COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

SECTION OF METEOROLOGICAL RESEARCH

PROPOSED INITIAL PROGRAMME OF WORK

by

C.H.B. Priestley

.....

Prepared 5/3/47

1. Approach to the Planning of a Programme

The most striking feature of the earth's atmosphere is its lack of homogeneity. Irregularities exist in phenomena at all points in the range of scale from the global to the molecular. The general circulation of the globe is interrupted by depressions and anticyclones of the order of 100 to perhaps 4,000 miles in extent. Regionally within these systems are found the variegations of weather, which itself is rarely uniform:- rain, fog, frost etc. are localised in incidence and intensity, the individual clouds of cloud systems vary in horizontal and vertical extent, and so on. Finally in conditions which appear steady to the casual observer, and even to the professional meteorologist equipped with standard weather-station instruments, sensitive and quick response instruments will show that the physical characteristics of the air (motion, temperature, moisture) are continually subject to apparently irregular variations both in space and time.

If for purpose of research we choose to enter this scale at any point, we find that the success of our investigations must depend on a knowledge of the processes occurring at a point one lower in the scale. If this knowledge is lacking, one must resort in essence to an empirical method of attack. Thus until the motion and development of pressure systems is properly understood, the climatologist can do little more than observe and classify the climate of different regions.

It is sometimes, but not always, possible to adopt an intermediate method of attack and take over empirical knowledge from a point lower in the scale and from this basis to attempt a scientific elucidation of the larger phenomenon. The theory of convection provides a good example of this last method. In this the pre-existing vertical distribution of the average temperature, pressure, humidity and wind are taken uncritically as a supposedly measurable starting point. The principles of mechanics and thermodynamics may then be applied towards an understanding of the subsequent developments. This method is often successful, but difficulties may arise since (a) it is not always possible to acquire the initial data over a sufficiently extensive sample of the medium in space and time, and (b) the smaller phenomena which are taken for granted may become significant in an unforeseen role. In the examples mentioned above (a) supervenes in climatology, and (b) in convection in that the calculated convective energy is largely dissipated by small scale turbulent eddies, whose magnitudes are unpredictable from the convection phenomenon itself (and which in fact have never been measured).

The examples serve to illustrate one main difficulty of meteorological research. Others, which have been more widely publicised, are found in the impossibility of controlling the variables (which are many and always interactive), of doing experiments (as opposed to taking samples), and of scaling down the phenomena to permit of laboratory investigations. One of two methods of approach is imposed. The first, the direct frontal attack on the widest possible scale of observation, which presupposes a large organisation on both the research and operational side : the result to be achieved is a detailed pictorial representation of all details of the phenomenon under investigation, but it is difficult to avoid becoming immersed in the data to the detriment of the critical attitude. The second, more circumspect, method of approach is to survey the chain of physical argument or knowledge of the phenomenon from all angles, in an attempt to identify and isolate one or two weak links which may open up useful lines of research. In practice the chain is always a tangled one if the phenomenon is at all large in scale, and specific problems or fields of work are hard to isolate. Unless this can be accomplished real fundamental progress is unlikely to emerge : if it can be done successfully, the knowledge so gained would usually be applicable in a wider field than that suggested by the original isolation of the problem.

The initial planning of a research programme, from the scientific point of view, is then largely ruled by two considerations : to enter the size scale of problems at a point or points at which the work will not be excessively hindered by ignorance of the processes occurring at adjacent points in the scale; secondly to select a line of work in which the problems are capable of isolation in the early stages and of more extended application as the work progresses. This last consideration is particularly important in a newly formed section, for the scope of the work in hand can be adjusted to the size of the staff and allowed to expand as the research staff grows in numbers and experience.

It is the above scientific considerations which are the crucial ones to be borne in mind in the selection of problems at this early stage of planning. There is an abundance of problems at all points of the scale whose elucidation would be of advantage to Australia and to the world; and, in particular, problems of importance to the primary industry of Australia and pure meteorological problems of special local interest are to be found everywhere along the scale.

2. Selection of a Main Line of Work

From the scientific point of view, the ideal point at which to enter the size scale discussed above is at the bottom. The meteorologist must accept the results of molecular physics as the established basis of his own science and will then ask the question:- 'what is the nature of the structure of the atmosphere on the scale next above the molecular in size?' This question carries him immediately from the laboratory to the open air, where he finds that increasingly sensitive field instruments reveal an increasing complex and heterogeneous structure. A wide range of problems in the 'micro-structure of the atmosphere' are immediately opened up. Such of these problems as refer to the micro-structure of the flow, under the generic name of 'turbulence', have proved of vital importance in the fields of hydro- and aero-dynamics. But the problems of the small-scale distribution of heat, physical and chemical composition, etc., are largely peculiar to the two sciences of meteorology and oceanography and, perhaps because of the relatively few research institutes engaged in these fields, they have not in the past received the attention which is their due.

It is proposed that an examination of the micro-structure of the atmosphere shall form the basis of the main line of work of the meteorological section. Apart from the very important scale aspect discussed above, four main questions have been considered when coming to this recommendation:-

(a) Are the problems capable of a sufficient degree of isolation to allow fundamental work to be carried out?

(b) Is there a reasonable chance of success, i.e. of a real gain in knowledge?

(c) Would the results be suitable for extensive and progressive application up the size scale of phenomena?

(d) Are the problems themselves, and those to which the solutions may be later applied, of importance in the wider field of meteorology and of practical importance to Australia?

The answers to (c) and (d) will be indicated in the next section, where possibilities of the later growth of the programme are discussed. In the following Section (4) an outline will be given of the proposed initial method of attack, against the background of which (a) and (b) must be judged.

3. Initial and Ultimate Scope of Research

A study of the micro-structure offers both a field for fundamental work and subsequently a wide variety of applications covering the whole range of meteorological problems. Some indication of this is most easily given in a diagram such as the one attached as Appendix I.

Fundamental work on the micro-structure falls broadly into two, and more narrowly into five, main divisions. We require to know both the average and the detailed distribution of momentum, heat, water and airborne solid substances, and the processes which control these distributions. Prominent among these processes is that of advection. A parcel of air will have certain characteristics in virtue of its recent history, and partly reflects its previous environment. Much of the contrast between adjacent parcels is due to the different surroundings through which they have recently passed. Thus the micro-structure of the flow plays an important role in the transport of all physical elements but the reverse is not true, e.g. the small details of water vapour distribution play little part in transport of momentum, i.e. friction. This requires that friction be distinguished from other transport phenomena in the first sub-division of the plan.

The next evolution requires little explanation. The five studies have distinctive features, require different instruments and observational techniques.

Up to this stage, the plan can be regarded as fixed and reasonably complete and self-contained. Beyond it, the diagram abandons any claim to completeness, and is content to indicate some lines of application : which of these, or others not mentioned, are ultimately followed will depend upon the needs of the moment, the size of the problem and the chances of success. In every case the last will rest on the progress made in the five fundamental studies listed above them.

Nineteen possible projects are listed in small type. Some of these, e.g., general circulation, are of interest mainly to the meteorologist, others more to the farmer, seafarer, aviator, fisherman, etc. Some of the interconnections and further applications are not shown in the diagram for the sake of simplicity, and there are almost certainly many others of which we are not yet aware.

At the bottom of the diagram a majority of the subjects are brought back into perspective as items in a meteorological research programme by indicating in large type the phase of his science in which the practising meteorologist will apply them. It would have been possible to plan a research programme with one or two of these headings as starting instead of finishing points, in fact such is the usual approach to adopt. When this is attempted, however, the resulting diagram is much more rapidly spreading than the one here presented. The essential virtue of co-ordination is lost, and the programme expands beyond the capacity of any but an extremely large organisation. Even then the subdivision is apt to finish at a level which is well short of the fundamental.

The diagram is not complete, nor is it final, but in endeavouring to relate a wide number of problems into a common plan, with a common starting point, it serves a useful purpose. Ad hoc problems which may arise hereafter can be referred to the general plan and their position in relation to it determined. The diagram is of the nature of a family tree in that each line of work has a common ancestor in the micro-structure : but each has other ancestors, and the many marriages may require that the plan be departed from as the scope of the work expands.

The programme as sketched is a flexible one, the advantages of which will increase with time. The large number of problems make a central focussing point all the more essential, and this should prove a double advantage in the early stages in that the maximum of personal direction can be given to the work over the period in which most of the staff will be finding their feet as research workers.

4. The Initial Method of Attack

The fundamental work which has been done in atmospheric turbulence has in the past mainly been directed towards observation and interpretation of the mean distribution of wind and temperature with height. Even this data appears to be sadly lacking in Australia. The word 'mean' refers to an average over a time (of order a minute) sufficiently long to smooth out the irregularities due to smaller eddies, but to display the full features of the slower changes such as are associated with changing cloud amount and the diurnal cycle. Study of the diurnal changes of these temperature and wind profiles is a striking and instructive one. So far as this aspect of micro-meteorology is concerned, the problems of observation may be said to have been solved, but those of interpretation still contain many pitfalls. It is fair to state that it is still impossible, from these observations alone, to obtain a reliable quantitative estimate of the rate at which heat is being transported by turbulence from one level to another. The best that can be done is to assume the rate to be proportional tothe gradient of (potential) temperature by an analogy with the process of molecular conduction. Despite the brilliance of this analogy when it was first propounded by G.I. Taylor it has certain limitations, pre-eminent among which are that it does not provide the meteorologist with the quantitative information which he requires. The coefficients of eddy-viscosity, eddy-conductivity, eddy-diffusivity vary with height above the surface and with the prevailing conditions by a factor of some hundreds or thousands, they have not successfully been related to each other, and there has recently arisen considerable doubt as to their real physical significance of at least one of them.

Measurement of the mean vertical profiles over representative Australian sites will thus be a necessary, but not a sufficient, part of the work. Small sensitive thermometers at fixed levels reveal a much more complex structure than the mean temperature profiles would suggest and it has been shown (Priestley and Swinbank, Proc. Roy. Soc. read 27th February, 1947) that a knowledge of the short fluctuations is vital to determination of the heat transfer. It is expected that the fluctuations will vary very markedly with the height above ground; general weather situation time of day, exposure of site and nature of the underlying surface. An analogous role in other transport problems is likely to be played by the fluctuations in wind velocity and humidity. All these require development of suitable instruments for the field, followed by a considerable programme of observational work and later by a critical reconsideration of the theories of turbulent transfer.

Although the recent work referred to above has seriously weakened the turbulent-molecular analogy, it has underlined the advantage, from the experimenter's point of view, which turbulent processes have over their molecular counterparts; namely that field instruments can be made small enough to be sensitive to individual eddies. If w denotes the upward velocity and T' the temperature anomaly of an individual eddy, the mean value of the product

$$\overline{w\,T'}$$

over a long period of time (i.e. long enough to include a fair sample of eddies) at a fixed point represents directly, with a known multiplying factor, the upward flux of heat at that level. w and T' range over both positive and negative values, and any net flux of heat depends on the magnitude of the correlation between them. Thus atmospheric turbulence is essentially a statistical study. In spite of its fundamental importance the mean product $\overline{w\,T'}$ has never been measured directly, and an attempt to design an instrument to do this will constitute the crux of the experimental work. Equally fundamental in the problems of friction and moisture transport, or evaporation from the ground, are the mean products

$$\overline{w\,u'} \quad \text{and} \quad \overline{w\,x'}$$

where u' and x' are the eddy-anomalies in horizontal wind speed and absolute humidity. The last, in particular, is likely to involve considerable instrumental research.

The early work will thus have a dual objective:-

(a) direct measurement of the three fundamental transports, $\overline{w\,u'}$, $\overline{w\,T'}$ and $\overline{w\,x'}$

(b) from these in conjunction with the fluctuation and mean profile observations, a better understanding of the turbulent processes at work.

This fundamental study would be of importance to Australia, and in turn Australia provides a very suitable region for the work to be pursued. Its great advantages are:

(i) the fairly wide range of latitude. Turbulence in low latitudes is of even greater importance than has so far been indicated, as it is probably an important determinant of the air mass trajectory.

(ii) the wide ranges of temperature, humidity, and wind conditions.

(iii) the relative flatness of the terrain over wide areas.

(iv) the availability of both land and sea exposures.

5. Secondary Lines of Work

The preponderance of ocean in the Southern Hemisphere and the position of Australia as the most level large land mass within it, make the region particularly suitable for two main fields of study. These comprise the general circulation, and the thermal adjustment between the atmosphere and its bounding sea or land surface. In turn, these fundamental studies are of particular importance to Australia.

Both are branches of dynamic meteorology and in such, since the atmosphere is everywhere turbulent, the micro-structure must play a major role in their processes. Full attention has already been given to this, and no more needs to be said here concerning the approach to the problems of air mass adjustment: but in general circulation, micro-structure assumes a less dominant role. Here it is probably possible to make some progress by entering the size-range at another point, and this is to be recommended as a secondary line of work. It is not possible in this case to draw up a closely co-ordinated diagram such as that evolving from the micro-structure. Rather we will enumerate a few lines of activity which might be followed over the next year or two in an exploratory fashion: some of these have found a place in the main diagram, so that their relation to the main line of work is already evident.

(a) Atmospheric motion, the dynamic structure of pressure systems, dynamical causes of surface pressure changes.

(b) The effects of friction over large areas of the atmosphere, and especially on the air motion in low latitudes.

(c) Equations of hydrodynamics and thermodynamics applied to the general (mean) circulation on a rotating globe.

(d) Circulation round the Australian thermal source (summer) or sink (winter), treated as a three-dimensional problem.

(e) Variability in intensity of the zonal circulation in the Southern Hemisphere.

(f) Energy exchanges between atmosphere and ocean. Location of the areas of maximum exchange in the Indian and Southern Oceans. Climatic effects of the distribution of sea surface temperature.

(g) Quantitative classification of Australian air masses, with their vertical characteristics over different regions of the continents.

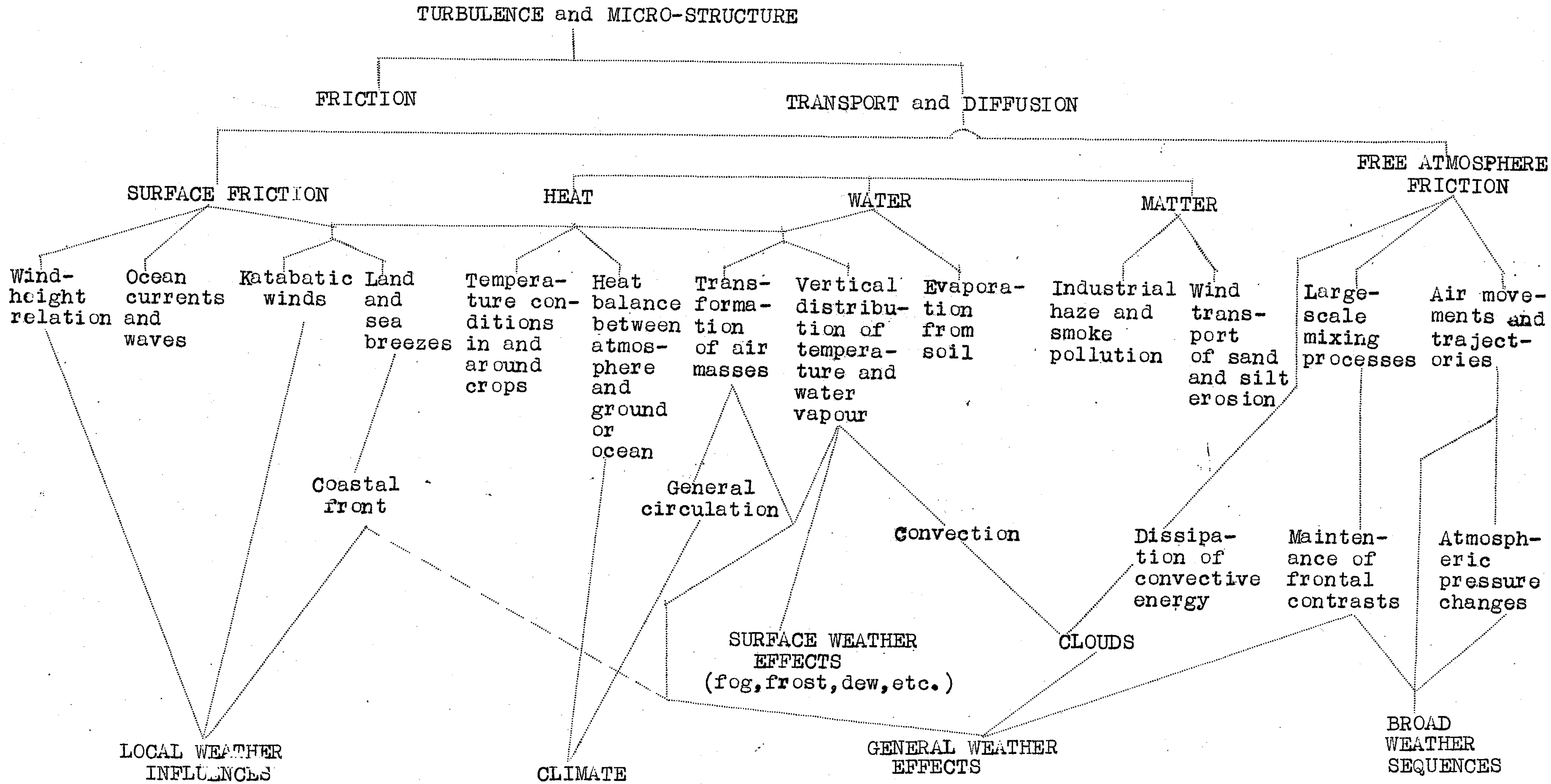
(h) Mean synoptic features, e.g. of pressure, temperature, wind, over wide areas associated with the local incidence of abnormal seasons.

(i) Significance of the Antarctic continent in the Southern Hemisphere circulation.

(j) Structure of the meridional front.

This secondary side of the plan is somewhat disjointed at present, but it is possible to visualise an eventual need for two co-ordinated groups: one engaged on the theoretical problems of dynamical meteorology, such as (a) to (d) above, the other on investigation of general and local circulations and the nature of the seasonal variations from year to year.

APPENDIX I. DIAGRAMMATIC PLAN OF RESEARCH PROBLEMS



APPENDIX II

RECOMMENDATIONS FOR ACTION

Subject to the approval of the Executive in principle to the programme here suggested, more specific recommendations may be made.

1. Place of Work

The four advantages (listed at the end of Section 4 above) of Australia as a region for micro-structure study should be retained so far as possible in choosing a place where the initial work should be centred. (ii) and (iii) suggest that Melbourne would be particularly suitable. For testing, calibration, etc., of instruments during the development stage a flat site, relatively free from buildings, trees, bushes with open exposure would be required. It should not be difficult to find a suitable area within reasonable reach of the city. (An airfield would not be appropriate, as it will probably be necessary to erect an instrument tower.) The workshop, offices, etc., could then most suitably be in Melbourne itself for a year or so, and the question of a final location and building be decided later. This will have the advantage of easy maintenance of contacts during the early stages of the work. So far as the secondary items (d) to (j) are concerned, very close contact with the headquarters of the Commonwealth Meteorological Bureau would be vital.

2. Staff.

In view of the difficulty which may be experienced in the recruitment of suitable scientific staff, a certain mutual flexibility of staff and programme is required at this stage. If a man specially suitable for some line of research not specifically mentioned here were to become available and interested, it would be wise to attract him. The wide variety of problems which exist would not justify rigid adherence to a preconceived plan.

At least five key scientific positions can be visualised, as follow:-

(a) Meteorologist, physicist or engineer by training, with a flair for instrumental research and development. Required in the first instance for the instrumental side of the main line of work, and later for problems as they arise.

(b) Meteorologist (analyst) with the maximum of local experience, and good knowledge of charting methods and modern analytical techniques. Required for the investigation of general and local circulations (Section 5).

(c) Theoretical meteorologist (mathematician) for work in dynamic meteorology (Section 5), and possibly also for the theory of turbulence.

(d) and (e) Not closely specifiable, but any meteorologist of suitable ability with expertise in theory of turbulence, advection phenomena, local meteorological effects, surface meteorology, problems of heat balance, or meteorological aspects of agriculture.

Of the above, (a) is of the most immediate urgency. This officer would be responsible for acquiring the necessary workshop facilities and equipment. An early appointment would be of further advantage in connection with the forthcoming Antarctic expedition, for which the bulk of preparatory work will be of an instrumental nature.

It is recommended that five vacancies be created, each with the alternative grading of Research Officer or Senior Research Officer, the final grading in each case being determined by the qualifications, age and experience of the most suitable applicant. Nos. (a), (c), (d), (e) should be advertised in England as well as in Australia. The vacancies (c), (d), (e) could be created on the understanding that they will only be filled if applications are received from men of high calibre: otherwise it would be preferable to recruit younger graduates and aim at a slower development of the section.

In addition a vacancy of typist, as assistant to Officer-in-Charge, should be created immediately.
