

Nowcasting Solar EUV with Magnetic Fields and Mg II

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Key Points:

- Improved nowcast models for commonly used extreme ultraviolet (EUV) and far ultraviolet (FUV) solar irradiance bands
- Utilization of well-calibrated Mg II observations decreases the error between the modeled and observed EUV values
- Real-time EUV observations are not required to correct and improve the EUV irradiance models

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Abstract

A new method to nowcast spectral irradiance in extreme ultraviolet (EUV) and far ultraviolet (FUV) bands is presented here, utilizing only solar photospheric magnetograms and the Mg II index (i.e., the core-to-wing ratio). The EUV and FUV modeling outlined here is a direct extension of the SIFT (Solar Indices Forecasting Tool) model, based on Henney et al. (2015). SIFT estimates solar activity indices using the earth-side solar photospheric magnetic field sums from global magnetic maps generated by the ADAPT (Air Force Data Assimilative Photospheric Flux Transport) model. Utilizing strong and weak magnetic field sums from ADAPT maps, Henney et al. (2015) showed that EUV & FUV observations can also be well modeled using this technique. However, the original forecasting method required a recent observation of each SIFT model output to determine and apply a 0-day offset. The new method described here expands the SIFT and ADAPT modeling to nowcast the observed Mg II index with a Pearson correlation coefficient of 0.982. By correlating the Mg II model-observation difference with the model-observation difference in the EUV & FUV channels, Mg II can be used to apply the 0-day offset correction yielding improvements in modeling each of the 37 studied EUV & FUV bands. With daily global photospheric magnetic maps and Mg II index observations, this study provides an improved method of nowcasting EUV & FUV bands used to drive thermospheric and ionospheric modeling.

1 Plain Language Summary

Ultraviolet irradiance from the Sun can create variability in Earth's atmosphere and cause problems, for example, with satellite communication and their orbital paths. However, we are limited in measuring solar ultraviolet irradiance since it must be observed from space and therefore models of the irradiance are important. In this paper, we present an improved way to model ultraviolet irradiance using solar magnetic fields and a well-calibrated solar activity proxy. We find that models of the irradiance improve when the proxy is used to correct daily variations compared to models driven using just the magnetic fields.

2 Introduction

Solar irradiance, specifically the ultraviolet (UV) band vacuum UV (VUV; 0.1 to 200 nm) which includes X-ray UV (XUV; 0.1 to 10 nm), extreme UV (EUV; 10 to 120 nm) and far UV (FUV; 120 to 200 nm), is an important driver for modeling variability in the earth's upper atmosphere. For example, the solar EUV flux causes ionization, dissociation, and excitation of the atoms and molecules in the terrestrial upper atmosphere (Lilensten et al., 2008). All of these interactions lead to heating, and this solar irradiance both creates the ionosphere and is the main source of energy in the thermosphere (Fuller-Rowell et al., 2004). The atmospheric variability induced by changes in the solar EUV irradiance can impact radio communications (due to an enhanced ionosphere e.g., Klobuchar, 1985; McNamara, 1985) and atmospheric drag on satellites (due to increased density at high altitudes e.g., De Lafontaine & Garg, 1982). Because of these impacts, real-time knowledge of solar irradiance is necessary to drive nowcast models of the terrestrial upper atmosphere (e.g., Goncharenko et al., 2021).

However, measurements of the solar EUV irradiance have serious limitations because these wavelengths are absorbed in the earth's upper atmosphere, so they must be observed from space. While such measurements began in the 1960s, this spectral range has been inconsistently observed and there are large gaps in both time and spectral coverage when no observatories were taking measurements (Pesnell, 2016). Furthermore, even when measurements exist, they are notoriously difficult to calibrate due to instrumental degradation (e.g., R. a. Hock et al., 2012).

61 Because of these observational difficulties, there is significant benefit to modeling
 62 rather than observing the solar EUV irradiance. Solar EUV originates in the solar at-
 63 mosphere from plasma at a wide variety of temperatures, from 50 kK in the upper chro-
 64 mosphere to 10 MK in the corona, and typically increases with solar activity. Many so-
 65 lar irradiance models use one (e.g., Richards et al., 1994) or more (e.g., P. C. Chamber-
 66 lin et al., 2020) activity proxies and correlate them with individual channels of EUV ir-
 67 radiance spectra. Then, simply by measuring the proxy, select EUV and FUV spectral
 68 bands can be estimated. Two commonly used proxies are the solar 10.7 cm (2.8 GHz)
 69 radio flux (Covington, 1947; Tapping, 2013), abbreviated as $F_{10.7}$ and the Mg II core-
 70 to-wing ratio (often referred to as the Mg II Index, and hereinafter referred to as Mg II;
 71 Heath & Schlesinger, 1986).

72 Besides using proxies similar to $F_{10.7}$, it is also possible to drive an EUV model us-
 73 ing solar magnetic field measurements (e.g., full-disk magnetograms and global magnetic
 74 maps) since the magnetic fields provide the energy to heat the solar atmosphere that pro-
 75 duces the EUV irradiance. Henney et al. (2012, 2015, hereafter Henney2012 and Hen-
 76 ney2015, respectively) used earth-side weak and strong solar photospheric magnetic field
 77 sums from global magnetic maps to estimate irradiance in EUV bands, along with $F_{10.7}$.
 78 Similar work by (Warren et al., 2021) utilized more bins in the magnetic field strength
 79 combined with principle component analysis and demonstrated similar success model-
 80 ing $F_{10.7}$, Mg II, and selected EUV emission lines.

81 This paper expands on the nowcasting components of Henney2012 and Henney2015
 82 by focusing on Mg II rather than $F_{10.7}$ and using it to correct EUV nowcasts. The Hen-
 83 ney2015 EUV forecast method required a recent EUV observation to determine and ap-
 84 ply a 0-day (nowcast) correction. The method described here instead uses the Mg II model
 85 to estimate corrections to EUV nowcast models. The data used in this study are described
 86 in Section 3. The addition of the Mg II modeling, its use as a corrective factor to the
 87 Solar Indices Forecasting Tool (SIFT), and the results of this study are described in Sec-
 88 tion 4. We provide a summary of the results in Section 5.

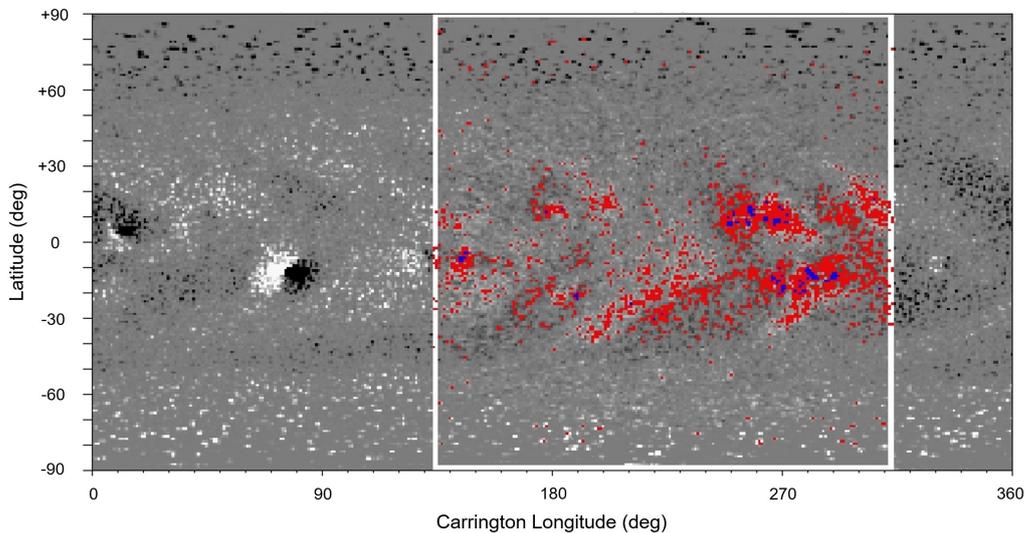


Figure 1. An example ADAPT global photospheric magnetic map, generated by data as-
 simulating NSO SOLIS/VSM magnetograms, utilized by SIFT to forecast solar indices. For this
 ADAPT map representing January 23, 2004 at 20:04 UT, the Earth pointing side of the sun is
 delineated by the white box. Within the earth-side region, pixel areas used to sum the active
 region and plage fields are highlighted in blue and red, respectively.

3 Solar Data Sources

3.1 Mg II Index

For this study we use the Mg II daily composite index from the University of Bremen (Snow et al., 2014), available online at http://www.iup.uni-bremen.de/gome/solar/MgII_composite.dat. The Bremen composite data set (Skupin et al., 2005) includes daily indices back to 1978. The solar Mg II Index is derived by taking the ratio between the spectral irradiance of the Mg II h and k absorption lines near 280 nm and the nearby background solar continuum (Heath & Schlesinger, 1986). Mg II varies with solar activity on many timescales (Dudok de Wit et al., 2008, 2009) and performs well as a proxy for solar activity and for some EUV emission (i.e., 25.0 - 35.0 nm Viereck et al., 2001). Since Mg II is generated from a ratio of measurements taken with the same instrument, despite requiring a spacecraft UV observation, the Mg II index is robust against instrument degradation and aging. The Mg II data is provided daily at 1200 UT.

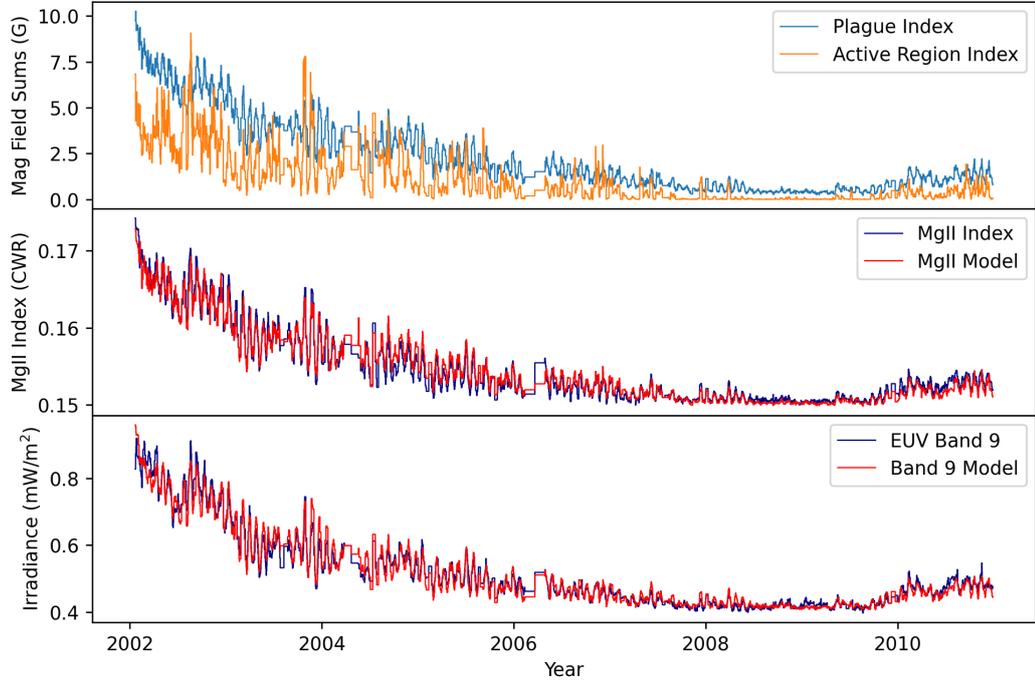


Figure 2. From top to bottom: the active and plage weighted magnetic sums, the Mg II nowcast model and observed values, and the Band 9 (29.0 - 32.0 nm) EUV nowcast model and observed values. Note that the magnetic Plage Index variability, both long and short term, agrees with Mg II and the EUV Band 9 time series over the full period. Similar figures for all 37 bands are available at doi: 10.5281/zenodo.10035713.

3.2 EUV and FUV Irradiance

The irradiance data used in this study are from the Thermosphere Ionosphere Mesosphere Energetic and Dynamics (TIMED) Solar EUV Experiment (SEE) observations from the EUV Grating Spectrograph (EGS) and XUV Photometer System (XPS) (Woods

et al., 1998). These data include low-resolution (~ 5 nm) diode measurements below 25 nm (XPS) and 0.4 nm resolution spectra between 25 and 195 nm (EGS) collected over ~ 3 -minute observation windows once per ~ 90 -minute orbit. We use the calibration version 11 EGS level 3 and XPS level 4 data products for this study. These data are averaged over a day to create this daily cadence data and flares have been removed. Additionally, we de-spike EUV Band 1 (i.e., range 0.05 - 0.4 nm) values above $0.7 \mu W/m^2$, replacing them with the average of the previous and following days' data points. Four data points (i.e., large "spikes") are removed from Band 1 across the entire nine-year period.

For this study, we re-bin these data into 37 bands between 0.05 nm to 175 nm shown in Table 1. These include the 22 bands defined in Solomon and Qian (2005) for input in general thermosphere and ionosphere models, plus 14 additional bands which cover the Shumann-Runge range (Torr et al., 1979), and the Lyman α line. While these 37 bands include XUV, EUV, and FUV irradiance, we will refer to them all as EUV bands and the spectrum they cover as the EUV for simplicity. The emission sources for each band include atomic transitions from the chromosphere through the corona. Shorter wavelengths (i.e., < 20 nm) are generally from coronal emission, and longer wavelengths (i.e., > 50 nm) generally come from the chromosphere and upper transition region (Doschek & Feldman, 2010), although this is not a sharp distinction. Beginning in 2002, the TIMED/SEE observations define the start of our investigation period which ends in 2011 to match Henney2015.

3.3 Photospheric Magnetic Field

Following Henney2012 and Henney2015, the magnetic field data used for this study are from global photospheric magnetic maps created by the ADAPT model (Arge et al., 2010, 2013; Hickmann et al., 2015). The ADAPT maps are generated by assimilating observations when available and applying surface flux transport based on Worden and Harvey (2000) to account for differential rotation, meridional circulation, and supergranulation flows between observations. The ADAPT sequence used in this study assimilates line-of-sight magnetograms from the Kitt Peak Vacuum Telescope (KPVT; Jones et al., 1992) and Vector Spectromagnetograph (VSM; Henney et al., 2009). These ground-based observations were obtained at irregular times, sometimes with many days between observations. For the model and observation comparison in this study, we applied a cubic spline interpolation to the TIMED/SEE EUV and Mg II daily indices to sample these series only when new data was assimilated into ADAPT.

4 EUV Nowcasts

4.1 SIFT: Solar Indices Forecasting Tool

The SIFT model uses empirical linear relationships to nowcast and forecast solar activity proxies and irradiance from photospheric magnetic fields. The fundamental assumption is that the magnetic field on the Earth-facing hemisphere of the Sun determines the observed solar irradiance. Following Henney2012 and Henney2015, the Earth-facing magnetic field in the ADAPT maps is summed into two bins corresponding to plage ($20 \text{ G} < B_r < 150 \text{ G}$), S_p , and active regions ($150 \text{ G} \leq B_r$), S_A . Although Henney2012 and Henney2015 started the plage bin at 25 G, we chose 20 G to remain consistent with the current SIFT implementation. The difference is also negligible to model performance. As outlined in Henney2012, the two sums are calculated as

$$S_p = \frac{1}{\sum \omega_\theta} \sum_{20\text{G} < |B_r|}^{|B_r| < 150\text{G}} |B_r| \omega_\theta \quad (1)$$

151 and

$$S_A = \frac{1}{\sum \omega_\theta} \sum_{|B_r| \geq 150\text{G}} |B_r| \omega_\theta, \quad (2)$$

152 where B_r is the radial magnetic field and ω_θ is an area weighting to account for the un-
 153 equal pixel areas in the plate carée ADAPT map (180 latitude pixels by 360 longitude
 154 pixels). All of the sums are over only the Earth-facing pixels. An example ADAPT global
 155 magnetic map, generated with NSO/GONG magnetograms, is illustrated in Figure 1,
 156 where the Earth-facing side of the sun is delineated by the white box and the regions
 157 with plage and active region fields are highlighted in red and blue, respectively. We then
 158 use linear regression to determine the coefficients for a model of the following form:

$$I_{model}^n = m_0^n + m_1^n S_P + m_2^n S_A \quad (3)$$

159 where n is the solar index or irradiance band number modeled and m_0 , m_1 , and m_2 are
 160 best fit coefficients. In Henney2012 and Henney2015 these models are trained indepen-
 161 dently for nowcasts and forecasts out to seven days. In this work, we create only now-
 162 cast models, although the procedures described below should work equally well for fore-
 163 casts.

164 4.2 Nowcasting the Mg II Index and EUV Irradiance

165 Using equation 3, independent models were generated for Mg II and each of the
 166 37 EUV bands using the entire 9-year data set. Timeseries of the magnetic sums (top),
 167 Mg II observations and model (middle), and EUV Band 9 (29-32 nm) observations and
 168 model (bottom) are shown in Figure 2. Consistent with the findings in Henney2012 and
 169 Henney2015, both the Mg II and EUV time series have similar variability to the mag-
 170 netic sums over all observed levels of solar activity. The simple multiple linear regres-
 171 sion Mg II model reproduces the observed Mg II well with a Pearson correlation coef-
 172 ficient of 0.982. The correlation of the observed and modeled EUV Band 9 is 0.978 and
 173 the correlations of all the EUV bands is given in Table 1. Note that the $r(I_{model}^n)$ val-
 174 ues in Table 1 slightly differ from Henney2012 and Henney2015. Since we chose to in-
 175 terpolate the Mg II and EUV timeseries to when new data was assimilated into ADAPT
 176 maps and the VSM magnetograms were recalibrated by NSO since Henney2012 and Hen-
 177 ney2015, some variation in our model correlation values are expected. In general, the EUV
 178 bands perform similarly well, although there are some with notably lower correlation co-
 179 efficients. Band 25, which has the lowest correlation of the 37 bands, is just blue-ward
 180 of Lyman α and the filter to ensure EGS does not saturate makes measuring this spec-
 181 tral range difficult (Woods et al., 2005). Meanwhile, Band 1 with the second worst cor-
 182 relation contains the highly-variable soft X-ray (SXR) that is particularly sensitive to
 183 solar flares. All the other EUV bands have a Pearson correlation better than 0.9.

184 The difference between the models and observed values in the various bands are
 185 not random in time. Figure 3 shows both the daily (points) and long-term trend (line)
 186 of the difference between the observed and modeled Mg II (top) and EUV Band 9 (bot-
 187 tom). These time series demonstrate the long-term deviation of the models from obser-
 188 vations (which are small) are temporally correlated over the nine-year period displayed
 189 in Figure 3. The daily differences are typically largest during maximum solar magnetic
 190 activity when the irradiance is most variable. This is expected because both the mag-
 191 netic sums and Mg II vary more during solar maximum than solar minimum, so the same
 192 relative difference results in larger absolute differences. Interestingly, the time-dependent
 193 long-term bias in these two models is largest at the intermediate activity levels during
 194 the decline of Solar Cycle 23.

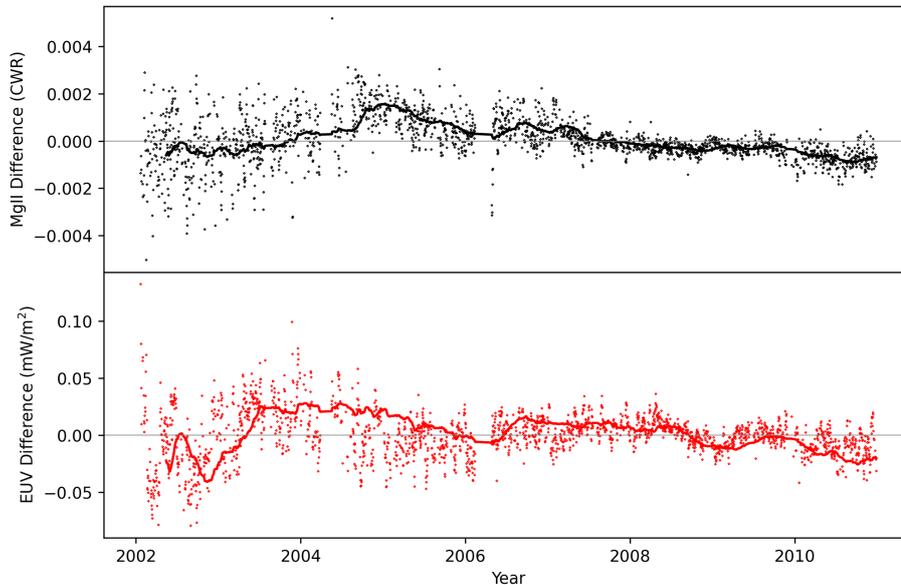


Figure 3. The daily (points) and 81-day running average difference between the observed Mg II (top) and EUV Band 9 (bottom). Notice that the Mg II and EUV offsets track each other well throughout the solar cycle.

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4.3 EUV Nowcast Correction

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The simple linear regression models applied in SIFT have a number of known limitations. Most fundamentally, while the magnetic field is responsible for solar activity (Petrie et al., 2021), the solar atmospheric response to photospheric magnetic fields is dynamic and non-linear (e.g., Tiwari et al., 2017), and may not always be well represented by a static model. Furthermore, solar EUV irradiance is often concentrated in active regions (depending on wavelength, see e.g., Kazachenko & Hudson, 2020), and the spatial information in the magnetic field is not included in the current SIFT modeling. Finally, the ADAPT maps that drive SIFT do not assimilate data near the limb (see Hickmann et al., 2015; Barnes et al., 2023) to reduce the introduction of artifacts from the line-of-sight magnetic field measurements that would otherwise be assumed to be radial (see, e.g., Harvey et al., 2007). This leads to a \sim two-day delay between when a flux concentration becomes visible on the Earth-facing solar hemisphere and when it is first assimilated into ADAPT.

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To mitigate signal delay issues, Henney2015 implemented a 0-day offset correction for the SIFT forecast models. For each set of daily forecasts, the difference between the model nowcast and associated observation was applied as a constant correction factor to all forecasts made on that day. The 0-day offset technique compensates for local inadequacies in the model while still utilizing the full-Sun nature of ADAPT that enables forecasting. However, the technique applied by Henney2015 requires an observation in each band of the model to determine and apply the corresponding correction. Currently, with aging EUV irradiance observatories and limited EUV spectral coverage (P. Chamberlin et al., 2023), selected bands of EUV observations are not reliably available. It is therefore valuable to apply a similar correction without the need for daily measurements in each EUV band.

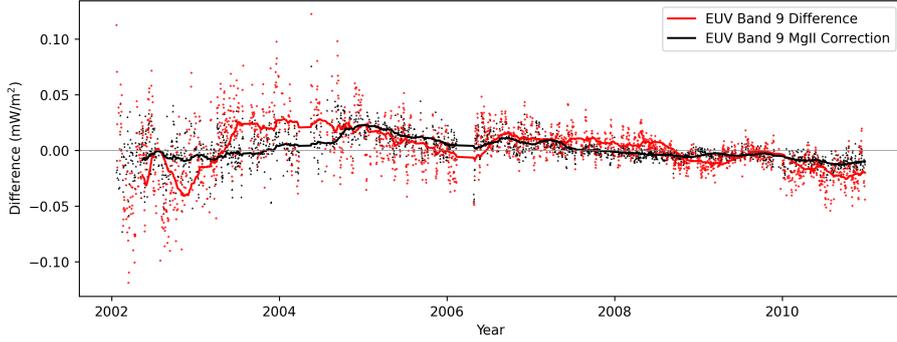


Figure 4. A plot of the difference between observed and modeled Band 9 EUV values, and the EUV difference model. The difference model was developed by comparing EUV to Mg II offset values.

220 The difference between the modeled and observed Mg II (top) and EUV Band 9
 221 (bottom) in Figure 3 appear to correlate somewhat over a solar cycle timescale. This sug-
 222 gests that the errors in the EUV band models could be reduced by applying a time-dependent
 223 correction to each band by using the difference between the daily observed and modeled
 224 Mg II. We create this correction model by linearly correlating the daily model-observation
 225 difference in Mg II with each of the EUV bands such that

$$I_{model}^n - I_{observed}^n = m_3^n \left(I_{model}^{Mg II} - I_{observed}^{Mg II} \right) = m_3^n C \quad (4)$$

226 and then applying this correction term to equation 3, we get the following

$$I_{corrected}^n = m_0^n + m_1^n S_P + m_2^n S_A - m_3^n C, \quad (5)$$

227 which yields an Mg II-corrected multiple linear regression for each band. We chose to
 228 model the Mg II correction term with only one coefficient, vice a multi-coefficient linear
 229 regression, because additional constants were several orders of magnitude smaller than
 230 the m_3 correction coefficient, as well as m_0 , m_1 , and m_2 . Therefore, additional coeffi-
 231 cients had no effect on model performance or improvement. The coefficients for these
 232 models are shown in Table A1 in the appendix. The Mg II correction term on EUV Band
 233 9 (i.e., $m_3^n C$) is plotted (black) in Figure 4 along with the original model-observation dif-
 234 ference (red) from the bottom panel in 3. If these points (and lines) overlapped perfectly
 235 then the Mg II correction term would allow perfect nowcasting of the EUV band, and
 236 anywhere that the two have opposite sign indicates when the Mg II correction harms the
 237 nowcast. This correction term does not provide improvements at all times, however, on
 238 average the model-observation difference is reduced with this correction.

239 Improved nowcasting is found to be consistent across all 37 bands as reported in
 240 Table 1 and displayed in Figure 5. This shows the Pearson correlation coefficient between
 241 both the original and corrected models and the observations of all bands over the entire
 242 period studied. The Mg II correction yields improved correlations across all bands, with
 243 particular improvement in Band 25 which has the worst correlation. The m_1/m_2 val-
 244 ues (see Table A1) also demonstrate why a Mg II correction term is suitable for these
 245 models. The m_1/m_2 Mg II and all of EUV band m_1/m_2 values, except for Band 1, are
 246 greater than 1, demonstrating that there is a larger dependence on plage regions for the
 247 Mg II and the EUV bands. Henney2015 found that m_1/m_2 for $F_{10.7}$ is less than 1, indi-
 248 cating that it is more strongly dependent on active regions. This indicates that the Mg
 249 II proxy, rather than the active-region dependent $F_{10.7}$, is more consistent with the be-
 250 havior of the solar EUV spectrum.

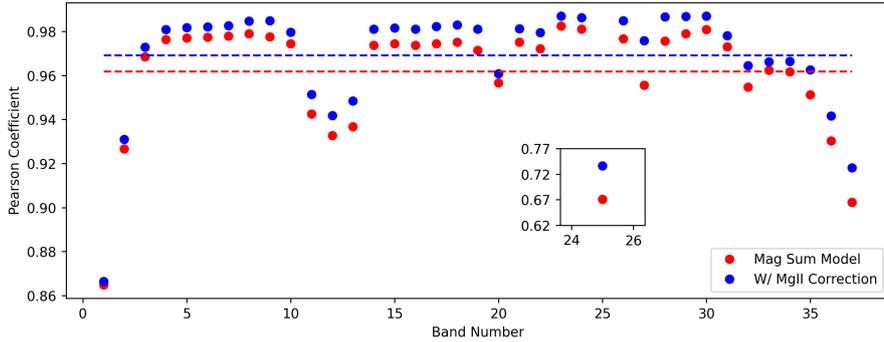


Figure 5. Pearson correlation coefficients which compare the relationship between each observed EUV spectral band and the nowcast models with and without a Mg II correction. Since Band 25 did not perform as well compared to the other bands, its Pearson coefficients are included on a separate, sub-graph to enhance the results of the other bands. The horizontal dashed lines indicate the average Pearson correlation coefficient across all bands (except band 25).

251 Additionally, Figure 6 exhibits the long-term variability of the band 9 models be-
 252 fore (blue) and after (orange) applying the Mg II offset correction. This plot shows that
 253 the error between the observations and model are typically smaller (i.e., the distribution
 254 shifts closer to 0) and the range in variation decreases (i.e., the vertical range of each box
 255 is smaller). Interestingly, the overall trend of the model-observation difference over the
 256 solar cycle does not change, with the model tending to predict more irradiance than ob-
 257 served during the decline of the solar cycle (2003-2007) and less during the rise and max-
 258 imum (2002 and 2010). Warren et al. (2021) identify a similar trend in their models which
 259 they attribute to discrepancies in the weak magnetic fields ($B_r < 80$ G) between the full-
 260 Sun magnetic maps and the original observed magnetograms. We identify two additional
 261 possible explanations for this effect. It could indicate that the conversion of magnetic
 262 energy into plasma heating in the solar atmosphere is slightly more efficient during the
 263 rising phase and solar maximum (leading to more emission than predicted) than the de-
 264 cline phase (with less emission than predicted). It could also be the result of some other
 265 long-term variation in the ADAPT maps. For example, because of the delay between the
 266 rotation of magnetic flux onto the Earth-facing hemisphere and the incorporation of this
 267 flux into ADAPT, the ADAPT maps in general under-represent the magnetic flux on
 268 the Earth-facing hemisphere. This effect will be stronger during the rising phase and max-
 269 imum of the solar cycle when flux emergence is greatest and therefore more flux appears
 270 on the farside and is not included in ADAPT until it rotates into the data assimilation
 271 window. A more detailed study is needed to better understand the source of this long-
 272 term residual trend (e.g., adding another solar cycle of data analysis and/or using dif-
 273 ferent magnetograph inputs, e.g., SDO/HMI and NSO/GONG).

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275 5 Summary

276 This study builds on the work of the SIFT model, outlined in Henney2012 and Hen-
 277 ney2015, that demonstrated the ability of ADAPT global photospheric magnetic maps
 278 to drive irradiance nowcasts and forecasts. The original SIFT EUV forecasts benefited
 279 greatly from daily calibration of the models to the observed irradiance which corrected

Band (n)	Range (nm)	r(Mg II)	$r(I_{model}^n)$	$r(I_{model}^n$ with offset)
1	0.05-0.4	0.845	0.865	0.866
2	0.4-0.8	0.920	0.927	0.931
3	0.8-1.8	0.965	0.969	0.973
4	1.8-3.2	0.975	0.976	0.981
5	3.2-7.0	0.976	0.977	0.982
6	7.0-15.5	0.976	0.977	0.982
7	15.5-22.4	0.977	0.978	0.983
8	22.4-29.0	0.980	0.979	0.985
9	29.0-32.0	0.982	0.978	0.985
10	32.0-54.0	0.975	0.974	0.980
11	54.0-65.0	0.948	0.942	0.951
12	65.0-79.8 (low)	0.937	0.933	0.942
13	65.0-79.8 (high)	0.945	0.937	0.948
14	79.8-91.3 (low)	0.978	0.974	0.981
15	79.8-91.3 (middle)	0.978	0.974	0.982
16	79.8-91.3 (high)	0.978	0.974	0.981
17	91.3-97.5 (low)	0.980	0.974	0.982
18	91.3-97.5 (middle)	0.981	0.975	0.983
19	91.3-97.5 (high)	0.979	0.971	0.981
20	97.5-98.7	0.955	0.957	0.961
21	98.7-102.7	0.978	0.975	0.981
22	102.7-105.0	0.977	0.972	0.979
23	105.0-110.0	0.982	0.982	0.987
24	110.0-115.0	0.982	0.981	0.986
25	115.0-120.0	0.714	0.671	0.736
26	121.6 (Lyman α)	0.981	0.977	0.985
27	120.0-125.0	0.975	0.956	0.976
28	125.0-130.0	0.985	0.976	0.987
29	130.0-135.0	0.985	0.979	0.987
30	135.0-140.0	0.983	0.981	0.987
31	140.0-145.0	0.974	0.973	0.978
32	145.0-150.0	0.963	0.955	0.965
33	150.0-155.0	0.961	0.962	0.966
34	155.0-160.0	0.962	0.962	0.966
35	160.0-165.0	0.962	0.951	0.963
36	165.0-170.0	0.941	0.930	0.942
37	170.0-175.0	0.918	0.902	0.918

Table 1. EUV irradiance bands and associated correlation coefficients. $r(\text{Mg II})$ is the correlation between the modeled band irradiance and the observed Mg II. $r(I_{model}^n)$ is the correlation between the modeled band irradiance and the observed band irradiance, and $r(I_{model}^n$ with offset) includes the Mg II correction term (i.e. equation 5) .

280 short-term errors between the models and observations. However, for periods without
281 real-time calibrated EUV spectral measurements, the original correction technique is not
282 an option for real-time predictions.

283 In the study presented here, we develop an alternative implementation of daily cor-
284 rections that does not rely on current EUV irradiance observations. Instead, the daily
285 model and observation is regularly measured for a proxy, in this case the Mg II index.

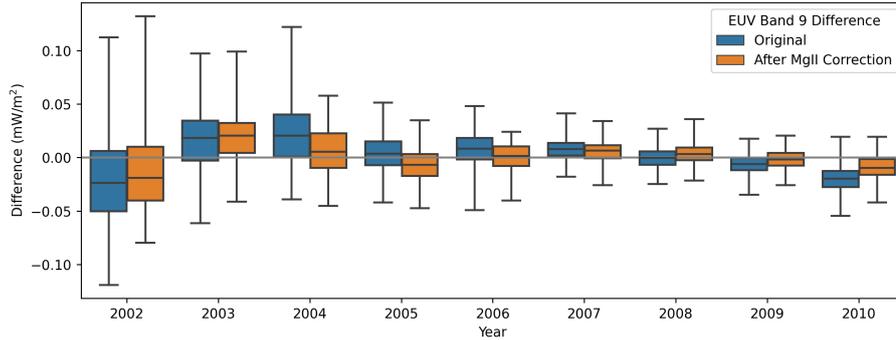


Figure 6. A box and whisker plot for EUV spectral band 9, highlighting the distributions of the difference between the observed and modeled offset values during the study period. The box indicates the extent of the 25% and 75% quartiles and the line through the box indicates the distribution median over one year of data. The whiskers (i.e., the vertical lines) indicate the minimum and maximum. The distributions including the Mg II correction do not strictly improve, however the improvements (i.e. 2004 and 2010) are much more significant than the occasional times when the distributions worsen (i.e. 2003 and 2005). Similar figures for all 37 bands are available at doi:10.5281/zenodo.10035713.

286 Then, that Mg II index nowcast offset is scaled and applied to each EUV irradiance band
 287 independently. Applying this correction term to simple multiple linear regression mod-
 288 els yields improved nowcasts across the entire spectral range, with the average Pearson
 289 correlation coefficient increasing from 0.962 to 0.969. This method can be applied us-
 290 ing existing operationally available data products and can also easily be extended to fore-
 291 casting EUV bands to drive terrestrial atmospheric models.

292 We also identify a solar-cycle trend in the regression models that typically under-
 293 predict the irradiance during the rising and maximum phases and over-predict the ir-
 294 radiance during the declining phase. This could indicate deficiencies in the ADAPT maps
 295 driving these irradiance nowcasts or an underlying nonlinear conversion of photospheric
 296 magnetic energy and chromospheric and coronal heating (e.g., not captured with the sim-
 297 ple linear regression models applied here). Future work is needed to better understand
 298 the source of the model and observation residuals over the solar cycle (e.g., besides adding
 299 another 10 years of data analysis, need to also use different magnetograph inputs that
 300 overlap, e.g., SDO/HMI and NSO/GONG).

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Open Research

Data Availability Statement

The Mg II composite index is provided by the University of Bremen at http://www.iup.uni-bremen.de/gome/solar/MgII_composite.dat. The Mg II index is also available with figures for all 37 EUV bands and scripts used to compile the models are available through Zenodo at doi: 10.5281/zenodo.10035713 (Kniezewski et al., 2023). The solar magnetic sums based on ADAPT are available through Zenodo at doi: 10.5281/zenodo.10070554 (Henney et al., 2023). The EUV indices are provided through Zenodo at doi: 10.5281/zenodo.10119832 (R. A. Hock et al., 2023).

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Appendix A

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Coefficients for the SIFT linear regression models are given in Table A1.

Band (n)	m_0	m_1	m_2	m_3	m_1/m_2
Mg II	1.494×10^{-1}	2.044×10^{-3}	5.321×10^{-4}	N/A	3.841
1	-6.375×10^{-9}	1.492×10^{-8}	2.068×10^{-8}	3.620×10^{-6}	0.721
2	-1.811×10^{-7}	6.190×10^{-7}	5.728×10^{-7}	2.065×10^{-4}	1.081
3	-1.393×10^{-6}	2.193×10^{-5}	1.352×10^{-5}	6.112×10^{-3}	1.622
4	1.449×10^{-5}	1.095×10^{-5}	5.350×10^{-6}	2.969×10^{-3}	2.047
5	5.734×10^{-5}	1.891×10^{-5}	9.077×10^{-6}	5.115×10^{-3}	2.083
6	1.054×10^{-4}	4.429×10^{-5}	2.129×10^{-5}	1.212×10^{-2}	2.080
7	3.860×10^{-4}	1.370×10^{-4}	6.407×10^{-5}	3.374×10^{-2}	2.138
8	9.538×10^{-5}	3.947×10^{-5}	3.314×10^{-6}	9.787×10^{-3}	11.910
9	3.916×10^{-4}	5.032×10^{-5}	8.284×10^{-6}	1.453×10^{-2}	6.074
10	2.461×10^{-4}	6.129×10^{-5}	1.234×10^{-5}	1.535×10^{-2}	4.968
11	1.462×10^{-4}	7.596×10^{-6}	4.128×10^{-6}	2.991×10^{-3}	1.840
12	5.954×10^{-5}	1.824×10^{-6}	1.226×10^{-6}	7.773×10^{-4}	1.488
13	3.210×10^{-5}	1.139×10^{-6}	7.029×10^{-7}	5.338×10^{-4}	1.620
14	4.117×10^{-5}	4.389×10^{-6}	7.483×10^{-7}	1.281×10^{-3}	5.866
15	1.148×10^{-4}	1.461×10^{-5}	2.240×10^{-6}	4.173×10^{-3}	6.525
16	5.311×10^{-5}	5.979×10^{-6}	1.019×10^{-6}	1.727×10^{-3}	5.868
17	1.776×10^{-5}	1.731×10^{-6}	3.693×10^{-7}	5.382×10^{-4}	4.687
18	4.001×10^{-5}	3.727×10^{-6}	9.899×10^{-7}	1.182×10^{-3}	3.765
19	1.720×10^{-5}	2.195×10^{-6}	3.766×10^{-7}	7.399×10^{-4}	5.831
20	5.417×10^{-5}	1.105×10^{-5}	1.422×10^{-6}	2.401×10^{-3}	7.769
21	8.049×10^{-5}	1.196×10^{-5}	2.418×10^{-6}	3.241×10^{-3}	4.945
22	8.414×10^{-5}	1.081×10^{-5}	2.200×10^{-6}	3.208×10^{-3}	4.913
23	7.619×10^{-5}	6.424×10^{-6}	1.795×10^{-6}	1.560×10^{-3}	3.579
24	6.830×10^{-5}	5.224×10^{-6}	1.423×10^{-6}	1.358×10^{-3}	3.671
25	1.626×10^{-4}	2.925×10^{-6}	2.125×10^{-6}	4.095×10^{-3}	1.377
26	5.444×10^{-3}	6.080×10^{-4}	3.115×10^{-5}	1.760×10^{-1}	19.519
27	8.198×10^{-4}	6.062×10^{-5}	8.048×10^{-6}	2.913×10^{-2}	7.533
28	1.978×10^{-5}	1.289×10^{-6}	2.281×10^{-7}	4.654×10^{-4}	5.652
29	3.588×10^{-4}	1.945×10^{-5}	5.450×10^{-6}	6.208×10^{-3}	3.569
30	1.812×10^{-4}	8.200×10^{-6}	2.413×10^{-6}	2.307×10^{-3}	3.398
31	2.249×10^{-4}	7.655×10^{-6}	2.082×10^{-6}	1.977×10^{-3}	3.677
32	3.242×10^{-4}	7.213×10^{-6}	2.338×10^{-6}	2.665×10^{-3}	3.085
33	5.609×10^{-4}	1.502×10^{-5}	5.474×10^{-6}	3.504×10^{-3}	2.744
34	7.857×10^{-3}	1.711×10^{-5}	4.471×10^{-6}	4.153×10^{-3}	3.828
35	1.114×10^{-3}	1.854×10^{-5}	5.369×10^{-6}	7.270×10^{-3}	3.454
36	2.053×10^{-3}	2.889×10^{-5}	7.706×10^{-6}	1.113×10^{-2}	3.749
37	3.391×10^{-3}	4.590×10^{-5}	7.587×10^{-6}	2.041×10^{-2}	6.050

Table A1. EUV model coefficients, including the difference model coefficients using Mg II.

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