SOLAR DATABASES FOR GLOBAL CHANGE MODELS

by
H.E. Coffey, E.H. Erwin and C.D. Hanchett
Solar-Terrestrial Physics Division
NOAA NESDIS National Geophysical Data Center
325 Broadway, Boulder, Colorado 80303

ABSTRACT

The National Geophysical Data Center (NGDC) is compiling a comprehensive solar database for use in global change models. Solar radiation drives the weather machine. Variations in the Sun's radiative output impact the Earth's climate. The NOAA Climate Analysis Center currently uses solar cycle data in their U.S. seasonal winter forecasts. Spacecraft observations show the Sun's output varied by 0.1% during the past 11-year solar activity cycle, producing a climate forcing of 0.24 W/m2. Climate forcing by increasing greenhouse gases from 1980 to 1986 was about 0.25 W/m2. Global change models need to discern between variations caused by anthropogenic and natural occurrences to provide a sound scientific basis for policy making on global change issues. The NGDC archives are part of a cross- disciplinary effort within NOAA to link observed changes on the Sun with terrestrial climate. To contact the NGDC on-line services, use the following addresses on the Geophysical On-Line Data (GOLD) system:
FTP access: ftp://ftp.ngdc.noaa.gov/;
Gopher: gopher://gopher.ngdc.noaa.gov/;
World Wide Web: http://www.ngdc.noaa.gov,
and to reach the bulletin board, telephone (303) 497-7319.

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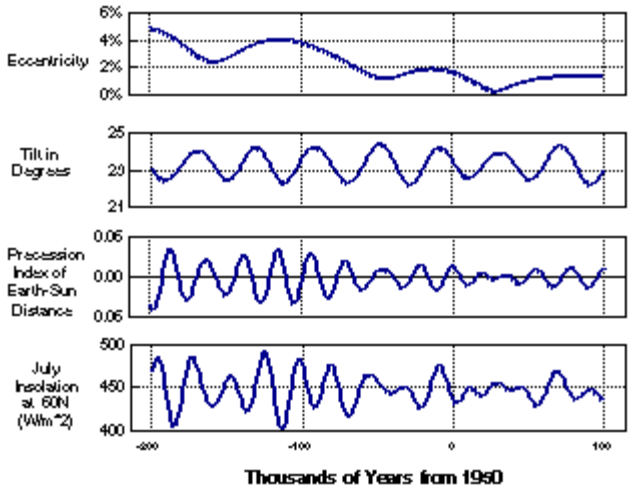
Introduction:

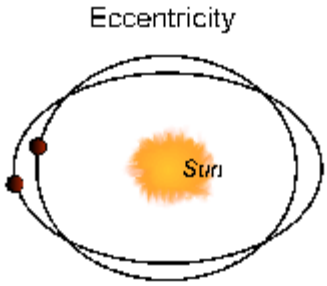


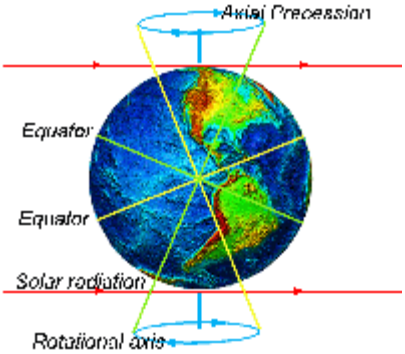
With the advent of total solar irradiance satellite measurements since 1978, it is now documented that the amount of energy from the Sun varies over decadal time scales. The Sun supplies the energy for the Earth's system heat budget. The major components that affect this heat budget are a.) changes in the Earth's orbit, b.) internal processes (such as cloudiness, ice cover, anthropogenic effects, etc.), and c.) variations in solar activity. Because the Earth's climate is changing, it is critical to understand the contributions of each component and take action when necessary to curb possible negative effects we might have control over. A good example of this kind of action is the worldwide effort to reduce the amount of chlorofluorocarbons (CFCs) emitted by man. Climate variability is a major issue and our understanding is still

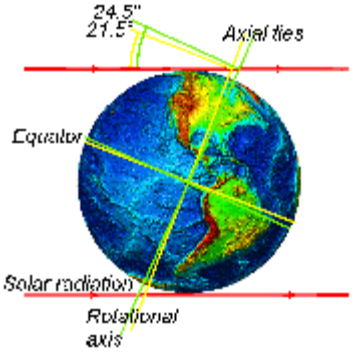
uncertain.

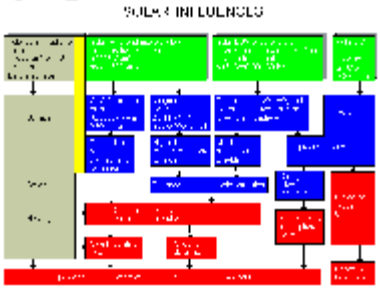
Click on the images below to see full-sized diagrams:

a.) Changes in the Earth's Orbit:









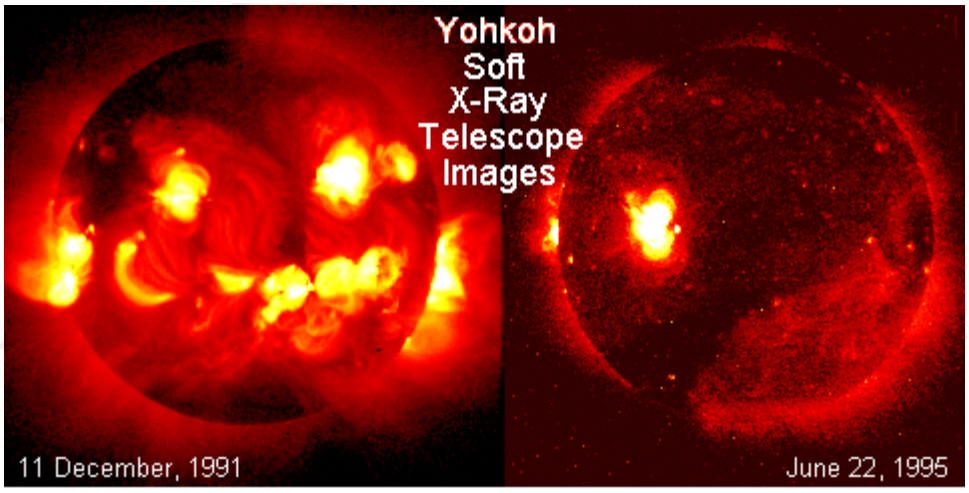
The largest effect on the amount of solar radiation reaching Earth is due to orbital changes in the Sun-Earth system. The Yugoslav mathematician Milutin Milankovitch studied the orbital parameters that cause seasonal variations on Earth. He calculated insolation curves for different latitudes. These data are available on the NGDC GOLD ftp anonymous account in the Paleo directory under Insolation. They were kindly supplied by Dr. A. Berger, Catholic University of Louvain (see Berger et al., 1991, for more details).

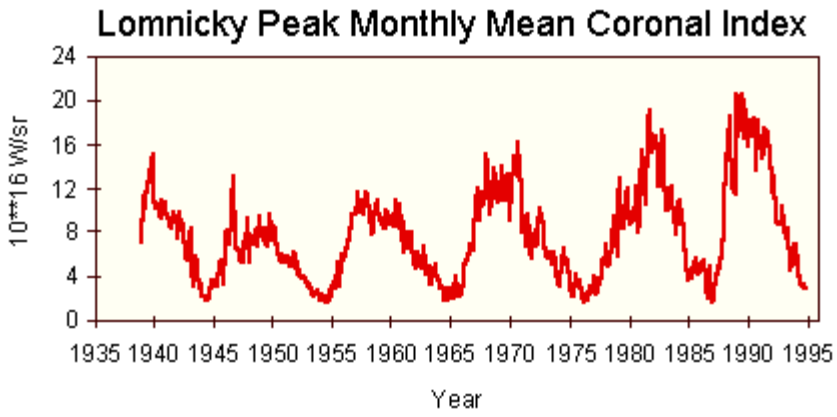
The degree of eccentricity changes the relative Sun-Earth distance on a 100,000 year cycle. The Earth is in an orbit around the Sun that is not quite circular because of the interactions with orbits and gravitational pull of other planets. The Earth's axis tilts (obliquity) between 21.5 and 24.5 degrees with respect to the orbital plane. It has a cycle of 41,000 years. Like a spinning top, the Earth precesses around a circular path in a 19,000 to 21,000 year cycle. Combining these effects, one can calculate when ice ages and warm intervals will tend to occur. The data show that at times of ice ages, 60N would receive as little insolation as 80N today. As noted by Thomson (1995), a lot of other smaller effects contribute to the overall total amount of radiation that the Earth receives and the picture is very complex.

b.) Complexities of Internal Processes:

The complicated internal processes that couple the atmosphere, the oceans, and terrestrial ecosystems are not well understood. NOAA scientists recently found that clouds absorb more of the Sun's radiation than previously believed -- 15% versus the 4% currently accepted theories predict. Thus, less solar radiation reaches the Earth's surface in cloudy areas (39% versus 50% traditionally assumed) (Cess et al., 1995). Other NOAA scientists recently found a significant increase in the levels of water vapor in the atmosphere from 1981-1994 which could lead to global warming and a greater ozone loss (Oltman et. al, 1995). A 1% drop in ozone levels causes a 2% increase in skin cancer.

Stone (1995) suggests the effects of global climate warming could contribute to deaths due to a rising incidence of summer heat waves. Just a 2 degree Celsius increase would double the number of unusually hot days. Also infectious diseases could contribute tens of millions of more cases as mosquitoes and other pests expand their ranges. Taubes (1995) points to a 2 degree Celsius warming since the 1880s that affected forests across Canada, Alaska and Siberia. Though initially speeding growth





and driving the forests farther into the Arctic at least in the 1930s and 1940s, since the 1970s the trees are showing stress probably because of increased moisture loss, leaving them open to more frequent insect attacks which proliferate in the warmer weather.

There are many uncertainties in our understanding of the internal processes. It is to the benefit of mankind to study the Sun-climate system and to understand the consequences of our impact on this system.

c.) Variations in Solar Activity:

NOAA's plan for the U.S. Global Change Research Program has a strong focus on solar influences. The solar influences research plan Atmospheric Responses to a Changing Sun (ARCS) studies solar inputs at the top of the Earth's atmosphere and their effects on the Earth's system, whether immediate, secondary or tertiary. This block diagram excerpted from the NOAA Climate and Global Change Special Report No. 8 (1994) indicates the different levels of effects. The top row lists the solar influences at the top of the Earth's atmosphere. We've indicated the estimated energy fluxes, their change (D) over the 11-year solar cycle, and the regions where this energy is deposited. This information is found in Table 1.1 of the National Research Council (NRC) report Solar Influences on Global Change (1994).

The group of blue blocks lists known immediate effects of solar radiation and its variations. These effects have not been fully quantified. The blocks in red list possible secondary and tertiary effects. These effects have not been investigated in any depth. The ARCS program will address these issues.

Several investigations have shown positive correlations of solar influences on climate change. The hydrological system is a major player in the weather system because 70% of the Earth's surface is covered by water. Dr. George Reid, senior NOAA scientist, examined the sea surface temperature record for the last 130 years and found an interesting correlation with the 11 year running mean sunspot number (Reid, 1987, 1991). Though not identical, the two time series have several features in common, including a prominent minimum during the early 1900s, a steep rise to maximum in the 1950s, a drop in the 1960s and early 1970s, and then a rise that continues to date. Sea surface temperature data are from the British Meteorological Office, Hadley Centre for Climate Prediction and Research. An updated improved version of these data will be provided soon and will reside in our ftp anonymous account under the GLOBAL_CHANGE subdirectory.

Drs. Eigil Friis-Christensen and K. Lassen, Danish Meteorological Institute, studied the length of the solar cycle as an indicator of solar activity closely associated with climate change (Friis-Christensen et al., 1991). They used the Northern Hemisphere land air temperature during the past 130 years and found a good correlation with the length of the solar cycle. While the temperature data do show the enhanced greenhouse effect due to increased CO2 in the atmosphere, it also shows a departure from this trend from 1940 to 1970. This occurs simultaneously with a decrease in

solar activity as seen in the solar cycle length database. Thompson (1995) recently ran extensive statistical tests on this database and raises questions about the interpretation, though S. Manabe counters these questions with the fact that we really do not understand how the atmosphere responds to changes in internal processes. The Northern Hemisphere land air temperature data were compiled by Jones et al., 1986, and are based on a large systematic set of temperature measurements. These data will also be put in the GLOBAL_CHANGE subdirectory.

The NOAA National Climatic Data Center (NCDC) holds long term databases back to 1895. Their www home page is http://www.ncdc.noaa.gov. Go to the selection- interactive visualization of climate data. The areas of interest would be CLIMVIS with access to U.S. Climate Division data back to 1895. Also check the Climate Research Programs section off the Home Page at the Global Climate Perspectives System (GCPS) and the U.S. Comprehensive Ocean-Atmosphere Data Set (COADS) database information. (Tom Ross, NCDC, private communication).

El Nino Southern Oscillation is a regional variation that has a major influence on global circulation. When solar activity is high, strong El Ninos occur farther apart than when it's low. The North Atlantic winter 700 mb wind circulation pattern for data 1950-1987 correlates with the 11-year solar cycle. The correlation appears only when observations during the west phase of the quasibiennial oscillation (QBO) of equatorial stratospheric winds were used. A similar correlation using geopotential height (30 mb height in summer) suggests that atmospheric dynamics play a major role in the response to the 11-year solar cycle (Labitzke et al.,1993).

NGDC Solar and Related Databases:

NGDC has collected and distributed a number of historical solar-terrestrial physics databases over the years. Many of these are made available through the monthly publication Solar-Geophysical Data (SGD). The SGD monthly data processing has contributed to a number of databases being stored in digital form. Many data are made available on diskettes and CD-ROMs. All of these give an indication of historical activity on the Sun. With the advent of the world wide web on the Internet, many of these databases are now available on-line. Over 100 Mbytes of solar and related databases now reside on the NGDC Geophysical On-Line Data (GOLD) ftp anonymous system. The URL address is http://www.ngdc.noaa.gov. To access ftp anonymous directly, ftp to ftp.ngdc.noaa.gov with your e-mail address as the password, cd to STP, then SOLAR_DATA. **Long-term databases on-line include:**

- SUNSPOT_NUMBERS -- yearly averages 1700-1994; monthly data 1749-1995, daily values 1818-1995;. These data were originally compiled by Waldmeier and updated by McKinnon (1985);
- GREENWICH -- Greenwich sunspot region data 1874-1979 -- summary daily data as well as individual region data. These data were made available by Doug Hoyt and Jack Eddy;
- CORONA subdirectory contains the Lomnicky Stit coronal index 1939-1991 as well as their actual database of daily coronal observations (supplied by V. Rusin and M. Rybansky). The HOLES subdirectory contains the A. Sanchez-Ibarra et al. (1992) compilation of coronal hole positions 1970-1991. The SYNOPTIC_MAPS subdirectory contains the Pat McIntosh et al. (1991) compilation of H-alpha synoptic charts 1966- 1987 that show the evolution of large scale magnetic fields and coronal holes.
- Under COSMIC_RAYS are the monthly averages from about 1953 to the present from five worldwide stations: Climax, Huancayo, Moscow, Deep River, Calgary. Daily tables for 8 stations are given for 1993 to present. These data appear monthly in SGD.
- Under SECTOR_BOUNDARIES are found Svalgaard's solar sector boundary crossings for the period 1947-1978. Inferred interplanetary magnetic field Away and Toward the Sun data from the individual stations Vostok (1971-1989) and Thule (1979-1981) are also included, along with polarity files 1957-1989 from A. Zaitsev, IZMIRAN.
- Under RELATED_INDICES are the aa index 1868-1995 monthly and yearly means as well as 3-hourly values. aa values provide a measure of the global level of magnetic activity. It is derived from 2 roughly antipodal stations. Also included are the KnKsKm (1983-1995) and amanas (1981-1993) 3-hourly data.
- Another index, the Polar Cap (PC) index, is found here. PC index is a 15 minute index for magnetic activity in the

Polar Cap generated by solar wind parameters such as the southward component of the IMF (Bz), the azimuthal component of the IMF (By) and the solar wind velocity v. The PC-index is based on an idea by Dr. Troshichev and developed by him and others (see Vennerstrom et al., 1994). The data appeared in Report UAG-103 and are published monthly in SGD. Files include data from Vostok (1978-1979 and 1983-1992) and Thule (1975-1995).

- Under SUDDEN_COMMENCEMENTS are the geomagnetic sudden storm commencements 1868-1975 by Fr. Mayaud (IAGA Bulletin 32) and continuing to the present preliminary data issued by the ISGI Bulletin, Debilt Netherlands (1983-1987) and now issued monthly by Fr. Cardus, Ebro Magnetic Observatory and the Institut de Physique du Globe, Paris. A subdirectory PSTORM gives the preliminary data reports from the individual stations as compiled for the monthly SGD.

- Under ATM_HANDBOOK is the Atmospheric Handbook compiled by Dr. Vern Derr, NOAA ERL (1984). The text appeared as a joint UAG Report by WDC-A for Meteorology (NCDC) and WDC-A for STP (NGDC). The data are largely from results published in journals. The descriptive text is in digital form along with over 200 data files. Data include attenuation coefficients for the atmosphere and H2O, atmospheric parameters for 1962 standard atmosphere, cloud drop size distributions, solar spectral irradiance, sky spectral irradiance, etc. Several FORTRAN programs exist for retrieving select data.

- STRATWARMS lists all the stratospheric warmings issued for 1987-1995 by the Frei University of Berlin. A STRATWARM is a major disturbance of the winter polar middle atmosphere (troposphere to D-region) resulting from a breakdown of the polar vortex into two cells. Air trapped in the vortex is mixed by the new meridional flow and can be exposed to sunlight. Solar Lyman alpha ionizes the nitric oxide, enhancing electron density and producing strong HF absorption. This STRATWARMS database is from the alerts received and issued by the NOAA SEL.

- The total SOLAR_IRRADIANCE, (Web Page for further Information) data cover the satellite observing time period 1978 to present and include data from Nimbus, SMM, NOAA, ERBS and UARS. Earlier proxy data on-line include the Greenwich sunspot area database (1876 to present) for sunspot blocking data and McMath Calcium II K-line plage data (1942-1987) for brightness data. Most of these Calcium data were reduced by Dr. Helen Dodson Prince. A digital database of calcium plage imagery from Mt. Wilson will soon be available from Dr. Peter Foukal. These include not only the active plage areas, but also the contribution from the plage network.

- On-line SOLAR_UV databases include SME (1982-1988), SERF3, UARS SOLSTICE (HI Lyman alpha, Mg core-to-wing ratio, Ca core-to-wing ration, and 200-205 nm integrated flux -- Oct 91-Sep 94), Nimbus-7 (1978-1984) and NOAA9 (1986-1988). Solar UV interacts significantly with the ozone layer -- a 1% drop in ozone levels can cause a 2% increase in skin cancer. Solar UV may be 50% of the variation of the total solar irradiance. Proxy data for UV include the Penticton solar radio flux at 2800 MHz (10.7 cm). We have on-line data from 1947 to the present. Johannesson et al. (1995) at Big Bear Solar Observatory recently found a high correlation of full disk Ca II K-Line emission with the UARS Lyman alpha database. NGDC currently has Calcium data from McMath for the period 1942-1987. Data from 1961-1987 are on-line. We expect to add additional databases in the near future.

- Event data, like solar flares (SOLAR_FLARES) and SOLAR_RADIO BURST and PARTICLES data can be found as well as background data, such as the CALCIUM plage daily values, the GOES SAT_ENVIRONMENT ELECTRONS and X-RAY background database, sunspot regions (SUNSPOT_REGIONS) and Stanford Sun-as-a-Star data (STANFORD_DATA). Other data will be added as time permits.

- In addition to the solar INSOLATION database, the NGDC Paleoclimate group has tree ring data (International Tree-ring Data Bank 6000 B.C. to 1991 A.D.) on-line, along with radio carbon (C14) data (10,000-2,000 ybp). They also hold other relevant databases.

NGDC holds archives of GOES, NOAA/TIROS and DMSP satellite environment data. Some of these data are available on-line and accessible through the GOLD on-line system. CD-ROMs of the data are also available. Extensive cosmic ray archives (hourly values from more than 100 stations) are available on CD-ROM.

A CD-ROM *Solar Variability Affecting Earth* is now being advertised. It has many of the databases listed above in addition to early flare and radio data, as well as software to select and view the data. Although this CD was pressed in 1990, an extensive descriptive text has only now become available in finished form. Anyone who received a copy of the CD should be on our mail list to receive the text as soon as it returns from the printer. Please contact the data center if you would like to order one of these CDs.

We refer the reader to the NOAA Climate and Global Change Program Special Report No. 8 *Solar Influences on Global Change -- A Strategic plan for a NOAA Program* (available on request) for an in-depth article by Dr. Brian Tinsley entitled *Review of Correlations, Processes, and Future Research.* Tinsley reviews recent work in the field, including criticisms, and addresses topics for further research. The comprehensive NRC report *Solar Influences on Global Change* is also a valuable tool for addressing future research.

Acknowledgments

Inspiration for this work came from the book Climate -- our future? by Ulrich Schotterer that uses artistic imagery and sophisticated scientific text to present a global analysis of the issues and processes affecting climate change. And also we are indebted to the recent National Research Council report *Solar Influences on Global Change* for an in-depth overall study of the effects of solar variations on our climate. Dr. Peter Sloss, NGDC, provided the planet Earth images. We owe a great debt to all of the researchers who have contributed to this field of study over many years and to the solar observatories and related observing stations who toil for years taking basic measurements of an ever-changing Sun. We invite all interested observers to send their data to the NOAA GOLD system for inclusion in the collected databases. NGDC is co-located with the World Data Center A (WDC-A) for Solar-Terrestrial Physics and the WDC-A for Paleoclimatology. On-line data are available at no charge over the Internet or can be obtained on diskettes for the cost of reproduction.

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