A SOLAR CONSTANT MODEL FOR SUN-CLIMATE STUDIES:1600-2000AD

Kenneth H. Schatten
Code 910.1
Laboratory for Atmospheres
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

and

Jerome A. Orosz
Dept. of Physics and Astronomy
Ohio University
Athens, OH 45701

ABSTRACT

This paper discusses the solar constant model published recently (Schatten, 1988), but with a modified the phasing and amplitude. Nevertheless, the asymmetry of the solar constant variations relative to solar activity may be one interesting feature of the present model. This model enables the "known" solar constant variations to be calculated from known active region and quiet region solar parameters. We use the term "known" in the previous sentence to indicate that this modelling effort does not utilize effects such as solar radius - solar luminosity changes, which we believe may be important, but which have not either been well substantiated or generally agreed upon by the scientific community. We do recognize that these other solar constant variations likely do exist, however, they are simply not understood well enough to incorporate them into a solar constant model. The "known" effects we consider are thus only those features which show contrast in white light for which we have some generally recognized data set to allow a modelling effort. The features which can be modelled are sunspots and faculae, the only two features which mark the photospheric continuum with their unusual contrast behavior. We include both the active region features (sunspots and faculae) and the quiet region features (global faculae). Although the direct influences of sunspots upon the solar constant leads to short term decreases, an opposite, nearly in phase, 11 year variation in the solar constant is modelled, thereby agreeing with the ACRIM and ERB secular trends observed. This opposite behavior results primarily from global faculae (polar, network, and active region). The main contributor to the global behavior are the network faculae. The model attributes the observed variations in the solar constant entirely to magnetic features in the solar atmosphere. Hence, the model does not require any indirect effect of the magnetic cycle on the brightness of non-magnetic elements of area on the Sun. The model utilizes the well studied active region influences upon the solar constant, together with the influences of global faculae, asociated with polar and general solar magnetism. The solar constant variations are calculated on a yearly basis and thus detailed comparisons with daily data should not be undertaken. The present model serves purely to model the secular (long term) trend in the solar constant. An advantage of this model is that one need only utilize such long baseline activity parameters as sunspot number or the Carbon 14 record as a base without resorting to modern parameters inaccessible in the distant past. The model suggests a change of ~0.5 W/m^2 for the differences between the late twentieth century solar constant and the 17th century solar constant. This supports Eddy's view that this difference could give rise to the glacial increase during the little ice age of the 17th century. Important for present day climate studies, is that it shows the recent peak activity (peaking in 1958) is associated with an atypically high value of the solar constant, with respect to the past few hundred years.

INTRODUCTION

Recent work by climate modelers (e.g. Hansen *et al.*, 1988) show a startling trend in the atmospheric global temperature. As suggested from "greenhouse" theories of the atmospheric temperature structure, these more elaborate models support a small but highly significant rise in temperature, on the order of 1C, in the Earth's climate over the next decade, associated with the accumulation of trace gases (CO_2, CH_4, N_2O, etc.). The effect is expected to be "at least three standard deviations above the climatology of the 1950's". This model does not consider solar variability, which has time constraints (from the 11 year solar cycle to the 80-100 year Gleissberg cycle) comparable to those being studied in the climate modeling. Although the changes associated with the trace gas constituency rise are likely to be of greater significance than the solar activity variations, it is important to understand the latter influence, since there is evidence (see Eddy, 1977; Grove, 1988) that long-term solar activity variations can also play a significant role in affecting the Earth's climate. Thus, to better understand the influence of anthropogenic changes to the atmospheric temperature structure, we must "remove" or understand as fully as possible those sources of temperature change associated with natural variability. These include volcanic dust veils (see Lamb, 1970), as well as solar activity. It will be the purpose of this paper to provide an update to our understanding of the influence of solar activity upon the solar constant, with a minor comment upon the degree to which this may affect the Earth's climate.

We first briefly review the influences of solar activity upon the solar constant. There are several well known, as well as some contentious, influences which we categorize as follows: 1) active region influences (sunspots and faculae - for which plague data are often employed to serve as a proxy data set (see Chapman, 1987), 2) global contrast features - for which network and polar faculae and the most prominent examples, although pores may also be considered in this category (see Foukal and Lean, 1988, and Schatten, 1988), 3) global size and shape changes - for which moderate evidence exists supporting changes in the solar size and less evidence for changes in the oblateness (see Endal and Sofia, 1981, and Sofia, *et al.*, 1985), and 4) other unknown changes which may affect the solar constant (temperature variations in the quiet photosphere, etc.).

Theory and modeling shows the following influence of category 1 features upon the solar constant: a moderate decline in the total irradiance as the cycle progresses, owing to the associated solar cycle reduction in latitude of active region features. The effect is of the order of 1 Watt per meter^2, due to the reasonably close "energy balance" which appears to exist over the week or fortnight lifetime of active regions.

The primary category 2 features are global faculae. These provide an increase in the total irradiance early in a solar cycle, followed by a decrease as the cycle progresses. These variations are also of the order of 1 Watt per meter^2 and are associated with the changing number and latitude of global faculae. Since faculae show their greatest contrast towards the Sun's limbs (Schatten *et al.*, 1986), polar faculae and early cycle network faculae (at high latitudes) provide for a marked increase in the solar constant early in the solar cycle associated with the large amount of time that these features spend at large heliocentric angles, where they are bright. As the cycle progresses, the Sun's polar fields and their associated faculae diminish, and thus also does their contribution to the solar constant.

Category 3 features may affect the solar constant. At present however, there exists evidence only that the Sun's diameter is varying by about 1" in timescales of tens to hundreds of years. Without further knowledge to what degree this may affect the solar constant, it is much too early to include these variations, as well as category 4 variations, in the present modeling effort.

MODEL AND RESULTS

We choose the solar constant model published recently (Schatten, 1988), but have modified the phasing and amplitude (Schatten and Orosz, 1990), since recently we have seen that the previous global faculae were instituted too early in the cycle. Nevertheless, the asymmetry of the solar constant variations relative to solar activity may be one important feature of the present model. We base the number of sunspots and faculae since 1610, upon the sunspot number shown by Waldmeier (1961). Figure 1 shows this modeled solar constant versus year from 1610 to the year 2000. One small difference exists in this figure from the published model--the phasing of the global faculae has been shifted roughly 1 year. The dashed line shows the smoothed 33-year running mean of the modeled solar constant, allowing the secular trend to be observed more clearly. Data past cycle 21 are based upon the predicted behavior from the dynamo theory model (Schatten *et al.*, 1977; Schatten and Sofia, 1987). A reduction in the solar constant is clearly observed during the Maunder minimum in the late 17th century. Following this, there has been a general rise in the modeled solar constant, with slight depressions near the turn of the last two centuries. This 80-100-year undulation is referred to as the "Gleissberg" cycle, although it appears to be more of a persistency than a true periodic cycle. It is unlikely that the general rise in the modeled solar constant over the last few hundred years is the actual source for the global climate warming that has been observed recently (Hansen *et al.*, 1988) for two reasons: 1) the observed heating trend follows the trace gas heating curve closely, and 2) the recent values for the modeled solar constant have not been increasing in the last three decades, since the largest solar cycle to date has been cycle 19, which peaked in 1957. Thus, it does not appear that we can explain the atmospheric global warming to the natural solar variability.

Figure 2 shows the modeled solar constant with recent Nimbus 7 observations (see Hickey *et al.*, 1988). As can be seen, there is a reasonably good agreement between the two. The recent upswing in the solar constant observations in 1987 matches the model quite well, however, the present model was chosen solely for the purpose of yearly comparisons to ascertain whether the secualr trend could be understood, not the daily variations.

CONCLUSIONS

The solar constant has been modeled from the years 1600 to 2000. The 11-year solar cycle is seen in the model as well as secular changes in the solar activity record (Gleissberg cycle), supporting Eddy's contention that the little ice age in Europe may have been associated with the dearth in sunspots during the Maunder Minimum. On the other hand, the recent increase in the global temperature of the Earth is not likely fully associated with the solar activity. Recent solar constant observations of a downward trend for the last half of solar cycle 21 followed by an upturn in the solar constant associated with the onset of high latitude faculae in the beginning of cycle 22 (Mecherikunnel *et al.*, 1988; and Willson and Hudson, 1988) support the model's general trend for the recent solar constant behavior. Using this model, we now calculate a "proxy" solar constant, based upon this model for: 1) the past four centuries, based upon the sunspot record, and 2) the next 20 years, based upon our dynamo theory model for the solar cycle (Schatten and Sofia, 1987). The proxy solar constant data displayed here may be useful for climate modelers studying global climate changes. It would be helpful in disentangling the solar influences from any anthropogenic changes associated with trace gas increases in the terrestrial atmosphere. We have not included short term fluctuations in the present model.

REFERENCES

Chapman, G. A., "Solar Variability Due to Sunspots and Faculae," J. *Geophys. Res.*, 92(D1), 809, 1987.

Damon, P. E., "Energetic Particles at One A.U.," in The Solar Output and Its Variations, ed. O. R. White, 429-445, Col. Assoc. Univ. Press, Boulder, 1977.

Eddy, J., "Climatic Change", 1, 173, 1977.

Foukal, P. and J. Lean, *Astrophys. J.*, 328, 347-357, 1988.

Grove, J. M., The Little Ice Age, Methuen, London, ch. 11, 354-378, 1988.

Hansen, J., I. Fung, A. Lacis, S. Lebedeff, D. Rind, R. Ruedy, and G. Russell, "Global Climate Changes as Forecast by the GISS 3-D Model," *J. Geophys. Res.*, to appear, 1988.

Hickey, J. R. *et al.*, "Total Solar Irradiance Measurements by ERB/Nimbus-7: A Review of Nine Years," Space Science Reviews, submitted, 1988.

Mecherikunnel, A. AT., R. B. Lee III, H. L. Kyle, and E. R. Major, "Intercomparison of Solar Total Irradiance Data from Recent Spacecraft Measurements," *J. Geophys. Res.*, 93, 9503-9509, 1988.

Schatten, K. H., "A Model for Solar Constant Secular Changes," *Geophys. Res. Lett.*, 15, 121-124, 1988.

Schatten, K. H., P. H. Scherrer, L. Svalgaard, and J. M. Wilcox, "Using Dynamo Theory to Predict the Sunspot Number During Solar Cycle 21," *Geophys. Res. Lett.*, 5, 411, 1978.

Schatten, K. H. and S. Sofia, "Forecast of an Exceptionally Large Even-Numbered Solar Cycle," *Geophys. Res. Lett*, 14, 632-635, 1987.

Schatten, K. H. and J. A. Orosz, "Solar Constant Secular Changes," *Solar Physics*, 125,179, 1990.

Sofia, S., P. De Marque, and A. Endal, "From Solar Dynamo Theory to Terrestrial Climate," American Scientist, 73, 326, 1985.

Waldmeier, M., The Sunspot Activity in the Years 1610-1960, Zurich Schultness and Co., 1961.

Willson, R. C., S. Gulkis, M. Janssen, H. S. Hudson, and G. A. Chapman, "Observations of Solar Irradiance Variability," Science, 211, 700, 1981.

Willson, R. C. and H. S. Hudson, Nature, 332, 810-812, 1988.

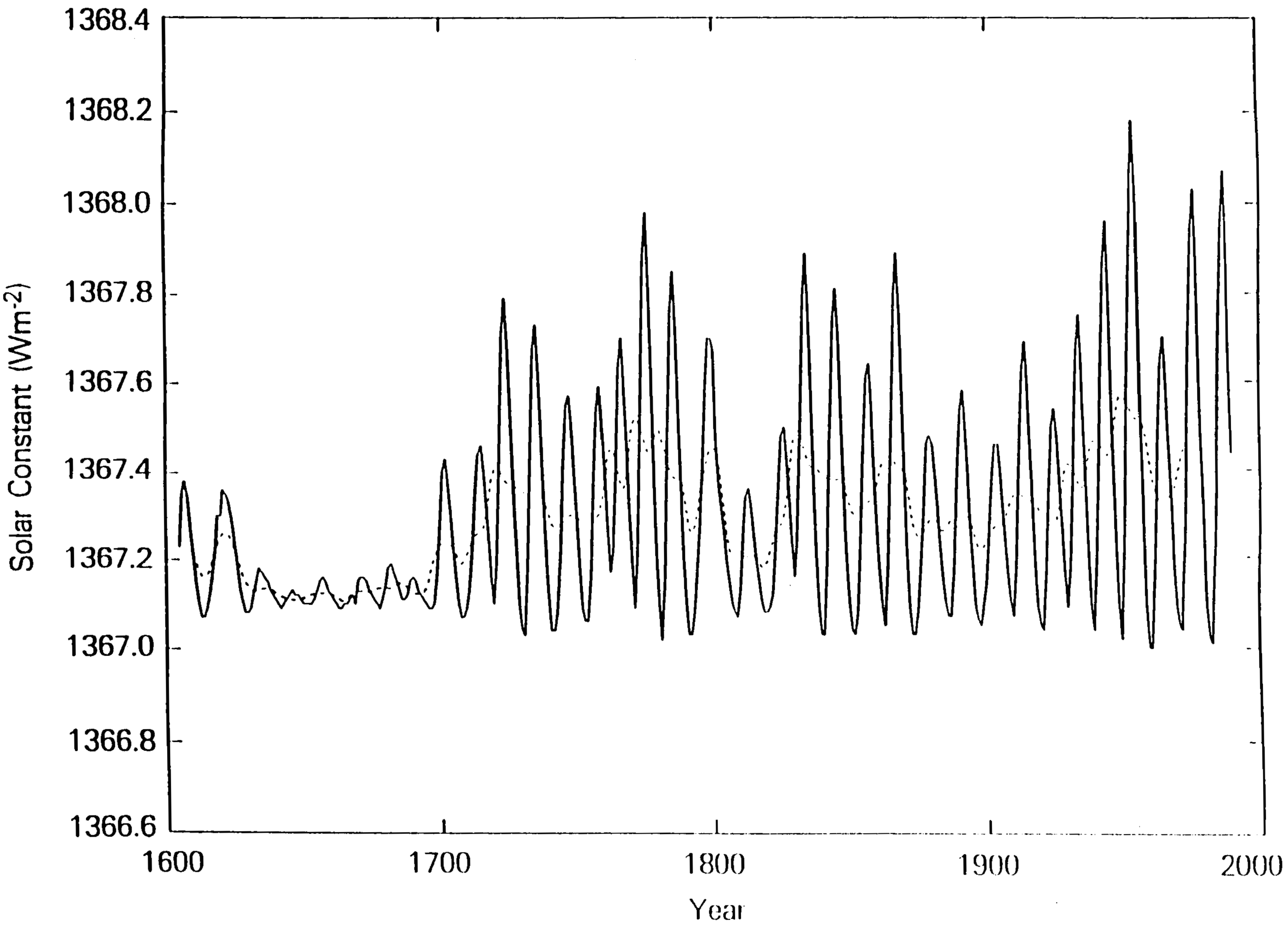
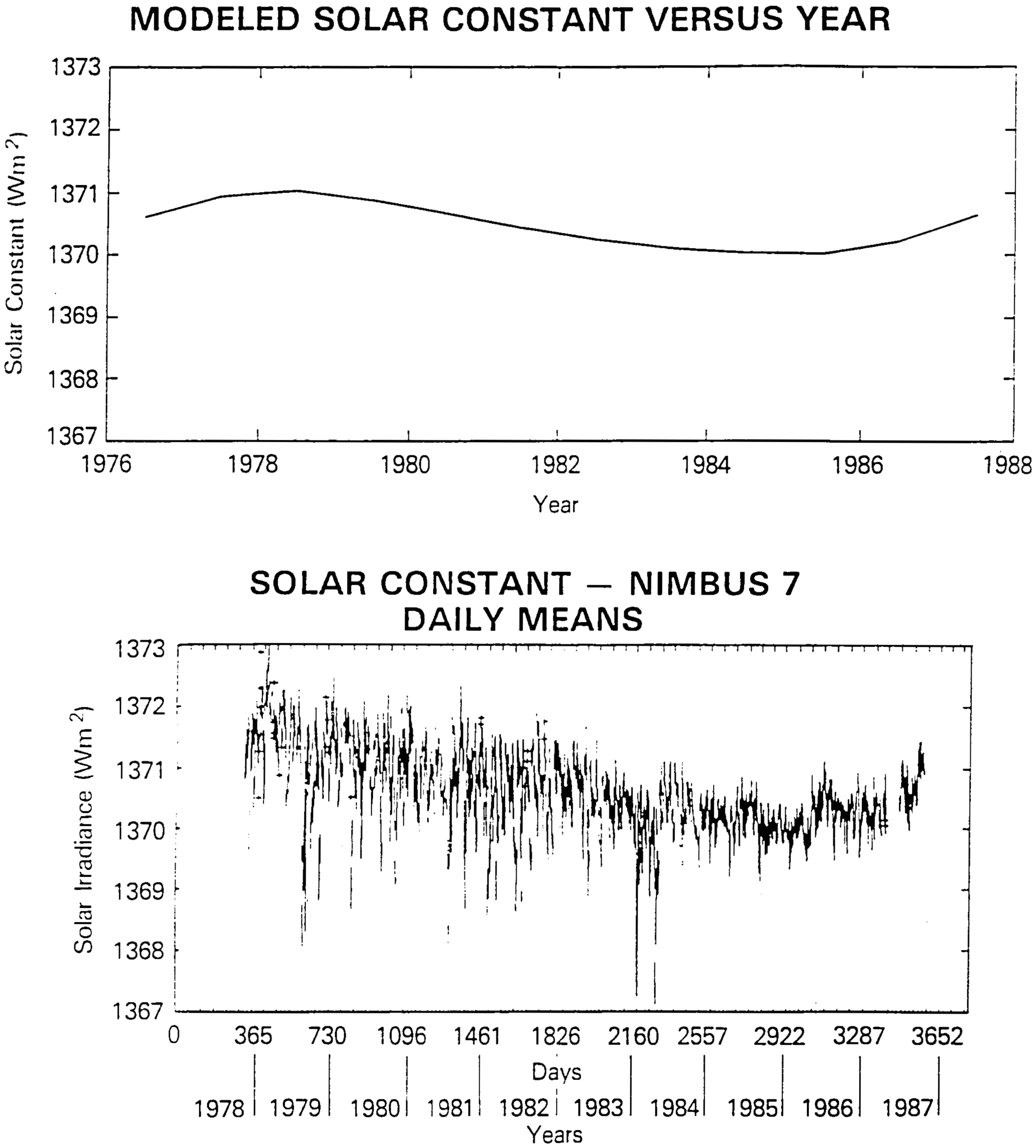


Figure 1. The solid line shows the modeled solar constant (with the Solar Maximum Mission's Active Cavity Radiometer experimental calibration) versus time in years from 1610 to 2000. The secular trend is seen better from the dashed line, which is a 33-year smoothing of the solid curve.



MODELED SOLAR CONSTANT VERSUS YEAR

SOLAR CONSTANT – NIMBUS 7 DAILY MEANS

Figure 2. Shown (top) is the modeled smoothed solar constant from mid-1976 to mid-1987 (using the Nimbus 7 calibration), with the solar constant observations fro Nimbus 7 (bottom) (see Hickey *et al.*, 1988). The values agree reasonably well throughout the time period, including the overall peak in 1979 and the valley at the end of 1985. The observations in 1987 appear to rise slightly faster than the model.