The 2004 NOAA Satellite Direct Readout Conference: "A Decade in Transition"

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Contents:

0. Overview/Key Points

- NOAA-N (NOAA-18) Launch 2005/03
- NOAA-N' to be rebuilt for launch 2007
- METOP 1 launch 2006/04, 1st decision point for DB users, no encryption
- NPP "In-Situ Ground System" for DB release mid-2006
- NPP launch 2007, subject to VIIRS issues, 2nd decision point for DB users
- NPOESS SafetyNET ground system complete 2009
- NPOESS 1st launch 2009/2010, fully operational 2013

1. Introduction & Context

The focus of the NOAA Direct Readout Conference is on Operational rather than Experimental Satellite Systems; i.e. satellites that are part of multi-year multi-mission programs aimed at providing a continuous and reliable service for use in operational fields, such as weather forecasting, aviation, search and rescue, or environmental monitoring. The NOAA POES system is the best known system of this type in current operation. Over the next five years the data stream provided by POES will be transitioned, via the EUMETSAT METOP series, and the NPP test spacecraft, into the NPOESS program at the end of the decade.

Users interested in the more experimental NASA EOS spacecraft (particularly Terra and Aqua) should also keep abreast of the EOS Direct Broadcast meeting series (see http://directreadout.gsfc.nasa.gov/links/meetings.html for past meeting information). The next EOS meeting will be held in Italy in October 2005.

The present conference was held in Miami Florida, December 6-10 2004. My report on the previous meeting in 2002 is on the EOC website and provides some useful context for this report (see http://www.eoc.csiro.au/reports/king/eking_miami02.pdf). My attendance in 2004 was supported by an EOC partnership funding in conjunction with Geoscience Australia.

The conference web site is http://directreadout.noaa.gov/miami04/. Presentations are available as PDF files from the 'Schedule' link at that URL.

This report focuses on the polar-orbiting satellites because:

1. The polar orbiters are evolving very rapidly at the moment and offer potentially the greatest benefit to Australian users over the next two decades.
2. With the exception of GOES-9 (currently over the Western Pacific) the NOAA geostationary systems are not visible from the Australian region. [Eumetsat's MET-5 is also over the Indian Ocean but was not discussed, at least not in a DB context].

The meeting was held over 5 days, each day nominally devoted to a different theme:

Monday: Introduction & Overview
Tuesday: International Cooperation
Wednesday: Polar Systems
Thursday: Geostationary Systems
Friday: Global Earth Observation System of Systems

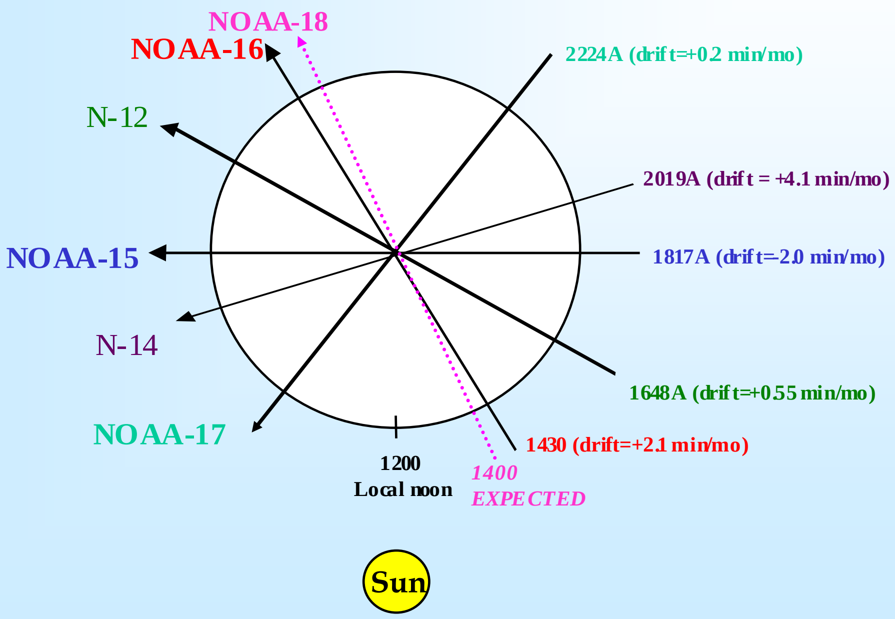
Rather than follow this formula, I have divided what follows into sections discussing topics that I believe will be of particular interest to the Australian user community.

2. Current POES

The Polar Operational Environmental Satellite (POES) program has provided a more-or-less continuous data flow with a pair of spacecraft in morning and afternoon orbits for over two decades. The POES data is virtually THE baseline remote sensing dataset for environmental measurement and monitoring at continental and global scales. Although the POES spacecraft have carried numerous instruments to sense the atmosphere and space environment, probably the most significant is the AVHRR imager. This single instrument produces the highest data rate by far and is responsible for the 1km 4 or 5 band imagery of the earth that constitutes the bulk of the legacy POES dataset.

There are presently 5 polar orbiters operating in some form or another. The following graphic from Hampton's talk illustrates their current orbital configuration and precession with respect to the sun. The arrowhead indicates the descending node, and the times give the LOCAL solar time of the ascending node. One point to note is that NOAA-18 will be quite close to NOAA-16 which is likely to result in overpass scheduling conflicts for ground reception stations.

Constellation Orbital Configuration



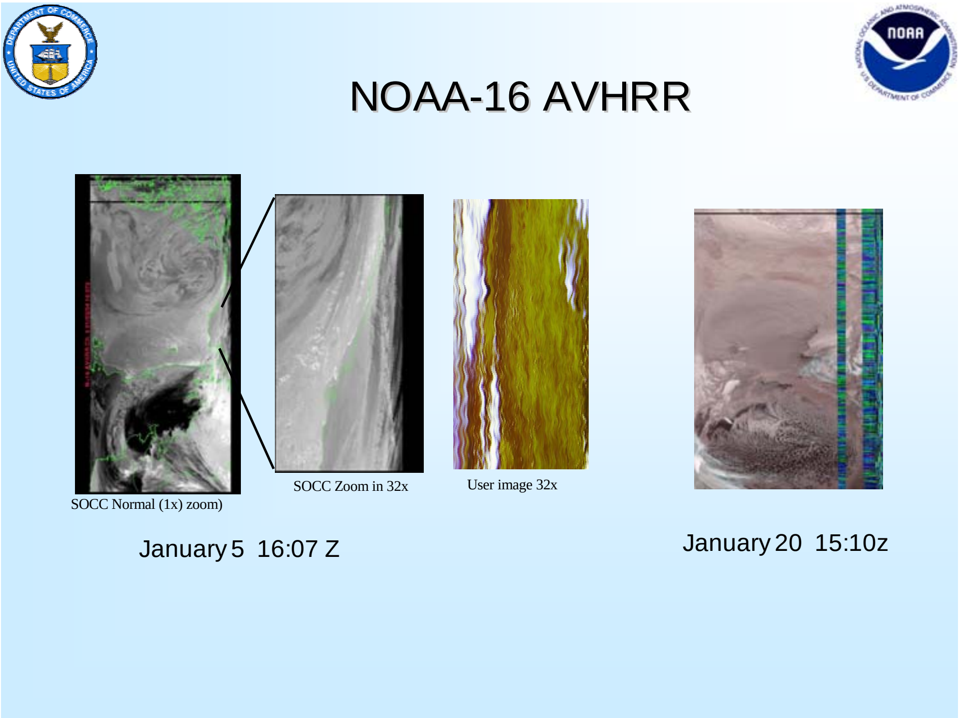
Not all instruments are working on all spacecraft. A comprehensive up-to-date status report can be found at http://www.oso.noaa.gov/poesstatus/. The following graphic provides a summary for the current spacecraft. Green indicates nominal performance, yellow implies functioning but either degraded to vulnerable to single-points of failure (ie no remaining redundancy), and red denotes failed instruments.

POES Status

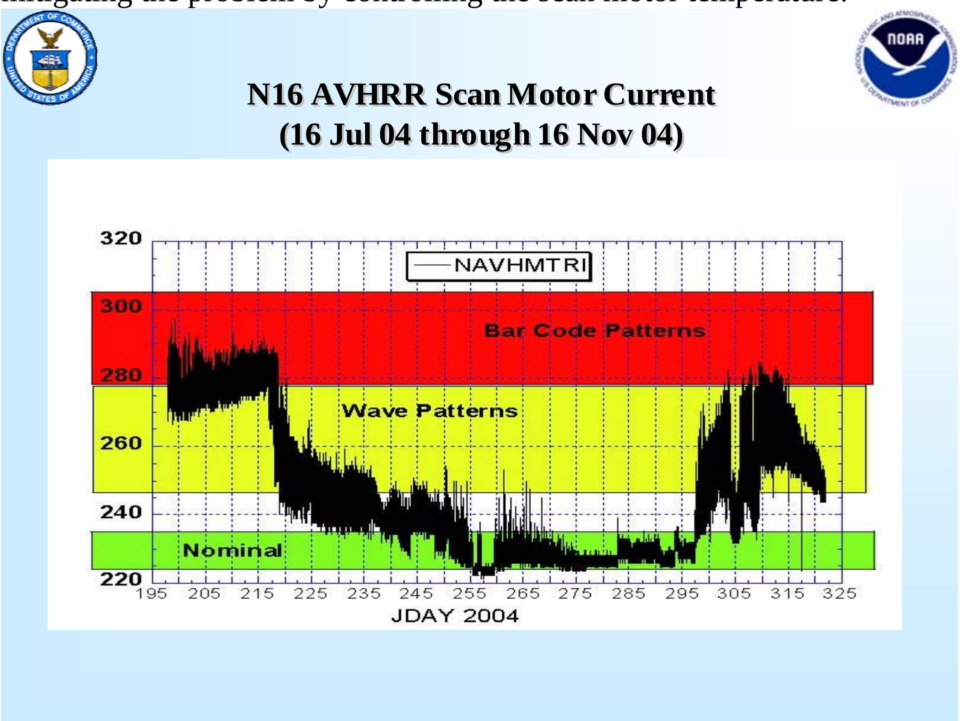
Spacecraft Subsystems	NOAA17	NOAA16	NOAA15	NOAA14	NOAA12
Ascending Node +/- 5 mins	2224	1430	1817	2019	1648
Mission Data Category	PRI	PRI	Back Up	SEC	SEC
Instruments					
Adv. Hi Resolution Radiometer (AVHRR)		Y	Y	R	
High Resolution Infrared Sounder (HIRS)			Y		R
Adv Microwave Sounding Unit (AMSU-A1)	R	Y	Y	N/A	N/A
Adv Microwave Sounding Unit (AMSU-A2)				N/A	N/A
Adv Microwave Sounding Unit (AMSU-B)			Y	N/A	N/A
Microwave Sounding Unit (MSU)	N/A	N/A	N/A	Y	R
Stratospheric Sounding Unit (SSU)	N/A	N/A	N/A		N/A
Data Collection Subsytem (DCS)					
Search and Rescue Repeater (SARR)		Y	Y		N/A
Search and Rescue Processor (SARP)				R	N/A
Space Environment Monitor (SEM)				Y	
Solar Backscatter UV Radiometer (SBUV)		Y	N/A	Y	N/A
Spacecraft Subsystems					
Command and Control				Y	
Electrical Power				Y	
Attitude Determination and Control					
Communications		Y	Y		
Thermal Control			Y		
Data Handling (Recorders)		Y		Y	Y

Notes on Particular Spacecraft:

- NOAA-11: This was decommissioned on June 16, 2004.
- NOAA-12: The most successful POES orbiter, with the exception of the HIRS and MSU, it is still operating after 13.5 years on orbit.
- NOAA-14: Although the AVHRR has failed, most of the atmospheric sounding equipment continues to operate.
- NOAA-15: There are numerous problems with most of the instruments yet all continue to produce data of some value.
- NOAA-16: The most significant problem for DB users is the problem with the AVHRR scan motor that creates image artefacts familiar to Australian users. The first of these is the presence of wavy patterns in the second part of the swath indicating non-uniformity in the mirror spin rate. The second are the so-called bar-code patterns which occur when the mirror spin rate changes so much that synchronisation is lost between the mirror and the data information processor. Both these effects are apparent in the example imagery below.



The presence of these artefacts is correlated with anomalous scan motor currents. It is believed that there is a lubrication problem causing the motor to have to work harder (see figure below). There has been some success in mitigating the problem by controlling the scan motor temperature.



- NOAA-17: The major problem with this spacecraft is that the main DB transmitter (STX3, 1707 MHz) has dropped its power output to about 25% of nominal. This is causing some severe signal to noise ratio issues for sites with smaller reception antennas.

There was very little mention of the Chinese polar orbiters, FY-1C and FY-1D. Carlos Cotlier from Argentina presented work comparing NOAA and FY-1D imagery for use in land-cover studies.

3. Future POES

Until now the POES program has sought to maintain spacecraft in both the morning and afternoon orbital planes. However NOAA-17 will be the last of the NOAA morning spacecraft, that role being taken over by the future EUMETSAT METOP program (see next section). There are two NOAA spacecraft remaining to be launched in the afternoon orbits. These are designated NOAA-N and N' ("N-primed") and will become NOAA-18 and 19 when established on orbit. These will provide direct broadcast data continuity with the existing system.

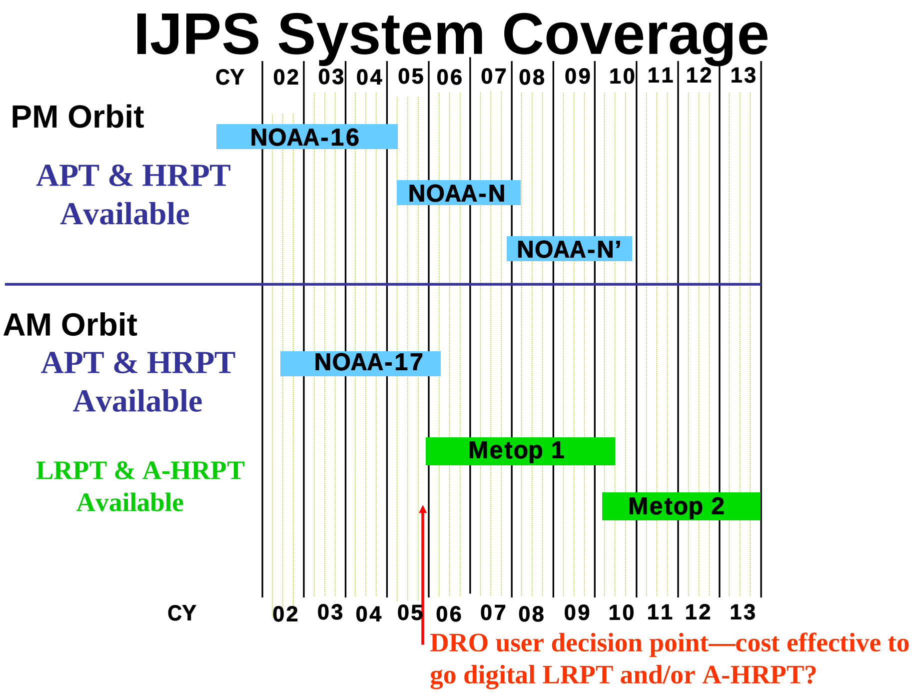
The launch of NOAA-N is planned for March 19 2005 from Vandenburg AFB in California. The planned orbit is for a local-time ascending node of 1400hrs. Instrument activation will be at launch+21 days. There will be some modification of the APT (low rate) data broadcast frequencies. Existing reception stations should however be able to continue to receive HRPT data without modification. The AVHRR/3 instrument will provide the same imaging capabilities as that on NOAAs 15, 16 and 17. The scan motors for the AVHRRs have been replaced with higher torque versions to try and avoid the problems seen with NOAA-16. Both NOAA N and N' will carry improved HIRS/4 and MSU atmospheric sounders. Progress towards launch can be followed on the web at http://poes.gsfc.nasa.gov/campaignn/launch.htm.

NOAA-N' was seriously damaged in a factory accident in late 2003 (see http://www.spaceref.com/news/viewsr.html?pid=10299). Following a damage review, a decision has been made to rebuild the spacecraft for launch in late 2007 in a similar orbit and configuration to that of NOAA-N. NOAA-N' will be the final spacecraft in the POES series and is expected to provide data continuity in the afternoon orbit out to 2010+.

4. METOP & the IJPS

METOP is the forthcoming EUMETSAT operational polar orbiter program consisting of a series of three satellites, each with a design life of five years. The first launch, that of METOP 1, is now planned for April 2006. All three METOP spacecraft will be in a morning orbit (approximately 9.30 am), replacing the AM platform in the POES program and complementing the final two POES spacecraft in the afternoon orbit. Together with POES, METOP is part of the Initial Joint Polar-orbiting System (IJPS), in which NOAA and EUMETSAT operate independent but fully coordinated systems and exchange data with each other to provide continuity and completeness. A Joint Transition Activity Agreement was signed in 2003 and provides for exchange of METOP-3 and NPOESS data and future activities leading to a Joint Polar System in the 2018+ timeframe.

The following graphic, modified from the presentation by Schott, illustrates the planned sequence and configuration.



A key element of the IJPS program is the data continuity and consistency that is being achieved by flying NOAA-provided instruments on the METOP spacecraft. A succinct comparison of the two programs is again provided by Schott:

IJPS

NOAA N & N’

- 1400 Orbit -Ascending Node
- Direct broadcast with existing HRPT and analog APT links
- **Instruments**
  - NOAA Provided
    - AVHRR/3
    - HIRS/4
    - AMSU-A
    - SEM
    - SARSAT
  - EUMETSAT Provided
    - MHS
  - Argos (Data Collection Sys)
  - NOAA Unique
    - SBUV/2

METOP 1 &2

- 0930 Orbit - Descending Node
- Direct broadcast with M-HRPT and digital LRPT links
- **Instruments**
  - NOAA Provided
    - AVHRR/3
    - HIRS/4
    - AMSU-A
    - SEM
    - SARSAT
  - EUMETSAT Provided
    - MHS
  - Argos (Data Collection Sys)
  - EUMETSAT Unique
    - IASI
    - ASCAT
    - GOME-2
    - GRAS

A detailed description of METOP-1 was provided in the presentation by Ashworth. More information is available on the EUMETSAT web site (http://www.eumetsat.de).

There will be significant changes for the direct broadcast community when METOP-1 is launched.

1. The APT transmission from POES will be replaced with Low Resolution Picture Transmission (LRPT) which will be a digital signal rather than analogue as in the past. The data will be transmitted at 137.1 and 137.9 MHz at 72 Kbit/sec. The LRPT service will include 3 AVHRR channels at full resolution but JPEG compressed, and all data from the HIRS, AMSU and MHS sounders.
2. The HRPT transmission will be replaced by Advanced HRPT (AHRPT) with a substantially increased data rate of 3.5 Mbits/sec compared with 0.67 Mbits/sec for HRPT. A 2.4m tracking antenna is recommended to receive these data. The transmission frequency will be 1701.3 MHz (1707.0 MHz backup) and the data will be Reed-Solomon coded. Data from all instruments at full resolution will be contained in the AHRPT service. Approximately half the increased data rate is due to the IASI spectrometer.
3. Data encryption has been a common EUMETSAT policy and has been discussed in the context of METOP direct broadcast data for some years. Possibilities have included full encryption, part time encryption and partial encryption of only the European-sourced instruments. It appears now that the METOP direct readout service will be classified as “essential data”, the implication being that it will be available without licence, without charge and without encryption. However, there remains the possibility that data encryption could be enabled “in crisis situations”, in which case ground stations will need a EUMETCast Key Unit and access keys.

The EUMETSAT web site has pages that explain how to obtain test data, test tools and local reception station design documentation, as well as product format guides.

5. NPP

The NPOESS Preparatory Project (NPP) is not an operational satellite mission. It is a single spacecraft serving a dual role:

1. as a bridge mission to provide environmental and climatic data continuity between the NASA EOS spacecraft (Terra, Aqua and Aura) and the NPOESS system.
2. as a risk reduction exercise and demonstrator/testbed for various communities involved with NPOESS, including sensor and algorithm development, as well as Direct Broadcast station operators.

It is likely to be important to Australian users for both these reasons. Currently the MODIS sensors on Terra and Aqua provide an imagery dataset of unprecedented quality and temporal frequency that is underpinning a great deal of new work in terrestrial, marine and atmospheric applications. Both these spacecraft are approaching the end of their design lives in 2005 and the next most capable systems onboard NPOESS are not due for launch until around 2009. NPP carries four critical NPOESS sensors including, most importantly, the VIIRS imager and will enable continuity of many of the new application products that MODIS has spawned. In this sense it has an operational role, but if it fails on launch, for example, there will be a coverage gap as no backup exists or is planned.

Secondly the changes in sensor design and operation with NPOESS (and hence NPP) will require significant modification of ingest and base processing techniques from those of the POES era. Much of the direct broadcast community has already been through a substantial transition with the EOS spacecraft and MODIS, and my sense is that the transition from there to NPP/NPOESS will not be so great. However there is a significant community of DB users who have not made the EOS step and for them the NPP mission is a crucial stepping stone to prepare for NPOESS before POES data becomes unavailable.

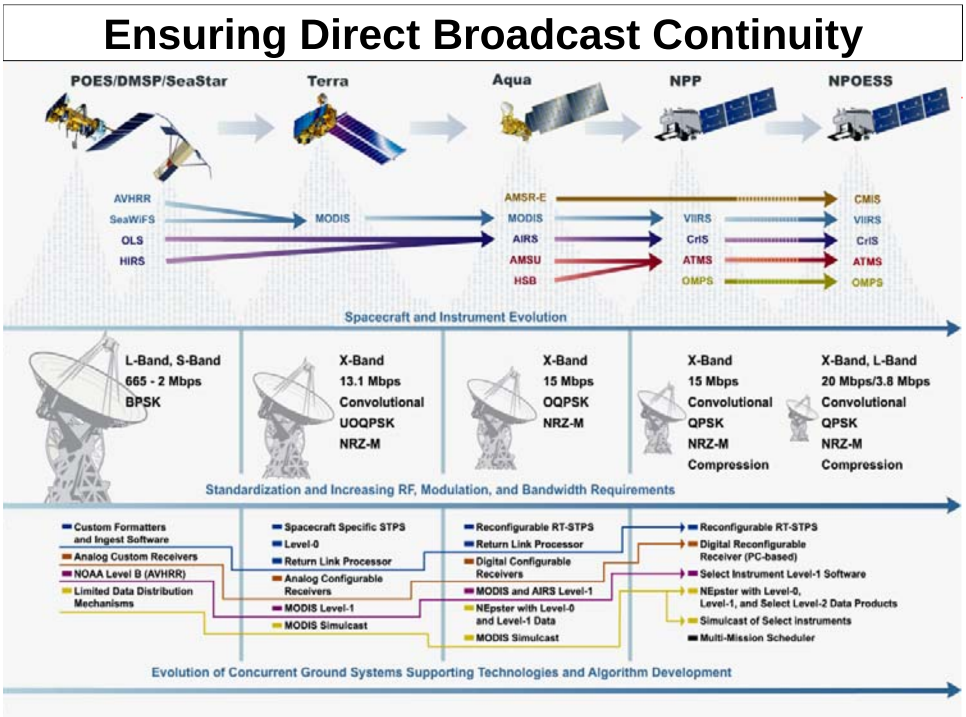
Reflecting the dual role of NPP, the mission is being jointly managed by NASA and NPOESS Integrated Program Office (IPO). The planned date to achieve launch readiness is October 2006, however some technical issues with the VIIRS mean that this is likely to slip to sometime in 2007. The other instruments are progressing to schedule and the spacecraft bus itself is a standard design and will be ready in early 2005.

The four sensors are the Advanced Technology Microwave Sounder (ATMS), Cross Track Infrared Sounder (CrIS), Ozone Mapping and Profiler Suite (OMPS), and the Visible/Infrared Imager Radiometer Suite (VIIRS). A wealth of information about these instruments (and NPP) can be found on the IPO web site (http://www.ipo.noaa.gov/) and summaries were given in several of the talks at the conference (notably those by Cunningham on the Monday and Wilczynski on the Wednesday).

NPP will usher in a number of changes that will be noticed by the direct broadcast community:

1. The VIIRS imager is similar to the MODIS sensor, having an array of detectors that scan multiple lines simultaneously, leading to a bowtie effect. However the optics are arranged so as to reduce the growth in pixel size across the scan. Five imaging channels produce 400m resolution pixels at nadir growing to 800m at the swath edge providing better than 1km resolution over the whole 3000km width swath. The other 16 channels provide moderate resolution imagery with approximately 1km NADIR pixels. A great deal of information about VIIRS, including a table of the bands and their centre frequencies and bandwidths can be found at http://www.ipo.noaa.gov/Technology/viirs_summary.html.
2. The direct broadcast downlink will be 15 Mbits/sec at 7.812 MHz. This downlink will provide complete access to all instrument data. Existing ground stations capable of receiving the EOS X-band spacecraft data should be able to receive NPP data without great front-end changes. The following graphic (from Wilczynski's presentation) summarises the evolution of the DB RF, modulation and reception systems through NPP and NPOESS. A 1-2m grade

antenna should be sufficient to receive the data.



3. Support for the Direct Broadcast community will be enormously improved from that for EOS. There appears to be a huge realisation and appreciation within NASA (and the IPO) of the importance of the DB application environment and a desire to support such users. The NASA Directreadout Office (http://directreadout.gsfc.nasa.gov) is well down the road towards a pre-launch release of a range of software for decoding the NPP data stream and managing the data in a DB environment . There also appears to be a commitment to make available standalone Level-1 and select Level-2 software and the ancillary data required to run them (ephemerides, calibration data etc). See the presentation by Coronado on the Wednesday for more details.
4. The NPP and NPOESS projects are moving away from the familiar, though arcane, terminology of Level-0,1,2,3 data processing stages. They will be replaced by:
    a. Raw data records (RDR) for level-0 (unpacked decoded raw data)
    b. Scientific data records (SDR) for level-1 (calibrated, geolocated data)
    c. Environmental data records (EDR) for level-2 products (geophysical parameters)
    d. Climate data records (CDR) for level-3 assimilated products

Of these elements, the availability of the software for processing beyond SDR (Level-1), appears the most nebulous and ill-defined. If everything turns out as the NASA Directreadout Group and the IPO speakers predict then the direct broadcast user experience will be enormously better than for the earlier EOS missions. Nevertheless Allen Huang from the University of Wisconsin presented a talk describing IMAPP and UW's heritage of successful support for DB missions and proposing a successor, the International NPP/NPOESS Processing Package (INPP). It is not clear at this stage what the funding status of this proposal is, but undoubtedly it is a good thing to have an institution with UW's track record keen to take on this project as it sets the quality bar pretty high for any "competing" IPO-sourced package. My sense is that the existing interaction between the UW group and the NASA Directreadout lab will most probably result in a single well integrated system from the start rather than the dual paths that were possible for EOS DB users.

6. NPOESS

The National Polar-orbiting Operational Satellite System (NPOESS) is a joint NOAA, Department of Defence and NASA program to place highly capable earth observing satellites in three polar orbits with equator crossing times of approximately dawn, mid-morning, and early afternoon. It represents the twin convergences of the POES program with the parallel military DMSP program, and of meterological observing with global environmental monitoring, together with a healthy dose of technology renewal and a great deal of forward thinking.

Rather than trying cover everything in detail here, there is an enormous amount of information about NPOESS available from the Integrated Program Office web site at http://www.ipo.noaa.gov/. This is the most up-to-date source of material describing the program. Good overviews of major parts of the program (and underlying philosophy) can be found in these conference presentations:

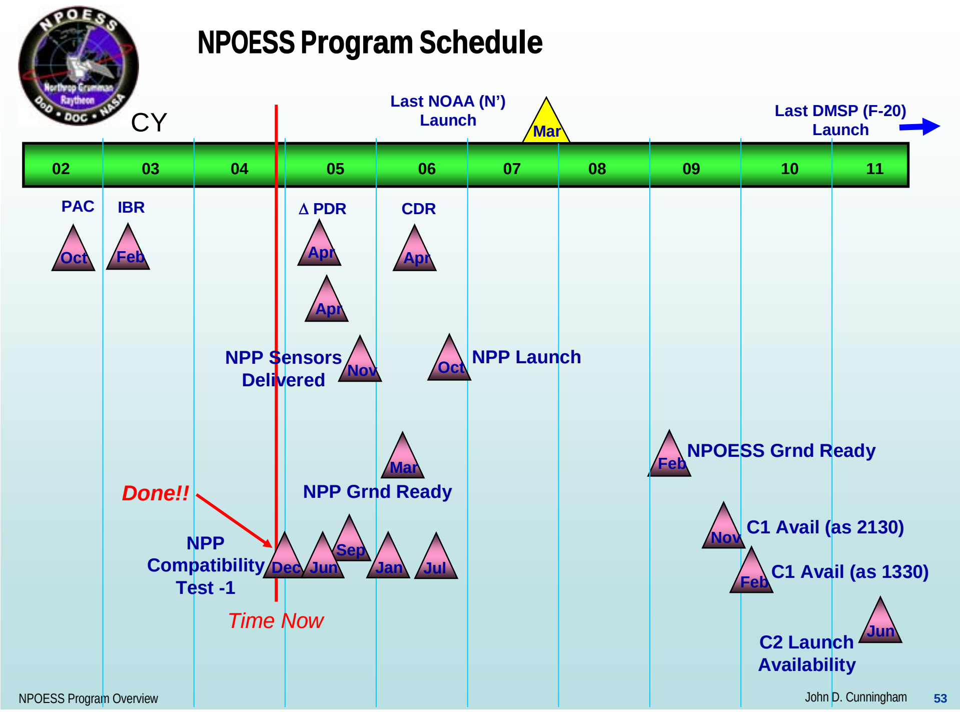
1. NPOESS Overview (Cunningham, Monday)
2. Frequency Spectrum Management (McGinnis, Tuesday)
3. Evolution of Weather Observing to Global Environmental Monitoring (Cunningham, Wednesday)
4. NPP - The NPOESS/EOS Bridge Mission (Wilczynski, Wednesday)
5. NPP In-situ Ground System (Coronado, Wednesday)
6. NPOESS Global Data for the Global Observation System (Haas, Wednesday)
7. NPOESS Direct Readout Mission (Overton, Wednesday)

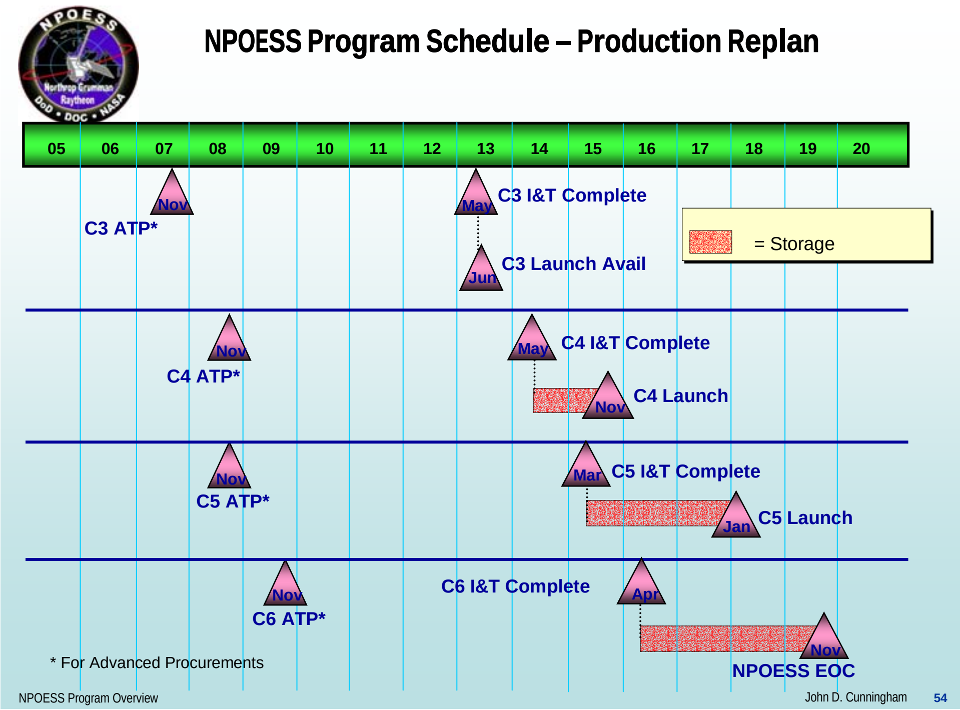
There will be three data downlinks:

- SMD – stored mission data including ALL data stored onboard since the last two ground station contacts. This will be at Ka band (18-31 GHZ) and 300 Mbits/sec. It will NOT be directly accessible to users but will be collected by a global network of 15 ground stations (see next section “SafetyNet”).
- HRD – high rate data including 100% of NPOESS data as it is observed. This is the primary DB data stream and will be 20 Mbits/sec at X-band (7750-7850 MHz) and will NOT conflict with the Deep Space Station requirements that caused the DB transmitters on the EOS platforms to have to be turned off from time to time. A novel feature will be dynamic ancillary data covering the swath region transmitted within the data stream.
- LRD – low rate data comprising a subset of the total data stream, including a 6:1 compression of the VIIRS data. It will also include the ancillary data and will be approximately 3.8 Mbit/sec at L-band (similar to METOP).

The ancillary data will be transmitted at double rate so that it will occur in the data stream twice within the time for an overpass. It will also be available in real time from a server on the internet. As already described, NPP is being used as a testbed for a number of DB-related technologies for NPOESS, including ground station development. The two presentations on the Wednesday by Haas and Overton are must-reads for potential DB users.

These two graphics from Cunningham's overview indicate NPOESS progress in the near-term and the intention over the next 15 years.



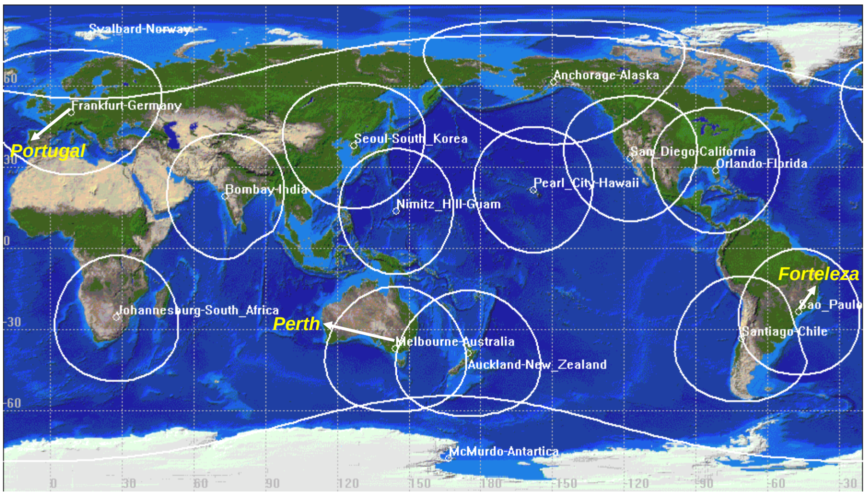


One of the more forward looking aspects of NPOESS is the recognition that there will be an evolution in sensor technology and techniques over the next decade and that it should be possible to support new or enhanced instruments over the course of the mission. This philosophy is referred to as "Pre-Planned Product Improvement" or P3I. It is intended that there will be periodic requests for proposals for experimental instuments or modifications to existing instruments. An "payload manual" has been developed for potential proposers. There is a substantial payload margin on all spacecraft. On the most heavily loaded spacecraft (early afternoon orbit), there is a margin of 365 kg and 326 W. The first mid-morning orbit spacecraft (C1) has fewer instruments and the margins there are >1000 kg and >1kW!

It now seems very likely that the Landsat Data Continuity Mission will be the first beneficiary of P3I, with the Operational Land Imager to be flown on C1. There was some evidence (in Cunningham's overview) of a serious attempt to explore the feasibility of mounting the OLI on the end of the C1 bus. With C1 due for launch in late 2009, the development schedule is going to be very tight. There was no discussion of OLI data access and redistribution policy.

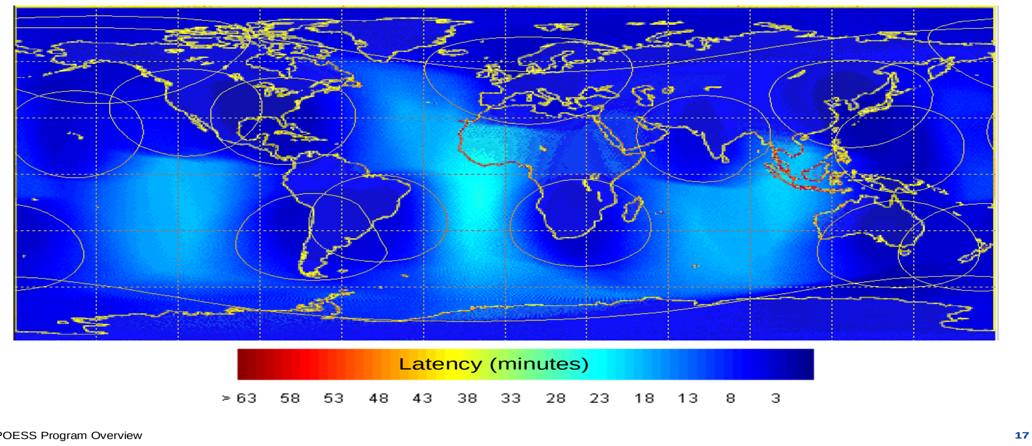
7. SafetyNet

A novel part of the NPOESS project is the SafetyNet ground station network. This will be a global network of 15 autonomous unmanned ground stations operating at K-band (~20 GHz) and providing command and control, telemetry status, and full stored mission data downlink capability. The locations of the stations are indicated on the graphic below (adapted from Cunningham). The locations of three stations are currently under review including, significantly Melbourne possibly to be relocated to Perth.

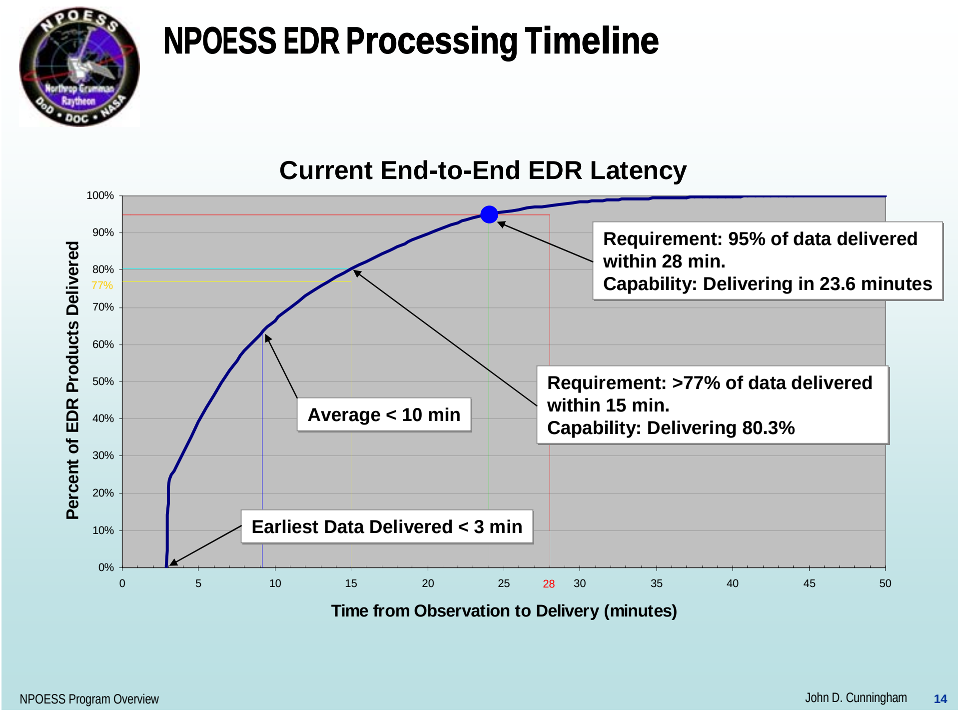


SafetyNet™ -- 15 globally distributed SMD receptors linked to the centrals via commercial fiber -- enables low data latency and high data availability

The SafetyNet stations will be directly linked to the US control centre by commercial fibre networks so rather than downlinking the stored mission data once per orbit it is delivered in a fraction of the time. This enables receipt of the global data virtually in near real time. The following graphic from the talk by Haas shows the expected worldwide data latency for EDRs (ie processed products). Roughly the capability is 75% of global products available at the US national weather centres within 15 minutes of observation, and virtually everything in less than 30 minutes.



A more detailed processing timeline for the NPOESS EDR generation is shown in the following graph from Cunningham's presentation:



The planned presence of one of these stations in Australia opened up some interesting possibilities for Australian participation which I explored with John Overton from the IPO after his talk. Firstly the data from the spacecraft can not be accessed between the ground station and the US centre. There are several reasons for this, including maintaining the integrity of the system and the fact that the data received is stored (from earlier in the orbit), not real time, and so will not necessarily include the local region. However the fibre link is full duplex and the uplink capacity requirement is trivial compared with the total data rate. It might therefore be possible to take Australasian regional data as it arrives in the US from throughout the global SafetyNet network and send it back down the fibre for access within Australia, most probably in Melbourne where the international fibre segment is likely to terminate.

This would effectively make virtually all the Australasian data available, in Australia, at a single location, in around twenty minutes or less without the need for any Australian DB capacity. That one of the most demanding real-time users of satellite data, the Bureau of Meteorology, is located in Melbourne is a happy coincidence, though the growth in network capacity within Australia means that it is likely that the data could be delivered to any of the major population centres just as easily. It would of course still be necessary to operate a number of DB stations in critical locations lest a problem with the fibre link to the US prevent data access via that route.

Overton thought this was a technically feasible goal and encouraged us to propose it as an international collaboration in NPOESS with the US. The proposal needs to go at Australian Government level (ie above agency level) and should be directed to John Cunningham at the IPO.

8. Suggested Actions

The following issues seem to me to be areas where Australian users and agencies should be directing effort now in order to make the most of the forthcoming changes.

1. METOP data will be available to DB users in a little over 15 months. Australian ground station operators should be actively planning the relevant hardware changes required to receive and demodulate the signal. The HRPT/AVHRR user community needs to coordinate itself to develop a means of either extracting the AVHRR data into a standard format, or at least standardising the METOP archive file format. Above all we need to avoid the plethora of different formats we've experience with POES HRPT data.
2. The SafetyNet ground station in Australia presents a remarkable opportunity for a National approach to data acquisition and archival. The window of opportunity is open NOW. Interested government agencies, both Federal and State, should get organised to arrange for the Federal government to make a proposal to the US as soon as possible.
3. To access the full data sets from the NPP and NPOESS missions X-band reception systems are essential. At present there are only three such systems in existence within Australia. If a small number of compatible installations can be established at strategic locations (e.g. Darwin and Townsville) Australia will be well placed to exploit these new data.
4. Processing software for higher level products is going to be essential to maximise utilisation of the new data streams. At present this software is, if not vapourware, at least somewhat hazily defined. The Australian DB community should not waste any opportunity to impress upon the IPO and NASA DRO group the importance of getting this right. Encouragement and public support for the University of Wisconsin group is one very effective way to do this.