

Reducing the age of the polar orbiting meteorological satellite observation data delivered to the end-user meteorological centers improves the availability of accurate forecasts.

III. The Goal: Halving the Data Latency without Impact on Availability

The basic concept to achieve the reduction in data latency is to supplement the baseline Arctic Data Acquisition ground station facility at Svalbard with an Antarctic Data Acquisition (ADA) capability.

Data latency is measured from the time of sensing on-board the satellite to arrival of the corresponding data products at end-user facilities. Sensed data must be stored on-board the satellite until such time that it comes into visibility of a data acquisition facility and that implies that the oldest data being dumped from the recorders to Svalbard would be one orbit, or around 100 minutes old. With the addition of the ADA facility, the data storage time on-board is effectively halved and this benefit is carried forward to the end-to-end delivery time to end-users. This storage time on-board the satellite is by far the most significant driver in the achievement of the stated delivery timeliness requirements. The goal was therefore to achieve a worst-case end-to-end delivery timeliness in the order of 65 minutes (compared with the original system specification of 135 minutes). Note that this worst-case time corresponds to the delivery of the oldest data recorded on-board the satellite (having just missed the dump of the previous orbit).

Figure 2 illustrates this with the left-hand diagram showing the dump at Svalbard only (SVL CDA), along with the extent of data which it acquires (full-orbit), with the right-hand diagram showing the addition of ADA and the data acquired there (half-orbit). It will be noted that a full-orbit of data is still acquired at Svalbard, despite the first-half having already been dumped over ADA. The reason for this is to ensure additional robustness of the system, in case the ADA facility was not to perform with the same reliability (taking into account also the delivery of data from Antarctica to EUMETSAT). It will be seen throughout this paper, that a strong emphasis was put on ensuring that the completeness of data which the users had come to expect during the operations of Metop-A would not be compromised by the addition of ADA and the related system changes. This has been a key driver to the design, implementation, verification and validation activities, and to the maintenance processes put in place.

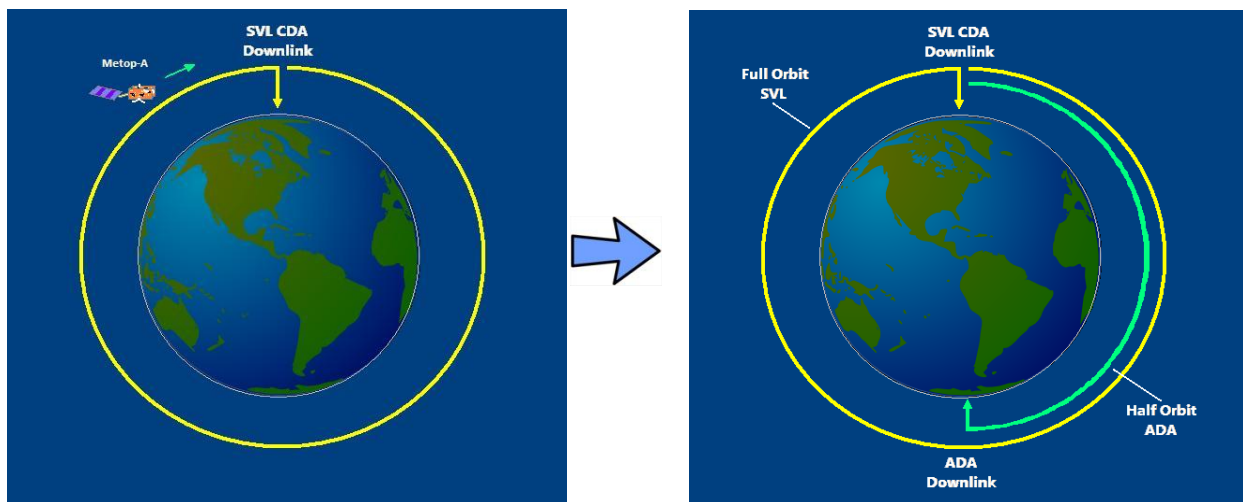


Figure 2. Metop dump strategy with Svalbard-only (left) & SVL with Antarctic Data Acquisition (right)

IV. The Team: An International Partnership

After having surveyed existing ground station infrastructure in Antarctica, EUMETSAT reached an agreement with NOAA for the usage of the McMurdo Sound facility to take the role of the ADA ground station supporting the Metop dumps. EUMETSAT and NOAA were already closely co-operating in the definition and operation of their Low Earth Orbit (LEO) meteorological satellite programs through the Initial Joint Polar System comprising the NOAA-18 and NOAA-19 satellites with an ascending equatorial crossing at a mean local solar time in the afternoon and EUMETSAT's Metop-A satellite which descends across the equator in the morning, ensuring global coverage at intervals of no more than six hours.

As part of the then National Polar-orbiting Operational Environmental Satellite System (NPOESS) program development, now Joint Polar Satellite System (JPSS), the Metop series of satellites had been foreseen to take the

role of the mid-morning orbit, such that the US would only supply afternoon satellite observations. This program also had demanding data latency requirements and as such, it was mutually beneficial to EUMETSAT and to the US to work together on providing early operational demonstration of low data latency delivery through ADA.

There are two phases identified within this agreement. A Demonstration Phase started in 2011 and is foreseen to last until early-to-mid-2014, when the Operational Phase commences. During the Demonstration Phase, an average of nine Metop passes per day were foreseen to be acquired at McMurdo, whereas in the Operational Phase, all passes of the prime Metop satellite will be acquired. The key factor allowing this shift from Demonstration to Operational phase will be the evolution of the Near-Earth Network (NEN) mission loading for the MG1 antenna, allowing Metop to be supported fully at the highest priority.

The McMurdo Station, located on the southern portion of Ross Island, is under the responsibility of the US National Science Foundation (NSF), while the McMurdo Ground Station (MGS) supporting the Metop acquisitions using the MG1 antenna is under the responsibility of NASA. Communication links for transferring the Metop data to EUMETSAT are under the responsibility of NSF and NOAA. EUMETSAT is responsible for commanding the Metop dumps over McMurdo, the data processing and dissemination to European users and to NOAA, with NOAA responsible for servicing their user community with the Metop data transferred from EUMETSAT.

A truly international partnership was therefore put in place to achieve the goal of the ADA Project. Reference 1 contains an in-depth discussion of this partnership and how it was able to ensure the success of the endeavor,



Figure 3. The Initial Joint Polar System combines operational data services support from both EUMETSAT and NOAA satellites

V. Target System with ADA

The implementation of ADA not only introduced new facilities to the EUMETSAT Polar System (EPS), but also required the upgrade of many existing operational facilities. It is the upgrade of the existing EPS ground segment which had to be most carefully handled when considering that there should be no adverse impact on the currently achieved reliability and data completeness to end-users. Figure 4 shows a simplified view of the EPS system with the addition of the McMurdo ADA facility and other additions made at system level, together with comments as to the nature of the changes made. The comment fields are also color-coded to indicate the responsible partner for the changes introduced.

With reference to Figure 2, EUMETSAT schedules the data dumps of Metop to occur over McMurdo in addition to the Svalbard Command and Data Acquisition (CDA) Facility. The planning of the dumps is performed in an iterative process adapted from that used between NOAA and EUMETSAT for IJPS planning. In this case, it is the NASA Wallops Orbital Tracking Information System (WOTIS) that is responsible for scheduling McMurdo pass support operations, as part of their overall responsibility for planning and scheduling the data acquisition network of NASA. Once the plan is confirmed, the EUMETSAT Mission Planning Facility (MPF) generates the schedule for Metop and the EPS ground segment, including the necessary Metop dump commands. The status of the McMurdo Ground Station and Metop Data Acquisition performance is made available using an internet-based monitoring screen derived from NASA generic monitoring and control displays. With the same information available to all partners, clear communication can take place in case of observed anomalies.

The EPS Mission Control System (MCS) has been adapted to calculate the Metop on-board Solid State Recorder (SSR) pointer position required in order to re-dump over Svalbard the descending part of the orbit already dumped over McMurdo. It shall be recalled that this re-dump has been implemented in order to ensure that unplanned unavailability of ADA data does not impact the completeness of data sent to end-users. The Metop satellite dump commanding therefore also includes the required pointer repositioning commands as calculated by the MCS.

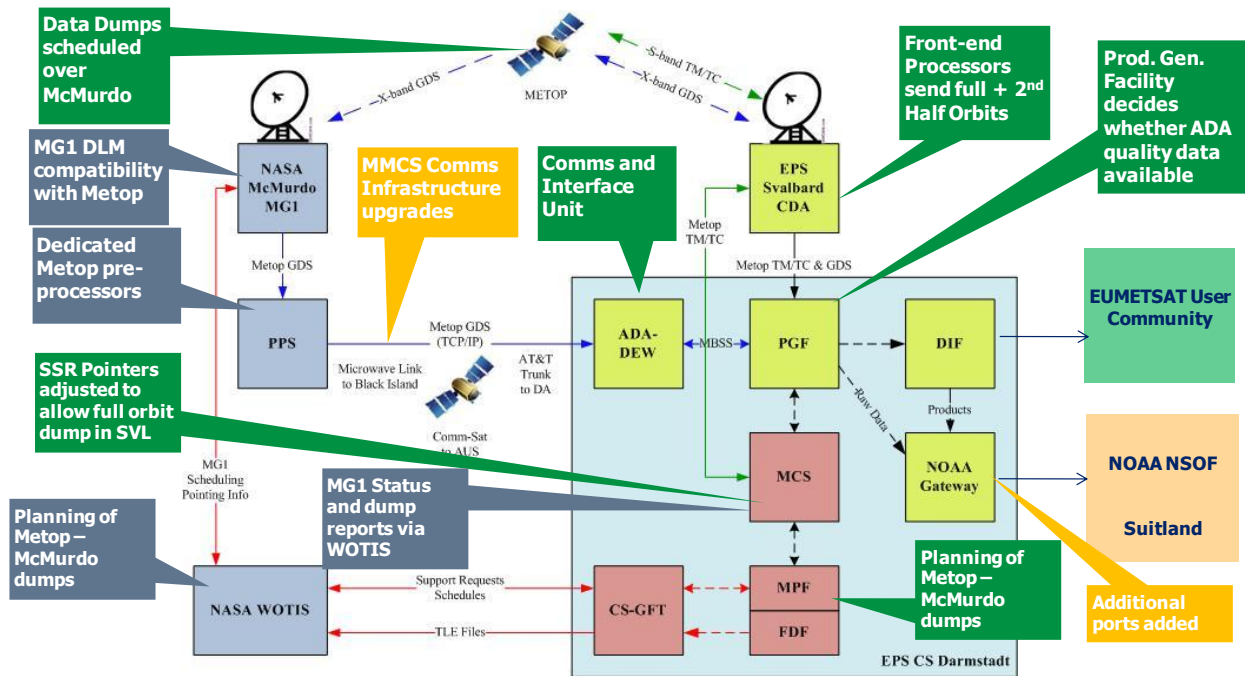


Figure 4. A summary of Metop-A Antarctic Data Acquisition System Upgrades and Changes. Comment fields are color-coded (Green for EUMETSAT; Grey for NASA, Gold for NOAA)

In preparation for the start of Metop operations, NASA performed a full refurbishment – or Depot Level Maintenance (DLM) – of the McMurdo Ground Station antenna. This included upgrading it to support Metop S-band autotrack and X-band data reception frequencies.

Acquired Metop data is pre-processed in McMurdo by a dedicated Pre-Processing System (PPS) supplied by NASA. The PPS communicates using accelerated TCP/IP with a dedicated facility at EUMETSAT (ADA DEW).

The communication link itself is multi-faceted, comprising firstly an NSF provided microwave link from the main McMurdo base on Ross Island to Black Island, some thirty kilometers away, in order to achieve a clear line-of-sight to Optus communications satellites which downlink the data to reception stations in Australia (Figure 5). Data is then transferred to a fiber-optic backbone under the responsibility of NOAA through to the EUMETSAT Central Site (CS) in Darmstadt, Germany. Data rates up to 20 Mbit/sec are achievable through this link.

A consequence of the decision to always dump a full-orbit at Svalbard is that if we simply transfer the full orbit through to EUMETSAT, the transmission time of the first half orbit, which nominally will have already been received by EUMETSAT from McMurdo, will delay the arrival of the second-half orbit containing the new data. Since the transmission data rate used from Svalbard is just 4Mbit/sec, this could add an additional 40 minutes to the delivery time. Therefore, the Front-End Processors have been upgraded to extract the second-half data from the full-orbit dump and transmit this in parallel to the full-orbit (both streams at 4 Mbit/sec).

With descending orbit data arriving from McMurdo and a full orbit, plus an ascending half orbit arriving from Svalbard, the Product Generation Facility (PGF) has been upgraded to deal with this. In particular, it is the PGF which is programmed with the logic to determine whether the ADA data from McMurdo meets quality criteria such that the data completeness expected by users is not significantly compromised. If the PGF determines that McMurdo data do not meet the required criteria, then any data



Figure 5. McMurdo and Black Island to Optus Communication

received will be discarded and the PGF will process the full-orbit data from Svalbard instead, meeting original data latency requirements.

Downstream of the PGF, the dedicated product processors (not shown in Figure 4) providing higher level products are essentially unchanged and the Dissemination Facility (DIF) has been able to cope with the peak loads without adding capacity. These peak loads occur when McMurdo dumps resume after a planned/unplanned unavailability. The overall margin in the end-to-end chain is a key factor allowing recoveries to a steady-state delivery timeliness in less than one orbit after the missing ADA dump. For NOAA, it was necessary to add more ports at the NOAA Gateway, which is responsible for the transmission of raw Metop data and higher level products sent to the NOAA Satellite Operations Facility (NSOF) in Suitland, Maryland, USA. No other hardware upgrades to support the ADA data flow were necessary at NSOF.

NSOF also act as the central coordinator of status and anomaly reports, taking inputs from the independent reporting systems of NOAA, NASA and EUMETSAT. NSOF also have the capability to raise new anomaly reports directly in the EUMETSAT Anomaly Processing Tool (APT) to allow for faster a clearer communication of information. Representatives from all these organizations coordinate investigations and actions, as well as general operational reviews and maintenance planning on a weekly basis.

VI. Implementing ADA across the System: The Challenge

A. Management Challenges

From a management perspective, implementing ADA had many challenges. As a multi-partner system involving several US agencies as well as EUMETSAT, clear coordination and understanding of each other's needs and perspectives were paramount to the success of the project (Reference 1). Furthermore, within the work conducted in EUMETSAT, most of the project team expertise had to be borrowed from operational maintenance or program development teams and as such little dedicated effort could be applied, making the project susceptible to unavailability of specific personnel due to higher priority commitments within the Organization. This rarely caused a problem progressing, since identification of back-up personnel, regular coordination and corresponding status and action reports and some flexibility in rescheduling tasks was available.

The schedule was however constrained by the preparations for Metop-B, in that the related upgrade of the Metop-A ground segment and procedures to support dual Metop operations had to be validated on a stable ground segment baseline design. A timely and low-risk Metop-B preparation was clearly a priority for the Organization over ADA activities. With validation testing of Metop-B scheduled to commence in the second-half of 2011, this was a hard constraint. Failure to achieve readiness before this would lead to delays in implementing ADA in the order of one to two years, due to the coordination with activities performed at McMurdo during the Austral summer.

This challenge was compounded when, due to US budgetary reasons, following the Preliminary Design Review at EUMETSAT, the program had to be put on hold for one year. A revised scope proposal was agreed by all parties in mid-2009, leaving less than 2 years to implement and validate all aspects of the endeavor.

B. McMurdo Ground Station Enhancements

The McMurdo Ground Station (MGS), currently consisting of a single antenna (designated MG1), is considered a single point of failure – a fact that is exacerbated by its remote location which is inaccessible for multiple months per year and therefore susceptible to possibly experience extended service outages. NASA uses MGS to recover launch vehicle telemetry and science data on a “best effort” basis and avoids relying on this site to fulfill spacecraft-critical health and safety requirements.

To support Metop, the dual requirements of extremely high availability of the MG1 antenna and the long mission life of the Metop series – five years past the future launch of Metop-C launch (currently planned for 2017) – along with the fact that MG1 would be the only antenna system available to meet the ADA requirements, dictated a DLM of the existing 10m antenna system which had been in continuous operational use since 1996. The DLM consisted of: pedestal overhaul; radome maintenance; replacement of obsolete equipment (motors, drive amplifiers, and data packages); replacement of degradable equipment (heaters and cables) and civil engineering to prepare for the crane lifts.

The upgrade would also transform MG1 into an “operational” system. Performing this DLM in parallel with the ground station electronics upgrades required to support Metop added a major complicating civil engineering activity to NASA and NSF portion of the ADA project.

The most significant challenges placed on NASA were the logistics of performing the DLM and ground station upgrade in Antarctica and the impact of weather constraints on the schedule (principally wind limits for the radome opening for the DLM, which were less than the average wind speed). The overall ADA schedule and the Austral summer work season at McMurdo Station required that MG1 be placed into Initial Operational Capacity by the end of February 2011. Also, the work window for all the activities would not open until mid-November 2010. Furthermore, NASA’s agreement with NSF to limit NASA’s permanent contractor staffing level at McMurdo to two contractors (excluding the MG1 upgrade staff and normal sustaining engineering trips) required the implementation of a Remote Monitor and Control capability from NASA’s Wallops Ground Station, which transformed the on-site personnel from operators to sustaining engineering roles for maintenance and troubleshooting.

MG1’s first acquisition of data from Metop-A satellite at occurred on 19 January 2011. This was followed by the continuation of extensive testing and data evaluation by NASA and EUMETSAT to conduct verification and validation activities and to trouble shoot issues.

C. Network Enhancements

One of the prerequisites for the McMurdo site to be capable to support NOAA programs (including the downlink service for Metop data) was a significant increase in the bandwidth of the data communications link to/from McMurdo.

The upgrade of the satellite communications segment required an agreement between NOAA and Optus for the inclusion of a McMurdo spot beam on the future Optus D1 and D2 satellites. Associated upgrades to the RF equipment and power generation equipment at Black Island needed to be planned and implemented without disruption to the existing communications links. To control access to the communications link, upgrades were needed to the communications equipment in McMurdo. To deliver the data the AT&T global MPLS backbone WAN service was used, providing access points in Belrose, the USA and EUMETSAT. Figure 7 shows the end-to-end communication architecture.

Long term analysis (2 years) of the Eb/N0 statistics from the existing satellite modems in Black Island and Belrose (near Sydney, Australia) showed no evidence of scintillation problems (which occur on the satellite link between EUMETSAT and Svalbard), but revealed problems with the reception at Belrose during the January - March period when very heavy rainfall can cause a loss of communications for up to 10 minutes. Further discussions between NOAA and Optus resulted in the solution of

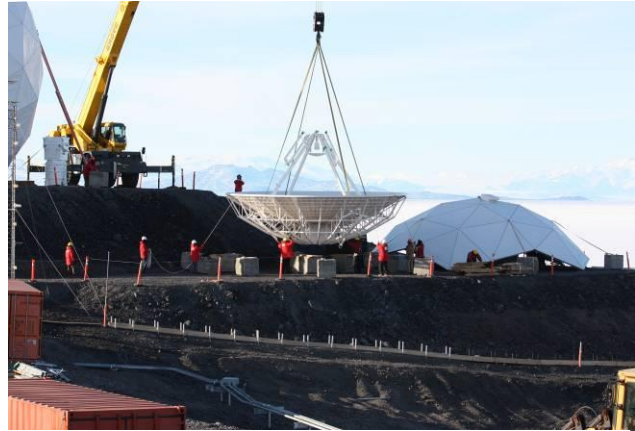


Figure 6. NASA-NSF Antenna DLM crew removes the MG1 reflector (7 December, 2010). Photo credit NASA.

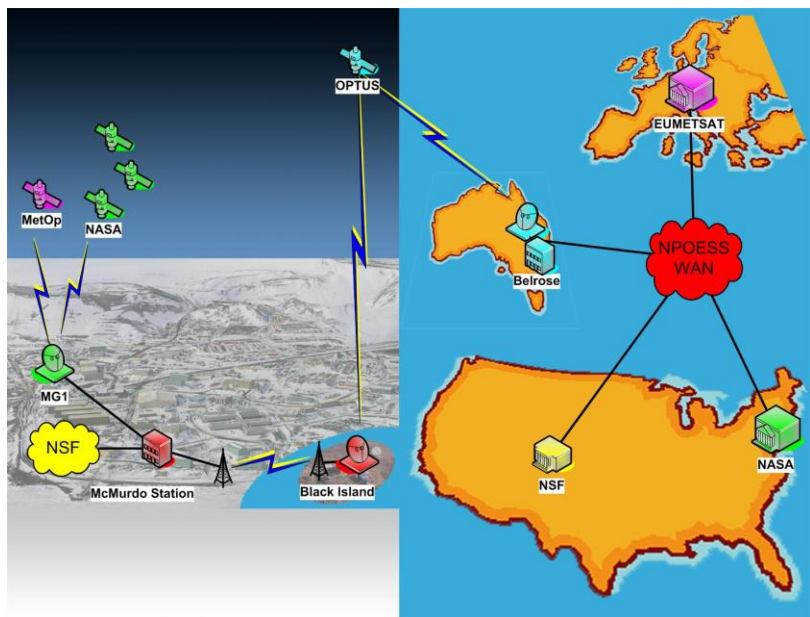


Figure 7. End-to-end ADA communications

using the Optus antennas in Perth during such periods and routing the data from Perth to Sydney over fiber links.

Simulations of the bandwidth needed to meet NSF requirements and the requirements for existing and future satellites (NOAA, NASA, EUMETSAT) indicated that the maximum bandwidth obtainable within the scope of feasible upgrades (60Mbit/sec outbound/20Mbit/sec inbound) would be insufficient at peak periods and that bandwidth control, based on priorities, needed to be introduced. In the case of the Metop data stream, a minimum of 5 Mbit/sec could be guaranteed, with a peak bandwidth of 20Mbit/sec available in the absence of higher priority data streams.

To handle the well known problem of using TCP for high rate transmission over a long delay path, Cisco WAE equipment was selected and link characterization tests were conducted by Raytheon to establish the optimal configuration of these devices. The WAE equipment and the link characterization servers are deployed at McMurdo, Belrose and Aurora, Colorado, USA. The characterization tests can be performed when necessary to check the links. Initially it was considered by EUMETSAT that the Front End Processor (FEP) equipment used in Svalbard to deliver the Metop data to EUMETSAT using reliable multicast should also be deployed in McMurdo. On detailed analysis of the logistics and lifetime maintenance aspects, EUMETSAT concluded that it did not have the necessary access or infrastructural framework needed to support and maintain the FEPs in McMurdo. NASA was asked to select suitable equipment to meet the EUMETSAT requirements and RTlogic equipment was selected (referred to a PPS in this paper). At the same time, the requirement for reliable multicast delivery was dropped, since the experience of EUMETSAT had been that its stability could be controlled sufficiently on a point to point link, but it was too risky to assume that it would be stable over a shared WAN service.

D. Changes to Satellite Operations

Due to the change in operational concept, at an early stage in the feasibility analysis, EUMETSAT requested the payload module contractor, Astrium GmbH to confirm the qualification limits for performing the additional ADA dumps were adequate to support the Metop operational lifetime. This was confirmed with sufficient margins to allow mission extension. A study was also performed as to how to change the SSR pointer positioning to enable full dumps to continue at Svalbard after a half-dump at McMurdo. A trade-off between a modification to on-board software versus an on-ground tool was performed. Although more robust when dealing with a potential SSR word-group memory failure, the on-board change was rejected, the on-ground solution being simpler and more affordable to implement, using in-house engineering support. SSR anomalies leading to unexpected pointer positions can be quickly detected by the on-ground system such that operator intervention can be made to revert to a Svalbard-only operation, until reprogramming is performed, thereby sacrificing timeliness, but not product availability.

E. Svalbard CDA Upgrades

As shown in Figure 8, the FEP at the Svalbard CDA sends the full-orbit dump to the Central Site PGF at a transfer rate of approximately 4 Mbit/sec, starting immediately after the data acquisition has started (i.e. while the dump is still being acquired).

At the centre of the dump acquisition window the FEP initiates a second data stream in parallel with the transfer described above, sending only the second half of the dump. This second transfer begins at a fixed but configurable time after the start of acquisition. This configurable value takes into account the shortest half-dump size already dumped over McMurdo. From the relative position of the Svalbard and McMurdo stations, and playback logic at highest elevation, it was possible to calculate minimum duration of ADA dump as 145 seconds.

Knowing that:

- the ADA dump cannot be shorter than 145 seconds,
- the SSR pointer is set back (including a small overlap to avoid any data gap) after the ADA dump,
- the SSR playback data rate is the same over Svalbard and ADA,
- the SSR playback command and acquisition parameters provided to the FEP are well synchronized,

it is possible to split the full dump in Svalbard by checking the Earth Received Time (ERT) of incoming data and skip the initial 145 seconds of data (currently configured to 143 sec to provide small overlap) to get the data not received over ADA station.

This “static” split has several advantages. It is very light on FEP resources as it only checks the timestamp of every 64th frame. To perform this check, there is no need to unpack the data. This method is not sensitive to acquisition problems and data gaps.

Implementing this approach requires a very simple change. Existing FEP commanding is untouched, and instead a second FEP distribution task must be added with a specific modification to filter data based on Earth Received Time.

There are some limitations though. As the difference in duration between the shortest and longest ADA dumps (caused by orbital geometry) is 11.5 seconds of acquisition (corresponding to almost 4 minutes of data mission

sensing time), the transmission of additional overlap data adds to the latency of the data. The implementation is also dependent on correct repositioning of the SSR read pointer after completion of the ADA dump. An additional element of overlap is mandated by the degree of accuracy with which the read pointer position is reported in telemetry and to the extent with which the future position of this read pointer can be estimated. More overlap in the SSR pointer repositioning contributes negatively to timeliness. Finally, this approach is sensitive to any time difference between the SSR playback time and the acquisition parameters provided to FEP, risking loss of data in the second half transfer to which the PGF would respond by defaulting to the full-orbit transfer with the resultant degradation of timeliness. This is not normally a significant issue but it can be a contributing factor when considering dump operations around significant spacecraft maneuvers.

Overcoming these inefficiencies would have been a major change to the fundamental design of the FEP and therefore a risk to the so-far excellent stability of the existing system. This simple solution was therefore clearly favorable.

GDS data transfer to CS as initiated by FEP

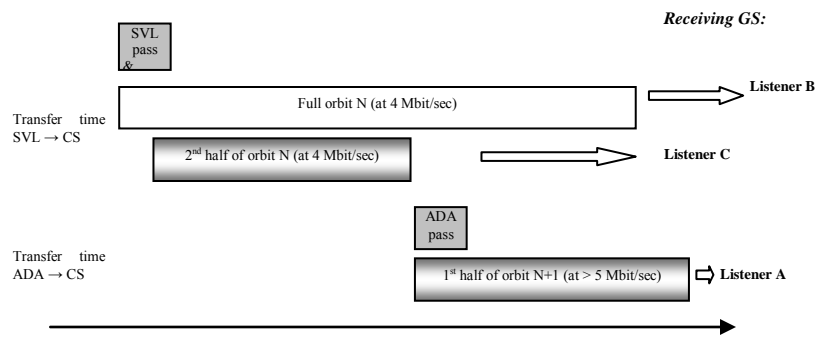


Figure 8. GDS data transfer to CS

F. Ensuring the system robustness against potential McMurdo data losses

To process data coming from different sources and handle different possible failure scenarios the PGF has required more significant changes. The initial design with the pipeline mode worked well with a single source of satellite data. With the addition of the ADA service, the first half of the dump was arriving from ADA while the previous dump was still being sent from Svalbard.

To account for this change in operation, the data reception function of the system needed to be de-coupled from the processing function. Multiple standalone receivers were therefore added, each listening to its own source of data (ADA, SVL, NOAA etc.) and writing received data to the disk. The processing function is still command driven, getting all needed parameters and list of sources from the commands generated by the M&C system.

From the command parameters, the PGF knows which sources should be processed and in which time window they are expected to arrive. As the quality of ADA service was not known in advance and with several years experience of reliable data reception from Svalbard, it was imperative that measures were taken to ensure that the introduction of ADA would not impact the baseline data service availability to end users. It should be noted that this implies the ADA system upgrades had to effectively meet data availability expectations which were significantly higher than the original baseline availability requirements. Figure 9 shows a typical availability of a level-1 product type over 6 months compared to the baseline availability specification. The quoted target

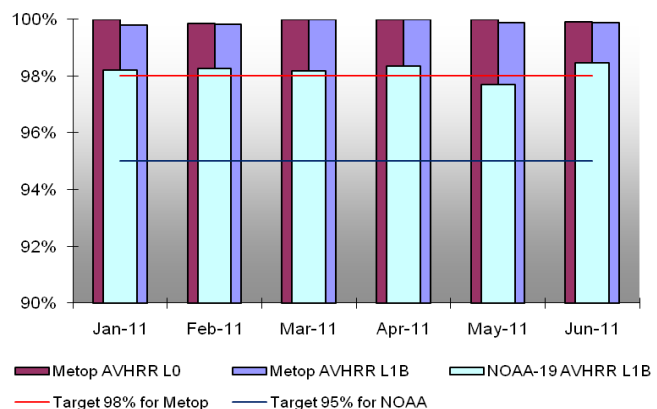


Figure 9. Delivery completeness statistics for AVHRR L0 and L1B products delivery to EUMETSAT users, covering the first-half of 2011

availability for Metop (98%) is already in excess of the baseline EPS requirement (95%), but even these targets are generally surpassed.

Logic was implemented to analyze incoming ADA data such that, should data completeness fall below a certain threshold (approximately 98%), the PGF would automatically switch to the Svalbard data (with poorer timeliness). As EUMETSAT also distributes Metop raw data to NOAA, this decision must be made before the data is processed by the PGF, at the level of VCDU, where only the ERT timestamp is easily available for analysis.

Knowing the ADA dump start time from the command, the PGF checks the timestamps of the first few VCDU frames coming from ADA; if the difference between the two is more than the configured threshold (indicating the loss of some data at the beginning of ADA dump), the PGF stops processing the ADA dump and switches to processing of the full-orbit dump to be received from Svalbard. Similar logic is implemented for the detection of data gaps within the ADA dump, with the PGF checking time differences between consecutive VCDU frames; if it is bigger than the configured threshold, it is added to the gap counter. When the total gap becomes bigger than the maximum allowed data gap, the PGF abandons processing of the ADA dump and switches processing of the full-orbit dump to be received from Svalbard.

If the ADA dump is determined to be of good quality (completeness in excess of the defined threshold), the PGF will complete processing the ADA dump then process the second half of the dump from Svalbard, received in parallel to full dump, keeping the timeliness of generated Level-0 products below 52 minutes.

G. Changes to the NOAA Ground Segment

To accommodate this difference in the operations concept, NOAA found that the system did not require major changes. The change was the addition of more ports at the NOAA Gateway. In conjunction with this, NOAA did take the opportunity to look at changes needed in its ground system for handling dual Metop satellites. Internal to the NOAA ground segment there was also the addition of a server to allow for reshipment of the GDS to the NOAA ingestors. Identification of the data source designation was established for the NOAA users. Data from MG1 was designated with the extension “MM”. These data sets would be ½ orbits from McMurdo and received on the south port. Files designated with “SV” would be from Svalbard on the North port.

NOAA also needed to verify that the receipt of ½ orbit data would not adversely impact product processing and productions from L1B to level 2 products.

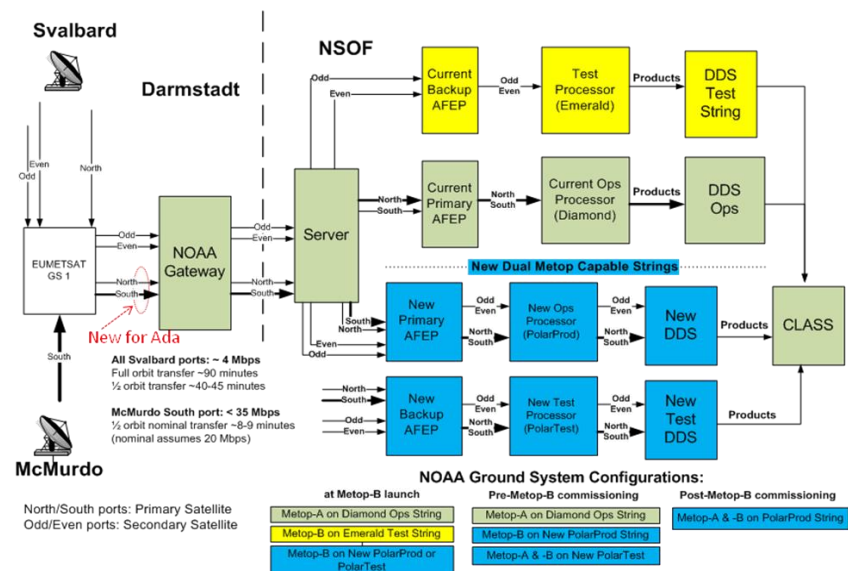


Figure 10. NOAA Ground Segment for ADA and Dual Metop

VII. Integration and Validation Challenges

Having a design and implementation is only half the story; The main challenge was to integrate these new components and significant functional upgrades to the already operational systems of the partner agencies and to ensure the full and timely validation of their performance with no impact to the availability or general quality of currently available operational services.

This required careful planning of inter-agency manpower and technical resources, taking into account the windows of opportunity provided by the Austral Summer period, when full engineering teams are available at McMurdo.

Focusing on the EUMETSAT perspective, the effective usage of verification and validation ground segments, combined with a thorough configuration management process was fundamental to the ability to manage the integration and validate it on a non-intrusive basis, or without excessive risk to existing operational services.

Some specific examples of methods used to integrate, verify and validate the key components and the system as whole are as described in the following paragraphs.

A. Early Testing of PPS

The NASA provided Pre-Processor System (PPS) is a key element for processing data from MG1 ground station and transferring the data to the ADA DEW component at EUMETSAT. Whereas in the data delivery from Svalbard, the FEP sends data by reliable multicast directly to the PGF elements, the PPS must send the Metop data in a TCP connection to the ADA DEW and the ADA DEW must then send the data by reliable multicast to the PGF elements. Because of these differences, it was essential to start testing between the PPS and the ADA DEW as early as possible, prior to deployment to the Antarctic. Not only did the software on the PPS need to be modified to meet EUMETSAT's requirements, but also the deployment of the PPS units and maintenance aspects had to be analyzed. The most critical requirements for the PPS related to autonomy (resilience to pass or link failures), redundancy and the longer term potential to handle data from multiple Metop satellites, two of which could be in orbit and need to dump data over McMurdo. To be fully autonomous both PPS units have to receive the Metop data and be ready to deliver it to either ADA DEW. They should be fully independent, but because of the bandwidth limitations only one should actually deliver the data to the ADA DEW. Should a PPS fail to deliver the data from a Metop pass (e.g. aborted pass or failure of the communications link), it should have an internal reset mechanism in order to be ready for the next pass.

Early testing over the internet between a PPS at Wallops, USA and an ADA DEW at EUMETSAT, allowed the above functionality to be tested. Different sets of recorded Metop data were injected into the PPS, simulating short and long passes. The data sets were modified to simulate different Metop satellites. The tests were focused on functional verification of the PPS to ADA DEW interactions, handling scenarios such as extended ADA DEW unavailability, VCID filtering, data aging threshold being reached during active transfer, link interruptions, abort of ADA DEW during transfer.

Although each PPS is acting autonomously, they are indirectly subject to control by the ADA DEWs, each PPS being configured to deliver data to a destination IP address. The actual address is a virtual IP address which can be activated on either ADA DEW. The PPS units are also configured with different destination TCP port numbers. When both PPS units have data they will independently try to open a TCP/IP connection to the virtual ADA DEW address. The ADA DEW which has the virtual IP address activated can select which PPS sends the data by listening only on the associated destination port number.

Note that these tests did not try to simulate the real-time telecommunications characteristics of the actual McMurdo to EUMETSAT link. This was not necessary in order to verify the software functionality. The performance of TCP/IP over the real link and the deployment of the WAE devices were tested in the link characterization tests described previously.

After the above tests were performed, two PPS units were shipped to McMurdo for early integration. The shipping of the third PPS (the cold spare) was delayed as long as possible so that it could be used for validation of software changes to fix any problems found at McMurdo. Although, due to budget and logistics constraints, no "local PPS" could be kept on US soil for trouble-shooting purposes, remote access mechanisms to PPS were available and became indispensable as end of Austral summer approached.

B. Early Downlink over McMurdo

The timely integration and validation of the newly refurbished MG1 antenna and supporting ground station equipment at McMurdo, within the constraints of the Austral Summer period was clearly fundamental to meeting the target date for the ADA Project. Indeed, failure to complete this process by the end of the summer would have automatically led to a one-year slip in McMurdo activities and possibly two-years to the start of the ADA Demonstration Phase, taking into account that the Metop-B launch and commissioning activities would most likely prevent EUMETSAT support during the following year.

In order to ensure a smooth verification of the space-ground link performance, EUMETSAT decided to put in place all operational changes to the satellite operation several weeks prior to the final integration of the MG1 antenna allowing good margin and ensuring that the operations were fully validated and reliable before EUMETSAT teams left for the holiday season. Dumps were scheduled over the MG1 position for every physical availability, such that no operational / test coordination had to be made between MG1 engineering teams and EUMETSAT. This implied that the satellite control aspects of ADA were fully operational many months before the data processing aspects of the system. Routine services with the Svalbard-only timeliness were not impacted, indicating a flawless operation of the pointer-repositioning tool and related satellite commanding.

C. Multiple Ground Segments for EUMETSAT Data Processing and Dissemination IV&V

The changes to the data processing aspects of the EUMETSAT ground system, comprising the Front-End Processor (FEP) and the Product Generation Facility (PGF) are the most significant of any existing facilities. It is critical that upgrades can be integrated and validated on a non-intrusive basis to on-going operations.

This upgrade process benefited greatly from the presence of three ground segment instances in EUMETSAT. The verification ground segment, (GS-3) is supplemented by a validation ground segment (GS-2) and the operational ground segment (GS-1). Note that each GS is internally redundant, meaning redundant equipment is not used for test purposes in GS-1. This allows failover testing and corresponding configurations to be fully validated and operators to be trained with no impact or risk to operational services.

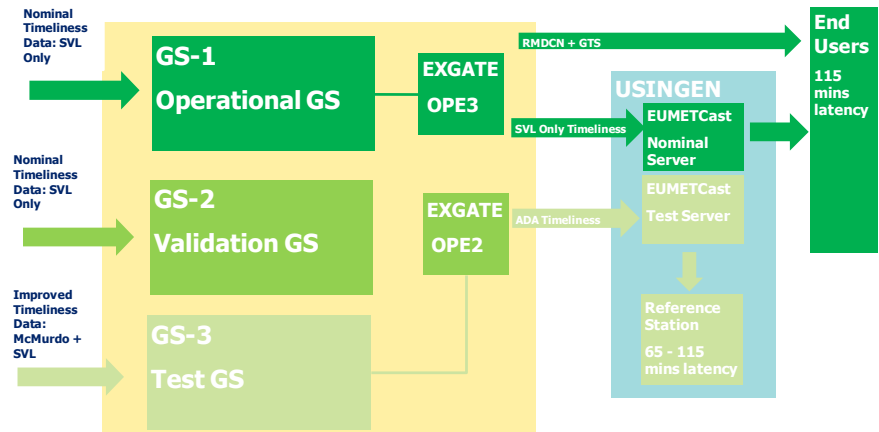


Figure 11. ADA Verification Testing using Ground Segment-3

A thorough configuration management process controls the authorization of new software versions, or hardware onto these GS instances, together with common elements and the Svalbard ground stations, ensuring completion of all necessary steps prior to roll-out onto the next level GS. None of these changes can take place without final approval by the Operations Configuration Management Meeting, held every working day, thus avoiding inadvertent impact with other activities or on the operational services themselves.

As part of this Ground Segment architecture, EUMETSAT had already procured an additional FEP located in the verification ground segment (GS-3). This is known as the “Local FEP”. Using simulated Svalbard satellite dump data, representative testing of modifications to the FEP functionality for the extraction of the half-orbit, in parallel with the full orbit extraction could therefore be completed. Adding simulated McMurdo satellite dump data, ingested from the ADA DEW, the new PGF-ADA functionality and the fundamentals of the ADA data processing concept could be tested, prior to deployment of facilities to remote locations and well before the availability of real satellite dump data from McMurdo.

Once McMurdo acquisitions had started, the PPS-ADA DEW data transfers had been validated and the FEP modifications had been installed on a FEP instance in each of the two operational ground stations in Svalbard, the full data processing chain verification and validation process was able to start. Figure 11 shows how GS-3 was able to ingest the ADA data flows from McMurdo and Svalbard, to be used for processing verification testing and transfer through the external gateway (EXGATE) facility to a test facility at Usingen, in Germany, where the “EUMETCast” data dissemination broadcast satellite terminals are located.

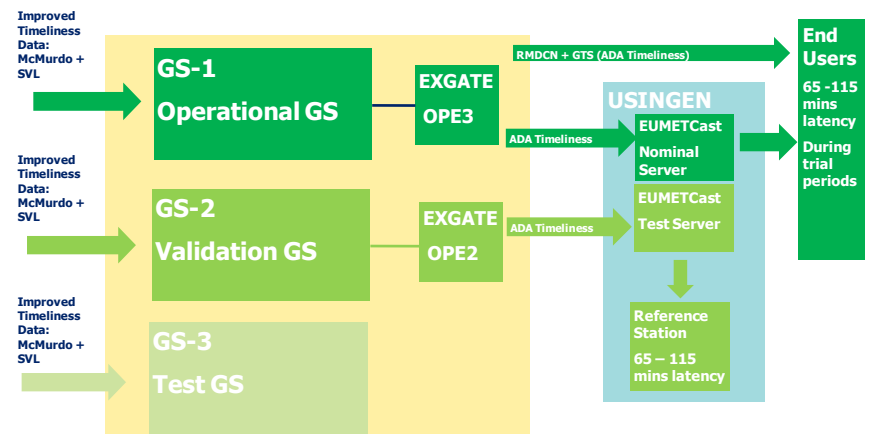


Figure 12. ADA Operational Trials using Ground Segment-1

This allowed both the functionality and the performance of the ADA system to be verified. It can be seen that, in parallel, both GS-1 and GS-2 were ingesting the pure Svalbard full-orbit data. Hence both nominal operational services and related validation activities for any non-related facility upgrades to that service could be performed.

Validation activities on GS-2 followed a similar scheme (not illustrated), with only the GS-1 operational ground segment still relying on the Svalbard-only data. Dissemination to the NOAA NSOF was made, entering their test data processing streams. Neither European nor NOAA end-users received these test data streams. It nevertheless had to be validated that end-user data assimilation systems

could actually correctly ingest and take advantage of the ADA timeliness data streams. Since dissemination data rates are high, it would have been too expensive to double the dissemination rates for nominal operational and ADA validation data streams. It was decided to use instead trial disseminations of ADA data from the operational ground segment (Figure 12). With intervals of not less than one week, for several orbits, the McMurdo and Svalbard-ADA configuration data streams were allowed to enter the GS-1 and operational dissemination of the resulting products occurred to the end-users. Similarly, NSOF received the data on their operational chain and disseminated the resulting, low latency products.

Excellent feedback was received from end-users from the first trial dissemination, such that only 3 of the 5 possible trials were necessary. Figure 13 indicates the difference in timeliness of data received for sensing times in the morning (left-hand plot) before the trial commenced, versus data received in the afternoon (right-hand plot) during the trial.

Once NSOF was able to provide similar confirmation that their user community had been fully able to process the low latency data and products, the system was ready to go into full operation.

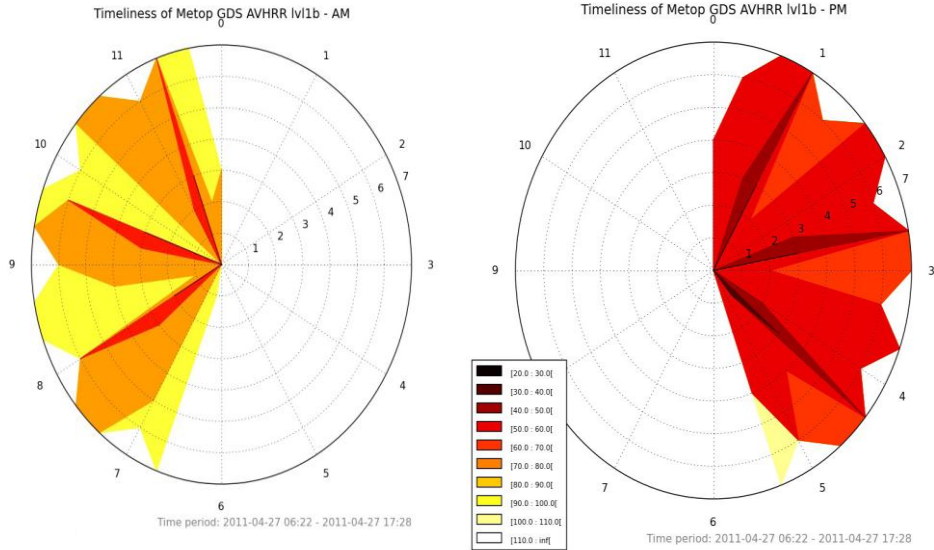


Figure 13. End-user data reception timeliness of data before (left) and during (right) operational trials. (Courtesy of SMHI)

VIII. Operational Experience

Since the start of the Demonstration Phase in June 2011, ADA has successfully served the user community with meteorological data observations delivered with a significantly improved overall timeliness.

The operational planning, scheduling and review interfaces have functioned smoothly, demonstrating an excellent approach to the execution of routine operations and a rapid and effective response to contingencies.

Implementation and subsequent testing of upgrades to the PPS have been effectively managed using the remote access capabilities overcoming some early transmission problems, but the robustness of the design virtually eliminated any impact to the end-user service.

Also, the number of orbits served from McMurdo has generally been in excess of the average of nine planned for this phase, (Figure 14).

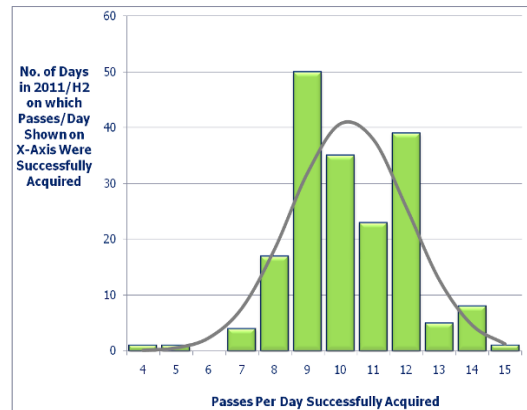


Figure 14. ADA Passes per day July-December 2011

IX. Conclusion: Key Success Factors

In conclusion, the following key factors were fundamental to the success of the Project and the ability to integrate, verify, validate and operate the upgraded system with ADA, avoiding at all stages any detrimental effects to existing, on-going user services:

- Close and open coordination at managerial and technical levels across four government organizations (NOAA, NASA, NSF and EUMETSAT), in the face of limited resources and hard deadlines;
- Reliability of data delivery from McMurdo resulting from the extensive design trade-offs between partners, early pre-deployment testing and the integration and test strategy;
- Innovative design solutions within existing constraints of the operational system were put in place, emphasizing simple design choices and avoiding excessive risk to the underlying capabilities of the core operational system and the corresponding user services;
- Ensuring the product availability and quality for the upgraded system meets user expectations based on their experience of the current system performance, rather than simply on the requirements specifications, such that there is no apparent degradations as a result of the upgrade;
- Introducing aspects of the upgrade, such as the satellite dumps to McMurdo into the EUMETSAT operational system at an early stage, in order to serve as a stable operational baseline for remaining data acquisition and processing testing;
- Using an underlying ground segment architecture with multiple instances, coupled with a strong configuration management system, allowing separate verification, validation and operations to occur simultaneously with well controlled version control;
- Willingness of the user community to accept the compromise between cost and service impact through trial approach (which was vindicated through no significant observed losses during the trials).

The definitive key factor must however be recognized as the absolute dedication and motivation of all team players in Europe, USA, Australia and at McMurdo who overcame obstacles too numerous to mention here.

Appendix A Acronym List

ADA	Antarctic Data Acquisition
ADA DEW	Antarctic Data Acquisition Dissemination facility Extension Workstation
APT	Anomaly Processing Tool
AVHRR	Advanced Very-High Resolution Radiometer
CDA	Command and Data Acquisition
CS	Central Site
DIF	Dissemination Facility
DLM	Depot Level Maintenance
EPS	EUMETSAT Polar System
ERT	Earth Received Time
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FEP	Front End Processor
GDS	Global Data System
GS	Ground Segment
IJPS	Initial Joint Polar System
IV&V	Integration, Verification and Validation
LEO	Low Earth Orbit
Mbit/sec	Mega bits-per-second
MCS	Monitoring and Control System

MPF	Mission Planning Facility
MG1	McMurdo Ground Station 1 (supporting Metop)
MGS	McMurdo Ground Station
MPLS	Multi-Protocol Label Switching
NASA	National Aeronautic and Space Administration
NEN	Near-Earth Network
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NSOF	NOAA Satellite Operations Facility
NSF	National Science Foundation
NWP	Numerical Weather Prediction
PGF	Product Generation Facility
PPS	Pre-Processing System
RF	Radio Frequency
SMHI	Swedish Meteorological and Hydrological Institute
SSR	Solid State Recorder
SVL	Svalbard
TCP/IP	Transmission Control Protocol/Internet Protocol
VCDU	Virtual Channel Data Unit
WAN	Wide Area Network
WAE	(Cisco) Wide-area Application Engine
WMO	World Meteorological Organization
WOTIS	Wallops Orbital Tracking Information System
WWW	World Weather Watch

Appendix B

Glossary

Eb/N0	Signal-to-noise ratio
EUMETCast	EUMETSAT dissemination system utilizing direct video broadcast satellites
EXGATE	External dissemination gateway for the EPS System
GEONETCast	Global network of satellite-based data dissemination systems for environmental data
Metop	Meteorological Operational (satellite of the EUMETSAT Polar System)

Acknowledgments

The authors would like to thank all team members from NOAA, NASA, NSF and EUMETSAT, together with all contracting companies who made this project a success. We would also like to thank additional contributors to this paper; Lakel A. Smith, NOAA/NESDIS-Office of Satellite and Product Operations and Joseph P. Green, NOAA/NESDIS-Office of Systems Development, as well as Michael Theurich, and James Miller, EUMETSAT Operations Department.

A particular dedication goes to the late Fritz Krug, whose enthusiasm in his role as lead system engineer in EUMETSAT put the project on course to success. He is greatly missed by all his colleagues and friends.

References

¹Valenti, J. M., Monham, A., Keegan, C., Munley, W. G., Smith, P. D., McCarthy, K. P., “Metop’s Antarctic Data Acquisition Project, An International Partnership Success”, *AIAA 2012 (SpaceOps Conference 2012 Paper #1275309* to be published).