Semi-Annual Report:

Analysis of Solar Spectral Irradiance Measurements from the SBUV/2-Series and the SSBUV Instruments

Period of Performance: 1 March 1996 to 31 August 1996

31 October 1996

Contract Number: NASW-4864

Principal Investigator: Richard P. Cebula

Co-Investigators: Matthew T. DeLand

Ernest Hilsenrath

1. SUMMARY OF ACTIVITY DURING THE CURRENT PERFORMANCE PERIOD

1.1 Development of the Long-term NOAA-11 SBUV/2 Solar Irradiance Data Set

The purpose of this research is to develop a NOAA-11 SBUV/2 solar spectral irradiance data set which is free from long-term instrument drift, then perform scientific analysis using the data set. Since the SBUV/2 instrument does not carry an onboard calibration system capable of end-to-end instrument characterization, the long-term calibration of the satellite instrument is being determined via regular comparisons with coincident SSBUV solar irradiance data. During the current period of performance, 29 February 1996 through 31 August 1996, we finalized the NOAA-11 SBUV/2 characterization using internal data. This included updating the instrument's electronic, photomultiplier tube gain, wavelength, diffuser degradation, and goniometric calibrations. We have also completed the SSBUV characterization, 1989-1994, and produced SSBUV irradiances for the first seven SSBUV flights. Both of these steps were needed before the long-term calibration of the NOAA-11 SBUV/2 solar spectral irradiance data set via SSBUV can be undertaken. This process is now underway.

1.2 Comparisons With Other Instruments

A second major aspect of this work is to compare solar spectral irradiances from the SBUV/2 instruments and SSBUV with corresponding data from other instruments. In the preceding six months, SSBUV data from the ATLAS-3 (November 1994) mission were compared to coincident SUSIM ATLAS-3 data. This comparison is shown in Figure 1. The agreement between the two instruments is comparable to that seen during the ATLAS-1 and ATLAS-2 missions (Cebula et al., 1996; Woods et al., 1996). The SSBUV ATLAS-1 data are also being used to validate the SOLSPEC irradiances in the near UV ($\lambda > 350$ nm).

The GOME instrument was launched by the European Space Agency in early 1995 and began making solar irradiance measurements in May 1995. Working with GOME scientists, we are using SSBUV data to validate the GOME solar irradiance data. Previously, the GOME irradiances were found to have a significant bias with respect to SSBUV. Based in part on those findings, the GOME absolute calibration data were reanalyzed. The resulting revised GOME solar irradiance data are compared to coincident SSBUV-8 data in Figure 2. The agreement between GOME data and SSBUV is much improved over the previous comparison. However, clear evidence of etaloning (the quasi-sinusoidal structure) is in evidence. This effect is thought to result from a build-up of a thin film ice layer on the GOME detector.

1.3 NOAA-14 SBUV/2 Analysis

The fourth instrument in the SBUV/2 series was launched on the NOAA-14 satellite in December 1994 and first observed the sun in February 1995. Due to significant grating drive problems, daily

sweep mode solar spectral irradiance measurements were terminated in October 1995. Discrete mode measurements at the Mg II index wavelengths commenced in late January 1996. Analysis indicated that these data are also severely impacted by the grating drive problems and that most of the Mg II data taken at the standard Mg II wavelengths are not useful in assessing solar rotational and long-term variations. Given the ongoing NOAA-14 SBUV/2 grating drive problems, we worked closely with NASA and NOAA scientists to develop alternate operations plans. Unfortunately, the instrument's wavelength drive mechanism "froze up" on 7 June 1996. Although controllers were able to free the grating drive, given the worsening drive system behavior, the decision was made to eliminate all NOAA-14 SBUV/2 solar measurements other than those required for ozone determination.

1.4 Mg II Proxy Index Analysis

SBUV/2 classical discrete mode Mg II proxy indexes were created using updated instrument characterizations. The NOAA-9 index, Figure 3, presently covers the period June 1986 through June 1996. The NOAA-11 index, Figure 4, covers the entire NOAA-11 data record, January 1989 through October 1994. These data are presently being compared to Mg II proxy indexes determined from UARS SUSIM (Figure 5a) and UARS SOLSTICE (Figure 5b). These comparisons and periodogram analysis (Figure 6) indicate comparable tracking of short and long-term solar variations. Figure 5a also indicates that the UARS SUSIM index drifted by roughly 1.5% with respect to the NOAA-11 SBUV/2 index during the initial phase of the SUSIM instrument's operation. Similar drifts are seen between SUSIM and NOAA-9 and between SUSIM and SOLSTICE during the first seven months of SUSIM operation. Analysis and validation of the SBUV/2 Mg II data sets continues.

1.5 SSBUV Analysis

The SSBUV experiment flew for final time on STS-72 from 11-20 January 1996. The instrument observed the sun on four separate occasions during the mission. We are presently analyzing the SSBUV prelaunch and postlaunch calibration data, and assessing in-flight calibration data. In the near UV, SSBUV-8 solar data processed using a preliminary radiometric calibration agree with data from previous missions to within 1%. Additional efforts are being made to further improve the consistency with previous missions.

1.6 SOLERS22 Activities

Dr. Cebula is Leader of the Middle Ultraviolet Working Group (WG2) of the Solar Electromagnetic Radiation Study for Solar Cycle 22 (SOLERS22). SOLERS22 held a workshop from 17-21 June 1996 at the Sacramento Peak Observatory, Sunspot, New Mexico. This workshop was designated as the 17th National Solar Observatory/Sacramento Peak Summer Workshop. Both Dr. Cebula and Mr. DeLand participated in the Workshop. Dr. Cebula served on the scientific organizing committee

for the Workshop and presented the WG2 workshop report. In addition, Dr. Cebula, Mr. DeLand, and Mr. Hilsenrath authored four contributed papers which were presented at the Workshop.

1.7 Presentations and Publications

Three papers discussing research that was supported by NASA Research Grant NASW-4864 were published in American Geophysical Union journals during the past six months. Four papers and the WG2 report were presented at the SOLERS22 1996 Workshop. In addition, two papers were submitted for presentation at the American Geophysical Union 1996 Fall Meeting. Reprints of the three AGU papers were previously delivered under separate cover. Copies of the two abstracts submitted for presentation at the Fall AGU meeting are attached.

Cebula, R. P., and M. T. DeLand, Mg II Index Comparisons: NOAA-11 SBUV/2, UARS SOLSTICE, and UARS SUSIM, National Solar Observatory 17th International Workshop/SOLERS22 1996 Workshop, *Workshop Agenda and Abstracts*, 1996.

Cebula, R. P., and E. Hilsenrath, SSBUV Measurements of Solar Spectral Irradiance Variations, 1989-1996, *AGU 1996 Fall Meeting*, submitted, 1996.

Cebula, R. P., G. O. Thuillier, M. E. VanHoosier, E. Hilsenrath, M. Herse, G. E. Brueckner, and P. C. Simon, Observation of the Solar Irradiance in the 200-350 nm Interval during the ATLAS-1 Mission: A Comparison Among Three Sets of Measurements - SSBUV, SOLSPEC, and SUSIM, *Geophys. Res. Lett.*, **23**, 2289-2292, 1996.

DeLand, M. T., and R. P. Cebula, Solar UV Activity at Solar Cycle 22 Minimum - Evidence for 13-day Periodic Variations, National Solar Observatory 17th International Workshop/SOLERS22 1996 Workshop, *Workshop Agenda and Abstracts*, 1996.

DeLand, M. T., R. P. Cebula, and E. Hilsenrath, Solar UV Contributions to Stratospheric Ozone Variations 1989-1994, *Proceedings of the XVIII Quadrennial Ozone Symposium*, submitted, 1996.

DeLand, M. T., R. P. Cebula, and E. Hilsenrath, Solar Spectral Irradiance Variations Observed by NOAA-11 SBUV/2 During 1988-1994, *AGU 1996 Fall Meeting*, submitted, 1996.

Hilsenrath, E., R. P. Cebula, M. C. Bories, J. J. Cerullo, P. W. DeCamp, L.-K. Huang, C. N. Hui, S. J. Janz, T. J. Kelly, K. R. McCullough, J. J. Mederios, J. T. Riley, B. K. Rice, and C. D. Thorpe, Contributions of the SSBUV Experiment to Long-Term Ozone Monitoring, *Proceedings of the XVIII Quadrennial Ozone Symposium*, submitted, 1996.

Janz, S. J., E. Hilsenrath, R. P. Cebula, and T. J. Kelly, Observations of the Lunar Albedo during the ATLAS-3 Mission, *Geophys. Res. Lett.*, **22**, 2297-2300, 1996.

VanHoosier, M. E., R. P. Cebula, G. E. Brueckner, and E. Hilsenrath, Solar Ultraviolet Spectral Irradiance Observations in the 200-400 nm Wavelength Range by the SUSIM and SSBUV Instruments During the ATLAS-3 Mission, National Solar Observatory 17th International Workshop/SOLERS22 1996 Workshop, *Workshop Agenda and Abstracts*, 1996.

Weber, M., J. P. Burrows, and R. P. Cebula, Solar UV and Visible Spectral Irradiance Measurements from GOME in 1995 and 1996, National Solar Observatory 17th International Workshop/SOLERS22 1996 Workshop, *Workshop Agenda and Abstracts*, 1996.

Woods, T. N., D. K. Prinz, J. London, G. J. Rottman, P. C. Crane, R. P. Cebula, E. Hilsenrath, G. E. Brueckner, M. D. Andrews, O. R. White, M. E. VanHoosier, L. E. Floyd, L. C. Herring, B. G. Knapp, C. K. Pankratz, and P. A. Reiser, Validation of the UARS and ATLAS Solar Ultraviolet Irradiances, *J. Geophys. Res.*, **101**, 9541-9569, 1996.

2.0 WORK PLANNED: 1 SEPTEMBER 1996 THROUGH 28 FEBRUARY 1997

During the upcoming period of performance, 1 September 1996 through 28 February 1997, efforts will concentrate on the development of the NOAA-11 SBUV/2 solar irradiance data set. The long-term calibration of the NOAA-11 SBUV/2 instrument is being determined via comparisons to the approximately yearly SSBUV flights. We are refining the details of this spectral and temporal calibration transfer. It is anticipated that this process will be completed in early 1997.

Analysis of the NOAA-11 SBUV/2 solar spectral irradiance data set will begin in earnest at that point. Time series at selected wavelengths will be developed and analyzed. The region near 205 nm, which is especially important for stratospheric chemistry, will receive particular attention. Also of special interest will be analysis of the data in the region near 230 to 250 nm, again due to the importance of this region for stratospheric chemistry. The SBUV/2 solar data will also be compared to coincident data from the UARS SOLSTICE and SUSIM instruments.

A data set consisting of NOAA-11 SBUV/2 solar irradiances on a standard 1 nm grid (corresponding to the UARS level 3BS product, which is available from the NASA GSFC DAAC) will be developed in parallel to the above activities. After quality checking and validation, this data set will be released to the scientific community via anonymous ftp.

Once validation and quality checking of the NOAA-9 and NOAA-11 SBUV/2 classical discrete Mg II proxy index data sets is complete, those data sets will also be made available via anonymous ftp.

After the long-term NOAA-11 SBUV/2 characterization is finalized via the comparisons with SSBUV data, work will resume on developing the SBUV/2 composite Mg II proxy index based on discrete mode data. Although it is well established that measurements of the Mg II proxy index can be used to model the short-term behavior of the middle UV solar spectral irradiance, it is not yet

proven that the Mg II index can be used to accurately predict long-term solar irradiance change in this spectral region. Long-term changes in the solar spectral irradiance measured by the NOAA-11 instrument will be compared with the variations predicted by the updated SBUV/2 Mg II index and scale factors.

Pre- and postflight calibration of the instrument and determination of SSBUV-8 solar spectral irradiances will be completed during this period.

As follow-up to the SOLERS22 1996 Workshop, Dr. Cebula will write the WG2 Workshop Report. This report will be included in the Proceedings of the Workshop, which will be published by Kluwer Academic Publishers and edited by Dr. J. M. Pap. The four contributed papers presented at the SOLERS22 1996 Workshop will be submitted for publication in *Solar Physics*.

Dr. Cebula and Mr. DeLand will also participate in the XVIII Quadrennial Ozone Symposium, from 12-21 September in L'Aquila, Italy. Two papers related to this research have been accepted for presentation at the Symposium. Presentations will be given and the papers will be submitted for publication in the Symposium's proceedings.

Finally, Dr. Cebula and Mr. DeLand will attend the AGU 1996 Fall Meeting. Dr. Cebula will chair a session entitled "Has the Sun Changed the Climate" on 19 December 1996. Two contributed papers will be presented at the meeting.

SSBUV Measurements of Solar Spectral Irradiance Variations, 1989-1996

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E Hilsenrath (NASA Goddard Space Flight Center, Code 916, Greenbelt, MD 20771; 301-286-6051; e-mail: hilsenrath@ssbuv.gsfc.nasa.gov)

The Shuttle Solar Backscatter Ultraviolet (SSBUV) experiment provided measurements of long-term solar spectral irradiance changes at 1.1 nm resolution in the wavelength region 200-405 nm during the maximum and declining phase of solar cycle 22. SSBUV flew eight Space Shuttle missions between October 1989 and January 1996. In addition to extensive preflight and postflight laboratory absolute radiometric calibrations, the instrument's sensitivity was tracked via an onboard calibration system and additional repeatability calibrations. The estimated 2σ absolute uncertainty in the SSBUV solar data ranges from 2.4% near 400 nm to 6.0% near 200 nm. The uncertainty in the long-term trend derived from the SSBUV data is significantly smaller than is the error in the absolute irradiance.

An overview of the SSBUV long-term solar spectral irradiance data base will be provided and the SSBUV data will be compared to coincident observations from other Space Shuttle and satellite-based instruments. For the period October 1989 through November 1994, SSBUV measured solar irradiance changes ranging from as much as approximately 7% shortward of the Al edge to 1% or less near 400 nm. These values will be updated to include the data from the final SSBUV mission in January 1996.

1. 1996 Fall Meeting

2. 00650983

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4. SH

5. (a) SH05 Has the Sun Changed the Climate?
(b) 0340 Middle atmosphere composition and chemistry; 7549 Ultraviolet emissions; 7594 Instruments and techniques
(c) Climate and Global Change

6. Oral preferred

7.

8. 15%; SOLERS22 Workshop

9. Charge $50 to credit card information on attached sheet

10. C

11. Schedule immediately prior to paper by DeLand, Cebula, and Hilsenrath

12. Yes, Solar and Heliospheric Physics Section;
Subject Area: Observations and Techniques

13. No

Solar Spectral Irradiance Variations Observed by NOAA-11 SBUV/2 During 1988-1994

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E Hilsenrath (NASA Goddard Space Flight Center, Code 916, Greenbelt, MD 20771; tel. 301-286-6051; *hilsenrath-@ssbuv.gsfc.nasa.gov*)

The NOAA-11 SBUV/2 instrument made daily measurements of the solar UV irradiance between 160 and 405 nm at 1.1 nm resolution from December 1988 to October 1994, covering the maximum and declining phase of solar cycle 22. Instrument sensitivity changes were significant, ranging from approximately 30% near 200 nm to roughly 4% near 400 nm. These changes are 3-4 times larger than the predicted solar irradiance variations in the middle and near UV over a solar cycle. The SBUV/2 data have been reprocessed using a long-term characterization determined from both internal and external sources. An onboard calibration system was used to monitor long-term diffuser reflectivity changes, and comparisons with coincident flights of the SSBUV experiment were used to remove additional long-term NOAA-11 instrument sensitivity drift.

We present NOAA-11 solar UV irradiance observations during 1988-1994 for spectral regions which drive atmospheric photochemistry. The NOAA-11 results indicate a decrease of approximately 5-7% at 205 nm from the maximum of solar Cycle 22 in 1989-1991 through the end of the NOAA-11 record in October 1994, well into the declining phase of Cycle 22. The NOAA-11 irradiance data indicate an upper limit of roughly 1.5% on long-term solar change between 290-310 nm during this period, consistent with predictions from proxy indexes and scaling functions. We will also compare the NOAA-11 observations to the daily spectral irradiances from the UARS SUSIM V16 and UARS SOLSTICE V8 data sets, both of which cover the period September 1991 - October 1994.

1. 1996 Fall Meeting

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4. SH

5. (a) SH05 Has the Sun Changed the Climate?

   (b) 7549 Ultraviolet Emissions
   0340 Middle atmosphere - composition and chemistry

   (c) Climate and Global Change

6. Oral preferred

7. None

8. 25%; Spring 1995 AGU

9. Charge $50 to credit card information on attached sheet

10. C

11. Schedule immediately after paper by Cebula & Hilsenrath

12. No

Figure 1

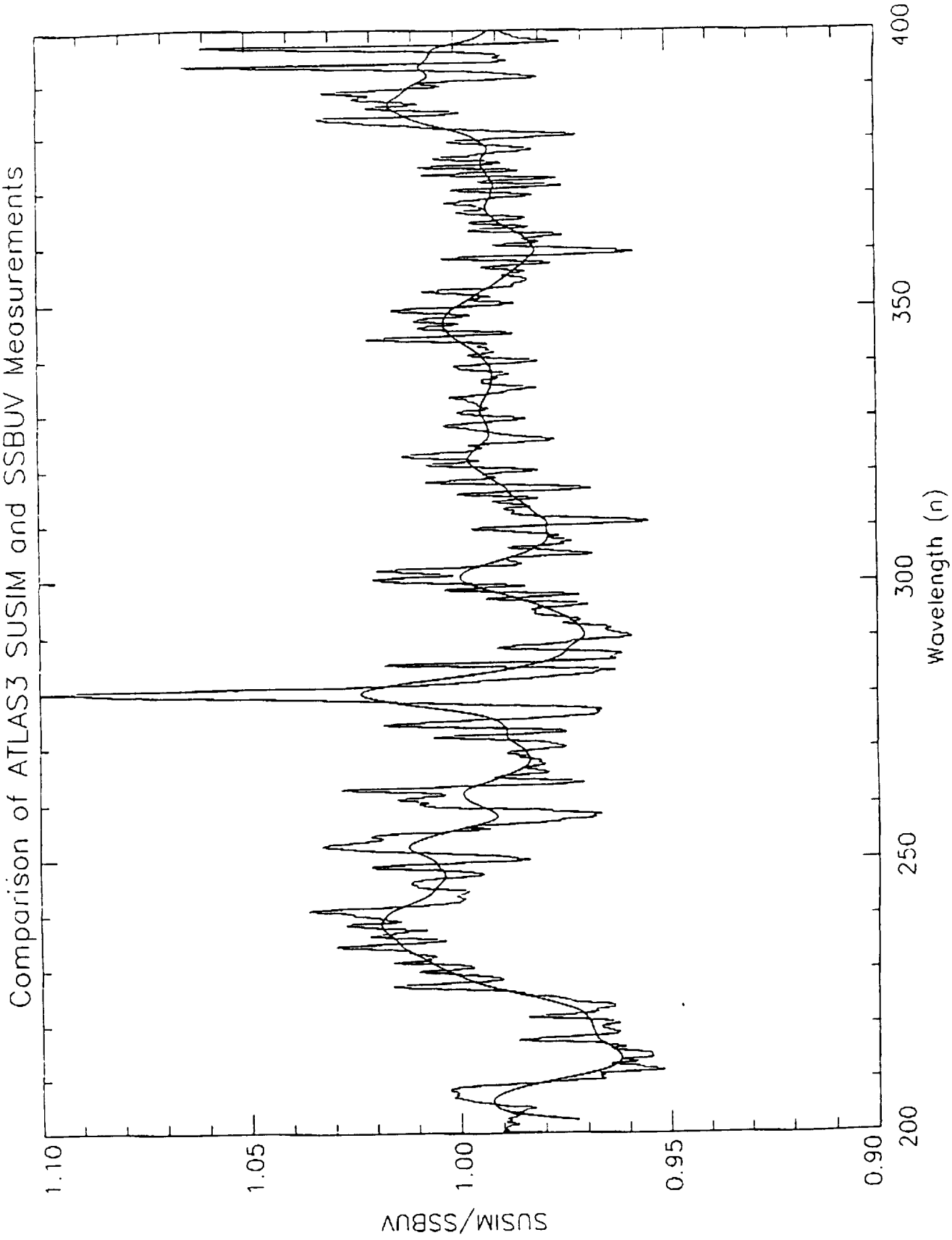

Comparison of ATLAS3 SUSIM and SSBUV Measurements
SUSIM/SSBUV
1.10
1.05
1.00
0.95
0.90
200
250
300
350
400
Wavelength (n)

Figure 2

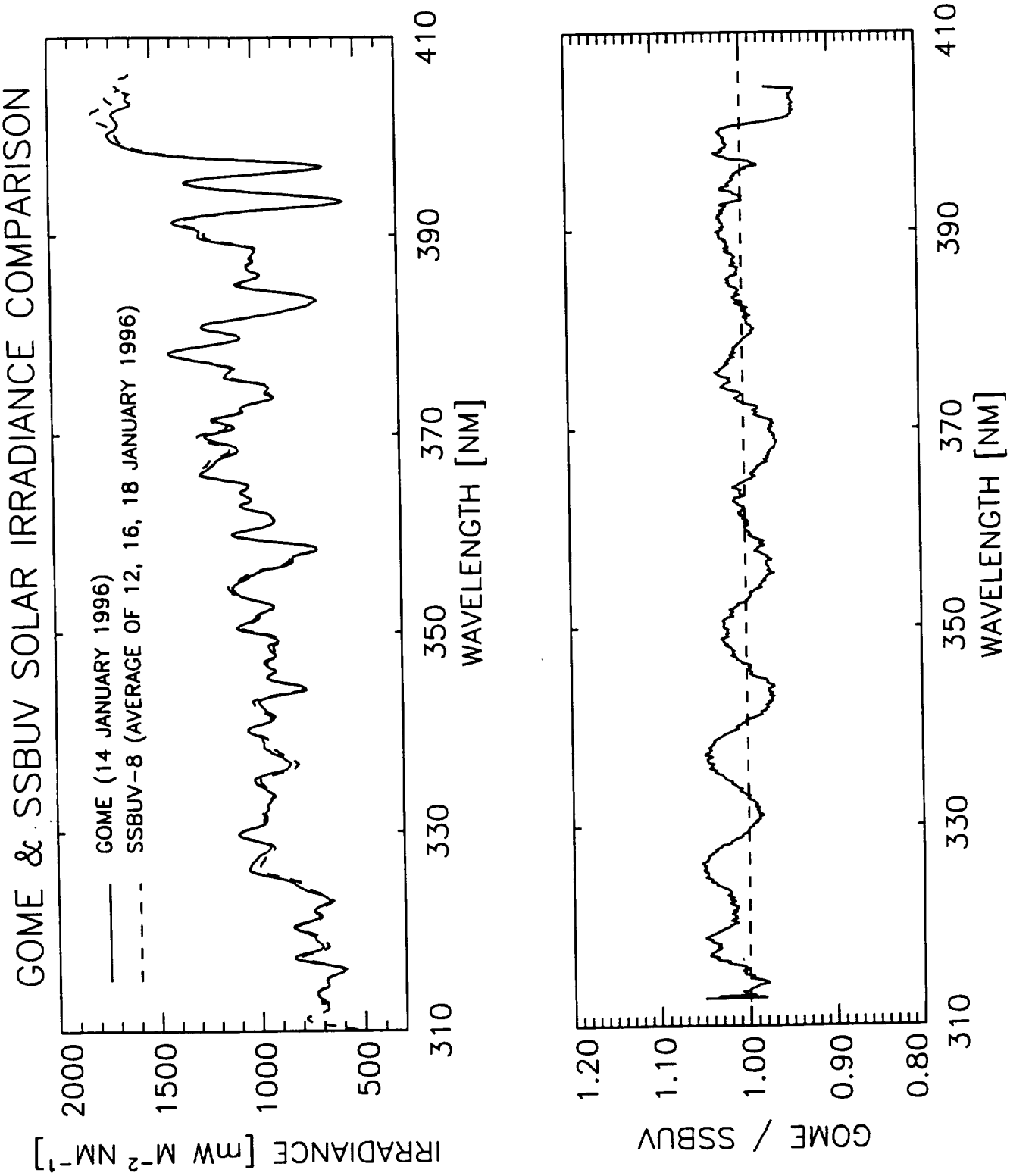

GOME & SSBUV SOLAR IRRADIANCE COMPARISON
GOME (14 JANUARY 1996)
SSBUV-8 (AVERAGE OF 12, 16, 18 JANUARY 1996)
IRRADIANCE [mW M-2 NM-1]
2000
1500
1000
500
310
330
350
370
390
410
WAVELENGTH [NM]
GOME / SSBUV
1.20
1.10
1.00
0.90
0.80
310
330
350
370
390
410
WAVELENGTH [NM]

Figure 3

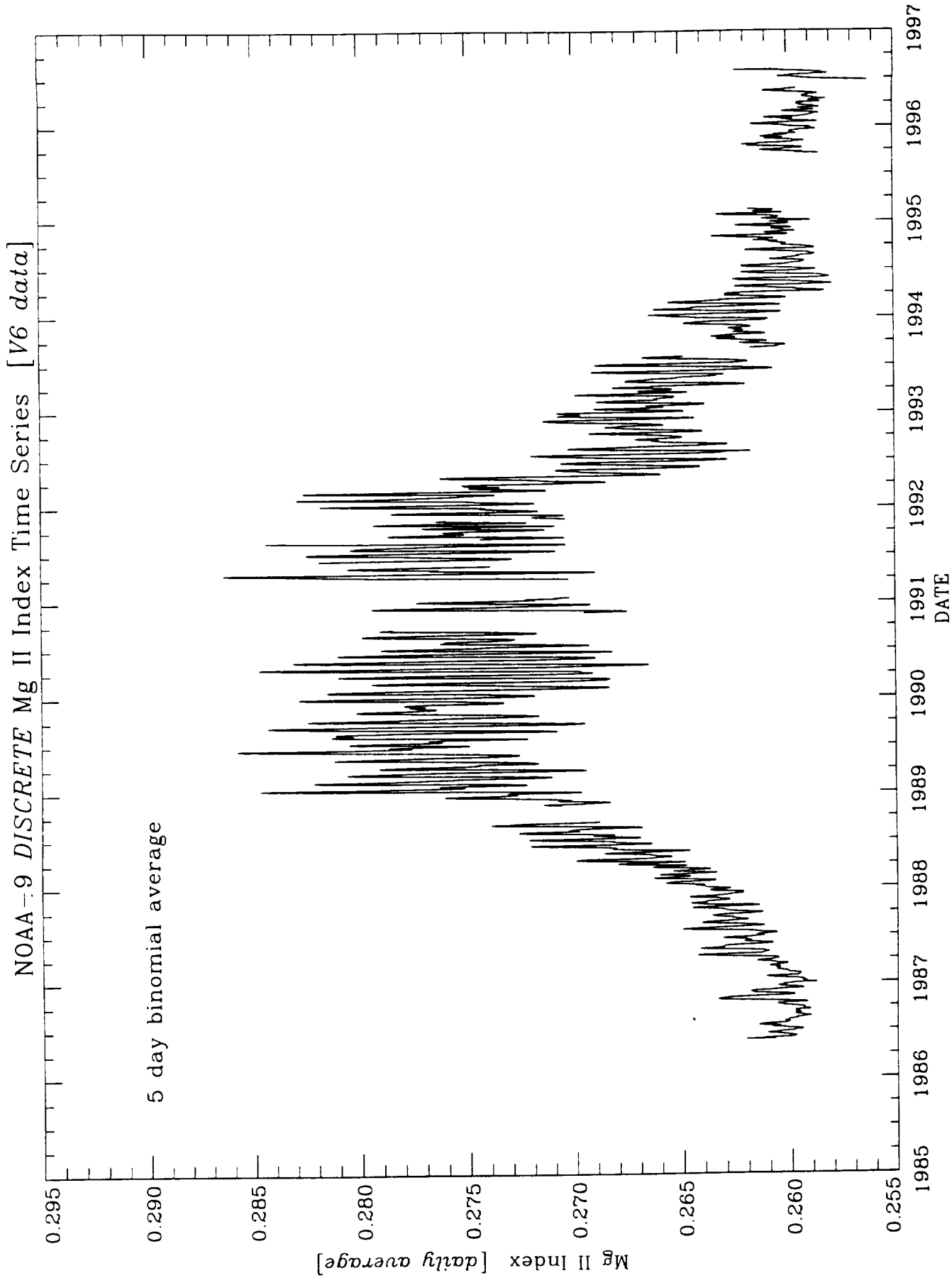

NOAA-9 DISCRETE Mg II Index Time Series [V6 data]
5 day binomial average
Mg II Index [daily average]
0.295
0.290
0.285
0.280
0.275
0.270
0.265
0.260
0.255
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
DATE

Figure 4

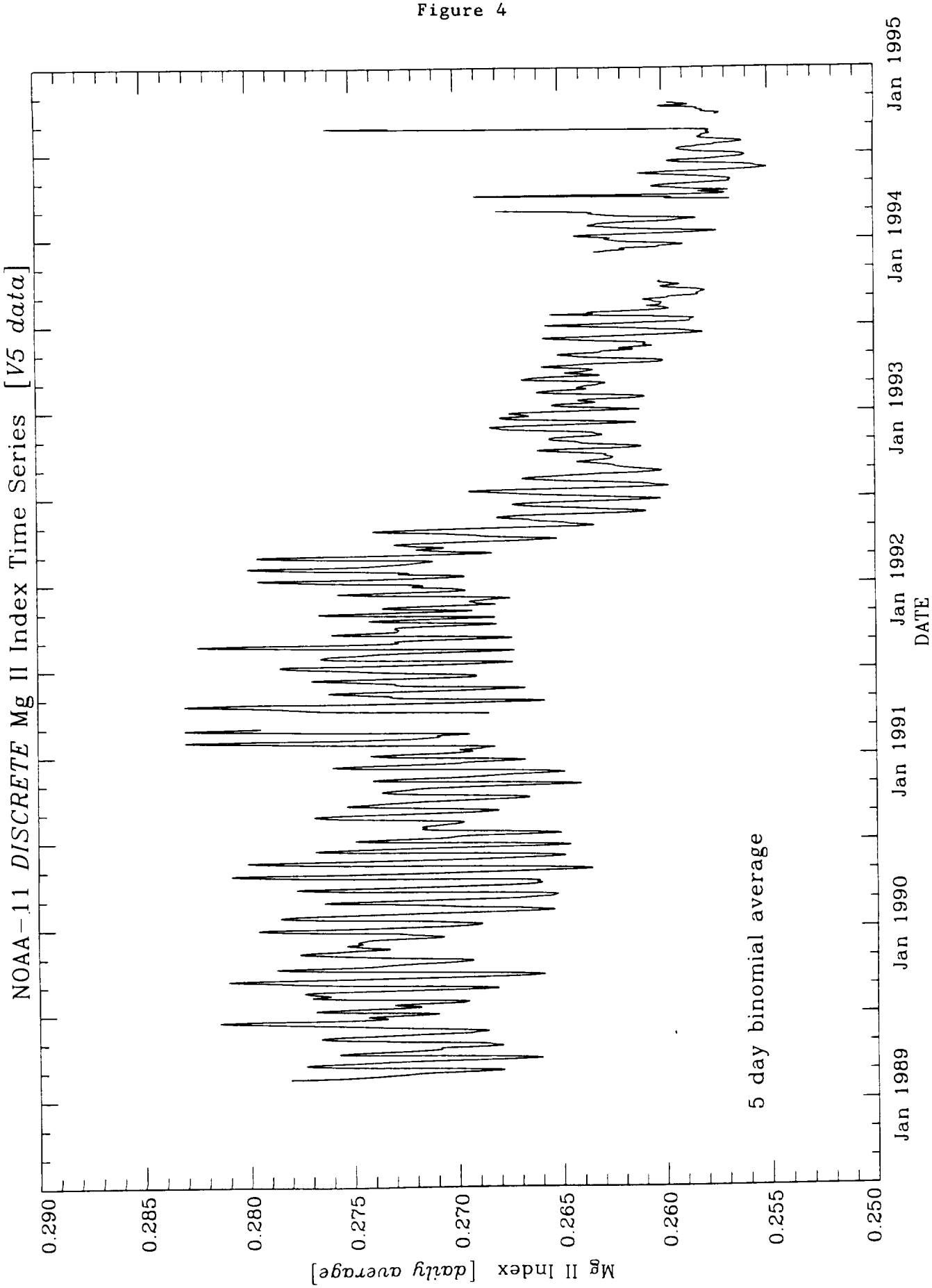

NOAA-11 DISCRETE Mg II Index Time Series [V5 data]
Mg II Index [daily average]
0.290
0.285
0.280
0.275
0.270
0.265
0.260
0.255
0.250
Jan 1989
Jan 1990
Jan 1991
Jan 1992
Jan 1993
Jan 1994
Jan 1995
DATE
5 day binomial average

Figure 5

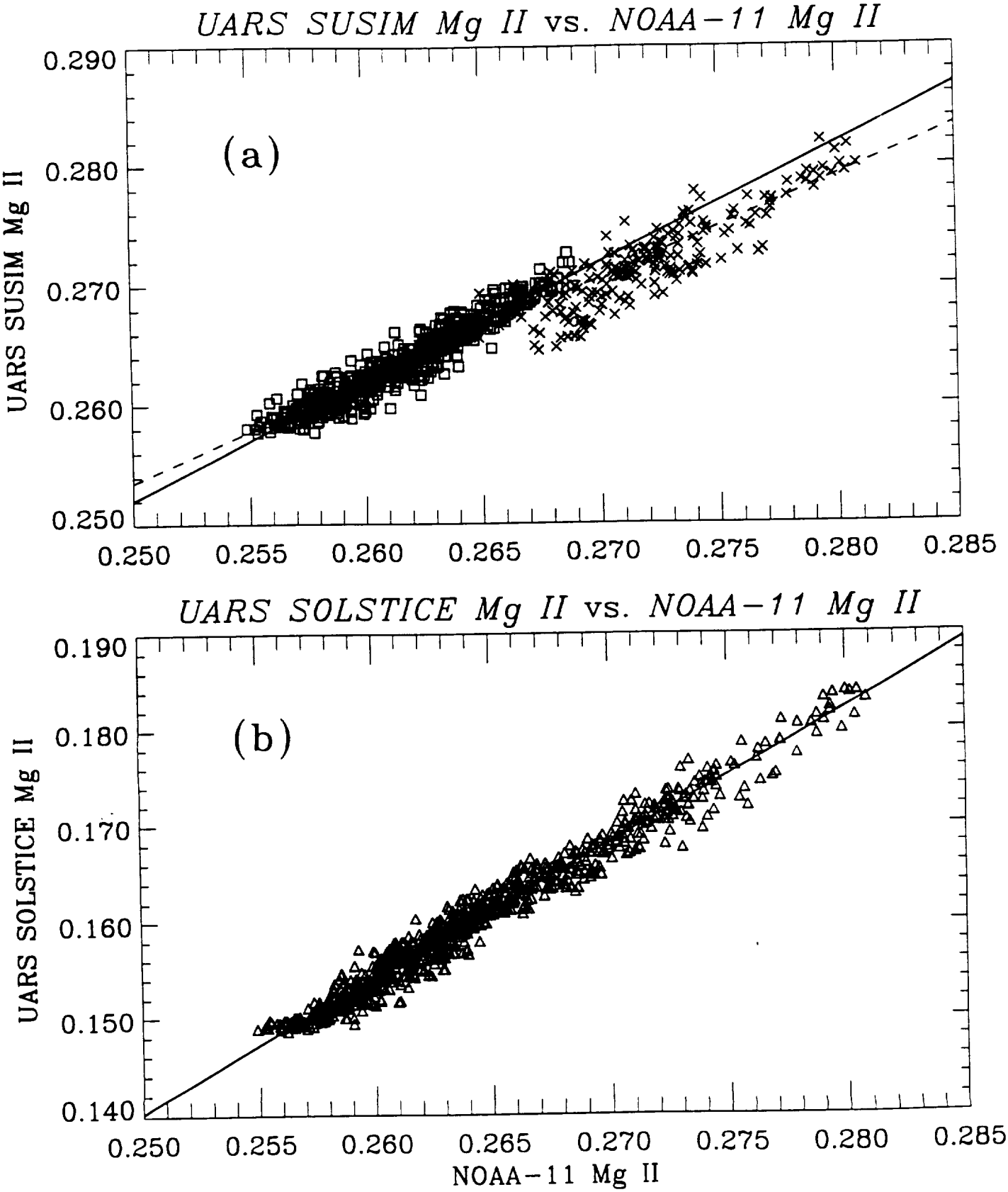
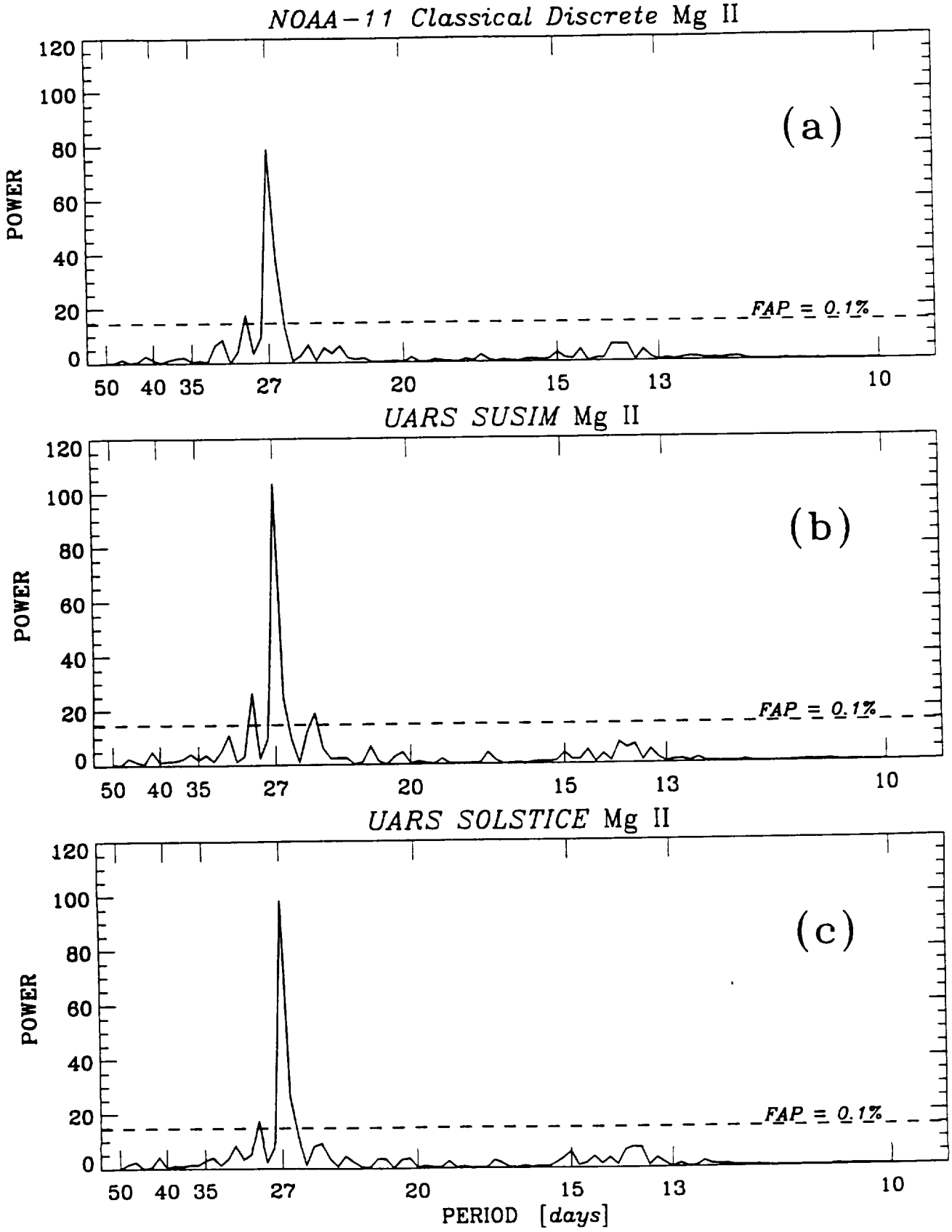

UARS SUSIM Mg II vs. NOAA-11 Mg II
(a)
UARS SUSIM Mg II
0.290
0.280
0.270
0.260
0.250
0.250
0.255
0.260
0.265
0.270
0.275
0.280
0.285
UARS SOLSTICE Mg II vs. NOAA-11 Mg II
(b)
UARS SOLSTICE Mg II
0.190
0.180
0.170
0.160
0.150
0.140
0.250
0.255
0.260
0.265
0.270
0.275
0.280
0.285
NOAA-11 Mg II

Figure 6


NOAA-11 Classical Discrete Mg II
(a)
POWER
120
100
80
60
40
20
0
FAP = 0.1%
50 40 35 27 20 15 13 10
UARS SUSIM Mg II
(b)
POWER
120
100
80
60
40
20
0
FAP = 0.1%
50 40 35 27 20 15 13 10
UARS SOLSTICE Mg II
(c)
POWER
120
100
80
60
40
20
0
FAP = 0.1%
50 40 35 27 20 15 13 10
PERIOD [days]