PROGRAM

Toronto Meteorological Conference

Joint Meeting

Royal Meteorological Society
American Meteorological Society

Toronto, Ontario, Canada

9-15 September 1953

Toronto Meteorological Conference

A Joint Meeting of the Royal Meteorological Society and the American Meteorological Society

(124th National Meeting of the American Meteorological Society)

Toronto, Ontario, Canada, 9 to 15 September 1953

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GENERAL INFORMATION

All sessions of the Toronto Meteorological Conference 1953 will be held in the Auditorium of the Economics Building, University of Toronto, 273 Bloor Street West. (See cover.)

A registration fee will be charged.

It is expected that accommodations will be very scarce during the period of the Conference in view of the fact that the Canadian National Exhibition will still be in progress. Advance reservations have been made with the King Edward Hotel and the University of Toronto. Guests may make hotel reservations directly with the Hotel. Limited accommodation in University residences is available. Guests can make reservations by writing to Mr. R. W. Rae, 315 Bloor Street West, Toronto 5, Canada. On arrival in Toronto, guests may obtain information regarding accommodation by telephoning Mr. R. W. (Bill) Rae at KI 2164 or CE 1-3888 (after 6 p.m.).

A reception under the auspices of the Royal Meteorological Society. Canadian Branch, for all delegates and wives will take place the first evening. Tea and coffee will be served during both morning and afternoon sessions through the courtesy of the American Meteorological Society.

In order to add interest to the Conference, it has been scheduled to overlap partially the dates of the Canadian National Exhibition, August 28 to September 12 in Toronto. The Exhibition is open each evening until 2200. No technical sessions have been planned for Saturday as it is expected that most delegates will wish to have one day free to visit the world's largest annual exhibition.

Arrangements have been made for a conducted tour to Niagara Falls on Sunday, September 13th. Bus tickets priced at approximately $3 each will be available at the registration desk.

The Conference banquet consisting of an excellent dinner and program will be held Monday evening, September 14th at the King Edward Hotel. Dinner tickets priced at $4 each may be obtained at the registration desk. However, it is recommended that reservations for the banquet be made in advance by writing to Mr. K. T. McLeod, Meteorological Office, 315 Bloor St. West, Toronto 5, Canada. A cocktail hour will precede the dinner and is sponsored by Friez Instrument Division of Bendix Aviation Corp., Times Facsimile Corp., and Dewey and Almy Chemical Co.

Day time tours and other activities are being arranged for wives.

PROGRAM

Wednesday Morning, September 9, 0930–1230

Registration.

Wednesday Afternoon, September 9, 1430–1700

DISCUSSION ON OZONE AND THE HIGH ATMOSPHERE

Ozone and the High Atmosphere, opening address by Sir Charles Normand, President, Royal Meteorological Society.

Discussors:

Atmospheric Winds and Temperatures to 60-km Altitude as Determined by Acoustical Propagation Studies, A. P. Crary, William B. Kennedy and Vivian C. Bushnell, Geophysics Research Directorate, Air Force Cambridge Research Center, Cambridge, Mass.

Atmospheric Temperatures at 30 Kilometers and Above, A. Arnold, Signal Corps Engineering Laboratories, Fort Monmouth, N. J.

Rocket Observations of Atmospheric Ozone, Francis S. Johnson, U. S. Naval Research Laboratory, Washington 25, D. C.

An Investigation of the 9.6 Ozone Band in the Telluric Spectrum, Dr. R. M. Goody, Cavendish Laboratory, Cambridge, England.

Wednesday Evening, September 9, 2000

Social "mixer." A reception under the auspices of the Royal Meteorological Society, Canadian Branch, for all delegates and wives, at the AMPS Club, 62 Wellesley W

Meteorological Hydrodynamics in Motion Pictures, Prof. Dave Fultz, University of Chicago.

Thursday Morning, September 10, 0930–1230

SYMPOSIUM ON RADIATION AND OTHER ENERGY TRANSFORMATIONS

Chairman: Dr. G. W. Robinson
Meteorological Office
Air Ministry
London

On the Methods of Computation of the Radiative Flux of Energy in the Atmosphere

Spectral Models and the Development of a Radiation Chart, Dr. Warren L. Godson, Meteorological Service of Canada, Toronto, Ont.

A Quasi-Statistical Approach to the Calculation of Atmospheric Transmission, Dr. Lewis D. Kaplan, U. S. Weather Bureau, Washington, D. C.

On Laboratory Investigations of Infra-Red Spectra Related to the Computation of Radiation in the Atmosphere

A Laboratory Investigation of the 9.6 μ Band of Ozone, Dr. R. M. Goody, Cavendish Laboratory, Cambridge, England.

The Calculation of Atmospheric Transmission from Laboratory Measurements of Carbon Dioxide and Ozone. Dr. Gilbert N. Plass, Department of Physics, The Johns Hopkins University, Baltimore, Md.

On the Application of Radiation Calculations to Atmospheric Circulation Studies

Distribution of Average Radiational Cooling for the Winter and Summer Seasons, Dr. Julius London, Department of Meteorology, New York University, New York, N. Y.

Thursday Afternoon, September 10, 1400–1615

SYMPOSIUM ON ARCTIC METEOROLOGY

Chairman: Andrew Thomson, Controller
Meteorological Service of Canada
Toronto, Ont.

Introduction by the Chairman.

Discussion Leader: Professor Gordon Manley, Bedford College, University of London, London.

Historical Survey of Arctic Meteorology, Dr. H. U. Sverdrup, Director, Norsk Polarinstitutt, Oslo, Norway.

Forecasting Problems in the Arctic with Special Reference to Northern Greenland, Matthew J. Toyli, W.O., USAF, Air Weather Service.

A Physical Study of Some Features of Antarctic Climate, Dr. G. Liljequist, Norsk-Brittisk-Svensa Antarktisexpeditionen, 1949–1952.

The Problems of Establishing and Maintaining Weather Stations in the Arctic, R. W. Rae, Meteorological Service of Canada, Toronto, Ont.

Cyclonic Trajectories Inside the Arctic Circle, H. P. Wilson, Meteorological Service of Canada, Edmonton, Alta.

Thursday Afternoon, September 10, 1630

Reception by the Lieutenant-Governor of the Province of Ontario, The Honourable Louis O. Breithaupt and Mrs. Breithaupt for all delegates and wives, the Lieutenant-Governor's Suite, Provincial Government Buildings, Queens Park.

Friday Morning, September 11, 0930–1230

SYMPOSIUM ON THE GENERAL CIRCULATION

Chairman: Professor P. A. Sheppard
Department of Meteorology
Imperial College of Science and Technology
London

Introductory Survey by the Chairman.

Some Aspects of the Mean Upper Air Flow Over the Earth, J. K. Bannon, Meteorological Office, Air Ministry, London.

The Flux of Angular Momentum and Heat in the General Circulation, Professor J. Bjerknes, Department of Meteorology, University of California, Los Angeles, Calif.

Theoretical Discussion of the General Circulation, Dr. E. T. Eady, Imperial College of Science and Technology, London.

Friday Afternoon, September 11, 1430–1700

SYMPOSIUM ON MODERN CYCLONE THEORY

Chairman: Professor Sverre Petterssen
Department of Meteorology
The University of Chicago
Chicago, Ill.

The Problem of Cyclogenesis from Helmholtz' Time to the Present, Professor J. Bjerknes, Department of Meteorology, University of California, Los Angeles, Calif.

Cyclones and Anticyclones—A Comparative Study, Dr. R. C. Sutcliffe, Meteorological Office, Dunstable, Beds., England.

Notes on East-Coastal Cyclogenesis, Prof. Jerome Spar, Department of Meteorology and Oceanography, New York University, New York, N. Y.

Formation of Tropical Cyclones, Professor Herbert Riehl, Department of Meteorology, The University of Chicago, Chicago, Ill.

On the Prediction of Cyclogenesis, Dr. Jule Charney, The Institute for Advanced Study, Princeton, N. J.

Some Aspects of Mobile Depressions in a Baroclinic Current Started by Means of the Two-Parameter Representations of the Atmosphere, J. S. Sawyer, Meteorological Office, Dunstable, Beds., England.

Remarks on the Cyclone Problem, Dr. E. T. Eady, Imperial College of Science and Technology, London.

Quasi-Periodic Cyclogenesis as Related to the General Circulation, Jerome Namias, U. S. Weather Bureau, Washington, D. C.

Sunday, September 13

Conducted tours to Niagara Falls for which reservations should be made at the registration desk.

Monday Morning, September 14, 0930–1230

Symposium on High-Level Forecasting

Chairman: Major General W. O. Senter, USAF
Commander, Air Weather Service, Washington, D. C.

Opening Remarks by the Chairman.

Forecasting Winds up to the 100-mb Level by the Contour Chart Technique, J. S. Sawyer and Dr. R. C. Sutcliffe, Meteorological Office, Air Ministry, Dunstable, Beds., England.

Forecasting High Clouds from High Level Constant Pressure Charts, J. E. French, Major, USAF, and K. R. Johannessen, Meteorological Consultant, Air Weather Service, Washington, D. C.

Jet Streams in Middle and High Latitudes, Dr. D. P. McIntyre and R. Lee, Canadian Meteorological Service, Toronto, Ont.

The "Critical" Eddies in the Upper Atmosphere, Robert C. Bundgaard, Lt. Col., USAF, Air Weather Service, MacDill AFB, Fla.

Jet Stream Detail with Respect to Other Meteorological Factors, Sidney Teweles, Jr., U. S. Weather Bureau, Washington, D. C.

Clear Air Turbulence at High Levels, LeRoy H. Clem, U. S. Weather Bureau, Washington, D. C.

Monday Afternoon, September 14, 1430–1700

Panel Discussion on Climatic Change

Panel Moderator: Professor Gordon Manley, Bedford College, University of London, London.

Panel Members:

Dr. Richmond W. Longley, Meteorological Service of Canada, Ralston, Alta.

C. D. Ovey, Department of Geography, University of Cambridge, Cambridge, England.

Prof. Hurd C. Willett, Department of Meteorology, Massachusetts Institute of Technology, Cambridge, Mass.

Dr. Harry Wexler, Chief, Scientific Services Division, U. S. Weather Bureau, Washington, D. C.

Monday Evening, September 14, 1900

Cocktails, courtesy of Friez Instrument Division of
Banquet, at 1945, Sheraton Room, King Edward Hotel,
ration, and Dewey and Almy Chemical Company.
Banquet, at 1945, Sheraton Room, King Edward Hotel, 37 King Street East.

Master of Ceremonies: Andrew Thomson, Controller
Meteorological Service of Canada

Guest Speakers:

Sir Charles Normand, President, Royal Meteorological Society.

Professor Horace R. Byers, President, American Meteorological Society.

The Honourable Lionel Chevrier, Minister of Transport for Canada.

Vernon Crudge, Executive Director, The Munitalp Foundation.

Dr. Vincent J. Schaefer, Scientific Adviser, The Munitalp Foundation, "The Munitalp Atmospheric Research Project," illustrated with 16 mm time-lapse motion pictures.

Tuesday Morning, September 15, 0930–1230

Symposium on Microclimatology and Micrometeorology

Chairman: Dr. H. E. Landsberg, Director
Geophysics Research Directorate
Air Force Cambridge Research Center
Cambridge, Mass.

Introductory Remarks by the Chairman.

Topoclimatology, Dr. C. W. Thornthwaite, Director, Laboratory of Climatology, The Johns Hopkins University, Seabrook, N. J.

Micrometeorology in the Potato Crop, J. M. Hirst, I. F. Long, and Dr. H. L. Penman, Rothamsted Agricultural Experiment Station, Harpenden, Herts, England.

Turbulent Transfer Over a Short Grass Surface—Some Recent British Work, Dr. G. D. Robinson, Meteorological Office, Air Ministry, London.

Some Measurements of the Shearing Stress and its Variation with Height in the Lowest 100 ft. of the Atmosphere, E. L. Deacon, Commonwealth Scientific Industrial Research Organization, Highett, Australia.

Atmospheric Pollution in Relation to Microclimatology and Micrometeorology, Dr. E. Wendell Hewson, Department of Civil Engineering, University of Michigan, Ann Arbor, Mich.

The Great Plains Turbulence Field Program, Dr. H. Lettau and B. Davidson, Geophysics Research Directorate, Air Force Cambridge Research Center, Cambridge, Mass.

Tuesday Afternoon, September 15, 1430–1700

SYMPOSIUM ON CLOUD PHYSICS AND INDUCED PRECIPITATION

Chairman: Professor Henry G. Houghton, Chairman
Department of Meteorology
Massachusetts Institute of Technology
Cambridge, Mass.

Introductory remarks by the chairman.

Factors Governing the Temperature of Ice Crystal Formation in Clouds, Dr. Charles L. Hosler, Pennsylvania State College, State College, Pa.

Observations and Measurements on Natural and Artificial Rain from Convective Clouds, Professor Horace R. Byers, Louis J. Battan, and Dr. Roscoe R. Braham, Jr., Department of Meteorology, The University of Chicago, Chicago, Ill.

An Analysis of Supercooled Cloud Characteristics Measured During Canadian Icing Experiments 1950–53, K. G. Pettit, Meteorological Service of Canada and National Research Council, Ottawa, Ont.

Growth of Hydrometeors from Calculations Based on Aircraft and Radar Observations, Dr. Robert M. Cunningham and David Atlas, Air Force Cambridge Research Center, Cambridge, Mass.

ABSTRACTS

ATMOSPHERIC WINDS AND TEMPERATURES TO 60-KM ALTITUDE AS DETERMINED BY ACOUSTICAL PROPAGATION STUDIES

A. P. Crary, William B. Kennedy and Vivian C. Bushnell

The results of wind and temperature determinations from several latitudes and of various seasons within the United States, as well as in the Panama Canal Zone and Alaska will be presented. In addition the results from experiments conducted on an average of three times per month over a ten-month period will be given.

ATMOSPHERIC TEMPERATURES AT 30 KILOMETERS AND ABOVE

A. Arnold

A program of daily high altitude balloon flights was started at Belmar, New Jersey, U. S. A., during November 1952, to obtain information on atmospheric temperatures and winds, particularly at 30 kilometers altitude and above. Between November 1952 and June 1953, marked temperature rises at 30 km similar to those reported by Scherhag, were observed on only one occasion. On 3 January 1953, the temperature at 30 km was $-58°C$, rising to $-53°C$ on 4 January, to $-34°C$ on 6 January and then falling to $-58°C$ by 9 January. This temperature rise was not propagated to lower levels. There was a marked increase in geomagnetic activity on 5 January 1953; however, an increase of equal magnitude on 24 December 1952 was associated with no marked temperature rise at 30 km. It is possible that the rise in temperature during the interval 4–6 January 1953 is due to advection of warmer air from the south, since the winds at 30 km during this interval were southwesterly, changing to northwesterly after 6 January 1953.

ROCKET OBSERVATIONS OF ATMOSPHERIC OZONE

Francis S. Johnson

Measurements of atmospheric ozone concentration have been made from rockets at altitudes up to 70 km. The results have been compared with distributions calculated from photochemical theory, and the agreement is good if the three body collision process $O + O + M \rightarrow O_2 + M$ is taken into account. The absorption of solar radiation by ozone has been used to calculate the diurnal temperature changes in the altitude range 30 to 70 km above White Sands, New Mexico, for June 14, 1949. The maximum diurnal temperature variation occurs at about 48 km altitude, in agreement with the altitude of the temperature maximum as calculated from rocket measurement of pressure and density.

AN INVESTIGATION OF THE 9.6 μ OZONE BAND IN THE TELLURIC SPECTRUM

R. M. Goody

This is a preliminary report on a two-year programme of observations of the 9.6 μ ozone band in the solar spectrum. Laboratory studies on the effect of pressure and amount upon band area enable the spectra to be interpreted in terms of a mean pressure in the manner suggested by Strong. Results for spring, summer and autumn 1952 indicate an unexpected seasonal trend with a maximum mean pressure at the beginning of August, and a negative correlation between short-period variations of mean pressure and ozone amount. In view of their unexpected nature and the difficulty of the experiment, these results are open to question, although a statistical analysis of the most likely systematic errors shows no reason why they should not be accepted. It can be shown that the results do not necessarily conflict with other measurements of the vertical distribution of ozone.

SPECTRAL MODELS AND THE DEVELOPMENT OF A RADIATION CHART

Warren L. Godson

The basic philosophy behind the construction of a radiation chart is the postulate that the radiative flux at any level in the atmosphere can be evaluated in a series of steps—the integrations over all directions and all wave lengths being essentially performed in advance, and actual atmospheric data only being introduced for the integration over all emitting layers.

The importance of spectral models for this approach is demonstrated, and the properties of various spectral models are compared. Using such models, the intensity transmission and flux transmission for non-homogeneous layers have been studied, and suitable computation techniques developed. The final stages in the preparation of a radiation chart are briefly outlined, and the possible utilization of atmospheric radiation data to effect empirical improvements suggested.

A QUASI-STATISTICAL APPROACH TO THE CALCULATION OF ATMOSPHERIC TRANSMISSION

Lewis D. Kaplan

A straightforward calculation of atmospheric transmission for use in energy transfer studies seems at first glance hopelessly complicated, even with the aid of high-speed computers. The principal complicating factor is the irregular distribution of spectral lines with regard to spacing and intensities, and temperature dependence of the latter. It is essential, however, that a method of calculating transmission takes into account the principal features of the bands, including the exact shapes of the central portions of the many weak lines that happen to fall irregularly in the vicinity of the stronger lines and are probably responsible for a large portion of atmospheric radiation transfer.

Every infrared band can be divided into overlapping sub-bands whose individual spacings, intensities and temperature dependence (lower-state population) can be represented by continuous and smooth generalized functions of frequency. Generalized transmissions for these sub-bands, therefore, can be calculated for predetermined frequencies that need not coincide with the individual line centers. It can be shown that the transmission at any frequncy in a band is given by the product of the generalized sub-band transmissions at that frequency, provided only that the lines in any sub-band are assumed to fall randomly with respect to the exact position of their immediate neighbors in the other sub-bands. Justification will be given for this assumption.

Some of the novel advantages of this method are:

1. It takes into account the temperature dependence of the absorption coefficients;
2. It is especially applicable to overlapping bands of different gases; and
3. It would require a relatively small basic memory for high-speed computation.

As an example, results of calculation of laboratory CO_2 absorption will be presented and compared with measurements.

The Calculation of Atmospheric Transmission from Laboratory Measurements of Carbon Dioxide and Ozone

Gilbert N. Plass

The direct theoretical calculation of atmospheric transmission functions is a matter of great complexity. It is very important to develop approximate methods for solving the problem, where an upper limit can be stated for the error due to the approximation. One such method is to use laboratory absorption experiments to determine the necessary information about line intensities, spacing and half-width. Theoretical calculations are necessary only to adapt these measurements to the variable conditions along the path in the atmosphere. This method can allow for the overlapping of the lines in the band and for the temperature dependence of the absorption. Recent measurements of carbon dioxide and ozone absorption will be presented and their application to the atmosphere will be discussed.

The Distribution of Average Radiational Cooling for the Winter and Summer Seasons

Julius London

Model atmospheres were set up depicting the mean distribution of temperature water vapor and clouds for the northern hemisphere winter and summer seasons. Graphical methods were then used to compute the vertical and latitudinal distribution of radiation flux and flux divergence. The average infrared cooling of the atmosphere is, in the tropics, almost 2°C per day for both seasons but decreases to about 1.5°C per day at high latitude during the summer and to about 1°C per day during the winter.

The vertical distribution of infrared cooling shows that at all latitudes and seasons the maximum cooling rate is 2° to 3°C per day in the middle troposphere. The height of this level of maximum cooling rate decreases with increasing latitude and is generally lower during the winter as compared to summer.

Historical Survey of Arctic Meteorology

H. U. Sverdrup

The climate of the Arctic is to a great extent determined by the characteristics of a thin layer of cold air that is separated from the free atmosphere by a more or less sharp temperature inversion. Some features of the physics of this layer are discussed, mainly on the basis of observations during the "Maud" expedition, 1918–25. It is pointed out that in the Arctic, observations near the ground render little information as to conditions aloft for which reason upper air observations are of special importance. Future efforts must be directed towards extending these observations towards utilizing them fully for weather forecasting both within the Arctic and in middle latitudes.

The General Circulation

Chairman's Introduction—Extended Summary

P. A. Sheppard

1. *The Validity of the Concept*

The validity of the concept of the general circulation of the atmosphere is to be judged in terms of its usefulness. The long-term temporal mean value of the horizontal vector wind as a function of latitude, longitude and height is useful in throwing up part of a dynamical field whose existence and relation with smaller scales of motion on the one hand and with climatic variation on the other calls for understanding.

2. *The Current Picture of the General Circulation*

A reasonably complete picture of the general circulation of the troposphere and lower stratosphere is only now beginning to emerge. Its main features will be presented by the second speaker who will bring the winds of lower latitudes and the variation of the wind system with longitude into clearer perspective than has been possible until lately.

The general circulation is only specified effectively when the mean fields of vertical motion, temperature and composition (water vapor, ozone etc.), and the superposed fields of turbulence are known. Much remains to be established in this context, and I hope that contributions to knowledge will be made by later speakers. In particular it is very desirable that the form and intensity of mean meridional circulations should be more fully investigated.

3. *Meridional and Vertical Transfer of Momentum and Energy*

Much work, particularly in Australia and the United States, has been carried out in recent years, on the computation of the meridional transfer of momentum and energy by the large-scale turbulence of the general circulation. A general pattern emerges of poleward transfer of westerly (or angular) momentum between tropical and moderately high latitudes, with a maximum in about 30° lat. and with some evidence of reversal in sense of transport in the polar basin. This transport is effectively confined to the upper troposphere and is against the gradient of mean zonal wind speed in low latitude. The pattern is consistent with the injection of westerly momentum into the atmosphere by surface friction in the lower-latitude easterlies and of its extraction by the same process in the surface westerlies. The contribution to meridional transport by mean meridional motion appears to be secondary but the pattern of mean zonal wind, particularly in the tropics, is likely to be intimately related with the meridional circulation. Conservation of angular momentum, however, is not required. No adequate scheme has yet been drawn up for the vertical limbs of the momentum transport field. While large scale systems (long waves etc.) are evidently dominant in horizontal exchange, smaller scale systems are also probably effective in vertical transfer. Apportionment between different parts of the eddy spectrum waits to be determined.

The distribution of energy transfer is in some respects more complicated, but data are accumulating and, with improvement in radiation theory, we may be less dependent on evaluation from the winds.

Our third speaker will elaborate on the current position of work in the transfer field.

4. *Theory of the General Circulation*

We have a rough quantitative description of the general circulation and of the momentum and energy transfer in the atmospheric shell from accumulated observations. Thus the theorist has the problem posed in more than outline. It is perhaps, however, the most complicated problem in meteorology, involving the laws of matter, heat and momentum transfer for all types of turbulence from the frictionally engendered small-scale motion to the convective and on to the large-scale turbulence of weather systems.

It is doubtful whether we can expect to obtain an *a priori* theory, since there is no given initial state other than the general circulation itself. We can, however, hope to be able to show that the observed circulation is a physically self-consistent system—this is explanation enough. Already several investigators have shown, from perturbation theory, how momentum and heat should be transferred by the larger-scale weather systems of a baroclinic atmosphere. It is a considerable step from that and perhaps a new kind of hydrodynamics will be required to show that the mean wind system, the temperature field and the energy balance can be maintained by the forms, intensities and frequencies of observed eddy systems. A notable attempt to deal with the problem as a whole has been made recently by Eliassen. He has shown how mean meridional circulations, weak compared with the zonal wind, must be related to the latter in the presence of a given distribution of sources and sinks of heat and momentum. Our last opening speaker will enlarge on these matters.

The subject has many other aspects and I hope these will be raised in the general discussion. In particular I look forward to contributions on the role of tropical motions in the general circulation problem.

Some Aspects of the Mean Upper Air Flow Over the Earth

J. K. Bannon

The Upper Air Climatology Branch of the British Meteorological Office is attempting to chart the mean air flow over the earth in the four mid-season months January, April, July, October. This is by way of a revision of previous charts of the mean seasonal flows (Brooks et al., 1950). Some of the preliminary results of this investigation are given and emphasis is laid on a few of the important features of the high level flow, but accuracy of detail is not attempted at this stage.

Mean winds in temperate and high latitudes may be shown by mean contour charts of the standard pressure levels sufficiently accurately for most purposes, geostrophic flow being assumed (Brooks et al., *loc. cit.*). Typical charts of the mean flow for the lowest layers (500 meters) and the 300 mb level are shown for January, April, July and October for latitudes greater than 30°.

In low latitudes the geostrophic approximation is not valid. The low level mean flow is well known. For example, the flow charts of Brooks (1937) show the mean features. For the flow at upper levels direct observations of winds have been used to prepare vector mean winds at the standard pressure levels up to 100 mb for the mid-season months in 1951 for as many stations as possible. From these observations an attempt has been made to sketch the flow patterns. Such patterns are shown for the 200 mb level which is near the level of strongest winds. These charts, relating to one year only, and prepared from few data, must be regarded as tentative and indicating broad features only. Observations from the Southern Hemisphere are very few in number and most of the discussion necessarily concerns the Northern Hemisphere. Meridional cross-sections for various longitudes and seasons are given to illustrate the discussion.

Important features of the high altitude mean flow are:

(i) *The Sub-tropical Strong Wind Belt*

The existence of this strong wind stream with its core between 200 and 170 mb is well known (e.g., Namias and Clapp, 1949). Over North Africa and Asia in winter this stream is intensified by confluence with the wind system of the polar front. The same thing occurs over North America but there the true sub-tropical and polar front streams may be distinct, the former having its axis at a higher level, being unassociated with fronts and occurring entirely above the 350 mb level. Over the Pacific and Atlantic Oceans the streams turn northeastwards, following the polar front disturbances, but it is likely that in the mean there is another weaker, though distinct, branch continuing eastwards and unassociated with the polar front. Over the Pacific this sub-tropical stream can be traced on many individual days.

In July the strong wind belt is further north in the Northern Hemisphere and speeds are much reduced.

The strong wind belt in the Southern Hemisphere is well marked over Australia and New Zealand (Gibbs, 1952; Hutchings, 1950) and it is likely that this belt is continuous round the earth.

(ii) *Equatorial Easterlies*

Equatorward of the sub-tropical strong wind belt is a region of easterly winds in the upper troposphere over large areas of the globe. These winds have their highest speed in general between 200 and 100 mb. In January it is probable that there is a mean easterly flow in the upper troposphere in all equatorial regions except over the Central and East Pacific. Speeds of this mean easterly flow are not great. In July this easterly stream may possibly encircle the earth but this is uncertain because of lack of observations. It is most pronounced and extensive in July to the south of Asia and over Africa where it is remarkably steady in direction and mean speeds of over 60 knots are attained in some places. Speeds of over 100 knots have been reported on occasions. The core of this strong easterly stream is between 150 and 100 mb. Over Central America in July the upper easterly stream is weak in the mean and winds are variable in the upper troposphere from day to day. It is concluded that the strong steady easterly stream over Africa and to south of Asia in July is associated with the relative northward movement of the thermal equator in those longitudes.

The easterly flows in the upper troposphere in April and October are less extensive and weaker than in January and July, respectively.

The few equatorial observations show some puzzling features. Thus, the high tropospheric easterlies at Singapore have their greatest speeds in July and January with well-marked maxima occurring in the upper troposphere. Nairobi's easterly winds also show maxima in the upper troposphere in January and July but westerlies occur there in April and October.

References

Brooks, C. E. P., 1937, *Bull. Amer. Met. Soc.*, 18, p. 313.

Brooks, C. E. P., Durst, C. S., Carruthers, N., Dewar, D., Sawyer, J. S., 1950, Geophys. Mem. 10, No. 85.

Gibbs, W. J., 1952, *J. of Met.*, 9, p. 279.

Hutchings, J. W., 1950, *J. of Met.*, 7, p. 94.

Namias, J., and Clapp, P. F., 1949, *J. of Met.*, 6, p. 330.

The Flux of Angular Momentum and Heat in the General Circulation

J. Bjerknes

The experience of the speaker in the field of this symposium stems mainly from project work for the U. S. Air Force conducted at the University of California at Los Angeles. The basic data comes from daily hemispheric maps for sea level, 700, 500, 300, 200 and 100 mb, analyzed for the periods January-February and July-August 1949. Grid point data from the maps of temperature and pressure-heights, processed with I.B.M. methods, supply a number of derived general circulation quantities among which the angular momentum and its meridional flux have so far attracted the greatest interest. The essential problem of the project has been to investigate the mechanism by which the relative angular momentum of the atmosphere is being maintained on a long range basis, as well as the mechanism of the interdiurnal fluctuations in angular momentum. The basic theoretical concepts for the treatment of those problems were defined by H. Jeffreys in 1926 and 1933.

Briefly, the theory of Jeffreys points out the convergence of meridional flux of angular momentum as the source of supply of positive (westerly) angular momentum for any given geographically fixed zonal ring comprising the full depth of the atmosphere. Under the condition of steady state maintenance of the angular momentum of each latitude belt, the supply must be equaled by a loss which in turn can only consist in a transfer of angular momentum to earth. Therefore, a belt of atmosphere with a net supply of angular momentum (through convergence of angular momentum flux) will attain westerly surface winds of such strength that the loss of angular momentum to the slower rotating earth can equal the supply. Conversely, if the supply becomes negative (through divergence instead of convergence of flux) the angular momentum will decrease until the surface winds become easterlies of such strength that they pick up angular momentum from the faster rotating earth at a rate sufficient to equal the loss.

The meridional flux of angular momentum may be divided in a geostrophic and a non-geostrophic part. The geostrophic part operates with a zero meridional mass flux in each level, whereas the non-geostrophic one operates with a small net meridional mass flux different from zero in every level combining into vertical-meridional circulations. Only the geostrophic part can be computed from measured data, while the non-geostrophic part must be studied by indirect methods.

The results of our project (so far only based on the winter data) may be summarized as follows:

1. In middle latitudes the convergence and divergence of the geostrophic type of meridional transfer of angular momentum account rather well for the observed variations of angular momentum. But the correlation of cause and effect is not as close as to exclude the idea of superimposed transfer processes linked with non-geostrophic meridional circulations. The strongest argument for the reality of these circulations lies in the observation that although the overwhelming maximum of geostrophic convergence and divergence of angular momentum is found at 20–30 cb elevation the effects in terms of angular momentum changes occur at sea level with amplitudes not so very much smaller than those aloft and with no observable lag in phase. Turbulence type of transfer of angular momentum between the tropopause and surface levels could hardly be fast enough to account for those facts, but meridional circulations would do it. These circulations may well be assumed to be the dominating factor in the vertical transfers (both up and down) of angular momentum, while at the same time they are factors of secondary importance in the meridional transfers of angular momentum across the middle latitudes.

2. Towards the low latitude the correlation deteriorates between geostrophic type of flux convergence of angular momentum and observed variations of angular momentum. Moreover, the variations of angular momentum of a cap with its southern rim at 30° N cannot be explained in terms only of the geostrophic input of angular momentum across 30° N and the loss of angular momentum to the earth north of that latitude. A residual non-geostrophic torque must also act on the cap across

its southern rim and an important part of that torque must be exerted by meridional circulations.

3. A northward extension of the tropical "Hadley circulation" beyond its average northern limit at 30° N leads to an accumulation of angular momentum in the cap north of that latitude. That process seems to be involved in all the major rises in cap angular momentum during the investigated period.

4. Conversely, a southward extension and intensification of the "Ferrel circulation" of middle latitudes leads to a depletion of the angular momentum of the cap (Ferrel circulation across 30° plus friction torque north of 30° overcompensating the geostrophic influx of angular momentum). This phenomenon is usually proceded by an angular momentum drop in higher latitudes which migrates southward to the rim of the cap.

5. The joint operation of the processes under 3 and 4 decides the alternating rises and falls of "zonal index." The thermally driven Hadley circulation builds up the "high index" westerlies of middle latitudes until a critical limit is reached that starts a momentum drop and lower "index" migrating from high to low latitudes.

6. The average meridional heat flux over periods of weeks or months is carried mainly by the geostrophic exchange process in middle and high latitudes and by the non-geostrophic Hadley circulation in low latitudes. The day-to-day changes of the temperature of narrow middle and high latitude belts (up to 20° wide) are strongly influenced by non-geostrophic meridional circulations of one or two days duration. This provides also a thermal indirect method for observing the non-geostrophic circulations in middle latitudes.

The Problems of Cyclogenesis from Helmholtz' Time to the Present

J. Bjerknes

The extratropical cyclones owe their formation and intensification to two kinds of spontaneous developments releasing stored-up instability; the one type is the Helmholtz instability at frontal surfaces (in principle known since 1888), the other is the deepening process of the upper waves in the westerlies centered at the level of strongest westerlies near the tropopause. No definite dynamical principle from classical hydrodynamics has been convincingly assigned to explain the latter spontaneous process, but contemporary meteorology may soon agree on the mechanism of it.

The Helmholtz instability principle applies in its simplest form to a zonal frictionless flow which is strongly baroclinic, best represented in nature at a stationary front parallel to the westerlies. Particles in such a model can slip away from the basic horizontal flow in isentropic direction (that is upward to the left or downward to the right as viewed in a meridional profile looking east), provided that the shear of the westerlies measured along the isentrope surpasses the Coridis factor, hence: $\frac{\partial u}{\partial \eta} > 2\Omega \sin \varphi$ (η being the isentropic coordinate in the meridional plane). That critical shear is of course more frequently reached in the saturated than in the unsaturated part of the model, because the saturation adiabatics have approximately the inclination of frontal surfaces in the meridional profile whereas the dry-adiabatics are flatter. Even in the saturation adiabatic case, that is inside the frontal cloud, Helmholtz instability is seldom found to exist in the form defined in (1) prior to the development of the incipient frontal cyclone. However, if the model is changed from one of basic parallel flow to one of slightly confluent flow, large scale upgliding on the front becomes part of the basic flow with an isentropic upglide component of

$$v_\eta = u\frac{\partial u}{\partial x}\Big/\left(2\Omega \sin \varphi - \frac{\partial u}{\partial \eta}\right). \tag{2}$$

According to (2) frontal upgliding will occur whenever the upper current is confluent $\left(u\frac{\partial u}{\partial x} > 0\right)$, and occur with greater intensity the closer the conditions approach Helmholtz instability, $\frac{\partial u}{\partial \eta} \rightarrow 2\Omega \sin \varphi$. These initial conditions occur frequently enough to account for the observed frequency of spontaneous frontal cyclogenesis. Moreover, the first concentration of cyclonic vorticity occurs low down, created by the same horizontal convergence which feeds air into the frontal upgliding, and thus accounts for the earlier occurrence of closed cyclonic isobars on the surface maps than on those higher up.

The other spontaneous concentration of cyclonic vorticity occurs at the level of maximum westerlies and in such parts of the map where there is initial cyclonic shear. Incipient waves in a current of that kind will have their troughs and ridges sheared into SE-NW orientation, and the maximum of wind velocity will be located near the point of inflexion on the west side of the troughs. The trough is then a "difluent" one (combining cyclonic curvature with difluence) in which the zero line separating pre-trough divergence from post-trough convergence runs a little west of the trough instead of right along the trough line as in the purely sinusoidal wave above the level of non-divergence. With horizontal divergence straddling the trough line the difluent trough becomes a deepening one which is gradually digging into lower latitudes from the latitude of the initial perturbation. During this process the southern part of the trough line pivots clockwise and usually ends in SW-NE orientation, which also involves the end of the difluent structure and the deepening.

The two types of spontaneous concentration of cyclonic vorticity can be visualized as independent processes, but in most cases they are observed to have a common cause: frontogenesis, which creates both Helmholtz instability and the upper jet stream to the north of which the extremes of cyclonic shear are built up. Once started, a spontaneous process usually influences also the medium in which the other may be released. For instance, the rising motion above the frontal upgliding builds up a wave crest in the upper current, which may be the beginning of an intensifying upper wave if the shear conditions are right. Or, the deepening upper trough will quite often be in the right phase relative to a frontal wave to intensify the frontal cyclones (westward tilt from surface center to upper trough). Big storm centers always have that dual source of energy.

The principal agent responsible for the filling of cyclones must be the frictional inflow near the ground. If left to operate alone it would increase the pressure at the center of the cyclone much faster than is ever observed. The normal filling process of cyclones can therefore be ascribed to the frictional inflow overcompensating a moderate version of the above mentioned deepening effects.

The spontaneous cyclogenetic processes have been, and will continue to be, the key problems of cyclone theory and weather forecasting.

Cyclones and Anticyclones—a Comparative Study

R. C. Sutcliffe

In broad features cyclonic and anticyclonic developments are complementary dynamical systems differing in the sign of the horizontal field. Perturbation theory applied to a simple baroclinic current leads to instability criteria which do not distinguish between the two modes. Development theory also indicates cyclogenesis or anticyclogenesis in temperature-pressure fields which are essentially similar apart from phase differences while the general dynamical equations introduced by several workers in a two parameter model (representing the mean flow and the mean thermal wind) are likewise symmetrical in the two modes of development. Since energy transformations take place in opposite senses in the two cases it would appear that, fundamentally, we are concerned with inertial instabilities and that thermodynamic energy exchanges are secondary factors. The dynamical development may be determined largely from the structure within the system, which may be regarded as a structural entity, but over-all energy transformations due to the system depend upon environmental changes and it may be impossible to define a single system realistically as a problem in energetics. A statistical treatment may be essential for energy studies.

In nature a baroclinic zone generally shows a preference for the cyclonic disturbance. This appears to be due to the more rapid growth rate of the cyclonic disturbance rather than any preference for the cyclonic perturbation. Synoptic evidence and dynamical theory suggest that this preference is most pronounced for smaller scale features and for regions with a supply of energy, from latent heat or surface heating, to offset the cooling due to forced ascent in a stable atmosphere. The cyclonic preference is not pronounced over winter continents where baroclinic anticyclones often become well developed, nor is it pronounced for the largest scale baroclinic developments.

Ridges of high pressure are the normal manifestations of anticyclogenesis in middle latitudes, complete evolution being prevented by the arrival of the next mobile depression which overtakes its stagnating predecessor. If, however, more or less accidental circumstances of phasing increase rather than decrease the distance between successive cyclones the anticyclonic development may have time to go through to a mature stage. The regular tendency for anticyclogenesis through the westerlies in middle latitudes, especially over the eastern oceans, is probably due to the existence of quasi-permanent long-waves of geographical origin at a wave length not greatly in excess of the limiting length for dynamical self-development. A shortening of this wave length or an increase zonal flow is always liable to initiate development on the largest possible scale when the systems move slowly and when the preference for cyclogenesis is less pronounced: anticyclonic cells may then develop freely.

The selection of disturbances in the atmosphere is not primarily due to the emergence of wave lengths of maximum growth rate from small unselective perturbations but is generally imposed on the situation by the distortions accompanying existing circulation systems. This fact makes it possible to predict new developments to some degree, one stage beyond what might be expected for essentially unstable systems.

Notes on East-Coastal Cyclogenesis

Jerome Spar

The initial phases of cyclogenesis in the east-coastal region of the United States have been studied with the aid of upper air soundings, dense networks of hourly reporting stations and airplane reconnaissance. Particular attention has been given in the analysis to the cloud structure, precipitation field and the micro-structure of young cyclones. Significant departures from model behavior and structure have been noted, particularly the occurrence of non-frontal cyclones. The apparently erratic movement of young cyclones is found to be associated with the existence of clusters of small, short-lived cyclones.

Stratospheric warming and lowering of the tropopause, resulting primarily from subsidence in the lower stratosphere, is found to be a consistent feature of cyclogenesis in agreement with the observations of Bjerknes, Palmén, Austin and Vederman. Evidence is presented in support of the hypothesis that cyclogenesis is associated with the coincidence of relatively warm stratosphere and troposphere and a diminution of the well-known negative correlation between stratospheric and tropospheric temperatures. The frequent occurrence of frontal wave cyclones and the existence of non-frontal cyclones are discussed in terms of the thermal theory. However, the causal relation between cyclogenesis and the temperature distribution is still obscure.

The association of southerly circulation in the troposphere and cyclogenesis is examined and it is observed that the former is almost always connected with some degree of cyclogenesis.

Formation of Tropical Cyclones

Herbert Riehl

Development of a tropical cyclone requires the existence of mechanisms quite analogous to those of all machines which are driven by a latent heat supply. There are five functional ingredients:

(1) The latent heat supply;
(2) A starting mechanism with an independent energy source;
(3) Conversion of latent to sensible heat energy, and to mechanical energy of the engine;
(4) Mechanical coupling to generate motion in any desired plane;
(5) A cooling system to carry off the excess heat not converted to mechanical energy.

The theories of hurricane formation are examined with respect to these five points. Then a model of hurricane formation is constructed within the limits of present knowledge. Difficulties are pointed out which frequently make it impossible for the atmosphere to fulfill one or more of the functions listed, so that no storm results in the end.

On the Prediction of Cyclogenesis

Jule Charney

The results of a series of numerical integrations of the quasi-geostrophic equations of motion for a cyclogenetical situation are discussed in relation to existing theories of cyclogenesis.

Some Aspects of Mobile Depressions in a Baroclinic Current Studied by Means of the Two Parameter Representation of the Atmosphere

J. S. Sawyer

Several authors have recently suggested that the main features of atmospheric systems on the scale of cyclones and anticyclones can be represented by the horizontal distribution of two parameters, one representing the height of a selected isobaric surface in mid-troposphere and the other the thickness of an appropriate isobaric layer. Results of the calculation of rates of change of 500 mb height and surface pressure on the basis of this representation will be illustrated in respect of a small fast-moving depression.

The equations for the rates of change of 500 mb height and surface pressures have a particular solution which resembles a mobile depression in a baroclinic current and this solution is used to compute approximate three-dimensional trajectories of the air. Air with widely different trajectories is brought into juxtaposition along surfaces which have many of the features of the fronts of a typical wave cyclone.

Quasi-Periodic Cyclogenesis in Relation to the General Circulation

Jerome Namias

A striking case of recurring cyclogenesis at ten day intervals during February 1953 with a tendency to continue until mid-May has been studied against the background of the planetary circulation averaged over periods up to thirty days. The data suggest a periodicity-producing mechanism whose period may be defined by the underlying long period (e.g., 30-day) mid-tropospheric wave pattern.

In this particular case the patterns of waves observed on 5-day mean charts oscillated about certain more stable centers of action in a manner consistent with vorticity considerations. These oscillations recurrently deployed continental polar and maritime tropical air masses into juxtaposition and set the stage for cyclone growth. The movement and development of these cyclones strengthened the westerlies, thereby temporarily permitting lateral expansion of the planetary wave. After the energy of thermal contrast was tapped and the cyclones moved off or filled, the regional westerlies declined leading to long wave retrogression and the initiation of the cycle anew.

The annoying "change in phase" which has beset workers in periodicity for years is shown to be associated with abrupt though logical rearrangements of the mean planetary circulation incident to change of season.

Forecasting Winds up to the 100 mb Level by the Contour Chart Technique

J. S. Sawyer and R. C. Sutcliffe

The various errors in the representation of winds by contour charts on the geostrophic assumption are analysed. The geostrophic approximation is probably not a major source of error in middle latitudes. Radar wind observations from the British network have a high standard of accuracy but heights compared from radiosondes become grossly inaccurate at the highest levels so that it is not possible to construct reliable contour charts at present without the aid of wind data. Forecast contour charts (prontours) are naturally less accurate than "actual" charts and at the highest levels may not be of much value. In view of the low interdiurnal variability of wind in the stratosphere an estimate of actual winds may then be as reliable on the average for 24 hours ahead as a forecast from prontours. The probable error due to forecasting on the basis of persistence may be reduced by statistical methods.

Forecasting High Clouds from High Level Constant Pressure Charts

J. E. French and K. R. Johannessen

Assuming a boundary condition of small vertical motions at the tropopause, one can expect the vorticity advection in the layers below the tropopause to be indicative of the vertical motions in the upper troposphere. An investigation of this relationship has been attempted by relating extensive layers of clouds above 25,000 feet, as observed from high flying aircraft, to synoptic 300 mb charts. The diagnostic and prognostic merits of this relationship are discussed.

Jet Streams in Middle and High Latitudes

D. P. McIntyre and R. Lee

From the earlier work of Palmén and others, the structure of the atmosphere in the vicinity of strong jet streams in middle latitudes is known. In this paper the structure of jet streams in early stages of their histories is described. In particular, it is found that a relationship exists between jet streams in the north and the arctic and inter-arctic fronts. This relationship is similar in many respects to the relationship found between mature jet streams and the polar front by Palmén. Studies of the histories and behavior of jet streams in middle and high latitudes are described. Application of these results to the forecasting of high level winds is discussed.

The "Critical" Eddies in the Upper Atmosphere

Robert C. Bundgaard

In the upper troposphere and stratosphere, there exists a great number of turbulent disturbances that are so small in intensity, duration, or extent that they completely escape detection even within a very dense network of the ordinary upper-air observations made as often as every six hours. This paper presents some evidence as to the nature of these turbulent disturbances from observations made by the high-level weather research Project BLACK SHEEP of the Air Weather Service.

Between 35,000 and 50,000 feet, small-scale atmospheric motions (with dimensions as small as 2–10 miles and 5–20 minutes) can be observed and followed in a semi-Lagrangian way by photographing the deforming exhaust trails persisting frequently up to two hours. Remote from the main synoptic jet streams, horizontal and vertical shears well in excess of 10^{-3} and 10^{-2} sec^{-1} have been observed, as well as narrow (ten mile wide) walls of vertical motion beneath undulating cirrus-forming bands.

Slowly growing festoons of virga are frequently seen apparently hanging upstream from the exhaust trail. These festoons resemble the trails of cirrus uncinus. From newly formed contrails, rapidly mushrooming protuberances, heavy, opaque, and cumuliform, are seen to bulge downward at the rate of 20 m/sec or more. These two types both result from large variations along the exhaust trail in the fall-out rates for the exhaust particles. It is shown that the fall-out rates are far in excess of the settling speed obtained from Stokes' Law using evidenced values for the particle size, shape and density. It is suggested that instead of the mechanics of individually falling particles, the hydrodynamics of "air drops" heavily laden with large ice crystals must be applied for finding the fall-out speed, as pointed out by V. J. Schaefer.

Finally, it is mentioned that a periodic succession of discharged, irregularly shaped vortex-loops is sometimes seen to move along the axis of the exhaust trail. These presumably take place at a certain critical Reynolds number. Although of no apparent interest when considering the turbulent disturbances of the atmosphere, these vortex sheets might nevertheless give clues as to the way in which the exhaust trails break up and dissipate.

Jet Stream Detail with Respect to Other Meteorological Factors

Sidney Teweles, Jr.

To aid the analysis of high level charts an attempt is made to establish some models in which features of the lower levels are associated with jet stream patterns. The application of such models is intended for use over areas where high level data are scarce.

Clear Air Turbulence at High Levels

Le Roy H. Clem

With the advent of modern high speed and high altitude aircraft, the problem of clear air turbulence has assumed major importance. Some actual cases of intense clear air turbulence and the associated meteorological conditions will be presented. In addition some preliminary results of the synoptic high altitude turbulence project of March 18–20, 1953 will be shown.

An attempt will be made to show the relationship of the turbulence in these situations to the jet stream maxima. A proposed mechanism for the occurrence and distribution of clear air turbulence will be given. Suggestions will be made for future observational programs. The successful solution of the clear air turbulence problem is partially dependent upon improved methods of observing and forecasting upper level winds.

Panel Discussion on "Climatic Change"

Gordon Manley

General Theme.—"Dimensions in space and time of climatic fluctuations, with particular reference to the study of transatlantic correlations. The character, extent and phase differences, if any, of climatic variations on either side of the Atlantic, with a view to the development of meteorological theory."

Chairman's Opening.—Introductory survey of the problem of transatlantic correlation. Importance, especially in Canada, of comparisons of recent climatic amelioration on either side of the N. Atlantic. Value of instrumental records and other climatic indicators; extent of correlation. Need for study of phase-differences; possible relationships between the minor fluctuations of the last few centuries and the greater developments since the Ice Age. The present as the key to the past; need for further evidence with a view to the development of meteorological theory.

Following speakers.—Contributions will review recent work in greater detail with regard to the meteorological instrumental evidence and to that provided by the botanists and geologists in Late and Post Glacial Lines. Comments on the current state of research on the sub-oceanic core-samples and its significance with regard to the N. Atlantic will follow. Later speakers will embark on the consideration of meteorological theory in the light of the available evidence of the character of climatic change.

It is expected that the discussion will then become more general. Contributions from the floor with regard to the possibility of parallel fluctuations in the Southern Hemisphere will be acceptable.

Topoclimatology

C. W. Thornthwaite

Topoclimatology is the study of local climates. It makes use of the data of both micrometeorology and microclimatology and employs methods of field study developed by geologists and soil surveyors. It undertakes to determine the various influences on the heat, moisture and momentum exchange between the earth's surface and the atmosphere. The end product of topoclimatology is an imposing series of maps showing the geographical variation of such edaphic factors as the color, apparent density, heat capacity, moisture content, and permeability of the soil; the characteristics of the vegetation cover and the albedo and roughness of the surface as well as its position, exposure and aspect.

Micrometeorology in the Potato Crop

J. M. Hirst, I. F. Long and H. L. Penman

Two main causes of reduced potato yields are virus diseases and blight—a fungus disease. Some of the virus diseases are aphid transmitted. Spot readings of temperature, humidity and wind have been made in potato crops to determine the environment of the aphids (Penman and Long, 1949; Broadbent, 1949, 1950). Results showed that weather among the plants was often favorable for aphid activity when weather outside was unfavorable.

During the summer of 1952 continuous readings of wet and dry bulb temperatures were recorded at six heights in and above a potato crop (10 to 320 cm) as part of a study of potato blight. For part of the period a dew balance was in use giving a continuous record of the changes in weight of a potato shoot as dew condensed and later re-evaporated. These changes were in phase with vapor pressure gradients in the air which was saturated or very nearly so at all levels up to 160 cm during the period the leaves were wet.

References

Penman, H. L., and Long, I. F. (1949), *J. Sci. Inst.*, 26, 77; Broadbent, L. (1949), *Q. J. Roy Met. Soc.*, 75, 302; —— (1950), *Q. J. Roy. Met. Soc.*, 76, 439.

Turbulent Transfer over a Short-Grass Surface—Some Recent British Work

G. D. Robinson

1. Mr. N. E. Rider at the School of Agriculture, Cambridge has made extensive simultaneous observations of surface drag (by drag plate) evaporation/condensation (by weighing), radiative flux, flow of heat to the soil, and profiles of mean wind, temperature, and water content to a height of 2 m, over a wide range of stability. His principal conclusions are:

(a) The profiles of wind, temperature, and humidity are usually similar (i.e., the ratio of the gradients is constant with height). Occasionally the humidity profile differs significantly from the other two.

(b) The eddy diffusivities for heat, momentum and matter are usually about equal. Occasionally, in unstable conditions, the eddy diffusivity for heat is greater than the other two.

2. At Kew Observatory simultaneous records of horizontal and vertical wind and temperature have been taken at heights of 25 cm and 150 cm. Time constant of apparatus 1/10 sec. Computed heat fluxes are about half the expected value. Frequency analysis of wind records shows turbulence isotropic at frequencies greater 2–3 c/s and energy spectrum αn^{-2} in this range.

Some Measurements of the Shearing Stress and its Variation with Height in the Lowest 100 Feet of the Atmosphere

E. L. Deacon

Results of the measurement of shearing stress over open grassland by the $u'w'$ method are presented in relation to the variation with stability and with height above ground in the range 1.5 to 29 m.

The influence of length of recording period as affecting the low frequency cut-off of the eddy spectrum is also discussed.

Atmospheric Pollution in Relation to Microclimatology and Micrometeorology: Problems

E. Wendell Hewson

Pollution of the atmosphere raises many important questions which require answers. For example:

1. Is atmospheric pollution affecting climate?
2. Is is affecting health?
3. Are natural cleansing processes rapid enough to maintain an acceptably low level of contamination?

The various phases of these problems are indicated and some of the available evidence bearing on them is examined.

The Great Plains Turbulence Field Program

Ben Davidson and Heinz Lettau

The Great Plains Turbulence Field Program has been organized by the Geophysics Research Directorate of the Air Force Cambridge Research Center. The primary purpose was to observe as completely as possible the physical processes within the entire atmospheric boundary layer under conditions of relatively uncomplicated large-scale flow patterns and well pronounced radiational heating and cooling of the earth-air interface. To insure uniformity of terrain, the site was chosen in the prairie country near O'Neill, Nebraska. To insure exhaustive detail of measurements, nine American universities actively engaged in studies of atmospheric turbulence have banded together with various government agencies to operate simultaneously at the site during 1 August through 12 September 1953. The observational program includes the direct measurement of soil factors and lower boundary conditions and detailed studies of physical and statistical variables with the aid of masts and towers in the lower 50 feet, and with the aid of kytoons, airplanes and radiosondes up to 5000 ft. A film will be shown to demonstrate observational procedures, instrumentation, and general progress of the field program.

Factors Governing the Temperature of Ice Crystal Formation in Clouds

C. L. Hosler

Laboratory experiments using water in capillaries, droplets deposited on surfaces and artificial clouds have demonstrated the importance of droplet size and the nature and concentration of foreign materials in solution in determining the temperature at which cloud droplets freeze. For a water-soluble condensation nucleus of given type and size, the freezing point of a droplet formed upon it may be lowered or raised depending upon the rate and extent of droplet growth. An hypothesis is offered to explain these results. The contribution of these processes to the precipitation mechanism in clouds is discussed.

Observations and Measurements on Natural and Artificial Rain from Convective Clouds

Horace R. Byers, Louis J. Battan and Roscoe R. Braham, Jr.

If the criterion of eligibility for artificial nucleation of convective clouds requires supercooling at the tops before rain forms, then it is difficult to find eligible clouds. This is demonstrated by radar data and flight observations in cumulus clouds which show that in many of them the drops have grown to 100 to 200 micron sizes before the cloud tops have reached the freezing isotherm. This puts the reports of some previous cloud-seeding successes in a questionable light.

The differences in behavior between various cumulus clouds or between clouds in different meteorological situations and different localities seem to depend on the size of the cloud, the height of the condensation level in relation to the height of the zero isotherm and the amount of entrainment in the updraft. The nature, size distribution and number of condensation nuclei also appear to have an effect. Some interesting electrical effects which may have a bearing on this problem are described.

Some new observational data and measurements in relation to the above factors are presented.

An Analysis of Supercooled Cloud Characteristics Measured During Canadian Icing Experiments 1950–53

K. G. Pettit

Measurements of supercooled cloud characteristics have been made for over a thousand icing encounters. The measuring techniques are discussed briefly and their limitations presented. An analysis is made of liquid water content and cloud droplet size in relation to temperature, cloud type and icing extent. Cross-sections illustrate cloud characteristics encountered during flight through typical synoptic situations.

Growth of Hydrometeors from Calculations Based on Aircraft and Radar Observations

R. M. Cunningham and D. Atlas

Flight observations and ground radar data for five cyclonic storms are discussed. Growth calculations from flight measurements are shown for some characteristic portions of each storm and results compared with the radar indications and ground measurements of the precipitation. The cloud structures and heights at which most of the hydrometeor growth occurs, are discussed in relation to the frontal structures and upper level flow patterns. Results are compared with the Classical Bergeron cyclone model. Modifications to this model are suggested.