Historical Precision of an Ozone Correction Procedure for AM0 Solar Cell Calibrations

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Abstract

In an effort to improve the accuracy of the high altitude aircraft method for calibration of high band-gap solar cells, the ozone correction procedure has been revisited. The new procedure adjusts the measured short circuit current, *Isc*, according to satellite based ozone measurements and a model of the atmospheric ozone profile then extrapolates the measurements to air mass zero, AM0. The purpose of this paper is to assess the precision of the revised procedure by applying it to historical data sets. The average *Isc* of a silicon cell for a flying season increased 0.5% and the standard deviation improved from 0.5% to 0.3%. The 12 year average *Isc* of a GaAs cell increased 1% and the standard deviation improved from 0.8% to 0.5%. The slight increase in measured *Isc* and improvement in standard deviation suggests that the accuracy of the aircraft method may improve from 1% to nearly 0.5%.

Introduction

The NASA GRC High Altitude Aircraft Method has been used to provide the aerospace industry with solar cells calibrated to orbital conditions for nearly 40 years. The method measures the short circuit current, *Isc*, with an accuracy of 1% for setting solar simulators to space conditions during ground-based measurements (ref.1). However, with the increased application of high band-gap and multijunction solar cells in space, it has become necessary to reassess and revise the method in order to continue to provide measurements correctly adjusted to air mass zero, AM0.

Aircraft based measurements are made at the lower edge of the stratospheric ozone layer (figure 1) where the ozone density is increasing with altitude. The Langley Plot method is used to extrapolate flight measurements to AM0. It assumes that the adsorption characteristics of the atmosphere are proportional only to pressure. The extrapolation will therefore be offset due to the non-uniformity of the ozone density. This has been accounted for by increasing the measured *Isc* by 1% based on an estimate of the influence of ozone absorption on silicon solar cells (ref.1). This procedure must now be adjusted for higher band gap solar cells.

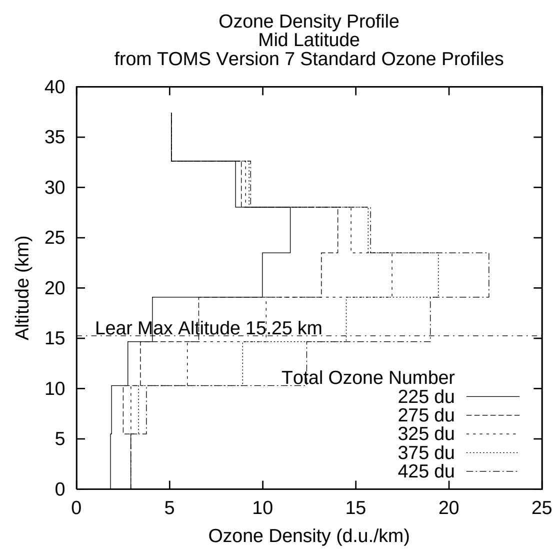

Figure 1. Ozone profiles for various total ozone numbers.

Initial work indicated that it was not sufficient to use the sun angle with the ozone number to calculate a correction factor (ref. 2) Instead correcting the measured Isc according to an ozone profile model, then performing the Langley extrapolation, looked promising. This paper applies the technique to historical data to see how it improves the precision and, presumably, the accuracy of the flight measurements.

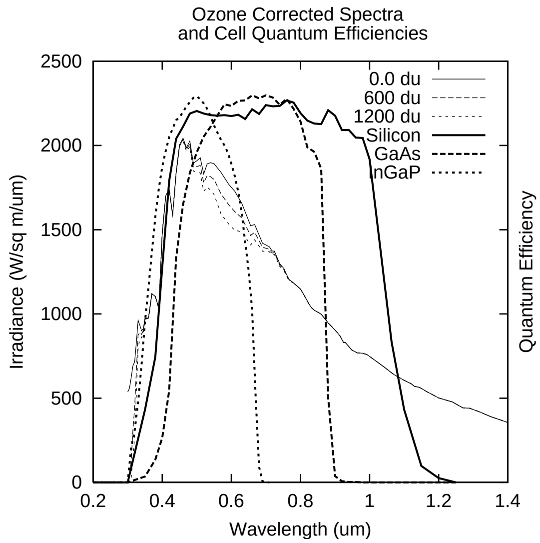

Figure 2. Ozone corrected irradiance and solar cell quantum efficiencies.

Procedure

A new ozone correction procedure has recently been developed (ref 2). The first step in the new procedure is to use spectral response data to calculate an ozone correction factor, *Foz*, for each cell technology. The measured *Isc* is then adjusted by a factor, 1+[O_3]**Foz*, where [O_3] is the Ozone column along the optical path. Examples of *Foz* are shown in Table 1 for various types of solar cells. Next, based on satellite data available the day after a calibration flight, an ozone profile is produced and used to correct the measured *Isc* as a function of air mass and altitude. The corrected *Isc* is then extrapolated via the Langley Plot method to AM0.

Cell type	***Foz (/*du)**
Silicon	$29.6\text{x}10^{-6}$
α Silicon	$50.4\text{x}10^{-6}$
GaAs	$42.6\text{x}10^{-6}$
InGaP top junction	$57.2\text{x}10^{-6}$
GaAs middle junction	$26.3\text{x}10^{-6}$
Ge bottom Junction	$2.43\text{x}10^{-6}$

Table 1. Ozone correction factors for various solar cell types.

The *Foz* calculation is based on the convolution of the ozone absorbed WM0 spectra with the spectral response data for a solar cell type as illustrated in figure 2. The ozone absorption region of the spectra that most affects solar cell performance is from about 500 nm to 800 nm. This means that high band gap cells tent to be affected more than low band gap cells.

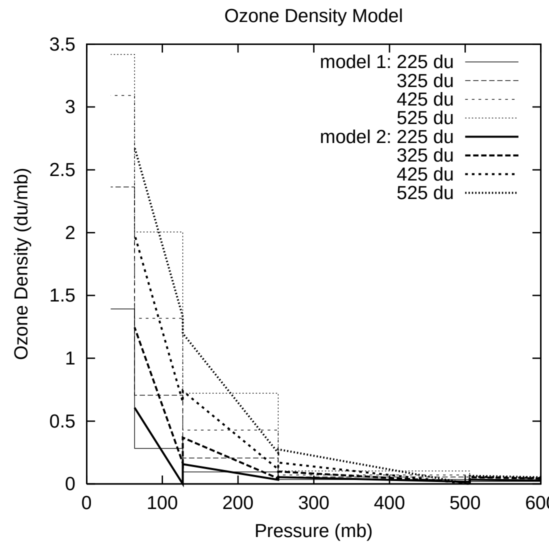

Figure 3. Pressure dependent ozone density model.

Next each *Isc* measurement during the flight is corrected using *Foz* and the ozone along the optical path by a factor of 1+[O_3]*Foz*. The total Ozone number, *On*, for the flight date and location is available from the Earth Probe satellite at the web site in reference 3. This is then adjusted by an ozone density model for the altitude, *f(p)*,as given by the pressure of the *Isc* measurement illustrated as Model 2 in figure 3. The ozone density model is based of the TOMS Version 7 Standard Ozone Profile as described in appendix A of reference 4. Finally , the optical path is corrected for the sun altitude, θ*,* approximately *1/sin(*θ*)*. So, [O3] = *On* * f*(p)*/*sin(*θ*)*.

Results

This paper reports on data from three solar cells. First, is a silicon solar cell that has been flown since 1985. It is used for two sets of data, first it a short term set of data set with 20 flights over a single flying season, second is a selection of 13 flights over an eight year period. The second cell examined is a GaAs cell. Selected flight data from 31 flights over ten years are examined. Finally, data from an InGaP top cell which was flown seven times in

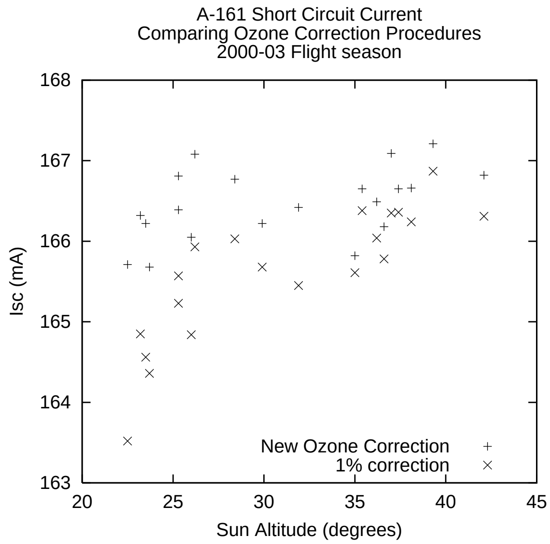

Figure 4. Variation in *Isc*(AM0) of a silicon solar cell as a function of sun angle during a flight season.

recent flight seasons are presented.

Si cell short term

The silicon solar cell A-161 has flown frequently on the Lear 25 as a monitor cell during calibration flights. It flew 20 times during the 2000-2001 flying season. Using the 1% ozone correction method, the short circuit current, *Isc*, measurements averaged 165.60 mA with a standard deviation of 0.81 mA. With the new ozone correction method the average *Isc* was 166.46 mA with a standard deviation of 0.43 mA. Figure 4 shows a comparison of the measurements plotted against sun angle during the measurement. The reduction in *Isc* at lower Sun altitudes using the 1% correction method, is interpreted as due to the increased optical path length through the ozone layer. The new correction method nearly removes this dependence.

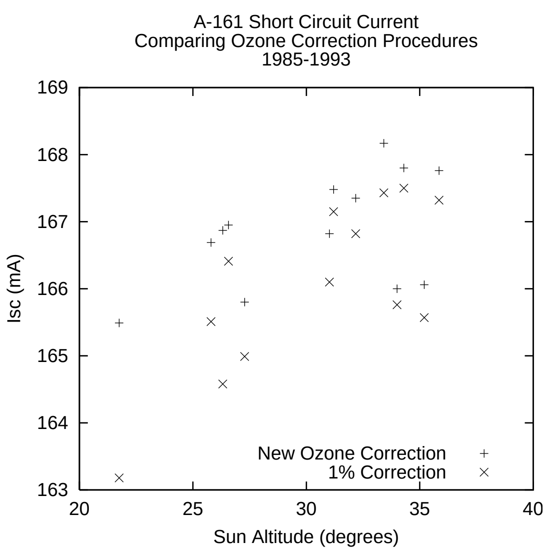

Figure 5. Long term comparison of *Isc*(AM0) of a silicon cell as a function of sun angle.

Si cell long term

Flight data is also available for A-161 since the 1985 flying season. Figure 5 shows some of the data over the interval 1985-1993. The ozone data for this period is available from the Nimbus 7 satellite (ref. 5). *Isc* from 13 flights over that interval averaged 166.0 mA with a standard deviation of 1.2 mA. Using the new procedure *Isc* averaged 166.9 mA with a standard deviation of 0.8 mA.

GaAs cell long term

A-133 is a GaAs cell that has flown frequently. Data was examined that was obtained in the period 1985-1994. Of 31 flights the old procedure gave a average of 110.16 mA with a standard deviation of 0.83 mA. The new ozone correction procedure gives an average of 111.29 mA with a standard deviation of 0.52 mA. A comparison is shown in figure 6.

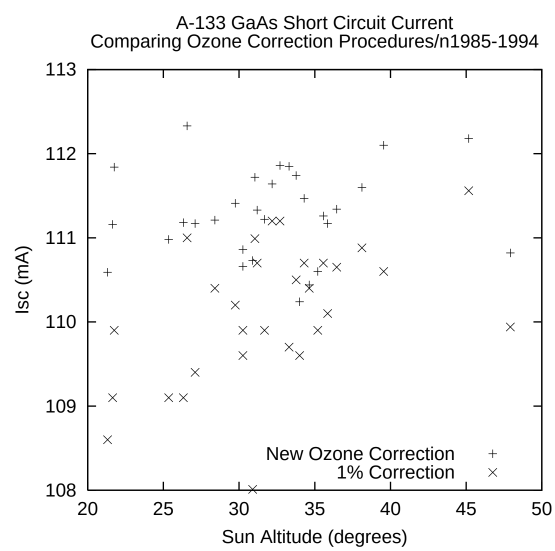

Figure 6. Long term variation in *Isc* measurements of a GaAs solar cell.

InGaP Top Cells

134-5-6 is an InGaP Top Cell, part of a pair of subcells for a dual junction solar cell. It has been flown several times over the past few

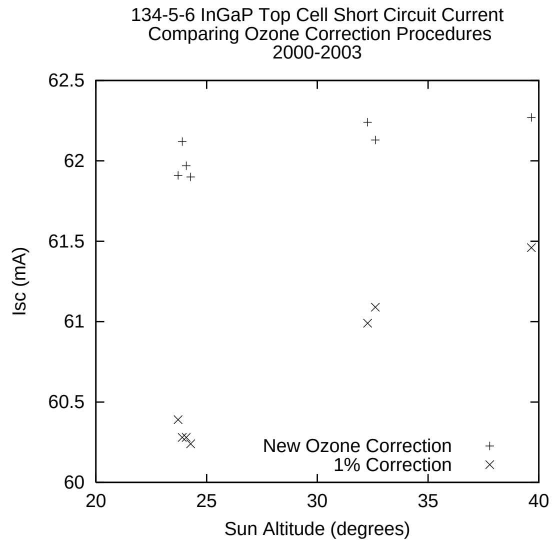

Figure 7. *Isc* of an InGaP cell as a function of sun angle.

years. Figure 7 compares results from seven flights in the 2000-2001 and 2002-2003 seasons. The 1% correction procedure gave an average of 60.68 mA with a standard deviation of 0.46 mA. The new method gives an average of 62.08 mA and a standard deviation of 0.14 mA.

Discussion and Conclusion

This paper has compared an old procedure for correcting Isc measurements for atmospheric ozone with a new one. Table 2 shows the changes due to this method. The slight increase in Isc is expected as the procedure accounts for the increased optical path due to low sun altitude. In addition, the correction increases with band gap.

Cell Type	Isc change	Standard Deviation	
		1%	new
Si short term	0.52%	0.49%	0.26%
Si long term	0.54%	0.72%	0.48%
GaAs long term	1.02%	0.75%	0.47%
InGaP	2.26%	0.76%	0.23%

Table 2. Relative changes is *Isc* measurements.

The standard deviation of each set of measurements also improves by at least one third because the dependence on sun angle is nearly removed. This suggests that the influence of atmospheric ozone has been an important uncertainty in the aircraft based measurements. The new correction procedure appears to produce a significant improvement in measurements. However, in order to have complete confidence in the procedure, results still must be compared to high altitude balloon measurements.

The new procedure has been used at NASA GRC for measurements beginning with the 2002-2003 flight season. It is anticipated that in the 2003-2004 season the capability of making a spectroscopic measurement of the ozone profile will refine these calibration measurements further.

References

[1] P.Jenkins, D. Brinker and D. Scheiman, “Uncertainty Analysis of High Altitude Air Mass Zero Solar Cell Calibration “, 26th IEEE PVSC, V26-206 ,1997, pp.857-860..

[2] D. Snyder, et al, “Ozone Correction for AM0 Calibrated Solar Cells for the Aircraft Method “, 29th IEEE PVSC,2002.

[3] <http://toms.gsfc.nasa.gov/eptoms/ep.html>

[4] McPeters, R.D. et al, Earth Probe Total Ozone Mapping Spectrometer (TOMS) Data Products Users Guide, NASA TP 1998-206895, 1998.

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