Article

Agroclimatic information system for Mexico-Central America

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Abstract

An information system was obtained consisting of monthly, seasonal and annual raster images, corresponding to climatic and agroclimatic parameters for the Mexico-Central America region. This achievement involved the creation of daily and monthly climatic data bases for the period 1961-2010, review of information to eliminate aberrant data and estimate lost data; geographic interpolation using the Anusplin method to generate monthly raster images of basic climatic variables (maximum temperature, minimum temperature, precipitation), map algebra and spatial analysis to generate agroclimatic parameters derived from the basic climatic variables; use of climate information from a network of automated agrometeorological stations to estimate parameters adjusted to the reference method; estimation of agroclimatic parameters through indirect methods and use of information derived from data assimilation models for the generation of complementary agroclimatic parameters. The results showed the obtaining of an information system composed of raster images that represent the average value for the 1961-2010 period of 144 monthly variables (maximum temperature Tx, minimum temperature Ti, average temperature Tm, thermal range RT, thermal sum ST, cumulative development day degrees GDD, photoperiod F, precipitation P, potential evapotranspiration ETP, humidity index IH, solar radiation Rs and relative humidity RH); 41 seasonal variables corresponding to the growing season (previous variables plus duration of growing season DEC, and number of wet months MH= P≥ ETP); 13 annual variables (same monthly variables plus number of wet months) and the variable altitude. The raster images are referenced in the WGS system, can be used in any geographic information system (SIG) and have a resolution of 30” arc. The system is potentially useful to characterize the variation of agroclimatic conditions in Mexico and Central America.

Keywords: Central America, seasonal and annual, growing season, raster images, Mexico, monthly agroclimatic parameters.

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Introduction

The spatio-temporal variation of the climate implies the need to have databases and information systems that allow to properly characterize this variation in quantitative terms. The availability of information systems is relatively limited when a certain level of information specialization is required and when the study regions are of considerable territorial extension.

Currently, the available national and international information systems refer basically to basic climatic variables (Medina and Ruiz, 2004, Hijmans *et al*., 2005, Díaz *et al*., 2008, SMN, 2017), this is maximum temperature, minimum temperature and rainfall, which in a geographic information system (SIG) can be transformed into other climatic or agroclimatic parameters. Even so, there are agroclimatic parameters that are hardly available through these information systems, such as potential evapotranspiration, humidity index, growing season, relative humidity and solar radiation.

For this reason, the motivation of this research was to generate an agroclimatic information system to be used in the SIG environment and corresponding to two regions that traditionally lack this type of information: Mexico and Central America.

The generation of an agroclimatic information system requires sources of climate information and additional data resources that allow inferring variables that cannot be derived easily from basic climatic variables, such as relative humidity, solar radiation and wind speed. A recent alternative as a source of information for these parameters are global models and data assimilation systems (Rodell *et al*., 2004; Friedl *et al*., 2010; Rui and Beaudoing, 2017).

Another interesting strategy to try to recover or generate information regarding agroclimatic parameters is the use of network data from automated agrometeorological stations, which; however, in Mexico, they lack an extensive data record, so they are not viable to be used directly in the generation of normal climatic or agroclimatic values (OMM, 2011), but they do work in the generation, validation or adjustment of models parameter estimates.

The networks of automated agrometeorological stations provide data on basic climatic variables and data on agroclimatic variables, this represents the advantage of modeling agroclimatic variables based on basic climatic variables and being able to infer information to a specific area of study through the application of estimative models. In the present investigation, data from a network of automated agrometeorological stations were used to generate monthly rasters of potential evapotranspiration (ETP) by the Thornthwaite method (1948) adjusted to the Penman-Monteith method (Allen *et al*., 1998), taking advantage of that the stations of this network throw the data of ETP with this last method.

With the recovery of all the parameters mentioned above, it is possible to form more robust information systems that allow improving the analysis and agroclimatic characterization capabilities of a given region. In the present study, thematic raster images of most of these parameters were obtained, which made possible, among other achievements, the generation of the growth season layer and the characterization of climatic and agroclimatic parameters referred to this period. It is expected that the information system presented through this document will be a valuable tool to develop more detailed applications of climate information in agriculture.

Materials and methods

Climate information

We worked with daily and monthly precipitation and temperature data from 3 026 meteorological stations located in Mexico and Central America (Figure 1). For the stations of Mexico, the period 1961-2010 was considered and for the stations of Central America the 1961-2014 period was taken into account.

Regarding the variables relative humidity and solar radiation, information derived from NASA’s global model and data assimilation system was used (NASA, 2017), which comes from the GEOS-4 meteorological satellite (Goddard Earth Observing System version 4) for the period 1983-2007, and the satellite GEOS-5.2 for the period 2008-2015.

To estimate the ETP variable, daily and monthly temperature information and Penman-Monteith ETP were used, derived from the network of agrometeorological stations of INIFAP, which provided data between 2000 and 2016.

Analysis and filtering of climatological information

From the information of the meteorological stations, text files were created for each year of each of the stations and we proceeded to identify the off-type data with the help of the Excel program and a computer program developed in the C^{++} language for this purpose. The out-of-type records were removed from the database. The corrections made with this tool were derived from the following criteria: the minimum temperature must not be greater than the maximum temperature, the difference between the data of the previous and the previous temperature must not be greater than 7 °C.

When this condition occurs the program reviews the possible causes and accepts as valid, the presence of a frost, the occurrence of precipitation or the presence of a north or cold front. In the case of precipitation, all rains over 90 mm were reviewed in a 24-h period, accepting as valid those events that were repeated in at least one neighboring station. For this, the climatological records of at least three nearby stations were reviewed, trying to present the same or similar agroecological, topographic and physiographic conditions. Subsequently, the information was filtered by data quality through the R-Climdex program (Zhang and Yang, 2004). In this program, the following criteria are taken into account: the minimum temperature must not exceed the maximum temperature, which must not exceed 50 °C, and the rainfall must not exceed 500 mm in 24 h.

The estimation of lost temperature data was made with the arithmetic mean for the case of a lost day, and following the trend of the data when there were up to five dates with missing information. In the case of precipitation, it was estimated with zero value for days located outside the rainy season, when they were up to five days without data, as long as they were normal years, this is without considering years as a child and as a girl.

For periods with missing data greater than 5 days, the CLIMGEN program (Nelson, 2003) was used to estimate temperature and precipitation data. This program is based on statistics generated from daily data. Only missing data were generated respecting the real data that was available. After these processes of correction and estimation of information, the text files that were kept for years were once again joined, to be pasted in an Excel spreadsheet designed with dynamic tables and formulas, through which the normal climatic statistics were obtained each of the stations selected based on basic climatic variables.

Normal climate statistics were calculated for the period 1961-2010 in the case of meteorological stations in Mexico and for the period 1961-2014 for meteorological stations in Central America. For this, Microsoft's Excel spreadsheet was used.

Procedures

Generation of normal monthly images of basic climatic variables

Based on the integrated daily and monthly climatological database and the geographical coordinates of the meteorological stations considered, a matrix of normal climatic data (historical averages) georeferenced was generated. This climate data matrix was used as input to feed geographic interpolation processes and through the Anusplin method obtain monthly images that were recovered in raster format in the Idrisi Selva system (Eastman, 2012) corresponding to the normal values of maximum temperature, minimum temperature and precipitation for Mexico and Central America. The interpolation processes were executed considering a resolution of 30" arc.

Climatic and agroclimatic parameters derived from basic climatic variables

Based on the basic climatic variables and with the application of map algebra procedures in the Idrisi Selva system, the following additional monthly parameters were generated: average temperature, range or thermal oscillation, thermal summation, degree-day development and photoperiod. The map algebra procedures were implemented in the Idrisi Selva system calculator and consisted of the following calculations:

$$Tm = (Tx + Ti)/2$$

Where: Tm= monthly average temperature (°C); Tx= average monthly maximum temperature (°C) and Ti= average monthly minimum temperature (°C).

$$RT = Tx - Ti$$

Where: RT= monthly range or thermal oscillation (°C).

$$ST = \sum_{i=1}^{n} Tm$$

Where: ST= monthly thermal sum (°C); n= number of days of the month in question.

GDD= (Tm - Tb)n

Where: GDD= degrees-day of development accumulated in the month; Tb= 10 °C (minimum threshold temperature or base temperature of various cultivated species).

F= 2h/15

Where: F= photoperiod (hours); h= hour angle of sunrise or sunset; h=ArcCos (-tan ϕ tan δ); ϕ= latitude in degrees; δ= solar declination in degrees; $\delta = 23.45\text{sen} = [360\left(\frac{284+\text{Dj}}{365}\right)]$; Dj = Julian day. For this study, the Julian day corresponding to the 15th day of the month in question was taken.

Since the calculation of F involved having a latitude image of the study area, it was obtained by interpolation with the weighted inverse distance method, using a georeferenced matrix of latitude values for each degree. The interpolation was done in the Idrisi Selva system.

Potential evapotranspiration, humidity index and growing season

From the daily and monthly temperature data of the INIFAP network of agrometeorological stations, the ETP was calculated on a daily and monthly basis by the Thornthwaite method (Thornthwaite, 1948, Thornthwaite and Mather, 1955, Feddema, 2005), Thornthwaite ETP monthly values (ETPTH) were compared with monthly values of Penman-Monteith ETP (ETPPM) and regional adjustment factors were obtained month by month to obtain ETPTH values adjusted to ETPPM. The regional adjustment factors were calculated considering an agroclimatic regionalization of Mexico-Central America made in this same study considering the aridity zones proposed by UNEP (UNEP, 1992a) and the thermal zones scheme used by García in adapting the climate classification system Köppen to the Mexican Republic (García, 2004).

The adjustment factors were obtained first by obtaining the differences ETPPM - ETPTH in each of the months and in each of the agrometeorological stations, then calculating the value of the median of these differences, but considering only the agrometeorological stations that belonged to the same agroclimatic region. Finally, the adjustment factors were used to update the ETPTH images and thus obtain the monthly rasters adjusted to ETPPM.

With the monthly values of precipitation and ETPPM adjusted, the humidity index (IH) was calculated:

IH = P/ETPPM adjusted

Where: IH= monthly moisture index (dimensionless) and represents the percentage of satisfaction of the water demand of the month in question; P= average monthly accumulated precipitation of the month in question (mm).

Obtained the 12 monthly images of IH for the study area, we proceeded to generate a matrix of georeferenced data of monthly IH by extracting IH values from the monthly images with the ArcGis system (ESRI, 2006) and for a 4.5’ arc grid. This matrix was worked in Excel to calculate the start date (IEC) and end date (FEC) of the growing season (EC), using the method of FAO

(FAO, 1978), which considers that the EC starts when IH and ends when IH≥ 0.5, and ends when IH≤ 0.5. The dates of IEC and FEC were transformed into Julian days and the parameter duration of the growing season (DEC) was calculated by the expression:

DEC= FEC - IEC

Where: DEC= duration of the growing season (days).

Generation of normal monthly images of variables derived from assimilated data

The variables relative humidity and solar radiation were obtained from information from assimilated data. For this purpose, information derived from NASA's global model and data assimilation system was used (NASA, 2017), which comes from the meteorological satellite GEOS-4 (Goddard Earth Observing System version 4) for the period 1983-2007 and of the GEOS-5.2 satellite for the period 2008-2015. This information was downloaded from the site: http://gmao.gsfc.nasa.gov/. Since this source of information has a resolution of 1° x 1° in length and latitude, for purposes of the data download a series of coordinate points representative of the nodes formed of the crossing of a mesh of 1° x 1° longitude x latitude within Mexico-Central America was considered.

The information download was made in an automated way by means of an application programmed on the R platform. From this data download a 1984-2015-time series of daily data of solar radiation and relative humidity for each coordinate node was formed. The daily data of these variables were used to calculate normal monthly average values and a georeferenced data matrix was formed from which interpolations were made with the ordinary kriging method and the best fit spatial model, which was obtained with the program GS+; in all cases the best model was the exponential one.

Results and discussion

Basic climatic variables

The raster images of average maximum temperature, minimum average temperature and average monthly accumulated precipitation were obtained for each of the months from January to December, giving a total of 36 rasters corresponding to the basic climatic variables of Mexico-Central America. Each image is composed of two files: a file with extension. RST that corresponds to the raster and one more with extension. RDC that corresponds to the documentation of the raster.

Climatic and agroclimatic parameters derived from basic climatic variables

From the basic climatic variables and with the application of map algebra procedures in the Idrisi Selva system, the following additional monthly parameters were generated: average temperature, photoperiod, thermal oscillation, thermal summation and degree-day development, producing a total of 60 more monthly images.

Potential evapotranspiration

The generation of the map of agroclimatic regions of Mexico and Central America produced 26 regions, for which a correction factor was obtained to adjust the Thornthwaite ETP (ETPTH) to Penman-Monteith ETP (ETPPM) regionally and for the entire study area. Adjustment values by agroclimatic region month by month from January to December are described below. These values have to be applied to the values of ETPTH to bring them to monthly millimeters values of ETPPM:

Cold wet region: 22.5, 25.2, 34.8, 34.9, 28.0, 14, 13.6, 12, 7.1, 12.7, 17.9, 21.4
R. Hyperarid semiwarm: 62.1, 71.6, 95.8, 101, 94.8, 30.2, -1.4, -8.5, 71.1, 42, -2.5, 57.9
R. Hyperarid warm: 63.7, 65.6, 98.6, 112.6, 108.2, 22.5, -28.5, -40.2, -26.8, 34.2, 82.4, 55.5
R. Arid: 74.4, 84.5, 112.9, 108, 98.4, 67.2, 52.8, 58.6, 45.8, 66.2, 62.3, 66.6
R. Arid semiwarm: 60.5, 77.6, 93, 89.5, 81.3, 37.9, 25.8, 23.2, 21.8, 49.7, 59.8, 60.3
R. Semi-arid semicold: 62.2, 73.3, 94, 90.5, 75.5, 49.4, 42.1, 49, 34.8, 52.4, 54, 59.4
R. Warm arid: 67.3, 77.4, 100.8, 102.3, 88.5, -4.7, -53, -53.8, -32.5, 26.3, 55.1, 62
R. Temperate semiarid: 67.8, 80.8, 102.6, 97.6, 82, 58.8, 48.6, 56.1, 40.7, 60.2, 58.8, 64.2
R. Subhumid-dry semicold: 56.5, 65.9, 85.3, 83.4, 69, 40, 35.6, 42, 28.9, 44.7, 49.2, 54.7
R. Semiarid semiwarm: 60.2, 70.4, 88.9, 82, 65, 46.3, 44.6, 52.4, 40.7, 52.6, 57.4, 54.9
R. Warm semiarid: 52, 63.7, 77.3, 73, 56.2, -15.2, -45.2, -47.2, -36.7, 11.9, 41.8, 50.8
R. Subhumid-humid semicold: 39.2, 71.4, 86, 74.5, 60.9, 40.8, 38, 48.4, 32.8, 50.6, 55.1, 57.6
R. Sub-humid-dry temperate: 62.6, 71.4, 86, 74.5, 60.9, 40.8, 38, 48.4, 32.8, 50.6, 55.1, 57.6
R. Very warm semiarid: 16.6, 4.5, 18.4, -10.6, -66, -54.9, -24, -19.5, -18.2, -14.2, -0.8, 7.8
R. Subhumid-dry semiwarm: 48.1, 60.6, 77.9, 66.3, 53, 36.9, 33.2, 40.4, 36.1, 47.5, 59.3, 56.1
R. Humid semicold: 33.7, 37.9, 52.3, 52.3, 42, 21, 20.4, 18, 10.7, 19, 26.9, 32.1
R. Warm sub-humid-dry: 39.2, 47.2, 53, 37.2, 23, 2.5, 2.2, 0.6, 6, 11.8, 27.5, 32.8
R. Subhumid-humid temperate: 52.8, 60.4, 72.4, 69.2, 50.8, 34.2, 32.3, 33.6, 23.6, 37.7, 41.4, 46.4
R. Subhumid-humid semi-warm: 45, 46.1, 53.7, 54.1, 41.5, 22.7, 17.4, 12.7, 15, 31.5, 35.9, 38.2
R. Subhumid- dry very warm: 15.2, 27.2, 43.9, 35.4, -5.8, -44.1, -52, -46, -43, -39.5, -10.6, -0.4
R. Humid tempered: 43, 45.6, 69.6, 61.8, 53.4, 29.5, 29.2, 16.8, 5.9, 15.3, 32.6, 39.8
R. Subhumid-humid warm: 29.6, 36.4, 39.5, 18.8, -5.9, -23.1, -20.9, -17.1, -15.4, 4.5, 23.9, 27.3
R. Humid semi-warm: 14, 17, 31.7, 10.2, 3.8, -3.4, 0.4, 6.5, -3.9, 13.4, 13.6, 15.1
R. Very humid subhumid- very warm: 24.5, 26.7, 30.1, 15.1, -15.8, -23.7, -17.6, -9.6, -14.9, 2.8, 21.3, 21.9
R. Warm humid: 13.6, 18.6, 23.6, -6.9, -28, -38.6, -33.4, -28.4, -25.9, -6.8, 3.9, 6.4
R. Very hot humid: 3.7, 13.5, 15.2, -5.2, -27.1, -40.1, -31.8, -27.7, -23.8, -13.4, 4.2, 10.1.

Humidity index and growing season

Once the ETP adjusted to Penman-Monteith was obtained, it was possible to perform a simple water balance by calculating the monthly humidity index (MHI) product of the P/ETPPM quotient month by month. With the IHM values the average start and end dates of the growing season were deduced, with which the duration of the growing season (DEC) parameter was obtained. The results of this parameter showed great diversity in terms of the availability of the number of DEC days in the Mexico-Central America region, since the values obtained range from 0 to 365 days a year, that is, there are regions where there is no growth, as well as regions where it is possible to grow all year round.

The IH and DEC parameters represent an important computing resource and a comparative advantage in relation to the environmental information systems currently available for Mexico and Central America, such as the WorldClim system, which is the most widely used system on a global and regional scale, does not contain information on these parameters (Hijmans *et al*., 2005). The availability of information on these parameters through the SIAMEXCA will allow to increase the precision in the diagnosis of the humidity conditions available for agriculture (Hargreaves and Allen, 2003).

Variables derived from global models and assimilated data

The monthly images of average relative humidity and average solar radiation were obtained satisfactorily and constitute a computer resource to characterize the availability of these parameters in the study region. Regional applications related to the presence and potential distribution of crop pathogens and the characterization of environmental comfort indexes for livestock (Marami *et al*., 2015), among others, are now possible with the availability of these parameters.

The agro-climatic information system of Mexico-Central America (SIAMEXCA) provides the user with the ability to generate raster images corresponding to additional climatic and agroclimatic variables in a simple way through algebra routines of maps within a geographic information system (SIG). This is the case of variables such as night temperature and daytime temperature, important for thermoperiodic cultures (Markovskaya *et al*., 1996) or CAM photosynthetic type (Yamori *et al*., 2014). Other important agroclimatic parameters such as cold hours, cold units or photothermal units can also be estimated by these procedures.

The obtained agroclimatic information system (SIAMEXCA) can be downloaded through the following link: http://www.inifapcirpac.gob.mx/siamexca.html.

Finally it is to comment that the SIAMEXCA system is susceptible to a process of continuous improvement, which we hope the authors will execute once the opportunity to incorporate new information is presented.

Conclusions

The agroclimatic information system obtained for Mexico and Central America can be constituted as a computer tool of great help for the characterization of the climatic availabilities for the practice of agriculture in these geographical regions. The SIAMEXCA system is susceptible to a continuous improvement process.

Gratefulness

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Cited literature

Allen, R. G.; Pereira, L. S.; Raes, D. and Smith, M. 1998. Crop evapotranspiration -Guidelines for computing crop water requirements-. FAO Irrigation and Drainage Paper 56. Rome. 176-28 pp.

Díaz, P. G.; Ruiz, C. J. A.; Medina, G. G. y Serrano, A. V. 2008. Estadísticas climatológicas básicas del estado de México (período 1961-2003). INIFAP-CIRGOC-C.E. Cotaxtla-Sitio Exp. Teocelo. Xalapa, Veracruz, México. Libro técnico núm. 20. 32-37 pp.

Eastman, J. R. 2012. Idrisi manual, the selva Edition. Clark Labs, Clark University. Massachusetts, USA. 106-113 pp.

ESRI. 2006. ArcGIS 9, ArcMap Tutorial. Manual de programa. Redlands, CA, USA. 31-39 pp.

Feddema, J. J. 2005. A revised thornthwaite-type global climate classification. Physical Geography. 26(6):442-466.

FAO (Food and Agriculture Organization). 1978. Agroecological zones project. World soil resources. Africa. Geneva, Switzerland. Report num. 48(1):8-35.

Friedl, M. A.; Sulla, M. D.; Tan, B.; Schneider, A.; Ramankutty, N.; Sibley, A. and Huang, X. 2010. MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. Remote Sensing of Environment. 114(1):168-182.

García, E. 2004. Modificaciones al sistema de clasificación climática de Köppen (para adaptarlo a las condiciones de la República Mexicana). 5ta. Edición. Serie Libros número 6. Instituto de Geografía-Universidad Nacional Autónoma de México, Ciudad Universitaria, México, D. F. 50-57 pp.

Hargreaves, G. H. and Allen, R. G. 2003. History and evaluation of Hargreaves evapotranspiration equation. J. Irrig. Drain. Eng. 129(1):53-63.

Hijmans, R. J.; Cameron, S. E.; Parra, J. L.; Jones, P. G. and Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas. Inter. J. Climatol. 25(15):1965-1978.

Marami, M. M. R.; Hense, A.; Rahmani, E. and Ploeger, A. 2015. A survey of the relationship between climatic heat stress indices and fundamental milk components considering uncertainty. Climate. 3(4):876-900. doi:10.3390/cli3040876.

Markovskaya, E. F.; Sysoyeva, M. I. and Bezdenezhnykh, V. A. 1996. Termoperiodicity of crop plants and strategies for climate control. J. Agric. Sci. 127(4):425-431.

Medina, G. G.; Ruiz, C. J. A. y Martínez, P. R. A. 1998. Los climas de México: una estratificación ambiental basada en el componente climático. Guadalajara, Jalisco, México. INIFAP-CIRPAC. Guadalajara, Jalisco, México. 103 p.

Medina, G. G. y Ruiz, C. J. A. 2004. Estadísticas climatológicas básicas del estado de Zacatecas (Período 1961-2003). INIFAP-CIRNOC-C.E. Zacatecas. Calera de V.R., Zacatecas, México. Libro técnico núm. 3. 26-30 p.

NASA. 2017. Recursos climatológicos. http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov. 1-21 pp.

Nelson, R. 2016. ClimGen user manual. URL: http://modeling.bsyse.wsu.edu/CS_Suite/ClimGen/manual/parameters/parameterization.htm. 1-28 pp.

OMM (Organización Meteorológica Mundial). 201. Guía de prácticas climatológicas. OMM No. 100. Ginebra, Suiza. 2/1-2/22 pp.

Rodell, M.; Houser, P. R.; Jambor, U.; Gottschalck, J.; Mitchell, K.; Meng, C. J.; Arsenault, K.; Cosgrove, B.; Radakovich, J.; Bosilovich, M.; Entin, J. K.; Walker, J. P.; Lohmann, D. and Toll, D. 2004. The global land data assimilation system, bull. Amer. Meteor. Soc. 85(3):381-394.

Rui, H. and Beaudoing, H. 2017. Readme document for GLDAS Version 2 data products. NASA Goddard Space Flight Center. Code 610.2. Greenbelt, MD 20771, USA. 1-21 pp.

SMN (Servicio Meteorológico Nacional). 2017. Normales climatológicas por estación. http://smn.cna.gob.mx/index.php?option=com_content&view=article&id=42&Itemid=75.

Thornthwaite, C. W. 1948. An approach towards a rational classification of climate. Geographical Review. 38(1):55-94.

Thornthwaite, C. W. and Mather, J. R. 1955. The water balance. Publications in Climatology. 8(1):14-33.

UNEP (United Nations Environmental Program). 1992a. Status of desertification and implementation of the United Nations Plan of Action to combat desertification. Report of the Executive Director. UNEP. 1-88 pp.

UNEP (United Nations Environmental Program). 1997. World Atlas of Desertification. Second Edition. Editorial commentary by Middleton N. and Thomas D. S. G. London: Edward Arnold. 1-182 pp.

Yamori, W.; Hikosaka, K. and Way, D. A. 2014. Temperature response of photosynthesis in C3, C4, and CAM plants: temperature acclimation and temperature adaptation. Photosynth. Res. 119(1-2):101-117. doi: 10.1007/s11120-013-9874-6.

Zhang X. and Yang, F. 2004. RClimDex (1.0). User manual. Climate research branch environment Canada. Downsview, Ontario, Canada. 1-23 pp.