Summary of GSFC's Role on MetOp-B

Introduction

The Meteorological Operational (MetOp)-B spacecraft is the second in a series of three European developed satellites used for weather forecasting and collecting long term data sets for climate records of the Earth. The GSFC Polar Operational Environmental Satellites (POES) Project provided five of the instruments for MetOp-B via a reimbursable agreement between NOAA and NASA. MetOp-B is scheduled to launch from Baikonur, Kazakhstan on a Soyuz launch vehicle on September 17, 2012. This paper presents an overview of the MetOp program, the NASA instruments on MetOp-B, the MetOp-B spacecraft, the integration of the U.S. instruments on MetOp-B, and the MetOp-B launch campaign.

MetOp Program

The MetOp program consists of a series of polar orbiting meteorological satellites operated by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). In November 1998, NOAA and EUMETSAT established the Initial Joint Polar System (IJPS) to collaborate on two polar-orbiting satellite systems and their respective ground systems. The purpose of the IJPS is to collect and exchange the polar satellite environmental data between NOAA and EUMETSAT and to disseminate the data to users worldwide in support of continued and improved operational meteorological and environmental forecasting and global climate monitoring. A third satellite, MetOp-C, was added to the IJPS in 2005. The MetOp satellites form the space segment space segment of EUMETSAT's Polar System (EPS). In addition to the space segment, the EPS comprises the ground segment, the launch system, and various infrastructure elements.

The MetOp series of spacecraft were jointly developed by EUMETSAT and the European Space Agency (ESA). Astrium built the MetOp spacecraft under contact to ESA. NOAA contributes instruments to EUMETSAT built by NASA. These instruments are also flown on the NOAA POES satellites developed by NASA for NOAA. The five NASA instruments on MetOp-B are described below. The MetOp-B spacecraft also carries instruments developed by the Europeans and Canadians. This global observing system is able to provide invaluable meteorological data from polar orbit to users within 2 hours and 15 minutes of measurements being taken.

MetOp-A, which was launched in October 2006, is in a sun synchronous "morning orbit" and passes over the Equator at the same local time each orbit at 9:30 am. MetOp-B will replace MetOp-A in a polar orbit 817 kilometers above earth and is expected to last five years. NOAA-19, launched in February 2009, was the final of 15 satellites developed by the POES Project for NOAA. NOAA-19 provides the "afternoon orbit" crossing the equator every orbit at 2:30 pm local time at an altitude of 870 km. The dual satellite system (MetOp am mission and the POES pm mission) ensures that every part of the earth is regularly observed at least twice every 12 hours and the data is used by NOAA's National Weather Service for weather forecasting. Low Earth Orbit ensures high-resolution data from the instrument suite. The solar incidence angle on the Earth's surface associated with a morning or afternoon polar orbit provides good contrast and shadow conditions for global imagery. The NASA developed instruments on MetOp-B measure temperature and humidity profiles of the atmosphere from the Earth's surface to the stratosphere

(45 km); image the Earth's surface and cloud cover; and monitor charged particles *in situ*.

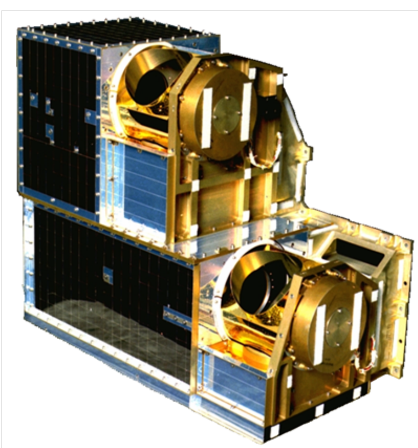
GSFC Developed MetOp-B Instruments

This section describes the five instruments developed by NASA for MetOp-B. These instruments are also flown on MetOp-A, NOAA-15, NOAA-16, NOAA-17, NOAA-18 and NOAA-19. The instruments are: the Advanced Microwave Sounding Unit (AMSU)-A1, AMSU-A2), the Advanced Very High Resolution Radiometer (AVHRR), the High Resolution Infrared Radiation Sounder (HIRS), and the Space Environment Monitor (SEM). The AMSUs measure global atmospheric temperature and moisture. The HIRS measures global scene radiation in the infrared spectrum. The AVHRR takes global imagery in the visible and infrared spectrum. SEM's science mission is space environment monitoring.

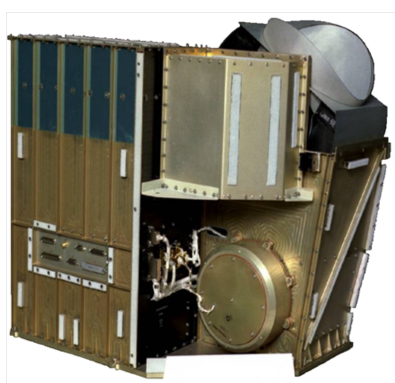
AMSU-A1 and AMSU-A2

The AMSU-A is a cross-track scanning total power radiometer. It was designed and manufactured by Aerojet (now Northrop Grumman Electronics Systems) in Azusa, CA under contract to NASA/GSFC. The AMSU-A instruments measure scene radiance (temperature) in the microwave spectrum. The data from the AMSU-A1 and AMSU-A2 are used in conjunction with the HIRS to calculate the global atmospheric temperature and humidity profiles from the Earth's surface to the upper stratosphere. The data is used to provide precipitation and surface measurements including snow cover, sea ice concentration, and soil moisture. AMSU data is even used to characterize the internal structure of hurricanes.

The AMSU-A is divided into two physically separate modules, each of which operates and interfaces with the spacecraft independently. AMSU-A1 contains 13 channels and AMSU-A2 contains 2 channels. Both AMSU-A1 and AMSU-A2 have an Instantaneous Field-of-View (IFOV) of 3.3° at the half-power points providing a nominal spatial resolution at nadir of 48 km (29.8 mi). The antennas provide a cross-track step scan, scanning ± 48.3° from nadir with a total of 30 Earth fields-of-view per scan line. Both AMSU-A1 and AMSU-A2 complete one scan every 8 seconds.



AMSU-A1



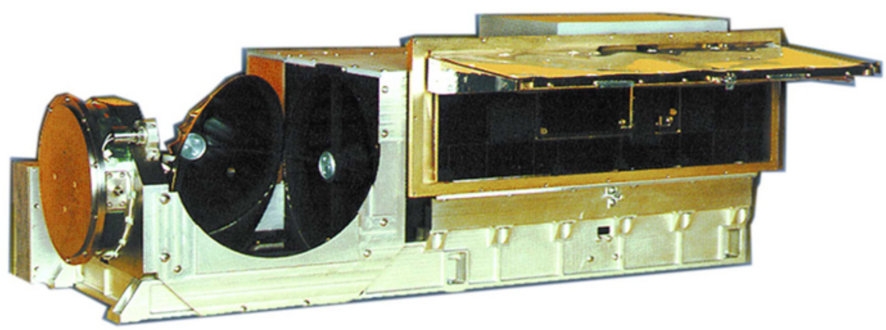
AMSU-A2

AVHRR

The AVHRR was developed and manufactured by ITT (now Exelis) in Ft. Wayne, IN under contract to NASA/GSFC. The AVHRR is a six-channel imaging radiometer which detects energy in the visible, near infrared, and infrared portions of the electromagnetic spectrum. The instrument measures reflected solar (visible and near-IR) energy and radiated thermal energy from land, sea, clouds, and the intervening atmosphere. Data from the AVHRR are used to produce numerous science products including imagery, cloud cover, snow and ice cover, sea surface temperatures, vegetation, smoke plumes, volcanic ash, aerosols, and absorbed incoming solar radiation to the Earth and out-going radiation from the Earth.

The AVHRR has an IFOV of 1.3 milliradians providing a nominal spatial resolution of 1.1 km (0.69 mi) at nadir. A continuously rotating elliptical scan mirror provides the cross-track scan, scanning the Earth from ± 55.4 degrees from nadir. The mirror scans at six revolutions per second using a 360 RPM Brushless DC motor to provide continuous coverage.

The AVHRR has 3 visible channels and 3 infrared channels although only 5 channels of science data are continuously downlinked. Channel 3A, a visible channel at 1.6 microns, provides snow, ice, and cloud discrimination and is downlinked during the daylight portion of the orbit. Channel 3B is an infrared channel that is downlinked during the night time portion of the orbit.



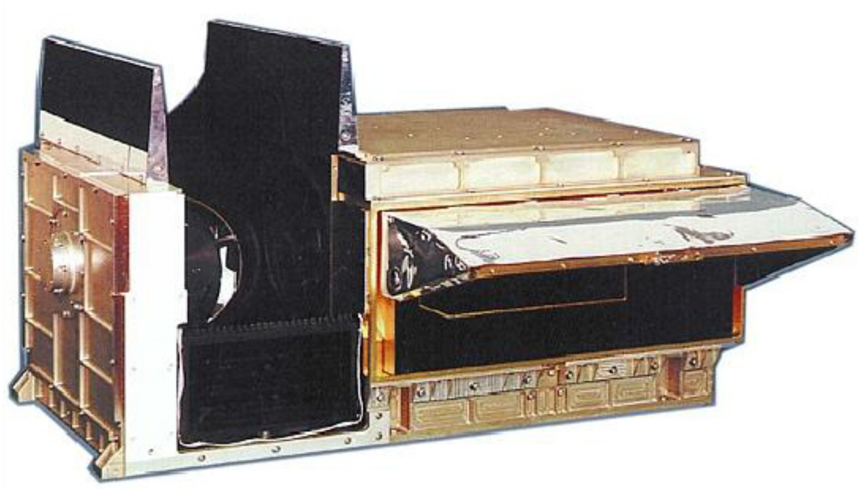
AVHRR

HIRS/4

The HIRS was developed and manufactured by ITT (now Exelis) in Ft. Wayne, IN under contract to NASA/GSFC. The HIRS measures the atmosphere's vertical temperature and humidity profiles and the pressure of Earth's surface.

The HIRS is an atmospheric sounding instrument that provides multi-spectral data from one visible channel (0.69 micron), seven shortwave channels (3.7 to4.6 microns), and 12 longwave channels (6.7 to 15 microns) using a single telescope and a rotating filter wheel containing 20 individual spectral filters. The IFOV for each channel is approximately 7.0 degrees that encompasses a circular area of 10 km (6.2 mi) in diameter at nadir on Earth. An elliptical scan mirror provides a cross-track scan of 56 steps of 1.8 degrees each. The mirror steps rapidly, and then holds at each position while the optical radiation passing through 20 spectral filters is sampled. Each Earth scan takes 6.4 seconds and covers ±49.5 degrees from nadir.

Data from the HIRS is used, in conjunction with the AMSU instruments, to calculate the atmosphere's vertical temperature profile from the Earth's surface to about 40 km (24.9 mi) altitude. The data is also used to determine ocean surface temperatures, total atmospheric ozone levels, perceptible water, cloud height and coverage, and surface radiance.

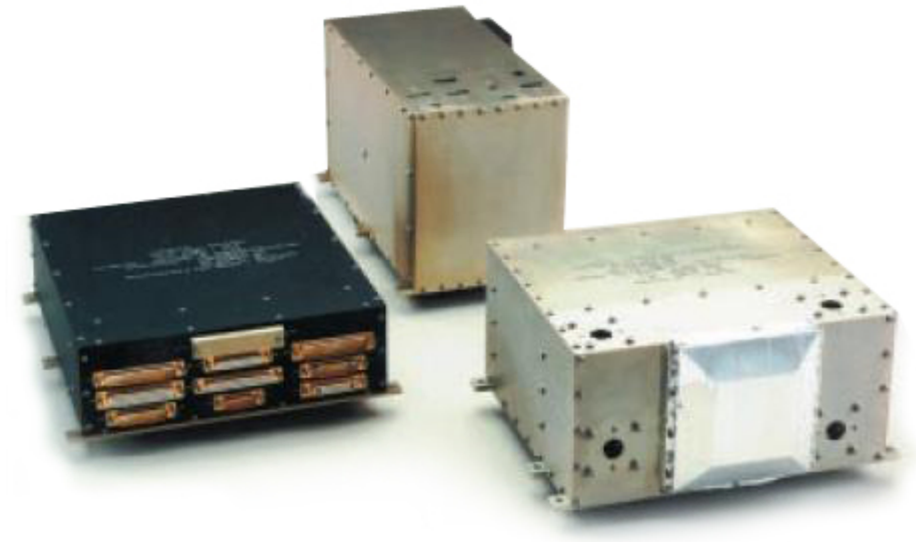


HIRS

SEM

The Space Environment Monitor was developed and manufactured by Panametrics in Waltham, MA under contract to NOAA and is now maintained by Assurance Technology Corporation (ATC) in Chelmsford, MA under contract to NASA/GSFC. The SEM measures the charged particle environment at satellite altitude including the intensities of energetic particles in the Earth's radiation belts and the solar wind. The SEM contributes to Space Weather forecasting by providing warnings of solar wind occurrences that may impair long-range communications, cause damage to satellite circuits and solar panels, or cause changes in drag and magnetic torque on satellites.

The SEM consists of two separate sensor units and a common Data Processing Unit (DPU). The sensor units are the Total Energy Detector (TED) and the Medium Energy Proton and Electron Detector (MEPED). The DPU serves as the interface between the sensors and the spacecraft. The TED senses and quantifies the intensity in sequentially selected energy bands. The particles of interest have energies ranging from 0.05 keV to 20 keV. The MEPED senses protons, electrons, and ions with energies from 30 keV to levels exceeding 6.9 MeV.



SEM

Other MetOp-B instruments

The MetOp-B payload consists of internationally developed instruments. MetOp-B carries eight instruments in addition to the five U.S. instruments described above. Four of these also flew on the POES NOAA-N Prime spacecraft: the English Microwave Humidity Sounder, the Canadian Search and Rescue Repeater, the French Search and Rescue Processor, and the French Advanced Data Collection System. Four European instruments were developed for the MetOp series: the French Infrared Atmospheric Sounding Interferometer, the German Advanced Scatterometer, the Swedish Global Navigation Satellite System Receiver for Atmospheric Sounding, and the Italian Global Ozone Monitoring Experiment. The MetOp-B payload is the same as MetOp-A. More information about the complete payload can be found at the URLs shown below.

MetOp-B Spacecraft

The MetOp-B spacecraft is large; its on-orbit dimensions are 17.6 × 6.5 × 5.2 meters and its mass is over 4,000 kg. MetOp-B has a modular construction. It consists of a Payload Module (PLM) developed by Dornier (now Astrium) in Friedrichshafen, Germany and a Service Module (SVM) developed by Matra Marconi (now Astrium) in Toulouse, France. All instruments are integrated on the PLM which distributes power, provides thermal control, provides instrument command and control, and provides data acquisition, handling and storage. The SVM provides power, attitude and orbit control, distribution of commands, telemetry generation, and launch vehicle interface. The MetOp-B spacecraft is shown below in a photo taken at the launch site; its size can be inferred from the people in the picture.

MetOp-B (ESA photo)

<u>U.S. Instrument Integration into MetOp-B</u>

The GSFC, ITT, Northrop Grumman, and ATC teams interfaced extensively with NOAA, EUMETSAT, ESA, and Astrium during the integration of the U.S. instruments into MetOp-B. There was excellent cooperation between all parties. The English language is used for communication and documentation in the MetOp program. Telecons, meetings, reviews, minutes of meetings, action items, anomaly review boards, Interface Control Documents, presentations, email, etc. are all conducted and written in English making it easier for the Americans. The GSFC team supported instrument delivery, annual instrument activation, spacecraft level environmental testing, and the launch campaign. GSFC supported reviews conducted by EUMETSAT and ESA providing the required documentation in the necessary format. NASA support for MetOp-B was provided on-site in Europe and Asia and remotely from the U.S.

GSFC had already accepted the instruments from the contractors before they were delivered to Astrium in Friedrichshafen, Germany. The HIRS was delivered to Astrium in 2003. The AMSU-A1 and AMSU-A2 were both delivered to Astrium in 2007. After recalibration, the AVHRR was redelivered to Astrium in 2011. After recalibration, the SEM sensors were redelivered to Astrium in 2011. Dynamics testing was performed in Toulouse, France in December 2003-January 2004 on the mated PLM and SVM. The PLM and SVM were then separated. Annual instrument activation on the PLM was performed in Friedrichshafen, Germany. Thermal vacuum testing was conducted on the PLM at ESA's Technical Center in Noordwijk, Holland in 2010. The PLM and SVM were mated into the MetOp-B configuration in September 2011 for final prelaunch testing in Toulouse. They were then separated and the PLM and SVM were flown from Toulouse to Moscow to the launch site in separate containers arriving in Baikonur on March 6, 2012 for the scheduled launch date of May 23, 2012.

MetOp-B Launch Campaign

The MetOp-B launch campaign proceeded on schedule at the launch site for several weeks. The SVM and PLM were mated into the MetOp-B flight configuration. All instruments were tested in March. In late April 2012, less than one month before the scheduled May 23 launch, the launch campaign was halted. Russia leases the Baikonur Cosmodrome, which had been part of the Soviet Union, from Kazakhstan. In April, Kazakhstan refused to grant permission to Russia to launch MetOp-B. Kazakhstan stated that the flight path of the Soyuz rocket to reach polar orbit would travel over heavily populated areas, creating risk and safety considerations when pieces of the launch vehicle were dropped. Kazakhstan felt that this flight trajectory was not covered by the lease agreement between Russia and Kazakhstan (this issue did not arise on the MetOp-A launch which followed the same path to orbit). This standoff between Russia and Kazakhstan impacted other launches in addition to MetOp-B. The dispute was finally settled by Russian President Putin and Kazakhstani President Nazerbayev. The MetOp-B launch campaign was resumed on July 10, 2012 with the new launch date of September 19, 2012 which was later accelerated by two days to September 17, 2012. An aliveness test of the U.S. instruments in early August showed that all NASA instruments were nominal.

GSFC and the instrument contractors provided continuous on-site support in Baikonur from February 21, 2012 through May 10, 2012. They traveled to Baikonur through Moscow and took charter flights arranged by ESA to and from Baikonur. The GSFC team and the European team stayed at the Sputnik Hotel where room and board were provided. NASA had a small office in the Cosmodrome facility where MetOp-B was undergoing launch preparations. They traveled to the Cosmodrome by bus and worked 6 days a week with Sunday off. On Sundays, the team toured the museums at the Cosmodrome and went into Baikonur city which had a big open-air bazaar and restaurants. All who went to Baikonur agreed that the trip had been a real adventure. GSFC and the instrument contractors will travel to Baikonur in September for final instrument inspections and prelaunch preparations.

MetOp-B is scheduled to be launched on a Russian Soyuz launch vehicle with a Fregat upper stage from Baikonur, Kazakhstan on September 17, 2012 at 16:28 GMT (12:28 pm EDT). MetOp-B will be operated by EUMETSAT in Darmstadt, Germany. GSFC and the instrument contractors will perform the post launch checkout of the U.S. instruments. When MetOp-B is declared operational, the data from the instruments will be used for operational weather forecasting by the Europeans and NOAA's National Weather Service. Historically, the GSFC developed instruments have significantly exceeded their designed life.

MetOp-B is expected to be operational for five years however, historically, the GSFC developed instruments have significantly exceeded their designed life. MetOp-C, the final satellite in the MetOp series, will probably be launched in 2017 or 2018. Metop-C will be launched on a Soyuz rocket from the European spaceport near Kourou in French Guiana.

URL references for more information

http://www.nesdis.noaa.gov/SatInformation.html
http://www.eumetsat.int
http://www.esa.int