AD 285 018

UNCLASSIFIED

AFCRL-62-825
AUGUST 1962

Instrumentation for Geophysics and Astrophysics
No. 22

Research Note

Measurement Range Required of Meteorological Equipment

ARNOLD COURT
HENRY SALMELA

METEOROLOGICAL DEVELOPMENT LABORATORY PROJECT 8624

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES, OFFICE OF AEROSPACE RESEARCH, UNITED STATES AIR FORCE, L.G. HANSCOM FIELD, MASS.

AFCRL-62-825
AUGUST 1962

Instrumentation for Geophysics and Astrophysics
No. 22

Research Note

Measurement Range Required of Meteorological Equipment

ARNOLD COURT
HENRY SALMELA

METEOROLOGICAL DEVELOPMENT LABORATORY PROJECT 8624

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES, OFFICE OF AEROSPACE RESEARCH, UNITED STATES AIR FORCE, L.G. HANSCOM FIELD, MASS.

Abstract

Meteorological instruments must operate properly so as to accurately measure conditions too extreme for the design and operation of other equipment. This report develops the "improbable extreme" conditions which surface instruments must be designed to measure: temperatures from -140°F tc +160°F, dewpoint at any temperature, T in deg F, given by T/2-80, rainfall during t minutes $2\sqrt{t}$ inches, wind speeds up to 250 mph, and pressure from 506 to 1062 mb.

Atmospheric sounding systems must be able to measure temperatures and corresponding dewpoints over the same range, winds up to 300 mph below 100,000 ft, and pressures whose ratio to the Standard Atmosphere pressure, p, at the maximum height they are expected to attain, is 0.1 (6 + log p) up to 133 km, and 0.1 at still higher levels.

Contents

Measurement Range Required of Meteorological Equipment

1. PURPOSE

Meteorological equipment must operate properly and measure accurately under conditions which may be too extreme for satisfactory operation of ordinary military equipment. This report summarizes an investigation of the required operating ranges for any devices intended to measure temperature, pressure, atmospheric moisture, air movement, and other properties.

For more than a decade, U. S. military equipment has been designed to operate within a broad range of environmental conditions, set forth in detail in MIL-STD-210A (2 August 1957) "Climatic Extremes for Military Equipment", and other related documents, such as the proposed MIL-STD-810 (USAF), "Environmental Test Methods for Military Equipment". The climatic extremes presented in MIL-STD-210A "do not necessarily represent the absolute extremes observed; rather they are the values determined by scientific judgement not to be surpassed on more than 10 percent of the most extreme month (three days)."

Meteorological equipment cannot be designed to these same standards, because extreme conditions themselves are of great importance, and must be measured precisely. Vehicles may not start when temperatures are too low, an air field may be closed when fog is too thick, and missiles may not fire when winds are too strong. The exact temperature, visibility, and windspeed under such non-operational conditions must be measured.

In contrast to the "Probable extremes" of MIL-STD-210A, this report offers some "improbable extremes" -- those which are physically possible, highly improbable, but which must be measured if they occur.

2. EQUIPMENT IN GENERAL

For military equipment in general, MIL-STD-210A distinguishes between ground operation (1) world-wide, (2) arctic winter, (3) moist tropics, (4) hot desert, as well as (5) shipboard and (6) airborne world-wide operation, and finally (7) world-wide short-term storage and transit.

(Received for publication, 19 June 1962)

For meteorological equipment, the storage and transit requirements of MIL-STD-210A are equally valid. They require ability to withstand, without damage, the following "probable extremes":

Pressure from 7.35 to 15.40 lbs/in^2 (505 to 1060 mb)

Temperatures of -80°F for 24 hours, -40°F indefinitely, and diurnal cycle ranging from 10 hours at 90°F to 24 hours at 160°F

Humidities from 0.01 to 13.0 grains/ft^3

Rain of 2 inches in 5 minutes, 7 inches in 1 hour, and 1 inch/hour for 12 hours

Steady winds (10 ft above the surface) of 60 to 80 mph with gusts of 90 to 120 mph, depending on the expected duration of the storage

Blowing snow, sand, dust, etc.

Extremes of the different meteorological elements rarely, if ever occur simultaneously. Hence an instrument intended to measure one element must operate satisfactorily over the complete " improbable" range of that element, but only over the normal range of other elements, i. e., need conform only to the requirements of MIL-STD-210A otherwise. This could mean that some meteorological records might be lost when environmental conditions, other than those it measures, are too severe for its operation. Such gaps in records, while undesirable, would be of minor consequence compared to an inability to determine the extremes themselves.

3. TEMPERATURE

Temperatures have been observed in standard weather shelters 5 or 6 feet above the ground as high as 129°F or 130°F; widely-cited world extremes of 134°F in Death Valley and 136°F in Libya are somewhat questionable. Readings as low as -126°F are reported from Russian stations in the Antarctic. Closer to the surface "improbable extremes" are even greater, ranging from perhaps -140°F just above the interior Antarctic snows to +160°F on the desert sands. Similar low temperatures occur in crevasses, and high temperatures inside closed structures such as trailers and small warehouses.

Therefore, meteorologists should be able to measure air temperatures over a range of 300 deg F, from -140° to +160°F. This is too great a range for thermometers of most types if they are to be read with satisfactory precision throughout the range. Fortunately, such extremes do not occur in any one location, so the same thermometer need not be used at both ends of the scale.

At few places in the world, if any, is the absolute "improbable" temperature range as great as 180 deg F. Consequently, four temperature ranges, each of 180 deg F, are proposed for meteorological thermometers (not airborne):

A: -20°F to +160°F
B: -60°F to +120°F
C: -100°F to + 80°F
D: -140°F to + 40°F

Normal meteorological use would require either ranges B or C, depending on location. Ranges A and D would be needed only for certain outposts in hot deserts or in the Antarctic, respectively. At some places, thermometers would be changed with the seasons: in western North Dakota, for example, temperatures below -60°F and above 120°F have been observed, so that range C would be used in winter, range A in summer.

4. HUMIDITY

Atmospheric moisture may be described in more than half-a-dozen different ways, but only four of them are actually measured by instruments in general use or under development. Organic fibres, such as hair or goldbeater skin, measure relative humidity directly. The difference between the drybulb and wetbulb temperatures is determined by a psychrometer. The absolute humidity, or water vapor concentration (grains /ft^3), controls the electrical resistance of a LiCl salt ("Dewcel") and also the light absorption in an infrared hygrometer. The actual dewpoint temperature is measured by dewpoint instruments in which a mirror or other element is cooled to that point.

4.1 Dewpoint

Physically, dewpoint is the measure of humidity whose "improbable extremes" can be estimated most readily. The dewpoint cannot be higher than the temperature of the body of water from which the vapor originated.

It cannot be lower than the lowest temperature to which the air parcel in which it occurs has been cooled during its entire history.

The highest dewpoints are thus almost 90°F, the temperature reached by the surface in some parts of the Gulf of California, the Red Sea, the Persian Gulf, and possibly in some tropical swamplands. Dewpoints of 87°F have been reported from India. The lowest dewpoints correspond to the lowest temperatures at or just above the tropopause, which may be as low as -130°F in the tropics and possibly -150°F in polar regions.

Dewpoint cannot be higher than air (drybulb) temperature, but can be far lower. Actually, air can be heated to extremely high temperatures only when it is relatively dry; air with a dewpoint of 90°F cannot warm much above 100°F, and temperatures over 120°F usually occur in air whose dewpoint is below 50°F, probably below 20°F.

Just how dry the hot desert air can be has not been determined, and standard weather instruments should be capable of accurately measuring dewpoints of 0°F when the air temperature is 120°F or higher. At the opposite extreme, at Antarctic temperatures of -140°F the dewpoint presumably is no lower than -150°F.

These considerations indicate that the "improbable extreme" dewpoint, T_d, at any air temperature, T_a, may be estimated as

$$T_d = T_a/2 - 80$$

This formula provides the minimum dewpoints, relative humidities, absolute humidities, and wetbulb depressions at various temperatures shown in Table 1.

5. OTHER ELEMENTS

Other weather elements whose "improbable extremes" should be measured accurately by surface meteorological instruments include precipitation, windspeed, and pressure.

5.1 Precipitation

Rainfall intensity is amount (depth) divided by duration (time). The maximum intensity decreases with duration, approximately according to the square root of the time. Thus the world record rainfall during 1 minute is 1.23 inches (Unionville, Md., 4 July 1956), but for 42 minutes it is

Table 1. "Improbable extremes" of dewpoint, absolute humidity (vapor concentration) and relative humidity at various temperatures, which meteorological instruments should be capable of measuring. Upper limit is saturation at any temperature up to 90°F, and dewpoint of 90°F at any higher temperature.

Air Temperature, F	-140	-120	-80	-40	0	40	80	120	160
Dewpoint Temperature, F	-150	-140	-120	-100	-80	-60	-40	-20	0
Abs. Humidity, grains/ft^3	.524*	18.04*	131*	753*	3738*	.0146	.0767	.2186	.5607
Relative Humidity, %	33.2	13.2	3.3	1.3	0.5	0.4	0.4	0.5	0.5
Abs. Humidity, g/m^3	1.2*	41.3*	300*	1724*	8560*	.0335	.1757	.5006	1.284
Dewpoint Temperature, C	-101	-96	-84	-73	-62	-51	-40	-29	-18
Air Temperature, C	-96	-84	-62	-40	-18	4	27	49	71

* $\times 10^{-6}$

12.0 inches (Holt, Mo., 22 June 1947), or only 9.8 times as much. For 18 hours (1080 minutes) the world record is 36.4 inches (Thrall, Tex., 9 September 1921), 29.6 times the 1-minute record; the square root of 1080 is 32.9.

Hence a good rule for the "improbable extreme" rainfall during t-minutes is $2\sqrt{t}$ inches. Raingages should be capable of accurately recording such rainfalls, if further world records are to be observed at weather stations. Specifically, they should be capable of measuring a 1-day accumulation of 72 inches.

5.2 Wind Speeds

Maximum wind speeds near the ground exceed 300 mph in tornadoes and 200 mph in hurricanes, and may be even greater on mountain tops; a speed of 225 mph (corrected) was reliably observed atop Mt. Washington, N. H., 12 April 1934, during an intense spring storm. Ideally, standard wind instruments should be able to record speeds up to 250 mph.

5.3 Atmospheric Pressure

Atmospheric pressures usually are "reduced" to sea-level values for meteorological purposes, resulting in quite high values for continental interior stations in winter. The actual pressure, however, as measured by a barometer, reflects the elevation above sea level. The extreme required in MIL-STD-210A of 15.4 lb/in^2 (1062 mb, 31.35 in Hg) is actually an "improbable extreme" and is adequate for barometers.

Minimum pressure depends primarily on elevation. Assuming that no weather station will be established higher than 15,000 feet above sea level, the minimum pressure which the barometer should be capable of indicating is likewise that provided by MIL-STD-210A, or 7.34 lb/in^2 (506 mb, 14.94 in Hg).

6. SOUNDING SYSTEMS

All the foregoing "improbable extremes" are for instruments installed and operated at weather stations on the ground. They also apply for the launch (or recovery) of instruments intended for vertical or horizontal sounding of the free atmosphere. Wider ranges are possible in the free air.

6.1 Temperature

Temperature, for example, over the hottest desert site may decrease from +130°F at the surface to -130°F at the tropopause, around 50,000 feet. There the dewpoint may be -150°F, possibly even lower. Present instrumentation cannot measure it. In general, the "improbable extremes" of dewpoint, given in Sec. 4.1 may be applied to sounding systems, which should be capable of reporting temperatures from -140°F to +130°F.

6.2 Wind Speeds

Winds are not measured directly by the airborne instrument, but instead are computed on the ground from its displacement. Such techniques should be capable of measuring the "improbable extreme" wind speeds at any level, as well as winds at levels above such extremes.

In the lowermost 100,000 feet of the atmosphere, the strongest winds usually are found at 30,000 to 40,000 feet, where the "improbable maximum" is about 300 mph. Above 25 km (82,000 ft), where the "improbable extreme" is only 40 m/s (90 mph), extreme speeds seem to increase about 2 m/s per km (13.6 mph per 1000 ft) to at least 105 km (350,000 ft) where the "improbable extreme" is 200 m/s (450 mph). Such strong winds cannot occur simultaneously at all levels, but wind information above 80,000 ft is so scarce, and so limited in general to middle latitudes, that layers of maximum speed, analogous to that at 30,000 to 40,000 ft, cannot be delineated. Hence sounding systems should be capable of measuring the "improbable extremes" of the levels at which they are intended to operate.

6.3 Atmospheric Pressure

Pressure requirements for sounding instruments depend on the altitudes they are intended to reach. The percentage variability of pressure increases as the pressure decreases, i. e., with height. Thus the "improbable extreme" minimum pressure at any height depends on the normal pressure there.

At any height, the ratio of this "improbable minimum" pressure, p_{min}, to p_{std}, the pressure of the U. S. Standard Atmosphere, 1962, at the same height is approximately

$$p_{min}/p_{std} = 0.1\ (6 + \log 10\ p_{std}), \quad p_{std} \geq 10^{-5},$$

and is simply 0.1 at pressures lower than 0.000 01 mb, i. e., above 133 km or 436,000 ft. This rule requires, for example, that instruments intended to measure pressures from the surface up to 49 km, or 160,000 ft, where the Standard Atmospheric pressure is about 1 mb, should be capable of reading as low as 0.6 mb. The upper limit, of course, remains at 1062 mb, if the instruments are to record correctly when released anywhere in the world at any season.

7. CONCLUSION

Design and operation of meteorological instruments so as to measure and record accurately the "improbable extremes" presented in this report will provide meteorologists with much more information than they now have on the full range of weather conditions occuring throughout the world.

Acknowledgments

Encouragement and stimulation to prepare this report came from Norman Sissenwine, Chief of the Meteorological Development Laboratory, and Andrew Carten, its chief engineer. Allen E. Cole helped in defining the various limits, and Murray Gutnick in the computation of Table 1.

INSTRUMENTATION FOR GEOPHYSICS AND ASTROPHYSICS

(Formerly: Instrumentation for Geophysical Research)

No. 1. A Digital Electronic Data Recording System for Pulse-Time Telemetering, *Gilbert O. Hall, Feb 1953.*

No. 2. A Rocket-Borne Equipment for the Measurement of Infrared Radiation, *R. M. Slavin, Feb 1953.*

No. 3. Balloon-Borne Conductivity Meter, *S. C. Coroniti, A. Nazarek, C. S. Stergis, D. E. Kotas, D. W. Seymour and J. V. Werme, Dec 1954.*

No. 4. Magnetic Compensation of Aircraft, *J. McClay and B. Schuman, Aug 1955.*

No. 5. Lovotron - A Low Voltage Triggered Gap Switch, *E. H. Cullington, W. G. Chase and R. L. Morgan, Sep 1955.*

No. 6. Balloon-Borne Air Sampling Device, *Charles W. Chagnon, Apr 1957.*

No. 7. Instrumentation for Studies of the Exploding Wire Phenomenon. *W. G. Chase and E. H. Cullington, Aug 1957.*

No. 8. Device for Lowering Loads from High-Altitude Balloons, *W. C. Wagner and F. X. Doherty, Jul 1958.*

No. 9. Equipment and Techniques for In-Flight Deployment of Long Train Instrumentation Packages from High-Altitude Balloons, *Arlo E. Gilpatrick and Romain C. Fruge, Sep 1958.*

No. 10. Study of a Phosphor Light Pulser, *Michael R. Zatzick, Sep 1960.*

No. 11. Study of a Pulsed Logarithmic Photometer, *Michael R. Zatzick, Sep 1960.*

No. 12. Theoretical Analysis of the PAR-Scope: An Oscilloscope Display for Weather Radars, *Edwin Kessler, III, Jul 1959.*

No. 13. Evaluation of Visual Distance Computer, CP-384(XD-1), *P. I. Hershberg, Apr 1960.*

No. 14. Hypsometer for Constant Level Balloon, *W. C. Wagner, Jun 1960.*

No. 15. Magnetic Photomultiplier with Large Cathode for Extreme Ultraviolet, *L. A. Hall and H. E. Hinteregger, Dec 1960.*

No. 16. AIDE--Altitude Integrating Device, Electronic, *P. I. Hershberg, J. R. Griffin and R. H. Guenthner, Dec 1960.*

No. 17. Switching Devices for Very High Currents, *E. H. Cullington and W. G. Chase, April 1961.*

No. 18. Cedar Hill Meteorological Research Facility, *D. W. Stevens, Jun 1961.*

No. 19. Evaluation of Control Monitor AN/GGA 11 Prototype, *R. S. Menchel, Aug 1961.*

No. 20. A Microwave Refractometer with Fast Response and Absolute Digital Recording, *R. H. Shaw and R. M. Cunningham, Mar 1962.*

No. 21. Superpressure Balloon for Constant Level Flight, *L. Grass, Jul 1962.*

AF Cambridge Research Laboratories, Bedford, Mass. Geophysics Research Directorate
MEASUREMENT RANGE REQUIRED OF METEOROLOGICAL EQUIPMENT by Arnold Court and Henry Salmela. August 1962. 9 pp. incl. illus.
AFCRL-62-825 Unclassified report

Meteorological instruments must operate properly so as to accurately measure conditions too extreme for the design and operation of other equipment. This report develops the "improbable extreme" conditions which surface instruments and atmospheric sounding systems must be able to measure.

UNCLASSIFIED

1. Meteorological Instruments—Humidity—Precipitation—Temperature

I. Court, Arnold
II. Salmela, Henry

UNCLASSIFIED

AF Cambridge Research Laboratories, Bedford, Mass. Geophysics Research Directorate
MEASUREMENT RANGE REQUIRED OF METEOROLOGICAL EQUIPMENT by Arnold Court and Henry Salmela. August 1962. 9 pp. incl. illus.
AFCRL-62-825 Unclassified report

Meteorological instruments must operate properly so as to accurately measure conditions too extreme for the design and operation of other equipment. This report develops the "improbable extreme" conditions which surface instruments and atmospheric sounding systems must be able to measure.

UNCLASSIFIED

1. Meteorological Instruments—Humidity—Precipitation—Temperature

I. Court, Arnold
II. Salmela, Henry

UNCLASSIFIED

AF Cambridge Research Laboratories, Bedford, Mass. Geophysics Research Directorate
MEASUREMENT RANGE REQUIRED OF METEOROLOGICAL EQUIPMENT by Arnold Court and Henry Salmela. August 1962. 9 pp. incl. illus.
AFCRL-62-825 Unclassified report

Meteorological instruments must operate properly so as to accurately measure conditions too extreme for the design and operation of other equipment. This report develops the "improbable extreme" conditions which surface instruments and atmospheric sounding systems must be able to measure.

UNCLASSIFIED

1. Meteorological Instruments—Humidity—Precipitation—Temperature

I. Court, Arnold
II. Salmela, Henry

UNCLASSIFIED

AF Cambridge Research Laboratories, Bedford, Mass. Geophysics Research Directorate
MEASUREMENT RANGE REQUIRED OF METEOROLOGICAL EQUIPMENT by Arnold Court and Henry Salmela. August 1962. 9 pp. incl. illus.
AFCRL-62-825 Unclassified report

Meteorological instruments must operate properly so as to accurately measure conditions too extreme for the design and operation of other equipment. This report develops the "improbable extreme" conditions which surface instruments and atmospheric sounding systems must be able to measure.

UNCLASSIFIED

1. Meteorological Instruments—Humidity—Precipitation—Temperature

I. Court, Arnold
II. Salmela, Henry

UNCLASSIFIED

UNCLASSIFIED

UNCLASSIFIED