Research Study

Development of a Monthly Archive of Climate Surfaces for the Occupied Palestinian Territory

(2000-2010)

Prepared by

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December 2012

The Applied Research Institute - Jerusalem (ARIJ) / Society
Towards A Sustainable Palestine

ABSTRACT

This research reports on the methods and results of modeling 11 years of mean maximum, mean and mean minimum air temperature in Celsius degree (°C) and of total precipitation in millimeter (mm) for the occupied Palestinian territory (oPt) for the period 2000 to 2010, using the ANUSPLIN interpolation process.

The main purpose of this research is to generate 528 raster grid files (11 years * 12 months * 4 variables), with 250 meter resolution from January 2000 to December 2012. The monthly grid files were interpolated within a working window which extends over the Occupied Palestinian Territory and Israel in order to include as many meteorological stations as possible.

The monthly climate archive can be used to provide the different Palestinian users with narrative and cartographic description for the climate in the occupied Palestinian territory during the study period (2000-2010), which helps to monitor and control further environment degradation and carry out many different researches like: climate change, land degradation and desertification, environment decision making and conservation of the Palestinian natural resources, etc. Also, it is necessary to mention that the climate archive was successfully used as main input data to Monitor the Land Condition in the oPt during the period (2000-2010) using the r2dRUE package.

This research has been carried out at the Department of Desertification and Geo-ecology. Estación Experimental de Zonas Áridas (EEZA), Consejo Superior de Investigaciones Científicas (CSIC) in Almería, Spain, under the supervision of Dr. Gabriel del Barrio Escribano between October 2011 and September 2012.

Keywords: Interpolation, ANUSPLIN, SPLINA, LAPGRD, OPT, r2dRUE, Signal, RTMSE.

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TABLE OF CONTENT

1. INTRODUCTION

Climate is the condition of the atmosphere at a particular location or region over a long period of time. It is the long-term summation of atmospheric elements such as solar radiation, temperature, humidity, precipitation type (frequency and amount), atmospheric pressure, and wind (speed and direction) and their variations (Tumeh, Salhab, 2009). Precipitation and temperature determine the potential distribution of terrestrial vegetation and constitute the principal factors in the genies and evolution of soil. Precipitation also influences vegetation production, which in turn controls the spatial and temporal occurrence of grazing and favors nomadic lifestyle. Vegetation cover becomes progressively thinner and less continuous with decreasing annual rainfall. Dryland plants and animals display variety of physical, anatomical and behavioral adaptations to moisture and temperature stress brought about by large diurnal and seasonal variations in temperature, rainfall and soil moisture. The generally high temperatures and low precipitation in the drylands lead to poor organic matter production and rapid oxidation. Low organic matter leads to poor aggregation and low aggregate stability leading to a high potential for wind and water erosion. (Qumsieh, Owewi, 1996).

With the signing of The Oslo II[1] Agreements between Palestine and Israel, and the beginning of implementation of these agreements, the Palestinian National Authority (PNA) started the formidable task of reconstruction and development of the Palestinian Territory. An essential prerequisite, for sound management of natural resources to ensure sustainable development, is the availability of reliable environmental information (WMO, 2005). Remote Sensing (RS) is the technique of deriving information about objects on the surface of the earth without physically coming into contact with them (Bastiaanssen, Molden, 2000). The remote sensing is considered as the main technique of establishing the climate archive for the Occupied Palestinian Territory (2000-2010) by providing an integrated environmental database from different sources.

The climate archive has been fully prepared in this research, the climate records were collected from different resources throughout the study area, and then the monthly records were interpolated and validated using ANUSPLIN in order to get the final results of the monthly grid files. The climate archive provides environmental information that can be used to describe the status of the environment in the Occupied Palestinian Territory (OPT), and can be used to create an environmental profile for the West Bank and Gaza Strip regions or for each district separately. Also, it can be used in several researches.

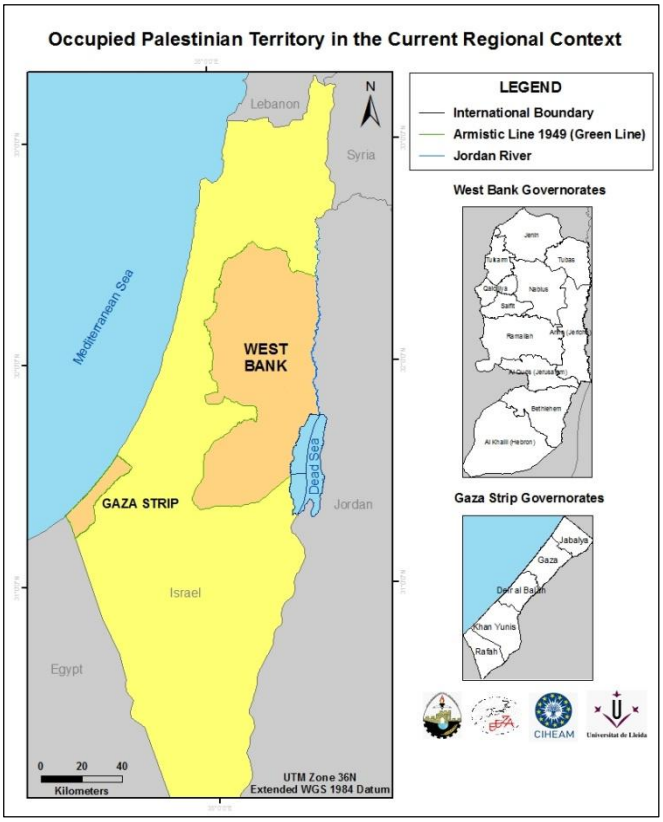
[1] Oslo II: the second phase of the process that had begun with the establishment of the Palestinian Authority in Gaza and Jericho in May 1994, it was signed in Washington DC on September 1995 by the Israeli prime minister Yitzhak Rabin and the president of the Palestinian National Authority Yasser Arafat.

2. DATA

2.1 Study area and period

Study area

The Occupied Palestinian Territory (OPT), with a total area of 6,023 km^2, is located in South-West Asia in the heart of the Middle East (map 1). It consists of two physically separated land masses: the West Bank and the Gaza Strip with a total area of 5,661 km^2 and 362 km^2 respectively (Isaac, Khair, 2011). The West Bank is surrounded by Israel on the west, north, south and the Jordan River on the east.. The Gaza Strip is a coastal zone at the eastern extreme of the Mediterranean Sea on the edge of Sinai Desert; it is surrounded by Israel to the east and north, Egypt to the South and the Mediterranean Sea to the west (Isaac, Salem, 2007).



Source: own elaboration based on data obtained from: (ARIJ - GIS unit, 2008, GIS & RS Department, *Gs Borders*, 2011, GIS & RS Department, *Ga Districts*, 2011, GIS & RS Department, *Opt Border*, 2011, GIS & RS Department, *Wb Borders*, 2011, GIS & RS Department, *Wb Districts*, 2011, NACIS, 2012)

Period

The study period was set between January 2000 through December 2010, to maximize the continuity of the monthly climate records for temperature and precipitation, that containing full hydrological years which encompass the whole annual pulses that include the seasons of maximum soil moisture recharge and of maximum evapotranspiration; hence the period is made of ten hydrological years starting 2000/2001.The temporal resolution over the study period was 1 month.

2.2 Reference system and working window

The maps sets have been managed using the Universal Transverse Mercator (UTM) geographic coordinate system, Zone 36 N and the World Geodetic System (WGS 1984 datum). The working window includes two different administrative entities: the OPT and Israel. The working window extends from Min X 597374.25, Max X 778124.25, Min Y 3325506 and Max Y 3687506 m.

2.3 Climate Records

In the development of the climate archive for the Occupied Palestinian Territory (OPT), two elements were studied the temperature (°C) and the total precipitation (mm).The climate archive consists of monthly records for (NWS, 2008):

- Mean Maximum Temperature (Tmax): the mean highest daily temperature recorded during the month.
- Mean Minimum Temperature (Tmin): the mean lowest daily temperature recorded during the month.
- Mean Temperature (Tmed): the average between the maximum and minimum temperature during the month.
- Total Precipitation (P): the total monthly water falling from the atmosphere.

2.3.1 Data Source

In order to complete the climate archive, the monthly records were derived from many different sources. 86 meteorological stations were used, 75 of them located in the Occupied Palestinian Territory (OPT) and 11 located in Israel, as they follow:

➢ **Data for the Occupied Palestinian Territory (OPT)**

- Yearly climate bulletins, for years 2007 (MAP, 2008), 2008 (MAP, 2009), 2009 (MAP, 2010), downloaded from the website of the Palestinian Meteorological Office (http://www.pmd.ps/) (accessed October 2011) (PMA, 2012).
- Weather Publications for years 2004 (Abduh, Abd Al-Rahman, 2005), 2005 (Hassiba, Abduh, 2006), 2007 (Tumeh, Abduh, 2008) and 2008 (Tumeh, Salhab, 2009), downloaded from the website of the Palestinian Central Bureau of Statistics (PCBS), (http://www.pcbs.gov.ps/) (accessed October 2011) (PCBS, 2012).
- Rainfall report 2010 (Alwahidy, 2010) downloaded from the website of the Palestinian Ministry of Agriculture (MOA) (http://www.moa.gov.ps/) (accessed October 2011) (MOA, 2000).
- Rainfall seasonal reports 2007/2008 (Al Aghbar and Al Arawi, 2008), and 2010/2011 (Abu Alhaija, Ganma, 2011), published by the General Director of Soil and Irrigation in the Palestinian Ministry of Agriculture.
- The Climate archive database for years (2000-2008) derived from the Water and Environment Research Unit (WERU), from the Applied Research Institute Jerusalem (ARIJ) (WERU, 2011).

➢ Data for Israel

- Monthly bulletin statistics derived from the website of Israel Central Bureau of Statistics (http://www.cbs.gov.il/) (accessed October 2011) (CBS, 2011).

The monthly records, the names and coordinates of each meteorological station (longitude and latitude in decimal degrees and altitude in meter) if available, were converted to an excel file. Figures 1 and 2 show the number of stations used in each year for the precipitation and temperature datasets:

Fig 1. Number of stations in the precipitation dataset

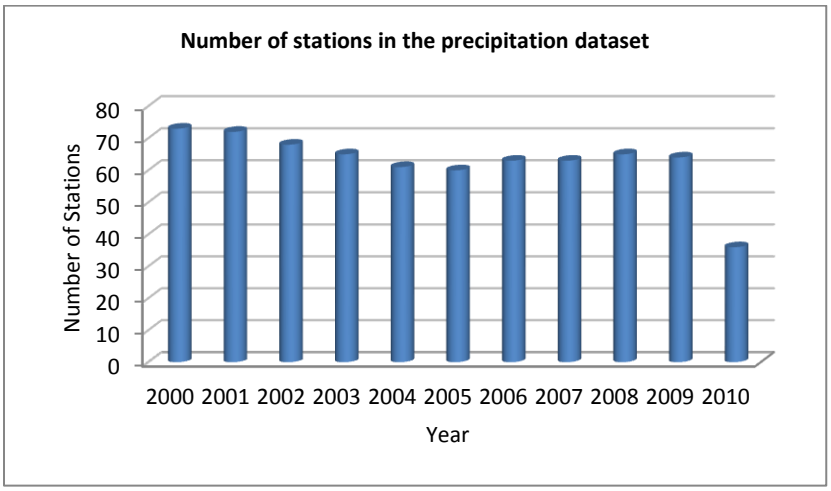
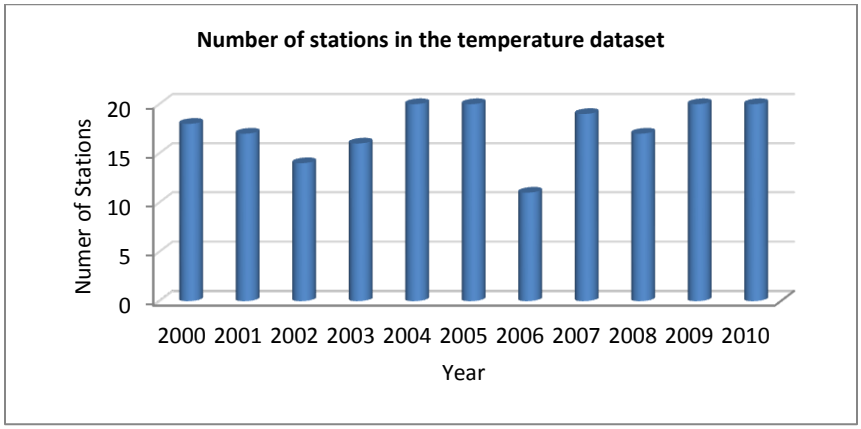


Fig 2. Number of stations in the temperature dataset



The number of stations used in the precipitation dataset ranges from 36 to 73 (822 km^2 per station) while in the temperature dataset ranges from 11 to 20 (3071 km^2 per station). The number of stations varies for two reasons: some of 2010 records were not published, there was a lack of daily, monthly and yearly records for many

meteorological stations, due to the political situation during the second intifada[2] period, when according to (Tumeh, Abduh, 2008) many stations did not take records.

2.3.2 Interpolation of the Climate records

There is a variety of approaches for conducting the interpolations. Some of them have been specialized in the interpolation of climate variables, and not all of these approaches have the same ability to take into account the main factors explaining the weather, or can effectively be used to produce maps based on data from irregular and low density sets of meteorological stations (Ruiz and del Barrio, 2005). The accepted technique to interpolate noisy multivariate data, such as climatic variables, is using the thin-plate smoothing as the one implemented in the ANUSPLIN package (del Barrio, Puigdefabregas, 2010). ANUSPLIN is a software package for the interpolation suite of FORTRAN[3] language. It provides comprehensive statistical analysis, data diagnostic and spatially distributed standard errors. Also, it supports flexible data input and interrogation procedures across an unlimited number of climate station locations (Hutchinson, 2001). This software has been developed and tested over several years and is now widely used, it has been applied in numerous regions including: Australia, New Zealand, Europe, South America, Africa, China and parts of southwest Asia (Price, McKenney, 2000).

The main advantages of ANUSPLIN are: ANUSPLIN enables better prediction in regions that have sparser station coverage and shorter records at high elevation sites, because it calibrate a spatially varying dependence on elevation that uses all available data points. This makes it an acceptable technique for the Occupied Palestinian Territory, which is characterized by a large degree of variation in topography (hilly nature). Also, ANUSPLIN has developed a square root transformation to reduce skewness in precipitation data which leads to more stable behavior in regions of low rainfall, such as the OPT. Finally, ANUSPLIN produces better results near the coast, where additional stations beyond the coastal boundary are not available. It produces a better result for the point near the edge of a region, where there are fewer climate stations close to that point, and the climate stations do not surround that point (Price, McKenney, 2000); this makes it suitable for the study area which located to the east of the Mediterranean Sea. Also this makes it suitable for the large working window.

Restrictions

The ANUSPLIN package computes monthly summaries for the corresponding years for only meteorological stations that have reference system (longitude, latitude and altitude), so some restrictions were applied to the construction of the climate archive:

[2] The second intifada start when Sharon the leader of the Israeli opposition went on an intentionally provocative visit to the Al Aqsa Mosque and the dome of the rock in Jerusalem, on 28 September 2000.
[3] FORTAN: is a general-purpose, procedural, imperative programming language that is especially suited to numeric computation and scientific computing, developed by IBM.

1. Any meteorological station without a coordinate system for which it was impossible to get the coordinate system from the different sources or throw using Google Earth, was not accepted.
2. Any year showings incomplete monthly or inaccurate record was not accepted.

Gaps in the records field were not filled using the statistical techniques; as a result 74 meteorological stations were used in the interpolation process. Figures 3 and 4 show the number of stations used in the interpolation process by year:

Fig 3. Number of stations in the precipitation dataset used in the interpolation

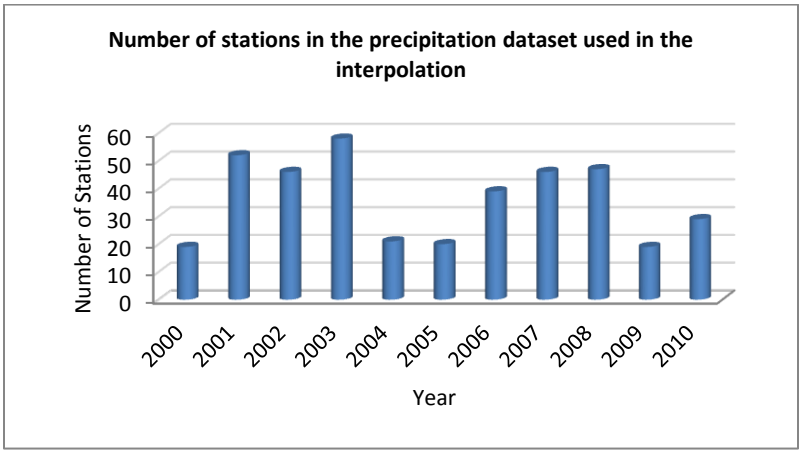
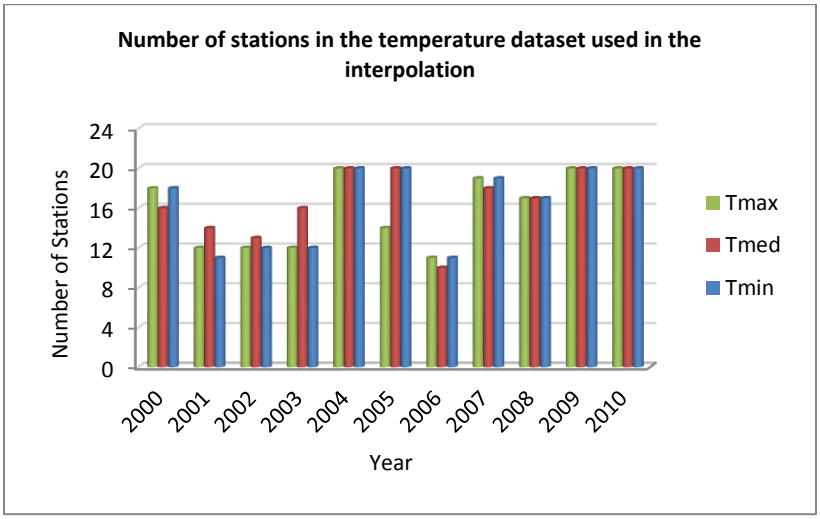
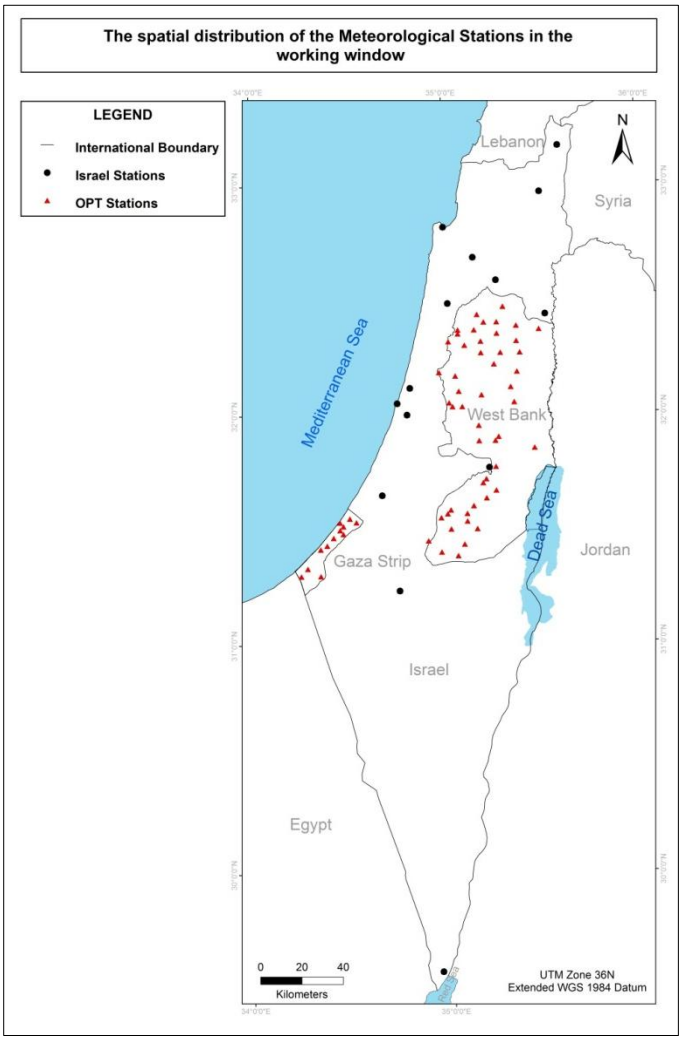


Fig 4. Number stations in the temperature dataset used in the interpolation



For the total precipitation dataset the number of meteorological stations ranges from 19 to 58 (1432 km^2 per station), while the temperature dataset numbers ranges from 11 to 20 (3222 km^2 per station) (see map 2).

Map 2: The spatial distribution of the Meteorological Stations in the working window



Source: own elaboration based on data obtained from: (NACIS, 2012),(GIS & RS Department, *Gs Borders*, 2011, GIS & RS Department, *Opt Border*, 2011, GIS & RS Department, *Wb Borders*, 2011)

ANUSPLIN Methods

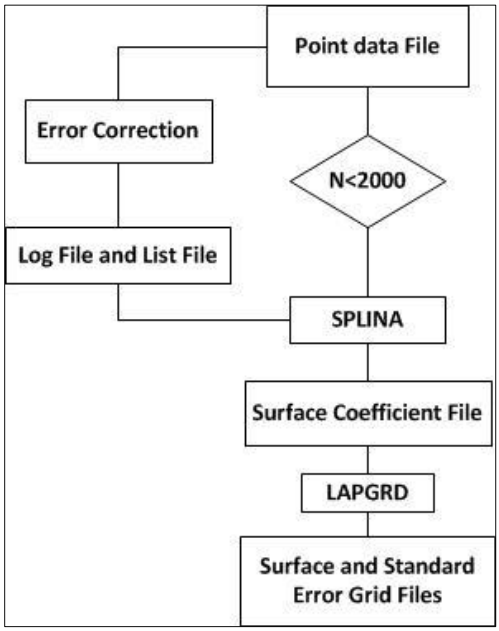
The ANUSPLIN package consists of nine different programs. Two programs were used in the interpolation of climate records in the study area, the SPLINA and the LAPGRD (Hutchinson, 2001):

1. SPLINA: this program fits an arbitrary number of partial thin plates smoothing spline functions of one or more independent variables. It is suitable for data sets with up to about 2000 points. Although, data sets can have

arbitrarily many points, this program provides up to six output files which provide statistical analyses that support data errors.

2. LAPGRD: this program calculates values and Bayesian standard error estimates of the partial thin plate smoothing spline surface on a regular rectangular grid, the Digital Elevation Module (DEM)[4] is required here as surface coefficient.

Fig 5. Main data flows through the ANUSPLIN package. (Hutchinson, 2001)



Point data file (N): which is a TXT file contains the names of the meteorological stations, and the independent spline variables (longitude, latitude and elevation), and the monthly records which have the same uniform weight.

2.3.3 Measure the Quality of Interpolation

ANUSPLIN provides several statistics to measure the quality of the interpolation. Two in particular are useful in judging the fit of the splines: the signal and the square root of the Mean Square Error (RTMSE) (del Barrio, Puigdefabregas, 2010). These statistics were provided by the output log files for SPLINA (Hutchinson, 2001).

- **The signal** is indicative of the degree of freedom associated with the surface. The very well fitting model should not exceed about half the number of data points, and the signal

[4] The DEM used in the study is the Shuttle Radar Topographic Mission (SRTM) digital elevation data, produced by NASA in 2008, with 90 m of resolution (Jarvis, Reuter, 2008).

larger than this can indicates insufficient data or positive correlation errors (Hutchinson, 2001). The ratio of the signal to the number of data points was calculated by dividing the values of the signal for every surface (month) by the number of data points. Then the average was taken for the 12 surfaces in order to calculate the yearly average.

- **The Square Root of the Mean Square Error (RTMSE)** considered as a true estimator of the overall interpolation error, is an absolute error in the same unit as the original variable, but its ratio to the mean produces a relative error that is related to the predictive error of the interpolated surface (del Barrio, Puigdefabregas, 2010). A box blot (Whisker Diagram) was done for each climate variable. This diagram displays the range (maximum to minimum) of the data, the first (25%) and the third (75%) quartiles are about the median. It gives a good overview of the data distribution and helps find skews in data.

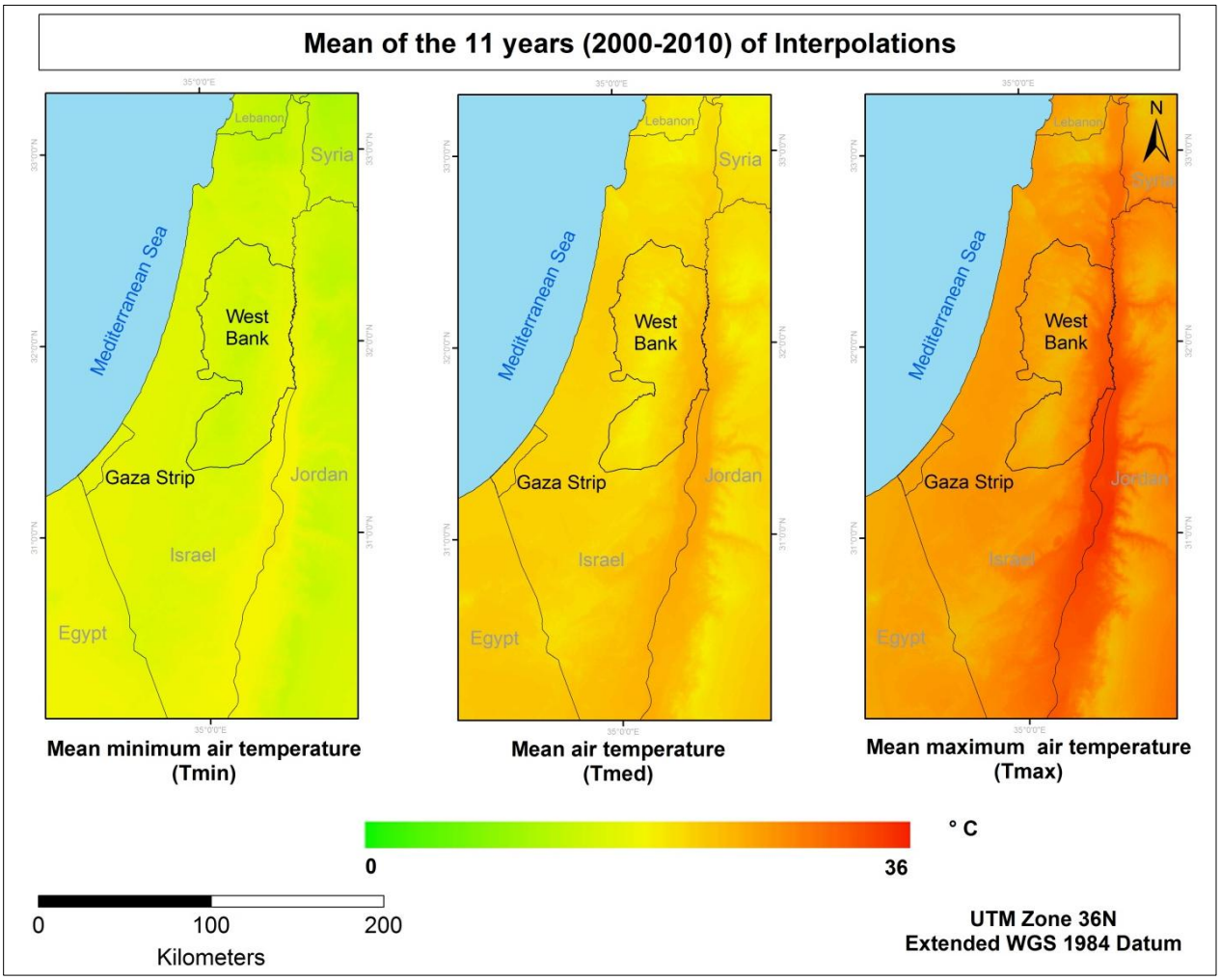
3. RESULTS

3.1 Climate Monthly Archive

3.1.1 Grid Files

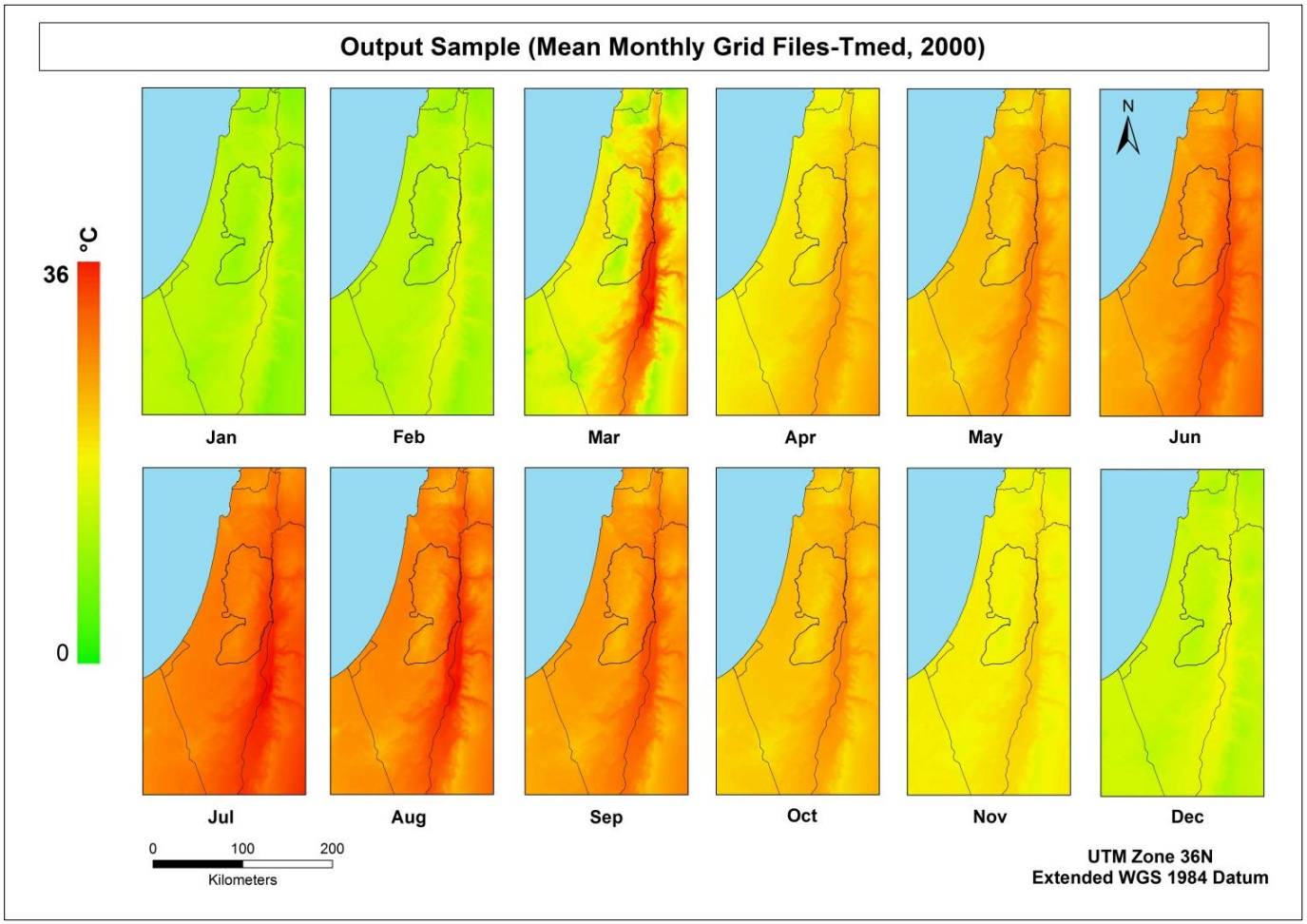
The interpolation process by ANUSPLIN has generated 528 grid files, 132 grid files for each climate variable (Tmax, Tmed, Tmin and total precipitation)(see maps 3, 4 and 5).

Map 3: Mean of the 11 years (2000-2010) of Interpolations



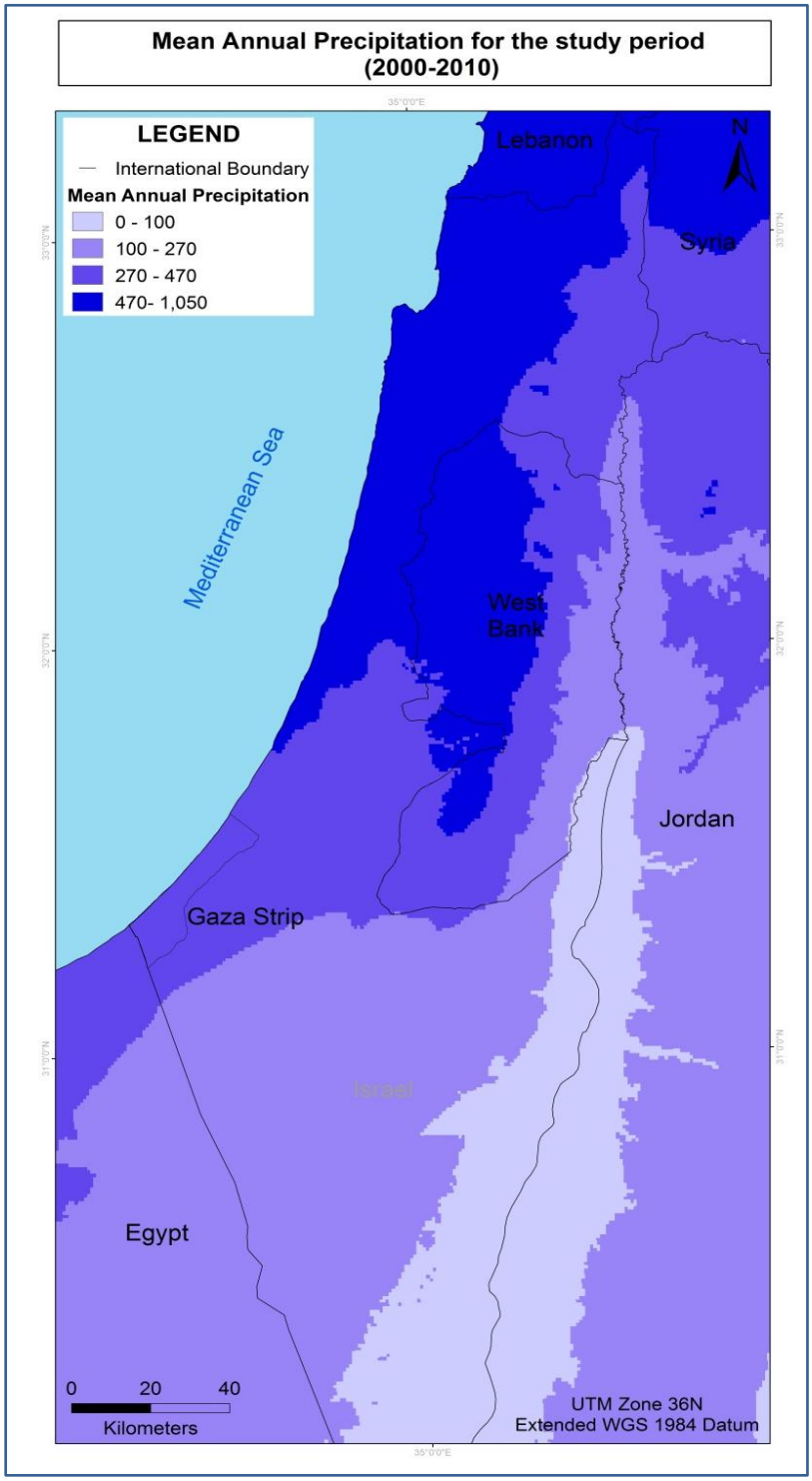
Source: own elaboration based on data obtained from: (GIS & RS Department, *Gs Borders*, 2011, GIS & RS Department, *Opt Border*, 2011, GIS & RS Department, *Wb Borders*, 2011).

Map 4: Output Sample (2000 Tmed Monthly Grid Files)



Source: own elaboration based on data obtained from: (GIS & RS Department, *Gs Borders*, 2011, GIS & RS Department, *Opt Border*, 2011, GIS & RS Department, *Wb Borders*, 2011)

Map 5: Mean annual precipitation for the period (2000-2010)

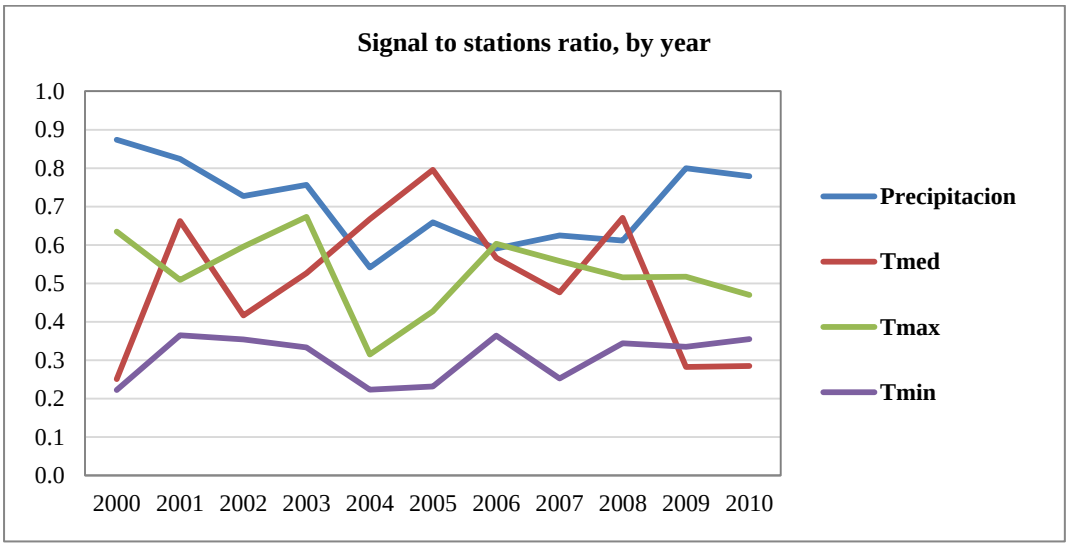


Source: own elaboration based on data obtained from: (GIS & RS Department, *Gs Borders*, 2011, GIS & RS Department, *Opt Border*, 2011, GIS & RS Department, *Wb Borders*, 2011)

3.1.2 Quality of the Interpolation

1. **The Signal:** the mean in the ratio of the signal to the number of data points by years, for the (Tmed, Tmax. Tmin and the total precipitation), did range from 0.22 through 0.87 (figure 6).

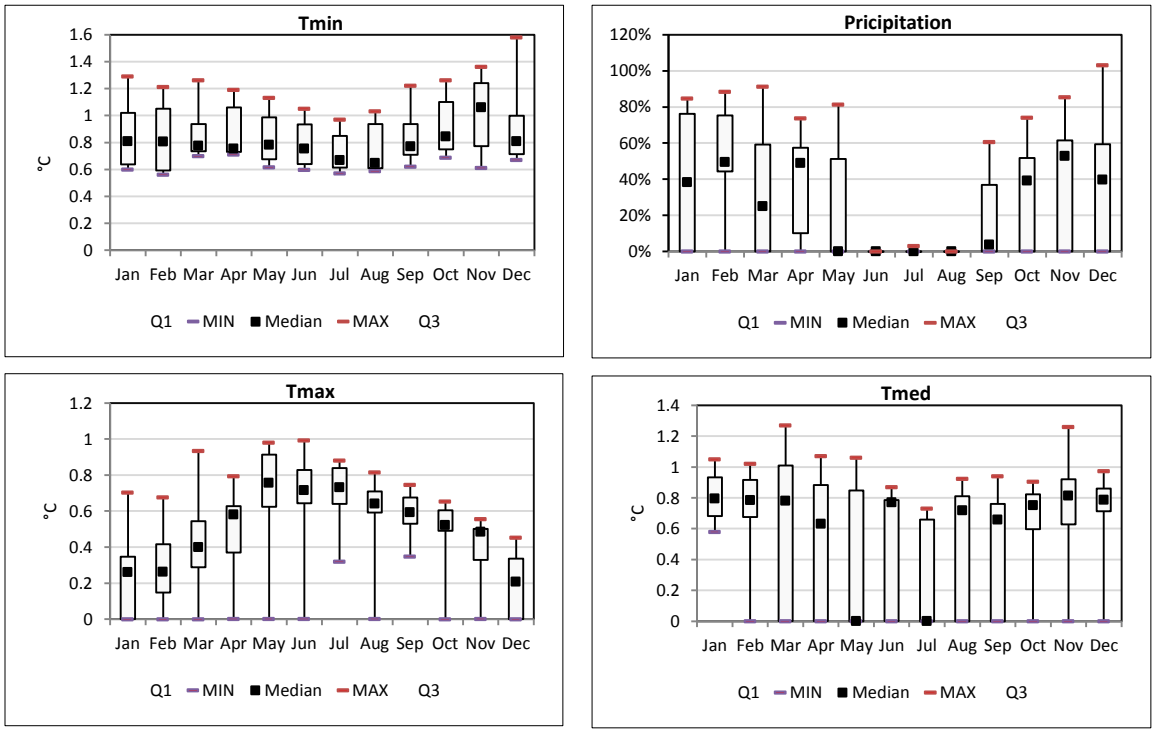
Fig 6. Signal to station ratio by year



The range for the total precipitation was from 0.54-0.87, mean air temperature (Tmed) was from 0.25-0.80, mean maximum air temperature (Tmax) was 0.31-0.67 and the mean minimum air temperature (Tmin) was 0.22-0.36.

2. **The Square Root of the Mean Square Error (RTMSE)** was lower than 1.6 °C for the temperature dataset, the highest error found in Tmin 1.6 °C in December, while for Tmed 1.3°C in March and Tmax 1°C in May and June. The average median of the error was 0.5 for Tmax, 0.6 for Tmed and 0.8 for Tmin). For the total precipitation the RTMSE was calculated in percentages. The highest error was 103% in December, and the average median was 25 %. While in June, July and August the results were 0, because the total precipitation in theses summer months was 0 (figure 7).

Fig 7: Boxplot (Whisker Diagram) for the Climate Variables



Note: Q1: quartile1 25%, Q3: quartile 3 75%.

4. DISCUSSION

In the Development of the Climate Monthly Archive, the ANUSPLIN is considered as an accurate process in the predicting of the climate variables at the locations of the meteorological stations withheld at random from the source dataset. It is also suitable for the study area where the climate station coverage is poor, notably at higher elevation sites, because the OPT is an area with non-uniform gradients. The two statistics provide by the ANUSPLIN to measure the quality of the interpolation were good parameters. The Signal (figure 6) for the mean (Tmed) and mean maximum (Tmax) air temperature shows that 55% of the signals values exceed the half number of data points which indicate insufficient data, poor density

and a pare distribution of the meteorological stations in some years, which resulted in losing some details for the interpolated surfaces (months). On the contrary for the mean minimum air temperature (Tmin) the data were sufficient. For the total precipitation the signal exceed the half number of data points during the study period as a result of the different sources of data, inaccurate records in some years, also the inaccurate information about the geographical location of some meteorological stations. According to (del Barrio, Puigdefabregas, 2010) this result is not necessarily bad in terms of broad spatial patterns, but it does indicate that absolute predictions should be used with caution for fine microclimatic patterns.

The Square Root of the Mean Square Error (RTMSE) (figure 7), ranges from 0.5 to 1.6 C° for the temperature surfaces. According to (del Barrio, Puigdefabregas, 2010) RTMSE less than 1.5 C° for the temperature is considered as to be comparable. In the precipitation dataset the RTMSE ranges from 0 % to 103%, the lowest value was for the summer months while the highest value was in the winter months especially December.

5. CONCLUSIONES

The climate archive of the Occupied Palestinian Territory (2000-2010), is considered to be an important tool in the conservation of the natural resources and land management, it provides the different users with monthly grid files that are important in a number of respects: they help us to plan for ongoing events such as land degradation and desertification; they help us to understand the causes of global warming and how to counter them in order to help us in managing our natural resources. The climate archive is available upon request. It can be shared; updated and new information can be added.

6. ACKNOWLEDGEMENT

The author would like to thank the research supervisor Dr. Gabriel del Barrio Escribano, and the Desertification and Geo-Ecology department in the Estación Experimental de Zonas Áridas (EEZA), Almeria, Spain, especially Alberto Ruiz Moreno and Marieta Sanjuan Martinez for their support and contribution in making this research possible. Also the author would like to acknowledge the academic and technical support of the Applied Research Institute Jerusalem (ARIJ) and its staff that provided the research with the necessary vector files and data.

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