The EUV spectral irradiance - internal report - AUGUST -2008

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1 New since previous report

A bug in the CDS analysis software one of us (GDZ) wrote was found. It meant that all post-SOHO loss intensities were underestimated, since the broadened line profiles were not taken into proper account. This accounted for a large variation (factor of 2) in the NIS 1 channel, were lines were particularly broadened.
Some of the comparisons with the TIMED EGS are now encouraging, but a few problems still persist.

2 Calibration rockets that can be used to check the NIS calibration

The EGS calibration rockets were launched on 8-feb-2002, 12-aug-2003, and 15-oct-2004. During these days, the Sun turned out to be relatively quiet, and no flares were present.
Full-Sun CDS measurements that could be used to cross-calibrate CDS are:
– 1997/05/15 Woods Rocket. Used to fix the absolute CDS calibration (Brekke et al. 2000)
– 1998/11/02 Woods-Hassler Rocket
– 2002/02/11 this is 'close' to the EGS rocket flight of 8-Feb-2002
– 2003/08/12 same day of the EGS rocket flight for TIMED/SEE
– 2004/10/15 same day of the EGS rocket flight for TIMED/SEE

Question: Are the data of the rocket flights available ?

We also have now two EUNIS rocket flights, in 2006 and 2007.

3 CDS/NIS calibration as in 1997

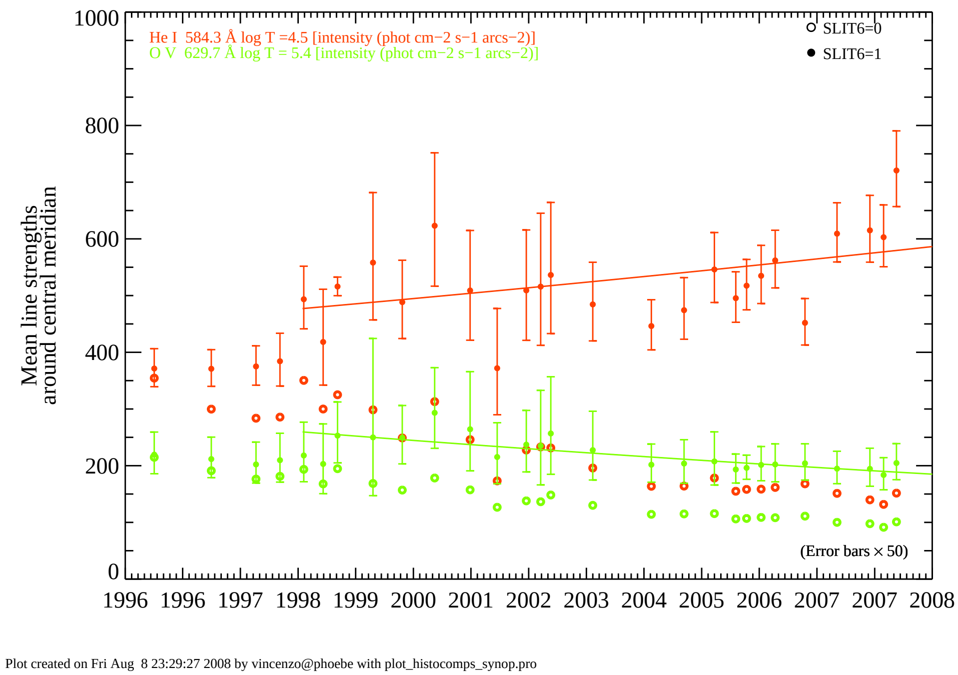
The 'standard' CDS calibration available through SolarSoft is based on a comparison between the EGS rocket flight of 1997/05/15 (Woods Rocket) and CDS/NIS FULL SUN NIS spectral radiance measurements. It is described in Brekke et al. (2000).
The Del Zanna et al. (2001) CDS radiometric calibration was obtained relative to the value at 584 Å. Once the same responsivity at 584 Å is used, the scaled Del Zanna et al. (2001) and the 'standard' calibrations agree within 30% or so, which is satisfactory. CDS Results shown here used the scaled Del Zanna et al. (2001) radiometric calibration.

4 CDS/NIS sensitivity corrections

The use of the wide slit (number 6) causes with time a drop in the CDS NIS sensitivity. A correction to the strongest line, the He I 584 Å, has been obtained by W.T.Thompson by analysing the long-term synoptic data, basically by assuming that in quiet Sun regions the He I 584 Å radiance should be constant with time. **Notice, however, that this sensitivity correction would also include a factor due to any unrelated decrease in the sensitivity.**
SUMER radiances over time have actually shown an increase in their values with the solar cycle (e.g. Schule et al. 2000, Pauluhn and Solanki 2003), however various other measurements appear to contradict this.
Most importantly, the ground-based measurements of Bill Livingston (see, e.g. Livingston et al. 2007), where equivalenth widths of photospheric and chromospheric lines (e.g. Ca II) over the 'quiet Sun' (often Sun centre) do not show significant trends with the solar cycle.
In any case variations, if present, are within 20-30%, i.e. well below the discrepancies we have found.
We have independently processed a few of the CDS synoptic data. Fig. 1 (above) shows the trends in the radiances in He I 584 and O V 630 Å, with and without the sensitivity corrections.
The trends have been determined by fitting only post-recovery data (data taken after November 1998). The radiances shown in Fig. 1 are obtained by estimating the "mode", or the peak of the radiance distribution in the CDS rasters away from the poles. Fig. 1 therefore shows estimates of the "quiet Sun mean radiance" at disk center: the effect of possible ARs crossing the meridian is small. Hence, there should be little or no influence on those radiances from solar cycle variations (except, of course, from possible, "intrinsic" variations in the quiet Sun.)
It appears that up to 2005 the correction has worked reasonably well for the He I, but after that an over-correction is present. There is a down-ward trend in the O V, which seems to indicate that the extension of the He I correction to this line does not work well.
The same downward trend is seen also in the radiances of the coronal lines Mg IX and Mg X (lower panel of the same figure). These lines, however, are weaker and their fitting is more uncertain (as the discontinuity between pre- and post-recovery profiles in the NIS 1 Mg IX line seems to suggest). Moreover, while we have been careful in choosing dates in the synoptic data base with no strong ARs near the meridian, a residual effect from the solar cycle cannot be excluded.

5 TIMED/SEE spectra

We have obtained the TIMED/SEE spectral line irradiances from the file:
'see__egs_L2_merged_2008150_009.ncdf', which was on-line and has the latest TIMED/SEE calibration (version 9) by fitting gaussian profiles and by subtracting a background.
There is a change in the TIMED spectra, in terms of either degradation in spectral resolution or detector sensitivity.
It is particularly marked for the strongest He I 584 Å, as shown in Fig. 3. This and a few



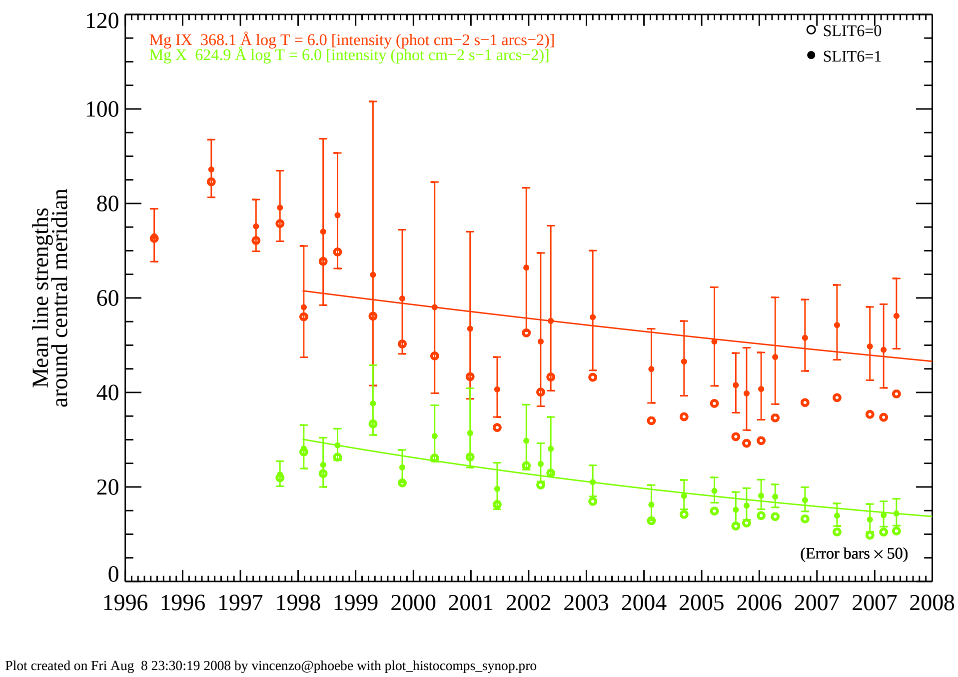


Figure 1: mean intensiites of NIS lines obtained from the CDS synoptic observations (along meridian in a central region of the Sun).

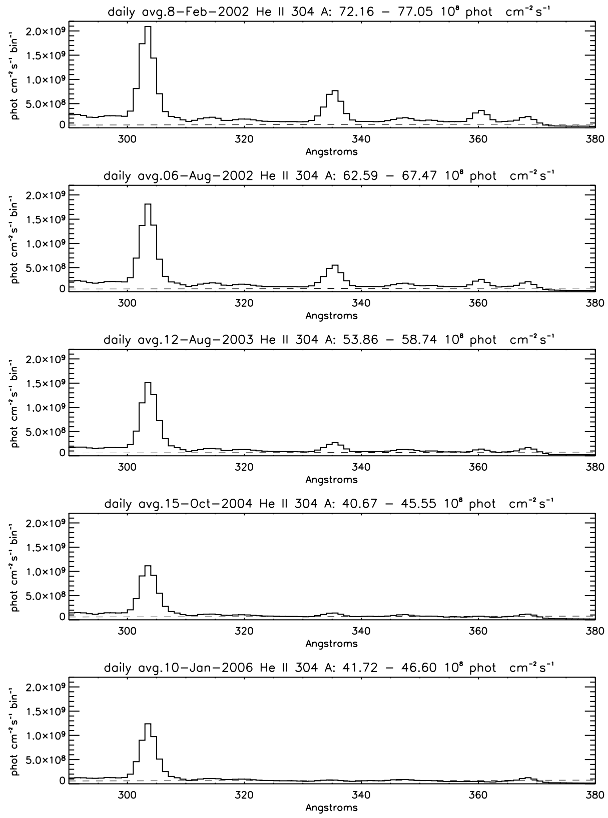


Figure 2: TIMED/SEE spectra in the NIS 1 spectral band.

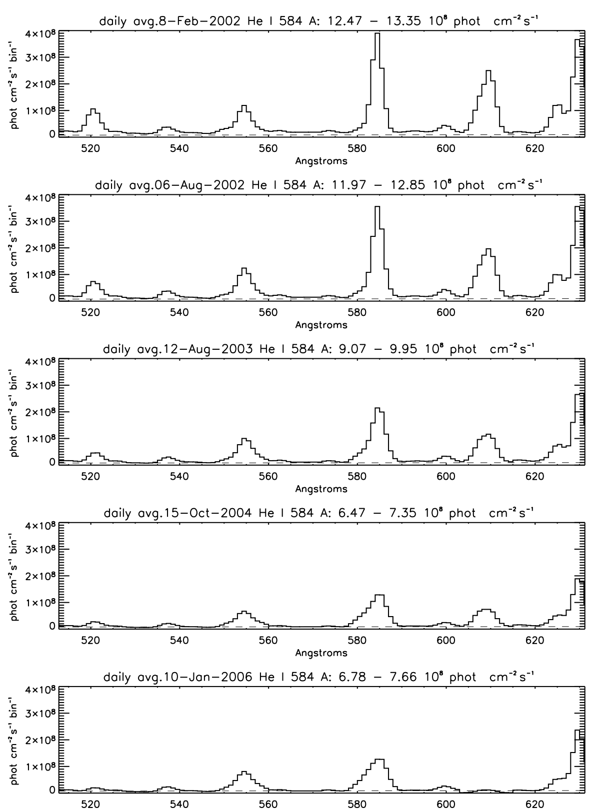


Figure 3: TIMED/SEE spectra in the NIS 2 spectral band.

other broad lines were fitted with multiple components and then intensities obtained from the total.
The file **timed_comp1.ps** shows our fits (black) with the points obtained from the see__L3_merged_2008150_009.ncdf file (red). One example is shown in Fig. 4. **Good agreement is generally found. We did this in order to extract further, mostly weaker, lines from the TIMED/EGS spectra.**
The red boxes indicate the irradiances from the CDS lines (summed up to account for blending) in Brekke et al. (2000). The green data are from SUMER irradiance measurements in 1996-1997 during solar minimum, whilst the blue ones are older irradiance measurements. The first ones are from Hall (1970), Chapman and Neupert (1974) Higgins (1976) Heroux et al (1974) etc.. while the more recent ones (1992-1994) are from rocket flights as described in Woods et al. (1998).
The dashed lines correspond to the irradiances obtained from the averaged quiet-Sun (QS) Skylab ATM radiances, without taking into account limb-brightening. They are good estimates for a QS irradiance for the He and cool lines, which do not show significant limb-brightening. For the other lines, it provides a lower limit.

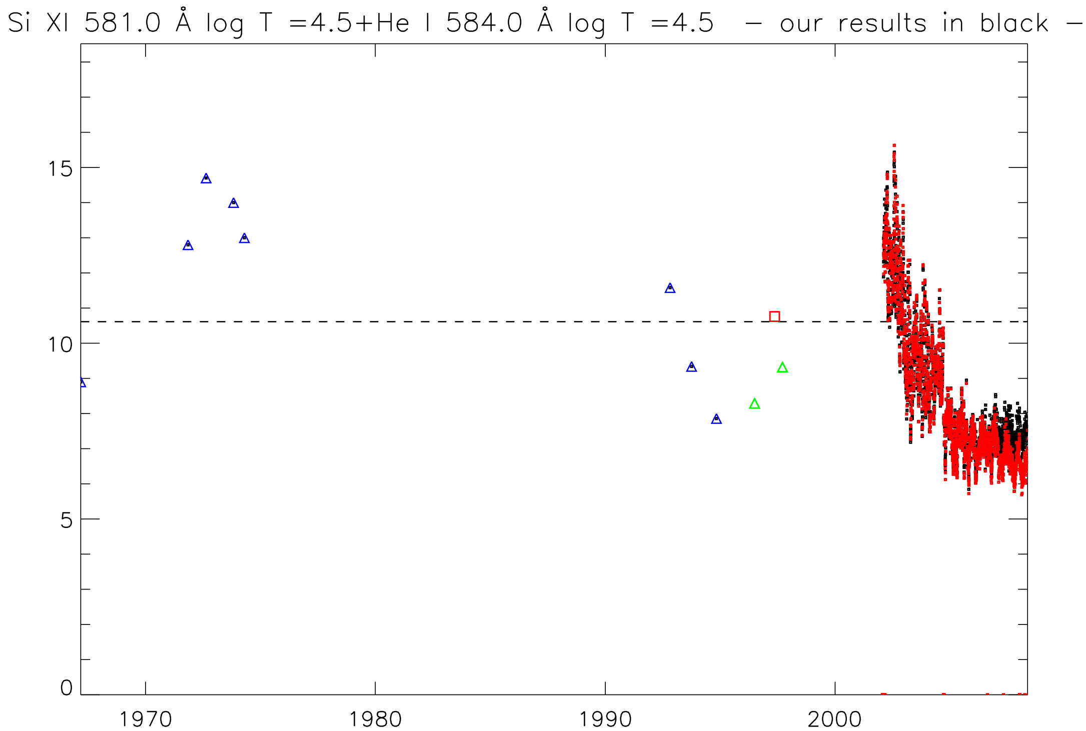


Figure 4: TIMED/EGS irradiances for the He I 584 Å line.

There are a few problems here. In many cases, TIMED irradiances appear to be too low. The TIMED irradiances of the last two years should compare well with all the measurements obtained in 1996-1997 during solar minimum.
Also, most TIMED/EGS lines still show a jump in 2004, presumambly because after October 2004 there have not been any rocket flights to check the in-flight calibration.

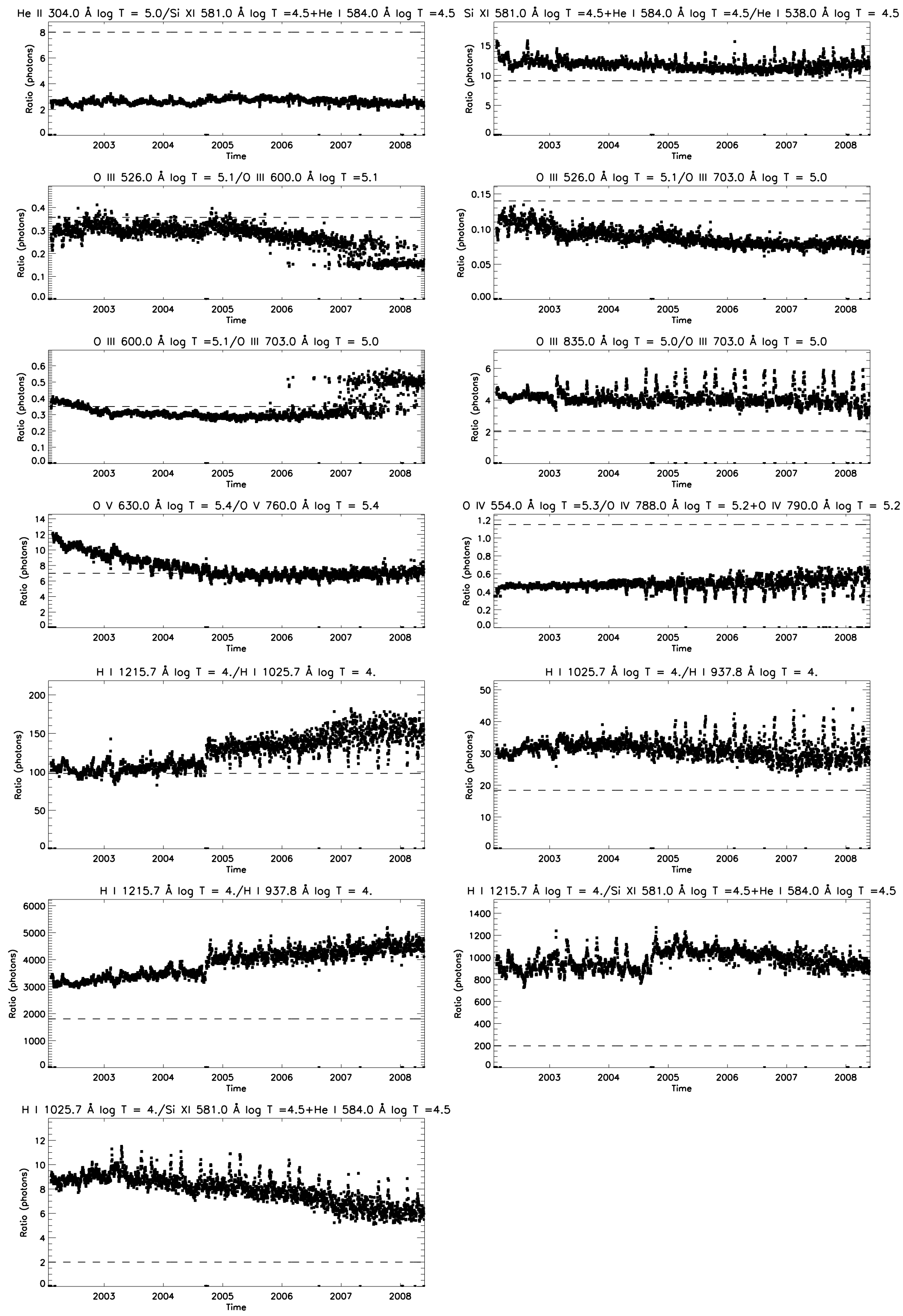


Figure 5: A selection of TIMED/SEE irradiance ratios. The dashed lines indicate the expected (approximate) values, based on older irradiance measurements. Notice that the He I 584 appears largely underestimated.

5.1 TIMED/SEE line ratios

Fig. 5 shows a selection of line ratios (with the expected values) which should be approximately constant with the solar cycle. The ratio of the He II 304/He I 584 Å stays constant at about 2.5, but should actually be about 8. The He I 584/He I (blend) 537 Å is instead closer to the expected value. O III shows some disagreement, while O V seems relatively OK (though the 760 Å multiplet is blended and weak). There is a worrying disagreement between the O IV multiplet at 554 Å and the O IV blend at 790 Å.

The ratio of the H I 1215/1025 Å is very close to what was previously measured, but the ratios with the He I 584 Å are off by a factor of 4.

6 SOHO/CDS vs TIMED/SEE irradiances

We have processed a number of full NIS spectral scans. We selected dates when no flares were present and when the minimum amount of active regions was observed.
We applied the standard flat-field corrections, but not the correction for the use of the wide slit. We fitted the spectra (in counts) to obtain integrated line count rates. The USUN observations subsample the Sun, so we have interpolated the values in the regions not observed.
The mosaic of NIS rasters do not observes the whole off-limb corona to great distances. We have therefore studied the off-limb behaviour of all the lines in the NIS spectra, and obtained an estimate of the off-limb contribution not observed. For the cooler lines, this is usually less than 1%. For the coronal lines, can be up to 5-6%. We have added this contribution.
Finally, we have added all the radiances to calculate the irradiances.
We have then applied the Del Zanna radiometric calibration and finally applied the standard correction factor for the use of the wide slit. This is of the order of a few percent for the weaker lines, but up to a factor of 3 for the strongest He I line.
Finally, we have scaled the irradiances to 1 AU.
For a meaningful comparison with the irradiances measured by TIME/SEE, we have summed all the main CDS/NIS lines contributing to those observed (at the lower resolution) by TIMED/EGS. The resulting irradiances are plotted as boxes in Fig. 6. The points are the data from TIMED/EGS.
The asterisks are the CDS/ rocket EGS measurements of May 1997 as in Brekke et al. (2000). Lines contributing to those observed by TIMED have been summed up.
There are clear discrepancies between the NIS 2 and the EGS irradiances. Most notably, with the He I 584 Å line, the strongest and best-calibrated line. Large discrepancies are also present with the strong O IV 554 multiplet and the weaker 537 Å blend. The discrepancies are not wavelenght-dependent or intensity-dependent. **There is also a discrepancy between the CDS He II 304 (second order) and the EGS 304.**
Surprisingly, there is good agreement with the weaker (coronal) lines, as for example the Mg IX 368 Å, Fe XVI 335,360 Å and Si XII 520.
Fig. 7 shows the same comparison, this time with the NIS irradiances not including any correction for the use of the wide slit.

6.1 SOHO/CDS ratios of irradiances

There are many consistency checks that can be done with the CDS data alone. One is shown in Fig. 8. The ratio of the He II 304 Å and the He I 584 Å is well-known to be nearly constant, and should have a value of 8. The ratio confirms the over-correction for the He I 584 Å line. The same is evident in the He I 584 Å / He I 537 Å ratio. Notice that the ratios without any gain corection are better, being nearly constant and with values close to the expected ones.
We are still checking further line ratios.

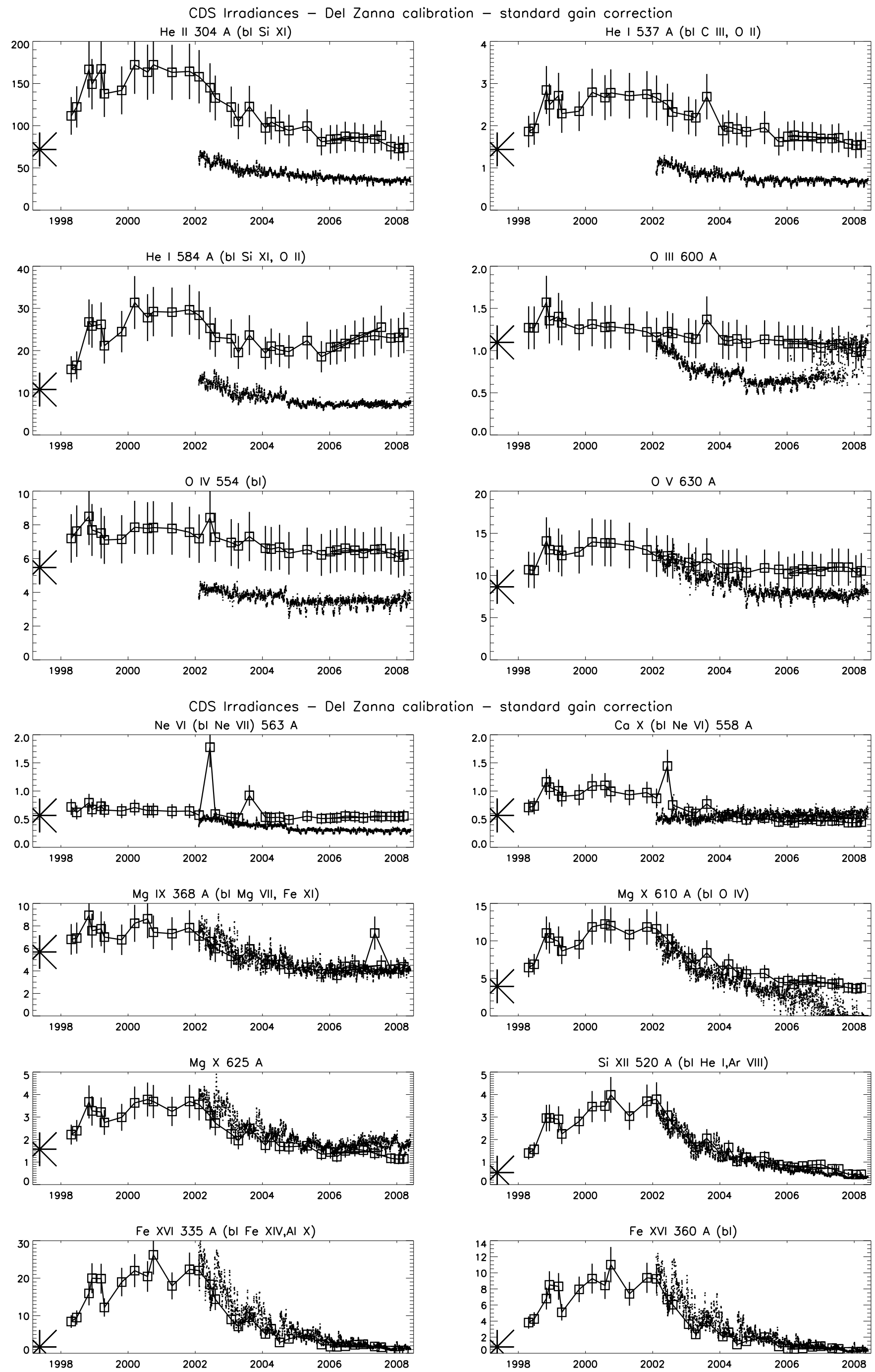


Figure 6: EUV irradiances (10^8 phot cm^{-2} s^{-1}) at 1 AU obtained from SOHO/NIS with the standard gain correction. The points are the data from TIMED/EGS. The asterisks are the CDS measurements of May 1997 (Brekke et al. 2000). CDS line intensities contributing to the features observed by TIMED/EGS have been summed up.

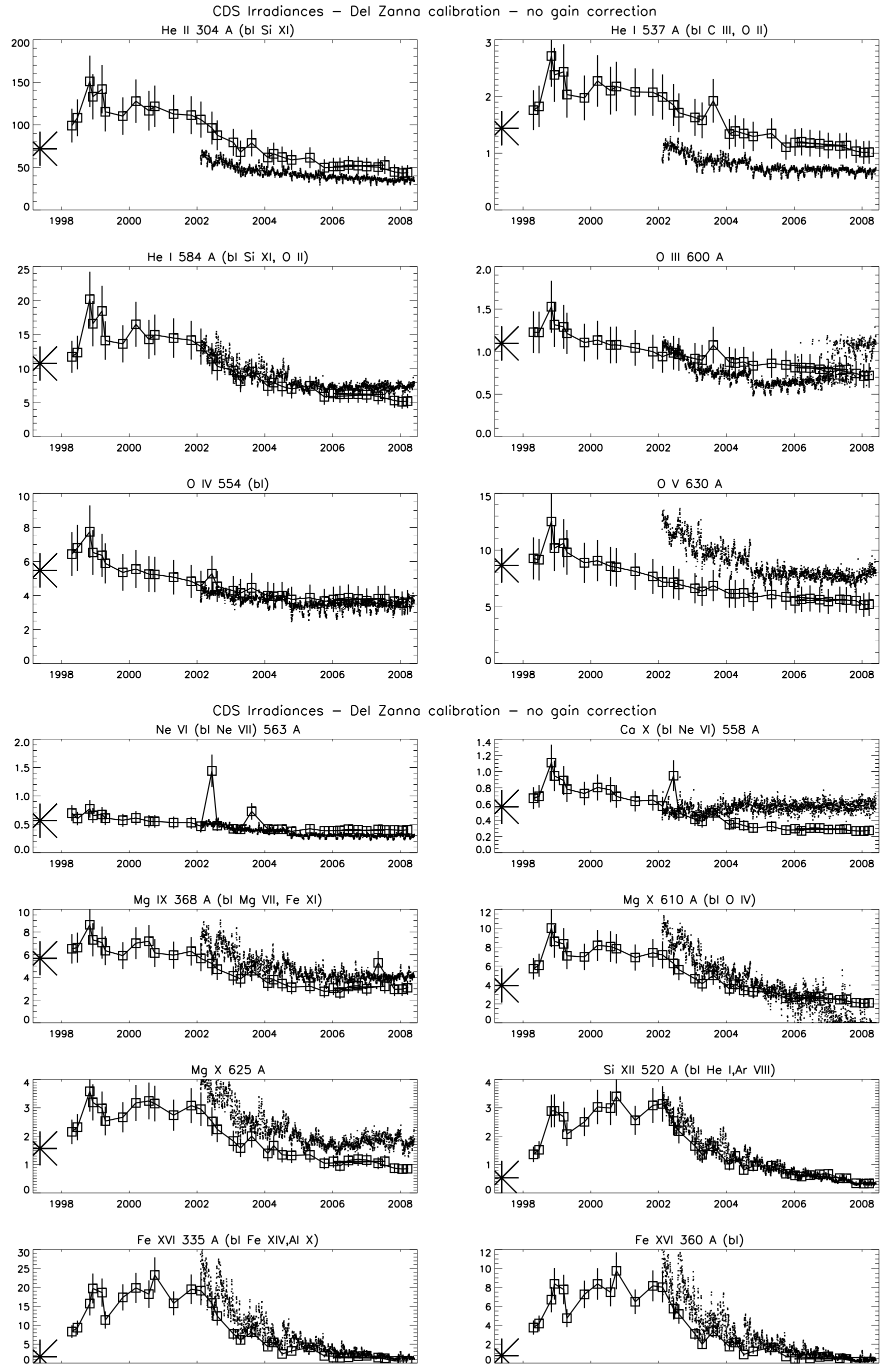


Figure 7: EUV irradiances (10^8 phot cm^{-2} s^{-1}) at 1 AU obtained from SOHO/NIS **without any correction for the use of the wide slit**. The points are the data from TIMED/EGS. The asterisks are the CDS measurements of May 1997 (Brekke et al. 2000). CDS line intensities contributing to the features observed by TIMED/EGS have been summed up.

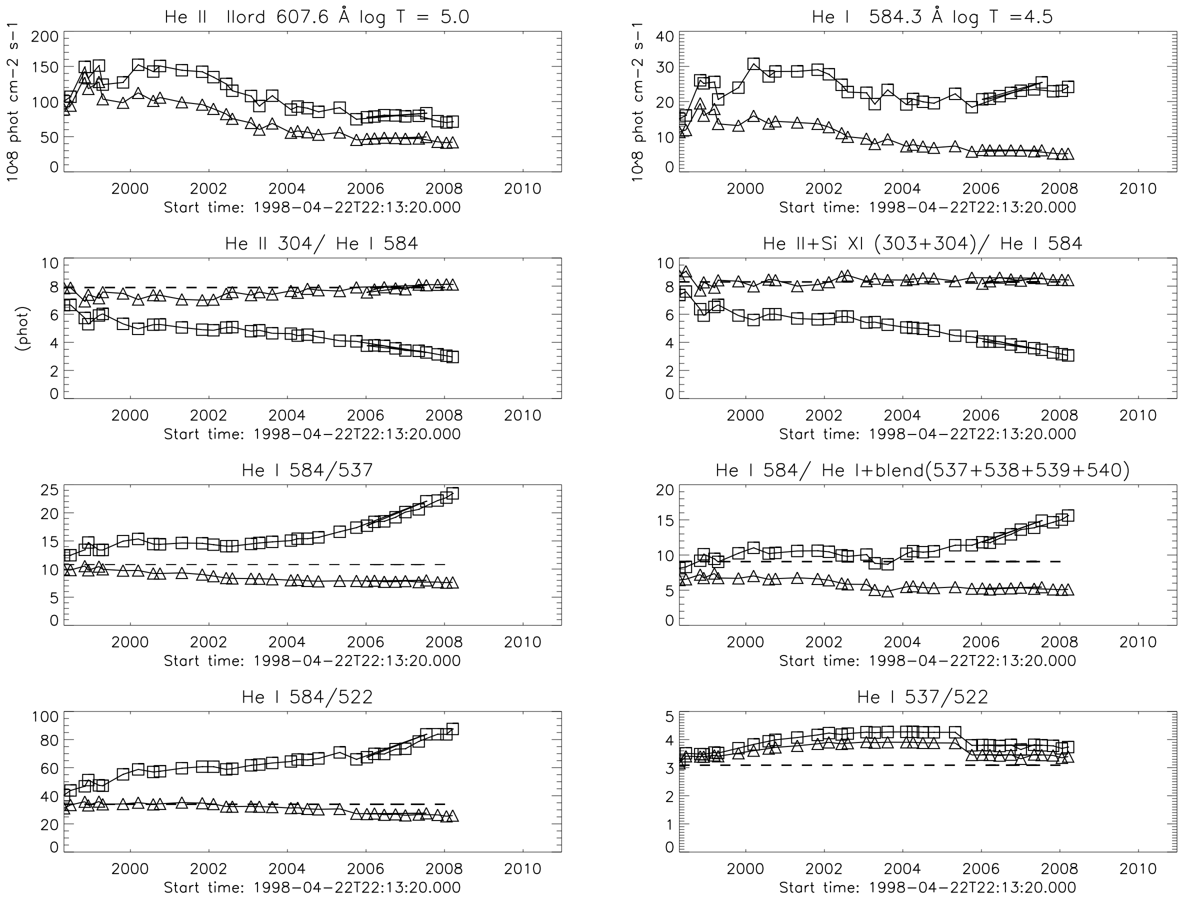


Figure 8: Top: EUV irradiances (10^8 phot cm^{-2} s^{-1}) of the He II 304 Å and He I 584 Å at 1 AU obtained from SOHO/NIS with (boxes) and without (triangles) the standard sensitivity correction. Below: ratios of He lines which should be approximately constant with the solar cycle.

7 NIS 1 calibration based on EUNIS

With the 2006 EUNIS rocket flight, it was possible to obtain an approximate calibration of the NIS 1 channel. The results are a drop of more than a factor of 2 at 368 Å, increasing to more than a factor of 4 at the shortest wavelengths (R. Thomas). We are awaiting a measurement for the He II 304.

8 Preliminary conclusions

We have now gathered enough evidence to conclude that many of the TIMED/EGS irradiances need revision. This is puzzling, considering that the data have been calibrated with 3 rocket flights. We can understand discrepancies after 2004, but not before.

We have enough evidence to believe that the CDS pre-SOHO loss irradiances were accurate. There is at least convergence there among CDS, SUMER, the EGS rocket flight and previous (historical) measurements.

We have independently confirmed (to within say 30%) that the method developed by W.Thompson to calibrate the CDS He I 584 is sound. It appears to have worked reasonably well until 2004.

We doubt, though, that the calibration of the He I 584 can be applied to all other NIS lines and that the drop in sensitivity in the He I 584 Å is solely due to the use of the CDs wide slit.

9 How to proceed

9.1 CDS

The apparent over-correction for the He I 584 could be adjusted, and all other corrections modified accordingly.

One relatively simple check could be to compare directly the CDS irradiances with the EGS rocket flight spectra.

A more time-consuming effort would be to redo the CDS internal (relative) calibration as done in Del Zanna et al. (2001).

9.2 TIMED/EGS

Further comparisons with other measurements in the UV could be done (have been done ?). Further use of line ratios could help to clarify where errors in the calibration occurred.