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Prepared by NOAA
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IMPLEMENTATION OF CGMS BEST PRACTICES FOR LEO DIRECT BROADCAST DATA AT NOAA

HLPP reference: 2.3.3

Working Paper summary: This paper presents status of implementation at NOAA of the CGMS Agency Best Practices in support to Local and Regional Processing of LEO Direct Broadcast data (CGMS/DOC/18/1008274, v1B) for NOAA-18, NOAA-19, S-NPP, NOAA-20 and NOAA-21.

Recommendation proposed: WG-I members are invited to take note and comment on the status of implementation at NOAA of the CGMS Best Practices in support to local and regional processing of LEO direct broadcast data.

IMPLEMENTATION OF CGMS BEST PRACTICES FOR LEO DIRECT BROADCAST DATA AT NOAA

1 INTRODUCTION

This paper describes the implementation status of the Coordination Group for Meteorological Satellites (CGMS) agency best practices in support to local and regional processing of Low Earth Orbiting (LEO) Direct Broadcast (DB) data at the National Oceanic and Atmospheric Administration (NOAA). The Best Practice document is labelled CGMS/DOC/18/1008274, v1C and it is available at: https://www.cgms-info.org/documents/CGMS_BP_LEO_DB_data_-_local_regional_processing.pdf

The Best Practices reflect the commitments taken by the CGMS agencies operating DB satellites with respect to the coordination and support provided to the DB user community. By adopting the Best Practices, CGMS Agencies are also increasing user's data access capability, while improving timeliness of satellite data in environmental models, and reducing the overall demands on alternative data distribution systems.

This paper focuses on the Polar Operational Environmental Satellites (POES) legacy missions (NOAA-18, NOAA-19); Suomi National Polar-orbiting Partnership (S- NPP) mission, NOAA-20 mission and NOAA-21 mission

The Office of Satellite and Product Operations (OSPO), National Environmental Satellite, Data, and Information Service (NESDIS) represents NOAA for this effort.

2 STATUS OF OPERATIONAL DIRECT BROADCAST SYSTEMS

The Status of Operational Direct Broadcast Systems at NOAA is summarized in Table 1 below:

POES		
Instruments	**NOAA-18**	**NOAA-19**
AMSU-A1	Green	Green
AMSU-A2	Green	Green
AVHRR	Yellow	Green
HIRS	Red	N/A
MHS	Red	Yellow
SUBV	Red	Green

JPSS			
Instruments	**SNPP**	**NOAA-20**	**NOAA-21**
ATMS	Green	Green	Green
CERES	Green	Green	Green
CrIS	Green	Green	Green
OMPS	Green	Green	Green
VIIRS	Green	Green	Green

Table 1: Status of Operational Direct Broadcast Systems at NOAA

NOAA complies with all ten of the Best Practices in regards to the current operational POES, S-NPP and NOAA-20 satellites. NOAA will continue to support the Best Practice effort by participating in the Intersessional and formal WG-I meetings.

2.1 BP.01 Global Specification for Direct Broadcast

Best Practice BP.01 Description: Operators should implement the agreed CGMS Direct Broadcast Services: Low-Rate Picture Transmission (LRPT)/ Advanced High-Resolution Picture Transmission (AHRPT) Global Specification (Document No. CGMS 04). The document is available at: https://www.cgms-info.org/documents/Direct_Broadcast_Services__LRPT_AHRPT_Global_Specification,_Issue_2_01.pdf

2.1.1 POES

Not applicable.

2.1.2 S-NPP, NOAA-20 and NOAA-21

Compliant. The HRD builds upon a set of applicable Consultative Committee for Space Data Systems (CCSDS) standards as described in the Joint Polar Satellite System 1 (JPSS-1) Spacecraft High Rate Data (HRD) to Direct Broadcast Stations (DBS) Radio Frequency (RF) Interface Control Document (ICD) (2014)

The Mission Data Formatter (MDF) within the Command and Data Processor (CDP) enables CCSDS Channel Access Data Units (CADU) to be generated from CCSDS Advanced Orbiting Systems (AOS) transfer frames provided by the CDP flight software.

The Joint Polar Satellite System (JPSS) Common Data Format Control Book –External (CDFCB-X), Volume VII – Part 1, JPSS Downlink Data Formats is available on the National Aeronautics and Space Administration (NASA) Direct Readout Laboratory website: https://directreadout.sci.gsfc.nasa.gov/links/rsd_eosdb/PDF/474- 00001-07-01_JPSS-CDFCB-X-Vol-VII-Part-1_0122-_20120126.pdf

2.2 BP.02 Timely provision of Space-to-Ground Interface Control Documents

Best Practice BP.02 Description: CGMS operators should provide up-to-date and satellite-specific Space-to-Ground Interface Control Documents in English language at least 3 years before the launch of each satellite, including at least:

a) Frequency usage

b) Polarization

c) Encoding

d) G/T requirements

e) Data stream layout and content

f) Conformance with CCSDS.

g) Conformance with the CGMS Global Specification (see section 1)

2.2.1 POES

Compliant. NESDIS updated the NOAA-KLM User Guide in 2014 and the revised version is available at:
https://www1.ncdc.noaa.gov/pub/data/satellite/publications/podguides/N-15%20thru%20N-19/pdf/0.0%20NOAA%20KLM%20Users%20Guide.pdf

Another resource is the: User's Guide for Building and Operating Environmental Satellite Receiving Stations (2009) which available at:
http://noaasis.noaa.gov/NOAASIS/pubs/Users_Guide-Building_Receive_Stations_March_2009.pdf

2.2.2 S-NPP, NOAA-20 and NOAA-21

Compliant. The Joint Polar Satellite System 1 (JPSS-1) Spacecraft HRD to DBS RF ICD is available to the public at: https://directreadout.sci.gsfc.nasa.gov/links/rsd_eosdb/PDF/JPSS-1SpacecraftHRDtoDBSRFICDRev-May302012-470-REF-00184.pdf

The ICD is listed as a reference on the WMO SATURN webpage titled JPSS-1 Data Access Mechanisms: https://www.wmo-sat.info/satellite-user-readiness/jpss-1-data-access-mechanisms-2/

The NOAA-21 HRD will have some differences compared to the NOAA-20 (JPSS-1) HRD. The JPSS Program briefed HRD users on the differences during an HRD User Group meeting in November 2018. NOAA briefed the changes during the WG-I Intersessional WebEx in March 2019. The JPSS Program posted an updated NOAA-21 Satellite High-Rate Data (HRD) to Direct Broadcast Stations (DBS) Radio Frequency(RF) Interface Control Document (ICD) on the JPSS website in October 2021. The document is available on the JPSS website at:

The NOAA-21 HRD differences compared to the NOAA-20 HRD are:

- The modulation type is offset quadrature phase shift keying (OQPSK) (NOAA-20 is QPSK).
- The data rate for NOAA-21 will increase to 25 Mbps (NOAA-20 data rate is 15 Mbps).
- Both missions use Reed-Solomon (RS) block coding. The NOAA-21 HRD Interleaves five blocks (I=5) and NOAA-20 interleaves four blocks I=4).
- The JPSS Program briefed the HRD User Group on the changes on November 8, 2018.

Table 1. Differences between NOAA-20 HRD and NOAA-21 HRD

	NOAA-20	NOAA-21 Spacecraft to DBS X-Band HRD Downlink
Center Frequency	7812 MHz	7812 MHz
Data Rate[1]	15 Mbps	25 Mbps

[1]Bit transition rate, measured after Reed-Solomon coding and prior to modulation.

Assigned Bandwidth (-20 dB)	30 MHz	50 MHz
Bit error Rate (BER)	10-8	10-8
PCM Format	NRZ-M	NRZ-M
Convolutional Coding Rate 1/2 length 7. G1 and G2-Invert	15 Mbps I + 15 Mbps Q	25 Mbps I + 25 Mbps Q
Modulation	QPSK	OQPSK Offset Quadrature Phase Shift Keying
Polarization	RHCP	RHCP
Block Coding: (255,223) Reed Solomon RS	Interleave=4 4 x 32 = 128 Parity Bytes	Interleave=5 5 x 32 = 160 Parity Bytes
Information Field	4 x 223 = 892 Bytes	5 x 223 = 1115 Bytes
Power Level	7.8 Watt	10.7 Watt (end-of life)
Antenna pattern 62 degrees nadir coverage	NOAA-20 Antenna Gain at ±62° = 5.87 dBi NOAA-20 EIRP = 42.9 dBm See JPSS-1 HRD DBS RF ICD, App B	NOAA-21//3/4 Antenna Gain at ±62° = 6.2 dBi JPSS-2/3/4 EIRP = 45.02 dBm See JPSS-2 HRD DBS RFICD, Addendum

2.3 BP.03 Provision of Current Orbit Information

Best Practice BP.03 Description: CGMS operators should ensure timely provision of accurate and up-to-date orbit information based on their operational orbit determination and knowledge of satellite maneuvers. The orbit information should be made available to Direct Broadcast reception station operators:

a) In TLE format via FTP or HTTP over the Internet;

b) Additionally, if required for the processing and geolocation of the sensor data, in the relevant mission specific format via FTP or HTTP over the Internet and/or via the satellite's Direct Broadcast signal;

c) Additionally, if the satellite operator chose to do so, in TLE format via the satellite's Direct Broadcast signal.

The satellite operator shall document:

d) The details of how and where the orbit information is made available;

e) For any mission specific format, the format definition and its application.

General Comment: NOAA no longer uses FTP or HTTP over the Internet and has moved to secure protocols such as HTTPS.

2.3.1 POES

Compliant. An overview of the NESDIS Polar Earth Location Process is available at http://www.ospo.noaa.gov/Products/ppp/overview.html

NOAA NESDIS documents:

- The details of how and where the orbit information is made available;
- For any mission specific format, the format definition and its application.

NESDIS OSPO maintains the POES Webpage at:
https://www.ospo.noaa.gov/Operations/POES/index.html

That webpage has a link for the POES Two-Line Orbital Elements (TLE). The link for the POES TLEs is: http://www.celestrak.com/NORAD/elements/noaa.txt

2.3.2 S-NPP, NOAA-20 and NOAA-21

Compliant with S-NPP, NOAA-20 and NOAA-21. The JPSS Field Terminal Support (FTS) provides Mission Support Data (ancillary data, auxiliary data and Mission Notices) and the necessary hardware and software specifications needed for processing the broadcasts. FTS distributes S-NPP and NOAA-20 (JPSS-1) TLEs, predicted post- maneuver TLEs, and definitive ephemeris files.

Orbital data is also provided on the FTS web portal, to assist the DB community indicating the satellites of interest
FTS webpage: https://fieldterminal.nesdis.noaa.gov

Users can also find S-NPP, NOAA-20 and NOAA-21 TLEs from the following OSPO run webpage: http://www.celestrak.com/NORAD/elements/noaa.txt

Spacecraft ephemeris and attitude information is included in the HRD broadcast from S-NPP, NOAA-20 and NOAA-21 and it is used for real-time geolocation processing in CSPP.

2.4 BP.04 Provision and maintenance of Product Processing software packages

Best Practice BP.04 Description: Each LEO satellite operator should therefore ensure that:

a) Software packages for the relevant instruments are made available with a test version made available prior to launch and the operational version made available after end of commissioning of the satellite and as soon as feasible for the satellite operator;

b) To enable deployment of the software packages within organizations not permitting installation of pre-compiled software, source code should be made available;

c) Global and local product processing shall be harmonised in that brightness temperature products derived from both paths agree within tolerances that are not greater than few tenths (goal is 10%) of the respective performance requirements for bias error at a reference brightness temperature;

d) User support and maintenance services are available for the duration of the mission;

e) Notifications for software changes are provided to the user community;

f) Complete and comprehensive user documentation and S/W release documentation is supplied in English language;

g) The software installation procedure is designed to be easily executed by an untrained user;

h) The software package is executable on a standard computer platform, typically Linux/x86-64, providing a performance compatible with the timeliness requirements defined in the Guide to DBNet (CGMS-44-WMO-WP-10);

i) For reasons of performance, it should be possible to configure the software to process only the instruments and processing levels required locally;

j) Test data for verifying the installation of the S/W packages are made available

k) The product processing software is robust against sporadically missing data packets from the instrument or satellite in the sense that the software limits the extent of degraded or lost observations in the generated product(s) to the minimum possible.

2.4.1 POES

The Community Satellite Processing Package (CSPP) supports the Direct Broadcast (DB) meteorological and environmental satellite community through the packaging and distribution of open source science software.

CSPP Software processes the following NOAA-18 and NOAA-19 data: AVHRR (Clouds, Aerosols, Land Surface, SST, Visualization), HIRS (Atmospheric Profiles), and AMSU and MHS (Atmospheric Profiles, Precipitation).

2.4.2 S-NPP, NOAA-20 and NOAA-21

NOAA's S-NPP, NOAA-20 and NOAA-21 product processor software complies with the elements of BP.04 as follows:

a) Software packages for the relevant instruments are made available prior to launch. Software is available for download prior to launch. CSPP software processes S-NPP and JPSS data from VIIRS, CrIS, and ATMS. Instructions for downloading CSPP software are on the CSPP Home Page located at: http://cimss.ssec.wisc.edu/cspp/

CSPP includes the RT-STPS Pre-Processor, developed and maintained by NASA DRL. Information about RT-STPS is available at: https://directreadout.sci.gsfc.nasa.gov/?id=dspContent&cid=69

The NASA DRL Simulcast Quality Monitoring Tool has been used to monitor the S-NPP and NOAA-20 HRD performance. More information is available at:

https://directreadout.sci.gsfc.nasa.gov/?id=dspContent&cid=70

b) In regards to making source code available, NOAA agrees with the BP.04 wording with a minor condition. For U.S. government agencies, the scope of licensing rights generally depends upon the source of the funding (i.e., government, mixed, or private), the nature of the data (commercial or non-commercial), and any negotiated terms of the contract. Also, NOAA must comply with deemed export control rules. Hence, as long as NOAA has unlimited rights to the source code and complies with all applicable laws, regulations, and policies, then NOAA should be able to make it available.

c) In regards to harmonizing global and local product processing, the CSPP software is compliant

d) In regards to user support and maintenance services CSPP is compliant. CSPP is sponsored by the JPSS Program Science Office.

e) Notifications for CSPP software changes are posted on the CSPP Website.

f) CSPP documentation is on the CSPP website: http://cimss.ssec.wisc.edu/cspp/

g) The software installation procedure is designed to be executed by an untrained user.

h) The CSPP software package is executable on a standard computer platform, typically Linux/x86-64, providing a performance compatible with the timeliness requirements defined in the Guide to DBNet (CGMS-44-WMOWP-10).

i) The CSPP software enables users to configure the software to process only the instruments and processing levels required locally.

j) Test data for verifying the installation of the CSPP software packages are available from the CSPP program.

2.5 BP.05 Provision of auxiliary data for instrument product processing

Best Practice BP.05 Description: Each operator of instruments requiring auxiliary data for the product processing must make available the necessary auxiliary data on the Internet in a user-friendly and timely manner. Announcements of the availability of new auxiliary data should be issued giving the Direct Broadcast reception station operators sufficient time to update their systems.

2.5.1 POES

Not applicable.

2.5.2 S-NPP, NOAA-20 and NOAA-21

Compliant with S-NPP, NOAA-20 and NOAA-21 auxiliary data are available on FTS. The FTS user portal web page is located at:
https://fieldterminal.nesdis.noaa.gov/

2.6 BP.06 Recommendations of channel selection for hyperspectral instruments

Best Practice BP.06 Description: Each CGMS operator of hyperspectral instrument is responsible for defining a recommended channel selection scheme for global NWP purposes. The channel selection shall be made available to DB station operators prior to the launch of the first instrument and subsequently whenever the channel selection is modified.

2.6.1 POES

Not applicable.

2.6.2 S-NPP, NOAA-20 and NOAA-21

Compliant. Users are notified of any changes through Environmental Satellite Processing Center (ESPC) Notifications. Contact the ESPC Help Desk to be added to the distribution list: ESPCOperations@noaa.gov

Notifications are archived at: https://www.ospo.noaa.gov/Operations/messages.html

2.7 BP.07 Spacecraft and Instrument Operational Status

Best Practice BP.07 Description: Each CGMS operator to publish and maintain up to date spacecraft and instrument operational status information on the Internet. The

CGMS operators should establish a scheme to review on a regular basis that the published status information is up to date.

2.7.1 POES

Compliant. Operationally implemented, see:
http://www.ospo.noaa.gov/Operations/POES/status.html

2.7.2 S-NPP, NOAA-20 and NOAA-21

Compliant with the exception of NOAA-21. NOAA-21 is non-operational at this time. S-NPP and NOAA-20 operational statuses are available at:
https://www.ospo.noaa.gov/Operations/JPSS/status.html

Product maturity level is available at:
https://www.star.nesdis.noaa.gov/jpss/AlgorithmOperational.php

NOAA-21 operational status and product maturity will be available post launch.

2.8 BP.08 Operational Announcements

Best Practice BP.08 Description: Each CGMS operator to announce planned operations and status changes as well as any observed degradation of the spacecraft and its instruments via e-mail and optionally via other channels.

2.8.1 POES

Compliant. ESPC Notifications are issued for both planned and unplanned events. The Notifications are also at: http://www.ospo.noaa.gov/Operations/messages.html

Contact the ESPC Help Desk to receive ESPC Notifications:
ESPCOperations@noaa.gov

2.8.2 S-NPP, NOAA-20 and NOAA-21

Compliant. Environmental Satellite Processing Center (ESPC) Notifications are issued for both planned and unplanned events. The Notifications are also available at: http://www.ospo.noaa.gov/Operations/messages.html

Contact the ESPC Help Desk to receive ESPC Notifications:
ESPCOperations@noaa.gov

2.9 BP.09 Satellite Direct Broadcast and Reception Station Performance Requirements

Best Practice BP.09 Description: When planning, designing, and developing satellite direct broadcast (DB) downlink capabilities, the CGMS agencies will strive to minimize, when possible, negative impacts on the DB community by communicating with manufacturers and users; coordinating with the other CGMS agencies; and considering these potential impacts during the CGMS agency's decision-making process.

The performance of the satellite's DB X-Band (7.8 GHz, ITU MetSat Band) downlink should be sufficient for nominal data reception at any reception station within the satellite's footprint at elevations above 5 degrees and a G/T value of at least 22.7 dB/K. The calculation of the satellite DB performance shall include an allocation of at least 8.55 dB for reception station losses, rain and atmospheric losses, and link budget margin. The G/T is defined at the input of the receiver interface, at 5-degree antenna elevation and clear sky conditions.

A reception station operator may be required to establish a reception station with additional performance margin to account for local conditions, including climate, RF interference or the impact of an antenna radome.

2.9.1 POES

Not applicable.

2.9.2 S-NPP, NOAA-20 and NOAA-21

Compliant. The Link Budget in Appendix A.1(SNPP, NOAA-20) and Appendix A.2 (NOAA-21, JPSS-3, JPSS-4) demonstrates a positive margin when assuming Reference Rain and Atmospheric losses and station Reference Performance.

2.10 BP.10 Monitoring of the Direct Broadcast Downlink

Operators of satellites with DB should routinely monitor the quality of the DB downlink and address any anomalies in accordance with each organization's established procedures, and notify users of degraded performance. Monitoring should include:

a) For each satellite, during the six months following DB signal activation, a validation that nominal reception is possible for a DB reception station anywhere within the footprint of the satellite DB antenna by acquiring all passes at an elevation of 5 degrees or more above the local horizon throughout a full satellite ground track repeat cycle. Nominal reception implies a positive link budget margin as well as the signal and data quality parameters defined under d) and e) below, being in their nominal range for a reception station corresponding to the minimum requirements of BP.09;

b) During at least one pass per day for each satellite, monitoring of the signal quality parameters and the data quality parameters, as defined under d) and e) below respectively, for the part of the pass which is at an elevation of 5 degrees or more above the local horizon;

c) During at least one pass per day for each satellite, monitoring of the data quality parameter degradation, attributable to frames or packets discarded or degraded on the spacecraft, prior to transmission to the ground; where

d) Signal quality parameters should include receive signal strength, signal to noise ratio, spectral power distribution, and carrier, bit and frame lock statistics; and

e) Data quality parameters should include discarded frames and packets (failing error free decoding/reconstruction), missing frames and packets (calculated from measured

frame and packet sequence counters), bad lengths (frame or packet out of tolerance length), and sequence errors (frame or packet detected gaps/sequence error) per Virtual Channel Identifier (VCID) for frames and Application Process Identifier (APID) for packets.

2.10.1 POES

Partially compliant. NOAA's ground stations in Fairbanks, AK and Wallops Island, VA each use a 13-meter antenna to receive the NOAA-15/18/19 HRPT and distribute the NOAA-15/18/19 HRPT post-pass transfer data to the NOAA Satellite Operations Facility(NSOF) in Suitland, MD.

2.10.2 S-NPP, NOAA-20 and NOAA-21

a) Compliant with S-NPP, NOAA-21 and NOAA-21. NASA DRL validates that nominal reception is possible for a DB reception station anywhere within the footprint of the satellite DB antenna by acquiring all passes at an elevation of 5 degrees or more above the local horizon throughout a full satellite ground track repeat cycle at NASA DRL in Greenbelt,MD. NASA DRL prepares a Commissioning Report for each new JPSS satellite. The NOAA-20 report is available at: https://directreadout.sci.gsfc.nasa.gov/?id=dspContent&cid=246

b) through e) Compliant with S-NPP, NOAA-20 and NOAA-21. OSPO is responsible for the NPP, NOAA-20 and NOAA-21 HRD broadcasts and OSPO's monitoring capability is based on the JPSS Requirement: L1RDS-2271 "The JPSS Ground System shall monitor the quality of the HRD Direct Broadcast downlinks during at least 3 passes per day for each of the JPSS managed satellites." OSPO routinely schedules HRD contacts at the Svalbard ground station. The Svalbard antenna receives HRD and an HRD Link Monitoring (HLM)report is created in the JPSS ground system. The HLM is distributed to the FTS so that DB users can retrieve and view the report. OSPO encourages users to report product quality issues that might have been caused by an anomaly on the spacecraft

The NASA Direct Readout Lab (DRL) monitors HRD ingest logs and can monitor signal quality. The University of Wisconsin – Madison (UW) Space Science and Engineering Center (SSEC)/ Cooperative Institute for Meteorological Satellite Studies (CIMSS) monitors ingest logs and monitors SDR quality using CSPP LEO. NASA DRL and DRL SSEC/CIMSS agree to report any anomalies noted during their normal working hours to OSPO.

The NOAA Direct Broadcast Real Time Network (DBRTN) is NOAA's contribution to the WMO DBNet. The goal is to deliver advanced infrared and microwave sounder data to NWP centers with low latency for rapid refresh data assimilation. Sounder data are acquired in real-time at NOAA and partner antenna sites, processed centrally at CIMSS/ SSEC to Level 1B, and delivered to NWP centers in BUFR format. UW/SSEC/CIMSS operates 5 DB sites in the DBRTN and 17 partner DB sites are also contributing data to the DBRTN. ATMS and CrIS data from SNPP and NOAA-20 are routinely ingested, processed, converted to BUFR, and then delivered to NOAA for dissemination on GTS. IASI and ATOVS data from Metop- B/C and NOAA-18/19 are also included in the NOAA DBRTN ingest/processing/delivery system. The EUMETSAT NWP-

SAF routinely compares the SDRs created from the JPSS HRD with SDRs created from the Stored Mission Data (SMD) and reports any outages or inconsistencies.

3 ACTIONS AND/OR RECOMMENDATIONS FOR CONSIDERATION BY CGMS WG-I

WG-I members are invited to take note and comment on the status of implementation at NOAA of the CGMS Best Practices in support to local and regional processing of LEO direct broadcast data.

APPENDIX A.1 Supporting information for BP.09 (SNPP, NOAA-20)

Link Analysis for HRD Downlink JPSS Payload Science Downlink (5 deg) at 15 Mbps				
Parameter	Symbol	Value	Unit	Source
Frequency	f	7.812	GHz	JPSS RF IRD 472-00173
Transmitter Power	p	7.8	Watt	Tx RF Po @ < 35° C
Total Transmit Power	P	38.92	dBm	P = 10 log(p)+30
S/C Antenna Gain	Gt	5.50	dBi	Ant Gain at ± 62°
Passive Loss	Li	-2.00	dB	Coax Cable, Filter, Switch Losses
Equiv. Isotropic Radiated Power	EIRP	42.4	dBm	EIRP = P+Gt+Li
Propagation Path Length	S	2835	km	Alt=824km, Elev Angle=5°
Free Space Dispersion Loss	Ls	-179.4	dB	Ls = -92.44 - 20log(S) - 20log(f)
Polarization Loss	Lp	-0.26	dB	Tx Ant AR Loss in Gain, Tx AR=3.58dB, Rx AR=2dB
Rain & Atmospheric Loss	La	-3.65	dB	NPP HRD IRD 429-03-02-24, Appendix A
Multipath Loss	Lc	-0.20	dB	JPSS RF IRD 472-00173
Ground Antenna Pointing Loss		-1.00	dB	JPSS RF IRD 472-00173, 3 Meter Ground Antenna
Ground Station G/T	Grp	22.70	dB/K	JPSS RF IRD 472-00173, 3 Meter Ground Antenna
Total Received Power/T		-119.34	dBm/K	
Boltzmann's Constant	k	-198.6	dBm/Hz-K	$k = 10\log(1.38*10^{-23})$
Total Received Power/kT		79.26	dB-Hz	
DATA CHANNEL (QPSK)				
Data Power/kT		79.26	dBm/Hz/KT	
Information Rate		71.18	dB-Hz	15 Mbps with Reed Solomon
Available E_b/N_o		8.08	dB	
Rqd E_b/N_o 10^{-5} BER from Viterbi		4.40	dB	JPSS RF IRD 472-00173
Implementation Loss		-2.50	dB	JPSS RF IRD 472-00173
Available Signal Margin		**1.18**	**dB**	**1 dB Margin Required**

The reception station losses (a), (c), (d), (e) rain and atmospheric losses (b), and link budget margin (f) add up to 8.79 dB, giving a positive margin of 1.74 dB relative to the 7.05 dB defined in BP.09 and sufficient for nominal data reception at any reception station within the satellite's footprint at elevations above 5 degrees.

APPENDIX A.2 Supporting information for BP.09 (NOAA-21, JPSS-3, JPSS-4)

JPSS X-Band High Rate Data Downlink			
Ground Station:		**JPSS HRD Ground Terminal**	
Parameters	**Units**	**Worst-Case Point* in XBA1/ XBA2 Coverage**	**Notes/Data Source**
		** Worst-Case point in coverage of either XBA1 or XBA2 Earth-coverage antennas, i.e. over 0-62 deg from XBA boresight.* *Worst-case point corresponds to 34.2 deg off boresight of XBA1 antenna.*	
Basic Parameters			
Transmit Frequency	MHz	7812.0	Per J2SRD, Table 6.6.2.5.3-1 Carrier Frequency
Information rate	kbps	21794.4	raw data rate from C&DH
CADU rate	ksps	25000.0	data rate after RS (255, 223) encoding
Transmit Data Rate	ksps	50000.0	Per J2SRD, Table 6.6.2.5.3-1 - fully encoded rate, including 1/2 convol. encoding
Min. Ground Elevation Angle	degrees	50.6	Per J2SRD-1589, min. Ground Elevation angle
Spacecraft Altitude	km	824	
SC Antenna Max Nadir Angle	degrees	34.2	angle off nadir +Z
Range	km	1028.01	
Transmit Parameters			
Transmitter Power	W	10.7	
	dBm	40.3	min. power over temperature on 4 transmitters tested - 0.3 dB for
Transmitter Network Loss	dB	-0.86	maximum path loss measured at S/C, hot case and 10% variability
Spacecraft Antenna Gain	dBi	-6.60	per worst-case unit data and SC-level antenna simulation results
EIRP	dBm	32.83	
Channel Parameters			
Space Path Loss	dB	-170.54	
Link Availability	%	99.0%	
Excess Path Loss	dB	-0.50	PER J2 SRD-1502, Includes Scintillation for 0.99 Availability for JPSS HRD Ground Terminal, assumed value (Hawaii X-Band)
Pointing Loss	dB	0.00	Per J2SRD-1518, Included in ground receiver G/T per table footnote
Polarization Loss	dB	-1.57	Based on worst-case S/C AR of 9.7 dB and GS AR of 2.0 (Estimated, J2SRD-1561), for Beta=90
Receiver Parameters			
Ground Station Receiver G/T	dB/K	23.59	Per J2SRD-1564, Table 6.6.2.5.3-1 Ground Station Minimum G/T
Power Summary			
Received Isotropic Power at Ground	dBm	-139.78	Received power into an isotropic (0 dB gain) antenna
Boltzmann's Constant	dBW/K/Hz	-228.60	
C/No at Ground Station	dB-Hz	82.41	

Viterbi Decoder Margin Analysis			
Code symbol rate into Viterbi Decod	ksps	50000.00	over-the-air transmit data rate
Bit Rate out of Viterbi Decoder	kbps	25000.00	CC encoding removed; equals CADU Rate, which includes Reed-Solomon Coding (255, 223, I = 5)
- RS Symbol Rate	dB-Hz	74.0	
Received Eb/No	dB	8.4	
Implementation / Multipath Loss	dB	-2.70	Per J2SRD-1586 and J2SRD-1587
Calculated Eb/No	dB	5.73	
Target BER		1.00E-05	After convolutional decoding portion
Required Eb/No per SRD		4.4	Per J2SRD-1590
Viterbi Decoder Margin		**1.3**	Per J2SRD-1589, HRD Margin requirement > 1.0 dB at 5 deg. El angle
Comments:			
1) **Worst-Case Point in Coverage** on either XBA1 or XBA2 Earth-coverage antennas, i.e. over 0-62 deg from XBA boresight. Corresponds to 34 d			
2) **At Edge of Coverage (EOC)** corresponds to worst-case link margin at 62 deg off XBA boresight			

Figure SC-GND-3318. HRD Detailed Link Calculation