Polar-orbiting Operational Environmental Satellites

Future Developments

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Satellite Direct Readout Conference

This document is a report based on my attendance at a NOAA sponsored conference "Satellite Direct Readout for the Americas" held in Miami, Florida, in December 2003. The purpose of the meeting was for NOAA to inform and receive feedback from the satellite direct broadcast community, particularly with regard to the evolution of the operational environmental satellite programs. Although a significant part of the meeting concerned the Geostationary satellite program, only the parts of the meeting concerning the Polar program are discussed here since the Geostationary spacecraft are not visible from the Australian region and so are of lesser interest to an Australian audience. The presentations from the meeting are online http://noaasis.noaa.gov/NOAASIS/pubs/MIAMI/program.html and the reader is referred to that site for more detail, in particular to the presentations on Wednesday 11 December.

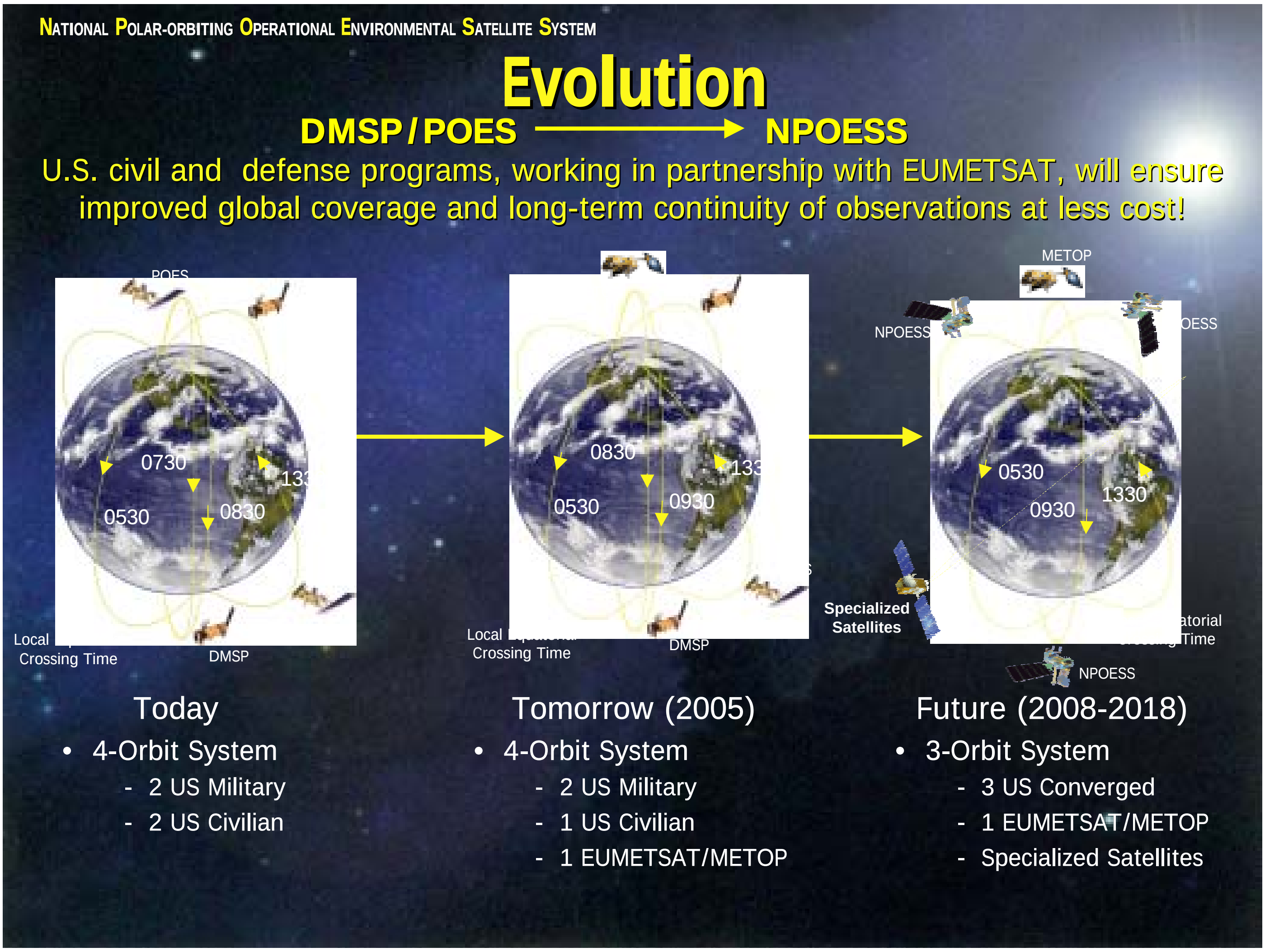
Summary

The NOAA polar orbiting environmental satellite (POES) series has provided an operational environmental remote sensing capability since the early 1980s. While there have been a number of changes in the instrumentation payload, the basic instrument suite and data transmission stream has remained essentially the same over more than two decades. Over the next 5 years the present program will evolve in significant ways via collaboration with EUMETSAT called the Initial Joint Polar system (IJPS). Ultimately the current system will be replaced by a new generation of spacecraft and instruments in the National Polar Orbiting Environmental Satellite System (NPOESS). While these will provide increased spatial, spectral and temporal coverage, they will also impact those sites receiving the data via direct broadcast, requiring changes to reception station engineering and user analysis software.

Although not strictly "operational" in same sense as the NOAA polar series, the MODIS sensors carried on the Terra and Aqua EOS platforms are in many ways engineering forerunners of the future systems and any sites and users able to receive and successfully process data from these sensors will be well placed, in terms of engineering, data handling and analysis expertise, to deal with the future operational systems.

System Evolution

The diagrams on the next two pages illustrate the evolution of the operational environmental satellite systems over the next 15 years. The diagrams are taken from a presentation at the conference by John Cunningham, NPOESS System Program Director.



Key Stages

The essential driver of the changes is efficiency and cost effectiveness. The US currently operates two separate polar programs, one military (DMSP) and one civilian (NOAA POES), each with a pair of spacecraft in sun-synchronous polar orbits, and both sets of spacecraft carrying a variety of instruments, some similar between the programs and some unique. These two programs will be merges to create the NPOESS program with 3 spacecraft carrying a substantially upgraded set of instrumentation capable of meeting the needs of both the former programs simultaneously.

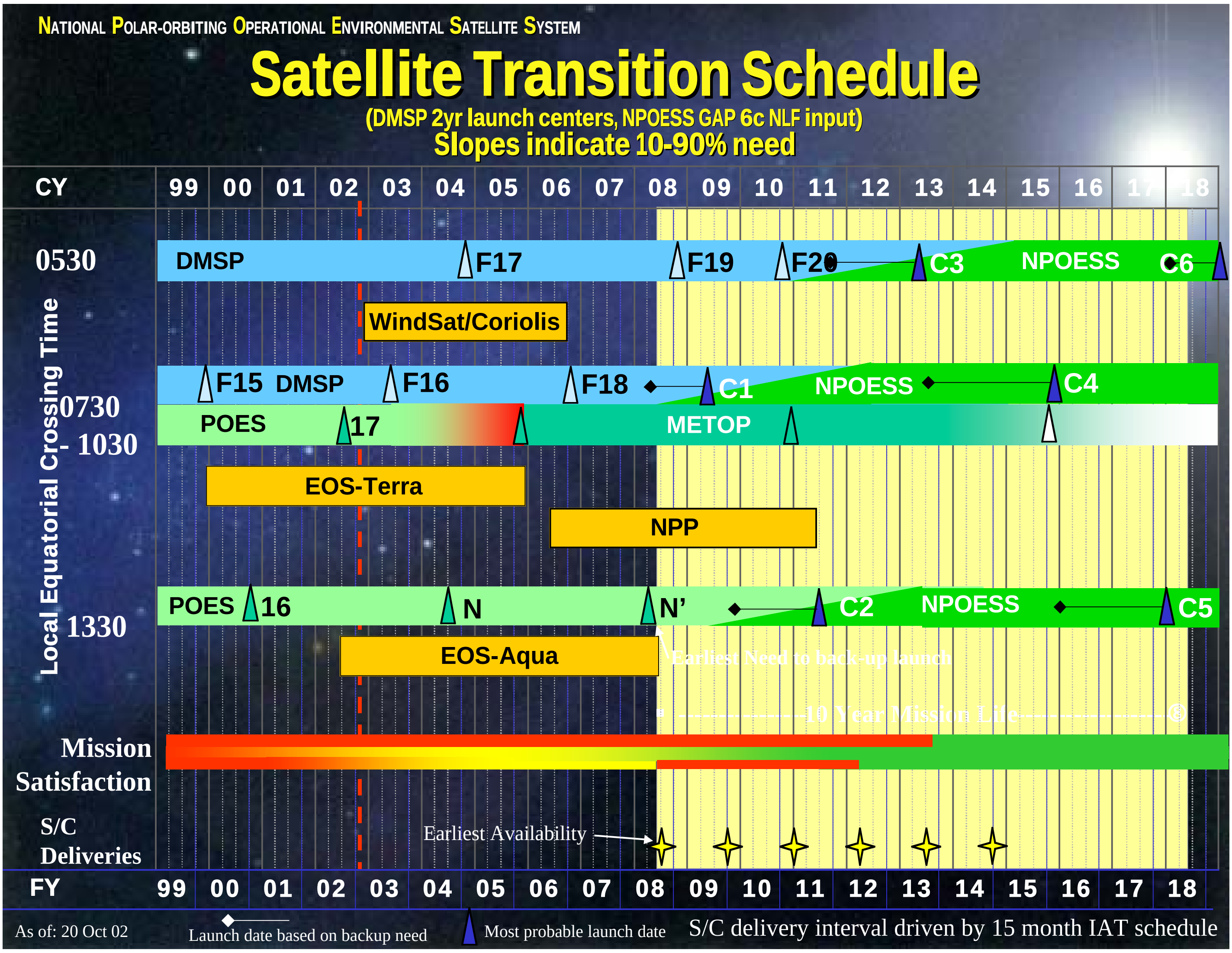
In the short term, EUMETSAT will launch a series of METOP spacecraft carrying some NOAA-provided instruments to assume the role of the morning NOAA orbit while NOAA will continue to launch and support the afternoon orbit. The military will continue to run the DMSP program. In the medium term (2006), NASA will launch the NPP (NPOESS Preparatory Project) spacecraft into a 1030am orbit. This spacecraft will carry a mission critical subset of the final NPOESS instrument suite and provide a test platform for the development of ground systems (including analysis software) to refine the NPOESS program implementation.

The first NPOESS launch is planned for 2009 to coincide roughly with the expected end-of-life of the final NOAA afternoon POES satellite, NOAA-N’. By 2013 NPOESS will have taken over and both the DMSP and POES programs will have ended. The EUMETSAT METOP program will continue to launch through 2015.

In summary:

- Currently 2 civilian POES (am=0730 Dsc, pm=1330 Asc) and 2 military DMSP (0630 Dsc, 0830 Dsc)
- 2005: 1 civilian POES (0730 Dsc) replaced by Eumetsat METOP (0930 Dsc)
- 2008+: 3 joint civilian/military NPOESS (0530 Dsc, 0930 Dsc, 1330 Asc) and 1 Eumetsat METOP (0930 DSC)

The following diagram, also from Cunningham's presentation, gives a detailed launch schedule over the next 15 years. Planned launches are indicated by the small triangles, the DMSP spacecraft by the letter 'F' and NPOESS the letter 'C'. Note also the EOS-Terra, EOS-Aqua and the NPP spacecraft are shown. EOS platforms, and NPP, play a key role in two ways: 1) in providing ground reception sites with incentive to improve their data acquisition systems to X-band high data rate capability, and 2) through the delivery of more complex datasets, akin to those that NPOESS will be capable of, allowing time to develop new preprocessing algorithms and products prior to the launch of NPOESS itself.



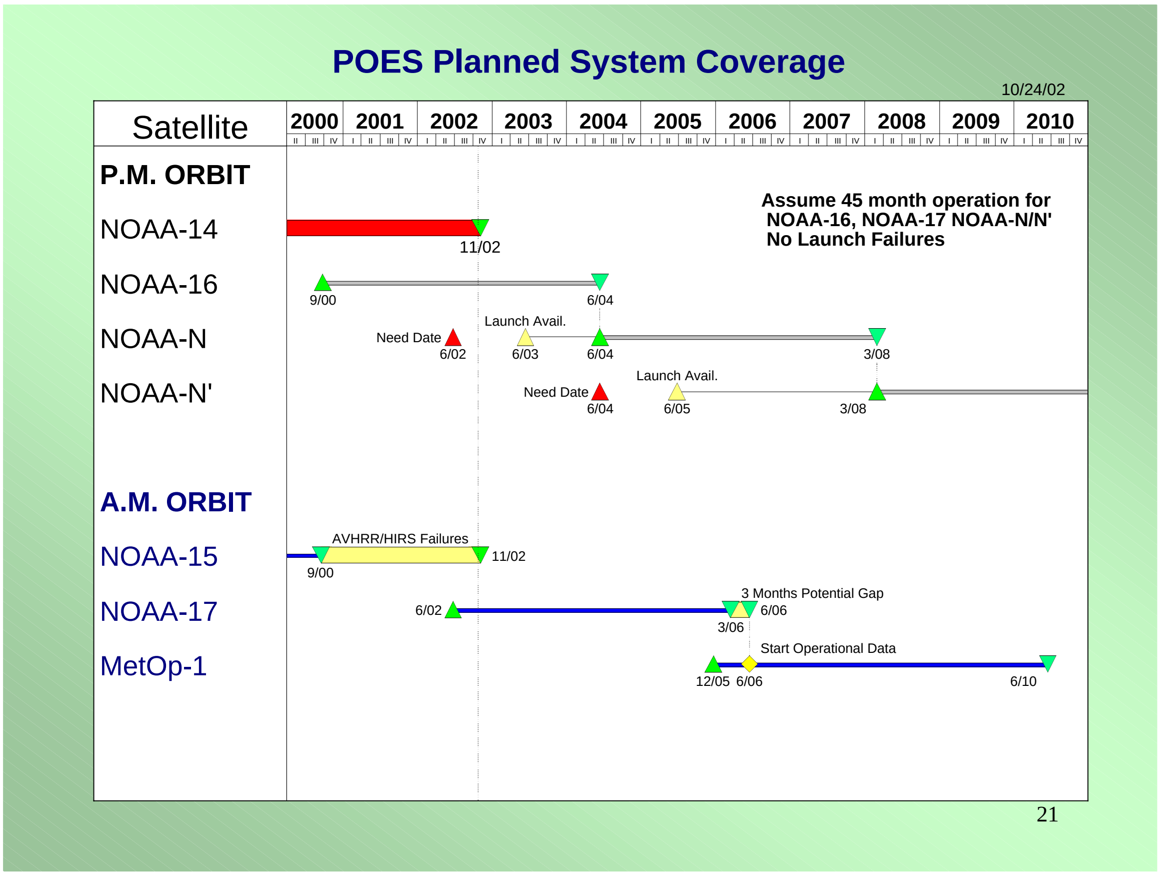
In the following sections the characteristics of all the relevant spacecraft/instrument combinations are briefly described.

1. NOAA POES

The planned civilian POES launch schedule is:

NOAA - N (pm)	Jun 2004
METOP-1 (am)	Dec 2005
NOAA - N' (pm)*	Mar 2008
METOP - 2 (am)	Aug 2010

The METOP spacecraft are operated by EUMETSAT and will be discussed in the next section. NOAA-N and N’ primed are essentially continuations of the NOAA-KLM series and will become NOAA-18 and NOAA-19 respectively. N’ may not be launched, depending on the operational lifetime of NOAA-N and the exact launch date of the second NPOESS spacecraft. NOAA-N and N’ constitute the US component of the IJPS. The detailed POESS launch schedule (from a presentation by Mignogno) is:



The final NOAA morning satellite NOAA-17, differs from NOAA-15 and its predecessors in that it has 10am descending node, some 2.5 hours later.

The instrument complement on the POES spacecraft is planned to continue as for the present NOAA-KLM spacecraft:

- •AVHRR - Imaging radiometer (ITT A/CD)
- •HIRS - Infrared sounder (ITT A/CD)
- •AMSU-A - Microwave sounder (Northrup Grumman)
- •AMSU-B - Microwave humidity sounder (U.K. Met Office)
- •SBUV - Ozone instrument (Ball Aerospace)
- •SEM - Space environment instrument (Panametrics)
- •DCS - Data collection system (France)
- •SARSAT - Search and rescue system (France & Canada)

Importantly, the data downlink parameters will remain essentially the same for all the planned NOAA POES spacecraft, ie direct broadcast with existing HRPT (L-band) and APT (136 MHz).

2. EUMETSAT Polar System (METOP)

The European component of the IJPS is the METOP spacecraft series. These will be launched into orbits with a mid-morning descending node and replace the US civilian morning satellites. Three METOP spacecraft are planned, each with an approximately 5-year mission lifetime and nominal launch dates of 2005, 2009/10 and 20014.

The AVHRR/3, HIRS/4, AMSU-A, DCS, SARSAT and SEM instruments already present onboard the NOAA POES spacecraft will be flown on the METOP platform. Several other instruments of European origin, but fulfilling similar niches to the other instruments on the NOAA POES spacecraft, will also be carried (See the presentation "METOP and the IJPS:" by Ken Ashworth for more detail). Although the METOP satellites are of European construction and will be operated by EUMETSAT an extensive data exchange program has been agreed to ensure continued timely availability of downlinked data.

However there are several significant differences to the data stream that will impact on direct broadcast users. Firstly it appears that the HRPT stream will change its internal format to allow commutation of the different instrument suites. The exact nature of this change will not be fixed until the critical design review in mid-2003 so potential ground station operators would be well advised to monitor the EUMETSAT WWW documentation in the latter half of 2003. My understanding is that the HRPT stream can still be received with existing hardware, but the data organisation (meaning of the words and bits) will be modified, so this should hopefully only be an issue for downstream software.

The second planned change, data encryption, will have a more significant impact on users. Receiving stations will have to be registered with EUMETSAT in order to receive the decryption keys. The process of station registration will incur a one-off, or possibly annual, fee and the decryption keys will be transmitted on a regular basis to allow legitimate users to decode the data. The procedure will generally follow that already used by EUMETSAT for the METEOSAT spacecraft series, and in fact will utilise the same Key Management centre, practices and key distribution channels currently in place. It appears that data from the US provided instruments will, as a matter of course, be broadcast unencrypted. EUMETSAT will enable encryption, selectively to implement data denial at the request of the US government "in times of crisis or war". It was unclear at the time of the conference (Dec '02) whether the European instruments would always be encrypted (there appears to be a capacity to selectively encrypt) or would be treated in the same way as the US instruments. In any case, additional decryption hardware will need to be obtained by reception stations that want to decode the data at all times.

A third change to the data broadcast for METOP is the low resolution LRPT (formerly APT, 136 MHz) data stream will become digital rather than analog. Users wishing to access this stream will require significant new hardware.

Many of these details were still fluid at the time of the conference and interested users are advised to monitor the situation in the latter half of 2003 to keep abreast of the changes as they are finalised.

3. NPP & NPOESS

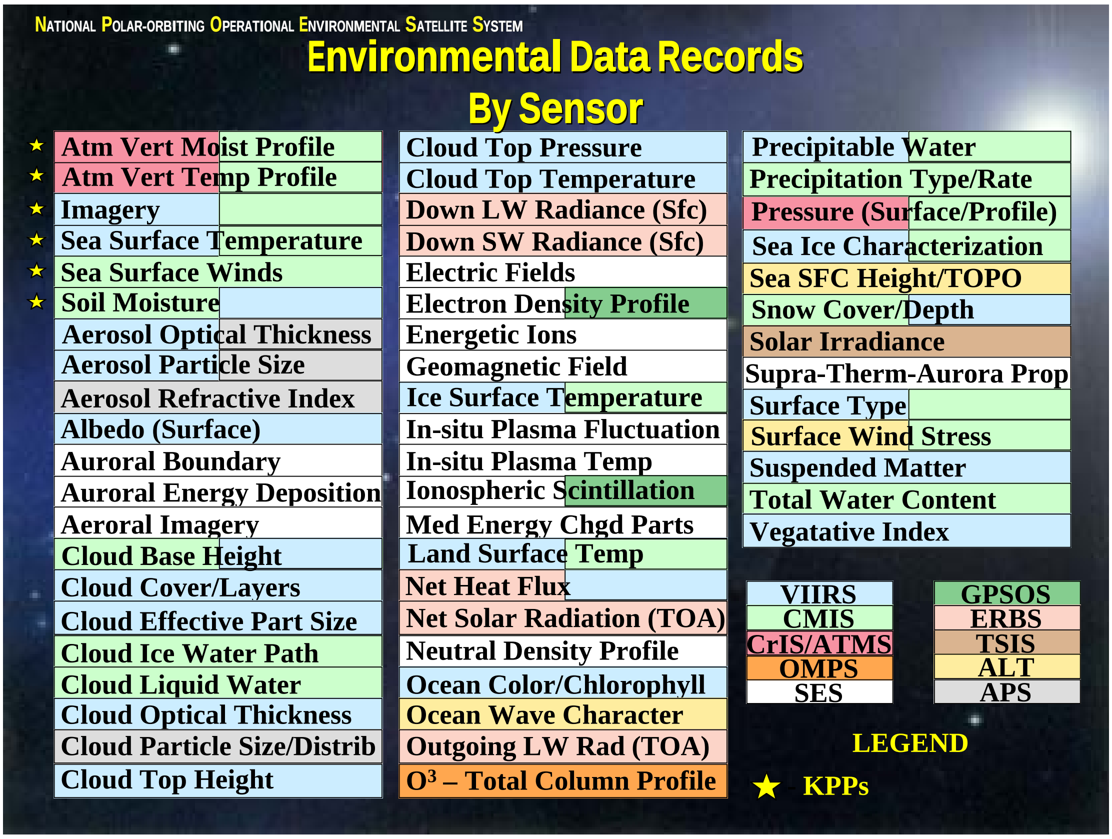
Undoubtedly the most dramatic, and exciting, change on the horizon is the advent of the NPOESS program in the latter half of this decade. This program will impact severely on reception stations and sites which choose not to upgrade will be able receive only a fraction of the rich data sets available from this platform. The primary reference presentations on the conference web site are those by Cunningham (*Introduction to the NPOESS Program*, already referred to), Bloom (*NPOESS Space Segment & Sensors*) and Overton (*NPOESS Ground Segment-Communications & Direct Readout Concept*). Much of what follows is highlighted from these three presentations, which are recommended references for the interested reader. Another useful starting point for more information is the Integrated Program Office (IPO) web site at: http://www.ipo.noaa.gov/.

The essential concept involves a three orbit system supporting am, pm and pre-dawn equator crossings (the latter to accommodate the military weather forecasting needs currently provided by DMSP). The choice of instrument suite for the platforms is driven by a desire to acquire no less than 55 different environmental data records. Six of these:

- atmospheric vertical moisture profile
- atmospheric vertical temperature profile
- imagery
- sea surface temperature
- sea surface winds
- soil moisture

are designated key records. The significance of key records is that they are required for the system to be "operational". In other words, failure of an instrument that provides one of these six records automatically mandates the launch of a replacement spacecraft.

The list of all 55 environmental data records appears conveniently in the following table from Cunningham. The first six records indicated by the stars are the key records. A total of ten instruments are planned, of which three are required to provide the key records.



A useful summary of the instruments on board NPOESS, in the context of the IJPS and NPP programs can be found in Bloom and appears below:

NPOESS Payloads

NPOESS Instruments	0530	0930	1330	METOP 0930	NPP 1030	TBD
IPO Developed						
Visible/IR Imager Radiometer Suite (VIIRS)*	X	X	X	X (AVHRR)	X	
Cross-track IR Sounder (CrIS)*		X	X	X (IASI/HIRS)	X	
Conical MW Imager/Sounder (CMIS)*	X	X	X			
Ozone Mapper/Profiler Suite (OMPS)			X	X (GOME)		X
GPS Occultation Sensor (GPSOS)			X	X (GRAS)		
Space Environmental Sensor Suite (SESS)			X	X (SEM)		
Aerosol Polarimetry Sensor (APS)		X				
Leveraged						
Advanced Technology MW Sounder (ATMS)*		X	X	X (AMSU/MHS)	X	
ARGOS-Data Collection System (A-DCS)	X		X	X		
Search and Rescue (SARSAT)	X	X	X	X		
Earth Radiation Budget Sensor (ERBS)			X			
Total Solar Irradiance Sensor (TSIS)	X					
Radar altimeter (ALT)	X					
Advanced Scatterometer (ASCAT)				X		

* Critical instrument - Failure constitutes need to replace satellite

Note that not all instruments are carried on all spacecraft in the NPOESS series, only the VIIRS Imager, CrIS Imager/Sounder and SARSAT search and rescue system being common to all platforms. The three critical instruments will all be flown on the NPP mission to "field test" them operationally and to ensure that ground segments (reception stations and processing facilities) are prepared when NPOESS becomes operational and the POES/DMSP programs cease.

The Visible Infra-red Imaging Radiometer Suite (VIIRS) is the replacement for the AVHRR. It will have 9 bands in the visible/near IR, 8 in the mid IR and 4 in the long wave IR. Six channels are designated 'Imaging' and have a spatial resolution of 400m at nadir increasing to 800m at the edge of scan. The remaining channels are somewhat lower resolution (~km) and a labelled 'Moderate' in the table below. The sensor optics and configuration will be very similar to those of MODIS so experience gained with Level1B processing of MODIS (eg geolocation, bowtie, striping etc) will be valuable with VIIRS. An excellent source of information on all the instruments is on the IPO web site at http://www.ipo.noaa.gov/Technology/sensors.html.

VIIRS Sensor Bands						
Band Name	Δc(nm)	$\Delta\lambda$(nm) **	Wavelength Type	Radiance Type	Spatial Resolution Type	Focal Plane Assembly
M1	412	20	VIS	Reflective	Moderate	VISNIR
M2	445	18	VIS	Reflective	Moderate	VISNIR
M3	488	20	VIS	Reflective	Moderate	VISNIR
M4	555	20	VIS	Reflective	Moderate	VISNIR
M5	672	20	VIS	Reflective	Moderate	VISNIR
M6	746	15	NIR	Reflective	Moderate	VISNIR
M7	865	39	NIR	Reflective	Moderate	VISNIR
M8	1240	20	SWIR	Reflective	Moderate	SMWIR
M9	1378	15	SWIR	Reflective	Moderate	SMWIR
M10	1610	60	SWIR	Reflective	Moderate	SMWIR
M11	2250	50	SWIR	Reflective	Moderate	SMWIR
M12	3700	180	MWIR	Emissive	Moderate	SMWIR
M13	4050	155	MWIR	Emissive	Moderate	SMWIR
M14	8550	300	LWIR	Emissive	Moderate	LWIR
M15	10763	1000	LWIR	Emissive	Moderate	LWIR
M16	12013	950	LWIR	Emissive	Moderate	LWIR
DNB	700	400	VIS	Reflective	Imaging	DNB
I1	640	80	VIS	Reflective	Imaging	VISNIR
I2	865	39	NIR	Reflective	Imaging	VISNIR
I3	1610	60	SWIR	Reflective	Imaging	SMWIR
I4	3740	380	MWIR	Emissive	Imaging	SMWIR
I5	11450	1900	LWIR	Emissive	Imaging	LWIR

The peak data rate from the VIIRS alone is 10.5 Mbits/sec, the full high rate data is40 Mbits/sec. This has lead to the need to increase the downlink frequency to obtain sufficient transmission bandwidth. The primary downlink frequency will increase from L-band (~1400 MHz) to X-band (~8400 MHz) and the data rate will grow by nearly a factor of 30. This change will affect reception hardware, archiving and processing systems deeply. Stations that have already upgraded to an EOS- MODIS X-band capability will be well placed to receive NPOESS, requiring only modifications to the demodulating hardware. A 7.7 Mbit/sec subset of the dataset will be available at a lower frequency of 1700 MHz.

A direct broadcast facility is planned as in the current POES program. However a selective encryption scheme will be implemented similar to that for METOP. Once again there is no intention to charge for the data, but the joint military role of the spacecraft imposes a requirement that selective data denial be possible in times of conflict. To quote from Overton "NPOESS will deliver data to users world-wide in accordance with US national data policy: 1) data will be downlinked openly around the world at no cost to the receivers, 2) capability for data encryption/data denial exists for national defence needs (denial can be done on a worldwide or geographic basis)".

In addition to the direct broadcast downlink, the NPOESS spacecraft will store full rate data onboard and downlink it rapidly at K-band (22 GHz) and one of 15 ground reception stations distributed round the world, including at least one in Australia. The intention is that the data will then be returned to the control centre in the US via high bandwidth terrestrial systems, so data from anywhere in the world will be rapidly available at the US data centre without having to wait for the satellite to complete a whole orbit. Whether this is achievable in practice remains to be demonstrated. It may be necessary to do initial processing at the ground sites to reduce the data volume sufficiently to enable such a rapid turnaround.

Data volume and archiving will be a problem throughout. Data was presented at the conference indicating that, even taking into account advances in computing expected over the next 6 years, a 4-processor PC will still be required to fully process all the data from a full pass within 15 minutes of acquisition.

In presentation related mostly to direct broadcast from the NASA EOS spacecraft pair (AQUA and TERRA), Jim Dodge of NASA provided a useful viewgraph giving a nominal engineering roadmap for getting from the current POES era through to NPOESS (or NPP). It is included below and gives a general guide to the RF, modulation and bandwidth requirements.

Users less interested in reception station engineering and more in the use of data from NPOESS for environmental monitoring may find the following reference of value:

J.R.G. Townshend and C.O. Justice, "Towards operational monitoring of terrestrial systems by moderate-resolution remote sensing", Remote Sensing of the Environment, 83 (2002), pp 351-359.

Direct Readout Roadmap to NPP