WMO Guidelines on the Calculation of Climate Normals

2017 edition

WEATHER CLIMATE WATER

WORLD
METEOROLOGICAL
ORGANIZATION

WMO-No. 1203

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EDITORIAL NOTE

METEOTERM, the WMO terminology database, may be consulted at http://public.wmo.int/en/resources/meteoterm.

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This document replaces WMO Technical Document WMO/TD-No. 341 (WCDP-10), *Calculation of Monthly and Annual 30-year Standard Normals* (WMO, 1989), and addresses climate normal calculation practices from 2017.

Note: The current document favours the notion "climate normals" over "climatological normals", but it keeps the latter notion for the term "climatological standard normals" (defined as in the *International Meteorological Vocabulary* (WMO, 1992)) as well as for historical references (for example, publications).

1. PURPOSE

The focus of this document is on observations at surface meteorological observing stations. However, many of the principles will also be valid for other forms of observations, including upper-air observations and datasets based on mobile or remotely sensed platforms (for example, satellites, radar or drifting buoys). In particular, as many key remotely sensed datasets begin in the 1970s, it is recommended that, where feasible, the current climatological standard normal period (1981–2010 at the time of writing) be used for these datasets to allow comparison among different data forms on a consistent basis. Many of the principles will also apply to datasets involving locations or regions other than surface meteorological observing stations, such as area averages or points in gridded datasets.

The procedures discussed below are recommended for all calculations of climate normals, in particular, for climatological standard normals exchanged among Members. However, it is recognized that, in some cases, systems are already in place that use methods and definitions which differ from those in this document (for example, stricter definitions for missing data), and that changes to those systems may be difficult or expensive to implement. In such cases, any deviations from these recommendations should be fully documented.

2. BACKGROUND

Climate normals are used for two principal purposes. They serve as a benchmark against which recent or current observations can be compared, including providing a basis for many anomaly-based climate datasets (for example, global mean temperatures). They are also widely used, implicitly or explicitly, as a prediction of the conditions most likely to be experienced in a given location.

Historical practices regarding climate normals, as described in the Guide to Climatological Practices (WMO, 2011), the *Technical Regulations* (WMO, 2016*b*) and the Handbook on *CLIMAT and CLIMAT TEMP Reporting* (WMO, 2009), date from the first half of the twentieth century. The general recommendation is to use 30-year periods of reference. The 30-year period of reference was set as a standard mainly because only 30 years of data were available for summarization when the recommendation was first made. The early intent of normals was to allow comparison among observations from around the world. The use of normals as predictors slowly gained momentum over the course of the twentieth century (WMO, 2011, section 4.8).

Taking into consideration issues identified in *The Role of Climatological Normals in a Changing Climate* (WMO, 2007) and elsewhere, the *Seventeenth World Meteorological Congress* (WMO, 2015) endorsed a number of changes, which are reflected in the *Technical Regulations*, in definitions relating to climate normals. The most significant of these changes was that the definition of a climatological standard normal changed, and it now refers to the most-recent 30-year period finishing in a year ending with 0 (1981–2010 at the time of writing), rather than to non-overlapping 30-year periods (1901–1930, 1931–1960, 1961–1990, and in the future 1991–2020) as was the case previously. However, the period from 1961 to 1990 has been retained as a standard reference period for long-term climate change assessments.

Many of the recommendations in this document draw on studies of various aspects relating to climate normals, in particular, their sensitivity to the length and timing of the averaging period, and incompleteness of data (whether for consecutive or non-consecutive data points). Readers are referred to *The Role of Climatological Normals in a Changing Climate* (WMO, 2007) for detailed information on these aspects.

3. DEFINITIONS

The *Technical Regulations* (WMO, 2016b) make the following definitions:

– **Period averages.** Averages of climatological data computed for any period of at least ten years starting on 1 January of a year ending with the digit 1.

– **Normals.** Period averages computed for a uniform and relatively long period comprising at least three consecutive ten-year periods.

– **Climatological standard normals.** Averages of climatological data computed for the following consecutive periods of 30 years: 1 January 1981–31 December 2010, 1 January 1991–31 December 2020, and so forth.

In addition, in accordance with The Role of Climatological Normals in a Changing Climate (WMO, 2007), the following definitions are used in the remainder of this document:

– **Average.** The mean of monthly values of climatological data over any specified period of time (not necessarily starting in a year ending with the digit 1). In some sources, this is also referred to as "provisional normal".

– **Element.** An aspect of climate that can be statistically described, such as temperature, precipitation or vapour pressure.

– **Parameter.** A statistical descriptor of a climate element. This is commonly the arithmetic mean, but it can also include values such as the standard deviation, percentile points, number of exceedances of a threshold or extreme values.

While the definitions in the *Technical Regulations* refer to means, this document also includes other statistical descriptors.

Finally, although no formal name was given under Resolution 16 of the *Seventeenth World Meteorological Congress* (WMO, 2015) to those 1961–1990 averages used as a benchmark for climate change assessment, in this document, they are referred to as reference normals.

4. CALCULATION OF CLIMATE NORMALS

4.1 Introduction

The guidance in this document is primarily directed towards the calculation of normals (in particular, climatological standard normals and reference normals as defined in Chapter 3 above), but it is also applicable to averages and period averages in many cases.

It is expected that data will have been subject to quality control processes before they are used in the calculation of normals.

Where data are complete and of good quality, most decisions relating to the calculation of normals are relatively straightforward. Many of the complications that occur arise as the result of the use of data that are not 100% complete. While one possible approach is only to consider, for the calculation of normals, those stations that have 100% completeness of daily data throughout the averaging period. However, in most countries, there are few (or no) such stations, and it is therefore necessary to make a compromise between maximizing the completeness of the data used in climate normals and having a substantial number of stations from which normals can be calculated, for which the "true" normal (that is, the normal that would be derived from 100% complete data) can be estimated within an acceptable level of uncertainty.

This chapter includes brief discussions of climate data quality control and homogenization. Detailed discussions of quality control and homogenization are beyond the scope of this document. Separate WMO guidance on both subjects is being developed at the time of writing, and should be referred to for detailed information.

4.2 Parameters and elements

Climate normals can be prepared for a wide variety of elements. While some elements, such as temperature and precipitation, will be relevant to all parts of the world, others, such as the occurrence of snow or exceedance of certain thresholds (for example, maximum temperatures below 0 °C in the tropics), will be of little or no relevance in some parts of the world. Countries may also wish to calculate normals for elements particularly relevant to their own circumstances.

This document defines the following categories:

– **Principal climatological surface parameters.** These are defined in *Calculation of Monthly and Annual 30-year Standard Normals* (WMO, 1989) (although that publication uses the term "elements"). Normals of these parameters should be reported for all stations that have sufficient data to allow this (see data completeness guidelines in section 4.4 below).

– **Secondary climatological surface parameters.** These are parameters not included in (a) above, but which are reported, or are relevant to something that is reported, in standard CLIMAT messages (which are the principal means of exchange for monthly climatological data). Members are encouraged to calculate and report normals for these parameters should appropriate data exist.

– **Other climatological surface parameters.** These are parameters that are not routinely exchanged using the standard CLIMAT message but may still be of interest for national or regional purposes.

Parameters in these categories are listed in Table 1, along with specific considerations (where applicable).

Table 1. Climatological surface parameters

Principal climatological surface parameters		
Parameter	*Units*	*Comments*
Precipitation total	mm	Definition of observation day should be according to national standards and documented in metadata (see also section 4.9)
Number of days with precipitation ≥ 1 mm	count	
Monthly mean values of maximum, minimum and daily mean temperatures	°C	Definition of observation day, and the way in which daily mean temperature is calculated, should be according to national standards and documented in metadata (see also section 4.9). Different methods are in operational use for the calculation of daily mean temperature.

Principal climatological surface parameters		
Mean value of sea-level pressure	hPa	Daily values should be calculated, if possible, as the mean of either eight evenly spaced 3-hourly observations or four evenly spaced 6-hourly observations. If this is not possible, they should use a set of observation times that is consistent over time at that station and documented in metadata. At high-elevation stations, mean geopotential height at a set pressure level (for example, 850 hPa or 700 hPa) may be used as a substitute for mean sea-level pressure.
Mean vapour pressure	hPa	Should be calculated as the mean of daily values. Daily values should be calculated, if possible, as the mean of either eight evenly spaced 3-hourly observations or four evenly spaced 6-hourly observations. If this is not possible, they should use a set of observation times that is consistent over time at that station and documented in metadata. It is important that monthly means of vapour pressure are calculated from daily values of vapour pressure and not from monthly means of relative humidity or dewpoint temperature, as those methods will give different results.
Total number of hours of sunshine	hours	
Secondary climatological surface parameters		
Parameter	*Units*	*Comments*
Mean value of station-level pressure	hPa	Calculated as for mean sea-level pressure above
Boundaries of quintiles of precipitation*	mm	See section 4.5
Mean number of days with maximum temperature ≥25, 30, 35, 40 °C	count	
Mean number of days with maximum temperature < 0 °C	count	
Mean number of days with minimum temperature < 0 °C	count	
Mean number of days with daily precipitation ≥ 5, 10, 50, 100, 150 mm	count	
Mean number of days with snow depth > 0, 1, 10, 50 cm	count	
Mean number of days with wind speed ≥ 10, 20, 30 m/s	count	Wind speed used for this element is the highest 10-minute mean wind recorded during the day. This is a different definition to the highest wind gust.
Mean number of days with visibility < 50, 100, 1000 m	count	Refers to days when visibility is reported as being below the specified threshold at any observation during the day
Highest and lowest recorded values of mean daily temperature	°C	
Highest recorded value of daily maximum temperature*	°C	
Lowest recorded value of daily minimum temperature*	°C	
Highest recorded value of daily precipitation	mm	
Highest recorded wind gust	m/s	
Mean number of days with thunder	count	
Mean number of days with hail	count	

Other climatological surface parameters
No specific guidance is given for these parameters. Examples of such parameters that may be of value for national or regional purposes include: Mean or total values of parameters relating to elements not listed above (for example, cloud amount, pan evaporation, solar radiation, wind speed, soil temperature or snow fall) and alternative expressions relating to an element (for example, relative humidity or dewpoint); Counts of days of values above/below thresholds other than those listed above; Mean values of parameters relating to observations at a specific time of day (for example, mean temperature at 0900); Counts of days with phenomena (other than thunder or hail); Statistical descriptors other than those listed (for example, lowest value of daily maximum temperature). Note that values for mean relative humidity and mean wind speed are reported for some stations in *1961-1990 Global Climate Normal*s (CLINO) (WMO, 1998), but no provision currently exists for these parameters in CLIMAT messages.

* Values for these parameters are reported for some stations in the published WMO global climate normals for the period 1961–1990 (WMO, 1998).

4.3 Calculation of normal values

Climate normals are calculated from monthly values during the averaging periods. Depending on the parameter under consideration, these monthly values may be:

– The mean of daily values recorded during the month (referred to here as mean parameters);

– The highest or lowest value recorded during the month (referred to here as extreme parameters);

– The sum of daily values recorded during the month (referred to here as sum parameters);

– The number of days above or below a given threshold, or on which an event occurs (referred to here as count parameters).

4.3.1 *Calculation of individual monthly values*

The individual monthly values are calculated as follows.

(a) Mean parameter

The mean of the daily values during the month.

(b) Extreme parameter

The highest or lowest (as appropriate) value recorded during the month.

(c) Sum parameter

The sum of the daily values during the month.

(d) Count parameter

For a count parameter, the number of days in which an event occurs (or a threshold that is exceeded) should be converted to a ratio or percentage of the number of days on which observations were made. For example, if the event occurred on 22 days and there were 25 days in the month with observations, this should be considered as 0.88 or 88%.

Note: The purpose of this procedure is to allow months with a limited amount of missing data to be considered for count parameters.

In all cases, a value for a month should be calculated only if the month meets the data completeness requirements described in section 4.4.1 for the variable concerned.

4.3.2 *Calculation of a monthly normal from individual monthly values*

The monthly normal for a given month should be calculated as follows.

(a) Mean parameter and sum parameter

The mean of all non-missing values during the averaging period for the month in question.

(b) Extreme parameter

The highest (or lowest) value during the averaging period for the month in question.

(c) Count parameter

Initially, a mean ratio/percentage for the month should be calculated from the ratio/percentage values for each month during the averaging period (see above). The mean ratio/percentages should then be reconverted to a mean number of days for the month by multiplying it by the number of days in the month. For example, a mean ratio of 0.88 for January converts to (0.88 x 31) = 27.28 days, or 27.3 days rounded (February values should be multiplied by 28.25 days).

In all cases, a normal value should be calculated only if the data completeness criteria in section 4.4.2 are met.

4.3.3 *Calculation of annual, seasonal and other multimonth normals*

Normals covering a period of more than 1 month (for example, annual or seasonal normals) should be calculated as follows.

(a) Mean parameter

The mean of the monthly normals for the months concerned.[1]

(b) Sum parameter and count parameter

The sum of the monthly normals for the months concerned.

(c) Extreme parameter

The highest/lowest of the monthly values for the months concerned.

In particular, annual normals should be calculated from the monthly normals, and not from the individual annual values. The two methods will produce identical results (apart, possibly, from small differences due to rounding) if there are no missing monthly values, but may differ if some monthly values are missing.

If the monthly normal for any of the constituent months of the period of interest is missing, then the multimonth normal should also be considered as missing.

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[1] Some National Meteorological and Hydrological Services weight monthly normals by the number of days in the month when calculating the multimonth normal, but this is not recommended for internationally exchanged products.

4.4 Data completeness

4.4.1 *Calculation of a single monthly value*

(a) Mean parameter

An extensive assessment was undertaken in *The Role of Climatological Normals in a Changing Climate* (WMO, 2007) as to the additional uncertainty introduced in the estimation of a mean monthly value from the existence of missing[2] data. This concluded that, if missing days are randomly distributed through a month, the width of the 95% confidence interval is, on average, 11% of the standard deviation of the underlying daily values for 5 missing days, and 17% of the standard deviation for 10 missing days. These equate, for example, to a few tenths of a degree Celsius for common values of standard deviation for daily maximum and minimum temperatures (higher in higher-latitude continental interiors in winter, and lower in tropical and many island locations).

An additional uncertainty is introduced if a substantial number of the missing days are consecutive. This is because most daily meteorological parameters are autocorrelated to some extent (that is, if the value on a given day is above (below) normal, there is a higher-than-climatology probability that the value on the next few days will also be above (below) normal).

Following the *Guide to Climatological Practices* (WMO, 2011),[3] it is therefore recommended that, where a monthly value is the mean of that month's daily values, it should not be calculated if either of the following criteria are satisfied:

– Observations are missing for 11 or more[4] days during the month;

– Observations are missing for a period of 5 or more consecutive days during the month.

However, it should be noted that countries which decided in the past to follow the 5/3 rule (accepting only 5 days of missing observations per month and not more than 3 consecutive missing days as per *Calculation of Monthly and Annual 30-year Standard Normals* (WMO, 1989)), or other missing data criteria that are stricter than those above, may wish to continue applying these stricter rules to ensure consistency of their national climate record. (In principle, this note applies also to the below paragraphs of section 4.4.1.)

(b) Extreme parameter

In the context of calculation of normals, the purpose of calculating an extreme value during an individual month is as an intermediate step of calculating extreme values over the entire period under consideration. At this point in the process, extreme values should be calculated for a month, regardless of the amount of available data during that month. (Whether sufficient data exist for the reliable reporting of an extreme value over the entire period is considered in section 4.4.2.)

(c) Sum parameter

A monthly value for a sum parameter (for example, total precipitation) can only be calculated if there are complete data over the month. This means that, in general, a sum parameter cannot be calculated if there are any missing observations during the month.

Two exceptions to this are:

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2 In the context of this section, a value that is found to be suspect or incorrect after undergoing quality control should be considered to be missing.

3 Note that the publication *Calculation of Monthly and Annual 30-year Standard Normals* (WMO, 1989) proposed stricter criteria (more than 5 days in total or more than 3 days consecutively), and these criteria are in operational use in some countries.

4 The *Guide to Climatological Practices* (WMO, 2011) defines this as "more than 10", which is equivalent.

- The potential for estimated data to be used to fill gaps in the observed data within a given month. The estimation of data in this context is discussed further in section 4.6.

- For some elements, a period of missing data may be followed by an observation that represents a cumulative value over the period of missing observations (for example, a raingauge that is not read over the weekend but then makes a report on Monday that is for total precipitation over the 3-day period). If it is known that such accumulated observations cover the full period of missing data, then a monthly sum can still be calculated.

In either case, a monthly total should only be calculated if the number of days in the month represented by estimated or accumulated data meets the same criteria as would apply for missing data for a mean parameter (that is, estimated or accumulated data do not represent 11 or more days during the month, or 5 or more consecutive days during the month).

(d) Count parameter

In the context of normals, a count parameter represents an indication of the probability that an event will occur on a given day during that month of the year. It is represented as an expected number of days rather than a percentage or ratio. The process of calculating a normal for a count parameter involves converting the observed number of days in a given month to a ratio or percentage (see section 4.3 for further details). Some caution should be used in this procedure as, for some elements/parameters, missing data may preferentially represent a particular condition (for example, yes/no reports on the occurrence of snow may be more likely to be missed on days with no snow).

A ratio or percentage should not be calculated for the month if there are 11 or more days with missing observations, or 5 or more consecutive missing days. In these cases, the monthly value should be considered to be missing.

In some circumstances, the number of days on which an event occurred may be known, even though the underlying daily data are missing (for example, it may be reported that there was 10 mm of rain over 3 days, with rain falling on 2 of the 3 days), but such information should be used with great care.

4.4.2 ***Number of years required for the calculation of a normal***

The *Guide to Climatological Practices* (WMO, 2011) recommends that, for a normal or average to be calculated for a given month, data should be available for at least 80% of the years in the averaging period. This equates to having data available for that month in 24 or more out of the 30 years for a climatological standard normal or a reference normal. The guide (WMO, 2011) also recommends not calculating a normal if values are missing in 3 or more consecutive years. However, in *The Role of Climatological Normals in a Changing Climate* (WMO, 2007), it was found that there were no significant benefits (in terms of the uncertainty of the calculated normal as an estimate of the true value) of a consecutive-years criterion. This was because the autocorrelation of monthly values 1 year apart is generally low, and requiring the presence of at least 80% of the years limits the influence of missing data at the start or end of an averaging period for elements that show a strong trend.

It is therefore recommended that normals or averages be calculated:

- For parameters other than extreme parameters: where there are valid monthly values (as defined in section 4.4.1 above) in at least 80% of the years in the averaging period (with no additional consecutive-years criterion);

- For extreme parameters: where there are valid monthly values for the mean of the underlying element (for example, if the parameter under consideration is the highest maximum temperature, there is a valid monthly mean value of maximum temperature for that month) in at least 80% of the years in the averaging period.

4.5 Calculation of quintile boundaries

A special type of parameter in the calculation of normals is the definition of quintile boundaries for monthly precipitation. There is no universally agreed method in the statistical literature for defining the boundaries of quintiles within a finite dataset. Two major methods involve defining the lowest recorded value as the zeroth percentile, or as the $(1 / (n + 1) \times 100)$-th percentile, where n is the number of observations in the dataset. In the case of quintile boundaries in climate normals, the former procedure is adopted, as it is considered useful to incorporate in the quintile boundaries information on the highest and lowest values recorded during the averaging period. This facilitates the reporting of future instances where the monthly precipitation is higher than, or lower than, any value recorded in the averaging period.

A procedure for the calculation of quintile boundaries is defined in the *Guide to Climatological Practices* (WMO, 2011). This procedure is only valid if there are exactly 30 values, and hence applies to climatological standard normals and reference normals when there are no missing monthly values, but not to cases where there are missing values, or for periods other than 30 years. As documented in *The Role of Climatological Normals in a Changing Climate* (WMO, 2007), this procedure will also result in a slight underrepresentation of the number of years in the first and fifth quintiles.

A general procedure is proposed in *The Role of Climatological Normals in a Changing Climate* (WMO, 2007) and is recommended for use. The results from this will, in the specific case of 30 years of complete data, be slightly different from those obtained using the method described in the Guide to Climatological Practices (WMO, 2011), but the differences between the two will generally be minor.

The recommended quintile boundaries are given in Table 2.

Table 2. Recommended quintile boundaries

Quintile boundary	*Data content*
Lower bound of quintile 1	Lowest observation during the averaging period
Upper bound of quintile 1	$(1 + (n - 1) / 5)$-th ranked observation during the averaging period (6.8 for a 30-year dataset)
Upper bound of quintile 2	$(1 + 2(n - 1) / 5)$-th ranked observation during the averaging period (12.6 for a 30-year dataset)
Upper bound of quintile 3	$(1 + 3(n - 1) / 5)$-th ranked observation during the averaging period (18.4 for a 30-year dataset)
Upper bound of quintile 4	$(1 + 4(n - 1) / 5)$-th ranked observation during the averaging period (24.2 for a 30-year dataset)
Upper bound of quintile 5	Highest observation during the averaging period

In all cases, a value with a fractional rank is calculated by linear interpolation between the integer values on either side (for example, the 6.8-th ranked value is calculated as (0.2 × sixth ranked value + 0.8 × seventh ranked value)).

Quintile boundaries should only be calculated for a given month if the completeness of monthly data meet the criteria given in section 4.4.2.

4.6 Estimation of data for use in calculation of normals

The possibility exists of incorporating estimated data into the calculation of climate normals. This has potential for increasing the quantity of usable data in the case of sum parameters, for which 1 day of missing data during a month prevents the calculation of a monthly value.

In the context of climate normals, possible estimation methods that can be used (either separately or in combination with each other) include:

– Spatial interpolation: the use of data interpolated from other sites in the vicinity.

– Temporal interpolation: the use of data from before or after a period of missing data. For the elements under consideration in these guidelines, values from other days are rarely useful in deriving the value for a missing day. However, the temporal interpolation of subdaily data may allow an otherwise missing daily value to be recovered (for example, where a daily maximum temperature is not reported by an automatic weather station because of a 30-minute outage away from the expected time of maximum temperature).

– Use of alternative elements: for example, using cloud amounts to estimate a missing daily sunshine value.

– Use of alternative observation methods: for example, using radar or satellite observations to estimate precipitation data where the original observation is missing.

It is also sometimes possible to use estimation methods in conjunction with observed data; for example, using spatial interpolation for each day to disaggregate a multiday rainfall total into its constituent daily totals.

Issues associated with the estimation of climatological data are discussed at some length in the *Guide to Climatological Practice*s (WMO, 2011), section 5.9, and users are referred to that publication, and the references within it, for comprehensive consideration of the topic. It is not the purpose of this publication to provide detailed guidance on estimation methods, and users considering the use of estimated data should make their own investigations of appropriate methodologies, taking into account their region's available data sources, climatic characteristics and geography.

Any estimation used in the calculation of climate normals should be carried out in an unbiased manner. For example, it would not be appropriate to use radar data to identify days with missing observations when no precipitation fell, without also producing estimated values on days with missing observations when precipitation did fall, as doing so would produce a downward bias in the overall data.

In the context of calculating normals at a station, estimation should only be used to fill relatively small gaps in datasets (up to 10 days in any individual month). It should not be used to calculate a normal at a station for an element that has never been observed there. (This is separate from the entirely appropriate practice of using calculated normals at stations to estimate expected conditions for the same period at other locations.)

4.7 Data precision and rounding

For most parameters, normals should generally be reported to a precision of one decimal place. It is not usually appropriate to report station normals to a higher level of precision, although it may be appropriate in some cases for area averages incorporating a large number of stations.

It needs to be considered at which point(s) in the calculation of normals should rounding be applied. The calculation of a climate normal usually has three steps:

– Calculation of an individual monthly value from the underlying daily data (for some variables, the underlying daily data may involve the calculation of a value from subdaily data);

– Calculation of a normal for a month from each of the individual monthly values during the averaging period;

– Calculation of normals for multimonth periods (for example, annual) from the monthly values.

In principle, maximum accuracy would be achieved by retaining maximum precision throughout the calculations and only rounding at the final step (that is, the reporting of a monthly or multimonth normal). However, a major obstacle to doing this on a consistent basis is that individual monthly values are usually available only to one decimal place, with national databases and the CLIMAT code for international transmission of monthly climate data, typically making provision for (at most) one decimal place. In many cases (particularly for international datasets based primarily on CLIMAT reports), the underlying daily data may not be available, making full-precision calculations impossible.

For consistency of practice, it is therefore recommended that individual monthly values be rounded to one decimal place before they are used to calculate the normal for that month, and that normals for multimonth periods be calculated from monthly normals rounded to one decimal place. While this practice may appear to involve some loss in precision, the differences are small. For example, the standard deviation of the difference between a 30-year normal calculated using monthly data rounded to one decimal place and a 30-year normal calculated using full-precision data is 0.005, which equates to a probability of approximately 5% that the two values will differ by 0.1 after being rounded. For most purposes, this difference is negligible.

A final rounding question is how to round values that are exactly halfway between data points (for example, is 0.15 rounded to 0.1 or to 0.2?). An important consideration here is that there should be no consistent bias in rounding, that is, such values should not be consistently rounded up or rounded down. Two practices that achieve this effect are “ties to odd” (where a value ending in .5 is rounded to the nearest odd number) or “ties to even” (where a value ending in .5 is rounded to the nearest even number). “Ties to odd” has been widely used in synoptic reporting by a number of countries. However, “ties to even” is the default rounding mode used in the Standard for Floating-Point Arithmetic of the Institute of Electrical and Electronics Engineers, and is therefore incorporated in many standard computing packages. For this reason, “ties to even” is preferred if a new system is being developed, although if “ties to odd” is already established national practice, it may be retained providing it is implemented on a consistent basis. Methods that do introduce a consistent bias in rounding, such as rounding ties away from 0 (the default in Microsoft Excel) or to the next highest value, are not appropriate.

4.8 Homogeneity, use of composite stations and introduction of automatic weather stations

4.8.1 *Homogeneity*

Note: This section gives only a brief introduction to climate data homogeneity. For a detailed discussion, readers are referred to the Guidelines on Climate Metadata and Homogenization (WMO, 2003) or the updated guidelines that are under development at the time of writing this publication.

As mentioned earlier, climate normals have two major purposes: as an indicator of the conditions most likely to be experienced at a given location under the current climate, and as a benchmark against which climatic conditions at a given location (or in a given region) in a given time period can be compared.

Both of these purposes require data during the averaging period to be consistent, and for data during the averaging period to be representative of the period for which the averaging period is being used as a benchmark. For example, if data from 2017 are being compared with those for an averaging period from 1981 to 2010, the site and instruments used in the 1981–2010 period need to be representative of those in use in 2017.

Meeting these requirements requires that the data used be homogeneous over the averaging period, and, if they are being used as a reference for the current period, from the averaging period to the present. This means that any changes in the data reflect only changes in the background climate, and not changes in the way the observations are made or in the environment in which they are made. Reasons why a dataset might be inhomogeneous include:

- Site moves;
- Changes in instruments;
- Changes in observation procedures (for example, a change in the definition of the climatological day);
- Changes in the local site environment (for example, a change in vegetation or the construction of a building in close proximity to the site).

Not all potential inhomogeneities will have a significant impact on the data, and those that do may affect some elements and not others. For example, the replacement of a grass surface with a paved surface near a site may affect temperature, but is unlikely to have any influence on precipitation. However, the question of whether they do or not needs to be considered on a site-by-site basis. In the context of data homogeneity, while it is desirable that an observation site meets the requirements of class 1 according to the siting classification for surface observing stations on land (WMO, 2014, Part I, Annex 1B), absolute conformance to standards is less critical than long-term consistency over time. For example, a temperature observing site at a lighthouse on top of a cliff would not meet the standards of the *Guide to Meteorological Instruments and Methods of Observation* (WMO, 2014), but if it has been at the top of the same cliff for 100 years (and has had no other significant changes), it is still likely to be homogeneous.

Even small site moves can have a significant impact on data homogeneity, especially in areas with complex topography, and on variables that are strongly influenced by local site exposure (such as wind speed).

The existence of an urban heat island is not an inhomogeneity per se. It has been found that in well-established urban areas, providing the environment in the immediate vicinity of the observing site is relatively stable, data can be reasonably homogeneous. Hence, for example, a 1981–2010 period in an established urban area, where any urban heat island was already well developed prior to 1980, is capable of being representative of the current environment in that area. However, the nature of an urban area is such that, even if the overall town or city is well established, there are likely to be significant changes to buildings within a short distance of the observing site over a period of some decades, unless the site is in a protected area (for example, a city park).

Due to the influence that inhomogeneities can have on climate normals, it is recommended that only homogeneous data be used in the calculation of climate normals. In particular, an inhomogeneity can mean that the averaging period is not representative of the present, and hence that current data are being compared to a normal that is not representative. However, it is recognized that not all Members currently have the resources to carry out homogenization of their national datasets, and may therefore have to calculate climate normals without the underlying data having been assessed for homogeneity.

There are two main approaches to the question of using homogeneous data in the calculation of climate normals:

– Use only those stations that have been found to be homogeneous;

– Make adjustments to historical data to remove inhomogeneities.

Both are reasonable approaches in principle. However, in many countries, only a relatively small proportion of stations may be homogeneous throughout. After the averaging period, especially in countries where there has been a significant change affecting a large part of the observing network (for example, a change in the definition of daily mean temperature, or a widespread transition from conventional to automatic instruments), it may therefore be necessary to use adjusted data to achieve an acceptable network density, and/or to have data on normals available for key locations.

There is extensive literature on climate data homogeneity, especially for temperature (less so for other elements), both on the detection of inhomogeneities and on methods for adjustment. These can involve the use of metadata, statistical methods or a combination of the two. Numerous software packages have also been developed for this purpose. Further information can be obtained from the *Guidelines on Climate Metadata and Homogenization* (WMO, 2003).

4.8.2 *Use of composite stations*

In many cases, there will be no single station that meets the data availability requirements for the calculation of a climate normal for a given averaging period. However, there may be a set of stations within a region that, between them, have complete data through the averaging period (for example, a site in a small town that operated from 1981 to 1995 may have been replaced by one at a nearby airport that has operated from 1995 to the present, with the combined set having complete data for a 1981–2010 averaging period).

The possibility exists for using a composite data series derived from such a combination of stations in the calculation of climate normals. The fundamental requirement here is that the merged dataset is homogeneous, either because the different sites used in the composite are sufficiently similar, or because appropriate adjustments have been made. This is a process that should be undertaken with considerable care, and the adjustment methods and the stations used in the composite should be documented in metadata. The stations also need to be sufficiently close in distance and sufficiently well correlated for the adjustment process to be carried out with a high level of confidence. A period of overlapping data between the stations in the composite is desirable in this context.

It should be noted that the definition of what is a "composite" station is somewhat arbitrary. In some countries, a station may retain its identifier even after a substantial move, while in others, even a small move may lead to the data being treated as being from two separate stations. (There are also cases where a station changes its domestic identifier but continues under a single WMO number, or vice versa.) From the perspective of data homogeneity, there is no real difference between homogenizing a merged dataset from multiple stations and doing so with an inhomogeneous dataset from a single station (except that a change in station identifier is a clear item of metadata).

4.8.3 *Introduction of automatic weather stations*

Over the last 20–30 years, automatic weather stations have become an increasingly prominent part of meteorological observation networks. In some countries, most or all synoptic observations are now automated, and it is likely that an increasingly high proportion of observations will be made through automated methods over the coming years.

Few automatic weather stations have been in place since 1981 (and effectively none since 1961). Making use of automatic weather stations – whose installation will, in most countries, be accompanied by a change in station identifier – in the calculation of climatological standard normals, or reference normals, therefore requires that they be composited with another station (or stations) as described in section 4.8.2 above.

In some cases, an automatic weather station is co-located with the conventional station it is replacing. In such cases, depending on the instruments used, there may be no significant inhomogeneity between the two for some elements, although this still needs to be checked. However, in many cases, an automatic weather station is some distance away from the conventional station. A common scenario is for a conventional station in a town to be replaced by an automatic weather station outside the town limits (often at an airport). Such a site move can cause a significant inhomogeneity, which needs to be dealt with before the composite data can be used in the calculation of climate normals.

Three other issues that can arise with the installation of automatic weather stations are:

– Conventional stations only make a limited number of observations per day, whereas most automatic weather stations report continuously. This means many more automatic observations are potentially available to calculate parameters such as the mean daily pressure or vapour pressure. It is preferred that the methods used for such calculations over time should be consistent at a station (or composite station), and if possible, across a network. For example, if the previous conventional station only made observations at 0900 and 1500, then means should be calculated using only the 0900 and 1500 observations, even though many more observations are available from the automatic station. The introduction of automatic stations can also lead to a change in the definition of the climatological day, as it is much more practical to make observations for a climatological day ending at midnight at an automatic station than it is at a station requiring human observers. While such changes in definitions are undesirable, it is recognized that in some countries, they have already taken place and that reversing them would be impractical. In such cases, a change in the number of observations per day used in the calculation of means, or in the definition of the climatological day, should be considered as a potential inhomogeneity (see section 4.8.2).

– Both conventional and automatic stations can occasionally have missing data (in the case of automatic stations, most often because of either an instrument failure or a communications failure). For many elements, missing data from the two types of systems can be treated equivalently. However, for precipitation, while a period of missing observations from a conventional station will often be followed by an accumulated observation over the period of missing data, at an automated station, once an observation is missing, it will often be lost altogether, thus preventing the calculation of a monthly total. This may make the use of estimated data to fill gaps (see section 4.6) more important.

– For some elements, the difference between conventional and automatic observation systems can be so great that it is difficult to compare them, even with adjustment. The most-common example is wind speed, which many conventional stations estimate using the Beaufort scale (or equivalent) – a dataset that is very difficult to merge with instrumental datasets from automatic stations.

4.9 **Metadata to accompany climate normals**

Metadata should be maintained for all stations for which climate normals are being calculated. Further information about appropriate metadata is contained in the *Guidelines on Climate Metadata and Homogenization* (WMO, 2003) and in the *Manual on the WMO Integrated Global Observing System* (WMO, 2017, Appendix 2.4).

While it is not practical to submit all available forms of metadata for the stations concerned when climate normals are being published, metadata that should be included with climate normals include:

– Current identifiers of each station (WMO number, domestic identifiers and station name);

- The latitude, longitude and elevation of each station as at the end of the averaging period;
- Information on any significant changes at stations during, or after, the averaging period, and, if any adjustments have been carried out, the methods used for doing so (see section 4.8);
- The definition of the climatological day;
- The method of calculation for daily means of temperature, pressure and vapour pressure.

It is expected that, over time, the uptake of the WMO Integrated Global Observing System metadata platform will lessen the need for metadata to be provided separately in conjunction with climate normals.

5. APPLICATION ASPECTS

5.1 Why calculate both climatological standard normals and reference normals?

As mentioned above, climate normals serve two major functions: as an implicit predictor of the conditions most likely to be experienced in the near future at any given location, and as a stable benchmark against which long-term changes in climate observations can be compared.

In a stable climate, these two purposes can both be served by a common reference period. However, as discussed in *The Role of Climatological Normals in a Changing Climate* (WMO, 2007), for elements where there is now a clear and consistent trend (most notably temperature), the predictive skill of climate normals is greatest if they are updated as frequently as possible. A 1981–2010 averaging period is much more likely to be representative of conditions in 2017 than the 1961–1990 period. On the other hand, there are clear benefits of using a stable benchmark as a reference point for long-term datasets, both in practical terms (not having to recalculate anomaly-based datasets every 10 years), and in terms of communication – an "above average" year does not suddenly become "below average" because of a change in reference period.

As these two primary purposes of climate normals have become mutually inconsistent in terms of their requirements for a suitable averaging period, WMO has decided that both should be calculated (subject to availability of data). While the best predictive skill would be achieved from updating climatological standard normals every year, it is recognized that this would be impractical for many countries, and hence it has been decided that these should be updated every 10 years, with the next update due after the end of 2020.

In practice, in most countries, long-term datasets used for the monitoring of climate change are reported in spatially aggregated form (for example, a gridded dataset or an area-averaged anomaly derived from gridded data or the averaging of stations). This means that reference normals at individual stations will most commonly be calculated as an intermediate step in the generation of a regional or gridded dataset, rather than as something widely used in their own right.

It is expected that, in most contexts, climate normals for stations will be reported using the climatological standard normal (1981–2010 at the time of writing). Some countries have the capability to report normals for multiple periods according to the requirements of the user; where this ability exists, it should be retained, although with the climatological standard normal established as the primary period. It is also expected that the climatological standard normal period would be used for monitoring products, such as monthly and seasonal anomaly maps, that are not specifically directed at climate change monitoring, as well as being the baseline for seasonal climate forecasting.

5.2 Potential uses of averages for non-standard periods

There are some contexts in which users may wish to make use of periods other than those for the climatological standard normal or reference normal. Some of these are described below.

5.2.1 *Use of non-standard 30-year periods in historical products*

In some historical products, there may be benefits of using a 30-year period other than that of the standard periods. One example is where a gridded dataset is being prepared by splicing an anomalies field, generated from station-level anomalies, onto a climatology (Jones et al., 2009).

For such a dataset, the highest priority is to maximize the number of stations with data during that period for which a normal can be calculated. In the dataset of Jones et al. (2009) (a historical gridded dataset covering Australia), in generating the grids for days in the years between 1911 and 1940, they used a 1911–1940 averaging period as the basis for the underlying climatology and the station anomalies spliced onto this to generate the final dataset. This was because many of the stations with data in the 1911–1940 period did not have sufficient data in more-recent years to allow the calculation of a 1961–1990 normal or a 1981–2010 normal. In addition, as the existence of a normal for a station is a prerequisite to calculating an anomaly for analysis, the use of a 1911–1940 averaging period allowed more stations to be used in the 1911–1940 analysis than would have been possible with a more-recent averaging period. Similarly, a 1941–1970 baseline was used in developing the grids for the 1941–1970 period.

5.2.2 *Use of a period longer than 30 years for deriving higher-order statistics*

A period of 30 years may not be sufficient to capture the full potential range of variation of an element, especially for an element such as precipitation that can be highly variable in time and space. While 30 years is still recommended as a standard averaging period for the calculation of quintile boundaries in climatological standard normals (and thus as the basis for the reporting of quintile values in CLIMAT messages), the stability of more-extreme statistics derived from that period is likely to be low for some elements.

Two approaches to that problem are to fit a statistical distribution, such as a gamma distribution, to the observed data within a standard 30-year period (an approach discussed in more detail in *The Role of Climatological Normals in a Changing Climate* (WMO, 2007)) or to use a period of data substantially longer than 30 years. As an example, precipitation quantiles for Australian rainfall data, including the fifth and tenth percentiles that form an integral part of standard definitions for drought monitoring, are derived using the full period of record from 1900 to present. (In most climates, it would be difficult to derive a stable fifth-percentile value from 30 years of data.)

Another application where the longest possible record is of interest is in the reporting of extreme values. Many users will be interested in the highest and lowest values ever reported at a location, whether they fall within a standard averaging period or not (although values of extremes over a 30-year period are still of value for some applications, such as standardized extreme value analyses). Where possible, extreme parameters should be reported both for the climatological standard normal period and for all available years of useful observations.[5]

5.2.3 *Use of shorter averaging periods*

Many stations will not have sufficient data available for the calculation of a climatological standard normal or a reference normal.

Users at such locations are still likely to want an indication of the most-probable climatic conditions at these locations, as well as anomalies of key elements. One option is to use a

[5] Not including periods where the data are clearly inhomogeneous with the present day, for example, nineteenth- or early-twentieth-century temperature observations made using non-standard instrument shelters.

composite record as described in section 4.8, which requires the existence of an older station (or stations) that can be included in a composite to cover the full standard averaging period. Such a station will not be available in all cases. The capacity to calculate anomalies at a station with some level of confidence is also important for data from that station to be incorporated into many gridded datasets.

In *The Role of Climatological Normals in a Changing Climate* (WMO, 2007), it was found that, for most mean and sum parameters (not extreme parameters or higher-order statistical properties such as quantiles), 10–12 years of data provided a predictive skill similar to that from a standard 30-year period. Furthermore, it was also found that shorter periods than 10–12 years still could be used effectively by combining observed data from the short-period data with spatially interpolated anomalies from longer-term stations in the region. While such short periods cannot be considered to be climatological standard normals or reference normals, they are still useful to many users, and in many cases, there will be benefits to calculating such averages operationally. Readers are referred to section 7.2 of *The Role of Climatological Normals in a Changing Climate* (WMO, 2007) for further details and potential methods.

6. COMMUNICATION ASPECTS

The definition and use of climate normals need to be documented and communicated clearly and precisely to avoid misinterpretation. Climate normals, in particular, climatological standard normals and reference normals, are widely used as references against which climate anomalies, climate variability and climate change are assessed. It is therefore strongly recommended to prominently quote the exact normal used for any climate product and service, where applicable.

In case of an update of the climatological standard normal, it is recommended to produce an explanatory note for all users of relevant products and services. Some National Meteorological and Hydrological Services issue internal documentation for the staff concerned, as well as a press release, explaining the nature of normals and their use, and changes in relevant products and services caused by application of the updated normals.

7. SUBMISSION PROCESS FOR CLIMATOLOGICAL STANDARD NORMALS AND REFERENCE NORMALS

Climate normals should be calculated for as wide a range of stations as possible, subject to the requirement that a station meets standards for the amount and completeness of available data. As a minimum, they should be calculated, if possible, for all stations whose data are distributed on the Global Telecommunication System (WMO, 2011, section 4.8.2).

Climatological standard normals have been and will be collected and made available by WMO through relevant technical arrangements. Calls for the provision of climatological standard normals from WMO Member observing stations will be issued by the WMO Secretariat, including detailed instructions on calculation and submission. Such WMO calls, which will be issued typically every 10 years after 1 January of a year ending with the digit 1, may be extended to include updates to 1961–1990 reference normals as more data become available worldwide due to data rescue activities.

Normals, ideally climatological standard normals, are also used for WMO data exchange through the international code FM 71 CLIMAT (report of monthly values from a land station). Relevant detailed regulations, including cases of normal updates, are provided in the *Manual on Codes* (WMO, 2016*a*).

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