## Appendix G

The First SEM-2 was launched on the NOAA-15 satellite on May 13, 1998. The TED unit in this SEM-2 was Serial Number 011 and the MEPED unit was Serial Number 010. Archived data from NOAA-15 are available from July 19, 1998 until the present. Both the TED and MEPED instruments on NOAA-15 are operating well, and there have been no technical difficulties.

An error in the archive processing of data from NOAA-15 was detected in late 1999. This error occurred on rare occasions when the sub-satellite geographic latitude location, either in the northern or southern hemisphere, exceeded by a small amount the maximum latitude that would have been determined from the satellite orbital inclination for that day's ephemeris. Under these circumstances, which generally lasted no more than 32 seconds at the very highest latitudes during the NOAA-15 orbit, the archive program miscalculated the pitch angles of the particles detected by the 30º TED, and the 0º and the 90º MEPED instruments. The omnidirectional energy fluxes calculated from the TED data depend upon knowledge of the particle pitch angles and during these short periods of time they will be slightly in error.

The error was corrected for all archive processing beginning on Jan 1, 2000. Prior to the correction being implemented, this error arises whenever the absolute value of the sub-satellite geographic latitude exceeds the value of the supplement of the satellite inclination. For example, if the satellite inclination in the archive record were 98.715º, the pitch angle error would occur whenever the absolute value of the sub-satellite latitude exceeded 81.285º. In these cases the correct pitch angles can be determined to within less than 1º by averaging the correct pitch angles on either side of the incorrect ones.

The second SEM-2 was successfully launched on NOAA-16 on September 21, 2000. This SEM-2 contains TED Serial Number 010 and MEPED Serial Number 011. With one exception, all SEM-2 instruments are operating properly and returning good data.

The sole exception is episodes of anomalous high background rates recorded by the 0º and 30º, TED high-energy proton sensors. This high background appears to be associated with spacecraft charging that accelerates positive ions into the electrostatic analyzers of these two sensors. Because there is a very low residue voltage between the analyzer plates during the background accumulation periods, these low energy ions pass through the analyzer and are counted by the channeltron detector. The periods of anomalous high background from these two sensors occurs when the satellite is in sunlight, not in darkness, strengthening the hypothesis that spacecraft charging is playing a role.

Fortunately, data taken from these two sensor systems during the energy sweep do not exhibit any indication of spurious counts. Both the sensor responses within specific energy bands and the integrated sensor responses, that provide the measure of the directional energy fluxes carried by ions between 1000 and 20,000 eV, are unaffected. The method for correcting sensor responses for penetrating radiation has been modified for NOAA-16 and later satellites so that a background correction is not applied to high-energy auroral ion energy flux values during times of anomalous background.

The third SEM-2 was successfully launched on NOAA-17 on June 24, 2002 and the SEM put into operation on July 12. This SEM-2 contains TED Serial Number 012 and MEPED Serial Number 012.

The NOAA-17 TED experiences the same anomalous high background rates as does the TED on NOAA-16, and for the same reason. The modification for correcting sensor responses that was implemented for the NOAA-16 TED data was used also for processing NOAA-17 data.

Beginning on November 25, 2002 the processing of NOAA SEM data to create the archive output was upgraded to new software. The new software is designed to better handle housekeeping information from these instruments and to provide better data quality control. The structure of the archive data was not affected by this upgrade and the material in this document remains valid.

Further updates added to Appendix G in July, 2006.

Errors in equations 2.3.1 and 2.3.2 of the archive data documentation have been corrected. An error in the unpack2.c routine in Appendix D has also been corrected. The equation numbering in Appendix F has been corrected and made consecutive.

The recipes in Appendix F for converting MEPED omni-directional detector count rates to particle fluxes in physical units were developed assuming that the fields of view of each of those detectors was not shadowed or obscured by the spacecraft or other instruments on the spacecraft and were defined only by the absorbing material in that detector alone. There is evidence that particles entering an omni-directional detector from large angles to the zenith can be shadowed by the dense absorbing material in other omni-directional detectors that are mounted close by. The effect of that additional shielding may account for the P6 omni-directional count rates in the South Atlantic Anomaly typically being some less than the P7 count rates, in spite of being sensitive to protons over a larger energy range.

T. Cayton of the Los Alamos National Laboratory has modeled the response of the SEM-2 omni-directional detectors to energetic electrons. His results show that the P6 omni-directional detector will respond to electrons of energies above

3.0 MeV with an efficiency that for 3.5 MeV electrons is about 10% of the sensitivity to >16 MeV protons. The P7 detector model results show a response to electrons of energies greater than about 6 MeV with a somewhat lower efficiency than the case for the P6 detector. The SEM-2 P8 and P9 detectors show negligible response to relativistic electrons. While significant, the SEM-2 omni-directional detectors have considerably less sensitivity to relativistic energy electrons than the earlier SEM-1 omni-directional detectors because of the very much larger energy loss in the solid-state detector that is required to register an event in the SEM-2 instruments.

The MEPED proton telescope instrument, described in Section 3.1 of the archive data documentation, is also sensitive to energetic electrons above about 800 keV because the magnetic field strength in the broom magnet becomes ineffective at preventing such energetic electrons from reaching the solid-state detector. Recent laboratory measurements indicate that the proton telescope efficiency for counting electrons of 1 MeV is about 30% of the proton counting efficiency. This is equivalent to a geometric factor for electrons >1 MeV of about .003 $cm^2$ ster.

An MeV energy electron gaining access to the solid-state detectors in the proton telescopes is capable of depositing 30 keV energy in the front detector, passing completely through the front detector and depositing 50 keV energy in the back detector. However, an electron, not matter what its energy, is not capable of depositing 2.5 MeV in the front detector. The signal handling logic shown in Table 3.2.1 of the archive data documentation shows that an MeV electron can produce an event registered in the telescope P6 channel, thus mimicking an event caused by a proton of energy >6.9 MeV. However, no energetic electron can produce an event registered in the telescope P5 channel and has a relatively low probably of registering an event in the telescope P4 channel. A situation where the MEPED proton telescope data displays elevated responses in both the lower energy P1 and P2 channels and the highest energy P6 channel but little or no response in the P5 channel is a very good indication that relativistic electrons are responsible. The alternative interpretation that protons are responsible for that telescope's response would require an physical proton energy spectrum with significant proton fluxes below 800 keV and above 6.9 MeV but no protons with energies between about 2.5 and 6.9 MeV.

This feature in the proton telescope data, together with significant response in the >300 keV electron telescopes can serve as a reliable indication that relativistic electrons may contribute significantly to the responses in the omni-directional P6 and P7 detectors.

As pointed out earlier, the TED ion analyzers can display anomalous background responses when the spacecraft changes several Volts negative. Under conditions of very intense electron fluxes in the auroral zone the spacecraft can become charged to potentials as high as –1000 V for short periods of time. In those instances thermal energy ions local to the spacecraft will be accelerated into the TED ion analyzers with energies equivalent to the spacecraft potential. The background responses in the TED analyzers remain low during these episodes but the measurement of integrated directional energy fluxes by the TED ion analyzers will be very much increased and will no longer represent a valid measurement of the down-going auroral ion fluxes. It is very rare that the spacecraft charges to the extent that the TED 1000-20000 eV ion analyzers respond to ions that have been accelerated into the instrument and invalid integrated energy flux measurements are confined to the 50-1000 eV ion analyzers.

The archive processing does not identify or flag instances of spacecraft charging from intense auroral electron fluxes that produce erroneous integrated energy flux observations by the two 50-1000 eV TED ion analyzers.

However, those instances can reliably be identified from the data from knowledge of the ion energy band containing the “maximum” energy flux (found in the sixth element of arrays ted0 and ted30) and through a comparison between the measure of the integrated 50-1000 eV ion energy flux (in the second element of arrays *ted0* and *ted30*) the corresponding TED ion sensor response in the “maximum” energy band (contained in the eighth element of arrays *ted0* and *ted30*.) With very rare exceptions, during the auroral charging episodes the energy band containing the “maximum” ion energy flux is in the 50-1000 eV range – energy band number 1 through 8. The “maximum” energy band response should then be multiplied by the product of the *particle energy weight* and *detection efficiency weight* factors found in the Appendix C TED Weighting Factors table for that TED serial number.

The result of this process is the contribution to the integrated ion energy flux value from the TED ion sensor response registered in the “maximum” energy band. If that contribution represents the majority, or all, of the integrated ion energy flux, it indicates that the bulk of the ion flux detected during an energy sweep was concentrated within a narrow energy band, a reliable indication of the spacecraft being charged to a negative potential.

It is recommended that whenever the ion energy flux values appear unusually large, that the above test be applied to the TED ion data to identify whether spacecraft charging has occurred that would invalidate the measurement.

The NOAA-18 satellite was launched in June, 2005 and included at SEM-2. The TED and MEPED serial numbers in the NOAA-18 SEM-2 were both 0013. As was the case in earlier SEM-2 instruments, the TED ion analyzers often exhibited a very high background, thought to be associated with spacecraft charging to a few Volts negative as described above. The NOAA-18 TED also shows indications of spacecraft charging to much larger negative potentials by intense auroral electron fluxes, also described above.

Originally the NOAA-18 TED data was mistakenly processed using sensitivity factors appropriate to the NOAA-17 TED instrument. Those data were reprocessed using what was thought to be the correct sensitivity factors for TED serial number 0013. However, in June 2006, it was further learned that the calibration package used for that reprocessing contained only preliminary information and the definitive calibration information not received until late June 2006. A second reprocessing of data from the NOAA-18 SEM will be required. However, that reprocessing will impact only the data from the TED instrument, not the MEPED. The original NOAA-18 archive data files may be used if only the MEPED data is needed.

A SEM-2 instrument is scheduled to be launched in July, 2006 on board the European METOP-1 satellite. The TED instrument in the METOP SEM-2 package is Serial Number 0014 (SEE CORRECTION BELOW).

Further updates to Appendix G added in September 2007

Reprocessing of NOAA-18 SEM-2 data using the correct calibration data for the TED instruments was completed in early July 2006. All archive files available through NGDC having dates of creation July 13, 2006 and later contain corrected TED data.

The European MetOp-A satellite was launched on October 19, 2006. This satellite carried a SEM-2 package. <u>However, it must be noted that SEM-2 Serial Number on this satellite was 016, and not 014 as mistakenly given earlier in this document.</u> The SEM-2 instrument was not turned on until early December 2006 and the earliest archive data available dates from December 3, 2006. The various conversion factors for the TED S/N 016 that are listed in Appendix C, revision 1 are the correct values for the SEM on the MetOp-A satellite.

Status of SEM-2 instruments as of September 2007:

**NOAA-15**

**MEPED proton telescopes**

The electronic discriminator levels and the noise levels of all the solid-state detectors in the NOAA-15 MEPED proton telescopes remain at nominal levels. However, NOAA-15 has been in orbit for over nine years and the front solid-state detectors in both the 0-degree and 90-degree proton telescopes have suffered significant radiation damage. The damage first became clearly apparent in late 2000 when the 0-degree telescope response began to exceed the 90-degree telescope response and by 2003 that response ratio regularly occurred 25% of the time whenever the 0- and 90-degree count rates were significant. Currently (2007) that ratio is exceeded in 80% of the cases. This damage has increased the effective proton energy discrimination levels from their original values (30 keV, 80 keV, 240 keV, 800 keV, and 2500 keV) by an unknown amount but probably a factor of 2 or more. While the proton instrument will still respond to changes in proton fluxes as a function of space and time caution should be used in converting the sensor responses to physical units.

**MEPED electron telescopes**

The electronic discriminator levels and the noise levels of all the solid-state detectors in the NOAA-15 MEPED electron telescopes remain at nominal levels. The solid-state detectors in the electron telescopes are less susceptible to radiation damage because of the nickel foil over the detector prevents the entry of low energy ions (which are the prime cause of damage). However, after nine years of operation some damage may have occurred that would increase the electron energy discrimination levels from their original values. This increase is unknown but probably not large.

**MEPED omni-directional detectors**

The electronic discrimination levels in the omni-directional solid-state detectors remain at their nominal levels. Because that discrimination level is 2500 keV, detector noise has never been a problem. The omni-directional detectors in the MEPED have not been affected by radiation damage.

**TED**

All 8 electrostatic analyzers in the NOAA-15 TED instrument are operating nominally and the channeltron gains (the main cause of sensor degradation) are all adequate.

**NOAA-16**

**MEPED proton telescopes**

The electronic discriminator levels and the noise levels of all the solid-state detectors in the NOAA-16 MEPED proton telescopes remain at nominal levels. However, NOAA-16 has been in orbit for seven years and the front solid-state detectors in both the 0-degree and 90-degree proton telescopes have suffered significant radiation damage. The damage first became apparent in late 2003 when the 0-degree telescope response began to exceed the 90-degree telescope response and by 2005 that response ratio regularly occurred 50% of the time whenever the 0- and 90-degree count rates were significant. This damage has increased the effective proton energy discrimination levels from their original values (30 keV, 80 keV, 240 keV, 800 keV, and 2500 keV) by an unknown amount but probably a factor of 2 or more. While the proton instrument will still respond to changes in proton fluxes as a function of space and time caution should be used in converting the sensor responses to physical units.

**MEPED electron telescopes**

The electronic discriminator levels and the noise levels of all the solid-state detectors in the NOAA-16 MEPED electron telescopes remain at nominal levels. The solid-state detectors in the electron telescopes are less susceptible to radiation damage because of the nickel foil over the detector prevents the entry of low energy ions (which are the prime cause of damage). However, after seven years of operation some damage may have occurred that would increase the electron energy discrimination levels from their original values. This increase is unknown but probably not large.

**MEPED omni-directional detectors**

The electronic discrimination levels in the omni-directional solid-state detectors remain at their nominal levels. Because that discrimination level is 2500 keV, detector noise has never been a problem. The omni-directional detectors in the MEPED have not been affected by radiation damage.

**TED**

The channeltron detector gains in the 4 TED electron analyzers on NOAA-16 are inadequate. This is especially true for the channeltron in the 0-degree, low-energy electron analyzer and data from that detector must be treated with great caution. The high voltage channeltron bias is currently at the next to highest level and an increase to the highest level is unlikely to significantly improve the situation and would increase the rate of channeltron degradation.

The channeltron detector gains in the 4 TED proton (ion) analyzers on NOAA-16 are also inadequate. This is especially true for the channeltrons in the 0- and 90-degree, high-energy proton analyzers and data from those detectors must be treated with some caution. The high voltage channeltron bias is currently at the second to highest level and an increase to the higher level is unlikely to significantly improve the situation and would increase the rate of channeltron degradation similar to the case for the channeltrons in the electron units. The gain degradation in the NOAA-16 TED instrument has been present since late 2003 (see earlier NOAA updates memos.) It is difficult to quantify the effect of channeltron gain loss on the quality of the TED data. However, comparisons between estimated hemispheric power inputs obtained from TED data from different spacecraft shows that in 2007 NOAA-16 returned estimates that were only 70-75% of estimates returned by other instruments. This may be a guide to the impact of gain degradation in the NOAA-16 TED instruments.

**NOAA-17**

**MEPED proton telescopes**

The electronic discriminator levels and the noise levels of all the solid-state detectors in the NOAA-17 MEPED proton telescopes remain at nominal levels. However, NOAA-17 has been in orbit for more than five years and the front solid-state detectors in both the 0-degree and 90-degree proton telescopes have suffered significant radiation damage. The damage first became clearly apparent in mid 2004 when the 0-degree telescope response began to exceed the 90-degree telescope response in 20% of the cases and currently (September 2007) that response ratio regularly occurred 50% of the time whenever the 0- and 90-degree count rates were significant. This damage has increased the effective proton energy discrimination levels from their original values (30 keV, 80 keV, 240 keV, 800 keV, and 2500 keV) by an unknown amount but probably approaching a factor of 2. While the proton instrument will still respond to changes in proton fluxes as a function of space and time caution should be used in converting the sensor responses to physical units.

**MEPED electron telescopes**

The electronic discriminator levels and the noise levels of all the solid-state detectors in the NOAA-17 MEPED electron telescopes remain at nominal levels.

The solid-state detectors in the electron telescopes are less susceptible to radiation damage because of the nickel foil over the detector prevents the entry of low energy ions (which are the prime cause of damage). However, after five years of operation some minor damage may have occurred that would increase the electron energy discrimination levels from their original values. This increase is unknown but probably not large.

**MEPED omni-directional detectors**

The electronic discrimination levels in the omni-directional solid-state detectors remain at their nominal levels. The omni-directional detectors in the MEPED have not been affected by radiation damage.

**TED**

All 8 electrostatic analyzers in the NOAA-17 TED instrument are operating nominally and the channeltron gains (the main cause of sensor degradation) are all adequate.

**NOAA-18**

**MEPED proton telescopes**

The electronic discriminator levels and the noise levels of all the solid-state detectors in the NOAA-18 MEPED proton telescopes remain at nominal levels. However, NOAA-18 has been in orbit for two years and there is <u>no</u> evidence that the front solid-state detectors in either the 0-degree and 90-degree proton telescopes have suffered radiation damage. At this time (September 2007) the NOAA-18 proton telescope data can be converted to physical units with a good degree of confidence.

**MEPED electron telescopes**

The electronic discriminator levels and the noise levels of all the solid-state detectors in the NOAA-18 MEPED electron telescopes remain at nominal levels. The solid-state detectors in the electron telescopes are less susceptible to radiation damage because of the nickel foil over the detector prevents the entry of low energy ions (which are the prime cause of damage). After only two years of operation there is no evidence that the detectors in the electron telescopes have suffered any radiation damage.

**MEPED omni-directional detectors**

The electronic discrimination levels in the omni-directional solid-state detectors remain at their nominal levels. The omni-directional detectors in the MEPED have not been affected by radiation damage.

**TED**

The electron gains in the channeltrons for the two low-energy electron analyzers on NOAA-18 are currently marginal although serviceable. A request has been made to increase the channeltron bias voltage by one step to increase the gain of these devices. The channeltron gains for the two high-energy electron and all four ion analyzers are currently adequate.

**MetOp-02**

**MEPED proton telescopes**

The electronic discriminator levels and the noise levels of all the solid-state detectors in the MetOp-02 MEPED proton telescopes remain at nominal levels. MetOp-02 has been in orbit for less than one year and there is no clear-cut evidence that the front solid-state detectors in either the 0-degree and 90-degree proton telescopes have suffered radiation damage. However, probably it will take another year before a trend will be clearly exposed. At this time (September 2007) the MetOp-02 proton telescope data can be converted to physical units with a reasonable degree of confidence.

**MEPED electron telescopes**

The electronic discriminator levels and the noise levels of all the solid-state detectors in the MetOp-02 MEPED electron telescopes remain at nominal levels. The solid-state detectors in the electron telescopes are less susceptible to radiation damage because of the nickel foil over the detector prevents the entry of low energy ions (which are the prime cause of damage). After only two years of operation there is no evidence that the detectors in the electron telescopes have suffered any radiation damage.

**MEPED omni-directional detectors**

The electronic discrimination levels in the omni-directional solid-state detectors remain at their nominal levels. The omni-directional detectors in the MEPED have not been affected by radiation damage.

**TED**

The electron gains in the channeltrons for the two low-energy electron analyzers on MetOp-02 are currently marginal although serviceable. A request has been made to increase the channeltron bias voltage by one step to increase the gain of these devices. The channeltron gains for the two high-energy electron and all four ion analyzers are currently adequate.