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CCRG 10

Weather and Weather Maps

Edited by
Gösta H. Liljequist

Birkhäuser

Weather and Weather Maps

A Volume Dedicated to the Memory of Tor Bergeron (15.8.1891 – 13.6.1977)

Edited by
Gösta H. Liljequist

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Tor Bergeron
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Foreword

Tor Bergeron died on 13th June, 1977. He was then nearly 86 years of age and had worked actively within the science of meteorology for almost 60 years. Here he belongs to the great pioneers.

A proposal for a Tor Bergeron Memorial Volume was suggested by Dr Helmut Weickmann, Boulder, Colorado, USA, in the summer of 1977. He knew Tor Bergeron well, ever since 1923, besides, they had one great scientific interest in common, namely cloud physics. By telephone and by letter Weickmann discussed the matter with several persons, including Dr Lennart Bengtsson and myself, both of us being close friends and previous pupils of Tor Bergeron.

The main problem was how to publish and to finance such a volume. The plan was also discussed with Dr Stan Ruttenberg, Secretary, IAMAP, who endorsed it enthusiastically and promised assistance should publication prove unsolvable. The problem was finally solved by Dr Weickmann and Professor Hans R. Pruppacher, the latter being one of the scientific editors of *Pure and Applied Geophysics*. It was possible to arrange the publishing in a manner that the incoming articles of the Memorial Volume would be collected and become part of the regular issue of *Pure and Applied Geophysics*, they would also make up a special issue.

Meanwhile I had consented to take on the responsibility of becoming the editor of the Bergeron Memorial Volume. It seemed appropriate to deal with subjects approaching the interests and scientific contributions of Tor Bergeron. A draft plan was set up, giving preliminary titles of articles and, in some cases, names of prospective authors. This plan, which was sent to Dr Weickmann, was discussed in the USA by a group of scientists consisting of Professors Bernhard Haurwitz, Chester W. Newton, Hans R. Pruppacher, Herbert Riehl and Dr Helmut Weickmann. A somewhat modified plan, containing proposals of authors to be contacted, was returned to me. Later, a similar discussion was held at the Swedish Meteorological and Hydrological Institute with Drs Olov Lönnqvist, Tage Andersson and Bengt Dahlström.

A list of subjects/authors was then prepared. The different authors could then be contacted. The authors were remarkably positive and helpful in spite of the very close deadline they were given.

As editor of the Bergeron Memorial Volume I wish to express my sincere gratitude to the publisher, Birkhäuser Verlag, Basel, Switzerland, who made the Memorial Volume a reality. I wish to thank the authors for their fine contributions and also the

meteorological scientists, who helped in the planning. Finally, I wish to express my sincere thanks to Dr Helmut Weickmann, to Mrs Vera Bergeron and to Professor H. U. Dütsch, Zürich, Switzerland, scientific editor of *Pure and Applied Geophysics*.

Financial help for covering some extra expenses was given by the Swedish Natural Science Research Council.

Uppsala, November, 1980 GÖSTA H. LILJEQUIST

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Tor Bergeron

A Biography

By G. H. Liljequist[1])

Author's Note

I met Tor Bergeron for the first time in 1939 at the Swedish Meteorological and Hydrological Institute (SMHI) in Stockholm. As a junior meteorologist in the weather service under him I had rich opportunities to get to know him well, also later as a student of meteorology, also under him, and as co-author of a duplicated text-book of meteorology.

In 1949–58 I was either away from Sweden or worked at Stockholm University, while Bergeron was a professor at Uppsala. We met only sporadically during that time.

In 1958 I too became a professor of the Meteorological Institute at Uppsala. After that we met almost every day, especially so in the 1970's. We talked a good deal on bygone days. In 1973 we did this more systematically and used a tape-recorder in order to preserve what he had to say on meteorological history and on events in his own life.

Much of the present biography is built upon my own knowledge of Tor Bergeron and upon our discussions and my interviews with him, and also upon interviews with Mrs Vera Bergeron. These data have been checked with the help of the available literature. Bergeron's visits to Russia and his work there are described in detail in a certificate which he received from the Russian authorities on his departure.

At the end of this biography is added a Curriculum Vitae, which was written by Tor Bergeron in 1966, and also a List of the Publications by Tor Bergeron, compiled by the author of this biography. The List of Publications is referred to under the abbreviation L.P.

The young Tor Bergeron

In 1908 a 17-year-old schoolboy was told by his teacher to read the barometer every morning during a whole month. The boy was a sixth former at the boarding school of Lundsberg, situated near the town of Filipstad in central Sweden.

This month of observation acted like a trigger: the boy became from the very start a keen observer of meteorological events – and so remained during a long active life.

Tor Bergeron was indeed a meteorological observer – in the very best sense of the word. The meteorological events might either appear in the sky or on the synoptic weather maps.

From now on he started to make other observations too, visibility, temperature, wind, clouds, etc. Lundsberg was an ideal place for visibility observations, there were

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many good objects to distinguish in the surrounding country. Very soon the schoolboy found that visibility varied markedly, even excluding situations with mist and fog and precipitation.

From 1909 onwards till a few years before his death Bergeron spent almost every summer at a place called Ånn (63°20′N, 12°30′E, 560 m above sea level) situated near the Norwegian border. It is an ideal place for observing visibility and clouds. There are good visibility objects at distances up to 45 km, and clouds and cloud systems spread inland from the Atlantic. Here in the lee of the mountains, lee-wave clouds are frequent and were noted by the young observer even before they were described in any cloud atlas. Not even the concept of 'cloud system' had yet been coined.

The young student was thrilled by the observational work, by the sceneries in the sky and by the problems and challenges they seemed to offer. These observations by the young student which, by the way, went on into his old age, decided his later career and, even at this early stage were to decide his principal interests and scientific contributions in meteorology.

Tor Bergeron's mother was acquainted with Nils Ekholm, meteorologist and polar explorer, who in 1914–18 was director of the Swedish Meteorological Institute. This acquaintance was of great value to Tor Bergeron. He was given good advice by the experienced scientist and thanks to Ekholm he could feel more at home at the meteorological institute. He was introduced into Ekholm's method of forecasting changes in the wind speed and wind direction with the help of isallobars on the weather map. When Tor Bergeron started his university studies in 1910, he was told by Ekholm that he had to study mathematics and physics as much as possible if he wanted to become a good meteorologist. He did and was so fascinated by physics that he now even planned to become a physicist. However, the old interest in weather science returned.

Around 1915 he became interested in atmospheric electricity. A treatise dealing with the correlation between the turbidity and the electric conductivity of the air inspired him to start an investigation of his own on these lines, especially so as his own scale for visibility measurements was better than the one which had been used for the treatise he had studied.

Together with an assistant he spent six weeks in the summer of 1917 in a tourist cottage in the Arå valley (63°N, 13½°E, 850 m above sea level). This place is situated not very far from Ånn, among the mountains of the Jämtland province. Bergeron did all the observational work, as no observations were taken during the night. The place was excellent for visibility observations. One could discern mountains as distant as 70 km. The observations were published later, in summarized form, in Bergeron's doctor's thesis of 1928, see L.P. Nos. 1, 2 and 6.

After his return to Stockholm later in the season, he visited the Meteorological Institute frequently in order to study the weather maps and try to find the causes of certain marked changes in visibility and also of other striking weather changes. It was remarkable that sudden changes in visibility often occurred in connection with changes in wind direction. J. W. Sandström, previous assistant to Vilhelm Bjerknes and later director of the Swedish Meteorological Institute, had instructed him how to draw streamlines on the weather maps. Bergeron now found that the changes of visibility seemed to occur in connection with passages of convergence lines (now called fronts). Bergeron had thus already (autumn 1917) got on the track of the air mass concept.

Next summer (1918) the same type of observation program was carried out, now for a month at Abisko, situated at Lake Torneträsk in the northern part of Swedish Lapland (68½°N, 19°E, 350 m above sea level). The visibility observations were now carried out day and night. A valuable finding was that there existed no correlation between visibility and terrestrial scintillation, Bergeron therefore concluded that he possessed counter-evidence to the so-called optical theory of visibility. In addition, the variations of the visibility did not seem to be caused by hygroscopic nuclei, as no relationship was found between visibility and humidity. These observations too were later on published in his doctor's thesis, though highly summarized. He dared not publish them immediately, as he had the idea – like so many other persons at the Swedish universities at that time – that he must first study *all* that had been written on the subject, but at that period he could not spare the time.

Contact with the Bergen meteorologists

When Bergeron visited the Meteorological Institute in the following autumn (1918) he met two young meteorologists, who had come as fresh B.Scs. from Uppsala University, Ernst Calwagen and Oskar Edlund. The former was to become a very close friend of his.

These two young men had been engaged to run a new side-branch to the ordinary weather forecasting service, viz. a 'weather service for the benefit of agriculture'. For that purpose a number of third-class observation stations were operating to supplement the synoptic stations. The observations were limited mainly to wind, cloudiness and weather. The ensuing forecast was given in a code by way of one single word, which was sent to those farmers who had subscribed for the service. A similar dense net of observing stations had been erected in Norway by Vilhelm Bjerknes at the same time.

Bergeron was now badly in need of employment. The old Meteorological Institute was being reorganized to include also hydrology. In this newly established institute Bergeron was given the post of 'extra assistant meteorologist' on 1 January 1919 – the birth date of the new organization SMHA, later SMHI.

Two months earlier two young Norwegian meteorologists had visited Stockholm, Jack Bjerknes – the son of Vilhelm Bjerknes – and Halvor Solberg. Both were assistants to Vilhelm Bjerknes, who, since 1917, was professor of meteorology at the Geophysical Institute in Bergen. As mentioned, Vilhelm Bjerknes had created a dense network of observing stations, which were mainly intended for his forecasts to the farmers, but they were also necessary for the research work which was planned.

The purpose of the visit was to procure weather observations and also to recruit Swedish students for the Norwegian Weather Service. At that time academic people could easily obtain well-paid positions in Norway, so there were few left to meteorology, which was a not fully accepted science. In Sweden conditions were the opposite, so in 1919 four young Swedish B.Scs. arrived in Bergen, among them Tor Bergeron and Carl-Gustaf Rossby. None of them, except Bergeron, had had any previous experience of synoptic meteorology. Bergeron had been granted leave for the specific purpose of learning the Bergen methods.

The first years of the Bergen School

Vilhelm Bjerknes was a physicist. He had studied in Germany under Heinrich Hertz and later held a professorship in physics, first at Stockholm University (1895–1907) then at Kristiania (Oslo) University (1907–13). At the turn of the century he had published his famous circulation theorem, and a few years later (1904) he presented ideas on what we would now call numerical forecasting. These 'modern' ideas gave him later, in 1913, a professorship in geophysics – in reality meteorology – at Leipzig, Germany, and also grants from the Carnegie Institution, Washington, D.C., which made it possible to collect a team of young meteorologists, among them Halvor Solberg and his own son Jack Bjerknes. Vilhelm and Jack Bjerknes, Halvor Solberg and later on Tor Bergeron became the nucleus of the Bergen School to be. Vilhelm Bjerknes and Solberg were the theorists and Jack Bjerknes and Tor Bergeron the synoptic meteorologists of the group. Vilhelm Bjerknes was the leader and organizer of the group. He was also the established and well-known scientist.

The conditions in Germany towards the end of World War 1 had become severe and the health of Vilhelm Bjerknes was suffering. He wanted to go back to Norway.

A professorship in meteorology was created at the Geophysical Institute at Bergen and was offered to him in 1917. This year may be considered as the birth date of the Bergen School of Meteorology.

The scientific work at Bergen was to be devoted both to theoretical and practical meteorology. In the first year a very dense network of observing stations was established. The stations were intended for special forecasts to the farmers in the summer season. They could also be used for investigations within synoptic meteorology. Already at Leipzig Jack Bjerknes and Halvor Solberg had been able to study convergence lines in the surface flow thanks to a very dense network of stations over Germany. In 1918 Jack introduced these lines in his first cyclone model, published in 1919 (BJERKNES, 1919).

The convergence lines were later termed fronts, of these the warmfront was a new concept in meteorology. Fronts and air masses had been studied earlier, though not so systematically as now.

There were many reasons for the great success of the Bergen School. One was that its leader, Vilhelm Bjerknes, was an established physicist with his eyes open to the problems of meteorology. He was able to provide meteorology with the necessary firm foundation. Second, the assistants of Vilhelm Bjerknes were young and very enthusiastic. They were not too greatly burdened with knowledge, so they were unbiassed and free to draw their own conclusions from what they saw on the weather maps and in the sky. This, on the other hand, often led them to neglect the findings of previous research workers in meteorology – and this sometimes involved *their* findings, in turn, being disregarded.

Another deciding factor was that the time was favourable. Aviation had developed during the war, and flight safety demanded reliable weather forecasts and information concerning atmospheric conditions at different heights. In addition, at the end of the war, and for a few years afterwards, there was a great scarcity of food. Reliable forecasts were greatly needed by the farmers.

Bergeron's stay at Bergen in 1919

When Bergeron arrived in Bergen in the spring of 1919, Vilhelm Bjerknes and his assistants had already established their dense network of stations. They had also, in the previous summer, gained some experience in forecasting the weather.

In 1919 representatives of the fishing industry asked for gale warnings, but Vilhelm, as well as Jack Bjerknes, were at first hesitant to take on that responsibility as they lacked experience.

The atmospheric flow was represented with the help of streamlines on the maps, which was not practical when dealing with predicting wind increases and decreases. Bergeron, before arriving in Bergen, had spent 2½ months in practical weather service in Stockholm. He was familiar with the use of isobars and isallobars as tools in weather forecasting. In July 1919 it also became necessary to introduce isobars and isallobars in the Bergen weather service, much to the surprise of Halvor Solberg, who was now chief of the Oslo weather service. Solberg, on the other hand, was not responsible for any gale warnings. His principal problem was precipitation, especially oreigenic effects and the development of shower centres. Here the use of streamlines is practical.

It may be of some interest to note how the new ideas and concepts were gradually introduced during the first years of the Bergen School.

The fronts – or convergence lines – were not drawn on the map as we do now. The warm front was drawn blue, instead of red, as it also represented the streamline of the cold air immediately in front of the warm air flow. Analogously the cold front was drawn red. In the summer of 1919 Rossby remarked that it would be much better to change the two colours – this was done.

Later, the symbols for warm and cold fronts in black print were proposed by Bergeron on a postcard to Jack Bjerknes sent from Leipzig and dated 8 January 1924 (JEWELL, 1979, see also Jewell's article in the present volume).

The cold front was called *squall line* by Jack Bjerknes. This front had been described previously, e.g. Köppen and Clement Ley. The warm front was called *steering line*. In Jack Bjerknes's cyclone model of 1919 (in reality the model of the unoccluded cyclone) the tangent to the warm front in the centre of the cyclone was supposed to be oriented in the direction of the motion of the cyclone. The terms convergence line of the first kind (= warm front) and of the second kind (= cold front) were also used at Bergen, probably introduced by Bergeron.

The term front seems to have been coined at the end of 1919 – the war had ended one year previously and the name seemed suitable. The terms warm front and cold front then seemed logical.

The British meteorologists Lempfert and Shaw had used the terms polar and equatorial air, corresponding to the polar and tropical air of the Bergen group. The boundary between the two air masses might then logically be called the polar front. The Arctic air and the Arctic front had not yet been classified or discovered on the maps. These terms were used for the first time by Bergeron in 1928 (L.P. No. 6).

The occlusion process and the occlusion front were discovered by Bergeron on 18 November 1919. He had for some time awaited a situation to arise when the cold front would catch up with the warm front. This was observed by him on the map of 18 November 1919. On the following night Bergeron sketched a vertical section to illustrate his ideas, viz. how the cold front climbs up over the warm front surface. The weather map of 18 November 1919, 18 GMT, is seen in the articles by BERGERON and JEWELL. Note, however, the front symbols used here. The warm front occlusion is situated along the Norwegian coast – more or less – while the upper cold front stretches southwards over Sweden. The phenomenon of seclusion, seen in the upper part of the map, was soon given up as unrealistic.

Jack Bjerknes did not approve of any modifications to his cyclone model and was especially definite on the point that the steering line (warm front) should have the correct orientation, viz. in the cyclone centre in the direction of the cyclone motion. With the occlusion process included, the different stages in the life history of a cyclone were introduced. However, Jack Bjerknes did not like the new concept, to begin with, but gradually accepted it and he and Bergeron often discussed the dynamic implications. Here Jack Bjerknes had an advantage over Bergeron, as he was better trained in hydrodynamics.

It is otherwise difficult to state who did this discovery or that, or who coined this term or that, etc. in the Bergen group. The young meteorologists worked in a group.

The next discovery was the cyclone family. Jack Bjerknes, Solberg and Bergeron had all seen cyclone families on the weather maps. In 1922 Jack Bjerknes and Solberg published *Life Cycle of Cyclones and the Polar Front. Theory of Atmospheric Circulation* (BJERKNES and SOLBERG, 1922). The occlusion process was presented here for the first time – but Bergeron was not even mentioned.

From the summer of 1919 may further be mentioned the look out for cloud systems. Similar observations had also been made in 1918, but were now done with greater zest and from a more suitable observation post, viz. from a mountain, Lyder Horn, 400 m above sea level. The weather service in Bergen was contacted by telephone and informed at an early stage. Bergeron spent an interesting fortnight here.

Back in Norway, 1922–23

Bergeron left Bergen soon before Christmas 1919 and did not return until 1922. Before returning to Bergen in 1922 he stayed for a few weeks, in February, at a health resort on a hill, Voksenkollen, 470 m above sea level, to the north of Oslo close to the better-known Holmenkollen.

The hill was often enclosed in Stratus clouds – here appearing as fog. On his walks along the narrow roads in the fir forest covering the hill Bergeron noted that the fog did not reach into the forest when the temperature was well below freezing, $-5°$ to $-10°C$. However, at temperatures above freezing the fog penetrated into the forest and along the road, see Fig. 1 with sketch from Bergeron's autobiographical notes (L.P. Nos. 71 and 75).

Bergeron knew that the saturation pressure of water vapour over ice is lower than over water at sub-freezing temperatures, and relatively much lower the lower the temperature. With humid air and temperatures well below 0°C there must take place a transfer, by diffusion, of water vapour from the droplets in the fog to the snow-covered firs. At temperatures above freezing such a transfer is not at hand, interception of the droplets assumed the same in both cases.

In the following years he observed phenomena which might add weight to his hypothesis, but he did not publish anything on the matter until 1928 in his doctor's thesis (L.P. No. 6). This thesis was written in German and his considerations on ice-nuclei occupied only a section and were not noticed. In practice, eleven years were to pass before his ideas on the release of precipitation by ice-nuclei attracted any attention, i.e. the meteorological effects arising from the difference in saturation pressure of water vapour over water and ice at sub-freezing temperatures. The ice-nucleus theory – or rather hypothesis – was presented at the meeting of the Union of Geodesy and Geophysics in Lisbon in September 1933 (L.P. No. 13).

In May 1922 Bergeron was back in Bergen, for ever as he then thought. His intention was, to begin with, to find practical methods for the air mass and front analysis.

Jack Bjerknes, the chief of the Bergen weather service, had one year's leave, and Bergeron acted as his substitute.

Among the meteorologists who worked in the weather service at that time and should be mentioned is the German G. Schinze. He was very careful in his analyses of the synoptic maps and created a good order in the map work. In 1926 Bergeron married Schinze's sister Elfriede Schinze.

In the previous years many foreign meteorologists had visited Bergen in order to