A Tribute to the Memory of

Carl-Gustaf Rossby

1898–1957

by Professor Sverker Sörlin

Royal Swedish Academy of Engineering Sciences (IVA)

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Presented at the 2015 Annual Meeting
of the Royal Swedish Academy of Engineering Sciences

by Professor Sverker Sörlin

The Royal Swedish Academy of Engineering Sciences (IVA) is an independent, learned society that promotes the engineering and economic sciences and the development of industry for the benefit of Swedish society. In cooperation with the business and academic communities, the Academy initiates and proposes measures designed to strengthen Sweden's industrial skills base and competitiveness.

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Foreword

Each year the Royal Swedish Academy of Engineering Sciences (IVA) produces a booklet commemorating a person whose scientific, engineering, economic or industrial achievements were of significant benefit to the society of his or her day. The Commemorative Booklet is published in conjunction with the Academy's Annual Meeting.

This year's Booklet is dedicated to Professor Carl-Gustaf Rossby (1898–1957), meteorologist and the first person to succeed in explaining the large-scale movements in the Earth's atmosphere. Today we call these *Rossby waves*.

Atmospheric Man

IVA would like to recognise Rossby's research on atmospheric thermodynamics, computer-based forecasts and atmospheric chemistry, all of which have laid the foundation for the role of meteorology as a key science to map far-reaching air pollution and climate change, and to improve air traffic safety.

We wish to express our sincere gratitude to the author, Professor Sverker Sörlin, for all of his work on this year's Commemorative Booklet.

Stockholm, 23 October 2015

Björn O. Nilsson
President of the Academy

Arne Kaijser
Chairman of the Medals Committee

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Atmospheric Man

Today meteorology is something we take for granted in society and in our everyday lives. We encounter it in weather forecasts and warnings communicated to us in various media. It is crucial for sectors such as fishing and agriculture, and its data and forecasts are used in aviation and shipping. It also has a critical role in modern climate change science.

Knowledge of the weather and wind is as old as the human race, but the roots of modern meteorology are usually tied to an event during the Crimean War in 1854 when the French-British fleet was badly damaged by a storm over the Black Sea that had raged over Western Europe a few days earlier. It had been possible to track the storm's easterly course and people realised that it would have been possible to send a warning by telegraph. This marked the beginning of the systematic gathering and coordination of observations – something that had been mostly sporadic up until then. In Sweden, for example, temperature series from Uppsala have been saved since 1722 and from Observatoriekullen (Observation Hill) in Stockholm since 1756. The needs of the armed forces have remained an important incentive for weather forecast information, but civil weather services were also starting to emerge from the end of the 1800s. What is now called the Swedish Meteorological and Hydrological Institute, (then *Meteorologiska Centralanstalten, SMHA*) was created in 1873.

Early on Scandinavia became a hub for meteorology and atmospheric science. One of the leading figures in this development was Swedish-born Carl-Gustaf Rossby. In December 1956 his portrait graced the cover of *Time Magazine,* and inside the writer did

The Observatory in Stockholm was opened in 1753 and its famous series of weather observations, with the longest unbroken series of daily temperature measurements in the world, started in 1756. This image shows the ascent of a 33 cubic metre hydrogen balloon in September 1784. The balloon ascent, the à la mode divertissement in Europe at the time, was witnessed on Observatory Hill by the King Gustav III together with many citizens of Stockholm. On board a cat was placed, as an experimental device. The crashed balloon was found on an island outside Stockholm a few weeks later – the only missing piece was the cat.

not mince words: "The history of modern meteorology is inescapably paralleled by Rossby's career." This was at the time of the breakthrough for computerised weather forecasts, the beginning of the jet aircraft era and the height of the Cold War, and Rossby had a role in all of them. To be heralded as the foremost expert in this field was remarkable and the fact that it was, of course, an American perspective that was expressed in *Time Magazine* did nothing to diminish this because the United States at the time had achieved a world-leading position, largely thanks to this "likable, high-spirited, round-faced Swede." Most of the leading meteorologists in the US and the world had at some point

been students or colleagues of Rossby and he himself had founded some of the world's foremost meteorological institutions.

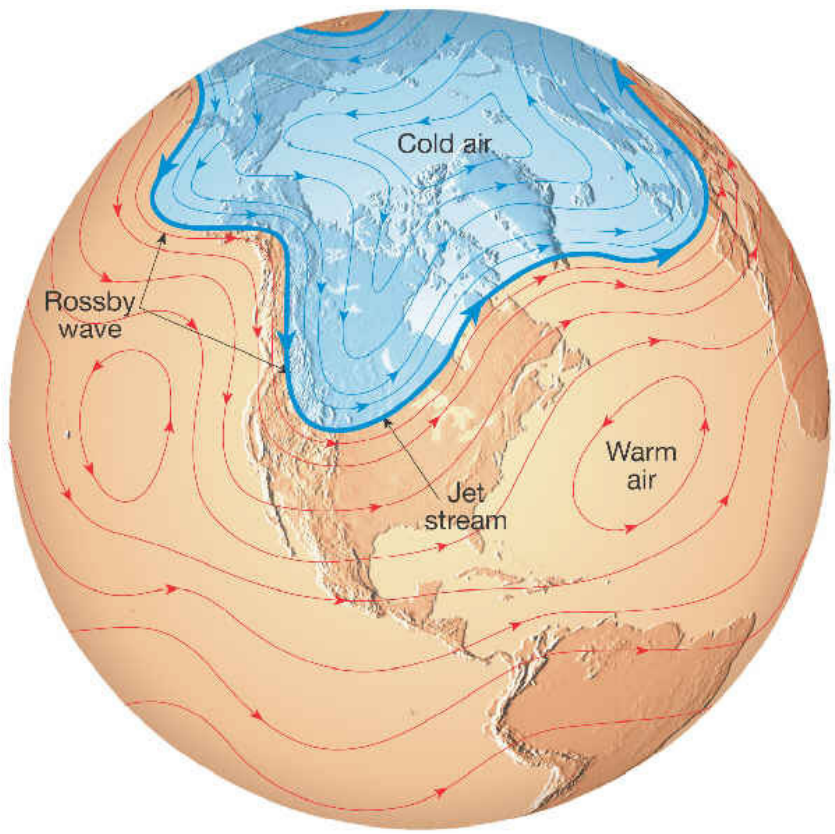
He lends his own name to the term Rossby waves – the most powerful waves in the atmosphere, which he identified and for which he developed a mathematical formula. His name also lives on in the Carl-Gustaf Rossby Research Medal, the highest award for atmospheric science in America. There is also the SMHI Rossby Centre in Norrköping. Other than this, more than a half century after his death, Rossby is not very well known, despite the fact that he was without doubt one of the most significant Swedish scientists of the 20th century and personally involved in some of the most important scientific discoveries in his field. He was also interested in the significance of greenhouse gases in global warming and took part in the discussions that led to the beginning of carbon dioxide measurement at the Mauna Loa observatory in Hawaii in 1957, resulting in the now well-known serrated curve (the Keeling Curve) – the iconic confirmation of the systematic rise in CO_2 levels. Rossby spent much of his career working on military motivated meteorology in the US and his research continued to play an important role in security policy there, even after he returned to his old homeland of Sweden in 1947.

As a young man, Rossby was already a skilful strategist and organiser, and over time he became a strong theorist as well – in that somewhat unusual order. He was a strong

team player. He surrounded himself with some of the world's foremost experts in applied mathematics. He also built an extensive international network and founded the *Tellus* journal in Stockholm in 1948, an important forum for what would become modern climate science in a key development phase. He was instrumental in founding the University of Chicago's Department of Meteorology (the "Chicago School") in the 1940s. In the 1950s he developed a programme in Stockholm that would help make the Swedish capital a world hub for numerical weather predictions and research in global climate and environmental change.

Rossby in Waikiki, Hawaii 1944, during a period when he traveled frequently to theatres of war in Asia, Africa and Europe commissioned by the US strategic war command. After the war he initiated work on climatological and meteorological projects in Hawaii in collaboration with the Pineapple Research Institute.

IPCC Chairman Bert Bolin, Rossby's student, was a prominent figure in this field. In many ways, Rossby was a phenomenon; at once a formidable idea factory, a mighty one-man institution who literally set the atmosphere of an entire planet in motion, and a reserved, sometimes mysterious figure who left few clear clues about his intensive commitments. How could he become one of Sweden's most important scientists in the 20th century? How can we understand and interpret his achievements?



Idealized airflow of the westerlies at the 500 millibar level. The five long-wavelength undulations, called Rossby waves, compose this flow. The jet stream is the fast core of this wavy flow.

European journeyman

Carl-Gustaf Rossby was born on 28 December 1898 in Stockholm, the eldest of five siblings – four brothers and one sister. Arvid, his father, was a construction engineer, his mother, Alma Charlotta, née Marelius, had roots in Gotland where her uncle was a pharmacist and where the family spent many summers. This was also where their son built his holiday paradise later in life. The family was not wealthy but they had enough money for the children to be educated. Carl-Gustaf's brother Åke, for example, became a prominent

Rossby playing Christmas carols for the Rossby 'clan' children at the Observatory Hill ca 1952.

High school graduation 1917 from the Classics program (latinlinjen).

cryptanalyst and bureau chief of the National Defence Radio Establishment *(Försvarets radioanstalt*, FRA). The young Carl-Gustaf was interested in a broad range of scientific fields, but was a humanities student in high school and learned Latin, the arts and music; he played the piano and was a fan of opera. He enjoyed engaging in discussion and was keen to drive arguments to their ultimate conclusion before abandoning them and admitting that it had all been a joke. He was proud. He preferred to hide his weaknesses and shortcomings and, outside the family circle, few people knew that under the restless, active exterior, beat an unreliable heart – the result of rheumatic fever when he was a boy. His heart was the reason he was excused from military service and also the reason his life came to an end suddenly one day in August 1957 at the desk where he had lived so much of it.

Rossby's Bachelor's degree from Stockholm University in 1918 (then called

Stockholms Högskola) included mechanics and astronomy as his main subjects as well as mathematics. On one occasion he attended a lecture by Vilhelm Bjerknes, who had at one time been a professor at the university, but was now running his own meteorology institute in Bergen, Norway. Rossby was inspired by what he heard and applied for a position as research assistant to Bjerknes. He was accepted and arrived in 1919 at the multifaceted institute which combined the theoretical and practical aspects in a way that Rossby immediately found appealing. The institute was also producing concrete weather forecasts that were of great importance for the southern Norwegian fishing industry and agriculture.

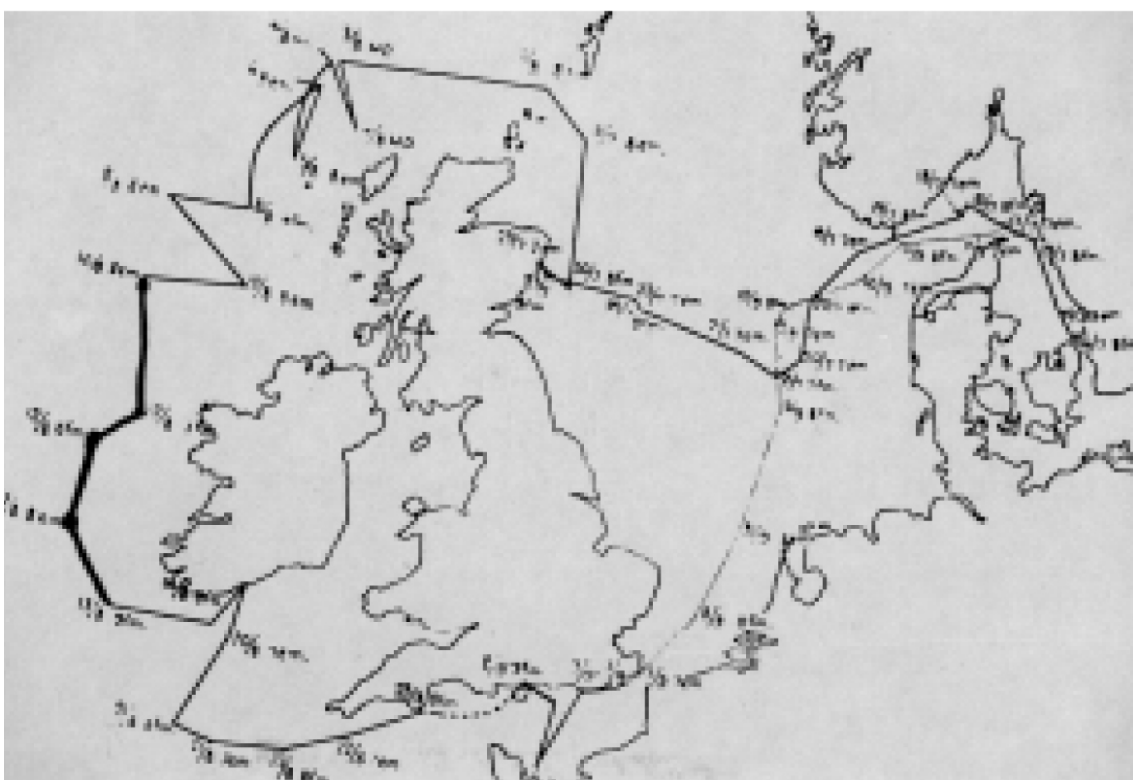
Vilhelm Bjerknes.

Rossby was a meteorological novice at the time, but quickly developed in this vigorous research environment. Vilhelm Bjerknes' core idea was that the weather was controlled by meetings between warm and cold air masses. He called the areas where they met "fronts," a term he had taken from the WWI trenches. For one and a half years, until the end of 1920, Rossby threw himself into balloon experiments, storm predictions and map analysis – all the while losing himself in the kind of frenzy he demonstrated in every task he took on for the rest of his life. His innovations included assigning colours to the two types of fronts: blue for cold fronts and red for warm ones. He enjoyed his work and distinguished himself among his assistant colleagues for his leadership skills and bold research ideas.

He subsequently left for Germany where he worked at the Prussian *Aeronautisches Observatorium* in Lindenberg close to Berlin and to Leipzig where Bjerknes' school had

good connections. Another stay in Bergen followed in summer 1922 when, before incredulous colleagues, Rossby tried to launch aerological balloon ascents of the type he had recently encountered in Germany. He also worked on his first scientific publication, ”Den nordiska aerologiens arbetsuppgifter,” which was published the following year in the Anthropological and Geographical Society’s yearbook *Ymer*.

He returned to Stockholm where he started working as a meteorologist at SMHA. He participated in various scientific expeditions, one with the ship Conrad Holmboe to Jan Mayen and East Greenland in 1923 – a voyage which became very dramatic due to difficult ice conditions. The voyage was covered in the Swedish daily newspaper *Dagens Nyheter* whose readers on 20 October were able to read about the Holmboe fighting for its



Rossby’s map of the path of the af Chapman, stopping at Aberdeen on 7 July, Queenstown (Cobh), on the south coast of Ireland on 14 August and continuing back through the English Channel and North Sea to Scandinavia.


HOLMBOES FÄRD
KAMP FÖR LIVET
I TVÅ MÅNADER.
Första berättelsen om färden framlagd.
Isflak i häxdans runt skrovet.
ISLAND

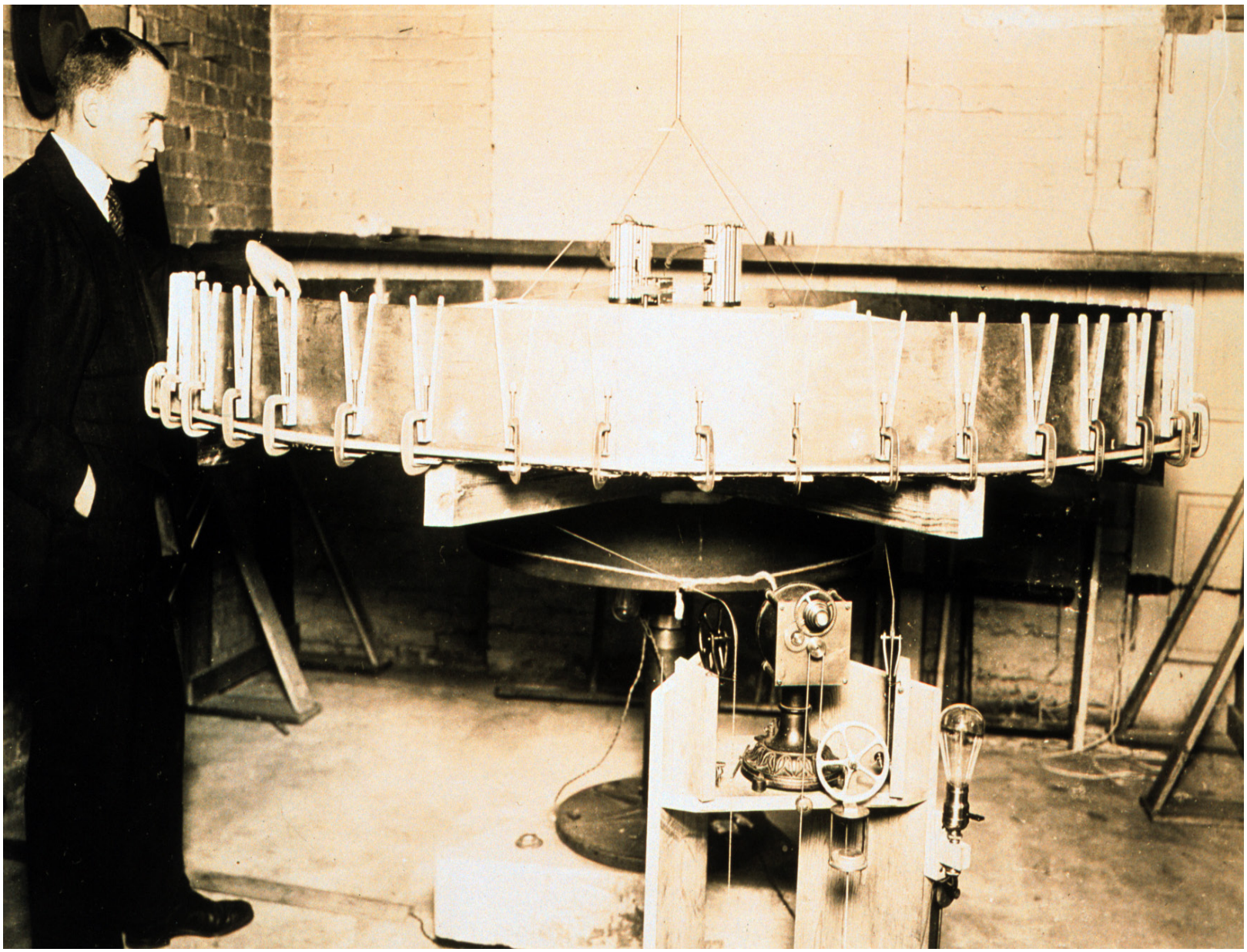
Extract from the Stockholm newspaper Dagens Nyheter describing the trip of the Conrad Holmboe. The headlines read "Holmboes trip, Fight for life for two months. First telling of the story is presented. Icefloes in witches' dance around the hull." The inset map shows the path of the Holmboe close to the coast, the approach of the rescue ship Polarulv from the northeast, and the final trip down to Iceland.

life for two months with ice floes dancing a "witch's dance" around the vessel's hull. Rossby made another oceanographic odyssey in the waters around Great Britain in 1924 in the naval vessel af Chapman. In 1925 he went on a voyage to Portugal and Madeira, also with af Chapman. During these expeditions Rossby gained valuable experience of meteorological fieldwork. He had few opportunities like these later on in his career. In 1925 he also gained his Licentiate degree in mathematics at Stockholm University. Rossby never completed his doctorate, but he would find the mathematics he learnt very useful.

Rossby becomes an American

One recurring theme in Rossby's career was his constant desire to move on to the next thing. He left Bergen once his ideas were established there. He also left SMHA, a bureaucracy controlled more by rules and routines than by imaginative new thinking, which Rossby needed in order to do his best work. A fellowship from the Sweden-America Foundation allowed him to spend most of 1926 at the U.S. Weather Bureau where he studied dynamic meteorology. Rossby wished to study "dynamic meteorology problems" beyond the confines of the Norwegian polar front theory and soon set out on atmospheric simulations using water tanks, again following his own mind rather than anybody else's. The Weather Bureau's body of research was weak and the US was lagging behind Germany and Scandinavia. Nor was it too keen on the Scandinavian weather forecasting methods and Rossby realised that not all institutions are guided by reason.

A random incident had a great impact on his career. In 1926, while Rossby was working on his atmosphere simulations in the Weather Bureau's basement in Washington DC, a private foundation, the Daniel Guggenheim Fund for the Promotion of Aeronautics, announced that it intended to allocate USD 2.5 million for a programme to promote education and research in aviation, "particularly in its use as a regular means of transportation of both goods and people." Commercial aviation was predicted to be an important industry of the future, but its safety needed to be ensured. The same year federal legislation was prepared pertaining to airports, aeroplanes and rules for air traffic and its supervision. It became clear that the aviation sector and the U.S. Weather Bureau should work



Rossby standing beside his rotating tank in the basement of the U.S. Weather Bureau in 1926.
It might be noted that that this rotating tank experiment anticipates what would decades later become a very active field: experimental geophysical fluid dynamics – even in these days of supercomputers (see dishpan in photo on page 63).

together. This led to contacts between the Guggenheim Fund and Rossby, whose ideas and enthusiasm made such a strong impression that the Fund employed him to run its newly formed aviation programme.

Military applications were in the picture from an early stage. Chemical engineer and naval lieutenant Francis W. Reichelderfer was an intermediary between Rossby and Guggenheim. Reichelderfer, who had become acquainted with Rossby and who himself, as he rose through the ranks in the years to come, would be an important player in the development of US military meteorology. They were both members of the Guggenheim Interdepartmental Committee on Aeronautical Meteorology which began its work in 1927. Other members were representatives for the military, weather service and ministry of trade.

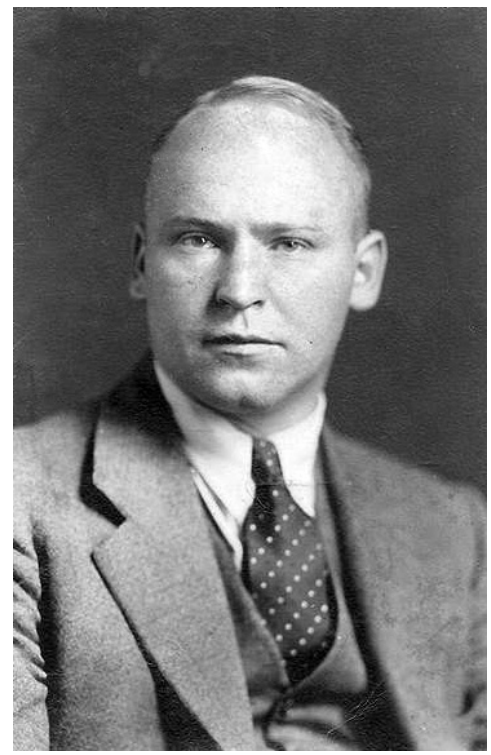
In the years that followed intensive efforts were made to establish what would be called "aerial roads," in other words, the air space equivalent of the motorways being built for the rapidly expanding motor vehicle traffic. These flight corridors were based on a network of weather observers in cooperation with airlines, telecommunications operators (to communicate weather information) and government authorities. California was selected as a test case, partly because there was a great need there, with the fast changes in weather where the Pacific met the Sierra Nevada mountain range, and partly because the Guggenheim Fund was at the time building up aeronautical engineering research capacity at the California Institute of Technology in Pasadena. Rossby was appointed to head the project. The aviators enlisted for aviation publicity purposes included Charles Lindberg, who was on the Guggenheim board. He flew to 82 cities in 48 states and held 147 lectures for the Fund. Another was Richard E. Byrd who, with support from the Fund, made a trans-Atlantic flight and later flew to both the North and South Poles. He also

helped to establish an American military presence in Antarctica. When Charles Lindbergh, who did not trust the Weather Bureau's forecasts, flew to Mexico City in December 1927, he asked Rossby to provide him with a freelance forecast. Rossby was reprimanded and in reality sacked by the Bureau – forecasts were their territory.

Rossby was further convinced that this was how bureaucrats behaved. In the unrestricted, experimental space of the Guggenheim Fund, with his natural leadership skills, his capacity for work and his endearing, diplomatic disposition, he was able to thrive and his star rose quickly on the US meteorological firmament. The most important outcome of his fellowship period was something he had not planned on at all: for the first time Rossby felt that he was part of something where he could really play a role. He would stay for a year, but remained in the US for more than 20 years, as an American citizen from 1939. He was essentially equal parts American and Swedish for the remainder of his life.

Francis Reichelderfer, 1940.

MIT



Rossby had a remarkable ability to be at the right place at the right time. His first academic position in the US was at the Massachusetts Institute of Technology, MIT. It was in the interests of the weather service to have educated meteorologists, and Rossby's background in mathematics and theoretical atmospheric physics was exactly the profile they wanted, unlike the older traditions where meteorology was linked to geology and geography. Contact was therefore made with MIT's President Samuel W. Stratton who personally met with Rossby in Washington DC in 1927. But Stratton's response was that this type of programme was not in line with MIT's priorities. A year later, however, the Navy was in need of six officers educated in meteorology and since the Navy together with the Army and the Guggenheim Fund could fund a professorship and future needs were anticipated, the decision was now easier to make. This model, in which the academic platform he worked from was secured with funds from the military, would keep recurring throughout Rossby's career.

Rossby wanted MIT to be a hub in an observation network with 20 stations located throughout New England. Students would be involved in the observation work. A curriculum took shape. Rossby was able to employ a few educators, and with his typical impa-

tience, he focused on forging contacts with colleagues and other institutions, including neighbouring Harvard University. A partnership was started with Woods Hole Oceanographic Institution (WHOI) at Cape Cod and the series of papers that he published would be called "Papers on Physical Oceanography and Meteorology." The arrangement was similar to the one in Bergen, where Bjerknes built his meteorological centre as a direct outcome of the oceanographic work pursued there by Bjørn Helland-Hansen and before him Fridtjof Nansen. The growing group of guest researchers and lecturers included some people from his old Norwegian network. Jacob Bjerknes, Vilhelm's son held a long series of lectures in 1933 on the general circulation in the atmosphere. He also organised a conference with the military authorities and the weather service.

In the midst of this intensive period of work, Rossby was also cultivating other aspects of his life. He enjoyed entertaining guests at Boston's best restaurants, making sure that everyone had a good time, including himself. His face, which grew rounder as the years went by, was always lit up with passion and interest at the dinner table. Boston was also

Samuel W. Stratton.

where he met his wife, Harriet Marshall Alexander, a doctor's daughter. They got married in 1929. Harriet was a trained physical education teacher and secured a position at a college in Pennsylvania, but moved back to Boston where she was soon expecting the pair's first child, Stig Arvid, born in 1931. Then came Thomas in 1937 and Carin in 1940. The children spent the first years of their lives in the US but moved with their parents to Sweden in 1947. Stig Arvid, who was already a high school student, had a difficult transition to school in the Swedish language and moved back to the US. Thomas remained in Sweden and attended Sigtuna School, and later the Royal Institute of Technology (KTH), before also returning to the US for a career as an oceanographer. Carin died after a

Royal Institute of Technology, Stockholm.

lengthy illness in Chicago in 1971. Harriet also returned to the US, and after getting re-married with geophysicist Al Woodcock in 1965, moved to Hawaii where she lived until her death in 1995.

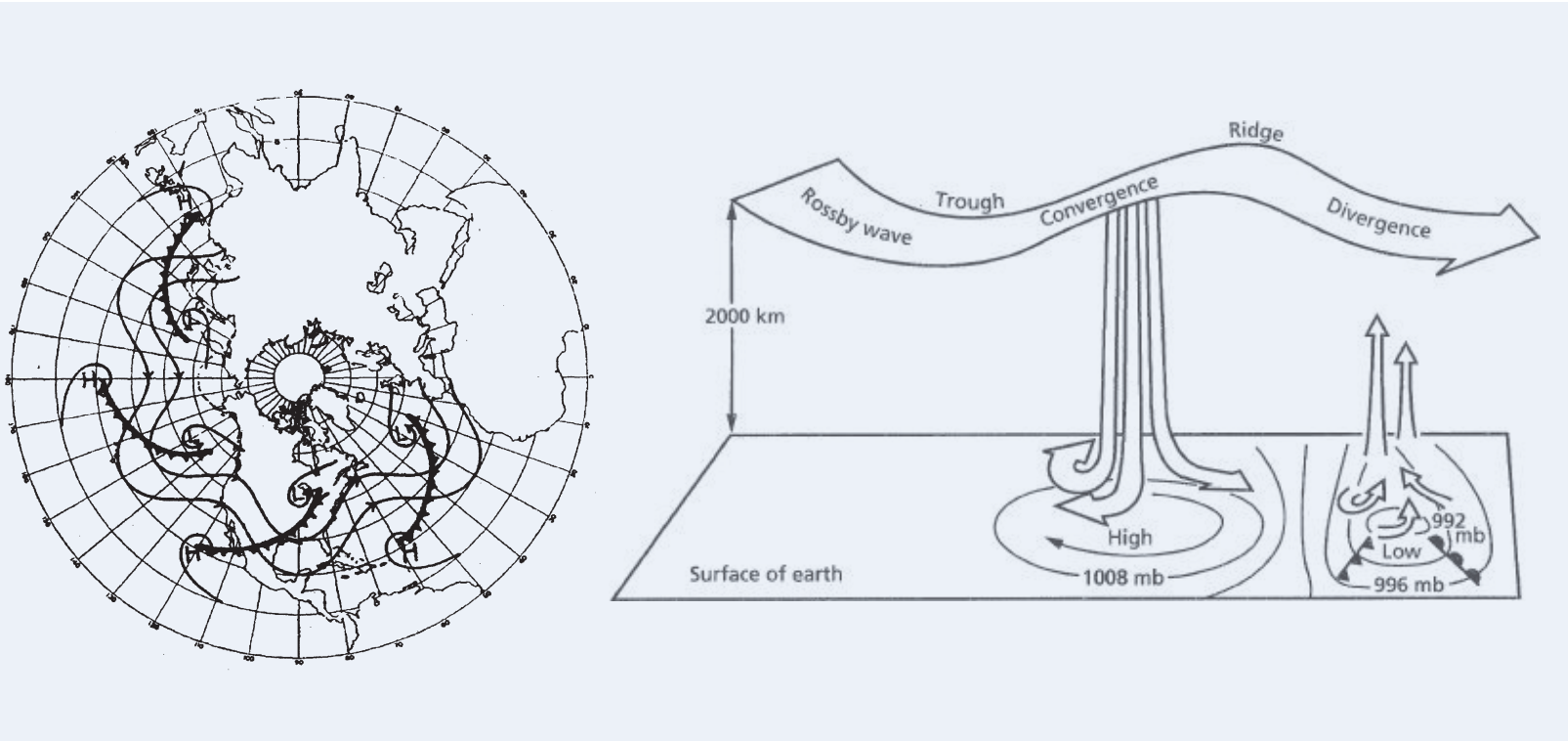
After a couple of successful years, Rossby was able to found the first department of meteorology in the US, at MIT in 1931. And he had no intention of allowing the pace of expansion to slow down. President Stratton of MIT was bombarded with suggestions (and budget requests) and he had to remind the eager Swede of the way things were normally done at a university. A research plane was acquired; a single-engine Cessna which made daily ascents from East Boston Airport (now Logan Airport) to just over five thousand metres with professor (and professional pilot!) Daniel Sayre at the controls. The scientific ambitions in studying air flows took occasional precedence over safety concerns and the result was one or two emergency landings.

A method that would prove more reliable in the long run involved balloons with radiosondes which sent down data from the upper atmosphere. Radiosonde technology had been developed along several roads in the US, France, Germany and the Soviet Union in the 1920s and beginning of the 1930s. It was based on a measuring device that could send information in the form of radio waves so that it could be registered without the need to physically read the instrument. It was Rossby's old faith in aerology that now celebrated a belated triumph. As always curious about the latest technology, he was at the front of the line at the start when Finnish entrepreneur Vilho Väisälä created a company for the commercial manufacture of radiosondes in 1936. The same year the company delivered its first order to Rossby and MIT. This observation technology would also lead to perhaps his most important scientific discovery. By analysing the radiosonde data, Rossby was able to identify long waves in the atmosphere at a high altitude; waves that can spread over many

Finnish inventor Vilho Väisälä conducts experiments with his new radiosonde equipment, Tampere 1934.

hundreds of kilometres and glide like great covers of air and power over mountains and oceans, meeting and growing stronger, and also acting as receptors and conveyors of enormous amounts of energy, which in turn forms what we call "weather" at lower altitudes. In 1939 and 1940 Rossby published his results on this powerful phenomenon, which would come to be called "Rossby waves."

When, after a decade of intense activity, MIT meteorology was at its peak, Rossby left suddenly and went back to the U.S. Weather Bureau in summer 1939. His successor at MIT was another product of the Bergen School, Sverre Petterssen, known as the one who used his weather forecasts to convince Eisenhower to delay the invasion of Normandy so that D-Day would take place on 6 June 1944, rather than 5 June as originally planned. Rossby himself continued working in partnership with Francis W. Reichelderfer, who had been named head of the bureau the previous year. In Reichelderfer Rossby saw a visionary, but he was disillusioned when he realised that the old forces still reigned at the bureau fifteen years after his first encounter with it. Rossby's intentions for his return say a lot about his self-confidence. He wanted to summarise the important results that he and his team at MIT had achieved over a whole



How Rossby saw "his" waves in 1941.

decade, show that he was capable of creating a research school of the same calibre as the Bergen School which had once nurtured his talent, and preferably apply this to the Weather Bureau's methods. None of this happened, at least not at the speed that Rossby desired. In desperation in autumn 1939 he wrote to MIT's new President, the legendary Karl T. Compton and asked if he could help him return to the university. Compton was understanding and advised him to leave the Weather Bureau as soon as possible. However, he was not able to find the financial resources necessary to take Rossby back during the academic year in session. Rossby remained in Washington DC and MIT would never see him again.

But there were other universities. In Chicago one of his former MIT students, Horace Byers, was training staff from the U.S. Weather Bureau, and during a visit by Rossby in 1940, the two men began to forge plans for a department of meteorology. The US West Coast and East Coast both had them and naturally the Midwest needed one too. Earlier attempts to establish meteorology in Chicago had failed, but Rossby came up with a tactical manoeuvre. He went back to Karl T. Compton and asked him to write to his brother Arthur H. Compton, a professor of physics in Chicago (and later a Nobel Prize Laureate), and suggest that he invite Jacob Bjerknes to hold a lecture on the subject. Bjerknes' equations won the confidence of the Department of Physics and when a private donor offered to provide funding, it became an easy decision for the university's legendary president Robert Hutchins to take. Rossby also brought in another former student, Harry Wexler, who had received his PhD at MIT the previous year and was taking a break from the weather service. He would later become head of the service.

Karl T. Compton, legendary president of MIT.

The attack on the Pearl Harbor naval base in the Pacific in December 1941 changed

the game for meteorology in the US in one fell swoop. Back in April 1940, President Roosevelt had announced the US intention to build 50,000 aircraft. This meant there would be a need for several thousands of officers educated in meteorology. Sverre Petterssen had informed the air force command that Luftwaffe had 2,700 highly educated meteorologists – the US had thirty. With a war that was soon being waged over essentially the entire planet – in tropical jungles and deserts, in oceans and arctic ice fields – and with a fast-growing air force fleet, including the first jet planes, meteorology was essential and sometimes even critical. The strategic need for meteorology remained after the war when the US developed its large bombers, the Boeing B-47 Stratojet and the Boeing B-52 Stratofortress – both named after the years they were first put into commission, and due to the radioactive fallout from nuclear weapons testing.

Chicago, alongside MIT, Caltech, New York University and UCLA, became involved on a large scale in educating meteorologists for the US war effort. The need was almost insatiable. The first programme was located at MIT. Rossby himself designed the curriculum in his capacity as advisor to Secretary of War Henry L. Stimson. At MIT alone around a thousand meteorologists were educated through the programme during the war years, 25 of them were women. In Chicago 1,700 were educated – an effort of true industrial proportions. Enrolment increased exponentially, from 15 in 1940 to 36 in January 1941, to a class of 500 students in 1943. Despite the huge amount of work involved, Rossby saw its obvious benefits: it guaranteed an inflow of resources and provided a critical mass of knowledgeable personnel with the help of whom Rossby could once again build a world-leading research environment. The Chicago School became an important name in meteorology. Chicago also remained his main connection point in the US, including the first of his Sweden years until the early 1950s.

During the war years, Rossby's reputation grew ever stronger in Washington DC. He was in direct contact with the war command and was an advisor to the Office of the Secretary of War and the Commanding General of the U.S. Army Air Forces. He initiated and chaired a University Meteorology Committee to coordinate the extensive education programme. It included representatives for the universities involved as well a long list of military authorities. Despite all of his assignments, including heading up the work in Chicago, he found time – again with military authorities – to create an Institute for Tropical Meteorology at the University of Puerto Rico, partnering with the Chicago School. His advising work also required him to travel to war zones, including Guam in the Pacific, Morocco, several locations in Europe, and even the Soviet Union.

Rossby was now the undisputed leader in the field and what could be more natural than that he would also be appointed as President of the American Meteorological Society, which he turned into yet another reform project. During the two years he served as President, 1944–45, he launched a scientific journal, set up offices in Boston and tried to encourage private sector players to establish private weather services in the US, principally to help the thousands of conscripted meteorologists who he and his colleagues had recently trained to find a livelihood in the face of the dreaded post-war depression. That was the only period in which he kept a diary – at least one that has been saved. When it was found in his Stockholm flat after his death, none of his colleagues could understand why he kept a diary at that particular time, and especially how he had time to write entries in it. He was constantly travelling. No one in Chicago could understand how he had time for research, apart from his family who knew his ability use the quiet hours of the night- and early morning. So he did, in fact, produce substantial theoretical articles on general circulation, the foundations for the new weather forecasts of the future.

The Princeton connection

One of the many talented researchers Rossby brought into his Chicago School was the young mathematician Jule Charney. Charney had defended his doctor's thesis at UCLA under the guidance of Jacob Bjerknes and Jörgen Holmboe, so he was familiar with the Bergen School's methods. He was otherwise quite frustrated and questioned the theoretical level of meteorology at UCLA. He learnt that colleagues in Norway had stronger mathematical skills, and Charney and his wife were on their way there in 1946 for a postdoc when he was invited by Rossby to come to Chicago. He ended up staying almost a year. The two men started working together and a loyal friendship was formed which would remain in place until Rossby's death in 1957.

Simply put, they needed each other; they were the perfect match. Rossby had the imagination and ideas; Charney could translate them into equations. Charney called Rossby his "intellectual godfather." They had only met once before, but Charney had read Rossby's work inside and out and now he would get to do equations for the master's atmospheric visions. It was essentially an extension of his doctorate work at UCLA where he had already confirmed and developed some of Rossby's earlier ideas. The equations increased the hope that it should be possible to use mathematical models to create reliable weather forecasts – an effort they were both involved in. Other than the year in Chicago, Rossby and Charney rarely worked at the same location, but they were in constant contact, writing scores of long and deep-delving letters to each other. Charney's published memoir of Rossby tells of an unusually deep intellectual affinity.

Jule G. Charney, who did much of the mathematics behind the early meteorological computing, first at Chicago, then Oslo, the computer project at the Institute for Advanced Study, Princeton, then back again for long working stints in Stockholm. Later in life Charney chaired the report to the National Academy of Sciences, Carbon Dioxide and Climate: A Scientific Assessment *(1979) that is commonly considered as the breakthrough of the modern orthodoxy of anthropogenic climate change. On Charney's team for the report was Bert Bolin, Rossby's Swedish student.*

Rossby was directly involved in Charney's connection with the Institute for Advanced Study in Princeton. The Institute, ideally located a stone's throw from the famous university, had been established in the 1930s based on a private donation. Under the leadership of its director, Abraham Flexner, and his unfailing belief in the idea of independent research – his programme article was entitled "The usefulness of useless knowledge," they set their sights as high as could be; the Institute's first employee was Albert Einstein. Another European wunderkind on the small but illustrious faculty was Hungarian mathematician John von Neumann who, in addition to his famous studies in game theory, was interested in the possibility of creating electronic computing devices. They emerged as increasingly essential and also possible to manufacture. One of von Neumann's visions

was a device of this kind that could quickly and reliably produce weather forecasts. The problems this work involved were legendary. Mathematician and meteorologist Lewis Fry Robinson in Cambridge had, in the years around 1920, made a series of attempts at numeric forecasts, but the manual computation took too long and the forecasts were still wrong.

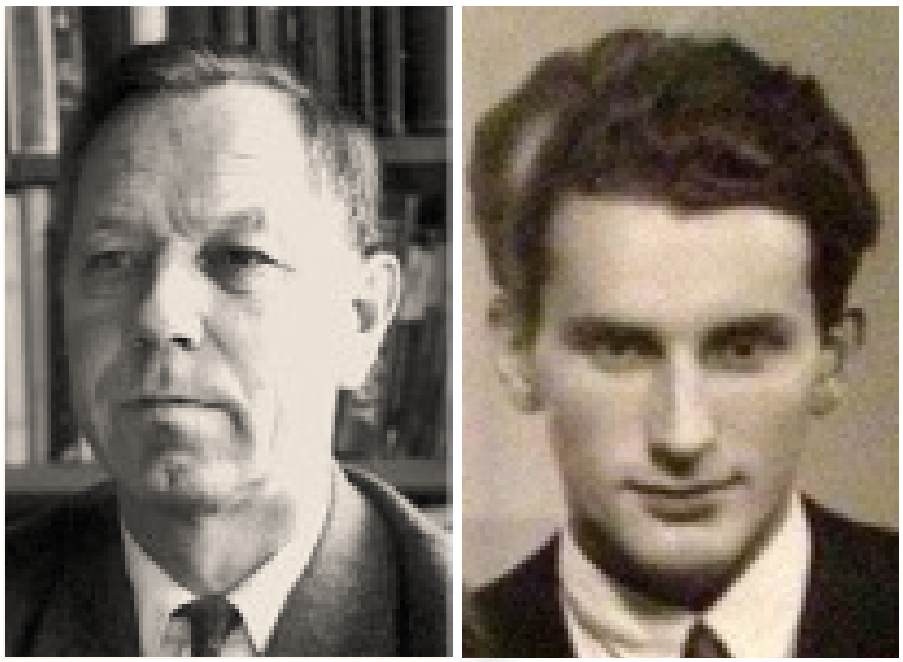
After the breakthrough of the Rossby wave theory, which followed the laws of physics and regarded the waves as essentially calculable, Charney was convinced that predicting the weather was primarily a calculation issue. What was required was "one highly intelligent machine" and a few people who could feed it with input data. This data would, of course, have to come from measurement points that were close enough together, but

John von Neumann (left) and Institute for Advanced Study (IAS) Director J. Robert Oppenheimer in front of the IAS Computer in Princeton, New Jersey.

this obstacle was now partially removed due to the great expansion of the observation network after the war years, which continued during the Cold War. What was missing was the actual machine.

During his time with Rossby in Chicago, Charney was invited to a meeting in Princeton lead by von Neumann and what he heard about the future outlook at the meeting in September 1946 made him curious. The details of the preparations for this meeting say a lot about Rossby's role in the development of modern meteorology and climate science. John von Neumann for his part started showing an interest in weather forecasts as part of his almost religious conviction that most things in the world could be expressed in mathematical terms and that therefore most of the world's future could be predicted – whoever could do that would control the world, and Neumann, one of the Cold War hawks, wanted that to be the West. Rossby met von Neumann for the first time in 1942, but it was not until after the war that all the threads – the Rossby waves, the concept of general atmospheric circulation, the essential predictability, Charney's mathematical abilities and access to computing devices – were interwoven so that the opportunities could be fully recognised. In April 1946 Rossby wrote to von Neumann and to his old partner "Reich" at the U.S. Weather Bureau suggesting that it should be possible for the Government to support a weather forecast project which would use the computer being built at Princeton based on von Neumann's ideas. In May von Neumann wrote to the Office of Naval Research. In August he convened a meeting in Princeton. It took place in September and that was when Charney realised what was brewing. After a period in Oslo in 1947 and 1948 Charney rejected several job offers, including in Chicago, to devote himself to the computer project in Princeton. He stayed there until 1956. He in turn encouraged his new Norwegian friends, mathematical meteorologists Arnt Eliassen and

Ragnar Fjørtoft, to come. Princeton became a new centre of theoretical meteorology, without Rossby, but with his spirit always hovering under the ceiling in the purpose-built pavilion that housed the growing monster of a machine and its hoard of male programmers and hole-punching female assistants. Rossby was in actual fact the invisible elephant in the room. Both von Neumann and the Institute's Director, J. Robert Oppenheimer, former head of the Manhattan Project which created the first atom bomb in 1945, would actually have liked Rossby in charge of the whole project. But Rossby had other plans. In autumn 1946 he had already decided to move to Sweden, and although there were many indications that we was tempted by the Princeton project, he chose not to go, perhaps in the knowledge that, through his many personal contacts and partners involved in it, he would be able to take part indirectly and in practice gain a great deal from it for his own work as well.



Arnt Eliassen and Ragnar Fjørtoft

At Princeton they instead tried to get the next best thing – Rossby as a guest professor. But that too would be a long time coming. Rossby not only had his new chair at Stockholm University, but also his commitments in Chicago to consider – he received half of his salary from there for a number of years at the end of the 1940s and beginning of the 1950s. He also had the Woods Hole Oceanographic Institution at Cape Cod, a place he enjoyed

Bert Bolin discussing weather maps, Stockholm circa 1955.

and where he wanted to spend time. Rossby was constantly wooed by von Neumann and Oppenheimer and he received the offer to stay as a full Institute member for two years on the same flexible and generous conditions as Paul Dirac and Niels Bohr had enjoyed. Rossby wrote to Oppenheimer in October 1949 that he was too busy to accept the offer, but that he had through visits and personal contacts already been involved in the meteorology project and that he intended to continue to contribute. He finally did come to Princeton in the winter of 1951. By then he had already found yet another important connection with Princeton through his contact with a young, promising Air Force meteorologist in Stockholm by the name of Bert Bolin. They had met back when Rossby visited SMHA in Stockholm for a seminar in 1945 and again when Rossby made a reconnaissance trip in January 1946 prior to his upcoming professorship in Stockholm. Bolin spent a long time at the Institute for Advanced Study in Princeton, became close friends with Charney and the Norwegian and US researchers, learnt a lot about how research was conducted and funded in America and essentially served as a strong link between the US computer-based weather research and the Swedish team led by Rossby in Stockholm. Rossby himself became the biggest commuter of them all.

A part of the "higher diplomacy"

Spring 1945, when WWII was coming to an end, the Swedish Government commissioned Stockholm University geography professor Hans Ahlmann and Uppsala professor in atmospheric electricity Harald Norinder to explore how to strengthen meteorology in Sweden. These men would propose a new infrastructure involving new professorships, better education programmes and other necessary measures. One of the top priorities proposed in the report was to contact Rossby. This happened even before there was time to consider anything else. Such was Rossby's status.

And such was the status of meteorology. Ahlmann wrote to Rossby on 12 April 1945 that he considered the assignment to be part of the "the higher diplomacy," a statement which, at first glance, may seem strange – a simple, academic inquiry – if it wasn't already clear what significance atmospheric sciences and geophysics were beginning to have at that time. WWII had been a high-tech war with air and naval forces playing important roles, and it revealed the need for knowledge of what would soon be called "the environment" – the US armed forces were among the first to talk seriously about environmental sciences. The status of the most prominent experts in the field rose quickly. The Norwegian oceanographer Harald Ulrik Sverdrup, who was head of the Scripps Institute in La Jolla, California, wrote in a letter to Ahlmann in October 1945 about how Vilhelm Bjerknes in the US was an obvious candidate for the Nobel Prize in Physics. The reason was that "weather forecasting has played an important part in winning the war." But even "men trained by him" had played a very significant role, claimed Sverdrup, and one of them was, of course, Rossby.

A key recommendation in the Ahlmann-Norinder report was to establish Rossby in Sweden and build a programme with him at the helm. A meeting was organised in Stockholm in January 1946 when Rossby met with Ahlmann and Norinder as well as Minister of Ecclesiastical Affairs, Tage Erlander. Another suggestion was to strengthen the meteorology programme in Uppsala. This would change later on, partly because Rossby had more faith in locating his activities in Stockholm, where ties could be created with the weather service whose staff also needed to be trained. In Uppsala the shift towards Stockholm was of course unpopular. A letter from winter 1946 confirms the fact that Ahlmann kept Rossby informed about the obstacles that existed in establishing the programme at Stockholm University, as well as to SMHI, which was expecting the new meteorological capacity to be built up there. Tage Erlander, on the other hand, was on board – both as Minister for Ecclesiastical Affairs when Rossby's professorship was granted and again in 1951 when, as Prime Minister, he supported Rossby's plans for a department of meteorology at the university with the diligent Lund physicist Torsten Gustafson, Erlander's trusted science advisor, providing the connection.

Exactly how the idea of bringing Rossby back to Sweden first came about and when is unclear. There is evidence that Rossby had wanted to come back for some time; among other things, he wanted to apply for a position in Lund in the mid-1930s. In 1935 Jacob Bjerknes wrote to his Swedish colleague Tor Bergeron (who had spent a long time in Bergen) to say that Rossby was interested in the position as Director General of SMHA following Axel Wallén, who had once been Rossby's boss when he received his fellowship to go to the US a decade earlier. How serious he was about this is hard to judge, but it is clear at least that he was always in close contact with his old homeland. He visited Sweden during several summers in the 1930s and on a few occasions Bergen as well. He arranged for his Stockholm

relatives to visit him in Boston in the late 1930s. Whatever he felt during these years, his growing commitments and the new, tempting opportunities that always came in between, made it difficult for him to leave the US; and when the war broke out it became impossible.

That Rossby and Ahlmann knew about each other was clear; they both had a strong connection to Bergen and both were renowned internationally in their fields. Ahlmann also had expertise in polar climate change, which proved to be important to the Americans during the war. His glaciological work had confirmed that warming was happening in the Arctic. At a lecture for the Swedish Society for Anthropology and Geography in March 1943

Hans W:son Ahlmann demonstrates the Norway exhibition in Stockholm To Swedish Crown Princess Louise, Lady Mountbatten, 1943.

Ahlmann suggested that melting was also taking place in Antarctica, which would explain the rising sea levels that had been observed since the 1800s. This lecture would be translated into English by Swedish-born Karin A. Gleim who worked in Rossby's department in Chicago (we do not know exactly when) and was sent from there in February 1947 to Captain Howard Hutchinson at the Office of Naval Research. Everything to do with knowledge of ice and cold had gained strategic significance as the military plans for the Arctic entered a more intense phase during the Cold War.

Another motive for Ahlmann could be that he saw the potential in a scientific collaboration with Rossby. Ahlmann, who was already convinced that climate change was happening on a large scale in the polar regions, needed the support of meteorological research to further his hypothesis, and Rossby could provide him with this. Rossby could also open doors for him in the US. There appeared to be a mutual interest. Rossby invited Ahlmann to a meeting attended by leading European climate scientists in Stockholm in 1948. This was a typical move by Rossby, one that would immediately give him a key role in his new position and place Stockholm meteorology on the map. Rossby was kept informed by Ahlmann about the upcoming Norwegian-British-Swedish Antarctic Expedition (NBSX), and Rossby published an essay by Ahlmann in *Tellus* in which Ahlmann launched his plans. Rossby worked with Ahlmann's students in preparation for a Festschrift entitled *Glaciers and Climate* honouring their professor on his sixtieth birthday in November 1949.

During the same period when contacts with Rossby intensified, 1945–1946, and by all accounts helped by these, Ahlmann forged his own relationships with leading figures in the military meteorological institutions in the US. In order to be on board a US flight over Greenland, he contacted General Dan Yates, who was head of the US Air Force in Europe and part of Rossby's personal wartime network. Yates made flights available to him and at

the same time took the opportunity to ask to be informed about all of the research results. Ahlmann's interest could have been motivated by the trip he made in summer 1945 to Leningrad and Moscow, where he obtained plausible information on the strong Soviet development in technology and science in the Arctic, with obvious military implications. After the war, and as the Soviet Union also had its own nuclear weapons from 1948, and when the US started testing nuclear weapons at home in Nevada in 1950, scientific intelligence was becoming increasingly significant.

It was clear that Rossby had maintained his contacts with those in political and military circles in the US, even after he moved back to Sweden. He chaired the Panel on Meteorology of the powerful Joint Research Development Board and was directly involved during the legendary Vannevar Bush's leadership of strategic US research planning in the post-war years. Rossby's good connections came in handy when Ahlmann in May and June of 1947 went on an extended trip to the US to lecture at some thirty universities and institutions around the country. During the trip Ahlmann and Rossby visited the Pentagon, where Ahlmann held a lecture about the impact of climate change on the conditions for warfare in the Arctic. The conclusion was that the Americans needed to strengthen their ties with Swedish research and that they should send officers and students to Stockholm. There were many indications that the planning for the US trip was the work of Rossby in cooperation with Harald Ulrik Sverdrup in La Jolla. It was Rossby's, and to some extent Sverdrup's, network of individual contacts and institutions that were visited and it was Rossby's questions, with a focus on the implications of the climate change that Ahlmann studied, that were on the agenda.

Rossby was part of an arrangement with the US Air Force's research department in Cambridge, Massachusetts involving sending officers from there for advanced training in

Stockholm. From 1947 up to the mid-1950s there were always a couple of US military personnel there at any given time. They were able to take the knowledge and methods they learnt about back with them to the US. Rossby also developed a proposal for the Office of Naval Research (ONR) in March 1949 about acting as a central "screening" venue for young, gifted meteorologists so that the best would be selected and enticed to the US where they could be useful to the US Navy. The idea was based on the way things had worked at his international seminar in Chicago, where there was a strong inflow of foreign talent. Rossby now thought the same thing could happen in Stockholm, but with an emphasis on Europe and Great Britain. He created a budget for twenty "visitors" a year, each of whom

The Norwegian-British-Swedish Expedition (NBSX), or Maudheim Expedition, to Antarctica, 1949-51.
From left: John Giæver, Prof. Dr. Harald Ulrik Sverdrup, and Captein Guttorm Jakobsen.
Photo: Norwegian Polar Institute.

would spend a couple of weeks in Stockholm. Rossby and his colleagues would, in other words, separate the wheat from the chaff for the US Navy. "The weakest factor in any system of direct importation of scientific talent into the U.S.A. is the lack of real knowledge relative to the actual or potential capabilities of suggested or possible candidates." At the same time he took it upon himself, with the help of his colleagues, to send reports, seminar papers and other materials that could be of interest to the Americans. For this service the ONR would pay USD 4,800 a year, which was equivalent to more than Rossby's full grant for his professorship, including "assistants and expenses" (a total of SEK 21,100).

Could the Americans gain anything from Rossby's move to Sweden? Regardless of the initial intentions, the answer was apparently yes. Although the US had unparalleled research capacity domestically, they could not do everything on their own. At the same time as they needed access to all possible kinds of intelligence because their geopolitical role had gone global. The Scandinavian countries were already prominent in meteorology and climate research. Rossby knew it and the US knew it too. Ahlmann was the undisputed authority on polar climate change. The Scandinavians had also been outstanding in weather forecasting ever since the early days of the Bergen School. Under Rossby, Stockholm could be developed into a European centre of excellence. This would be entirely in line with the official US post-war strategy which, as historian John Krige has shown, was to allow various centres of excellence in Europe to work uninhibited but with financial support from US sources so that the Americans could get access to the results. An American military man, Flight Lieutenant and meteorologist Philip D. Thompson, who was the first director of the computer project in Princeton 1948–49 and who had very good insight into research in both the US and Europe, considered Rossby's Department of Meteorology in Stockholm to be a perfect "listening post for meteorological intelligence."

Once in Stockholm, Rossby started working at SMHI, located on the top floor of the post office building at Fridhemsplan, and at Stockholm University in an office on Fleminggatan nearby. These were two essentially very different organisations and Rossby preferred the latter. He maintained the view he had developed in the US: the public sector and academic research needed to work together, but the latter needed to be given greater freedom. The major goal was to try to produce numerical forecasts. A course of events not unlike those at MIT and Chicago would be repeated. Rossby applied for grants – most of them still from the US and primarily from military sources – to realise his research programme. In a letter to Ahlmann as late as June 1957, he stated that two thirds of his funding was still coming from the US.

He had barely landed in his old homeland before he started to ask university president and mediaeval historian Sven Tunberg, about extensive leaves of absence. Before the 1948–49 academic year began he wanted to arrange to "be able to spend winter and parts of spring at the University of Chicago." He thought, somewhat sanguinely, that SAS and "possibly the Sweden-America Line" could cover his Atlantic commuting by giving him free trips. He provides a fairly bleak characterisation of the status of meteorology in Sweden, describing the small grants for assistants, unclear career paths and difficulties for foreign students to graduate in Sweden and compete with the few Swedes in the field. This isolation – the opposite of what his own career was based on "is helping to support a tendency for a lack of imagination and fresh ideas, for which thoroughness can only partially compensate."

As the institution builder he was, Rossby launched a new journal, *Tellus*, in Stockholm. He

had already founded *Journal of Meteorology* (later changed to *Journal of the Atmospheric Sciences*) which had quickly become a leading forum. *Tellus* was equally successful. In its very first year it published articles by some of the big names in meteorology from all around the world. Also during the first few years, it was in *Tellus* that groundbreaking studies were published by names such as John von Neumann, Jule Charney, Canadian Gilbert Plass, who was the first person to scientifically re-establish the theory of the effect of carbon dioxide on global warming, and, of course, a growing band of Rossby's own students and colleagues in Stockholm.

He also gathered members of his large international network in the Swedish capital. The research programme moved with him, just like the snail and its home. He was still interested in the large atmospheric waves, the global circulation and the weather forecasts they made possible. In comparison with the big Princeton project, Stockholm may have seemed like a

MIT's meteorology department in the mid-1950s, where atmospheric scientists and Rossby collaborators and colleagues, Jule Charney, Edward Lorenz, Norman Phillips, and Victor Starr, among others, helped drive the transformation of weather forecasting from an intuitive craft into a branch of fluid dynamics, complete with computerized predictions.

dead end, but in practice it was almost the opposite. The Swedes were determined to build their own computer, the so-called BESK, *Binär Elektronisk Sekvenskalkylator*. It was being built at the Royal Institute of Technology's former location on Drottninggatan. One of the main stakeholders was the Swedish Air Force, which had an interest in computer-based support for airplane construction at SAAB industries. But Rossby and his colleagues, and the Swedish Air Force, also hoped for better and automated weather forecasts.

Rossby understood (even better now that the Princeton project had started) the enormous potential of computers and wrote to von Neumann to make sure that the Swedes travelling to the US to learn about them would get the best possible help. What he meant was of course that they would get what they needed to build a computer in Sweden. Erik Stemme was one of the Swedes who went to the US. His destination was Princeton and when he returned in 1950 he was assigned the task of developing BESK, which was put into operation in 1953. Meanwhile, Bert Bolin, an Air Force meteorologist, also spent a year in the US, 1950–51, first in Chicago then six months in Princeton with Charney. When Bolin was in Princeton the Princeton computer was not sufficiently developed so, in order to test weather forecasts, he had to go down to the US military base in Aberdeen, Maryland, where the so-called ENIAC computer was located. Bert Bolin acted as a bridge between the Air Force and Rossby's department at the university, where he became a research student and started to teach.

Rossby also enlisted the help of Germund Dahlqvist at the Royal Institute of Technology (KTH) who became the leading mathematician in the meteorology team and now started working on BESK. With Norman Phillips, who Rossby had met in Chicago, also now in Stockholm, a project to determine how a computer could be used for weather forecasts, also supported by the so-called *Matematikmaskinnämnden* (Swedish Board for Computer Machinery), got started in autumn 1953. Phillips' role was to re-write the code that existed

Mexikan och indier studerar svenskt väder

"Männen kring BESK" en enda stor familj

— Vädret blåser vart det vill, och du vet inte vadan det kommer eller vart det far, skriver evangelisten Johannes. Man kan lugnt utgå ifrån, att det bibelordet inte står särskilt högt i kurs bland det 20-tal unga män av olika nationaliteter, som dag efter dag ställer sina steg till Lindhagensgatan 124 för att ge sig i kast med att vetenskapligt granska, hur väder och vind beter sig.

Professor Carl-Gustaf Rossby pekar med glasögonen som pekpinne ut en meteorologisk finess för fr. v.: kommendör Max Eaton, dr Earl W. Barrett, major William H. Best, samtliga från USA, mr C. Ramaswamy, Indien, dr Walter Hansen, Tyskland, mr Hess am Taba, Iran, Odd Haug, Norge, M. Dady, Frankrike, och mr Frank Ludlam, England.

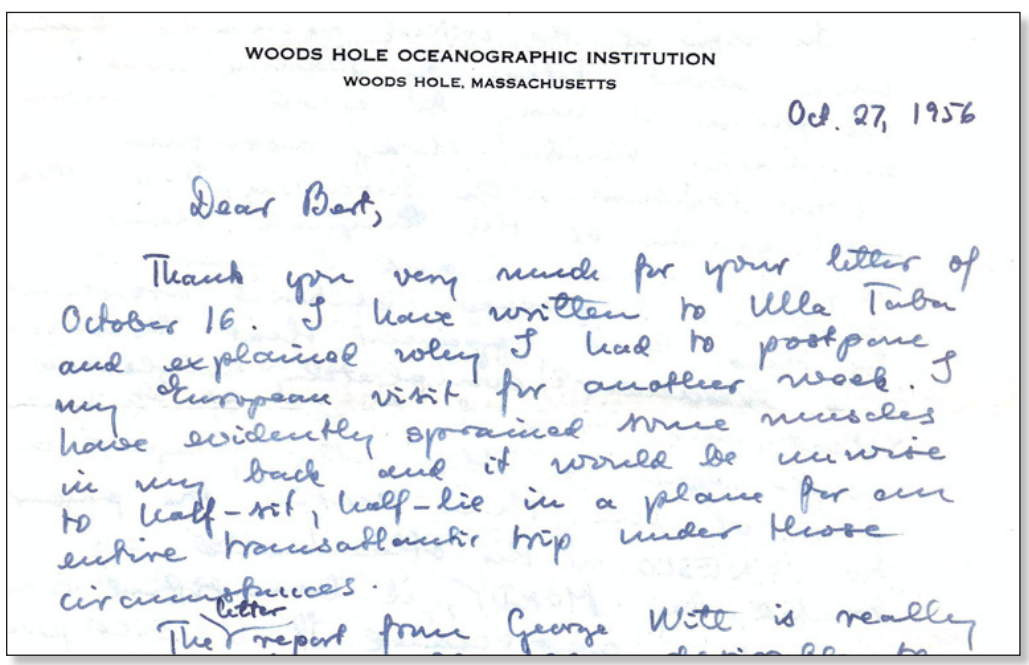
Rossby built an international research community around numerical weather predictions. On this photo from 27 December 1954 there are scientists from France, Norway, Germany, Mexico, India and, as always, Americans, two of whom were representatives of the US military. The caption reads: "The men around 'BESK' [the Swedish computer] is one big family." Photo: Stockholms Tidningen.

The BESK computer was tested by making historical predictions. This 12 hour prediction from 24 November 1951 was considered very successful and was published in the tabloid Expressen *in the fall of 1953.*

for ENIAC for BESK. Rossby's brother Åke also had a small role to play. The Swedish National Defence Radio Establishment (FRA), where Åke was bureau chief from the time the agency was established in 1942, was a big stakeholder in a Swedish computing device, but for reasons of secrecy, could not be at the forefront. The two brothers were, however, in touch with each other. Thus, early Swedish computer development was able to benefit from two Rossby brothers collaborating.

The weather project was an experimental workshop for what had been called the early mainframe computers' "elite users," i.e. public authorities, researchers and the military. They worked around the clock for two months as the autumn nights grew longer. Bert Bolin has described how the Swedish Air Force created weather maps that were sent by military couriers to Drottninggatan where observational data was extracted and fed into the computer. The computer worked throughout the night and early in the morning the results were couriered back to the Air Force which could then produce a weather forecast for the following day and for two days. The first experimental runs were done in late 1953 and it would take a year and a half before the Americans were able to produce their first forecast, in July 1955.

On some level it could be regarded as a race between the BESK team and the Princeton team to see who would be first to generate computer-supported numerical forecasts. In real-



WOODS HOLE OCEANOGRAPHIC INSTITUTION
WOODS HOLE, MASSACHUSETTS

Oct. 27, 1956

Dear Bert,

Thank you very much for your letter of October 16. I have written to Ulla Talbo and explained why I had to postpone my European visit for another week. I have evidently sprained some muscles in my back and it would be unwise to half-sit, half-lie in a plane for an entire transatlantic trip under those circumstances.

The letter report from George Witt is really

Letter to Bert Bolin sent from Woods Hole Oceanographic Institution on Cape Cod, where Rossby enjoyed several research stints during the later years of his life. While Rossby spent long periods in the US during the 1950s Bolin made sure that things worked back home at the Meteorological Institute in Stockholm, where he would assume leadership after his mentor's death in August 1957.

The main Swedish user of the early numerical weather predictions were the military and especially the Air Force. The first 24 hour predictions were ready in late 1953 and operational real life predictions were completed in connection with a large military training operation in the spring of 1954.

Photo: Air Force chief meteorologist Nils Herrlin, portrayed in the Svenska Dagbladet 8 December 1954, reiterates the fact that the Swedes at this point in time were ahead of the rest of the world.

ity the opposite was true; it was a close cooperation, led by Rossby and von Neumann and with large security policy interests in the balance. The two teams consisted of a long series of personal connections. The results and information were exchanged on an ongoing basis in a way that would not have been possible without Rossby as the common denominator for the projects, building relationships between individuals, groups and authorities, and ultimately between nations.

Rossby himself had numerous opportunities to communicate information to the US side. John von Neumann, a member of the influential Atomic Energy Commission, was well informed about the BESK computer at KTH and was was very impressed. It performed at least as well if not better than the IAS computer in Princeton.

But Rossby would not be Rossby if he had not, in his typical style, started to take an interest in entirely different problems. Air pollution was one of his interests. Several of his research colleagues in Stockholm had gathered data on the chemical composition of the atmosphere and it was clear that large quantities of acidifying substances were entering Swedish air space from Denmark, Germany and the British Isles. Over the next few decades this would be an important environmental issue – a term that in the mid-1950s was not yet in common use – and would lead to negotiations between the countries involved. Rossby was also interested in nitrates and how they could be carried into the atmosphere affecting the nutritional content of the ground and water, leading to eutrophication.

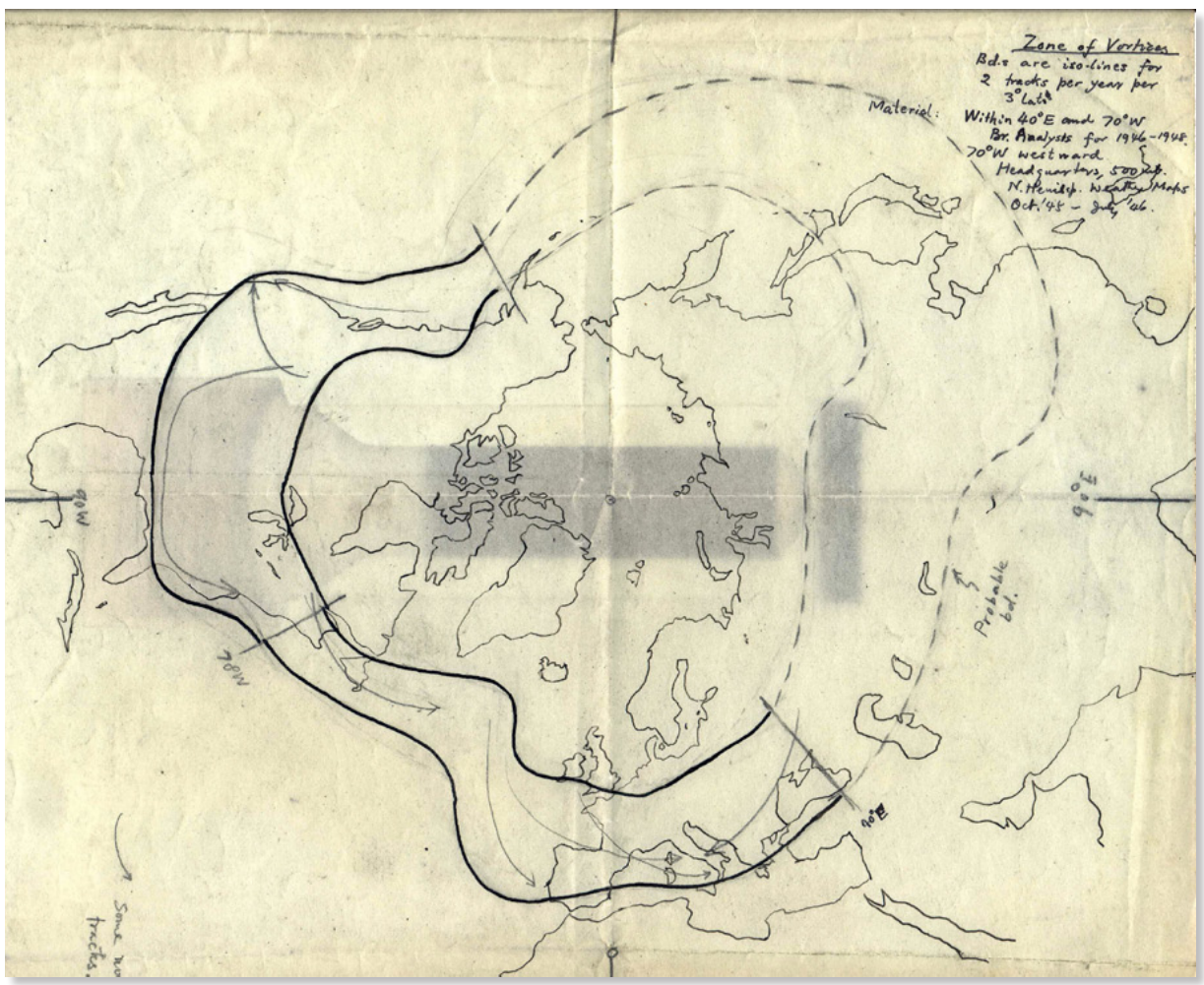
The meteorological world which was taking shape in the 1950s was not just focused on civil aviation and military strategy needs. A world with a growing population and the dramatically increasing consumption of natural resources and energy was also a world in which the composition of the atmosphere was changing. In an article on "Current Problems in Meteorology," written in 1956, printed in 1957 and available in English in the posthumous commemorative tome published in 1959, Rossby took up these new lines for the science he had shaped in a more fundamental way than any other person in the 1900s. The composition of air, not least the "pollution" as people were now starting to say, impacted both humans and nature. This is also how Rossby was presented in the *Time Magazine* article in 1956. The title of the article was "Man's Milieu." The terminology was still fluid – referring both to what impacted humans and the impact humans had on the environment. There was also the related issue of the climate. Could this also change as a result of human

impact on the composition of the atmosphere? The idea was not a new one; theoretically the greenhouse effect had been known since the 1800s, and one of Rossby's predecessors at Stockholm University, Svante Arrhenius, back in 1896 had presented convincing evidence showing that changes in the CO_2 composition would result in rising temperatures, just as falling levels could cause ice ages. Arrhenius' ideas were largely forgotten and the general conception for more than half a century was that humans did not have the power to impact anything as great as the planet or its climate. But a few voices expressed a different view. One belonged to the British engineer Guy Stewart Callendar, who in 1938 made detailed calculations of the earth's increasing average temperature since the 1800s and related them to human use of fossil fuels. Few people agreed with Callendar's ideas. Rossby did not seem to have paid attention to them either from his position at MIT, where the impending war kept him occupied with more pressing challenges.

But signals came from his network from time to time. One of his first PhD students, Chaim Pekeris, had been interested in these issues as early as the 1930s. At the same time Rossby made his first contact with Finnish chemist Kurt Buch, who had been gathering data for many years on CO_2 uptake in the ocean and had found that the amounts were constantly increasing. In 1953 Buch got in touch with Rossby again and explained that he was thinking along the same lines as Callendar. Receptive and curious as always, Rossby picked up on the idea. He did not launch a comprehensive research programme, but he gradually allowed more space for the study of atmospheric chemistry in his department, including carbon dioxide. His department at Stockholm University took the initiative to build a Scandinavian network tasked, among other things, with measuring CO_2levels in the air.

As Chairman of the Swedish National Committee for the International Geophysical Year, IGY, 1957/58, with Bert Bolin as his secretary and right-hand man, Rossby made sure

that CO_2 measurements were included in the Swedish programme. He was also directly involved in the discussions about where and how Charles David Keeling's measurements of greenhouse gases, an IGY project, should be pursued. In the Swedish IGY programme, CO_2 measurements were made from a base on Spitsbergen. Several articles were published in *Tellus* presenting the ideas about climate change when these were brand new and perceived by most people as wild guesswork. A more common line of thought at that time focused on the long-term trend towards a new ice age and an entire research generation was raised on



Handdrawn map in the Rossby collection, Meteorological Institute Archives, Stockholm University. The map shows atmospheric conditions over the Arctic region based on observations immediately after the Second World War.

these ideas, which made them disinclined to later accept the notion of climate change even as the evidence was mounting. This sort of scepticism was not for Rossby, who was always prepared to discuss every new idea and change his mind if necessary. In the mid-1950s, which in this context was very early, Rossby was on the side of those who kept an open mind about whether or not humans were responsible for large-scale climate change:

> *"It has been pointed out frequently that mankind is now performing a unique experiment of impressive planetary dimensions by now consuming during a few hundred years all the fossil fuel deposited during millions of years. The meteorological consequences of this experiment are as yet by no means clarified, but there is no doubt that an increase of carbon-dioxide content in the atmosphere would lead to an…increase of the mean temperature of the atmosphere."*
>
> Rossby, "Current Problems in Meteorology," originally published in Swedish in 1957, in English translation posthumously in Bolin, ed., *The Atmosphere and the Sea in Motion* (1959).

When Rossby died suddenly and unexpectedly of a heart attack on 19 August 1957, he was in the middle of a workshop. He was restlessly active to the very end. As a visionary, he was also focused on the future and on opportunities, rather than what he had already achieved. In his final years he talked to friends and colleagues about how he actually wanted to move on again, this time to the Middle East. This wasn't just a daydream; he had already started some preparations for a meteorological institute in Beirut. He wanted to once again create something new for the general good.

Rossby was extremely successful and effective as a researcher, even if not all of his contemporaries or successors fully realised the breadth of his achievements. How can we understand or, in fact, explain his success? There is no simple answer. His colleagues and contemporaries thought his personality had a lot to do with it. Rossby was extremely determined and prepared to work very hard for something he believed in. Added to this was a large measure of ambition, but not of the vain kind; being visible was not important to him, but he knew what a job well done was and he had nothing against doing it himself with his colleagues.

He can also be described as highly independent. In every step he took along his career path there was a personal aspect behind the great dedication he showed to the institutions that employed him. Tor Bergeron noted that when he was a young man of twenty in Bergen, Rossby learnt everything he possibly could about the Bjerknes methods and not least how to build a successful research environment. But deep down Rossby was already thinking about how he would take what he had learnt there and apply it to greater projects in the future. He was always moving on – never standing still. Many have testified to his impatience. He struck while the iron was hot and could become almost desperate when someone or something placed obstacles in the way of his plans, or displayed common human sluggishness or indifference – which he hated the most. Added to this was his well-known joviality, his positive outlook on life, his appreciation of good things, including in a very material sense, such as food and drink, which could have helped him cope with his restless nature. When he and his

wife Harriet entertained guests at the house in Näsby Park at the end of the 1940s, the quotas in the ration book of the state alcohol retail monopoly (*Systembolaget*) would not suffice. Luckily he was able to obtain gin and other necessities through his contacts at the American Embassy. He also made sure he had space to breathe in his daily life. After long days at work and the trip home on the train along the *Roslagsbanan* line in the direction of the archipelago, he enjoyed the refreshing walk to his house and sitting on the sofa with Harriet, enjoying a dry martini before his children were called to the dinner table.

As a research director he had qualities that sociological research has identified as fundamental for successful research environments. He was charismatic, he was full of ideas, he was a strong visionary with a strategic focus, he had good relationships with funding sources and was able to incentivise and generate enthusiasm for the projects he wanted to implement. He was also able to get others, including non-experts, to see the point of making a certain type of research happen, even if its significance lay in the distant future. He had an eye for talent.

Family dinner at Observatory Hill, fall 1953. Daughter Carin to the right.

Harriet 1953.

He understood, often quickly and almost intuitively, which people had real talent and he succeeded with singular precision to surround himself with many such individuals in all of the environments in which he worked. He often nurtured talent in research students. These included Horace Byers from Berkeley who came to MIT, Jule Charney who got his PhD at the less enticing meteorology environment at UCLA, but was soon brought into Rossby's magic circle, or Bert Bolin, the wise and multi-talented meteorologist in Stockholm whom he could entrust with anything in the knowledge that he would always do a good job. Their careers all followed the same pattern. They met Rossby as a teacher or mentor, then, through dialogue or mutual understanding, adopted his research agenda and worked faithfully on it in the network. Rossby retained his leadership role through all turns in the road and regardless of the subsequent successes of the individual members of his network. In many ways they outshone Rossby in individual achievements, not least in mathematics or research methods. But there was never any doubt about which roles the various researchers had. Interestingly, few of them seemed to complain about this arrangement. Similarly, Rossby was never envious; the more successful the others were, the better it was for him.

The arrangement included mobility. That was actually the idea – never stay still, always move on. That is how he himself lived and he required it of others too. He explains his philosophy of how to build successful research environments in a letter to Byers in Chicago in July 1952: "I am quite concerned with the evils of the desire for 'security' and 'stability'." But perhaps there should be limits to mobility. Some of his friends and colleagues were concerned that he pushed himself too hard. Philip Thompson, then at MIT, comments on 1 April 1952 when Rossby could not participate in a conference at MIT because he had returned to Sweden: "How you are able to withstand the pace of commuting between Chicago, Stockholm and Princeton is a mystery deeper than confluence theory." Statements like these

were hard to interpret; they mixed admiration, which could be ritualistic, with consideration and concern, sometimes alarm. Rossby had superhuman traits.

In correspondence there are elements of resignation, which could be understood as tongue-in-cheek, from some colleagues about his legendary tardiness and inability to keep promises – for example delivering a manuscript – and to keep appointments, or even answer letters (the latter would to some extent seem refutable by the fact that he wrote so many letters, although nowhere near as many as he received). There was asymmetry in his relationships insofar as when Rossby spoke he expected others to react, but the reverse was not the case in the same way. Jule Charney alluded to this sometimes, with a touch of irritation, but it did not affect his basic loyalty which was also emotional and had elements of admiration and empathy for a figure who everyone knew worked hard, even if not everyone knew exactly where he was or exactly what he was doing. If the expression were not such a cliché, it might be tempting to call him a father figure; he could be slightly insufferable, but no one could deny his goodness and wisdom and the way he cared about everyone's best interests in the long term. People who were in his hands felt as if they were taking part in something big and important.

Rossby was a reformer. He saw, often immediately, the weaknesses in an organisation and his impulse was to change it. A case in point was the U.S. Weather Bureau, where traditionalism ruled and prevented the change he felt was necessary. He saw the same phenomenon at the Swedish SMHI and in the Air Force, where there were timid and often ignorant administrative types who held fast to their hidebound ideas, their formal authority and pettiness to the detriment of the greater good, which was, of course, obvious to him. It is hard not to think of a word such as elitism – not describing someone who is boastful or outwardly assertive, but a person who sees shortcomings and inability as obstacles to success and the greater good.

He was also a pragmatist. Not much is known about his real attitude towards commercial and military interests in meteorology. He does not appear to be a devoted businessman, nor a clever and ideologically-motivated Cold Warrior of the John von Neumann type, but he was probably not a conscious or reflexive critic either. What he felt and thought deep down is hard to say based on the sources that have been available up to now. He was an internationalist. His association with Charney, who moved in San Francisco's politically aware Jewish circles, perhaps hinted at a touch of radicalism. But Rossby always worked with the interests that exist-

Rossby with his mother Alma photographed in Sigtuna in the early-1950s visiting his son Tom who was a student at Sigtunaskolan, a private boarding school there.

ed, as long as they were in line with his own. Essentially, he must at least have been loyal to US security policy.

But his personal qualities can only explain part of Rossby's significance. Another key explanation was that he was born in Stockholm – one of the environments in the world where geophysical issues had long had a certain status and where links to Bergen and Bjerknes were already established. He was catapulted from the Nordic region out into the world and like a boomerang, he came back. The ties between

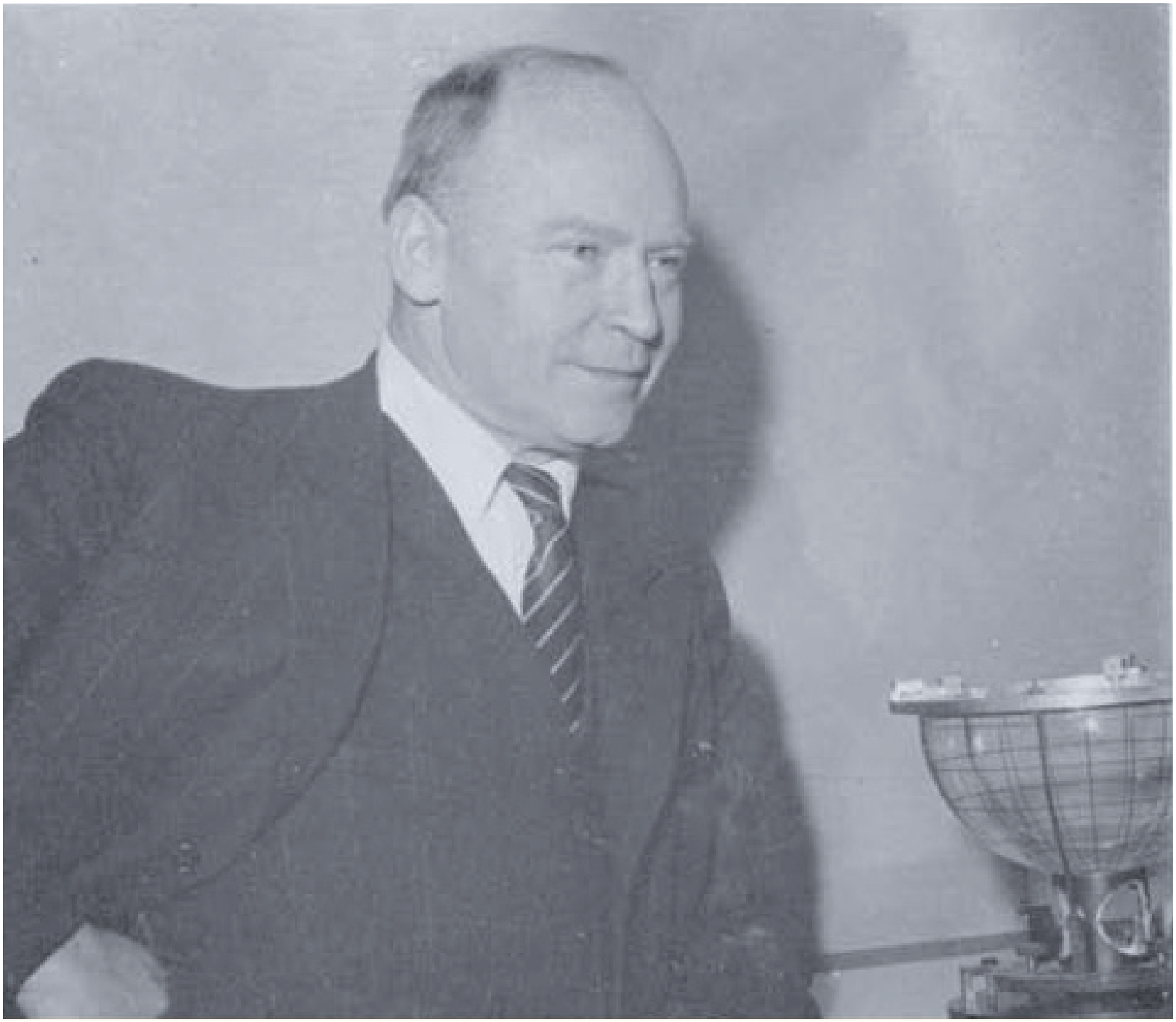
Christmas at the Blackstone Avenue apartment in Chicago 1950. Rossby with daughter Carin and neighbor's boy Tony.

the Nordic environments had been established since the end of the 1800s. Bjerknes' chair at Stockholm University was the most important one. They were strengthened after the First World War by geographer and glaciologist Hans Ahlmann's work in Western Norway with Bergen as the base, and Tor Bergeron, who became the Bergen School's important missionary in Sweden. He was also the one to first suggest that the Rossby family should be allowed to take over the Ahlmann's flat at the top of the Observatory on "the Hill" when Ahlmann became Ambassador in Oslo in 1950. The cupola overlooking the Swedish capital became their home until 1955.

Rossby with his daughter Carin in front of house in Näsby Park around spring 1949.

Rossby's own important and original steps were those he took over to the US; what Bergeron called his life's most decisive "ski jump." He was alluding to Rossby's persistent attempts to learn ski jumping on the Fiskartorpet slope on Norra Djurgården, which he actually managed! But there too, he was part of a pattern. The 1920s was the decade when postdoc studies abroad started to pick up institutional speed among Swedish graduates. In several areas the traffic was being diverted from Germany and the European Continent – traditional destinations both for study and research – to North America which was especially popular in new fields such as economics and technology-inspired applied disciplines. And perhaps most important of all was that Rossby arrived just at the time when civil aviation was on the rise, 1926–27, and the fact that at that moment he had the exact combination of theoretical, methodological and institutional experience to make him the ideal bearer of American meteorology during the upcoming years. The fact that a major war was about to break out and the US was being drawn into it was, from this perspective, no disadvantage – it was another reason why Rossby's qualifications were so useful.

His continuing successes after the war were not only attributable to Rossby's singular perseverance and ravenous appetite and ambition. This later phase in his development also had a broader security and geopolitical framework. He was a top US researcher with unique institutional resources and was recruited to come to Sweden to work in a field and during a period where Sweden and the US had extensive security policy collaboration and where Swedish research was also greatly motivated by military needs, especially when the technically advanced Swedish Air Force was expanding rapidly. It was, or at least could have been, an asset for all parties, including Rossby himself, who seems to have used the situation with his normal pragmatic finesse, but also at his usual, almost self-destructive pace. And with great self-confidence – he was number one and was aware of it, and he also *wanted* to be



Rossby standing next to Dave Fultz's rotating dishpan experiment in Chicago.

number one. In an annual report from his department in Chicago in 1945, he stated with what for him was far too calm and obvious hubris, that anyone who used administrative decisions to hinder the work in his department, was impacting meteorology in the whole country "since our department without question is the leading one in its field." This would have been unforgivably boastful if it were not so obviously and undeniably true. When he stood at the peak of his fame the American magazine *Look* listed him, in the fall of 1955, as one of the world's one hundred most influential persons, along with Winston Churchill, Mao Zedong, and fellow Swede Dag Hammarskjöld.

Even an incurable workaholic has some spare time. Rossby was a curious and competent amateur botanist. He was particularly fond of the flora of Gotland. When guests visited what had been his summer paradise since childhood, he was happy to "educate" them about the island's orchids. He was also known for his interest in art. He enjoyed listening to music. He had time for people. His conversations about work were deep and probing and were with people who shared his passion and curiosity for the unknown. This included nature and the Earth itself. What these non-linear forces had in store for us could ultimately never be figured out. In the issue of *Time Magazine* with Rossby on the cover in 1956, he concluded by saying: "We should have a great deal of respect for the planet on which we live."

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