OOISHI'S OBSERVATION

Viewed in the Context of Jet Stream Discovery

BY JOHN M. LEWIS

Wasaburo Ooishi observed strong upper-level westerlies over Japan well before the beginning of World War II.

In 1947, over 50 years ago, the celebrated paper on the jet stream was published under the collective name, "staff members," representing a coterie of researchers in the Department of Meteorology, University of Chicago (Staff Members 1947). This paper, along with two others by Rossby (1947) and Riehl (1948), captured that initial thrust of research energy directed toward understanding the jet stream (H. Riehl 1994, personal communication). When one examines these papers collectively, a visual picture of the jet emerges where the structure is intimately tied to the broad baroclinic zone above the polar front that extends to the tropopause. It is also apparent that the hemispheric nature of the meandering stream was not fully appreciated at this early stage. Quoting from Riehl's study that examined the stream over the North American continent: "Jet streams build over a period of 2–3 days. The increase of wind speed is usually first observed at the Pacific Coast, from which it proceeds eastward . . . Finally, the current covers the whole country, and apparently extended also into the east Pacific and west Atlantic Oceans, or even larger areas" (Riehl 1948, p. 177).

It would take another 10-plus years to unravel mysteries related to the jet and to quantitatively clarify the mechanisms of its maintenance. The assiduous and painstaking work that led to this more complete understanding has been documented in Reiter (1961, 1963), Palmén and Newton (1969, chapters 1, 2), Riehl (1990), and Lewis (1998).

Without doubt, the stimulus for research on the jet stream came from experiences of the bomber squadrons that flew at the 30,000–35,000-ft levels in both the Pacific and European theaters of war. There now exists a sizeable body of evidence related to these aircraft encounters with the strong westerlies. (See references and summaries in Table 1.) Knowledge of these encounters set researchers abuzz, as recalled by Herbert Riehl 1994, personal communication):

> I first heard that term [jet stream] when coming to Chicago [in] July 1942 as an instructor. It was first used tentatively but was soon taken seriously, as it indicated not only the speed of the current but also the narrowness . . . to be sure, we were most impressed by the news of flight performances of new military aircraft . . . Planes went much faster or much slower than predicted . . . Once the news was out, of course, everyone started to calculate the geostrophic winds through the troposphere.

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Table 1. Aircraft encounters with strong westerlies prior to and during World War II.

Reference	Brief summary
Seilkopf (1939) [maritime meteorology text] Scherhag (1948) [synoptic meteorology text]	Strong winds at midtropospheric levels (500 mb: 18,000 ft) based on instrumented aircraft measurements over western Europe in the mid-1930s. Term *Strahlströmmung* (jet stream) introduced by Seilkopf (1939, p.142)
Flohn (1992, p. 13) [Oral history memoir]	An English bomber squadron encountered NNE headwinds of 380 km h^{-1} (~106 m s^{-1}) on return from a raid over Gironde (west coast of France) in 1943. Crews parachute from stalled aircraft and are captured by German Army.
Phillips (1998, appendix B) [journal article] Shields (1997) [World War II history book]	Winds of 103 m s^{-1} at 25,000 ft reported by an American bomber squadron over central Germany in early 1945
Kraus (1999) [journal article—letter to the editor]	Strong winds at the 28,000–35,000-ft levels while on photographic reconnaissance flights over Europe (1942–45)
Hiatt (2002) [oral history on tape]	Robert Hiatt (U.S. Army Air Force pilot) recounts the first encounter of B-29 bombers with the jet stream over Japan. On the path from Kyoto to Tokyo, the bomber squadron experienced a SSE tail wind of 140 kts (~72 m s^{-1}). The event occurred on 24 Nov 1944.
Bryson (1990) [memoir] Craven and Cate (1957) [World War II history] Plumley (1994) [journal article] Reiter (1961, 1963) [meteorology books]	Incidents are mentioned where B-29 bombers encounter westerlies of 160–200 kt (~80–100 m s^{-1}) on flights from the Mariana Islands to Japan in late 1944. C.-G. Rossby is credited with introducing the name "jet stream" to identify these strong westerlies. (Godske et al. 1957, p. 540; Bryson 1990)

What is little known to meteorologists worldwide is that these strong westerlies were observed over Japan well before the beginning of World War II. These observations were made in the early to mid-1920s by Wasaburo Ooishi, the first director of Japan's upper-air observatory at Tateno (60 km northeast of Tokyo). On the grounds of the upper-air station at Tsukuba (formerly Tateno), Ooishi's observations are memorialized by a modest stone monument (Fig. 1).

Ooishi's observations will be examined in view of earlier measurements of winds aloft. For completeness, we also include a brief summary of work conducted in the 1930s that sheds light on the existence of strong westerlies in the upper air.

UPPER-AIR WINDS: STATE OF AFFAIRS IN THE EARLY TWENTIETH CENTURY.

Theory/concepts. The theoretical foundation for extrapolating surface information into the upper air came with the work of William Ferrel during the third quartile of the nineteenth century. Much of Ferrel's work was done in connection with the study of cyclones and this has been thoroughly discussed by Kutzbach (1979). His classic paper, "The Motions of Fluids and Solids Relative to the Earth's Surface" (Ferrel 1860), placed Buys–Ballot's empirical law of wind on a rock solid foundation—the wind tended to flow along the lines of equal barometric pressure, but the controls on speed and direction were now firmly clapsed to the earth's rotation rate and the barometric gradient. It became known as the geostrophic wind law in the early twentieth century (so named by Napier Shaw). Ferrel subsequently derived the equation relating the change of the geostrophic wind with height to the horizontal temperature gradient (later called the thermal wind equation). Despite the absence of upper-air wind observations in the late nineteenth century, the use of these wind laws ". . . made it possible to offer informed and objective statements about the upper wind field on the basis of surface wind and temperature observations . . ." (Kutzbach 1979, p. 114).

The Belgian meteorologist, Leon Tiesserenc de Bort, made use of the thermal wind equation to

Fig. 1. The monument commemorating the early measurements of the strong westerlies over Japan. The pedestal upon which the winds-aloft instrumentation was placed is the foundation of the monument. (Courtesy Y. Nomura.)

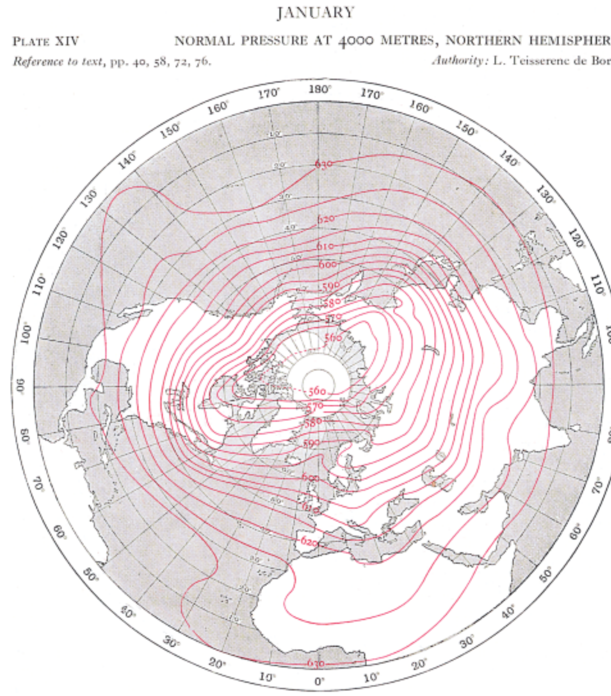

Fig. 2. Pressure field (mb) at the 4-km level over the Northern Hemisphere in January. Map constructed by Belgian meteorologist Tiesserenc de Bort and featured in Shaw (1923, plate 14). (Reprinted with the permission of Cambridge University Press.)

construct hemispheric maps of the pressure field at the 4-km level (~ 13,000 ft). These were climatological maps appropriate for January and July (the cool and warm season, respectively). Construction relied on knowledge of the mean temperature and pressure fields in these seasons. These seasonal surface maps were available from world data centers such as Seewarte (Sea Watch) in Hamburg, Germany. To extrapolate from the surface to the upper level, it is necessary to assume a rate of temperature decrease with height in the atmosphere (the lapse rate). De Bort had made many observations of this vertical temperature structure through the use of balloonsondes in the late nineteenth century. In fact, through analysis of these observations he is credited with discovery of the tropopause—the isothermal layer beginning at roughly 10 km in midlatitudes.

De Bort's map of the upper-level pressure field for January is shown in Fig. 2. To estimate winds on this map, we make use of the geostophic wind law.[1] We find that the winds are generally westerly with maximum speed on the order of 15 m s^{-1}.

Observations. The first reliable observations of upper-air winds came from instrumented kites and pilot balloons. The kite observations began in earnest during the late 1890s, spurred by the development of steel piano wire to support the weight of kites and instrument packages. Pilot balloons, so named because aeronauts used them to determine wind direction before takeoff and during flight, came into prominence in the first decade of the 20th century. Pilot balloon observations make use of ground-based optics to track the balloon; consequently, obscured skies make it difficult or impossible to observe the balloon. Wind speed measurements via instrumented kites are not limited by visibility, albeit direction determination is problematic with obscuration. On the other hand, kites need a breeze to become airborne and difficulties accrue in the presence of strong wind conditions, while a pilot balloon will ascend in virtually any

[1] We refer the reader to the textbook by Holton (1972, chapter 3) for derivation and discussion of the geostrophic and thermal wind laws.

surface wind condition. Because of the complementary nature of these two methods of observation, both were generally used at upper-air observatories in the early twentieth century.

Under typical circumstances, kites were flown to elevations less than a kilometer (~ 3000 ft), although De Bort and the English upper-air specialist W. H. Dines were known to attain heights well above 10,000 ft.[2] Often times, 10 or more kites would be used in tandem to elevate the instrument package to these high levels, and such an event is captured by the drawing shown in Fig. 3. The escape of such a train over Paris is reported by Cave (1947). De Bort had 11 kites on 7 km of wire when a break occurred over the city. The resulting entanglement of the loose wire with various structures and vehicles had serious consequences including the disruption of telegraphic communication and interference with public transportation on land and over the Seine.

Leroy Meisinger, U.S. Weather Bureau meteorologist and aeronaut, analyzed thousands of upper-air wind observations from the U.S. kite network (a total of 16 stations east of the Rocky Mountains). He made a gallant effort to create a wind climatology that would be useful for aviators (Meisinger 1922), but in retrospect, the primary accomplishment of his work was validation of the geostrophic and thermal wind equations (Lewis 1995).

The height limitation associated with kites is overcome by the pilot balloon. In essence, hydrogen-filled (later helium filled) rubber balloons nominally 2–4 ft in diameter are released and followed with a specialized surveyor's theodolite mounted on a tripod. At 1-min intervals, the azimuth and elevation angles associated with the balloon's position are determined by manual tracking through a telescope. From knowledge of the balloon's height, either by single theodolite tracking where the ascent rate must be assumed constant, or by double-theodolite[3] tracking where triangulation is used, the balloon's horizontal displacement through successive layers of the atmosphere is determined. This displacement within a given stratum

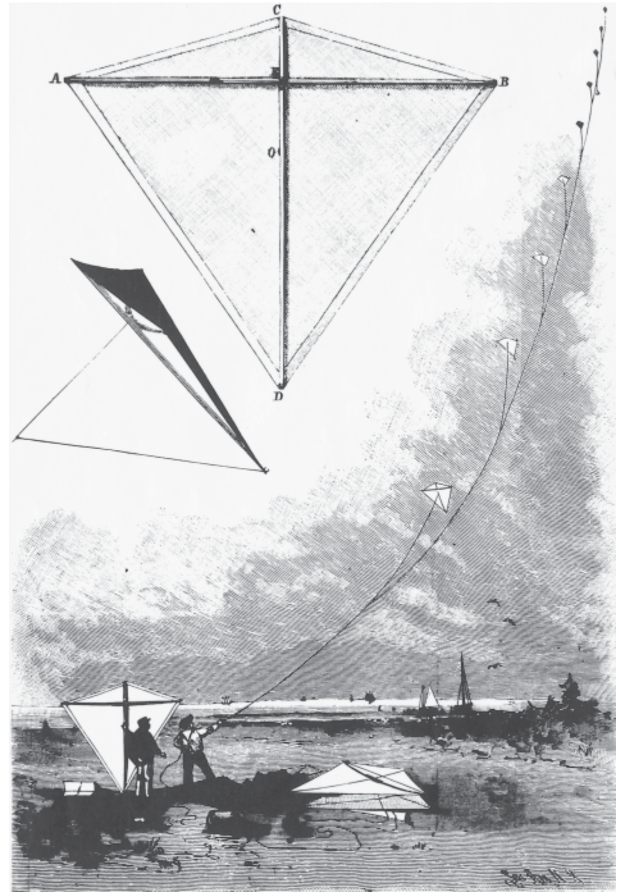

Fig. 3. Pen and ink drawing depicting upper-air measurement via a train of kites (instrument package near the top). (Source unknown; author's collection.)

of atmosphere along with knowledge of the time interval associated with the displacement gives the speed and direction of the wind in the stratum.

The following description of pilot balloon observations made by the U.S. Signal Corps during World War I is informative. This comes from a review paper written by future Noel laureate Robert Millikan (1923, physics), who served as chief of the Science and Research Division of the Signal Corps during the war. He writes (Millikan 1919, p. 215):

> Within the past year approximately 5000 . . . [pilot balloon] observations have been taken by the Meteorological Service of the Signal Corps . . . the balloon is kept in sight up to distances as great as 60 miles and up to heights as great as 32,000 meters, or approximately 20 miles . . . observations show air currents increasing in intensity with increasing altitude and approaching the huge speed of 100 miles per hour. Such speeds are perhaps exceptional but not at all uncommon.

[2] G. I. Taylor used Dines's kites and instrument package when he made his well-known study of fog off the Banks of Newfoundland (Taylor 1917). In one of his last public lectures, Taylor (1963) paid tribute to this pioneer of upper-air observations.

[3] The terminology "double theodolite" makes reference to the use of two theodolites that are typically spaced a mile or so apart and ideally situated such that the wind direction is perpendicular to the line connecting the instruments.

OOISHI AND THE OBSERVATORY AT TATENO. We know little about Wasaburo Ooishi, the founder of Japan's first upper-air observatory. In the most authoritative book on the history of meteorology in Japan, *A Hundred Years of Meteorology* (Takahashi et al. 1987), Ooishi is briefly mentioned three times (on pages 35, 43, and 91). The book mentions that he "... discovered that there is a strong wind zone in the upper air . . . [and] that he inferred the existence of the jet stream." Interestingly, the book also mentions that he was an expert in Esperanto, the auxiliary language intended for people of all countries and devised by the Polish linguist Lazarus Zamenhof in 1887. Most of what we know about Ooishi comes from *Memoirs of Nagamine,* the testament to his work at Tateno written shortly before his death (Ooishi 1950). These memoirs have been used to write an interesting note for meteorologists in Japan (Nyoumura 1998). Data from the memoirs along with other official documents have been used to prepare Ooishi's résumé (Table 2). It should be added that he was a member of the International Meteorological Organization's (IMO) Aerology Commission in 1927 [The IMO became the World Meteorological Organization (WMO) in 1951][4], and his photograph along with other members of that commission is shown in Fig. 4.

Despite the absence of details, we can reconstruct aspects of Ooishi's early life, especially his education, by recourse to historical studies.

Ooishi was born in the smallest prefecture [district] of Japan's southernmost island, Kyushu. His birth occurred shortly after the overthrow of the feudal government (*bakufu*) in 1867, the point in time when Japan opened its doors to the West after centuries of self-insulation. This was the beginning of the Meiji Restoration.[5] Abruptly, Western knowledge and approach to education inundated Japan. Quoting Schoppa (1991, p. 25) ". . . this reflected the conviction of the Maeji reformers that education was what the nation needed to . . . 'catch up' with the west."

His matriculation and graduation from Tokyo Imperial University (founded in 1877) put him among the elite. Based on statistics from the early twentieth century (Schoppa 1991), we know that only 1 in 1000 of those who completed the six years of compulsory education made it to the top, that is, entry into the supreme institute of learning (*saiko gakufu*), the Imperial University. We also know that the physics department at the University was among the best, led by Yale-educated physicist Yamagawa Kenjiro (Watanabe 1976, chapter 2).

Graduation from the Imperial University was a guarantee of placement in a government agency or

[4] Aerology was a term introduced into meteorology in 1906 by W. Köppen, noted synoptician at Seewarte (Kutzbach 1979, p. 152). The term has fallen into disuse except by the U.S. Navy. It basically signifies the study of the "free atmosphere" (the atmosphere above the boundary layer).

[5] This period (1867–1912) coincides with the reign of Emperor Mutsuhito who adopted the title Meiji (pronounced "may-gee") which means "enlightened rule."

Table 2. Résumé of W. Ooishi (prepared by K. Gambo and H. Niino).

1874 (Mar):	Born in Saga Prefecture (Kyushu)
1889 (Sep):	Entered Kyoritsu Junior High School
1890 (Jul):	Entered Daiichi High School
1895:	Entered Tokyo Imperial University (University of Tokyo)
1898:	Graduated from Tokyo Imperial University (physics)
1899 (Feb):	Joined the Central Meteorological Observatory (CMO) (now the Japan Meteorological Agency)
1911 (Mar–Apr):	Traveled to Germany, worked at the Lindenberg Aerological Observatory (near Berlin)
1913 (Jan):	Returned to the CMO from Germany
1919 (Oct–Dec):	Traveled to the United States
1920 (Mar):	Returned to CMO from United States
1920 (Aug):	Aerological Observatory founded, appointed director
1934 (Aug):	Awarded the Order of the Sacred Treasure
1943 (Mar):	Retired from the CMO.
1950 (Dec):	Died at age 76

Fig. 4. Meeting of the Aerology Commission in Leipzig, Germany, 1927. Members of the commission and others at the meeting are grouped by rows. Front row (seated), back row (four men standing), and middle row. Numbering from left to right in each row, the following people have been identified (along with the country they represent). Front row: R. Lempfert, England (1); H. Hergesell, Germany (3); N. Shaw (president of the Commission), England (6); V. Bjerknes, Norway (8); R. Súring, Germany (9); L. Weickmann, Germany (10); A. Wallén, Sweden (11). Middle row: E. Alt, Germany (1); H. Arctowski, Poland (2); G. Marczell, Hungary (4); L. Lammert, Germany (5); Moltchanov, Russia (7), T. Hesselberg, Norway (8); E. Fontseré, Spain (10); G. Walker, England (11); E. Mariolopoulos, Greece (12); L. Richardon, England (13); E. von Everdingen, Netherlands (15); A. Schmaus, Germany (17); F. Linke, Germany (18); W. Ooishi, Japan (19); H. von Ficker, Austria (20); S. Róna, Hungary (21). Back row: Enge (1), P. Mildner (2); K. Keil (3), and H. Hermann (4), all from Germany (Courtesy of M. Schwerdtfeger via H. Lettau.)

business, with good chances for advancement to a position of leadership. Perhaps Ooishi was attracted to the Central Meteorological Office (CMO) by its director, Takematsu Okada. Okada was acquainted with Shigekata Syono, post–World War II professor of meteorology at University of Tokyo, and mentor to a collection of meteorologists who immigrated to the United States (Lewis 1993a,b). Some of these protégés knew of Okada through conversation with Syono, and according to two of them [paraphrased from oral history interviews with A. Kasahara and Y. Sasaki (1990)],

> Okada was an internationally known meteorologist as well as a public figure. He was known as the "father of meteorology" in Japan, and possessed expertise in mathematics and mathematical physics.

Twelve years after joining CMO, Ooishi was sent to the Lindenberg Aerological Observatory near Berlin, Germany. It was the premier center for upper-air observation in Europe that had been established by order of the Kaiser in the 1890s (Flohn 1992). It enjoyed an outstanding reputation in response to the work of instrument-maker Richard Assmann and his colleague Hugo Hergesell. Furthermore, the observatory had a rich archive of upper-air observations that served a host of researchers investigating the dynamics of the atmospheric boundary layer (see, e.g., Hesselberg and Sverdrup 1915).

This type of travel abroad by a young scientist typified the transplantation of Western science to Japan in the late nineteenth and early twentieth centuries. Over 600 Japanese were sent abroad for specialized training in the scientific and technological fields during the Meiji period (Basalla 1967). France and Germany were the favored destinations during this period, but the United States joined the group in early twentieth century.

Viewing the time line on Ooishi's résumé (Table 2), it is clear that World War I interrupted Japan's plan to start upper-air observations. According to information in the *Memoirs of Nagamine,* equipment and supplies could not be obtained from Germany until the early 1920s.[6] He visited the U.S. following the war and made arrangements for importing upper-air equipment to Japan. We also know that he traveled to Royal Center, Indiana, and Ellendale, North Dakota, to observe operations at these two upper-air stations.

Prior to his departure for the United States in October 1919, Ooishi had searched the countryside

[6] It appears likely that Ooishi's departure from Germany in early 1913 was due to Japan's sympathy with the allied nations that opposed the central powers. Japan declared war on Germany in August 1914.

on the outskirts of Tokyo to find a suitable site for the upper-air station. Traveling northeast of Tokyo, he found approximately 100 acres of land, relatively free from obstruction and bordered to the east by lowland that adjoined the Pacific Ocean. Fujiyama (Mount Fuji, elevation 12,000 ft) was 100 miles to the southeast and provided a basis for determining the upper limits of atmospheric visibility. The CMO purchased this land in the town of Tateno in April 1919, and the building of the rudimentary observatory was completed in August 1920. Ooishi was appointed director of the observatory.

THE OBSERVATION. Upper-air observation at Tateno began in April 1921. Based on information in the *Memoirs* (Ooishi 1950), a series of technical problems led to delays in operational upper-air observation. By late 1921, records were routinely archived; yet discussion in the first annual report (Ooishi 1926) leads one to believe that data suitable for climatic summaries were not available until early 1923.

On 2 December 1924, Ooishi awoke to clear skies over Tateno. A cold front had passed over the city on the previous day. The surface synoptic maps for 1–2 December, unavailable to Ooishi at the time of his upper-air observations on these days, are shown in Figs. 5 and 6. The salient features on these maps are the following:

1) a deep low pressure center (cyclone) resides over the Sea of Okhotsk (central pressure of 732 mm Hg or ~ 975 mb), and this center moves 7° latitude (~ 800 km) northward in 24 h;
2) a trailing high pressure center (anticyclone; central pressure of

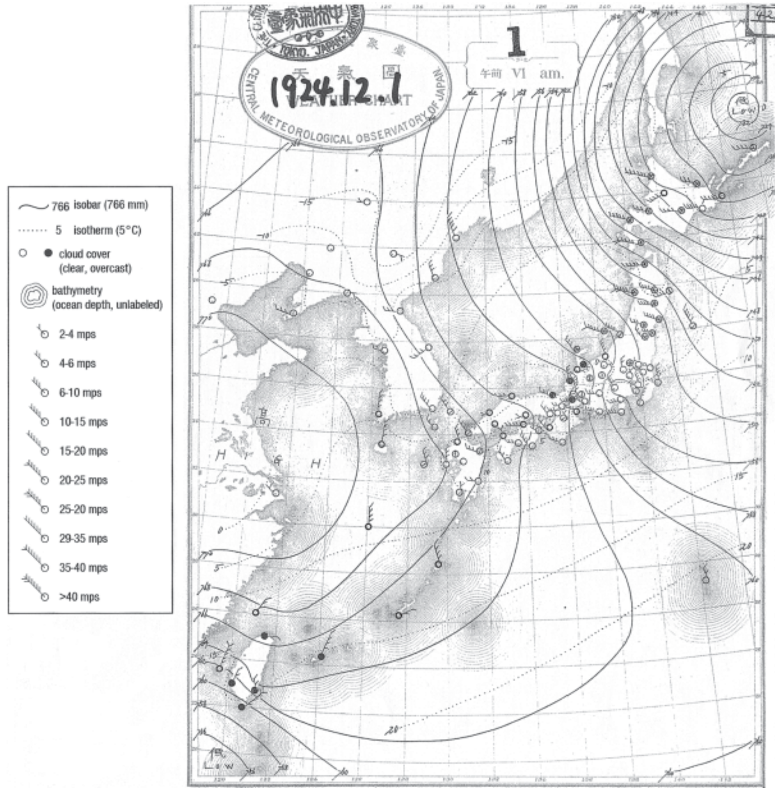

Fig. 5. Surface synoptic weather map for 6 A.M. (LST), 1 Dec 1924. Isobars are drawn at interval of 2 mm Hg (~3 mb) and wind speeds are represented in accord with the Beaufort scale of wind force shown on the left of the figure. (Courtesy of the Japan Meteorological Agency)

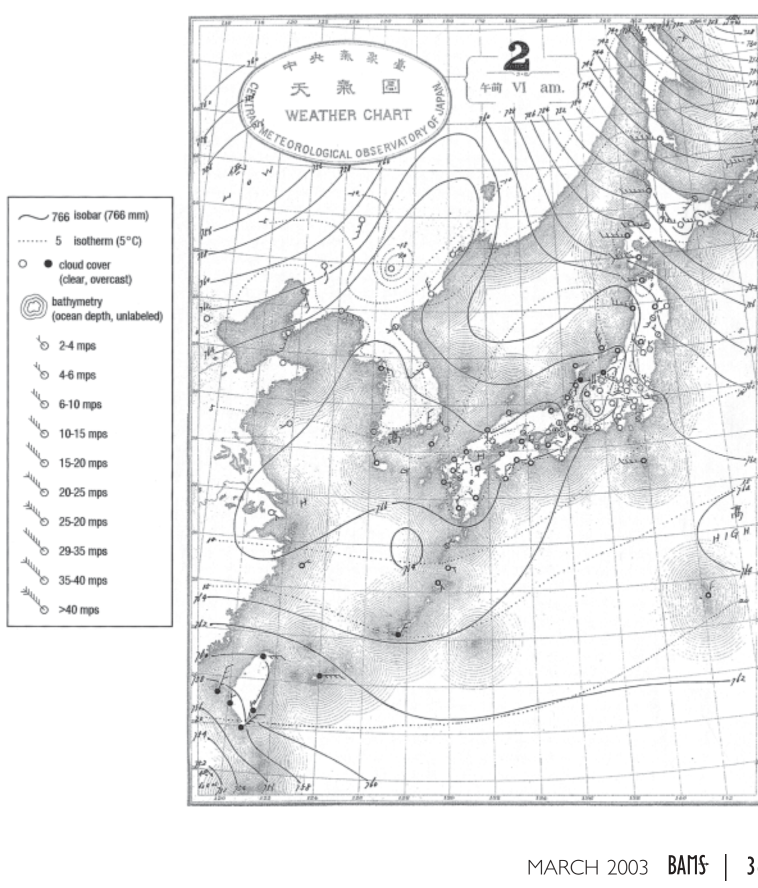

Fig. 6. Same as Fig. 5, except that the date is 2 Dec 1924.

770 mm Hg or ~ 1025 mb) moves from the Chinese mainland to a position over the Yellow Sea in the 24-h period; and

3) strong surface westerlies are in existence from Hokkaido (northernmost island of Japan) to southern Honshu (Japan's main island).

The strongest surface wind is 29–35 m s^{-1} at Haboro, on the northwest coast of Hokkaido. Furthermore, a pronounced north–south gradient of temperature is in existence from northeast China down through Taiwan—a temperature differential of ~ 30°C over this latitudinal swath. Except for a limited stretch of coastline on the western border of Honshu, skies are clear over the islands of Japan.

In this setting, Ooishi launched a 120-g balloon (~ 1 m-diameter) on 2 December (10 A.M., LST) and followed it with the single theodolite. With a nominal ascent rate of 300 m min^{-1}, the balloon reached the 9-km level in ~ 30 min. Analysis of the data from this launch revealed a west wind of 72 m s^{-1} (~ 140 kts) just below the 10-km level (~ 33,000 ft). Ooishi's plot of the wind profile is shown in Fig. 7. Without knowledge of the theodolite's optical precision, assessment of the probable error in the wind speed measurement is difficult. Yet, if we rely on information in the British Meteorological Office's (BMO) official guide for upper-air observations [British Meteorological Office (1961), their Table I, section 2.3.3], we find a probable error of ± 15 m s^{-1} at the 10-km level. This calculation assumes errors in azimuth and elevation of 0.1°. Ooishi's averaging procedure (see Ooishi 1926) and the constancy of the wind direction would likely lower this estimate to ±10 m s^{-1}.

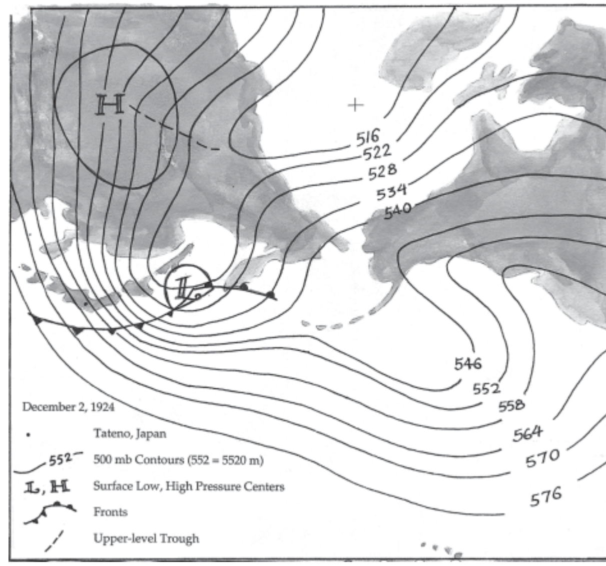

FIG. 8. Upper-air analysis and associated surface features that are thought to be representative of conditions over Japan and the neighboring region on 2 Dec 1924. The map is drawn on a polar stereographic projection where "+" marks the North Pole.

Based on our current knowledge of upper-air patterns associated with strong midlatitude weather systems, we have reconstructed a midtropospheric map that is representative of the situation over Japan on 1–2 December 1924. The reconstructed 500-mb chart (at ~ 5.5 km or 18,000 ft) is shown in Fig. 8. The upper-air features over Asia, the Pacific Ocean, and the western United States are constructed in a manner consistent with a five-wave pattern around the hemisphere. A short wave has been imbedded in the long-wave pattern to reflect the passage of a weaker disturbance at Tateno on 5–6 December that has been inferred from tethered balloon observations during the period 1–7 December.

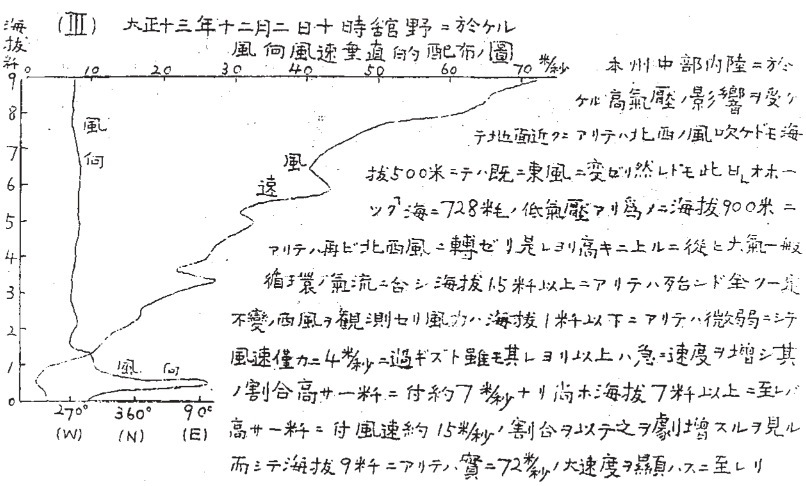

FIG. 7. Plot of the wind speed and direction obtained from the pilot balloon launched at Tateno, Japan, on 2 Dec 1924 (10 A.M., LST). Direction is in accord with the standard meteorological convention (i.e., 270° is a wind from the west). Speed (m s^{-1}) shown along the abscissa at the top. Height (km) is given along the ordinate.

WINTER WINDS OVER TATENO (THE REPORT OF 1926).

Ooishi discovered that the strong westerly wind he observed in December 1924 was not unusual, at least not for the active weather season (late fall–early spring). In 1926, he stratified his upper-air data by season (he had a total of 1288 observations between March 1923 and February 1925). From these data, he determined mean wind speed and direction. The plots of the seasonal wind speed profiles are shown in Fig. 9 (from Ooishi 1926). The profile for winter shows markedly stronger winds than for the other seasons, with an average wind speed of ~ 70 m s^{-1} at 10 km. The average wind direction for winter is 276°, essentially a west wind. For the first time, there was evidence that strong westerlies were not anomalies as suspected by Millikan (and presumably others), but were a persistent feature, at least over Japan in winter.

One can imagine Ooishi's excitement over this result, which he certainly must have suspected from the firsthand experience of collecting the data over several winters. The report was published in Esperanto, and undoubtedly written by Ooishi.[7] His intention must have been to maximize the comprehension of the report by a world community that had little acquaintance with the Japanese language. The report was distributed worldwide, certainly to members of the IMO's Aerology Commission, but it was essentially ignored (Ooishi 1950).

[7] According to the Web site of the Japan Esperanto Society (Japan Esperanto-Instituto), Ooishi was the second director of the Society, serving in that capacity from 1930 to 1944. Nineteen annual reports from the upper-air observatory were published between 1926 and 1944. All of them are written in Esperanto.

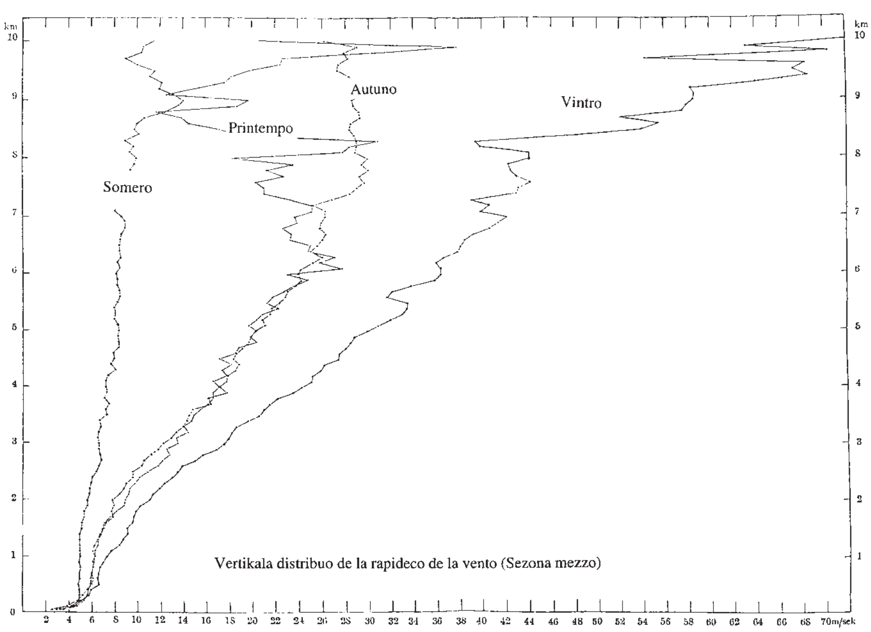

FIG. 9. Seasonal wind speed profiles from pilot balloon observations at Tateno, Japan, for the period 1924–26. Abscissa indicates wind speed (m s^{-1}) while ordinate gives height (km). The labeling is in Esperanto, where Vintro, Printempo, Somero, and Autuno, indicate winter, spring, summer, and fall, respectively. Legend translation: vertical distribution of the wind speed (seasonal mean).

SUBSEQUENT EVIDENCE OF STRONG WESTERLIES. In addition to the experiences of the bomber squadrons during World War II that confirmed existence of the jet stream, we briefly discuss the swarm-ascent study of the mid-1930s.

During the period 1928–1930, an ambitious plan was envisioned to explore the upper atmosphere over Europe through the simultaneous release of balloonsondes, balloons equipped with the lightweight meteorographs that had been designed by J. Jaumotte [see Middleton (1969, p. 313) for a discussion of this instrument]. With organizational help from the Aerological Commission, 18 observatories (from 11 countries) agreed to take part in the experiment. The plan called for identification of a period when cyclone formation was likely to occur over western Europe. Then, upon telegraphic notice from the Geophysical Institute in Bergen, Norway, the observatories would launch the instrumented balloons in a coordinated fashion. The massive field experiment took place during the period 15–17 February 1935, in conjunction with a cyclone that formed over England and moved onto the continent. As expected, there was a large toll in lost instruments, but 120 balloonsondes were recovered and formed the basis for construction of elaborate north–south cross sections that spanned distances upwards of 3000 km (Bjerknes and Palmén 1937). Retrospectively, examination of these cross sections reveals the broad baroclinic zone discussed by Riehl (1948). Using the geostrophic wind law, wind speeds normal to the cross sections were calculated. Quoting from Bjerknes and Palmén (1937, p. 49), "The geostrophic wind over Sealand [west coast of England] measured on the 40 cb [400 mb (~ 24,000 ft)] map reaches the high value of about 130 m s^{-1} [from the SW]. Since the trajectories of the air parcels in the same region is definitely cyclonic . . . , the gradient wind is much less, certainly well under 100 m s^{-1}, but no exact value can be deduced with the insufficient synoptic data at hand."

BALLOON BOMBS. There are several scholarly accounts of the Japanese balloon bomb program that commenced near the end of World War II. The most comprehensive study was conducted under the auspices of the Smithsonian Institution (Mikesh 1973). Two other accounts that provide complementary information are McKay (1945) and an anonymously written article in the *Coast Artillery Journal* (1946). Independent information based on Japanese records is found in Abe (1997). Details concerning the construction and operation of the balloon bombs are found in these articles. We concentrate on those aspects of the program that led to information on the strong westerlies.

In April 1942, 16 B-25 Mitchell bombers made a surprise attack over Tokyo. It became known as the "Doolittle Raid," named after James Doolittle, the leader of the squadron. It was the first appearance of American planes over Japan during the war. Quoting from the *Coast Artillery Journal* (1946) article: "When the first bombing attack on Japan occurred in 1942, the effect on Japanese morale was such that all-out efforts were made to devise retaliatory measures. The Japanese general staff considered the use of airplanes, submarines, and free balloons, and as a result, development of a paper bombing-balloon was initiated."

In his summary of the meteorological issues related to the balloon bomb program, Mikesh (1973) indicates that CMO Meteorologist Hidetoshi Arakawa was ". . . able to develope [sic] logical wind-flow patterns extending across the Pacific" (Mikesh 1973, p. 7). In a post-World War II account, Arakawa makes it clear that Ooishi's climatological statistics played an integral part in his development of the flow pattern (Arakawa 1956).

Arakawa was unaware of the extreme accuracy of Ooishi's wind statistics. His tentativeness about these wind statistics led him to say, "To inquire into the realness of the tremendous wind speed as much as 76 m s^{-1} over Tateno, I treated the problem from a purely dynamical point of view" (Arakawa 1956, p. 240). At that time, there was no way to know the quality of these statistics. Yet, with the benefit of the Japan Meteorological Agency's archive of recent upper-air observations, we can assess the quality. The post-World War II upper-air observations have been obtained with technologically superior equipment—radio-controlled direction-finding equipment (rawinsonde). The comparison between Ooishi's pilot balloon observations and those from the radio-tracked rawinsonde is displayed in Fig. 10. Although there is a slight difference in the periods of averaging—winter in Ooishi's case, and December–January–February in the other case—both averages are representative of the active transient weather season in midlatitudes (that time interval when the jet stream is most pronounced). The only significant difference in the wind speed profiles is at the highest levels attained by the pilot balloons, and here the difference is on the order of 5–10 m s^{-1}. The average wind directions are essentially identical.

Arakawa developed his flow pattern over the Pacific Ocean by coupling Ooishi's upper-air winds (over Japan) with surface wind and temperature patterns over the broad expanse of the ocean. Extrapolation to the upper-levels followed methodology previously discussed in regard to DeBort's work. Based on these derived flow patterns at the 30,000–35,000-ft level, Arakawa estimated that it would take 30–100 h for a balloon to transit the Pacific Ocean. Postwar research indicated that a more reasonable estimate of the transit time from Japan to the west coast of the United States was 72–120 h (McKay 1945).

Nine thousand balloon bombs were launched between November 1944 and April 1945. By all accounts, from America, Canada, and Japan, it is estimated that 300 balloons (about 3% of those launched) reached the North American continent.

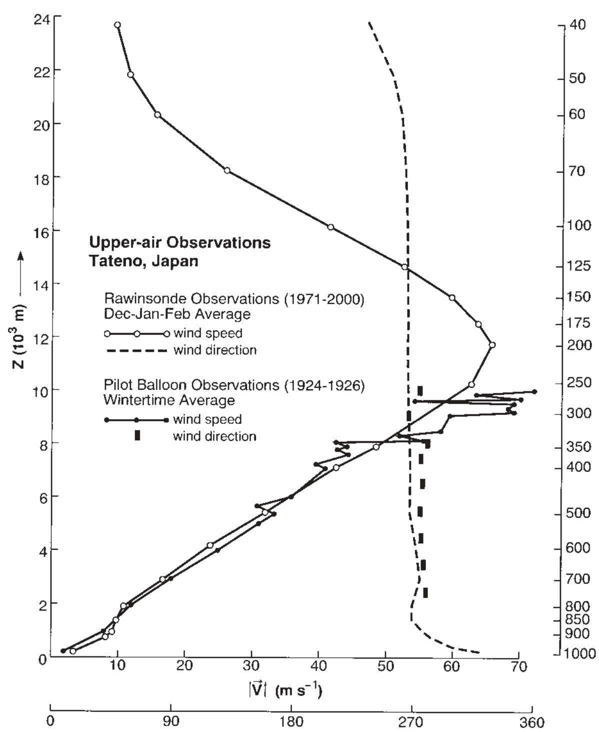

FIG. 10. Two sets of upper-air winds from Tateno, Japan: Ooishi's averaged winds (based on visual tracking of the pilot balloon), and the averaged winds from the past three decades (based on radio tracking of the rawinsonde balloon).

EPILOGUE. As we think about discovery in science, our first thought tends toward those who collect and analyze the data—a Leeuwenhoek who first viewed microbes with his ingeniously designed microscope. But it would take a Pasteur to establish the relationship between microbes and disease. And, of course, there are those incremental steps made by the body of scientific soldiers that add to the mosaic and complete the picture. The discovery of the jet stream, for the most part, followed this paradigm in science.

In retrospect, earlier discovery of the jet stream would have seemed possible, especially in light of Ooishi's observations and the analysis of the swarm ascents by Bjerknes and Palmén (1937). It is interesting to visit this thought in the form of a quotation from Reginald Sutcliffe (1983, p. 23), distinguished English meteorologist who worked with upper-air observations for the British Meteorological Organization in the late 1930s.

> They [the Bergen School] put so much emphasis on the sloping level of the discontinuity, and the refraction of the isobars and the isotherms across it that it gave you the wrong picture of the wind structure . . . and the actual front in between was rather a detail. It was an important thing, but the real thing was the baroclinic zone and the jet stream up there. If it hadn't been for frontal theory perhaps we should have had a better idea.

This viewpoint was shared by German synoptician Richard Scherhag who said, *"Warum gibt es in der Höhe keine Fronten?"* (Why is there no front in the upper air?) He made this statement as he grappled with the complexity of upper-air wind analysis over Europe during the 1930s (Flohn 1992, p. 9).

Would knowledge of Ooishi's winter wind profile have changed the course of research on upper-air dynamics? That is certainly a difficult question to answer. The 1930s will be remembered as a decade of vigorous research activity into issues related to the upper air, issues such as the vertical structure of midlatitude disturbances and identification of the physical constraints that govern the movement of these disturbances. It is indeed hard to believe that the fertile scientific minds that were involved in these research efforts would not have been stimulated by Ooishi's observations.

Although European and American meteorologists ignored Ooishi's observations, these same observations were certainly known to the Japanese military. The military assumed control of the aerological observatory at Tateno in the early 1930s, and the climatic summaries of upper-air winds were instrumental in planning the balloon bomb program. A scientist does not know how his/her work will eventually be used. In this case, it was as an aid to military weaponry.

FIG. 11. Official portrait of W. Ooishi near the end of his career (ca. 1940). The medal he displays is the Sacred Treasure—Gold and Silver, honoring his service to Japan in the 1920s. (Courtesy of the Japan Meteorological Agency.)

To some extent, the obscurity of Ooishi's work can be understood. Japan was in the throes of transplanting Western science into her culture and had a modest reputation in scientific research. But science certainly has precedence in this regard where Gregor Mendel is the classic example. This Austrian monk, whose laboratory was the quiet garden in a Brünn monastery, published a short paper that laid the foundation for genetics, yet few took the work seriously. He died in 1884, still working in his garden at the age of 62, virtually unknown to the world of science (Pfeiffer 1964; Fischer and Lipson 1988).

Ooishi's official portrait near the end of his career is shown in Fig. 11. He was only a few years from death when the University of Chicago team published its landmark paper on the jet stream. It is improbable that he knew of this publication given the delay in transmission of scientific literature during the period of occupation. Undoubtedly, he would have been pleased had his observations impacted this important study. Unlike Leeuwenhoek who jealously guarded his secrets on microscopy and thereby slowed the progress of medicine, Ooishi exhibited a spirit of cooperation beyond the ordinary—the commendable effort to publish his results in Esperanto rather than Japanese in an effort to accommodate scientists in Europe and America. Despite the outcome, Ooishi must have taken pride in his accomplishments. He was fortunate to receive an education from the Imperial University and to be chosen for scientific training abroad. Knowledge gained helped establish the Aerological Observatory and he became an active participant in forging an independent scientific tradition in Japan, only a dream in those early years of the Meiji Restoration.

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