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SYNOPTIC TECHNIQUES IN THE CANADIAN METEOROLOGICAL SERVICE

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Abstract: A brief description is given of the synoptic concepts and procedures involved in the "philosophy of analysis" which has been developed in the Meteorological Service of Canada in the years since World War II. The techniques which are described have proved their usefulness under operational conditions. It is possible that modified versions of some of these techniques will prove to be of value in Antarctic regions.

1. THE METEOROLOGICAL SERVICE OF CANADA

The Meteorological Service of Canada (more correctly, the Meteorological Branch, Department of Transport) is responsible for nearly all the operational meteorological work carried out in the country and for a large proportion of the research work - though there are active and growing research groups in several Canadian universities. The major part of the Canadian output in the more restricted field of synoptic meteorology has been produced by personnel of the Meteorological Service, and this survey will be restricted to a consideration of some of the more important synoptic techniques which have been developed by the Service and which are used operationally in Canadian weather offices. Before going on to describe these techniques, it may be of interest to examine some more general points concerning the Meteorological Service of Canada, which serve as a background to the discussion which follows.

Although the Canadian climate is far from being as rigorous as many Australians think, there is no doubt that Canadian winters are sufficiently severe to play a very important role in ordering the life of every resident of the country. The day to day variations in the weather are of great practical importance, not only to the individual, but also to many firms and government organizations. In the light of this, it is not really surprising to discover that (in terms of professional staff) the Canadian Meteorological Service is the third largest in the world, and that the cost of running this service comes to approximately one dollar per head of population per year (which is about 35 per cent higher than the comparative Australian figure).

In common with the Australian Weather Bureau, the Meteorological Service of Canada has an able and assertive administrative staff, all of whom are former forecasters, and who thus have a first-hand knowledge of the nature of the problems that face the operational meteorologist. All the forecasters in the Service who are classified as Meteorologists (who are responsible for issuing the principal public, aviation and marine forecasts) are required to have a Master's degree in Meteorology. In the past, nearly all of these degrees have been taken at the University of Toronto, and much of the lecturing and supervision of practical work has been carried out by members of the Meteorological Service's own Research and Training Branch. This has led to a degree of what might be termed "professional inbreeding", but any weaknesses inherent in this system are now being largely eliminated with the setting up of a reorganized Department of Meteorology at the University of Toronto, and the infusion into the Service of some fresh blood in the form of a substantial number of new Meteorologists holding Master's degrees from McGill University.

Partly as a result of the relatively high qualifications that are required before one becomes an operational Meteorologist, much useful research work is carried out by men who are working as forecasters in the field. When this work is added to the output of the full-time research staff, quite an impressive total results. (For example, in 1963 the Meteorological

Branch published over 50 of its own Technical Circulars, and in addition numerous papers were published in the various journals.) Much of the work that is done by the field forecasters is, naturally enough, in climatology and in synoptic meteorology, and they can claim to have played a significant part in the development of a distinctively Canadian outlook in the synoptic field.

In the years since World War II, the Meteorological Service of Canada has developed what has been described by Godson (1955) as a "philosophy of analysis". This basic philosophy provides a foundation for the training of meteorologists as well as for synoptic work in forecast offices, and thus serves as a connecting link which enables the newly-trained analyst to adapt himself quickly to the nature of his work when he is sent out into the field. In addition, the existence of a uniform philosophy is a prerequisite to the successful operation of the Central Analysis Office. The analyses and prognoses produced at the Central Analysis Office are transmitted to forecast offices across the country, but the usefulness of these charts would be negligible unless the meteorologists preparing the charts and those utilizing them share a common synoptic viewpoint. Co-ordination between offices is also important if aircrew and other consumers, who have occasion to visit various offices, are to retain confidence in office procedures and products.

These considerations apply to any national meteorological service, and the Canadian service is of course not unique in having developed its own "philosophy of analysis". However, the Canadians have produced some theories and working principles which are original and distinctive, and though they may not be especially applicable to synoptic problems in Australia, it is thought that a brief discussion of them would be of interest to Australian meteorologists.

2. FRONTS AND AIR MASSES

In nearly all atmospheric models, or theories of the organization of the atmosphere's dynamic and thermal structure, two of the most important concepts are those of a front and of an air mass. These are, in fact, complementary concepts, and we cannot think of one without the other. We shall first consider the Canadian definition of a front (as given in Anderson, Boville and McClellan (1955)). It was found that, to agree with Godson's mathematical theories (see Godson (1951)), and to provide an operationally useful model which distinguishes fronts from marine strata and from certain types of dry inversions, the following definition is required:-

(i) A front is an ensemble of two approximately parallel surfaces, each of which exhibits a first-order discontinuity in the temperature and wind fields. These surfaces are separated by a relatively stable zone with a vertical thickness of the order of 50-150 mb (referred to by Godson as a "hyperbaroclinic zone").

(ii) It is a quasi-substantial surface which moves with the wind flow.

(iii) It is a reasonably continuous feature of the chart in both space and time.

Clearly, the effectiveness of this definition rests upon the interpretation of the phrase "reasonably continuous in both space and time". Operationally, this means that a front must exhibit sufficient four-dimensional continuity to be a significant feature for both diagnosis and prognosis. However, it must not be thought that the only significant fronts are those that are both very extensive and extremely persistent. Fronts must be able to dissolve in one place and reform in another – as pointed out by Godson (1955), this is a fundamental requirement of the general circulation, with regard to the poleward transport of heat. Enhanced radiative cooling of warm air masses when in polar regions and enhanced convective heating of cool air masses while in sub-tropical regions are not enough; there must be a complete cutting-off of some such air masses, followed by their stagnation and gradual transformation and assimilation into the normal air masses of the polar and sub-tropical regions respectively. This process implies the rupture and reformation of frontal surfaces. It is usually found that the dissolution of a front in one area is accompanied by the reformation of what is essentially the same front in another area. This can lead to temporary analysis difficulties, as it is often the case that neither the diagnosis of the frontolysis, nor the location of the frontogenesis, can be carried out with confidence until the respective evolutionary processes have been completed.

We now turn our attention to the Canadian definition of an air mass. Some writers have tended to place the primary emphasis upon the concept of an air mass and have regarded fronts as having significance only in that they represent the boundaries of an air mass. In the Canadian philosophy this viewpoint is reversed and an air mass is defined as a large body of air which exhibits considerably less baroclinicity than the frontal zones bounding it. No assumptions are made concerning the generation of the air mass over a source region of uniform surface characteristics, and the air mass term applies quite simply to the atmospheric volumes separated by fronts. Nevertheless, air masses are usually considered to be quasi-homogeneous in the horizontal.

3. THE THREE-FRONT MODEL

The atmospheric model which is described by the Canadian analysis philosophy has often been termed the "three-front model", for, through a study of frontal contour charts, it has been found that the most frequent synoptic structure over North America and the adjacent oceans is one which involves three fronts (and hence four air masses). However, it should be pointed out that the Canadians by no means always insist that there be three, and only three, fronts indicated on the charts – experience has shown that if there is a pronounced meridional flow a two-front model may be more appropriate, while with a pronounced zonal flow there may be four relatively weak fronts present.

Under normal conditions, with three fronts present, the air masses and the fronts are named as follows: the continental Arctic front separates continental Arctic air (cA) from maritime Arctic air (mA); the maritime Arctic front separates mA air from maritime Polar air (mP); and the polar front separates mP air from maritime Tropical air (mT). (Continental Tropical air (cT) is not regarded as a significant air mass over North America, except on occasion over the southwestern United States, and it is considered unnecessary to differentiate between continental Polar air (cP) and cA.) It must be emphasized again that the air mass nomenclature specifies only properties of an air mass and does not refer to its source region – i. e. the name of an air mass is its least important property. Some representative air mass properties (for middle latitudes) are listed in Table 1, which is taken from Penner (1955).

Table 1. Typical Air Mass Properties (for Middle Latitudes)

	Winter				Summer			
Air Mass / Pressure (mb)	mT (°C)	mP (°C)	mA (°C)	cA (°C)	mT (°C)	mP (°C)	mA (°C)	cA
850	15	6	-4	-25	18	14	2	has been
700	4	-3	-16	-25	8	1	-10	modified
500	-15	-23	-36	-40	-9	-17	-28	to cold
400	-27	-36	-48	-46	-19	-28	-42	mA in
300	-42	-53	-50	-45	-35	-44	-48	middle
Tropopause (mb)	200	275	350	400	125	250	300	latitudes
θ_w range for mid-troposphere (°C)	13-18	8-12	2-7	<2	>15	10-14	4-9	< 4

(θ_w = wet bulb potential temperature)

The polar front is usually continuous at upper levels around the hemisphere, and is one of the main dynamical features of the westerlies (see McIntyre and Lee (1954)). Exchange processes take place across it through the cutting-off of domes of cold air (cold lows) south of the main westerly stream, and the cutting-off of pools of warm air (warm highs) to the north of the westerlies. The maritime Arctic front is the result of the intrusion of freshly modified maritime Arctic air into the westerly stream, while the continental Arctic front is maintained by the marked temperature and moisture contrasts along the boundary of the ice and snow cover of the Arctic regions. In winter this front is of great synoptic inportance in Canada, but in summer the cA air retreats to the icecap and the front is no longer of real operational

significance. Despite this, three fronts are still frequently needed to give an adequate description of the thermal structure over North America, and an intermediate front is analyzed, usually called the cold maritime Arctic front.

4. FRONTAL TOPOGRAPHY AND FRONTAL CONTOUR ANALYSIS

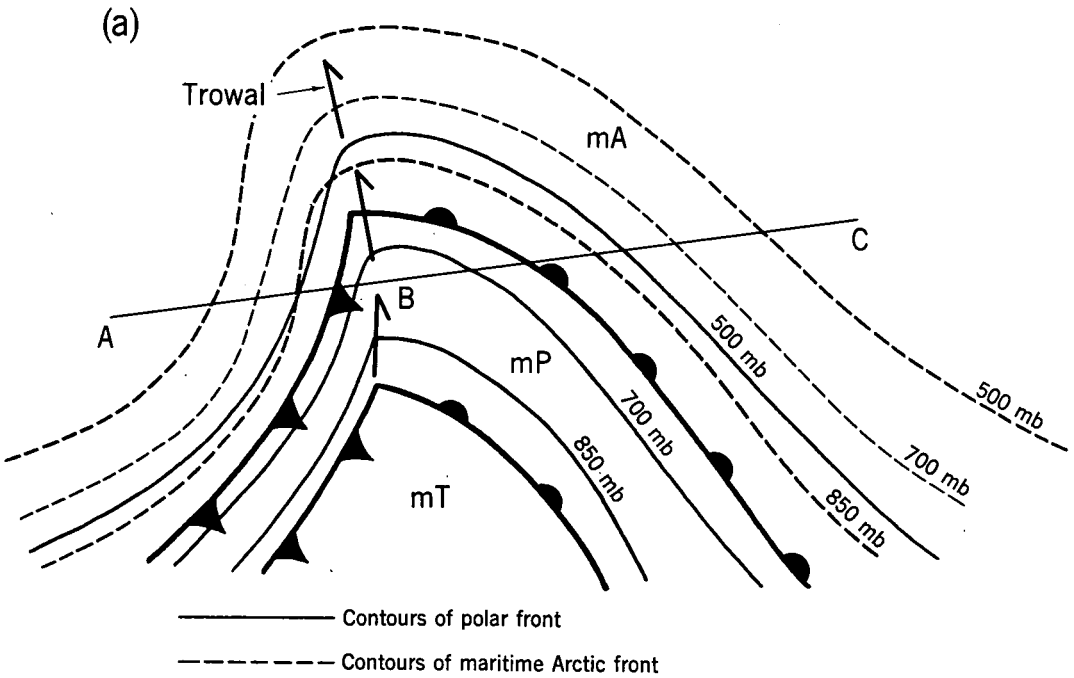
Two fronts will usually be found to be participating in the structure of any well-developed frontal cyclone, and, especially in the winter-time storms that form off the east coast of the United States, it is not uncommon to find all three fronts in phase and very close together, especially on the cold front side of the storm. In this case it is often very difficult to distinguish between the fronts at the surface, but a study of the available upper-air data will nearly always enable an analyst to locate the separate and distinct fronts at higher levels. (It is found that the polar front usually has a steep slope, the maritime Arctic front a shallower slope, and the continental Arctic or cold maritime Arctic front a shallower slope still. In this way two or, on occasion, three fronts may merge into one effective front near the surface, while remaining distinct in the mid-troposphere. This low-level merging of fronts is of course a reversible process.)

Figure 1 is an example of the structure of a frontal cyclone involving two fronts. It also illustrates another typically Canadian synoptic concept, the "trowal". The trough of warm air aloft (abbreviated to trowal) which lies (in the northern hemisphere) to the north of an occluding frontal wave, is a well-defined line of weather discontinuity, and it is frequently useful to indicate this line on a surface analysis (or prognosis). The trowal on the surface map represents the projection of the trough of warm air aloft, i. e. the projection of the frontal wave crests at successively higher levels. It should be noted that the occlusion process is neither a necessary nor a sufficient condition for the presence of a trowal; a distinct wave structure at upper levels is required. Since trowals can form on any one of the three fronts, they are common in Arctic regions. It is the author's experience that the identification and accurate location of trowals is essential to successful forecasting in these regions.

It will be noted how in Figure 1 the structure of the trowal is clearly indicated by drawing in the frontal contours for different levels. This is one example of the use of a "frontal contour analysis", which is a chart showing the frontal positions at the standard pressure levels (850, 700 and 500 mb) for all significant fronts. It thus presents a graphical representation of the frontal topography, and a carefully analyzed frontal contour chart is of great assistance to the analyst in the diagnosis of significant synoptic features, such as trowals, upper fronts, cold domes and warm pools, which are not readily analyzed using a surface chart alone. The analysis of these features is often of great assistance to the prognostician also – for instance, a trowal will often initiate cyclogenesis on a frontal surface at lower levels, or an upper front may "surface" as a result of rapid surface heating and low-level turbulent mixing. It is also important for the prognostician to be able to distinguish between an isolated cold dome and a normal cold trough which is completely filled with cold air and which will often exhibit several closed height contours. Frontal waves to the west of such a trough cannot be propagated across it; however, it is quite possible for a frontal wave to push through on the poleward side of a cold dome (usually in the form of an upper front or a trowal). Similar arguments apply to the case of a warm pool.

Frontal contour charts are also very useful in the preparation of thickness analyses. When preparing upper level analyses for regions of sparse data, differential analysis is a very valuable tool as it enables the analyst to make full use of every piece of information that is available to him. The preparation of thickness fields for use in differential analysis is made considerably easier by the use of a frontal contour chart, since the thickness lines for the layer between pressures p_1 and p_2 will tend to be concentrated between the frontal contours for p_1 and p_2, and they will also be roughly parallel to the contours. In the words of Godson (1951) "the three-dimensional frontal model implies a general structure of thickness lines with which existing data can be co-ordinated to give the most accurate representation of the atmosphere's thermal structure".

Thickness fields prepared in this way are also very useful in the preparation of jet-stream analyses. Each jet can be dynamically linked to the corresponding front and, in regions of sparse data, the 500 mb frontal contour is often the most reliable guide the analyst



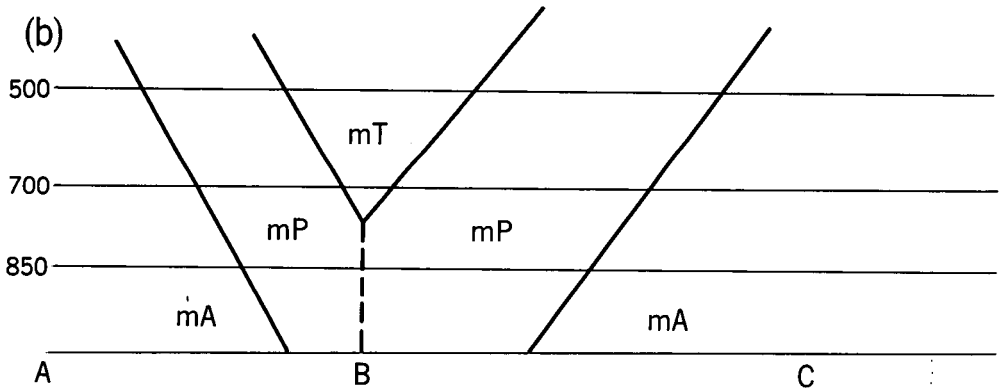


Fig. 1 (a) Plan view and (b) Vertical cross - section of a typical frontal wave involving two fronts (in this case the Polar and Maritime Arctic fronts).

has concerning the location of the jet axis (in the horizontal plane). In fact, the success of this technique of jet-stream analysis is perhaps the most convincing evidence in favour of the three-front model - in nearly all cases, a front whose existence has been diagnosed on the basis of low-level data can be shown to be associated with a definite jet-stream aloft.

When the Canadian Central Analysis Office first started drawing up frontal contour charts on a regular basis, they were looked on as the most important analytic tool used in the office and each chart was prepared with a great deal of care and attention to detail (see Anderson, Boville and McClellan (1955)). Six-hourly surface, and twelve-hourly 700 mb, 500 mb, 300 mb and frontal contour charts were used, but the analysis of the frontal contours was based primarily on the evidence of frontal structure obtained from tephigrams and hodographs, which were plotted for nearly all the upper air observing stations in North America, the Arctic regions, and the North Atlantic and North Pacific Oceans. The information extracted from the tephigrams and hodographs was plotted on the frontal contour chart. When a significant frontal inversion was found on a tephigram, a record was made of the following parameters: (i) the height (in pressure co-ordinates) of the frontal surface; (ii) the wet-bulb potential temperature (θ_w) of the warm air mass above the frontal surface; (iii) the orientation of the front, as indicated by the shear hodograph (if any); and (iv) the "intensities" of the frontal inversion and the frontal shear zone, judged on a simple objective basis. The pressure and potential temperature at the tropopause were also recorded, as these parameters were found to be of value in frontal identification.

The top of the frontal zone was taken to represent the frontal surface since it was found that this point was more readily and consistently identifiable than the base of the frontal zone. It was also found that each frontal surface, for both identification and continuity purposes, should be associated with the warm air lying above the surface rather than the cold air beneath it. This is not in agreement with the traditional air mass-frontal nomenclature scheme, but it does agree with the surface-analysis procedure of locating the front along the boundary of the relatively homogeneous warm air mass. Frontal contour charts prepared on this basis are of considerable assistance in maintaining continuity in the analysis of surface fronts and also of jet-streams.

In recent years, with computers beginning to take over much of the routine work in both analysis and prognosis, and with the Central Analysis Office attempting to speed up its output of charts, despite an increase in the amount of data to be handled, less emphasis has been placed upon the role of the frontal contour chart as a means to an end. It is not now regarded as being the primary analytic tool used in the office, but it still plays a major role in ensuring that all analyses are four-dimensionally consistent with regard to the frontal structure. It is still of great use in checking on the nature and extent of synoptic features such as trowals and upper fronts, and in the drawing of thickness fields for use in differential analysis. The procedure used in the preparation of the chart has also been changed - the frontal contours for any particular level are now drawn up initially by fitting them with the principal air-streams that are evident on the analysed height-contour chart for that level (making due allowance for history and for well marked horizontal discontinuities in temperature and/or humidity). Final detail adjustments of frontal positions are then made by examining tephigrams and hodographs, as in the past, though the number of upper-air soundings that are plotted and analysed in this fashion has been considerably reduced outside those areas which are of immediate interest to Canadian forecast offices.

The Canadian Meteorological Service has obtained its own Bendix G20 computer and is devoting a considerable research effort towards incorporating numerical techniques of analysis and prediction into the regular routine of the Central Analysis Office. A barotropic prediction model is already in operational use, and the Godson-Robert four-level baroclinic model is now being tested and may become operational by the end of 1964. With the wide-spread introduction of computer techniques and the development of completely new analytic procedures based on satellite observations, it is probable that some modifications of the Canadian philosophy of analysis will be called for. However the three-front model (combined with the use of the frontal contour analysis) has been shown in the past to give an operationally adequate representation of the main synoptic features within the troposphere, and we may expect that the basic features of this model will be retained for use in the future.

5. POSSIBLE APPLICATIONS IN THE SOUTHERN HEMISPHERE

A major portion of the area which is of direct interest to Australian analysts falls within the tropics or sub-tropics, where the concepts that have been developed in Canada are not relevant. Even in the mid-latitude belt, the great disparity in the geographical features of the two hemispheres makes it unlikely that a model which gives an adequate description of the general synoptic features in one hemisphere will be directly applicable in the other. In the mid-latitudes of the southern hemisphere the almost complete absence of significant land-masses and the consequent lack of well-defined temperature and humidity contrasts, mean that fronts will in general tend to be weak and ill-defined, and to be rather transitory in nature. Gibbs (1960) has indicated that well-defined frontal zones, extending through a considerable depth of the troposphere, are the exception rather than the rule in the southern hemisphere - and even when fronts of this nature do exist, it is obvious that the almost complete lack of upper-air data from vast areas of the Southern Ocean would make detailed analysis of the frontal topography (on the scale practised by the Canadians) an impossibility.

However, there is considerable evidence to show that fronts are a reality in Antarctic regions, and that they play an important role in determining weather conditions at stations on and near Antarctica (see, for example, Gray (1960), Alvarez and Lieske (1960) and Astapenko (1960)). Gray, in fact, proposes what might in this context be termed a "two-front model", and suggests that motions of systems on the southern front are frequently dependent on those of systems on the northern front, the two being connected by trowals or upper fronts. It is also interesting to note that, in their discussion of frontal analysis in the southern hemisphere, Taljaard, Schmitt and van Loon (1961) state that "It is our view that where upper air soundings are available more importance should be attached to discontinuities in the upper air than to surface discontinuities. Therefore, surface fronts should be entered only when direct or indirect evidence indicates that surface discontinuities are accompanied by upper air discontinuities which reach through an appreciable part of the lower troposphere". (However they do not make any reference to the preparation of a frontal contour analysis or the possible uses of this chart as an aid in surface analysis.) The same authors also advocate the use of the wet-bulb potential temperature (θ_w) as a criterion for determining frontal passages, and point out its usefulness in distinguishing between the effects of vertical motion and advection.

Thus some of the concepts and procedures which make up the "philosophy of analysis" of the Canadian Meteorological Service have already been shown to be operationally useful in the southern hemisphere. It is the author's opinion that, when a greater amount of observational data becomes available, it may well be found, in Antarctic regions at least, that a suitably modified version of the three-front model and the use of frontal contour charts as an analytical tool will prove to be of value to the southern hemisphere meteorologist.

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