VOL. 6, No. 1

Royal Meteorological Society

METEOROLOGY – 2000 A.D.

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CANADIAN BRANCH

25¢

VOL. 6 NO. 1

Published by

ROYAL METEOROLOGICAL SOCIETY, CANADIAN BRANCH

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METEOROLOGY - 2000 A.D.

by

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Presidential address presented to the Royal
Meteorological Society, Canadian Branch, at
its regular meeting, Thursday, February 24, 1955.

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> It is more important to know where you are going than to get there quickly. Do not mistake activity for achievement.
> -Mabel Newcomber.

INTRODUCTION

As a science Meteorology is both old and young. It was one of the first sciences to receive study in recorded history, yet it remained relatively undeveloped for thousands of years. There are reasons why this was inevitable. Meteorology is a physical science and its development had to await the development of Physics, which has itself occurred only in the last 300 years or so. In addition data on the behaviour of the atmosphere were needed. These had to await the development of modern communications. Modern meteorology can be considered to have started with the coming of the telegraph. Even so, data were largely restricted to those which could be observed from the ground. With the appearance of the radiosonde and rawinsonde, meteorology has come of age. Within the last 15 years we have witnessed a revolution in Meteorology. Practical forecast methods and procedures have undergone radical change. Practical applications of forecasts and of other knowledge of the atmosphere have multiplied. The breadth and depth of problems tackled by research meteorologists have also suffered a remarkable expansion.

The meteorologist is conservative by nature. Yet it is apparent that he cannot remain static. With the changes that have been taking place in his science, corresponding changes have taken place in his practices. Even greater changes will take place in the future. The time has come when he must pause, survey the past, and consider the future. It is indeed more important to know where one is going than to try to get there quickly. He must therefore determine the most probable course for the future, based on the trends of the past. It is a forecast problem of the utmost importance. Much of the economic future of the country - of the world - will depend on the action he takes as a result of his own forecast. He must also consider whether the practicing members of the profession have been able to keep pace with these rapid developments, and whether, perhaps, the time has not come, to develop an effective refresher training system.

It is just such a review and forecast that I plan to make today. I am mindful that it may not coincide with the forecasts that other meteorologist might make. It may even diverge sharply from those of some. Even the timing may be greatly in error, and indeed the date 2000 A.D., which sounds rather precise, should be taken only as a rough indicator of the valid time of my forecast, for I am far from possessing the temerity to say that these things may not come to pass in say, 25 years, if we proceed with vigour and skilled planning. Let us say then that this is just the imaginative estimate of one meteorologist and hope that it may serve as a target for the attacks of more farsighted men than I in order to produce through free and active discussion some reasonable forecast of our future development. Let us hope further that farsighted leaders may be available to act on such plans to ensure that our development unfolds in a most efficient manner.

GROWTH OF GOVERNMENT METEOROLOGY

Meteorology, more than any other science, has been developed by National Governments. This has been true in all countries, and the reasons are not hard to find. Up to the present time the practical importance of meteorology has lain in the provision of services in the form of weather data, climatological data, and weather forecasts. All of these require a large and expensive network of observing stations. Furthermore, since the weather knows no national boundaries, but is related to hemispheric motions of the atmosphere, uniformity in reporting and other procedures amongst the countries of the world is essential, and this is best arranged by representatives of the National governments. In the discussion which follows I shall confine my remarks largely to the growth of forecasting services.

The development of the telegraph provided the rapid communications required for the production of daily forecasts. These forecasts were prepared by meteorologists who often plotted their own weather maps and took their own observations. Thus all the operations from the original data - plotting, analysis, progging (mentally) - were carried out by the same individual.

We have come a long way since those days, and each new change has been heralded as the solution which would finally put forecasting on a good and firm basis. Each change has indeed helped to do this. But each has fallen far short of its advertising. We now know that meteorology and the forecasting of the weather are extremely complicated. We no longer expect each change or advance to do more than provide a small improvement in the service. We are content to take progess more slowly. This is a healthy and realistic mental attitude. Fortunately the new ideas which feed the changes are coming forth at a comforting rate.

What are the factors which have contributed to this development? Firstly there is the radiosonde and rawinsonde - the sister instruments which provide us with twice daily upper air measurements of the temperature, pressure, humidity, and wind. These inventions made possible the three dimensional analysis of the atmosphere. They have also led to considerable fundamental research in Meteorological Science as well as clearing the way for extended range forecasting. Next there is the teletype and radio network which has made possible the rapid collection of raw observational data and dissemination of forecasts. Thirdly there is facsimile which makes possible the transmission of processed weather maps.

As a result of these increased data plus a great expansion in the observational network and the rather rapid communication system, it is no longer possible for one forecaster to plot and analyse all the data at his command. This has lead to an assembly line type of approach to the forecast problem. The exploitation of this idea is still in progress. At the present state of development the situation in Canada is this. We have a Central Analysis Office (CAO) whose job it is to produce basic analyses. Sub-professional staff plot the surface and upper air data on suitable charts. These charts are then analysed by specialists in this type of professional work. These analysts have no other duties. They are not burdened with a forecast schedule. Nor have they any direct contact with the public or other consumer. The analysed charts are then transmitted by facsimile to stations across the country. Next on the assembly line are the Main Meteorological Offices, District Aviation and Forecast Offices, and the Dominion Public Weather Offices. These offices still plot and analyze their own weather maps, but increasingly depend on the CAO for analyses beyond the area of immediate interest. The basic aviation and public forecasts are made from charts, some of which are prepared locally, and some of which come from the CAO. Finally there are the Aviation Forecast Offices which, as of April of this year, will receive Maps and Forecasts and certain auxiliary charts by facsimile and teletype from the CAO and the forecast offices mentioned above, plus hourly and special aviation weather reports. Their job is to brief aircrew and supporting units such as control tower personnel. For this purpose various specialized types of analyses will be made which will permit very accurate timing of the expected weather features for local areas important to the operation of the station.

The result of this assembly line type of procedure is that more accurate forecasts are made possible through distributing the experience. We have however, realized that one man cannot assimilate all the experience that is needed. By specialisation the breadth of experience for each man is reduced thus permitting a greater detph.

We are now approaching the limit of the accuracy of forecasting which can be obtained by such a procedure. But this is the present state of affairs and will serve as a jumping-off point for my forecast for the future (2000 A.D.)

GROWTH OF NON-GOVERNMENT METEOROLOGY

As in other sciences the Universities have more and more come to be the font of knowledge in meteorology. This is a healthy sign for in our society the Universities have traditionally been the institutions responsible for stability in science. They have been the centres of learning where independent thinkers may advance the science through fundamental research, and to which those in search of knowledge may come and find it and be instilled with the thirst for more. In this country we have been slow to develop departments devoted to Meteorology. Let us hope that this situation may soon change.

The development of interest in the Universities, particularly in the United States, has been greatly accelerated by provision of funds by Government for the financing of research projects. Nevertheless there is a danger in this approach since Government, and perhaps more especially the military services which are presently the more active in this field, may demand practical and useful results. This danger has not yet become serious. Nevertheless it is there, and unless care is exercised on both sides, may reduce the effectiveness of the Universities by turning them into technological research institutes and lowering their educational standards as a logical and inevitable result.

In recent years meteorology has expanded beyond the purely government and university activities. Certain phases of it are now becoming a part of the business world. These phases are usually termed "Industrial Meteorology". In my opinion this is a condition to be hailed with cheers and certainly not one to be deplored. One needs only to look at the present stage of development in the other sciences. In almost all sciences - physics, geophysics, chemistry, biology, etc., scientists are well distributed throughout industry. They are highly specialized and work in all phases of their sciences including fundamental as well as technological research, development, and production. In short, these scientists are well integrated into all phases of our economy as is natural in an economy which is built on science. Meteorology has not yet reached that stage, but the trend is clear, and in this field a great advance may be expected in the coming years. With it will come changes in the nature of the education provided for meteorologists.

Undoubtedly the coming of industrial meteorology will cause great problems. There may be arguments and jealousies between private and government meteorologists. Indeed this is inevitable as the fields most suitable for each are felt out. This is a period during which the ultimate in understanding and restraint will be demanded of all parties. In general I think we will find industrial meteorology aimed at supplying the needs of businesses in regard to knowledge of the atmosphere and its behaviour. This will mostly take the form of tailored forecasts or advisories, consultation services, research on the application of meteorology, and weather modification. These services will be provided initially by private firms of meteorologists but ultimately, as the science becomes more fully integrated into the economy, meteorologists will be employed by industry in the same manner as other scientists.

FACTORS AFFECTING THE FUTURE

Up to this point I have been laying the foundation for my forecast. This has been the analysis, so to speak, in preparation for the prognosis. It is very necessary to know what has happened in the past and to prepare an accurate analysis of these events before proceeding to the future. This is the place where any good forecaster pauses to consider the implications of his analysis - to fasten his attention on the pertinent features which are important to his forecast, and to consider any new data which may have come in.

In summary then I find that (1) in the field of forecasting we are, by increasing specialization and assembly line techniques, approaching the limit of the traditional forecast method based on experience of the forecaster supplemented by a sound education in the physics of the atmosphere. For the future we can expect the completion of this process by refined organization and a programme of field training. Further progress in short range forecasting must be based on other approaches based on quantitative physical methods. (2) Fundamental research is increasingly passing to the Universities although Government still is active in this field. Technological research and development is on the increase too, and is divided between Government and the Universities. (3) Private meteorological organizations have come into being and are already a potent force. They have so far been concerned largely with providing specialized forecast advice of importance to the consumers. Their activities may be expected to develop considerably in the years to come.

Before proceeding to my forecast I must also consider certain other factors which will have profound bearing on the future of meteorology. The first of these is the electronic computer. The efforts to apply the electronic computer for the purpose of producing prognostic weather charts are now well known. So well indoctrinated in the traditional methods of forecasting are most meteorologists that they tend to look on numerical weather prediction with some suspicion - as a new and untried tool which may be useful as a catalyst in the forecast procedure at some later date. I would like to suggest a completely different place and level of importance of this device in the forecast scheme. Let us look at the forecast problem as a problem in physics and forget for the moment the historical background. The atmosphere is a fluid and as such is subject to the laws of hydrodynamics as applied to a compressible fluid on a rotating sphere. To be sure the problem is complicated by the effects of radiation and conduction of heat, complex boundary conditions, and other factors, but these do not change the fundamental problem. It is natural then that the short range forecast problem should be approached by way of the equations of motion. Surely this is what any scientist would have done had he been able to solve these equations. The cold facts, however, are that these equations are too complex for us to solve in a functional form. We have succeeded in doing this only for highly simplified forms of the equations. A numerical solution can be produced even by the older computers, but only for a simplified model, and after exceedingly long and laborious calculations. This approach to the forecast problem was therefore not available to earlier meteorologists. They were forced into using the highly subjective techniques I have just described. The electronic computer has changed this picture completely. Its great speed and high capacity brings the vision of a computed prognostic chart and even a computed forecast within the realm of possibility. Furthermore, since this has been the logical scientific approach from the start, I think it is not too much to expect that the great bulk of pent-up frustration which meteorologists have generated over the past 50 years will flow into this problem - not in controlled fashion with which we are accustomed to seeing in research progress, but in an unstable fashion, as in the sudden release of energy accompnaying a bursting dam. I suggest then that the electronic computer is not another forecast accessory - it is THE forecast method, and our present techniques are the accessories. Failure to realize this fact and to act on it by establishing an active numerical computation research unit, may well result in a Service being left behind in the new era. We are past the stage where mere knowledge of a new process will permit its immediate and effective use. In this connection let me quote from an article 'The "Atomic" Rivals', by Sir Francis Simon[1] - "The really important information

[1] Financial Times (London), 6 August 1954.

is the technical know-how. In most modern industrial processes this know-how is a complex sum of technical and scientific knowledge and art which cannot be described even in the most lengthy patent description. ..... In order to sell the know-how of a technical process from one firm to another, it is now quite common for teams of highly skilled people to be sent off for years to the purchaser in order to give him the benefit of the new development. To suggest that such knowledge could be acquired and handed over to an enemy by one or two persons, whispering a few words over the lunch table, or by stealing some 'secret formula', is simply not realistic". Sir Francis was, of course, referring to atomic information and know-how. The lesson clearly applies also to meteorological knowledge and know-how.

There are other ways in which the electronic computer will change our lives. Many statistical techniques and new methods of analysis are possible through the use of the computer. These will certainly produce additional forecast tools which were impossible in the earlier days of meteorology.

The coming of the punched card has also opened up new vistas to the meteorologist. Punched card data and the great variety of machines now available for processing them are a sure indication that statistical methods are due for an upsurge which may revolutionize meteorology. In combination with the electronic computer the possibilities are immense. No doubt these possibilities will be heavily exploited by 2000 A.D. and I venture to say that every self-respecting Meteorological Service will have its complement of statisticians and mathematicians.

Another development which may confidently be expected in the next 45 years is in the field of communications. Our present vast teletype, radio and facsimile networks are strained to the limit to carry the traffic imposed on them, and speed of communication is essential to the short range forecast. While more traffic could be carried by expansion and duplication of the existing networks, this is probably uneconomical and does not solve the problem of speed. I therefore look to development of equipment capable of transmitting information at speeds many times faster than is now possible so that the capacity of existing networks would be vastly increased, and the time lapse between the time of an observation and its receipt at an analysis point greatly reduced.

Commercial television, too, has made its appearance and represents a method of communication which may have application in meteorology.

New instruments and developments of old ones will certainly appear. Radar networks will supplement the present reporting system. Great improvements in accuracy of upper air instruments will take place, particularly in the measurement of humidity.

In the matter of coverage of observations, improvement is vitally needed now, and is held back largely as a result of economic factors due to the high price of information from certain quarters of the Globe, particularly the large water areas which constitute a very large percentage of the earth's area. Without more information from these areas very severe limitations are imposed on meteorology both from the practical and the research viewpoints. Solutions will be found for the problems and at least adequate observational coverage will be obtained long before 2000 A.D. These solutions will probably include (1) Robot floating stations for surface data, (2) Aircraft reports from regular and special weather flights, (3) Constant level balloons, (4) Drop-sondes from Aircraft and from balloons, and (5) Weather ships or platforms. In addition, the development of rockets will provide information in the higher reaches of the atmosphere and we may also expect that rocket photography and television will permit observation of cloud masses over large areas of the earth. Establishment of one or more artificial earth satellites is a probability. These will provide many services to earth-bound men. One of these will be a televised picture of the earth and its cloud formations.

Another feature to be considered is the possibility of weather control. At present most of us think of such control in terms of inducing precipitation. With the great increase in data and research into the mechanisms of the atmosphere, made both with and without the use of computers, we can expect that control will take many forms. Dissipation of Tropical hurricanes and tornadoes, or reduction of their intensities is one such possibility for the distant future, but I feel that a better understanding of energy transmission, transformation, and storage, in the atmosphere together with means (probably atomic) of introducting energy sources at strategic points may give us the means of altering at least some of the larger phenomena of the atmosphere.

With the development of the Rocket and atomic energy, space travel is on the books before the year 2000 A.D. at least in a limited form. Present day writers in astronautics leave little doubt that serious attempts to establish an artificial satellite to the earth will soon be made. Rocket ship flights to the satellite will then become routine. Such flights will provide valuable information on the high atmosphere and serve as a new base for observation of the atmosphere from above. This will also pose new problems for the forecaster. What kind of a forecast will a rocket flight require before take-off for a flight to outer space? What kind of forecast will the returning flight require? What are the critical limits of accuracy required for these flights? Meteorologists will indeed face brand new problems in the coming years.

WEATHER FORECASTS OF THE FUTURE

Now we come to the business of forecasting Meteorology as of 2000 A.D. The basis of these predictions has been given in the preceding sections but we must now crystalize the results as given by these trends. In the field of forecasting we must indicate the methods used for short range, extended period, and longer period forecasts, together with the type of organization which may exist at that time.

The short range forecast procedure I have in mind for the year 2000 A.D. is based on the following: (1) More accurate observations. (2) Far more complete surface and upper air observing networks. (3) High speed communications systems. (4) Highly developed electronic computing equipment and mathematical models of the atmosphere. (5) High speed statistical computing machines. (6) Specialization of professional meteorological operations.

By this advanced date I believe observations of sufficient accuracy will be available from a sufficient network over the world to permit full implementation of the methods to be described. Analyses of a variety of types will be carried out by men and machines in various combinations. The basic analysis of the wind and pressure fields for surface and upper air will be carried out in a Central office entirely by the electronic computing machine. Included in this analysis will be a good frontal analysis which while not as accurate as that which can be produced by professional analysis specialists, will be good enough for the computations the machine will be required to make. This analysis will be made by the machine by fitting the observational data to an atmospheric model and by fitting mathematical functions to the pressure and wind field. The machine will be hooked directly into the communications system so that data will be assimilated as fast as they are received. Thus the complete analysis will be available within minutes of the time of observation. The main purpose of an analysis of this sort is to provide a basis for a forecast, or more immediately, a prognostic chart. Since the machine already has within it an analysis, it can proceed to produce a prognostic chart. This operation should require no more than a few minutes so that the basic prognostic chart for a day or two in advance will be available within a few minutes of the original observation time. In this procedure much more advanced mathematical models will be used than are presently available and the prognostic chart so produced will not only be produced faster than the man-made product but will also be much more accurate than anything we can produce by the most refined methods in 1955.

Does this eliminate the analyst? - not at all. By a combination of man and machine a better prognostic chart can be produced than by either working separately. What the machine does is raise the level of objectivity on which the analyst builds his structure. The analyst must work subjectively using subjective methods and good judgement. I do not believe that, even in the year 2000 A.D., it will be possible to solve completely the equations of motion as they apply to the atmosphere. What the machine will do is solve a somewhat simplified problem, although it will be a problem which is much too complex for the tools of present day meteorology. Since the mechanics of the simplified problem are known it is the deviations of the behaviour of the atmosphere from that of the model with which the analyst will be concerned. In his work he will utilize a great deal of experience, much of which will be stored in the form of tables and punched cards. The application of this experience will require great skill and a high degree of judgement and will result in improvements to the machine-produced prognostic charts. As his tools this analyst will probably use auxiliary charts of a type unknown to us now. By a similar use of machine-processed data other analysts will prepare the current weather charts which, together with the prognostic charts, will be transmitted by high speed facsimile to the other offices on the assembly line, which is devoted to production of the forecast. Other auxiliary data derived from the machines, such as fields of vertical velocity, vorticity, divergence, etc., will be transmitted for use in the forecast as well. Closed-circuit television networks will permit briefing and verbal transmission of information between specialists working in different offices, on different portions of the forecast procedure.

Regional forecast offices will analyse no basic weather maps or prognostic charts of flow patterns and frontal surfaces, but will receive these from the Central Analysis Office by means facsimile as described above. They will be concerned with a detailed study of the weather elements as they relate to the flow patterns provided by the Central Office. While electronic computers may be used in this work it seems likely that statistical relations will be the basic tool though many of the correlations used may be derived through the use of such computers. Undoubtedly a number of auxiliary charts will be analysed and used in this work. Once again the objective plateau will be built as high as possible but there will still be a pyramid of subjective skill and judgement to be built on this structure. The forecasts will be issued to consumers and also to ultra-short-range forecasters, some of whom may be located in the regional forecast offices, but most at smaller offices. The ultra-short-range forecasters will be responsible for taking into account local effects in the forecasts for individual stations and pinpointing the changes of weather with great accuracy. This is similar to the procedure now being introduced in Canada and little more need be said here. It need only be

mentioned that high speed procedures and communications will result in rapid and accurate forecasts. Since the forecast will always be a perishable commodity the extra hours saved will add greatly to the effective accuracy of the forecast.

Longer range forecasts generally require methods which are somewhat different from those used for short range forecasts. For this reason they are usually prepared in a separate office. Only one such office is necessary for a country such as ours since the District Forecast Offices can act as clearing houses for the product and additional outlets are unnecessary. These facts are unlikely to be changed in the future. We may therefore look to a single longer range forecast office which will be linked to the Central Analysis Office since here there are available a unique set of maps and the analysts who produce them.

By 2000 A.D. we should have forecasts for 5 days, 1 month, 1 season, and 1 year in advance. It would serve little purpose to try to guess the methods which will be used in producing these various types of forecasts but certain things can be said with reasonable confidence. Not all of the forecasts of different ranges will be produced by the same methods. Some methods will depend on the equations of motion and will use computer techniques, flavoured with statistics and the necessary professional experience and judgement. Other methods, probably for the longer range forecasts, will depend on statistical correlations, which will mainly be based on physical processes but which are not susceptible to treatment by the usual mathematics of physics. This would indicate that the Longer Period Forecast Center would have a number of units within it working more or less independently except for co-ordination by consultation.

One feature of the organization I have said little about as yet. That is the Research Section. No organization such as the one pictured here can be developed, much less remain healthy without the backing of first-rate fundamental and applied research. It would be inappropriate to place this Research Section far from the centre in which the combined analysis and longer range forecast operations are carried on. It should, in fact, be housed in adjacent offices. In this way new methods, suggested by the latest research, can be developed into operational techniques much more quickly and effectively than would be possible if the units were physically separated, I therefore predict that by the year 2000 this union will take place. Operating in close harmony with these units will be an effective training section, an important function of which will be to ensure that all professional staff throughout the organization will be kept aware of the latest development in the science and the operational tools it has made possible.

One other aspect of forecasting in the year 2000 A.D. I have kept separate from the preceding remarks. This is because it is so different from present day forecasting that I cannot even be sure that it will be the responsibility of the same meteorological organization. This is the problem of forecasting for rocket flights in the high atmosphere and the related operation of space flight. By the year 2000 A.D. and probably long before, man will have built ships capable of flight well beyond our atmosphere. This will create problems which will dwarf our present problems of providing service to jet flights in the lower stratosphere. Such flights will probably coast in for landing from very high levels and will require accurate landing forecasts hours in advance. Little is known of conditions in the upper reaches of the atmosphere. We have a general picture of conditions as formed by rockets, ozone studies, meteors, etc. This picture is very simple and we have a tendency to think that the conditions are simple. From bitter experience with the lower atmosphere we can confidently expect to find our picture getting steadily more complex as more data are obtained. By 2000 A.D. I expect we will have a good deal of information from the high atmosphere. This will come from rocket-sondes and rocket ship pilot reports and by other means. By that time, too, I expect much will be known about the atmospheric problems related to such flights. Both the problems and the atmosphere will be complex and I believe we will have to develop a new type of meteorologist known as the astronautical meteorologist and an organization to go with him. The qualifications for such a position may be exacting but the prospect of "fam" flights to the moon and Mars will probably ensure a flow of recruits.

In the same vein we may muse on the problems of the first meteorologist who is called upon to produce forecasts for other planets. This is a serious problem which may well become a pressing question by the year 2000 A.D. Already books and articles are appearing on the meteorology of other planets. The Meteorologists of the Earth are shortly going to be called upon to solve some knotty problems regarding these planets. I believe we will find here a developing field and the specialist on Martian Weather and climate will find himself in great demand.

Other fields of meteorology, e.g., micrometeorology, turbulence, etc., will certainly undergo remarkable development in the next 45 years. In the interests of brevity these cannot be considered in detail here.

OTHER ASPECTS OF METEOROLOGY OF THE FUTURE

We have spent a good deal of time on meteorological problems related to forecasting. This I justify by my belief that government meteorlogy will always be a major part of any science which is so expensive and so universally needed as meteorology. Nevertheless there will be important and interesting developments along other lines which I must not neglect here.

In the absence of any other agency to the job, the National Weather Services have, in the interests of public service, tried to satisfy any and all consumers. This demand in 1955 can barely be met but with full utilization of weather information in 2000 A.D., the National Weather Service will long since have ceased to attempt such a task. Private firms of weather consultants and meteorologists employed directly by the larger industries will supply most of the highly specialized information required by them. To do this the private firms will use a great deal of processed material provided by the National Weather Service and will have connections on many of the latter's communication lines since it would be quite uneconomical for them to try to duplicate this work. For the privilege of using this information for gain, the private meteorologists, or the firms for which they work, will pay a fee. These fees will form a sizable portion of the funds available for the operation of the National Weather Service. As to the proper dividing line between the field of the private meteorologist and that of the government meteorologist J.J. George[2] (of the George Report) suggests the following:

"..... matters involving risk of life or extensive property damage should be the Province of the National Weather Bureau, and matters involving efficiency of operations, especially where a profit is concerned, should be the field of private meteorology". This seems to be a reasonable zone of division and I presume will fit reasonably well the practice of the year 2000. But this remains to be seen.

In keeping with the mature state of the science, all major universities will offer courses in meteorology and more particularly a full Honours course. Much of the present Honours course in Mathematics and Physics could be dispensed with for the Meteorologist. In its place other meteorological material could be inserted. While a meteorologist must have a sound background in mathematics and physics, the breadth of course required to prepare professional meteorologists for work in industry as well as in National Weather Services will necessitate stripping some of the fat from present undergraduate courses.

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[2] Bull. Amer. Met. Soc., 35, p 43 (Feb. 1954)

CONCLUSION

The year 2000 A.D. is still a long way away from us. It is unlikely that the events I have described will come to pass in precisely the way I have imagined them. Nevertheless some phases of this forecast may hit rather close to the mark. Regardless of the accuracy of the forecast, if it serves to stimulate thought and discussion on the future of our science and its applications, it will have achieved a worthwhile purpose. We will then be in a better position to "know where we are going".