WMO Guidelines on generating a defined set of national climate monitoring products

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Annex

# **Introduction and context**

Due to the impact of varying and changing climate 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 summarise climate conditions at a national scale and show how current climate conditions compare with the past.

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

At a regional and international level, 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 status of global climate (WMO, 2017) and the Bulletin of the American Meteorological Society’s State of the Climate reports (Blunden and Arndt, 2016). Standardised indices of climate change have also been used in the Intergovernmental Panel on Climate Change’s periodic assessment reports. Countries that routinely produce standard climate monitoring products therefore have a ready platform to promote their national capability and wider understanding of their national climate.

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

To address the challenge of inconsistency and to provide the tools whereby countries with less developed capabilities could profit from the advantages of routine national climate monitoring , the WMO Commission for Climatology (CCl) developed a short list of key, well-defined NCMPs.

The aim of this document is to provide a specification for that short list 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.

Section 1 of this guideline describes each NCMP, gives a basic definition and provides the background necessary to understand them. Section 2 describes the important role played by NCMP focal points who will be responsibile at a national level for ensuring the calculation and dissemination of NCMPs. Section 3 provides a proposed standard means of calculating NCMPs. Section 4 details how and in what form the NCMPs should be disseminated. Section 5 is a glossary of terms and References are found in Section 6. A detailed software specification including formats for transmitting the NCMPs is provided in an Annex, which more precisely describes all the steps required to calculate NCMPs to enable NMHSs to develop their own software.

# **1. National Climate Monitoring Products**

## **1.1.1Base period**

In order to ensure that NCMPs are comparable between countries, it is essential to have a consistent base period. A base period can also facilitate the 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, the WMO guidance on the calculation of standard climatological normals recommends a rolling 30-year period, updated every 10 years, with the most recent period at the time of writing this publication being 1981-2010, followed by 1991-2020 from 2021 etc. 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 this guidance. An anomaly is the difference of a measurement from the base-period average.

## 1.1.2 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 section 3, indices are calculated for each station and the values of the index are then interpolated onto a regular grid which is then used to calculate the area-average of that index for the country.

## 1.2 NCMP 1: mean temperature anomaly

**Basic Definition -** NCMP 1 is the mean temperature anomaly. This is the mean-temperature anomaly for each month and year averaged across the country. Units are °C.

**Discussion** - The mean temperature anomaly is a measure of overall warmth or cold relative to normal conditions. Mean temperature anomaly 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 recognisable 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 National Climate Monitoring Products (ET-NCMP) to assess the capabilities of countries to produce NCMPs. The majority of countries routinely measure and quality control temperature data. Maps and time series of temperature anomalies are also produced by many countries and are typically reported in synthesis reports such as BAMS State of the Climate report (Blunden and Arndt, 2016), WMO statement on the status of the global climate (WMO 2016) and the various reports of the Intergovernmental Panel on Climate Change (IPCC).

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 places, from season to season: for example in the UK, temperature variability is typically higher during winter months than summer months.

## **1.3** NCMP 2: total rainfall anomaly

**Basic Definition** - NCMP 2 is the rainfall anomaly for each month and year calculated in two ways: (1) as a simple difference from the base-period average averaged across the country; (2) as a simple difference from the base-period average expressed as a percent of the base-period average averaged across the country. Units are milimeters and percent (%).

**Discussion** – The two types of precipitation anomalies are both standard metrics used to monitor climate variability and change. Extremes of precipitation can lead to drought or flooding and 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 the longer-term changes.

The majority of countries (WMO Survey 2015, see above) routinely measure and quality control precipitation data. 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 (Blunden and Arndt, 2016), WMO statement on the status of the global climate (WMO 2016) and the various reports of the Intergovernmental Panel on Climate Change (IPCC).

In areas where average rainfall is low, large percentages can be recorded at individual stations due to very localised 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 partly offset by also including the average anomaly expressed as a simple difference within the NCMP report.

## **1.4 NCMP 3:** standardized precipitation index

**Basic Definition** - NCMP 3 is the standardized precipitation index (SPI). This is a percentile-based measure of the standardized rainfall anomaly for each month and year averaged across the country. NCMP3 is dimensionless, so there are no units specified.

**Discussion** - SPI is a standard metric used to monitor rainfall and drought. Extremes of precipitation can lead to drought or flooding and even in less extreme cases can affect agriculture, health, tourism and other important sectors. Standardization means that the 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 between 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 around 5% of the time, regardless of local conditions. SPI has been identified by the WMO and GWP (WMO, GWP Handbook of Drought Indicators and Indices 2016) as a starting point for meteorological drought monitoring, indicating periods of unusually low rainfall for the region.

SPI is calculated using precipitation measurements. The majority of countries (WMO Survey 2015, see above) routinely measure and quality control precipitation data. Maps of SPI are also produced by many countries and are used in synthesis reports such as the BAMS State of the Climate report (Blunden and Arndt, 2016), WMO statement on the status of the global climate (WMO 2016) and the various reports of the Intergovernmental Panel on Climate Change (IPCC).

## 1.5 NCMP 4: warm days

**Basic Definition** - NCMP 4 is the warm days index. This is a measure of the percentage of days in each month and year that exceeded the 90th percentile of the base-period distribution for maximum temperatures for the day averaged across the country. Units are percentage of days.

**Discussion** - The number of warm days is sensitive to high impact events such as heat 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 between 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 (created by the Expert Team on Climate Change and Detection Indices[[1]](#footnote-2)) index. The RCLIMDEX indices have been widely used in scientific reports including the IPCC. They provide a consistent way to monitor the occurrence and the change in frequency of moderate extremes.

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

**Basic definition** - NCMP 5 is the cold nights index. This is a measure of the percentage of days in each month and year that fall below the 10th percentile of the base-period distribution of minimum temperatures for the day averaged across the country. Units are percentage of days.

**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 between countries. It is a standard index produced by the RCLIMDEX software index. The RCLIMDEX indices have been widely used in scientific reports including the IPCC. They provide a consistent way to monitor the occurrence and change in frequency of moderate extremes.

## **1.7 NCMP 6: temperature and precipitation records**

Basic definition - This product 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 to be counted separately.

Discussion - The aim is to flag the most exceptional events, events which often have the most extreme impacts. Extremes of temperature – both hot and cold extremes – 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 if life. Such extremes can be very localised, so this NCMP is based on records at stations, without aggregation.

NCMP6 cannot characterise or define the full range of very extreme events that affect countries and people around the world, which include such things as tropical storms, tornadoes, hail, lightning, flooding, dust storms, wind storms, wind gusts, heat stress etc. The choice was made to focus on extremes of temperature and precipitation as these are widely measured.

## **1.8 Strengths, caveats and limitations of NCMPs**

By providing country-level information, NCMPs have some obvious limitations and strengths. The most obvious limitation is that the geography of 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 context for current conditions, are important for understanding these changes. In addition, aggregating information across a larger area can reduce the effect of measurement error (which is present even in the most advanced measurement network) and provide a more 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. There are specific provisions in the guidance for small countries or island countries (see Section 3.7).

# **2 National focal points for NCMPs**

National focal points for NCMP have the responsibility to facilitate the calculation of NCMPs at a national level and to disseminate the NCMPs. WMO members were invited[[2]](#footnote-3) to nominate a focal point for NCMP 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 the National Meteorological and Hydrological Service (NMHS) staff and other relevant stakeholders on the need for and the importance of NCMP;
* To facilitate the calculation of NCMPs including its dissemination via agreed protocols;
* To prepare and submit feedback on the challenges and the need for improvement emanating from the preparation and dissemination of the NCMPs.

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

# **3 Generating the NCMPs**

The procedure detailed in this section and in the Annex has been developed to provide a consistent means of calculating the NCMPs as defined in Section 1.

It is noted that this method is not the only way by which NCMPs matching the basic definitions in Section 1 can be created. Some countries may already have the means to calculate NCMPs matching those definitions, or have existing systems which 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 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 the NCMPs 1 to 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 e.g. 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 that 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. Quality control the daily station data of temperature and precipitation
2. Consider 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

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

Detailed instructions for calculating the indices and performing the interpolation is provided in the annex. The following sections describe the pre-processing that is necessary, and then provides a walkthrough of steps 3-6 using the particular example of Australian precipitation.

For countries with only a single station or limited station networks, see section 3.7.

## **3.1 Quality control (QC)**

Quality Control (QC) is an important step in any data analysis. The aim of QC is to ensure that the data are not contaminated with values that are badly in error and that they meet the basic requirements of the analysis.

The definition of general methods for quality control is beyond the remit of this guidance. However, it is recommended that the data are quality controlled prior to their use in calculating NCMPs. (For further guidance on Quality Control see e.g. WMO-No. 1131, WMO-No. 100, WMO-No. 488, WMO/TD-No. 111, WMO/TD-No. 1376, WMO-No. 305.)

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

## **3.2 Homogenisation**

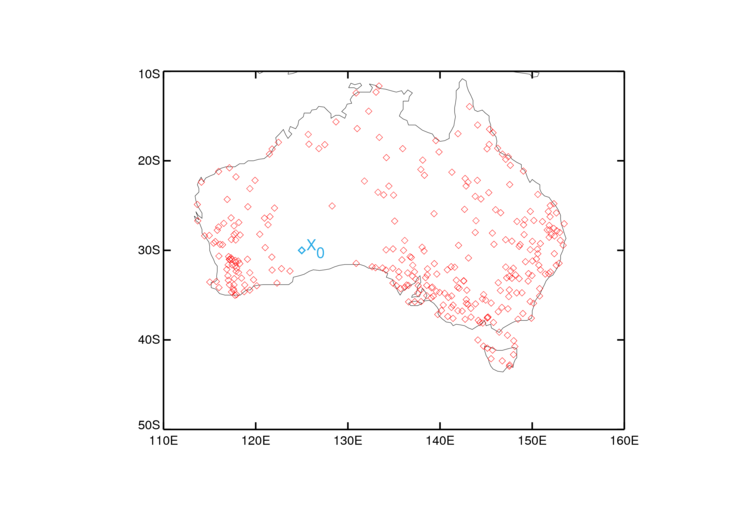
A key difficulty in accurately assessing long-term trends is that instrumental observations including rainfall and temperature may be influenced by non-climate related factors over time. Non-climate-related influences include the relocation of observing stations, shifting exposure due to changes in the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

Homogenisation is complex and is outside of the remit of this guidance. However, it is recommended that data are homogenised prior to the calculation of NCMPs. An alternative is to assess the homogeneity of each station and use only those sections of the station data that appear free from inhomogeneities. The RH-test software (Aguilar et al. 2003), develope by the ETCCDI and used in the ETCCDI workshops, can be used to assess the homogeneity of the station data, but there are many other methods.

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

## **3.3 Calculating the station indices**

The indices form the basis for the next stages. There are six different indices that need to be calculated (mean temperature anomaly, percent 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 the example for Australia, the stations used to illustrate the steps of calculating the NCMPs are shown in *Figure* ***1***. The data have already been quality controlled and homogenised.



*Figure 1: map of station locations for Australia. Each of the red lozenges represents a station.*

## **3.4 Calculating a variogram**

A variogram describes how much you expect the index (mean temperature anomaly, for example) to change as you move 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.

The variogram is found 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 the empirical variogram. It is always positive and is typically small for small separations and larger for large separations. A schematic example is shown in .

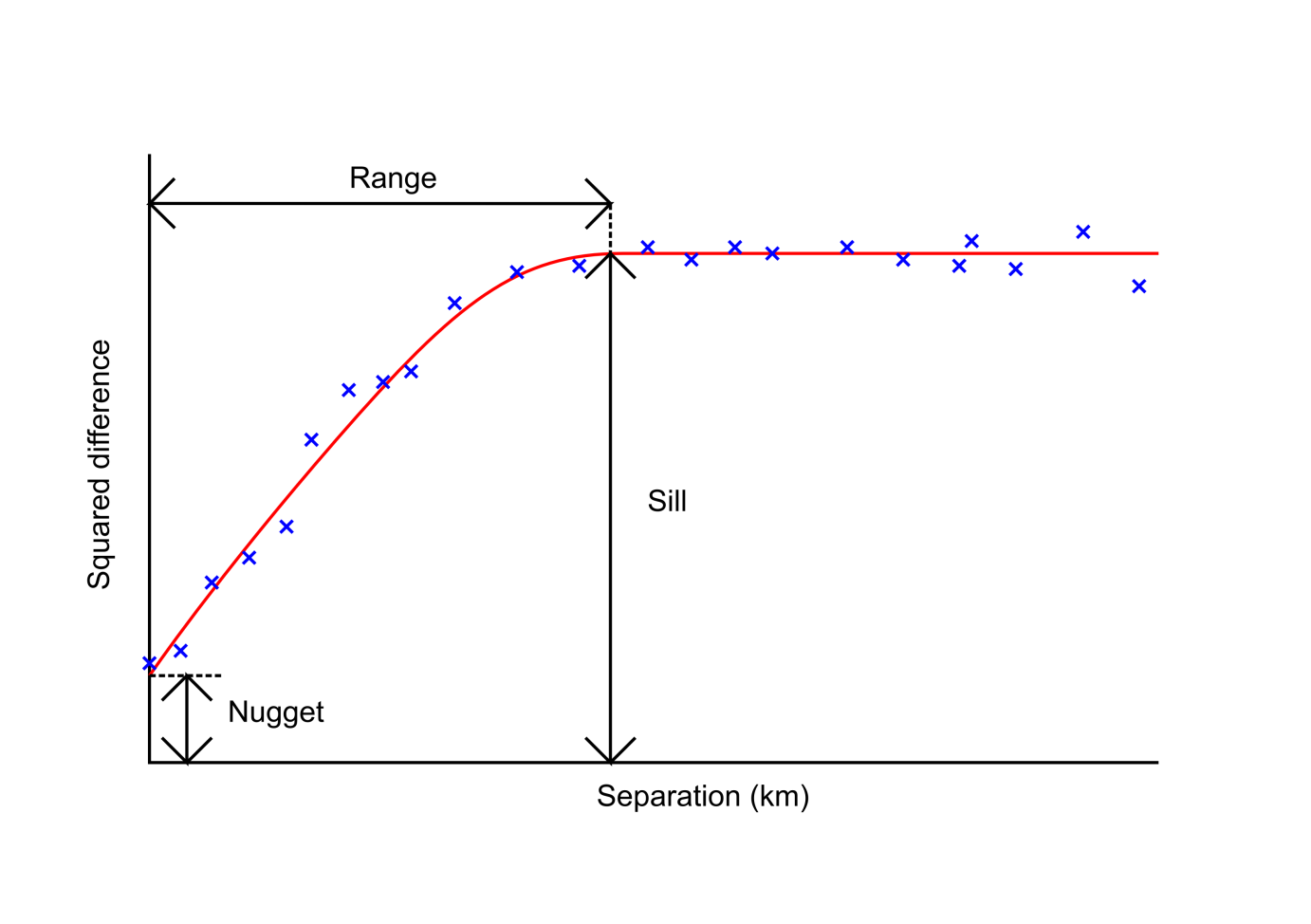
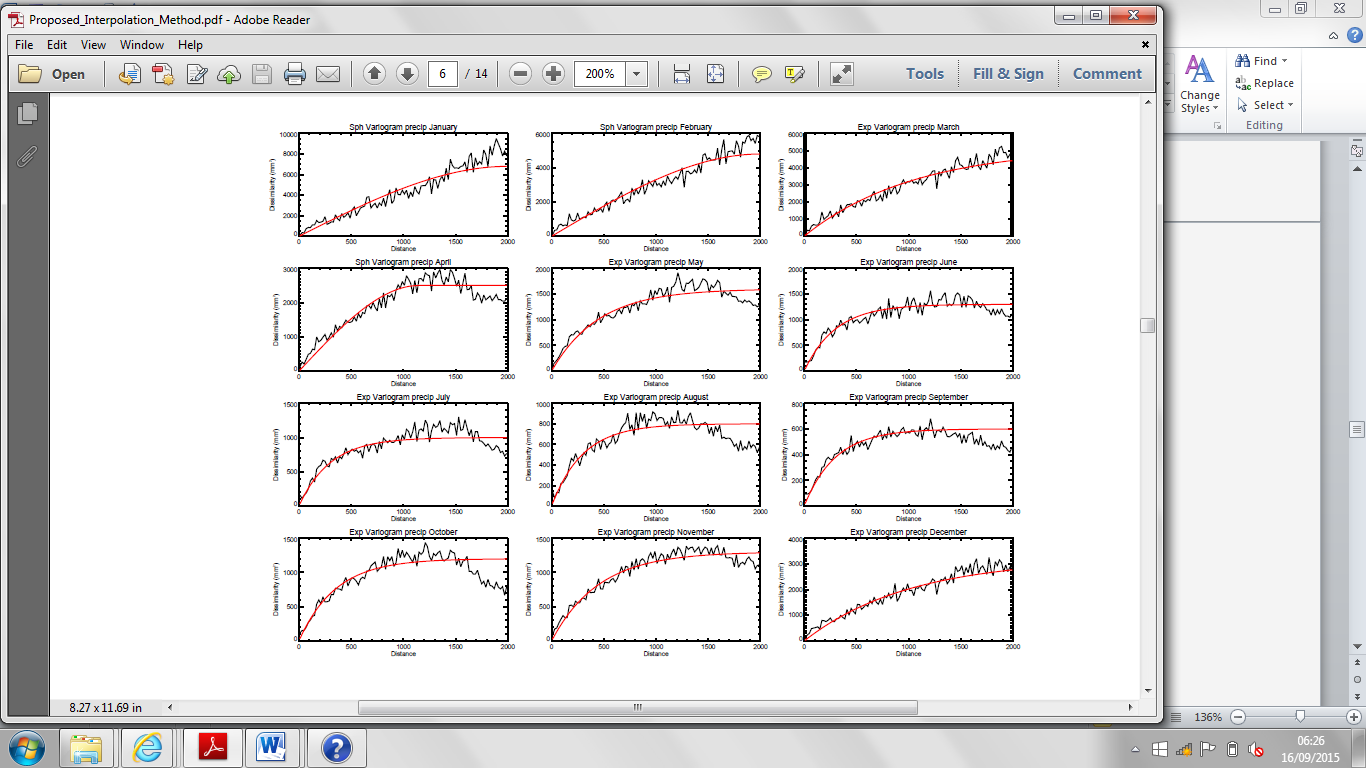


Figure *: Schematic of variogram indicating the meaning of the range, nugget and sill.*

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

In order to perform the interpolation, a function is needed that can be used to 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. The functional variograms fitted to the data are also shown in *Figure* ***3*** as red lines. A separate variogram model has to be calculated for each index and 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 the seasons. The empirical variogram (in black) often starts to drop at large separations e.g. between April and November in the example shown below. This is normal and it is only the first part of the variogram – the rise and plateau – that we are trying to model 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 this is available. For countries with a single station or 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 happen when there are outliers in the data, or the stations are so distantly separated that the climatic conditions at each station are more or less uncorrelated. In these cases, it would also be best to use a pre-calculated variogram.



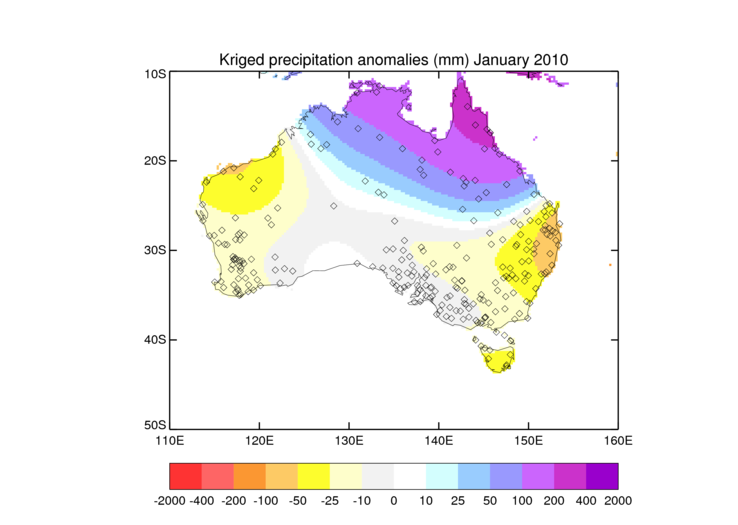
*Figure 3: Sample variograms for Australian precipitation for each month from January (top left) to December (bottom right). The black line is the empirical variogram. The red line is the functional variogram. The average difference is typically small for small separations and increases as the separation of the stations increases.*

## **3.5 Interpolating the data**

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

The interpolation method recommended in this guidance 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 we will use Ordinary Kriging to estimate the value of the index at points on a regular latitude-longitude grid, which covers the country. The resolution of the grid should be sufficiently high that the borders and coastlines of the country are reasonably well resolved.

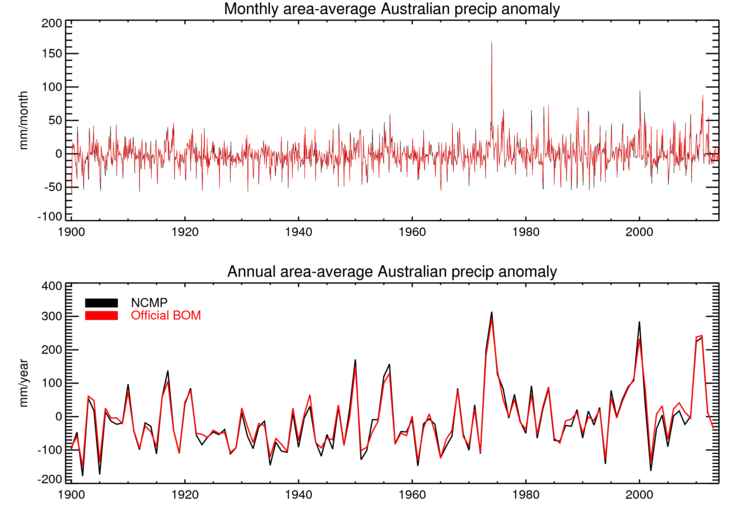
*Figure* ***4*** shows an example interpolated field of precipitation anomalies for January 2010 for Australia. The interpolated fields are generally somewhat smoother than might be expected based on the individual station records. A grid resolution of 0.1° latitude by 0.1° longitude resolution was used here. 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: Map showing station locations (black lozenges) and the interpolated precipitation anomalies (mm) for January 2010 for Australia.*

## **3.6 Averaging the index**

The final step in the calculation of the 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 of 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 NCMP2, 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 series are shown in red for comparison purposes.*

## **3.7 Countries with a single station or limited networks**

For countries with a limited network of stations, there are a number of 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[[3]](#footnote-4). 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 which are non-contiguous or which have overseas dependencies

Some countries, such as the United States, are non-contiguous. That is, the country is not comprised of a single continuous land mass. In the case of the US, the area of the country includes Alaska, which is separated from the rest of the country 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 CONUS (the contiguous part of the country) and Alaska separately.

## **3.9 NCMP 6 temperature and precipitation records**

NCMP 6 is intended to capture some of the more 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 which recorded their highest daily Tmax during the period when compared to all previous equivalent periods.
2. The number of stations with records exceeding 30 years in length which recorded their lowest daily Tmin during the period when compared to all previous equivalent periods.
3. The number of stations with records exceeding 30 years in length which 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 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 the NCMPs**

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

# **4 Production and dissemination**

The NCMPs are designed to be compared, and to form the basis of ongoing climate monitoring activities nationally and internationally.

## 4.1 Initial Production

When the NMCPs are first calculated it will be necessary to calculate the NCMP for every month for which station data are available. Once the 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 is updated to 1991-2020, the 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 quality control 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 quality control) 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 the 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 homogenisation, or quality control are done. Homogeneity should be rechecked periodically. Finally, there might be occasional updates to this guidance or software derived from it, which would necessitate a recalculation of the NCMPs.

## **4.5 Data to be transmitted**

The precise format for each NCMP is given in the Annex. It contains the following information that is necessary for understanding the NCMPs.

* Year
* Month
* Country
* NCMP value with appropriate units
* For NCMP 6, the counts of stations exceeding daily records.
* The 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 were quality controlled.
* Base period. This will be 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 the NCMP focal point and other users of NCMPs. It might help to think of the implementation of the above method as giving a set of general purpose tools, which are used to create the NCMPs but which could be adapted for wider use.

Up-to-date sets of station indices would be one 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, but these could be saved in a consistent format, such as NetCDF, or output as images in a standard format (png, eps, pdf). The location of the stations is also of interest. In conjunction with maps of the indices, station location 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 provided to WMO ([wcdmp@wmo.int](mailto:wcdmp@wmo.int)) as an email attachment in time for inclusion in the annual WMO statement on the status of global climate. The deadline for submissions is usually late January each year. A coded message will be developed to make frequent dissemination more efficient.

# 5 References

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**Annex**

**Specifications for the calculation of National Climate Monitoring Products**

The following specifications detail the mathematical steps necessary to calculate the six National Climate Monitoring Product (NCMPs).

The specifications are split into four sections. The first is the calculation of indices for individual stations. The second concerns the use of those indices to calculate area-averages which constitute the NCMPs. The third describes the calculation of NCMP6 and the fourth section describes the output format, which should be transmitted to the WMO once the calculation is complete.

~~This specification has been implemented in a software suite (R-NCMP) which can be obtained from~~ [~~https://github.com/ET-NCMP/NCMP~~](https://github.com/ET-NCMP/NCMP) ~~. Also available from the website is an R-NCMP User Manual which provides step-by-step instructions on the installation of R, preparation of input data, quality control, computation of the indices at station level, and computation of the variograms and region-averages. It also includes the mathematical description of each NCMPs.~~

**1. Calculating the indices at station level which are needed to produce the 6 NCMPs.**

Let *Txij*and *Tnij* be the daily maximum and minimum temperature for day i and period j, *Tmij* is the daily average temperature and is the mean of *Txij* and *Tnij* when both values are available. *Prij* is the daily precipitation amount on day i and period j. Temperatures are given in °C and precipitation totals in mm.

~~Monthly totals and averages are calculated if no more than 10 days are missing in a month; annual totals or averages are calculated if no more than 36 days are missing in a year; the climatology is calculated if there is at least 9 years of data available in the 30-year period; otherwise it is missing.~~ The climatology is the mean of all monthly values of the base period. 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.

~~The base period is 1981-2010 throughout.~~

**Input data**

* ASCII text file, one file by station
* columns are Year, Month, Day, *Prij, Txij, Tnij*
* example: 1950 07 15 2.5 25.0 10.2
* missing value is -99.9
* records must follow the calendar date order

**NCMP1: mean temperature anomalies (°C)**

Calculate the following:

* monthly and annual mean temperature (*TMj*): average of *Tmij* over the month (year)
* climatology (*CTj)*: average of *TMj* over the base period
* monthly and annual mean temperature anomaly (*TMAj*): *TMj* - *Cj*

**NCMP2: percentage rainfall anomaly (%)**

Calculate the following:

* monthly and annual total precipitation (*PRj*): sum of *Prij* over the month (year)
* climatology (*CPj*): average of *PRj* over 1981-2010
* monthly and annual precipitation normalized anomalies (*PRNAj*): 100 x (*PRj* - *CPj*) / *CPj*
* monthly and annual precipitation anomalies (*PRAj*): (*PRj* - *CPj*)

**NCMP3: standardized precipitation index**

Calculate the following:

* Prepare 13 precipitation series (1 for each month and 1 for 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
* The adjusted cumulative probability 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 normal distribution with mean zero and standard deviation one.

**NCMP4: warm days**

Calculate the following:

* Calculate the calendar-day 90th percentile centered on a 5-day window for *Txij*for the base period *(Txin90)*.
* Calculate monthly and annual percentage of days when *Txij* > *Txin90 (Tx90p)*.

**NCMP5: cold nights**

Calculate the following:

* Calculate the calendar day 10th percentile centered on a 5-day window for *Tnij* for the base period *(Tnin10)*
* Calculate monthly and annual percentage of days when *Tnij* < *Tnin10 (Tn10p)*

**NCMP6: extremes of temperatures and precipitation**

Calculate the following:

* monthly and annual highest *Txij* *(TXxj)*
* monthly and annual lowest *Tnij (TNnj)*
* monthly and annual highest *Prij (RX1dayj)*
* date and value of highest *TXxj* for each month and entire period
* date and value of lowest *TNnj* for each month and entire period
* date and value of highest *RX1dayj* for each month and entire period

**Output data for index calculation**

* csv file, one file for each station and NCMP combination
* File name format: [Station name]\_[Index name].csv
* Index names are: 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 are 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 country-wide averages**

NCMPs 1 through 5 are defined as country-wide averages of various indices. This section describes the calculation of the country-wide averages from the previously calculated station indices.

Let *N* be the number of stations in the country for which we have station indices in year *y* and month *m* where 1≤*m*≤12 where *m*=1 corresponds to January, *m*=2 corresponds to February etc.

The value of the index for NCMP *k*, at station *i,* in year *y* and month *m* is *Ikiym*.

* For NCMP1, I1 is the mean temperature anomaly
* For NCMP2, I2 is the precipitation anomaly normalized in percent
* For NCMP3, I3 is the Standardised Precipitation Index
* For NCMP4, I4 is the percentage of warm days
* For NCMP5, I5 is the percentage of cold days.

The difference in the index between two stations *i* and *j* is *Δijym* and the separation between the stations is *Dij*. The separation is assumed to be constant in time. ~~The climatology period is 1981 to 2010.~~

**Input data**

The input data are those output by the station index calculation previously described.

**Calculating the variogram**

The first step is to calculate the 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

*Δijym=Ikiym – Ikjym.*

Choose a maximum separation, *Dmax*, which is the smaller of the following two distance: maximum separation between stations (max(Dij)) and 2000 km for precipitation indices and 3000 km for temperature indices.

Separate the *Δijym* into bins of width *w* based on their separations *Dij*. Typically, the bin width is set to 20 km. Bin *l* contains the *Δijym* where

*lw ≤ Dij < (l+1)w* where *(l+1)w < Dmax.*

In each bin *l*, calculate the bin average *Bl* by taking the arithmetic mean of the *(Δijym)2* in the bin:

*Bl = (Σ(Δijym)2)/nl*

where *nl* is the number of *Δijym* in bin *l*. The bin separation *Dl*is

*Dl = lw - w/2*.

Plot *Bl* versus *Dl* for all *l*. The plot shows how the difference in the index varies as a function of separation between two stations. The aim is next to find a function which approximates this relationship. This function is known as the functional variogram *Vm(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 = Σl [Bl – Vm(Dl, n, r, s)]2*

A list of typical functions that are used for *V* is provided in Appendix A. 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:

*MAE = Σl |Bl – Vm(Dl, n, r, s)*.

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

**Output data format for variogram**

* 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 are month, function, *n* ,*r*, *s*, mean-squared error
* Month should be the name of the month in double quotes or “Annual”
* The functional name should be in double quotes, e.g. “Spherical”
* Columns should be separated by a single comma.
* Values should be given to a 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 which shows the empirical variogram and the best-fitting functional variogram.

**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* which falls within the country’s borders is *Ao.*

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

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

*di = Ikiym* for *1 ≤ i ≤ N*  (where *N* is the total number of stations)

*dN+1 = 1.*

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

*Cij = Vm(Dij, n, r, s) for 1 ≤ i ≤ N*

*Ci, N+1 = 1 for 1 ≤ i ≤ N*

*CN+1, j = 1 for 1 ≤ j ≤ N*

*CN+1, N+1 = 0*

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

*Fio = Vm(Dio, n, r, s) for 1 ≤ i ≤ N*

*FN+1,o = 1*

Where *Dio* 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:

*Ikoym = dTC-1F.*

This process is repeated for each grid box.

**Output data format for interpolation onto a regular grid**

* 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 are 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 are 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 which falls within the country’s borders.
* There should be no missing data.

**Calculation of the country 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*. That is:

*NCMPkym = (Σo=1,M AoIkoym) / (Σo=1,M Ao).*

**Output data format for country averages.**

* 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 are 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 a 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.

**Input data**

The input data are those output by the station index calculation previously described.

**Counts of record stations**

For each variable *k*, which includes TXx, TNn, Pr, set the count *Ck* to zero and eligible station count *Ek* to zero.

For each station *i* and variable *k*, determine the length of record *Lik* for that station.

If the length of the record is greater than 30 years the add one to *Ek*.

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* Vikym is the highest (TXx, Precip) in the record i.e.

*Vikym >= max(Vikm)*

or lowest in the record (TNn) i.e.:

*Vikym <= min(Vikm)*

then add one to *Ck*.

**Output data format for NCMP6**

The output for NCMP6 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 are Year, Month, Ck, Ek 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 NCMP6 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 NCMPs**

The files combining the regional averages and NCMP6 should be combined into a single file along with metadata which includes the version of the guidance used to generate the NCMPs, the base period start and end dates and flags to indicate whether data were quality controlled and homogenised.

* 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 are
  + 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 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 Tmax records in the month
  + number of stations reporting Tmax during the month
  + number of stations that reported Tmin records in the month
  + number of stations reporting Tminduring the month
  + number of stations that reported precip records in the month
  + number of stations reporting precip during the month
  + Flag set to 1 if temperature data have been quality controlled or 0 otherwise
  + Flag set to 1 if temperature data have been homogenised or 0 otherwise
  + Flag set to 1 if precipitation data have been quality controlled or 0 otherwise
  + Flag set to 1 if precipitation data have been homogenised or 0 otherwise
  + Base period start which should be 1981
  + Base period end which should be 2010
  + Version of the guidance used, in this case 1.4
* 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

**Appendix A: 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)(1 – exp(-D/r)) + n*

**Spherical**

*V(D,n,r,s) = (s-n)( 3D/2r – D3/2r3) + n, for D<r*

*V(D,n,r,s) = s, for D>r*

**Gaussian**

*V(D,n,r,s) = (s-n)(1 – exp(-D2/r2a)) + n*

1. Expert Team on Climate Change and Detection Indices <http://www.wcrp-climate.org/unifying-themes/unifying-themes-observations/data-etccdi> [↑](#footnote-ref-2)
2. WMO letter of 10 November 2015, reference: OBS/WIS/DMA/NCMP [↑](#footnote-ref-3)
3. Even contries 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. [↑](#footnote-ref-4)