to close this data gap completely. Given this, it is clear the launch and availability of NOAA-16 and NOAA-17 along with DMSP F-15 and SeaWiFS, all of which are available at McMurdo Station clearly

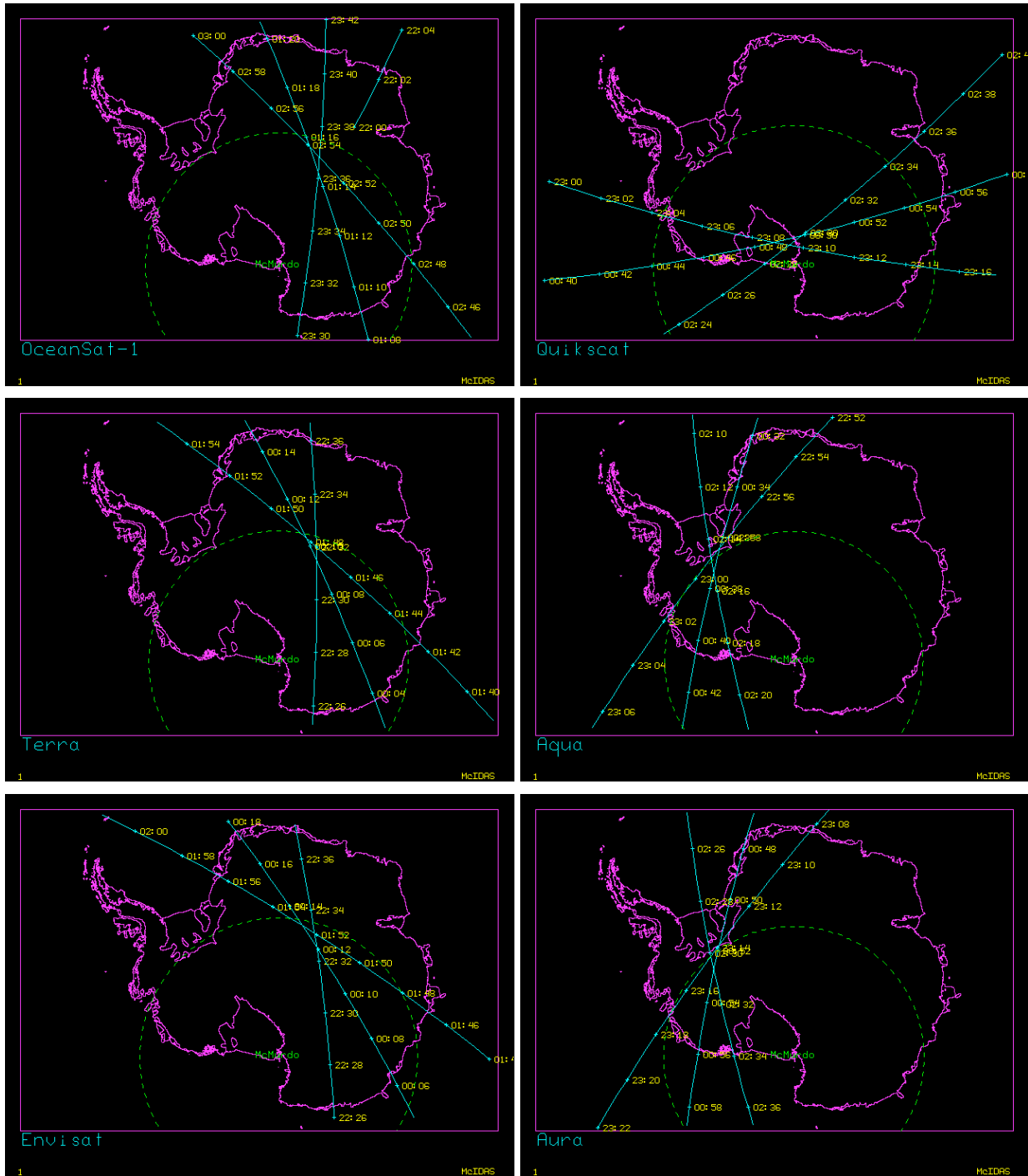
have been of great help to forecasting efforts. The new Dual L-band/X-band satellite reception system adds Terra and Aqua overpasses which will support this effort. It is not clear that this new system will receive OceanSat-1 or Aura data (and Aura's sensor suite, even if it is directly broadcast, may not have the best sensors for forecasting operations). Envisat would offer some sensors of interest, however there maybe some issues with regard to processing, encryption, and permission that would need to be worked out with Envisat's operator (ESA) for this data stream to be used.



Panel 1. This first panel displays the orbital analysis for the DMSP F-13, F-14, F-15 and NOAA-12 (listed top to bottom, right to left) satellites during McMurdo's "data gap" period of 22 UTC to 3 UTC daily.



Panel 2. This panel displays the orbital analysis for the NOAA-15, NOAA-16, NOAA-15, FY-1C, FY-1D, and SeaStar (listed top to bottom, right to left) satellites during McMurdo's "data gap" period of 22 UTC to 3 UTC daily.



Panel 3. This panel displays the orbital analysis for the OceanSat-1, Quikscat, Terra, Aqua, Envisat and Aura (listed top to bottom, right to left) satellites during McMurdo's "data gap" period of 22 UTC to 3 UTC daily.

Potential Additional Forecasting Applications

There are several applications of meteorological satellite data that could be put to use operationally that potentially offer the chance to aid and improve weather forecasting for the USAP. Two classes of applications will be discussed: those for direct use by the forecaster, and those for direct use by numerical modelers, for indirect benefit of the forecaster. In many cases, the same product or application can benefit both classes at the same time. As a note, with the update of this document, some of the activities suggested here have started to take place (Straka et al. 2006).

Cloud Drift and Water Vapor Target Winds

One of the first applications that could be put into use is deriving satellite observed winds (See Figures 4 and 5). Recently placed on the web, the Cooperative Institute for Meteorological Satellite Studies (CIMSS) has a near real-time operational ability to compute winds from a series of consecutive NOAA AVHRR, Aqua, and Terra MODIS imagery. This data maybe of great value to the forecaster for flight forecasting as well as input to the mesoscale numerical models run over the Antarctic in support of USAP operational forecasting activities. With limited radiosonde launches around the Antarctic, these winds offer a significant increase in this class of observations. Plans for the 2004-2005 operational field season included making these datasets from Terra and Aqua MODIS data from the new dual L-band/X-band system to be installed at McMurdo Station. This has taken place and data is now beginning to be utilized and distributed for the benefit of the USAP and others.

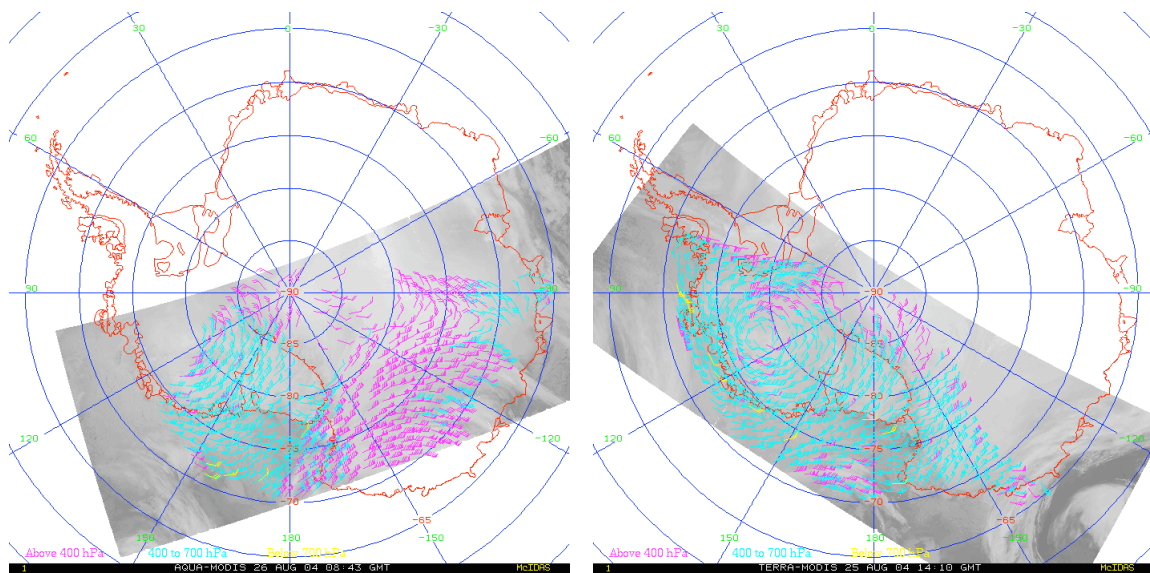


Figure 3. Sample cloud drift winds from Aqua (left) and Terra (right) depicting the wind regime over the Ross Ice Shelf region (Courtesy of J. Key and CIMSS).

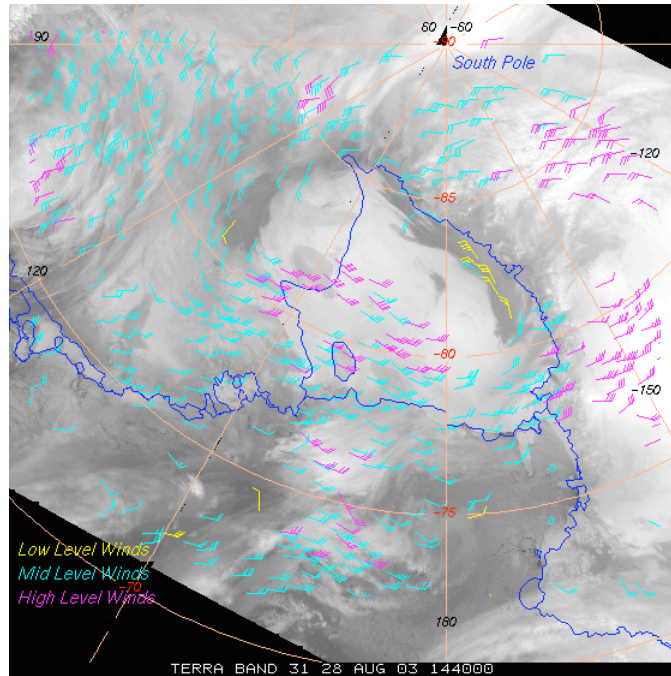


Figure 4. Another sample of satellite-derived winds, showing a closer view over the Ross Ice Shelf sector of the Antarctic (Courtesy of J. Key and CIMSS)

Cloud Detection and Cloud Properties

The ability to put cloud detection products from satellite to use may be of equal importance to forecasters, pilots, and numerical modelers alike (See Figure 6). The ability to offer pilots a depiction of where there are or are not clouds with some level of confidence is of significant value. Having mesoscale models correctly represent the cloud field allows for better forecasts of clouds and precipitation in the forecast.

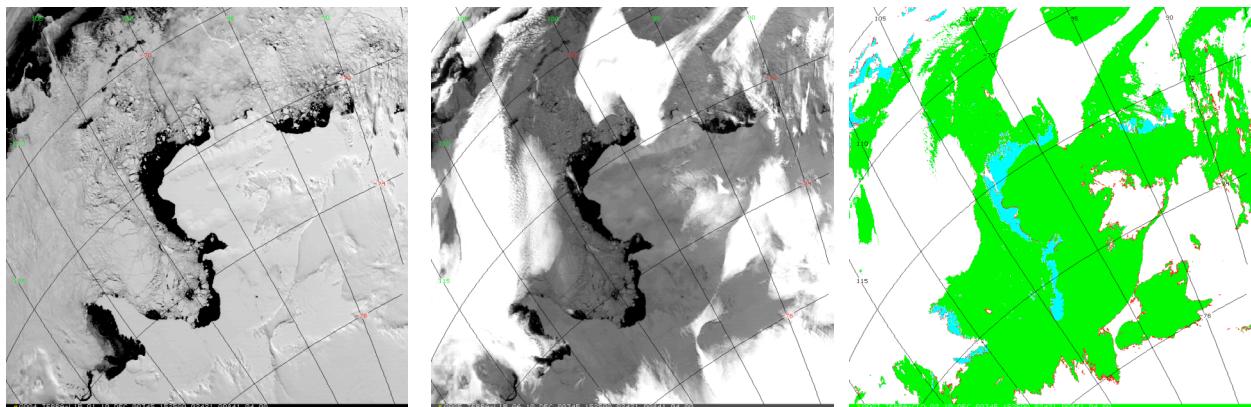


Figure 5. Examples of two channels (visible, left and infrared, center) and the cloud product (right) derived from the Terra MODIS over Pine Island Bay, Antarctica showing clear (green), cloudy (white), and perhaps open water areas (cyan) (Courtesy of R. Frey and CIMSS).

Additionally, cloud properties can also be derived from satellite sensing. Possible products include cloud top pressure, cloud phase, and total precipitable water content (See Figure 7). These products will likely have primary interest to numerical modelers, but may also be handy for forecasters, as forecast situations often call for this kind of information.

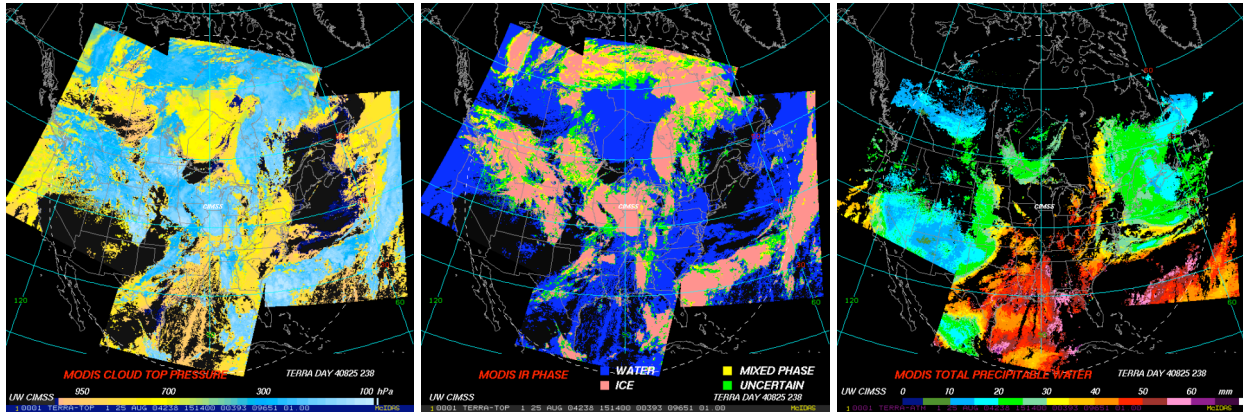


Figure 6. Examples of cloud top pressure (left), cloud phase (center), and total precipitable water (right) from Terra MODIS over the Continental United States taken at the University of Wisconsin Direct Broadcast system (Courtesy of K. Strabala and CIMSS). Colors of the display varying in meaning from product to product above.

Fog Detection

Another application is the possibility of being able to depict fog from satellite, giving forecasters aid with this number one aviation forecast problem. Efforts are currently underway to learn more about fog. It is too early to know if a fog detection method will be available from the research, but at the very least the improvement in enhancing and tracking fog may very well be possible from new satellite sensors such as MODIS over older sensors such as AVHRR.

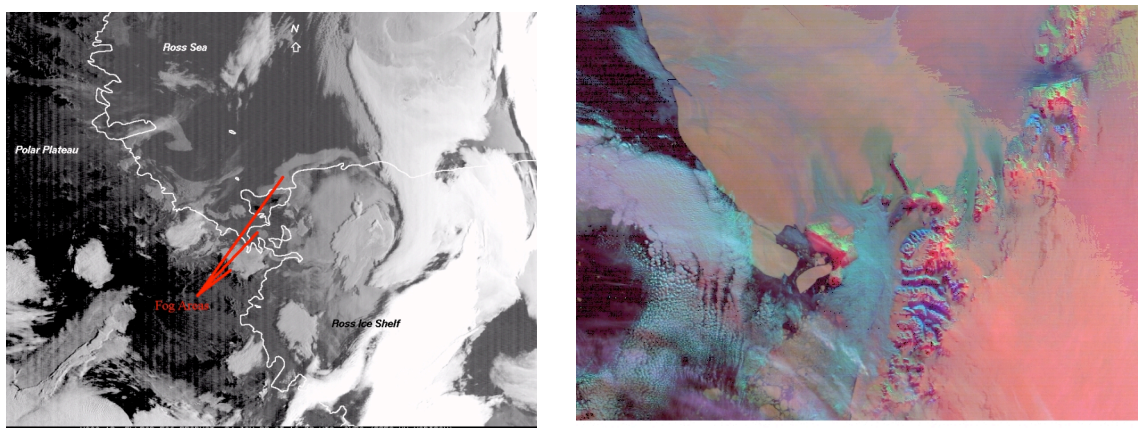


Figure 7. This display shows two separate example fogs over the Ross Island Region of Antarctica as seen on enhanced NOAA AVHRR (red pointers, left) and Terra MODIS (blue middle area, right) imagery. (Courtesy of AMRC)

Precipitation

A top problem for weather forecasters is precipitation. Microwave sensors are used in the middle and tropical latitudes to detect precipitation, and more specifically are used to estimate precipitation rates. Research on this topic in the Polar Regions faces some challenges and is in its infancy. Efforts in this area are underway for the Antarctic, and future results may offer improved information on precipitation to forecasters.

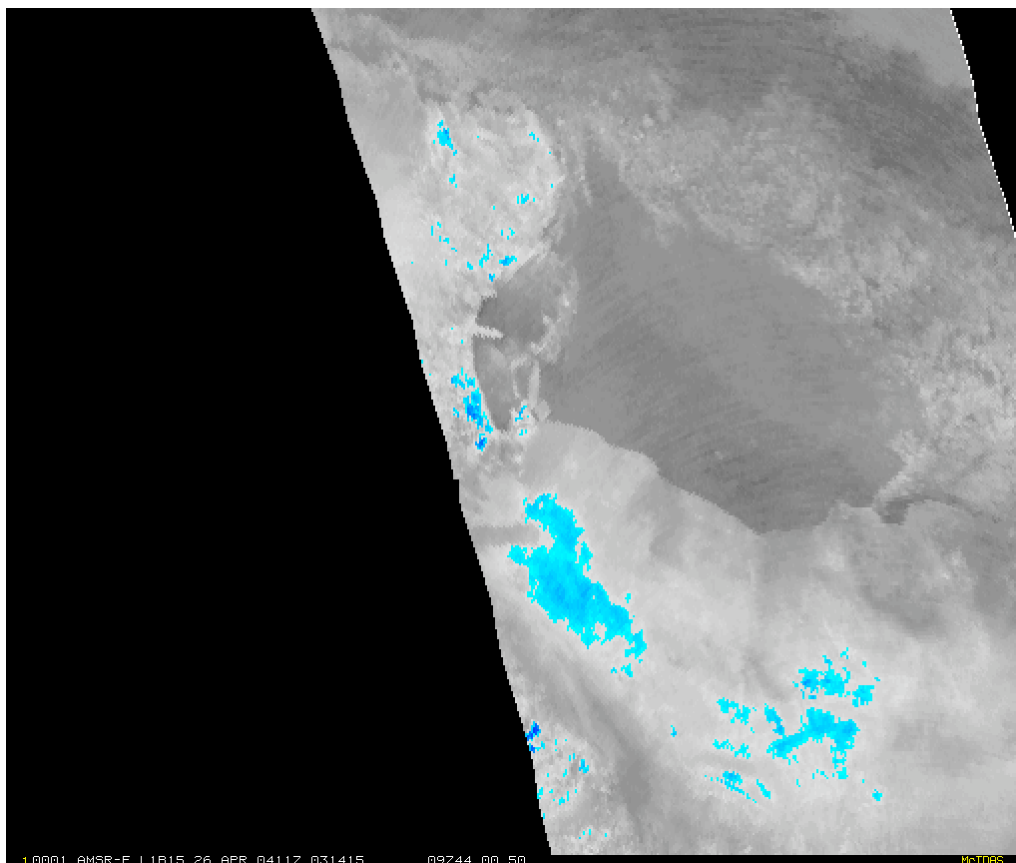


Figure 8. An example AMSR-E image over the Ross Sea and Ross Ice Shelf region of Antarctica with colder brightness temperatures enhanced in blue. Microwave information may be utilized in the future to assist with precipitation determinations (*Courtesy of S. Knuth*)

Profiles of Temperature and Moisture

A product that may benefit both the numerical modeling efforts and forecasters are the profiles of temperature and moisture from the sounder sensors available on some satellite platforms. The NOAA satellites offer the HIRS and AMSU sensors – together making up the ATOVS system. On the Aqua satellite, the combination of the AIRS, AMSU, and HSB sensors allow for the

retrieval of vertical profiles of temperature and moisture. With limited radiosonde soundings around the Antarctic, the use of the satellite for this information over much more of the Antarctic may provide key information. With the availability of direct broadcast data from Aqua, additional high-resolution profiles from the several thousand-channel AIRS sensor may provide improved profiles beyond the POES ATOVS system (See Figure 10). In any case, both systems offer information that is currently under utilized in the forecasting arena. In addition, in the near future as a complement to these systems, COSMIC will start to come on-line and offer profiles as well. The combination of the two may prove to be powerful information throughout the Antarctic and adjacent waters region.

Polar Inversions

High sensitivity to inversion thickness:

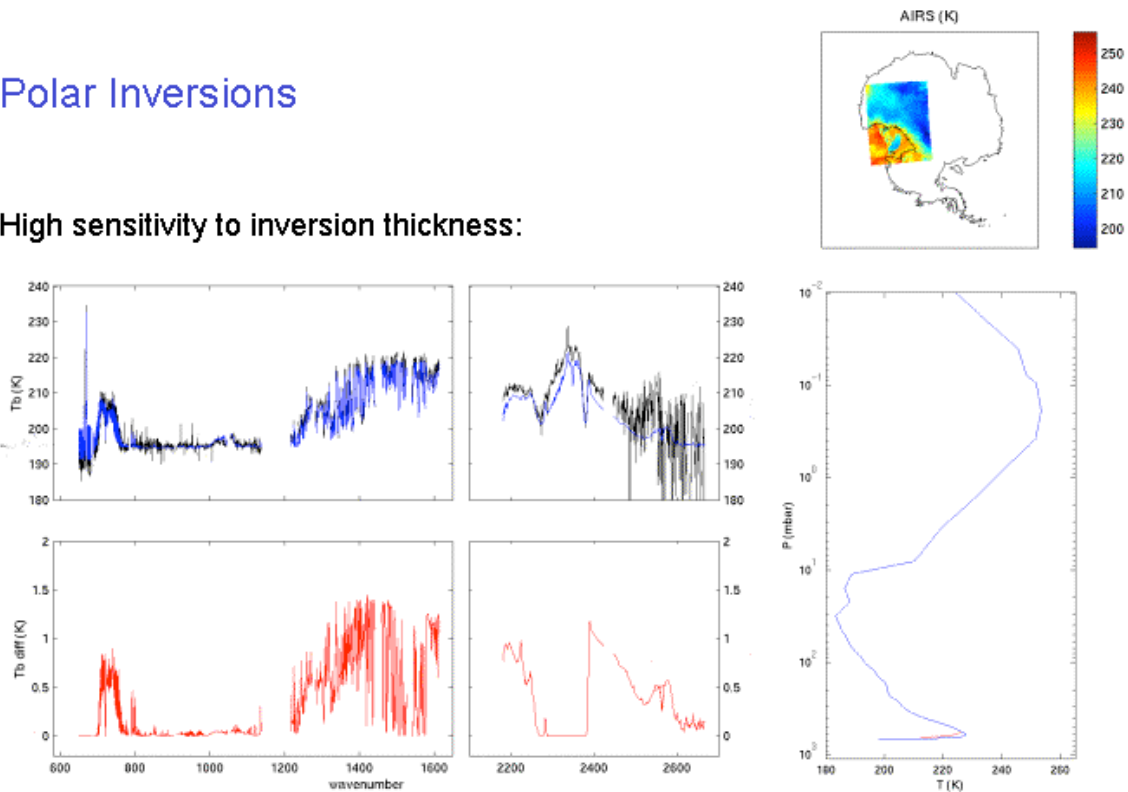


Figure 9. Sample displays of spectra, profile, and image from the AIRS instrument on Aqua (Courtesy of David Tobin)

Sea Ice Depiction and Iceberg Monitoring

Sea ice and icebergs can pose problems for USAP shipping interests - both supply and research vessels. Since the 2001-2002 field season, the icebergs outside McMurdo Sound have changed the sea ice dynamics and ocean current flow in the Western Ross Sea. Hence, now more than ever, sea ice and iceberg monitoring has become an important concern for ship routing and forecasting. Existing sensors such as the SSM/I on the DMSP (see Figure 11) satellite system as

well as new sensors on the research satellites, such as AMRS-E on Aqua, offer improved monitoring. In addition to microwave sensors, SAR and scatterometer sensor capabilities offer an all weather means to monitor sea ice, although these datasets are not always available in real-time to USAP forecasters.

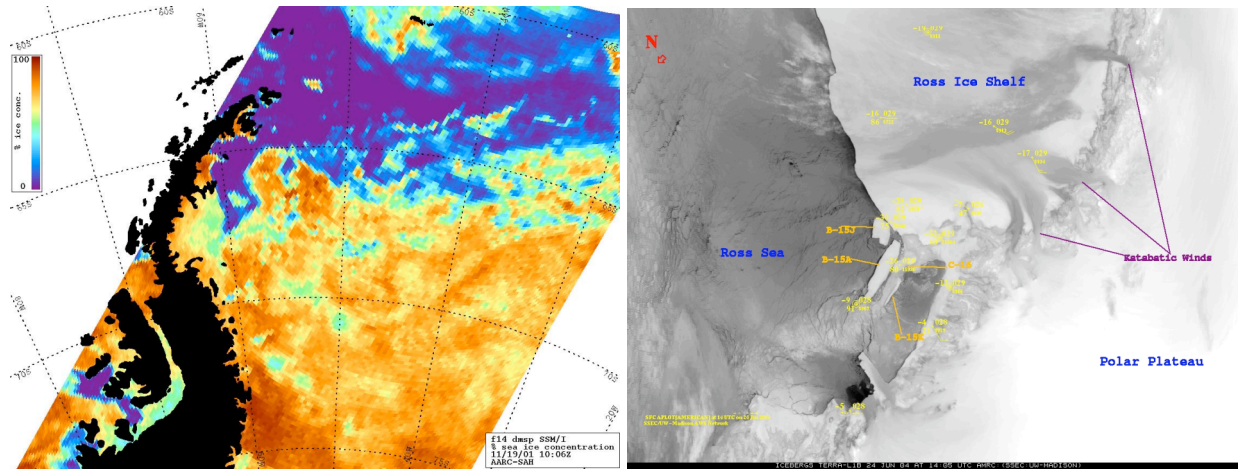


Figure 10. Sample sea-ice depiction products using DMSP SSM/I sensor with oranges and reds denoting high concentrations of sea-ice, and blues and purples showing lower concentrations of sea-ice (left, *courtesy of AARC*) and iceberg monitoring products using Terra MODIS (right, *courtesy of AMRC*).

Spectral Channel Combinations

A seemingly simple, yet powerful application of satellite data are the combinations of the various spectral channels to enhance features in the data that are of keen interest to forecasters. For example, as depicted in Figure 12, the combination of three channels can clearly enhance cloud features, and give indications of the height of the clouds (low, middle, high), based on color, shading and depiction. Some of the depictions are only possible with available sunlight, but other combinations can be done with infrared channels only as the figure denotes. Other multi-channel and “super-channel” combinations are being researched actively as newer sensors such as AIRS offer thousands of channels and require the deluge of data to be converted into a more easily used and understood presentation.

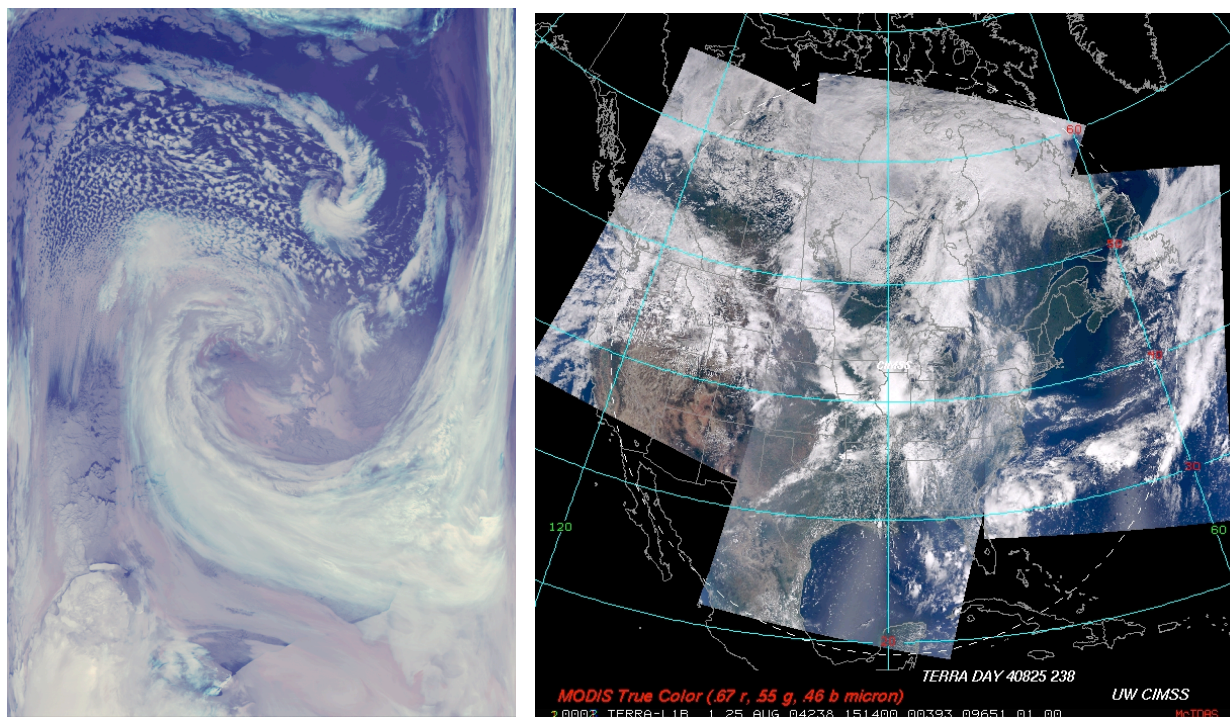


Figure 11 Two examples of three channel combinations from NOAA-16 AVHRR using the shortwave, window and longwave infrared channels (left), and Terra MODIS using the three natural color visible channels (right, *courtesy of K. Strabala and CIMSS*) Both of these combinations enhance features in the imagery.

Potential Satellites to Benefit USAP Operations

In the short run, it is clear that the USAP will continue to need to utilize the traditional polar orbiting satellite platforms (NOAA and DMSP). Meanwhile, in the coming years, the next generation polar orbiting satellites (Terra, Aqua, etc.) will need to be integrated into the forecast office. The learning curve to work with these new satellites is not trivial. Lessons and experience with these next generation satellites will prepare the USAP for the use of future operational polar orbiting platforms (NPOESS, MetOp, etc.).

In the mid-term, the USAP may benefit from the ability to acquire and utilize other satellites such as OceanSat or FY-1 series satellites. In the long run, the polar stationary satellite platform offers the most promise. If the platform becomes available, it gives the Antarctic its first “geostationary” like observing, with routine hourly, half-hourly or even rapid-scan coverage of a large portion of the Antarctic (Lazzara, 2004).

Each of these satellite systems offers huge gains in capability in terms of improved spatial resolution, larger spectral depth and greater temporal coverage. These are the capabilities that will place Antarctic meteorology in the best position possible with the assets available or soon to be available in space.

Data Encryption

The availability of satellite observations over the years has encountered some issues with availability and data encryption. For many years, some satellite systems have been and currently are encrypted, including DMSP, SeaStar/SeaWiFS and INSAT. DMSP observations have been unencrypted from 60 degrees South to 90 degrees South, in respect of the Antarctic treaty, providing an important source of weather satellite information for the Antarctic, and adjacent waters. With SeaStar/SeaWiFS being a public/private satellite system, NASA has arranged for data to be freely available and unencrypted for registered users who have a science research project use for the data stream, as is the case for the US Antarctic Program, although this service has come to an end. Other satellite systems have in recent years been added to this list, such as the Meteosat satellite series. These data are not all encrypted due to international treaty. Data every six hours is available in real-time without encryption. Other rules on redistribution of Meteosat data also apply, depending on availability. Redistribution restrictions have also in the past been imposed on GMS data as well.

Recently, new partial data encryption policies have been announced on the MetOp and NPOESS future satellite platforms. For the MetOp satellite series, the sensors will be encrypted all of the time, however decryption keys will be provided. Data denial will be done by EUMETSAT when asked to do so by the US Government (ESA, 2006). It also appears that DCS (Service ARGOS) and all Search and Rescue (SAR) capabilities will never be encrypted. For NPOESS, the policy will be similar. With the Integrated Program Office (IPO) planning to offer a required software and key registration for anyone to acquire and use NPOESS data streams, the encryption will be tiered. It is expected that during nominal operation, all NPOESS sensors and data streams will be available freely. However, at the request of the US Government, encryption can be imposed over a geographical region, by sensor, and/or by registered user. Like MetOp, it is expected that DCS (Service ARGOS), and all SAR capabilities will never be encrypted.

In general, there have been concerns over the limited availability of some satellite systems observations. This is a part of a larger discussion that the World Meteorological Organization (WMO) has taken up in the past, and specifically what is widely known as WMO Resolution number 40. Although this resolution has much of the middle and tropical latitudes in mind, it is hoped that the Antarctic Treaty, and the free exchange and availability of data will dominate for the Antarctic and adjacent waters.

Frequency Spectrum Threats

In recent years, the portions of the electromagnetic spectrum that are used or may be used in the future for meteorological remote sensing from satellite platform have been under attack. As it turns out, not all of the likely frequencies that have or may be of important value to meteorological satellite observations are completely protected by international agreement, and are reserved for passive remote sensing. Hence, some of these frequencies have been requested by other industries for commercial and consumer use, such as for car radar systems which are under development (Rochard, 2004). Currently this threat impacts some of the microwave portion of the spectrum (near 24 Ghz), as well as some of the frequencies used for satellite data

transmission. This threat will likely grow. If current and future research efforts reveal important applications in these threatened regions of the spectrum, they may suffer from debilitating interference from other uses. Hence, it is important for the USAP, and more formally, the NSF to encourage that these unprotected bands become protected by international agreement and reserved for remote sensing applications and Earth discovery.

Summary and Considerations

Several key findings from this report can be summarized as follows:

- Review of the status of current and future meteorological and related satellites.
- The USAP forecast operations currently benefit greatly from meteorological satellites.
- Meteorological satellite observations and products over the Antarctic have to be put to increased use in numerical modeling efforts. This effort should be continued and increased especially for those observations and products that positively impact the numerical forecast output. Derived products from satellite observations not only are input for numerical modeling efforts but also must be available for direct use by weather forecasters.
- The USAP is starting to become active in acquiring new data streams of satellite data (i.e. X-band polar orbiting platforms). This effort is applauded and must continue with backup and additional systems for reliability and increased acquisition.
- The USAP must strongly consider the polar stationary satellite, as a long-term solution to its meteorological satellite and possibly communications needs. If such a platform becomes available, it offers the chance to nearly eliminate the data gap. It also offers a geostationary like set of routine and more frequently available observations to forecasters.
- The USAP and NSF have a duty to inform satellite-operating agencies such as NOAA, the Department of Defense, and NASA of its support requirements for operations and research. The USAP has, from an operational point of view, articulated its meteorological satellite needs to satellite operator agency NOAA in 2002 (Cayette, 2002). It is important for the USAP to continue to communicate its needs, both operational and research, to NOAA and to the other important satellite agencies named above as well as partnership agencies such as the IPO. This needs to be a done in a routine, regular fashion (annually perhaps).

There is no question that there are some issues that must be considered in facing the future of Antarctic operational satellite meteorology. Some of these limiting issues must be kept in mind for any future Antarctic meteorological satellite activities:

- Limited ground receiving abilities
- Processing needs on station
- High data volume connectivity for return to the mid-latitudes for supporting use.
- Satellite coverage and data gap issues
- Training and education along with operational integration

- Funding to solve these problems and meet goals as well as maintain an active research, development and operational program.
- Data encryption issues
- Threats to the frequency spectrum

It is hoped that this report will serve to aid the USAP with these important issues.

Acknowledgements

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On-line Resources

This document was almost completely created using information available via Internet from official and unofficial sources. In some cases, some of the information available, especially launch dates, conflicts with other information. The author made the best assessment of the information and sources of information in compiling this report. Due to the diversity of information and time limitations, a limited set of explicit references (see above) have been made with the text. However, a list of web sites is given below that were the major sources for much of the information contained within this report. It is important to note that this report, especially the future launch dates and status of operating satellites, is subject to change. Within three to six months the contents of this report is apt to be somewhat outdated.

United States Antarctic Program Meteorological/Satellite Data sites:

<http://amrc.ssec.wisc.edu/>

<http://arcane.ucsd.edu/>

<http://nsidc.org/usadcc/>

Japanese Meteorological Agency (JMA):

<http://www.kishou.go.jp/english/index.html>

http://mscweb.kishou.go.jp/general/future_plan/index.htm

<http://mscweb.kishou.go.jp>

Russian Federation:

<http://sputnik.infospace.ru/>

http://sputnik.infospace.ru/goms/engl/goms_e.htm

Chinese Meteorological Agency (CMA):

<http://nsmc.cma.gov.cn/indexe.html>

<http://www.cma.gov.cn/ywwz/constitute/nsmc.php>

<http://nsmc.cma.gov.cn/fy2e.html>

Australian Bureau of Meteorology (ABOM):

<http://www.bom.gov.au/>

<http://www.bom.gov.au/sat/MTSAT/MTSAT.shtml>

<http://www.bom.gov.au/sat/Othersat/othersats.shtml>

United States/NOAA/NASA:

<http://www.noaa.gov>

<http://www.nasa.gov>

<http://noaasis.noaa.gov/NOAASIS/ml/launch.html>

<http://www.oso.noaa.gov/operation/index.htm>

<http://www.oso.noaa.gov/goesstatus/>

<http://www.oso.noaa.gov/poesstatus/>

<http://www.ipo.noaa.gov>

<http://www.jpl.nasa.gov/calendar/calendar.html>
<http://rsd.gsfc.nasa.gov/goes>
http://poes2.gsfc.nasa.gov/campaign/campaign_home.htm
<http://liftoff.msfc.nasa.gov/RealTime/JTrack/3d/JTrack3d.html>
<http://nssdc.gsfc.nasa.gov/nmc/sc-query.html>

India Meteorological Department (IMD)/ Indian Space Research Organization (ISRO):

<http://www.isro.org/>
<http://www.imd.ernet.in/>
<http://www.isro.org/programmes.htm>:
<http://www.isro.org/insat3e/pg1.html>

EUMETSAT/ESA:

<http://www.eumetsat.de/>
<http://www.esa.int/>
http://www.esa.int/export/esaME/ESAPY1094UC_index_0.html
http://www.esa.int/export/esaME/ESAMG1094UC_index_0.htm
http://www.eumetsat.int/idcplg?IdcService=SS_GET_PAGE&ssDocName=005264&l=en&ssTargetNodeId=114

France/CNES:

<http://smc.cnes.fr/PARASOL/index.htm>

Canadian Space Agency:

http://www.space.gc.ca/asc/eng/media/press_room/news_releases/2004/040206.asp

Taiwan:

<http://www.nspo.gov.tw/e50/home/index.html>
<http://www.nspo.gov.tw/e50/home/index.html>

Miscellaneous:

<http://fas.org/spp/guide/china/earth/index.html>
<http://fas.org/spp/index.html>
<http://www.teamencounter.com/>
<http://groups.yahoo.com/group/weather-satellite-reports/>
http://www.itc.nl/research/products/sensordb/Launch_Schedule.aspx
<http://www.satsignal.net>
<http://celestrak.com/>
<http://www.satelliteonthenet.co.uk/launch.html>
<http://pages.ivillage.com/spacehorizons/id23.html>
<http://www.spaceflightnow.com/tracking/index.html>
http://www.boeing.com/defense-space/space/bss/factsheets/601/goes_nopq/goes_nopq.html
<http://www.astronautix.com/craft/insat3.htm>
http://www.spaceandtech.com/spacedata/logs/2002/2002-043a_metsat-1_sumpub.shtml
http://www.tbs-satellite.com/tse/online/mis_meteo_geo.html

http://www.tbs-satellite.com/tse/online/mis_meteo_defilement.html

http://www.allmetsat.com/en/weather_satellites.html

<http://www.sinodefence.com/space/spacecraft/fy1.asp>

<http://www.solidgoldman.com/DMSP.Sensor.Ste.html>

<http://www.designation-systems.net/dusrm/app3/s-1.html>

Satellite Sensor Band/Channel Listings

As a compliment to this report, the following on-line resource offers a good listing of several satellite sensor systems' bands or channels offerings.

http://www.ssec.wisc.edu/mcidas/doc/users_guide/2005/app_d-1.html#16239

Appendix A: Memo to NOAA/NESDIS November 15, 2005

Benefits Of A South American/Southern Hemisphere Dedicated GOES Mission For The United States Antarctic Program And Possible Contributions To The International Polar Year

Recommendations to the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS)

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Abstract

Recent consideration of a Geostationary Operational Environmental Satellite (GOES) mission, likely GOES-10, dedicated for the remote sensing needs for South America and the Southern Hemisphere, would also have benefits for the polar regions as well. This essay outlines how such a mission may have benefits for the United States Antarctic Program (USAP), specifically the Antarctic satellite composite project at the University of Wisconsin, as well as being a contribution to the International Polar Year (IPY).

GOES and Antarctic Composites Satellite images

For over 13 years, the Antarctic Meteorological Research Center (AMRC) has been funded by the National Science Foundation's (NSF) Office of Polar Program (OPP) to generate a mosaic of satellite observations centered on the Antarctic continent and adjacent Southern Ocean (Lazzara et al. 2003a, Lazzara et al. 2003b, and Stearns et al. 2003). The resulting infrared (~11 microns) composites (Figure 1) cover a significant portion of the Southern Hemisphere using a combination of both geostationary and polar orbiting satellites and are made at a nominal resolution of five kilometers. The AMRC also makes composites in additional spectral channels such as water vapor (~6.7 microns) and has begun to experiment with visible channel (~0.6 microns) (AMRC, 2005). In the near future, additional channels will be created such as short wave and long wave infrared, with the advent of those channels being common among a sufficient number of the base satellites used in the composites. However, these composites are only generated every three hours, meant to coincide with the availability of the GOES West and GOES East full disk imagery. The prospect of having a GOES mission dedicated to imaging operations in the Southern Hemisphere with a primary objective of improved imaging for the South American continent is very beneficial to the AMRC's activities. This GOES mission would have secondary benefits for these composites, especially if the imaging schedule and coverage of the Southern Hemisphere missions will be more frequent with full disk or at least full Southern Hemisphere imaging on an hourly basis or better. With improved temporal resolution of GOES imagery matching the similar temporal resolution of other geostationary satellites, Antarctic composite imagery on an hourly basis can become a reality. With a more frequent composite, synoptic systems around the Southern Ocean and

Antarctic region will be able to be tracked more closely for operational and research activities, for example, among other possible applications.

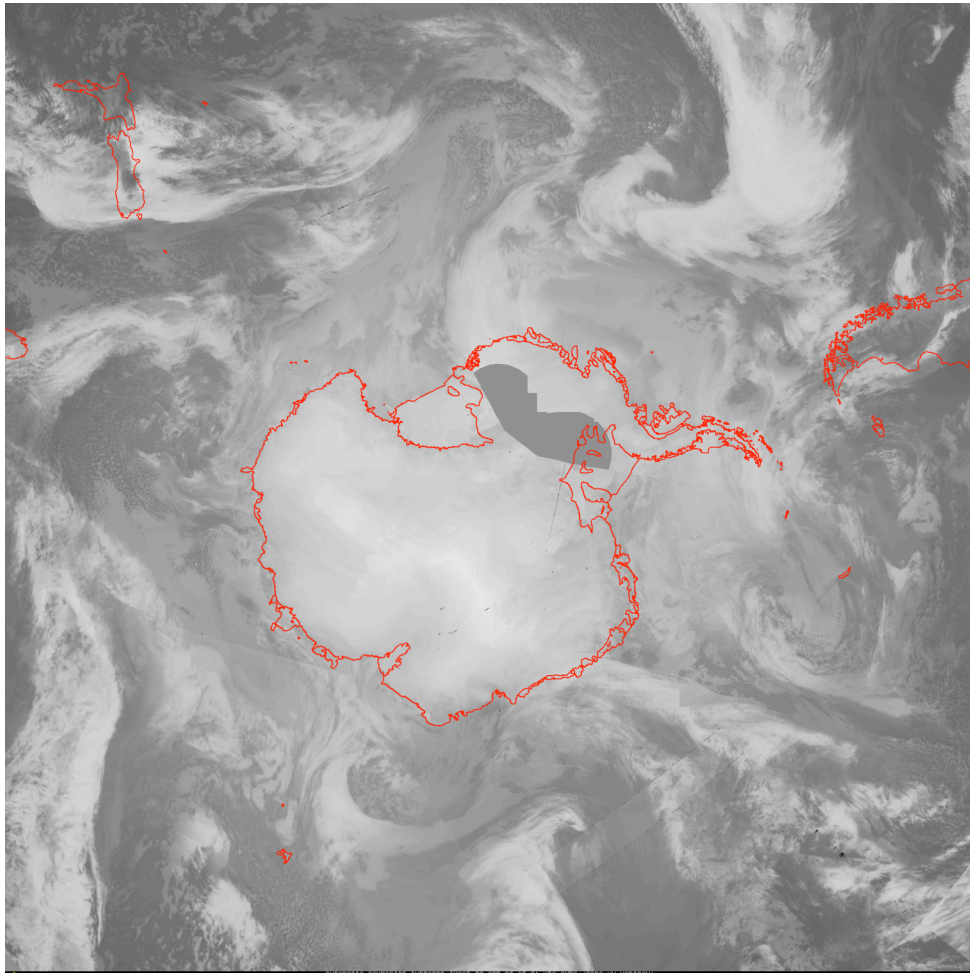


Figure 1. A sample Antarctic Composite infrared image made from a combination of GOES, Meteosat, MTSAT-IR, FY-2C, NOAA, DMSP, Terra and Aqua satellites, with data within 50 minutes of the top of the synoptic hour.

GOES for the International Polar Year

The potential time line for having a Southern Hemisphere GOES mission in place by late 2006, and with operations into 2007 and beyond, coincides with the International Polar Year (IPY) (NAS, 2004). Hence, without additional cost, NOAA is in the unique position of having this GOES mission have a secondary application – special observing that can benefit the activities of the International Polar Year. In addition to the AMRC Antarctic composite, there may be other Southern Ocean activities that may benefit from enhanced and increased satellite observations over this time frame. The IPY proposes to be an exciting time of field study, data collection and analysis. NOAA has the chance to contribute to this effort while achieving the main objective of this particular GOES mission.

Recommendations

NOAA is strongly urged to consider the following recommendations:

1. Implement the South American/Southern Hemisphere GOES mission.
2. If at all possible, have the imaging schedule for the GOES imager on this mission take full disk or at least full Southern Hemisphere imaging (from the South Pole to at least 35 degrees South latitude) on a basis more frequently than current GOES missions. Hourly imaging is ideal.
3. Strongly consider this extraordinary mission to not only meets the needs of the South American region of the Western Hemisphere, but also to potentially contribute to monitoring and observing for the International Polar Year (IPY) in the Southern Ocean region.

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Lazzara, M.A., C.R. Stearns, J.A. Staude, and S.L Knuth, 2003b: 10 years of Antarctic composite images. Conference on Polar Meteorology and Oceanography, 7th, and Joint Symposium on High-latitude Climate Variations, Hyannis, MA, 12-16 May 2003. Proceedings. Boston, MA, American Meteorological Society, Paper 9.4.

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Distribution

This document has been distributed to the following:

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Appendix B: Memo T. Schmit December 2005

Thoughts on Possible Schedules of GOES-10 near 60W

T. Schmit, NOAA/NESDIS/STAR
Madison, WI

December 2005

Introduction

To arrive at the best schedule for a GOES operated near 60W one would need to canvas the needs of the various effected countries and user communities. One method is to suggest a possible schedule based on known requests. For example the requests made at the “Direct Read-out Conferences” for more frequent GOES Imager and Sounder coverage. These scans would be independent of GOES-East rapid scan operations. In general, the operational concept of operations needs to be defined before any benefits can be finalized.

First, any operational constraints need to be defined. In this case we are assuming no special scans, etc. Other groups (WMO, AMS Satellite group, VAACs, NWS Aviation Weather Center, NWP community, etc) could be canvassed for inputs.

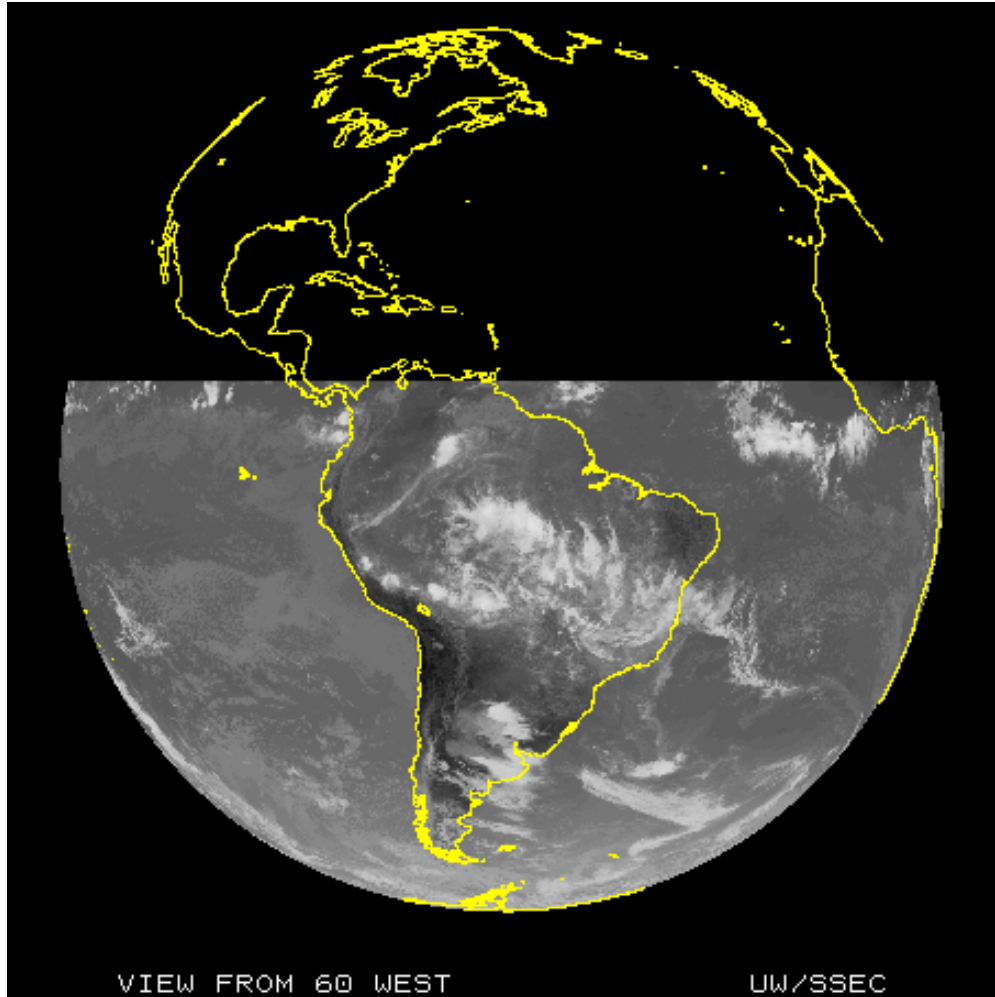
The following proposed scan scenarios are suggested as a starting point and are based on current routine coverage for the northern hemisphere and with an effort to keep the schedules simple.

Imager (15min Extended Southern Hemisphere (ESH))

For access by many countries, the Antarctic community, and other groups, the imager could scan from limb to limb at least each hour down to the South Pole region. The northern extent could be north of the equator (say 10N). [The exact extents may need to be modified if more time is needed for navigation. For example, by reducing the west-east extent.] This scan would help short-term aviation forecasts via improved satellite composites. This scan may take approximately 15 minutes.

During the other (approximately) 45 minutes of each hour, the same scans could be generated. This would provide higher time resolution images for monitoring southern hemisphere clouds, storms, fires, etc. This is similar to the routine 15 coverage over the CONUS.

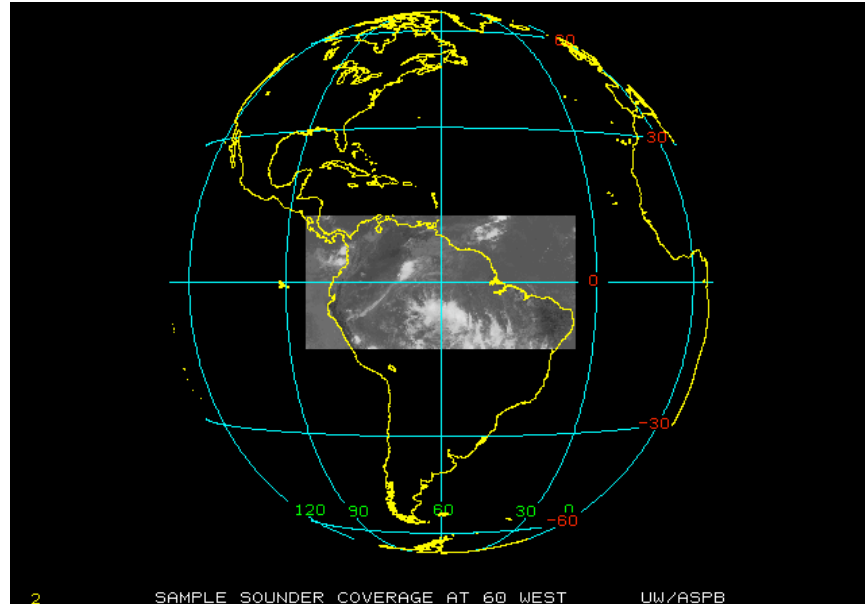
As with the GOES-East and West Imagers, consider a full disk image scan. The start times could be staggered, compared to GOES-East and West. So, these would be nominally 1:30UTC, 4:30UTC, 7:30UTC, etc. Another option would be to just scan a full disk image during the spring/fall outage times of the GOES-East imager. This can help reduce the outage times by approximately one hour (due to the differing outage times which is in turn due to the differing satellite positions).



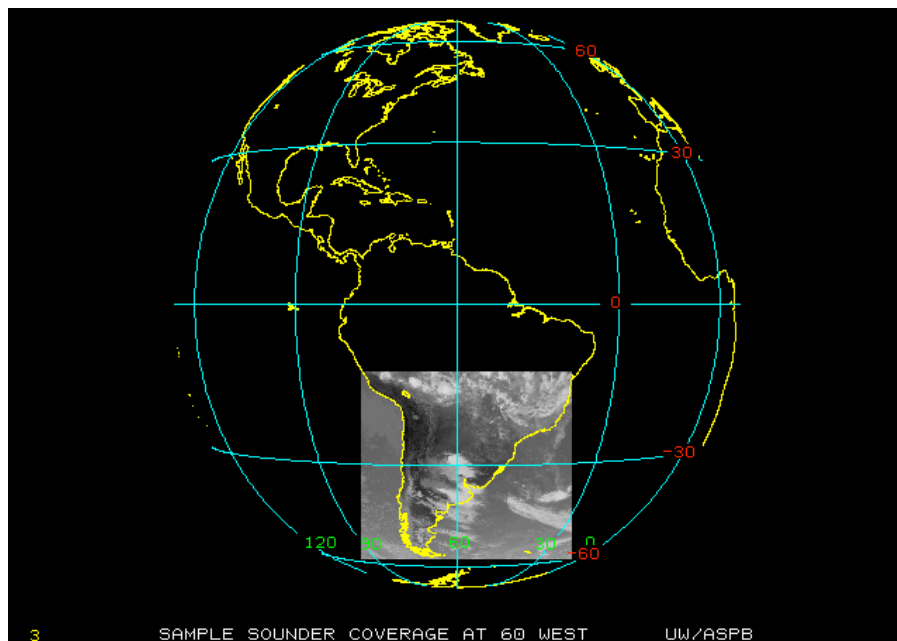
Sample image from a geostationary perspective at 60W. The northern extent is 10N and this region would take approximately 15 minutes to scan by the Imager.

Sounder (Alternating Hourly South America scans)

The GOES Sounder scans much slower than the GOES Imager. Consider alternating hourly scans centered on (0S, 60W) and (30S, 58W). This would be the first ever-routine GOES Sounder coverage of the Southern Hemisphere. This scenario allows most locations an image loop every two hours. A number of products could be produced: retrievals; Derived Product Images (DPI) such as Total Precipitable Water (TPW), Lifted Index (LI), etc.; cloud top properties; radiances; etc. Details of who would do the product generation and distribution would need to be defined. The exact coverage is a function on how much area can be covered in one hour. The figures (below) are only estimates of the coverage area per hour.



Sample image from a geostationary perspective at 60W. The image is centered on 0S, 60W and would take approximately one hour to scan with the sounder.



Sample image from a geostationary perspective at 60W. The image is centered on 30S, 58W and would take approximately one hour to scan with the sounder.

Disclaimer

The many colleagues are thanked who have given insight to these possible schedules. The McIDAS system was used to generate these images. The views, opinions, and findings contained in this document are those of the author and should not be construed as an official National Oceanic and Atmospheric Administration or U.S. Government position, policy, or decision.