WMO Guidelines on Generating a Defined Set of National Climate Monitoring Products

2017 edition

WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

WMO-No. 1204

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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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INTRODUCTION

Owing to the impact of varying and changing climatic conditions on society and ecosystems, countries around the world have created a variety of climate monitoring products at different spatial and temporal scales. National climate monitoring products (NCMPs) are products that specifically summarize climatic conditions at a national scale and show how current conditions compare with those in the past.

These NCMPs underpin the routine provision of consistent and comparable information on the state of the climate. They are useful within a country because they raise awareness and understanding of the effects of climate variability and change, as well as demonstrate the importance of national monitoring networks and services. They can help to make the connection between climate impacts and variations in the climate (natural or caused by humans), providing a context for current events while fresh in peoples' minds. Monitoring capabilities can provide a means for identifying longer-term anomalies, such as drought, as they develop. Climate monitoring products are also valuable for understanding seasonal forecasts, as they give the starting point from which the ensuing season will unfold.

At regional and international levels, NCMPs aid the synthesis of information from different countries to provide a broader, regional or global view of climate variability and change. Such summaries are routinely published in high-profile annual publications such as the WMO statement on the state of the global climate (http://www.wmo.int/pages/prog/wcp/wcdmp/statement.php) and the Bulletin of the American Meteorological Society state of the climate reports (https://www.ncdc.noaa.gov/bams). Standardized indices of climate change have also been used in the Intergovernmental Panel on Climate Change assessment reports (https://ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1). Countries that routinely produce standard climate monitoring products have a ready platform to promote their national capability and wider understanding of their national climate.

A wide variety of climate monitoring products are produced around the world, and there are many inconsistencies among the methods used by different countries. Inconsistencies make comparisons among products – and therefore among countries and regions – difficult or impossible. This limits their usefulness.

To address the challenges of inconsistency and to provide the tools whereby countries with less-developed capabilities could benefit from the advantages of routine national climate monitoring, the WMO Commission for Climatology has developed a shortlist of key, well-defined NCMPs. These are defined in Chapter 1 below.

The aim of this publication is to provide a specification for the shortlist of NCMPs that can be produced consistently and easily by most countries. By having clearly defined NCMPs, it should be possible for countries with fewer resources to focus their efforts on a small number of products that have wide applicability and interest.

Chapter 1 of these guidelines describes each NCMP, gives their basic definitions and provides the background necessary to understand them. Chapter 2 describes the important role played by NCMP focal points, which are responsible at a national level for ensuring the calculation and dissemination of NCMPs. Chapter 3 provides a proposed standard means of calculating NCMPs. Chapter 4 details how and in what form the NCMPs should be produced and disseminated. Detailed software specifications, including formats for transmitting NCMPs, are provided in the annex, which describes all the steps required to calculate NCMPs to enable National Meteorological and Hydrological Services to develop their own software.

1. NATIONAL CLIMATE MONITORING PRODUCTS

1.1 Base period

To ensure that national climate monitoring products (NCMPs) are comparable among countries, it is essential to have a consistent base period. A base period can also facilitate calculation of NCMPs and provide a fixed period against which changes in the climate can be assessed.

Such a base period is often referred to as a climate normal. For operational climate monitoring, WMO guidance on the calculation of standard climatological normals recommends a rolling 30-year period, updated every 10 years (WMO, 2017). The most-recent period at the time of writing this publication is 1981–2010, which will be followed by 1991–2020 from 2021 and so on. The standard climatological normal is adopted for the calculation of NCMPs and is referred to as the "base period" in the following text.

The term "anomaly" is used frequently in these guidelines. An anomaly is the difference of a measurement from the base-period average.

1.2 Area averaging

In the following definitions, area averages are intended to be based on values that are comparable to indices calculated at a station level. For example, in the method outlined in Chapter 3, indices are calculated for each station, and the values of the indices are then interpolated onto a regular grid, which is then used to calculate the area average of that index for the country.

1.3 NCMP 1: mean temperature anomaly

1.3.1 *Basic definition*

NCMP 1 is the mean temperature anomaly. It is the mean temperature anomaly for each month and year averaged across the country. Units are degrees Celsius.

1.3.2 *Discussion*

The mean temperature anomaly is a measure of overall warmth or cold relative to normal conditions. It is a standard metric used to monitor climate change and is widely used in monitoring reports. The global average temperature anomaly, which is an aggregate of local and regional temperature anomalies, is one of the most widely used and recognizable indices of climate science. Monitoring the mean temperature anomaly at a national level is important for understanding the relative importance of year-to-year variability and the longer-term changes caused by human activities.

A survey was undertaken by the WMO Commission for Climatology Expert Team on National Climate Monitoring Products to assess the capabilities of countries to produce NCMPs (https://www.metoffice.gov.uk/hadobs/opace2_tt_ncmp/). Most countries routinely measure and conduct quality control (QC) on temperature data. Maps and time series of temperature anomalies are also produced by many countries and are typically reported in synthesis reports such as the Bulletin of the American Meteorological Society (BAMS) state of the climate report (https://www.ncdc.noaa.gov/bams), the WMO statement on the state of the global climate (http://www.wmo.int/pages/prog/wcp/wcdmp/statement.php) and the assessment reports of the Intergovernmental Panel on Climate Change (IPCC; https://ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1).

Changes in the mean temperature do not distinguish between variability in maximum temperatures and variability in minimum temperatures. The variability of mean temperature anomalies also varies from place to place and, in some locations, from season to season. For example, in the United Kingdom of Great Britain and Northern Ireland, temperature variability is typically higher during winter months than in summer months.

1.4 NCMP 2: total rainfall anomaly

1.4.1 *Basic definition*

NCMP 2 is the rainfall anomaly for each month and year calculated in two ways: (a) as a simple difference from the base-period average averaged across the country and (b) as a simple difference from the base-period average expressed as a percentage of the base-period average averaged across the country. Units are millimetres and per cent.

1.4.2 *Discussion*

The two types of precipitation anomalies are both standard metrics for monitoring climate variability and change. Extremes of precipitation can lead to drought or flooding. Even in less-extreme cases, precipitation variations can affect agriculture, health, tourism and other important sectors. Precipitation anomalies are widely used in monitoring reports. Monitoring precipitation anomalies at a national level is important for understanding the relative importance of year-to-year variability and longer-term changes.

Most countries routinely measure and conduct QC on precipitation data (https://www.metoffice.gov.uk/hadobs/opace2_tt_ncmp/). Maps and time series are also produced by many countries and are typically reported in synthesis reports such as the BAMS state of the climate report (https://www.ncdc.noaa.gov/bams), the WMO statement on the state of the global climate (http://www.wmo.int/pages/prog/wcp/wcdmp/statement.php) and IPCC assessment reports (https://ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1).

In areas where average rainfall is low, large percentages can be recorded at individual stations due to very localized rainfall. Although the technique used to interpolate the data partly accounts for uneven spatial sampling, there could be problems in countries with sparse measuring networks. This issue is can be partly offset by also including the average anomaly expressed as a simple difference within the NCMP report.

1.5 NCMP 3: standardized precipitation index

1.5.1 *Basic definition*

NCMP 3 is the standardized precipitation index (SPI). It is a percentile-based measure of the standardized rainfall anomaly for each month and year averaged across the country. NCMP 3 is dimensionless, so it does not have units.

1.5.2 *Discussion*

This index is a standard metric used to monitor rainfall and drought. Extremes of precipitation can lead to drought or flooding. Even in less-extreme cases, precipitation variations can affect agriculture, health, tourism and other important sectors. Standardization means that SPI is adapted to the climatic conditions at a particular station. It is a way of comparing the “unusualness” of rainfall at stations from different climatic zones within a country and among countries, where the mean and variability of rainfall might differ substantially. For example, an SPI of 2 or higher indicates this amount of rainfall occurs about 5% of the time, regardless of local conditions. In the *Handbook of Drought Indicators and Indices* (WMO/GWP, 2016), this index has been identified as a starting point for meteorological drought monitoring, indicating periods of unusually low rainfall for the region.

Precipitation measurements are used to calculate SPI. Most countries routinely measure and conduct QC on precipitation data (https://www.metoffice.gov.uk/hadobs/opace2_tt_ncmp/). Maps of SPI are also produced by many countries and are used in synthesis reports such as the BAMS state of the climate report (https://www.ncdc.noaa.gov/bams), the WMO statement on the state of the global climate (http://www.wmo.int/pages/prog/wcp/wcdmp/statement.php) and IPCC assessment reports (https://ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1).

1.6 NCMP 4: warm days

1.6.1 *Basic definition*

NCMP 4 is the warm days index. It is a measure of the percentage of days in each month and year that exceeded the ninetieth percentile of the base-period distribution for maximum temperatures for the day averaged across the country. Units are percentage of days.

1.6.2 *Discussion*

The number of warm days is sensitive to high-impact events such as heatwaves, and is relevant to the seasonally varying climatic conditions at each station. It is a way of comparing stations from different climatic zones within a country and among countries. This NCMP captures some information about moderate extreme temperature events over a significant fraction of the country. It is a standard index produced by the RCLIMDEX software index (created by the Expert Team on Climate Change Detection and Indices (ETCCDI); http://www.wcrp-climate.org/unifying-themes/unifying-themes-observations/data-etccdi). The RCLIMDEX indices have been widely used in scientific reports including those of IPCC. They provide a consistent way to monitor the occurrence and change in frequency of moderate extremes.

1.7 NCMP 5: cold nights

1.7.1 *Basic definition*

NCMP 5 is the cold nights index. It is a measure of the percentage of days in each month and year that fall below the tenth percentile of the base-period distribution of minimum temperatures for the day averaged across the country. Units are percentage of days.

1.7.2 *Discussion*

The number of cold days is sensitive to high-impact events such as cold waves, and is relevant to the seasonally varying climatic conditions at each station. It is a way of comparing stations from different climatic zones within a country and among countries. It is a standard index produced by the RCLIMDEX software index (created by ETCCDI; http://www.wcrp-climate.org/unifying-themes/unifying-themes-observations/data-etccdi). The RCLIMDEX indices have been widely used in scientific reports including those of IPCC. They provide a consistent way to monitor the occurrence and change in frequency of moderate extremes.

1.8 NCMP 6: temperature and precipitation records

1.8.1 *Basic definition*

NCMP 6 gives a simple count of the number of stations with records exceeding 30 years in length that report their highest recorded daily maximum temperature, lowest recorded daily minimum temperature and highest recorded daily precipitation total for each month and year. Records for each element are counted separately.

1.8.2 *Discussion*

The aim is to flag the exceptional events, that is, events that often have extreme impacts. Extremes of temperature – both hot and cold – can lead to a range of health problems and, in the most acute cases, death. High rainfall totals can lead to flooding and associated impacts including damage to crops, destruction of infrastructure, displacement of people and loss of life. Such extremes can be very localized, so this NCMP is based on records at stations, without aggregation.

NCMP 6 cannot characterize or define the full range of very extreme events that affect countries and people around the world, which include tropical storms, tornadoes, hail, lightning, flooding, duststorms, windstorms, wind gusts or heat stress. The choice was made to focus on extremes of temperature and precipitation, as these are widely measured.

1.9 Strengths, caveats and limitations of national climate monitoring products

By providing country-level information, NCMPs have some obvious limitations and strengths. The most-obvious limitation is that many countries span multiple climatological zones. Climates can vary within a country, sometimes to a great extent. Thus, region-specific information will be lost in calculating NCMPs, particularly when averaging rainfall over large areas. Balanced against this is the fact that NCMPs, by averaging out local variations in temperature and precipitation, will increase the signal-to-noise ratio for detecting changes in climate over time, although this is more relevant for temperature than precipitation. Long historical records, which provide a context for current conditions, are important for understanding these changes. In addition, aggregating information across a large area can reduce the effect of measurement error (which is present in even the most-advanced measurement network) and provides a reliable basis for understanding long-term change.

While a country is not necessarily a coherent climatic unit, it is usually a coherent psychological, or administrative, one. People across society are used to thinking at this level for many other indicators; gross domestic product, crop production, population changes and other indicators are routinely calculated and discussed with great interest at the national level. The guidance provided here could easily be adapted to provide information for different climatic zones within a country to complement the understanding and production of NCMPs.

There are particular challenges for calculating NCMPs for small countries and small island States, where station numbers and coverage might be limited. Therefore, there are specific provisions in these guidelines for small countries or island countries (see section 3.7).

2. NATIONAL FOCAL POINTS FOR NATIONAL CLIMATE MONITORING PRODUCTS

National focal points for NCMPs are responsible for facilitating the calculation of NCMPs at a national level and for disseminating NCMPs. Members of WMO have been invited to nominate a focal point for NCMPs as per the following terms of reference:

- To collaborate on identifying existing national sources for climate monitoring products and related capacities as well as related training and capacity-building needs

- To raise awareness of National Meteorological and Hydrological Service staff and other relevant stakeholders on the need for and the importance of NCMPs

- To facilitate calculation of NCMPs including dissemination via agreed protocols

- To prepare and submit feedback on the challenges and the need for improvement emanating from the preparation and dissemination of NCMPs

The focal points for NCMPs are expected to have knowledge about national climate data and monitoring activities. A basic knowledge of statistics is advantageous, but not essential. It is desirable for the focal points to be acquainted with the guidelines in this publication and the annex below relating to calculation of NCMPs.

3. GENERATING NATIONAL CLIMATE MONITORING PRODUCTS

The procedure detailed in this chapter and in the annex has been developed to provide a consistent means of calculating the NCMPs defined in Chapter 1.

It is noted that this method is not the only way by which NCMPs matching the basic definitions in Chapter 1 can be created. Some countries may already have the means to calculate NCMPs matching those definitions, or have existing systems that might be adapted to do so. In such cases, and understanding that the implementation of new systems may be an unnecessary burden, or that the calculation of alternative indices for the same measure may cause confusion, the use of existing systems and methods may provide a practical alternative. However, for the purposes of reporting and dissemination, the output format as described in the annex should be adhered to in all cases.

The basic procedure, which is common to NCMPs 1–5, is to calculate a set of monthly indices for each station used in the calculation, then interpolate the station values for each month using ordinary kriging (a standard method in geosciences; see, for example, Cressie, 1993) to obtain a spatially complete analysis on a regular grid. The spatially complete analysis is then averaged across the area covered by the country to calculate the NCMP for that month. In this way, a time series is built up, month by month, which can be used to examine climate change over time and to place each month into historical context.

The basic steps for calculating NCMPs 1–5 are:

1. Conduct QC on the daily station data of temperature and precipitation;
2. Consider the homogeneity of the data at each station;
3. Generate the indices at each station for each month and year;
4. Interpolate the data for each index for each month and year;
5. Average each index across the country using the interpolated data;
6. Output the NCMP.

NCMP 6 simply reports daily temperature and precipitation records and is described separately.

Detailed instructions for calculating the indices and performing the interpolation are provided in the annex. The following sections describe the pre-processing that is necessary, and then provide a walk-through of steps 3–6 above using an example of Australian precipitation.

3.1 Conducting quality control

Performing QC is an important step in data analysis. The aim is to ensure that the data are not contaminated with values that are badly erroneous and that they meet the basic requirements of analysis.

The definition of general methods for conducting QC is beyond the remit of this guidance. However, it is recommended that the data undergo QC prior to their use in calculating NCMPs. (For further guidance, see, for example, WMO, 1986, 1993, 2007, 2011, 2013, 2014.)

It should be noted that no QC procedure is perfect and that certain kinds of data errors are not immediately apparent from first processing. Data and output should be checked after each substantial stage of processing.

3.2 Homogenization

A key difficulty in accurately assessing long-term trends is that instrumental observations including rainfall and temperature may be influenced by non-climate-related factors over time. These non-climate-related influences include the relocation of observing stations, shifting exposure due to changes in the environment surrounding the station and new observing practices such as automation of observations. If not accounted for, these changes can lead to non-climatic artefacts in data and affect estimated long-term trends. The process of assessing and reducing the effects of non-climatic changes is known as homogenization.

Homogenization is complex and is outside the remit of this publication. (For further guidance, see, for example, WMO, 2003). However, it is recommended that data are homogenized prior to the calculation of NCMPs. An alternative is to assess the homogeneity of each station and use only those sections of station data that appear free from inhomogeneities. The RH-test software (WMO, 2003), developed by ETCCDI and used in ETCCDI workshops, can be used to assess the homogeneity of the station data, but there are many other methods.

If the data have been homogenized, this should be noted in the metadata of the NCMP by setting the appropriate homogenization flag to 1 (see section 4.5 below). If the data have not been homogenized, then the appropriate homogenization flag should be set to 0. There should be separate flags for temperature and precipitation data.

3.3 Calculating station indices

The indices form the basis for the next stages. There are six different indices that need to be calculated (mean temperature anomaly, percentage precipitation anomaly, precipitation anomaly, SPI, percentage of warm days and percentage of cold nights). Each index needs to be calculated separately for each station. In an example for Australia, the stations used to illustrate the steps for calculating NCMPs are shown in Figure 1. The data from these stations have already undergone QC and have been homogenized.

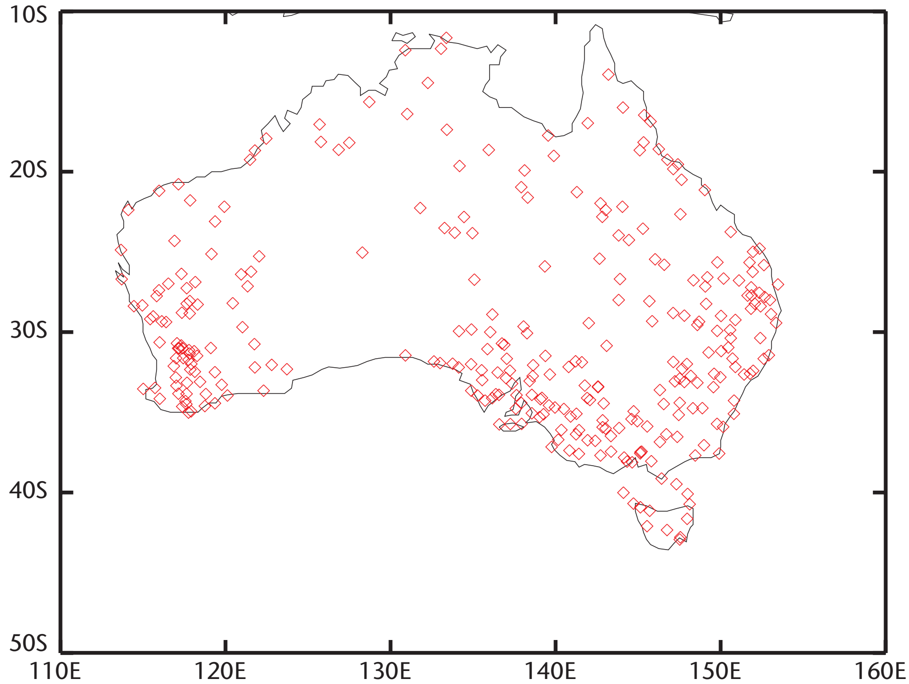

Figure 1. Station locations used to illustrate NCMP calculation (red diamonds) in Australia

Source: Met Office, UK, using data obtained from the Australian Bureau of Meteorology

3.4 Calculating a variogram

A variogram describes how much it is expected that an index (for example, mean temperature anomaly) will change when moving away from a location (Cressie, 1993). It encapsulates the intuition that weather conditions at points that are close to one another are more closely related than conditions at locations that are far apart.

A variogram is obtained by plotting half the squared difference in the index at all pairs of stations as a function of the distance between them and then averaging the differences into regular bins. This is called an empirical variogram. It is always positive and is typically small for small separations and large for large separations. A schematic example is shown in Figure 2.

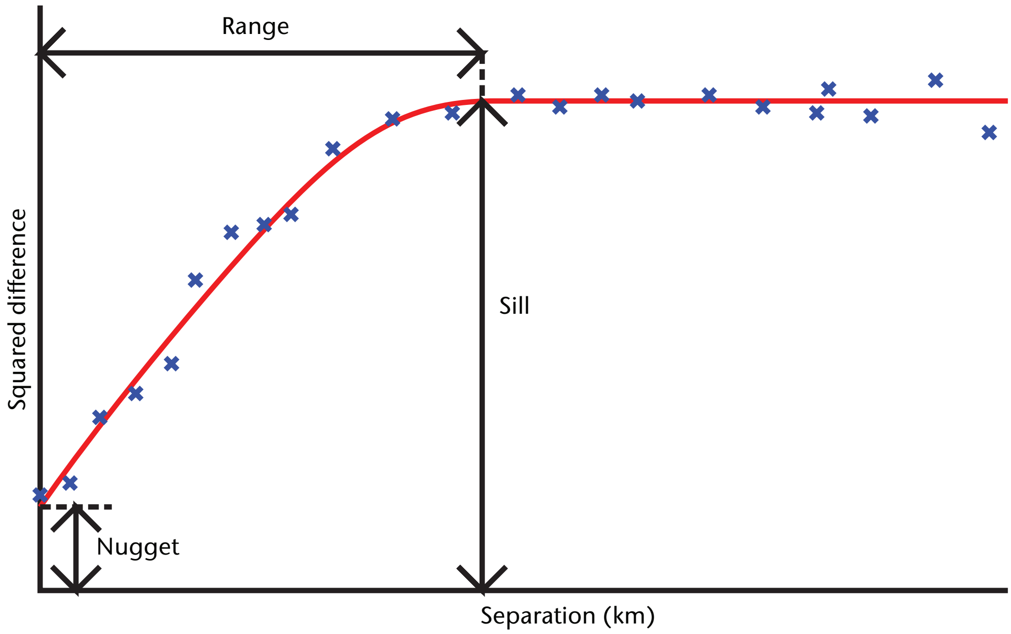

Figure 2. Schematic variogram indicating the range, nugget and sill

Source: Met Office, UK

An empirical variogram is often interpreted in terms of three parameters: the nugget, range and sill. A nugget is the value of the variogram at zero separation. It represents the contribution of measurement error to differences among station values. A sill represents the variance of the difference among station values at separations that are sufficiently large that the values are effectively unrelated or uncorrelated. A range is a measure of the separation distance at which the squared difference first reaches the sill value, and is related to the correlation length scale. Examples of empirical variograms for the stations in Figure 1 are shown in black in Figure 3.

To perform interpolation, a function is needed that can give an estimate of what the variogram would be for any separation. This is found by fitting a particular functional variogram model to the empirical variogram. Functional variograms fitted to the data are shown in Figure 3 as red lines. A separate variogram model has to be calculated for each index, for each calendar month and for the year as a whole. The 12 panels in Figure 3 correspond to the 12 calendar months. The 12-monthly variograms show that precipitation variability changes with season. The empirical variogram (in black) often starts to drop at large separations, for example, between April and November in the example shown. This is normal and it is only the first part of the variogram – the rise and plateau – that is being modelled with the functional variogram (in red).

A reliable variogram model can typically only be calculated if there are more than 10 stations. In most cases, countries with fewer than 10 stations will either have to use a pre-calculated variogram, or use shared data from neighbouring countries if available. For countries with a single station or a limited network, see section 3.7. It might also happen that there is no clear pattern in the variogram, even when there are more than 10 stations. This can occur when there are outliers in the data, or the stations are so distantly separated that the climatic conditions at each station are uncorrelated. In these cases, it would also be best to use a pre-calculated variogram.

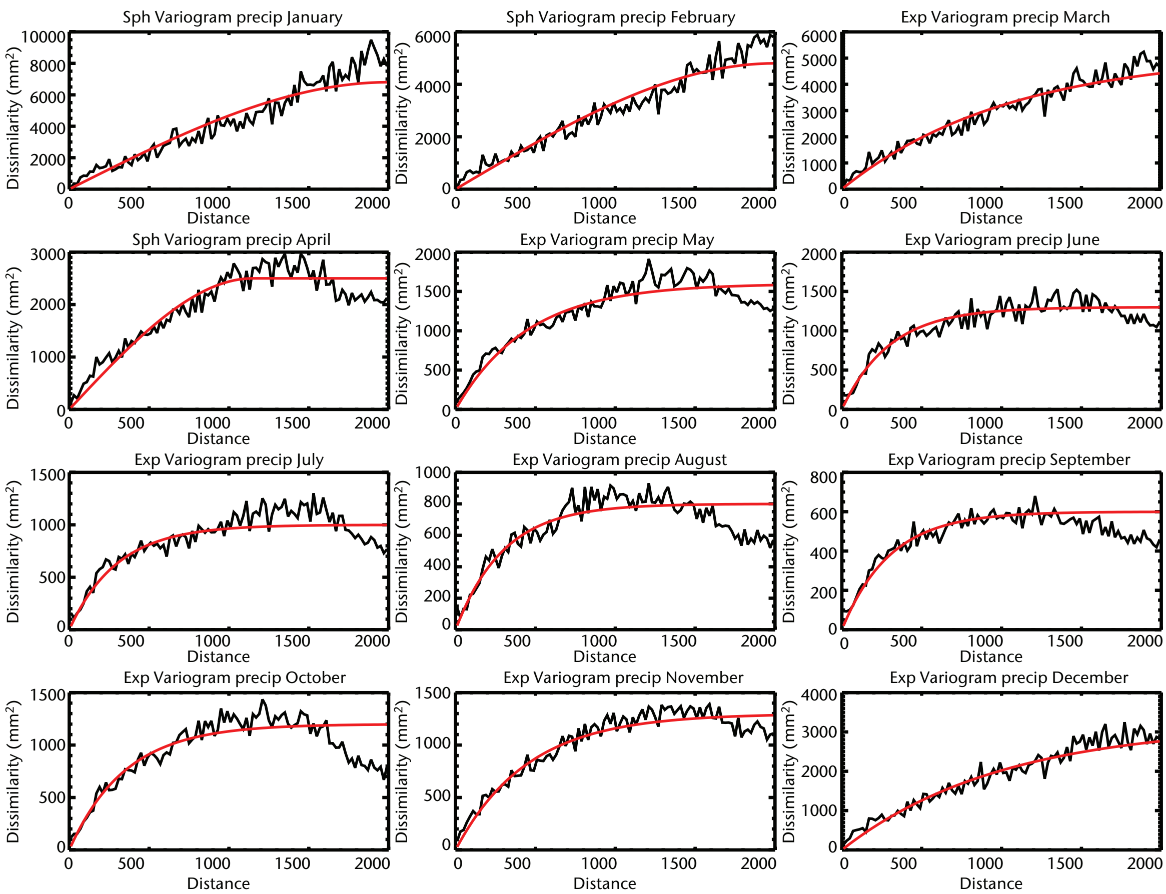

Figure 3. Sample variograms for Australian precipitation for each month from January (top left) to December (bottom right). The black lines are the empirical variograms. The red lines are the functional variograms. The average differences are typically small for small separations and increase as the separation of the stations increases.

Source: Met Office, UK, using data obtained from the Australian Bureau of Meteorology

3.5 Interpolating data

A method for estimating the national average of an index (for example, mean temperature anomaly) is to spatially interpolate the station-based indices across the country. An interpolated map of an index is also useful for understanding how variabilities at local and national levels are related and for identifying areas within a country where conditions were more extreme. This can be useful, for example, in mapping the extent of an area affected by a heatwave or by heavy rain.

The interpolation method recommended in these guidelines is called ordinary kriging (Cressie, 1993) and is widely used in geostatistics. This method naturally accounts for the uneven distribution of stations and provides a reasonable, though not perfect, estimate of what the index would be at intermediate locations. Here, ordinary kriging is used to estimate the value of the index at points on a regular latitude–longitude grid that covers the country. The resolution of the grid should be sufficiently high that the borders and coastlines of the country are reasonably well resolved.

Figure 4 shows an example interpolated field of precipitation anomalies for Australia in January 2010. The interpolated fields are generally somewhat smoother than might be expected based on the individual station records. A grid resolution of 0.1° latitude by 0.1° longitude resolution was used. Note how the grid closely follows the coastline. Using too coarse a grid will lead to errors in the estimation of the area average because of the difficulty of deciding whether a grid cell should be assigned to land or sea or whether it falls inside or outside the country's borders.

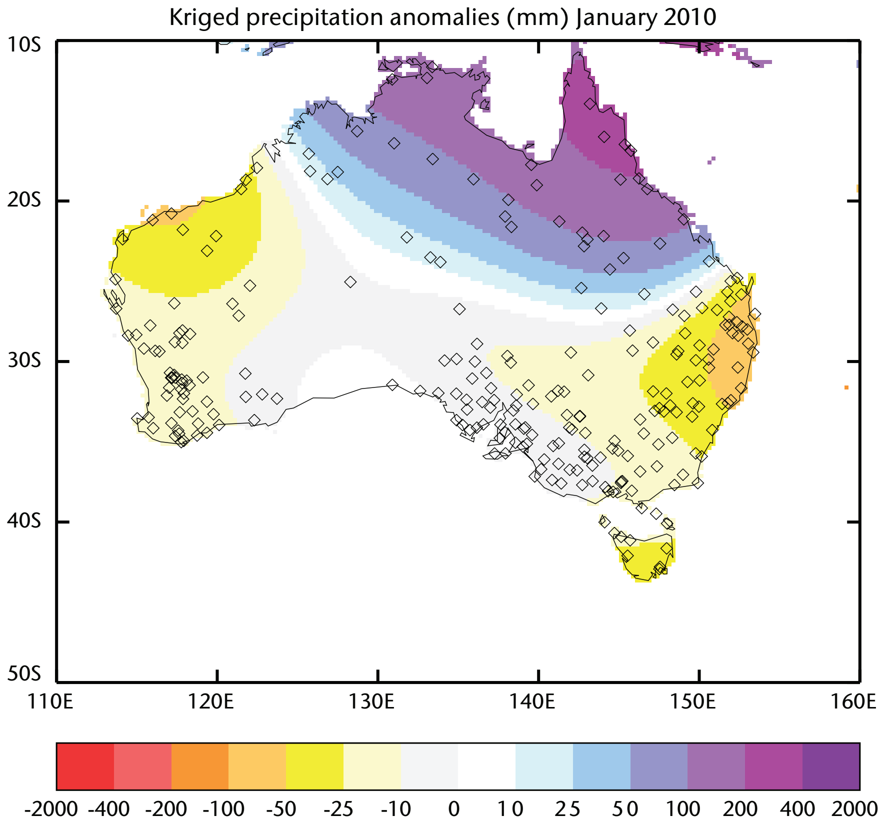

Figure 4. Station locations (black diamonds) and interpolated precipitation anomalies (in mm) for Australia in January 2010

Source: Met Office, UK, using data obtained from the Australian Bureau of Meteorology

3.6 Averaging the indices

The final step in the calculation of NCMPs is to calculate the area average. This is achieved by excluding all grid cells that fall outside the country's borders and then calculating an area-weighted average of those that remain. In the example shown in Figure 4, there are areas outside Australia, to the north, for which interpolated values have been calculated, and these were excluded before calculating the Australian NCMP. The interpolation and averaging steps should be repeated for each month and year for which data are available from at least one station. In this way, a time series of the NCMP, such as that shown in Figure 5, can be built up.

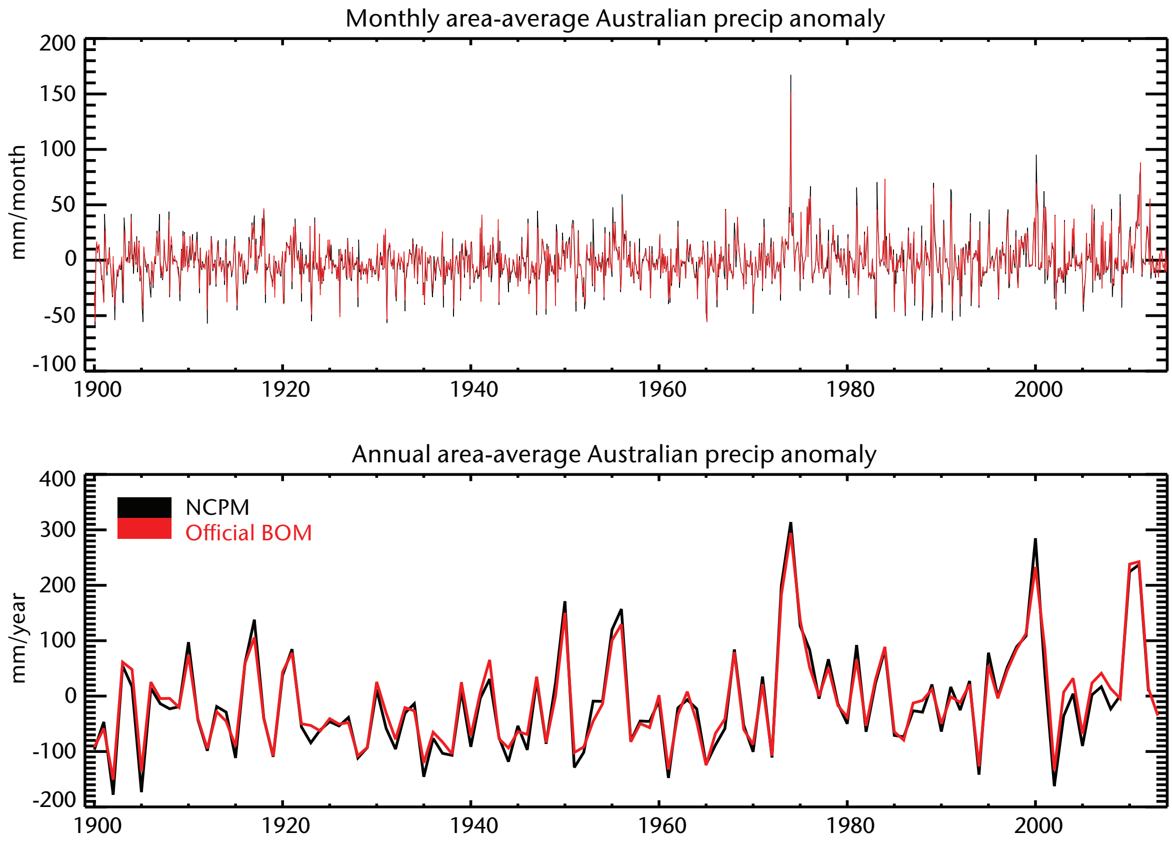

Figure 5. Time series of the example NCMP 2 country-average precipitation anomalies (in mm) for Australia. The monthly series is shown in the top panel in black and the annual series is shown in the lower panel in black. The official Australian Bureau of Meteorology (BOM) series are shown in red for comparison purposes.

Source: Met Office, UK, using data obtained from the Australian Bureau of Meteorology

3.7 Countries with a single station or a limited network

For countries with a limited network of stations, there are several possible ways of calculating an NCMP. Stations from neighbouring countries could be used, where such data are available, to supplement the station network within the country. (Even countries with dense station networks could benefit from using stations in neighbouring countries. Using data from neighbouring countries will help to improve the interpolated fields along borders.) The calculation of the variogram and interpolation would then proceed as described above. An alternative is to use standard forms of the functional variogram.

Where a country has a single station and using data from neighbouring stations is not possible, the area average for the country for a particular month (season or year) will be equal to the value of the index at the station for that same period.

3.8 Countries that are non-contiguous or that have overseas dependencies

Some countries, such as the United States of America, are non-contiguous. That is, the country does not comprise a single, continuous land mass. In the case of the United States, the country includes Alaska, which is separated from the rest of the United States by Canada, and islands such as Hawaii. In such cases, there can be no definitive guidance and it is left to the judgement of the NCMP focal point to decide what combination of land elements forms a meaningful average. In the case of the United States, statistics are usually quoted separately for the contiguous part of the country and Alaska.

3.9 NCMP 6 temperature and precipitation records

NCMP 6 is intended to capture some of the extreme events that occur within a particular month or year. NCMP 6 consists of three counts:

1. The number of stations with records exceeding 30 years in length that recorded their highest daily temperature (maximum temperature, Tmax) during the period when compared to all previous equivalent periods;

2. The number of stations with records exceeding 30 years in length that recorded their lowest daily temperature (minimum temperature, Tmin) during the period when compared to all previous equivalent periods;

3. The number of stations with records exceeding 30 years in length that recorded their highest daily precipitation total during the period when compared to all previous equivalent periods.

NCMP 6 is intended to indicate that particularly extreme events have occurred, but it cannot, on its own, give a well-rounded account of what happened. The focal point should be able to provide further context for such events. In particular, the focal point should have access to the names and locations of the stations reporting record temperatures or precipitation as well as the date on which the record was broken and the value of the new record.

3.10 Output of national climate monitoring products

Once NCMPs 1–5 have been calculated, the results need to be output in a standard format. The exact format is described in the annex.

4. PRODUCTION AND DISSEMINATION OF NATIONAL CLIMATE MONITORING PRODUCTS

At both national and international scales, NCMPs are designed to be compared and to form the basis of ongoing climate monitoring activities.

4.1 Initial production

When NCMPs are first calculated, it will be necessary to calculate the NCMP for every month for which station data are available. Once NCMPs have been calculated, it should be possible to save certain parts of the processing (for example, the variograms) to speed up the production of regular updates. The variograms need only be calculated once and can then be reused, unless major changes are made to the historical data used to calculate them, including updates of the base period.

4.2 Annual updates

It is intended that NCMPs initially be updated annually, moving to a more timely update schedule – monthly or seasonal – as expertise improves and as the process is made more efficient. It is not necessary to recalculate the variogram for regular updates unless there have been major changes to the station data or network during the base period.

When performing annual updates, it is necessary to check whether the base period has changed. At the time of writing, the base period is 1981–2010, but when this period moves to 1991–2020, NCMPs will need to be recalculated from the beginning.

4.3 Monthly or seasonal updates

When performing monthly or seasonal updates, it is necessary to conduct QC and process only a limited number of months – typically those that have been added since the last update. Usually, this will be a single month or season, but in cases where processing of the data (such as conducting QC) takes longer, it might be necessary to reprocess several months at a time. It is not necessary to recalculate the variogram for regular updates, unless there have been major changes to station data during the base period.

4.4 Irregular updates

Updates might be desirable at times other than those described above. For example, recalculation of NCMPs is recommended when large changes (revisions, additions or deletions) are made to the station data or network, or if there are improvements to the way that homogenization or QC are carried out. Homogeneity should be rechecked periodically. There might also be occasional updates to these guidelines or software derived from them, which would necessitate a recalculation of NCMPs.

4.5 Data to be transmitted

The precise format for each NCMP is given in the annex. It contains the following information, which is necessary for understanding NCMPs:

- Year
- Month
- Country
- NCMP value with appropriate units
- For NCMP 6, the counts of stations exceeding daily records
- Number of stations reporting each element used that month to calculate the NCMP
- A flag [0,1] to indicate whether the station data used were homogenized
- A flag [0,1] to indicate whether the station data used had undergone QC
- Base period (at the time of writing, this was 1981–2010 in all cases)
- Version of the software or guidance used to calculate the NCMP

4.6 Auxiliary data

In addition to the main data, the method described above will produce many intermediate products that could be useful for NCMP focal points and other users of NCMPs. It might help to consider the implementation of the above method as providing general purpose tools that are used to create NCMPs but which could be adapted for wider use.

Up-to-date sets of station indices could be a simple output that may be of interest to those working in climate science, services or other sectors. Spatial maps of the indices are generated at the interpolation step. These can be used to assess the quality of the interpolated fields, and can be saved in a consistent format, such as NetCDF, or output as images in a standard format (png, eps or pdf). The locations of stations are also of interest. In conjunction with maps of indices, station locations will give an idea of spatial bias in station coverage, locations of outliers and potentially erroneous data, as well as the spatial extent of unusual events.

4.7 Dissemination

Calculated NCMPs should be sent to WMO (wcdmp@wmo.int) as an email attachment in time for inclusion in the annual WMO statement on the state of the global climate. The deadline for submissions is usually late January each year. A coded message will be developed to make frequent dissemination more efficient.

ANNEX. SPECIFICATIONS FOR CALCULATING NATIONAL CLIMATE MONITORING PRODUCTS

The following specifications detail the mathematical steps necessary to calculate the six national climate monitoring products (NCMPs).

The specifications are split into four sections: the first is the calculation of indices for individual stations; the second concerns the use of these indices to calculate area averages that constitute NCMPs; the third describes the calculation of NCMP 6; and the fourth describes the output format, which should be transmitted to WMO once calculation is complete.

1. Calculating the indices at station level that are needed to produce the six national climate monitoring products

Let Tx_{ij} and Tn_{ij} be the daily maximum and minimum temperatures, respectively, for day *i* and period *j*, Tm_{ij} be the daily average temperature and the mean of Tx_{ij} and Tn_{ij} when both values are available and Pr_{ij} be the daily precipitation amount on day *i* and period *j*. Temperatures are given in degrees Celsius and precipitation totals in millimetres.

Percentiles are calculated for each day using a 5-day running mean for the base period. Indices are calculated for each calendar month and for the year as a whole.

1.1 *Input data*

The input data format is:

- ASCII text file, one file by station
- Columns: year, month, day, Pr_{ij}, Tx_{ij}, Tn_{ij}
- Example: `1950  07  15  2.5  25.0  10.2`
- Missing values should be set to –99.9
- Records must follow the calendar date order

1.2 *NCMP 1: mean temperature anomalies*

Calculate the following:

- Monthly and annual mean temperature (TM_j): average of Tm_{ij} over the month (year)
- Climatology (CT_j): average of TM_j over the base period
- Monthly and annual mean temperature anomaly (TMA_j): $TM_j – CT_j$

1.3 *NCMP 2: percentage rainfall anomaly*

Calculate the following:

- Monthly and annual total precipitation (PR_j): sum of Pr_{ij} over the month (year)
- Climatology (CP_j): average of PR_j over 1981–2010
- Monthly and annual precipitation normalized anomalies ($PRNA_j$): $100 \times (PR_j – CP_j) / CP_j$
- Monthly and annual precipitation anomalies (PRA_j): $(PR_j – CP_j)$

1.4 *NCMP 3: standardized precipitation index*

Carry out the following:

- Prepare 13 precipitation series (one for each month and one annual)

- Calculate the fraction of months in the base period with zero rain and the fraction of months in the base period with non-zero rain
- Fit gamma distributions to the non-zero values during the base period in each series separately
- Calculate the cumulative probability of each non-zero monthly (annual) value computed from the observations
- Calculate the adjusted cumulative probability, which is the cumulative probability multiplied by fraction of months with non-zero rain plus fraction of months with zero rain
- Convert the adjusted cumulative probability from monthly (annual) values to obtain the equivalent precipitation deviation from the normal distribution with a mean of 0 and a standard deviation of 1

1.5 ***NCMP 4: warm days***

Calculate the following:

- Calendar-day ninetieth percentile centred on a 5-day window for Tx_{ij} for the base period ($Tx_{in}90$)
- Monthly and annual percentage of days when $Tx_{ij} > Tx_{in}90$ ($Tx90p$)

1.6 ***NCMP 5: cold nights***

Calculate the following:

- Calendar-day tenth percentile centred on a 5-day window for Tn_{ij} for the base period ($Tn_{in}10$)
- Monthly and annual percentage of days when $Tn_{ij} < Tn_{in}10$ ($Tn10p$)

1.7 ***NCMP 6: extremes of temperatures and precipitation***

Calculate the following:

- Monthly and annual highest Tx_{ij} (TXx_j)
- Monthly and annual lowest Tn_{ij} (TNn_j)
- Monthly and annual highest Pr_{ij} ($RX1day_j$)
- Date and value of highest TXx_j for each month and entire period
- Date and value of lowest TNn_j for each month and entire period
- Date and value of highest $RX1day_j$ for each month and entire period

1.8 ***Output data for index calculation***

The output data format is:

- csv file, one file for each station and NCMP combination
- File-name format: [Station name]_[Index name].csv
- Index names: TMA, PrA, PrAN, SPI, TX90p, TN10p
- Example file-name: Toronto_TX90p.csv
- The first line of the file should read: – `"Year","January","February","March","April","May","June","July","August","September","October","November","December","Annual"`
- Columns: year, January index value, February index value, …, December index value, annual index value
- Columns should be separated by a single comma
- Values should be given to at least two decimal places where appropriate
- Example line in output: `1950,−10.21,−5.62,0.33,2.53,8.41,12.27,19.91,19.01,13.0,11.0,0.01, −3.01,8.40`
- Missing values should be set to −99.9

– Example line in output with missing values: `1950,-99.9,-99.9,0.33,2.53,8.41,12.27,19.91,19.01,13.0,11.0,0.01,-3.01,8.40`

2. Programming the calculation of countrywide averages

NCMPs 1–5 are defined as countrywide averages of various indices. This section describes the calculation of the countrywide averages from the previously calculated station indices.

Let N be the number of stations in the country for which there are station indices in year y and month m, where $1 \leq m \leq 12$, and $m = 1$ corresponds to January, $m = 2$ corresponds to February and so on.

The value of the index for NCMP k, at station i, in year y and month m is I_{kiym}:

- For NCMP 1, I_1 is the mean temperature anomaly
- For NCMP 2, I_2 is the precipitation anomaly normalized in per cent
- For NCMP 3, I_3 is the standardized precipitation index
- For NCMP 4, I_4 is the percentage of warm days
- For NCMP 5, I_5 is the percentage of cold days

The difference in the index between two stations i and j is Δ_{ijym} and the separation between the stations is D_{ij}. The separation is assumed to be constant in time.

2.1 *Input data*

The input data are the outputs from the station index calculations previously described.

2.2 *Calculating a variogram*

The first step is to calculate a variogram, which relates the separation between two stations to the expected difference. One variogram is calculated for each NCMP and for each calendar month m. The variograms only need to be calculated once for each NCMP. They can be saved and reused in all future calculations of the NCMP. However, if an important change is made to the available station data due to improved quality control, homogenization, new base period or a large change in the number of stations, then the variograms should be recalculated.

The variogram for month m is calculated as follows. For every pair of stations i and j where $j > i$ and for every year y in the climatology period, calculate:

$$\Delta_{ijym} = I_{kiym} - I_{kjym}$$

Choose a maximum separation, D_{max}, which is the smaller of the following two distances: maximum separation between stations ($\max(D_{ij})$) and 2 000 km for precipitation indices and 3 000 km for temperature indices.

Separate Δ_{ijym} into bins of width w based on their separations D_{ij}. Typically, the bin width is set to 20 km. Bin l contains Δ_{ijym} where:

$$lw\ D_{ij} < (l + 1)w, \text{ where } (l + 1)w < D_{max}$$

In each bin l, calculate the bin average B_l by taking the arithmetic mean of $(\Delta_{ijym})^2$ in the bin:

$$B_l = \left[\sum(\Delta_{ijym})^2\right] / n$$

where n_l is the number of Δ_{ijym} in bin l. The bin separation D_l is:

$$D_l = lw - w / 2$$

Plot B_l versus D_l for all l. The plot shows how the difference in the index varies as a function of separation between two stations. The aim is to next find a function that approximates this relationship. This function is known as the functional variogram $V_m(D, n, r, s)$.

The functional variogram is found by finding the function *V* and parameters *n*, *r* and *s* that minimize the mean-squared error (*E*):

$$E = \sum_l \left[B_l - V_m(D_l, n, r, s)\right]^2$$

Typical example functions that are used for *V* are given below. It is possible, but not generally advisable, to perform this fit by eye. It is always advisable to check that the fit is reasonable. If there are very few stations, it might work better to minimize the mean absolute error (MAE) instead:

$$\text{MAE} = \sum_l \left|B_l - V_m(D_l, n, r, s)\right|$$

This process should be repeated to find a functional variogram V_m and parameters *n*, *r* and *s* for each of the 12 calendar months and for each NCMP.

Example functions for variograms

In each case, *n*, *r* and *s* are the parameters of the function: *n* corresponds to the variance at zero separation, *r* is a range parameter that controls how quickly or slowly the variance changes with separation and *s* corresponds to the variance at large separations.

Exponential:

$$V(D, n, r, s) = (s - n)\left[1 - \exp(-D / r)\right] + n$$

Spherical:

$$V(D, n, r, s) = (s - n)(3D / 2r - D^3 / 2r^3) + n, \text{ for } D < r$$
$$V(D, n, r, s) = s, \text{ for } D > r$$

Gaussian:

$$V(D, n, r, s) = (s - n)\left[1 - \exp(-D^2 / r^2 a)\right] + n$$

2.3 ***Output data for variograms***

The output data format is:

- csv file
- File-name format: [country name]_[index name]_Variogram.csv
- Example file-name: Canada_PrA_Variogram.csv
- The first line of the file should read: `"Month","Function","n","r","s","Mean Sq Err"`
- Columns: month, function, *n*, *r*, *s*, mean-squared error
- Month should be the name of the month in double quotes or "Annual"
- Functional name should be in double quotes, for example "Spherical"
- Columns should be separated by a single comma
- Values should be given to at least two decimal places
- Example line in output: `"February","Gaussian",1078.61,966.35,4347.32,10443102.33`

It would also be useful to provide a plot that shows the empirical variogram and the best-fitting functional variogram.

2.4 ***Interpolation onto a regular grid***

The next step is to estimate the value of the index for all points on a regular grid. This will be done using ordinary kriging, which is a standard method in geostatistics.

Define a regular grid across the country. The grid should have regular spacing in latitude and longitude such that there are at least 100 grid boxes within the country's borders. A particular grid box will be referred to using the letter *o* for a total of *M* grid boxes. The area of grid box *o* that falls within the country's borders is A_o.

The interpolated value in grid box *o* for year *y* and month *m* proceeds as follows.

Create a data vector *d* that contains the station indices:

$$d_i = I_{kiym} \text{ for } 1 \le I \le N \text{(where } N \text{ is the total number of stations)}$$

$$d_{N+1} = 1$$

Next, create a matrix *C* with *N* + 1 by *N* + 1 elements:

$$C_{ij} = V_m(D_{ij}, n, r, s) \text{ for } 1 \le i \le N$$

$$C_{i,N+1} = 1 \text{ for } 1 \le i \le N$$

$$C_{N+1,j} = 1 \text{ for } 1 \le j \le N$$

$$C_{N+1,j} = 0$$

and a matrix *F* with *N* + 1 by 1 elements:

$$F_{io} = V_m(D_{io}, n, r, s) \text{ for } 1 \le i \le N,$$

$$F_{N+1,o} = 1,$$

where D_{io} is the separation between station *i* and the centre of grid box *o*. The interpolated value of the index for grid box *o* is then given by:

$$I_{koym} = d^T C^{-1} F.$$

This process is repeated for each grid box.

2.5 *Output data for interpolation onto a regular grid*

The output data format is:

- csv file containing values of the index for each grid box participating in the average for year *y* and month *m*
- File-name format: NCMP_[index name][year][month].csv
- Example file-name: NCMP_TMA2015September.csv
- The first line of the file should read: "Grid","Lat","Long","Area","Index"
- Columns: grid number, latitude in degrees, longitude in degrees, area in square kilometres, index in appropriate units
- Columns should be separated by a single comma
- Values should be given to at least two decimal places
- Longitudes in the western hemisphere should be negative, longitudes in the eastern hemisphere should be positive; longitudes should be in the range [–180.00, 180.00]
- Example line in output: 9,58.50,-136.00,26203.23,2.95
- There should be one line in the file for each grid cell that falls within the country's borders
- There should be no missing data

2.6 *Calculation of countrywide average*

The countrywide average for month *m* and year *y* is calculated by taking the area-weighted average of all grid boxes within the country's borders. The countrywide average is the NCMP for month *m* and year *y*:

$$\text{NCMP}_{kym} = (\Sigma_{o=1,M}\, A_o I_{koym}) \,/\, (\Sigma_{o=1,M}\, A_o)$$

2.7 *Output data for countrywide averages*

The output data format is:

- csv file
- File-name format: [country name]_[index name]_Region_Avg.csv
- Example file-name: Canada _ TN10p _ Region _ Avg.csv
- The first line of the file should read: "Year","Month","Index","No of Stns"

- Columns: year, month, NCMP, number of stations
- Month is the number of the month: 1 for January, 2 for February and so on; annual values are denoted as month 13
- Columns should be separated by a single comma
- Values should be given to at least two decimal places where appropriate
- Example line in output: `1952,8,81.578,15`
- There should be one line in the file for each month and year from the first month for which an NCMP could be calculated to the most recent month for which an NCMP could be calculated; the annual value should be given after the 12 monthly values and denoted as month 13
- Missing values should be set to –99.9
- Example line in output with missing values: `1950,1,-99.9,0`

3. NCMP 6

NCMP 6 consists of counts of stations that have broken their daily temperature and precipitation records in a particular period.

3.1 *Input data*

The input data are the outputs from the station index calculations previously described:

- csv file, one file per station, one file per NCMP
- Columns: year, January, February, …, December, annual
- Example file-name: `Toronto _ TMA.csv`
- Example format: `1950 –10.2  –5.6  0.3 … 8.4`
- Missing values should be set to –99.9

3.2 *Counts of record stations*

For each variable *k*, which includes *TXx*, *TNn*, *Pr*, set the count C_k to 0 and eligible station count E_k to 0.

For each station *i* and variable *k*, determine the length of record L_{ik} for that station.

If the length of the record is greater than 30 years, then add 1 to E_k.

If the length of the record is greater than 30 years and the value of the variable *V*, for the year *y* and month *m*, V_{ikym} is the highest (*TXx*, *Precip*) in the record,

$$V_{ikym} \geq \max(V_{ikm})$$

or the lowest in the record (*TNn*),

$$V_{ikym} \geq \min(V_{ikm})$$

then add 1 to C_k.

3.3 *Output data for NCMP 6*

The output data format is:

- csv file
- File-name format: [country name]_NCMP6.csv
- Example file-name: `Canada _ NCMP6.csv`

– The first line of the file should read: `Year,Month,Number of TXx records, Number of stations reporting Tmax, Number of TNn records, Number of stations reporting Tmin, Number of Pr records, Number of stations reporting Pr`.
– Columns: year, month, C_k, E_k for each *k* in (*TXx*, *TNn*, *Pr*) in that order
– Columns should be separated by a single comma
– Example line in output: `1950,12,3,170,12,170,0,250`
– There should be one line in the file for each month for which NCMP 6 was calculated
– Missing values should be set to *–99.9*
– Example line in output with missing values: `1950,12,3,180,12,170,–99.9,–99.9`

4. Final formatting of all national climate monitoring products

The files combining the regional averages and NCMP 6 should be combined into a single file along with metadata, including the version of the guidance used to generate NCMPs, the base-period start and end dates and flags to indicate whether data had undergone QC and had been homogenized:

– csv file
– File-name format: [country name]_NCMP_Summary.csv
– Example file-name: Canada_NCMP_Summary.csv
– The first line of the file should read: `"Year","Month","NCMP1","No of Stns NCMP1" ,"NCMP2","No of Stns NCMP2" ,"NCMP2b","No of Stns NCMP2b" ,"NCMP3","No of Stns NCMP3" ,"NCMP4","No of Stns NCMP4" ,"NCMP5","No of Stns NCMP5" ,"Tmax records","No of Stns reporting Tmax", "Tmin records","No of Stns reporting Tmin" ,"Precip records","No of Stns reporting precip","Temp QC flag","Temp homogenisation flag" ,"Precip QC flag","Precip homogenisation flag","Base period start","Base period end","Version"`.
– Columns:

  - Year
  - Month
  - Country average of *TMA*
  - Number of stations contributing to the country average of *TMA*
  - Country average of *PrAn*
  - Number of stations contributing to the country average of *PrAn*
  - Country average of *PrA*
  - Number of stations contributing to the country average of *PrA*
  - Country average of standardized precipitation index (SPI)
  - Number of stations contributing to the country average of SPI
  - Country average of *TX90p*
  - Number of stations contributing to the country average of *TX90p*
  - Country average of *TN10p*
  - Number of stations contributing to the country average of *TN10p*
  - Number of stations that reported highest daily temperature (maximum temperature; Tmax) records in the month
  - Number of stations reporting Tmax during the month
  - Number of stations that reported lowest daily temperature (minimum temperature; Tmin) records in the month
  - Number of stations reporting Tmin during the month
  - Number of stations that reported precipitation records in the month
  - Number of stations reporting precipitation during the month
  - Flag set to 1 if temperature data have undergone QC or 0 otherwise
  - Flag set to 1 if temperature data have been homogenized or 0 otherwise
  - Flag set to 1 if precipitation data have undergone QC or 0 otherwise
  - Flag set to 1 if precipitation data have been homogenized or 0 otherwise
  - Base-period start, which should be 1981
  - Base-period end, which should be 2010

  - Version of guidance used
- Columns should be separated by a single comma
- Example line in output: `1999,2,2.32,57,13.42,90,100.21,90,1.51,90,3,57,0,57,2,57,0,57,2,90,1,1,1,0,1981,2010,1.4`
- Missing values should be set to –99.9
- Example line in output with missing values: `1999,2,-99.9,0,13.42,90,100.21,90,1.51,90,-99.9,0,-99.9,0,-99.9,0,-99.9,0,2,90,1,1,1,0,1981,2010,1.4`

REFERENCES

Cressie, N., 1993: *Statistics for Spatial Data*. New York, Wiley.

World Meteorological Organization, 1986: *Guidelines on the Quality Control of Surface Climatological Data* (WMO/TD-No. 111/WCP-85). Geneva.

———, 1993: *Guide on the Global Data-Processing System (GDPS)* (WMO-No. 305). Geneva.

———, 2003: *Guidelines on Climate Metadata and Homogenization* (WMO/TD-No. 1186). Geneva.

———, 2007: *Guidelines on Climate Data Management* (WMO/TD-No. 1376). Geneva.

———, 2011: *Guide to Climatological Practices* (WMO-No. 100). Geneva.

———, 2013: Guide to the Global Observing System (WMO-No. 488). Geneva.

———, 2014: *Climate Data Management System Specifications* (WMO-No. 1131). Geneva.

———, 2017: *WMO Guidelines on the Calculation of Climate Normals* (WMO-No. 1203). Geneva.

World Meteorological Organization/Global Water Partnership, 2016: *Handbook of Drought Indicators and Indices* (WMO-No. 1173). Geneva.

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