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U. S. DEPARTMENT OF AGRICULTURE

WEATHER BUREAU

INSTRUCTIONS TO MARINE METEOROLOGICAL OBSERVERS

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National Oceanic and Atmospheric Administration

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AN APPRECIATION

During the past century seamen have made a priceless contribution to meteorology in the form of observational material. From the days of Redfield, Reid, Piddington, and other pioneers in the science, mariners have been sending to the meteorological offices of different nations a constant stream of observations.

In the early years of this century of cooperation interest centered in the so-called "revolving storm," later to be christened "cyclone" by Piddington. It is safe to say that the observations contributed by seamen hastened by many years the true conception of the nature of storms. Later, in the time of Maury, it was again the observations of seamen that led to an understanding of the great wind systems of the globe, of tremendous practical import to world commerce.

With these major concepts of the science established and with steam superseding sail there came a period when land meteorology claimed attention over that of the sea and the art of forecasting was developed. In this, progress was hastened by a rapid extension of the systems of land communication.

Another era is now at hand, in which the meteorology of the sea and that of the land are to be inseparably bound together as a result of the development in radiotelegraphic communication. It is perhaps too soon to appraise the full import of this epochal event in its relation to meteorology but that it is destined to exert a very great influence is certain.

The United States Weather Bureau is deeply sensible of the debt it owes to all those who have so faithfully cooperated with it in the past in the field of ocean meteorology. In this work the Bureau has an unfinished task, in the discharge of which it continues to desire and request the assistance of seamen, promising on its own part to continue to make the best possible use of the observations which they may supply.

C. F. Marvin,
Chief of Bureau.

PREFACE

The ocean meteorological program of the Weather Bureau calls in general for the making of but one regular observation a day, this, as well known, being made at noon G. M. T. (civil). However, in certain designated areas from which observations are transmitted by radiotelegraphy an additional regular observation is provided for at Greenwich midnight. Supplementing these regular observations are extra ones made under conditions of threatening or severe weather, gale and storm reports, and descriptive notes of weather experienced between observations, the last-named taking the form of a Daily Journal. The total requirements are such, however, as to make the smallest possible demands on observers consistent with the needs of the Bureau in meeting its responsibilities for the issuance of forecasts and warnings, the procuring of data for publication on charts, and otherwise effectively carrying out its marine meteorological program.

The provision that observations over the entire ocean should be made at the same moment of time is to make possible the construction of synoptic weather maps of large areas. While this object has been attained in part, nevertheless, owing to the varying observational requirements of different countries, the hope of a world synoptic weather map has never been completely realized. Generally speaking, in the Western Hemisphere where land observations are customarily made at 12 and 13 hours, G. M. T., land and sea observations are in close agreement as to time, whereas in the Eastern Hemisphere agreement is almost wholly lacking.

The value of simultaneous observations has received fresh recognition with the development of radio communication. The exchange of weather advices at sea and the growing practice among ships' officers of constructing weather maps has had the effect of renewing interest in the entire subject.

Development in radiotelegraphy does not act to diminish the demands of meteorology upon seamen, but rather to increase them. There is compensation for this, however, in the form of weather bulletins and warnings broadcast by different meteorological services, the value of which has been amply testified to by recipients.

Instructions for the transmission of observations by radio are contained in a separate publication, "Radiographic Weather Code for Vessel Weather Observers."

The material contained in these Instructions has been restricted for the most part to information considered essential or helpful in observational work. For information on the general subject of meteorology observers are referred to the publications named in the bibliography on pages 79 to 81.

GENERAL INSTRUCTIONS

Supplies and publications.—Before leaving port the master of a vessel or the observer should assure himself that he is provided with an adequate supply of blank forms, envelopes, barometer comparison cards, and other requisites for observational work. These will be supplied upon request by the official in charge of the local office of the Weather Bureau.

Location of Weather Bureau offices.—Weather Bureau offices are maintained in the larger United States ports and also at Honolulu, Hawaii, and San Juan, P. R. The addresses of these several offices are as follows.

Portland, Me., First National Bank Bldg., 57 Exchange Street.
Boston, Mass., Public Building, Post Office Square.
New York, N. Y., Whitehall Building, No. 17 Battery Place.
Philadelphia, Pa., Public Building, Ninth and Chestnut Streets.
Baltimore, Md., Public Building, Gay and Water Streets.
Norfolk, Va., Royster Building, Granby Street and City Hall Avenue.
Wilmington, N. C., Public Building, Front and Chestnut Streets.
Charleston, S. C., Public Building, 200 East Bay Street.
Savannah, Ga., The Oglethorpe Building, Bull and Broughton Streets.
Jacksonville, Fla., Graham Building, Laura and Forsyth Streets.
Key West, Fla., Weather Bureau Building, Eaton and Front Streets.
San Juan, P. R., U. S. Weather Bureau Building, Stop 3, Puerta de Tierra.
Tampa, Fla., Public Building, Florida Avenue.
Pensacola, Fla., American National Bank Building, Palafox and Government Streets.
Mobile, Ala., City Bank Building, 12–14 St. Joseph Street.
New Orleans, La., Post Office Building, Camp and Lafayette Streets.
Port Arthur, Tex., Public Building, Austin Avenue and Fifth Street.
Galveston, Tex., Trust Building, Post Office and Tremont Streets.
Tacoma, Wash., Fidelity Building, Broadway and Eleventh Streets.
Seattle, Wash., Hoge Building, Second Avenue and Cherry Street.
Portland, Oreg., Public Building, Eighth and Broadway Streets.
San Francisco, Calif., Merchants Exchange Building, California and Leidsdorff Streets.
San Diego, Calif., Public Building, F Street, between Union and State Streets.
Honolulu, Hawaii, Public Building, King, Miliiani and Richards Streets.

All offices are supplied with books, charts, and pamphlets relating to meteorology. They are equipped with standard meteorological instruments, both land and marine, which shipmasters and officers are invited to inspect and with which they may have their own instruments compared, free of cost.

The Division of Meteorology and Hydrography of The Panama Canal, through the Captains of the Ports at Cristobal and Balboa, distributes and collects Weather Bureau forms, supplies and publications, compares and adjusts navigational and meteorological instruments and publishes daily weather indications.

Addresses for communications.—Communications for the Weather Bureau may be addressed to the official in charge of any of the offices named or to the Chief of Bureau at Washington, D. C. The post-office address to which communications for masters and observers are to be sent should be given in the appropriate place on the back of the Weather Report. The names of both master and observing officer should be entered in each Report.

Forwarding reports.—It is desirable that Weather Reports be forwarded promptly at the end of each voyage, if practicable, or even upon arrival at the first port of call, if the voyage be a long one, instead of being held until the return of the vessel to the United States. Reports should be inclosed in the envelope provided by the Bureau.

If in a foreign port, envelopes should be addressed to U. S. Weather Bureau, Washington, D. C., and *handed* to the United States consul, who is under instructions to forward them with his official mail, free of all expense. If *mailed* at any port outside of the United States, postage must be prepaid at letter rates.

Envelopes mailed in any United States port should be addressed to the nearest office of the Weather Bureau. The franked envelope does not require postage when mailed within the United States, Hawaii, the Philippine Islands, Porto Rico, Panama Canal Zone, Virgin Islands, Guam Island, Tutuila Island, or Midway Island.

Acknowledgment of reports.—As soon as the Weather Bureau receives the completed Report, an acknowledgment is at once addressed to the master of the vessel sending it. Any inquiry or request that the master or the observer may have made on his Report will be answered or complied with as fully as possible.

Instruments.—Since the essential meteorological instruments, the barometer and thermometer, form a part of the equipment of every well-found vessel the Weather Bureau does not attempt to provide its marine observers (except those engaged in the hurricane warning service) with instruments. It does recommend, however, that only instruments recognized to be of reliable manufacture be used, that they be properly exposed on shipboard and that they be regularly and carefully compared with standard instruments, provision for which is made by nearly all national weather services.

Pilot Charts.—Monthly Pilot Charts of the North Atlantic, North Pacific, and Indian Oceans, and Central American Waters, and quar-

terly charts of the South Atlantic and South Pacific Oceans are issued by the Hydrographic Office, Navy Department, the data appearing thereon being furnished jointly by the Hydrographic Office and the Weather Bureau. Pilot Charts are available for free distribution to mariners who regularly contribute data to these two services.

Special observations by radiotelegraph.—Vessel masters who observe premonitory indications of West Indian hurricanes are urged to communicate same immediately to the Weather Bureau either directly or by relaying through other vessels. Radiograms should be addressed, "Observer, Washington." This request applies to all vessel masters, whether or not they are regularly reporting to the Bureau by mail or radiotelegraph. If not provided with a Radiographic Code Book the entire observation may be sent in plain language, but it is quite desirable that the code be used because of the expense involved in radio tolls. A complete observation may be sent by code in 4 to 6 words, but an uncoded message containing the same information requires a message several times that length. Any shipmaster willing to cooperate with the Weather Bureau will be furnished a code book (Radiographic Weather Code for Vessel Weather Observers) on application to the Chief of the Weather Bureau, Washington, D. C.

Observations should include the position of the vessel, date, time (local mean time), height of barometer, change of barometer in two hours preceding observation, temperature of air, direction and force of wind, direction and state of sea (including swell, if any), state of weather, and brief pertinent remarks that might enable the Bureau to locate the center of the disturbance. Should the circumstances be such that the indications become increasingly marked subsequent observations at regular intervals of about two hours should be radiographed until the influence of the disturbance is plainly diminishing.

PART I

INSTRUCTIONS FOR THE TAKING AND RECORDING OF OBSERVATIONS

Blanks known as Forms No. 1201–Marine, or Weather Reports, are issued to observers in book form, each book containing 20 blank forms, numbered consecutively, made up in sets of two sheets each.

These blank forms should be used in numerical order so that the Bureau may know how many sets remain on hand.

Sheet A has space for 19 observations and on the back the Daily Journal.

Sheet B provides for gale and storm reports, fog reports, communications on subjects relating to marine meteorology, and on the back requests for forms, charts, etc., name of vessel, voyage, and date.

The preliminary pages of the Weather Report are devoted to definitions and brief instructions. These should be carefully read and fully comprehended.

Instructions for taking observations, printed in English, French, German, Italian, and Spanish, will be found on pages 6 and 7 of the Weather Report, and are also reproduced herewith.

INSTRUCTIONS TO OBSERVERS

1. Take the single daily weather observation at the local time corresponding to Greenwich Mean Noon (see first page of cover and page 1).

2. Record the *true* direction of the wind and not the *magnetic*. When your vessel is under way, her course and speed should be taken into account. Use tables on page 5.

3. **Record the barometer and thermometers exactly as read.** All necessary corrections will be applied after the reports have been received by the Weather Bureau.

4. The wet and dry-bulb thermometers should be inclosed in a small wooden lattice case, placed in a position sheltered from the direct rays of the sun and from the spray, but allowing a free circulation of the air. The wick of the wet-bulb thermometer should be clean and thin, and its cistern should be replenished with clean, fresh water after each day's observation. (See table on page 4 for obtaining relative humidity.) In taking the temperature of the sea water at the surface, use an ordinary thermometer and allow it to remain immersed not less than three minutes.

5. In describing state of weather at the time of observation, employ a single symbol for each feature—upper atmosphere, lower atmosphere, precipitation, etc. (See page 2.)

6. The ruled columns call for a precise statement of the meteorological conditions prevailing at the actual time of observation. Conditions following the

hour of observation, general character of weather, shifts of wind, squalls, etc., should all be noted in the "Daily Journal" on the back of sheet A.

7. Use the "Gale or Storm Reports" and "Fog Reports," copying from the ship's log when necessary.

INSTRUCTIONS AUX OBSERVATEURS

1. Prendre les observations du temps une fois par jour à l'heure locale correspondant au midi moyen de Greenwich (Voir 1ère page de la couverture et page 1).

2. Noter la direction vraie du vent et non sa direction magnétique. Quand votre navire est en route et est à sa vitesse normale, il faut tenir compte de cette route et de cette vitesse. Se servir pour celà des tables à la page 5.

3. Noter exactement les indications du baromètre et des thermomètres telles qu'elles sont. Toutes les corrections nécessaires seront faites après réception des rapports par le "Weather Bureau."

4. Le thermomètre mouillé et le thermomètre ordinaire devront être enfermés dans une petite boîte en bois à jour, placée dans un endroit abrité des rayons directs du soleil et des embruns, mais permettant la libre circulation de l'air. La mousseline du thermomètre mouillé devra être propre et mince, et l'eau de son réservoir devra être renouvelée avec de l'eau propre après chaque observation quotidienne. (Employer la table à la page 4 pour obtenir l'humidité relative.) En prenant la température de l'eau de la mer à la surface, se servir d'un thermomètre ordinaire et le laisser immergé pendant au moins 3 minutes.

5. En décrivant l'état du temps au moment de l'observation, employer un seul symbole pour chaque élément: atmosphère supérieure, atmosphère inférieure, précipitation, etc. Voir page 2.

6. Mettre sur la page contenant les colonnes, l'indication précise des conditions météorologiques au moment de l'observation. Les conditions après l'heure de l'observation, le caractère général du temps, les sautes de vent, les grains, etc., seront notés dans le "Daily Journal" au revers de la feuille A.

7. Se servir des "Gale or Storm Reports" et "Fog Reports," en notant au besoin les indications du journal du bord.

INSTRUKTIONEN FÜR BEOBACHTER

1. Man nehme die einzelne tägliche Wetterbeobachtung zu der Ortszeit vor, welche der Greenwicher Mittagszeit entspricht (siehe die erste Seite des Umschlages und S. 1.)

2. Man verzeichne die *wahre* Richtung des Windes und nicht die, die der Magnet anzeigt. Wenn das Schiff unterwegs ist, so sind sein Kurs und seine Geschwindigkeit in Betracht zu ziehen. Man benutze die Tafeln auf Seite 5.

3. Man zeichne den Barometer und Thermometerstand genau so auf, wie man ihn abliest. Alle notwendigen Korrekturen werden gemacht werden, nachdem die Berichte von dem Wetterbureau erhalten worden sind.

4. Die Thermometer mit nassen und trockenen Kugeln sollen in ein kleines hölzernes, gitterartiges Kästchen gelegt, und dieses so aufgestellt werden, dass es vor den direkten Sonnenstrahlen und dem heraufspritzenden Seewasser geschützt ist, aber eine freie Cirkulation der Luft zulässt. Der Docht an dem Thermometer mit nasser Kugel soll sauber und dünn sein, und sein Wasserbehälter muss nach jeder Tagesbeobachtung wieder mit reinem frischem Wasser angefüllt werden. (Man benutze die Tafel auf S. 4 um die relative Feuchtigkeit zu bekommen.) Bei Aufnahme der Temperatur des Seewassers

an dem Wasserspiegel benutze man ein gewöhnliches Thermometer und lasse es drei Minuten eingetaucht.

5. Bei Beschreibung des Wetterstandes zu der Beobachtungszeit benutze man für jede Erscheinung ein besonderes Zeichen: höhere Atmosphäre, niedere Atmosphäre, atmosphärischer Niederschlag, u. s. w. Siehe Seite 2.

6. Die angelegten Spalten verlangen eine genaue Darlegung der meteorologischen Verhältnisse, welche zu der jeweiligen Beobachtungszeit vorherrschend sind. Verhältnisse, die nach der Beobachtungsstunde eintreten, allgemeiner Charakter des Wetters, Umspringen des Windes, Sturmböen, etc., sollten alle auf des Rückseite von Bogen A im „Daily Journal" verzeichnet werden.

7. Man benutze die „Gale and Storm Reports," „Fog Reports" und „Abstract Storm Log" indem man sie, wenn es nötig ist, von dem Schiffslogbuch abschreibt.

ISTRUZIONI PER GLI OSSERVATORI

1. Si faccia l'unica osservazione giornaliera del tempo all'ora locale corrispondente al mezzodì (T. M.) Greenwich (vedi la copertina e pag. 1).

2. Si registri la direzione vera del vento (e non la magnetica). Quando la nave è in moto, si tenga conto della sua rotta e velocità. Si usino le tavole a pag. 5.

3. Si legga e registri il barometro e termometro, esattamente come è. Tutte le correzioni saranno poi apportate dal "Weather Bureau."

4. I termometri a bulbo umido ed asciutto dovranno essere rinchiusi in una piccola gabbia di legno e messi in posizione protetta dai raggi del sole e dagli spruzzi, ma tale che la circolazione dell'aria sia libera. La miccia del bulbo umido deve essere pulita e sottile e la vaschetta deve essere riempita di acqua dolce e pulita dopo compiuta l'osservazione giornaliera (vedi tavola a pag. 4 per ottenere l'umidità corrispondente). Nel prendere la temperatura dell'acqua marina alla superficie, si usi un termometro ordinario e lo si mantenga immerso per lo meno 3 minuti.

5. Nel descrivere le condizioni del tempo, al momento delle osservazioni, si impieghi un solo simbolo per ogni osservazione, atmosfera alta, atmosfera bassa, precipitazione, etc. (vedi pag. 2).

6. Le colonne degli stampati esigono la specificazione esatta delle condizioni meteorologiche prevalenti all'epoca dell'osservazione. Le condizioni del tempo posteriori all ora dell osservazione, il suo carattere, i cambiamenti azimutali del vento, delle raffiche, etc., devono essere tutti registrati nella pagina appositamente riservata per il "Daily Journal" (Giornale del tempo incontrato), che si trova al dosso del foglio A.

7. Si usino gli stampati "Gale or Storm Reports," e "Fog Reports," copiando dal giornale di bordo quando sarà necessario.

INSTRUCCIONES PARA TOMAR LAS OBSERVACIONES

1. Tómese la observación diaria del tiempo a la hora local correspondiente al medio-día del meridiano de Greenwich. (Véase página de la cubierta y pag 1.)

2. Regístrese la *verdadera* dirección del viento, no la magnética, tomando en consideración cuando el buque está en marcha su velocidad y rumbo. (Empléense las tablas de la pag. 5.)

3. Regístrese el barómetro y el termómetro con exactitud. El Weather Bureau hará las correcciones necesarias después de recibidos los informes.

4. Los termómetros de ampolleta seca y húmeda deben tenerse en una pequeña jaula de madera al resguardo de los rayos del sol y de la acción directa del agua, pero donde el aire circule libremente. La mecha del la ampolleta

del termómetro húmedo debe ser limpia y fina, y el depósito de agua debe llenarse diariamente después de la observación. (Empléense las tablas de la pag 4 para obtener la humedad relativa.) Para tomar la temperatura del agua del mar, empléese un termómetro ordinario sumergiéndolo a lo menos durante tres minutos.

5. Al describir el estado del tiempo empléese un solo símbolo para cada uno, Despejado, Cerrado, etc. Véase pag 2.

6. Los formularios encasillados son para la anotación exacta de las condiciones meteorológicas existentes al tiempo de la observación.

El estado del tiempo a partir de la hora de la observación, su estado general, cambio y dirección del viento, borrascas, etc., deben anotarse en la página correspondiente del "Diario del tiempo experimentado" que se halla al reves de la hoja A.

7. Las observaciones sobre temporales (Gale or Storm Reports), nieblas (Fog Reports), velocidad de las tormentas, copíense cuando sea preciso del Cuaderno de Bitácora.

1

SHEET A.

GREENWICH MEAN NOON OBSERVATIONS.

Vessel: *President Lincoln.*
Nationality and rig: American; steamship.
Voyage from: San Francisco. Toward: Shanghai, China.

Ocean: Pacific and China Sea.
Captain: Ryland Drennan.
Observer: W. Calcutt, 2d officer.

DATE.		TIME.	PORT OR POSITION.		WIND.		PRESSURE.			TEMPERATURE.			WEATHER.	CLOUDS.			SEA.	
Month.	Year. 1923-1924.	Local mean time.	Latitude N.	Longitude (Greenwich) W.	True direction.	Force 1—12.	Barometer as read.	Att. Ther.	Pressure corrected.	Air, dry bulb.	Air, wet bulb.	Water at surface.	State of, by symbols.	Form of, by symbols.	Direction moving from.	Amount, scale 0—10.	Direction of.	State of.
Dec.	30	3.31 a. m.	36° 24′	127° 28′	NW.	8	30.15	--------	30.14	54	49	56	b. c.	Cu.	NW.	5	NW.	Rough.
	31	3.05 a. m.	33° 50′	133° 48′	NW.	3	30.33	--------	30.32	60	52	63	c.	A-St.	NW.	10	NW.	Long swell.
Jan.	1	2.36 a. m.	30° 42′	141° 00′	E.	3	30.27	--------	30.26	64	58	64	b. c.	Cu.	E.	6	E.	Large swell.
	2	2.08 a. m.	27° 12′	147° 54′	S.	3	30.15	--------	30.14	70	68	64	b. c.	Cu.	SE.	4	E.	Mod. swell.

Weather Bureau List Barometer No. 3839.
On (date) May 31, 1923.

Kind (Aneroid or Mercurial): Aneroid.
Reads too high by (amt.): .01.

Last compared at San Francisco.
Too low by (amt.): ———.

Record barometer and thermometers precisely as read.

See instructions on cover.

Sample form, illustrating manner of recording observations.

Notes on instruments used.—State the kind of barometer, whether aneroid or mercurial, and the identification number furnished by the Weather Bureau.

The same barometer should be employed continuously. If for any reason it becomes necessary to use another instrument, the fact should be stated, the reasons given, and the second instrument fully described, in order that the readings of the latter may not be confused with the readings of the barometer listed by the Weather Bureau.

Give the error of the barometer as determined by the last comparison with a standard; also the place and date of this last comparison in the space provided at the bottom of observation sheet A.

If a mercurial barometer, state the scale of the attached thermometer employed, whether Fahrenheit, Centigrade, or Absolute.

The readings of the barometer may be given in millimeters, millibars, or English inches, and the temperatures on any scale. All are alike acceptable.

Record the barometer and thermometers exactly as read. It is unnecessary for observers to apply corrections except when observations are to be transmitted by radio.

Observations should begin on the day of sailing and should continue without interruption up to and including the day of arrival in port.

The date.—The date given in the column at the left of each page should be the civil day, beginning at a given midnight and ending at the following midnight.

In crossing the one hundred and eightieth meridian, observers aboard westward-bound vessels sometimes make the mistake of dropping a day from the record of the Greenwich mean noon observations, and conversely of using the same date twice when eastward bound. This is incorrect. The observations in both cases should be dated consecutively, as a little consideration will show.

Take the case of a vessel westward bound and at longitude 178° W., at noon G. M. T. of April 15. The local date and time of observation would be April 15, 12 hr. 8 min. a. m.; also recorded as 12:08 a. m. The time by chronometer for the next observation would be 24 hours later or at noon of the 16th. At such hour the vessel making 4° of longitude a day would be at longitude 178° E., and the true local date and time of observation would be April 16, 11 hr. 52 min. p. m.; also recorded as 11:52 p. m.

Again, let a vessel be eastward bound and at longitude 178° E. at noon G. M. T. of April 15. The local date and time of observation would be April 15, 11 hr. 52 min. p. m.; also recorded as 11:52 p. m. The time by chronometer for the next observation would be 24 hours later or at Greenwich mean noon of April 16. At such

hour the vessel making 4° of longitude a day would be at 178° W. and the true local date and time of observation would be April 16, 12 hr. 8 min. a. m.; also recorded as 12:08 a. m.

It will be seen, in the cases mentioned, that according to local mean time the interval between the two observations of the vessel bound westward would be 23 hr. and 44 min., and the interval between the two observations of the vessel bound eastward would be 24 hr. and 16 min., while by chronometer time the interval between consecutive observations taken at the proper time, or noon, is invariably 24 hours.

Local mean time.—The small chart given on page 90 shows the local time corresponding to Greenwich mean noon, for each 15° of longitude east and west, i. e., the local (ship's) time at which the daily observation should be taken, to the nearest hour. The exact local time at which the observation in any longitude, east or west, should be taken may easily be found from the table of longitude and time (Table X). In east longitude the observation should always be taken during the afternoon hours; in west longitude during the forenoon hours. The table for conversion of time will be found on pages 88 and 89.

Port or position, latitude and longitude.—In these columns should be entered the latitude and longitude of the vessel at the actual time of the meteorological observation. These columns should always be filled out to the best of the observer's ability, even though no astronomical observations have been obtained. When the given position is doubtful, a note should be made to that effect.

The remaining ruled columns call for a precise statement of the meteorological conditions prevailing at the *actual time of observation*, and nothing should be entered in them which refers to any other hour. Previous changes, shifts of the wind, readings of the barometer, etc., should all be briefly noted under the heading, "Daily Journal."

Wind, direction and force.—The direction of the wind to be recorded is the *true* direction, not the *magnetic*. Its direction as given by the compass should therefore be corrected for the magnetic variation and for the deviation, if this is large, as is sometimes the case.

The shifts of the wind should be noted under the heading, "Daily Journal." In recording any large shift, specify the time at which it occurred, the direction of the shift, and the force; for example, "at 10 a. m. wind shifted from SE., 3, through S. to W. 8."

Observers sometimes fail to distinguish between shifting winds and variable winds. The former term applies to winds whose direction is changing in accordance with some decided cyclonic or anticyclonic system, the latter to winds of feeble intensity (force 3 or

less) whose direction is indefinite, coming in puffs first from one point, then from another.

In recording the force of the wind the scale devised by Admiral Sir Francis Beaufort is employed. According to this scale, the wind varies from 0, a calm, to 12, a hurricane, rated as the highest force ever attained by the wind at sea. The scale, with estimated equivalent velocities in statute miles per hour and meters per second, will be found on page 88.[1]

The apparent and the true direction and force of the wind.—When steaming or sailing with any speed, the apparent direction and force of the wind as determined from a vane or pennant aboard ship, or from the smoke emerging from the funnel, may differ considerably from the true direction and force. For instance, let the wind have a velocity of 20 miles an hour (force 4) and take the case of two vessels, each steaming 20 knots, but in opposite directions, the first with the wind dead aft, the second with the wind dead ahead. The former vessel will be moving with the same velocity as the air, and in the same direction. The relative velocity of the two will thus be the difference of the two velocities, or zero, and on the deck of the vessel an apparent calm will prevail, and the pennant will hang up and down. The latter vessel will be moving with the same velocity as the air, but in the opposite direction. The relative velocity of the two will thus be the sum of the two velocities, or 40 miles an hour, and on the deck of the latter the wind will apparently have the velocity corresponding very nearly with a fresh gale.

The apparent direction and velocity of the wind is thus the resultant of both motions, that of the vessel and that of the air. As an example of this, take the case of a vessel steaming westward 20 knots, and let the *true* direction of the wind be due north, or 8 points off the starboard bow, its *true* velocity 20 miles an hour (force

[1] The version of the Beaufort Scale given in these Instructions is one having international sanction and should be used by observers of the Weather Bureau. It supersedes the version appearing in editions of the Weather Report prior to and including that of 1923.

The attention of observers is here invited to the fact that in the issuing of forecasts and warnings it is impracticable to adhere strictly to the Beaufort notation. The designation of wind force as employed by the Weather Bureau in this connection is as follows:

Designation used in forecasts and warnings	Beaufort equivalent, force
Gentle or light winds	0-3
Moderate winds	4
Fresh winds	5
Strong winds	6-7
Gales	8-9
Whole gale	10-11
Hurricane	12

4). Let *A D* (fig. 1) represent the *true* direction and velocity of the wind; *B D* the direction (west) and the velocity (20 miles an hour) of the wind created by the motion of the steamer. Then *C D*, the resultant of *A D* and *B D* will be the apparent direction and velocity of the wind as observed aboard the steamer; i. e., the wind, while its true direction is due north (8 points off the starboard bow) and its true velocity 20 miles an hour (force 4), will apparently be NW. (4 points off the starboard bow) and will have an apparent velocity of 28 miles an hour (nearly force 6).

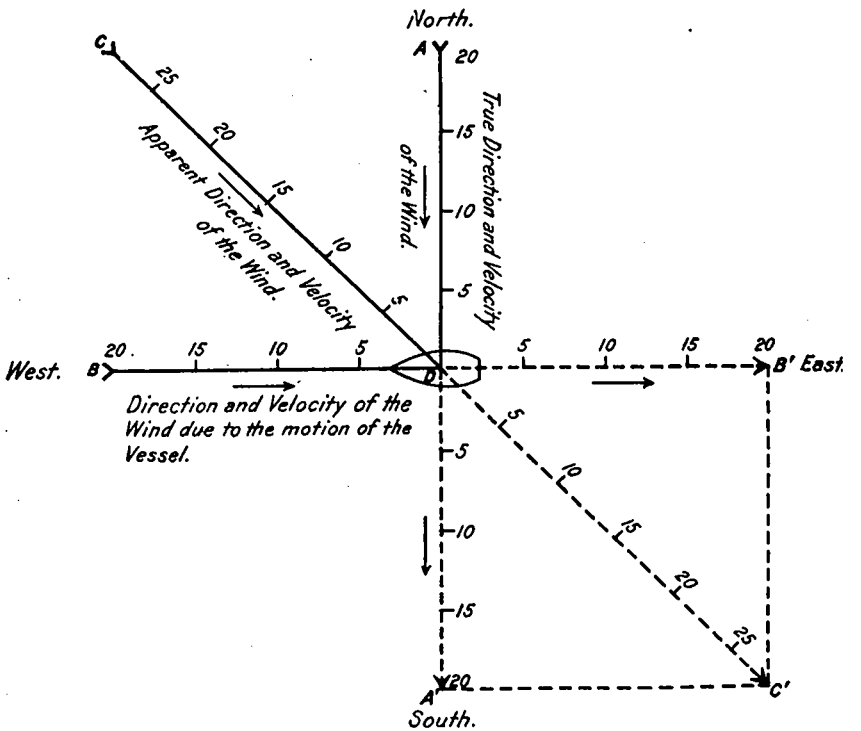


FIG. 1

The true direction of the wind is thus always farther from the bow than the apparent direction.

The true velocity of the wind is greater than the apparent as long as the apparent direction is aft of the beam.

The true velocity of the wind is less than the apparent as long as the true direction is forward of the beam.

Having observed the apparent force and direction of the wind, in points off the bow, the *true* force and direction may be taken from the table on pages 86 and 87.

The following examples will serve to illustrate the manner of using the table:

1. Let the true course and speed of the vessel be SSW., 20 knots, the apparent force of the wind, 0 (dead calm). The true direction of the wind is NNE. (16 points off the bow); its true force is 3.

2. Let the true course and speed be WSW., 15 knots, and let the apparent wind be NW. (6 points off the bow), force 1; referring to the table we see that the true direction of the wind in this case is 14 points off the bow (NE.) and that its true force is 3.

3. Let the true course and speed be E., 10 knots, the apparent wind SW. (12 points off the bow), force 3. The true direction of the wind is 14 points off the bow (WSW.), the true force is 5.

4. Let the true course and speed be NE., 20 knots, the apparent wind SW. (16 points off the bow), force 6, the true direction is still SW.; the true force, however, is 9.

Pressure of the air.—In the column "Barometer as read" should be recorded the exact reading of the barometer to the nearest hundredth of an inch or tenth of a millimeter or millibar. A second column, "Pressure, corrected," is provided in which to enter the reading of the barometer *after* the correction for instrumental error furnished by the Weather Bureau has been applied. This correction includes reduction to sea level. It is preferred that observers do not make entries in the second column unless observations are being transmitted by radio. *Only the corrected reading of the barometer should be radiographed.*

Since the accurate reading of the barometer depends largely upon a familiarity with the construction and adjustment of the instrument, detailed instructions for its reading have been placed under the heading "Instruments."

Barometer comparison.—Notwithstanding that the greatest care may be taken in the construction and handling of barometers certain errors due to various causes can hardly be eliminated. In the case of mercurial barometers the errors are usually small and fairly constant. In aneroids, however, the instrumental error may be quite large and undergo irregular changes. Reference to errors in barometers will be found under "Instruments."

In order to obtain satisfactory readings of barometers it is necessary to find the error of each instrument and apply a correction of the opposite sign. The errors are determined by comparison with a standard instrument. In order to obtain such a comparison it is only necessary to make and record several readings of the ship's barometer when in some port where a standard instrument is located, the readings being made at the same hours at which the latter is read. In United States ports the barometer is read each day at 8 a. m. and 8 p. m., 75th meridian time. In European ports observations are

made generally at 7 and 18 hours, G. M. T. Such observations ultimately reach the Weather Bureau and are available for use in checking comparative readings.

In making comparisons it is desirable that at least three readings of the ship's barometer should be made at uniform intervals of 12 or 24 hours. During the comparison the instrument should hang in its accustomed place aboard ship. If possible the readings should be made by the officer charged with the duty of making the meterological observations.

Blank cards, known as Barometer Comparison Cards (Form No. 1202–Marine), for recording comparative readings are supplied by the Weather Bureau. A sample card, filled out and with corrections made, is shown on page 13.

The successive readings of the barometer, at the hours selected by the observer, are entered in column 1 of the Barometer Comparison Card. If the barometer is a mercurial instrument, the readings of the attached thermometer will be entered in the adjacent column. The card should then be dispatched to the nearest office of the Weather Bureau. Readings of mercurial barometers are here corrected for temperature and reduced to standard gravity (Latitude 45°), the results being entered in column 2. In column 3 are given the corresponding readings of the standard Weather Bureau barometer, likewise corrected for temperature and reduced to standard gravity, as well as to sea level. The differences between the simultaneous readings of the two barometers are entered in column 4, and the mean of these differences, if accepted, is adopted as the instrumental error of the ship's barometer. This is at once inscribed upon a Barometer Tag (Form No. 1203–Marine), a Weather Bureau identification number is given to the barometer, and the tag mailed to the observer. A sample of this tag, properly filled out, is given below.

Form No. 1203—Marine.

U. S. DEPARTMENT OF AGRICULTURE.
WEATHER BUREAU BAROMETER TAG.

	Nationality.	Rig.	Name.
VESSEL,	Amer.	S.S.	Argonne

Capt., C. P. Snyder Observer, G. A. Bryan

W. B. List Barometer No. 3430 Merc., Aner. Merc.

Date of comparison, Sept. 17–19, 1923 Place, San Francisco

This correction includes reduction to sea level. THE BAROMETER READS .04 Inch TOO XX

..... Mm. LOW ☞ Over.

INSTRUCTIONS.

Please attach this tag to the barometer used in taking observations for the U. S. Weather Bureau.

In Weather Report, Form 1201, Barometer Comparison Card, etc., enter Weather Bureau number of barometer.

When another barometer is substituted for the regular instrument please report the fact on Form 1201 and forward comparative readings.

The correction should not be applied to the entry made in the Weather Report, Form 1201, except when the observation is to be transmitted by radio. Record the actual barometer reading with the temperature of the attached thermometer.

C. F. MARVIN,
Chief of Bureau.

Lack of agreement in the observations.—In case any one of three or more individual values differ from the final mean value by as much as six hundredths (.06) of an inch (=1.5 millimeters) the card is returned to the observer with the statement that the several observations do not agree sufficiently well among themselves to furnish a reliable correction for the instrument, and with a request for another set of readings.

In some instances differences indicated by comparative readings are due to errors on the part of observers, but more often are occasioned by defects in the instrument. The true source of such differences is generally revealed by a second set of comparative readings, and if these indicate that the instrument is unreliable, it should be repaired or replaced in the interest of safe navigation.

Frequency of comparisons.—On account of the severe usage a barometer is subjected to aboard ship its instrumental error is liable to be disturbed. Observers should therefore take advantage of every opportunity to obtain a comparison with a standard instrument. Aboard steam vessels such a comparison should be made at least once a month. Aboard sailing vessels a comparison should be made immediately before each sailing and immediately after each arrival in port.

Adjustments.—In the case of aneroids no attempt should be made to adjust a barometer, unless the error exceeds a half inch. Such attempts are likely to increase the irregularities of the instrument. The error should be allowed to accumulate, and should be determined by frequent comparisons, as explained on pages 10 and 11.

Form No. 1202—Marine.

U. S. WEATHER BUREAU BAROMETER COMPARISON CARD

Vessel, Amer. S. S. Argonne. Captain, C. P. Snyder.
In port of San Francisco. Observer, G. A. Bryan.
W. B. List Barometer No. 3430. Mercurial or Aneroid? Mercurial.
Address tag to U. S. Transport Service, San Francisco.

The observer is requested to make at least three barometer readings in order that a reliable correction may be obtained. In United States and Canadian ports please make the readings on three successive days, at 8 a. m., 75th meridian time, or if in a United States port for a shorter period, make three readings as many hours apart as possible. In European ports make the readings at 7 a. m., Greenwich time.

If the mean of the corrections does not differ more than 0.06 inch (1.5 mm.) from any entry in column 4, it will be satisfactory, and a tag will be furnished showing the instrumental error of the ship's barometer.

Date, 1923	Time (local).	Ship's barometer (as read off) 1	Attached thermometer	Observers will leave these columns blank		
				2 Reduced	3 Standard	4 Correction
17 Sept.	8 a. m.	29.83	75	29.68	29.71	−.03
18 Sept.	8 a. m.	30.06	67	29.94	30.00	−.06
19 Sept.	8 a. m.	30.16	66.5	30.04	30.07	−.03

In United States ports no postage is required; in foreign ports hand to United States consul.

Change in barometers.—Ordinarily only a barometer bearing an identification number assigned by the Weather Bureau should be used in the regular meteorological work of the Bureau. This number should be stated in every Weather Report and on every Barometer Comparison Card. If, for any reason, another barometer is used, the fact should be made clear in order that no mistake may be made in applying corrections. If a new barometer is used comparative readings should be furnished with the first report, or as soon thereafter as possible.

Accuracy of aneroids at abnormally low pressures.—On account of the importance of obtaining accurate measurements of the abnormally low pressures occurring in tropical cyclones the Weather Bureau has provided its offices at New York and New Orleans with apparatus for testing aneroids at such pressures. Masters and officers are invited to avail themselves of the opportunity thus afforded for making these desirable comparisons.

Temperature of the air.—In order to obtain the true temperature of the air it is necessary that reliable thermometers be employed and that they be properly exposed and accurately read. When practicable, thermometers should be compared with a standard instrument, and if an appreciable error is shown to exist a correction should be applied to the readings. Comparisons may be made at any Weather Bureau office.

Recording temperatures.—Readings of the Fahrenheit thermometer should be recorded to the nearest whole degree; of the Centigrade thermometer, to the nearest half or tenth of a degree.

Atmospheric moisture.—The quantity of moisture mixed with the air under different conditions of temperature and degree of saturation may be measured in several distinctly different ways. Some of these, however, are not practicable methods for daily observations or are not sufficiently accurate. Probably the most convenient of all methods and the one most generally employed is to observe the temperature of evaporation—that is, the difference between the temperatures indicated by wet and dry-bulb thermometers.

Ventilating wet-bulb thermometer.—A column is provided in the Weather Report for recording the temperature of the wet-bulb thermometer. In obtaining the true temperature of the wet bulb it is essential that a strong ventilation be obtained and this is best done by whirling the instrument. If a stationary wet bulb is employed, as illustrated in Figure 15, page 40, some form of forced ventilation should be used. A simple and very satisfactory form of hygrometer, known as the sling psychrometer, is described on pages 38 and 39.

Relative humidity.—Knowing the temperature of the wet and dry bulbs the relative humidity is determined from the known relationship that exists between the temperature of the air, the depression of the wet bulb, and the amount of moisture present in the atmosphere. For convenience in determining the humidity this relationship is expressed in the form of a table, as shown on page 85.

A mere inspection is sufficient for an understanding of this table. For instance, if the temperature of the air (dry bulb) be 60°, and the temperature of evaporation (wet bulb) be 56°, the difference being 4°, look in the column headed "Temperature of the air" for 60°, and for the figures in the same row in the column headed 4°. Here 78 will be found, which means that the air is 78 per cent saturated with water vapor, i. e., that the amount of water vapor present in the atmosphere is 78 per cent of the total amount that it could carry at the given temperature (60°). This total amount, or saturation, is thus represented by 100, and any increase of the quantity of vapor beyond this point would result in precipitation.

Temperature of ocean surface water.—The temperature of the ocean water has a more or less marked effect upon the weather and the climate of adjacent land areas, depending upon the relative position of water and land with respect to the prevailing winds. The general and accurate observance of the temperature of the surface water of the oceans, particularly of the principal currents, is therefore a matter of importance and should be carried on whenever possible.

Experience has shown that numerous difficulties exist in the making of accurate water temperature observations. In the first place it is not an easy matter to dip up from the sea, from the deck of a moving vessel, a sufficient quantity of water so that the influences which immediately begin to operate to change its temperature shall not make too great headway before the thermometric reading can be made. Often the bucket used can be only partially filled, even by the most skillful handling. Some vertical stiffening of the ordinary canvas bucket and an extra middle ring to prevent collapse on entering the water are desirable. Sometimes a small quantity of water of a different temperature is in the bucket when the final dip is made. In the case of canvas buckets evaporation from the surface of the fabric operates to change the temperature of the contents. Sometimes the temperature of the water drawn up has been affected by the discharge through ejection pipes.

If the temperature of the wet bulb is different from that of the water the latter is affected as soon as the water is dipped from the sea. By the time a bucket can be drawn upward through a distance of from 30 to 60 or more feet, landed upon the deck, and the thermometer immersed in the water for a suitable period of time the temperature of the water will have undergone a definite change—in the direction of that shown by the wet bulb.

Instructions that have heretofore been given for making water temperature observations provide that the water shall be drawn in a canvas bucket from a point forward of the ejection pipes and that the bulb of the thermometer shall be immersed for three minutes and read with the bulb still in the water in the bucket. At times, however, there is a rapid cooling of the water in the bucket due to strong cold winds and on such occasions a shorter period of immersion is desirable. With a reasonably active stirring the thermometer will indicate the water temperature in one minute. Experience shows that readings should be made only in buckets not less than two-thirds full and that the bucket should be protected from sun and wind.

On account of the increasing value attached to ocean temperatures observers are urged to exercise their best judgment and skill in making these observations.

Weather.—To record the state of the weather a system of notation devised by Admiral Beaufort is employed. The system is as follows:

Upper Atmosphere:

b.—Blue sky.

c.—Cloudy sky (detached clouds).

o.—Overcast sky.

Lower Atmosphere:

v.—Visibility (exceptionally clear).

z.—Haze.

m.—Mist.

f.—Fog.

Precipitation:

d.—Drizzling.

p.—Passing showers.

r.—Rain.

s.—Snow.

h.—Hail.

Electric Phenomena:

l.—Lightning.

t.—Thunder.

Wind:

q.—Squally.

Important.—The use of other than the proper letter for the state of weather may render the observation valueless. Thus *c* should not be used for clear, *f* for fair, *s* for showers, nor *h* for haze.

To indicate greater intensity, underline the letter thus: *r*, heavy rain; *r*, very heavy rain, etc.

Those letters should be employed which describe the weather at the actual time of observation; not the average conditions throughout any period.

The information desired is a statement, by letters, for each of the following particulars at the actual time of observation, using in general a single letter for each; note that the absence of a letter is in many cases significant:

1. The appearance of the sky.
2. The clearness of the lower atmosphere.
3. The character of the precipitation, if any (rain, snow, hail, etc.).
4. The character of the wind, whether constant in force or squally.
5. The occurrence of lightning and thunder.

Appearance of the sky.—The letters *b*, *c*, *o* (blue sky, cloudy, overcast) refer to the character of the sky at the time of observation.

The letter *b* implies that the sky is a clear blue, although detached clouds may be abundant—a "fine weather" sky.

The letter *c* implies that the sky is cloudy, although patches of blue are visible.

The letter *o* implies that the sky is completely overcast, no blue appearing.

Amount of cloud.—In the scale for the amount of cloud, 0 represents a sky which is cloudless at the time of observation, and, proceeding by successive steps, 10 a sky completely overcast.

The reported "Amount of cloud" should agree in general with the recorded "Appearance of the Sky"; *b* corresponding to a proportion of clouded sky not greater than four-tenths; *c* to a proportion of clouded sky not less than five-tenths and not greater than eight-tenths; *o* to a sky that is at least nine-tenths covered. These rules are, however, by no means rigid.

In estimating the form, motion, and amount of cloud, attention should be devoted mainly to the neighborhood of the zenith. Near the horizon all of these features are much distorted by the effects of perspective.

In case the true sky is obscured by fog, mist, or haze, it should be described simply as overcast (*o*) with the amount, 10. The remaining spaces should be left blank.

In addition to the above always enter under the heading "Daily Journal," a brief statement of the general character of the weather—"very fine weather," "fine weather," "cloudy weather," etc.

Classification of clouds.—In recording clouds, observers should conform strictly to the International system of classification adopted in 1905, a full description of which will be found commencing on page 43, accompanied by illustrations to aid observers in identifying the various cloud forms.

The attention of observers may be here called, however, to several points to be noted in connection with the classifying of certain clouds.

The term *stratus* should not be applied to the thin cloud sheet seen near the horizon about sunset. These clouds are really at a considerable height and should be classed as *alto-stratus* or *strato-cumulus*.

With the exception of the ordinary thundercloud, which should be classed as *cumulo-nimbus*, any heavy cloud sheet from which rain or snow is actually falling or threatens to fall should be recorded *nimbus*.

The thin, even haze-like cloud which sometimes overcasts the sky at high levels, below which other clouds may be floating, should be classed as *cirro-stratus*. *Alto-stratus* is applied to layers of distinctly greater density at lower levels; when heavier and lower still they become *stratus*.

Cloud movement.—The movement of upper clouds serves as an index to the upper currents of the atmosphere, which are always much steadier than the lower currents and at times quite distinct from the latter. The direction and velocity of this movement are

very important features in weather changes. Thus observations of cirrus clouds in temperate latitudes disclose their rapid and almost constant drift from some westerly point. Departures therefrom are always associated with passing cyclonic disturbances.

In estimating the point of the compass from which the clouds proceed, the direction and velocity of the vessel should be taken into account, precisely as in the case of the wind. The direction required is the *true* direction, *not* the magnetic.

In case the motion of the clouds is exceptionally rapid, always so specify.

The clearness of the lower atmosphere.—The letters *f*, *m*, *z*, *v*, (fog, mist, haze, visibility) refer to the clearness of the lower atmosphere at the time of observation.

The absence of a letter implies that the atmosphere is of the ordinary clearness.

The letter *v* implies that distant objects (at sea, the horizon) are more sharply defined than usual, demanding exceptional clearness as well as exceptional steadiness of the lower atmosphere.

The letters *f*, *m*, *z*, imply that distant objects are more or less obscured.

The letter *f* should be employed when the fog is lying in banks, even though the ship is not actually enveloped at the time of observation. Always enter the occurrence of fog on Sheet B of the Weather Report.

Precipitation.—The letters *d*, *h*, *p*, *r*, *s* (drizzling, hail, passing showers, rain, snow) refer to the character of the precipitation, if any, at the time of observation.

The absence of a letter implies that precipitation was not in progress at the time of observation.

Precipitation at other hours should, however, always be entered in the space "Daily Journal," with the time at which it occurred.

The character of the wind.—The letter *q* refers to the character of the wind and implies that the latter, instead of blowing steadily, is squally or subject to marked fluctuations in intensity.

The absence of a letter implies that the wind is steady in force.

Lightning and thunder.—The letters *l* and *t* (lightning and thunder) imply that these phenomena have been noted within one hour of the actual time of observation.

All other phenomena, such as thunderstorms, squalls, etc., and all previous changes, such as shifts of the wind, lowest and highest barometer, etc., should be recorded, with the hour of their occurrence, under the heading "Daily Journal."

SEA DISTURBANCE

The following scales should be used in recording the character of the sea:

Scale of sea disturbance

Scale	Description	Height of waves, crest to trough
0	Calm	0.
1	Very smooth sea	Less than 1 foot.
2	Smooth sea	1 to 2 feet.
3	Slight sea	2 to 3 feet.
4	Moderate sea	3 to 5 feet.
5	Rather rough sea	5 to 8 feet.
6	Rough sea	8 to 12 feet.
7	High sea	12 to 20 feet.
8	Very high sea	20 to 40 feet.
9	Precipitous sea	40 feet and above.

CHARACTERISTICS OF SWELL

Provisional description of scale

1. No swell.
2. Slight swell.
3. Moderate swell.
4. Rather rough swell.
5. Rough swell.
6. Heavy swell.
7. Very heavy swell.
8. Abnormal swell.

Gale and storm reports.—A summary of every gale encountered during the period covered by each voyage should be entered on Sheet B of the Weather Report.

In cases of important storms, especially tropical hurricanes, observers are urged to make special reports in detail. Extra observations may be entered on Sheet A, between those made at Greenwich mean noon. The lowest point reached by the barometer, the local mean time at which this occurred, and the shift of the wind accompanying it, are of the greatest importance; also the direction in which the wind shifted during the squalls. These data are essential for the accurate determination of the facts regarding the storms. Always state whether or not the vessel was hove to, and if so, in what manner and for what length of time.

SHEET B.

GALE OR STORM REPORTS.

NOTE.—If no gales or storms have been observed, please write across these blanks "No gales or storms."

(Use civil date and local time.)

Beginning.		Lowest barometer.						End.		Highest force of wind and direction.	Shifts of wind. Give compass points to show shifts of wind about time of lowest barometer.
Date.	Wind.	Date and time.	Direction and force of wind.	Barometer. As read off.	Barometer. Att. ther.	Latitude.	Longitude (Greenwich).	Date.	Wind.		
1924 Mar. 7	N. 8	7th 12 Mid.	W. 8	29.20		N. 45° 41′	E. 168° 50′	Mar. 9	SW. 7	NW. 9	N.-NW.-SW.

FOG REPORTS.

NOTE.—If no fog has been observed, please write across these blanks "No fog."

Entered.						Cleared.						Character of fog.
Civil date.	Local mean time.	Latitude.	Longitude (Greenwich).	Temperature. Air.	Temperature. Water.	Civil date.	Local mean time.	Latitude.	Longitude (Greenwich).	Temperature. Air.	Temperature. Water.	
Mar. 15	4 p. m.	N. 48° 57′	W. 154° 25′	43	42	Mar. 17	5 p. m.	N. 49° 00′	W. 143° 40′	46	45	Dense.

GENERAL REMARKS OR COMMUNICATIONS—MISCELLANEOUS PHENOMENA.

Fog.—The civil date and local mean time of entering and emerging from fog should be given on Sheet B, together with other special information as indicated by the headings of the Fog Report. When the fog occurs in banks the date and hour of entering and of final clearing should be given and the word "Banks" added under the heading "Character of fog." Note should be made of fog seen at a distance even though not passed through by the observer's vessel. In case no fog is observed during the period covered by the report a statement should be made to that effect. Negative information is often of much value.

Miscellaneous phenomena.—The occurrence of such phenomena as halos, coronas, waterspouts, and meteors should be recorded on Sheet B or on an inset sheet, as convenient. Owing to the exceptional opportunity which seamen have to observe meteors, special instructions for their observation are given herewith.

Instructions for observing meteors.—It would be of great value to science if the officers of ships would record the paths of brilliant or exceptional meteors and fireballs seen by them. The data needed include the approximate position of the ship at the time the object appeared and the Civil Greenwich Mean Time of its appearance, certainly to the nearest five minutes. If any other time than G. M. T. is used, it should be so specified. For the object itself the angular coordinates of its points of appearance and disappearance are desired. These are preferably expressed in right ascension and declination, which can readily be read off from a star map if the path is plotted thereon, or by the altitudes and azimuths if more convenient. Notes giving the brightness, color, character of train, and particularly the estimated number of seconds the object was visible are desired. If an explosion is either seen or heard it should be recorded, especially the time interval between these features if both are observed.

Records of brilliant objects, regularly made, would in a short time furnish data for the calculation of many real heights and orbits for such bodies—data which possess definite meteorological as well as astronomical value, since they aid in the determination of the height of the atmosphere.

In addition to the foregoing, which it is desirable that all should be willing to cooperate in securing, it is hoped that a few persons, especially interested in astronomy, will wish to make regular observa-

tions at certain periods of the year when meteors are most abundant.[1] These are:

Radiant in—	Epoch	Maximum
Ursa Major	January 1–3	January 2.
Lyra	April 17–22	April 20.
Aquarius	May 1–8	May 4.
Aquarius	July 27–31	July 28.
Perseus	August 8–14	August 11, 12.
Orion	October 14–27	October 19-22.
Leo	November 13–16	November 14.
Gemini	December 8–15	December 12.

[1] To anyone who cares to make observations of some of these showers, regular charts, blanks, and full instructions for making the observations will be furnished on application to Chas. P. Olivier, Leander McCormick Observatory, University, Va., who has charge of this work for the American Meteor Society. Other observations should be entered in the Weather Report.

PART II

INSTRUMENTS

Barometers.—At the Maritime Conference held at Brussels in 1853 the general use of mercurial barometers for the measurement of atmospheric pressure was recommended. This was to apply to the sea as well as to the land—where they had long been the standard in use—inasmuch as the mercurial barometers gave absolute results, while the aneroids gave only relative values. If, however, a mercurial barometer in its simple form should be placed on board a vessel at sea, the column of mercury would surge up and down the tube more or less violently with every motion of the vessel, and readings of the air pressure, especially in a rough sea, would be inaccurate or even rendered impossible.

Mercurial barometer of marine type.—The difficulties encountered in the use of the ordinary type of mercurial barometer have been overcome in a form of instrument known as the Kew, or marine, barometer. Its distinguishing characteristics consist in substituting for the simple straight tube of uniform bore commonly employed in land barometers, a tube having a wide bore for 6 or 8 inches of the upper portion only. Below this the tube has thick walls with a small capillary bore only a few hundredths inch in diameter. Near the bottom end the bore of the tube is again enlarged to form an air trap, all as shown in Figure 2. If small quantities of air chance to enter the open end of the tube they are not likely to enter the small point of the inner tube, but lodge instead in the surrounding space, as indicated, where the air must remain and does not affect the barometric readings. It may even be removed from the trap when the barometer is undergoing repairs.

The flow of mercury through the capillary bore takes place so slowly that the column can not surge up and down the tube seriously with the relatively quick motions of the ship. At the same time the height of the column adjusts itself to the slow changes of atmospheric pressure, and thus more or less perfectly answers the desired objects.

Figure 3 shows a high grade mercurial barometer adapted to all the requirements of marine use, together with a special gimbal supporting bracket and wooden box, into which the barometer and bracket are folded and thoroughly protected and secured when not in use.

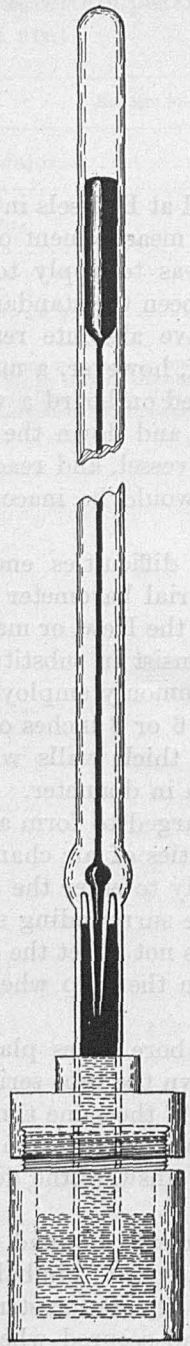


FIG. 2.—Tube and cistern of marine barometer

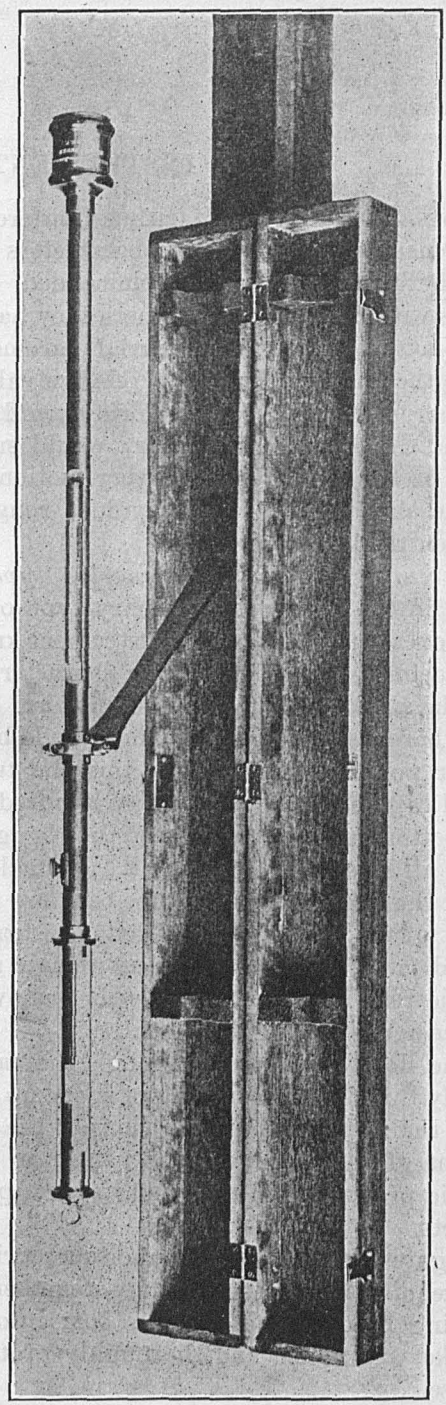


FIG. 3.—Marine barometer and box

Fig. 3 is inverted

The glass tube and boxwood cistern, all as shown in Figure 3, are secured inside the bronze-metal jacket provided at the top with a long, slotted opening through which the top of the glass tube and mercurial column can be seen. A scale of graduations is fixed beside the opening and a vernier is arranged to slide up and down so as to enable accurate measurements of the height of the mercurial column to be made.

For marine use it is necessary that the barometer be free to hang in a vertical line despite the rolling and pitching of the vessel. For this purpose the well-known arrangement of gimbal rings is formed upon the outer extremity of a hinged bracket and secured to the barometer at a point some inches above the middle.

In the position shown in the picture the barometer is ready for reading, and the tube will swing on the gimbals so as to remain nearly or quite vertical. After a reading has been taken the barometer must not be left exposed, as it is very liable to injury by violent oscillations in heavy weather. In the equipment of the standard Weather Bureau design the whole bracket, barometer, and all are arranged to fold up compactly within the small mahogany case, the lid of which closes with a spring clasp, and not only secures the barometer from accidental damage but from undue exposure to atmospheric influences as well.

Types of barometers.—Standard types of both land and marine mercurial barometers are found in offices of the Weather Bureau at the principal United States ports, and seamen are invited to visit such offices for the purpose of familiarizing themselves with these and other meteorological instruments.

Explanation of scale of marine barometer.—All marine barometers are of the fixed-cistern type, as it is called, and the only setting required is to bring the lower edge of the vernier accurately to the level of the top of the mercurial column, whereupon the scale reading gives directly the observed or uncorrected air pressure. This result is realized by shortening the graduations on the scale so that instead of representing true standard inches, millimeters, or millibars, as the case may be, the graduations have such a value as to eliminate or take account of the slight rise and fall of the level of the mercury in the cistern as the column rises or falls.

If, for example, the column of mercury in the tube falls say 1 inch, there will be a rise of the mercury in the cistern, but the amount will be small because the area of the cistern is so much greater than that of the tube. For example, in the barometer from which the illustration in Figure 2 was prepared, the rise of the mercury in the cistern for a fall of 1 inch in the tube amounts to only about three hundredths of an inch (0.03). Consequently, in this barometer, an observed fall

of 1 inch in the tube means a fall of 1.03 inches in the pressure. If, now, we prepare a special scale for this barometer such that each true inch of space on the scale represents 1.03 inches of the arbitrary scale values, and, if we set this scale so that the barometer reading at any one point of the scale agrees exactly with the reading of a standard barometer alongside of it, then the readings should agree closely at all other points of the scale. Slight irregularities in the bore of the tube and diameter of the cistern may introduce small errors; otherwise, the contracted-scale barometer, with settings made only at the top of the mercurial column, is capable of yielding pressure readings of great accuracy, and this artifice is universally employed in the ordinary marine barometer.

Errors of mercurial barometers.—No matter how carefully a barometer may be made, certain errors due to various causes can hardly be eliminated. In the first place, if any air or other gaseous matter remains in the top of the barometer tube, the column of mercury will be prevented from rising as high as it should. It is known, likewise, from physical laws, that the capillary forces acting between the free surface of mercury and the glass walls at the top of the column also operate to prevent the mercury from rising as high as it should in the tube. Still other errors arise from faults in the graduation of the scale and from failure to place the scale and vernier at exactly the positions they should occupy.

It is not practicable, nor is it necessary, as a rule, to determine these errors separately. When an instrument is completed, its readings are carefully compared with those of a standard barometer. The difference found in this way represents the combined effect of the several errors mentioned and is commonly called the "correction for instrumental error and capillarity."

Another source of considerable variation in the readings of mercurial barometers is the influence of temperature, a rise of temperature expanding both the metal scale and the mercurial column. If both mercury and scale expanded the same amount, no correction would be necessary, but the mercury expands much more than the metal scale, so that a large correction is required, as will be explained more fully on page 30.

Location of the mercurial barometer.—If the ship carries a mercurial barometer, it should invariably be employed in the meteorological work of the Weather Bureau. It should, therefore, be so located as to be readily accessible.

It should be hung in a place where the temperature is fairly uniform; that is, at some distance from any source of heat, such as steam pipes, stove, or lamp, and where there is a good light. It should be at such a height from the deck as to admit of the observer's

eye being brought opposite the level of the mercury in the tube. It should also be free, so far as possible, from the jar of the machinery.

Any simple method of suspension may be employed, so long as the instrument is secure. An excellent device is a stout bracket 10 or 12 inches in length, firmly attached to the bulkhead, at the outer extremity of which is a ring swung on gimbals, in which ring the barometer is clamped at a point one-half of its length from the top. See Figure 3. A spiral check spring or a strong rubber band, carried from the grommet at the top of the barometer to the deck above, serves to prevent the cistern from collision with the bulkhead or other object during heavy weather. At the moment of observation it is absolutely essential that the barometer be vertical, as any deviation from the plumb line will make the reading too high. At this moment, therefore, and only at this moment, the check spring should be detached, and the tube allowed to swing freely, not even being steadied by the hand. In order that this interval be as brief as possible, the following method of procedure should be followed:

1. Read and record the temperature of the attached thermometer.
2. Bring the lower edge of the vernier to coincide with the top of the arched surface of the mercury, as nearly as the pumping will permit.
3. As the ship is approaching an even keel, release the check spring from the grommet at the top of the tube; with a touch of the set screw once more bring the edge of the vernier to the top of the mercurial surface, and immediately attach the check spring.
4. Read and record the position of the vernier.

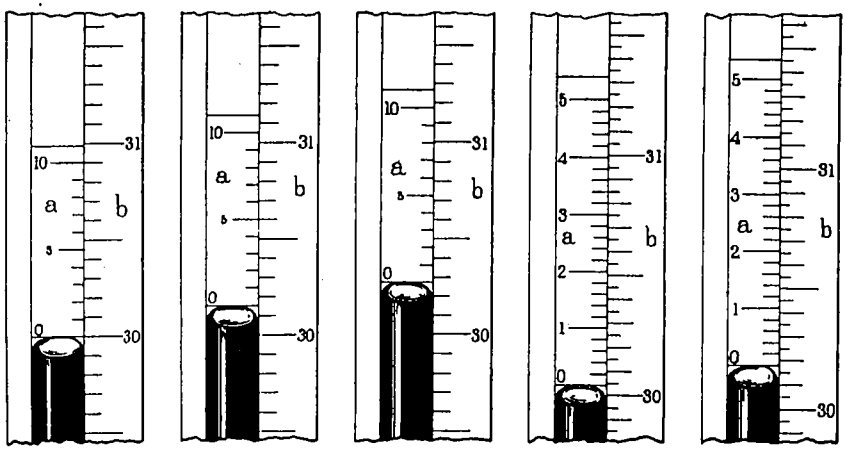
In setting the vernier, the eye of the observer should be brought to the same level as the top of the mercury. A piece of clean white paper placed immediately behind the tube will be found of great assistance in the final adjustment. When observing at night, a strong light should be thrown on this paper.

The principle of the vernier and the method of reading it.—The vernier is a device by which one is able to ascertain accurately much smaller fractional subdivisions of a graduated scale than could otherwise be observed by the eye without the aid of a microscope. For example, with a scale having only 20 subdivisions to the inch a vernier enables us to ascertain accurately the one-thousandth part of an inch. The name of the device is derived from its inventor, Pierre Vernier.

A vernier consists, essentially, of a small graduated scale, the spaces upon which are just a certain amount smaller or larger than those on the main scale. When two such scales are placed together some particular line of the one will always be coincident, or very nearly so, with a line on the other, and from this circumstance the position of the zero line of the vernier in reference to the scale can

be very accurately determined, as will be readily understood from a study of the following figures and explanation:

Figure 4 exhibits the manner of graduating a vernier so as to subdivide the spaces upon the scale into tenths. In the figure, *b* is the scale and *a* is the vernier. The lower edge of the vernier, which in this case is also the zero line, is exactly opposite or coincident with 30 on the scale. The tenth line on the vernier is coincident with the ninth line above 30—that is, a space of 9 divisions on the scale is divided into 10 spaces on the vernier, so that each space on the latter is one-tenth part shorter than a space on the scale. In the present case the spaces on the scale represent inches and tenths; hence the difference between the length of a space on the vernier and one on the scale is $\frac{1}{10}$ of $\frac{1}{10}=$ of an inch. This principle of matching



30.00 FIG. 4 | 30.15 FIG. 5 | 30.277 FIG. 6 | 30.034 FIG. 7 | 30.177 FIG. 8

Verniers

two scales having spaces of slightly different magnitude is always followed in the construction of verniers, though, of course, the number of spaces embraced by the vernier is varied to suit the circumstances and the degree of minuteness desired. Moreover, in some instances, the vernier embraces one more space on the scale, instead of one less, than the number of its own subdivisions—that is, 10 spaces on the vernier may be made to correspond to 11 spaces on the scale.

If, as we have seen, the spaces on the vernier are one-tenth smaller than on the scale, then, in the adjustment shown in figure 4, the first line above the zero on the vernier is one-tenth part of the space, the next line two-tenths, the next three-tenths, etc., distant from the line next above on the scale. When, therefore, we find the vernier in such a position as shown in Figure 5, where the fifth line on the ver-

nier is coincident with a scale line, it is very clear that the zero line of the vernier must be just five-tenths above the scale line next below. Now, since we imagine these scales to represent inches and tenths, then Figure 5 will read, 30.15 inches.

Estimation of fractions on a vernier.—In many cases it will happen that no single line on the vernier will be exactly coincident with a scale line, but that one line will be a little above while the next line on the vernier will be a little below the corresponding scale lines.

In the case shown in Figure 6 the seventh and the eighth lines on the vernier are each nearly in coincidence, but neither one is exactly so. This indicates that the reading is somewhere between 30.27 and 30.28. Moreover, we can clearly see that the eighth line is nearer coincidence than the seventh. We, therefore, estimate that the true reading is about 30.277. We might, probably, with as great accuracy have selected 30.278.

If the scale and vernier are accurately graduated, such readings by a practiced observer will rarely be in error by more than 0.002 inch. It is important in estimating the fractions that the eye be exactly in front of the lines being studied.

In Figures 7 and 8 are shown verniers applied to a barometer scale having 20 parts to the inch. In this case 24 parts on the scale are divided into 25 parts on the vernier. By the principle already explained on pages 27 to 29, the value of the subdivisions affected by such a vernier, or, as it is most frequently expressed, the least count of the vernier, will be $\frac{1}{25}$ of $\frac{1}{20} = \frac{1}{500}$ of an inch. In reading the vernier, therefore, each line will represent 0.002 inch, so that the fifth, tenth, fifteenth, twentieth, and twenty-fifth lines will represent one, two, three, four, and five hundredths of an inch, respectively, and are so numbered.

As already stated, the lines in this kind of vernier also may not be exactly in coincidence; but in such a case, owing to the smallness of the spaces, it is not of any special advantage in making our estimate to consider whether coincidence is nearer one line than the other. In ordinary practice we simply take midway between. Thus in Figure 8 the reading is between 30.176 and 30.178; we therefore adopt 30.177 as the proper reading.

Caution against error.—When the zero line of this style of vernier is next above one of the shortest lines on the scale, as was the case in the example above, some attention is necessary in order to take off the correct reading. For example, in Figure 8 we find that coincidence on the vernier is between lines designated 26 and 28, which corresponds to a reading of 0.026 or 0.028, or, taking midway between, 0.027. On the scale itself, however, we see the graduation next below the first line of the vernier is 30.150. The complete read-

ing is found by adding the parts thus: 30.150 + 0.027 = 30.177. It frequently happens with beginners that the 0.050 represented by the short line on the scale is overlooked and omitted entirely—that is, the above reading might be called 30.127. Whenever readings are made with a scale and vernier of this character special pains must be taken not to omit adding 0.050 to the vernier reading when the first line below the zero of the vernier is a short one.

In recording the height of the mercury always use two whole numbers and two decimals, even though the final is zero. Thus, 30 inches should be recorded 30.00.

Correction of barometer readings.—The readings of a mercurial barometer are affected by four conditions, temperature, gravity, elevation, or height above sea level, and imperfections in the instrument. The last two of these influences are more or less constant as affecting barometers on board vessels and corrections therefor are embodied in a so-called "barometer correction," obtained in the manner described on pages 10 and 11. It is necessary, however, in order to obtain a barometer reading that will be comparable with normal values, such as are published on the monthly Pilot Charts, to determine and apply corrections for temperature and gravity.

Correction for temperature.—Other things being equal, the mercury will stand higher in the tube when it and the metal scale are warm than when they are cold, owing to expansion. To eliminate this effect, and for the purpose of comparison, all observations of mercurial barometers must ultimately be reduced to a standard temperature. The standard universally adopted is the freezing point of water, corresponding to 32° on the Fahrenheit scale and to 0° on the Centigrade scale. The appropriate corrections to be applied to reduce barometric readings to this standard temperature have been determined and expressed in tabular form. Table 1, page 82, gives the value of this correction for each degree Fahrenheit.

Reduction to standard gravity.—The following will elucidate the nature of the gravity correction as applied to barometric observations—an important matter that is often but indifferently considered in the ordinary textbooks of meteorology:

By the well-known principle of hydrostatics on which the action of the mercurial barometer is based the pressure of the atmosphere is equal to the pressure of the column of mercury that it will support. But this latter pressure is only another name for the weight of the mercury, and for columns of equal section the weight varies both with the height of the column and with the force of gravity.

The force of gravity varies with latitude and altitude; therefore the height of the barometer, even when corrected for temperature and instrumental error, does not give us a true measure of the at-

mospheric pressure unless we first eliminate the small variations that are due to gravity; that is, observations taken over a widely extended region to be strictly comparable must be reduced to a standard force of gravity.

The standard gravity adopted by physicists is that at the level of the sea in latitude 45°.

A table of corrections for gravity is given on page 83.

Aneroid barometers are compensated for temperature and their behavior is not influenced by gravity.

As an example, let the observed reading of the mercurial barometer on board a vessel in the Caribbean Sea, midway between Colon and the Windward Passage, be 29.95 inches and the temperature as given by the attached thermometer, 74° F.

We then have—

	Inches
Observed height of the mercury	29.95
Correction for temperature, 74° (Table 1)	—0.12
	29.83
Correction for gravity, latitude 15° (Table 3)	—0.07
	29.76
Correction for height above sea level and instrumental error, *assumed* (Barometer Tag)	+0.06
Corrected barometer reading	29.82

The normal pressure values given on the monthly Pilot Charts are for the hour noon G. M. T. (civil), and in order to make a strict comparison with such values the barometer should be read at that hour. This is especially important in low latitudes where the diurnal range of pressure is considerable.

Aneroid barometers.—Figure 9 represents one of the more important types of aneroid or holosteric barometers, showing, principally, the internal mechanism. The essential feature consists of the small metallic box or cell, *M*, the upper and lower walls of which are made of very thin circular sheets of corrugated German silver, which are soldered together on their outer edges, forming a very short cylinder. The air is thoroughly exhausted from this cell through a tube at one side, which, when the vacuum is as perfect as desired, is pinched tightly together, cut off, and hermetically sealed with solder, producing the projection seen at *c*. The flexible corrugated surfaces, which tend to be collapsed by the pressure of the outside air, are forcibly held apart by the action of a strong steel spring, *R*. As the pressure of the air increases the spring is compressed and the corrugated surfaces approach each other slightly, returning again or separating still farther with diminution of pres-

sure. To measure the changes in atmospheric pressure, it is only necessary to measure the minute movements of this flexible cell.

In the common aneroid a lever, *l*, attached directly to the spring, connects by a link, *m*, with a very short arm of a sort of bell-crank lever, *r*, *t*, having a horizontal axis on pivots at each end.

The longer arm, *t*, of this bell-crank lever is connected by means of a wire, *s*, with a very fine chain, the other end of which winds around a small wheel or drum on the axis, *a*, upon which is mounted the hand as seen. At *b* is shown a small spiral steel spring, like the hair-spring of a watch, which serves to take up the slack in the loose connections of the numerous joints, levers, and links.

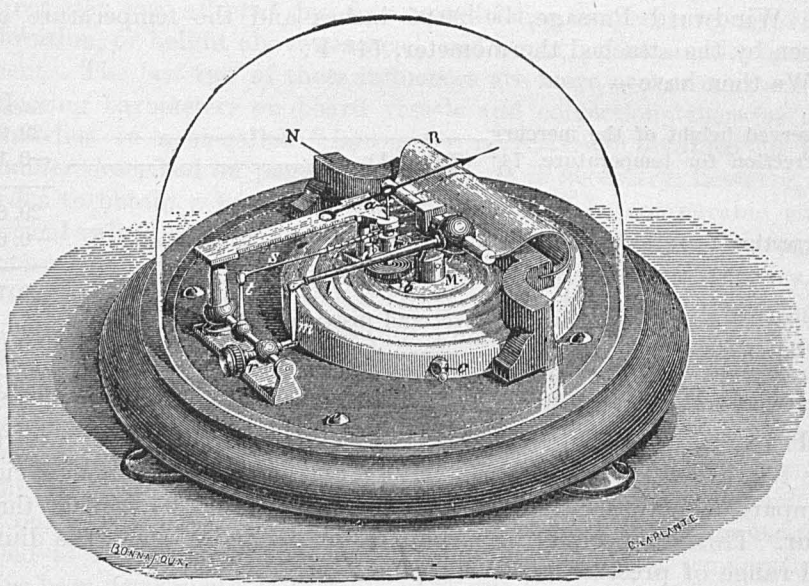


FIG. 9.—Aneroid barometer

At *r* is shown, also, a small counterpoise weight attached to the bell-crank lever to aid in securing a more stable position of the index when the barometer is placed in different positions; that is, whether the dial is horizontal, or vertical, or turned to one side or the other.

The point of attachment of the link, *m*, to the bell-crank lever is sometimes adjustable so that the movements of the hand can be made to correspond to the value of the scale graduations.

The steel spring, *R*, is also slightly adjustable by means of a screw from the underside threaded into the part, *N*. This permits adjusting the hand to any particular point of the scale to give correct readings.

Effects of temperature.—The steel spring and the feebler elastic reaction of the composition metal of the vacuum chamber are appreciably weakened by increase of temperature, so that in some

cases a rise of the pressure may seem to occur which is really caused by the weakening of the spring. In some cases efforts are made to compensate for this by leaving a small quantity of air in the vacuum chamber, which when heated increases its pressure upward and tends to offset the weakening effect upon the springs. A better plan is to make the lever, *l*, of two different metals, viz, brass and iron, firmly brazed together. The differential expansion of these two metals with temperature changes produces flexure in the lever. By filing and adjusting the bimetallic bar, the flexure due to temperature can be made very nearly to balance the effect of temperature on the spring. The aneroid is then said to be "compen-

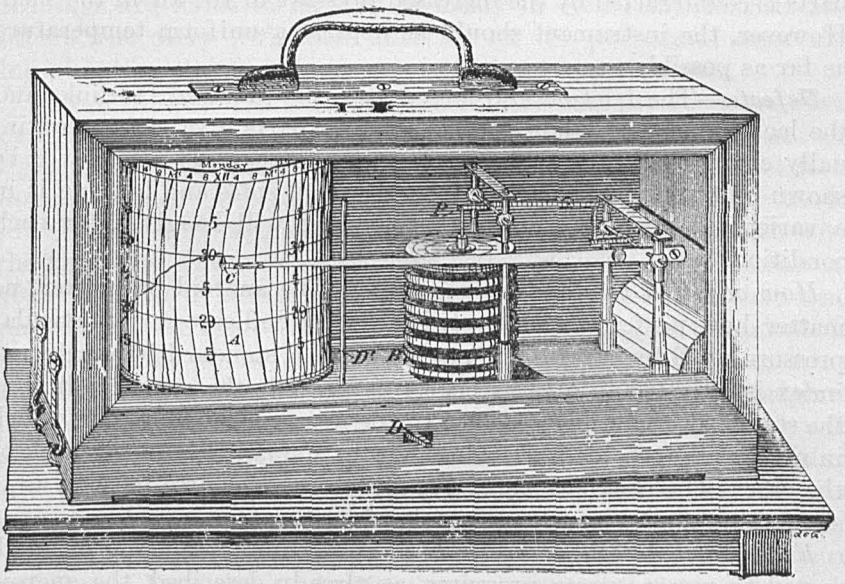


FIG. 10.—Richard's aneroid barograph

sated" and this word is often found on the dial. In many cases this word is there when the compensation is very imperfect.

Aneroid barographs.—Extremely simple and portable barographs are constructed upon the aneroid principle, of which that of Richard, being widely used, is here described. (See fig. 10.)

It consists of a cylinder, *A*, on which the recording paper is wound, revolving once a week by means of a clockwork contained inside. A series of corrugated metallic shells, *B*, eight in number, joined one above the other and exhausted of air, forms an aneroid system eight times as sensitive as a single chamber. The movement of the shells is still further greatly magnified and is transmitted to the recording pen, *C*, by a series of connecting levers. The pen may be released from contact with the paper by pushing the lever, *D*, to the right.

The corrugated shells are the same as used in ordinary aneroids, the steel springs for distending the shells being placed inside. The shells are made into a vertical column by screwing one to another. The lower base of the column being fixed, the upper end rises and falls with every variation in the atmospheric pressure, by a quantity which is the sum of the displacements of the elementary shells.

The compensation for temperature is accomplished by leaving a sufficient quantity of air in one of the shells, ascertained by experiment when the instrument is made, so that with a rise of temperature the tendency of the barometer to register too low on account of the weakening of the springs, and the expansion of the levers and other parts is counteracted by the increased pressure of the air in the shell. However, the instrument should be kept at a uniform temperature as far as possible.

Defects.—The friction and looseness in the joints of the links and the lack of perfect balance in the various parts give rise to continually changing errors in the reading of the aneroids. This will be shown by tapping the aneroid from different sides and holding it in a variety of positions; a different reading will be given for each condition.

How adjusted to standard pressures.—The aneroid barometer, no matter how perfectly constructed, does not indicate any particular pressure until by careful comparison with a standard barometer its index is adjusted to give as nearly as possible the same reading as the standard. This adjustment is made by means of the screw, which in nearly all aneroids is seen just within a small hole in the back of the case. The graduations of the dial must of course be such as to show changes of pressure on a scale of millimeters or inches.

Errors and defects of aneroids in general.—After being once adjusted to give accurate pressures, as already described, the aneroid should be handled with great care. Violent knocks and shaking will, especially with the common aneroid, almost certainly change or shift the various links and levers in their joints and change, more or less permanently, the position of the index. For such reasons aneroids are very liable to acquire unknown and often large accidental errors, and can not, therefore, be regarded as very satisfactory instruments.

Errors due to very slow changes, "creeping."—If an aneroid adjusted to read correctly under ordinary air pressures is placed within the receiver of an air pump, the index will quickly fall to a lower pressure when a partial vacuum is formed. If, however, the vacuum be maintained constantly at the same pressure for many days in succession, the reading of the aneroid will be found gradually to become lower and lower, but after three or four weeks

further changes cease or are very small. The amount of this slow change differs greatly and may be from one-half inch or less to over an inch, according to the diminution of pressure and other circumstances. Again, when the barometer is removed from the air pump it does not immediately return to its original correct reading, but its indications will be found to be too low, several weeks being again consumed in a slow return to approximately its former correct reading.

The "creeping" action depends, no doubt, upon some molecular changes, as yet not clearly understood, that take place within the materials of the aneroid box and steel springs. In any case the readings are liable to be very seriously in error, and tourists and others who carry with them aneroids for the purpose of ascertaining elevation should have means to determine such errors.

Test of condition of aneroid.—Aneroids, seemingly good, are often defective, because some of the joints of the levers and pivots are too tight, causing the hand to stick and not move with the perfect freedom it should. The condition of an aneroid can be quickly tested in this respect by tapping the instrument on the side or bottom with the fingers or knuckles, or perhaps better by lifting the instrument about one-fourth of an inch from a table or cane-seated chair and placing it back again somewhat sharply. Under this treatment, if the joints and levers are perfectly free, the hand will jump away and then return quickly with a vibratory movement to its original position. If the instrument is defective, the hand in some cases will not respond to the slight knocks, or will do so without exhibiting any vibratory movement, or upon being disturbed it may move a little, but will not return to its original position.

Thermometers.—Thermometers should be of reliable manufacture and should have the graduations etched upon the glass stem. For some years after a mercurial thermometer has been made the glass in the bulb contracts and notwithstanding that a certain period of "curing" is allowed by good manufacturers this contraction not infrequently results in appreciable error in the readings. On this account it is necessary to compare the readings of a thermometer with those of a standard instrument to ascertain if any error exists in the former and if so the proper correction to be applied to its readings. Ordinarily no thermometer should be employed the indications of which at any point on the scale differ by more than 1° from the true temperature as given by a standard instrument.

Exposure of thermometers.—The use of thermometers in meteorological observations is for the purpose of obtaining the temperature of the *free air*, and this fact should always be borne in mind in choosing a location for these instruments.

The air near the surface of the earth is nearly always in motion, more or less, and when not confined in a comparatively closed space the several portions thoroughly intermingle with each other and have nearly or quite the same temperatures. When any portion of the air is confined, however, so that it can not intermingle freely with the general air masses, its temperature will be influenced to a marked extent by the local surroundings and will not be a free-air temperature.

These ideas show us at once that if we mean to make observations of the real air temperatures our instruments must, if possible, be placed in a perfectly open space where the circulation of the air is entirely unobstructed. It will not do, however, to place the thermometers simply in the open air, exposed freely to the sky and the direct rays of the sun. The sunshine would cause the thermometer to register too high, and even if not exposed directly to the sun it could not be depended upon to indicate the true air temperature.

To overcome these difficulties, it is necessary to employ a suitable shelter. The form adopted by the Weather Bureau is a box with louvered sides and a double roof made in such a way that the air can move through it with the greatest possible freedom. To minimize the effects of insolation and conduction of heat, shelters should be made of wood and painted white. This is an essential condition for proper exposure. The object of the shelter is simply to screen off the direct and reflected sunshine and the radiation to and from the sky and to keep the instruments dry. If a shelter is not available the thermometers should be placed where they will be at all times in the shade and where the conditions are as nearly as possible like those within a shelter.

Maximum thermometer.—The maximum thermometer is *always* filled with mercury. It differs from the ordinary thermometer, however, in that the form of the glass tube is constricted at a point just above the bulb. As the mercury expands under the influence of heat it is forced through this constricted portion of the tube in little spurts. When the air cools, however, the mercury above the constriction does not recede into the bulb but remains in the tube until forced back by mechanical means, usually a rapid swinging movement.

Minimum thermometer.—As used by the Weather Bureau the minimum thermometer is filled with alcohol. Within the alcohol column is a minute glass rod, about one-third inch in length, having a rounded head on each end, and usually colored black so as to be plainly visible. This is known as the index. This index slides freely up and down within the column of alcohol, but will not leave it owing to the surface tension of the liquid at the top of the column.

Thus the index is pushed backward in the tube as the alcohol recedes into the bulb, and left at the lowest point reached by the head of the alcohol column. The minimum thermometer is "set" by lifting the bulb end and causing the index to move to the top of the column.

The Weather Bureau method of mounting the maximum and minimum thermometers is illustrated in Figures 11 and 12.

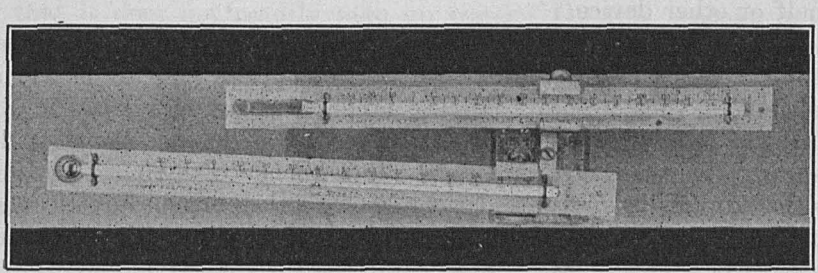


FIG. 11.—Thermometer supports. Townsend pattern

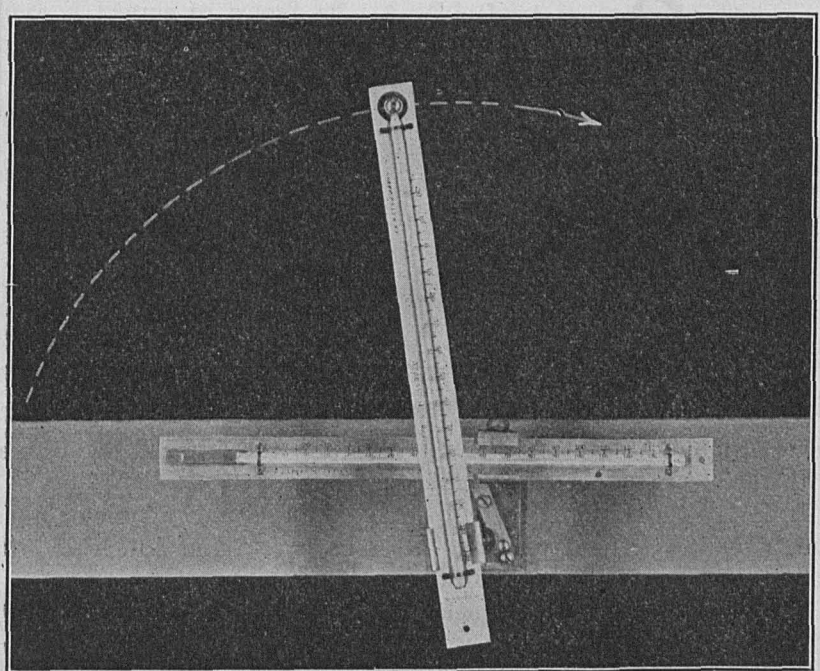


FIG. 12.—Thermometer supports. Pawl disengaged, maximum rotating

Thermographs.—A thermograph, or self-registering thermometer, of a pattern employed by the Weather Bureau in its meteorological work, is shown in the accompanying illustration (fig. 13).

The instrument is adapted to secure a continuous and automatic registration of temperatures, and, for this purpose should be located

within a shelter, of the construction indicated for thermometers. When placing a thermograph within a shelter containing also maximum and minimum thermometers, interference of the instruments with each other must be avoided, but, at the same time, the several thermometer bulbs should be placed relatively as near together as may be convenient, the thermograph being elevated on a suitable shelf or other device.

The hygrometer.—There are two general types of hygrometers. In one of these use is made of the hygroscopic properties of certain substances, such as hair. In the other there is first obtained the so-called "temperature of evaporation," or difference between the readings of two thermometers, the bulb of one of which is covered with thin muslin and wetted with water, both thoroughly ventilated at the time of reading. From this temperature difference which

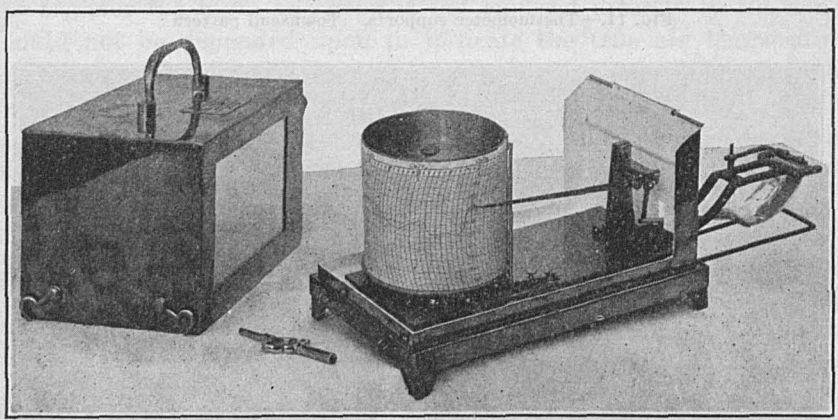


FIG. 13.—Short-range thermograph, with cover detached

bears a known relationship to the humidity the latter is determined with the aid of appropriate tables.

In instruments of the first type only the relative amount of moisture is indicated and readings must be checked at intervals with actual values obtained with instruments of the latter type.

The most reliable instrument for determining humidity is the sling, or whirled psychrometer. In special cases fans or other means may be employed to move the air rapidly over the thermometer bulbs. In any case satisfactory results can not be obtained from observations in relatively stagnant air. A strong ventilation is absolutely necessary to accuracy.

Sling psychrometer.—This instrument consists of a pair of thermometers, provided with a handle, as shown in Figure 14, which permits the thermometers to be whirled rapidly. The bulb of the

lower of the two thermometers is covered with thin muslin, which is wet at the time an observation is made.

The wet bulb.—It is important that the muslin covering for the wet bulb be kept in good condition. The evaporation of the water from the muslin always leaves in its meshes a small quantity of solid material, which sooner or later somewhat stiffens the muslin so that it does not readily take up water. On this account it is desirable to use as pure water as possible, and also to renew the muslin from time to time. New muslin should always be washed to remove sizing, etc., before being used. A small rectangular piece wide enough to go about one and one-third times around the bulb, and long enough to cover the bulb and that part of the stem below the metal back, is cut out, *thoroughly wetted* in clean water, and neatly fitted around the thermometer. It is tied first around the bulb at the top, using a moderately strong thread. A loop of thread to form a knot is next placed around the bottom of the bulb, just where it begins to round off. As this knot is drawn tighter and tighter the thread slips off the rounded end of the bulb and neatly stretches the muslin covering with it, at the same time securing the latter at the bottom.

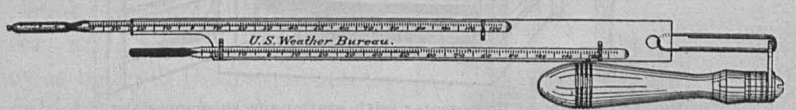


FIG. 14.—Sling psychrometer

Observation.—The so-called wet bulb is thoroughly saturated with water by dipping it into a small cup or wide-mouthed bottle. The thermometers are then whirled rapidly for fifteen or twenty seconds; stopped and quickly read, the *wet bulb* first. This reading is kept in mind, the psychrometer immediately whirled again and a second reading taken. This is repeated three or four times, or more if necessary, until at least two successive readings of the wet bulb are found to agree very closely, thereby showing that it has reached its lowest temperature. A minute or more is generally required to secure the correct temperature.

When the air temperature is near the freezing point it very often happens that the temperature of the wet bulb will fall several degrees below freezing point, but the water will still remain in the liquid state. No error results from this, provided the minimum temperature is reached. If, however, as frequently happens, the water suddenly freezes, a large amount of heat is liberated, and the temperature of the wet bulb immediately becomes 32°. In such cases it is necessary to continue the whirling until the ice-covered bulb has reached a minimum temperature.

Whirling and stopping the psychrometer.—It is impossible to effectually describe these movements. The arm is held with the forearm about horizontal, and the hand well in front. A peculiar

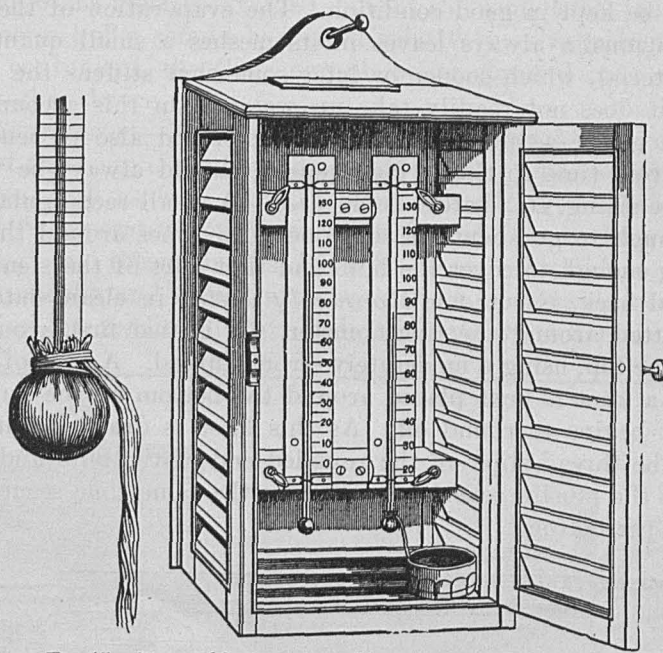


FIG. 15.—Form of hygrometer with stationary thermometers

swing starts the thermometers whirling, and afterward the motion is kept up by only a slight but very regular action of the wrist, in harmony with the whirling thermometers. The rate should be a

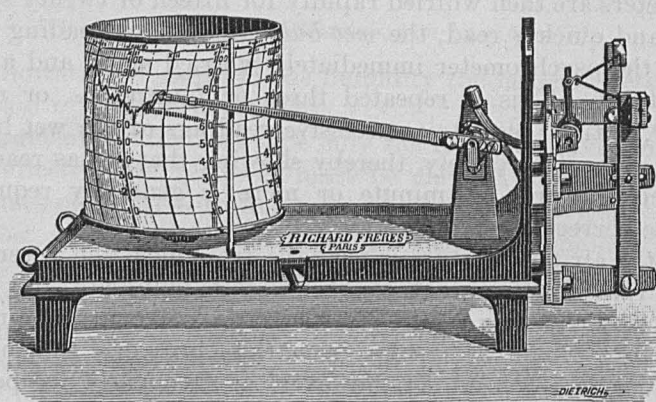


FIG. 16.—Richard hygrograph

natural one, so as to be easily and regularly maintained. If too fast, or irregular, the thermometers may be jerked about in a violent and dangerous manner.

The stopping of the psychrometer, even at the very highest rates, can be perfectly accomplished in a single revolution, when one has learned the knack. This is only acquired by practice, and consists of a quick swing of the forearm by which the hand also describes a circular path, and, as it were, follows after the thermometers in a peculiar manner that wholly overcomes their circular motion without the slightest shock or jerk. The thermometers may, without very great danger, be allowed simply to stop themselves; the final motion in such a case will generally be quite jerky, but, unless the instrument is allowed to fall on the arm, or strikes some object, no injury should result.

Exposure.—While the psychrometer will give quite accurate indications, even in the bright sunshine, yet observations so made are not without some error, and, where greater accuracy is desired, the psychrometer should be whirled in the shade of the deck house, or, as may sometimes be possible, under an awning. In all cases there should be perfectly free circulation of the air, and the observer should face the wind, whirling the psychrometer in front of his body. It is a good plan, while whirling, to step back and forth a few steps to further prevent the presence of the observer's body from giving rise to erroneous observations.

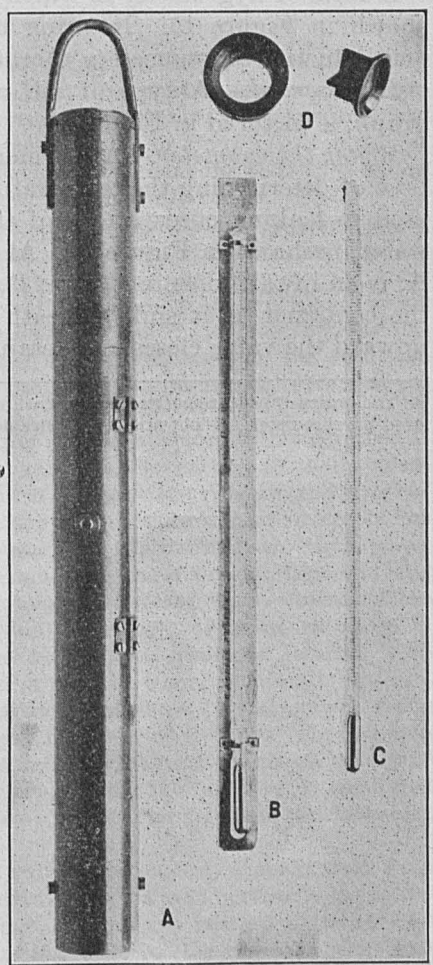


FIG. 17.—Water thermometer

1. *Preparation of wet-bulb thermometer.*—Certain precautions must be observed in preparing and fitting muslin covering of the wet bulb as follows:

(*a*) Fine, preferably loosely woven, muslin is the best, and, if new material is used, it must first be thoroughly washed with water to remove all sizing as far as possible.

(*b*) The covering must be carried up on the stem of the thermometer above the bulb a distance so that the stem near the bulb, as well as the bulb itself, is cooled by the evaporation.

(*c*) The muslin must be thoroughly wetted when a new piece is to be applied to the bulb, and fitted in the manner already explained.

A form of hygrometer in which the thermometers are stationary is shown in Figure 15. In using this device care must be taken to ventilate the thermometers thoroughly in making an observation.[1]

Hygrograph.—A type of self-registering hygrometer, or hygrograph, is pictured in Figure 16.

Water thermometer.—A thermometer mounted for the special purpose of determining the temperature of a body of water, and chiefly used in making observations of the temperature of the surface sea water, is shown in Figure 17. At the bottom of the brass container, A, is an inward-opening valve, D, which permits the water to enter the container as it sinks beneath the surface. Upon being drawn upward the valve closes and retains the water.

[1] The ordinary psychrometric tables, of which the constants were determined for a ventilated psychrometer, are not strictly applicable to the readings of a stationary hygrometer.

PART III

CLOUDS AND FOGS[1]

The deposition of dew, the forming of hoarfrost, and the sweating of ice pitchers, all examples of surface condensation, show that atmospheric moisture promptly condenses upon any object whose temperature is below the dew point. Similarly, volume condensation takes place in the form of a fog or cloud of innumerable droplets, or ice spicules, throughout the body of ordinary air whenever by expansion or otherwise it is sufficiently cooled.

Volume condensation may be induced in the atmosphere by any cooling process, whether by radiation, as on clear nights; mixing warmer with colder masses of air; movement of relatively warm air over cold surfaces, as in the case of winter south winds (Northern Hemisphere); or expansion, owing either to convection or barometric depression. But the cooling process has much to do with determining the extent of the condensation, the kind and amount of precipitation from it, and its general appearance, according to which it is chiefly classified.

Whenever warm, humid air drifts over a cold surface its temperature is reduced throughout the lower turbulent layers by conduction to that surface and by mixture with remaining portions of the previous cold air and a correspondingly dense fog produced. Hence fog often occurs during winter in the front portion of a weak cyclone; also whenever air drifts from warm water to cold—from the Gulf Stream, for instance, to the Labrador Current; and wherever gentle ocean winds blow over snow-covered land—circumstances that justify the terms "winter fog" and "sea fog" (drifting on shore in places, and even some distance inland at times). Similarly, a cold wind drifting or spreading under and through a body of warm, humid air also produces a fog, though usually a comparatively light one. This explains the fog that frequently forms during winter along the front of a "high," and the thin fog that occasionally is seen over lakes on frosty autumn mornings, when the water appears to be steaming—actually evaporating into air already saturated and thus inducing condensation. It also explains the frequent occurrence of "frost smoke" on polar seas.

If the wind is strong the turbulence extends through a comparatively deep layer. Hence in the case of warm air drifting over a cold surface if the movement is rapid the total duration of contact between any portion of the air and that surface is likely to be so brief that but little cooling can take place and no fog be formed. Similarly, it usually also happens that fog does not form when the cold wind blowing over a warm, humid region is even moderately strong. Here the turbulence mixes the excessive moisture near the surface through so large a volume that saturation commonly is not produced, nor, therefore, any trace of fog.

From the above it appears that all fogs that result from the drifting of warm, humid air over cold surfaces, as also those that are produced by the flow

[1] Abridged from Physics of the Air, W. J. Humphreys, and Cloud Forms, U. S. Weather Bureau.

of cold air over warm, humid regions, are but effects of temperature changes induced by the horizontal transportation of air.

Distinction between fog and cloud.—Volume condensation is divided primarily into fog and cloud, but a sharp distinction between them that would enable one always to say which is which is not possible. In general, however, a fog differs from a cloud only in its location. Both are owing, as explained, to the cooling of the atmosphere to a temperature below its dew point, but in the case of the cloud this cooling usually results from vertical convection, and hence the cloud is nearly always separated from the earth, except on mountain tops. Fog, on the other hand, is induced by relatively low temperatures at and near the surface, and commonly itself extends quite to the surface, at least during the stage of its development. In short, fog consists of water droplets or ice spicules condensed from and floating in the air near the surface; cloud, of water droplets or ice spicules condensed from and floating in the air well above the surface. Fog is a cloud on the earth; cloud a fog in the sky. Light fog is sometimes designated as haze, though in practice it is preferable to restrict the use of the word "haze" to the obscurity, when the air is dry, due to dust or smoke.

Classification of clouds.—The classification of clouds is based upon their form and appearance. However, there is a close relationship between the form of clouds and their height, as shown by actual measurements, so that a classification according to form or appearance is also in effect one according to height. There is a single exception to this general rule, the alto-stratus. This form of cloud occurs over a wide range of heights, with no well-defined one of maximum frequency.

The relationship between the form and height of clouds makes it possible, when clouds are present, to gain information regarding the wind aloft by assigning the clouds to the height of their maximum frequency and observing their direction and velocity.

The heights of the principal cloud forms, according to measurements made at Blue Hill, Mass.,[2] are as follows:

Cirrus.—Maximum frequency, both summer and winter, 8,000 to 8,400 meters, with a secondary summer maximum between 10,800 and 11,200 meters and a secondary winter maximum between 10,000 and 10,400 meters. Seven-tenths of all cirrus occur between the heights of 7,600 and 11,200 meters.

Cirro-stratus.—Maximum summer frequency, 10,000 to 10,800 meters, the remainder occurring mostly between 8,000 and 12,400. In winter this form occurs at lower levels, all the way from 4,400 to 12,000, with a not very well defined maximum frequency between 8,400 and 8,800 meters.

Cirro-cumulus.—Maximum frequency, 6,000 to 7,200 meters, the remainder occurring about equally above and below these levels but with none above 9,600 meters.

Alto-cumulus.—Maximum frequency, 3,000 meters, with a secondary summer maximum at 5,000 meters and a secondary winter one at 6,400 meters.

Strato-cumulus, cumulus, and nimbus.—These forms occur comparatively near the ground, mostly below 2,000 meters and seldom above 3,000 meters.

The following definitions are taken from the International Cloud Atlas, 2d edition:

Cirrus (Ci.).—*Detached clouds of delicate and fibrous appearance, often showing a feather-like structure, generally of a whitish color.* Cirrus clouds take the most varied shapes, such as isolated tufts, thin filaments on a blue

[2] Clayton, H. Helm: Observations made at the Blue Hill Meteorological Observatory: Annals of the Astronomical Observatory of Harvard College, Vol. XL, Part V, p. 253.

sky, threads spreading out in the form of feathers, curved filaments ending in tufts, sometimes called *Cirrus uncinus*, etc.; they are sometimes arranged in parallel belts which cross a portion of the sky in a great circle, and by an effect of perspective appear to converge toward a point on the horizon, or, if sufficiently extended, toward the opposite point also. (Ci.-St. and Ci.-Cu., etc., are also sometimes arranged in similar bands.)

Cirro-stratus (Ci.-St.).—*A thin, whitish sheet of clouds* sometimes covering the sky completely and giving it only a milky appearance (it is then called *Cirro-nebula*), at other times presenting, more or less distinctly, a formation like a tangled web. This sheet often produces halos around the sun and moon.

Cirro-cumulus (Ci.-Cu.), **Mackerel Sky.**—*Small globular masses or white flakes without shadows, or showing very slight shadows, arranged in groups and often in lines.* [Small A.-Cu. may also be "Mackerel Sky."]

Alto-stratus (A.-St.).—A thick sheet of grey or bluish colour, sometimes forming a compact mass of dark grey colour and fibrous structure. At other times the sheet is thin, resembling thick Ci.-St. and through it the sun or the moon may be seen dimly gleaming as through ground glass. This form exhibits all changes peculiar to Ci.-St., but from measurements its average altitude is found to be about one-half that of Ci.-St.

Alto-cumulus (A.-Cu.).—*Largish globular masses, white or greyish, partly shaded, arranged in groups or lines, and often so closely packed that their edges appear confused.* The detached masses are generally larger and more compact (resembling St.-Cu.) at the center of the group, but the thickness of the layer varies. At times the masses spread themselves out and assume the appearance of small waves or thin slightly curved plates. At the margin they form into finer flakes (resembling Ci.-Cu.). They often spread themselves out in lines in one or two directions.

Strato-cumulus (St.-Cu.).—*Large globular masses or rolls of dark cloud often covering the whole sky, especially in winter.* Generally St.-Cu. presents the appearance of a grey layer irregularly broken up into masses of which the edge is often formed of smaller masses, often of wavy appearance resembling A.-Cu. Sometimes this cloud-form presents the characteristic appearance of great rolls arranged in parallel lines and pressed up against one another. In their centers these rolls are of a dark colour. Blue sky may be seen through the intervening spaces, which are of a much lighter colour. St.-Cu. clouds may be distinguished from Nb. by their globular or rolled appearance, and by the fact that they are not generally associated with rain.

Cumulus (Cu.), **Woolpack Clouds.**—*Thick clouds of which the upper surface is dome-shaped and exhibits protuberances while the base is horizontal.* These clouds appear to be formed by a diurnal ascensional movement which is almost always noticeable. When the cloud is opposite the sun the surfaces facing the observer have a greater brilliance than the margins of the protuberances. When the light falls aslant, as is usually the case, these clouds throw deep shadows; when, on the contrary, the clouds are on the same side of the observer as the sun, they appear dark with bright edges.

True cumulus has well-defined upper and lower limits, but in strong winds a broken cloud resembling cumulus is often seen in which the detached portions undergo continual change. This form may be distinguished by the name *Fracto-cumulus* (Fr.-Cu.).

Cumulo-nimbus (Cu.-Nb.), **Thunder Cloud; Shower Cloud.**—*Heavy masses of cloud rising in the form of mountains, turrets, or anvils, generally surmounted by a sheet or screen of fibrous appearance (false cirrus), and having at its base a mass of cloud similar to nimbus.* From the base local showers of rain

or snow (occasionally of hail or soft hail) usually fall. Sometimes the upper edges assume the compact form of cumulus, and form massive peaks round which delicate "false cirrus" floats. At other times the edges themselves separate into a fringe of filaments similar to cirrus clouds. This last form is particularly common in spring showers.

The front of thunderclouds of wide extent frequently presents the form of a large arc spread over a portion of a uniformly brighter sky.

Nimbus (Nb.), **Rain Clouds.**—*A thick layer of dark clouds without shape and with ragged edges,* from which *steady* rain or snow usually falls. Through the openings in these clouds an upper layer of Ci.-St. or A.-St. may be seen almost invariably. If a layer of Nb. separates up in a strong wind into shreds, or if small loose clouds are visible floating underneath a large Nb., the cloud may be described as *Fracto-nimbus* (Fr.-Nb.) ("Scud" of sailors).

Stratus (St.).—*A uniform layer of cloud resembling a fog but not resting on the ground.* When this sheet is broken up into irregular shreds in a wind, or by summits of mountains, it may be distinguished by the name *Fracto-stratus* (Fr.-St.).

Cirrus, tufted form

Mount Wilson, Calif.

F. Ellerman

PLATE II

Cirrus merging into cirro-stratus

Washington, D. C.

A. J. Henry

PLATE III

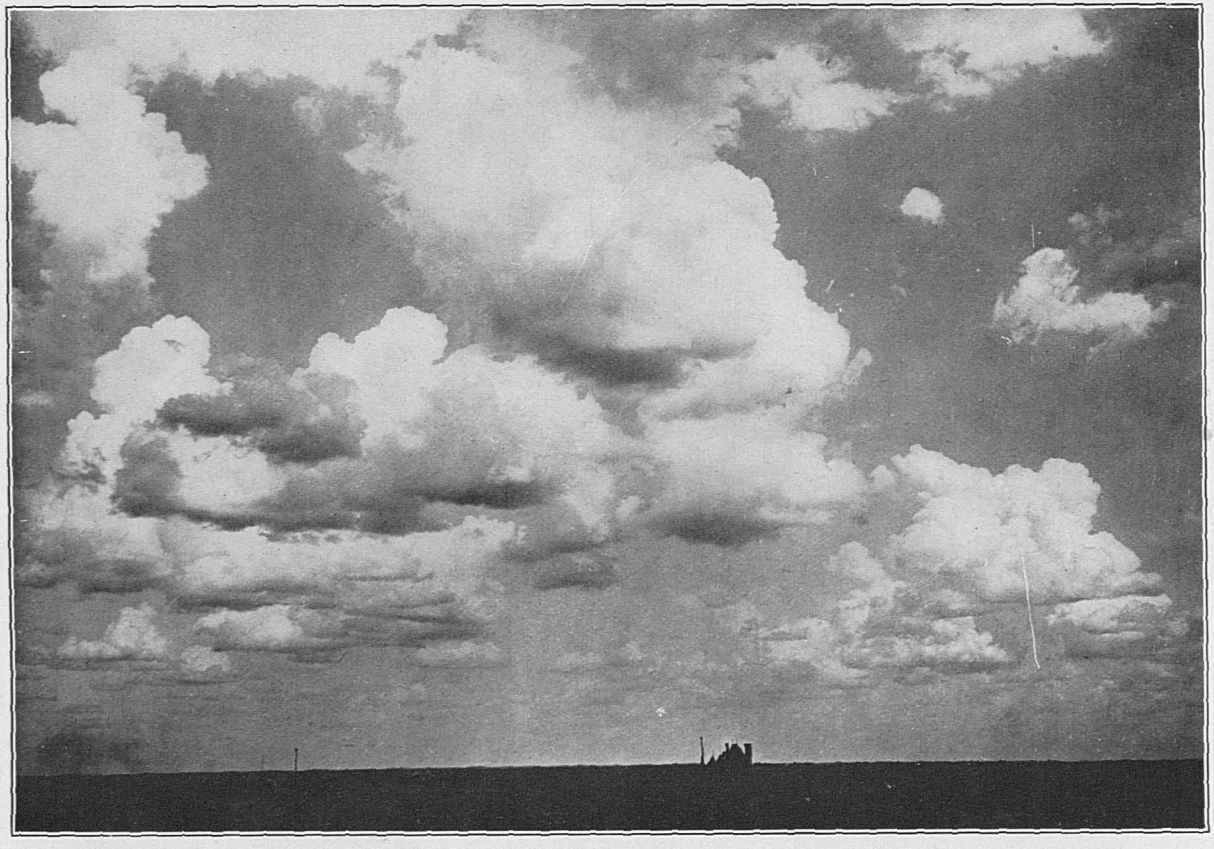
Cirro-cumulus, overhead

Mount Wilson, Calif. E. E. Barnard

Alto-cumulus

Mount Weather, Va

A. J. Weed



Cumulus

Topeka, Kans

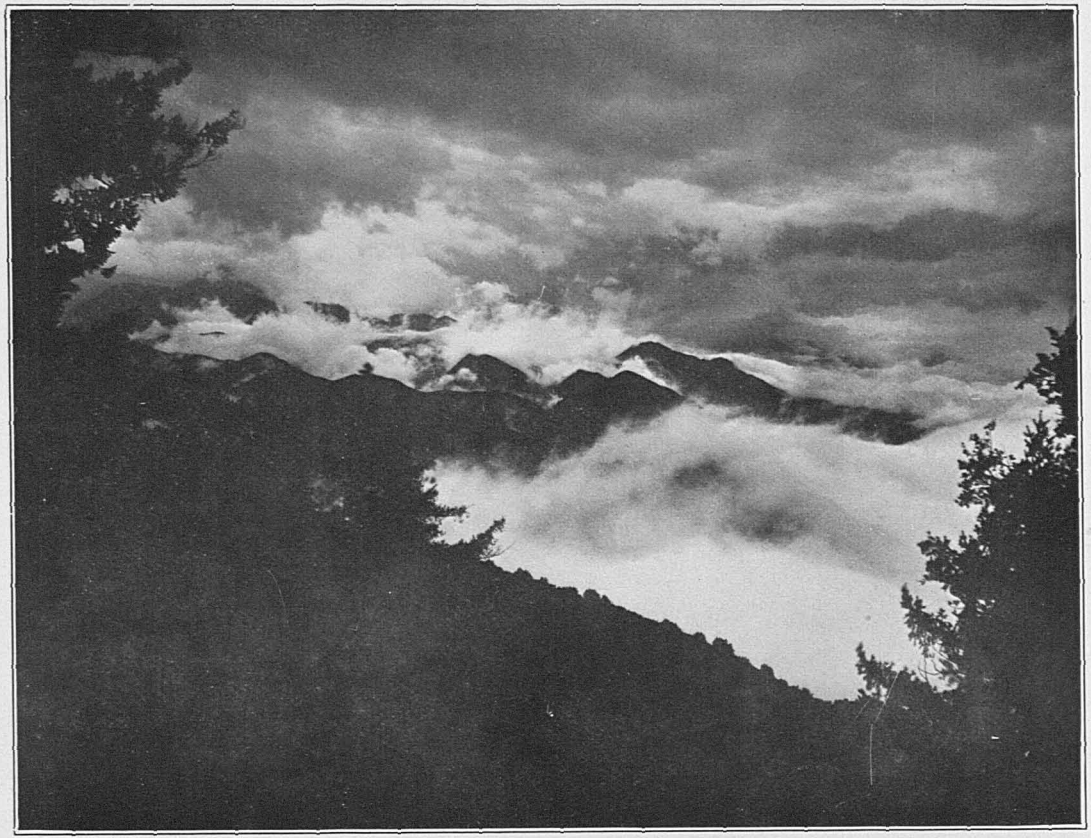
W. M. Lyon

Cumulo-nimbus, just grown from cumulus

Mount Wilson, Calif. F. Ellerman

Strato-cumulus or alto-cumulus, photographed from an altitude of about 5,700 feet. These same clouds would be called strato-cumulus by an observer nearer to them and alto-cumulus by an observer farther from them (as at sea level).

Mount Wilson, Calif. F. Ellerman



Nimbus, with fog or stratus below

Mount Wilson, Calif.

F. Ellerman

PART IV

OPTICAL PHENOMENA

The material appearing under this heading has been taken, with some modifications, from the work, "Physics of the Air," by Prof. W. J. Humphreys, of the Weather Bureau. It is, of necessity, very much abridged from the original and consists principally of definitions and descriptions.

Many curious and beautiful phenomena, of which the mirage, the rainbow, the halo, the azured sky, and the twilight glow, are some of the more conspicuous, are due to the optical properties of the air and the foreign substances suspended in or falling through it. All, or nearly all, of them have been the objects of innumerable observations and many careful studies, the results of which, fortunately, have been summarized and discussed by various authors, of whom perhaps the best known are Pernter and Exner.

Most optical phenomena attract the attention of observers, some by their beauty, others on account of the rarity of occurrence. Many of them are more or less closely connected with the weather. All are of importance for one reason or another and call for careful observance and accurate description.

PERSPECTIVE PHENOMENA

Apparent stair-step ascent of clouds.—The stair-step appearance of the echelon cloud is perhaps, the simplest sky phenomenon due to perspective. The clouds producing this effect on the eye of the observer are more or less evenly spaced, flat-bottomed cumuli of the same base elevation—flat-bottomed and of constant level because of the approximately uniform horizontal distribution of moisture.

Since the clouds are at a higher level than the observer, each successive cumulus, as the distance increases, is seen at a lower angle than its predecessor; and the dark bases of any two adjacent clouds appear to be connected by the lighter side of the farther one, thus forming the alternate "tread" and "riser" of the stair-step.

Apparent arching of cloud bands.—The arching of narrow cloud bands, in a curve resembling the conchoid, is an optical illusion, due entirely to the projection of the cloud (above the observer's level) upon the sky. The amount of arching increases with the closeness (and elevation) of the cloud.

Apparent divergence and convergence of crepuscular rays (sunbeams).—Everyone is familiar with the beautiful phenomenon of the "sun drawing water," in which sunbeams, finding their way through rifts in the clouds, are rendered luminous by the dust in their courses, in the same manner as when

passing through a window into a room. Equally familiar and equally beautiful are also those streaks and bands of pearly light (when the lower atmosphere is illuminated) and azure shadows (where only the upper atmosphere is illuminated) that often at twilight and occasionally at dawn radiate far out from the region of the sun, and at times even converge towards the opposite point of the horizon. These, too, are only beams of sunlight and shadow bands caused by broken clouds or irregular horizon. Coming, as they do, from the sun, some 93,000,000 miles away, necessarily the beams are practically parallel. Their apparent divergence, convergence, and arching are all illusions due to perspective, just as in the case of the seeming convergence of rails on a long straight track.

Other phenomena due to perspective are the apparent divergence of auroral streamers; the apparent flattening of the dome of the sky (more noticeable when the sky is covered with high cirrus clouds); the change, with elevation, of the apparent size of sun and moon, and a similar change in the apparent distance between neighboring stars.

REFRACTION PHENOMENA

Refraction phenomena are due to irregularities in the density of the atmosphere. Some, such as the scintillation or twinkling of stars, have been observed and studied since remote times, certainly since the days of Aristotle (384–322 B. C.), who noted the fact that stars twinkle while planets shine with comparatively steady lights.

It is true that on account of their sensible disks the scintillation of planets is much less than that of fixed stars, but under favorable circumstances it is quite perceptible. Even the rims of the sun and moon boil or "scintillate" while, of course, any fine marking on either or on a planet is quite as unsteady as the image of a fixed star.

Nature of irregularities.—It is well known that the atmosphere, generally, is so stratified that with increase of elevation many more or less abrupt changes occur in temperature, composition, density, and therefore, refrangibility. As such layers glide over each other, billows are formed, and the adjacent layers thereby corrugated. The several layers frequently also heat unequally, largely because of disproportionate vapor contents, and thereby develop, both day and night, and at various levels, innumerable vertical convections; each moving mass differing, of course, in density from the surrounding air, and by the changing velocity being drawn out into dissolving filaments. Optically, therefore, the atmosphere is so heterogeneous that a sufficiently bright star shining through it would produce on the earth a somewhat streaky pattern of light and shade.

Shadow bands.—A striking proof of the optical streakiness of the atmosphere is seen in the well-known shadow bands that at the time of a total solar eclipse appear immediately before the second, and after the third, contact.

Terrestrial scintillation.—A bright terrestrial light of small size, such as an open electric arc, scintillates when seen at a great distance, quite as distinctly as do the stars and for substantially the same reason; that is optical inequalities due to constant and innumerable vertical convections or conflicting winds.

Shimmering.—The tremulous appearance of objects. The common phenomenon of shimmering, seen through the atmosphere immediately over any heated surface, is another manifestation of atmospheric refraction, and is due to the innumerable fibrous convections that always occur over such an area.

Optical haze.—The frequent indistinctness of distant objects on warm days when the atmosphere is comparatively free from dust, and ascribed to optical haze, is due to the same thing, namely, optical heterogeneity of the atmosphere, which causes that unsteadiness or dancing of star images that so often interferes with the positional and other exact work of the astronomer. Both are but provoking manifestations of atmospheric refraction.

Times of rising and setting of sun, moon, and stars.—An interesting and important result of astronomical refraction is the fact that the sun, moon, and stars rise earlier and set later than they otherwise would. For places at sea level the amount of elevation of celestial objects on the horizon averages about 35′, and therefore the entire solar and lunar disks may be seen before (on rising) and after (on setting) even their upper limbs would have appeared, in the first case, or disappeared, in the second, if there had been no refraction. This difference in time of rising, or setting, depends on the angle or inclination, of the path to the horizon.

Green flash.—As the upper limb of the sun disappears in a clear sky below a distant horizon its last star-like point often is seen to change rapidly from pale yellow or orange to green and finally blue, or, at least, a bluish-green. The vividness of the green, when the sky is exceptionally clear, together with its almost instantaneous appearance, has given rise to the name "green flash" for this phenomenon. The same gamut of colors, only in reverse order, occasionally is seen at sunrise.

Terrestrial refraction.—The curving of rays of light is not confined to those that come from some celestial object, but applies also to those that pass between any points within the atmosphere, whether at the same or different levels. This latter phenomenon, known as terrestrial refraction, causes all objects on the earth or in the atmosphere to appear to be at greater altitudes than they actually are, except when the surface air is so strongly heated as to cause an increase of density with elevation.

The distance to the horizon, corresponding to a given altitude, therefore obviously depends upon the rate of vertical density decrease.

Looming.—When there is an increase over the normal rate of vertical density decrease, such as often happens over water in middle to high latitudes, it gives rise to the phenomenon known as looming, or the coming into sight of objects normally below the horizon.

Towering.—This phenomenon is similar to looming, and sometimes is so designated. It occurs, as occasionally happens, when the inversion layer is so located that rays to the observer from the top of an object are more curved than those from the bottom. The effect is to make the top appear more elevated—it will tower and seem to draw near.

Sinking.—A phenomenon, exactly the reverse of looming, also frequently observed at sea. It is caused by a *decrease* below the normal in the rate of vertical density decrease of the atmosphere.

Stooping.—The reverse of towering. Occasionally rays from the base of an object may be curved downward much more rapidly than those from the top, with the obvious result of apparent vertical contraction, and the production of effects quite as odd and grotesque as those due to towering.

REFRACTION BY WATER DROPS

Rainbow.—The ordinary rainbow, seen on a sheet of water drops—rain or spray—is a group of circular or nearly circular arcs of colors whose common center is on the line connecting the observer's eye with the exciting light (sun, moon, electric arc, etc.), or rather, except rarely, on that line extended in the

direction of the observer's shadow. A very great number of rainbows are theoretically possible and doubtless all actually occur, though only three (not counting supernumeraries) certainly have been seen on sheets of rain.

Rainbows are produced by a complicated process of refraction of sunlight as it enters and passes out of the raindrops, internal reflection of the light within the drops, and interference of the rays after leaving the drops (Davis).

The records of close observations of rainbows soon show that not even the colors are always the same; neither is the band of any color of constant angular width; nor the total breadth of the several colors at all uniform; similarly the purity and brightness of the different colors are subject to large variations. The greatest contrast, perhaps, is between the sharply-defined brilliant rainbow of the retreating thunderstorm and that ill-defined faintly tinged bow that sometimes appears in a mist—the "white bow" or "fog bow."

All these differences depend essentially upon the size of the drops, and therefore inequalities often exist between even the several portions, especially top and bottom of the same bow, or develop as the rain progresses. Additional complications occasionally result from the reflection of bows and from bows produced by reflected images of the sun, but though unusual and thus likely to excite wonder and comment such phenomena are easily explained.

Supernumerary bows.—Rather narrow bands of color, essentially red, or red and green, often appear parallel to both the primary and the secondary bows, along the inner side of the first and outer of the second. These also differ greatly in purity and color, number visible, width, etc., not only between individual bows but also between the several parts of the same bow. No such colored arcs, however, occur between the principal bows.

REFRACTION BY ICE CRYSTALS

The cirrus clouds and others formed at temperatures considerably below 0° C. usually consist of small but relatively thick snowflakes with flat bases, or ice spicules with flat or, rarely, pyramidal bases, always hexagonal in pattern and detail.

Light from the sun, for instance, obviously takes many paths through such crystals and produces in each case a corresponding and peculiar optical phenomenon. Several of these phenomena, the halo of 22° radius, the halo of 46° radius, the circumzenithal arc, parhelia, etc., are quite familiar and their explanations definitely known. Others, however, have so rarely been seen and measured that the theories of their formation are still somewhat in doubt. Finally, many phenomena, theoretically possible, as results of refraction by ice crystals, appear so far to have escaped notice. The more common forms of halos, as well as some phenomena less frequently observed, are illustrated in figures 18 and 19.

The most frequent of the numerous phenomena caused by the passage of light through ice crystals, of which the halo of 22° is an example, are occasioned by prismatic refraction between the sides of the hexagonal spicules, forming angles of 60° with each other. The less numerous phenomena, among which is the halo of 46°, are caused by refraction between the sides and bases of spicules, forming angles of 90° with each other.

Parhelia of 22°.—Whenever the air through any depth or at any level contains innumerable hexagonal snow crystals with their sides vertical (the position about which relatively broad crystals oscillate), two colored bright spots, known as parhelia or sun dogs, appear at 22°, or more, from the sun, one to the right, the other to the left. Each bright spot is in the direction of maximum light or minimum refraction, and has the same altitude as the sun.

Halo of 22°.—When the refracting edges of the ice crystals are vertical, as they tend to be in the case of relatively thin snowflakes falling through still air, parhelia are produced, as just explained. But, in general, these edges lie in all directions, especially at the windy cirrus level and when the crystals

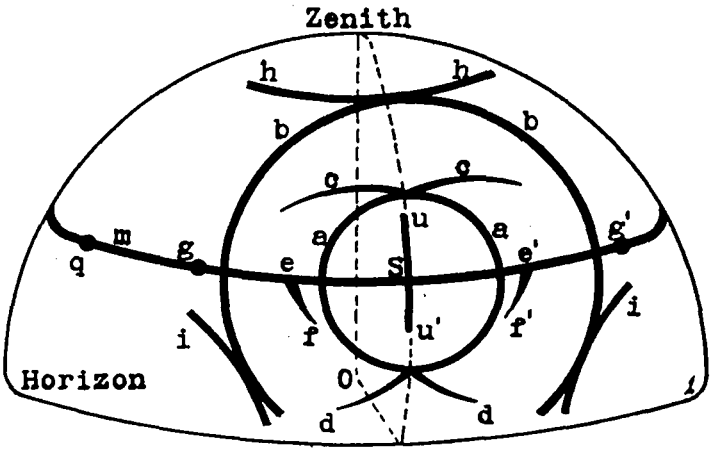


FIG. 18.—Perspective view of the sky, showing the Sun (S); ordinary halo of 22° (a); great halo of 46° (b); upper tangent arc of the halo of 22° (c); lower tangent arc of the halo of 22° (d); ordinary parhelia of 22° (e, e'); Lowitz arcs (f, f'); parhelia of 46° (g, g'); circumzenithal arc (h); infralateral tangent arcs of the halo of 46° (i); the parhelic circle (m); a paranthelion of 90° (q); plane of the horizon; the observer (O)

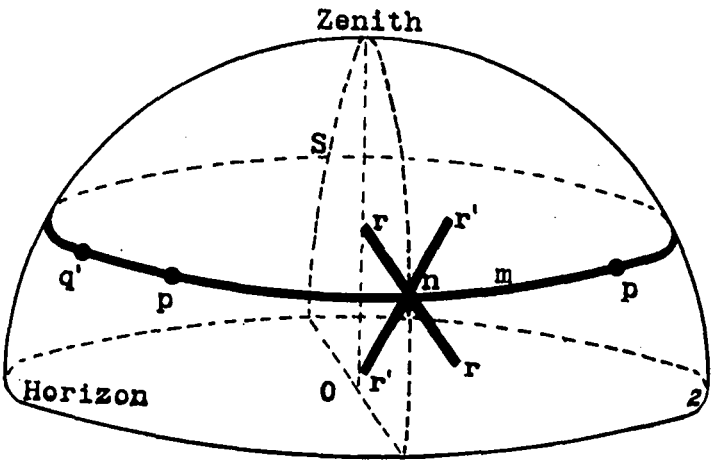


FIG. 19.—Perspective view of the sky, showing the observer (O); his horizon, and his meridian (O S zenith, n); the parhelic circle (m); ordinary paranthelia of 120° (p); the paranthelion of 90° (q'); the oblique arcs of the anthelion (r, r'); and the anthelion (n)

are of the short columnar type; and as refracted light reaches an observer in every plane through his eye and the sun (or moon) to which the refracting edges are approximately normal, it follows that the effect produced by fortuitously directed snow crystals must be more or less symmetrically dis-

tributed on all sides of the exciting luminary. There may, however, be a maximum brightness both directly above and directly below the sun since ice needles tend to settle with their refracting edges horizontal.

This condition gives rise to the halo of 22°, the most frequent and best known of the halo family. Its inner portion is red, because light of that color is least refracted. Other colors follow, with increase of distance, in the regular spectral sequence, but with decrease of wave length they so rapidly fade that even green is indistinct and blue seldom detected.

When the sun is within 10° of the horizon, the halo of 22° and the parhelia of 22° are practically superimposed. At greater altitudes they become distinctly separated.

Tangent arcs of the halo of 22°.—These are the well-known and fairly common arcs that occur above and below the circular halo. These arcs change with the elevation of the sun. Portions below the natural horizon can only be seen from sufficient height. The horizontal tangent arcs are produced by crystals whose principal axes are horizontal, which is the position in which ice spicules or needles tend to float.

Arcs of Lowitz, or vertical arcs of the 22° parhelia.—On rare occasions oblique extensions of the parhelia of 22°, concave toward the sun and with red inner borders, are seen. These are known as the arcs of Lowitz, after the astronomer who described them as seen in the famous Petersburg halo complex of July 18, 1794.

Produced by crystals whose principal axes oscillate in that particular vertical plane that passes through the sun, they are nearly always too faint to be seen, because, in part, this unique attitude can only rarely be assumed by any considerable proportion of the crystals present.

Parhelia of 46°.— Similar to the parhelia of 22°, but due to refraction between the sides and ends of snow crystals, having an angle of intersection of 90°, when the intersection is vertical.

Halo of 46°.—The image of the sun produced in the principal plane of a 90° refracting angle of an ice crystal, as seen by the observer, is 45° 44′ from the sun itself. Hence it follows that when such crystals are very abundant and set at random in all directions the innumerable images so produced must together assume the shape of a ring about the sun of radius 45° 44′. This is the well-known, though not very common, halo of 46°.

Halo of 90°.—Occasionally a faint white halo, sometimes called the halo of Hevelius, is seen at 90° from the sun.

Circumzenithal arc.—Occasionally, an arc of, perhaps, 90°, having its centre at the zenith, and, therefore, known as the circumzenithal arc, is seen some 46°, or a little more, above the sun. It generally lasts only a few minutes, about five on the average, but during that time often is so brilliantly colored, especially along that portion nearest the sun—red on the outside, to violet inclusive—as to be mistaken by persons unfamiliar with it for an exceptionally bright rainbow. It occurs most frequently when the altitude of the sun is about 20° and at times when the parhelia of 22° are conspicuous. Presumably, therefore, when the principal axes of a large portion of the crystals are practically vertical.

Kern's arc.—So called from the name of the first observer to report it. It occurs exactly opposite the corresponding circumzenithal arc and on the same circle. It might, therefore, also be called the anticircumzenithal arc.

Circumhorizontal arc.—A colored arc, red on the upper side, of perhaps 90° in extent, occasionally seen parallel to the horizon and about 46°, or a little more, below the sun.

Lateral tangent arcs of the halo of 46°.—Just as flat-topped crystals with vertical sides produce a circumzenithal arc when the altitude of the sun is between 0° and 32° 12′, so, too, similar crystals whose axes are horizontal and directed toward any point whose solar distance is between 90° and 57° 48′, or between 0° and 32° 12′, produce a colored arc—red next the sun—about this directive point as a centre. And as there are two such points corresponding to each solar distance, one to the right, the other to the left, of the solar vertical, it follows that arcs formed in the above manner are symmetrically situated with respect to this vertical. Further, when the solar distance of the directive points is 67° 52′ or 22° 8′, the resulting arc is tangent to the halo of 46°, and as always some, at least, of the innumerable crystals are turned toward this point, except when the altitude of the sun is greater than these values, respectively, it follows, with the same exceptions, that the blend of the numerous arcs produced by the various directed crystals is always tangent to the halo of 46°, and also that except near the point of tangency only the red of these blends is reasonably pure.

Infralateral tangent arcs of the halo of 46°.—Produced when the altitude of the sun is less than 67° 52′.

When the altitude of the sun is 57° 48′, or a little greater, the two tangent arcs, springing from a common point on the solar vertical, form a wide V.

When the solar altitude equals 67° 52′, the two arcs, now merged into a smooth continuous curve, are tangent to the halo at its lowest point.

Finally, for altitudes of the sun greater than 67° 52′, the arcs, still appearing as a single curve, are slightly separated from the circular halo even at its lowest and closest point.

Supralateral tangent arcs.—When the altitude of the sun is less than 22° 8′ supralateral tangent arcs similar to the infralateral are produced.

Halos of unusual radii.—Halos of various radii other than those already given have occasionally been reported. They can readily be accounted for on the assumption that the columnar ice crystals have certain pyramidal bases that afford the appropriate refraction angles.

Secondary halos.—Obviously, each bright spot of the primary halo phenomena, especially the upper and lower points of the 22° circle and its parhelia, must in turn be the source of secondary halos. Doubtless, the 22° halos of the lateral parhelia contribute much to the flaring vertical column through the sun that occasionally has been seen; and, perhaps, the brilliant upper and lower points of the halo of 22° may produce faint secondary parhelic circles. In general, however, very few of the secondary halos are ever bright enough to be seen even when carefully looked for.

Singular halos.—A few halos not included in any of the above classes have been once reported. No satisfactory explanations of them have been offered. Clearly, though, since the ice crystal appears in many modified forms—with flat tabular, and pyramidal ends, for instance—and even in orderly clusters, it is obvious that although only a few halos are well known, a great many are possible.

DIFFRACTION PHENOMENA

Coronas.—Coronas consist of one or more sets of rainbow-colored rings, usually of only a few degrees radius, concentrically surrounding the sun, moon, or other bright objects when covered by a thin cloud veil. They differ from halos in having smaller (except in rare cases) and variable radii, and in having the reverse order of colors; that is, blue near the sun, say, and red farthest away.

Clearly, then coronas are caused by diffraction, or the distribution of effective (nonneutralizing) quantities of light off the primary path, resulting from the action of cloud particles on radiation from a distant source.

When coronas are seen in clouds whose temperature is above 0° C., or in which halos do not form, it is certain that they are due to droplets. The most brilliant coronas, however, are formed by very high clouds, whose temperatures often must be far below freezing, from which it has been assumed that these coronas must be due to the diffractive action of ice needles. There are reasons, however, for believing that they are due instead to very small undercooled water droplets of approximately uniform size.

Iridescent clouds.—Thin and perhaps slowly evaporating cirro-stratus and cirro-cumulus clouds occasionally develop numerous iridescent borders and patches of irregular shape, especially of red and green, at various distances from the sun up to 30° or more. A brilliantly colored iridescent cloud of considerable area is justly regarded as one of the most beautiful of sky phenomena. Imperfectly explained until recently it is now believed that these colored patches are only fragments of unusually large and exceptionally brilliant coronas, formed as described in the preceding paragraph.

MIRAGE

The mirage is a refraction phenomenon occasioned when the air is calm and a strong temperature inversion exists at a short distance above the surface, say 30 or 40 feet. Under such conditions the relation of decrease of density to increase of elevation is irregular, and therefore the velocity of light traveling horizontally through the air must also increase irregularly with increase of elevation. Where the density of the layers decreases from the ground upward more rapidly than the normal rate, as it does when the ground is covered with a layer of very cold air, the rays of light are bent toward the earth and the mirage is seen raised above the object, which may be below the horizon at the time. This form of the phenomenon, in which the mirage appears as if reflected from an overhead plane mirror, is known as the *superior* mirage.

If, on the other hand, the density increases from the ground upward faster than the normal rate, as it does over highly heated deserts, the rays are bent upward and the image appears as if reflected from a plane mirror below the observer. This is the *inferior* mirage, common in flat desert regions, especially during the warmer hours of the day. The phenomenon closely simulates, even to the quivering of the images, the reflection by a quiet body of water of objects on the distant shore, the "water" being the image of the distant low sky.

In addition to these simpler forms of mirage there is one of complex displacements and distortions known as the *Fata Morgana*, which, apparently, results from the coexistence of the temperature disturbances peculiar to both the superior and inferior mirage. The name Fata Morgana has become generic for all such multiple images, wherever they occur.

AURORA POLARIS

The aurora polaris is a well-known but imperfectly understood luminous phenomenon of the upper atmosphere.

Types.—While no two auroras are exactly alike, several types have been recognized, such as arcs, bands, rays, curtains or draperies, coronas, luminous patches, and diffuse glows. The arcs normal to the magnetic meridian, often, but not always, reach the horizon. Their under edge is rather sharply

defined, so that by contrast the adjacent portion of the sky appears exceptionally dark. The rays, sometimes extending upward from an arch, at other times isolated, are parallel to the lines of magnetic force. Many auroras are quiescent, others exceedingly changeable, flitting from side to side like wandering searchlights, and in some cases even waving like giant tongues of flame.

Latitude variation.—The aurora of the Northern Hemisphere occurs most frequently, about 100 per year, at the latitudes 60° (over the North Atlantic and North America) to 70° (off the coast of Siberia). Its frequency appears to be less within this boundary, while with decrease of latitude it falls off so rapidly that even in southern Europe it is a rare phenomenon. At the same latitude it is distinctly more frequent in North America than in either Europe or Asia.

The distribution of auroras in the Southern Hemisphere is not so well known, but it appears to be similar, in general, to that of the Northern.

Periodicity.—It is well established that on the average auroras are more numerous during years of sun spot maxima than during years of spot minima. They also appear to be more numerous before midnight than after. Relations of frequency to phase of the moon, season, etc., have also been discussed, but with no conclusive results.

Color.—Many auroras are practically white. Red, yellow, and green are also common auroral colors. Some streaks and bands are reddish through their lower (northern) portion, then yellowish, and finally greenish through the higher portions. Much of the light is due to nitrogen bands, but the source of the prominent green line of the auroral spectrum is not known. It has often been attributed to krypton, but other conspicuous krypton lines are absent; besides krypton is too heavy to exist at auroral heights in sufficient abundance to produce a spectrum of such brilliance.

There is good evidence that this green light, the light that produces the "auroral line," is always present in the sky, though whether wholly of auroral origin, or due in part to bombardment by meteoric dust, or to some other cause, is not known.

Height.—The problem of the height of auroras has often been investigated, but only recently solved. By simultaneously photographing the same aurora from two stations against a common background of stars, many excellent height measurements have been secured. The upper limits of the auroral light vary from about 100 kilometers to over 500 kilometers; and the lower limits from perhaps 85 kilometers to 170 kilometers, with two well-defined maxima, one at 100 kilometers, the other at 106 kilometers.

Cause.—The fact that brilliant shifting auroras are accompanied by magnetic storms renders it practically certain that they, and presumably therefore all auroras, are due to electrical discharges; and the further fact that they vary in frequency with the sun-spot period indicates that this current either comes from or is induced by the sun.

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PART V

UTILIZATION OF WEATHER DATA AT SEA

For current use weather data are best presented and interpreted by means of the weather map. With the development of radio communication at sea such maps have come into quite general use on shipboard and have become so familiar as scarcely to call for description. However, several of the steps in their construction, as well as certain general features of the weather which they so well exhibit, are of sufficient importance to warrant some repetition in the way of explanation.

It is desirable that observations to be entered on any single map be made as nearly as possible at the same moment of time and on successive maps, at uniform intervals. It is then possible, by comparing maps, to learn what changes have taken place in weather conditions over a given area within known periods of time and to draw therefrom inferences as to the character of subsequent changes and the time when they will occur.

In certain ocean areas this desideratum of simultaneous observations is realized in considerable measure as a result of arrangements made by various national meteorological services for the taking of observations on board vessels and their transmission by radio to central stations. As the hour selected for these observations is generally the same as that of the regular observations at land stations, or at any event near thereto, the arrangement provides a means whereby vessels within the same general area can obtain one or more times each day a number of simultaneous observations. In addition there are available in many areas observations from selected lists of well distributed land stations, broadcast by various national weather services. Finally, many observations are independently exchanged by vessels. From the several sources indicated a sufficient number of observations are frequently available to make possible the construction of very satisfactory weather maps.

Since the observations collected officially are transmitted by code it is necessary that persons wishing to make use of them should be able to decode the messages. Explanations of the systems employed are issued by the various national services. In collecting observations the Weather Bureau uses a word code, similar to that long used in collecting its land observations, which it has found to be more desirable and reliable for such purposes than a numerical code. In broadcasting observations, however, a numerical code is employed. As the details of broadcasting are subject to modification from time to time, it has been found desirable to describe them in circulars or in periodical publications, which may be obtained upon request. The word code being less subject to change, a description thereof has been included in these Instructions and will be found on pages 58 to 63.

Method of plotting weather data.—In the procedure followed by the Weather Bureau the first step after providing a suitable base map is to locate on the map by latitude and longitude the exact place at which the observation to be plotted was made. Here is constructed a small circle. This is left clear or is half shaded or completely shaded according as the weather is clear, partly

cloudy, or cloudy. From the circle is then drawn a short line in the direction *from* which the wind is blowing. Commencing at the extremity of this line, providing the wind is not calm or variable, small barbs or feathers are drawn, one for each number on the Beaufort scale of wind force, according to the force of the wind at the time of observation. If the wind was calm, no radial line is drawn; if variable, one or more very short radial lines, the number depending upon the force, are drawn from the circle in different directions.

The height of the barometer, generally with the first figure (2 or 3) omitted to save space, is then entered to the right of the circle, as also the air temperature. Near the circle are then placed the appropriate symbols for rain, fog, and other details of the weather included in the observation.

After all the available observations are thus plotted lines are drawn through certain selected points of equal pressure. These lines are called *isobars*. Other lines are drawn through points of equal temperature; these are called *isotherms*. Practice varies in the selection of the points for the drawing of these lines. A commonly used scale is a line for each tenth of an inch of pressure and each ten degrees of temperature.

Upon inspecting a weather map so constructed certain facts will be noted. One is that the regions of low and high barometer are more or less well defined. These are known, respectively, as cyclones and anticyclones or, more briefly, lows and highs. Within these regions the winds will be observed to blow with marked uniformity of direction and velocity. If the map represents a region in the Northern Hemisphere, the winds in an area of low pressure will be found to blow anticlockwise around the center while those in an area of high pressure blow in the opposite direction. In the Southern Hemisphere the system of wind circulation is the reverse of that in the Northern Hemisphere. There will also be observed a relationship between the closeness of the isobars and the strength of the wind, the force increasing as the isobars lie closer together.

It will also be noted that the character of the weather varies in the different parts of the cyclone and anticyclone. On the eastern side of the cyclone the winds are southerly and easterly, and if here exposed to a water area the weather is mild, unsettled, and humid, generally with rain or snow. If the cyclone is well developed, or deep, the general character of the weather on the eastern side will be stormy. These conditions as affecting moisture are modified if a land area is to the eastward of the cyclone.

For example, the weather in the different parts of two cyclones of similar size and intensity would differ materially if one were situated on the Atlantic coast of the United States and the other over the British Channel. In the one case the easterly and southerly winds on the eastern side would be blowing from a water area and therefore moisture laden, while in the other they would be blowing off a land area and contain relatively little moisture. On the western side of the cyclone conditions are, in general, the reverse of those on the eastern. Continentality must always be considered in connection with the features and behavior of cyclones and anticyclones.

If a series of maps are considered together it will be found that the areas of high and low pressure are constantly appearing and disappearing, each having a length of life depending upon widespread and more or less unknown influences. In middle and higher latitudes they also have a progressive movement from west to east. Cyclones which originate near the Equator first have a westerly movement, generally changing later to an easterly one.

Weather forecasting is based essentially upon the progressive movement of cyclones and anticyclones, each with its attendant system of winds and types of weather.

The characteristics of cyclones and anticyclones are in general determined by the circumstances of the axial rotation of the earth from west to east coupled with an interchange of air between the warm region near the Equator and the cold regions surrounding the poles.

Reproduction of synoptic charts.—On the following pages appear reproductions of two weather charts of the North Atlantic Ocean, the data for which were furnished by cooperative marine observers of the Weather Bureau. These charts were selected to show the appearance, on successive days, of representative types of winter storms. Only data for wind and pressure are reproduced.

EXPLANATION OF WEATHER BUREAU RADIOGRAPHIC CODE

The code is so devised that it may be translated without the aid of a code book, provided the key is known. The code is made up of selected words in which certain significant letters have assigned values when they appear in certain positions. Each significant letter has different values according to its position in a word and the position of the word in a message. The letters and their assigned values are as follows:

Consonants (regular)

Letter	Numerical value	Direction value
B	10	N. and NNE.
D	20	NE. and ENE.
F	30	E. and ESE.
G	40	SE. and SSE.
M	50	S. and SSW.
N	60	SW. and WSW.
R	70	W. and WNW.
S	80	NW. and NNW.
T	90	

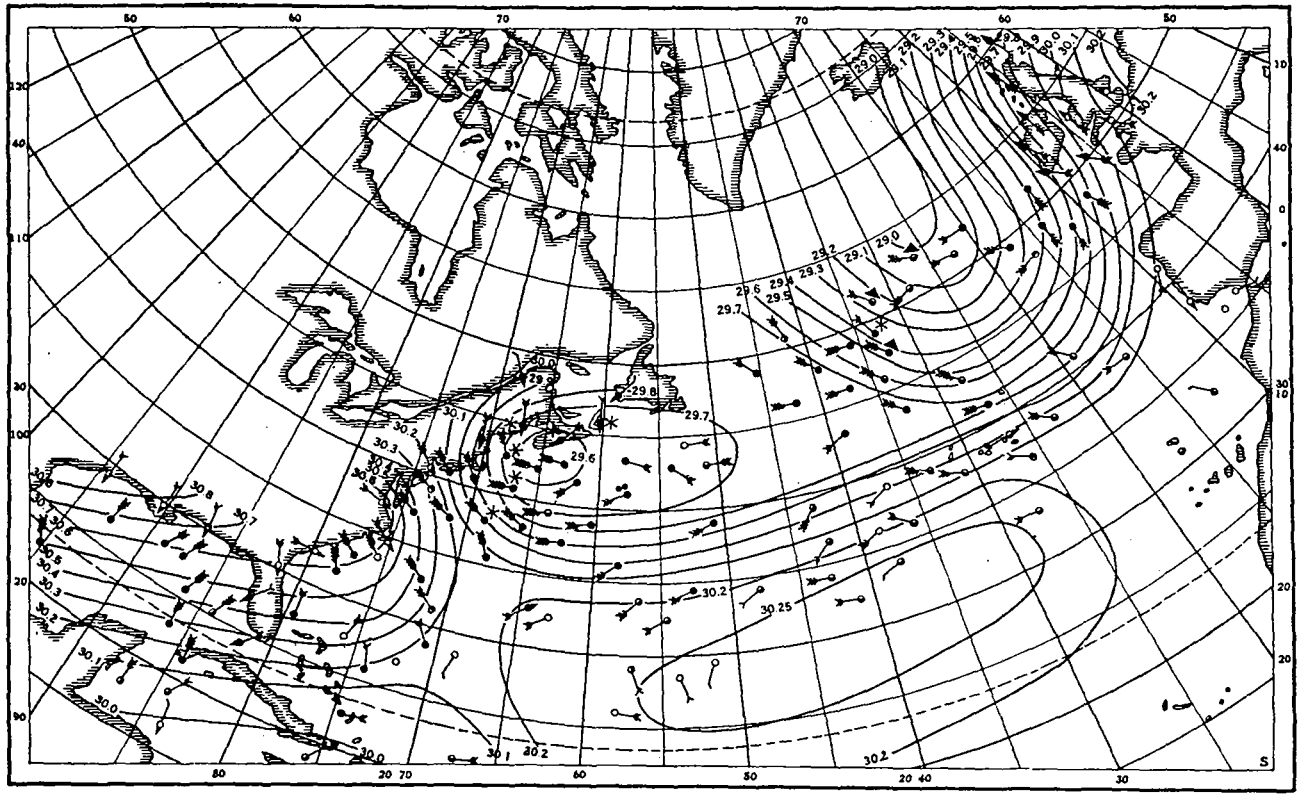
Consonants (miscellaneous)

C——cloud and date words (a. m.) begin with C.
K——pressure-change words begin with K.
H——date words (p. m.) begin with H.

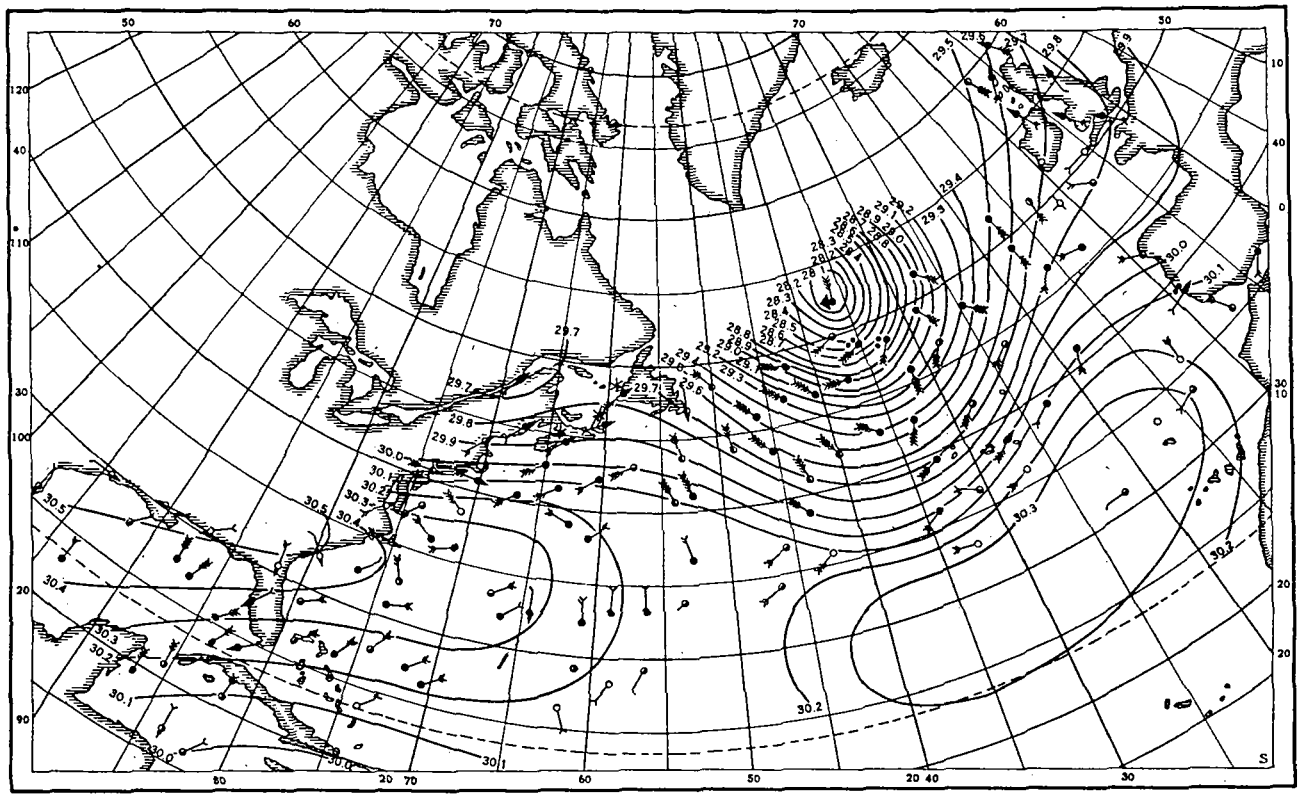
Vowels

Letter	Numerical value	Wind force	Weather	Amount of clouds
U or Y	0	Calm	Clear	1 tenth or less.
A	2		Partly cloudy	2 or 3 tenths.
E	4		Cloudy	4 or 5 tenths.
I	6		Raining	6 or 7 tenths.
O	8		Snowing	8, 9, or 10 tenths.

It will be apparent from the foregoing how any even number from 0 to 98 can be coded by using a vowel alone or a combination of a consonant and vowel, as A=2, BU or BY=10, DE=24. It is necessary, however, also to code



Weather Map, North Atlantic Ocean, January 6, 1924.



Weather Map, North Atlantic Ocean, January 7, 1924.

odd numbers in transmitting certain values, such as dates, latitude and longitude, and wind force. This detail is explained further on.

All date words begin with CA, CO, HA, or HO and all consist of two or more syllables, except the words for the first day, COACH and HOLD. C indicates an a. m. observation; H, a p. m. observation. CA and HA signify that the observation is of the even date indicated by the second syllable, while CO and HO signify that the observation is of the odd date next following. Examples:

(CA)NV(A)S. CA=morning observation.
A=day of month, or 2. The letter V has no value.

(CO)LL(A)R. CO=morning observation.
A=2, which number is to be increased by one, making observation morning of 3d.

(HA)N(DY). HA=evening observation.
DY=day, 20; D=20, Y=0.

(HO)N(DU)RAS. HO=evening observation, but value of second syllable (20) to be increased by one, making date 21st.

Latitude and longitude are coded to the nearest even six minutes. The words for latitude and longitude constitute, respectively, the second and third *code* words in a message. The first syllable of each word indicates degrees, the second syllable, minutes. The values of the second syllable always fall within two ranges, 0 to 18 and 60 to 78. If 18 or less the value is multiplied by 3 to obtain minutes. If 60 or more, since there are 60 minutes in a degree, the value of the first syllable is increased by one and the difference between 60 and the coded value is multiplied by three to obtain the minutes. Thus in the code word GARRISON, the value indicated by the first syllable, expressing degrees, is 42 (G=40, A=2). The value indicated by the second syllable, expressing minutes, is 76 (R=70, I=6), or 60+16. Adding 1 to 42 and multiplying 16 by 3 the values 43 and 48 are obtained, interpretated as 43° 48′. Other examples follow.

US. U=0; no second syllable.

(U)(NU)SUAL. $\begin{cases} \text{U=0; NU=60.} \\ 0^\circ\ 60' = 1^\circ\ 0'. \end{cases}$

(DA)MP. DA=22.

(DA)(NU)BE. $\begin{cases} \text{DA=22; NU=60.} \\ 22^\circ\ 60' = 23^\circ\ 0'. \end{cases}$

(GA)M(BI)T. $\begin{cases} \text{GA=42; BI=16; } 3\times16=48. \\ 42^\circ\ 48'. \end{cases}$

(GA)R(RI)SON. $\begin{cases} \text{GA=42; RI=76=60+16; } 3\times16=48. \\ 42^\circ+60'+48'=43^\circ\ 48'. \end{cases}$

(TE)R(RO)R. $\begin{cases} \text{TE=94; RO=78=60+18; } 3\times18=54. \\ 94^\circ+60'+54'=95^\circ\ 54'. \end{cases}$

North latitude and west longitude, are always understood unless the words EAST or SOUTH, as appropriate, precede the proper code word. When the degrees of longitude exceed 100 only the amount in excess of that number is coded.

Words commencing with the letter K appear in some messages. Such words indicate that there has been a rise or fall in the barometer of 0.10 inch or more within the two hours immediately preceding the observation. If the first vowel is A or E, a rise is indicated; if I or O, a fall. The amount of change is indicated by the first two letters of the second syllable. Examples:

(KA)L(BY). KA=rising; BY=10, or 0.10 inch.

(KI)NG(FI)SH. KI=falling; FI=36, or 0.36 inch.

Cloud words may or may not appear in a message, being radiotelegraphed only under certain conditions. They commence with the letter C, as follows: CU, Cirrus, or Cirro-Stratus; CA, Cirro-Cumulus or Alto-Cumulus; CE, Alto-Stratus; CI, Cumulus; CO, Strato-Cumulus; CH, Stratus; CL or CR, Nimbus or Cumulo-Nimbus. The direction from which moving is indicated by the consonant of the second syllable and the amount, in tenth, by the vowel. Examples:

(CI)N(N)(A)MON. CI=Cumulus; N=SW.; A=2 or 3 tenths.
(CR)OSS(B)(O)W. CR=Nimbus; B=N.; O=8–10 tenths.

The twelve divisions of the Beaufort scale of wind force are coded according to their approximate value in miles per hour. Thus the letter A, having the numerical value 2, is used to indicate force 1; I, numerical value 6, is used for force 2; BU, value 10, for force 3; BI, or 16, for force 4; DA, force 5; DO, force 6; FE, force 7; GA, force 8; MY, force 9; NY, force 10; RY, force 11; SY, force 12. For calm the word US is sent.

The significant letters have interpretive value only when they appear in the first or second syllables of the code words and the appropriate value is determined by the position of the word in the message. The order of words is as follows:

Address, as OBSERVER, WASHINGTON.

Name of observing vessel, as PRESIDENT JACKSON.

First code word. Date of observation, a. m., or p. m. If taken at any hour except 7 a. m. or 7 p. m., 75th meridian time (Greenwich mean noon and midnight) will be preceded by appropriate numeral, as SIX, TEN, NOON, etc.

Second and third code words. Latitude and longitude, to nearest even six minutes. The words EAST or SOUTH prefixed when appropriate.

Fourth code word. First syllable, pressure to nearest even hundredth of an inch (all corrections applied); second syllable, temperature to nearest even degree (Fahr.). When pressure is below 29.40 or above 30.38 this code word will be preceded by appropriate numeral for inches, SEVEN, EIGHT, NINE, THIRTY, or ONE.

Fifth code word. First syllable, wind direction to eight points, and state of weather; second syllable, wind force (Beaufort scale).

Sixth code word. Pressure change during two hours immediately preceding observation, if change amounts to 0.10 inch or more.

Seventh and subsequent code words. Cloud words. Sent only under certain conditions.

In addition to the coded data provision is made for miscellaneous uncoded information when conditions warrant. Most messages, however, consist of but five code words.

Examples of complete messages, except operator's checks, etc.:

OBSERVER, WASHINGTON. S. S. WESTERN WORLD. CODICIL. BEAVER. GIRAFFE. IRATE. FEUDAL.

Translation:

CODICIL=date word, a. m. 27th.
BEAVER=latitude, 14° 12′ (north).
GIRAFFE=longitude, 47° 36′ (west).
IRATE=pressure, 30.06 inches; temperature, 72°.
FEUDAL=wind direction, E; weather, cloudy; force, 5.

OBSERVER, WASHINGTON. S. S. SUNDANCE. CANVAS. FABELLA. RENEW. RAINY. SEGAR. CONSIST.

Translation:

CANVAS=date, a. m. 2d.
FABELLA=latitude, 32° 42′ (north).
RENEW=longitude, 75° 12′ (west).
RAINY=pressure, 29.72 inches; temperature, 60°.
SEGAR—wind direction, NW.; weather, cloudy; force, 8.
CONSIST=cloud word. Six to seven tenths St. Cu. from NW.

OBSERVER, SAN FRANCISCO. S. S. WEST JENA. HADES. GENA. RIBALD. UNGUARD. NOONDAY.

Translation:

HADES=date, a. m. 24th.
GENOA=latitude, 45° 24′ (north).
RIBALD=longitude, 176° 36′ (west). This vessel being in the Pacific Ocean the longitude must exceed 100° for any latitude above 18°. Only amount above 100° is coded.
NINE UNGUARD=Pressure, 29.00 inches; temperature, 40°.
NOONDAY=Wind direction, SW.; weather, snowing; force, 5.

OBSERVER, SAN FRANCISCO. S. S. PRESIDENT JACKSON. CADAVER. GERBILLE. EAST. NAMBY. RUDDOCK. RENDABLE.

Translation:

CADAVER=date, a. m. 22d.
GERBILLE=latitude, 44° 48′ (north).
EAST NAMBY=longitude, 162° 30′ (east).
RUDDOCK=pressure, 29.70 inches; temperature, 28°.
RENDABLE=wind direction, W.; weather, cloudy; force, 5.

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GLOSSARY

NOTE.—A majority of the definitions given herewith are reprinted (in some cases in slightly abridged form) from the Glossary appended to C. F. Talman's "Meteorology, the Science of the Atmosphere" (New York: P. F. Collier & Son Co., 1922). A few are taken, with adaptations, from the Meteorological Glossary of the British Meteorological Office. Lastly, original definitions are given of a certain number of terms of special interest to mariners, not included in the glossaries above mentioned. It should be understood that the present collection of definitions represents only a small fraction of the vast vocabulary of meteorology.

Absolute extremes.—The highest and lowest values of a meteorological element (especially temperature) that have ever been recorded at a station, known, respectively, as the *absolute maximum* and the *absolute minimum.* (The term is sometimes improperly applied to the highest and lowest values for a specified year.)

Absolute temperature.—The temperature of the centigrade thermometer, increased by 273°, more properly called the temperature on the absolute or thermodynamic scale. On the Fahrenheit scale the absolute zero is approximately 459° below the Fahrenheit zero.

Actinometer.—An instrument for measuring the intensity of radiation received from the sun.

Adiabatic.—Occurring without gain or loss of heat. Adiabatic changes of atmospheric temperature are those that occur in consequence of expansion or compression only. Such changes are also described as *dynamic heating and cooling.*

Aerology.—The branch of meteorology dealing with the "free" atmosphere; i. e., all parts of the atmosphere not near the earth's surface. Aerological investigations are made with kites and balloons, and also include observations of clouds, meteor trails, the aurora, etc.

Afterglow.—The glow in the western sky after sunset.

Air.—The mixture of gases which forms the atmosphere.

Altimeter.—An aneroid barometer graduated to show height instead of pressure.

Alto-cumulus; Alto-stratus.—Forms of cloud. (See Part III.)

Anemogram.—The record traced by a self-registering anemometer.

Anemometer.—An instrument for measuring the force or speed of the wind.

Anemoscope.—An instrument for indicating the existence of wind and showing its direction.

Aneroid barometer.—(See Part II.)

Aneroidograph.—A self-recording aneroid barometer. The more common form of barograph.

Anthelion.—A rare species of halo, consisting of a brilliant, usually white, image of the sun opposite the latter in azimuth. (This term has also been applied to the *glory*, q. v.)

Anticrepuscular rays.—The continuation of the crepuscular rays, converging toward a point in the sky opposite to the sun.

Anticyclone.—An area of high barometric pressure and its attendant system of winds. (Cf. *Cyclone.*)

Antitrades.—Term formerly applied to the prevailing westerly winds of middle latitudes, but now more frequently applied to the westerly return-currents lying over the trade winds. Some writers prefer to call the former the *antitrades* and the latter the *countertrades.*

Antitwilight arch.—The pink or purplish zone of illumination bordering the shadow of the earth (*dark segment*) in the part of the sky opposite the sun after sunset and before sunrise.

Aqueous vapor.—Water vapor. (Cf. *Humidity.*)

Arcs of Lowitz.—A pair of rare halo phenomena. These arcs are directed obliquely downward from the parhelia of 22° on either side of the sun toward the halo of 22°.

Atmometer.—An instrument for measuring evaporation; also called *atmidometer, evaporimeter,* etc.

Atmosphere.—The whole mass of air surrounding the earth.

Atmospheric electricity.—The electrical phenomena of the earth's atmosphere; also, the branch of science relating thereto.

Aurora.—A luminous phenomenon due to electrical discharges in the atmosphere; probably confined to the tenuous air of high altitudes. It is most commonly seen in sub-Arctic and sub-Antarctic latitudes. Called *aurora borealis* or *aurora australis,* according to the hemisphere in which it occurs. Observations with the spectroscope seem to indicate that a faint "permanent aurora" is a normal feature of the sky in all parts of the world.

Back.—Of the wind, to shift in a counterclockwise direction; opposite of *veer.* In scientific practice this definition now applies to both hemispheres.

"*Backstays of the sun.*"—A sailor's name for crepuscular rays extending downward from the sun.

Baguio.—The name current in the Philippines for a tropical cyclone.

Ballistic wind.—A military term applied to a fictitious wind, which, if affecting a projectile throughout its flight, would produce the same total effect in deflecting it from its course and altering its range as do the various winds that it actually encounters.

Ballon-sonde.—A sounding balloon (*q. v.*).

Bar.—A unit of pressure equal to 1,000,000 dynes per square centimeter. A bar=100 *centibars*=1,000 *millibars.* A barometric pressure of one bar is sometimes called a "C. G. S. atmosphere," and is equivalent to a pressure of 29.531 inches of mercury at 32° F. and in latitude 45°.

Barocyclonometer.—One of several instruments that have been devised for locating tropical hurricanes without the aid of a weather map.

Barogram.—The continuous record made by a self-registering barometer.

Barograph.—A self-registering barometer.

Barometer.—An instrument for measuring the pressure of the atmosphere. The two principal types are the *mercurial* and the *aneroid.* The *microbarometer* is used to show minute changes of pressure. Certain forms of hygroscope are popularly miscalled barometers.

Barometric tendency.—The change of barometric pressure within a specified time (usually three hours) before one of the regular observations.

Beaufort scale.—The scale of wind force devised by Admiral Sir Francis Beaufort in 1805. (See Table IX.)

Bishop's ring.—A large corona due to fine dust in the atmosphere. It has been seen after certain great volcanic eruptions, especially that of Krakatoa, in 1883.

Blizzard.—A violent, intensely cold wind, laden with snow.

Bora.—A cold wind of the northern Adriatic, blowing down from the high plateaus to the northward. Also, a similar wind on the northeastern coast of the Black Sea.

Brave west winds.—The boisterous westerly winds blowing over the ocean between latitudes 40° and 50° S. This region is known as the "Roaring Forties."

Breeze.—A wind of moderate strength. Also, a wind that periodically reverses its direction; used in this sense in the expressions "land and sea breezes," "mountain and valley breezes," etc.

Bright segment.—The broad band of golden light that, in clear weather, borders the western horizon just after sunset and the eastern just before sunrise.

Brontide.—A sound resembling a distant muffled detonation, usually indefinite as to direction. Brontides are probably of subterranean origin in most cases.

Brontometer.—A combination of apparatus for following and noting all the details of the phenomena of weather during a thunderstorm.

Bull's-eye.—1. A patch of clear sky at the center of a cyclonic storm; the "eye of the storm." 2. A small isolated cloud seen at the beginning of a bull's-eye squall, marking the top of the otherwise invisible vortex of the storm.

Bull's-eye squall.—A squall forming in fair weather, characteristic of the ocean off the coast of South Africa; so called on account of the peculiar appearance of the small isolated cloud that marks the top of the invisible vortex of the storm.

Bump.—An upward jolt experienced by an aviator, as if running over an obstruction. A bump may be caused by any condition that suddenly increases the lift of the machine, but is perhaps most frequently due to rising air currents. Air in which bumps are experienced is said to be "bumpy." (Cf. *Hole in the air.*)

Buys Ballot's law.—In the Northern Hemisphere, if you stand with your back to the wind the atmospheric pressure decreases toward your left and increases toward your right. In the Southern Hemisphere the reverse is true. The law is useful in locating centers of cyclones and anticyclones.

Callina.—A Spanish name for dry fog.

Calm.—Absence of appreciable wind. (Generally less than 1 mile an hour but other numerical definitions have been proposed.)

Calms of Cancer; calms of Capricorn.—The belts of high pressure lying north of the northeast trade winds and south of the southeast trade winds, respectively.

Cat's-paw.—A slight and local breeze, which shows itself by rippling the surface of the sea.

Center of action.—Any one of several large areas of high and low barometric pressure, changing little in location, and persisting through a season or through the whole year; e. g., the Iceland low, the Siberian winter high, etc. Changes in the intensity and positions of these pressure systems are associated with widespread weather changes.

Centibar.—(See *Bar.*)

Centigrade.—A thermometric scale on which 0° denotes the temperature of melting ice, and 100° the temperature of boiling water, both under standard atmospheric pressure.

Ceraunograph.—A self-registering thunderstorm recorder.

Chinook, or *Chinook wind.*—A foehn blowing down the eastern slopes of the Rocky Mountains over the adjacent plains, in the United States and Canada. In winter, this warm, dry wind causes snow to disappear with remarkable rapidity, and hence it has been nicknamed the "snow-eater." (Cf. *Foehn.*)

The "wet chinook" is a wind of a different character, blowing from the Pacific Ocean over the northwestern United States.

Circumscribed halo.—A halo formed by the junction of the upper and lower tangent arcs of the halo of 22°, when the luminary is about 40° or more above the horizon. As the altitude of the luminary increases, the circumscribed halo gradually assumes an elliptical form and finally merges into the halo of 22°.

Circumzenithal arc.—A rainbow-tinted halo, often very bright, convex to the luminary and 46° or a little more above it. It is sometimes called the *upper quasi-tangent arc of the halo of 46°*, but the circumzenithal arc and the halo of 46° are rarely seen at the same time.

Cirro-cumulus; Cirro-stratus; Cirrus.—Forms of cloud. (See Part III.)

Climate.—The prevalent or characteristic meteorological conditions of any place or region.

Climatology.—The study of climate.

Cloud-banner.—A banner-like cloud streaming off from a mountain peak.

Cloud-burst.—A sudden and extremely heavy downpour of rain; especially in mountainous regions.

Cloud-cap.—A cap-like cloud crowning (1) a mountain summit, or (2) another cloud, especially a mass of cumulo-nimbus.

Col.—A neck of relatively low pressure between two anticyclones; also called a *saddle.*

Cold wave.—A rapid and marked fall of temperature during the cold season of the year. The United States Weather Bureau applies this term to a fall of temperature in 24 hours equaling or exceeding a specified number of degrees and reaching a specified minimum temperature or lower; the specifications varying for different parts of the country and for different periods of the year.

Collector.—A device used in measurements of atmospheric electricity for determining the potential gradient.

Continental climate.—The type of climate characteristic of the interior of a continent. As compared with a marine climate, a continental climate has a large annual and daily range of temperature.

Corona.—(See Part IV.)

Corposant.—(See *St. Elmo's fire.*)

Countertrades.—(See *Antitrades.*)

Counter-sun.—(See *Anthelion.*)

Crepuscular rays.—(See Part IV.)

Critical period.—A period in the growth of a plant when it is especially susceptible to the effects of atmospheric conditions.

Cumulo-nimbus; Cumulus.—Forms of cloud. (See Part III.)

Cyclone.—An area of low barometric pressure with its attendant system of winds. The cyclones of the region within the Tropics (*tropical cyclones*) are usually violent storms; those of higher latitudes (*extra-tropical cyclones*) may be stormy or otherwise. Tropical cyclones are also called *hurricanes, typhoons,* or *baguios.* Extra-tropical cyclones are commonly known as *lows* or *barometric depressions.*

Dark segment.—The shadow of the earth which, in clear weather, rises from the eastern horizon at sunset and sinks below the western horizon at sunrise.

Debacle.—Breaking up of the ice in the spring in rivers and seas.

Depression.—A cyclonic area, or low.

Deviation of the wind.—The angle between the wind and the line of gradient, which is normal to the isobar. (Cf. *Indraft, angle of.*)

Devil.—The name applied to a dust whirlwind in India. The term is also current in South Africa.

Dew.—Atmospheric moisture condensed, in liquid form, upon objects cooler than the air, especially at night.

Dew-point.—The temperature at which, under ordinary conditions, condensation of water vapor begins in a cooling mass of air. It varies with the absolute humidity.

"*Doctor.*"—A colloquial name for the sea breeze in tropical climates. The name is sometimes applied to other cool, invigorating breezes.

Doldrums.—The equatorial belt of calms or light, variable winds, lying between the two trade-wind belts.

Drought.—A protracted period of dry weather.

Dry bulb.—A name given to an ordinary thermometer used to determine the temperature of the air, in order to distinguish it from the wet bulb.

Dry fog.—A haze due to the presence of dust or smoke in the air.

Dust-counter.—An instrument for determining approximately the number of dust particles or condensation nuclei per unit volume in a sample of air.

Dynamic meteorology.—The branch of meteorology that treats of the motions of the atmosphere and their relations to other meteorological phenomena.

Eddy.—A more or less fully developed vortex in the atmosphere, constituting a local irregularity in a wind. All winds near the earth's surface contain eddies, which at any given place, produce "gusts" and "lulls." Air containing numerous eddies is said to be "turbulent."

Etesians.—Northerly winds blowing in summer over the eastern Mediterranean.

Evaporimeter.—(See *Atmometer.*)

Exposure.—In meteorology, the method of presentation of an instrument to that element which it is destined to measure or record, or the situation of the station with regard to the phenomenon or phenomena there to be observed.

Extremes.—The maximum and minimum values of a meteorological element.

Eye of the storm.—A calm region at the center of a tropical cyclone, or a break in the clouds marking its location.

Fahrenheit.—A thermometric scale on which 32° denotes the temperature of melting ice, and 212° the temperature of boiling water, both under standard atmospheric pressure.

Fall-wind.—A wind blowing down a mountain-side; or any wind having a strong downward component. Fall-winds include the foehn, mistral, bora, etc.

False cirrus.—Cirrus-like clouds at the summit of a thunder cloud; probably identical in structure with true cirrus, or cirro-stratus. Sometimes more appropriately called "thunderstorm cirrus."

Fata morgana.—A complex form of mirage, characterized by marked distortion of images.

Festoon cloud.—Mammato-cumulus.

Flashing arcs.—Visible atmospheric sound waves, or explosion waves.

Flat.—Featureless; said of weather maps.

Foehn.—A dry wind with strong downward component, warm for the season, characteristic of many mountainous regions. The air is cooled dynamically in ascending the mountains, but this leads to condensation, which checks the fall in temperature through the liberation of latent heat. The wind deposits its moisture as rain or snow. In descending the opposite slope it is strongly heated dynamically and arrives in the valleys beyond as a warm and very dry wind. Some writers apply this term to any wind that is dynamically heated by descent; e. g., the sinking air of an anticyclone.

Foehn-wall (German, *Föhnmauer*).—A wall of cloud that forms along the crest of a mountain ridge over which the foehn is blowing.

Fog.—A cloud at or near the earth's surface. A fog and a cloud are identical in structure, though the former is due to thermal conditions of the earth's surface, while the latter is most frequently due to the dynamic cooling of ascending air. In ordinary speech the term "fog" generally implies an obscurity of the atmosphere sufficiently great to interfere with navigation or locomotion. (Cf. *Dry fog.*)

Fogbow.—A rainbow, colorless or nearly so, formed in a fog.

Fog-drip.—Moisture that is deposited on terrestrial objects by fog, and drips from them to the ground.

Fracto-cumulus; Fracto-nimbus; Fracto-stratus.—Forms of cloud. (See Part III.)

Freeze.—Freezing temperatures prevailing generally over a region; not exclusively nocturnal and not confined to the air close to the earth's surface. (Cf. *Frost.*)

Frost.—1. The act or state of freezing. In America a "frost" generally means the occurrence, near the beginning or end of the growing season, of nocturnal temperatures low enough to be injurious to vegetation; distinguished from "freeze," which is more general and severe. The Weather Bureau classifies frosts, according to their effects, as "light," "heavy," and "killing." 2. Atmospheric moisture condensed upon terrestrial objects in the form of ice; sometimes frozen dew. Also called *hoarfrost.*

Frost-smoke.—Frozen fog rising from the water.

Gale.—Wind with an hourly velocity exceeding some specified value. In American practice a wind of or exceeding force 8 on the Beaufort scale is counted a gale.

Garúa.—A wet fog of the west coast of South America.

Glaze.—Term applied by the U. S. Weather Bureau to a smooth coating of ice on terrestrial objects due to the freezing of rain; often popularly called "sleet." In Great Britain such a deposit is called *glazed frost.* A deposit of glaze on an extensive scale constitutes an "ice storm".

Glory.—A series of concentric colored rings seen around the shadow of the observer, or of his head only, cast upon a cloud or fog bank. It is due to the diffraction of reflected light.

Gradient.—Change of value of a meteorological element per unit of distance. The gradients commonly discussed in meteorology are the horizontal gradient of barometric pressure, the vertical gradient of temperature, and the vertical gradient of electric potential. British meteorologists now prefer the term *lapse-rate* to *vertical gradient.*

Gradient wind.—A wind of the velocity which is necessary to balance the pressure-gradient. The direction of the gradient wind is along the isobars, and the velocity is so adjusted that there is equilibrium between the force pressing the air inwards, towards the low pressure, and the centrifugal action to which the moving air is subject in consequence of its motion.

Graupel.—A kind of granular snow, sometimes called *soft hail.*

Green flash.—A bright green coloration of the upper edge of the sun's disk, sometimes seen when the rest of the disk is below the horizon at sunrise or sunset.

Gregale.—The northeast wind on the Mediterranean; especially a stormy northeast wind at Malta.

Gust.—A sudden brief increase in the force of the wind. Most winds near the earth's surface are made up of alternate gusts and *lulls*, the majority of which are too brief to be registered by an ordinary anemometer.

Hail.—Balls or irregular lumps of ice, often of considerable size, having a complex structure; large hailstones generally have a snowlike center, sur-

rounded by layers of ice, which may be alternately clear and cloudy. Hail falls almost exclusively in connection with thunderstorms. For so-called "soft hail" *see graupel.* (Cf. *Sleet.*)

Halo.—A generic name for a large group of optical phenomena caused by ice crystals in the atmosphere. The commonest of these phenomena is the *halo of 22°* (i. e., of 22° radius) surrounding the sun or moon. The *halo of 46°* and the rare *halo of 90°, or halo of Hevelius,* also surround the luminary. Other forms of halo are the *tangent arcs, parhelia* (or *paraselenae*), *parhelic* (or *paraselenic*) *circle, anthelion,* etc.

Harmattan.—A dry, dusty wind of the west coast of Africa, blowing from the deserts.

Haze.—A lack of transparency in the atmosphere; sometimes due to irregularities in the density of the air (*optical haze*), sometimes to dust (*dust haze,* which when dense constitutes *dry fog*), sometimes to fine particles of water or ice (grading into true *fog*).

High.—An area of high barometric pressure; an anticyclone.

Hoarfrost.—(See *Frost.*)

Hole in the air.—A colloquial name for any condition in the atmosphere that suddenly decreases the lift of an aeroplane. (Cf. *Bump.*)

Horse latitudes.—The regions of calms and variable winds coinciding with the subtropical high-pressure belts lying on the poleward sides of the trade winds. (The term has generally been applied only to the northern of these two regions in the North Atlantic Ocean, or to the portion of it near Bermuda.

Hot wave.—A period of abnormally high temperatures. It has sometimes been defined, in the United States, as a period of three or more consecutive days during each of which the maximum temperature is 90° F. or over.

Hot wind.—A hot, parching wind characteristic of certain continental interiors; especially Australia, northern India and the prairie region of the United States.

Humidity.—The degree to which the air is charged with water vapor; viz, the actual amount of water vapor present (*absolute humidity*), which may be expressed in terms of weight per volume or as vapor pressure, or the ratio which this amount bears to the maximum amount the air can contain at the prevailing temperature (*relative humidity*), expressed in percentage.

Hurricane.—A tropical cyclone; especially one of the West Indian region. (A cyclone originating in this region and passing northward into the Temperate Zone is still called a "West India hurricane," even after it has assumed the character of an extra-tropical cyclone, and, if sufficiently severe, justifies the display of "hurricane warnings" at ports of the United States. "Hurricane" is also the designation of the highest wind force on the Beaufort scale, and is thus applied to any wind exceeding about 75 miles an hour.)

Hyetograph.—A form of self-recording *rain gage.*

Hygrograph.—A self-recording *hygrometer.*

Hygrometer.—Any instrument for measuring the humidity of the air.

Hygroscope.—A device that gives a rough indication of the relative humidity of the air. Most hygroscopes are mere toys.

Iceberg.—A large mass of ice that breaks from the tongue of a glacier running into the sea and floats away.

Ice-blink.—A white, luminous appearance near the horizon caused by the reflection of light from ice.

Ice rain.—1. A rain that causes a deposit of glaze. 2. Falling pellets of clear ice (called *sleet* by the U. S. Weather Bureau).

Ice storm.—(See Glaze.)

Inclination of the wind.—(See *Indraft, angle of.*)

Indian summer.—A period of mild, calm, hazy weather occurring in autumn or early winter, especially in the United States and Canada; popularly regarded as a definite event in the calendar, but weather of this type is really of irregular and intermittent occurrence.

Indraft, angle of.—The angle which the wind makes with the direction of the isobar at the place of observation; also called the *inclination of the wind.* (Cf. *Deviation of the wind.*)

Ignis fatuus.—Will-o'-the-wisp.

Insolation.—Solar radiation, as received by the earth or other planets; also, the rate of delivery of the same, per unit of horizontal surface.

Instrument shelter.—The American name of the cage or screen in which thermometers and sometimes other instruments are exposed at meteorological stations. Called *thermometer screen* in Great Britain.

Inversion.—More fully, *temperature inversion;* an increase of air temperature with increase of altitude, instead of the normal decrease.

Irisation.—Irregular patches or fringes of iridescence sometimes seen in clouds (called *iridescent clouds*), not corresponding in location with the ordinary corona or the known forms of halo (such as parhelia). They are probably fragments of coronas of unusual size, produced by exceedingly fine cloud particles.

Isobar.—A line of equal barometric pressure. (Isobars are generally drawn on maps to show the horizontal distribution of pressure reduced to sea level, or the pressure at some specified altitude; but in a broader sense any line on a chart or diagram drawn through places of equal pressure is an isobar.)

Isogram.—A line drawn on a chart or diagram to show the distribution of some physical condition in space or time (or both), by connecting points corresponding to equal values of the phenomenon represented. Most of the isograms used in meteorology are drawn on geographical charts, and show the distribution of a meteorological element in space only. A special form of isogram, known as the *isopleth,* shows the variation of an element in relation to two coordinates; one of the coordinates representing the time of the year (month), and the other usually the time of the day (hour), but sometimes space (especially altitude). The following list includes the more important meteorological isograms: *Anisallobar,* isogram of rise of barometric pressure in a given time; *Equiglacial line,* isogram of condition of the ice in rivers, lakes, harbors, etc.; *Isallobar,* isogram of the amount of change in barometric pressure within a specified period; *Isametral,* isogram of the temporary departure of an element, during a particular period, from the local normal value, *Isanemone,* isogram of wind velocity, *Isanomal,* or *Isanomalous line,* isogram of anomaly; i. e., of the departure of the local mean value of an element from the mean pertaining to the latitude; *Isobar,* isogram of barometric pressure; *Isobront,* a thunderstorm isochrone; i. e., a line connecting places where a thunderstorm began (or some specified feature thereof occurred) at the same time; *Isoceraunic,* isogram of thunderstorm frequency; *Isochion,* any isogram relating to snow; *Isoclimatic line,* any isogram of climate; *Isogeotherm,* isogram of the temperature of the ground; *Isohel,* isogram of duration of sunshine; *Isohyet,* isogram of the amount of rainfall; *Isoneph,* isogram of cloudiness; *Isophene,* isochrone of the occurrence of any periodic phenomenon of plant or animal life; *Isotalantose,* isogram of range or amplitude of any element; *Isotherm,* isogram of temperature; *Isothermobath,* isogram of temperature in a vertical section of a body of water; *Isothyme,* isogram of evaporation; *Katisallobar,* isogram of fall of barometric pressure in a given time.

(For definitions of less common meteorological isograms see Monthly Weather Review, April, 1915, pp. 195–198.)

Isotherm.—A line of equal temperature. (See *Isogram.*)

Isothermal layer.—(See *Stratosphere.*)

January thaw.—A period of mild weather popularly supposed to recur each January, especially in New England.

Katathermometer.—A device consisting of a dry-bulb and a wet-bulb thermometer, designed for measuring the cooling power of the atmosphere, with reference to its physiological effects. It was invented by Leonard Hill.

Khamsin.—A hot, dry southerly wind occurring in Egypt during the spring.

Kiosk.—The name given by the U. S. Weather Bureau to a small street pavilion in which are displayed meteorological instruments, maps, tables, etc.

Land and sea breezes.—The breezes that, on certain coasts and under certain conditions, blow from the land by night and from the water by day.

Lapse-rate.—(See *Gradient.*)

Lenticular cloud.—A cloud having approximately the form of a double-convex lens, marking the position of a standing wave in the atmosphere.

Leste.—A hot, dry, easterly wind of the Madeira and Canary Islands.

Levanter.—A strong easterly wind of the Mediterranean, especially in the Straits of Gibraltar, where it is attended by damp or foggy weather.

Lightning.—A disruptive electrical discharge in the atmosphere, or, generally, the luminous phenomena attending such a discharge.

Light-pillar.—A form of halo, consisting of a column of light, vertical or nearly so, extending from or through the sun or moon. Called a *sun-pillar*, or a *moon-pillar*, as the case may be.

Lightning rod.—A metallic rod, connected with a suitable "ground," in earth or water, set up for the purpose of protecting some structure from lightning.

Line-squall.—A more or less continuous line of squalls and thunderstorms traveling broadside over the country.

Looming.—An apparent elevation of distant objects by mirage.

Low.—An area of low barometric pressure, with its attendant system of winds. Also called a *barometric depression* or *cyclone.*

Mackerel sky.—An area of sky covered with cirro-cumulus clouds; especially when the clouds resemble the patterns seen on the backs of mackerel.

Mammato-cumulus.—A form of cloud showing pendulous sack-like protuberances.

March.—The variation of a meteorological element in the course of a day, year, or other interval of time; e. g., the diurnal march of temperature; the annual march of barometric pressure.

Mares' tails.—Cirrus in long slender streaks.

Marine climate.—A type of climate characteristic of the ocean and oceanic islands. Its most prominent feature is equability of temperature.

Maximum.—The highest value of any element occurring during a given period.

Meniscus.—The curved upper surface of liquid in a tube.

Meteorograph.—Autographic apparatus for recording simultaneously two or more meteorological elements. Certain types of meteorograph are connected, electrically or otherwise, with some of the instruments at meteorological stations; others are sent aloft attached to kites and balloons.

Meteorology.—The science of the atmosphere.

Microbarograph.—An instrument designed for recording small and rapid variations of atmospheric pressure.

Millibar.—(See *Bar.*)

Minimum.—The lowest value of any element occurring during a given period.

Mirage.—An apparent displacement or distortion of distant objects by abnormal atmospheric refraction. Sometimes the images of objects are inverted, multiplied, etc.

Mist.—Generally, a wet fog or a very fine drizzle of rain; hence the expression "It is misting." The "Scotch mist" of mountainous or hilly regions is a combination of thick fog and heavy drizzle.

Mistpoeffer.—(See *Brontide.*)

Mistral.—Along the Mediterranean coast, from the mouth of the Ebro to the Gulf of Genoa, a stormy, cold northerly wind, blowing down from the mountains of the interior. (The name is sometimes applied to northerly winds on the Adriatic, in Greece, and in Algeria.)

Mock-sun.—(See *Parhelion.*)

Monsoon.—A wind that reverses its direction with the season, blowing more or less steadily from the interior of a continent toward the sea in winter, and in the opposite direction in the summer.

Moon-dog.—A paraselene. (See *Parhelion.*)

Mountain and valley breezes.—The breezes that, in mountainous regions, normally blow up the slopes by day (*valley breeze*) and down the slopes by night (*mountain breeze*).

Nephoscope.—An instrument for measuring the movement of clouds.

Nimbus.—The rain cloud. (See Part III.)

Noctilucent clouds.—Luminous, cirrus-like clouds sometimes visible throughout the short nights of summer; supposed to be clouds of dust at great altitudes shining with reflected sunlight. Such clouds were observed during several summers after the eruption of Krakatoa (1883) and are still occasionally reported.

Normal.—The average value which, in the course of years, any meteorological element is found to have on a specified date or during a specified month or other portion of the year, or during the year as a whole. Also used as an adjective in such expressions as "normal temperature," etc. Thus, for any station at which records have been maintained for many years, we may compute the normal temperature of January 1, the normal pressure of February, the normal rainfall of the year, etc. The normal serves as a standard with which values occurring in a particular year may be compared in order to determine the *departure from the normal.*

Norther.—A northerly wind; especially, strong northerly winds of sudden onset occurring during the colder half of the year over the region from Texas southward, including the Gulf of Mexico and the western Caribbean.

Nucleus.—A particle upon which condensation of water vapor occurs in the free atmosphere in the form of a water drop or an ice crystal.

Oblique arcs of the anthelion.—A rare form of halo, consisting of intersecting arcs, usually white, passing through the anthelion or the place where the anthelion would occur if visible.

Ombrometer.—A rain gage.

Ozone.—An allotropic form of oxygen which occurs transiently in small quantities in the lower atmosphere and is supposed to be permanently present and relatively abundant at high atmospheric levels.

Pampero.—A southwest squall blowing over or from the pampas of South America. Off the coast of Argentina these squalls are most prevalent from July to September.

Paranthelion.—A halo phenomenon similar to a parhelion, but occurring at a distance of 90° or more in azimuth from the sun. The solar distance of

the ordinary paranthelia is 120°. (Analogous phenomena produced by the moon as source of light are called *parantiselenæ.*)

Paraselene (plural *paraselenæ*).—(See *parhelion.*)

Paraselenic circle.—(See *parhelic circle.*)

Parhelic circle.—A halo consisting of a white circle passing through the sun and parallel to the horizon. A similar phenomenon in connection with the moon is called a *paraselenic circle.*

Parhelion (plural *parhelia*).—A mock-sun, or sun-dog; a form of halo consisting of a more or less distinctly colored image of the sun at the same altitude as the latter above the horizon, and hence lying on the parhelic circle, if present. The ordinary parhelia are 22° from the sun in azimuth, or a little more, according to the altitude of the luminary. Parhelia have occasionally been seen about 46° from the sun. Analogous phenomena seen in connection with the moon are called *paraselenæ, mock-moons,* or *moon-dogs.*

Penetrating radiation.—A form of radiation that has the property of passing through a great extent of air without being absorbed and of ionizing the air inside hermetically sealed metal vessels. It is supposed to consist of a special kind of Gamma rays and to come from the higher levels of the atmosphere.

Pentad.—A period of five days.

Phenology.—The study of the periodic phenomena of animal and plant life and their relations to weather and climate.

Pilot balloon.—A small free balloon the drift of which, as observed from the ground, indicates the movements of the air aloft.

Pluviograph.—A self-registering rain gage.

Pluviometer.—A rain gage.

Pocky cloud.—Mammato-cumulus.

Polar front.—The boundary between the cold air of a polar region and the warmer air of lower latitudes. According to a current hypothesis, the region of the polar front, which varies in location, is the principal breeding ground of extra-tropical cyclones.

Potential gradient.—(See *Gradient.*)

Potential temperature.—The temperature that a body of air or other gas would assume if brought adiabatically to the normal or standard pressure.

Precipitation.—The collective name for deposits of atmospheric moisture in liquid and solid form, including rain, snow, hail, dew, hoarfrost, etc.

Pressure.—An elliptical expression, current in meteorological literature, for *atmospheric pressure,* or *barometric pressure.*

Prevailing westerlies.—The belts of winds lying on the poleward sides of the subtropical high-pressure belts.

Psychrometer.—An instrument for measuring atmospheric humidity, consisting usually of a *dry-bulb thermometer* and a *wet-bulb thermometer.* The former is an ordinary mercurial thermometer. The latter has its bulb covered with muslin or other fabric, which is either permanently wet or is wetted before use. In some psychrometers there is only one thermometer, readings being taken both before and after moistening the bulb. In the *aspiration psychrometer* the air is drawn past the bulb by a revolving fan.

Pumping.—Unsteadiness of the mercury in the barometer caused by fluctuations of the air pressure produced by a gusty wind, or due to the oscillation of a ship.

Purple light.—The purple or rosy glow observed over a large area of the western sky after sunset and the eastern sky before sunrise; it lies above the *bright segment* that borders the horizon.

Pyrheliometer.—An instrument that measures solar radiation by its heating effects.

Rain.—Drops of water falling from the sky.

Rain-balls.—Mammato-cumulus.

Rainbow.—A luminous arc formed by the refraction and reflection of light in drops of water. (See Part IV.)

Rainfall.—A term sometimes synonymous with *rain*, but most frequently used in reference to amounts of precipitation (including snow, hail, etc.).

Rain gage.—An instrument for measuring rainfall.

Recurrence.—The tendency of any particular type of weather to occur at about the same period every year, independently of and generally in contrast to the regular march of the seasons.

Reduction.—As applied to meteorological observations, generally means the substitution for the values directly observed of others which are computed therefrom and which place the results upon a comparable basis.

Refraction.—*Astronomical refraction*, change in the apparent position of a heavenly body, due to atmospheric refraction; *Terrestrial refraction*, change in the apparent position of distant terrestrial objects, due to the same cause.

Relative humidity.—(See *Humidity.*)

Réseau.—A collection of meteorological stations operating under a common direction, or in the same territory. An *international réseau* is a group of stations in different countries cooperating for any purpose. The *réseau mondial* is a world-wide system of selected stations, the observations of which may be utilized in studies of the meteorology of the globe.

Ridge.—An extension of a high area shown on a weather chart, corresponding to the ridge running outward from a mountain system. It is the opposite of a trough of low pressure.

Rime.—1. Hoarfrost. 2. A rough or feathery coating of ice deposited on terrestrial objects by fog. (The second meaning is the one now used in technical literature.)

Roaring forties.—(See *Brave west winds.*)

Saddle.—(See *Col.*)

St. Elmo's fire.—A luminous brush discharge of electricity from elevated objects, such as the masts and yardarms of ships, lightning rods, steeples, etc., occurring in stormy weather. Also called *corposant.*

Scarf cloud.—A thin cirrus-like cloud which often drapes the summits of tall cumulo-nimbus clouds.

Scotch mist.—(See *Mist.*)

Scud.—Shreds or small detached masses of cloud moving rapidly below a rain cloud or other heavy clouds.

Sea breezes.—(See *Land and sea breezes.*)

Secondary.—A small area of low pressure on the border of a large, or "primary," one. The secondary may develop into a vigorous cyclone while the primary center disappears.

Semicircle.—The "dangerous semicircle" of a cyclonic storm at sea is the half of the storm area in which rotary and progressive motions of the storm reinforce each other, and the winds are also directed in such a way as to drive a vessel running before the wind across the storm track ahead of the advancing center. The other half is called the "navigable" semicircle.

Sensible temperature.—The temperature felt at the surface of the human body; formerly identified, by some authorities, with the temperature indicated by a wet-bulb thermometer.

Shamal.—A northwesterly wind of Mesopotamia and the Persian Gulf.

Silver thaw.—A term variously applied to rime, glaze, and a thin coating of ice deposited on cold objects by a damp wind.

Simoom.—An intensely hot and dry wind of Asian and African deserts; often described as a sand storm or dust storm, but certain authorities state that the typical simoom is free from sand and dust.

Sirocco.—A name applied to various types of warm wind in the Mediterranean region. Some of these siroccos are foehns. The term is also used as the generic name for winds blowing from a warm region toward an area of low pressure in a normally colder region.

Sleet.—1. Frozen or partly frozen rain; frozen raindrops in the form of particles of clear ice. (The official definition of the U. S. Weather Bureau.) 2. Snow and rain falling together. (The British use, and the one occurring in publications of the International Meteorological Organization. In popular and engineering use in the United States the word is often applied to a coating of glaze on trees, wires, rails, etc.)

Snow.—Precipitation in the form of small ice crystals, falling either separately or in loosely coherent clusters (snowflakes).

Snow-roller.—A mass of snow rolled by the wind; generally muff-shaped.

Soft hail.—Graupel.

Solar constant of radiation.—The intensity of solar radiation outside the earth's atmosphere at the earth's mean distance from the sun. Recent investigations indicate that this intensity may vary and that its mean value is 1.938 gram-calories per minute per square centimeter of area lying normal to the incident solar rays.

Sounding balloon.—A free, unmanned balloon carrying a set of self-registering meteorological instruments.

Specter of the Brocken.—The shadow of an observer and of objects in his immediate vicinity cast upon a cloud or fog bank; sometimes attended by a series of colored rings, called the *glory* or *Brocken-bow.*

Squall.—1. A sudden storm of brief duration; closely akin to a thunderstorm but not necessarily attended by thunder and lightning. 2. A sudden brief blast of wind, of longer duration than a gust.

Static.—(See *Stray.*)

Statoscope.—A very sensitive form of aneroid barometer, used to show whether a balloon is rising or sinking. The range of its index is very small and it has to be set from time to time by opening a tap leading to the interior of the box.

Storm.—A marked disturbance in the normal state of the atmosphere. The term has various applications, according to the context. It is most often applied to a disturbance in which strong wind is the most prominent characteristic, and sometimes specifically to a wind of force 11 on the Beaufort scale. It is also used of other types of disturbance, including thunderstorms, rainstorms, snowstorms, hailstorms, dust storms, sand storms, magnetic storms, etc.

Storm-card.—A device intended for use on shipboard in determining the direction of a storm center from the ship.

Strato-cumulus.—A form of cloud. (See Part III.)

Stratosphere.—The upper region of the atmosphere, formerly called the *isothermal layer,* in which there is no marked or systematic decrease of temperature with altitude. The stratosphere is free from clouds (except occasional dust clouds) and from strong vertical air currents, and its circulation appears to be more or less independent of that of the lower atmosphere. The height of its base, which varies with latitude and otherwise, averages between 6 and 7 miles. (Cf. *Troposphere.*)

Stray.—A natural electromagnetic wave in the ether. The term is used in reference to the effect of such wave in producing erratic signals in radiotelegraphic receivers. Strays are also known as *atmospherics*, and collectively, as *static*.

Sun-dog.—A mock-sun or parhelion.

"*Sun drawing water.*"—The sun is popularly said to be "drawing water" when crepuscular rays extend down from it toward the horizon.

Sun-pillar.—(See *Light-pillar.*)

Sunshine recorder.—An instrument for recording the duration of sunshine; certain types also record the intensity of sunshine.

Surge.—A general change in barometric pressure apparently superposed upon cyclonic and normal diurnal changes.

Synchronous chart.—A form of synoptic chart, such as the ordinary weather map, which shows the meteorological conditions prevailing over any area at a given moment of time.

Synoptic chart.—A chart showing the distribution of meteorological conditions over an area at a given moment or the average conditions during a given period of time, such as a month or a year.

Tablecloth.—A sheet of cloud that sometimes spreads over the flat top of Table Mountain, near Cape Town.

Tangent arc.—Any halo that occurs as an arc tangent to one of the heliocentric halos.

Term hours.—Prescribed hours for taking meteorological observations.

Thermal belt.—A well-defined zone, found on some mountainsides, in which vegetation is particularly exempt from frost in spring and autumn. Also called *verdant zone.*

Thermogram.—The continuous record of temperature made by a thermograph.

Thermograph.—A self-registering thermometer.

Thermometer.—An instrument for measuring temperature; in meteorology, generally the temperature of the air. *Maximum and minimum thermometers* indicate, respectively, the highest and lowest temperatures occurring between the times of setting the instruments. A *wet-bulb thermometer* is used in measuring humidity. (See *Psychrometer.*)

Thermometer screen.—A construction designed to screen a thermometer from the direct rays of the sun and from other conditions that would interfere with the registration of the true air temperature; usually a wooden cage with louvred sides. In the United States commonly called *instrument shelter.*

Thunder.—The sound produced by a lightning discharge.

Thunderstorm.—A storm attended by thunder and lightning. Thunderstorms are local disturbances, often occurring as episodes of cyclones, and, in common with squalls, are marked by abrupt variations in pressure, temperature, and wind.

Tornado.—1. A violent vortex in the atmosphere, attended by a pendulous, more or less funnel-shaped cloud. 2. In West Africa, a violent thundersquall.

Trade winds.—Two belts of winds, one on either side of the equatorial doldrums, in which the winds blow almost constantly from easterly quadrants.

Tropopause.—The lower limit of the stratosphere.

Troposphere.—The part of the atmosphere lying below the stratosphere.

Trough.—1. A line drawn at right angles to the path of a cyclonic area through all points at which the pressure has reached a minimum and is about to rise. 2. An elongated area of low barometric pressure.

Twilight.—*Astronomical twilight* is the interval between sunrise or sunset and the total darkness of night. *Civil twilight* is the period of time before sun-

rise and after sunset during which there is enough daylight for ordinary outdoor occupations.

Typhoon.—The name applied in the Far East to a tropical cyclone.

Ulloa's ring.—1. A glory. 2. A halo (also called *Bouguer's halo*) surrounding a point in the sky diametrically opposite the sun; sometimes described as a "white rainbow."

V-shaped depression.—A trough of low barometric pressure bounded, on the weather map, by V-shaped isobars.

Vane.—A device that shows which way the wind blows; also called *weather vane* or *wind vane.*

Variability.—*Interdiurnal variability* is the mean difference between successive daily means of a meteorological element.

Veer.—Of the wind, to shift in a clockwise direction; opposite of *back.* In scientific practice this definition now applies to both hemispheres.

Visibility.—The transparency and illumination of the atmosphere as affecting the distance at which objects can be seen. It is often expressed on a numerical scale.

Waterspout.—A tornado-like vortex and cloud occurring over a body of water.

Wedge.—A wedge-shaped area of high barometric pressure.

Wet bulb.—(See *Psychrometer.*)

Williwaw.—A sudden blast of wind descending from a mountainous coast to the sea. (Especially applied to such blasts in the Straits of Magellan.)

Willy-willy.—A violent storm of wind and rain on the northwest coast of Australia. (The name is also applied in some parts of Australia to a local dust whirl.)

Wind.—Moving air, especially a mass of air having a common direction of motion. The term is generally limited to air moving horizontally, or nearly so; vertical streams of air are usually called "currents."

Wind rose.—1. A diagram showing the relative frequency and sometimes also the average strength of the winds blowing from different directions in a specified region. 2. A diagram showing the average relation between winds from different directions and the occurrence of other meteorological phenomena.

Woolpack.—Cumulus.

Zodiacal light.—A cone of faint light in the sky which is seen stretching along the zodiac from the western horizon after the twilight of sunset has faded and from the eastern horizon before the twilight of sunrise has begun.

LIST OF WORKS ON METEOROLOGY

GENERAL TREATISES

Angot, Alfred. Traité élémentaire de météorologie. 3d ed. Paris. 1916.

Davis, William Morris. Elementary meteorology. Boston. 1894.

Geddes, A. E. M. Meteorology; an introductory treatise. London. 1921.

Great Britain, Meteorological office. The Weather map; an introduction to modern meteorology. 5th issue. London. 1921. 2 vols. (The second volume bears separate title, Meteorological glossary.)

Greely, Adolphus W. American weather. New York. 1888.

*Hann, Julius von. Lehrbuch der Meteorologie. 3d ed. Leipzig. 1915.

Humphreys, William Jackson. Physics of the air. Philadelphia. 1920.

McAdie, Alexander. Principles of aerography. Chicago. 1917.

Milham, Willis I. Meteorology. New York. 1912.

Moore, Willis L. Descriptive meteorology. New York. 1910.

National research council. Introductory meteorology. New Haven. 1918.

Talman, Charles Fitzhugh. Meteorology, the science of the atmosphere. N. Y. 1922. Republished 1925 under the title: Our weather.

Waldo, Frank. Elementary meteorology. New York. 1896.

WEATHER AND WEATHER FORECASTING

Abercromby, Ralph. Weather. London. 1887.

Bliss, George S. Weather forecasting. 3d ed. Washington. 1921. (U. S. Weather bureau. Bull. 42.)

Brooks, Charles F. Why the weather? New York. 1924.

Defant, Albert. Wetter und Wettervorhersage. Leipzig. 1918.

Humphreys, W. J. Weather proverbs and paradoxes. Baltimore. 1923.

Inwards, Richard. Weather lore; a collection of proverbs, sayings, and rules concerning the weather. 3d ed. London. 1898.

Kassner, Carl. Das Wetter und seine Bedeutung für das praktische Leben. 2d ed. Leipzig. 1918.

Shaw, Sir Napier. Forecasting weather. 2d ed. London. 1923.

U. S. Weather bureau. Weather forecasting in the United States. Washington. 1916.

DYNAMIC METEOROLOGY

Abbe, Cleveland. The mechanics of the earth's atmosphere. A collection of translations (2d. collection). Washington. 1891. Third collection. Washington. 1910. (Published by Smithsonian institution.)

Exner, Felix M. Dynamische Meteorologie. Leipzig. 1917.

Ferrel, William. A popular treatise on the winds. New York. 1889.

Ferrel, William. Recent advances in meteorology. Washington. 1886. (Annual report of the chief signal officer, 1885. Appendix 71.)

Lempfert, Rudolph G. K. Meteorology. London. 1920.

Shaw, Sir Napier. Manual of meteorology, pt. 4. Cambridge. 1919.

STORMS

Algué, José. Cyclones of the far east. 2d ed. Manila. 1904.

Bowie, Edward H., & Weightman, R. Hanson. Types of storms of the United States and their average movements. Washington. 1914. (U. S. Weather bureau. Monthly weather review. Supplement 1.)

* A 4th edition is now (1925) appearing in parts.

Fassig, Oliver L. Hurricanes of the West Indies. Washington. 1913. (U. S. Weather bureau. Bull. X.)

Finley, John P. Tornadoes; what they are and how to observe them. New York. 1887.

Mitchell, Charles L. West Indian hurricanes and other tropical cyclones of the North Atlantic Ocean. Washington. 1924. (U. S. Weather bureau. Monthly weather review. Supplement 24.)

MARINE METEOROLOGY

Allingham, William. A manual of marine meteorology. London. 1900.

Great Britain, Meteorological office. The seaman's handbook of meteorology. 3d ed. London. 1918.

FROST

[Young, Floyd D.] Frost and the prevention of damage by it. Washington. 1920. (U. S. Dept. of agriculture. Farmers' bull. 1096.)

Reed, William Gardner. Frost and the growing season. Washington. 1918. (U. S. Dept. of agriculture. Atlas of American agriculture, part 2, sect. 1.)

CLOUDS

Clarke, George A. Clouds. London. 1921.

Clayden, Arthur William. Cloud studies. London. 1905.

Clayton, H. Helm. Observations made at the Blue Hill meteorological observatory. . . . Discussion of the cloud observations. Cambridge, Mass. 1896. (Annals of the Astronomical observatory of Harvard college, vol. 30, pt. 4.)

International meteorological committee. International cloud-atlas. 2d ed. Paris. 1910.

Ley, William Clement. Cloudland. London. 1894.

U. S. Weather bureau. Cloud forms according to the international system of classification. Washington. 1924.

ATMOSPHERIC ELECTRICITY

Covert, Roy Norton. Modern methods of protection against lightning. Washington. 1922. (U. S. Dept. of agriculture. Farmers' bull. 842.)

Kähler, Karl F. Luftelektrizität. Berlin. 1913.

Mache, Heinrich, & Schweidler, E. von. Die atmosphärische Elektrizität. Braunschweig. 1909.

Peters, Orville S. Protection of life and property against lightning. Washington. 1915. (U. S. Bureau of standards. Technologic paper 56.)

Swann, W. F. G. Atmospheric electricity. (In Journal of Franklin institute, Philadelphia, Nov., 1919, pp. 577–606.)

METEOROLOGICAL OPTICS

Pernter, Josef M., & Exner, Felix M. Meteorologische Optik. 2d ed. Wien, etc. 1922.

INSTRUMENTS, INSTRUCTIONS, AND TABLES

Great Britain, Meteorological office. The computer's handbook. London. 1915–. [In course of publication, in parts.]

Great Britain, Meteorological office. The observer's handbook. London. 1921.

Smithsonian institution. Smithsonian meteorological tables. 4th ed. Washington. 1918.

U. S. Weather bureau. Instructions for aerological observers. Washington. 1921.

U. S. Weather bureau. Instrument division circulars. Washington. A. Instructions for obtaining and tabulating records from recording instruments. B. and C. combined. Instructions for coöperative observers. D. Installation and maintenance of wind measuring and recording apparatus. E. Measurement of precipitation. F. Barometers and atmospheric pressure. G. Care and management of sunshine recorders. I. Instructions for erecting and using weather bureau nephoscopes. L. Installation and operation of class A evaporation stations.

U. S. Weather bureau. Psychrometric tables. Washington. 1912.

AGRICULTURAL METEOROLOGY

Smith, J. Warren. Agricultural meteorology. New York. 1920.

CLIMATOLOGY

Hann, Julius. Handbuch der Klimatologie. 3d ed. Stuttgart. 1908–11. 3 vols. [The second edition of the first volume has been translated, with some additions, by R. DeC. Ward, New York, 1903, but the translation is out of print and rare.]

Köppen, W. Die Klimate der Erde. Berlin. 1923.

Ward, Robert DeCourcy. Climate, considered especially in relation to man. 2d ed. New York. 1918.

Weber, F. Parkes, & Hinsdale, Guy. Climatology; health resorts; mineral springs. Philadelphia. 1902. 2 vols. (Cohen, S. S. A system of physiologic therapeutics, vols. 3 and 4.)

CLIMATOGRAPHY

Kendrew, W. G. Climates of the continents. Oxford. 1922.

The only other comprehensive descriptive work on the climates of all parts of the world, with tabulated statistics and references to all the important literature of climatography, is J. Hann's Handbuch der Klimatologie, 3d ed., Stuttgart, 1908–11. Vols. 2 and 3, dealing with climatography, have not been translated.

The leading collection of climatic charts for the whole world is J. G. Bartholomew's Atlas of meteorology, Westminster, 1899 (Bartholomew's physical atlas, vol. 3).

On the climate of the United States consult Alfred J. Henry, Climatology of the United States, Washington, 1906 (U. S. Weather bureau. Bull. Q).

The chief collection of rainfall data for the world at large, exclusive of Europe, is Alexander Supan's Verteilung des Niederschlags auf der festen Erdoberfläche, Gotha, 1898 (Petermann's Mitteilungen, Ergänzungsheft 124).

There is a voluminous literature on regional and local climatography.

LEADING METEOROLOGICAL JOURNALS

Beiträge zur Physik der freien Atmosphäre. Strassburg. 1904–.

Bulletin of the American meteorological society. Worcester, Mass. 1920–.

Marine observer. London. 1924–. (Published by Meteorological office.)

Meteorological magazine. London. 1866–. (Published by Meteorological office.)

Meteorologische Zeitschrift. Braunschweig, etc. 1884–.

Monthly weather review. Washington. 1872–. (Published by U. S. Weather bureau.)

Quarterly journal of the Royal meteorological society. London. 1871–.

TABLES

TABLE I.—*Correction of mercurial barometer for temperature, English measures*

ADD

Temp. ° F.	Observed reading (inches)					Temp. ° F.	Observed reading (inches)				
	28.5	29.0	29.5	30.0	30.5		28.5	29.0	29.5	30.0	30.5
0	0.07	0.08	0.08	0.08	0.08	16	0.03	0.03	0.03	0.03	0.04
1	.07	.07	.07	.08	.08	17	.03	.03	.03	.03	.03
2	.07	.07	.07	.07	.07	18	.03	.03	.03	.03	.03
3	.07	.07	.07	.07	.07	19	.02	.02	.03	.03	.03
4	.06	.06	.07	.07	.07	20	.02	.02	.02	.02	.02
5	.06	.06	.06	.06	.07	21	.02	.02	.02	.02	.02
6	.06	.06	.06	.06	.06	22	.02	.02	.02	.02	.02
7	.06	.06	.06	.06	.06	23	.02	.02	.02	.02	.02
8	.05	.05	.06	.06	.06	24	.01	.01	.01	.01	.01
9	.05	.05	.05	.05	.05	25	.01	.01	.01	.01	.01
10	.05	.05	.05	.05	.05	26	.01	.01	.01	.01	.01
11	.05	.05	.05	.05	.05	27					
12	.04	.04	.04	.04	.05	28					
13	.04	.04	.04	.04	.04	29					
14	.04	.04	.04	.04	.04	30					
15	.04	.04	.04	.04	.04						

SUBTRACT

31	0.01	0.01	0.01	0.01	0.01	67	0.10	0.10	0.10	0.10	0.11
32	.01	.01	.01	.01	.01	68	.10	.10	.10	.11	.11
33	.01	.01	.01	.01	.01	69	.10	.11	.11	.11	.11
34	.01	.01	.01	.02	.02	70	.11	.11	.11	.11	.11
35	.02	.02	.02	.02	.02	71	.11	.11	.11	.12	.12
36	.02	.02	.02	.02	.02	72	.11	.11	.12	.12	.12
37	.02	.02	.02	.02	.02	73	.11	.12	.12	.12	.12
38	.02	.02	.02	.03	.03	74	.12	.12	.12	.12	.12
39	.03	.03	.03	.03	.03	75	.12	.12	.12	.13	.13
40	.03	.03	.03	.03	.03	76	.12	.12	.13	.13	.13
41	.03	.03	.03	.03	.03	77	.12	.13	.13	.13	.13
42	.04	.04	.04	.04	.04	78	.13	.13	.13	.13	.14
43	.04	.04	.04	.04	.04	79	.13	.13	.14	.14	.14
44	.04	.04	.04	.04	.04	80	.13	.14	.14	.14	.14
45	.04	.04	.04	.04	.04	81	.14	.14	.14	.14	.14
46	.04	.05	.05	.05	.05	82	.14	.14	.14	.14	.15
47	.05	.05	.05	.05	.05	83	.14	.14	.14	.15	.15
48	.05	.05	.06	.05	.05	84	.14	.14	.15	.15	.15
49	.05	.05	.05	.06	.06	85	.15	.15	.15	.15	.16
50	.06	.06	.06	.06	.06	86	.15	.15	.15	.16	.16
51	.06	.06	.06	.06	.06	87	.15	.15	.16	.16	.16
52	.06	.06	.06	.06	.06	88	.15	.16	.16	.16	.16
53	.06	.06	.06	.07	.07	89	.16	.16	.16	.16	.17
54	.06	.07	.07	.07	.07	90	.16	.16	.16	.17	.17
55	.07	.07	.07	.07	.07	91	.16	.16	.17	.17	.17
56	.07	.07	.07	.07	.08	92	.16	.17	.17	.17	.18
57	.07	.08	.08	.08	.08	93	.17	.17	.17	.17	.18
58	.08	.08	.08	.08	.08	94	.17	.17	.17	.18	.18
59	.08	.08	.08	.08	.08	95	.17	.17	.18	.18	.18
60	.08	.08	.08	.08	.09	96	.17	.18	.18	.18	.19
61	.08	.08	.09	.09	.09	97	.18	.18	.18	.18	.19
62	.09	.09	.09	.09	.09	98	.18	.18	.18	.19	.19
63	.09	.09	.09	.09	.10	99	.18	.18	.19	.19	.19
64	.09	.09	.10	.10	.10	100	.18	.19	.19	.19	.20
65	.09	.10	.10	.10	.10						
66	.10	.10	.10	.10	.10						

TABLE II.—*Reduction of barometric reading to mean sea level*

[Reading, 30 inches. The correction is always to be added]

Height in feet	Temperature of air (dry bulb in shelter)									
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	------	------	------
10	.01	.01	.01	.01	.01	.01	.01	0.01	0.01	0.01
15	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
20	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
25	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03
30	.04	.04	.04	.04	.03	.03	.03	.03	.03	.03
35	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04
40	.05	.05	.05	.05	.04	.04	.04	.04	.04	.04
45	.06	.05	.05	.05	.05	.05	.05	.05	.05	.05
50	.06	.06	.06	.06	.06	.06	.05	.05	.05	.05
55	.07	.07	.06	.06	.06	.06	.06	.06	.06	.06
60	.07	.07	.07	.07	.07	.07	.06	.06	.06	.06
65	.08	.08	.08	.08	.07	.07	.07	.07	.07	.07
70	.09	.08	.08	.08	.08	.08	.08	.07	.07	.07
75	.09	.09	.09	.09	.08	.08	.08	.08	.08	.08
80	.10	.10	.09	.09	.09	.09	.09	.08	.08	.08
85	.10	.10	.10	.10	.10	.10	.09	.09	.09	.09
90	.11	.11	.11	.10	.10	.10	.10	.10	.09	.09
95	.12	.11	.11	.11	.11	.11	.10	.10	.10	.10
100	.12	.12	.12	.12	.11	.11	.11	.11	.10	.10

TABLE III.—*Reduction of the mercurial barometer to standard gravity (45°) (30 inches)*

Lat.	Cor.	Lat.	Cor.	Lat.	Cor.	Lat.	Cor.
°	*Inch*	°	*Inch*	°	*Inch*	°	*Inch*
0	−0.08	25	−0.05	45	0.00	70	+0.06
5	−.08	30	−.04	50	+.01	75	+.07
10	−.08	35	−.03	55	+.03	80	+.08
15	−.07	40	−.01	60	+.04	85	+.08
20	−.06	45	.00	65	+.05	90	+.08

TABLE IV.—*Equivalent temperatures (centigrade and Fahrenheit)*

(C°=temperature centigrade; F°=temperature Fahrenheit; F°=$\frac{9}{5}$C°+32°)

C°	F°	C°	F°	C°	F°	C°	F°	C°	F°
−10	14.0	0	32.0	10	50.0	20	68.0	30	86.0
−9	15.8	1	33.8	11	51.8	21	69.8	31	87.8
−8	17.6	2	35.6	12	53.6	22	71.6	32	89.6
−7	19.4	3	37.4	13	55.4	23	73.4	33	91.4
−6	21.2	4	39.2	14	57.2	24	75.2	34	93.2
−5	23.0	5	41.0	15	59.0	25	77.0	35	95.0
−4	24.8	6	42.8	16	60.8	26	78.8	36	96.8
−3	26.6	7	44.6	17	62.6	27	80.6	37	98.6
−2	28.4	8	46.4	18	64.4	28	82.4	38	100.4
−1	30.2	9	48.2	19	66.2	29	84.2	39	102.2

TABLE V.—*Equivalent lengths (millimeters and inches)*

(1 millimeter=0.0393700 inch)

Mm.	0	1	2	3	4	5	6	7	8	9
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
690	[a]27.16	27.20	27.24	27.28	27.32	27.36	27.40	27.44	27.48	27.52
700	27.56	27.60	27.64	27.68	27.72	27.76	27.80	27.84	27.87	27.91
710	27.95	27.99	28.03	28.07	28.11	28.15	28.19	28.23	28.27	28.31
720	28.35	28.39	28.42	28.46	28.50	28.54	28.58	28.62	28.66	28.70
730	28.74	28.78	28.82	28.86	28.90	28.94	28.98	29.02	29.06	29.09
740	29.13	29.17	29.21	29.25	29.29	29.33	29.37	29.41	29.45	29.49
750	29.53	29.57	29.61	29.65	29.68	29.72	29.76	29.80	29.84	29.88
760	29.92	29.96	30.00	30.04	30.08	30.12	30.16	30.20	30.24	30.28
770	30.32	30.35	30.39	30.43	30.47	30.51	30.55	30.59	30.63	30.67
780	30.71	30.75	30.79	30.83	30.87	30.90	30.94	30.98	31.02	31.06
790	31.10	31.14	31.18	31.22	31.26	31.30	31.34	31.38	31.42	31.46

[a] For example, 690 millimeters=27.16 inches

TABLE VI.—*Conversion of millibars to inches*

(Equivalents in mercury inches at 32° and latitude 45° of millibars)

Mb.	Inches	Mb.	Inches	Mb.	Inches	Mb.	Inches
925	27.32	960	28.35	995	29.38	1,025	30.27
926	27.35	961	28.38	996	29.41	1,026	30.30
927	27.37	962	28.41	997	29.44	1,027	30.33
928	27.40	963	28.44	998	29.47	1,028	30.36
929	27.43	964	28.47	999	29.50	1,029	30.39
930	27.46	965	28.50				
931	27.49	966	28.53	1,000	29.53	1,030	30.42
932	27.52	967	28.56	1,001	29.56	1,031	30.45
933	27.55	968	28.59	1,002	29.59	1,032	30.48
934	27.58	969	28.62	1,003	29.62	1,033	30.51
				1,004	29.65	1,034	30.53
935	27.61	970	28.65				
936	27.64	971	28.67				
937	27.67	972	28.70	1,005	29.68	1,035	30.56
938	27.70	973	28.73	1,006	29 71	1,036	30.59
939	27.73	974	28.76	1,007	29.74	1,037	30.62
				1,008	29.77	1,038	30.65
940	27.76	975	28.79	1,009	29.80	1,039	30.68
941	27.79	976	28.82				
942	27.82	977	28.85				
943	27.85	978	28.88	1,010	29.83	1,040	30.71
944	27.88	979	28.91	1,011	29.86	1,041	30.74
				1,012	29.89	1,042	30.77
945	27.91	980	28.94	1,013	29.92	1,043	30.80
946	27.94	981	28.97	1,014	29.94	1,044	30.83
947	27.97	982	29.00				
948	28.00	983	29.03				
949	28.03	984	29.06				
				1,015	29.97	1,045	30.86
950	28.05	985	29.09	1,016	30.00	1,046	30.89
951	28.08	986	29.12	1,017	30.03	1,047	30.92
952	28.11	987	29.15	1,018	30.06	1,048	30.95
953	28.14	988	29.18	1,019	30.09	1,049	30.98
954	28.17	989	29.21				
955	28.20	990	29.24	1,020	30.12	1,050	31.01
956	28.23	991	29.26	1,021	30.15	1,051	31.04
957	28.26	992	29.29	1,022	30.18	1,052	31.07
958	28.29	993	29.32	1,023	30.21	1,053	31.10
959	28.32	994	29.35	1,024	30.24	1,054	31.13

TABLE VII.—*For obtaining the relative humidity of the air*

Temperature of the air, dry-bulb thermometer	Difference between dry bulb and wet bulb readings									
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
°	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
24	87	75	62	50	38	26	------	------	------	------
26	88	76	65	53	42	30	------	------	------	------
28	89	78	67	56	45	34	24	------	------	------
30	90	79	68	58	48	38	28	------	------	------
32	90	80	70	61	51	41	32	23	------	------
34	90	81	72	63	53	44	35	27	------	------
36	91	82	73	64	55	47	38	30	22	------
38	92	83	75	66	57	50	42	34	26	------
40	92	84	76	68	59	52	44	37	30	22
42	92	84	77	69	61	54	47	40	33	26
44	92	85	78	70	63	56	49	43	36	29
46	93	85	79	72	65	58	51	45	38	32
48	93	86	79	73	66	60	53	47	41	35
50	93	87	80	74	67	61	55	49	43	37
52	94	87	81	75	69	63	57	51	46	40
54	94	88	82	76	70	64	59	53	48	42
56	94	88	82	77	71	65	60	55	50	44
58	94	89	83	78	72	67	61	56	51	46
60	94	89	84	78	73	68	63	58	53	48
62	95	89	84	79	74	69	64	59	54	50
64	95	90	85	79	74	70	65	60	56	51
66	95	90	85	80	75	71	66	61	57	53
68	95	90	85	81	76	71	67	63	58	54
70	95	90	86	81	77	72	68	64	60	55
72	95	91	86	82	77	73	69	65	61	57
74	95	91	86	82	78	74	70	66	62	58
76	95	91	87	82	78	74	70	66	63	59
78	96	91	87	83	79	75	71	67	63	60
80	96	92	87	83	79	75	72	68	64	61
82	96	92	88	84	80	76	72	69	65	62
84	96	92	88	84	80	77	73	69	66	63
86	96	92	88	84	81	77	73	70	67	63
88	96	92	88	85	81	77	74	71	67	64
90	96	92	88	85	81	78	74	71	68	65

The constants of this table were determined for a ventilated psychrometer and are not strictly applicable to the readings of a stationary hygrometer.

TABLE VIII.—*Table for obtaining the true direction and force of the wind from the deck of a moving vessel*

Apparent force of the wind (Beaufort scale)	Speed of the vessel, knots	Apparent direction of the wind (points off the bow) 0: True direction, points off the bow	0: True force, Beaufort scale	1: True direction, points off the bow	1: True force, Beaufort scale	2: True direction, points off the bow	2: True force, Beaufort scale	3: True direction, points off the bow	3: True force, Beaufort scale	4: True direction, points off the bow	4: True force, Beaufort scale	5: True direction, points off the bow	5: True force, Beaufort scale	6: True direction, points off the bow	6: True force, Beaufort scale	7: True direction, points off the bow	7: True force, Beaufort scale	8: True direction, points off the bow	8: True force, Beaufort scale	9: True direction, points off the bow	9: True force, Beaufort scale	10: True direction, points off the bow	10: True force, Beaufort scale	11: True direction, points off the bow	11: True force, Beaufort scale	12: True direction, points off the bow	12: True force, Beaufort scale	13: True direction, points off the bow	13: True force, Beaufort scale	14: True direction, points off the bow	14: True force, Beaufort scale	15: True direction, points off the bow	15: True force, Beaufort scale	16: True direction, points off the bow	16: True force, Beaufort scale
0	10	16	1	16	1	15	1	15	1	16	1	15	1	15	2	15	2	15	2	15	2	15	2	15	2	15	2	15	2	15	2	16	2	16	2
	15	16	2	16	2	16	2	15	2	15	2	15	2	15	3	15	3	15	3	15	3	15	3	15	3	15	3	16	3	16	3	16	3	16	3
	20	16	3	16	3	16	3	16	4	15	4	15	4	15	4	15	4	15	4	15	4	15	4	15	4	16	4	16	5	16	5	16	5	16	5
1	10	16	0	14	0	13	0	12	1	12	1	12	1	12	2	13	2	13	2	13	2	14	3	14	3	14	3	15	3	15	3	16	3	16	3
	15	16	1	15	1	14	2	14	2	14	2	14	2	14	3	14	3	14	3	14	3	14	4	14	4	15	4	15	4	15	4	16	4	16	4
	20	16	2	15	2	15	3	15	3	14	3	14	3	14	4	14	4	14	4	14	4	15	5	15	5	15	5	15	5	15	5	16	5	16	5
2	10	0	0	6	0	7	0	8	1	9	1	10	2	10	2	11	3	12	3	12	3	13	3	13	4	14	4	14	4	15	4	15	4	16	4
	15	16	0	13	0	12	1	12	1	12	2	12	2	12	3	12	3	13	4	13	4	13	4	14	5	14	5	15	5	15	5	16	5	16	5
	20	16	1	15	2	14	2	13	2	13	3	13	3	13	4	13	4	13	5	14	5	14	5	14	6	15	6	15	6	15	6	16	6	16	6
3	10	0	1	3	1	5	1	6	2	8	2	8	2	9	3	10	3	11	4	12	4	12	4	13	5	14	5	14	5	15	5	15	5	16	5
	15	0	0	8	0	8	1	9	1	10	2	10	3	11	3	11	4	12	4	12	5	13	5	13	6	14	6	14	6	15	6	15	6	16	6
	20	16	0	13	1	12	1	12	2	12	3	12	3	12	4	12	5	13	5	13	6	13	6	14	6	14	7	15	7	15	7	16	7	16	7
4	10	0	2	2	2	4	2	6	2	7	3	8	3	9	4	10	4	10	4	11	5	12	5	13	5	13	6	14	6	15	6	15	6	16	6
	15	0	1	4	1	6	1	7	2	8	3	9	3	10	4	11	5	11	5	12	6	12	6	13	6	14	7	14	7	15	7	15	7	16	7
	20	----	0	9	0	9	1	10	2	10	3	10	4	11	4	12	5	12	5	12	6	13	7	14	7	14	7	14	8	15	8	16	8	16	8
5	10	0	3	2	3	3	3	5	3	6	4	7	4	8	5	9	5	10	5	11	6	12	6	12	6	13	7	14	7	15	7	15	7	16	7
	15	0	2	3	2	5	2	6	3	7	3	8	4	9	5	10	5	11	6	12	6	12	7	13	7	14	7	14	7	15	8	15	8	16	8
	20	0	0	5	1	7	2	8	3	9	3	10	3	10	5	11	6	12	6	12	7	13	7	13	8	14	8	14	8	15	8	15	8	16	8

6	10	0	4	2	4	3	4	4	4	6	5	7	5	8	6	9	6	10	6	11	7	11	7	12	7	13	7	14	7	14	8	15	8	16	8
	15	0	3	2	3	4	3	5	4	7	4	8	5	9	6	10	6	10	7	11	7	12	7	13	8	13	8	14	8	15	8	15	8	16	8
	20	0	2	3	2	5	2	7	3	8	4	9	5	10	6	10	7	11	7	12	7	12	8	13	8	14	8	14	9	14	9	15	9	16	9
7	10	0	5	1	5	3	5	4	6	5	6	6	6	7	7	8	7	9	7	10	7	11	8	12	8	13	8	14	8	14	8	15	8	16	8
	15	0	4	2	4	3	4	5	5	6	5	7	6	8	6	9	7	10	7	11	8	12	8	12	8	13	9	14	9	15	9	15	9	16	9
	20	0	3	2	3	4	4	6	4	7	5	8	6	9	7	10	7	11	8	11	8	12	9	13	9	13	9	14	9	15	10	15	10	16	10
8	10	0	6	1	6	3	7	4	7	5	7	6	7	7	8	8	8	9	8	10	8	11	9	12	9	13	9	14	9	14	9	15	9	16	9
	15	0	5	2	6	3	6	4	6	6	7	7	7	8	8	9	8	10	8	11	9	11	9	12	9	13	10	14	10	15	10	15	10	16	10
	20	0	4	2	5	4	5	5	6	6	6	8	7	9	8	9	8	10	9	11	9	12	10	13	10	13	10	14	10	15	10	15	11	16	11
9	10	0	8	1	8	2	8	4	8	5	8	6	8	7	9	8	9	9	9	10	9	11	10	12	10	13	10	13	10	14	10	15	10	16	10
	15	0	7	1	7	3	7	4	7	5	8	6	8	8	8	9	9	10	9	10	10	11	10	12	10	13	10	14	11	14	11	15	11	16	11
	20	0	6	2	6	3	6	5	7	6	7	7	8	8	8	9	8	10	9	11	10	12	10	12	10	13	11	14	11	15	11	15	11	16	11
10	10	0	9	1	9	2	9	4	9	5	9	6	9	7	10	8	10	9	10	10	10	11	11	12	11	13	11	13	11	14	11	15	11	16	11
	15	0	8	1	8	3	8	4	8	5	9	6	9	7	9	8	10	9	10	10	11	11	11	12	11	13	11	14	11	14	11	15	11	16	11
	20	0	7	2	7	3	8	4	8	6	8	7	9	8	9	9	10	10	10	11	11	11	11	12	11	13	12	14	12	15	12	16	12	16	12
11	10	0	10	1	10	2	10	4	10	5	10	6	10	7	11	8	11	9	11	10	11	11	11	12	11	12	12	13	12	14	12	15	12	16	12
	15	0	9	1	9	3	9	4	10	5	10	6	10	7	11	8	11	9	11	10	11	11	12	12	12	13	12	14	12	14	12	15	12	16	12
	20	0	9	1	9	3	9	4	9	5	10	7	10	8	10	9	11	10	11	10	12	11	12	12	12	13	12	14	12	14	12	15	12	16	12
12	10	0	11	1	11	2	11	3	11	4	11	6	12	7	12	8	12	9	12	10	12	11	12	12	12	12	12	13	12	14	12	15	12	16	12
	15	0	11	1	11	2	11	4	11	5	11	6	11	7	12	8	12	9	12	10	12	11	12	12	12	13	12	13	12	14	12	15	12	16	12
	20	0	10	1	10	3	10	4	11	5	11	6	11	7	12	8	12	9	12	10	12	11	12	12	12	13	12	14	12	14	12	15	12	16	12

TABLE IX.—*Scale of velocity equivalents of the so-called Beaufort scale of wind*

Beaufort number	Explanatory titles	Mode of estimating aboard sailing vessels	Specification for use on land	Meters per second	Miles per hour Statute
0	Calm		Calm, smoke rises vertically.	Less than 0.3	Less than 1
			Direction of wind shown by smoke drift, but not by wind vanes.	0.3- 1.5	1-3
1	Light air	Sufficient wind for working ship.	Wind felt on face; leaves rustle; ordinary vane moved by wind.	1.6-3.3	4-7
2	Slight breeze				
3	Gentle breeze		Leaves and small twigs in constant motion; wind extends light flag.	3.4-5.4	8-12
4	Moderate breeze.	Forces most advantageous for sailing with leading wind and all sail drawing.	Raises dust and loose paper; small branches are moved.	5.5-7.9	13-18
5	Fresh breeze		Small trees in leaf begin to sway; crested wavelets form on inland waters.	8.0-10.7	19-24
6	Strong breeze	Reduction of sail necessary with leading wind.	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.	10.8-13.8	25-31
7	High wind (*Mod. gale*)		Whole trees in motion; inconvenience felt when walking against wind.	13.9-17.1	32-38
8	Gale (*Fresh gale*)	Considerable reduction of sail necessary even with wind quartering.	Breaks twigs off trees; generally impedes progress.	17.2-20.7	39-46
9	Strong gale		Slight structural damage occurs (chimney pots and slate removed).	20.8-24.4	47-54
10	Whole gale	Close reefed sail running, or hove to under storm sail.	Seldom experienced inland; trees uprooted; considerable structural damage occurs.	24.5-28.4	55-63
11	Storm		Very rarely experienced, accompanied by widespread damage.	28.5-33.5	64-75
12	Hurricane	No sail can stand even when running.		33.6 or above	Above 75

TABLE X.—*Time of observation*

WEST LONGITUDE, A. M., CIVIL DATE

Ship's longitude	Local mean time, a. m.	Ship's longitude	Local mean time, a. m.	Ship's longitude	Local mean time, a. m.	Ship's longitude	Local mean time, a. m.
° *W.*	*h. m.*	° *W.*	*h. m.*	° *W.*	*h. m.*	° *W.*	*h. m.*
0	Noon	45	9 00	90	6 00	135	3 00
1	11 56	46	8 56	91	5 56	136	2 56
2	11 52	47	8 52	92	5 52	137	2 52
3	11 48	48	8 48	93	5 48	138	2 48
4	11 44	49	8 44	94	5 44	139	2 44
5	11 40	50	8 40	95	5 40	140	2 40
6	11 36	51	8 36	96	5 36	141	2 36
7	11 32	52	8 32	97	5 32	142	2 32
8	11 28	53	8 28	98	5 28	143	2 28
9	11 24	54	8 24	99	5 24	144	2 24
10	11 20	55	8 20	100	5 20	145	2 20
11	11 16	56	8 16	101	5 16	146	2 16
12	11 12	57	8 12	102	5 12	147	2 12
13	11 08	58	8 08	103	5 08	148	2 08
14	11 04	59	8 04	104	5 04	149	2 04
15	11 00	60	8 00	105	5 00	150	2 00
16	10 56	61	7 56	106	4 56	151	1 56
17	10 52	62	7 52	107	4 52	152	1 52
18	10 48	63	7 48	108	4 48	153	1 48
19	10 44	64	7 44	109	4 44	154	1 44
20	10 40	65	7 40	110	4 40	155	1 40
21	10 36	66	7 36	111	4 36	156	1 36
22	10 32	67	7 32	112	4 32	157	1 32
23	10 28	68	7 28	113	4 28	158	1 28
24	10 24	69	7 24	114	4 24	159	1 24
25	10 20	70	7 20	115	4 20	160	1 20
26	10 16	71	7 16	116	4 16	161	1 16

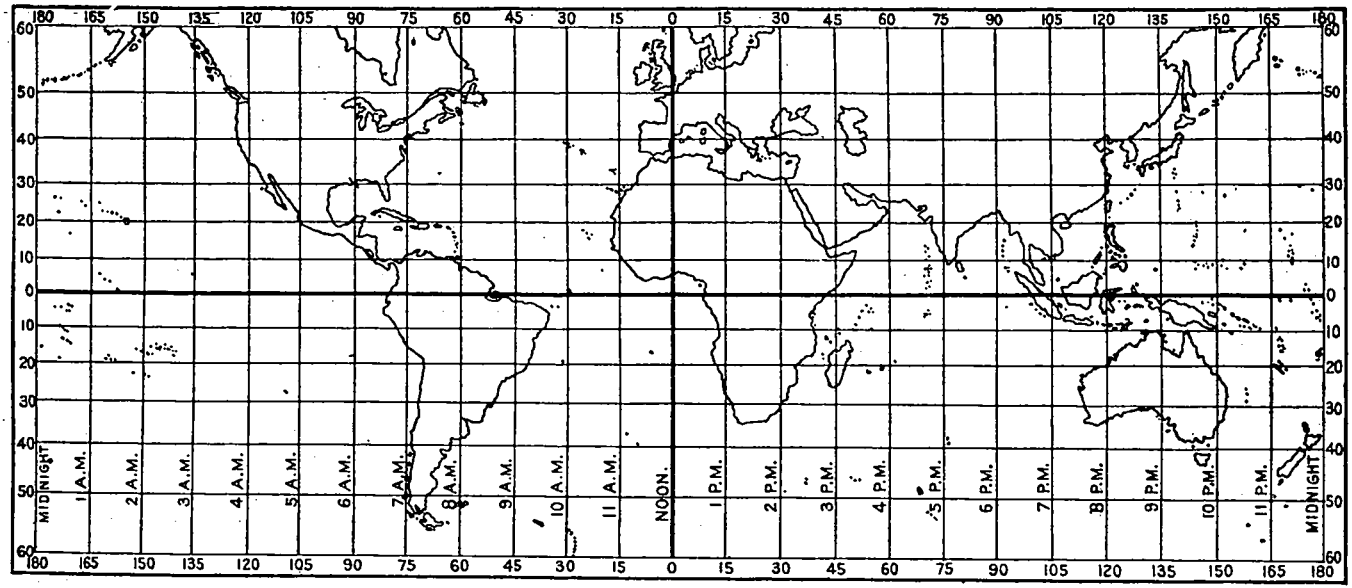
TABLE X.—*Time of observation*—Continued

WEST LONGITUDE, A. M., CIVIL DATE—continued

Ship's longitude	Local mean time, a. m.	Ship's longitude	Local mean time, a. m.	Ship's longitude	Local mean time, a. m.	Ship's longitude	Local mean time, a. m.
° *W.*	*h. m.*	° *W.*	*h. m.*	° *W.*	*h. m.*	° *W.*	*h. m.*
27	10 12	72	7 12	117	4 12	162	1 12
28	10 08	73	7 08	118	4 08	163	1 08
29	10 04	74	7 04	119	4 04	164	1 04
30	10 00	75	7 00	120	4 00	165	1 00
31	9 56	76	6 56	121	3 56	166	12 56
32	9 52	77	6 52	122	3 52	167	12 52
33	9 48	78	6 48	123	3 48	168	12 48
34	9 44	79	6 44	124	3 44	169	12 44
35	9 40	80	6 40	125	3 40	170	12 40
36	9 36	81	6 36	126	3 36	171	12 36
37	9 32	82	6 32	127	3 32	172	12 32
38	9 28	83	6 28	128	3 28	173	12 28
39	9 24	84	6 24	129	3 24	174	12 24
40	9 20	85	6 20	130	3 20	175	12 20
41	9 16	86	6 16	131	3 16	176	12 16
42	9 12	87	6 12	132	3 12	177	12 12
43	9 08	88	6 08	133	3 08	178	12 08
44	9 04	89	6 04	134	3 04	179	12 04

EAST LONGITUDE, P. M., CIVIL DATE

Ship's longitude	Local mean time, p. m.	Ship's longitude	Local mean time, p. m.	Ship's longitude	Local mean time, p. m.	Ship's longitude	Local mean time, p. m.
° *E.*	*h. m.*	° *E.*	*h. m.*	° *E.*	*h. m.*	° *E.*	*h. m.*
1	12 04	46	3 04	91	6 04	136	9 04
2	12 08	47	3 08	92	6 08	137	9 08
3	12 12	48	3 12	93	6 12	138	9 12
4	12 16	49	3 16	94	6 16	139	9 16
5	12 20	50	3 20	95	6 20	140	9 20
6	12 24	51	3 24	96	6 24	141	9 24
7	12 28	52	3 28	97	6 28	142	9 28
8	12 32	53	3 32	98	6 32	143	9 32
9	12 36	54	3 36	99	6 36	144	9 36
10	12 40	55	3 40	100	6 40	145	9 40
11	12 44	56	3 44	101	6 44	146	9 44
12	12 48	57	3 48	102	6 48	147	9 48
13	12 52	58	3 52	103	6 52	148	9 52
14	12 56	59	3 56	104	6 56	149	9 56
15	1 00	60	4 00	105	7 00	150	10 00
16	1 04	61	4 04	106	7 04	151	10 04
17	1 08	62	4 08	107	7 08	152	10 08
18	1 12	63	4 12	108	7 12	153	10 12
19	1 16	64	4 16	109	7 16	154	10 16
20	1 20	65	4 20	110	7 20	155	10 20
21	1 24	66	4 24	111	7 24	156	10 24
22	1 28	67	4 28	112	7 28	157	10 28
23	1 32	68	4 32	113	7 32	158	10 32
24	1 36	69	4 36	114	7 36	159	10 36
25	1 40	70	4 40	115	7 40	160	10 40
26	1 44	71	4 44	116	7 44	161	10 44
27	1 48	72	4 48	117	7 48	162	10 48
28	1 52	73	4 52	118	7 52	163	10 52
29	1 56	74	4 56	119	7 56	164	10 56
30	2 00	75	5 00	120	8 00	165	11 00
31	2 04	76	5 04	121	8 04	166	11 04
32	2 08	77	5 08	122	8 08	167	11 08
33	2 12	78	5 12	123	8 12	168	11 12
34	2 16	79	5 16	124	8 16	169	11 16
35	2 20	80	5 20	125	8 20	170	11 20
36	2 24	81	5 24	126	8 24	171	11 24
37	2 28	82	5 28	127	8 28	172	11 28
38	2 32	83	5 32	128	8 32	173	11 32
39	2 36	84	5 36	129	8 36	174	11 36
40	2 40	85	5 40	130	8 40	175	11 40
41	2 44	86	5 44	131	8 44	176	11 44
42	2 48	87	5 48	132	8 48	177	11 48
43	2 52	88	5 52	133	8 52	178	11 52
44	2 56	89	5 56	134	8 56	179	11 56
45	3 00	90	6 00	135	9 00	180	Mid.



This chart gives the local time corresponding to Greenwich mean noon

International meteorological symbols

Symbol	Meaning	Remarks
⊛	Rain.	
*	Snow.	
⊗	Rain and snow together ("sleet" of British usage).	
⊠	Thunderstorm.	Thunder and lightning.
T	Thunder.	Without lightning.
⚡	Lightning.	Without thunder, "heat-lightning."
▲	Hail.*	
△	Graupel	Sometimes called "soft hail." French, *grésil*. Resembles little snow-pellets.
≡	Fog.	
≡	Ground fog.	Not exceeding the height of a man.
≡	Wet fog.	One which wets exposed surfaces.
⊥	Hoarfrost.	
⊥	Dew.	
<	Rime.	A rough frost deposit from fog
∽	Glaze; glazed frost.†	Ice coating due to rain, "ice-storm." In America often called "sleet."
⊥→	Driving snow.	Ger., *Schneegestöber;* Fr., *bourrasque de neige*.
⊥—	Ice-crystals.	Ice-needles sometimes seen floating or slowly falling in the air in clear, cold weather.
⊠	Snow on ground.	Ground near station more than half covered.
⚑	Gale.	Wind of force 8–12, Beaufort scale. (Rept. Int. Met'l Comm., Berlin, 1910, English ed., p. 17.) Formerly used for "strong wind." A 3-barbed arrow is introduced in the 2d German ed. of the Int. Met'l Codex to denote "strong wind," but no authority is cited. According to the Observer's Handbook of the British Met'l Office "the number of barbs on the arrow may conveniently be made to represent the strongest wind force noted," but there is no international sanction for such variants.
⊙	Sunshine.	In German edition of Int. Met' lCodex, but has never been definitely recognized by the international organization. (See Rept. Int. Met'l Comm., Southport, 1903, Engl. ed., p. 19 and 101.) Widely used in German and Austrian publications.
⊕	Solar halo.	
⊕	Solar corona.	
☽	Lunar halo.	
☽	Lunar corona.	
⌒	Rainbow.	
⌒	Aurora.	
⊠	Zodiacal light.	
∞	Haze.	Due to fine dust, or to the disturbance of atmospheric transparency by air-currents of different densities ("optical turbidity"), and not to water drops. In practice, this is often difficult to distinguish from light fog (≡°), or "mist" of British observers. Prussian and Austrian observers underscore this symbol (∞) to denote a definitely *smoky* atmosphere ("Moorrauch").
⊠	Mirage.	
O	Exceptional visibility.	

* True hail, which occurs chiefly with summer thunderstorms, should be distinguished from the snowy pellets, like miniature snowballs, known as *graupel*, or *soft hail* (△); also from the small particles of clear ice, called *sleet* by the U. S. Weather Bureau, for which there is no international symbol. On the history of the word *sleet* see *Monthly Weather Review*, May, 1916, pp. 281–286.

† *Glaze* is the official term in the United States; *glazed frost* in Great Britain.

International meteorological symbols

The International Meteorological Symbols were adopted at the Vienna meteorological congress of 1873. A few additions and modifications have been made at subsequent international meteorological meetings. The forms of these symbols are more or less flexible. Those shown in the accompanying table are the forms which have generally been used in the United States, and with two exceptions ("wet fog" and "zodiacal light") are identical with those used by the Prussian Meteorological Institute and given in the German editions of the International Meteorological Codex. The principal variants found in the meteorological publications of the different countries are given in the *Monthly Weather Review* (Wash., D. C.), May, 1916, p. 268.

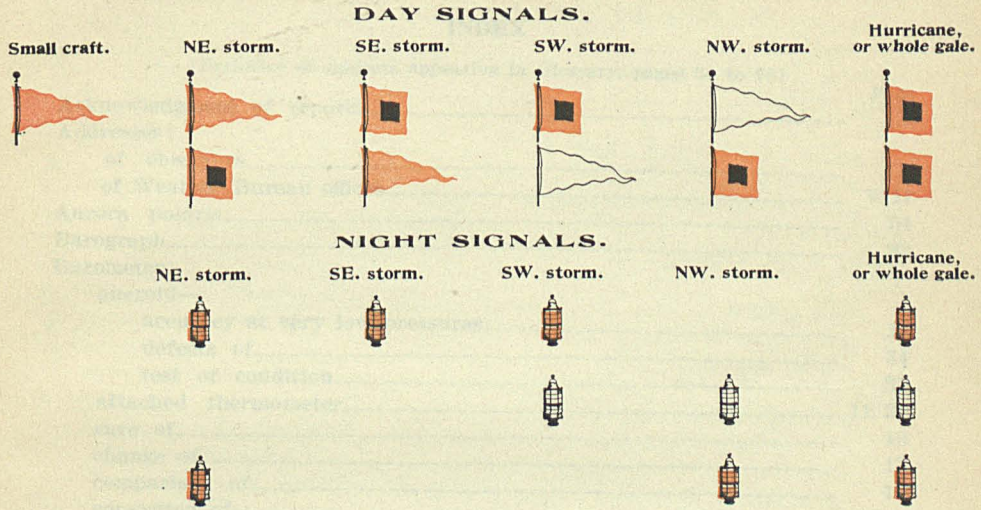
Exponents.—An exponent added to a symbol indicates the degree of intensity, ranging from ^{0} weak (light, etc.) to ^{2} strong (heavy, etc.). Thus, ⓡ^{0}, light rain; ⓡ^{2}, heavy rain. German and French observers use the exponent ^{1} to denote medium intensity, in accordance with the German and French versions of the report of the Vienna congress, and the German editions of the Codex. The English version of the above-mentioned report and the English edition of the Codex provide for the use of only two exponents, ^{0} and ^{2}; hence in English-speaking countries the omission of the exponent indicates medium intensity.

Time of occurrence.—When hours of occurence are added to symbols, the abbreviation *a* is used for a. m., and *p* for p. m. Thus, ⓡ 10a—4p denotes "rain from 10 a. m. to 4 p. m." 12*a*=noon; 12*p*=midnight. The abbreviation *n* means "during night." Stations taking tri-daily observations may use *a* to mean between the first and second observation; *p*, between the second and third; and *n*, between the third and the first.

For further information concerning the International Symbols and other meteorological symbols, see "Meteorological Symbols," by C. Fitzhugh Talman, MONTHLY WEATHER REVIEW (Wash., D. C.), May, 1916, pp. 265–274.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

SMALL CRAFT, STORM, AND HURRICANE WARNINGS.



The small-craft warning.—A red pennant indicates that moderately strong winds that will interfere with the safe operation of small craft are expected. No night display of small-craft warnings is made.

The northeast storm warning.—A red pennant *above* a square red flag with black center displayed by day, or two red lanterns, one above the other, displayed by night, indicates the approach of a storm of marked violence with winds beginning from the *northeast.*

The southeast storm warning.—A red pennant *below* a square red flag with black center displayed by day, or one red lantern displayed by night, indicates the approach of a storm of marked violence with winds beginning from the *southeast.*

The southwest storm warning.—A white pennant *below* a square red flag with black center displayed by day, or a white lantern *below* a red lantern displayed by night, indicates the approach of a storm of marked violence with winds beginning from the *southwest.*

The northwest storm warning.—A white pennant *above* a square red flag with black center displayed by day, or a white lantern *above* a red lantern displayed by night, indicates the approach of a storm of marked violence with winds beginning from the *northwest.*

Hurricane, or whole gale warning.—Two square flags, red with black centers, one above the other, displayed by day, or two red lanterns, with a white lantern between, displayed by night, indicate the approach of a tropical hurricane, or of one of the extremely severe and dangerous extra-tropical storms which occasionally occur.

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