

NOAA NESDIS-NGDC

TED Data Processing ALGORITHM THEORETICAL BASIS DOCUMENT Version 1.0

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ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 2 of 81

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 3 of 81

TITLE: TED DATA PROCESSING THEORETICAL BASIS DOCUMENT
VERSION 1.0

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NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 4 of 81

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing

Algorithm Theoretical Basis Document

Page 5 of 81

TED DATA PROCESSING ALGORITHM THEORETICAL BASIS DOCUMENT VERSION HISTORY SUMMARY

Version	Description	Revised Sections	Date
1.0	Created by Janet Green	New Document	Mar 2013

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 6 of 81

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 7 of 81

TABLE OF CONTENTS

TABLE OF CONTENTS.....	7
LIST OF FIGURES	9
LIST OF TABLES.....	10
LIST OF ACRONYMS	11
ABSTRACT.....	12
1.0 INTRODUCTION	13
1.1 Purpose of This Document.....	13
1.2 Who Should Use This Document	13
1.3 Inside Each Section.....	13
1.4 Related Documents	14
1.5 Revision History	14
2.0 OBSERVING SYSTEM OVERVIEW	14
2.1 Product Generated.....	14
2.2 Instrument Characteristics	15
2.2.1 Separating the Species	15
2.2.2 Limiting the direction	16
2.2.3 Selecting the energy range	17
2.2.4 Amplifying the signal	18
2.2.5 Assessing the background.....	19
3.0 ALGORITHM DESCRIPTION.....	20
3.1 Algorithm Overview	20
3.2 Processing Outline	20
3.3 Algorithm Input	20
3.3.1 Primary Sensor Data	20
3.3.2 Ancillary Data.....	22
3.4 Processing Procedure	24
3.4.1 Reading the Level-1B files and Calibration Tables.....	24
3.4.2 Take the ones complement of the sensor data	24
3.4.3 Decompress data to raw counts.....	24
3.4.4 Calculate magnetic parameters needed to map to the ionosphere	25
3.4.5 Check for backwards times and resort	25
3.4.6 Linearly interpolate the backgrounds.....	25
3.4.7 Subtract backgrounds.....	25
3.4.8 Change counts to physical units using a calibration table	26
3.4.9 Calculate pitch angles at the satellite and at the foot of the field line	26
3.4.10 Calculate energy flux at the 110 km	28
3.5 Algorithm Output.....	29
4.0 TESTING	30

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 8 of 81

4.1 Input Data Sets	30
4.2 Comparisons of Test Data and Algorithm Output	30
5.0 PRACTICAL CONSIDERATIONS	35
5.1 Numerical Computation Considerations	35
5.2 Programming and Procedural Considerations	35
5.3 Quality Assessment and Diagnostics	36
5.5 Algorithm Validation	36
6.0 ASSUMPTIONS AND LIMITATIONS	36
6.1 Performance	36
6.2 Assumed Sensor Performance	36
6.3 Pre-Planned Product Improvements	36
7.0 REFERENCES	36
Appendix A: Ancillary Data Tables	37
Appendix B: Outputs	45
Appendix C: Level1B files and telemetry.	52

LIST OF FIGURES

Figure 1: Schematic showing the configuration of the 8 ESA's 16

Figure 2: Comparison of magnetic field components (nT). Legacy values shown in blue and new values shown in red. Top panel shows the components at the foot of the field line and bottom panel shows the values at the satellite. 32

Figure 3: Comparison of pitch angle calculations. Legacy values shown in blue and new values shown in red. Top panel shows the pitch angles at the satellite and bottom panel shows the values at the foot of the field line..... 33

Figure 4 : Comparison of location calculations. Legacy values shown in blue and new values shown in red. Top panel shows the geographic latitude and longitude at the foot of the field line. Middle panel shows the magnetic latitude and longitude at the foot of the field line and the bottom panel shows the corrected geomagnetic latitude at the foot of the field line. 34

Figure 5 Comparison of energy flux into the atmosphere calculations. Legacy values shown in green and dark blue with new values shown in black and cyan. Top panel shows the electron energy flux into the atmosphere from the high energy range in green (legacy) and black (new) and the low energy range in blue(legacy) and cyan (new). Second panel from the top shows the proton energy flux into the atmosphere from the high energy range in green (legacy) and black (new) and the low energy range in blue(legacy) and cyan (new). Third panel from the top shows the total electron energy flux into the atmosphere blue (legacy) and cyan (new) and the total proton energy flux into the atmosphere in black(legacy) and green (new). Bottom panel shows the total particle flux into the atmosphere in blue(legacy) and black (new). 35

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 10 of 81

LIST OF TABLES

Table 1: TED Energy Bands

Table 2: L1b TED Sensor Data Input to Processing

Table 3: TED Energy Flux Calibration Conversion Values

Table 4: TED Differential Number Flux Calibration Conversion Values

Table 5: TED Onboard Processing Background Conversion Tables

Table 6: NOAA-15 Plug and PROM factors

Table 7: NOAA-16 Plug and PROM factors

Table 8: NOAA-17 Plug and PROM factors

Table 9: NOAA-18 Plug and PROM factors

Table 10: NOAA-19 Plug and PROM factors

Table 11: MetOp-02 (A) Plug and PROM factors

Table 12: MetOp-01 (B) Plug and PROM factors

Table 13: MetOp-3 (C) Plug and PROM factors

Table 14: Data Decompression Look-up Table

Table 15: Processing Output

Table 16: Description of the contents of the header record

Table 17: Description of Data Record

Table 18: SEM-2 data allocations in TIP words 20 and 21 for a single TIP 32 second major frame.

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 11 of 81

LIST OF ACRONYMS

ATBD	Algorithm Theoretical Basis Document
eV	electron volt
keV	kilo-electron-volt
L1b	Level 1b
L2	Level 2
MeV	mega-electron-volt
TED	Total Energy Detector
NGDC	National Geophysical Data Center
NESDIS	National Environmental Satellite, Data, and Information Services
POES	Polar Orbiting Environmental Satellite
MetOp	Meteorological Operational

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 12 of 81

ABSTRACT

This document provides a description of the algorithms and procedures used to transform the output from the Total Energy Detector (TED) into higher level data products including local energy flux, energy flux at the atmosphere, and differential particle flux. Error propagation, validation and examples of the algorithm are discussed. The logical flow of the algorithm is outlined.

1.0 INTRODUCTION

1.1 Purpose of This Document

The purpose of this document is to describe the algorithms used by the NOAA National Geophysical Data Center (NGDC) processing system to translate the output from the Total Energy Detector (TED) into physically meaningful values. The TED instrument is part of the Space Environment Monitor (SEM)-2 instrument suite on the POES/MetOp satellites. (The SEM-2 suite also includes the MEPED instrument that is described in a separate ATBD). The algorithms and processing system described here were developed and implemented after April 2013. Prior to April 2013 the SEM-2 data was processed using a system developed and maintained by the NOAA Space Weather Prediction Center. That system failed on Jan 1 2013. Many of the techniques used are similar but the code and file formats are new. The old system is described by the document referenced in section 1.4.

1.2 Who Should Use This Document

All users of the TED data should refer to this document to be cognizant of what the instrument can provide, how the data is processed, and potential limitations of the dataset that could impact interpretation.

1.3 Inside Each Section

Section 2.0 OBSERVING SYSTEM OVERVIEW:

Describes the POES/MetOp TED instrument and the measurements that serve as input to the processing.

Section 3.0 ALGORITHM DESCRIPTION:

Describes the development, theory and mathematics of the algorithm. Describes the logical flow of the algorithm, including input and output flow.

Section 4.0 TESTING:

Describes the methods used to test the algorithm and characterize the performance and the data product quality.

Section 5.0 PRACTICAL CONSIDERATIONS:

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0
Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 14 of 81

Discusses issues involving numerical computation, programming and procedures, quality assessment and diagnostics and exception handling.

Section 6.0 ASSUMPTIONS AND LIMITATIONS:

Describes assumptions made in the implementation, validation, testing, and error handling of the algorithm.

Section 7.0 REFERENCES:

Provides all references mentioned in the ATBD.

1.4 Related Documents

Polar Orbiting Environmental Satellite Space Environment Monitor-2: Instrument Descriptions and Archive Data Documentation, Evans and Greer, 2000.

The document above describes the previous legacy version of the TED processing system.

1.5 Revision History

Revision Number	Date	Author	Revision Description	Reason for Revision

2.0 OBSERVING SYSTEM OVERVIEW

2.1 Product Generated

The TED data processing inputs level 1B files provided by the NOAA NSOF Data Distribution System (DDS) and generates two files referred to as raw and processed. The raw files contain outputs in sensor units such as counts and the processed files contain outputs in physical units such as energy flux. The files are aggregated for 1 day but are updated as data is received in near real time and made available immediately to users for all current POES/MetOp satellites carrying the TED instrument (7 satellites at the time this document was produced). The complete processing system manipulates both the SEM-2 TED

and MEPED instrument data. This document only describes the TED data processing.

2.2 Instrument Characteristics

The primary output of the TED instrument is proton and electron energy flux in 2 look directions integrated over 2 broad energy bands. TED relies on a set of 8 electrostatic analyzers (ESA's) to make these measurements. The instrument performs 5 main functions described in more detail below:

- 1) Separates the species (proton or electron)
- 2) Limits the direction
- 3) Selects the particle energy range
- 4) Amplifies the signal
- 5) Assesses backgrounds

2.2.1 Separating the Species

The TED instrument separates the particle species simply by having separate ESA's for measuring each: 4 of the 8 ESA's measure protons and 4 measure electrons. The basic design of any electrostatic analyzer consists of a set of curved plates with a voltage applied across the plates (See Figure 1). The voltage bends the trajectories of incoming particles. The trajectories of protons and electrons will bend in opposite directions. Thus, the shape of the detector and the direction of the applied voltage dictate whether protons or electrons successfully traverse through the plates to be counted.

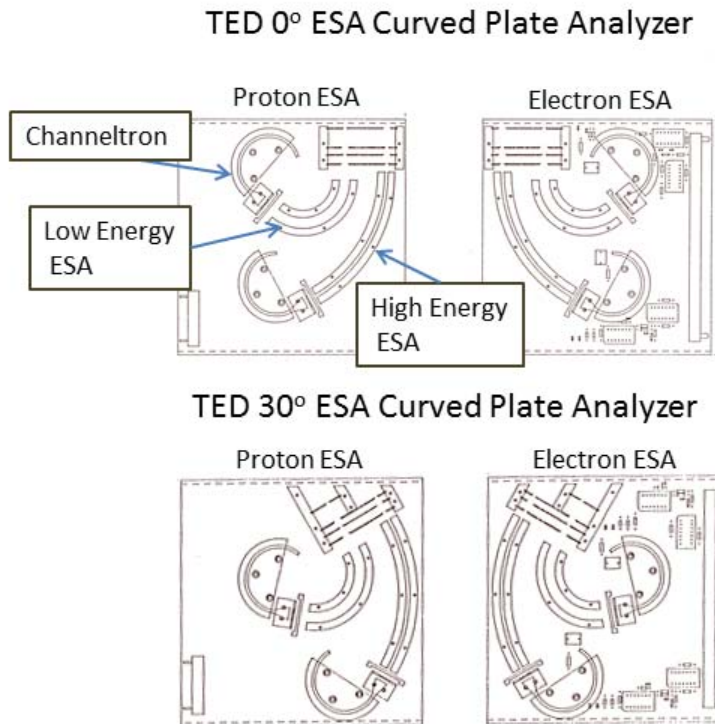


Figure 1: Schematic showing the configuration of the 8 ESA's

2.2.2 Limiting the direction

The directional selections are made by having separate ESA's with limited apertures pointed in different directions. Two proton ESA's and 2 electron ESA's are aligned along the zenith direction of the satellite to measure particles that primarily flow down along the magnetic field lines. The remaining 2 electron and 2 proton ESA's are aligned 30 degrees off the zenith direction to measure those particles that will likely hit the ionosphere and atmosphere at an angle. The ESA's are each divided again by the energy range they measure. One of the 2 proton ESA's pointed along the zenith measures low energy protons (50 eV to 1 keV) and the other measures high energy protons (1-20 keV). The same goes for the 2 zenith pointing electron ESA's. In an identical fashion, one of the 2 proton ESA's pointed 30 degrees to the zenith measures low energy protons and the other measures high energy protons. The same applies to the remaining electron ESA's pointed at 30 degrees. With this configuration the TED instrument can estimate the total particle energy flux flowing from the magnetosphere into the ionosphere and atmosphere. The size of the aperture to each ESA depends on

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 17 of 81

the species and the energy range. The high energy proton and electron ESA's have openings that are 1.5 by 9 deg half angles. The low energy electron ESA's have openings that are 6.7 by 3.3 degree half angles while the low energy proton ESA's have openings that are 6.6 by 8.7 degree half angles.

2.2.3 Selecting the energy range

The applied voltage across the ESA plates selects the particle energy in addition to the species. The trajectory of an incoming particle through the applied voltage is dependent on the energy of that particle. Particles with too little or too much energy will bend too much or not enough to successfully navigate through the plates with a given voltage applied. The voltage on each ESA is swept at the same time from low to high with the full range divided by 8 distinct bands as given in Table 1. (Energy bands 1-8 are measured by the low energy proton and electron ESA's and energy bands 9-16 are measured by the high energy proton and electron ESA's).

Table 1: TED Energy bands

Energy Band	Low-Energy edge (eV)	Center energy (eV)	High-energy edge (eV)	Total Energy Band Width (eV)
1	50	61	73	23
2	73	89	106	33
3	106	130	154	48
4	154	189	224	70
5	224	274	325	101
6	325	399	473	148
7	473	580	688	215
8	688	844	1000	312
9	1000	1227	1454	454
10	1454	1784	2115	661
11	2115	2595	3075	961
12	3075	3774	4472	1397
13	4472	5488	6503	2031
14	6503	7980	9457	2954
15	9457	11605	13753	4296
16	13753	16877	20000	6247

The counts in each of the 8 bands are multiplied onboard by a weighting factor and summed before being telemetered to the ground as a raw energy flux count value. (The weighting factors are instrument dependent and are included in Appendix A Tables 5-12). These values are then compressed into a number between 0 and 255 using an onboard compression scheme. (Table 14 contains the mapping from compressed values to actual counts). A complete voltage sweep takes 2 seconds. Energy flux in each of the 8 bands is accumulated for .2 seconds for a total of 1.6 seconds. It takes .2 seconds to return the voltage to 0. Then finally, a background measurement is made for the last .2 seconds. The background measurement is made while the plate voltage is 0 so presumably no particles are entering the aperture. The measurement is intended to specify the penetrating radiation that has enough energy to enter through the sides of the instrument irrespective of the voltage sweeping. The background measurement is made every 2 second cycle but the counts are accumulated for 16 cycles. This background must be removed from the measured energy flux.

2.2.4 Amplifying the signal

Particles that successfully pass through the plates now must be counted through some measureable signal. The TED instrument uses a channeltron to create a measureable signal. An incoming particle that hits the channeltron creates a shower of cascading electrons. Those electrons are collected and transformed into a voltage pulse. This step in the instrument function is explicitly called out because the degradation of the channeltron affects the stability of the measurements over time. As the channeltron degrades, the pulse height generated by incoming particles decreases causing fewer particles to be counted. The overall effect is for the energy flux to steadily decrease with time. The degradation of the channeltron can be compensated for by increasing the voltage applied to the channeltron onboard the satellite to enhance the electron cascade. However, in practice, there is always some observable degradation of the data. The choice to increase the voltage is complicated by trade-offs in performance and lifetime. There is one voltage source for all 4 proton channeltrons and one for all 4 electron channeltrons. Increasing the voltage shortens the lifetime. Not all the channeltrons degrade at the same rate. Thus, trade-offs are made when the degradation is variable to allow some of the channeltrons to suffer minor performance changes in order to extend the lifetime of the overall instrument. The degradation is measured monthly by an In-Flight-Calibration (IFC). In theory, the results from the IFC could be used to correct the data for any noticeable degradation. Details about the IFC and its interpretation

will be provided in a separate ATBD because the IFC is performed monthly and the analysis is not included as part of the daily processing algorithms.

2.2.5 Assessing the background

The last major task of the instrument is to assess the background that must later be subtracting by ground processing. The primary sources of background are energetic protons predominantly in the South Atlantic Anomaly and energetic electrons from the radiation belts at subauroral latitudes. As mentioned previously, the background measurement is made by setting the plate voltage to 0 once per energy sweep. Details about how this background is removed are given in Section 3.4.7.

3.0 ALGORITHM DESCRIPTION

3.1 Algorithm Overview

The algorithm consists of a number of different steps or procedures because the instrument puts out a variety of measurements sometimes at different time cadences. These outputs include integrated energy flux in 2 bands for both protons and electrons and two look-directions, characteristic energy, energy flux at the characteristic energy, differential particle flux at 4 energies and background measurements at a lower time cadence (for a complete list of outputs see Appendix B table 15).

3.2 Processing Outline

These are the basic functions performed by the level-2 processing algorithm

1. Read the level1-b file and calibration tables
2. Take the ones complement of the sensor data
3. Decompress data to raw counts
4. Calculate magnetic parameters needed to map to the ionosphere
5. Check for backwards times and resort
6. Linearly interpolate background measurements
7. Subtract backgrounds
8. Change counts to physical units using calibration table values
9. Calculate pitch angles at the satellite and at the foot of the field line
10. Calculate energy flux at the 110 km
11. Calculate errors

3.3 Algorithm Input

The inputs to the algorithm consist of the sensor data, calibration tables, and International Geomagnetic Reference Field (IGRF) coefficient tables.

3.3.1 Primary Sensor Data

Table 2. L1b TED sensor data input to level 2 processing

L1b Quantity	Sampling	Number of Values	Units	Purpose in L2 Calculations
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NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 21 of 81

L1b Quantity	Sampling	Number of Values	Units	Purpose in L2 Calculations
Compressed integrated electron energy flux counts	2s	4 channels (2 energy bands and 2 directions)	Integrated energy flux counts**	Starting point for electron energy flux
Compressed integrated electron energy flux counts	2s	4 channels (2 energy bands and 2 directions)	Integrated energy flux counts**	Starting point for proton energy flux
Electron Characteristic Energy	2s	2 (full energy range, 2 look directions)	Energy band	Defines the energy with the maximum flux
Proton Characteristic Energy	2s	2 (full energy range, 2 look directions)	Energy band	Defines the energy with the maximum flux
Compressed electron characteristic flux	2s	2 (full energy range, 2 look directions)	Integrated energy flux counts**	Starting point for defining the maximum electron flux measured within the broader energy band
Compressed proton characteristic flux	2s	2 (full energy range, 2 look directions)	Integrated energy flux counts**	Starting point for defining the maximum proton flux measured within the broader energy band
Compressed electron detector background	Measured for .2s every 2s but accumulated for 16 cycles or 3.2 s	4 (2 energy bands, 2 look directions)	Integrated Counts**	Used to subtract contaminating background signal from the electron energy flux
Compressed proton detector background	Measured for .2s every 2s but accumulated for 16 cycles or 3.2 s	4 (2 energy bands, 2 look directions)	Integrated counts**	Used to subtract contaminating background signal from the proton energy flux

**Units are given as 'Integrated energy flux counts' to mark the fact that some calibration and energy factors are applied onboard before integration. This onboard manipulation is not reversible on the ground. Units given as 'integrated

counts' apply to sensor output with no onboard processing. Details are described in section 3.4.

3.3.2 Ancillary Data

Ancillary data are defined as data that are not generated on-orbit by TED or the spacecraft. The TED data processing requires 2 types of ancillary data: calibration data and magnetic field data.

3.3.2.1 Calibration data

The calibration data consists of three files or tables. Two contain values by which the raw sensor data is multiplied to translate sensor counts to physical units. The third file contains weighting factors used by the onboard DPU processing that must be applied to background measurements.

The first file, `ted_cal_coefficients.txt`, contains the values needed to change the 8 energy flux measurements from energy flux counts to energy flux units (milliWatts/m^2). These values are given in Table 3 in Appendix A. (The values are taken from Table 3.9 of the TED Calibration Report given in the Data Packages specific for each instrument provided by the instrument vendor). The columns in the table are the satellite number (e.g. 15-19 for POES or 1-3 for MetOp), the serial number of the instrument placed on that satellite, the satellite ID (ground processing number defined after launch), the 0 degree low energy calibration coefficient, the 30 degree low energy calibration coefficient, the 0 degree high energy calibration coefficient and the 30 degree high energy calibration coefficient.

The second file, `spectrum_coefficients.txt`, contains the values needed to change the counts measured in the 16 smaller energy bands to differential particle flux ($\text{\#/cm}^2\text{-s-str-eV}$). (Counts from these smaller energy bands are not output by the instrument at regular intervals. Only the counts from the band with the maximum flux are output at the normal 2 s cadence). These values are given in Table 4. They were derived by taking $1/(G_{fe} * E_{average} * dt)$ where G_{fe} is the geometric factor, $E_{average}$ is the energy range over which the data is integrated, and dt ($=.2$) is the time over which the data is integrated. Values for G_{fe} and $E_{average}$ are given in table 3.6 and 3.5 respectively of the Data Packages specific to each instrument model (TIR-ENG-126).

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 23 of 81

The third file, ted_weights.txt, given in Table 5 contains values needed by the ground processing algorithm to change the background counts that have no onboard processing to the same units as the energy flux counts. The onboard processing includes a set of PROM prescale factors and a slope correction factor called the Configuration Plug. The ESA counts sent to telemetry are calculated onboard as follows, using the raw input counts from the 8-channel ESA:

$$ef_low_energy_counts_{species,direction} = \sum_{i=1}^4 c_i \times PROM_i + plug_{species,direction} \times \left(\sum_{i=5}^8 c_i \times PROM_i \right)$$

And

$$ef_hi_energy_counts_{species,direction} = \left(\sum_{i=9}^{16} c_i \times PROM_i + plug_{species,direction} \times \left(\sum_{i=9}^{16} c_i \times PROM_i \right) \right) 32$$

where ef_low_energy_counts refers to the energy flux counts accumulated in the low energy range, ef_hi_energy_counts refers to the energy flux counts accumulated in the high energy range, c_i refers to the counts in each energy band. The PROM and plug values are unique to each satellite and species. These values are provided in tables 6-13. The PROM values for each instrument are pulled from the TED Calibration Report (TIR-ENG-156) Table 3.5 in the Data Packages provided by the instrument vendor. The plug values are pulled from Table 3.8 of the same reports. The plug values for the low energy detectors are referred to as $PS_{LE(5-8)_{config}}$ and the plug values for the high energy detectors are referred to as $PS_{HE(13-16)_{config}}$. Values given in parenthesis in the report are the values used in the onboard DPU processing while the values not in parenthesis are the measured values. The values used in the ground processing to convert the background measurement in tab15 are obtained from

$$cal_low_energy_{species,direction} = \sum_{i=1}^4 PROM_i + plug_{species,directions} \times \left(\sum_{i=5}^8 PROM_i \right) \text{ and}$$
$$cal_low_energy_{species,direction} = \left(\sum_{i=9}^{16} PROM_i + plug_{species,direction} \times \left(\sum_{i=9}^{16} PROM_i \right) \right) 32$$

3.3.2.2 Magnetic field data

The magnetic field ancillary data is contained in ascii tables that provide the coefficients for expanding Earth's internal field as spherical harmonics. These tables are used to predict the magnetic field at the satellite location because there is no magnetometer onboard to provide that measurement. The magnetic field is critical for determining how the particle measurements relate to the field

direction and which particles are expected to continue along the field lines to the atmosphere. Due to some legacy code being used in the processing, the IGRF coefficients are duplicated in several files. The file called `igrf11coefficients.txt` contains all the igrf data from 1900 to 2010 at five year intervals. This file must be updated at regular 5 year intervals. Additionally, the igrf coefficients are also contained in individual 5 year files (`dgrf00.dat`, `dgrf05.dat`, `igrf05.dat`, and `igrf00.dat`). These will need to be updated every 5 years as well and supplemented to reprocess any older data prior to 2000. The IGRF coefficients can be obtained from <http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html>.

3.4 Processing Procedure

This section describes the processing outline in greater detail.

3.4.1 Reading the Level-1B files and Calibration Tables

Data from the POES/MetOp satellites are downloaded from the satellites generally once per orbit to a number of ground stations (Wallops Island, VA; Gilmore Creek, AK; McMurdo, Antarctica; Svalbard, Norway). The raw telemetry is deciphered and packaged into level1-B files specific to each instrument at NSOF in Silver Springs MD where they are distributed via the Data Distribution System. The NGDC processing system checks the DDS system for new data every 2 minutes and pulls any new files to NOAA NGDC for processing. The format of these data files and additional description of the telemetry is described in Appendix C. The ancillary calibration and magnetic field tables are maintained at NGDC as static ascii files and are read every time a file is processed. The correct coefficients for the calibration files are chosen based on the satellite ID which is provided in the header of each level1B file.

3.4.2 Take the ones complement of the sensor data

The output from the TED instrument is given as single bytes. For an unknown reason, the instrument puts out information as the ones complement of normal binary. The first processing step is to swap all the 1's and 0's of the sensor output.

3.4.3 Decompress data to raw counts

The particle energy flux data are compressed to values between 0 and 255 in order to fit into a single 8 bit value. These values are decompressed into counts using a static look up table given in Table14.

3.4.4 Calculate magnetic parameters needed to map to the ionosphere

Knowledge of the magnetic field is necessary to determine which particles will be guided by the magnetic field such that they are absorbed by the atmosphere. The processing determines the local magnetic field at the satellite, traces that field line to the atmosphere at 110 km and then calculates the magnetic field at the atmosphere. The calculations are done using the IGRF coefficients for the internal magnetic field.

3.4.5 Check for backwards times and resort

Once all the data has been read, the processing checks to see that the data are ordered correctly by time. Frequently, times are repeated in the level1-B files because the telemetry download from the satellites was stopped, backed up, and then restarted. Any duplicate times are replaced with data records appearing earlier in the file replaced by later data records.

3.4.6 Linearly interpolate the backgrounds

The primary sensor data is output every 2 seconds but the background measurements are output every 32s so they must be interpolated. The processing uses a simple linear interpolation. At the beginning and end of the data file the background values are filled in with the nearest value.

3.4.7 Subtract backgrounds

Subtracting the backgrounds from the primary energy flux data requires some manipulation of both data streams because they are accumulated and processed onboard in different ways and are effectively different units. Outlining a full 2 second instrument cycle shows the differences. A full instrument cycle is as follows. First, the voltage is swept through 8 increasing steps (The 8 energy bands from the low energy detectors are referred to as 1-8 and the 8 energy bands for the high energy detectors are referred to as 9-16 even though the high and low detectors cycle at the same time). The counts accumulated at each step are multiplied by different calibration factors given in table 5. The counts are finally summed at the end of the sweep which takes 1.6 s. After the sweep, the voltage is dropped back to 0 which takes .2 s. The background measurement is made with the voltage at 0 for .2s. The energy flux data is output and refreshed

every instrument cycle. However, the background counts are accumulated for 16 instrument cycles for a total accumulation time of 3.2 seconds. Thus, before subtracting the background counts they must first be multiplied by the same weighting factors as during the normal sweep. Here we assume that the background counts in each of the 16 bands are constant such that:

$$energyflux = \sum_{i=1}^8 w_i (b + c_i) = \sum_{i=1}^8 w_i c_i + \sum_{i=1}^8 w_i b = \sum_{i=1}^8 w_i c_i + b \sum_{i=1}^8 w_i$$

Where w_i is the onboard weighting factors, c_i are the normal energy flux counts, and b is the background counts. Accounting also for the different accumulation times, the background counts to be subtracted are:

$$background = \frac{b}{2} \sum_{i=1}^8 w_i$$

The values for each w_i are given in Table 5.

3.4.8 Change counts to physical units using a calibration table

Changing the sensor counts to physical units is a simple multiplication by a constant calibration factor. The 8 background corrected energy fluxes are each multiplied by the corresponding calibration factors given in Table 3 to provide output in mW/m^2 . The flux at the maximum energy is multiplied by the corresponding factor given in Table 4 to give differential number flux $\#/cm^2-s-str-eV$. To change the number flux to energy flux simply multiply by the center energies given in table 1.

3.4.9 Calculate pitch angles at the satellite and at the foot of the field line

Calculating the pitch angle at the satellite requires knowing the orientation of the sensors and the magnetic field in the same coordinate system. The processing relies on the spacecraft coordinates defined with B_x radially Earthward, B_y in the direction opposite the velocity of the satellite, and B_z completes the right hand set ($B_x \times B_y$). In this coordinate system, the 0 degree TED detectors are aligned in the $-B_x$ direction and the 30 degree detectors are rotated 30 degrees about the $+y$ -axis with the x -axis rotating towards $+z$.

The magnetic field parameters are first determined in the geodetic reference frame using the IGRF spherical harmonic expansion and then rotated into the spacecraft frame. The spacecraft coordinates are defined for every 2 second

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 27 of 81

measurements as follows. First, the radial spacecraft x direction is defined by the latitude and longitude provided in the level 1 B file.

$$X1 = \sin(90 - \text{latitude}) \cos(\text{longitude})$$

$$X2 = \sin(90 - \text{latitude}) \sin(\text{longitude})$$

$$X3 = \cos(90 - \text{latitude})$$

$$\vec{X}_{sc} = [X1, X2, X3]$$

The spacecraft z component, Z_{sc} , is determined from the cross product of these vectors for 2 subsequent times where first refers to the point earlier in time and last refers to the point later in time.

$$Z1 = X2_{last} * X3_{first} - X3_{last} * X2_{first}$$

$$Z2 = X3_{last} * X1_{first} - X1_{last} * X3_{first}$$

$$Z3 = X1_{last} * X2_{first} - X2_{last} * X1_{first}$$

$$\vec{Z}_{sc} = -[Z1, Z2, Z3]$$

Next the ram direction or $-y$ direction is defined as the cross product of z and the x direction defined above. The B field in spacecraft coordinates is defined by:

$$B_{x_{sc}} = \vec{B} \cdot \vec{X}_{sc}$$

$$B_{y_{sc}} = \vec{B} \cdot \vec{Y}_{sc}$$

$$B_{z_{sc}} = \vec{B} \cdot \vec{Z}_{sc}$$

Finally, the pitch angle directions are defined by taking the dot product of B_{sc} with the negative of the detector direction. This is because the particle entering the detector is moving in the direction opposite to the look direction.

At the foot of the field line the pitch angle is determined by assuming that the first invariant, $\mu = W_{perp}/B$, and the total energy of the particle is conserved. In this case,

$$W_{perp} = W \sin^2 \alpha$$

$$\mu = W_{perp} / B$$

$$\alpha_{foot} = a \sin \left(\frac{B_{foot} \sin^2 \alpha}{B_{local}} \right)^{\frac{1}{2}}$$

3.4.10 Calculate energy flux at the 110 km

The next step is to calculate the energy flux entering the atmosphere at 110 km based on the previous pitch angle calculations using the following equation.

$$EF_{atmo} = \int EF_{local} \sin \alpha \cos \alpha d\alpha d\varphi$$

Where EF_{local} is the locally measured energy flux and EF_{atmo} is the energy flux into the atmosphere. We assume the distribution is gyrotropic so the equation above quickly integrates to:

$$EF_{atmo} = 2\pi \int EF_{local} \sin \alpha \cos \alpha d\alpha$$

Next we perform the integration over pitch angle using the 2 detector measurements. There are 3 cases to consider: case 1) Both the 0 degree and 30 degree detectors measure particles that will hit the atmosphere, case 2) Only one detector measures particles that will hit the atmosphere, and case 3) neither detector measures particles that will reach the atmosphere.

Case 1: If both detectors measure particles that will hit the atmosphere then the integration is split into 2 pieces spanning the 2 pitch angle ranges sampled by the 0 and 30 degree detectors. First, we define a mid point pitch angle between the 2 detectors as $\alpha_{mid} = (\alpha_0 - \alpha_{30})/2$. The integration becomes:

$$EF_{atmo} = 2\pi \int_0^{\alpha_{mid}} EF_1 \sin \alpha \cos \alpha d\alpha + \int_{\alpha_{mid}}^{90} EF_2 \sin \alpha \cos \alpha d\alpha$$

We assume that the energy flux across the range is constant so that integration of the above equation becomes

$$EF_{atmo} = \pi * (EF_1 * \sin^2 \alpha_{mid} + EF_2 * (1 - \sin^2 \alpha_{mid}))$$

Case 2: Case two describes situations where only one detector measures particles that reach the atmosphere. In this case the above equation integrates to $\pi \cdot EF_0$ or $\pi \cdot EF_{30}$ where EF_0 is the local energy flux measured by the 0 degree detector and EF_{30} is the local energy flux measured by the 30 degree detector.

Case3: This case describes the situation where neither detector measures particles that will hit the atmosphere. In this case, the atmosphere energy flux is set to -1.

3.4.11 Error calculations

Lastly, the algorithm calculates errors for all physical quantities. Here only the error due to Poisson counting statistics is included. We limit the calculation to this error because other errors such as in the calibration factors are not well known. The Poisson errors do to counting statistics are given as $\pm\sqrt{N}$ where N is the count value. In cases where counts are combined, standard error propagation is used. For example, the error in the background corrected energy flux combines the Poisson error of the energy flux counts and the Poisson error of the background measurement.

3.5 Algorithm Output

The algorithm outputs are given in Appendix B Table 15 that includes all outputs from the TED and MEPED processing algorithms. These outputs are divided into two files: raw and processed. The second column of the table gives a single letter that identifies which file the element is in. Those labeled 'a' are in all files, those labeled 'p' are in the processed files, and those labeled 'r' are in the raw files.

4.0 TESTING

There are two objectives to testing the performance of the TED data processing algorithms. The first objective is to ensure that there are no flaws in the method or implementation of the algorithms. This objective is met by simply comparing the output to that from the legacy processing. The results of the comparison are discussed in section 4.2. The second objective is to provide users with an assessment of the accuracy of the output data. We consider several accuracy indicators. We provide uncertainty values estimated from Poisson counting statistics along with all physical quantities. Other factors not considered here that may significantly affect performance are the intercalibration of the satellites and degradation of the sensors. These additional factors are discussed further in section 6.1 but are beyond the scope of the current processing level. Users should consider how these limitations in the data accuracy might impact their use or interpretation of the data.

4.1 Input Data Sets

The legacy files used to compare to the new processing are the full resolution daily binary archive files produced by NOAA SWPC up until Jan 2013 and archived at NGDC. The contents of the files are described by Greer and Evans [2000].

4.2 Comparisons of Test Data and Algorithm Output

To ensure that there are no fundamental flaws in the new processing we compare all values contained in the legacy archive files to the newly processed files for the same time periods. Both files are produced from the same input files. In some cases, the outputs from two processes should be exactly the same because the algorithms used by both are identical. For example, both systems produce energy flux counts from the same simple look-up table translation. In these cases, our comparisons show no difference demonstrating no issues with the new implementation. In other cases, the outputs may be different because of small difference in the methods. Therefore, we focus our attention on comparing these values. The outputs that fall into this category are the magnetic field parameter outputs, the background corrected energy flux and the energy flux into the atmosphere.

The magnetic field parameters from both systems are generated using the same IGRF field model however, the implementation is slightly different. The legacy

software relied on static files of the IGRF field model as a function of latitude and longitude that were updated once per year. The new processing calls the IGRF field model for every 2 second data record and provides a more up-to-date representation. Figure 2 shows a comparison of the magnetic field parameters from the two systems for one orbit on Jan 27, 2012. The plot shows virtually no difference in the field components. Figure 3 shows a comparison of the pitch angle measured by the 30 and 0 degree detectors at the location of the satellite and mapped to the atmosphere. The local pitch angles differ by ~2 degrees at most. The pitch angles at the foot of the field line show larger differences of up to 10 degrees. However, these differences occur near the equator in regions where the TED instrument is not expected to measure any auroral particle fluxes. Thus, the differences do not have a big impact on the data interpretation. Figure 4 shows the location where the field lines map to the atmosphere in different coordinates: geographic, magnetic, and corrected geomagnetic coordinates. The only quantity that differs significantly is the magnetic longitude. Here the new processing provides the magnetic longitude of the field line at the equator.

Lastly we consider the energy flux into the atmosphere. We expect the energy fluxes to be different because the calibration factors applied are not the same and the background correction is handled in a different manner. The calibration factors used in the legacy processing system were derived using an undocumented method. The new processing relies on calibration factors provided by the instrument vendor that are described in the Data Packages provided for each unique instrument. Additionally, there are a number of differences in the way the two systems handle the background measurements. The legacy system interpolated the background by simply repeating the nearest value while the new system used a linear interpolation. The legacy system did not do a background correction at low latitudes and the new system does it for all data points. More noticeably, the new system does not remove negative energy flux values whereas the legacy system set them to 0. The negative values are unphysical. However, a common practice is to average or integrate the total energy flux over a satellite pass. Removing the negative values would bias those results in a positive direction. Figure 5 shows the comparison of the energy flux outputs. Even with the variations in the 2 processing methods the final values track well.

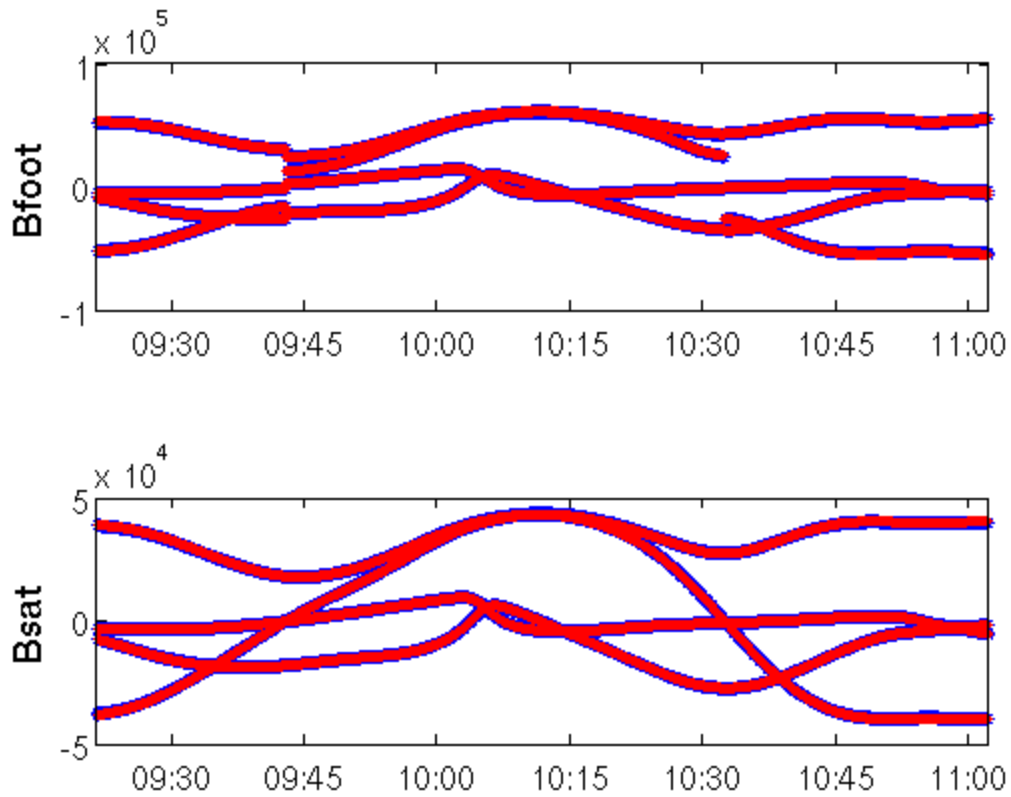


Figure 2: Comparison of magnetic field components (nT). Legacy values shown in blue and new values shown in red. Top panel shows the components at the foot of the field line and bottom panel shows the values at the satellite.

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 33 of 81

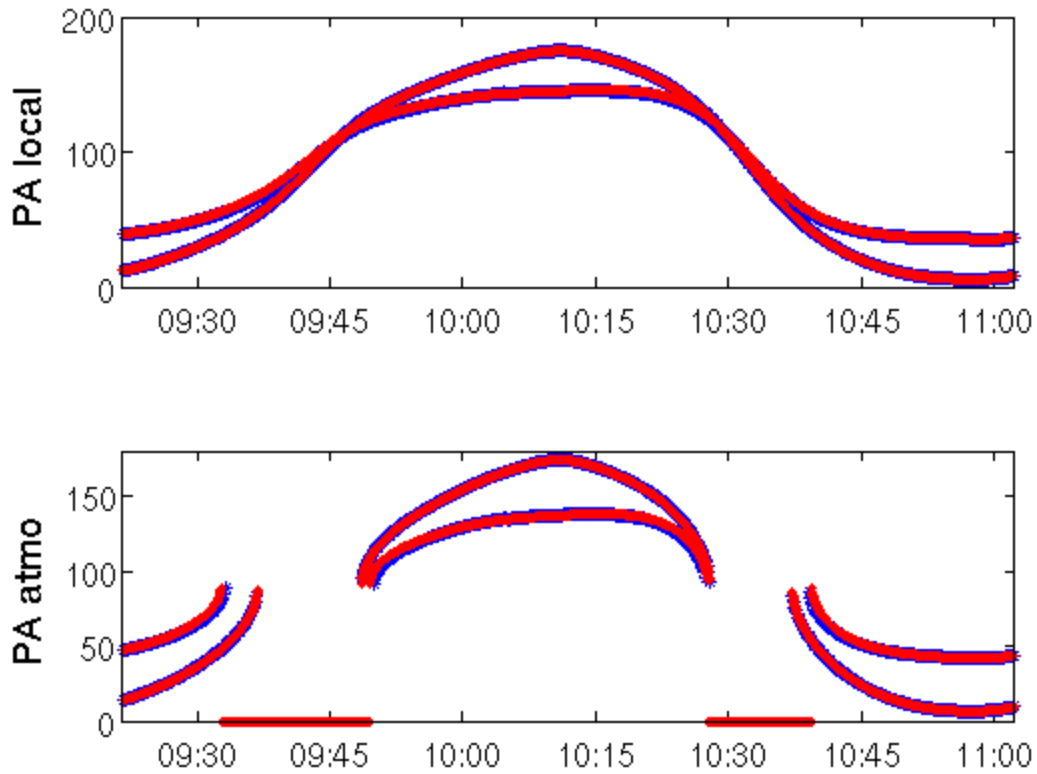


Figure 3: Comparison of pitch angle calculations. Legacy values shown in blue and new values shown in red. Top panel shows the pitch angles at the satellite and bottom panel shows the values at the foot of the field line.

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 34 of 81

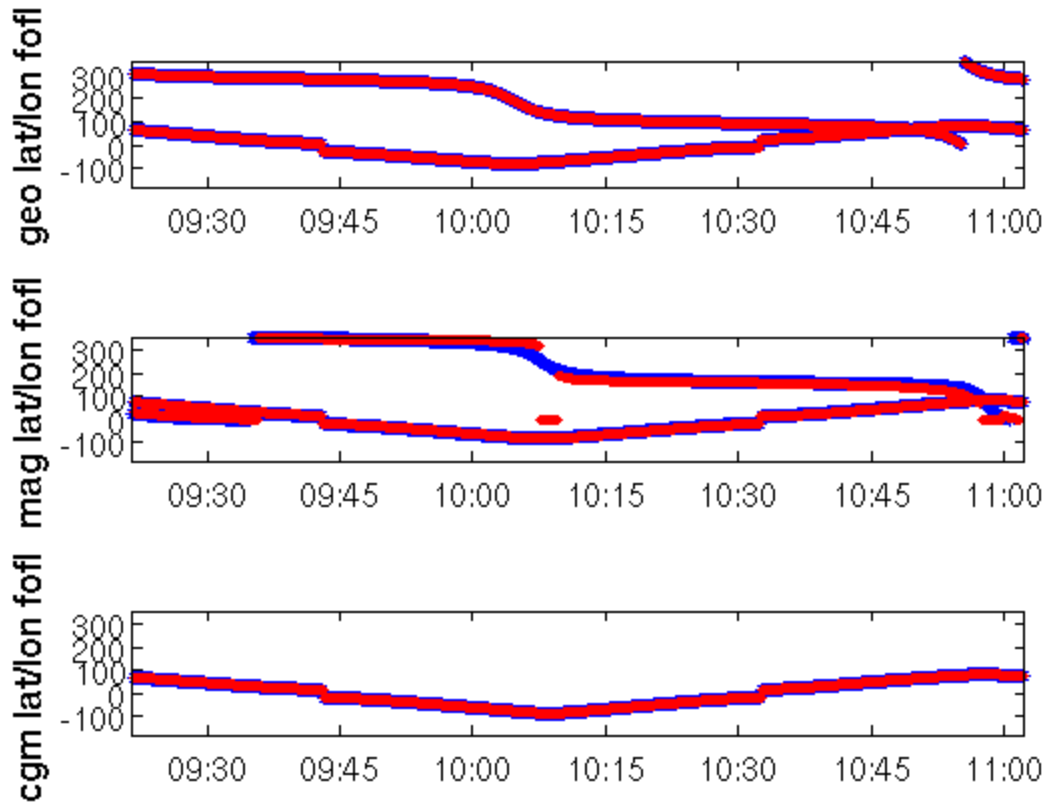


Figure 4 : Comparison of location calculations. Legacy values shown in blue and new values shown in red. Top panel shows the geographic latitude and longitude at the foot of the field line. Middle panel shows the magnetic latitude and longitude at the foot of the field line and the bottom panel shows the corrected geomagnetic latitude at the foot of the field line.

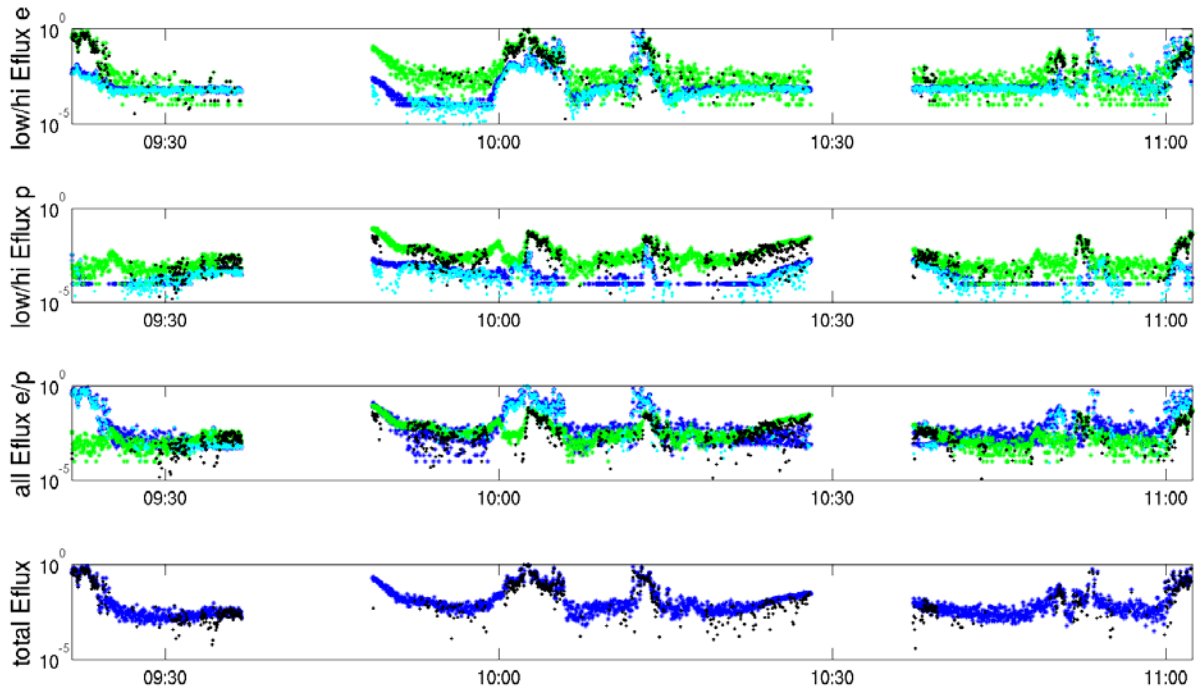


Figure 5 Comparison of energy flux into the atmosphere calculations. Legacy values shown in green and dark blue with new values shown in black and cyan. Top panel shows the electron energy flux into the atmosphere from the high energy range in green (legacy) and black (new) and the low energy range in blue(legacy) and cyan (new). Second panel from the top shows the proton energy flux into the atmosphere from the high energy range in green (legacy) and black (new) and the low energy range in blue(legacy) and cyan (new). Third panel from the top shows the total electron energy flux into the atmosphere blue (legacy) and cyan (new) and the total proton energy flux into the atmosphere in black(legacy) and green (new). Bottom panel shows the total particle flux into the atmosphere in blue(legacy) and black (new).

5.0 PRACTICAL CONSIDERATIONS

5.1 Numerical Computation Considerations

The algorithm is straightforward to implement in software and does not require special considerations for computing power.

5.2 Programming and Procedural Considerations

The operational algorithm has been implemented in C++ and fortran with a groovy wrapper.

5.3 Quality Assessment and Diagnostics

Quality assessment of the operational product should be based on the error bars provided in the datafiles.

5.5 Algorithm Validation

An additional Possibility for validating the algorithm and the data would be to compare to additional datasets. Data from the Special Sensor J (SSJ) instrument on the DMSP satellites is the most logical set to compare to because the instruments are similar and the satellites are in similar orbits. Such a comparison is beyond the scope of the current work.

6.0 ASSUMPTIONS AND LIMITATIONS

6.1 Performance

The algorithm provides error bars to describe performance. However, these errors only include those due to poisson counting statistics of the instrument. Other sources of error such as calibration errors, instrument degradation, and satellite intercalibration differences are not considered. Calibration errors are not included simply because they are not well characterized. Degradation of the sensors is possibly a significant source of error. As discussed in section 2.2.4, the channeltron that amplifies the signal of an incoming particle degrades over time. The degradation is tracked with a monthly In-Flight-Calibration and the voltage on the channeltron is increased to increase the sensitivity. Lastly, there may be differences between the data from different satellites because of variations in the orbits or other factors. Intercalibration of the data is beyond the scope of this work.

6.2 Assumed Sensor Performance

NA

6.3 Pre-Planned Product Improvements

None at this time.

7.0 REFERENCES

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 37 of 81

Appendix A: Ancillary Data Tables

Table 3: TED Energy Flux Calibration Conversion Values

Satellite	Serial number	Satellite ID	0-low-e,	30-low-e	0-hi-e	30-hi-e	0-low-p	30-low-p	0-hi-p	30-hi-p
15	11	2	1.564E-6	2.083E-6	5.04E-5	5.43E-5	9.29E-7	1.002E-6	3.47E-5	2.57E-5
16	10	4	2.58E-6	3.12E-6	6.07E-5	5.44E-6	1.158E-6	1.675E-6	4.75E-5	3.70E-5
17	12	6	1.672E-6	2.176E-6	6.36E-5	7.79E-5	1.106E-6	1.093E-6	5.28E-5	3.85E-5
18	13	7	2.45E-6	2.18E-6	8.09E-5	5.14E-5	1.34E-6	1.50E-6	6.08E-5	4.30E-5
19	17	8	1.133E-6	1.402E-6	5.20E-5	3.51E-5	2.281E-6	1.988E-6	6.60E-5	3.77E-5
2	16	12	2.345E-6	2.672E-6	7.50E-5	7.25E-5	1.516E-6	2.714E-6	4.86E-5	3.93E-5
1	15	11	2.875E-6	2.460E-6	8.39E-5	6.13E-5	1.532E-6	3.433E-6	6.41E-5	5.19E-5
3	14	-	2.805E-6	2.734E-6	8.05E-5	6.32E-5	1.774E-6	2.624E-6	7.08E-5	5.61E-5
-	-1	-	1.708E-6	3.12E-6	7.76E-5	7.47E-5	2.105E-6	2.305E-6	5.47E-5	4.33E-5

Table 4: TED Differential Flux Calibration Conversion Values

Satellite	Serial number	Satellite ID	Energy Band	0 electron	30 electron	0 proton	30 proton
15	11	4	1	6.964E+02	9.272E+02	4.022E+02	4.121E+02
15	11	4	2	4.773E+02	6.355E+02	2.608E+02	2.758E+02
15	11	4	3	3.268E+02	4.351E+02	1.690E+02	1.843E+02
15	11	4	4	2.248E+02	2.993E+02	1.101E+02	1.237E+02
15	11	4	5	1.550E+02	2.064E+02	7.193E+01	8.333E+01
15	11	4	6	1.065E+02	1.418E+02	4.678E+01	5.587E+01
15	11	4	7	7.324E+01	9.752E+01	3.047E+01	3.753E+01
15	11	4	8	5.033E+01	6.702E+01	1.983E+01	2.518E+01
15	11	4	9	5.567E+01	5.984E+01	1.058E+02	7.990E+01
15	11	4	10	4.292E+01	4.625E+01	6.579E+01	4.900E+01
15	11	4	11	3.311E+01	3.568E+01	4.074E+01	3.006E+01
15	11	4	12	2.553E+01	2.760E+01	2.528E+01	1.845E+01
15	11	4	13	1.968E+01	2.134E+01	1.568E+01	1.132E+01
15	11	4	14	1.521E+01	1.649E+01	9.729E+00	6.946E+00
15	11	4	15	1.171E+01	1.275E+01	6.034E+00	4.262E+00
15	11	4	16	9.032E+00	9.843E+00	3.741E+00	2.615E+00
16	10	2	1	1.146E+03	4.476E+02	5.389E+02	7.404E+02
16	10	2	2	7.857E+02	4.476E+02	3.338E+02	4.741E+02
16	10	2	3	5.379E+02	4.476E+02	2.066E+02	3.031E+02
16	10	2	4	3.700E+02	4.476E+02	1.285E+02	1.950E+02

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 38 of 81

16	10	2	5	2.552E+02	4.476E+02	8.025E+01	1.257E+02
16	10	2	6	1.753E+02	4.476E+02	4.983E+01	8.064E+01
16	10	2	7	1.206E+02	4.476E+02	3.101E+01	5.187E+01
16	10	2	8	8.286E+01	1.002E+02	1.927E+01	3.330E+01
16	10	2	9	6.397E+01	4.476E+02	1.493E+02	1.132E+02
16	10	2	10	5.087E+01	4.476E+02	9.100E+01	7.024E+01
16	10	2	11	4.048E+01	3.595E+01	5.537E+01	4.349E+01
16	10	2	12	3.223E+01	4.476E+02	3.371E+01	2.698E+01
16	10	2	13	2.566E+01	4.476E+02	2.057E+01	1.672E+01
16	10	2	14	2.041E+01	1.689E+01	1.253E+01	1.037E+01
16	10	2	15	1.626E+01	4.476E+02	7.639E+00	1.037E+01
16	10	2	16	1.294E+01	4.476E+02	4.658E+00	6.431E+00
17	12	6	1	7.445E+02	9.689E+02	4.959E+02	4.564E+02
17	12	6	2	5.103E+02	6.641E+02	3.146E+02	3.027E+02
17	12	6	3	3.493E+02	4.546E+02	1.994E+02	2.004E+02
17	12	6	4	2.403E+02	3.127E+02	1.271E+02	1.335E+02
17	12	6	5	1.657E+02	2.157E+02	8.121E+01	8.915E+01
17	12	6	6	1.138E+02	1.481E+02	5.165E+01	5.922E+01
17	12	6	7	7.830E+01	1.019E+02	3.293E+01	3.944E+01
17	12	6	8	5.381E+01	7.003E+01	2.096E+01	2.622E+01
17	12	6	9	7.162E+01	9.076E+01	1.663E+02	1.235E+02
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17	12	6	14	1.832E+01	2.075E+01	1.389E+01	9.744E+00
17	12	6	15	1.394E+01	1.544E+01	8.448E+00	5.870E+00
17	12	6	16	1.062E+01	1.148E+01	5.143E+00	3.531E+00
18	13	7	1	1.052E+03	1.066E+03	6.163E+02	7.066E+02
18	13	7	2	7.392E+02	6.860E+02	3.848E+02	4.322E+02
18	13	7	3	5.190E+02	4.416E+02	2.404E+02	2.653E+02
18	13	7	4	3.654E+02	2.857E+02	1.503E+02	1.643E+02
18	13	7	5	2.581E+02	1.854E+02	9.455E+01	1.019E+02
18	13	7	6	1.816E+02	1.193E+02	5.911E+01	6.266E+01
18	13	7	7	1.281E+02	7.766E+01	3.700E+01	3.866E+01
18	13	7	8	9.017E+01	5.020E+01	2.314E+01	2.389E+01
18	13	7	9	8.490E+01	5.636E+01	1.922E+02	1.372E+02
18	13	7	10	6.770E+01	4.372E+01	1.168E+02	8.268E+01
18	13	7	11	5.412E+01	3.392E+01	7.084E+01	5.005E+01
18	13	7	12	4.315E+01	2.629E+01	4.288E+01	3.018E+01
18	13	7	13	3.451E+01	2.038E+01	2.603E+01	1.826E+01
18	13	7	14	2.748E+01	1.582E+01	1.578E+01	1.103E+01
18	13	7	15	2.198E+01	1.227E+01	9.574E+00	6.659E+00
18	13	7	16	1.753E+01	9.526E+00	5.798E+00	4.025E+00
19	17	8	1	4.529E+02	6.404E+02	1.112E+03	1.039E+03
19	17	8	2	3.324E+02	4.322E+02	6.680E+02	5.958E+02

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing

Algorithm Theoretical Basis Document

Page 39 of 81

19	17	8	3	2.469E+02	2.914E+02	4.042E+02	3.430E+02
19	17	8	4	1.800E+02	1.960E+02	2.427E+02	1.960E+02
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19	17	8	6	9.790E+01	8.951E+01	8.825E+01	6.493E+01
19	17	8	7	7.184E+01	6.071E+01	5.321E+01	3.732E+01
19	17	8	8	5.289E+01	4.114E+01	3.202E+01	2.146E+01
19	17	8	9	5.739E+01	3.956E+01	2.156E+02	1.220E+02
19	17	8	10	4.432E+01	3.002E+01	1.279E+02	7.295E+01
19	17	8	11	3.428E+01	2.288E+01	7.616E+01	4.349E+01
19	17	8	12	2.650E+01	1.741E+01	4.522E+01	2.593E+01
19	17	8	13	2.047E+01	1.326E+01	2.688E+01	1.547E+01
19	17	8	14	1.582E+01	1.011E+01	1.598E+01	9.228E+00
19	17	8	15	1.224E+01	7.694E+00	9.511E+00	5.510E+00
19	17	8	16	9.435E+00	5.867E+00	5.654E+00	3.284E+00
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2	16	12	4	3.379E+02	3.414E+02	1.588E+02	2.702E+02
2	16	12	5	2.337E+02	2.180E+02	9.650E+01	1.569E+02
2	16	12	6	1.607E+02	1.386E+02	5.829E+01	9.061E+01
2	16	12	7	1.108E+02	8.833E+01	3.533E+01	5.247E+01
2	16	12	8	7.624E+01	5.615E+01	2.139E+01	3.032E+01
2	16	12	9	8.134E+01	8.069E+01	1.509E+02	1.262E+02
2	16	12	10	6.355E+01	6.187E+01	9.159E+01	7.575E+01
2	16	12	11	4.966E+01	4.746E+01	5.553E+01	4.555E+01
2	16	12	12	3.874E+01	3.650E+01	3.371E+01	2.737E+01
2	16	12	13	3.027E+01	2.795E+01	2.043E+01	1.648E+01
2	16	12	14	2.364E+01	2.146E+01	1.241E+01	9.898E+00
2	16	12	15	1.849E+01	1.651E+01	7.519E+00	5.951E+00
2	16	12	16	1.445E+01	1.266E+01	4.565E+00	3.578E+00
1	15	11	1	1.318E+03	1.204E+03	6.819E+02	1.676E+03
1	15	11	2	8.819E+02	7.738E+02	4.348E+02	1.007E+03
1	15	11	3	5.890E+02	4.976E+02	2.767E+02	6.038E+02
1	15	11	4	3.954E+02	3.211E+02	1.772E+02	3.644E+02
1	15	11	5	2.664E+02	2.081E+02	1.138E+02	2.207E+02
1	15	11	6	1.785E+02	1.342E+02	7.269E+01	1.327E+02
1	15	11	7	1.199E+02	8.664E+01	4.655E+01	8.049E+01
1	15	11	8	8.038E+01	5.589E+01	2.977E+01	4.828E+01
1	15	11	9	8.763E+01	6.573E+01	2.203E+02	1.756E+02
1	15	11	10	6.989E+01	5.171E+01	1.262E+02	1.019E+02
1	15	11	11	5.553E+01	4.065E+01	7.271E+01	5.910E+01
1	15	11	12	4.416E+01	3.192E+01	4.179E+01	3.432E+01
1	15	11	13	3.518E+01	2.510E+01	2.398E+01	1.994E+01
1	15	11	14	2.797E+01	1.977E+01	1.380E+01	1.156E+01
1	15	11	15	2.232E+01	1.550E+01	7.935E+00	6.701E+00
1	15	11	16	1.774E+01	1.219E+01	4.558E+00	3.888E+00

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 40 of 81

3	14	0	1	1.281E+03	1.318E+03	8.100E+02	1.271E+03
3	14	0	2	8.630E+02	8.564E+02	5.080E+02	7.675E+02
3	14	0	3	5.819E+02	5.558E+02	3.181E+02	4.628E+02
3	14	0	4	3.937E+02	3.624E+02	2.004E+02	2.808E+02
3	14	0	5	2.672E+02	2.370E+02	1.266E+02	1.710E+02
3	14	0	6	1.803E+02	1.543E+02	7.961E+01	1.036E+02
3	14	0	7	1.221E+02	1.007E+02	5.018E+01	6.288E+01
3	14	0	8	8.251E+01	6.561E+01	3.158E+01	3.810E+01
3	14	0	9	8.763E+01	6.918E+01	2.440E+02	1.922E+02
3	14	0	10	6.819E+01	5.369E+01	1.401E+02	1.108E+02
3	14	0	11	5.323E+01	4.162E+01	8.028E+01	6.359E+01
3	14	0	12	4.140E+01	3.231E+01	4.600E+01	3.660E+01
3	14	0	13	3.231E+01	2.503E+01	2.641E+01	2.104E+01
3	14	0	14	2.516E+01	1.946E+01	1.513E+01	1.210E+01
3	14	0	15	1.958E+01	1.506E+01	8.686E+00	6.960E+00
3	14	0	16	1.527E+01	1.171E+01	4.988E+00	3.998E+00
0	-1	0	1	7.604E+02	1.389E+02	1.003E+03	1.093E+03
0	-1	0	2	5.211E+02	9.522E+01	6.120E+02	6.688E+02
0	-1	0	3	3.568E+02	6.519E+01	3.727E+02	4.087E+02
0	-1	0	4	2.454E+02	4.484E+01	2.285E+02	2.512E+02
0	-1	0	5	1.693E+02	3.093E+01	1.406E+02	1.550E+02
0	-1	0	6	1.162E+02	2.124E+01	8.601E+01	9.515E+01
0	-1	0	7	7.997E+01	1.461E+01	5.269E+01	5.852E+01
0	-1	0	8	5.496E+01	1.004E+01	3.225E+01	3.593E+01
0	-1	0	9	8.801E+01	8.454E+01	1.677E+02	1.319E+02
0	-1	0	10	6.673E+01	6.413E+01	1.038E+02	8.195E+01
0	-1	0	11	5.044E+01	4.866E+01	6.423E+01	5.084E+01
0	-1	0	12	3.829E+01	3.690E+01	3.979E+01	3.162E+01
0	-1	0	13	2.902E+01	2.803E+01	2.462E+01	1.959E+01
0	-1	0	14	2.198E+01	2.124E+01	1.524E+01	1.219E+01
0	-1	0	15	1.664E+01	1.614E+01	9.448E+00	7.559E+00
0	-1	0	16	1.261E+01	1.224E+01	5.843E+00	4.695E+00

Table 5: TED Onboard Processing Background Conversion Tables

Satellite	Serial number	Satellite ID	0-low-e,	30-low-e	0-hi-e	30-hi-e	0-low-p	30-low-p	0-hi-p	30-hi-p
15	11	2	37.5	37.5	73.5	73.5	27.5	38	65	65
16	10	4	37.5	37.5	105.5	73.5	27.5	27.5	65	65
17	12	6	37.5	37.5	73.5	73.5	27.5	38	65	65

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0
Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 41 of 81

18	13	7	52.5	37.5	105.5	73.5	27.5	27.5	65	65
19	17	8	52.5	37.5	73.5	73.5	27.5	20.5	65	65
2	16	12	37.5	37.5	73.5	73.5	27.5	20.5	65	65
1	15	11	37.5	37.5	105.5	73.5	27.5	27.5	49	49
3	14	-	37.5	37.5	73.5	73.5	27.5	27.5	49	49
-	-1	-	0	0	0	0	0	0	0	0

Table 6 NOAA 15 Plug and PROM Factors

NOAA 15 low energy detectors								NOAA 15 high energy detectors				
Plug value				1	1	1	1.5	Plug value	1/1.5	1/1.5	1	1
Satellite	Serial number	Satellite ID	Energy band	0-low-e PROM	30 low-e PROM	0 low-p PROM	30-low-p PROM	Energy band	0 hi-e PROM	30-hi-e PROM	0-hi-p PROM	30-hi-p PROM
15	11	2	1	1	1	1	9	32	96			
			2	1.5	1.5	10	48	128				
			3	2	2	11	96	128				
			4	3	2	12	128	192				
			5	4	3	13	256	256				
			6	6	4	14	512	384				
			7	8	6	15	768	384				
			8	12	8	16	1536	512				

Table 7 NOAA 16 Plug and PROM Factors

NOAA 16 low energy detectors								NOAA 16 high energy detectors				
Plug value				1	1	1	1	Plug value	1	1/1.5	1	1
Satellite	Serial number	Satellite ID	Energy band	0-low-e PROM	30 low-e PROM	0 low-p PROM	30-low-p PROM	Energy band	0 hi-e PROM	30-hi-e PROM	0-hi-p PROM	30-hi-p PROM
16	10	5	1	1	1	1	9	32	96			
			2	1.5	1.5	10	48	128				

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 42 of 81

			3	2	2	11	96	128
			4	3	2	12	128	192
			5	4	3	13	256	256
			6	6	4	14	512	384
			7	8	6	15	768	384
			8	12	8	16	1536	512

Table 8 NOAA 17 Plug and PROM Factors

NOAA 17 low energy detectors								NOAA 17 high energy detectors				
Plug value				1	1	1	1.5	Plug value	1/1.5	1/1.5	1	1
Satellite	Serial number	Satellite ID	Energy band	0-low-e PROM	30 low-e PROM	0 low-p PROM	30-low-p PROM	Energy band	0 hi-e PROM	30-hi-e PROM	0-hi-p PROM	30-hi-p PROM
17	12	7	1	1	1	1	9	32	96			
			2	1.5	1.5	10	48	128				
			3	2	2	11	96	128				
			4	3	2	12	128	192				
			5	4	3	13	256	256				
			6	6	4	14	512	384				
			7	8	6	15	768	384				
			8	12	8	16	1536	512				

Table 9 NOAA 18 Plug and PROM Factors

NOAA 18 low energy detectors								NOAA 18 high energy detectors				
Plug value				1.5	1	1	1	Plug value	1	1/1.5	1	1
Satellite	Serial number	Satellite ID	Energy band	0-low-e PROM	30 low-e PROM	0 low-p PROM	30-low-p PROM	Energy band	0 hi-e PROM	30-hi-e PROM	0-hi-p PROM	30-hi-p PROM
18	13	5	1	1	1	1	9	32	96			
			2	1.5	1.5	10	48	128				

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 43 of 81

			3	2	2	11	96	128
			4	3	2	12	128	192
			5	4	3	13	256	256
			6	6	4	14	512	384
			7	8	6	15	768	384
			8	12	8	16	1536	512

Table 10 NOAA 19 Plug and PROM Factors

NOAA 19 low energy detectors								NOAA 19 high energy detectors				
Plug value				1.5	1	1	1/15	Plug value	1/1.5	1/1.5	1	1
Satellite	Serial number	Satellite ID	Energy band	0-low-e PROM	30 low-e PROM	0 low-p PROM	30-low-p PROM	Energy band	0 hi-e PROM	30-hi-e PROM	0-hi-p PROM	30-hi-p PROM
19	17	8	1	1	1	1	9	32	96			
			2	1.5	1.5	10	48	128				
			3	2	2	11	96	128				
			4	3	2	12	128	192				
			5	4	3	13	256	256				
			6	6	4	14	512	384				
			7	8	6	15	768	384				
			8	12	8	16	1536	512				

Table 11 MetOp-2 (MetOp-A) Plug and PROM Factors

MetOp-2,A low energy detectors								MetOp-2,A high energy detectors				
Plug value				1	1	1	1/1.5	Plug value	1/1.5	1/1.5	1	1
Satellite	Serial number	Satellite ID	Energy band	0-low-e PROM	30 low-e PROM	0 low-p PROM	30-low-p PROM	Energy band	0 hi-e PROM	30-hi-e PROM	0-hi-p PROM	30-hi-p PROM
2	16	12	1	1	1	1	9	32	96			
			2	1.5	1.5	10	48	128				

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 44 of 81

			3	2	2	11	96	128
			4	3	2	12	128	192
			5	4	3	13	256	256
			6	6	4	14	512	384
			7	8	6	15	768	384
			8	12	8	16	1536	512

Table 12 MetOp-01(MetOp-B) Plug and PROM Factors

MetOp-1,B low energy detectors								MetOp-1,B high energy detectors				
Plug value				1	1	1	1	Plug value	1	1/1.5	1/1.5	1/1.5
Satellite	Serial number	Satellite ID	Energy band	0-low-e PROM	30 low-e PROM	0 low-p PROM	30-low-p PROM	Energy band	0 hi-e PROM	30-hi-e PROM	0-hi-p PROM	30-hi-p PROM
1	15	12	1	1	1	1	9	32	96			
			2	1.5	1.5	10	48	128				
			3	2	2	11	96	128				
			4	3	2	12	128	192				
			5	4	3	13	256	256				
			6	6	4	14	512	384				
			7	8	6	15	768	384				
			8	12	8	16	1536	512				

Table 13 MetOp-3 (MetOp-C) Plug and PROM Factors

MetOp-3,C low energy detectors								MetOp-3,C high energy detectors				
Plug value				1	1	1	1	Plug value	1/1.5	1/1.5	1/1.5	1/1.5
Satellite	Serial number	Satellite ID	Energy band	0-low-e PROM	30 low-e PROM	0 low-p PROM	30-low-p PROM	Energy band	0 hi-e PROM	30-hi-e PROM	0-hi-p PROM	30-hi-p PROM
3	14	-	1	1	1	1	9	32	96			
			2	1.5	1.5	10	48	128				

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 45 of 81

			3	2	2	11	96	128
			4	3	2	12	128	192
			5	4	3	13	256	256
			6	6	4	14	512	384
			7	8	6	15	768	384
			8	12	8	16	1536	512

Table 14 Data Decompression Look-up Table

Conversion table=

(0.0,1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,9.0,10.0,11.0,12.0,13.0,14.0,15.0,16.0,17.0,18.0,19.0,20.0,21.0,22.0,23.0,24.0,25.0,26.0,27.0,28.0,29.0,30.0,31.0,32.0,34.5,36.5,38.5,40.5,42.5,44.5,46.5,48.5,50.5,53.0,56.0,59.0,62.0,65.5,69.5,73.5,77.5,81.5,85.5,89.5,93.5,97.5,101.5,106.5,112.5,118.5,124.5,131.5,139.5,147.5,155.5,163.5,171.5,179.5,187.5,195.5,203.5,213.5,225.5,237.5,249.5,263.5,279.5,295.5,311.5,327.5,343.5,359.5,375.5,391.5,407.5,427.5,451.5,475.5,499.5,527.5,559.5,591.5,623.5,655.5,687.5,719.5,751.5,783.5,815.5,855.5,903.5,951.5,999.5,1055.5,1119.5,1183.5,1247.5,1311.5,1375.5,1439.5,1503.5,1567.5,1631.5,1711.5,1807.5,1903.5,1999.5,2111.5,2239.5,2367.5,2495.5,2623.5,2751.5,2879.5,3007.5,3135.5,3263.5,3423.5,3615.5,3807.5,3999.5,4223.5,4479.5,4735.5,4991.5,5247.5,5503.5,5759.5,6015.5,6271.5,6527.5,6847.5,7231.5,7615.5,7999.5,8447.5,8959.5,9471.5,9983.5,10495.5,11007.5,11519.5,12031.5,12543.5,13055.5,13695.5,14463.5,15231.5,15999.5,16895.5,17919.5,18943.5,19967.5,20991.5,22015.5,23039.5,24063.5,25087.5,26111.5,27391.5,28927.5,30463.5,31999.5,33791.5,35839.5,37887.5,39935.5,41983.5,44031.5,46079.5,48127.5,50175.5,52223.5,54783.5,57855.5,60927.5,63999.5,67583.5,71679.5,75775.5,79871.5,83967.5,88063.5,92159.5,96255.5,100351.5,104447.5,109567.5,115711.5,121855.5,127999.5,135167.5,143359.5,151551.5,159743.5,167935.5,176127.5,184319.5,192511.5,200703.5,208895.5,219135.5,231423.5,243711.5,255999.5,270335.5,286719.5,303103.5,319487.5,335871.5,352255.5,368639.5,385023.5,401407.5,417791.5,438271.5,462847.5,487423.5,511999.5,540671.5,573439.5,606207.5,638975.5,671743.5,704511.5,737279.5,770047.5,802815.5,835583.5,876543.5,925695.5,974847.5,1023999.5,1081343.5,1146879.5,1212415.5,1277951.5,1343487.5,1409023.5,1474559.5,1540095.5,1605631.5,1671167.5,1753087.5,1851391.5,1949695.5,1998848.0;)

Appendix B: Outputs

Table 15: Processing Output

year	a	int	4	1950	2050	year
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NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0
Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 46 of 81

day	a	int	3	0	366	day
msec	a	int	8	0	86400000	millisec
satID	a	int	2	0		ID
minor_frame	r	int	3	0	320	frame
major_frame	r	int	3	0	7	frame
sat_direction	a	int	1	0	1	
alt	a	float	7.3	800	1000	km
lat	a	float	7.3	-90	90	degrees
lon	a	float	7.3	0	360	degrees
mep_pro_tel0_cps_p1	r	float	9.1	0	1998848	#/s
mep_pro_tel0_cps_p2	r	float	9.1	0	1998848	#/s
mep_pro_tel0_cps_p3	r	float	9.1	0	1998848	#/s
mep_pro_tel0_cps_p4	r	float	9.1	0	1998848	#/s
mep_pro_tel0_cps_p5	r	float	9.1	0	1998848	#/s
mep_pro_tel0_cps_p6	r	float	9.1	0	1998848	#/s
mep_pro_tel90_cps_p1	r	float	9.1	0	1998848	#/s
mep_pro_tel90_cps_p2	r	float	9.1	0	1998848	#/s
mep_pro_tel90_cps_p3	r	float	9.1	0	1998848	#/s
mep_pro_tel90_cps_p4	r	float	9.1	0	1998848	#/s
mep_pro_tel90_cps_p5	r	float	9.1	0	1998848	#/s
mep_pro_tel90_cps_p6	r	float	9.1	0	1998848	#/s
mep_pro_tel0_flux_p1	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel0_flux_p2	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel0_flux_p3	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel0_flux_p4	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel0_flux_p5	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel0_flux_p6	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel0_flux_p1_err	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel0_flux_p2_err	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel0_flux_p3_err	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel0_flux_p4_err	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel0_flux_p5_err	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel0_flux_p6_err	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel90_flux_p1	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel90_flux_p2	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel90_flux_p3	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel90_flux_p4	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel90_flux_p5	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel90_flux_p6	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel90_flux_p1_err	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel90_flux_p2_err	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel90_flux_p3_err	p	float	14.5	0		#/cm2-s-str-keV

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 47 of 81

mep_pro_tel90_flux_p4_err	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel90_flux_p5_err	p	float	14.5	0		#/cm2-s-str-keV
mep_pro_tel90_flux_p6_err	p	float	14.5	0		#/cm2-s-str-keV
mep_ele_tel0_cps_e1	r	float	9.1	0	1998848	#/s
mep_ele_tel0_cps_e2	r	float	9.1	0	1998848	#/s
mep_ele_tel0_cps_e3	r	float	9.1	0	1998848	#/s
mep_ele_tel90_cps_e1	r	float	9.1	0	1998848	#/s
mep_ele_tel90_cps_e2	r	float	9.1	0	1998848	#/s
mep_ele_tel90_cps_e3	r	float	9.1	0	1998848	#/s
mep_ele_tel0_flux_e1	p	float	14.5	0		#/cm2-s-str
mep_ele_tel0_flux_e2	p	float	14.5	0		#/cm2-s-str
mep_ele_tel0_flux_e3	p	float	14.5	0		#/cm2-s-str
mep_ele_tel0_flux_e4	p	float	14.5	0		#/cm2-s-str
mep_ele_tel0_flux_e1_err	p	float	14.5	0		#/cm2-s-str
mep_ele_tel0_flux_e2_err	p	float	14.5	0		#/cm2-s-str
mep_ele_tel0_flux_e3_err	p	float	14.5	0		#/cm2-s-str
mep_ele_tel0_flux_e4_err	p	float	14.5	0		#/cm2-s-str
mep_ele_tel90_flux_e1	p	float	14.5	0		#/cm2-s-str
mep_ele_tel90_flux_e2	p	float	14.5	0		#/cm2-s-str
mep_ele_tel90_flux_e3	p	float	14.5	0		#/cm2-s-str
mep_ele_tel90_flux_e4	p	float	14.5	0		#/cm2-s-str
mep_ele_tel90_flux_e1_err	p	float	14.5	0		#/cm2-s-str
mep_ele_tel90_flux_e2_err	p	float	14.5	0		#/cm2-s-str
mep_ele_tel90_flux_e3_err	p	float	14.5	0		#/cm2-s-str
mep_ele_tel90_flux_e4_err	p	float	14.5	0		#/cm2-s-str
mep_omni_cps_p6	r	float	10.2	0	1998848	#/s
mep_omni_cps_p7	r	float	10.2	0	1998848	#/s
mep_omni_cps_p8	r	float	10.2	0	1998848	#/s
mep_omni_cps_p9	r	float	10.2	0	1998848	#/s
mep_omni_flux_p1	p	float	11.5	0		#/cm2-s-str
mep_omni_flux_p2	p	float	11.5	0		#/cm2-s-str
mep_omni_flux_p3	p	float	11.5	0		#/cm2-s-str
mep_omni_flux_flag_fit	p	int	2.0	-1	2	flag
mep_omni_flux_flag_iter_lim	p	int	2.0	0	1	true/false
mep_omni_gamma_p1	p	float	9.1			
mep_omni_gamma_p2	p	float	9.1			
mep_omni_gamma_p3	p	float	9.1			
ted_ele_tel0_cps_4	r	float	9.1	0	1998848	counts
ted_ele_tel0_cps_8	r	float	9.1	0	1998848	counts
ted_ele_tel0_cps_11	r	float	9.1	0	1998848	counts
ted_ele_tel0_cps_14	r	float	9.1	0	1998848	counts
ted_ele_tel30_cps_4	r	float	9.1	0	1998848	counts

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 48 of 81

ted_ele_tel30_cps_8	r	float	9.1	0	1998848	counts
ted_ele_tel30_cps_11	r	float	9.1	0	1998848	counts
ted_ele_tel30_cps_14	r	float	9.1	0	1998848	counts
ted_pro_tel0_cps_4	r	float	9.1	0	1998848	counts
ted_pro_tel0_cps_8	r	float	9.1	0	1998848	counts
ted_pro_tel0_cps_11	r	float	9.1	0	1998848	counts
ted_pro_tel0_cps_14	r	float	9.1	0	1998848	counts
ted_pro_tel30_cps_4	r	float	9.1	0	1998848	counts
ted_pro_tel30_cps_8	r	float	9.1	0	1998848	counts
ted_pro_tel30_cps_11	r	float	9.1	0	1998848	counts
ted_pro_tel30_cps_14	r	float	9.1	0	1998848	counts
ted_ele_tel0_flux_4	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_ele_tel0_flux_8	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_ele_tel0_flux_11	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_ele_tel0_flux_14	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_ele_tel30_flux_4	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_ele_tel30_flux_8	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_ele_tel30_flux_11	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_ele_tel30_flux_14	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_pro_tel0_flux_4	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_pro_tel0_flux_8	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_pro_tel0_flux_11	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_pro_tel0_flux_14	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_pro_tel30_flux_4	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_pro_tel30_flux_8	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_pro_tel30_flux_11	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_pro_tel30_flux_14	p	float	13.1	0	4E+09	[/cm2-s-str-eV]
ted_ele_tel0_low_eflux_cps	r	float	9.1	0	1998848	counts
ted_ele_tel30_low_eflux_cps	r	float	9.1	0	1998848	counts
ted_ele_tel0_hi_eflux_cps	r	float	9.1	0	1998848	counts
ted_ele_tel30_hi_eflux_cps	r	float	9.1	0	1998848	counts
ted_pro_tel0_low_eflux_cps	r	float	9.1	0	1998848	counts
ted_pro_tel30_low_eflux_cps	r	float	9.1	0	1998848	counts
ted_pro_tel0_hi_eflux_cps	r	float	9.1	0	1998848	counts
ted_pro_tel30_hi_eflux_cps	r	float	9.1	0	1998848	counts
ted_ele_tel0_low_eflux	p	float	15.9	-200	200	mW/m2-str
ted_ele_tel30_low_eflux	p	float	15.9	-200	200	mW/m2-str
ted_ele_tel0_hi_eflux	p	float	15.9	-200	200	mW/m2-str
ted_ele_tel30_hi_eflux	p	float	15.9	-200	200	mW/m2-str
ted_pro_tel0_low_eflux	p	float	15.9	-200	200	mW/m2-str
ted_pro_tel30_low_eflux	p	float	15.9	-200	200	mW/m2-str
ted_pro_tel0_hi_eflux	p	float	15.9	-200	200	mW/m2-str

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 49 of 81

ted_pro_tel30_hi_eflux	p	float	15.9	-200	200	mW/m2-str
ted_ele_tel0_low_eflux_error	p	float	15.9			mW/m2-str
ted_ele_tel30_low_eflux_error	p	float	15.9			mW/m2-str
ted_ele_tel0_hi_eflux_error	p	float	15.9			mW/m2-str
ted_ele_tel30_hi_eflux_error	p	float	15.9			mW/m2-str
ted_pro_tel0_low_eflux_error	p	float	15.9			mW/m2-str
ted_pro_tel30_low_eflux_error	p	float	15.9			mW/m2-str
ted_pro_tel0_hi_eflux_error	p	float	15.9			mW/m2-str
ted_pro_tel30_hi_eflux_error	p	float	15.9			mW/m2-str
ted_ele_eflux_atmo_low	p	float	15.9	-6400	6400	mW/m2
ted_ele_eflux_atmo_hi	p	float	15.9	-6400	6400	mW/m2
ted_ele_eflux_atmo_total	p	float	15.9	-12800	6400	mW/m2
ted_ele_eflux_atmo_low_err	p	float	15.9	-6400	6400	mW/m2
ted_ele_eflux_atmo_hi_err	p	float	15.9	-6400	6400	mW/m2
ted_ele_eflux_atmo_total_err	p	float	15.9	-6400	6400	mW/m2
ted_pro_eflux_atmo_low	p	float	15.9	-6400	6400	mW/m2
ted_pro_eflux_atmo_hi	p	float	15.9	-6400	6400	mW/m2
ted_pro_eflux_atmo_total	p	float	15.9	-12800	12800	mW/m2
ted_pro_eflux_atmo_low_err	p	float	15.9	-6400	6400	mW/m2
ted_pro_eflux_atmo_hi_err	p	float	15.9	-6400	6400	mW/m2
ted_pro_eflux_atmo_total_err	p	float	15.9	-12800	12800	mW/m2
ted_total_eflux_atmo	p	float	16	-25600	25600	mW/m2
ted_total_eflux_atmo_err	p	float	16	-25600	25600	mW/m2
ted_ele_energy_tel0	p	int	2	0	15	energy channel
ted_ele_energy_tel30	p	int	2	0	15	energy channel
ted_pro_energy_tel0	p	int	2	0	15	energy channel
ted_pro_energy_tel30	p	int	2	0	15	energy channel
ted_ele_max_flux_tel0	p	float	13.1	0	4E+09	[#/cm2-s-str-eV]
ted_ele_max_flux_tel30	p	float	13.1	0	4E+09	[#/cm2-s-str-eV]
ted_pro_max_flux_tel0	p	float	13.1	0	4E+09	[#/cm2-s-str-eV]
ted_pro_max_flux_tel30	p	float	13.1	0	4E+09	[#/cm2-s-str-eV]
ted_ele_eflux_bg_tel0_low	p	float	15.9	0	200	mW/m2-str
ted_ele_eflux_bg_tel30_low	p	float	15.9	0	200	mW/m2-str
ted_ele_eflux_bg_tel0_hi	p	float	15.9	0	200	mW/m2-str
ted_ele_eflux_bg_tel30_hi	p	float	15.9	0	200	mW/m2-str
ted_pro_eflux_bg_tel0_low	p	float	15.9	0	200	mW/m2-str
ted_pro_eflux_bg_tel30_low	p	float	15.9	0	200	mW/m2-str
ted_pro_eflux_bg_tel0_hi	p	float	15.9	0	200	mW/m2-str
ted_pro_eflux_bg_tel30_hi	p	float	15.9	0	200	mW/m2-str
ted_ele_eflux_bg_tel0_low_cps	p	float	9.1	0	1998848	counts
ted_ele_eflux_bg_tel30_low_cps	p	float	9.1	0	1998848	counts
ted_ele_eflux_bg_tel0_hi_cps	p	float	9.1	0	1998848	counts

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 50 of 81

ted_ele_eflux_bg_tel30_hi_cps	p	float	9.1	0	1998848	counts
ted_pro_eflux_bg_tel0_low_cps	p	float	9.1	0	1998848	counts
ted_pro_eflux_bg_tel30_low_cps	p	float	9.1	0	1998848	counts
ted_pro_eflux_bg_tel0_hi_cps	p	float	9.1	0	1998848	counts
ted_pro_eflux_bg_tel30_hi_cps	p	float	9.1	0	1998848	counts
microA_V	r	float	5.1			V
microB_V	r	float	5.1			V
DPU_V	r	float	5.1			V
MEPED_V	r	float	5.1			V
ted_V	r	float	5.1			V
ted_sweepV	r	float	5.1			V
ted_electron_CEM_V	r	float	5.1			V
ted_proton_CEM_V	r	float	5.1			V
mep_omni_bias_V	r	float	5.1			V
mep_circuit_temp	r	float	5.1			K
mep_proton_tel_temp	r	float	5.1			K
TED_temp	r	float	5.1			K
DPU_temp	r	float	5.1			K
Br_sat	p	float	6.1	-32000	32000	nT
Bt_sat	p	float	6.1	-32000	32000	nT
Bp_sat	p	float	6.1	-32000	32000	nT
Btot_sat	p	float	6.1	-32000	32000	nT
Br_foot	p	float	6.1	-32000	32000	nT
Bt_foot	p	float	6.1	-32000	32000	nT
Bp_foot	p	float	6.1	-32000	32000	nT
Btot_foot	p	float	6.1	-32000	32000	nT
geod_lat_foot	p	float	4.1	-90	90	deg
geod_lon_foot	p	float	4.1	0	360	deg
aacgm_lat_foot	p	float	4.1	-90	90	deg
aacgm_lon_foot	p	float	4.1	0	360	deg
mag_lat_foot	p	float	4.1	-90	90	deg
mag_lon_foot	p	float	4.1	0	360	deg
mag_lat_sat	p	float	4.1	-90	90	deg
mag_lon_sat	p	float	4.1	0	360	deg
Bx_sat	p	float	6.1	-32000	32000	nT
By_sat	p	float	6.1	-32000	32000	nT
Bz_sat	p	float	6.1	-32000	32000	nT
ted_alpha_0_sat	p	float	4.1	0	180	deg
ted_alpha_30_sat	p	float	4.1	0	180	deg
ted_alpha_0_foot	p	float	4.1	0	180	deg
ted_alpha_30_foot	p	float	4.1	0	180	deg
meped_alpha_0_sat	p	float	4.1	0	180	deg

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 51 of 81

meped_alpha_90_sat	p	float	4.1	0	180	deg
meped_alpha_0_foot	p	float	4.1	0	180	deg
meped_alpha_90_foot	p	float	4.1	0	180	deg
L_IGRF	p	float	4.1	0	20	
MLT	p	float	4.1	0	25	hours
HK_data	r	float	10.2			variable
HK_key	r	int	4			key value
ted_ele_PHD_level	r	int	2.0	0	3	level
ted_pro_PHD_level	r	int	2.0	0	3	level
ted_IFC_on	a	int	1.0	0	1	on/off
mep_IFC_on	a	int	1.0	0	1	on/off
ted_ele_HV_step	r	int	2.0	0	7	step
ted_pro_HV_step	r	int	2.0	0	7	step

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 52 of 81

Appendix C.

Table 26: The byte by byte description of the contents of the header record of a SEM incremental file.

Byte	Contents	Comments
001-003	3-character code for incremental file creation site	EBCDIC, normally NSS, ASCII
004	ASCII blank character	ASCII 032 decimal
005-006	Level 1b data format version number	currently 001
007-008	Year of level 1b data format creation	currently 1998
009-010	Day of level 1b data format creation	currently 051
011-012	Number of bytes in logical record	currently 512
013-014	Record block size	currently 512
015-016	Number of header records in this incremental file	normally 001
017-018	not used	
019-060	42-character name of this incremental data file	EBCDIC, ASCII as of 2005
061-068	8-character processing block ID	EBCDIC, ASCII as of 2005
069-070	Spacecraft ID	note (1)
071-072	Instrument ID	normally 000
073-074	Data type code	is 009 for SEM
075-076	TIP source code	normally 000
077-080	Day number from 1 Jan. 1950 at start of this data set	19546 for July 8, 2003
081-082	Year at start of this data set	4-digit year
083-084	Day of year at start of this data set	3-digit day of year
085-088	UT time in milliseconds at start of this data set	all 4 bytes used
089-092	Day number from 1 Jan. 1950 at end of this data set	19546 for July 8, 2003
093-094	Year at end of this data set	4-digit year
095-096	Day of year at end of this data set	3-digit day of year
097-100	UT time in milliseconds at end of this data set	all 4 bytes used
101-102	Year of last CPIDS update	note (2)
103-104	Day of year of last CPIDS update	note (2)
105-112	Not used	
113-116	TIP word 08, status 1 and 2 at start of this data set	note (3)
117-118	Not used	
119-120	Data record number of any status change in TIP 08	note (4)
121-124	TIP word 08, status 1 and 2 after a status change	note (4)
125-126	Number of 2-second data records in this data set	note (5)
127-128	Number of data gaps in this data set	
129-130	Number of TIP minor frames without sync errors	note (5)
131-132	Number of TIP parity errors detected by PACS	
133-134	Sum of all sync errors detected in this data set	

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 53 of 81

Byte	Contents	Comments
135-136	Time sequence error flag	note (6)
137-138	Time sequence error code	note (7)
139-140	SOCC clock update indicator	note (8)
141-142	Earth location error indicator	note (9)
143-144	Earth location error code	note (10)
145-146	PACS status bit field	note (11)
147-148	PACS data source	1 is Fairbanks, 2 is Wallops
149-176	Not used	
177-184	8-character code for reference ellipsoid model ID	EBCDIC
185-186	Nadir earth location tolerance	units are tenths of km
187-188	Earth location bit field	note (12)
189-190	Not used	
191-192	Spacecraft roll attitude error	units are .001 degrees
193-194	Spacecraft pitch attitude error	units are .001 degrees
195-196	Space craft yaw attitude error	units are .001 degrees
197-198	Epoch year for satellite orbit vector	4-digit year
199-200	Epoch day of year for satellite orbit vector	3-digit day, near byte 083-084
201-204	Epoch UT time in milliseconds for orbit vector	all 4 bytes used
205-208	Semi-major axis of orbit	note (13)
209-212	Orbit eccentricity	note (14)
213-216	Orbit inclination	note (15)
217-220	Argument of perigee	note (16)
221-224	Right ascension of the ascending node	note (16)
225-228	Mean anomaly	note (16)
229-232	Satellite location, x coordinate	note (17)
233-236	Satellite location, y coordinate	note (17)
237-240	Satellite location, z coordinate	note (17)
241-244	Satellite velocity vector, x component	note (18)
245-248	Satellite velocity vector, y component	note (18)
249-252	Satellite velocity vector, z component	note (18)
253-256	Earth/sun distance ratio	note (19)
257-512	Not used	

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 54 of 81

Notes for Table 16

The bit numbering convention used below is the least significant bit within a byte is bit 01 and the most significant bit is bit 08. In the case of multiple bytes, the bit count increments from bit 01 of the highest numbered byte to bit 08 of the lowest numbered byte.

- (1) Satellite ID is 2 for NOAA-15, 4 for NOAA-16 and 6 for NOAA-17
- (2) CPIDS refers to a comprehensive calibration data set and these bytes provides the year and day-of-year of the latest data set update.
- (3) These bytes contain the contents of status1 and status2 from TIP word 08 at the beginning time of this data set. The bit assignments are

bytes 113 and 114	not used
bit 8, MSB of byte 115	microprocessor system identifier
bit 7	TED IFC flag
bit 6	MEPED IFC Flag
bit 5	MSB of the TED electron pulse discriminator level setting
bit 4	LSB of the TED electron pulse discriminator level setting
bit 3	not used
bit 2	not used
bit 1, LSB of byte 115	not used
bit 8, MSB of byte 116	microprocessor A watchdog error
bit 7	microprocessor B watchdog error
bit 6	MSB of the TED proton pulse discriminator level setting
bit 5	LSB of the TED proton pulse discriminator level setting
bits 4-1	not used

See also the Notes for Table VI B-2
- (4) If the contents of status1 or status2 change during the course of this data set, bytes 119-120 contain the data record number of that change. Bytes 121-124 contain the contents of status1 and status2 after that change with the bit assignments in note (3). Normally a change in the contents of status1 or status2 is associated with an in-flight calibration.
- (5) Bytes 125-126 contain the number of 2-second SEM data records in this incremental file. Bytes 129-130 contain the number of TIP minor frames within this incremental file that did not have sync errors. If there were no sync errors records, the integer number in bytes 129-130 should be exactly 20 times the integer number in bytes 125-126 because there are 20 TIP minor frames in each 2-second data record. If sync errors are present, the value of bytes 129-130 will be less than 20 times the integer value of bytes 125-126.
- (6) 0 = no time error; otherwise the record number of the first occurrence of an error

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 55 of 81

- (7) If there is a time error, the following provides details of that error.
if a bit is set to 1, then the statement is true.
- | | |
|------------------------|---|
| byte 137 | not used |
| bit 8, MSB of byte 138 | time field is bad but can probably be inferred from the previous good time. |
| bit 7 | time field is bad and can't be inferred from the previous good time. |
| bit 6 | this record starts a sequence that is inconsistent with previous times (i.e., there is a time discontinuity). This may or may not be associated with a spacecraft clock update. |
| bit 5 | start of a sequence that apparently repeats scan times that have been previously accepted. |
| bit 4 to 1 | not used |
- (8) =0 if no clock update during this orbit; otherwise the record number of the first occurrence of a clock update. Typically there is a spacecraft clock update of a few milliseconds each day.
- (9) =0 if no error during this orbit; otherwise the record number of the first error in earth location.
- (10) If there is an earth location error, the following provides details of that error.
if a bit is set to 1, then the statement is true.
- | | |
|------------------------|---|
| byte 143 | not used |
| bit 8, MSB of byte 144 | not earth located because of bad time; earth location fields zero filled. |
| bit 7 | earth location questionable because of questionable time code (See time problem flags.) |
| bit 6 | earth location questionable—only marginal agreement with reasonableness check. |
| bit 5 | earth location questionable—fails reasonableness check |
| bits 4 to 1 | not used |
- (11) These bytes not used in SEM data processing. For the record,
- | | |
|------------------------|---|
| byte 145, | not used |
| bit 8 MSB of byte 146 | not used |
| bits 7-4 | not used |
| bit 3 | 0 if data stream is normal, 1 if data is pseudo noise |
| bit 2 | 0 if tape playback was in reverse, 1 if forward |
| bit 1, LSB of byte 146 | 0 if data stream is test, 1 if data stream is flight data |
- Normally, the value of byte 146 is decimal 3, bits 1 and 2 set to 1
- (12) This is not used in SEM processing
- (13) The integer number in bytes 205-208 is divided by decimal 100000. to obtain the semi-major axis in kilometers.
- (14) The integer number in bytes 209-212 is divided by 100000000. to obtain the orbit eccentricity. Note that a survey of header files shows the eccentricity (and the semi-major axis) varies a great deal day to day. The orbit eccentricity given in the 2-line

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 56 of 81

NORAD orbit elements obtained from

<http://celestrak.com/NORAD/elements/noaa.txt>

do not show nearly that variation and the NORAD eccentricities generally do not agree with those obtained from this header record. There is no explanation for this.

- (15) The orbit inclination in degrees is obtained from the integer number in bytes 213-216 by dividing by decimal 100000. The orbital inclination is used in SEM data processing.
- (16) The integer values of these parameters are divided by decimal 100000. to obtain the physical parameters in degrees.
- (17) The integer values of these 4-byte signed integers are divided by decimal 100000. to obtain the satellite location in kilometers at the epoch time given in bytes 197-204 in earth-centered inertial coordinates. That is, the Z axis directed north parallel to earth's axis of rotation, X axis directed toward the vernal equinox, and the Y axis completing the right handed Cartesian coordinate system.
- (18) The integer values of these 4-byte signed integers are divided by decimal 100000000. to obtain the satellite velocity vector in kilometers per second at the epoch time given in bytes 197-204. The coordinate system is earth-centered inertial.
- (19) The earth/sun distance ratio is obtained by dividing the integer value of bytes 253-256 by decimal 1000000. The definition of the earth/sun distance ratio is not known although the numerical value of this ratio is close to 1.0

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 57 of 81

Table 17

A sequence of data records follow the header record in an incremental file. Usually an incremental file contains about one orbit's data or about 6000 seconds. A single physical 512 byte data record in the file contains 2-seconds of data so that each incremental file contains about 3000 physical data records. Each 2-second data record contains 20 TIP minor frames of data, parsed so that the first minor frame is always mod 020. That is, the first TIP minor frame in each data record is either 000, 020, 040, 060, 080, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, or 300. The following is a byte by byte description of the contents of an incremental file data record.

Table 17: Description of Data Record

Byte	Contents	Comments
001-002	TIP major frame number 0 to 7	
003-004	TIP minor frame number at start of this 2-second data record	
005-006	4-digit year at start of this 2-second data record	
007-008	3 digit day of year at start of this 2-second data record	
009-010	Not used	
011-012	Satellite clock drift relative to UTC in milliseconds	nominally near zero
013-016	Time in milliseconds the day at start of this 2-second record	
017-018	Satellite travel direction indicator, north or south	note (1)
019-028	Not used	
029-032	Quality indicator flags	note (2)
033-036	Time quality and satellite location quality flags	note (3)
037-048	Not used	
049-052	Satellite orbital navigation/attitude status flags	note (4)
053-056	Time associated with TIP Euler angles	note (5)
057-058	Roll Euler angle	note (5)
059-060	Pitch Euler angle	note (5)
061-062	Yaw Euler angle	note (5)
063-064	Satellite altitude above reference geoid in tenths km	
065-068	Geodetic sub-satellite latitude	note (6)
069-072	Geodetic sub-satellite longitude	note (6)
073-080	Not used	
081-088	Missing data flags, 20 entries each for TIP word 20 and 21	note (7)
089	TIP word 20, start TIP minor frame plus 00	
090	TIP word 21, start TIP minor frame plus 00	
091	TIP word 20, start TIP minor frame plus 01	
092	TIP word 21, start TIP minor frame plus 01	
093	TIP word 20, start TIP minor frame plus 02	
094	TIP word 21, start TIP minor frame plus 02	
095	TIP word 20, start TIP minor frame plus 03	
096	TIP word 21, start TIP minor frame plus 03	

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 58 of 81

097	TIP word 20, start TIP minor frame plus 04	
098	TIP word 21, start TIP minor frame plus 04	
099	TIP word 20, start TIP minor frame plus 05	
100	TIP word 21, start TIP minor frame plus 05	
101	TIP word 20, start TIP minor frame plus 06	
102	TIP word 21, start TIP minor frame plus 06	
103	TIP word 20, start TIP minor frame plus 07	

Byte	Contents	Comments
104	TIP word 21, start TIP minor frame plus 07	
105	TIP word 20, start TIP minor frame plus 08	
106	TIP word 21, start TIP minor frame plus 08	
107	TIP word 20, start TIP minor frame plus 09	
108	TIP word 21, start TIP minor frame plus 09	
109	TIP word 20, start TIP minor frame plus 10	
110	TIP word 21, start TIP minor frame plus 10	
111	TIP word 20, start TIP minor frame plus 11	
112	TIP word 21, start TIP minor frame plus 11	
113	TIP word 20, start TIP minor frame plus 12	
114	TIP word 21, start TIP minor frame plus 12	
115	TIP word 20, start TIP minor frame plus 13	
116	TIP word 21, start TIP minor frame plus 13	
117	TIP word 20, start TIP minor frame plus 14	
118	TIP word 21, start TIP minor frame plus 14	
119	TIP word 20, start TIP minor frame plus 15	
120	TIP word 21, start TIP minor frame plus 15	
121	TIP word 20, start TIP minor frame plus 16	
122	TIP word 21, start TIP minor frame plus 16	
123	TIP word 20, start TIP minor frame plus 17	
124	TIP word 21, start TIP minor frame plus 17	
125	TIP word 20, start TIP minor frame plus 18	
126	TIP word 21, start TIP minor frame plus 18	
127	TIP word 20, start TIP minor frame plus 19	
128	TIP word 21, start TIP minor frame plus 19	
129-132	Not used	
133-134	TIP word 08 status1 and status2 availability flags	note (8)
135-136	TIP word 08 status1 and status2 contents	note (9)
137-140	Not used	
141-144	TIP word 09 and word 10 housekeeping availability flags	note (10)
145-166	TIP word 09 and word 10 housekeeping values	note (11)
167-512	Not used	

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 59 of 81

Notes for Table 17

This documentation is obtained from Table 8.3.1.8.3-1 of the NOAA KLM Users Guide available from URL <http://www2.ncdc.noaa.gov/docs/klm/index.htm>. As noted below, it appears some of this documentation is in error.

- (1) The direction of satellite travel is required for calculation of sensor look angles with respect to the geomagnetic field
- (2) These bytes key various timing and earth location problems according to the following bit assignments. If the bit is set to 1, the statement is true.

bit 8, MSB of byte 29	this 2-second frame is not valid
bit 7	time sequence error in this 2-second frame
bit 6	a data gap precedes this 2-second frame
bit 5	not used
bit 4	earth location data not available (bytes 65-72 set to zero)
bit 3	first good time following a s/c clock update
bit 2	SEM instrument status changed beginning this frame
bit 1, LSB of byte 29	not used
bytes 30-32	not used
- (3) These bytes provide details of the problems flagged in bytes 29-32. If the bit is set to 1 the statement is true.

byte 33	not used
bit 8, MSB of byte 34	time is bad but probably can be inferred from previous time
bit 7	time is bad and cannot be inferred from previous time
bit 6	there is a time discontinuity, including a clock update
bit 5	this time starts a sequence that duplicates previous times
bits 4-1	not used
byte 35	not used
bit 8, MSB of byte 36	no earth location because of bad time. (bytes 65-72 set to zero)
bit 7	earth location questionable because of questionable time
bit 6	earth location questionable – marginal agreement with ‘reasonableness check’
bit 5	earth location questionable – fails ‘reasonableness check’
bits 04-01	not used.
- (4) These bytes key satellite location and attitude problems. Detailed documentation of the contents of these bytes is given in the NOAA KLM Users Guide. However, a survey of

the data in the incremental files shows that bytes 49-52 are always zero and it seems that

satellite attitude quality flags are not introduced in the SEM-2 incremental data file
- (5) These bytes contain information about the actual satellite attitude. Detailed

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 60 of 81

documentation of the contents of these bytes is given in the NOAA KLM Users Guide. However, a survey of data in the incremental files shows that bytes 53-62 are always zero and it seems that satellite attitude status data are not introduced in the SEM-2 incremental data file

- (6) The signed integer values bytes 65-68 and 69-72 are divided by decimal 10000. to obtain the sub-satellite latitude and longitude respectively. Latitudes are negative in the southern hemisphere and the longitude is negative in the western hemisphere.

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 61 of 81

- (7) The incremental data file flags those instances when data from TIP words 20 and 21 could not be recovered because of bit sync loss and the data padded with value 000. This information is important to the further processing of SEM-2 data. The bit assignments in bytes 81-88 are as follows

bits 8-1, byte 81 not used

bits 8-1, byte 82 not used

bits 8-2, byte 83 not used

bit 1 LSB of byte 83 if 1, TIP word 21, minor frame +19 is padded

bit 8, MSB of byte 84 if 1, TIP word 20, minor frame +19 is padded

bit 7 if 1, TIP word 21, minor frame +18 is padded

bit 6 if 1, TIP word 20, minor frame +18 is padded

bit 5 if 1, TIP word 21, minor frame +17 is padded

bit 4 if 1, TIP word 20, minor frame +17 is padded

bit 3 if 1, TIP word 21, minor frame +16 is padded

bit 2 if 1, TIP word 20, minor frame +16 is padded

bit 1, LSB of byte 84 if 1, TIP word 21, minor frame +15 is padded

bit 8, MSB of byte 85 if 1, TIP word 20, minor frame +15 is padded

bit 7 if 1, TIP word 21, minor frame +14 is padded

bit 6 if 1, TIP word 20, minor frame +14 is padded

bit 5 if 1, TIP word 21, minor frame +13 is padded

bit 4 if 1, TIP word 20, minor frame +13 is padded

bit 3 if 1, TIP word 21, minor frame +12 is padded

bit 2 if 1, TIP word 20, minor frame +12 is padded

bit 1, LSB of byte 85 if 1, TIP word 21, minor frame +11 is padded

bit 8, MSB of byte 86 if 1, TIP word 20, minor frame +11 is padded

bit 7 if 1, TIP word 21, minor frame +10 is padded

bit 6 if 1, TIP word 20, minor frame +10 is padded

bit 5 if 1, TIP word 21, minor frame +09 is padded

bit 4 if 1, TIP word 20, minor frame +09 is padded

bit 3 if 1, TIP word 21, minor frame +08 is padded

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 62 of 81

bit 2 if 1, TIP word 20, minor frame +08 is padded
bit 1, LSB of byte 86 if 1, TIP word 21, minor frame +07 is padded
bit 8, MSB of byte 87 if 1, TIP word 20, minor frame +07 is padded
bit 7 if 1, TIP word 21, minor frame +06 is padded
bit 6 if 1, TIP word 20, minor frame +06 is padded
bit 5 if 1, TIP word 21, minor frame +05 is padded
bit 4 if 1, TIP word 20, minor frame +05 is padded
bit 3 if 1, TIP word 21, minor frame +04 is padded
bit 2 if 1, TIP word 20, minor frame +04 is padded
bit 1, LSB of byte 87 if 1, TIP word 21, minor frame +03 is padded
bit 8, MSB of byte 88 if 1, TIP word 20, minor frame +03 is padded
bit 7 if 1, TIP word 21, minor frame +02 is padded
bit 6 if 1, TIP word 20, minor frame +02 is padded
bit 5 if 1, TIP word 21, minor frame +01 is padded
bit 4 if 1, TIP word 20, minor frame +01 is padded
bit 3 if 1, TIP word 21, minor frame +00 is padded
bit 2 if 1, TIP word 20, minor frame +00 is padded
bit 1, LSB of byte 88 not used

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 63 of 81

- (8) Bytes 133 to 134 key whether updated instrument status data from TIP word 08 is in this minor frame. The bit assignments are as follows
- | | |
|------------------------|--|
| bit 8, MSB of byte 133 | if 0, update of microprocessor system ID occurred |
| bit 7 | if 0, update of TED IFC status occurred |
| bit 6 | if 0, update of MEPED IFC status occurred |
| bit 5 | if 0, update of TED electron PHD level occurred, MSB |
| bit 4 | if 0, update of TED electron PHD level occurred, LSB |
| bits 3-1 | not used |
| bit 8, MSB of byte 134 | if 0, update of microprocessor A watchdog occurred |
| bit 7 | if 0, update of microprocessor B watchdog occurred |
| bit 6 | if 0, update of TED proton PHD level occurred, MSB |
| bit 5 | if 0, update of TED proton PHD level occurred, LSB |
| bits 4-1 | not used |
- (9) Bytes 135-136 contain the actual instrument status bits according to the following assignments
- | | |
|------------------------|---|
| bit 8, MSB of byte 135 | microprocessor system ID, 0 for processor A |
| bit 7 | TED IFC, 0=off, 1=on |
| bit 6 | MEPED IFC, 0=off, 1=on |
| bit 5 | TED electron PHD level, MSB |
| bit 4 | TED electron PHD level, LSB |
| bits 3-1 | not used |
| bit 8, MSB of byte 136 | microprocessor A watchdog, 0=normal |
| bit 7 | microprocessor B watchdog, 0=normal |
| bit 6 | TED proton PHD level, MSB |
| bit 5 | TED proton PHD level, LSB |
| bits 4-1 | not used |
- (10) Bytes 141-144 key whether updated instrument analog housekeeping data from TIP words 09 and 10 are in this minor frame. The bit assignments are as follows
- | | |
|----------|----------|
| byte 141 | not used |
|----------|----------|

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 64 of 81

bit 8, MSB of byte 142	not used
bit 7	if 0, update of primary bus voltage monitor
bit 6 control)	if 0, update of backup pitch coil driver monitor (attitude
bit 5 control)	if 0, update of primary pitch coil driver monitor (attitude
bit 4	if 0, update of backup roll/yaw coil driver
bit 3	if 0, update of primary roll/yaw coil driver
bit 2	if 0, update of Z axis gyro torque current monitor
bit 1, LSB of byte 142	if 0, update of Y axis gyro torque current monitor
bit 8, MSB of byte 143	if 0, update of X axis gyro torque current monitor
bit 7	if 0, update of S gyro torque current monitor
bit 6	if 0, update of DPU temperature monitor
bit 5	if 0, update of TED temperature monitor
bit 4	if 0, update MEPED proton telescope temperature monitor
bit 3	if 0, update of MEPED circuit temperature monitor
bit 2	if 0, update of Omni detector bias voltage monitor
bit=1, LSB of byte 143 monitor	if 0, update of TED proton CEM high voltage

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 65 of 81

- | | |
|------------------------|---|
| bit 8, MSB of byte 144 | if 0, update of TED electron CEM high voltage monitor |
| bit 7 | if 0, update of TED sweep voltage monitor |
| bit 6 | if 0, update of TED +5V monitor |
| bit 5 | if 0, update of MEPED +5V monitor |
| bit 4 | if 0, update of DPU +5V monitor |
| bit 3 | if 0, update of microprocessor B +5V monitor |
| bit 2 | if 0, update of microprocessor A +5V monitor |
| bit 1, LSB of byte 144 | not used |
- (11) Actual values of TIP analog housekeeping words 09 and 10 refreshed only when the corresponding bit in bytes 142-144 is set to 0.
- | | |
|----------|---|
| byte 145 | microprocessor A +5V monitor |
| byte 146 | microprocessor B +5V monitor |
| byte 147 | DPU +5V monitor |
| byte 148 | MEPED +5V monitor |
| byte 149 | TED +5V monitor |
| byte 150 | TED sweep voltage monitor |
| byte 151 | TED electron CEM high voltage monitor |
| byte 152 | TED proton CEM high voltage monitor |
| byte 153 | MEPED Omni detector bias voltage monitor |
| byte 154 | MEPED electronics circuit temperature monitor |
| byte 155 | MEPED proton telescope temperature monitor |
| byte 156 | TED temperature monitor |
| byte 157 | DPU temperature monitor |
| byte 158 | S gyro torque current monitor |
| byte 159 | X gyro torque current monitor |
| byte 160 | Y gyro torque current monitor |
| byte 161 | Z gyro torque current monitor |

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 66 of 81

byte 162	Primary roll/yaw coil driver current monitor
byte 163	Backup roll/yaw coil driver current monitor
byte 164	Primary pitch coil driver current monitor
byte 165	Backup pitch coil driver current monitor
byte 166	Primary bus voltage monitor

An extensive survey of SEM incremental data files was done to verify this documentation. Of the bytes between 29 and 62 inclusive, that include navigation error flags and information about the Euler angles, only bytes 29, 34, and 36 ever show values other than 000. The conclusion is that, the documentation notwithstanding, navigation/attitude status flags (bytes 49-52) and Euler angle information (bytes 53-62) are not provided.

Moreover, certain bits in bytes 29, 34, and 36, that are defined as providing status, never seem to be used. Specifically: bit 3 in byte 29 (first good time following a s/c clock update) is never set to 1; bit 8 in byte 34 (time is bad but probably can be inferred from previous time) nor bit 5 in byte 34 (this time starts a sequence that duplicates previous times) are never set to 1; bit 6 in byte 36 (earth location questionable – marginal agreement with ‘reasonableness check’) nor bit 5 in byte 36 (earth location questionable – fails ‘reasonableness check’) are never set to 1.

The study did confirm that bit 2 in byte 29 (SEM instrument status changed beginning this frame) is a reliable indicator of when the TED or MEPED are undergoing IFC. The combination of bit 8 in byte 29 (this 2-second frame is not valid) set to 1, bit 7 in byte 29 (time sequence error in this 2-second frame) set to 1, bit 4 in byte 29 (earth location data not available) set to 1, AND bit 8 in byte 36 (no earth location because of bad time) set to 1 proves to be a reliable indicator of zero fill in the earth location field (bytes 65 to 72.)

Information about when the magnetic torque coils were energized, a procedure required to maintain S/C attitude control, was introduced into the SEM data record. This was done because of concern that when the coils were energized the measurement of low energy particles by the TED would be compromised. The analysis to determine whether or not the TED observations are influenced by the torque coils has not been done. However, it was verified that data in bytes 162 to 165 do reflect those times when the

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 67 of 81

roll/yaw and pitch coils are energized and so that analysis of any impact on TED can be done.

Table 18: SEM-2 data allocations in TIP words 20 and 21 for a single TIP 32 second major frame. Refer to notes for those entries in bold (data channels whose content depends upon the DPU major frame count) or italic.

TIP minor frame count	TIP word 20 contents	TIP word 21 contents	TIP minor frame count	TIP word 20 contents	TIP word 21 contents
000	CHECK SUM	0 P1	040	TED E CEM HV	0 P1
001	0 P2	0 P3	041	0 P2	0 P3
002	0 P4	0 P5	042	0 P4	0 P5
003	0 P6	0 E1	043	0 P6	0 E1
004	0 E2	0 E3	044	0 E2	0 E3
005	90 P1	90 P2	045	90 P1	90 P2
006	90 P3	90 P4	046	90 P3	90 P4
007	90 P5	90 P6	047	90 P5	90 P6
008	90 E1	90 E2	048	90 E1	90 E2
009	90 E3	P6	049	90 E3	P6
010	P7	P8	050	P7	P8
011	0 DE1	0 DE2	051	0 DP1	0 DP2
012	0 DE3	0 DE4	052	0 DP3	0 DP4
013	0 EF-L	30 EF-L	053	0 EF-L	30 EF-L
014	0 PF-L	30 PF-L	054	0 PF-L	30 PF-L
015	0 EF-H	30 EF-H	055	0 EF-H	30 EF-H
016	0 PF-H	30 PF-H	056	0 PF-H	30 PF-H
017	0 EM/ 0 PM	0 DEM	057	0 EM/ 0 PM	0 DEM
018	0 DPM	30 EM/ 30 PM	058	0 DPM	30 EM/ 30 PM
019	30 DEM	30 DPM	059	30 DEM	30 DPM
020	TED Swp V Mon	0 P1	060	TED P CEM HV	0 P1
021	0 P2	0 P3	061	0 P2	0 P3
022	0 P4	0 P5	062	0 P4	0 P5
023	0 P6	0 E1	063	0 P6	0 E1
024	0 E2	0 E3	064	0 E2	0 E3
025	90 P1	90 P2	065	90 P1	90 P2
026	90 P3	90 P4	066	90 P3	90 P4
027	90 P5	90 P6	067	90 P5	90 P6
028	90 E1	90 E2	068	90 E1	90 E2
029	90 E3	P6	069	90 E3	P6
030	P7	P9	070	P7	P9
031	30 DE1	30 DE2	071	30 DP1	30 DP2
032	30 DE3	30 DE4	072	30 DP3	30 DP4
033	0 EF-L	30 EF-L	073	0 EF-L	30 EF-L

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 68 of 81

034	0 PF-L	30 PF-L
035	0 EF-H	30 EF-H
036	0 PF-H	30 PF-H
037	0 EM/ 0 PM	0 DEM
038	0 DPM	30 EM/ 30 PM
039	30 DEM	30 DPM

074	0 PF-L	30 PF-L
075	0 EF-H	30 EF-H
076	0 PF-H	30 PF-H
077	0 EM/ 0 PM	0 DEM
078	0 DPM	30 EM/ 30 PM
079	30 DEM	30 DPM

TIP minor frame count	TIP word 20 contents	TIP word 21 contents
080	MEP OMNI BV	0 P1
081	0 P2	0 P3
082	0 P4	0 P5
083	0 P6	0 E1
084	0 E2	0 E3
085	90 P1	90 P2
086	90 P3	90 P4
087	90 P5	90 P6
088	90 E1	90 E2
089	90 E3	P6
090	P7	P8
091	0 DE1	0 DE2
092	0 DE3	0 DE4
093	0 EF-L	30 EF-L
094	0 PF-L	30 PF-L
095	0 EF-H	30 EF-H
096	0 PF-H	30 PF-H
097	0 EM/ 0 PM	0 DEM
098	0 DPM	30 EM/ 30 PM
099	30 DEM	30 DPM
100	Analog S/C 1	0 P1
101	0 P2	0 P3
102	0 P4	0 P5
103	0 P6	0 E1
104	0 E2	0 E3
105	90 P1	90 P2
106	90 P3	90 P4
107	90 P5	90 P6
108	90 E1	90 E2
109	90 E3	P6
110	P7	P9
111	30 DE1	30 DE2

TIP minor frame count	TIP word 20 contents	TIP word 21 contents
120	Analog S/C 2	0 P1
121	0 P2	0 P3
122	0 P4	0 P5
123	0 P6	0 E1
124	0 E2	0 E3
125	90 P1	90 P2
126	90 P3	90 P4
127	90 P5	90 P6
128	90 E1	90 E2
129	90 E3	P6
130	P7	P8
131	0 DP1	0 DP2
132	0 DP3	0 DP4
133	0 EF-L	30 EF-L
134	0 PF-L	30 PF-L
135	0 EF-H	30 EF-H
136	0 PF-H	30 PF-H
137	0 EM/ 0 PM	0 DEM
138	0 DPM	30 EM/ 30 PM
139	30 DEM	30 DPM
140	Analog S/C 3	0 P1
141	0 P2	0 P3
142	0 P4	0 P5
143	0 P6	0 E1
144	0 E2	0 E3
145	90 P1	90 P2
146	90 P3	90 P4
147	90 P5	90 P6
148	90 E1	90 E2
149	90 E3	P6
150	P7	P9
151	30 DP1	30 DP2

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 69 of 81

112	30 DE3	30 DE4	152	30 DP3	30 DP4
113	0 EF-L	30 EF-L	153	0 EF-L	30 EF-L
114	0 PF-L	30 PF-L	154	0 PF-L	30 PF-L
115	0 EF-H	30 EF-H	155	0 EF-H	30 EF-H
116	0 PF-H	30 PF-H	156	0 PF-H	30 PF-H
117	0 EM/ 0 PM	0 DEM	157	0 EM/ 0 PM	0 DEM
118	0 DPM	30 EM/ 30 PM	158	0 DPM	30 EM/ 30 PM
119	30 DEM	30 DPM	159	30 DEM	30 DPM

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 70 of 81

TIP minor frame count	TIP word 20 contents	TIP word 21 contents
160	Analog S/C 4	0 P1
161	0 P2	0 P3
162	0 P4	0 P5
163	0 P6	0 E1
164	0 E2	0 E3
165	90 P1	90 P2
166	90 P3	90 P4
167	90 P5	90 P6
168	90 E1	90 E2
169	90 E3	P6
170	P7	P8
171	0 DE1	0 DE2
172	0 DE3	0 DE4
173	0 EF-L	30 EF-L
174	0 PF-L	30 PF-L
175	0 EF-H	30 EF-H
176	0 PF-H	30 PF-H
177	0 EM/ 0 PM	0 DEM
178	0 DPM	30 EM/ 30 PM
179	30 DEM	30 DPM
180	TED IFC V	0 P1
181	0 P2	0 P3
182	0 P4	0 P5
183	0 P6	0 E1
184	0 E2	0 E3
185	90 P1	90 P2
186	90 P3	90 P4
187	90 P5	90 P6
188	90 E1	90 E2
189	90 E3	P6
190	P7	P9
191	30 DE1	30 DE2
192	30 DE3	30 DE4
193	0 EF-L	30 EF-L
194	0 PF-L	30 PF-L
195	0 EF-H	30 EF-H
196	0 PF-H	30 PF-H

TIP minor frame count	TIP word 20 contents	TIP word 21 contents
200	MEP IFC V	0 P1
201	0 P2	0 P3
202	0 P4	0 P5
203	0 P6	0 E1
204	0 E2	0 E3
205	90 P1	90 P2
206	90 P3	90 P4
207	90 P5	90 P6
208	90 E1	90 E2
209	90 E3	P6
210	P7	P8
211	0 DP1	0 DP2
212	0 DP3	0 DP4
213	0 EF-L	30 EF-L
214	0 PF-L	30 PF-L
215	0 EF-H	30 EF-H
216	0 PF-H	30 PF-H
217	0 EM/ 0 PM	0 DEM
218	0 DPM	30 EM/ 30 PM
219	30 DEM	30 DPM
220	<i>Digital Status 1</i>	0 P1
221	0 P2	0 P3
222	0 P4	0 P5
223	0 P6	0 E1
224	0 E2	0 E3
225	90 P1	90 P2
226	90 P3	90 P4
227	90 P5	90 P6
228	90 E1	90 E2
229	90 E3	P6
230	P7	P9
231	30 DP1	30 DP2
232	30 DP3	30 DP4
233	0 EF-L	30 EF-L
234	0 PF-L	30 PF-L
235	0 EF-H	30 EF-H
236	0 PF-H	30 PF-H

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 71 of 81

197	0 EM/ 0 PM	0 DEM
198	0 DPM	30 EM/ 30 PM
199	30 DEM	30 DPM

237	0 EM/ 0 PM	0 DEM
238	0 DPM	30 EM/ 30 PM
239	30 DEM	30 DPM

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 72 of 81

TIP minor frame count	TIP word 20 contents	TIP word 21 contents	TIP minor frame count	TIP word 20 contents	TIP word 21 contents
240	<i>Digital Status 2</i>	0 P1	280	0 E-H BKG	0 P1
241	0 P2	0 P3	281	0 P2	0 P3
242	0 P4	0 P5	282	0 P4	0 P5
243	0 P6	0 E1	283	0 P6	0 E1
244	0 E2	0 E3	284	0 E2	0 E3
245	90 P1	90 P2	285	90 P1	90 P2
246	90 P3	90 P4	286	90 P3	90 P4
247	90 P5	90 P6	287	90 P5	90 P6
248	90 E1	90 E2	288	90 E1	90 E2
249	90 E3	P6	289	90 E3	P6
250	P7	P8	290	P7	P8
251	0 DE1	0 DE2	291	0 E-L BKG	30 E-L BKG
252	0 DE3	0 DE4	292	0 P-L BKG	0 P-H BKG
253	0 EF-L	30 EF-L	293	0 EF-L	30 EF-L
254	0 PF-L	30 PF-L	294	0 PF-L	30 PF-L
255	0 EF-H	30 EF-H	295	0 EF-H	30 EF-H
256	0 PF-H	30 PF-H	296	0 PF-H	30 PF-H
257	0 EM/ 0 PM	0 DEM	297	0 EM/ 0 PM	0 DEM
258	0 DPM	30 EM/ 30 PM	298	0 DPM	30 EM/ 30 PM
259	30 DEM	30 DPM	299	30 DEM	30 DPM
260	System Status	0 P1	300	30 E-H BKG	0 P1
261	0 P2	0 P3	301	0 P2	0 P3
262	0 P4	0 P5	302	0 P4	0 P5
263	0 P6	0 E1	303	0 P6	0 E1
264	0 E2	0 E3	304	0 E2	0 E3
265	90 P1	90 P2	305	90 P1	90 P2
266	90 P3	90 P4	306	90 P3	90 P4
267	90 P5	90 P6	307	90 P5	90 P6
268	90 E1	90 E2	308	90 E1	90 E2
269	90 E3	P6	309	90 E3	P6
270	P7	P9	310	P7	P9
271	30 DE1	30 DE2	311	SYNC F3	30 P-L BKG
272	30 DE3	30 DE4	312	SYNC 50	30 P-H BKG
273	0 EF-L	30 EF-L	313	0 EF-L	30 EF-L
274	0 PF-L	30 PF-L	314	0 PF-L	30 PF-L
275	0 EF-H	30 EF-H	315	0 EF-H	30 EF-H
276	0 PF-H	30 PF-H	316	0 PF-H	30 PF-H
277	0 EM/ 0 PM	0 DEM	317	0 EM/ 0 PM	0 DEM
278	0 DPM	30 EM/ 30 PM	318	0 DPM	30 EM/ 30 PM

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 73 of 81

279	30 DEM	30 DPM	319	30 DEM	30 DPM
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TED Data Processing Algorithm Theoretical Basis Document

Notes for Table VI B-1

Digital status 1, TIP word 20, minor frame 220, is an 8-bit word with the following bit assignments

Bit 8, MSB	the microprocessor system identifier, 0 identifies processor A, 1 identifies processor B
Bit 7	not used
Bit 6	not used
Bit 5	microprocessor error flag, 0 indicates no error, 1 indicates an error
Bit 4	MSB of the 4-bit DPU major frame counter
Bit 3	second MSB of the 4-bit DPU major frame counter
Bit 2	third MSB of the 4-bit DPU major frame counter
Bit 1, LSB	LSB of the 4-bit DPU major frame counter

The DPU major frame counter cycles from 00 to 15 and determines the content of the TED Swp V Mon, System Status, Analog S/C 1, Analog S/C 2, and Analog S/C 3 data channels.

Digital status 2, TIP word 20, minor frame 240, is an 8-bit word with the following bit assignments

Bit 8, MSB	MEPED IFC phase, 0 is phase 0, 1 is phase 1
Bit 7	MEPED IFC flag, 1 is MEPED IFC in progress, 0 is MEPED IFC off
Bit 6	TED IFC pulser status, 1 is pulser on, 0 is pulser off
Bit 5	TED IFC flag, 1 is TED IFC on, 0 is TED IFC off
Bit 4	MSB of the TED proton pulse discriminator level setting (1 of 4 levels)
Bit 3	LSB of the TED proton pulse discriminator level setting (1 of 4 levels)
Bit 2	MSB of the TED electron pulse discriminator level setting (1 of 4 levels)
Bit 1, LSB	LSB of the TED electron pulse discriminator level setting (1 of 4 levels)

System Status, TIP word 20, minor frame 260 is an 8-bit word with the following assignments that depend upon the DPU major frame value that cycles from 00 to 15

DPU major frames 00 and 08, TED CEM high voltage setting

Bit 8, MSB	not used
Bit 7	not used
Bit 6	MSB of TED proton CEM voltage setting (1 of 8 levels)
Bit 5	second MSB of TED proton CEM voltage setting (1 of 8 levels)
Bit 4	LSB of TED proton CEM voltage setting (1 of 8 levels)
Bit 3	MSB of TED electron CEM voltage setting (1 of 8 levels)
Bit 2	second MSB of TED electron CEM voltage setting (1 of 8 levels)
Bit 1, LSB	LSB of TED electron CEM voltage setting (1 of 8 levels)

DPU major frames 01 and 09 are the active microprocessor watchdog counter

DPU major frames 02 and 10 are the specifics of the last level command sent

DPU major frame 03 is the system test status 1 with the following bit assignments

Bit 8, MSB	active microprocessor watchdog error, 0 is no error, 1 is an error
Bit 7	active microprocessor read/write error, 0 is no error, 1 is an error
Bit 6	command processing error, 0 is no error, 1 is an error

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 75 of 81

Bit 5	power up error, 0 is no error, 1 is an error
Bit 4	TED serial link parity error, 0 is no error, 1 is an error
Bit 3	data accumulation interval error, 0 is no error, 1 is an error
Bit 2	digital A data control error, 0 is no error, 1 is an error
Bit 1, LSB	major frame sync error, 0 is no error, 1 is an error

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 76 of 81

DPU major frame 04 is byte 1 of the TED data processing scale factor

DPU major frame 05 is byte 2 of the TED data processing scale factor

DPU major frame 06 is byte 3 of the TED data processing scale factor

DPU major frame 07 is byte 4 of the TED data processing scale factor

DPU major frame 11 is the system test status 2 with the following bit assignments

Bit 8, MSB not used

Bit 7 not used

Bit 6 not used

Bit 5 not used

Bit 4 not used

Bit 3 compression counter overflow flag, 0 is no error, 1 is an error

Bit 2 accumulation time interval error, 0 is no error, 1 is an error

Bit 1, LSB TED scale plug decode error, 0 is no error, 1 is an error

DPU major frame 12 is the microprocessor ROM 1 checksum

DPU major frame 13 is the microprocessor ROM 2 checksum

DPU major frame 14 is the 50% of full scale calibration of the DPU analog to digital converter using a low impedance source

DPU major frame 15 is the 50% of full scale calibration of the DPU analog to digital converter using a high impedance source

TED Sweep Voltage Monitor, TIP word 20, minor frame 20 is an analog monitor of the TED electrostatic analyzer sweep voltage at 8 points during the sweep. The exact point in the sweep is determined by the DPU major frame value that cycles from 00 to 15 and has the following assignments.

DPU major frames 00 and 08, monitor of step 000 of 255 steps in the sweep.

DPU major frames 01 and 09, monitor of step 032 of 255 steps in the sweep.

DPU major frames 02 and 10, monitor of step 064 of 255 steps in the sweep.

DPU major frames 03 and 11, monitor of step 096 of 255 steps in the sweep.

DPU major frames 04 and 12, monitor of step 128 of 255 steps in the sweep.

DPU major frames 05 and 13, monitor of step 160 of 255 steps in the sweep.

DPU major frames 06 and 14, monitor of step 192 of 255 steps in the sweep.

DPU major frames 07 and 15, monitor of step 224 of 255 steps in the sweep.

Analog Sub-Commutator 1, TIP word 20, minor frame 100 monitors housekeeping data channels from 8 sources depending on the DPU major frame value according to the following assignments.

DPU major frames 00 and 08, microprocessor A +5 Volt monitor

DPU major frames 01 and 09, microprocessor B +5 Volt monitor

DPU major frames 02 and 10, DPU +5 Volt monitor

DPU major frames 03 and 11, DPU +10 Volt monitor

DPU major frames 04 and 12, DPU +6 Volt monitor

DPU major frames 05 and 13, DPU -6 Volt monitor

DPU major frames 06 and 14, DPU temperature monitor

DPU major frames 07 and 15, DPU analog-digital converter reference voltage monitor

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 77 of 81

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 78 of 81

Analog Sub-Commutator 2, TIP word 20, minor frame 120 monitors housekeeping data channels from 8 sources depending on the DPU major frame value according to the following assignments.

- DPU major frames 00 and 08, MEPED +6.5 Volt monitor
- DPU major frames 01 and 09, MEPED +7.8 Volt monitor
- DPU major frames 02 and 10, MEPED -7.8 Volt monitor
- DPU major frames 03 and 11, MEPED +5 Volt monitor
- DPU major frames 04 and 12, MEPED +6.2 Volt monitor
- DPU major frames 05 and 13, MEPED -6.2 Volt monitor
- DPU major frames 06 and 14, MEPED proton telescope detector bias voltage monitor
- DPU major frames 07 and 15, MEPED electron telescope detector bias voltage monitor

Analog Sub-Commutator 3, TIP word 20, minor frame 140 monitors housekeeping data channels from 8 sources depending on the DPU major frame value according to the following assignments.

- DPU major frames 00 and 08, MEPED IFC reference voltage monitor
- DPU major frames 01 and 09, MEPED 0° telescope pulse threshold reference voltage monitor
- DPU major frames 02 and 10, MEPED 90° telescope pulse threshold reference voltage monitor
- DPU major frames 03 and 11, MEPED proton telescope temperature monitor
- DPU major frames 04 and 12, MEPED electron telescope temperature monitor
- DPU major frames 05 and 13, MEPED omni-detector temperature monitor
- DPU major frames 06 and 14, MEPED circuit board temperature monitor
- DPU major frames 07 and 15, TED temperature monitor

Analog Sub-Commutator 4, TIP word 20, minor frame 160 monitors housekeeping data channels from 8 sources depending on the DPU major frame value according to the following assignments.

- DPU major frames 00 and 08, TED +8 Volt monitor
- DPU major frames 01 and 09, TED +5 Volt monitor
- DPU major frames 02 and 10, TED -6 Volt monitor
- DPU major frames 03 and 11, TED +30 Volt monitor
- DPU major frames 04 and 12, TED -30 Volt monitor
- DPU major frames 05 and 13, TED +100 Volt monitor
- DPU major frames 06 and 14, TED -1000 Volt monitor
- DPU major frames 07 and 15, TED IFC reference voltage monitor

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0
Date: 3/27/2013

TED Data Processing Algorithm Theoretical Basis Document

Page 79 of 81

Table VI B-2

SEM-2 data allocations in TIP words 08, 09, and 10 for a single TIP 32 second major frame. These data channels are controlled by the TIP system and not the DPU. Refer to notes for the bit assignments for TIP word 08 data words. See Appendix VI A for the acronym list.

TIP minor frame count	TIP word 08 contents	TIP minor frame count	TIP word 09 contents	TIP minor frame count	TIP word 10 contents
026	Digital Status 1	119	DPU Temp	002	DPU +5 V
027	Digital Status 2	127	TED Temp	003	MEPED +5 V
058	Digital Status 1	135	Proton. tele.temp	004	micro A +5 V
059	Digital Status 2	143	MEPED cir. temp	096	TED +5 V
090	Digital Status 1	214	Omni bias voltage	097	TED Sweep V
091	Digital Status 2	222	TED p CEM HV	108	micro B +5 V
122	Digital Status 1	230	TED e CEM HV	162	DPU +5 V
123	Digital Status 2	279	DPU Temp	163	MEPED +5 V
154	Digital Status 1	287	TED Temp	164	micro A +5 V
155	Digital Status 2	295	Proton. tele. Temp	256	TED +5 V
186	Digital Status 1	303	MEPED cir. Temp	257	TED Sweep V
187	Digital Status 2			268	micro B +5 V
218	Digital Status 1				
219	Digital Status 2				
250	Digital Status 1				
251	Digital Status 2				
282	Digital Status 1				
283	Digital Status 2				
314	Digital Status 1				
315	Digital Status 2				

Notes for Table VI B-2

Digital status 1, TIP word 08, minor frames 26, 58, 90, 122, 154, 186, 218, 250, 282, and 314, is an 8-bit word with the following bit assignments

- Bit 8 MSB the microprocessor system identifier, 0 identifies processor A, 1 identifies processor B
- Bit 7 TED IFC flag, 1 is TED IFC on, 0 is TED IFC off
- Bit 6 MEPED IFC flag, 1 is TED IFC on, 0 is TED IFC off
- Bit 5 MSB of the TED electron pulse discriminator level setting (1 of 4 levels)
- Bit 4 LSB of the TED electron pulse discriminator level setting (1 of 4 levels)
- Bit 3 Not used

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 80 of 81

Bit 2	Not used
Bit 1 LSB	Not used

NOAA/NESDIS/NGDC

ALGORITHM THEORETICAL BASIS DOCUMENT

Version: 1.0

Date: 3/27/2013

TED Data Processing
Algorithm Theoretical Basis Document

Page 81 of 81

Digital status 2, TIP word 08, minor frames 27, 59, 91, 123, 155, 187, 219, 251, 283, and 315, is an 8-bit word with the following bit assignments

Bit 8 MSB	Microprocessor A watchdog error, 0 is no error, 1 is an error
Bit 7	Microprocessor B watchdog error, 0 is no error, 1 is an error
Bit 6	MSB of the TED proton pulse discriminator level setting (1 of 4 levels)
Bit 5	LSB of the TED proton pulse discriminator level setting (1 of 4 levels)
Bit 4	Not used
Bit 3	Not used
Bit 2	Not used
Bit 1 LSB	Not used