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The Remarkable Scientist and Writer Ukichiro Nakaya and His "Black Moon" and "White Moon" Worlds

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Abstract.

The physicist Ukichiro Nakaya (1900-1962) is renowned in Japan for his contributions to snow and ice science and for his outstanding achievements as a writer and film maker. His meticulous field observations and his laboratory investigations led to seminal discoveries about snow crystals. Notably in 1936 Nakaya produced the world's first artificial snow crystal created in a cloud chamber. This allowed him to determine the systematic dependence of snow crystal shapes on the conditions at formation, a result now summarized in the widely known "Nakaya diagram". In the 1950's Nakaya began collaborations with the US Snow, Ice and Permafrost Research Establishment investigating the properties of glacial ice, notably including fieldwork in Greenland during the pioneering years of the deep ice coring project there. Nakaya was a very prolific writer of essays published in Japanese magazines, and his essays were often republished in book collections, many still in print today. His writing for the general public about science has led to his reputation as "The Carl Sagan of Japan", but his writing extended more broadly to many areas of culture. Nakaya was also a pioneer in making educational documentary films and he was instrumental in the formation of a major film studio in Japan.

This article was initiated to mark Nakaya's 125th anniversary year and aims to introduce his life and achievements to a broad international audience. We review Nakaya's biography and highlights of his scientific career, and include some brief discussion of the Japanese cultural context for his scientific work. We recount some particularly dramatic aspects of Nakaya's life which was shadowed by the great historical developments of his era, notably the Second World War. We also review his contributions to Japanese literature of his time. We sample a handful of Nakaya's articles written for the general public in order to convey the scope and flavour of his literary *oeuvre*. We describe in detail two of Nakaya's most ambitious magazine essays: "World of the Black Moon" and "World of the White Moon", which are of particular interest as vivid first person accounts of middle 20th century research field trips (to Hawaii and Greenland, respectively). "World of the White Moon" is also notable for including a very early description for the general public of the issue of anthropogenic climate change.

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1 Introduction

The history of science is enlivened by colorful stories of breakthroughs resulting from unexpected observations that initially appeared incidental to the main investigation. Famous examples include the discoveries in the 1890's of radioactivity by Becquerel and X-rays by Roentgen, Fleming's 1928 discovery of the antibiotic action of penicillin, and the 1964 discovery of the cosmic radio background by Arno and Penzias; each of these discoveries led to a Nobel Prize for the investigators.

Physical meteorology has its own intriguing story of a serendipitous laboratory discovery that opened important vistas in research. In early 1936 the staff at a small laboratory at Hokkaido Imperial University (today's Hokkaido University) in Sapporo, Japan, were investigating the structure of snow crystals and trying to understand the processes that led to the amazing variety of forms that they had observed. After extensive observations of naturally occurring snowflakes, the researchers felt a need to produce snow crystals artificially so that the factors affecting their growth could be systematically investigated. Unfortunately, it proved very difficult to find a substrate that allowed a single ice crystal to form. Attempts with "many" types of thin filaments produced the discouraging result that "*frost crystals grew over the filament making it look like a hairy caterpillar*" (Nakaya, 1954, pg. 151). Then an investigator happened to notice an ice crystal at the tip of a hair on a rabbit fur jacket that was hanging in the icy cold laboratory. This was a crucial breakthrough and the use of the rabbit hair substrate allowed the first artificial snow crystal to be produced in the laboratory's cloud chamber on March 12, 1936. Hokkaido University has commemorated the creation of the world's first artificial snow crystal with a marble sculpture on their campus at the original site of the laboratory (Fig. 1).

Figure 1: The marble monument erected on the Hokkaido University campus marking the site of the laboratory where the world's first artificial ice crystal was produced on March 12, 1936. Photo courtesy of Yoshio Kawatani.

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The leader of this research project was Hokkaido Imperial University professor of physics Ukichiro Nakaya (1900-1962; Fig. 2). Nakaya and his associates went on to show how the meteorological conditions at the crystal formation determined the complex forms of snowflakes. From this research emerged the "Nakaya diagram" summarizing the forms of crystals as a function of temperature and humidity. The idea that the atmospheric conditions at formation were imprinted on the snowflakes observed at ground level led Nakaya to famously state that "snow crystals are letters sent from heaven" (*yuki wa ten kara okurareta tegami dearu*). Nakaya became a leading expert on the microphysics of snow and went on to author perhaps the 20th century's most influential monograph on that subject (Nakaya, 1954). In the 1950's he worked with American colleagues in Greenland on pioneering efforts in ice core research. Nakaya attained high honors in Japanese science and the centenary of his birth in 2000 was marked by the issuance of a Japanese postage stamp (Fig. 3).

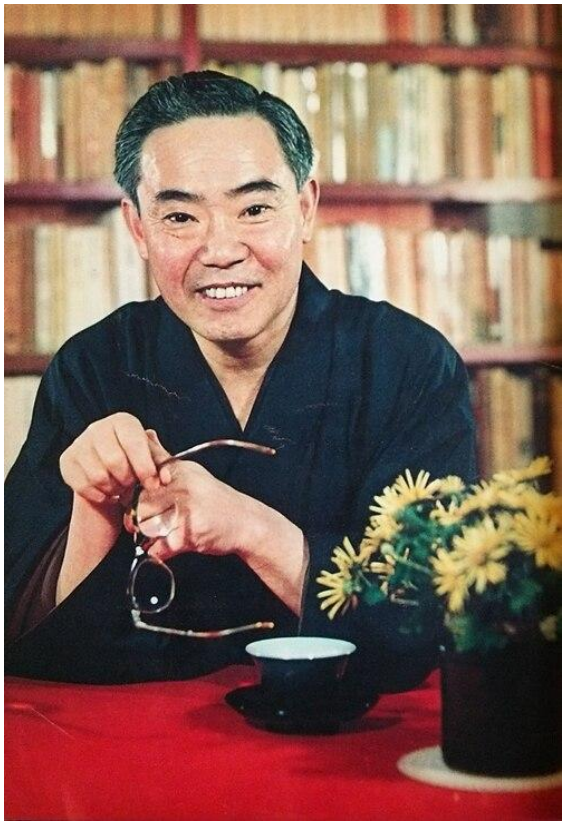

Figure 2: Ukichiro Nakaya in 1959. Bungei Shunju Shin Sha via Wikimedia Commons. Original source: Shukan Bunshun, December 21, 1959.

Nakaya's impact extended well beyond his research discoveries and he became a renowned essayist widely published in Japan, as well as a pioneer in making scientific documentary films. According to Daub and Asano (2003, pg. vii) Nakaya's popular

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writing about science *"…has led many in the postwar generation of Japanese scientists to refer to him as the Carl Sagan of Japan"*. Nakaya was mentored by the prominent literary scientist Torahiko Terada (1878-1935), and he would himself mentor a prominent glaciologist who was also a prolific, award winning essayist: Keiji Higuchi (1927-2018). Remarkably, this chain of mentorship extends back to one of the towering figures of Japanese literature: the novelist Sōseki Natsume (1867-1916) who was a teacher and close associate of Terada.

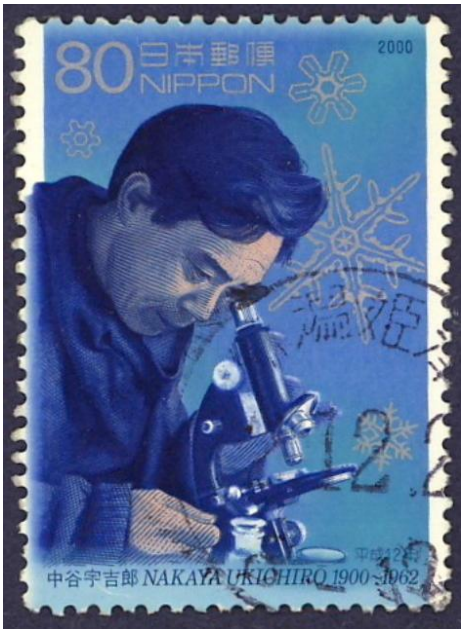

Figure 3: Japanese postage stamp issued in 2000 to celebrate Nakaya's 100th birthday.

While famous in Japan and in the global cloud microphysics community, Nakaya is less well known internationally among scientists in other specialties. In this article we take the occasion of the recent 125th anniversary of Nakaya's birth to briefly introduce his life and career accomplishments. A focus is on two of Nakaya's most ambitious essays from 1957 that were written for the general public: "World of the Black Moon" (*Kuroi Tsuki no Sekai*) and "World of the White Moon" (*Shiroi Tsuki no Sekai*). Each of these essays describes Nakaya's field research during a season in a remote and exotic locale. First in his "Black Moon" essay Nakaya describes his research on natural snow crystals undertaken during a winter on Mauna Loa in Hawaii. Then Nakaya's "White Moon" essay describes his participation in a summer campaign to study the Greenland ice cap. The history of geoscience is surely enriched by these first person descriptions of pioneering scientific field work in the middle 20th century, written by a widely admired author.

The "White Moon" essay is notable for an account of the early days of modern ice core research, as well as presenting Nakaya's ideas concerning anthropogenic climate change. The research he describes in his essay did not produce many immediate returns in terms of published refereed journal papers, but it stands near the beginning of the development of the field of ice core studies that ultimately revolutionized our understanding of the earth's climate history.

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Nakaya's ideas on climate change presented in his 1957 "White Moon" essay are also very interesting to consider. Today, of course, anthropogenic climate change is a mainstream concern; by contrast, the state of knowledge on this issue among both scientists and the public in the 1950's was remarkably limited. Schmidt (2010, pg. 64) writes about the state of knowledge in the mid-1950's, noting that *"the idea that carbon dioxide affected climate was very much a fringe concern"* and that a very prescient article (by the Canadian-American physicist Gilbert Plass) published in the journal *American Scientist* in 1956 was *"only the start of a quite rocky road to modern respectability for* [this] *idea"*. In this context, Nakaya's essay appears "ahead of its time" in featuring his discussion of the possibility that fossil fuel burning could lead to global warming and his idea that the record of carbon dioxide in ice cores could be crucial in confirming this concern. It seems Nakaya broke new ground in Japan by raising the possibility of anthropogenic climate change for the general public. Indeed, the claim has been made in at least one publication that Nakaya's 1957 essay was the first notable public discussion of the issue in Japan (Anker and Sörlin, 2022).

Our article begins with a brief discussion of the place of snow in traditional Japanese culture and the beginnings of Japanese scientific contributions to the study of snow in the 19th century (Section 2). This provides background to the outline of Nakaya's life and research accomplishments presented in Section 3. Section 4 describes the scope of Nakaya's contribution as an essayist and includes some background on Japanese publishing during his lifetime. Section 5 presents excerpts from, and a discussion of, Nakaya's "Black Moon" essay. Section 6 first presents background discussion to provide context for the 1957 essay "World of the White Moon" which is then excerpted and reviewed in detail. Section 7 is a brief recapitulation and the conclusion to our article.

Before proceeding we review here some basic facts of Japanese history that will be relevant to our later discussion. A long period of civil wars ended in 1603 with the establishment of the governing Tokugawa shogunate in the newly proclaimed capital of Edo (modern Tokyo). The subsequent centuries are now known as the "Edo period" and were an era of peace and national unity and featured an official policy of isolation of Japan from foreign influences. The isolation was not total, however, as trading with the Dutch was allowed at an island in Nagasaki harbor. The items imported into Japan included Dutch books and some scientific instruments (Screech, 2002). Notably Dutch compound microscopes are known to have been used in Japan by 1765 (Screech, 2002). The arrival of American warships in 1853 forced an end to the policy of isolation and led to internal conflicts that resulted in the end of the shogunate and the Edo period in 1868 and the establishment of a modern government, initially under the leadership of Emperor Meiji. In the 1930's and 1940's Japan became embroiled in foreign wars which culminated in the surrender to the United States in 1945, marking the end of World War II. Postwar Japan was occupied by the United States military until 1952 and the populace in these early postwar years had to deal with significant privations as the national reconstruction began.

Note that Japanese names here will be given in the westernized format with family name last (exceptions for some famous Japanese historical figures living before the 17th century).

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2 Japanese perspectives on snow

Traditional Japanese culture is famous for a focus on the passage of the seasons (Shirane, 2012). Famously, several forms of traditional poetry, including *haiku*, must include a *kigo*, i.e. a word with seasonal reference. Snow (*yuki*) plays a leading role in this deeply rooted appreciation for nature's cycles. In her scholarly paper on the Japanese aesthetics of snow, Saito (1996, pg. 94) writes that "*snow is appreciated in the Japanese tradition for symbolizing transience. …The transience of snow is particularly cherished because it provides an aestheticized parallel to human impermanence*."

The appreciation of snow inspired sophisticated social customs among the aristocracy. The revered tea master Sen no Rikyu (1522-1591) "*delighted in holding a special tea ceremony whenever snow fell*" (Saito, 1996, pg. 89). Some traditional Japanese gardens include special stone lanterns or *yuki-mi-doro*, which are intended as gathering places for snow viewing (*yuki-mi*) parties. Fig. 4 shows a *yuki-mi-doro* in the garden of the Katsura Rikyu Imperial Villa in Kyoto (completed in 1645), a garden widely regarded as a pinnacle of Japanese culture.

The *yuki-mi-doro* often have a hexagonal cross-section suggestive of the appearance of individual snow crystals. The six-fold symmetry of snow crystals is also seen in other Edo period designs (Hibi and Niwa, 2001).

Figure 4: A "snow viewing lantern" (*yuki-mi-doro*) in the garden of the Katsura Rikyu Imperial Villa in Kyoto.

The famous zen master and prolific poet Dogen (1200-1253) began a poem with:

"*Snow is falling far and wide/Each snowflake neither the very same or completely different from the other ones*" (Heine, 1997, pg. 127).

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Of course, such a statement could just reflect a conventional view at the time, but forming such a view must have depended on a considerable effort at (naked eye) snowflake observations by Japanese people in this distant era. Keen naked eye observation must also underlie the convention of hexagonal shapes that appeared in the design of *yuki-mi-doro* and other items, notably including kimono. Anonymous (2020) describes the snow designs on kimono both before and after the introduction of the microscope to Japan:

"*The use of snow as a pattern dates back to the Muromachi period (1336-1573) … Yukiwa* [is] *a pattern that represents a snowflake, resembling a round six-petaled flower. There are six large hollows, some of which are filled with seasonal plants. … When snowflakes were first observed in Japan using microscopes in the late-Edo period, a* [greater] *variety of snowflake patterns were created. The sekka (snowflower) pattern shows the shape of snowflakes arranged like flowers. … Today, the snowflakes are used in countless kimono and obi, and are also popular as a pattern for yukata.*"

The systematic study of snow in Japan took a major step forward with the work of Toshitsura Doi (1789-1848) who was the feudal ruler (*daimyo*) of the Koga Domain (a region in modern day Ibaraki Prefecture). Doi and his collaborator Senseki Takami, a scholar and a top ranking samurai official, conducted observations of snowflakes using an imported Dutch microscope beginning about 1812 (Hunter et al., 1986). In 1832 Doi published "*Sekka Zustetsu*" ("Illustrations of Snow Blossoms") including 86 sketches of individual snowflakes. A second edition with 97 sketches was published in 1839. Doi's publication was limited and meant primarily for his family, but his observations became better known when many of his sketches were reproduced in another book "*Hokuetsu Seppu*" ("Snow Country Tales"; Hunter et al., 1986). The *Hokuetsu Seppu* was authored by Bokushi Suzuki (1770-1842) and has been described as "*a collection of facts, tall tales, first hand ethnographic studies and other musings*" about rural life in winter (Klampert, 2021). The *Hokuetsu Seppu*, first published in 1837, was a great success and is still read in Japan today. According to Anonymous (2015):

"*The delicate beauty of the stylistic snow patters found in Toshitsura's research soon became all the mode among the common people during the Edo period ... and were used to add grace to kimono and accessories*".

Nakaya recorded his admiration for Doi and Takami's work in his own 1954 classic monograph "Snow Crystals: Natural and Artificial" (Nakaya, 1954). Nakaya wrote in his introduction (pg. 2): "*The sketches by Doi are very nearly equal in quality to the illustrations of snow crystals by the English meteorologist James Glaisher published ….23 years later… which are considered the most accurate observations published before the development of photomicrography*". Nakaya's pride in his countrymen's achievements is evident and, by including this in the introduction to his own *magnum opus*, he makes a point of placing his own research in the lineage of the 19th century Japanese pioneers.

3 Nakaya's life and scientific career

3.1 Sources

Some basic facts of Nakaya's life and career are in English language sources such as his obituaries published in scientific journals (Higashi, 1962; Rigby 1962, Bender, 1962; Magono, 1963), a brief article published by Hokkaido University

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(Anonymous 2022), a recent article in a popular magazine (McGee, 2025) and a scholarly article primarily focused on the period 1928-29 when Nakaya was studying abroad in London (White, 2016). The preface to Nakaya's own 1954 monograph on snow crystals (Nakaya, 1954) also has some valuable autobiographical details. An interesting essay about Nakaya is published on a website supported by the Ukichiro Nakaya Foundation in Japan (Okazaki, 2017). Nakaya's pioneering work on educational films is described in the history of a Japanese film studio in a Yale University doctoral thesis by Tsunoda (2015).

Anonymous (2006) includes excerpts of the texts of six English language lectures that Nakaya presented in August 1959 on Radio France that described his research interests. This provides us with one instance of Nakaya writing about science for the general public in English.

Daub and Asano (2002) present English translations of excerpts from a book "*Kagaku no Houhou*" (The Methods of Science) that was based on a series of nine radio lectures given by Nakaya on Japanese national broadcaster NHK in spring 1961.

Nakaya's activities as a young scientist are referred to in a Harvard University doctoral thesis on the history of theoretical physics in Japan during 1920-1940 (Ito, 2002).

We were able to supplement these references with Japanese language sources. His colleagues at the Hokkaido University Department of Geophysics published an article "Mourning the Passing of Professor Ukichiro Nakaya" in the Geophysical Bulletin of the Hokkaido University (Anonymous, 1963). This reference includes an extensive bibliography of Nakaya's publications including: 62 English language scientific articles published during 1926-1962, 48 Japanese language scientific journal publications published during 1933-1958, 43 popular books published during 1938-1961 (most are collections of his shorter writings), as well as a list of 12 documentary films that he produced during 1939-1961.

Other Japanese language sources include (i) Sugiyama (2015), a book length biography of Nakaya with an assessment of his career achievements and his public influence in Japan, (ii) Kuroiwa (1982) which is a history of snow and ice research at Hokkaido University, (iii) Kanda (2001) which is a short biographical sketch.

3.2 Early life and education

Ukichiro Nakaya was born in July 1900 in Katayamazu Town, which today is in Kaga City, Ishikawa Prefecture (Anonymous 1963). His father owned a *gofuku-zakka* shop (a traditional store selling kimono fabrics and other dry goods). Ukichiro's parents thought Katayamazu, a hot spring town, might not be a good place for education, and this led to a somewhat itinerant childhood. In 1906, Ukichiro was sent to his mother's family home and entered a nursery school in Daishoji. In 1907, Ukichiro began elementary school and was moved to the house of a distant relative and pottery maker, Ichimou (Ichigou) Asai. In 1908, Ukichiro was moved again to another relative's house. Later, Ukichiro began English lessons from another pottery maker, Shutou Nakamura, but Ukichiro was reportedly more interested in the local traditional pottery (known as *kutaniyaki*) than in learning English. Ukichiro's father died in 1913, the same year Ukichiro entered Komatsu Junior High School where he lived in a dormitory for five years. He graduated from his junior high school in March 1918. His mother encouraged him to continue education to the university level but his path was complicated because he had failed the entrance examination for a high school

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in Kanazawa (Anonymous, 1963). He attended preparatory school in Tokyo and further high school classes in Kanazawa. During this time he became particularly interested in physics after reading a book by Japanese philosopher Hajime Tanabe (1885-1962; see Anonymous, 1962; Moreno, 2022).

Finally in 1922 Nakaya entered the Tokyo Imperial University (today's University of Tokyo). As an undergraduate Nakaya began research under the Professor of Physics Torahiko Terada (1878-1935). Nakaya would graduate in 1925 and continue research as an assistant to Terada at Japan's advanced scientific research organization, RIKEN (*Rikagaku Kenkyusho*) working on the physics of electrical discharges. In a 1926 English-language guide to RIKEN, Terada is listed as heading one of the institute's 24 research groups. Nakaya is listed working under Terada on "Experimental Researches of Spark Discharge" (RIKEN, 1926).

Ito (2002) provides an interesting glimpse into Nakaya's time at Tokyo Imperial University and his earliest days employed at RIKEN. Ito notes that some physics students in Tokyo felt resentment at the domination of the department by a faction of older, conservative faculty, particularly when discussing the early ideas of quantum theory then making their appearance in Japan. Some young Tokyo graduates who moved on to RIKEN, including Nakaya, set up their own "Physics Reading Group" to facilitate unfettered discussion. According to Ito (2002, pg. 142) Terada championed the young scientists of the Physics Reading Group and told Nakaya:

"*that it would be interesting if RIKEN, with its excellent minds, would plot a rebellion. He also called the young participants of the Physics Reading Group gōketsu (heroes)… The participants called themselves akudō, or bad boys*."

In later publications Nakaya would acknowledge the influence of his early mentor Terada, and Nakaya even successfully advocated for posthumous publication of a major book manuscript by Terada (see Sect. 4.3 below). Terada was a physicist with varied scientific interests mainly focused on geophysical problems but also was a well regarded writer and poet (Komiya, 2022). As a high school student Terada's language teacher had been Kinnosuke Natsume (1867-1916) who, under the pen name Sōseki, would later become one of Japan's greatest literary figures (Nathan, 2018). Sōseki and Terada maintained a continuing association and it is generally believed that Sōseki used Terada as a model for at least two characters in his famous novels.

3.3 Study in London

According to White (2016) and Sugiyama (2015), in late 1957 Nakaya was chosen to be one of 17 scholars sent by the Japanese government to study abroad as preparation for their later employment at the newly established Faculty of Science at Hokkaido Imperial University (today's Hokkaido University). In April 1928 Nakaya began a year of study at King's College in London under the guidance of Professor Owen Willians Richardson (1879-1959), a distinguished experimental physicist who would win the Nobel Prize later in 1928 for his pioneering work on thermionics.

Nakaya's work involved studying how the photoelectric effect stimulated by the impact of low energy X-rays on a metal plate was affected by a layer of adsorbed gas on the plate. Nakaya completed a manuscript on his experimental results in March 1929 just before he left England. Richardson's verdict on Nakaya's year in his laboratory was that he was "very glad that you

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have found so many new facts in such a short time" (White, 2016). Nakaya's paper "On the Emission of Soft X-Rays by Different Elements, with Reference to the Effect of Adsorbed Gas" was published in July 1929 in *Proceedings of the Royal Society*. His affiliation on the paper is given as "Research Scholar of the Government of Japan, King's College, London" and the paper was communicated (effectively sponsored) by Richardson.

Among the leading scientists Nakaya met during his time in London were two who made important contributions to meteorology: Sir George C. Simpson (1878-1965) and C.R.T. Wilson (1869-1959). Simpson had a long career including service as the meteorologist for Robert Falcon Scott's notorious expedition to the South Pole in 1910-1913 (Simpson remained at Cape Evans base camp while Scott made his final, and tragic, journey towards the Pole). From 1920 to 1938 Simpson served as Director of the British Meteorological Office. Several years after Nakaya returned to Japan, Simpson would weigh in on a modest controversy involving Nakaya, as explained below (Sect. 3.6). C.R.T. Wilson was the inventor of the cloud chamber for which he shared the 1927 Nobel prize in physics. Wilson would later communicate a *Proceedings of the Royal Society* paper by Nakaya that reported on use of a Wilson cloud chamber to investigate electrical discharges (Nakaya and Yamazaki, 1936). In 1936 Wilson wrote to Nakaya asking for assistance for a British scientific party that was to be sent to Hokkaido to observe the June 1936 total solar eclipse (White, 2016). Nakaya gladly agreed and, despite by his own admission having no knowledge of astronomical observations, he actually joined the British expedition for 4 days at the observation location in eastern Hokkaido, an adventure that he recorded in a magazine article "Impressions of the British Solar Eclipse Team" (*Eikoku Nichishokuhan no Inshou*) that was republished in a book *Fuyu no Hana* ("Winter Flowers") in 1938 by the publisher Iwanami Shoten.

After finishing at King's College Nakaya would spend the rest of 1929 travelling in Europe including a visit to his younger brother Jiujirō who was then studying archaeology in Paris. Nakaya returned to Japan at the end of the year. In February 1931 he would be awarded a D.Sc. from Kyoto Imperial University (today's Kyoto University) with a thesis with title identical to that of his 1929 Royal Society paper.

We were intrigued by the fact attested by Sugiyama (2015) and White (2016) that Nakaya received his doctorate from Kyoto Imperial University despite apparently never studying there. At that time copies of many of the doctoral theses in Japan were deposited in the National Diet Library archives and there we found Nakaya's thesis (Fig. 5) which is bound in two volumes, one with just the reprint of Nakaya's Proceedings of the Royal Society article and one that collects reprints of 15 earlier English language papers he had published, mainly dealing with electrical discharges. So Kyoto Imperial University seems to have awarded Nakaya a D.Sc. for work conducted entirely at King's College and in Tokyo at Tokyo Imperial University and RIKEN. This seems odd in light of contemporary international practices, but, even today it is possible in some Japanese universities to obtain a doctorate without actually attending a graduate school in a process called "*ronbun hakase*" (doctorate awarded for published papers).

Nakaya's mentor Terada had moved within the Tokyo Imperial University from the Faculty of Science to the Earthquake Research Institute and possibly that this may have led Terada to orchestrate the award of Nakaya's degree from Kyoto Imperial

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University (likely with the support of Masamichi Kimura, who was then the professor of physics at Kyoto and a prominent atomic physicist; see Konagaya, 2020).

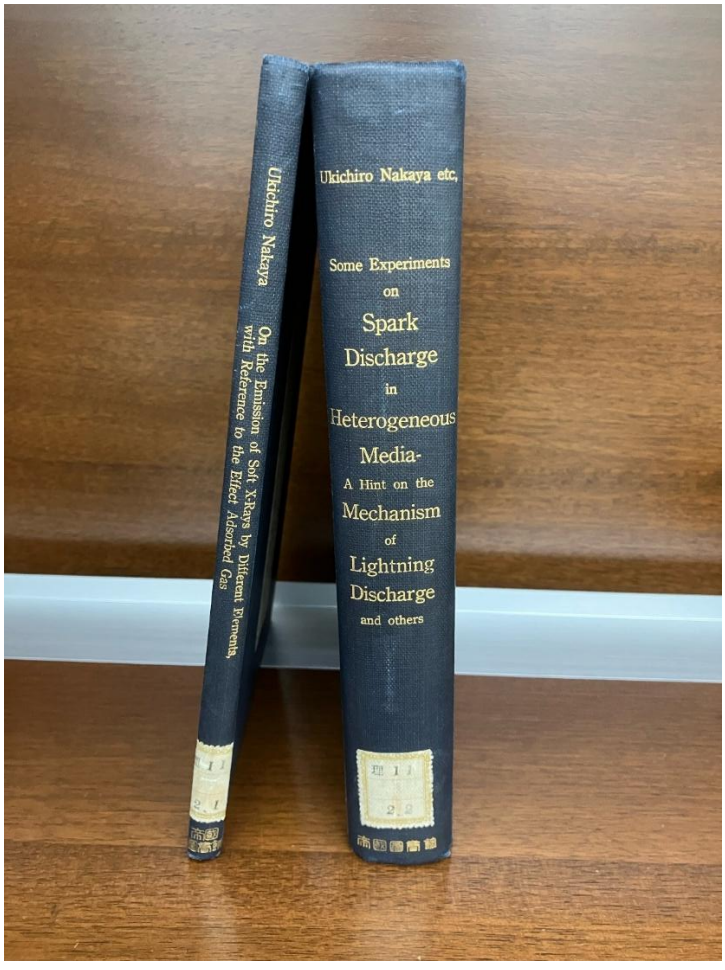

Figure 5: Photo of the two bound volumes of Nakaya's thesis in the *Kansai-kan* of the Japanese National Diet Library in Kyoto.

3.4 Snow crystal research before 1932

By 1932 the observation and documentation of snow crystals had advanced considerably over the 1830's work of Doi and Takami discussed in section 2 above. Quoting from Nakaya's own brief history of the field (Nakaya, 1954, pg. 3):

"*In Europe, with the development of photomicrography, research on snow crystals made remarkable progress, particularly since the end of the nineteenth century. Many meteorologists in England, Germany and Russia took photomicrographs of snow crystals. …*[they] *classified snow crystals into three kinds – planar, columnar, and combinations of the two. The basic idea of this system remains in the general classification of snow crystals to the present day*".

In the early 20th century a major contribution was made by the American amateur scientist Wilson A. Bentley (1865-1931). Bentley perfected a technique capturing snow crystals on a black velvet cloth and then photographing them quickly before the

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crystals sublimated. His set of over 6000 photomicrographs was unmatched as a survey of the variety of snow crystals (Blanshard, 1998). Many of his photographs were published in a 1931 book coauthored with US Weather Bureau meteorologist William J. Humphries (1862-1949). Nakaya was aware of the Bentley and Humphreys book and later wrote (Nakaya, 1954, pg. 4) of his appreciation of Bentley's work, but also noted important limitations:

"*A series of famous photomicrographs was made by Bentley of the United States in this century. ...Approximately 3000 of these photographs were published in 1931 ... in book form (Bentley and Humphries, 1931). It may be said that in all subsequent works in meteorology ...dealing with this subject, Bentley's pictures are reproduced. His collection made a great contribution toward inspiring many people with the beauty of snow crystals, but, as scientific material, it is regrettable that his pictures were retouched and were published without details of magnification* ".

3.5 At Hokkaido Imperial University: Natural snow crystals

Nakaya began his appointment as an associate professor of physics at Hokkaido Imperial University in 1930. In 1932 he became a professor. His published papers during 1931-1934 (that appeared in a journal published by RIKEN) show that he continued his work on electrical discharges including ongoing collaboration with his old mentor Terada (e.g., Nakaya et al., 1931). Nakaya wrote a monograph in Japanese titled "Recent Study of Spark Discharge" (*Hibana hoden no kinnen no kenkyu*), that was published by the prominent publisher Iwanami Shoten in 1936 as an inaugural book in their series "Compendium of Scientific Literature" (*Kagaku Bunkenshō*).

However, according to White (2016), Nakaya regarded his laboratory at the university as poorly equipped for his experimental investigations. Nakaya began to turn his attention to the study of snow crystals, of which he had an abundance each winter in Hokkaido. According to his own account: "[Nakaya] *and his colleagues started their study of snow toward the end of 1932, with extensive observations of natural snow. The observations were conducted at Sapporo and Mount Tokachi ... near the center of Hokkaido*." (Nakaya, 1954, pg. 4). The mountain laboratory was just above 1000 m altitude, about halfway up Mount Tokachi, and included primitive living quarters.

Nakaya was able to develop his photomicrography technique to the point of producing over 3000 detailed, and quite beautiful, images of the individual crystals that he sampled (Furukawa and Wettlaufer, 2007). Based on these observations Nakaya (1954, pg. 4) states that he "*made a general classification of snow crystals, and then carried out some investigations on the mass, speed of fall, electrical nature, frequency of occurrence, etc. of each type of crystal*".

Furukawa and Wettlaufer (2007; pg. 70) write that "*In the course of taking more than 3000 photographs in a few years, Nakaya classified snow crystals into some 40 morphological categories*".

3.6 Seligman review in *Nature*

Nakaya published his early discoveries about snow crystals principally in several English language articles that appeared in the *Journal of the Faculty of Science of Hokkaido Imperial University*, notably the eight papers: Nakaya and Iizima (1934), Nakaya and Hasikura (1934), Nakaya and Terada (1934, 1935), Nakaya (1935), Nakaya and Sato (1935), Nakaya et al. (1936)

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and Nakaya and Sekido (1936). Note that his collaborator in the listed papers authored by Nakaya and Terada was his assistant Tõiti Terada, son of Tokyo professor Torahiko Terada.

The prominent British glaciologist Gerald Seligman (1886-1973), founder of both the International Glaciological Society and the *Journal of Glaciology* (Glen, 1973), published an unusual article in the August 28, 1937 issue of *Nature*, titled "Physical Investigations on Falling Snow" (Seligman, 1937a). The title includes a footnote that reads (pg. 345) "*Based on a series of eight papers by Prof. U. Nakaya and his assistants, published in the Journal of the Faculty of Science, Hokkaido Imperial University*" and then lists the titles of the 8 papers published during 1934-36 that we mentioned above. Indeed, Seligman's article is entirely devoted to reviewing and critiquing Nakaya's work on snow crystal formation described in those papers. Such an article is highly unusual, of course, and Seligman's paper provided a broader dissemination of Nakaya's work under the spotlight of a *Nature* review paper. Seligman even reproduced four of Nakaya's photomicrographs.

Seligman's article concludes with an assessment (pg. 348): "*Each of the eight papers is illustrated with carefully captioned photomicrographs… Nakaya's technique of photographing snowflakes is exquisite and far superior to any that I have seen … there is no doubt that* [Nakaya's] *work in total adds very considerably to our knowledge of the nature of falling snow*."

Nakaya surely must have appreciated the boost his international visibility received from Seligman's article and, two years later, Nakaya's first movie "Snow Crystals" would open with the image of the first page of Seligman's *Nature* article (see Sect. 3.8).

In his article Seligman (1937a) did disagree with Nakaya on a point of nomenclature. Specifically, Nakaya in his English language articles had never referred to "snowflakes" but always to "snow crystals". Seligman came out strongly for using the term "snowflake". This touched off a minor controversy in the letters department of *Nature*, with Sir George Simpson of the United Kingdom Meteorological Office defending Nakaya's use of "snow crystal" (Simpson, 1937), prompting a reply from Seligman (1937b).

3.7 Artificial snow crystals

By 1935 Nakaya had been studying snow crystals via photomicrography for three years and, while he had made a significant advance in terms of classification of the observed forms of snow crystals, he had not made much progress in understanding the mechanisms that produced the amazing variety of crystal types. He tried to find empirical connections between the forms of crystals observed at the ground with the concurrent meteorological conditions, but found this task too challenging. Nakaya (1954, pg. 101) wrote that:

"*In our observations in Hokkaido, so many types of crystals were observed in one snowfall in many cases, being intermixed with one another, … that we could not pick out any one type of crystal as representing the meteorological condition at the time*".

Hoping to clarify the dependence of snow crystal shape on the meteorological conditions during formation, Nakaya made preparations for laboratory experiments. According to Nakaya (1954, pg. 143):

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"*In the spring of 1935 the authorities of the Hokkaido University began to build a low-temperature laboratory, which was completed at the beginning of 1936. This laboratory is provided with a cold chamber 4 x 4 x 4 m in dimensions, the whole chamber being designed to be cooled down to -50°C by a refrigerating mechanism. …* [To deal with the cold] *we had to wear a flying suit while carrying on the experiments*."

Experiments involving the formation of ice crystals on cooled plates had been conducted earlier by Adams (1930), and Nakaya and Sato (1935) had also reported on such investigations. To Nakaya the crystals thus formed should be considered artificial versions of frost or rime rather than snow crystals (a view shared by Seligman, 1937a). The laboratory production of individual ice crystals in a manner closer to that for natural snow remained a challenge. As noted earlier in Sect. 1, Nakaya's initial attempts to grow crystals on thin threads were failures until the accidental discovery of rabbit hairs as a substrate. Specifically Nakaya (1954, pg. 152) states that:

"*we found after some trials that a fine rabbit hair which was thoroughly dried in a desiccator was most suitable for getting isolated ice crystals on the filament*".

Nakaya dated his first successful artificial snow crystal to March 12, 1936. As noted earlier in Sect. 1 Hokkaido University now records that date on a monument erected on the location of Nakaya's cold laboratory (Fig. 1).

Furukawa and Wettlaufer (2007, pg 70) summarize Nakaya's achievement in his laboratory experiments:

"[Nakaya] *surmised that the shapes were a consequence of the temperature and supersaturation of the atmosphere through which the crystals moved, and he quantified his intuition by creating nearly all the natural morphological categories in the laboratory. His results…are elegantly summarized in the so-called Nakaya diagram. In the diagram one can read the meteorological information written on a snow crystal. ... Nakaya was often quoted as referring to the snow crystal as "a letter from the sky". ... Nakaya clearly appreciated that the complex spacetime history of an object in a turbulent, nonequilibrium environment cannot be captured in its entirety. Nonetheless, the Nakaya diagram embodies the basic physics associated with the principal dynamic shape transitions…One of* [the Nakaya diagram's] *salient features is that, depending on the temperature regime of growth, the forms at small supersaturation are either hexagonal plates or prisms, and the transitions from one regime to the other are abrupt. For some 50 years,* [many] *researchers have grappled with the challenge of explaining that alternating plate-prism growth sequence.*"

Several versions of the "Nakaya diagram" typically showing the form of snow crystal as a function of the air temperature and water vapor supersaturation at formation have been published. Versions with various attractive design enhancements are easily available on the internet (e.g. https://www.snowcrystals.com/morphology/morphology.html; last accessed July 29, 2026). Here in our Fig. 6 we reproduce one of Nakaya's own versions published in his 1954 monograph. This shows individual points, each representing results for a particular set of conditions at formation. Nakaya believed that a key discovery in his experiments was the strong (often dominant) influence of air temperature; from Nakaya (1954, pg. 248):

"*It has generally been believed that the degree of supersaturation determines the form of the crystal, but this "common-sense" belief was found not to be the truth. …* [in fact] *the chief factor controlling the form of the crystal is the air temperature*"

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Nakaya published the first results on his artificial snow crystals in two papers in the *Journal of the Faculty of Science of Hokkaido Imperial University* (Nakaya et al., 1938a,b). Then he published a short article "Artificial Snow" in the *Quarterly Journal of the Royal Meteorological Society* (Nakaya, 1938) summarizing - and effectively "advertising" - the results reported in Nakaya et al. (1938a,b). Interestingly in this summary article Nakaya addresses the snowflake/crystal controversy. He recounted the positions of Seligman and Simpson and then very reasonably writes that he (Nakaya, 1938, pg. 619):

"*… agrees that the English names of the snow forms should be standardized and is willing to follow the standard nomenclature when it is settled among English scientists. Until that time, however, … it is wise to continue to use his old nomenclature*."

Later in his article Nakaya reviews his conclusions from his Hokkaido snow observations and experiments. Specifically, he (pg. 620):

"*was led to consider the snow crystal is a hieroglyph from the heavens and that the various strata of the atmosphere may be inferred to some extent by investigating the delicate form and design of a falling snow crystal*…"

Here Nakaya formulates his famous dictum, *yuki wa ten kara okurareta tegami dearu* - often translated as "letter from heaven" or "letter from the sky" - directly in English as the striking (and alliterative) phrase "hieroglyph from the heavens."

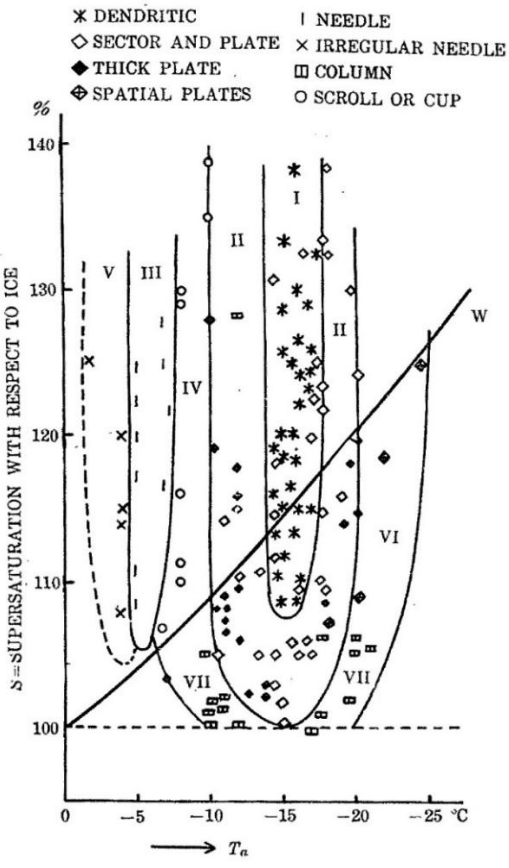

Figure 6: The version of the "Nakaya diagram" that appeared on page 249 in Snow Crystals: Natural and Artificial by Ukichiro Nakaya, Cambridge Mass.: Harvard University Press, Copyright 1954 by the President and Fellows of Harvard College. Copyright renewed 1982 by Mrs. Ukichiro Nakaya. Used by permission. All rights reserved.

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3.8 Educational films

Near the end of Nakaya's first decade at Hokkaido Imperial University he became interested in producing a film presenting his research on snow. Such an interest was in line with his ongoing efforts popularizing science through his writings and may have also been motivated by a desire to publicize his work internationally even among his professional colleagues (and at a time when it was difficult for him to travel to international meetings). He collaborated with the Culture Film Division of the major studio Toho Film Corporation. Toho was founded in 1932 and today is still a major film studio, perhaps most famous for producing the first Godzilla movies in the 1950's. In 1939 with experienced cinematographers from Toho, Keiji Yoshino and Teizō Oguchi, Nakaya created the movie "Snow Crystals" (*Yuki no Kesshō*). According to Tsunoda (2015, pg. 39) this was:

"*arguably the most distinguished science film of the era. Shot almost exclusively inside Nakaya's ... laboratory, the film contained the world's first moving film image of the gradual formation of snowflakes ... The full-blown execution of the of the time-lapse cine-photomicrography ... was extremely challenging, and the effort ... was celebrated worldwide. Nakaya submitted a version with English narration to the International Commission of Snow* [meeting] *held* [in Washington] *in September of 1939. Along with its scholarly value, the film won laurels for its aesthetic novelty, receiving a testimonial from the Commission* [even] *in the midst of the political anxiety developing between the US and Japan*".

(The Commission referred to is now the International Commission for Snow and Ice Hydrology).

Nakaya's movie "Snow Crystals" (in a version with mostly English-language narration and credits) is available online (last accessed July 21, 2026) at https://m.youtube.com/watch?v=Ed_cScAXmQ4&pp=0gcJCR4Bo7VqN5tD. The film soundtrack begins with the first 1:20 without narration but with a full orchestra. The original music was composed by a young Hokkaido musician, Akira Ifukube (1914-2006), who became one of Japan's most famous movie composers (Okazaki, 2017). After a few seconds of credits (identifying it as a Toho Films production "photographed by" Yoshino and with Nakaya as "Technical Advisor") the visuals open with a camera shot of a *Nature* magazine issue which is then paged to the review article by Seligman (1937a) mentioned above, and then a closeup of Seligman's first paragraph which is held long enough to be read by the viewer. After 1:20 the narration begins and the film shows scenes from Sapporo in winter, an aerial view of the Hokkaido Imperial University campus and a view of the science building on campus (today this building houses the university museum). The narration notes the snowy nature of Hokkaido and that "*conditions are ideal for the study of snow crystals and snow drift*". Then Nakaya is introduced and shown working in his office and the narration notes that "*Professor Nakaya began his detailed study of snow crystals in 1932*". The Mt. Tokachi laboratory is introduced and wintry exterior scenes alternate with scenes of people working inside. After about 7:00 the focus of the film is mainly on showing the microphotographs of a number of the Nakaya lab's artificial snow crystals and then moving images of some crystals actually growing, what Tsunoda (2015, pg. 40) calls "*the world's first moving film image of the gradual formation of snowflakes*". Even today these beautiful old black and white images are quite engaging to watch.

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Nakaya followed "Snow Crystals" with other educational films, and Yoshino and Oguchi continued to film activities in Nakaya's laboratory even during the war years. After the war, according to Tsunoda (2015, pg. 42):

"[Yoshino's and Oguchi's] *enthusiasm for science projects – and their bond with Nakaya – remained solid. The research footage they had filmed at Nakaya's laboratory during the war was edited in the postwar years and released as "Frost Flowers" (Shimo no Hana, 1948) and "Snow on Daisetsuzan" (Daisetsuzan no Yuki, 1948)…These shorts…were characterized as "sequels" (zokuhen) of "Snow Crystals" and earned a prestigious Asahi Bunka Award*".

According to Higashi (1962, pg. 379) the film "Snow Crystals" was shown at the 1948 International Union of Geodesy and Geophysics general assembly in Norway where it "*won much praise from those who saw it, even though* [Nakaya] *could not be at the conference*".

In 1948 the book publisher Iwanami Shoten decided to expand into documentary film production. Iwanami Shoten had published some of Nakaya's books and the company executive in charge, Isamu Kobayashi, recruited Nakaya and his cinematographers to spearhead the new venture, which became Iwanami Productions (*Iwanami Eiga Seisakusho*). Tsunoda (2015) states that the new studio "was born" at a meeting Kobayashi arranged at Nakaya's house with Nakaya, Yoshino and Ogura. Iwanami Productions (which operated from 1950 until 1998) provided a home for Nakaya's later film making, and blossomed into an important player in Japanese cinema as a production company for ground breaking documentary films, and as a cradle for the development of prominent filmmakers in the 1960's and beyond (Sharp, 2011; Tsunoda, 2015).

The first film produced by the new Iwanami Productions in 1950 was a Nakaya, Yoshino and Ogura collaboration "Convex Lens" (*Totsu Renzu*) for which Nakaya was able to secure a subsidy from the Ministry of Education (Tsunoda, 2015). It expanded Nakaya's filmmaking from documenting his own research to more general science education ventures. Nakaya continued his filmmaking activity in later years and the memorial article Anonymous (1963) lists a film produced as late as 1961.

3.9 Nakaya's monograph "Snow Crystals: Natural and Artificial"

Nakaya (1954, pg. vii) states that in the years following the commencement of his laboratory work with artificial snow crystals he felt that the "*basic problem* [was] *nearing a complete solution*"; here "basic problem" seems to be the relation of snow crystal forms to the conditions at formation. This led him to summarize his work in a major monograph that had a difficult path to publication, but that emerged as his *magnum opus*. Nakaya's manuscript was completed sometime during World War II but only appeared a decade later in 1954 as "Snow Crystals: Natural and Artificial" (Fig. 7).

The story of its publication is briefly described in the Nakaya's preface (dated February 1953) to the published volume (Nakaya, 1954, pg. vii). An English language manuscript was completed and "*printing was making slow but steady progress under the adverse conditions of the War, when unfortunately, the printing office was bombed and the whole copper type* [i.e. printing plates] *and original* [manuscript] *were burnt*." Fortunately, Nakaya did have a printed proof of his text, but under the circumstances "*it was impossible to reset the type and I gave up hope of publication*" (Nakaya, 1954, pg. vii).

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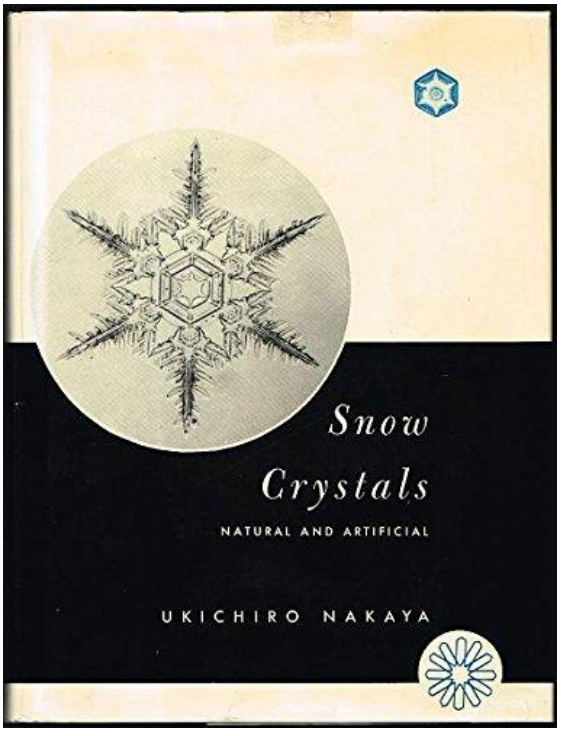

Figure 7: The cover of Snow Crystals: Natural and Artificial by Ukichiro Nakaya, Cambridge Mass.: Harvard University Press, Copyright 1954 by the President and Fellows of Harvard College. Copyright renewed 1982 by Mrs. Ukichiro Nakaya. Used by permission. All rights reserved.

The path towards his book's eventual publication by the American publisher Harvard University Press, apparently began in 1949 with an encounter with (pg. vii) "*Dr. H.C. Kelly of the Economic and Scientific Section*" of the allied occupying forces headquarters who encouraged him to publish his photographs. Nakaya (1954, pg. vii) then notes that his book's "*publication has been made possible by the kindness and sympathy of many people, especially … Dr. Charles F. Brooks of the Blue Hill Observatory of Harvard University and of Dr. B.C. Dees of the Economic and Scientific Section*" of the allied headquarters. He also acknowledges a monetary grant from the American Academy of Arts and Sciences. Nakaya also writes that he avoided taking time for a revision of his original text (except for adding a brief chapter on later developments) "*being afraid of losing the opportunity again*", a statement that vividly conveys the precarious conditions in the post-war period facing Japanese scientists.

Nakaya's book was reviewed by outstanding researchers in cloud physics at the time and their reviews appeared in the leading journals. Vincent J. Schaefer (who is generally credited with inventing cloud seeding) reviewed for the *Bulletin of the American Meteorological Society*, Basil J. Mason (who later wrote a major monograph on cloud physics and who eventually became Director of the United Kingdom Meteorological Office) reviewed for the *Quarterly Journal of the Royal Meteorological Society*, Gerald Seligman reviewed for *Nature* (Seligman, 1955), and Herbert Nichols reviewed for *Science* (Nichols, 1955).

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These reviews were all extremely positive and all noted the scientific importance of the results reported, as well as the book's accessible writing and the beautiful photographs. Schaefer wrote that "*... its simple but informative language and wealth of beautiful pictures make it a book to be treasured*." Noting that the 1954 publication relied on the much earlier initial manuscript, Schaefer opined that "*more recent studies have confirmed most of the findings of Professor Nakaya and his students reported here*." Mason in his review was particularly warm in his assessment of the book and Nakaya's contributions to the field, writing (pg. 300) "*It is given to few scientists to amass such a beautiful collection of photographs, much less to have them printed on such a lavish scale.* [his book] *is a fitting memorial to Professor Nakaya's lifetime of devoted study in this field*." Nichols' review in *Science* concludes "*…scientists working in meteorology and allied fields will find a gold mine of needed data. No one can open the volume without some gain, however, for much of the text is simple and easily understood. Featured in the illustrations are more than 1500 beautiful crystals, a source of much inspiration for readers with artistic or designing abilities*."

3.10 Wartime and immediate postwar activities

From the mid-1930's Japan was embroiled in warfare in Asia, but the war particularly dominated life in Japan from the time the United States entered in December 1941 until the end of the war in August 1945. Nakaya's laboratory responded to the needs of the Japanese military for research on the effects of cold weather. The university created its Institute for Low Temperature Science (ILTS) in 1941 (the ILTS is still a major research institute of Hokkaido University). In the war years ILTS studied such practical issues as the effects of frost heaving on railways, icing on aircraft and the formation of fog over airport runways (Magono, 1963). After the Japanese defeat in the war, Nakaya's collaboration with the Japanese military was criticized by some of his colleagues (Kuroiwa, 1982). Later Japanese media reported that he received assistance for his film making activities that was subsidized by the US Air Force and this was also criticized in Japan. These controversies contributed to Nakaya's decision to resign as Principal Researcher of the ILTS (Kuroiwa, 1982), although he remained affiliated with the institute as an adjunct.

The end of the war changed Nakaya's situation and he looked for a new direction for his research. In an essay written immediately after the end of the war, Nakaya was direct (see Rotondo, 2022, pg. 9):

"*With the end of the war the natural destiny of* [his laboratory] *was to be shut down. …The staff …thinks that, since the war is over wartime research should be discontinued; the facility would be dismantled too*."

Nakaya was ready with a new proposal for research in an area of urgent national need (Rotondo, 2022, pg. 9):

"*However, considering the hard work of the last five years to build it up, we cannot accept … that the laboratory shall be destroyed. Upon pondering at length over the matter, I eventually came to the idea that we could give it a new birth as a research laboratory for agricultural physics*."

Nakaya was reacting to a national food crisis that developed during the war years and became even more severe in the year 1945 which featured a very poor harvest throughout much of Japan (Dower, 1999). Magono's (1963) obituary shows his admiration for Nakaya's response to the war's end (pg. 1):

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"*After the war, while the general public was quite at a loss what to do*, [Nakaya] *was quick to find the vocation of scientists in their active support to the expansion of food production, and he dared to go into farming villages of Hokkaido … This fact speaks for his positive attitude of research and is never to be forgotten, together with the pioneering role of his subsequent researches on flood damage, water resources and land planning*."

Nakaya's brisk pace of publication of articles in the professional literature through 1939 slowed down markedly during the war and in the years immediately after. The bibliography in Anonymous (1963) lists no English language journal articles during 1940 through 1950 and only a handful of Japanese language articles on subjects like fog and floods - notably a three-part paper authored by Nakaya in 1948 titled "*Suigai no sōgō teki kenkyū*" ("A comprehensive study of flood damage") published in the Japanese journal *Kagaku* ("Science").

3.11 Collaboration with SIPRE in the USA

Nakaya resumed publishing in English in 1951 when he was invited to write the article "Formation of Ice Crystals" for the American Meteorological Society's major reference work *Compendium of Meteorology* (Nakaya, 1951). This was followed up by many journal articles and other publications on cloud physics and glaciology over the next decade. This decade also saw a major shift in Nakaya's career. According to Higashi (1962, pg. 379):

"*In 1949* [Nakaya] *paid a visit to Canada and the United States, which shaped the course of his life in his fifties. After having attended a special meeting for the international classification of snow crystals in Canada, he went to the United States and was consulted about a plan* [by the U.S. Army] *to establish a new research institute for the study of cold environments. The institute was founded as the Snow, Ice and Permafrost Research Establishment* [SIPRE] *in Wilmette, Illino*is [now the Cold Regions Research and Engineering Laboratory in New Hampshire]. *He accepted an invitation and stayed there as a contract scientist for two years from 1952 to 1954 on leave from Hokkaido University. During this period at SIPRE, he began a new type of research on the physical properties of single crystals of ice. … Also in this period he compiled many data on plastic deformation of ice crystals …* "

In a public lecture broadcast in 1959 (Anonymous, 2006) Nakaya explained his interest in laboratory studies of the properties of large single ice crystals (pg. 18):

"*It has been known … among the scientists who study glaciers, that large single crystals of ice are found in temperate glaciers. The Mendenhall Glacier near Juneau, Alaska, is one of the best examples of glaciers that produce large single crystals of ice. Blocks of ice more than 30 cm in long dimension, which are pure single crystals, are not at all rare … I worked for two years in the refrigerated laboratory* [at SIPRE] *and made a comprehensive study of the mechanical properties of single crystals of ice by using samples brought from Alaska*".

Nakaya returned to Hokkaido University but continued collaboration with SIPRE throughout the 1950's including research trips to Hawaii in the winter of 1956-57 and to Greenland in the summers of 1957, 1958, 1959 and 1960 (Higashi, 1962). In some SIPRE reports (e.g. Nakaya, 1958a) Nakaya is identified as "contract physicist" and it seems likely that during these years Nakaya had some contract employment with SIPRE in addition to his faculty position at Hokkaido University.

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Nakaya would write about his Hawaii trip in his popular essay "World of the Black Moon", which we will discuss in detail in Sect. 5 below.

While Nakaya's 1956 Hawaii trip was undertaken to study natural snow crystals, his focus was increasingly on studying glacial ice. Higashi (1962, pg, 379) explains:

"*From 1957 to 1960* [Nakaya] *spent every summer on the Greenland Ice Sheet with SIPRE expeditions. He had great success in the investigation of visco-elastic properties of snow and ice which were cored down to more than 3,000 feet*."

Nakaya wrote an account for the general public of his first summer in Greenland in his 1957 essay "World of the White Moon" which we will discuss in Sect. 6.

Nakaya's international reputation continued to grow. Again quoting Higashi (1962, pg. 379):

"*In 1957 he was elected a Vice-President of the International Commission on Snow and Ice at the I.U.G.G. conference in Toronto, Canada. In 1958 he travelled to Europe and attended the conference on ice movement held at Chamonix, France. He was also an active organizer of the International Conference of Cloud Physics at Woods Hole in 1959*."

Near the end of his life, Nakaya would lead a team conducting field research in another exotic Arctic venue, namely the giant iceberg known as Fletcher's Ice Island (or "T-3"). According to Duncombe (2019):

"*Researchers set up camp on Fletcher's Ice Island … during the Cold War as part of a strategic and scientific campaign. The ice island stretched more than 77 square kilometers, an area larger than Manhattan, and its level surface made it ideal for landing aircraft. The U.S. Air Force established a weather station on the island in the 1950s*".

"*A collection of other government agencies, university research groups, and indigenous residents employed by the Naval Arctic Research Laboratory began scientific studies on the ice island …* [In the early years] *the researchers living on the island tracked their location with techniques similar to those of early 20th century Arctic explorers, using a theodolite to note the position of the Sun and the stars*".

Nakaya led his Hokkaido University junior colleagues Kou Kusunoki, Jiro Muguruma and Keiji Higuchi who each spent extended periods living on T-3 to conduct the various oceanographic and glaciological observations during the May 1959 to December 1960 project (Nakaya et al., 1962).

The paper of Muguruma and Higuchi (1963) describes the glaciological observations in this project. They note that (pg. 709):

"*Glaciological studies at T-3 were carried out as part of a research programme of the Arctic Institute of North America under contract to the* [US Air Force] *Geophysics Research Directorate … Professor Ukichiro Nakaya, who directed the research project, unfortunately died in 1962. The authors express their heartfelt regret over Professor Nakaya's death and their sincere thanks for his guidance throughout the work*".

"*The field study was carried out in 1960. After completing the field investigations, the ice samples were packed in dry ice and carried back to Hokkaido University, where supplementary physical investigations were made in the cold room of the Low Temperature Institute*."

The conclusion of the T-3 field campaign at the end of 1960 coincided with Nakaya's cancer treatment (see Sect. 3.12). Nakaya was the lead author of two reports on the T-3 project published in 1962 by the Arctic Institute of North America (Nakaya and

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Muguruma, 1962; Nakaya et al., 1962), but he is not included as a coauthor of the project's extensive *Journal of Glaciology* paper (Muguruma and Higuchi, 1963).

3.12 Later life and legacy

In 1960 when Nakaya returned from his fourth summer in Greenland he became ill and underwent surgery for prostate cancer in Tokyo. He died of complications in April 1962.

Despite his illness Nakaya contributed to the reporting on the 1959-1960 T-3 expedition (Nakaya and Muguruma, 1962; Nakaya et al., 1962) and may have been working on another major book project at the time of his death. According to Magono (1963, pg. 2):

"*Dr. Nakaya used to say that he was making preparations for a book regarding single crystal of ice, comparable with his* [1954 monograph] "*Snow Crystals*".

Magono (1963, pg. 2) even relates a moving deathbed story:

"*In his last moments his lips moved as if he tried to say "ko-o-ri, ko-o-ri" (this Japanese means ice), the writer has heard*".

This - possibly hagiographic - detail is perhaps what we could expect for a man whose accomplishments were already making him legendary in Japan.

Nakaya's daughter Fujiko Nakaya (born 1933) became a professional artist, studying art at Northwestern University in the USA. Ukichiro himself was a skilled practitioner of ink painting in the *sumi-e* tradition, and according to Setsuda (2017, pg. 26):

"*...though* [Fujiko] *ultimately chose not to pursue a career in the traditional media of painting, she and her father held a joint exhibition of Ukichiro's ink paintings and Fujiko's oil paintings at Sherman Art Gallery in Chicago in 1960*".

Fujiko has become well known internationally for her art installations featuring artificially produced clouds, notably including a famous "fog sculpture" at the 1970 World Exposition in Osaka, Japan.

Another daughter, Sakiko Olsen (1932-2020), became a geologist and a lecturer at Johns Hopkins University (obituary in the Baltimore Sun, August 12, 2020).

Over his career Ukichiro Nakaya worked with many students and other younger collaborators. Among the most notable are Keiji Higuchi (1927-2018) and Akira Higashi (1922-2000) who both obtained D.Sc. degrees at Hokkaido University under Nakaya's supervision. Higuchi had a distinguished career as a cloud physicist and glaciologist mainly at Nagoya University, while Higashi continued for most of his career as a glaciologist at Hokkaido University (Mae, 2001). Higuchi (and to a lesser extent Higashi) were also known for their writing for the general public.

Higashi (1962, pg. 379) wrote about Nakaya's influence on younger scientists:

"[Nakaya] *excelled in teaching physics in the University. His lectures on electromagnetism and general physics left very clear impressions in the minds of his students. He was always a kind and considerate teacher. He inspired his students to work with care*".

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4 Nakaya the Essayist

In this section we will discuss Nakaya's achievements as a writer for the general public. He was an amazingly prolific writer over the last three decades of his life, publishing well over 300 articles for the public, many quite substantial and many in leading Japanese magazines. His productivity makes it challenging to completely assess his achievements as a writer. Likely only a true specialist Japanese literary scholar would even attempt to read his entire *oeuvre* today. Here we have a more modest goal: to briefly convey the flavor and magnitude of Nakaya's achievements to the international community of earth scientists that constitutes the prime readership of HGSS. To do this we first introduce some background on Japanese publishing at the time of Nakaya's activity (Sect. 4.1). Sect. 4.2 is a summary of available sources of the original Japanese language texts of Nakaya's essays as well as some extant English translations. Sect. 4.3 provides a general introduction to Nakaya's writings with very brief discussion of two particularly intriguing works. Examples of his major essays are then discussed in somewhat more detail: the "Egg at Springtime" in Sect. 4.4, the "World of the Black Moon" in Sect. 5, and "World of the White Moon" in Sect. 6. The "Black Moon" essay is a description of Nakaya's scientific activities on Hawaii's Mauna Loa during the 1956-57 winter, while his "World of the White Moon" describes his activities in on the Greenland ice cap in the summer of 1957.

4.1 Japanese publishing during Nakaya's career

The 20th century in Japan was marked by very high levels of literacy and a proliferation of newspapers and magazines meant for the general public (Dower, 1999). Several serious general interest monthly magazines played an important role in Japanese public life throughout the 20th century (Dower, 1999). Among the more important outlets that published numerous Nakaya essays were two notable magazines founded in the late 19th and early 20th centuries and still published today: *Bungei Shunjū* ("Annals of Art and Culture") founded in 1923, and *Chūō Kōron* ("Central Review") founded in 1887. Nakaya would also write for the influential magazine *Sekai* ("World") published starting in 1946 by Iwanami Shoten (Dower, 1999).

Dower (1999) discusses the importance of magazines in Japan, particularly in the period around midcentury. He notes especially the remarkable recovery of Japanese publishing in the challenging immediate postwar period (Dower, 1999, pg. 180):

"*Despite formidable obstacles, publishing was one of the first commercial sectors to recover in defeated Japan. ... Until 1951, paper was in short supply and was subject to complicated and onerous rationing regulations. Despite all this, the recovery was rapid and vigorous*."

Readers may get a feeling for the serious Japanese general interest magazines of Nakaya's time by perusing the English language *Japan Quarterly* which was published by the prominent newspaper company Asahi Shimbun, starting in 1954. This magazine's stories illustrated Japanese culture and covered current events in Japan and Asia. The goal seems to have been a serious tone that was accessible to the educated public in Japan and abroad. The initial Editorial Advisory Board included the Nobel prize physicist Hideki Yukawa and the presidents of several leading Japanese universities. At least in the 1950's, contributors included many scholars - including some scientists. Contributors were mostly Japanese with some foreigners who

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were generally Japan resident American or European scholars. A frequent contributor was the American Donald Keene, the famous Japan based scholar of Japanese culture (Keene, 2008). Some fiction by Japanese authors translated to English also appeared. Contributors in the 1950's included writer Kenzaburo Oe who later won the 1994 Nobel prize for literature. The *Japan Quarterly* would continue publication until 2001.

The July-September 1955 issue of *Japan Quarterly* published a brief article (titled "Encyclopedia Brittanica: Two anecdotes") by Nakaya. Nakaya's charming article was a nostalgic portrait of early 20th century academic life in Hokkaido - a time when the purchase of an encyclopedia could be a major event in a professor's life (Nakaya, 1955).

4.2 Sources for Nakaya's texts

The Japanese language texts of 307 (as of April 11, 2026) of Nakaya's essays are available in the digital library *Aozora Bunko* ("Blue Sky Library"), which is a repository of many thousands of Japanese fiction and non-fiction books and articles now in the public domain (available at https://www.aozora.gr.jp). A machine translation of 75 of the 386 titles of the essays listed for Ukichiro Nakaya (https://www.aozora.gr.jp/index_pages/person1569.html) on the *Aozora Bunko* (as of July 13, 2026) are presented in Appendix A. The selected 75 titles were chosen to demonstrate the range of Nakaya's interests.

In writing the present paper we have made our own English translations of three of the essays in this library: "Egg at Springtime" which is excerpted and discussed in 4.4 below, "World of the Black Moon", which is excerpted and discussed in Sect. 5 and "World of the White Moon" which is excerpted and discussed in Sect. 6). These translations began with machine generated versions that were then reviewed and improved.

Daub and Asano (2002; hereinafter DA2002) published a book "Reflections on Science – An Advanced Japanese Reader" consisting of 15 brief excerpts from Nakaya's essays together with Daub and Asano's own English translations. The prime purpose of their book was to serve as a set of examples for English speakers who are "*advanced students of the Japanese language*", and the authors' choice of Nakaya's essays for their book reflects their admiration for Nakaya's writing. DA2002 (pg. vii) refer to Nakaya's "*significant career in Japan as a populizer of science and brilliant essayist*".

Recently Rotondo (2022) has published his English translation of "*Nougyou Butsurigaku Yobanashi*" ("Night talk on agricultural physics") a 1945 essay published initially in an agricultural journal ("Farming Techniques") and later included in one of Nakaya's essay collections.

4.3 Nakaya's essays

Nakaya had an interest in writing from an early age and as an undergraduate he wrote some essays for a publication of the Tokyo Imperial University's faculty of science (Sugiyama, 2015). Interestingly, according to Sugiyama (2015) his mentor Torahiko Terada recognized Nakaya's talent for writing but asked him to concentrate on science at the beginning of his career. Sugiyama (2015) claims that Terada "prohibited" Nakaya from writing essays until 1934 after he was well established in his position at Hokkaido Imperial University.

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Nakaya then began writing magazine articles for the general public. Already by the late 1930's his essays were being republished in book collections offered by major publishers. Anonymous (1963) lists 42 such collections starting from 1938. DA2002 note that Nakaya's popular writing falls within (pg. viii) "*a genre known as "literary jottings (zuihitsu)*", which exemplify a "*longstanding tradition of Japanese scientists writing random essays expressing their thoughts about science and culture*". DA2002, in their selection of excerpts to feature, were mostly interested in Nakaya's ideas about science and its connections with broader culture. However, DA2002 do note that the subjects of Nakaya's essays extend more widely, a point that is easily confirmed just by perusing the titles we present in Appendix A. DA2002 particularly noted that Nakaya wrote essays about American life inspired by his time living in Illinois working for SIPRE. Interestingly DA2002 claim that Nakaya's American coworkers at SIPRE were unaware of these essays or, indeed, any of his literary efforts.

In the next section (Sect. 4.4) we will present a brief review of Nakaya's 1947 delightful essay "Egg at Springtime". Then in Sect. 5 and Sect. 6 we discuss and extensively excerpt two of Nakaya's most ambitious essays: "World of the Black Moon" and "World of the White Moon" which were written in 1957 and which each present a vivid picture of his field research.

Here, however, we want to conclude this section with brief descriptions of two essays with very personal inspiration for Nakaya. Specifically DA2002 include excepts from two of Nakaya's writings reporting on the ideas of long deceased men who had been close to him.

First DA2002 present an excerpt from "The Curves of Tea Bowls" (*Chawan no kyokusen*) that Nakaya published in the April 1951 issue of the magazine *Tanko*, which is devoted to tea culture in Japan. This essay was later reprinted in a book collection by Iwanami Shoten. This essay was inspired by his long deceased younger brother Jiujirō Nakaya (1902-1936). Jiujirō was an archaeologist who studied at Tokyo Imperial University and went on to study in Paris for several years. He became ill and returned to Japan in 1935 and died in 1936. In his brief career Jiujirō made important contributions to the study of Japanese stone age culture.

Nakaya writes (DA2002, pg. 82-83):

"*My younger brother was majoring in archaeology at Tokyo* [Imperial] *University and was pursuing earthenware research in the anthropology lab.* [He] *precisely measured the shapes of a variety of earthenware and drew many curves that corresponded to their cross-sections. As the shapes of all the earthenware were all different, … there were aspects that in a way resembled each other so that it appeared that there was some unifying rule. If this rule could be adeptly expressed mathematically, then his goal should be attainable*."

It seems Jiujirō was attempting a pioneering effort in classifying/authenticating artworks by algorithm, a problem that has been addressed more recently using modern computers (e.g., Lyu et al., 2004). Nakaya proceeds with his description of Jiujirō's work (DA2002, pg. 84):

"*And so he tried diverse ways to analyze the curves. The simplest one was to measure the curvature at every point and to examine how the value changes as one moves from the top to the bottom of the jars. … As a proposal, the method seemed very clever, but in the actual attempt…it was found to be very difficult*".

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"*My brother was considerably distressed at this dilemma, and while he had still not completed his research, it happened that he went to Paris, where he became ill. He died shortly after returning to Japan and thus his eccentric research to consider mathematically the shapes of earthenware abruptly ended without seeing the light of day. Looked back upon today, the mathematical consideration of the shapes of earthenware was an engagement in bold, daring research*."

Another excerpt selected by DA2002 was from a work that concerned Nakaya's mentor Torahiko Terada and that first appeared in 1947 as Nakaya's afterword to a posthumously published book authored by Terada (the text is available at https://www.aozora.gr.jp/cards/001569/card57306.html, accessed July 29, 2026). As recounted by Nakaya, shortly after the war he received an intriguing request from a friend of a kind that could arise in the challenging postwar conditions in Japan, which included rationing of paper (DA2002, pg. 79):

"*Immediately after the war, I received a difficult question from a friend in Kyushu. He said that … he had a small amount of paper available, and wanted to preserve it as a resource for the newly reborn Japan by creating a book to distribute to a limited number of people. He asked me to select, from the Meiji, Taisho, and Showa periods* [i.e. any time after 1868], *just one book that would best serve this purpose*."

"*After mulling various thoughts to the point of weariness, in order to meet this extremely difficult request, I finally made the very bold proposal of recommending Terada's "Introduction to Physics" … Actually I had previously been somewhat involved with this book. The manuscript nearly failed to come to anyone's attention and was in danger of being completely lost … According to the compiler of Terada's complete works, the manuscript – though incomplete, stopping just beyond one-third of its intended length – was dated from November 1920*."

Nakaya goes on to explain that as a student he had heard Terada mention his intention to write such a book and so that after his mentor's death in 1935, he alerted the publisher Iwanami Shoten when they began to compile Terada's complete works, and this led to the discovery of Terada's unfinished manuscript.

Terada's book was more than a standard physics textbook and dealt with the philosophical foundations of physics. Nakaya writes "*Among literary works of this sort from our country, two or three that come to mind were by philosophers discussing science*" and contrasts this with Terada's unique position as a literary scientist who was also an outstanding research physicist. Terada's 1920 manuscript was written as the subatomic world was being actively explored, but before the early breakthroughs of quantum mechanics (notably the famous 1926 papers of Schrödinger and Heisenberg, see e.g. Wood, 2025). Nakaya emphasizes Terada's insightful view of the nature of reality at the subatomic level. Nakaya quotes Terada (writing circa 1920): "*If one were to say today that the electron is black or red, there is no doubt that scientists would laugh, but they do not doubt that the electron is a rigid body …* [also] *the person who doubts the impenetrability of the electron is rare. However, I cannot discern any necessity for such assumptions … I believe a day may come when* [the nature of reality at the subatomic scale and] *related concepts are completely reformulated*" (DA2002, pg. 82).

Terada's "agnostic" view was prophetic as the subsequent development of quantum mechanics would show. Indeed the reconciliation of any kind of classical physics understanding of the world with the observations of the subatomic realm remains an extremely controversial issue even today (e.g. Wood 2025).

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Nakaya's verdict on his mentor's book was (DA2002, pg. 79)

"*This book is unfinished. It was, one might say, a rough draft, and had not yet undergone extensive editing. However, it is a unique literary work, matched by few in our land. I would urge all who love learning and want to understand the essence of science to give it, even in its present state, a careful reading*."

4.4 "Egg at Springtime" (*Risshun no Tamago*)

Nakaya took on what had become something of an international craze for balancing chicken eggs upright in a 1947 essay that illustrates his light touch as a writer as well as his ability to speak to his readers about science at a rather sophisticated level. His essay "Egg at Springtime" (*Risshun no Tamago*) was published in *Sekai* in April 1947 and was later included in an essay collection book. This essay is one of Nakaya's most popular and has been included in some Japanese school textbooks (Sugiyama, 2015).

Nakaya discusses the background to the contemporary events that inspired his essay. He emphasizes a key point that balancing eggs seems to most people as obviously impossible. Famously, in arguments about his trans-Atlantic expeditions, the explorer Christopher Columbus (1451-1506) supposedly used balancing eggs as an example of a task that is clearly impossible. However, in China there is an ancient belief that standing eggs on end is possible, but only on one day each year, specifically *Li Chun* (in Japanese, *Risshun*) which is the beginning of spring in the lunar calendar. The idea seems to have achieved some international attention in 1945 due to the efforts of a local official of the Chinese Ministry of Information in Chongqin who summoned the foreign correspondents stationed there to view a demonstration of standing eggs on *Li Chun* (February 4 in that year). The story of the Chongqin egg demonstration was then reported in the very prominent popular American magazine *Life* (Jacobi, 1945) in a story that even quoted a skeptical Albert Einstein(!).

Gardiner (1996) discusses the "urban legend" now widespread throughout the world that eggs can only stand upright on a particular day (in the west this has typically focused on the vernal equinox), and he traces the origin of the continuing international interest in this belief to the publicity stunt in 1945 Chongqin; indeed stories about egg balancing became subjects of journalism for years afterward. Nakaya in his essay was specifically responding to a report in a Japanese newspaper that on Risshun in 1947 demonstrations of egg balancing took place in Japan. Quoting Nakaya's essay:

"*The Asahi Shimbun published a photo of many young scientists gathered in the forecasting room of the Central Meteorological Observatory conducting this experiment. In the photo, seven eggs are standing upright on a smooth wooden table*."

Nakaya considered the reported events and wrote:

"*The story that eggs stand upright at the beginning of spring was an unusually delightful one. … In Shanghai, this story became a major issue a few days before this year's Risshun. People hurriedly bought eggs to try the experiment exactly on Risshun, causing the price of a 50 yuan egg to soar to 600 yuan*."

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Nakaya then described his own home experiments to see if eggs can be balanced (at any time of year). He began with an egg that happened to be in his kitchen and tried unsuccessfully to balance it on his dining room table. Then he moved to another room and he found that, with patience, he could reliably make it stand upright:

"*I sat calmly on the tatami mat and tried to make it stand on the table I use every day, made of smooth quince wood, and in three or four minutes I was able to make it stand properly. Since the table was smooth, almost like rosewood, I thought it might be a bit difficult, but if it stands this easily, then there is no issue at all. My wife tried it on another table, and it also stood easily*."

Nakaya goes on to consider the physics involved. He notes that an object can stay standing at rest as long as the center of gravity is within the "base" that rests on the surface. But he goes on to note that, as a practical matter, the stability of a standing object depends on the range of displacements that still allow the center of gravity to remain above the base:

"*It is better to describe stability in terms of the width or narrowness of the stable range. A good example is the Leaning Tower of Pisa. It tilted to its current angle due to a poor foundation, but even at that angle, the vertical line from its center of gravity still passes sufficiently within the base, maintaining a stable equilibrium. Therefore, even during a small earthquake, it does not collapse. The only difference compared to a tower standing perfectly straight is that the range of stability for an egg is narrower. When standing an egg upright, the base area — that is, the area of contact between the eggshell and the board — is extremely small*."

Nakaya went on to estimate the diameter of the depression the weight of a normal size egg would make on a table surface assumed to have the elasticity of typical wood. His estimate was about 0.02 mm. Nakaya's intuition was that such a small base couldn't allow a person to stand an egg upright. He then considered another explanation for the effective base for the egg:

"*An egg's surface is not a perfect sphere or ellipsoid, but rough. When discussing dimensions on the order of one-hundredth of a millimeter, this roughness certainly becomes significant. If the surface has slight bumps and depressions, the egg will rest on three or four protrusions, like the legs of a tripod, supporting the egg. Thus, the "base area" of the egg would correspond to the area covered by three or four neighbouring protrusions. ... This area would likely be much wider than the previously mentioned value of 0.02 mm. During lunch in the classroom, I brought up this topic, and a colleague suggested we observe it under a microscope. He ... is accustomed to manipulating snow crystals under a microscope, so observing the bumps and depressions on an egg is trivial for him. He quickly applied ink on a surface, stood an egg on it, and marked a black dot on its bottom. Then, he cut the shell vertically at the marked spot and examined the cut surface under a microscope*."

"*The first surprising thing was that the surface of the egg has an extremely smooth wave-like texture ... the distance between the convex parts, that is, the wavelength, is about 0.8 mm for this egg. This clarified the problem. The spacing of the three or four legs is about 0.8 mm, so if the center is carefully positioned ... an egg can stand perfectly well. With that level of precision, a human hand can also adjust it with some patience...*[while] *an accuracy of 0.02 mm would be quite difficult.*"

In the end the most important result of Nakaya's investigation was that:

"*To make an egg stand, you need to choose a quiet place with a stable surface free from vibrations, calmly and slowly work at it, and spend about five to ten minutes, repeating careful adjustments over and over. Under the assumption that eggs cannot*

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stand, such a task is nearly impossible, and nobody likely tried it. In that sense, the ancient Chinese texts that mentions eggs standing on the first day of spring carry unexpectedly deep significance. If I had not seen the photograph in the newspaper, I probably would not have succeeded in making an egg stand. For hundreds of years, eggs failed to stand worldwide simply because everyone believed they could not."

Nakaya concludes by noting that consideration of the trivial issue of standing eggs actually teaches an important lesson about the human condition:

"*Everyone knows that the human eye has a blind spot. However, it seems that not many people are aware that humanity as a whole also has blind spots. A blind spot as minor as thinking that an egg cannot stand on its end is nothing significant. Yet similar things appear to exist in various fields. And it is possible that human history has been remarkably influenced by such seemingly trivial blind spots. The story of the egg on the day of Risshun is quite an intriguing example when considered as evidence of humanity's blind spots*."

5 "World of the Black Moon" (*Kuroi Tsuki no Sekai*)

In August 1957 Nakaya published his essay "World of the Black Moon" in the magazine *Bungei Shunjū*. This described his two month visit the previous winter to the Big Island of Hawaii to conduct research at high altitude on Mauna Loa (accompanied by two younger Hokkaido University colleagues: Mikio Shoda and Juji Sugaya). This essay is a substantial work exceeding 14000 words (in English translation). In it Nakaya described his own research project but also provided vivid accounts of the geology and meteorology of Hawaii, as well as interesting scientific background to his research activities and descriptions of some of the other scientists who he met during the trip or who otherwise contributed.

(Note that Nakaya also reported on the cloud physics research he conducted during the expedition in a technical paper published in the *Hokkaido University Journal of the Faculty of Science*, Nakaya et al., 1957).

Nakaya opens his essay with an impressive description of the geology and meteorology of the Hawaiian islands and his vivid account can be read today with pleasure, although it is marred now by his understandable neglect of modern plate tectonic theory (which became widely accepted only in the following decade):

"*A long, long time ago, of course, in an era when humans had not yet appeared on Earth, perhaps tens of millions of years ago, a large fissure formed on the floor of the Pacific Ocean. The crack began east of the current Hawaiian Islands, then extended all the way west, passing through Midway Island and reaching near the southern part of Japan. Along this crack, lava from far beneath the seabed erupted at various points*".

"*These are volcanoes formed on the deep-sea floor, and during an eruption, they must have presented an incredible spectacle. The area around Hawaii is currently about 20,000 feet underwater. From the seabed 20,000 feet below, lava at a temperature of a thousand or so degrees would have erupted with terrifying force. ... Compared to this, even an underwater atomic bomb explosion would be like a toy*".

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"*… Today, the Hawaiian Islands consist of several dozen islands of varying sizes, of which eight are relatively large. These islands have all formed along fractures in the Earth's crust at the bottom of the Pacific Ocean through volcanic activity, but the islands did not form all at once. … Among the many volcanoes in Hawaii, there are still some that retain glimpses of the Earth's formative stages, such as Mauna Loa on the Big Island of Hawaii*".

"[the Big Island of Hawaii] *has two volcanoes, Mauna Loa and Mauna Kea. …Many people are surprised to learn that Hawaii has mountains over a thousand feet taller than Mount Fuji. Although it is located around the latitude of southern Taiwan and belongs to the tropics, snow falls on the peaks of these high mountains in winter. In an ordinary year, snow falls four or five times during the winter, so to study this snow, I spent about two months—from December of last year through January of this year—living near the summit of Mauna Loa. This gave me ample opportunity to fully appreciate the volcanic landscape, which still bears traces of the Earth's formation*."

For a modern discussion of the snow climatology on the tallest mountains in Hawaii, see Zhang et al. (2017). Nakaya then begins a narrative of his expedition:

"*We … arrived in Hilo, the main city on the island of Hawaii, on* [December 5, 1956]. *Then, on the 7th, we loaded about one ton of equipment into two large jeeps and set out to climb Mauna Loa. Twenty miles from Hilo, at an altitude of 5,000 feet, there is a prison called Kulani, which is the last point where humans live. About three miles beyond Kulani, the scenery suddenly changes dramatically, and you enter a lava field. As far as the eye can see, there is a black expanse of lava. At the very first step, the words that involuntarily came to my mouth were 'world of the black moon*.'"

"*Within this world of the black moon, surprisingly good roads stretch continuously. Although they are merely roads made by crushing and compacting lava, they are better than rural Japanese roads. However, there are some places with rather steep slopes, so a four-wheel drive vehicle is necessary*".

After a description of the different types of lava rocks he saw, Nakaya continues the narrative:

"*We drove about twenty miles until the Mauna Loa Observatory appeared as a tiny dot on the distant ridge. This observatory was built last summer by the U.S. Weather Bureau. Its elevation is 11,340 feet. This is where our base was. Our plan was to reside at this observatory, wait for snowfall forecasts, head up to the summit, and there take microscopic photographs of snow crystals*".

"*Near the summit, at an altitude of 13,400 feet, there is a small hut … which serves as a workspace. However, it consists only of four wooden walls and a roof, and it might be better described as a wooden box. There is no water, heating, or bed—nothing at all. It is a facility completely unfit for human habitation … It was built to house a meteorological self-recording instrument, but it has not yet been put to use*."

"*The observatory* [at 11,340 feet] *was a fine concrete block building, with three bedrooms and a kitchen in addition to a large central workroom. … However, despite having such excellent facilities, it seems that they had hardly been used until now. We were told that we were the first to stay there*."

Mauna Loa Observatory was initially a joint project of the US Weather Bureau and the National Bureau of Standards and was opened in July 1956. A history of the observatory (Price and Pales, 1963) confirms that Nakaya's party in December 1956

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were indeed the first outside scientists to make an extended visit. (It is worth noting here that the famous regular observations of carbon dioxide concentration in the air by Charles Keeling began only in March 1958, i.e. over a year after Nakaya had returned to Japan).

Nakaya noted that the location meant that his small party was extremely isolated:

"*The party consisted of three people: Dr. Sugaya, Dr. Shoda and myself. After the staff from the weather station who guided us descended the mountain, we began a life in which, within a thirty-mile radius, any living things, including plants, were limited to just the three of us"*.

Of course, the notion that there were no plants at all in the vicinity of the observatory likely overstates the matter! In any event Nakaya continues:

"… This place is considered to have the cleanest air in the world … we came to examine the shapes of snow that falls in such clean air."

Nakaya's project required waiting for snow to fall at the summit and during his planned two month stay he anticipated there might be only one, or at most a very few, snowfalls. Nakaya searched for productive activities for the extensive periods of waiting and he added two interesting research projects to his main agenda.

One activity was inspired by the famous American cloud physicist Vincent Schaefer. According to Nakaya:

"*I had previously coordinated with Dr. Schaefer regarding research on clouds. Speaking of Dr. Schaefer, he is well known in Japan as the first person to attempt artificial rainfall experiments. Currently, he is the director of the Munitalp Association's research institute. This strangely named association … is a peculiar organization. 'Munitalp' is 'Platinum' spelled backwards. The association was established by wealthy Americans who had made their fortunes in platinum and decided to pool money for a hobby. Its purpose is to keep 'eccentric scientists' under lifelong sponsorship, letting them conduct independent research in independent settings. The research topic can be anything, but preferably something of little practical use. … It is quite an unusual organization*".

Nakaya thought there was a message here for his Japanese readers about American culture:

"*The United States is a strange country, where such whimsical ideas, like those one might hear at a drinking party, are actually put into practice*".

When we examine the later essay "Moon World in White" (Sect. 6) we will see Nakaya again remarking on aspects of the American outlook in a way that combined admiration with a dose of amusement.

Nakaya's notes that recently:

"*Dr. Schaefer came up with the idea that perhaps he could determine the location of the jet stream from the shapes of high-altitude clouds*."

This followed from observations taken in 1953 during the US Air Force's "Project Jet Stream" (Endlich et al., 1954). This program surveyed the atmosphere over Florida and the southeastern US using the Air Force's B29 and B47 planes. The scientists on board made naked eye observations of the cloud fields including heights of cloud layers, and these observations

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were then plotted relative to the jet stream. A tendency was found for high clouds to appear in elongated formations parallel to the jet stream and often slightly equatorward of the jet stream core (McLean, 1957). Returning to Nakaya's account:

"*… As work to do while waiting for the snow, studying these high-altitude clouds seemed most suitable ... So, before departure from Japan, I consulted Dr. Schaefer about it, and he was very supportive. He immediately sent two cameras and three thousand feet of 16mm natural color film* [from the Multinalp Association] ."

The second of Nakaya's supplementary projects also relied on support from the Multinalp Association through its provision of an automatic condensation nuclei counter (Nakaya et al., 1957). Nakaya travelled up and down the mountain sampling the condensation nuclei concentration in the air near ground. He wrote:

"*I decided to use the daytime on days without snow to study condensation nuclei. This turned out to be very successful*."

Nakaya provides the context for his observations of condensation nuclei:

"*The progress of material civilization and air pollution are like light and shadow; it is not possible to simply eliminate the shadow. ... we cannot stop burning things. Therefore, basic research on smog revolves around the problem of the generation of condensation nuclei through combustion. For such research, remote locations like Mauna Loa, where there is no combustion, are extremely advantageous*. …"

"*Because Mauna Loa is a place with such clean air, when new condensation nuclei are created by combustion, their effects can be clearly observed. On a clear, calm day, if you go out to the lava fields and measure the condensation nuclei, there are about a hundred* [particles per cubic cm]. *... if a car passes thirty feet away,* [the count] *immediately jumps up to one hundred thousand*".

"*I repeatedly traveled back and forth from Hilo to the mountaintop in a jeep and tried measuring the altitude distribution* [of condensation nuclei concentration]."

"*Since the lava has reached the wooded areas, the beautiful alpine shrublands unique to high mountain regions have mostly been swallowed by the lava. However, there is a stretch of about a mile near an elevation of 8,000 feet where the lava flow has been avoided. This area is a representative alpine shrubland, and a region of dreamlike beauty that remains like an island amidst the desolate lava plains*."

"*As you descend from the summit while continuously measuring condensation nuclei, on clear days, their number hardly changes. ... When entering the shrubland, the scenery changes drastically, suddenly entering a world of life. Dwarf trees of the genus Ohia common on this island bloom crimson even in winter, and among the seemingly withered ground grass, yellow flowers are interspersed. Here, for the first time, you hear the voices of small birds. The world seems to completely transform, shifting from a realm of death to one of life. Interestingly, the number of condensation nuclei does not change at all. This holds true not only in the shrubland but also when entering the lower forested areas."*

"The influence of the human world usually appears [in the polluted boundary layer] *at around four thousand feet in altitude* [where] *the number of condensation nuclei increases suddenly*."

Nakaya summarizes his results simply:

"*In short, as long as there are no humans, the air remains clean".*

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As Nakaya's team furnished the summit hut with equipment, oxygen tanks and other supplies, they had to rely on their single vehicle based at the observatory. This led to trouble and an opportunity for Nakaya to include a small adventure in his narrative. On one trip he and Sugaya had engine problems and were stuck on the road to the summit. The situation was concerning:

"*As far as the eye could see, there was a plain of black lava rocks in all directions, and the nearest neighbor was the Kulani Prison twenty miles below. ... Even if we abandoned the car and tried to walk back* [to the observatory]*, at an altitude of 12,000 feet I could not catch my breath*."

Fortunately:

"*We had left Dr. Shoda at the observatory, and just to be safe, I had taken a walkie-talkie before heading to the summit with Dr. Sugaya ... we were able to get in touch with Shoda at the observatory, and he requested assistance from the Hilo Weather Station via wireless. However, it was too difficult for help to come directly from Hilo, so the neighboring Kulani prison agreed to send assistance.*"

Nakaya then notes an interesting development:

"*American prisons proved to be very convenient; one of the prisoners was an automobile technician, so we were able to safely return to the observatory*".

"*Meanwhile, since snow could arrive anytime, maintaining the summit hut needed to be attended to. The mountain hut was not originally built for lodging, so no thought was given to keeping warm. The walls, made of just a single plank, let drafts pass freely. Moreover, at altitudes above 13,000 feet, the cold feels about twice as severe due to the lack of oxygen. Oxygen tanks had been brought, but once work begins, there is hardly time to calmly use them. I gave in easily and didn't stay a single night, but Dr. Sugaya stayed for about a week, ... and created a cover outside for the microscope photography equipment, since sufficient cold is only available outdoors for the microscopic photography*".

"*Everything was thoroughly prepared, and it was decided that we would be okay no matter when the snow came, but the crucial snow didn't fall at all. On December 15 and January 6, only a tiny amount of snow fell, enough to take two or three photographs. Apart from that, the sky was clear blue every day, and there was nothing we could do about it*."

While waiting for the snow Nakaya seems to have acted as the *de facto* host for visitors to the observatory. Visitors included Harry Wexler (1911-1962), the head of research for the US Weather Bureau, who was the man most responsible for the creation of the Mauna Loa Observatory. Nakaya writes:

"*On December 30th, Dr. Wexler suddenly came to visit. In fact, it was thanks to him that we were able to use the Mauna Loa observatory, so he was considered a very important guest. After spending about three hours there, he quickly descended the mountain. He had no particular business; he said he had "stopped by Hawaii for a short visit during a trip to check on things."*

Then:

"*After Dr. Wexler had returned, about ten days later, Professor Hans Pettersson arrived, this time staying for a visit. His purpose was to conduct research on cosmic dust*."

Petterson (1888-1966) was a very prominent Swedish geochemist and oceanographer who then was a professor at the University of Hawaii. He had made major contributions to the sampling of ocean sediments (Deacon, 1966) and his research

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at the Mauna Loa observatory was inspired by the question of how much of the sediment accumulation could be attributed to extraterrestrial sources. He had speculated that the source of observed nickel concentrations in ocean sediments was meteoritic dust. His Mauna Loa experiment estimated this meteoritic flux by observing in the clean atmosphere far above human sources of pollution. Nakaya includes in his essay a concise, but extremely impressive, background on meteors and the science of ocean sediment accumulation. Petterson wrote an important paper in *Nature* based on his results of his Mauna Loa observations (Petterson, 1958).

Meanwhile Nakaya's own project was about to take a step forward:

"*After waiting nearly forty days, patience finally paid off, and on January 13th, there was a forecast for snowfall. According to the forecast, it would start snowing the next day and continue for about a week. Excited by this news, Sugaya set out to the mountaintop hut carrying food and water. The long-awaited snow began to fall on the evening of the following day, the 14th. I was a bit surprised, as I did not expect the weather forecast to be so accurate*."

"*When it started snowing, Dr. Sugaya had a hard time. The temperature was often around minus two or three degrees Celsius … Taking microscopic photographs of snow crystals is not difficult when the temperature is around minus ten degrees Celsius. However, when it is near zero, the crystals melt rapidly from the light of the illumination alone. If a good crystal is found, it must be photographed immediately. If there is even the slightest hesitation, it won't work. Moreover, to make matters inconvenient, snow usually falls heavily at night. As a result, it often involves working through the night*".

Nakaya and his team would be rewarded for their patience with the discovery that the Mauna Loa summit snow was quite different from the snow they had observed over many years in Hokkaido:

"*Interestingly, many single-needle crystals were falling. Needle-shaped crystals can occasionally be observed even in places like Hokkaido if one is careful, but almost all of them consist of a structure where several needles are bundled together. Among our 3,000 photographs taken so far* [in Hokkaido] *there were only about two images of single needles. But now* [on Mauna Loa], *single needles fell abundantly, covering an entire glass plate with several dozen overlapping each other. In addition, various unusual needles were falling. One type had tiny hexagonal prism crystals attached to the sides of the needles, which is also quite rare among extant collections* [of photomicrographs]".

Nakaya goes on to describe the remarkable changes they observed in the crystal structure of the falling snow: from mainly needles to hexagonal prisms etc. within just a few minutes. He notes that:

"*Such remarkable changes have not been frequently observed in the past, but here they are quite ordinary*".

Nakaya wrote that unfortunately he had no plausible explanation for the rapid changes in dominant snow crystal form and so:

"*In the end, nature is such that the more you study it, the more you find things you don't understand rather than things you do, making it endless. However, I felt that this is truly the way research on natural phenomena should be, so I was in high spirits, thinking that the long journey all the way to the summit of Mauna Loa had been well worth it*."

Nakaya concludes his essay with a glimpse at his plans for a research trip to Greenland:

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"*Seeing rare places and encountering interesting things while conducting research is not so bad. By the time this manuscript goes to print, I might possibly be on top of the Greenland ice cap ... On top of seven thousand feet of ice, I will likely find various other rare things. Next, I might end up writing about the 'World of the White Moon.'*"

6 "World of the White Moon" (*Shiroi Tsuki no Sekai*)

6.1 Interest in glacial ice

Nakaya in fact made his first trip to Greenland in summer of 1957 (late June to early August) and wrote about it soon after in an essay "World of the White Moon" (*Shiroi Tsuki no Sekai*). This was a substantial essay (more than 7500 words in English translation) and was first published in the popular literary magazine *Bungei Shunjū* in November 1957. It was reprinted in later book collections. The choice of titles and fact that Nakaya teased a possible "White Moon" essay at the end of his "Black Moon" essay suggests a link. In fact the articles do share similarities – each serves as a narrative report on an extended scientific expedition and each provides extensive background on relevant scientific issues as well as vivid descriptions of the landscapes encountered.

While the "Black Moon" essay described one of Nakaya's last investigations of natural snow crystals, the "White Moon" essay is devoted to his late-career interest in glacial ice, which would be his main scientific preoccupation until his death.

We noted in Sect. 3.11, the expansion of Nakaya's interests to include studying the properties of glacial ice coincided with his appointment in 1952-54 at SIPRE. The evolution of his interests is understandable – basically following up his study of the formation of snow in the atmosphere with exploration of the fate of snow after reaching the glacial surface. Nakaya's famous dictum:

"*Snow crystals are letters from the heavens*"

is matched by a saying (e.g. Langway, 2008b, pg. 101) attributed to the Swiss-American glaciologist Henri Bader (1907-1998, who was SIPRE's Chief Scientist when Nakaya was there):

"*Snowflakes fall to earth and leave a message*"

In his 1959 Radio France lectures (Anonymous 2006) Nakaya stated that (pg. 17):

"*Ordinary ice forms by freezing of liquid water, but glacier ice is formed by the compaction of snow by its own weight. A part of the air contained in snow is trapped in the glacier ice as air bubbles. These air bubbles are very small, usually on the order of one-tenth of a millimeter. The process of the transformation of surface snow into glacier ice can be studied by using the snow of an icecap, which is a glacier that does not move. This research was carried out on the Greenland icecap in the summer of 1957*".

6.2 The issue of anthropogenic climate change in the 1950's

Nakaya's lengthy 1957 "World of the Black Moon" described the natural environment of Hawaii as well as several environmental science investigations that were conducted there (by his own team and others), but without a single mention of

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the idea of climate change. By contrast, Nakaya's "White Moon" essay, published later in 1957, is notable for displaying his - apparently newfound - interest in anthropogenic climate change (ACC) and enthusiasm for related scientific investigations. He notably makes a clear statement of the core of contemporary climate concerns with human greenhouse gas pollution. Nakaya's statement would be unremarkable today, but in 1957 it could be regarded as quite revelatory for almost any audience, but perhaps even more for a general audience in Japan. As noted earlier, it has been claimed that this essay was the first time the Japanese general public was exposed to our modern concerns about ACC (Anker and Sörlin, 2022).

In the 1950's the concept of ACC had remarkably muted penetration into the general culture. Even in the US – which arguably then led the world in atmospheric and oceanic science – the first official government attention to the issue of ACC did not occur until 1965 (PSAC, 1965). Given the rather sensational early 20th century prediction by Svante Arrehenius (1908) of strong climate warming expected from continued burning of fossil fuels, the lack of interest among the public and among governments is quite remarkable. Some scholars have noted that the limited cultural influence of the idea of ACC over the first several decades of the 20th century is particularly regrettable. One of us (Hamilton, 2023) has written earlier that:

"*With hindsight we can see that an opportunity was missed for humanity to seriously assess the practical implications of global warming, and then to take some appropriate mitigating actions. As today we face the need for extremely urgent action to avoid looming catastrophes it is reasonable to lament this "lost half-century" in the battle to control global warming*."

After discussing the very limited published media stories referencing ACC before the 1960's, Bell (2021) makes a similar point:

"*Sitting where we are today, such early coverage of the climate crisis is hard to read. How dare they be so blasé! ... It's easy to wail over the missed opportunities to act*."

Kellogg (1987) summarized the surprising early history (pg. 113):

"*The first inklings of an understanding of the role played by infrared absorbing gases in maintaining the warmth of the surface of our planet were voiced early in the 19th century, and by the turn of the* [20th] *century the calculations that had been carried out demonstrated how a change in atmospheric carbon dioxide would alter the earth's mean temperature. However it wasn't until the 1960's that much attention was paid to this matter*."

In addition to Kellogg (1987) there have been several published scholarly works relevant to the issue of the slow penetration of global climate change into the general culture. An example discussed earlier in Sect. 1 is Schmidt's (2010) re-examination of the mid-1950's work of the physicist Gilbert Plass (e.g., Plass, 1956). Schmidt (pg. 64) notes that at the time "*the idea that carbon dioxide affected climate was very much a fringe concern*" and that the ground-breaking paper of Plass (1956) represented "*only the start of a quite rocky road to modern respectability for* [this] *idea*". Other studies relevant to this issue include those focused on the history of the scientific research into ACC (Weart, 2008; Sörlin, 2013), as well as those focused on tracing the influence of the idea of ACC in news media (Bell, 2021, 2022), in the deliberations of government and industry (Fanta, 2022; Speth, 2022) and in popular literature (Vint, 2021). The conclusion of earlier studies has been that the significant penetration of the issue of ACC into general culture (and official concern) had to wait until the 1960's, 1970's and even 1980's.

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Having said this, we also acknowledge that there was some movement on the ACC issue apparent in the mid to late 1950's. On the science side important advances were made in measuring the carbon dioxide as part of efforts to understand the atmosphere's carbon budget (Bolin and Eriksson, 1959) as well as improved calculations of the effects of atmospheric carbon dioxide on the climate (e.g. Plass, 1956). The concern about greenhouse warming was taken seriously enough by the scientific community that issue was considered in planning the 1957/58 International Geophysical Year (IGY; Bader, 1958; Field, 1958). There were also a scattered few relevant articles appearing in major US media. Notably a short (4 paragraph) *Time* magazine article "Invisible Blanket" appeared in 1953 (Time, 1953). In 1956 a slightly longer (6 paragraphs) article appeared in *Time* magazine titled "One Big Greenhouse" that quoted leading American geochemist Roger Revelle (1909-1991) on his concerns about carbon dioxide and climate (Time, 1956a). However, it is notable that later in 1956 a very long cover story (more than 50 paragraphs) was devoted to the leading Swedish-American meteorologist Carl-Gustaf Rossby (1898-1957) and his views on weather and climate (Time, 1956b). This included just a single brief paragraph about the possibility of climate change. Also in 1956 the *New York Times* published an article by science reporter Waldemar Kaempffert titled "Warmer Climate on Earth May be Due to More Carbon Dioxide" that focused on Plass's work (Kaempffert, 1956). As discussed earlier, however, despite these early public stirrings on the ACC issue, there seemed to be a very limited penetration at the time into the public discussion.

Here we add to the late 1950's context for Nakaya's "White Moon" essay by noting some published reports that show instances of sophisticated people at the time who seem to have not encountered the notion of ACC, or otherwise completely disregarded it. The information we consider here is anecdotal but, we believe, provides evidence of the extremely muted cultural penetration of the idea of ACC. This background allows an appreciation for how exceptional at the time were Nakaya's views on ACC that he shared with the general public in his 1957 essay.

An interesting anecdote - coincidently connected with Nakaya – provides an example of a world class intellectual in the late 1950s being completely ignorant of the climate change issue. In the spring of 1958, the prominent English poet and novelist Stephen Spender (1909-1995) conducted an extended lecture tour of Japan which is recorded in his detailed personal journal (Spender, 1986). His tour included a lecture in Sapporo in May and he wrote his impressions in the May 21 entry in his journal (pg. 199):

"*Some professors then took us to lunch ... one of them was Nakaya, a great expert on snow. He goes to Greenland and takes segments of snow at a depth of 1500 metres and 10,000 years old. He said that the temperature of the world had risen by 1 degree in the present century, and, if this continues, within 150 years the North and South Poles will have melted. By analyzing a bubble of air enclosed in snow 10,000 years ago they can compare the atmosphere then with that of today*".

The clear implication is that before this meeting Spender was completely in the dark about climate change. It is interesting that Nakaya pointed out the idea of using air bubbles within ice cores to look at the atmosphere in the distant past. In 1958 this was still a possibility for the future, but one for which Nakaya expressed great enthusiasm in his "White Moon" essay (see the discussion in Sect. 6.4 below).

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Another interesting example from Japan is a 1954 article "Weather and the Japanese" that was published in the English language *Japan Quarterly* (see Sect 4.1 above for a description of this magazine). The author, Kiyoo Wadachi (also transliterated as "Wadati", 1902-1995), was then Director of the Japan Central Meteorological Observatory (predecessor of today's Japan Meteorological Agency). His 1954 article is a very broad survey of the features of the Japanese climate apparently aimed primarily at a foreign audience. Wadachi (1954) includes graphs comparing the climatological annual cycle of surface air temperature and precipitation at Tokyo with other major midlatitude locales (London, New York…). He discusses the remarkable contrast in precipitation between the Pacific and Japan Sea sides of Japan and he describes the typical typhoon season in Japan. Wadachi also addressed even broader concerns, discussing the role of the seasonal cycle in Japanese culture (see the present Sect. 2 for our brief discussion of this aspect) and even speculating on the role of climate in the formation of the character of the Japanese populace. In all this wide-ranging discussion of Japanese climate, Wadachi makes no mention at all of the possibility of climate change.

Another striking example relevant to the state of knowledge at the end of the 1950's is provided by interactions of the renowned Hungarian-American nuclear physicist Edward Teller (1908-2003) with scientific colleagues and others. As described in an article by the chief scientist of the Shell Oil Corporation at the time (Matthews, 1959), Teller surprised a December 1957 meeting of the American Chemical Society with a "*solemn warning about the effects of burning coal and oil fuel on the atmosphere*." Two years later Teller presented at a symposium "Energy and Man" organized by the American Petroleum Institute (a major industry trade group in the USA) and the Columbia University Graduate School of Business that was held on the Columbia Campus in November 1959. According to the proceedings volume (Brown, 1960), the meeting attracted over 300 "*government officials, economists, scientists and business executives*." Teller's lecture introduced the audience to the notion that fossil fuel burning would increase the atmospheric carbon dioxide concentration and warm the climate. Teller seems to have believed that this idea would be completely novel even for his audience of people professionally involved in the energy sector (Teller, 1960, pg. 56):

"*I would like to talk to you about a more hypothetical difficulty* [concerning fossil fuels] *which I think is quite probably going to turn out to be real. Whenever you burn conventional fuel, you create carbon dioxide. … If the rate of burning conventional fuels continues to increase by a factor of 2 each ten years, the result will be that by the end of the century there will be an increase of carbon dioxide in the atmosphere by more than 10 per cent. … Its presence in the atmosphere causes a greenhouse effect in that it will allow the solar rays to enter, but it will to some extent impede the radiation from the earth into outer space*."

Teller goes on to suggest that even the 10 per cent increase in atmospheric carbon dioxide could result in melting of the polar ice caps. Teller does not explain where he got this extreme prediction, but the notion of anthropogenic climate change from fossil fuels was introduced to allow Teller to make a stronger case for recommending the adoption of nuclear power. None of the other lectures in the proceedings volume even mention any possible concern about atmospheric carbon dioxide.

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6.3 Ice core research in the 1950's

Before we consider in detail Nakaya's essay reporting on his participation in the SIPRE 1957 research expedition to study ice on Greenland, we will review the state of ice core research at that time. Of course, today we have the benefit of more than 50 years of detailed analysis of the composition of deep ice cores and the gas bubbles trapped within. However, at the time of Nakaya's Greenland expeditions the field of ice core research was in its infancy.

Writing near the beginning of this type of research, Bader (1958, pg. 177) succinctly explained the motivation for studying cores of the polar ice caps:

"*Two thirds of the area of the Greenland ice sheet and practically all of the Antarctic ice sheet are permanently dry. Summer melt is rare and usually affects a surface layer only a few centimeters thick. Thus every snowfall, including everything that fell with it, is, so to say, filed for future reference by being buried under later snowfalls*".

While scientists had first dug pits into the ice to explore the structure of alpine glaciers in the 19th century, the significant scientific exploration of ice on Greenland began with the work of the German glaciologist Ernst Sorge (1899-1946) during the 1930-31 German Greenland expedition. This famous expedition was led initially by the renowned geoscientist Alfred Wegener (1880-1930) who tragically lost his life in the enterprise (an event discussed in Nakaya's "White Moon" essay; see Sect. 6.4 below). Sorge's pioneering contributions included the first estimate of the thickness of the ice cap from seismic measurements.

Also, according to Langway (2008a; pg. 5):

"[Sorge] *was the first to study the near-surface snow/firn strata in a 15 m deep pit … Sorge determined the characteristics of the individual limits of annual snow accumulation. This research validated the feasibility of measuring the preserved annual snow accumulation cycles*.".

A key breakthrough was the work of Dansgaard (1954) who showed that isotope ratios in glacial ice could be used to infer aspects of the weather at the time of its formation. Also in the 1950's the technique of investigating the glacial ice by digging a pit was supplemented by mechanical coring of the ice, allowing a much deeper layer to be sampled. SIPRE led the efforts to core deeply into glacial ice in its annual Greenland summertime expeditions which began in 1953 (Langway, 2008a,b).

Apparently writing before the summer campaign in 1957, Bader (1958) discussed recent developments in glacial sampling and plans for the 1957/1958 IGY. Bader saw SIPRE as central to the recent and pending developments. Specifically he wrote that (pgs. 178-179):

"*During the last few years the records of the snow layers in Greenland have been delved into more deeply and in more detail by means of methods and instruments developed mainly by … SIPRE. The deepest penetration into the past will be done in the US IGY deep drilling program which has been entrusted to SIPRE. In preparation, SIPRE, in 1956, drilled to 300 m at its experimental station on the Greenland ice sheet some 200 miles east of Thule*."

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6.4 The text of the "World of the White Moon"

Nakaya joined the 5th SIPRE Greenland expedition in 1957 and was on the Greenland ice cap from late June to early August. Technical reports of his investigations in the 1957 expedition are presented in Nakaya (1958b) and Nakaya (1959).

Nakaya opens his "White Moon" *Bungei Shunjū* magazine article with a section titled "The Black Moon and the White Moon" connecting his topic of the lunar like landscape of Greenland with his earlier observations of the black lunar landscape of Mauna Loa:

"*The high peak Mauna Loa on the Big Island of Hawaii is surrounded by an area larger than Kanagawa Prefecture, covered in black lava, centered around a summit of 13,700 feet. No trees, grass, insects, or birds can survive in this land … I have earlier written about that black lunar world. However, there is also a white moon world on the earth. It is the landscape on the ice cap of Greenland. An ice cap is formed from snow that has accumulated since ancient times without melting, gradually piling up and becoming ice due to its own weight. You can think of it as a stationary glacier formed on flat land*."

"*Greenland is the largest island in the world and, except for Antarctica, the land closest to a pole. … When looking at a map of Greenland, only a very narrow area along the coast is colored, while the interior is pure white. This white remnant is the ice cap, which is at least six times the territory of Japan. And there is nothing but snow and ice, no trees, no rocks. In short, it is a world in which there is nothing black*."

"*What is even more astonishing is the thickness of the ice cap. The elevation of the ice cap has been measured over almost the entire area, with the highest point exceeding eleven thousand feet and averaging around seven thousand feet. By measuring the thickness of the ice cap using artificial seismic waves commonly used in underground exploration, the thickness is found to be roughly close to the elevation or slightly greater. The bottom of the ice is near sea level or below it. In short, the Greenland ice cap can be thought of as being about as thick as the Japanese Alps and as a large ice rice cake approximately six times the size of all of Japan. In summary, it is an extraordinary thing*."

Reading Nakaya's essay now reminds us of how in 1957 discovery of even the basic features of the earth's polar ice caps was still quite recent. Nakaya even feels that readers may doubt the plausibility of the immense thickness of the Greenland ice and points out that a similar determination for Antarctica had only recently been obtained (e.g. Sullivan, 1957) as part of the activities of the IGY or "Earth Observation Year" as he refers to it:

"*Some may think that the thickness of the ice cap being so great is a mistake. However, it has recently been discovered that there is similar ice in Antarctica. Bertrand is one of the American bases, located roughly halfway between the Antarctic Circle and the pole. There, using artificial seismic waves to measure the thickness of the ice, a value of about ten thousand feet was obtained. This is one of the findings of the current Earth Observation Year*."

Nakaya continues with a new section "Melting Glaciers" that includes his eyewitness description of the summer melt in Greenland as well as his discussion of the issue of climate change.

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"*The ice cap in Greenland, as well as its surroundings, is reportedly retreating at a noticeable speed. In the United States, SIPRE … has been leading expeditions to Greenland every summer for the past four years. This year marks the fifth expedition. According to them, even in just these five years, the retreat of the ice cap is clearly observable*".

"*This summer, the melting of the ice cap was particularly remarkable. I arrived at the end of June, and soon after, intense melting began. I was near the edge of the ice cap for a while, so it was especially noticeable. Countless rivers of meltwater formed on the ice field, flowing with tremendous force. The water gathered to create temporary lakes, and then flowed out to the sea, resembling a flood. … the torrent splashed and twisted across the ice field like a giant serpent. The melting of this ice cap showed no signs of abating until I left the area in early August*".

"*It is a fact that the Earth's temperature has gradually risen since the beginning of this century. In Hokkaido and other places, elderly residents often talk about how it used to be colder and there was more snow*".

"*… In the United States, this issue has become a problem, and the meteorological agency has investigated the temperatures of weather stations across the country, going back over the past sixty years. As a result, it was concluded that the average annual temperature has risen by one degree Celsius during this period*."

It seems likely that Nakaya is referring here to the work of American meteorologist J. Murray Mitchell (1928-1990). In Mitchell (1953) he described his investigation of trends in surface air temperature observations at 77 US Weather Bureau stations starting in 1900. He found a warming trend that he attributed largely to the effects of urbanization in the regions around the stations. In Japan, Fukui (1957) was apparently inspired by Mitchell's work to conduct a similar study of Japanese temperature records.

Nakaya then concisely lays out the key issues underlying the possibility of anthropogenically driven global warming. First he notes that natural fluctuations in global temperature are expected on various time scales:

"*Here, the problem can be divided into two parts. The temperature on Earth has changed periodically in the past. The so-called ice ages have repeatedly struck for this reason. However, in addition to such major fluctuations, there have also been shorter-period variations with smaller changes. For example, there are changes where the temperature rises and falls slightly over a period of several hundred years. Now, if the temperature rise since the beginning of this century is part of this wave of change, then there is no problem. If we wait another half century, a cold period will likely come again*".

Nakaya then introduces the notion of climate warming driven by human activity:

"*… another possibility can be considered … that the current rise in temperature may be due to human activities. The progress of material civilization since the beginning of this century has been truly abnormal, with fuel consumption reaching enormous levels. In the city of Los Angeles alone, a million gallons of gasoline are burned in a single day. The consumption of coal and oil worldwide is staggering. Combustion inevitably produces carbon dioxide. On the other hand, carbon dioxide is absorbed by the photosynthesis of plants, but deforestation is only progressing. Both are moving in the direction of increasing the amount of carbon dioxide in the atmosphere*".

"*If the amount of carbon dioxide in the atmosphere increases, it will absorb more of the sun's radiation, causing the Earth's temperature to rise".*

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Nakaya's statement here is surprisingly sloppy as he should have known that the main effect of atmospheric carbon dioxide on global climate is through the absorption of terrestrial infrared radiation.

"Therefore, the recent increase in temperature is likely due to the rise in carbon dioxide levels, which raises the question of whether there are significant human factors contributing to this increase…."

"*So the first question is whether the amount of carbon dioxide in the atmosphere has increased in recent years. … according to Dr. Junge* [German chemist Christian Junge, 1913-1996]*, an expert in this field, carbon dioxide in the atmosphere has increased by ten percent over the past fifty years. However, even if that is a fact, whether it is due to human activity is a separate issue. Since seawater dissolves carbon dioxide well, we cannot say anything without thoroughly investigating the amount of carbon dioxide in seawater. In any case, this is a problem that requires significant research from the perspectives of meteorology and oceanography…*".

"*In any case, some scholars say that if temperatures continue to rise at the current rate for another fifty years, the sea ice in the Arctic Ocean will largely melt during the summer, making it considerably easier for ships to pass through. That would be fine, but if the ice caps in Greenland, Antarctica, and the ice in Northern Europe and Siberia all melted, a major event would occur. Scholars have calculated the total amount of ice currently existing on Earth. The estimates vary significantly, but in any case, it is an enormous amount, and if it all melted and flowed into the sea, sea levels would rise significantly higher than they are now. Some people estimate that it could increase by as much as one hundred eighty feet. … If New York, London, and Tokyo all ended up at the bottom of the sea, it would be a disaster*".

Nakaya then claims that the topic of anthropogenic climate change had been written about in America and Japan. It is not clear to us what Japanese articles he might have but it is possible that he knew of the 1956 articles in *Time* magazine and the *New York Times* mentioned in Sect. 6.2 above.

He then notes the limited influence of any resulting public discussion:

"*Of course, no one is seriously worried about what will happen two or three hundred years from now, so this story has only stirred up some "conversation in the living room". However, the question remains whether this issue is just a "somewhat interesting story" or if it truly has substantial scientific basis; for now, it is uncertain either way*".

"*If we were to address this issue scientifically, we would need to study long-term climate changes. In fact, long-term climate changes are a topic worth researching even apart from this issue. Therefore, as part of the upcoming International Year of Earth Observations, the U.S. Greenland Expedition has decided to incorporate this issue into their research plan*".

"*Choosing Greenland for the study of long-term climate change is quite an interesting idea. That ice cap is made up of snow that has accumulated since ancient times, compressed under its own weight without melting, turning into ice. Therefore, if ice samples are taken from the depths of the ice cap, they represent ancient water. The deeper you go, the older the water sampled. Moreover, the ice that makes up the ice cap contains countless air bubbles. When snow is compressed and turns into ice, the air trapped in the snow forms bubbles that are sealed within the ice. Thus, the air in these bubbles is from the atmosphere of the past. The actual atmosphere and water from thousands or tens of thousands of years ago are preserved within the ice cap. By skilfully utilizing this natural data, it may be possible to extract some knowledge about long-term climate change. To do*

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this, it is first necessary to thoroughly investigate the properties of the ice in the ice cap. The main purpose of my trip to Greenland this summer was focused on this point".

"*The talk of going to Greenland came up last year at the end of the year. Last summer, an expedition from SIPRE successfully collected ice samples from deep within the ice cap through drilling. The drilling reached a depth of a thousand feet, and nearly perfect samples were obtained up to about eight hundred feet. This year, with support from the International Year of Global Observations, a plan was made to drill down to two thousand feet. If we could reach two thousand feet, we would be able to obtain ice samples that are over a thousand years old. Such opportunities are rare, so I decided to participate enthusiastically* [and] *to immediately create measuring equipment. Ice has the property of elasticity as a solid, but at the same time, it also has a viscous property like syrup. Since these two properties of elasticity and viscosity are considered the most important characteristics of ice, I decided to measure these two properties from samples taken at various depths of the ice cap."*

Nakaya would determine the elasticity and viscosity of a sample by measuring the vibrational response to imposed periodic forcing (his technique is explained in detail in Nakaya, 1959). The essay continues:

"The device was built by Dr. Kuroiwa from Hokkaido University and Mr. Shindo, and it is an electronic instrument that uses an electromagnetic oscilloscope and a cathode ray oscilloscope. Using this precision instrument on the Greenland ice cap was quite a reckless idea, but it actually worked splendidly without a single malfunction, yielding very interesting results…"

"*This instrument was finally completed about three days before I left Japan. I loaded it onto a plane, flew to Chicago, and tested it in the cryogenic chamber of SIPRE in Wilmette, a suburb of Chicago. The results were excellent, so I flew to Greenland with peace of mind*".

Nakaya vividly records his journey and his impressions on first encountering the landscape of Labrador, Baffin Island and Greenland:

"*A town called Thule was built just north of the west coast of Greenland, slightly beyond latitude 76 degrees north. The United States has leased this area of land from Denmark and constructed a splendid airfield, designating it as the first line of defense in the north. … There is a regular flight from the east coast of the United States once a day. Thus, Thule is within the realm of civilization. After taking off from an airport in the suburbs of Philadelphia, you arrive at Goose Bay Airport in Labrador, Canada, five hours later. After refuelling here and heading straight north, you can reach Thule in about nine hours".*

"[In his trip] *after taking off from Goose Bay, within an hour, the scenery completely turns into the Arctic. All that can be seen are bare mountains and narrow, winding fjords. There are no signs of human habitation, cultivated land, or roads…"*

"*Baffin Island, located north of Labrador, is a large island, much bigger than all of Japan. Most of this island is within the Arctic Circle. The entire island is covered in terrifying mountains, with dark blue rocks exposing bare rock faces, reminiscent of ancient geology. It certainly feels like it has endured countless ages of ice and snow. There are no trees, and not a single patch of grass can be seen*".

"*The coast* [features] *fjords everywhere, and the long bays extend deep inland. Steep mountains plunge directly into the sea, forming the banks of these fjords. The sea is partially covered with drifting ice, and on the mountains that continue far inland,*

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glaciers and perennial snow shine white, lying beneath layers of lead-colored clouds. It is a world completely unrelated to human society, and in terms of the scenery, this island is even more desolate than Greenland".

"*This world, consisting only of white ice and bluish-black rocks, is like a monochrome photograph, but it is the colors of the sunset clouds that give it vibrancy. Since we left Goose Bay in the evening, it seemed reasonable to expect it to be night. However, the sun had begun to set, yet it remained close to the horizon for a long time. Indeed, if one goes as far as Thule, the sun shines even at midnight during this season. … Above the lead-colored stratocumulus clouds, various shapes of cirrus clouds are stretched out high above. The sun on the horizon paints the edges of the lead-colored stratocumulus clouds a deep red, illuminating the cirrus clouds above in golden hues. The air is astonishingly clear, and the translucent sky in a celadon color beautifully blends into the pale pink layer near the horizon. This is a sky color often seen in high-latitude regions".*

"From near the northern tip of Baffin Island, crossing Baffin Bay to the northeast, you arrive at Thule in northern Greenland. After flying over the sea filled with pack ice and icebergs for about two hours, I dozed off a little, when someone exclaimed, "Ah, Greenland." Indeed, the mountains of the Greenland coastal range were right in front of us. Even though it was past midnight, the sun was high, and perhaps because of that, the color of the sea was deep blue, with white shining icebergs that looked like a flock of swans".

"*Beyond the coastal mountains, the interior is completely covered in white, shrouded in ice caps, and from the valleys here and there, majestic glaciers flow down to the sea. Where the glaciers meet the sea, there are vertical ice cliffs, and their cut surfaces shine white like the cross-section of a broken chalk. We arrived at Thule at one o'clock in the middle of the night. The wind was indeed cold, but the sun was blazing in the sky*".

Nakaya then remarks on the town of Thule:

"*It is difficult to find flat land suitable for building towns. However, Thule is unusually blessed with its terrain. The bay has the conditions to be a good harbor, and there is about fourteen miles of flat land up to the edge of the ice cap. This flat land appears to be a gravel plain, which melts during the summer. Although it is called gravel, it is actually a moraine brought by the ice cap".*

"*On this moraine plain, an airfield was constructed and buildings were erected to create the town of Thule, but this was quite a difficult undertaking, as the surface is a typical sandy gravel plain, and digging just five feet down reveals permafrost extending much deeper*".

Just as in his "Black Moon" essay here Nakaya remarks on the American approach to life in a way that perhaps conveys a slightly amused view:

"*In permafrost regions, the most troublesome aspect is the concern that if a building is constructed on top, the frozen ground below may melt. If the permafrost melts, the house may sink into the ground or tilt. Therefore, buildings in Thule are designed with elevated floors that allow wind to pass underneath. This has already been attempted in places like North Manchuria and is not particularly new. However, the large buildings being constructed recently completely enclose the area beneath the floor, resembling ordinary concrete structures. … Of course, the inside is kept warm, so I asked if there was any concern about melting the permafrost. To my surprise, I learned that such buildings are equipped with refrigeration units that circulate cold*

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air underneath all year round. In that case, there is no worry about the permafrost melting. However, I was a bit surprised to hear that they are running refrigeration units continuously in the Arctic. It is indeed an American way of doing things".

After a further discussion of the science of permafrost, Nakaya begins a new section titled "Ocean of Ice":

"*The ice cap … is a completely flat expanse of snow and ice, so standing within it gives the feeling of being in a completely white sea*. […over 200 miles northeast of Thule] *on the ice cap, there is an observation station called Site Two*."

For a history and description of Site Two see Bierman and Schmidt (2022). This was to be the prime location for Nakaya's activities in this summer and in the following years when he joined SIPRE expeditions. Unfortunately, transportation around Greenland was a challenge and the aviation option was apparently particularly dangerous:

"*For transport to Site Two, both airplanes and sled trains were used.* [From Thule] *it takes two and a half hours by plane and five days and nights by sled. Since being jostled around for five days and nights is unbearable, everyone wants to take the plane, but there is no airport there, so they land on a snow-packed runway using skis. Therefore, they won't fly unless the conditions are very good. In my case, I was fortunate with the weather on the way there and flew in two and a half hours. However, on the way back, the plane that came to pick me up crashed along the way, so I had no choice but to return after being jostled for five days and nights*. [in the airplane crash] *two people were injured, but fortunately, no one died*."

The non-fatal accident Nakaya mentioned involved a US Air Force Fairchild C-119 which crashed at Site Two (see https://campcentury.omeka.net/items/show/207, accessed July 19, 2026).

"*It seems that about two planes crash each year. As far as the eye can see, everything is pure white, with no landmarks whatsoever. If the weather is good, the horizon can be seen, but once fog rolls in, visibility drops to zero. This fog over the ice cap is called a whiteout and is greatly feared. In severe cases, visibility can be reduced to less than six feet. If you make even a slight mistake in direction* [as you walk around], *you might have to walk the equivalent distance from Tokyo to Aomori* [*~700 km*] *to get to the other side*."

Nakaya then describes the Site Two development. Note that the term "kamaboko tents" refers to semicylindrical tents whose shape resembles a traditional Japanese *kamaboko* fish cake. Such tents can be seen in the photo from Site Two included here as Fig. 8.

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Figure 8: Photo taken at Site Two on the Greenland ice cap in 1956 or 1957. From Langway (2008a).

"*… the gateway to Site Two, is a small village with a population of about sixty people, of which around twenty are scientists. There are only two rows of kamaboko tents … Human presence contaminates the ice cap, so the laboratories, which are either kamaboko tents or snow caves, are located about half a mile away from the tent village*".

Nakaya then discusses the weather on the ice cap as he experienced it. He notes the implications for safety of the expedition members and he recounts the story of the tragic end of Alfred Wegener almost 3 decades earlier. (Note that in our translation we use the word "Inuit" for the indigenous inhabitants):

"*During the summer, the temperature is surprisingly mild. There are days when the weather is nice, and beautiful cirrus clouds decorate the blue sky, lasting for about four or five days to a week. During this time, the temperature is a few degrees below zero. The sun circles the sky day and night, but at "night," it is slightly lower in altitude, and the temperature drops a bit. After such good weather, a blizzard inevitably comes, lasting for four or five days before returning to good weather. … Even during a blizzard, the temperature is around minus ten degrees, so it doesn't get too cold. The frightening part is the wind; once a snowstorm starts, visibility drops to ten feet. I traveled back and forth between the dormitory and the laboratory using a small snow vehicle called a weasel, but on a day when the wind blew at a hundred knots, I almost lost my way. Fortunately, there are black markers lined up along both sides of the pathway, and I was able to reach the dormitory by hitting one of them. On that day, the Danish expedition lost two members. One fell into a crevasse, and the body was recovered. The other man lost his way and disappeared into the ice cap. He will likely never be found*".

"*The ice cap of Greenland has claimed the lives of many scholars in the past. Among them, the most tragic is the death of Professor* [Alfred] *Wegener. This outstanding geophysicist, well-known in Japan as the proponent of the continental drift theory, met his end within the Greenland ice cap. The food and fuel for his expedition's hole-dwelling crew inside the ice cap*

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had become scarce. To secure food … Wegener planned to break through the ice cap with a loyal Inuit guide. However, soon after, a fierce blizzard in Greenland took Wegener's life. This was in 1930. The loyal Inuit buried the body in the snow, erected a marker, and set out alone to cross the ice cap … but he also ultimately did not reach his destination. When spring came, the rescue team that saved the survivors learned of Professor Wegener's death for the first time and, thanks to the marker, discovered the body".

Nakaya then begins a new section in which he explains how ice samples are dated:

"*To investigate past climate conditions by taking ice samples from the depths of the ice cap, it is first necessary to know their age. This research began in 1954 and has finally been able to trace back to about eighty years ago. During those eighty years, the age can be determined accurately year by year. The clue lies in the vertical distribution of density. Summer snow and winter snow differ in crystal form and compaction. Therefore, summer snow and winter snow are thought to have different densities within the snow layers. If there is a regular pattern of highs and lows in the vertical distribution of density, one high or low can be interpreted as a year's snowfall. However, when actually measured, the highs and lows are very complex, making it difficult to determine which one to consider as a year's peak. In particular, the newest layers are confusing, and the first twenty years are very troublesome. Beyond that, a little regularity begins to emerge*".

"*… we identify a peak* [in density] *and take it as* [marking] *a year, gradually tracing back to determine the ages. However, within the layer estimated to be from 1914, there was a small amount of volcanic ash. So, when we investigated whether there was a major eruption around that time, we found records of a significant eruption at the Katmai volcano in Alaska on June 6, 1912. Therefore, it seems better to consider this layer as dating to 1912. After making this two-year correction, we then looked for minima, and were able to match the depths and ages even more skilfully than before. Thus, the ages were definitively determined up to 1912. This layer is located at a depth of about 110 feet from the surface. Beyond that, the density peaks become quite regular, making it relatively easy to determine the ages*."

"*However, the farthest back that can be traced using this method is around 1850, and the depth is limited to about 200 feet. For ice older than that, the difference in density becomes too small to locate the peaks. Therefore, if samples were to be taken from boreholes up to 2000 feet, another method would have to be used to determine the age. However, for such old ice, precision to the year is not necessary, and it is sufficient to know roughly which century the ice is from*."

"*The method for determining this ancient age has not yet been found. This summer's samples were cut in half, leaving one half in Greenland and transporting the other half to the Wilmette SIPRE facility*."

Nakaya then describes the role of his own investigations:

"*The problem I have taken on, namely the work of measuring the elasticity and viscosity of ice, is somewhat related to determining the age of ice caps. The ice in the deep layers of the ice cap, as I mentioned before, contains many air bubbles. These bubbles are trapped air that was in the snow. Under high pressure, the ice is compressed over long periods, and the properties similar to syrup come into play, causing the volume to shrink and crushing the bubbles inside. Therefore, the bubbles in the deep ice are very small. As the bubbles become smaller while remaining trapped in the ice, the internal pressure*

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increases. At a depth of six hundred feet, the pressure reaches about fourteen atmospheres. When such a sample is exposed to sunlight and melts, tiny bubbles make a popping sound and burst."

"*The ice deep within the ice cap is a truly strange substance, containing countless very small high-pressure bubbles. Such peculiar things are unlikely to be found elsewhere. Because it is so strange, its properties are also unusual, and when measuring its elasticity and viscosity, many surprising results emerged. For example, at low temperatures, this bubble-filled ice becomes far less viscous than pure ice. In other words, it becomes a more perfect elastic body. This is indeed surprising, and it is certain that these high-pressure microbubbles play an important role.*"

"*By the way, when these high-pressure microbubbles are formed, the most significant factor is time. Pressure alone does not cause ice to exhibit properties like syrup. If the pressure is increased too much, it simply breaks. When pressure is applied for a long time beyond a certain level, deformation of the ice occurs as a function of time. Therefore, by investigating the mechanism that creates these microbubbles, and knowing that there must be significant internal strain in the ice, it should be possible to calculate the time required for contraction from the pressure within the bubbles. Of course, it is necessary to experimentally investigate the relationship between pressure and compression for extremely slow deformations. More importantly, it is essential to thoroughly study the elasticity and viscosity of this special ice*."

"[With all these considerations] *a month or so of research on the ice cap was simply not enough* [for me]. *It was necessary to be satisfied with just finding the problem, and the only option left was to bring the ice samples back to Japan and study them at leisure*."

Nakaya ended his essay with a section describing his effort to transport his ice sample to Japan:

"*Finally, when it comes to bringing ice from the Greenland ice cap to Japan, the task becomes quite complicated. The first hurdle is the transportation from Thule to the Wilmette research institute. Since I didn't have a thermos ready, I had no choice but to use wooden boxes. I filled a large wooden box with fiberglass insulation and placed the ice inside. Fortunately, [a colleague] had some dry ice left over from his research … so I crushed it and filled the surrounding area with it. Additionally, I packed a box of dry ice to be replenished in Philadelphia and boarded the plane*."

"*Philadelphia was in the middle of summer. ... I opened the box in scorching heat, and white steam rose up, while the ice remained secure. I immediately poured the prepared dry ice onto the cobblestones and smashed it with a hammer, ensuring a sufficient supply. The fragments of dry ice scattered everywhere, vigorously emitting white smoke. The people at the airport looked puzzled, but they did not scold me.* [Then from Philadelphia it only took] *half a day to get to Chicago*."

"*For three weeks, I fiddled with this ice in the low-temperature chamber in Wilmette* [i.e. at SIPRE's facility near Chicago] "

"*In the end, I decided to bring the specimen back to Japan, preparing a large thermos filled with ice and dry ice to load onto the plane. The thermos was reliable in terms of insulation, but there was a concern about it breaking. Additionally, if it was laid on its side, cold air would escape, so I had to hold it upright next to my seat on the plane, which made me a bit anxious. After all, I had dug out ice from the depths of the Greenland ice cap dating back to the Kamakura period and brought it all the way here. I could not just let it melt now*."

The reference is to the era 1185-1333 when Japan was ruled by the shogunate based in Kamakura.

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"*The most troublesome part was the supply of dry ice. Most stores have a minimum unit of fifty pounds and won't sell just two pounds. However, when I explained the situation, Americans, who like unusual things, either shared it with me or gave it to me for free. With this cumbersome load, I continued my seemingly leisurely journey for three days to the University of Utah in the middle of the desert, one day to San Francisco, and another night in Honolulu, bringing it all the way to Japan. Once I reached Tokyo, I could leave it at the low-temperature room of the Ministry of Transport … so there was no need to worry after that. Eventually, I safely arrived in Sapporo, and this Greenland ice is currently taking a break in the low-temperature room at Hokkaido University*."

Nakaya concludes his essay with more reflection on the age of his ice sample and again puts it into historical context. Here "Yoritomo" is Minamoto no Yoritomo (1147-1199), an epic figure in Japanese history as the founder of the Kamakura shogunate.

"*This ice contains the air that Yoritomo was breathing. I would like to ask someone to analyze the carbon dioxide in this air. If it is significantly different from modern air, this will become a major issue that should be studied more seriously*. […] *Once the experiment is completely finished, this ice will no longer be needed. Then, I am thinking of making cocktails with this Kamakura period ice and treating my friends*."

Despite the rigors and substantial danger of research in Greenland, Nakaya would join the SIPRE expeditions in the summers of each of the following three years (1958-1960). After Nakaya's death at the age of 62, his close friend, the Japanese physicist and University of Tokyo president Seiji Kaya (1898-1988), said that he felt that Nakaya had traded years of his life for the opportunity to explore Greenland (Kaya, 1966, pg. 11):

"*It is deeply regrettable to me that it seemed as though a life-or-death struggle had taken place with Greenland*."

This sentiment seems shared by his Hokkaido colleague (and former student) Magono (1963, pg. 1):

"*But, though regret cannot mend the matter now, we cannot help thinking that his death might have been quickened by his 4th expedition to Greenland*."

The work of the SIPRE expeditions in the 1950's would pay off dramatically in the following decade. The US military would construct a major installation for scientific research (among other purposes) at Camp Century roughly 100 km west of Site Two. For several years a project was conducted there to drill an ice core to the bedrock. According to Langway (2008a, pg. 21) "*The total experimental drilling operation took a strenuous six-year field effort by the crew to recover the first-ever continuous ice core to bedrock*." This "Camp Century Core" became famous as it was analyzed in a project resulting in the classic paper of Dansgaard et al., (1969) "One thousand centuries of climate record from Camp Century on the Greenland ice sheet", opening a major new chapter in the field of paleoclimatology.

7 Conclusion

Born at the beginning of the 20th century in small town Japan, Ukichiro Nakaya became one of the century's most intriguing intellectual figures. His contributions to snow science were groundbreaking and still have a place in fundamental textbooks in

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that subject. In addition to his research accomplishments, Nakaya was exceptional in his activities as a popularizer of science, producing both notable writing and documentary films. His literary efforts include several hundred essays whose subjects extend beyond science to include other aspects of culture. In his obituary of Nakaya, his Hokkaido University colleague Choji Magono (1963; pg. 2) wrote that

"[Nakaya's] *activity was manifested not only in the physical and geophysical fields, but also in several tens of volumes of his essay collections* [and in] *production of the cinema, … so that some people may have, by mistake, regarded him as* [only] *a literary man*."

At age 29 Nakaya began as an inaugural faculty member in the newly established Faculty of Science at Hokkaido Imperial University. Born and raised in snowy Ishikawa prefecture he would spend the bulk of his adult life in the notoriously cold and snowy Hokkaido prefecture and, perhaps inspired in part by the 19th century Japanese snow observation pioneers Toshitsura Doi and Senseki Takata, Nakaya would choose snow crystals as his research focus in Hokkaido. His world class research on snow at Hokkaido Imperial University and his role in establishing the Institute of Low Temperature Science there helped put the university on the course to its present day outstanding global reputation in the geosciences.

Nakaya's career played out against the great historical events of the time, notably World War II. The controversy over his involvement in military research during the war, the near total destruction by American bombing of his great monograph on ice crystals and its subsequent publication with the assistance of the American occupying authorities, and the alteration of his research priorities in the immediate postwar period in response to national food shortages, are all incidents infused with a kind of drama generally unknown to academic scientists in today's (hopefully) more peaceful and prosperous world.

During his lifetime Nakaya received many important Japanese awards for his accomplishments. Further demonstration of the enduring significance of his career is provided by several exceptional examples of posthumous recognition. A small group of islands in Antarctica was named the "Nakaya Islands" to honor his work in polar science. The "Ukichiro Nakaya Snow and Ice Museum" opened in 1994 in his hometown of Kaga. The asteroid "10152" was discovered in 1997 by a Japanese astronomer who honored Nakaya's memory by naming his discovery "10152 Ukichiro". As noted in Section 1 above, in 2000 a Japanese postal stamp was issued to commemorate Nakaya's 100th birthday (Fig. 3).

While the present article is not meant to be a comprehensive biography or a critical assessment of Nakaya's scientific output, we hope our outlines of his life and career will help raise his profile in the international scientific community and provide a fitting 125th birthday tribute. In particular, we have tried to convey the flavor and extent of Nakaya's overall literary contribution. We focused on two 1957 essays describing Nakaya's major research expeditions to Hawaii ("World of the Black Moon") and Greenland ("World of the White Moon") for which we provided our commentary and extensive excerpts in English translation. Nakaya's "White Moon" essay describes his contribution to the very earliest years of ice core research. In his essay Nakaya presents his vision of ice core analysis that could document the composition of the atmosphere over long periods to help study climate change and its possible anthropogenic drivers. While it would take another decade before ice cores could be used in this fashion in published research, ultimately the field of ice core analysis would revolutionize climate science. Nakaya's essay may be the first notable public discussion of the issue of anthropogenic global warming in Japan. In

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his clear statement of the climate concerns facing modern society he was almost unmatched at that point even in the international English language media.

Appendix A

A selection of titles of 75 of the almost 400 essays and other articles authored by Ukichiro Nakaya intended for the general public that are listed on the *Aozora Bunko* ("Blue Sky Library"). The titles were selected to emphasize the range of Nakaya's interests. Titles given are machine translations of the Japanese originals.

The Story of Extracting Oil; American-style *Rakugo* [comic storytelling]; American Deserts;
American Newspapers; Travels in America; The Story of Rain;
Alaska's Glaciers; Strange Fish; The Usefulness of Pain;
Does a Dog's Bark Break Glass?; A Day in the Rice Field; Autumn in Winnetka;
Roast Beef; The Science of Space Travel; The Movie 'History of Humanity';
A Story About Making Movies; Permafrost Zone; The British Physics Community and Physicists;
From the Land of the Inuit; Heatwave; Osaka People and the Spirit of Science;
A Walk on the Seafloor; A Consideration of Scientific Films; Science and Culture;
The Limits of Science; The United Nations of Science; Is Science Useful?;
Twenty Years of Artistic Work; Spring in the Northern Country; Theory of National Salvation;
Story of Dispelling Fog; Kutani Ware; Miscellaneous Talks on Atomic Bombs;
The Duty to Protest; Confucius and America; A Talk on Proofreading;
A Talk on "The Pressure of Light"; National Defense and Science; Powdered Snow;
Hideo Kobayashi [20th century Japanese author] and Beauty; Buddha in a Grain of Rice; The Mystery of Salad;
The Charm of Salt; Nature's Blessings - A New Snow Story for Young Citizens; Memories of the Laboratory;
How to Write Characters; Write as you speak; The Unknown America;
Inkstone and Ink; The Culture of Discarding; The Science of Sports;
Physical Research on Ink and Inkstones; About the "Tea Bowl's Hot Water"; Journey to the Tundra;
Gerontology - The existence of a science for longevity; Incense Fire; Two Pieces on Mount Daisetsu;
Memories of Terada Sensei - Memories Before and After University Graduation; Science Programs on Television;
The Story of Frost Heave; Morning in Tokachi; Melting Glaciers;
Snow in the Antarctic, Arctic, and Tropics; About 'Outline of the Japanese Stone Age'; The Future of Japan;
Mouse's Hot Spring; Colors of Hawaii; Peter Pan; Inflation in Argentina;
Beauty and Science; Climate and Tradition; Hibernation;
Mural Copying; Traditional Houses in Hokuriku; 80 Billion Yen Disappeared in Hokkaido Development;

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Data availability

No data sets were used in this article.

Author contributions

KH researched the life and career of Nakaya using English language sources. KH selected the passages from Nakaya's essays that we have included. KH wrote the first draft of the manuscript with discussion and input from WO. WO researched many issues discussed in our article using both English and Japanese language sources and provided detailed comments on the initial drafts.

Competing interests

Editorship CI! The authors have the following competing interests: At least one of the (co-)authors is a member of the editorial board of History of Geo- and Space Sciences.

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