# CLIMATE MONITORING PRODUCTS IN GEOGRAPHIC INFORMATION SYSTEM (GIS)

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#### **A. National Climate Monitoring Products:**

Proposal National Climate Monitoring Products:

- 1. Monthly area-average mean temperature time series (max+min)/2. Anomaly to be defined relative to 1971-2000. (or WMO preferred alternative) with the actual normal temperature for 71-00 included in metadata. Units degC. (Olga Bulygina)
- 2. Monthly area-average of total precipitation anomalies expressed as percentages. Anomalies to be defined relative to 71-00 period (or WMO preferred alternative). Units none (A.Watkins)
- 3. Monthly area-average of standardised precipitation index (SPI) calculated for each station. Standardisation will be to the 71-00 period (or WMO preferred alternative). Based on proposed ETCCDI index definition. Units none (D. Arndt).
- 4. Monthly area-averaged Percent of Time Tmax > 90th Percentile of Daily Maximum Temperature 71-00 period for standardisation (or WMO preferred alternative). Based on ETCCDI definitions. Units none (P. Booneeady).
- 5. Monthly area-averaged Percent of Time Tmin < 10th Percentile of Daily Minimum Temperature 71-00 period for standardisation (or WMO preferred alternative). Based on ETCCDI definitions. Units none (P. Booneeady).
- 6. Significant climate and weather event relevant to the area or region. This product consists of zero or a number of these events coded from a predefined table: cold snaps, heat waves, snow storms, dust storms, wind storms, sea level or heavy swell events, flooding, heavy rainfall, volcanic ash. Referring to guidance from the WMO task team on the definition of extreme weather and climate events. (J. Kennedy, D. Arndt and A. Watkins with input from WMO Region VI monitoring).

The next three indicators – the SPI based index, and the percentage of warm days and percentage of cold nights indices – were chosen to be widely representative of more extreme events.

#### **B.** A Tool/Tools for National Climate Monitoring Products:

In generally, climate services are using two platforms for preparing climate monitoring products, which are Linux and MS Windows, also other kinds of platform can be used. Therefore, national climate monitoring tool/tools must be an open source and platform-independent.

The software packages for data homogeneization (RHtestsV3) and indices calculation (RClimDex) are based on a very powerful and freely available statistical package R which runs under both MicroSoft Windows and Unix/Linux. There are climate indices software which are RClimdex (runs with statistical package R), FClimDex (is a FORTRAN program) and ClimDex (An older MicroSoft Excel based indices software) and can be downloaded from webpage of ETCCDMI/CRD Climate Change Indices (http://cccma.seos.uvic.ca/ETCCDMI/software.shtml).

Data format, is used in RClimDex, are daily maximum and minimum temperature and precipitation amount ((NOTE: PRCP units = millimeters and Temperature units= degrees Celsius)). The RclimDex can calculate daily mean temperature from daily maximum and minimum temperature.

Item 3 of Proposal NCMP must be added to software. Cold spell duration indicator (CSDI) can be used for cold snaps and warm spell duration indicator (WSDI) is can be used for heat wave which are mentioned in item 6 of PNCMP.

The other issue is that RClimDex works station by station and gives separately results for every station as data and graphics. Therefore extra action is needed to collect stations results to in a sheet to prepare maps. It must be added a tool or add-on to RClimDex to collect results to one sheet. Additionally, it must be added a mapping tool to interpolate and visualisation area-average NCMP.

# C. Geographical Information System (GIS) Software for Mapping National Climate Monitoring Products:

There are many software and library for mapping esp. in Linux base. Some of these software's are familiar in climatology services. Climatology services are used this software for mapping climate monitoring product and visualising climate model outputs. Especially, programs that produced under the name of Geographic Information Systems (GIS) are more skilful to make simple climate monitoring products as well as detailed product through modelling. WMO must take an active role supplying of program and it's training to developing or least developed countries. There is large number of GIS and mapping programs

and model that leads to produce maps in many different formats. So it needs identification of the standard format for digital maps

#### C.1 Open source – free software:

Open Source – free software are generally developed by universities and released under GNU General Public License.

# R

R is the open source version of the S language for statistical computing (1). R provides a wide variety of statistical (linear and nonlinear modelling, classical statistical tests, time-series analysis, classification, clustering, . . ) and graphical techniques, and is highly extensible. To run geostatistical analysis in R, you will need to add the following R packages: gstat (gtat in R), rgdal (GDAL import of GIS layers in R), sp (operations on maps in R), foreign, spatstat (spatial statistics in R) and maptools (http://cran.r-project.org/).

### ILWIS

ILWIS (Integrated Land and Water Information System) is a stand-alone integrated GISpackage developed at the International Institute of Geoinformation Science and Earth Observations (ITC), Enschede, Netherlands. ILWIS was originally built for educational purposes and low-cost applications in developing countries.



Figure 1. ILWIS Screenshot

# SAGA

SAGA (System for Automated Geoscientific Analyses) is an open source GIS that has been developed since 2001 at the University of Gottingen, Germany, with the aim to simplify the implementation of new algorithms for spatial data analysis (Conrad, 2006). It is a full-fledged GIS with support for raster and vector data, which includes a large set of geoscientific algorithms, being especially powerful for the analysis of DEMs. With the release of version 2.0 in 2005, SAGA works under both Windows and Linux operating systems (http://www.saga-gis.org/en/index.html).



Figure 2. SAGA's GUI elements and displays.

# **GRASS GIS**

GRASS (Geographic Resources Analysis Support System) is a general-purpose Geographic Information System (GIS) for the management, processing, analysis, modelling and visualisation of many types of georeferenced data. It is Open Source software released under GNU General Public License. The main component of the development and software maintenance is built on top of highly automated web-based infrastructure sponsored by ITC-irst (Centre for Scientific and Technological Research) in Trento, Italy with numerous worldwide mirror sites. GRASS includes functions to process raster maps, including derivation of descriptive statistics for maps, histograms, but also to generate statistics for time series (http://grass.osgeo.org/intro/index.php).

## QGIS

Quantum GIS (QGIS) is a powerful and user friendly Open Source Geographic Information System (GIS) that runs on Linux, Unix, Mac OSX, Windows and Android. QGIS supports vector, raster, and database formats. QGIS is licensed under the GNU Public License. The Quantum GIS project was officially born in May of 2002 when coding began. The idea was conceived in February 2002 when Gary Sherman began looking for a GIS viewer for Linux that was fast and supported a wide range of data stores. That, coupled with an interest in coding a GIS application led to the creation of the project. In the beginning Quantum GIS was established as a project on SourceForge in June 2002. The first code was checked into CVS on SourceForge on Saturday July 6, 2002, and the first, mostly non-functioning release came on July 19, 2002. The first release supported only PostGIS layers (http://www.qgis.org/).



**Figure 3.** GRASS module v. generalize to smooth a vector map. The procedure described above can be used in other equivalent situations. If you have a raster map of precipitation data, for example, then the same method will be used to create a vector map of isohyetal (constant rainfall) lines.

## **DIVA-GIS**

DIVA-GIS is a free computer program for mapping and geographic data analysis (a geographic information system (GIS). With DIVA-GIS you can make maps of the world, or of a very small area, using, for example, state boundaries, rivers, a satellite image, and the locations of sites where an animal species was observed. We also provide free spatial data for the whole world that you can use in DIVA-GIS or other programs (<u>http://www.diva-gis.org/</u>).

DIVA-GIS is particularly useful for mapping and analyzing biodiversity data, such as the distribution of species, or other 'point-distributions'. It reads and write standard data formats such as ESRI shapefiles, so interoperability is not a problem. DIVA-GIS runs on Windows and (with minor effort) on Mac OSX.

It can used to analyze data, for example by making grid (raster) maps of the distribution of biological diversity, to find areas that have high, low, or complementary levels of diversity. And you can also map and query climate data. You can predict species distributions using the BIOCLIM or DOMAIN models.



Figure 4. DIVA-GIS's main window in Data view.

## **C.2** Commercial software:

## Idrisi

Idrisi is one of the medium-cost GIS packages but possibly with largest numbers of raster and vector operations. The price per a single licence is about US\$1250, but you can always order a 30-day evaluation version to test it. Idrisi provides statistical tools for spatial analysis of raster images, including simple regression, autocorrelation analysis, pattern analysis, trend analysis, logistical regression, and many more (http://www.clarklabs.org/).

### Isatis

Isatis11 is probably the most expensive geostatistical package (>10K e) available in the market today, but is definitively also one of the most professional packages for environmental sciences. Isatis was originally built for Unix, but there are MS Windows and Linux versions also (http://www.geovariances.com/en/isatis-ru324).

# ArcGIS

ArcGIS is a complete system for designing and managing solutions through the application of geographic knowledge. It enables you to perform deep analysis, gain a greater understanding of your data, and make more informed high-level decisions. Esri's ArcGIS is a geographic information system (GIS) for working with maps and geographic information. It is used for: creating and using maps; compiling geographic data; analyzing mapped information; sharing and discovering geographic information; using maps and geographic information in a range of applications; and managing geographic information in a database.

ArcGIS Spatial Analyst is an extension to ArcGIS for Desktop that provides powerful tools for comprehensive, raster-based spatial modeling and analysis.

ArcGIS Geostatistical Analyst is an extension to ArcGIS for Desktop that allows you to probe your data with advanced statistical tools, bridging the gap between geostatistics and GIS analysis. It enables you to model spatial phenomena, assess risk, and accurately predict values within your study area.

For climatological mapping and interpolation of data it must be included Spatial Analyst (SA) and Geostatistical Analyst (GA) extensions. License requires for an ArcInfo or Basic Single Use with Spatial Analyst and Geostatistical Analyst. Kriging, Spline and Inverse Distance Weighted (IDW) are interpolation methods of SA. IDW, Local Polynomial, Global Polynomial, Radial Basis Functions (RBS), Kriging and Cokriging are the deterministic methods available in Geostatistical Analyst. Geographically Weighted Regression (GWR) is Spatial Statistic's tool and performs a local form of linear regression used to model spatially varying relationships. The price per Basic Single Use ArcGIS for Desktop licence is about

US\$65000 with SA and GA extention but you can always order a 60-day free trial version to test it.

#### **D.** Basic Mapping with GIS for National Climate Monitoring Products:

In climate indices study, there are two results; trend value and confidence level (statistical importance). Results generally visualise with symbol or point in different colour and magnitude according to values for trend values and a colour for confidence level on an area to show spatial distribution of indices.



100 year trends in Tn10P

**Figure 5**. Linear least squares trends per century of the index for cool nights, the percentage of days when the minimum temperature was less than the 10th percentile of the 1971-2000 base period (Tn10p). Red represents increases, and blue represents decreases. Filled circles represent trends that are significant at the 5% level. The blue dots indicate widespread warming of extreme minimum temperatures (Sensoy, S., at all, 2007).



Figure 6. Number of cool nights (c) and cool days (d) prepared by ArcGIS (Sensoy, S., Demircan, M., and Alan, I., 2008)



Figure 7. Number of warm nights(c) and warm days (d) prepared by ArcGIS (Sensoy, S., Demircan, M., and Alan, I., 2008)

# **E.** Area-Average (Interpolate) Mapping with GIS for National Climate Monitoring Products:

National Climate Services (NCS) generally use to interpolation methods to prepare spatial distribution of climate parameters maps for country area. For these purpose, one of Kriging, Spline and IDW interpolation methods are used.



Figure 8. Number of warm nights for period of 1971-2004 is prepared by ArcGIS.



**Figure 9**. Turkey's temperature normal (1971-2000). Distributions of mean annual temperature values with IDW by ArcGIS (Demircan, M. and Friends, 2011).



**Figure 10**. Temperature anomalies for June 2012 is prepared by TSMS Climatology Division (<u>http://www.mgm.gov.tr/veridegerlendirme/sicaklik-analizi.aspx#sfU</u>)



**Figure 11**. Temperature departures from normal for June 2012 is prepared by TSMS Climatology Division (<u>http://www.mgm.gov.tr/veridegerlendirme/sicaklik-analizi.aspx#sfU</u>)



**Figure 12.** SPI Index map prepared by TSMS Agro-meteorology Division (http://www.mgm.gov.tr/veridegerlendirme/kuraklik-analizi.aspx#sfU)



**Figure 13**. Turkey's total precipitation normal (1970-2010) distribution prepared by TSMS Hydro-meteorology Division



**Figure 14**. Precipitation departures from normal for 2011 prepared by TSMS Hydrometeorology Division

#### F. Model Mapping with GIS for National Climate Monitoring Products:

Meteorological measurements cannot be done in every part of country both due to lack of appropriate topographical condition and high costs of measurement. In countries, with a large and mountainous geography, observation stations often cannot be covered all country. For this reason, different models can be used to detection of changes in temperatures depending on the topography and to derive temperature data. Geographical Information Systems (GIS) used to increase the resolution of the climate model output and meteorological measurements maps, particularly has been a tool since the 2000's. There are some model studies which are made by Geo-statistical and Geographical Weighted Regression (GWR) tools of GIS programs, and using temperature, height, slope and aspect data and the maps were produced. However, these models, although statistically correct, does not reflect the distribution of the temperature depending on topography as climatological perspective (Demircan, M. and Friends, 2011).



**Figure 15**. Turkey modelling temperature map is produced by ArcGIS (Demircan, M. and Friends, 2011).



**Figure 16**. Temperature values are extracted to grid point (resolution 1x1Km) from WORLDCLIM by ArcGIS (Demircan, M. and Friends, 2011).

COST Action719, The Use Of Geographic Information Systems In Climatology And Meteorology, is a very important works that doing in Europe, can lead to development of NCMP's and GIS using in NCS's.

After the introduction of GIS in the computer systems of the National Meteorological Services (NMSs), during the last 5-10 years, there has been increasing activity within this field. Initially the tool was used to establish continuous maps of climate reference values of several elements. Many of the attempts were carried out using the built-in, though very limited, possibilities for spatial interpolation (Final Report COST Action719).

Most European NMSs realised that their knowledge in using GIS in the most efficient way, also as a tool in spatial interpolation was limited, and that cooperation primarily for exchanging knowledge was needed. The result was a project within the frame of ECSN (Dobesch et al. (2001). This project concluded that the work in developing and testing different spatialisation schemes had to be proceeded as well as designing of algorithms for gridded data bases. Beside this, strong connections (or easier access to) GIS-based information tools with database applications had to be established nationally and internationally. Special emphasis has to be put on GIS based climate data quality control tools.

Spatial interpolation is not a new topic in COST actions and has been highlighted in several previous actions. Particularly within the agro-meteorological actions (COST Action79, COST Action718) interpolation of meteorological elements has been an issue. Also other European projects have addressed this topic such as VOLTAIRE, MAP, NORDKLIM (Tveito et al., 2000, 2001), ECSN (Dobesch et al., 2001), SIC'97 (Dubois, 2003) and COST Action725.

The different methods for assessing spatial distribution of meteorological and climatic elements presented in the previous chapter are used in several European countries. Some of the applications are included as a part of the operational meteorological or climatological service, others are developed for research purposes. Most of the applications, are however, developed for climatic applications, and by climatologists. It is therefore not a surprise that the applications dominating at the start of the Action were concentrating on developing national climate maps, showing e.g. 1961-90 or 1971-2000 mean monthly, seasonal or annual values of selected climate elements. The development of applying spatial interpolation methods with GIS has accelerated during the Action period, and now applications describing the spatial distribution of climate elements at daily scales and even synoptic scales are implemented in several NMSs in Europe.



#### **Gridding Temperature**

**Figure 17**. Mean annual air temperature (1961-90) final monthly prediction maps (January and July), with residual kriging of multivariate regression (using altitude and distance to sea).



Figure 18. Mean Temperature (1971-2000) for the Spanish National Atlas (5 km resolution).



Figure 19. Mean Monthly temperature maps for January and April.



Figure 20. Mean Annual Temperature in Slovenia (Period: 1971-2000).

# Gridding precipitation



Figure 21. Annual Precipitation (1971-2000): Spanish National Atlas (5 km resolution)



Figure 22. The procedure for deriving precipitation grids in Norway.



**Figure 23**. The spatial distribution of the 55 pluviographs (2) and 166 classical precipitation stations (in Slovenia) with daily observations (1), 30 of them are collocated.

#### **Climate indices**

One of the frequent applications of climate data is to derive climate indices for different environmental and societal applications. Gridded climate datasets offer a unique possibility to provide such information as spatially continuous fields based on the gridded datasets themselves, or in combination with other types of data.

#### Climatological season and degree-days

The length of a climatological season or the degree-day sum for a defined temperature interval, are often used as climate indicators for various applications/purposes.



**Figure 17**. Winter spatial distributions of monthly mean precipitation fields (mm) of: (a) Observed data; (b) HIPOCAS; (c) NCEP and (d) ERA.



**Figure 17**. Number of growing degree days (days with daily mean temperatures  $> 5^{\circ}$ C) in the Nordic Countries (Tveito et al, 2001).



Figure 17. Number of frosty days (1995) (Lhotellier R., 2005, data from Météo-France and IGN)

Source:

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