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QUANTITATIVE STUDY OF LONG-TERM SOLAR AND CLIMATIC CHANGES

NASA Grant NSG-5345

Final Report

For the Period 1 May 1979 through 30 September 1981

Principal Investigator

John A. Eddy

March 1982

Prepared for

National Aeronautics and Space Administration
Greenbelt, Maryland 20771

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
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NASA Grant NSG-5345 was initiated in 1979 for one year during the stay of the Principal Investigator as a Visiting Research Associate at the Harvard-Smithsonian Center for Astrophysics. It was granted several extensions on a no-cost basis through 1981 to cover the Principal Investigator's work on a series of shorter, return visits to the CfA from his regular employment as a Senior Scientist at the National Center for Atmospheric Research in Boulder, Colorado.

The basic purpose of the Grant was to cover a broad area of research in Long-Term Solar an Climate Changes. The specific project charged exclusively to the Grant was the research carried out by Dr. Eddy on long-term variations of the solar diameter as derived from the analysis of records in the historical holdings of the Harvard College Libraries. Several other studies of long-term solar and climate changes were partially supported by the grant and resulted in the papers listed at the end of this report.

The purpose of the solar diameter study was to test for evidence of any secular variations in the diameter or shape of the sun: a fundamental parameter of the sun and its variations which can be shown to be related to the solar luminosity and in turn, to climatic response. Studies of the solar diameter also serve as a diagnostic of internal properties of the star, and particularly of conditions in the solar convective zone.

Work accomplished on solar diameter variations under the Grant were the analysis and interpretation of daily observations of the sun's diameter made at the Greenwich Observatory in the period 1836-1953. The original data were obtained in the form of noontime meridian transit

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timings for purposes of celestial mechanics studies, but one can derive from them information on the apparent horizontal and vertical diameters of the sun. A number of world observatories have accumulated such measurements in the course of their routine work. The Greenwich data were selected for this study because of their continuity: such measurements were begun there in 1750 and have continued on a daily basis until the present day. The Greenwich data have the added advantage of prior, though less thorough, examination by other investigators, and were readily available in the accessible libraries at Harvard.

In the initial phases of the work the original data were transferred from daily, published measurements to digital form which were then screened and processed in the computational facilities of the Center for Astrophysics. In addition the less accessible data from the earlier century (1750-1836) were also located and copied for later analysis. Published, early descriptions of the observational procedures employed at Greenwich and the characteristics of the instruments employed (chiefly the Airy Transit Circle and Airy Chronometer) were also investigated to remove systematic effects.

When the characteristics of the historical data were understood a study was made of their temporal behavior, employing corrections to update the ephemerides used in their original reduction to more modern, accurate values. This study resulted in the finding, announced in 1970, that the horizontal diameter of the sun measured at Greenwich appeared to have decreased systematically between 1880 and 1953, at a rate of about 0.1 per cent (or 2" arc) per century.

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This preliminary finding was later corrected to a final, apparent rate of decrease of 1.2 ± 0.6 "arc/century (or roughly half of the originally announced value), after continued tests of the data revealed that the effect of two systematic factors had been underestimated in the original analysis. These important systematic effects were those of observer error (or bias) and of secular trends in the transparency of the sky at Greenwich. The Principal Investigator was able to derive from the data an "exact correction" for the latter, atmospheric effect by taking advantage of trends in a systematic annual cycle in the apparent diameter of the sun that resulted from the seasonal change in the altitude of the sun at Greenwich. A new and objective way was also derived to identify relative observer error. A discussion of these corrections, along with revised values for the secular trend in apparent diameter and a comparison with other analyses of secular changes in the diameter of the sun are included in a paper now in preparation by Eddy and Boornazian, who assisted as a contract employee in the original reduction of the Greenwich data at the Center for Astrophysics.

Other Results of the Study

The original findings of the work supported by this grant (that the sun appeared to change its diameter or shape over periods of decades) has prompted a new interest in this fundamental parameter of the sun as a possible index of the total solar luminosity and as a diagnostic of internal conditions within the sun. A number of other studies of possible changes in the solar diameter have been initiated by other investigators as a direct result of the specific work funded by this grant,

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including examinations of historical solar eclipse data and data on the transits of Venus, a re-examination of solar transit data taken from other observatories, and a re-examination of photographic and photoelectric images made of the sun in routine patrols. This has resulted in the publication of at least eight other related papers.

A comparison of findings so far published shows little agreement, except to suggest a general trend toward a smaller solar diameter in the past century and the possibility of long-term oscillations in the diameter with periods of about 76 and perhaps 11 years. The disagreement in the amplitude of possible changes in the sun's diameter emphasizes the possibility of cyclic expansion and contraction on secular time scales, but it also points to the fact that the historical data now known are probably inadequate to answer the question of secular changes more than approximately. This in turn has prompted the initiation of two new observing programs (at the High Altitude Observatory and the Kitt Peak National Observatory), the building of a new solar observatory solely dedicated to solar diameter measurements (at HAO/NCAR in Boulder), and the funding of a preliminary Design Study by NASA Headquarters to look at the feasibility of measuring the solar diameter from space: the so-called "Solar Beacon" Science Study Group initiated in 1981. The Principal Investigator is a member of this Study Group and a collaborator in the HAO program of daily measurements of the sun's diameter. Thus it seems fair to say that the impact of the original study funded by Grant NSG-5345 has been significant and widespread. Probably its most important result has been to call attention to the practical importance of a parameter of solar variability that had long been ignored.

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Scientific Colloquia Presented by the Principal Investigator on the Specific Subject of Grant NSG-5345 (Solar Diameter Variations in the Greenwich Data):

May 24, 1979	High Altitude Observatory, Boulder
July 24, 1979	Los Alamos Scientific Laboratory
September 20, 1979	Harvard-Smithsonian Center for Astrophysics, Cambridge
September 25, 1979	Columbia University, New York City
December 5, 1979	Boston University
March 26, 1980	Sandia Laboratories, Albuquerque
May 14, 1980	California Institute of Technology, Pasadena
February 11, 1981	University of New Hampshire, Durham
March 3, 1981	University of Colorado, Boulder
April 22, 1981	University of Toledo, Ohio
September 22, 1981	Colorado School of Mines, Golden
September 23, 1981	Denver University, Colorado
December 3, 1981	NOAA Space Environment Laboratories, Boulder
February 22, 1982	Middlebury College, Vermont

Papers Published with Full or Partial Support of the Grant

Eddy, J.A. and Boornazian, A.A. (1979), Secular Decrease in the Solar Diameter, 1836-1953, Bulletin AAS 11, 427.

Eddy, J. A. (1980), Climate and the Role of the Sun, Journal of Interdisciplinary History 10, 725-747.

Eddy, J. A. (1980), The Historical Record of Solar Activity, in The Ancient Sun R. O. Pepin, J. A. Eddy, and R. B. Merrill, Eds., Per-

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gamon Press, 119-134.

Paper in Preparation (1982)

Eddy, J. A. and A. A. Boornazian, A re-Analysis of the Greenwich Transit Data for Evidence of Solar Diameter Variations.