Antarctic Meteorological Satellite Report 2013

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This report is dedicated to Elaine Neva Fountain Posner for her encouragement and inspiration over the years and is dedicated to Ed and Cindy Mikolajczyk for their support.

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A. Introduction

Any forum that addresses Antarctic meteorology cannot do so without the inclusion of satellite platforms used to make observations over one of the most data sparse regions of the planet. Weather satellites for decades have been providing critical observations needed for operational forecasting and meteorological research. The aim of this report is to include a status report on the variety of meteorological satellites that provide those needed observations over the Antarctic and adjacent Southern Ocean. Two very traditional classes of satellites are reviewed here: geostationary and polar orbiting satellite programs. An additional third section is included in this report on other classes of satellites and satellite displays that are of benefit to the Antarctic. These are included to highlight existing and some up-and-coming capabilities being considered for the near future. Unique displays such as the Antarctic satellite composite imagery are highlighted, as they have been in active use for over two decades. A graphical review of the satellite data "gap" that is experienced locally at McMurdo Station, Antarctica will be appraised as a part of this report.

This report is an update to a series of reports, created over the years from 2002 through 2006 including:

- 2002's Meteorological Satellite Status Report
    - (Lazzara, 2002)
- 2004's Antarctic Meteorological Satellite Status Report
    - (Lazzara, 2004)
- 2006's Antarctic Meteorological Satellite Status Report 2006
    - (Lazzara, 2006a)
- 2006's Satellite Applications Report: Fog detection and monitoring
    - (Lazzara, 2006b)

The primary focus of this report will be the current and future state of meteorological satellites acquired by or available to the United States Antarctic Program (USAP) via its contractors, grantees or collaborators. Some material will cover select satellites not acquired or available to the USAP. It is important to note that while every effort has been made to provide the most current information, the material presented here is often changing in an ever-evolving environment, and thus making some of this information perishable. One of the ever-improving sources of information used in this report is from the WMO (WMO-OSCAR, 2013).

B. Geostationary Satellites

Although geostationary satellites may not seem to be of great value 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., 2003; Lazzara et al., 2011; Kohrs et al., 2013) because they show systems that will impact Antarctic weather (Figure 1 and discussed further in section D).

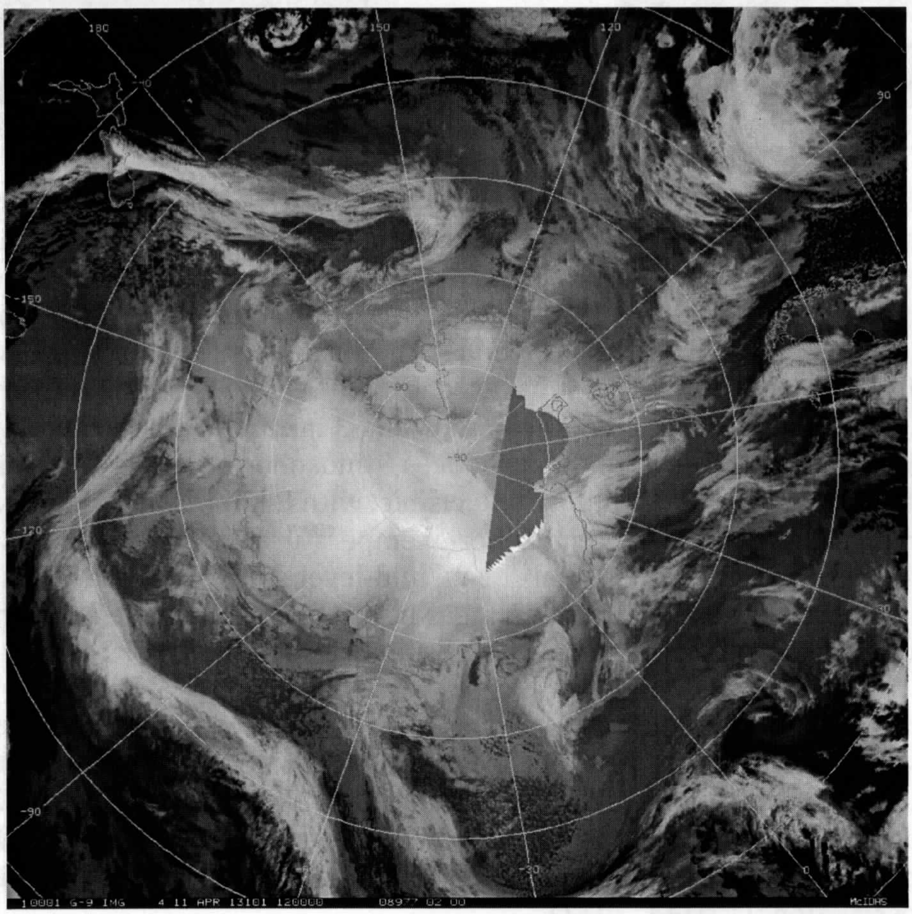
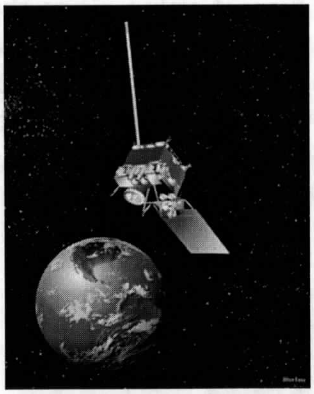
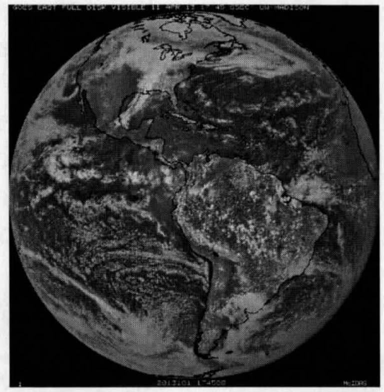


Figure 1. An Infrared Antarctic composite satellite image combined from both geostationary and polar orbiting satellite platform observations. (*Courtesy of AMRC*)

B.1. Geostationary Operational Environmental Satellite (GOES)



NOAA



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, as the World Meteorological Organization (WMO) states. GOES-15 (West – 135° West), and GOES-13 (East – 75° West) are the current operational satellites, with GOES-14 (89.5° West) in stand-by mode. The instrumentation aboard each of these GOES satellites includes the GOES Imager and the GOES Sounder. The imager has 5 channels: one visible channel at 1 km resolution, and 3 infrared and 1 water vapor channel, each at 4 km resolution. The sounder produces atmospheric temperature and humidity soundings. It has 19 channels, including one visible, with 8 km resolution for each channel. The sounder also has channels for atmospheric temperature, including temperatures of the stratosphere, troposphere, and upper-level, mid-level, and lower-level temperatures. Tropospheric moisture values can also be measured (SSEC, 2013). The scanning technique for the sounder is a mechanical, bi-axial, 3-axis stabilized satellite.

GOES-12 was launched on 23 July 2001. It was initially stored in a back-up position at 105° West. It was moved to 75° West in the spring of 2003 to replace GOES-8 as GOES-E, and finally relocated to its current location for South America coverage on 10 May 2010 (WMO, 2013). This satellite will halt operations as of 16 August 2013 due to a lack of fuel for station keeping and its increasing inclination (and thus wobble in the spacecraft and impact on observations) (NOAA, 2013).

GOES-13 was launched on 24 May 2006. It was initially stored in the back-up position at 105° West, and it was moved to its current position at 75° West in January 2009 to replace GOES-12 as GOES-E (WMO, 2013). Its expected end of life is roughly in 2015. From 23 September to 18 October 2012, GOES-14 was moved toward 75° West to backup GOES-13 due to IMAGER and SOUNDER operations being interrupted on GOES-13 (EarthSky, 2013).

GOES-14 was launched on 27 June 2009 and initially stored in the back-up position at 105° West (WMO, 2013). After moving towards 75° West in the fall of 2012 to backup GOES-13, GOES-14 moved back to 89.5° West, where it currently resides. This satellite is expected to be available until 2016.

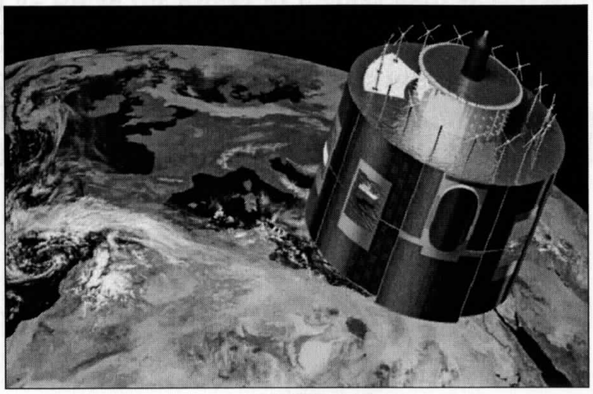
GOES-15 was launched on 4 March 2010. Initially, it was stored in stand-by at 89.5° West. In December 2011, it moved to 135° West to replace GOES-11 as GOES-W (WMO, 2013). A recent incident on GOES-13, where a micrometer(s) likely struck the spacecraft, resulted in NOAA bringing GOES-15 out of storage for use as the GOES-East satellite. Once GOES-13 operations were restored, GOES-15 was placed back into storage. It is hoped that GOES-15 will remain available for service until 2020 or beyond.

Sensors	**Description**
Imager	5 Channel imager
Sounder	19 Channel sounder
SEM	Space Environment Monitor
MAG	Magnetometer
DCIS	Data Collection and Interrogation Service

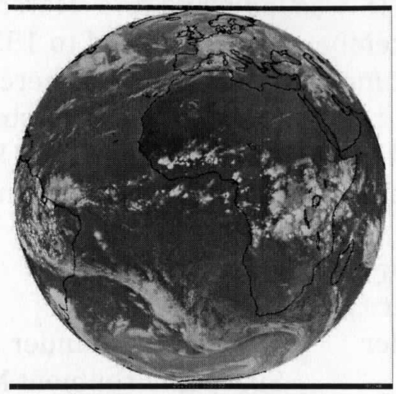
The GOES satellite program, (NOAA, 2013), will continue with the GOES-R series. The first scheduled launch for this GOES third generation program is set for 2015 with the launching of GOES-R. After initial checkout, it is expected that the satellite will be placed in storage until it is needed operationally. These four third-generation satellites will be initially placed either at 137° West or 75° West (WMO, 2013).

Platform	Launch Date	Estimated End Date
GOES-R	2015	2026
GOES-S	2017	2028
GOES-T	2019	2030
GOES-U	2024	2035

B.2. Meteosat



EUMETSAT



UW-Madison/SSEC

The European Organization oversees the Meteosat geostationary satellite program for the Exploitation of Meteorological Satellites (EUMETSAT) with assistance from the European Space Agency. Currently, EUMETSAT has four satellites in orbit (WMO, 2013). Meteosat-10 (0°), Meteosat-8 (9.5° East), and Meteosat-7 (Indian Ocean Data Coverage (IODC) – 57.5° East) are the current operational satellites. Meteosat-9 (10.4° East) is in stand-by mode. Meteosat-9 was the primary operational satellite at 0° from 11 April 2007 to 21 January 2013, when it was replaced by Meteosat-10.

The instrumentation aboard these satellites, with the exception of Meteosat-7, includes the Spinning Enhanced Visible Infrared Imager (SEVIRI). Its scanning technique is a mechanical, spinning satellite with 12 channels. Eleven of those channels are narrow-bandwidth (3 km), and one is a high-resolution (1 km) broad-bandwidth visible channel (HRV) (EUMETSAT, 2013). Eight of these channels are in the thermal infrared and can measure low-level to upper-level temperatures and moisture. Additionally, there is a band for ozone measurement (SSEC, 2013). Meteosat-7 is also a mechanical, spinning satellite but has the Meteosat Visible Infrared Imager (MVIRI) onboard. This instrument has three spectral channels, one in the visible wavelength range and two in the infrared.

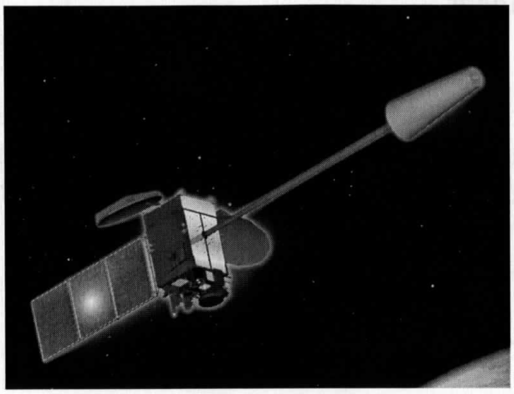
Meteosat-7 was launched on 5 December 2006, which also marks the beginning of the IODC service. Meteosat-8 was launched on 28 August 2002 and became operational on 13 May 2008. Meteosat-9 was launched on 21 December 2005, became the primary satellite at 0° on 11 April 2007, and was replaced by Meteosat-10 on 21 January 2013. Meteosat-9 took over the Remote Sensing Systems (RSS) service from Meteosat-8 in April 2013. Meteosat-10 was launched on 5 July 2012 and was initially placed at 3.4° East. As mentioned above, Meteosat-10 replaced Meteosat-9 at 0° on 21 January 2013 (WMO, 2013). The current Meteosat-7 is expected to remain in place for the IODC until 2016. Meteosat-9 and Meteosat-10 will both be utilized until 2019.

Sensors	**Description**
SEVIRI	Spinning Enhanced Visible and InfraRed Imager (MSG)
MVIRI	Meteosat Visible and InfraRed Imager (Meteosat 1-7)
GERB	Geostationary Earth Radiation Budget
DCS	Data Collection Service

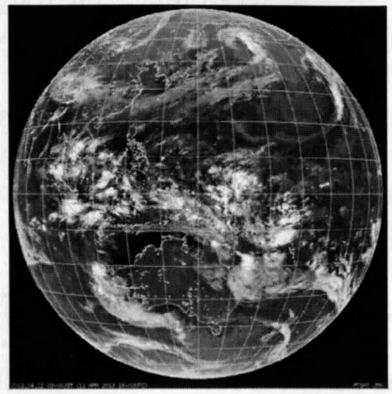
Meteosat Third Generation (MTG) is planned to have two separate spacecraft series, with one devoted to satellite imaging and the other dedicated to atmospheric sounding. The capabilities of the atmospheric sounder are expected to be the next generation of hyperspectral sounding.

Platform	Launch Date	Estimated End Date
Meteosat-11	2015	2022
MTG-I1	2019	2027
MTG-S1	2021	2029
MTG-I2	2024	2032
MTG-I3	2027	2035
MTG-S2	2029	2037
MTG-I4	2032	2040

B.3. Multi-functional Transport Satellite (MTSAT)



MTSAT-2/JMA



JMA

The Multi-functional Transport Satellite (MTSAT) system is part of the Geostationary Meteorological Satellite System (GMSS), from the Japan Meteorological Agency (JMA). There are currently two satellites in orbit, MTSAT-1R (also known as Himawari-6, 140° East) and MTSAT-2 (also known as Himawari-7, 145° East). As of 1 July 2010, MTSAT-2 became the primary operational spacecraft, with data dissemination performed by MTSAT-1R. These two satellites are three-axis stabilized satellites that carry a five-channel imager. The infrared (shortwave, window, and longwave) and water vapor channels are at 4 km resolution, and the visible band is at 1 km resolution (WMO, 2013).

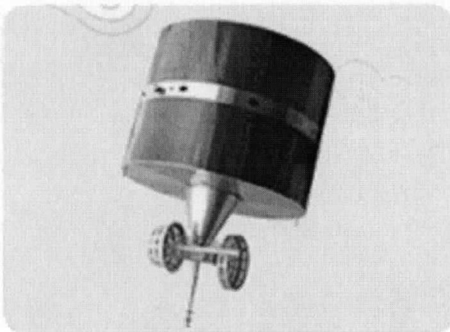
Due to a failed launching of MTSAT-1 in 1999, MTSAT-1R was launched into orbit as a replacement on 26 February 2005. On 18 February 2006, MTSAT-2 was launched into orbit. It serves as the primary image recorder, transmitting the data it collects to MTSAT-1R, which then disseminates the data to utilization stations. MTSAT-1R is expected to be available for operations until 2015, while MTSAT-2 is expected to be available until 2017 or beyond.

Sensors	Description
S-VISSR	Stretched Visible Infrared Spin Scan Radiometer

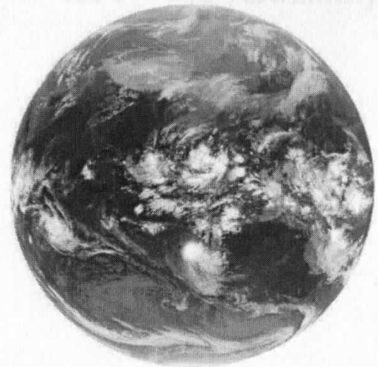
JMA has plans to launch two new satellites in the near future, according to the Meteorological Satellite Center (MSC) of JMA (MSC-JMA, 2013). Himawari-8 is scheduled to be launched into orbit in 2014 and begin its operation in 2015. Himawari-9 is scheduled for 2016, and will be placed in stand-by mode until approximately 2022, when it will replace Himawari-8. These two satellites will be placed at or around 140° East to cover nearly the exact spatial extent that the MTSAT series currently covers. The improvements with these two new satellites include higher spatial resolutions (0.5-1 km for visible, 2 km for IR), more frequent observations, and more spectral bands (16 total).

Platform	Launch Date	Estimated End Date
MTSAT-2 (Himawari-8)	2014	2029
MTSAT-3 (Himawari-9)	2016	2031

B.4. Feng Yun (FY)



FY-2F/CMA



CMA

The Chinese geostationary satellite series, operated by the Chinese Meteorological Agency (CMA), is Feng Yun 2 (FY-2, Feng Yun means Wind and Cloud). Currently, the CMA has three satellites in orbit. FY-2D (86.5° East) and FY-2E (105° East) are the two operational satellites. FY-2F (112.5° East) is currently in stand-by mode. The FY-2 series of satellites features the Stretched Visible and Infrared Spin Scan Radiometer (S-VISSR) aboard each of the satellites. It has one visible channel, at 1.25 km resolution, and 5 km resolution for all three IR channels and the water vapor channel.

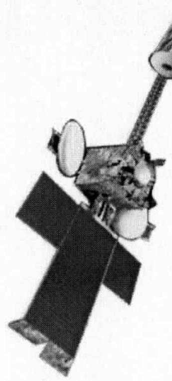
FY-2E was launched on 19 October 2004, according to WMO. It is in the primary operational position of the two operational satellites. FY-2D was launched on 15 November 2006, and it is in the secondary operational position. The scanning schedules of FY-2E and FY-2D are interwoven to encourage optimal spatial coverage. FY-2F was launched on 13 January 2012. Its mission is primarily for use in operational meteorology. As of this writing, FY-2G is scheduled to be launched in 2013, with its primary mission, according to the WMO website, being operational meteorology. It will be positioned at 105° East. The end of life of current orbiting FY satellites will have FY-2D perhaps cease operations later in 2013, with FY-2E in 2014, and FY-2F in 2016.

Sensors	**Description**
S-VISSR	Stretched Visible and Infrared Spin Scan Radiometer
DCS	Data Collection System
SEM	Space Environment Monitor
SXM	Solar X-ray Monitor

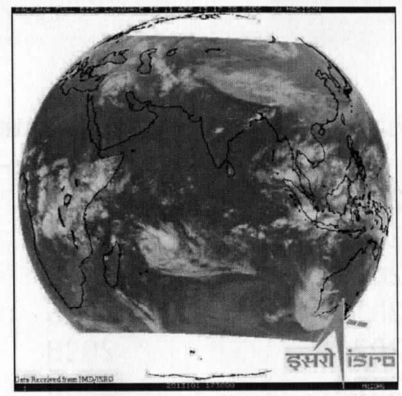
The future for CMA satellite meteorology consists of the launching of a new generation of geostationary satellites beginning in 2014: FY-4. According to the National Satellite Meteorological Center (NSMC) of the CMA, the main objectives of this new generation of satellites include attitude stabilization for the three-axis stabilized mechanisms and improved time resolution observations. CMA also strives to improve the imaging performance, including atmospheric sounding measurements via three-dimensional high-orbit remote sensing. The Atmospheric Sounding Interferometer is planned for the FY-4 series, featuring multi-channel visible and infrared imaging as an infrared hyperspectral sounder.

Platform	Launch Date	Estimated End Date
FY-2G	2014	2018
FY-2H	2016	2020
FY-4A	2017	2022
FY-4B	2019	2026
FY-4C	2021	2028
FY-4D	2023	2030
FY-4E	2027	2034
FY-4F	2030	2037
FY-4G	2033	2040

B.5. Indian National Satellite (INSAT) System



INSAT-3/ISRO



UW-Madison/SSEC/IRSO

The Indian National Satellite (INSAT) System is part of the Indian Space Research Organization (ISRO). Among many satellites in the INSAT system, there are several that have meteorological uses. Kalpana-1 (originally known as Metsat-1) was launched on 12 September 2002, according to WMO. It is an operational satellite of the Indian Space Research Organization (ISRO), located at 74° East. Aboard Kalpana-1 is a Very High Resolution Radiometer (VHRR) that has one 2-km resolution visible channel and two 8-km resolution infrared channels. Kalpana-1 is a mechanical, 3-axis stabilized satellite. Arrangements have been made to relay data obtained from Kalpana-1 through NOAA. These data are available from the University of Wisconsin-Madison data center and thus used in the AMRC Antarctic composites. INSAT-3A was launched on 10 April 2003, according to ISRO. It is positioned at 95.5° East. It carries a three-channel VHRR just like Kalpana-1. It also carries a Charge Coupled Device (CCD) camera that operates in the visible, and near and shortwave infrared bands, providing a spatial resolution of 1 km. The Data Relay Transponder (DRT) operating in the UHF band is incorporated for real-time hydro-meteorological data collection from unattended locations on land and river basins. This satellite is expected to operate until 2015.

Sensors	**Description**
VHRR	Very High Resolution Radiometer
CCD	Charge Coupled Device
DRT	Data Relay Transponder

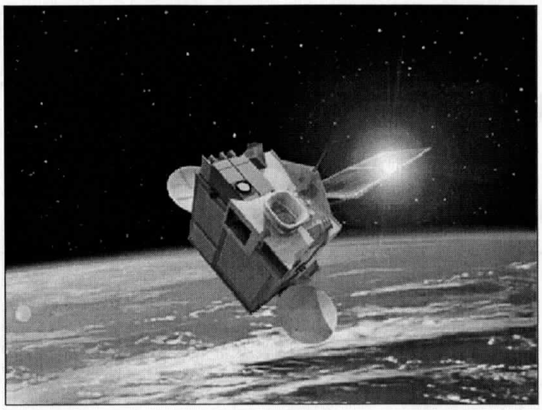
India's next satellite in the series, INSAT-3D, (replacing Kalpana-1) has just been launched on 25 July 2013. It is located at 82° East and has a life expectancy through 2021. This satellite is much like the current GOES satellites with a 5-channel imager and 19-channel sounder.

Sensors	**Description**
IMAGER	INSAT imager
SOUNDER	INSAT sounder
DCS	Data Collection System
SAS&R	Advanced Search and Rescue

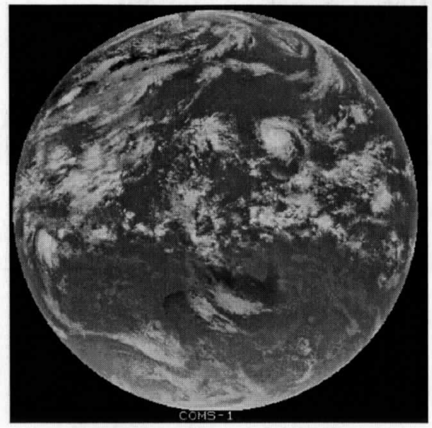
An additional future launch is planned – INSAT-3D' (prime) satellite. This will continue India's geostationary program into the next decade.

Platform	Launch Date	Estimated End Date
INSAT-3D'	2015	2023

B.6. COMS



KARI/KMA



UW-Madison/SSEC

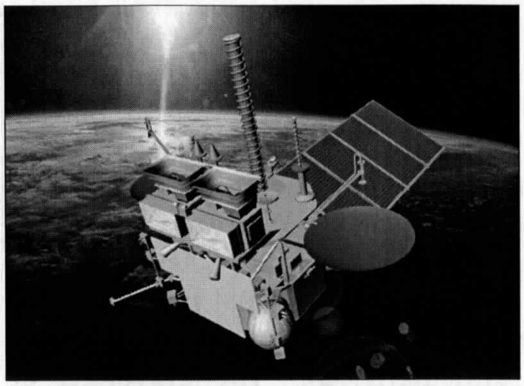
South Korea has launched its first geostationary meteorological satellite on June 26, 2010 (eo-Portal, 2013). The Communications, Ocean, and Meteorological Satellite-1 (COMS-1) is also known as Chollian, meaning long distance view, and is stationed at approximately 130° East. The Korean Meteorological Administration, along with the Korea Aerospace Research Institute and the vendor of the satellite, Astrium, oversees this satellite. Meteorological Imager (MI) is the main sensor, with a Geostationary Ocean Color Imager (GOCI) available as well. The MI is much like the current GOES satellites, as a 5-channel imager, carrying roughly the same 5 channels (0.675, 3.75, 6.75, 10.8 and 12.0 microns). The GOCI is an 8-channel instrument, with all of its measurements in the visible between 0.412 microns and 0.865 microns. The primary field of view of the GOCI is over the Korean peninsula and adjacent region only, while the MI covers the full disk of the Earth and has the additional ability to scan specific regions. This satellite also carries a communication payload system. COMS-1 is expected to operate through 2018.

Sensors	Description
MI	Meteorological Imager
GOCI	Geostationary Ocean Color Imager

Future COMS satellites are anticipated. One mission, COMS-2 will continue the meteorology-focused mission of the current COMS satellite. An additional mission will primarily be for oceanography. Advanced meteorological imagers and follow-on sensors are planned.

Platform	Launch Date	Estimated End Date
COMS-2	2017	2028
COMS-3	2018	2028

B.7. Elektro – Russian Geostationary Satellite



Roshydromet/Planeta

NTsOMZ

The Russian Geostationary Operational Meteorological Satellite-2 (GOMS-2) or Elektro-L1 satellite was launched 20 January 2011. This is a follow on from the first Russian geostationary satellite, Elektro-L (GOMS-1) (eoPortal, 2013). The Multispectral Scanner-Geostationary (MSU-GS) has a 10-channel imager, much like the Meteosat SEVIRI sensor (with 0.57, 0.72, 0.85, 3.7, 6.4, 8.0, 8.7, 9.7, 10.7, and 11.8 micron channels). The satellite also has other sensors for solar X-ray measurements, a data collection system as well as a search and rescue system that is part of the COSPAR-Search & Rescue system. This system is expected to operate until 2018.

Sensors	**Description**
MSU-GS	Multispectral Scanner-Geostationary
GGAK-E	Heliogeophysical Instrument Complex
ODSS	Onboard Data Sampling System
GEOSAT	Geostationary Search & Rescue system

Future GOMS/Elektro-L satellites are anticipated. The additional series of satellites in the current generation will continue to be like the current satellite with meteorology and space weather observing planned. A second generation, Elektro-M, satellite series will offer, in addition to space weather observing, hyperspectral sounding, lightning mapper, and radiation budget measurements along with operational meteorology capabilities.

Platform	Launch Date	Estimated End Date
Elektro-L N2	2014	2021
Elektro-L N3	2016	2023
Elektro-M N1	2016	2026
Elektro-M N2	2017	2027
Elektro-M N3	2021	2031

B.8. Future Geostationary Satellite System: GeoMetWatch

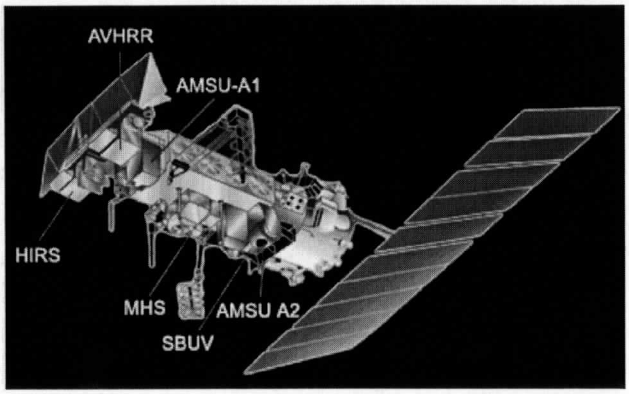
In prior reports, the GIFTS instrument development was discussed, including plans for the US to launch a next-generation satellite imaging/sounding system. However due to budget cuts and priority changes, this has been cut from current operational plans. In the meantime, efforts have continued to capitalize on the investment in the demonstration systems already built and the capability this sensor system offers. A private company, GeoMetWatch, has recently entered into an agreement with AsiaSat (Asia Satellite Telecommunications Company Limited) to launch in 2016 the first STORM hyperspectral sensor (the new name for the GIFTS instrument). GeoMetWatch will have the instrument built by Utah State University Advanced Weather System (AWS). The University of Wisconsin-Madison's Space Science and Engineering Center will provide expert help with the hyperspectral algorithm development as well as be the data center for the satellite systems. The data will be a fee-for-service/data-buy styled model. See Appendix J for the media press release on this system.

Sensors	**Description**
STORM	Hyperspectral sounder

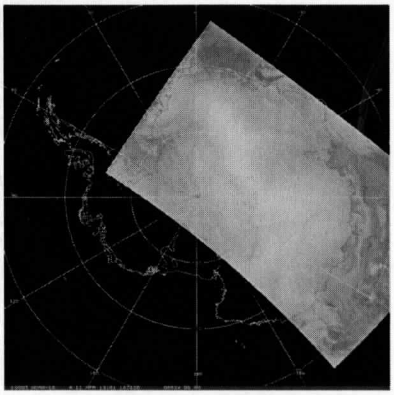
Platform	Launch Date
GeoMetWatch	~2016

C. Polar Orbiting Satellites

C.1. Polar Operational Environmental Satellite (POES)



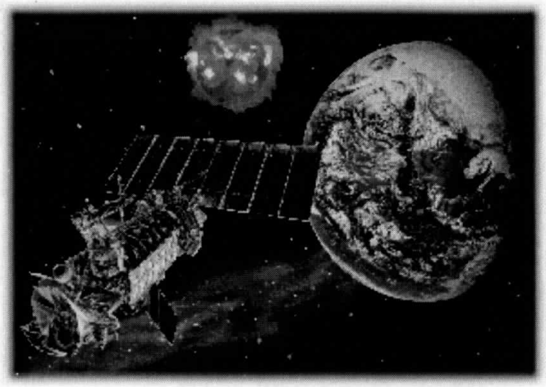
NESDIS/NOAA


UW-Madison/SSEC

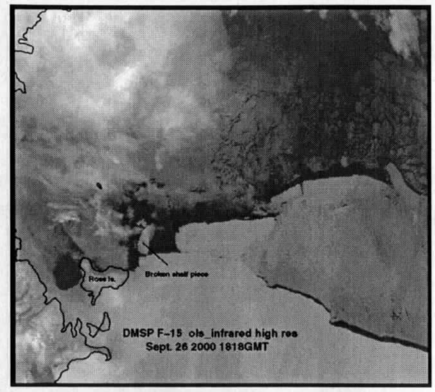
The US Polar Operational Environmental Satellite (POES) system operated by NOAA currently has four satellites in either primary or secondary mode. NOAA-15, NOAA-16, and NOAA-18 are in secondary mode, while NOAA-19 is in primary mode. Since the last satellite report, NOAA-12 and NOAA-14 were decommissioned on 10 August 2007 and 23 May 2007, respectively. NOAA-17 was decommissioned on 10 April 2013 (OSO, 2013). NOAA-15 was launched on 13 May 1998 into an AM orbit. The AMSU-B (Advanced Microwave Sounding Unit) and HIRS (High resolution Infrared Radiation Sounder) subsystems are currently not operational. The AMSU-A1, Advanced Very High Resolution Radiometer (AVHRR), and communications subsystems are operational with limitations (OSO, 2013). NOAA-16 was launched on 21 September 2000. The AMSU-A1, AVHRR, communications system, Data Collect System (DCS), and HIRS subsystems are all operational with limitations. The ADACS (Attitude Determination And Control System) subsystem is operational with degraded performance. NOAA-18 was launched on 20 May 2005. The ADACS subsystem is operational with limitations. The HIRS and Solar Backscatter Ultraviolet Version (SBUV) subsystems are not operational. NOAA-19 was launched on 6 February 2009. Currently, all instrumentation is fully operational. No future launches are planned in this series, with other satellite series planned to become the future US polar orbiting satellite series (see Suomi-NPP and JPSS sections). The original follow-on satellite system, National Polar Orbiting Environmental Satellite System (NPOESS), has been canceled. Operational life expectancy for all of the NOAA satellites is beyond original designed specifications. NOAA-15 and -18 are no longer primary in 2013, as they are well beyond their expected end of life dates. NOAA-19 is expected to operate in a primary role through 2014.

Sensors	Description
AVHRR	Advanced Very High Resolution Radiometer
AMSU-A/B	Advanced Microwave Sounding Unit
HIRS	High-resolution Infrared Radiation Sounder
DCS	Data Collection System

C.2. Defense Meteorological Satellite Program (DMSP)



NGDC/NOAA



USAP

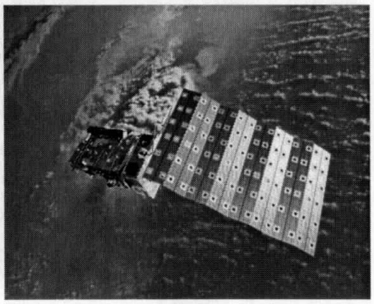
The Defense Meteorological Satellite Program (DMSP) satellite system is a polar orbiting satellite series, operated by the United States (NOAA) for both military and civilian (in non-realtime) use. Over the Antarctic (south of 60° South), the DMSP send clear transmissions in what would otherwise be an encrypted satellite data signal. The current operational satellites are DMSP-F16 (backup in mid-morning orbit), -F17 (secondary in morning orbit), and –F18 (primary in mid-morning orbit). Future plans for the coverage of the three standard orbits are for NOAA to cover the afternoon orbit, with no more US satellites in the mid-morning orbit, and the follow-on to the DMSP satellite to cover the morning orbit (CBO, 2013). At this time, DMSP F-13 through 17 will operate in their role through 2013 (most beyond original expected end of life), with DMSP F-18 expected life to be through 2014.

The future satellite systems that were planned, both the NPOESS and the Defense Weather Satellite System (DWSS), have been canceled. In their place, a Weather Satellite Follow-on (WSF) is currently under discussion (CBO, 2013). Parts of the discussions include other possible options for DMSP replacement including looking at full replacement, a mid-range option or even small satellite options (such as Cube satellites). Additionally, partnerships with other agencies with satellite systems, and looking across multiple satellite systems, are being considered. Even the possibility of not having satellites and stopping the fielding of satellites is included in the discussions.

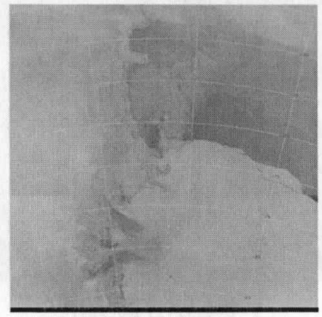
Sensors	**Description**
OLS	Operational Linescan System
SSMIS	Special Sensor Microwave Imager Sounder

Platform	Launch Date
DMSP F-19	2014
DMSP F-20	2020
WSF-1 ?	mid-2020s
WSF-2 ?	~2030

C.3. Metop



ESA



AMRC/SSEC

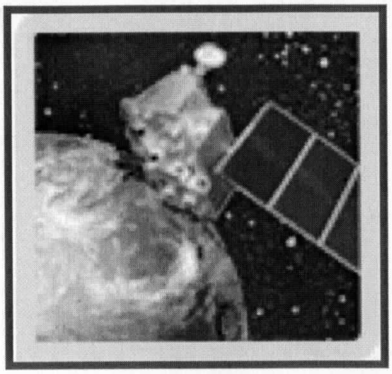
EUMETSAT, in addition to its geostationary Meteosat satellite series, operates a polar orbiting satellite series, Metop, also known at the EUMETSAT Polar System (EPS). Currently, there are two operational systems, Metop-A, launched in 2006, and Metop-B, recently launched in 2012. While the satellites are expected to have 5-year lifespans, EUMETSAT plans to run Metop-A for as long as it will operate nominally, in parallel with the Metop-B satellite. Combined with the US polar orbiting program, these satellites are a part of the Initial Joint Polar System Agreement (IJPS), which includes the NOAA POES, Suomi-NPP, as well as JPSS satellite series. This system carries a combination of US and European sensors. The AVHRR has been a standard on the NOAA/POES satellite series, as has AMSU-A, MHS, and HIRS sensors. A significant contribution from the European community is the Infrared Atmospheric Sounding Interferometer (IASI), an 8461-channel sounding unit, one of the most advanced in orbit today, which is able to retrieve profiles of temperature and moisture, among many other applications.

Sensors	**Description**
AVHRR	Advanced Very High Resolution Radiometer
IASI	Infrared Atmospheric Sounding Interferometer
AMSU-A	Advanced Microwave Sounding Unit
MHS	Microwave Humidity Sounder
HIRS	High Resolution Infrared Radiation Sounder
ASCAT	Advanced Scatterometer
GOME-3	Global Ozone Monitoring Experiment-2
GRAS	Global Navigation Satellite System Receiver for Atmospheric Sounding
A-DCS	Argos - Advanced Data Collection System

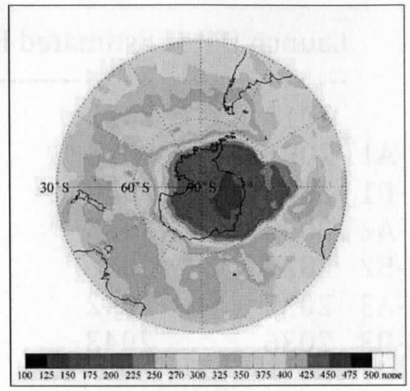
One additional satellite is expected in this series. A follow-on system is in the planning stages, known as EUMETSAT Polar System – Second Generation (EPS-SG). Plans are to have optical instruments on the A series and microwave instruments on the B series of satellites. The B series will also carry the Data Collection System (DCS), the system by which most of the current Antarctic automatic weather stations transmit their real-time weather observations.

Platform	Launch Date	Estimated End Date
Metop-C	2017	2022
Metop-SG-A1	2021	2028
Metop-SG-B1	2022	2029
Metop-SG-A2	2028	2035
Metop-SG-B2	2029	2036
Metop-SG-A3	2035	2042
Metop-SG-B3	2036	2043

C.4. Feng Yun (FY)



CMA



NMSC

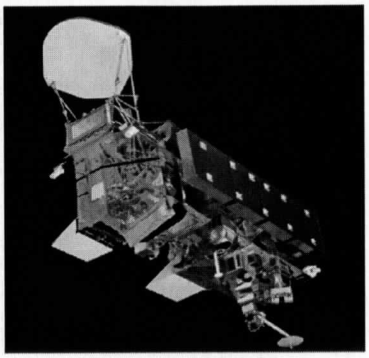
The Feng Yun (FY-3) is the operational polar orbiting satellite series operated by the Chinese Meteorological Agency (CMA) for China. Currently, FY-3A and FY-3B are the operational satellites (NSMC-CMA, 2013). FY-3 is the extension of the FY-1 polar-orbiting series of satellites from CMA. FY-3A was launched on 27 May 2008, and it has a 10:15 am (morning) equatorial cross time. FY-3B was launched on 4 November 2010, and it has a 13:40 pm (mid-morning) equatorial cross time (WMO, 2013). All FY-1 satellites are no longer operational. Both FY-3A and -3B are to continue operations through 2013.

Sensors	**Description**
ERM-1	Earth Radiation Measurement-1
IRAS	InfraRed Atmospheric Sounder
MERSI-1	MEdium Resolution Spectral Imager-1
MWHS-1	MicroWave Humidity Sounder-1
MWRI	MicroWave Radiation Imager
MWTS-1	MicroWave Temperature Sounder-1
SBUS	Solar Backscatter Ultraviolet Sounder
SEM	Space Environment Monitor
SIM-1	Solar Irradiance Monitor-1
TOU	Total Ozone Unit
VIRR	Visible and InfraRed Radiometer

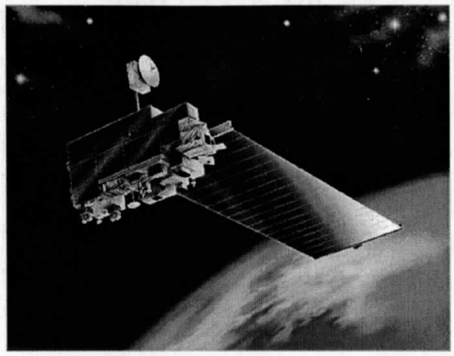
Additional satellites are planned in this series. Future launch dates are currently estimated to be the following:

Platform	Launch Date	Estimated End Date
FY-3C	2013	2016
FY-3D	2015	2018
FY-3E	2016	2019
FY-3F	2018	2021
FY-3G	2020	2023

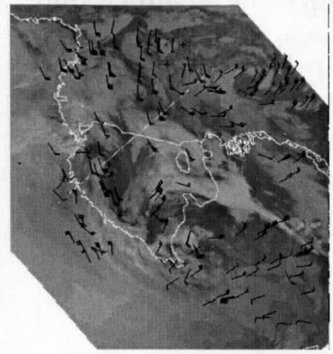
C.5. Earth Observing Satellite (Aqua and Terra)



Aqua (NASA)



Terra (NASA)



SSEC/UW-Madison

The Earth Observing System (EOS) is a coordinated series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. The flag satellites of this mission are Aqua, launched on 4 May 2002; Terra, launched on 18 December 1998; and Aura, launched on 15 July 2004. All satellites are operating well beyond their expected end of life. Aqua and Terra offer direct broadcast of data, while Aura does not (EOSPSO-NASA, 2013). There are other satellites that are a part of EOS, and they are discussed in the section "Other Polar-centric Satellites and Products."

These satellites offer a suite of instruments and sensor systems. The MODIS instrument, which has been derived from AVHRR and is on the Terra and Aqua satellites, 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, on the Aqua satellite, offers thousands of spectral channels of data that allow high-resolution profiles of temperature and moisture to be generated.

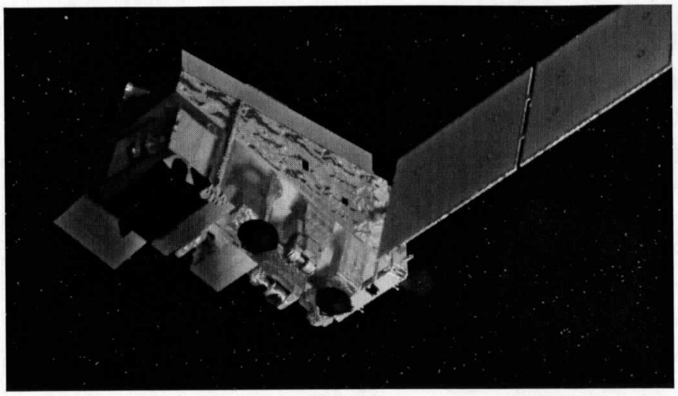
EOS-Aqua

Sensors	**Description**
AIRS	Atmospheric Infrared Sounder
AMSR-E	Advanced Microwave Scanning Radiometer for EOS
AMSU-A	Advanced Microwave Sounding Unit – A
CERES	Clouds and the earth's Radiant Energy System
HSB	Humidity Sounder for Brazil
MODIS	Moderate-resolution Imaging Spectro-radiometer
HiRDLS	High-Resolution Dynamics Limb Sounder
MLS	Microwave Limb Sounder
OMI	Ozone Monitoring Instrument
TES	Tropospheric Emission Spectrometer

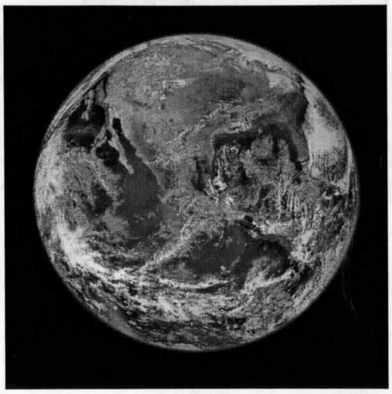
EOS-Terra

Sensors	**Description**
ASTER	Advanced Spaceborne Thermal Emission and Reflection radiometer
CERES	Clouds and the Earth's Radiant Energy System
MISR	Multi-angle Imaging Spectro-Radiometer
MODIS	Moderate-resolution Imaging Spectro-radiometer
MOPITT	Measurement Of Pollution In The Troposphere

C.6. Suomi National Polar-orbiting Partnership (Suomi NPP)



NASA



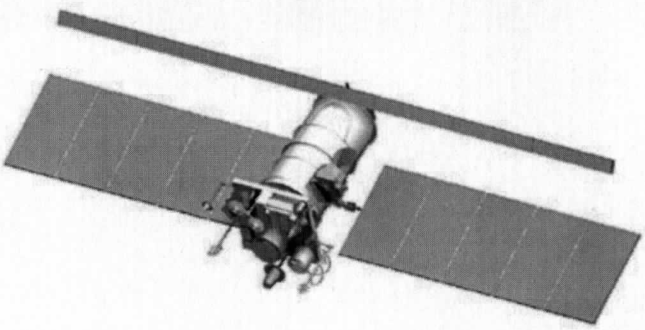
NASA

The Suomi-NPP satellite was launched on 28 October 2011 (WMO, 2013). It has an equatorial crossing time of 1:30 pm (NASA/Suomi-NPP, 2013). This satellite is currently operational for NOAA after an 18-month check out by NASA. It is expected to be a primary satellite for NOAA through 2016. Some of the instruments aboard Suomi-NPP have direct benefits to weather forecasting. The ATMS instrument aboard Suomi-NPP is a 22-channel passive microwave radiometer that has the ability to create global models of temperature and moisture, which meteorologists can enter into weather forecasting models. The CrIS instrument monitors characteristics of the atmosphere, such as moisture and pressure, which can be used to produce improvements in both short- and long-term weather forecasting (NASA/Suomi-NPP, 2013).

Other instruments aboard this satellite have benefits to the research community. The Ozone Mapping and Profiler Suite (OMPS) is a suite of hyperspectral-imaging spectrometers that will measure Earth's ozone levels, particularly near the poles. VIIRS is a 22-band radiometer similar to the MODIS instrument aboard the Aqua and Terra satellites that collects visible and infrared views of the earth. CERES is a 3-channel radiometer, which measures the reflected solar radiation, emitted terrestrial radiation, and total radiation, giving an accurate measurement of Earth's total thermal radiation budget (NASA/Suomi-NPP, 2013).

Sensors	**Description**
ATMS	Advanced Technology Microwave Sounder
CERES	Clouds and the Earth's Radiant Energy System
CrIS	Cross-track Infrared Sounder
OMPS	Ozone Mapping and Profiler Suite
VIIRS	Visible/Infrared Imager Radiometer Suite

C.7. Meteor-M



VNIIEM

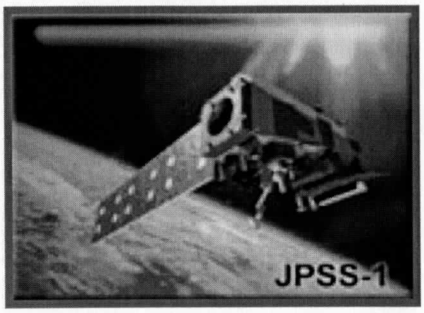
The Russian Federation has continued the Meteor series of polar orbiting satellites, which began during the Soviet Union era. Historic missions include the Meteor-3M, which was launched 10 Dec 2001 and ceased functioning on 6 March 2006 due to battery/power system failure. A next generation Meteor series has been started, including the launch of Meteor-M N1 on 17 September 2009 (with expected operations through 2014) and Meteor-M N2 planned in 2013.

Sensors	**Description**
MSU-MR	Global and regional cloud cover mapping
KMSS	Multichannel scanning unit for Earth surface monitoring
MTVZA	Imager/sounder - atmospheric temp. & humidity profiles & sea surface wind
IRFS-2	Advanced infrared sounder for atmospheric temperature and humidity profiles
Severjanin	Synthetic Aperture Radar for ice monitoring
Radiomet	Radio occultation unit for atmospheric temperature and pressure profiles

A break in the series will be with the Meteor-M N3, which will instead focus on an ocean mission with an ocean radar sensor system. Additional meteorological satellites are expected in future years.

Platform	Launch Date	Estimated End Date
Meteor-M N2	2013	2017
Meteor-M N2-1	2014	2019
Meteor-M N2-2	2015	2020
Meteor-M N3	2017 (Ocean radar)	2022
Meteor-MP N1	2017	2022
Meteor-MP N2	2018	2023
Meteor-MP N3	2019	2024

C.8. JPSS – US Polar-orbiting Satellite program



The Joint Polar Satellite System (JPSS), developed by NASA, is the next generation polar orbiting operational satellite for NOAA (Raytheon, 2013). There are five satellites and one experimental payload in the JPSS system. The aforementioned Suomi-NPP polar-orbiting satellite (Section C.5) is in the JPSS system, along with plans for four more: JPSS-1, JPSS-2, Free Flyer-1, and Free-Flyer-2 (JPSS, 2013). These four satellites will have afternoon orbits (WMO, 2013). JPSS-1 is scheduled for launch in early 2017. It will have the same instruments as Suomi-NPP. JPSS-2 will feature the same instruments as JPSS-1, but will have a new CERES instrument aboard. Direct broadcast transmissions will be via X-band, and will likely not have an L-band version, unless the US Navy (the only interested party within the US) is willing to fund that capability. JPSS-1 and likely JPSS-2 will not make use of the Common Ground System (CGS) formally known as SafetyNet under the NPOESS program. Free Flyer-1 is scheduled for launch in early 2017, while Free Flyer-2 is scheduled in 2022. They will both carry three instruments: Advanced Data Collection System (A-DCS), Search And Rescue Satellite Aided Tracking (SARSAT), and Total Solar Irradiance Sensor (TSIS). The experimental payload under the JPSS system is the Total Solar Radiance Calibration Transfer Experiment (TCTE). It is being hosted aboard the U.S. Air Force Satellite STPSat-3. The tentative launch date for TCTE will be some time in the summer of 2013.

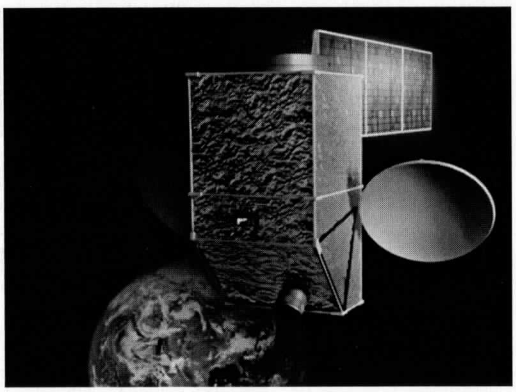
Sensors	**Description**
VIIRS	Visible/Infrared Imager Radiometer Suite
ATMS	Advanced Technology Microwave Sounder
CrIS	Cross-track Infrared Sounder
CERES	Clouds and Earth's Radiant Energy System
A-DCS	Advanced Data Collection System
SARSAT	Search And Rescue Satellite Aided Tracking
TSIS	Total Solar Irradiance Sensor

Platform	Launch Date	Estimated End Date
JPSS-1	2017	2024
JPSS-2	2022	2029
Free Flyer-1	2016-2017	2021
Free Flyer-2	2021	2026

D. Other Satellites and Products

There are other satellites that are being proposed or are in development with the potential to be of benefit for applications in the Antarctic. Additionally, the Antarctic Satellite Composites developed at the University of Wisconsin-Madison are providing the best hemispheric view of the Antarctic and adjacent Southern Ocean. Developments in both of these areas are outlined here.

D.1. PCW Satellite Project



CSA

The Canadian Space Agency (CSA) has begun development of a Polar Communications and Weather (PCW) satellite. The final orbit for this satellite has yet to be determined; however, it will be some form of highly elliptical orbit or Molniya orbit. Beyond the communication capabilities, the possibility of a meteorological imager on board may be of benefit to the Antarctic, depending on the final orbit selection. However, with a focus on the Canadian territory along the Arctic, it is not clear the final orbit will have Antarctic applications. The National Science Foundation has provided input into over-arching US Government input and comment to the CSA. The US DoD, as well as NOAA, has provided additional input. Significant effort has been invested into the benefit of these spacecraft in capturing atmospheric motion vectors (AMVs) and other basic meteorological observations found on most geostationary and polar orbiting meteorological spacecraft (Trishchanko and Garand, 2011; Lachance, 2012; Trishchanko et al., 2012; and Trishchanko and Garand, 2012).

Platform	Launch Date	Estimated End Date
PCW-1/POLARSAT1	2018	2025
PCW-2/POLARSAT2	2018	2025

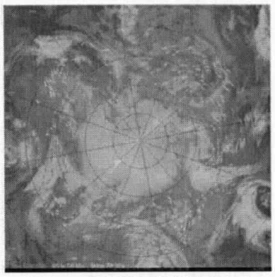
D.2. Arktika-M Molniya Satellite

Roskosmos

The Russian Federation, which historically has been a user of Molniya-orbiting satellites for communications, does have some plans for Molniya satellite systems or highly elliptical orbiting (HEO) systems in the future. These satellites are expected to have meteorological and space weather applications. The Arktika-M series is planned to be a HEO-type orbiting satellite with a 12-hour orbit, and Elektro-L type sensor on board.

Platform	Launch Date
Arktika-M 1	2015
Arktika-M 2	NA

D.3. Antarctic Composite Satellite Imagery



AMRC/SSEC

For over 20 years, the University of Wisconsin-Madison, Antarctic Meteorological Research Center has been generating Antarctic satellite composite imagery. Targeted to serve the broad Antarctic community, for operational and research use, the composites have been steadily improved over the years in temporal, spatial and spectral coverage (Kohrs et al., in review) (Figure 2). In 2013, the composite is now being made at 4 kilometers resolution, on an hourly basis, in over 5 different spectral channels (see Table 1):

Table 1. Spectral channel description of the Antarctic satellite composite imagery.

Channel	Wavelength (microns)	Application
Visible	0.65	Daytime cloud detection; visible clouds, ice and surface features; reflectance; albedo
Shortwave Infrared	3.8	Low cloud, fog, hot spot (fire/volcano) detection
Water Vapor	6.7	Water vapor detection (mid-troposphere)
Infrared Window	11.0	Infrared surface & cloud top temperature and nighttime cloud detection
Longwave Infrared	12.0	Infrared surface and cloud top temperature, low level water vapor, and nighttime cloud detection.

Efforts are underway to provide the latest generation composites to the community. In the fall of 2013, the composites will be further enhanced via two new additional features. First, the composites will be reoriented to have the Prime Meridian (0° longitude) be at the top of the image. The existing orientation (with 140° West at the top of the image) will continue to be made as well. Beyond this, the composites will be recreated 12 to 24 hours later to take advantage of late available satellite observations to decrease the "hole" in the composite imagery. Real-time composite imagery will continue to be made roughly 3 hours after the synoptic time it is valid for. A new methodology for the compositing process is also being implemented, with an aim to reduce parallax, and keep the highest resolution observations on the "top" of the combined observations. Plans beyond this are not clear, as

NSF science funding will end in 2014 for this project. Without additional funding or direction, this effort may end in late 2014 or early 2015.

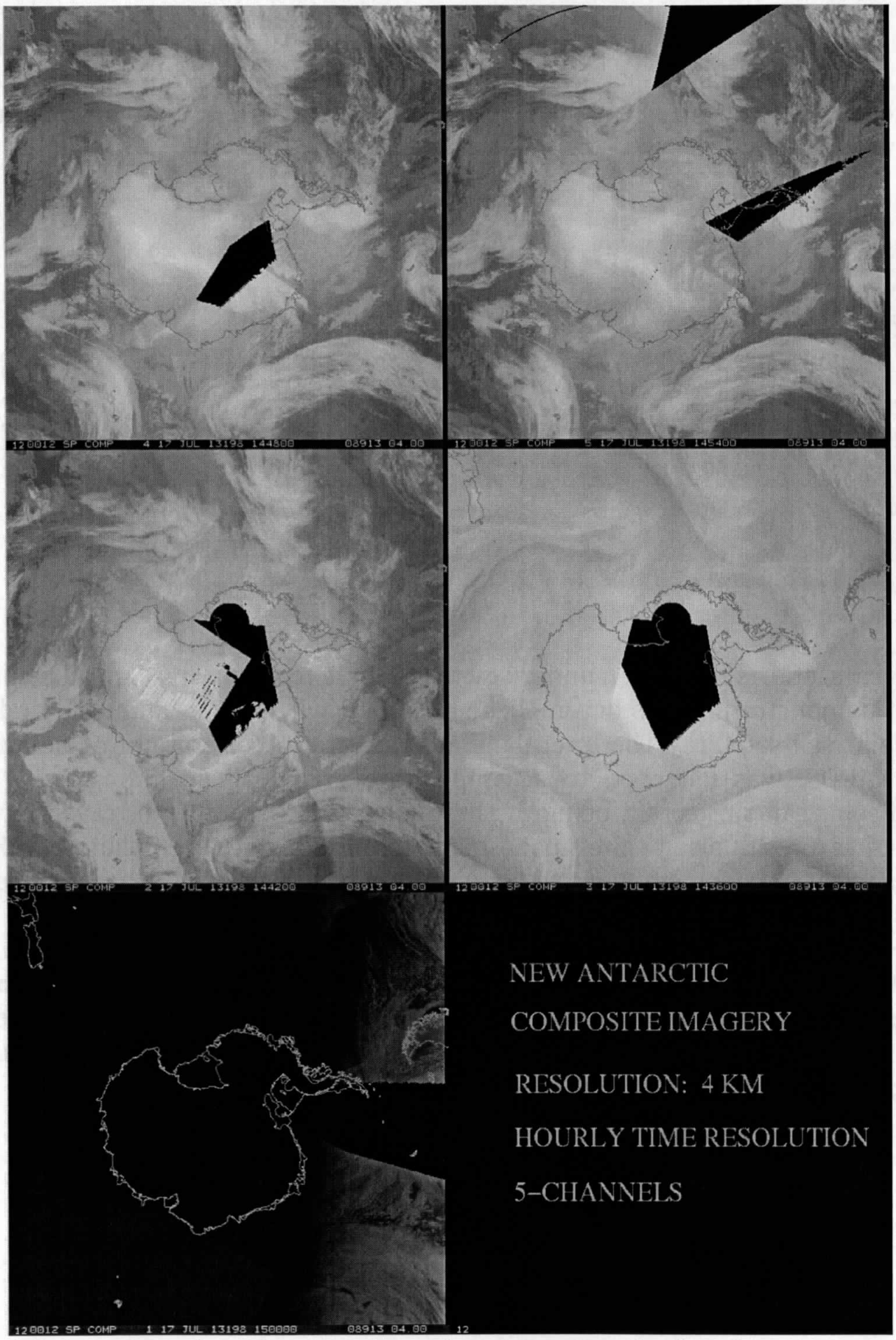
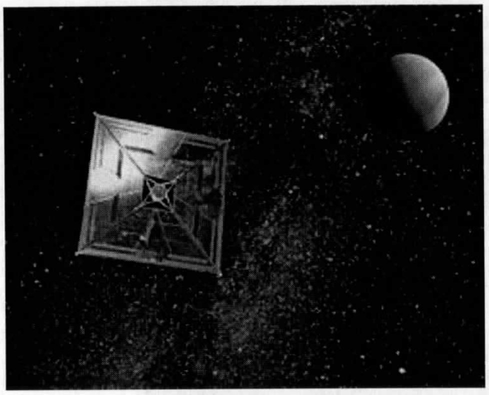


Figure 2. These examples of new Antarctic composites in development at the AMRC show the 5-channel, 4-kilometer resolution composites using a new compositing methodology resulting in a slightly increased field of view.

D.4. Solar Sail and Associated Satellites

Advances in solar sail technology and novel satellite orbits, such as at natural or even artificial LaGrange points, offer perhaps some of the best options for improved Antarctic satellite coverage (Lazzara, 2011). This section updates the recent developments and breakthroughs in this area.

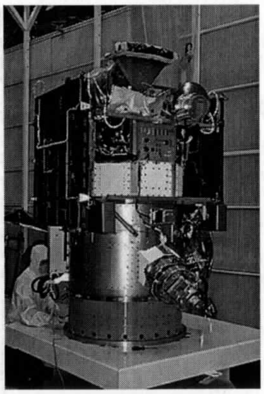
D.4.1 IKAROS Satellite



JAXA

In recent years, efforts have been underway to continue to advance solar sail technology. A significant demonstration was accomplished in 2010 when Japan launched and unfurled the first solar sail satellite. The Interplanetary Kite-craft Accelerated by Radiation Of the Sun, or IKAROS, was launched to accomplish several goals including being the first successful solar sail spacecraft, being the first solar sail spacecraft to travel between two planets, and as a result also be the smallest spacecraft flying between planets (JAXA, 2013). This demonstration gives credence to proposals to have solar sail spacecraft be used for Earth observations, and especially for the Polar Regions as outlined by Lazzara, 2005 and Lazzara et al., 2011. Several other smaller solar sail missions have begun work since the success of IKAROS along with larger versions (some funded by NASA). Close monitoring of the efforts in this area may be important for the future observation of the Antarctic. Every three years an International Solar Sailing Symposium is hosted that offers a forum for this technology to be discussed and reviewed.

D.4.2 DSCOVR Mission



NOAA

Efforts within the NOAA have revitalized plans to refurbish and launch the DSCOVR satellite mission to the LaGrange-1 or L-1 point between the Earth and Sun. The primary objective would be to observe the sunlit side of the Earth for climate monitoring purposes and for space weather requirements. The main sensors were built and have been in storage since the mid-1990s. They were formerly a part of a project known as Trianna before the launch was canceled. This satellite has potential uses for the Antarctic during the field season. The future for this spacecraft is in the hands of NOAA, rather than the original NASA development team, due to funding. Currently it is scheduled for launch in 2014/2015. (NASA Science, 2014)

Sensors	**Description**
NISTAR	NIST Advanced Radiometer
EPIC	Earth Poly-Chromatic Imaging Camera
PHA	Pulse Height Analyzer
Electron Spectrometer	

Platform	Launch Date
DSCOVR	2014/2015

E. McMurdo Local Satellite Data Gap Analysis

As a part of this analysis, DMSP data was not considered due to the lack of readily available navigation information for the analysis. The SSEC Desktop Ingestor (SDI) system that the AMRC utilizes at McMurdo Station and Palmer Station, while having a capability to work with DMSP, has not been upgraded for newer software in over a decade, rendering its application to the most recent DMSP satellite and navigation outdated. With DMSP satellites configured into similar orbits as the NOAA POES, Suomi-NPP, Metop, and EOS Aqua and Terra satellites, the additional analysis of DMSP observations is unlikely to significantly alter the analysis presented here (Figures 3 and 4).

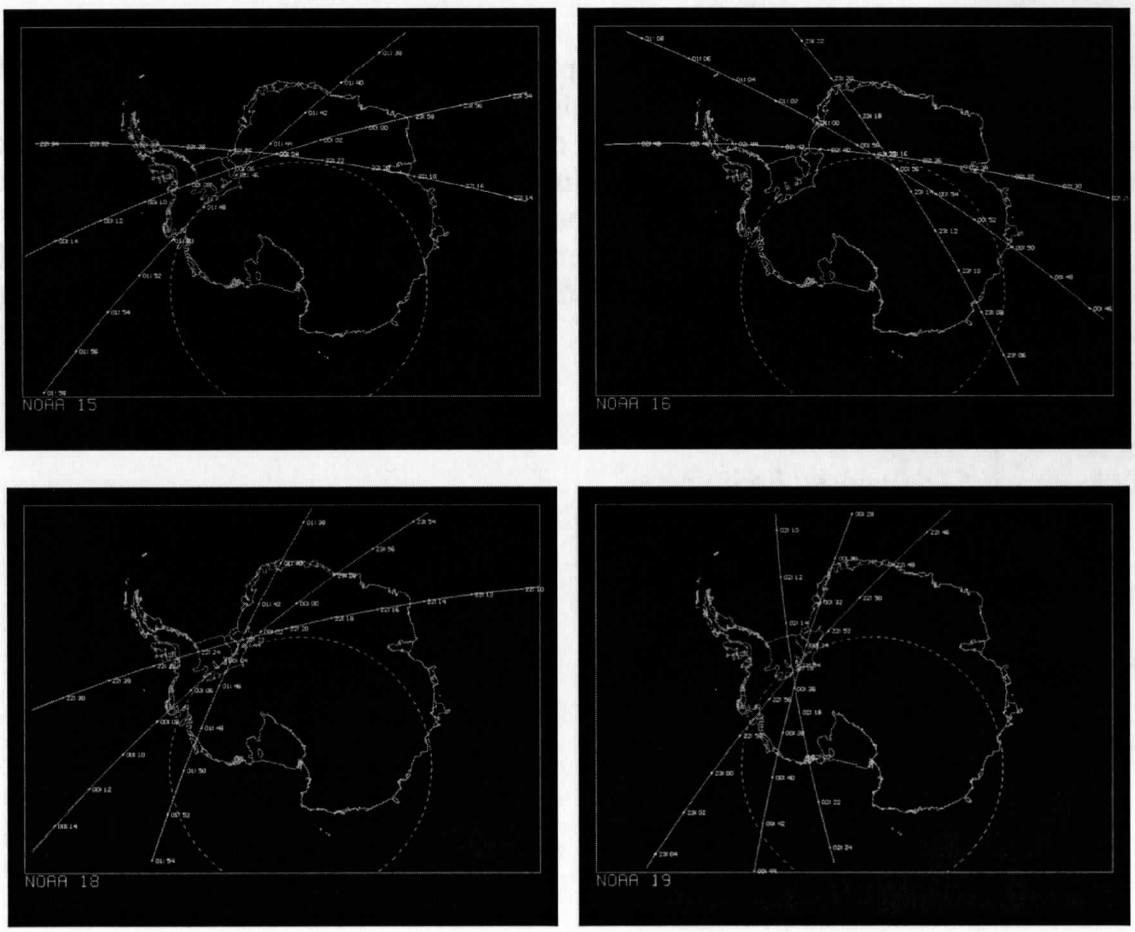


Figure 3. This figure displays the orbital analysis for the NOAA-15, NOAA-16, NOAA-18, and NOAA-19 (listed top to bottom, left to right) satellites during McMurdo's "data gap" period of 22 UTC and 3 UTC daily.

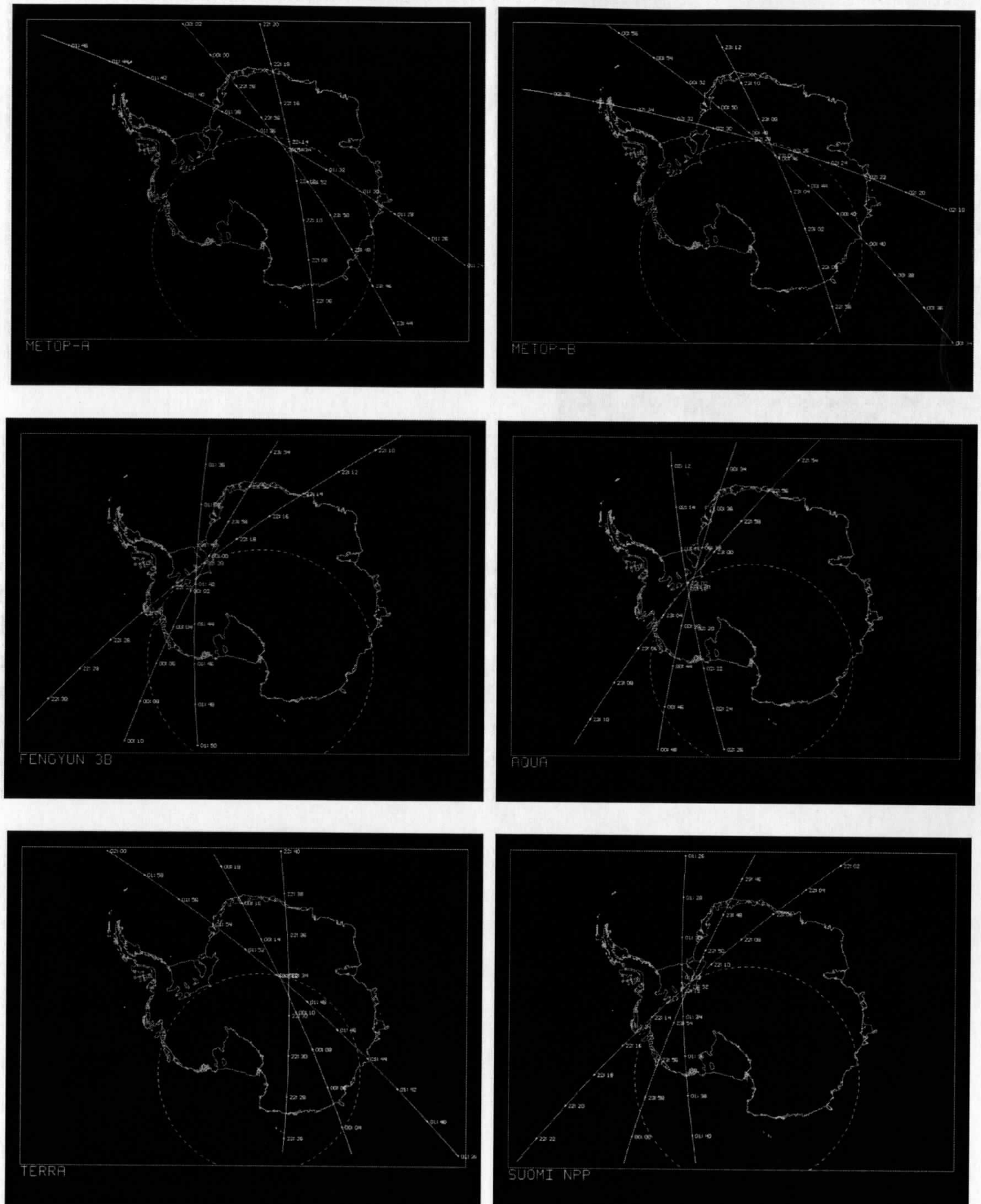
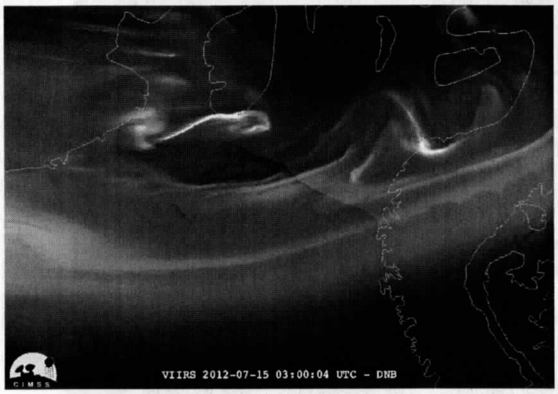


Figure 4. This figure displays the orbital analysis for the METOP-A, METOP-B, FY-3B, Aqua, Terra, and Suomi-NPP (listed top to bottom, left to right) satellites during McMurdo's "data gap" period of 22 UTC to 3 UTC daily.

F. New Satellite Product – Day Night Band



CIMSS/SSEC/UW-Madison

One of the newest satellite capabilities available includes the Day Night Band (DNB) as a part of the VIIRS instrument on the Suomi-NPP satellite. Expanding beyond the capabilities found on the visible channel of the DMSP Operational Linescan System (OLS), the DNB offers the opportunity to view a host of low-light phenomena including aurora and moonlit clouds (Lee et al., 2006; Hillger et al., 2013, Seaman and Miller, 2013, etc.). This new capability, based on demonstrations worldwide, has the potential to be a critical new tool for weather forecasting in the Antarctic, especially targeted for Winter Fly-in, or WINFLY, operations and winter-over medical evacuations.

G. Acknowledgements

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World Meteorological Organization (WMO):
http://www.wmo.int/pages/prog/sat/satellitestatus.php#geocurrent

Information on all satellites:
http://en.allmetsat.com/index.html

Site with info on GOES-13 malfunction:
http://earthsky.org/earth/goes-14-satellite-drifts-eastward-to-replace-malfunctioning-goes-13

Information on future NOAA satellites:
http://www.nesdis.noaa.gov/SatInformation.html

Information about EUMETSAT:
http://www.eumetsat.int/Home/Main/AboutEUMETSAT/index.htm?l=en

Meteorological Satellite Center (MSC) of JMA
http://mscweb.kishou.go.jp/himawari89/index.hmtl

National Satellite Meteorological Center (NSMC) of Chinese Meteorological Agency (CMA)
http://nsmc.cma.gov.cn/NewSite/NSMC_EN/Home/Index.html

Indian Space Research Organization:
http://www.isro.org/

NOAA Office of Satellite Operations (OSO)
http://www.oso.noaa.gov/poesstatus

NASA – Suomi-NPP:
http://npp.gsfc.nasa.gov/mission_details.html

JPSS information
http://www.jpss.noaa.gov/satellites.html

JPSS from Raytheon
http://www.raytheon.com/capabilities/products/jpss/

POLARSAT/PCW
http://www.goes-r.gov/downloads/2012-Science-Week/posters/tues/13_Trishchenko.pdf

J. Appendix B: GeoMetWatch Press Release

Media Release

**GeoMetWatch Partners with AsiaSat to Launch
Advanced Severe Weather Payload**

NORTH LOGAN, UTAH/HONG KONG, April 3, 2013 – Asia Satellite Telecommunications Company Limited (AsiaSat) and GeoMetWatch Corp today announced that the two companies have entered into a strategic partnership to host the first of six Sounding & Tracking Observatory for Regional Meteorology (STORM™) instruments on board a new satellite planned to be launched by AsiaSat in 2016.

"We are pleased to have reached this cooperation agreement with GeoMetWatch. We are excited to take part in this ground breaking project that will provide advanced data to improve weather forecasting, natural disaster monitoring and climate modeling. This new partnership with GeoMetWatch will open up new opportunities to expand our satellite services into new areas, and allow us to explore a new source of revenue for the company," said William Wade, President and Chief Executive Officer of AsiaSat.

"GeoMetWatch's partnership with AsiaSat is a significant step towards the implementation of our global geostationary hyperspectral sounder constellation. The first STORM™ sensor will provide unprecedented atmospheric and weather data over Asia and the Pacific region, for which we have already had significant interest to purchase the data when available," said David Crain, Chief Executive Officer of GeoMetWatch. "For the past 25 years, AsiaSat has been the preeminent satellite operator in Asia and we are pleased that our first STORM™ hyperspectral sounder will be hosted on their satellite."

Planned for launch in 2016 and to be positioned at 122 degrees East, this new AsiaSat satellite will host the first hyperspectral STORM™ sensor that will collect and return to Earth sophisticated and critical weather data not currently available. This hyperspectral data will enable meteorologists to provide better daily forecasts, predict severe weather and atmospheric instability more accurately, and improve location and storm tracking and analysis of the intensity of hurricanes and typhoons, resulting in earlier evacuations that can improve the preservation of lives and property.

“STORM™ will provide significantly earlier warning for severe weather and climate instability, and it will do so faster, more frequently and with finer detailed measurements than any capability in orbit today,” Crain said.

The first STORM™ sensor is currently being manufactured by Utah State University's Advanced Weather Systems. AWS is part of Utah State's rich heritage of designing, building and testing state-of-the-art space based sensors. “AWS is thrilled to be a part of the GMW-AsiaSat partnership,” said Robert T Behunin, AWS Board Member and USU vice president for commercialization. “This unprecedented partnership and the activities that will come from it will revolutionize the weather sensor and data community; it will also provide a more efficient business model to secure and distribute weather data.”

Partnering with Space Science and Engineering Center (SSEC) of University of Wisconsin for expertise in hyperspectral algorithm development and data processing, the GeoMetWatch system will provide high-resolution, visible and infrared images of atmospheric conditions as well as a complete set of quasi-continuous measurements that are high resolution in vertical, spatial and temporal dimensions. These include profiles of temperature, water vapor, pressure, clouds and wind, three-dimensional fields of aerosols, pollutants, and trace gases, volcanic ash and gases, weather instability, precipitation and flood forecasts, hurricane intensity and ground track, and other data. GeoMetWatch's products and services will be available globally under an innovative fee-for-service data-buy model that enables its clients to meet their critical atmospheric data needs with increased accuracy, efficiency and affordability.

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About GeoMetWatch

GeoMetWatch Corp is a commercial technology and innovation leader specializing in global hyperspectral weather services. GeoMetWatch provides state-of-the-art hyperspectral sensors as well as a range of meteorological data products. GeoMetWatch is headquartered in North Logan, Utah. For more about GeoMetWatch, visit us at www.geometwatch.com

About AsiaSat

Asia Satellite Telecommunications Company Limited (AsiaSat), the leading regional satellite operator in Asia, serves over two-thirds of the world's population with its four satellites, AsiaSat 3S at 105.5ºE, AsiaSat 4 at 122ºE, AsiaSat 5 at 100.5ºE and AsiaSat 7 at 105.5ºE. The AsiaSat satellite fleet provides services to both the broadcast and telecommunications industries. Over 450 television and radio channels are now delivered by the company's satellites offering access to over 620 million TV households across the Asia-Pacific region. AsiaSat also provides telecommunications operators and end users services such as voice networks, private VSAT networks and broadband multimedia. AsiaSat's latest satellites, AsiaSat 6 and AsiaSat 8, are planned to be launched in the first half of 2014. It is a wholly-owned subsidiary of Asia Satellite Telecommunications Holdings Limited, a company listed on The Stock Exchange of Hong Kong Limited (Stock Code: 1135). For more information, please visit www.asiasat.com

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K. Appendix C: Polar-orbiting Satellite Lifespan

Table A – Current operational satellites launch dates and their lifespan status.

Satellite	Launch Date	Lifespan/End of Life
NOAA-15	1998	Operating beyond end of life
NOAA-16	2000	Operating beyond end of life
NOAA-18	2005	Operating beyond end of life
NOAA-19	2009	2014
Suomi-NPP	2011	2016
Metop-A	2006	2013
Metop-B	2012	2018
DMSP F13-15	1995, 1997, 1999	Degraded Operating beyond end of life
DMSP F16	2003	Operating beyond end of life
DMSP F17	2006	Operating beyond end of life
DMSP F18	2009	2014
FY-3A	2008	Degraded Operating beyond end of life
FY-3B	2010	2013
Terra	1999	Operating beyond end of life
Aqua	2002	Operating beyond end of life
Meteor M N1	2009	2014

Table B – Planned satellites launch dates and their lifespan expectations.

Satellite	Planned Launch Date	Expected Lifespan
DMSP F-19	2014	2019
DMSP F20	2020	2025
WSF-1	mid-2020	TBD
WSF-2	~2030	TBD
Metop- C	2017	2022
Metop-SG-A1	2021	2028
Metop-SG-B1	2022	2029
Metop-SG-A2	2028	2035
Metop-SG-B2	2029	2036
Metop-SG-A3	2035	2042
Metop-SG-B3	2036	2043
FY-3C	2013	2016
FY-3D	2015	2018
FY-3E	2016	2019
FY-3F	2018	2021
FY-3G	2020	2023
Meteor-M N2	2013	2017
Meteor-M N2-1	2014	2019
Meteor-M N2-2	2015	2019
Meteor-M N3	2017 (Ocean radar)	2022
Meteor-MP N1	2017	2022
Meteor-MP N2	2018	2023
Meteor-MP N3	2019	2024
JPSS-1	2017	2024
JPSS-2	2022	2029
Free Flyer-1	2016-2017	2021
Free Flyer-2	2021	2026