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RESEARCH STUDY ON DYNAMICS
OF THE SOLAR ATMOSPHERE

Barbara Bell
Donald H. Menzel
John G. Wolbach

Harvard University
Harvard College Observatory
Cambridge, Massachusetts 02138

October 1976

Final Report for Period 1 July 1974 - 30 Sept 1976

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This report summarizes the research carried out with a varying degree of major or minor support from Contract F19268-75C-0016 between Harvard University and the United States Air Force, over the 27-month period ending 30 September 1976. → The first section summarizes the theoretical studies carried out on loop prominences as current loops rather than magnetic lines of force, and on problems connected with the general.																					

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20. (Cont....) → theory of relativity. The latter studies lead to the conclusion, among others, that Black Holes are a mathematical fiction, impossible of physical existence. The following section deals with research in the general area of solar-terrestrial relations, one investigation directly in this area and the other, climate history, having at present only a potential for linkage to solar activity, and receiving only minor support from this contract. The former, begun under the predecessor contract, explores the relations between the intensity of coronal Fe XV emission, the level of geomagnetic activity, and the velocity of the solar wind, and was completed and published during the period of this contract. The research in climate history focused primarily on time-variations since 1881 in temperature and rainfall over the North American continent, and will continue following the conclusion of this contract.

19. (Cont..) Climate history

North American rainfall
temperature
river flow
African rainfall
Nile River

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I. INTRODUCTION

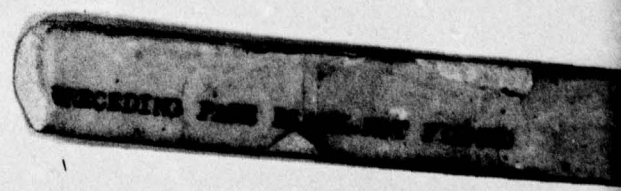
Contract F19628-75-C-0016, of which this is the Final Report, was instituted on 1 July 1974 as the latest in a series of contracts between the United States Air Force and Harvard University for research on the observation and interpretation of solar phenomena. The task of the contract is to conduct research on the dynamics of the solar atmosphere by means of theoretical and interpretive studies of available data.

No Scientific Reports were issued under the contract.

II. THEORETICAL STUDIES

Dr. Donald H. Menzel continued his theoretical investigation into the dynamics of the solar atmosphere, using the equations of electrical engineering to study the stability of current loops, in particular whether such loops would tend to separate and multiply or to coalesce and diminish in number. He attended the Solar Theoretical Workshop at the Kitt Peak National Observatory in Tucson, Arizona, in October 1974, where he presented a short paper on loop prominences as current loops, rather than magnetic lines of force, the latter being the prevalent view at the meeting. The recent discovery of 'bright spots', regions of high temperature emitting x-rays, strongly suggests that some non-thermal source is present. The possibility that they could be small current loops appears attractive, but definitive results are not yet available.

With partial support from the contract, Dr. Menzel continued his researches, reported previously, on problems



connected with interpretation of the general theory of relativity. Einstein's field equations or 'law of gravitation' has two long-known exact solutions, found in 1916 by the German astronomer K. Schwarzschild. One of these solutions provides the well-known equation for the mass and radius of stars, as

$$r \leq 2GM/c^2, \quad (1)$$

where G is the constant of gravity, c is the velocity of light, M the mass and r the radius, under which a star will satisfy the conditions of a Black Hole, so-called because its gravity is so great that no light can escape.

Dr. Menzel found, however, that Einstein's series solutions for the field equations of gravitation are valid only for weak gravitational fields such as apply in the solar system and explaining the gravitational deflection of light by the sun. He found general solutions of the Einstein field equations in which the velocity of light equals zero at radius r for the condition

$$r = GM/nc^2 \quad (2)$$

with n being any value. The Schwarzschild solution is valid for an isotropic universe only when $n = 1/2$, providing the formula (1) relied on by those who argue for the reality of Black Holes.

Further transformations by Dr. Menzel lead to results--obtained independently by Dr. Hüseyin Yilmaz by different methods--in which general solutions with simplified expressions are attained for $n = \infty$ and $r = 0$. Had these solutions been found by Schwarzschild, it is possible that the concept of the Black Hole would never have originated. Using finite values of n, despite what proponents of Black Holes

regard as merely alternative mappings of space and r , one finds different trajectories for each value of n , because real coordinates must be used in the equations to determine a real physical trajectory.

Dr. Menzel concludes that a small correction is required to Einstein's field equations, whence Schwarzschild's exact solution would no longer express the conditions for a Black Hole because zero radius and infinite density are implied by the correction. From further solutions, including Special Relativity and other physical arguments, Dr. Menzel concludes that the concept of a Black Hole of finite radius is untenable.

Where Einstein and other relativists have attacked the problem of the deflections of starlight by a gravitational field as a problem in ballistics (particle theory of light), Dr. Menzel worked it out as a problem in optics (wave theory of light) and found, surprisingly, that the two approaches do not always yield the same result. In particular the optical solution indicates that the increase in the 'gravitational' deflection of light approaches zero with increasing (very great) mass and decreasing radius, that is, as we approach the hypothetical condition of a Black Hole.

Further doubt is cast on the Einstein equations as physically valid by mathematical solutions based on Special Relativity. (The relationships of Special Relativity are well established, having been verified by laboratory experiments with linear accelerators and other atomic equipment.) Solutions by Dr. Menzel show that a frequency of light equal to zero (i.e., infinitely red-shifted)--as when a massive star satisfies the condition $r \leq 2GM/c^2$ for a Black Hole--is inconsistent with Special Relativity.

He independently derived the Yilmaz Relativity Metric, which is isotropic, removing the discrepancy between the

ballistic and optically predicted deflections of light. The Relativity Metric accounts for basic physical phenomena to the second order of expansion. It invalidates the concept of a Black Hole as more than a mathematical fiction, but leaves the possibility for the existence of infrared and radio (i.e., extremely red-shifted) 'holes'. Hence Dr. Menzel expanded his relativity studies to consider the existence of superstars, objects with mass as high as 10^8 or 10^9 that of the sun. (Previously such bodies were considered impossible, because they would have collapsed into Black Holes.) Such gravitating masses would exhibit a very strong, but not infinite red-shift. He is investigating the possibility that such superstars may provide explanations for quasars and, perhaps, also for the nuclei of Seyfert galaxies.

A summary of this research has been published by Dr. Menzel in Mémoires Société Royale des Sciences de Liège, 6e serie, tome IX, pp. 343-353, 1976.

In collaboration with Dr. Winfield W. Salisbury (independent of the contract), Dr. Menzel has also carried out a study of the expanding universe according to General Relativity. The primary conclusion of this research is that the apparent expansion of the universe is the result of a gravitational effect by intergalactic matter, which causes the observed red-shift usually interpreted as a recession of galaxies or expanding universe, that increases with distance of the galaxy from ours. They advocate an infinite universe which is completely static.

III. SOLAR-TERRESTRIAL RELATIONS

Research continued on two projects, the first directly in the area of solar terrestrial correlations and the second, climate history, having at present only a potential for linkage to solar activity (and receiving only minor support from the contract).

1. Fe XV Coronal emission, geomagnetism, and solar wind

Dr. Barbara Bell, in collaboration with Dr. Giancarlo Noci (a visiting scientist from the Arcetri Observatory, independent of contract support), completed an investigation into relationships between the intensity of the extreme ultraviolet ($284\text{\AA}$) coronal emission-line of Fe XV, the level of geomagnetic activity, and the velocity of the solar wind. This work was begun under the predecessor contract, in whose Final Report, AFCRL-TR-74-0357, the objectives, data, method, and preliminary results were detailed.

During preparation of the work for publication, Dr. Bell added the conclusion that in the case of non-equatorial coronal holes (regions of exceptional weakness in Fe XV emission), it is to be expected that the hole is more effective as a source of recurrent geomagnetic storms when it is on the same (favorable) side of the solar equator as the earth. This conclusion is supported by a previously overlooked study published in 1957 by K. Sinno which indicates that the weak $5303\text{\AA}$ green-line regions in Fe XIV which were associated with the major recurrent storms in the years 1950-53 were regions (coronal holes) which on the average did not cross the solar equator. The years 1950-53 were studied in detail under an early contract of this series by Dr. Bell and H. Glazer, and their analysis of the relation between intensity of the 5303 line of Fe XIV and geomagnetism

indicated that weak green-line emission on the central meridian of the sun was much more likely to be followed by a recurrent geomagnetic storm when the weak region and the earth were on the same side of the solar equator, or when the earth was in the 'favorable' solar hemisphere. Thus Dr. Bell now believes that the favorable-hemisphere effect is to be expected only in the case of coronal holes which do not cross the solar equator, and will not appear with coronal holes of the equatorial type. From the data of the period May 1972 to Dec 1973, it is postulated that large holes in intermediate latitudes, avoiding the solar equatorial region, will produce the strongest enhancement of recurrent geomagnetic activity and solar-wind velocity.

Under this contract, the work was completed for publication, and revised to take account of the criticisms of a referee. It was recently published, in the Sept. 1 issue of the Journal of Geophysical Research, 81, 4508-16, 1976. The published Abstract summarizes the work as follows:

"The average solar wind velocity and the level of geomagnetic activity (kp) following central meridian passage of coronal weak and bright features identified from OSO 7 isophotograms of Fe XV (284Å) are determined by the method of superposed epochs. Results are consistent with the concept that bright regions possess magnetic fields of closed configuration, thereby reducing particle escape, while coronal holes possess open magnetic field lines favorable to particle escape or enhanced outflow of the solar wind. Coronal holes are identified with Bartels' M regions not only statistically but by linking specific long-lived holes with individual sequences of geomagnetic storms. In the study of bright regions a subdivision by brightness temperature (T_b) of associated 9.1-cm radiation was found to be significant, with the regions

of higher T_b having a stronger inhibiting power on the outflow of the solar wind when they were located in the solar hemisphere on the same side of the solar equator as the earth. Regions of highest T_b most strongly depress the outflow of solar wind but are also the most likely to produce flare-associated great storms."

2. Climate History

Research into climate history was begun with partial support from predecessor contracts (see Final Report of Contract F19628-69-C-0077, AFCRL-72-0094; and Contract F19628-72-C-0146, AFCRL-TR-74-0357) by Dr. Bell and Mr. John G. Wolbach, and has continued with minor support from this contract, but funded in major part from other sources. This research, aimed at eventually correlating surface and upper-atmosphere climatic and meteorological parameters with solar activity, has as its more immediate objective the identification of medium-term (one to a few decades) climate fluctuations over the period of modern measurements, on a worldwide basis so far as possible. The previous Final Reports discuss the objectives and general procedures more fully.

Independently of the contract, Mr. Wolbach had already obtained on computer tape the meteorological data published in WORLD WEATHER RECORDS, as described in the Final Report of the predecessor contract -0146; he had also engaged Stan Ross & Co., systems analysts, to do the necessary programming and computing.

Initially the data of the four parameters--temperature, rainfall, sea-level pressure, and station-level pressure--were processed for all available stations of long-record, worldwide -- about 200 in number. The

computations yielded monthly and annual averages over the years 1881-1940, the deviation of each value from its mean in units of the standard deviation, and the cumulative sums of these deviations (deficits and excesses) over the period of record of each station. These cumulative sums of the deviations--hereafter called 'cum sums' for brevity--were printed out in tabular and in graphical form.

Because the curves had such widely differing characteristics, the tabular and graphical printouts did not reveal any meaningful geographical distribution in the time-variations of the station-parameters. Mr. Wolbach therefore directed Stan Ross & Co. to develop a program for production of contour maps by computer, showing the cum sums at selected points in time. After assorted difficulties and adjustments in presentation of the data, satisfactory maps were produced for the region of North America. Test plots of world maps, showing only the location of stations, made it evident that the 200 stations of long record were concentrated in a few areas and hence unsuitable for analysis of climate variations on a worldwide basis.

The statistics were therefore recalculated, taking averages and standard deviations over the years 1931-1960 to define the 'norm'. While this average over the 30 years, 1931-1960 will henceforth be called the Norm, we intend thereby no implication that it has any absolute normative significance. It is purely a terminological convenience. Use of the 1931-60 norm permitted the addition of more recently established stations and brought the number available for mapping to between 800 and 900. Because of the relative slowness and limited storage in the memory of the CDC 6400, and the competing requirements of other scientists at the Observatory for computer time, the statistics have not yet

been completed worldwide. The initial effort has been directed to producing isoplethic representations of the North American data.

To obtain information on the dates when climatic changes occurred, we had maps produced for each month and year at five-year intervals from 1920 to 1970, and ten-year intervals from 1880 to 1920. Such maps, plotting the value of the cum sum of the deviations in units of the standard deviation, showed that a period from 18.. or from 19.. to 1930, or to 1960, was at a geographical point colder, or warmer, than its 1931-60 norm. By subtracting cum sums at five-year intervals after, and ten-year intervals before 1920, one could compare rainfall (or temperature) at a short time distant from the norm, or for a shorter period within the 30-year interval of the norm, with that of the norm.

At the conclusion of the Contract, the temperature and rainfall maps for North America had been completed, and subjected to preliminary perusal by Mr. Wolbach. Various significant climate fluctuations could be seen in them, with 'significant' defined as follows: let n be a number of years, and a period $(t_0 - t_n)$ be of n years duration, take cum sums in units of the standard deviation (σ) and set the cum sum = 0 at t_0 . Then random walk statistics predict a cum sum will be within $\pm\sqrt{n} \sigma$ at t_n approximately 95 percent of the time. If we set $\sqrt{n}\sigma = \sigma'$, then $\sigma' \leq 2$ is considered a non-chance or statistically significant deviation (at the 95% confidence level). When an isopleth encloses a number of stations at $\leq 2\sigma'$, then we consider that a significantly cooler, or drier (e.g.) regime occurred, relative to the norm, in the geographical area so enclosed over the time-period considered.

North American Rainfall. After studying the tabulations and graphs of monthly and annual cum sums, Mr. Wolbach concluded that intervals of significant deviation from the norm were common, especially for stations of long record. Some twenty years ago, E.B. Kraus showed, by the method of cum sums relative to a norm of 1881-1940, that certain widely separated stations--e.g., Charleston, S.C.; Freetown, West Africa; Brisbane, Australia; and others--had a wetter rainfall regime prior to about 1900 than over the following several decades. When he examined plots for individual months of North American stations, Mr. Wolbach noted that the annual cum sum was often strongly influenced by three or four months which had the wet followed by drier regime (as found by Kraus) although the date of transition can vary by as much as a decade or two; typically two or three other months would have a trend opposite to that of the year, while still others would be trendless or weakly Krausian.

Turning now to the maps, Mr. Wolbach found that the yearly maps show, over practically the entire United States, that the 1881-1890 decade was significantly wetter than the 1931-60 average. This is particularly true for Dec and Jan, but not necessarily true of every individual month; for example, Feb was very wet in the east; June was dry in the east and wet in the midwest over this decade. It is not meaningful--even if space permitted--in terms of a meteorological or climatological concept, to describe each month of the 1881-1890 decade, nor individual months of other intervals, and the remainder of the summary will be limited to annual patterns of time-variation. However, we may note that if 10-20 stations in an area of a million or so square miles are having a wet (warm) period in one month, in the following month some or all of the area may be having a period drier

(cooler) than the norm, while the wet (warm) region may be displaced and changed in size or shape.

The principal features of the annual rainfall maps are summarized by decade, unless otherwise stated, in the accompanying table.

For comparison with rainfall trends, Dr. Bell computed and computer-plotted cum sums, in standard deviation units, showing variations in the annual volume of flow of some 25 North American rivers at 32 recording stations. Most of the rivers show a reduced flow beginning between 1925 and 1930 to 1940, followed after 1940 by an increased flow--trends most conspicuous in the region of the Great Plains drought of the 1930's from the Arkansas in the south to the Saskatchewan in Canada, but appearing also in flow volume of the Niagara and St. Lawrence in the northeast, and the Snake and Columbia in the northwest. The trend does not appear in rivers east of the Mississippi and south of the Great Lakes; and rivers east of the Appalachians show no noteworthy trends within the years of record available to us.

The reduced flow of the Missouri in the late 1930's is particularly striking, since its flow was well above the 1931-60 average from 1928 back to 1891 (our earliest records). This is in good general accord with the rainfall maps since most of the Rocky Mountain stations and some in the western plains, over much of the Missouri River basin, show a rainfall regime wetter than the norm from 1880 to 1930. It may be noteworthy that the region of rainfall above the norm shrinks during the decade preceding the Great Plains drought of the 1930's. The rainfall pattern is also in general agreement with the flow records of the Colorado, which diminishes around 1930 but not to the extent of conspicuous

TABLE I

PRINCIPAL DEVIATIONS OF ANNUAL RAINFALL FROM THE NORM (1931-1960 Av)
BY DECADES IN THE UNITED STATES UNLESS OTHERWISE STATED

<u>Decade</u>	<u>Regions wetter than norm</u>	<u>Regions drier than norm</u>
1881-1890	United States, Mexico, generally.	New York state and north thereof.
1891-1900	Northern United States Rockies, Central Great Plains; Southern Appalachians.	South of Great Lakes, from Mississippi to East Coast; Florida; Mexico; Southern California.
1901-1910	Rockies and Northern Great Plains (Missouri, Snake, and Colorado River Basins).	Most of the United States east of Mississippi, especially Carolina Coast; Canadian Pacific coastal regions.
1911-1920	Rockies, and Northwest Great Plains.	Most of the eastern half of the country, especially the Carolina coast; Canadian Pacific Coastal Region.
1921-1930	Northern United States Rockies and West Central Plains (some shrinkage of wet area, compared to two previous decades); Southeast and West Alaska.	Most of Appalachians; Pacific Northwest, Canadian Rockies and Plains.
1931-1940	South Carolina; Louisiana and Texas; Canadian Pacific Coast and Southeast Alaska; Northeast United States.	Most of the United States, with strongest drought in Great Plains and Idaho.
1941-1945	Western and North Central United States.	Southeastern states; Pacific Northwest and Canadian Coastal Region.
1946-1950	Most of the United States	Northeast; southern part of continent west of Mississippi, especially Calif.
1951-1960	Patterns weak and fragmented: Canadian Rockies and North Pacific coast; North Central States.	Southern California, Central Rockies, Southeast Alaska.
1961-1970	Eastern Rockies; Southern Appalachians, Ohio; Southeast Alaska.	South Central States, Mexico; Pacific Northwest, Canadian Rockies; West Alaska.

participation in the drought. Unlike the Missouri, the upper Mississippi (above the Missouri confluence) shows no such notable and prolonged pre-1931 deviations from the norm, even back to 1860, in accord with the maps which show no prolonged systematic deviations from the norm over the upper Mississippi basin.

The Niagara and the St. Lawrence, and also the Columbia, show diminished flow setting in about 1920. Variations in the levels of the Great Lakes were analyzed by the same method, with records extending from 1860 to 1960. While Lake Superior has unexplained anomalies, the other lakes and the flow of the Niagara and St. Lawrence rivers agree in indicating a particularly wet regime from 1860 to about 1890-1895, an intermediate regime to about 1920, and the driest regime then up to 1942 (also 1962-66), followed by a return to the wet regime (1943-56) (1967-72, end of record).

Examination of tabulations and maps for comparison with the river data led Mr. Wolbach to conclude that many rainfall stations in the eastern half of North America shifted to a relatively drier regime between 1890 and 1910 (the Krausian pattern). The trends in the levels and outflow of the Great Lakes is in accord with the rainfall trends which show a relatively drier regime setting in around 1900 in the eastern North America. The later dry regime, affecting all areas except some west coastal (southern California and Canada) and northeastern areas from 35° to 55°N started in the 1920's and became clearly manifest around 1930; this accentuated the lowering of the Great Lake levels and the reduction in river volume. After 1940, the maps show a wetter regime consistent with rising Lake levels and increased flow in a majority of the rivers analyzed.

North American Temperatures. The maps showing cum sums of annual temperature at selected intervals indicate that North America, including the entire continental United States and settled parts of Canada was cooler in the interval 1881-1920 than during the years 1931-60 of the norm. After 1920 warming appeared first in a narrow north-south zone to the west of the Mississippi, in the position of a boundary between dry-regime stations at that time in the east and wet-regime stations in the west. By 1925 the Rocky Mountain stations had warmed to their 1931-60 norm, with the east still remaining cool. During 1931-35, Canada and Mexico remained cooler than the norm while the entire United States was above the norm. From 1936-40, the East was cooler than the norm while the West was warmer. In the decade 1946-55, the East warmed while the West cooled. Only the northwest and Alaska remained warmer than the norm over the years 1956-60. In the decade of the 1960's, temperatures below the norm appeared over most of North America.

From examination of monthly cum sum maps, Mr. Wolbach concluded that temperature trends show more consistency from month to month than does rainfall. In the cooler period from 1881 through 1920, the summer months showed in 1880 larger positive values of cum sums, in standard deviation units, than did winter months, while Feb, Mar, and Nov showed the smallest positive values. Much before 1920 these anomalous months generally showed negative (-) values of the cum sums, indicating weather warmer than that of the norm.

Although the summer months showed the largest values of the cum sums, the standard deviations are nearly always larger in winter, late fall, and early spring, than they are for summer months. Taking this fact into account, Mr. Wolbach drew the following principal conclusions: from 1881 to

1920 winters were, on average, shorter and colder than in the 1931-60 period of the norm; there was an earlier spring and more prolonged fall than in the period of the norm; the six or seven seasonally warmer months averaged about as much colder as the two winter months, about 1°C cooler than the corresponding months in the interval of the norm. However, Feb, Mar, and Nov remained essentially constant in temperature, with only random fluctuations from 1881 to 1960. After 1961 their anomalous behavior is less significant, with smaller areas remaining warm.

At the present stage of the investigation, no correlation has been found between temperature and rainfall deviations from the norm, except possibly for the 1930's, a decade that was both warmer and drier than the norm over nearly all of North America.

Following the conclusion of the Contract, it is planned to continue this research with production and study of North American pressure maps, then expand to worldwide data, subsequently to upper air data, and to the search for a linkage between climate fluctuations and variations in solar activity.

Supplementary Rainfall Data: Africa and Mediterranean.

With minor support from the contract, Dr. Bell continued with the collection, computerization, and updating of her file of supplementary rainfall data for Africa and the Mediterranean Basin, as described more fully in the Final Report of the predecessor contract, AFCRL-TR-74-0357. The Weather Bureau of the Department of Transport, Pretoria, generously provided a computer tape containing records of monthly and annual rainfall for South African stations with 20+ years of record, which provides a valuable addition to the collection particularly because they have a number of stations with records from 1881 or earlier. Although many of the records are usable, various difficulties were encountered in reading the tape, and the

Weather Bureau has proposed to send an improved edition within the next few months.

In addition to the countries noted in the previous Final Report, rainfall data from 1931 or earlier have been provided for a number of stations by the respective meteorological services of the Ivory Coast, Central African Republic, Congo Republic (Brazzaville). From the annual publications of Mozambique and of Angola the rainfall data for a substantial number of stations were computerized through 1968, the latest available. Other additions, noteworthy for long records, include rainfall from Luanda (Angola) from 1878, several records from Portugal beginning before or shortly after 1881, and Bathurst/Banjul (The Gambia) from 1884. As a return favor, computer printed tables of their own data were offered, and sent to the cooperating national meteorological services who indicated an interest in the offer. A goal of Dec 1975 was adopted for the updating and closing of the supplementary files, and achieved by the closing date of the Contract for Greece, Israel; the Sudan, the East African countries of Kenya, Tanzania, Uganda, Burundi, and Rwanda; Madagascar; Congo Republic, Gabon; Nigeria, Ghana, Sierra Leone; Mali, Upper Volta, and the Ivory Coast.

Dr. Bell also made some 'improvements' in the East African data, by substituting for missing data estimates from the regional average or from several nearby stations in place of the previously-used average of the ten surrounding years. This change is particularly advantageous where missing records pertain to an abnormally wet, or abnormally dry interval, because the new estimates should more closely approximate the actual conditions.

A program was developed by S. Ross & Co., at Dr. Bell's request, for graphing on the Observatory's Versetec plotter the cum sums for up to ten stations simultaneously. This technique should greatly facilitate and speed up the search

for significant rainfall fluctuations within the period of record. It is expected that some of the stations from the supplementary rainfall file will be used also in the program of world-mapping, to provide more adequate representation for Africa.

Nile Flood Levels. Finally, Dr. Bell resumed work on a project, begun several years ago with partial support from a previous contract (see AFCRL-72-0094), to analyze for time-variations by the method of cumulative deviations from a 'norm' the available records of the height of annual Nile flood at Roda (near Cairo) from AD 622 to modern times. Surviving records are nearly complete from 622 to 1522, and from 1700 onward, but, unfortunately for purposes of correlation with solar activity, they are quite rare during the years of the Maunder minimum (the latter half of the 17th century), the most extreme deviation known to scientists from the modern-normal in solar activity and characterized by great rarity of sunspots.

The principal obstacle to definitive analysis of these data is the disagreement between scholars (W. Popper, and O. Ghaleb) on the changes made from time to time in the nilometer scale of cubits and fingers, hence in the correct translation to meters above sea level in a homogeneous series. Toussoun (1925), the original compiler of the data from medieval texts, assumed a constant relation between cubits and meters above sea level. From a later study of Arabic texts, Popper (1951) concluded that two discontinuities had occurred in the relation between cubits and meters above sea level, the first in AD 1522 with the Turkish conquest of Egypt, the second (and less important) in 1860. In 1970-71, Dr. Bell had converted Toussoun's data to Popper's calibration-scale and carried out a preliminary analysis for time-variations, when she discovered yet another study of ancient texts, published in Cairo by Ghaleb (1951) who concluded that five

different relations between cubits and meters had existed, with one change at AD 861 undetected (or disbelieved) by Popper; the next at 1522 (where Popper and Ghaleb agree on the date); and two others subsequently, in 1737, and 1886. The research was suspended at this point, largely in the hope that a revised table on Ghaleb's calibration scale might be obtained from Cairo, since he had urged the making of such a revised table. However letters of inquiry produced no reply, neither a table nor any information on whether or not a new table had ever been compiled.

In view of the rapidly growing interest in climate fluctuations in historical times, Dr. Bell decided to resume the investigation and make her own conversion of the data to Ghaleb's scale. Since the relation between the scale is non-linear at High Water Level (HWL), she prepared a set of graphs showing the relation at each period, in meters above sea level, between the Toussoun and the Ghaleb scales, and used the graphs with Toussoun's original table to compile a table of HWL's on the Ghaleb scale. The three sets of HWL data, on the scales of Toussoun, Popper, and Ghaleb, were punched on computer cards for analysis--with each set corrected for a rise of one meter per 1000 years in the level of the riverbed and alluvium. The data from Toussoun's tables for the so-called Low Water Level (LWL) have been similarly computerized. Since the relations among the scales are linear at LWL, conversion to the Popper or Ghaleb scales can easily be done by computer, and this capacity was incorporated into the program for statistical analysis of the HWL and LWL data for time-variations. The analysis will be carried out following the conclusion of this contract.