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# Numerical Weather Prediction and Synoptic Meteorology

CAPT. T. D. MURPHY

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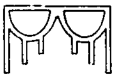

A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

U. S. DEPARTMENT OF COMMERCE
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WEATHER BUREAU

Weather Bureau Technical Memorandum WR-30

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TECHNICAL MEMORANDUM NO. 30

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# PREFACE

This paper was originally written to fulfill a term paper requirement assigned when Captain Murphy was enrolled in my Advanced Synoptic Meteorology Course at the University of Utah during the 1968 Winter Quarter. Captain Murphy's summary of important numerical weather prediction developments and his discussion of their relationship to and effect on the practice of synoptic meteorology were so well done that I thought his paper should be shared with all Western Region personnel. I am grateful to Captain Murphy and the U. S. Air Force for their kind permission to publish this term paper as a Western Region Technical Memorandum.

L. W. Snellman

L. W. Snellman, Chief
Scientific Services Division

# NUMERICAL WEATHER PREDICTION AND SYNOPTIC METEOROLOGY

by

Captain Thomas D. Murphy, U.S.A.F.*

Numerical Weather Prediction (NWP) has had a spectacular impact on synoptic meteorology. Indeed, the development of NWP is one of the most significant advances in the science of meteorology [1]. Although most of the impact of this development has been in the last two decades, the theoretical foundation for NWP was begun as early as the midnineteenth century. Before going into the details of this development, let us briefly review the basis for NWP.

NWP can be regarded as an initial value problem. That is, if the initial state of the atmosphere and the laws governing atmospheric motions are known, then the future state of the atmosphere can be determined from these laws [2]. The laws governing atmospheric motions are embodied in the following hydrodynamical equations:

(1) $\frac{du}{dt} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + fv$ - 1st Equation of Motion

(2) $\frac{dv}{dt} = -\frac{1}{\rho}\frac{\partial P}{\partial y} - fu$ - 2nd Equation of Motion

(3) $\frac{\partial P}{\partial z} = - \rho g$ - Hydrostatic Equation

(4) $\frac{\partial \rho}{\partial t} = - \frac{\partial}{\partial x}(\rho u) - \frac{\partial}{\partial y}(\rho v) - \frac{\partial}{\partial z}(\rho w)$ - Continuity Equation

(5) $P\propto = RT$ - Equation of State

(6) $\frac{d}{dt} T \left(\frac{Po}{p}\right)^{\kappa} = 0$ - 1st Law of Thermodynamics

This set of equations is complete since there are six independent equations in six dependent variables; namely, temperature, pressure, density, and the three components of velocity. These hydrodynamical equations are in a form such that their solution is determined for all time by the initial values of the six dependent variables at every point in the atmosphere. This provides the basis for NWP, for the problem is essentially one of integrating this set of differential equations starting with initial conditions [3].

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*The views expressed herein are those of the author and do not necessarily reflect the views of the Air University, the United States Air Force or the Department of Defense.

This complete set of hydrodynamical equations was studied as early as 1858 by von Helmholtz as a possible means of dealing with meteorological problems. But these equations are very difficult to solve. Analytical methods fail to solve them and purely numerical methods were not fully developed until the early 1900's. This and the scarcity of observations were insurmountable obstacles to von Helmholtz. Nevertheless, he must be credited with providing the theoretical foundation of NWP [4].

The first real attack on the problem of NWP was begun by a group of meteorologists at the Norwegian Geophysical Institute just after the turn of the twentieth century. This brilliant group of scientists (Bergen School) was led by Vilhelm Bjerknes and included such men as Godske, Solberg, and Jakob Bjerknes. In 1904, Vilhelm Bjerknes stated that the only rational approach to the problem of NWP was in solving the hydrodynamical equations which express the physical laws governing the behavior of the atmosphere*.

Building on von Helmholtz's theoretical foundation, these men carried out a systematic study of idealized mathematical models. Their work was aimed at classifying the atmospheric motions and identifying them with the solutions of linearized forms of the hydrodynamical equations. Two factors, however, prevented them from reaching the real core of the problem of NWP. These factors were limited mathematical methods at their disposal and the lack of detailed observations of the large-scale atmospheric motions. Nevertheless, these men did make a truly significant contribution to our general understanding of the kinds of motion that occur in the atmosphere [5].

Even as Bjerknes and his colleagues struggled with their work, an idea was taking shape in the mind of Lewis F. Richardson, a British meteorologist-mathematician. About 1910, Richardson began to realize that the hydrodynamical equations could be solved by working them out in step-by-step computations using simple addition, subtraction, multiplication and division [6]. This realization that these complex equations could be solved by purely numerical methods and sheer brute force was one of the milestones in the development of NWP [7].

Essentially, Richardson worked with the three equations of motion, the continuity equation and the law of conservation of energy for an adiabatic process. This is a complete set of five independent equations and five dependent variables. Richardson realized that these equations could be written in the following form:

*Editor's Note: See Western Region Technical Memorandum No. 13.

$$(7)\quad \frac{\partial u}{\partial t} = -(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}) - \frac{1}{\rho}\frac{\partial P}{\partial x} + 2\Omega(v \sin\phi - w \cos \phi)$$

$$(8)\quad \frac{\partial v}{\partial t} = -(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}) - \frac{1}{\rho}\frac{\partial P}{\partial y} - 2\Omega\, u \sin\phi$$

$$(9)\quad \frac{\partial w}{\partial t} = -(u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}) - \frac{1}{\rho}\frac{\partial P}{\partial z} - 2\Omega\, u \cos\phi - g$$

$$(10)\quad \frac{\partial \rho}{\partial t} = -(u\frac{\partial \rho}{\partial x} + v\frac{\partial \rho}{\partial y} + w\frac{\partial \rho}{\partial z}) - \rho(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z})$$

$$(11)\quad \frac{\partial P}{\partial t} = -(u\frac{\partial P}{\partial x} + v\frac{\partial P}{\partial y} + w\frac{\partial P}{\partial z}) - \gamma P(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z})$$

Hence, Richardson had written these equations with all time derivatives on the left and all space derivatives on the right. He realized that this meant that the instantaneous local rates of change of each of the five dependent variables could be computed from a knowledge of the distribution in space of these variables at a given moment. Since it is theoretically possible to measure the spatial distribution of the variables at a given time, he knew that he should be able to determine their rates of change from Equations 7 through 11 [8].

Richardson had a lively interest in the new finite-difference methods and was able to solve these hydrodynamical equations by finite-difference methods. Briefly, he replaced the derivatives by finite differences which reduced the set of differential equations to a set of algebraic equations. Thus he was able to compute the initial rate of change of each of the variables of the hydrodynamical equations. Knowing the initial value and the initial rate of change of each variable, he then extrapolated its value over a certain time interval at each point in his grid network. Since this new information is just what was needed to begin the process, he laboriously repeated this process until he reached a forecast for the desired period of time [9]. Hence, Richardson, by about 1920, had completed the first genuine attempt at NWP.

After many months of laborious hand computation, Richardson obtained very disappointing results. His calculations predicted that the large-scale weather disturbances would travel at about the speed of sound and in the wrong direction. There seem to be three primary causes for these gross errors.

First, his observations were not sufficiently accurate or representative, nor did he have adequate coverage, especially aloft. Since the success of any program of NWP depends upon accurate and extensive observations, his experiment was doomed on this basis alone.

The second cause of his failure was that although his equations were theoretically adequate, they contained certain grave drawbacks. The main problem was compensation of terms in the equations which Richardson did not take into account. For example, in curved flow the three terms on the right hand side of Equation (8) nearly cancel themselves out. Hence, each term must be measured with considerable accuracy in order to obtain $\partial v/\partial t$ within sufficient accuracy.

The third cause of his failure was a purely mathematical one. This was the computational instability that arose from his choice of grid and time intervals. The hydrodynamical equations are ones that permit a wide variety of wave motions ranging from fast sound waves to slow Rossby waves. In 1928, Courant, Friedrichs and Lewy showed that in the solution of these equations the grid interval, d, must not be less than the product of the chosen time interval, $\Delta t$, and the speed of the fastest wave, c, permitted by the equations. ($d \geqslant c\Delta t$.) If this condition is not satisfied, then small observational and round-off errors are amplified during the iterative process of the solution of the finite-difference equations until they mask the desired physical solution. This situation is known as computational instability and was unknown to Richardson. As a result of this initial failure and the awesome amount of computations required, interest in NWP withered rapidly and lay dormant for nearly two decades [10].

During the late 1930's some meteorological research was being carried on at the Massachusetts Institute of Technology under the leadership of C.-G. Rossby. Some of his collegues in these primarily synoptic investigations were Jerome Namias, H. C. Willett, and J. Holmboe. This research work coupled with two major developments of the 1940's led to a rapid development of NWP and its tremendous impact on synoptic meteorology.

In 1939, Rossby and his colleagues set forth the principle of conservation of absolute vorticity. In their research they had been studying the case of purely horizontal motion in a highly idealized atmosphere. They discovered that by eliminating pressure, the two equations of motion could be reduced to a single equation expressing the conservation of absolute vorticity [11], i.e., $\zeta + f$ = constant.

In addition, Rossby pioneered the study of the upper atmosphere. As a result of the wartime expansion of the meteorological network, data were regularly collected from a dense network of stations covering a very large geographic area. This meteorological data extended into the upper atmosphere through the use of radiosonde and rawinsonde equipment. Hence, for the first time there were adequate data available for detailed descriptive studies of atmospheric motions on a macroscopic scale. These studies revealed that many aspects of the general behavior of fluids are not essential to the operation of the atmosphere's weather-producing mechanism. Rossby realized that these studies, which he had advocated, also suggested how the general hydrodynamical equations could be simplified without sacrificing their essential meteorological content. Most importantly, these studies showed Rossby that the simple barotropic model would provide a basis for the prediction of large-scale atmospheric motions [12].

The wartime expansion of the weather services was the first of two major developments of the 1940's that revived interest in NWP. The second and more important development was the invention of computers [13].

In the mid-1940's, John von Neumann, a mathematician at Princeton, began designing a computer. Six years later he had developed the first computer for weather research which he dubbed MANIAC for Mathematical Analyzer, Numerical Integrator and Computer. Early in the development of the MANIAC, a group of meteorologists proposed that it be used in NWP [14]. This idea intrigued von Neumann and in 1946, he and one of his colleagues, Jule Charney, established a special project for formulating the problem of NWP with computers. Two other prominent members of this research team at the Institute for Advanced Study were A. Eliassen and Ragnar Fjörtoft [15]*.

The realization that computations on the scale of Richardson's could soon be carried out in a matter of hours caused a number of other theoretical meteorologists to turn their attention to this same problem. Soon there were similar research groups at the Geophysics Research Directorate of the U. S. Air Force Cambridge Research Center, the International Meteorological Institute at the University of Stockholm, the Napier Shaw Laboratory of the British Meteorological Office, the Research Division of the West German Weather Service, and Japanese Meteorological Agency, and the Massachusetts Institute of Technology [16].

Much of the initial effort of these research groups went into eliminating the causes of Richardson's failure. Cognizant of the problem of computational instability, these groups experimented with modifying the hydrodynamical equations such that there would be no solutions corresponding to sound and gravity waves, but that the solutions corresponding to the large-scale weather disturbances would be left essentially intact. If this could be done, the conditions for computational stability would be much less stringent since they would depend on the speed of the much slower large-scale disturbances [17].

The research workers at Princeton had the initial breakthrough in this area. Jule Charney in 1948, discovered that the judicious use of the geostrophic and hydrostatic approximations had just this desired effect of excluding the solutions corresponding to high-speed waves [18]. Charney devised a filtering method to eliminate this "meteorological noise" which essentially consisted of replacing the primitive hydrodynamical equations by combining the geostrophic and hydrostatic equations with the conservation equations for potential temperature and potential

*Editor's Note: Dr. G. P. Cressman was also a member of this team for a limited time.

vorticity. This gave Charney a single equation in pressure for the motion of large-scale systems [19]. This equation was of the first order of time, hence the motion could be determined solely from a knowledge of the initial pressure field [20]. Charney set forth a program for NWP in early 1949 which proposed a hierarchy of atmospheric models whose study would lead to an increasing comprehension of the physical and numerical aspects of NWP [21].

Arnt Eliassen was working closely with Charney at this time. At first they studied the simplest model in the proposed hierarchy, the barotropic atmosphere. Motion in this model was regarded as consisting of small perturbations on the zonal current. The problem of forecasting these perturbations is, of course, the simplest NWP problem. In this initial effort Charney and Eliassen dealt extensively with the numerical properties of the linearized barotropic equations. They used this model as a step toward more complex models and hence, a step toward the realization of the general problem of NWP [22]. In 1949, they proposed a numerical forecast method for the height profile of the 500-mb surface at a fixed latitude. They also calculated the constants necessary for twenty-four hour forecasts at 45° N. This was the first attempt to replace qualitative and subjective forecasting with an objective, numerical method [23]*.

With this background, von Neumann, Charney and Fjörtoft were, in 1950, able to numerically integrate the nonlinear barotropic equations by a method of successive time extrapolations. As von Neumann's computer, MANIAC, was not quite finished, they borrowed a computer, ENIAC, for these computations [24]. The good results of the first test meant that these men had made the first successful barotropic forecast on a computer. These encouraging results showed that the simplest of dynamical methods could forecast large-scale atmospheric motions as well as an experienced forecaster. Later trials, however, produced wildly fictitious forecasts such as a July blizzard in Georgia [25]! These later results pointed to the fact that a computer forecast was only as good as the equations fed into it [26]. What is more important, however, is that the initial success showed that the theoretical approach to NWP coupled with the speed and accuracy of a computer was a practical solution to the problem [27].

As more and more computers became available to meteorologists, the barotropic model was tested under a large number and variety of weather conditions. Despite the simplicity of the model, it was found that it accounted for most of the day-to-day changes in the pressure and flow patterns in the middle troposphere.

Naturally, the barotropic model did not exhibit all of the essential features of the atmosphere. The motions forecast by this model were governed by the principle of conservation of vorticity. This principle

*Editor's Note: Weather Bureau forecasters were first introduced to this forecasting technique in 1950 by Dr. Herbert Riehl during an experimental forecasting course given at the Chicago Weather Bureau Forecast Center under the auspices of the University of Chicago. See AMS Monograph Volume 1, No. 5, pages 3 and 55.

states that each air parcel retains its original rate of spin throughout its history. Hence, the number and intensity of the absolute vorticity centers associated with cyclonic and anticyclonic vortices in the model could not change. In other words, the equations for this barotropic model could not forecast cyclogenesis [28].

From 1948 to 1952 several methods similar to Charney's were developed for filtering out the "meteorological noise". Much research work was carried out to extend these methods to increasingly more general equations of atmospheric motion. Bushby, Eady, Eliassen, Phillips, Sawyer and Thompson had particular success along these lines [29]. Between 1951 and 1953 these men developed more generalized models as the second step in the hierarchy of models. These models aimed at eliminating the shortcomings of the barotropic model.

All of these more general models kept the problem mathematically two-dimensional by approximating the vertical motion. These "2-1/2"-dimensional models developed by Phillips (1952), Eliassen (1952), Eady (1952), and Bushby and Sawyer (1953) were essentially equivalent. They attempted to account for the baroclinicity of the atmosphere in a simple manner[30]. All of these men relied heavily on the research work that Sutcliffe had been doing in this area. Sutcliffe had considered the three-dimensional contour field as composed of two parts. These were the 1000-mb contour pattern which applies equally at all levels and the thermal field which varies with height.

By mid-1953, methods of NWP based on several variations of these more general models had been carefully tested in selected cases of rapid cyclogenesis. Encouragingly, these models were found to be capable of forecasting the correct trend in these specially selected cases. Since situations of rapid cyclogenesis are quite difficult to handle by subjective forecast methods, it was apparent that the methods of NWP were potentially superior to subjective forecasting [31].

The realization of the potential superiority of NWP caused a number of civilian and military meteorologists to bring this to the attention of the Joint Meteorological Committee under the Joint Chiefs of Staff. As a result, a special subcommittee was formed to look into this matter and make recommendations on the feasibility of establishing an operational NWP unit. This subcommittee recommended that such a unit should be established by pooling the resources of the U. S. Weather Bureau, the Naval Weather Service and the Air Weather Service of the U. S. Air Force. As a result, the Joint Numerical Weather Prediction (JNWP) Unit under the direction of Dr. George Cressman was established on July 1, 1954. An important part of this first operational NWP unit was a research and development group. This group*

*Editor's Note: Dr. Frederick Shuman, present NMC Director, and Mr. Arthur Bedient of NMC were members of this group. Mr. Bedient made very important contributions in Automatic Data Processing (ADP). Until ADP became operational in 1958, NWP products were not available in time for NMC forecasters to use them in preparing facsimile charts.

made a substantial contribution to the development of improved NWP methods during the late 1950's. Its first big success was a barotropic model which could successfully compete with manual products. The JNWP unit has since been turned over to the Weather Bureau and incorporated into the National Meteorological Center (NMC) at Suitland, Maryland [32].

Much of the impact of NWP on synoptic meteorology can be attributed to automatic data processing of incoming and outgoing data by computers [33] and the vast improvements in computer equipment at NMC since the early 1950's. The many-fold increase in the storage capacity of computers and the great increase in the speed of computations have been a real boon in this area. The improvements in the curve follower which was introduced in the 1950's have also been very significant in heightening the impact of NWP on synoptic meteorology.

A good example of the impact of improved NMC equipment is the vast expansion of the NWP forecast area. Larger and faster computers enabled the forecast area to be expanded from one not much larger than the United States and Canada in 1955 to practically the entire Northern Hemisphere by as early as 1962. This expansion eliminated the previous large errors which resulted from the inflow across the Pacific boundaries of the forecast areas used in the 1950's [34].

During the late 1950's, several of the systematic errors of barotropic forecasts were eliminated. One such error was the false anticyclogenesis which occurred on the west side of large subtropical highs. In 1956, Shuman showed that this error could be corrected by using the balance equation. Thompson had already demonstrated that this truncated form of the divergence equation was a more generalized filtering approximation than the geostrophic assumption. Shuman demonstrated that the use of the geostrophic wind approximation in the vorticity equation increased anticyclonic vorticity in southerly flow and increased cyclonic vorticity in northerly flow. The results of this increased negative vorticity in the southerly flow resulted in building and retrogression of highs to the east of the flow. Shuman showed by numerical experiment that the use of the balance equation eliminated this large error in barotropic forecasts [35].

In 1958, Wolff showed that certain large height errors in the barotropic forecasts were due to false retrogression of the very long atmospheric waves. He devised an empirical method for eliminating this error. Later that year, however, Cressman demonstrated that this false retrogression of the very long waves could be eliminated by including a large-scale divergence term in the barotropic equation [36].

The stage was now set for the JNWP Unit's first big success. The introduction of the balance equation and the large-scale divergence term in the barotropic equations coupled with the parallel development of automatic preprocessing of data gave an improved barotropic forecast available on a timely basis. Hence, the JNWP Unit now had a barotropic model that competed favorably with the manual product. There was a corresponding sharp rise in the 500-mb forecast accuracy in 1958 due to this improved barotropic model. See Figure 1. By 1960 the new model had proved itself superior, so the 500-mb numerical forecast replaced the manual forecast on the National Facsimile Circuit. This was the beginning of a trend which will continue for a number of years [37].

Another systematic error of the barotropic forecasts that received much attention during the late 1950's was the one associated with the higher mountain ranges. The crude mountain term which was being used produced large errors in the daily barotropic forecasts. In 1960, Cressman introduced an improved mountain term and a new surface-friction term. Although these new terms improved the barotropic forecasts, they did not completely eliminate the error [38].

In 1958 some comparative tests were made at Suitland between the operational barotropic model and a two-parameter model derived by Thompson at the Air Force Cambridge Research Center. The results of these tests showed that the sophisticated baroclinic model was not significantly better than the simpler barotropic model in 500-mb forecast skill. These results suggested that a simple substitute procedure for obtaining forecasts at other levels should be tried. Hence, in 1958 Ellsaesser meshed the barotropic model with the thickness forecast-equation in Thompson's model to obtain forecasts of levels other than the 500-mb level. This mesh model soon became the basis for all NWP forecasts at levels other than the 500-mb level and was especially successful for high troposphere forecasting [39].

Since 1958, an enormous amount of time has been spent in constructing multilevel baroclinic models. Research workers were confronted with the dilemma that the simpler barotropic model gave more accurate 500-mb forecasts than the more sophisticated baroclinic models. It seemed that more information simply lessened the accuracy of the forecasts. It was found that problems of both a numerical and a physical nature were involved in this dilemma [40]. Two different approaches were used in the development of these multilevel baroclinic models.

The first approach uses the Newtonian or primitive equations of motion. The hydrostatic approximation is used to remove the motion of sound waves; however, the controlled motion of gravity waves is allowed in this approach. By 1959, Hinkelman, Smagorinsky, Phillips and Elliassen had demonstrated some success with primitive-equation models. By 1961, Shuman had developed a 3-level primitive equation model [41].

It was generally agreed that a two-level baroclinic model could not capture the development mechanism of large-scale atmospheric systems at the 500-mb level. However, in 1965, Okland succeeded in integrating a two-level primitive-equation model using Lagrangian techniques which successfully forecast baroclinic development. This success reopened the question of the worth of two-level models. Since two-level models cannot provide the necessary information for operational requirements, this question became only academic [42].

In the early 1960's, a six-layer primitive-equation model was developed at NMC. This model was suitable for daily operational NWP but the necessary resources were not available. By 1966, however, these resources became available. First and foremost was the arrival of the powerful CDC-6600 computer at Suitland. Secondly was the development by the U. S. Air Force of a system of rapid collection and transmission of hemispheric upper-air reports which allowed an earlier start of the forecast. With these resources available, the six-layer primitive equation model replaced the operational three-level filtered equation model in June 1966. Despite the advances that have been made with the primitive equation models, there are still problems with them. Much research is still being carried out to eliminate the remaining problems [43].

The second approach in constructing these multilevel baroclinic models uses the filtered equations. The filtered equations are a system in which the vorticity equation has both sound and gravity waves removed by using the hydrostatic approximation and the balance equation. Cressman was instrumental in developing the first operational version of the filtered model at Suitland in 1963 [44]. Cressman's model was a three-level filtered equation model which was the principal numerical model used at the NMC from 1963 to June 1966 [45]. There are still problems associated with this approach to multilevel baroclinic models and work continues in this area today.

The rapid development of NWP in the last two decades has indeed had a spectacular impact on synoptic meteorology. This decade has seen the basis of many forecasts change from a highly subjective art to the purely logical and mathematical process of NWP. As many of the NWP forecasts have proven themselves superior to their corresponding manual products, they have been transmitted directly from computer to field forecast offices via facsimile, thus replacing the manually produced product. These computer forecasts emerge virtually untouched by human hands in a readily usable form [46]. Hence, the synoptic meteorologist has been freed from many of the time-consuming prediction methods of the past. Consequently, he has had much more time for analyzing the synoptic weather information, more time for considering the details of the forecast. This new freedom has had a profound effect on the synoptic meteorologist's general frame of mind. He has developed an entirely new attitude toward his science [47] and this, I feel, has been the greatest impact of NWP on synoptic meteorology.

Until recently, NWP has been almost exclusively devoted to the problems of the large-scale circulations and processes. As a result there have been significant advances made in these areas. This is in contrast to the lack of corresponding improvement in forecasting the more specific weather elements. Much attention is now being given in NWP to these smaller-scale circulations and processes. In particular, there has been much work done recently in the NWP of precipitation. This area of specific weather elements, I feel, is where NWP will have its greatest impact on synoptic meteorology in the future.

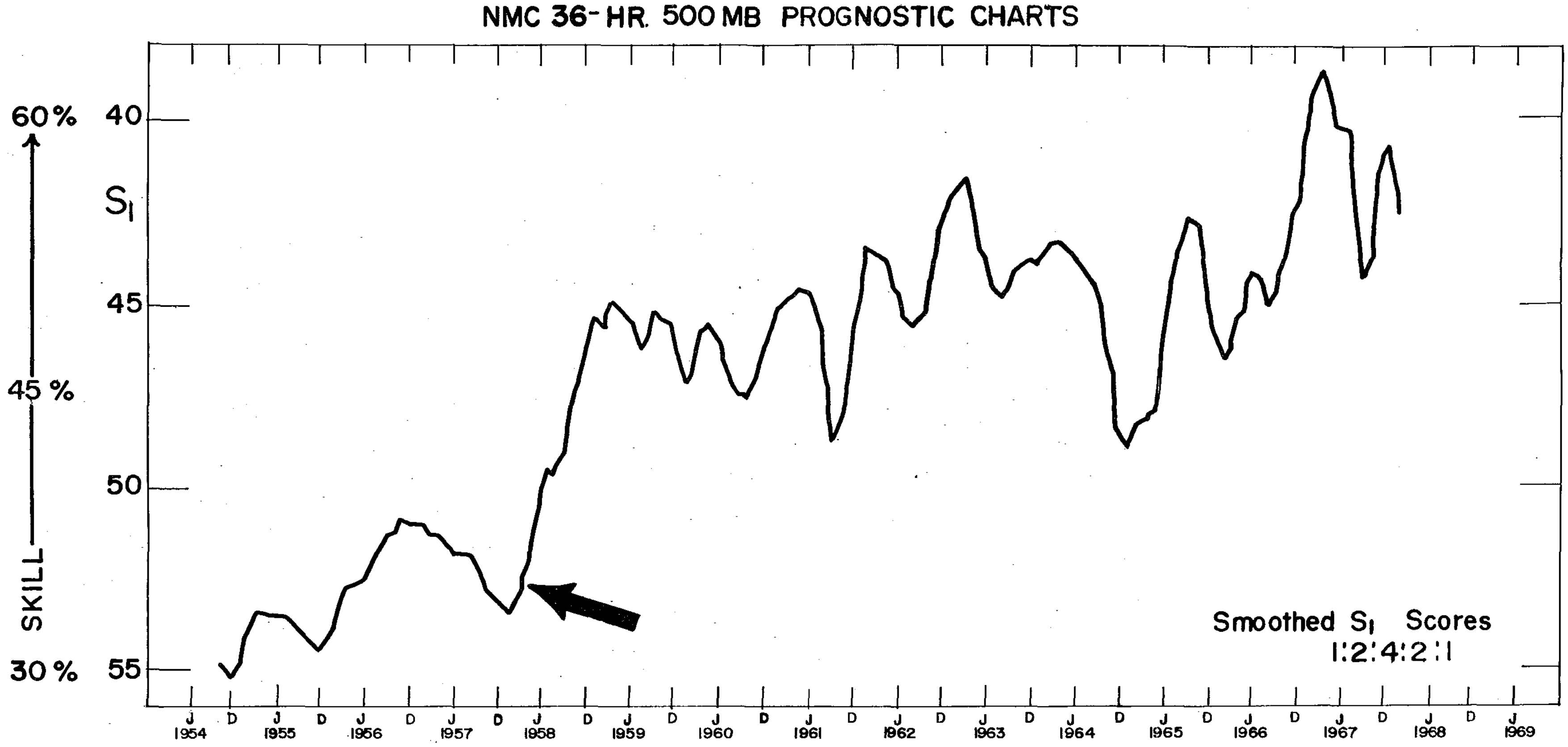

FIGURE 1 - SMOOTHED PLOT OF MONTHLY 500-MB $S_1$ VERIFICATION SCORES FROM JULY 1954 TO APRIL 1968. THE YEARS ARE LABELED AT JULY. THE ARROW INDICATES THE START OF A DRAMATIC IMPROVEMENT ATTRIBUTED TO AUTOMATIC DATA PROCESSING AND IMPROVED NWP PRODUCTS. THE SKILL PERCENTAGES INDICATED ARE BASED ON A PERSISTENCE FORECAST ($S_1$=70) CONSIDERED AS 0%, AND A PERFECT FORECAST ($S_1$=20) AS 100%.

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