Tellus (1999), 51A-B, 4–12
Printed in UK – all rights reserved

TELLUS
ISSN 0280–6495
ISSN 0280–6509

Carl-Gustaf Rossby
The Stockholm period 1947–1957

By BERT BOLIN, *Department of Meteorology, Arrhenius Laboratory, University of Stockholm, S-10691, Stockholm, Sweden*

(Manuscript received 17 August 1998; in final form 28 September 1998)

1. Introduction

Few have had a more decisive influence on the development of meteorology in the world during the 20th century than Carl-Gustaf Rossby. This was of course basically due to his fundamental contributions in dynamic meteorology, but also to his ability to recognise quickly the importance of new findings not only in this special field but in the field of geosciences in general.

However, equally important was his profound interest in seeing the results of fundamental research developed into practical use. *"The proof of the pudding lies in eating it"* he often said. There are many examples of this attitude as will be seen from the following presentation.

Thirdly, Rossby also recognised early the fundamental importance of the atmospheric processes as being part of the interplay between the atmosphere, the oceans and the terrestrial systems, and that in doing so, simultaneous consideration must be given to physical, chemical and biological processes. In this way, he contributed greatly to biogeochemistry, and atmospheric chemistry in particular, becoming a research field of significance during the last decade of his life.

Norman Phillips (1998) has given a most interesting account of Carl-Gustaf Rossby's life with emphasis on his early years and particularly his way towards becoming the leading meteorologist in the United States by the end of the Second World War, and in doing so, focussing on the human being behind this remarkable career. Tor Bergeron (1958) and Horace Byers (1958) have recalled interesting details about his life in the *Rossby Memorial Volume*. I will limit my presentation to Rossby's expanding vision of meteorology and oceanography and his striving for realising it during his last 10 years, 1947–1957. Such an analysis must necessarily be somewhat subjective, as I primarily will base it on my own experience of the man in action. I knew him as his assistant and research associate at the University of Stockholm from 1948 until his death in 1957.

2. Why did Rossby leave the United States at the peak of his career?

The 2 years at the Department of Meteorology at the University of Chicago after the end of the war represented a culmination of Rossby's scientific and organisational skills as developed before and during the war. He brought together scientists from many parts of the world as a preparation for the expansion of meteorology in a post-war society. The Department was indeed a buoyant place. Why did he then leave Chicago in 1947? Why did he want to return to Europe that had been so severely struck by a devastating war? Why would he move to Sweden with its very limited resources?

We will never have the complete answers to these questions, but in the midst of Rossby's restless mind, one could also find an admiration for European culture and traditions. He undoubtedly saw the challenge of trying to develop

meteorology and oceanography in "his old Europe" on the basis of the dynamic evolution that he had led in the US, and wanted to face up to it. And he loved his native country. He had spent many summers as a boy on the isle of Gotland, where his family had occupied one of the ancient buildings in the medieval town of Visby. He often returned to Gotland during his years in Sweden and liked to bring visitors to that "Pearl of the Baltic Sea", particularly when the orchids flowered in the meadows in springtime.

He may also have had the wish to reduce his engagements and to live a somewhat more quiet life. The creation of that unique institution in Chicago in just about 7 years had undoubtedly been a strain on his health. But the paradox then is that his constant wish to meet new people and new challenges led him rather to develop a third leading research institution, after having established the Departments of Meteorology at MIT in Cambridge in the 1930s and at University of Chicago in the 1940s. His reputation in the US quickly flew across the Atlantic Ocean. He soon knew a number of key personalities in meteorology and oceanography in Europe.

3. Developing meteorology in Sweden

Rossby's career in the United States during the 1930s was soon noticed in Sweden and he was approached just before the war by some leading scientists in meteorology and oceanography in an attempt to bring him back "home". Obviously, the time was not ripe for that move and the need for meteorological information and services in the war effort rather became his major challenge.

Sweden was never drawn into the war but was still in the midst of it, being surrounded by fighting nations. The need for meteorological information for the military forces was obvious and the prospects of an expanding civilian air traffic was quickly recognised when the war was over. Rossby was invited to Stockholm in 1946 by Harald Norinder, Professor of high-voltage research at the University of Uppsala, who had been given the task by the Swedish Government to advise on how to strengthen meteorological training and research in Sweden. Rossby expressed the view to build such an effort around available skills within the country and he emphasised, on the basis of his experience from the United States, that this should be done in a university setting. Furthermore, theory and observations should go hand in hand. He proposed that an additional Chair in Meteorology be created at the University of Uppsala for Tor Bergeron, a key member of the Bergen school. Hilding Köhler, a cloud physicist, theoretician and Professor of Meteorology in Uppsala for about a decade, and Bergeron were to be given the task of developing research as well as undergraduate and graduate training in meteorology in Sweden. Rossby stressed that services to aviation and the development of instruments were also important tasks.

Almost as an afterthought Norinder's proposal to the Swedish Government for expanding resources for meteorology in Sweden also included the idea of creating a special chair for Rossby at Stockholm's Högskola (University) with the task of introducing modern methods for weather forecasting into the Swedish Weather Service, i.e., the Swedish Meteorological and Hydrological Institute (SMHI). Only small resources for research and teaching were, however, proposed. What was needed should rather be provided for by the Weather Service.

I think that Rossby's willingness to start with quite limited resources was an expression of his wish not to be tied by the existing Swedish academic structures. He rather wanted to begin his European crusade from scratch by using some modest financial resources that he was able to bring with him from the United States, but otherwise with the intention to create what was required in the course of the process. It is also noteworthy that he was anxious to associate himself professionally with the Weather Service, even though he formally also would be Professor at the Stockholms Högskola. These arrangements were of course quite extraordinary and would only temporarily slow down the hectic life that he had lived in Chicago during the preceding years.

By and large Norinder's (and Rossby's) proposals were accepted. Rossby returned to Sweden in the fall of 1947 and began his activities with a lecture series at the Weather Service, using his famous paper of 1939 on the long waves in the westerlies (Rossby, 1939) and the recently published paper by Staff of the Department of Meteorology in Chicago (1947), as his starting point. He later also addressed the theoretically

more advanced issue of the interactions between the "Rossby"-waves and inertia-gravity waves. In this context, it is of interest to recall how clear Rossby already was about the interplay of motions in the atmosphere of different kinds and origin. In an address to the Third Hydraulics Conference in Iowa in 1946, he had said the following about numerical weather forecasting (Rossby, 1947): *"... the general hydrodynamic equations upon which such a computational approach would have to be based, contain within them a variety of phenomena, from acoustic waves to the large-scale permanent trade systems of the atmosphere, that these equations themselves, without additional specifications, cannot be expected to provide an adequate starting point for a computational attack."*

I attended this series of lectures while carrying out my compulsory military service at the Swedish Air Force and I was asked to summarise his talks for a group of meteorologists at the Headquarters. In retrospect, it is obvious that Rossby with these initial lectures laid the foundation for recognition and more close collaboration with the people engaged in the practical application of meteorological research both in the civilian and military weather services. Within a couple of years, he was also better known outside the meteorological profession than his two colleagues at Uppsala.

To begin with, Rossby had no Swedish students at undergraduate or graduate level, nor had as yet any foreign students been invited to Sweden. What did he then do? Well, he was still deeply engaged in what happened in the United States. Every week he received letters from all over the US. There were those from staff members or graduate students in Chicago, particularly long and detailed letters from George Platzman, that all tell about an unusual respect and devotion to the absent master. And Rossby still felt a responsibility for visitors to Chicago, that he had invited before he left for Sweden. He kept in touch with Jule Charney, who was in Oslo, preparing for his new job in Princeton, where the development of numerical weather forecasting was getting under way. Rossby was frequently in communication with Francis Reichelderfer, head of the US Weather Bureau. He was informed about what happened at MIT, with Hurd Willett, H. G. Houghton and Victor Starr in the lead. The contacts with the Woods Hole Oceanographic Institution, F. C. Fuglister, Columbus Iselin and Henry Stommel, were dear to him. He was consulted by the American Meteorological Society on urgent matters and he took a great deal of interest in the affairs of the National Academy of Sciences. He was as much engaged in the development of US meteorology as in getting started on the European side of the Atlantic.

Rossby also started the scientific journal *Tellus*. Even if at the beginning, more than 50% of the articles in *Tellus* dealt with meteorological issues, it is interesting to note that this was intended to be a geophysical journal. This was an expression of Rossby's wish to view meteorology in a wider perspective. It is also obvious that a number of the papers in *Tellus* were solicited, and that to a considerable degree, it was intended to be an outlet for Rossby's ideas and the activities in Stockholm.

4. Developing relations within Europe

However, how to develop his new Stockholm base? Rather quickly, he settled on the idea of transforming the small Institute into a place where leading researchers as well as young scientists from Europe (and elsewhere) could meet and work with their counterparts from the US. This would also serve Swedish interests. The subject matter was primarily to be dynamic and synoptic meteorology and weather forecasting. Rossby received financial support from the US Weather Bureau through Reichelderfer and Harry Wexler, and he negotiated a contract with the Department of Meteorology in Chicago, that was financially supported by the Office of Naval Research (ONR) in the US, in order to get started with this idea. This support gave him, as he formulated it, *"the opportunity and mandate to assist in the re-establishment of scientific contacts (in Europe) that were intercepted or destroyed during the war"*. This should also be attractive to the ONR in that, as Rossby pointed out: *"It is suggested that the maintenance of international scientific exchange is a necessary requirement for the continued development of a strong school of meteorology in the United States and is therefore, of direct interest to the US Navy as an operating agency."* Dan Rex from the ONR was assigned to Stockholm as a graduate student and served as a liaison officer.

Thus, the building of the Institute was to serve

the dual purpose of strengthening European meteorology and improving the US knowledge about the European meteorological profession. An example of this dual rôle was his visit to East Germany in November 1949. All travel arrangements were taken care of by the US Embassy and Rossby afterwards wrote a report to appropriate institutions in the US. He was, however, also genuinely interested in establishing professional contacts with the Academy of Sciences in East Berlin and in particular Hans Ertel (with whom he published the theorem of the conservation of potential vorticity, Ertel and Rossby, (1949)). Through these arrangements, a good number of European scientists were also given an opportunity to spend some time in the US, however, after having in a way "been screened" in Stockholm.

Rossby's early contacts with Finland (Erik Palmén) and Norway (Arnt Eliasen, Ragnar Fjörtoft and Einar Höiland) were gradually widened to include Austria (Albert Defant, and Heinz Reuter), Belgium (Jacque van Mieghem), England (Eric Eady, Peter Shepherd and Reginald Sutcliffe), France (Paul Queney), Germany (Karl Hinkelmann, Ernst Kleinschmidt, Paul Raetjen), The Netherlands (W. Bleeker). From the US he brought in Horace Byers (Chicago), Jerome Namias (US Weather Bureau long-range forecasting office), Morris Neiburger (University of California, Los Angeles), and in 1951, Chester and Harriet Newton from Chicago.

After merely a few years, the development of the Stockholm Institute was obviously under way, but the situation was financially not stable, being based primarily on temporary and sometimes short-term arrangements. How should the Institute attain international recognition? While Rossby was pondering about this, he was also under pressure to return permanently to the US. He was still employed at the University of Chicago, and only on temporary leave. Many wanted him back in Chicago. Houghton (MIT) tried to convince him that he should accept an offer to become Director of the Air Force Research Laboratories in Massachusetts.

Above all John von Neumann, head of the project for developing electronic computers at the Institute for Advanced Studies in Princeton and a most distinguished mathematician, and Jule Charney, in charge of the project on numerical weather forecasting, wanted Rossby to become a permanent member of the research staff at the Institute, at that time under the directorship of Robert Oppenheimer. Charney wrote (in March 1949) a very pleading letter to Rossby, which he ended by saying: *"Your coming would do more to establish a liaison with other mathematical and physical sciences than all the dry ice in Scenectady."* The remark about dry ice referred to the attempts by Vincent Schäffer to induce precipitation artificially, which was a hot issue at the time, and it interested Rossby a great deal, but obviously not Charney. Rossby did not accept anyone of these invitations. He felt his presence in Europe was more than a purely scientific challenge.

5. The creation of an International Meteorological Institute in Stockholm

By 1950, Rossby was quite well established in Sweden. He had been elected member of the Royal Swedish Academy of Sciences, he had become acquainted with Professor Bertil Lindblad, Chairman of the Science Research Council in Sweden, as well as Torsten Gustafsson, Professor of Physics at the University of Lund, a close friend of the Swedish Prime Minister, Tage Erlander. He also knew Rickard Sandler, the senior member of the First Chamber of the Parliament, social democrat and former Foreign Secretary, as well as the Under-Secretary in the Ministry for Research and Education, Ragnar Edenman. Some strings could now be pulled.

Rossby's idea was to get UNESCO to acknowledge the Institute in Stockholm as an International Research Institute and to approach some US foundations with a request for financial support, primarily the Rockefeller and the MUNITALP Foundations. He estimated that an annual budget of about $200,000 would ultimately be needed (corresponding to at least about $5 million today). This was about 25 times the support that the Institute received from the Swedish Government through the Stockholm Högskola. The Swedish Government offered 500,000 Swedish Crowns (about $100,000) to provide for a building. Rossby could also muster support from several European countries (he suggested, for example, to the Italians that the Swedish Institute on the isle of Capri in Italy could house a subsidiary to the Stockholm

Institute). And he had support from Reichelderfer at the US Weather Bureau. But his British colleagues did not like the proposal and their objections were supported by the French delegates to the UNESCO Conference. The proposal was not accepted, but referred to the WMO.

However, Rossby did not give up. The analysis by WMO did not help much, but the real blow came when the US changed its view. The chief of the US Weather Bureau, Reichelderfer, was very disappointed about the instructions that he received from the US Government and refused to go to the 1951 UNESCO session in Paris. I do not know the reasons for the change of the US attitude. The resistance in Europe, however, was partly due to disbelief amongst meteorologists in the UK in Rossby's efforts to develop numerical weather forecasting (above all by Richard Scorer and the head of the UK Meteorological Office, Sir Nelson Johnson). Rivalry was probably also part of the resistance.

Rossby commented on this issue in a letter: *"I do not wish to admit defeat"*. He continued to pursue his efforts in Sweden. The Swedish Government appointed a committee (later changed to become the Governing Board of the Institute) under the chairmanship of Sandler. Plans for expanded activities in 1952 were developed. Resources were still primarily coming from the US, even though the Swedish Science Research Council and some private funds also provided some support.

By 1954, activities had expanded further, and Rossby was deeply engaged in the development of atmospheric chemistry and cloud physics. The Board then understood that a formal international acceptance of the Institute would not be achievable in the near future. Sandler was able to convince the Prime Minister that the best approach would rather be to establish core funding from the Swedish Government and then gradually get the formal acceptance as a "fait accompli". The proposal from the Board was agreed upon by the Riksdagen (Parliament) in the spring of 1955. As of the first of July of that year, the International Meteorological Institute in Stockholm (IMI) became an independent research institution with direct financial support from the Swedish Government, but still closely associated with the Stockholm's Högskola.

Few of the visitors to the Institute during this time knew much about this play in the background. Rossby was at times deeply disturbed about this bureaucracy, but let this seldom be known. Research activities developed rapidly at the Institute. My presentation will next discuss these activities against the background just described.

6. Numerical weather forecasting

Rossby's scientific achievements before going to Sweden had primarily been in the field of dynamical meteorology and oceanography, particularly related to the large-scale motions and the general circulation of the atmosphere and the oceans, and he retained this interest throughout his life. He devoted a good part of his overview article, *"Current Problems in Meteorology"* to this topic. The article was written for the Swedish Science Research Council and was actually Rossby's last written scientific contribution (Rossby, 1956, 1959). I note, however, that his last paper on the dynamics of the atmosphere or the oceans was already submitted for publication in 1950.

Still, he was deeply engaged in the development of numerical weather forecasting and remained in close contact with Charney at the Institute for Advanced Studies in Princeton (cf. Phillips, 1998). He did, however, not write a single paper on the subject but had anyhow a profound influence on the development. This can clearly be seen from the account given by Wiin Nielsen (1997) of how numerical weather forecasting developed during the 20th century.

Charney was very fond of Rossby as can be sensed in a letter written in March 1951, *"I suppose co-operation is a rare thing, and this makes me certain of one thing, that I will get to Sweden even if I had to ski all the way."* He did not think that John von Neuman knew the dynamics of the atmosphere well, but he was still confident about the work he was doing: *"The Princeton project is the nobodies child of meteorology, but the orphan shows surprising potentialities for growth, even in an unfavourable environment."*

However, Rossby's interest in numerical forecasting was not exclusively scientific. He wanted to see this new technique be used in the weather services as soon as possible. He was fortunate in that the Technical Research Council

in Sweden in the late 1940s had sent 6 engineers to the US to explore the possibilities offered by the new computers, one of whom, Erik Stemme, went to Princeton. When he returned to Sweden in 1950 he was given the responsibility of developing the first Swedish electronic computer, BESK, which was similar to that which just had been completed in Princeton. It became operational in 1953 and was supposed to be one of the very fastest computers in the world at that time.

I went to Princeton 1953 for a second visit with Charney. Rossby engaged Germund Dahlquist, later Professor of Numerical Analysis at the Royal Institute of Technology in Stockholm, as the leading mathematician of the Stockholm group, and in 1953, Norman Phillips was invited to develop the computer programme for the barotropic model. In the course of that year, a number of experiments were carried out to test the model (cf. Staff Members, Institute of Meteorology, University of Stockholm, 1954). This all made it possible to launch the project, *"The use of computers in weather forecasting"* in the fall that year.

A real time experiment was organised. The Air Force Weather Service arranged for the logistics required, being more flexible and therefore able to supply quickly the necessary resources than the Weather Service. They prepared the weather maps, which were sent by a military courier to the computer in the centre of the city, where the initial data were extracted. One- and two-day forecasts were made in the course of the night and returned to the Air Force early in the morning to be used in predicting the weather for the next 2 days. The experiment was run for 10 days, but could of course not be maintained in this voluntary manner. This effort made headlines in the newspapers, which Rossby could exploit later.

7. Oceanography

Rossby recognised early the similarities between the dynamics of the atmosphere and the oceans. His dual rôle at MIT and in Woods Hole in the 1930s is an expression of this. To begin with, however, oceanography was not given priority in the development of a research programme in Stockholm, although he kept in close touch with leading oceanographers in the US, e.g., Walter Munk and Henry Stommel. However, when a remarkable north-westerly storm in 1954 flooded the coasts of The Netherlands and Germany causing severe damage, Rossby became engaged. With his usual energy, he quickly established a research team at the Institute in collaboration with Walter Hansen at the University of Hamburg. A young student of his, Heinz-Otto Kreiss, was engaged, and studies of water-level variations in coastal regions and estuaries were put on the agenda of the Institute. At about that same time, Rossby also convinced Pierre Welander to engage himself in geophysical fluid dynamics rather than continuing his work on the kinetic theory of gases, that had been the theme for his PhD thesis. Both these "acquisitions" to the Institute illustrate Rossby's remarkable ability to attract highly skilful scientists from other fields of the sciences into geophysics.

8. Cloud physics

Rossby also became fascinated by the possibility of artificial precipitation, but he was not primarily interested in the fundamental aspects of the science, but rather how to exploit this technique. The financial support that he received (to engage Vincent Schäfer from the US and Frank Ludlam from England) came from the MUNITALP Foundation in US and the Technical Sciences Research Council in Sweden. Schäfer and Ludlam were the key persons at a Conference in October 1952, but Rossby also tried to interest representatives of the development of hydro-power in Sweden. He invited them to the Conference and arranged a dinner party one evening, which later resulted in some financial support for the practical aspects of the problem. This money was later also used to explore the possibility to enhance melting of snow and simultaneously to reduce evaporation, however, without much success.

Ludlam argued that convection in mountainous regions might be a first suitable target for some field studies and Rossby was able to obtain the necessary support to launch a major campaign in central Sweden (Jämtland) in the summer of 1955. He also wanted to make use of the experience gained in the field of numerical weather forecasting to develop numerical models for the dynamics of convective clouds. This task was pursued by

Joanne Malkus from the US and George Witt, a young refugee from Hungary.

It so happened that the summer of 1955 was one of the driest summers in central Sweden for a long time and hardly any results were obtained. The clear skies during the nights, however, offered excellent opportunities to observe the "mysterious" noctilucent clouds that appear rather frequently in late July and early August. There was not going to be any further field studies of tropospheric clouds, but Witt became interested in trying to understand the physics of noctilucent cloud formation, and this became a research topic at the Institute for a number of years to come. Studies of the stratosphere and the mesosphere at the Institute were initiated in this way.

9. The rôle of the atmosphere in biogeochemistry

In the spring of 1952, Anders Ångström (Director General of the Swedish Weather Bureau) and Linus Högberg published an article (Ångström and Högberg, 1952) in *Tellus*, which caught Rossby's interest. The data base for the analysis in the paper had been brought together by Hans Egnér, Professor of Soil Science at the Ultuna Agricultural College at Uppsala, and his assistant Erik Eriksson. The paper described deposition of fixed nitrogen over Sweden, but Rossby quickly recognised the importance of viewing this issue in a global perspective. In a letter to Eriksson in the summer that same year, he estimated the global depositions of nitrogen to about 50 million tons per year and asked the questions: From where does this come? How important is this transfer of nutrients for the natural ecosystems, forestry and agriculture? What is the importance of human-induced emissions for the circulation of fixed nitrogen? Air pollution had since long been an important meteorological topic, but the possible importance of the *natural* circulation of chemicals through the atmosphere had really not been recognised earlier in a global context.

Rossby was at the time engaged in planning a Conference in October 1952, and in addition to weather forecasting and cloud physics, he now added *"The nitrogen cycle in the atmosphere"* as a third theme on the programme. Rossby extended invitations to the Conference in personal letters to everyone that he thought might contribute and he financed their travel. He approached Artturi Virtanen, biochemist in Finland and Nobel laureate in chemistry. Christian Junge came from Germany to present an analysis of the rôle of aerosols for trace gases in the atmosphere, and Rossby's good old friend Olle Arrhenius, son of Svante Arrhenius, talked about chemical soil denudation in Sweden. The issue was broadened and this Conference constituted a major step towards the initiation of atmospheric chemistry as a central research topic at the Institute. It represented the beginning of studying the rôle of large-scale atmospheric processes in biogeochemistry.

Rossby was attracted by this research topic, because of its fundamental character and that it tied the atmospheric sciences closer to the broad field of biogeochemistry, but he also considered it important because of its likely practical significance for agriculture and forestry. He also seized on the idea that analyses of the chemical stratification in peat bogs might be used to deduce the past chemical climate. Within a few years, a network of stations for collecting aerosols and rainwater for chemical analysis had been established in north-western Europe, and field work in a Swedish peat bog began. It did not take long either before Erik Eriksson was employed at the Institute.

Rossby has summarised his views about atmospheric chemistry in his 1956 overview article, *"Current problems in meteorology"* (Rossby, 1956, 1959). He discussed at length the spatial distribution of the ratio of basic elements in precipitation, attempting to distinguish between natural and human-induced emissions. He showed that sulphur in the atmosphere to a significant part must be of industrial origin and already noted then the low pH-values in rain water that occasionally were observed in south-west Sweden. He did not, however, recognise the threat that acid precipitation might represent to terrestrial and limnic ecosystems. It actually took 10 years until Svante Odén drew that conclusion, based on data for more than 10 years from the network of stations that Rossby initiated in the middle of the 1950s, however, also having directly observed changes of the acidity of lakes and soils.

Since well before the war, Rossby had been interested in the possible increase of carbon dioxide in the atmosphere and its implications for the earth's climate. He knew Karl Buch from Finland who had participated in the German oceanographic cruise

with "Meteor" in the 1930s and studied the carbonate system in the sea. Roger Revelle of the Scripps Oceanographic Institute, the leading US scientist in the field, was also a good friend of Rossby, which undoubtedly was important when he now engaged himself anew in Stockholm. The first plans for the International Geophysical Year (IGY) 1957–58 were being drawn up and Rossby wanted to see a Swedish expedition go to Svalbard (Spitsbergen) in order to gather chemical observations including carbon dioxide from pristine regions. An increase of carbon dioxide in the atmosphere had not yet been established, because accurate analytical methods for measuring carbon dioxide concentrations were not available. It would take until 1957 before Keeling could present a reliable technique and a few years later show that atmospheric concentrations were steadily increasing. However, Rossby's interest in the issue stimulated me to get to grips with some of the key scientific issues. He told me after my dissertation on numerical weather forecasting in 1956: *"You should change gear now and try to determine the residence times for different elements in the atmosphere."* This piece of advice meant much when I later set my own research priorities.

Rossby's engagement in atmospheric chemistry was also partly due to the recognition of the usefulness of radioactive tracers for atmospheric studies and observations that the ongoing nuclear bomb testing changed the concentrations of those naturally occurring. C14 would obviously be important for studies of the carbon cycle and H3, tritium, would tag the water molecules. New kinds of data had suddenly become available and could be useful for atmospheric and oceanographic studies. This should be seized upon. His close association with Roger Revelle implied that he knew early about the work of using C14 as a tracer for sea water that was pursued at the Scripps Institution of Oceanography and he convinced the leading researchers in the field (Harmon Craig; Roger Revelle and Hans Suess; and J. Arnold and E. Anderson) to publish their first applications of this technique to ocean circulation studies in *Tellus* (Vol. **9**, 1957). A C14 laboratory was under development at the Swedish Geological Survey and Rossby had soon interested the man in charge, Göte Östlund, to take an interest in the geophysical and geochemical problems that might be addressed with the aid of this new technique. Another acquisition for the geosciences had been achieved.

10. Concluding remarks

Carl-Gustaf Rossby was indeed a unique person. I was particularly struck by his deep engagement in fundamental scientific research in meteorology and oceanography, and simultaneously being wholeheartedly devoted to the application of his research results to practical issues in society and willing to set aside a substantial part of his time to achieve this. Few have started with an advanced degree in mathematics and theoretical physics to become a pioneer in attempting to bring together geophysics and geochemistry into a unified field for scientific exploration of global issues. And finally, Rossby's unique appreciation of global interactions as gained from studies of the general atmospheric and oceanic circulation was invaluable for his widening of the often limited local or regional views of the atmosphere and the oceans in order rather to consider global issues. This approach has been instrumental in providing a basis for later addressing the truly global environmental issues.

One of the most important characteristics of a first class scientist is undoubtedly his or her capability to judge intuitively what is important and what is less so. Rossby indeed constantly exercised this quality. But he was also adventurous and not all of his initiatives succeeded. Furthermore, his readiness to accept reality and put the issue behind himself was another equally necessary quality in order not to waste time and efforts.

His remarkable achievement to create a leading research Institute in Stockholm also naturally implied that he had become deeply emotionally engaged in the further development of the activities in Sweden. But again, in 1956, he sensed that he had to slow down his rather hectic life. He decided to go back to the US for 8 months and to spend most of this time at the Woods Hole Oceanographic Institution. I was asked to be his deputy, having received my PhD less than half a year earlier. In retrospect I do not think that I really understood the magnitude of the task that was handed over to me. There was at that time at the Institute a sizeable group of young Scandinavian researchers and more than half a dozen visitors from all over the world engaged in research in many different fields. But Rossby was available by mail.

I remember the saying in Chicago, when I spent

5 months there in 1950, that Rossby never answered letters. Even his close friend Palmén could sometimes complain, but of course then in his humorous and slightly ironic manner as when he writes (in the summer of 1950): *"I have since long had a bad conscience because I seem to have succeeded you in your rôle of not answering letters."* The truth is that Rossby was quite selective in his correspondence, but he indeed wrote very many letters. During his absence in the US 1956/57, he was obviously anxious to help me as his deputy. The Institute was close to his heart. During this period of time, I received 29 letters, all written by hand, and summing up to altogether about 140 pages.

Rossby and his wife ended their return to America with a visit to Mexico and were overwhelmed. They saw the recently completed university in Mexico City, visited a number of historical sites and were fascinated by the Mexican culture. It is not surprising that Rossby wanted to develop some co-operation between the University of Mexico and the Institute in Stockholm. He had long been interested in tropical problems. During his time in Chicago, he had initiated field activities in Puerto Rico. In trying to reach international recognition for the Institute in Stockholm, he raised with the WMO in the early 1950s the issue of improving weather forecasting in the tropics.

Maybe he had some dreams about working in the tropics. I recall what Byers wrote about Rossby after his death: *"During the months before he died, the great master was thinking about other areas where he could practice his magic touch. He thought of the Middle East. Yes, he was going to settle in that area and found an Institute of Meteorology, where the regional needs for scientific development could be met, and met by the dynamic impact of Rossby. One can only conjecture what would have happened in that rapidly awakening region had Rossby lived another 10 years."* There is, however, nothing in his correspondence, that I have had access to, that confirms this statement. It was apparently still largely a dream. But dreams can be developed into reality. The whole life of Rossby was filled with attempts to realize his dreams. And he often succeeded.

Rossby was a remarkable human being. He was full of ideas, constantly on the move, charming and with a good sense of humour, enthusiastic in his manner of convincing people of the importance of what he wanted to do and generous in his relation to people. He had a remarkable influence on many and I know that my own life would have been very different if not having encountered him early in my life and had the opportunity to work with him for 10 years.

REFERENCES

Ångström, A. and Högberg, L. 1952. On the content of nitrogen (NH_4–N and NO_3–N) in atmospheric precipitation. *Tellus* **4**, 31–42.

Bergeron, T. 1958. The young Carl-Gustaf Rossby. In B. Bolin (ed.): *The atmosphere and the sea in motion*, pp. 51–55. The Rockefeller Institute Press, New York.

Byers, H. 1958. Carl-Gustaf Rossby, the organizer. In B. Bolin (ed.): *The atmosphere and the sea in motion*, pp. 56–59. The Rockefeller Institute Press, New York.

Ertel, H. and Rossby, C.-G. 1949. A new conservation theorem of hydrodynamics. *Geofisica Pura e Applicata* **16**, 189–195.

Phillips, N. 1998. Carl-Gustaf Rossby: his times, personality, and actions. *Bull. Am. Meteorol. Soc.* **79**, 1097–1112.

Rossby, C.-G. 1939. Relation between variations in the intensity of the zonal circulation of the atmosphere and the displacement of the semi-permanent centers of action. *J. Marine Res.* **2**, 38–55.

Rossby, C.-G. 1947. Recent advances and probable future trends in basic and applied meteorology. *Proc. of the Third Hydraulics Conf., Bull.* **31**, Univ. of Iowa Studies in Engeneering, pp. 103–120.

Rossby, C.-G. 1956. Aktuella meteorologiska problem. In: *Svensk Naturvetenskap*. Statens Naturvetenskapliga Forskningsråd, Stockholm.

Rossby, C.-G. 1959. Current problems in meteorology. In B. Bolin: (ed.): *The atmosphere and sea in motion*, pp. 9–50. Rockefeller Institute Press, New York.

Staff of the Deptartment of Meteorology, University of Chicago, 1947. On the general circulation of the atmosphere in the middle latitudes. *Bull. Am. Meteorol. Soc.* **28**, 255–280.

Staff Members, Institute of Meteorology, University of Stockholm, 1954. Review of forecasting with the barotropic model on an electronic computer (BESK *Tellus* **6**, 139–149.

Wiin Nielsen, A. 1997. Everybody talks about it ... *Matematisk-fysiske Meddelelser* **44**:4. The Royal Danish Academy of Sciences and Letters. Commissioner: Munksgaard-Copenhagen, 96 pp.