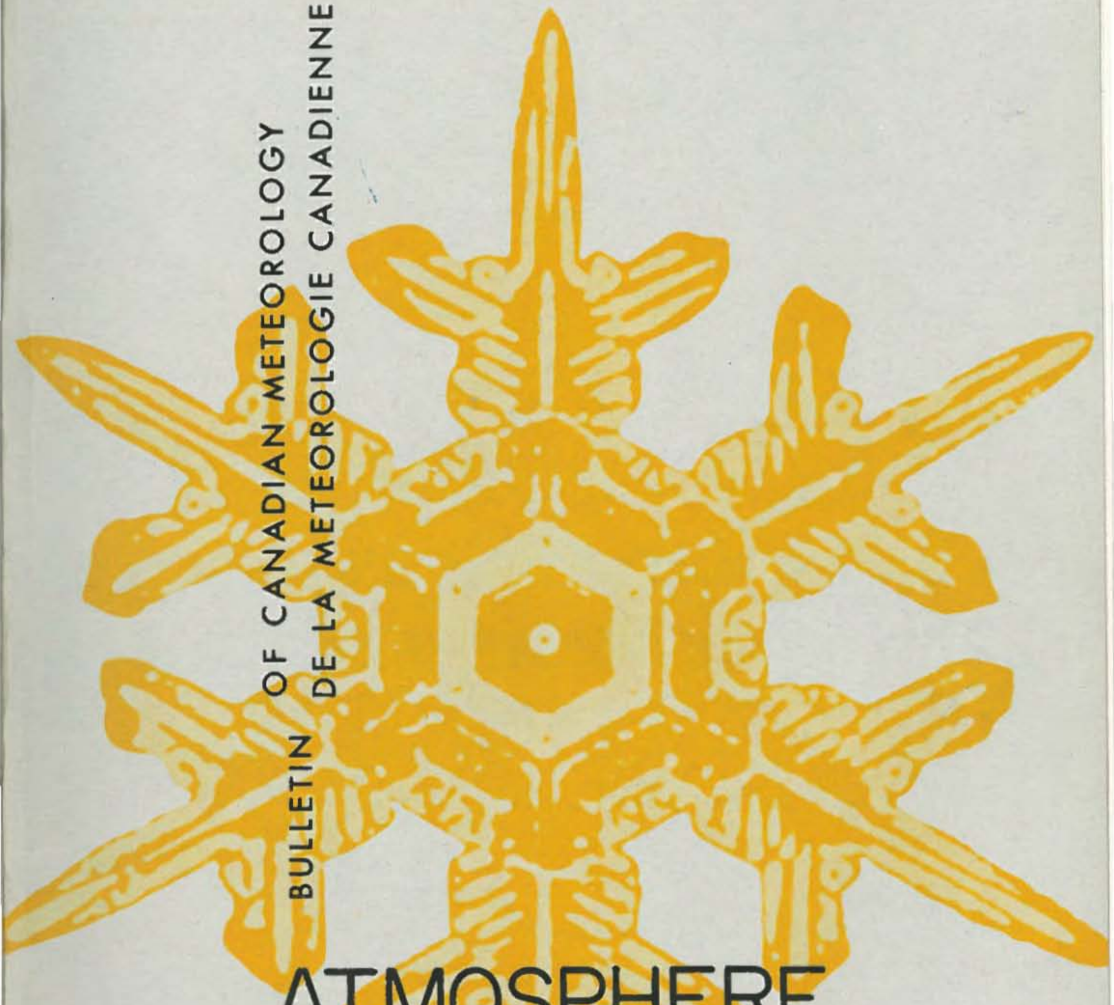

BULLETIN OF CANADIAN METEOROLOGY
DE LA METEOROLOGIE CANADIENNE

ATMOSPHERE

VOLUME 1, NO2
SPRING 1963

ATMOSPHERE

a publication of the Canadian Branch

Royal Meteorological Society

2 nd Issue : May 1963

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An Editorial

Come to the Congress !

This second issue of ATMOSPHERE is a Congress issue and realises further policy decisions on the conduct of Branch affairs.

In past years the venue of the Annual General Meeting of the Branch was the location of the Executive. The Annual Report and other relevant documents were distributed to Fellows in accordance with established procedure. On the initiation of a National Congress of the Branch an ad hoc committee distributed a booklet containing the programme and abstracts of papers, and a report of the proceedings eventually appeared in one of the publications of the parent Society. This year the Annual General Meeting is taking its rightful place in the National Meeting. This issue of ATMOSPHERE is a Congress issue and will serve as the basic document for the entire proceedings. Bring it with you to Quebec !

The reporting of meteorological meetings in Canada has never been wholly satisfactory. In the parent Society, copies of papers to be read are made available either in published form, or proof, in time to enable Fellows to make a considered contribution to the discussion. Fellows are invited to write in a summary of what they have said - or what they think they have said or think they ought to have said - which with replies from the author, duly appears in print. In this way the published paper is rounded off. In a limited fashion this method was applied in the 1953 joint meeting at Toronto of the Society and the American Meteorological Society and it was tried at the Montreal Congress of 1961. This year an attempt is being made , in the case of previously unpublished papers, to provide extended summaries in advance, which form the bulk of this issue, and maximise time for discussion. This has unfortunately not been accomplished without the regrettable rejection of some proffered papers.

We think that the Branch can be justifiably proud that meteorology in Canada is taking its place in the annual gathering of Canadian scientists, and, in addition to its own specialisation, sharing sessions with the physicists and being an invitée of the Royal Society. This year's programme promises well. But it is to be noted that there is no separate session for synoptic meteorology, although this is the concern of the majority of Canadian meteorologists. The programme has, however, to be set up from the available material. Remember that this year's work is next year's paper.

Our Congress is an affair to be cherished and nourished. Come to it before it comes to you. When you come, say your say in the meetings, and in the waiting years, or at any time, write to us as to how it may be better done. Congress is good but it can be only as good as you make it.

Editorial

Venez au Congrès !

Le deuxième numéro de notre brochure ATMOSPHERE vous donne tous les renseignements au sujet du congrès qui se tiendra à Québec, ainsi que les décisions prises antérieurement sur la politique que nous entendons suivre en ce qui regarde les affaires de notre société.

Jusqu'a maintenant , l'assemblée annuelle se tenait dans la ville où demeuraient les membres du comité exécutif. Le rapport annuel et autres pièces justificatives étaient distribués aux membres selon la procédure alors en vigueur. Avant le congrès national , un comité ad hoc fut chargé de la distribution d'une brochure qui contiendrait le programme, un résumé des communications et le compte rendu des délibérations. Ceci fut publié dans un numéro de la revue Royal Meteorological Society. Cette année, l'assemblée annuelle se tiendra lors du congrès national à Québec. Ce numéro de notre brochure ATMOSPHERE est consacré entièrement au prochain congrès. Il servira d'ordre du jour pour toutes les réunions. Nous vous conseillons fortement de l'apporter à Québec.

Le compte rendu des assemblées météorologiques tenues au Canada n'a jamais été fait d'une manière efficace. Par contre la Royal Meteorological Society envoie à ses membres une épreuve ou un fascicule de la communication avant toutes réunions. Les membres sont donc en mesure de discuter en toute connaissance de cause. Après quoi on invite les participants à envoyer un résumé de leurs propos, de ce qu'ils croient avoir dit, de ce qu'ils croient qu'ils auraient dû dire. L'auteur de la communication répond aux critiques et le tout est ensuite publié. Le lecteur est donc informé du pour et du contre. En 1953 nous avons suivi cette politique lors de la réunion conjointe de notre société et de 'American Meteorological Society tenue à Toronto. Nous avons aussi essayé de faire de même au congrès de Montréal en 1961. Cette année, nous faisons circuler parmi les membres, un résumé des communications originales. La présente brochure sert à cette fin et nous espérons que vous vous joindrez à l'auteur pour animer les discussions prévues. Certains impératifs nous ont contraints à refuser des communications.

Nous sommes fiers que la météorologie soit enfin reconnue au Canada et que notre société soit invitée par la Royal Society à se joindre aux autres sociétés savantes et à siéger avec les physicistes. Cette année notre congrès promet d'être des plus intéressants. Il faut noter qu'aucune séance est consacrée exclusivement à la météorologie synoptique. C'est à déplorer car la plupart des météorologistes canadiens s'y intéressent exclusivement. Le programme des séances a été préparé avec soin, compte tenu des communications dont nous disposions. Souvenez vous que vos recherches en cours pourraient servir à des communications à l'assemblée de l' an prochain.

Notre congrès mérite tout votre respect et demande votre collaboration. C'est pourquoi nous vous invitons à y participer par vos discussions et vos communications. Nous serons toujours heureux de recevoir vos suggestions en vue de l'améliorer. Il sera ce que tous voudront bien qu'il soit.

CANADIAN BRANCH

ROYAL METEOROLOGICAL SOCIETY

MINUTES OF THE 22ND ANNUAL BUSINESS MEETING, MAY 14, 1962

The meeting was called to order by the President, Professor R.H. Douglas, at 8.15 p.m., in the Faculty Club, McGill University, Montreal.

The minutes of the 21st Annual Business Meeting, held May 11, 1961, at the same locale, had previously been distributed to all members. It was moved by Professor B.W. Boville and seconded by Mr. J. Tissot that they be adopted; carried.

The Annual Report of the Executive Committee for 1961-62, which had been circulated to all Branch members, was submitted to the meeting. During the discussion it was noted that the report did not include coverage of the National Congress held in Montreal June 6 and 7, 1961. Although reports and discussion on the proceedings of the Congress were published in the Quarterly Journal and Weather, it was recommended that in future, the Annual Report should also contain an outline of such proceedings for reference and historical purposes. A motion for adoption of the report was made by Professor J.S. Marshall and seconded by Professor K.L.S. Gunn; carried.

Mr. F.J. Mahaffy presented the Treasurer's Report and stressed the fact that although a surplus was shown for 1961, this was somewhat misleading in view of the recent downward trend in the exchange rate. He pointed out that at the present rate of exchange only about 45¢ per member was available to the Branch out of the annual fee of $ 10.00 and that, if the Branch was to operate effectively, an increase in annual fees would be required. Mr. Mahaffy then moved the adoption of the report; seconded by Mr. J.M. Leaver; carried.

The question of fees for 1963 was placed before the meeting. After outlining the situation, Professor Douglas asked for a motion from the floor. It was moved by Mr. L.W. Hubbert, seconded by Mr. R.A. Parry, that the initiation fee remain unchanged but that the annual fee be increased to $ 12.00 per member. Professor Marshall stated that, under the circumstances, he favoured the fee increase but felt that the additional funds should not be given over to the additional support of the larger, well-established Centres, which should be partially self-supporting; rather, greater support should be provided for the development of new and young Centres and for other interests of the Branch. Professor Marshall moved an amendment to that effect, seconded by Professor W. Hitschfeld, but this motion was later withdrawn when it was pointed out by Mr. J.L. Galloway that By-Law 59 permitted the Executive Committee, at their discretion, to authorize the expenditure of Branch funds on behalf of a local Centre and that the amended motion, if passed, would require an amendment to the By-Laws. The original motion that the fees be raised to $ 12.00 per year was then put to a vote and carried.

Mr. Mahaffy moved that Mr. A. High, who had been approached in this regard, be appointed Auditor for 1962-63; seconded by Mr. R. Anderson; carried. At the same time, the meeting went on record with a vote of thanks to Mr. High. The Corresponding Secretary was instructed to send a letter of appreciation to Mr. High for his services in the past and for his willingness to act as auditor during the coming year.

The report of the Prize Committee was presented by Professor Douglas.

Mr. Galloway suggested that the Branch should take note of the fact that a Canadian (Professor Marshall) had recently been awarded the Hugh Robert Mill Award by the Parent Society, and that another Canadian (Dr. Hines) had been awarded the Napier Shaw Memorial Prize.

Professor Douglas reviewed the programme for the National Meteorological Congress to be held at McMaster University June 6th and 7th. This programme had just been completed and would be distributed to all Branch members in the near future.

Professor Hitschfeld stated that indications point to the National Congress becoming an annual event and suggested that this would be a suitable occasion for holding the Annual Meeting of the Branch , in order that a greater representation of the membership-at-large might attend. He moved that the Executive Committee take this suggestion under consideration and, if at all feasible, take appropriate action towards implementation; seconded by Professor Marshall; carried.

Since, by custom, the Vice-President for Canada is nominated on a motion at the Annual General Meeting of the Branch, it was moved by Mr. R. Anderson that Professor J.S. Marshall be nominated to this office for the coming year; seconded by Mr. H.M. Hutchon; carried.

The Executive Committee for 1962 -63

President	-	Prof. B.W. Boville
Vice-President	-	Prof. R.H. Douglas
Treasurer	-	Mr. F.J. Mahaffy
Corresponding Secretary	-	Mr. L.W. Hubbert
Recording Secretary	-	Mr. C.L. Johnstone
Vice-President for Canada	-	Prof. J.S. Marshall
Councillors	-	Mr. R.V. Dexter (Halifax)
	-	Prof. R.W. Longley (Edmonton)
	-	Mr. L.B. MacHattie(Ottawa)
	-	Mr. J.B. Wright (Vancouver)
Chairmen	-	Montreal Centre
	-	Toronto Centre
	-	Winnipeg Centre

The President-elect, Professor B.W. Boville then assumed the chair and addressed the meeting. He expressed his appreciation for the interest shown and for the constructive nature of the discussion that had taken place. The Annual General Meetings in the past have been non-representative of the membership-at-large and Professor Hitschfeld's suggestion that an effort be made to hold future Annual meetings in conjunction with the National Congresses was welcomed. He felt there is a need to promote Centre activities, as well as activities as a whole, across the country and to achieve something definite in the field of publications.

The meeting adjourned at 9: 15 p.m.

R.H. Douglas
President

C.L. Johnstone
Recording Secretary

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE FOR 1962 - 63

Report from the President

The National Meteorological Congress at McMaster University in Hamilton set the tone for another active Canadian year in our science. At Winnipeg, Montreal and Toronto the fine tradition of centre scientific meetings continued and the Toronto Centre also sponsored an international meeting on agricultural meteorology. The growing University research has become a major factor through Quebec, Ontario and the Prairies and budding projects are evident from coast to coast.

To keep pace with the scientific growth , our new bulletin "Atmosphere" has been launched to provide an improved communication link and verbal forum. The organization and publication changes in the American Meteorological Society, in which many of our members are very active, also reflect the changing scientific climate and it is likely that we will soon need further adjustments.

Following last year's recommendation, the annual meeting time has been changed and the 1963 Congress in June at Laval University in historic Quebec City should provide a complete focal point for the coming year.

The Executive Committee

The committee met regularly during the 1962-63 period to consider the business of the Branch. The quorum at each meeting again consisted of the resident Montreal members. Temporary transfer forced Mr. Mahaffy to resign and the Executive is grateful to Mr. H.M. Hutchon for accepting the Treasurer's responsibilities.

Members, 1962 - 63

President	-	Prof. B.W. Boville
Vice-President	-	Prof. R.H. Douglas
Secretary (recording)	-	Mr. C.L. Johnstone
Secretary (corresponding)	-	Mr. L.W. Hubbert
Treasurer	-	Mr. H.M. Hutchon
Vice-President for Canada	-	Prof. J.S. Marshall
Councillors	-	Mr. R.V. Dexter (Halifax)
	-	Prof. R.W. Longley (Edmonton)
	-	Mr. L.B. MacHattie (Ottawa)
	-	Mr. J.B. Wright (Vancouver)
Chairmen	-	Montreal Centre : Mr. R.A. Parry
	-	Toronto Centre : Dr. J. Clodman
	-	Winnipeg Centre : Mr. D.G. Black

Committees

Nominating Committee	-	K.L.S. Gunn
		W. Hitschfeld
Prize Committee	-	M. Kwizak
		J.S. Marshall
Planning Committee National Meetings	-	R.H. Douglas
		A. Robert
		J. Clodman
		K.L.S. Gunn
		R. Perrier

Editorial Committee	-	S. Orvig (Editor)
		W. Hitschfeld
		J.L. Galloway
		R. Lee

Membership Statistics, 1962

	31 Dec 61	31 Dec 62	Elected	Withdrawn
Life Fellow	5	5		
Fellow	356	358	23	21
Student member	1	1		
	362	364		

REPORTS FROM CENTRES

Report of the Montreal Centre

Six meetings of the Montreal Centre were held during 1962 at which the following papers were read : "Singularities in Rainfall" by Dr. E.G. Bowen; "Some Problems on the Glaciology and Glacial Meteorology on Axel Heiberg Island" by Messrs. F. Muller and J.M. Havens; " Automatic Weather Instruments " by Mr. R.E. Vockeroth; " Hail Swathes in Alberta" by Dr. E. Carte; " A Review of Three Years of Numerical Experiments with the Barotropic Model at the Central Analysis Office"by Mr. A.J. Robert; and " M.Sc. Research at McGill " by Prof. J.S. Marshall.

The following officers were elected for 1962 : Chairman, Mr. R.A. Parry; Secretary, Mr. R.L. Swansburg ; Treasurer, Mrs. K. Larsson.

Report of the Toronto Centre

The third session of the W.M.O. Commission for Agricultural Meteorology was held in Toronto, July 9 to July 27, and the scientific sessions on July 13 were jointly sponsored by the Toronto Centre. Dr. Andrew Thomson was Chairman for this session and the portion on water balance of the soil included papers by Dr. K.M. King (Canada), Mr. C.E. Hounam (Australia), Dr. L.D.I. Deij (Netherlands), Prof. R.A. Shaw (U.S.A.), and Dr. R.H. Holmes (Canada). The session on forest meteorology included papers by Mr. L.B. MacHattie (Canada), Dr. F. Schnelle (Germany), Prof. W.E. Reifsnyder (U.S.A.), and Dr, M.D. Fransilla (Finland).

Eight meetings were held by the Toronto Centre during 1962, at which the following topics were presented : " Forecasts made with a Three-level Model" by Dr. G.P. Cressman; "Meteorological Services for Aviation in the Tropics " by Mr. V.Rath ; " Science and Scientists in a Changing World " by Dr. W.E. Swinton ; "Dynamical Prediction of Hurricane Movement " by Dr. G.W. Platzman ; " An Evening with the Research Section " by Dr. W.L. Godson and Messrs. C.L. Mateer and J.D. Holland ; " Two Years in Geneva with W.M.O. " by Mr. K.T. McLeod ; " The Final Warming Phenomenon" by Dr. W.L. Godson.

A panel discussion on " Meteorology and Meteorologists in the Next Decades " was also held.

Officers from June 1, 1962 , were : Chairman, Dr. J. Clodman ; Treasurer , Mr. T.L. Wiacek ; Secretary, Mr. L.K. McGlening ; Program Secretary, Mr. R.E. Vockeroth.

Report of the Winnipeg Centre

The officers of the Winnipeg Centre in 1962 were : Honorary Chairman, Mr. D. M. Robertson; Chairman, Mr. D.G. Black ; Vice-Chairman, Mr. D.G. McGeary; Secretary-Treasurer, Mr. F.T. Upton.

Six meetings of the centre were held. Mr. G. Pincock reported on a "Conference on Agricultural Meteorology at St. Louis, November 1961"; Mr. F.T. Upton presented a paper on an "Investigation of an unusual occurrence of aircraft icing and turbulence, December 1961" ; Dr. P.D. McTaggart -Cowan spoke on "Weather and Food" ; Mr. P. Johns reported on the " First International Meteorological Satellite Workshop, Washington, D.C., March 1961" ; Prof. R.H. Douglas spoke on " Recent Progress in Hail Research" ; and Mr. W.B. Watson reported on the " Precipitation Project at North Bay ".

PRIZE COMMITTEE

President's Prize	-	to Mr. Geo Gilbert in reference to the paper " An approach to the quantitative prediction of the anomalous blast effects " J.A.M. , March, 1962.
Prize in Applied Meteorology	-	to Mr. W.L. Gutzman in reference to the paper "An investigation of broad-scale vertical motion in an eastern North American storm" Monthly Weather Review, October, 1962.
Recommended for the Canadian Darton Prize-		Mr. K. Hardy with reference to the paper "The description of rain by means of sequential raindrop-size distributions " Q.J.R.M.S., July, 1962.

TREASURER'S REPORT FOR YEAR ENDING 31 DECEMBER 1962

The change in foreign exchange rates which occurred during 1962 substantially reduced the net revenue of the Canadian Branch. However, the increase in fees for 1963 is expected to provide a net income of about $ 800. Of this, some $ 300 will be required for operating expenditures, including the contributions to the Centres. The remainder is available for financing the new publication. On the assumption of a continued stable exchange rate, no further change in fees is recommended at this time. There is no indication of a revision to the fee structure within the Royal Meteorological Society.

CASH ACCOUNT

Receipts				
Fees :	Initiation	37.60		
	1961 Fellows	155.85		
	1962 Fellows	3095.87		
	1963 Fellows	24.00		
Bank and Bond Interest		94.88		
National Meteorological Congress		30.00	3438.20	
Bank Balance 31 December 1961			1789.10	
				5227.30

Expenditures

Bank charges	15.49		
Postage	55.65		
Payments to Centres : Toronto	30.10		
Montreal	28.00		
Winnipeg	25.90		
Stationery	66.27		
Remission of Fees to R.M.S. London	3652.14		
Printing (Annual report and N.M.C. programme)	94.91		
Miscellaneous	30.60	3999.06	
Bank Balance 31 December 1962		1228.24	
			5227.30

BALANCE SHEET AS OF 31 DECEMBER 1962

Assets

Bank Balance 31 December 1962			
Royal Bank of Canada	858.74		
Bank of Montreal	369.50	1228.24	
Bonds (Market value plus accrued interest to 31 Dec. 1962)			
$ 1000 G. of C. 3-3/4% - 1978	874.86		
$ 300 G. of C. 4-1/2%- 1983	381.26	1256.12	
Total Assets			2484.36

Liabilities

1963 fees paid in advance	24.00		
Accounts payable (Toronto Centre)	10.60		
Net liabilities		34.60	
Surplus 31 December 1961	2485.40		
Deficit for 1962	35.64	2449.76	
Total Liabilities and Surplus			2484.36

AUDITOR'S REPORT

I have studied the accounts of the Canadian Branch of the Royal Meteorological Society , and am satisfied that the Treasurer's Report presents a proper statement of the Branch's financial status as of 31 December ,1962.

A. High
Auditor

NOMINATIONS

The following slate is presented for the 1963 -64 Executive Committee :

President	-	B. W. Boville
Vice-President	-	H. Hutchon
Treasurer	-	D. E. McLellan
Corresponding Secretary	-	D. K. Smith
Recording Secretary	-	A. Robert
Councillors	-	R. V. Dexter (Halifax)
		R. W. Longley (Edmonton)
		G. H. Gilbert (Ottawa)
		J. B. Wright (Vancouver)

Vice-President for Canada (Nominated by the Executive Committee to the Council of the Society) - R.H. Douglas

NATIONAL METEOROLOGICAL CONGRESS

June 5 - 6, 1963

This, the second issue of ATMOSPHERE, devotes itself largely to the programme of the Meteorological Congress, June 5 and 6, at Laval University, Quebec City. This programme constitutes the major portion of the report of the Congress Committee to the Executive and Fellows of the Canadian Branch.

The response of the Fellows, and of interested colleagues outside the Society, to our call for papers was overwhelming : a total of thirty titles and abstracts were submitted. From the outset, the problem of the Committee has been to accommodate as many contributions as possible within the limited time available, to yield the best integrated programme providing the maximum time for the discussion which ought to constitute the most important feature of a meeting of this kind. The Committee has preferred to limit the number of presentations and to encourage discussion, rather than to crowd the sessions with a large number of very short papers, each suffering from a lack of time for proper consideration.

The selection was not an easy task; in the end, eight contributions could not be accommodated. To those whose contributions could not be accepted , the Committee expresses its appreciation for the offer, its regrets that it has been unable to include them in the programme, and its hope that you will nevertheless attend the Conference, sharing enthusiastically in the discussions.

Thanks to the co-operation of the participants, you will find in this issue summaries of most of the papers. These represent a compromise between the short abstract and the complete preprint. These are intended to encourage succinct delivery on the part of the speakers and free-wheeling discussion on the part of the audience, and also to be informative to those Fellows who are unable to attend the proceedings.

PROGRAMME, METEOROLOGICAL CONGRESS, 1963
LAVAL UNIVERSITY

WEDNESDAY, JUNE 5

<u>9.30 - 11.30 a.m.</u> Jointly with the Royal Society of Canada, Interdisciplinary Division, Section III

ATMOSPHERIC and OCEANIC CIRCULATION

Chairman: J.S. Marshall

A.W. BREWER: Ozone as a tracer element in the stratosphere.

N.P. FOFONOFF : Dynamics of ocean currents.

<u>Noon - 2.30 p.m.</u> Grand Boulevard Restaurant

Luncheon, Annual Meeting of the Royal Meteorological Society, Canadian Branch, and Presentation of Awards.

3.00 - 5.40 p.m.

RADIATION and TURBULENCE

Chairman : J. Clodman

20*	L. W. GOLD and D. W. BOYD :	The annual heat balance at a grass covered site at Ottawa.
20	E. VOWINCKEL and SVENN ORVIG :	Insolation and absorbed solar radiation at the ground in the Arctic.
20	G. SABOURIN and J. S. MARSHALL:	Températures maximum et minimum à l'Observatoire McGill.
20	G. R. KENDALL :	The mean daily temperature range in Canada.
20		RECESS
20	P. W. SUMMERS :	An urban ventilation model.
20	G. T. CSANADY :	The buoyant motion in smoke plumes.
20	E. R. WALKER :	Wind spectra from Suffield, Alberta.

8.00 p.m.

SYMPOSIUM ON SPACE PHYSICS

This symposium, to which Fellows of the Canadian Branch are cordially invited, is sponsored jointly by the Royal Society of Canada, and by the Canadian Association of Physicists.

J.R. WINCKLER: Solar terrestrial relationships.

J.H. CHAPMAN : The Canadian satellite.

THURSDAY, JUNE 6

9.00 - 11.40 a.m.

DYNAMIC METEOROLOGY and NUMERICAL WEATHER PREDICTION

Chairman : M. Kwizak

15	CHAIRMAN :	Introduction.
20	H. B. KRUGER :	Objective analysis of synoptic scale meteorological phenomena.
20	D. L. HOLYOKE :	A simple derived height for 300 mb.
20	AMOS EDDY :	Space autocorrelation of some meteorological parameters.
20		RECESS
15	ANDRE ROBERT :	Fourier analysis on a spherical surface.
15	DAVID DAVIES :	Stability properties of the Godson 4-level model.
15	B.E. O'REILLY :	Instability in the middle stratosphere.
20	W. L. GODSON :	The 26-month wind oscillation in the equatorial stratosphere.

* Time, including discussion.

2.00 - 4.45 p.m. Jointly with the Canadian Association of Physicists

PHYSICAL METEOROLOGY

Chairman : W. Hitschfeld

15 MARCELI WEIN and K.L.S. GUNN :Facsimile output for weather radar.

20 P.M. HAMILTON : Precipitation profiles for operations and research.

20 L.H. DOHERTY : Measurements of scattering from rain, using a Doppler system.

20 D.R. HAY, M.B. BELL, and R.W. JOHNSTON : Observations upon clear-air stratification in the lower troposphere.

15 R.S. BOURKE and J. KLEIN : The M.S.C. Tethersonde

20 RECESS

20 J.A.W. McCULLOCH and C. PAYNE : An evaluation of some neph - analyses prepared from TIROS cloud photographs.

15 B.A. POWER and P.W. SUMMERS : Effect of snow crystal forms on snowfall density.

20 J.P. BRUCE : Atmospheric water vapour and precipitation on the Prairies.

The morning and afternoon sessions will take place in the PURE SCIENCE BUILDING :

June 5, a.m.	:	Room 3870
June 5, p.m.	:	Room 2820
June 6, a.m.	:	Room 2820
June 6, p.m.	:	Room 2850

A sketch map of Quebec City will be found on the last page of this issue.

THE ANNUAL HEAT BALANCE AT A GRASS COVERED SITE AT OTTAWA

L. W. Gold and D. W. Boyd
National Research Council, Ottawa

Observations relevant to the heat balance at a natural grass covered surface have been made at Ottawa, Ontario, for the two year period January 1, 1961, to December 31, 1962. These observations include net total radiation, soil temperature, dew point and wind velocity two meters above the soil surface, shielded air temperature about 1.2 meters above the soil surface and evaporation from a class A pan. The observations on net total radiation were made with a shielded type radiometer designed by the Commonwealth Scientific and Industrial Research Organization of Australia.

The average annual total net radiation and Fourier components of period one year were calculated from the radiation observations. This approximation to the net total radiation was found to be $R = 125 + 157 \sin(wt + 274^{o})$ cal/cm^2, day. The Fourier component of period one year accounts for between 80 and 90% of the dependence of the average net total radiation on time.

The average thermal conductivity and diffusivity of the soil at the observation site had been determined in an earlier study of Pearce and Gold (1). The average Fourier component of period one year was calculated from the soil temperature observations made 10 cm below the soil surface. Using this approximation for the time variation of the soil temperatures, and the thermal constants of the soil determined earlier, the component of the ground heat flow of period one year was found to be $G = 18.5 \sin(wt + 100^{o})$ cal/cm^2, day.

Observations on evaporation rate from the class A pan, rainfall and vapour pressures indicated that the average maximum evapotranspiration loss in summer was about 200 cal/cm^2, day and the average minimum sublimation loss was very close to zero. The difference between the average daily vapour pressure of air at the two meter level and the vapour pressure of air saturated at a temperature equal to that of the average ground surface temperature, was calculated. The Fourier component with period of one year was calculated for these differences. Using the estimated evapotranspiration rate made from the observations with the class A pan and on rainfall, and the phase angle associated with the first Fourier component approximation of the difference in vapour pressures, the following approximation was obtained for the heat loss associated with mass transfer : $E = -100 + 100 \sin(wt + 76^{o})$ cal/cm^2, day. Making use of the energy balance, the following approximation was obtained for the convective exchange : $C = -25 + 52 \sin(wt + 127^{o})$ cal/cm^2, day.

It is considered that the expressions given for the net total radiation and the ground heat flow account for at least 80% of these two components of the surface heat balance. The observations on the vapour pressure difference indicate that the actual evapotranspiration and sublimation losses probably deviate considerably from the approximation given, but it is considered that the average summer and winter extremes are accurate to $\pm$ 30 cal/cm^2, day. The summer and winter average extreme values of the components of the heat transfer calculated from the given approximations

(in cal/cm^2, day) and the dates upon which they occur are as follows :

	Summer Extreme	Date	Winter Extreme	Date
Net Total Radiation	282	June 27	-32	Dec. 27
Ground Heat Flow	- 18	June 21	18	Dec. 21
Mass Transfer	- 200	July 16	0	Jan. 14
Convection	- 77	May 25	27	Nov. 24

Reference:

(1) Pearce, D. C. and Gold, L. W. " Observations of Ground temperature and Heat Flow at Ottawa, Can ada ", Jour. Geophysical Res., Vol. 64, No. 9, Sept. 1959, p. 1293 - 1298.

INSOLATION AND ABSORBED SOLAR RADIATION AT THE GROUND IN THE ARCTIC

E. Vowinckel and Svenn Orvig
McGill University, Montreal .

The observational data available for a regional study of short wave radiation in the Arctic are still quite inadequate and the value of stations with short records is limited. Regional differences in insolation are quite marked, and two methods are available for obtaining an estimate of the radiation available in areas with few stations or stations with short records :

1) an empirical method of finding, from existing radiation stations the relation between radiation and another readily available element, e.g. cloudiness. With this relation the vast number of observations of the readily available element can be used and accordingly radiation maps can be drawn.

2) a method, where use is made of the knowledge of processes influencing the radiation from outside the atmosphere until it reaches the ground.

The calculation of insolation was based on two steps : determination of clear sky radiation, and correction to actual conditions dependent on cloud conditions. The following information is necessary to calculate clear sky radiation : Extra-terrestrial radiation, solar height (air mass), ozone absorption, water vapour absorption, atmospheric dust, and ground albedo. With these basic data the clear sky radiation at the ground was calculated. Correction to actual radiation on the ground was then performed using previously published studies on cloud type frequencies and depletion by different cloud types over the Arctic. Finally, the insolation figures were multiplied by (1 - albedo). Insolation and absorbed solar radiation at the ground are given for grid points for various months, and on monthly mean maps.

TEMPERATURES MAXIMUM ET MINIMUM A L'OBSERVATOIRE McGILL

George Sabourin et J.S. Marshall
Service Météorologique, Dorval — McGill University, Montreal

Nous avons analysé les distributions des températures quotidiennes, maximum et minimum, enregistrées a l'Observatoire McGill durant 88 années, d'août 1874 à juillet 1962.

Voici les principaux caractères qui émergent de cette analyse :

1. Les distributions de fréquence (d'après les graphiques sur coordonnées de probabilité) se divisent en quatre classes bien définies. Le type-été correspond à une distribution normale des températures, le type-hiver à une distribution asymétrique; des types de transition caractérisent le printemps et l'automne.
2. L'écart quartile, à la fois pour les maximum et les minimum, est le plus élevé à la mi-hiver et le plus bas à la mi-été, avec occurrence de minimum secondaires en novembre et à la fin de mars ou d'avril.
3. L'asymétrie est preque nulle en juin, juillet et août, à la fois pour les températures maximum et minimum. Il y a asymétrie négative prononcée de la température maximum aux mois d'hiver, décembre, janvier et février. L'asymétrie négative la plus élevée des températures minimum survient à la fin de novembre et de mars.
4. La probabilité d'enregistrer un minimum de 32°F ou moins après le 8 juin et avant le 11 septembre est d'une partie dans dix mille.
5. L'écart quadratique moyen des températures maximum et minimum les plus élevées et les plus basses est le plus grand en novembre et en avril.
6. L'intervalle entre les médianes se maintient à un maximum presque constant durant les mois d'été , de mai à août, avec un maximum secondaire bien marqué en janvier . Deux minimum se présentent, l'un à la fin de mars, le second à la fin de novembre.

On peut relier plusieurs des singularités aux périodes de gel et de dégel; les dates moyennes de ceux-ci , telles qu'obtenues des 32 années d'enregistrement des températures du sol au Macdonald College, sont le 5 décembre et le 1 avril respectivement.

The distributions of daily maximum and minimum temperatures recorded at McGill Observatory during the 88 year period from August 1874 to July 1962 have been analysed.

The following main features emerge :

1. The frequency distributions (as judged by plots on arithmetic probability paper) fall into four well defined categories. A summer type corresponds to a normal distribution of temperatures. A winter type corresponds to a skew distribution, and transition types occur in the spring and the fall.

2. The interquartile range for both the maximum and minimum temperature is highest in mid-winter and lowest in mid-summer, with secondary minima occurring in November and late March or April.

3. Skewness is near zero in June, July and August for both the maximum and minimum temperatures. There is a strong negative skewness of maximum temperature in the winter months December, January and February. The largest negative skewness of minimum temperatures occurs in late November and late March.

4. The probability of recording a minimum temperature of $32^{\circ}F$ or less on or after June 9, and on or before September 10, is down to one part in ten thousand.

5. The standard deviation of the extreme high and low maximum and minimum temperatures is greatest in November and April.

6. The median range is at a fairly constant maximum through the summer months May to August, with a secondary but well defined maximum in January. Two minima occur , one at the end of March, the other in late November.

Many of the singularities can be related to period of freeze-up and thaw , the mean dates of which, as obtained from 32 years of soil temperature records taken at Macdonald College , are December 5 and April 1 respectively.

THE MEAN DAILY TEMPERATURE RANGE IN CANADA

G. R. Kendall

Meteorological Branch, Toronto

The mean daily range is the difference between the mean daily maximum and mean daily minimum temperature . Maps showing the values of this parameter for each month are presented and discussed.

The distribution of a series of the mean daily range in successive years is commented on. Some representative values of the standard deviation as computed by a linear estimation technique are presented, together with a brief discussion of this method of estimation.

AN URBAN VENTILATION MODEL

Peter Summers

McGill University, Montreal

Preliminary qualitative analyses of smoke concentrations in the central Montreal area have been presented at previous meetings of the Canadian Branch. Sufficient data are now available to allow a more quantitative approach to the problem of urban ventilation. In many months the characteristic diurnal variation strongly suggests the exponential growth and decay of smoke concentration with time. Using the general ideas of exponential growth, where the rate of change of a variable depends only on its value at the time, and also introducing the concept of a time constant of ventilation, a simple model of urban ventilation is proposed.

The following assumptions are made :-

1. The atmosphere over the city has an effective volume V. This will vary with time and be proportional to the mixing depth.
2. The amount of smoke in this volume is M.
3. The rate of production of smoke per unit time is P.
4. Ventilation is considered as the replacement of a fraction of V, containing a corresponding fraction of M, by an equal amount of CLEAN AIR , let this rate of ventilation per unit time be D.

It follows from (4) that the amount of smoke lost by ventilation per unit time is proportional to the amount present and is equal to DX, where X = concentration per unit volume = M/V. Therefore the rate of change of M is given by

$$\frac{dM}{dt} = P - DX$$

In practice there are periods of time of up to several hours when V, P and D are all essentially constant. Thus dM = VdX. The basic equation now becomes :

$$\frac{dX}{dt} = \frac{1}{V}(P - DX)$$

This can now be integrated giving a solution of the form $X = A + Be^{-at}$ where 1/a is the time constant of ventilation (t_c), and t_c , A and B are functions of the ratios P/D and V/D.

The solution of the equation is fitted to those sections of the diurnal curves of X which exhibit exponential growth or decay characteristics and for which P, V, and D are known to be approximately constant The two independent ratios P/D and V/D are then evaluated. By assuming a daily pattern for one of these variables the variations in the other two can be evaluated . In particular a direct comparison can be made between the value of P on week-ends and on week-days since both V and D do not have a weekly cycle. Also, D can be separated into two components : horizontal proportional to wind speed, vertical related to stability By making assumptions about the effective horizontal dimensions of the city, a useful comparison of the order of magnitude of these two components can be made at various seasons of the year Some results will be presented and discussed .

THE BUOYANT MOTION IN SMOKE PLUMES

G. T. Csanady

Assumption University, Windsor

This treatment purports to apply to smoke plumes in a moderately strong wind, at some distance from the source where the axis of the plume is almost horizontal, the temperature excess small and mean velocities in the vertical produced by buoyancy much smaller than wind speed. The plume is under such conditions usually "slender", i. e. , its diameter grows only slowly along wind. Bodily displacements of the plume produced by large eddies in the atmosphere do not affect the buoyant movements while the effects of the smaller eddies may be taken into account by introducing eddy exchange coefficients for heat and momentum, i. e. , eddy conductivity and viscosity, to describe the relative diffusion of heat and vertical momentum away from the plume centre.

With these assumptions, the Navier-Stokes equations and the energy equation may be linearized and become uncoupled, except that the temperature distribution provides a field of buoyancy forces which produce slow, eddy-viscosity dominated motions in vertical cross sections of the plume . By introducing a non-dimensional stream-function $\psi(x, y)$ for the flowin such a cross section and assuming self-preservation of the flow pattern the following differential equation is derived :

$$\nabla^4\psi - \gamma\nabla^2\psi = -y\, e^{\frac{y^2+z^2}{2}}$$

Herein the characteristic constant γ depends on the regime of relative turbulent diffusion. In the "quasiasymptotic " regime (in which Richardson's 4/3 power law of relative diffusion applies) $\gamma = -1/3$. The solution of the equation yields a flow pattern resembling that observed in isolated thermals : there is upward flow in the centre of the plume, downward return flow on either side along a horizontal diameter, so that the pattern is characterized by two vortices of opposite sign lying on either side of the plume. The centre velocity is a constant (which is a function of γ) times the velocity scale C :

$$C = \frac{F}{2\pi \nu_T U}$$

where F is the "flux of buoyancy", ν_T is eddy kinematic viscosity and U is wind speed. In the quasiasymptotic regime this result gives an upward velocity decreasing with the square of the distance from the source. After integration the mean path of the plume is obtained and shows an asymptotic height only in the quasiasymptotic regime. The level reached asymptotically is given by :

$$z_a = K \frac{F}{\pi g^3 U^3}$$

where K is a constant of order unity and g is "gustiness", $\sqrt{\overline{u^2}}/U$. This formula shows remarkably good agreement with observation.

WIND SPECTRA FROM SUFFIELD, ALBERTA

E. R. Walker

Defence Research Board, Ralston, Alberta

Characteristics of lower atmosphere turbulence have been measured by cup anemometers and quick-response wind vanes over prairie terrain at Suffield Experimental Station. These measurements were analysed to yield wind speed spectra, and spectra of the angular deviations of vertical and horizontal vanes.

Sheppard-Casella cup anemometer records, each about two hours long , were available for about 30 periods in connection with atmospheric dispersion experiments. Several years' records from standard M. S. C, cup anemometers were used. Data were mainly in digital form. Cup heights were about 40 feet. Analog records of the angular variations of light vertical and horizontal wind vanes were also available from the dispersion experiments. The vanes were attached to transducing potentiometers whose outputs , proportional to vane angle, were recorded on magnetic tape or on high speed paper charts. Vane heights ranged up to 16 metres.

Digital data were obtained from magnetic tape records by a device sampling the tape each second by counting the pulses in the frequency modulation. Digital data were also obtained by eye assessment of paper chart records. Digital data were used in a spectral analysis based on Tukey's methods. Computations over a wide frequency range were usually done in sections to provide adequate resolution without excessive computation. When it was more convenient , spectra were obtained directly from magnetic tape. The tape was passed through an electronic spectrum analyzer containing 22 band pass filters spaced at intervals of one-third octave. Comparison of the analog and digital methods, using the same data, showed good agreement.

In a wind speed spectrum computed digitally and covering a range from 120 to 0.0001 cycles per hour a peak appeared at 90 cycles per hour. A flat 'spectral gap' spread from 1 to 20 cycles per hour while the main peaks of the spectrum occurred at periods of 1 and 4 days.

Spectra of the vertical vane angles were strongly dependent in shape and magnitude on atmospheric stability. In the frequency range above 1 cycle per hour, the spectra, when plotted in a linear-power logarithmic-frequency form, were flat under very stable conditions. As instability increased the spectra approached the cocked-hat shape, peaked at about 100 cycles per hour.

Spectra of the horizontal vane angles were also strongly dependent on atmospheric stability. In very stable conditions spectra were small in magnitude. As instability increased spectra assumed the shape of a smooth curve rising from high frequencies to apparent peaks at less than 10 cycles per hour.

Wind spectra have been computed using a variety of methods. Both shapes and magnitudes of the spectra were strongly related to atmospheric stability.

OBJECTIVE ANALYSIS OF SYNOPTIC SCALE METEOROLOGICAL PHENOMENA

H. B. Kruger

Meteorological Branch, Dorval

The objective analysis scheme under development on the Bendix G-20 computer at the Central Analysis Office in Montreal is a further evolution of a method developed in 1961 by Eddy, McClellan and Robert on the McGill IBM 650 computer. The scheme is similar to the methods of Bergthörssen and Döös (1955) and Cressman (1959) in that field of grid-point values of a meteorological variable, adopted as a trial analysis, is adjusted to fit observed values. The most significant differences are in the selection of the weighting functions and in the distribution of weighted corrections.

The 500 mb contour height is the first data-time variable to be analyzed because a highly reliable 12-hour numerical 500 mb prognosis is available for use as the trial analysis. The discrepancy between the trial and observed value is calculated at each station. The problem is to weight and distribute these corrections to the grid point trial values in such a way that the variance of the analysis is minimized . The weight of a particular correction on the trial value at a specified grid point is a function of the discrepancy variance at the station, the discrepancy correlation between the station and the grid point, the discrepancy correlations between the station and all other stations contributing significant corrections to the grid point trial value, and of the weights of those corrections at the grid point. The weights which would exactly minimize the variance of the improved value may be obtained by solving the matrix of linear equations existing for the grid point by the method of determinants. This procedure applied at every grid point would require excessive computation time. Weight computations may be simplified and accelerated by assuming that :

1. The discrepancy correlation between station and grid point is a function of distance ;
2. The terms in the diagonal of the matrix, each involving the variance of the trial value errors at a station , are considerably larger than the other terms of the matrix; and
3. The discrepancy correlations between stations may be replaced by grid point-station discrepancy correlations wherever they occur in the matrix.

The weight may then be expressed as a function of another quantity which may be evaluated statistically as a direct function of the distance between a grid point and a station. The resulting distance relationship has the advantage that it may be approximated by a regression equation. It is noted that the matrix is not changed when a station discrepancy correlation is replaced by a grid point to station correlation provided that the station to station distance is the same as the grid point to station distance. An error in the weight will occur whenever this condition is not satisfied, and the size of the error will be a function of the differences in the distances over which the pairs of discrepancy correlations are calculated. The probability that the variance of the analysis is not completely minimized is partially overcome by performing several passes over the field with decreasing data influence area.

In the second pass, observed winds are used to further modify the trial height field on the basis of geostrophically computed gradient errors. Again, the weights obtained by the method of determinants may be approximated by a function of another quantity which is, in this case, not easily evaluated statistically but may be interpreted qualitatively. It is argued that the quantity is a function of distance, rising from zero at the observation point to a maximum, and then tapering off to zero with increasing distance. It is further argued that the quantity is also a function of direction, and that thus the data influence area should be elliptical, with the long axis in the direction of the wind, in order to give the station height value more weight at grid points upwind and downwind from the station. The proposed regression equation having these distance-direction characteristics may be adjusted empirically to give best results.

In the final pass, the data influence area is decreased, and both reported heights and winds are utilized to increase the resolution of the analysis and to achieve a balance between height corrections determined from height and wind observations.

Trial fields for other levels and variables are derived statistically from the 500 mb contour analysis.

Preliminary results indicate that charts analysed objectively under this scheme compare favourably with conventional analyses.

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Bergthörssen, P. and Döös, B. " Numerical Weather Map Analysis", Tellus, Vol. 7, No. 3, 1955, p. 329 - 340.

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A SIMPLE DERIVED HEIGHT FOR 300 MB

D. L. Holyoke

Meteorological Branch, Dorval

In numerical forecasting, barotropic models applied at the "level of non-divergence" (usually taken to be 500 mb), have thus far yielded better results than multi-level baroclinic models which are continually being improved. In the meantime the need for height and wind forecasts at standard pressure levels above 500 mb has stimulated efforts to derive prognostic charts at these levels by statistical means.

Two models of derived fields have been developed and programmed at the Central Analysis Office (CAO) on the Bendix G-20 computer for operational use. The first of these (referred to as Mark 1) requires only a 500 mb forecast height field as input and utilizes characteristics of the 500 mb field to derive 300 mb height and wind fields. The second model (designated Mark 2) requires input in addition to the 500 mb barotropic forecast height field, namely, analyses at the 500, 300, 200 and 100 mb levels valid at time t = 0. It is the purpose of this paper to describe the Mark 1 model.

Need for Mark 1

In the operational program of numerical weather forecasting planned for the CAO a series of "preliminary" 500 mb height forecasts will be computed twice daily. Each series will begin as soon as a preliminary 500 mb objective analysis has been computed. This analysis will be prepared (because of time considerations) before complete hemispheric data have been received and processed. Operationally a 300 mb height forecast field corresponding to each of the 500 mb series is required. Mark 1 is a statistical technique of achieving this using only the 500 mb forecast and analysis as input.

Concept and Origin

The concept for Mark 1 grew from observation of certain characteristics of 500 mb space-mean-vorticity and contemporary 300 mb contour analyses by members of the CAO staff. It was noted that the location of 300 mb jet maxima coincided geographically, to a remarkable degree, with regions on the 500 mb space-mean-vorticity chart where the product of the relative vorticity ascendant, $\nabla \zeta_5$, and the height gradient, $-\nabla Z_5$, was also a maximum. The concept was developed by Eddy (1) into a computational scheme to obtain a "derived 300 mb wind speed field which was programmed to run on the IBM 650 computer located at McGill. It has since been extended to "derive" a height field at 300 mb as well as temperature fields at 300 mb and 500 mb.

Description

Let Z_5, V_3, V_5 and ζ_5 be the height, geostrophic wind speed, geostrophic wind velocity and relative vorticity respectively for the barotropic prog. It is assumed, in general agreement with the aforementioned observations, that a wind speed field, V_3, valid at 300 mb, is given by

$$V_3 = V_5 + K\vec{V}_5 \cdot \nabla \zeta_5 \qquad (1)$$

or

$$V_3 = V_5(1-K[\nabla \zeta_5] \cos \theta) \qquad (1a)$$

In equation (1a), "K" is a coefficient determined by a "least squares" technique, and "θ" is the angle between the directed isopleths of vorticity and the directed contours of the 500 mb forecast.

If the wind direction at 300 mb is assumed to be the same as at 500 mb, a wind vector is therefore computable at each point on the 300 mb surface. Therefore the vertical component of relative vorticity at 300 mb is obtainable at each point. The geostrophic "balance" equation, applied at 300 mb is

$$\nabla^2 Z_3 = g/f \, \nabla^2 \zeta_3 \qquad (2)$$

where g and f are the acceleration of gravity and the Coriolis parameter, respectively. Equation (2) is solved numerically by means of an over-relaxation technique after an initial 300 mb height field has been obtained. This initial field is obtained by means of a simple regression equation relating 300 mb and 500mb heights. The linear equation used has been designed particularly to minimize "first guess" error at the grid boundaries.

Conclusion

Twenty-four hour, 300 mb prognostic height fields obtained by use of Mark 1 have shown a r.m.s. error varying from 250 to 300 feet. This may be compared with typical r.m.s. height errors in 24 hour, 500 mb barotropic progs which range from 180 to 240 feet.

References:

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SPACE AUTOCORRELATION OF SOME METEOROLOGICAL PARAMETERS

Amos Eddy

McGill University, Montreal

The transformation of a network of observations of some observed parameter into a field consisting of an array of evenly spaced values of this parameter presupposes a continuity in space of the variable which allows interpolation between the observed values to the grid point values. This continuity across the two-dimensional space which defines the field can be expressed in terms of an autocorrelation function. This function will define the relative "weights" to be assigned to each observation when it is used, in conjunction with the others, to find the best value of the parameter at any particular grid point.

One system for combining several observations for the purpose of predicting a grid point value of the parameter is given by the following equation :

$$X_p = A_1 X_1 + A_2 X_2 + \dots + A_k X_k + B$$

The constants are evaluated by using many sets of observations of the same variables with respect to the same grid point and making a least squares fit of the linear regression equation to the data.

From many points of view, the making of an objective analysis by this scheme, is time consuming to the point of being impossible . Indeed the set of observations at the grid points are, in general, not available to permit the evaluation of the constants.

If the assumption is made that the intercorrelations between the variables are not fuctions of any specific positions, but rather are functions only of the separation between the observations, then a set of constants which can be used anywhere in the field can be developed. The added assumption is made that the variance and noise level is constant across the field when a long enough data period is considered.

The various correlation coefficients necessary in the computation of any coefficient in the equation can, under the above assumptions, be taken from a graph showing correlation coefficients plotted against separation distance. This graph is clearly a form of the normal autocorrelation curve. Apart from giving the weights for an objective analysis, these curves give an idea of the wavelength of the principal wave in the field. The γ intercept on the curve can be shown to define the noise level in the data. This noise is taken to be a combination of error and scales of motion below those indicated by the autocorrelation curve itself.

The following discussion gives some results for various meteorological parameters for which autocorrelation curves have been determined. Twenty-four hour height change observations for 850, 500 and 300 mb all indicate correlations of about 0.83 at the origin which means that about 17% of the variance in these fields can be considered as noise. The quarter wavelength indicated by the curve was in all cases about 750 miles. (The curve crossed the zero line of correlation at about a 750 mile separation).

500 mb, 24-hour temperature change observations yielded the same quarter wavelength but the noise level was at 23%.

The information contained in such curves is considered necessary for any statistically sound objective analysis, and can be produced fairly readily by means of an electronic computer.

FOURIER ANALYSIS ON A SPHERICAL SURFACE

André J. Robert

Meteorological Branch, Dorval

Meteorologists generally subdivide atmospheric phenomena into different "size" classes such as the planetary scale and the synoptic scale. Scientific papers frequently use the expression "wave length" to describe the size of a weather system. With the computers available today it is now possible to break down a weather map into its basic constituents with respect to wave number or wave length. It then becomes possible for the research meteorologist to restrict his investigation to a particular part of the wave spectrum. This classification is feasible and in most cases desirable because it facilitates research and frequently provides us with a better understanding of the atmosphere.

The method commonly used to break down a weather map into its basic components makes use of information along latitude circles. A Fourier analysis is performed at each latitude producing an amplitude and a phase angle for each component. For any particular wave number , both the amplitude and the phase angle depend on latitude. These values are used to reconstruct the chart representing this particular component. One chart is drawn up for each Fourier component analyzed.

The main deficiency of this method is that only a longitudinal breakdown is performed, whereas in many cases a latitudinal classification is also desired. In other words, the method described above is basically one-dimensional, whereas in most cases a two-dimensional analysis is desired. The only problem that needs to be examined is the choice of basic components. In general, Fourier series are used, but any other set of orthogonal functions may be adopted. For some problems , Bessel functions or Legendre polynomials are more appropriate. Meteorologists have to deal with a spherical surface and because of this peculiarity they use spherical polar coordinates to represent variables. Because of the particular form taken by the equations of motion in such a coordinate system, the method of separation of variables suggests a special set of basic functions.

With respect to longitude, Fourier series are used as before and with respect to latitude, polynomials of trigonometric functions are used. These polynomials are determined by the method of separation of variables and are such that they will not result in any discontinuities at the poles. The two-dimensional breakdown suggested above also has the advantages that it is closely connected to the barotropic vorticity equation. Retrogression speeds are determined and compared with the retrogressive motion observed during the integration of the barotropic model. Momentum transport and other possible applications of harmonic analysis are discussed. In conclusion, a few remarks are made concerning the advantages and disadvantages of the method.

STABILITY PROPERTIES OF THE GODSON FOUR-LEVEL MODEL

David Davies

Meteorological Branch, Dorval

A four-level baroclinic statistical-dynamical model (suggested by Godson) is being developed for operational use in the numerical weather prediction program at the Central Analysis Office :

$$\frac{D_k}{Dt}\left[f+\nabla^2\psi_k+\sum_{i=1}^{4}C_{ki}\psi_i\right]=0 \qquad k=1,2,3,4;$$

where $\frac{D_k}{Dt}\equiv\frac{\partial}{\partial t}+u_k\frac{\partial}{\partial x}+v_k\frac{\partial}{\partial y}$) the ψ_k are the stream functions

at the four levels $\left(u_k\equiv-\frac{\partial\psi_k}{\partial y}, v_k\equiv\frac{\partial\psi_k}{\partial x}\right)$, f is the Coriolis parameter,

and the C_{ki} are the sixteen statistical-dynamical parameters (the non-diagonal elements representing the degree of feedback between the various levels). Some of the main properties of the model, such as long wave retrogression and the stability of waves corresponding to particular wave numbers can be determined by a mathematical analysis of the behaviour of harmonic perturbations on a given zonal current profile: without actually running any test cases. If $\psi_k=\bar{\psi}_k+\psi'_k$, where the $\bar{\psi}_k$ correspond to a given zonal current profile, U_k, and $\psi'_k=A_k\sin\lambda(x-ct)$ where λ is simply proportional to the wave number, c is the speed of propagation of the perturbation, and the A_k its amplitudes at the four levels. Robert and Laflamme have shown that the c's must satisfy the following quartic equation in determinant form (where $\beta=\frac{\partial f}{\partial y}$, δ_{ij} is the

Kronecker delta, and the sixteen elements of the determinant are obtained by allowing the indexes i and j to range from 1 to 4) :

$$\left| (U_i - c) C_{ij} + \left[\beta - (U - c)\lambda^2 - \sum_{n=1}^{4} C_{in} U_n \right] \delta_{ij} \right| = 0$$

Real solutions for c correspond to stable waves : complex solutions for c correspond to unstable waves.

This determinant has been programmed for solution on the Bendix G-20 computer. For the initially-chosen set of parameters, dynamically-derived and empirically-adjusted, with a climatological average zonal current, at 45°N, this analysis shows a moderate retrogression of one long-wave component and a band of unstable short waves. The effect of variation of the zonal current, the latitude, and the sixteen parameters, is discussed.

INSTABILITY IN THE MIDDLE STRATOSPHERE

B. E. O'Reilly

McGill University, Montreal

During the past five years a considerable amount of synoptic data has been accumulated on the region of the middle stratosphere between 60 - 100,000 feet. Studies of the energetics of the circulation at this level suggest that it is inertly driven in summer, but in winter is a resonance region for major tropospheric disturbances, propagating upward. Questions concerned with the existence of independent baroclinic activity, or with the mechanism of propagation, require a sound knowledge of vertical motion. Because of data inaccuracies, standard tropospheric methods of vertical motion calculation are inadequate, and recourse has been made to linearized perturbation models. One such model by R. Fleagle (1957) is critically reviewed , and found to require modification to meet the conditions of high static stability and planetary-scale disturbances characteristic of the middle stratosphere. Some pitfalls in the application of such models are discussed along with some general analytic principles.

THE 26-MONTH WIND OSCILLATION IN THE EQUATORIAL STRATOSPHERE

Warren L. Godson

Meteorological Branch, Toronto

The recently-discovered oscillation of the equatorial stratospheric zonal wind (from easterly to westerly, and vice versa, with a period of about 26 months) poses many interesting problems, in both physical and dynamical meteorology. A theoretical approach to this problem will be outlined, based on the hypothesis of a thermal forcing function, which may be internal or external in nature. Analytic solutions of the complex mathematical equations governing the behaviour of the entire atmosphere (from ground level to stratopause) will be presented and these solutions will be compared to observational data, both for the 26-month oscillation and for annual variations, to which the theory also applies. In addition, a survey will be made of possible radiative mechanisms (both solar and internal) for the thermal forcing function, and various implications re solar influences noted, together with pertinent data on a generalized harmonic analysis of a number of atmospheric and solar parameters. In this latter connection, a new and more efficient scheme for harmonic analysis will be presented.

FACSIMILE OUTPUT FOR WEATHER RADAR

Marceli Wein and K. L. S. Gunn

McGill University, Montreal

For the past three years, the McGill Weather Radar has provided constant altitude maps with intensity indicated on a stepped grey scale. Records for research study are accumulated on 35-mm film, while pictures for operational use have been Polaroid Land camera prints. The recent installation of a rapid processor has eliminated the manually operated Land camera so that now a 35-mm transparency is available automatically within a few seconds after it is exposed. This transparency is scanned to provide a facsimile picture for immediate use.

Facsimile is a most economical form of bright display. Its only link with the radar site is a narrow band-width telephone line, so that pictures can be provided at a low cost at several outlets in the neighbourhood of the radar. At each of these outlets the user has a semi-permanent record for study of the weather of the past few hours. A most notable advantage is the areal integration that results from scanning. The fluctuations recorded on the film are smoothed, the boundaries between successive shades of the stepped grey scale are enhanced, and so is the apparent contrast.

In the rapid processor the film is advanced immediately after processing to a projection gate. We have used the optical system of this projector in reverse to provide an image on the film of a flying spot as it generates a rectangular raster on a CRT. The diameter of the imaged spot is about one mile on the scale of the CAPPI map. The transmitted light is collected by a photomultiplier tube behind the film mounted in place of the bulb of the original projector. The low frequency signal at the output of the photomultiplier is direct-coupled to a modulator, which step modulates a 2500-c/s carrier. There are seven steps in the original CAPPI photograph, and the seven threshold voltages in the modulator are adjusted to match those steps. The modulated carrier is transmitted over a balanced audio line to the facsimile recorder.

The recorder is a conventional wire-photo facsimile set (Muirhead D611F) using electrolytic paper as the recording medium. The maximum black to white range in reflection density of the paper is about 10 db. The width of the paper is 11 " and it advances 4.5" in the 212-sec that it takes to complete each CAPPI cycle. In order to use the full width of the record during that time two pictures are reproduced side by side. In one picture echo intensities 1, 2, 3 and 4 are reproduced and in the other, intensities 4, 5, 6 and 7. This makes it possible to have about 2.5 db between steps making for easy visual descrimination between intensity levels. The two pictures are derived from the same photograph by scanning twice for each line on the facsimile recorder, with alternate scans routed appropriately in the modulator.

The facsimile signal has a secondary use. Because the scanning raster is rectangular, duration of signal is proportional to area. By feeding the modulated carrier to counting circuits, the total count for each of the seven levels will give a measure of the area covered by precipitation in each of the seven intensity intervals. Thus the data for profiles, plots of areal coverage against height, are available at the same time as the facsimile picture.

PRECIPITATION PROFILES FOR OPERATIONS AND RESEARCH

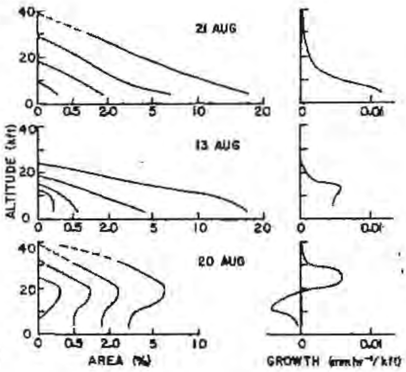
P.M. Hamilton

McGill University, Montreal

Weather radar is capable of providing insight into the nature of the physical processes occurring within precipitation systems. This insight is valuable for research into precipitation physics; if the relevant information can be rapidly digested and suitably displayed it may also be useful to the synoptic meteorologist. A suitable display of the information is in the form of vertical profiles showing areal coverage, flux and rate of growth of precipitation as functions of height.

To assess the value of these profiles in operational meteorology we have set up equipment which readily provides the necessary data. The equipment is operated in conjunction with the McGill CPS-9 radar which automatically produces constant altitude maps of precipitation intensity. The basic data are accumulated on film from an A-scope display of signal intensity against range. By photographing through a cylindrical lens, signals of the same intensity from all ranges are superimposed. One frame of film records the signals at one constant altitude from all bearings. Thus density on the film is a measure of echo area.

A few examples of profiles obtained during August and September 1962 are shown in the illustration.



The area profiles illustrated show the fraction of the area between 20 and 80 nmi covered with echo exceeding intensities equivalent to the rainfall rates 0.1, 0.4, 1.6, 6.4 mm hr^{-1}. The rate of growth profiles are expressed as an increase in rainfall rate averaged over the whole area (mm hr^{-1}) per 1000 ft of descent, and ignore the possibility of solid precipitation and vertical motion. The flux profiles are not illustrated, but can be obtained by integrating the growth profiles from the top of the storm . Both area and flux almost always showed a steady increase with descent, with the single exception of 20 August. But the growth profiles showed striking differences, falling into two main classes: those showing a steady increase in growth rate with descent (21 August), and those showing a maximum in growth rate aloft (13 August). The former were generally associated with widespread light to moderate rain, although 21 August was a case of thunderstorms in a weak low. The latter were associated with the squall lines propagated ahead of cold fronts. The profile of 20 August (the most severe storm of the period) is apparently an extreme example of this type of profile in which there is even evaporation below the maximum aloft. A severe squall line extended over 250 mi from West to East with thunderstorms and hail. At one place 2.5 inches of rain fell in less than three hours.

It seems that profiles are likely to be useful in operational meteorology, and apparatus is being developed at McGill to provide current profile information on our facsimile output (see M. Wein and K. L. S. Gunn : Facsimile Output for Weather Radar).

MEASUREMENTS OF SCATTERING FROM RAIN USING A DOPPLER SYSTEM

L.H. Doherty

National Research Council, Ottawa

Observations were made during the summer and autumn of 1962 of the forward scattering from rain of radio waves of wavelength 3.2 cm. The transmitter and receiver were separated by 840 meters. The antennas were directed along the vertical plane through the transmitter and receiver sites but were elevated 30° above the horizontal. A scatter volume common to the two antenna beams was thus defined midway between transmitter and receiver and 250 meters above ground. Rain falling through the scatter volume resulted in a received signal whose frequency was Doppler - shifted by an amount proportional to the vertical velocity of the rain drops. Mixing this signal with a reference frequency yielded an audio frequency signal whose power was proportional to the scattered power, and whose frequency spectrum was related to the spectrum of vertical velocities of the raindrops. Two tipping-bucket rain gauges were situated on the ground: one immediately under the scatter volume, and one 150 meters to the side. The scattered power, average Doppler frequency, the record of the two rain gauges, and a time signal were all recorded on a multichannel recorder.

A major portion of the analysis of the data has been concerned with determining the values of the parameters A and α in the relationship $\sigma = AR^{\alpha}$, where σ is the scattering coefficient and R the rainfall rate. Considerably greater detail is present in the radio record than in the rain gauge record and use could be made of this detail by raising the above equation to the power $1/\alpha$ and integrating in time between tips of the rain gauge. The right-hand side of the equation is then a constant and no assumption of constant rainfall rate between tips of the rain gauge need be made. By a least-squares method A and α were determined for various sets of data. If all the data involving 209 mm of rain are used, a value of $\alpha = 1.59$ is obtained. This is in good agreeement with commonly accepted values. A is however a factor of 4 less than the commonly quoted value. The method used here is basically very accurate and it is unlikely that such a large discrepancy can be due to experimental error.

Large variations in A and α are, however, obtained with different sets of data. In particular, systematic changes in A and α are observed as the range of rainfall rates included in the set is increased. A and α are consequently not independent of R and a more complicated relationship between σ and R should be sought.

A comparison of average Doppler frequency with scattered power has been made. Using a relationship between drop size and terminal velocity based on experimental data, and assuming an exponential drop-size distribution, a theoretical Doppler-frequency-scattered- power relationship can be deduced. This is found to be in good agreement with the experimental observations. Some discrepancies can be assigned to vertical motions of the air in thunderstorms. Correlation of Doppler frequency with rainfall rate leads to the same result, but with less confidence since in some cases the raindrops falling through the scatter volume and the raindrops into the rain gauge are not identical.

OBSERVATIONS UPON CLEAR-AIR STRATIFICATION IN THE LOWER TROPOSPHERE

D. R. Hay, M. B. Bell and R. W. Johnston

University of Western Ontario, London

A study of radar reflections from the clear air within the layer of frictional influence has been underway for four years at the University of Western Ontario. The earlier observations have shown that the incidence of anomalous reflecting centers changes with the type of air mass overhead, that no reflecting centers are present when the surface air temperature is below 20°F , and that the lifetime of these centers depends upon the wetness of the ground and the surface air temperature. The interpretation of these observations has suggested that the radar reflection occurs at a horizontal stratum of air whose depth is only a few centimeters and whose temperature or humidity differs slightly from that of its environment. Such stratification may result from the adiabatic transfer of air within a turbulent eddy, together with erosion of the air parcel by wind shear.

More recent studies have demonstrated the association of reflecting strata with well-known weather features. Within a clear air mass, the short-lived reflections have maximum incidence at 300 meters above ground; the change in signal power reflected from these strata at various heights above ground suggests that the reflecting region is essentially flat over a horizontal distance of several meters. The incidence of short-lived reflections fluctuates quasi-periodically in time, with a period of about ten minutes; this observation suggests that potential reflecting centers undergo compression and expansion in conjunction with internal gravity waves. The incidence of the radar reflection decreases monotonically with increasing duration; the longest-lived reflections have persisted for about 20 minutes. The vertical distribution of both short - and long-lived reflecting strata is modified by the intrusion of a weather front, by convective thermals below cumulus cloud and apparently by local stratification of temperature and humidity. Unlike the short-lived reflections, the longer-duration reflections occur most frequently at the lowest level of observation, and their incidence decreases very gradually with increasing height. These observations are consistent with the theory that the local stratification of temperature or humidity is dispersed by molecular diffusion in the case of long-lived reflections, and by turbulent diffusion in short-lived reflections.

Auxiliary measurements have been made on the fluctuations of temperature and refractivity of the air within 100 feet of the ground, by special airborne instruments. The existence of the shallow microstructure as predicted by the radar observations, has been verified at these lower levels.

THE M. S. C. TETHERSONDE

R. S. Bourke and J. Klein

Meteorological Branch, Toronto

A need for convenient temperature sounding within the lower 2000 feet of the atmosphere has existed for some time, particularly in micrometeorological and microclimatological field research projects. Various systems have been used, employing temperature - pressure measuring devices carried aloft by pilot or radiosonde balloons, tethered balloons, or small rockets. In many cases, these systems were complex and expensive, had inconvenient data decoding, or other disadvantages which limited their use.

The M. S. C. Tethersonde was developed to provide accurate temperature -height profiles and humidity measurements with relative simplicity and minimum expense. The system employs a self-contained chronometric sonde carried aloft by a helium-filled blimp, and tethered by a nylon cord and motor-operated winch. A continuous sequence of temperature, pressure and relative humidity signals is transmitted by radio to an inexpensive F. M. tuner, and recorded graphically by a standard M. S. C. radiosonde recorder. Unlike baroswitch systems, the continuous signal sequence allows recorded soundings to be made on ascent and descent, at various rates, or at any one level. All equipment used is easily dismantled and readily protable.

The tethersonde instrument is a direct modification of the M. S. C. chronometric radiosonde, operating on an Olland time cycle. Each parameter is measured by time-lapse from fixed reference signals. A disc, equipped with a chronometric spiral groove, rotates at a constant angular velocity; a period of 13.5 seconds is maintained by a small reed-governed D. C. motor and gear train. Pen arms, controlled by the sensors, produce signal pulses on contact with the spiral groove, and thus each parameter is measured once every period.

Temperature is sensed by a brass-invar bi-metallic coiled strip, mounted on a thermally insulated post. Any range of 30C degrees can be obtained by a rotational setting of the bi-metal mounting shaft prior to flight; this method maintains a high sensitivity, while permitting flights to be made over a wide range of surface temperature conditions. For each range setting, the calibration curve is selected from a family of curves by a base line temperature check with a mercury thermometer. Thus, temperature accuracy of $\pm$ 0.3 °C can be attained.

The pressure sensor consits of two 3-element copper aneroids, temperature compensated, statically balanced, and pivoted in cascade. The aneroid system yields a fixed range from 1030 mb to 900 mb, and an accuracy of $\pm$ 1 mb. In sounding computations, pressure differences are employed to determine height, and so accuracy of $\pm$ 0.5 mb or better is possible.

Relative humidity is measured by the contraction and expansion of a strip of gold beater skin, producing a measurement range of 0 to 100 % R.H. and an accuracy of ± 5%. Since the inclusion of the sensor was relatively recent, development is currently being undertaken to improve accuracy.

The main frame and aneroid system are housed in a louvered aluminum enclosure; temperature and humidity sensors are shaded from solar radiation by a cylindrical duct, which also provides ventilation for the sensors. A motor-driven fan moves air through the duct at a rate of 500 fpm, reducing the temperature sensor lag coefficient to only 14 seconds.

To reduce the weight of the power pack, a transistorized transmitter was developed for the airborne vehicle. The transmitter produces 25 mW power and operates over a range of 90 to 100 mcps, this frequency range allows the use of a standard broadcast F.M. tuner for receiving signals. The current requirements of the instrument and transmitter are low enough to allow the use of miniature batteries in the power pack, and to permit operating times of 2 to 8 hours on one set of batteries. The total vehicle weight is approximately 2.2 pounds.

The M.S.C. Tethersonde has been used quite successfully at several microclimatological research projects during the past two years, and shows promising results as a research tool. The instrument has demonstrated good accuracy and versatility during flights both from land and from lake research vessels. Future development is planned to increase the versatility of the instrument by the addition of wind sensors, and eventually to convert to audio modulation.

AN EVALUATION OF SOME NEPHANALYSES PREPARED FROM TIROS CLOUD PHOTOGRAPHS

J.A.W. McCulloch and C. Payne

Meteorological Branch, Toronto

The Tiros system of cloud photography, data acquisition and processing, and presentation of the information obtained have slowly evolved with each succeeding flight. However, the unsolved problems are still legion. Many of them can be eliminated if an adequate manual analysis is performed. (Fujita has developed a completely general method for manually rectifying satellite cloud photographs).

In order to provide the cloud data within an operationally-significant time interval, a manual analysis is not possible. Latitude-longitude grids derived from tracking data by small computers are used. This introduces a positional uncertainty of at least plus or minus two degrees of latitude.

A second major problem arises from the difficulty in interpretation of the photographic images. For example, moderately-dense cirrus produces the same image as scattered-to-broken fair weather cumulus or strato-cumulus. Other similar uncertainties exist.

This study was undertaken by C. Payne as a summer employee of the Meteorological Branch under the direction of the senior author. Several operationally-prepared nephanalyses of cloud photographs taken during August and September, 1961, were considered. Several comparisons were made. The cloud observations on a contemporary synoptic chart were compared with the interpretations on the satellite neph. The surface and upper-air analyses were superimposed on the satellite neph to test for correspondence. Other conventional analyses and derivations were considered.

The major deficiencies of the material being tested are noted below:

1. The vortex determined from the cloud photographs was never coincident with the surface cyclone except with an occluded low.
2. Thin cirriform clouds could not be detected .

3. Cloud amounts were frequently estimated incorrectly in both directions.

4. The difference between stratiform and cumuliform clouds was often mistaken.

On the other hand, the following benefits may be derived :

1. While the positional errors are serious enough to prevent absolute location of individual elements, the overall size of the cloud system is preserved. (This statement weakens somewhat in areas remote from the sub-satellite point where perspective foreshortening becomes serious.)

2. The existence of moderately-or well-developed convective clouds that escape our synoptic network can be observed.

3. A continuing study of such nephs could suggest orographic cloud structures between synoptic stations.

It must be emphasized that this study covered only well-observed areas . It is easy for one who is steeped in conventional methods to be critical of new ones, especially when they do not provide him with the detail and accuracy of the older ones. At present , the information being provided from sparsely-observed areas is of immeasurable value.

The earth-oriented , polar-orbiting NIMBUS system that is soon to be flown should eliminate some of the problems noted above. In addition, it will provide Canadians with surveillance of the sparsely-observed Arctic regions, from which any information will be most welcome .

In summary, the satellite nephanalyses that are currently being provided have only limited operational value in areas that have a good coverage of conventional data However, in the future, with the advent of improved techniques and flying hardware, they should become more useful. In addition, satellites will soon be observing the great expanses of our northland and contiguous waters, from which any information will be most welcome.

EFFECT OF SNOW CRYSTAL FORMS ON SNOWFALL DENSITY

B.A. Power and P.W. Summers

Weather Engineering Corporation of Canada Ltd, Montreal

McGill University, Montreal

Although considerable information on the variations in the density of newly-fallen snow is available, the basic causes for such variations are almost unknown. In order to test the possibility that density variations are related to the shape and size of the predominant crystal which makes up a snowfall, studies were carried out at Montreal during the winter of 1960 - 61 and 1961 -62. Snow crystals were caught in a portable cold box periodically during snowfalls and the crystal types recorded; these types were then correlated with the snowfall densities determined from a recording snow gauge and depth measurements.

It was found that snowfall density did vary systematically with crystal form. Densities increased in the general sequence, dendrites, needles, columns and plates, irregular assemblages, rimed crystals.

A marked influence of riming in increasing the snowfall density was found with density increases ranging from about 0.02 up to 0.06 grams/cm^3 over mean values for unrimed pure crystal types. The data also indicate a greater collection of cloud droplets by plates and dendrites than by needles and this would appear to be a consequence of the geometry of the crystals. A consideration of the form of snow crystals in precipitation studies involving accretion would appear to be indicated as desirable.

The predominance of irregular crystals in major Montreal snowfalls was confirmed. Studies of such cases indicated that they could be explained as a consequence of the multi-layered structures of typical winter low pressure systems --- the generating level for crystals being in the upper levels of the storm with subsequent growth occurring in one or more lower layers.

Evidence was found that in some cases the snow growth levels were associated with high relative humidity found at the base of a frontal inversion aloft. The general case of high relative humidity being produced under an inversion by the process of vertical mixing is well known. Evidence is presented to show that this process may be important in producing winter precipitation in Quebec.

In order to eliminate as much uncertainty as possible in the determination of the crystal types falling during each storm a continuous automatic snow crystal recorder was devised . It utilizes the formvar replica method due to Schaefer; a strip of plastic film is continuously drawn through a formvar solution bath, then exposed to the falling snow under a sampling port, and then allowed to dry at below freezing temperatures preserving the crystal imprints and giving a complete record of crystal types and sizes for later study and measurement.

ATMOSPHERIC WATER VAPOUR AND PRECIPITATION ON THE PRAIRIES

J.P. Bruce

Meteorological Branch, Toronto

The amount of atmospheric water vapour over a station can be expressed as the precipitable water, or liquid equivalent, and computed by the well known Solot equation. To permit ready computation of precipitable water by means of an IBM 602 or 609, a 5 -term approximation to the Solot equation was prepared. The variables in the equation were changed to relative humidity and saturation vapour pressure, at successive standard pressure levels, to make use of the data in monthly summary cards of radiosonde data. Mean monthly precipitable water was then calculated for a ten year period of record for 2 radiosonde stations in Canada, Edmonton and The Pas, and 3 in the U.S.A., Great Falls, Glasgow and Bismark. Computations were performed by the Machine Processing Section, Climatology Division of the Canadian Meteorological Service, and by the U.S. Weather Bureau.

Monthly mean precipitable water was then studied as a climatological variable. Seasonal variations at all 5 radiosonde stations show summer values about 4 times those in mid-winter, with maximum amounts occurring in July. Latitudinal changes in precipitable water amounts are not significant with The Pas (54°N) and Bismarck (47°N) having remarkably similar values.

However, a marked decrease in amounts of atmospheric water vapour from east to west is evident. July values at Edmonton and Glasgow are about 85% of those at The Pas and Bismark, and the average July amount at Great Falls is only 60% of that at The Pas and Bismark. This westward decrease is due to two factors, decreasing frequency of inflow of maritime Tropical air from the Gulf of Mexico, and greater elevation of the stations.

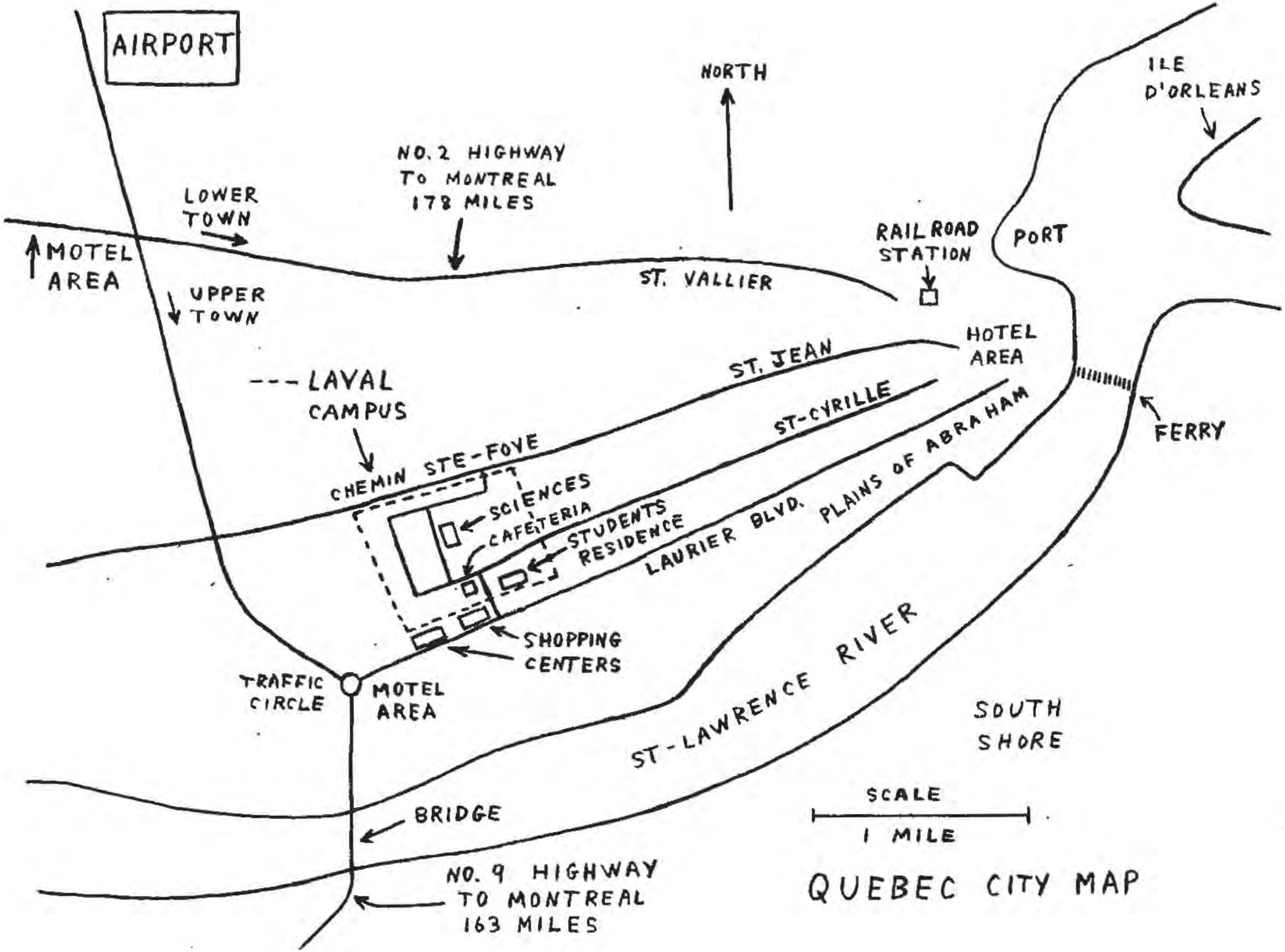
The monthly precipitation for the very dry region of the Prairies between 50° and 52°N and 104° and 111 °W, including Medicine Hat, Swift Current, Saskatoon, Regina, etc. was studied in relation to the monthly precipitable water values. Correlation coefficients between these two variables for 10 years of record are given below :

Correlation Coefficients (r) between precipitation and precipitable water (1951 -60)

Month	(r)	Month	(r)
January	-0.35	July	0.85
April	0.23	October	0.03

These results indicate that only during summer is there a statistically significant correlation (at the 0.05 level) between precipitation and atmospheric water vapour in this region of low annual precipitation (11 to 20 inches). At other times of the year, other factors affecting precipitation production appear to be dominant and to obscure the relationship between atmospheric water vapour and precipitation.

These results suggest that the efficiency of storm mechanisms in winter, spring and fall are largely independent of the water vapour content of the atmosphere, but that summer storm mechanisms are themselves sensitive to the amount of water vapour present.


AIRPORT
NORTH
ILE D'ORLEANS
NO. 2 HIGHWAY TO MONTREAL 178 MILES
LOWER TOWN
MOTEL AREA
UPPER TOWN
ST. VALLIER
RAILROAD STATION
PORT
HOTEL AREA
ST. JEAN
--- LAVAL CAMPUS
ST-CYRILLE
FERRY
CHEMIN STE-FOYE
SCIENCES
CAFETERIA
STUDENTS RESIDENCE
LAURIER BLVD.
PLAINS OF ABRAHAM
SHOPPING CENTERS
TRAFFIC CIRCLE
MOTEL AREA
ST-LAWRENCE RIVER
SOUTH SHORE
SCALE
1 MILE
BRIDGE
NO. 9 HIGHWAY TO MONTREAL 163 MILES
QUEBEC CITY MAP